Multi-PMT development for Hyper-K project

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JENNIFER2 kickoff meeting
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Università degli Studi di Napoli Federico II

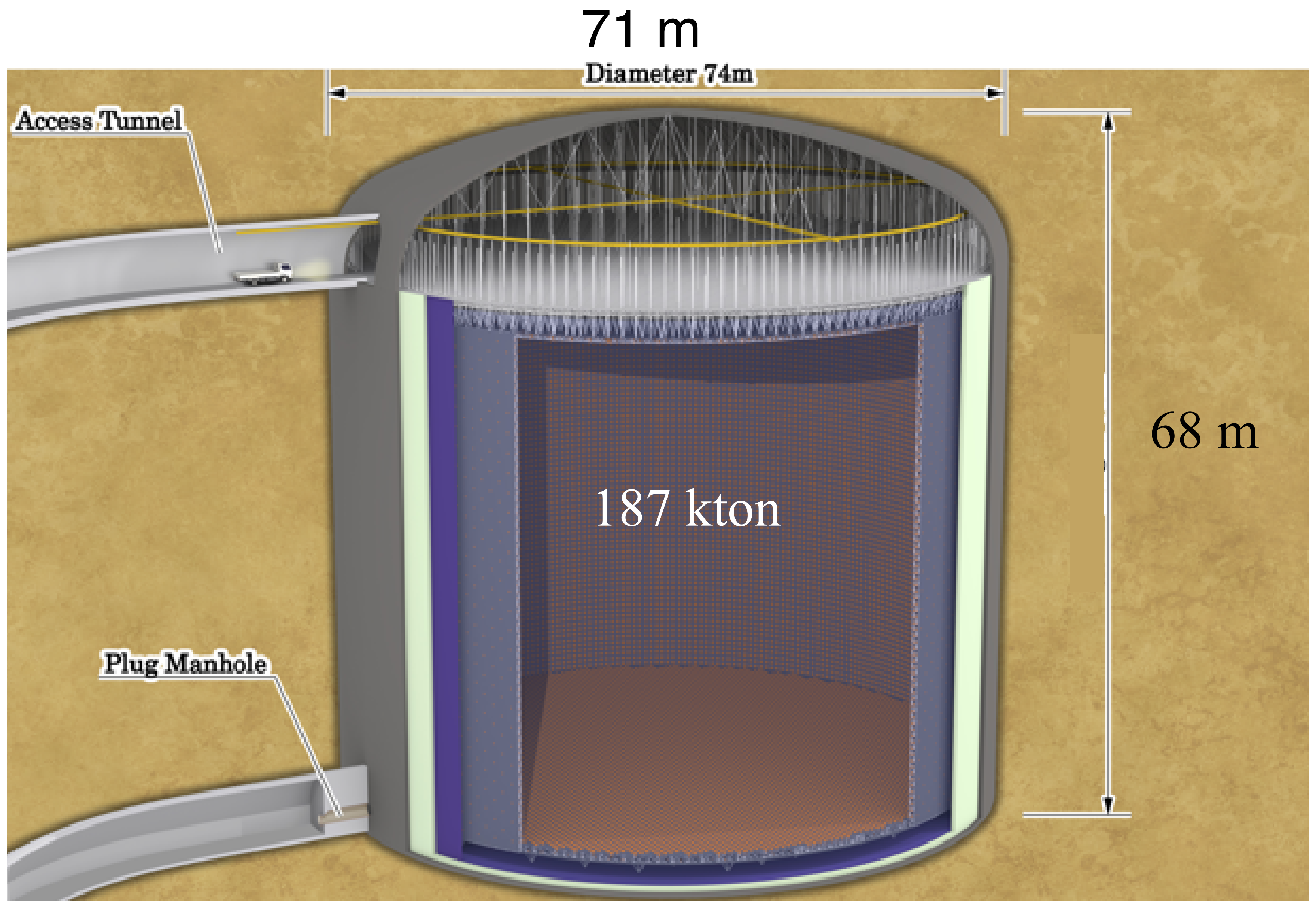
INFN Napoli

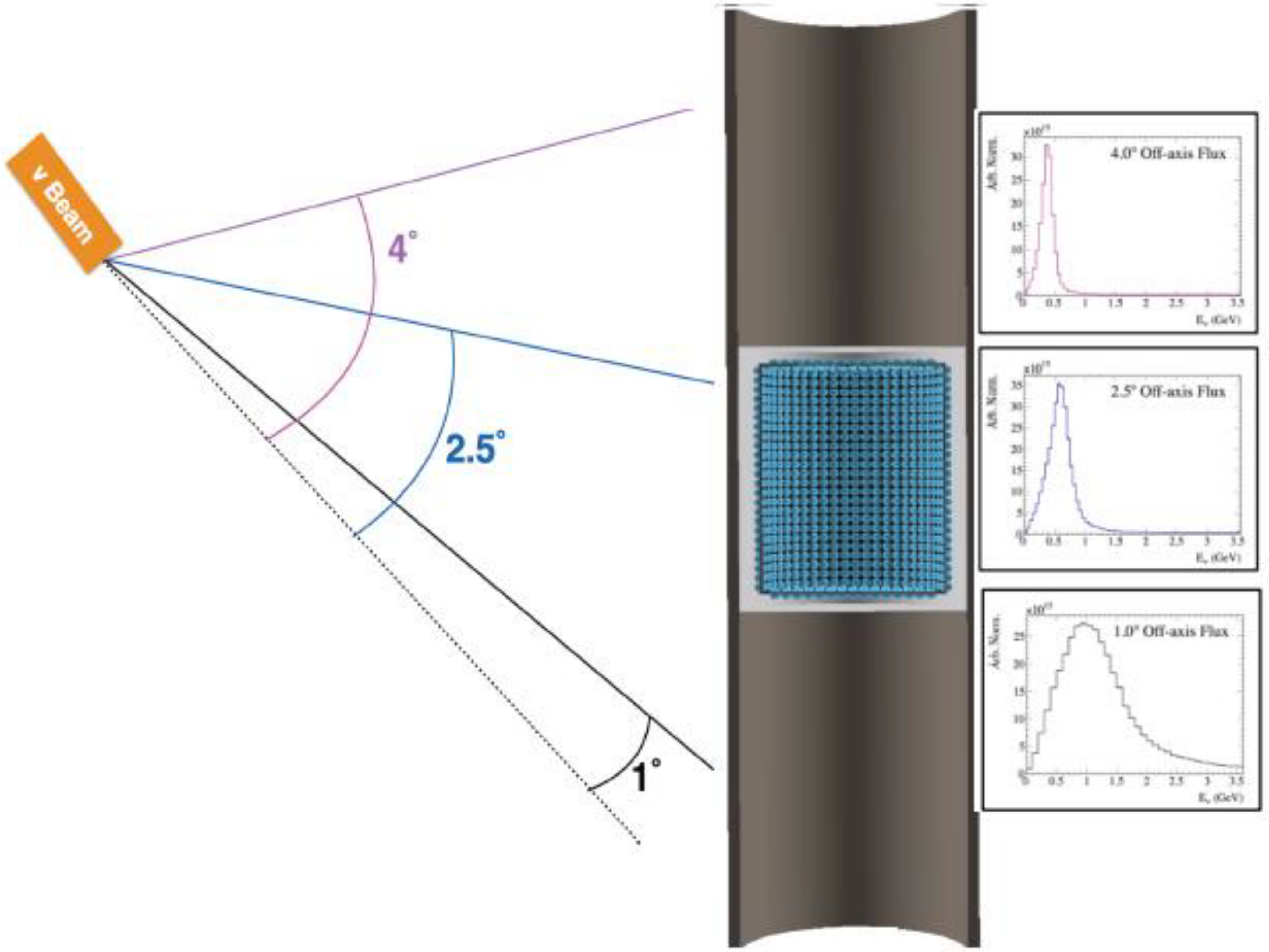
Overview

- The next generation water Čerenkov detectors: Hyper-Kamiokande (HK) and the intermediate Water Čerenkov Detector (IWCD)
- Photosensors options for HK and IWCD: 20-inch PMTs and multi-PMTs (mPMT)
- Simulation studies
- mPMT components
- Present and future activities on mPMT
- Conclusions

Future Japanese Neutrino Program

Start construction in April 2020





Wide range of phenomena investigated:

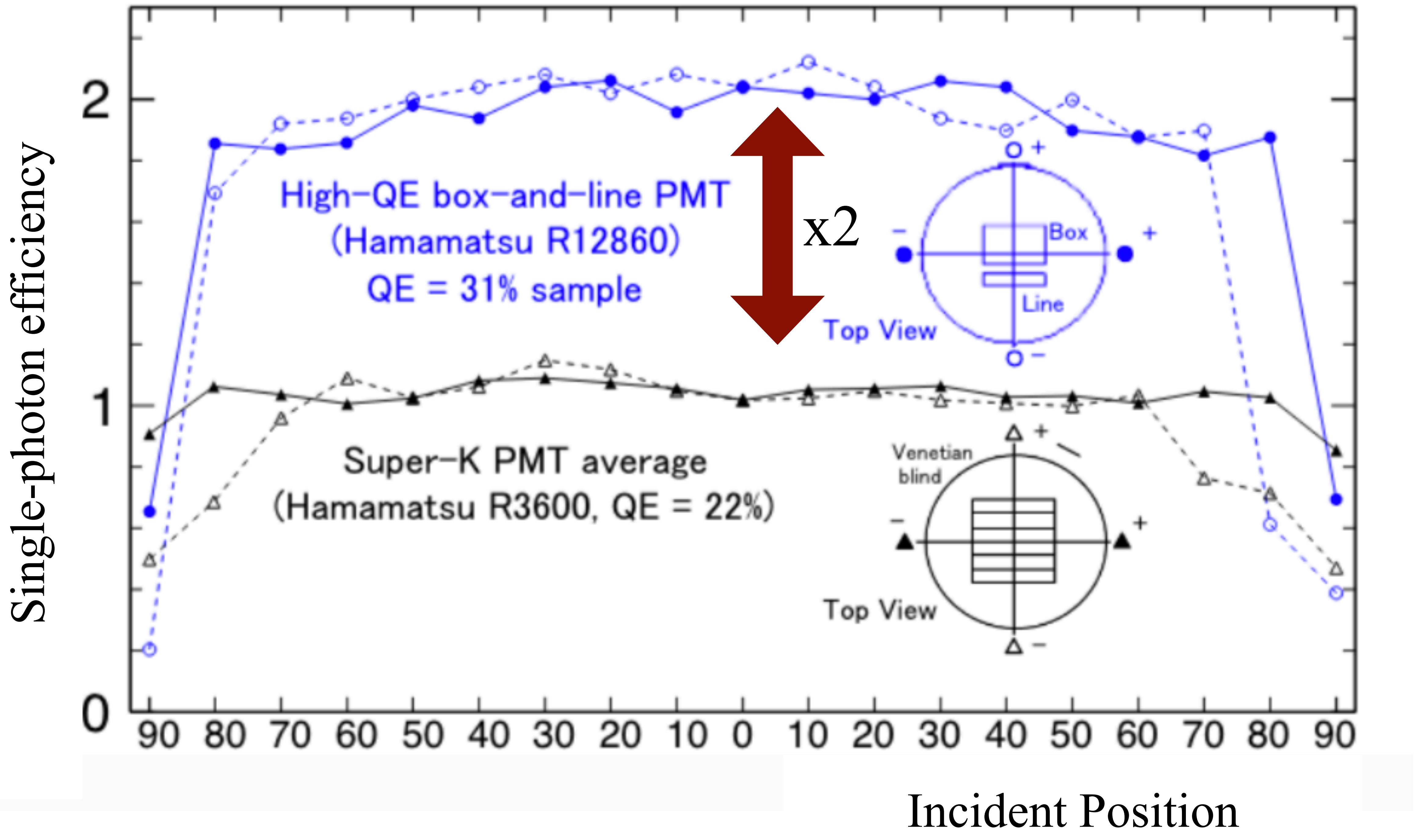
- Far detector for the LBL program: T2HK
- Atmospheric, solar and supernova neutrinos
- Nucleon decay search

