JENNIFER 2 Kickoff meeting, Vienna 12.-13.9.2019

WORK PACKAGE 4: NEW PHOTODETECTORS DEVELOPMENT

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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	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)

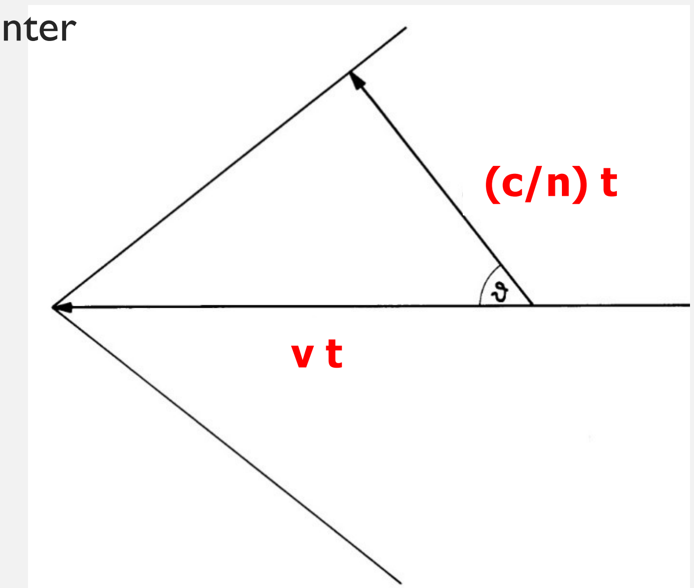
Common deliverable: Support organization and participation to photon detectors training sessions for PhD students at NDIP 2020 conference (month 18)

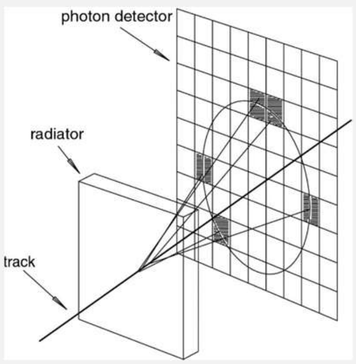
PARTICLE IDENTIFICATION IN PARTICLE PHYSICS: USE OF CHERENKOV RADIATION

A charged track with velocity $v=\beta c$ exceeding the speed of light c/n in a medium with refractive index n emits polarized light at a characteristic (Cherenkov) angle, $\cos\theta = c/nv = 1/\beta n$

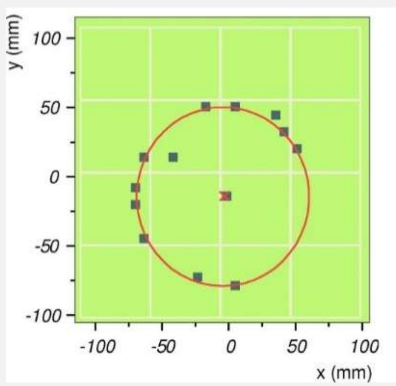
Cherenkov photons detected on a plane → Ring Imaging Cherenkov counter

ring radius → Cherenkov angle → velocity





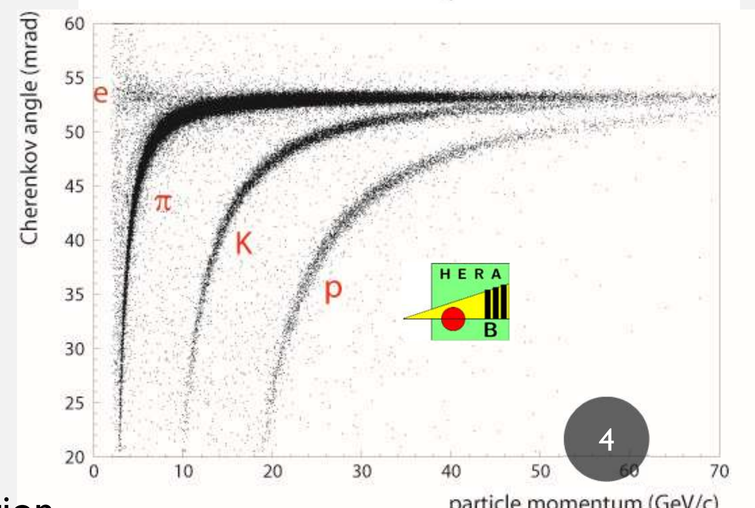
ARICH prototype for Belle II



Very low light level = few photons

Efficient fine granularity photo sensor for single photons with low noise and high time resolution

R. Pestotnik, WP4/T4.1&T4.2@JENNIFER2 Kickoff , Vienna 2019



e.g. in Belle II 2 RICH detectors used: Aerogel RICH and Time-of-Propagation

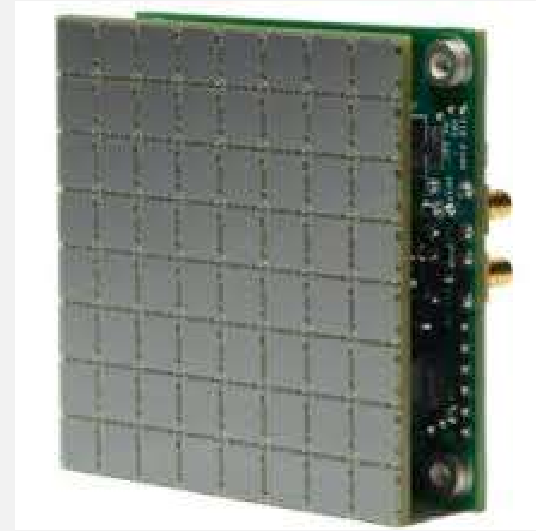
PHOTON COUNTING IN HIGHLY IRRADIATED ENVIRONMENTS

Background:

