1. Project Summary

IceCube represents a truly unique opportunity not only for scientific discovery but also for education of and outreach to people regardless of their level of scientific understanding. Our approach to planning IceCube Maintenance & Operations (M&O) and Physics Analysis—from science event to publication—defines the full range of tasks required to maximize the detector's scientific discovery and educational potential and distributes these tasks among a central M&O organization and the IceCube collaborating institutions. This proposal describes $45.9M of Core M&O support, including approximately $3.2M of Euro & Asia Pacific contributions to a Common Fund, resulting in a request to the NSF of $42.7M over five years for the central M&O award. In addition, our MOUs secure In-kind contributions of distributed M&O labor and computing resources from collaboration institutions of approximately 40 FTE per year of labor and over 2,250 guaranteed CPU cores and 500 TB of storage for distributed computing.

Intellectual Merit. The intellectual merit of IceCube is especially compelling because of its potential for transformative discovery in multiple scientific disciplines including, but not limited to, astronomy, astrophysics, nuclear and particle physics and cosmology. IceCube opens a new window for extragalactic astronomy and astrophysics, exploring a range of neutrino energies that are not available from any terrestrial source built by nuclear and particle physicists. Its potential includes discovering the nature of Dark Matter; the nature of black holes, supernovae explosions and gamma ray bursts; and new celestial objects and phenomena. Historically, new ways of looking at the sky have discovered unanticipated phenomena resulting in significant advances in our understanding of the universe.

UW offers NSF a proven approach to providing M&O for IceCube based on our experience both constructing the detector and beginning operations while it is still under construction. Lessons learned that shaped this proposal include the need for 1) more resources for both distributed and centrally managed activities, and 2) additional accountability mechanisms for in-kind and institutional contributions—with both necessary to ensure that the detector maintains its capability to produce data at the level required to achieve its scientific discovery objectives. The proposal describes an effective balance between Core tasks, which are centrally funded through UW-Madison, and In-kind tasks, which are funded through the IceCube Collaborating Institutions. Our organization and management approach maintains clear lines of accountability to the NSF.

Broader Impacts. The mystique of the South Pole environment and the compelling science are an alluring mix. IceCube scientists and staff eagerly share the excitement of their experiences at the South Pole Station and of the discovery potential of this project with people of all ages, genders, and underrepresented groups. Building on this excitement, our approach to education and outreach facilitates initiatives and distinct E&O proposals with NSF and coordinates execution among collaborators, which maximizes the educational value and public knowledge of IceCube science.

Completion of the detector and full-scale mining of data are just the beginning of IceCube's enhancement of the infrastructure for research and education. IceCube will soon enter a phase of modifications and enhancements of capabilities resulting from experience operating the detector and from new science opportunities. Our M&O plans include organizing an R&D program, funded separately, that would capitalize on the current IceCube scientific program. This will further enhance the scientific infrastructure along with expected growth over time of the IceCube Collaboration from its more than 30 academic institutions and national laboratories.

The results of IceCube science will enhance scientific and technological understanding on many levels through broad dissemination of discoveries and experiences. Our distributed model results in educational opportunities and mentoring at all levels, from undergraduates to postdoctoral researchers, in a broad set of disciplines including operations management, engineering, computing, and scientific analysis.

IceCube is in a unique class of projects that inspire the innovative capacity of a new generation of American scientists and engineers to solve the most vexing scientific problems by applying new knowledge of the universe around us.

2. Achievement of Scientific Vision

Enabling our scientific vision requires reliable operation of the IceCube Neutrino Observatory facilities and timely transition from event data to quality publications. The mission for M&O of IceCube is to optimize the investments of NSF and its partner funding agencies, UW and the IceCube Collaboration to deliver on its scientific objectives. Following completion of the detector in 2011, IceCube will transition to stable M&O operations structured to maximize its discovery potential.

This proposal is presented in a basic engineering framework. This section reviews the scientific vision and objectives that IceCube is designed to achieve and provides a timeline of key milestones. Section 3, Technical Approach, specifies the M&O requirements necessary for IceCube to achieve its design objectives. Section 4, Management Approach, identifies the tasks required to meet the technical requirements and explains how we will perform them. Section 5, Relevant Experience, provides lessons learned in IceCube M&O. Section 6, Cost, provides a breakdown of costs by funding source.

2.1. Vision for Scientific Discovery

Although IceCube was conceptually designed as a discovery instrument, with time, its main scientific goals have attained a sharper focus and the IceCube concept is as relevant as ever. We know now that the goals are achievable because detector operation with 22 and 40 strings[1] has demonstrated performance better than anticipated (**Figure 2.1-1**). A list of scientific missions[2], far from exhaustive, follows.

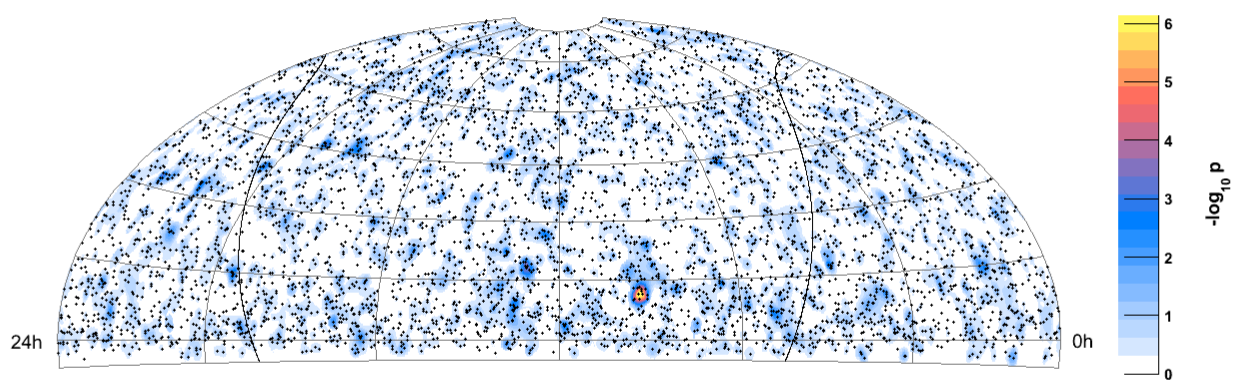

Figure 2.1-1. IceCube Detector Performance. *The map of the Northern sky shows the arrival directions of all neutrinos detected by IceCube operating with 22 strings for 270 days. The "hottest spot" in the map, at a location of 153° right ascension and 10° declination, represents an excess of 11 events on a background of 3 atmospheric neutrino events. After taking into account all trial factors, the probability for this event to happen anywhere in the sky map is 0.0134, leading to focus on this hot spot, as new strings are added to IceCube, as a potential new discovery.*

Astrophysical Neutrinos. A major discovery for IceCube will be the first observation of neutrinos that are expected from cosmological point sources such as gamma-ray bursts and active galactic nuclei. IceCube has the ability to detect astrophysical neutrinos produced in cosmic sources with an energy density comparable to their energy density in cosmic rays. Supernova remnants satisfy this requirement if they are indeed the sources of the galactic cosmic rays as first proposed by Baade and Zwicky; their proposal is a matter of debate after more than seventy years. Also gamma ray bursts fulfill this prerequisite if they are the sources of the highest energy cosmic rays. In general, the sources of the extragalactic cosmic rays naturally yield similar energy in neutrinos when particles accelerated near black

[1] A. Achterberg et al. [IceCube Collaboration], Astropart. Phys. 26, 155 (2006), arXiv:astro-ph/0604450; T. Montaruli et al. [IceCube Collaboration], in Proc. of Topics in Astroparticle and Underground Physics (TAUP07), Sendai, Japan, 2007; S. R. Klein [IceCube Collaboration], arXiv:0807.0034 [physics.ins-det].

[2] For a recent review, see F. Halzen, arXiv:0901.4722 [astro-ph.HE].

holes, like the central engines of active galaxies or gamma ray bursts, collide with photons in the associated radiation fields[3]. While the secondary protons may remain trapped in the acceleration region, approximately equal amounts of energy escape as neutrons, secondary neutrinos and electromagnetic radiation. The energy escaping the source is distributed between cosmic rays, and gamma rays and neutrinos produced by the decay of neutral and charged pions, respectively. The IceCube detector has at this point achieved a sensitivity that is at the level of the anticipated neutrino flux from Galactic supernova remnants[4], and at the level of the neutrino flux associated with gamma ray bursts[5].

Neutrino Physics. IceCube discoveries in neutrino astronomy have the potential for an improved understanding of the content and evolution of the universe. IceCube looks for cosmic neutrinos through a foreground of atmospheric neutrinos produced in the Earth's atmosphere. This is a curse and a blessing; the background of neutrinos produced by cosmic rays in interactions with atmospheric nuclei provides a beam essential for calibrating the instrument. It also presents us with an opportunity to do particle physics. The energy range of background atmospheric neutrinos is unique, covering the interval 1-10^{5} TeV, including energies not within reach of accelerators[6]. Cosmic beams of even higher energy may exist, but the atmospheric beam is guaranteed. IceCube is expected to collect a data set of approximately one half million neutrinos over ten years. The data should address physics topics ranging from the relatively straightforward to the positively exotic. Even in the absence of new physics, just measuring the predicted neutrino cross section at this energy level would be a powerful confirmation of the Standard Model.

Especially interesting in this context is the decrease in threshold to approximately 10 GeV over a significant fraction of IceCube's fiducial volume that will be achieved with the deployment of six Deep Core strings[7]. We will accumulate atmospheric neutrino data covering the first oscillation dip at roughly 28 GeV with unprecedented statistics. The equivalent instrumented volume is of order 10 Mton. It has been shown[8] that the event statistics with five years of data open the possibility to explore the mass hierarchy of neutrinos. The key is to measure the Earth matter effects associated with the angle θ_{13} that governs the transitions of electron neutrinos into muon and tau neutrinos. A positive result will require a sufficient understanding of the challenging systematics of the measurement; this is under investigation.

Dark Matter Search. IceCube may very well identify the particle nature of dark matter. The detector searches for neutrinos from the annihilation of dark matter particles gravitationally trapped at the center of the Sun and the Earth. In searching for generic weakly interacting massive dark matter particles (WIMPs) with spin-independent interactions with ordinary matter, IceCube is only competitive with direct detection experiments if the WIMP mass is sufficiently large. On the other hand, for spin-dependent interactions, IceCube has already improved on the best limits from direct detection experiments on spin-dependent WIMP cross sections by two orders of magnitude (**Figure 2.1-2**)[9].

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[3] J.K. Becker, Phys. Rept. 458}, 173 (2008) [arXiv:0710.1557 [astro-ph]].

[4] F. Halzen, A. Kappes and A. O'Murchadha, Phys. Rev. D78}], 063004 (2008) [arXiv:0803.0314 [astro-ph]]; M.C. Gonzalez-Garcia, F. Halzen and S. Mohapatra, arXiv:0902.1176 [astro-ph.HE].

[5] The search for muon neutrinos from Northern Hemisphere gamma-ray bursts with the Antarctic Muon and Neutrino Detector Array (AMANDA) (IceCube and IPN collaborations), Astrophysical Journal **674** 1 357-370 (2008); astro-ph/07051186; M. Ackermann et al. [IceCube Collaboration], Astrophys. J. 675 (2008) 1014 [arXiv:0711.3022 [astro-ph]]; IceCube Collaboration (A. Kappes *et al.*), in arXiv:0711.0353 [astro-ph] , pages 127-130. Prepared for 30th International Cosmic Ray Conference (ICRC 2007), Merida, Yucatan, Mexico.

[6] M. C. Gonzalez-Garcia, F. Halzen and M. Maltoni, Phys. Rev. D 71, 093010 (2005) [arXiv:hep-ph/0502223].

[7] D.F. Cowen [IceCube Collaboration], Journal of Physics: Conference Series 110, 062005 (2008).

[8] O. Mena, I. Mocioiu and S. Razzaque, Phys. Rev. D 78, 093003 (2008) [arXiv:0803.3044 [hep-ph]].

[9] R.~Abbasi, et al. [IceCube collaboration] arXiv:0902.2460 [astro-ph.CO].

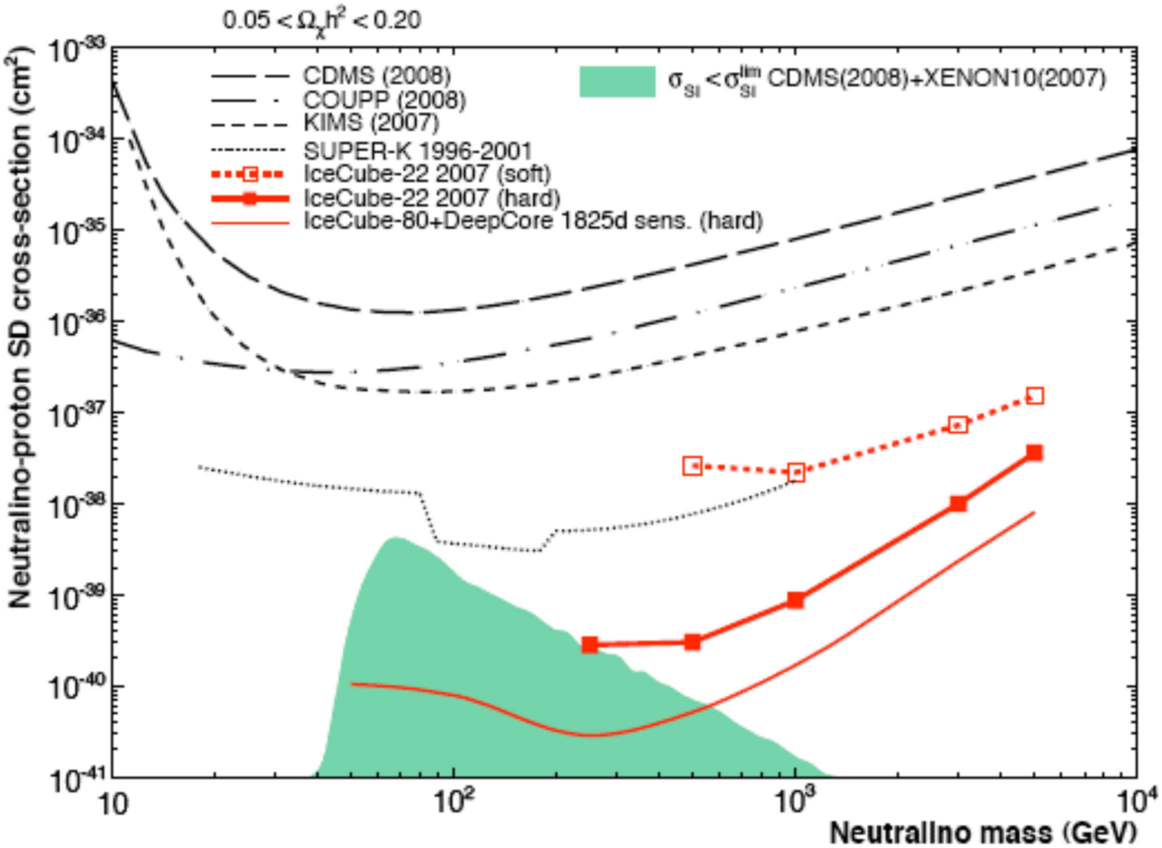

Figure 2.1-2. Dark Matter Search. *The red boxes show the upper limits at 90% confidence level on the spin-dependent interaction of dark matter particles with ordinary matter. The two lines represent the extreme cases where the neutrinos originate mostly from heavy quarks (top line) and weak bosons (bottom line) produced in the annihilation of the dark matter particles. Also shown is the reach of the complete IceCube and its Deep Core extension after 5 years of observation of the sun. The shaded area represents supersymmetric models not disfavored by direct searches for dark matter. Also shown are previous limits from direct experiments and from the Superkamiokande experiment. The results are noteworthy in that they improve by two orders of magnitude on the sensitivity previously obtained by direct experiments, further enhancing the potential for major discoveries as to the nature of dark matter.*

Breadth of Discovery Potential. IceCube opens a new window for extragalactic astronomy and astrophysics. By looking for sources of high-energy neutrinos, it has the potential to discover objects and phenomena not accessible to conventional telescopes. IceCube explores a range of neutrino energies not otherwise accessible. It is also a large, three-dimensional cosmic-ray detector, and it is the world's largest detector of TeV muons. Its capability to observe particles accelerated to TeV scale energies creates the potential for truly high-impact discoveries of unanticipated phenomena. For example, IceCube is using downward muons to study the enigmatic large and small scale anisotropies observed in the cosmic ray muon flux recently identified by Northern detectors (**Figure 2.1-3**). Expanding the measurement to the southern hemisphere should help to discover the cause of this unanticipated phenomenon.

Another example worth mentioning is that IceCube is a member of the SNEWS network. The passage of a large flux of MeV-energy neutrinos produced by a galactic supernova over a period of seconds will be detected as an excess of the background counting rate in all individual optical modules. Although only a counting experiment, IceCube will measure the time profile of a neutrino burst near the center of the Galaxy with statistics of about one million events, equivalent to the sensitivity of a 2 megaton detector.

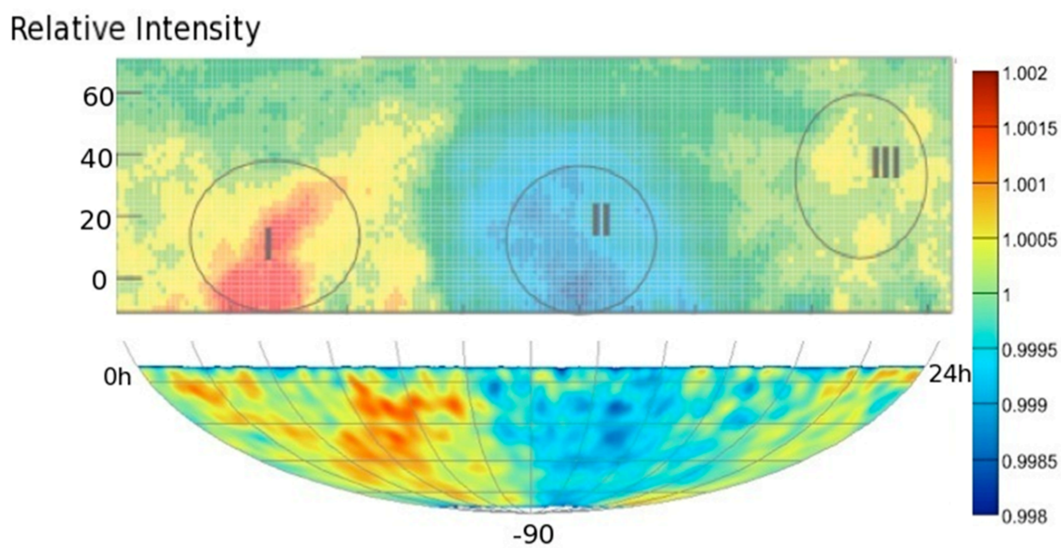

Figure 2.1-3. Potential for New Discovery. *Shown is the anisotropy in arrival direction of 10 TeV cosmic rays in equatorial coordinates.* **Top:** *Tibet Array observation in the northern hemisphere.* [10] *Region I represents the excess in the cosmic ray intensity, region II the deficit, and region III a feature not related to cosmic rays.* **Bottom:** *IceCube southern hemisphere observation with 22 strings. The color scale represents the relative intensity per declination. Note that the two observations match giving a clear full-sky view. The origin of this effect is unknown. There is evidence for smaller scale structure superimposed on the large scale anisotropy in the northern hemisphere, which is attributed to cosmic rays.*[11] *The observation of smaller scale structure in the southern hemisphere by IceCube may corroborate the notion that close-by young sources of cosmic rays might contribute to the large scale anisotropy.*

2.2 Five-Year Roadmap

The Maintenance & Operation (M&O) program defined in this proposal, combined with research support for each of the IceCube collaborating groups, will ensure the full exploitation of the discovery potential of the observatory from April 1, 2010 through March 31, 2015. The proposed IceCube M&O program is informed by the experience gained during construction and the initial M&O phase. Over the next five years, IceCube transitions from construction to stable maintenance and operations. Our approach acknowledges three discrete phases—construction, transition, and stable M&O—and harnesses the talents and resources of the entire IceCube collaboration. As we move into stable operations we will maximize IceCube's scientific and educational value by fully engaging the capabilities of our collaborators in both physics analysis and M&O activities. We anticipate that the collaboration will continue to grow, expanding both the scope of physics analysis and M&O activities and the opportunities for additional contributions.

Stable facility operations and timely data analysis are possible through a combination of the central M&O support requested through this proposal and direct support by funding agencies to collaborating groups. The five-year roadmap is based on a forecast of data rates, volumes, processing, and access requirements that are derived from both the initial operations experience and a projection of the requirements of the final 86-string detector. The facility operations and data preparation require strong technical coordination between the Collaboration and UW-Madison as described in Section 4.

The substantial investment made by the NSF and its partner funding agencies in constructing the IceCube facilities, a $275 million expenditure, produced not only a detector that meets or exceeds original performance goals, but data management and computing facilities that provide for continuous data

[10] M. Amenomori et al. [The Tibet AS-Gamma Collaboration], Astrophys. J. 633, 1005 (2005) [arXiv:astro-ph/0502039].

[11] A.A. Abdo et al., Phys. Rev. Lett. 101(Nov. 24):221101 (2008).

collection, data production, and data processing. The first milestone in the transition of the facility from construction, primarily supported by the NSF Major Research Equipment and Facilities Construction (MREFC) program, to M&O was in 2007 (**Figure 2.2-1**) with issuance of a three-year Cooperative Agreement between NSF and the University of Wisconsin for IceCube M&O. The IceCube International Oversight and Finance Group (IOFG), a group composed of NSF and representatives of German, Swedish, and Belgian funding agencies, endorsed the original M&O program, agreeing to support initial operations and research to ensure the early exploitation of the construction investment. The transition phase is from April 1, 2007 to March 31, 2010. Construction of the IceCube facility will be completed in 2011. At present there are Digital Optical Modules (DOMs) installed on 59 strings and 120 surface tanks. The construction endgame over the next two years is to install 18 additional strings in 2009/10 and the final 9 strings in 2010/11. At completion, the final configuration of the facility will include 86 strings and 160 surface tanks with 6 of the strings forming the Deep Core array.

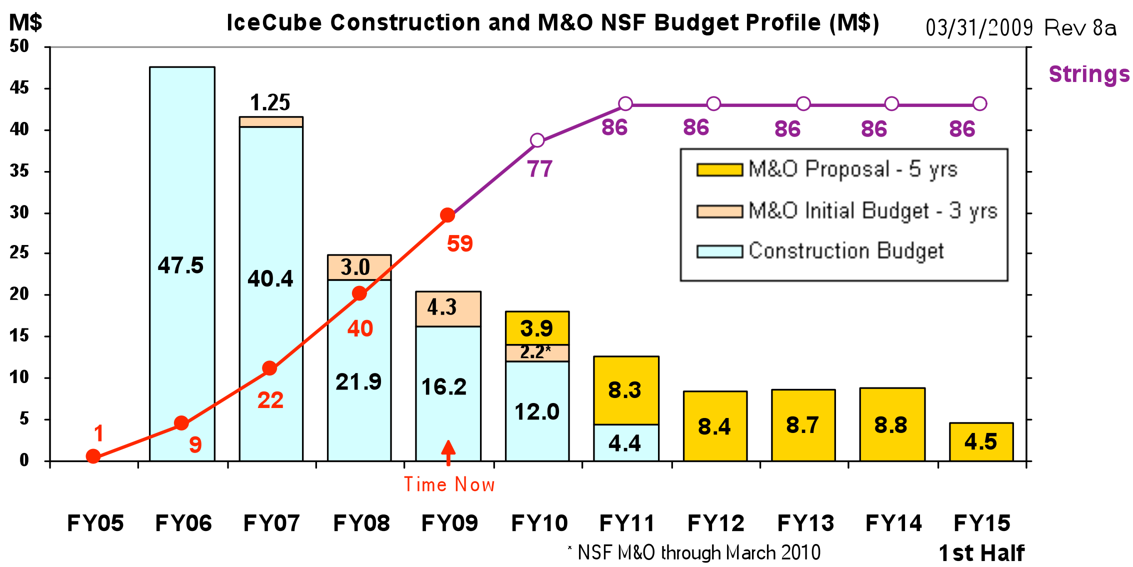

Figure 2.2-1. IceCube Transition to M&O. *As construction activities ramp down, IceCube transitions to stable M&O operations structured to maximize its discovery potential.*

The original IceCube M&O proposal submitted in 2007 focused primarily on the centrally funded M&O work with less complete coverage of distributed "in-kind" work and the relationship of the M&O tasks to physics analysis activities. This approach was a legacy of the construction phase when 90% of the work was centrally funded. This M&O proposal relies on a more distributed model of support that requires management arrangements better suited for defining and coordinating distributed, in-kind work.

Resource constraints during M&O required an increased investment in construction activities in hardware and automation in primarily data systems and pre-operations. These investments helped to reduce the M&O requirements both in the short and longer terms. UW-Madison also made substantial resource contributions to the initial M&O phase helping to limit the impact of the slow ramp-up in M&O support.

3. Technical Approach

IceCube as a discovery instrument with multiple scientific objectives requires many varied search strategies. It will look for steady point sources of muon neutrinos in the northern sky—for example, active galactic nuclei or supernova remnants. Other searches target transient point sources such as gamma-ray bursts or supernovae in progress. Yet another search strategy is to look for an extraterrestrial neutrino flux coming from the entire sky or from a large part of it—for example, the Milky Way. To achieve these multiple objectives, IceCube must be properly calibrated, and continuously monitored to ensure high quality data. It also requires computing and facilities infrastructure, and the corresponding maintenance and updates necessary to achieve high standards of reliability and quality.

This section sets the technical M&O requirements and specifications ensuring IceCube reliably and continuously provides the capability to achieve its scientific objectives.

3.1. Detector Description and Performance

Required Capabilities. IceCube is designed to detect muons and cascades over a wide energy range. The string spacing was chosen in order to reliably detect and reconstruct muons with over 1 TeV energy and to precisely calibrate the detector using flashing LEDs and atmospheric muons. Because of attenuation and scattering of light, a certain density of sensors is required to be sure to obtain many measurements along each track, which is important for pointing accuracy, background rejection, and energy measurement. The optical properties of the South Pole ice have been measured with various calibration devices and are used for modeling the detector response to charged particles. Muon reconstruction algorithms allow measuring the direction and energy of tracks from all directions.

The depth requirement was driven by two constraints: a) go below the region where air bubbles contribute to light scattering (1400 m), and b) maximize the use of the remaining depth without risking too close an approach to bedrock (2800 m). Exploratory measurements with the Antarctic Muon And Neutrino Detector Array II (AMANDA-II) verified that the ice would be clearer in the region below 2100m. The greater clarity helps with reconstruction and the greater depth minimizes background effects.

Some of the high level design goals include:

- Angular resolution for muons (E^{-2} spectrum): <1° (IceCube 40 strings: 0.8°)
- Angular resolution for muons at 1000 TeV: <0.7° (IceCube 40: <0.5°)
- Muon Effective area at 10 TeV: 0.9km^2 (Expected: >0.9km^2)
- Livetime: >95% (Expected: >97%)

Infrastructure. In its final configuration (**Figure 3.1-1**), the detector will consist of 86 strings with an instrumented depth range from 1450 m to 2450 m below the surface. There are 60 optical sensors mounted on each string, with equal spacing for standard strings. On the six strings of the Deep Core, 50 sensors are deployed at a smaller spacing of 7 m between 2100 m and 2450 m with 10 sensors above 1950m for additional veto functions. In addition there will be 320 sensors deployed in 160 IceTop detector tanks on the surface of the ice directly above the strings. The sensors are connected to the central counting house with copper cables, one twisted pair for one pair of sensors. The central counting house supports all data processing infrastructure to build events and process the data.

M&O Requirements. All subsystems in the IceCube infrastructure require effort to maintain and operate. Even though some hardware systems are frozen into the ice, the overall system will undergo changes in time. Calibration constants change over time, data rates change due to the change of the atmosphere, and sensors may display defects and need quick attention to avoid serious system-wide problems. The major effort is required for maintenance and operation of the complex computer systems in the IceCube Lab (ICL) and for data management.

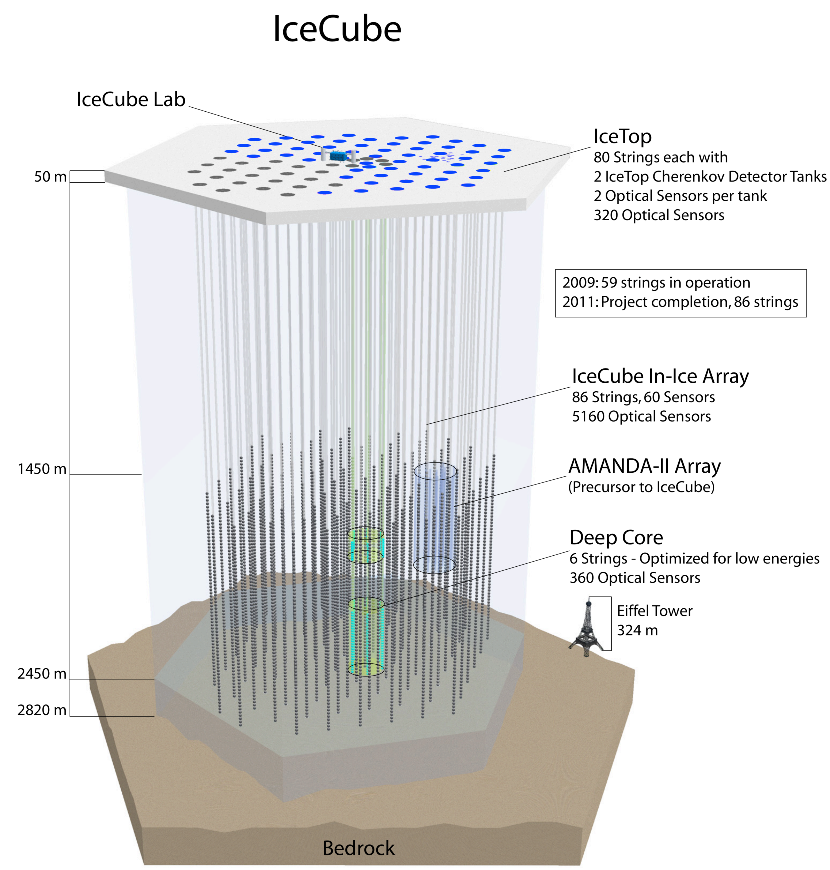

Figure 3.1-1. Schematic View of IceCube Detector. *The detector must be calibrated and continuously monitored to ensure collection of high-quality scientific data.*

3.1.1. Digital Optical Modules (DOMs)

Required Capabilities. Each sensor is required to detect the Cherenkov light emitted by the charged particles with high sensitivity and a time resolution of a few nsecs and high dynamic range. Requirements include:

- Time resolution: 5 nsec (Actual: ~3 nsec)
- Time synchronization to Masterclock: <3 nsec (Actual: 1.5 nsec)
- Noise rate (w deadtime): 500 Hz (Actual: ~350 Hz)
- Linear dynamic range: 200PE/15nsec (Actual: ~500 PE/15 ns)
- Failure rate (permanent failures): <5%/15yr (Forecast: <2.5%/15yr)
- Deadtime within run: <1% (Actual: < 0.01%)

For IceCube, timing precision at the level of a few nsec is necessary to maximize the accuracy of angular reconstruction; when looking for point sources of neutrinos in the sky, having two tracks pointing to the same spot within 0.5 degrees is more significant than having them point to the same spot within 1 degree, because random background tracks are four times more likely to occur within 1 degree.

The dynamic range of 250 photoelectrons per 15 ns is relevant in IceCube DOMs in order to measure light near high energy tracks, which is directly proportional to their energy (loss). For extremely high energies, the light will saturate nearby DOMs, and then energy must be measured increasingly with far-away DOMs, requiring a precise simulation of the photon propagation over large distances. For IceTop DOMs, the dynamic range is important because cosmic ray air showers are studied across a wide energy spectrum (about four orders of magnitude), and the signals grow with shower energy.

The noise rate affects the trigger rate, the bandwidth, and most importantly the reconstruction quality and the sensitivity to neutrino bursts from the core collapse of supernovae. Aside from the goal of a low noise rate, it is equally important that the noise is predictable, stable and free of spikes.

Infrastructure—the As-built DOM. Each sensor consists of a 25 cm photomultiplier tube (PMT), connected to a waveform recording data acquisition circuit capable of resolving pulses with nanosecond precision and performing within the requirements as listed above.

Each DOM (**Figure 3.1-2**) triggers autonomously on single photons and sends time-stamped, packetized hit data to the surface. A 33.0 cm diameter pressurized glass sphere holds the Hamamatsu R7081-02 photomultiplier tube plus associated electronics. These electronics include a high voltage generator, a resistive divider PMT base, a flasher board (containing 12 light emitting diodes, with programmable drivers), and a "Main Board" containing a complete data acquisition (DAQ) system. The DAQ includes two separate waveform digitizer systems. The first is the analog transient waveform digitizer (ATWD), which uses a custom switched-capacitor array chip to collect 128 samples of the PMT output at 300 megasamples per second (MSPS). The ATWD has three independent channels for each PMT providing 16 bits of dynamic range. The second digitizer system uses a commercial 40 MSPS 10-bit ADC chip to record 6.4 □s of data after each trigger.

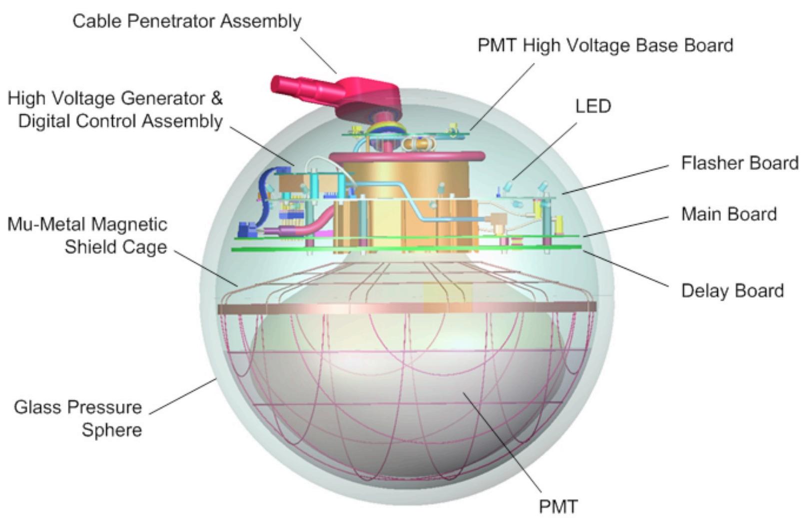

Figure 3.1-2. Digital Optical Module. *As the heart of the detector, DOMs require regular monitoring to detect performance issues that affect the quality of physics data.*

M&O Requirements. More than 5400 optical modules will be operated. The system parameters, such as gains of all amplifiers, noise rates, time resolution, master clock synchronization, photodetection efficiency, and trigger thresholds need to be monitored from run to run, and even in shorter time intervals. Due to the large number of sensors, even occasional perturbations of individual sensors can have detrimental effects on the data quality. While overall a high reliability and stability has been achieved, experience shows that regular monitoring and a rigorous assessment of the observed and often complex issues is required to ensure high data quality. Detailed calibration programs need to be performed on all sensors in regular time intervals. Higher level tests with LED flashers and downward-going cosmic ray muons are used to verify the system time stability between neighboring DOMs and monitor the DOM charge response.

3.1.2 IceTop

Required Capabilities. The IceTop surface detector array is designed to detect cosmic ray airshowers in the energy range from 500 TeV to energies well beyond 1EeV. A full trigger efficiency is required above 1 PeV for events with the core in the array. Coincidences with the In-Ice detector string array, the main detector of IceCube, allow performance of 3 tasks: a) cosmic ray physics over a wide energy range

b) special cross calibrations, and c) certain veto functions. The ice in the tanks must be clear and remain clear without cracks over many years. The stations are exposed to and must survive annual temperature cycles down to below -50°C.

Infrastructure—the As-built IceTop Detector. The surface air shower array, IceTop, consists of ice Cherenkov detector tanks each containing two DOMs, which are operated at different gain for increased dynamic range. Two such tanks are associated with each string. The tanks are embedded in the snow just below the surface to minimize drifting of snow. IceTop detects and measures the position and direction of cosmic ray air showers, which also contain muons that penetrate to IceCube depth.

M&O Requirements. The DOMs used in the IceTop tanks must be serviced like all other DOMs. However, the lower gain of every other sensor and the different noise condition from cosmic rays result in different observables and make the IceTop array a complete detector system on its own. Special expertise is needed to service the IceTop array, both at the DOM level as well as at the DAQ level. The increase of the snow layer on top of the tanks requires annual measurement of the depth of snow on all tanks and then updating this information in the data base for reconstruction and simulation.

Comparing the IceCube (In-Ice) measurement of these muons with the IceTop system is one important test of proper calibration and of the reconstruction software. This will be an ongoing comparison through the life of IceCube to make sure that everything continues to function as designed, i.e., calibrations or reconstructions or their interfaces have not become corrupted.

