Work package 4 Report

New Photodetectors Development

Rok Pestotnik (Jožef Stefan Institute), Dec 12, 2022

Jennifer2 - Mid Term Review meeting @ REA Brussels

Main research objectives

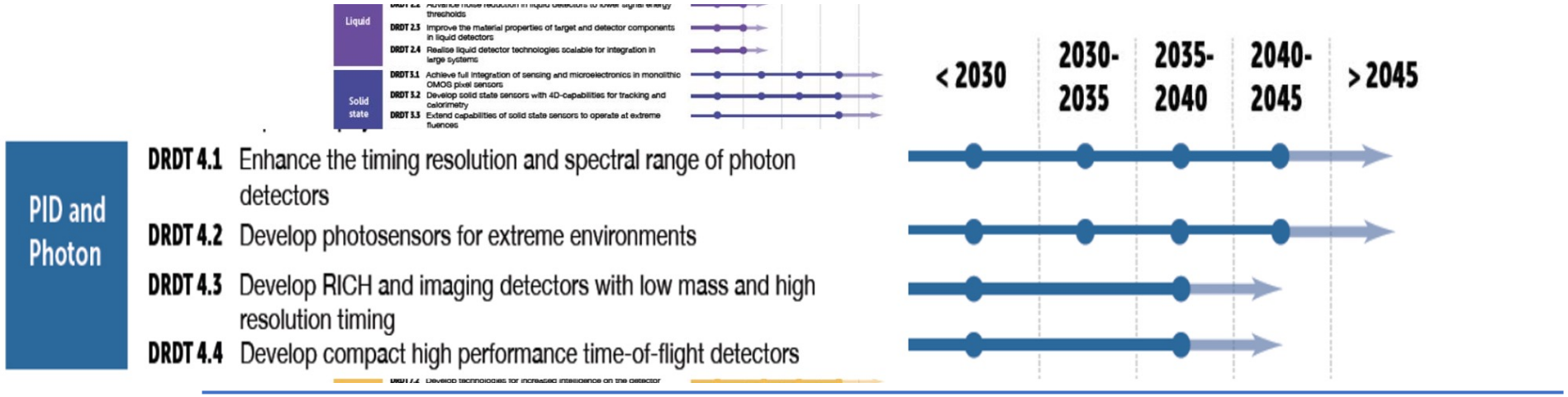
- Develop and test few types of **new photodetectors** aiming to different applications in particle physics, while building an high level of knowledge exchange among the developers.

- 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

General Status of the Work Package 4

- 4 tasks with clear objectives and work program
- Different level of technology readiness
- From basic understanding of the operation to the application.
- All tasks are progressing well.
- The development of new photodetection techniques recognized by ECFA Detector R&D Roadmap https://europeanstrategyupdate.web.cern.ch



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Deliverables and implementation

Done

Task	Name	Partners	Responsible contact	Milestones - MS / Deliverables - D
4.1	R&D of Silicon-PMs as single photon counters in neutron irradiated areas	JSI,FBK, KEK	**Rok Pestotnik (JSI)**	D4.4: Report on the design and performance of the prototype module (M35)
4.2	Development of long-lived MCP photomultipliers	INFN, KEK	**Ezio Torassa (INFN)**	D4.2: 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 (INFN)**	MS4.1: Report on the Acrylic properties for the external vessel of the mPMT module (M12) D4.3: Realisation of the mPMT prototype (M24)
4.4	Study of innovative organic photosensors	INFN, KEK	**Alberto Aloisio, P. Branchini (INFN)**	MS4.2: Report on electrical characterization of photo-transistors (M24) D4.5 : Final R&D report on organic light detection (M48)

Common deliverable:

D4.1 Support organization and participation to photon detectors training sessions for PhD students at NDIP 2022 conference (M18)

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Link between secondments, tasks and deliverables

Institution	Tasks	Done (months)	Planned	% done
INFN	2,3,4	1,5	19,0	8,1%
JSI	1	3,7	8,0	45,8%
NCBJ	3	0,0	3,0	0,0%
CAEN	3	0,0	1,0	0,0%
FBK	1	0,0	1,0	0,0%
KEK	1,2,4	0,0	2,0	0,0%
Total		5,2	34,0	15,3%

