IceCube Upgrade Technical Coordination

Mike DuVernois, Technical Coordinator
WBS 1.1

ICNO/Upgrade Project – NSF Site Visit Review
17 March 2020

IceCube Upgrade

Outline

- **Scope** of the project and of Technical Coordination
- **Processes** controlling the Technical Baseline
- **Status** of important systems and subsystems

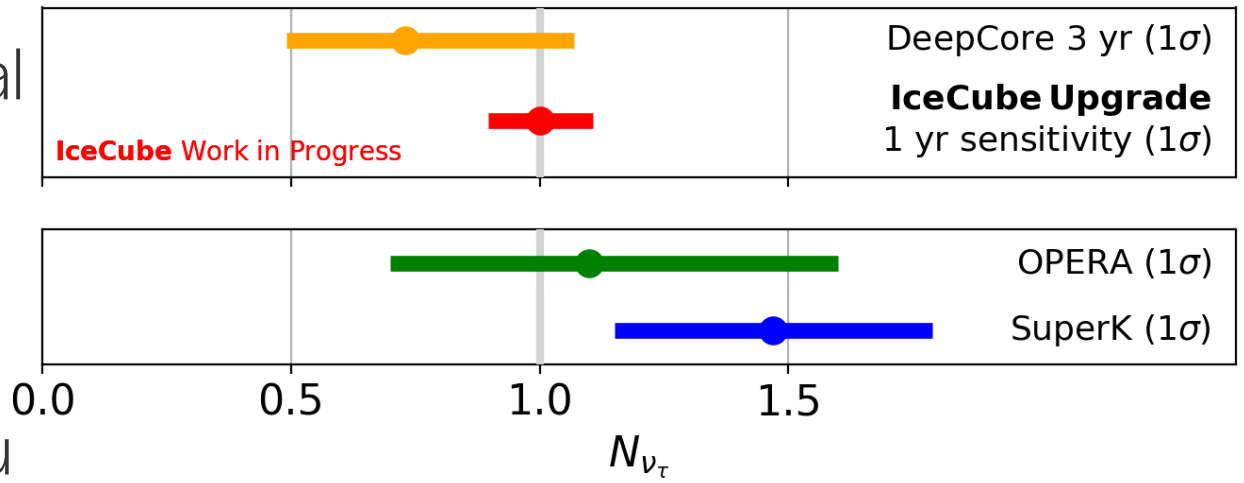
Scope

IceCube Upgrade Project Scope

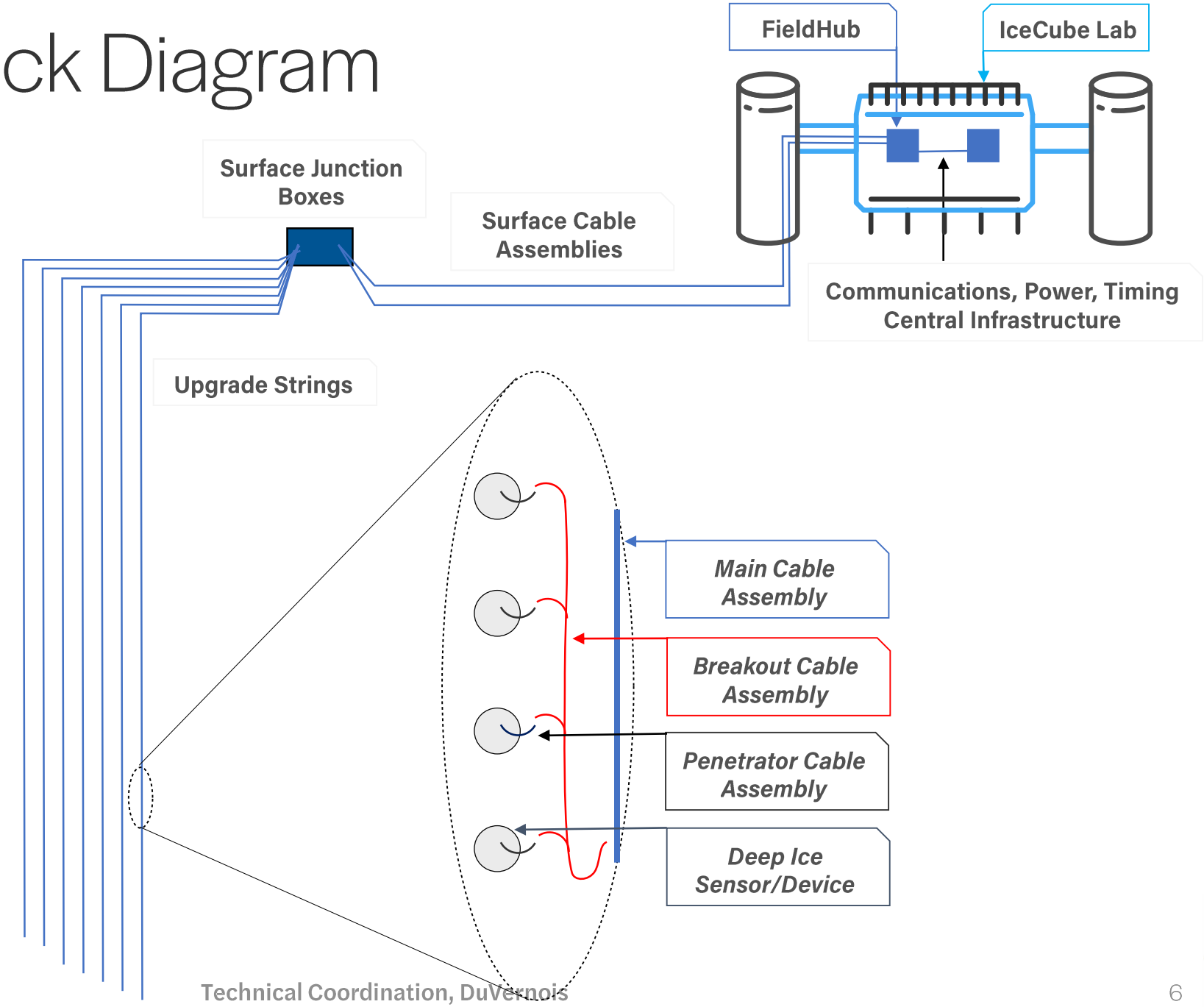
- Neutrino Oscillation Physics (“Physics”)
  - Primarily with a dense array of photosensor modules in the deep, clear ice
  - Modules of two types (D-Egg and mDOM)
- Ice & Detector Calibration Improvements (”Calibration”)
  - Enhances the science return of the full IceCube array, including prior data
  - Devices on each optical module (cameras, LED pulsers, inclinometers, etc.) and stand-alone modules (POCAM, Pencil beam, Acoustics, pDOM)
- Research & Development toward Gen2 IceCube (“R&D”)
  - Small numbers of various R&D sensors, potential optical modules, test stands for radio detection, and tools for managing the Gen2 strings