3.1.3 Central Electronics and Data Processing System (Counting House)

Required Capabilities. The array of DOMs in the deep ice and in IceTop needs to be supplied with power, communication and control functions. The most obvious requirement comes from the data stream of about 15MB/sec that needs to be read out and processed. All sensors are connected to the central data acquisition electronics by copper cables. A pair of DOMs shares one twisted pair cable. The data are collected in a central counting house, located at the geometric center of the IceTop array. Data include full waveforms for all hits in time coincidence between two neighboring DOMs, plus summaries of isolated hits. The data streams from the sensors arrive asynchronously via a digital communications protocol. In the counting house, higher multiplicity coincidences are formed to trigger on muons or cascades in the deep ice, or air showers observed in IceTop. The bandwidth allocation depends on the satellite bandwidth availability at the South Pole. The planning assumptions are at the level of 75 GB per day via satellite. It is a system requirement to store data locally in case of a extended failure of the satellite transmission system.

Infrastructure—Data Acquisition and Data Processing System. An overview of the system architecture is given in **Figure 3.1-3**. Each string (5 cm diameter and typically 3 km long cable) is connected to one stringHub, a computer with special boards that perform the three low level functions listed below. The central data acquisition performs 3 functions:

- Receive data streams from DOMs, perform format changes, form event triggers and build events
- Provide power and slow control functions to DOMs
- Perform synchronization of all DOM clocks with the system masterclock.
- **M&O Requirements**. IceCube software running at the South Pole consists of an estimated total of more than 200,000 lines of code. (This is after a restructuring effort was made during construction, which resulted in a reduction by ~50%). While the system is designed to perform most functions automatically, the maintenance and operation require professional staff to ensure long term reliability and stable operation of the experiment.

3.2. IceCube Infrastructure

3.2.1. United States Antarctic Program (USAP) Infrastructure

Required Capabilities. The IceCube Laboratory (ICL) is one of the core facilities that make up the IceCube Observatory at the South Pole. It fulfills the requirement for a centralized computing facility that

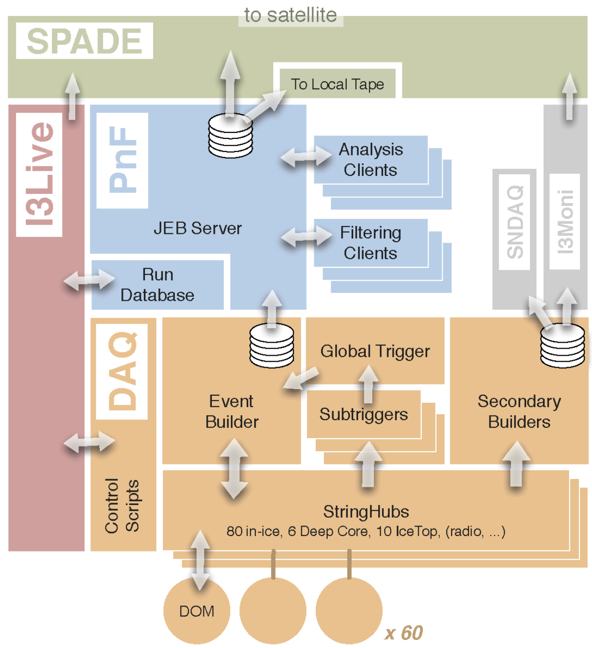

Figure 3.1-3. Detector Data System Architecture. *The data system controls the detector and collects, processes, transmits and stores IceCube and IceTop scientific data.*

also is the physical interface between the IceCube surface cables and the DOM hubs and associated data processing equipment. Additional infrastructure that is required for IceCube maintenance and operations functions are the South Pole Station and the cargo and logistics capability provided by the NSF support contractor, Raytheon Polar Services Company (RPSC) and the Science Coordination Office for Astrophysical Research in Antarctica (SCOARA) group. IceCube also requires network access to the South Pole and within the South Pole Station network for data transfer and communications for basic services such as network access, email, and other basic services. In addition, IceCube needs the capability of transferring data from the South Pole to the IceCube Data Warehouse in Wisconsin in a number of different ways depending on the priority of the data.

Infrastructure. The IceCube computing systems located in the ICL (**Figure 3.2-1**) produce in excess of 30kW of waste heat which must be removed from the Data Center. To reduce energy consumption of the Data Center the cold external air is used for cooling through an air mixing and handling system. Due to the very high density of equipment in the ICL a failure of the cooling system can result in damaging temperatures within 30 minutes. A high level of reliability and monitoring of the cooling system is therefore required. RPSC is responsible for the operations, maintenance, monitoring, and response to incidents of the cooling system. The communications infrastructure in the form of satellite connections, CONUS connections to I2, and physical backbone at South Pole are also maintained by RPSC.

M&O Requirements. The basic framework of frequent communication (weekly conference calls), one-on-one contacts (RPSC program manager, NSF program officer), Support Information Package (SIP) development, and ad hoc meetings will ensure that the USAP program will continue to provide IceCube with needed USAP infrastructure.

3.2.2. IceCube South Pole System (SPS)

Required Capabilities. IceCube requires a surface computing system capable of collecting random and asynchronous events, that are subsequently merged or processed into standard payloads representing physics data. The hardware and processing needed to accomplish that must scale to meet the real-time constraints associated with sampling 5480 sensors (86 strings and IceTop tanks). Near-line storage and archive systems must be able to handle the subsequent Level 0 data volume generated from the fully-

Figure 3.2-1. IceCube Laboratory (ICL). *The ICL at the South Pole houses the online computing system which is critical to mining data from IceCube.*

scaled IceCube detector. IceCube will require adequate margins and stability to reliably power the South Pole System (SPS) for the many operational seasons that follow detector construction.

Infrastructure. Operationally, in its final configuration, the SPS will be capable of supporting 86 in-ice strings, and 80 IceTop stations. The SPS is comprised of various hardware and software subsystems, with nearline storage of approximately 40TB. Average power dissipation is 30-35 kW. Data archiving volumes average 750 GB/day (compressed) in 2009 (59 strings) and are projected to reach 1200 GB/day (compressed) in the final configuration.

M&O Requirements. The SPS requires periodic hardware and software maintenance to guarantee reliable operation and maximum detector uptime. System administrators in conjunction with on-site Winterover operators monitor the health of the various subsystems to quickly diagnose and respond to data run failures, misconfigurations, and assorted anomalies. Customized solutions are provided and best practices followed to maintain the data system complement in a stable, quiescent state. The level of support required must scale with the size of the detector and will increase in future seasons. An incremental three year hardware update cycle is projected.

3.2.3. IceCube UW Infrastructure

3.2.3.1. South Pole Test System (SPTS)

Required Capabilities. IceCube requires an independent test system capable of replicating basic functional and performance characteristics of the operational SPS surface computing complement. The South Pole Test System (SPTS) located at UW-Chamberlin Hall continues to provide an environment to build and verify software subsystems prior to deployment on the operational system at the South Pole. To that end, the SPTS will continue to be a mission-critical tool that is utilized to minimize detector downtime. As the operational system scales and especially as it experiences upgrades, the SPTS must follow suit to maintain close hardware and operating system proximity.

Infrastructure. The SPTS is a scaled down version of the operational SPS, filling 8 computer racks. All major subsystems are represented with some at quantity levels below the operational system. For example only 4 DOM hubs are included in the system. The Processing and Filter function (PnF) and Calibration and Verification subsystem are substantially smaller than that deployed operationally. System infrastructure is similar to that deployed on the operational system including matching power and networking devices.

Additional subsystems of the SPTS are maintained to perform specific test functions and simulate entire strings in the lab. One system is referred to as the South Pole Calibration Test System (SPCTS), which can be used for testing DOM calibration software. Another test configuration (S-CUBE) includes 60 DOM mainboards wired in a realistic way to perform data throughput and trigger efficiency tests. In another test configuration, a set of 16 DOMs is arranged in dark freezers with adjustable cable lengths from 300m to 3.8 km. This system allows for detailed performance tests with DOMs that operate in realistic conditions. Finally, the PSL Cable Test System (PCTS) is based on a realistic full-size string cable of 3km length with DOMs attached.

M&O Requirements. The SPTS requires periodic hardware and software maintenance to guarantee reliable operation and maximum system uptime. System administrators manage the test system in a similar fashion to the operational system responding to software developers and other engineering concerns with customized solutions following standard best practices. The various subsystems are monitored to analyze and respond to misconfigurations and other assorted anomalies. The level of support required will remain constant as the size of the detector scales and will increase slightly in future seasons. An incremental three year hardware update cycle is projected for computer hardware. DAQ expertise is required to perform the required tests on the lower level test systems.

3.2.3.2. Data Warehouse and Storage Infrastructure

Required Capabilities. IceCube requires a Data Warehouse consisting of software to facilitate the transfer of data from the South Pole and archiving of this data, software for the orderly input of data into the Data Warehouse, standards for organizing the data, such as directory structure and metadata, and hardware for storage of the data.

Infrastructure. The current Data Warehouse consists of 450TB of online storage organized in a storage area network (SAN) architecture. Data is stored in 3 categories, simulation data, experimental data, and analysis data. Supplementing the SAN storage is an HSM system (tape-based file-system) that currently has a capacity of 500TB and can be expanded to over 1PB. A backup system provides nightly backups of priority data and creates backup tapes for off-site storage.

There are 2 main software applications involved in the flow of data from the SPS to the Data Warehouse. In the SPS, an application called SPADE ensures the orderly delivery of data from the SPS via 3 mechanisms based on priority and limited by bandwidth. At the Data Warehouse an application called Ingest insures data is entered into the Data Warehouse in an orderly fashion and all data catalogued and accounted for. There is additional software for data access and monitoring of data flow from the SPS.

M&O Requirements. The complete IceCube data set will grow as data is collected, simulated, and analyzed. The final phase of the data life cycle will be long-term storage on the tape-based file system. Growth in data processing, simulation and analysis requirements will require expansion of SAN storage. Projections for online and tape-based storage requirements are shown in **Figure 3.2-2**. (All data are compressed using the gzip algorithm.) Expansion of SAN storage will require corresponding expansion of backup systems for error and disaster recovery. While the software systems in place for the Data

	Tape Storage	Data Accessible From Online Disk			
	Experimental Raw Data [TB]	Experiment [TB]	Simulation [TB]	Analysis [TB]	Total [TB]
2010	900	250	300	90	**640**
2011	1,400	350	450	120	**920**
2012	1,900	450	650	160	**1260**
2013	2,400	550	850	250	**1650**
2014	2,900	650	900	350	**1900**

Figure 3.2-2. Online and Tape-based Storage Requirements

Warehouse are mature, as requirements for data transfer, access, monitoring, and control change the software will need to be upgraded and also maintained for system changes. Data standards will also evolve with changing requirements of the experiment.

3.2.3.3. Core High Performance Computing (HPC)

Required Capabilities. IceCube requires a core HPC cluster to perform real time offline analysis of data from the South Pole and for production of key simulation data sets.

Infrastructure. Currently IceCube has a 600 Core HPC cluster called NPX2. The much larger distributed resources of the collaboration and local resources at UW Madison, such as the GLOW system, supplement this resource. The system is closely coupled to the Data Warehouse storage for high throughput computing.

M&O Requirements. The current NPX2 system is adequate for the support of the incomplete IceCube experiment. As the final strings are added, analysis requirements expand, and simulation requirements increase, additional HPC resources will be required. Many requirements will be met using distributed resources, and this work will require close coupling to the Data Warehouse to provide high through put. Technological advances will also require replacement of hardware in the longer term. Additional clusters commensurate with the existing system will be required on a 2 to 3 year cycle. In addition to hardware the support of batching software, such as PBS and Condor, an interface such as Grid tools is required.

3.2.3.4. Data Center Infrastructure

Required Capabilities. The Data Center infrastructure is the glue that connects the major computing resources of IceCube (components such as the HPC, Data Warehouse) and controls, and allows access to resources. Core systems include essential services such as distributed authentication, web services, and email systems.

Infrastructure. The current IceCube Data Center is located at the IceCube Research Center in Madison, Wisconsin (**Figure 3.2-3**). The Data Center is approximately 400 square feet with redundant cooling and power for over 100kW of equipment. Additional infrastructure is allocated for IceCube at the UW Physics Department with cooling capacity of more than 60kW and associated rackspace.

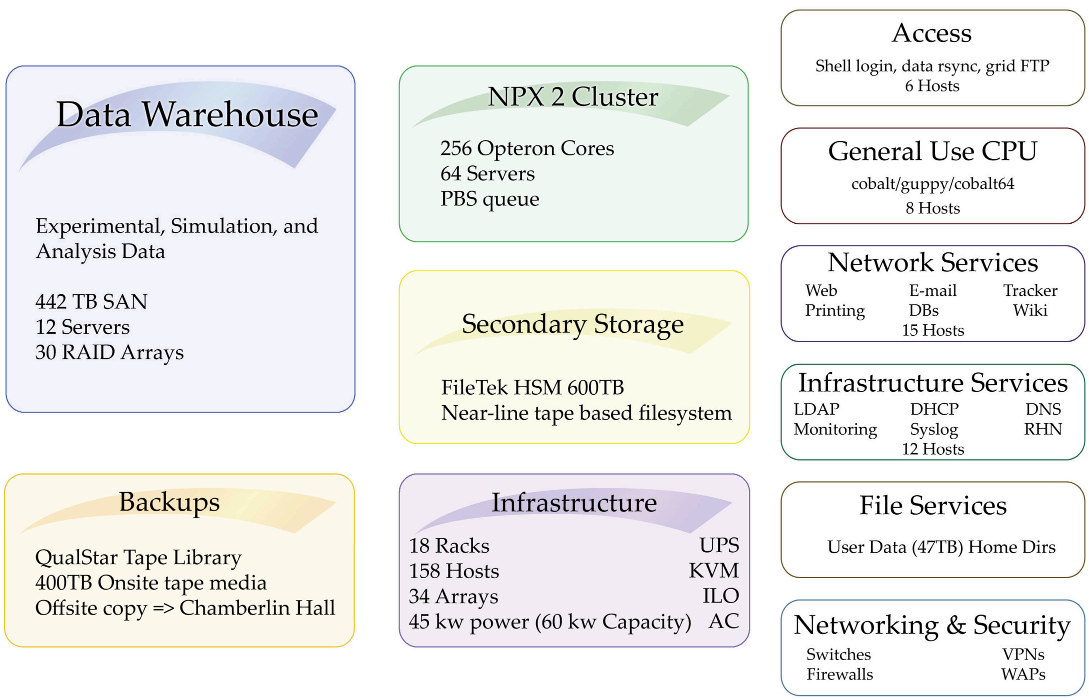

Figure 3.2-3. Data Center Infrastructure. *The Data Center provides data storage, high performance computing capability, and access to distributed computing resources throughout the collaboration.*

M&O Requirements. Network services will require continual operational maintenance, while hardware will need to be replaced on a periodic cycle, and services such as HVAC and power will need maintenance and service contracts.

3.2.4. IceCube Collaboration Computing Infrastructure

Required Capabilities. The analysis of experimental data requires a suitable amount of Monte Carlo simulation data that reproduces the detector response to a well-defined set of physics events. The IceCube Observatory event rate is overwhelmingly dominated by cosmic ray induced background events that must be eliminated through a complex event selection process. A large amount of Monte Carlo data needs to be generated in order to perform high quality physics analyses. The goal of a background simulation of a natural muon spectrum at a rate identical to the trigger rate of the detector would require the simulation of order 10^{11} events/year or an average use of approximately 6000 computing cores. Weighting techniques allow producing relatively more livetime at higher energies and reduce the total number of required cores. According to current estimates the need for sufficient computing resources at the level of several thousand cores will be mandatory to complete physics analyses and publish results. In practice there is often a burst need to run a simulation in an updated configuration.

Infrastructure. The current distributed computing infrastructure consists of contributions from Collaboration institutions in the U.S. and Europe (Germany, Sweden and Belgium) (**Figure 3.2-4**). We also have access to the Louisiana Optical Network Initiative (LONI), a fast network connection among universities and research institutions in the State of Louisiana. The main storage facility is the Data Warehouse located at UW-Madison, but other farms provide disks for temporary data storage, even if they are primarily intended for physics analyses. All the final data are transferred to UW-Madison through GridFTP and portions can be stored locally at the institutions that produced them. Existing distributed computing resources are sufficient to allow background simulation of the current detector configuration and for current analysis goals. Access to additional guaranteed HPC resources (more than 2000 cores) will be needed in the future to provide sufficient statistics of simulation data.

	Institute	Cores		Disk Space	Farm Type	FTE
		Guaranteed	Available	TB		In-kind
US	**UW GLOW (US)**	140	800	190	Grid	
	UW NPX2 (US)	100	256		Batch	
	UW CHTC (US)	100	700		Batch	
	UMD (US)	140	278	5	Batch	0.40
	PSU (US)	100	560		Batch	0.40
	LBNL PDSF (US)	50	700	2	Batch	0.20
	UDEL (US)	40	136	50	Batch	0.40
	LONI (US)	200			Batch	0.20
Germany	**Aachen (DE)**	90	200	15	Grid	0.40
	Dortmund (DE)	150	300	30	Grid	0.40
	Dortmund (DE)	100		20	Batch	
	Mainz (DE)	230	400	26	Grid	0.40
	Wuppertal (DE)	64	128	17	Grid	0.40
	Wuppertal (DE)	150		30	Batch	
	DESY (DE)	400	700	100	Batch	0.40
	DESY (DE)	100	200	20	Grid	
Sweden	**SweGrid (SE)**	100	400		Grid	0.20
Belgium	**Brussels (BE)**					0.20
	Totals	**2,254**	**5,758**	**505**		**4.00**

Figure 3.2-4. Distributed High Performance Computing Resources. *A total of 18 computing clusters are available worldwide, which provide access to about 5800 cores, of which 2250 are guaranteed to priority use of IceCube. Some of the clusters are operated in batch mode, others by grid access. Local disk space facilitates production. The FTE commitments include only labor directly associated with IceCube simulation production, not the maintenance of the computing facilities.*

The effective use of the distributed computing infrastructure is based on a custom-made software package tool called IceProd to manage simulations. IceProd allows for coordinating multiple sites, which share a single centralized database in order to distribute the workload across multiple disconnected clusters and grids.

M&O Requirements. The maintenance of the core and distributed computing infrastructure is essential for a stable and efficient simulation production. The computing farms throughout the Collaboration are managed as contributions by the individual institutions. The storage hardware, mainly located in the UW data center, but also distributed across the production sites (mainly for temporary storage), needs maintenance and replacement on a periodic cycle to insure proper functionality and efficiency.

3.3. Overview of Events to Publications

Reconstructing neutrino events with energies from 100 GeV to 100 PeV, the energy range in which we are most likely to observe cosmic neutrinos, requires precise recording of everything from single photons up to large pulses lasting several microseconds. Proper maintenance and operation of the detector and its supporting infrastructure (Sections 3.1 and 3.2) allow for capture of the targeted events, analysis of the data, and publication of results that contribute to science and education (**Figure 3.3-1**).

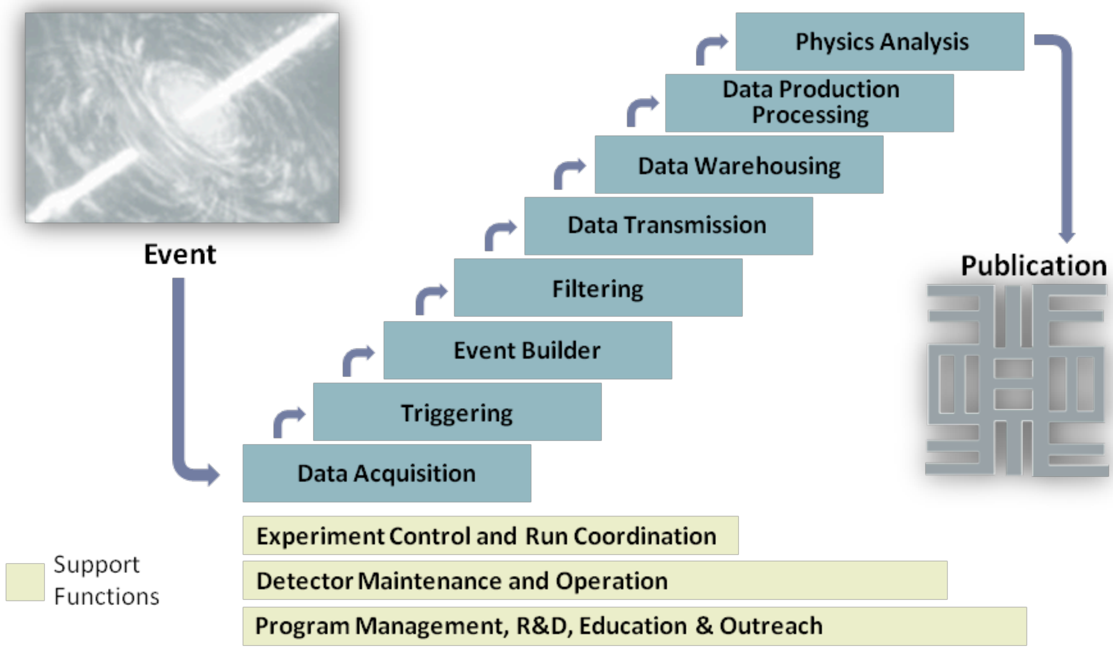

Figure 3.3-1. IceCube Path to Discovery. *Our approach to IceCube M&O is structured to support all tasks required to produce science—from event to publication.*

Detector M&O and computing and data management provide the framework for the collection of targeted data. A key element is DOM calibration, which is performed with a special program at regular time intervals of about 1 to 2 months. The time period of 1-2 months is a compromise between the value of perfect tracking of drifts and the desire to maximize live time of the experiment.

Whenever the detector is live, it is acquiring data by recording light pulses (hits) on a string and sorting these hits in time. A Run Coordinator oversees and controls the experiment through a global experiment control system called IceCube Live to focus data collection on areas of scientific interest prioritized by the IceCube Collaboration. This requires filtering of the data resulting in more than 10 data streams selected by special filter requests. Examples include upgoing muons, extremely high energy events, gamma ray burst stream, moon (for shadow of the moon), cascade like events, cosmic ray events, ultra low energy events, and WIMPs. These filters are designed by working groups in the Collaboration and are reviewed by the Trigger, Filter, Transmit (TFT) Board.

Once a trigger is issued, hits close to the trigger times are collected by event builder processes. Preliminary event reconstruction is performed in the Processing and Filtering farm (PnF) which also reduces the data volume from about 750 GB/day to about 55 GB/day (estimated values for full IceCube: 1200 GB/day and reduced to 80 GB/day), small enough to be transmitted by satellite to the data center in the North. A separate process (SPADE) takes care of managing the data streams, buffering data, sending the PnF stream to the satellite and writing the bulk of the data on tape.

Each data stream is reprocessed after transmission to the northern hemisphere data center, where more computing power is available and more sophisticated reconstruction algorithms can be applied. The refined data streams are first sent to channel working groups for initial analysis, then to the physics working groups for high-level analysis and development of specific tools needed to execute the analyses. The Analysis Coordinator manages both the analysis process and Publication Committee manages the publication review processes.

3.4. Enhancements

Within the current construction program plans have already emerged to optimize and augment the final IceCube configuration to further increase its science reach. To provide a full discussion of IceCube's scientific potential, this proposal describes two extensions designed to improve its reach at the low and high ends of the neutrino energy spectrum. IceCube's Deep Core sub-array will lower IceCube's energy threshold by about an order of magnitude, while its High Energy Extension, if implemented, will improve its sensitivity at the highest energies by 30-40%. An extension with additional strings at larger distances could increase the effective area at PeV energies by more than a factor of 2. We are also exploring new technologies of radio and acoustic detection of the highest energy cosmogenic (GZK) neutrino flux [Berezinsky & Zatsepin, 1970; Stecker, 1973]. We will seek or have sought funding for these enhancements in separate proposals.

3.4.1. Deep Core

Enhanced Capabilities. The IceCube Deep Core (ICDC) sub-array (**Figure 3.4-1**) will replace the original AMANDA detector and provide IceCube with sensitivity to neutrinos at energies over an order of magnitude lower than originally envisioned. Consisting of six new strings and seven neighboring standard IceCube strings, the sub-array will dramatically improve on AMANDA's capabilities through a combination of increased module density, higher quantum efficiency photomultiplier tubes (PMTs), deployment in the clearest ice at depths below 2100 m, and the use of the surrounding standard IceCube modules above and around ICDC as a powerful active veto against the copious downward-going cosmic-ray muon background. IceCube Deep Core will provide enhanced sensitivity to solar WIMP annihilations, extending IceCube's reach to the experimentally and theoretically most interesting WIMP mass range below 100 GeV. It will give improved acceptance for low energy atmospheric neutrinos at $E_{\nu} \sim 10$ GeV, opening a useful new window for atmospheric neutrino oscillation measurements, including ν_{μ} disappearance, ν_{τ} appearance and

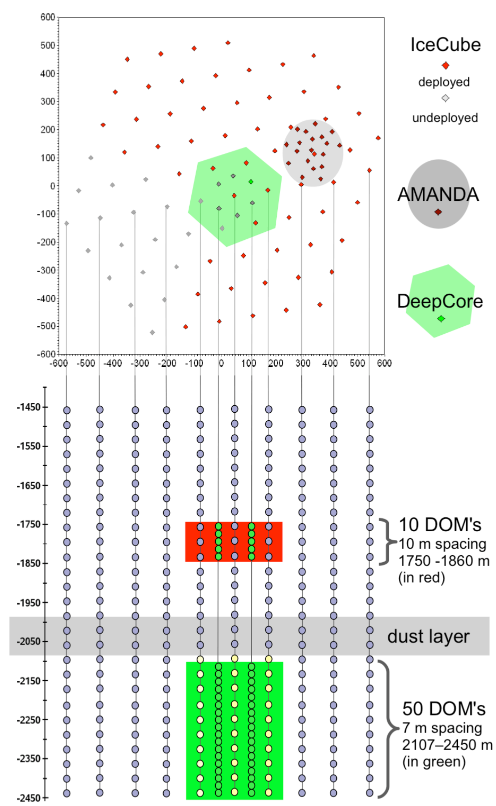

Figure 3.4-1. Deep Core Sub-array.

possibly the sign of the neutrino hierarchy. Taking advantage of the active vetoing capability provided by the surrounding IceCube array, ICDC will also be able to explore the southern sky for possible neutrino sources such as AGN, GRBs, and the Galactic Center.

Infrastructure Requirements. IceCube Deep Core will use high quantum efficiency PMTs and a vertical DOM-to-DOM spacing of 7 m and a horizontal string-to-string spacing of 72 m (the uppermost 10 DOMs of ICDC will have a 10 m vertical spacing). In contrast, IceCube spacings are 17 m and 125 m, respectively. The ICDC DOM spatial density will thus be higher by about an order of magnitude than standard IceCube DOMs, making it more capable of detecting sufficient light from compact, low energy neutrino interactions to perform reliable reconstructions. In its position at the bottom center of IceCube, ICDC will be surrounded by 37 layers of DOMs above and 3 layers of strings in all horizontal directions. The requirements for cables, power (300W/string) and readout are identical to other IceCube strings. Each Deep Core string will require 400 Watts of power for a total of 2.4 kW. While superior in sensitivity, it requires much less power than the AMANDA array (15kW), now decommissioned, to be replaced by the Deep Core strings.

3.4.2. High Energy Optimized Array

Enhanced Capabilities. The science goals of the ongoing optimization are focused on the highest energy sources of cosmic neutrinos. AMANDA has reached a limit on the flux of gamma ray bursts (GRB) that is at the level of the flux predicted by conventional fireball phenomenology supplemented with the hypothesis that GRB are the sources of the highest energy cosmic rays. In general, improvement to the reach of IceCube in the PeV energy range will increase the instrument's sensitivity to any high energy neutrino flux that extends into that range, e.g. to some models of cosmic ray production in active galaxies. The performance increases for the proposed geometry are 25% at 1 PeV and 30% at 10 PeV. Substantially larger increases are expected for EeV energies (GZK neutrino flux). In addition, the effective area is larger than baseline above energies of ~10 TeV. The effective area for cosmic ray showers above 10^{17} eV will grow by approximately a factor of 1.7 compared to the baseline, almost doubling the rate of events in the region where the physics and the statistics is most important.

Infrastructure Requirements. In this scenario, strings that are identical or very similar to IceCube strings would be deployed in a configuration similar to the one shown in **Figure 3.4-2**. IceTop detector stations would be deployed with each string, with cables leading back to the counting house. No additional infrastructure is anticipated for this scenario as all cable hardware and readout systems remain unchanged from the regular 86 string IceCube configuration.

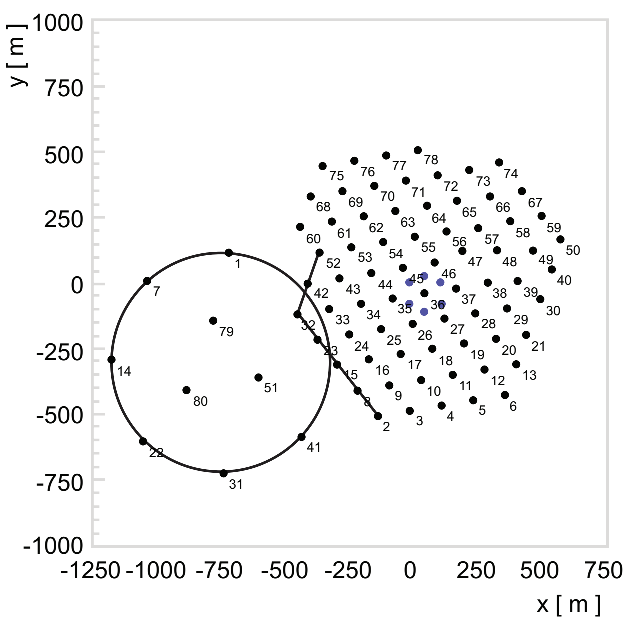

Figure 3.4-2. High Energy Optimized Array.

3.4.3. Optical, Radio and Acoustic Technologies for Cosmogenic Neutrinos

Enhanced Capabilities. Coincident events between novel radio or acoustic sensors and an optical detector component could be used to bootstrap these technologies, reduce systematic errors and cross calibrate the novel techniques with the well understood optical detector system. While worldwide there are many initiatives on novel neutrino detection methods (e.g. RICE, Anita, Salsa, Onde..), the IceCube site is the only place where this bootstrapping can be achieved within the foreseeable future. One suggested extension adds 20 to 24 optical detector strings, configured in two large outrigger clusters (**Figure 3.4-3**), doubling the size of baseline IceCube. The rate for IceTop - In-Ice coincidences would grow quadratically to a factor of 4. The technology would be identical to IceCube. Another enhancement sets the stage for a large scale radio array, large enough to detect the cosmogenic neutrino flux in the energy range from 10^{17} eV to 10^{18} eV. IceRay (see figure) is detector configuration where the spacing of radio detector stations/strings is of o(1) km. With appropriate instrumentation this array simultaneously could also be used to study radio signals from air showers. This would increase the reach of IceTop to higher energies as well as help InIce to veto backgrounds. Additional acoustic sensors could help to disentangle environmental effects and provide extra leverage for signal interpretation.

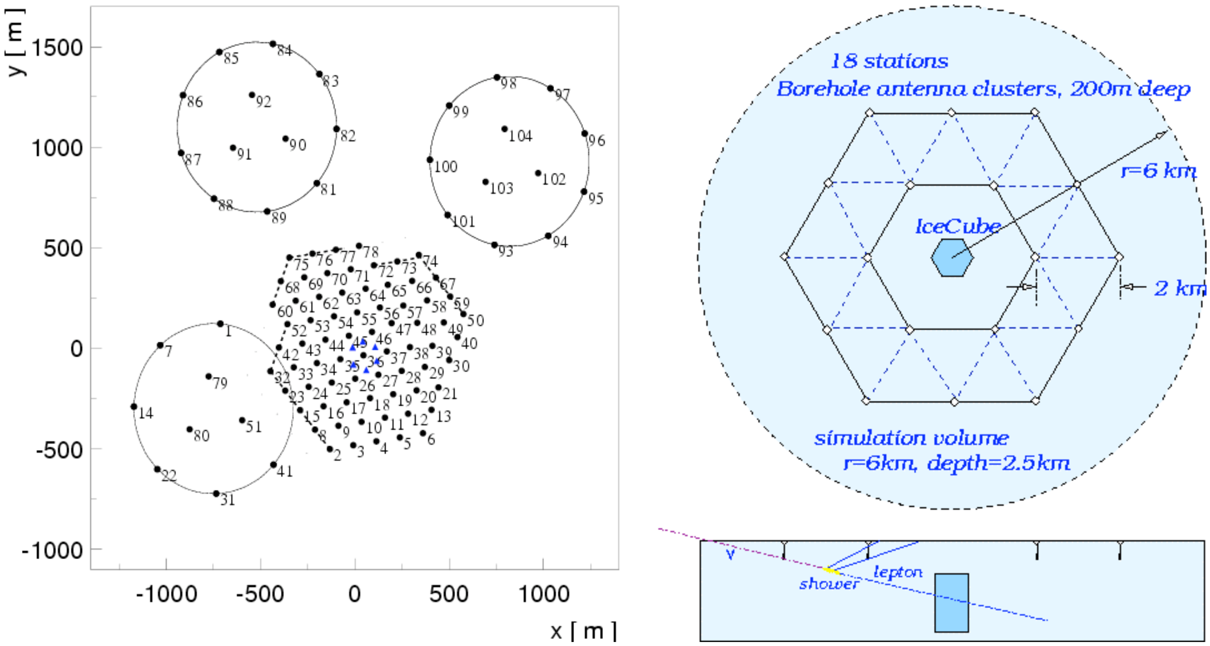

Figure 3.4-3. IceCube Extensions For High Energy Cosmic Neutrino Sources: *An optical extension to 110 strings for GRB, AGN (left). An extension based on radio detectors for GZK neutrinos (right).*

Infrastructure Requirements. For the described scenarios a maximum benefit from the unique infrastructure of the IceCube site can be drawn not only from the science perspective but also from the presence of the existing IceCube infrastructure described in section 3.2. The optical extension would be based on standard IceCube technology. The GZK neutrino extension would also be anchored in IceCube, but require much less drilling and deployment and only a minimal power (<5% of IceCube).

4. Management Approach

Our approach to IceCube M&O—from science event to publication—is to maximize scientific discovery potential by drawing on talent and resources from Collaboration institutions to support both M&O and science tasks. The first part of this section (Section 4.1) describes how we are organized to perform the M&O functions for IceCube in this distributed model and how we provide accountability for task execution. The second part (Section 4.2) identifies the tasks required to meet the technical requirements and specifications discussed in Section 3, and explains how we perform each task.

4.1. Management Organization

The IceCube M&O management organization integrates the IceCube Collaboration and the Host Institution, University of Wisconsin-Madison (**Figure 4.1-1**). The Collaboration Spokesperson appoints collaborating scientists to serve as the coordinators in each of the major M&O functions, Physics Analysis, and Research and Development. These appointments are subject to the concurrence of the Collaboration. The Director of Operations appoints technical professionals to serve as managers of the two M&O functions that are predominately centered at UW-Madison: Detector Maintenance & Operations and Computing & Data Management. The managers in these areas work with their scientific counterparts to ensure the detector operates reliability and the data taken by the detector can be analyzed

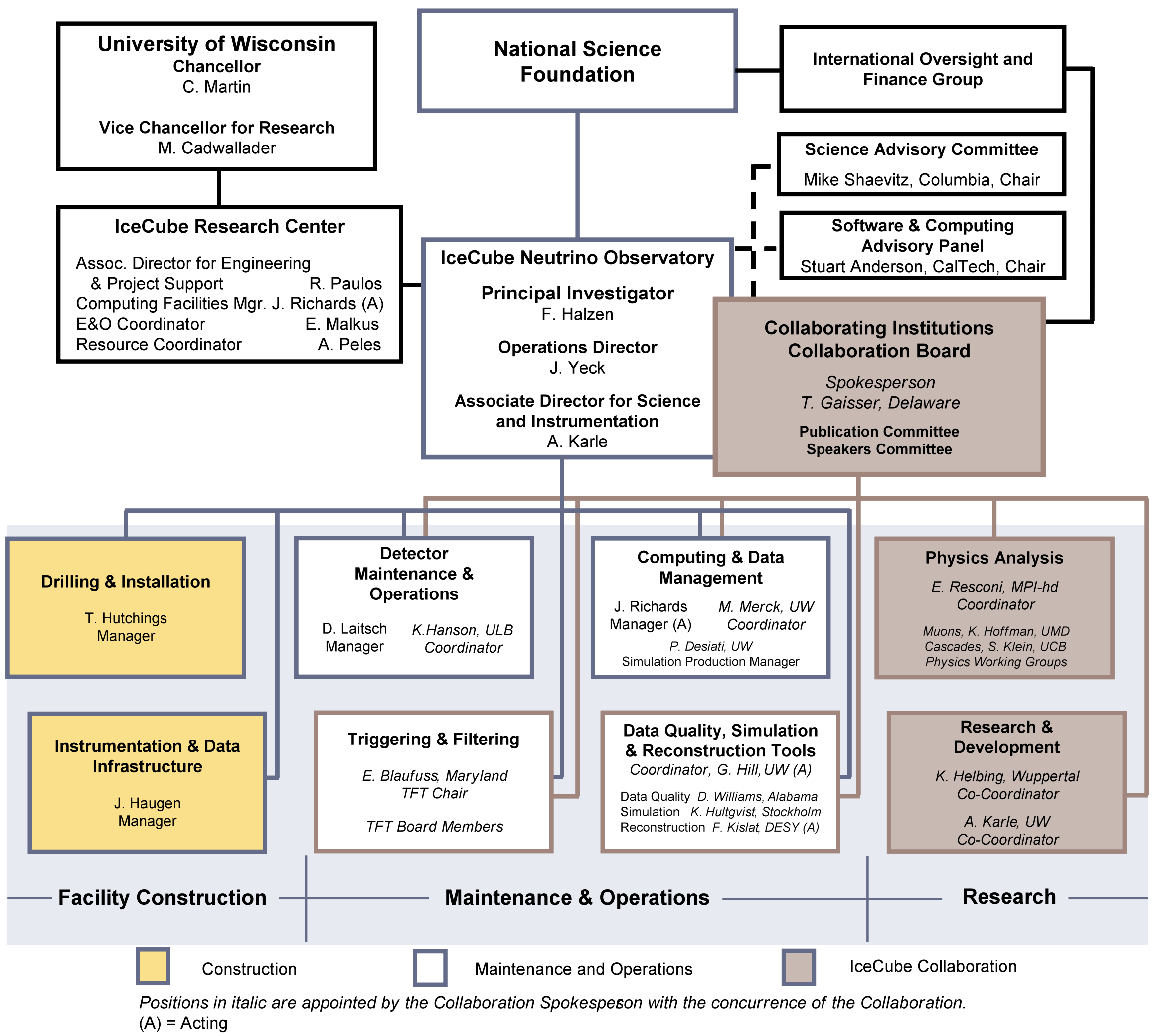

Figure 4.1-1. IceCube Organization. *Our organization maximizes the use of both Collaboration resources and Core resources managed by UW while maintaining clear lines of accountability to the NSF.*

in a timely way. The IceCube Spokesperson and the Director of Operations are jointly responsible for the success of the IceCube M&O program with the Spokesperson directly accountable to the Collaboration and the Director of Operations accountable to the National Science Foundation through the University of Wisconsin-Madison as the host institution for the M&O program.

