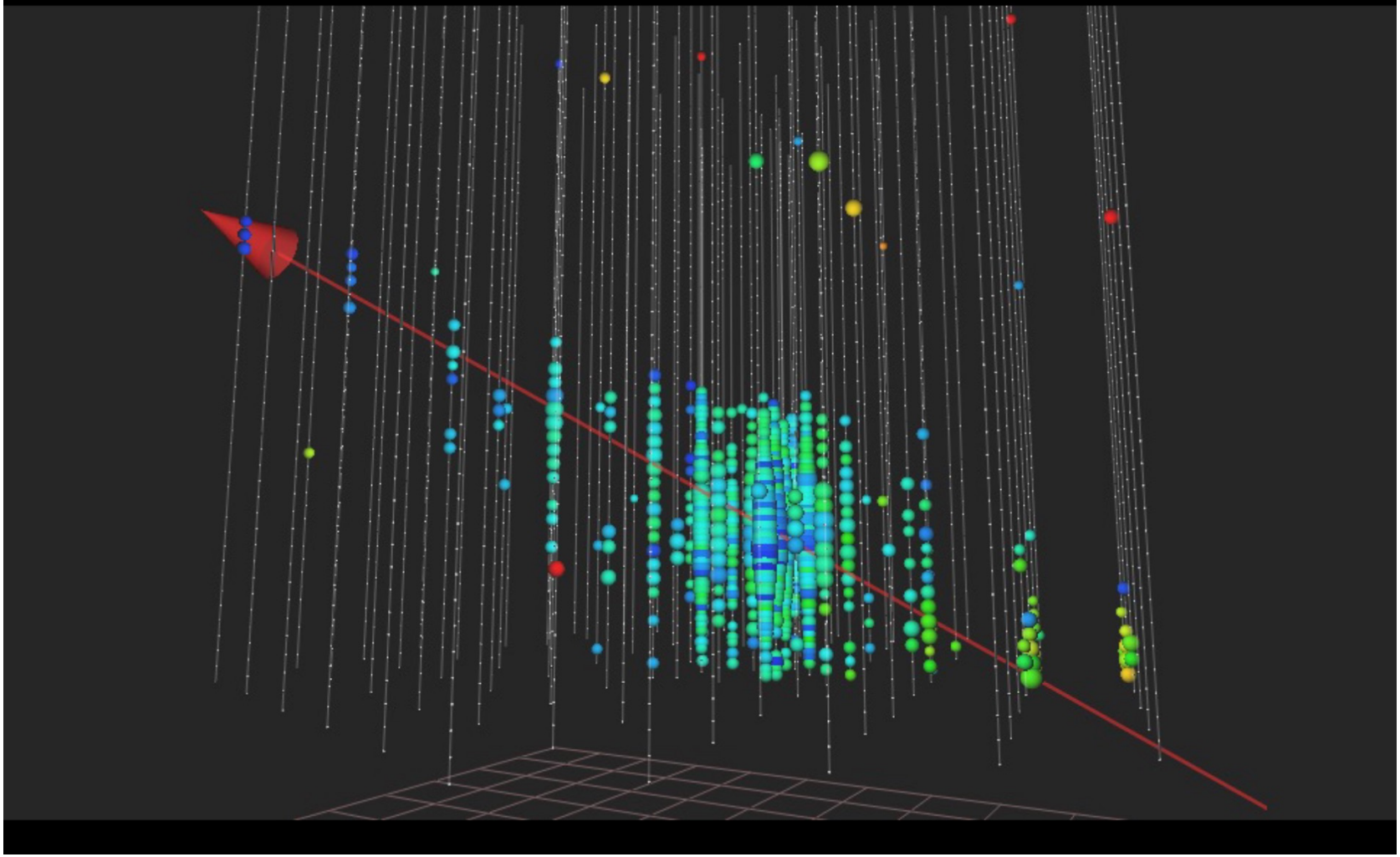
IceCube Upgrade

Mike DuVernois

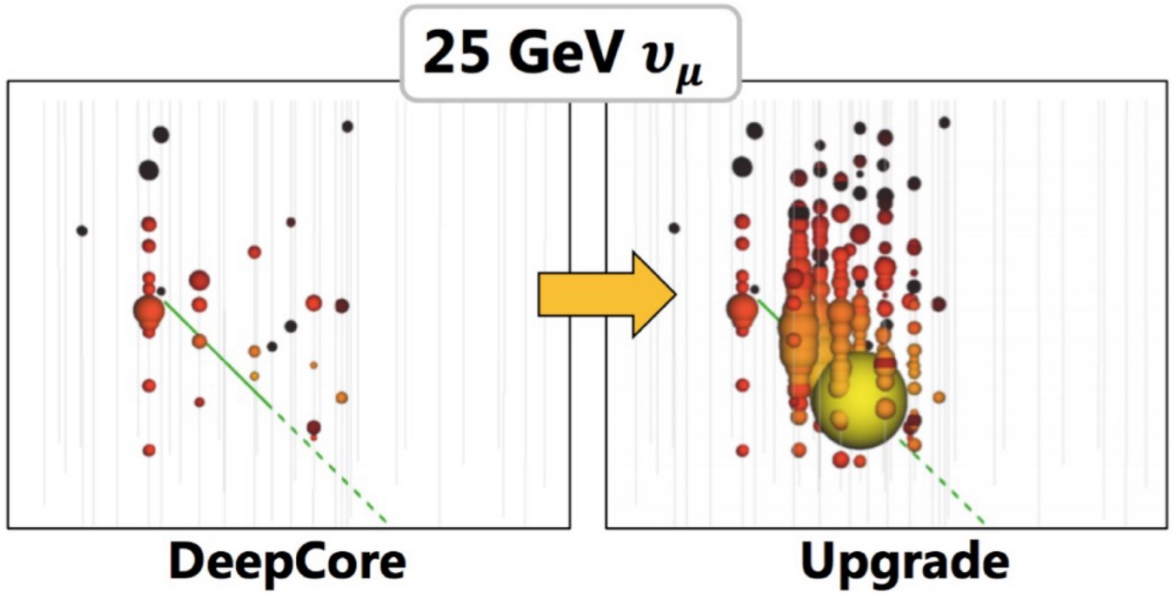
IceCube Upgrade (& Gen2) Technical Coordinator

Science

IceCube and DeepCore



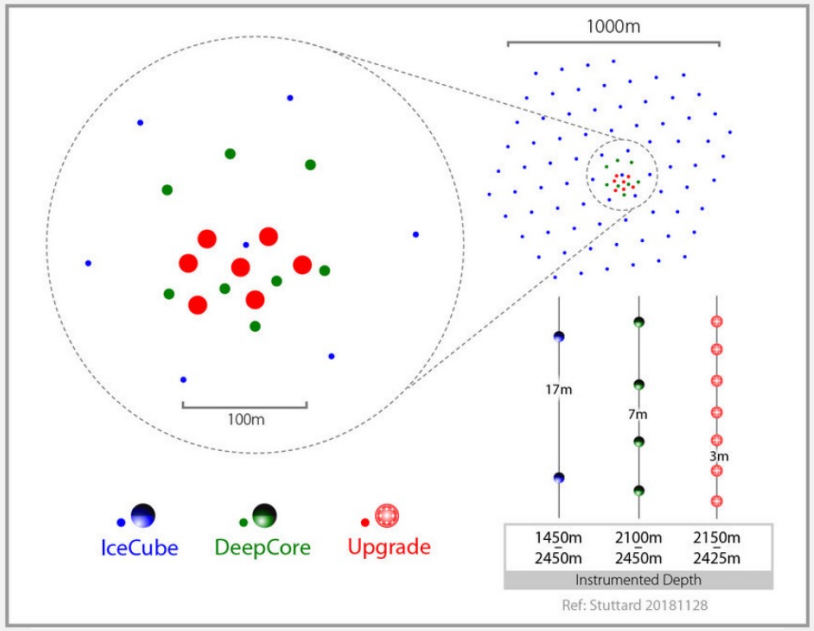
Low energy neutrinos in the Upgrade



IceCube Overview

- IceCube
  - DeepCore
  - IceTop

  } Done & Delivering
- Upgrade } Underway
- IceCube-Gen2
  - Full } Astro2020 Review Preliminary Design in Preparation



- 10 megaton volume
- string spacing : 125m → 35m → 22m
- module spacing: 17m → 7m → 3 m

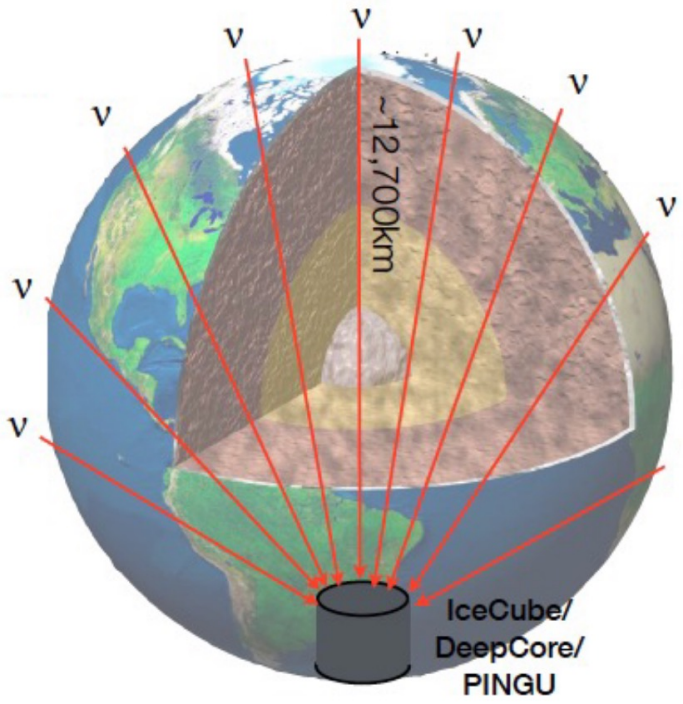
Next step: the IceCube upgrade

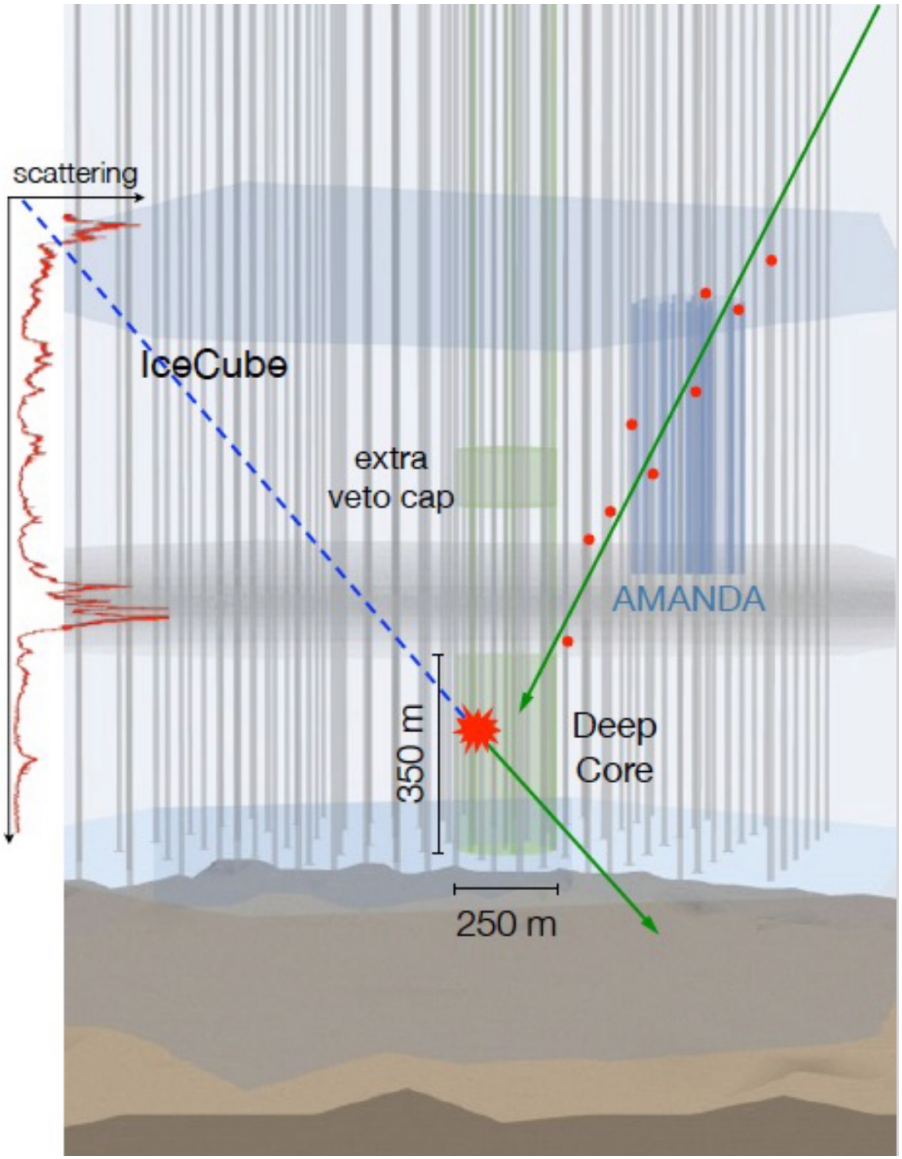
- improve the scientific capabilities of IceCube at low energies
- improve the scientific capabilities of IceCube at high energies with improved optics of the ice using the information obtained with the Upgrade's small string spacings and novel calibration devices