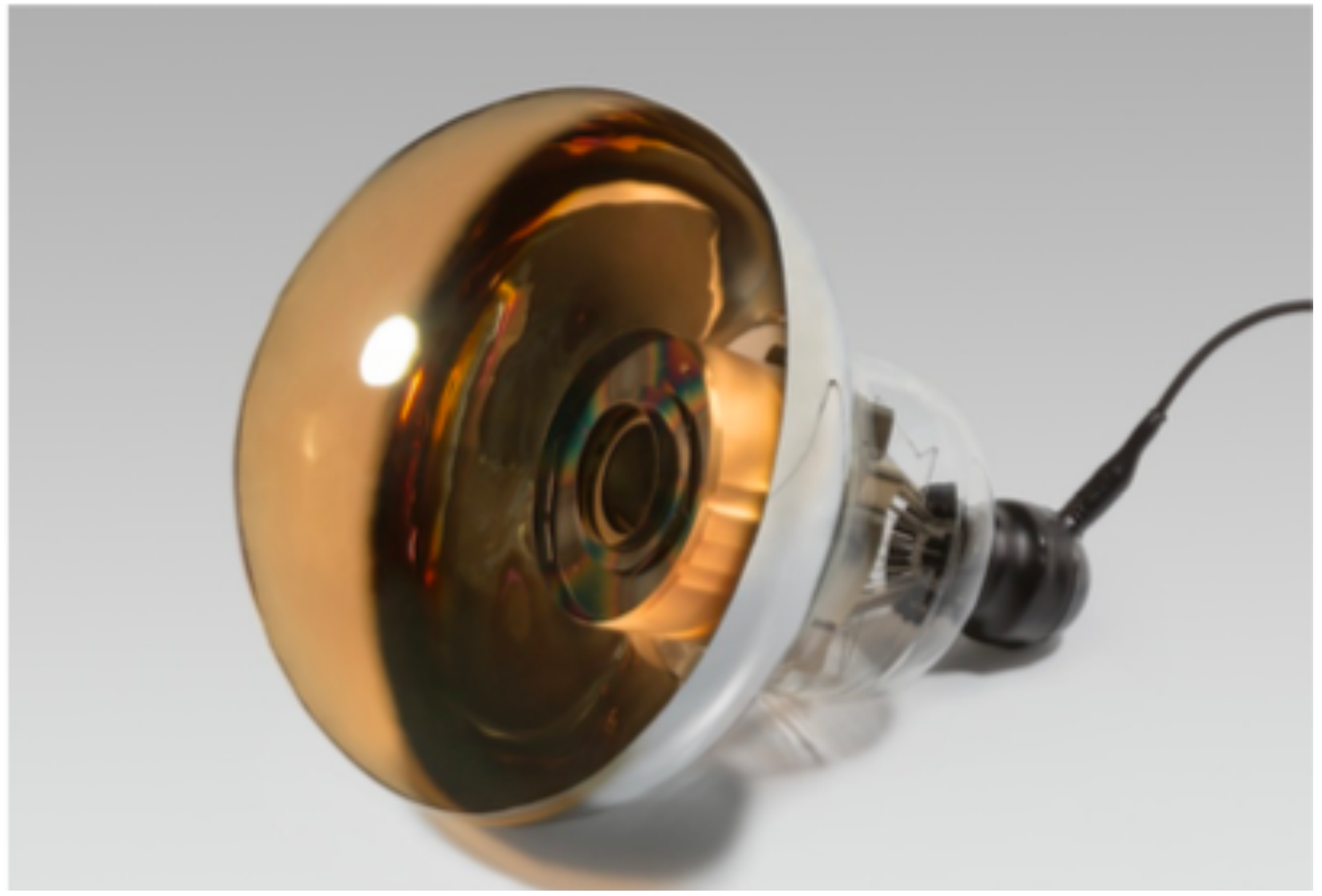
Intermediate Čerenkov detector for the LBL program T2HK

- Movable Water Čerenkov detector
- Inner diameter 8 m
- Inner detector height 6-8 m

New 20-inch PMT

- New Hamamatsu PMTs:
  - Better single photon detection efficiency
  - Better charge and timing resolutions
  - Operate under higher pressures



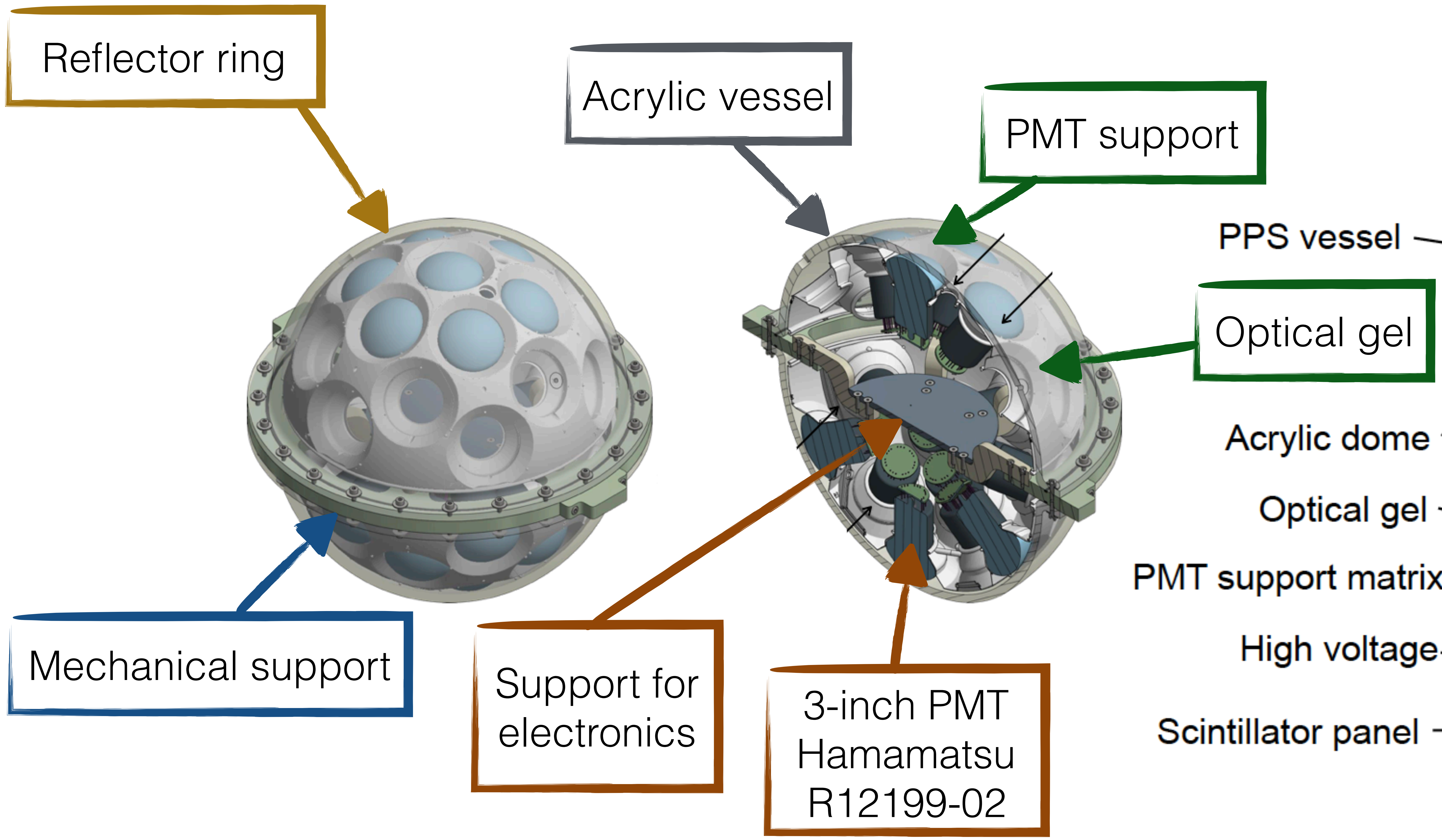


Shape	Hemispherical
Photocathode area	50cm diameter (20”) ←
Bulb material	Borosilicate glass ($\sim$ 3mm)
Photocathode material	Bialkali (Sb-K-Cs)
Quantum efficiency	30% typical at $\lambda = 390$nm ←
Collection efficiency	95% at 10^7 gain ←
Dynodes	10 stage box-and-line type
Gain	10^7 at $\sim$ 2000V
Dark count rate	$\sim$ 8kHz at 10^7 gain and 13°C (after stabilization)
Transit time spread	2.7ns FWHM for 1PE
Weight	9kg (without cable)
Volume	61,000cm^3
Pressure tolerance	1.25MPa water ←

TABLE XXXVI. Specifications of the 50cm R12860-HQE B&L PMT by Hamamatsu.

