JENNIFER 2 General meeting, Prague 17.-18.11.2022

WORK PACKAGE 4: NEW PHOTODETECTORS DEVELOPMENT

Rok Pestotnik
Jožef Stefan Institute, Ljubljana, Slovenia

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)

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

NDIP20 @ TROYES 2022

GRANTS

Thanks to the *JENNIFER²* program*, a very special rate is available to support young scientists' participation to NDIP20.

*JENNIFER² (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. JENNIFER² 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.

JENNIFER²
EU grant n.822070

	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

PHOTON COUNTING IN HIGHLY IRRADIATED ENVIRONMENTS

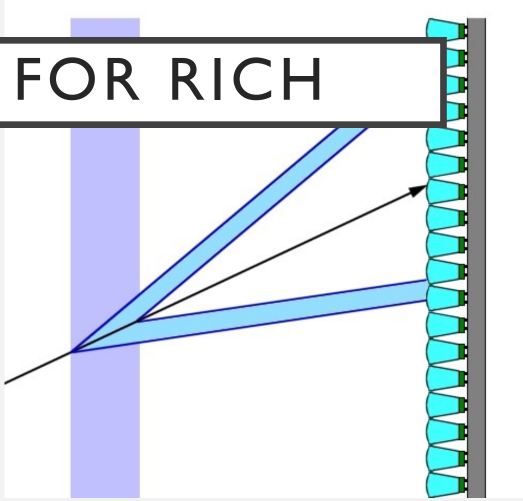
Background:

- Belle II Upgrade (2030) – 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

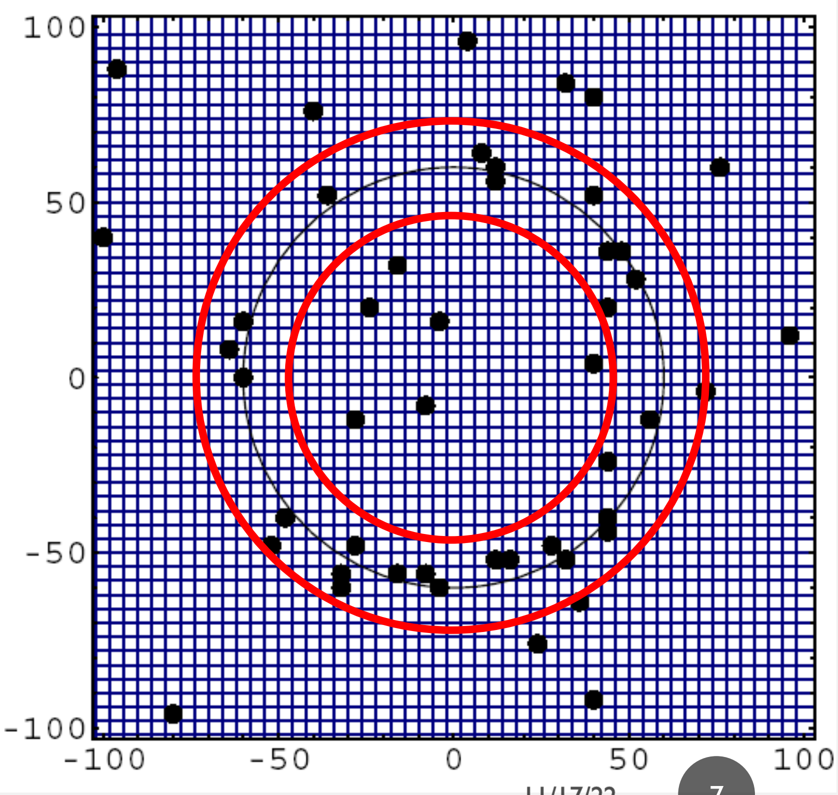
SIPMS AS PHOTON DETECTORS FOR RICH



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 / micro lenses) to increase effective area of the sensor**
- **operating the sensor at a lower temperature**



