WWU MÜNSTER

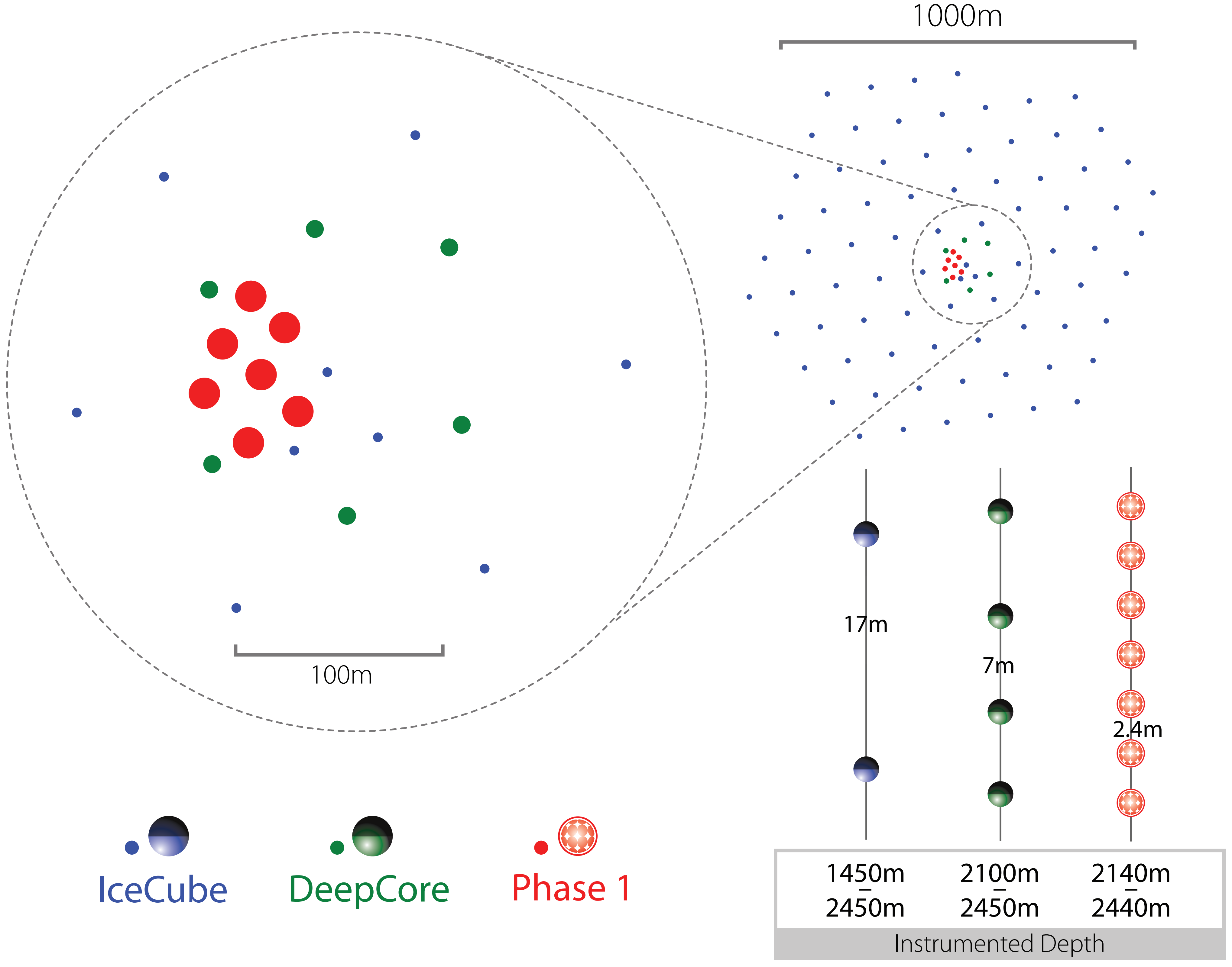
ICECUBE GEN2

The multi-PMT optical module for the IceCube-Upgrade

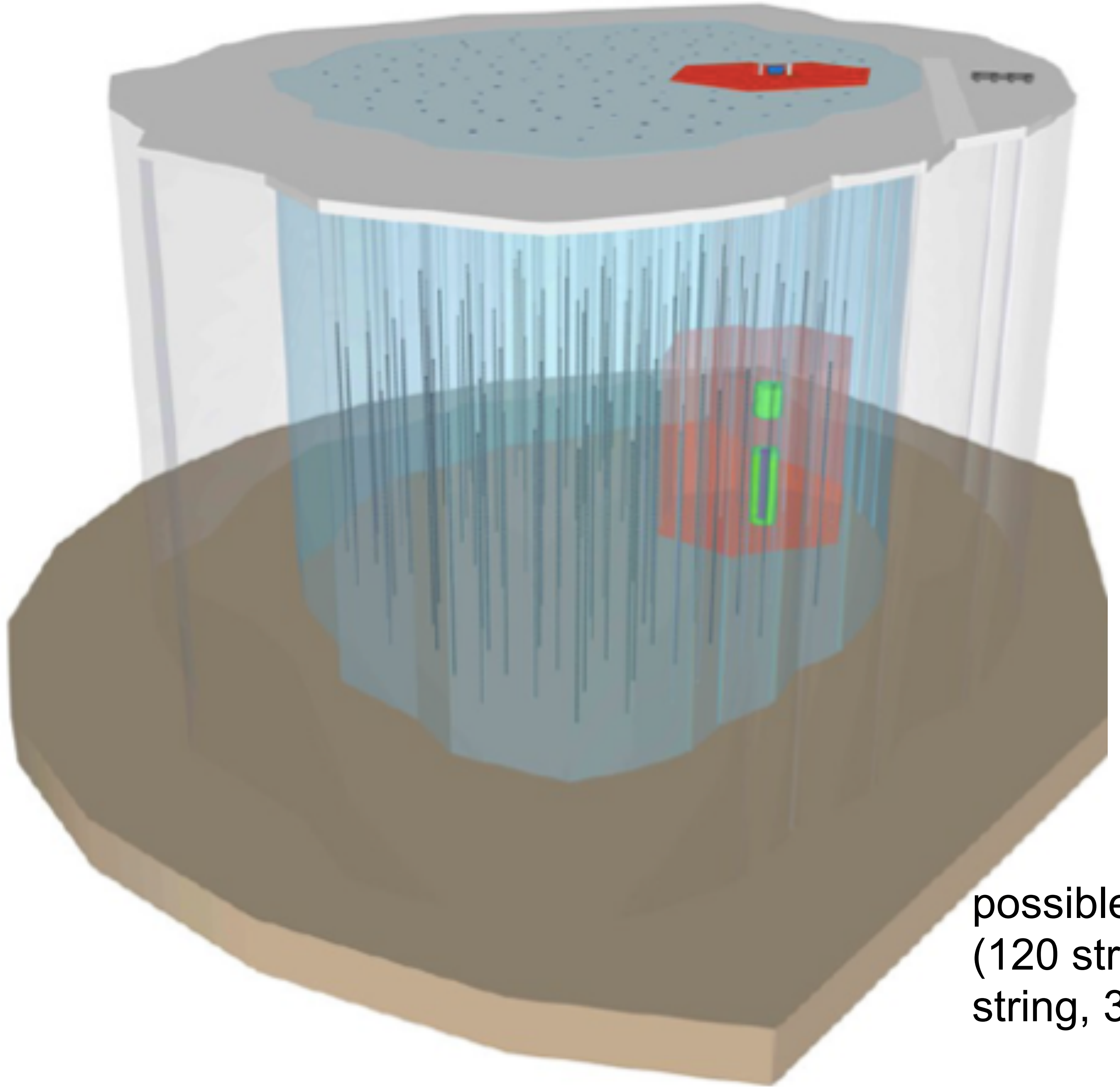
Alexander Kappes for the IceCube Collaboration
VLVnT Workshop
Dubna, 2–4. Oct. 2018

Detector plans for the South Pole

IceCube Upgrade
(7 strings, ~900 modules)

