Optical Sensors.

A Summary

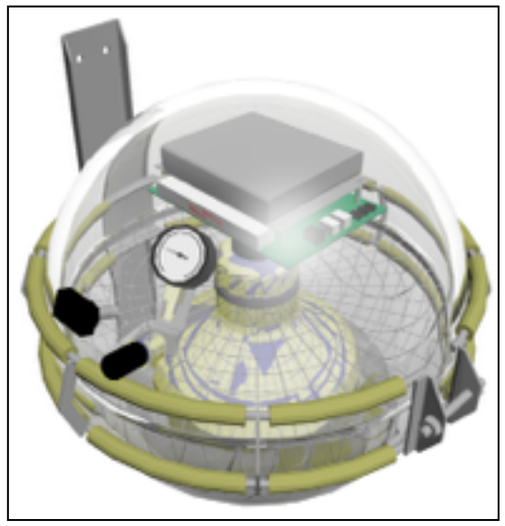
Timo Karg
DESY

MANTS-GNN Meeting
21 September 2014 @ CERN

HELMHOLTZ ASSOCIATION

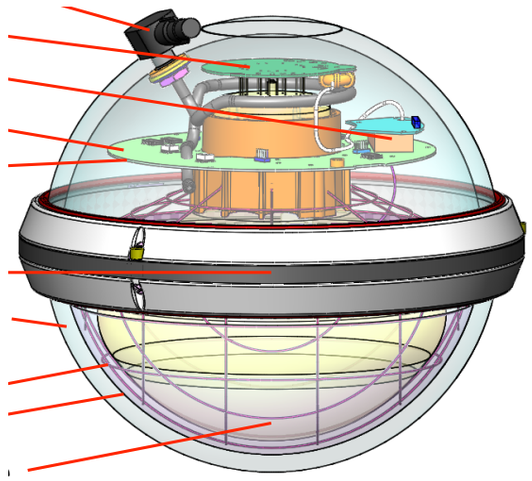
DESY

Overview: Baseline Designs



10 inch HQE PMT
in 17 inch sphere

presented by V. Aynutdinov



10 inch HQE PMT
in 13 inch sphere

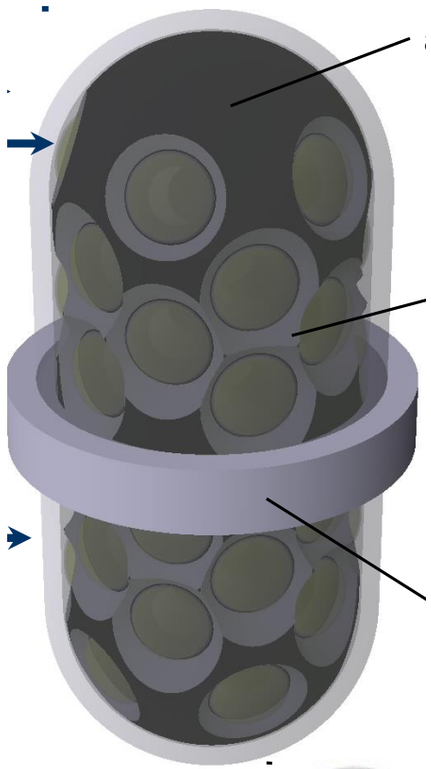
presented by J. Kelley

31 × 3 inch PMT
in 17 inch sphere

presented by A. Heijboer

All presentations:
https://events.icecube.wisc.edu/sessionDisplay.py?sessionId=18&confId=56#20140921

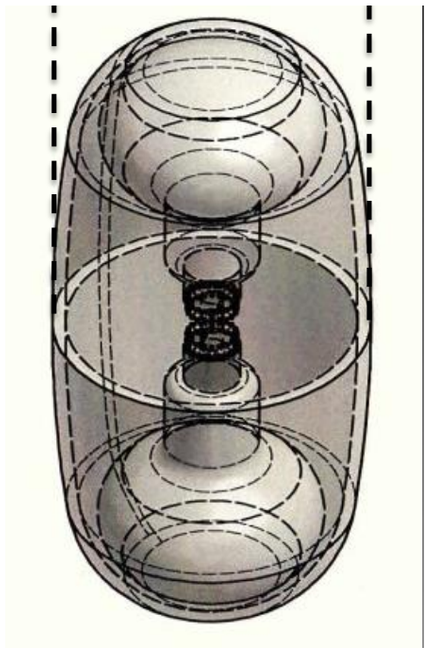
Overview: Alternative Design Studies



41 × 3 inch PMT

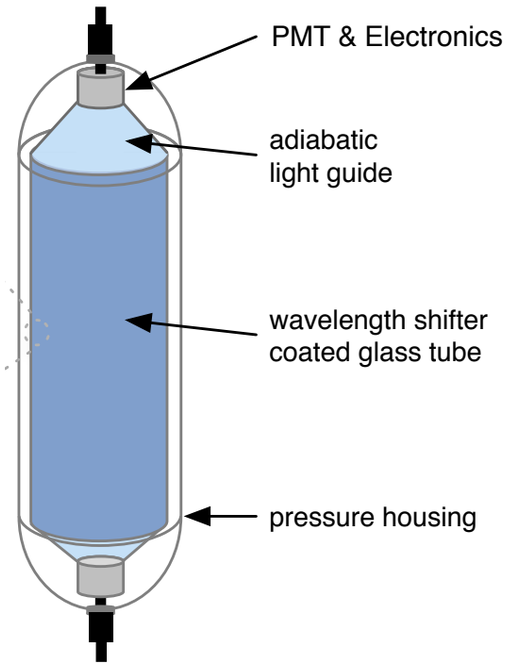
based on
KM3NeT mDOM

ECAP/U. Erlangen
presented by A. Kappes



2 × 8 inch HQE PMT

Chiba University
presented by R. Gaior



wavelength-shifting &
light-guiding to
2 small diameter PMTs

U. Bonn / U. Mainz
presented by S. Böser

Baseline Designs

GVD OM

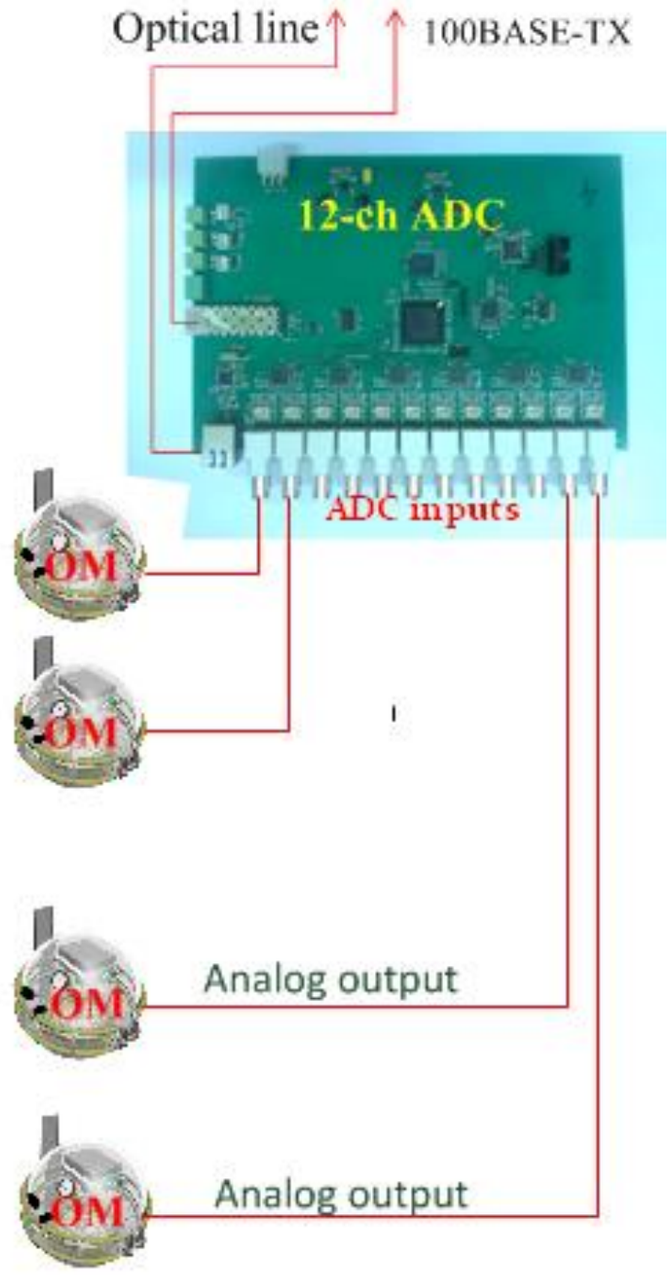
Rationale: Keep OM as simple as possible

Mu-metal grid

OM electronics: HV converter, amplifier, controller, LEDs

Design is basically finalised.

GVD Section



2 readout modes for section:
- triggered mode (local coincidences)
- all data to shore via optical line

GVD OM: Performance in Water

Results from April 2012 up to September 2014
(without stress tests of electronics during prototyping phase)

Prototype arrays: 2012: 36 OM, 2013: 72 OM, 2014: 120 OM

A summarized time of the OMs operation is ~170 years

3 OM failures during this period:

- 1 OM: HV control system out of operation (2013).

- 2 OM: not reliable connection via RS485 bus (2014).

The OM electronics failure rate ~2% / year

Repairing possibility: 8% / year for 100 strings installation (GVD Phase 1).

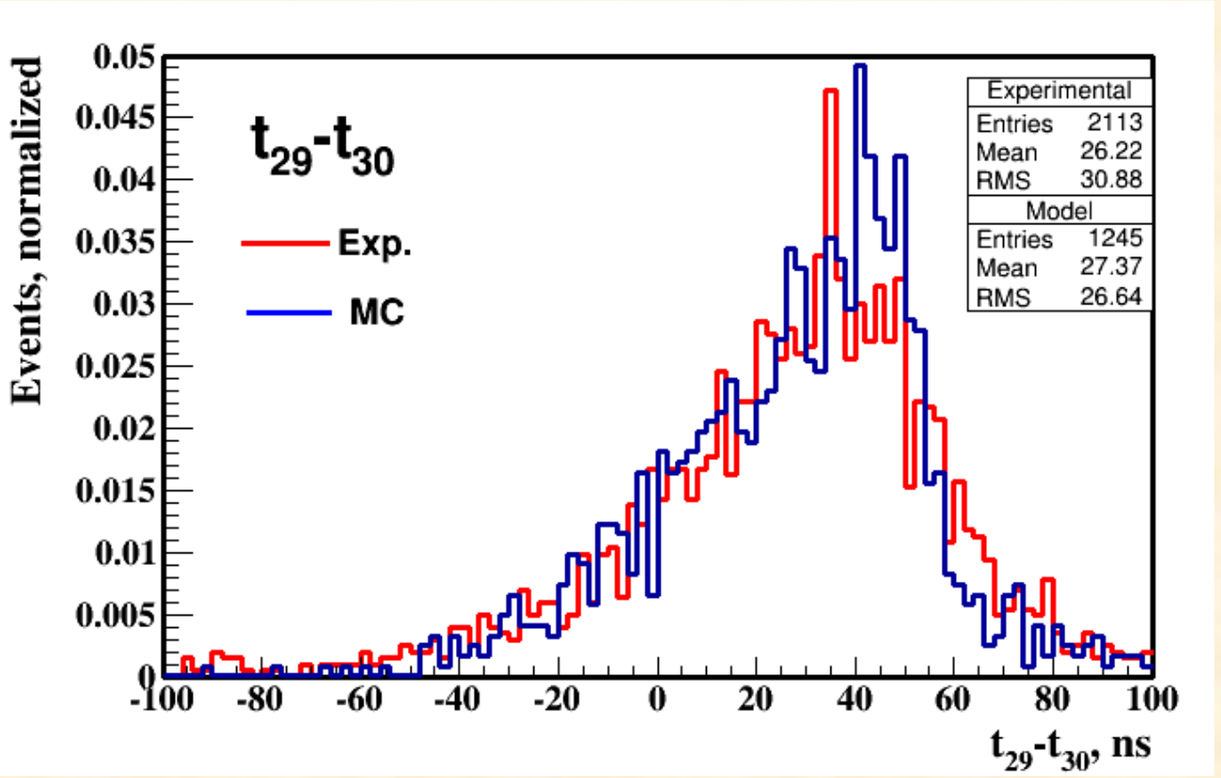
GVD OM: Atmospheric Muons

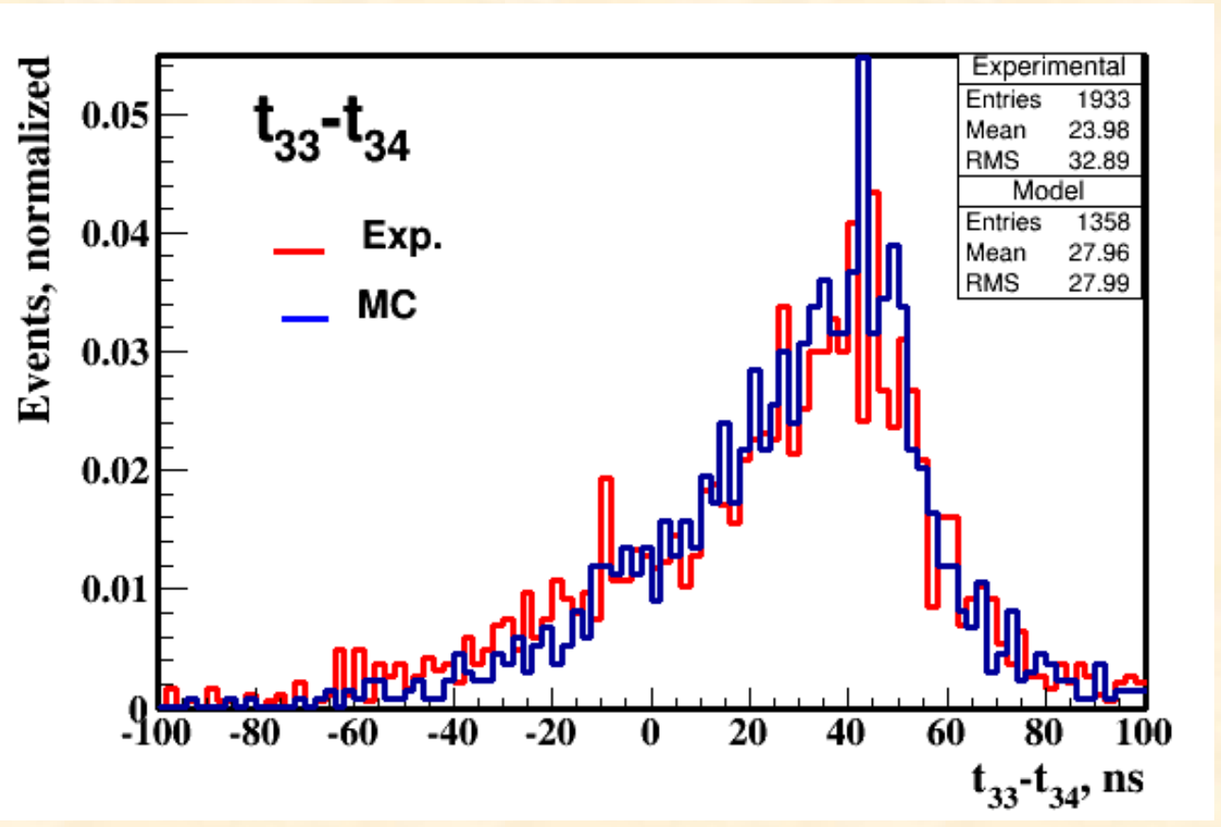
Statistics - 1707896 events

Selection – Q > 2 ph.el.