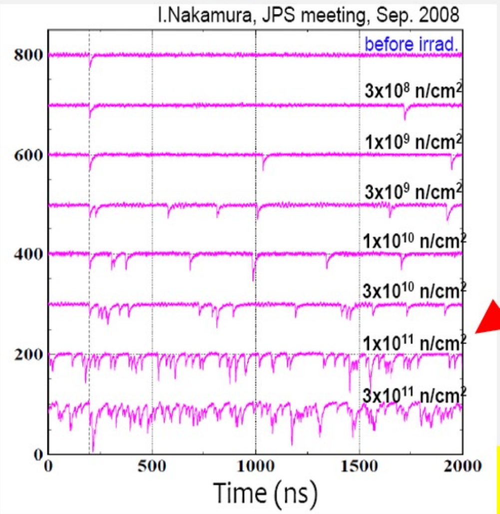
NEUTRON DAMAGE IN SIPMS

When irradiated SiPM signal baseline is degraded

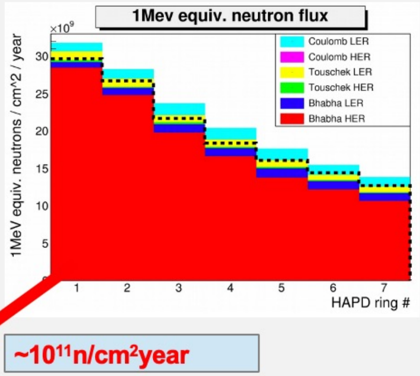
How to mitigate it ?

- **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**

Time evolution of a SiPM signal

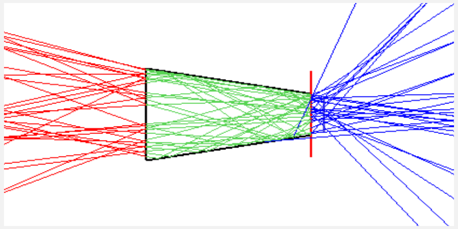


Expected neutron fluence per year as a function of the distance from the beam



Noise hits after one year

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



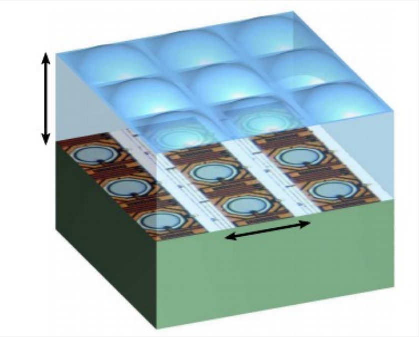
OBJECTIVES

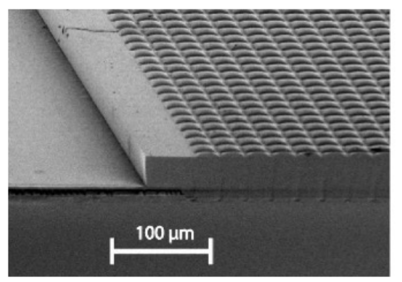
- Study of silicon PM samples before and after irradiation with neutrons:
- time and pulse height distribution, waveform analysis, background noise counts, effect of annealing .
- Design requirements, selection of SiPM, design and fabrication of readout electronics.
- Development of light concentrator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

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





CHARACTERIZATION OF SIPMS - SELECTION OF DIFFERENT HIGH SPEED/HIGH POWER AMPLIFIERS

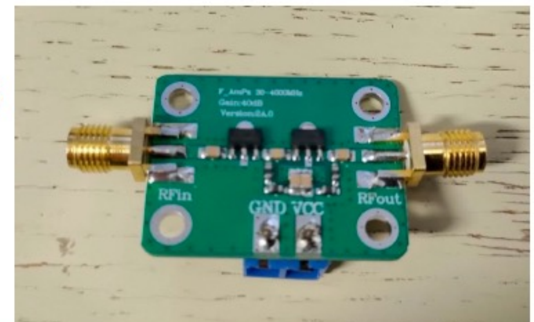
all used amplifiers
(PM1125, ov 4V (-> 29V), low light)

divider (cuts the signal in half, other end coupled with 50 ohm)

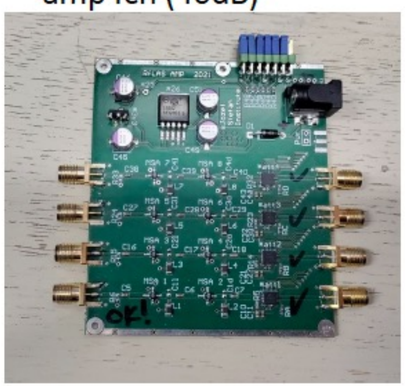
Low Pass Filter

ampCN (40dB)

