A SiPM-based optical readout system for the EIC dual-radiator RICH

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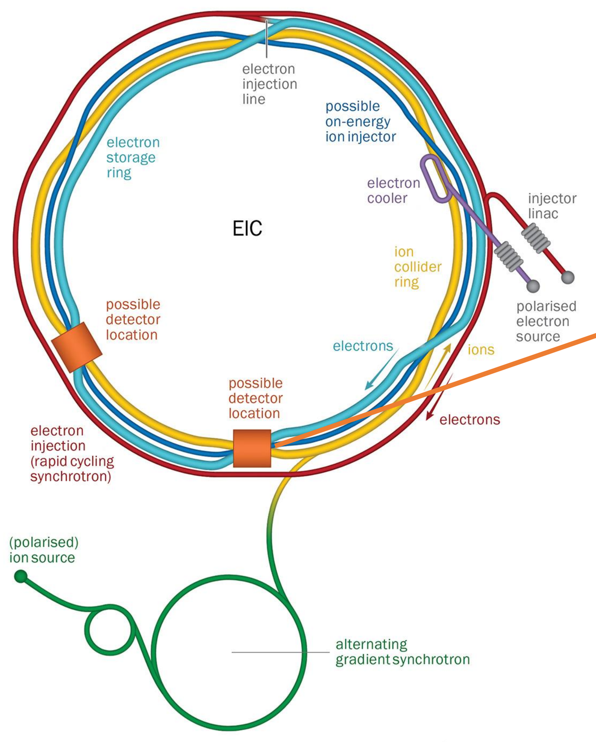
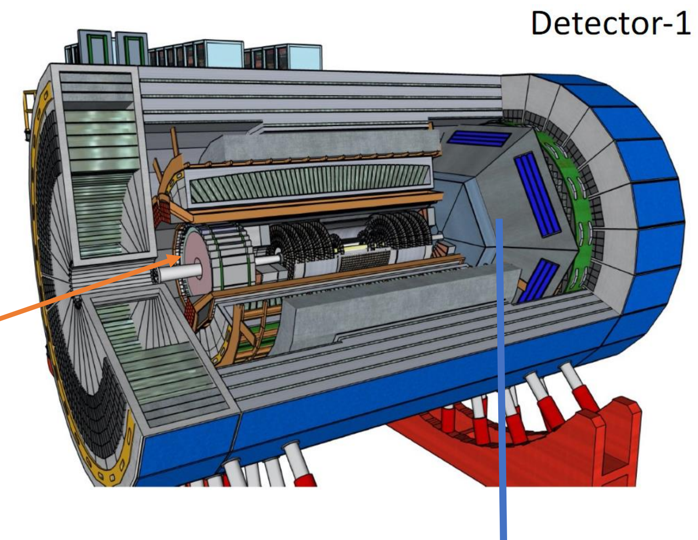
The EIC

The **E**lectron **I**on **C**ollider (**EIC**) will be a large-scale innovative **particle accelerator** planned to be built at **Brookhaven National Laboratories** in Long Island, New York (**U.S.A.**). Constitutes the **major project** in the **nuclear physics** field.

Highly **polarized electrons** collide with **protons** and **nuclei** providing access to those regions in the nucleon and nuclei where their structure is dominated by gluons.
Polarized beams in the **EIC** will give unprecedented access to the **spatial** and **spin structure** of the **proton**, **neutron**, and **light ions**

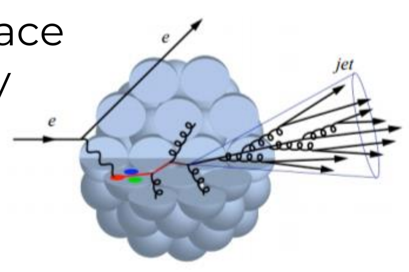
The **EIC** covers a **center-of-mass** energy range for **e+p** collisions of **$\sqrt{s}$** of **20** to **140 GeV**
The **first beam** operations are expected to start in the **early 2030s**.