WP4 secondments are running a liitle bit slower than expected
Impact of the COVID lockdowns
Shift of the Task 2 toward Task 1

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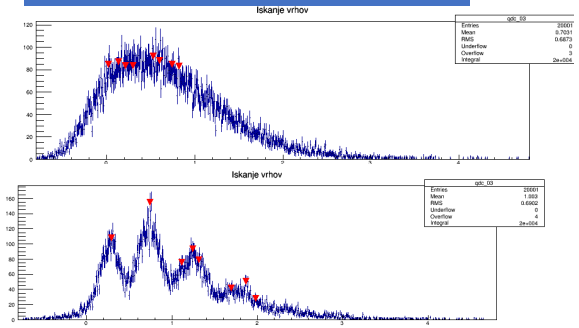
Task 1 - R&D of SiPM as single photon counters in neutron irradiated areas

Irradiation @ TRIGA, JSI

Fluence 10^{12}n/cm2

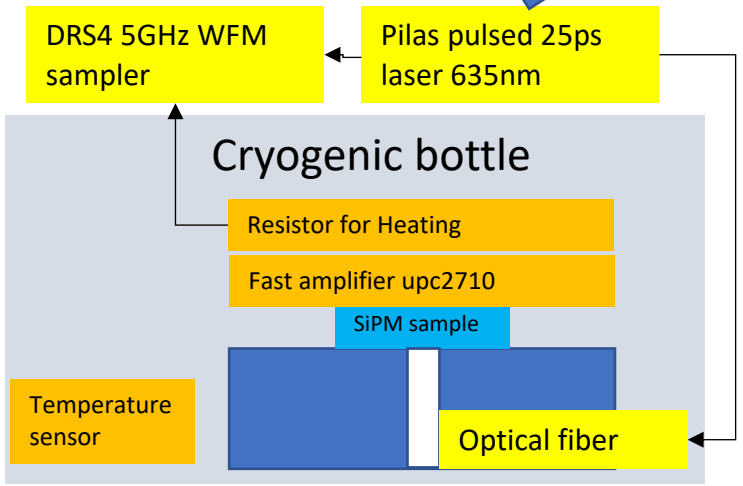
-50°C

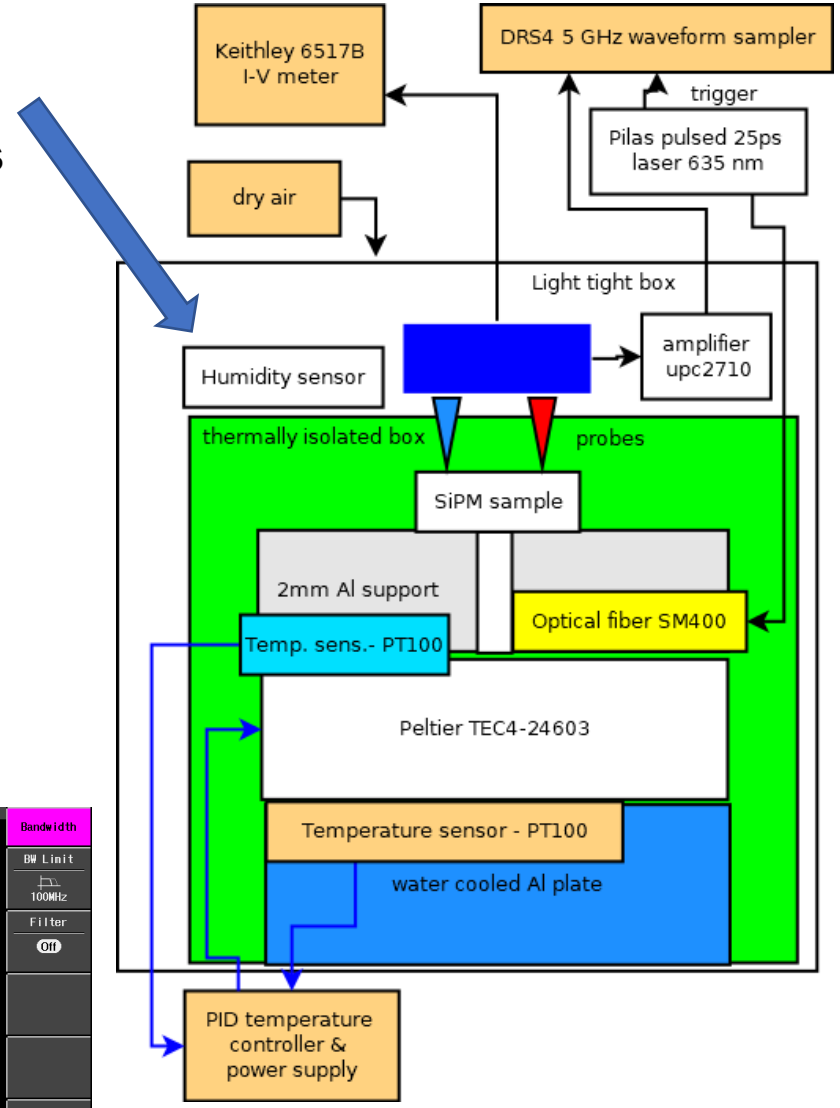
-100°C