LED – calibration

Data consistent with expectation

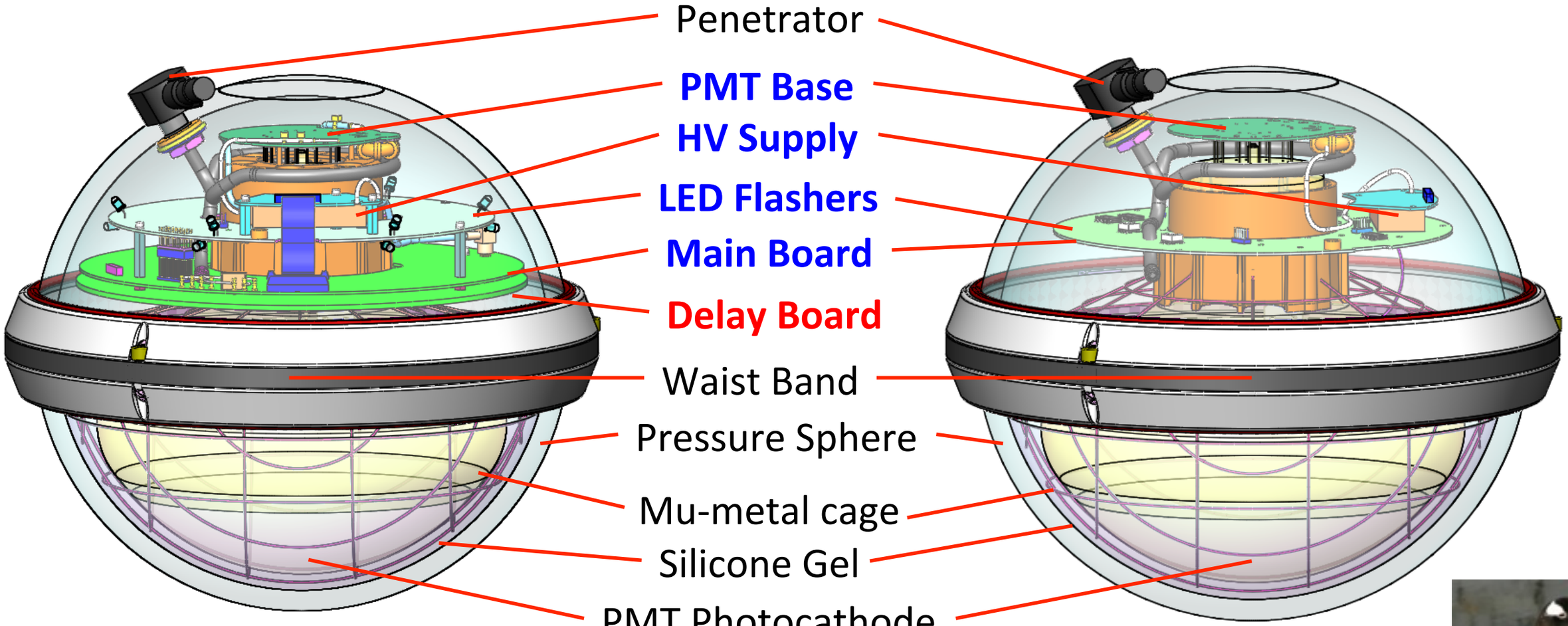




dt distribution between neighboring channels

IceCube Generation2 (Gen2) DOM

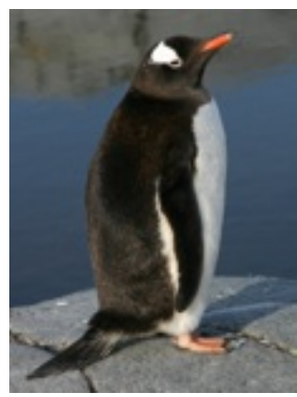
Rationale: Keep as close as possible to IceCube design



IceCube DOM

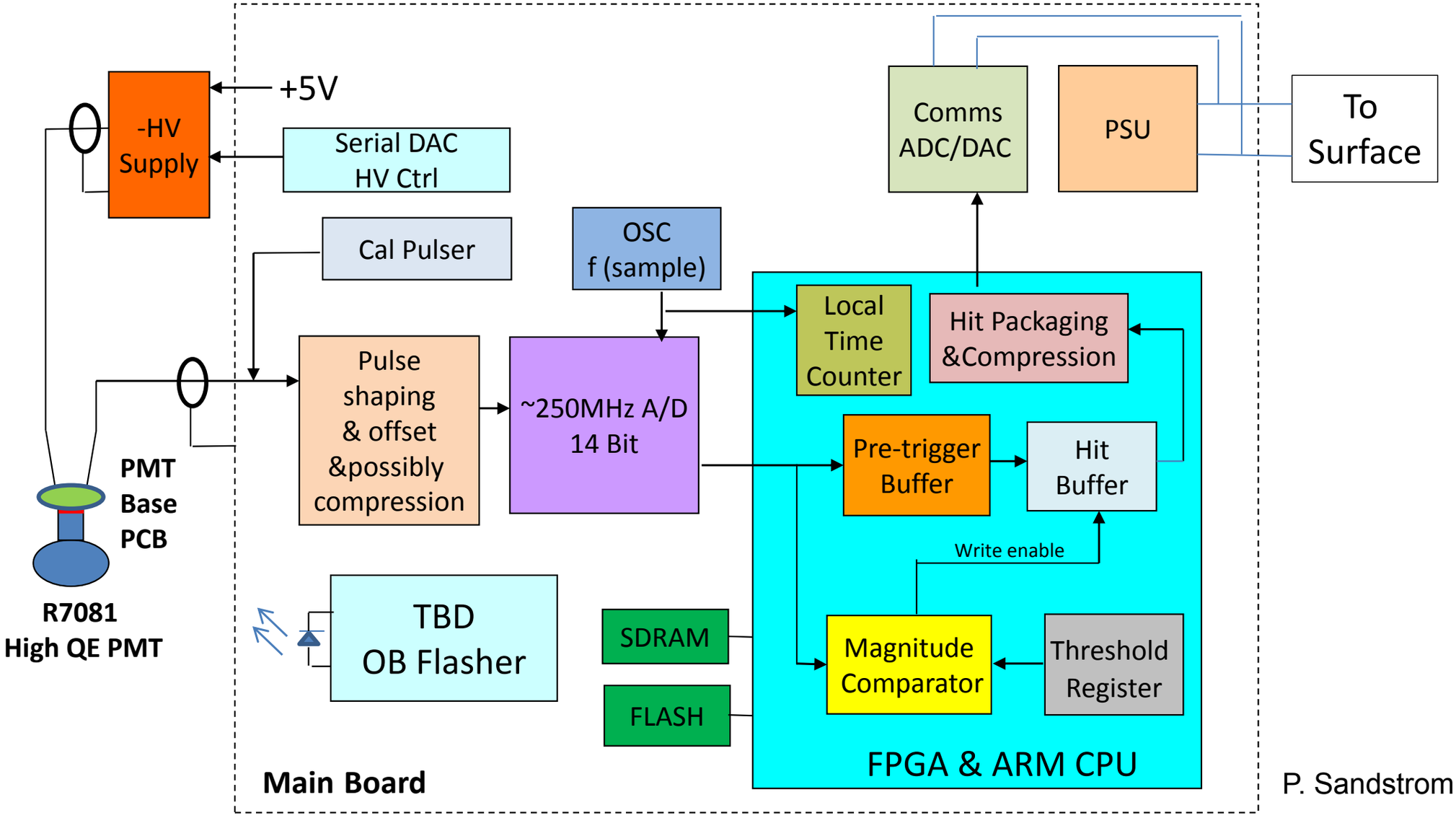
KEY:
Component identical
Component eliminated
Component redesigned

Gen2 DOM



P. Sandstrom et al., VLVvT 2013

Gen2 DOM: Block Diagram

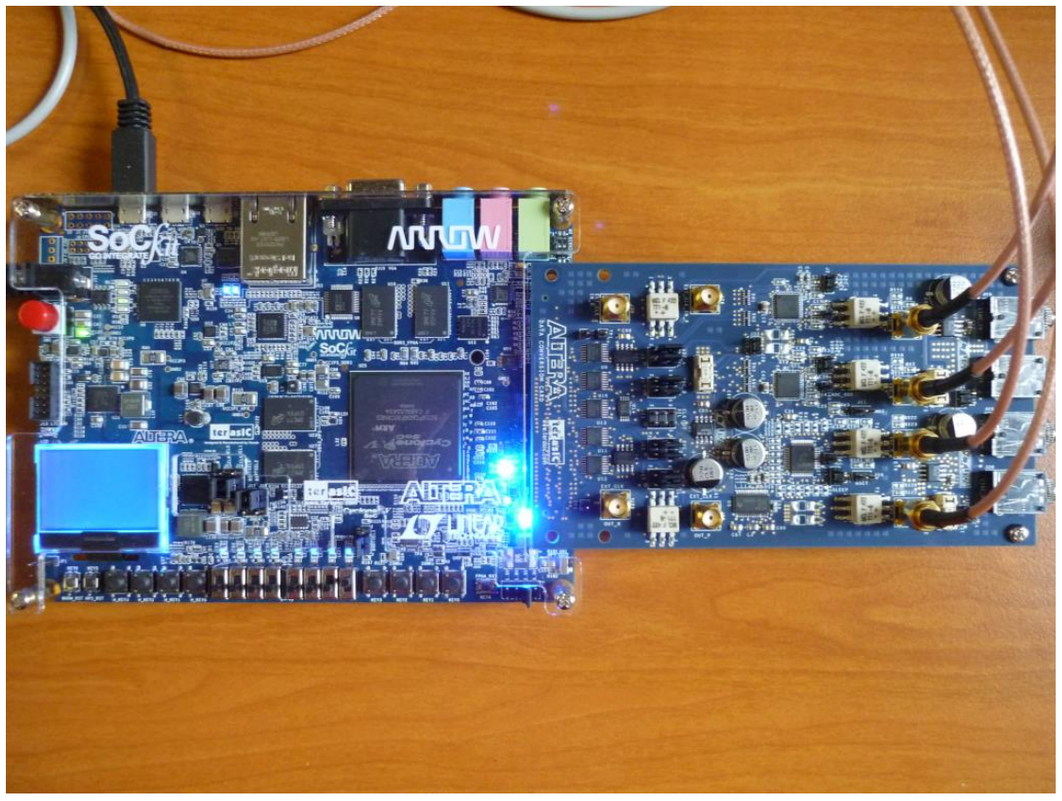


- Modernize obsolete / unavailable components (ATWDs, FPGA)
- Simplify by using high-resolution ADC (single gain channel), digital triggering