The Spokesperson-appointed coordinators and the Operations Director-appointed managers are successful through the efforts of collaborating scientists, technical professionals, and managerial and administrative support staff. The entire M&O scope of work is detailed in a Work Breakdown Structure (WBS) and the WBS tasks are defined in a detailed Memorandum of Understanding (MOU) approved by the IceCube Collaborating institutions. Every task in the MOU is assigned to an institution. The Principal Investigators (PI) at the institutions are responsible for ensuring that the work is completed on schedule. If an institution is not able to fulfill an agreed upon commitment the Institutional PI is responsible for ensuring that the work is assigned to another institution before there are adverse impacts to the M&O program. The MOU is still under development. The goal is to finalize it by the end of the second ICB meeting on May 1, 2009.

The lessons learned from the initial M&O phase are addressed in the approach with clear lines of accountability for both distributed and centrally managed activities and additional accountability mechanisms for In-kind and institution contributions. There is an effective balance between Core tasks that are centrally funded through UW and In-kind tasks that are funded through the IceCube Collaborating Institutions.

4.1.1. University of Wisconsin-Madison

IceCube Oversight. The lead executive officer of the University of Wisconsin-Madison is the Chancellor. The Chancellor delegates responsibility for research activities to the Vice Chancellor for Research. The Vice Chancellor for Research maintains oversight of the IceCube Neutrino Observatory and appoints the IceCube Operations Director.

The IceCube Principal Investigator and the Operations Director report directly to the Vice Chancellor for Research and report regularly, typically quarterly, to the university's IceCube leadership. The leadership team includes the Chancellor, Provost, Vice Chancellor for Research, and Vice Chancellor for Administration/Budget, Planning & Analysis. The meetings are called by the Vice Chancellor for Research and provide a forum for the IceCube Principal Investigator and the IceCube Operations Director to inform the university leadership team of significant issues pertinent to the management of the IceCube Neutrino Observatory. The Operations Director provides a written monthly report highlighting significant issues to the university leadership team. The Operations Director contacts the Vice Chancellor for Research when significant developments occur or important issues arise.

IceCube Research Center. The UW support to the IceCube M&O Program is primarily through the IceCube Center and the Center's connection to the university's infrastructure and services. UW-Madison established the IceCube Research Center within the Graduate School to coordinate the multiple roles of the university:

- Lead institution for the IceCube Construction Project;
- Host institution for initiating and continuing IceCube Maintenance and Operations;
- Coordinating institution for IceCube Education and Outreach activities;
- Coordinating institution for Research and Development directed at technologies for increasing the IceCube neutrino detection volume; and
- Collaborating institution with the largest participating research group.

4.1.2. IceCube Collaboration

The Collaboration plays a leading role in IceCube, guiding both science and M&O. The benefits of this distributed organizational model are 1) the ability to draw highly qualified and specialized personnel from Collaboration institutions to perform specific tasks in support of science or M&O, and 2) the education and training opportunities through hands-on IceCube participation for faculty, postdocs and students from multiple Collaboration institutions.

IceCube Collaboration Board. The Collaboration Board (CB) is the policy-making entity that guides and governs the scientific activities of the Collaboration. It consists of a representative from each collaborating institution as described in the IceCube Governance Document. It establishes, and as necessary, amends governance procedures and has oversight and authority over science policy and goals, membership, data access, publications, representation of IceCube at topical and general conferences, analysis teams, and education and outreach.

Executive Committee. The Spokesperson, in consultation with the Collaboration Board and the P.I. and the Project Director, appoints and chairs an Executive Committee of the Collaboration Board (**Figure 4.1-2**). The term of the members is two years. The job of the Executive Committee is to advise the Spokesperson in proposing actions to the Collaboration Board and in making interim decisions. The members of the Executive Committee represent major groups, functions and competences within the Collaboration.

	Name and Institution	Area of Expertise/Responsibility
Spokesperson	Tom Gaisser, University of Delaware	Cosmic-ray Physics, Overall direction of IceCube Collaboration
Member	Albrecht Karle, University of Wisconsin	All aspects of detector operation, Associate Director for Science & Instrumentation, liaison with R&D
	Dave Nygren, Lawrence Berkeley National Laboratory	Hardware design and innovation, Member of NAS / Generalist
	Lutz Koepke, Universität Mainz	High-energy experiments, Supernova subsystem
	Per Olof Hulth, Stockholm University	Neutrino physics, Lead for Deep Core Sub-array
	Greg Sullivan, University of Maryland	Neutrino and gamma-ray astronomy, MREFC Lead for Data Systems
	Doug Cowen, Pennsylvania State University	Neutrino astronomy / L2 Lead for Verification in MREFC
	Daniel Bertrand, Université Libre de Bruxelles	High-energy experiment / Detector operations
Ex-Officio Member	Francis Halzen, Principal Investigator, University of Wisconsin	Neutrino astronomy & high-energy physics, overall scientific direction
	Christian Spiering, former Spokesperson, DESY Zeuthen	Neutrino astronomy, operations & strategy
	James Yeck, Operations Director University of Wisconsin	Project and Operations Management, NSF Primary Contact for IceCube Operations

Figure 4.1-2. Executive Committee of Collaboration Board. *The Executive Committee provides guidance and direction to the Collaboration to address issues occurring between full Board meetings.*

Collaboration Institution Tasks. Tasks will be rotated in a fair and equitable manner, taking account of the special interests and capabilities of each institution. Tracking and transparency will be provided by a task matrix of the form shown in summary in **Figure 4.1-3**. (The full version of the task matrix appended to Section 6 (Cost) provides an initial breakdown of tasks by Collaboration institution that provides the foundations of new MOUs negotiated with each institution and provides a guide to NSF as to our recommendations for base grant support to these institutions.)

4.1.3. Key and Critical Personnel

Our key and critical personnel form the leadership team that ensures the success of the IceCube M&O and the timely exploitation of its scientific discovery and education and outreach potential. This section discusses the roles and responsibilities of these personnel and their respective qualifications.

	US (FTE)		Europe & Asia Pacific (FTE)	In-kind Totals
	Core	Base Grants		
2.1 Management	7.92	2.75	2.25	5.00
2.2 Detector M&O	12.60	3.04	2.11	5.15
2.3 Computing & Data Management	15.30	1.40	6.65	8.05
2.4 Triggering & Filtering	0.30	4.40	2.30	6.70
2.5 Data Quality, Simulation and Reconstruction Tools	1.90	4.75	4.80	9.55
In-kind Effort Still To Be Distributed		3.00	2.50	5.50
Totals	**38.02**	**19.34**	**20.61**	**39.95**

Figure 4.1-3. IceCube Task Matrix Summary. *The Collaboration provides more than half of the resources required for IceCube M&O from U.S. and Europe & Asia Pacific In-kind contributions.*

4.1.3.1. Key Personnel

Key personnel (**Figure 4.1-4**) are employees of the Host Institution, University of Wisconsin-Madison. UW-Madison will seek concurrence from the NSF prior to any changes in the appointments.

Name & Position	Responsibilities	Qualifications
Principal Investigator ***Francis Halzen***	Responsible for the overall success of the IceCube Neutrino Observatory	▪ UW Hilldale and Gregory Breit Distinguished Professor, and Director of the UW Institute for Elementary Particle Physics Research ▪ Service on advisory committees, including those for the SNO and HiRes experiments ▪ Consultant for the Exploratorium in San Francisco
Co-Principal Investigator, Director of Operations ***Jim Yeck***	O&M of IceCube facilities to ensure operations meet established performance goals and the needs of NSF and the IceCube Collaboration	▪ UW Senior Scientist ▪ Experienced Director and Manager of Large Science Facilities sponsored by DOE and NSF including RHIC, U.S. LHC Construction Project, and IceCube construction ▪ Service on advisory committees including Advanced LIGO, and the National Synchrotron Light Source-II
Co-Principal Investigator, Associate Director for Science and Instrumentation ***Albrecht Karle***	Technical performance of the IceCube detector infrastructure and ensuring the it meets IceCube science objectives	▪ UW Faculty ▪ Associate Director for the IceCube Construction Project ▪ Technical leader in AMANDA construction and operations ▪ Scientific and technical lead for the IceCube construction ▪ Co-PI for Science Coordination Office for Astrophysical Research in Antarctica

Figure 4.1-4. IceCube Key Personnel.

4.1.3.2. Critical Personnel

Our critical personnel (**Figure 4.1-5**) form the core team that balances resources from the central M&O Cooperative Agreement and from Collaboration members to maximize value and efficiency to IceCube.

Name & Position	Responsibilities	Qualifications
Collaboration Spokesperson ***Tom Gaisser***	Effective governance of the Collaboration, and coordinating the resources of the members to support IceCube M&O	▪ Martin A. Pomerantz Prof. of Physics, University of Delaware ▪ Distinguished member of IceCube Collaboration ▪ Head of IceTop group at University of Delaware ▪ Leading researcher in astroparticle physics and high-energy cosmic rays, and astrophysical and cosmological neutrinos
Detector M&O Coordinator ***Kael Hanson***	Ensuring the necessary Collaboration resources are identified and applied to bring the highest value to IceCube	▪ Faculty member of the Université Libre de Bruxelles ▪ Associate Instrumentation Innovator for IceCube – Data Acquisition Systems Lead and Detector Ops Coordinator ▪ Oversaw design, production, and testing of optical sensor hardware for IceCube project

Name & Position	Responsibilities	Qualifications
Detector M&O Manager ***Denise Laitsch***	Managing detector O&M to support researchers with consistently high detector availability and data quality	▪ Eight years of collaboration with IceCube institutional, science, technical, and administrative leads ▪ Designed, built and delivered the U.S. Geostationary Satellite Archive System for the National Climatic Data Center ▪ O&M of computing infrastructure for scientific users
Computing & Data Management Coordinator ***Martin Merck***	Coordinating computing and data management policies, plans and resources across the entire Collaboration	▪ Astroparticle physicist with experience in several major experiments (HEGRA, EGRET, MAGIC) ▪ Extensive IT industry experience as System Engineer and Consultant for Giesecke & Devrient GmbH, SUN Microsystems and IFS Informationstechnik GmbH
UW Computing Facilities Manager ***John Richards (Acting)***	Managing UW computing facilities to ensure that data is optimized for physics analysis	▪ Designed and implemented 450 TB disk storage, distributed file systems and backup systems for IceCube data ▪ Coordinated development with physicists, and adapted and expanded designs to respond to needs of the project
Simulation Production Coordinator ***Paolo Desiati***	Responsible for coordinating simulation production across the entire Collaboration	▪ Associate Scientist at the University of Wisconsin – Madison ▪ Conceived simulation production software requirement design ▪ Initiated the concept of IceCube distributed computing infrastructure as a way to utilize the collaboration resources for producing and processing Monte Carlo simulation data
Trigger, Filter, Transmission Board Chair ***Erik Blaufuss***	Coordinating triggering and filtering M&O function and chairing TFT Board that sets priorities for the Collaboration	▪ University of Maryland Research Scientist ▪ Technical lead for online filtering system and offline software analysis framework ▪ Served on review and advisory committees for NSF and UM Physics department
Data Quality, Simulation & Reconstruction Tools Coordinator ***Gary Hill (Acting)***	Detector data quality, release of upgrades to the detector simulation programs, and reconstruction algorithms	▪ Inaugural IceCube Analysis Coordinator, 2006-08 ▪ Detector Verification and Physics Benchmarks lead, 2004-07 ▪ Diffuse neutrinos working group co-lead, 2006-08 ▪ Author of several novel event reconstruction and simulation techniques used extensively in AMANDA and IceCube

Figure 4.1-5. IceCube Critical Personnel.

4.1.4. Advisory Committees

4.1.4.1. Science Advisory Committee

In consultation with the collaboration, the Principal Investigator and the Spokesperson appoint a Scientific Advisory Committee (SAC) (**Figure 4.1-6**) of external experts. The role of the SAC is to make recommendations on the IceCube scientific goals and on any other matters that may affect the scientific activities of the IceCube Neutrino Observatory. The SAC meets annually.

Position	Name and Affiliation	Area of Expertise/Responsibility
Chair	Mike Shaevitz, Columbia University	Neutrinos, Research Management
Member	Lothar Bauerdick, Fermilab	Particle Physics Computing, USCMS Software & Computing Manager
	Howard Gordon, Brookhaven National Lab	Collaboration Management, USATLAS Deputy Research Director
	Rocky Kolb, University of Chicago	Astrophysics, Theorist
	Karol Lang, University of Texas	Neutrinos, Collaboration Management
	Eckart Lorenz, ETH Zurich, MPI	Astroparticle Physics, HEP, Detectors
	Paul Mantsch, Fermilab	Cosmic Ray Detectors, Auger Project Manager
	Jay Marx, Caltech	Laboratory Management, LIGO Director
	Wyatt Merritt, Fermilab	Particle Physics, D0 Experiment and Dark Energy Survey (DES)
	Steven Ritz, UC Santa Cruz	Astroparticle Physics, GLAST Project Scientist

Figure 4.1-6. IceCube Science Advisory Committee.

4.1.4.2. Software & Computing Advisory Panel

The IceCube Software & Computing Advisory Panel (SCAP) (**Figure 4.1-7**) is composed of experts in the fields of software development and scientific computing. The SCAP advises the IceCube Spokesperson and Director of Operations on the most efficient and effective computing resources for IceCube, including on-line computing; on-line and off-line data processing and filtering; off-line computing facilities; and simulations and analysis tools support. The Spokesperson and the Director of Operations appoint the SCAP members and the Chairperson. Meetings are held once each year.

Position	Name and Affiliation	Area of Expertise/Responsibility
Chair	Stuart Anderson, CalTech	Astronomy, Data Analysis, LIGO
Member	Sridhara Dasu, University of Wisconsin	CMS Physics, Triggering, Data Processing, and Distributed Computing in HEP
	Michael Ernst, BNL	Scientific Computing Facilities, RHIC/ATLAS Computing Facility Manager
	Tom Paul, Northeastern	Elementary & Astroparticle Physics, Auger, CMS
	John Pretz, LANL	Astroparticle Physics, IceCube Analysis Software Framework, Milagro Data Analysis
Ex-Officio Member	Lothar Bauerdick, Fermilab	CMS Physics, USCMS Software & Computing Manager, SAC Member

Figure 4.1-7. IceCube Software & Computing Advisory Panel.

4.1.5. M&O Coordination Boards and Organizations

The purpose of coordination organizations is to ensure that M&O tasks from events to publications are properly planned and executed. These organizations make certain that the resources committed in their areas of activity are realized and used efficiently and effectively. Examples include the following.

Coordination Committee. The role of the Coordination Committee is to provide high-level coordination of IceCube M&O, analysis, and R&D. The committee is chaired by the Associate Director for Science and Instrumentation and is comprised of the Spokesperson-appointed coordinators (shown in **Figure 4.1-1**), UW M&O managers, and others as needed. The committee typically meets on a bi-weekly basis to address technical and resource issues, and to advance strategic goals. The committee is the primary point for determining priorities and resolving resource conflicts that arise at lower levels in the organization. Issues that cannot be resolved by the Coordination Committee are resolved by the Spokesperson and Operations Director.

Trigger Filter Transmit (TFT) Board. The role of the TFT Board (**Figure 4.1-8**) is to maximize transmission of scientifically valuable data within the constrained resources of the South Pole system in support of IceCube's scientific objectives. It coordinates proposals for and execution of new technologies and software to continuously enhance detector output.

Position	Name and Affiliation	Area of Expertise
Chair	Erik Blaufuss - University of Maryland	Online filtering system
Member	Azriel Goldschmidt, LBNL	Run Coordination
	Kael Hanson - Université Libre de Bruxelles	DAQ System
	Teresa Montaruli - University of Wisconsin - Madison	Physics working groups
	Carlos de los Heros - Uppsala Universitat	Physics working groups
	Marek Kowalski - Humboldt Universitat	Physics working groups
	Paolo Desiati - University of Wisconsin - Madison	Physics working groups
	Dave Seckel - University of Delaware	Physics working groups
	Doug Cowen - Pennsylvania State University	Physics working groups
Ex-Officio	Albrecht Karle - University of Wisconsin - Madison	Detector Operations

Figure 4.1-8. Trigger Filter Transmit Board.

Detector Operations Coordination Committee. This committee (**Figure 4.1-9**) ensures that Collaboration resources committed in MOUs for critical detector M&O functions is provided as required and performing effectively. It also identifies resources within Collaboration institutions and in the M&O organization to resolve detector operational issues and provides oversight of issue resolution.

Position	Name and Affiliation	Area of Expertise/Responsibility
Chair	Denise Laitsch, University of Wisconsin	Detector M&O Coordinator
Member	Azriel Goldschmidt, LBNL	Run Coordinator
	Erik Blaufuss, University of Maryland	Processing and Filtering
	Kael Hanson, Université Libre de Bruxelles	DAQ Coordinator
	Dawn Williams, University of Alabama	Calibration and Verification
	Jason Koskinen, Penn State University	High-level Detector Monitoring
	Kirill Filimonov, University of California - Berkeley	Data Monitoring
	Martin Merck, University of Wisconsin	Computing and Data Management
	John Richards, University of Wisconsin	Computing Facilities
	Mark Krasberg, University of Wisconsin	Low-level Detector Monitoring
	John Jacobsen, University of Wisconsin	IceCube Live
	Winterovers, University of Wisconsin	Detector Operations
	Serap Tilav, University of Delaware	IceTop

Figure 4.1-9. Detector Operations Coordination Committee

Analysis Coordination Working Groups. The responsibility of the Working Groups is to provide a framework for coordinating analysis with operations and technology development for an integrated focus on IceCube science and technology issues and needs. The Working Groups provide specialized expertise and general support to M&O tasks that include maintaining the data warehouse; developing data preparation scripts; and supporting detector calibration and verification of its performance. Tasks for each collaboration member are described in general in their MOUs. The Collaboration assigns a leader responsible for each functional area to coordinate Collaboration institution resources in that area

4.2. Maintenance and Operations Plan

Building on our experience over the last three years we have developed a plan to maintain and operate the detector and manage our collaboration resources to go from raw data to physics publications in a timely and efficient manner. Our plan maximizes IceCube's scientific potential and educational value by distributing both analysis and M&O tasks among collaborators. This structure draws the best expertise from collaborating institutions while also offering opportunities to educate scientists and engineers through hands-on experience with IceCube. We provide accountability mechanisms in MOUs and strong leadership to coordinate distributed resources. In this section we present our plan by explaining how we will perform each task required to meet the technical requirements and specifications described at a top level in Section 3 and listed in detail in our draft Statement of Work in Appendix 3.

4.2.1. Program Management

4.2.1.1. Program Administration

Challenges. The initial two years of M&O Program Management confirm the need for a strong program management effort during the period covered by this proposal. The concurrent period of construction and initial operations enabled the M&O program management support to be less than required, with the construction funding the dominant source of support. This cost-sharing arrangement is not feasible in the future when the construction project is complete. The primary program administration challenge is to ensure that the resources needed to perform each task, regardless of source, are available when needed and used efficiently to accomplish the task requirements.

Approach. Our approach focuses resources on achievement of IceCube's scientific objectives and provides accountability to NSF for taxpayer funds. The approach has four primary elements:

Operations Management and Science Support. We provide leadership to manage the effectiveness and efficiency of all services and ensure communication among the Collaboration, NSF, partner funding agencies, and the M&O functions. We prepare strategic plans and conduct formal risk management to achieve objectives.

Computing Infrastructure Management. We manage computing resources to maximize uptime of all computing services and availability of required distributed services, including storage, processing, database, grid, networking, interactive user access, user support, and quota management.

Financial Management. We manage IceCube finances, including the NSF funding requested in this proposal, a Common Fund supported by cash and invoice payments by European and Asian Pacific collaborating institutions, and in-kind contributions from collaborating institutions, providing accountability through an audit trail for all funds regardless of source.

Performance Management and Reporting. We establish objective performance measures in cooperation with NSF, which are meaningful to evaluating our performance against M&O objectives. We also establish with NSF a set of reporting deliverables that fulfill NSF internal and external requirements for oversight. Initial proposed performance measures and deliverables are in **Figure 4.2.1-1** and **Figure 4.2.1-2,** respectively.

4.2.1.2. Engineering and R&D Support

Challenges. Reliable IceCube operations require specific technical support from scientific, engineering, and software professionals on an as-needed basis to avoid the costs of permanent technical staff that is not fully utilized. This technical expertise assists IceCube M&O personnel with planning and completing specialized maintenance tasks and upgrades, and solving problems.

Approach. The engineering and R&D tasks included in the cost proposal are limited to the minimum tasks required to support day-to-day operations of the detector. R&D supports efforts to address Electromagnetic Interference (EMI) in the Dark Sector, enhancements to the performance of the IceCube Laboratory electronics and computing, and the ability to interface with externally funded R&D activities, especially those that intend to use the IceCube facilities. Our general approach is to purchase specialized

Key Performance Indicator	Objective	Rationale
Detector Uptime	99%	Key performance measure of time that the detector was sensitive to transient astrophysical events or signals
Detector Clean Uptime	95%	Key indicator of production of pristine data for physics analysis with no contamination and no serious alerts
Monitoring & Paging Uptime	99.9%	Critical to detection of problems that impact detector performance and quality of data
IceCube Live Uptime	99.9%	Critical to ability to resolve detector performance issues
South Pole System Uptime	99%	Critical to collection and storage of data

Figure 4.2.1-1. Initial Proposed Performance Measures.

Deliverable	Description	Frequency
Program Status	Update of performance against KPIs and financial objectives	Monthly
Program Performance	Analysis of performance against M&O strategic objectives, analysis of program risks, and performance forecasts	Quarterly
State of IceCube Science	Analysis of progress toward IceCube scientific objectives	Annually
Economic Contributions	Accounting and analysis of U.S. economic benefits of IceCube investments by source of funding	Annually

Figure 4.2.1-2. Initial Proposed Reporting Deliverables.

technical support from the most qualified source. M&O program and technical leads define support requirements and procure the needed support.

R&D projects for significant detector performance enhancements to better achieve its scientific objectives or to expand its scientific reach are based on separate applications for funding from multiple sources.

4.2.1.3. USAP Infrastructure Support

Challenges. The success of the IceCube M&O program depends on support managed by the U.S. Antarctic Program. IceCube supports an annual planning cycle that includes the formal submission of a Support Information Package (SIP) to NSF that details the specific support requirements for the facility.

Approach. IceCube personnel prepare detailed support requirements and identify the most cost effective approach to meeting the requirements, either through the SIP process or through coordination with the Science Coordination Office for Astrophysical Research in Antarctica (SCOARA). SCOARA provides limited resources for the science community working in the South Pole's Dark Sector. The dominant source of USAP infrastructure support is from NSF's support contractor as a result of the SIP.

4.2.1.4. Education and Outreach (E&O) Coordination

Challenges. The primary challenge is to coordinate financial and in-kind resources from multiple sources to maximize the science and education benefit of IceCube and enhance public support.

Approach. As a part of Collaboration MOUs, each member contributes support to E&O. The E&O Coordinator working with NSF and IceCube leadership establishes E&O priorities, provides support to ongoing activities and responds to outside requests that support priorities by identifying appropriate resources within the collaboration, assigning tasks and providing oversight. **Figure 4.2.1-4** describes examples of ongoing and proposed high-impact IceCube E&O activities.

E&O Activity Title	Description	Benefit
Support to Upward Bound Program	National, basic skills summer program for underrepresented high school students	Emphasizes importance of science and scientific opportunities to underrepresented groups
Support to Pre-service Teachers	Mentoring of pre-service teachers by South Pole-expert Master Teachers	Extends educational value of IceCube exponentially by engaging new teachers
Support to Polartrec	NSF-funded outreach program that pairs polar researches with teachers	Provides new teachers in-depth science & technology training
Support to Post-doc Exchange	Mentoring by IceCube post-docs of undergraduates in research possibilities	Encourages undergraduates to pursue careers in basic science
Support to QuarkNet (proposed)	Provide IceCube data in a form for use of high school students through the QuarkNet Program at Fermilab	Promotes interest in physics and basic science research careers at the high school level
Support to Event Viewer (proposed)	Provide visualization of IceCube neutrino events in user-friendly viewer with output in multiple formats	Enhances understanding of the IceCube detector's operation and its science for both scientists and the public

Figure 4.2.1-4. Examples of E&O Activities.

4.2.1.5. Distributed Computing and Labor Reserve

Challenges. Distributed computing is an essential and cost effective approach to meeting the IceCube computing requirements. The challenge is to ensure that the U.S. groups secure institutional contributions as part of the plan for meeting the overall IceCube computing requirements.

Some of the distributed in-kind labor that is assumed to be provided through NSF base grants will not be realized if the grant funding is less than required. The challenge is to ensure the IceCube M&O performance goals are not adversely affected from modest shortages in base grant support.

Approach. A relatively small amount of M&O core support will be provided to U.S. collaborating groups on an ad hoc basis to leverage significant institutional contributions. This will reduce the demand for centralized computing resources at UW.

A labor reserve is created to provide the flexibility needed to complete M&O tasks with NSF core M&O support rather than the assumed NSF based grant support.

4.2.2. Detector Maintenance and Operations

Challenges. The management responsibility under IceCube Maintenance and Operations has evolved over the past two years. For example, under the original M&O organization, the SPS and SPTS hardware, operating systems, networking and data archive were managed by an IT professional in parallel with Operations and Maintenance, which managed run coordination, DAQ support, monitoring, calibration and verification. In 2009, we reorganized these efforts under a single structure to improve reliability, visibility and accountability of the overall detector data collection and delivery processes.

Approach. The IceCube Maintenance and Operations Coordinator is accountable for the overall performance of the people, hardware and processes required to execute the operational plan of the detector at the South Pole. The Coordinator holds weekly phone calls on run coordination and detector operations matters, prepares monthly and annual reports to NSF, prepares budgets, manages expenses, serves as a member of the Coordination Board, resolves personnel matters, organizes planning for the austral summer, supports the SPTS, and is generally responsible for the overall coordination and performance of the detector through management of subsystem leads.

4.2.2.1. Run Coordination

4.2.2.1.1. Coordinate Detector Runs

Challenges. During normal operations, most typical of the austral winter, the Run Coordinator ensures that data is being taken with high uptime and that the data is of the highest quality, with emphasis on data stability. This translates into large data sets of physics quality data that can be readily processed and analyzed. The austral summer brings increased activity to the detector through the addition of new strings and planned maintenance of the computing networking and detector subsystems. The on-ice lead assumes a day-to-day coordination role while the Run Coordinator provides overall coordination and oversight.

Approach. The Run Coordinator manages the activities of sub-system experts and operators both at the South Pole and in the Northern Hemisphere carefully documenting the run operation and auditing its effects on the data. Documentation and communication includes daily monitoring reports, daily reports of data transfers from the South Pole, e-mail alerts on error conditions, regular data verification reports, weekly Winterover reports, and other communications with stakeholders using a variety of media.

4.2.2.1.2. Operate Detector (Winterovers)

Challenges. The South Pole System (SPS) requires full-time, on-site attention by two professionals who winter over at the South Pole Station each year in highly challenging conditions. As the first line of defense in maintaining live detector time, Winterovers may be frequently cut off from communication with the Northern Hemisphere and must be prepared to make independent critical decisions.

Approach. A dedicated Winterover manager coordinates the activities of the Winterovers, including training and activities at the South Pole. The manager prioritizes requests to Winterovers for support. Concurrent with the final months of the Winterovers on-site at the South Pole, two additional Winterovers prepare for the next season by training on system architecture, operating systems, and other key aspects of detector operations, and monitoring and maintenance. At the beginning of the three-month period in which the South Pole Station is open, the Winterovers prepare their replacements with hands-on experience and methodologies before their departure.

4.2.2.2. Data Acquisition (DAQ)

4.2.2.2.1. Maintain DAQ Hardware

Challenges. The DOMHubs and their internal components, as well as associated cabling, must be maintained to prevent malfunctions and repaired quickly if a breakdown occurs to minimize detector downtime and maintain a high quality of data. The basic DAQ hardware surface component is the DOMHub, which houses customized hardware including 2 Acopian power supplies, 1 DOM Service Board (DSB), and 8 DOM Readout Cards (DORs). A DOMHub is fed by up to 64 DOMs. A GPS feeds the DSBs, which provides IceCube with an accurate timing system.

Approach. The Winterovers maintain and repair the DAQ hardware at the South Pole. The SPTS and PCTS DAQ hardware managers maintain and upgrade the system to improve functionality, designing upgrades and testing them in the SPTS prior to deployment at the SPS.

4.2.2.2.2. Maintain DAQ Software Systems

Challenges. DAQ software collects raw hits from the individual DOMs, rejecting noise hits and forming triggers with all the relevant data for physics events in the detector. Diagnostic and calibration data is also collected as are raw counting rates for all DOMs, used for the supernova triggers. Performance of the DAQ software is a major driver of the quality of data for physics analysis.

The DAQ system has a limited amount of available readout capacity. To increase the physics reach of the IceCube detector, especially at lower energies, reducing the trigger threshold for the simple multiplicity trigger is not an option. Instead, special trigger algorithms that take advantage of event pattern differences between signal and background events are needed.

Approach. DAQ software engineers are accountable for the uptime of the DAQ and the integrity, correctness and completeness of the data it produces. They also provide appropriate documentation for the operators. They regularly test and troubleshoot DAQ software systems—including DOM software, DOR card device drivers, StringHubs, system subtriggers and global trigger, event builder, secondary builders, and control scripts—as new strings are added and new triggers are required in response to evolving science needs.

Collaboration physicists from physics working groups, using Monte Carlo simulation of signals, develop new triggering algorithms for use in the DAQ. Physics working groups propose new trigger algorithms to the Trigger, Filter, Transmission (TFT) Board. Once approved by the Board, the triggers are adapted, tested and deployed within the DAQ triggering system.

4.2.2.2.3. Provide Digital Optical Module (DOM) Firmware Technical Support

Challenges. The DOM firmware consists of a low-level FPGA design responsible for controlling the DOM hardware. Its primary tasks include collecting readout hit data and buffering it in memory, as well as supporting a large variety of configuration and control operations that are critical to DOM operation and resulting data quality. Two DOM FPGA designs require support, one for testing and DOM production and a more complete design for use during normal physics data collection. An additional design is required for the DOR cards to control power and communication with up to 8 DOMs per DOR card.

Approach. DOM Firmware Engineers supply required FPGA modifications, maintain the code base, and update documentation as needed. A small amount of DAQ software engineering effort and expertise are required to support testing and troubleshooting. Both DOM and DOR firmware are relatively stable, but as remaining strings are added during constructions, firmware is likely to require adjustments or troubleshooting. In addition, new physics requirements during the stable experimental program will require additional features in either the DOM or DOR FPGA designs.

4.2.2.2.4. Maintain DOM Calibration (DOMCal System)

Challenges. Calibration runs are taken monthly, studied and fed into the main IceCube database. These results are then used as part of online reconstruction, affecting data rates and data selection by IceCube filtering (**Figure 4.2.2-1**). Up-to-date DOM calibrations are a necessary part of understanding what the data taken by IceCube means.

Approach. The Detector Operator is responsible for running DOMCal, with waveform calibration support to help interpret the results from DOMCal runs and to upgrade the DOMCal system as required. During stable operations, the Detector Operator will perform upgrades in response to evolving science program needs. The waveform calibration support lead provides upgrades to calibration software as required.

4.2.2.2.5. Monitor and Maintain DOMs

Challenges. Some DOMs have malfunctioned and must be operated as part of normal data-taking in a non-standard configuration (for IC40, this figure was approximately 100 DOMs). To date, a small number of DOMs have broken down, which results in the need for a detector reconfiguration. The typical solution

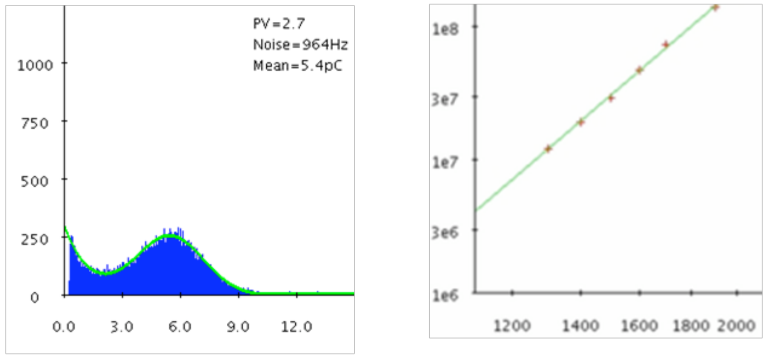

Figure 4.2.2-1. DOM Calibration Maintenance. *Monitoring DOM voltage and gain ensures proper calibration. Illustrated is a charge distribution based on noise data for one DOM (left). The peak corresponds to the most probable charge generated by a single photoelectron. Also shown is the gain vs. voltage correlation for that sensor.*

is to bypass the failed or malfunctioning component within the DOM or to bypass the DOM completely. During stable operations, we expect that the number of problem DOMs will increase as the detector ages. The challenge is to minimize the number of DOMs taken out of service, which adversely impacts detector data collection capabilities.

Approach. The Detector Operator, working with the Winterovers, excludes problem DOMs from the array and attaches them to the "wczar" DOMHubs. The Detector Operator conducts DOM hardware maintenance runs and creates new standard run configurations as needed, tracking problem DOMs and performing studies on problem DOMs to develop solutions or workarounds that minimize impact of malfunctions on data quality. To date, new standard runs have been created quickly in response to DOM problems. Studies of problem DOMs in the past have produced solutions to significant DOM hardware malfunctions that allowed for their full reintegration into the standard configuration of the array.

4.2.2.3. Online Filters (Processing and Filtering—P&F)

4.2.2.3.1. Maintain P&F Software and Online Filters

Challenges. The volume of data produced by the data acquisition system far exceeds the limited bandwidth available in IceCube's TDRSS satellite allowance. Instead of taping the entire data sample, an online filtering system is used to apply a set of first-level event selections to the collected data, transmitting only those selected events. In normal operations, P&F system expertise is required to maintain the online system, ensure filters are being properly applied, and respond to and debug unexpected errors. This effort will ensure that the online filtering system produces the highest quality data.

Approach. P&F system maintenance work requires a software engineer knowledgeable of the IceTray software framework. Maintenance is performed at the start of each new physics run (April of each year) and on an as-needed basis at other times. This may include requests from the Trigger, Filter, Transmission (TFT) Board to support new analysis priorities.

4.2.2.3.2. Design Software and Deploy Online Filters in P&F

Challenges. The P&F system must collect triggered events from the data acquisition system, run any required calibrations and reconstruction algorithms, apply any filtering algorithms, write the data into a format that contains the results of reconstructions and filters applied, and categorize the output data into data sets for transmission and archiving. The primary challenge is to ensure proper implementation of filters without impacting detector efficiency.

Approach. Collaboration physicists implement and test new online filters in advance of each new physics run after approval by the TFT Board. Implementation requires support with expertise in both reconstruction tools and the online filtering system. This process includes testing filters and working with filter proposal writers to ensure that filter designs achieve objectives and are properly implemented.