- one million atmospheric neutrinos
- 10 megaton
- at analysis level:

DeepCore: one every 15 min

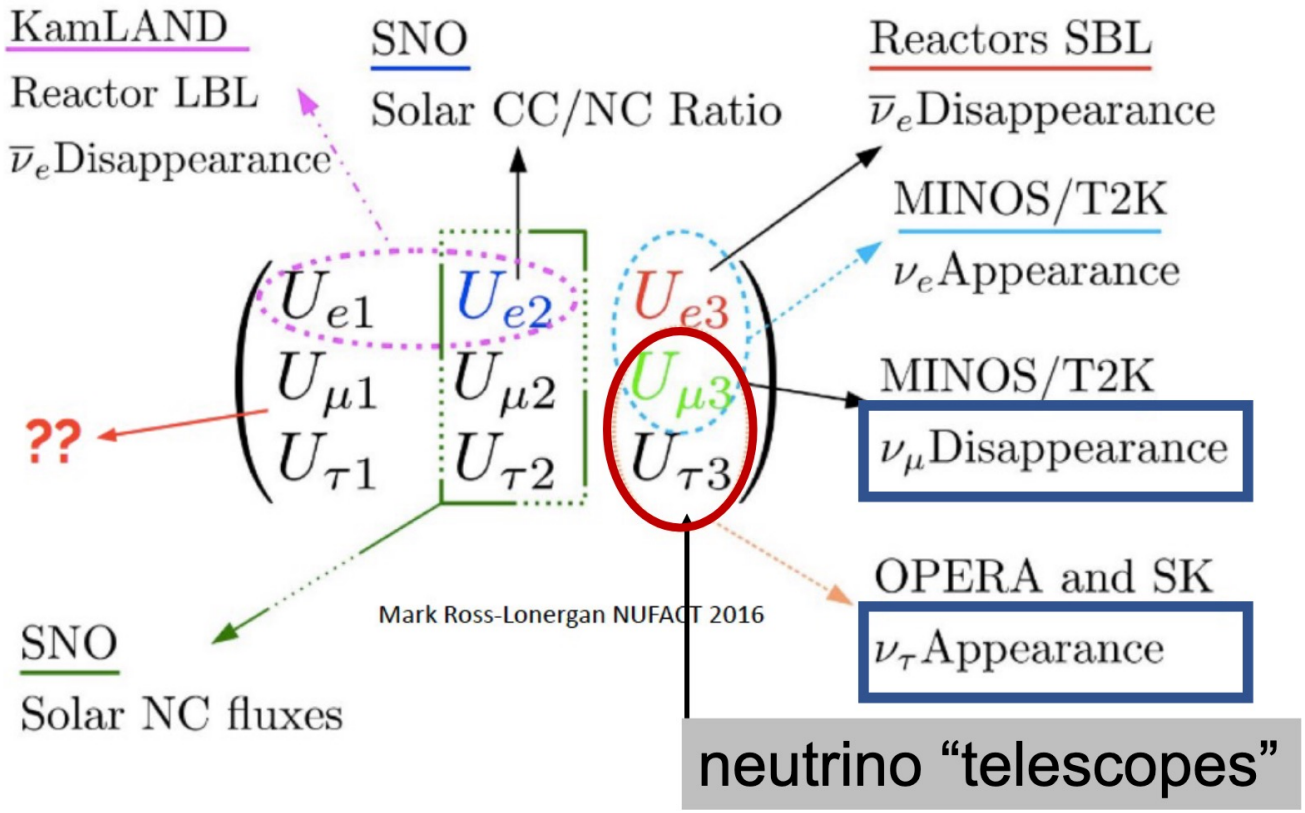
Upgrade: one every 4 min





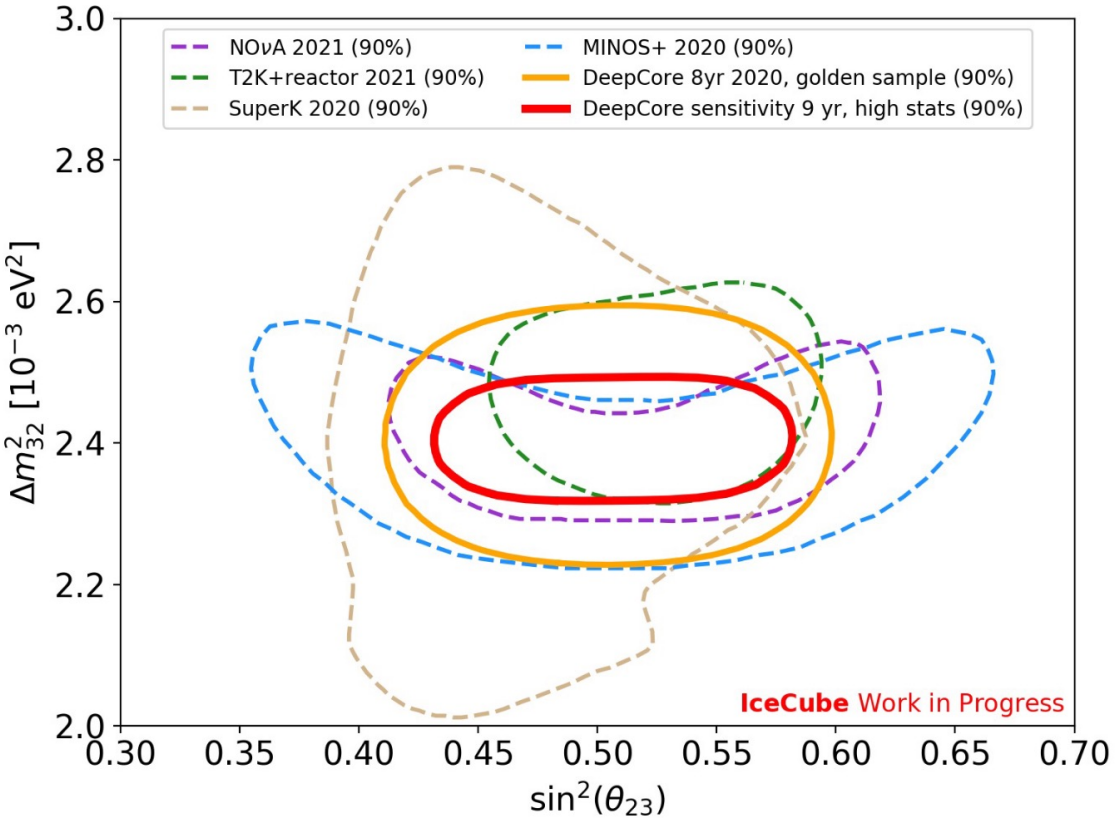
neutrino oscillations with a neutrino telescope:
access to tau neutrinos in the atmospheric (and cosmic beam)

The PMNS mixing matrix



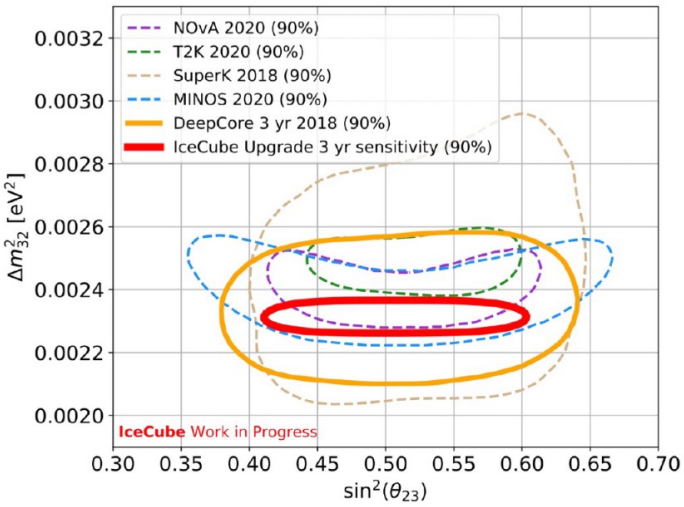
imminent unblinding:

- analysis with a sample of 210,000 neutrinos (9.3 years and 97.3% purity)
- higher energy than accelerator experiments and SuperK (5~55 GeV)
- 6900 tau neutrinos
- improved calibration of the data, event reconstruction using machine learning and new treatment of systematics



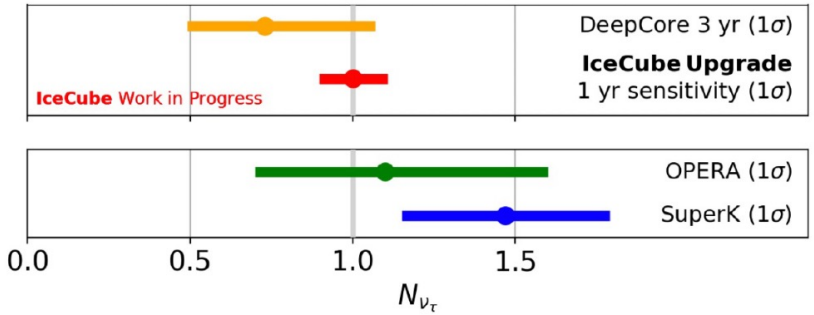
… and with the Upgrade

Atmospheric oscillation parameters



Strong sensitivity in 3 yrs or less

ν_τ normalisation

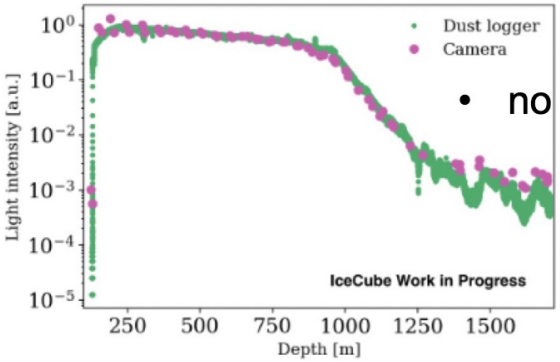


10% ν_τ norm in 1 yr
(6% in 3 yrs)

… and the improvements implemented between the 3 and 9.3-year DeepCore analyses have not been applied !

ice: step by step

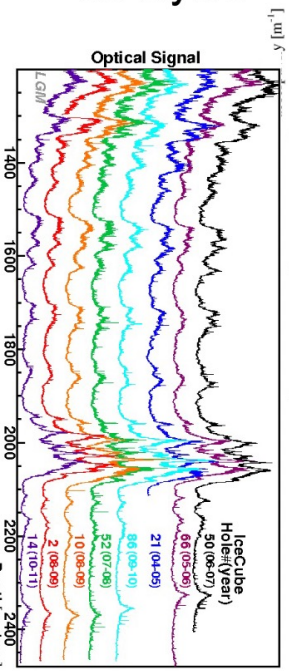
- hole ice ?