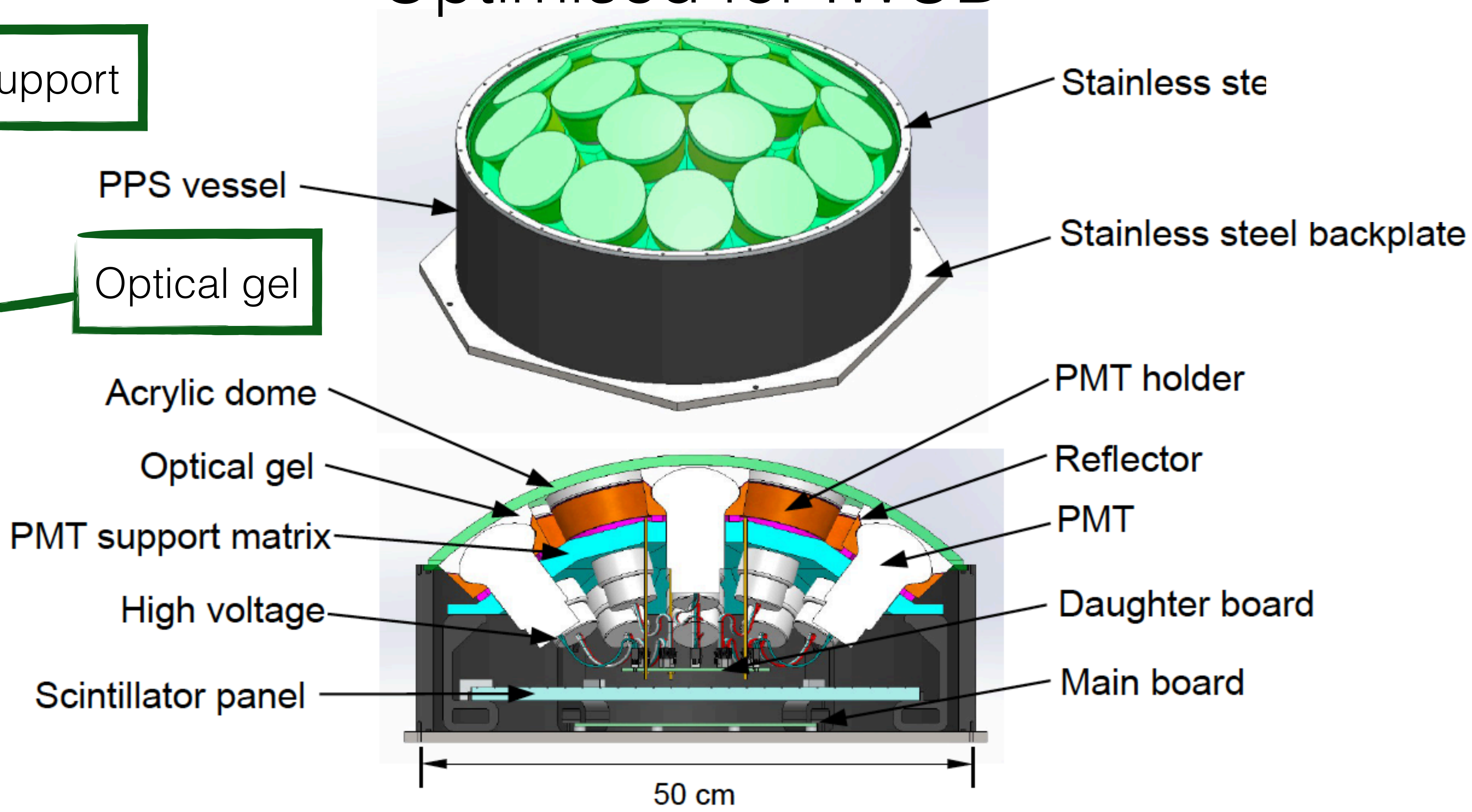
An alternative option: mPMT

Original mPMT design from KM3Net experiment.



Working prototype based on this design

Optimised for IWCD



Working prototype ready by the end on the year

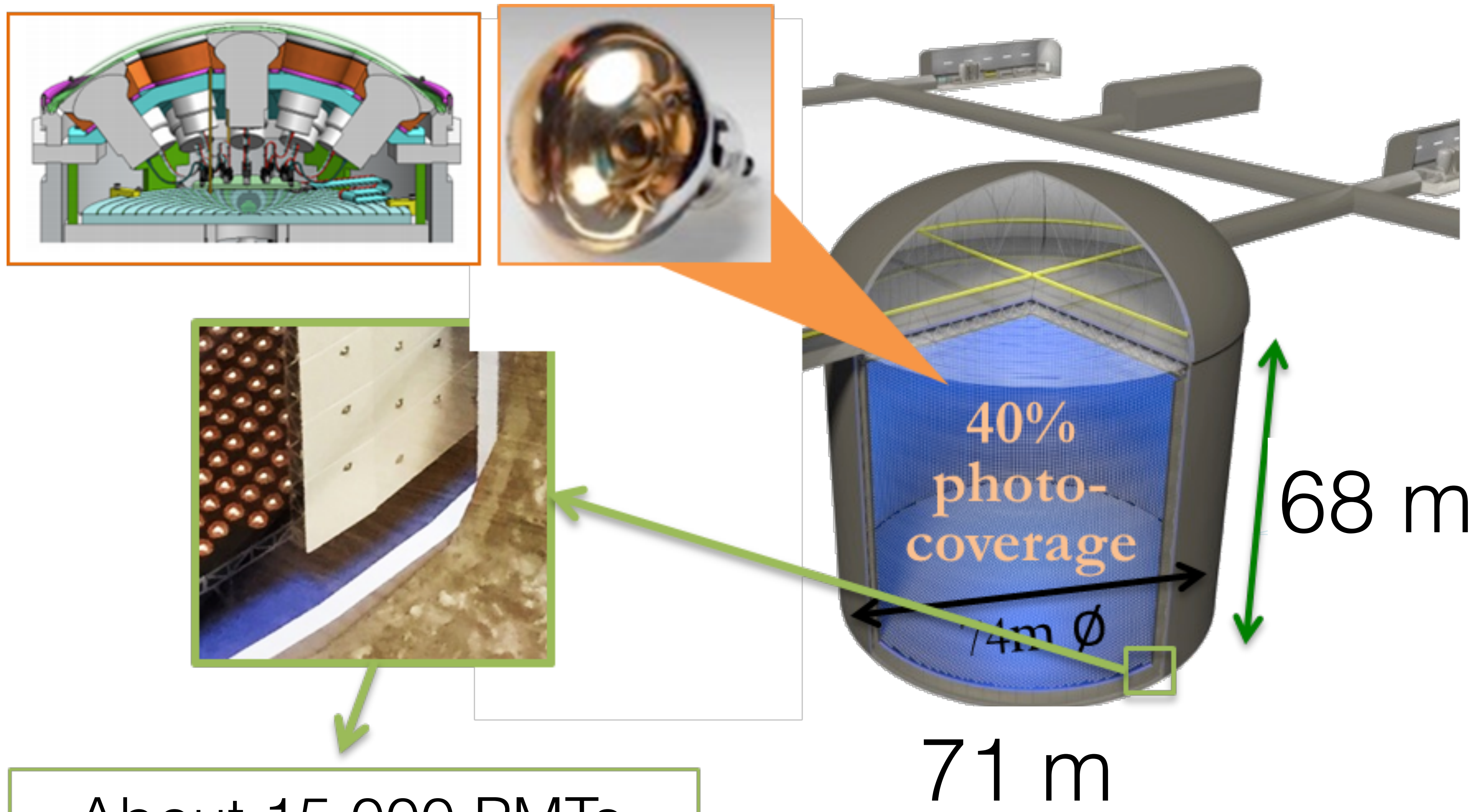
Motivation for mPMT modules in HK

- Smaller size can improve reconstruction for events happening near the wall
  - Increase fiducial volume
  - Improve ring counting ability
  - Better directionality
- Twice better time resolution: Better vertex resolution
  - Better vertex resolution
  - Improved PID close to the wall
- Improvements for low energies and proton decay

Hybrid configuration for HK

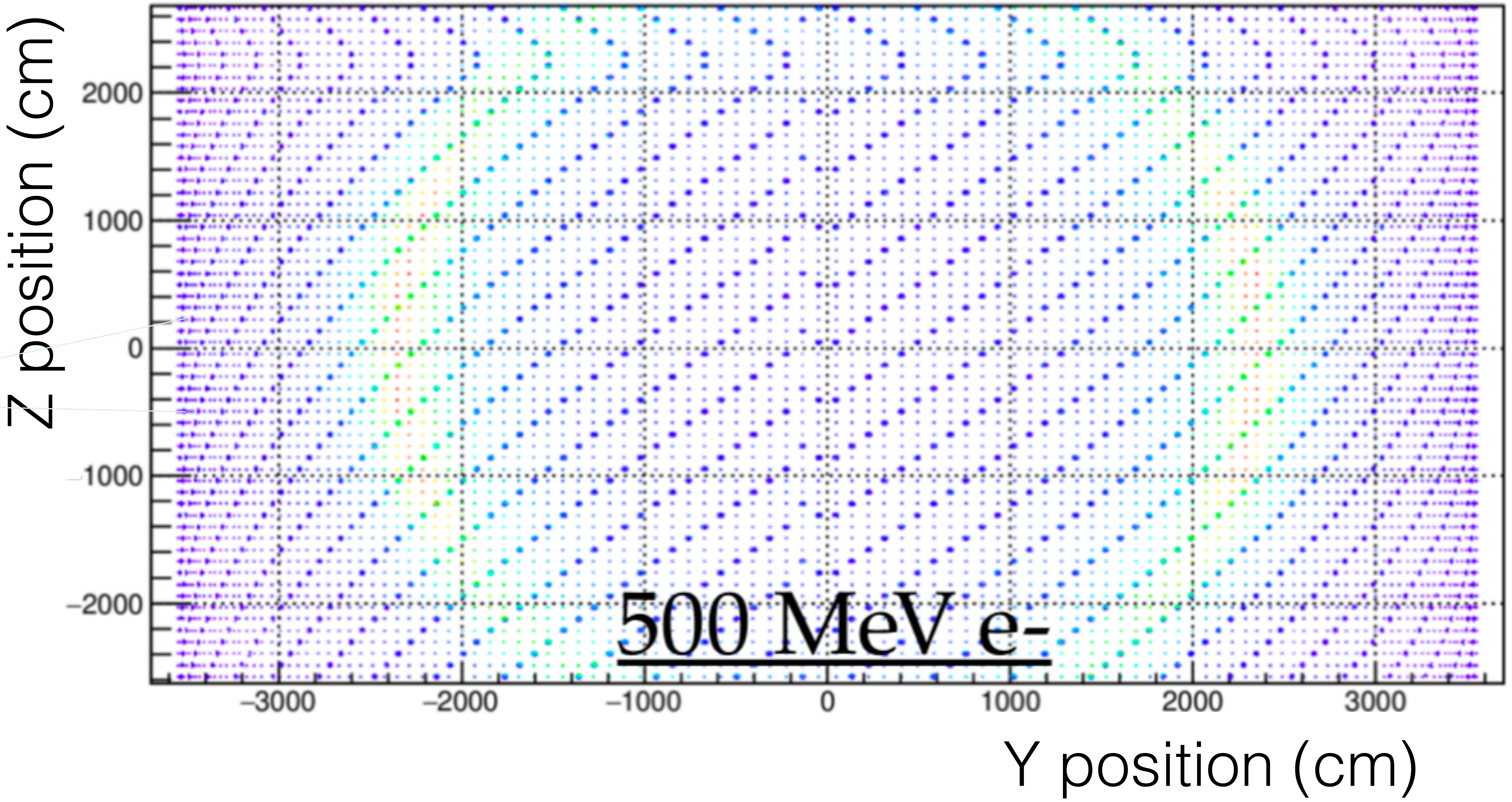
Hybrid configuration: 20% PMT coverage + 5k or 10k mPMT

