JENNIFER 2 General meeting, Prague 17.-18.11.2022

WORK PACKAGE 4: NEW PHOTODETECTORS DEVELOPMENT

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JENNIFER2
EU grant n.822070

WP4 OBJECTIVES

- Develop and test few types of **new photodetectors** aiming to different applications in particle physics, while building an high level of knowledge exchange among the developers.
- Explore a very **innovative** and interdisciplinary **technique** to detect photons, based on **organic** substrates, through a strong partnership with Japanese institutions.
- Provide high quality **training** opportunities in the field of photon detection both for ERs and for ESRs, including contacts with technology industries operating in this field.

WORK PACKAGE TASKS & DELIVERABLES

Task	Name	Partners	Responsible contact	Milestones / Deliverables
4.1	R&D of Silicon-PMs as single photon counters in neutron irradiated areas	JSI,FBK, KEK	**Rok Pestotnik**	Report on the design and performance of the prototype module (M35)
4.2	Development of long-lived MCP photomultipliers	INFN, KEK	**Ezio Torassa**	Report on the lifetime properties of the MCP PMTs (M24)
4.3	Development of multi PMTs for a large water Cherenkov detector	INFN,NCBJ, CAEN,U-Tokyo	**G. De Rosa, Vincenzo Berardi**	Milestone: Report on the Acrylic properties for the external vessel of the mPMT module (M12) + Realisation of the mPMT module prototype (M24).
4.4	Study of innovative organic photosensors	INFN, KEK	**Alberto Aloisio, P. Branchini**	Milestone: Report on electrical characterization of photo-transistors (M24) Deliverable: Final R&D report on organic light detection (M48)

Common deliverable: Support organization and participation to photon detectors training sessions for PhD students at NDIP 2020 conference (M18)

Task 4.1: R&D OF SIPM AS SINGLE PHOTON COUNTERS IN NEUTRON IRRADIATED AREAS

→ SiPM as potential replacement for Belle II single photon detectors in future upgrade (2030)
(due to highly increased backgrounds existing photon detectors not usable)

Main challenge: incdeased dark count rate due to neutron damage

Ways of mitigation:

- **Boreated Polyethylene shielding**
- Smaller sensor size: **light collection – focus photons on smaller sensitive area**
- Operation at **lower temperature**:
  - Background rates double when T is increased for 8 deg.
  - -20 °C .. -100 °C
- **Annealing** – recover operation
- **Use of fast / integrated electronics**
- **Change of internal design of SiPMs**

Objectives:

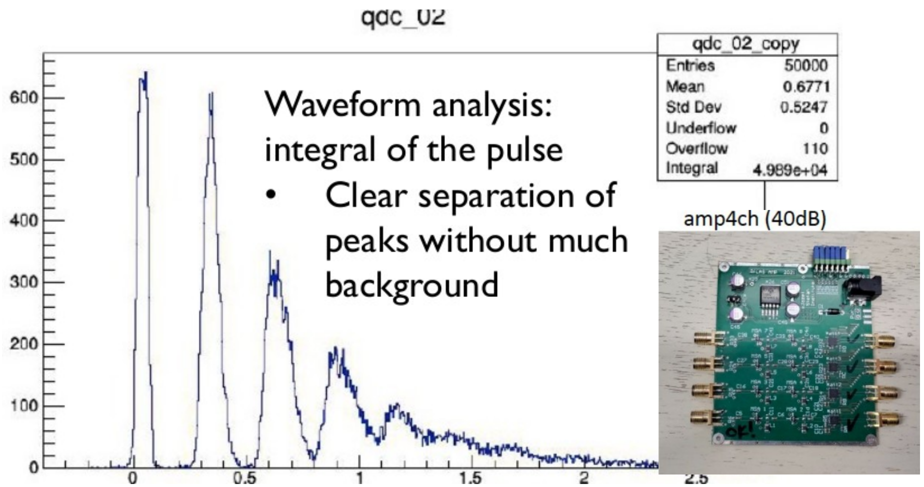
→ neutron irradiation tests of SiPM samples
→ effect of annealing
→ design and fabriaction of readout electronics
→ light concentrator development
→ technology and prototype validation in the lab, test beam, and operational environment

Key people: Rok Pestotnik (JSI), Prof. Samo Korpar (JSI), prof. Nishida Shohei (KEK), Alberto Gola (FBK) custom technology team leader