More CPU power in DOM available:
e.g. waveform unfolding in DOM

Gen2 DOM: Communications

comms prototyping setup



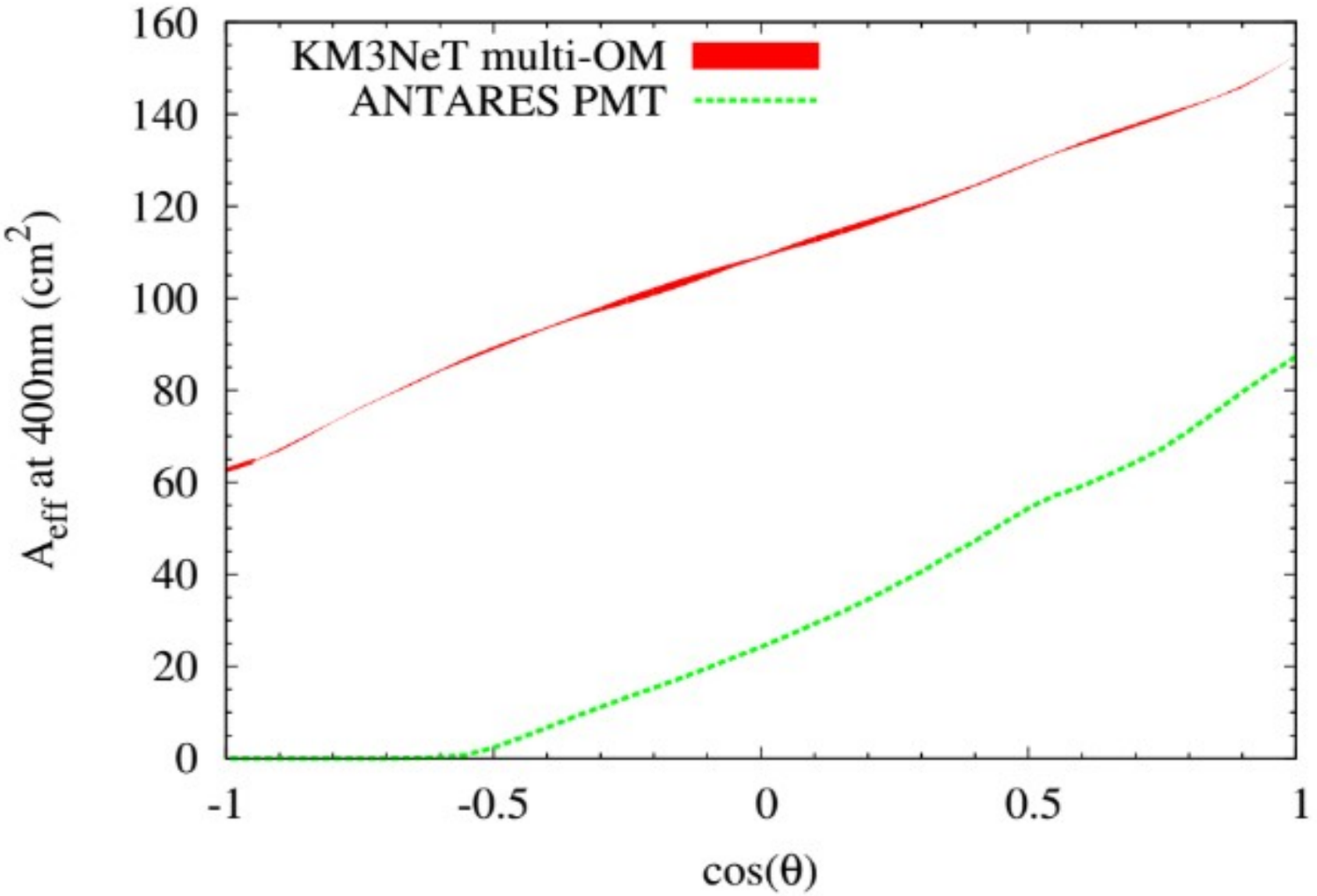
K. Hanson, E. Pinat *Université Libre de Bruxelles*

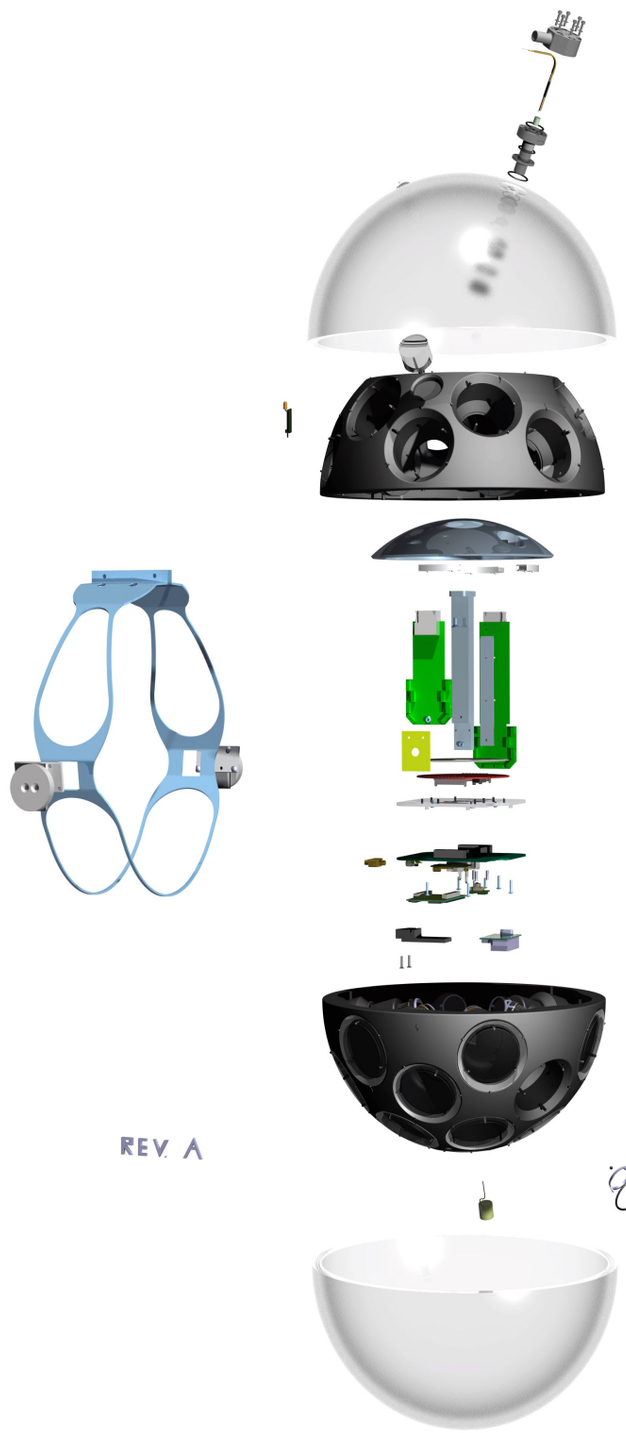
- IceCube: custom amplitude shift key protocol
  - half duplex
  - 0.5 Mbps / DOM
  - 2 DOMs / twisted pair
  - time synchronization separate, requires comms silence

- Gen2 DOM: 16-QAM
  - full duplex
  - 0.25 Mbps down + 1.0 Mbps up / DOM
  - 4 DOMs / twisted pair
  - time synchronization integrated with phase recovery

KM3NeT Multi-PMT DOM: Rationale

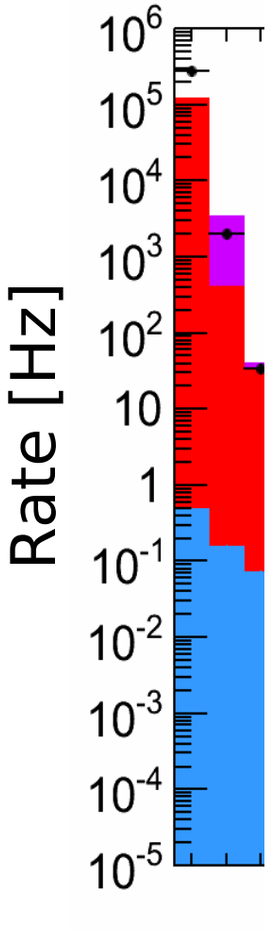
- Segmented photocathode to allow photon-counting
- Comparing 31 3 inch PMTs to a single 10 inch:
  - $(31 \times \pi\ 1.5^2) / (\pi \times 5^2) = 2.8$
  - The price per area of photocathode is (somewhat) lower for 3 inch PMTs





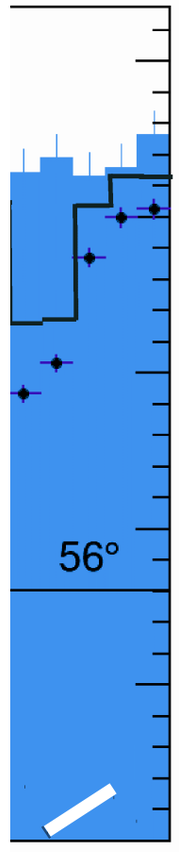
KM3NeT Multi-PMT DOM: In-situ Measurements

1st prototype



arXi

Working in water since 17 months



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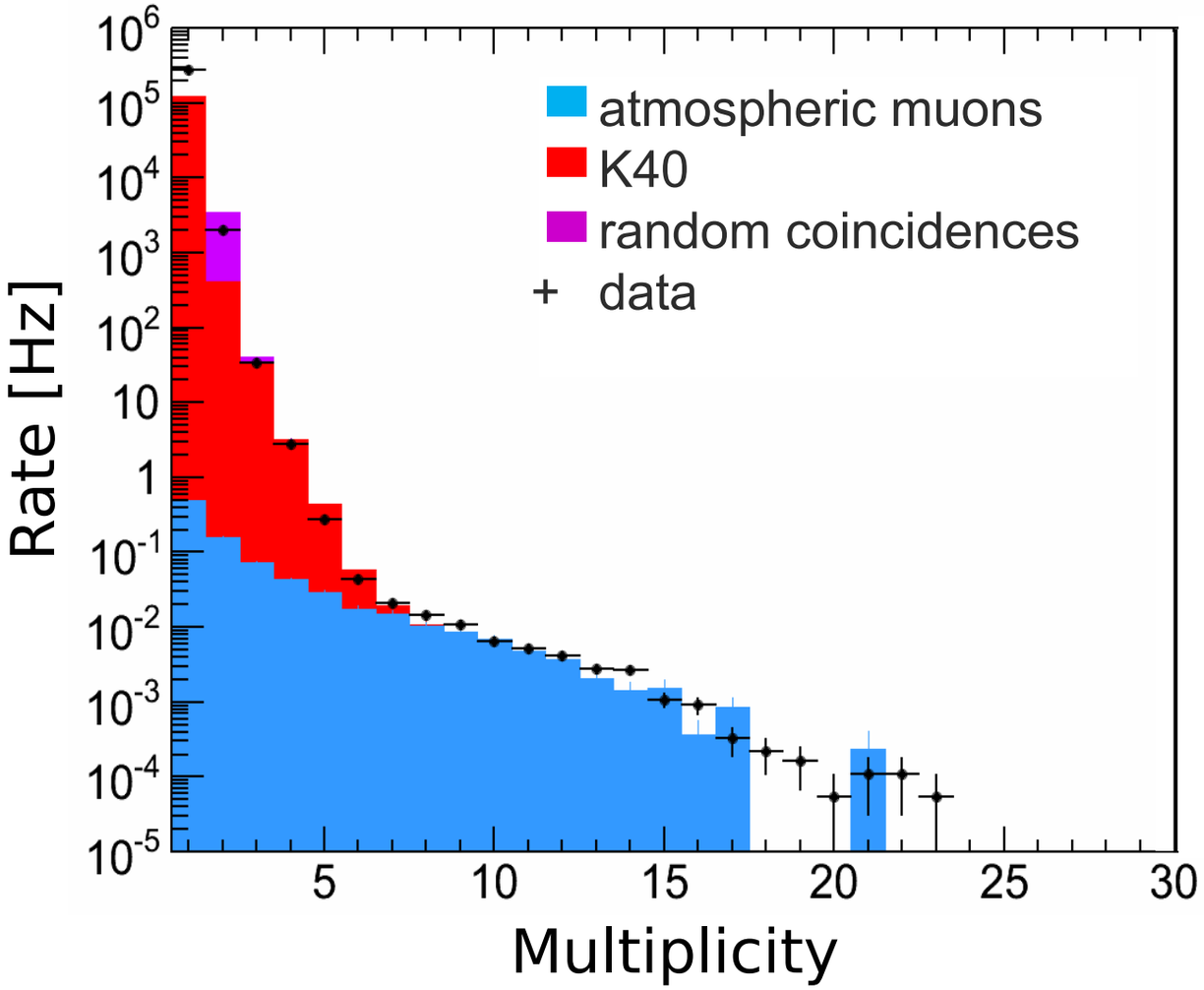
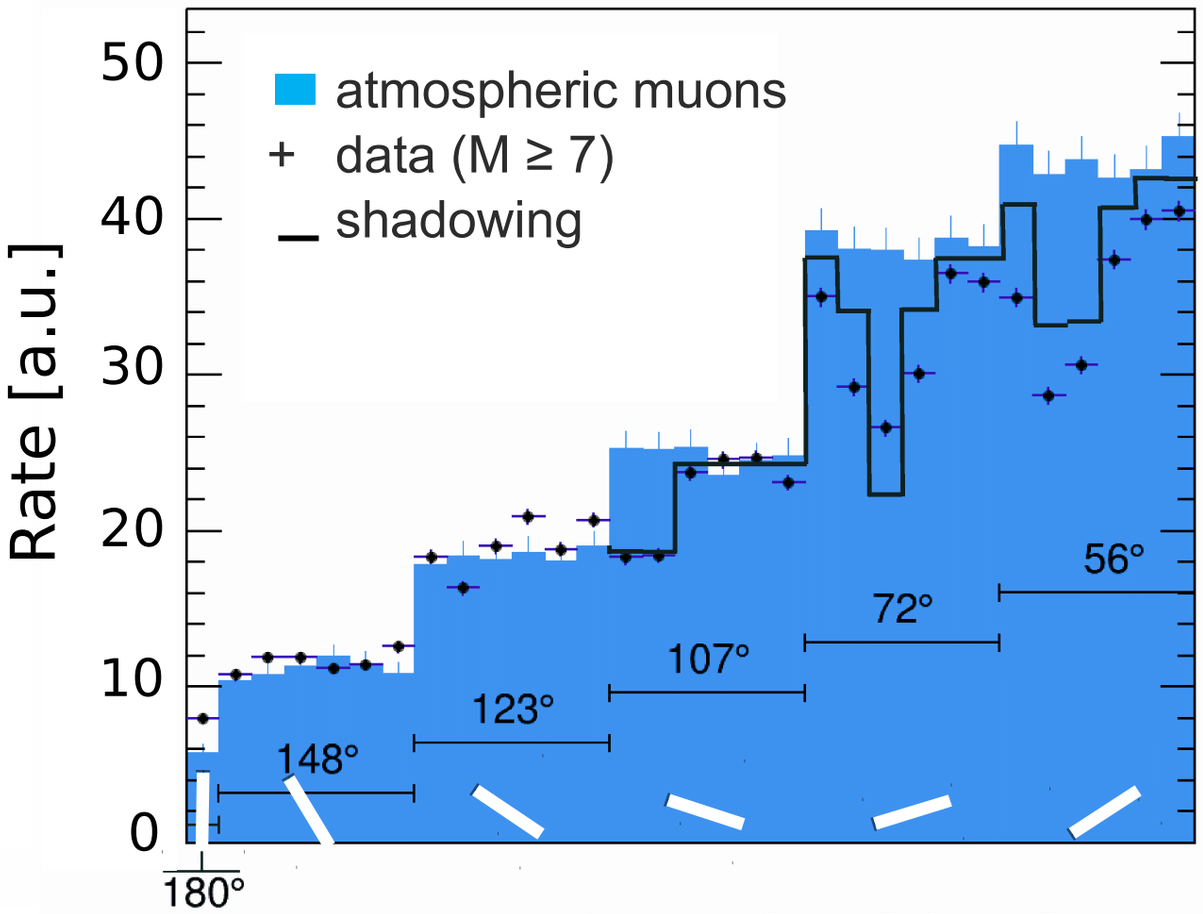
KM3NeT Multi-PMT DOM: In-situ Measurements