This configurations has been compared with 40% PMT coverage

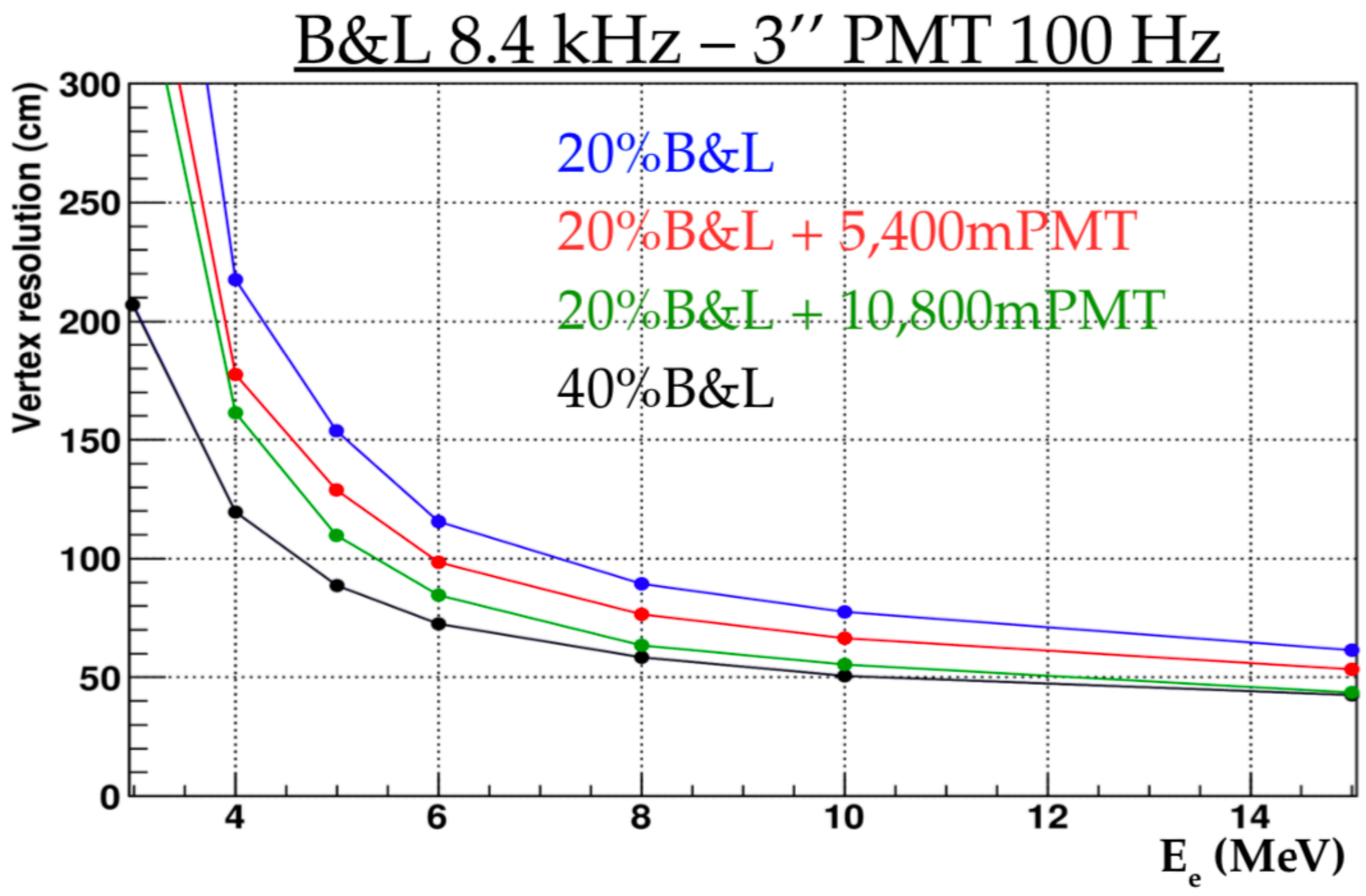


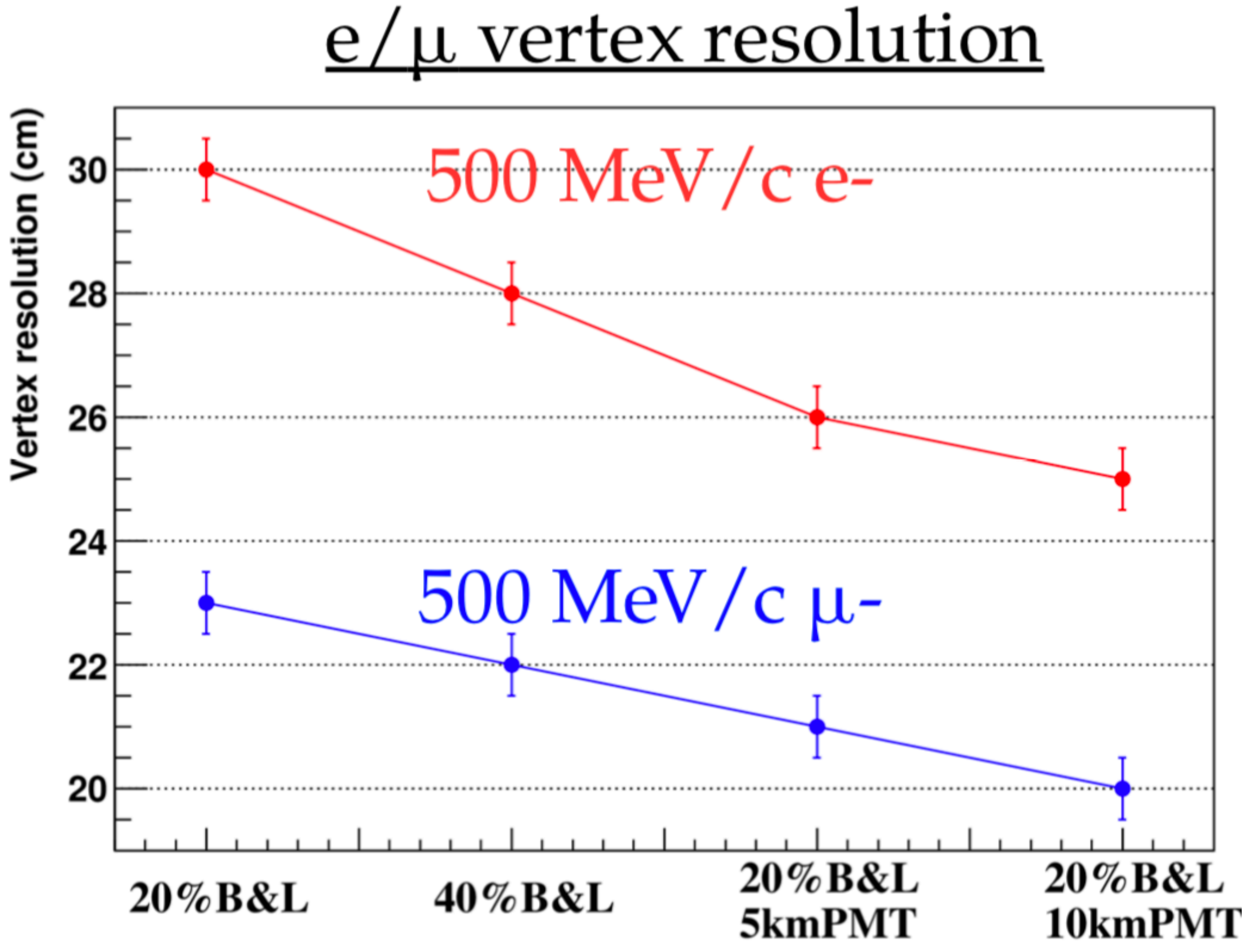
About 15,000 PMTs for Outer Veto Detector

Particle gun generated at the center of the tank



Simulation studies for HK





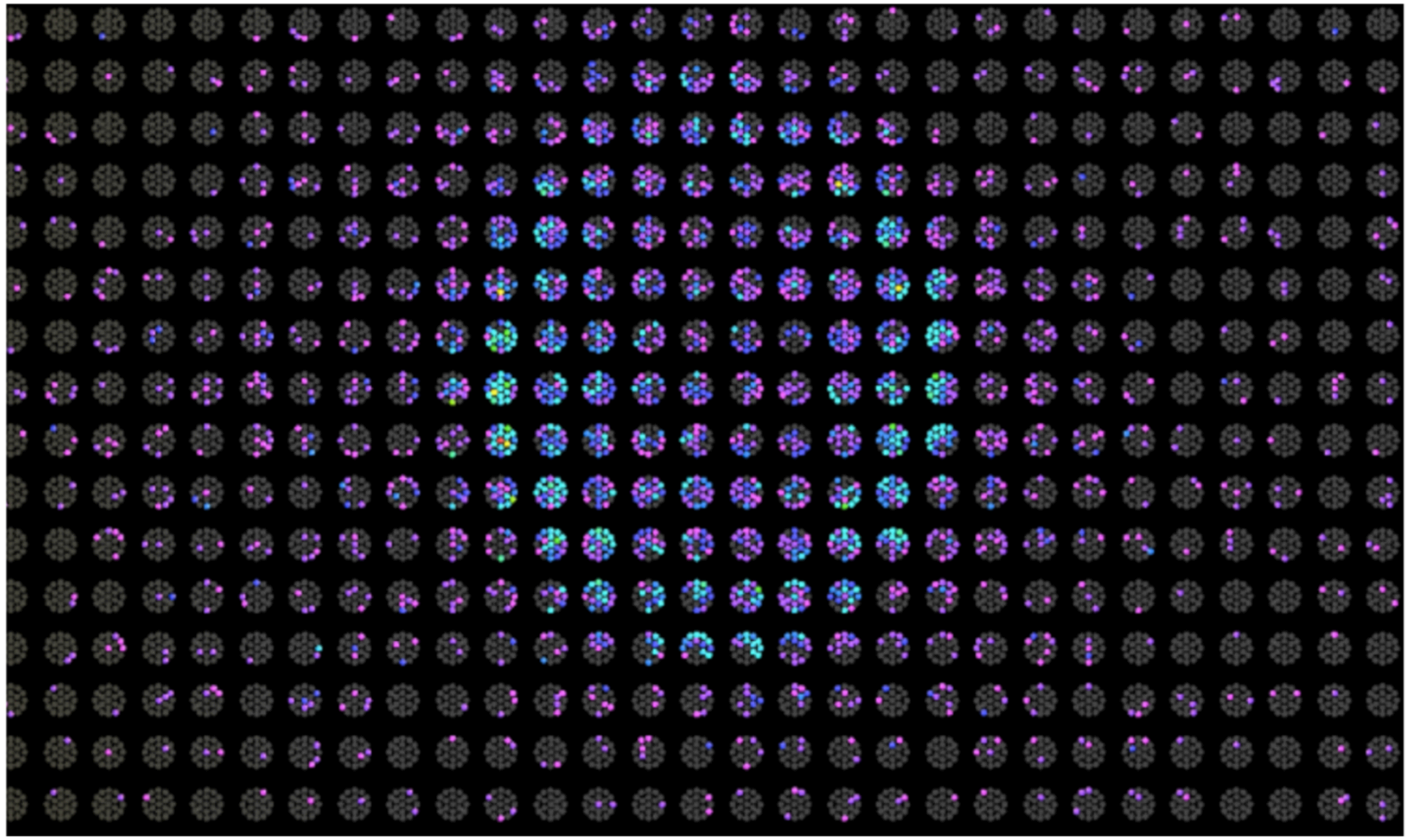
Better vertex resolution in case of 20% PMT + 5k mPMT