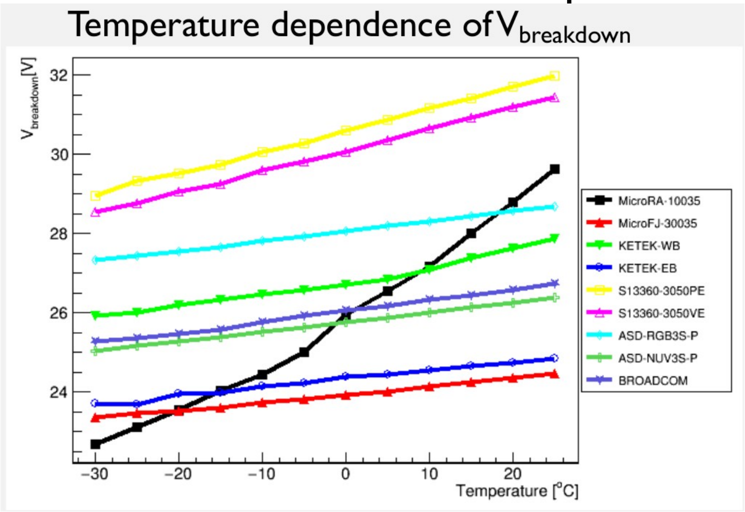
Activities in Ljubljana

- Preparation of the setup for LN measurements and online monitoring of the irradiation in the TRIGA Mark II reactor@JSI
- Test of optoelectronic chain with FastIC chip (O~25ps)
- Studies of different scenarios how to mitigate the SiPM neutron
  - Application of metalenses in the SiPM design : study of incidence angles to determine the acceptance limits

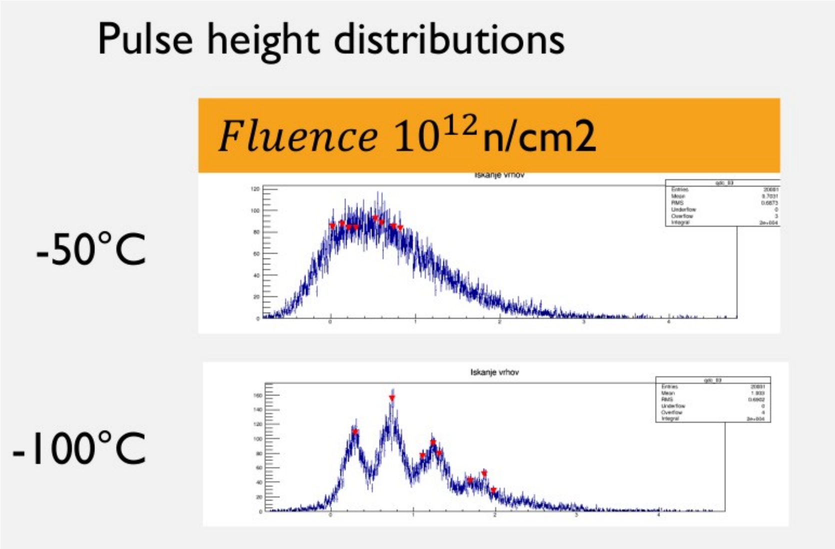
Selection of best amplifier



Tests of SiPMs at different temperatures



Irradiation tests @ TRIGA, JSI, Ljubljana



Ongoing tests of full chain with FastIC multichannel front-end electronics

- **FastIC: new Front-End chip in 65 nm**
  - Multipurpose chip: SiPMs, MCPs, etc
    - Single ended (pos/neg), differential and active summation
    - Binary (linear / non-linear ToT) and Analog output
  - Received samples : 8 ch
  - Final chip: 32 channel (power < 10 mW/ch)

Developed by CERN (KT funded) and
University of Barcelona (ICCUB)

Activities at FBK

→ Preparation of the clean room to perform the production of samples
(funds for the production AIDAInnova Innovation Pilot)

→ R&D of different design changes

→ monthly meetings with FBK

Task 4.2: Development of long-lived microchannel-plate photomultipliers

(presented by E. Torassa, INFN Padova)