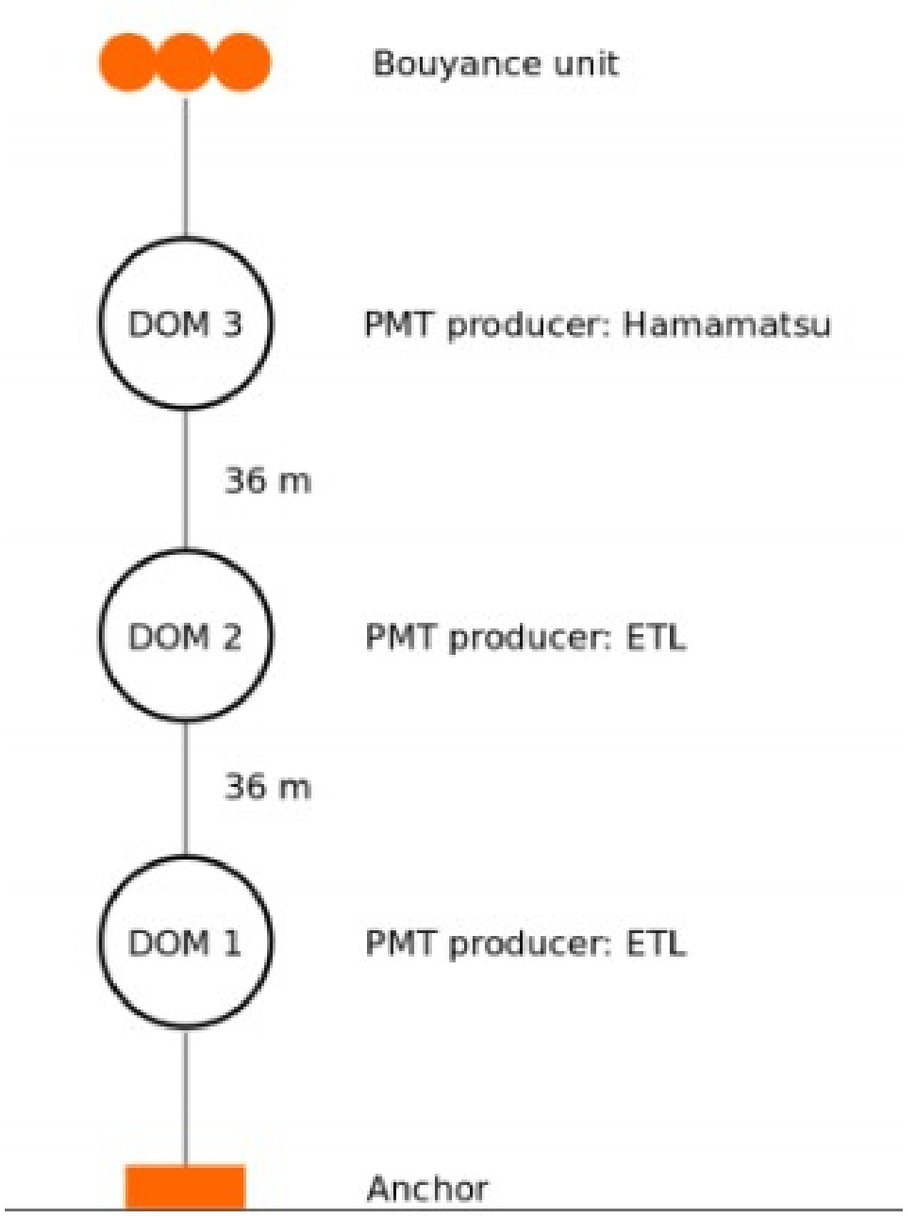




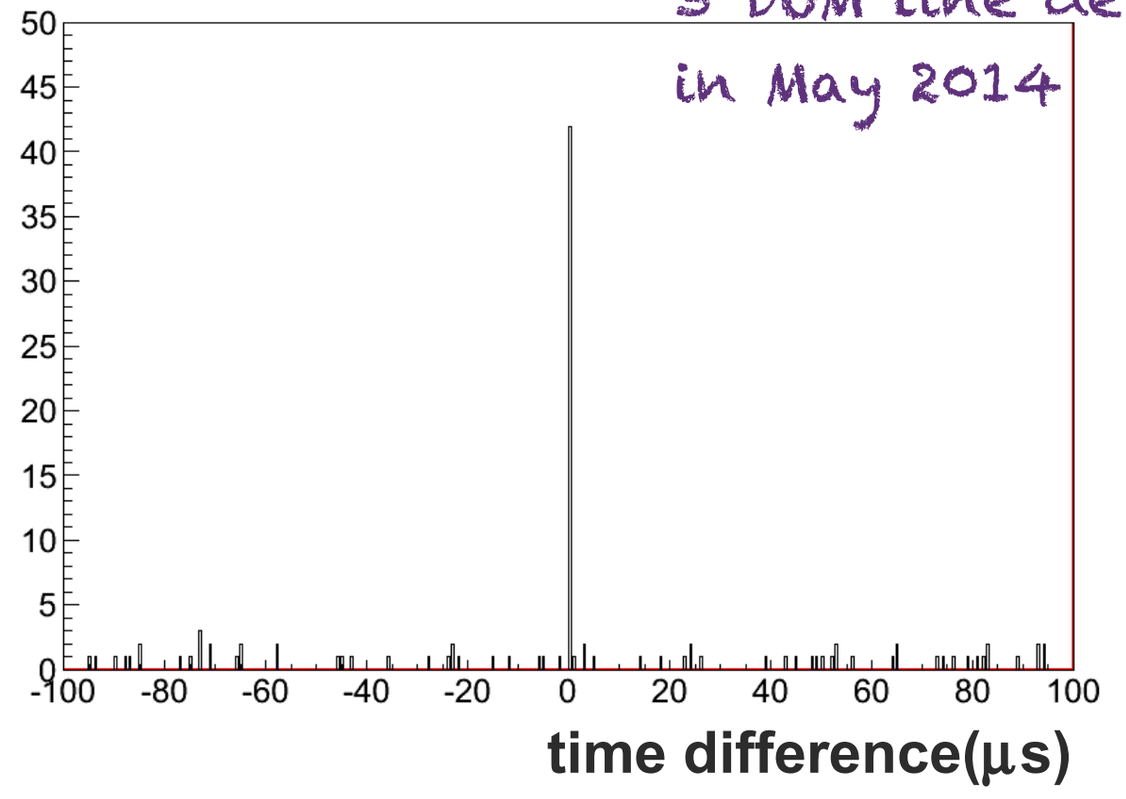
arXiv:1405.0839 [astro-ph.IM]

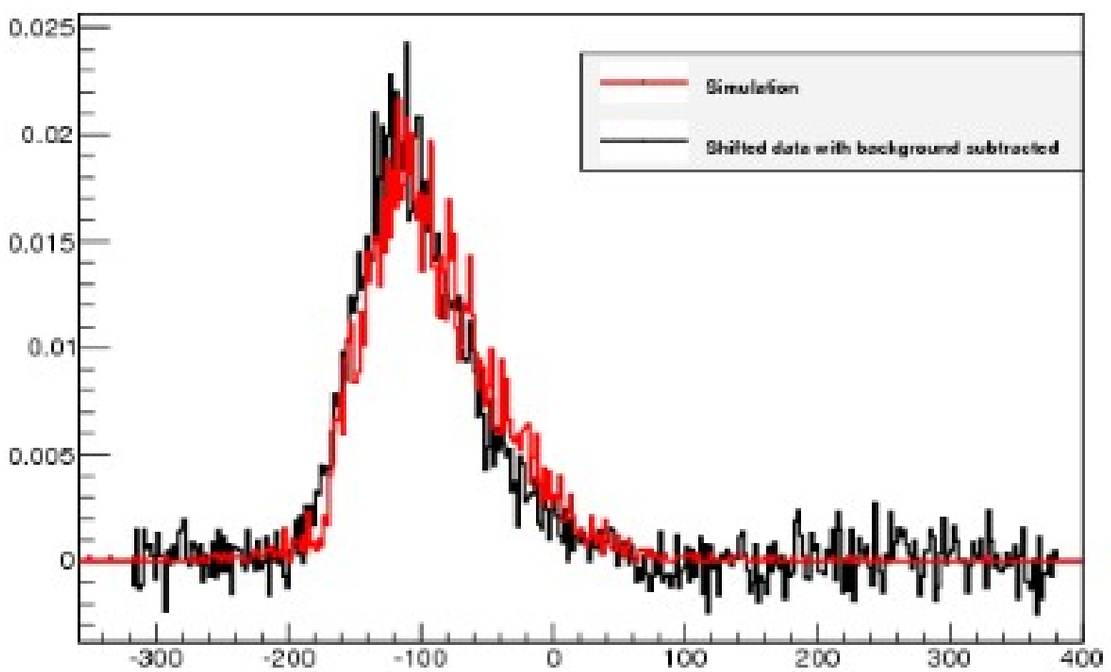
– time calibration in lab, and with ^{40}K decays
– very rich analysis on single DOM

