JENNIFER 2 General meeting @ KEK June 2, 2024

WORK PACKAGE 4: NEW PHOTODETECTORS DEVELOPMENT

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JENNIFER 2
EU grant n.822070

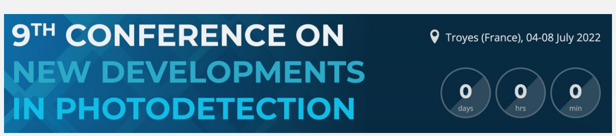
WP4 OBJECTIVES

- 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)



PHOTON COUNTING IN HIGHLY IRRADIATED ENVIRONMENTS

Background:

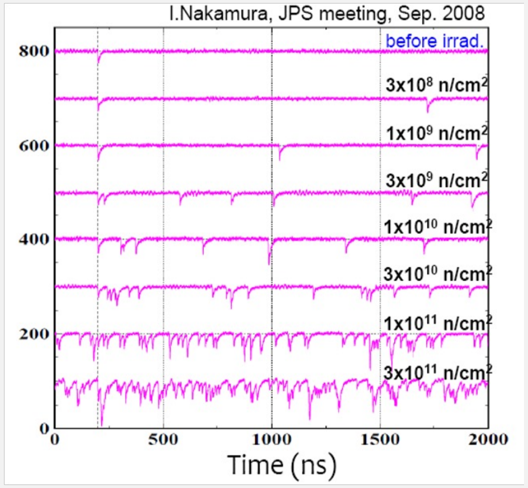
- Future Belle II Upgrade (2034) – 5x increase of luminosity
- Photon detectors used today will not be usable:
  - Hybrid Avalanche Photo Diode – Belle II ARICH: increase of leakage current, signal drop
  - MCP-PMT: the device lifetime limited due to high photon flux
- New photo detectors and operating conditions are being searched for their use in such an environment

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

JSI,FBK,KEK

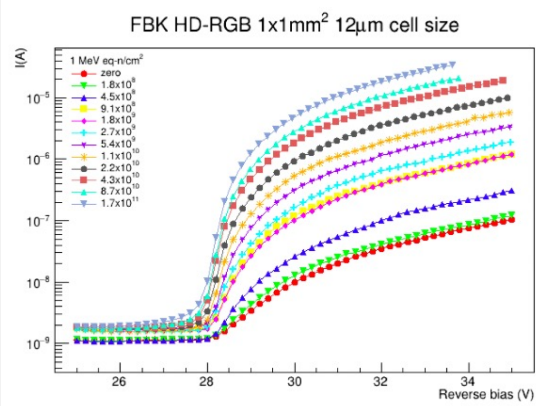
NEUTRON IRRADIATION OF SIPMS

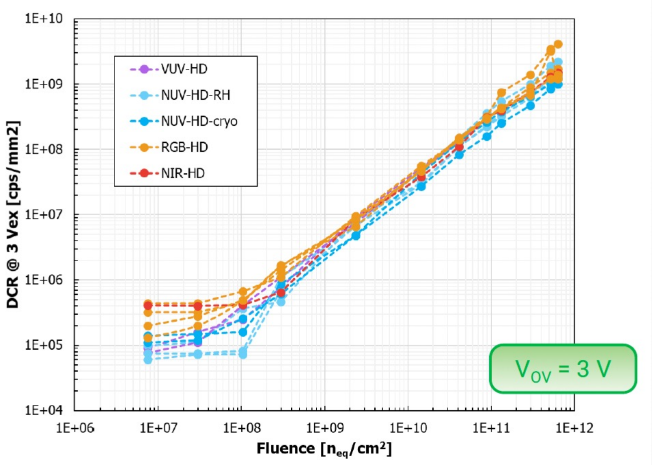
- Problem with SIPM after neutron irradiation
- Waveforms are distorted
- Single photons cannot be distinguished any more



Increase of a dark count rate

For higher fluences, all the technologies seems to behave the same.





Bias current increase after the irradiation

OBJECTIVES

- Study of silicon PM samples before and after irradiation with neutrons:
- time and pulse height distribution, waveform analysis, background noise counts, effect of annealing .
- Design requirements, selection of SiPM, design and fabrication of readout electronics.
- Development of light concentrator to increase signal to noise.
- Integration of the module and study of the module in the relevant environment .
- technology design and validation in the lab and in the test beam,
- system prototype demonstration in operational environment.

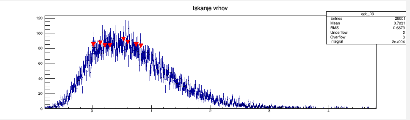
- Key people: Rok Pestotnik (JSI), Prof. Samo Korpar (JSI), prof. Nishida Shohei (KEK), Alberto Gola (FBK) custom technology team leader.