Projected improvements with the Upgrade

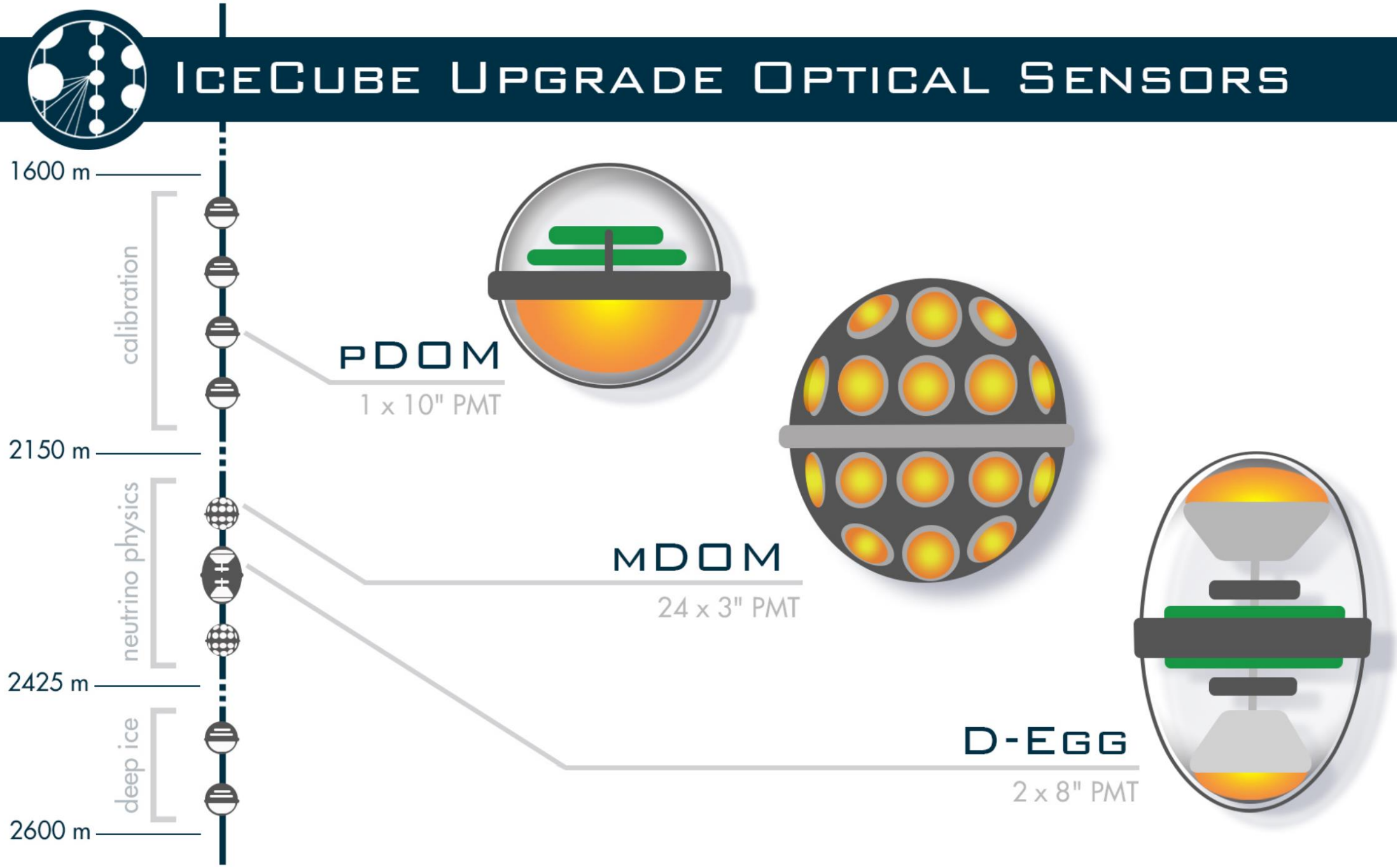
- 3x improvement in atmospheric tau neutrino appearance sensitivity
- 4x/2x improvement in astrophysical cascade/track events
- 2x more astrophysical cascade events
- 3σ observation of astrophysical tau neutrinos in 12 years of recalibrated IceCube data