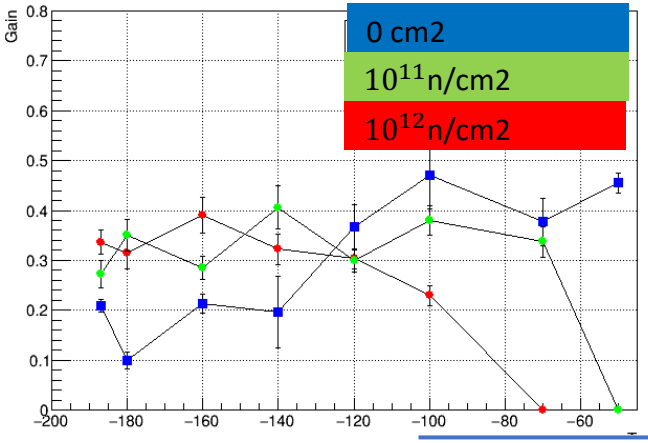
Pulse height distributions

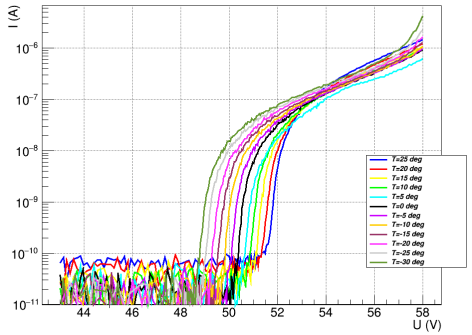
2 SiPM Characterization setups

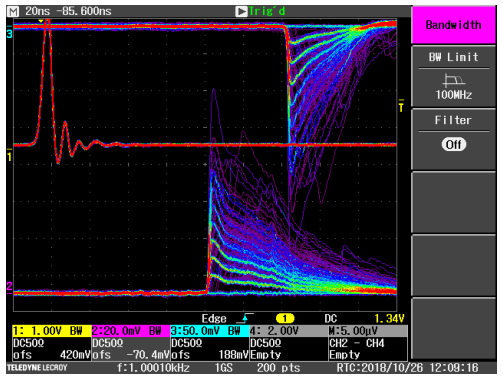




Hamamatsu -3050PE







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Task 1-Status

SiPM development + board design

SiPM Design changes – synergy with H2020 - AIDAinnova Innovation - Pilot Advancement and Innovation for Detectors at Accelerators
https://aidainnova.web.cern.ch/