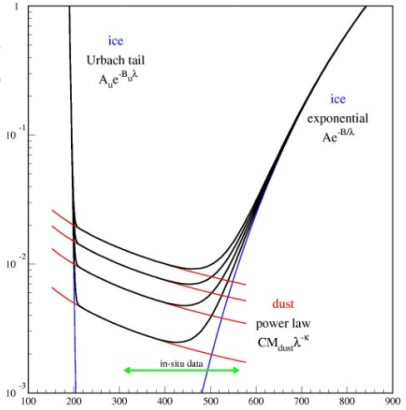


- no air bubbles/hydrates below 1350 m

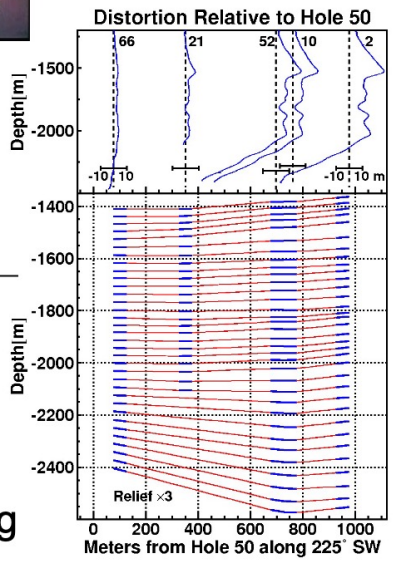
- > 100 m absorption length limited by dust

- ice layers

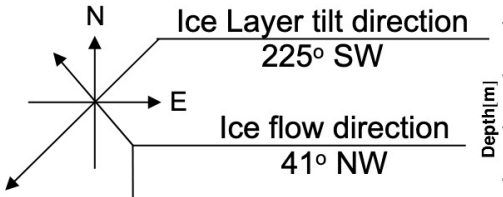




- tilted ice layers

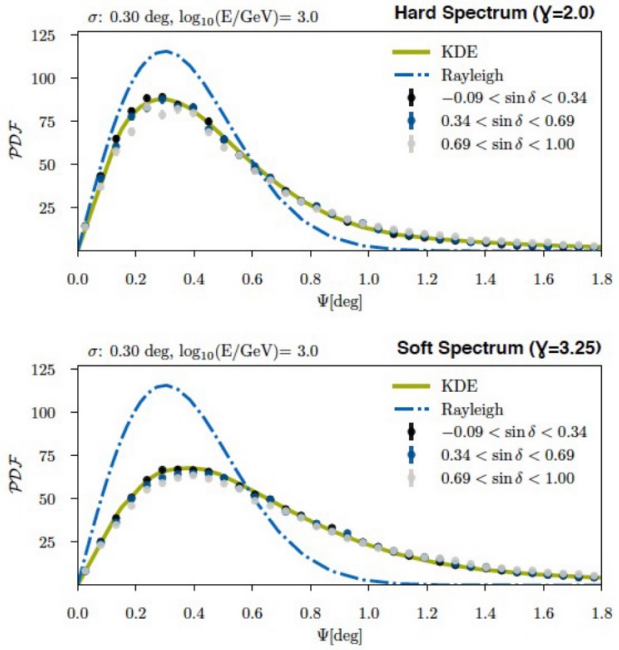


- birefringence



- anisotropy
~8% less scattering
41° NW

- improved detector calibration (pass 2)
- improved modeling of the optics of the ice
- DNN (energy) and BDT (pointing) reconstruction
- point spread function consistent with simulation
- insensitive to systematics

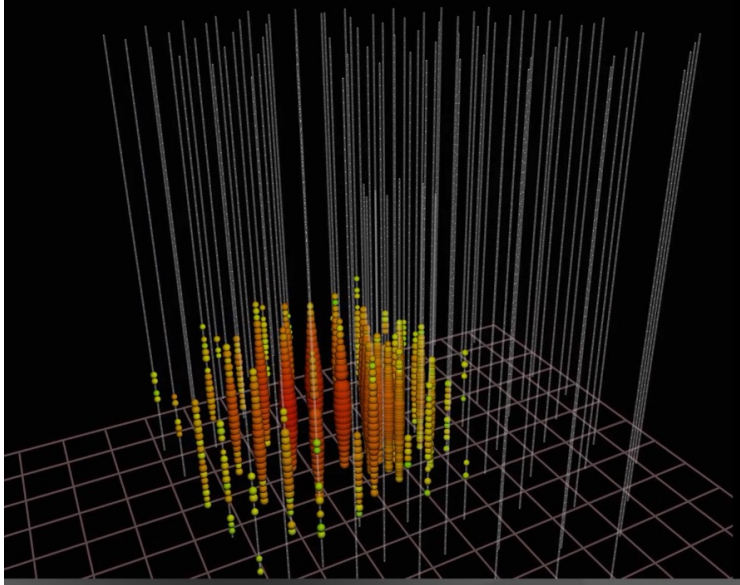


- Rayleigh (1D-projection of 2D Gauss) doesn't describe our Monte Carlo accurately → Tails are suppressed
- The distribution depends on the spectral index!
- Effect mainly visible at < 10 TeV energies where the kinematic angle between neutrino and muon matters
- **Solution:** Obtain a numerical representation of the γ-dependent spatial term from MC simulation (for example using KDEs)

$$\frac{1}{2\pi\sigma^2} e^{-\frac{\psi^2}{2\sigma^2}} \rightarrow \mathcal{S}\left(\psi \,|\, \sigma,\, E_\mu,\, \gamma\right)$$

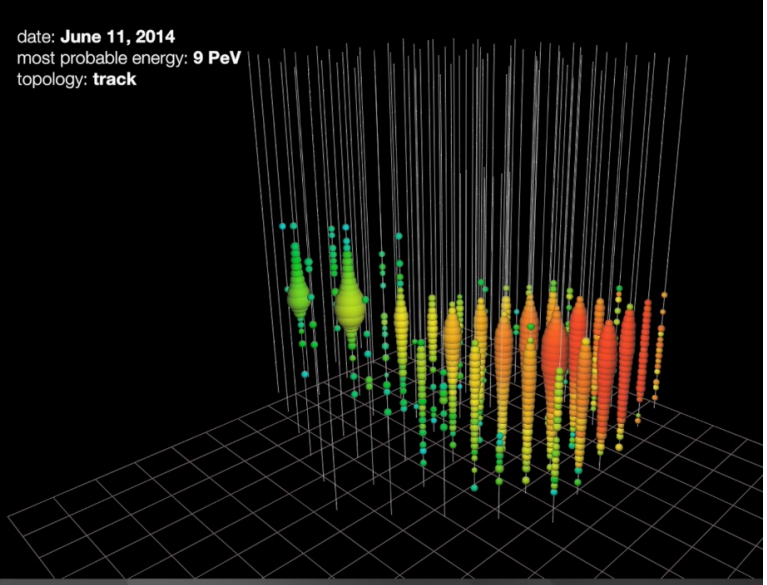
very soon!

neutrinos interacting
inside the detector



superior total energy
measurement
to 10%, all flavors, all sky

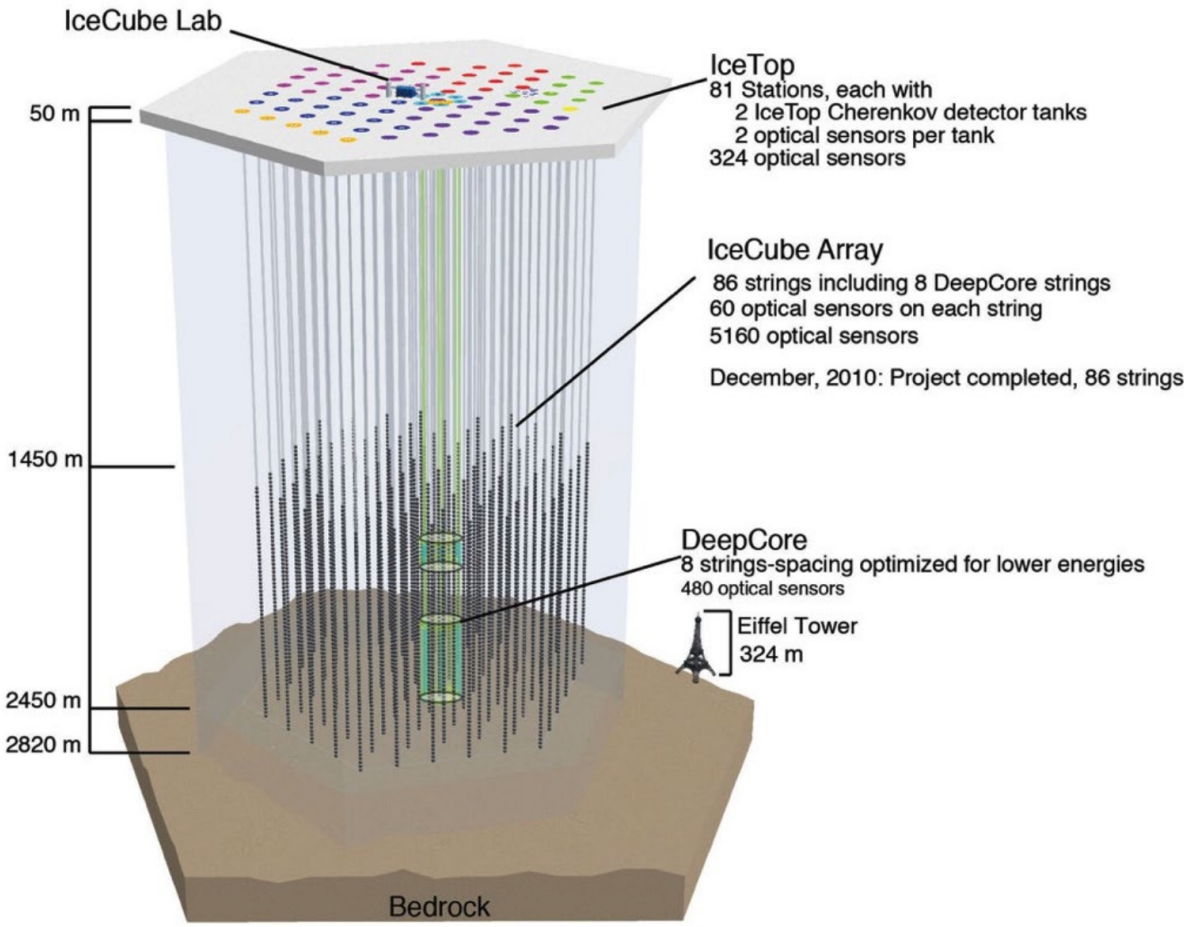
muon neutrinos
filtered by the Earth



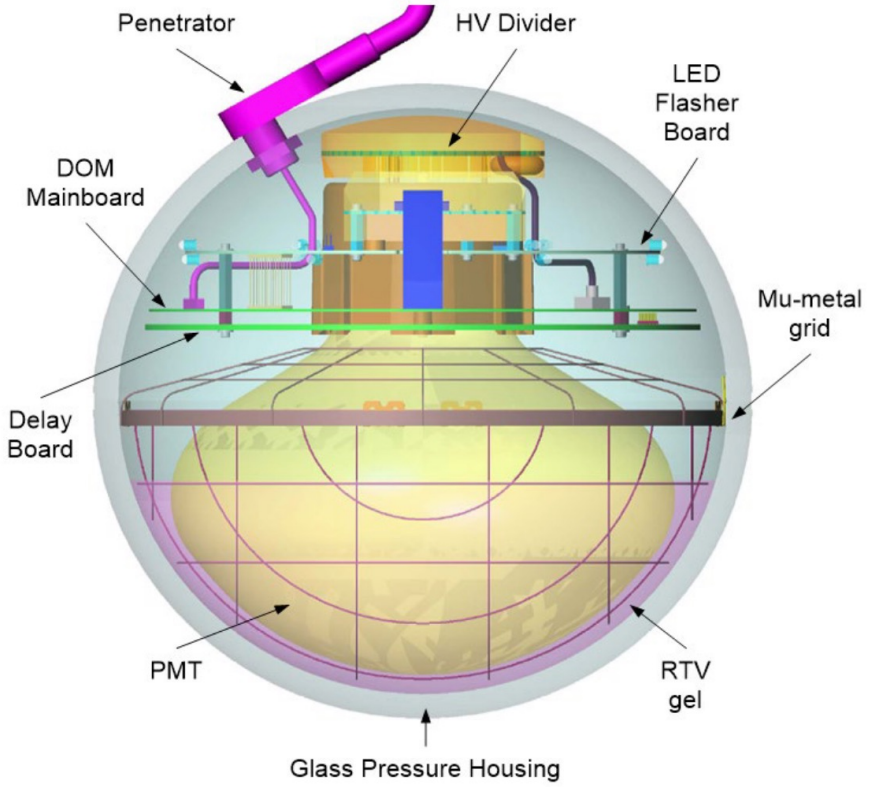
astronomy: superior
angular resolution
superior (< 0.3^{o})