Current limit related to dark rate: 100 Hz allow to explore low energy range; actual 3-inch PMT DR about 200 Hz

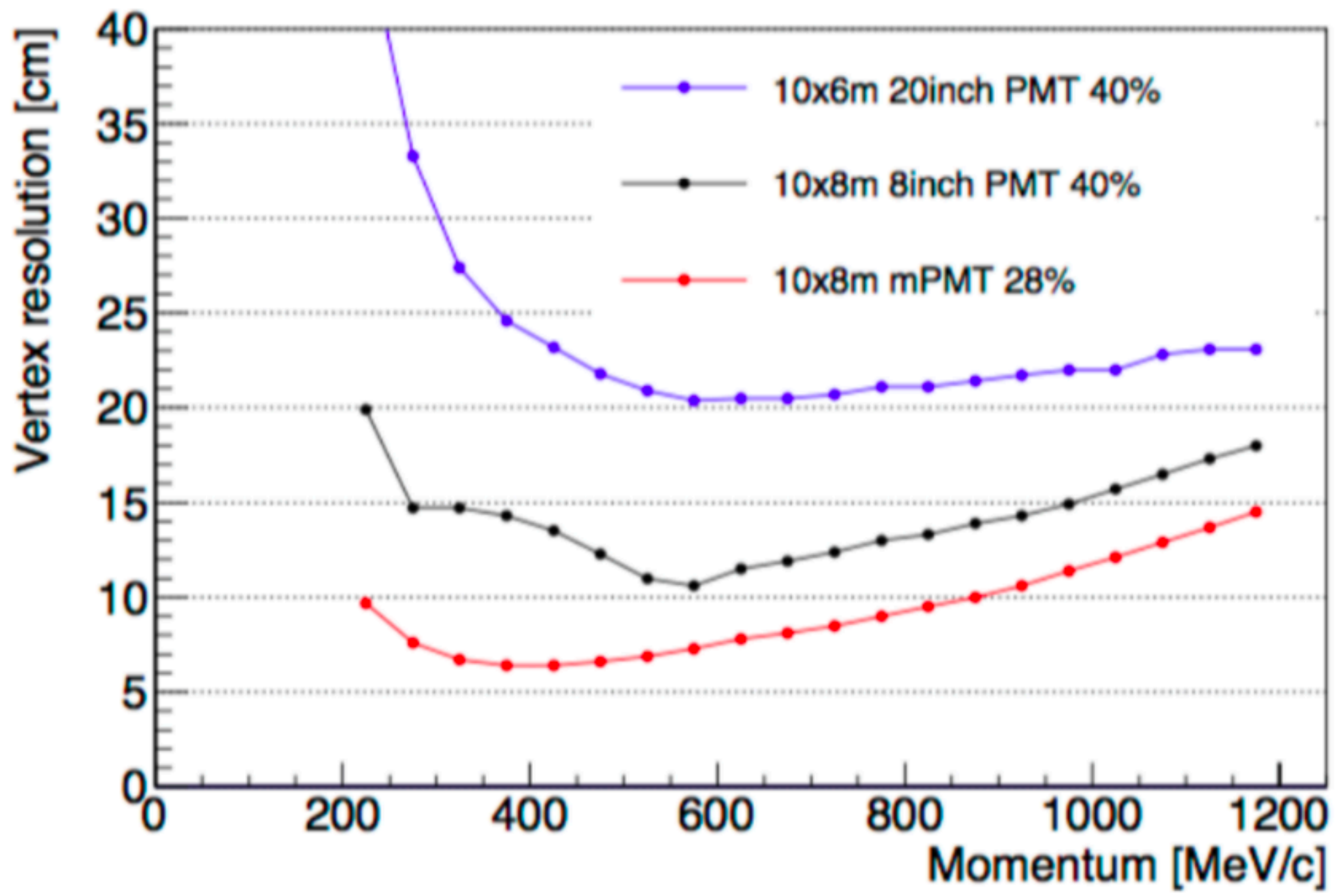
Impact on IWCD

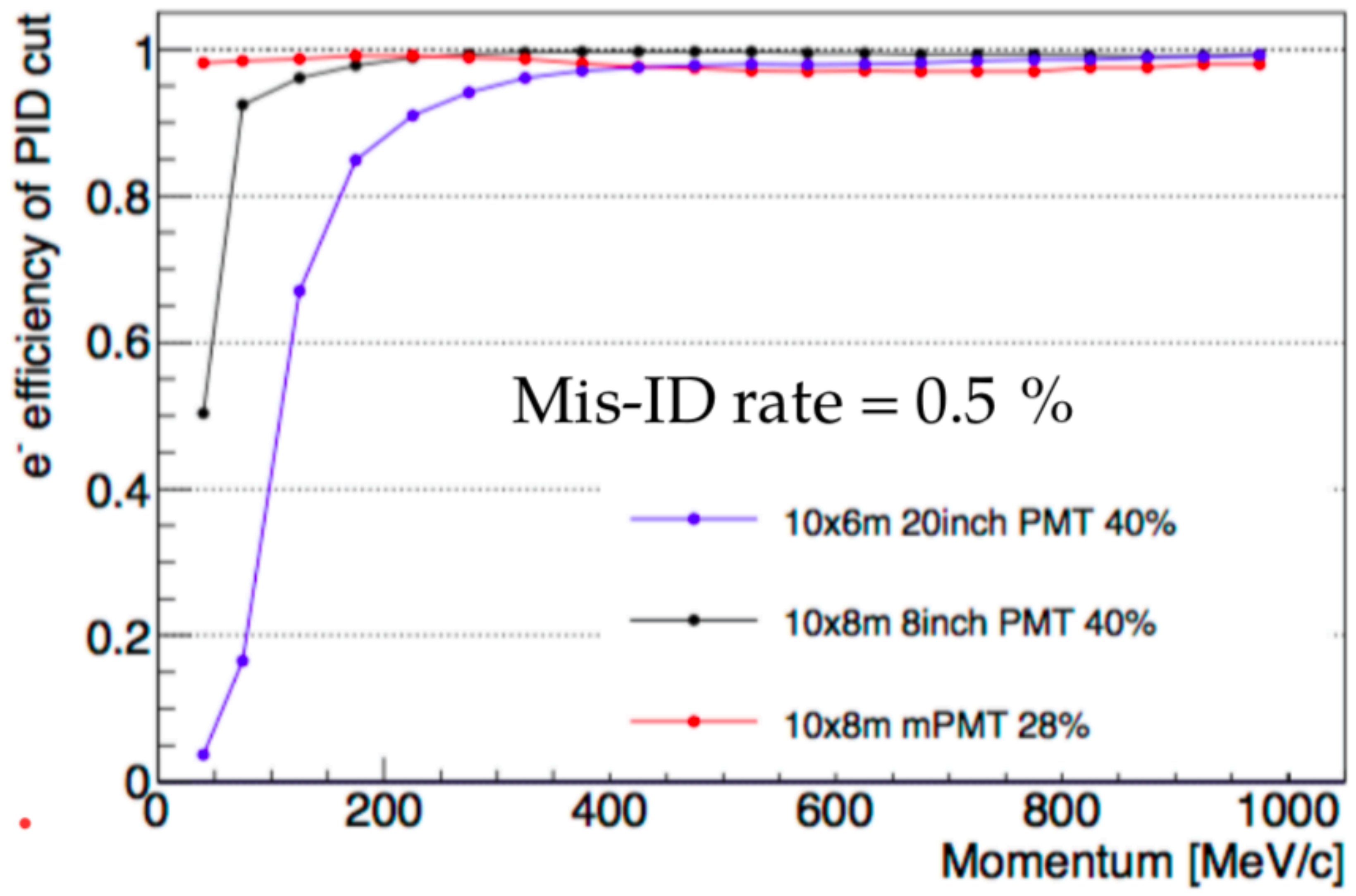
mPMT are also the primary candidates for the IWCD