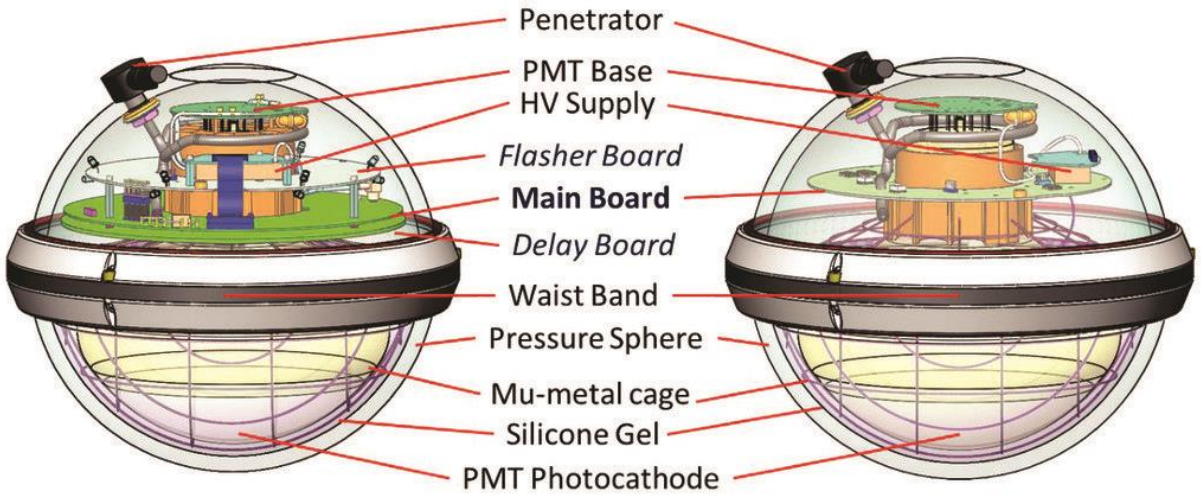
Upgrade Block Diagram



IceCube Upgrade Optical Sensors



Optical Sensors

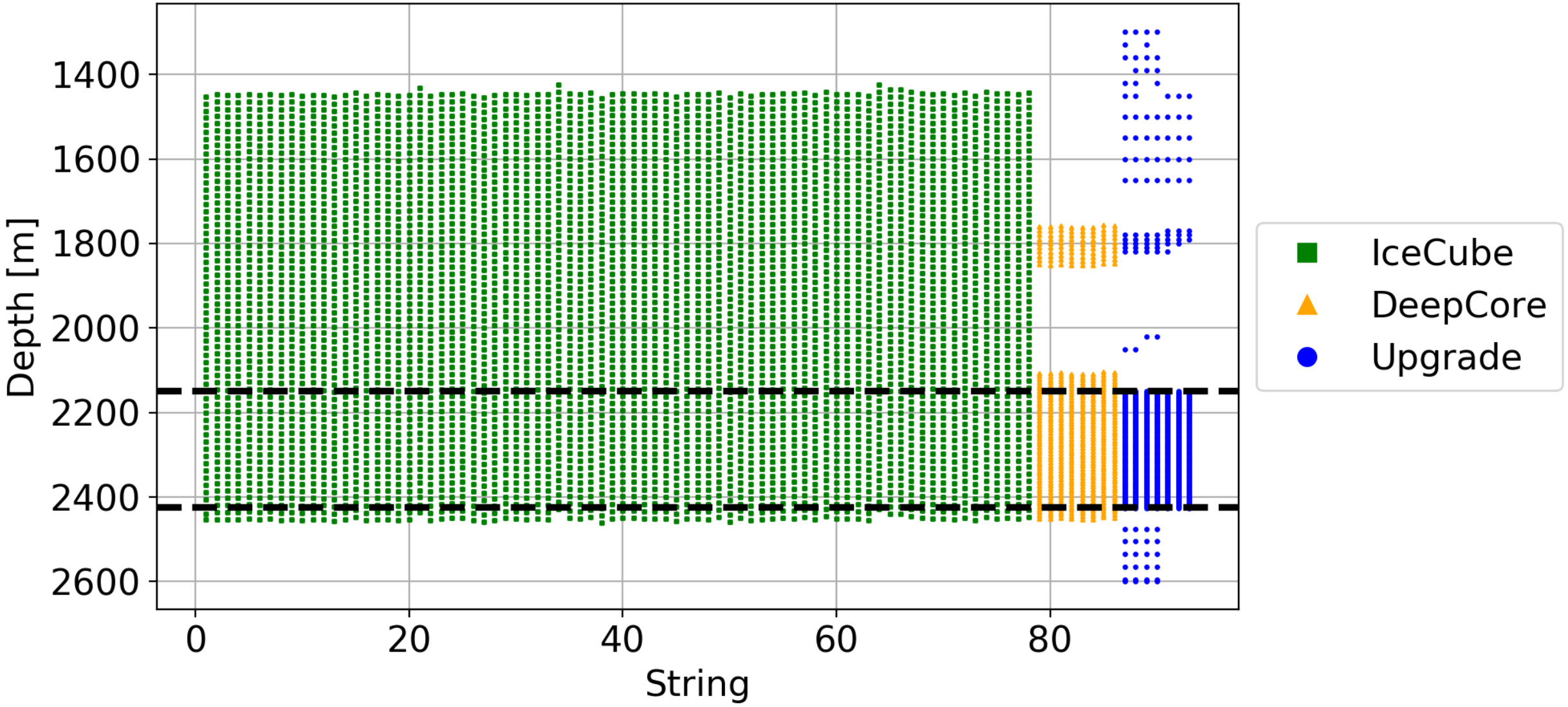


DOM PDOM

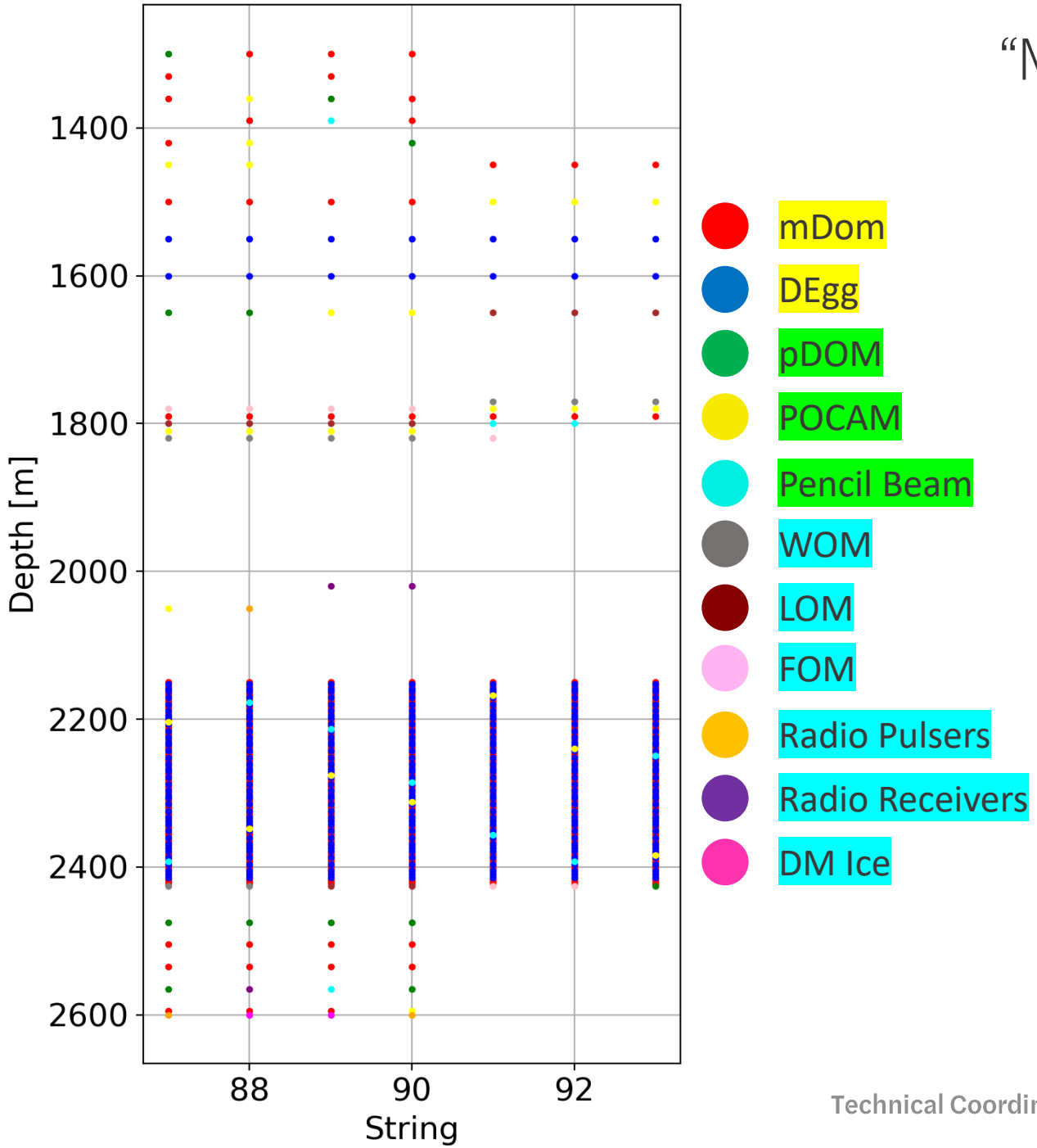
D-Egg

mDOM

Gen1 + DeepCore + Upgrade Layout



“Many module types, one project”