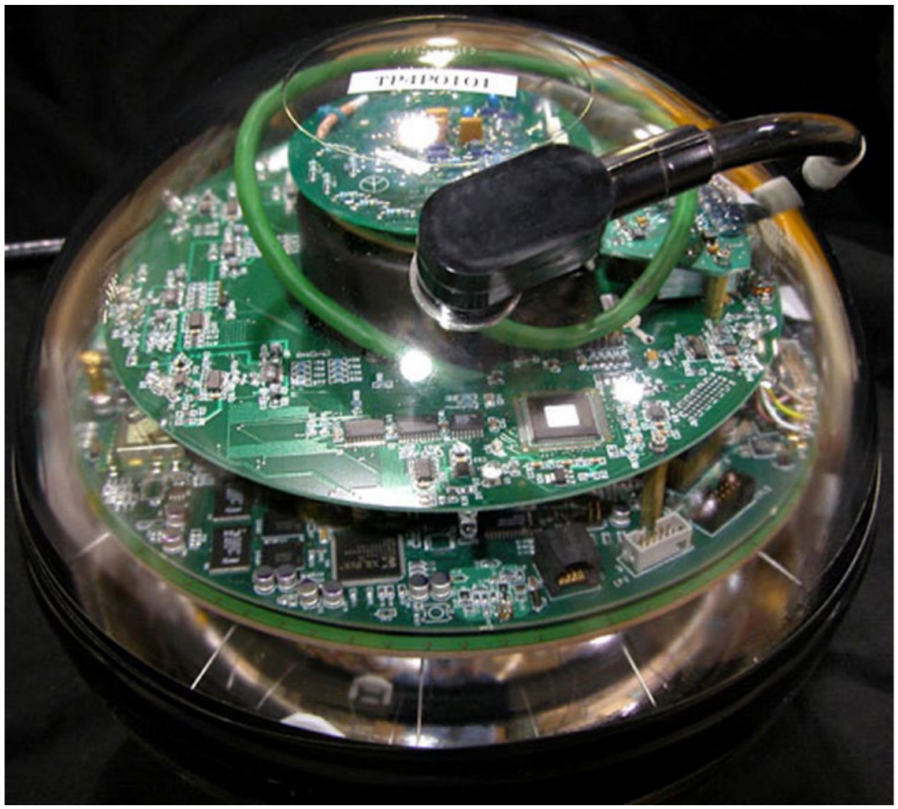
Detector & Installation

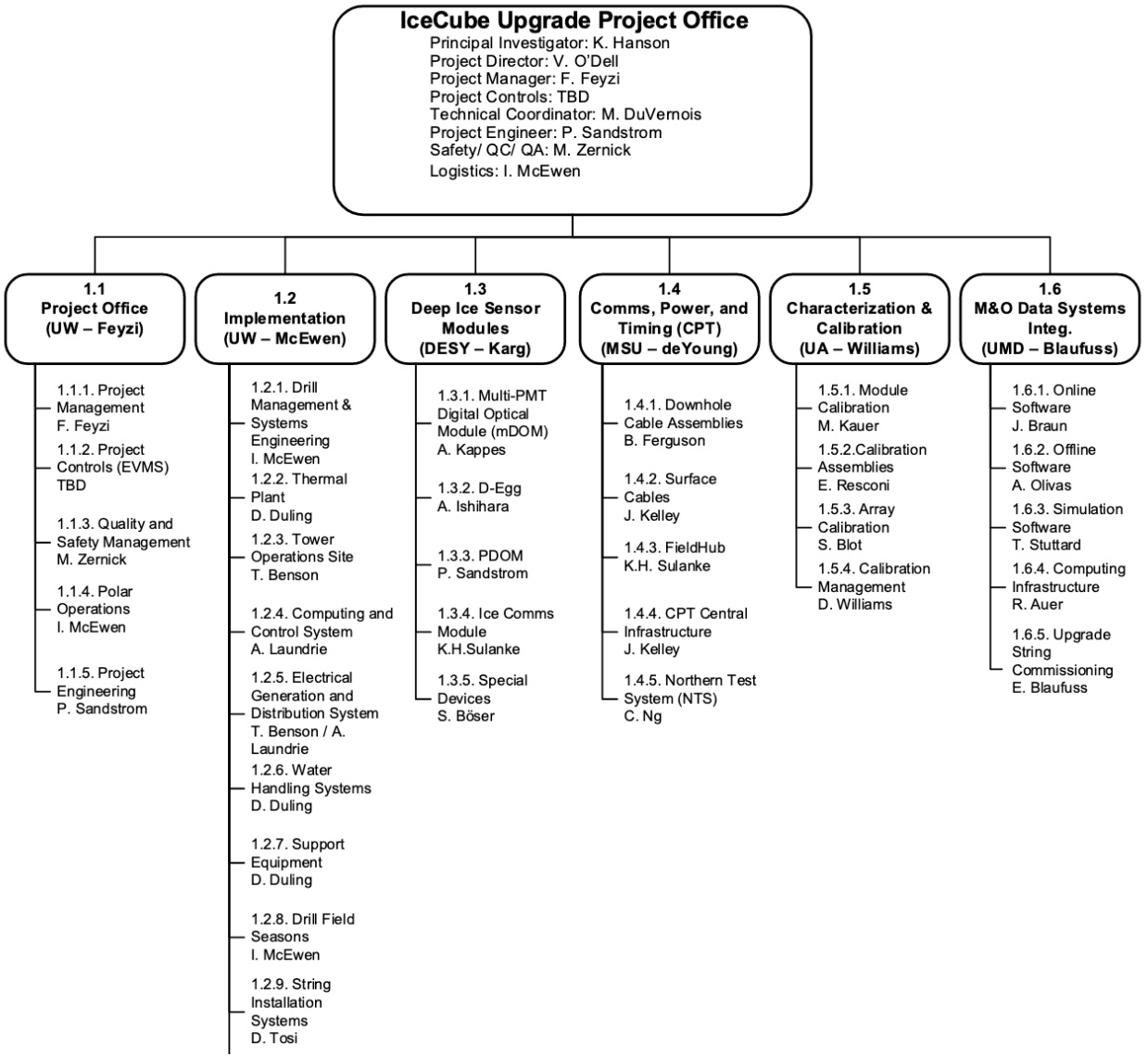
IceCube: The Detector Array

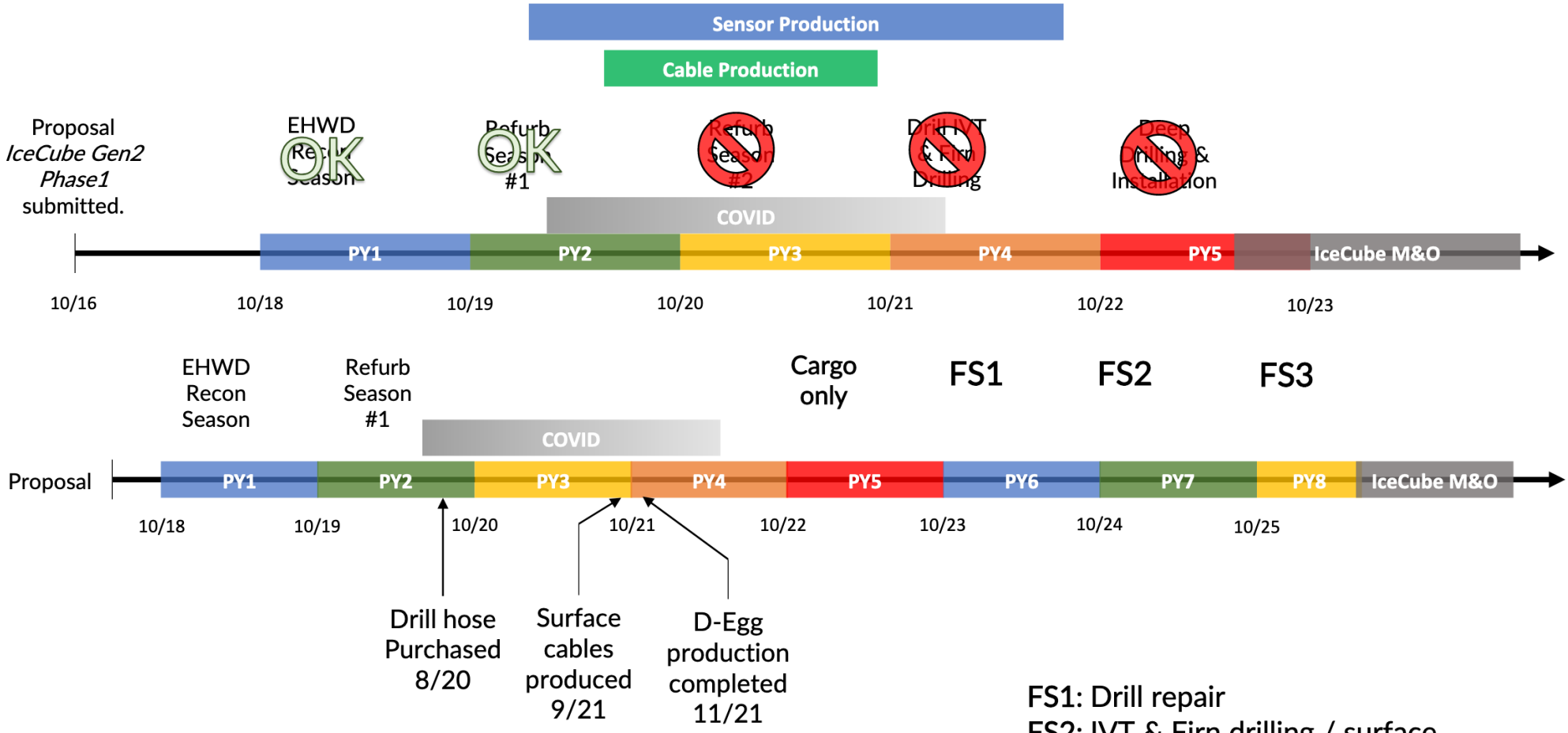


IceCube Detector Element: The Digital Optical Module

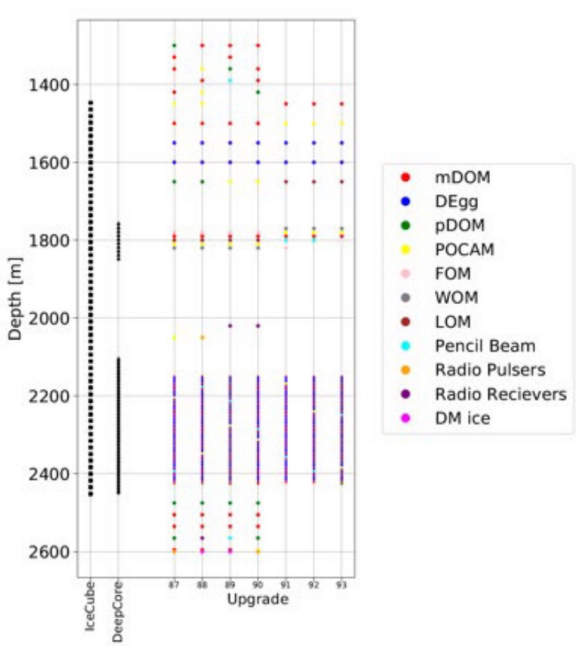


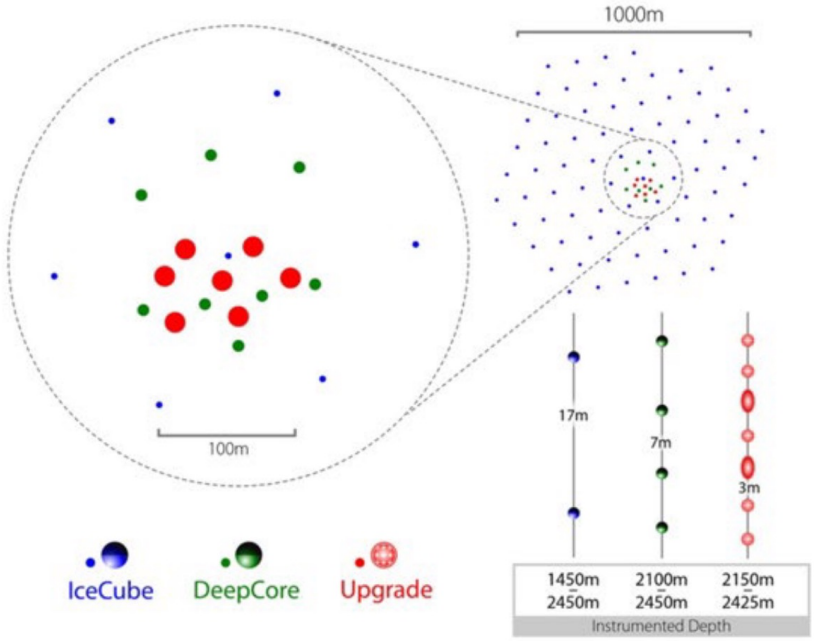



IceCube Upgrade Project Office
Principal Investigator: K. Hanson
Project Director: V. O'Dell
Project Manager: F. Feyzi
Project Controls: TBD
Technical Coordinator: M. DuVernois
Project Engineer: P. Sandstrom
Safety/ QC/ QA: M. Zernick
Logistics: I. McEwen
1.1 Project Office (UW – Feyzi)
1.1.1. Project Management F. Feyzi
1.1.2. Project Controls (EVMS) TBD
1.1.3. Quality and Safety Management M. Zernick
1.1.4. Polar Operations I. McEwen
1.1.5. Project Engineering P. Sandstrom
1.2 Implementation (UW – McEwen)
1.2.1. Drill Management & Systems Engineering I. McEwen
1.2.2. Thermal Plant D. Duling
1.2.3. Tower Operations Site T. Benson
1.2.4. Computing and Control System A. Laundrie
1.2.5. Electrical Generation and Distribution System T. Benson / A. Laundrie
1.2.6. Water Handling Systems D. Duling
1.2.7. Support Equipment D. Duling
1.2.8. Drill Field Seasons I. McEwen
1.2.9. String Installation Systems D. Tosi
1.3 Deep Ice Sensor Modules (DESY – Karg)
1.3.1. Multi-PMT Digital Optical Module (mDOM) A. Kappes
1.3.2. D-Egg A. Ishihara
1.3.3. PDOM P. Sandstrom
1.3.4. Ice Comms Module K.H.Sulanke
1.3.5. Special Devices S. Böser
1.4 Comms, Power, and Timing (CPT) (MSU – deYoung)
1.4.1. Downhole Cable Assemblies B. Ferguson
1.4.2. Surface Cables J. Kelley
1.4.3. FieldHub K.H. Sulanke
1.4.4. CPT Central Infrastructure J. Kelley
1.4.5. Northern Test System (NTS) C. Ng
1.5 Characterization & Calibration (UA – Williams)
1.5.1. Module Calibration M. Kauer
1.5.2.Calibration Assemblies E. Resconi
1.5.3. Array Calibration S. Blot
1.5.4. Calibration Management D. Williams
1.6 M&O Data Systems Integ. (UMD – Blaufuss)
1.6.1. Online Software J. Braun
1.6.2. Offline Software A. Olivas
1.6.3. Simulation Software T. Stuttard