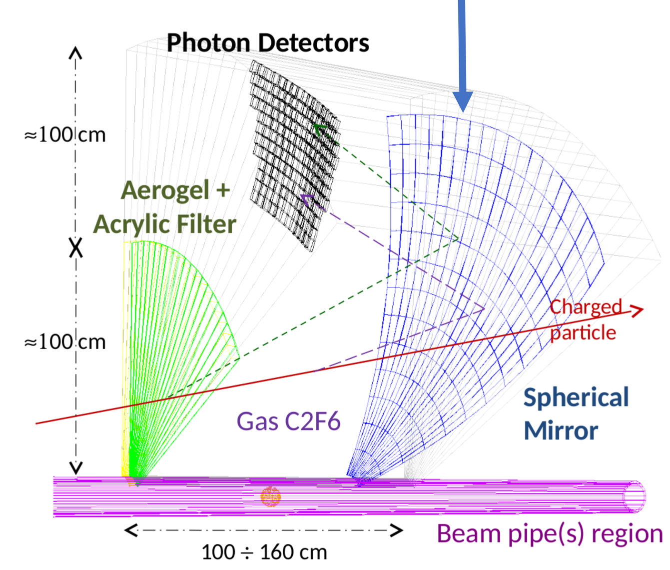




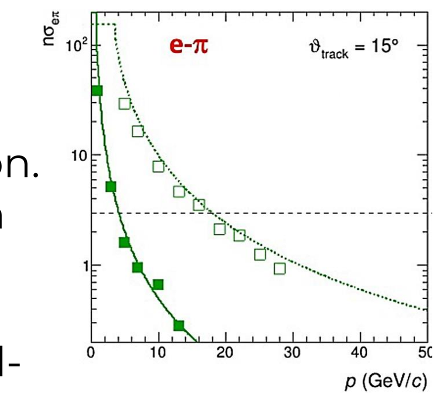
The EIC detectors are in the interaction regions where space is constrained due to the requirements of high luminosity and will have:

- Tracking and Vertexing Detector Systems
- **Particle Identification Detector Systems**
- Calorimeter Detector Systems





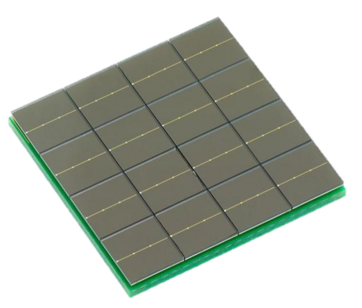
A dual-radiator (**dRICH**) is in charge for the forward **P**article **Id**entification **PID.**
It is c compact and cost-effective solution for continuous momentum coverage (3-60 GeV/c).
It shows interesting capability in the elctron-pion separation.



Radiators are made in aerogel (n ~ 1.02) and C2F6 (n ~ 1.0008).
Mirrors: large outward-reflecting, 6 open sectors.
The Photon Detectors is made by 3x3 mm^2 **SiPMs** arranged in six 0.5 m^2 / sector for a total of 3m^2 surface (~ 300 k channels).
The SiPM technology allows **single-photon** detection inside high B field (~ 1 T).
SiPMs have **fast time resolution** but there are consideration on **dark noise** and **radiation hardness**.

SiPMs and redout

SiPMs are a valuable option for the **dRICH** optical readout:

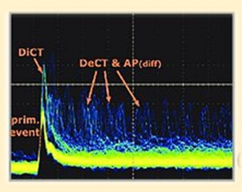


- **Cheap**
- Low voltage operation
- **Excellent time resolution**
- Single photon detection
- **Insensitive to magnetic field**
- High spatial resolution

- **High noise as Dark Count (DCR)**
- **Prone to radiation damage (10^{11} n_{eq}/cm^2)**

DCR is reduced by a factor 50 every 30° C of temperature reduction. The dRICH SiPMs will be operated at **-30° C.**
Radiation damage is produced by Non-ionizing Energy Loss (**NIEL**) leading to **displacement** damages and build up of **crystal defects** that results in:

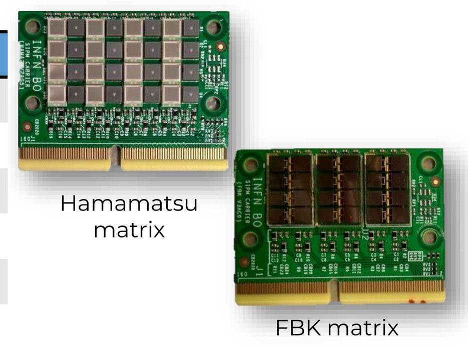
- Increased **DCR**
- Increased **After Pulses**
- Change in **charge collection**



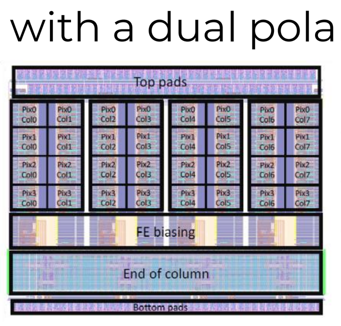
Performance can be recovered by using annealing techniques. High temperature re-order out-of-lattice atoms to their former positions reconvening performance
https://arxiv.org/pdf/1805.07154.pdf, https://www.osti.gov/pages/servlets/purl/1477958, https://ieeexplore.ieee.org/document/9059772, https://arxiv.org/abs/1804.09792

3x3 mm^2 SiPMs from different vendors and with different cell sizes are mounted in matrixes were studied to evaluate their performance after irradiation and annealing.

Vendor	Version	Cell size (μm)	V_{BD} (V)	DCR (kHz/mm^2)
Hamamatsu	S13360-3050VS	50	53	55
Hamamatsu	S13360-3025VS	25	53	44
Hamamatsu	S14160-3050HS	50	38	160
Hamamatsu	S14160-3015PS	15	38	78
FBK	NUV-HD-CHK	40	31	50
FBK	NUV-HD-RH	15	31	40

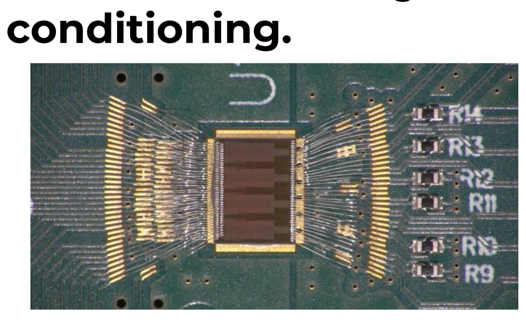

Hamamatsu matrix
FBK matrix

The **ALCOR-ASIC** (developed by INFN-TO) is a **32-pixe**l matrix mixed signal with a dual polarity **frontend** for **amplification** and **conditioning.**



Each pixel features

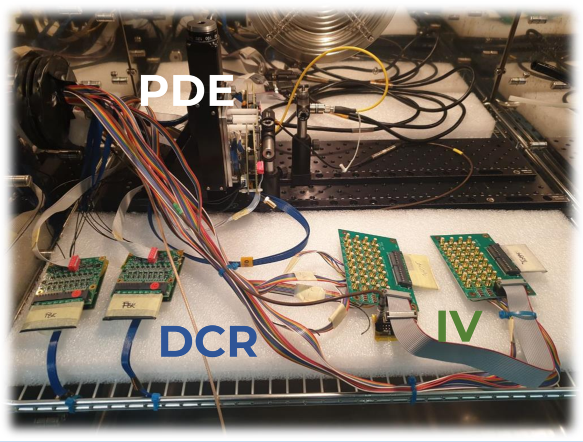
- dual-polarity front-end amplifier
- 2 leading-edge discriminators
- 4 TDCs based on analogue interpolation

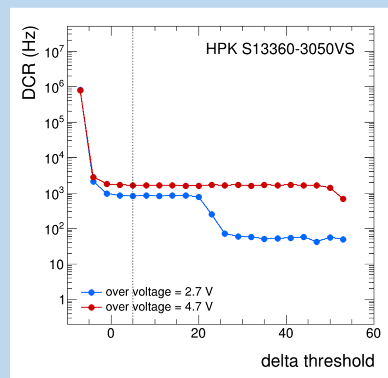


Test set-up

To mimic the **operative conditions**, sensors are tested in a **climatic chamber** at **-30° C**.
3 different automated measures are performed in parallel on the matrixes:

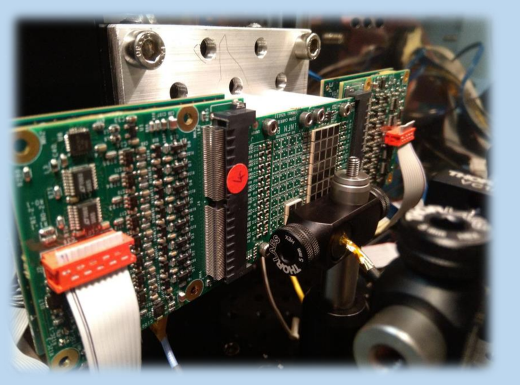
- Dark Count Rates (**DCR**)
- Current over Voltage curves (**IV**)
- Light response (**PDE**)



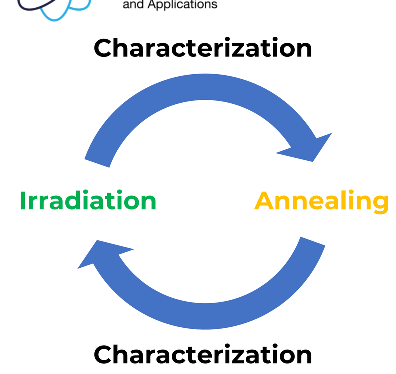


DCR is measured by the full dressed **ALCOR redout**. The ASIC streams **TDC** hits to an **FPGA** through a LVDS. **Threshold** and bias **voltage scan** are used to automatically compute the threshold level and the bias voltage.
IV curves are measured by a Keithley 2450 **SMU** and a **multiplexer** (up to ***64 SiPMs***) to measure the **Dark Current.**

For the PDE, a sensor's matrix is mounted on a 2-axis stage. The fixed **LED** source (λ = 570 nm) is powered with a pulser at **1 MHz** for **50 ns**. The number of **counts** measured in **coincidence** with the pulser is compared to the same measure of a **reference sensor** to evaluate **losses** in the **PDE** after the **irradiation/annealing**

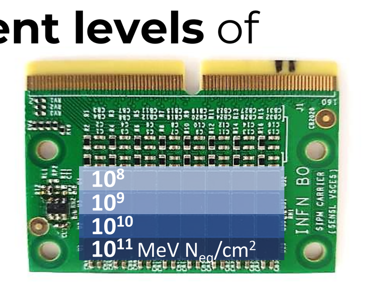


Irradiation and annealing



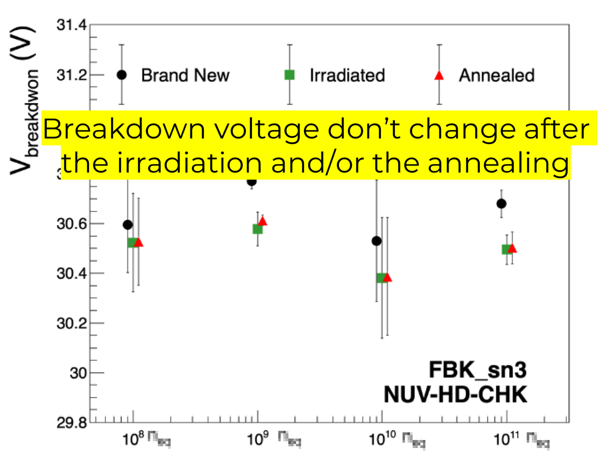
Detectors are **characterized before** and **after** the **irradiation** at **TIFPA**. **After** the **annealing** they are **characterized** again.
Irradiation at **INFN TIFPA** facility in Trento with **148 Mev protons**.
Differential approach to test **different levels** of damage (**10^8-10^{11} n_{eq}/cm^2)**

