IceCube Upgrade Rebaseline Review
April 26-28, 2022

Timo Karg
WBS 1.3 Deep Ice Sensor Modules
Breakout Session: Instrumentation

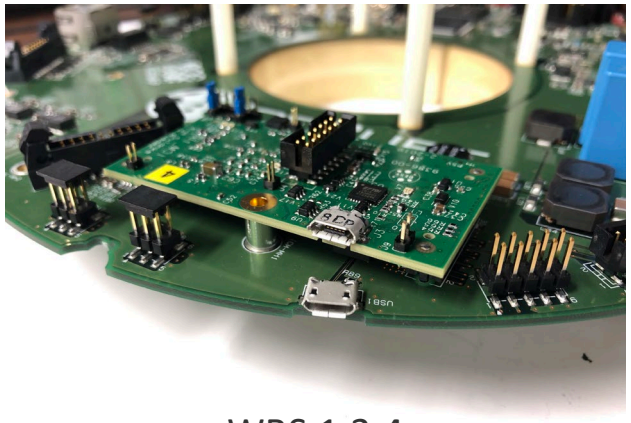
NSF

IceCube Upgrade

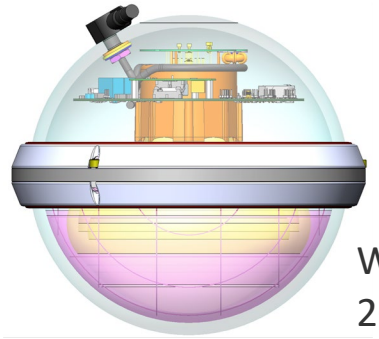
WBS 1.3 Scope

WBS 1.3.1
430 mDOMs

WBS 1.3.2
310 D-Eggs



WBS 1.3.4
900 Ice Comms Modules

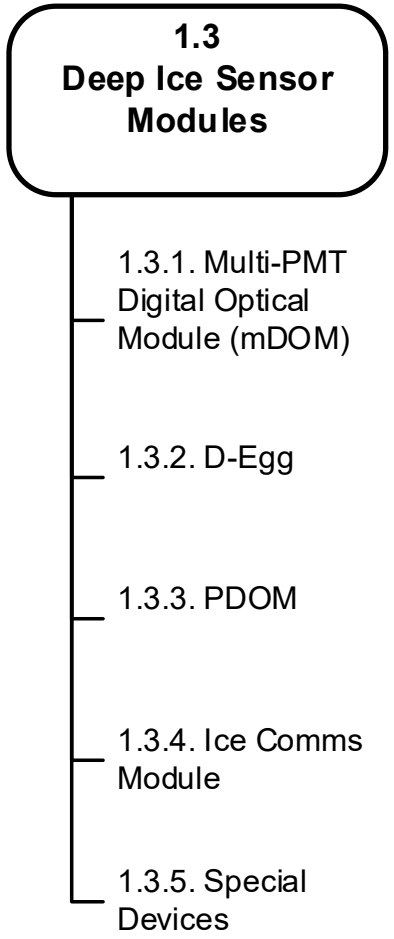


WBS 1.3.3
20 Refurbished IceCube DOMs

WBS 1.3.5
Coordination of R&D Sensors

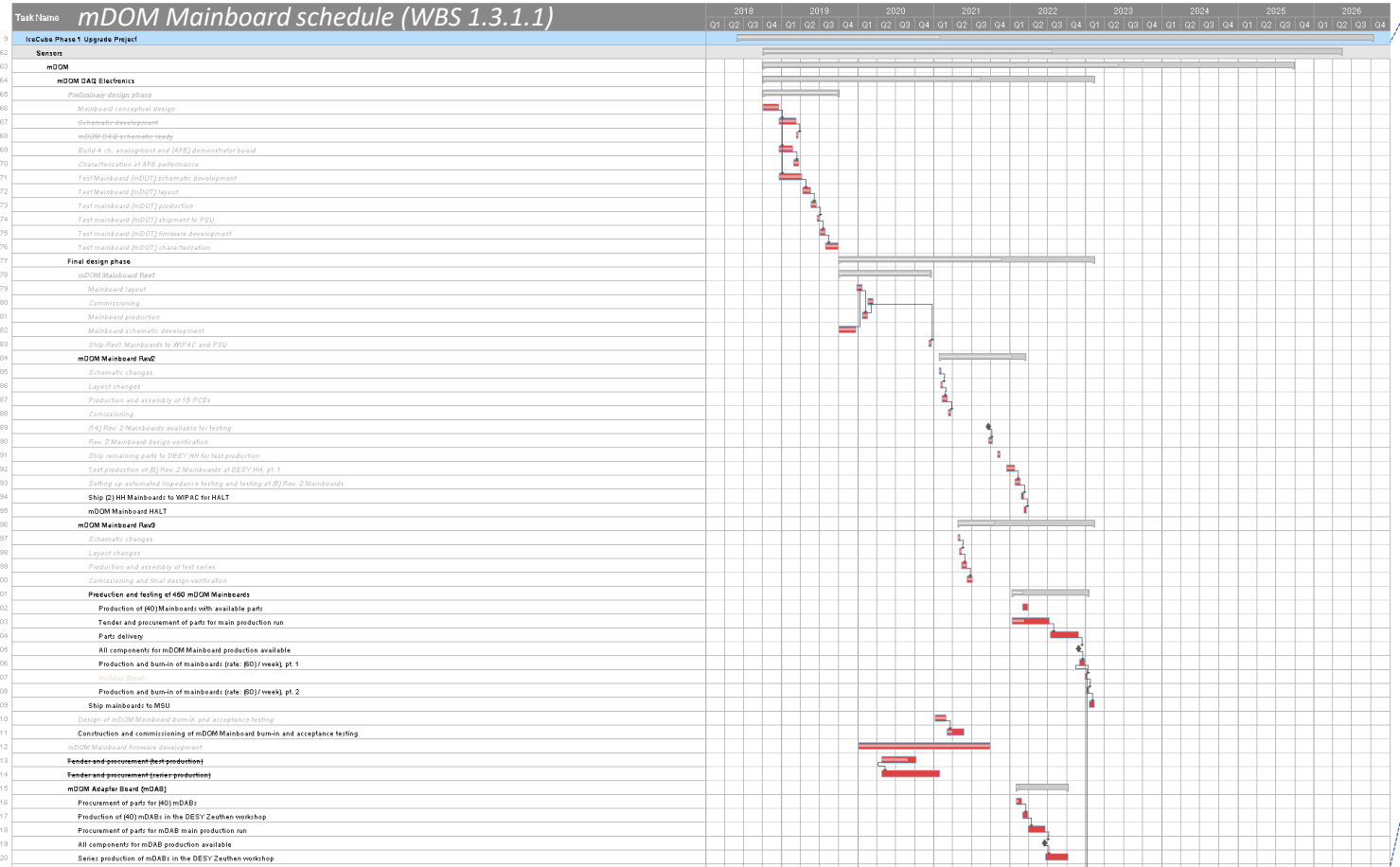
WBS 1.3: Overall Deliverables and Spares