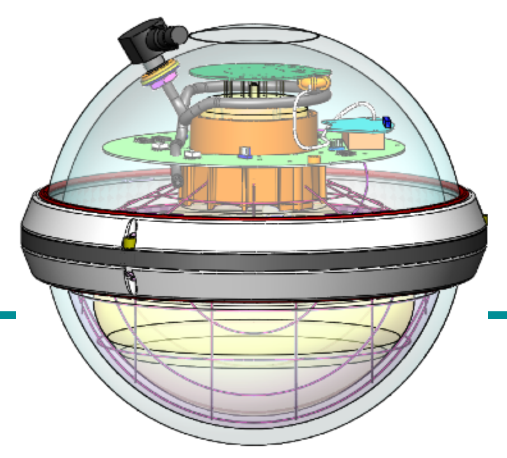


IceCube-Gen2
(120 strings, ~10,000 modules)



possible configuration (120 strings, 80 DOMs/ string, 300 m spacing)

Gen2 DOM



D-Egg

mDOM

WOM

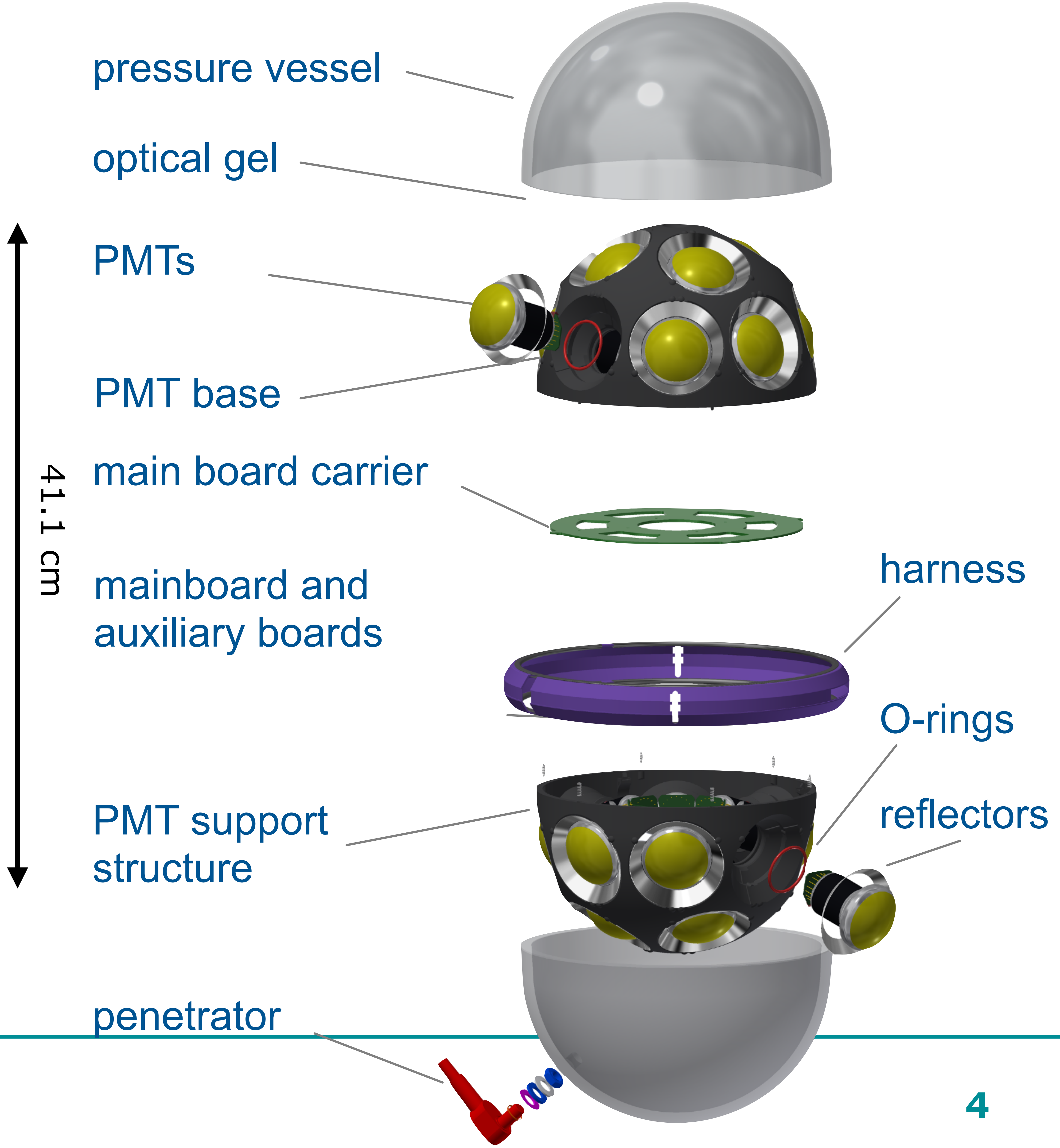
Challenges for optical modules at the South Pole

- Have to withstand up to 700 bar pressure during freeze-in
- Have to operate at −40°C
- Tight space constraints inside module
  (outer diameter limited to < 14” by max. bore hole diameter)
- Tight power constraints
- Limited data bandwidth (copper cables for data transfer)
- High reliability over >10 years (no repairs possible)

mDOM overview

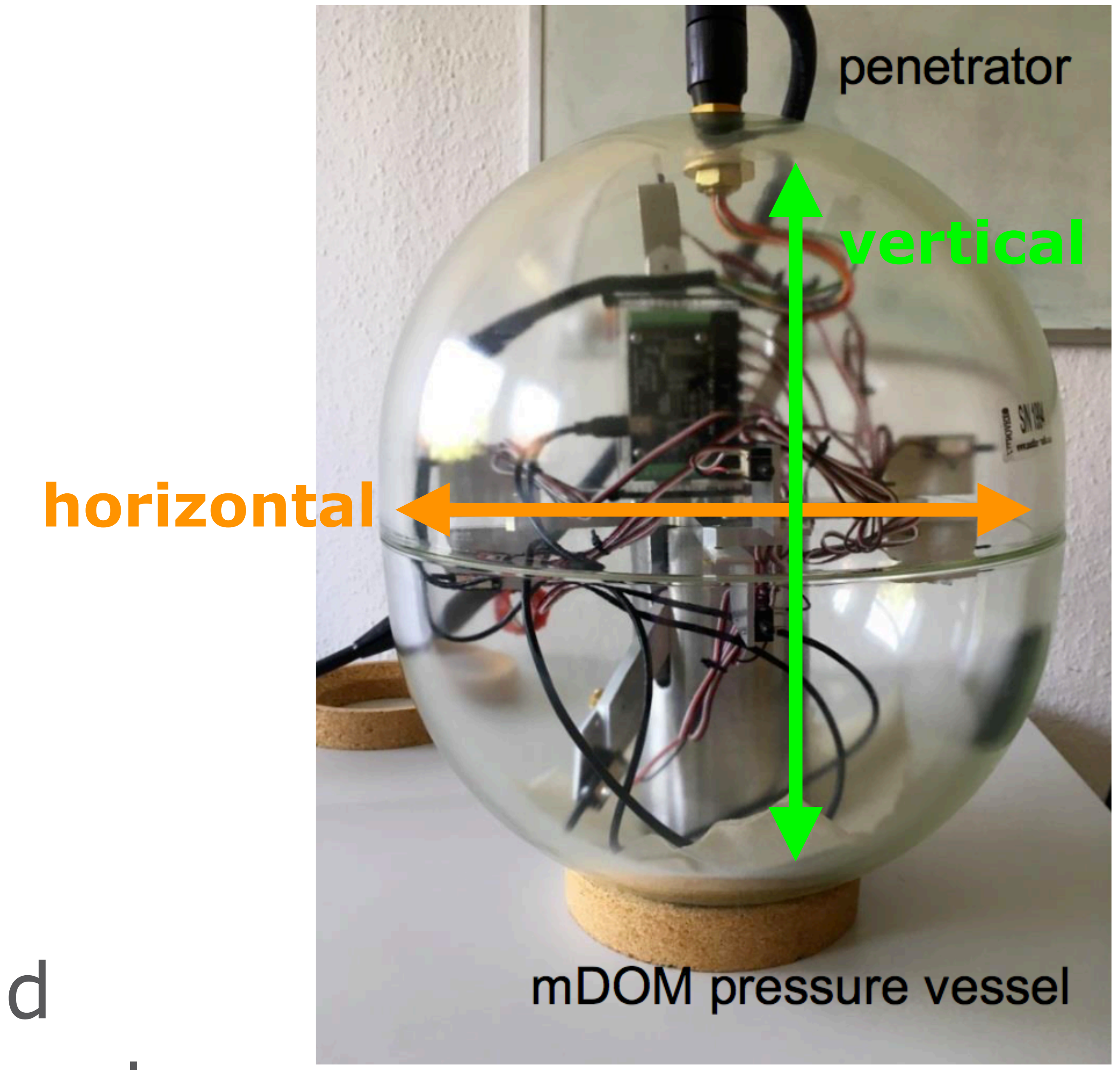
Features of multi-PMT optical module design

