Hyper-K Photodetectors

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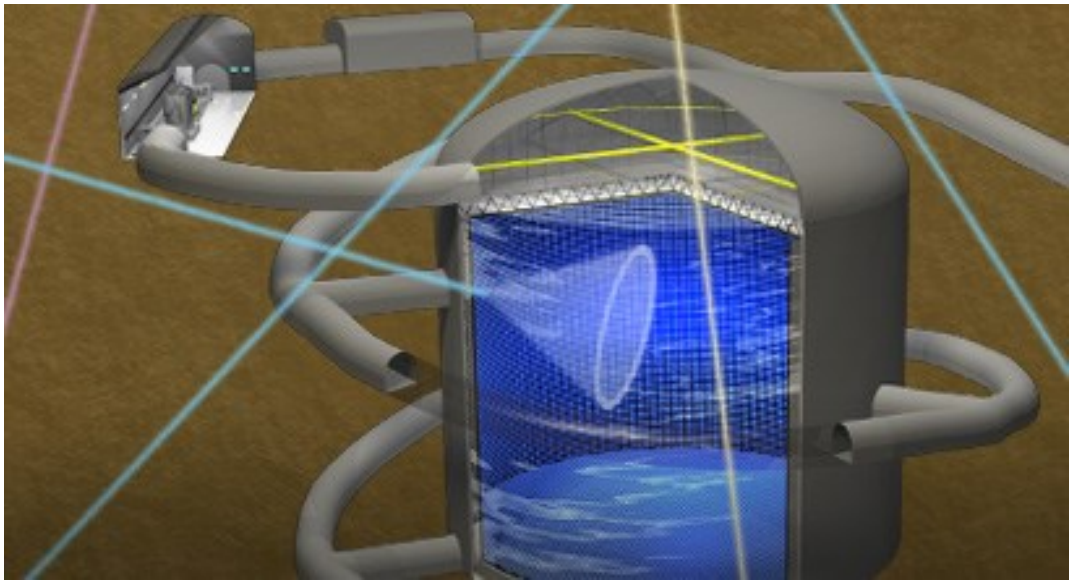
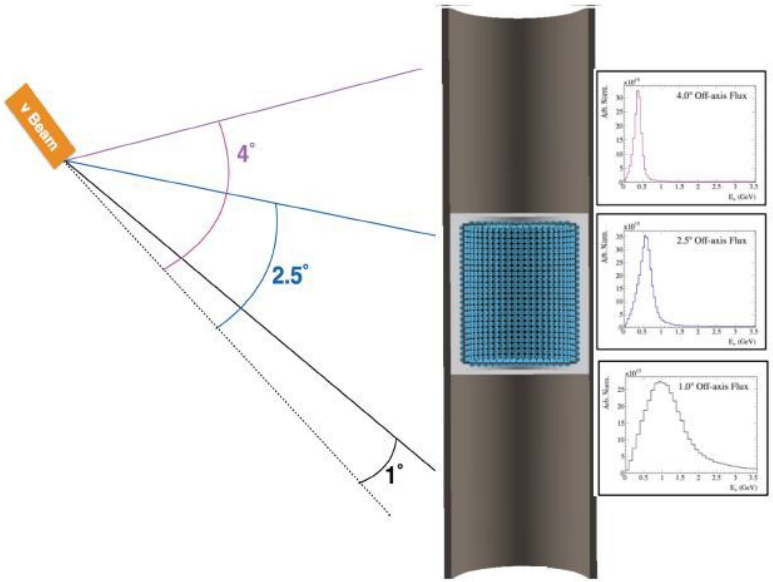
Hyper-Kamiokande





Hyper-Kamiokande Detector
60 m(H)x74m(D)
Total volume 260 kt
Fiducial volume 190 kt ~10x Super-K

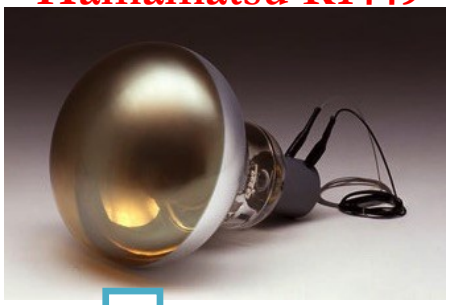
Inner-detector: 40000 20" PMTs
Outer-detector: 6700 8" PMTs

E61 – Intermediate detector for Hyper-Kamiokande Project
Movable Water Cherenkov detector
Inner diameter 8 m
Inner detector height 6-8 m

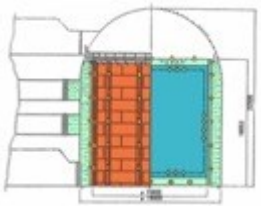
ID: 50 cm Photo-Detectors

First 20-inch (50 cm) Photomultiplier Tube (PMT)

Hamamatsu R1449 (Venetian blind dynode)



For Kamiokande



(1983-1996)

1k PMTs / 3 kton water

Supernova ν observation!

R3600 (Venetian blind dynode, improved)

For Super-Kamiokande

(1996-)

11k PMTs / 50 kton water

ν oscillation discovery!

For Hyper-Kamiokande

For other experiments

42 cm (17") Box&Line PMT

R7250

(Box&Line dynode) with 50 cm bulb of R3600

For KamLAND

50 cm MCP PMT

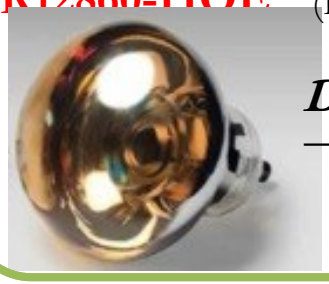
By NNVC, IHEP

For JUNO

Recently developed in **China**

50 cm Box&Line PMT

R12860-HQE (Box&Line dynode)

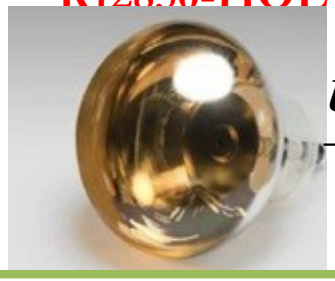


Developed

→ Photo-detector in Hyper-K baseline design

50 cm Hybrid Photo-Detector (HPD)

R12850-HQE (Avalanche diode)



Under development

→ Possible further improvement of Hyper-K

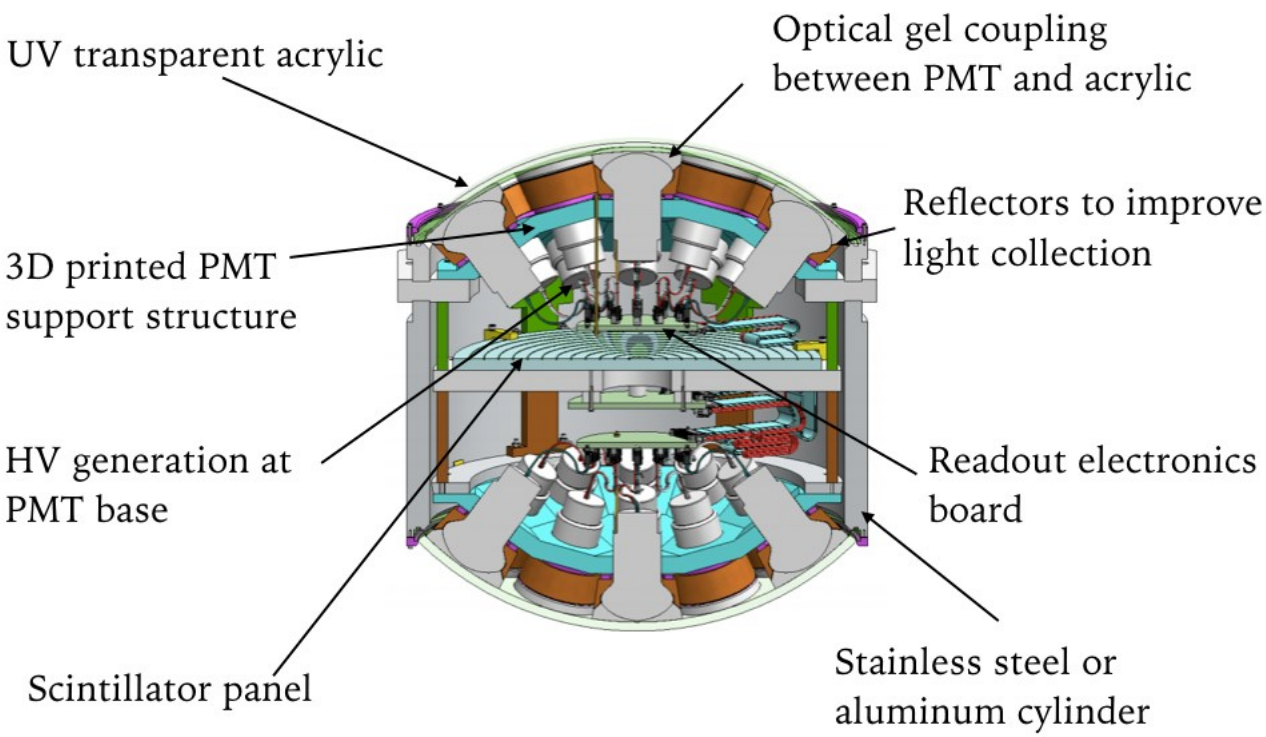
ID: Alternative option

to increase the yield of the effective area of the optical system introducing intrinsic directional sensitivity

Multi-PMT
Digital Optical Module

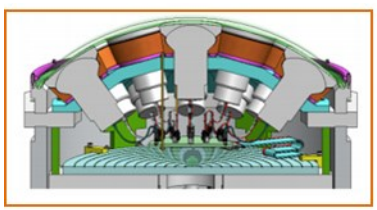
Firstly proposed by KM3Net Collaboration

