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Design and performance of the multi-PMT optical module for IceCube Upgrade

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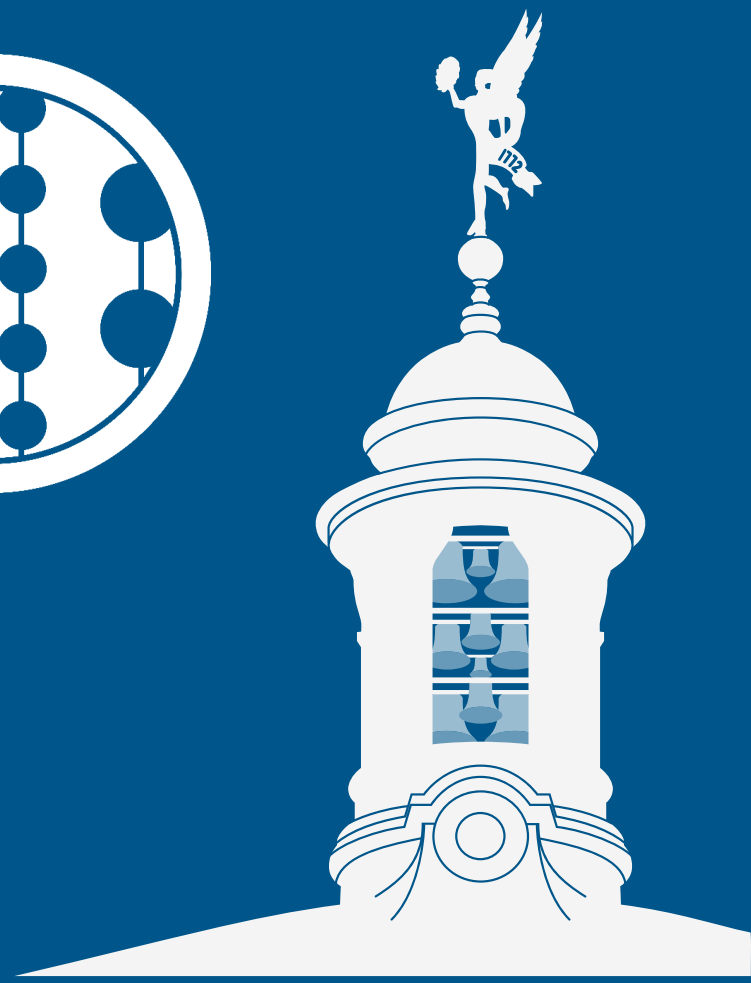
for the IceCube Collaboration

37th International Cosmic Ray Conference
Berlin, Germany
13.07.2021



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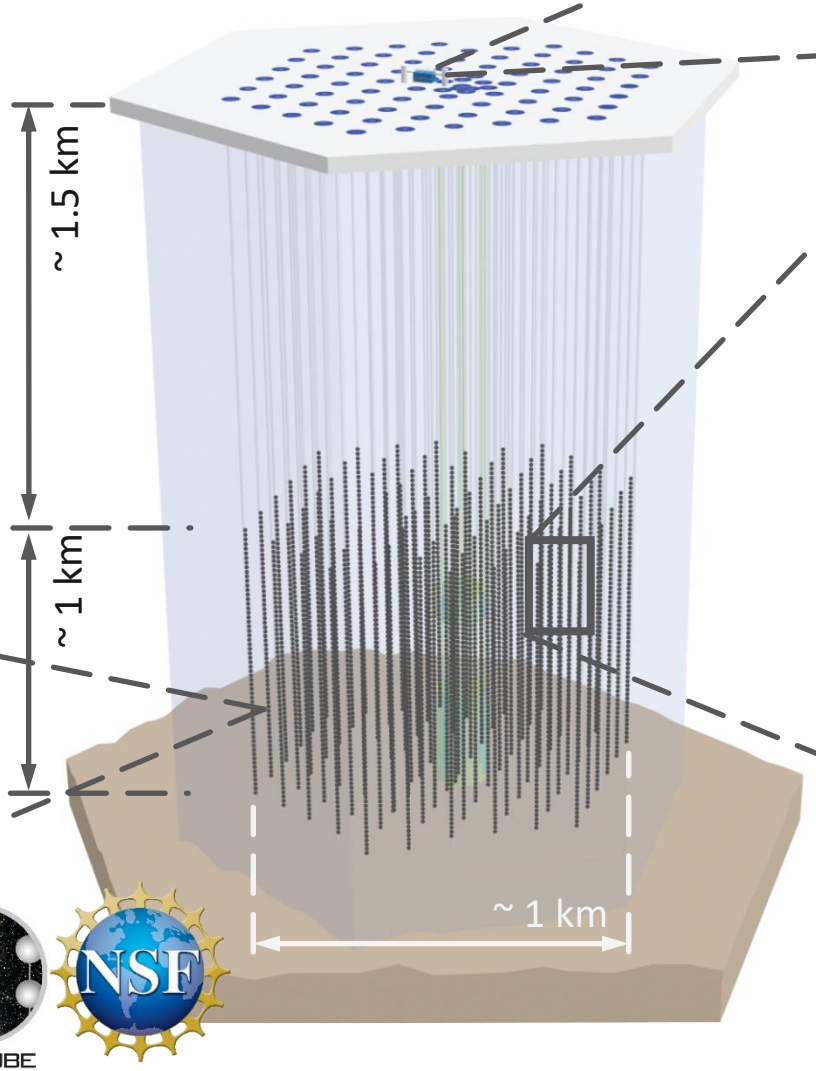
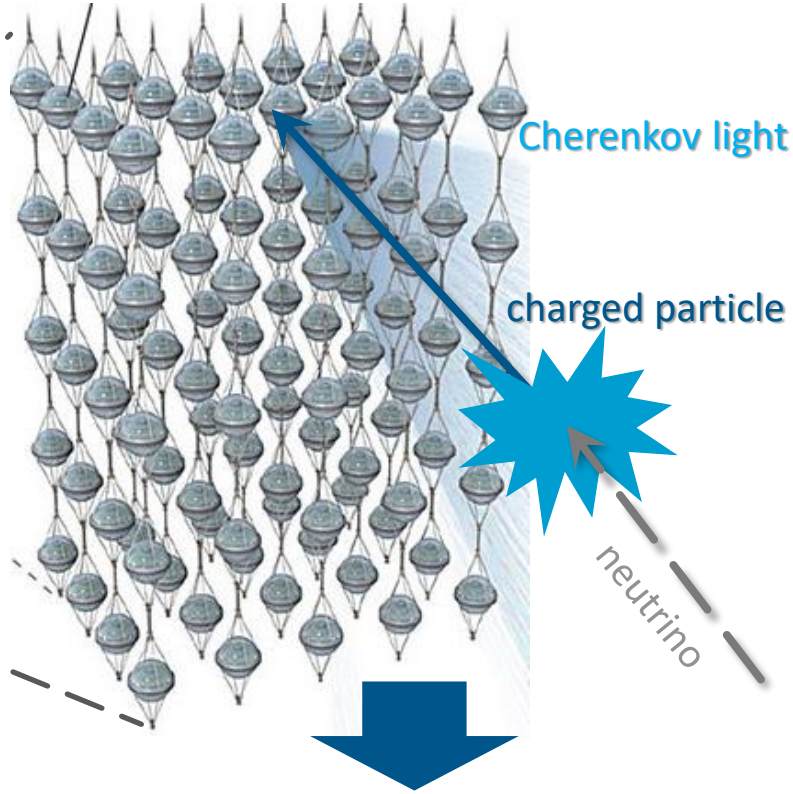
IceCube Neutrino Observatory