- Large photocathode area
- Uniform solid angle coverage
- Local coincidences, e.g. for background suppression
- Information on photon arrival direction
- Exact photon counting if different PMTs are hit

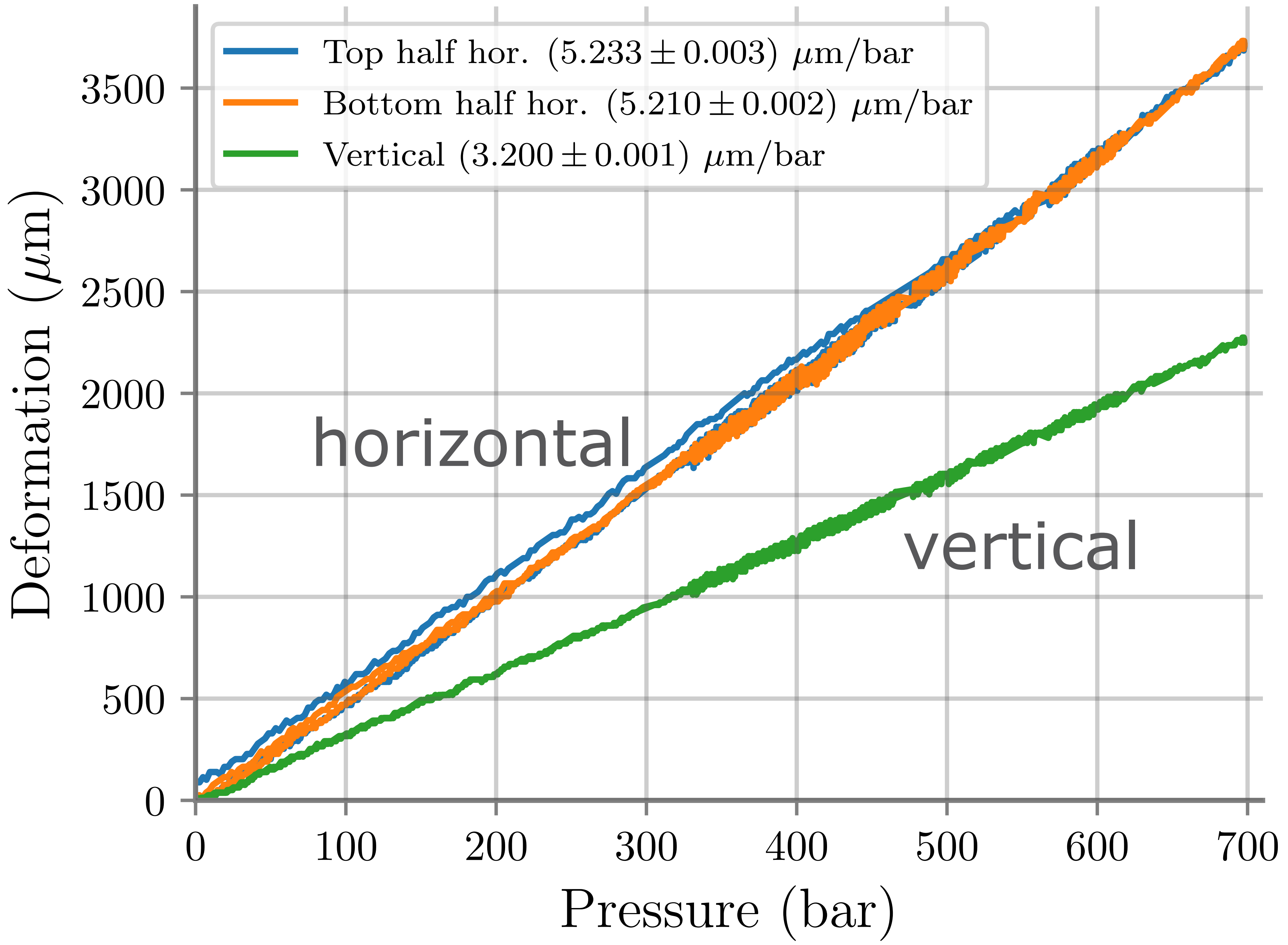


Pressure vessel

- Two spherical half vessels with 14” diameter and 27.5mm cylindrical extension at equator (developed with and manufactured by Nautilus)
  - Glass type: borosilicate glass (total weight 13 kg)
  - Glass thickness: 14 mm



- Pressure tests successfully concluded in July (included semi-realistic deployment pressure cycle)

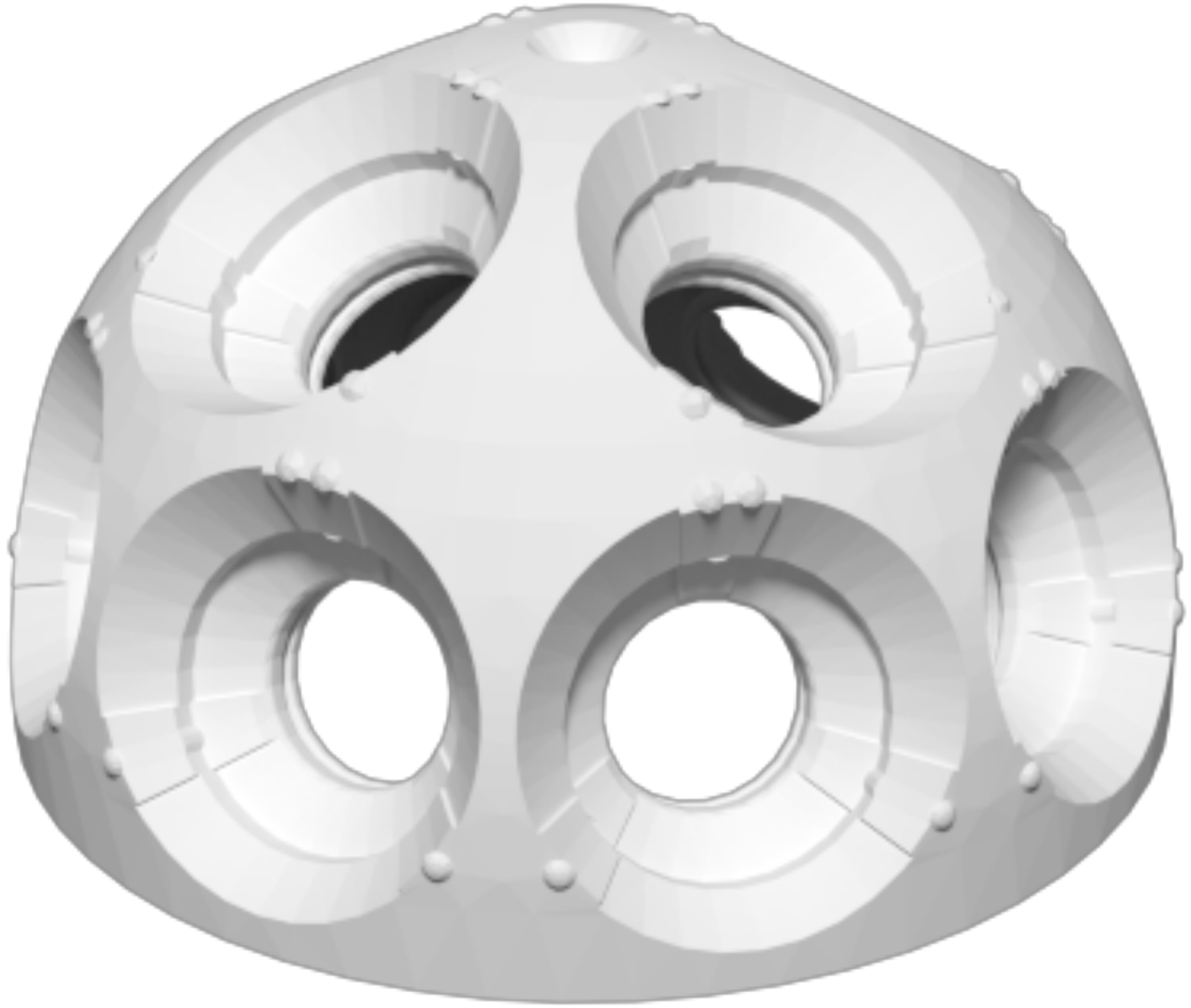


- Deformation is reversible and follows external pressure linearly
- Maximal deformation agrees with FE simulations within 2%
- Thorough inspections after pressure tests have revealed no damage to glass or chamfer