1.6.4. Computing Infrastructure R. Auer
1.6.5. Upgrade String Commissioning E. Blaufuss



FS1: Drill repair
FS2: IVT & Firn drilling / surface
FS3: Deep drilling & installation





7 strings - 693 Optical sensors:

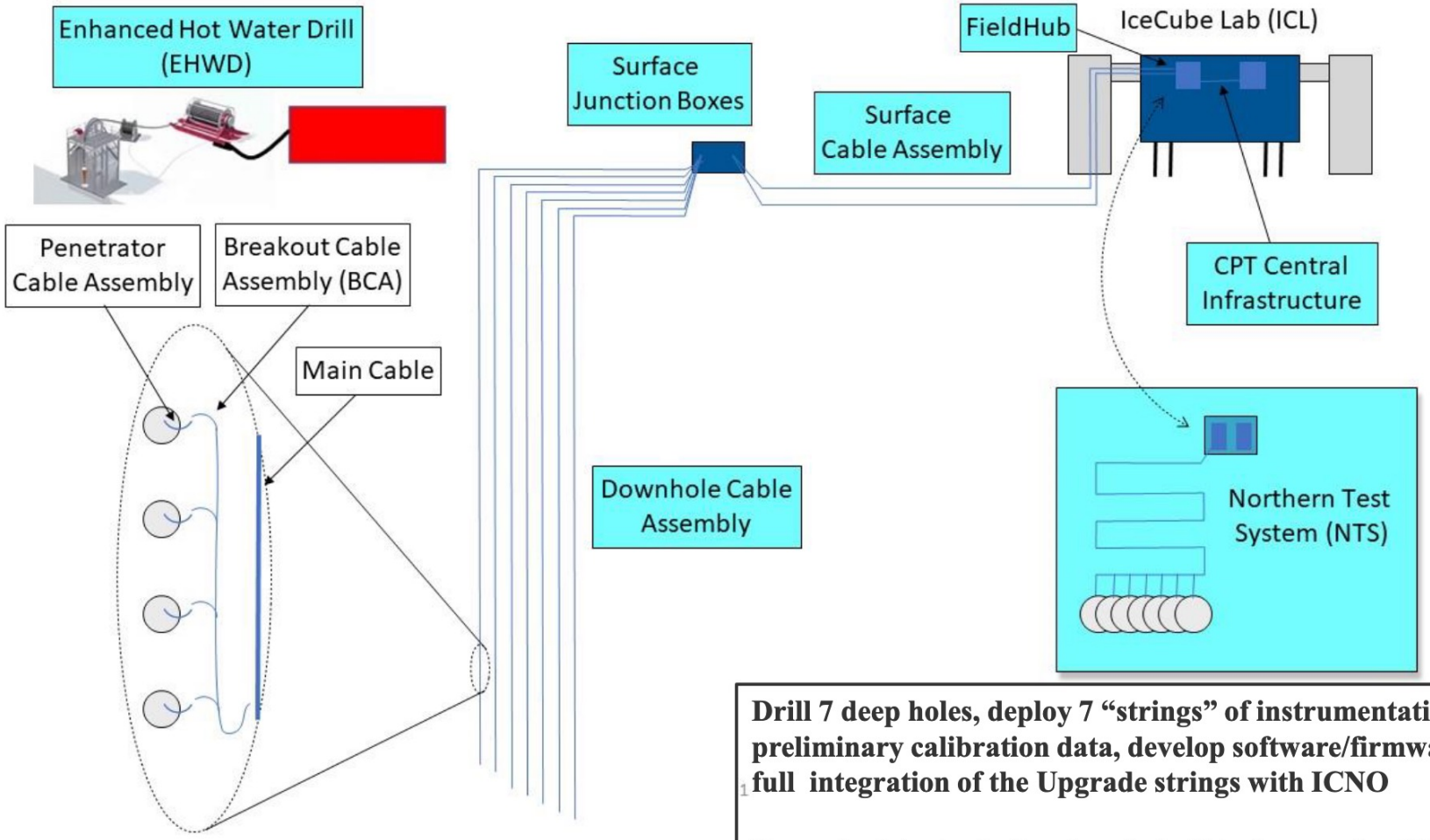
- 277 D-Eggs (2x 8” PMT)
- 402 mDOMs (24x 3” PMT)
- 14 PDOMs
- Calibration devices

2 Mton effective volume for LE neutrino events:

- trigger down to 1 GeV
- 90% efficient at 3 GeV

Single Drill / Install Season

1. **Neutrino Properties**
2. **Recalibration and Reanalysis of IceCube Data**
3. **IceCube-Gen2 Research and Development**



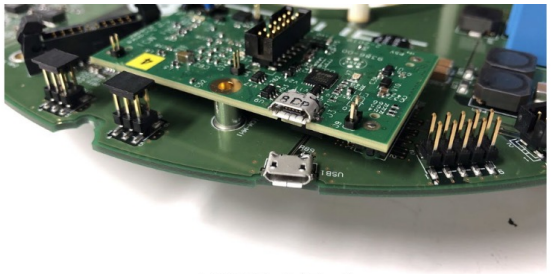
Drill 7 deep holes, deploy 7 "strings" of instrumentation, deliver preliminary calibration data, develop software/firmware for the full integration of the Upgrade strings with ICNO

Upgrade detector is then handed off to the ongoing Maintenance and Operations program.

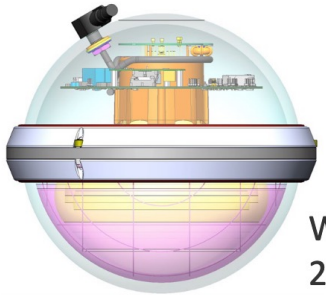
IceCube Upgrade

WBS 1.3.1
430 mDOMs

WBS 1.3.2
310 D-Eggs

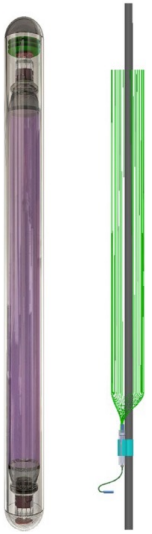


WBS 1.3.4
900 Ice Comms Modules



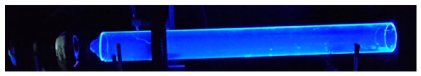
WBS 1.3.3
20 Refurbished IceCube DOMs

WBS 1.3.5
Coordination of R&D Sensors



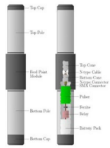
WBS 1.3.5: Special Devices Overview

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



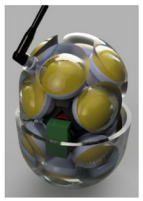
Fiber-Optic Module R&D Sensor

DM-Ice Dark Matter Detector



Radio Pulser
PDR passed 2021-09-02

Radio Receiver

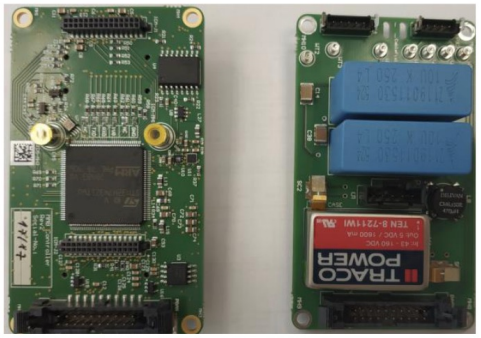


eLongated Optical Module
(Gen2 Prototype Sensor)
PDR passed 2021-12-14

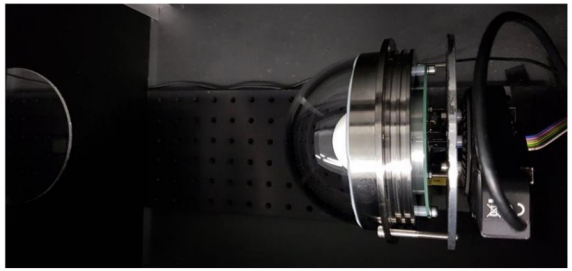
Very Broadband Seismograph

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

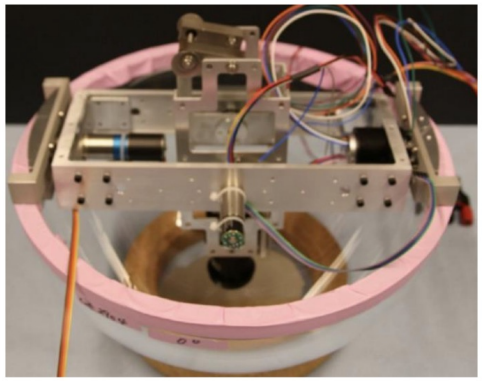


Mini-mainboard Rev2
(Christoph Guenther, RWTH Aachen)

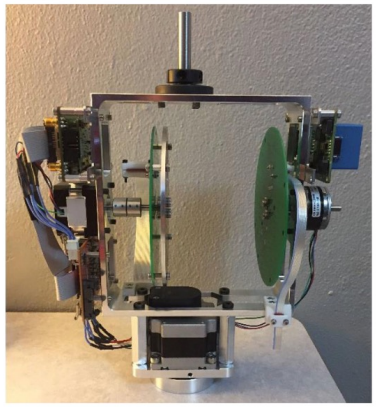


POCAM testing
TU Munich

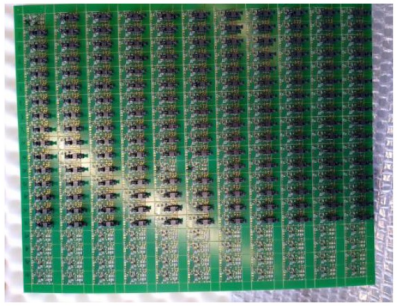
mDOM Camera
Kalle Sulanke, DESY-Zeuthen



Sweden Camera prototype
Matthias Hudl, Stockholm U.