KM3NeT Multi-PMT DOM: Test Line



3 DOM line deployed in May 2014





Time correlation checked with muons

Alternative Design Studies

Multi-PMT DOM for IceCube

Rationale: Make advantages of multi-PMT DOM available to IceCube

reuse
PMTs
bases
connectors

adaptation/ new development
pressure vessel
PMT holder
reflectors
electronics

Multi-PMT DOM for Ic

Rationale: Make advant available to IceCube

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PMTs
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adaptation/ new development
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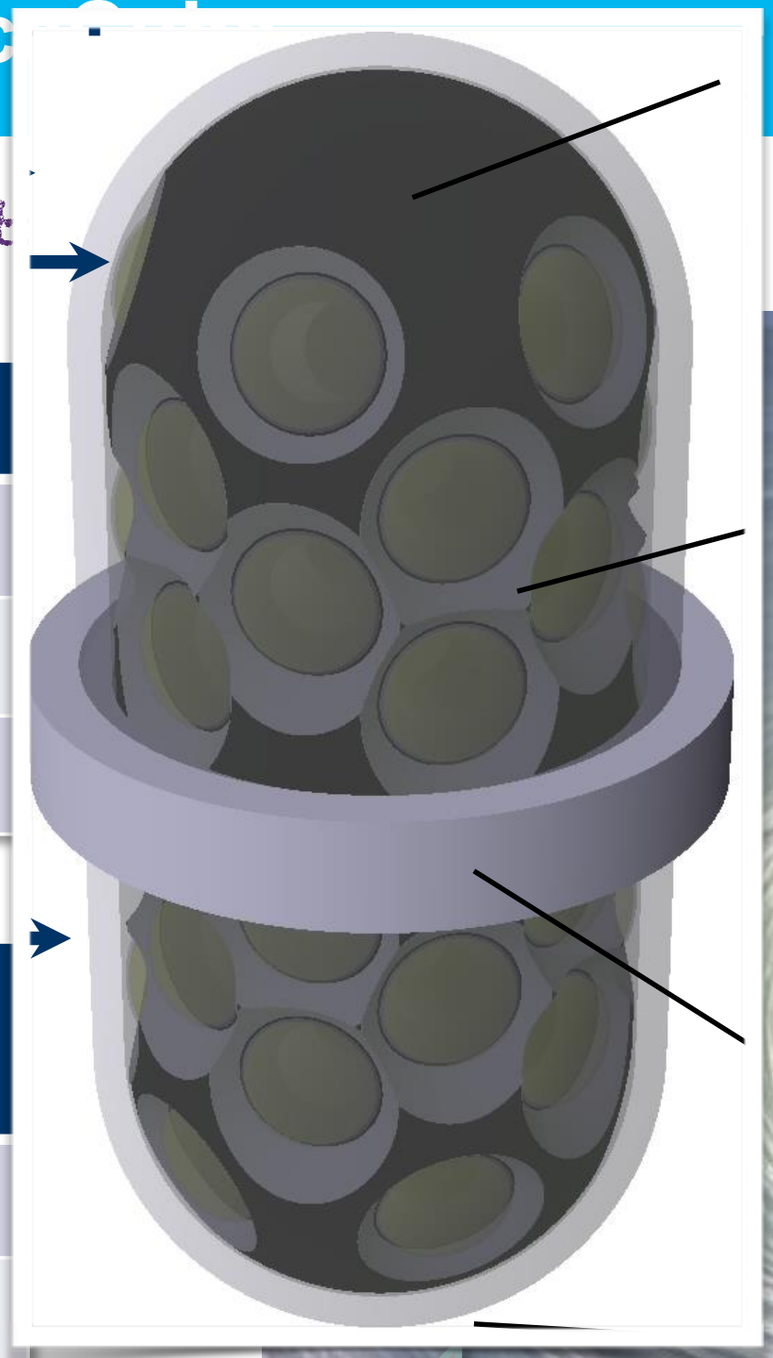
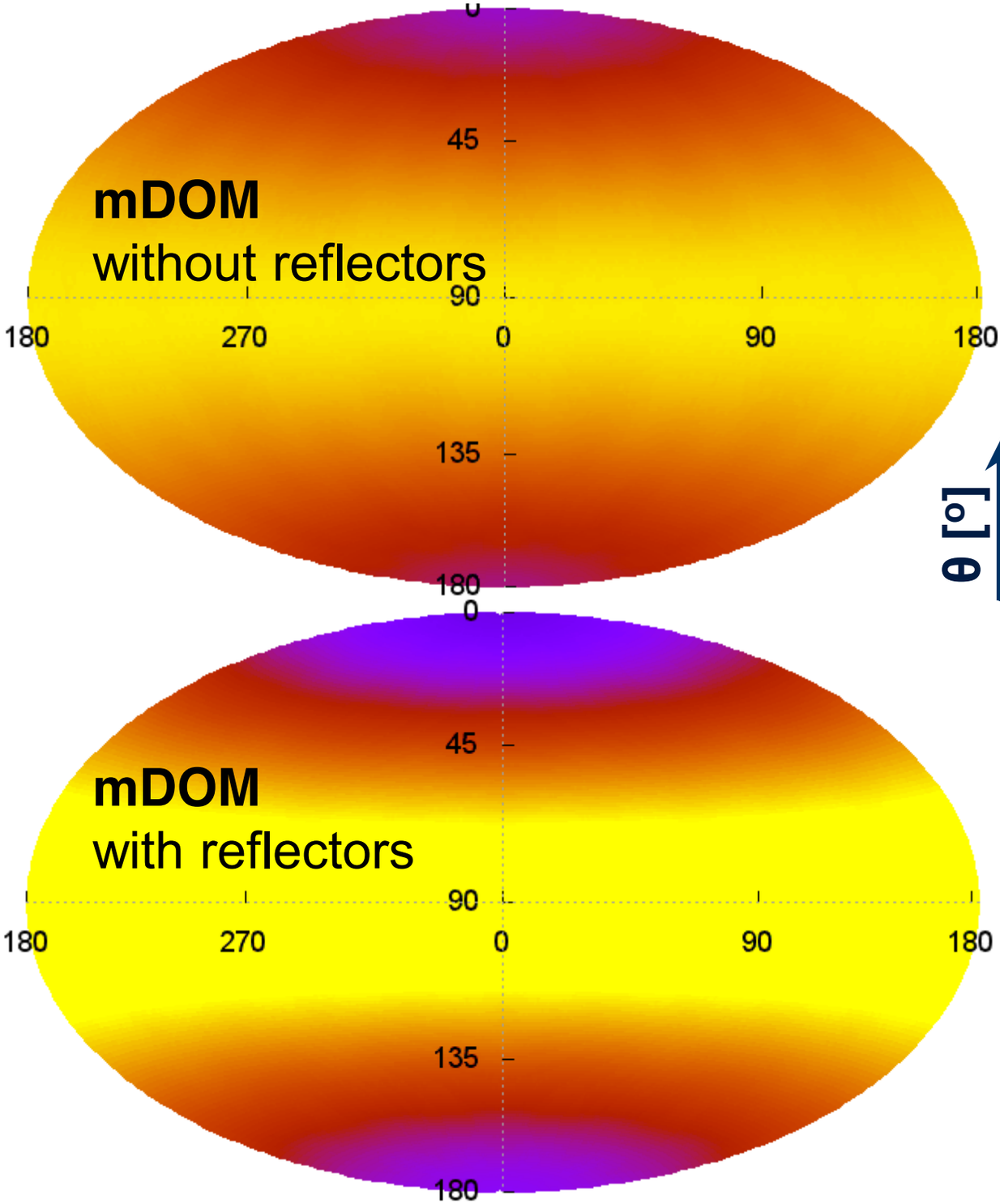
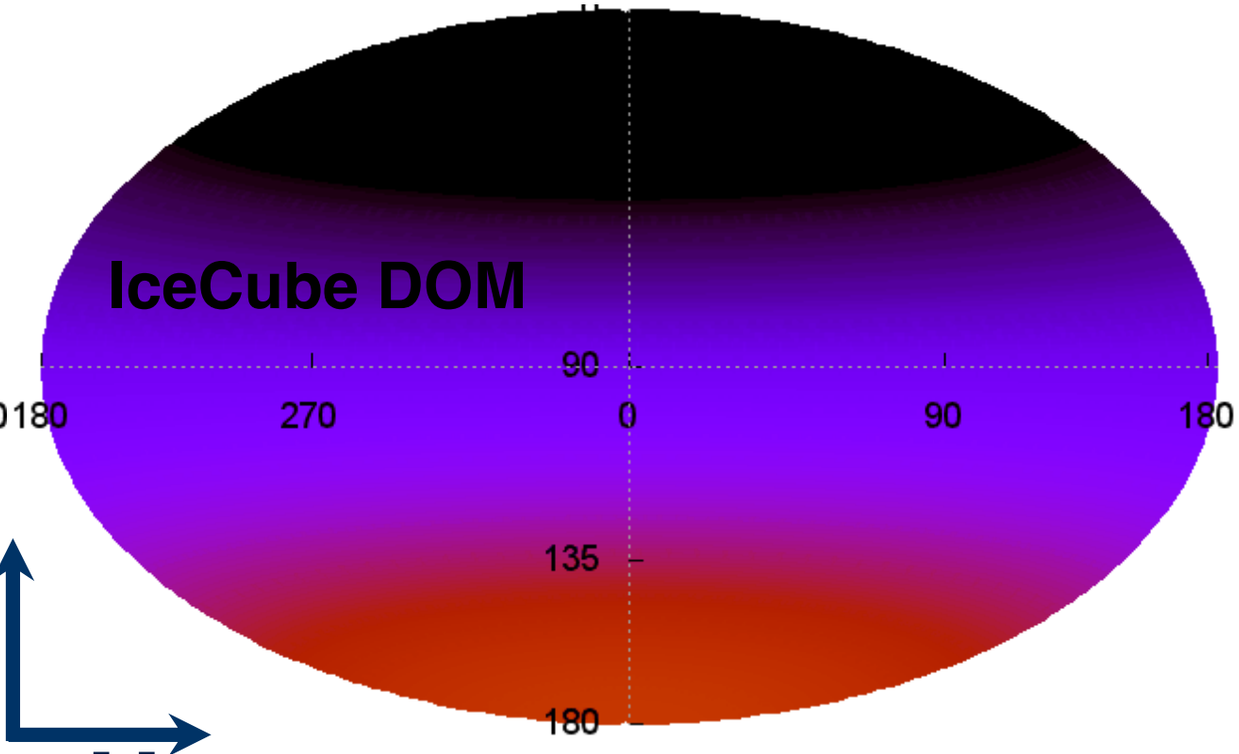
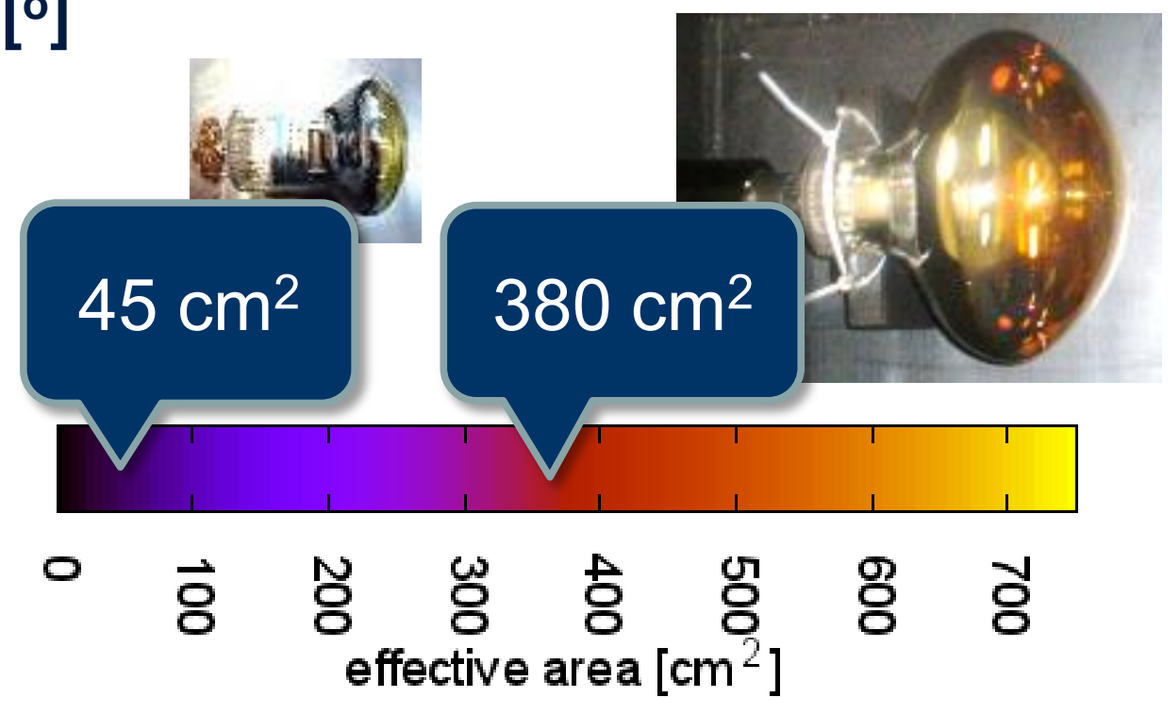


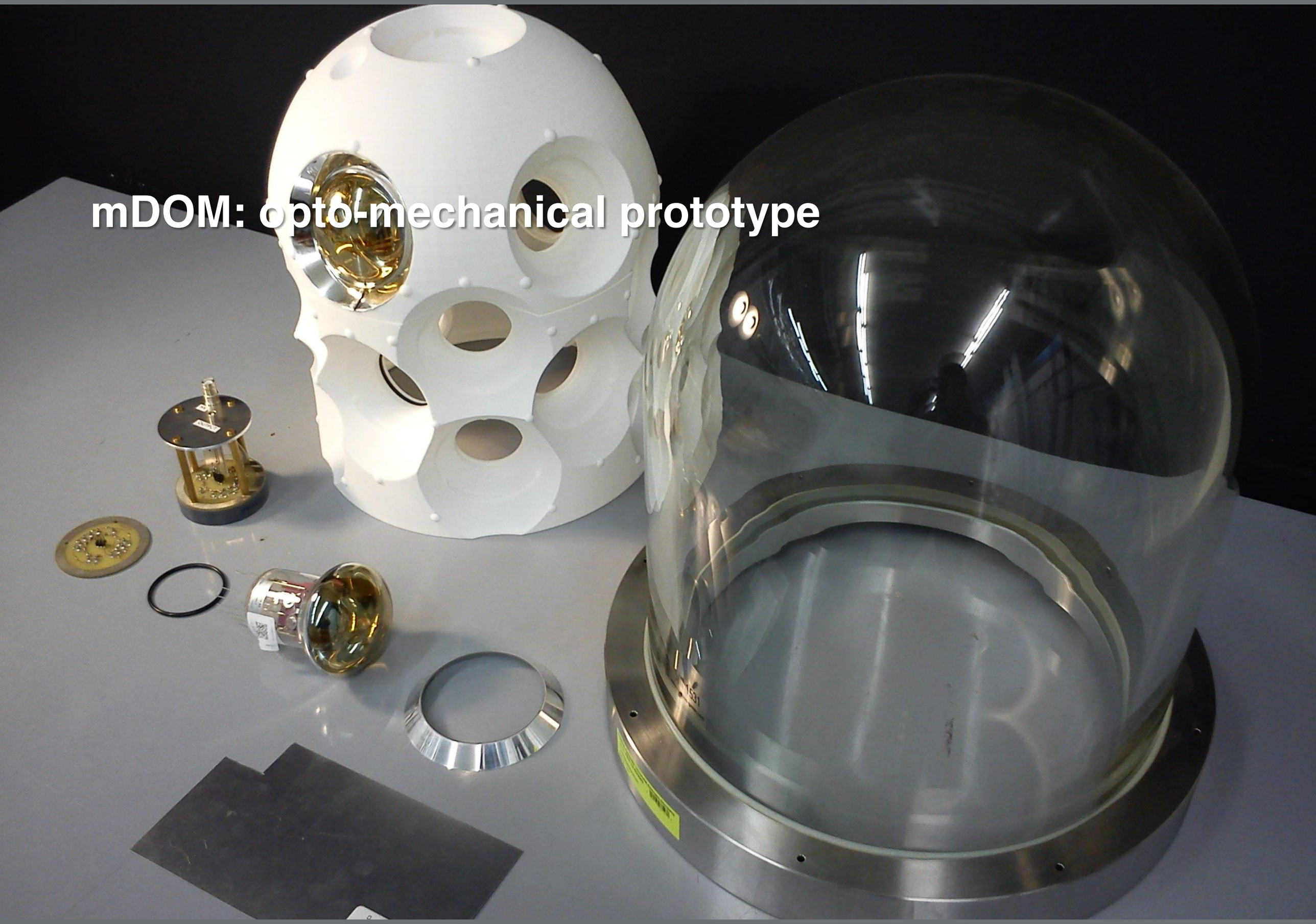
Multi-PMT DOM for IceCube: Geant 4 Simulation