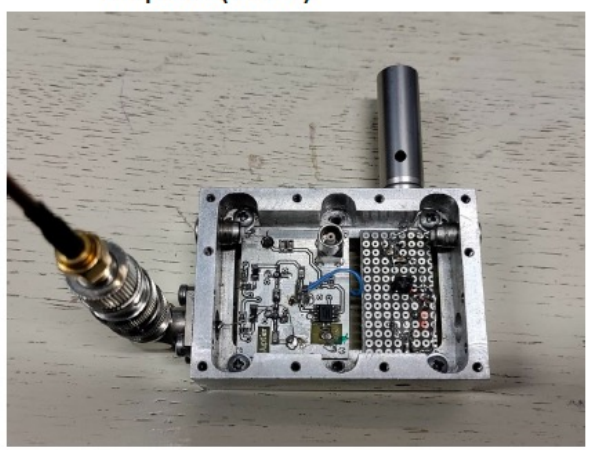
new40dB

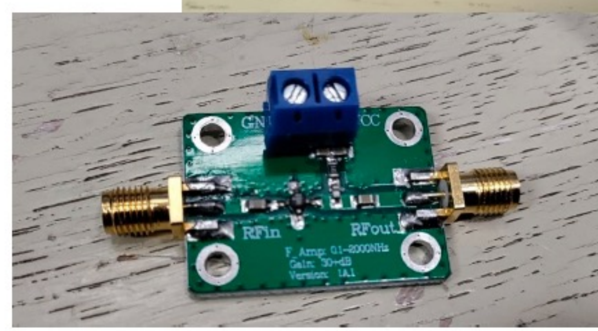


amp4ch (40dB)



amp3rd (30dB)

