Photosensor Development for the IceCube Upgrade

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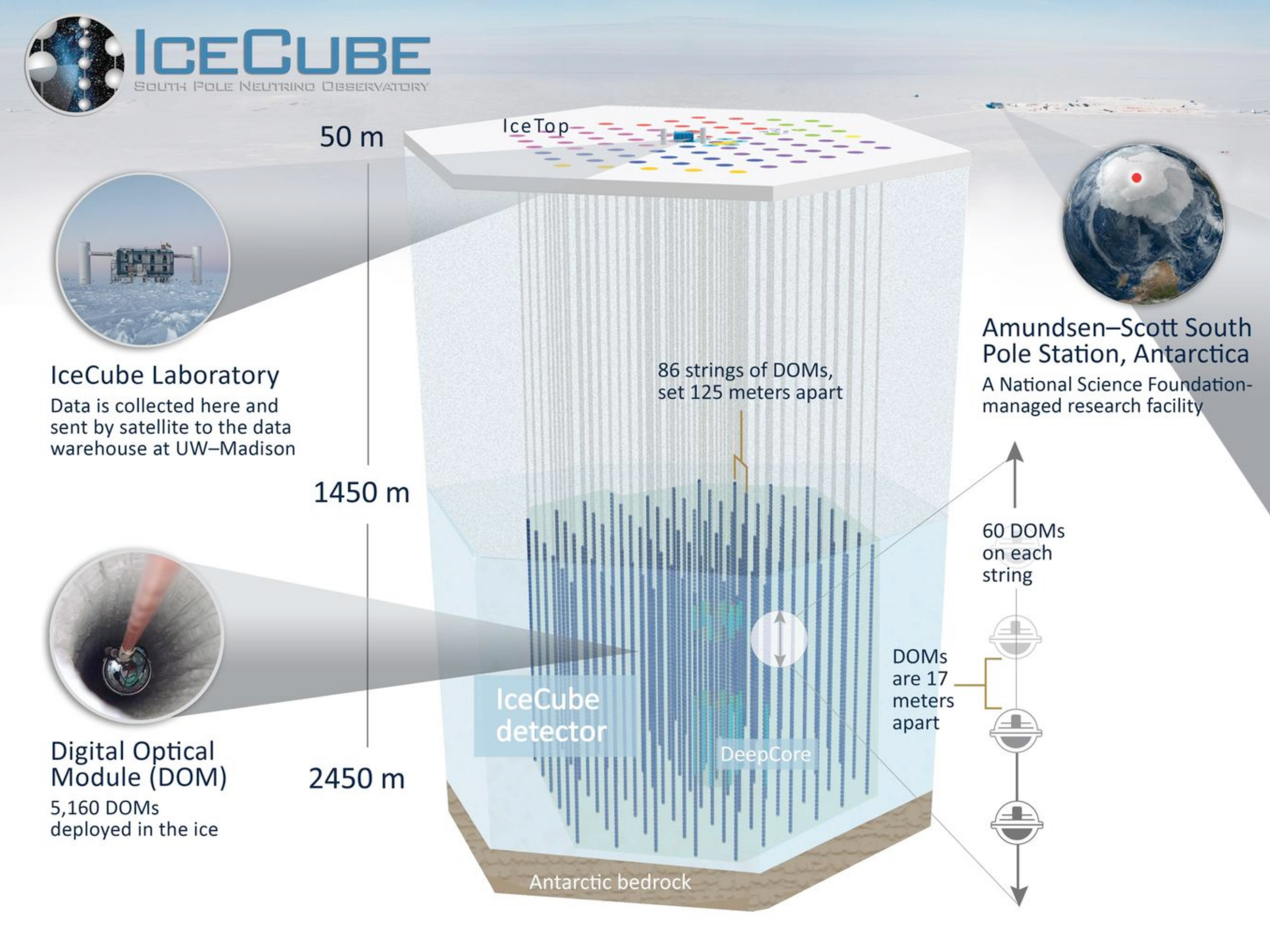
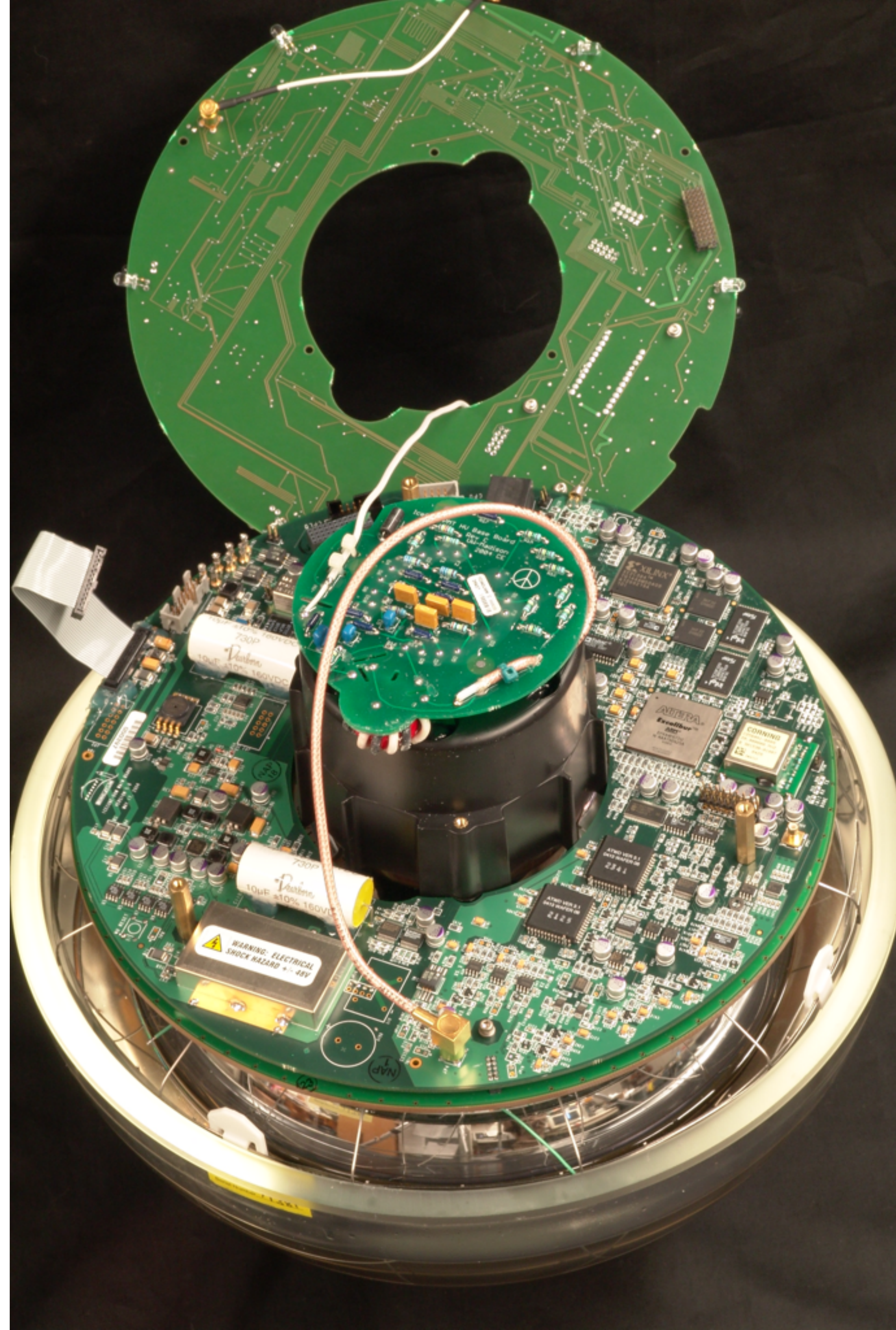
ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY



IceCube
South Pole Neutrino Observatory
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
Antarctic bedrock

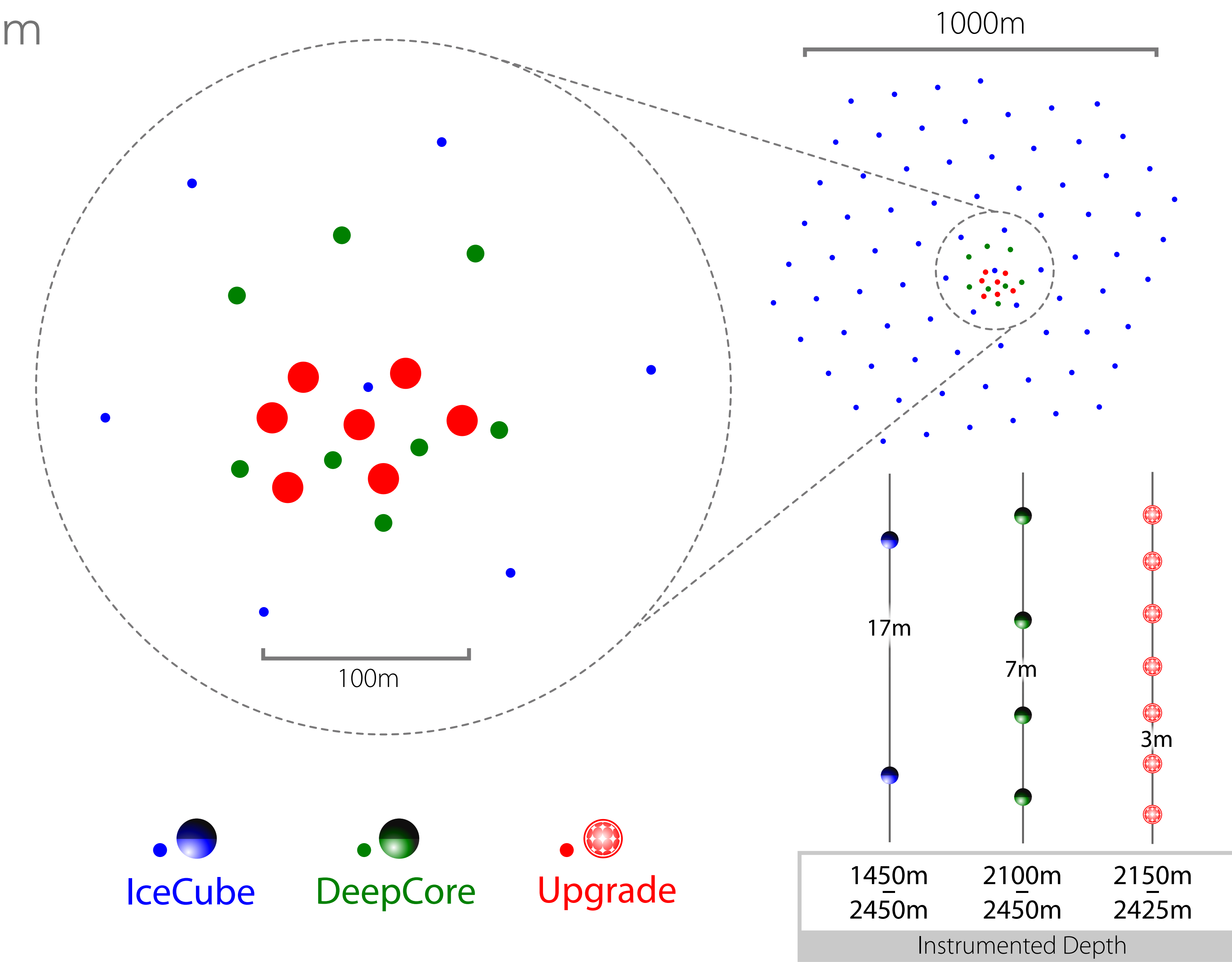
Digital Optical Module

- 10″ Hamamatsu PMT (super-bialkali in DeepCore)
- Onboard capture of PMT waveforms
    - Two sets of digitizers operating in ping-ping mode
    - 300 MSPS x 400 ns: custom ATWD chip
    - 40 MSPS x 6.4 μsec with fADC
    - Dead time < 1%
    - Dynamic range ~1000 p.e./10 ns
- Absolute timing < 2 ns RMS
- Noise rate ~600 Hz (underlying Poisson rate 260 Hz)