IceCube

- 1 km³ ice volume
- 5160 optical modules
- E_ν = 100 GeV – few PeV
- targets cosmic neutrinos
- main goal: neutrino astronomy

Digital
Optical
Module





- single photon counting
- nanosecond timing precision

IceCube & DeepCore

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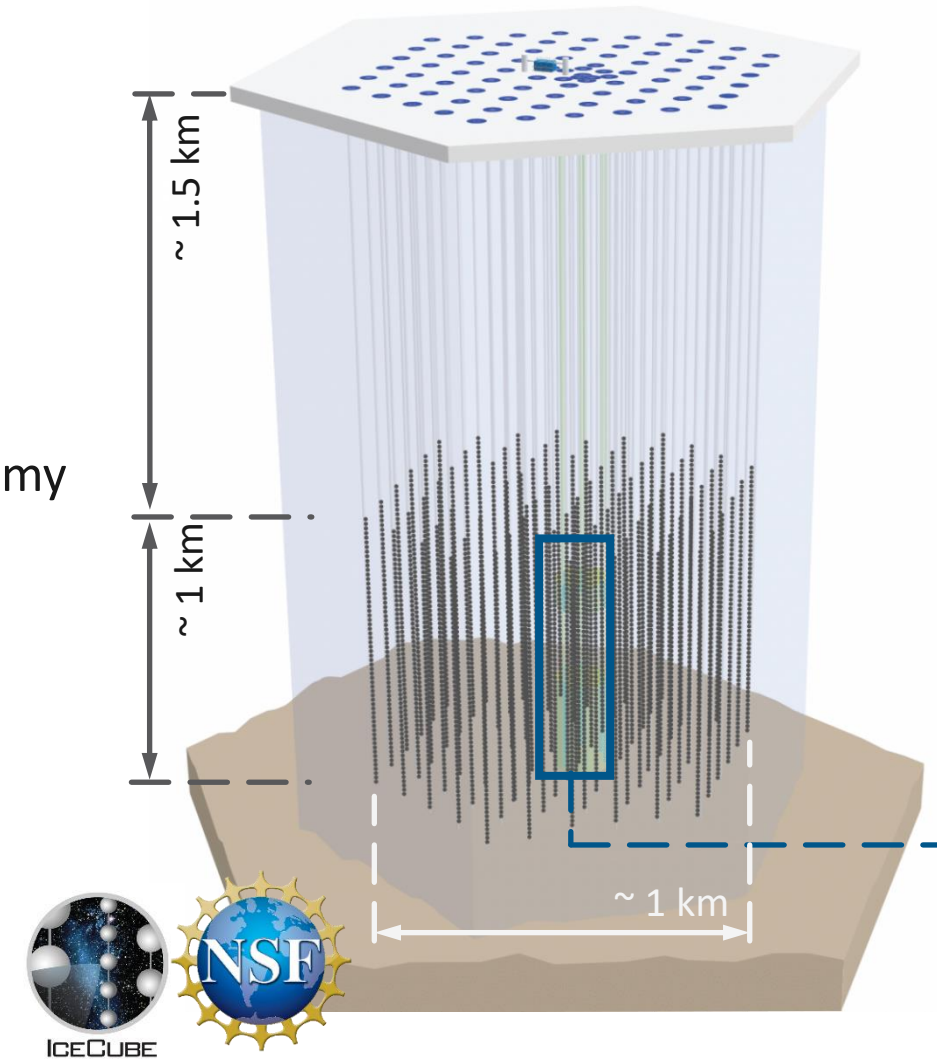


DeepCore

- 500 optical modules of dense central sub-array
- energy threshold ~ 5 GeV
- targets atmospheric neutrinos
- main goals:
  atmospheric neutrino physics
  indirect dark matter searches

