Advancement and Innovation for Detectors at Accelerators

2nd Annual Meeting, Valencia, Spain, 24-27 April

Task 8.4.1

Innovative SiPM and future applications in PID Detectors

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Jožef Stefan Institute, Ljubljana
April 25, 2023

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Institutions in the task

Collaborating institutions with contacts and research interests/ projects

Institution	Contact name	Contact e-mail	Projects
CERN	Carmelo D'Ambrosio	ambrosio@cern.ch	LHCb RICH
INFN-Padova	Ezio Torassa	ezio.torassa@pd.infn.it	Belle II TOP
INFN-Torino	Roberto Mussa	Roberto.Mussa@to.infn.it	Belle II TOP
JSI Ljubljana	Rok Pestotnik (task coordinator)	Rok.Pestotnik@ijs.si	LHCb RICH Belle II ARICH
FBK Trento RTO	Alberto Gola	gola@fbk.eu	SiPM design
University of Bergen	Gerald Eigen	gerald.eigen@ift.uib.no	AHCAL
FOTON Prague Industrial	Jaroslav Moravec	moravec@fotons.cz	AHCAL
FZU Prague	Jiri Kvasnicka	kvas@fzu.cz	AHCAL

single photons

many photons

Motivation

Use of SiPM sensors for light detection in new generation of PID detectors

- Detection of **single photos**
  - Ring Imaging Cherenkov detectors – use of SiPMs in highly irradiated environments
- Detection of **many photons**
  - Calorimeters – gain stabilization - linearity

Task divided to cover different use cases:

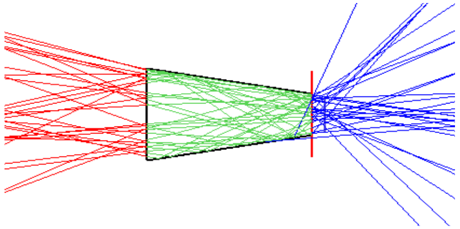
- CALICE Analog Hadron Calorimeter
- LHCb RICH
- Belle II Aerogel RICH + Time-Of-Propagation

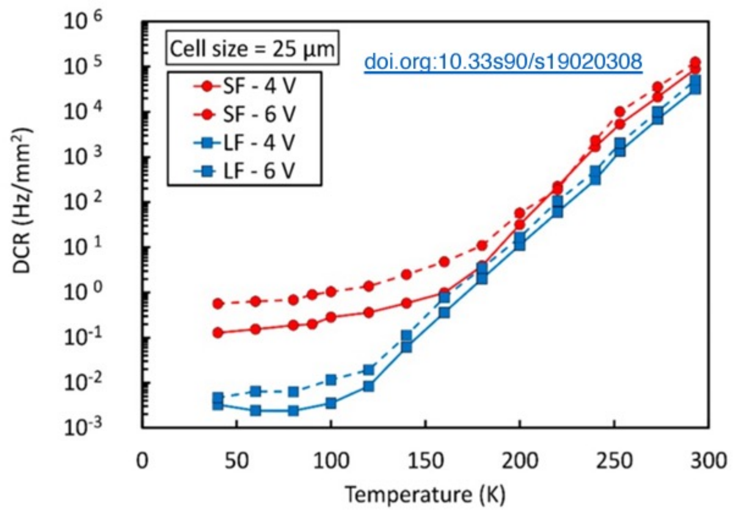
Task 8.4.1 - Innovative SiPMs and future applications in PiD Detectors	*Rok Pestotnik*
https://cern.zoom.us/j/62314643878?pwd=cm9qTURPekVDS2RadWZ0cE9SY1ZNQT09, Aula 2.4	15:15 - 15:35
SiPM test for the Belle II barrel PID detector upgrade	*Ezio Torassa*
https://cern.zoom.us/j/62314643878?pwd=cm9qTURPekVDS2RadWZ0cE9SY1ZNQT09, Aula 2.4	15:35 - 15:50
Task 8.4.1 Subtask multi channel readout and adaptive power supply	*Gerald Eigen*
https://cern.zoom.us/j/62314643878?pwd=cm9qTURPekVDS2RadWZ0cE9SY1ZNQT09, Aula 2.4	15:50 - 16:05

Subtask: Low level light sensors

Goal : Improve robustness under neutron irradiation, while maintaining low cost, high efficiency & good time resolution

- Development of SiPMs with improved radiation resistance
  - In collaboration with FBK: Review the production process, change of the design and production
- Systematic study of neutron irradiated SiPMs at different temperatures
  - Study the dark-count noise performance at different temperatures

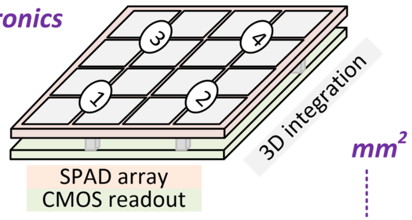




How to mitigate degradation of SiPM signal during the irradiation?