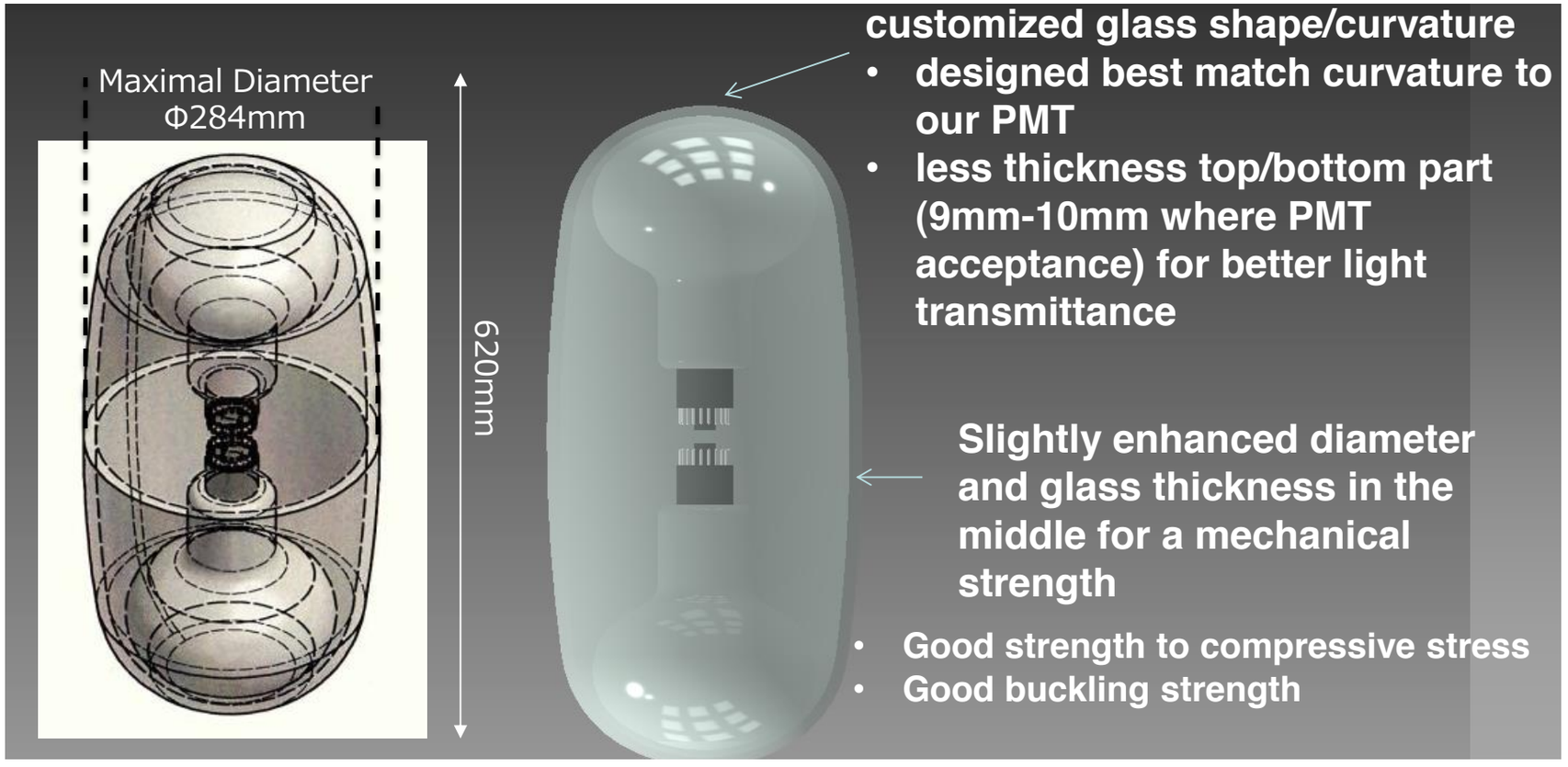


mDOM: opto-mechanical prototype



Ellipsoidal DOM

Concept: two 8’ PMT back to back in a elliptical glass house



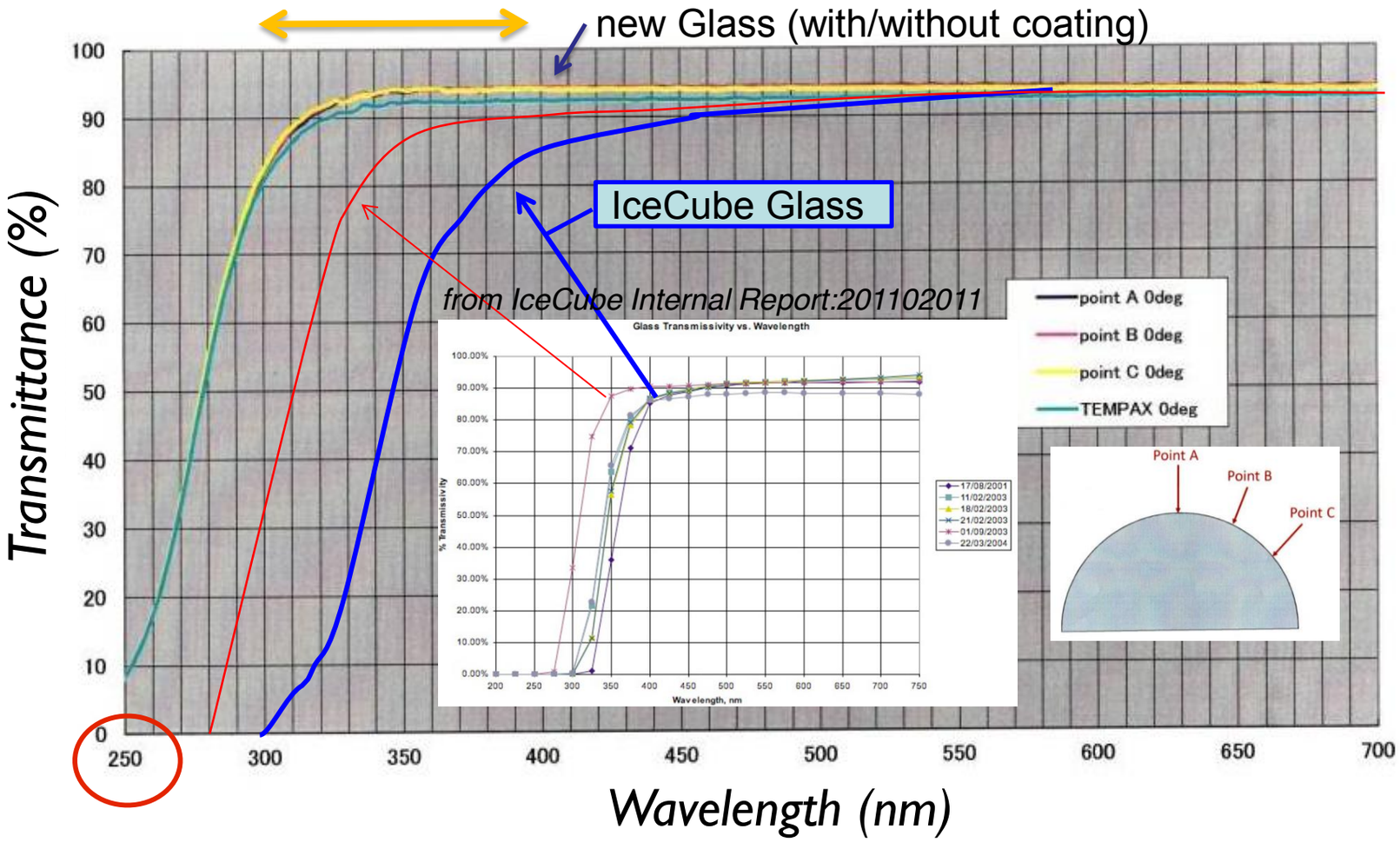
- **2 PMTs back to back**: up/down symmetry for **veto, reconstruction**

- **2 PMTs** instead of 1: **better saturation response**

- **Ellipsoidal** glass shape: customed for PMT curvature and **smaller diameter**

- **Simple design**: close to IceCube design

Ellipsoidal DOM: Improvements wrt. IceCube DOM

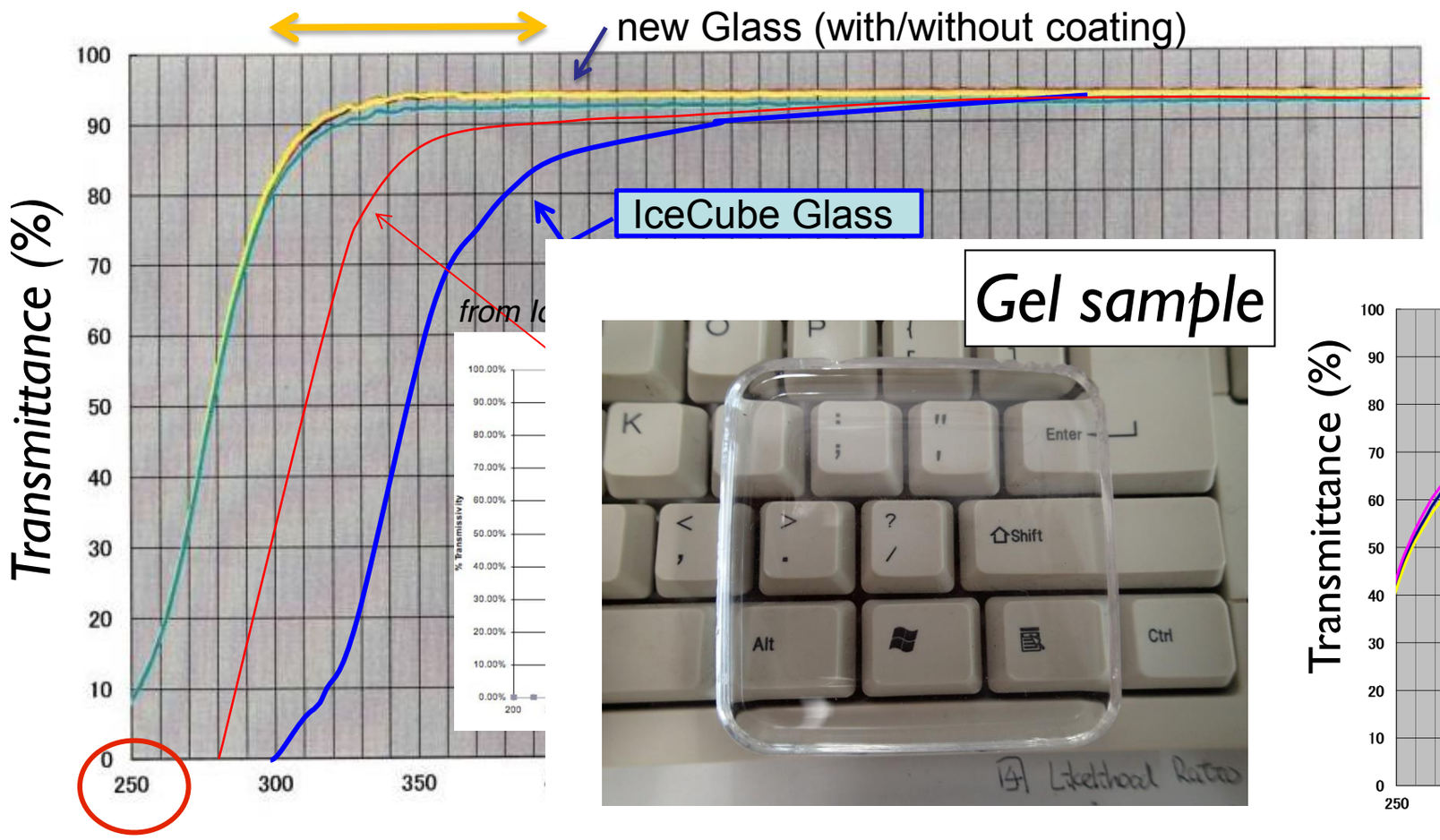


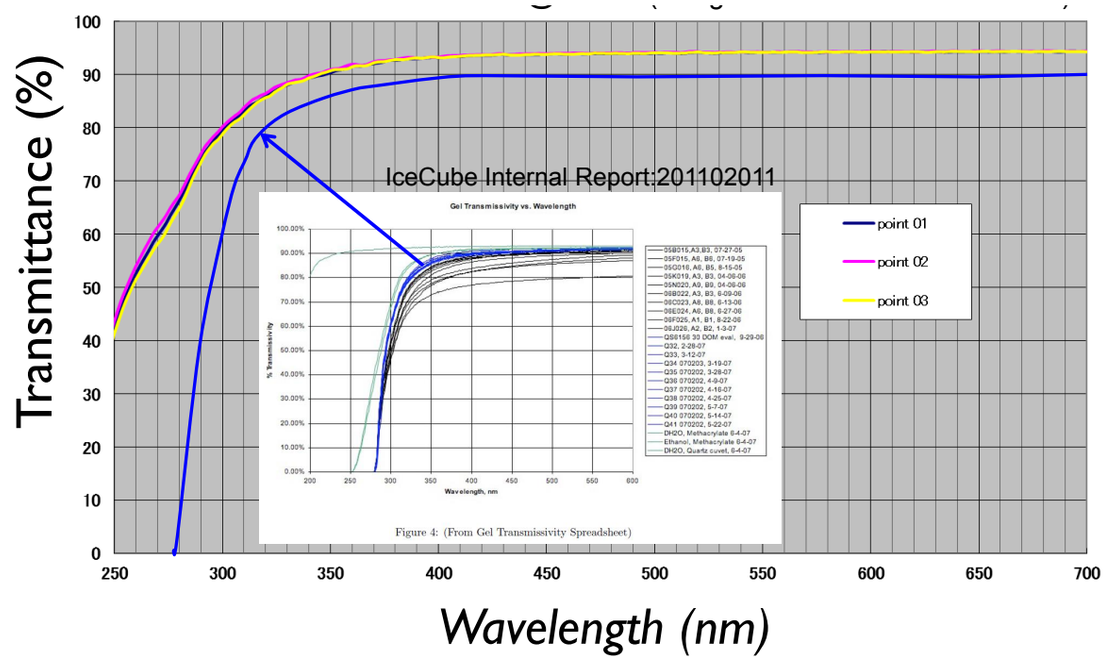
Large improvement down to 250 nm

(Cherenkov spectrum $\propto 1/\lambda^2$)