- Belle II Upgrade (2027) – 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 SIPMS AS SINGLE PHOTON COUNTERS IN NEUTRON IRRADIATED AREAS

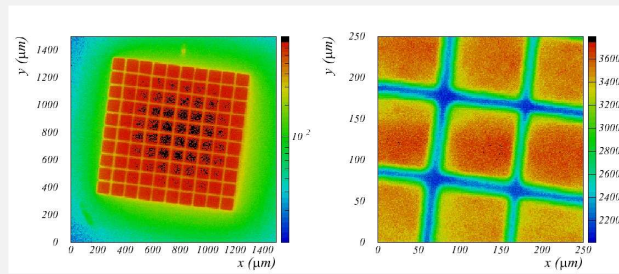
JSI,FBK,KEK

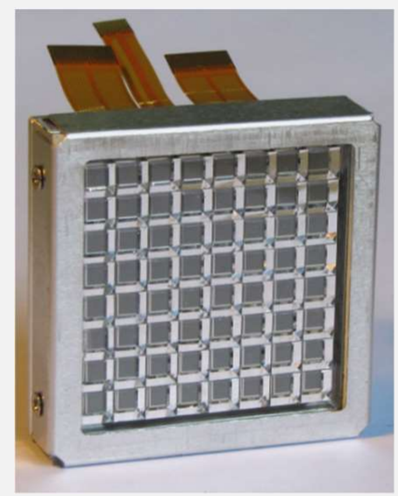


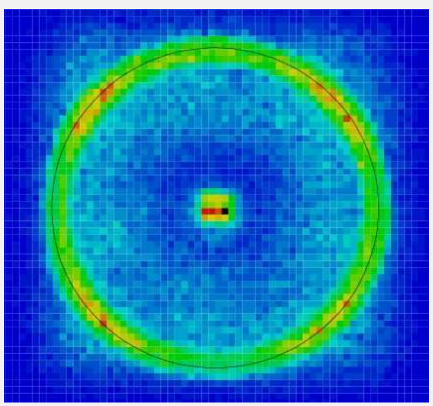
SiPMs as a photon detector for Belle II ARICH upgrade:

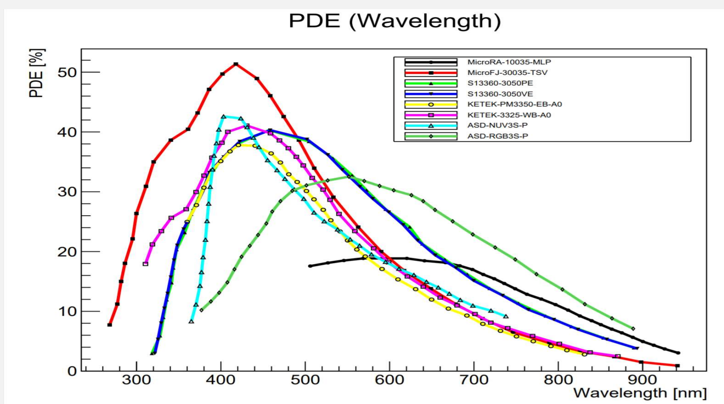
Tested as a candidate for current photon det. of Belle II RICH :

- ❑ Array of APDs working in a limited Geiger mode
- ❑ Easy to operate Vbias ~20-70V
- ❑ High Gain ~10^6
- ❑ Works in a magnetic field
- ❑ High PDE 40-50%
- ❑ Disadvantages:
  - ❑ high background. rate
  - ❑ Sensitivity to neutrons