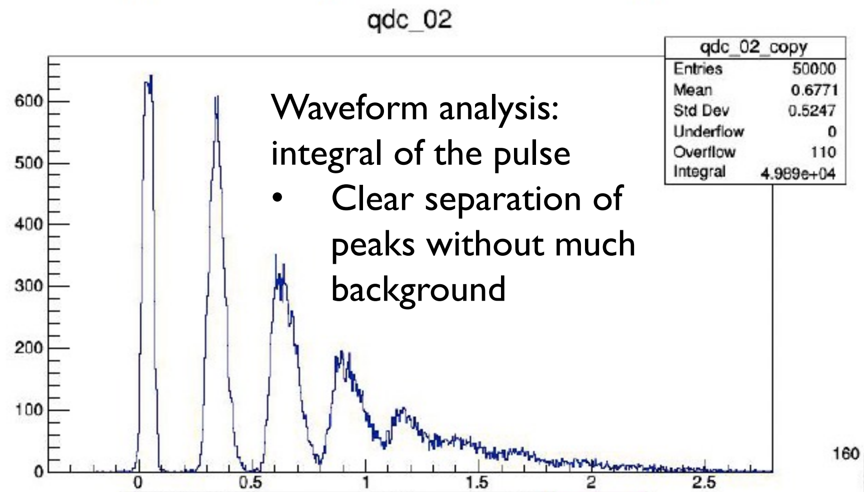




new 30dB

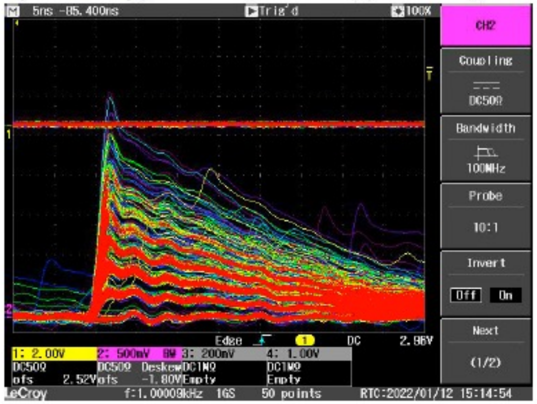
BEST AMPLIFIER SELECTED

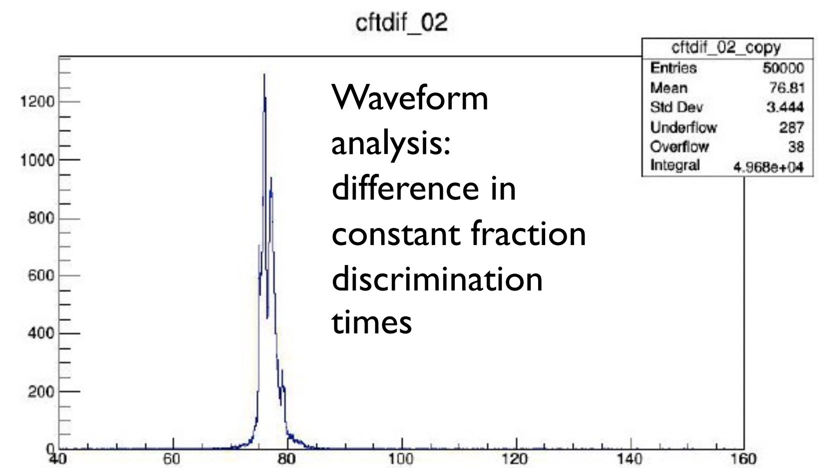
amp4ch (12V bias): ch1



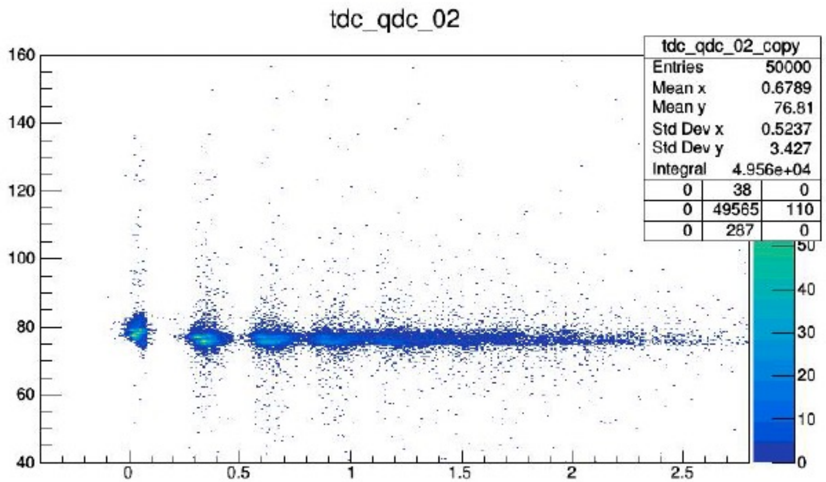