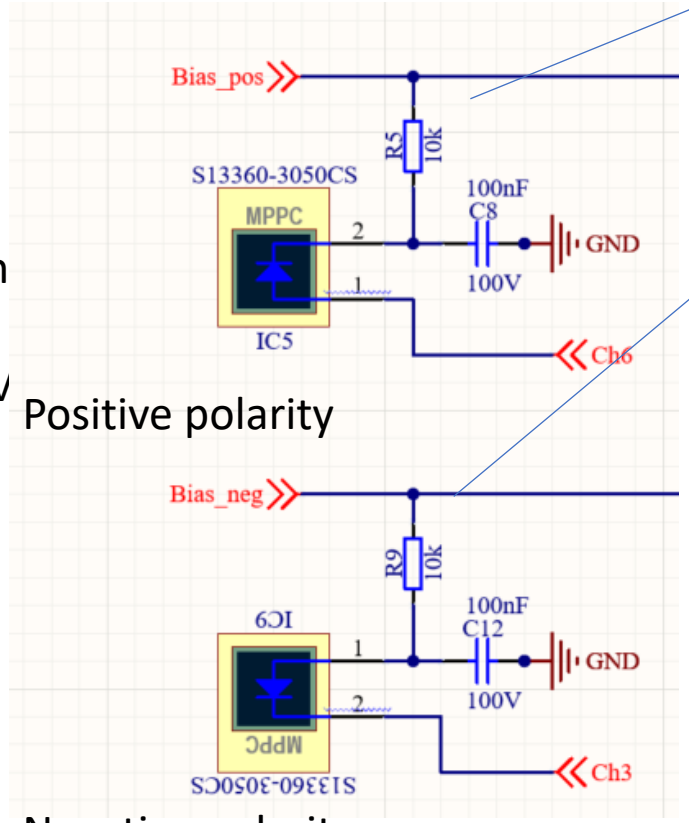
@FBK:

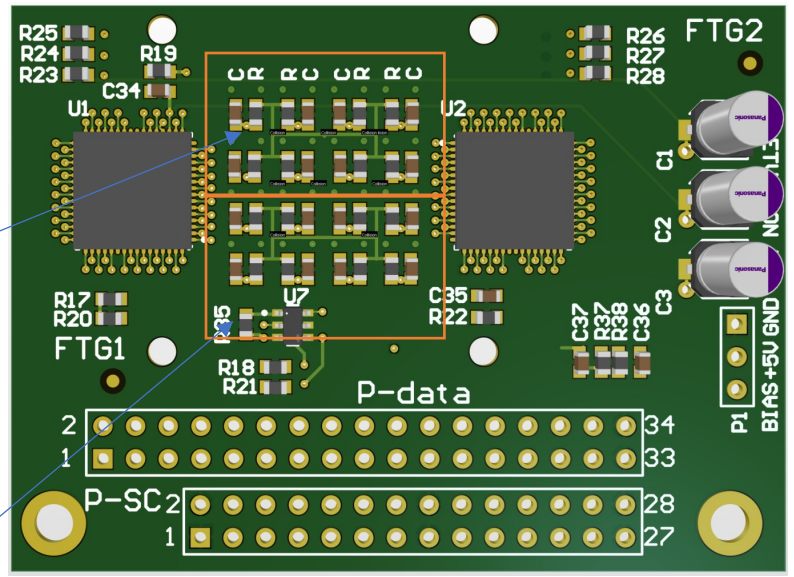
- Preparation of the clean room for production of samples
- Study of different design changes of HD-NUV
- Provide samples for irradiation

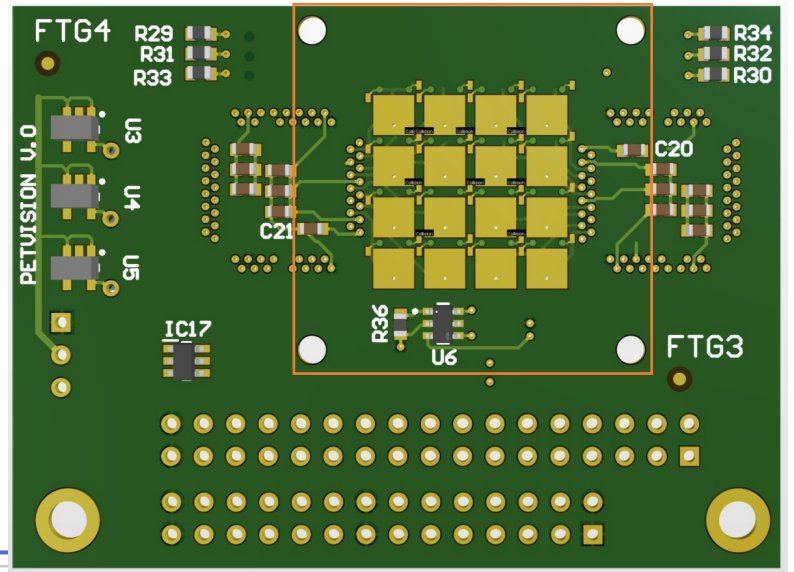
Regular monthly meetings

Electronics: Test of novel **FastIC** low power chip for fast timing applications – joint development of Uni Barcelona and CERN