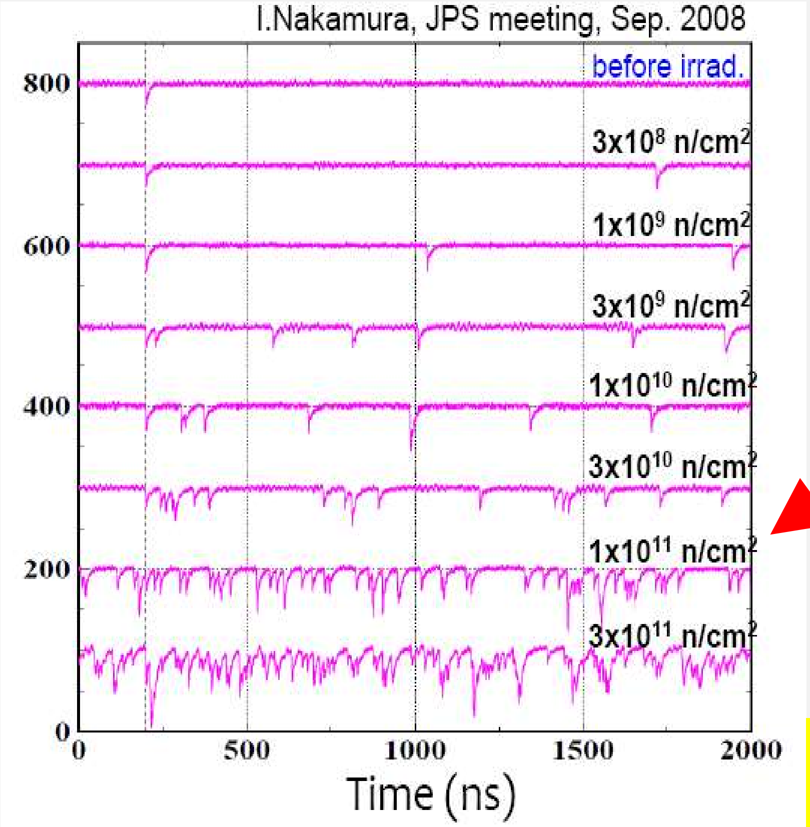




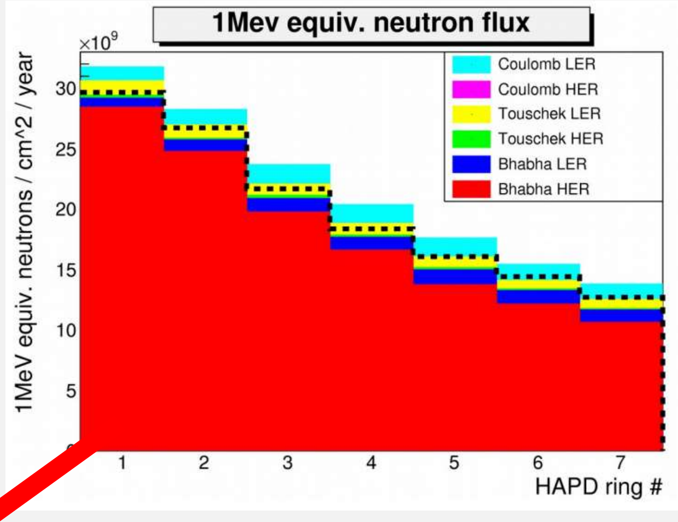


Sensitivity to neutron irradiation

Time evolution of a SiPM signal



Expected neutron fluence per year as a function of the distance from the beam



~10^{11}n/cm^{2}year

Noise hits after one year

Unfortunately due to such a neutron load, we decided not to use it in Belle II

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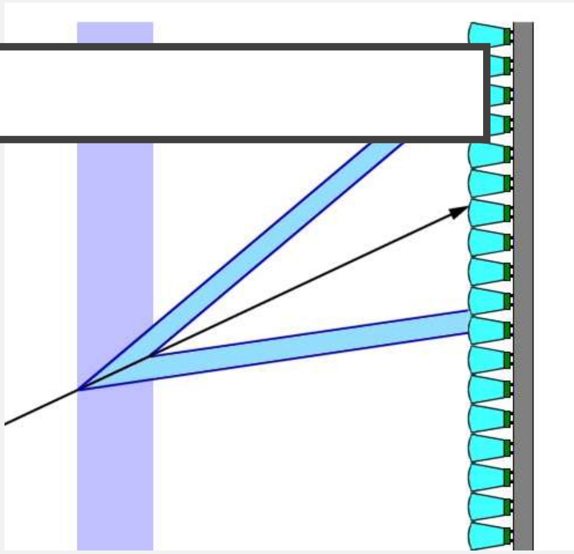
R. Pestotnik: SiPMs for RICH

