A readout system based on SiPM for the dRICH detector at the EIC

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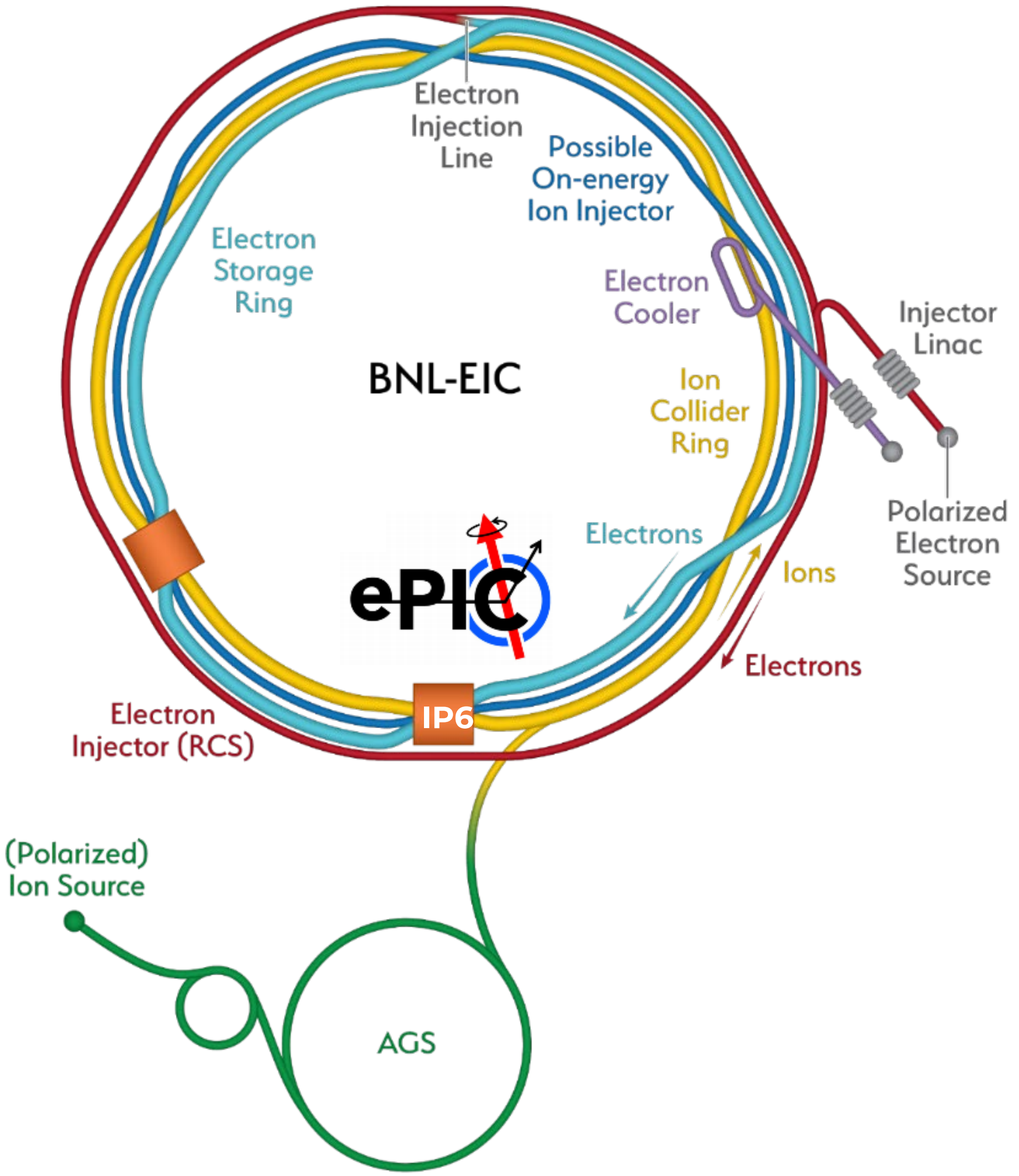
Outline

- The context: The **Electron-Ion Collider** and the **EPIC** detector
- **SiPM and radiation damage**
- First SiPM readout system
- **Characterization and Test beam results**
- Towards the final system