Board under design
Test at KEK







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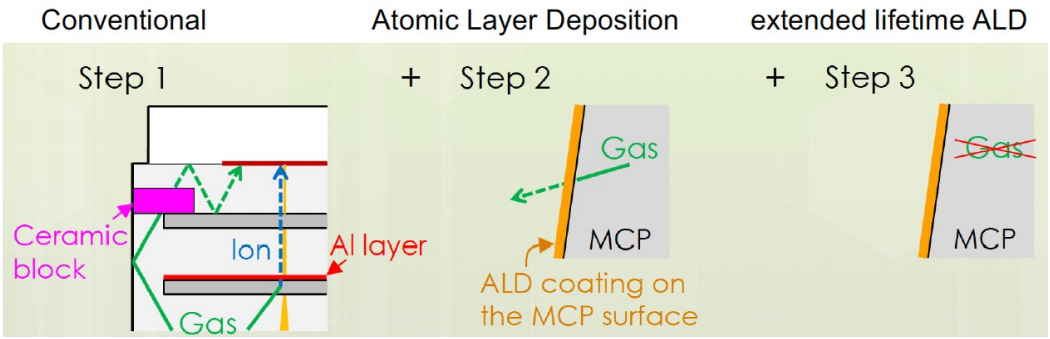
Task 2 - Development of long-lived MCP PMTs

The goal : produce a new MCP-PMT generation with increased lifetime

Main objective - 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.



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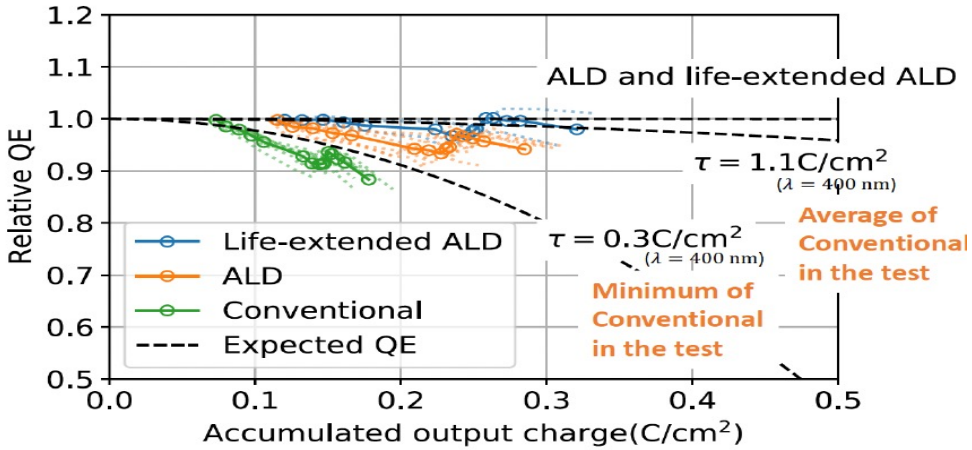
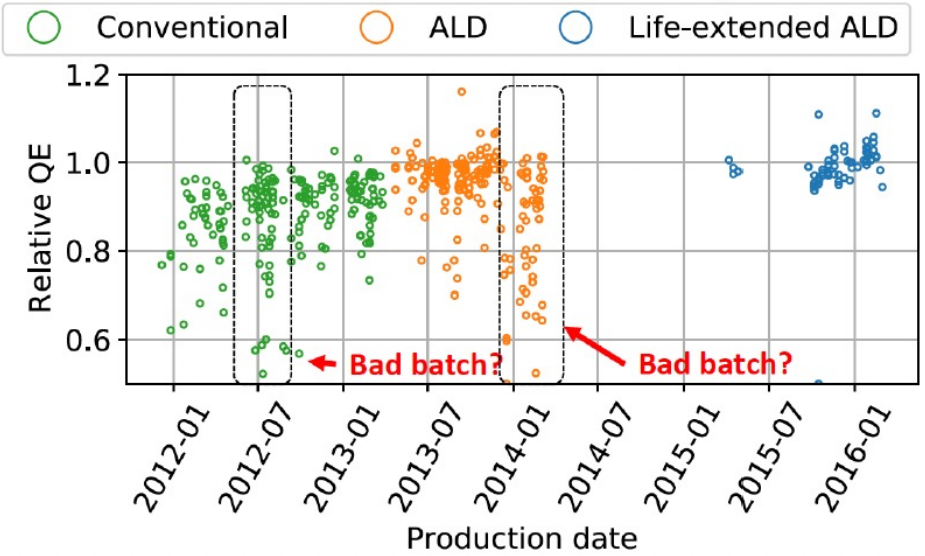
Task 2 - Lifetime measurements