Waveform analysis: integral of the pulse

- Clear separation of peaks without much background

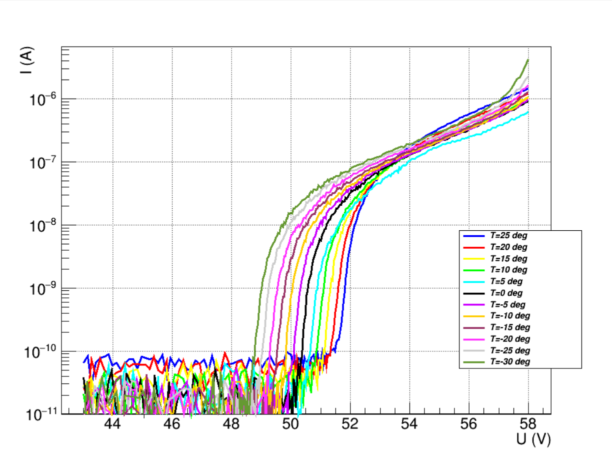




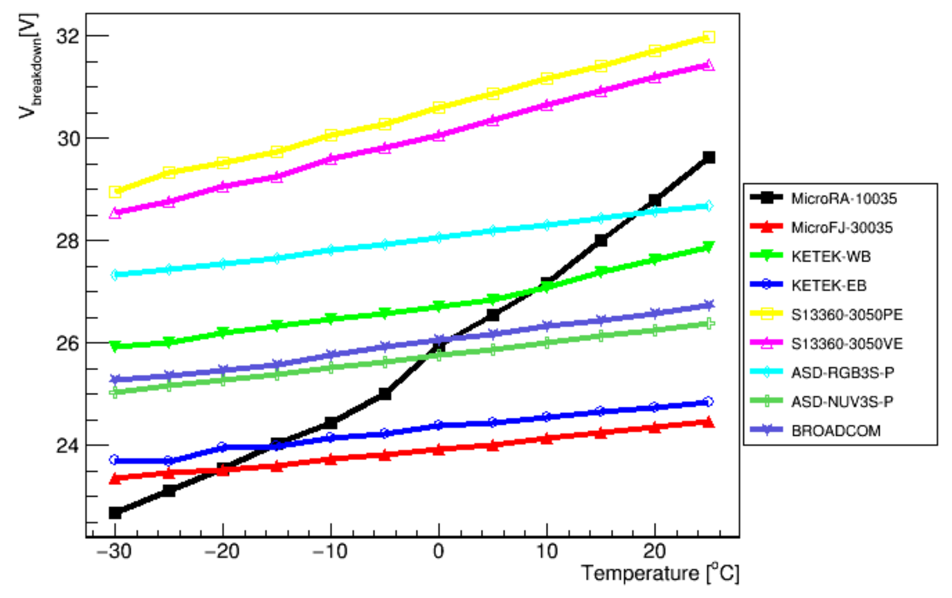
Waveform analysis: difference in constant fraction discrimination times