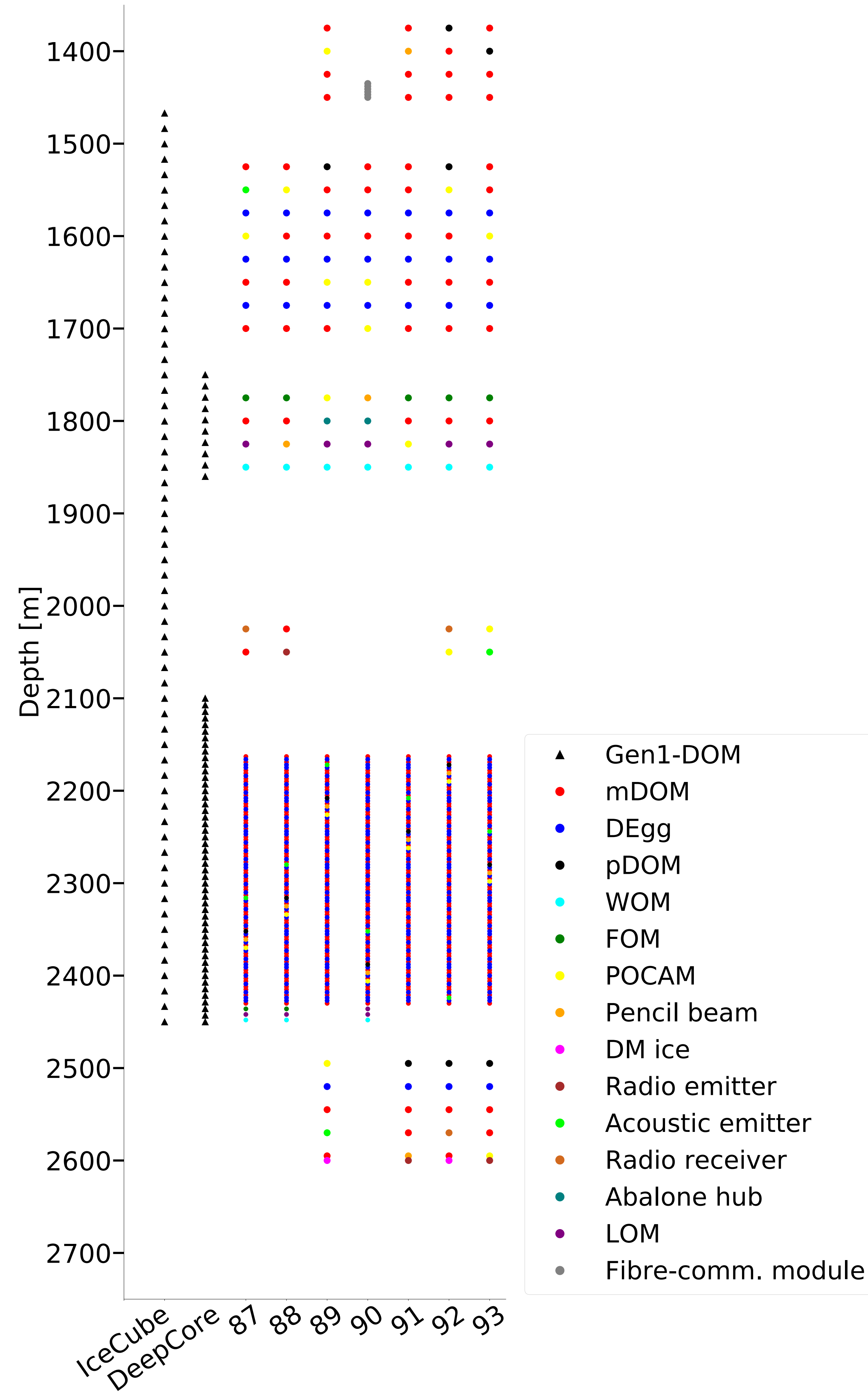
Next Step: the IceCube Upgrade

- Seven new strings of multi-PMT mDOMs in the DeepCore region
  - Inter-string spacing of ~22 m
- Suite of new calibration devices to reduce detector-related systematics
- R&D for IceCube Gen2
- Technical constraints:
  - Radius (drill time)
  - Power (target <4 W/chan)