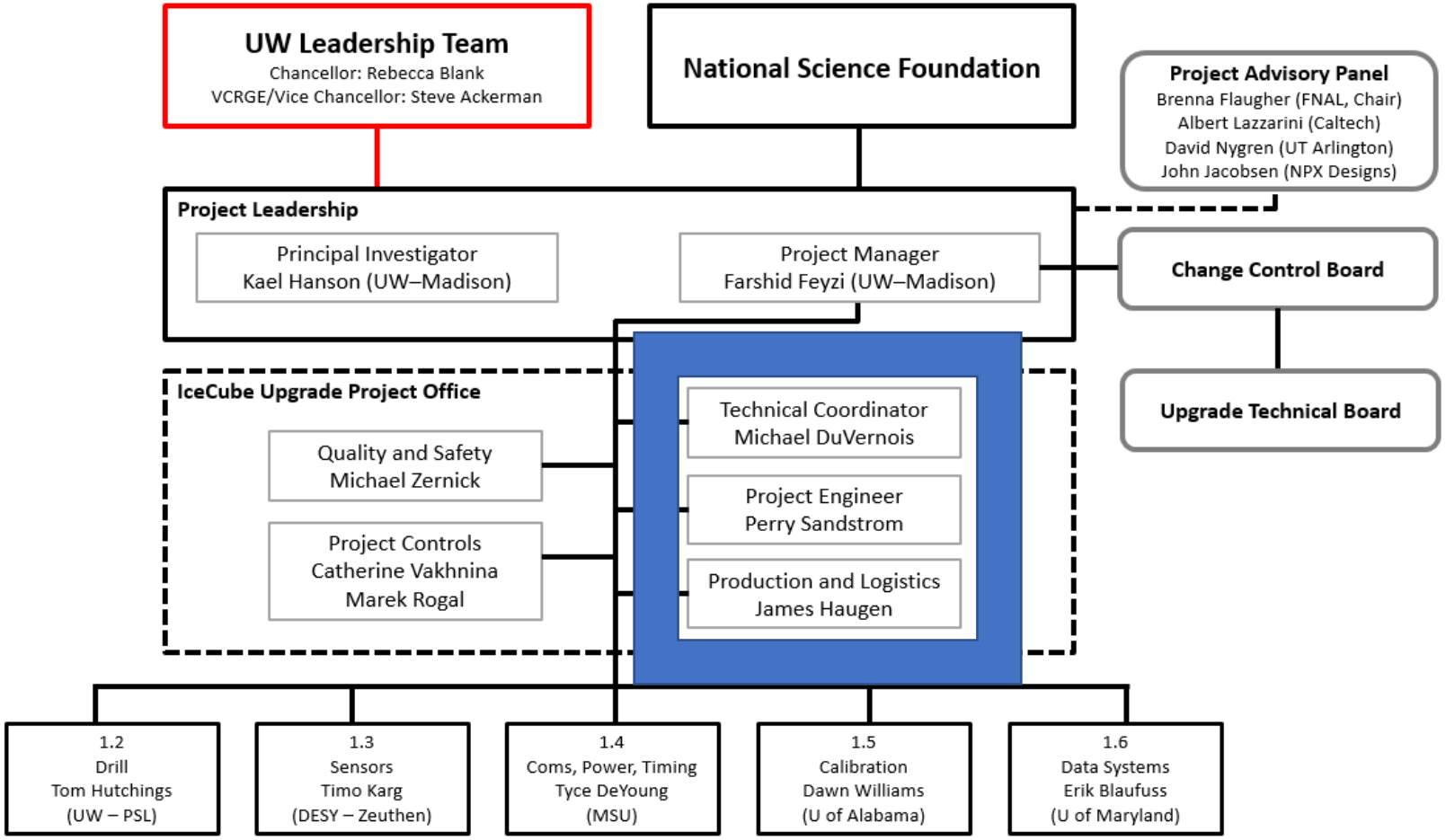
- mDOM & D-Egg
  - Primary optical modules (concentrated in physics region)
- pDOM, Pencil Beam, POCAM, & Acoustics
  - Calibration modules
- Others
  - Special devices or R&D modules for IceCube-Gen2
- All devices
  - Common comms, power, timing, DAQ & mechanical interfaces

Cable and Communications

- See more in the WBS 1.4 Talk
- New production quads support 2 Mbps on a wire pair with IceCube Upgrade (ICM and FieldHub) devices
- All in-ice modules have an ICM and are readout on the surface with a FieldHub
- On-module feature extraction to compress hits
- 20% overhead for multi-PE, 5% protocol overhead
- 8b10b encoding
- ~14kHz of compressed hits per 1 Mbps in pair
- This is sufficient for two mDOMs per pair

Field	Bits required
Channel ID	5
Trigger flag	0–2
Clock LSBs	20–25
Pulse amplitude	7–8
Pulse offset	7–8
Total	**39–48 (5–6B)**

WBS 1.1: Tech Coordination, Project Engineering, Production Coordination, &



Scope of Technical Coordination & Project Engineering

- Design Baseline Library – Defines the technical design of the project – System Engineering scheme using four document templates
  - Configuration Management Document (CMD): hierarchical subsystems listing
  - Engineering Requirements Document (ERD): traceable to physics requirements
  - Design Status Notes (DSN): ongoing change log, links to meeting updates, vendor links
  - Interface Description Document (IDD): manages interfaces
- Project Technical Board – weekly call with Issue Tracking
- Project Change Control Board – weekly L2 call plus change control process
- Design Reviews
- Production Coordination, assistance with vendor relations, contracting, and purchasing

Processes

Weekly calls

- Technical Board Call (0730 Madison Tuesdays)
  - General updates of technical progress (D-Egg reporting recently for example)
  - Managing the technical issue tracker
  - Connects Europe, US, and Asia groups, open attendance
- Change Control Board (CCB/L2) (1100 Madison Wednesdays)
  - L2 Reports, Change Control, Budgets & schedules
- Gen2 Hardware Call (0800 Madison Thursdays)
  - Mainboard electronics have been a major topic recently
- Calibration Group, mDOM Group, Mainboard Firmware & Software, IceCube "Extensions," NSF Coordination, ASC Coordination Calls
- Local WIPAC Upgrade and Drill meetings

TB Call Agendas Examples

Agenda 2/18:

- Issue Tracker
- D-Egg Final Design Review
- D-Egg Review Action Items/Questions/Issues for the wider group
- D-Egg Mainboard Noise: Perry/Ryo/et al.
- D-Egg Harness finalize: Aya/Chris Ng
- Upgrade String Design Complete (May 1 deadline): Mike
- mDOM harness: Anna P.

Agenda 2/25:

- mDOM PMTs (Hamamatsu visiting DESY): Timo
- Camera mounting finalized post-shock tests: Carsten
- Discussion of the Upgrade String finalization: Mike
- Implementation Update: Terry
- Revisit D-Egg action items

Agenda 3/3

- Issue Tracker Update: Mike
- New call time starting next week: Mike
- D-Egg Status: Aya
- Cable Update: Ty
- microBase Update: Chris W.
- FAT workshop report & plans: Erik
- AOB

Change Management Process

- Change Request Form filled out by L2
- Change Request presented at weekly Technical Board Call
- Technical Board sends recommendations to L2/Change Control Board
- Recommendations discussed by CCB, they make a go/no-go recommendation to Project Manager
- Project Manager makes the decision and, if necessary, coordinates with the PIs, the host institutions, and the funding agencies
- Baseline costs, schedule, and technical documentation are updated
- Change Request Log is kept up to date with signatures obtained/logged
- Process documented in the Change Request Form maintained by Quality Control

Reviews

- Designs pass through conceptual, preliminary, final, and (for some mass-produced systems) production reviews
  - Due diligence and another opportunity to catch issues, prevent complacency
  - Later there are shipping readiness & deployment readiness reviews
- Most recent reviews:
  - Final Design Review for the D-Eggs (Feb 2020) with *
  - Preliminary Design Review for the POCAM (Oct 2019)
  - Preliminary Design Review for the mDOM electronics (Aug 2019)
- Reviewers are a mix of internal (IceCube) and external people
- Will show overall status of critical systems in “Status”
- Design flow through the reviews on next slide…