Additional coating improves another 2-4%

Ellipsoidal DOM: Improvements wrt. IceCube DOM





Large imp

(Chere

Additional c

New gel: *Shinsetsu Silicone*

Easy to treat and shape

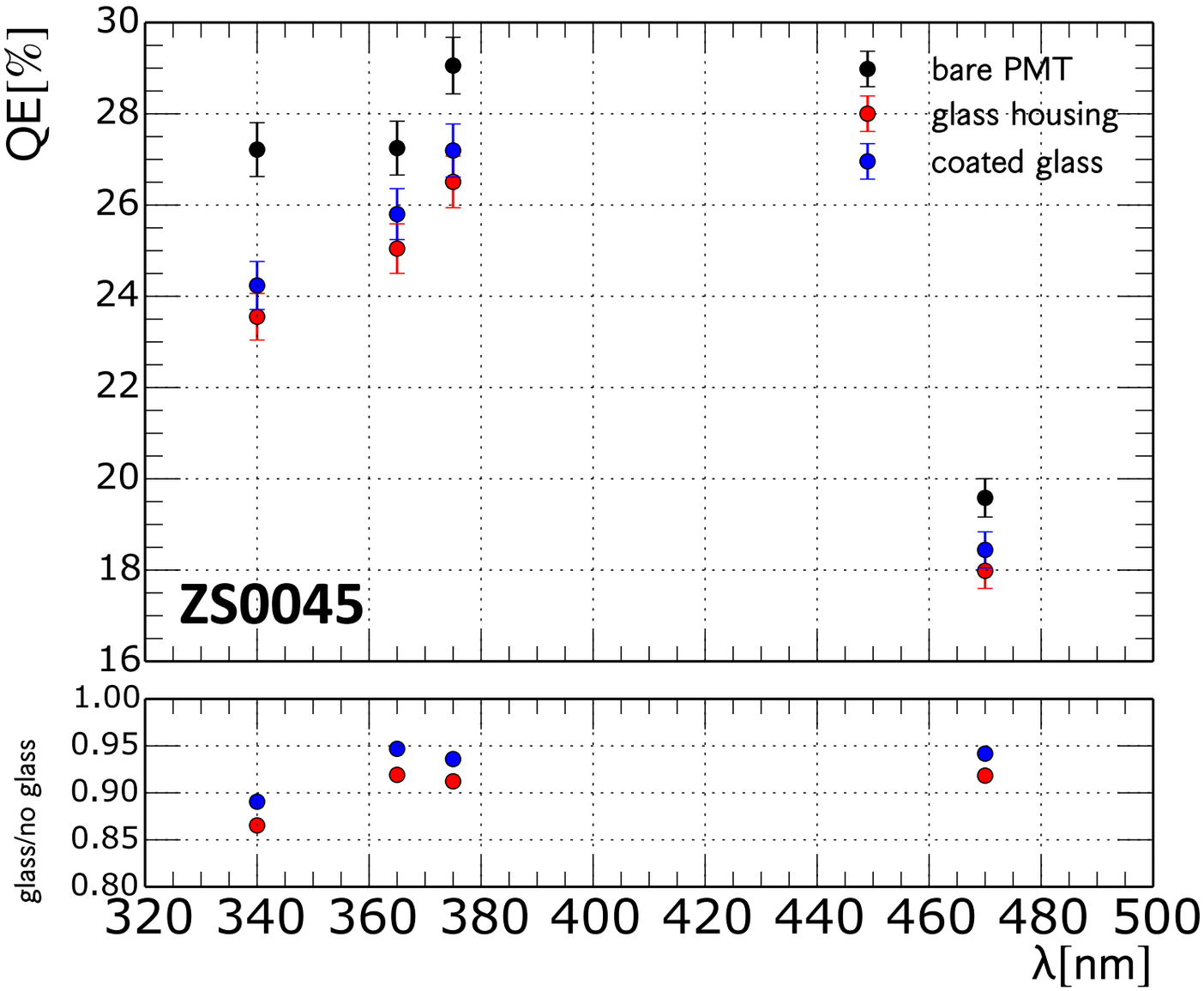
Transmittance improved at all λ

Larger improvement at small λ (< 300nm)

→ *still needs test at low temp*

Ellipsoidal DOM: Lab Tests of PMT and Glass Housing

All credits Hans Niederhausen (Stony Brooks Uni.)



Current IC DOM:
max QE at 400nm: 22%
QE at 350nm: 7%

PMT QE improvement confirmed at low λ
~6% reduction for coated glass

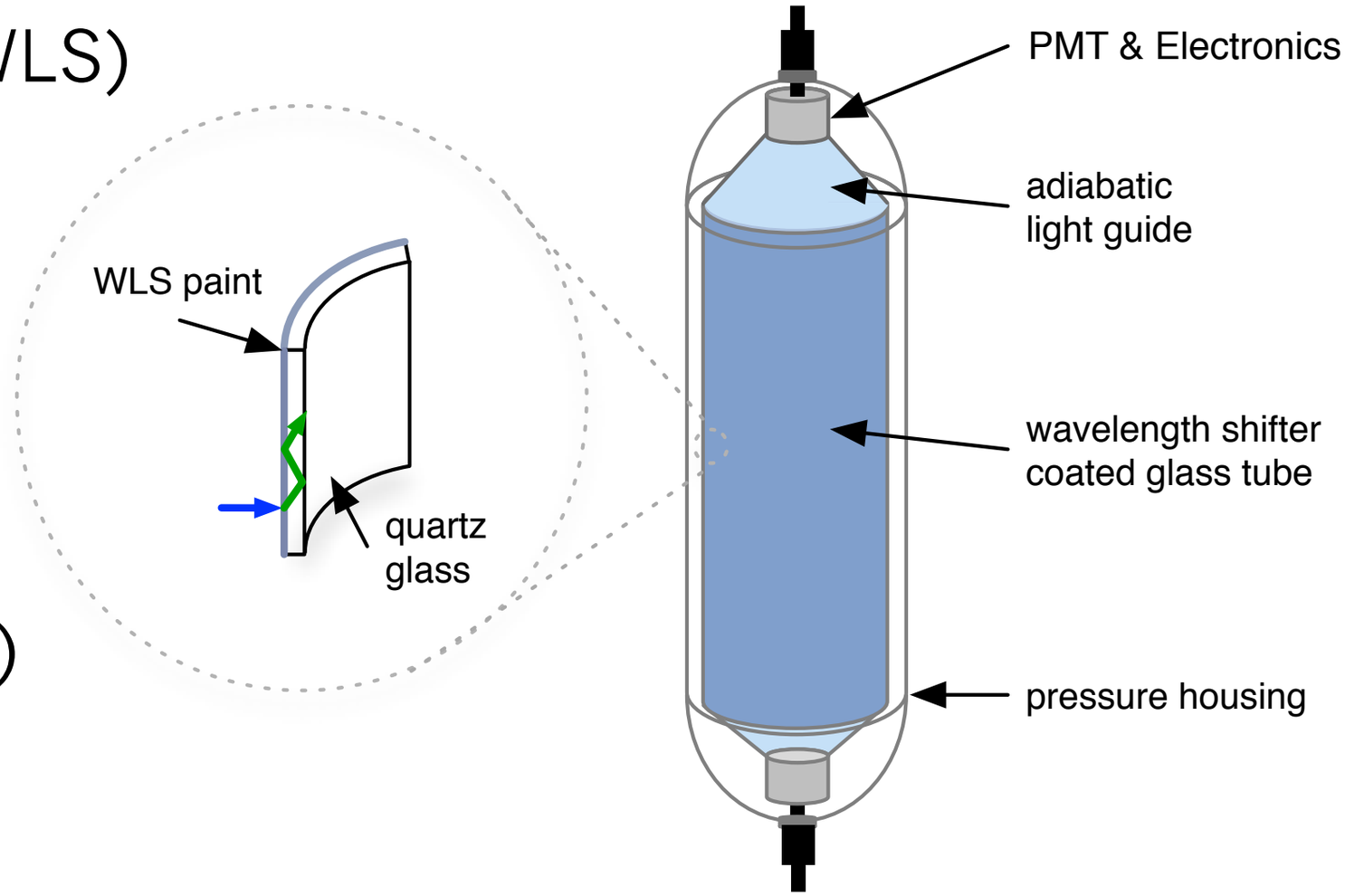
Wavelength-Shifting Optical Module — WOM: Rationale

Basic concept

- Wavelength shifters (WLS)
  - concentrate light

Features

- large collection area
- low noise rate (few Hz)
- better UV sensitivity
- cost effective



