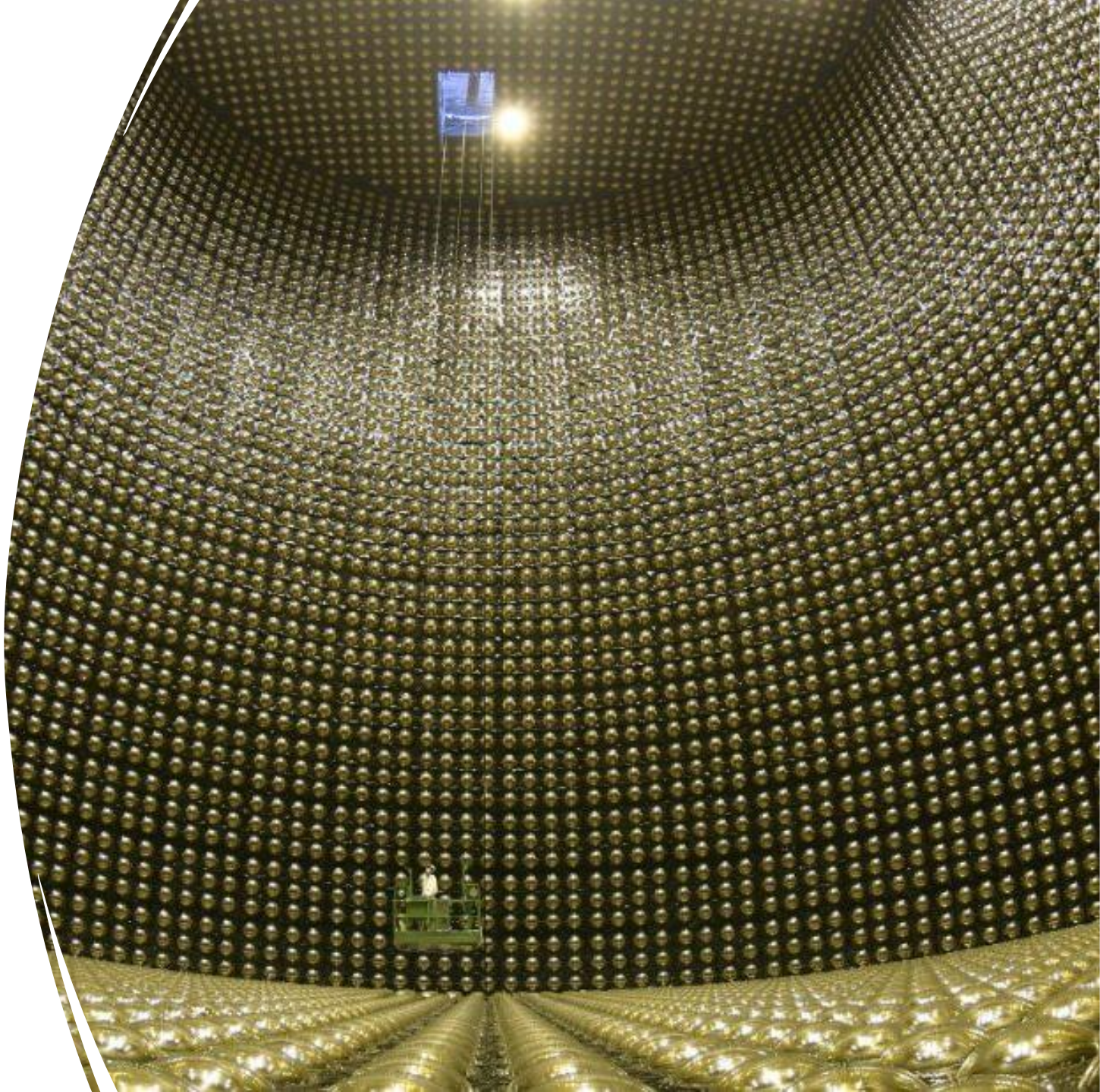
Development of multi PMTs for a large water Cherenkov detector

G. De Rosa – INFN Napoli

4th JENNIFER2 General Meeting

3 April 2025

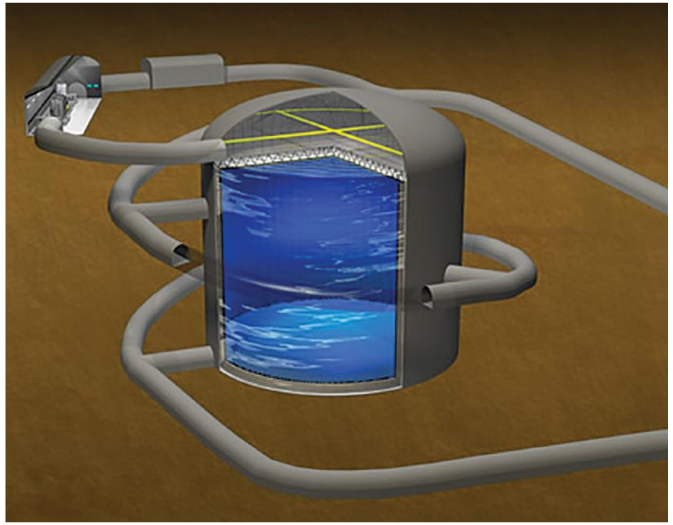


The multi-PMT in the WCD

- First hints of ‘’multi-PMT’’ idea already in the tanks of Auger and HAWC and Antares.
- Real first proposal and realization of a multi-PMT is the DOM of KM3Net.
- Hyper-K will also adopt multi-PMTs
- SWGO is studying the possibility to use multi-PMTs in the tanks.

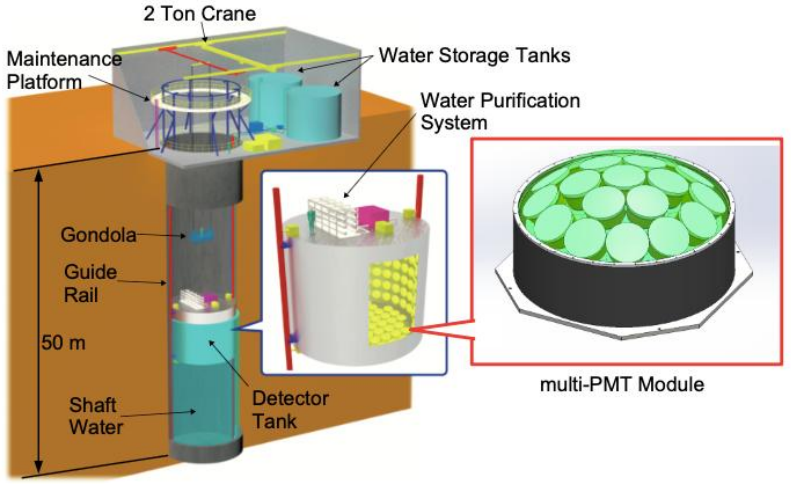
mPMT in Hyper-K

Hyper-K Far Detector (HK FD)



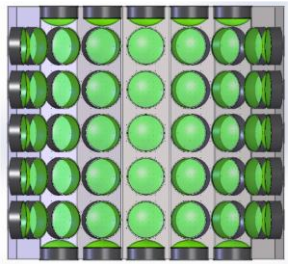
Hybrid configuration
20k 50 cm PMT + mPMTs

Intermediate Water Cherenkov Detector (IWCD)



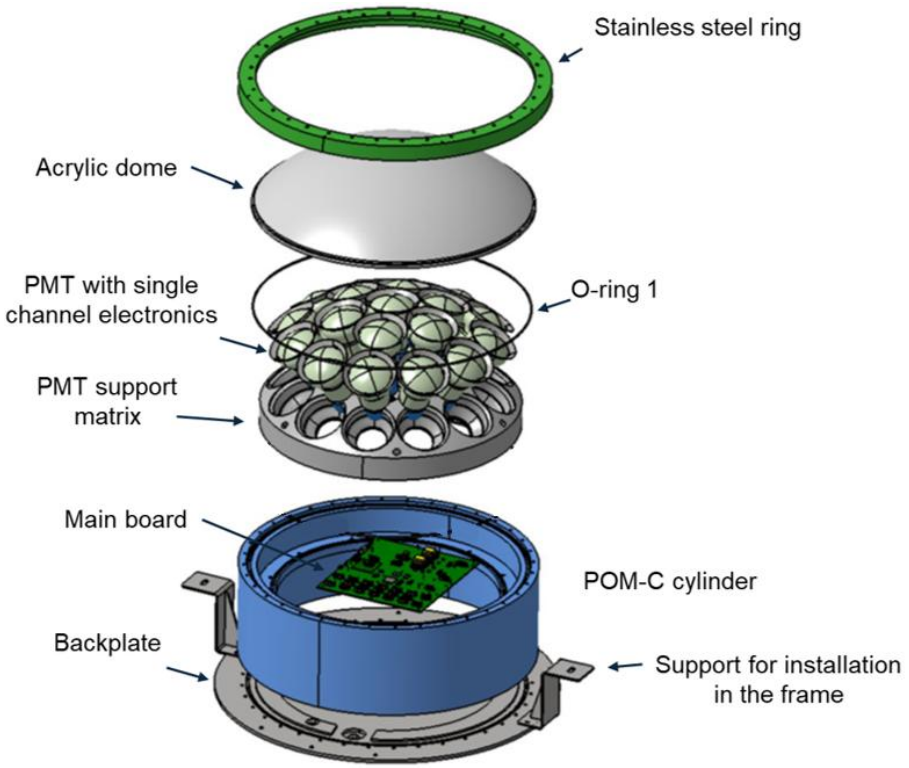
Inner Detector fully instrumented with 480 mPMTs
Outer Detector PMTs:
480