IceCube Upgrade

physics goals

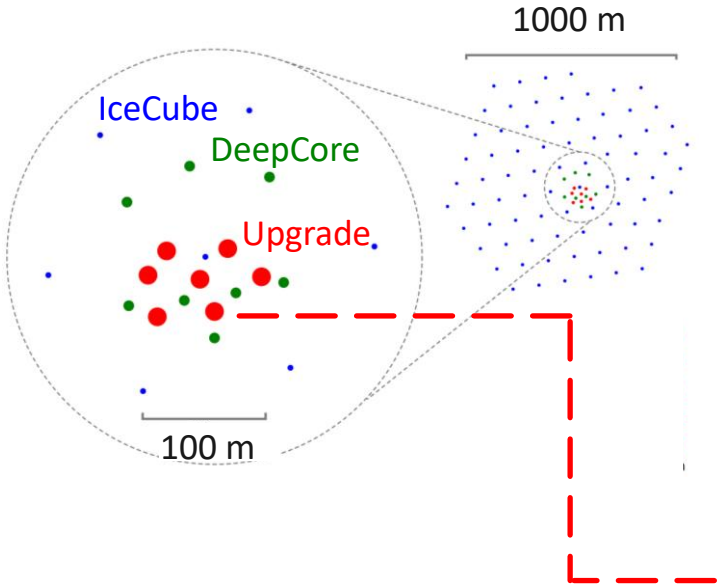
- enhanced precision neutrino physics
- reanalysis of 10+ years of archival IceCube data with reduced uncertainties

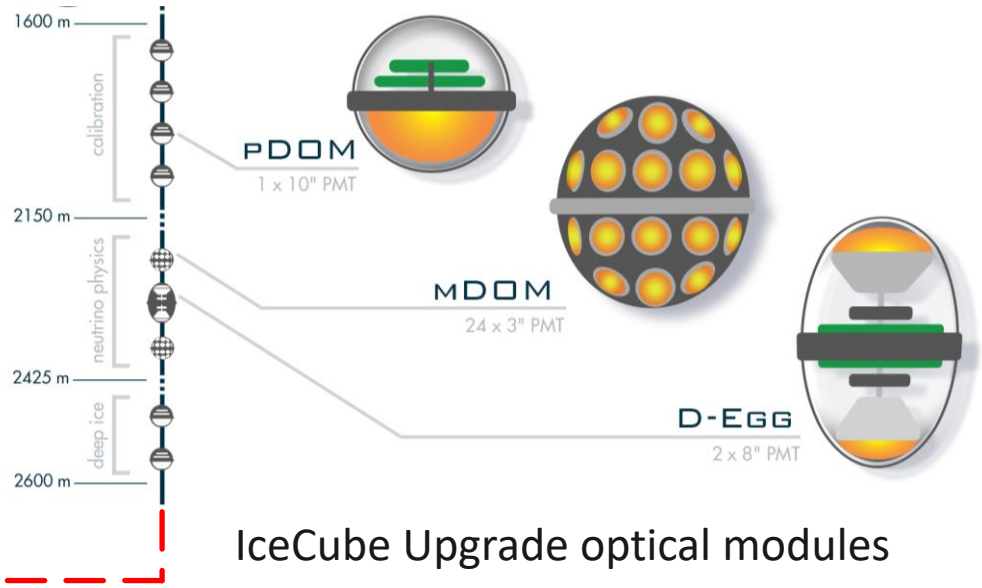
improvement directions

- increase sensor density
- enhance knowledge of ice optical properties

new detector

- seven additional strings in DeepCore region
- ~ 700 additional optical modules in clearest ice
- precision calibration devices
- advanced optical module designs