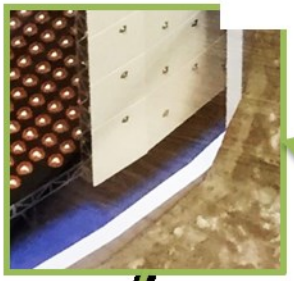
multi-PMT in Hyper-K and E61

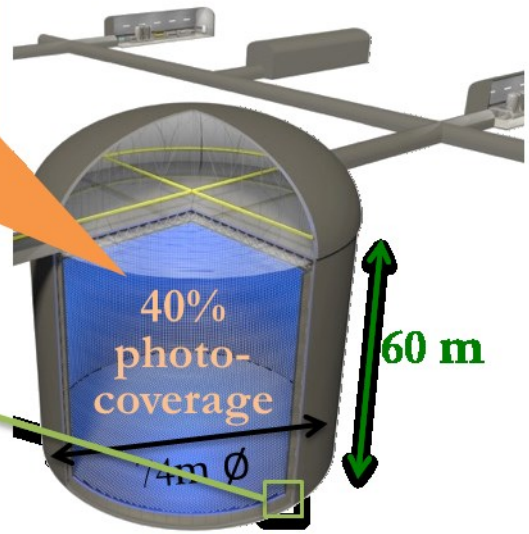


- The E61 baseline design is equipped with multi-PMT modules (mPMT) as photodetction system
- Hybrid configuration considered for Hyper-K: 20” + mPMT

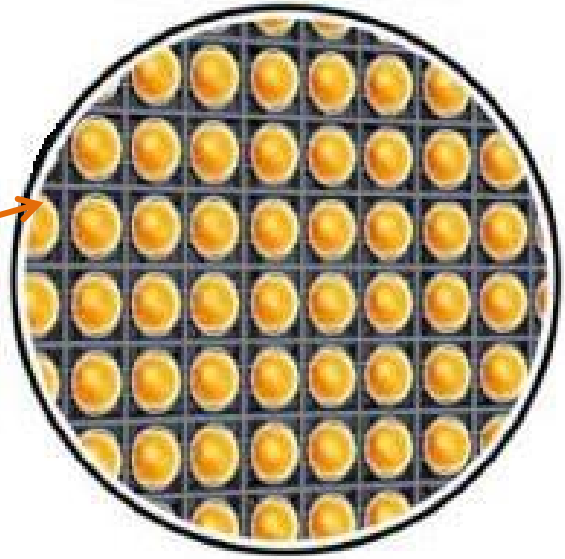
Hybrid configuration for Hyper-K







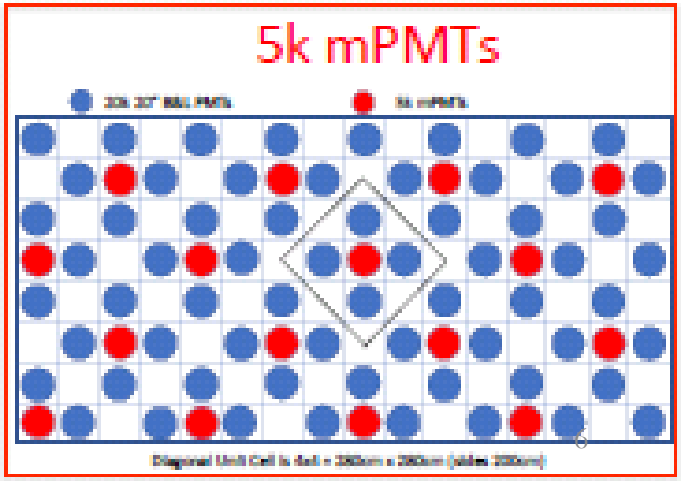
×2 tanks



About 15,000 PMTs
for Outer Veto Detector

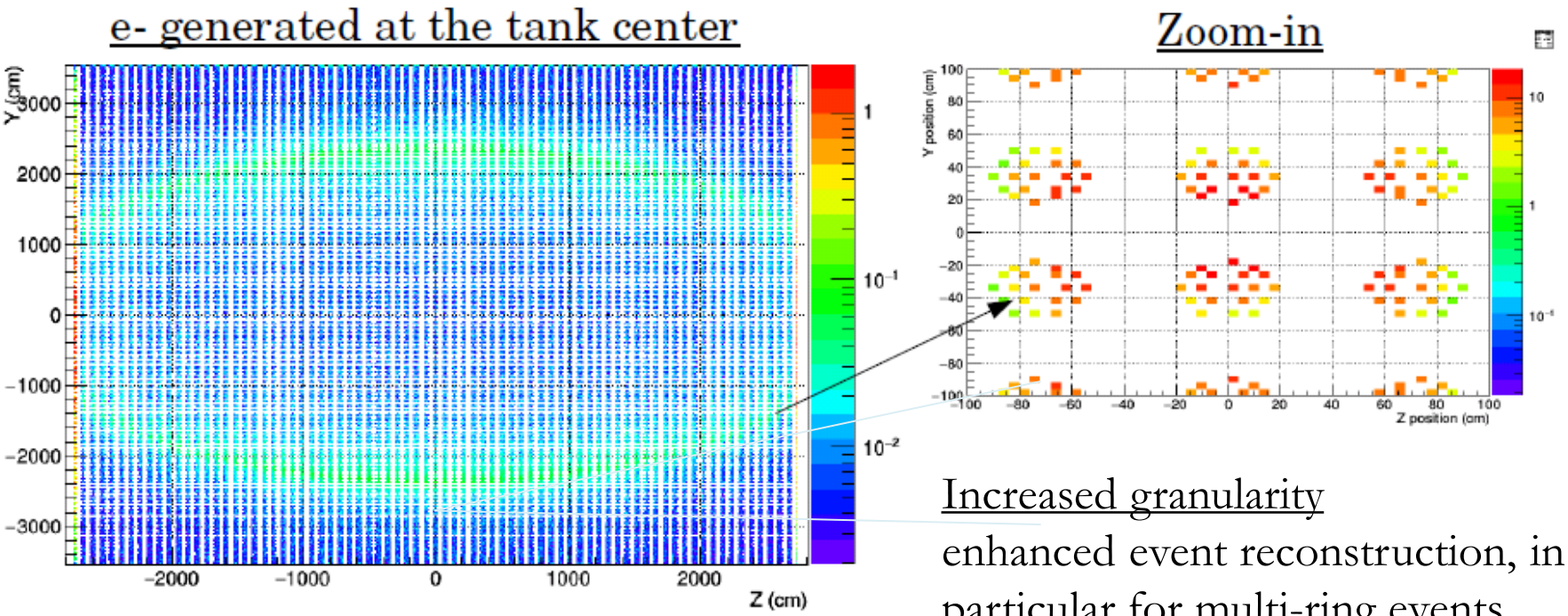
Baseline
configuration:
- 40k of 20" PMTs

Hybrid
configuration:
- 20k of 20" PMTs
- 5k mPMTs



Large PMT vs mPMT?

Intermediary goal: determine capabilities of standalone mPMTs
→ Hyper-K with 40 % coverage of mPMTs: compare with 20”

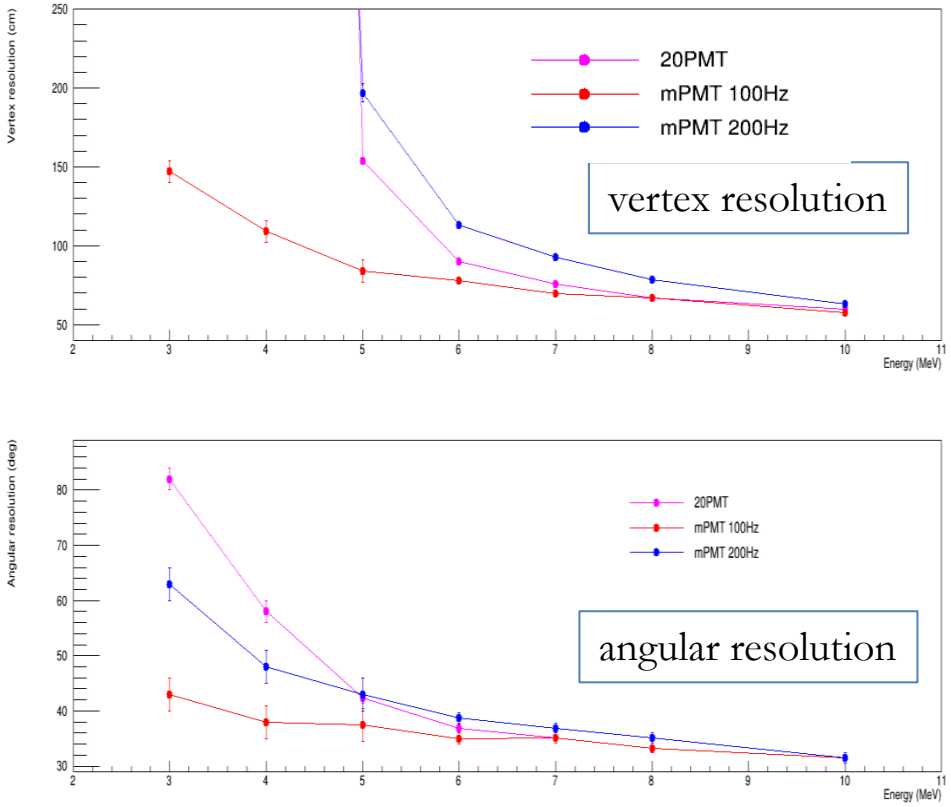


Increased granularity
enhanced event reconstruction, in particular for multi-ring events

Complete simulation and reconstruction chain has been developed and validated

Performance Studies for mPMTs in HK

Variation of resolutions with ν energy



- Vertex and angular resolution better for low energy with reduced dark rate in mPMTs
- At high energy: muon/electron separation improved near the wall; vertex resolution improved
- Improvements strongest near edges of FV
- Introduce (theta,phi) dependent efficiency functions for individual PMTs in mPMT

<u>Mixed geometry next step</u>

If operate 100Hz: improved vertex resolution and lower down the Energy threshold from 5 to 3 MeV

→ Access to low energy neutrino physics!

mPMT Prototype

Main limits of KM3NeT solution for HK project:

- Vessel:
  Km3Net experience demonstrated that glass spheres are characterized by high ^{40}K and other radioactive contamination.