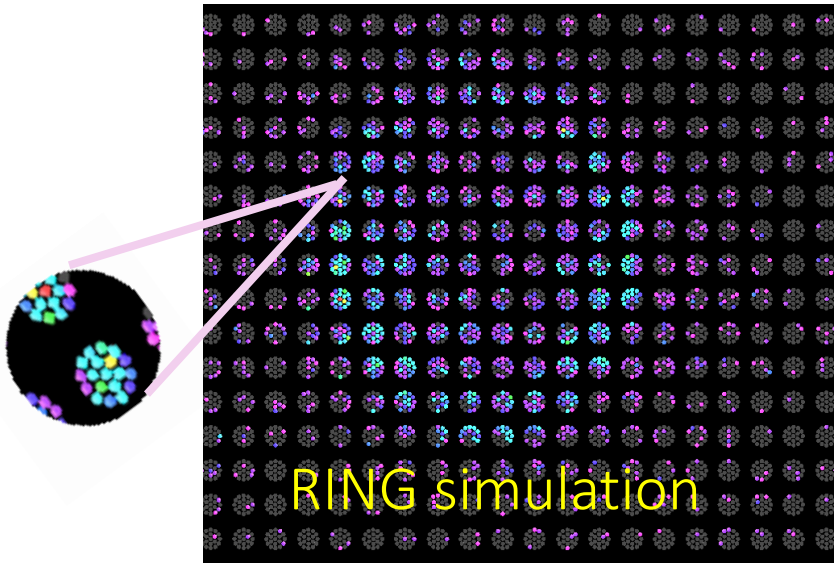
CERN Test Beam Experiment (WCTE)



Inner Detector PMTs:
~100 mPMTs

Hyper-K multi-PMTs



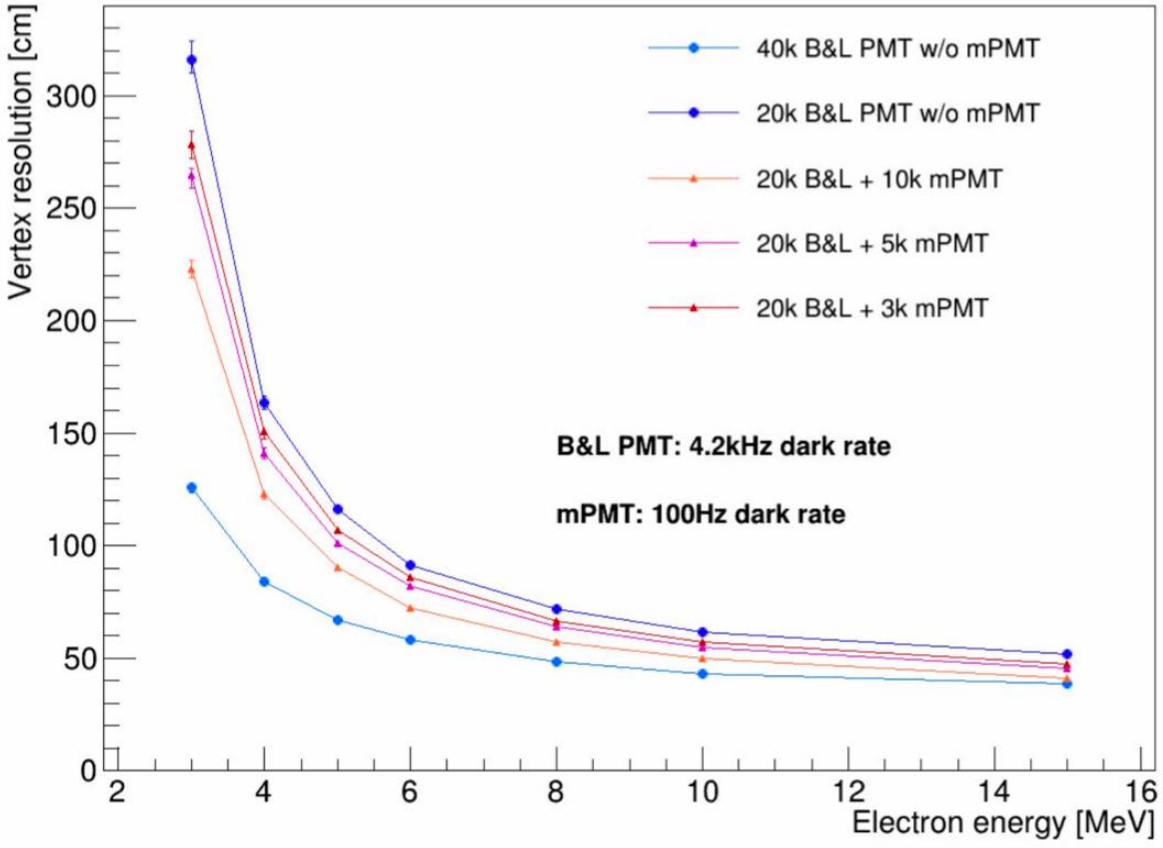


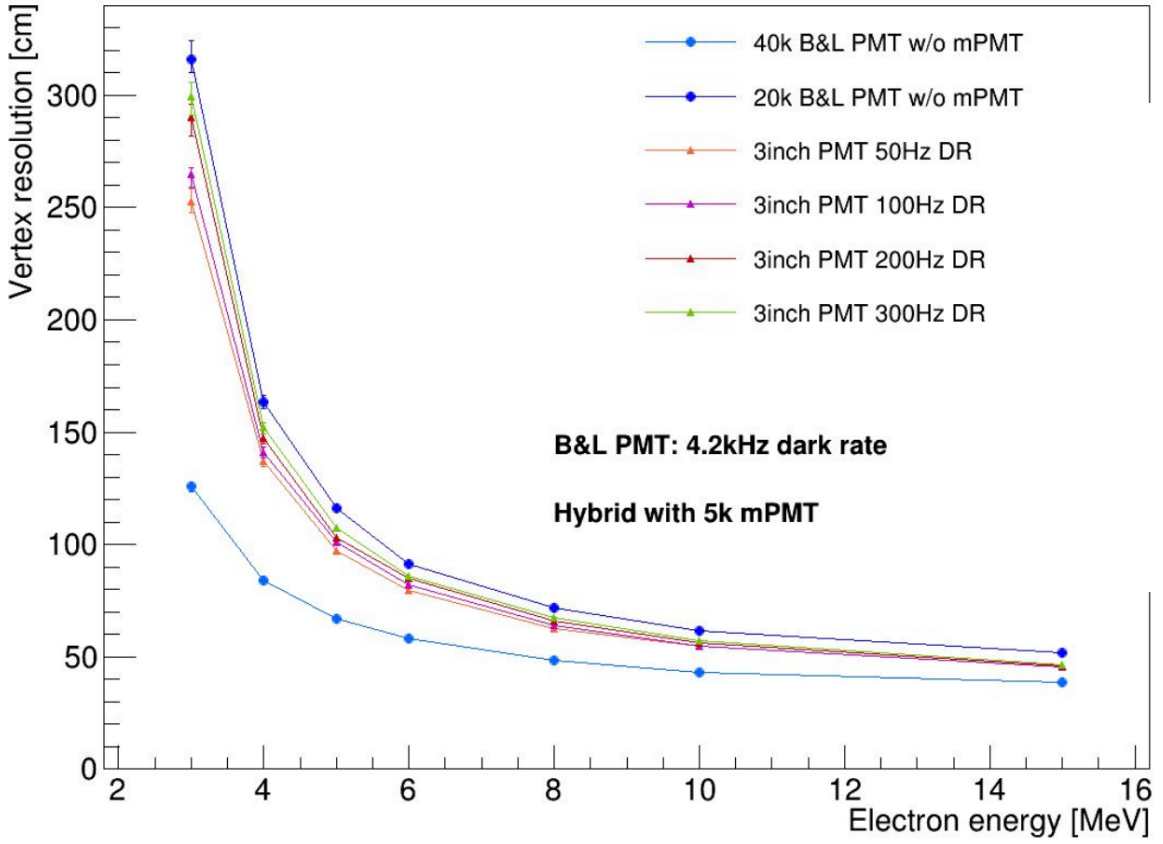
Based on a full INFN proposal and development. Starting from the KM3Net experience in INFN and customized to HK requirements

Low radioactive materials to lower the threshold

Vertex reconstruction

Vertex resolution is important for low energy physics to suppress contamination of background from edge of detector

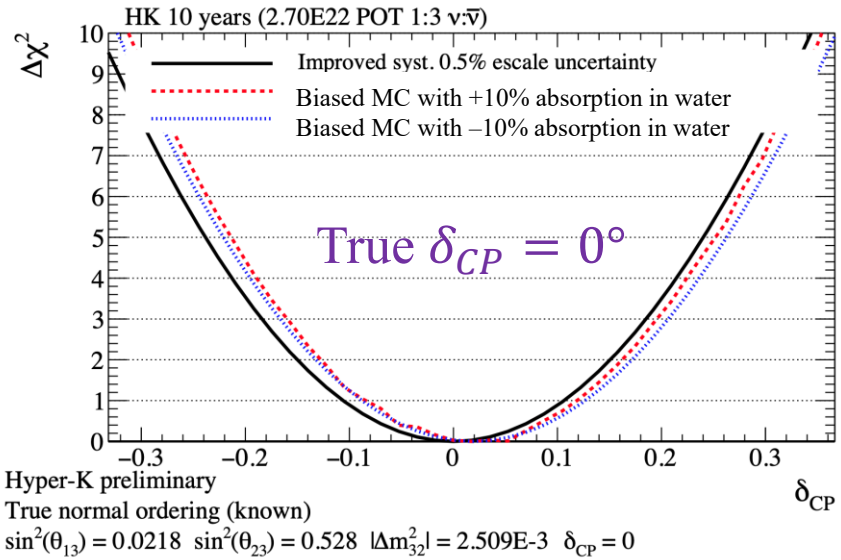


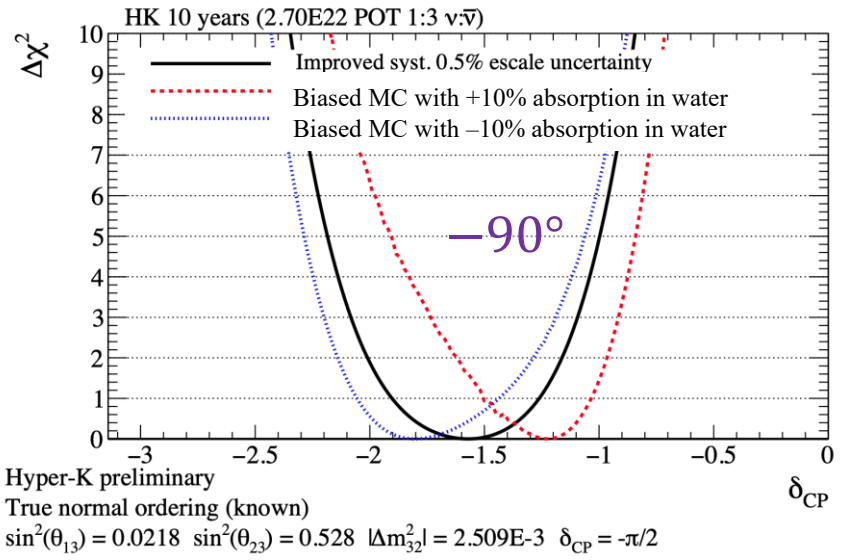


Using multi-PMTs significantly improves performances both at LE&HE for far detector.
A significant impact at LE requires DR ≤ 100Hz