PMT support structure

Currently 3d printed from polyamide via laser sintering

- Advantages
  - allows realization of complex structures
  - modifications possible on short timescales
- Disadvantages
  - expensive in series production (~400 EUR per half)
  - long production time (~2 days including cooling)

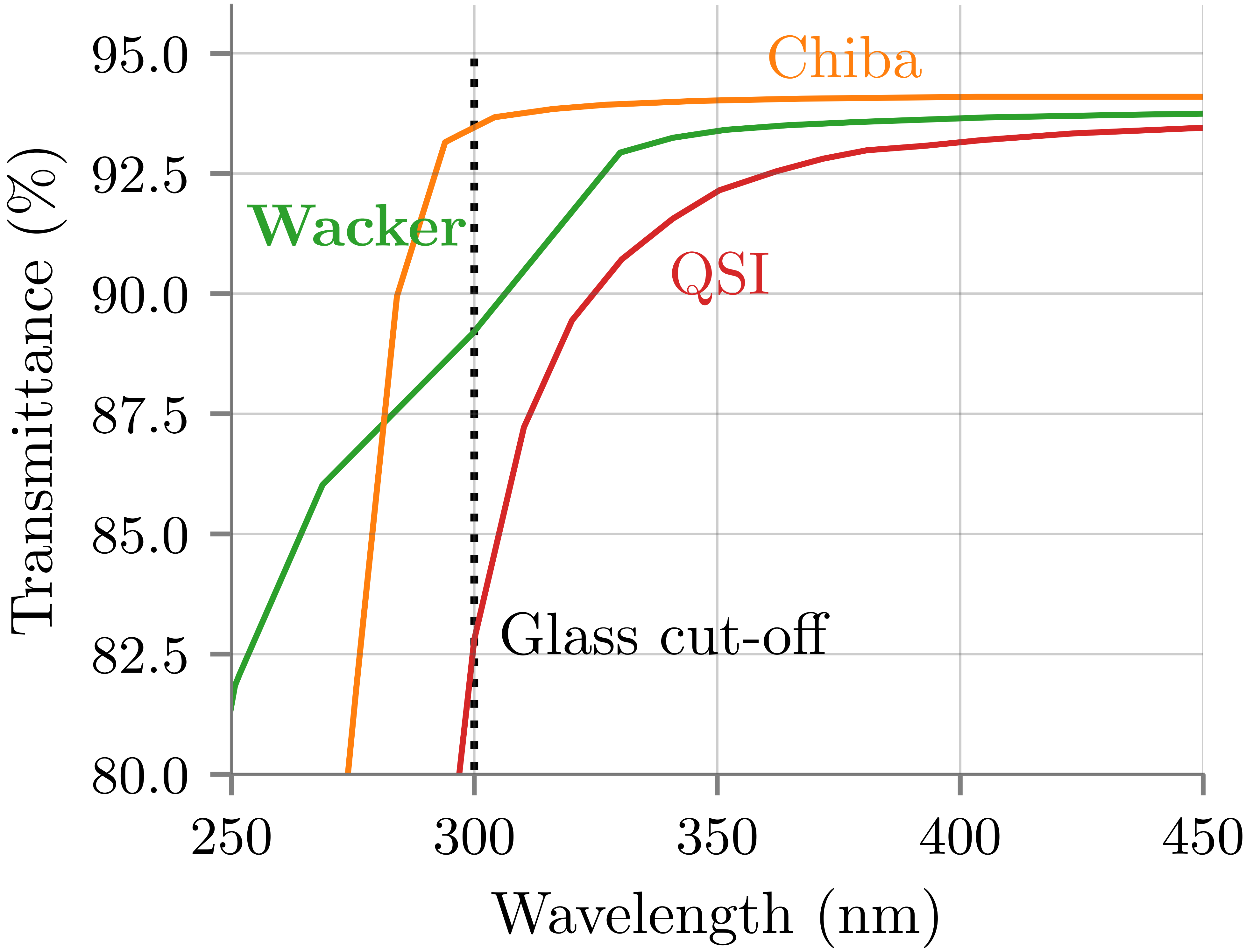


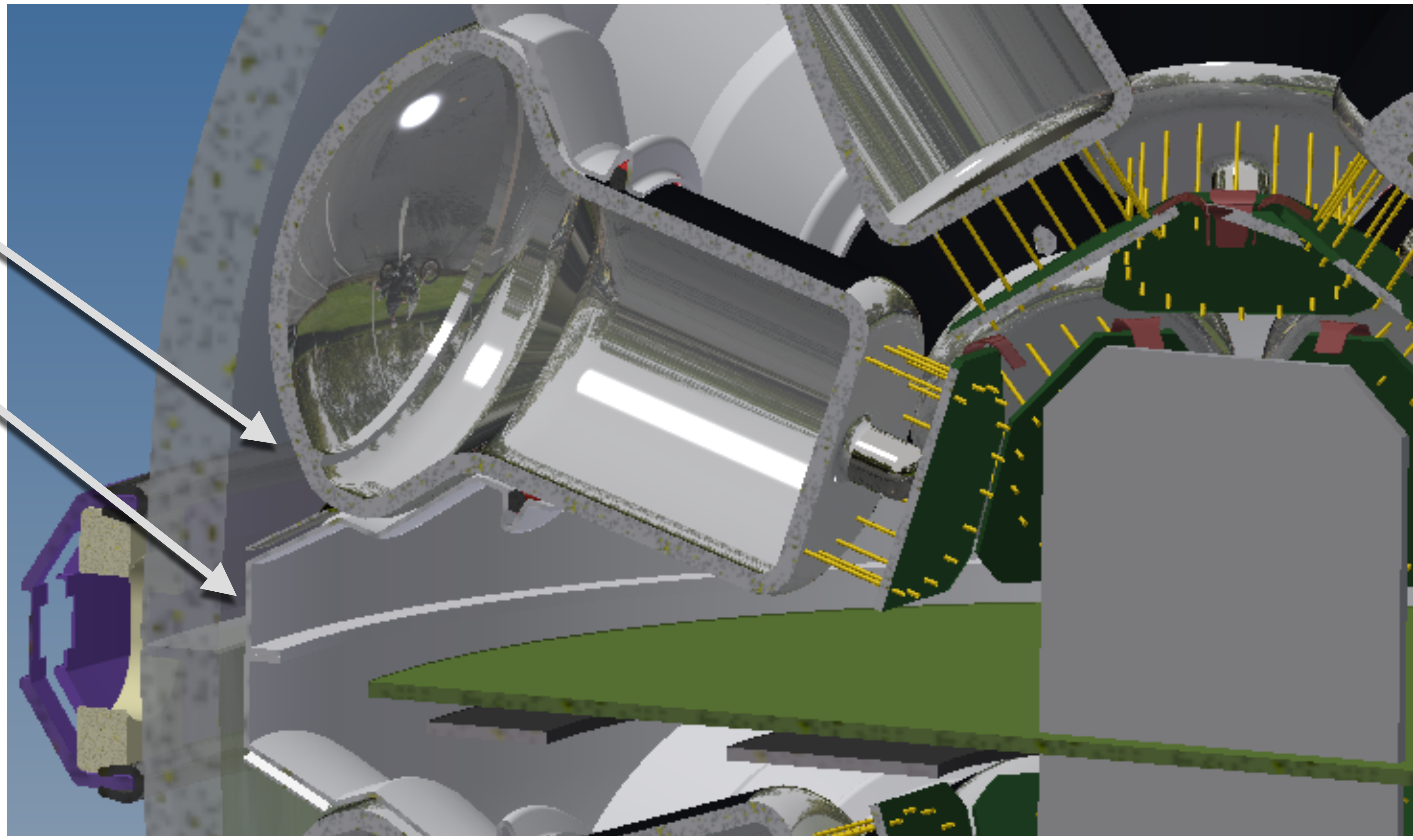
Alternative: Injection molding

- Advantages
  - Low price for large quantities
  - Much higher production capacity
- Disadvantages
  - half-sphere structure and PMT cups have to be produced separately and assembled afterwards
  - price for tools high (several 10 kEUR)

Optical gel

- Gel fills gap between PMT support structure / PMTs and pressure vessel
- Transmission properties vary significantly between brands