CHARACTERISATION OF IRRADIATED DEVICES

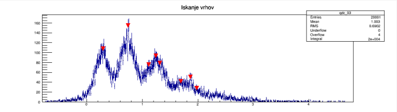
Pulse height distributions

Fluence 10^{12}n/cm2

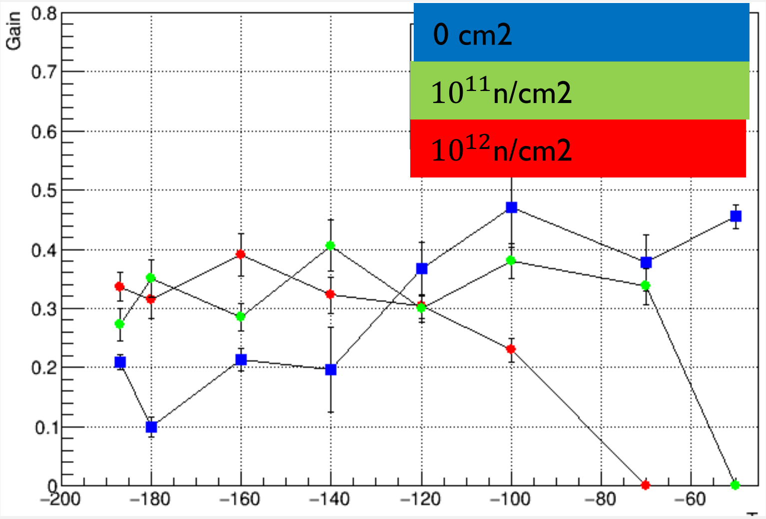
-50°C



-100°C

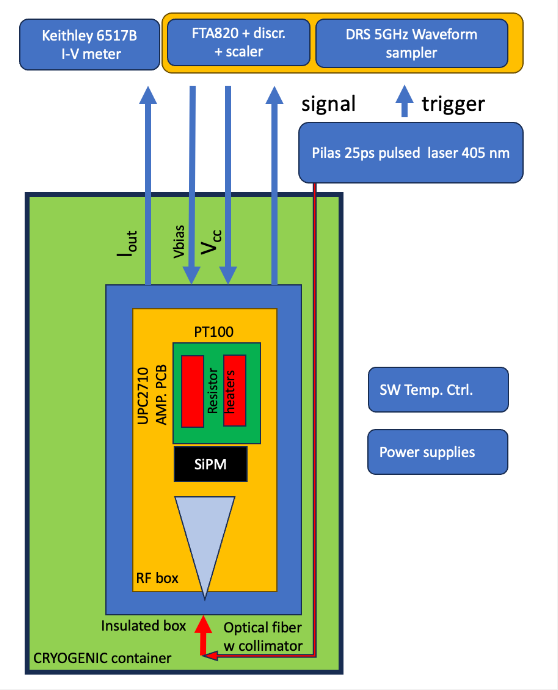


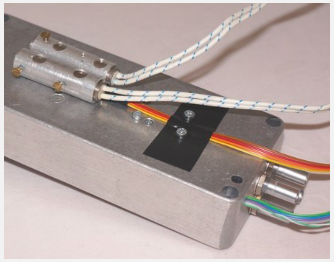
Hamamatsu -3050PE

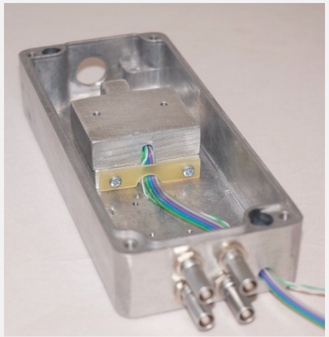


Setup - Probe station to measure:

- IV curves
- Waveform acquisition with DRS4
- DCR







Key Question:
Temperature of stable operation

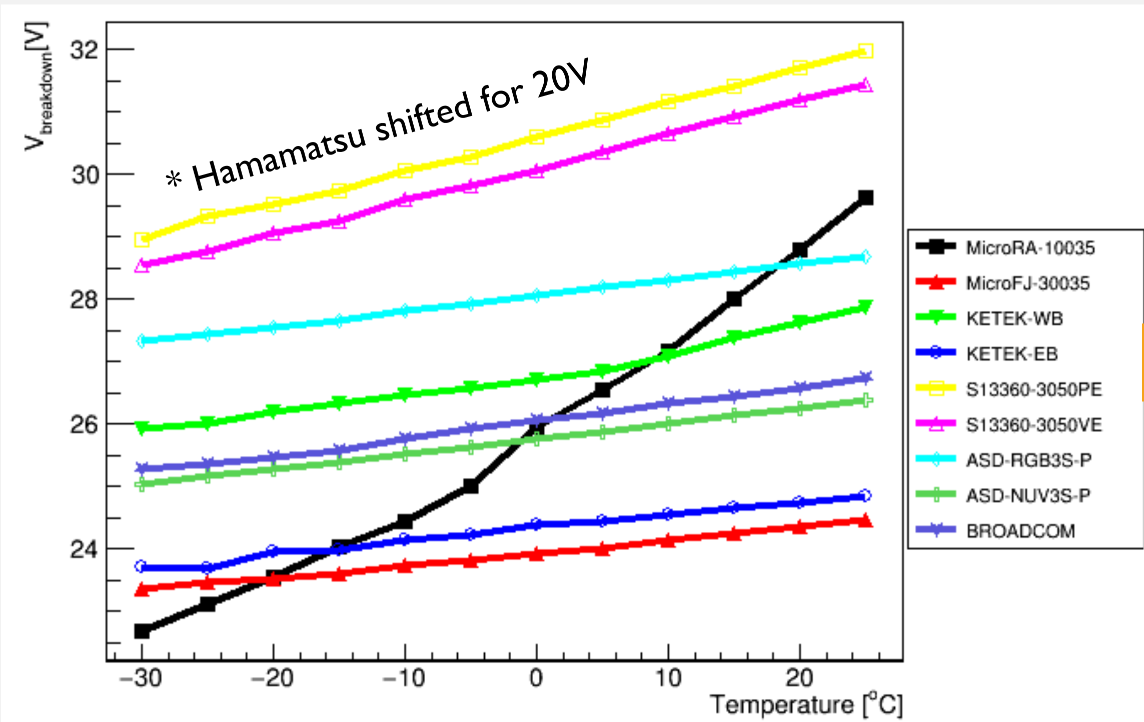
I-V MEASUREMENTS

Extraction of $V_{breakdown}$

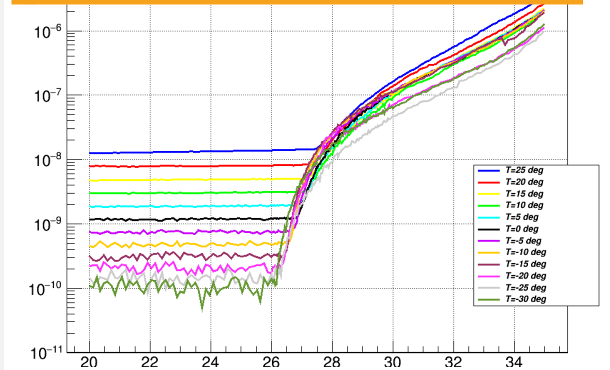
Temperature dependence

Similar behavior of samples from different producers

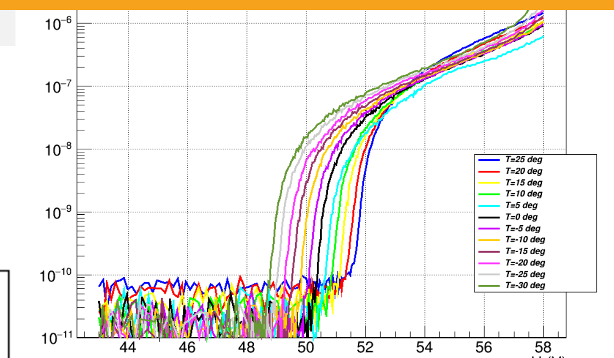
- Sensl 1x1 mm2 shows the biggest dependance



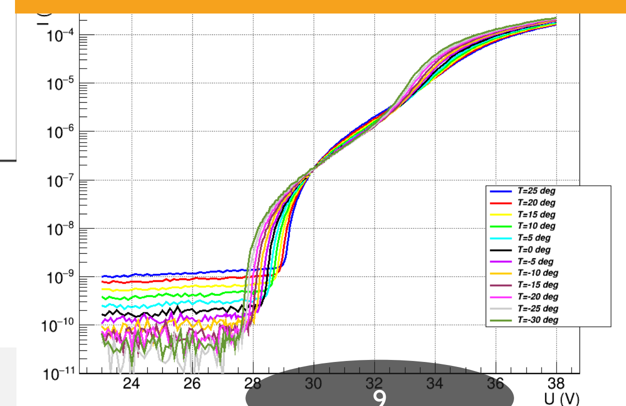
KETEK – PM3325-WB



Hamamatsu S13360-3050VE

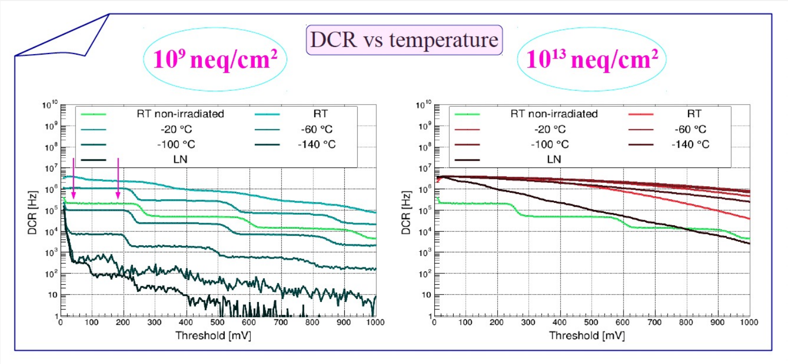


AdvanSiD – ASD-RGB3S-P



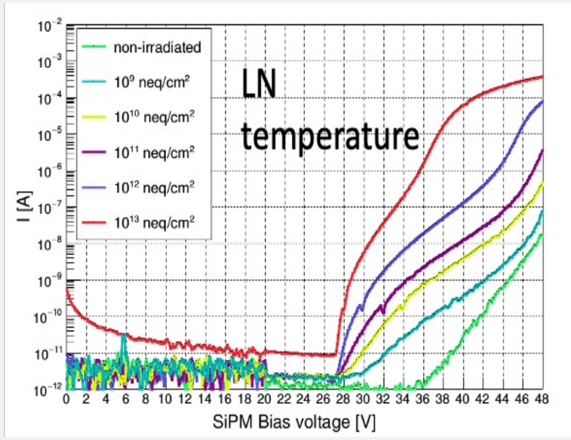
CHARACTERISATION AT LIQUID N2

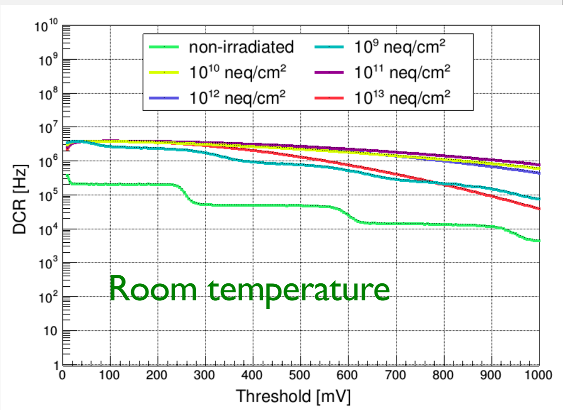
- 1 mm2 FBK NUV-HD-RH samples
- **HF high power cryogenic readout**
- Irradiated with neutrons : 10^9 … 10^{13} n/cm2
- Cooled down to -196 deg. in steps of 40 deg.