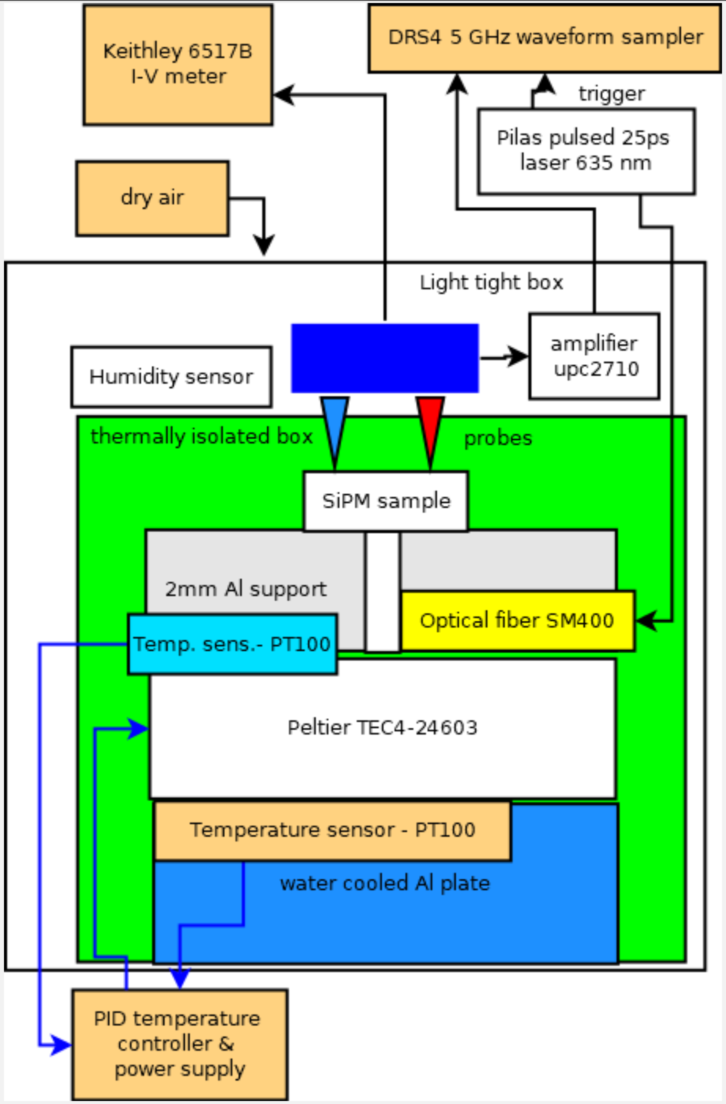


TESTS OF SIPM AT DIFFERENT TEMPERATURES



Temperature dependence of $V_{breakdown}$



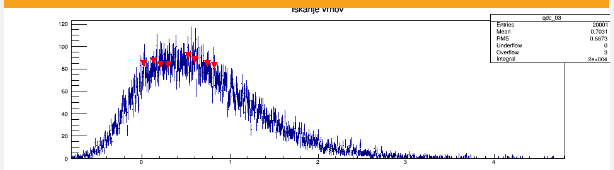


IRRADIATION @ TRIGA, JSI, LJUBLJANA

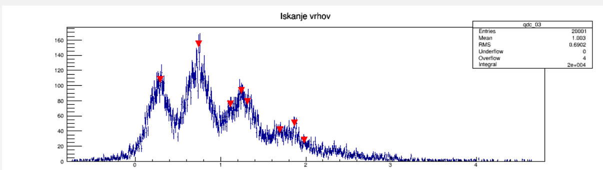
Pulse height distributions

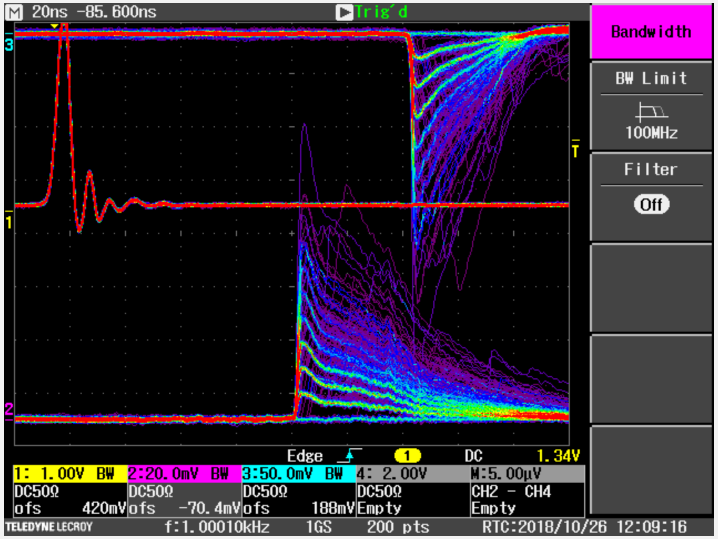
Fluence 10^{12}n/cm2

-50°C

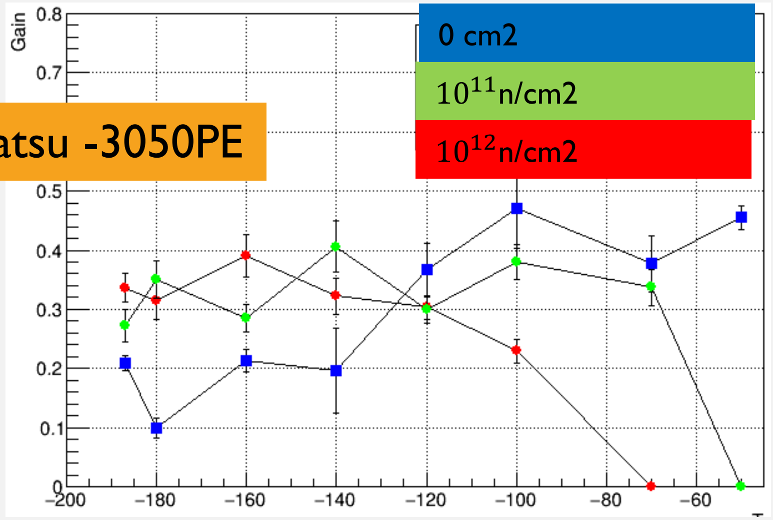


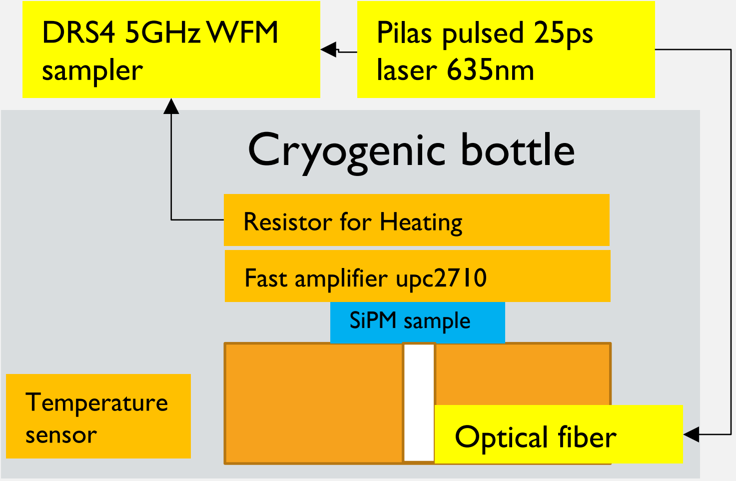
-100°C





Hamamatsu -3050PE

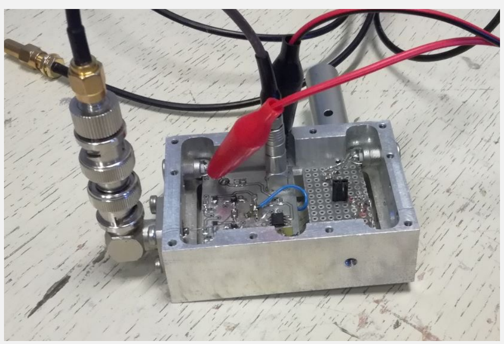