- Initially Wacker SilGel 612 → crystallizes at −45°C into a hard and opaque state
- Now QGel 900 from QSI (used in IceCube DOMs)

Photomultiplier

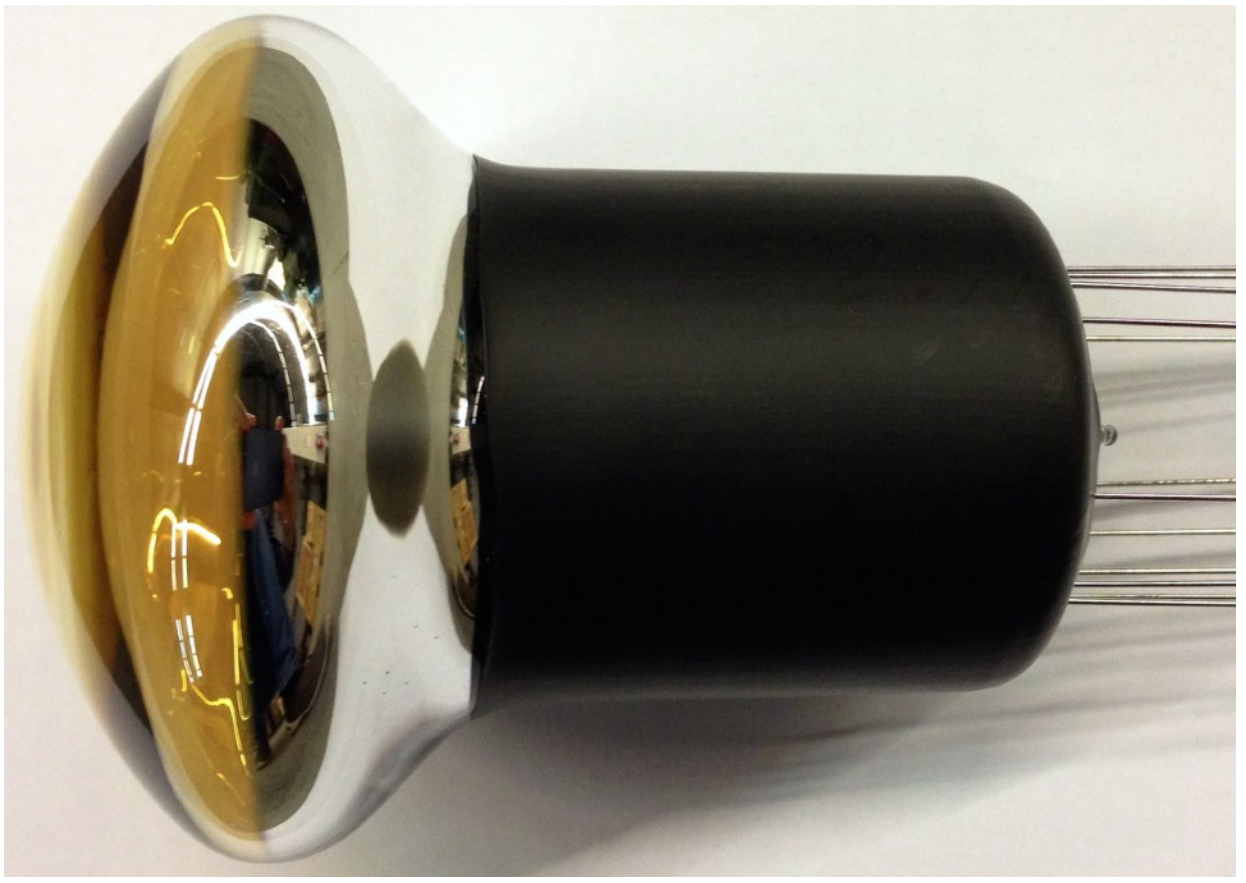
Will likely operate with negative HV at photocathode

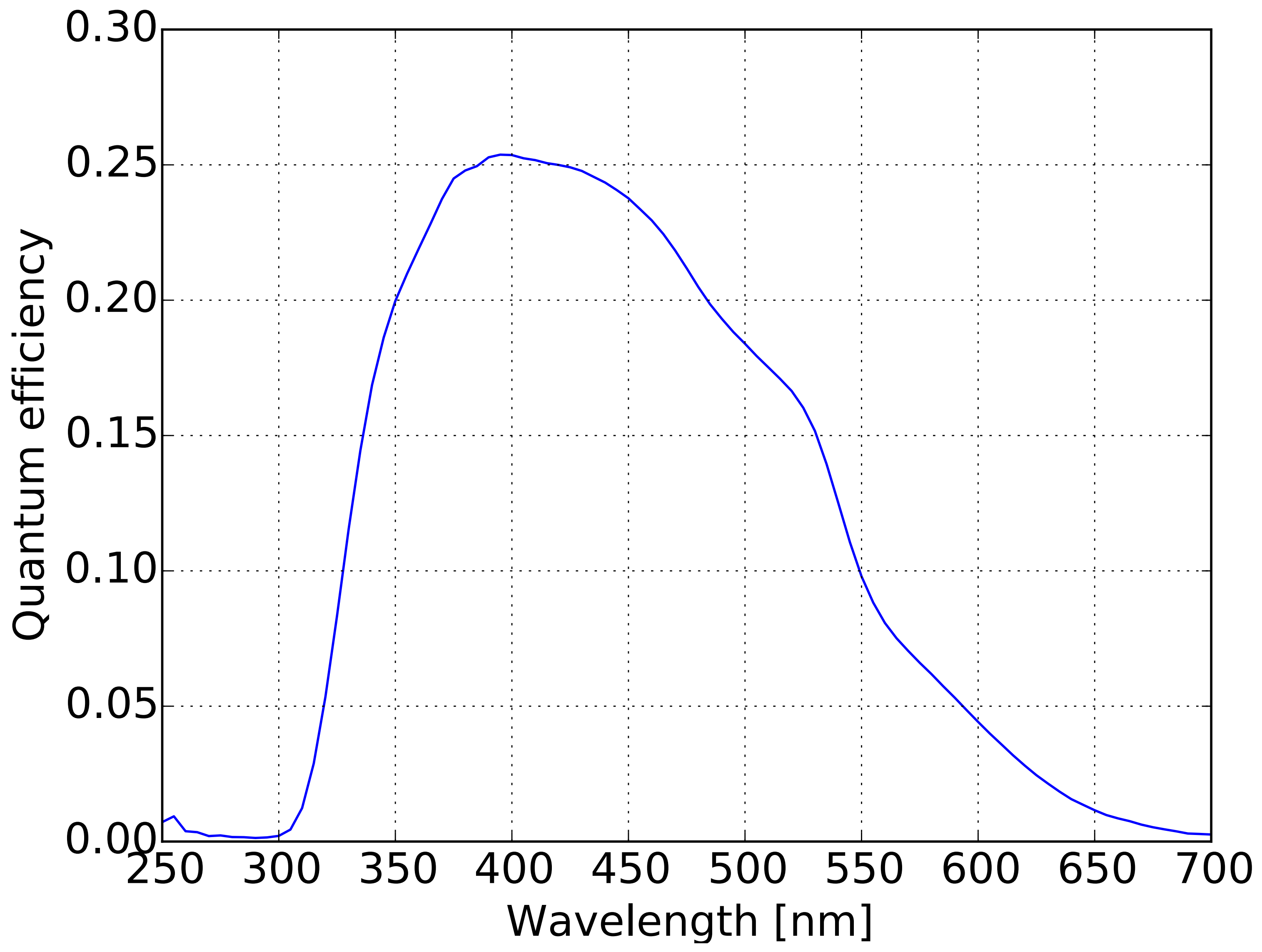
For demonstrator development: Hamamatsu R12199-02 HA MOD