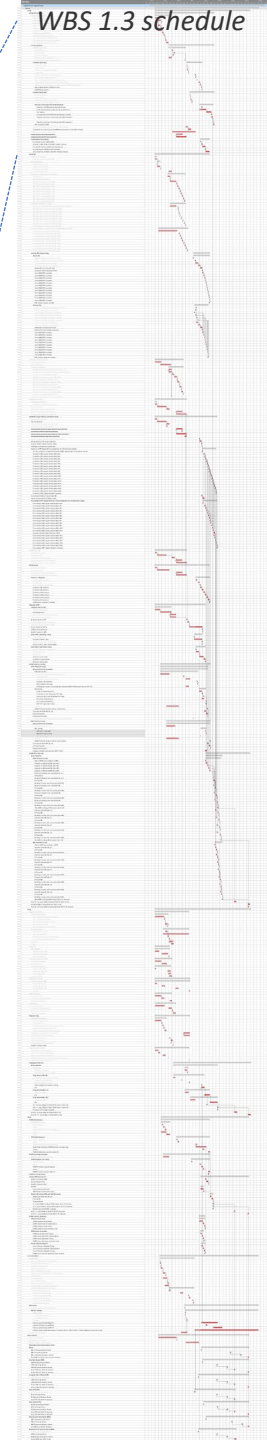
- WBS 1.3.1 **430 mDOMs**
  (402 to be deployed + 28 spares + 10 DVT modules)
- WBS 1.3.2 **310 D-Eggs**
  (277 to be deployed + 33 spares + 10 DVT modules)
- WBS 1.3.3 **20 refurbished IceCube DOMs** (PDOMs)
  (14 to be deployed + 6 spares + 10 DVT modules)
- WBS 1.3.4 **900 Ice Communication Modules**, incl. firmware
  (803 in to-be-deployed devices + 97 spares, R&D)
- WBS 1.3.5 **Coordination of Special Devices**
  (all Special Devices are contributed in-kind)



WBS 1.3: Schedule

- Full schedule, including in-kind contributions, in project-wide Smartsheet
- Percent-complete for all activities updated monthly to track progress of in-kind contributions