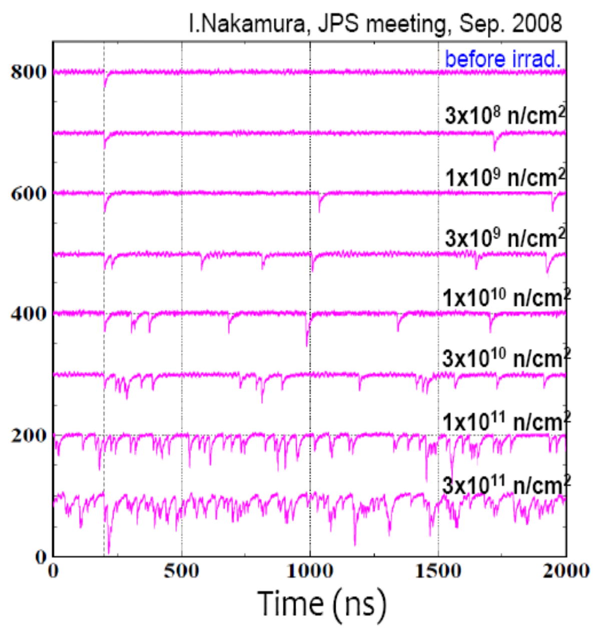
- **Boreated Polyethylene shielding**
- Smaller sensor size: **light collection – focus photons on smaller sensitive area**
- Operation at **lower temperatures**: DCR doubles every 8 deg., -20 °C .. -100 °C
- **Annealing** – recover operation
- **Use of fast / integrated electronics**
- **Change of internal design of SiPMs**

3D integration to hybridize sensor and electronics



Work program

Degradation of signal baseline when irradiated



- Systematic study of neutron irradiated SiPMs at different temperatures
    - White paper of measurement protocols for different operating conditions
    - Comparison of SiPMs of different producers
    - Optimization of a SiPM design
    - Define the operation limits for different use cases

MDPI sensors

Special Issue "New Developments on Photodetectors and Sensors for Particle Identification"

- Print Special Issue Flyer
- Special Issue Editors
- Special Issue Information
- Keywords
- Published Papers

A special issue of *Sensors* (ISSN 1424-8220). This special issue belongs to the section "**Intelligent Sensors**".

Deadline for manuscript submissions: **20 November 2023** | Viewed by 200

Milestone and deliverable

Milestone **Completed**

- Number: MS33
- Due: M18
- Definition of SiPM requirements and performance studies with simulations of different use cases.
- Type: Report to StCom
- Lead: JSI

Deliverable

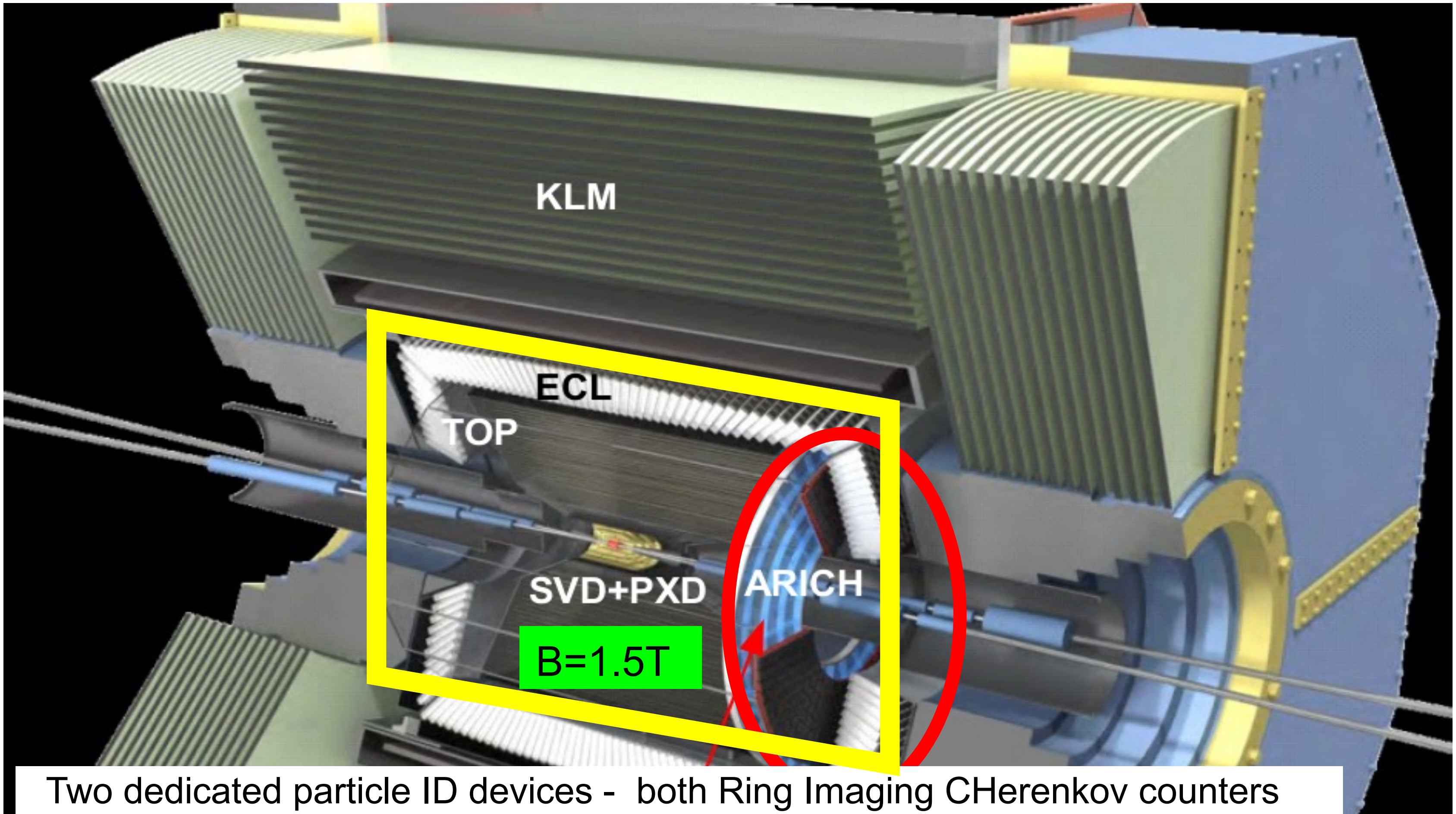
- Number: D8.3
- Due: M44
- Qualification of neutron irradiated SiPMs at different temperatures.
- Lead: JSI