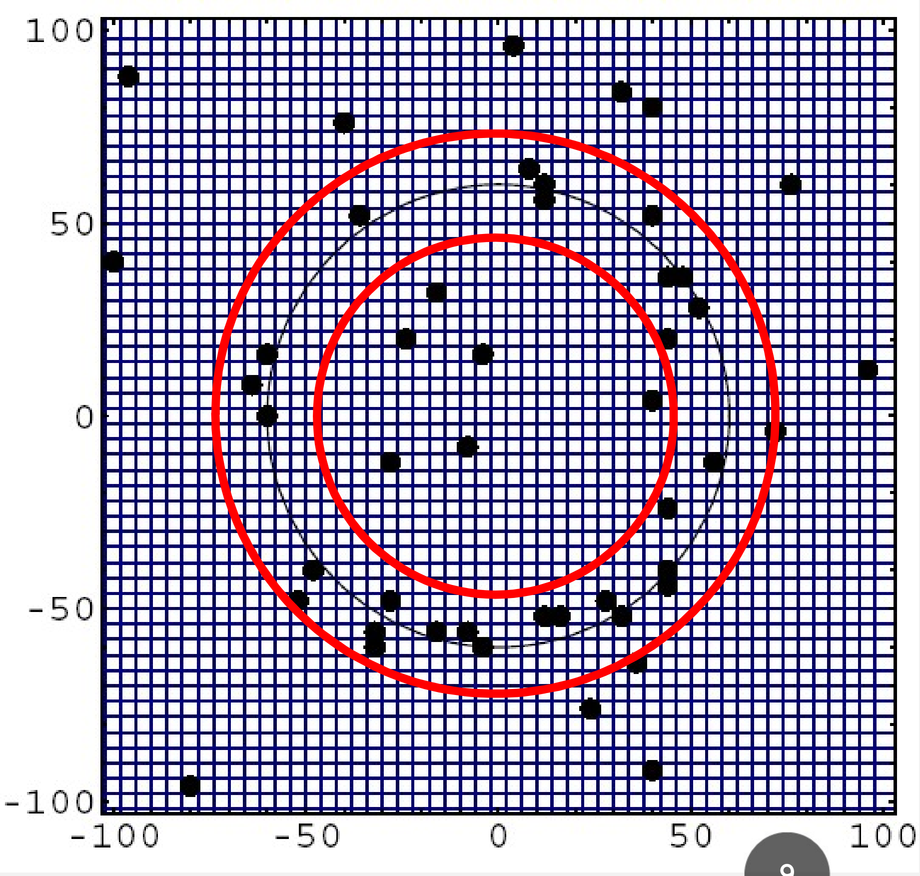
SIGNAL TO NOISE



How to use such a sensor in RICH

S/N ratio can be increased by:

- smaller ring image area
- narrower analysis time window
- use of light collection system (light guides / micorlenses) to increase effective area of the sensor
- operating the sensor at a lower temperature

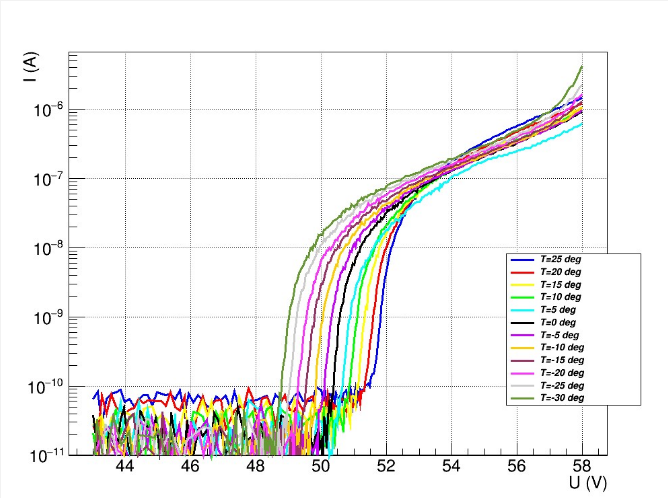


OBJECTIVES

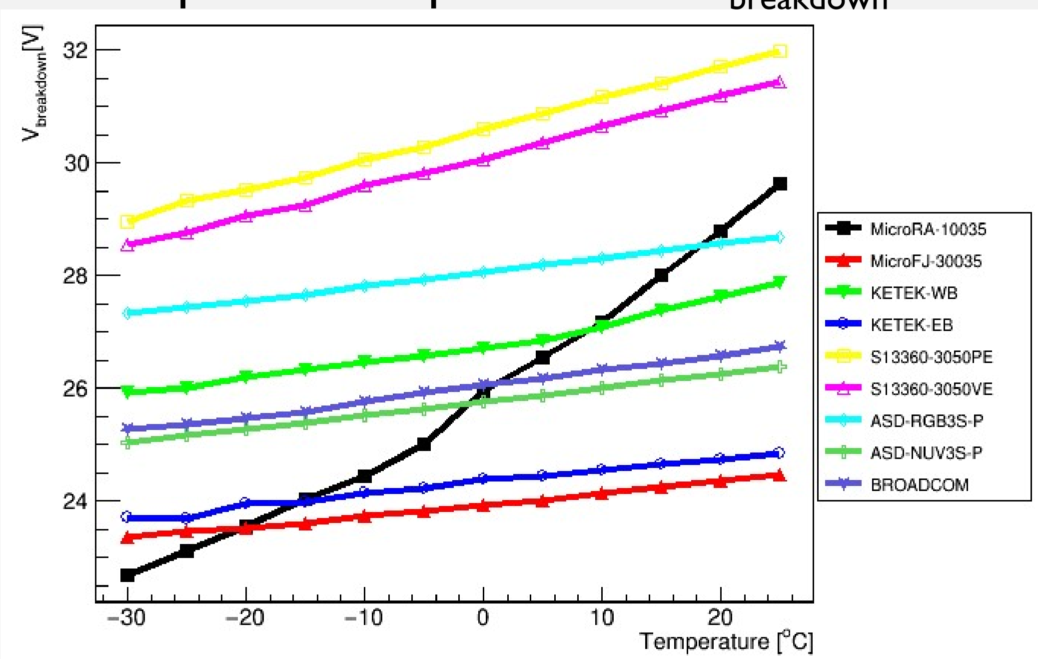
- ❑ Study of silicon PM samples before and after irradiation with neutrons:
- ❑ time and pulse height distribution, waveform analysis, background noise counts, effect of annealing .
- ❑ Design requirements, selection of SiPM, design and fabrication of readout electronics.
- ❑ Development of light concentrator 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.