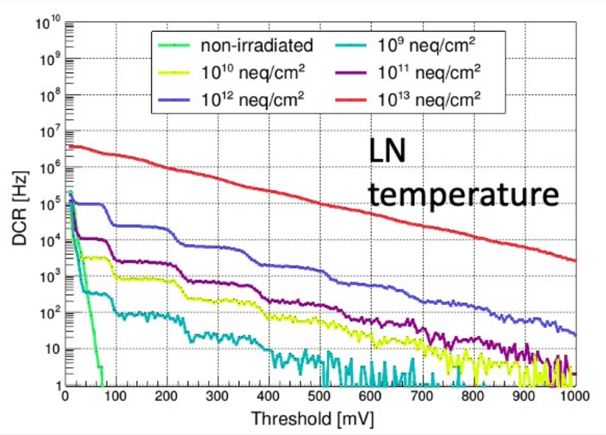


Current Voltage characteristics

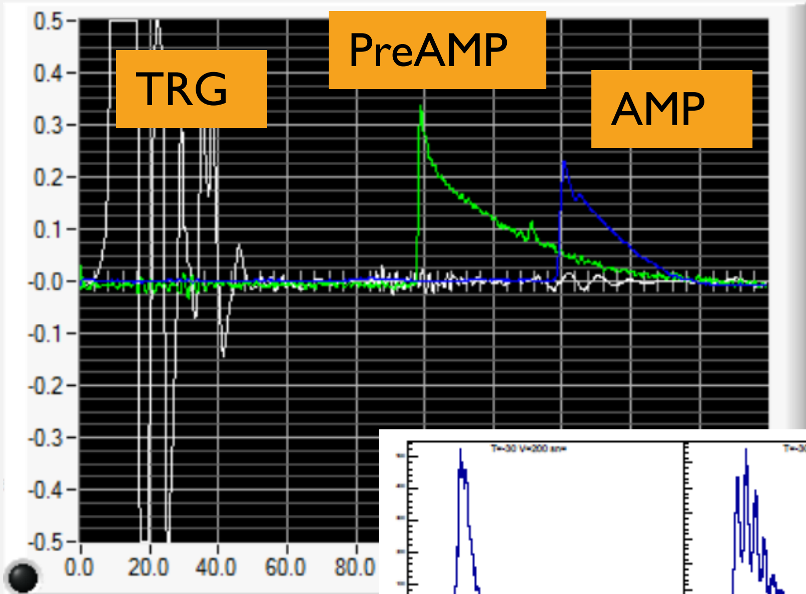
Dark count rate as a function of threshold