- PMT Read-Out:
  In KM3Net the time over threshold (ToT) strategy is exploited; this is not a good solution for Hyper-K project in which charge measurement is important

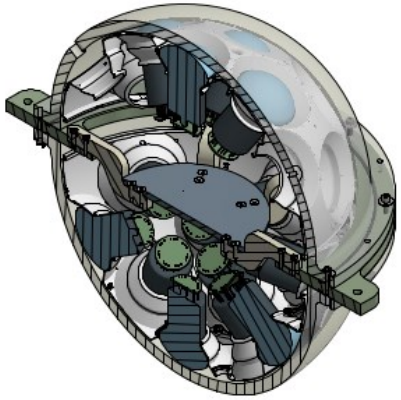
- Assembling procedure:
  mPMT production time

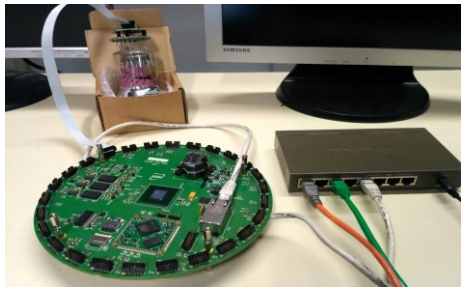
Prototype module design and testing

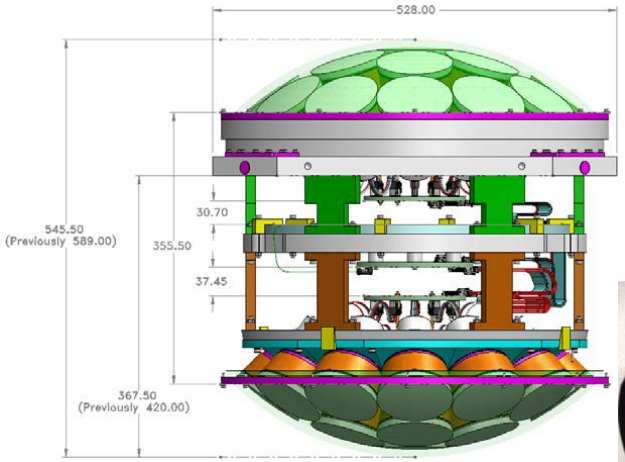
Two prototypes under construction and test

@INFN:
same design as KM3Net: vessel 17inch;
spherical shape;
goal:
test the acrylic vessel and new electronics

@TRIUMF:
new design and mechanics optimized for HK/E61
goal:
HK/E61 design: test mechanics and assembling procedure



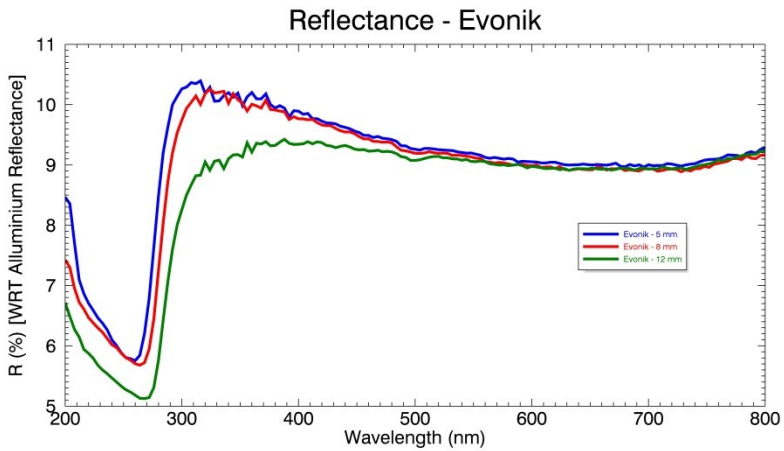


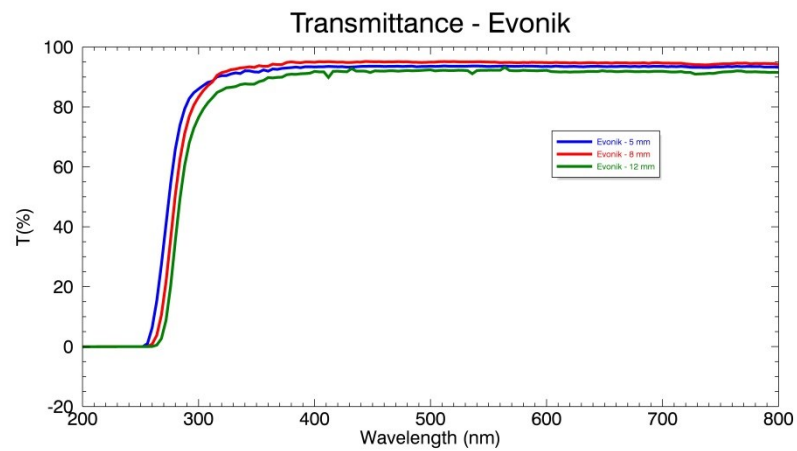


Canada, Italy, Japan, Poland groups collaborating on development of parts for the multi-PMT module

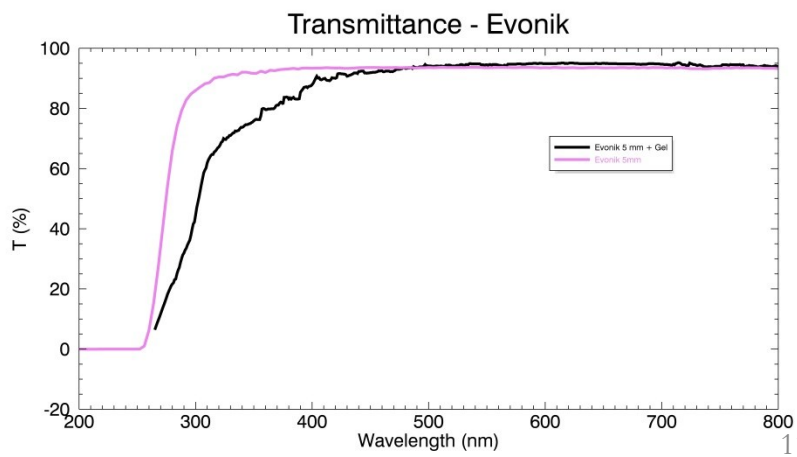
Acrylic vessel - Optical properties

Several acrylics tested: PLEXIGLAS® GS UV Transmitting by Evonik choosen for the construction of mPMT for Hyper-K and E61





Checked compatibility between optical gel and acrylic and measuread the transparency of acrylic+optical gel.



Acrylic vessel - Radioactivity

- **Radioactivity measurements** (at LNGS)
- Contamination results are here reported

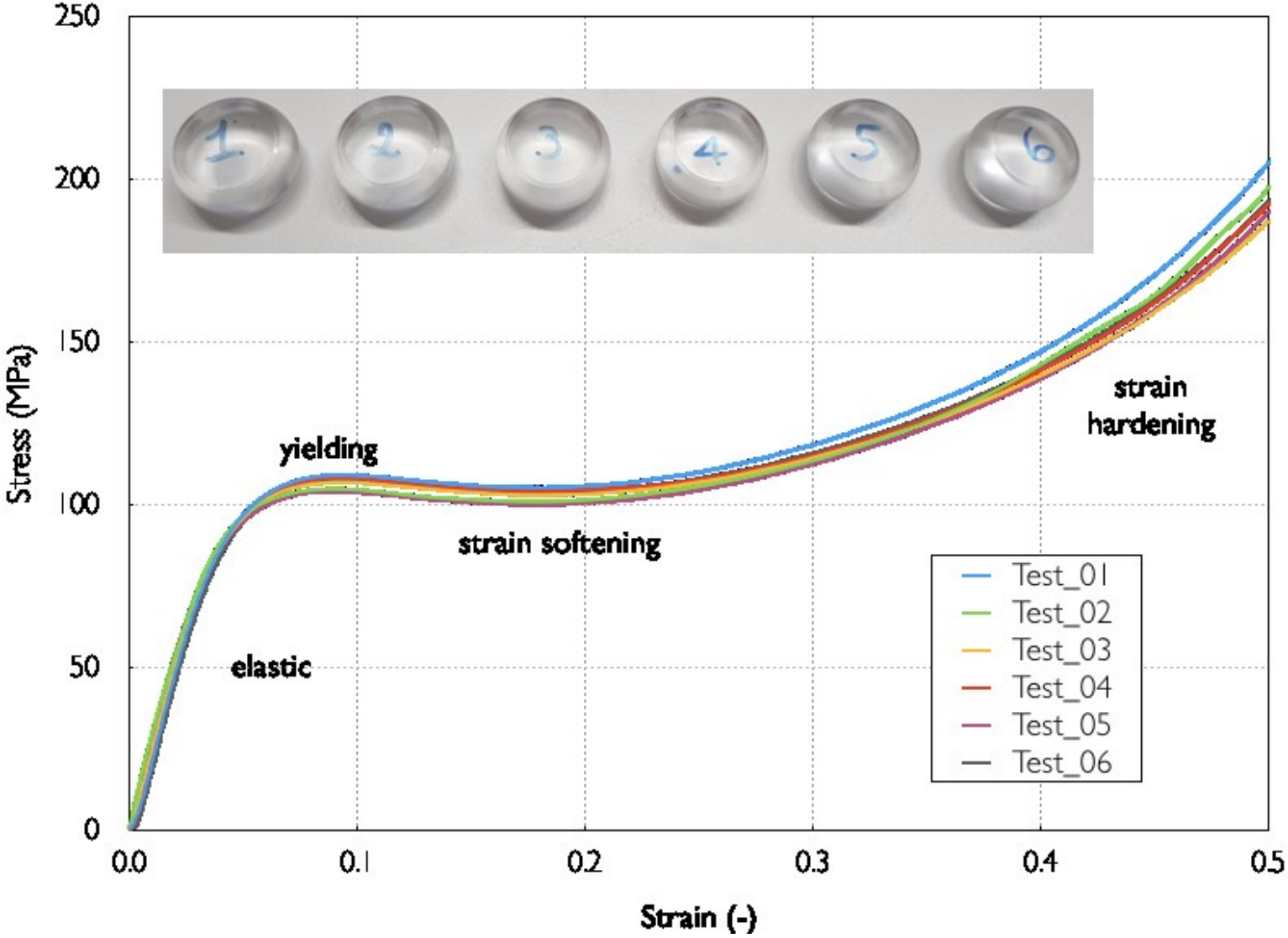
Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	$(3 \pm 1)\cdot 10^{-1}$ ppb
K-40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