Description of Work and Role of Specific Beneficiaries / Partner Organisations

Task 4.2: Development of long-lived MCP photomultipliers

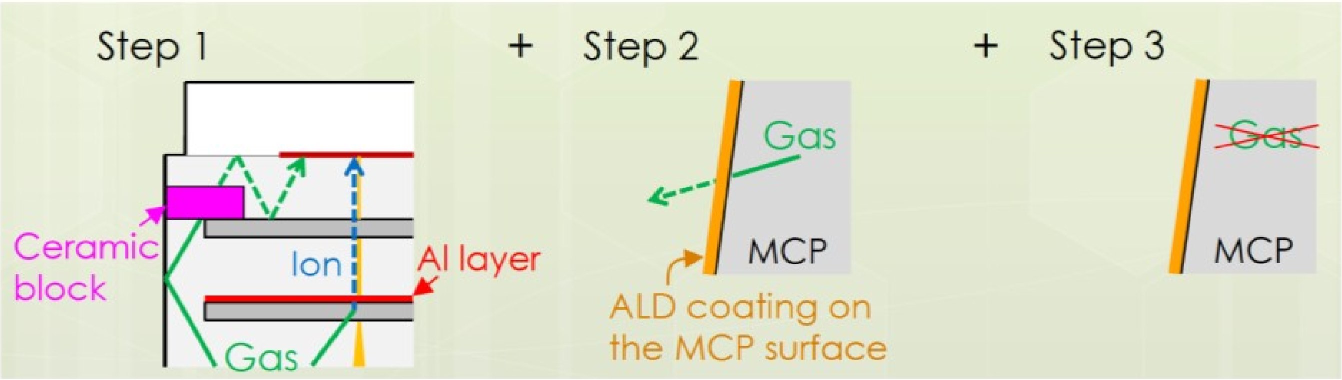
[INFN,KEK] Person Months allocated = 7

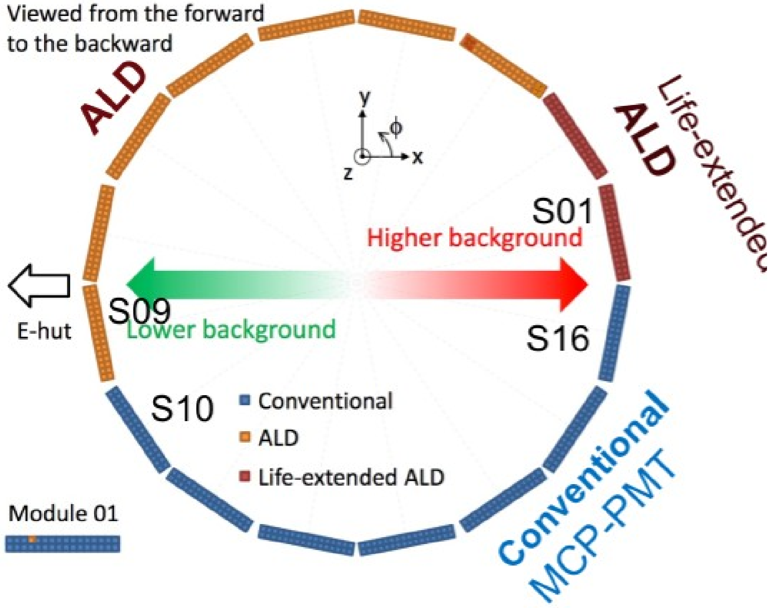
- The main objective is reduction of residual gas components, responsible for lifetime reduction in the MPC production procedure. Study of MCP-PMT samples: time and pulse height, photocathode lifetime analysis. Identification of ions responsible for lifetime reduction.
- Institutions' roles: INFN – leading partner, sample characterization,
  Hamamatsu Photonics – sample provider,
  KEK – integration of components.
- Key people: Ezio Torassa (INFN), senior researcher. Prof. Kenji Inami (KEK).

Description of deliverables

Task 4.2: Report on the lifetime properties of the MCP PMTs (month 24)

Lifetime measurements of MCP-PMTs installed in TOP counter of Belle II





Methods of lifetime measurements

→ LED illumination in lab (at the testing stage)