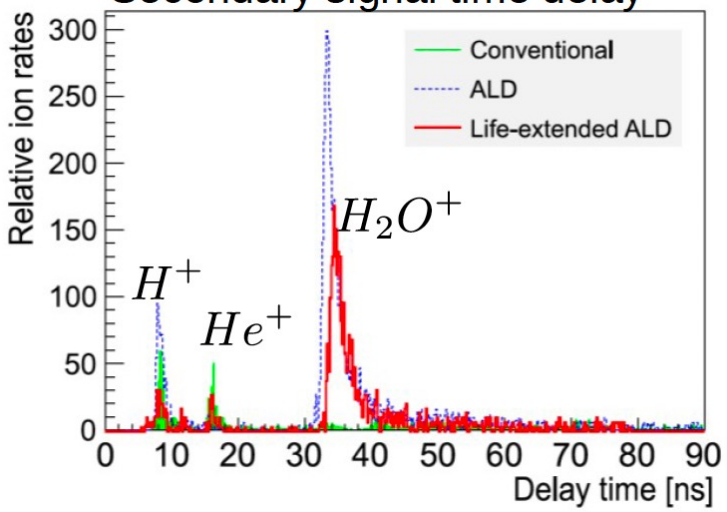
In the lab with the laser + with the dimuon events in the Belle II TOP





Some modules aging faster than expected

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

There is currently no budget to start this new development.

→ backup for MCP-PMT in future upgrades : SiPMs - Task 1

Similar requirements, synergies with other partners

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Task 3 - Multi PMT for the HyperK detector

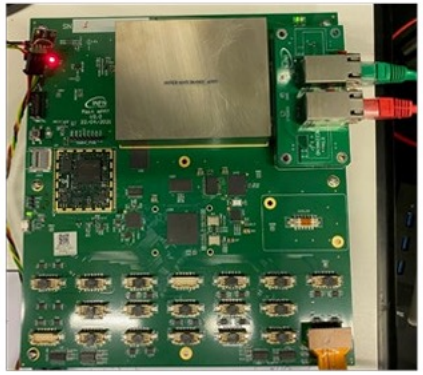
New approach: Using small PMTs to cover large effective area of an optical system and to introduce intrinsic directional sensitivity multi-PMT (Digital Optical Module)

mPMT - a vessel which houses and protects an array of 19 3” PMTs:

- common effort from Italy, Canada, Czech Republic, Mexico and Poland

Started from KM3NeT design, with more stringent requirements for radiation free vessel, readout electronics, mechanics
Two designs:

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



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

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Task 3 - Status

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

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.