Evonik acrylic.
Weight: 13.4567 kg;
Live time: 22 days

Requirements:
U-238 < 0.3 ppb
Th-232 < 1 ppb
K-40 < 0.3 ppm

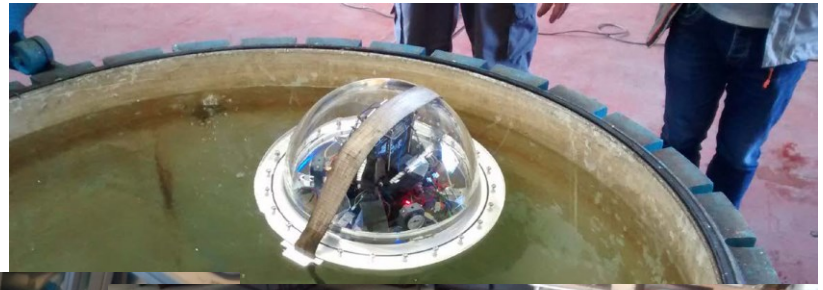
The Evonik acrylic is very clean, no radioactivity contamination

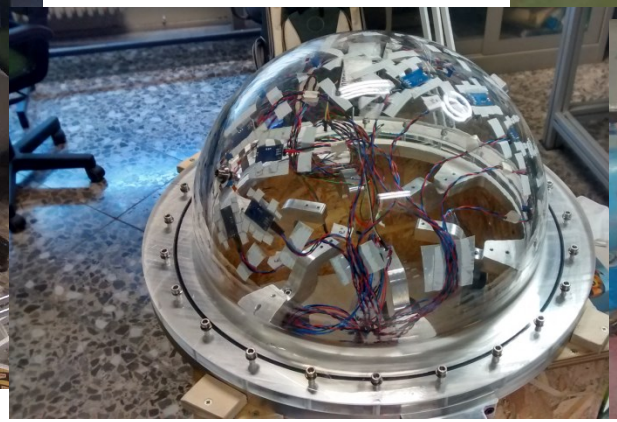
Acrylic vessel - Mechanical tests



Acrylic vessel - Hydrostatic Pressure test

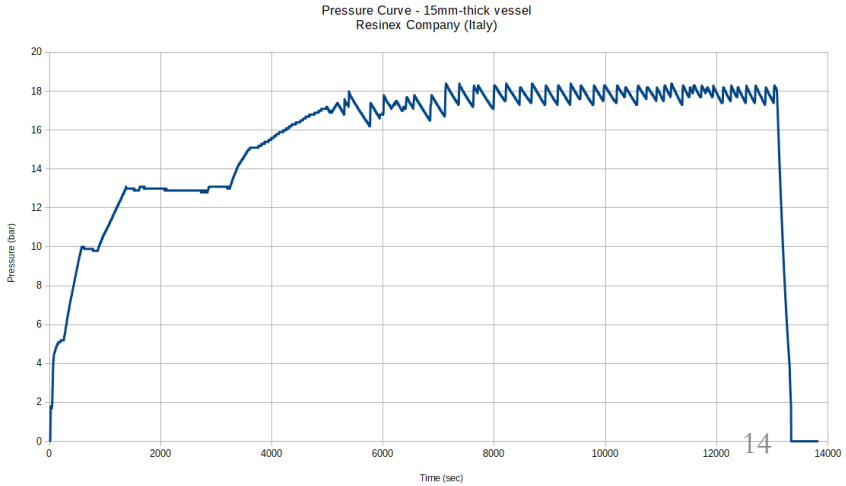
15mm and 20mm-thick vessels tested
Arduino pressure sensors for minitoring





Constrain: resist up to 1.26 MPa
Pressure test results: vessel resisted to 18 bar.
No damage at the 15mm-thick vessel!
The 20mm-thick vessel was inserted into a 400-bar tank for a crash test
Implosion at 86 bar

Acrylic: PLEXIGLAS® GS, UV transmitting by Evonik



mPMT Electronics Performance Requirements

Performance Requirements
– Timing resolution: better than 3” PMT TTS
- ~300-500ps timing resolution from electronics for 1PE.
- Better timing resolution (100-200ps) for large PE pulses..

– Charge resolution ~0.05PE up to 25PE.

Power consumption:
– For Hyper-K <3-4W per mPMT
Driven by water circulation requirements
– For E61 ~5-10W per mPMT
• Not as strongly constrained as Hyper-K

Moderately low cost: ideally ~$50 per channel for digitization part.

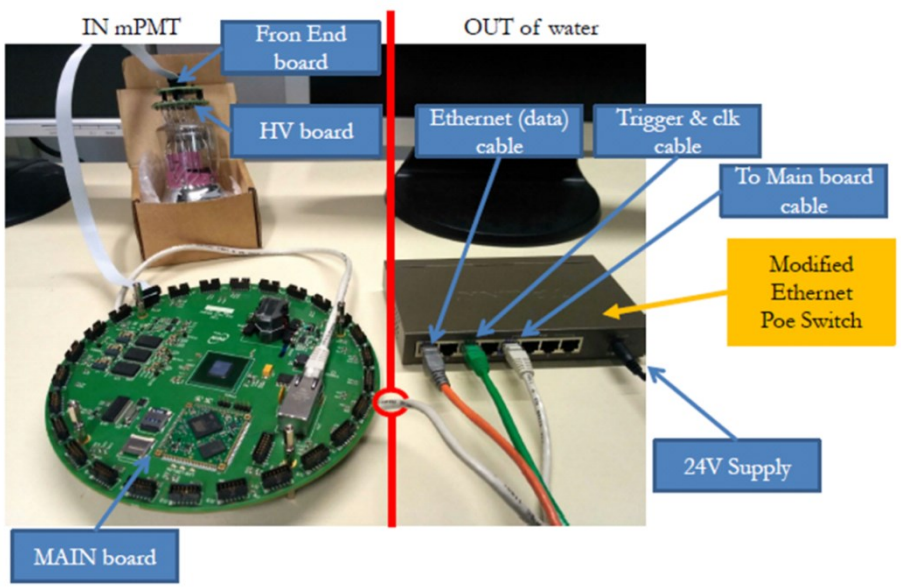
Electronics Design for mPMTs

Currently working on two different designs for the mPMT digitization

Design A:

Q/T digitization based on discrete components (INFN Naples)

Simple, low power, low cost



Design B:

FADC digitization, with on-board signal processing (TRIUMF, WUT)

Fully active during spill.

Noise suppression in FPGA.

Can export raw ADC information.