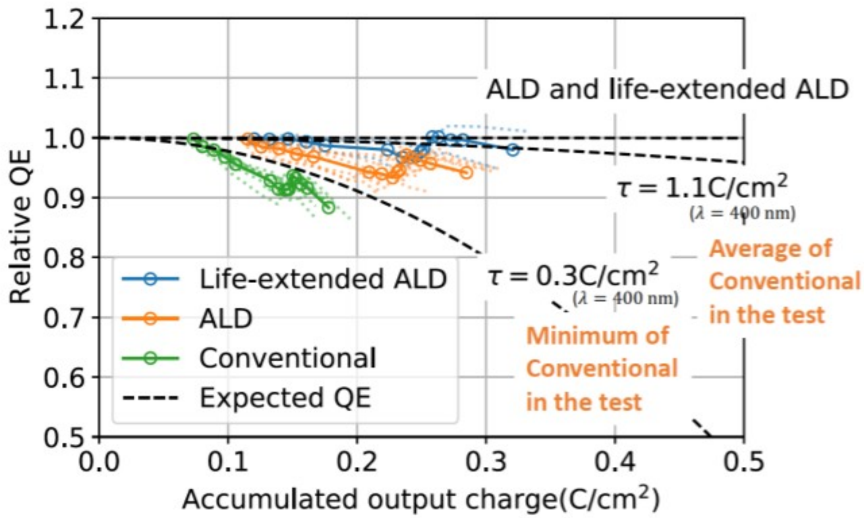
→ dismount from the detector and test in the lab

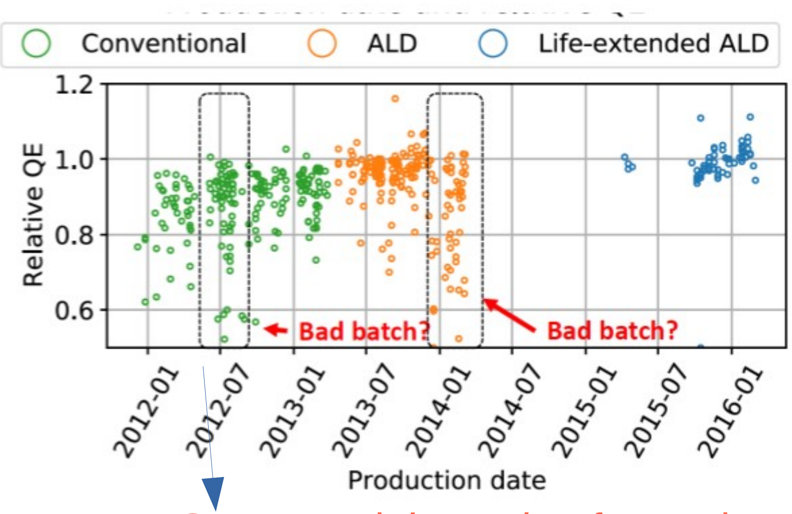
→ use detector laser calibration system
(meant for timing calibration → not reliable for QE)

→ use di-muon events (“standard candle”)

Lifetime – QE drop to 80% of original value

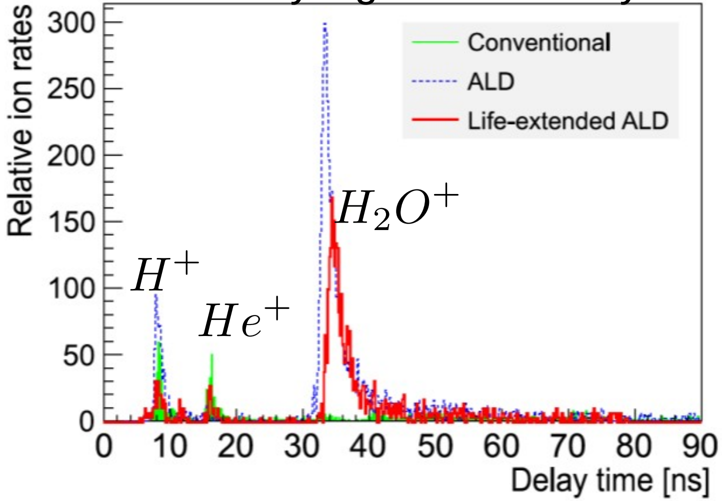
Lifetime determinations from di-muon events





Some modules aging faster than expected → bad batches?

Secondary signal time delay



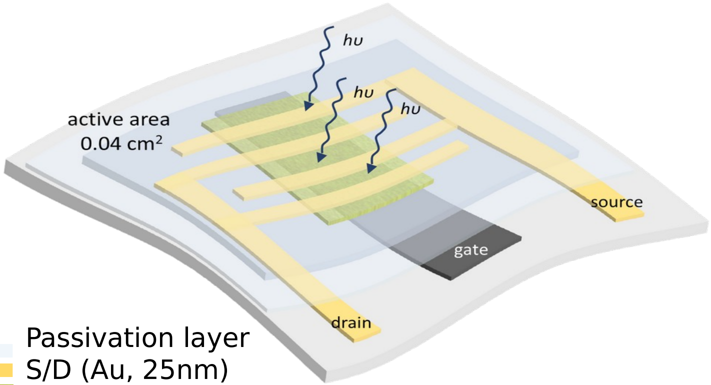
→ better understanding of the current MCP-PMT QE degradation is needed