mPMT in HK: Physics impact

Fake data study with absorption in water $\pm 10\%$



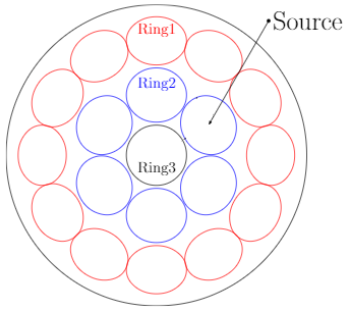


- Shift of δ_{CP} due to 10% bias in absorption/scattering lengths in water
  - $\sim 1°$ for $\delta_{CP} = 0° \rightarrow$ negligible comparing with target precison of $\sim 7°$
  - $\sim 15°$ for $\delta_{CP} = -90° \rightarrow$ non-negligible to target precison of $\sim 20°$

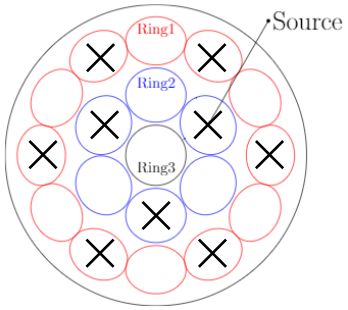
  $\Rightarrow$ Water property need to be measured with a few % precision by the calibration

Calibration study

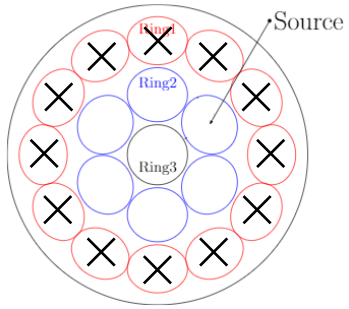
Full ring



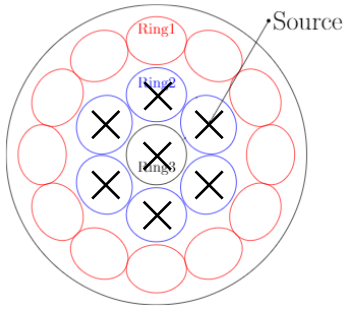
Half ring

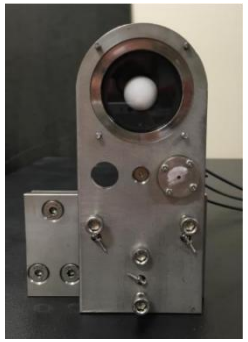


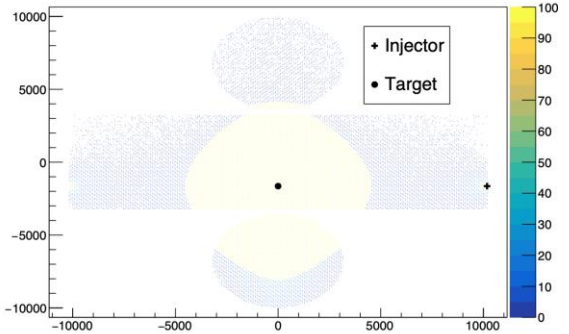
No outer



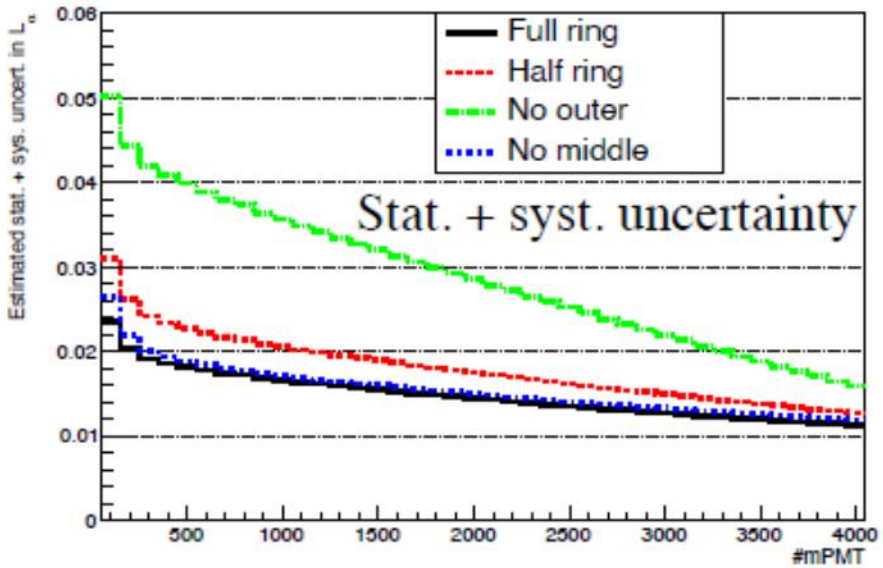
No middle

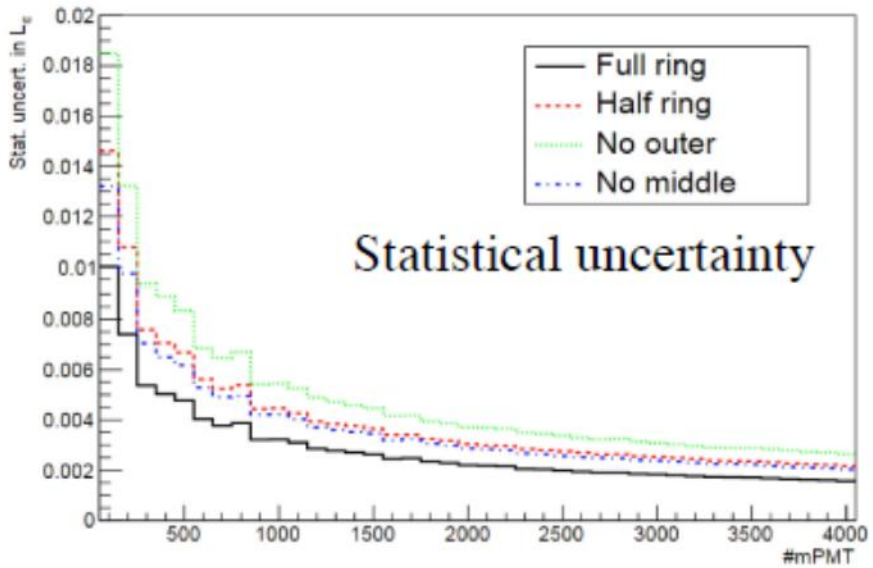






Uncertainty on light attenuation length in water

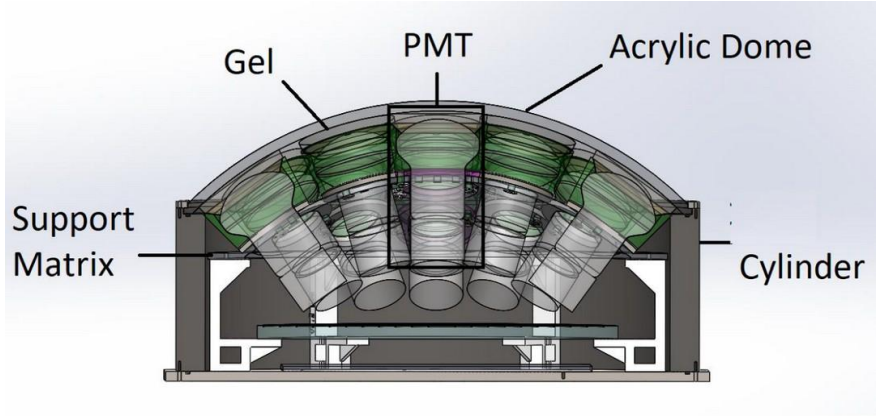




- mPMT improves calibration of water parameter: >5% w/o mPMT → ~2% with ~300 mPMT
  Precision will be enhanced with more mPMT modules. Other calibration parameters (eg PMT angular response)
- 3-inch PMTs in outer ring have critical role in calibration

mPMTs in HK

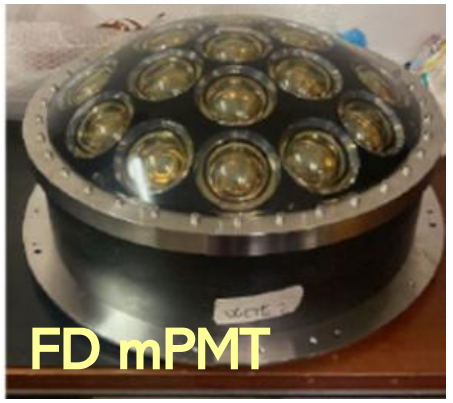
mPMT: 19 3'' PMTs and electronics arranged inside a pressure resistant vessel