AIDA innova

Single photon applications

Application	ARICH@BelleII	TOP@BelleII	RICH@LHCb
Sensor size	5 mm	6 mm	1 / 3 mm
Single photon sensitivity	+	+	+
Low DCR	+	+	+
Peak PDE	Blue	Green	Green
SPTR (ps)	50	50	100
Operating T(deg. C)	-20 .. 20	20 (in contact with quartz bars)	-100 (Gas vessel @ 20 deg. C)
Light focusing	+	-	+
Area to cover	4.5 m2	0.4m2	1m2/9m2
Fluence neq/cm^2	**10^{12}**	**10^{11}**	**$3x10^{13}$**
Trigger rate	30 kHz	30 kHz	40 MHz
Phot. incident angle deg	0-30	0-90	0-10
Start	**2035**	**2028**	**2033**

Belle II

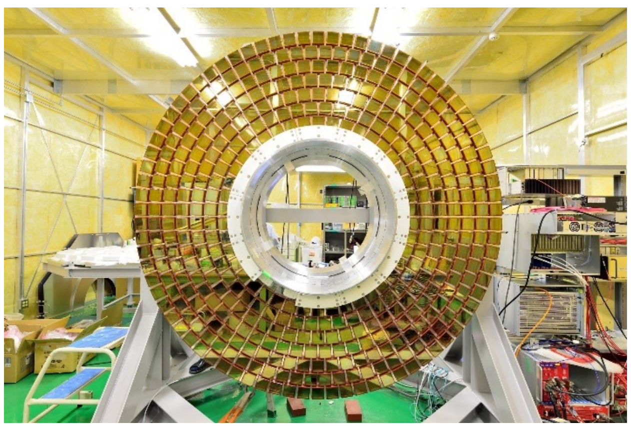


Two dedicated particle ID devices - both Ring Imaging CHerenkov counters

- Barrel: imaging **Time-Of-Propagation (TOP)**
- End-cap: **Proximity focusing Aerogel RICH (ARICH)**

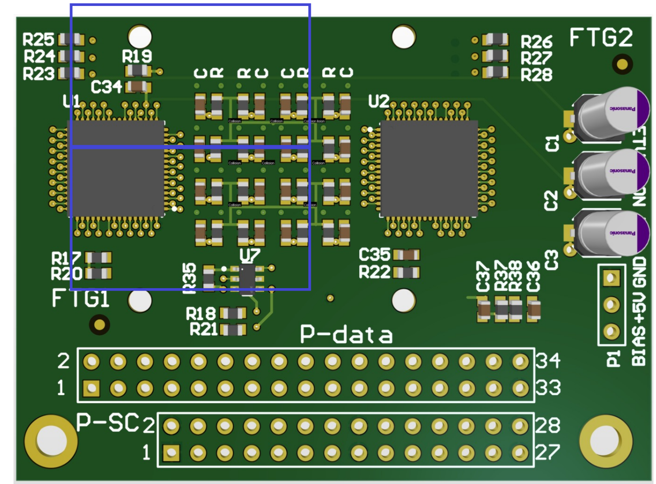
Belle II Aerogel RICH

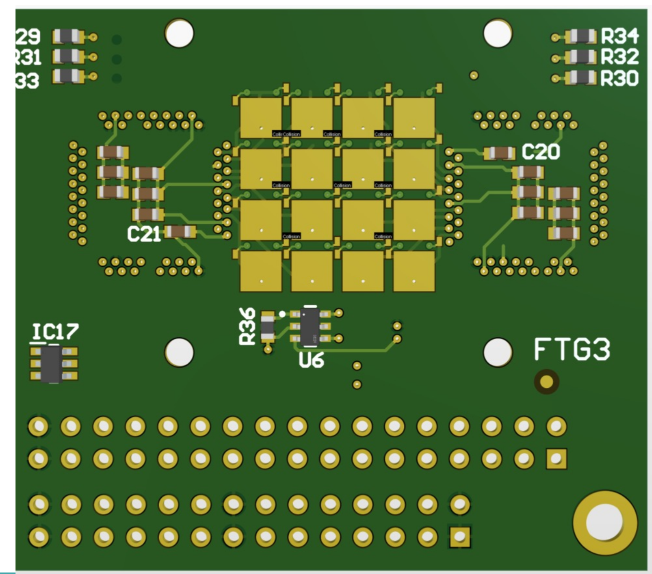
- Replace the HAPDs which are currently in operation
- Design of a test module with individual SiPMs