Design Flow

Instrumentation Design Deliverable	Work Product/Baseline Document	to exit Conceptual Design, you need	to exit Preliminary Design, you need	to exit Final Design, you need	to exit Production Readiness, you need	Comment
Description	Design Status Notes (DSN) and ConfCMD	Initial	Update	Update and controlled		
Requirements	ERD	Initial	Update	Update and controlled		
Block Diagram	slide 4 in DSN	Initial	Update	Update and complete		
Mechanical Drawings	slide 5 in DSN	Initial	Update	Update and controlled		integrate with Bill of Materials if possible
Schematic Circuit Diagrams	slide 5 in DSN	Initial	Update	Update and controlled		if applicable
Circuit Board Layout	slide 5 in DSN	Initial	Update	Update and controlled		if applicable
Bill of Materials	slide 5 in DSN	Initial	Update	Update and controlled		integrate with Mechanical Drawings if possible
Interfaces Identified	IDD	Initial	Update	Complete		
Design Verification	Coordinate with Project Engineer	Initial	Update	Update and controlled		
Investigate alternatives, rationale for design	Slide 6 in DSN, if needed	Initial	Complete			
Risk Assessment	Risk Register	Initial	Update	Update	Update	Document changes throughout lifetime of product, apply to project
Conceptual Design Review		**Completed Review**				**Exit to Preliminary Design with meeting minutes 'approval' or Skip review and proceed with Preliminary Design with L2 / CCB OK**
Integration Procedure	Integration PCR		Initial	Update and controlled		must include materials, tools, process, training
Test Procedure	Test PCR		Initial	Update and controlled		must include materials, tools, pass/fail criteria, process
Shipping Procedure	Shipping PCR		Initial	Update	Finalize	must consider all transport modes for delivery
Installation Procedure	Installation PCR		Initial	Update and controlled		if needed
Production Plan	slide 11 in DSN		Initial	Update	Finalize	include labor, sites, rate, equipment, capacity, bottleneck indentificaiton, shipping plan
Procurement Plan ppt	slide 11 in DSN		Initial	Update	Finalize	
Prototype - Rev 0	something in hand + slide 8 in DSN		Initial			
Preliminary Design Review			**Completed Review**			**Exit to Final Design with meeting minutes 'approval' or Skip review and proceed to Final Design with L2 / CCB OK**
Prototype Yield	slide 8 in DSN			Initial	Update	if applicable, include failure analysis, pareto chart, actions to fix
Prototype - Rev 1 or more	slide 8 in DSN			Update	Update	if needed
Hazard Analysis	Coordinate with Safety Engineer			Initial	Finalize	if needed
Final Design Review				**Completed Review**		**Exit to Production Readiness with meeting minutes 'approval'. All instrumentation MUST have a Final Design Review.**
Production Readiness Review					**Completed Review**	**Exit to Production / Procurement with meeting minutes 'approval'**

Status

Status of critical systems

In-ice modules

- **D-Egg:** Passed FDR. One additional revision of the mainboard planned. In pre-production now, full production Summer 2020.
- **mDOM:** Passed PDR. Some parts have passed FDR. FDR in Summer 2020, production start 2020.
- **POCAM:** Passed FDR. Awaiting common parts delivery.
- **Pencil Beam:** In design process. Review expected Spring 2020.
- **pDOM:** Mainboard work drives the D-Egg mainboard.

Other components

- **ICM/FieldHubs:** Passed FDR. Common to all in-ice devices. “Speak DOM.”
- **Mini-Mainboard:** To be reviewed Spring-Summer 2020. To support R&D and Calibration modules.
- **Main cables:** MSU-Vendor work, PDR in April
- **Breakout cables:** Conceptual design available, interfaces being defined
- **Cable entry logistics:** Evaluated at South Pole this past season. Detailed plan Spring-Summer 2020.

Current issues

- D-Egg schedule in Japan has been aggressive, and has forced a number of subsystems to be developed earlier than originally planned.
- Need to develop a general approach to dealing with non-conforming materials. Production processes need to be developed. We will do a high-level Failure Mode and Effects Analysis at the string level.
- Communications and timing system spans WBS 1.3, 1.4, and 1.6 and corresponding labor is divided up. Some transfers of hardware and software have delayed work.
- Some of our critical personnel are “double-booked”.

Significant upcoming milestones

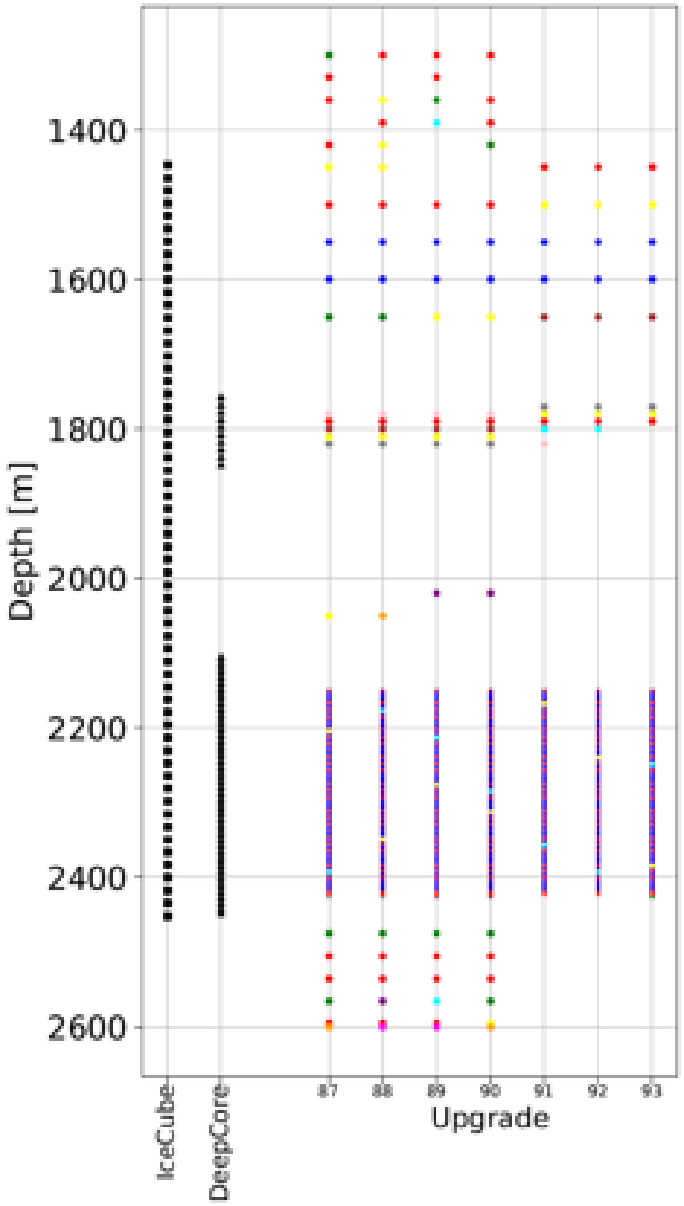
- **April:** Downhole cable Preliminary Design Review
- **April:** Delivery of pre-production batch (50) D-Eggs
- **May 1:** Upgrade String Design complete (see next slide)
- **Mid-May:** R&D sensor review at collaboration meeting
- **Spring:** Acoustics and Pencil Beam Reviews
- **Summer:** mDOM Final Design Review, D-Egg Production Readiness Review & Production Facility Audit
- **Autumn:** mDOM Production Readiness Review

