New optical sensors for IceCube-Gen2

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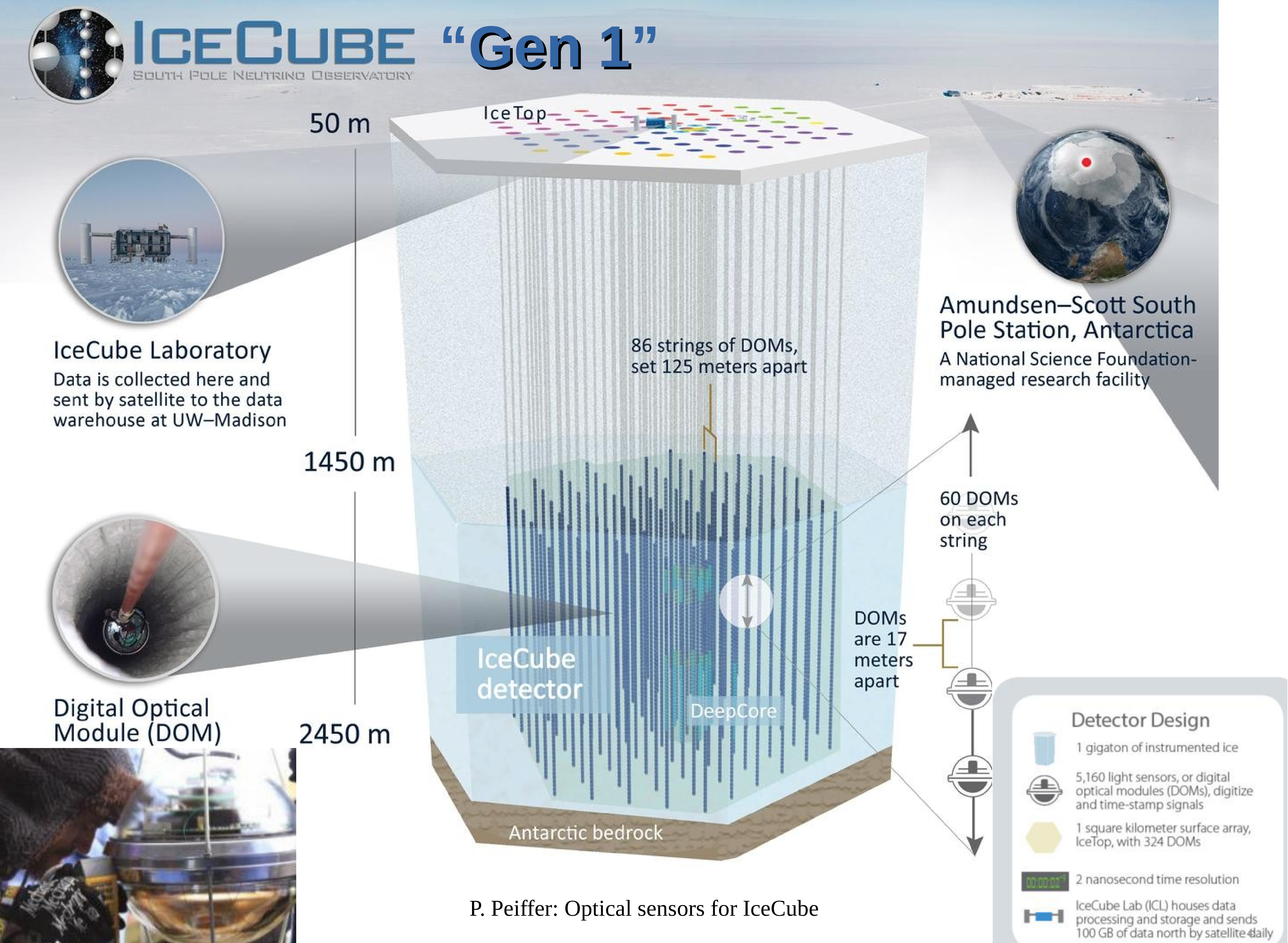
HAP non-thermal workshop
Erlangen, September 21st 2016

IceCube
SOUTH POLE NEUTRINO OBSERVATORY

JOHANNES GUTENBERG UNIVERSITÄT MAINZ
JG|U

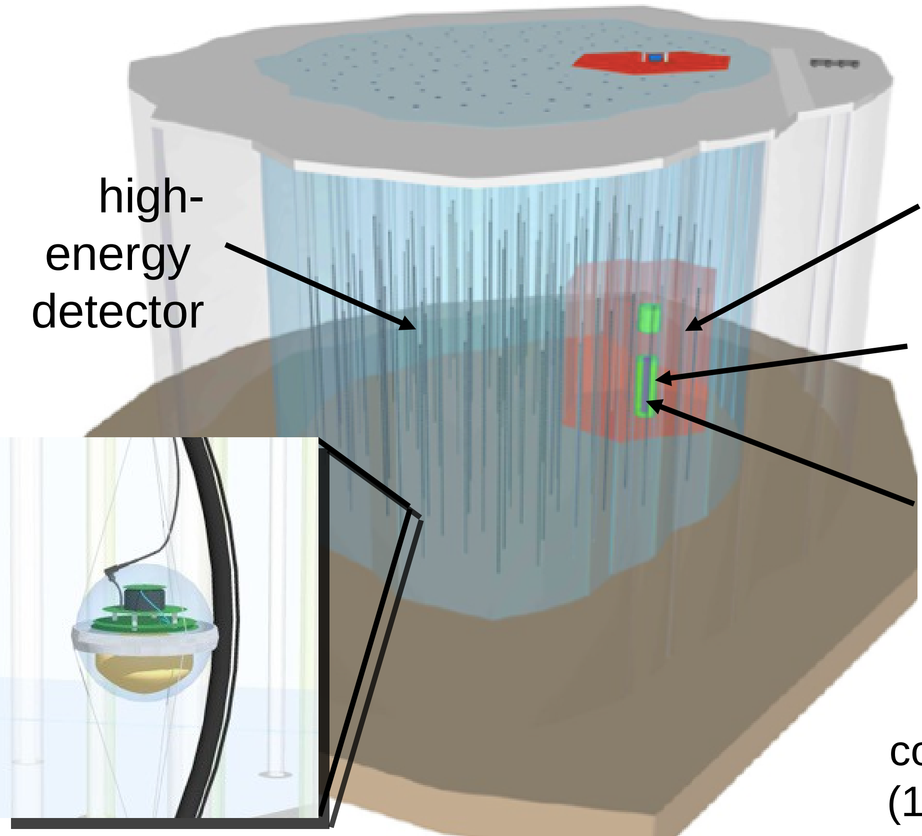
IceCube "Gen 1"



IceCube Generation 2

Next-generation neutrino telescope at the South Pole

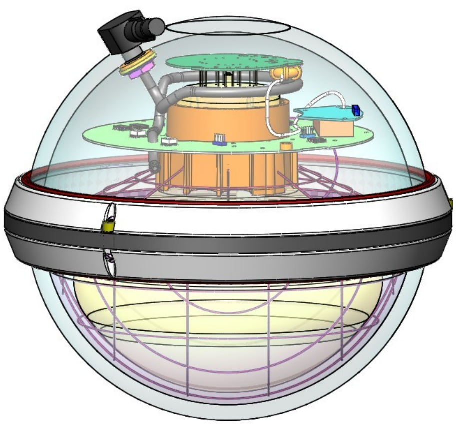
- Physics goals:
  - neutrino astronomy (high-energy detector)
  - neutrino oscillation physics (PINGU)
- Instrumentation
  - ~10,000 optical sensors on *O*(140) strings
  - 5-10 km^3 instrumented volume
- Limitations
  - Extreme ambient conditions (e.g. 550 bar pressure)
  - Technical limitations (e.g. weight and power per cable)
  - Cost (e.g. drilling cost and speed)



Different sensor-concepts for Gen2

- In sequence of boldness

Gen2 DOM
(baseline)