PencilBeam prototype
Jack Nuckles, UW Madison

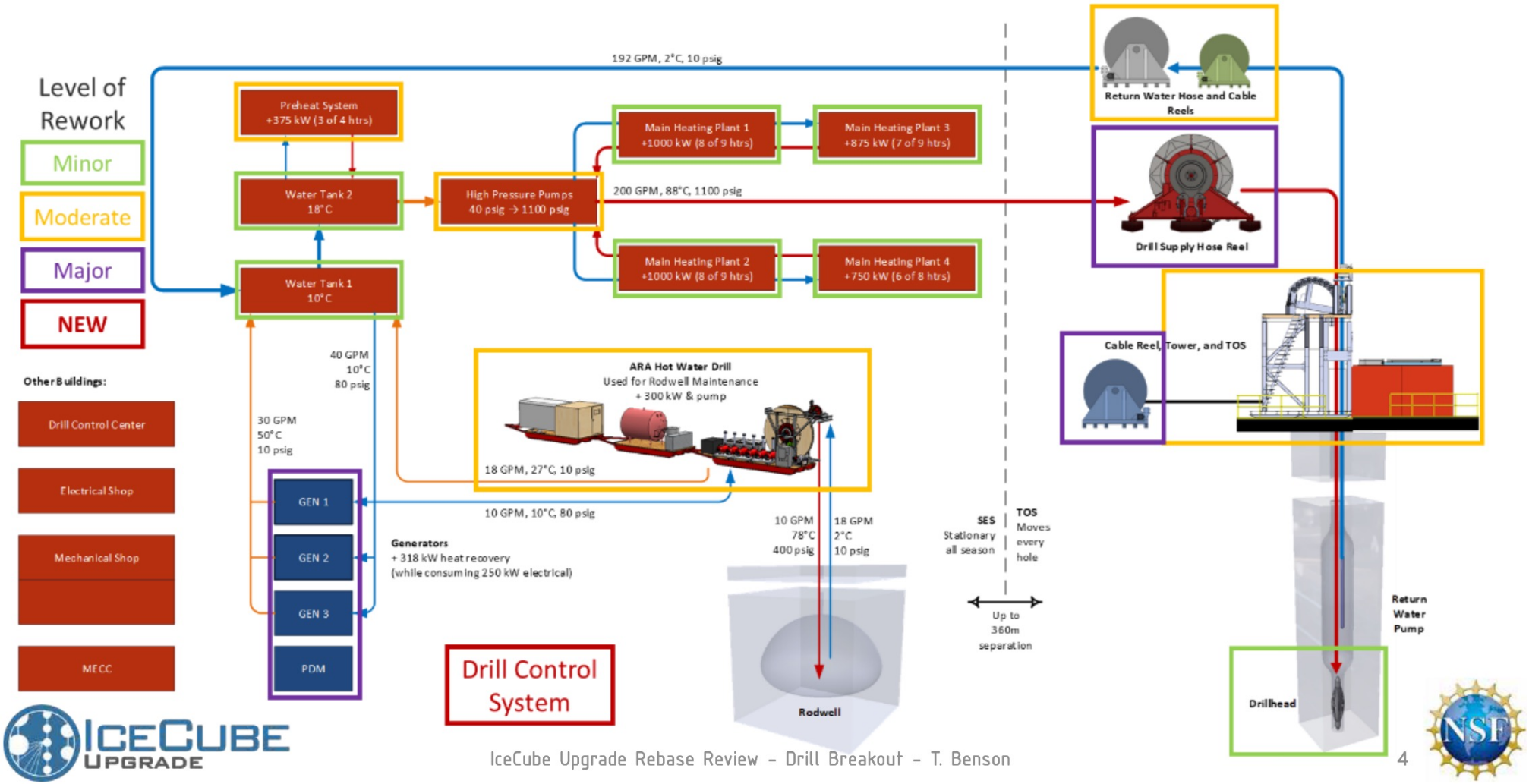


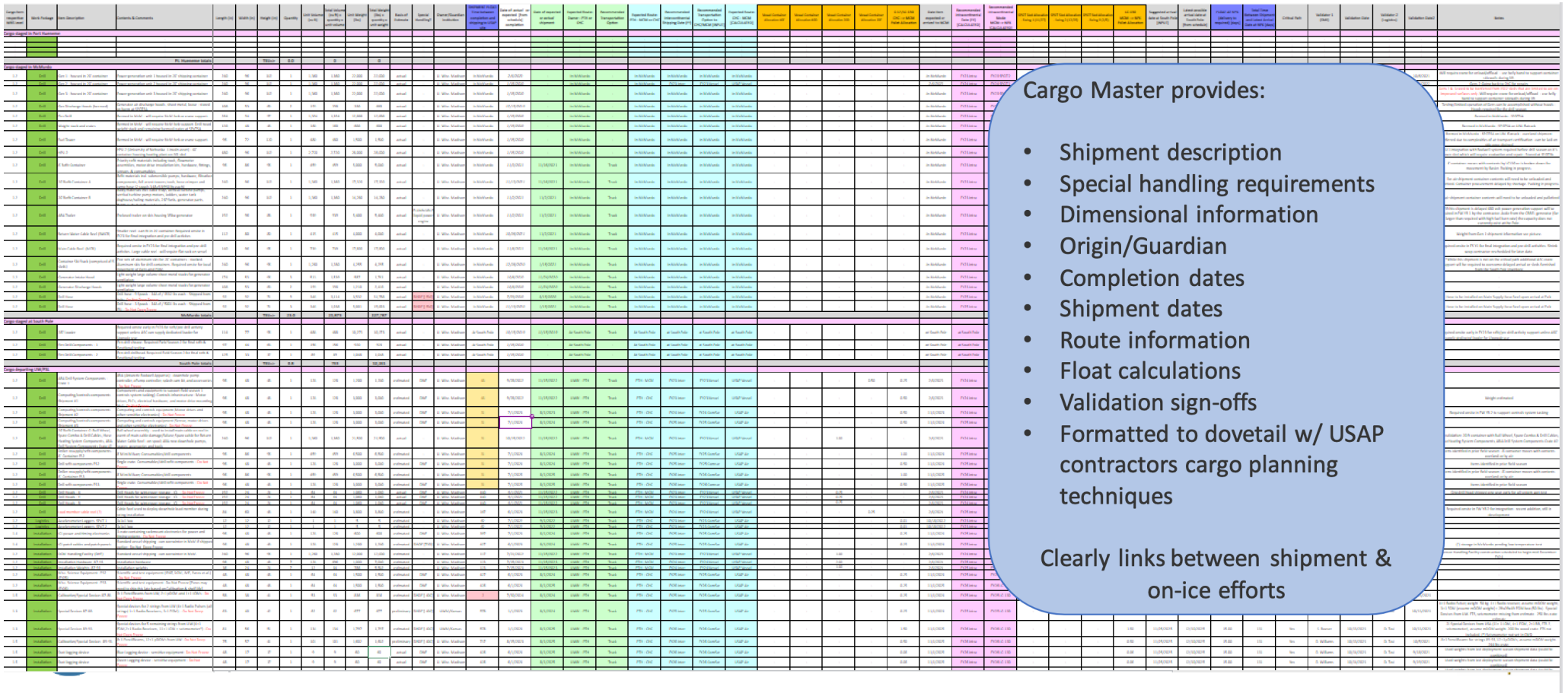
mDOM flasher production
Martin Rongen, Mainz U.

IceCube Upgrade

NSF

ICU Drill Schematic



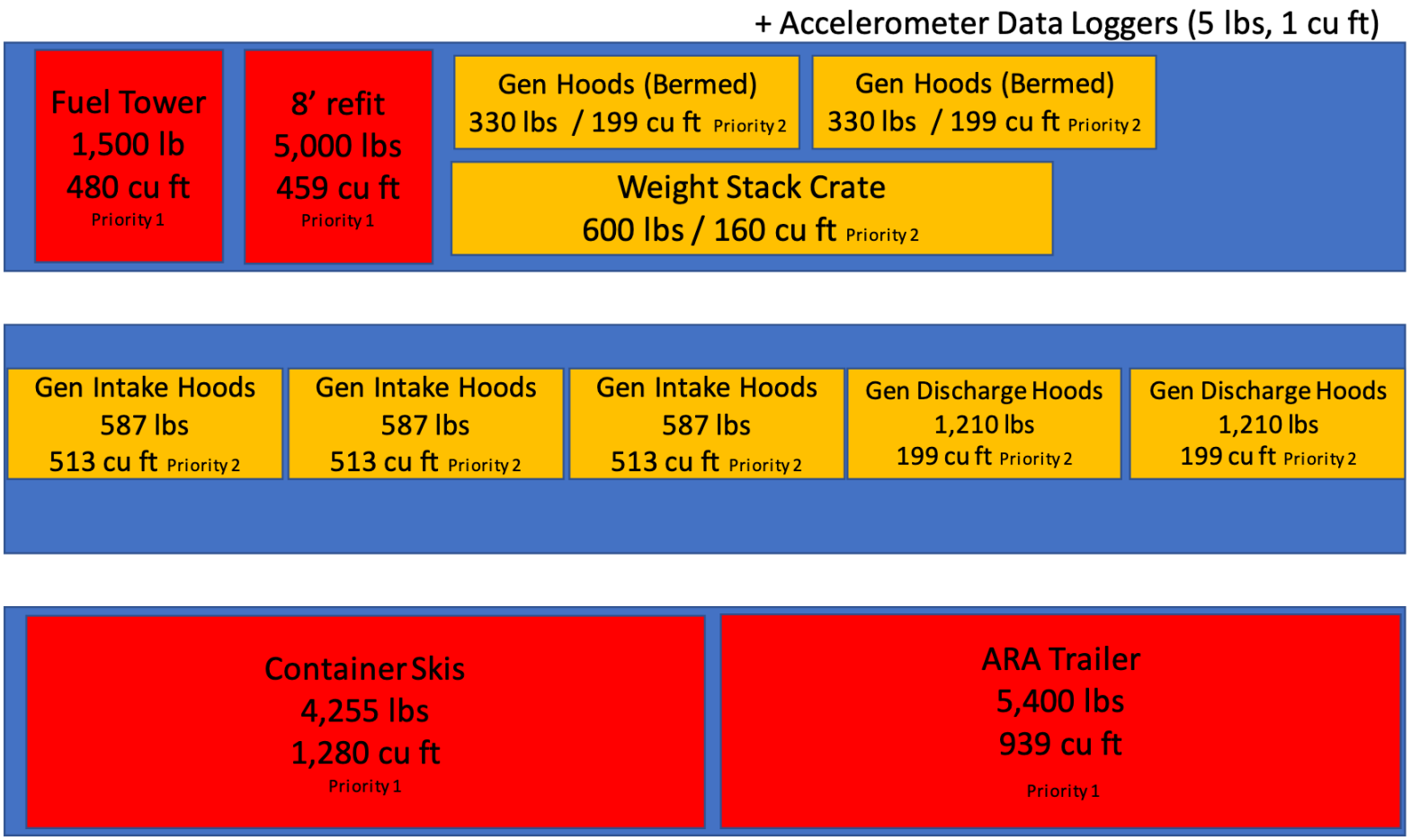


Cargo Master provides:

- Shipment description
- Special handling requirements
- Dimensional information
- Origin/Guardian
- Completion dates
- Shipment dates
- Route information
- Float calculations
- Validation sign-offs
- Formatted to dovetail w/ USAP contractors cargo planning techniques

Clearly links between shipment & on-ice efforts

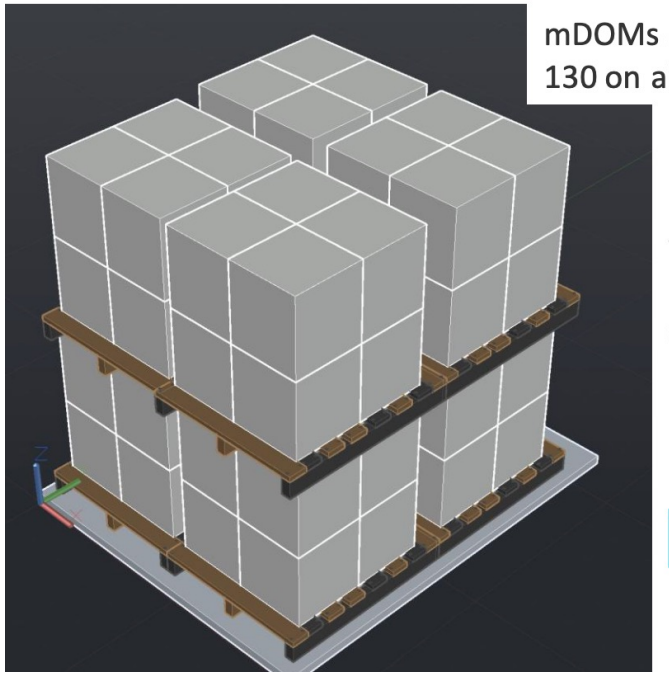
Overland Capacity Analysis - FY23 SPOT 1 South



Total FY23 SPOT 1 weight: 21,601 lbs / volume: 5,654 cu ft

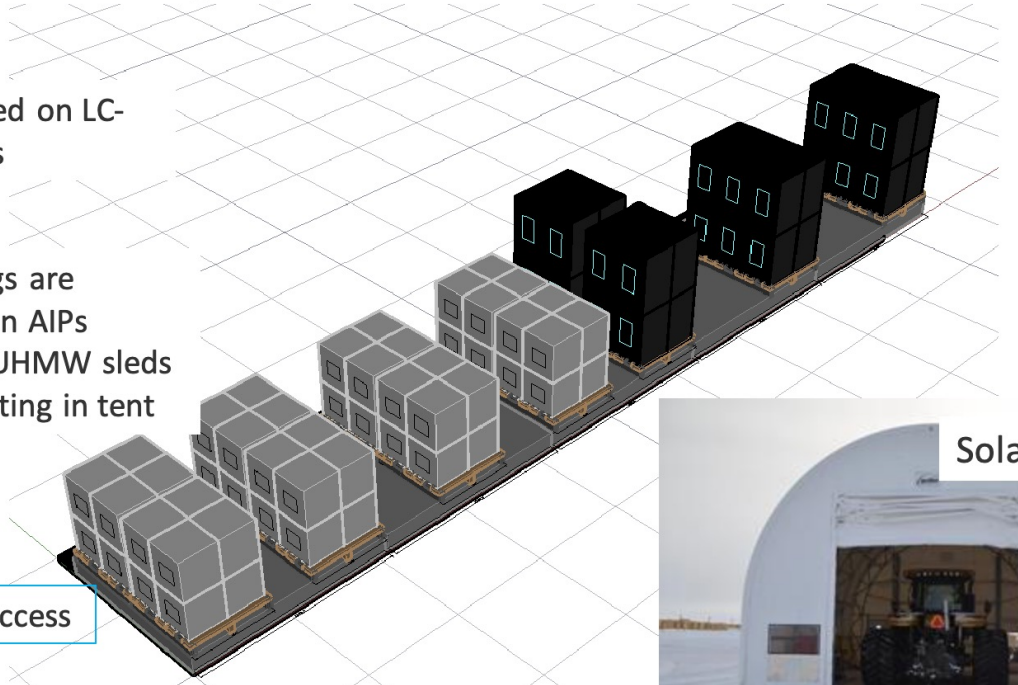
1.2.9.1 Sensor Handling in Upgrade

- Sensor Handling: details are intertwined with point of origin constraints, sensor dimensions, Antarctic logistics, and how sensors are moved at the South Pole and tested prior to deployment.
- Sensor packing fully developed, discussion undergoing with ASC to use on-ice sleds/AIPs/tent for sensor testing



mDOMs are transported on LC-130 on air force pallets

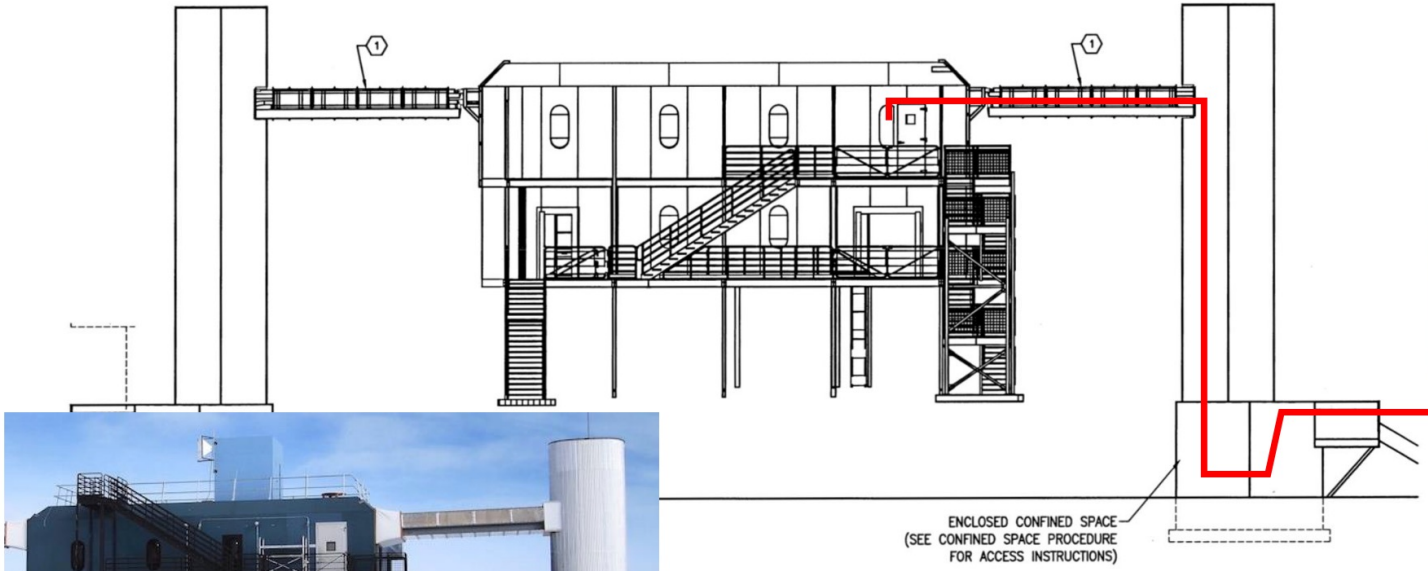
mDOMs/DEggs are transported on AIPs mounted on UHMW sleds at NPX for testing in tent



Penetrator access

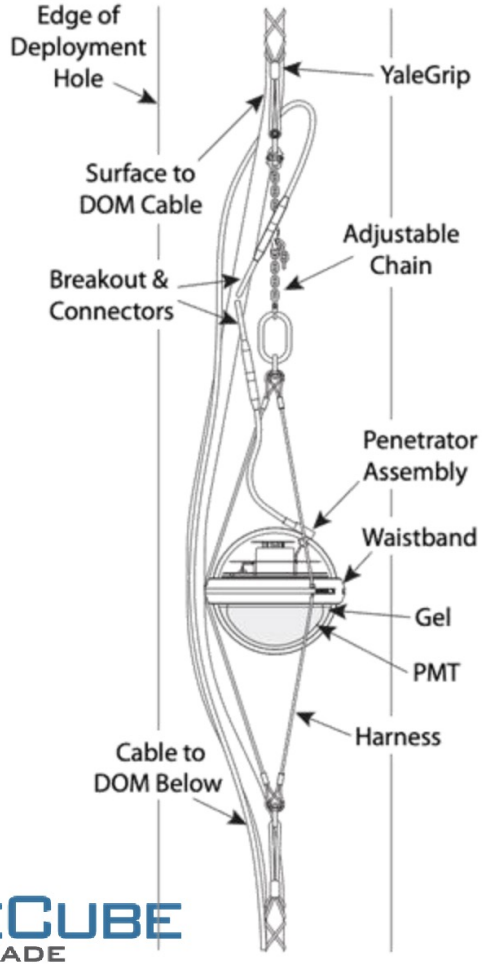
Surface Cable Assembly Entry in East Tower

A couple options investigated jointly with ASC in 2019-20, plan developed shortly before COVID in spring 2020 with ASC meeting

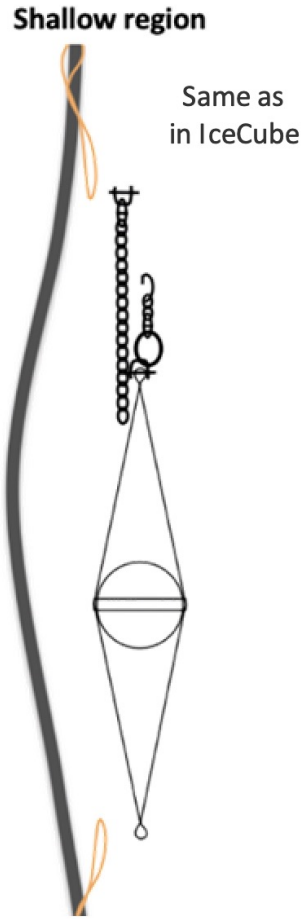


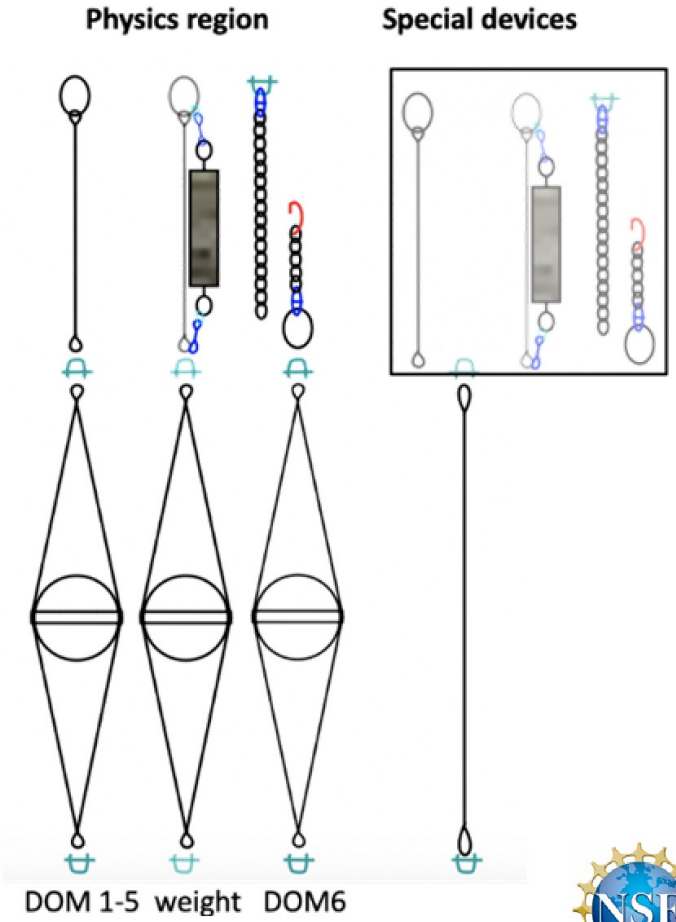
Installation video from IceCube Gen1
https://youtu.be/Lclhveinvmw