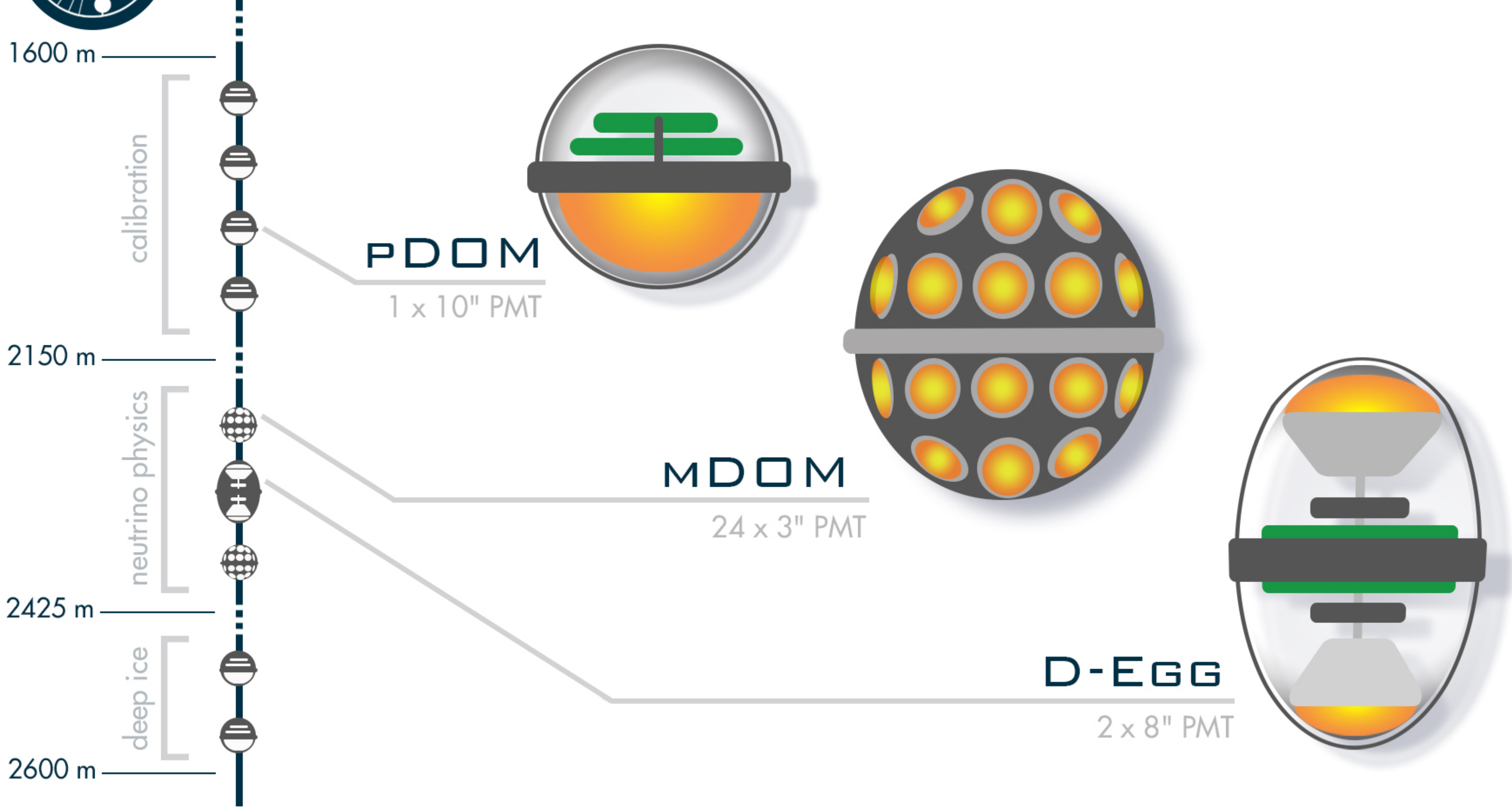


Form & Function

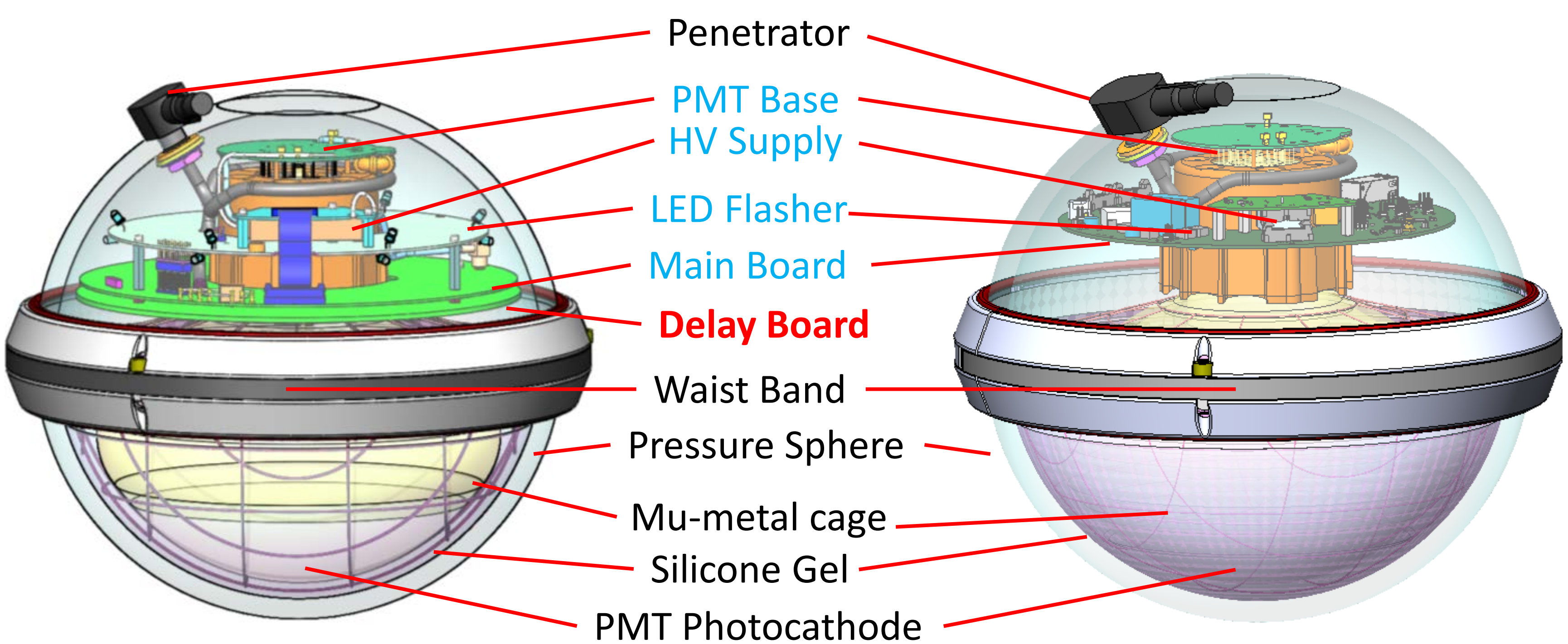
- Densely instrumented neutrino physics region within DeepCore
- Calibration light sources and detectors embedded in physics region and in deeper and shallower ice
  - Measure properties of “bulk” (undisturbed) and “hole” ice around DOMs
- R&D devices taking advantage of available connections



IceCube Upgrade Optical Sensors



Updated IceCube DOM (pDOM)



IceCube Gen1 DOM

Gen2 DOM

KEY:
Component identical
Component eliminated
Component re-designed

IceCube DOM with revised electronics: commercial 250 MSPS ADC and modern FPGAs for data buffering and compression