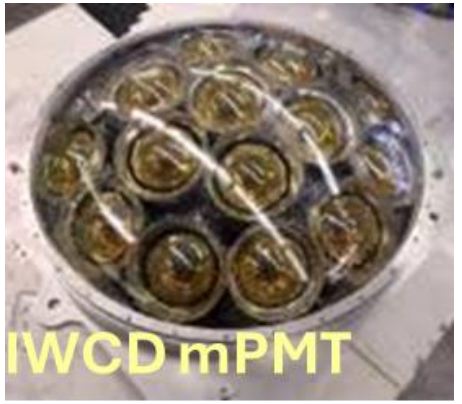


LED-mPMT: 5 PMTs replaced with LED

808 mPMTs for the Hyper-K FD
- Italy: 300 mPMTs
- Poland: 300 mPMTs
- Canada: 200 LED-mPMT

400 mPMTs for IWCD





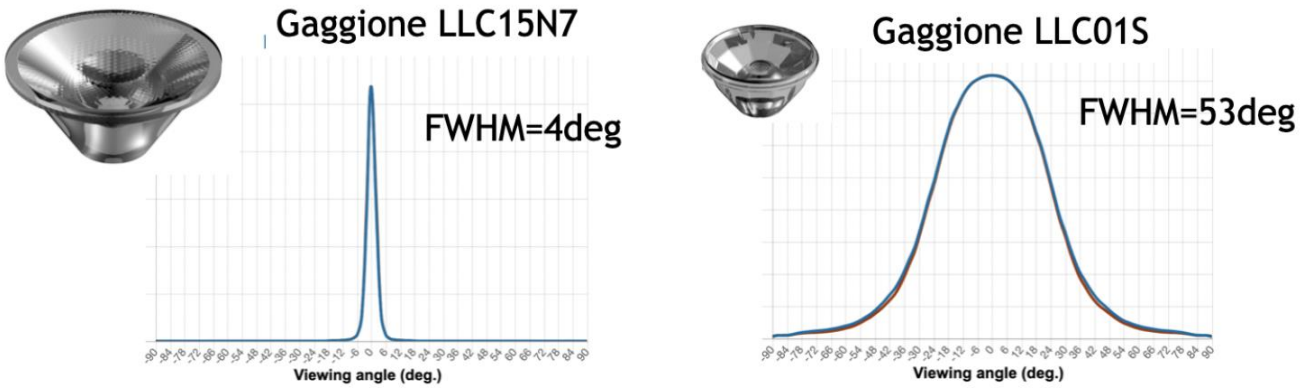
Common R&D but :

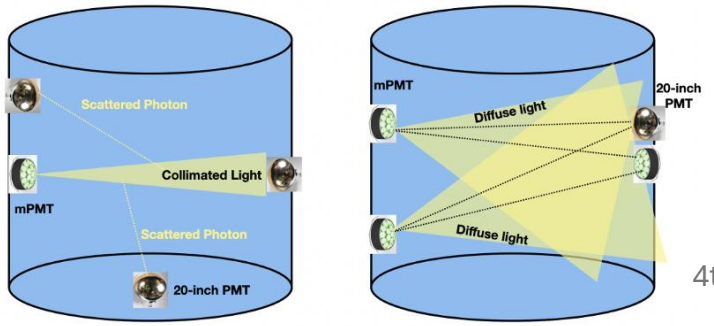
FD mPMT different from IWCD mPMT:
- Withstand pressure → robust backplate, POM-C cylinder
- Low radioactive contamination
- Different (slower, low power) electronics

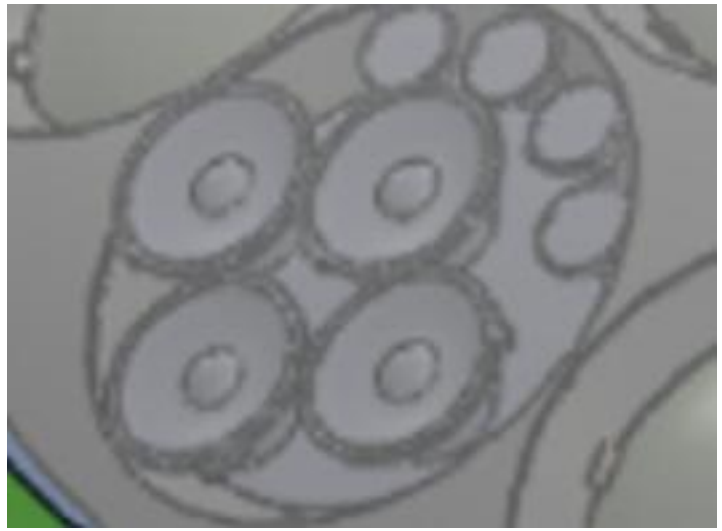
LED-mPMT
- Mechanics: same as FD mPMT except for PMT support
- Electronics: same as FD mPMT

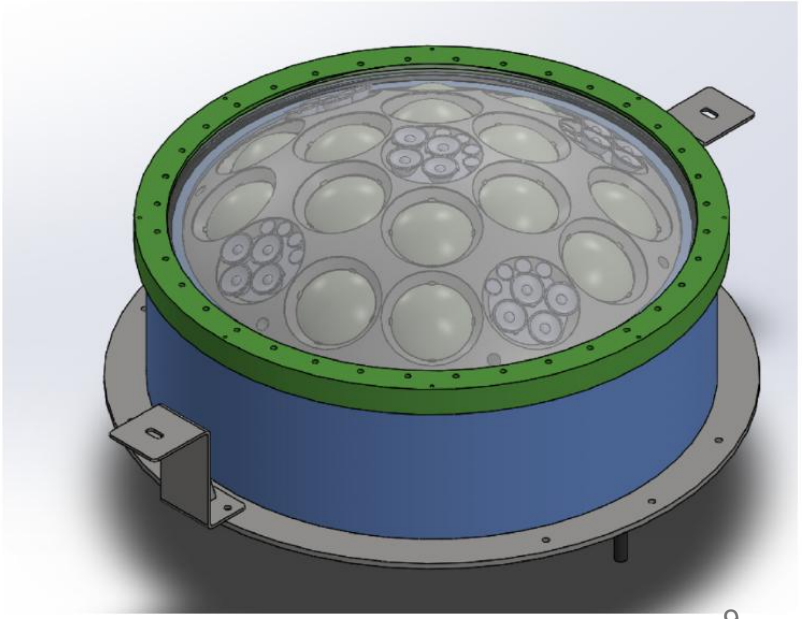
LED-mPMTs

- For 200 mPMTs we replace 5 PMTs with LED units.
- Each of the five LED units will have 8 LEDs with
  - LEDs of 290, 365, 405, 475nm wavelength
  - A narrow and wide collimator for each wavelength