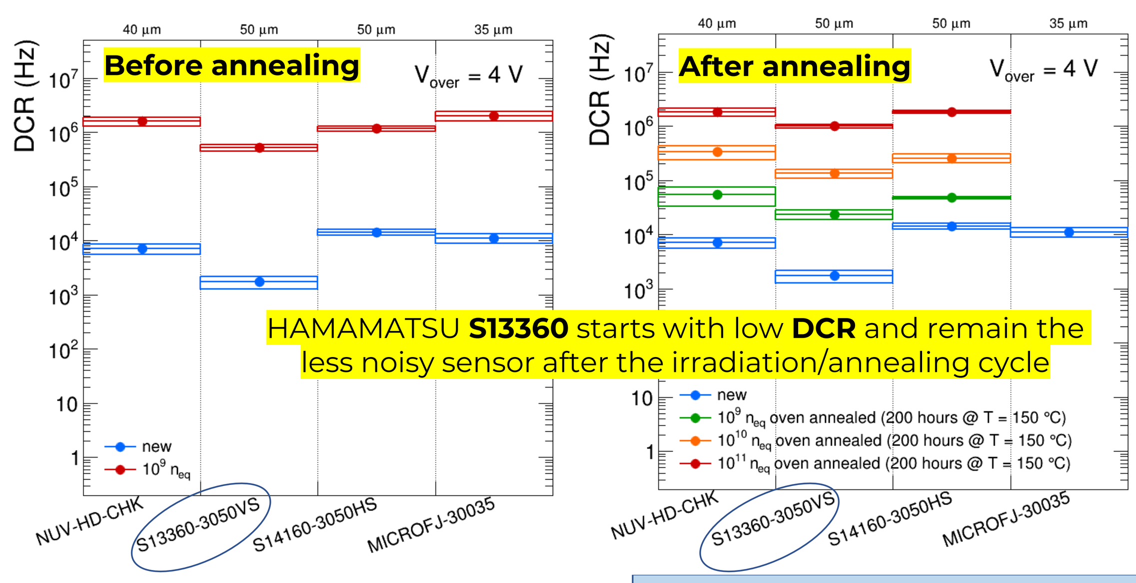
The annealing is performed in a temperature-controlled oven at **150° C** for **200 hours** in Ferrara. More than **150 SiPMs** undertook this **cycle**.