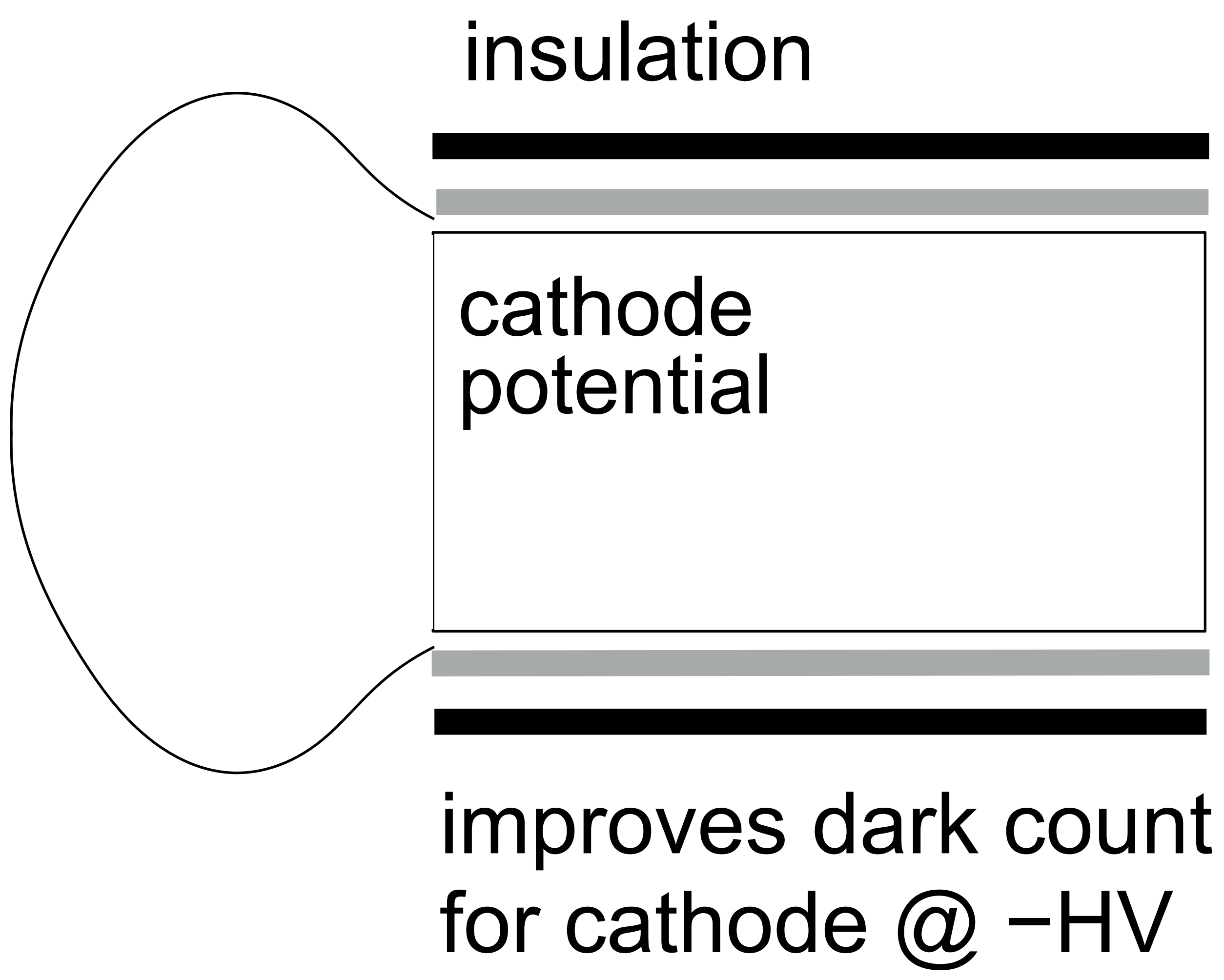
- Modified version which is 5 mm shorter and has HA coating
- HA coating puts glass outside photocathode area on HV thereby reducing dark-noise rate due to electrons hitting glas from inside
- PMT characteristics
  - diameter 80 mm (cathode >72 mm)
  - length 93mm
  - gain ~3×10^6 @ ~900 V
  - TTS (FWHM) = ~3.5 ns
  - typical quantum efficiency curve (25% @ 400 nm)

Alternative PMTs under investigation

Hamamatsu R12199-02 HA







Alternative PMTs: 3.5” PMTs from HZC

- Type: HZC XP82B2F
- Characteristics (for details see talk Lew Classen)

Daan van Eijk (Madison)

	SN80187	SN80171	SN80169
Gain slope (log/log)	6.99 ± 0.06	6.55 ± 0.09	6.60 ± 0.07
Supply voltage @ gain 1x10^7 [V]	1147 ± 96	1252 ± 171	1424 ± 158
Pre-pulses [%]	0.8	0.9	0.8
Delayed pulses [%]	1.9	1.8	1.4
Late after-pulses [%]	-	-	-
Transit time spread (FWHM) [ns]	4.3	4.2	3.2
Uncorrelated noise (20°C) [Hz]	391 ± 2	417 ± 3	1828 ± 10
Uncorrelated noise (-30°C) [Hz] *	18 ± 1	21 ± 1	21 ± 1

* Noise (−30°C) with 1 μs window: ~70 Hz

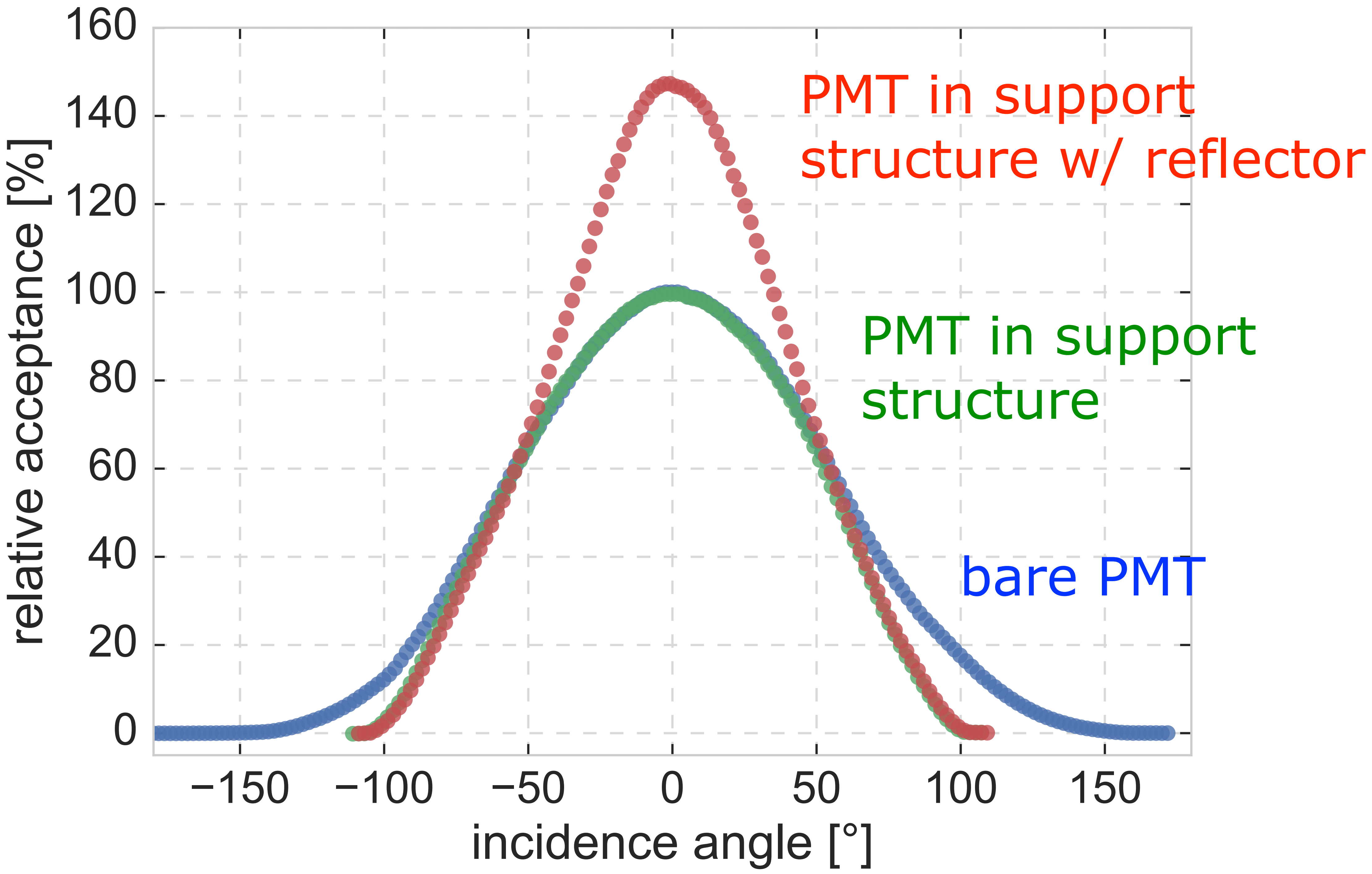
- Characteristics comparable to Hamamatsu R12199-02 with ~25% increased photocathode area → appears to be an attractive alternative