Trade off between bandwidth and power consumption

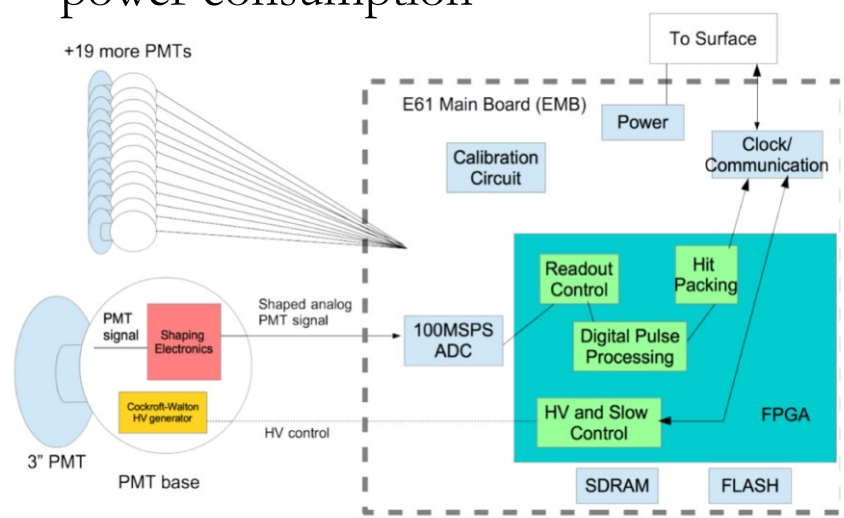
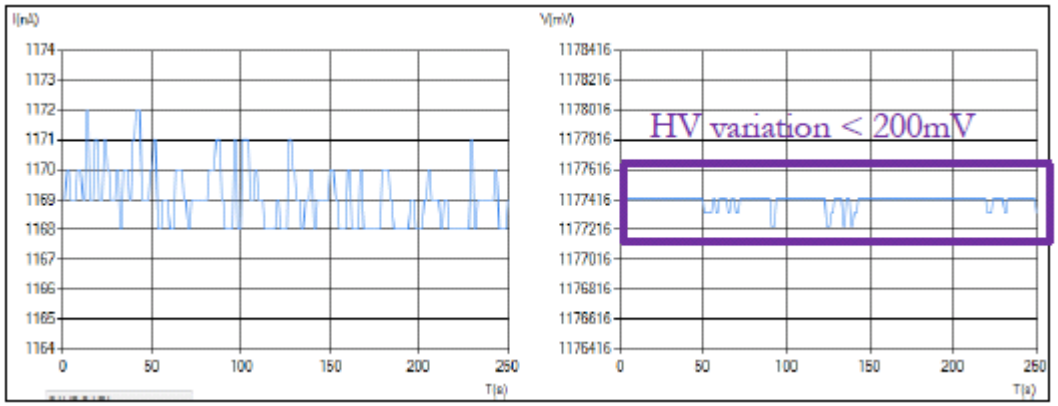


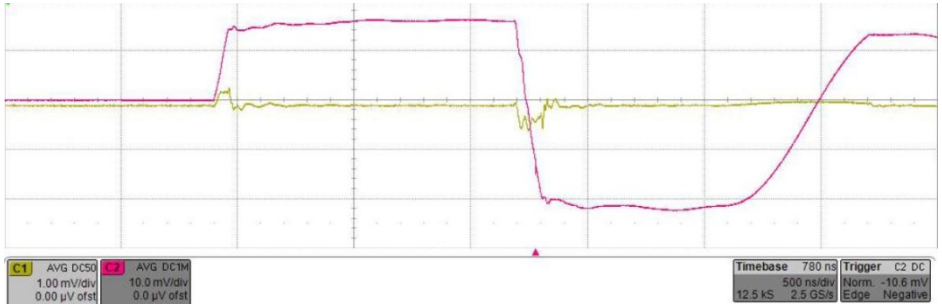
Figure 2: conceptual block diagram for the mPMT E61 Main Board (EMB).

mPMT prototype: HV

Cockcroft-Walton (CW) voltage multiplier, as in KM3Net



Voltage&current monitoring: stable HV



Switching noise 500μV(~1pC)

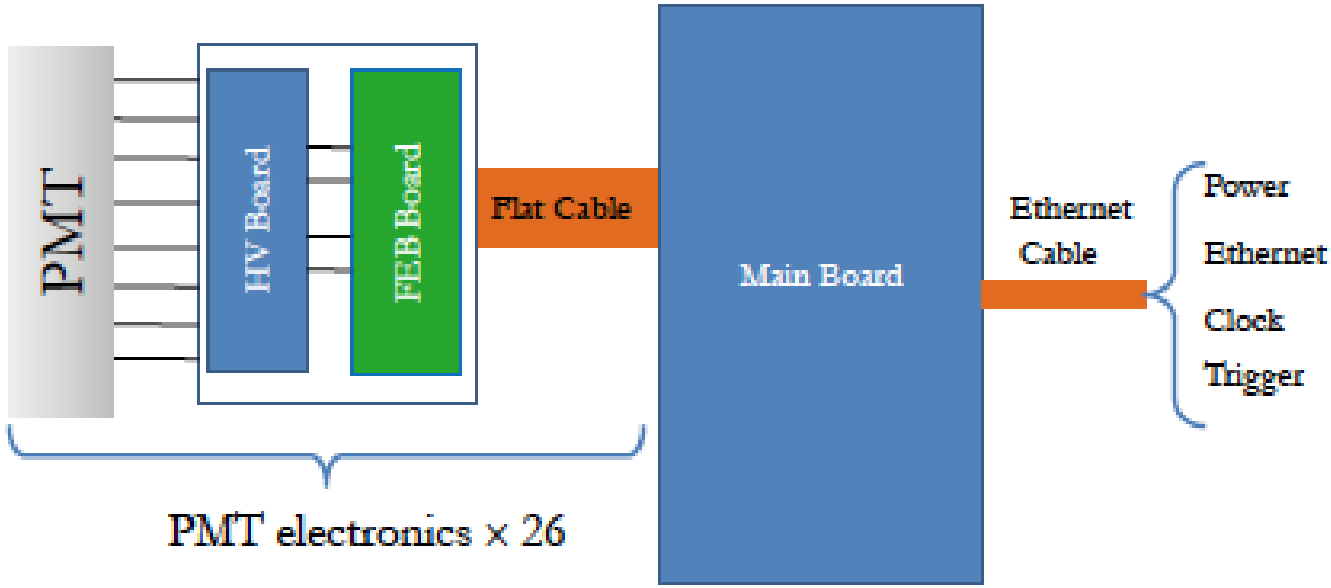
Power consumption:

-12.5 mW/ch

- ID: 19 ch → 237.5 mW

Design A: mPMT digitization

Sample&Hold
+
ADC
based on discrete components



Single channel electronic

- System integrated with the HV board
- Same MCU for both boards and only one connection

Main board

Single Board Computer-Linux:

Slow control (HV and Threshold set, I/V)

Data acquisition and transmission

Power consumption and temperature

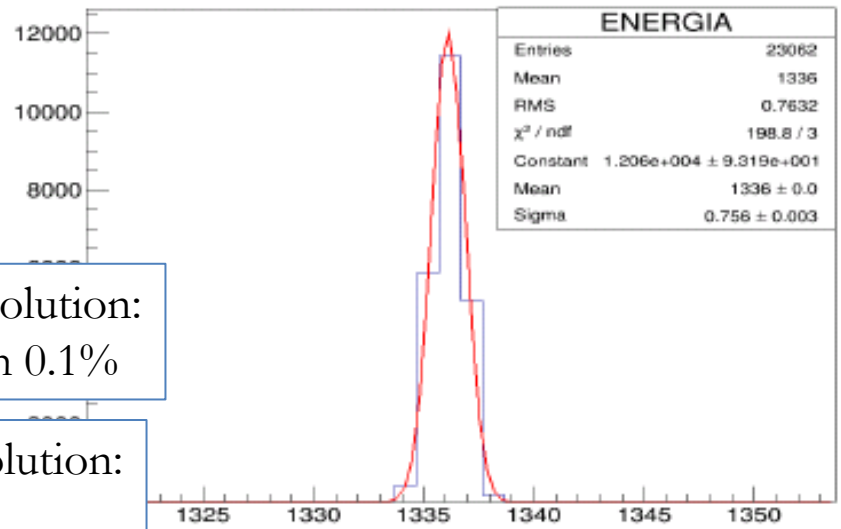
FPGA:

TDC/ADC control

Time stamp

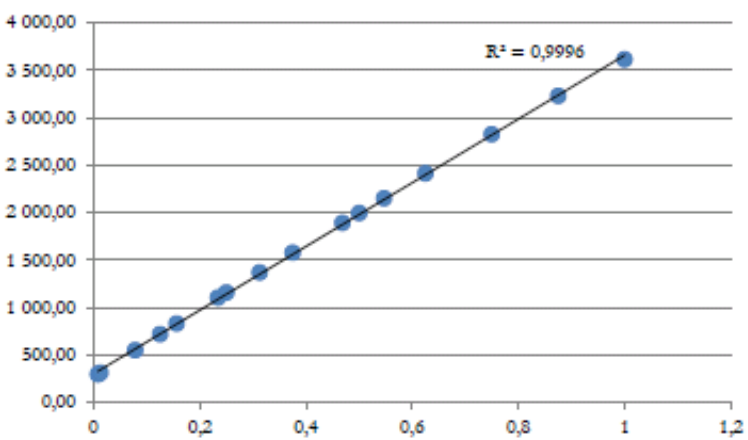
Design A: FEB

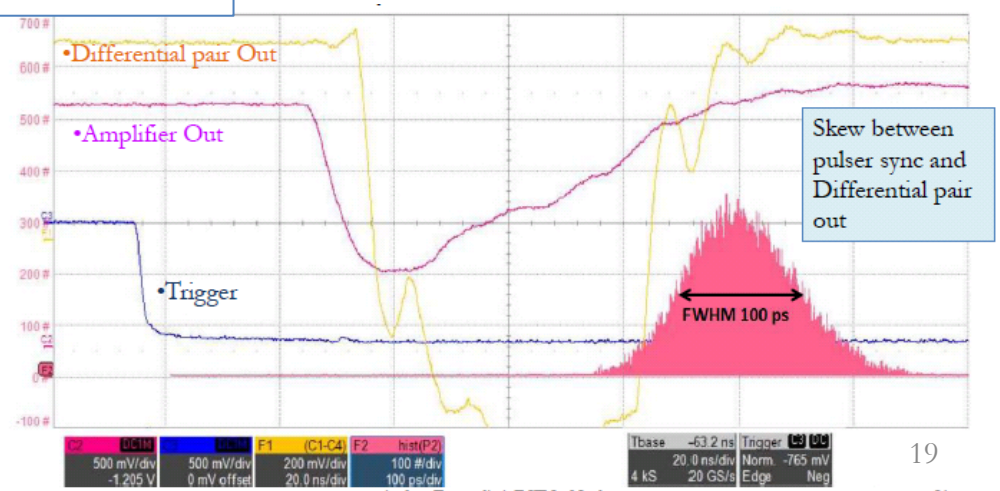
Pow DAQ circuit observed ~ 40.5 mW



Energy resolution: FWHM/ch 0.1%

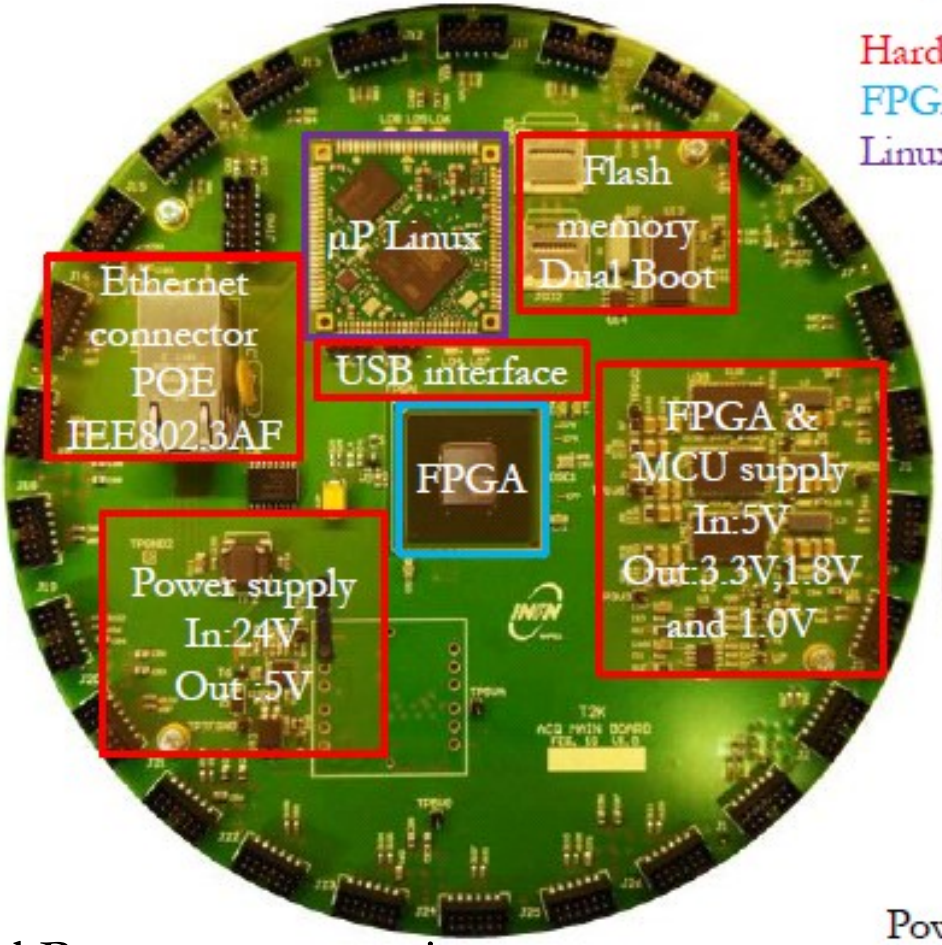
Time resolution: 100ps



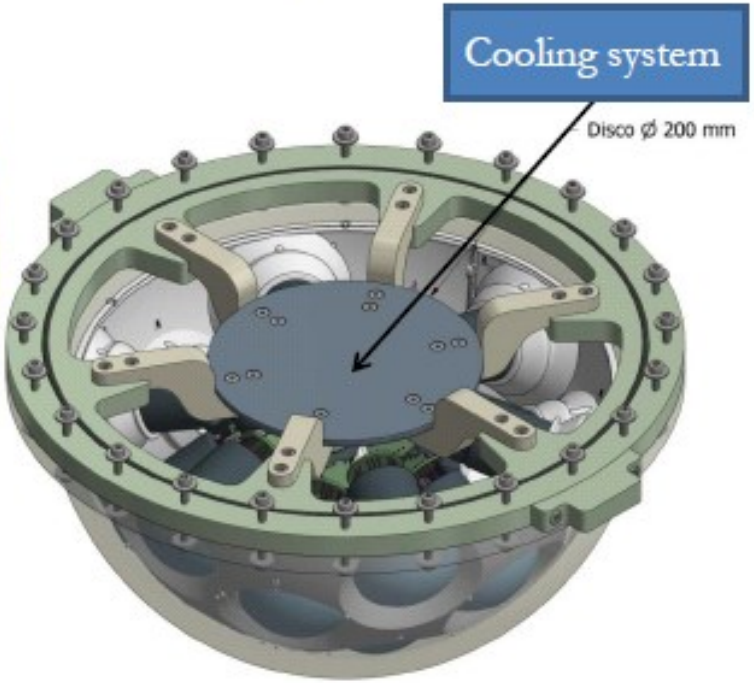


Design A: main board

Block Diagram



Hardwere & CPU linux: Fully debugged
FPGA Firmware: To debug
Linux software: To improve



Power (1 Channel + Main board) 3.2 W

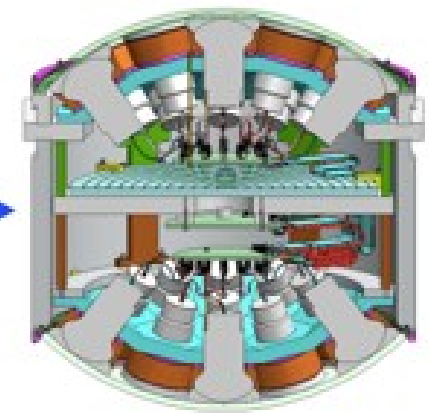
Total Power consumption:
- ID: 19 ch → ~ 4.1 W

Evolution in Hyper-K and E61 design

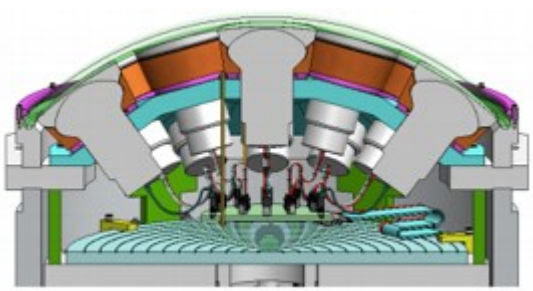
KM3Net (31 PMTs)

Spherical → Cylindical
19(ID)+7(OD)

2-Sided mPMT Design
(26 PMTs)



ID-mPMT (19 PMTs)



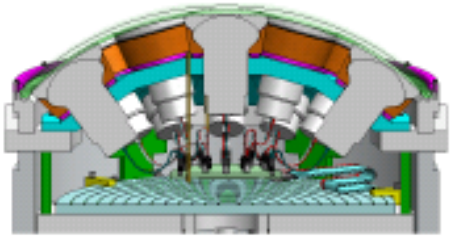
Single-sided mPMT module:

- Lighter, less dead space, simple feedthrough at back of module
- mPMT full module weight ~ 80 kg → Single-sided mPMT module weight as 20″ PMT
- only one OD photosensors system for the whole Hyper-K

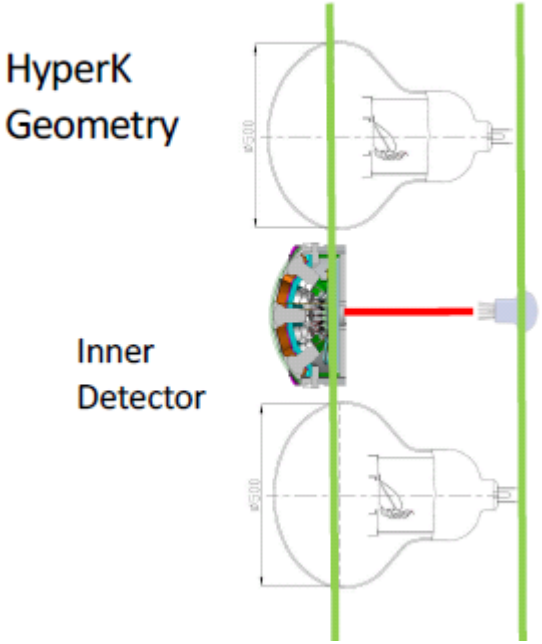
ID-mPMT

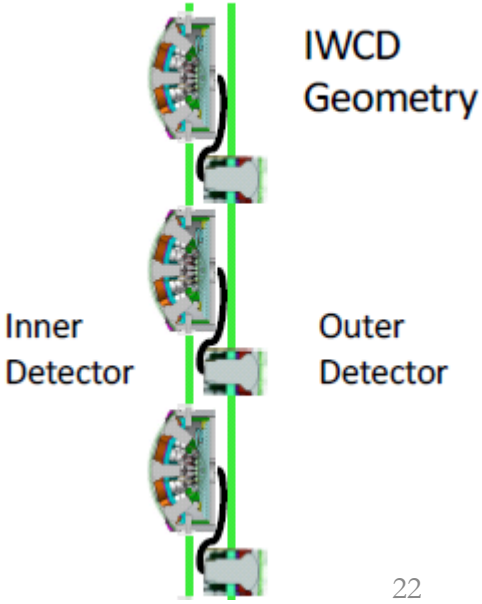
Single-sided mPMT module:

- 19 3 inch PMTs system observing the inner detector
- Lighter, less dead space
- only one OD photosensors system for the whole Hyper-K