Focusing aerogel radiator

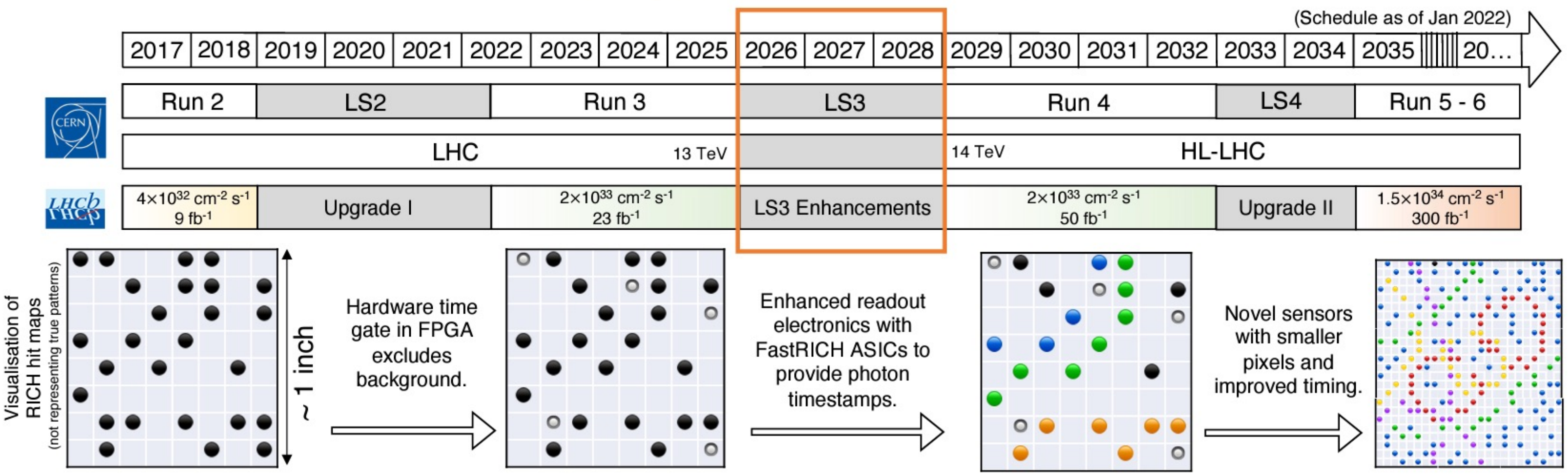
Photon detector



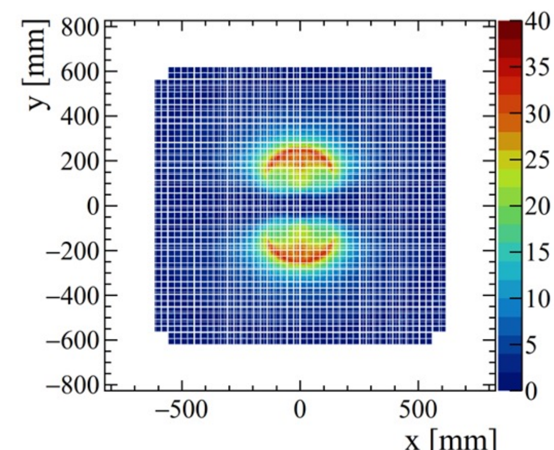


Evolution of the RICH photon detector: LS3 enhancements

Relatively long period of LS3 central to the RICH evolution.



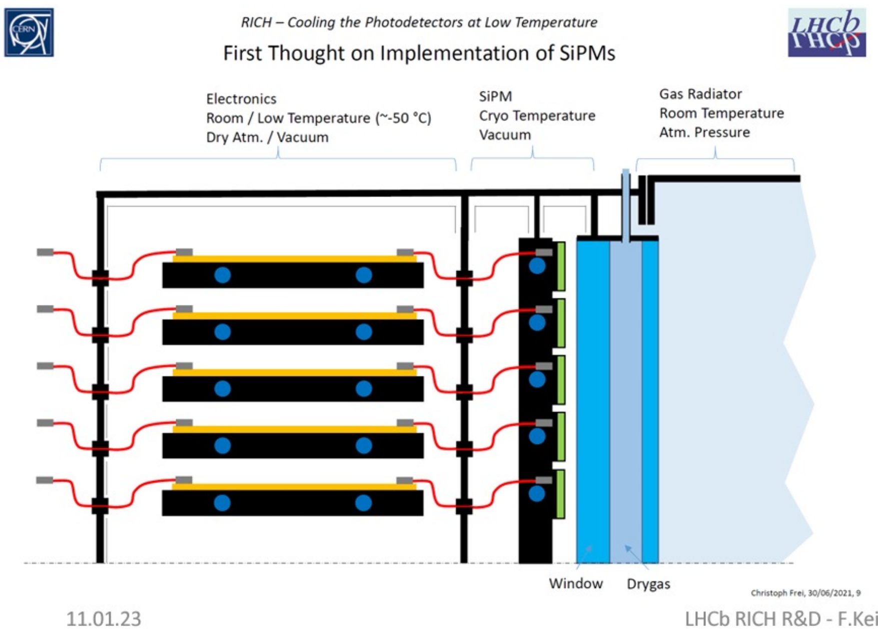
- LS3 / Run 4 : focus on **FastRICH** readout electronics with fast timing and wide input dynamic range.
- LS4 / Run 5 : focus on **sensor technology**. Fast-timing is essential for the luminosity challenge after Upgrade II.