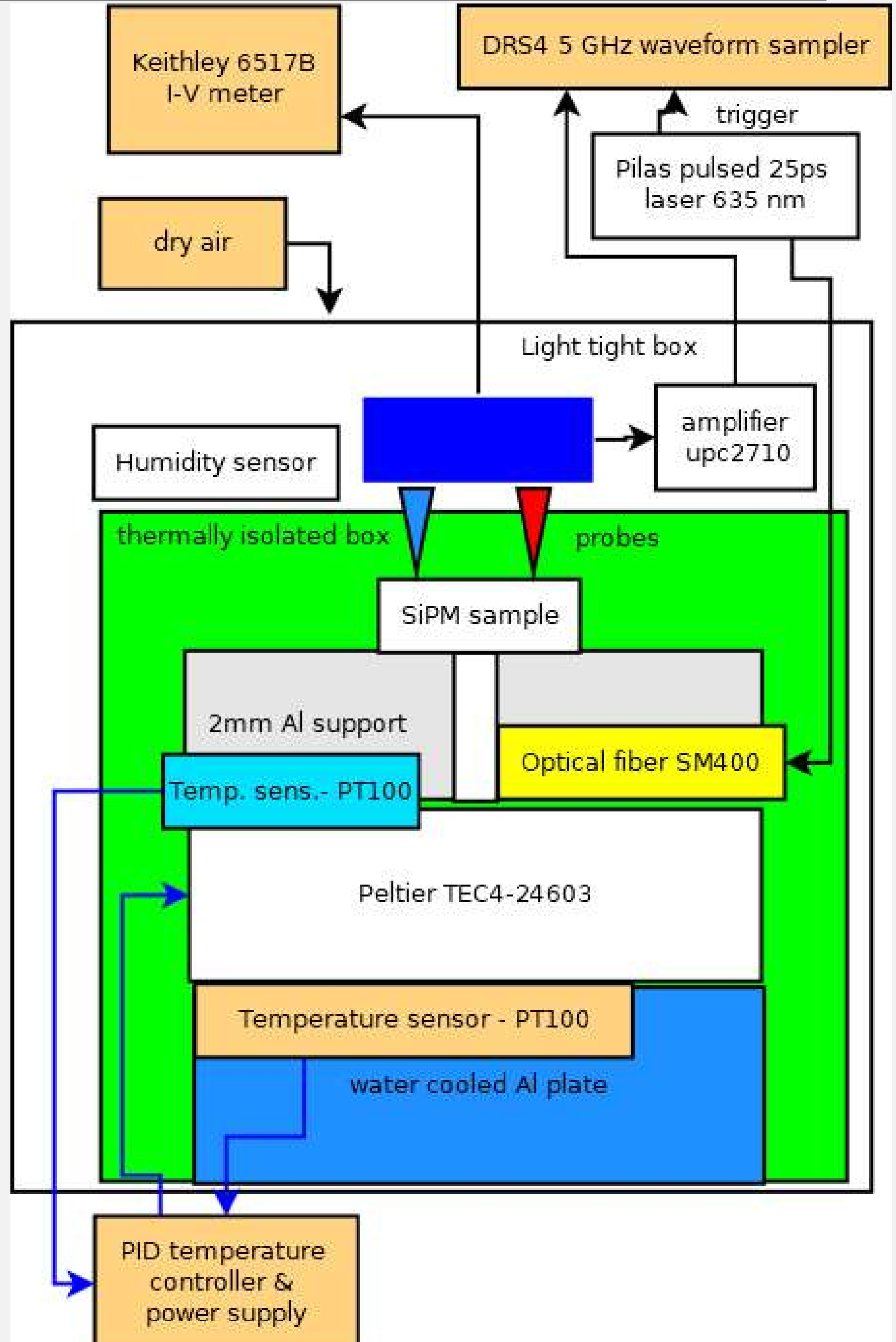
- ❑ Key people: Rok Pestotnik (JSI), Prof. Samo Korpar (JSI), prof. Nishida Shohei (KEK), Alberto Gola (FBK) custom technology team leader.