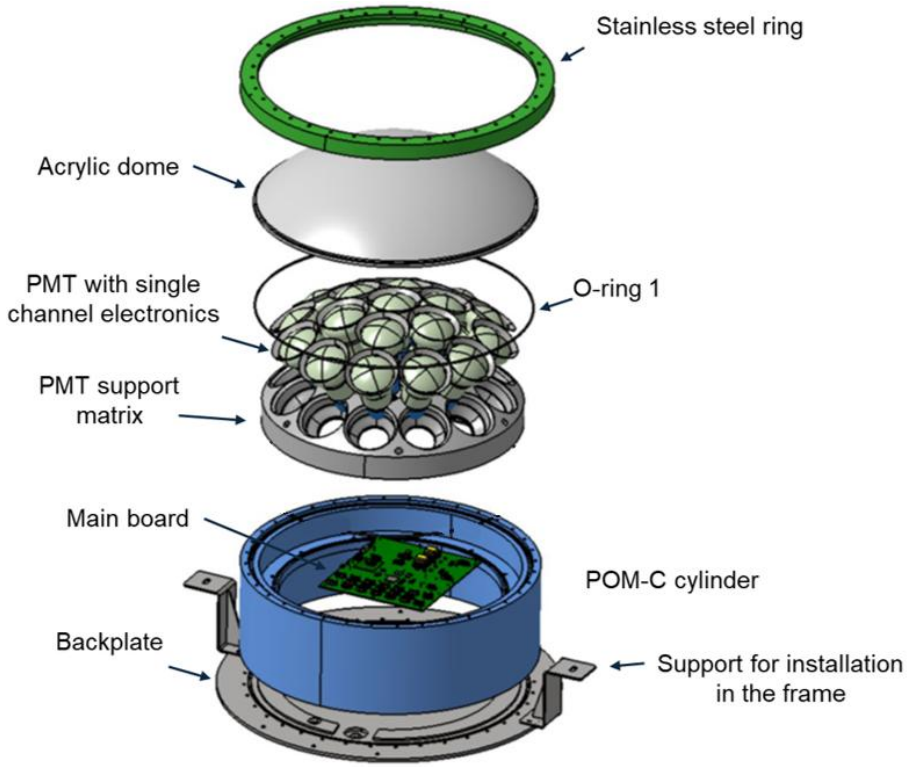






mPMT for HK FD

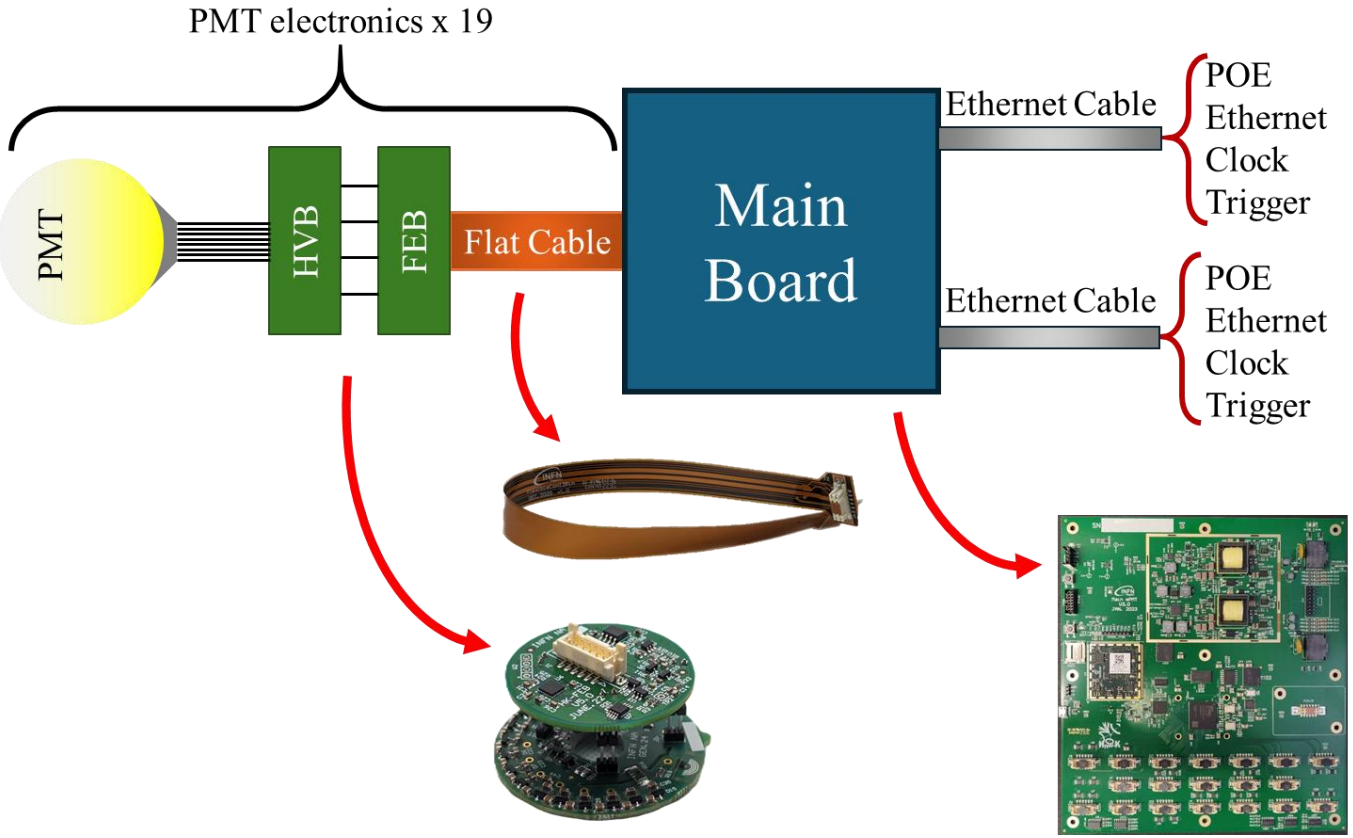
- mPMT vessel: acrylic dome + cylinder
- PMTs
- PMT reflector rings
- PMT support structure
- Optical-gel
- mPMT Electronics: PMT HV supply, Read-out, Main Board
- Concentrator card to connect the mPMTs to the DAQ
- Ethernet cable, penetrator/feedthrough/connectors
- Calibration system
- Temperature/Humidity/Pressure sensors online monitoring
- mPMT validation tests
- mPMT assembly



Canada, Czechia, Italy, Mexico, Poland (alphabetic order)

The multi-PMT in the WCD

- Electronics

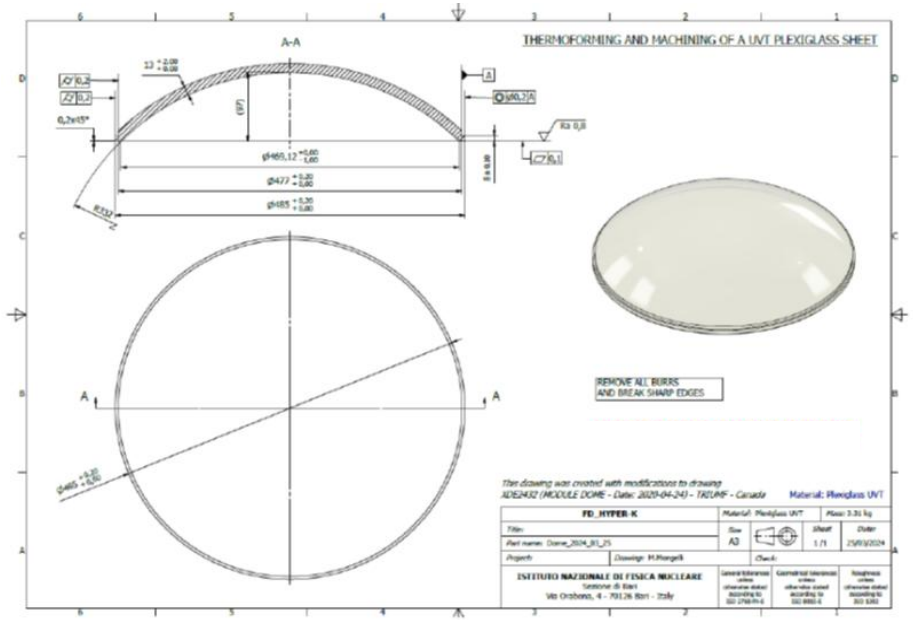


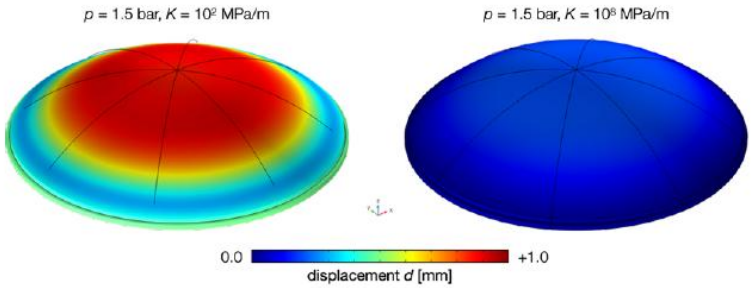
Modular and low power electronics but with excellent performances.

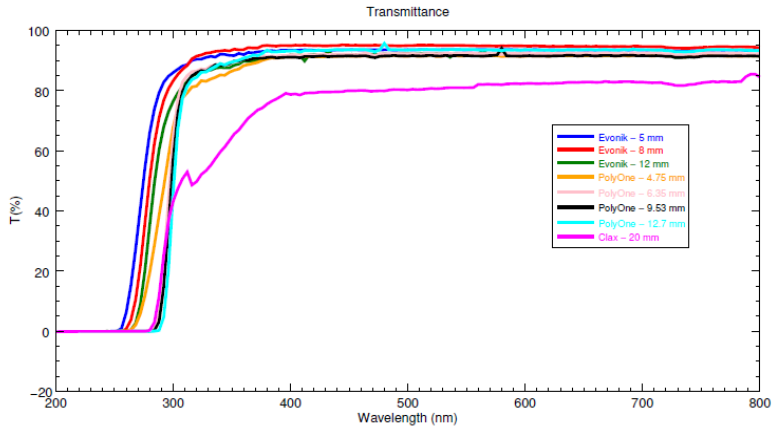
Charge resolution 0,05 pC
Time resolution 100 ps
Power consumption of a full module < 4 W