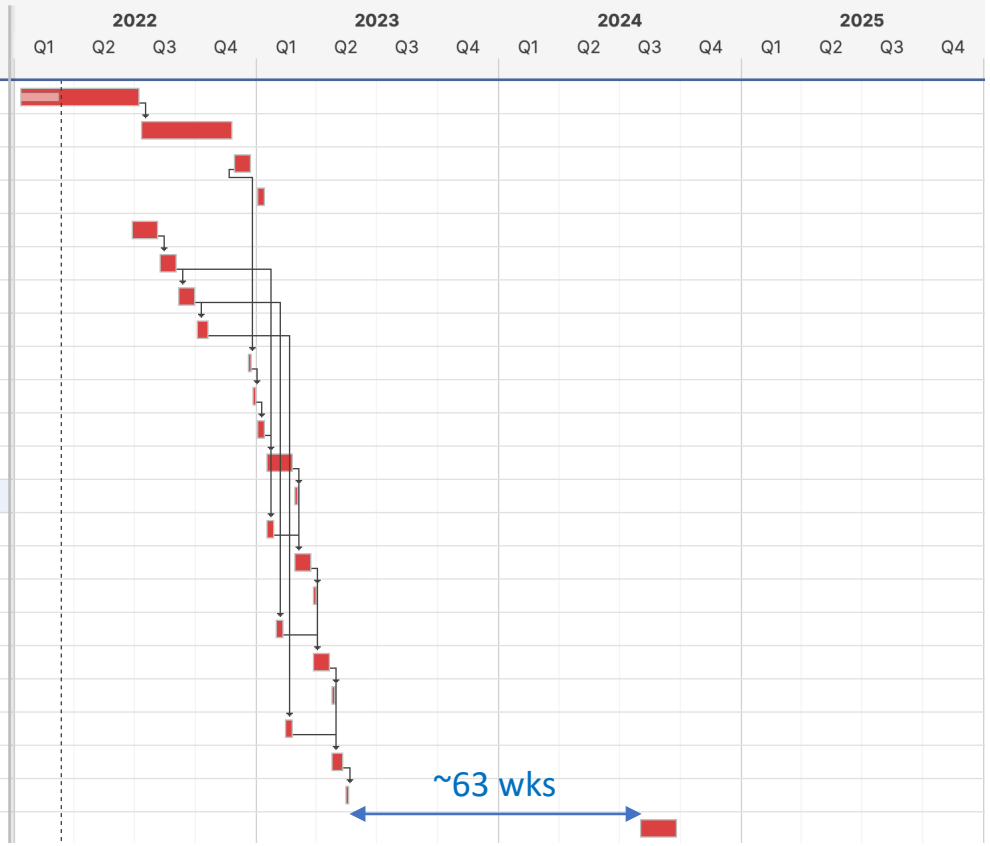
WBS 1.3: Shipping Schedule

- Sensors for first two strings are shipped in summer 2024
  - Will be tested on arrival at South Pole and stored DNF during the winter
- Remaining sensors are shipped on summer 2025
- Reasonable float for all sensor shipments (63 wks to 116 wks)

Cargo Item respective WBS Level	Work Package	Item Description	Contents & Comments	Owner/Guardian institution	SHIPMENT FLOAT: Time between completion and ship-by-date to USAP site	Date of *actuaL* or expected [from schedule] completion	Ship by date or *actual shipment date*	Expected Route: Owner - PTH or CHC	Recommended Transportation Option
1.3	Installation	String Sensors 87-88 (mDOMs DESY)	Optical sensors for 2 strings from Germany (mDOMs) (spares included) - Do Not Deep Freeze	DESY	440	5/19/2023	8/1/2024	DESY - CHC	ComSur
1.3	Installation	String Sensors 87-88 (mDOMs DESY)	Optical sensors for 2 strings from Germany (mDOMs) (SPARES) - Do Not Deep Freeze	DESY	440	5/19/2023	8/1/2024	DESY - CHC	ComSur
1.3	Installation	String Sensors 89-93 (mDOMs DESY)	Optical sensors for 5 strings from Germany (mDOMs) - Do Not Deep Freeze	DESY	721	8/11/2023	8/1/2025	DESY - CHC	ComSur
1.3	Installation	String Sensors 89-93 (mDOMs MSU)	Optical Sensors for 5 strings from MSU (mDOMs) - Do Not Deep Freeze	MSU	686	9/15/2023	8/1/2025	MSU - PTH	Truck
1.3	Installation	String Sensors 89-93 (mDOMs MSU)	Optical Sensors for 5 strings from MSU (mDOMs) containers (TBD) - Do Not Deep Freeze	MSU	686	9/15/2023	8/1/2025	MSU - PTH	Truck
1.3	Installation	String Sensors 87 & 88 (D-Eggs-8x)	Sensors (D-Eggs) pallets with 8 sensors at Pole overwinter - Cryo location - Do Not Deep Freeze	Chiba	736	7/27/2022	8/1/2024	ChibaU - CHC	Cargo shipment by CHU
1.3	Installation	String Sensors 87 & 88 (D-Eggs-8x)	Sensors (D-Eggs) pallets with 8 sensors at Pole overwinter (SPARES - TBD) - Cryo location - Do Not Deep Freeze	Chiba	736	7/27/2022	8/1/2024	ChibaU - CHC	Cargo shipment by CHU
1.3	Installation	String Sensors 87 & 88 (D-Eggs-12x)	Sensors (D-Eggs) pallets with 12 sensors at Pole overwinter - Cryo location - Do Not Deep Freeze	Chiba	736	7/27/2022	8/1/2024	ChibaU - CHC	Cargo shipment by CHU
1.3	Installation	String Sensors 87 & 88 (D-Eggs-12x)	Sensors (D-Eggs) pallets with 12 sensors at Pole overwinter (SPARES - TBD)- Cryo location - Do Not Deep Freeze	Chiba	736	7/27/2022	8/1/2024	ChibaU - CHC	Cargo shipment by CHU
1.3	Installation	String Sensors 89-93 (D-Eggs-8x)	Sensors (D-Eggs) pallets with 8 sensors - Do Not Deep Freeze	Chiba	812	5/12/2023	8/1/2025	ChibaU - CHC	Cargo shipment by CHU
1.3	Installation	String Sensors 89-93 (D-Eggs-12x)	Sensors (D-Eggs) pallets with 12 sensors - Do Not Deep Freeze	Chiba	812	5/12/2023	8/1/2025	ChibaU - CHC	Cargo shipment by CHU