4.2.2.4. South Pole System (SPS)

4.2.2.4.1. Maintain SPS Computing Hardware Infrastructure

Challenges. The SPS architecture maximizes parallel operation to enable random asynchronous events to be observed and collected into meaningful physics data. The SPS hardware fills 17 standard computer racks with DOMHub computers, standard server class computers, calibration equipment, remote connectivity equipment, network hardware, and power supplies. The DAQ server component consists of 14 hosts. The online filtering cluster requires 40 SMP hosts to scale with future computing speeds as needed. Near-line storage for the system currently approaches 40 TB, which provides real-time buffering margins and increased fault tolerance through RAID implementations. The average power dissipation of the system is 30-35 KWatts, and is designed to scale with the detector.

Approach. System administrators are responsible for hardware maintenance and operations of the South Pole computing hardware. The administrators respond to the support requirements of Winterovers, software developers and engineers to maximize hardware reliability and provide customized solutions to increase detector uptime. This includes preventive maintenance, troubleshooting, and upgrades.

4.2.2.4.2. Maintain SPS Computing Operating Systems

Challenges. The software covered by this task includes the South Pole System (SPS) operating within the IceCube Laboratory (ICL) at the South Pole. The operating systems software is licensed through RedHat and is managed with RedHat Network (RHN). It allows system administrators and Winterovers to efficiently manage operating system version control, perform patching, software updates, monitoring and maintenance. Optimal configuration and operation of the local RHN server is critical to detector performance.

Approach. System administrators and Winterovers are responsible for system maintenance, troubleshooting and upgrades for the South Pole computing base. Typically, upgrades are in the form of individual machine patches, but can, in the case of damaged systems, involve full system reconstruction. RHN is deployed on a single server within the SPS and provides complete functionality to the South Pole computing base that subscribes locally to its services. These services include patch management, monitoring and system configuration control. The local server connects with RedHat's servers over the Internet to download updates and meta-data.

4.2.2.4.3. Maintain SPS Networks and Network Security

Challenges. The IceCube network is the core fabric that integrates major project work groups, remote work sites, and ongoing operations. It provides secure connectivity through virtual private network (VPN) tunnels terminating at remote project endpoints. The network also operates in the public domain with exposed web, e-mail and database services. In addition, the IceCube network must interface to points of presence and comply with policies and regulations of NSF and the University of Wisconsin (UW).

Approach. The IceCube Network Engineer is responsible for uptime and performance optimization of the IceCube network, including maintenance, support, configuration, and customization of the system when necessary. During stable operations, the Network Engineer supports the requirements of scientists, software developers, project engineers and detector operators to maximize network reliability. The Network Engineer also monitors the health of the devices and configurations to identify system bottlenecks and potential hardware problems. Security logs are monitored for suspicious behavior and traffic signatures. Corrective action is enforced according to NSF, project and UW policy.

4.2.2.5. South Pole Test System (SPTS)

4.2.2.5.1. Maintain SPTS Hardware

Challenges. The primary purpose of the SPTS is to build and test software in advance of operational deployment in the SPS. Software developers use the SPTS to debug system changes safely in a non-production environment. The close physical and logical match to the SPS allows system maintainers to verify hardware, determine precise cable routing and lengths, and identify potential system side effects introduced by software upgrades, configuration mismatches and environmental variables. The SPTS is a critical piece of the IceCube operational matrix and must be regularly maintained over the life of the detector.

The SPTS is a scaled-down replica of the South Pole System (**Figure 4.2.2-2**). To test firmware and software changes, an assortment of hardware is used as part of a multifaceted approach to emulating conditions at the South Pole. This includes DOMs in dark boxes attached to cable emulators connected to DOMHubs, DOMs in dark freezers attached to long cables (750 m cables for IceTop and ~3 km cables for "in-ice") connected to DOMHubs, and DOM mainboards attached to a programmable pulser attached to DOMHubs used to simulate an entire string.

Approach. IceCube system administrators are responsible for hardware maintenance and operations of the SPTS. During testing, system administrators support software developers and engineers to maximize hardware reliability and provide customized solutions to increase testing time. The SPTS includes a mix of server-class hardware, and power and networking infrastructure. System administrators perform periodic maintenance and updating of each component. Computing hardware maintenance follows a three-year replacement cycle on backwardly compatible server class hardware averaging a total of 5 hosts per year.

The SPTS DOM hardware managers maintain and upgrade the system to ensure maximum uptime when the system is required for testing. They provide support to users, software and hardware engineers to add features as required in response to evolving science needs and to improve the functionality of the SPTS as appropriate.

4.2.2.5.2. Maintain SPTS Operating Systems

Challenges. The software covered by this task includes the SPTS operating at the University of Wisconsin-Madison. Operating system software is licensed through RedHat and managed with RedHat Network (RHN). It allows system administrators to efficiently manage operating system version control,

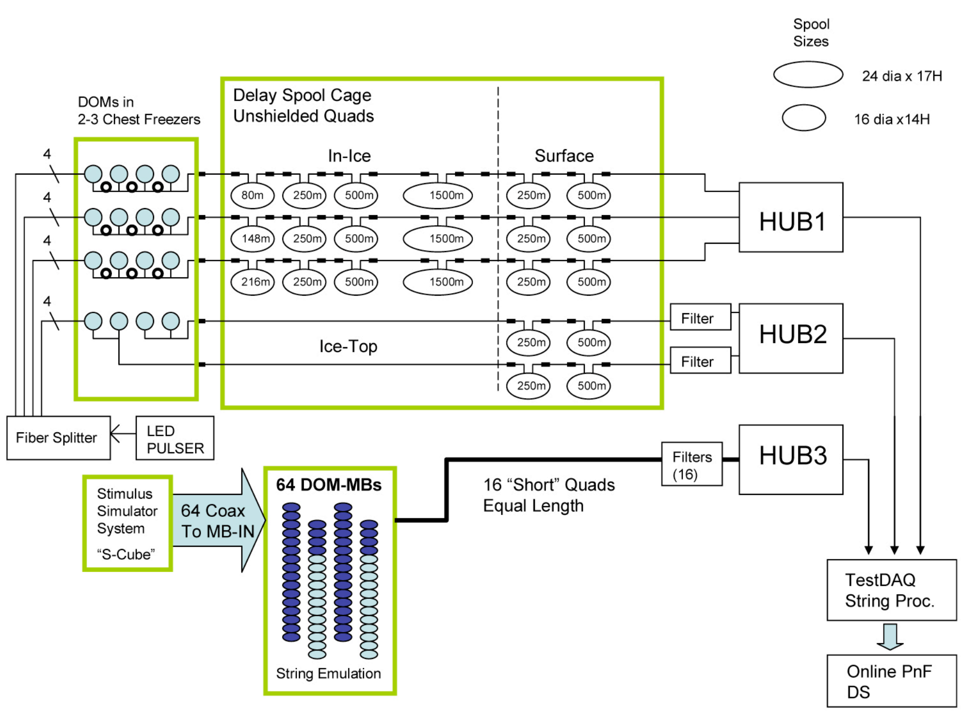

Figure 4.2.2-2. South Pole Test System Schematic. *The SPTS provides a prototype environment for subsystem testing prior to operational deployment on the SPS.*

and perform patching, software updates, monitoring and maintenance. Optimal configuration and operation of the local RHN server is critical to SPTS uptime to ensure availability to resolve critical problems at the South Pole.

Approach. System administrators are responsible for system maintenance, troubleshooting and upgrades for the SPTS operating systems. Typically, upgrades are in the form of patches, but can, in the case of damaged systems, involve full system reconstruction. RHN is deployed on a single server within the SPTS and provides complete functionality to the SPTS computing base that subscribes to its services. These services include patch management, monitoring and system configuration control. The local server connects with RedHat's servers over the Internet to download updates and meta-data.

4.2.2.6. Experiment Control

4.2.2.6.1. Maintain and Update IceCube Live Experiment Control System

Challenges. IceCube Live is the system that integrates control of all of the detector's critical subsystems into a single, virtual command center. It provides an interface for monitoring the detector both via automated alerts and with interactive screens for displaying the current and historical state of the detector and associated subsystems. Web-based and command-line user interfaces provide maximum accessibility and flexibility to the operators located both locally at the South Pole and remotely in the Northern Hemisphere. The system requires a fully redundant hot spare at the ICL because of its criticality to detector operations. It also requires highly reliable access to the detector sub-network, and a software component which runs on the Experiment Control node. IceCube Live is mirrored on the SPTS to test upgrades and changes before deployment.

Approach. The IceCube Live Software Engineer is accountable for uptime of IceCube Live and for maintaining, troubleshooting, supporting and evolving the interface to subsystems that control the detector. During the remainder of the construction phase, the Software Engineer will continue development of IceCube Live to integrate all subsystems, and add features as the behavior of the detector changes and strings are added. During the stable operation phase, the Software Engineer supports physics working groups and operators to add needed functionality and to respond to evolving science needs.

4.2.2.7. Detector Monitoring

4.2.2.7.1. Coordinate Detector Monitoring, and Maintain and Upgrade Systems

Challenges. IceCube Detector Monitoring (**Figure 4.2.2-3**) is the system that provides a comprehensive set of tools for assessing and reporting the data quality. It collects and analyzes raw subsystem data on the SPS immediately on completion of a run. It then sends results to the Northern Hemisphere via satellite where they are processed and presented through a web-based user interface. Detector Monitoring runs on a dedicated node on the SPS. It is also mirrored on the SPTS to test upgrades and changes before deployment, which requires a stand-alone server in the Northern Hemisphere. The system is critical to the ability to perform short-term and long-term analyses of detector performance.

Approach. The IceCube Detector Monitoring Developer/Coordinator is responsible for maintaining, troubleshooting, supporting and evolving the monitoring system. The Developer/Coordinator continues development of the system during the remaining construction phase to integrate added strings, add features and improve algorithms for automated problem detection. During stable operations, the Developer Coordinator continues to coordinate monitoring among collaborating institutions and support physics working groups and users to improve user interfaces and system efficiency and functionality.

4.2.2.7.2. Monitor Detector Stability and Performance

Challenges. Detector Monitoring web pages summarize data in a tabular and graphical form and provide tools for the shift-takers to detect problematic DOMs and/or runs, compare data with the reference values, issue alerts and report any unusual detector behavior on a run-by-run basis. This function is important to ensuring that the detector is operating at peak performance toward collecting the highest quality physics data.

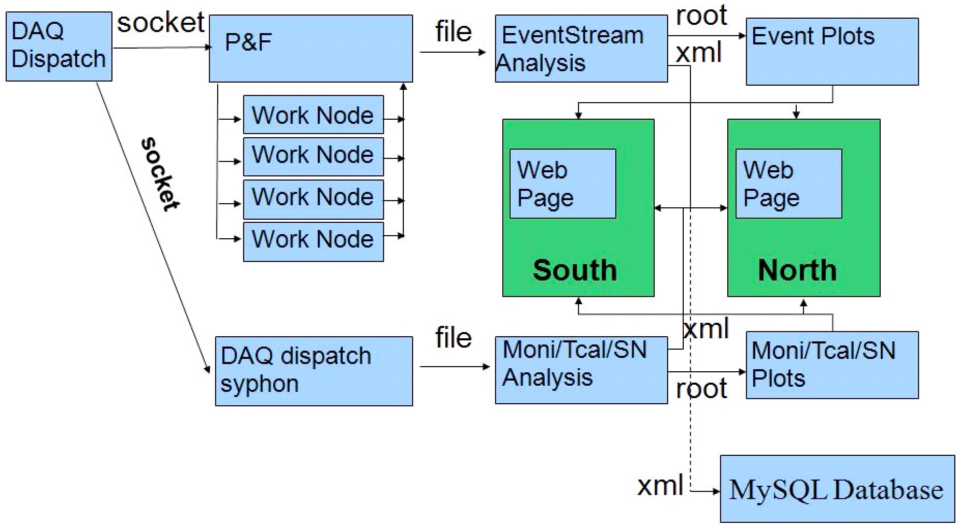

Figure 4.2.2-3. Data Flow of the IceCube Monitoring System. *The assimilation, display and historic archive of monitoring data enables the collection of high quality physics data.*

Approach. The monitoring shift compiles reports on detector performance during each shift and sends the reports daily along with an automatically generated list of identified problems to designated coordinators, managers and sub-system experts, who verify that the detector is operating as expected or take action to correct malfunctions.

4.2.2.7.3. Run and Evaluate Verification Test Data

Challenges. The quality of IceCube data must be checked at multiple points in the data path to isolate and solve quickly any malfunctions that degrade data quality. The tests are performed at the South Pole on all acquired data, using local CPU power, and then the resulting histograms are transmitted to the Northern Hemisphere. These histograms are checked against expectations and any deviations are flagged and automatically brought to the attention of the verification group.

Approach. Collaboration graduate students and postdocs perform the data quality verification tasks under the supervision of a postdoc coordinator. A software engineer maintains the underlying code and supports upgrades and enhancements directed by the physics working groups. The software engineer also runs tests on data whenever a new version of the DAQ software is deployed or whenever a new version of the standard processing code is implemented to ensure data integrity as software evolves.

4.2.2.7.4. Provide Real-time System Monitoring and Paging

Challenges. Problems can occur with individual DOMs, groups of DOMs, DOMHubs (entire strings), or racks of DOMHubs (groups of strings). Detector operators must be alerted immediately when a problem occurs since the loss of a single DOM affects the overall quality of the data. More serious problems, such as when large numbers of DOMs drop from the data stream, cause detector outages. Automatic alerting and automatic diagnosis of the problem help to limit the amount of time of a detector outage or degradation in data quality. Currently, the DOMHubMonitor and checkdisk scripts exist and provide notifications by e-mail. They and IceCube Live feed the centralized paging system, which has been customized to meet the needs of the Winterovers. The main challenge is to integrate all of these elements into a single Network Management System (NMS). In addition to alerting operators to problems, the system must also limit the number of false alarms.

Approach. The Detector Operator is responsible for overseeing development, maintenance and monitoring of the monitoring and paging system. During the construction phase, development of the system will continue to integrate disparate monitoring and paging elements and to accommodate new strings as they come online. During stable operations, the Detector Operator supports system administrators, Winterovers and users in improving the functionality of the system as appropriate.

4.2.2.8. Calibration

4.2.2.8.1. Prepare and Evaluate Flasher Calibrations

Challenges. Every DOM includes a flasher board capable of generating light pulses of programmable intensity and duration. Flashers are enabled in special runs as needed to support ongoing studies relevant to physics data analysis. Operation of flasher runs requires tuning of flasher parameters to meet diverse requirements of studies related to detector performance. Substantial attention is required to minimize effects on detector uptime by fully exploiting capabilities of the hardware and DAQ software.

Approach. The Flasher Team is responsible for designing run parameters to meet requirements, executing the runs, validating the data, providing documentation of the runs, and providing technical assistance for corresponding simulation runs. Over the course of IceCube running, the Flasher Team maintains a centralized repository of documentation relating to all flasher runs for general use by physics working groups. This repository is kept updated with links to corresponding simulation data sets and analyses performed in the working groups. Simulation data sets are created by other collaboration members with advice from Flasher Team experts regarding technical information on flasher hardware and run parameters.

4.2.2.8.2. Evaluate Calibration Runs and Update Calibration Constants

Challenges. The correct and efficient analysis of IceCube data relies on the use of a common set of calibrations and calibration tools. The IceCube Run Coordinator orchestrates many of these tasks since they either require inactivation of detector segments or illumination of the fiducial volume. Often, specialized datasets are produced and analyzed offline, either on computers at the South Pole or in the Northern Hemisphere using collaboration-maintained algorithms.

Approach. Collaboration graduate students and postdocs perform the specific calibration tasks under the supervision of the Run Coordinator. They perform regular calibrations of individual DOM responses to single photoelectrons and check that DOM timing resolutions remain at the required few nanosecond level. They regularly verify that the DOM-to-DOM local coincidence circuitry is performing correctly. Annually, they perform geometry calibrations with cosmic-ray muons to follow small displacements of the deepest DOMs due to ice flow. Several times annually, they take data with flashing *in situ* light sources to track the overall detector response to Cherenokov-like light. They take additional data to study the linearity and saturation response of DOMs and to ensure the light sources themselves continue to produce the expected output of photons.

4.2.2.9. IceTop Operations

4.2.2.9.1. Coordinate IceTop Operations

Challenges. IceTop by itself includes all aspects of a major experiment, requiring its own tools for calibration, monitoring, reconstruction and simulation. The environment for operation and the character of the data of the DOMs in IceTop are qualitatively different from those of DOMs deep in the ice. The IceTop DOMs are embedded in ice contained in tanks on the surface, which are subject to environmental changes that must be monitored. Data rates in individual DOMs are significantly higher, and typical signals are much larger than in the deep detector. In addition, specialized modes of operation are needed to capture the science accessible to a detector on the surface, which includes study of solar particle activity and high-altitude weather in addition to the basic cosmic-ray science.

Approach. The IceTop Data Specialist, who is a scientist with special expertise in all aspects of IceCube operations, is the point of contact for all critical technical support personnel in IceCube operations. The Data Specialist coordinates monitoring of the physical condition of the IceTop detectors, including annual surveys of the tanks, snow accumulation above the tanks, and surrounding environmental conditions at the South Pole. The Data Specialist also coordinates monitoring the quality of IceTop data and any corrective actions required to address malfunctions or other conditions that degrade IceTop data.

4.2.2.10. Supernova Operations

4.2.2.10.1. Support Supernova Operations

Challenges. Supernova data acquisition (sni3daq) picks up the single photoelectron trigger scaler data produced by pDAQ and looks for rate excess over the entire detector. For runs with no rate excess, the data is compressed to monitor the entire detector. In the event that an excess is found, an alarm is issued and sent via the IceCube Transport System (ITS) to a server located in Mainz, Germany, and more detailed data is saved. If monitors conclude that the alarm is significant, an additional alarm is sent to the Supernova Early Warning System (SNEWS).

Approach. Students in Mainz and a scientist from UW-Madison are accountable for the uptime of sni3daq and for maintaining, troubleshooting, supporting and upgrading the system as IceCube evolves into its final configuration. As new strings and DOMs are added during the remaining construction phase, they are added to the sni3daq. Data acquisition, processing, transfer, storage and quality are monitored. Much of the monitoring process is already automated, but high-significance SNEWS alerts are manually checked for validity. The Supernova Working Group maintains a shift system to ensure that at least one monitor is checking alerts at all times.

4.2.3. Computing and Data Management

Challenges. The management challenge for Computing and Data Management is to obtain and integrate from multiple sources the technology resources needed to collect and manage data optimized for physics analysis. Achieving the optimum configuration of these resources is critical to reducing the cost of technology resources while providing computing and data management capabilities and capacity required for discovery level science.

Approach. The Computing and Data Management Technical Coordinator is accountable for the overall performance of the people, hardware, software and processes required to support IceCube computing and data management from event to publication. The Coordinator holds weekly teleconferences on operations issues, provides input to status reports to NSF, prepares and manages budgets, serves as a member of the Coordination Board, resolves personnel issues, and develops long-term strategies to maximize the benefit to IceCube science from evolving computing and data management technologies.

4.2.3.1. Core Software Systems

4.2.3.1.1. Maintain Core Analysis Framework

Challenges. The IceTray software framework, including a set of common classes for holding IceCube data, a set of basic modules, and a selected set of tools on which this system is based, is a part of the IceCube core software library. This core set is used in the development of calibration, simulation, reconstruction and analysis modules. A robust set of bindings to the python programming language is also included, which facilitates use of advanced analysis environments and advanced 3-D graphical event displays.

Approach. The IceTray Lead Architect is responsible for maintenance of IceTray and adaptation of its framework to new or updated operating systems and analysis tools. The Lead Architect maintains the software repository system, continuous-build testing system, and external libraries and build tools as newer operating system versions emerge. The Lead Architect also conducts regular training sessions for new collaborators and software contributors in the Collaboration.

4.2.3.1.2. Maintain Reconstruction Framework

Challenges. The IceTray framework supports an advanced maximum likelihood estimation based fitting. This allows physicists to easily develop high-level reconstructions by defining event hypotheses and probability density functions (PDF) of the measured quantities. The framework also allows for the configuration of different minimization strategies and libraries to be used to construct high-performance and robust reconstructions.

Approach. A scientist with a strong background in software engineering provides support for the reconstruction framework. The scientist tracks bugs and feature requests using an open source tracking system. Based on these requests, new releases are made available to the Collaboration on a regular basis. During the release process, a full regression test is conducted. Training on the use of the reconstruction framework is conducted in connection with the new user training on the core IceTray framework.

4.2.3.1.3. Maintain and Operate Database Systems

Challenges. Central databases with mirrors in key locations to enhance efficiency of data access store key IceCube information such as detector geometry, DOM calibration information, configuration information for DOM settings, configuration information for triggers, and run summary information. Database locations include the South Pole, Belgium, and Madison, Wisconsin. Keeping the contents of these databases well organized, synchronized, operating and available is key to ensuring that all parts of IceCube data analysis are understood and repeatable.

Approach. A lead developer maintains and extends the database tables and maintains all code to update and query the database. A database administrator supports reliable operation and monitoring of the database and tunes the database configuration for best access. Continuous support for data insertion at the South Pole and in the Northern Hemisphere provides all necessary information for data processing. The bi-directional update process is periodically updated and improved to minimize manual intervention. Standard monitoring of the database provides input for optimization to accommodate rapid growth in the quantity of stored data.

4.2.3.1.4. Maintain Simulation Production Software

Challenges. Simulation production in a varied set of computing environments including batch processing systems and open GRID clusters requires a dedicated middleware framework to coordinate dataset allocation and result tracking. The simulation production software, IceProd, keeps track of all datasets and distributes individual simulation steps among all available computing resources. It takes into account the individual capabilities available at the different sites and optimizes distribution of tasks to achieve the best use of the resources.

Approach. A computer scientist with a background in physics maintains and adapts this system to allow easy configuration of the available resources and to adapt to individual policies and restrictions of distributed production sites. Support to the local simulation production coordinators to resolve problems and incompatibilities of different systems is a major task to achieve best resource usage.

4.2.3.1.5. Maintain Data Processing Software

Challenges. The software for processing data for physics analysis is comprised of submission scripts for processing jobs to the compute elements of the central HPC cluster, processing scripts, database software to monitor job execution, and web pages to display processing progress and quality parameters.

Approach. A software engineer is accountable for maintaining, troubleshooting, supporting and improving the data processing software. The software engineer adapts processing based on the evolving detector configuration and required reconstruction algorithms developed by the Collaboration. The software engineer also adapts submission and execution monitoring to make the best use of the available computing resources. A fully processed dataset is available to the Collaboration not later than 3 months after the corresponding physics run with a target date of 1 month after the run.

4.2.3.1.6. Maintain Core Software Repository

Challenges. The software development in IceCube is a worldwide-distributed effort with more than 100 contributors and several hundred software components. A central software repository is essential to managing this software collection. Corresponding configuration management allows consistent reproduction of IceCube results.

Approach. A computer scientist is responsible for operating the central software repository that tracks all changes to the software developed by members of the Collaboration. The computer scientist uses a standard subversion software repository coupled with easy-to-use open-source management and monitoring tools as the basis for performing configuration management.

4.2.3.1.7. Maintain Verification Software Framework

Challenges. Quality of data in a complex experiment like IceCube is important to enabling the best physics results. A long list of tests has been developed to identify problems in data collected by the IceCube detector and to identify individual malfunctioning detector channels. This information is used at higher-level reconstructions and for final physics analysis. To achieve a flexible and expandable set of tests that can be automated for mass production, we have developed a framework that automatically detects variations in test quantities by comparison with automatically updating templates. Future tests can be easily added by implementing only the algorithms to derive the test quantities. All comparison logic and deviation detection algorithms are already part of this framework.

Approach. A research associate with a background in physics maintains the data quality verification framework. This position also coordinates the development of new and expanded tests with the working groups.

4.2.3.2. Data Storage and Transfer

4.2.3.2.1. Archive at South Pole and Transfer Data to Data Warehouse in North

Challenges. Data is transferred from the South Pole using three mechanisms: 1) very small data samples over e-mail; 2) data up to hundreds of megabytes per day using the TCP/IP network; and 3) the bulk of the IceCube data over the dedicated high-capacity SPTR (South Pole TDRS Relay) system. The network and data transfer systems are very limited resources that require careful management.

Approach. IT specialists monitor the data transfer and archive. All data is archived onto magnetic tape at the South Pole in two main tape sets. The raw data stream is archived in case of significant issues with online filtering or for temporally transitory data that may need re-analysis. To mitigate the risk of catastrophic failure of the SPTR system, another tape set is maintained to facilitate fast recovery from such a failure. Data transfers use the allowed bandwidth allocated to IceCube and buffer data for at least 3 days to compensate for any short-term outages of satellite connectivity.

4.2.3.2.2. Maintain Data Transfer Software (SPADE)

Challenges. The SPADE application gathers data files from multiple clients at the South Pole, archives all files on magnetic tape, and transfers data from the South Pole at three different levels of speed/priority depending on the size and urgency of the file. As a distributed application, it runs on several servers and balances the transfer and processing requirements to archive a stable and sustained throughput from all clients to the tape systems and the different transfer channels. Because data integrity cannot be guaranteed over satellite transfers, the software maintains checksums of all files. It processes e-mails received from the systems at the Data Warehouse with instructions to retransmit corrupted files. It also maintains unsuccessfully transferred files for as long as needed to be accessible for retransmission.

Approach. A Software Engineer with more than 20 years of experience in application development and relational database design maintains SPADE. The Software Engineer monitors the correct operation of the programs, troubleshoots issues, designs and develops all enhancements and feature requests, trains Winterovers, and writes SPADE support documentation.

4.2.3.2.3. Maintain Data Warehouse Standards, Software, Data Access, and Web Interface

Challenges. The Ingest software application registers the arrival of each file from the South Pole in its catalog database as well as the contents of the metadata files that are paired with each data file. It calculates checksums of each file received and returns the checksum values to SPADE via e-mail for verification of the correct transfer of each file. Ingest automatically creates directories within the data storage system for the incoming files and creates metadata files to document the new directories on disk.

Approach. A Software Engineer maintains the Ingest and web interface applications, including fixing bugs and adding new features to Ingest. The Software Engineer expands Ingest and the web interface as necessary to provide user access to the catalog database including information on the status of each file produced at the South Pole.

4.2.3.2.4. Maintain and Operate Data Storage Infrastructure

Challenges. Data from the detector is processed, analyzed, and stored in intermediate and final stages both on disk for fast access and on tape for long-term backup and archive. More than 400 TB of data is currently maintained on disk, and significant turnover and expansion of data as the experiment operates must be handled efficiently and securely.

Approach. System administrators experienced in disk enclosures, storage networks, servers and their operating systems and application software maintain and operate the data storage infrastructure. They ensure that active data is available at several different levels depending on requirements for latency, throughput, and quantity. High-speed disks with multiple servers serve the most active data and the high-performance computing clusters. Lower-demand individual servers handle simpler requirements such as single user analysis data. Tape media serves both backup and archive functions.

4.2.3.2.5. Transform Data for Long-Term Persistence and Archive

Challenges. IceCube data formats are generally dependent on the software used to produce the data. This offers the best performance and presents no limitations as long as the data are processed with compatible software products. For long-term persistence, a software and programming language-independent data format is preferable since it will offer persistence independent of the retrieval or mining technology used. To achieve this long-term data persistence, a transformation of relevant datasets to a standardized hierarchical data format (such as NASA's HDF5 format) will be required, including evolution of the storage schema to accommodate long-term, consistent access.

Approach. A computer scientist will develop and evolve the data layout schema to allow for a consistent dataset at the analysis level to be used for combined analysis over the experiment's lifetime. Transformations will be performed as needed to keep the dataset homogenous for data mining. The developer will provide detailed documentation of the chosen data schema.

4.2.3.3. Computing Resources

4.2.3.3.1. Coordinate and Support Grid and Distributed Computing

Challenges. Core high performance computing (HPC) is the method required to process data transferred from the South Pole daily and to produce a core sample of simulation data. To obtain the computing resources required to process vast amounts of data, IceCube relies on distributed resources available from Collaboration institutions. This generates the need for coordination of these hardware resources in terms of interfaces such as GRID tools and general job scheduling and distribution. The increased usage of the existing GRID computing clusters in the US and Germany and the planned installations in Sweden and Belgium will allow IceCube to produce simulation data at volumes in excess of 2 TB per day. These data must be transferred back to the central data warehouse using high-throughput links and the GRIDFtp protocol. The GRID resources must be managed locally for optimal utilization with local storage of intermediate results and optimal scheduling of processing steps.

Approach. Support personnel at all sites coordinate and manage the distributed computing effort to produce MonteCarlo datasets as required to achieve IceCube's scientific goals. In addition, an IT professional at the central IceCube datacenter manages the IceCube GRID middleware needed for the GRID access to the data. Standard GRID tools are used where possible to achieve high throughput of data from the distributed sites to the central IceCube computing center.

4.2.3.3.2. Maintain Core High Performance Computing System

Challenges. The core HPC systems support the delivery of science-ready data and various analysis efforts. In addition to the routine processing of data, occasional reprocessing is necessary and new analyses are developed. Careful attention is required to ensure that the workload is managed in accordance with project goals.

Approach. Systems administrators experienced in troubleshooting distributed computing systems maintain the HPC systems and support users working on HPC resources by giving guidance and advice on HPC use and coding best practices. The systems administrators support the delivery of science-ready data by ensuring that all incoming data is run through offline processing software, which produces the data filtered to appropriate levels for analysis, verification and monitoring purposes. The systems administrators operate the present HPC cluster at the IceCube data center, which is a 300 core cluster, with each core a 2.4 GHz Opteron CPU. IceCube also participates in the Grid Laboratory of Wisconsin (GLOW), which provides guaranteed access to 120 cores with each core being a 2.8 GHz Intel CPU, and opportunistic usage of another 1200 cores.

4.2.3.3.3. Maintain Data Center Networking and Security

Challenges. The IceCube network is the main fabric that integrates major project work groups, remote work sites, and on-going operations. It provides security connectivity through virtual private network (VPN) tunnels terminating at remote project endpoints. The network also operates in the public domain with exposed web, e-mail and database services. In addition, the IceCube network must interface to points of presence and comply with policies and regulations of NSF and UW-Madison.

Approach. The IceCube Network Engineer is responsible for uptime and performance optimization of the IceCube network, which includes maintenance, support, configuration, and customization of the system when necessary. During operations, the Network Engineer responds to the needs of scientists, software developers, project engineers and detector operators to maximize network reliability and provide customized solutions to optimize performance. The Network Engineer monitors the health of the devices and configurations to identify system bottlenecks and potential hardware problems. Security logs are analyzed for suspicious behavior and traffic signatures. Any corrective actions are enforced according to NSF and UW-Madison policies. The IceCube network is implemented with primarily OEM, commercially available devices. Cisco Support maintenance contracts provide for quick turnaround from device failure and access to software/firmware device patches as needed. System monitoring is provided through a composite of open-source and vendor-supplied products.

4.2.3.3.4. Maintain Data Center Infrastructure

Challenges. IceCube requires a flexible and highly available set of computer systems to support operations. Some are highly visible, such as e-mail, web servers and home directories. Others operate in less visible but equally vital roles, such as username and password authentication using LDAP, name resolution via DNS, IP address assignment via DHCP. Numerous other systems add necessary features, such as public access systems, software test systems, and monitoring systems. Several non-computer facilities also fall into this area, such as maintaining power (capacity and battery backup) and cooling in the server rooms.

Approach. Several systems administrators share duties to perform these tasks, which includes maintenance of more than 40 general purpose servers in addition to those used for HPC and data storage, all of which are housed within the central server room. This includes patching, monitoring, troubleshooting, and responding to user needs, among other routine tasks.

4.2.3.4. Data Production Processing

4.2.3.4.1. Unpack, Decode and Calibrate Rate Data in North

Challenges. Data arriving in the north are compressed and stripped of all unnecessary information to conserve transfer bandwidth. In a first processing step, the data must be unpacked and uncompressed, and calibrations must be applied to these data to convert raw DAQ measurements into physical quantities. The reconstructions used at the South Pole to form the filter decisions must then be reapplied to the calibrated data and all intermediate results stored together with the data to allow studies of the filter performance.

Approach. A software engineer monitors the execution of the processing scripts and verifies regularly the quality of the data. The processing is performed on the HPC cluster at the IceCube data center. The software engineer ensures that unpacked and calibrated data are available in the data warehouse not more than 1 week after all inputs (e.g., filtered data and calibration constants) are received in the north.

4.2.3.4.2. Run Common Reconstructions on IceCube Compute Cluster in North

Challenges. The complex reconstructions required allowing the suppression of the high muon background from cosmic ray initiated air showers from the neutrino signal are computationally intensive. To make the best use of limited computing resources in the IceCube Collaboration, these reconstructions must be run centrally and results made available in the data warehouse for consumption by the different physics analysis working groups.

Approach. A software engineer monitors the execution of the processing scripts and verifies regularly the quality of the data. Using a web interface, the software engineer also provides plots of reconstruction parameters to the Collaboration for quality assurance. Processing is run on the central HPC cluster at the IceCube data center. Processing for a full physics run is completed no later than 2 months after the end of a run to allow for timely analysis and publication of IceCube results.

4.2.3.5. Simulation Production

4.2.3.5.1. Coordinate Simulation Production and Resources

Challenges. This task involves management of multiple dependencies across M&O and the Collaboration. These include, for example, detector geometry calibration, charge and time calibration, and detector configuration uploaded into the database; maintenance of simulation software; and physics demand and dataset priority agreed with the Collaboration and matched with current computing infrastructure capacity. Close coordination in all of these areas is required to produce stable and consistent long-term production of Monte Carlo simulation data and their filtering and processing.

Approach. The Simulation Production Coordinator is responsible for coordinating with other groups in the Collaboration to assess the impact of these tasks on physics analyses and understand issues involving computing infrastructure. The Coordinator ensures proper production of data to verify simulation releases before full production is enacted. This includes low-level data quality assessment to verify configuration parameters. It also includes global verification to compare simulation with experimental data to verify uniformity of data quality across the distributed computing infrastructure and through the software release history. The Coordinator also defines and reaches agreement on required computing capacity from each production site based on its capacity and infrastructure. The Coordinator periodically assesses actual production to verify if expectations have been met. The Coordinator produces quarterly reports on global simulation production status, and a weekly status report on simulation production.

4.2.3.5.2. Produce Simulation Dataset in Compute Cloud

Challenges. For IceCube to detect physics events caused by high-energy neutrinos, the large background of cosmic muons events must be rejected while retaining the highest signal efficiency. Simulation data are essential in this analysis procedure and a large number of cosmic muon events must be produced. This requires a large computing infrastructure distributed across the Collaboration, as well as in other external facilities if and when available. Trained personnel at each institutional production site are necessary to support the operation of simulation production.

Approach. Personnel required at each production site are physicists with programming skills and basic knowledge of operating systems, and system administrators who can address local computing issues. These personnel make sure production daemons are properly set and running at the local site; submit and monitor datasets assigned to that site; check that jobs successfully complete and ensure that files are properly copied to the data center; and report issues and problems. Site personnel contribute to a quarterly report on production status.

4.2.3.5.3. Maintain Production Templates, Perform Test Productions and Maintain Production Web Portal

Challenges. The highest degree of simulation complexity is the dependence on large lookup tables for the description of photon propagation fields in the ice. No machine in the distributed computing infrastructure has memory large enough to load all of the tables at once for processing. Complexity is also introduced from the need to generate events with multiple detector configurations as part of the same processing run. The addition of data filtering and processing adds further complexity. A procedure to detect these errors must be in place before freezing the configuration for usage throughout the distributed computing infrastructure.

Approach. A physicist supports this task by performing runtime basic data checks to verify evident configuration errors; low and high level data verification by comparing simulation data from different production sites and different historical simulation releases to experimental data; and analysis-level data checks expected by working groups for the very early stages of physics analyses. The full procedure includes production tests to verify that the output is what was expected and can involve direct interface back to simulation software development if errors are traced back to software. The correct execution of this task prevents data produced across the production sites from containing errors that should have been detected early in the chain. Finally, the physicist maintains the simulation production web portal to keep all stakeholders informed of simulation production status and issues.

4.2.4. Triggering and Filtering

4.2.4.1. Trigger, Filter and Transmission (TFT) Coordination

4.2.4.1.1. Coordinate Process for Filter Requests and Bandwidth

Challenges. The TFT Board's purpose is to evaluate proposals and execute plans to ensure that the IceCube detector operates in a configuration that meets the physics needs of the Collaboration while ensuring that the limited resources available from the South Pole System are utilized within their constraints in a controlled, consistent and efficient manner. As a working committee, the TFT Board members dedicate a large fraction of their time to serving on the Board, especially in the months running up to the start of each season's physics run.

Approach. The TFT Board Chair is responsible for organizing all TFT processes, including meetings, proposals and oversight activities. The Board meets regularly via teleconference and in person during Collaboration meetings. The majority of the Board's work is centered around the start of each new season's physics run, typically spanning the period from April 1—after newly deployed strings are frozen and verified ready for inclusion in physics data taking—to March 31 of the following year. Ahead of this yearly transition, the Board issues a request for proposals for the upcoming season, coordinates production of expected trigger and DAQ settings and Monte Carlo data sets to match the expected detector configuration, sets deadlines for physics working groups to draft proposals, and evaluates proposals to generate the standard data taking configurations for the upcoming year. At each point in the process, the TFT actively involves the physics working groups to ensure that their needs are met by any changes and compromises required during the review process. Following the transition to the new season's configuration, the TFT Board tasks all physics working groups to provide brief reports on all online filter proposals summarizing the status and quality of selected events.

