Hyper-Kamiokande

A multi-PMT photodetector system for the Hyper-Kamiokande experiment

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on behalf of the

Hyper-Kamiokande Proto-Collaboration

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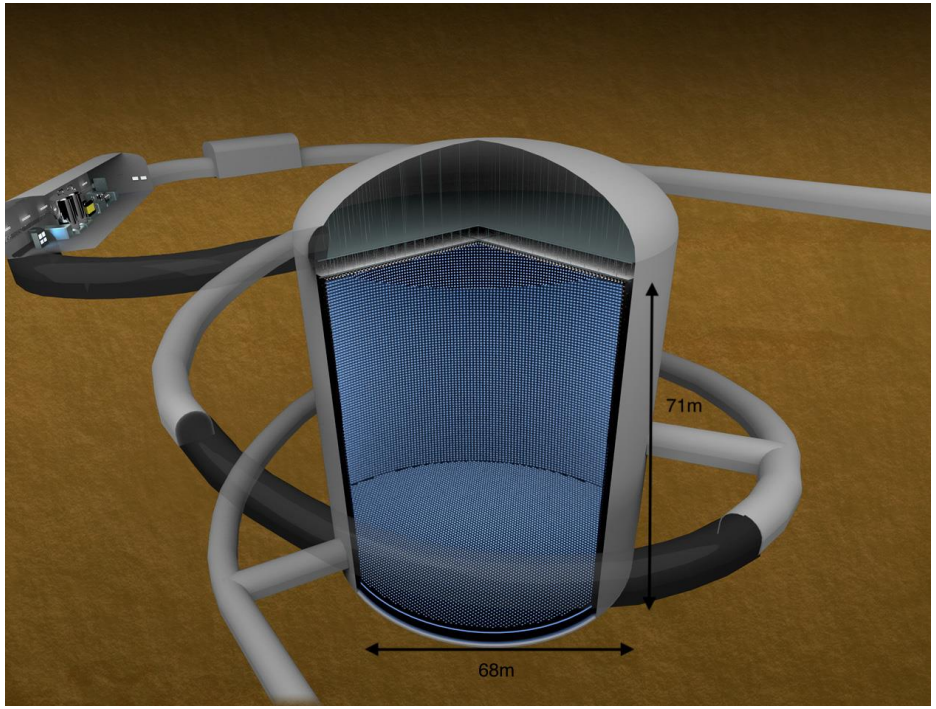
INFN Napoli

ICHEP 2020, July 31, 2020

Hyper-Kamiokande: overview

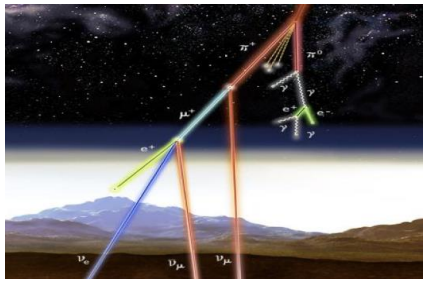


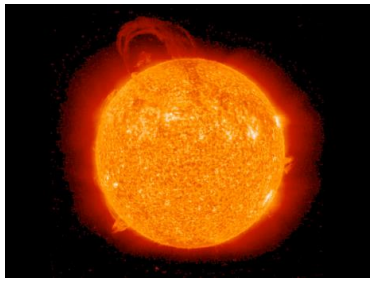
Hyper-Kamiokande (HyperK) is a multi-purpose **Water-Cherenkov detector** with a variety of scientific goals:

- ✧ Neutrino oscillations (atmospheric, accelerator and solar);
- ✧ Neutrino astrophysics;
- ✧ Proton decay;
- ✧ Non-standard physics.

See talks by:
M. Scott, Wed 29 July,
T. Yano, Thu 30 July

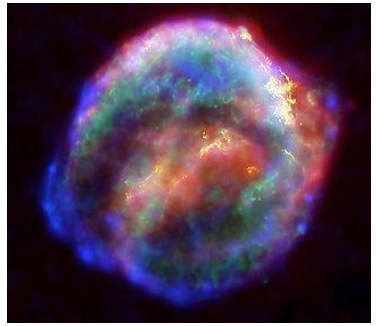
Atmospheric ν



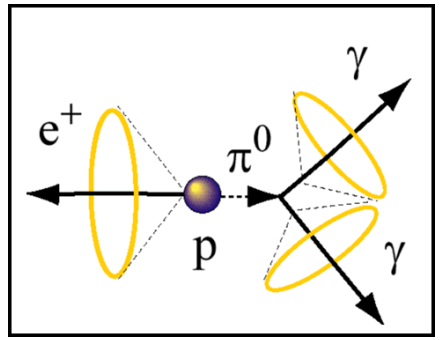


Solar ν

Supernova ν

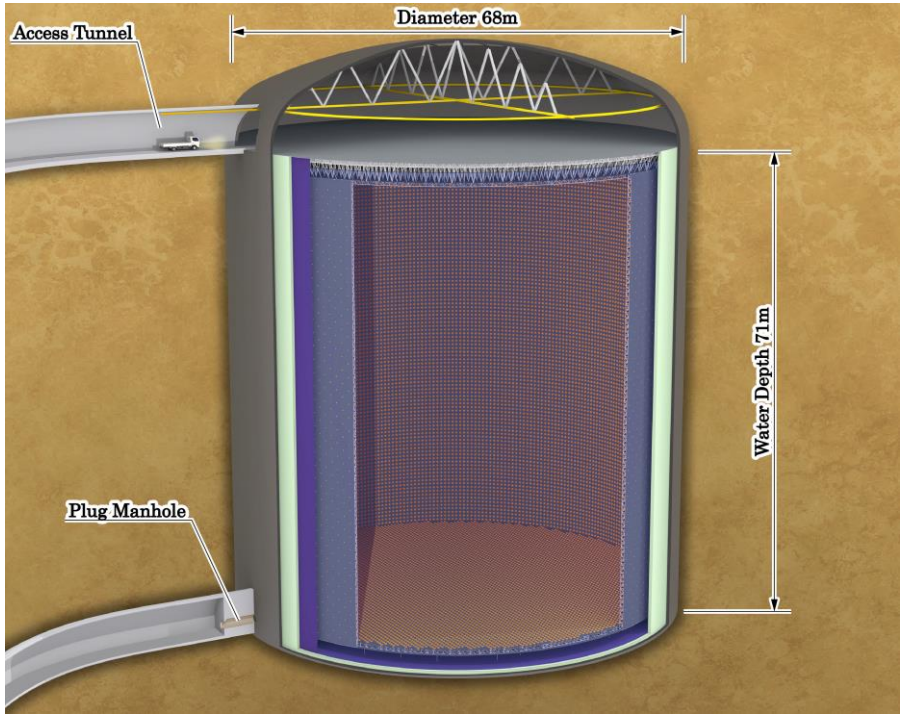


Accelerator ν



Proton decay

Hyper-Kamiokande design



HyperK builds on the successful strategies used to study neutrino oscillations in Super-Kamiokande, K2K and T2K with:

- Larger detector for increased statistics
- Improved photo-sensors for better efficiency
- Higher intensity beam and updated/new near detector for accelerator neutrino part