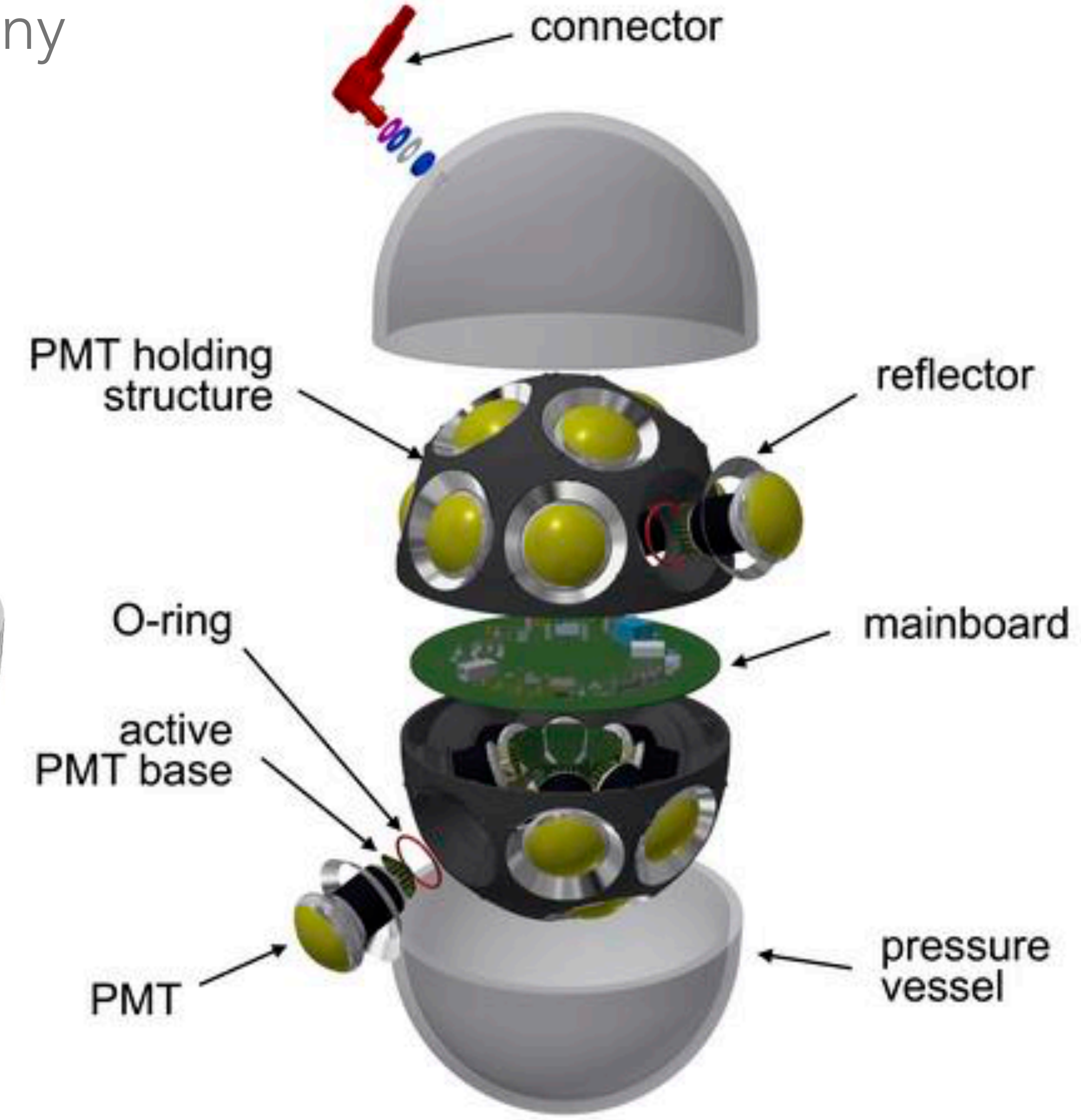
Primarily for cross-calibration

Double-PMT Digital Optical Module (DEgg)

- Evolutionary design from the Chiba University group
- Two 8" Hamamatsu high-QE PMTs in elongated pressure vessel
  - Roughly 2x the effective photon collection area of an IceCube DOM (wavelength dependent)
- Common electronics with pDOM
- Available volume for calibration devices, etc.

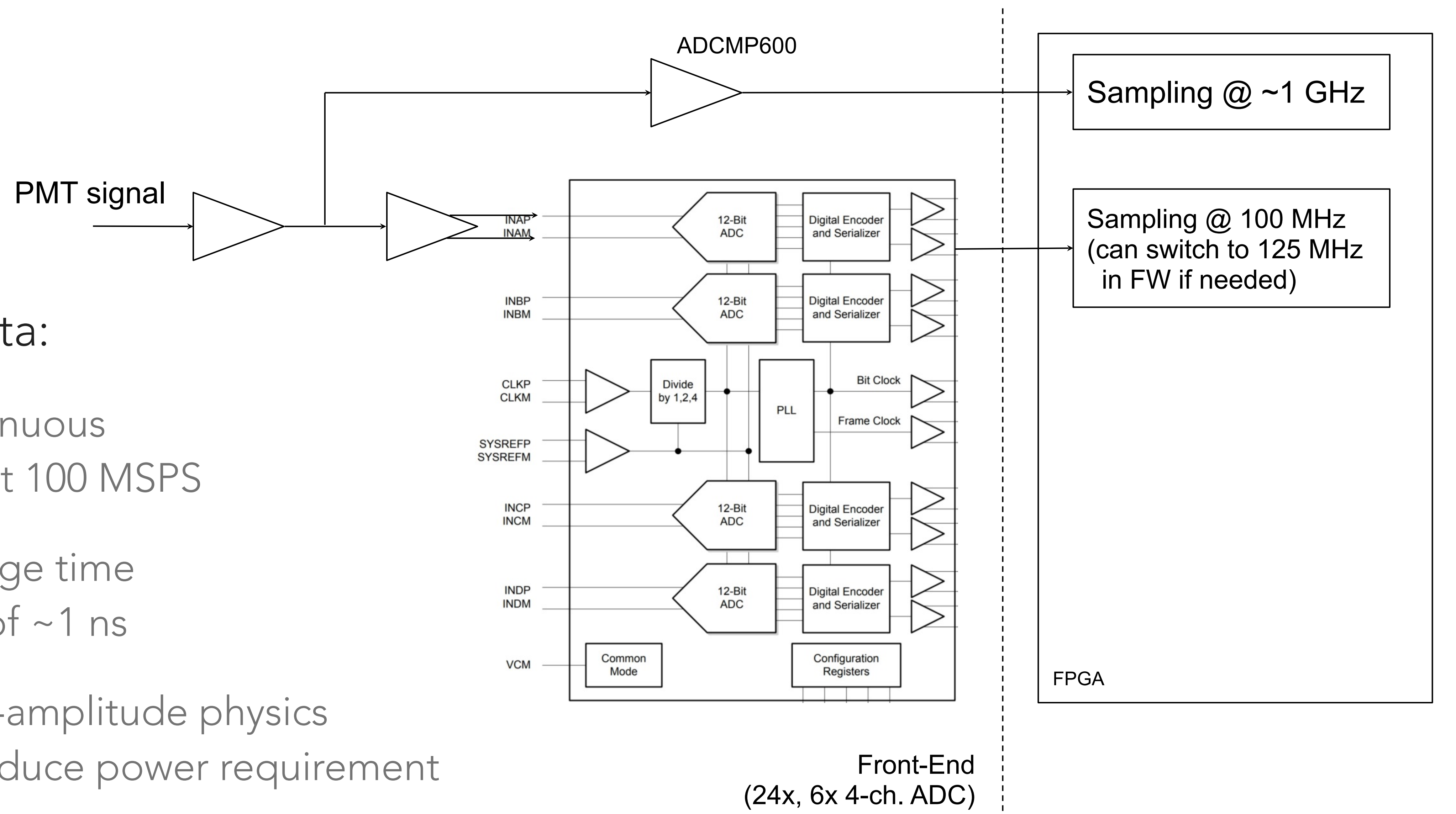
Multi-PMT Digital Optical Module (mDOM)