4.2.4.1.2. Prepare Datasets for Filter Testing and Common Monte Carlo Datasets for Testing

Challenges. When preparing proposals for the TFT Board, Collaboration members require data sets (real data and Monte Carlo simulation) that have been generated to match the proposed configuration for the upcoming year. Minimally triggered samples are also required for new trigger algorithm development.

Approach. A Collaboration physicist familiar with simulation and detector settings is responsible for preparing the required datasets. Taking input from the TFT Board on expected DAQ and trigger settings, the physicist produces simulation and real data samples to match the expected settings. As the TFT Board approves proposals for new triggers, the physicist also updates these samples. The Monte Carlo simulation samples are also used to perform a first cross-check of real filter performance at the start of each season. The physicist generates the data samples using standard simulation production and IceTray software framework tools. The samples are stored in the IceCube data warehouse. The data sets must be prepared in advance of the TFT request for proposals for the upcoming season each year.

4.2.4.2. Physics Filters

4.2.4.2.1. Develop Filter Requests and Code for Pole Filtering

Challenges. Each year, the filters that select events for immediate transmission to the Northern Hemisphere for further analysis must be evaluated to ensure that they meet the evolving physics needs of the Collaboration and that the most effective reconstruction and filtering tools are in use online.

Approach. Collaboration physics working group members with expertise in the available analysis tools and goals of the physics program provide filters to the TFT Board for evaluation. Significant effort from these physics working group members is required. They first research and write initial proposals, participate in internal working group discussions, make presentations to the TFT Board, and report on the filtered data quality once the season has begun. Filter development is based on data samples generated for the season's physics run in the IceTray software framework, and using reconstruction tools. The filtering system must be approved by the TFT Board and ready for deployment at the start of each new year's physics run in April.

4.2.4.2.2. Verify Filter Code and Physics Efficiency

Challenges. Filters that operate in the online filtering system at the South Pole are developed each season as new strings of DOMs are deployed, frozen, and begin to collect data. Once filter output from these new strings is available, the data must be checked to ensure that filter output matches expectations from simulation predictions used in writing filtering proposals.

Approach. Each season, the TFT Board calls for reports on the performance of physics filters with a deadline shortly after the start of the new physics run. Members of Collaboration physics working groups perform filtered data verification using filter output data and data samples using the IceTray software framework and reconstruction tools. They submit reports with findings and recommendations to the TFT Board, which assigns any required follow-up actions.

4.2.5. Data Quality, Reconstruction and Simulation Tools

4.2.5.1. Simulation Programs

4.2.5.1.1. Manage Simulation Software Projects

Challenges. The large body of code used to generate signal and background events and simulate them in the detector undergoes regular improvements. These improvements are made as we acquire a better understanding of the ice properties, implement new possible signals to search for, and work to reduce the simulation's CPU and memory usage.

Approach. Continued development and improvements to IceSim are mainly the tasks of Collaboration physicists as part of in-kind physics service work. An expert simulation programmer/coordinator is responsible for coordinating all Collaboration effort on the simulation program to maintain continuity and control of the overall event and detector simulation packages. The programmer/coordinator tracks issues and helps to set priorities in development. This position also serves as the central point of contact for resolving build and operating system issues, tracking bugs, and coordinating troubleshooting to ensure accuracy of the detector simulation data, and speed, performance and reliability of the simulation package.

4.2.5.1.2. Maintain Detector Simulation (IceSim)

Challenges. The large body of code used to generate signal and background events and simulate them in the detector also requires regular maintenance. This maintenance is performed to keep all elements of the IceSim simulation package current with changes in the computing environment due to, for example, operating system and compiler upgrades. Leveraging the extensive set of tests and underlying software framework used to verify data quality, a similar suite of tests is also run on the simulated data at the start of each new simulation production run to check the quality of the new data.

Approach. The Simulation Manager, coordinating the activities of Collaboration physicists under the guidance of the physics working groups, is responsible for IceSim maintenance, which includes development and installation of patches, troubleshooting, and upgrading systems.

4.2.5.1.3. Maintain Simulation of the Physics of Event Generation

Challenges. The physics of the generation of neutrino events and shower events, both in the atmosphere and in the ice, is an ongoing scientific field, as is the physics of neutrino and particle generation at possible astrophysical sources. Changes to the event generation program will continue as IceCube data contributes to our understanding of these events.

Approach. The Simulation Manager, coordinating the activities of Collaboration physicists under the guidance of the physics working groups, is responsible for updating event generation parameters to enhance scientific output and system efficiency as IceCube science evolves.

4.2.5.1.4. Maintain and Verify Simulation of Photon Propagation and Update Ice Properties

Challenges. IceCube reconstructs tracks by using the number and time of arrival of photons at the photomultiplier tubes or DOMs. An accurate model of the photon propagation is critical to our ability to reconstruct tracks. To model the propagation accurately, a detailed model of ice properties and a custom software package to make arrival time distributions is required.

Approach. This task has two primary elements—modeling the ice properties and developing the photon propagation model from the ice property model. We continue to improve the ice properties model by using data logged during drilling, and data gathered during flasher calibration runs and reconstructing muons. With each improvement in the ice model, the propagation model is improved to generate updated tables of photon arrival time distributions for reconstruction.

4.2.5.1.5. Maintain and Run Geometry Calibration Software

Challenges. Accuracy of the detector geometry is critical to the accuracy of physics analysis.

Approach. Collaboration physicists as part of their normal service work run the DOM geometry software on various sets of data to determine precise DOM locations through analysis of flasher data and muon tomography. The geometry is maintained in an analysis database.

4.2.5.1.6. Develop New Simulation Tools

Challenges. In many aspects, analysis capability is limited by the accuracy and amount of simulation data. Improving the simulation enables us to lower systematic error, improve signal efficiency and reduce background toward producing larger amounts of higher-quality physics data.

Approach. Continued development and improvements to IceSim are mainly the tasks of Collaboration physicists as part of in-kind physics service work. An expert simulation programmer/coordinator is responsible for coordinating development of new tools from proposal through development and testing to implementation.

4.2.5.2. Reconstruction and Analysis Tools

4.2.5.2.1. Develop Core Common Reconstruction Tools

Challenges. The IceCube detector provides calibrated and verified raw waveform data. This raw data must be processed to ultimately reconstruct muon tracks, shower events, direction, energy, and background probability of in-ice events, as well as to reconstruct cosmic-ray air showers. The physics discovery potential of IceCube is limited by the quality of these reconstructions.

Approach. The physics working groups evaluate evolving scientific objectives and priorities and improve existing reconstruction algorithms or develop new ones. They rely on data from the data warehouse, core software systems and reconstruction tools to improve angular resolution, signal efficiency, background rejection, physics reach and signal sensitivity.

4.2.5.2.2. Develop and Maintain Analysis Tools

Challenges. IceCube science requires common, high-level analysis tools to maximize the efficiency of turning reconstructed data into physics results. This enhanced efficiency helps to reduce the time lag between data reconstruction and publication of results.

Approach. Collaboration working group members with expertise in analysis tools propose development or modification of tools, participate in working group and Coordination Board discussions, develop the tools, work with M&O staff and resources to implement tools, and train users in their operation and maintenance.

4.2.5.3. Data Quality

4.2.5.3.1 Support Final Selection of Science-ready Data

Challenges. IceCube detector operation is run-based with configuration defined for each run. Occasionally, runs are short or aborted at start, or may have significant faults. These runs must be identified and marked in the common database for exclusion from physics analysis. In addition, for each run there are occasionally DOMs that malfunction and must also be marked for exclusion from analysis.

Approach. Collaboration physicists are assigned this task as a part of regular service work. The physicists use information gathered from the run coordinator, run configuration database, monitoring software and verification software to create lists of problematic runs and DOMs. The lists are then imported into the database with tools and support from IceCube core software.

4.2.5.4. Offline Data Processing

4.2.5.4.1. Coordinate and Develop Common Reconstruction for Production Processing

Challenges. The first levels of production processing, which are executed on every event and use significant computer and network resources, must be performed in common for all events for consistency of data for analysis. This common processing must also maintain maximum efficiency in its use of limited computing resources.

Approach. Collaboration physicists under the guidance of physics working groups complete this task as regular service work. They analyze calibrations, successful runs, malfunctioning DOMs, and common reconstructions to further develop common programs ready for mass production processing.

4.2.5.4.2. Monitor Reconstruction Processing and Stability of Reconstruction Results

Challenges. Production processing must be monitored to ensure that it is producing data of the high quality required for physics analysis. Failure to identify issues requires data to be reprocessed, which wastes valuable processing resources.

Approach. Collaboration physicists under the guidance of physics working groups monitor the processing output data to ensure its quality and consistency, which is an indicator of the stability of the production processing code. They also monitor the length of time required for production processing to identify inefficiencies that waste computing resources.

4.2.6. Physics Analysis Coordination

Physics analysis includes tasks that are not included in the M&O Core and In-kind budgets but are essential to complete the process from science event to publication. These tasks are supported through research grants to the collaborating groups.

4.2.6.1. Analysis Coordinator

4.2.6.1.1. Coordinate All Physics Analysis

Challenges. IceCube reaches its greatest potential both in achieving its scientific objectives and in education and outreach by balancing centralized M&O resources with resources distributed among

Collaboration members. The challenge is to coordinate the efforts so as to maximize the benefits of the specialized expertise of each collaborating institution, both in M&O and in analysis.

Approach. The distributed model is illustrated in **Figure 4.2.6-1**. (Data storage/preparation tasks are discussed in Section 4.2.6.1.2 below.) Analysis tasks are divided among channel working groups and physics working groups. The three channel working groups perform initial analysis at the level of the typology of the IceCube events. They also develop and benchmark new reconstruction algorithms, energy estimates and filtering scripts. They also interface between the physics working groups and supporting M&O functions. The physics working groups develop the high-level analysis strategies as well as the specific tools needed to execute the analyses. The physics working groups also debate the statistical interpretation of results and updates on physics scenarios. IceCube data analysis is coordinated by the IceCube Collaboration under the leadership of the Analysis Coordinator, a position appointed by the Spokesperson with concurrence of the Collaboration Board. Analysis funding is provided directly to the IceCube collaborating groups by their respective funding agencies.

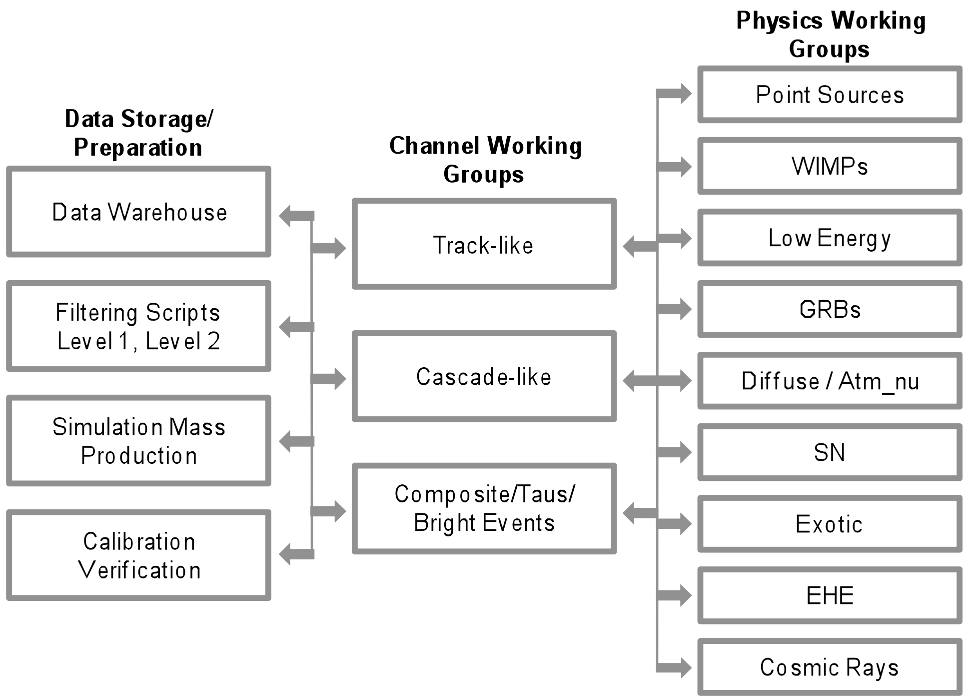

Figure 4.2.6-1. Data Analysis. *Shown is a schematic view of the distributed data analysis organization and its connection with M&O data storage and preparation functions.*

The Analysis Coordinator uses four primary communication mechanisms to coordinate analysis activities and ensure high quality data analysis using the best resources available to the Collaboration. The weekly data analysis teleconference discusses activities of the physics working groups and their connection with the channel working groups. The physics working groups hold biweekly teleconferences, supplemented by two weekly plenary teleconferences on topics of more general interest.

4.2.6.1.2. Coordinate Physicist Resources for Operations

Challenges. For operations tasks, the distributed model not only brings valuable expertise from Collaboration members, but also provides the most value to participating institutions and the scientific community in general through training and hands-on experience maintaining and operating the IceCube detector. The main challenge is to obtain the right expertise or resource at the right time.

Approach. Collaborating institutions provide specialized expertise and general support to M&O tasks that include maintaining the data warehouse; developing data preparation scripts; maintaining key databases of information such as detector geometry, calibration constants, run information and bookkeeping; monitoring key systems for stability and quality of data taking; maintaining the IceTray data analysis framework; supporting mass production of simulated data; and supporting detector calibration and verification of its performance. Tasks for each collaboration member are described in general in their MOUs. The Collaboration assigns a leader responsible for each functional area. Follow-up to ensure performance is through formal, public reviews of Collaboration performance in all of the tasks for which it is responsible, relying on the formal documentation of the obligation as well as peer pressure to deliver.

4.2.6.1.3. Coordinate Blinding of Data

Challenges. Conscious and unconscious biases can affect physics analysis resulting in the need for blinding of data. The blinding procedure for IceCube cannot prevent full exploration of the data, especially for calibration, verification and reconstruction. Moreover, in the event of multiple analyses of the same data sample, the unblinding of one analysis cannot bias the status of any other analysis.

Approach. The IceCube Collaboration uses a blinding process for its analyses of data. It is neither centralized nor controlled by a specific authority; rather, the group assigned to perform the analysis is responsible for blinding the final answer while analysis procedures are being set. Once the analysis is approved by the Collaboration, the permission to unblind is granted, and the final results are produced.

4.2.6.1.4. Coordinate Review of Papers

Challenges. After discussion and positive reception by the Collaboration of the results of an analysis, a working group produces a draft paper with supporting web pages. To be acceptable, physics papers must have significantly better sensitivity than previous IceCube published results, and/or demonstrate a substantially improved method.

Approach. The Publication Committee regulates and manages the review process for IceCube papers. It consists of six senior physicists, the Analysis Coordinator and the Collaboration Spokesperson. The Publication Committee sets standards and procedures for publication of papers and conference proceedings to ensure a high standard of quality and integrity for IceCube scientific papers. Moreover, the Committee participates actively in the refereeing process of each paper and conference proceeding by organizing review panels. In most cases, members of the Committee serve on the review panels.

4.2.6.1.5. Publish Archival Data for Public Use

Challenges. NSF expects significant findings from research and education activities it supports to be promptly submitted for publication, with authorship that accurately reflects the contributions of those involved. It expects investigators to share with other researchers, at no more than incremental cost and within a reasonable time, the data, samples, physical collections and other supporting materials created or gathered in the course of the work.

Approach. Although IceCube is a breakthrough facility and a facility-class experiment, no neutrino point sources have been detected yet. After sources have been discovered, and their number and characteristics are better understood, we will be in a better position to formulate a realistic plan to release meaningful data to the public. One example of an initial concept for the framework is to develop an Associates program driven by the science potential.

5. Relevant Experience

UW and the IceCube Collaboration continue to successfully complete each step in the process of creating the IceCube Neutrino Observatory, which began with AMANDA, and continued through IceCube into the current initial operations phase. Early operations have enabled the use of instrumentation as it is installed with physics runs beginning less than two months after each South Pole installation season is complete. The 59 string physics run will begin in April 2009, and the physics run with 77 or more strings is scheduled to begin in April 2010, the start of the five-year period covered under this proposal. UW and the IceCube Collaboration successfully demonstrated the entire process from taking data to publications. This management and collaboration team also has the best understanding of how to improve these processes and implement the most cost effective program using distributed resources.

The IceCube Collaboration will continue to grow during the next five years. Some of this growth will be similar to the recent experience, i.e., existing collaborators moving to new institutions, along with new institutions joining to enhance the IceCube physics program. This growth is necessary to fully exploit the potential of the observatory. Future possibilities include opportunities to enhance the physics reach of IceCube through the existing physics working groups and the R&D program. There is also the possibility of partnerships with neutrino observatories located in the northern hemisphere. This growth will bring additional resources contributing to physics analysis and M&O service work. It will also increase the demand for services supported with the M&O central award given the roughly equal split between central and distributed support.

The experience with the initial M&O phase provided a solid basis for planning the steady-state operating phase when construction activities are complete. In February 2009, UW hosted an M&O Lessons-Learned Review with the objectives of evaluating the experience from the first two years of operation, identifying opportunities for improvement, and strengthening future plans. The review had broad participation from M&O task managers, activity coordinators, and other stakeholders. There were two overarching areas of improvement identified: 1) better definition and accountability mechanisms for "in-kind" work; and, 2) more resources for both the distributed in-kind work and the centrally managed activities.

The proposed IceCube M&O program is informed by the experience gained during construction and the initial M&O phase and advice from outside experts. The IceCube Science Advisory Committee and the Software & Computing Advisory Panel review the status of M&O annually. The result is that a number of significant improvements were made to the approach to organizing and coordinating M&O, task definition and tracking, and the mechanisms for ensuring performance and accountability for distributed, in-kind tasks.

5.1. Original Plan and Experience

The original IceCube M&O proposal submitted in 2007 focused primarily on the centrally funded M&O work with less complete coverage of distributed "in-kind" work and the relationship of the M&O tasks to physics analysis activities. This approach was a legacy of the construction phase when 90% of the work was centrally funded through the NSF Cooperative Agreement with UW for IceCube Start-up and Construction. During the M&O phase the amount of work that is supported under the NSF Cooperative Agreement is less than two-thirds of the total estimated effort and UW and the collaboration must rely on more distributed support that requires management arrangements better suited for defining and coordinating distributed, in-kind work.

Resource constraints during the initial M&O phase required an increased investment in construction activities for hardware and pre-operations activities. While these investments did reduce the requirements for M&O support in the short term, it confirmed that increased M&O support would be required once the construction project ended. UW-Madison made an additional construction investment during the initial operations phase as well as substantial resource contributions to the initial M&O phase, which helped to limit the impact of the slow ramp-up in M&O support.

During the construction phase, Level 2 and Level 3 managers controlled budgets and authorized funding to collaborating institutions for the effort of individuals completing construction tasks. There was a direct line of accountability to the manager of each WBS element. This approach worked well for the construction phase but is not feasible when the work is mostly in-kind effort contributed by the collaborating institutions. The institutional leads must be in the accountability chain with clear responsibility for ensuring that their institution, not just the individual with the task assignment, delivers.

5.2. Improved M&O Program

The IceCube M&O Program now proposed is greatly improved over the original program, building on the experience during the initial period and incorporating a number of significant improvements.

- **Comprehensive Plan from Data to Publications** - The M&O program is a complete description of all of the M&O tasks required for producing physics-ready data, the organization of data analysis, and finally the process for presenting results and publishing papers.
- **Detailed Task Definition and Accounting** – The M&O program is planned down to the task level with a consensus on the annual level-of-effort required for completing each task.
- **Institutional Responsibility Assigned at the Task Level** - The detailed task list identifies institutional responsibility for each task. The institutions are accountable for delivering on their assigned work and ensuring that the work is transferred to another institution if they conclude that the will be unable to fulfill their commitments.
- **Organizational Structure** – The organizational structure for management of M&O and the Collaboration has evolved in response to the needs of IceCube steady-state M&O and analysis phase by establishing an integrated structure that improves communication and accountability.
- **UW Management and Support** – UW established the IceCube Center to coordinate support for IceCube research and operations. The UW IceCube organization is aligned with the two major host institution M&O responsibilities: Detector Maintenance & Operations and Computing & Data Management. UW is well positioned to fulfill its management responsibilities as the host institution for steady-state operations.

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Key Personnel Biographical Sketches

1. Francis Halzen, Principal Investigator

Professional Preparation

1966 M.Sc., Physics, University of Louvain, Belgium
1969 Ph.D., Physics, University of Louvain, Belgium
1972 Agrégé de l'Enseignement Superieur, University of Louvain, Belgium

Appointments at the University of Wisconsin, Madison

Hilldale and Gregory Breit Distinguished Professor
Director of the Institute for Elementary Particle Physics Research

Selected Publications

High Energy Neutrino Detection in Deep Polar Ice (with J.G. Learned), *Proceedings of the 5th International Symposium on Very High Energy Cosmic Ray Interactions*, Lodz, Poland (1988).

Observation of Muons Using the Polar Ice Cap as a Cerenkov Detector (with D.M. Lowder, T. Miller, R. Morse, P.B. Price and A. Westphal), Nature **353**, 331 (1991).

Optical Properties of South Pole Ice at Depths Between 0.8 km and 1 km (with P. Askebjer *et al.*), Science **267**, 1147 (1995).

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Limits on a muon flux from neutralino annihilations in the Sun with the IceCube 22-string detector (IceCube collaboration), *in press*, Phys. Rev. Lett. (2009); astro-ph.CO/09022460.

Synergistic Activities

- IceCube Principal Investigator
- Physics in the Arts: a hands-on laboratory course for non-science majors covering acoustics and musical instruments, optics and color.
- Astronomy in the Ice: masters program for high school teachers at University of Wisconsin, River Falls. Course is built upon the science related to the AMANDA project.
- Consultant for the Exploratorium in San Francisco.

Recent Honors

2006 International Helmholtz Award of the Alexander von Humboldt Foundation, Germany.
Doctor of Philosophy Honoris Causa, Uppsala University, Sweden (2005)
"Best American Science Writing 2000" for the essay *Antarctic Dreams*, published in *The Sciences*, New York Academy of Sciences (1999).

Collaborators and Other Affiliations

The IceCube Collaboration
The AMANDA Collaboration

Other Collaboration:

Ahlers, M	DESY
Anchordoqui, L	Northeastern
Alvarez-Muñiz, J.	Santiago de Compostella, Spain
Gonzalez-Garcia, M	University of Barcelona
Hooper, D	Fermilab
Ringwald, A	DESY
Sarkar, S.	Oxford University
Torres, D.F.	Barcelona CSIC
Weiler, T	Vanderbilt

2. James H. Yeck, Co-Principal Investigator, Director of Operations

Professional Preparation

University of Illinois	B.S., Engineering Mechanics	1982
Northwestern University	M.S., Mechanical & Nuclear Engineering Thesis - Neutron Activation in the Compact Ignition Tokamak	1988
University of Pennsylvania	Doctoral Studies, Energy Management & Policy Dissertation research on risk assessment for large science projects	

Appointments

Director	University of Wisconsin - Madison IceCube Research Center	2003 – present
Project Director	DOE – Fermi National Accelerator Laboratory U.S. Large Hadron Collider Construction Project	1998 – 2003
Project Manager	DOE – Brookhaven National Laboratory Relativistic Heavy Ion Collider Construction Project	1991 – 1998
Project Manager	DOE - Princeton Plasma Physics Laboratory Tokamak Fusion Test Reactor Operations	1987 – 1990
Management Intern	DOE – Argonne National Laboratory	1985 – 1987
Project Engineer	U.S. Peace Corps - Thailand	1982 – 1984
Research Assistant	U.S. Army Corp of Engineers	1981 – 1982

Synergistic Activities

- Provide project management assistance for Brookhaven National Laboratory for the National Synchrotron Light Source–II project.
- Serve on the advisory boards for the Facility for Rare Isotope Beams (Michigan State University), Advanced LIGO (CalTech/MIT), and the Open Science Grid.
- Continuing service on numerous committees and review panels for the National Science Foundation, Department of Energy, and for institutions managing large U.S. research facilities.
- U.S. Department of Energy Secretary and National Science Foundation Director Appreciation Award in 2003 – "In recognition of your visionary leadership in creating and nurturing a uniquely capable, proactive and disciplined Project Office for the combined Department of Energy and National Science Foundation U.S. Large Hadron Collider Construction Project."
- U.S. Department of Energy Project Manager of the Year Award for 2000 – "For his leadership and project management skills, which were instrumental in the successful completion of the large, technically challenging Relativistic Heavy Ion Collider (RHIC) project."
- Founding President and former Board Member of Friends of Science East, Inc., a not-for-profit corporation that promotes science education on eastern Long Island, New York.

3. Albrecht Karle, Co-Principal Investigator, Associate Director for Science and Instrumentation

Professional Preparation

Baccalaureate in Philosophy, *Hochschule für Philosophie,* Munich, Germany, 1984.
Diploma in Physics, University of Munich, Munich, Germany 1990.
Ph.D., University of Munich (Research performed at MaxPlanck for Physics), Munich, Germany, 1993 (Thesis: Measurements of high energy cosmic and gamma rays between 30 and 500 TeV, Advisor: E. Lorenz).

Appointments

Professor of Physics, University of Wisconsin-Madison (2005 – present)
Associate Professor, University of Wisconsin-Madison (2003 – 2005)
Assistant Professor, University of Wisconsin-Madison (1999 – 2003)
Assistant Scientist, University of Wisconsin-Madison (1997 – 1999)
Postdoctoral Researcher, DESY-Zeuthen, Germany (1995 – 1997)
Research Assistant, Max-Planck Institute for Physics, Munich (1991 – 1994)

Selected Publications

Search for point sources of high-energy neutrinos with final data from AMANDA-II, IceCube collaboration, *Phys.Rev.**D79**:062001,2009*; astro-ph/08091646.

Methods for point source analysis in high energy neutrino telescopes, J. Braun, A. Karle, T. Montaruli, F. De Palma, Ch. Finley, Astrparticle Physics Astropart.Phys. **29**:299-305,2008. ePrint arXiv:0801.1604

Search for ultra-high-energy neutrinos with AMANDA-II (IceCube collaboration), Astrophys. J. **675** 1014-1024 (2008); astro-ph/07113022.

Detection of atmospheric muon neutrinos with the IceCube 9-string detector (IceCube collaboration), Phys. Rev. D **76**, 027101 (2007); astro-ph/07051781.

Multi-year search for a diffuse flux of muon neutrinos with AMANDA-II (IceCube collaboration), Phys. Rev. D **76** 042008 (2007); astro-ph/07051315.

Five years of searches for point sources of astrophysical neutrinos with the AMANDA-II neutrino telescope, (IceCube collaboration), Phys. Rev. D **75** 102001 (2007); astro-ph/0611063.

First year performance of the IceCube Neutrino Telescope (IceCube collaboration), Astroparticle Physics **26** 155-173 (2006); astro-ph/0604450.

Multi-year search for a diffuse flux of muon neutrinos with AMANDA-II, IceCube collaboration, Phys. Rev. D **76** 042008 (2007); *erratum ibid*. 77 (2008) 089904(E); astro-ph/07051315.

Limits on diffuse fluxes of high energy extra-terrestrial neutrinos with the AMANDA-B10 detector, AMANDA collaboration, J. Ahrens, *et al*., Phys. Rev. Lett. **90** 251101 (2003).

Observation of high energy atmospheric neutrinos with AMANDA, AMANDA collaboration, Phys. Rev. D **66** 012005 (2002).

Synergistic Activities

- URA Visiting Committee to Fermilab, 2005 to present, Assess overall Fermilab Research Program
- South Pole Users Committee, 2000 to 2006, Advisory committee to the National Science Foundation (NSF) and Raytheon Polar Programs, the NSF contractor for Polar Operations
- Scientific Committee on Antarctic Research (SCAR) – Member of the Scientific Research Programme Planning Group on Astronomy and Astrophysics from Antarctica (AAA)
- Research interest in high-energy particle astrophysics, specifically high-energy neutrino astronomy and cosmic rays physics. Leading a great part of experimental activities in the neutrino astronomy program at UW-Madison, first AMANDA, then with IceCube, including detector design work and analysis of data.
- Graduated seven Ph.D. graduate students (six of whom moved on to postdoctoral research positions).

Collaborators and Other Affiliations

IceCube Collaboration

Amanda Collaboration

HEGRA Collaboration (until 1995)

Baikal Collaboration (1994-97)

Appendix 1: IceCube Maintenance and Operations Proposal - Task List

04/07/2009

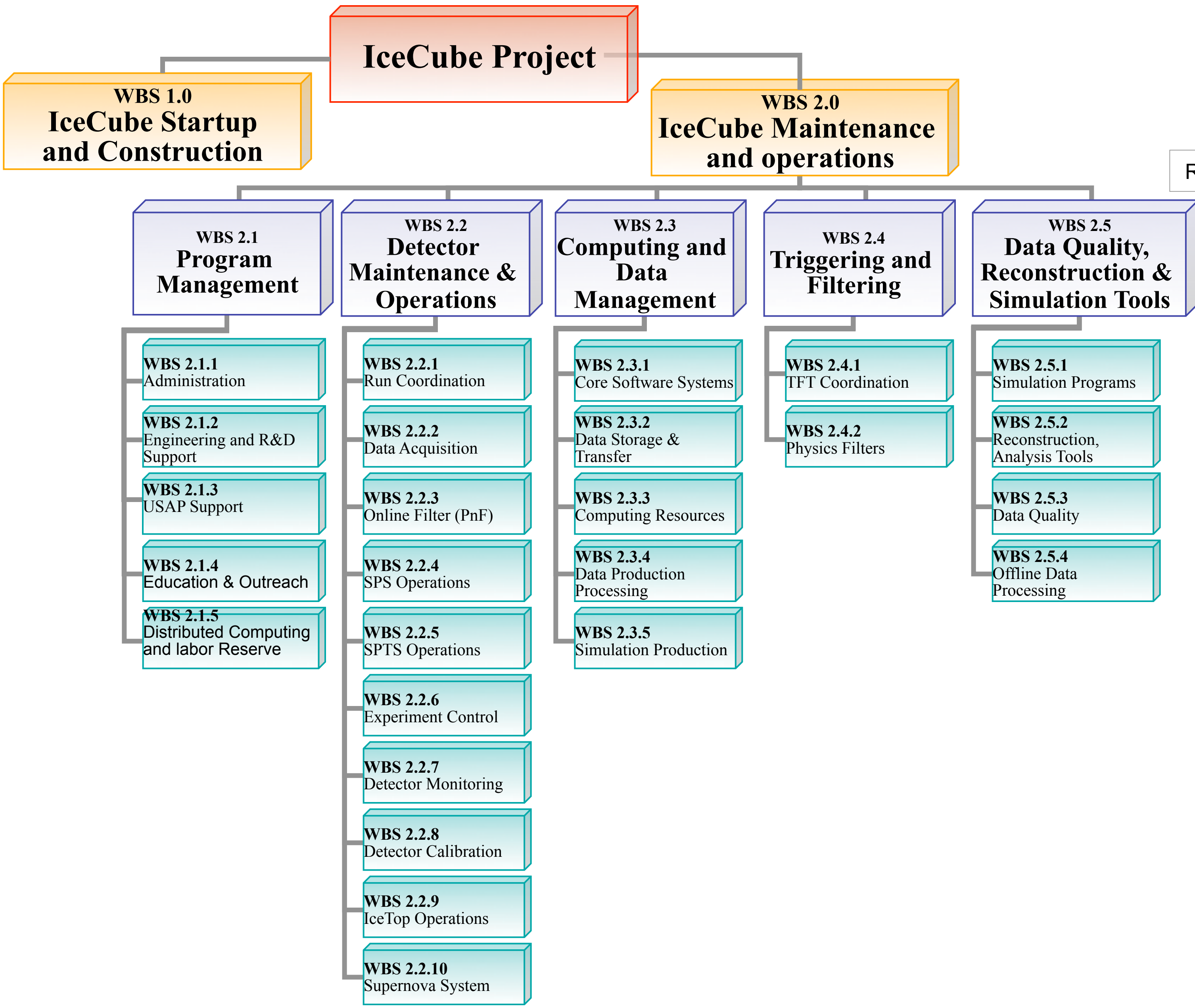
Category	Subcategory	M&O WBS	Tasks	FTE M&O Core	M&O Core Institutions and Labor Categories	FTE In-kind	In Kind Contributor
Rev Final	**4/6/09**						
Program Management		**2.1**					
	Administration	**2.1.1**	Operations Management	1.25	UW Key Personnel: Director 0.75 FTE Associate Director 0.5 FTE		
			Resource Coordination Support	0.50	UW Manager Supporting the Spokesperson		
			Computing Infrastructure Management	1.00	UW IceCube Computing Facilities Manager		
			Science Support: Executive Committee, ICB, etc.	0.17	UW Key personnel: Principle Investigator, Associate Director	2.00	1 month of key personal for each major collaborating institution
			Administrative Support	0.50	UW Admin	1.00	Collaboration
	Engineering and R&D Support	**2.1.2**	Engineering Support	1.00	UW Engineers		
			EMI, Instrumentation, I/F	1.00	UW Scientist 0.25 FTE, UW Engineer 0.5 FTE UW Computer Sceince Eng. 0.25 FTE	1.00	Collaboration
	USAP Support	**2.1.3**	South Pole Coordination (SIP, SCOARA, etc.)	0.25	UW Manager, SCOARA		
	Education & Outreach	**2.1.4**	Education & Outreach Coordination	1.25	UW Admin 1.25 FTE	1.00	Collaboration
	Distributed Computing and Labor Reserve	**2.1.5**	Tier 2 Hardware reserve	0.00			
			Missing In-Kind Labor	1.00	UW Technician		
			Total	**7.92**		**5.00**	
Detector Maintenance & Operations		**2.2**	Detector Maintenance and Operations Coordination	1.00	UW Manager		
	Run Coordination	**2.2.1**	Run Coordination	0.50	LBNL Scientist		
			Operate Detector (Winter-Overs)	3.25	UW Winter Overs: 2 FTE (with 6m overlap) = 3 FTE UW Scientist 0.25 FTE coordination		
	Data Acquisition	**2.2.2**	Maintain DAQ Hardware (Hubs, DOR, Clocks, GPS,...)	0.55	UW Engineer 0.25 FTE UW Computer Science Eng. 0.15 FTE LBNL Computer Science Eng. 0.15 FTE	0.25	Brussels Senior Scientist 0.10 FTE, DESY 0.15 FTE
			Maintain DAQ Software Systems (incl. triggers, DOM SW, etc. up to Event Builder)	1.40	UW Computer Science Eng. 1.00 FTE PSU Postdoc 0.15 FTE LBNL Computer Science Eng. 0.25 FTE (FY10)	0.20	Brussels Senior Scientist 0.1 FTE PSU Postdoc 0.1 FTE
			DOM Firmware Technical Support	0.00		0.15	DESY
			DOM Cal Maintenance	0.35	UW Scientist	0.25	UW Grad Student 0.25 FTE
			DOM Monitoring and troubleshooting	0.25	UW Scientist		
	Online filter (PnF)	**2.2.3**	Maintain PnF Software and Online Filters	0.50	UMD Computer Science Eng. 0.3 FTE UMD Scientist 0.2 FTE		
			SW Design and Deployment of Online Filters in P&F	0.00		0.25	UMD Grad Student
	South Pole System Operations	**2.2.4**	Maintain South Pole Computing Hardware Infrastructure	0.50	UW Engineers		
			Maintain South Pole Computing Operating Systems	0.50	UW Engineers		
			Networking and Security Maintenance	0.25	UW Technician		
	South Pole Test System Operations	**2.2.5**	Maintain South Pole Test System Hardware	0.50	UW Engineers		
			Maintain South Pole Test Operating Systems	0.25	UW Engineers		
	Experiment Control	**2.2.6**	IceCube Live Maintenance and Upgrades	1.00	UW Computer Science Engineers		
	Detector Monitoring	**2.2.7**	Detector Monitoring Coordination	0.00		0.50	Ucb Scientist
			Monitor Detector Stability and Performance	0.00		1.50	Shift work
			Run and Evaluate Verification Test Data	0.00		0.25	PSU Postdoc
			Provide Real-time System Monitoring and Paging	0.45	UW Scientist 0.2 FTE, UW Undergrad 0.25		
	Calibration	**2.2.8**	Prepare and Evaluate Flasher Calibrations	0.25	UW Scientist	0.50	U. Alabama, PSU
			Evaluate (DomCal) Calibration Runs and update Calibration constants	0.10	UW Scientist	0.30	Grad Students
	IceTop Operations	**2.2.9**	Coordinate IceTop Operations	1.00	UD Scientist		
	Supernova System	**2.2.10**	Supernova Operations			1.00	Mainz 0.5, UW 0.5

Category	Subcategory	M&O WBS	Tasks	FTE M&O Core	M&O Core Institutions and Labor Categories	FTE In-kind	In Kind Contributor
			Total	**12.60**		**5.15**	
Computing and Data Management		**2.3**	Computing and Data Management Coordination	1.00	UW Manager		
	Core Software Systems	**2.3.1**	Maintain Core Analysis Framework (IceTray)	1.50	UMD Computer Science Engineers	0.50	Grad Student
			Maintain Reconstruction Framework (Gulliver)	0.00		0.50	Aachen, DESY
			Maintain and Operate Database Systems (I3DB)	0.50	UW Technician	1.00	Brussels
			Maintain Simulation Production Software	1.00	UW Technician		
			Maintain Data Processing Software	0.50	UW Scientist		
			Maintain Core Software Repository	0.50	UMD Computer Science Engineer		
			Maintenance of the Verification software framework	0.75	PSU Postdoc		
	Data Storage & Transfer	**2.3.2**	Transfer Data from S. Pole to UW Data Warehouse and Archive at S. Pole	0.50	UW Computer Science Eng. 0.25 FTE UW Technician 0.25 FTE		
			Maintain Data Transfer Software (SPADE)	0.50	UW Computer Science Eng.		
			Maintain Data Warehouse Standards, Software (Ingest), Data Access (FTP), and Web Interface	1.00	UW Computer Science Eng. 0.15 FTE UW Technician 0.85 FTE		
			Maintain and Operate Data Storage Infrastructure	1.25	UW Technician		
			Transformation of Data for Long-Term Persistence and Archival, e.g., HDF5	0.25	UW Scientist	0.25	DE
	Computing Resources	**2.3.3**	Coordination and Support for Grid and distributed computing	1.00	UW, UD, UMD Technician 0.25 FTE each PSU Postdoc 0.25 FTE	1.80	DE
			Maintain Core High Performance Computing Systems	1.00	UW Technician		
			Maintain Data Center Networking and Security	0.75	UW Technician		
			Maintain Data Center Infrastructure	1.50	UW Technician		
	Data Production Processing	**2.3.4**	Unpacking, Decoding and Calibration of Raw Data in the North (Level1)	0.20	UW Technician		
			Run Common Reconstructions on UW IceCube Compute Cluster (Level2)	0.30	UW Technician		
	Simulation Production	**2.3.5**	Coordination of Simulation Production	1.00	UW Scientist 0.7 FTE UW Technician 0.3 FTE		
			Produce Simulation data in distributed computing infrastructure	0.00		4.00	US 1.6 FTE (UW,PSU,UMD,LBNL,UD) DE 2.0 FTE, SE 0.2 FTE , BE 0.2 FTE
			Maintain production configurations, manage test production and maintain web portal.	0.30	UW Technician		
			Total	**15.30**		**8.05**	
Triggering and filtering		**2.4**					
	TFT Coordination	**2.4.1**	Coordinate process for filter requests, bandwidth	0.30	UMD Scientist	1.00	Scientist 1.0 FTE (TFT Board - Collaboration)
			Prepare datasets for filter testing and common Monte Carlo datasets for testing			0.20	UMD Grad student
	Physics Filters	**2.4.2**	Develop filter request and code for pole filtering			4.00	Working Groups
			Verify filter code and physics efficiency			1.50	Working Groups
			Total	**0.30**		**6.70**	
Data Quality, Reconstruction & Simulation Tools		**2.5**	Data Quality, Reco. & Simulation Tools Coordination	0.50	UW Scientist		
	Simulation Programs	**2.5.1**	Simulation Software Project Management	0.40	UMD Postdoc		
			Maintain Detector Simulation (IceSim)			1.50	MPI, UW, UMD Postdocs
			Maintain Simulation of the Physics of Event Generation			1.50	Collaboration
			Maintain and Verify Simulation of Photon Propagation and update Ice Properties	1.00	UW Scientist 0.5 FTE UCB Scientist 0.5 FTE	2.00	UW Postdoc, Grad Students 1.5 FTE UCB 0.50 FTE
			Maintain and run Geometry calibration software			0.30	Collaboration
			Development of new Simulation tools			2.00	Collaboration
	Reconstruction,	**2.5.2**	Develop core common reconstruction tools			2.50	Collaboration

Category	Subcategory	M&O WBS	Tasks	FTE M&O Core	M&O Core Institutions and Labor Categories	FTE In-kind	In Kind Contributor
	Analysis tools		Develop and maintain analysis tools (e.g., Flat Ntuple)			1.00	Collaboration
	Data Quality	**2.5.3**	Final selection of science ready data	0.00		1.50	PSU, OSU, UA, UD
	Offline data processing	**2.5.4**	Coordinate/develop common reconstruction for production			2.00	Working Groups
			Monitor reconstruction processing and stability of reconstruction results (L2 Processing)			0.25	
			Total	**1.90**		**14.55**	
Physics Coordination							
	Analysis Coordinator		Coordinate all physics analysis			0.50	Non-US In-Kind
			Total	**0.00**		**0.50**	
			Grand Total	**38.02**		**39.95**	

Appendix 2 - IceCube Work Breakdown Structure (WBS)

Rev 2009.0403



Appendix 3

Draft Statement of Work for M&O of the IceCube Neutrino Observatory

1.0. Overview

IceCube is a high-energy neutrino observatory located at the South Pole. IceCube detects high-energy neutrinos that are thought to be messengers that can teach us about the underlying physical processes and dynamics that drive exotic phenomena. The neutrinos are detected through their interactions in or near the cubic kilometer IceCube array of optical sensors deployed deep in the ice at the South Pole. These interactions produce high-energy muons (charged particles) that pass through an array of more than 5000 sensors, which provides researchers a way to look back and determine the arrival direction and energy of the primary neutrino, as well as the number of such events. IceCube also includes a surface component called IceTop, which includes more than 320 sensors that detect and reconstruct cascades of particles produced by interactions of cosmic rays of high energy above the detector. IceTop provides calibration and partial veto of the cosmic ray background for the deep detector, as well as direct study of cosmic radiation.