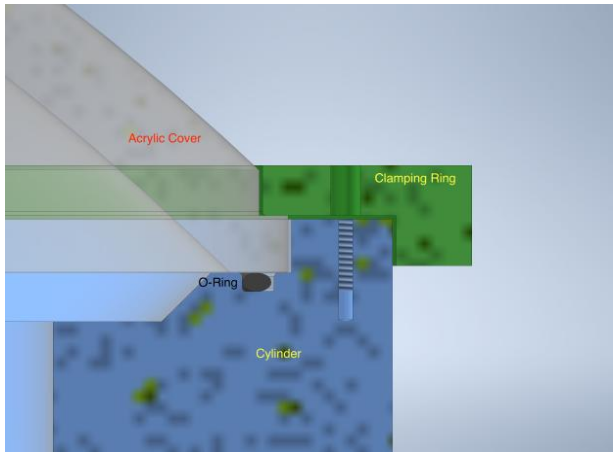
The multi-PMT in the WCD

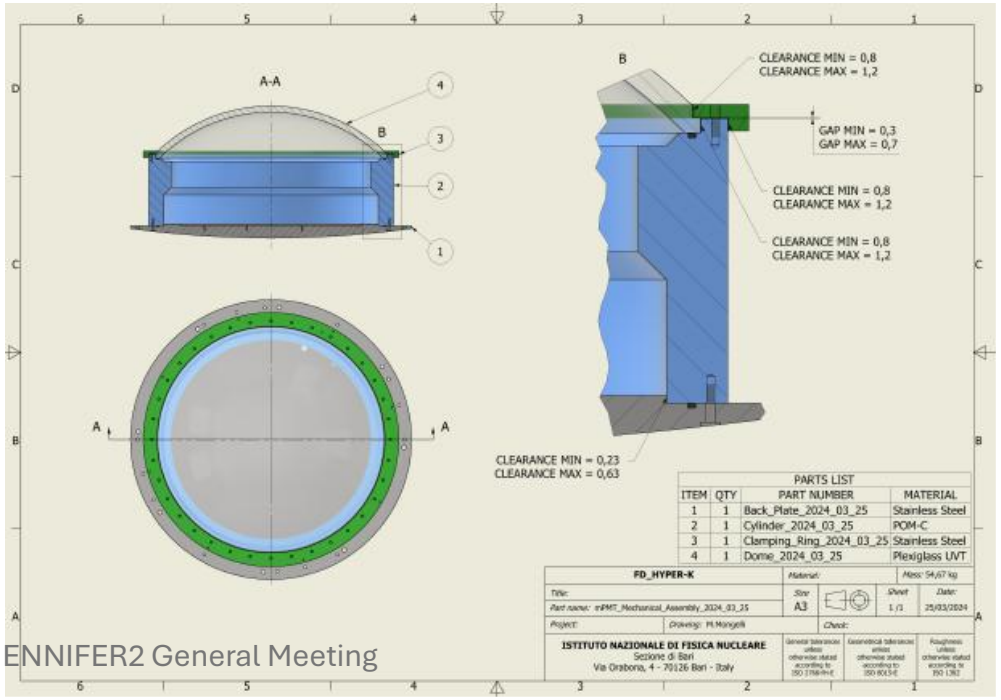
- Mechanics



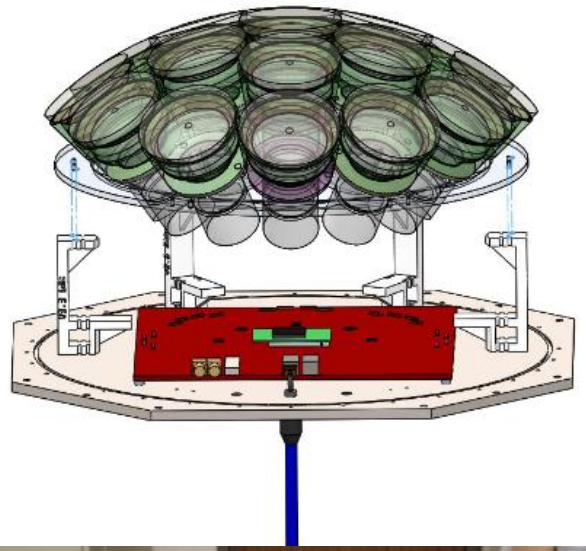


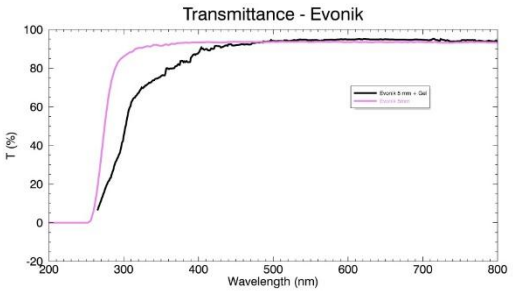


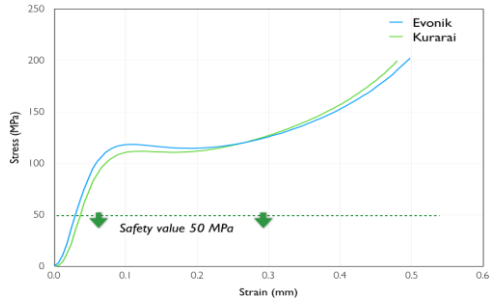




mPMT R&D for HK FD







Optical, mechanical, radioactivity contamination measurements on acrylics and other mPMT parts

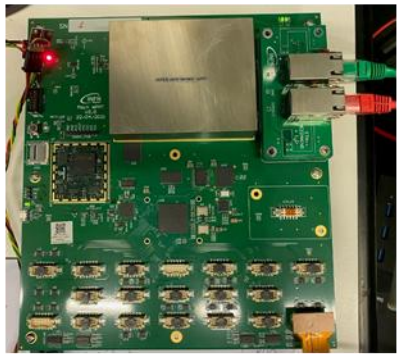
Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	$(3 \pm 1)\cdot 10^{-1}$ ppb
K-40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

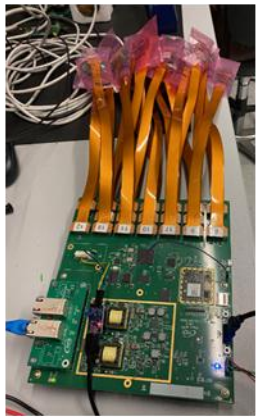
Prototype at TRIUMF

HK FD mPMT Electronics at INFN

mPMT in Memphyno water tank in France

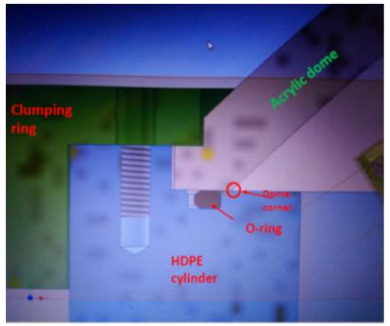
R&D activities



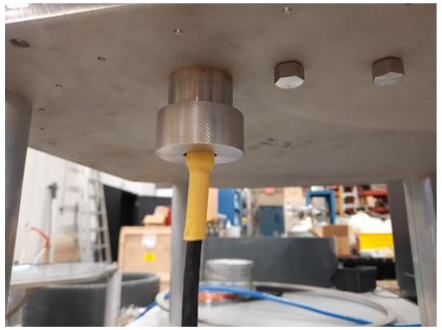


mPMT electronics

All validation tests completed
Ready for mass production
QA/QC systems ready

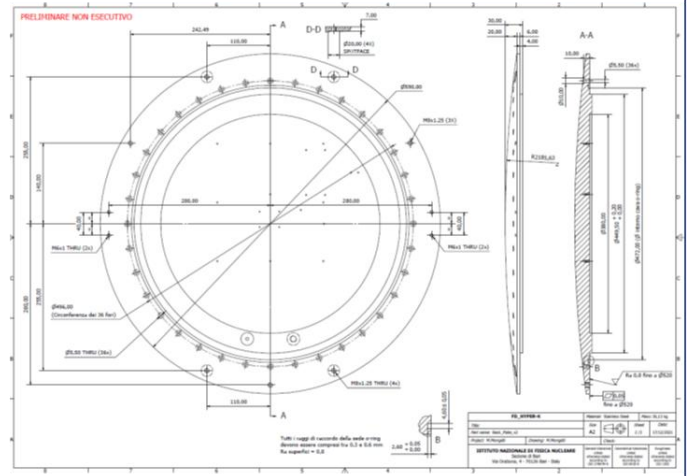


Improved closure system



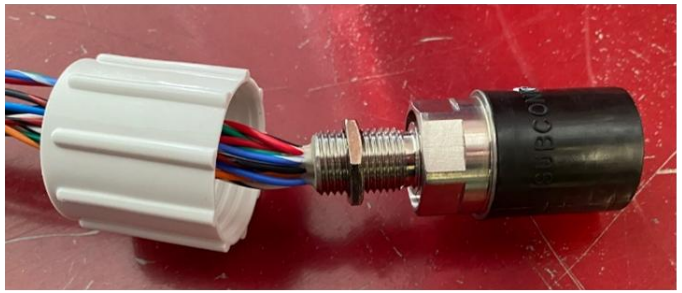
VIIT Feedthrough: Installed mPMT with VIIT feedthrough in water. No leaks over 1 month. High pressure test neeed for FD

Cylinder in POM-C



Backplate with curvilinear shape

Cables mPMT-MCC, connectors by MacArtney
Validation for 20 years
Nuclear contamination and soak tests planned:
Materials HDPE and AISI304
First prototype used for the mPMT prototype at INFN



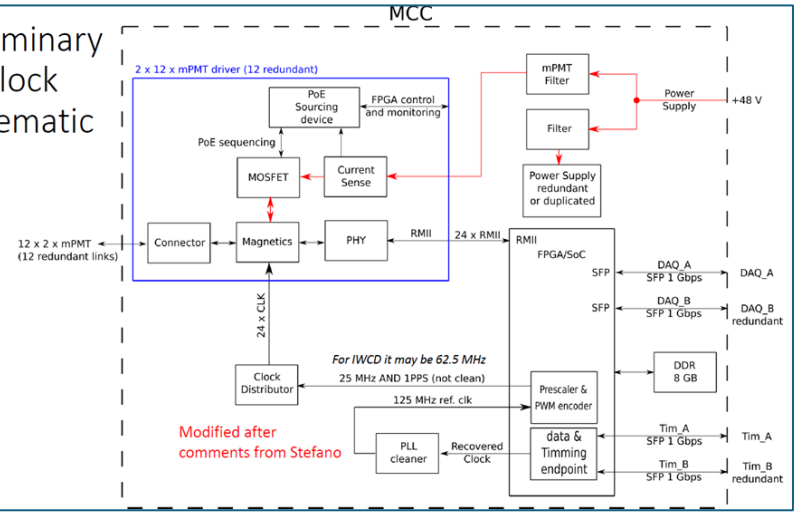
All the mPMT parts have been tested and validated

Ready for mass production

MCC Electronics

Final tests ongoing
QA/QC systems almost ready

Preliminary block schematic

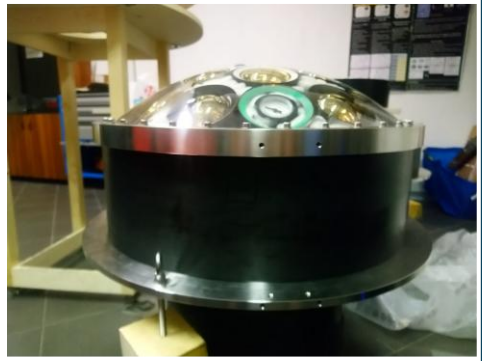


Pressure tests

Accelerated testing
Soak test
Measurements for effects of ageing, humidity
Water absorption effects on vessel and acrylic dome and Test the mechanical stability of materials after absorbing water

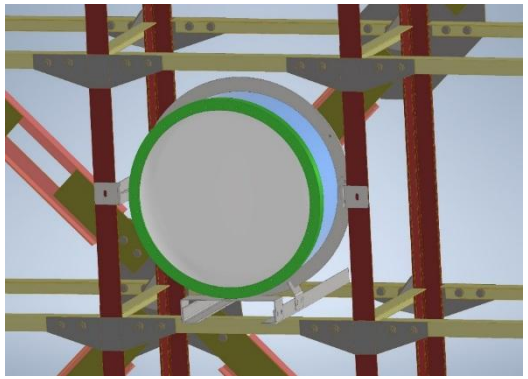
Implosion test

Mechanical mPMT prototype used for implosion tests.



Implosion test relevant to investigate if any implosion of 50cm PMT can affect the mPMT vessel (cracks or damages) and its fixing in the frame. We did no expect an implosion of the mPMT

Installation test



The mPMT module is designed to occupy the same 70×70 cm^2 footprint as the 50 cm PMT to aid integration within the Hyper-K photosensor support structure.