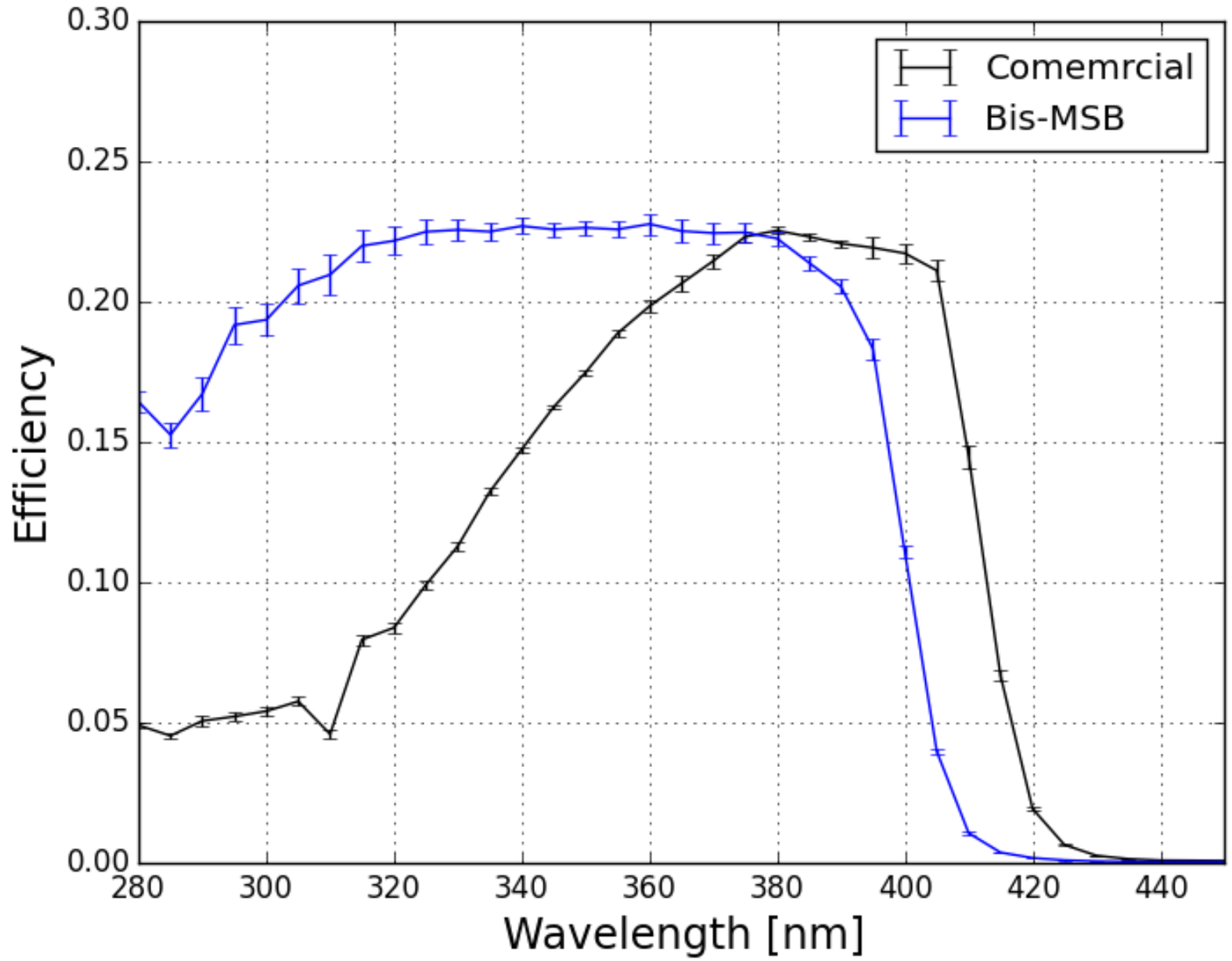
WOM: Wavelength-Shifting Coating

Best paint

- Bis-MSB
- PMMA
- Anisole

Performance

- large gain in UV region
- emission slightly more green



Efficiency includes absorption, re-emission, and light guiding to photosensor

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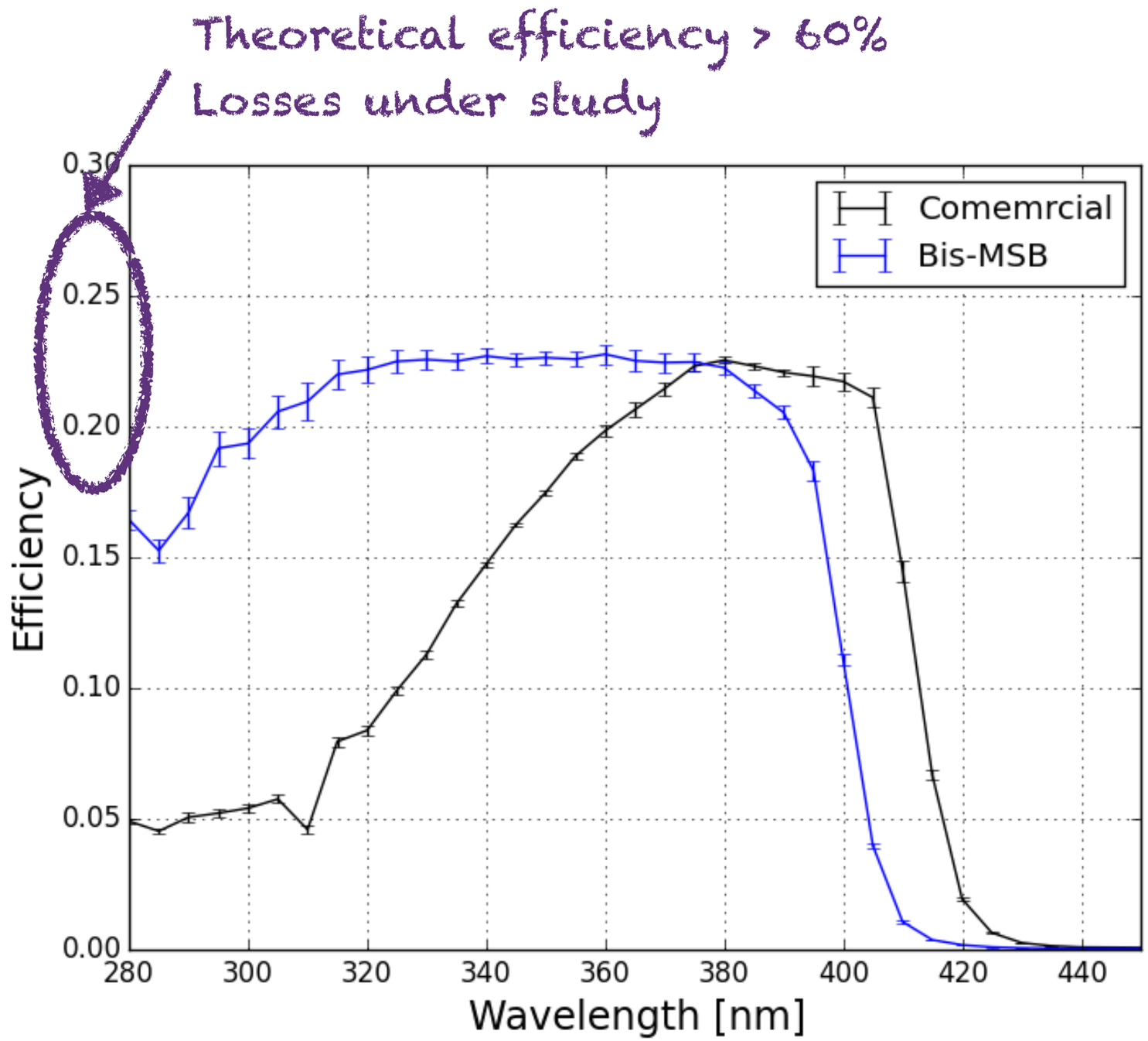

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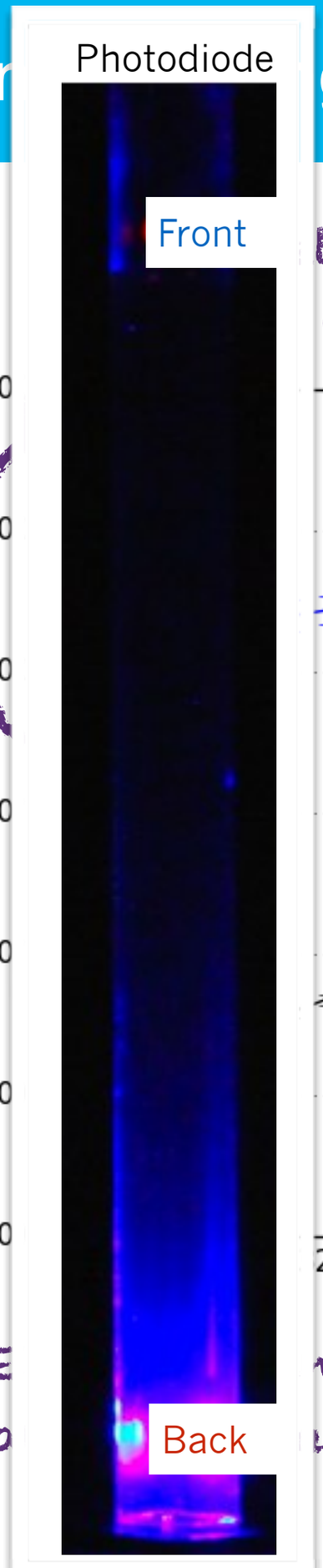


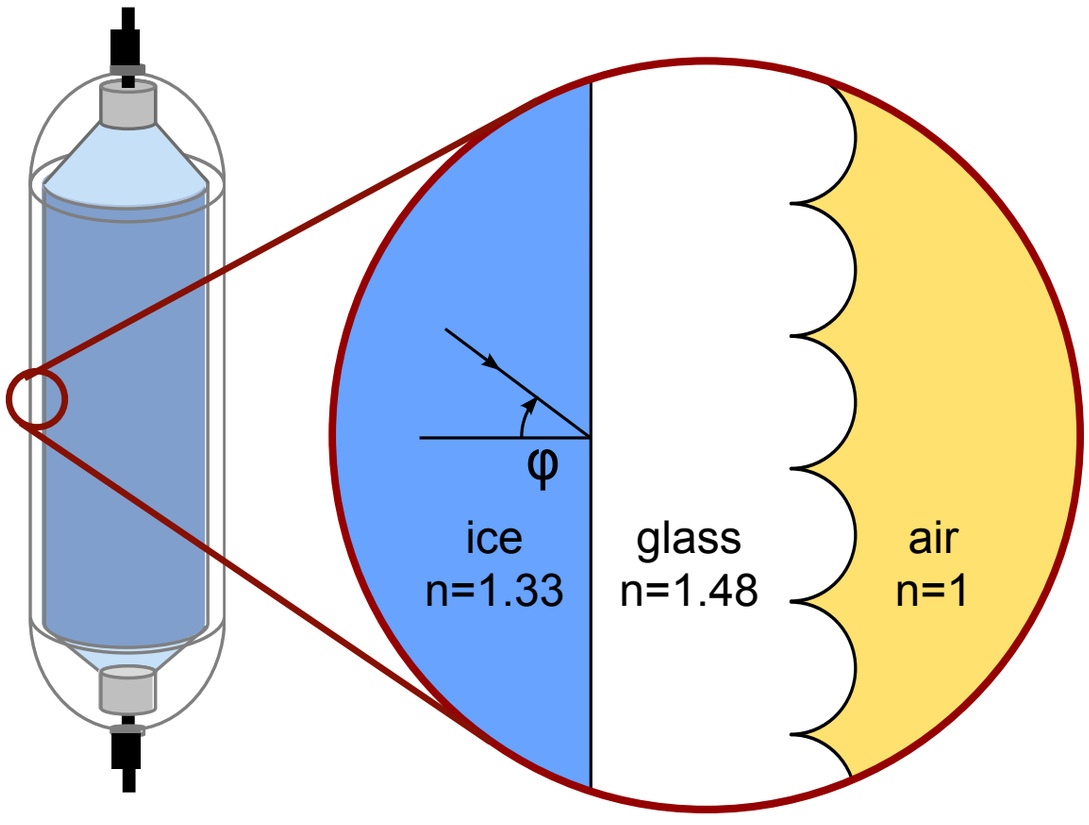
tical efficiency > 60%
under study

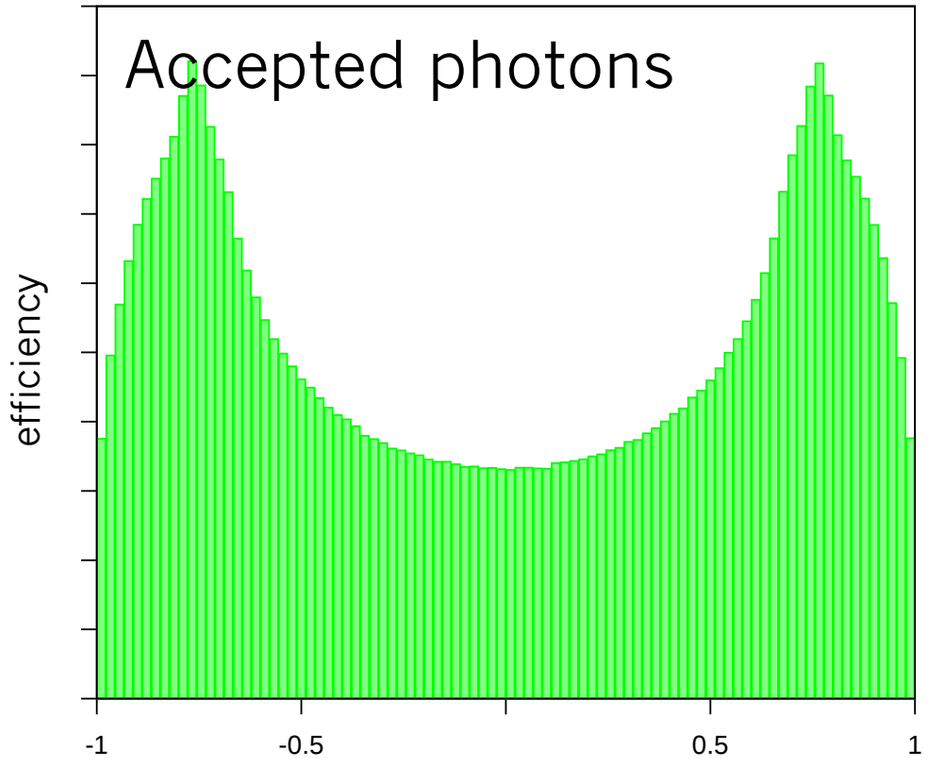
E ncludes absorption, re-emission,
o iding to photosensor

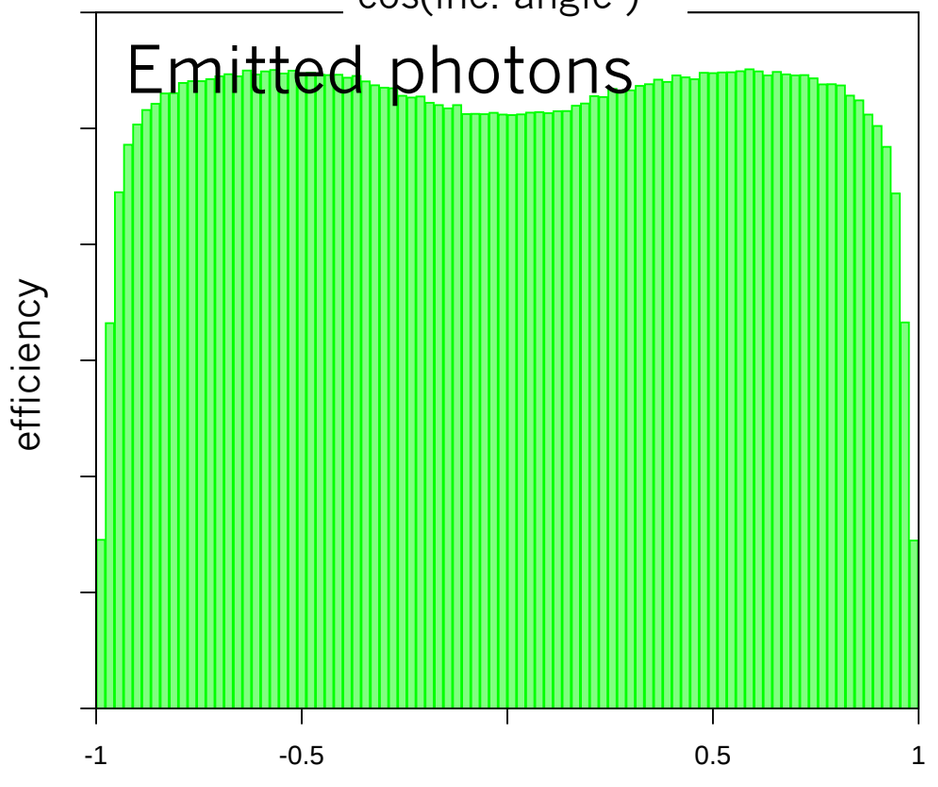
WOM: Future Improvements

Semi-spherical surface grid (lenticular arrays)

- maximizes acceptance
- gain **37%** w.r.t. flat







Conclusions

- Baseline optical module designs of all experiments
  - GVD, KM3NeT: Prototypes operating successfully in-situ
  - IceCube extension: close to IceCube DOM, changes in design phase

- Several ideas for alternative optical modules being developed

- There seems to be potential for synergetic activities between groups
  - Modelling and simulation of optical sensors (Geant 4, …)
  - Laboratory setups / facilities for characterisation and calibration

Helmholtz Alliance for Astroparticle Physics

Detector Design and Technology for Next Generation Neutrino Observatories

HAP Workshop Topic 4: Advanced Technologies

Program

- Neutrino detection from MeV to EeV energies
- Air shower physics with surface detectors
- Veto strategies
- Optical sensor development
- Radio and acoustic detection technology
- Design studies of future detectors
- New ideas

picture credit: Stadt Aachen/Andreas Herrmann (Aachener Weihnachtsmarkt); ESA/NASA/JPL-Caltech/Whitman College (A puzzling cosmic ring, called NGC 7538, discovered by the Herschel Space Observatory)

December 08-10, 2014 at RWTH Aachen

Local Organisation:
Jan Auffenberg, Christopher Wiebusch

Program Committee:
Gisela Anton (Uni Erlangen),
Klaus Helbing (Uni Wuppertal),
Timo Karg, Marek Kowalski (DESY)

hap2014@physik.rwth-aachen.de
http://hap2014.physik.rwth-aachen.de

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