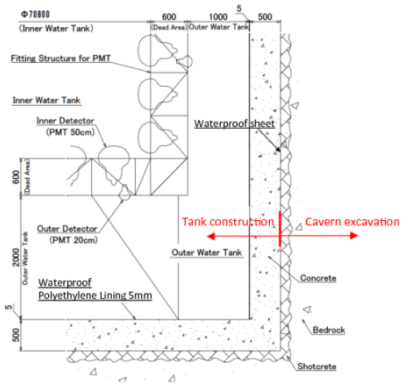
Weight: ~44kg
Volume: ~46L
Length: ~300mm



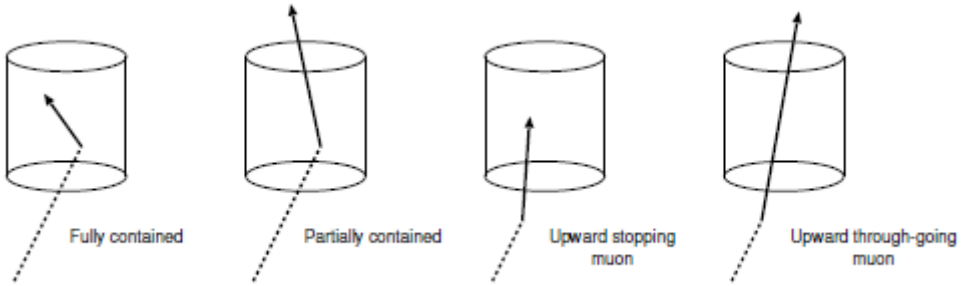


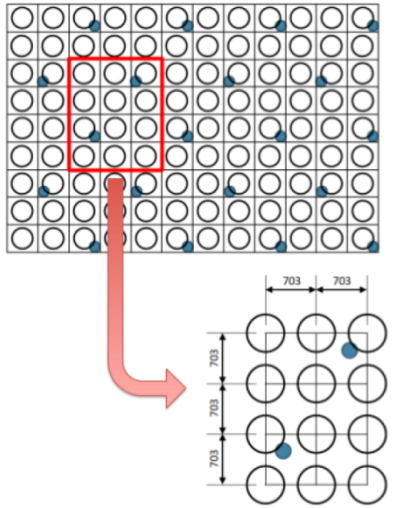
Outer-detector

- Design based on Super-K Outer-detector
  - ~ 6700 20 cms (8”) PMTs facing outward
  - → 1% coverage
  - OD Water thickness : 1m barrel / 2m top and bottom



- The outer-detector is a **veto** for background particles
  - Classify **Fully Contained** (FC), **Partially Contained** (PC), and **Upward-going** muons