WBS 1.3: Critical Path and Float

WBS	Task Name	Started
1.3.1.1.2.3.5.2	Tender and procurement of parts for main production run	Started
1.3.1.1.2.3.5.3	Parts delivery	Not Started
1.3.1.1.2.3.5.5	Production and burn-in of mainboards (rate: (60) / week), pt. 1	Not Started
1.3.1.1.2.3.5.7	Production and burn-in of mainboards (rate: (60) / week), pt. 2	Not Started
1.3.1.10.1.1.2	Integration of (54) half-mDOMs (Batch #1)	Not Started
1.3.1.10.1.1.3	Integration of (54) half-mDOMs (Batch #2)	Not Started
1.3.1.10.1.1.4	Integration of (54) half-mDOMs (Batch #3)	Not Started
1.3.1.10.1.1.5	Integration of (54) half-mDOMs (Batch #4)	Not Started
1.3.1.10.1.1.6	Mainboard integration and sealing Batch #1, pt. 1	Not Started
1.3.1.10.1.1.7	Holiday Break	Not Started
1.3.1.10.1.1.8	Mainboard integration and sealing Batch #1, pt. 2	Not Started
1.3.1.10.1.1.9	FAT Batch #1	Not Started
1.3.1.10.1.1.10	Mounting of harness wires and packing (Batch #1)	Not Started
1.3.1.10.1.1.11	Mainboard integration and sealing Batch #2	Not Started
1.3.1.10.1.1.12	FAT Batch #2	Not Started
1.3.1.10.1.1.13	Mounting of harness wires and packing (Batch #2)	Not Started
1.3.1.10.1.1.14	Mainboard integration and sealing Batch #3	Not Started
1.3.1.10.1.1.15	FAT Batch #3	Not Started
1.3.1.10.1.1.16	Mounting of harness wires and packing (Batch #3)	Not Started
1.3.1.10.1.1.17	Mainboard integration and sealing Batch #4	Not Started
1.3.1.10.1.1.18	FAT Batch #4	Not Started
1.3.1.10.1.1.19	Mounting of harness wires and packing (Batch #4)	Not Started
1.3.1.10.2	Ship 116 + 12 spare mDOMs for Strings 87-88 from DESY to CHC	Not Started



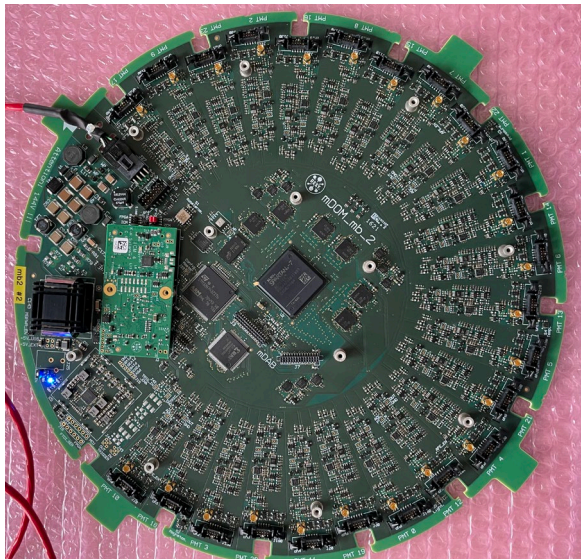
- Critical path is procurement of mDOM Mainboard parts, mainboard production, and integration in mDOMs for first two strings
- Also large schedule uncertainty due to supply chain issues

WBS 1.3.1: mDOM Technical Status

- Integrated mDOM Final Design Review completed April 11-13, 2022
- Purchases of major components for series production have been expedited
  - PMT assemblies — produced and delivered
  - Glass pressure vessel — produced and delivered
  - Optical gel — produced and delivered
  - Internal cabling — tendered and in production
  - PMT support structure — tender published, deadline for submission is May 6
  - Mainboard — various electronics parts backordered
    - Severe supply chain issues, esp. for main FPGA (first 200 parts expected May 2023, rest unclear)
    - Same situation for similar parts and similar-sized parts from other manufacturers
    - Evaluating re-design of mainboard using available parts
    - Latest possible start date for redesign is January 2023

Design Verification mDOMs in Dark Freezer Lab for testing

24-ch. mDOM Mainboard



IceCube Upgrade

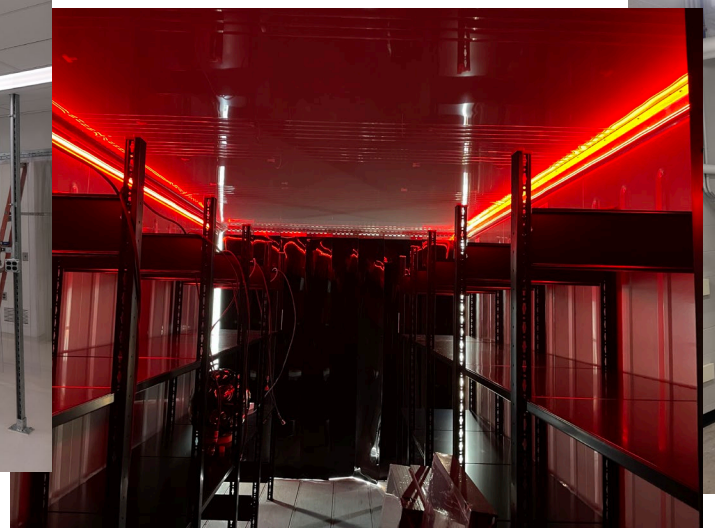
WBS 1.3.1: mDOM Production and Testing Plan