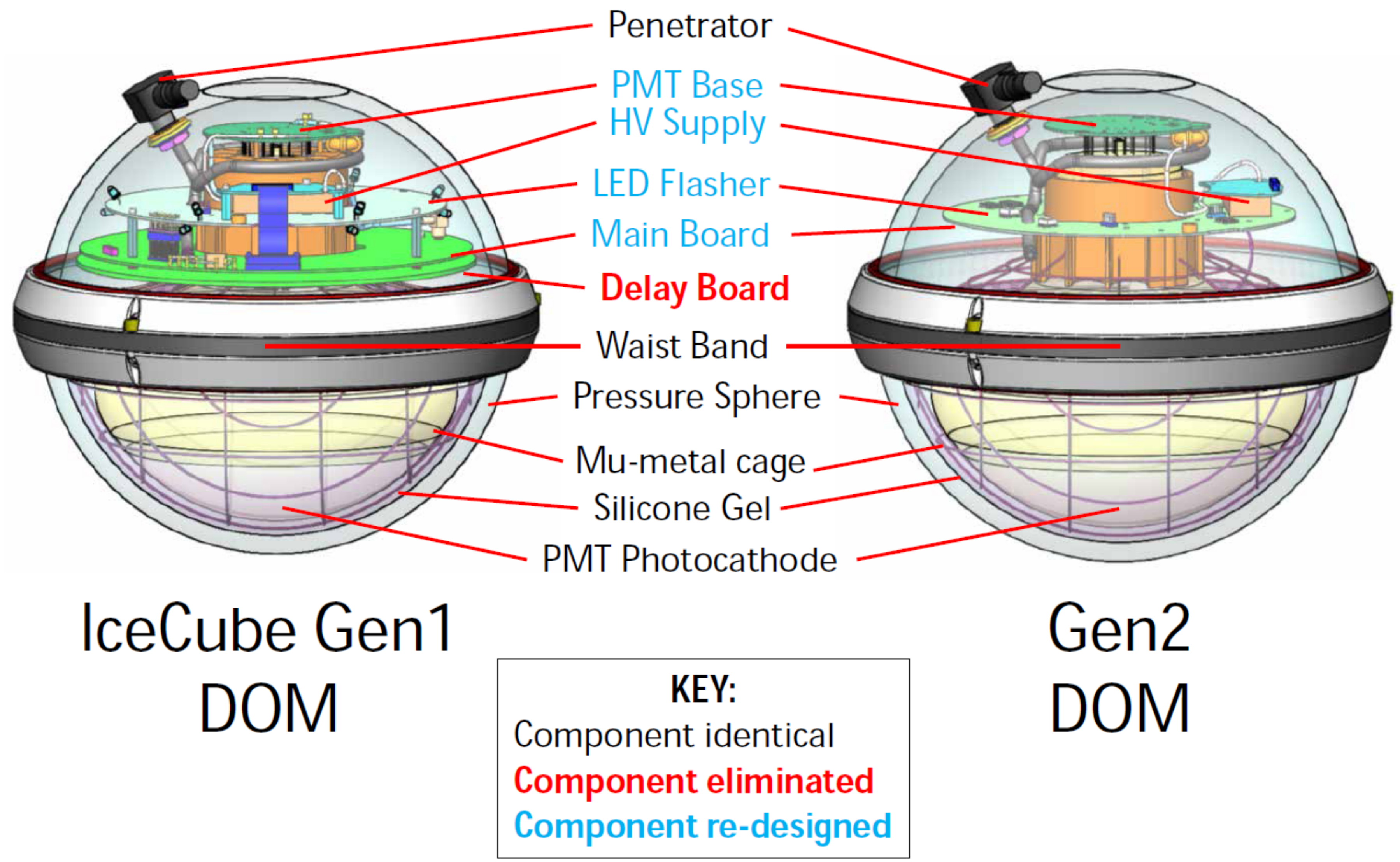
Modernized Gen1
Digital Optical Module

D-Egg

mDOM

WOM

Baseline: Gen2 DOM



Plan: add inclination sensor to monitor orientation of DOM

D-Egg

Dual optical sensors in an ***E***llipsoid **G**lass for ***G***en2

千葉大学
Chiba University

D-Egg concept

- 2 x 8-inch PMTs (Hamamatsu R5912-100 HQE)
- custom made elliptical pressure vessel

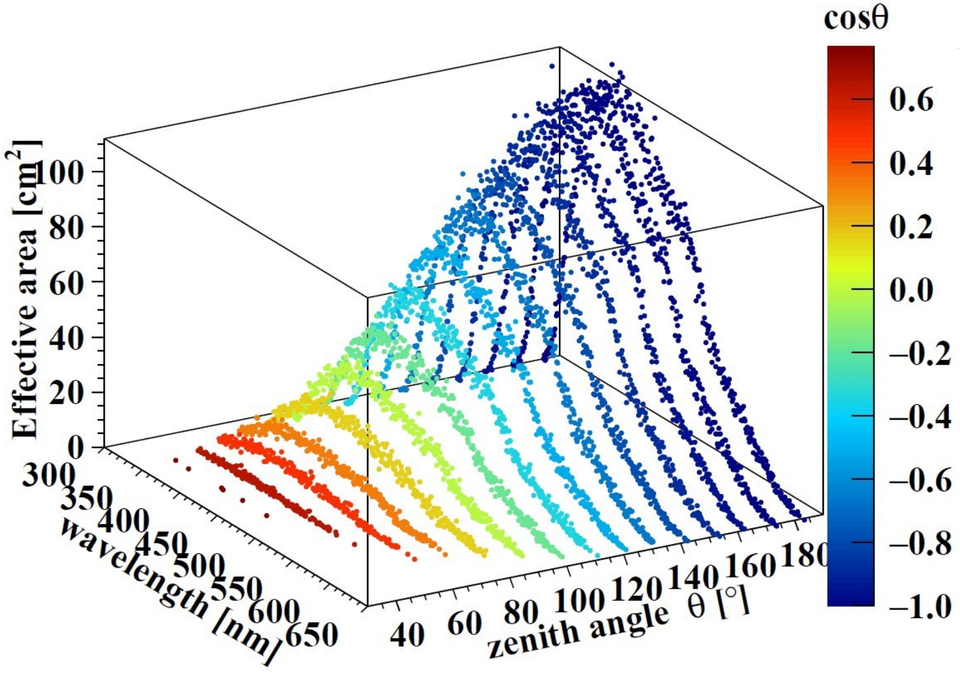
(Ø 12 inch = 300 mm, length 535 mm)

- refined borosilicate glass (Fe_2O_3 depleted)
- stability tested at 700 bar

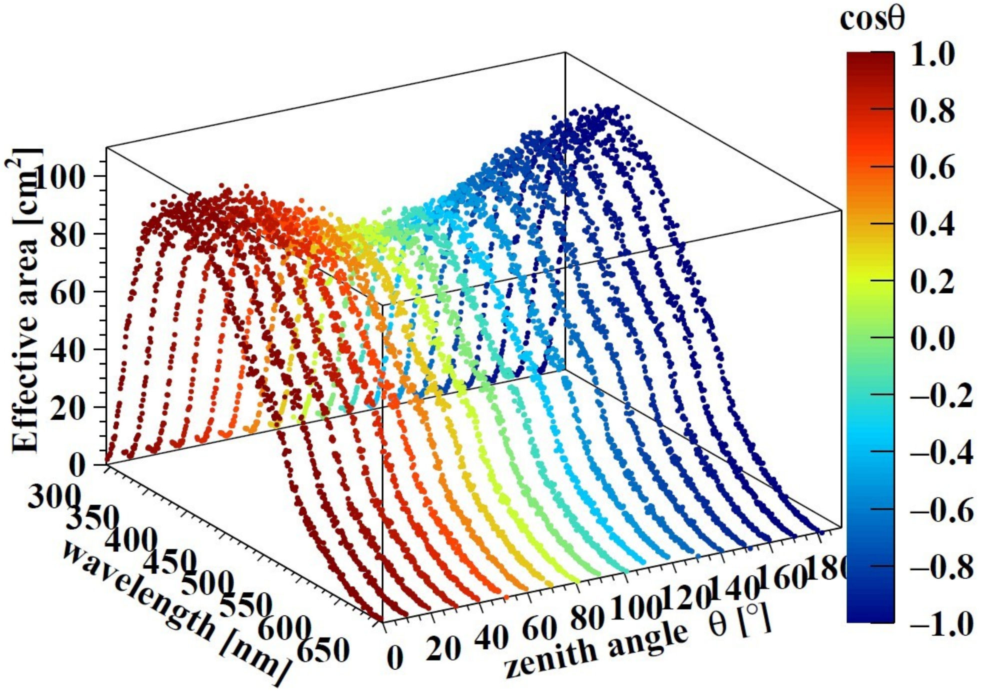
Advantages:

- increased sensitive area
- 4π angular sensitivity
- increased UV sensitivity
- muon veto
- smaller diameter saves drilling cost
- will be equipped with a calibration device to study ice properties