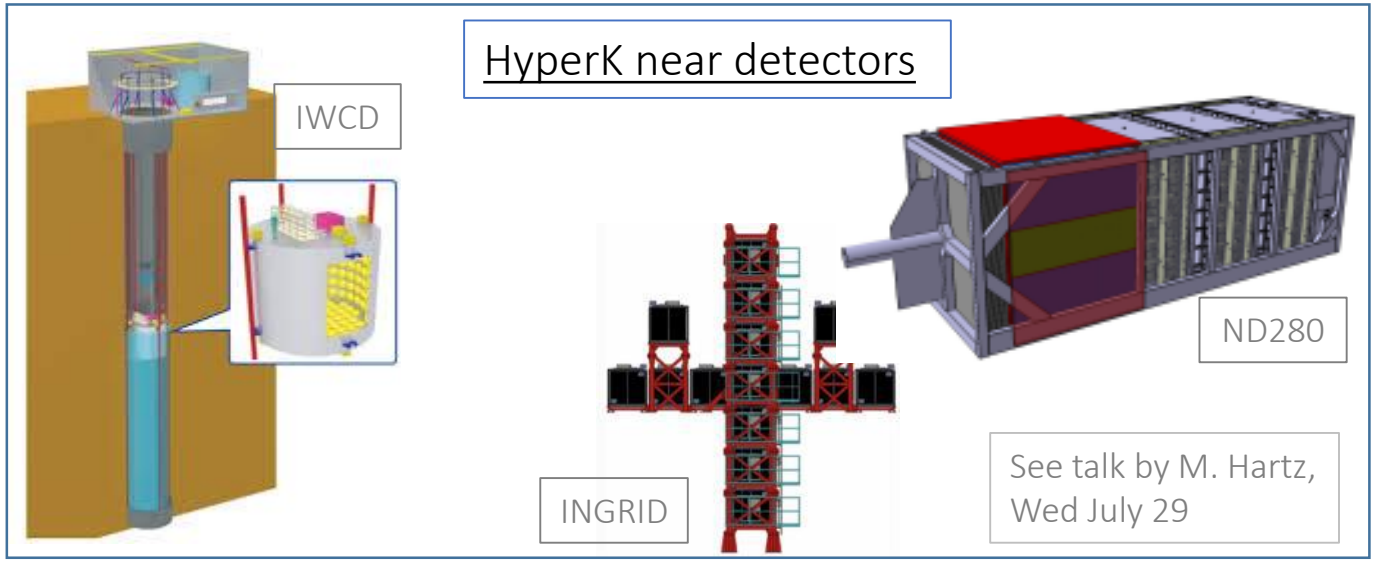
HyperK is under construction
Operation will begin in 2027

HyperK Far Detector (HK-FD)

- Cylindrical tank: Φ 68 m and H 71 m
- Fiducial volume: 0.19Mtons;
  ~ ×8 SK → HK-FD

Intermediate Water Cherenkov Detector (IWCD)

- 1 kilo-ton scale water Cherenkov detector located ~1 km from the neutrino beam source



Photodetectors

Requirements

Wide dynamic range

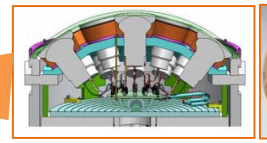
High time&charge resolutions, high detection efficiency, ..

~nsec time resolution

low background

Clear photon counting,

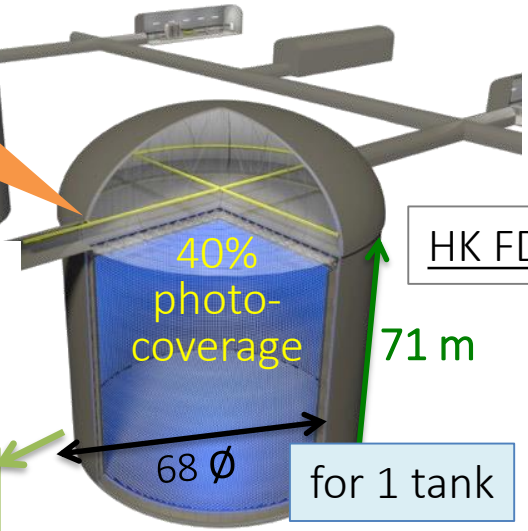
High rate tolerance



multi-PMT

Outer Veto Detector

See talk by S. Zsoldos, Fri July 31



HK FD

for 1 tank

Fiducial volume: 188 kt

New high-QE 20'' Box&Line PMT

×2 high pressure bearing

×2 high detection efficiency and half time&charge resolutions

compared to Super-K PMT (up to ~40m depth)

See talk by T. Tashiro, Fri July 31

MCP-PMT

Originally developed for JUNO

Multi-PMT

Firstly proposed by KM3Net Collaboration

Photodetectors and electronics arranged inside a pressure resistent vessel

Increased granularity

enhanced event reconstruction, in particular for multi-ring events

HK FD

Baseline Design: 20'' PMTs

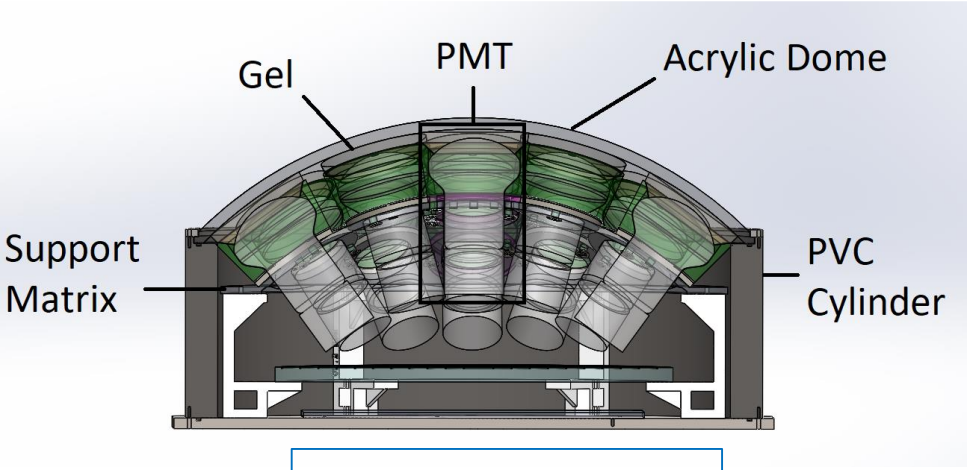
Hybrid Design:

20'' PMTs and mPMTs

IWCD

mPMTs

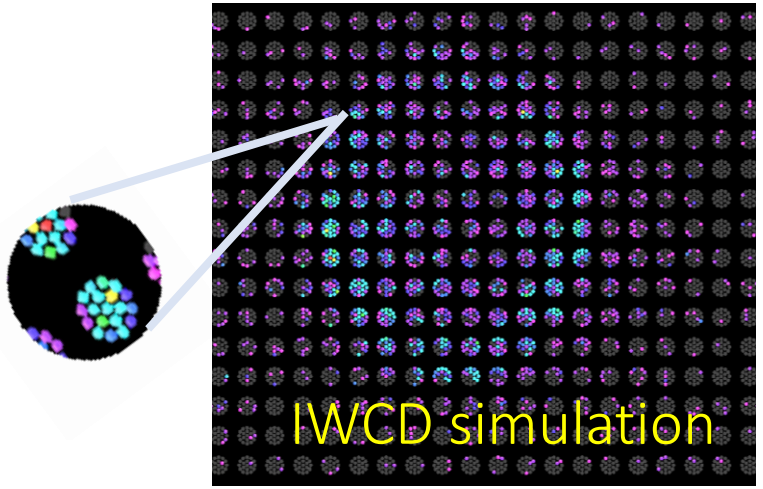
The mPMT Option



ID-mPMT (19 PMTs)

Advantages:

- Superior photon counting
- Improved angular acceptance
- Extension of dynamic range
- Intrinsic directional sensitivity
- Local coincidences

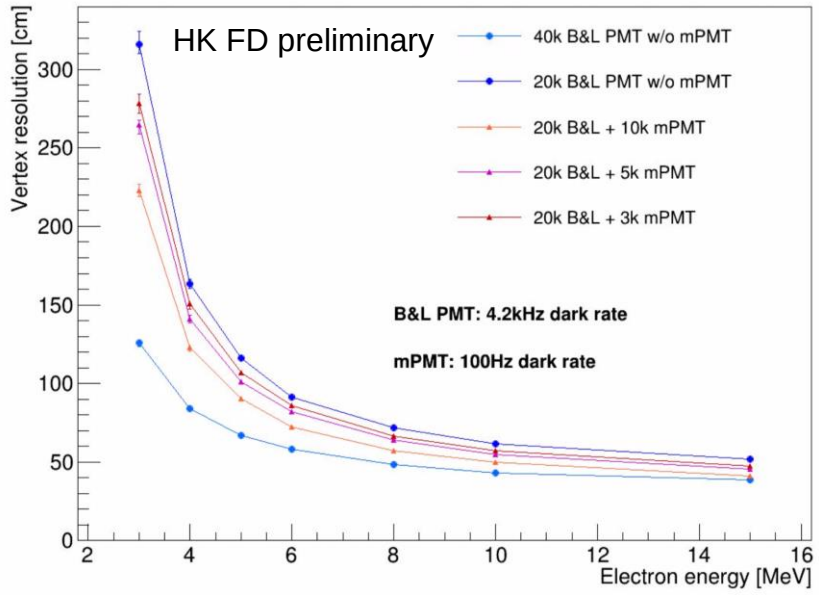


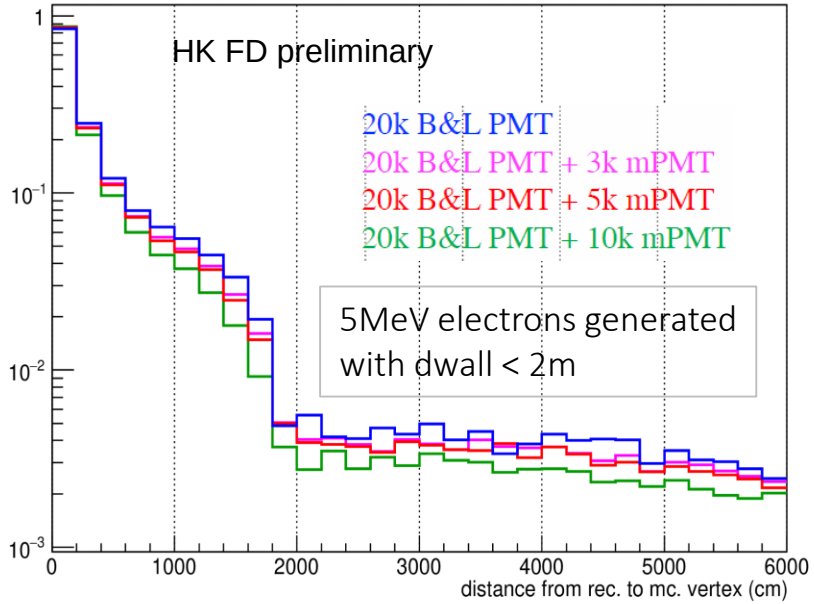
See talk by N. Prouse, Wed July 29

HK FD Simulation studies

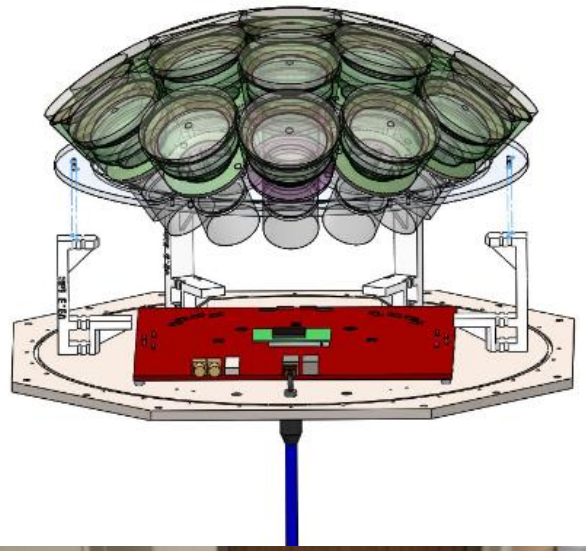
Preliminary results:

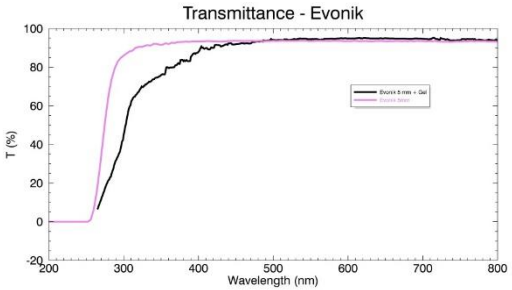
- Vertex and angular resolution better for low energy
- At high energy: muon/electron separation improved near the wall; vertex resolution improved
- Improvements strongest near edges of FV