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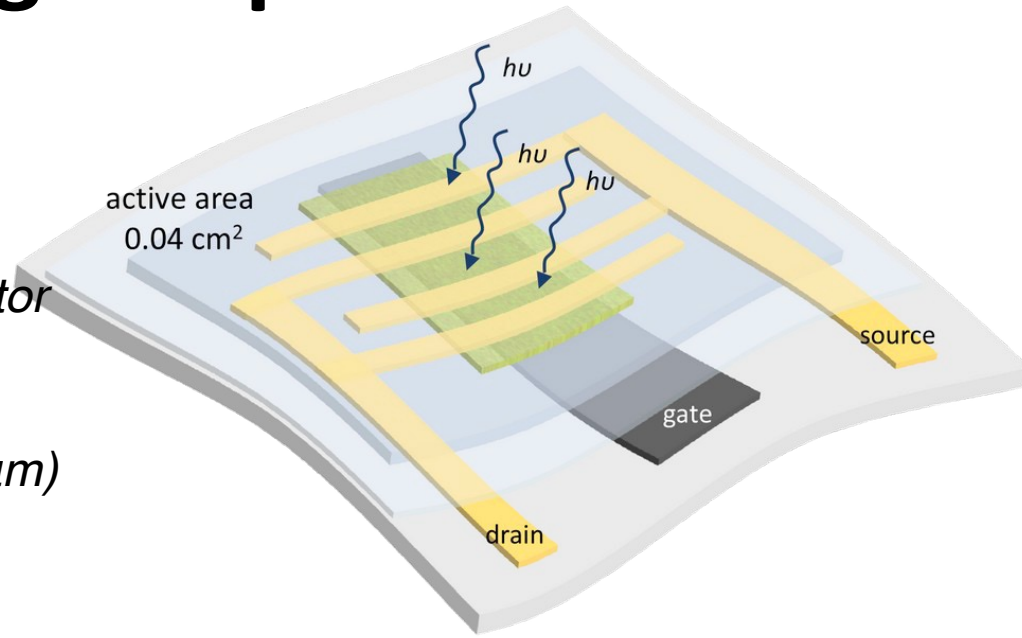
Task 4 - Study of innovative organic photosensors

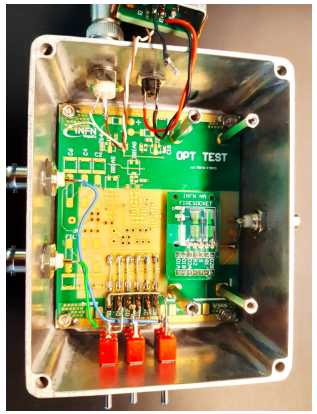
Flexible fully organic sensor for radiation detection (OPT – organic photo-transistor)

Both electrical components and photo-sensors can be integrated in the same thin support.

Very flexible and cheap..

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





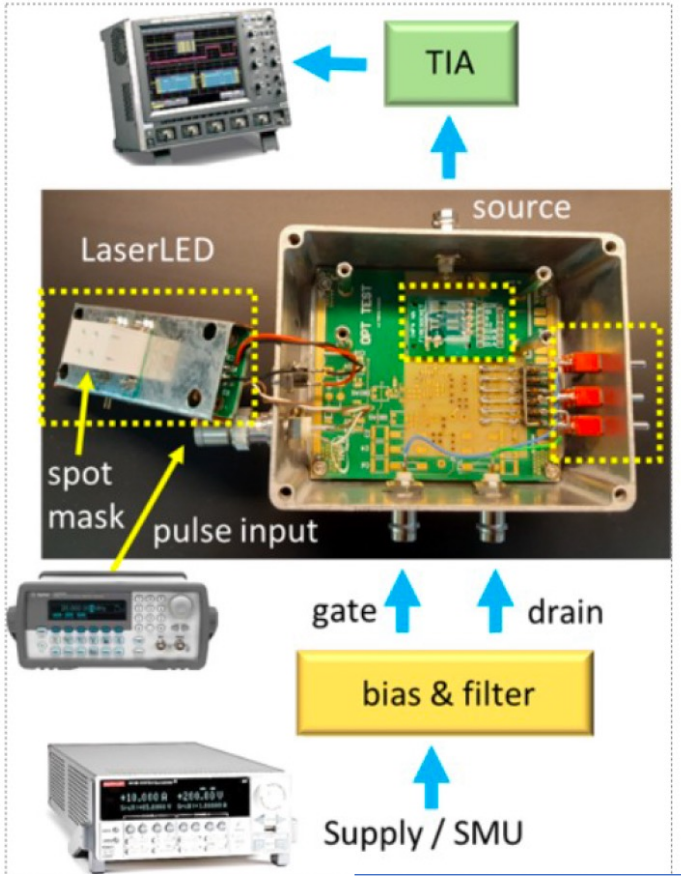
The OPT is mounted on a socket which allows to perform tests.