IceCube



IceCube Upgrade



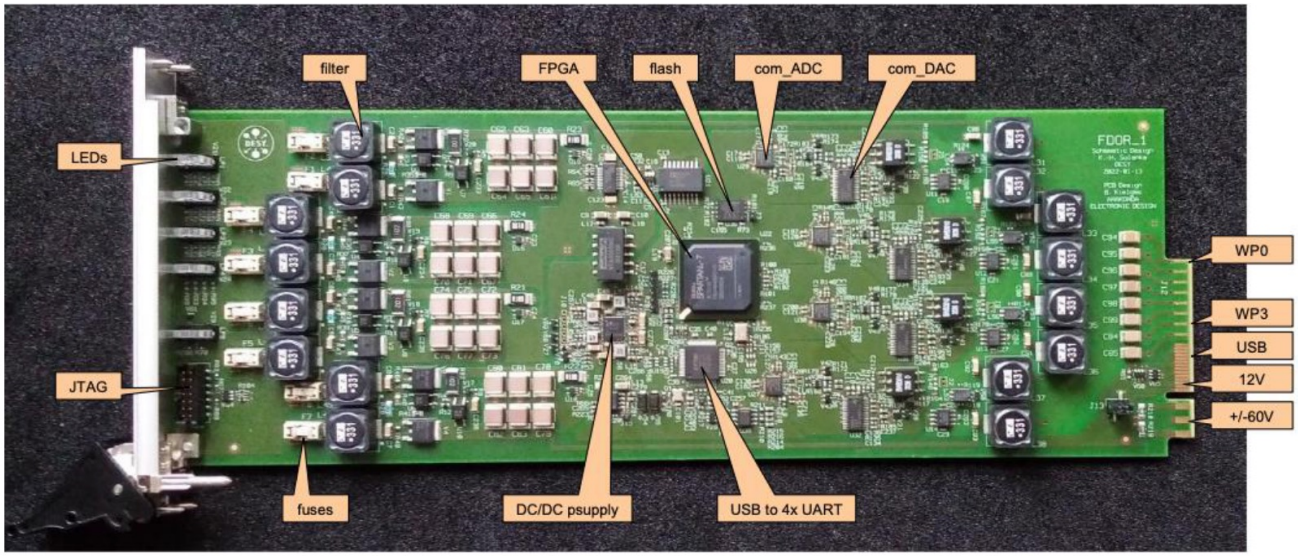


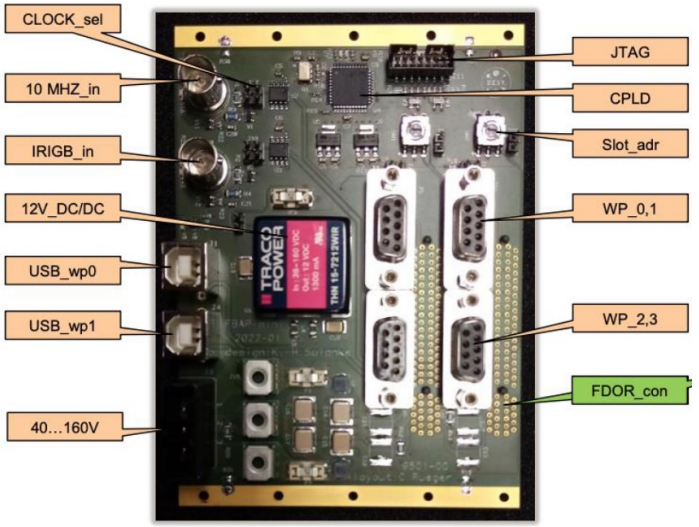
A deployment tower exists at PSL, in connection with a deep cased well (18" diameter to 50', then 10" diameter to 250’)

- It was used for deployment training every year during IC construction
- Will be used to practice procedures in as much as detail as possible.

FieldHubs

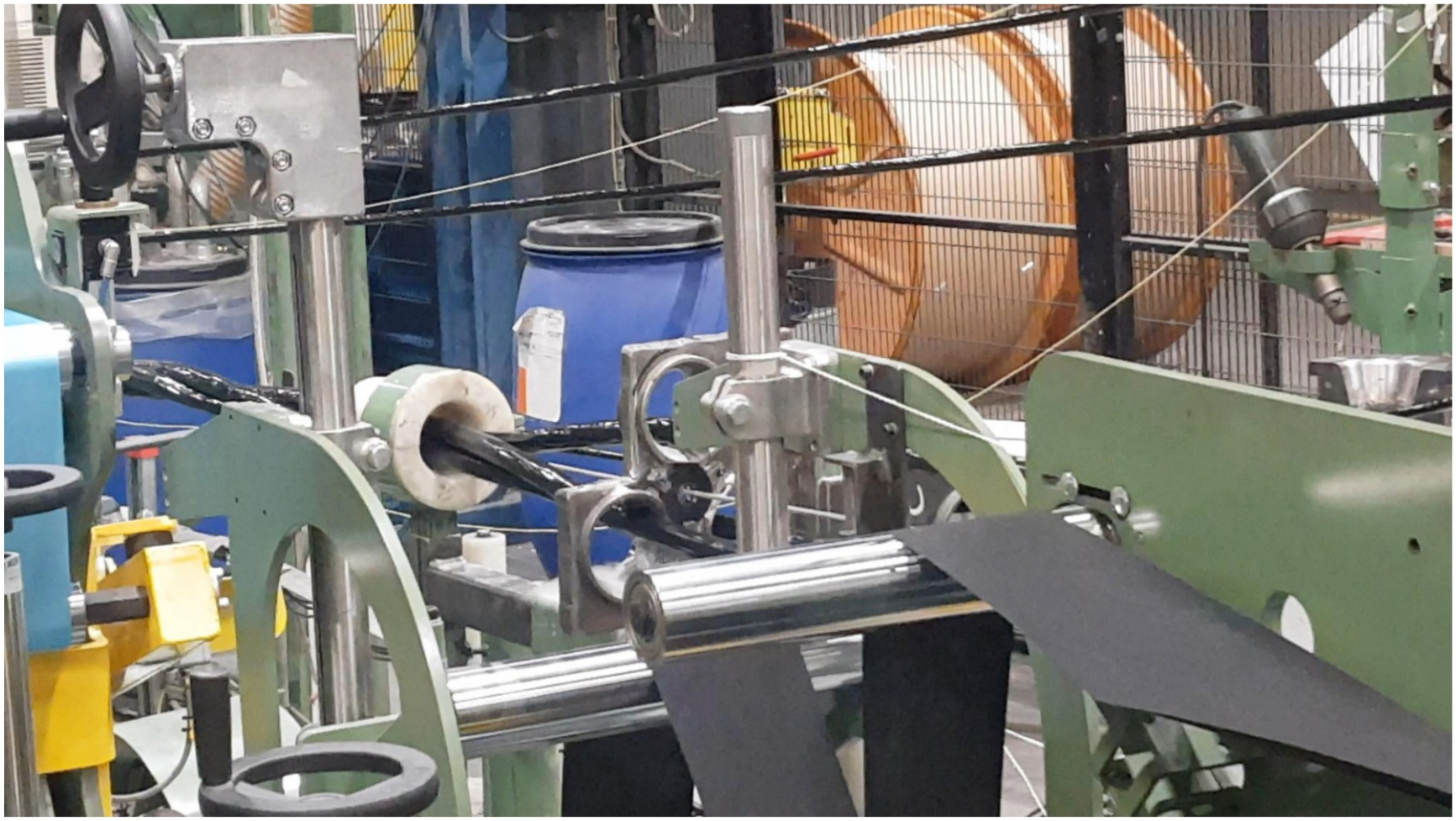
- Evolution from “mini-FieldHubs” used for DOM development, acceptance testing
- Rev1 prototype now assembled, in testing
  - Additional prototype cycles in 2022
- Production in summer/ fall 2023



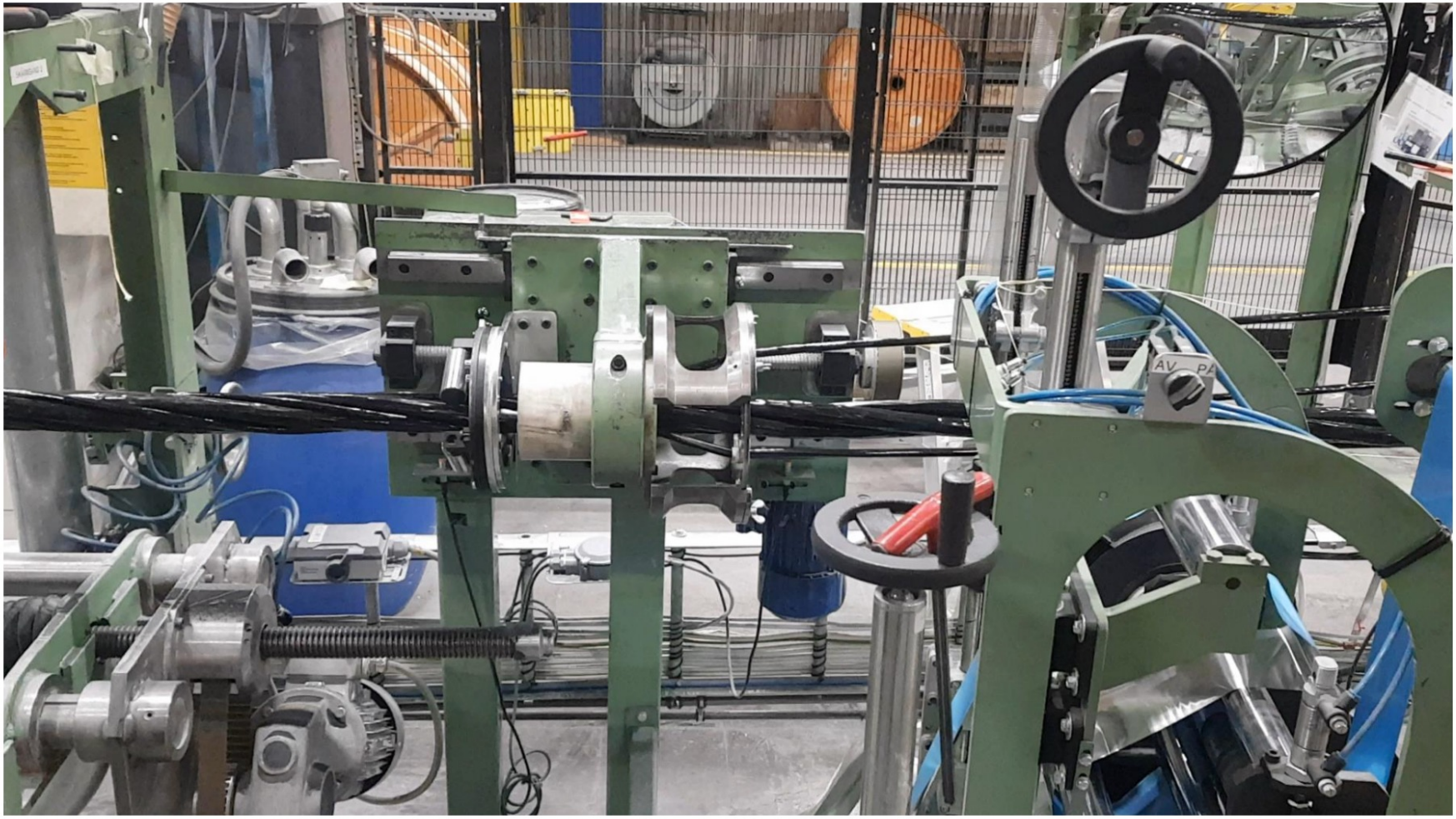


IceCube Upgrade

Winding primary sub-components (signal cables)



Winding primaries with auxiliary quads



IceCube Upgrade Recap

- Science goals of lower energy neutrinos, for oscillation physics, plus a finer look at the ice for re-calibration of existing & future data
- Gets us back to the South Pole with a working hot water drill, and detector R&D for Gen2 IceCube
- Project/construction effort is spread across a subset of the IceCube Collaboration, distinction between project & experiment
- With work at Pole now planned for 2023-24 (drill prep), 2024-25 (firn drilling, full drill test), and 2025-26 (main drill & deploy season)