L1 Milestone: Upgrade String Design Complete

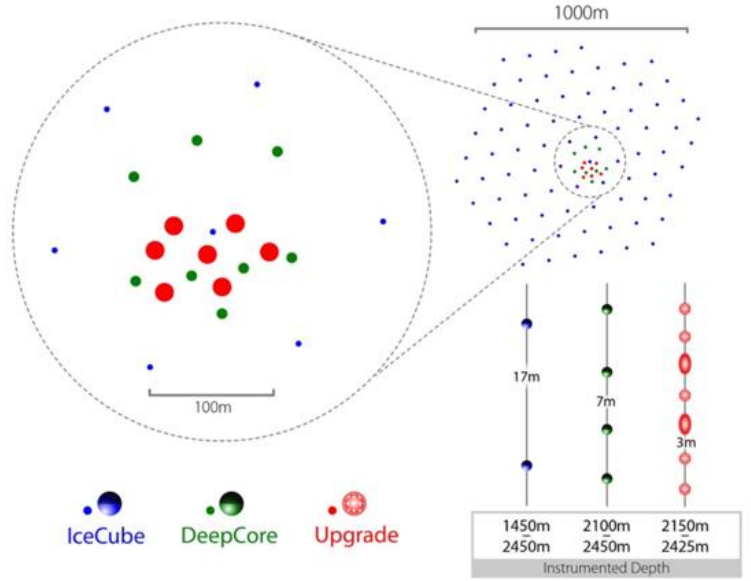
- Finalize what goes onto each string:
  - Optical modules, special devices, types of breakout cables, harnesses
- Finalize what each hole looks like:
  - Location, depth, degas hole (yes/no), surface junction box, cable lengths
- This has been in the design baseline library for about a year
  - Some changes now with some R&D sensors being deleted
  - Some changes in numbers/positions of devices
  - Requires formal Change Request internally
- Deliverable for this milestone: short report organized by WBS and corresponding updates in the Project documentation
- Key existing document: Upgrade String CMD (and secondarily the drill maps and drill procedures)

Upgrade String CMD

Includes precise depths, cable assignments, etc.



- mDom
- DEgg
- pDOM
- POCAM
- Pencil Beam
- WOM
- LOM
- FOM
- Radio Pulsers
- Radio Receivers
- DM Ice



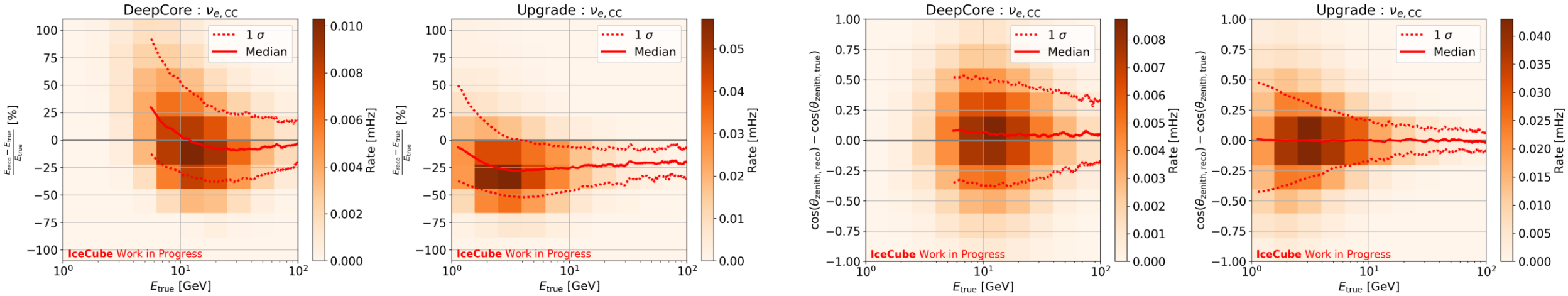
String	87	88	89	90	91	92	93	TOTAL
mDom	55	56	58	53	61	59	60	**402**
Degg	39	39	40	39	40	40	40	**227**
pDOM	1	1	2	1	2	4	3	**14**
WOM	2	2	1	2	1	1	1	**10**
FOM	2	2	0	0	1	1	1	**7**
POCAM	2	2	5	3	2	3	4	**21**
PB	1	2	1	2	3	1	1	**11**
PS	1	1	1	1	1	1	1	**7**
DM ice	0	0	1	0	0	1	0	**2**
RP	0	1	0	0	1	0	1	**3**
RR	1	0	0	0	0	2	0	**3**
AH	0	0	1	1	0	0	0	**2**
LOM	2	1	1	3	0	1	1	**9**
AP	2	1	2	1	1	1	2	**10**
Total	**108**	**108**	**113**	**106**	**113**	**115**	**115**	**778**

Backup

		SCIENCE OBJECTIVES - THE ICECUBE UPGRADE										
		Tau Neutrino Appearance and the Unitarity of the PMNS Matrix (2.1)	Neutrino Oscillations (2.2)	Sterile Neutrinos (2.2)	Indirect Dark Matter (2.2)	Ice Characterization for better LE & HE flavor physics (2.3)						
PRIMARY SCIENCE REQUIREMENTS	Event Energy Range	**few to 100 GeV**	**few to 100 GeV**			**TeV to >PeV**						
	Expected Detectable Event Rate	**Measurement in 2-3 years**	**5-10% tau measurement**	**Any detection/improved limit**	**Any detection/improved limit**	**100s / year**						
	Desired Angular Resolution	**<5 deg at O(20 GeV)**										
	Time Resolution Within Event	**2-5** ns	**2-5ns**									
	Absolute Time Accuracy					50 ns						
Ice Sensor Array Geometry	Instrumented Ice Volume	About 2 million cubic meters							√	√	√	√
	Array Shape	Compact							√	√	√	√
	Effective Volume	Varies with energy level and event orientation (derived from other properties)							√	√	√	√
	Number of Strings	7							√	√	√	√
	multi-PMT Digital Optical Modules (mDOM) per String	108 (90 in the dense physics region, others above and below for primarily calibration purposes) - 46 mDOMs, 38 D-Eggs, & 6 pDOMs							√	√	√	√
	Total Number of mDOM	~750 (photocathode area is key parameter here)							√	√	√	√
	mDOM Spacing - Horizontal	22 meters (compromise between closer and drill constraints)							√	√	√	√
	mDOM Spacing - Vertical	3.0 m							√	√	√	√
	Detector Depth	Physics region: 2150-2425m Upper region: 1450-2150 Deep region: 2425-2600m							√	√	√	√
Individual mDOM Performance	Sensitivity of mDOM	Single Photo Electron (SPE)							√	√	√	√
	mDOM Photon Event Dynamic Range	SPE to >200 PE / 15 ns							√	√	√	√
	mDOM Field of View	Spherical with <10% variation, except for cable shaddowing.							√	√	√	√
	Digitization Rate Waveforms < 400 ns	300 megasamples / second							√		√	√
	Digitization Rate Waveforms > 400 ns	40 megasamples / second							√		√	√
	Absolute Amplitude Calibration Accuracy	< 5 %							√	√	√	
	Timing Accuracy	< 5 ns							√	√	√	
Event / Background Discrimination (Noise Reduction)	mDOM Noise Rate	O(10kHz) total noise rate, <850 Hz per PMT									√	√
	mDOM Data Processing	Initial waveform capture and digitization in DOM, context sensitive compression of data prior to transfer							√		√	
	Local Coincidence Function	In mDOMs, might require N of 24 PMTs hit within time window to suppress noise.							√		√	
	Event Trigger Function	Global (surface) trigger logic to package event data and discriminate noise							√	√	√	√
	Veto Function	Surface Array (IceTop) allows identification and discrimination of downgoing background							√	√	√	√
Data Transport and Storage	Incoming Data Stream from Sensor Array	150 Gig / day							√	√	√	√
	Non-Volatile Storage at South Pole	1-2 Day Buffer / Archive Capacity & Full Redundancy Requirements						√			√	
	South Pole High Priority Communications	At all times, it must be possible to complete a minimum 10KB transfer to the Northern Hemisphere within 10 minute period. (SNEWS and GRB Reporting)						√			√	
	South Pole Medium Priority Communications	500 MB / day						√			√	
	South Pole High Volume Data Transfer	>30 GB / day						√			√	
	Northern Hemisphere Data Warehouse	Fully Buffered / Archive Capacity & Redundancy Requirements						√			√	