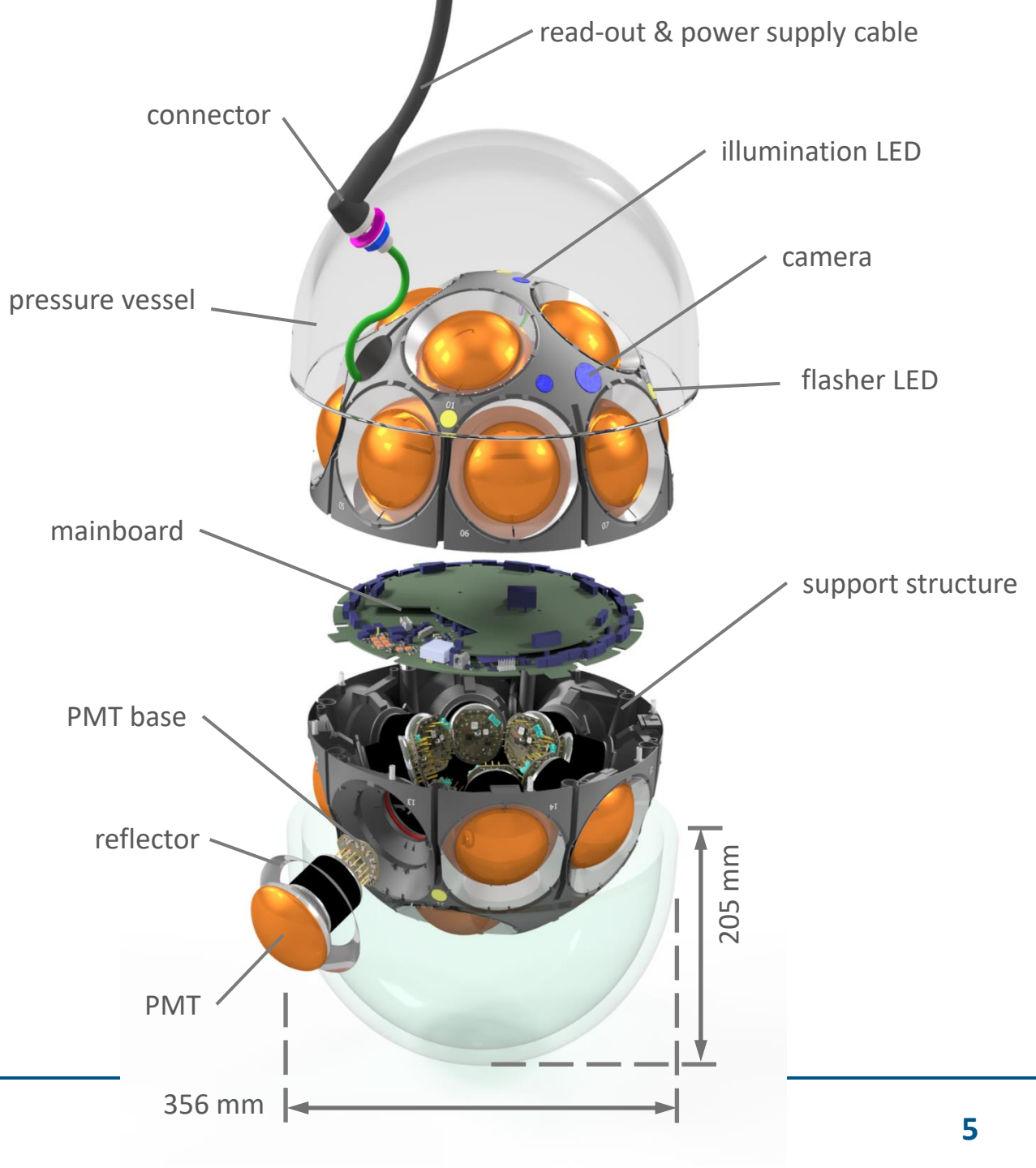


IceCube Upgrade optical modules

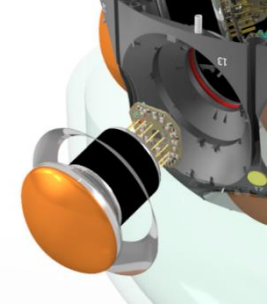
mDOM

- **m**ulti-PMT **D**igital **O**ptical **M**odule
- 24 x 3-inch PMTs (diameter 80mm)
- large sensitive area
  (≡ ca. 2.4 IceCube DOMs)
- uniform 4 π angular acceptance
- intrinsic directional sensitivity
- use of in-DOM local coincidences
- easy photon counting & wide dynamic range
- on-board calibration devices

- more photons
- more information

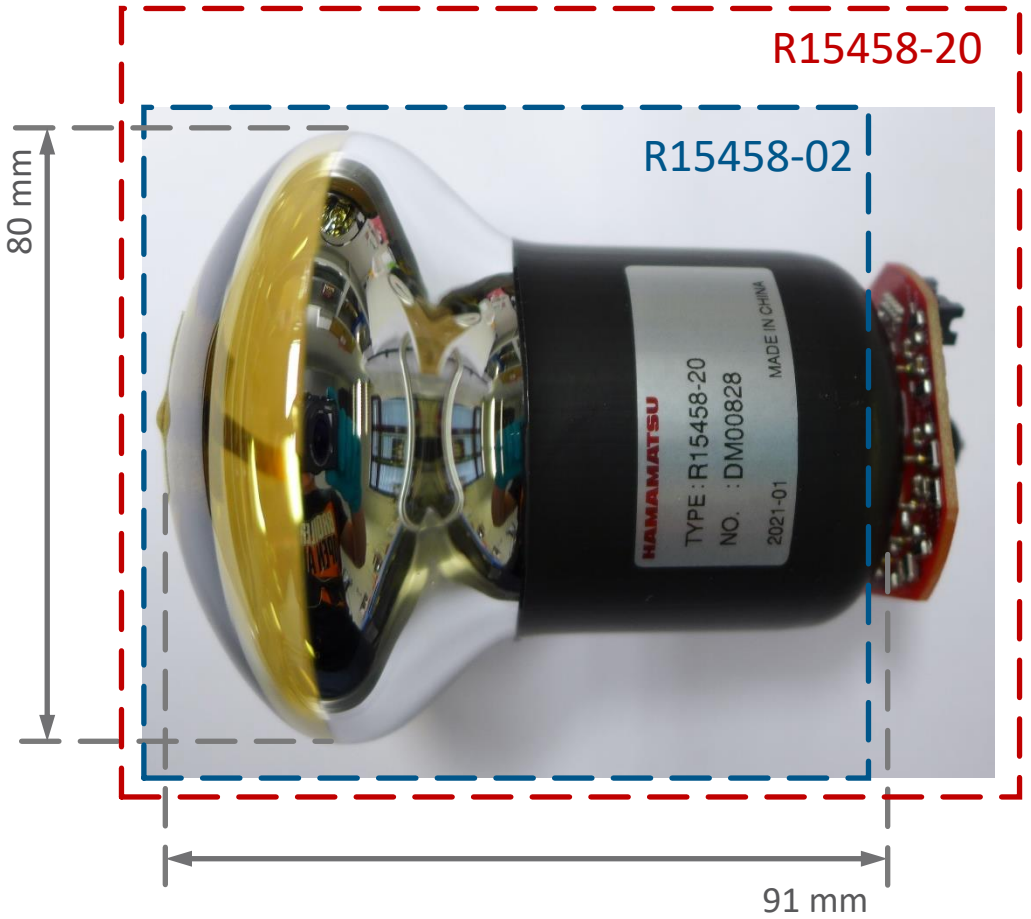


Photomultipliers

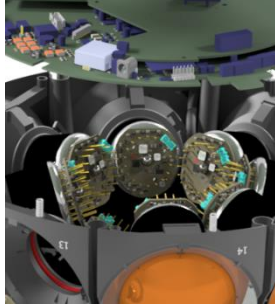


- model: Hamamatsu R15458-02
- optimized for short length
- common gain, individual high voltage
- active base mounted by manufacturer
- delivery of 10 000 units during 2021
- performance of all mDOM PMTs will be tested