Alternative PMTs: 3.5″ PMTs from HZC

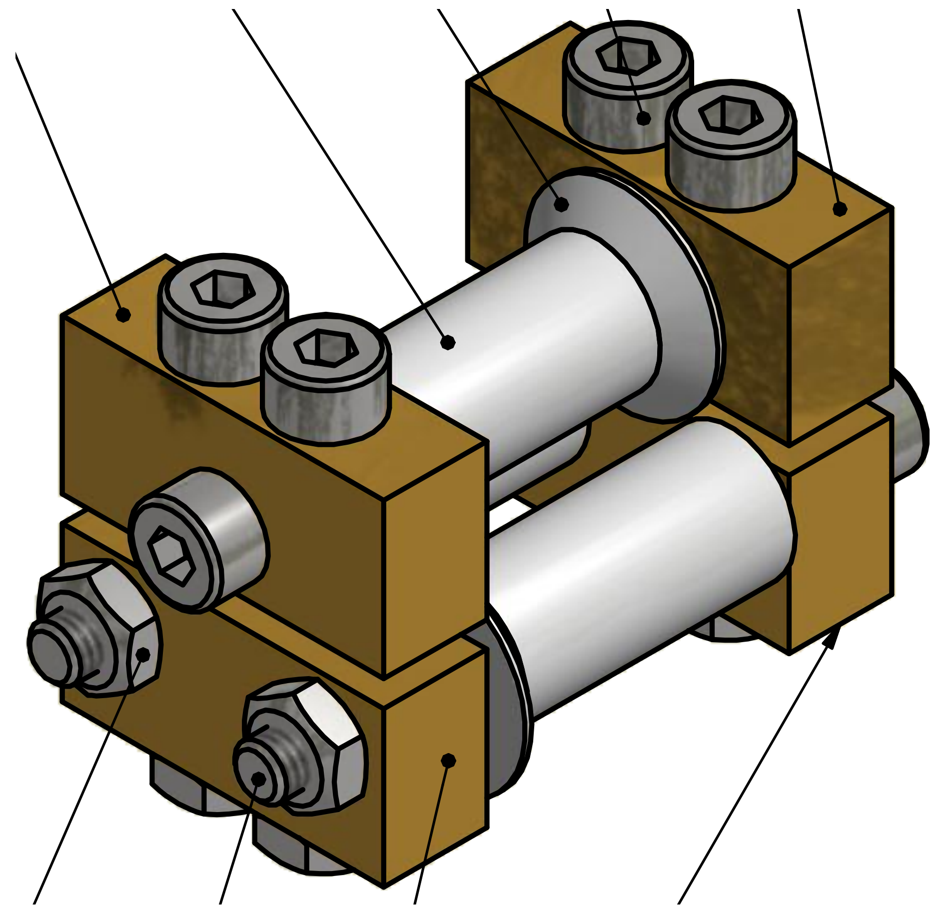
- Though mushroom diameter of HZC 3.5″ is significantly larger, overall length and stem diameter are quite similar to Ham 3"
  - Mushroom diameter
    HZC: 87.5 mm HA: 80.5 mm
  - Overall length
    HZC: 94.5 mm HA: 93.0 mm
  - Stem diameter
    HZC: 53.2 mm HA: 52.2 mm
- CAD drawings suggest that 24 3.5″ PMTs fit into a mDOM
- Plan to build 2nd demonstrator with HZC PMTs

Reflectors

- Reflector increases photon-collection area and directionality
- Laser-cut from coated aluminum sheet (Almeco V95)
- Bent by simple hand-held device



Reflector with PMT in test support structure



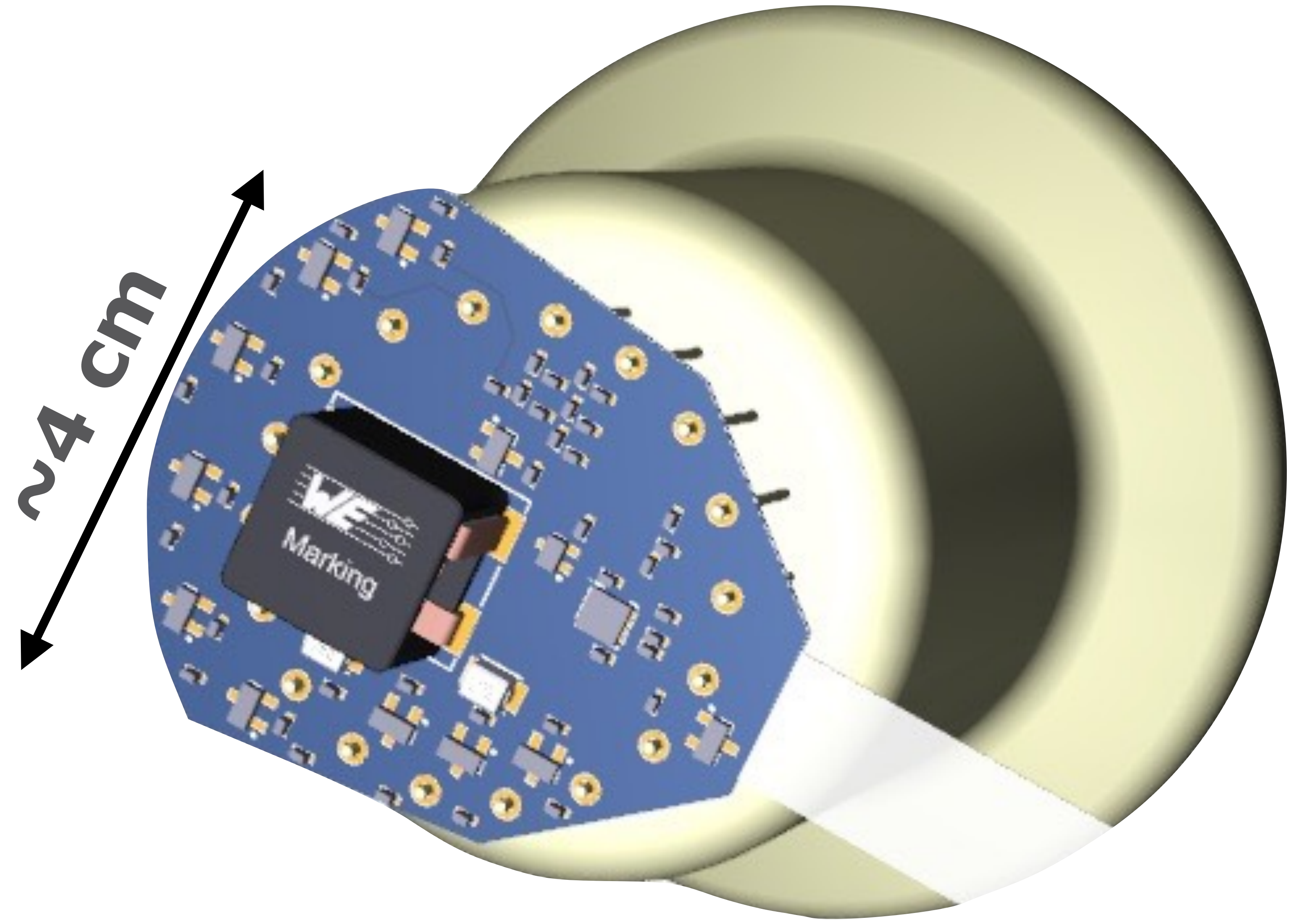
Bending tool

Bended reflector

Electronics

General requirements /constraints for readout and HV

- Sampling of semi-complex PMT waveforms
- Low power consumption (total ≲ 150 mW per PMT)
- Low sensitivity to interference signals (cross talk)
- Low footprint if placed on PMT base
- High reliability