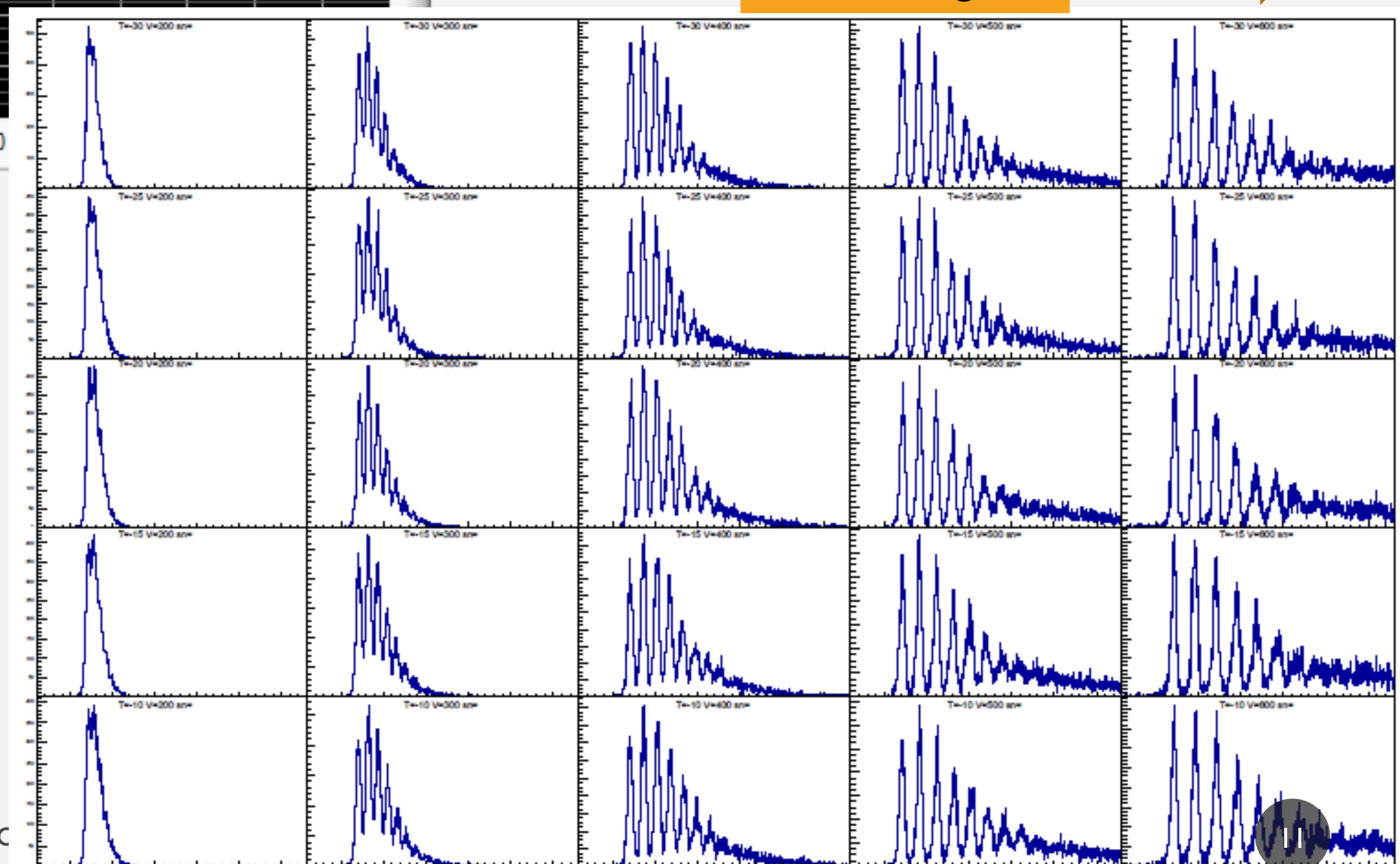




WAVEFORM ANALYSIS



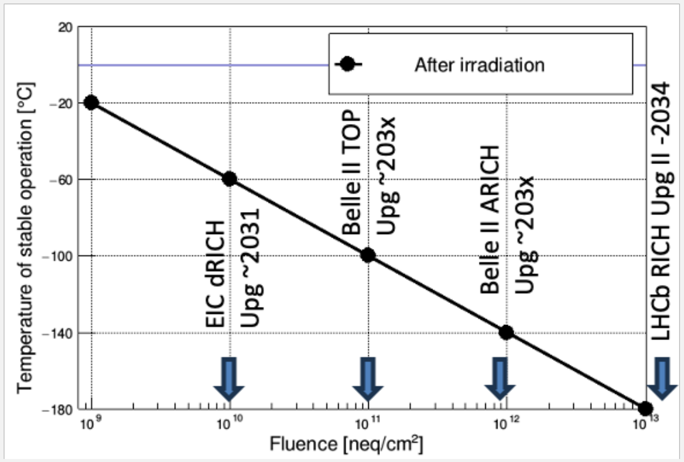
Accumulated charge distributions:
Clear separation of single photon signals in all samples before irradiation



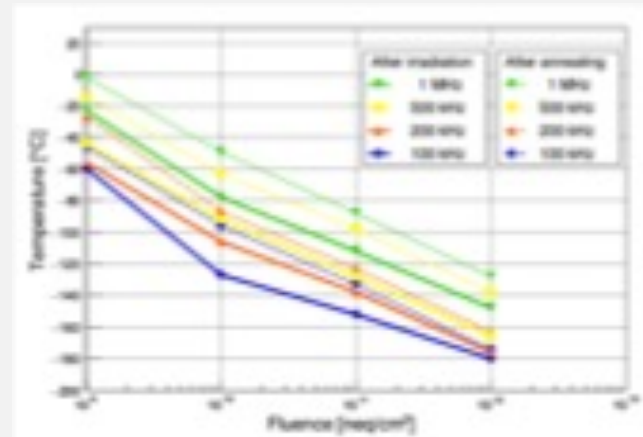
TEMPERATURE DEPENDENCE OF STABLE OPERATION

T at which the SiPM are "usable" :
where 1 p.e. peak is separated from the bgr.
Depends on the readout electronics

T at which the DCR is decreased to a certain level

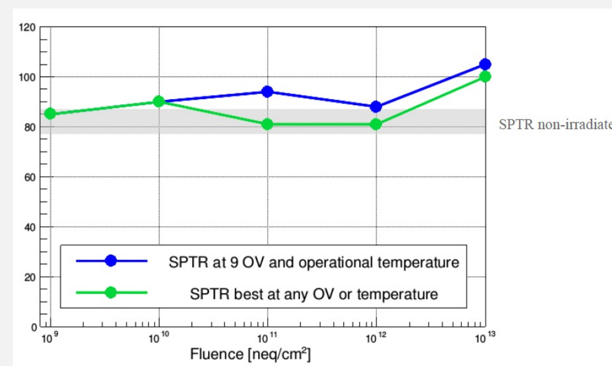


Consistent results



SPTR does not seem to be affected by irradiation as long as 1 p.e. cut is possible, up to 10^{13} neq/cm2

SPTR – FWHM (ps)



MULTICHANNEL ELECTRONICS FOR SINGLE PHOTON SENSORS - 65 NM FE: FASTIC/FASTIC+/FASTRICH

- Collaboration between CERN (and University of Barcelona (ICCUB)

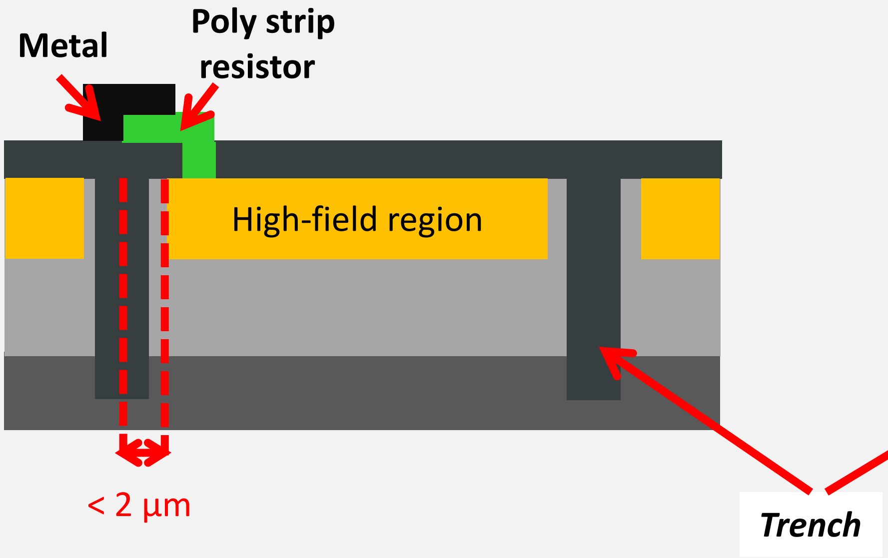
- Technological advancement in detector and FE technology
  - Enormous progress in SiPMs and MCPs
  - New TDC development @ CERN: picoTDC (~3 ps bin).
- **2022 - FastIC: Front-End chip in 65 nm**
  - Multipurpose chip: SiPMs, MCPs, etc
    - Single ended (pos/neg), differential, Binary (linear / non-linear ToT) and Analog output
- **2024 – FastIC+:**
  - FastIC + TDC with 25 ps bins
- **2025 – FastRICH:**
  - FastIC without energy measurements
  - constant fraction discriminator +
  - TDC + lpGBT interface
  - 40 MHz measurements