→ lifetime can be improved if residual quantity of H^+, He^+, H_2O^+ ions is reduced

→ backup for MCP-PMT in future upgrades is SiPM, tests and R&D of these are ongoing

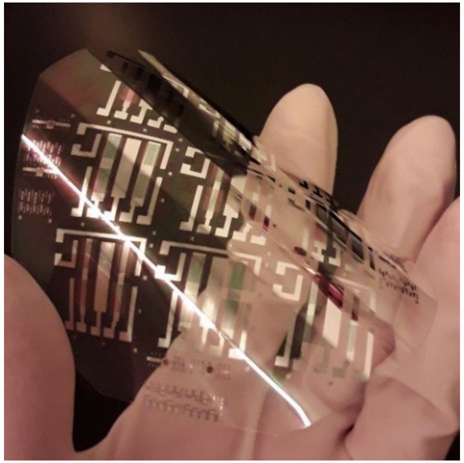
Task 4.4: Study of innovative organic photosensors (presented by P. Branchini, INFN Roma Tre)

Flexible fully organic sensor for radiation detection (OPT – organic photo-transistor)

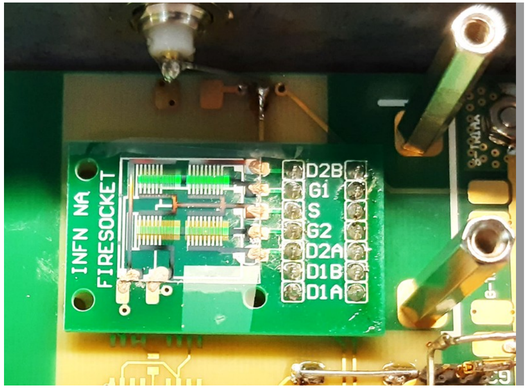


- Passivation layer
- S/D (Au, 25nm)
- Organic semiconductor
- Gate dielectric
- Gate (Al, 70nm)
- PEN substrate (100µm)

Fabricated by
CNR-IMM and RomaTre INFN
within the FIRE
Collaboration.



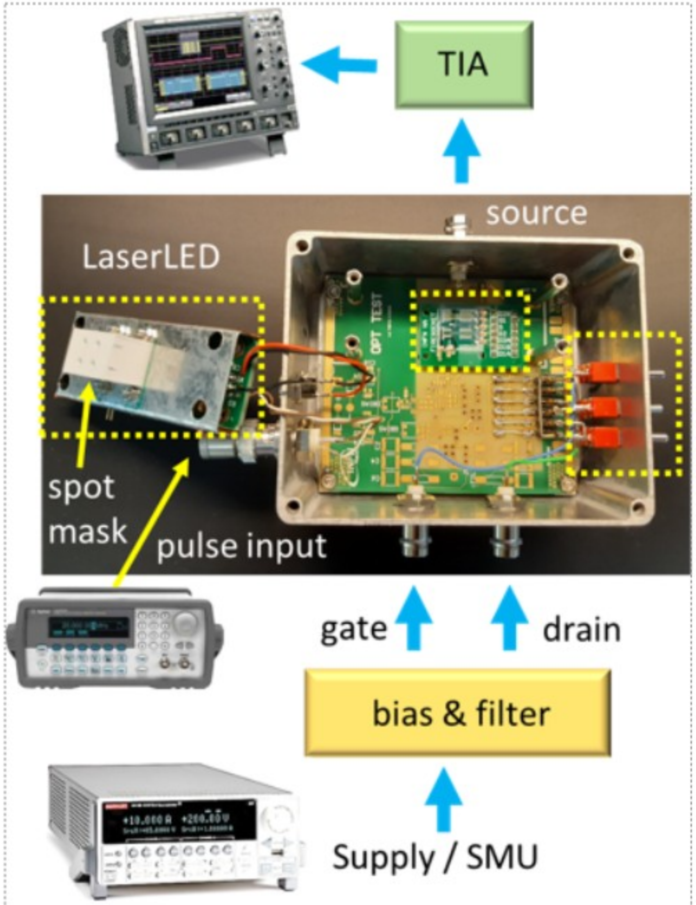
The OPT is mounted on a socket which allows to perform tests.