D-Egg angular acceptance



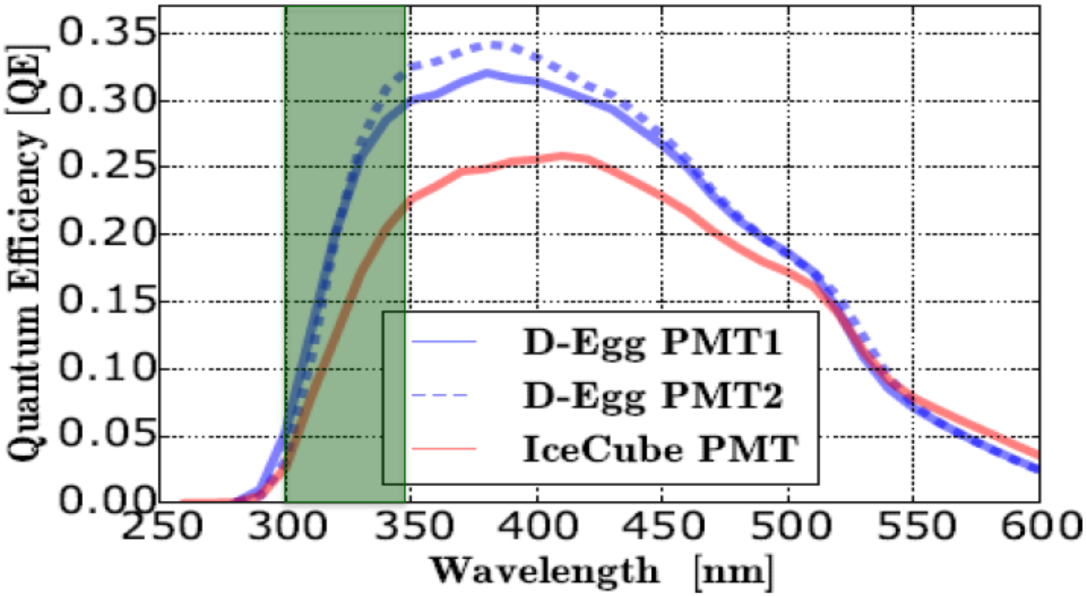
Ice-Cube DOM

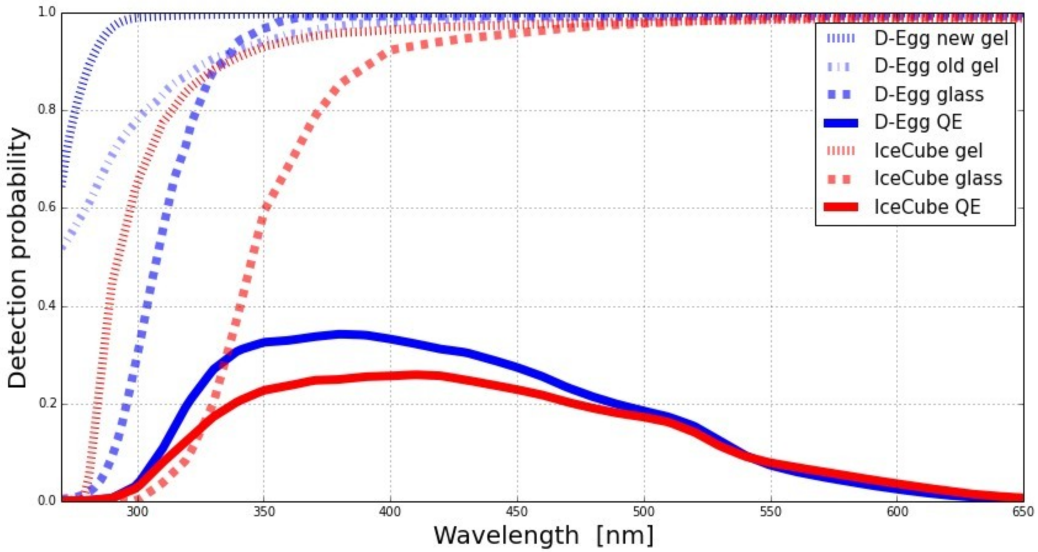


D-Egg

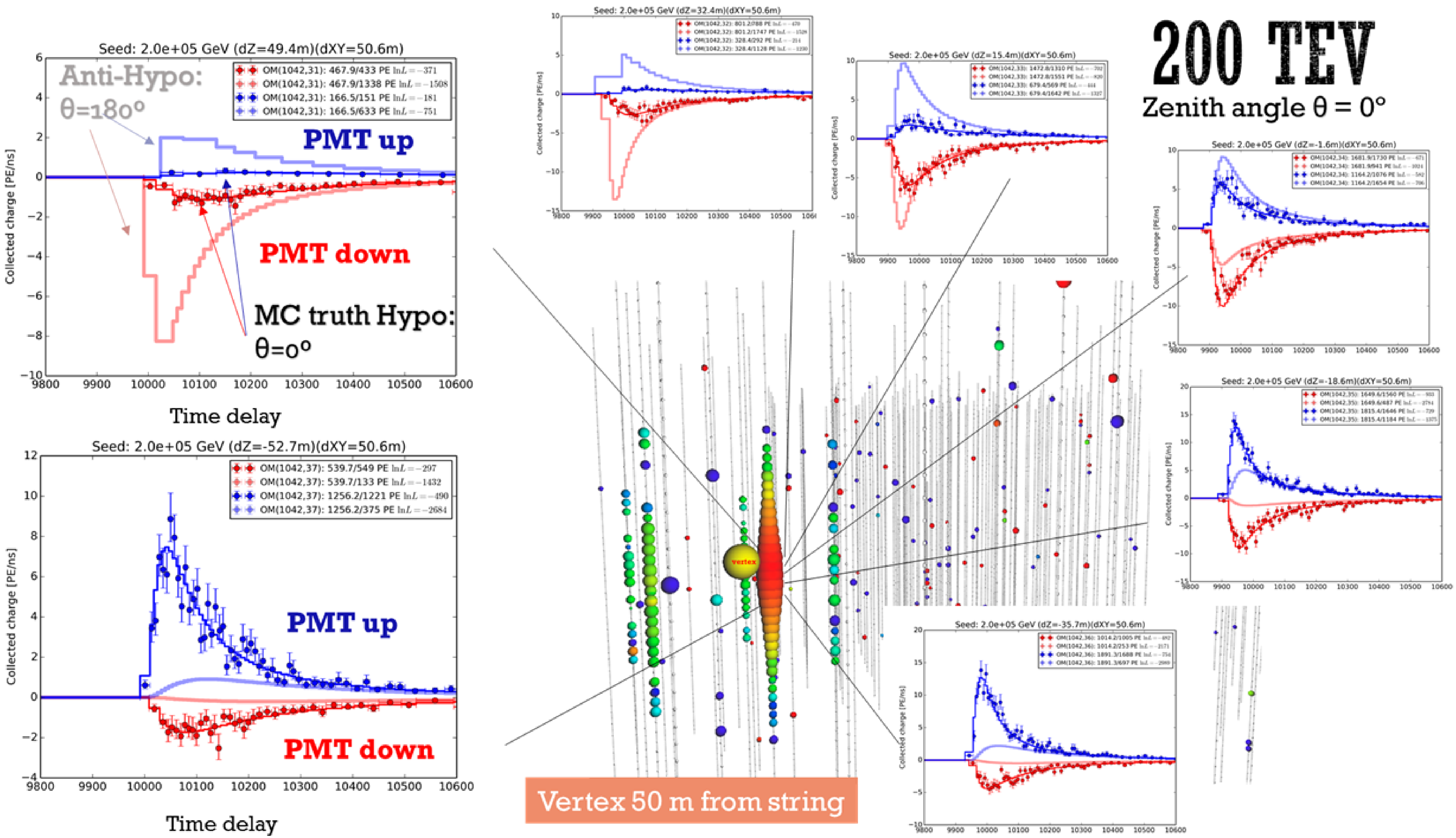
PMT quantum efficiency included

UV-sensitive glass, gel and PMT





D-Egg event simulation



Upward looking PMT:

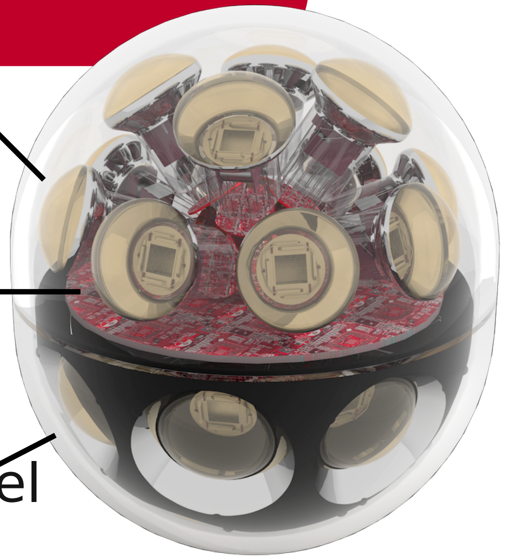
independent timing and signal information for improved reconstruction.

mDOM

multi-PMT Optical Module

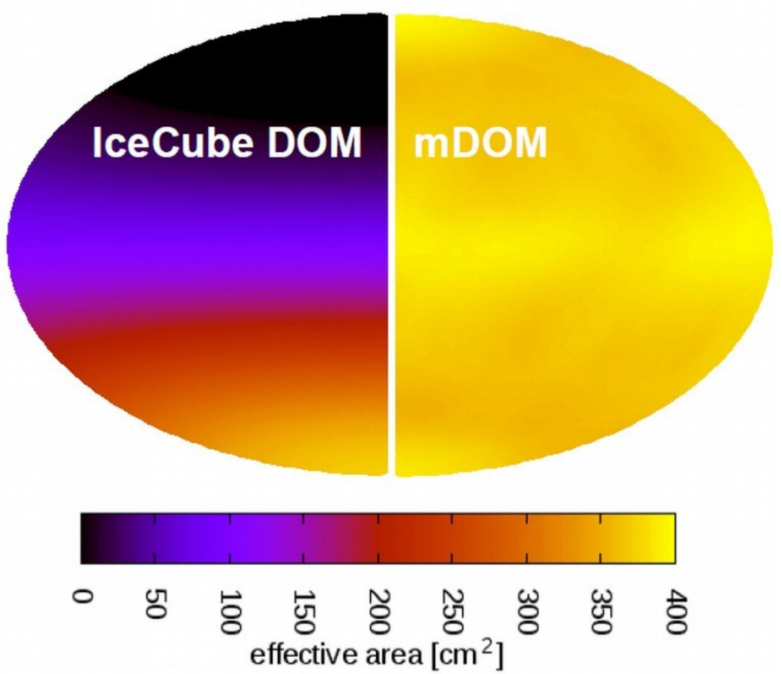
mDOM basics

- Based on KM3NeT design
- Pressure vessel diameter: 14 inch
- 24x 3 inch PMTs
- Signal digitization for each PMT



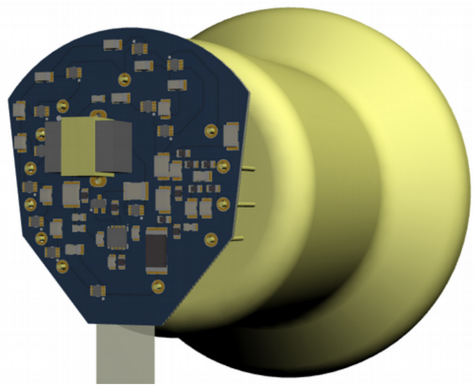
Features

- More than doubled effective area compared to IceCube-DOM
- Uniform 4π angular effective area
- Directional sensitivity
- Local coincidences
  (e.g. for background suppression)
- Improved photon counting



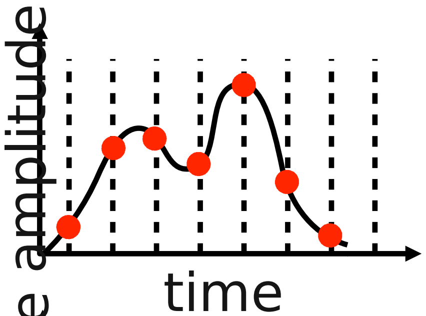
For λ = 470 nm without QE

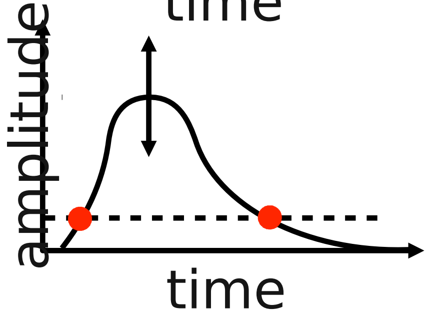
Challenge: electronics and space



New optimized board shape with HV circuitry

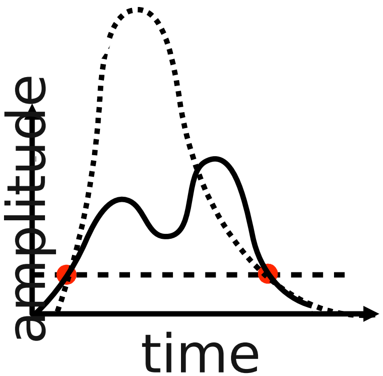
- HV generation on base (Cockcroft Walton design, © Nikhef)
  - low power (3−5 mW)
  - adapted to optimized board shape
- Front-end electronics for signal processing on backside

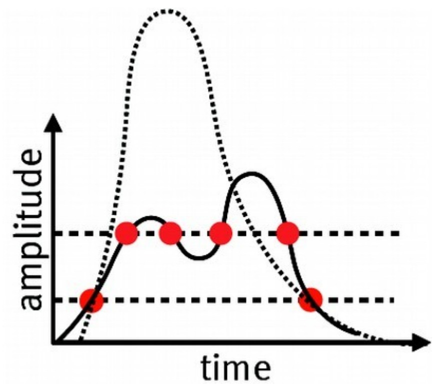




Alternative readout method to save bandwidth, power and space:

Time over threshold (ToT)
- Use known spe-pulse shape to extract pulse
- Baseline design: 4 comparators in discrete design
- More ambitious goal: 63 comparators in ASIC design