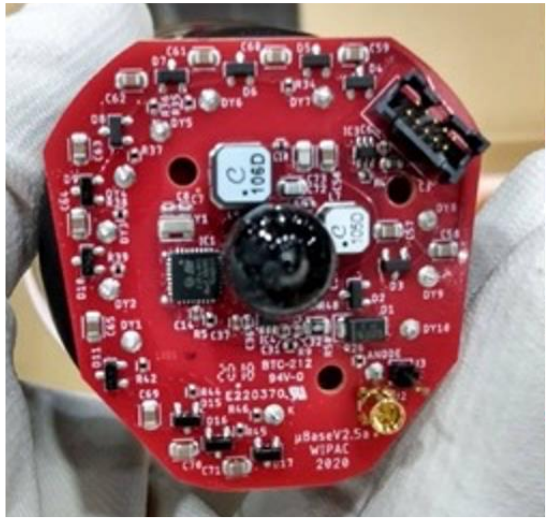
PoS(ICRC2021)1056

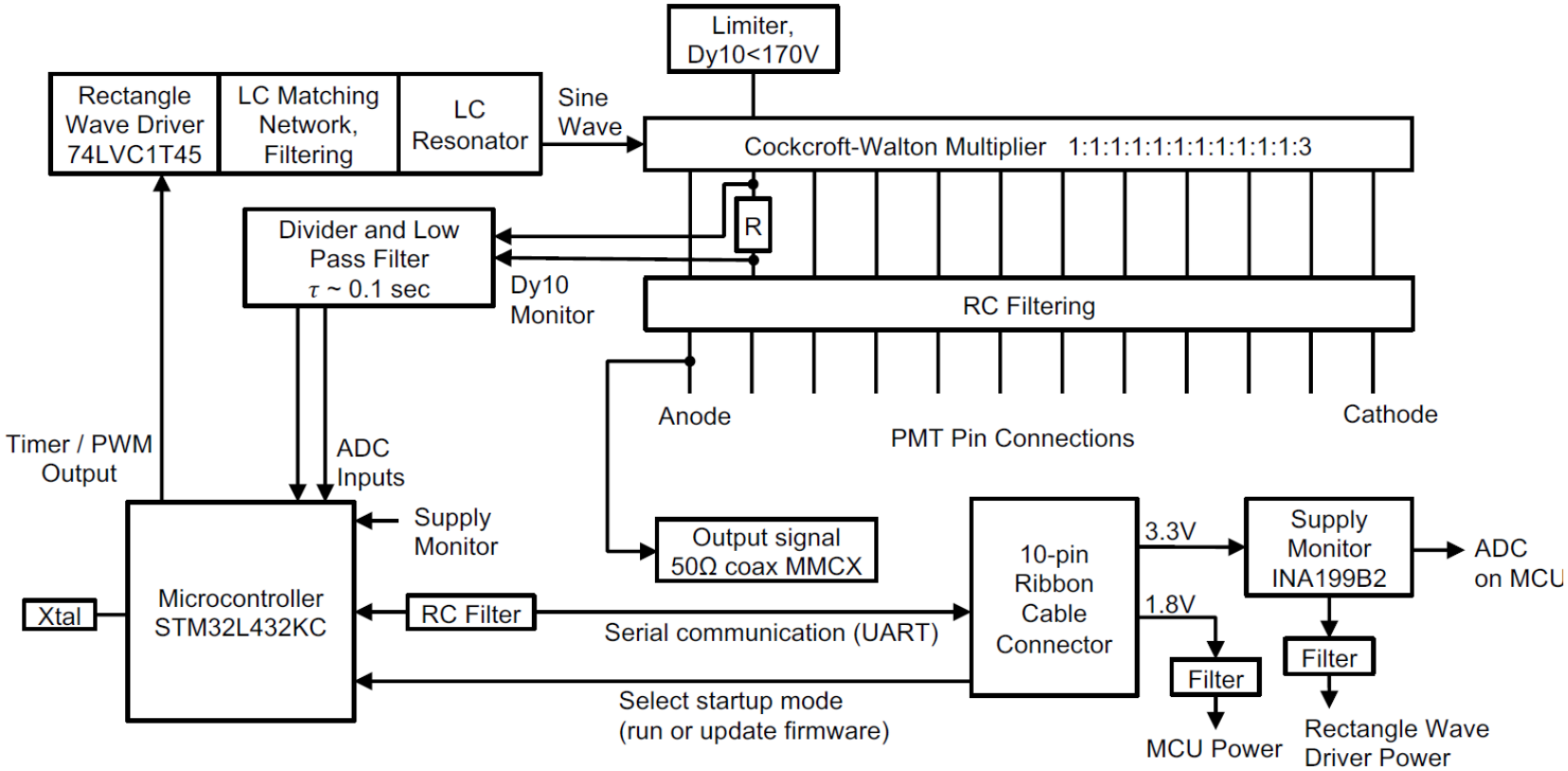


Microbases

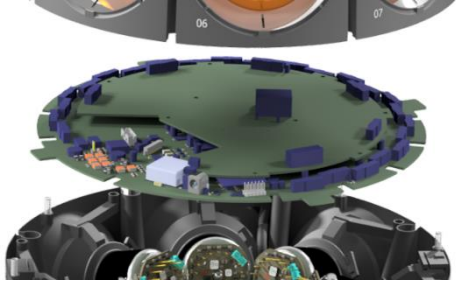


- custom-made active Cockcroft-Walton high voltage generation
- custom ASIC design
- low power consumption: < 10 mW
- compact profile
- produced and soldered to PMTs by PMT manufacturer