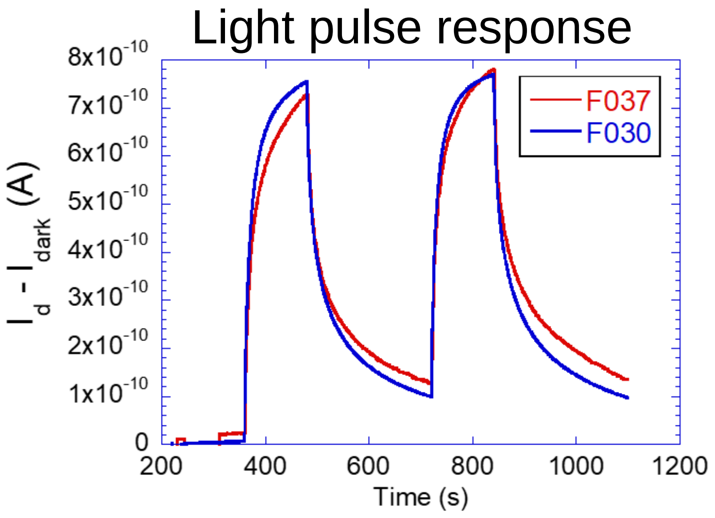


Effects of illumination on the electrical characteristics in organic thin-film transistors based on dinaphtho [2,3-b:2′,3′-f] thieno[3,2-*b*] thiophene (DNTT): Experiment and modeling, Synthetic Metals Volume 283, January–February 2022, 116985, HouaidaBecharguia[a]MouniraMahdouani[a]RamziBourguiga[a]PaoloBranchini[b] AndreaFabbri[b] Stefania De Rosa[b]SabrinaCalvi[bc]LuigiMariucci[bc]AntonioValletta[bc]LucaTortora[bd]

Highly sensitive oonicrganic phototransistor for flexible optical detector arrays Organic Electrs. Organic Electronics Volume 102, March 2022, 106452. S.Calvi[ab]M.Rapisarda[b]A.Valletta[b]M.Scagliotti[b]S.De Rosa[a]L.Tortora[ca] P.Branchini[a]L.Mariucci[b]

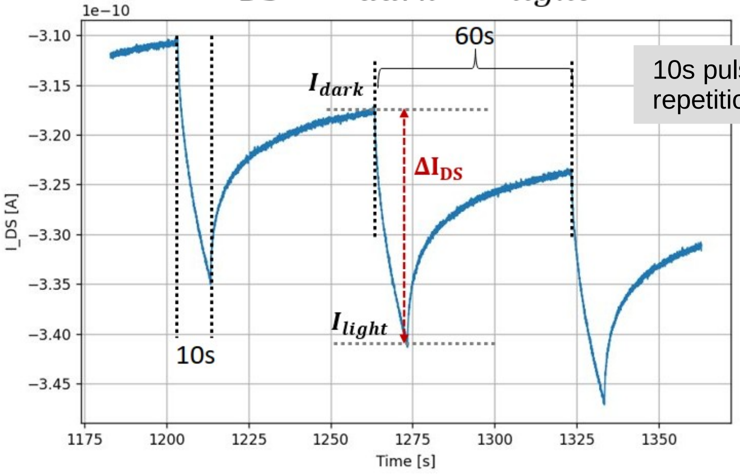
A setup has been built to perform measurements as a function of incident light source power (LaserLED pulser)





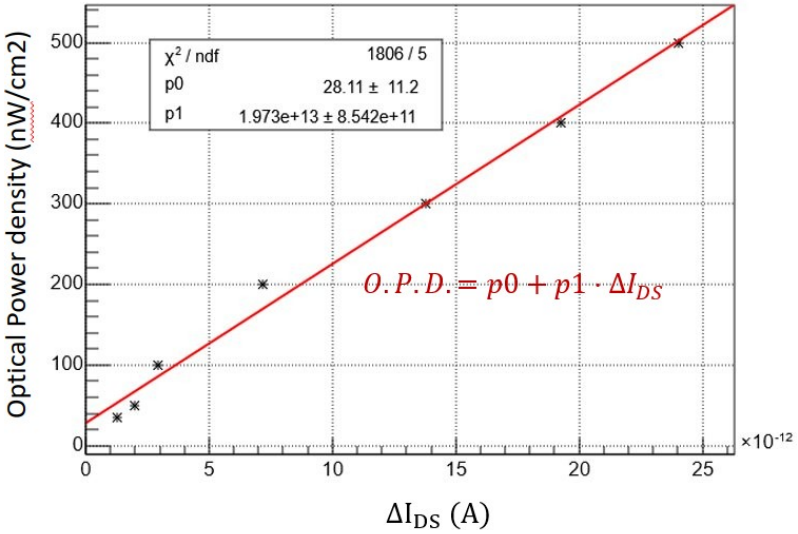
Process stability: current output to **35 nW/cm²** light pulses at **λ =450 nm**