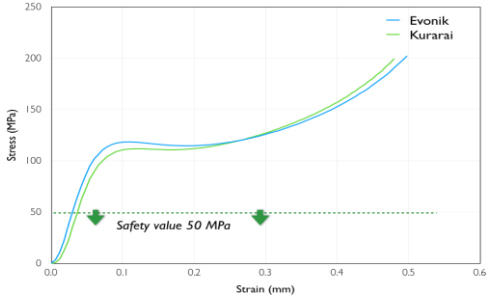




mPMT R&D for HyperK







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

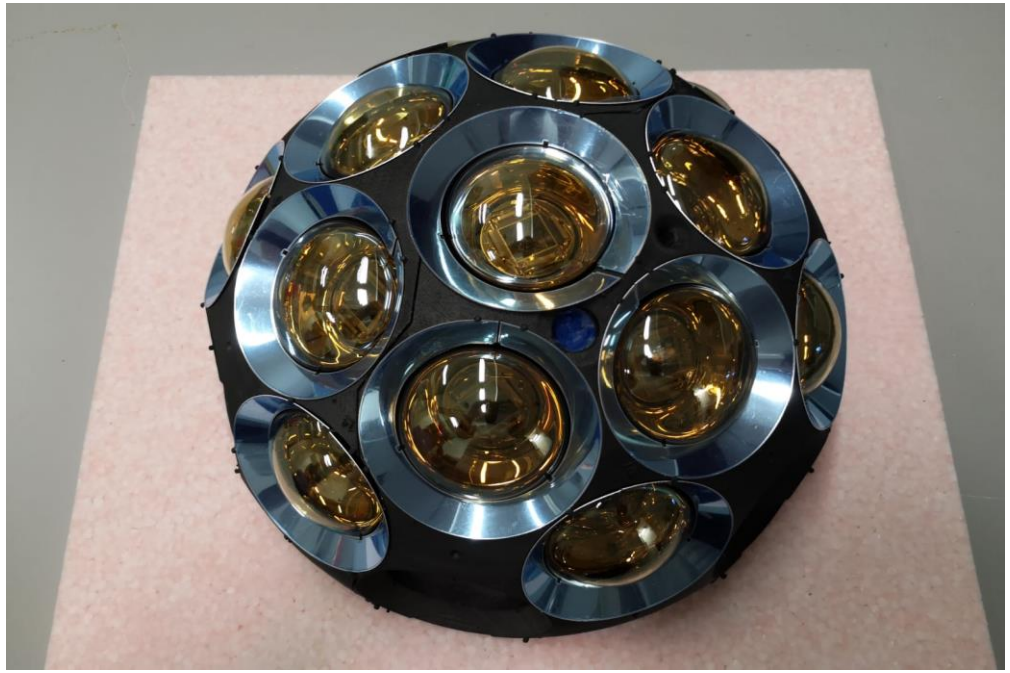
Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	$(3 \pm 1)\cdot 10^{-1}$ ppb
K-40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

mPMT prototypes for HyperK



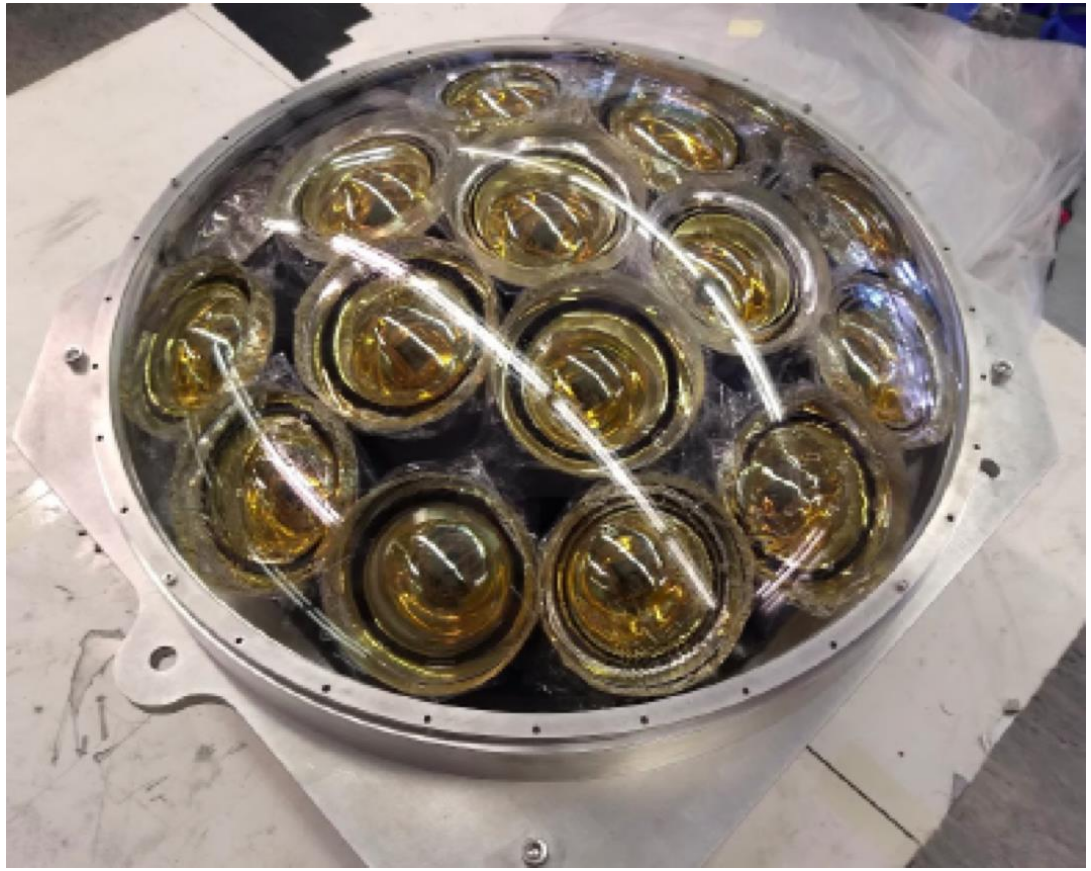
mPMT Electronics prototype @INFN
- test the HV and PMTs read-out

Tests at Memphyno ongoing

mPMT Optical Prototype@TRIUMF
- test assembly procedure and optical properties

Tests ongoing

mPMT pressure prototype
- **@INFN** Acrylic vessel resisted to 1.8 MPa
- **@TRIUMF** Metal plate welded to cylinder:test to 0.7MPa (70m water depth) with no problem.



3’’ PMTs

Hamamatsu Photonics K.K., ET Enterprises Ltd., MELZ FEU Ltd. and HZC Photonics Ltd. developed similar 3" PMTs