SIPM MODULE
FASTIC READOUT BOARD

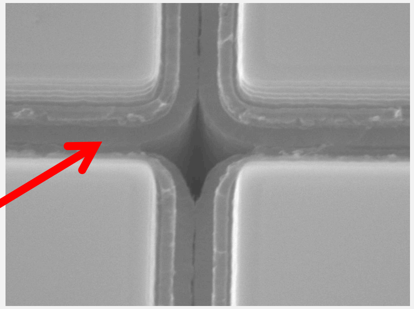
- Several samples of FastIC ASIC available at Ljubljana
- A.Seljak: Readout board with SiPMs and 2 FastIC chips constructed
  - Opal Kelly FPGA plug in for configuration
  - SLVS 16 differential channels read by VME 25ps CAEN TDC
  - Currently under debugging
  - Beamtest at KEK in 2024/2025

Production of new samples at FBK
AIDAinnova project

NUV-HD technology



Advantages:
- Lower cross-talk



Trenches between cells filled with highly doped polysilicon as light absorbing material

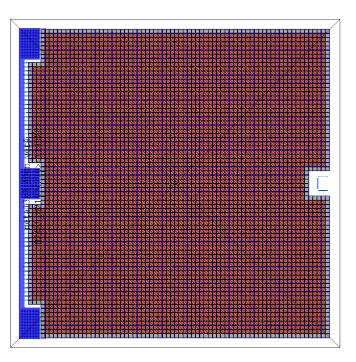
Sensors **2019**, *19*(2), 308

NUV-HD for AIDAInnova

The test structures will include several different SiPM and pixel sizes

3x3 mm²

- Aim: timing tests
- Die size: 3.15 mmx3.15mm
- Cell pitch: 15um, 25um, 40um, 75um
- Metal grid
- 3 bonding pads

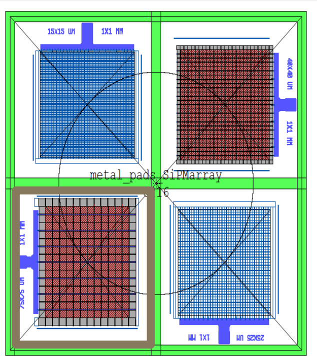


2x2 array of 1x1 mm² and mini-SiPM

- Die size: 3.15 mmx3.15mm
- Cell size: 15um, 25um, 40um, 75um
- Array of 2x2 with active area:
- 1x1 mm2, ~ 0.75x0.75 mm2, ~ 0.5x0.5 mm2, ~ 0.25x0.25 mm2
- Same bonding PADs
- Same center of active areas
- The 2x2 array variants can be sub-singulated in 4 individual pieces of 1.57x1.57mm2

Variants of 2x2 arrays:

1) 2x2 array of SiPM 1x1mm2 with 15um-25um-40um-75um cell size
2) 2x2 array of SiPM 0.75x0.75mm2 with 15um-25um-40um-75um cell size
3) 2x2 array of SiPM 0.5x0.5mm2 with 15um-25um-40um-75um cell size
4) 2x2 array of SiPM 0.25x0.25mm2 with 15um-25um-40um-75um cell size
5) 2x1 array of SiPM 1.5x1.5mm2 with 15um+25um cell size - (or slightly less, so that they still fit in the 3.15x3.15mm2 die)
6) 2x1 array of SiPM 1.5x1.5mm2 with 40um+75um cell size - (or slightly less, so that they still fit in the 3.15x3.15mm2 die)
7) single SiPM 2x2mm2 with 15um cell size
8) single SiPM 2x2mm2 with 40um cell size



TASK 4.2 DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

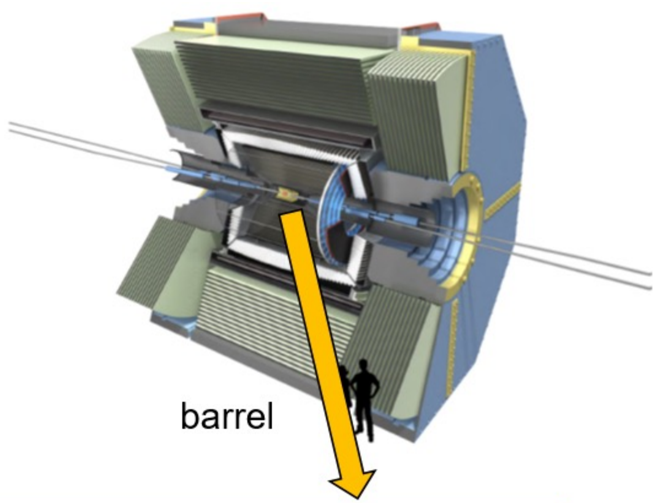
INFN,KEK

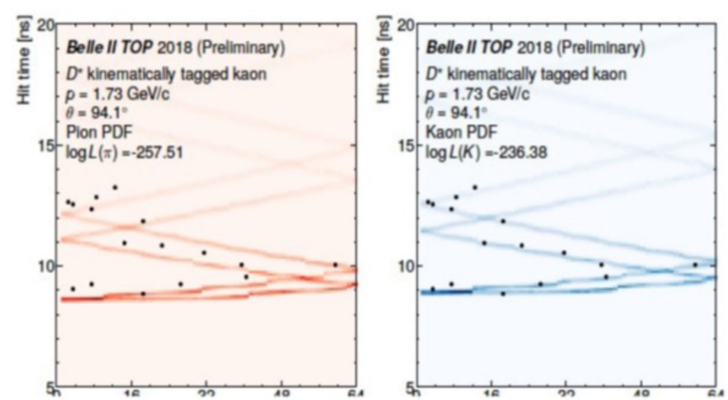
K. Inami & E. Torassa

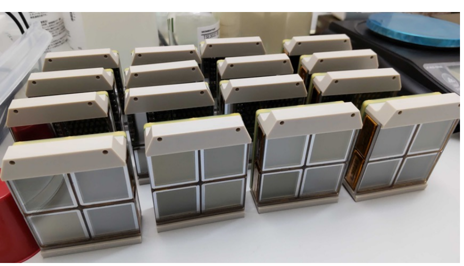
Photon detector studies for Belle II TOP