$$\Delta I_{DS} = I_{dark} - I_{light}$$



10s pulses,
repetition time: 60s

Determining limit of detection



$$\mathrm{LoD}_2 = P_B + 3\sigma_B$$

P_B = 28 nW/cm²

σ_B = 11 nW/cm²

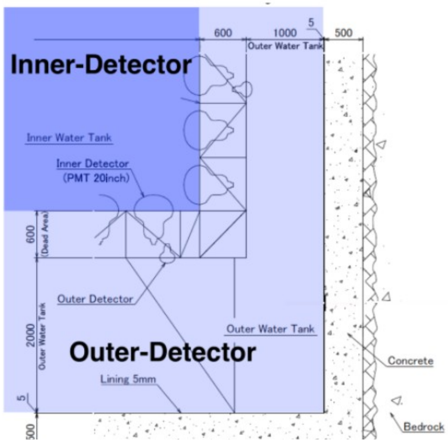
LoD_2 = 61 nW/cm² $S/N > 4\ (@LoD)$

Next steps:

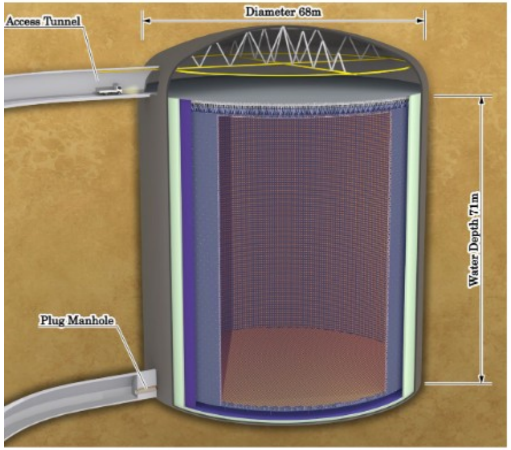
- couple a scintillator to the OPT in order to build an indirect sensor.
- characterize the sensor to different particle beams.

Task 4.3: Development of multi PMTs for large water Cherenkov detector

(presented by Alan C. Ruggeri, Charles University)



Hyper-K overview

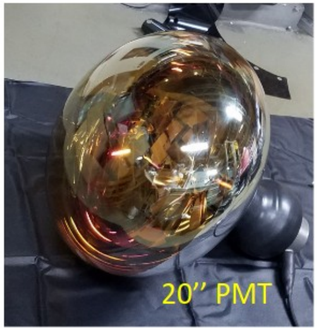


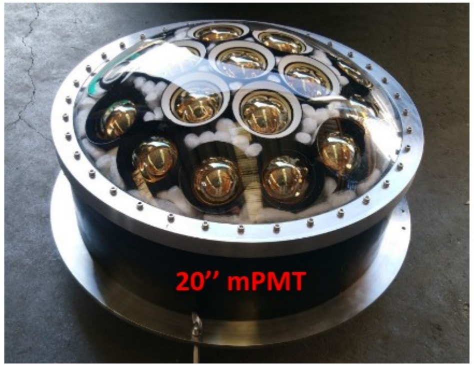
Hyper-Kamiokande (Hyper-K, HK) is a multi-purpose **Water-Cherenkov detector** with a variety of scientific goals:

- ✧ Neutrino oscillations and CP violation
  (by atmospheric, accelerator and solar ν)
- ✧ Neutrino astrophysics
- ✧ Proton decay
- ✧ Non-standard physics

Inner detectors (IDs):

- ❖ 20'' PMTs (#20'000)
- ❖ 20'' mPMTs (->19 3'' PMTs inside) (#thousands)
  - ❖ [Photo-coverage (PC) 20%)]





Hyper-K Far Detector (HK-FD)

- ➢ Cylindrical tank: Φ 68 m and H 71 m
- ➢ Filled with 0.25 Mtons of ultra-pure water
- ➢ Fiducial volume: 0.19Mtons (~8 times SuperK)