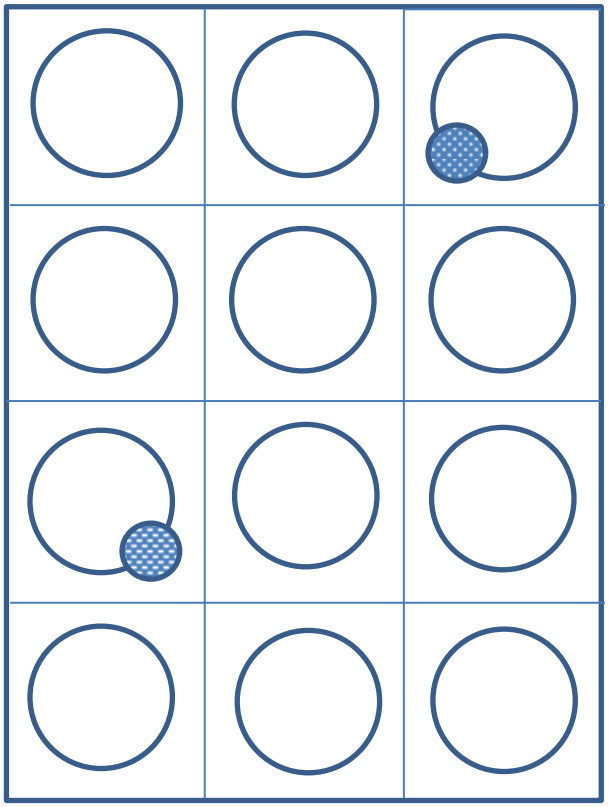


  - Shield from **gamma** particles

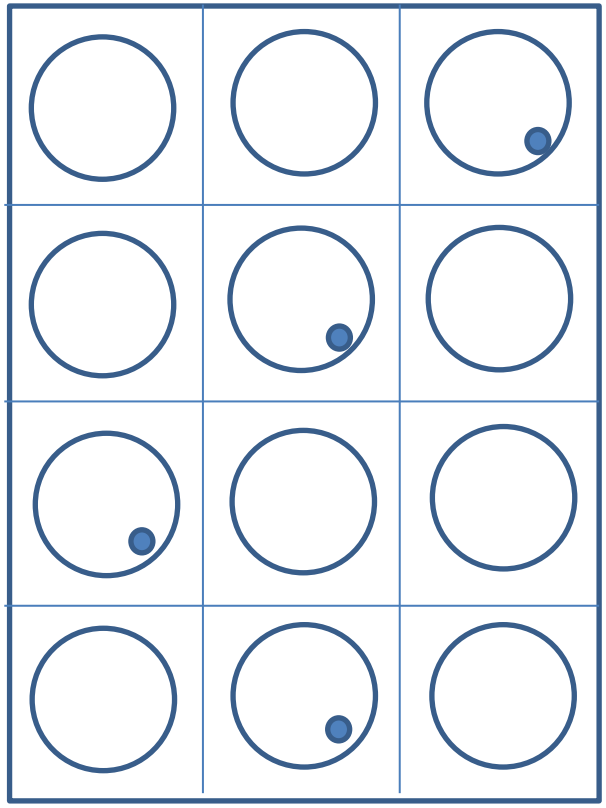
OD: Alternatives Designs

- Alternative design with 10k 3” PMTs

1% OD coverage with 2x8” PMTs in 3x4 cells



0.28% OD coverage with 4x3” PMTs in 3x4 cells

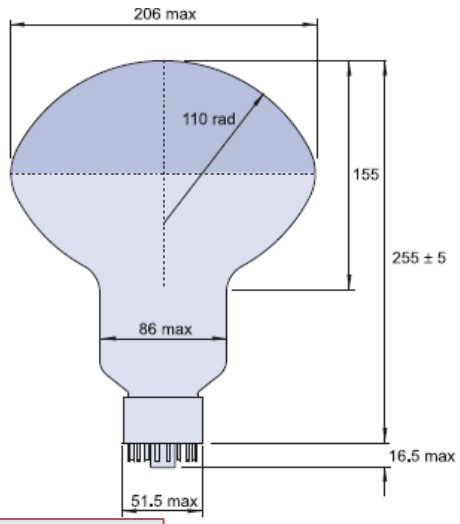


Smaller tubes give better redundancy, spatial and angular resolution

Candidates PMTs

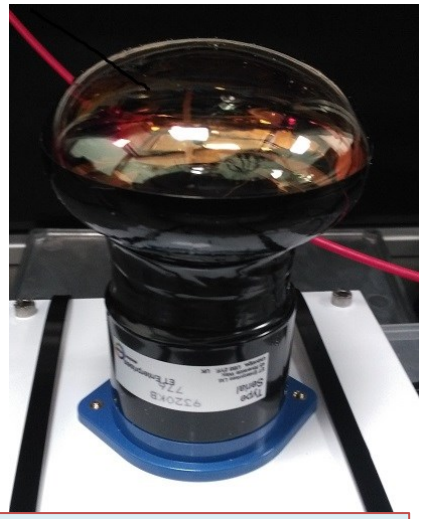
8” Hamamatsu
R5912

8” ETEnterprise
9354KB



+ WLS plates

3” ETEnterprise
9302KFLB



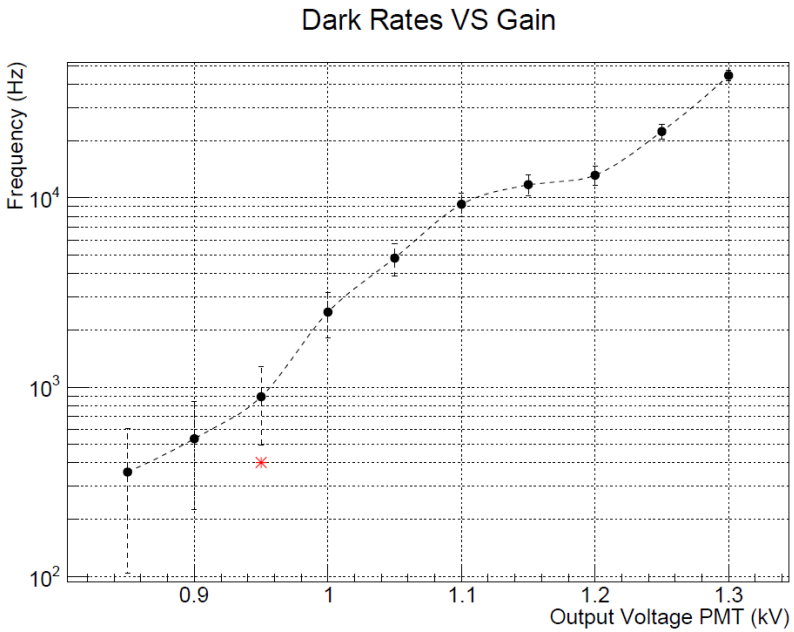
+ WLS plates

+ Cost saving
+ Deadzone

- 2 more PMTs from Hamamatsu incoming :
  - 3.5" R14689
  - 3” R14374

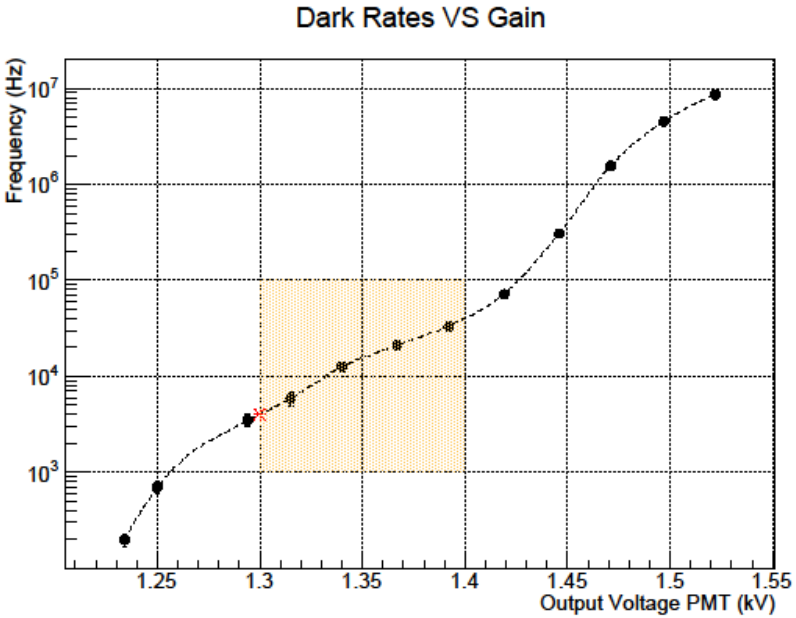
Dark rates comparison

3” ETEL 9302KFLB



- Datasheet @20deg :
  - **400 Hz** at 950V

8” ETEL 9354KB



- Datasheet @20deg :
  - **4000 Hz** at 1300V

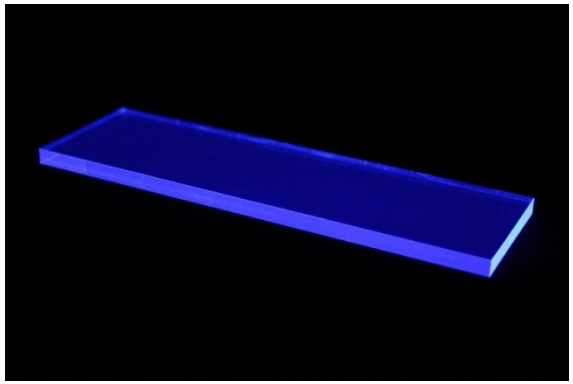
Dark rates don’t scale to photocoverage !

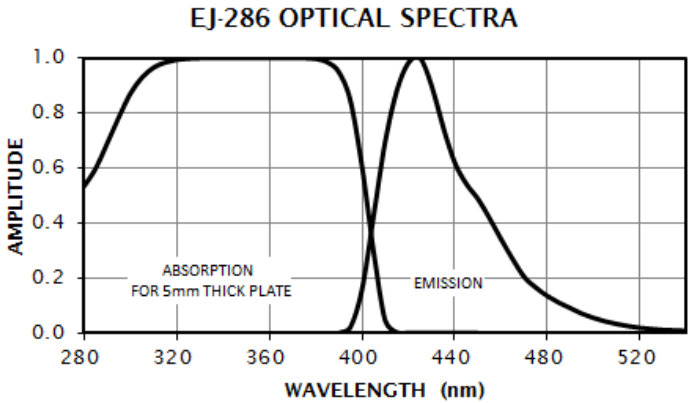
More data will be taken with more statistics

Photons traps

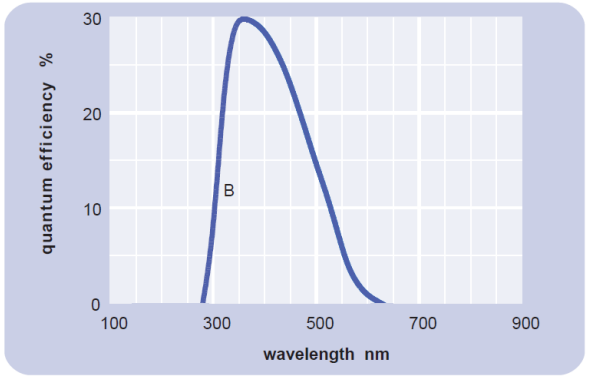
- WLS plates are made of plastic, with $n_{WLS} = 1.58$
- They are at the interface with water, $n_{water} = 1.33$
  - When photon exit the plastic they bend **towards** it !

Candidates WLS Plates: Eljen EJ-286

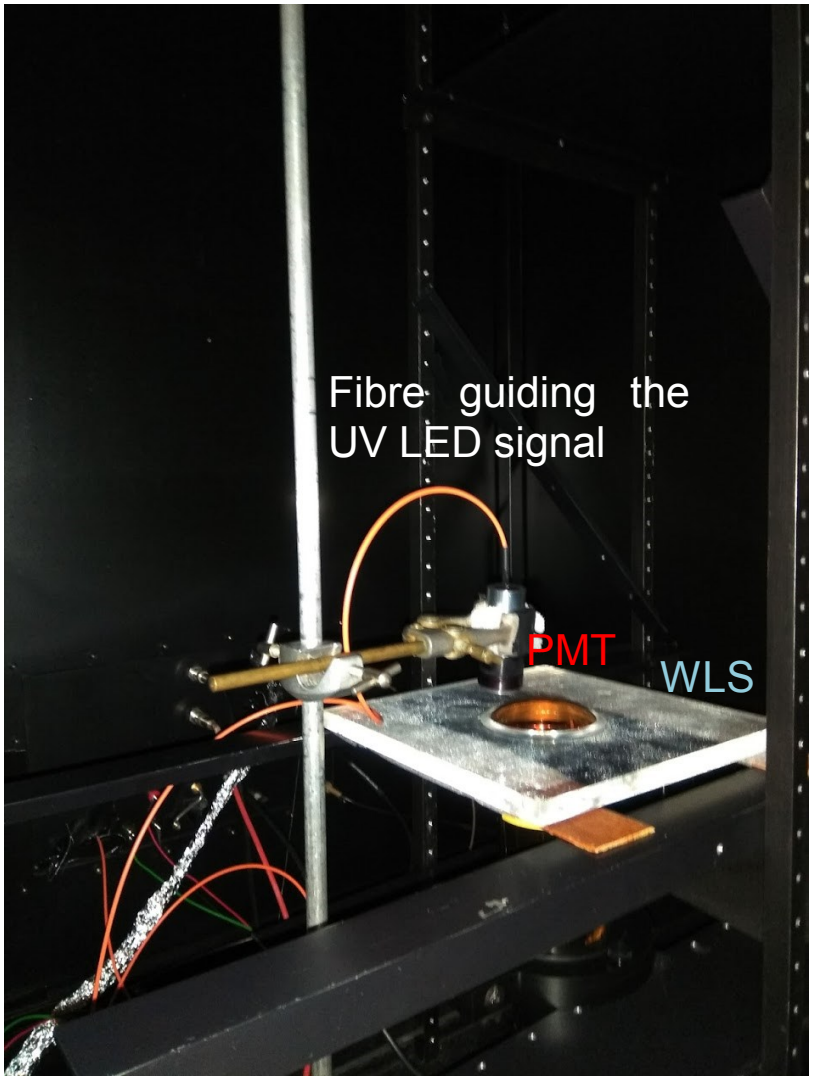




- Max absorption in UV (Cerenkov photons)
- Max emission at **420 nm**
- Material **defines** critical angle



Test Setup



- 3“ PMT (9320KFLB) and Wavelength Shifter Plate (WLS – EJ286)
- UV LED @ 375 nm
- Neutral Density filter @ 2.0
- A pulser provides signal to the UV LED with rate: ~ 10 kHz
- A fibre is used to guide the LED signal to the PMT.
- <u>Plan</u>: Take data in different points of the WLS plate to estimate the efficiency

Simulation studies

- Study photocollection for 3” and 8” PMTs :
  - Muons particle gun coming towards the side of HK
    - “sand muons”
  - Cosmic muons generator
    - Muons selected in a 10m sphere around centre of tank
    - Energy and momenta are randomly generated accorded to Super-K flux extrapolated at Hyper-K
    - Vertex generated outside Hyper-K

Mean PE collected per event

OD Design	13.3k **3”**	15k **3”**	20k **3”**	6.8k **8”**
Cosmics	238	314	414	**1254**
Sand Muons	46	69	118	**203**
Thru-going	14	25	44	**51**

Every 3” configurations collects enough light to detect events

Conclusions

mPMTs offer several benefits compared to large area PMTs

- Directionality, Improved granularity and timing resolution, lower dark noise, less magnetic field sensitivity, pressure tolerance

Reconstruction studies show improvement with respect to large area PMTs for the E61 and Hyper-K detectors

- Optimisation of the design for physics underway
- Studying impact of 5000 mPMTs on Hyper-K physics

R&D plan:

- Construction and test of the mPMT module prototype
- Further tests on materials to be used
- Optimization of the PMT read-out system

Hyper-K OD:

– compare 3" and 8" configurations to define the future OD

Thank you!

Milestones in JENNIFER2

Main limits of KM3NeT solution for HK project:

- Vessel:
  Glass spheres as used in KM3Net are characterized by high ^{40}K and other radioactive contamination

  → Comparative studies on commercial acrylics:
  - Optical propertied
  - Radioactive contamination
  - Mechanical tests
  - Pressure tests

- PMT Read-Out and HV:
  Time over threshold (ToT) strategy is exploited in KM3Net; in HK charge measurement is important

  → HV: Cockcroft-Walton (CW) voltage multiplier
  PMT Read-out: Sample&Hold+ADC based on discrete components

Construction and test of the mPMT module prototype