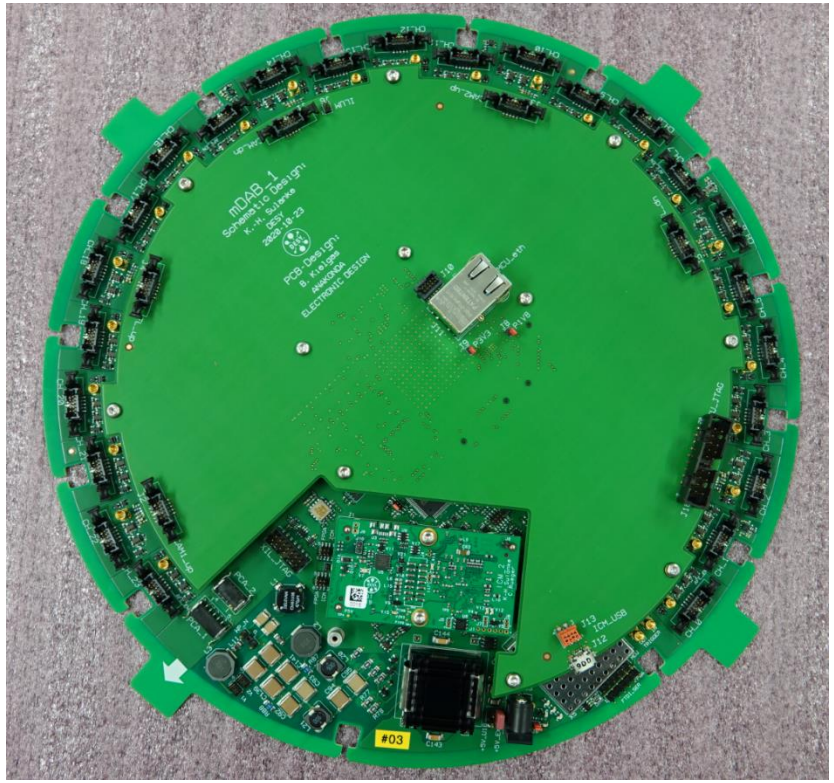


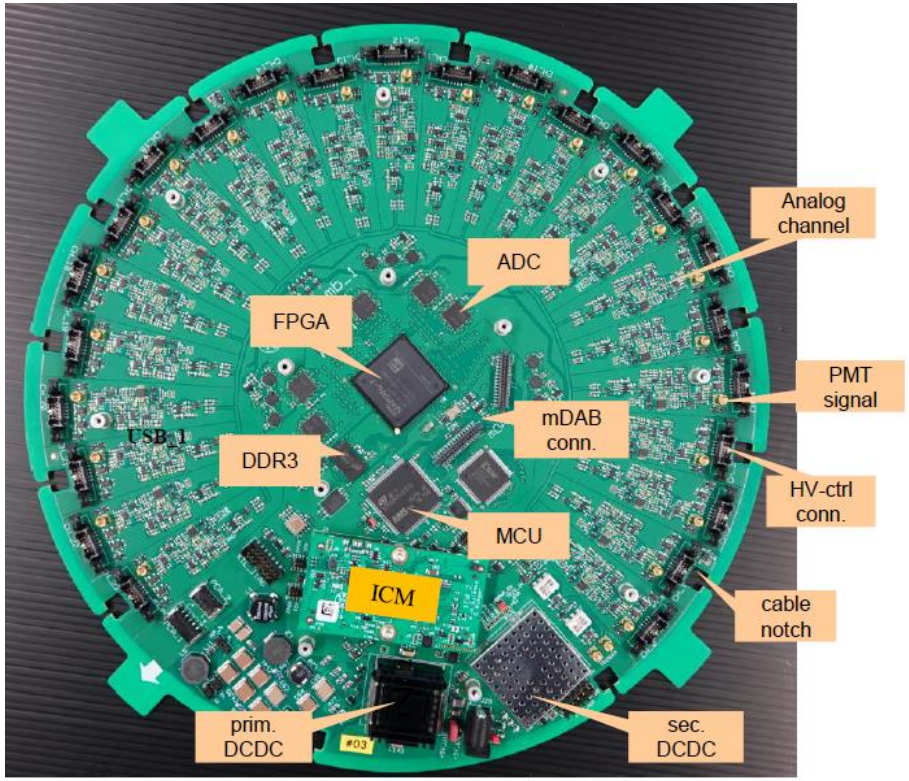


Mainboard

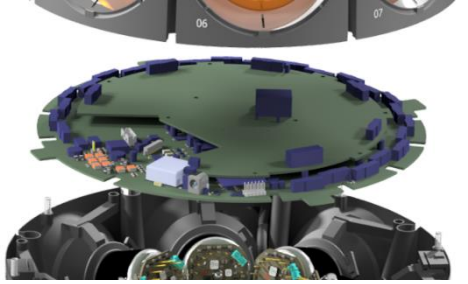


- dual readout scheme
  - precision leading-edge timing from comparator (1 GHz sampling)
  - full waveform sampling with 12-bit ADC @ 120 MHz
- surface communication via Ice Communication Module (ICM), common to all in-ice devices