IceCube has the potential for transformative discovery in multiple scientific disciplines including, but not limited to, astronomy, astrophysics, nuclear and particle physics, cosmology and glaciology. IceCube opens a new window for extragalactic astronomy and astrophysics, exploring a range of neutrino energies that are not available from any terrestrial source built by nuclear and particle physicists. Its potential includes discovering the nature of dark matter; the nature of black holes, supernovae explosions and gamma ray bursts; and new celestial objects and phenomena. Historically, new ways of looking at the sky have discovered unanticipated phenomena resulting in quantum leaps in our understanding of the universe.

2.0. IceCube M&O Tasks

The awardee shall maintain and operate the IceCube Neutrino Observatory at the South Pole and support researchers to exploit IceCube fully for science and education.

2.1. Program Management

The awardee shall provide efficient and effective program management support to operations and science through responsible stewardship of taxpayer funds to meet IceCube scientific objectives.

2.1.1. Program Administration

The awardee shall define and continuously improve the operational systems, processes and policies that support the IceCube scientific mission. The awardee shall also define and track requirements and ensure the proper configuration for all IceCube computing infrastructure; manage IceCube finances in compliance with the terms of the NSF Cooperative Agreement and other applicable laws and regulations; and manage performance through measurable indicators that can be systematically tracked to assess progress made in achieving operations goals. The awardee shall provide regular reporting to NSF on program status and issues as defined in the attached List of Deliverables.

2.1.2. Engineering and R&D Support

The awardee shall provide technical support from scientific, engineering and software professionals to assist IceCube M&O personnel with planning and completing specialized maintenance tasks and upgrades, and solving problems.

2.1.3. US Antarctic Program (USAP) Infrastructure Support

The awardee shall support the annual NSF planning cycle for the USAP by providing a detailed Support Information Package (SIP) that details the support requirements from USAP for IceCube.

2.1.4. Education and Outreach (E&O) Coordination

The awardee shall provide education and outreach coordination throughout the IceCube collaboration. This can take the form of providing images and video, artifacts such as DOMs and South Pole weather gear, or posters and other printed materials. The awardee shall work with outside groups, science venues, special programs, and/or various media (such as television, web and print) to showcase the IceCube project toward maximizing the educational value and public knowledge of IceCube science.

2.1.5. Distributed Computing and Labor Reserve

The awardee shall provide for a reserve of computing resources if collaboration resources are unavailable or insufficient. The awardee shall also create a reserve of labor to complete M&O tasks assigned to base grant support in the event base grant resources are unavailable or insufficient.

2.2. Detector Maintenance and Operations

The awardee shall provide operational support to researchers to run experiments and maintain the detector to achieve consistently high data quality at volumes that fully exploit IceCube's discovery potential.

2.2.1. Run Coordination

2.2.1.1. Coordinate Detector Runs

The awardee shall coordinate detector runs to ensure that IceCube data is of high quality, live detector time is maximized, and data is stable for physics analysis. This task extends from production of the data in the DOMs through the triggers and online filters and over the satellite link to the Data Center in the Northern Hemisphere.

2.2.1.2. Operate Detector (Winterovers)

The awardee shall provide full-time, on-site winter-over support at the South Pole Station to perform all tasks required to maximize live detector time, including collecting physics data, resolving problems, supporting data transfer, and performing urgent maintenance tasks and daily system monitoring.

2.2.2. Data Acquisition (DAQ)

2.2.2.1. Maintain DAQ Hardware

The awardee shall maintain DAQ hardware located both at the South Pole, as part of the South Pole System (SPS), and in the Northern Hemisphere, as part of the South Pole Test System (SPTS), to maximize detector uptime and quality of data. The awardee shall also add features as required in response to evolving science needs and respond to the needs of users to improve functionality as appropriate.

2.2.2.2. Maintain DAQ Software Systems

The awardee shall maintain the software comprising the IceCube DAQ System from the DOM software through the output of the Event Builder to ensure the integrity, correctness and completeness of detector data. The awardee shall develop and support new triggering algorithms and methods for their deployment into the DAQ triggering system at the South Pole to extend the physics reach of the detector.

2.2.2.3. Provide Digital Optical Module (DOM) Firmware Technical Support

The awardee shall support firmware for DOMs and DOM Readout Cards (DORs), delivering and testing appropriate bug fixes or feature adjustments as required.

2.2.2.4. Maintain DOM Calibration (DOMCal System)

The awardee shall conduct monthly runs of the DOMCal system to provide accurate calibration constants and to discover DOM problems. The awardee shall also provide updates as needed to the DOMCal software to meet the needs of users as detector operations mature.

2.2.2.5. Monitor and Maintain DOMs

The awardee shall monitor DOM performance to detect malfunctions and reconfigure the detector when they are identified. The awardee shall also track, study and repair or reconfigure these problem DOMs to maximize the number of DOMs in the data stream.

2.2.3. Online Filters (Processing and Filtering—P&F)

2.2.3.1. Maintain P&F Software and Online Filters

The awardee shall provide maintenance support for the online P&F system, verifying proper application of filters and debugging unexpected errors to ensure transmission of high-quality, well understood and controlled filtered data sets to the Northern Hemisphere for analysis.

2.2.3.2. Design Software and Deploy Online Filters in P&F

The awardee shall provide support for implementing and testing online filters in the P&F system in response to decisions from the Trigger, Filter, Transmission (TFT) Board to ensure high-quality data samples.

2.2.4. South Pole System (SPS)

2.2.4.1. Maintain SPS Computing Hardware Infrastructure

The awardee shall provide full and coordinated support for the SPS, IceCube's South Pole computing hardware base, to ensure maximum performance in the collection, delivery, storage and initial processing of IceCube physics data.

2.2.4.2. Maintain SPS Computing Operating Systems

The awardee shall support SPS computing operating systems to manage version control, perform patching, implement software updates, and monitor system performance to maintain a stable operating system base to support IceCube application programs.

2.2.4.3. Maintain SPS Networks and Network Security

The awardee shall maintain the IceCube network infrastructure to maximize network reliability and provide customized solutions to optimize performance as required. The awardee shall also implement and monitor network security systems as required to ensure compliance with National Science Foundation and host institution network security policies and directives.

2.2.5. South Pole Test System (SPTS)

2.2.5.1. Maintain SPTS Hardware

The awardee shall maintain and operate the SPTS computing hardware base to provide high availability of the foundation to build and test software in advance of operational deployment at the South Pole. The awardee shall maintain configuration control to ensure that the SPTS architecture replicates that of the SPS to ensure that pre-deployment testing on the SPTS prevents system failures in the live environment. The awardee shall also maintain hardware, such as DOMHubs, DOMs, DOM mainboards, signal pulsers, and other equipment required for testing firmware and software prior to deployment in the detector. The awardee shall ensure that the hardware accurately emulates conditions at the South Pole to minimize the risk of DOM hardware failures in the operational system.

2.2.5.2. Maintain SPTS Operating Systems

The awardee shall support SPTS computing operating systems to manage version control, perform patching, implement software updates, and monitor system performance to maintain a stable operating system that emulates the SPS for development and pre-deployment testing of IceCube application programs.

2.2.6. Experiment Control

2.2.6.1. Maintain and Update IceCube Live Experiment Control System

The awardee shall provide an integrated, high-level command and control system that notifies operators of the detector's operational status and the types of physics data being collected. The system shall also provide for remote and hands-on control and operation of the detector to allow the operator to perform basic control operations on major systems and subsystems.

2.2.7. Detector Monitoring

2.2.7.1. Coordinate Detector Monitoring, and Maintain and Upgrade Systems

The awardee shall provide and maintain a system that monitors the physics quality of data collected by the IceCube detector. The system shall also provide an automatic alert mechanism for early detection of potential problems with the data, as well as an archive of historic monitoring data for long-term studies of detector stability and performance. This will include monitoring environmental variables, such as pressure and atmospheric temperature profile, which are related to rates of different classes of events in the detector.

2.2.7.2. Monitor Detector Stability and Performance

The awardee shall provide continuous monitoring of detector stability and performance to ensure that data collected is of the highest quality for physics analysis.

2.2.7.3. Run and Evaluate Verification Test Data

The awardee shall provide and monitor a system to examine and test acquired data for the quality level required for physics analysis. The awardee shall maintain the underlying code for running the tests at the South Pole, evolve the thresholds for flagging problems as the detector ages, and improve the code with new tests as needed.

2.2.7.4. Provide Real-time System Monitoring and Paging

The awardee shall provide and maintain a real-time, centralized monitoring and paging system to produce alerts in the event of a detector problem. For serious problems, the system shall also notify operators via a centralized paging system with multiple levels of escalation that continue until the problem is addressed.

2.2.8. Calibration

2.2.8.1. Prepare and Evaluate Flasher Calibrations

The awardee shall provide validated LED flasher datasets as needed to study and address systematics issues that affect the efficiency of physics analysis, detector calibration, and DAQ and trigger performance.

2.2.8.2. Evaluate Calibration Runs and Update Calibration Constants

The awardee shall perform regular calibrations IceCube components from individual DOMs to the detector as a whole to ensure quality data for physics analysis.

2.2.9. IceTop Operations

2.2.9.1. Coordinate IceTop Operations

The awardee shall provide design, acquisition, and maintenance of data sets to monitor the performance of all DOMs installed in the IceTop surface tanks to ensure the quality of IceTop data. The awardee shall also monitor the physical condition of the IceTop detectors over time so that any changes in their response may be accounted for in analysis.

2.2.10. Supernova Operations

2.2.10.1. Support Supernova Operations

The awardee shall provide and maintain a command and control system to collect and compress the data for detection of supernovae to ensure that detection capability is maximized and that significant triggers are immediately analyzed.

2.3. Computing and Data Management

The awardee shall maintain and manage software and hardware resources to maximize application of technology within available resources to ensure collection and management of data optimized for researcher analysis and scientific discovery.

2.3.1. Core Software Systems

2.3.1.1. Maintain Core Analysis Framework

The awardee shall maintain the IceTray software framework, which is used as the basis for all calibration, analysis, reconstruction and simulation tasks in IceCube, including bug fixes and new feature support; maintenance of the software repository system and continuous-build testing system; maintenance of the external libraries and build tools as newer operating system versions emerge; and training of new users.

2.3.1.2. Maintain Reconstruction Framework

The awardee shall maintain the maximum likelihood framework used to implement the high-level reconstruction algorithms to ensure their application to the greatest number of events within the limited computing resources available. This includes maintenance, bug fixes and new features support; optimization of the framework on different processors; and training and support in the development of new reconstructions.

2.3.1.3. Maintain and Operate Database System

The awardee shall maintain and operate a central database with mirrors in key locations, which are well organized, synchronized and reliable to ensure continuous access to critical IceCube data content at low latency.

2.3.1.4. Maintain Simulation Production Software

The awardee shall maintain and extend the simulation production middleware coordinating the distributed Monte Carlo dataset production. This includes the addition of new clusters or Grid resources as well as adapting to new software requirements.

2.3.1.5. Maintain Data Processing Software

The awardee shall maintain all software required to process IceCube data filtered at the South Pole, adapting the processing based on changing detector configurations and required reconstruction algorithms developed by the collaboration. The awardee shall adapt the submission and execution monitoring to make the best use of the available computing resources.

2.3.1.6. Maintain Core Software Repository

The awardee shall provide and maintain a central software repository allowing standard configuration management of the IceCube software to ensure consistent reproduction of results obtained from IceCube data.

2.3.1.7. Maintain and Verify Software Framework

The awardee shall maintain a software framework for verification of physics data. The framework shall include high-level data quality tests to assess the quality of physics data and verify the stability of the detector for physics analysis.

2.3.2. Data Storage and Transfer

2.3.2.1. Archive at South Pole and Transfer Data to Data Warehouse in North

The awardee shall provide reliable data transfer from the South Pole to a central data warehouse located in the Northern Hemisphere. The data warehouse shall be accessible to all collaborating researchers and offer online storage of raw, processed and simulated data of the current physics run as well as archived storage of all IceCube data.

2.3.2.2. Maintain Data Transfer Software (SPADE)

The awardee shall maintain the data transfer software (SPADE) to include periodic thinning of database tables to maintain reliable, fast SQL queries; adding and removing data streams from database registries to allow new data producers to be integrated into the system; resolving bugs and adding new features; and adapting software to new or upgraded hardware.

2.3.2.3. Maintain Data Warehouse Standards, Software, Data Access, and Web Interface

The awardee shall maintain software to receive all files sent from SPADE at the South Pole via e-mail, direct network transfer, or TDRSS. The awardee shall also provide and maintain easy-to-use tools for users to store data in the Data Warehouse.

2.3.2.4. Maintain and Operate Data Storage Infrastructure

The awardee shall maintain and operate data storage hardware and associated software, including backup systems, to safely store experimental data and other key files.

2.3.2.5. Transform Data for Long-Term Persistence and Archive

The awardee shall store processed data files in a format consistent with long-term persistence to allow combination of several years of data into a single dataset. The data shall also be available for historical data mining over the full lifetime of IceCube.

2.3.3. Computing Resources

2.3.3.1. Coordinate and Support Grid and Distributed Computing

The awardee shall provide an efficient and stable data transfer system based on GRID technologies, and leverage the available distributed computing resources. The awardee shall also coordinate and support the distributed computing resources available to the IceCube collaboration.

2.3.3.2. Maintain Core High Performance Computing System

The awardee shall support an HPC system capable of IceCube data preparation and core computing tasks necessary to deliver science-ready data in a timely fashion. Tasks include filter of data from raw to level 2 science-ready data, simulation production, and basic analysis for collaboration physics working groups.

2.3.3.3. Maintain Data Center Networking and Security

The awardee shall support IceCube network infrastructure maintenance and implement security measures as required. The IceCube network is a mission-critical, fully distributed mix of wide-area, host institution, local, and wireless configurations deployed across public and private networks linking multiple remote sites. The IceCube network shall comply with networking and security policies and regulations of NSF and the host institution.

2.3.3.4. Maintain Data Center Infrastructure

The awardee shall maintain, upgrade and expand computer infrastructure as required to support data processing, storage and simulation production required to meet IceCube science objectives.

2.3.4. Data Production Processing

2.3.4.1. Unpack, Decode and Calibrate Rate Data in North

The awardee shall process all data received in the north to be usable by standard IceCube tools for production and analysis in a timely manner.

2.3.4.2. Run Common Reconstructions on IceCube Compute Cluster in North

The awardee shall run common high-level reconstructions on the filtered data to provide a consistent dataset for final physics analysis.

2.3.5. Simulation Production

2.3.5.1. Coordinate Simulation Production and Resources

The awardee shall ensure high-level coordination of production of Monte Carlo simulation data and their filtering and processing. The awardee shall also coordinate between M&O and the Collaboration to ensure proper production is performed to provide quality data for physics analysis.

2.3.5.2. Produce Simulation Dataset in Compute Cloud

The awardee shall maintain simulation production software installation and data processing runtime across the distributed computing infrastructure, monitor status and ensure that final data files are properly stored in the IceCube data center and made available to the Collaboration for analysis.

2.3.5.3. Maintain Production Templates, Perform Test Productions and Maintain Production Web Portal

The awardee shall maintain the simulation production configuration files and vet them with a systematic series of production tests. This involves maintenance of a basic runtime simulation quality assessment based on a set of dedicated histograms as compared to previous simulation datasets and experimental data. The awardee shall also maintain the simulation production web portal to report the online status of simulation production across the distributed computing infrastructure.

2.4. Triggering and Filtering

The awardee shall maximize collection and transmission of physics quality data within the constrained resources of the South Pole System in support of IceCube's scientific objectives.

2.4.1. Trigger, Filter and Transmission (TFT) Coordination

2.4.1.1. Coordinate Process for Filter Requests and Bandwidth

The awardee shall provide a coordination mechanism to ensure that the detector is operated in a configuration that meets the physics needs of the collaborating researchers utilizing the limited resources of the South Pole System in a controlled and consistent manner.

2.4.1.2. Prepare Datasets for Filter Testing and Common Monte Carlo Datasets for Testing

The awardee shall provide for coordinated collection of data sets that are to be used by collaborating physics working groups to develop and benchmark physics filters to ensure compatibility with the proposed configuration for the upcoming year.

2.4.2. Physics Filters

2.4.2.1. Develop Filter Requests and Code for Pole Filtering

The awardee shall provide for development of filters to operate at the South Pole that select events for immediate transmission to the Northern Hemisphere for further analysis, ensuring that the filters meet the physics needs of collaborating researchers toward analysis of the most meaningful data.

2.4.2.2. Verify Filter Code and Physics Efficiency

The awardee shall provide for verification of filters deployed in the online data filtering system to ensure that the filters meet the needs of the physics working groups and have high efficiency for collecting signal events.

2.5. Data Quality, Reconstruction and Simulation Tools

The awardee shall provide, maintain and manage a common set of calibration, basic reconstruction, simulation, analysis and verification tools and processes to ensure that real and simulated data are of sufficient quality for physics analysis.

2.5.1. Simulation Programs

2.5.1.1. Manage Simulation Software Projects

The awardee shall coordinate and manage the IceSim program, code repository, version, documentation, test modules, and builds to ensure the highest quality simulations of signal and background events. The awardee shall also coordinate in-kind collaboration physicist effort in developing improved simulations.

2.5.1.2. Maintain Detector Simulation (IceSim)

The awardee shall maintain the detector simulation for quality and CPU performance ensuring the highest reliability and speed of simulation program performance.

2.5.1.3. Maintain Simulation of the Physics of Event Generation

The awardee shall maintain the physics event simulation for quality and CPU performance to maintain event generation program alignment with changes in understanding of the physics of the generation of neutrino events and shower events.

2.5.1.4. Maintain and Verify Simulation of Photon Propagation and Update Ice Properties

The awardee shall model the propagation of photons in the ice from their creation at a track to their detection by a phototube in the detector to ensure accuracy of the model, which is critical to the ability to reconstruct tracks.

2.5.1.5. Maintain and Run Geometry Calibration Software

The awardee shall maintain and update geometry of the detector DOM positions to ensure accuracy in reconstructing tracks and events.

2.5.1.6. Develop New Simulation Tools

The awardee shall develop new detector simulation tools and continuously improve existing tools to enable lower systematic error, improved signal efficiency and reduced background.

2.5.2. Reconstruction and Analysis Tools

2.5.2.1. Develop Core Common Reconstruction Tools

The awardee shall continue development of reconstruction algorithms and program code to be executed on the raw data to enhance the physics capability of the detector and maximize its science potential.

2.5.2.2. Develop and Maintain Analysis Tools

The awardee shall develop common high-level analysis tools, such as data summary files, plotting packages, statistical tools, and others, to maximize efficiency of producing results from reconstructed data.

2.5.3. Data Quality

2.5.3.1 Support Final Selection of Science-ready Data

The awardee shall develop and maintain common lists of high-quality detector runs and a run-by-run list of performing and non-performing DOMs for entry into a common database, which defines the science-ready data sets.

2.5.4. Offline Data Processing

2.5.4.1. Coordinate and Develop Common Reconstruction for Production Processing

The awardee shall develop common reconstruction production processing to be run on the filtered data as it arrives in the Northern Hemisphere data warehouse, and identical processing for the simulated datasets, to ensure efficiency in production processing and quality of data.

2.5.4.2. Monitor Reconstruction Processing and Stability of Reconstruction Results

The awardee shall monitor the output of the common reconstruction production processing for quality and stability of the production processing code to ensure data quality for physics analysis.

2.6. Physics Analysis Coordination

The awardee shall manage, support and coordinate the analytical and review resources of the collaborators and the scientific community to maximize IceCube's contribution to science and to produce publications of the highest quality and scientific integrity.

2.6.1. Analysis Coordinator—IceCube Collaboration Responsibility

Appendix 4
Cost Overview

Our approach to IceCube M&O identifies the resources required from all sources supporting all tasks to maintain and operate IceCube at the minimum level necessary to achieve its basic design capabilities. This proposal describes $45.9M of Core M&O support, including approximately $3.2M of Euro & Asia Pacific contributions to a Common Fund, resulting in a request to the NSF of $42.7M over five years for the central M&O award. In addition, our MOUs secure In-Kind contributions of distributed M&O labor and computing resources from collaboration institutions of approximately 40 FTE of per year of labor and over 2,250 guaranteed CPU cores and 500 TB of storage for distributed computing.

This represents a transition from a centralized management and funding approach during IceCube's construction phase to a more distributed model of management and funding for M&O (**Figure 4-1**).

The distributed model results in increased financial contributions to the Common Fund and in-kind labor contributions to M&O tasks from Euro & Asia Pacific collaborators. It also results in a greater emphasis on direct NSF funding to U.S. Collaborating institutions and a reduced fraction of funding to the central UW M&O budget while keeping the total NSF funding for IceCube within parameters previously discussed. Total in-kind contributions by each Collaboration institution (Appendix 5) will be finalized in an MOU with Collaboration members in May 2009.

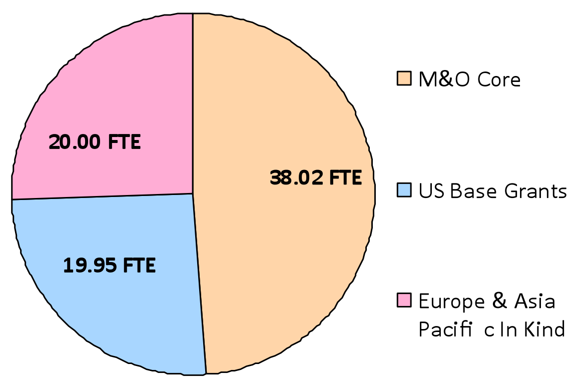


Figure 4-1. Distributed Management and Funding Model

The M&O budgets in this section are based on a detailed, bottom-up analysis of the costs required to complete each task in the M&O Work Breakdown Structure (WBS). These costs are very well understood and are based on actual experience during the initial M&O phase. There is no explicit budgeting for contingency as was done for the MREFC project. There is a very small unallocated budget within Program Management, one person-year of labor, $45K of capital equipment and $75K of Materials & Supplies, as a reserve to support tasks that are not covered by NSF research grant support, as is currently assumed in the MOUs.

4.1. Cost Summary

Cost Elements. The IceCube Neutrino Observatory is beginning the third and final year of the initial M&O program ending on March 31, 2010. This 5-year M&O proposal addresses the M&O support requirements from April 1, 2010 to March 31, 2015.

Figure 4.1-1 summarizes the M&O Core Cost by IceCube Project Year. All other tables in this section and in appendix 6, are by Federal Fiscal Year which matches work plans.

IceCube M&O Core Cost	Year 1	Year 2	Year 3	Year 4	Year 5	5 Yrs Proposal Total ($K)
By Project Years	Apr 2010 - Mar 2011	Apr 2011 - Mar 2012	Apr 2012 - Mar 2013	Apr 2013 - Mar 2014	Apr 2014 - Mar 2015	Apr 2010 - Mar 2015
Total	8,701	8,979	9,179	9,397	9,596	$45,852

Figure 4.1-1. M&O Core Funds by IceCube Project Year (in $K)

The cost of the M&O program is primarily driven by labor and computing costs. The cost breakdowns by WBS are presented in the table (K$) and in the Pie chart (FTE), in **Figure 4.1-2** and by major cost categories in **Figure 4.1-3**.

WBS Level 2	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15	5-Year Total
2.1 Program Management	910	1,873	1,927	1,983	2,040	1,050	**9,782**
2.2 Detector Operations & Maintenance	1,423	2,819	3,023	2,961	2,982	1,534	**14,743**
2.3 Computing and Data Management	1,699	3,798	3,646	3,920	3,984	2,033	**19,080**
2.4 Triggering and Filtering	28	57	59	61	62	32	**299**
2.5 Data Quality, Simulation and Reconstruction Tools	181	372	384	395	407	210	**1,948**
Total M&O Core Cost	**4,241**	**8,919**	**9,039**	**9,319**	**9,475**	**4,858**	**45,852**

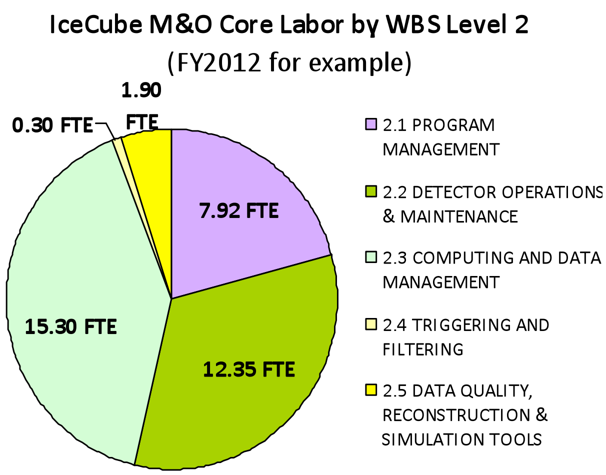


Figure 4.1-2. M&O Core Costs Graph by WBS Level 2 ($K and FTE)

Cost Category	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15	5-Year Total
Labor	3,053	6,226	6,469	6,650	6,837	3,521	**32,756**
Travel	124	249	259	265	270	139	**1,306**
Capital Equipment	280	689	644	559	559	280	**3,010**
Materials & Supplies	496	1,089	1,055	1,157	1,193	578	**5,569**
Service Agreement	288	667	612	688	616	340	**3,210**
Total M&O Core Cost	**4,241**	**8,919**	**9,039**	**9,319**	**9,475**	**4,858**	**45,852**

Figure 4.1-3. M&O Core Costs by Cost Category (in $K)

Funding Sources and Trends. The M&O Core Scope of Work does not include the In-Kind contributions supported by research grants and Institutional contributions. The two sources of funds for the M&O Core activities are the NSF M&O Core and European & Asia/Pacific Funding for the Common Fund (CF). The MREFC project scope includes Pre-Operations, construction activities that are directed at reducing the future M&O requirements and enabling a clear transition from construction to operations. Pre-Operations activities conclude in the 1st half of FY2010, the initial year of this M&O proposal.

Funds Request	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15	5-Year Total
NSF M&O Proposal	3,921	8,278	8,397	8,678	8,833	4,537	**42,644**
Euro & Asia/Pacific CF *	321	642	642	642	642	321	**3,208**
NSF MRE Pre-Operations	0	0	0	0	0	0	**0**
Total MAO Core Funds	**4,241**	**8,919**	**9,039**	**9,319**	**9,475**	**4,858**	**45,852**

* **Figure 4.1-6** summarizes the Common Funds contribution calculation methodology

Figure 4.1-4. M&O Core Funds Sources (in $K)

The funding profile as IceCube transitions from the construction phase to the M&O phase as illustrated in **Figure 4.1-5** shows the transition into FY2011, the end of construction and the start of steady-state M&O.

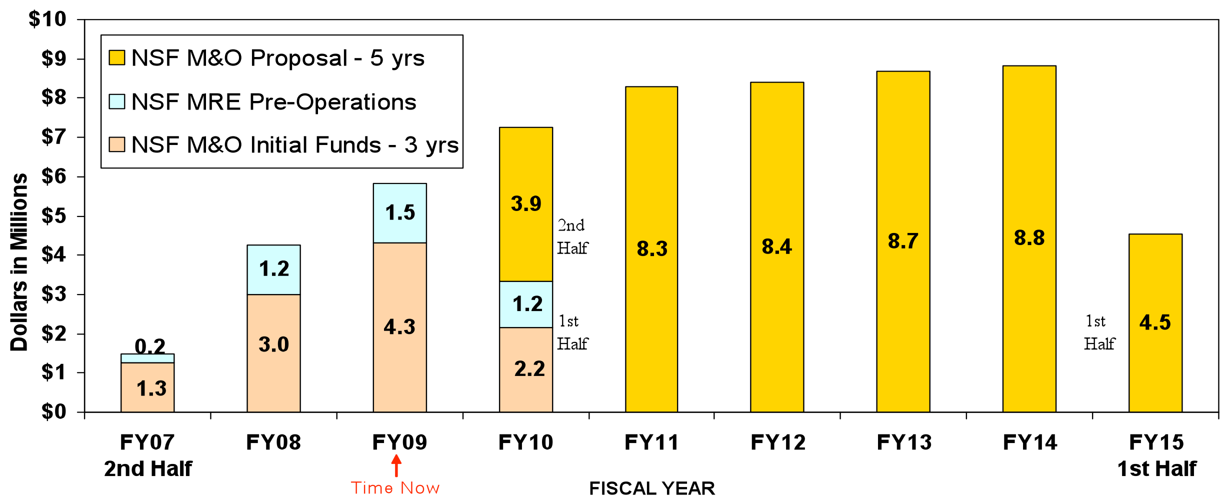


Figure 4.1-5. NSF M&O Funds Profile

The M&O Common Fund (CF) is a fund to cover work within the M&O Core Scope of Work supported by both US and Euro & Asia Pacific contributions. The contributions are based on the number of authors per each institution. We have increased the assumed contribution per author by 50% resulting in a corresponding increase in the total CF.

Common Funds (CF)	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15	5-Year Total
CF per author per year *	$6.8	$13.7	$13.7	$13.7	$13.7	$6.8	
US # of Authors	*71*	*71*	*71*	*71*	*71*	*71*	
US Funds	$485	$969	$969	$969	$969	$485	**$4,846**
Euro/Asia/Pacific # of Author	*47*	*47*	*47*	*47*	*47*	*47*	
Euro/Asia/Pacific Funds	$321	$642	$642	$642	$642	$321	**$3,208**
Total Common Funds	**$805**	**$1,611**	**$1,611**	**$1,611**	**$1,611**	**$805**	**$8,054**

* Assumes a 50% increase of the current annual contribution per author per year which is $9.1K.

Figure 4.1-6. M&O US and Euro & Asia Pacific Common Funds ($K)

4.2. Labor Cost

The basis of estimate for labor costs is the FTE allocation in the detailed IceCube M&O Task List (Appendix 1) and detailed bases of labor estimates (Appendix 6). The total fully burdened cost **(Figure 4.2-1** and Appendix 6) has been calculated as follows:

FTE * Hourly Direct Rate * (1+Fringe Rate) * (1+Indirect Rate) * (1+Escalation Rate)

FTE: The FTE allocation per WBS and task was initially determined during an M&O planning workshop in the month of February 2009 in Madison, and was continuously evaluated since then. The primary basis of estimate for FTEs is experience over the past two years executing identical or similar tasks. Management judgments applied to estimates include whether past FTE allocations were correct for each task, and the extent to which the task over time will require the same, more or fewer FTE resources.

Hourly Direct Rate: The basis of estimate for the Hourly Direct Rate is the average 2009 rate for each Labor Category at the UW-Madison. UW-Madison sets its rates through surveys and other analyses of rates for similar scientific, technical and engineering resources in the local region. We have applied UW-Madison labor rates for all labor calculations because in past experience with both construction and initial M&O, these rates provide a good approximation for the Collaborating institutions across the U.S.

Fringe Rate: 2009 fringe rates per Labor Category at the UW-Madison were used for calculating the Fringe Cost. These fringe rates are being recalculated on an annual basis by the University and disclosed and audited, as required, for all Federal contracts and grants.

Indirect Rate: The current 2009 indirect rate of 48.5% at the University of Wisconsin was used for calculating the Indirect Cost. This Indirect rate is being negotiated every year and is disclosed and audited, as required, for all Federal contracts and grants. We have assumed that this rate will be used for the entire 5 year period of performance.

Escalation Rate: A 3% escalation rate was applied on the 1st day of each Federal Fiscal Year (October 1st). The rates are based on the official rates used in the MREFC project phase. We expect this rate to remain constant for both labor and materials. The labor market for scientific, engineering and technical skills in the Madison region has been somewhat less affected than other regions of the country by the current economic downturn. We still face significant competition in the market for these skills. The majority of our materials and equipment are also in categories less affected by the economic downturn, such as computing hardware.