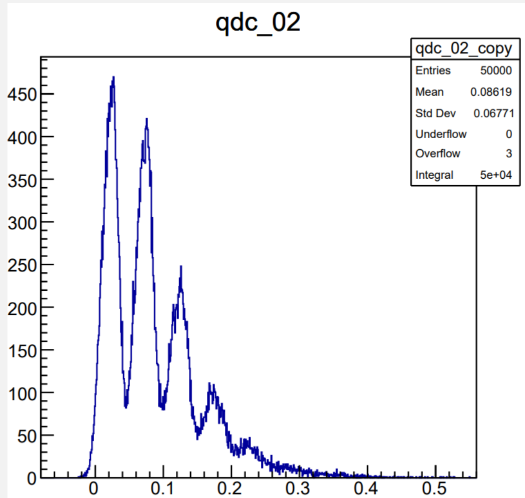
TESTS OF DIFFERENT HIGH SPEED AMPLIFIERS @JSI:

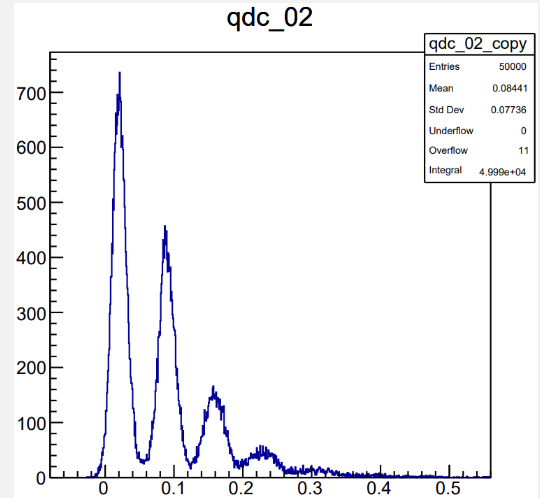
PM3335, bias 30V, ov 7V

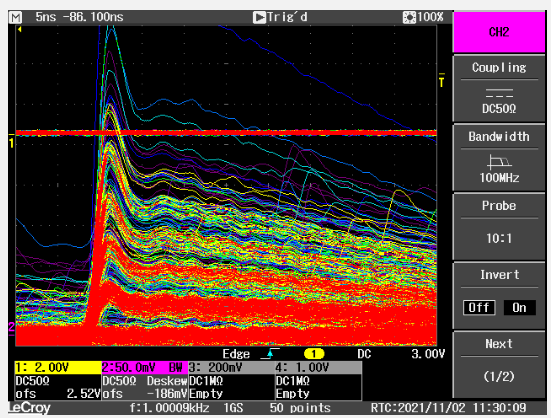
ampKETEK (bias 12V)



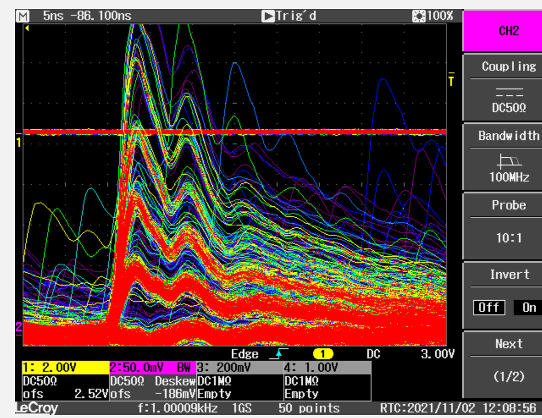
amp3rd (bias 6.3V)







ampKETEK



amp3rd

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

- Technical and financial collaboration between CERN (**KT funded**) and University of Barcelona (ICCUB) (**Grant FPA2016-80917-R**)