CURRENT ACTIVITIES



Temperature dependence of $V_{breakdown}$



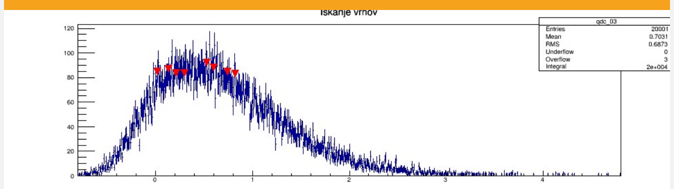


IRRADIATION @ TRIGA, JSI, LJUBLJANA

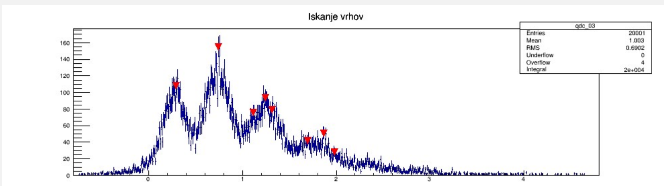
Pulse height distributions

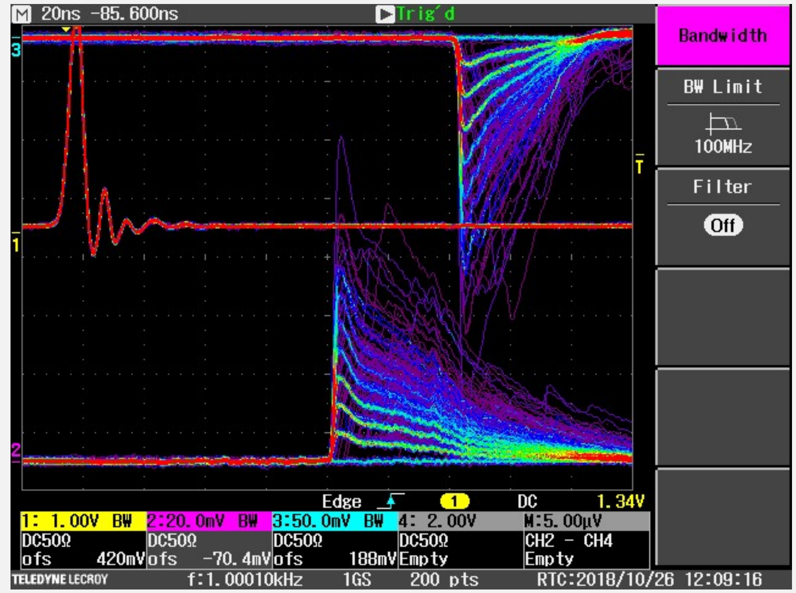
Fluence 10^{12}n/cm2

-50°C

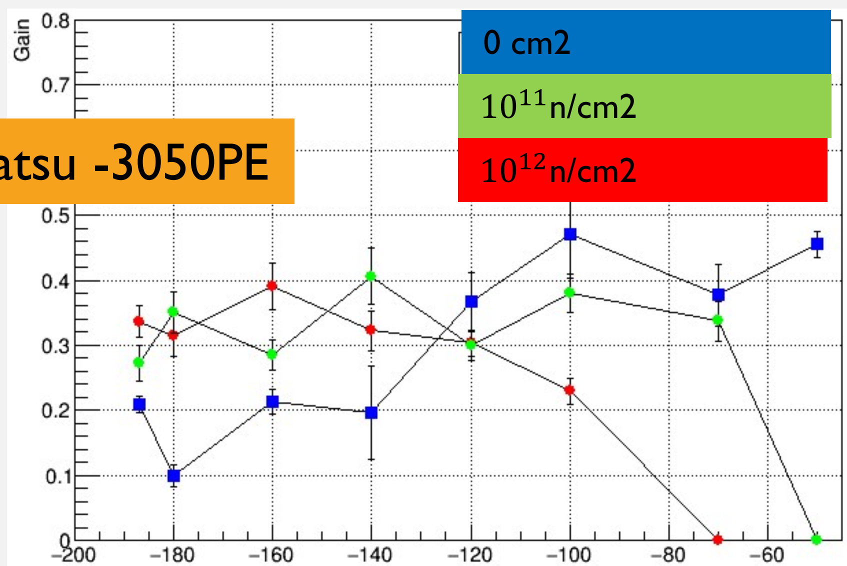


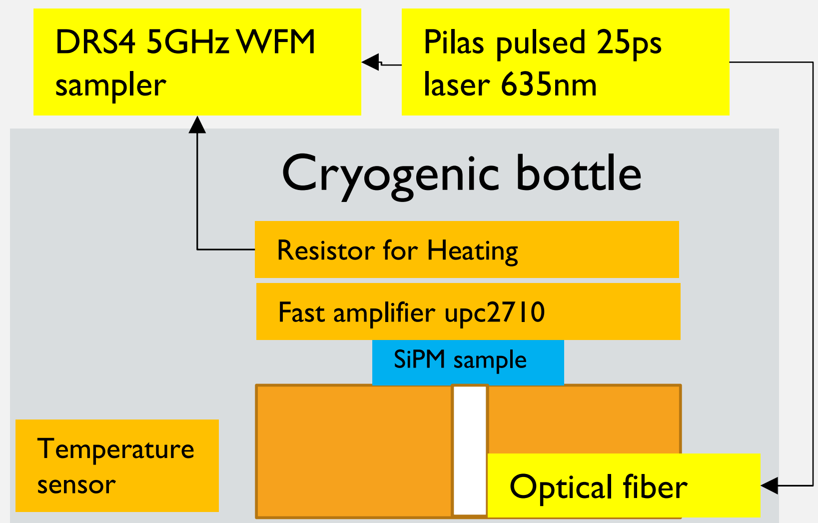
-100°C





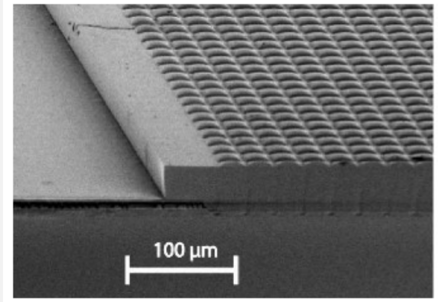
Hamamatsu -3050PE





SIPM FOR RICH IN HIGHLY IRRADIATED AREAS

- ❑ Decrease active area
- ❑ Decrease number of SPADs
- ❑ Focus light by using microlenses
- ❑ Digital readout – connect several SPADs to a TDC



Digital Photosensor Specifications

- Time *accuracy* one order of magnitude better than the current MD-SiPM design (TDC resolution <20 ps).
- Implemented on a CMOS process with **optimized SPADs for NUV detection** (PDE >20% at 350 nm)
- Improved **light collection** by combining microlenses with photonic crystals
- Lower Dark Count Rate (**DCR**<50 kcps/mm2)
- Flexible low-power and high-speed LVDS readout