Locate at ~1-2 km away from JPARC beam line



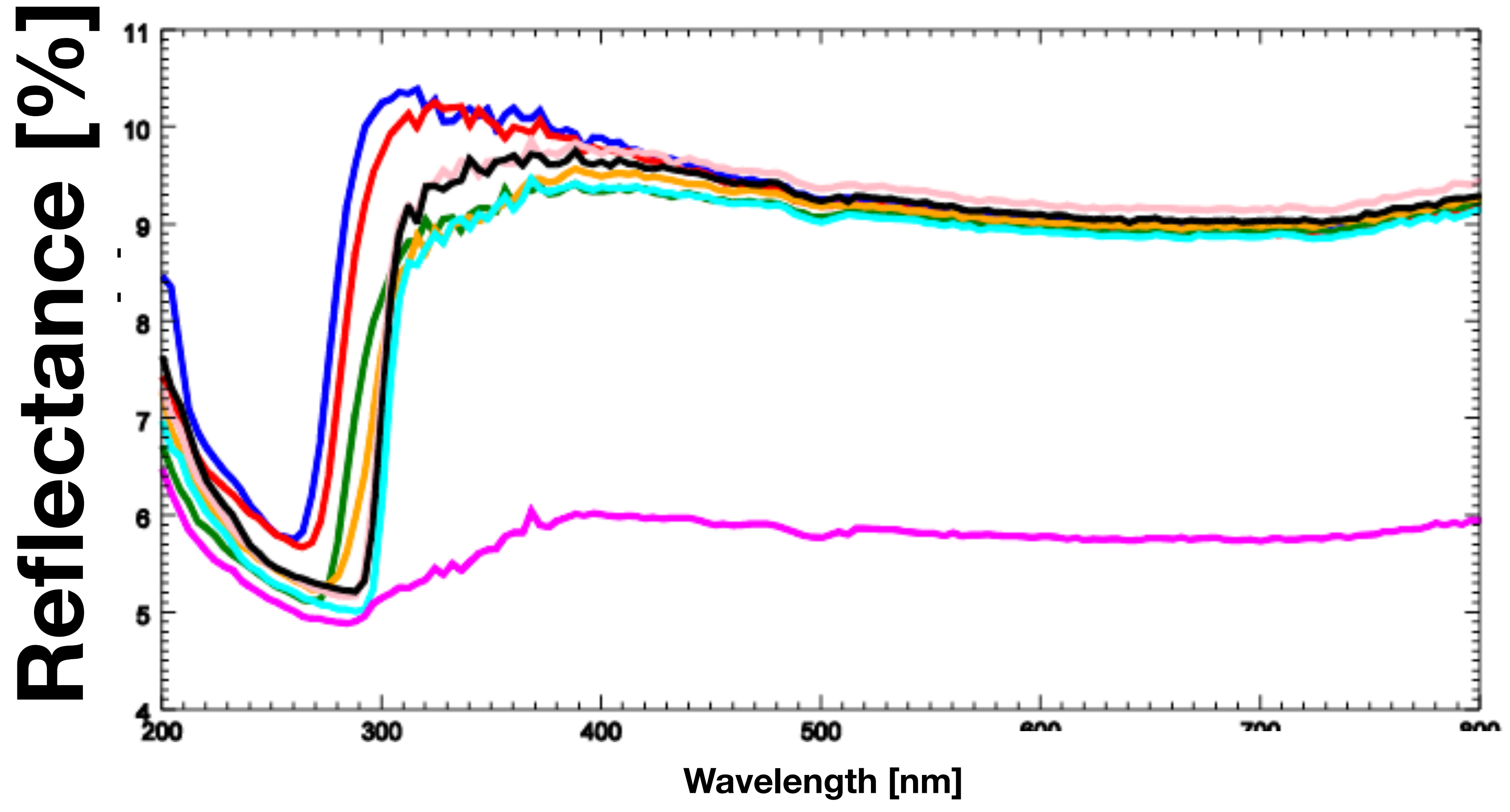
Better vertex resolution and PID

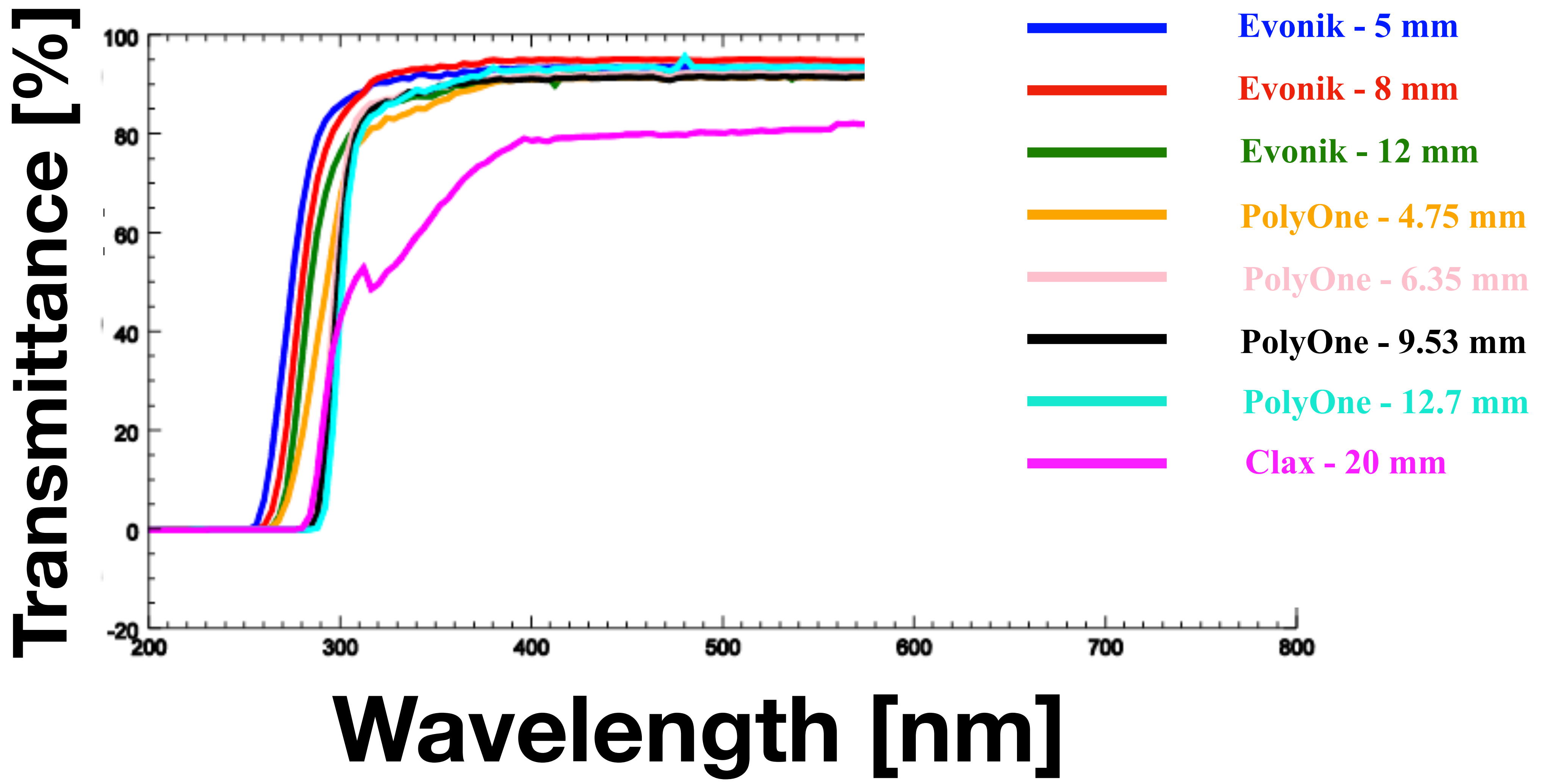




Acrylic vessel: optical tests

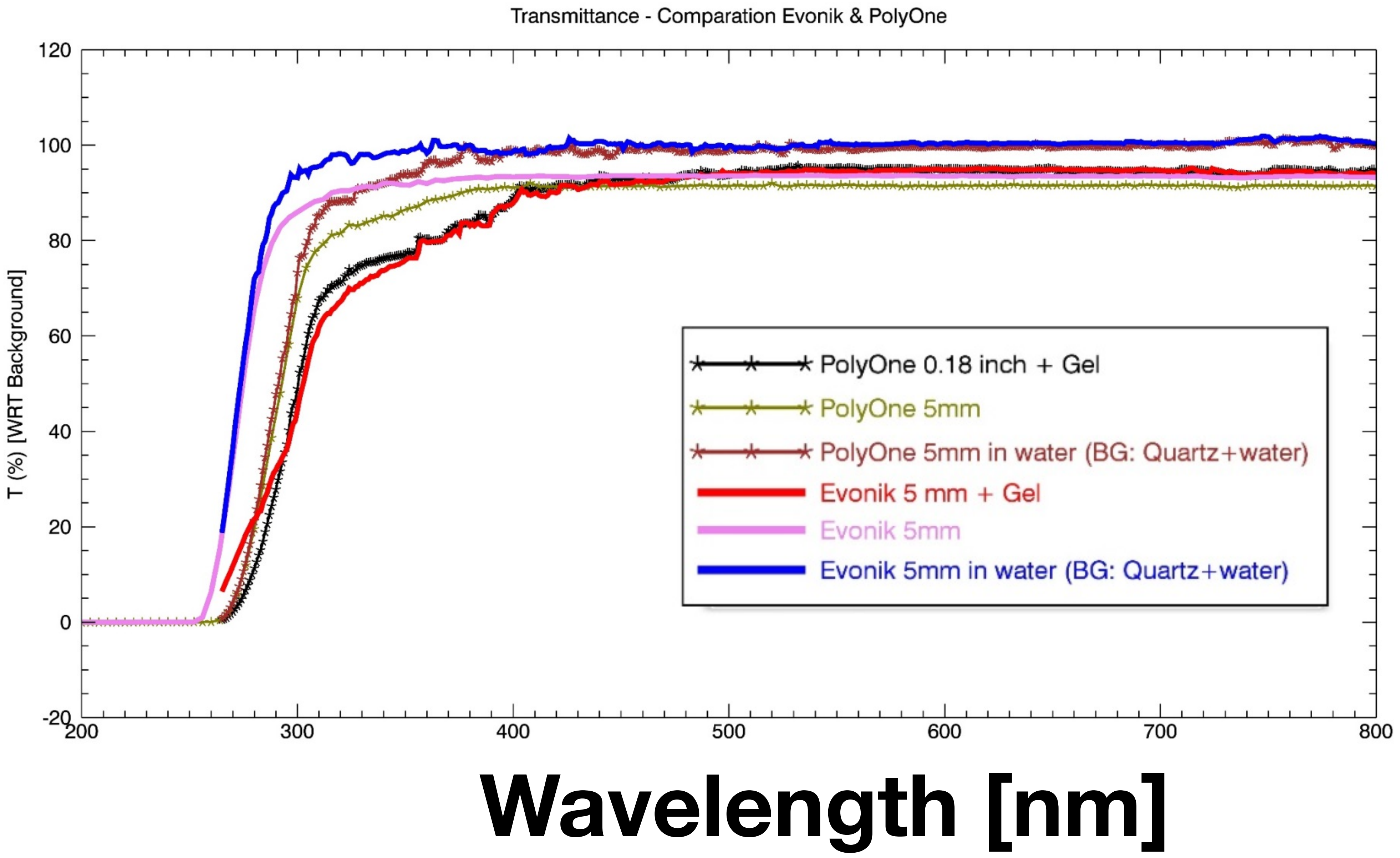
Optical tests done by using a Perkin Elmer Lamda 900 UV/VIS/NIR spectrophotometer





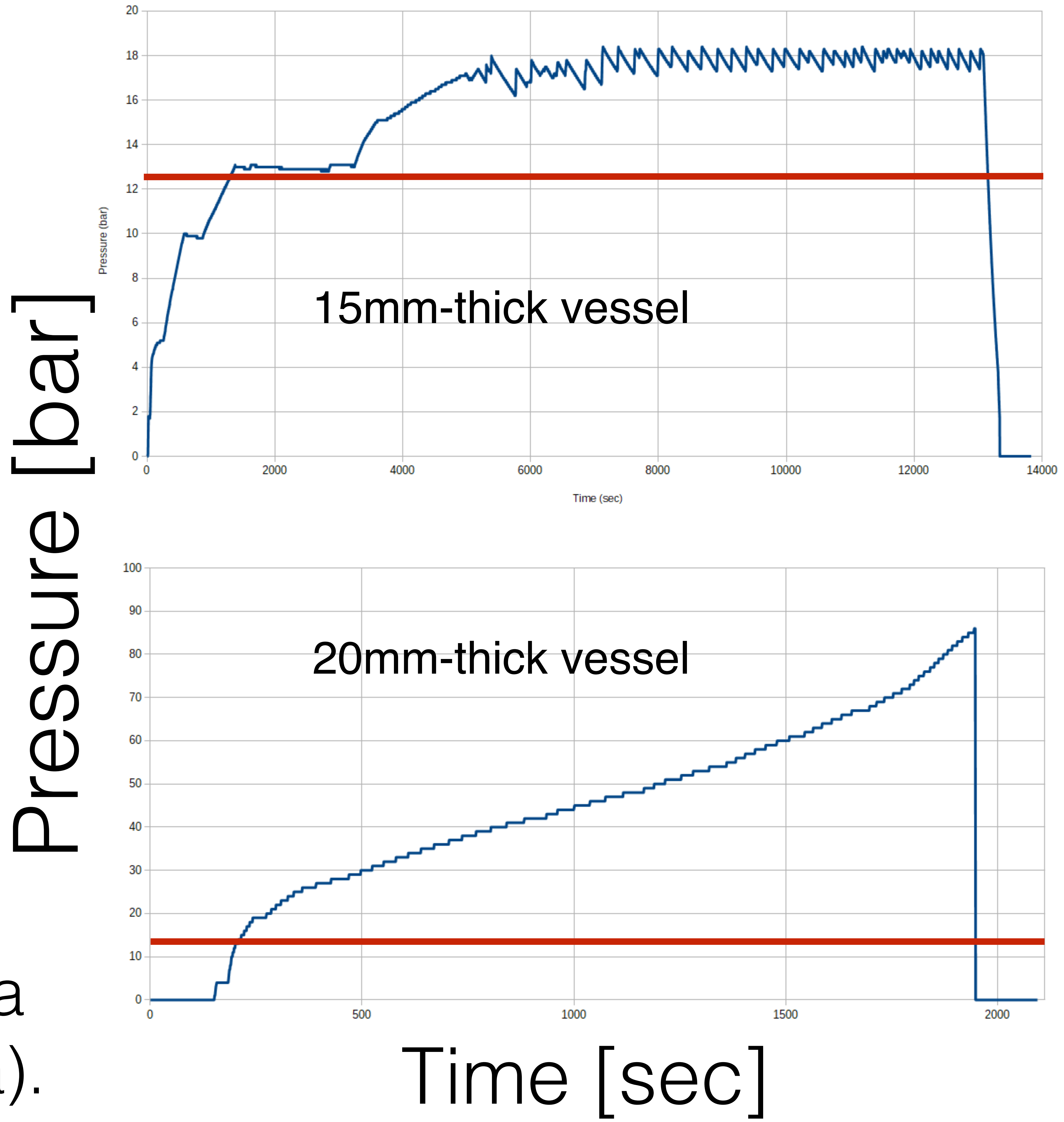
Waker SilGel 612 A + B (the same used by the KM3NeT)