- 24 x 3″ PMTs in a 14″ DOM with independent readouts
  - KM3NeT-inspired, implemented in Germany
  - 2.2x the photocathode area of IceCube DOMs
  - Segmentation provides directional information for detected photons
- Onboard LEDs
  - Ice and hole calibration
  - Ability to mimic tau events

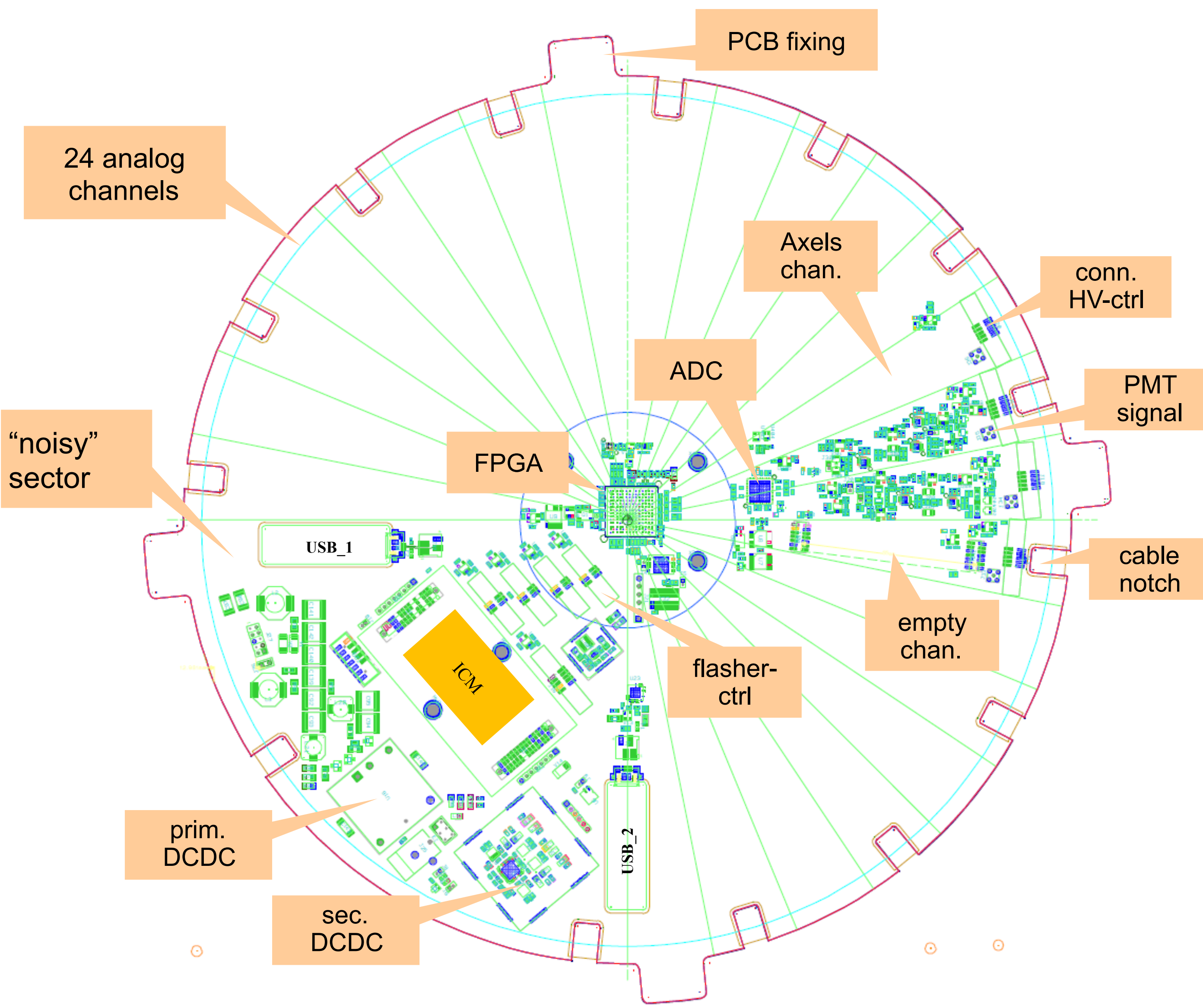


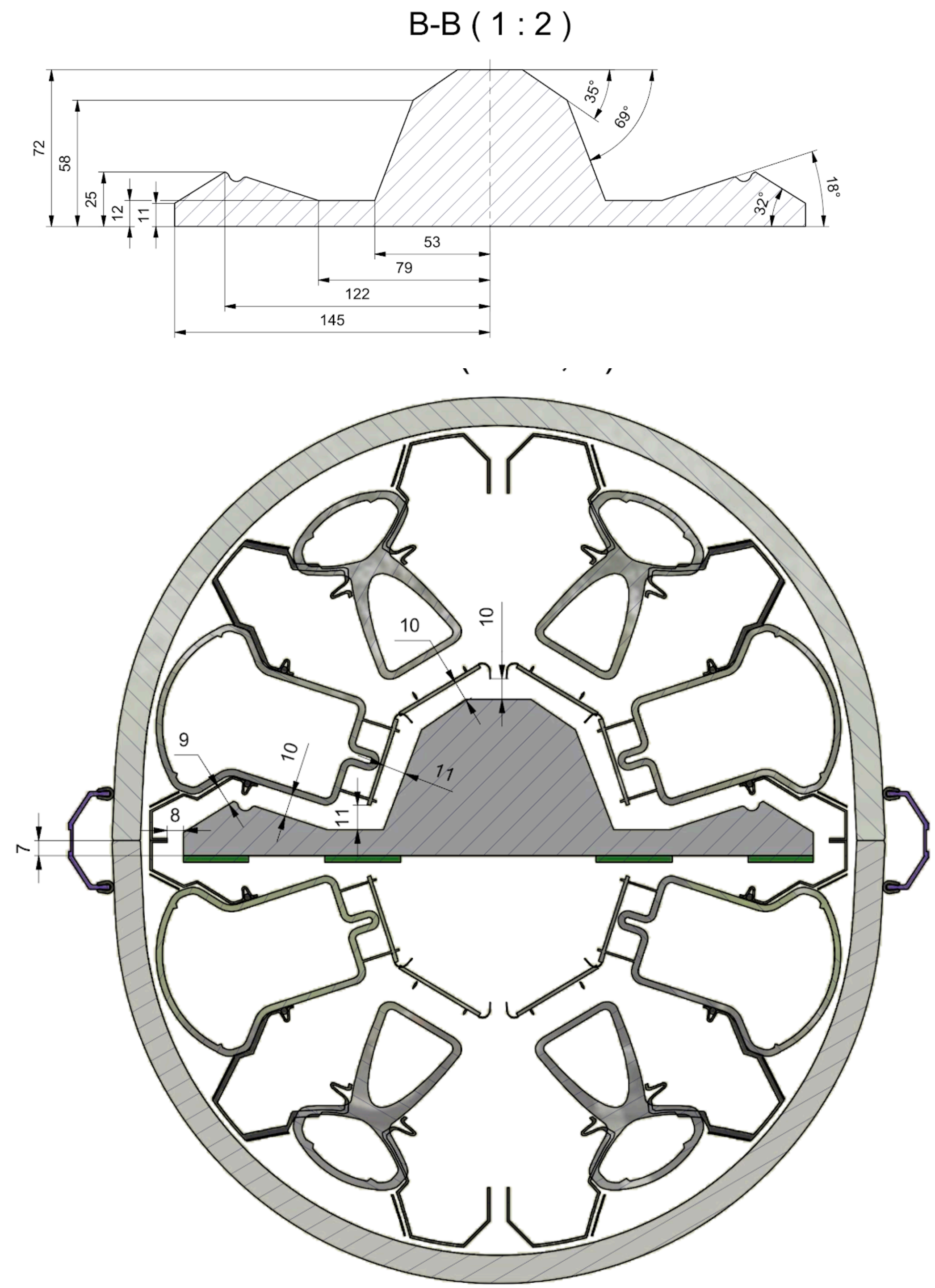
mDOM Readout

- Off-the-shelf circuits, readout power 3.4 W (plus comms, management)
- Continuously running, no wake-up, no dead time
- Recorded data:
  - 12-bit continuous waveform at 100 MSPS
  - Leading edge time resolution of ~1 ns
  - Exploit low-amplitude physics target to reduce power requirement