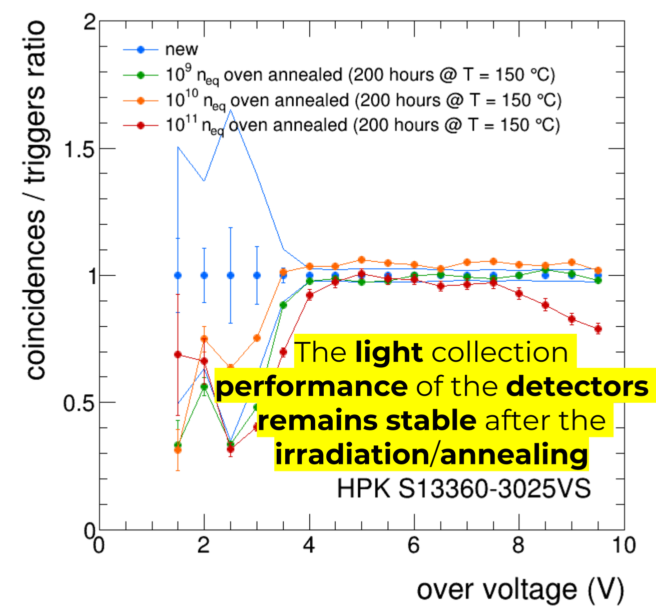


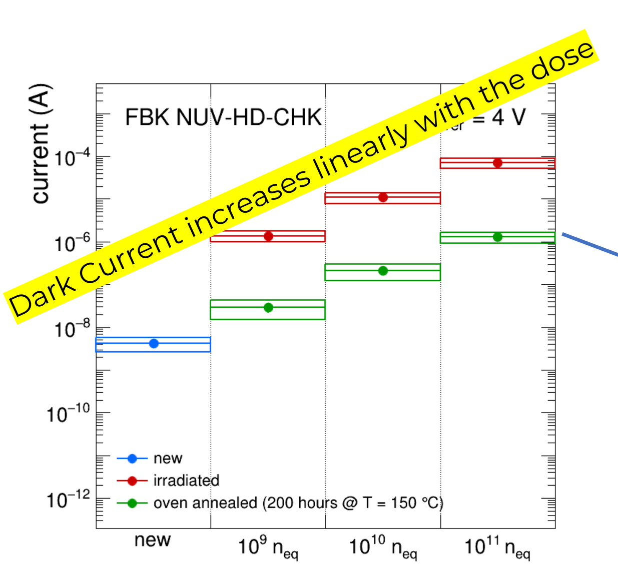
If directly polarized, **current** flows into the **SiPM**, **heat** is generated and contributes to the **annealing**. For a small sample of devices, a new method of direct current annealing is tested @**175**° C for **2.5 hours**.

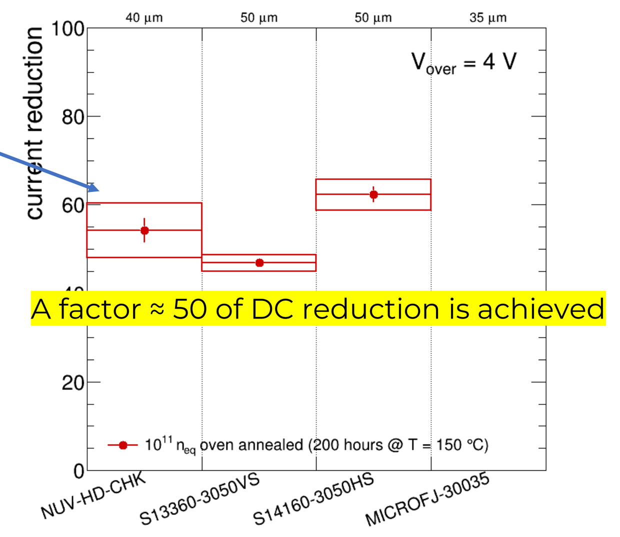
Results

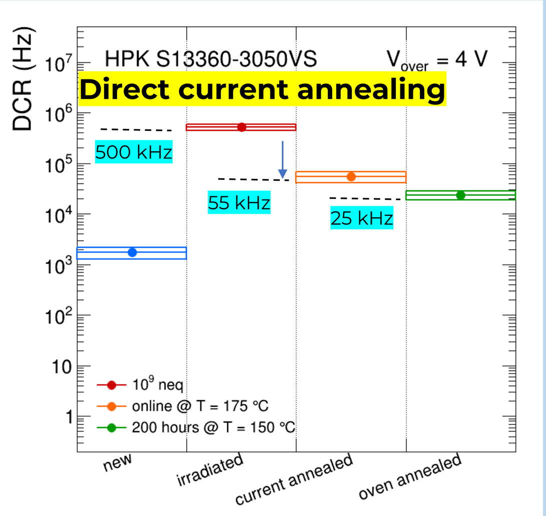












At 1.8 W delivered, the sensors reach 175° C. With the S13360-3050 we measure a dark current reduction of **10x**.
This annealing takes **2.5 h** with respect to the oven annealing that takes **200 h** at **150° C** (but results in a **20x** dark current reduction)

SUMMARY

R&D to explore use of **SiPM *as baseline* for the EIC-dRICH *optical* readout** in conjunction with a **prototype** chain of **electronics** based on the **ALCOR** front-end **ASIC** important to test details for this specific application.
A complete setup for testing **SiPMs** matrixes can automatically **characterize** the devices.
The **annealing** procedure proves to be a reliable method to **decrease** the **DCR** maintaining the **main characteristics** of the devices **unaltered** (**V_{BD}** and **PDE**).
Hamamatsu **S13360** shows the best **DCR** at all stages off **irradiation/annealing** (factor 50 reduction).
We show promising **results** with online **direct current annealing** for in situ **fast annealing**.
The irradiation/annealing campaign is ongoing and will show us further results in the next months.