WOM

Wavelength-shifting Optical Module

WOM basics

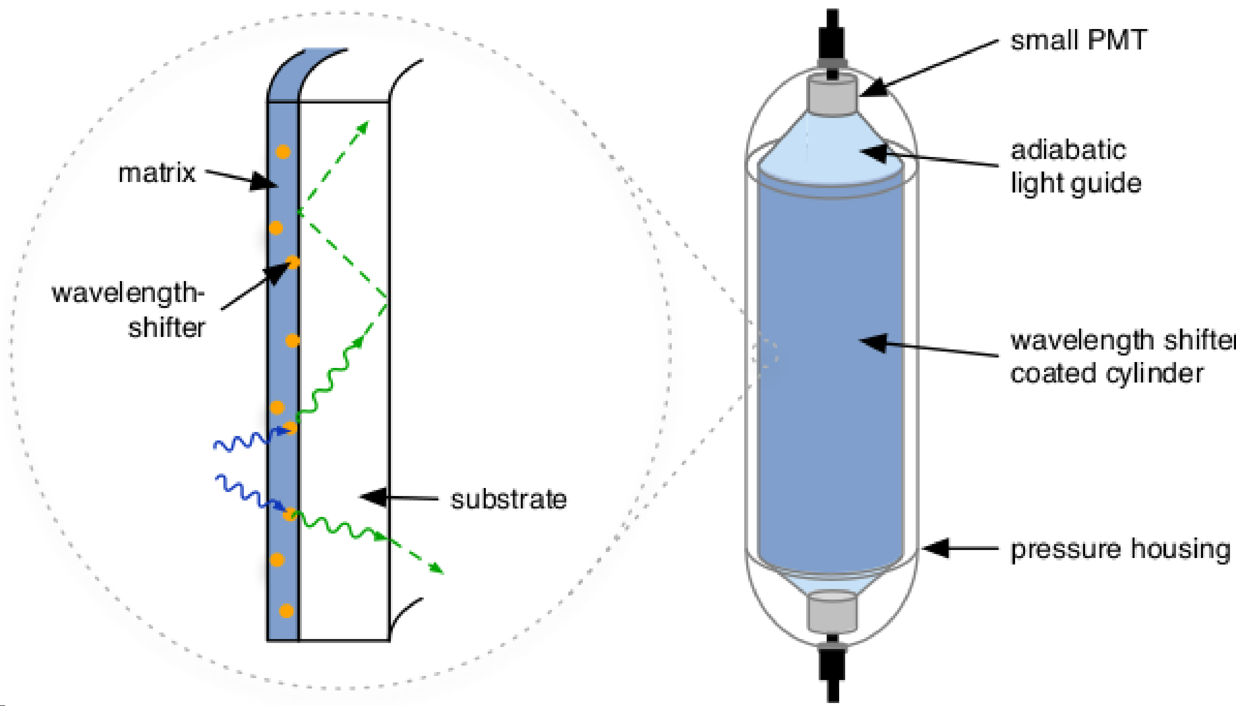
- Quartz glass cylinder (Ø11 cm, L=113 cm)
- Wavelength-shifting tube inside
- Light collection via total internal reflection
- 2 small PMTs (e.g. KM3NeT)

Advantages:

- UV sensitivity
- Large effective area
- Low noise
- Cost effective

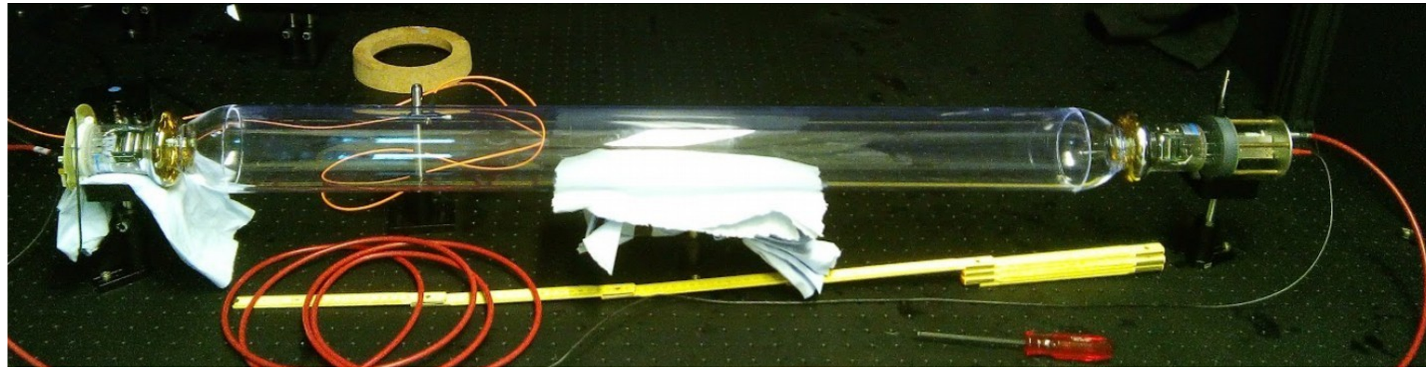
Status

- Dip-coater running reliably
- Pressure vessel tested

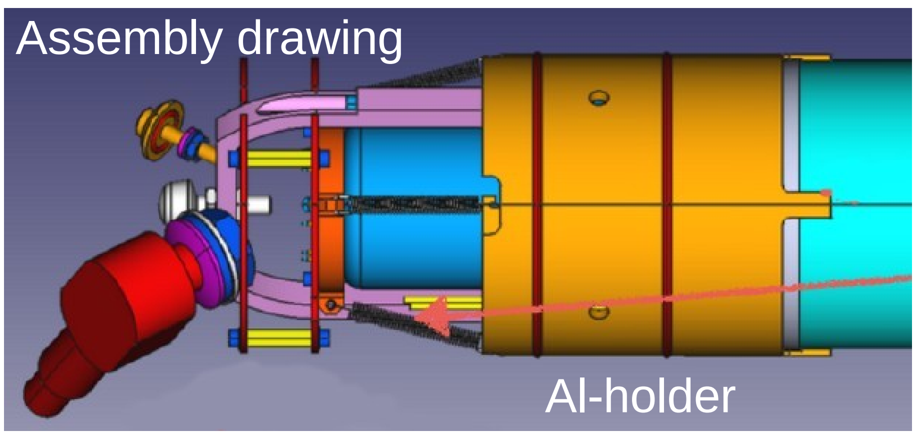


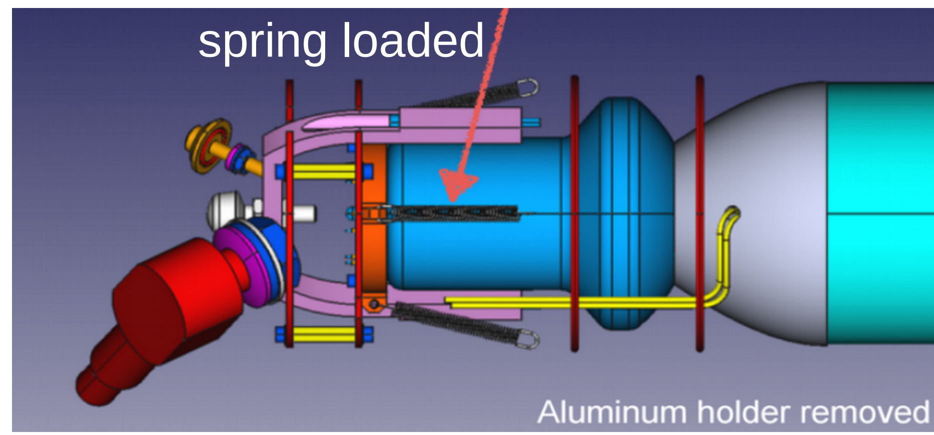
Mounting

Adiabatic light guide



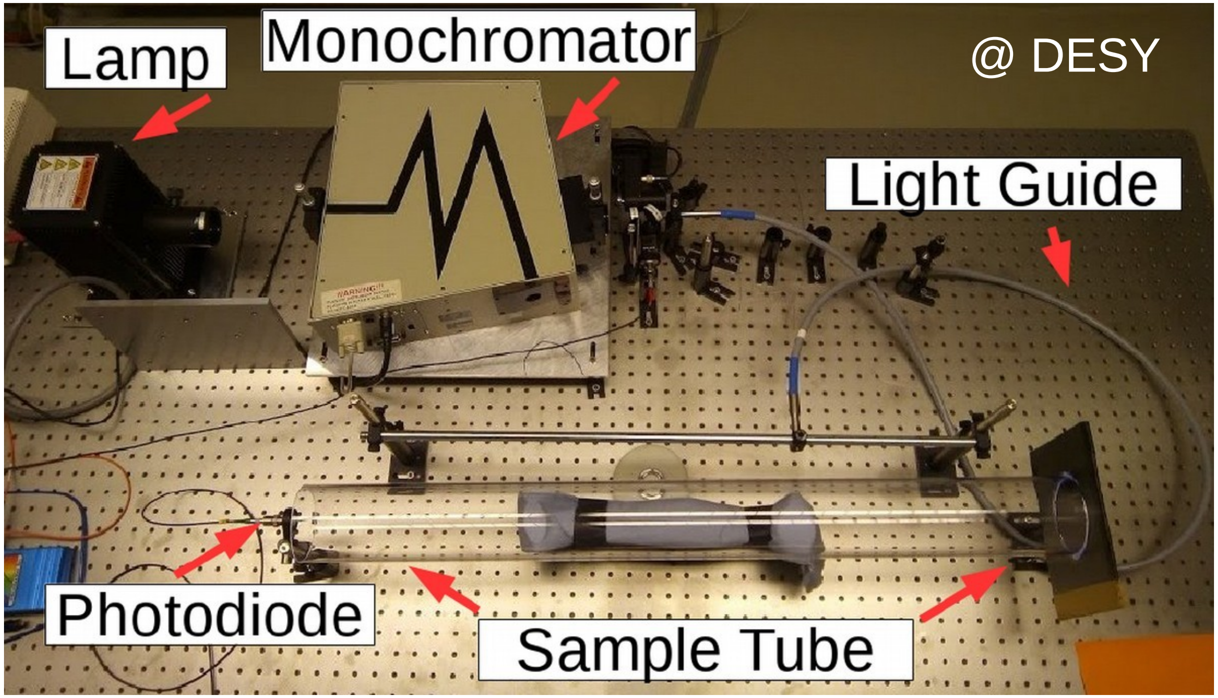
...mounted on tube with UV curing glue





Assembly test

Measurements

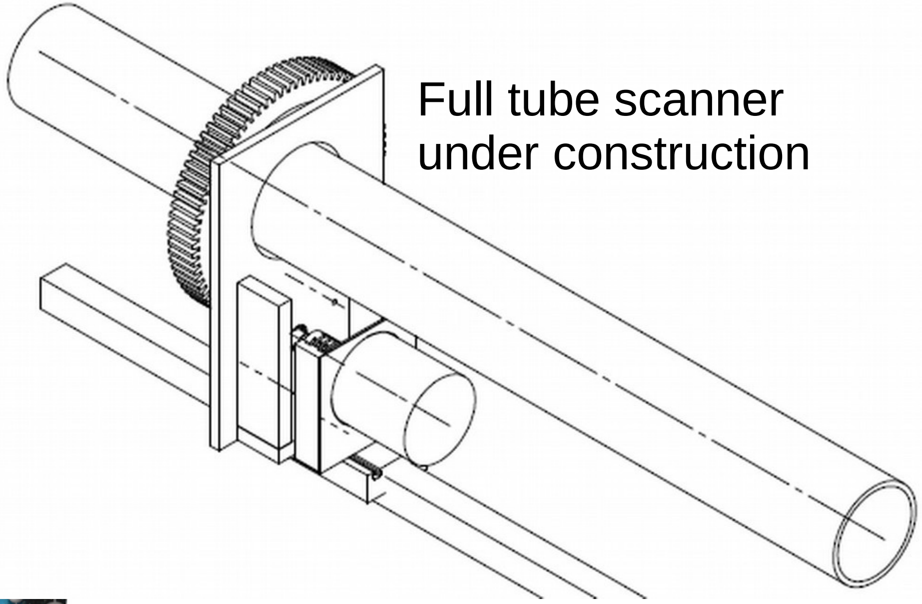


+ similar setup at SKKU

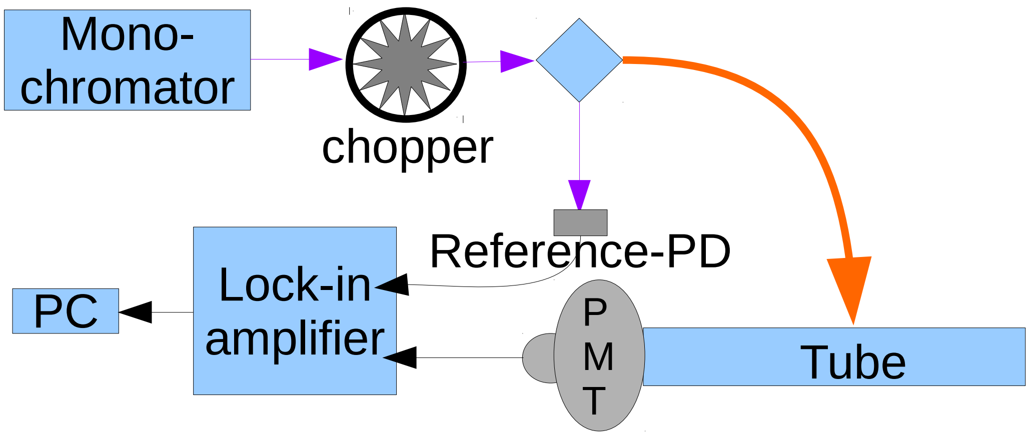
Measurement:
Photo-diode / PMT signal
vs. reference diode
using lock-in amplifier setup

Definition Efficiency:

$$\epsilon = \frac{photons\ detected}{photons\ emitted}$$

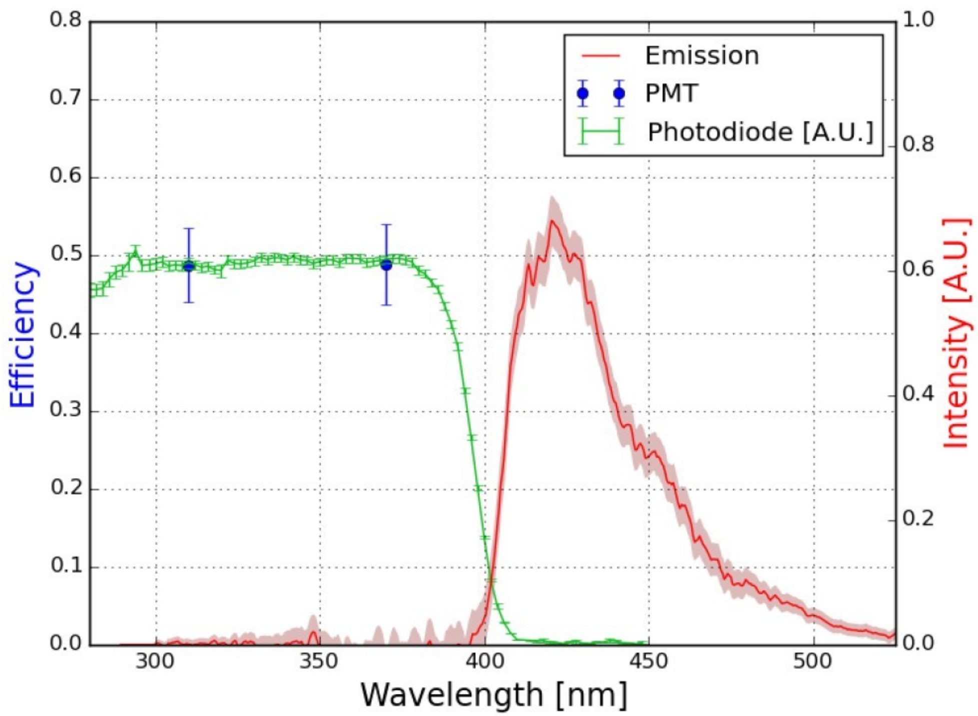


Full tube scanner
under construction

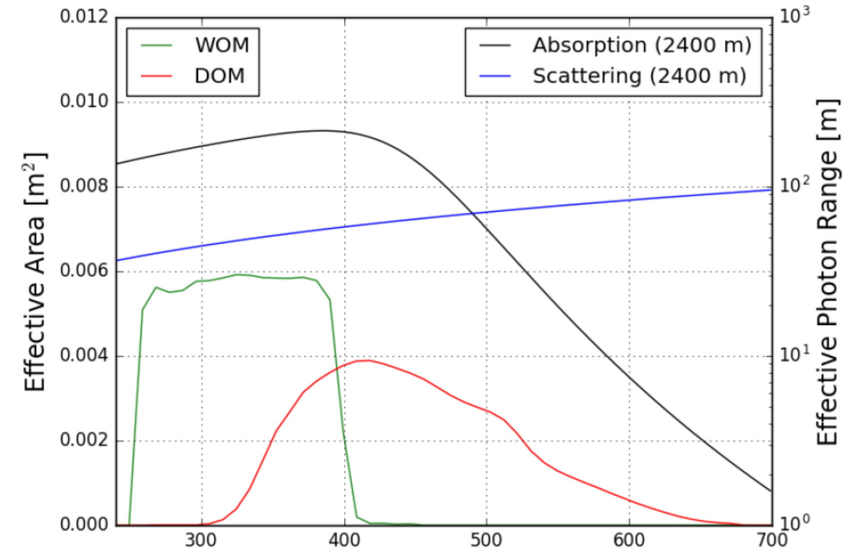


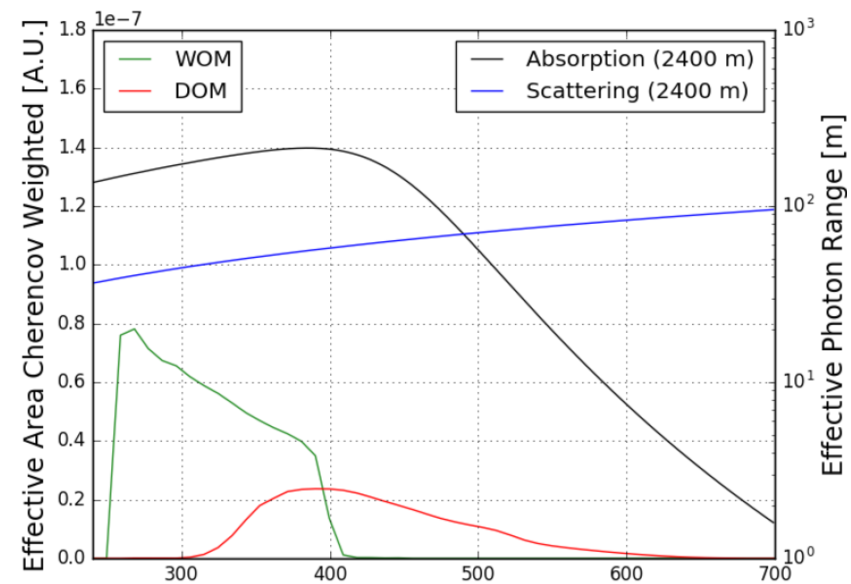
Efficiency

WLS absorption and emission



Effective area



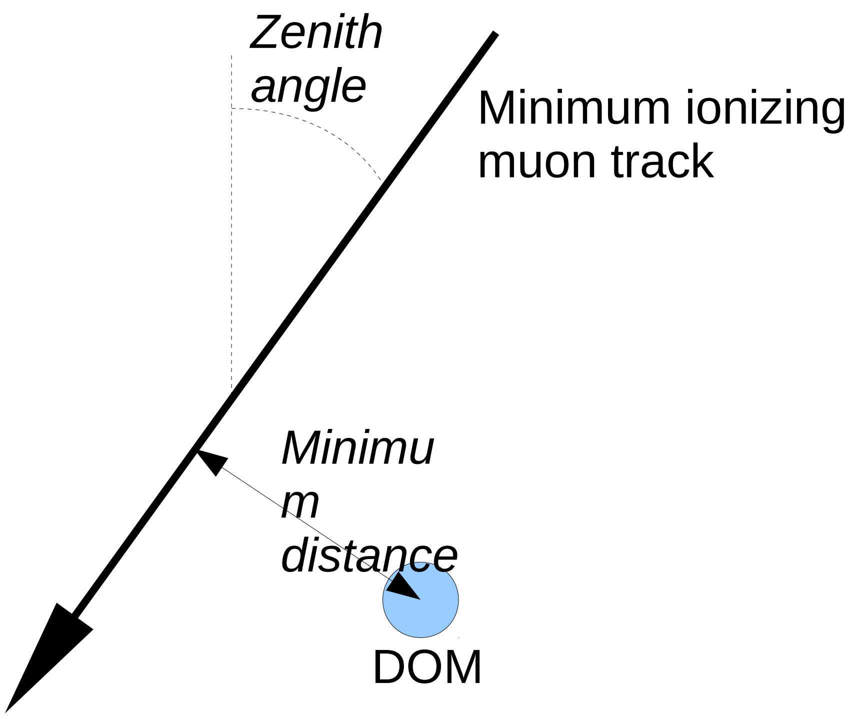


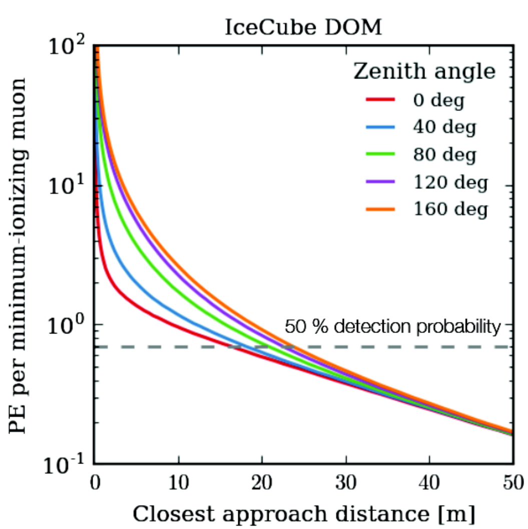
...Cherenkov weighted.