- Integration and testing will be done at DESY (225 mDOMs) and MSU (205 mDOMs)
  - Facilities at DESY and MSU ready
  - Each module will be operated in the cold for three weeks during Final Acceptance Testing before shipping to Antarctica
- Pre-production of 20 mDOMs at each site in spring/summer 2022 to exercise and optimize facilities and procedures
- Supply chain delays for several parts on the mainboard, most notably the main FPGA
  - Mitigate by producing half-mDOMs and filling in Mainboards as last step once they become available

DESY Integration Lab

MSU Integration Lab

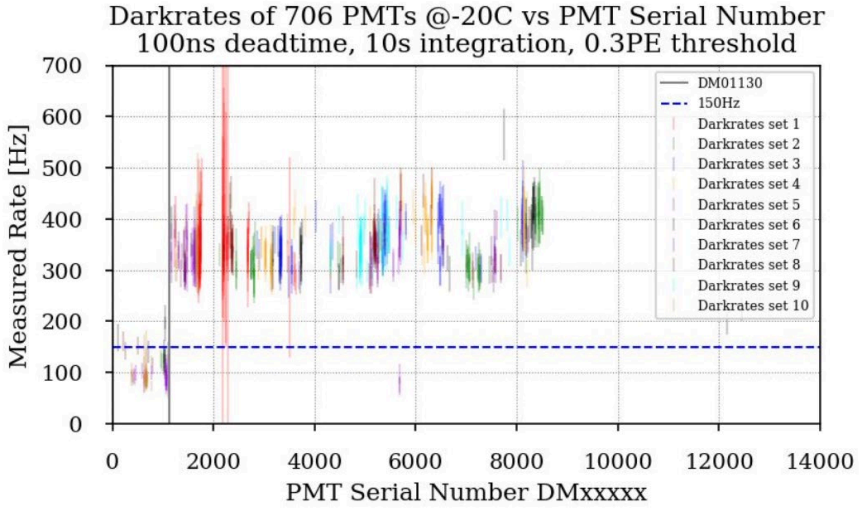
DESY Dark Freezer Lab



MSU Dark Freezer Lab

WBS 1.3.1: mDOM PMT Dark Count Rates

- It was discovered that the dark count rate of mDOM PMTs increases significantly for serial numbers > 1130 (*)
- Increase is caused by highly time-correlated noise and is only observable at low temperature
- Root cause analysis by Hamamatsu identified radioactive contamination of the PMT glass in a newly introduced melting furnace
- All screened PMTs across the full production exceed the dark rate specification of < 150 Hz at −20°C



- Replacing the PMTs has prohibitively long lead time of 2 yrs before production start at the manufacturer
- Detailed studies resulted in reasonable mitigation strategies for the increased data rate and predict only minor impacts on physics performance
- It was decided to start mDOM production with the available high-dark rate-PMTs
- Remaining risks are tracked in the risk register: TECH45, TECH48, TECH49

(*)10,700 PMTs have been produced for the mDOM

WBS 1.3.2: D-Egg Technical Status

- Final Design Review passed in Feb. 2020
- All 310 D-Eggs have been integrated
- Final Acceptance Testing (FAT) pending
  - Each module will be operated in the cold for three weeks during FAT before shipping to Antarctica
  - D-Egg FAT is a first system integration test, including communications, DAQ, and timing system
  - Progress is slowed down by COVID travel restrictions
  - We are establishing a project-wide effort to support the D-Egg team to start final acceptance testing as quickly as possible

D-Egg Integration

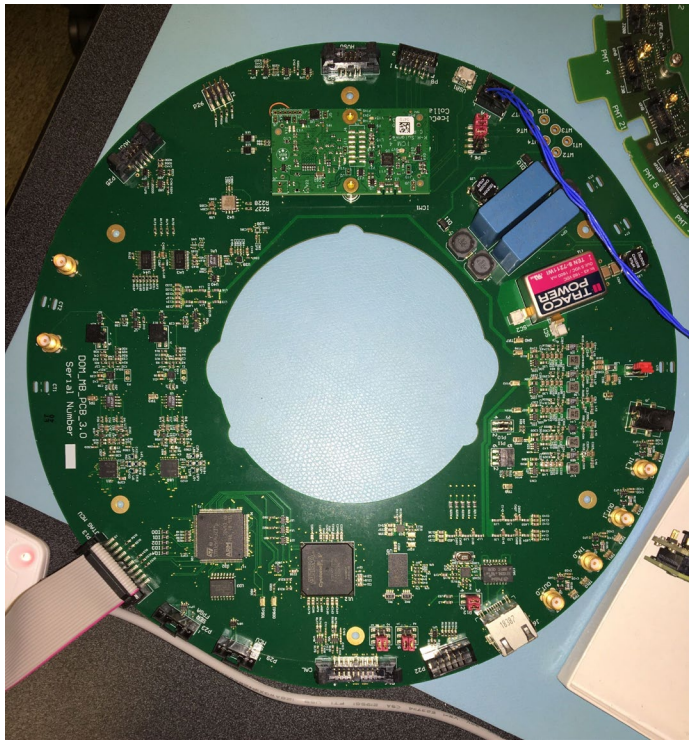
D-Egg FAT box w/ camera test pattern

Chiba Dark Freezer Lab

WBS 1.3.3: PDOM Technical Status

- PDOMs are Gen1 IceCube DOMs refurbished with modern electronics
  - Improve cross calibration between IceCube and the Upgrade
- Synergies used with D-Egg development
  - PDOM and D-Egg Mainboards use the same schematics
  - Expedited D-Egg development
- PDOM prototype mainboards built and comissioned
- Gen1 facilities will be used for IceCube DOM refurbishment