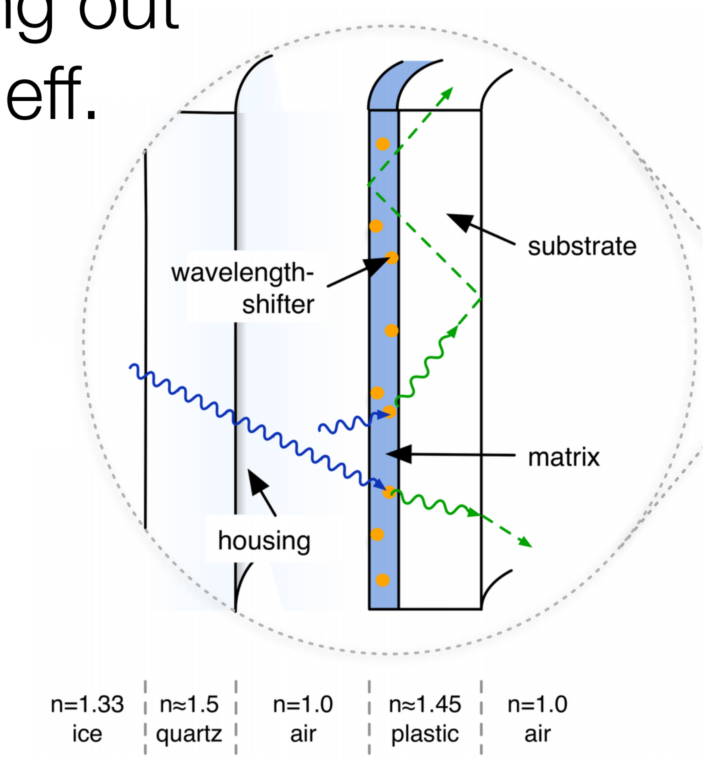
mDOM Circuit Board Design

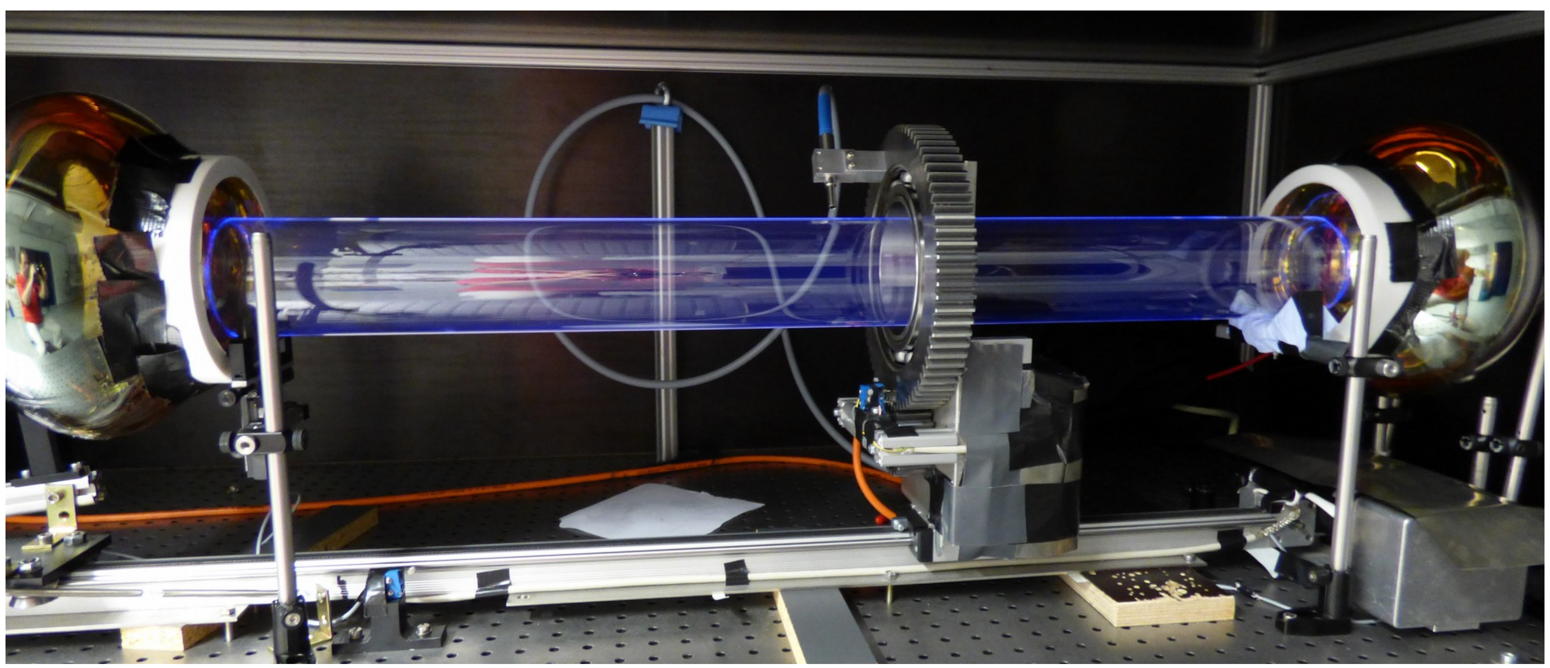


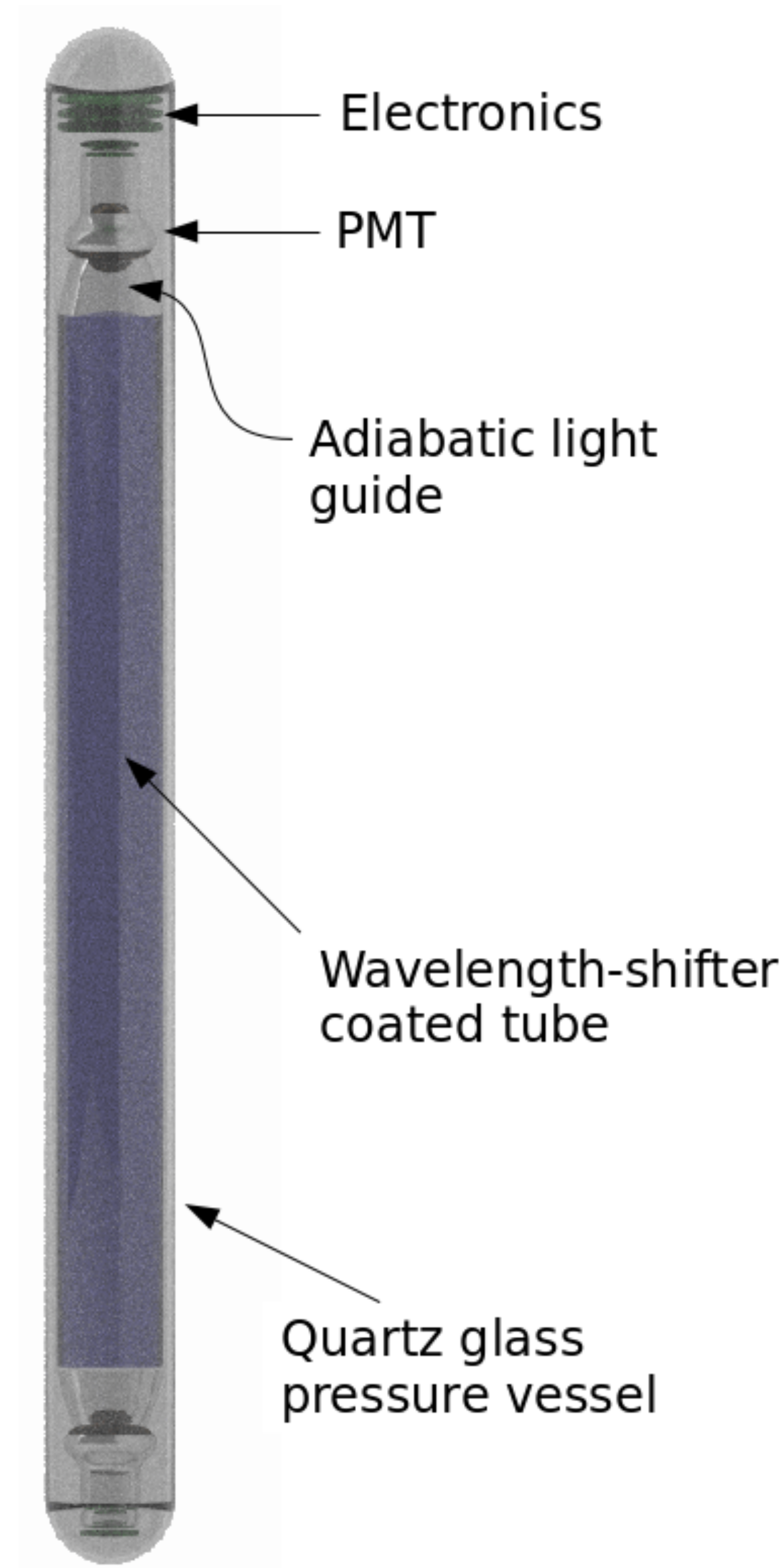


R&D: Wavelength Shifting Optical Module (WOM)

Two small (e.g. 3”) PMTs reading out a WLS-coated tube: 45% opt. eff.







R&D: Fiber Optical Module (FOM)

- Bare WLS fibers channel photons to a single small PMT (double-ended readout also possible)
  - Light collection with fibers (~$2/m for 1 mm), cheaper than large PMTs
  - No absorptive glass surrounding the main light collector – more UV collection
  - Easy to transport, deploy in narrow hole
- Many fibers required for reasonable collection area, but could provide quasi-continuous sensitivity
- Reduced timing precision (like WOM)