A layer of optical gel was set down onto the 5mm-thick Evonik and 0.18’’-thick Poly One samples and transmittance was measured.



Acrylic vessel: pressure test

The 15mm-thick vessel before the first test at the Resinex Company, in a 25-bar tank.



Our constrain was to resist up to 1.26 MPa and our vessel resisted to 18 bar (1.8 MPa).

Acrylic vessel: contamination

Nuclear contaminations test have been carried out both in the INFN-Naples, and then at the Laboratori Nazionali del Gran Sasso (LNGS) on a sample of Evonik acrylic

Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	$(3 \pm 1)\cdot 10^{-1}$ ppb
K-40	< 0.69 mBq/kg	< 0.022 ppm
Cs-137	< 25 μBq/kg	-

Table 5: Results of nuclear contamination of Evonik samples.

Requirements for HK:

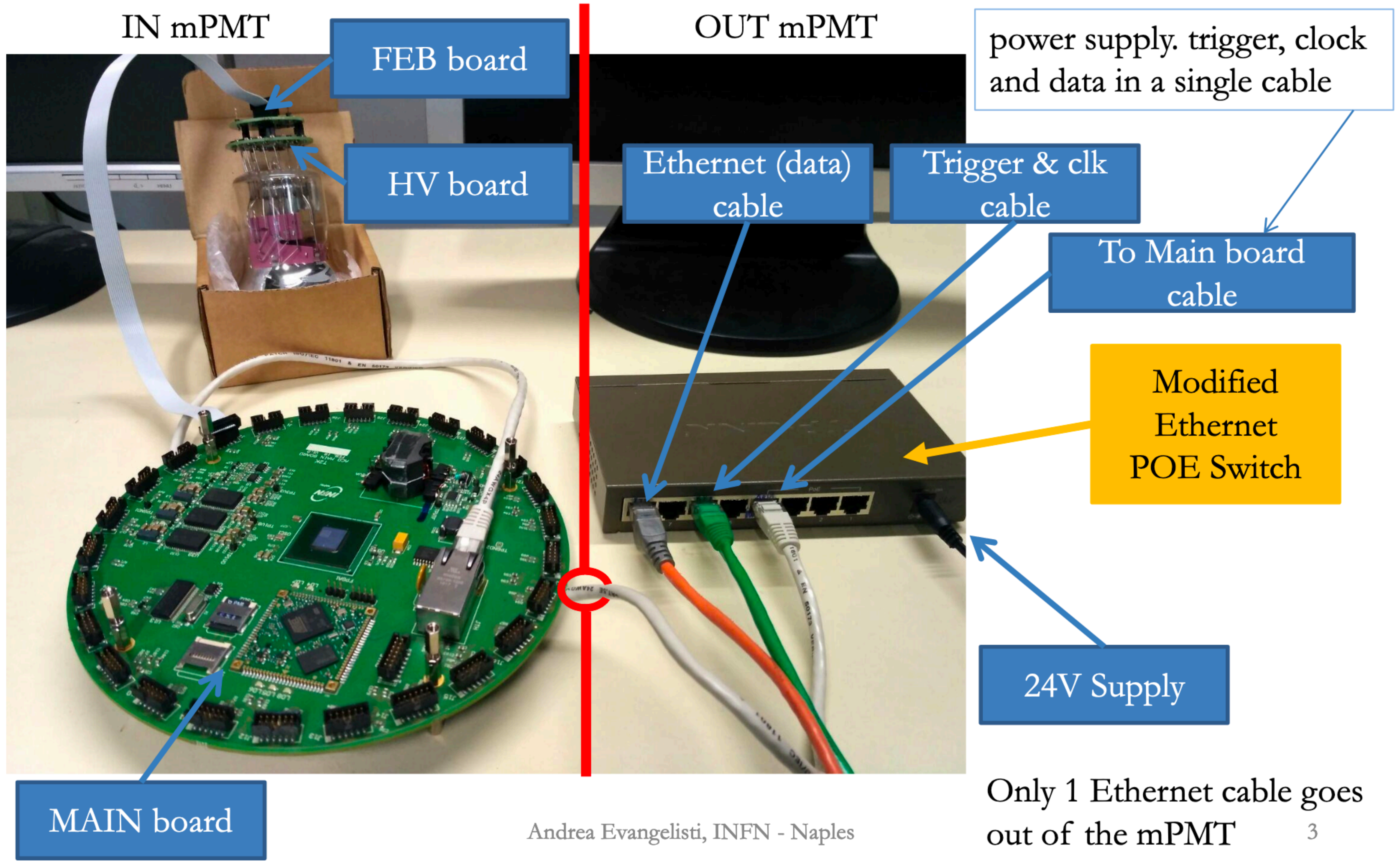
Th-232 < 1 ppb

U-238 < 0.3 ppb

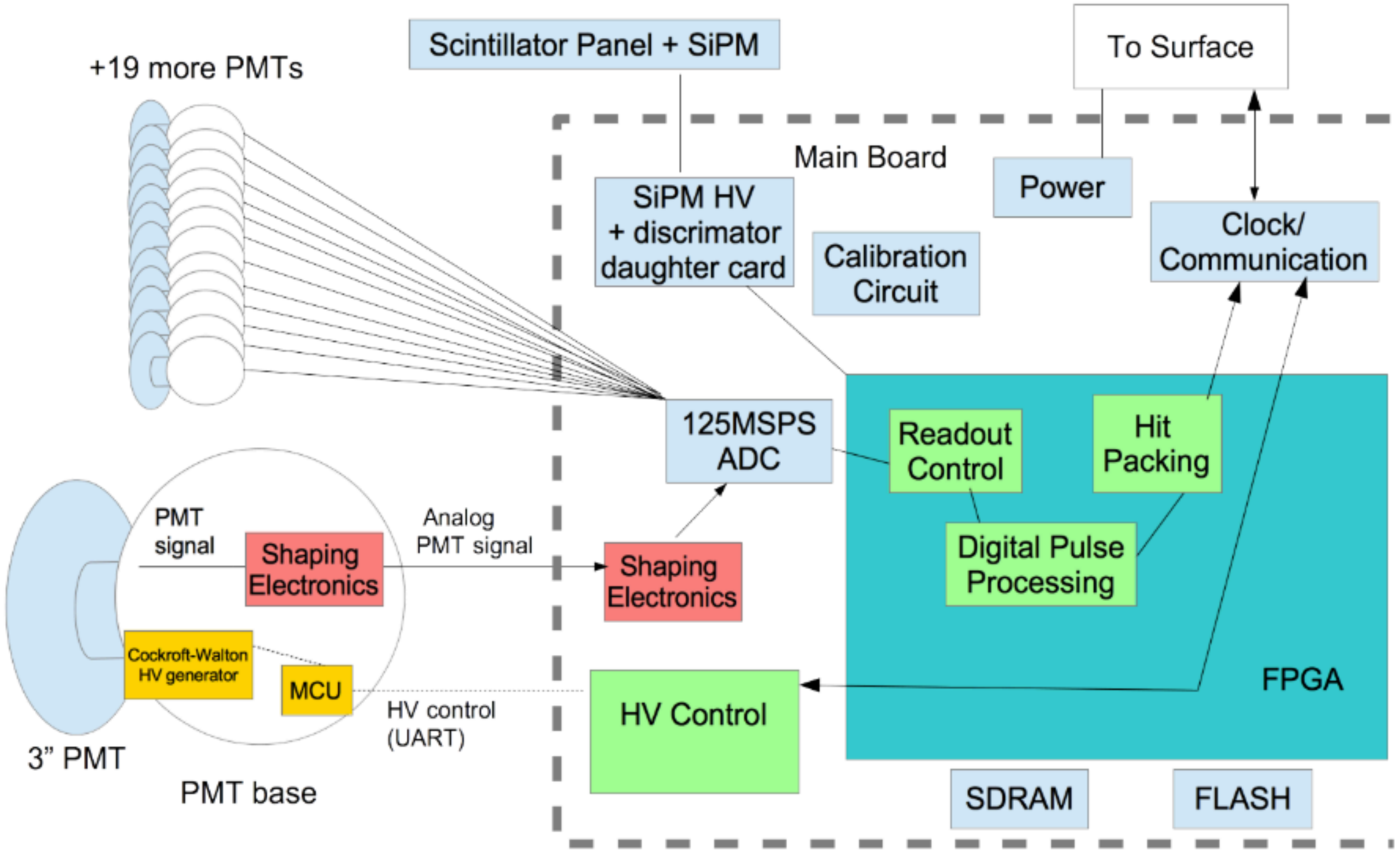
K-40 < 0.3 ppm

mPMT Electronics

<u>Design for HK mPMT:</u>
Q/T digitisation based on discrete components (INFN Naples)
Simple, low power, low cost