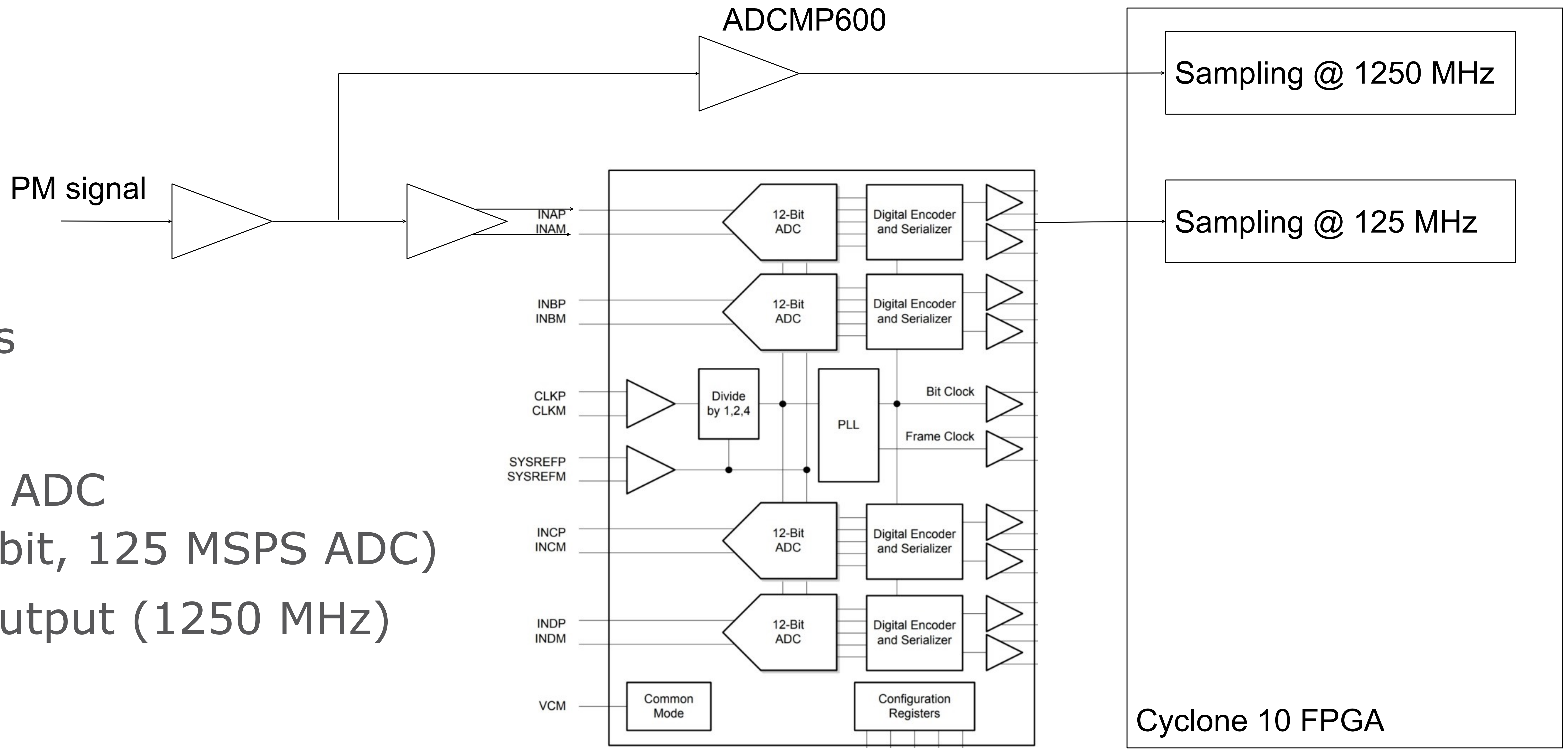


Remark: modular design of common electronics components (communication, timing calibration etc.) with well-defined interfaces
→ used in all module designs together with module-specific components

Baseline readout scheme: “slow” ADC design

Features

- Individual readout of all 24 PMTs
- For each PMT
  - sampling of signal with “slow” ADC (ADC3424 Quad-Channel, 12-bit, 125 MSPS ADC)
  - fast sampling of comparator output (1250 MHz) for precise leading-edge time
- Dead-time free
- Low power consumption: 98 mW / Ch



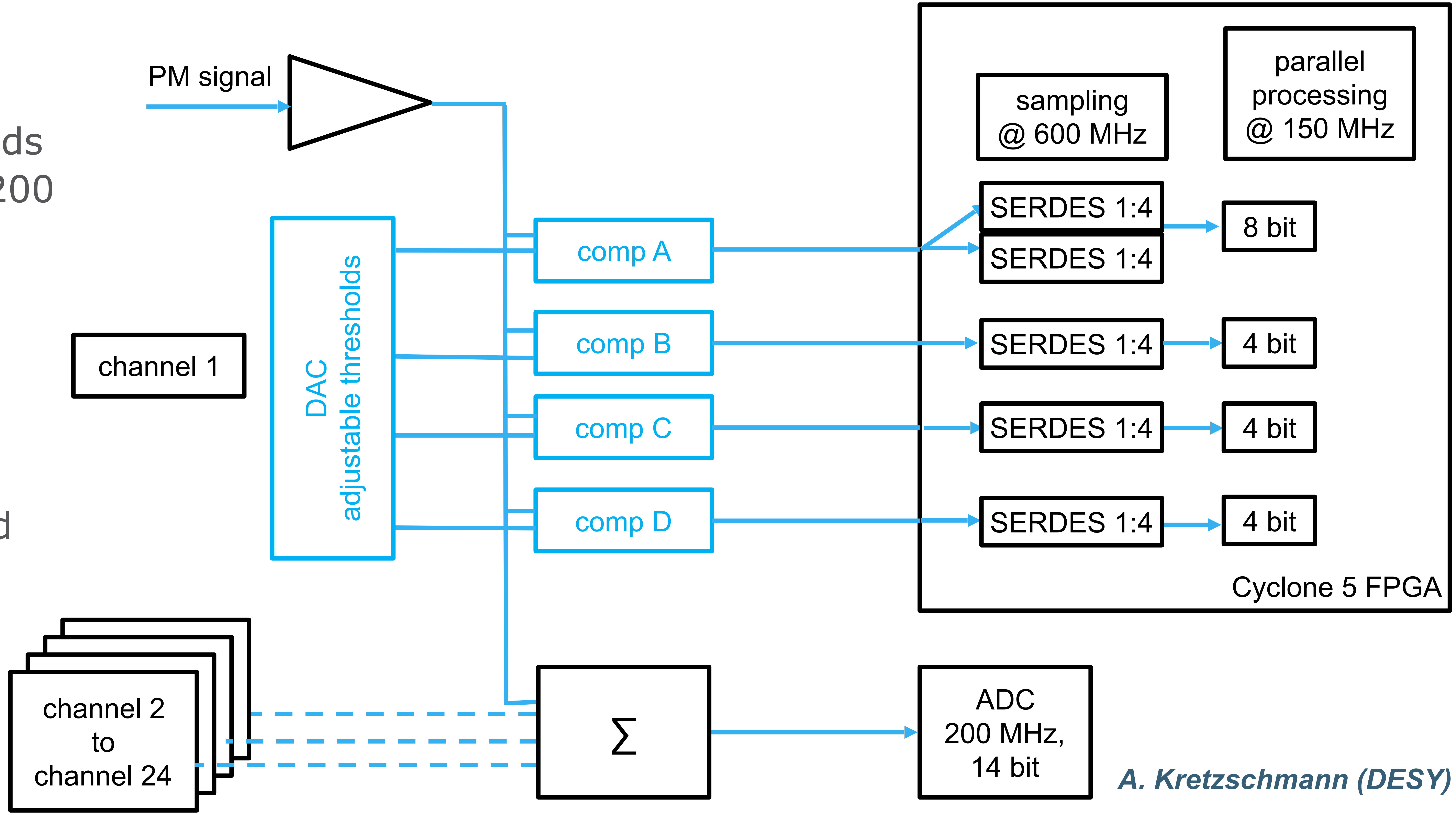
A. Kretzschmann (DESY)

Fallback: 4-comparator (ToT) design

Features

- 24 channels
- 4 programmable thresholds per PMT, sampled with 1200 (600) MS/s
- analog sum of all PMT signals sampled with 200 MS/s ADC
- dead-time free

Prototype exists (will be used for mDOM demonstrator)



A. Kretzschmann (DESY)

Summary and outlook

- A multi-PMT optical module is being developed for deployment in the deep ice at the South Pole for future IceCube extensions (IceCube-Upgrade, IceCube-Gen2)
- Harsh environmental conditions and available infrastructure pose stringent limits on module parameters like size, power consumption and reliability
- Mechanical design well advanced → optimizations towards final design
- Several options for readout have been under evaluation → selected baseline design: sampling of each PMT channel with "slow" (125 MHz) ADC + precision leading-edge time

mDOM timeline for IC-Upgrade

- end of 2018: demonstrator
- end of 2019: final design
- 2020—2021: production
- 2022/23: deployment

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