Mainboard



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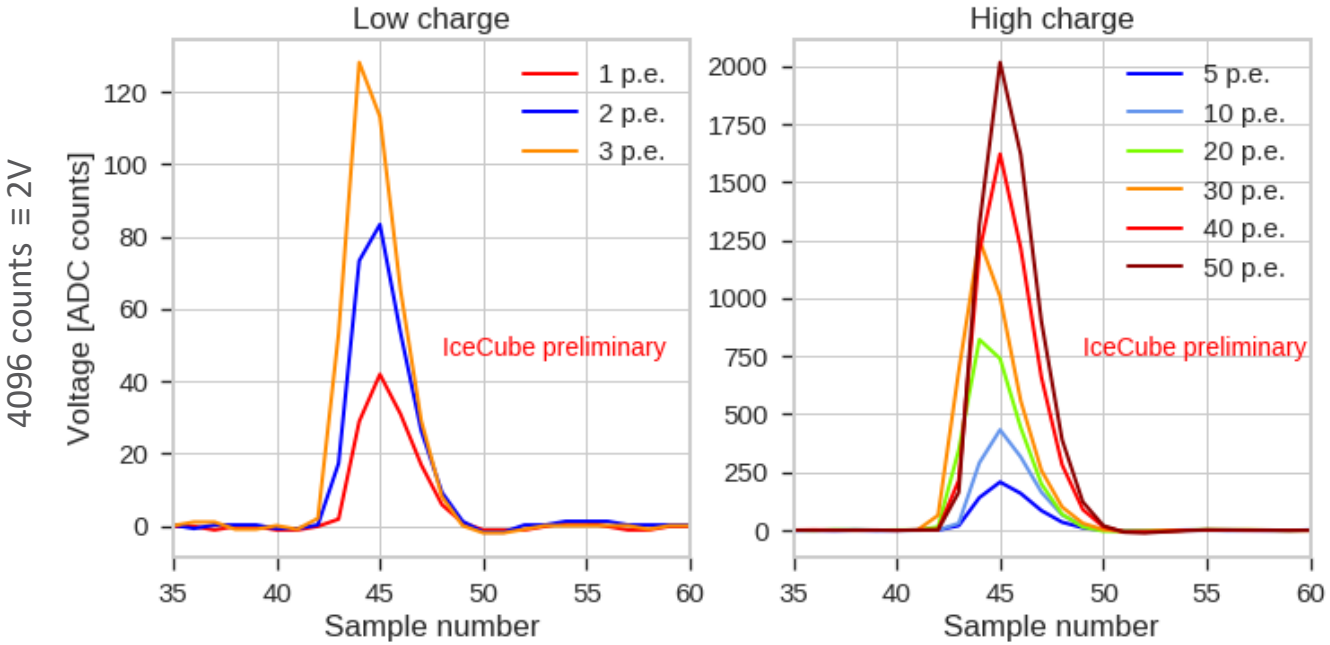
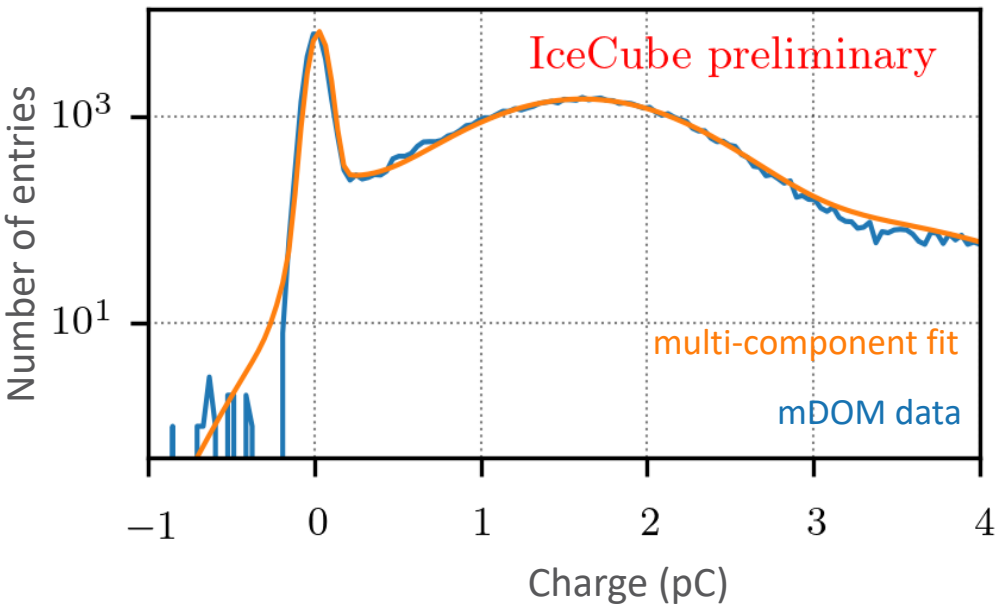
sampled PMT pulses

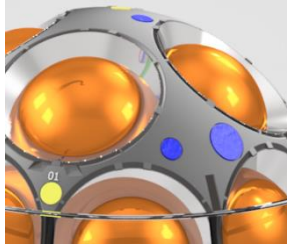


time sampling 100 MSPS

single-photoelectron charge histogram



On-board calibration devices



camera

3 per module

- image sensor: Sony IMX225 CMOS
- FPGA-controlled

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illumination LED

4 per module

- LED: SSL 80 GB CS8PM1.13
- spectrum: 470 ± 25 nm
- power: 1 W
- flux: 43 lm

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flasher LED

10 per module

- LED: Roithner XRL-400-50
- Kaputsinsky driver
- spectrum: 405 ± 10 nm
- up to 10^9 photons per pulse
- pulse length: 7.5 ns

arXiv:1908.10780v2

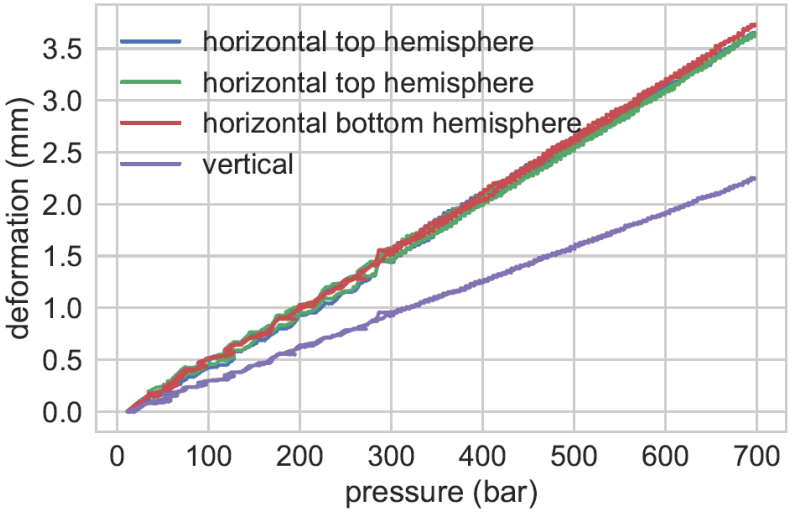
- reduction of primary systematic uncertainties
  - in-situ calibration of optical sensors
  - improve understanding of ice optical properties