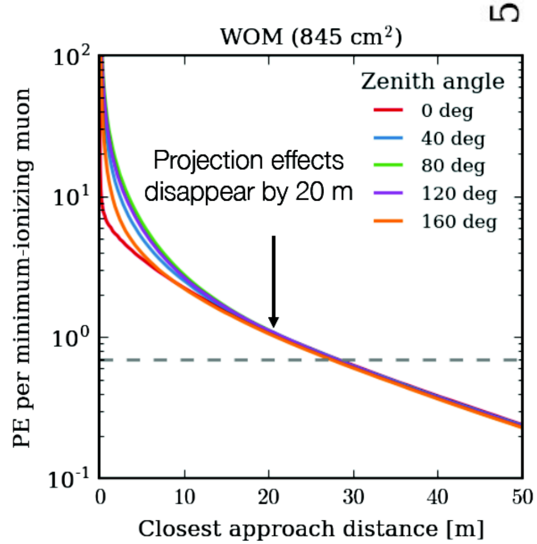
- Factor ~3 higher effective area than DOM (integrated over λ = 250-700 nm including Cherenkov weighting.)
- Improved angular acceptance (though not at mDOM level)
- But timing resolution ~10 ns

- Full detector simulation ongoing

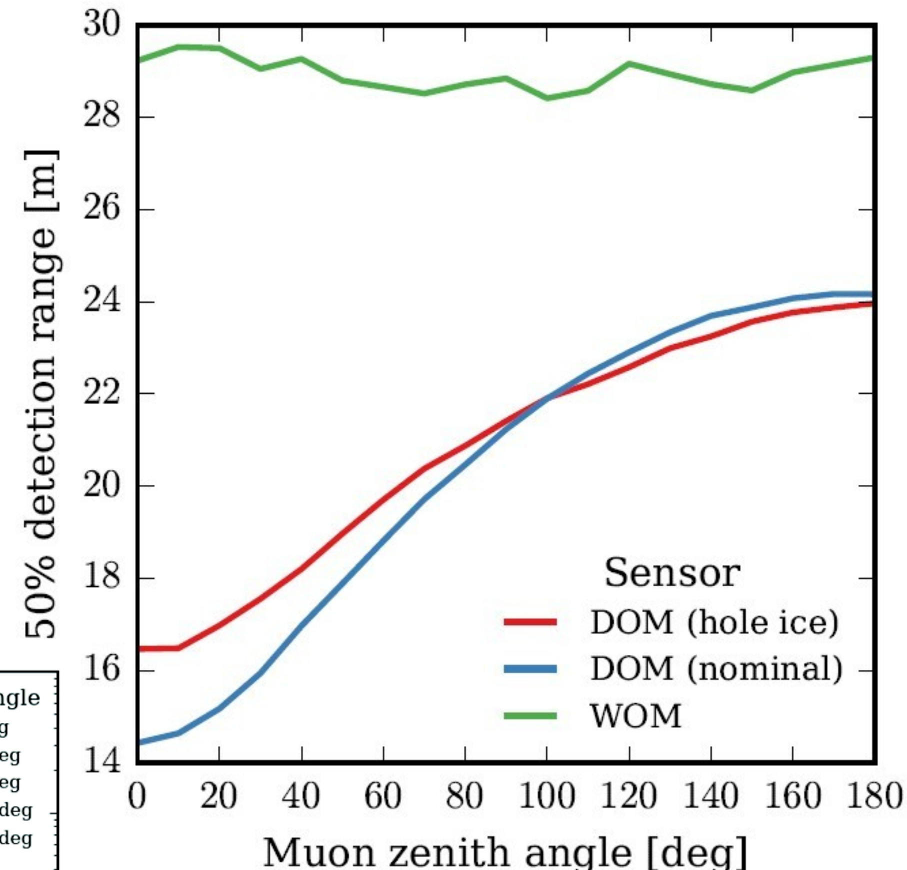
Performance







Muon detection range



Summary

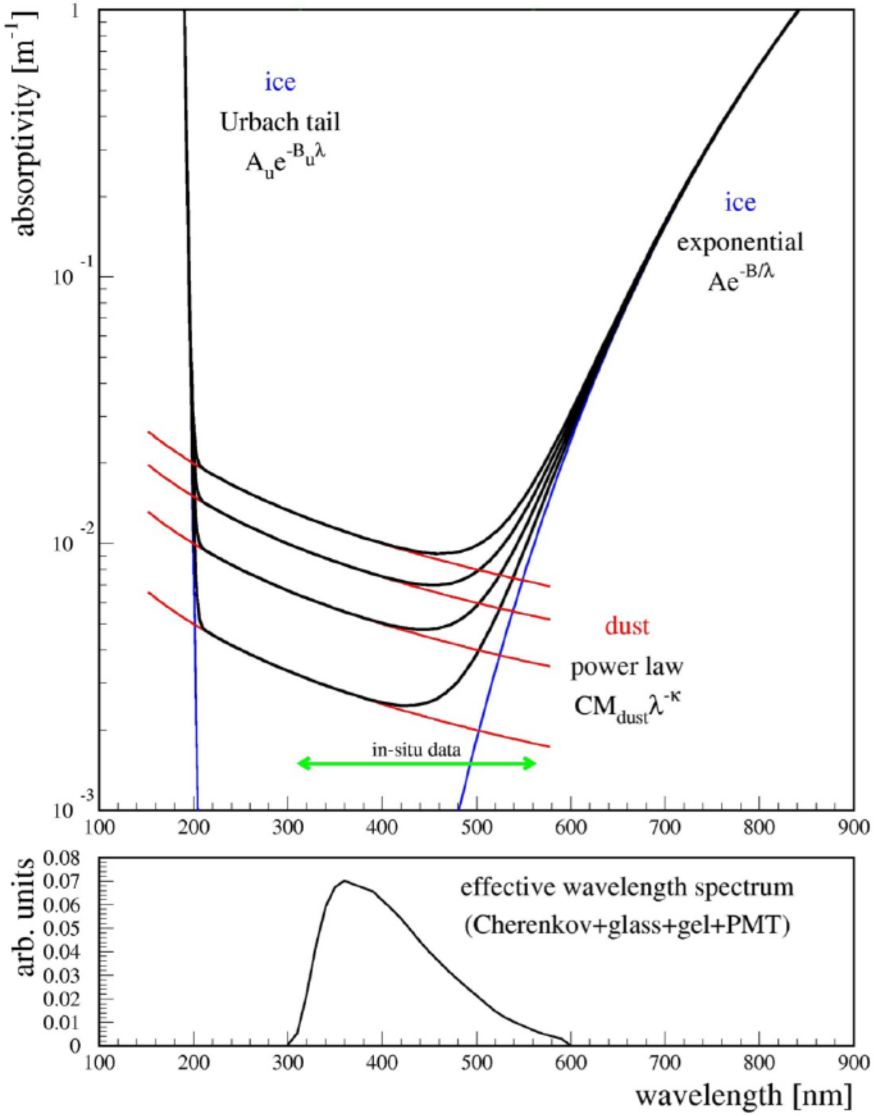
- Several promising optical modules are in development
- Focusing on different advantages over the baseline DOM
  - Spectral sensitivity
  - Angular acceptance
  - Noise reduction
  - Cost per module
  - Drilling speed and cost
- Final module will have to find an optimum between performance and cost (and thereby number of modules)
- Will probably include properties and R&D from several modules (e.g. wavelength-shifter option)
- Possibly different modules for different purposes