Resolutions

- Energy resolution: DeepCore vs. Upgrade
- Angular resolution: DeepCore vs. Upgrade

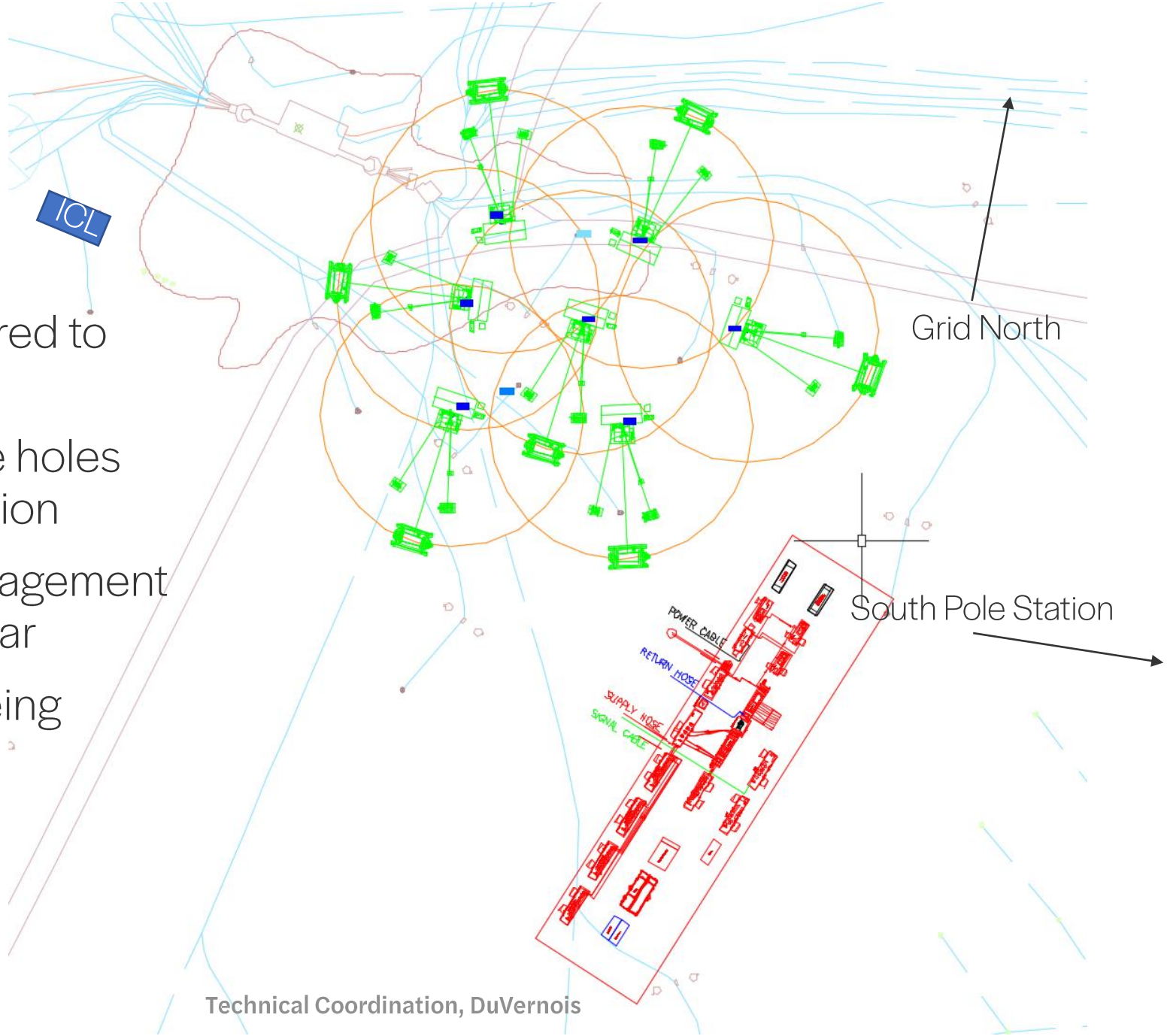


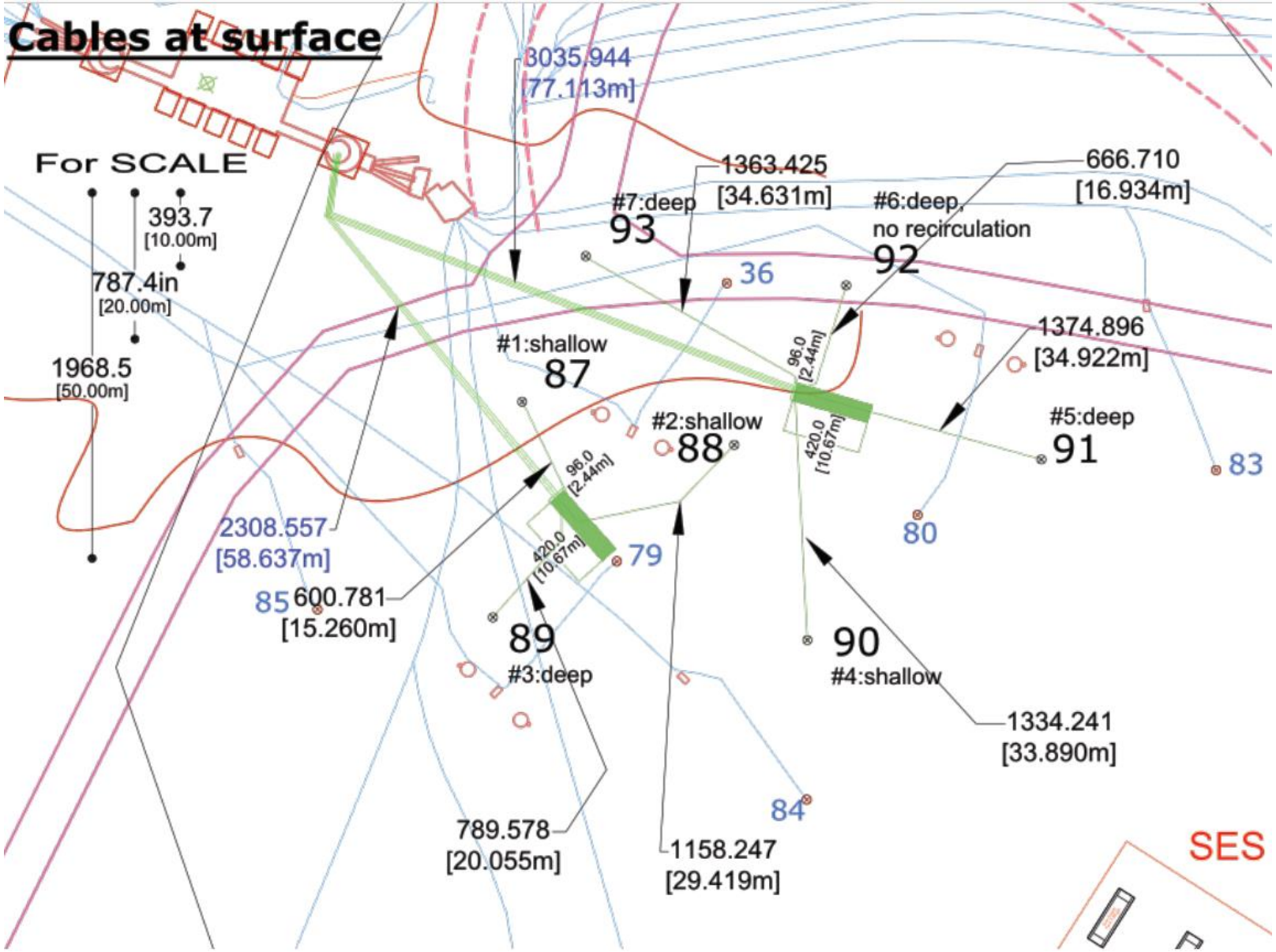
2x improvement in energy resolution @ O(20 GeV) (tau appearance region)