Most efforts have focused on the Hamamatsu R14374 and the HZC XP82B20

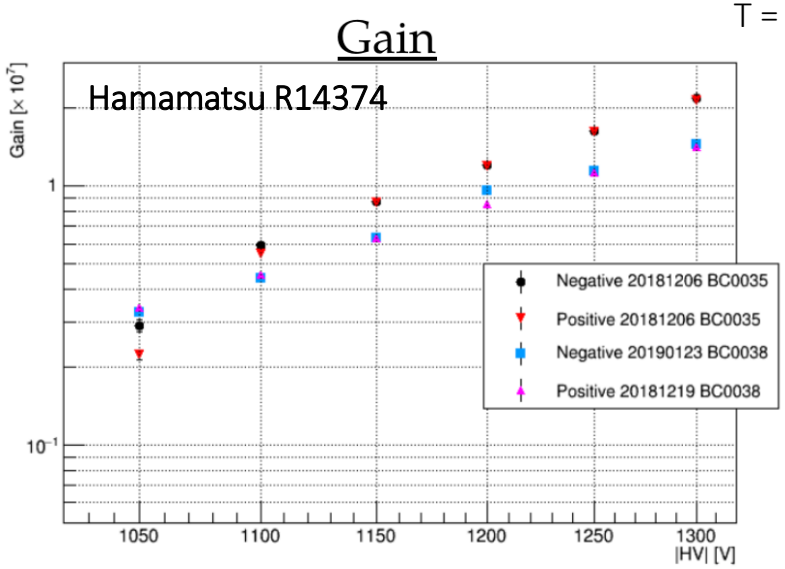
Hamamatsu R14374

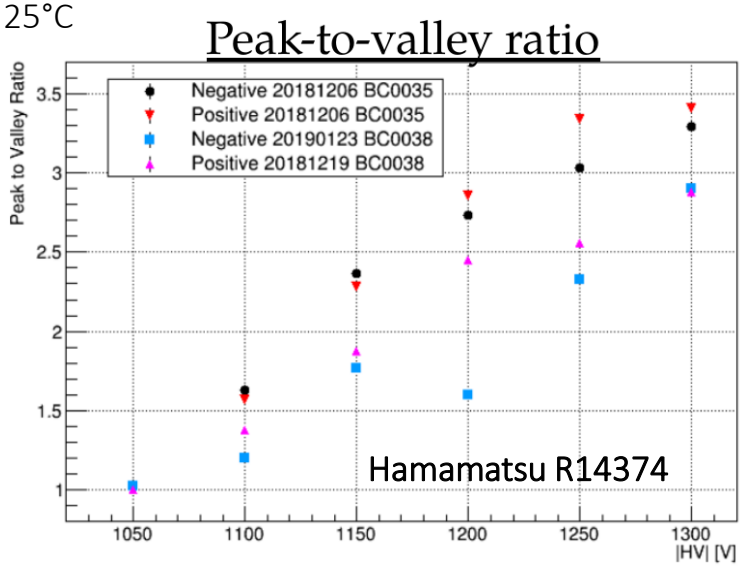
HZC XP82B20

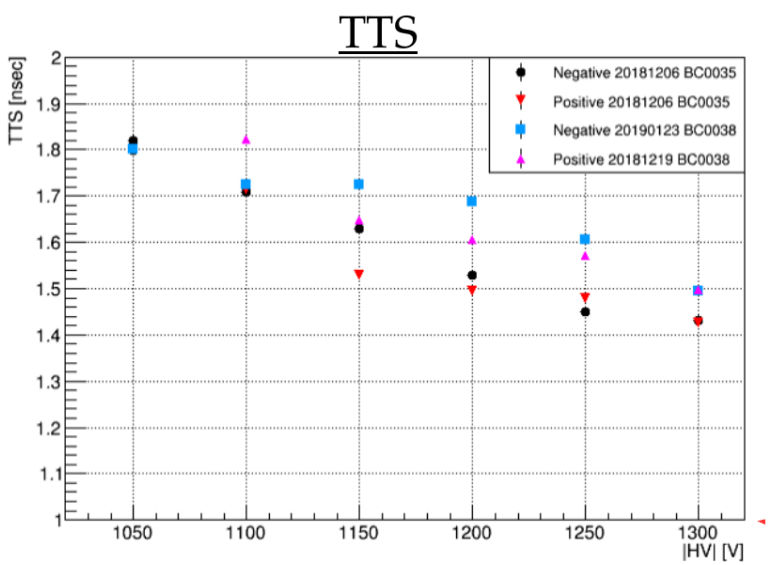
Manufacturer	PMT	HV	Gain ($\times 10^6$)	Q resolution	TTS
Hamamatsu	R14374: BC0032	-1159V	5.19 ± 0.07	0.36	1.34 ns
	R14374: BC0036	$+1113$V	5.12 ± 0.04	0.37	1.52 ns
HZC	XP82B20: 80148	-1324V	4.88 ± 0.04	0.33	3.62 ns
	XP82B20: 80149	$+1229$V	5.16 ± 0.05	0.35	3.75 ns

Charge resolutions of the Hamamatsu and HZC 3" PMTs are similar, but the timing resolution offered by Hamamatsu PMT is currently significantly better than HZC PMT

T = 25°C

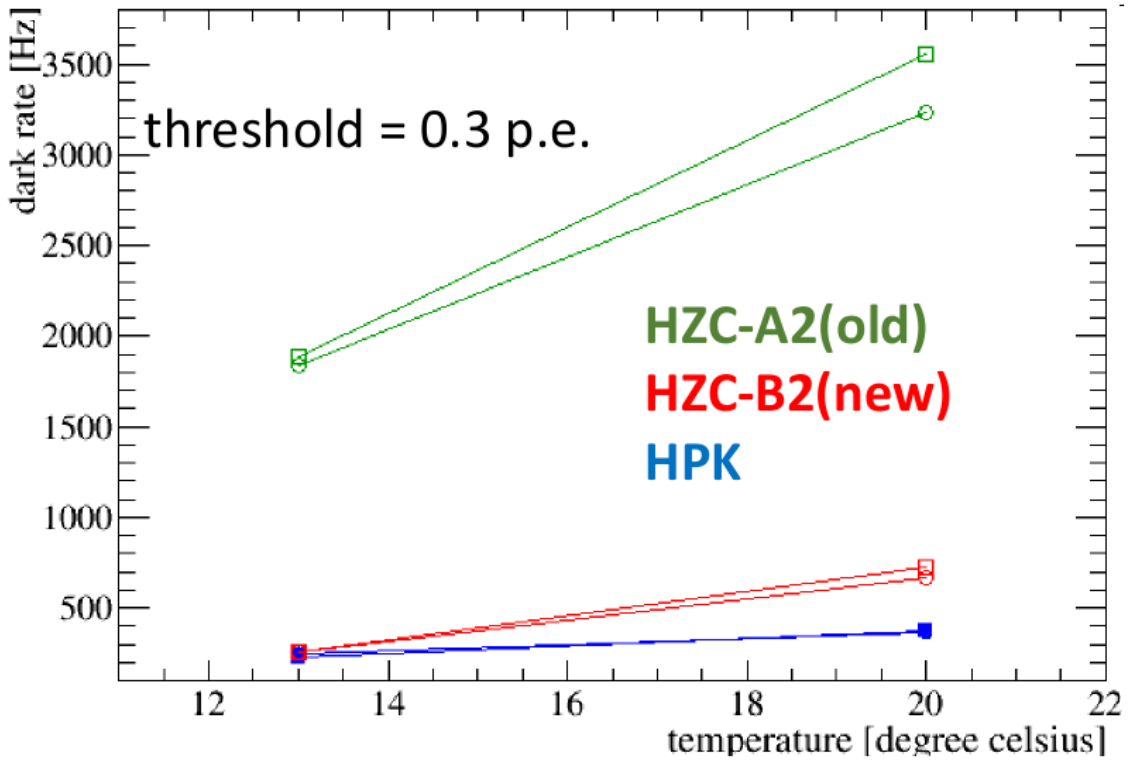






TTS measurements at the centre of the photocathode

3’’ PMTs dark count rate



Hamamatsu R14374 3’’ PMT:
Typical dark rate about 200Hz-300Hz, ranging from 100Hz to 500Hz
HZC 3’’ PMT:
New PMTs with improved dark rate

Strategies under study to improve dark counts:

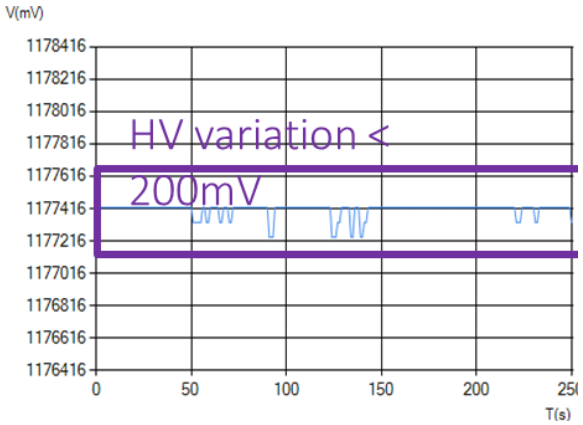
- add a dielectric material (HA-coating) to insulate the PMT surface and reduce the probability for accidental discharges
- adopt a conformal coating as in KM3NeT experiment
- reduce continuous pulses
- R&D together with manufacturers to reduce radioactive material in the PMT glass

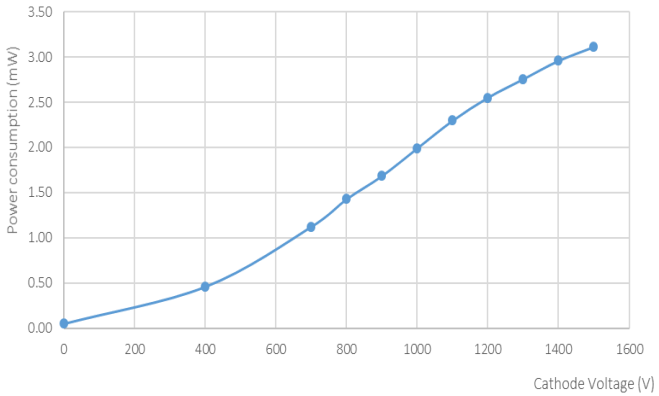
We plan to conduct a series of tests to decide on the treatment of the PMT and the preferred HV polarity

mPMT electronics: HV

Basic Cockcroft-Walton (CW) voltage multiplier circuit designed for negative and positive HV

Negative HV Board





Voltage&current monitoring:
stable HV
HV board swithching noise :
noise subtraction circuit ~0.4pC

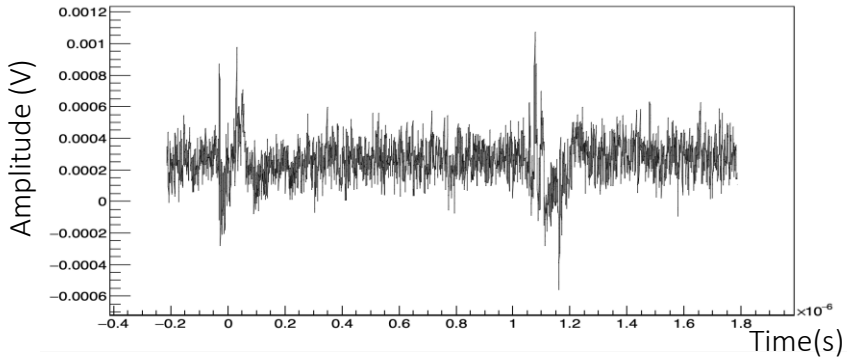
Power consumption:
- 3.1 mW/ch @1.5kV
- ID: 19 ch → 59 mW

Tested in the complete configuration of the mPMT

Positive HV Board

Same input and output control of the negative HV Board

Currently under test at INFN



differential signal of the noise induced on the output

Active base designs for negative and positive HV voltage have been realized and tested. The best solution to have a reduced dark rate will be adopted.

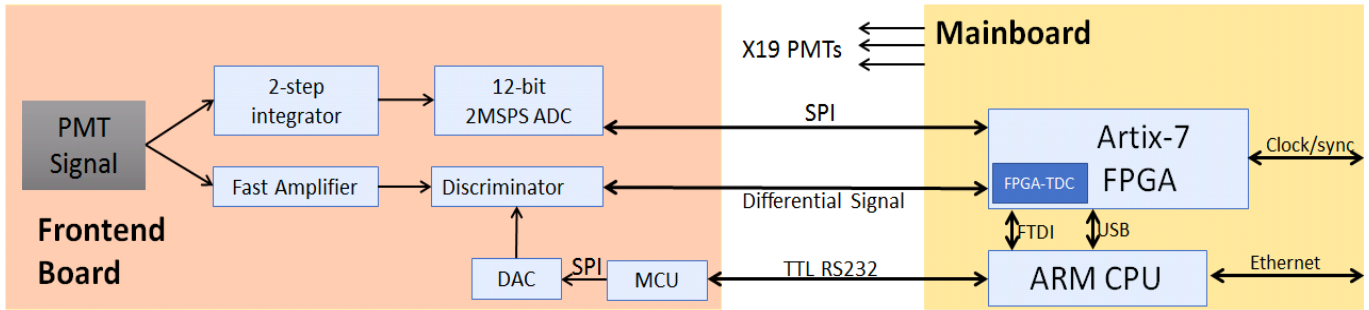
Electronics Designs for mPMTs

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 HK-FD <3-4W per mPMT
    Driven by water circulation requirements
  - For HK-IWCD ~10-20W per mPMT
- For HK-IWCD:
  Capability to distinguish between different hits in different bunches

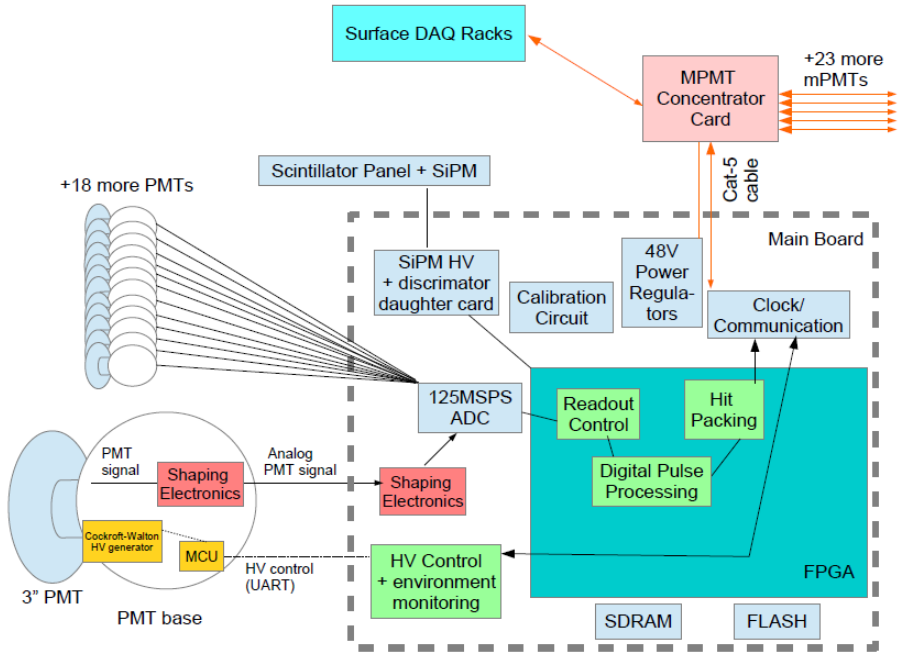
HK FAR Detector:

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

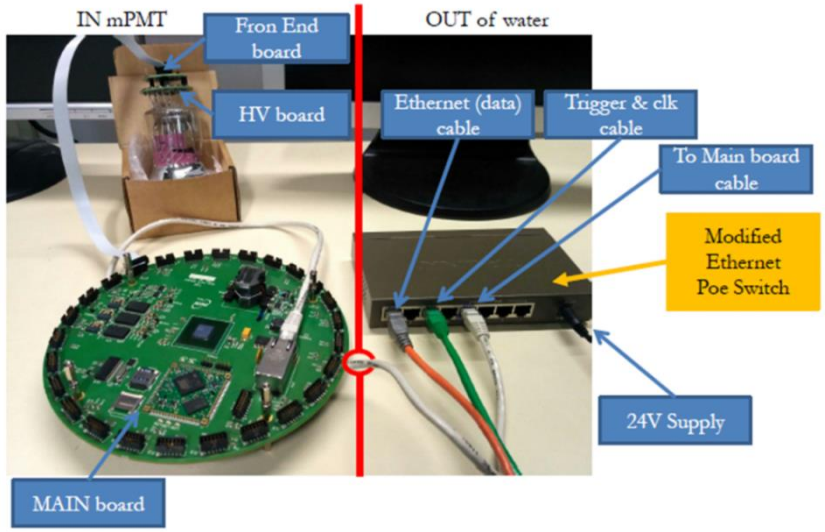


IWCD:

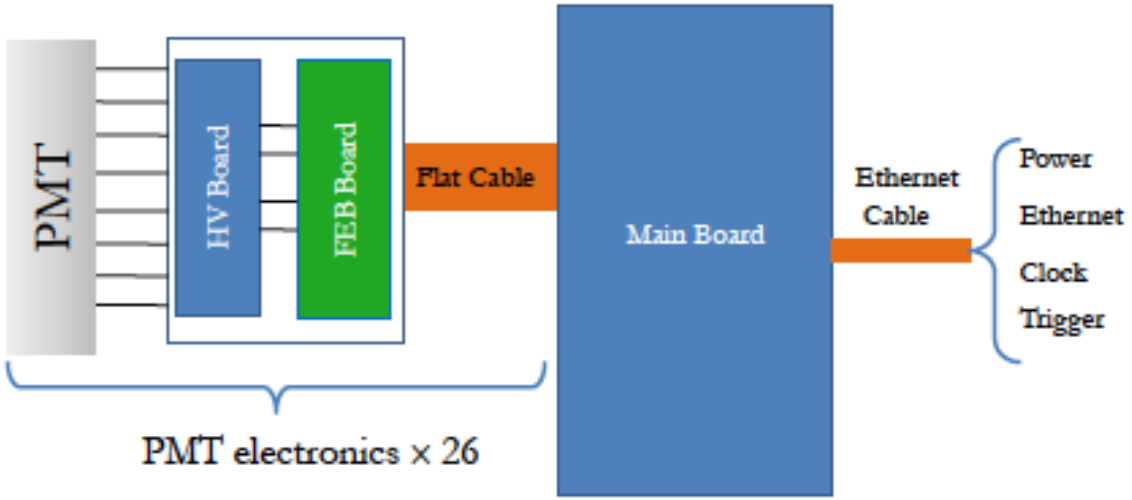
FADC digitization, with on-board signal processing (TRIUMF, WUT)



HK Far Detector: mPMT digitization



Sample&Hold
+
ADC
based on discrete components

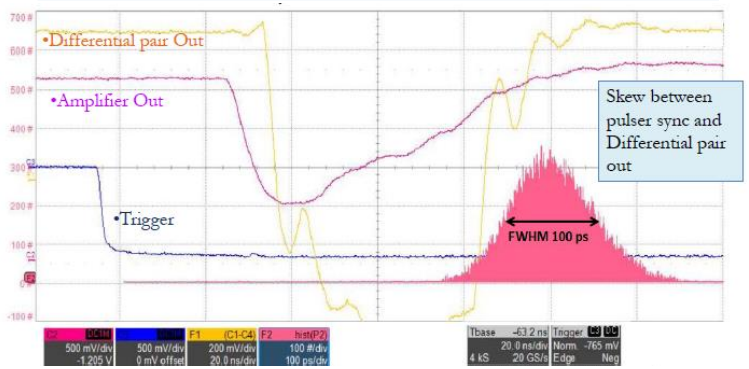


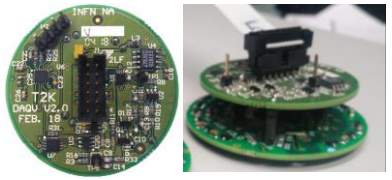
Energy resolution with pulser: FWHM/ch 0.1%

Time resolution with pulser : 100ps

TDC test: Time resolution FWHM $\Delta T(CH1\text{-}CH2)$: 297 ps

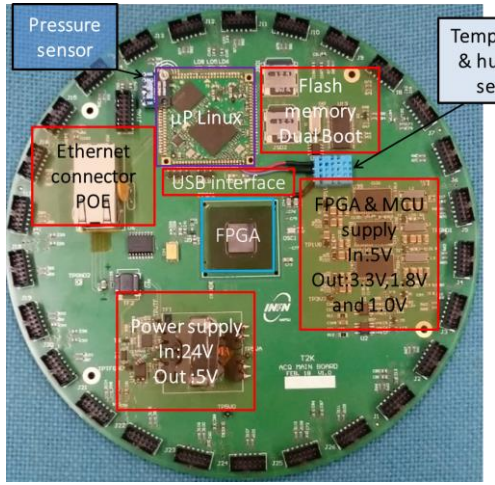
Single channel electronics





- System integrated with the HV board
- ~40.5 mW

Main board



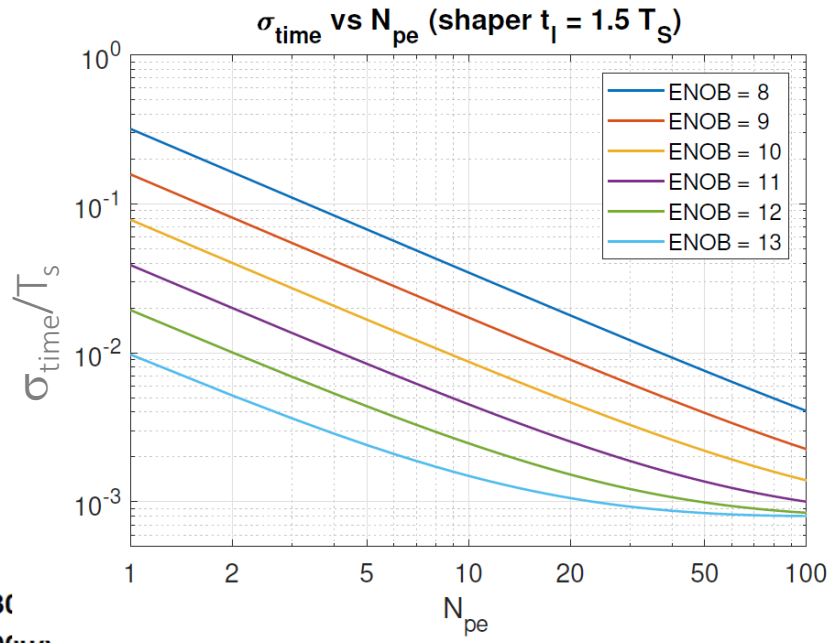
Single Board Computer-Linux:
Slow control (HV and Threshold set, I/V)
Data acquisition and transmission
FPGA:
TDC/ADC control
Time stamp