The Electron-Ion Collider

The major US project in the field of nuclear physics

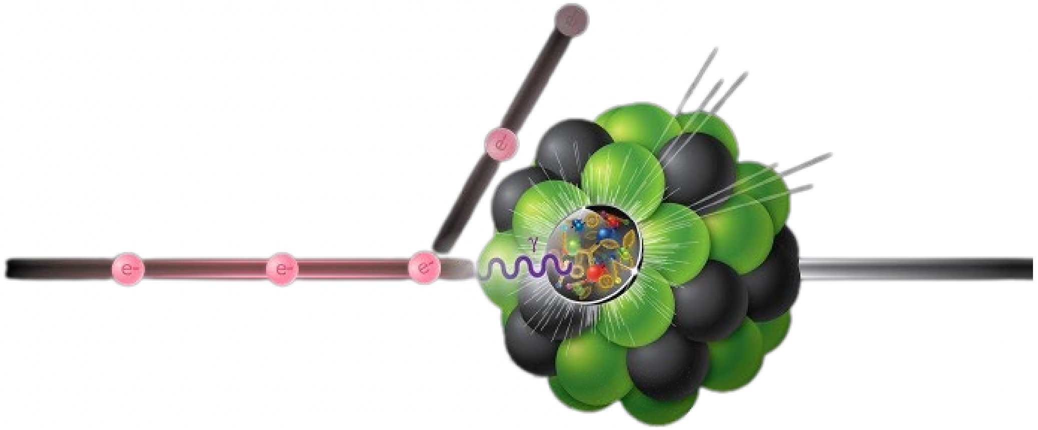
- one of the most important scientific facilities for the future of nuclear and subnuclear physics