K. Inami & E. Torassa

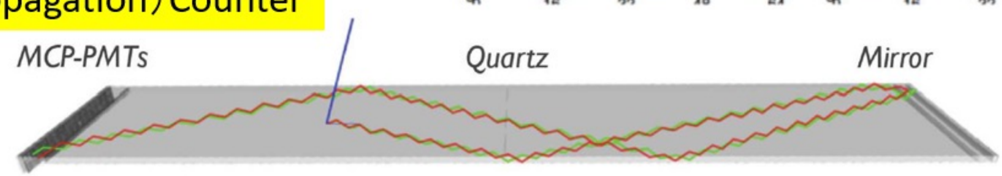
- MCP-PMT for TOP detector at Belle II experiment
  - R&D and mass-production with Hamamatsu photonics
  - Operation in the Belle II detector (512 1-inch MCP-PMTs)
  - Preparation for coming replacement to life-extended version
    - R&D for further improvement of lifetime







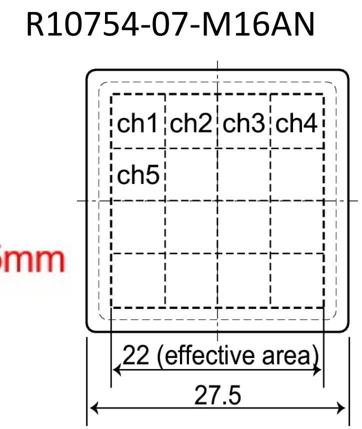
TOP (Time-Of-Propagation) Counter

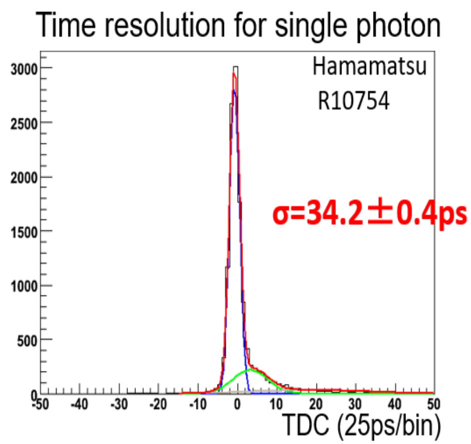


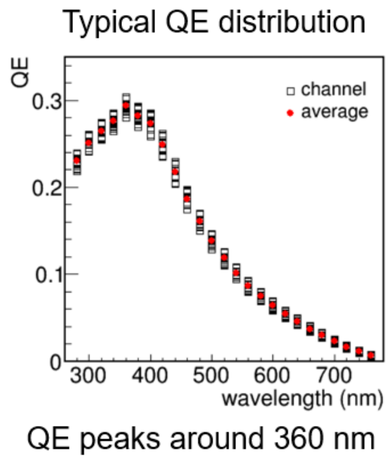
Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.

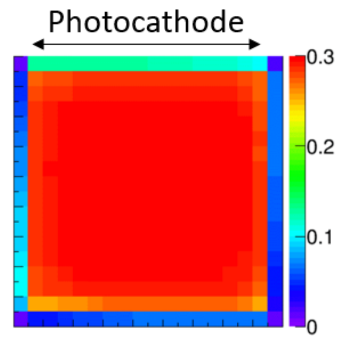
MCP-PMT for TOP

K. Inami & E. Torassa

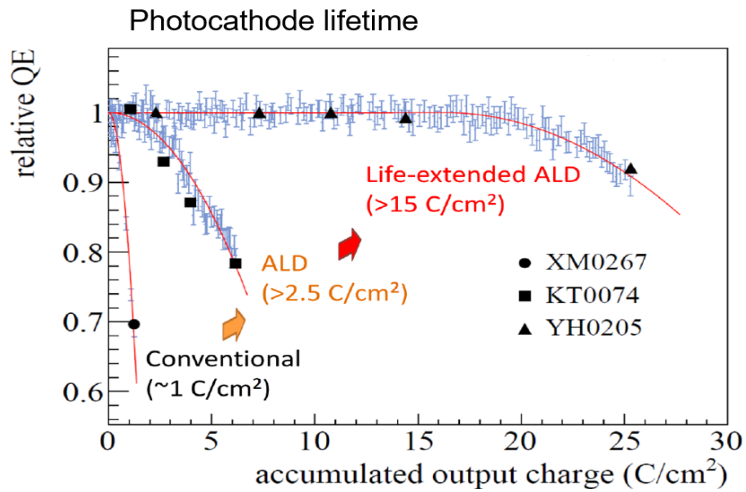


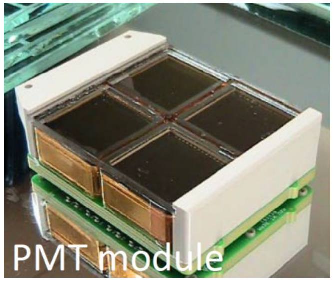






- 1-inch square MCP-PMT
  - By Hamamatsu
- 16 individual channels
- Excellent timing resolution
  - < 50ps
- Peak QE ~28% at 360nm
  - Good flatness