3-4x improvement in cos(zenith) resolution @ O(20 GeV) (tau appearance region)

Surface Plan

- Very close holes compared to IceCube Gen1
- Integration with IceCube holes and cables needs attention
- Logistics and cable management planning starting this year
- Integration with ICL is being assessed




Cables at surface
For SCALE
393.7
[10.00m]
787.4in
[20.00m]
1968.5
[50.00m]
3035.944
[77.113m]
1363.425
[34.631m]
#7:deep
93
#6:deep,
no recirculation
92
666.710
[16.934m]
36
#1:shallow
87
96.0
[2.44m]
1374.896
[34.922m]
#2:shallow
88
420.0
[10.67m]
#5:deep
91
83
2308.557
[58.637m]
96.0
[2.44m]
420.0
[10.67m]
79
80
85
600.781
[15.260m]
89
#3:deep
90
#4:shallow
1334.241
[33.890m]
84
789.578
[20.055m]
1158.247
[29.419m]
SES

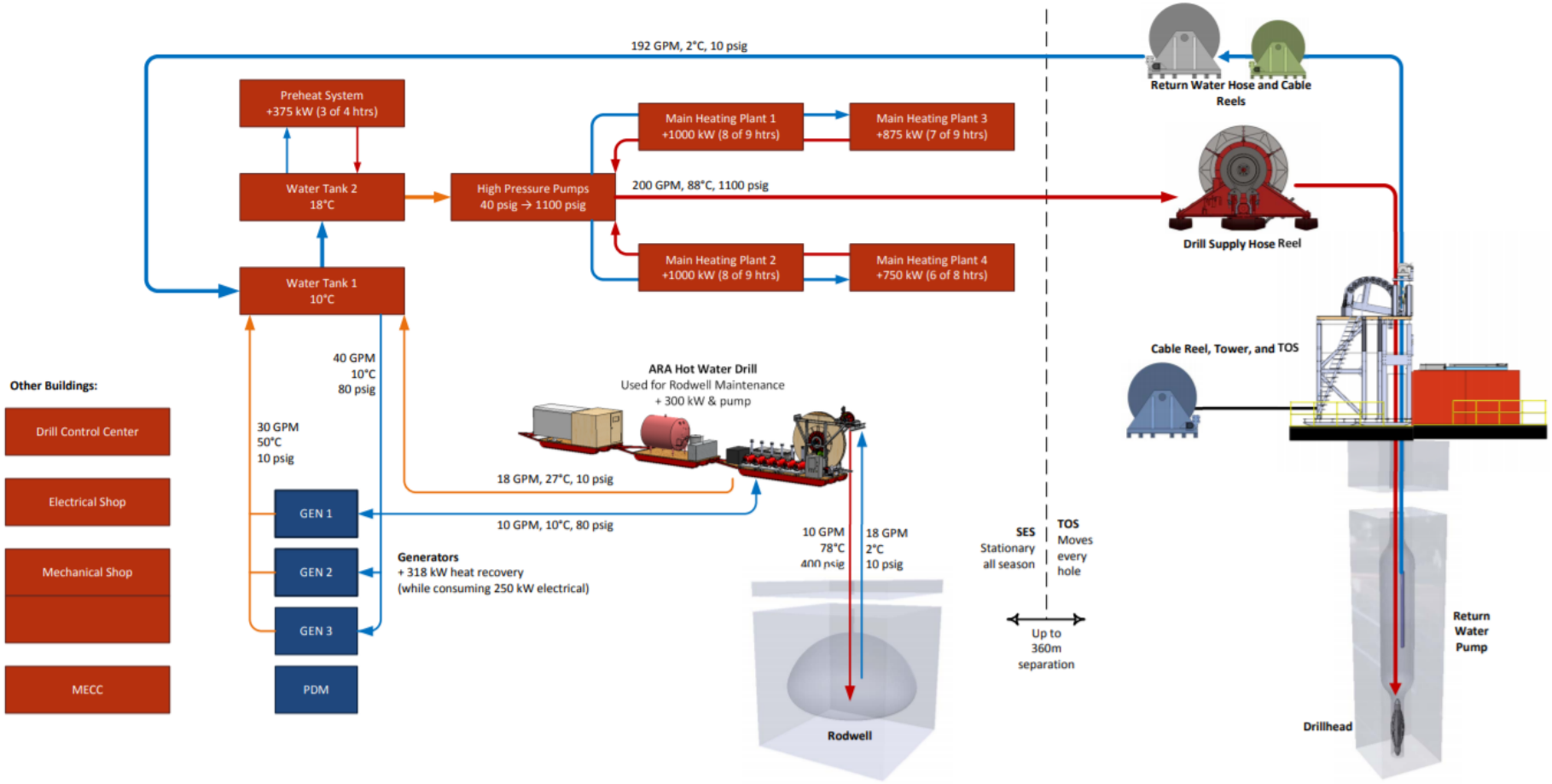
Drill - Schematic

ENHANCED HOT WATER DRILL – IceCube Upgrade

PSL v20190301

SYSTEM SCHEMATIC

Intent: Drill 7 IceCube-magnitude holes in one season to support installation of the IceCube Upgrade
Capacities: 4.6 MW thermal delivered to drill nozzle; 250 kW system electrical load
Run two gensets at a time, each at 125 kW, third genset is online backup
Makeup water obtained from stationary Rodwell, supported by ARA Hot Water Drill (pump, heat, hose reel – RWS no longer available)



IceCube Upgrade

NSF