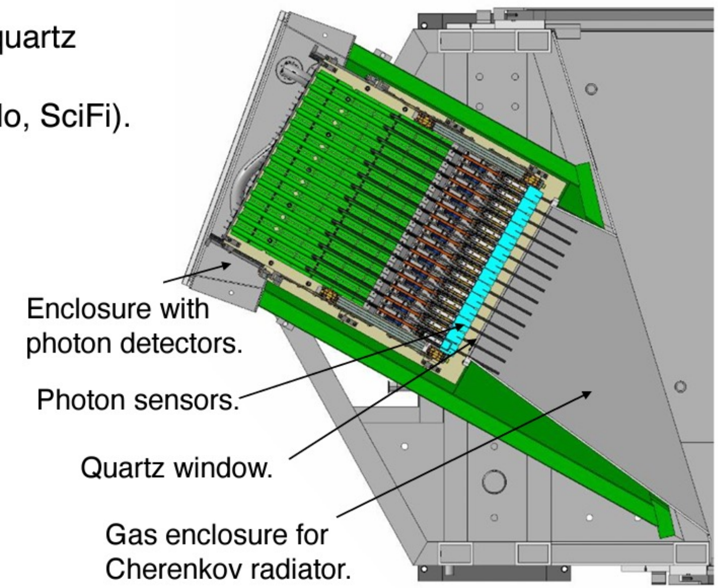


Low temperature / cryogenic cooling of photon detectors [1/2]

R&D into compact vessel structures has started and several meetings held with the cryogenics experts at CERN (TE-CRG-CI).

- One of the ideas could be to use two specially-coated quartz windows separated by a vacuum.
- Exploring synergies with other LHCb sub-detectors (Velo, SciFi).





https://indico.cern.ch/event/1175130/

Demonstrator cryostat for LHCb RICH

Detailed design of a demonstrator cryostat for R&D is progressing well.

Small-scale cryostat for test beam and pulsed laser studies, addressing key challenges such as:

- RICH entrance window, avoiding condensation, low absorption in the optical (blue/green) range and for example a coating for infrared reflection.
- Thermal coupling of the SiPMand its substrate to a cold (liquid nitrogen) plate in vacuum.
- Routing of analogue (single-photon) signals from the sensor to readout ASIC (along transmission line), maintaining its fast-timing characteristics.
- CTE(coefficient of thermal expansion) mismatches.
- Operation of electronics (including the FastRICH ASIC and lpGBT/VTRX+ chips) at cryogenic and/or room temperatures, and how this affects the thermal coupling back into the sensors.
- (Timing) performance of SiPMs at a range of (low) temperatures.

FastIC and FastRICH ASICs


RICH front-end board with FastIC ASICs.

The Fast Integrated Circuit (FastIC) is an ASIC designed in 65 nm CMOS technology by the University of Barcelona (ICCUB) and CERN-EP-ESE.

- 8-channel chip with **wide input dynamic range** (5 uA to 25 mA) for pos/neg signal polarities.
- Fast discriminator (~ 30 ps jitter).
- **Not** designed to be specifically **radiation hard**.

Next-generation FastRICH is based on the FastIC and specific requirements of the RICH detector.

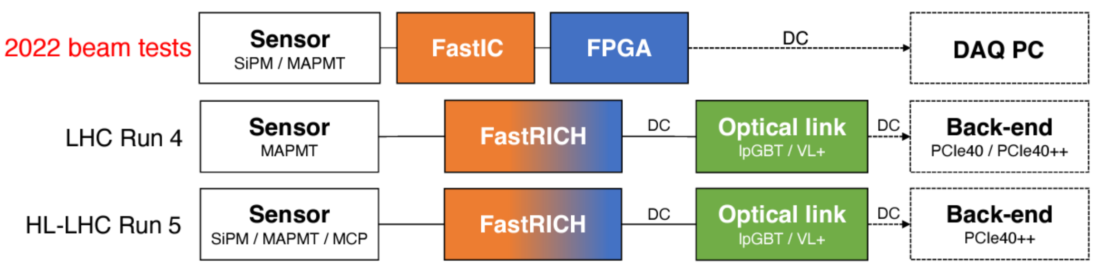
- 16-channel chip with additional **digital** signal **processing**.
- **TDC** with ~ 25 ps time bins and 40 MHz readout rate.
- **Hardware shutter time** (configurable) to limit the timestamp range to ~ 1 to 2 ns.
- **Constant-fraction discrimination** (CFD) to reduce data throughput.
- **Zero-suppressed** output over configurable number of output links to lpGBT.
- **Radiation hard** by design (~ 10^{13} n_{eq}/cm^2 and ~ 5 kGy).
- **Compatibility with lpGBT/VTRX+** and the architecture of the Run 4 and Run 5 DAQ.

FastRICH design is ongoing (CERN-ICCUB) with the analog parts far advanced.

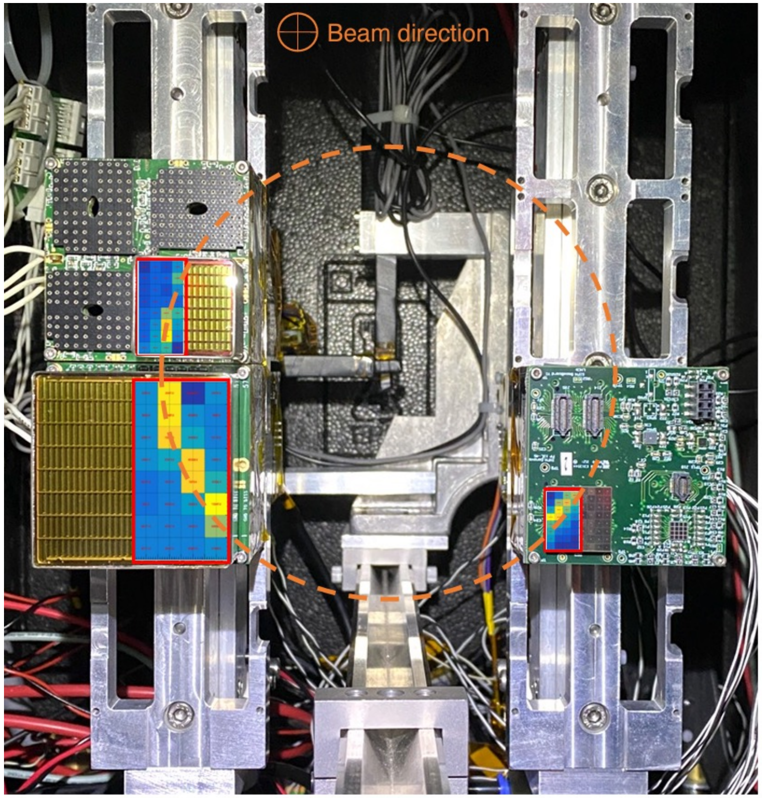
15.09.22 RICH LS3 enhancements - F.Keizer 12