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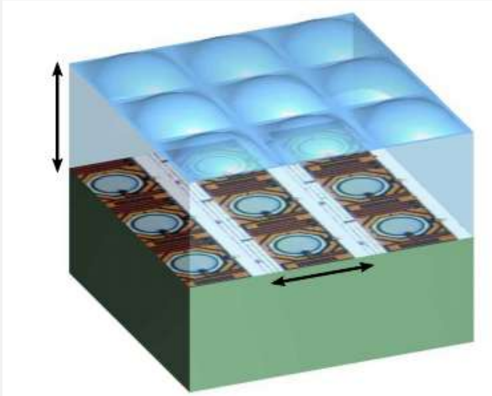


TASK 4.2 DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

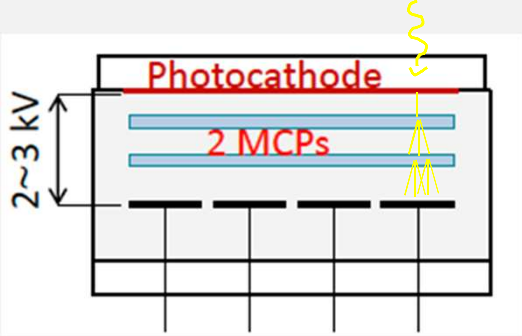
INFN,KEK

LONG LIVED MCP PMTS

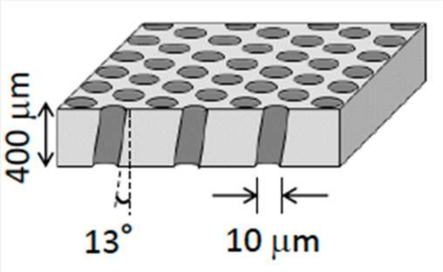
Introduction

The Time-Of-Propagation (TOP) detector must measure the arrival time of Cherenkov photons with a time resolution lower than 100 ps. Inside high background environment the quantun efficiency of the photocatode is degraded by gas or positive ions desorbed form the MCP layer during the electron multiplication inside microchannels.

MCP-PMT suqare shape for high fill factor (73%)



Two MCP to have enough gain(5 10^5) to detect single photon. Charge collected with 16 (4x4) anodes.



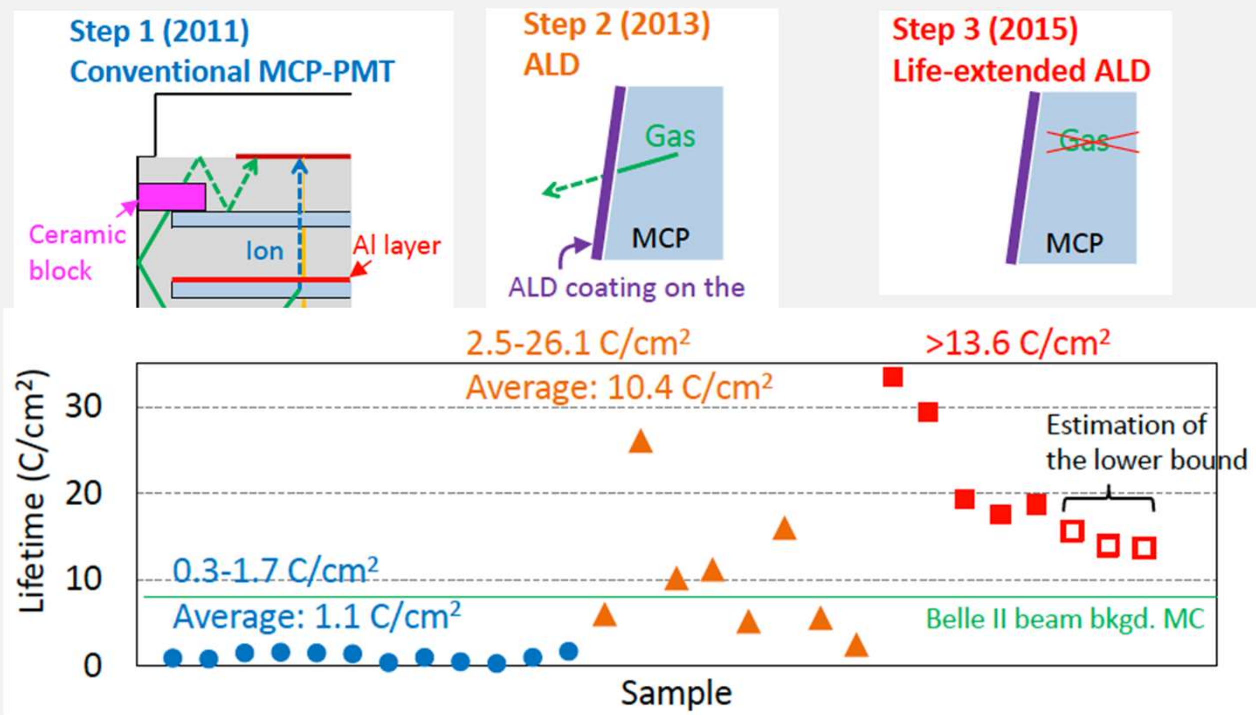
Small channels (10 µm) for a limited transit time spread (TTS < 40 ps)

TASK 4.2: DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

Goal

Improve the MPC-PMT photocathode lifetime as much as possible:

- to replace older MCP-PMT;
- to survive many years with high luminosity (high background) conditions.