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

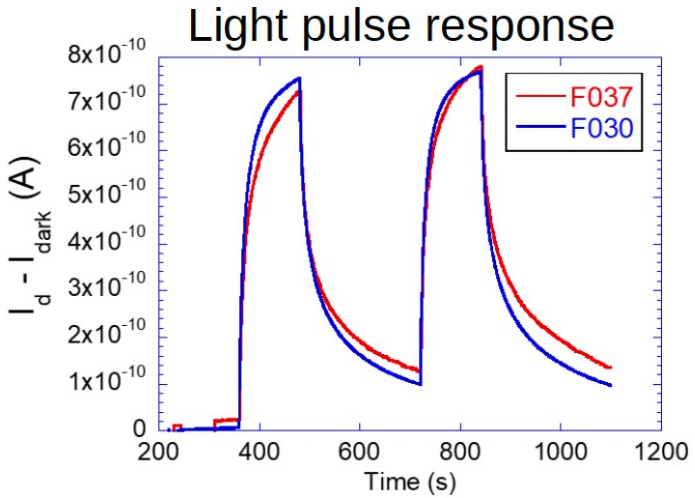
Highly sensitive organic phototransistor for flexible optical detector arrays. Organic Electronics, Volume 102, March 2022, 106452.

Task 4 - Status

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

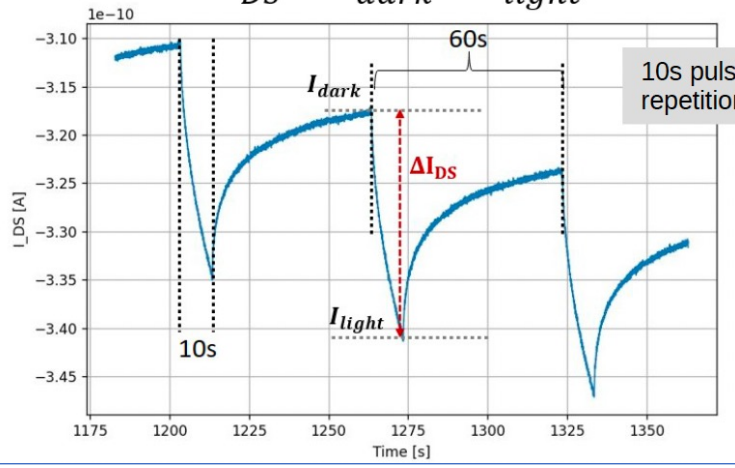


Slow response



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

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

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NDIP20 @ Troyes 2022

- Support organization and participation to photon detectors training sessions for PhD students at NDIP 2020 conference (M18)
- Well received by the organizers

GRANTS

Thanks to the *JENNIFER*^{2} program*, a very special rate is available to support young scientists' participation to NDIP20.

*JENNIFER^2 (Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research) is funded under the Horizon2020 program of the European Union as a Marie Sklodowska Curie Action of the RISE program and includes among its activities a work package dedicated to photodetectors. JENNIFER^2 is committed to promote training and dissemination in the scientific fields in which it is involved, and supports the participation of young students to the NDIP conference, an outstanding European event in photon detection.

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	Early birds Before June 15, 2022	Late birds After June 15, 2022	Comments
First 10 Under graduate students (2 max/lab)	FREE**	/	Students (Master level or lower) must prove to be students registered in a University - Late cancellation or no show will cause a charge of € 205 VAT incl.**
From 11th Under graduate students' rate	€ 170 VAT incl.***	€ 205 VAT incl.	Students (Master level or lower) must prove to be students registered in a University

JENNIFER2 provided photo-detection techniques training opportunity for undergraduate students

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Conclusions

PID methods have become an indispensable experimental tool, in particular for heavy flavour physics, heavy ion collisions, electron & hadron experiments and particle astrophysics.

JENNIFER2 funding is an important pilar for connecting European and Japanese groups in the development of the new technologies for photon detection.

Impact: Key photon detector developments performed JENNIFER2 represents the seeds of the future DRD4 envisaged by European particle physics R&D strategy formulated in ECFA Detector R&D Roadmap

The implementation of the WP4 is progressing well. No major obstacles are foreseen in the continuation of the JENNIFER2.

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