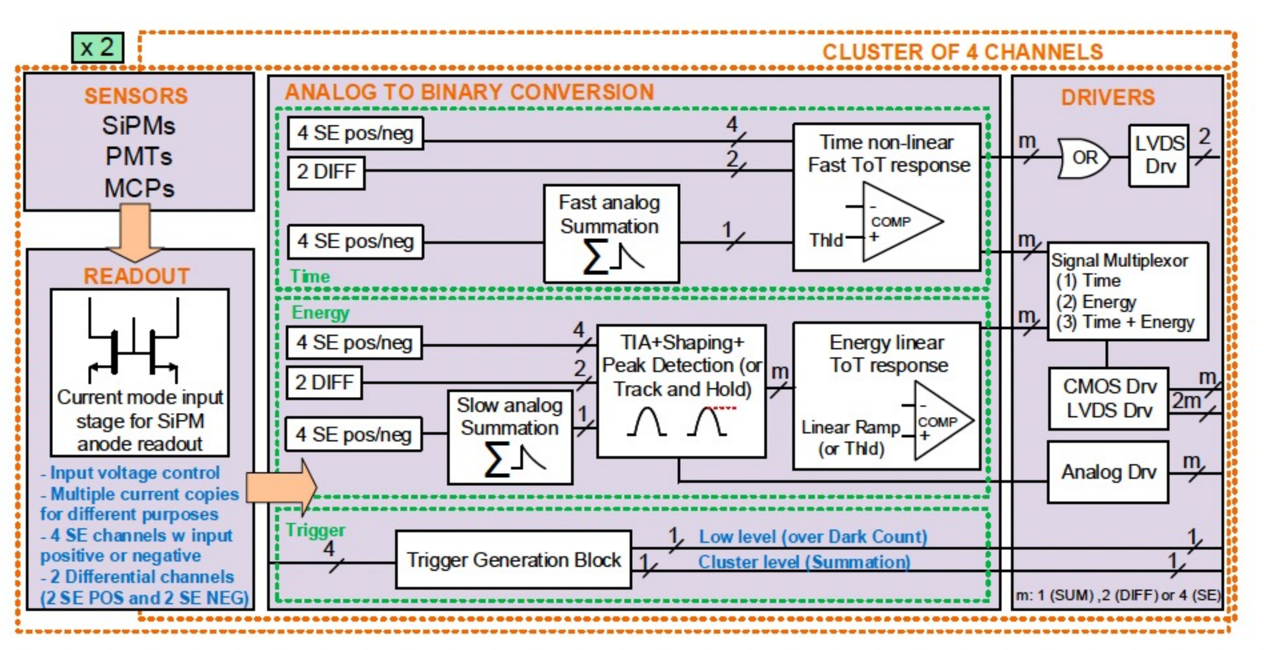
- Technological advancement in detector and FE technology
  - Enormous progress in SiPMs and MCPs
  - New TDC development @ CERN: picoTDC (~3 ps bin).
- **FastIC: new Front-End chip in 65 nm**
  - Multipurpose chip: SiPMs, MCPs, etc
    - Single ended (pos/neg), differential and active summation
    - Binary (linear / non-linear ToT) and Analog output
  - Received samples : 8 ch
  - Final chip: 32 channel (power < 10 mW/ch)

Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

M. Campbell, R. Ballabriga, N. Egidos, J.M. Fernandez, X. Llopart
D. Gascon, S. Gomez, R. Manera, J. Mauricio, A. Sanmukh

FASTIC SPECIFICATIONS

Parameter	Value
Technology	65 nm CMOS
Power consumption	~ 6 mW/ch in SE mode (V_{DD} = 1.2 V), depends on operation mode (~ 3 mW/Input Stage)
Number of channels	8 SE / 4 DIFF
Connection Type	Configurable SE (Pos/Neg polarity), DIFF, Sum of 4 (Pos/Neg polarity)
Electronics Time Jitter	~ 25 ps_{rms} SPTR (330 pF 3x3 SiPM, LCT5 S13360 SiPM, Vov = 4.5 V, L = 1.2 nH)
Energy Resolution	Linear (~ 2.5 % Linearity error)
Dynamic Range	5 uA - 20 mA
Maximum Rate	~ 2 MHz (Linear ToT readout), > 50 MHz (Non-linear ToT. Pulse-shape-dependent)
Testing and Calibration	Yes
Interface	I2C (compatible with picoTDC)
Output	Configurable Digital (single-ended CMOS or differential SLVS) or Analog output (10 pF load).



ACTIVITIES AT FBK

- Preparation of the clean room to perform the production of samples (funds for the production AIDAInnova Innovation Pilot)
- Praparation of samples for irradiation
- Study of different design changes
- We hold monthly meetings with FBK for the information exchange
  - Presentation of the setup and discussion of the results
  - Possible solutions: backside illuminated SiPMs, low field design implementation