LABOR COST	2nd Half FY10		FY11		FY12		FY13		FY14		1st Half FY15	
	FTE	Labor $K	FTE	Labor $K	FTE	Labor $K	FTE	Labor $K	FTE	Labor $K	FTE	Labor $K
2.1 Program Management	4.0	766	7.9	1,577	7.9	1,624	7.9	1,673	7.9	1,723	4.0	888
2.2 Detector Operations & Maintenance	6.4	995	12.2	1,948	12.4	2,042	12.1	2,090	11.9	2,140	5.9	1,102
2.3 Computing and Data Management	7.5	1,098	15.2	2,301	15.3	2,390	15.3	2,462	15.3	2,535	7.7	1,306
2.4 Triggering and Filtering	0.2	26	0.3	53	0.3	55	0.3	56	0.3	58	0.2	30
2.5 Data Quality, Reconstruction and Simulation Tools	1.0	169	1.9	348	1.9	358	1.9	369	1.9	380	1.0	196
TOTAL	**18.9**	**3,053**	**37.5**	**6,226**	**37.8**	**6,469**	**37.5**	**6,650**	**37.3**	**6,837**	**18.6**	**3,521**

Figure 4.2-1. M&O Core Labor Cost Summary (Fully Burdened)

4.3. Travel Cost

The travel budget (**Figure 4.3-1**) is calculated from the number of estimated domestic and foreign trips for each labor category based on actuals from the past three years, and projected forward using management judgments. The resulting factors are multiplied by the relevant FTE numbers in each WBS Level2 according to the following formulae:

Domestic Travel Cost = FTE * Domestic Factor * Domestic Direct Rate * (1+Indirect rate) * (1+Escalation rate)

Foreign Travel Cost = FTE * Foreign Factor * Foreign Direct Rate * (1+Indirect rate) * (1+Escalation rate)

The estimated domestic trip duration is 5 days while a foreign trip is 8 days. The domestic and foreign direct rates take into consideration airfare and transportation, lodging and per diem. Valid trips under the M&O are for the purpose of Collaboration meetings, workshops, training, reviews and maintenance trips.

TRAVEL COST	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
Number of Domestic trips	39	75	76	75	75	37
Total Domestic Travel Cost	**$83K**	**$166K**	**$173K**	**$176K**	**$180K**	**$93K**
Number of Foreign trips	10	19	19	19	19	9
Total Foreign Travel Cost	**$41K**	**$83K**	**$86K**	**$88K**	**$90K**	**$46K**

Figure 4.3-1. M&O Core Travel Cost Summary (Fully Burdened)

4.4. Capital Equipment Cost

Based on a review by IceCube's newly appointed Software and Computing Advisory Panel (SCAP) in March 2009, we made significant changes to our Capital Equipment and Materials & Supplies Cost plan, which are included in this cost estimate. Computing infrastructure is the major cost driver in capital equipment. The revised plan assumes consolidation of redundant computing storage infrastructure and more favorable pricing on purchase agreements. Cost estimates are based on actual spending during current operations, and budget for an expected upgrade of 25% of existing systems each year (approximately 25 of 100 systems both at the South Pole and in the north), 256 cores of high performance computing each year, and supporting networking and other hardware such as tape drives for backup. Total server systems will remain constant through retirement of older systems, with advancing technology creating some performance increases to adapt to new needs.

Capital Equipment line items are above $5K and are either based on expanding the detector systems volume or improving their capacity and performance through an upgrade. A detailed Capital Equipment Plan is provided in Appendix 6.

CAPITAL EQUIPMENT COST		2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
WBS L2	**WBS L3**						
	2.1.2 Engineering and R&D Support	23	45	45	45	45	23
	2.1.5 Distributed Computing & Labor	18	35	35	35	35	18
2.1 Program Management		**40**	**80**	**80**	**80**	**80**	**40**
	2.2.4 SPS Operations	46	93	178	93	93	46
	2.2.5 SPTS Operations	23	46	46	46	46	23
2.2 Detector Operations & Maintenance		**69**	**138**	**223**	**138**	**138**	**69**
	2.3.2 Data Storage & Transfer	33	66	66	66	66	33
	2.3.3 Computing Resources	138	405	275	275	275	138
2.3 Computing and Data Management		**171**	**471**	**341**	**341**	**341**	**171**
Total		**280**	**689**	**644**	**559**	**559**	**280**

Figure 4.4-1. M&O Core Capital Equipment Cost Summary ($K)

4.5. Materials and Supplies Cost

Materials and supplies related to computing infrastructure are also the major cost driver in this category. Cost estimates support several different operational tasks. For example, planned operations require sufficient tape media at the South Pole to store 2TB per day of raw and filtered data to two separate copies, and sufficient tape media for the northern datacenter to back up the data and provide for online tape-based storage of the raw data. Annual replacement of 25% of existing disk storage with higher capacity disks as they become available allows for expansion of the primary data repository from the existing 442 TB to over 1000TB in FY11 and beyond 2000TB in FY14 at the minimum cost, while still supporting our projected growth in storage capacity needs. Other expenses include storage area network replacements and software purchases along this trajectory of growth in storage requirements.

Indirect and Escalation rates have been applied to all Materials & Supplies items. A detailed Materials & Supplies plan can be found in Appendix 6.

MATERIALS & SUPPLIES COST		2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
WBS L2	**WBS L3**						
	2.1 Program Management	3	5	6	6	6	3
	2.1.1 Administration	8	16	17	17	18	9
	2.1.2 Engineering and R&D Support	35	73	75	78	80	41
	2.1.4 Education & outreach	32	65	67	69	71	37
	2.1.5 Distributed Computing & Labor	4	8	8	9	9	5
2.1 Program Management		**81**	**168**	**173**	**179**	**184**	**95**
	2.2 Detector Operations & Maintenance	5	11	11	12	12	6
	2.2.1 Run Coordination	16	33	34	35	36	18
	2.2.2 Data Acquisition	16	33	34	35	36	18
	2.2.4 SPS Operations	93	193	199	205	211	109
	2.2.5 SPTS Operations	11	23	24	24	25	13
	2.2.9 IceTop Operations	2	3	3	3	4	2
2.2 Detector Operations & Maintenance		**143**	**295**	**304**	**313**	**323**	**167**
	2.3 Computing & Data Management	6	12	12	13	13	7
	2.3.2 Data Storage & Transfer	181	439	386	467	481	211
	2.3.3 Computing Resources	85	175	180	186	192	99
2.3 Computing and Data Management		**272**	**626**	**578**	**665**	**686**	**317**
	Total	**496**	**1,089**	**1,055**	**1,157**	**1,193**	**578**

Figure 4.5-1. M&O Core Materials & Supplies Cost Summary (Fully Burdened $K)

4.6. Service Agreement Cost

Computing infrastructure and software both at the South Pole and at UW are also the major cost drivers for service agreements, which include licenses, operating systems, warranties, technical support and software programming consultants **(Figure 4.6-1)**. The decision to enter into service agreements is made on a case-by-case basis on cost-benefit analysis. Because of the need for high availability and reliability of computing infrastructure, we reduce risk through having service agreements with vendors of major COTS equipment. We also weigh the costs of on-staff technical support personnel against the costs of outside specialized, on-demand consultant labor and make decisions based on best value.

Indirect and escalation rates have been applied to all Service agreement items. A detailed Service Agreement Cost Plan is in Appendix 6.

SERVICE AGREEMENT COST		2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
WBS L2	**WBS L3**						
	2.2.2 Data Acquisition	19	38	39	41	42	22
	2.2.4 SPS Operations	27	55	57	58	60	31
	2.2.5 SPTS Operations	11	22	23	23	24	12
	2.2.6 Experiment Control	105	217	223	183	139	72
2.2 Detector Operations & Maintenance		**161**	**332**	**342**	**305**	**266**	**137**
	2.3.2 Data Storage & Transfer	5	82	10	115	74	61
	2.3.3 Computing Resources	122	252	260	267	275	142
2.3 Computing and Data Management		**127**	**334**	**269**	**383**	**350**	**203**
	Total	**288**	**667**	**612**	**688**	**616**	**340**

Figure 4.6-1. M&O Core Service Agreement Cost Summary (Fully Burdened $K)

Appendix 5 - In-Kind Contributions by Collaboration Institutions (Draft - April 2009)

04/07/2009

Institution (Lead) **Authors** (Faculty Scientist/Post Doc Grad Student) *Monitoring is based on 0.03 FTE/week*	2.1 Program Management	2.2 Detector Operations & Maintenance	2.3 Computing & Data Management	2.4 Triggering & Filtering	2.5 Data Quality, Reconstruction & Simulation Tools	Total
University of Alabama (Dawn Williams) **2** (1 1 0)		0.33			0.6	**0.93**
University of Alaska (Katherine Rawlins) **1** (1 0 0)		0.02			0.4	**0.42**
Clark Atlanta (George Japaridze) **1** (1 0 0)		0.015				**0.015**
Georgia Tech (Ignacio Taboada) **1** (1 0 2)		0.03		0.25		**0.28**
LBNL (Spencer Klein) **6** (3 3 0)	0.4	0.79	0.2	0.25		**1.64**
Ohio State University (James Beatty) **3** (1 2 0)		0.23		0.15	0.3	**0.68**
Pennsylvania State University (Doug Cowen) 7 (3 4 4)	0.25	0.66	1.4	0.65	0.55	**3.51**
Southern University (Ali Fazely) **4** (2 2 0)		0.015	0.2		0.3	**0.515**
University of California, Berkeley (Buford Price) **5** (1 4 2)	0.1	0.88		0.25	0.5	**1.73**
University of Delaware (Paul Evenson, acting for T. Gaisser) **8** (4 4 2)	0.6	1.06	0.2	0.25	0.3	**2.41**
University of Kansas (Dave Besson) **1** (1 0 0)	0.1	0.02				**0.12**
University of Maryland (Greg Sullivan) **7** (4 3 6)	0.25	0.29	0.4	1.0	0.9	**2.84**
University of Wisconsin, River Falls (Jim Madsen) **4** (2 2 0)	0.25	0.03				**0.28**
University of California, Irvine (Steve Barwick) **2** (1 1 1)		0.02				0.02
University of Wisconsin, Madison (Albrecht Karle) **19** (5 14 11)	2.22	2.54	1.5	0.9	2.8	**9.91**
US Institutions Subtotal **71** (31 40 28)	**4.17**	**6.93**	**3.85**	**3.7**	**6.65**	**25.3**
RWTH Aachen (Christopher Wiebusch) **3** (1 2 5)	0.2	0.045	0.65	0.15	0.6	**1.645**
DESY-Zeuthen (Christian Spiering) **9** (6 3 8)	0.8	0.48	2.25	0.15	0.1	**3.78**
Stockholm University (Per Olof Hulth) **5** (4 1 1)	0.15	0.06	0.2	0.25	0.9	**1.56**
Universität Dortmund (Wolfgang Rhode) **2** (2 0 2)		0.03	0.65			**0.68**
Universität Mainz (Lutz Köpke) **1** (1 0 6)	0.15	0.56	0.4			**1.11**
Universität Wuppertal (Klaus Helbing) **3** (2 1 4)	0.2	0.06	0.4			**0.66**
Universite Libre de Bruxelles (Daniel Bertrand) **2** (2 0 2)	0.25	0.23	1.1	0.1		**1.68**
MPI Heidelberg (Elisa Resconi) **2** (1 1 2)	0.6	0.145			0.7	**1.445**
Humboldt Universität Berlin (Hermann Kolanoski) **2** (2 0 2)	0.5	0.03		0.6	0.5	**1.63**
Universite de Mons-Hainaut (Philippe Herquet) **1** (1 0 1)		0.03				**0.03**
University of Canterbury (Jenni Adams) **3** (2 1 4)		0.02			0.3	**0.32**
Chiba University (Shigeru Yoshida) **3** (1 2 3)		0.03		0.4	0.6	**1.03**
University of Gent (Dirk Ryckbosch) **2** (1 1 4)	0.1	0.03			0.2	**0.33**
Utrecht University (Nick van Eijndhoven) **1** (1 0 1)		0.02			0.2	**0.22**
Uppsala University (Olga Botner) **3** (3 0 2)	0.2	0.16		0.35		**0.71**
Vrije Universiteit Brussel (Catherine de Clercq) **1** (1 0 2)		0.03	0.1	0.15		**0.28**
University of Oxford (Subir Sarkar) **2** (1 1 0)		0.02			0.5	**0.52**
Ecole Polytechnique Federale de Lausanne (Mathieu Ribordy) **2** (1 1 2)		0.13			0.2	**0.33**
Non-US Institutions Subtotal **47** (33 14 49)	**3.15**	**2.11**	**5.75**	**2.15**	**4.8**	**17.96**
Grand Total US & Non-US **118** (64 54 77)	**7.32**	**9.04**	**9.6**	**5.85**	**11.45**	**43.26**

Appendix 6 M&O Proposal - Cost Detail.xls
WBS Summary

IceCube Maintenance and Operations Budget by WBS and Budget Elements

M&O NSF Core Activities		FY10 2nd Half K$ Mar'10 - Sep'10 PLAN							FY11 K$ Oct'10 - Sep'11 PLAN							FY12 K$ Oct'11 - Sep'12 PLAN						
		FTE	Labor	Capital	M&S	Travel	Service Agree.	Total	FTE	Labor	Capital	M&S	Travel	Service Agree.	Total	FTE	Labor	Capital	M&S	Travel	Service Agree.	Total
PROGRAM MANAGEMENT	2.1	0.0	0	0	3	23	0	26	0.0	0	0	5	48	0	54	0.0	0	0	6	50	0	55
Administration	2.1.1	1.7	401	0	8		0	408	3.4	825	0	16		0	841	3.4	850	0	17		0	866
Engineering and R&D Support	2.1.2	1.0	184	18	32		0	233	2.0	380	35	65		0	480	2.0	391	35	67		0	493
USAP Support	2.1.3	0.1	25	0	0		0	25	0.3	51	0	0		0	51	0.3	53	0	0		0	53
Education & Outreach	2.1.4	0.6	80	0	4		0	84	1.3	166	0	8		0	174	1.3	171	0	8		0	179
Distributed Computing & Labor	2.1.5	0.5	75	23	35		0	133	1.0	155	45	73		0	273	1.0	160	45	75		0	280
Subtotal		**4.0**	**766**	**40**	**81**	**23**	**0**	**910**	**7.9**	**1,577**	**80**	**168**	**48**	**0**	**1,873**	**7.9**	**1,624**	**80**	**173**	**50**	**0**	**1,927**
DETECTOR OPERATIONS & MAINTENANCE	2.2	0.4	75	0	5	55	0	135	0.9	180	0	11	107	0	297	1.0	212	0	11	113	0	335
Run Coordination	2.2.1	1.9	312	0	16		0	328	3.8	643	0	33		0	676	3.8	662	0	34		0	696
Data Acquisition	2.2.2	1.5	250	0	16		19	285	2.5	432	0	33		38	503	2.5	445	0	34		39	518
Online Filter (PnF)	2.2.3	0.4	60	0	0		0	60	0.5	80	0	0		0	80	0.5	91	0	0		0	91
SPS Operations	2.2.4	0.6	105	46	93		27	271	1.3	216	93	193		55	557	1.3	223	178	199		57	656
SPTS Operations	2.2.5	0.4	62	23	11		11	106	0.8	127	46	23		22	218	0.8	131	46	24		23	223
Experiment Control	2.2.6	0.5	11	0	0		105	117	1.0	23	0	0		217	240	1.0	24	0	0		223	247
Detector Monitoring	2.2.7	0.1	4	0	0		0	4	0.3	7	0	0		0	7	0.3	7	0	0		0	7
Detector Calibration	2.2.8	0.2	30	0	0		0	30	0.4	62	0	0		0	62	0.4	64	0	0		0	64
IceTop Operations	2.2.9	0.5	86	0	2		0	87	1.0	177	0	3		0	180	1.0	182	0	3		0	186
SuperNova Operations	2.2.10	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**6.4**	**995**	**69**	**143**	**55**	**161**	**1,423**	**12.2**	**1,948**	**138**	**295**	**107**	**332**	**2,819**	**12.4**	**2,042**	**223**	**304**	**113**	**342**	**3,023**
COMPUTING AND DATA MANAGEMENT	2.3	0.5	97	0	6	32	0	134	1.0	200	0	12	65	0	278	1.0	206	0	12	68	0	286
Core Software	2.3.1	2.2	307	0	0		0	307	4.6	672	0	0		0	672	4.8	712	0	0		0	712
Data Storage & Transfer	2.3.2	1.8	226	33	181		5	445	3.5	466	66	439		82	1,053	3.5	480	66	386		10	941
Computing Resources	2.3.3	2.1	325	138	85		122	669	4.3	669	405	175		252	1,501	4.3	689	275	180		260	1,404
Data Production Processing	2.3.4	0.3	38	0	0		0	38	0.5	78	0	0		0	78	0.5	80	0	0		0	80
Simulation Production	2.3.5	0.7	105	0	0		0	105	1.3	217	0	0		0	217	1.3	224	0	0		0	224
Subtotal		**7.5**	**1,098**	**171**	**272**	**32**	**127**	**1,699**	**15.2**	**2,301**	**471**	**626**	**65**	**334**	**3,798**	**15.3**	**2,390**	**341**	**578**	**68**	**269**	**3,646**
TRIGGERING AND FILTERING	2.4	0.0	0	0	0	2	0	2	0.0	0	0	0	4	0	4	0.0	0	0	0	4	0	4
TFT Coordination	2.4.1	0.2	26	0	0		0	26	0.3	53	0	0		0	53	0.3	55	0	0		0	55
Physics Filters	2.4.2	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**0.2**	**26**	**0**	**0**	**2**	**0**	**28**	**0.3**	**53**	**0**	**0**	**4**	**0**	**57**	**0.3**	**55**	**0**	**0**	**4**	**0**	**59**
DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5	0.3	43	0	0	12	0	55	0.5	88	0	0	24	0	113	0.5	91	0	0	25	0	116
Simulation Programs	2.5.1	0.7	126	0	0		0	126	1.4	259	0	0		0	259	1.4	267	0	0		0	267
Reconstruction/ Analysis tools	2.5.2	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Data Quality	2.5.3	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Offline Data Processing	2.5.4	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**1.0**	**169**	**0**	**0**	**12**	**0**	**181**	**1.9**	**348**	**0**	**0**	**24**	**0**	**372**	**1.9**	**358**	**0**	**0**	**25**	**0**	**384**
IceCube M&O NSF Core Total		**18.9**	**3,053**	**280**	**496**	**124**	**288**	**4,241**	**37.5**	**6,226**	**689**	**1,089**	**249**	**667**	**8,919**	**37.8**	**6,469**	**644**	**1,055**	**259**	**612**	**9,039**

M&O NSF Core Activities		FY13 K$ Oct'12 - Sep'13 PLAN							FY14 K$ Oct'13 - Sep'14 PLAN							FY15 1st Half K$ Oct'14 - Mar'15 PLAN						
		FTE	Labor	Capital	M&S	Travel	Service Agree.	Total	FTE	Labor	Capital	M&S	Travel	Service Agree.	Total	FTE	Labor	Capital	M&S	Travel	Service Agree.	Total
PROGRAM MANAGEMENT	2.1	0.0	0	0	6	51	0	57	0.0	0	0	6	53	0	59	0.0	0	0	3	27	0	30
Administration	2.1.1	3.4	875	0	17		0	892	3.4	901	0	18		0	919	1.7	464	0	9		0	474
Engineering and R&D Support	2.1.2	2.0	403	35	69		0	507	2.0	415	35	71		0	521	1.0	214	18	37		0	268
USAP Support	2.1.3	0.3	55	0	0		0	55	0.3	56	0	0		0	56	0.1	29	0	0		0	29
Education & Outreach	2.1.4	1.3	176	0	9		0	184	1.3	181	0	9		0	190	0.6	93	0	5		0	98
Distributed Computing & Labor	2.1.5	1.0	165	45	78		0	287	1.0	170	45	80		0	295	0.5	87	23	41		0	151
Subtotal		**7.9**	**1,673**	**80**	**179**	**51**	**0**	**1,983**	**7.9**	**1,723**	**80**	**184**	**53**	**0**	**2,040**	**4.0**	**888**	**40**	**95**	**27**	**0**	**1,050**
DETECTOR OPERATIONS & MAINTENANCE	2.2	1.0	218	0	12	114	0	343	1.0	225	0	12	115	0	351	0.5	116	0	6	59	0	181
Run Coordination	2.2.1	3.8	682	0	35		0	717	3.8	703	0	36		0	738	1.9	362	0	18		0	380
Data Acquisition	2.2.2	2.5	458	0	35		41	534	2.5	472	0	36		42	550	1.3	243	0	18		22	283
Online Filter (PnF)	2.2.3	0.5	94	0	0		0	94	0.5	97	0	0		0	97	0.3	50	0	0		0	50
SPS Operations	2.2.4	1.3	229	93	205		58	585	1.3	236	93	211		60	600	0.6	122	46	109		31	308
SPTS Operations	2.2.5	0.8	135	46	24		23	228	0.8	139	46	25		24	234	0.4	72	23	13		12	120
Experiment Control	2.2.6	0.8	12	0	0		183	195	0.5	0	0	0		139	139	0.3	0	0	0		72	72
Detector Monitoring	2.2.7	0.3	8	0	0		0	8	0.3	8	0	0		0	8	0.1	4	0	0		0	4
Detector Calibration	2.2.8	0.4	66	0	0		0	66	0.4	68	0	0		0	68	0.2	35	0	0		0	35
IceTop Operations	2.2.9	1.0	188	0	3		0	191	1.0	193	0	4		0	197	0.5	100	0	2		0	101
SuperNova Operations	2.2.10	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**12.1**	**2,090**	**138**	**313**	**114**	**305**	**2,961**	**11.9**	**2,140**	**138**	**323**	**115**	**266**	**2,982**	**5.9**	**1,102**	**69**	**167**	**59**	**137**	**1,534**
COMPUTING AND DATA MANAGEMENT	2.3	1.0	212	0	13	70	0	295	1.0	219	0	13	72	0	304	0.5	113	0	7	37	0	156
Core Software	2.3.1	4.8	733	0	0		0	733	4.8	755	0	0		0	755	2.4	389	0	0		0	389
Data Storage & Transfer	2.3.2	3.5	494	66	467		115	1,142	3.5	509	66	481		74	1,130	1.8	262	33	211		61	568
Computing Resources	2.3.3	4.3	709	275	186		267	1,438	4.3	731	275	192		275	1,473	2.1	376	138	99		142	754
Data Production Processing	2.3.4	0.5	82	0	0		0	82	0.5	85	0	0		0	85	0.3	44	0	0		0	44
Simulation Production	2.3.5	1.3	230	0	0		0	230	1.3	237	0	0		0	237	0.7	122	0	0		0	122
Subtotal		**15.3**	**2,462**	**341**	**665**	**70**	**383**	**3,920**	**15.3**	**2,535**	**341**	**686**	**72**	**350**	**3,984**	**7.7**	**1,306**	**171**	**317**	**37**	**203**	**2,033**
TRIGGERING AND FILTERING	2.4	0.0	0	0	0	4	0	4	0.0	0	0	0	4	0	4	0.0	0	0	0	2	0	2
TFT Coordination	2.4.1	0.3	56	0	0		0	56	0.3	58	0	0		0	58	0.2	30	0	0		0	30
Physics Filters	2.4.2	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**0.3**	**56**	**0**	**0**	**4**	**0**	**61**	**0.3**	**58**	**0**	**0**	**4**	**0**	**62**	**0.2**	**30**	**0**	**0**	**2**	**0**	**32**
DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5	0.5	94	0	0	26	0	120	0.5	97	0	0	27	0	123	0.3	50	0	0	14	0	64
Simulation Programs	2.5.1	1.4	275	0	0		0	275	1.4	283	0	0		0	283	0.7	146	0	0		0	146
Reconstruction/ Analysis tools	2.5.2	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Data Quality	2.5.3	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Offline Data Processing	2.5.4	0.0	0	0	0		0	0	0.0	0	0	0		0	0	0.0	0	0	0		0	0
Subtotal		**1.9**	**369**	**0**	**0**	**26**	**0**	**395**	**1.9**	**380**	**0**	**0**	**27**	**0**	**407**	**1.0**	**196**	**0**	**0**	**14**	**0**	**210**
IceCube M&O NSF Core Total		**37.5**	**6,650**	**559**	**1,157**	**265**	**688**	**9,319**	**37.3**	**6,837**	**559**	**1,193**	**270**	**616**	**9,475**	**18.6**	**3,521**	**280**	**578**	**139**	**340**	**4,858**

Grand Total: 45,852

Appendix 6 M&O Proposal - Cost Detail.xls
Subawards

M&O Core Cost		2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
Cost Category	Institution	Fully Burdened	Fully Burdened	Fully Burdened	Fully Burdened	Fully Burdened	Fully Burdened
Labor	**Total**	**$3,053,316**	**$6,226,172**	**$6,468,515**	**$6,650,225**	**$6,837,013**	**$3,521,202**
	LBNL	$95,436	$112,960	$116,349	$119,839	$123,434	$63,566
	PSU	$58,498	$120,502	$124,117	$127,840	$131,675	$67,815
	UCB	$62,614	$128,986	$132,855	$136,841	$140,946	$72,587
	UD	$104,751	$215,786	$222,260	$228,928	$235,796	$121,435
	UMD	$255,740	$521,369	$566,105	$583,088	$600,580	$309,300
	UW	$2,476,276	$5,126,570	$5,306,830	$5,453,689	$5,604,581	$2,886,499
Capital Equipment	**Total**	**$279,500**	**$689,000**	**$644,000**	**$559,000**	**$559,000**	**$279,500**
	LBNL	$0	$0	$0	$0	$0	$0
	PSU	$7,500	$15,000	$15,000	$15,000	$15,000	$7,500
	UCB	$0	$0	$0	$0	$0	$0
	UD	$7,500	$15,000	$15,000	$15,000	$15,000	$7,500
	UMD	$7,500	$15,000	$15,000	$15,000	$15,000	$7,500
	UW	$257,000	$644,000	$599,000	$514,000	$514,000	$257,000
Materials & Supplies	**Total**	**496,381**	**1,088,582**	**1,055,295**	**1,157,159**	**1,193,051**	**578,285**
	LBNL	$0	$0	$0	$0	$0	$0
	PSU	$0	$0	$0	$0	$0	$0
	UCB	$0	$0	$0	$0	$0	$0
	UD	$2,103	$4,336	$4,470	$4,609	$4,752	$2,450
	UMD	$526	$1,084	$1,118	$1,152	$1,188	$612
	UW	$493,753	$1,083,163	$1,049,707	$1,151,398	$1,187,112	$575,223
Travel	**Total**	**123,835**	**248,744**	**259,160**	**264,712**	**270,364**	**139,245**
	LBNL	$6,049	$6,948	$7,156	$7,371	$7,592	$3,910
	PSU	$4,925	$10,146	$10,450	$10,764	$11,087	$5,710
	UCB	$3,747	$7,720	$7,951	$8,190	$8,435	$4,344
	UD	$6,692	$13,785	$14,199	$14,625	$15,063	$7,758
	UMD	$14,963	$28,066	$29,874	$30,770	$31,693	$16,322
	UW	$87,458	$182,080	$189,530	$192,993	$196,493	$101,202
Service Agreement	**Total**	**288,320**	**666,833**	**611,758**	**688,009**	**615,547**	**339,820**
	LBNL	$0	$0	$0	$0	$0	$0
	PSU	$0	$0	$0	$0	$0	$0
	UCB	$0	$0	$0	$0	$0	$0
	UD	$0	$0	$0	$0	$0	$0
	UMD	$0	$0	$0	$0	$0	$0
	UW	$288,320	$666,833	$611,758	$688,009	$615,547	$339,820
Total	**Total**	**4,241,352**	**8,919,332**	**9,038,727**	**9,319,105**	**9,474,975**	**4,858,052**
	LBNL	$101,485	$119,908	$123,505	$127,210	$131,026	$67,476
	PSU	$70,923	$145,648	$149,567	$153,604	$157,762	$81,025
	UCB	$66,362	$136,705	$140,807	$145,031	$149,382	$76,932
	UD	$121,045	$248,907	$255,929	$263,161	$270,611	$139,142
	UMD	$278,729	$565,519	$612,096	$630,010	$648,461	$333,734
	UW	$3,602,808	$7,702,646	$7,756,824	$8,000,089	$8,117,733	$4,159,743
						Grand Total:	**45,851,544**

Appendix 6 M&O Proposal - Cost Detail.xls
Labor FTE By Institution

Institution	WBS L2	WBS 3 Code	WBS L3	Labor Cat.	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
LBNL	DETECTOR OPERATIONS & MAINTENANCE	2.2.1	Run Coordination	SC	0.25	0.50	0.50	0.50	0.50	0.25
		2.2.2	Data Acquisition	CS	0.25	0.00	0.00	0.00	0.00	0.00
				EN	0.08	0.15	0.15	0.15	0.15	0.08
LBNL Sum					**0.58**	**0.65**	**0.65**	**0.65**	**0.65**	**0.33**
PSU	DETECTOR OPERATIONS & MAINTENANCE	2.2.2	Data Acquisition	PO	0.08	0.15	0.15	0.15	0.15	0.08
	COMPUTING AND DATA MANAGEMENT	2.3.1	Core Software	PO	0.38	0.75	0.75	0.75	0.75	0.38
		2.3.3	Computing Resources	PO	0.13	0.25	0.25	0.25	0.25	0.13
PSU Sum					**0.58**	**1.15**	**1.15**	**1.15**	**1.15**	**0.58**
UCB	DETECTOR OPERATIONS & MAINTENANCE	2.2.8	Detector Calibration	SS						
	DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5.1	Simulation Programs	SS	0.25	0.50	0.50	0.50	0.50	0.25
UCB Sum					**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
UD	DETECTOR OPERATIONS & MAINTENANCE	2.2.9	IceTop Operations	SC	0.50	1.00	1.00	1.00	1.00	0.50
	COMPUTING AND DATA MANAGEMENT	2.3.3	Computing Resources	TE	0.13	0.25	0.25	0.25	0.25	0.13
UD Sum					**0.63**	**1.25**	**1.25**	**1.25**	**1.25**	**0.63**
UMD	DETECTOR OPERATIONS & MAINTENANCE	2.2.3	Online Filter (PnF)	SC	0.35	0.45	0.50	0.50	0.50	0.25
	COMPUTING AND DATA MANAGEMENT	2.3.1	Core Software	SC	0.25	0.50	0.50	0.50	0.50	0.25
				CS	0.25	0.50	0.50	0.50	0.50	0.25
				TE	0.31	0.88	1.00	1.00	1.00	0.50
		2.3.3	Computing Resources	TE	0.13	0.25	0.25	0.25	0.25	0.13
	TRIGGERING AND FILTERING	2.4.1	TFT Coordination	SC	0.15	0.30	0.30	0.30	0.30	0.15
				TE	0.00	0.00	0.00	0.00	0.00	0.00
	DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5.1	Simulation Programs	PO	0.20	0.40	0.40	0.40	0.40	0.20
UMD Sum					**1.64**	**3.28**	**3.45**	**3.45**	**3.45**	**1.73**
UW	PROGRAM MANAGEMENT	2.1.1	Administration	KE	0.71	1.42	1.42	1.42	1.42	0.71
				MA	0.25	0.50	0.50	0.50	0.50	0.25
				SC	0.00	0.00	0.00	0.00	0.00	0.00
				SE	0.50	1.00	1.00	1.00	1.00	0.50
				AD	0.25	0.50	0.50	0.50	0.50	0.25
		2.1.2	Engineering and R&D Support	SC	0.13	0.25	0.25	0.25	0.25	0.13
				SE	0.70	1.40	1.40	1.40	1.40	0.70
				EN	0.05	0.10	0.10	0.10	0.10	0.05
				TE	0.13	0.25	0.25	0.25	0.25	0.13
		2.1.3	USAP Support	MA	0.13	0.25	0.25	0.25	0.25	0.13
		2.1.4	Education & Outreach	AD	0.63	1.25	1.25	1.25	1.25	0.63
		2.1.5	Distributed Computing & Labor	TE	0.50	1.00	1.00	1.00	1.00	0.50
UW	DETECTOR OPERATIONS & MAINTENANCE	2.2	DETECTOR OPERATIONS & MAINTENANCE	MA	0.38	0.88	1.00	1.00	1.00	0.50
		2.2.1	Run Coordination	SC	0.13	0.25	0.25	0.25	0.25	0.13
				WO	1.50	3.00	3.00	3.00	3.00	1.50

Appendix 6 M&O Proposal - Cost Detail.xls

Labor FTE By Institution

Institution	WBS L2	WBS 3 Code	WBS L3	Labor Cat.	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
		2.2.2	Data Acquisition	SC	0.40	0.80	0.80	0.80	0.80	0.40
				SE	0.63	1.25	1.25	1.25	1.25	0.63
				CS	0.08	0.15	0.15	0.15	0.15	0.08
				EN	0.00	0.00	0.00	0.00	0.00	0.00
		2.2.4	SPS Operations	SE	0.13	0.25	0.25	0.25	0.25	0.13
				CS	0.38	0.75	0.75	0.75	0.75	0.38
				EN	0.13	0.25	0.25	0.25	0.25	0.13
		2.2.5	SPTS Operations	SE	0.05	0.10	0.10	0.10	0.10	0.05
				CS	0.13	0.25	0.25	0.25	0.25	0.13
				EN	0.20	0.40	0.40	0.40	0.40	0.20
		2.2.6	Experiment Control	CS	0.43	0.85	0.85	0.68	0.50	0.25
				TE	0.08	0.15	0.15	0.08	0.00	0.00
		2.2.7	Detector Monitoring	UG	0.13	0.25	0.25	0.25	0.25	0.13
		2.2.8	Detector Calibration	SC	0.18	0.35	0.35	0.35	0.35	0.18
	COMPUTING AND DATA MANAGEMENT	2.3	COMPUTING AND DATA MANAGEMENT	SE	0.50	1.00	1.00	1.00	1.00	0.50
		2.3.1	Core Software	PO	0.25	0.50	0.50	0.50	0.50	0.25
				CS						
				TE	0.75	1.50	1.50	1.50	1.50	0.75
		2.3.2	Data Storage & Transfer	PO	0.25	0.50	0.50	0.50	0.50	0.25
				EN	0.50	1.00	1.00	1.00	1.00	0.50
				GR	0.25	0.50	0.50	0.50	0.50	0.25
				TE	0.25	0.50	0.50	0.50	0.50	0.25
				AD	0.50	1.00	1.00	1.00	1.00	0.50
		2.3.3	Computing Resources	EN	1.38	2.75	2.75	2.75	2.75	1.38
				TE	0.38	0.75	0.75	0.75	0.75	0.38
				AD						
		2.3.4	Data Production Processing	PO						
				SE						
				TE	0.25	0.50	0.50	0.50	0.50	0.25
		2.3.5	Simulation Production	SC	0.35	0.70	0.70	0.70	0.70	0.35
				PO						
				SE						
				TE	0.30	0.60	0.60	0.60	0.60	0.30
	DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5	DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	SC	0.25	0.50	0.50	0.50	0.50	0.25
		2.5.1	Simulation Programs	SC	0.25	0.50	0.50	0.50	0.50	0.25
UW Sum					**15.26**	**30.64**	**30.77**	**30.52**	**30.27**	**15.13**
Grand Total					**18.92**	**37.47**	**37.77**	**37.52**	**37.27**	**18.63**