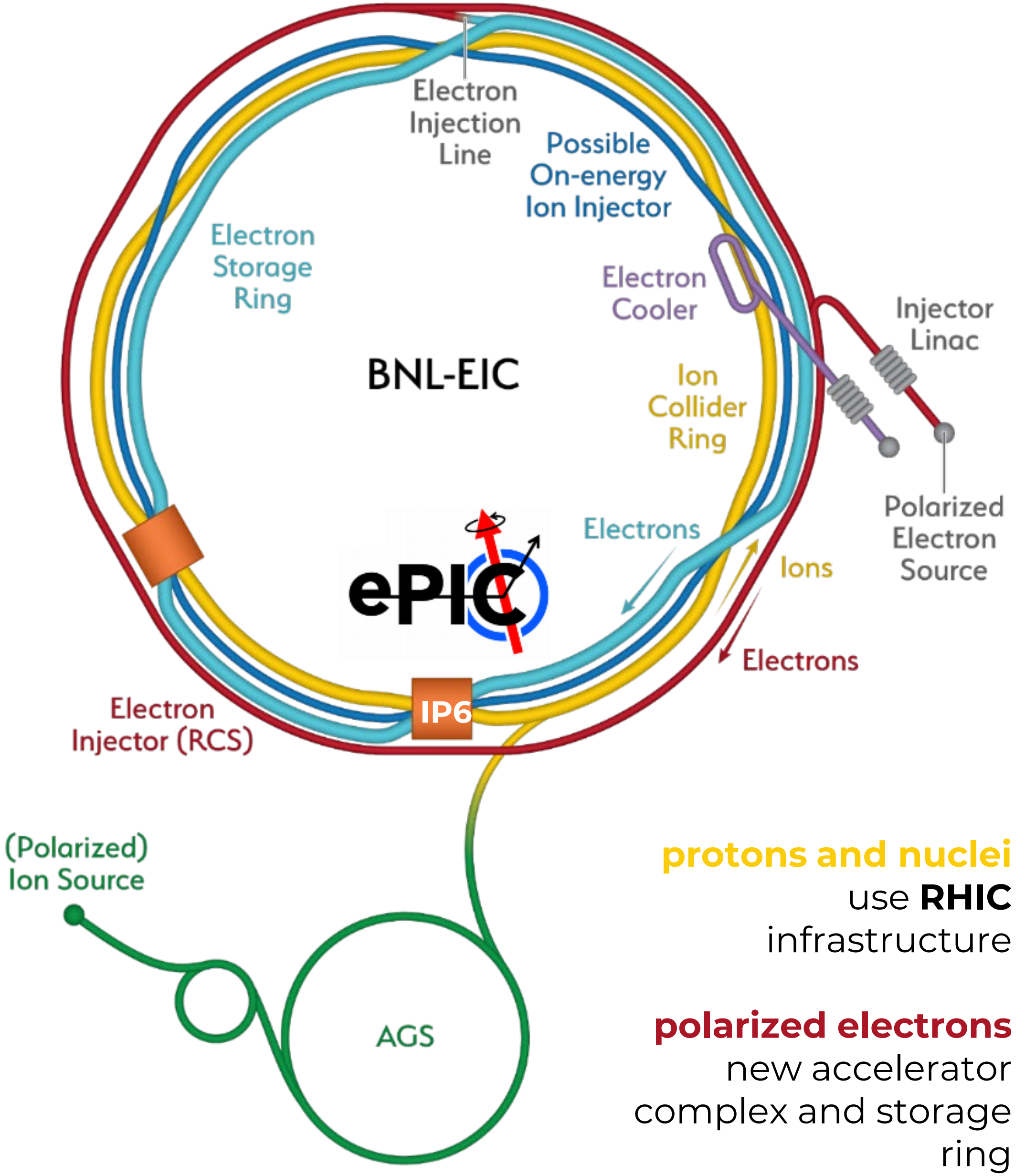
•the world's first collider for

- polarized electron-proton (and light ions)
- electron-nucleus collisions

•will allow to explore the secrets of QCD

- understand origin of mass & spin of the nucleons
- extraordinary 3D images of the nuclear structure





protons and nuclei use **RHIC** infrastructure

polarized electrons new accelerator complex and storage ring

The ePIC detector

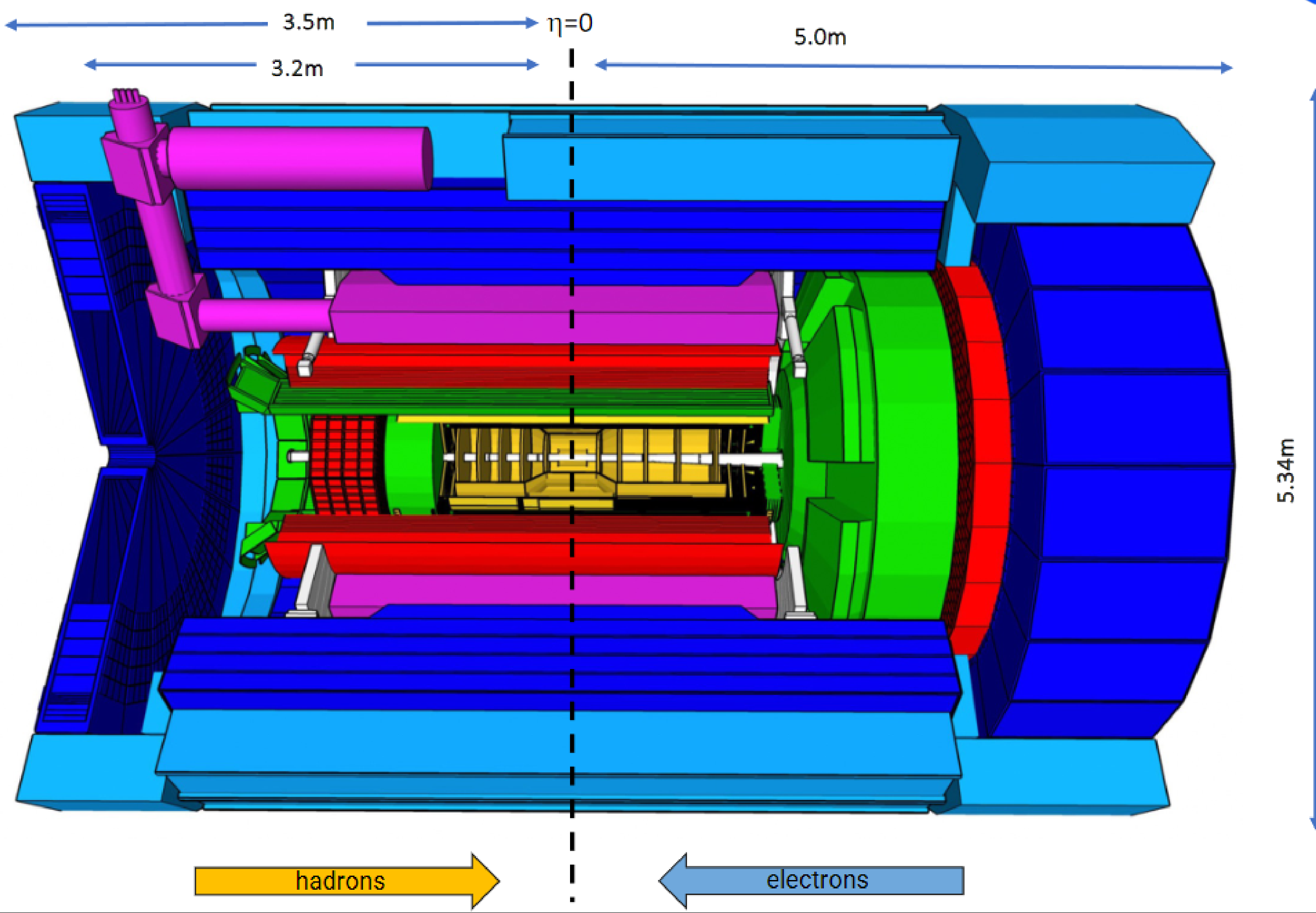
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (µRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