Thank you for listening

Backup slides

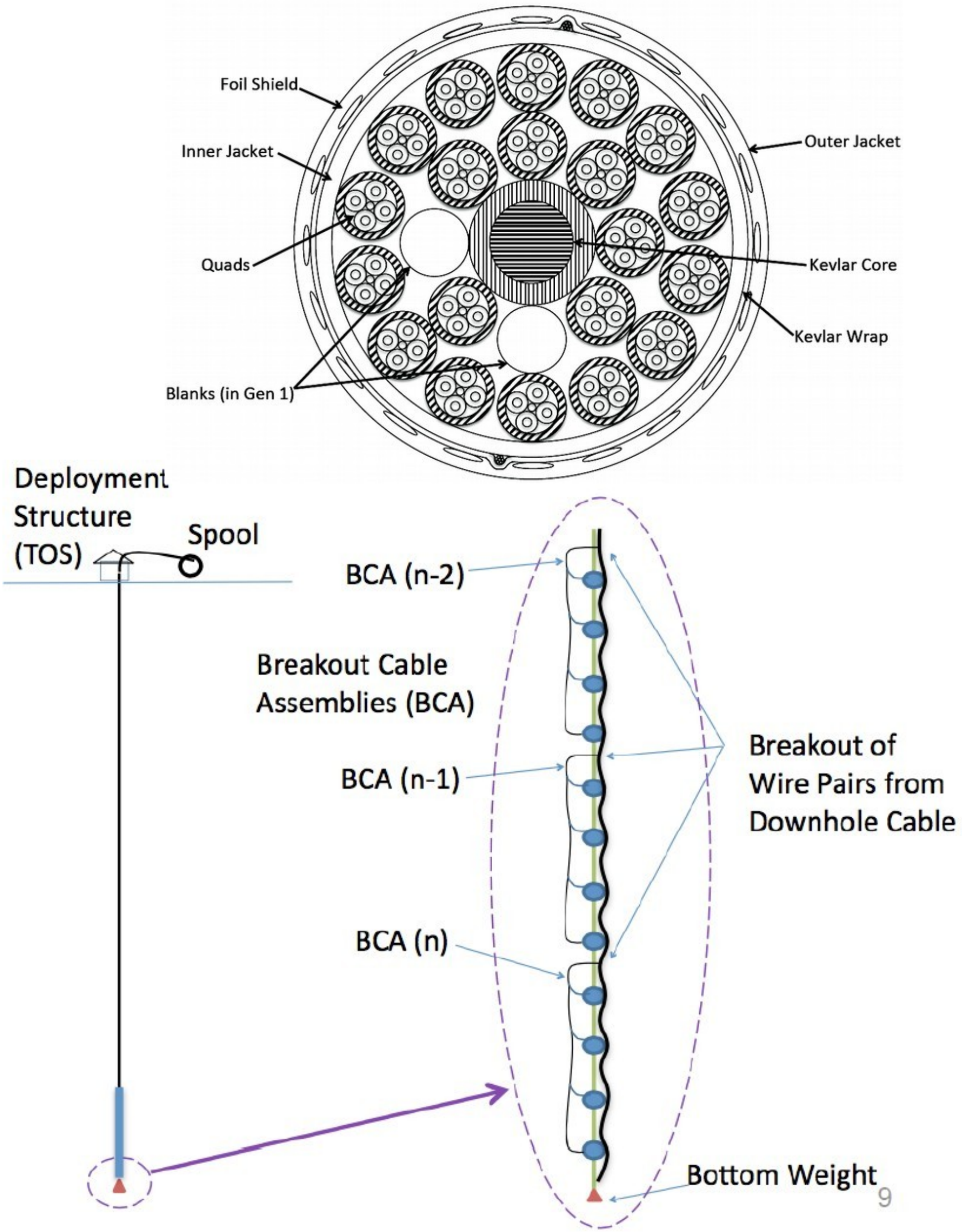
Ice Cube ambient conditions

- temperature down to −45°C
- pressure up to 550 bar (freeze-in)
- low radioactivity (optical noise)
- low light-absorption, but more scatte than in water
- optical modules limited to ∅ ~14 inch

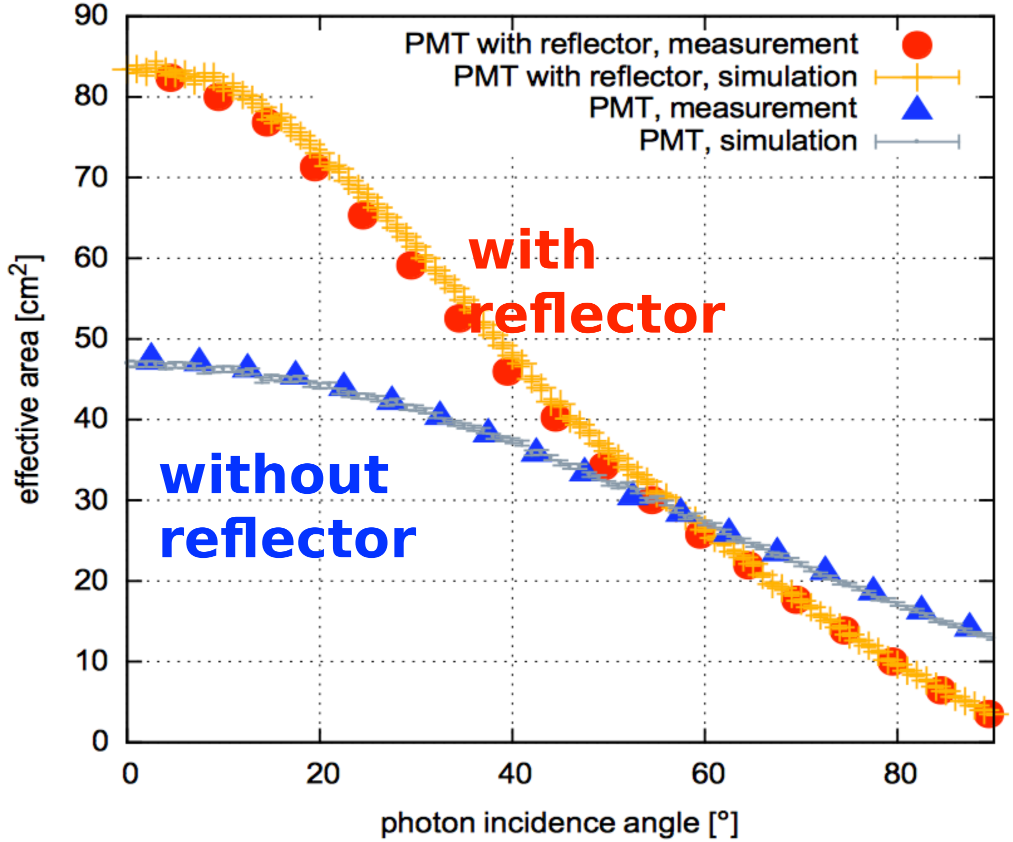


Technical limitations

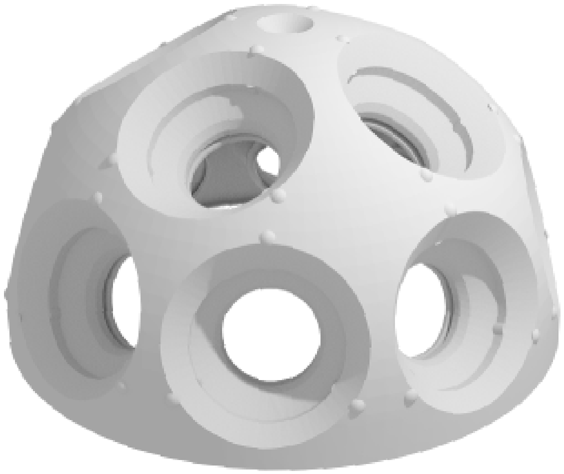
- Power & communication via copper cables
- Power budget limited by voltage drop (2500 m cable)
- 4 DOM per breakout:
  < 2.3 W each
- 3 DOM per breakout
  < 3.2 W each
- Bandwidth per OM ~ 1Mbit/s
- Weight limit ~20 kg/module



Reflectors and angular acceptance



PMT holding structure



PMT with reflector

- Reflectors significantly increase directionality of PMT

IceCube

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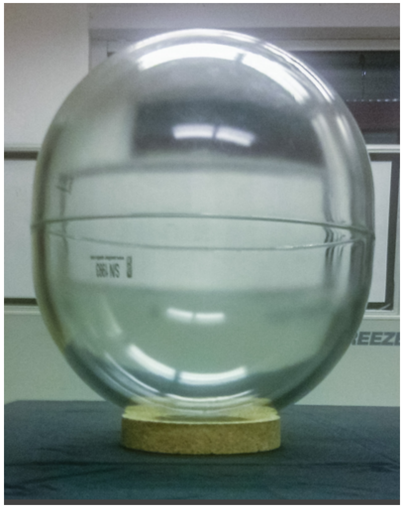
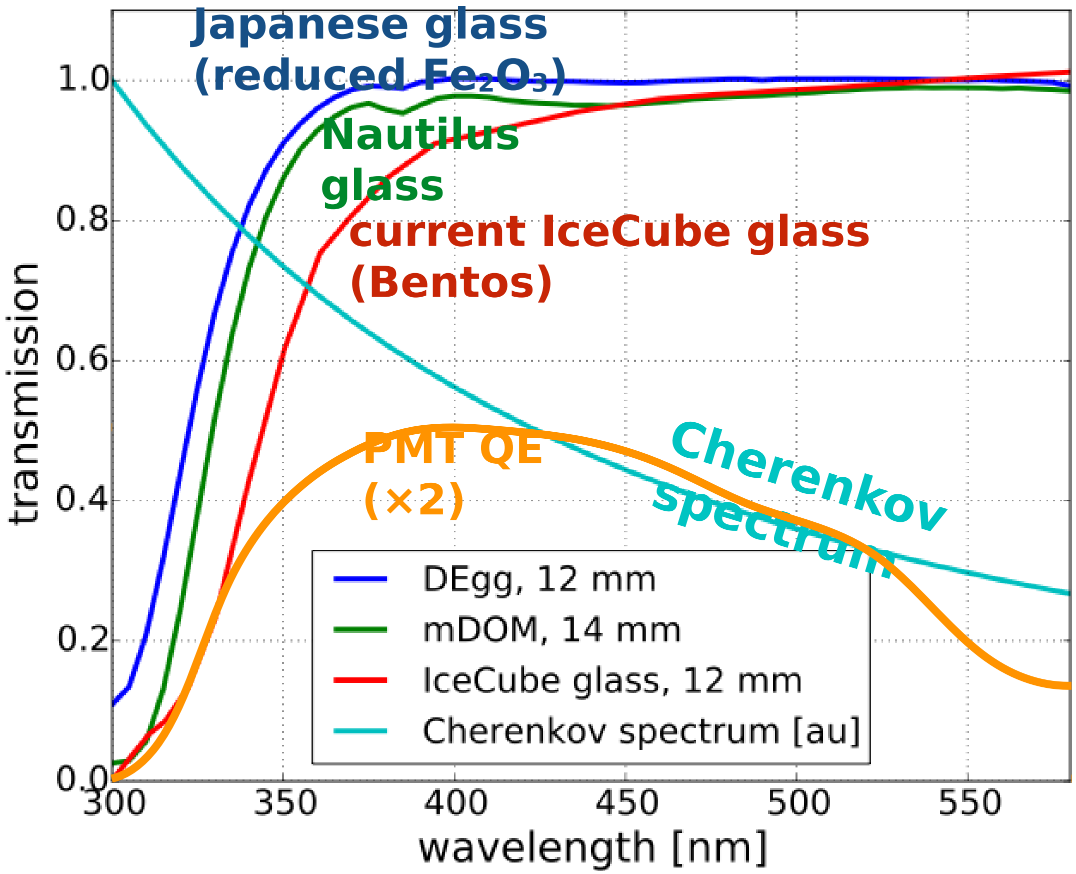
Pressure vessel