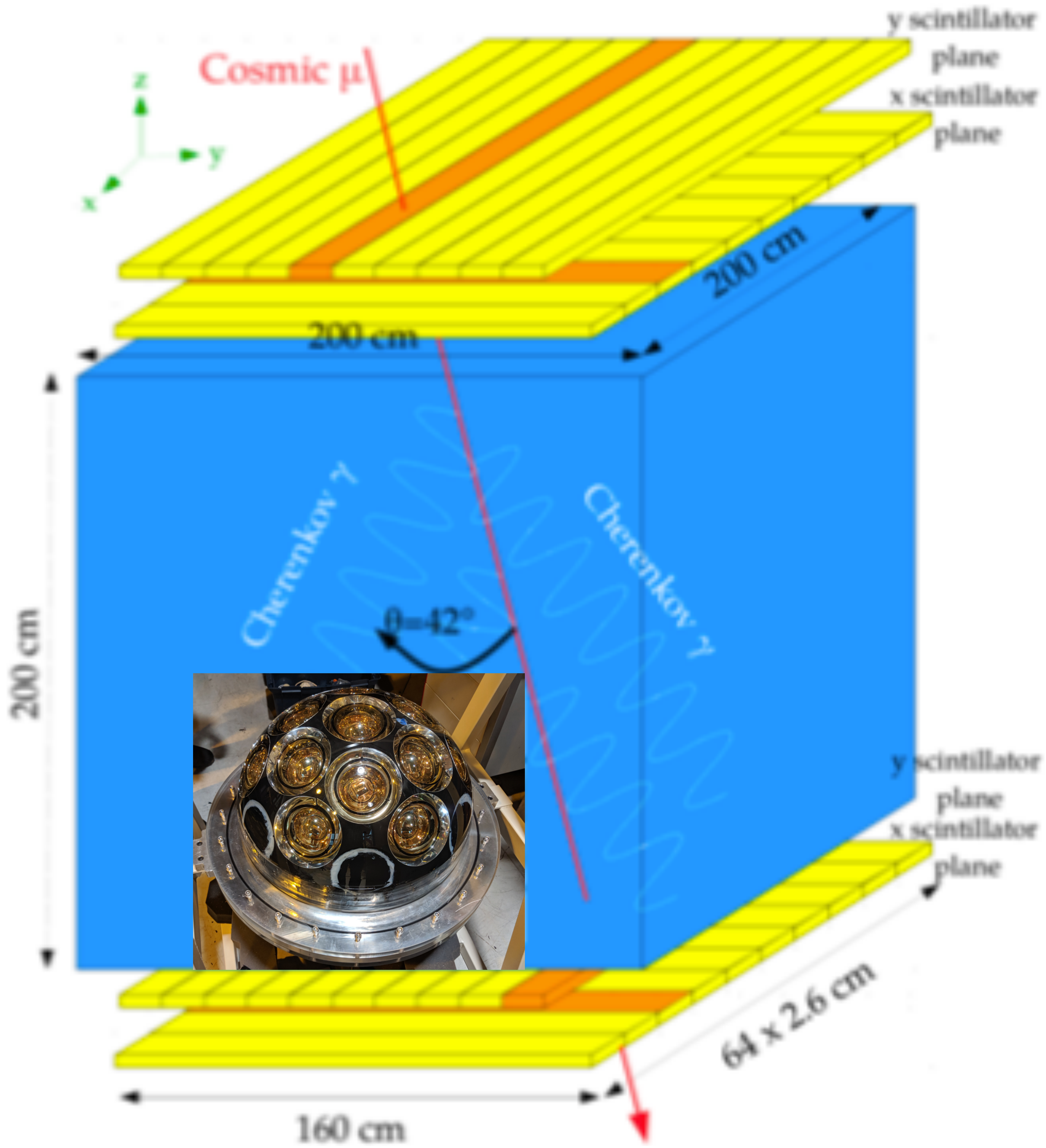


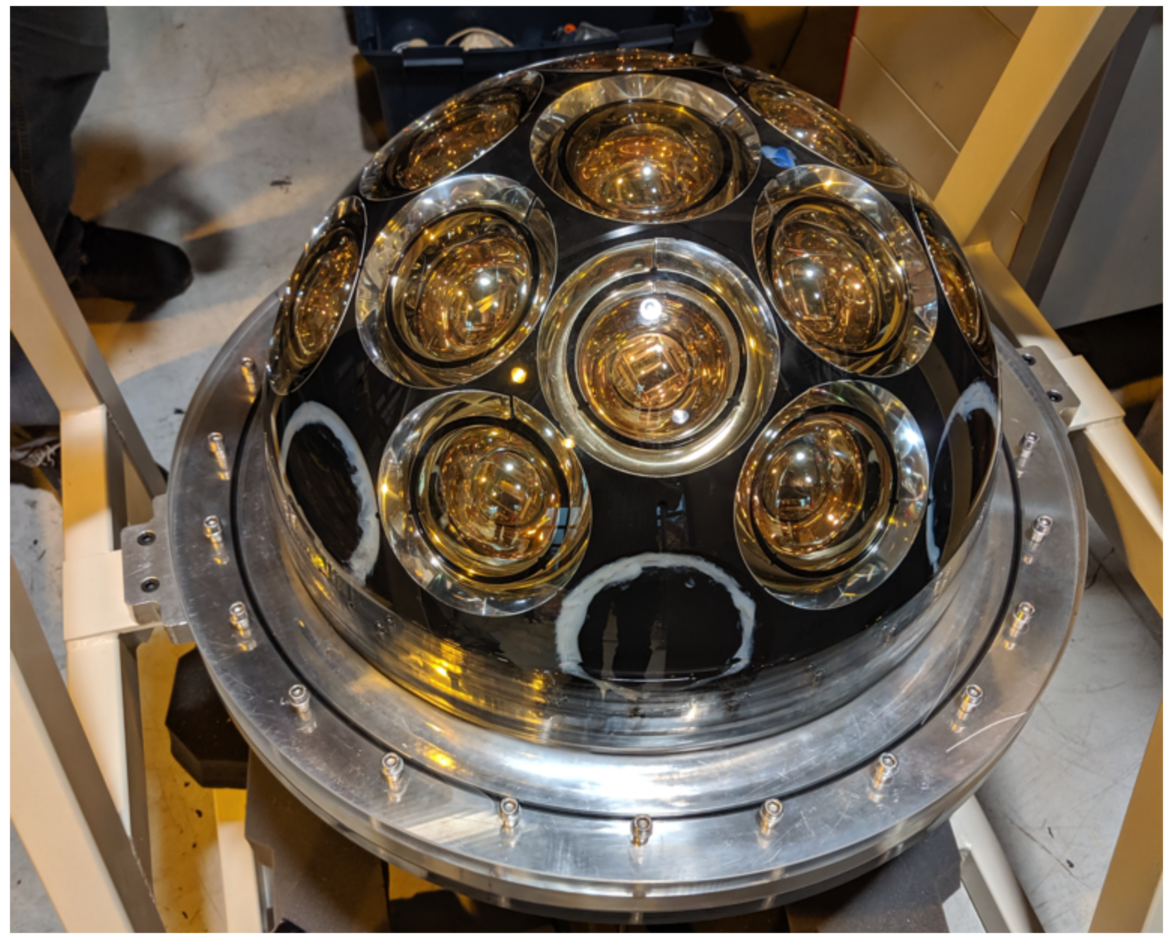
<u>Design for IWCD mPMT:</u>
FADC digitisation, with on-board signal processing (TRIUMF, WUT)
Noise suppression in FPGA.



Tests of the first prototype

Recently a prototype has been assembled

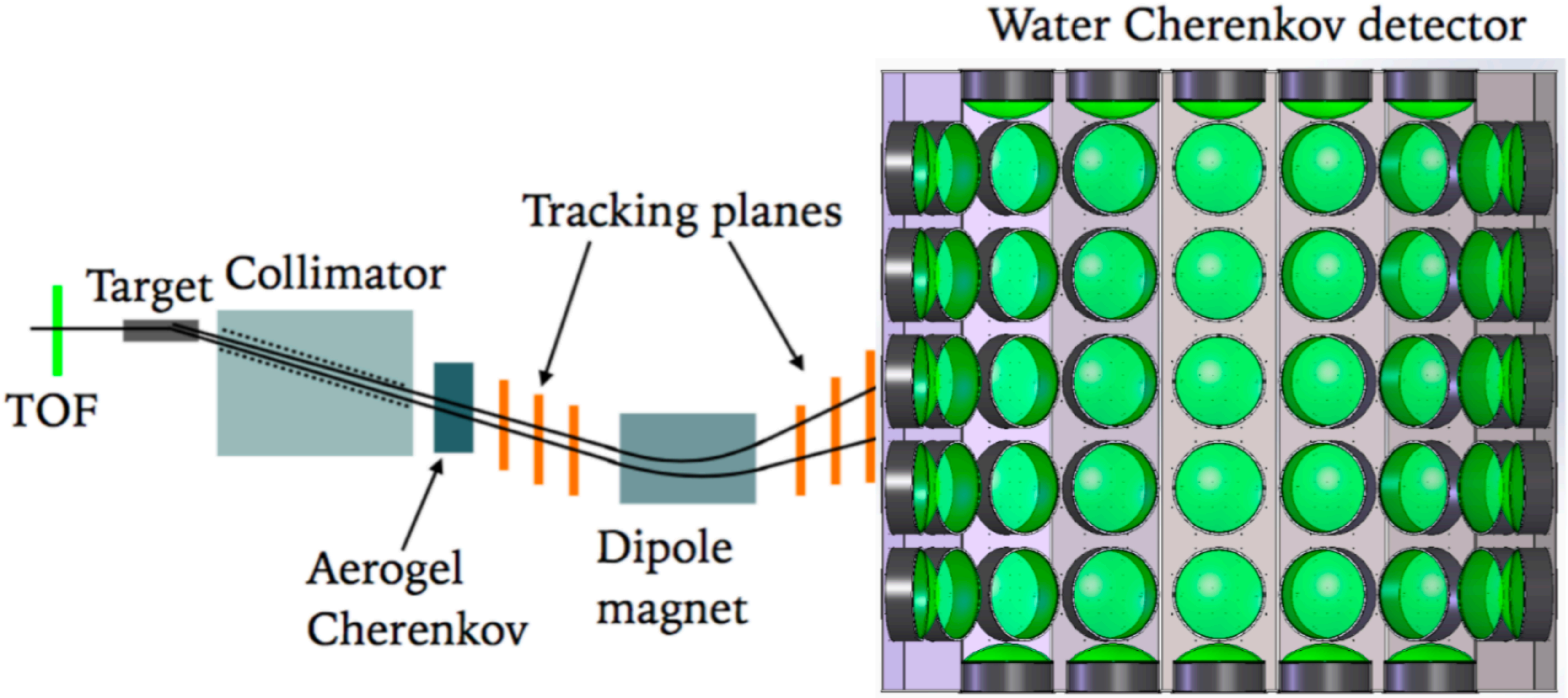




It will be tested in a water tank located in the lab *AstroParticule et Cosmologie* in Paris

Future tests at CERN

mPMT photodetection system will be finally tested at CERN: Water Cerenkov test beam planned in 2021/22 at Neutrino Platform



LoI in preparation for submission at CERN before October SPSC meeting; proposal by end of 2019

Conclusions

- HK will be the next generation water Čerenkov in Japan
- IWCD will be the intermediate water Čerenkov of the LBL program
- The mPMT has been presented as alternative option to 20-inch PMTs
- Acrylic Vessel fully characterised
- 3-inch PMT fully tested but we need a lower dark rate
- Test in air at INFN Naples of the first mPMT prototype
- Testing the prototype at MEMPHYNO setup at APC
- New prototype based on second design by end 2019

Backup