The mechanical design has been optimized for the installation in the detector support structure.
Mechanical prototype installed in the mock-up HK frame

Vibration and stress test

Lab and equipment for vibration test at Tecnológico de Monterrey (Mexico)

Setup for top and bottom mPMT orientation

mPMT in HK FD: through mass production

808 mPMT will be installed in HK FD

- Assembly sites in Italy, Poland, Canada
  - Assembly will start in Jan. 2026

- PMT testing station in Olomouc, Czechia

- Electronics testing station in Naples, Italy

- Mechanics testing station in Bari, Italy

QC and Tracking of the products - Electronics and cables

- PMT with a QR code for Unique serial number from Hamamatsu
- QA value sent by the company and loaded in central DB
- HV board tagged with a RFID tag

When soldered to PMT transfer of the PMT serial number in the RFID tag

- FE board tagged by the MCU unique serial number

When soldered to PMT RFID information transferred to the MCU

- HASS Procedure defined
- Cables by MacArtney

Cables will be tested at assembly site before connecting to the mPMT electronics. A dedicated test bench has been developed

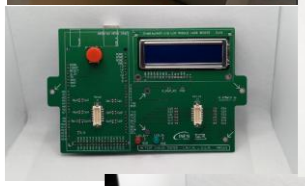
QC results loaded into the HK DB automatically

HV QA:
Automatic inspection
Test system ready and tested

FE QA:
Automatic Optical inspection
Test system ready and tested

Internal cables and mPMT-MCC QA:
Automatic Optical inspection
Test system ready and tested

Single channel Assembly (SCA) QA:
PMT will be tested with the FD electronics
PMTs tester box in preparation

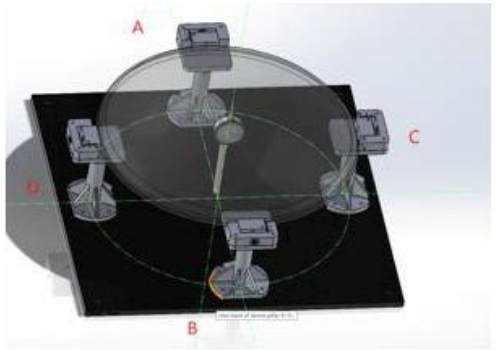


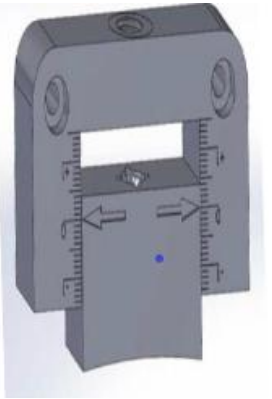
QC and Tracking of the products - Mechanics

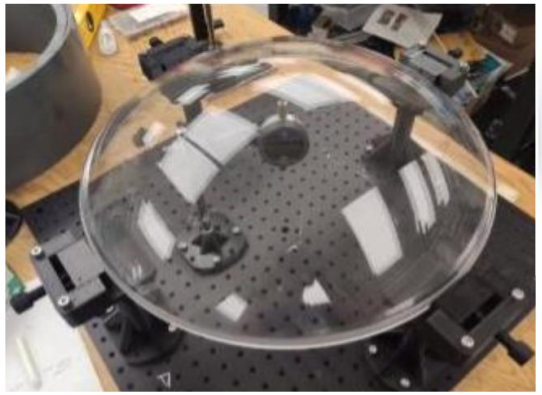
- For each component defined specifications and QC protocols to be asked to suppliers
- Tools for QC at suppliers and assembly sites almost ready

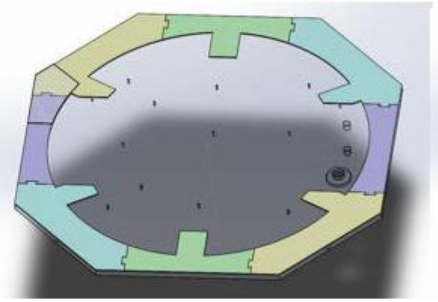
QC results loaded into the HK DB automatically

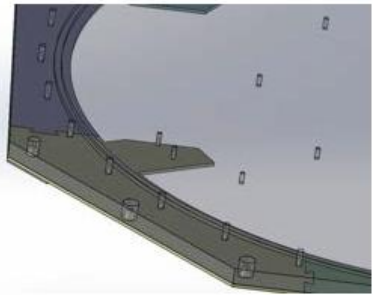
Measurements on samples for mechanics properties, RI, ….for each batch by HK WG











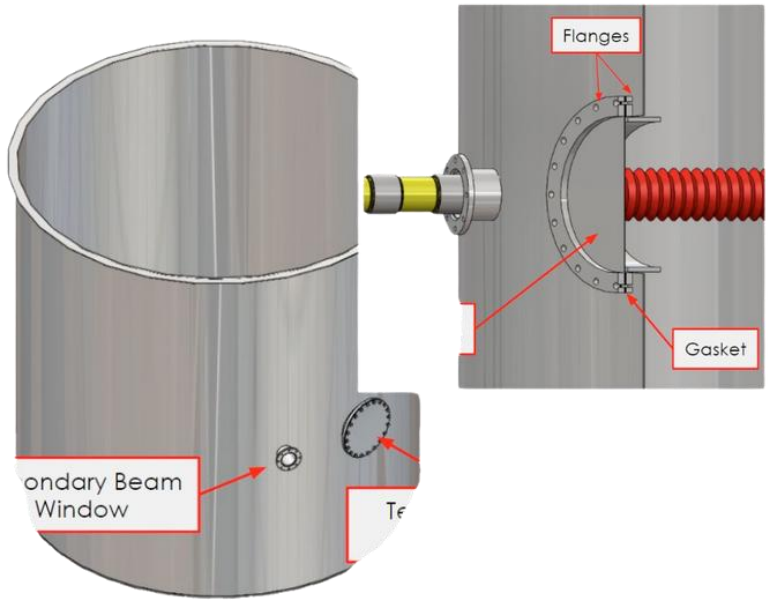
Water Cherenkov Test Experiment @CERN

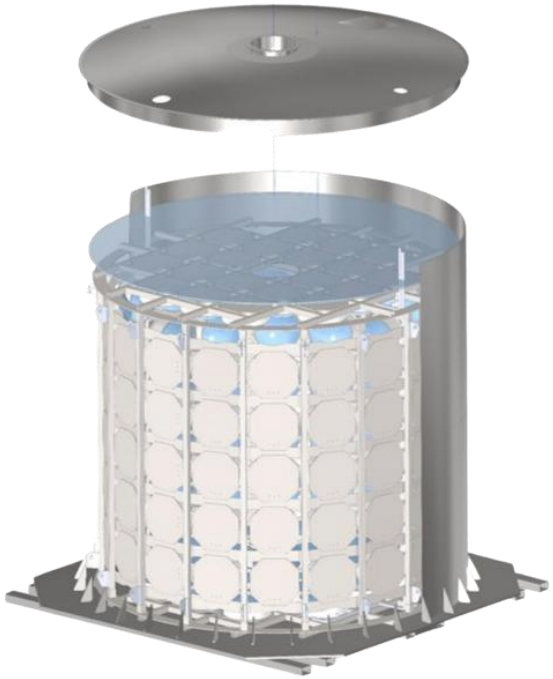
Small (d = 4 m, h = 4 m) water Cherenkov detector that used for

- developing percent level calibration of water Cherenkov detector
- measuring physical processes (pion scattering in water, Cherenkov light profile, secondary neutron production)

Beam: electron, muon and hadron beams (0.2 - 1.2 GeV/c)