- Cherenkov photon spectrum ~ $1/\lambda^2$
  → transparency in UV range important
- Significant differences though same material (borosilicate glass)
- But also radioactive contamination important → optical background

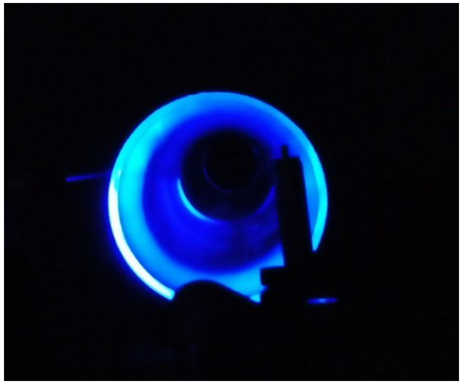


prototype of pressure vessel

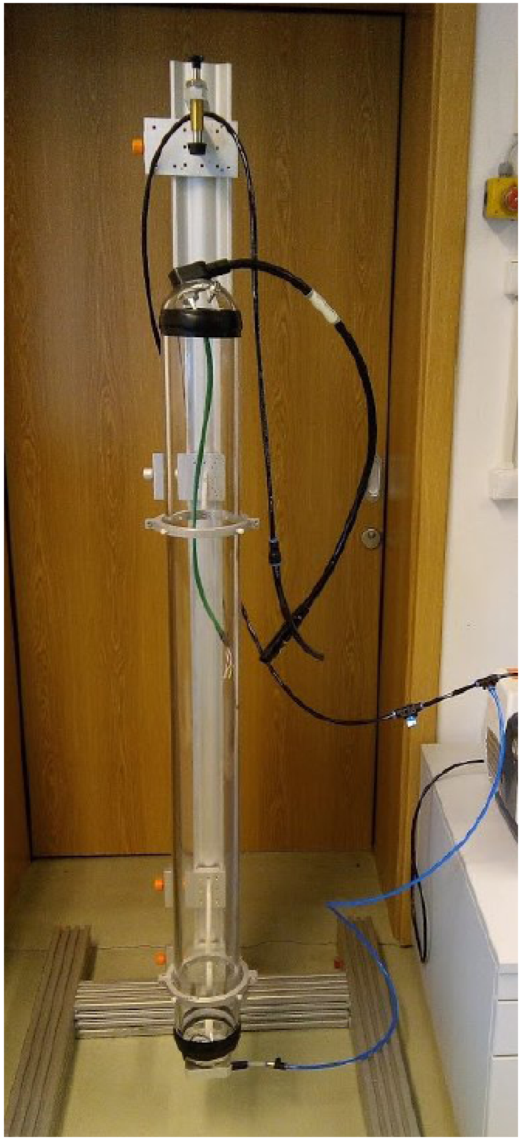


Milestones

Dip coater for
WLS tubes



Coated tube under
UV irradiation



Prototype pressure
vessel assembled

- vacuum tested at DESY Zeuthen
- stable since ~9 months

- pressure test up to 320 bar in Madison

L-OM or Brussels sprouts OM

- 'Long Optical Module'
- Hybrid between WOM and mDOM
- Inherits benefits (and R&D) of both
  - Increased angular acceptance
  - Decreased drilling cost
- Idea: fit as many PMTs as possible into a small diameter (drilling cost)
- Don't exceed weight limit

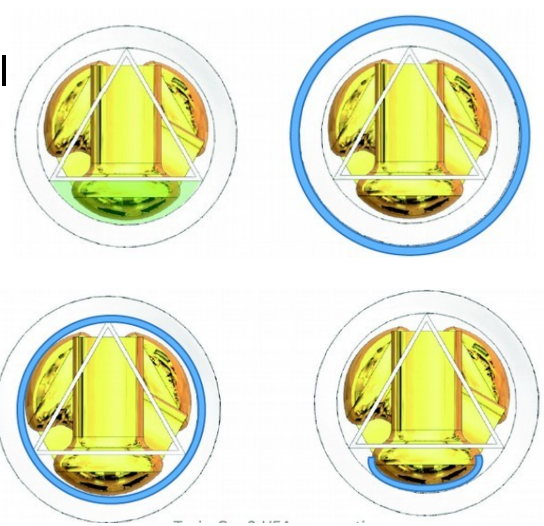
- WLS options under investigation (could also be applied to other OM)

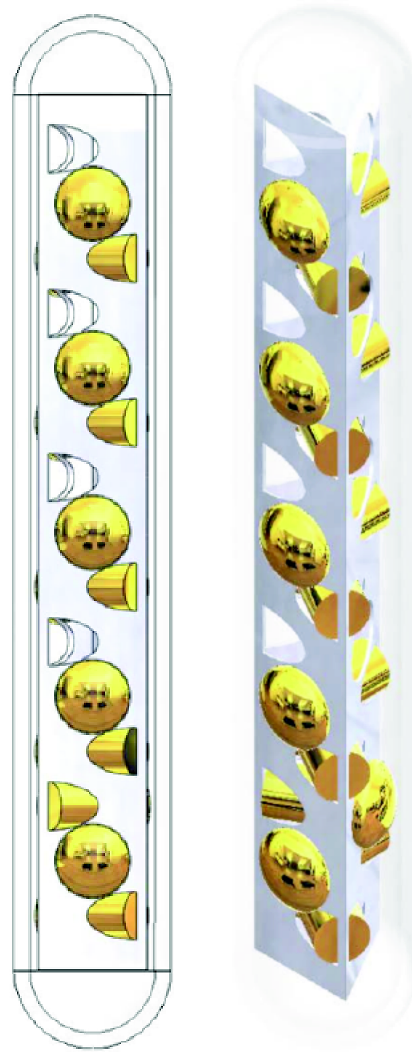
In optical gel

On tube (stability in Ice?)

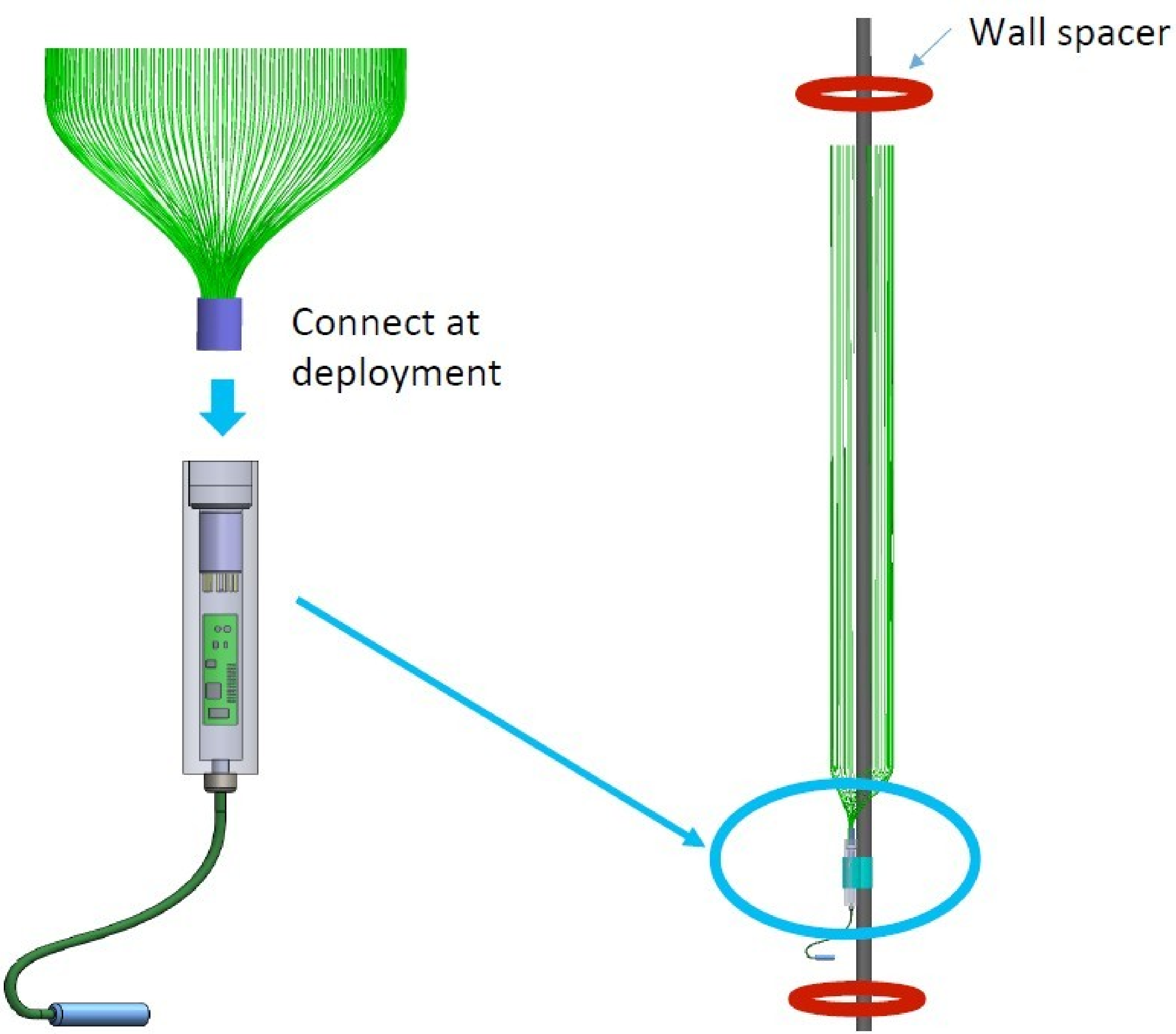
In tube

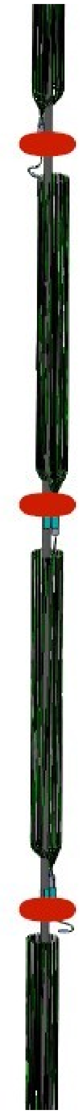
On PMT





WLS-fiber module





Advantages:
- Inexpensive
- Simple mounting and scalable design
- High linear density possible
- Compact and light-weight (shipping)
- Low-risk pressure vessel

Challenges:
- Freeze-proof interface to fibers
- Resilient attachment of fiber skirt to cables
- Miniaturized low power electronics

Milestone: successful freeze-test of fibers in -50°C ice.