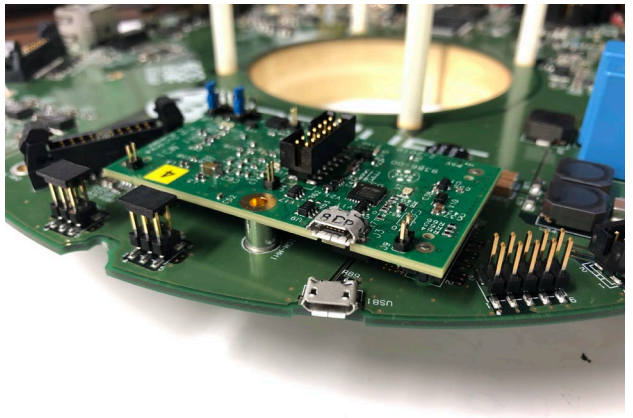
PDOM prototype mainboard in remote test system



WBS 1.3.4: Ice Comms Module (ICM) Technical Status

- ICM is the common interface in all Upgrade devices: DOMs, special devices, stand-alone calibration devices
- All ICMs have been produced and delivered for D-Egg integration and development and production of all devices
- ICM “Golden Image” firmware cannot be changed after installation
  - must enable communication and uploading of new firmware at all times
  - significant design, implementation, and testing effort on-award (WIPAC)

ICM mounted on D-Egg mainboard

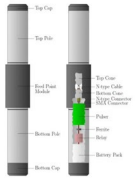


WBS 1.3.5: Special Devices Overview

Wavelength-shifting Optical Module R&D Sensor
PDR passed 2021-12-10

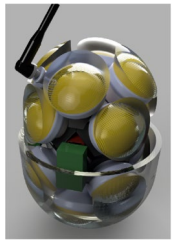
Fiber-Optic Module R&D Sensor

DM-Ice Dark Matter Detector



Radio Pulser
PDR passed 2021-09-02

Radio Receiver



eLongated Optical Module
(Gen2 Prototype Sensor)
PDR passed 2021-12-14

Very Broadband Seismograph — CR pending

String	87	88	89	90	91	92	93	TOTAL
mDOM	59	57	57	53	60	58	58	402
DEgg	39	41	40	38	40	39	40	277
pDOM	1	1	2	1	2	4	3	14
WOM	4	4	0	4	0	1	1	14
FOM	2	1	1	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	1	0	1	0	0	0	2
RP	0	1	1	1	0	0	1	4
RR	1	0	0	0	0	2	0	3
AH	0	0	1	1	0	0	0	2
LOM	0	1	2	1	3	3	2	12
AM	2	1	2	1	1	1	2	10
FTS	0	0	0	6	6	0	0	12
SWE	1	1	0	1	0	1	1	5

- All instrumentation provided in-kind by collaborators
- Reviews
  - 2022 Preliminary Design Reviews for individual devices
  - 2023 Final Design Reviews for individual devices
  - 2024 Deployment Readiness Reviews for individual devices

Backup Material

WBS 1.3.4: ICM “Golden Image” Design Verification & Review

- Golden Image Design Review (March 2021) passed
- Communication test setup with 2.8 km of Hexatronic triplet connected to 4 D-Egg Mainboards in a freezer
- Selected test results:

FR3-B: In-ice reboot: PCR 10.2

Test Goal

Confirm that devices can reliably be booted into another firmware remotely regardless of termination setting on the string.

Success/Failure

Temperature		DESY			
	Termination	0,0,1,1	1,0,1,1	0,1,1,1	1,1,1,1
-25C	Runs	60	60	60	60
	failures	0	0	0	0
-36 → -27 C	Runs	60	60	60	60
	failures	0	0	0	0

Test Procedure

Run preparation (common):
1. Power cycle wire pair
2. Read register state of in-ice devices
3. Check relevant register values
   1. Firmware version
   2. Gold image vs runtime image
   3. FPGA temperature
   4. Termination setting

Verification section:
1. Issue reboot command into runtime image
2. Check relevant register values:
   1. Firmware version
   2. Golden image ID
3. Confirm device booted into new image
4. Reboot to golden image

Statistics:
- Repeat for all devices on WP: 3
- Repeat test for all accessible te
- Re

Typical Flash occupancy during tests:

memory ID	0	1	2	3	4	5	6
Firmware rev	21.2.10	21.2.11	21.2.10	21.2.10	21.2.10	21.2.10	21.2.10
Image indicator	0x2	0x1	0x200	0x300	0x400	0x500	0x600
		Under test					

FR3-E: Bit error rate

Test Goal

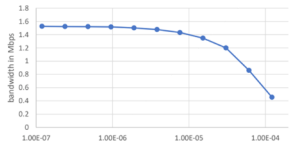
1. Confirm that raw (uncorrected) bit error rate is below $1x10^{-10}$/b on the wire pair.
2. Check CRC performance under various string bit error rates