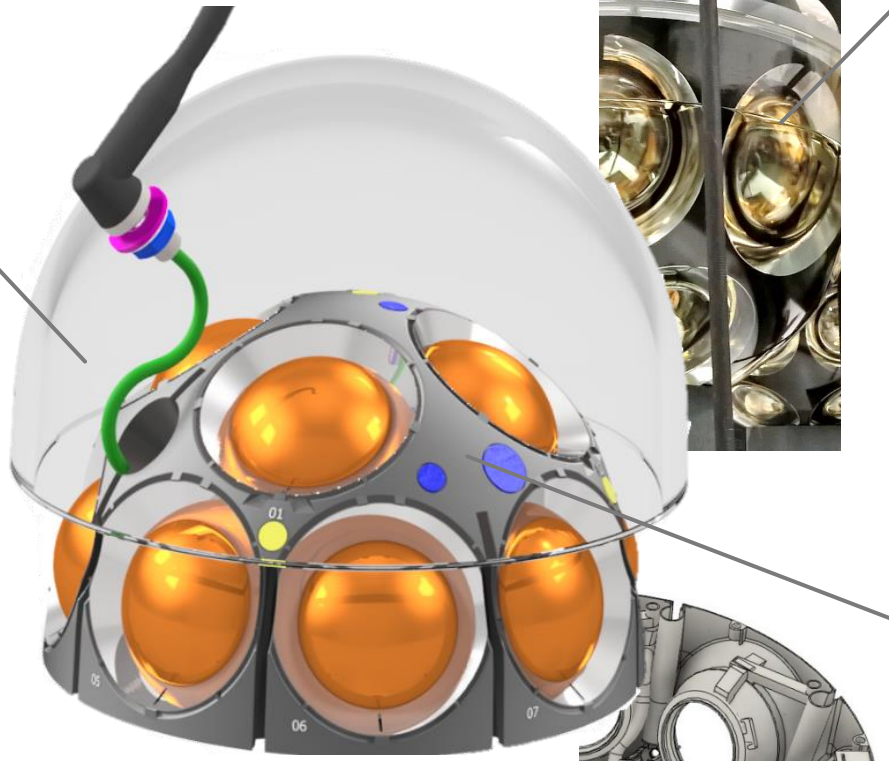
Mechanical structure

pressure vessel

transparent sensor protection

- half spheres
  with cylindrical extensions
- optical transmittance:
  > 90% above ~360 nm
- pressure rating: 700 bar

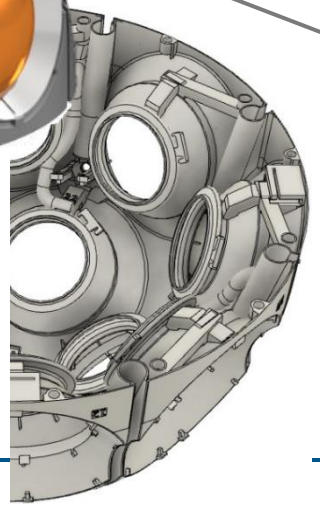




optical gel

optical coupling of PMTs to pressure vessel

- two components, silicone-based
- UV transparent
- low-temperature stable

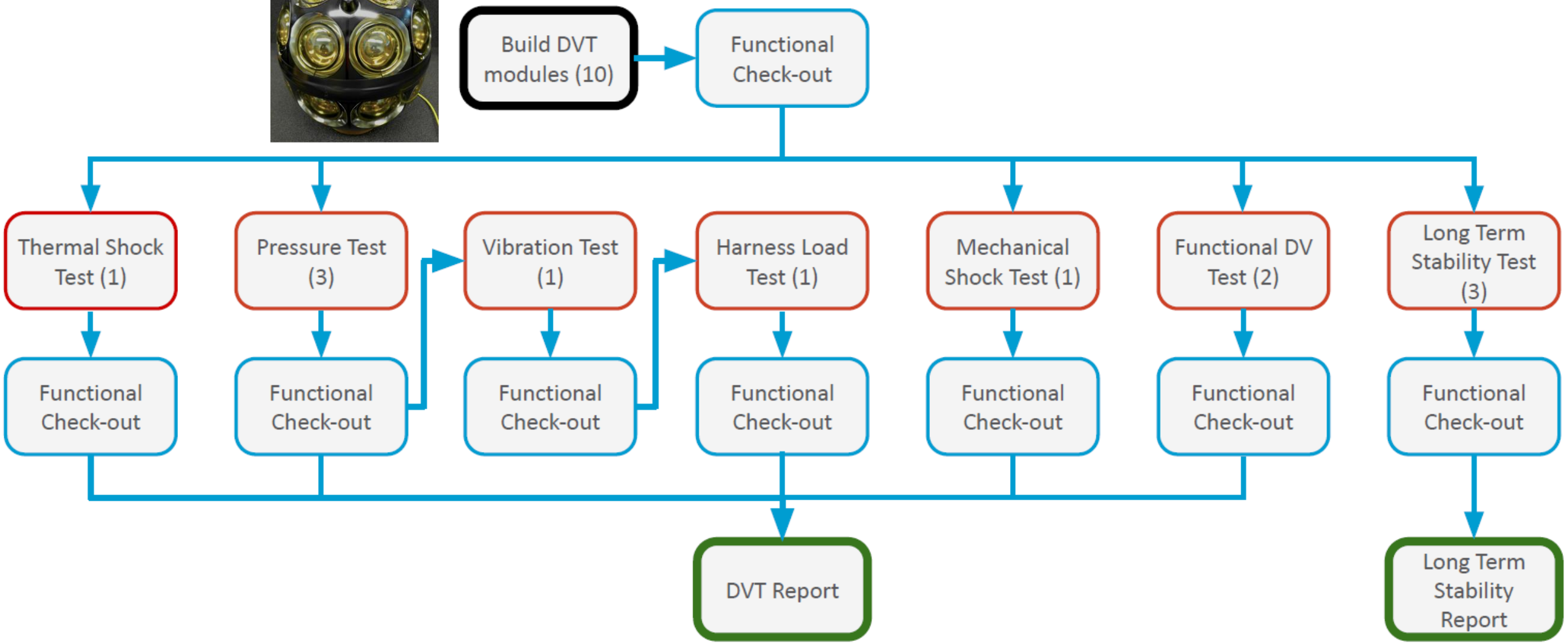


support structure

the mDOM's backbone

- 3D-printed polyamide structure
- dyed black
- hosts PMTs, reflectors, calibration devices and mainboard

mDOM status - Design Verification Test



Summary & outlook

- large sensitive area and additional information on arriving photons
- will contribute to reaching physics goals of IceCube Upgrade

- currently in final testing phase
- deployment in IceCube Upgrade in the near future

- mDOM-like segmented modules also foreseen for IceCube-Gen2

Stay tuned...