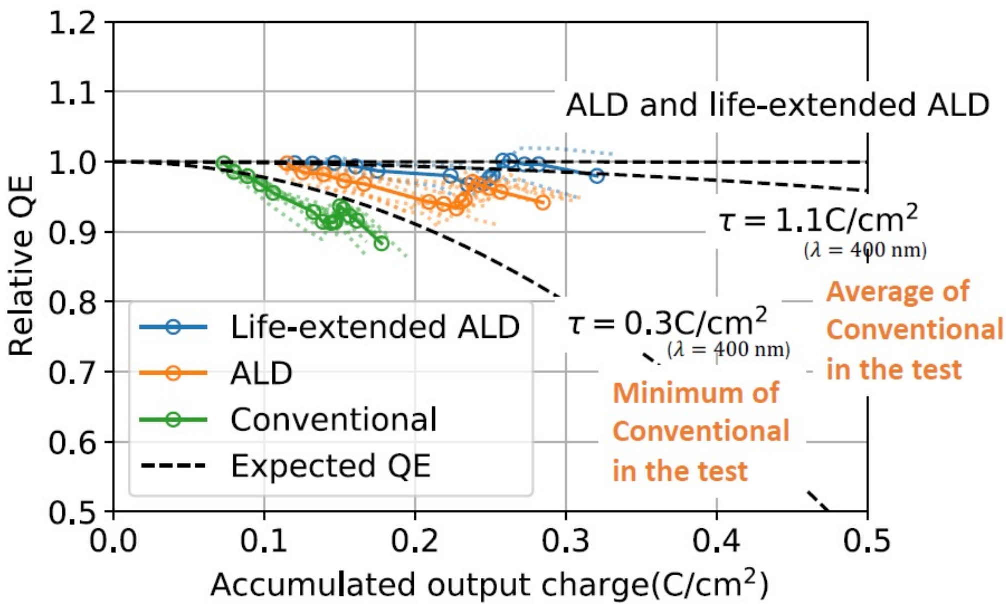


- Issues in photo-cathode lifetime
  - Improved by changing MCP coating

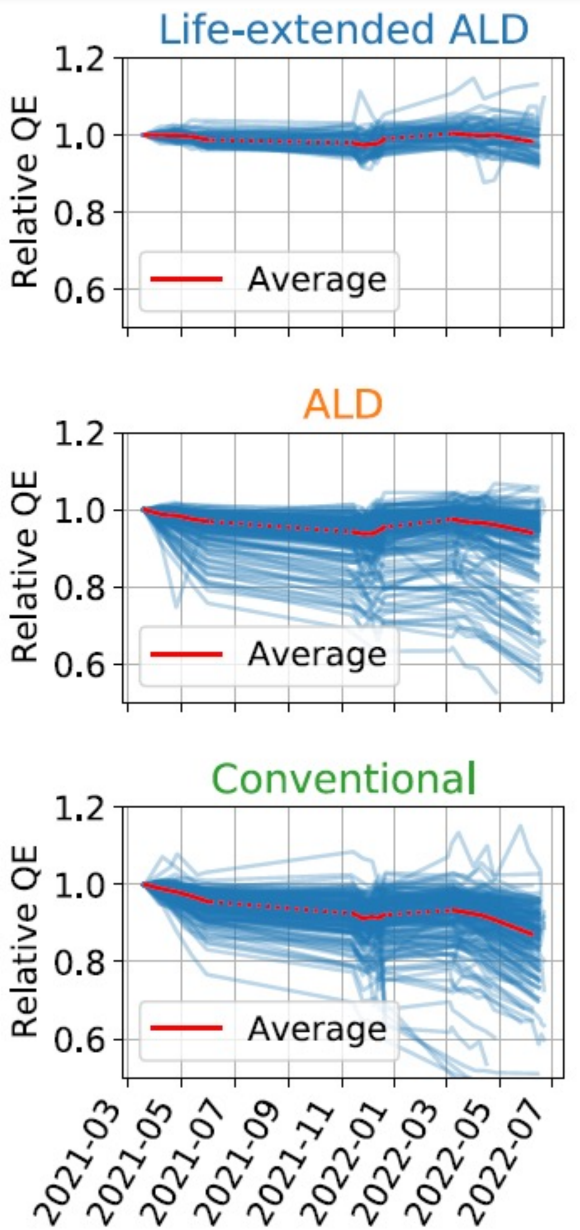
QE variation during the operation

K. Inami & E. Torassa

- QE variation is monitored by di-muon samples.
- We see larger QE degradation than expected for conventional and normal ALD PMTs.
- Confirmed actual QE degradation by measuring QE for removed PMTs from the detector.

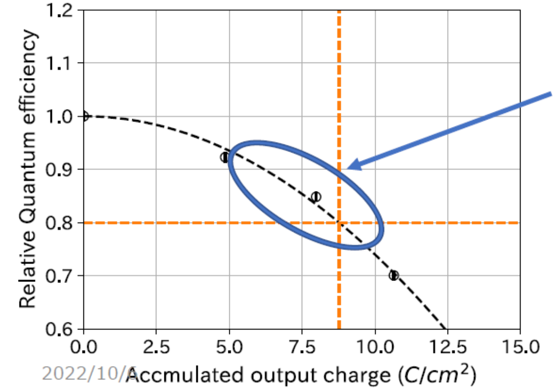


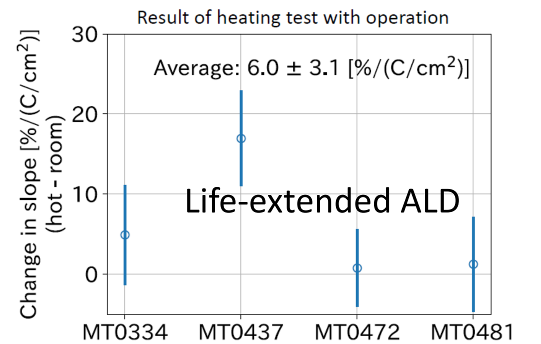
Dotted line : SLOT average
Solid line : Type average



Lifetime test at high temperature

- QE stability under high temperature (~40°C)
  - Check slope dependence on temperature
  - No significant effect in life-extended PMTs
  - Indication of faster degradation in high temperature for conventional PMTs





Setup

Use of thermostatic chamber to maintain temperature.