LHCb RICH - SPS test beam campaign

- Development and testing of a prototype readout chain with fast-timing information.
- The FastIC - predecessor of the FastRICHfor LS3.
- The FastIC ASIC coupled to 8x8 ch. Arrays of SiPMs/MAPMTs and read out by a TDC-in-FPGA.
- Integration with lpGBT



- Next beamtests: June & September 2023

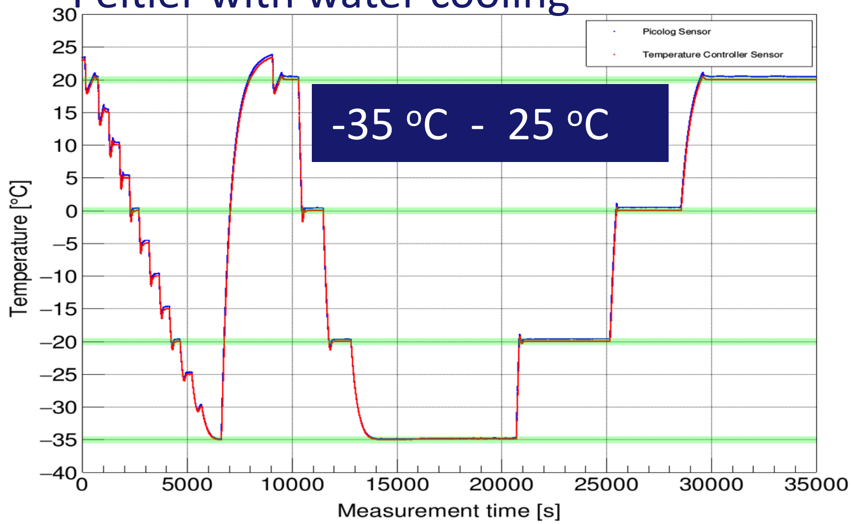


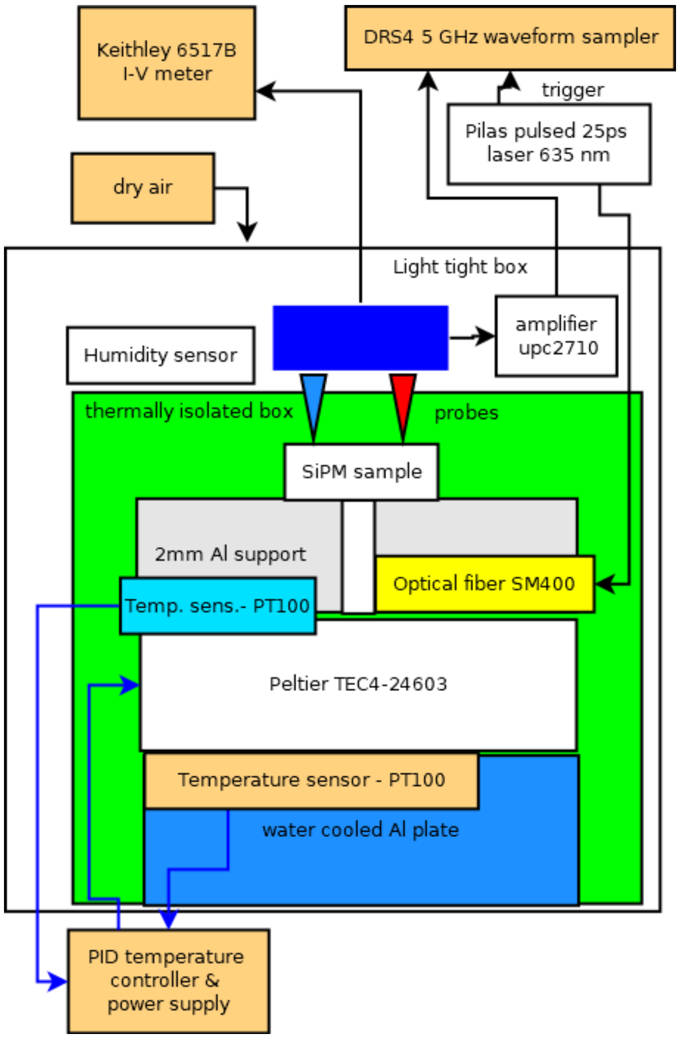
Experimental setup measurements down to -35 °C

Probe station to measure:

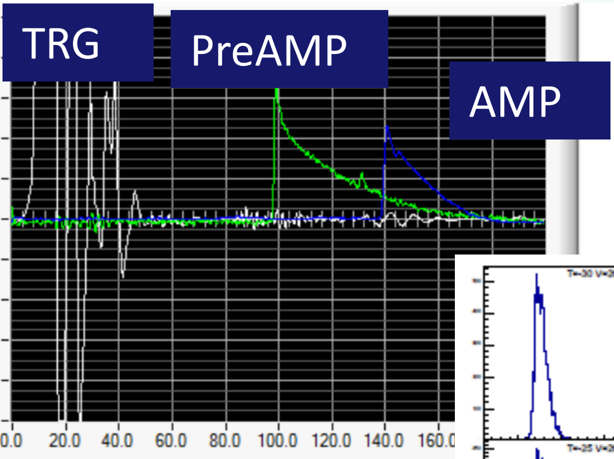
- IV curves
- Waveform acquisition with DRS4
- DCR with NIM counter
- Optimization of an amplifier for the measurements

PID temperature controller:
Peltier with water cooling



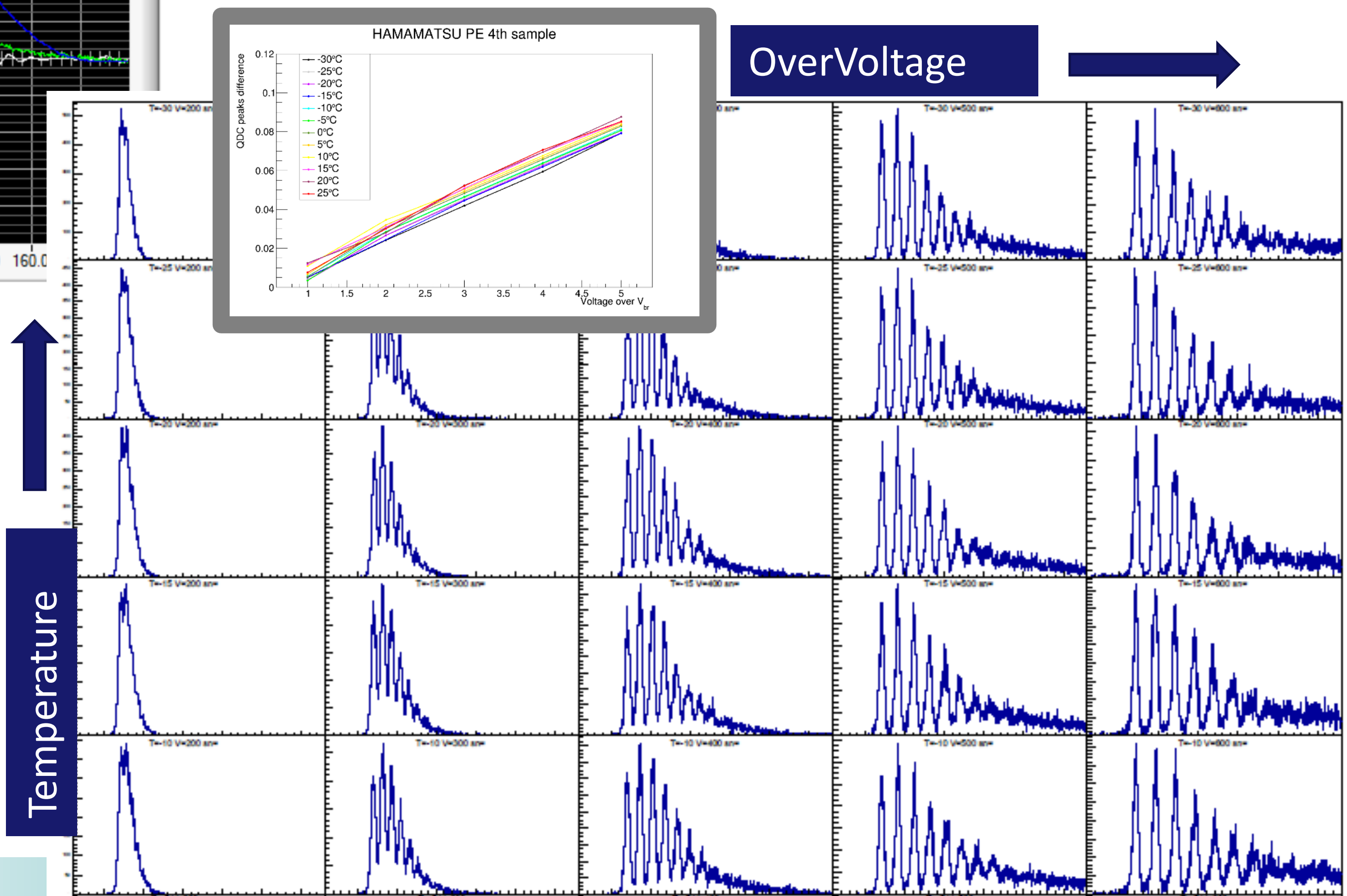


Waveform analysis



Accumulated charge distributions:

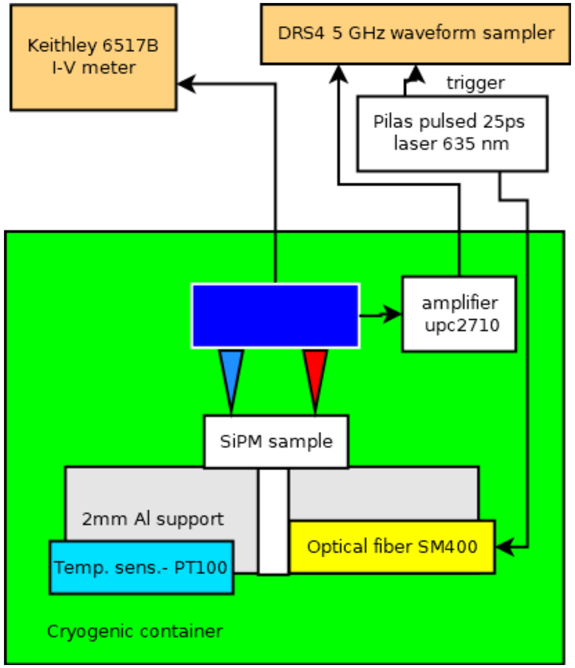
Clear separation of single photon signals in all samples