Results

Raw Error Rate
Success: CRC error count is 0 and all data is transmitted

Injected Error Tests
Success:
- Dropped packet count is 0 and all data is transmitted up to extremely high error rates
- Bnadwidth requirement can be maintained up to an injected rate of 8E-6 /b

DESY setup (2.8km cable)
No packets dropped up to $6.1x10^{-5}$ /b



DRTS setup (short cable)
No packets dropped up to $3.1x10^{-5}$/b

Test Procedure

Verification section:
1. Set BER injection rate on MFH (during MFH RX):
2. Read status registers of devices before and after test
   1. Use STF bandwidth test to transfer 12Gb of data from in-ice device (for **goal 1**)
   2. Use STF bandwidth test to transfer 40Mb of data fro device (for **goal 2**)
3. Confirm that the CRC error count is 0

FR3-C: In-ice flash rewriting: PCR 10.3

Test Goal

Confirm that firmware images can be successfully written to all devices, regardless of termination setting on the string.

Success/Failure

Tempe rature		DESY			
	Termination	0,0,1,1	1,0,1,1	0,1,1,1	1,1,1,1
-25C	Runs	18	18	18	18
	failures	0	0	0	0

Test Procedure

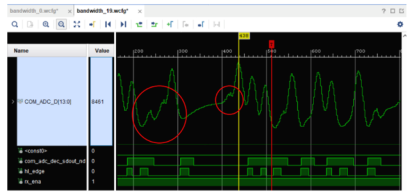
Verification section:
1. Delete all runtime images
2. Write runtime image to memory ID 2 – 7
3. Reboot into written image
4. Check relevant register values to confirm reboot:
   - Firmware version
   - Gold image vs runtime image ID
5. Reboot back to golden image

Statistics:
- Repeat tes for all devices: 3
- Write into all 6 memory IDs
- Repeat test for all termination settings: 4
- Total run-count: 72

Additional notes:
- Writing one image takes ~25 seconds
- Average data rate: 500kb/s due to small packets

Crosstalk measurements

Crosstalk test
- Data amplitude: 2000 DAC counts
- Perform STF bandwidth test: sending 5MB from in-ice device to MFH
- Increase disturbance amplitude until comms break to find breaking point
- Then test the two levels near the breaking point with higher statistics
- NOTE: Failure occurs abruptly
- Basic assumption: DAC counts can be directly related → calibrate with reference measurements

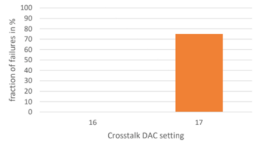


Acceptable crosstalk levels are:
- DAC=16 for WP0: 8.5 +/- 2mVpp
- DAC=18 for WP1: 9.3 +/- 2mVpp

The data input level is: 2000DAC: 1142mVpp

Ratio:
- WP0: -42.6dB → -45dB (including error)
- WP1: -41.8dB → -44dB (including error)

WP0 failure rate (dev 7),
8 tests at each level



IceCube Upgrade

WBS 1.3: On-Award Cost

	PY1-PY4	PY5-PY8	Total
Baseline	$1,174,963	$155,778	$1,330,741
Current/Actual	$71,262 (PY4 est.)	$218,668	$289,930

- Major non-COVID contributions to cost difference
  - ($756,956) cost-neutral transfer of firmware work packages from WBS 1.3 to 1.6 (Change Request #27)
  - ($236,960) cost reduction due to reducing the number of PDOMs from 120 to 20 (Change Request #1)
- Major COVID-affected elements
  - Development and production have been delayed due to COVID

WBS 1.3: Off-Award Cost

- Cost and cost risk are tracked by in-kind partners
  → only rough estimates available here

- Majority of WBS 1.3 are in-kind contributions
  - mDOM ~$5.6M from German collaborators, not including production facilities at DESY and MSU and labor for development, integration, and testing
  - D-Egg ~$2.7M from Japanese collaborators, not including production facilities and labor for development and testing
  - ICM $130k from DESY, not including labor development, production, and testing
  - Special Devices contributed in-kind from various collaborators