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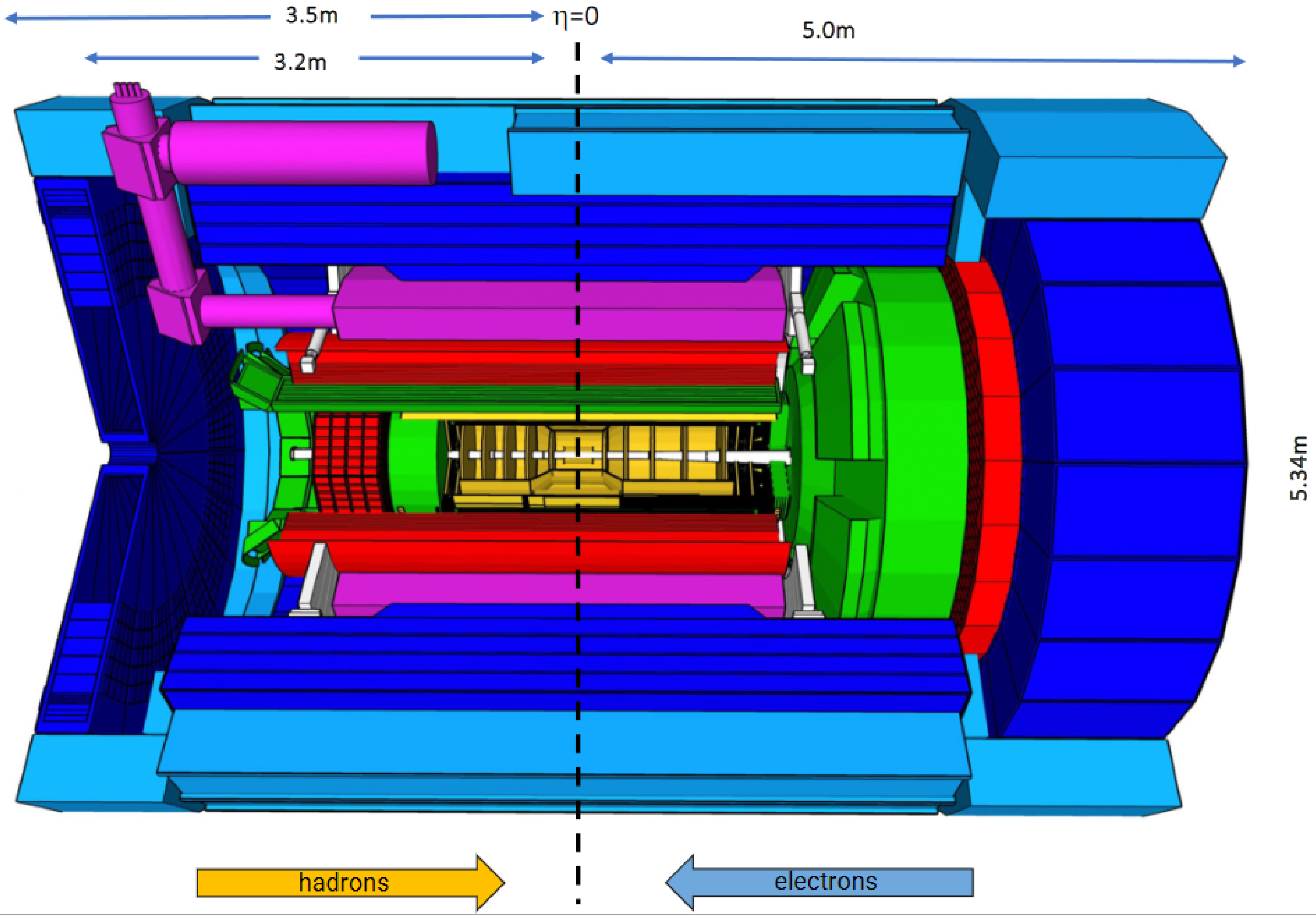