Total Power consumption: ID: 19 ch → ~ 4 W

IWCD: mPMT digitization

IWCD Electronics

FADC-based digitizers
- to preserve timing resolution and pulse separation
- No dead-time

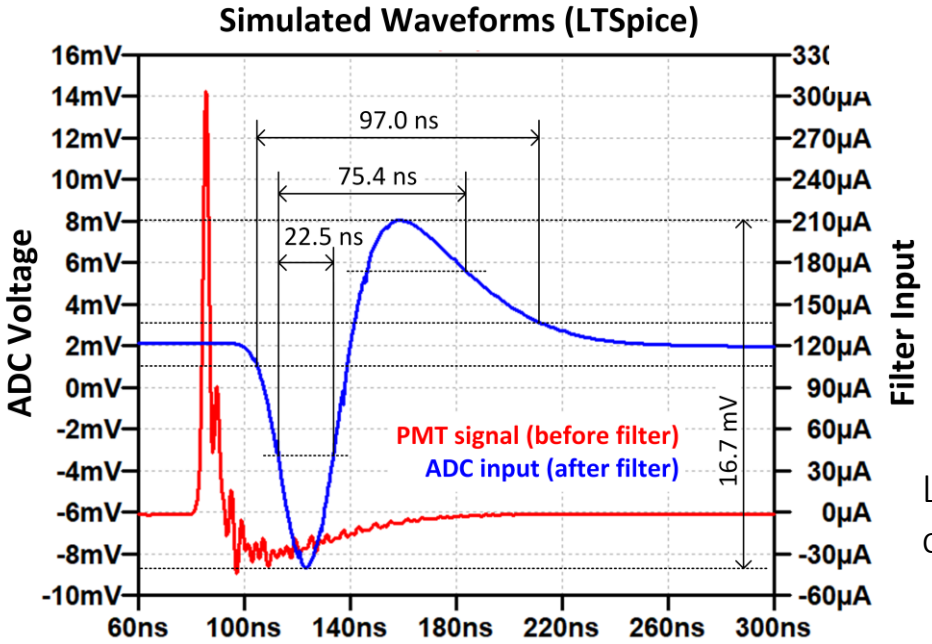


Expected timing resolution at various resolutions of the FADCs
(ENOB: ADC converter's effective number of bits)

125 MSPS system

T_S = 8 ns, resolution of 12-bits, as it offers
Reasonable power consumption of the ADC (approx. 100 mW per channel).
The chosen ADC is ADC3424 from Texas Instruments

Noise suppression in FPGA

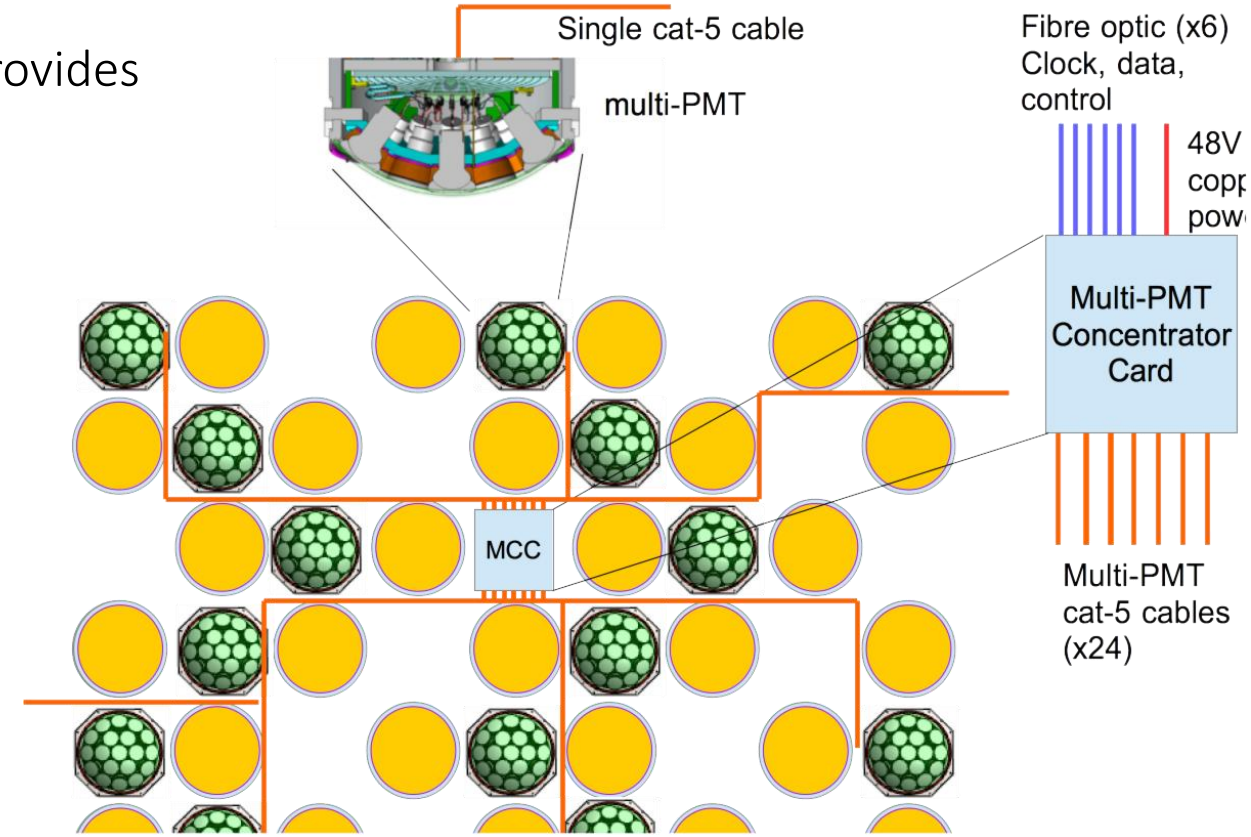


LTSpice simulations of the implemented circuit - Single photoelectron response

MPMT Concentrator Card (MCC)

Each mPMT has a single waterproof cat-5e cable that provides power, clock, sync signals and network connection.

MCC in water connects to 24 different mPMTs



MCC has the same set of interfaces to the surface equipment as the 20'' PMTs frontend electronics

- use the same clock and data transfer scheme

Summary

✧ Hyper-Kamiokande is officially approved in Japan

Hyper-Kamiokande is under construction and will begin operation in 2027

✧ mPMTs are considered as an option in HK FD and used in IWCD

Preliminary studies show that adding mPMTs improve HyperK physics capability

✧ International R&D is actively ongoing to optimize mPMT design and performaces

New collaborators are welcome to contribute to the detectors and the physics program!

Thank you!