- Secondary beam for electrons and muons
- Tertiary beam for pions and protons

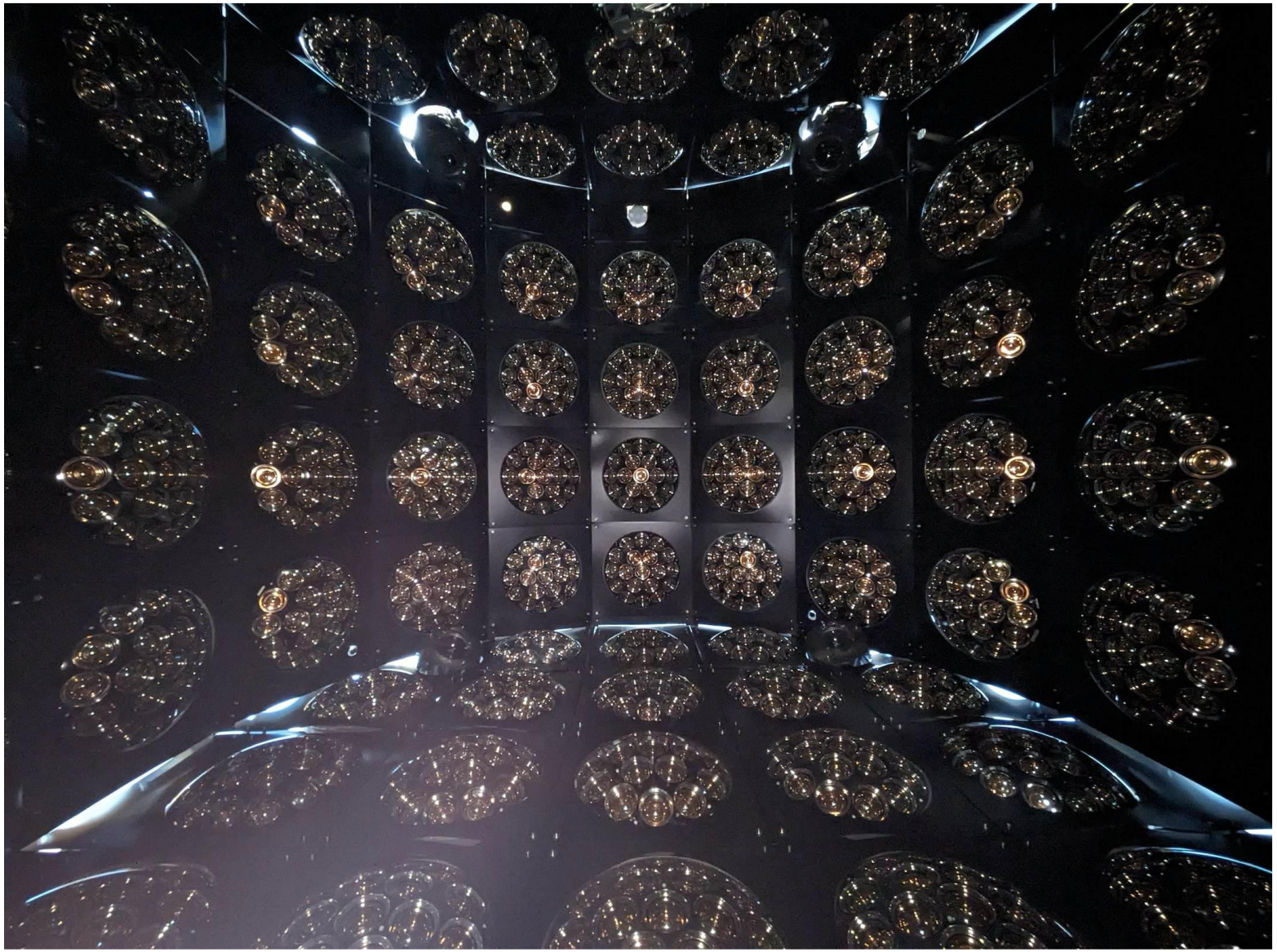




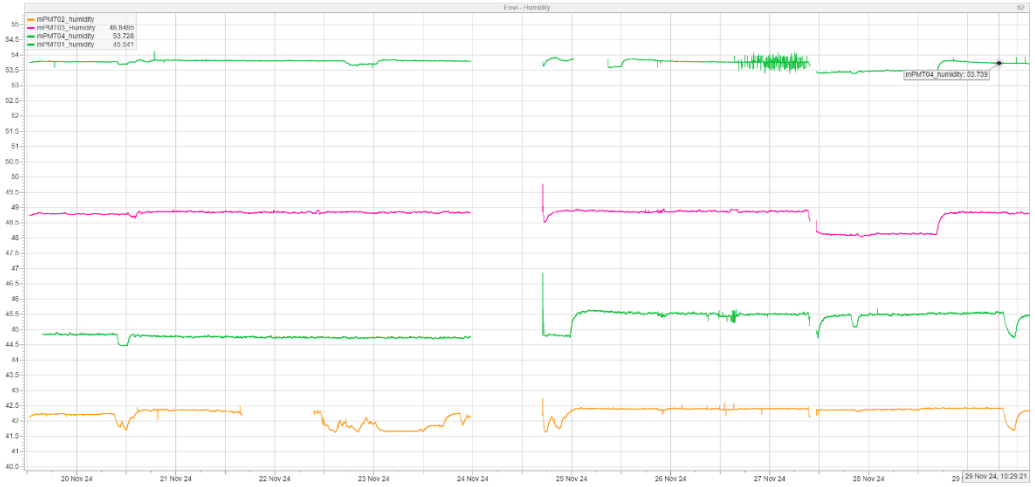
WCTE

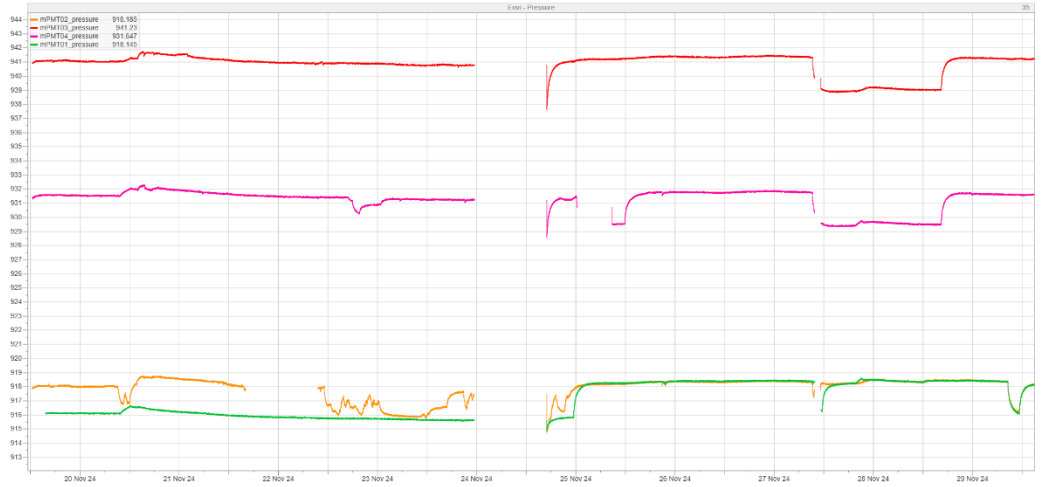
~ 100 mPMTs for WCTE

4 FD mPMTs



Pressure, temperature and humidity@WCTE





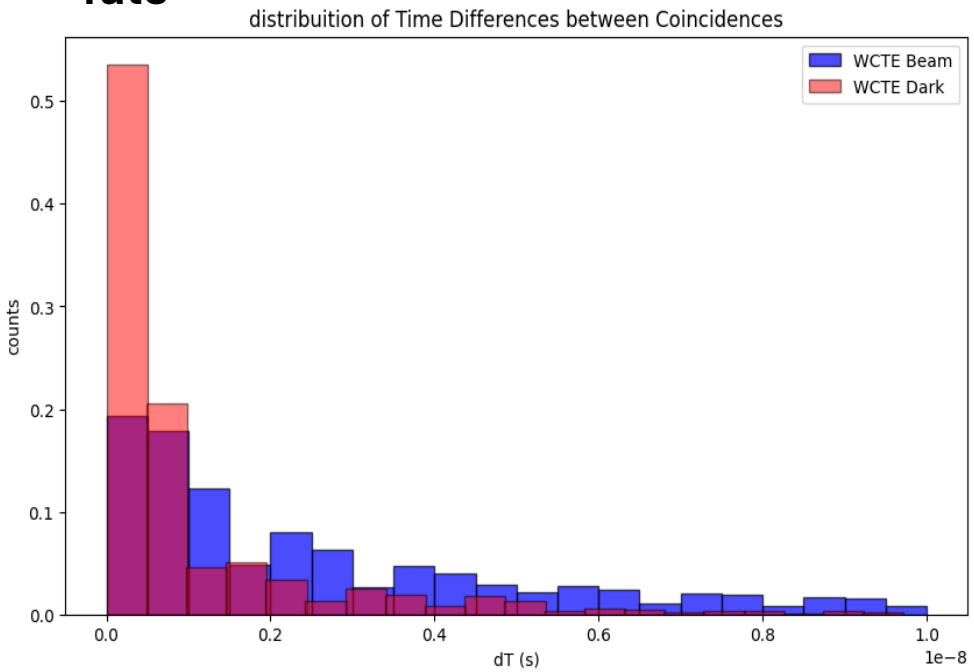
All the systems are very stable
No pressure or humidity increase/decrease

ZYNQ temperature as expected less than 10 degrees over the PCB temperature

FD mPMTs @WCTE: Preliminary results

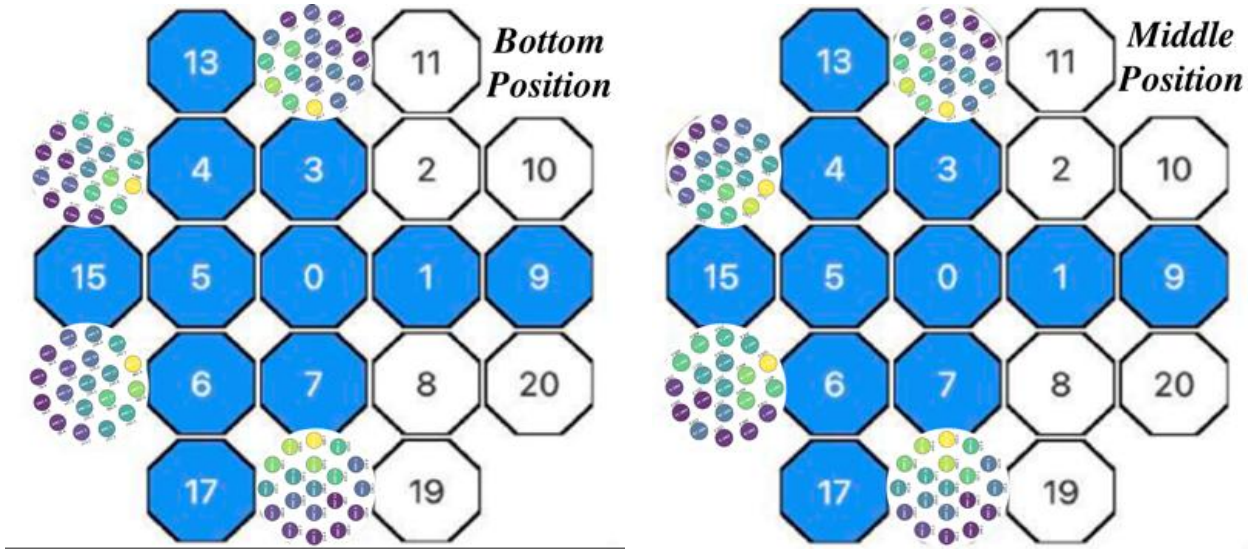
Several improvements on FD mPMT electronics and firmware based on WCTE experience

Studies on random coincidence's rate



→ reducing background noise in reconstruction

Measurements with NiCf calibration source



→ As expected, higher rate for PMTs looking the calibration source

Conclusions

- mPMTs improve physics capabilities in WCD
- In Hyper-K ~800 mPMTs will be installed in the FD
- Completed validation tests
- QA procedure defined
- Mass production for mPMT components will start soon
  - Assembly of mPMT will start in Jan 2026

- JENNIFER2 Milestones:
  - Paper on measurements of acrylic covers just published
  - 6 mPMT prototypes assembled and tested

Thank you!