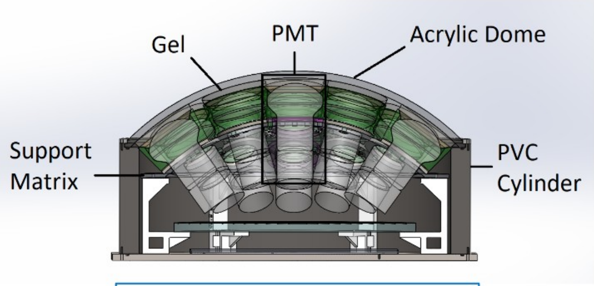
Today, Hyper-K is under construction and its operation will begin in 2027!

+ ~500 m-PMTs for Intermediate water Cherenkov detector (IWCD)

Hyper-K multi-PMT design

The mPMT is a vessel which houses and protects an array of 19 3” PMTs, and the original concept was realized for the **KM3NeT** experiment.
WRT single 20’’ PMTs the mPMT configuration:

- ✓ improves the granularity and timing response over larger number of photo-sensors
- ✓ has got an additional intrinsic directional information



ID-mPMT (19 PMTs)

Principal mPMT componets	Characteristic for the FD	Caracteristic for the IWCD
Dome	UV-transmitting acrylic	UV-transmitting acrylic
3’’ PMT	19 items	19 items
Vessel cylinder	POM-C material (TBC)	PVC material
Back plate	AISI-304 stainless steel (SS)	AISI-304 SS
Optical gel	For an optical connection between the acrylic dome and the PMT photo-cathode	For an optical connection between the acrylic dome and the PMT photo-cathode
Clamping ring	AISI-304 SS	AISI-304 SS
Electronic board	Q/T digitization based on discrete components	FADC digitization, with on-board signal processing

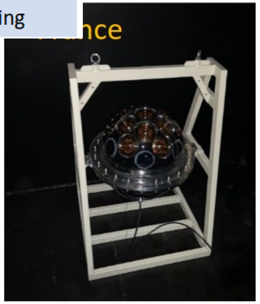
Many tests on the mPMT prototype and its material/components:

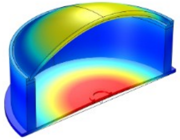
- Optical, mechanical and nuclear contamination tests on the UV-transmittance acrylic material

- Water absorption into acrylic sample

- Pressure tests of the external-component vessel

- Functional test of the first prototype in MEMPHYNO lab (a second test is scheduled soon with the last design)





Ruggeri A.C. - JEN

Electronics of multi-PMT

Performance requirements

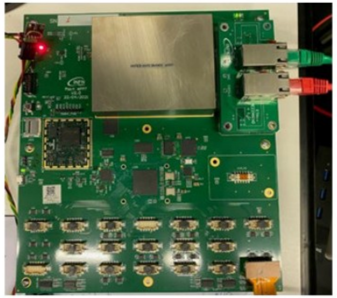
– Timing resolution: better than 3” PMT TTS

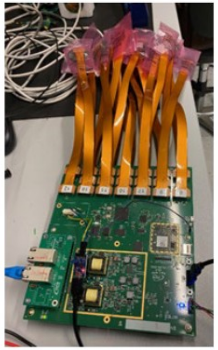
- ~300-500ps timing resolution from electronics for 1PE.
- Better timing resolution (100-200ps) for large PE pulses

– Charge resolution ~0.05PE up to 25PE.

Power-consumption requirments:

- For HK FD <3-4W per mPMT
  - Cooling driven by water circulation requirements
- For HK-IWCD ~5-10W per mPMT
  - Not as strongly constrained as Hyper-K





mPMT electronics
Ready to start reliability validation:
Contract started with company
Automatic testing procedure defined
Installed in INFN mPMT prototype
LED calibrator card integration started

HV board
Basic Cockcroft-Walton voltage multiplier circuit designed for HV up to 1.5 kV

Further technical details:

- Design Report is available (https://arxiv.org/abs/1805.04163).
- Technical Report will be published soon.

Project status:

- Japanese construction budget was approved by MEXT in Japan, in 2020.
- We are in construction phase:
  - Cavern excavation is ongoing
  - Mass production of new 20-inch PMTs started
- Basic design of tank, mPMT, electronics, etc., will be finalized soon.
  - Their mass production is scheduled at the end 2023
- PMT installation is foreseen in 2025-2026
- Hyper-K observation will start in 2027.