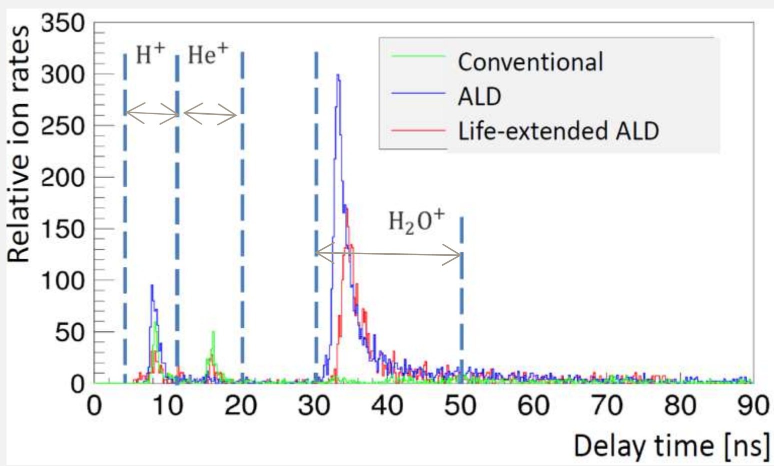
TASK 4.2: DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

MPC-PMT developments

To understand the mechanism of photo-cathode deterioration, we measure feed-backed ion's signals using different developed MCP-PMTs. The three different delay times correspond to feed-backed H^+, He^+ and H_2O^+. There is no evident correlation between secondary signal height and type of MCP-PMTs. The main responsible of photo-cathode deterioration are not charged ions, could be are neutral residual gas ions. Additional test and studies will be performed.

Priority:

Restart MCP-PMTs production reducing test failure rate and increasing production rate.



2018 test

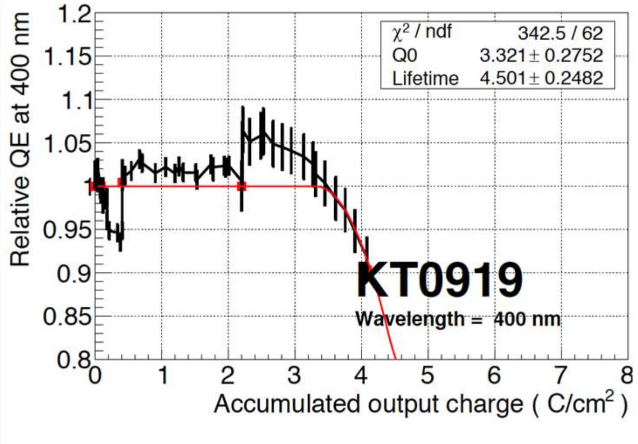
TASK 4.2: DEVELOPMENT OF LONG-LIVED MCP PHOTOMULTIPLIERS

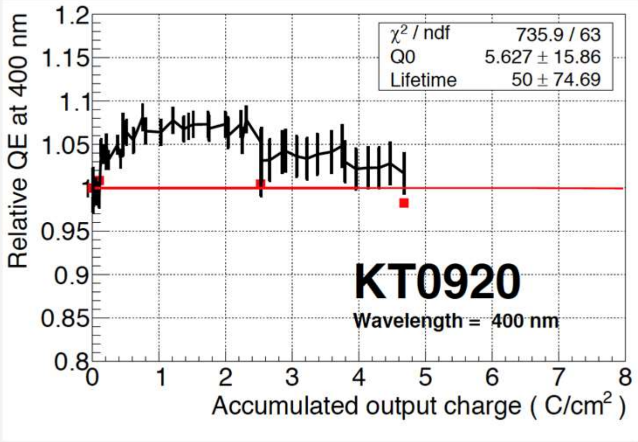
PMT ID	Dec. 2018	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019
KT0919	→	→	0.7 C/cm^2		2.2 C/cm^2		4.1 C/cm^2
KT0920	→	→	0.8 C/cm^2		2.5 C/cm^2		4.7 C/cm^2
MT0112					→		1.9 C/cm^2
MT0115					→		1.9 C/cm^2

Current activities:

- Evaluation of lifetimes for the current samples
- 4 MPC-PMT under measurements,
- Collected charge: 2 samples @4-5C/cm2 , 2 samples @ 2C/cm2
- One of them (KT919) look like to have a shorted lifetime than expected but additional charge collection is needed.
- **Plan: speedup the measurement with more intense light.**
- MCP-PMT developments:
- Padova&Roma3 proposed to measure the photocathode film properties before and after aging
- Waiting for Hamamatsu to provide a photocathode film sample on a small air isolated glass
- If there is now success in increase of lifetime: change photosensor to SiPM – focus on task 4.1.

- Study the maximum acceptable Dark Current Rate
- Study the irradiation hardness requirements
- Effect of temperature on the operation of the SiPM (change of operation temperature from 297K to 250K?)





WP4 SUMMARY

- Photon detection is very active area with lots of different activities
- In the framework of JENNIFER2 we will capitalize the knowledge to push the technologies into new particle detectors.