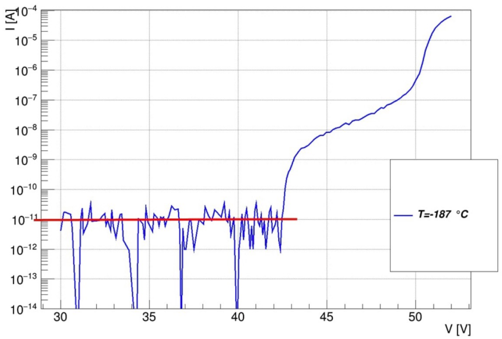


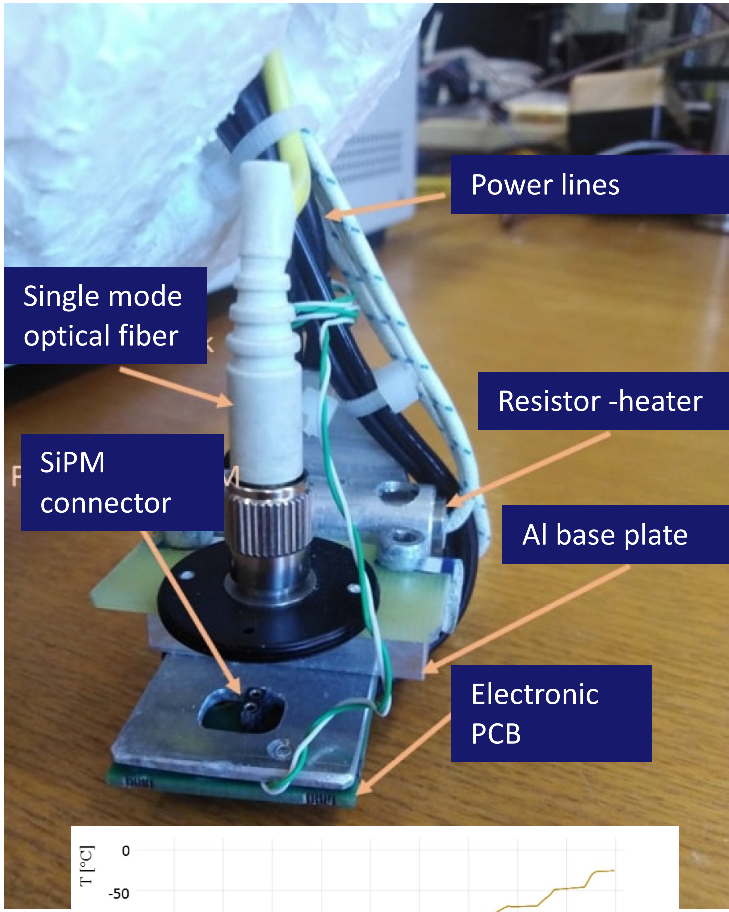
Fitting of the waveforms with superposition of signals and extracting timing

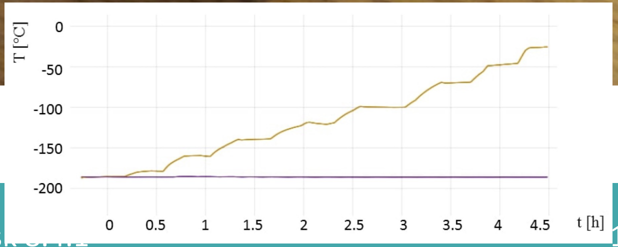
Liquid Nitrogen setup

- Characterizatation of SiPMs in Dry Cryogenic container
- Isolated setup and heater allows to measure SiPM in the range from -196 °C to -20 °C









FBK activities

- *Current work:*
  - *Analysis and review of the data on currently available FBK SiPM* technologies, including NUV-HD-RH and new variantsDefine *suitable testing procedures* for future measurements in collaboration with AIDAinnova partners
- *Plan:*
  - Study / modeling of the effects of radiation damage on SiPM characteristics, under different sources of radiation.
  - *Design an optimized SiPM run*
  - *Fabricate SiPMs in FBK clean-room – in Q3/Q4 2023.*
  - Characterize the newly produced SiPMs.

Summary

The goal of the task is to study and define the
- ***best procedures for the measurement of SiPM characteristics*** during / after irradiation.
- Make the results of different groups comparable

- Single SiPM measurements:
  - Dosimetry measurements of the neutron fluxes in the TRIGA reactor (JSI)
  - Online monitor + calibration with spectroscopy measurements
  - Procurement of SiPMs from different producers focusing to small samples (1 mm2 not easy to obtain)
- Timing measurements:
  - High power Amplifiers – Comparing performance of different amplifiers for single channel measurements.
  - Low power multi channel readout for arrays of SiPMs
    - CERN SPS Beam-tests of FastIC + SiPM : analog and digital board designed
  - FastIC integration in the measurement chain for irradiaton measurements (JSI) – board under test
- Study of irradiated samples and preparation of infrastructure for a dedicated SiPM run forseen in Q3/Q4 2023 (FBK)