WBS 1.3: Risks

Major risks that have been discussed in plenary session

Risk Identification and Tracking			Revision History			Pre-Mitigated Risk Evaluation							Current Risk Response					Major Risk Flag
						Probability and Impacts				Exposure								
Risk ID	Associated WBS	Risk Description	Risk Title	Risk Origin Date	Last modified Date	Risk Retirement Date	Risk Probability	Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score	Risk Owner	Risk Occurrence Timeframe	Risk Handling Approach / Response	Risk Trigger	Risk Mitigation Plan and Actions	
TECH31	1.3	If one of the planned sensor types does not pass FDR as scheduled the project schedule could be severely disrupted	OM FDR	8/13/2018			Low	High	Moderate	Low	Moderate	Moderate	Low	OM Lead	Until FDR, April 2022	Mitigate	FDR fails	Design and plan the production capacity of all production facilities with sufficient flexibility to be able to fall back to a different OM type	
TECH32	1.3.1	If bubbles remain in the mDOM Optical Gel, the optical sensitivity of the mDOM might worse than expected	mDOM Bubbles		1/27/2022		Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	mDOM Lead	Until FDR, April 2022	Mitigate	Design does not meet requirements	Optimize surface of support structure (use MJF, chemically smoothing, remove sharp edges) Implement bubbles in simulations and investigate impact on physics Gel-pad mDOM: Will delay the start of series production by several months	
EXT9	1.3.1	If electronics parts for the mDOM Mainboard cannot be procured in time, the mDOM production and testing will be delayed	mDOM Electronics Supply Chain		1/27/2022		High	Moderate	Low	Low	High	Moderate	Moderate	OM Lead	Until procurement	Mitigate	External	Continuously monitor market throughout collaboration and centrally collect information of availability of critical components Place orders / publish calls for tender as early as possible Develop plans for series integration of half-mDOMs, add in mainboards as late as possible	
EXT10	1.3.1	If suppliers don't have sufficient capacity to 3D-print mDOM PMT Support Structures, the mDOM production and testing will be delayed	mDOM Support Structure Supply Chain		1/27/2022		Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	OM Lead	Until procurement	Mitigate	External	Foresee production of PMT Support Structures in several batches that can be tendered to different manufacturers	
TECH33	1.3.1	If mDOM series production does not reach the projected rate of 9 mDOMs / site / week, the shipping date for the mDOMs for Strings 87+88 will be missed	mDOM Production Yield		1/27/2022		Low	Moderate	Low	Low	Moderate	Low	Low	mDOM Lead	Until OM shipping	Mitigate	Technical problems	Produce mDOM test batches at DESY and MSU as early as possible to excercise integration and FAT procedures see also risk ORG5	
EXT11	1.3	If integrated sensors have to be stored for too long before deployment, the vacuum seal might leak and re-sealing might become necessary	Sensor Long-Term Storage		1/27/2022		Low	High	Low	Low	Moderate	Low	Low	OM Lead	Until deployment	Mitigate		Regularly monitor the inside pressure of a sample of stored sensors Store sensors such that they are accessible for monitoring (not McM?)	
TECH34	1.3.2	If during D-Egg FAT a high failure rate or design flaw is found, reworking D-Eggs will lead to significant cost and schedule slippage	D-Egg FAT Yield		1/27/2022		Low	Low	Low	Moderate	Low	Low	Moderate	D-Egg Lead	Until FAT	Mitigate		Commence D-Egg FAT as early as possible Work closely with D-Egg team on executing and interpreting FAT	
EXT12	1.3.5	If one of the Special Devices is not delivered, the string design must be updated and verified	Special Device Cancellation	1/15/2022	1/27/2022		Very High	Low	Low	Very low	Moderate	Moderate	Moderate	OM Lead, Deployment Lead	Until deployment readiness review	Mitigate		Start early developing contingency plans how to replace or bypass missing Special Devices during deployment	
TECH35	1.3.3	Because PDOM pressure vessels are re-furbished from Gen1, handling and resealing with new PCA may introduce subtle flaws that could cause PV flooding after deployment.	PDOM PV leak	1/15/2022	1/27/2022		Low	Moderate	Moderate	Low	Moderate	Moderate	Low	PDOM Lead	Until after freeze-in	Mitigate	No comms with deployed PDOM	Inspection of sealing surfaces, comparison of Gen1 and Gen2 PCA sealing surfaces, High Pressure testing.	
EXT18	1.3.1	If mDOM planned main board electronics parts remain unavailable, a few mainboard redesign will be required: this includes hardware design effort (off of the NSF budget) and software & firmware effort (on NSF budget).	mDOM redesign	4/6/2022	4/6/2022		High	Moderate	High	Low	High	High	Moderate	mDOM lead	Calendar 2022	Mitigate	Parts delivery delays/unavailable parts	Begin planning and design work ahead of risk trigger on the new mainboard design	
TECH36	1.3	Because NPX is very dry, sensor electronics could be damaged by ESD during NPX testing or deployment	xDOM Electronics ESD Damage	1/15/2022	1/27/2022		Low	Low	Moderate	Low	Low	Moderate	Low	OM Lead, Deployment Lead	Until deployment	Mitigate	Modules failures, procedure errors during deployment	Employ appropriate internal ESD protection circuitry in the xDOM and ICM. Ensure that ESD mitigation is used on floors, people, and equipment at NPX. Ensure charge neutralization is emplloyed by procedure and equipment during NPX testing. Ensure that charge neutralization is present between electrical cables, TOS and xDOMs as they are being deployed.	

WBS 1.3: L2 Milestones

- mDOM
  - April 2022 mDOM Final Design Review
  - Aug. 2022 mDOM Production Readiness Review (DESY site; after integration and testing of first 20 modules at DESY)
  - Oct. 2022 mDOM Production Readiness Review (MSU site; after integration and testing of first 20 modules at MSU)
  - Nov. 2022 All components for mDOM Mainboard full production available
  - May 2023 128 mDOMs for Strings 87-88 ready to ship from DESY to CHC
  - Aug. 2023 96 mDOMs for Strings 89-93 ready to ship from DESY to CHC
  - Sept. 2023 200 mDOMs for Strings 89-93 ready to ship from MSU to Pt. Hueneme
- D-Egg
  - July 2022 78 + 18 spares D-Eggs for Strings 87-88 ready to ship from Chiba to CHC
  - May 2023 197 + 11 spare D-Eggs for Strings 89-93 ready to ship from Chiba to CHC
- PDOM
  - Sept. 2022 PDOM Final Design Review
  - Jan. 2023 14 + 6 spare PDOMs ready to ship from PSL to Pt. Hueneme