Appendix 6 M&O Proposal - Cost Detail.xls
Labor FTE By WBS

WBS L2	WBS 3 Code	WBS L3	Institution	Labor Cat.	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
PROGRAM MANAGEMENT	2.1.1	Administration	UW	KE	0.71	1.42	1.42	1.42	1.42	0.71
				MA	0.25	0.50	0.50	0.50	0.50	0.25
				SC	0.00	0.00	0.00	0.00	0.00	0.00
				SE	0.50	1.00	1.00	1.00	1.00	0.50
				AD	0.25	0.50	0.50	0.50	0.50	0.25
			UW Sum		**1.71**	**3.42**	**3.42**	**3.42**	**3.42**	**1.71**
		Administration Sum			**1.71**	**3.42**	**3.42**	**3.42**	**3.42**	**1.71**
	2.1.2	Engineering and R&D Support	UW	SC	0.13	0.25	0.25	0.25	0.25	0.13
				SE	0.70	1.40	1.40	1.40	1.40	0.70
				EN	0.05	0.10	0.10	0.10	0.10	0.05
				TE	0.13	0.25	0.25	0.25	0.25	0.13
			UW Sum		**1.00**	**2.00**	**2.00**	**2.00**	**2.00**	**1.00**
		Engineering and R&D Support Sum			**1.00**	**2.00**	**2.00**	**2.00**	**2.00**	**1.00**
	2.1.3	USAP Support	UW	MA	0.13	0.25	0.25	0.25	0.25	0.13
			UW Sum		**0.13**	**0.25**	**0.25**	**0.25**	**0.25**	**0.13**
		USAP Support Sum			**0.13**	**0.25**	**0.25**	**0.25**	**0.25**	**0.13**
	2.1.4	Education & Outreach	UW	AD	0.63	1.25	1.25	1.25	1.25	0.63
			UW Sum		**0.63**	**1.25**	**1.25**	**1.25**	**1.25**	**0.63**
		Education & Outreach Sum			**0.63**	**1.25**	**1.25**	**1.25**	**1.25**	**0.63**
	2.1.5	Distributed Computing & Labor	UW	TE	0.50	1.00	1.00	1.00	1.00	0.50
			UW Sum		**0.50**	**1.00**	**1.00**	**1.00**	**1.00**	**0.50**
		Distributed Computing & Labor Sum			**0.50**	**1.00**	**1.00**	**1.00**	**1.00**	**0.50**
PROGRAM MANAGEMENT Sum					**3.96**	**7.92**	**7.92**	**7.92**	**7.92**	**3.96**
DETECTOR OPERATIONS & MAINTENANCE	2.2	DETECTOR OPERATIONS & MAINTENANCE	UW	MA	**0.38**	**0.88**	**1.00**	**1.00**	**1.00**	**0.50**
			UW Sum		**0.38**	**0.88**	**1.00**	**1.00**	**1.00**	**0.50**
		DETECTOR OPERATIONS & MAINTENANCE Sum			**0.38**	**0.88**	**1.00**	**1.00**	**1.00**	**0.50**
	2.2.1	Run Coordination	LBNL	SC	**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
			LBNL Sum		**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
			UW	SC	**0.13**	**0.25**	**0.25**	**0.25**	**0.25**	**0.13**
				WO	**1.50**	**3.00**	**3.00**	**3.00**	**3.00**	**1.50**
			UW Sum		**1.63**	**3.25**	**3.25**	**3.25**	**3.25**	**1.63**
		Run Coordination Sum			**1.88**	**3.75**	**3.75**	**3.75**	**3.75**	**1.88**
	2.2.2	Data Acquisition	LBNL	CS	**0.25**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
				EN	**0.08**	**0.15**	**0.15**	**0.15**	**0.15**	**0.08**
			LBNL Sum		**0.33**	**0.15**	**0.15**	**0.15**	**0.15**	**0.08**
			PSU	PO	**0.08**	**0.15**	**0.15**	**0.15**	**0.15**	**0.08**
			PSU Sum		**0.08**	**0.15**	**0.15**	**0.15**	**0.15**	**0.08**
			UW	SC	**0.40**	**0.80**	**0.80**	**0.80**	**0.80**	**0.40**
				SE	**0.63**	**1.25**	**1.25**	**1.25**	**1.25**	**0.63**
				CS	**0.08**	**0.15**	**0.15**	**0.15**	**0.15**	**0.08**
				EN	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
			UW Sum		**1.10**	**2.20**	**2.20**	**2.20**	**2.20**	**1.10**
		Data Acquisition Sum			**1.50**	**2.50**	**2.50**	**2.50**	**2.50**	**1.25**
	2.2.3	Online Filter (PnF)	UMD	SC	**0.35**	**0.45**	**0.50**	**0.50**	**0.50**	**0.25**
			UMD Sum		**0.35**	**0.45**	**0.50**	**0.50**	**0.50**	**0.25**
		Online Filter (PnF) Sum			**0.35**	**0.45**	**0.50**	**0.50**	**0.50**	**0.25**

WBS L2	WBS 3 Code	WBS L3	Institution	Labor Cat.	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
	2.2.4	SPS Operations	UW	SE	0.13	0.25	0.25	0.25	0.25	0.13
				CS	0.38	0.75	0.75	0.75	0.75	0.38
				EN	0.13	0.25	0.25	0.25	0.25	0.13
			UW Sum		0.63	1.25	1.25	1.25	1.25	0.63
		SPS Operations Sum			0.63	1.25	1.25	1.25	1.25	0.63
	2.2.5	SPTS Operations	UW	SE	0.05	0.10	0.10	0.10	0.10	0.05
				CS	0.13	0.25	0.25	0.25	0.25	0.13
				EN	0.20	0.40	0.40	0.40	0.40	0.20
			UW Sum		0.38	0.75	0.75	0.75	0.75	0.38
		SPTS Operations Sum			0.38	0.75	0.75	0.75	0.75	0.38
	2.2.6	Experiment Control	UW	CS	0.43	0.85	0.85	0.68	0.50	0.25
				TE	0.08	0.15	0.15	0.08	0.00	0.00
			UW Sum		0.50	1.00	1.00	0.75	0.50	0.25
		Experiment Control Sum			0.50	1.00	1.00	0.75	0.50	0.25
	2.2.7	Detector Monitoring	UW	UG	0.13	0.25	0.25	0.25	0.25	0.13
			UW Sum		0.13	0.25	0.25	0.25	0.25	0.13
		Detector Monitoring Sum			0.13	0.25	0.25	0.25	0.25	0.13
	2.2.8	Detector Calibration	UW	SC	0.18	0.35	0.35	0.35	0.35	0.18
			UW Sum		0.18	0.35	0.35	0.35	0.35	0.18
		Detector Calibration Sum			0.18	0.35	0.35	0.35	0.35	0.18
	2.2.9	IceTop Operations	UD	SC	0.50	1.00	1.00	1.00	1.00	0.50
			UD Sum		0.50	1.00	1.00	1.00	1.00	0.50
		IceTop Operations Sum			0.50	1.00	1.00	1.00	1.00	0.50
DETECTOR OPERATIONS & MAINTENANCE Sum					6.40	12.18	12.35	12.10	11.85	5.93
COMPUTING AND DATA MANAGEMENT	2.3	COMPUTING AND DATA MANAGEMENT	UW	SE	0.50	1.00	1.00	1.00	1.00	0.50
			UW Sum		0.50	1.00	1.00	1.00	1.00	0.50
		COMPUTING AND DATA MANAGEMENT Sum			0.50	1.00	1.00	1.00	1.00	0.50
	2.3.1	Core Software	PSU	PO	0.38	0.75	0.75	0.75	0.75	0.38
			PSU Sum		0.38	0.75	0.75	0.75	0.75	0.38
			UMD	SC	0.25	0.50	0.50	0.50	0.50	0.25
				CS	0.25	0.50	0.50	0.50	0.50	0.25
				TE	0.31	0.88	1.00	1.00	1.00	0.50
			UMD Sum		0.81	1.88	2.00	2.00	2.00	1.00
			UW	PO	0.25	0.50	0.50	0.50	0.50	0.25
				TE	0.75	1.50	1.50	1.50	1.50	0.75
			UW Sum		1.00	2.00	2.00	2.00	2.00	1.00
		Core Software Sum			2.19	4.63	4.75	4.75	4.75	2.38
	2.3.2	Data Storage & Transfer	UW	PO	0.25	0.50	0.50	0.50	0.50	0.25
				EN	0.50	1.00	1.00	1.00	1.00	0.50
				GR	0.25	0.50	0.50	0.50	0.50	0.25
				TE	0.25	0.50	0.50	0.50	0.50	0.25
				AD	0.50	1.00	1.00	1.00	1.00	0.50
			UW Sum		1.75	3.50	3.50	3.50	3.50	1.75
		Data Storage & Transfer Sum			1.75	3.50	3.50	3.50	3.50	1.75
	2.3.3	Computing Resources	PSU	PO	0.13	0.25	0.25	0.25	0.25	0.13
			PSU Sum		0.13	0.25	0.25	0.25	0.25	0.13

Appendix 6 M&O Proposal - Cost Detail.xls
Labor FTE By WBS

WBS L2	WBS 3 Code	WBS L3	Institution	Labor Cat.	2nd Half FY10	FY11	FY12	FY13	FY14	1st Half FY15
			UD	TE	0.13	0.25	0.25	0.25	0.25	0.13
			UD Sum		**0.13**	**0.25**	**0.25**	**0.25**	**0.25**	**0.13**
			UMD	TE	0.13	0.25	0.25	0.25	0.25	0.13
			UMD Sum		**0.13**	**0.25**	**0.25**	**0.25**	**0.25**	**0.13**
			UW	EN	1.38	2.75	2.75	2.75	2.75	1.38
				TE	0.38	0.75	0.75	0.75	0.75	0.38
			UW Sum		**1.75**	**3.50**	**3.50**	**3.50**	**3.50**	**1.75**
		Computing Resources Sum			**2.13**	**4.25**	**4.25**	**4.25**	**4.25**	**2.13**
	2.3.4	Data Production Processing	UW	TE	0.25	0.50	0.50	0.50	0.50	0.25
			UW Sum		**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
		Data Production Processing Sum			**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
	2.3.5	Simulation Production	UW	SC	0.35	0.70	0.70	0.70	0.70	0.35
				TE	0.30	0.60	0.60	0.60	0.60	0.30
			UW Sum		**0.65**	**1.30**	**1.30**	**1.30**	**1.30**	**0.65**
		Simulation Production Sum			**0.65**	**1.30**	**1.30**	**1.30**	**1.30**	**0.65**
COMPUTING AND DATA MANAGEMENT Sum					**7.46**	**15.18**	**15.30**	**15.30**	**15.30**	**7.65**
TRIGGERING AND FILTERING	2.4.1	TFT Coordination	UMD	SC	0.15	0.30	0.30	0.30	0.30	0.15
				TE	0.00	0.00	0.00	0.00	0.00	0.00
			UMD Sum		**0.15**	**0.30**	**0.30**	**0.30**	**0.30**	**0.15**
		TFT Coordination Sum			**0.15**	**0.30**	**0.30**	**0.30**	**0.30**	**0.15**
TRIGGERING AND FILTERING Sum					**0.15**	**0.30**	**0.30**	**0.30**	**0.30**	**0.15**
DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS	2.5	DATA QUALITY, RECONSTRUCTION & SIMULATI	UW	SC	0.25	0.50	0.50	0.50	0.50	0.25
			UW Sum		**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
		DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS Sum			**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
	2.5.1	Simulation Programs	UCB	SS	0.25	0.50	0.50	0.50	0.50	0.25
			UCB Sum		**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
			UMD	PO	0.20	0.40	0.40	0.40	0.40	0.20
			UMD Sum		**0.20**	**0.40**	**0.40**	**0.40**	**0.40**	**0.20**
			UW	SC	0.25	0.50	0.50	0.50	0.50	0.25
			UW Sum		**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
		Simulation Programs Sum			**0.70**	**1.40**	**1.40**	**1.40**	**1.40**	**0.70**
DATA QUALITY, RECONSTRUCTION & SIMULATION TOOLS Sum					**0.95**	**1.90**	**1.90**	**1.90**	**1.90**	**0.95**
Grand Total					**18.92**	**37.47**	**37.77**	**37.52**	**37.27**	**18.63**

						2nd Half FY10			FY11			FY12			FY13			FY14			1st Half FY15			
WBS L2	WBS L3	WBS Code	Institution	Budget Element	Description	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Direct $ Budget	Total $ (Fully Burdened)
PROGRAM MANAGEMENT	PROGRAM MANAGEMENT	2.1	UW	Materials & Supplies	M&S per FTE for office supplies and miscellaneous	2.5	$667	$2,628	5.0	$667	$5,420	5.0	$667	$5,588	5.0	$667	$5,761	5.0	$667	$5,940	2.5	$667	$1,667	$3,062
				Materials & Supplies Total			$667	$2,628		$667	$5,420		$667	$5,588		$667	$5,761		$667	$5,940		$667	$1,667	$3,062
	PROGRAM MANAGEMENT Total						$667	$2,628		$667	$5,420		$667	$5,588		$667	$5,761		$667	$5,940		$667	$1,667	$3,062
	Administration	2.1.1	UW	Materials & Supplies	M&S for Administration (Excluding Laptops)	1.0	$5,000	$7,885	1.0	$10,000	$16,259	1.0	$10,000	$16,763	1.0	$10,000	$17,283	1.0	$10,000	$17,819	1.0	$5,000	$5,000	$9,186
				Materials & Supplies Total			$5,000	$7,885		$10,000	$16,259		$10,000	$16,763		$10,000	$17,283		$10,000	$17,819		$5,000	$5,000	$9,186
	Administration Total						$5,000	$7,885		$10,000	$16,259		$10,000	$16,763		$10,000	$17,283		$10,000	$17,819		$5,000	$5,000	$9,186
	Education & Outreach	2.1.4	UW	Materials & Supplies	Materials and Supplies for E&O	1.0	$2,500	$3,942	1.0	$5,000	$8,129	1.0	$5,000	$8,382	1.0	$5,000	$8,642	1.0	$5,000	$8,910	1.0	$2,500	$2,500	$4,593
				Materials & Supplies Total			$2,500	$3,942		$5,000	$8,129		$5,000	$8,382		$5,000	$8,642		$5,000	$8,910		$2,500	$2,500	$4,593
	Education & Outreach Total						$2,500	$3,942		$5,000	$8,129		$5,000	$8,382		$5,000	$8,642		$5,000	$8,910		$2,500	$2,500	$4,593
	Engineering and R&D Support	2.1.2	UW	Capital Equipment	CE for Engineering Support	1.0	$7,500	$7,500	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$7,500	$7,500	$7,500
					Equipment for R&D	1.0	$10,000	$10,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	1.0	$10,000	$10,000	$10,000
				Capital Equipment Total			$17,500	$17,500		$35,000	$35,000		$35,000	$35,000		$35,000	$35,000		$35,000	$35,000		$17,500	$17,500	$17,500
				Materials & Supplies	Materials and Supplies for Engineering support	1.0	$10,000	$15,770	1.0	$20,000	$32,518	1.0	$20,000	$33,526	1.0	$20,000	$34,566	1.0	$20,000	$35,638	1.0	$10,000	$10,000	$18,372
					Materials and Supplies for R&D	1.0	$10,000	$15,770	1.0	$20,000	$32,518	1.0	$20,000	$33,526	1.0	$20,000	$34,566	1.0	$20,000	$35,638	1.0	$10,000	$10,000	$18,372
				Materials & Supplies Total			$20,000	$31,540		$40,000	$65,035		$40,000	$67,053		$40,000	$69,132		$40,000	$71,277		$20,000	$20,000	$36,744
	Engineering and R&D Support Total						$37,500	$49,040		$75,000	$100,035		$75,000	$102,053		$75,000	$104,132		$75,000	$106,277		$37,500	$37,500	$54,244
	Distributed Computing & Labor	2.1.5	UW	Capital Equipment	Distributed Tier2 Computing Support Equipment	1.0	$22,500	$22,500	1.0	$45,000	$45,000	1.0	$45,000	$45,000	1.0	$45,000	$45,000	1.0	$45,000	$45,000	1.0	$22,500	$22,500	$22,500
				Capital Equipment Total			$22,500	$22,500		$45,000	$45,000		$45,000	$45,000		$45,000	$45,000		$45,000	$45,000		$22,500	$22,500	$22,500
				Materials & Supplies	Distributed Tier2 Computing Support M&S	1.0	$22,500	$35,482	1.0	$45,000	$73,165	1.0	$45,000	$75,434	1.0	$45,000	$77,774	1.0	$45,000	$80,186	1.0	$22,500	$22,500	$41,337
				Materials & Supplies Total			$22,500	$35,482		$45,000	$73,165		$45,000	$75,434		$45,000	$77,774		$45,000	$80,186		$22,500	$22,500	$41,337
	Distributed Computing & Labor Total						$45,000	$57,982		$90,000	$118,165		$90,000	$120,434		$90,000	$122,774		$90,000	$125,186		$45,000	$45,000	$63,837
PROGRAM MANAGEMENT Total							$90,667	$121,477		$180,667	$248,008		$180,667	$253,219		$180,667	$258,592		$180,667	$264,131		$90,667	$91,667	$134,921
DETECTOR OPERATIONS & MAINTENANCE	DETECTOR OPERATIONS & MAINTENANCE	2.2	UD	Materials & Supplies	M&S per FTE for office supplies and miscellaneous	0.5	$667	$526	1.0	$667	$1,084	1.0	$667	$1,118	1.0	$667	$1,152	1.0	$667	$1,188	0.5	$667	$333	$612
				Materials & Supplies Total			$667	$526		$667	$1,084		$667	$1,118		$667	$1,152		$667	$1,188		$667	$333	$612
			UW	Materials & Supplies	M&S per FTE for office supplies and miscellaneous	4.5	$667	$4,731	9.0	$667	$9,755	9.0	$667	$10,058	9.0	$667	$10,370	9.0	$667	$10,691	4.5	$667	$3,000	$5,512
				Materials & Supplies Total			$667	$4,731		$667	$9,755		$667	$10,058		$667	$10,370		$667	$10,691		$667	$3,000	$5,512
	DETECTOR OPERATIONS & MAINTENANCE Total						$1,333	$5,257		$1,333	$10,839		$1,333	$11,175		$1,333	$11,522		$1,333	$11,879		$1,333	$3,333	$6,124
	Run Coordination	2.2.1	UW	Materials & Supplies	M&S for Winter Overs (excluding laptops)	1.0	$10,000	$15,770	1.0	$20,000	$32,518	1.0	$20,000	$33,526	1.0	$20,000	$34,566	1.0	$20,000	$35,638	1.0	$10,000	$10,000	$18,372
				Materials & Supplies Total			$10,000	$15,770		$20,000	$32,518		$20,000	$33,526		$20,000	$34,566		$20,000	$35,638		$10,000	$10,000	$18,372
	Run Coordination Total						$10,000	$15,770		$20,000	$32,518		$20,000	$33,526		$20,000	$34,566		$20,000	$35,638		$10,000	$10,000	$18,372
	Data Acquisition	2.2.2	UW	Materials & Supplies	M&S for DAQ Hardware (excluding personal laptops)	1.0	$10,000	$15,770	1.0	$20,000	$32,518	1.0	$20,000	$33,526	1.0	$20,000	$34,566	1.0	$20,000	$35,638	1.0	$10,000	$10,000	$18,372
				Materials & Supplies Total			$10,000	$15,770		$20,000	$32,518		$20,000	$33,526		$20,000	$34,566		$20,000	$35,638		$10,000	$10,000	$18,372
	Data Acquisition Total						$10,000	$15,770		$20,000	$32,518		$20,000	$33,526		$20,000	$34,566		$20,000	$35,638		$10,000	$10,000	$18,372
	IceTop Operations	2.2.9	UD	Materials & Supplies	M&S for IceTop Operations (excluding laptops)	1.0	$1,000	$1,577	1.0	$2,000	$3,252	1.0	$2,000	$3,353	1.0	$2,000	$3,457	1.0	$2,000	$3,564	1.0	$1,000	$1,000	$1,837
				Materials & Supplies Total			$1,000	$1,577		$2,000	$3,252		$2,000	$3,353		$2,000	$3,457		$2,000	$3,564		$1,000	$1,000	$1,837
	IceTop Operations Total						$1,000	$1,577		$2,000	$3,252		$2,000	$3,353		$2,000	$3,457		$2,000	$3,564		$1,000	$1,000	$1,837
	SPS Operations	2.2.4	UW	Capital Equipment	HP Proliant DL3XX & BLXXX server upgrades for SPS	4.5	$7,500	$33,750	9.0	$7,500	$67,500	9.0	$7,500	$67,500	9.0	$7,500	$67,500	9.0	$7,500	$67,500	4.5	$7,500	$33,750	$33,750
					Tape drive upgrades for SPS' Qualstar TLX 8466 tape library	1.0	$7,500	$7,500	2.0	$7,500	$15,000				2.0	$7,500	$15,000	2.0	$7,500	$15,000	1.0	$7,500	$7,500	$7,500
					Total Tape Library upgrade for the SPS							1.0	$100,000	$100,000										
					Cisco Network Switch replacement	0.5	$10,000	$5,000	1.0	$10,000	$10,000	1.0	$10,000	$10,000	1.0	$10,000	$10,000	1.0	$10,000	$10,000	0.5	$10,000	$5,000	$5,000
				Capital Equipment Total			$25,000	$46,250		$25,000	$92,500		$117,500	$177,500		$25,000	$92,500		$25,000	$92,500		$25,000	$46,250	$46,250
				Materials & Supplies	HP Proliant DL3XX & BLXXX spare servers	0.5	$7,500	$5,914	1.0	$7,500	$12,194	1.0	$7,500	$12,572	1.0	$7,500	$12,962	1.0	$7,500	$13,364	0.5	$7,500	$3,750	$6,889
					LTO-4 800 GB tape media for the SPS	800	$50	$63,079	1600	$50	$130,071	1600	$50	$134,105	1600	$50	$138,265	1600	$50	$142,553	800	$50	$40,000	$73,487
					Promise Array replacement/spare disk storage	1.0	$10,000	$15,770	2.0	$10,000	$32,518	2.0	$10,000	$33,526	2.0	$10,000	$34,566	2.0	$10,000	$35,638	1.0	$10,000	$10,000	$18,372
					Uninterruptable power supply replacements	2.5	$2,200	$8,673	5.0	$2,200	$17,885	5.0	$2,200	$18,439	5.0	$2,200	$19,011	5.0	$2,200	$19,601	2.5	$2,200	$5,500	$10,105
				Materials & Supplies Total			$19,750	$93,436		$19,750	$192,667		$19,750	$198,643		$19,750	$204,804		$19,750	$211,157		$19,750	$59,250	$108,853
	SPS Operations Total						$44,750	$139,686		$44,750	$285,167		$137,250	$376,143		$44,750	$297,304		$44,750	$303,657		$44,750	$105,500	$155,103
	SPTS Operations	2.2.5	UW	Capital Equipment	HP Proliant DL3XX & BLXXX server upgrades for SPS	2.5	$7,500	$18,750	5.0	$7,500	$37,500	5.0	$7,500	$37,500	5.0	$7,500	$37,500	5.0	$7,500	$37,500	2.5	$7,500	$18,750	$18,750
					Cisco Network Switch replacement	0.5	$8,000	$4,000	1.0	$8,000	$8,000	1.0	$8,000	$8,000	1.0	$8,000	$8,000	1.0	$8,000	$8,000	0.5	$8,000	$4,000	$4,000
				Capital Equipment Total			$15,500	$22,750		$15,500	$45,500		$15,500	$45,500		$15,500	$45,500		$15,500	$45,500		$15,500	$22,750	$22,750
				Materials & Supplies	HP Proliant DL3XX & BLXXX spare servers	0.5	$7,500	$5,914	1.0	$7,500	$12,194	1.0	$7,500	$12,572	1.0	$7,500	$12,962	1.0	$7,500	$13,364	0.5	$7,500	$3,750	$6,889
					Uninterruptable power supply replacements	1.5	$2,200	$5,204	3.0	$2,200	$10,731	3.0	$2,200	$11,064	3.0	$2,200	$11,407	3.0	$2,200	$11,761	1.5	$2,200	$3,300	$6,063
				Materials & Supplies Total			$9,700	$11,118		$9,700	$22,925		$9,700	$23,636		$9,700	$24,369		$9,700	$25,125		$9,700	$7,050	$12,952
	SPTS Operations Total						$25,200	$33,868		$25,200	$68,425		$25,200	$69,136		$25,200	$69,869		$25,200	$70,625		$25,200	$29,800	$35,702

						2nd Half FY10			FY11			FY12			FY13			FY14			1st Half FY15			
WBS L2	WBS L3	WBS Code	Institution	Budget Element	Description	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Total $ (Fully Burdened)	Quantity	Price per unit	Direct $ Budget	Total $ (Fully Burdened)
DETECTOR OPERATIONS & MAINTENANCE Total							**$92,283**	**$211,927**		**$113,283**	**$432,718**		**$205,783**	**$526,860**		**$113,283**	**$451,285**		**$113,283**	**$461,002**		**$92,283**	**$159,633**	**$235,510**
COMPUTING AND DATA MANAGEMENT	COMPUTING AND DATA MANAGEMENT	2.3	UMD	Materials & Supplies	M&S per FTE for office supplies and miscellaneous	0.5	$667	$526	1.0	$667	$1,084	1.0	$667	$1,118	1.0	$667	$1,152	1.0	$667	$1,188	0.5	$667	$333	$612
				Materials & Supplies Total			**$667**	**$526**		**$667**	**$1,084**		**$667**	**$1,118**		**$667**	**$1,152**		**$667**	**$1,188**		**$667**	**$333**	**$612**
			UW	Materials & Supplies	M&S per FTE for office supplies and miscellaneous	5.0	$667	$5,257	10.0	$667	$10,839	10.0	$667	$11,175	10.0	$667	$11,522	10.0	$667	$11,879	5.0	$667	$3,333	$6,124
				Materials & Supplies Total			**$667**	**$5,257**		**$667**	**$10,839**		**$667**	**$11,175**		**$667**	**$11,522**		**$667**	**$11,879**		**$667**	**$3,333**	**$6,124**
	COMPUTING AND DATA MANAGEMENT Total						**$1,333**	**$5,782**		**$1,333**	**$11,923**		**$1,333**	**$12,293**		**$1,333**	**$12,674**		**$1,333**	**$13,067**		**$1,333**	**$3,667**	**$6,736**
	Computing Resources	2.3.3	PSU	Capital Equipment	CE for Computing Resources at PSU	1.0	$7,500	$7,500	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$7,500	$7,500	$7,500
				Capital Equipment Total			**$7,500**	**$7,500**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$7,500**	**$7,500**	**$7,500**
			UD	Capital Equipment	CE for Computing Resources at UD	1.0	$7,500	$7,500	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$7,500	$7,500	$7,500
				Capital Equipment Total			**$7,500**	**$7,500**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$7,500**	**$7,500**	**$7,500**
			UMD	Capital Equipment	CE for Computing Resources at UMD	1.0	$7,500	$7,500	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$15,000	$15,000	1.0	$7,500	$7,500	$7,500
				Capital Equipment Total			**$7,500**	**$7,500**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$15,000**	**$15,000**		**$7,500**	**$7,500**	**$7,500**
			UW	Capital Equipment	HP Proliant BL6XXX server blade upgrades for HPC	8.0	$10,000	$80,000	16.0	$10,000	$160,000	16.0	$10,000	$160,000	16.0	$10,000	$160,000	16.0	$10,000	$160,000	8.0	$10,000	$80,000	$80,000
					HP Proliant DL3XX server upgrades for Data Center	5.0	$5,000	$25,000	10.0	$5,000	$50,000	10.0	$5,000	$50,000	10.0	$5,000	$50,000	10.0	$5,000	$50,000	5.0	$5,000	$25,000	$25,000
					Cisco Network Switch replacement	0.5	$20,000	$10,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	1.0	$20,000	$20,000	0.5	$20,000	$10,000	$10,000
					Cisco 6509 Network Switch replacement				1.0	$130,000	$130,000													
				Capital Equipment Total			**$35,000**	**$115,000**		**$165,000**	**$360,000**		**$35,000**	**$230,000**		**$35,000**	**$230,000**		**$35,000**	**$230,000**		**$35,000**	**$115,000**	**$115,000**
				Materials & Supplies	LTO-4 800 GB tape media for the Data Center	800	$50	$63,079	1600	$50	$130,071	1600	$50	$134,105	1600	$50	$138,265	1600	$50	$142,553	800	$50	$40,000	$73,487
					Miscellaneous software (SSL Certificates, HP Mgt SW, etc)	0.5	$10,000	$7,885	1.0	$10,000	$16,259	1.0	$10,000	$16,763	1.0	$10,000	$17,283	1.0	$10,000	$17,819	0.5	$10,000	$5,000	$9,186
					Promise Array replacement/spare disk storage	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	$0
					Uninterruptable power supply replacements	4.0	$2,200	$13,877	8.0	$2,200	$28,616	8.0	$2,200	$29,503	8.0	$2,200	$30,418	8.0	$2,200	$31,362	4.0	$2,200	$8,800	$16,167
				Materials & Supplies Total			**$22,250**	**$84,842**		**$22,250**	**$174,945**		**$22,250**	**$180,371**		**$22,250**	**$185,966**		**$22,250**	**$191,734**		**$22,250**	**$53,800**	**$98,841**
	Computing Resources Total						**$79,750**	**$222,342**		**$232,250**	**$579,945**		**$102,250**	**$455,371**		**$102,250**	**$460,966**		**$102,250**	**$466,734**		**$79,750**	**$191,300**	**$236,341**
	Data Storage & Transfer	2.3.2	UW	Capital Equipment	HP Proliant DL3XX server upgrades for Data Storage	3.0	$6,000	$18,000	6.0	$6,000	$36,000	6.0	$6,000	$36,000	6.0	$6,000	$36,000	6.0	$6,000	$36,000	3.0	$6,000	$18,000	$18,000
					Tape drive upgrades for Data Center's Qualstar XLS tape library	2.0	$7,500	$15,000	4.0	$7,500	$30,000	4.0	$7,500	$30,000	4.0	$7,500	$30,000	4.0	$7,500	$30,000	2.0	$7,500	$15,000	$15,000
				Capital Equipment Total			**$13,500**	**$33,000**		**$13,500**	**$66,000**		**$13,500**	**$66,000**		**$13,500**	**$66,000**		**$13,500**	**$66,000**		**$13,500**	**$33,000**	**$33,000**
				Materials & Supplies	Promise Array replacement/spare disk storage	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	0.0	$10,000	$0	$0
					Storage Area Network replacement switches	1.0	$15,000	$23,655	2.0	$15,000	$48,776	2.0	$15,000	$50,289	2.0	$15,000	$51,849	2.0	$15,000	$53,457	1.0	$15,000	$15,000	$27,558
					NEXSAN SATABeast replacement disk storage	2.5	$40,000	$157,698	5.0	$40,000	$325,176	5.0	$40,000	$335,263	5.0	$40,000	$345,661	5.0	$40,000	$356,383	2.5	$40,000	$100,000	$183,719
					NEXSAN SATABeast spares for repair use (in lieu of 1-maint. warranties)				1.0	$40,000	$65,035				1.0	$40,000	$69,132	1.0	$40,000	$71,277				
				Materials & Supplies Total			**$65,000**	**$181,353**		**$105,000**	**$438,988**		**$65,000**	**$385,552**		**$105,000**	**$466,643**		**$105,000**	**$481,117**		**$65,000**	**$115,000**	**$211,276**
	Data Storage & Transfer Total						**$78,500**	**$214,353**		**$118,500**	**$504,988**		**$78,500**	**$451,552**		**$118,500**	**$532,643**		**$118,500**	**$547,117**		**$78,500**	**$148,000**	**$244,276**
COMPUTING AND DATA MANAGEMENT Total							**$159,583**	**$442,477**		**$352,083**	**$1,096,856**		**$182,083**	**$919,216**		**$222,083**	**$1,006,283**		**$222,083**	**$1,026,918**		**$159,583**	**$342,967**	**$487,353**
Grand Total							**$342,533**	**$775,881**		**$646,033**	**$1,777,582**		**$568,533**	**$1,699,295**		**$516,033**	**$1,716,159**		**$516,033**	**$1,752,051**		**$342,533**	**$594,267**	**$857,785**

				2nd Half FY10		FY11		FY12		FY13		FY14		1st Half FY15			
WBS L2	WBS L3	WBS Code	Description	Quantity	Total $ (Fully Burdened)	Quantity	Total $ (Fully Burdened)	Quantity	Total $ (Fully Burdened)	Quantity	Total $ (Fully Burdened)	Quantity	Total $ (Fully Burdened)	Quantity	Total $ (Fully Burdened)	Total Quantity	Total $ (Fully Burdened)
	Data Acquisition	2.2.2	NPX Designs DAQ Software Programmers	135	$18,584	270	$38,283	270	$39,432	270	$40,615	270	$41,833	135	$21,544	**1350**	**$200,290**
	Data Acquisition Total				**$18,584**		**$38,283**		**$39,432**		**$40,615**		**$41,833**		**$21,544**		**$200,290**
	SPS Operations	2.2.4	Qualstar LTO-3 tape drives for the SPS (4 in library, 1 spare) 1-yr maint. Warranty	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0	0.0	$0	**0**	**$0**
			Qualstar TLX 8466 SPS tape library 1-yr maint. warranty	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0	0.0	$0	**0**	**$0**
			Qstar - Silver 1-yr maint. plan for Pole HSM	0.5	$3,059	1.0	$6,302	1	$6,491	1.0	$6,686	1.0	$6,886	0.5	$3,546	**5**	**$32,970**
			World-link Iridium Modem 1-yr service plan	0.5	$13,001	1.0	$26,782	1	$27,586	1.0	$28,413	1.0	$29,266	0.5	$15,072	**5**	**$140,121**
			DLT Solutions RedHat 1-yr Satellite Server License for Operating Systems	0.5	$7,648	1.0	$15,754	1	$16,227	1.0	$16,714	1.0	$17,215	0.5	$8,866	**5**	**$82,424**
			Zenoss 1-yr server monitoring service at SPS	0.5	$3,059	1.0	$6,302	1	$6,491	1.0	$6,686	1.0	$6,886	0.5	$3,546	**5**	**$32,970**
	SPS Operations Total				**$26,767**		**$55,140**		**$56,794**		**$58,498**		**$60,253**		**$31,030**		**$288,484**
	SPTS Operations	2.2.5	DLT Solutions RedHat 1-yr Satellite Server License for Operating Systems	1	$7,648	1	$15,754	1	$16,227	1	$16,714	1	$17,215	1	$8,866	**5**	**$82,424**
			Zenoss 1-yr server monitoring service at SPS	1	$3,059	1	$6,302	1	$6,491	1	$6,686	1	$6,886	1	$3,546	**5**	**$32,970**
	SPTS Operations Total				**$10,707**		**$22,056**		**$22,718**		**$23,399**		**$24,101**		**$12,412**		**$115,394**
	Experiment Control	2.2.6	NPX Designs DAQ Software Programmers	765	$105,310	1530	$216,938	1530	$223,446	1215	$182,765	900	$139,443	450	$71,813	**6390**	**$939,715**
	Experiment Control Total				**$105,310**		**$216,938**		**$223,446**		**$182,765**		**$139,443**		**$71,813**		**$939,715**
DETECTOR OPERATIONS & MAINTENANCE Total					**$161,368**		**$332,417**		**$342,390**		**$305,278**		**$265,631**		**$136,800**		**$1,543,883**
	Data Storage & Transfer	2.3.2	NEXSAN SATABeast 1-yr maint. warranty	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0	0.0	$0	**0**	**$0**
			NEXSAN SATABoy 1-yr maint. warranty	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0	0.0	$0	**0**	**$0**
			Qlogic SANbox 3-yr. maint. warranty			3.0	$16,178					3.0	$17,678			**6**	**$33,856**
			Qualstar 1-yr maint. warranty on Data Center's XLS LRM tape library							1.0	$7,100	1.0	$7,313	0.5	$3,766	**3**	**$18,179**
			Qualstar StorageWorks FC HBA 1-yr maint. warranty for Data Center							2.0	$4,412	2.0	$4,545	1.0	$2,341	**5**	**$11,298**
			Qualstar XLS LTO-4 Data Center tape drives 1-yr maint. warranty							10.0	$30,336	10.0	$31,246	5.0	$16,091	**25**	**$77,673**
			Qualstar XLS MEM Data Center library expansion 1-yr maint. warranty							1.0	$3,264	1.0	$3,362	0.5	$1,731	**3**	**$8,358**
			FileTek - StorHouse S/W 2-yr site license for Data Center HSM			1.0	$56,716			1.0	$60,170			0.5	$31,917	**3**	**$148,802**
			Qstar - Silver 1-yr maint. plan for Data Center HSM	0.5	$4,589	1.0	$9,453	1	$9,736	1.0	$10,028	1.0	$10,329	0.5	$5,320	**5**	**$49,454**
	Data Storage & Transfer Total				**$4,589**		**$82,346**		**$9,736**		**$115,310**		**$74,473**		**$61,166**		**$347,621**
	Computing Resources	2.3.3	Atempo Backup S/W 1-yr tech support	1	$8,413	2	$17,330	2	$17,850	2	$18,385	2	$18,937	1	$9,752	**10**	**$90,666**
			Inacom/Cisco Smartnet 1-yr tech support for network switch	1	$38,239	1	$78,772	1	$81,135	1	$83,569	1	$86,076	1	$44,329	**5**	**$412,120**
			Campus network connection for 1-yr	1	$27,532	1	$56,716	1	$58,417	1	$60,170	1	$61,975	1	$31,917	**5**	**$296,726**
			H&H Industries Data Center cooling system maint. for 1-yr	1	$3,824	1	$7,877	1	$8,113	1	$8,357	1	$8,608	1	$4,433	**5**	**$41,212**
			Data Center fire suppression system maint. for 1-yr	1	$3,824	1	$7,877	1	$8,113	1	$8,357	1	$8,608	1	$4,433	**5**	**$41,212**
			Data Center Power Distribution system maint. for 1-yr	1	$3,824	1	$7,877	1	$8,113	1	$8,357	1	$8,608	1	$4,433	**5**	**$41,212**
			DLT Solutions RedHat 1-yr Satellite Server License for Operating Systems	1	$11,472	1	$23,632	1	$24,340	1	$25,071	1	$25,823	1	$13,299	**5**	**$123,636**
			Zenoss 1-yr server monitoring service at Data Center	1	$6,118	1	$12,603	1	$12,982	1	$13,371	1	$13,772	1	$7,093	**5**	**$65,939**
			Altiris PBS SW 1-yr service plan for cluster control	1	$7,648	1	$15,754	1	$16,227	1	$16,714	1	$17,215	1	$8,866	**5**	**$82,424**
			HP Mgmt Monitoring System for HP HW 1-yr service plan	1	$11,472	1	$23,632	1	$24,340	1	$25,071	1	$25,823	1	$13,299	**5**	**$123,636**
	Computing Resources Total				**$122,364**		**$252,070**		**$259,632**		**$267,421**		**$275,444**		**$141,853**		**$1,318,784**
COMPUTING AND DATA MANAGEMENT Total					**$126,953**		**$334,416**		**$269,368**		**$382,731**		**$349,917**		**$203,020**		**$1,666,405**
Grand Total					**$288,320**		**$666,833**		**$611,758**		**$688,009**		**$615,547**		**$339,820**		**$3,210,287**