The dual-radiator (dRICH) for forward PID

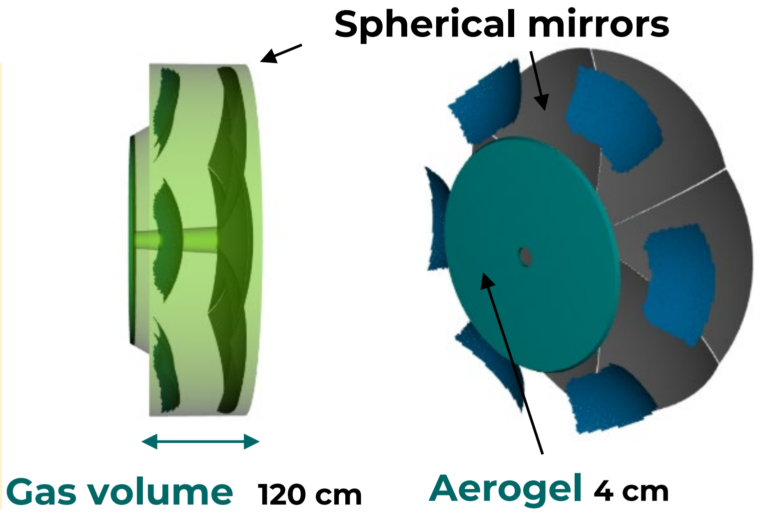
Compact and cost-effective solution for broad momentum (3-50 GeV/c) coverage at forward rapidity

π/K 3σ separation at 50 GeV/c

RADIATORS: aerogel (n ~ 1.02) and C_2F_6 (n ~ 1.0008)

MIRRORS: 6 open sectors of large outward-reflecting

Photosensors: 3x3 mm^2 pixels 0.5 m^2 per sector in 1 T magnetic field and radioactive environnement (10^{11} n_{eq}/cm^2 total exposure 12 y operation) for low light levels.



SiPM is the best **photosensor candidate:**

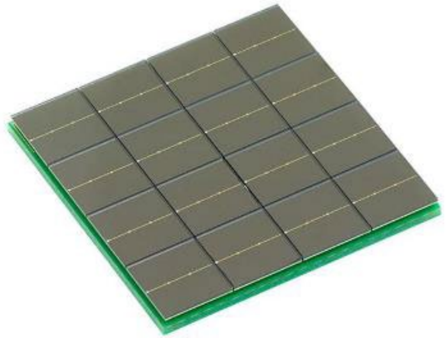
Single Photon sensitivity ~ 10 phs per Cherenkov event

Good **timing** performance **< 100 ps**

Cheap and **insensitive** to **magnetic** fields

BUT

High DCR and **high radiation sensitivity**



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π/K 3σ separation at 50 GeV/c

Spherical mirrors

RADIATORS: ae

MIRRORS: 6 op

Photosensors:

magnetic field

n_{eq}/cm^2 total ex

SiPM is the best

Single Photon s

Good **timing** pe

Cheap and **inse**

BUT

High DCR and **high radiation sensitivity**

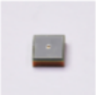
What can be done?

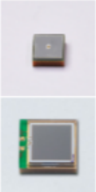
Cooling the sensors down to **– 30° C reduces** the **DCR** by a factor **~ 100**

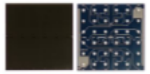
Radiation damage by Non-ionizing Energy Loss (**NIEL**) leads to **displacement** damages and build up of **crystal defects** that results in increased **DCR** but performance can be recovered by using **annealing** techniques (**high temperature**).

Sub ns time resolutions allow **coincidence** cuts that greatly reduces DCR contribution in the measurements

Extensive studies on different kind of SiPM from different vendors (more than 200 devices tested)







board	sensor	uCell (μm)	V_{bd} (V)	PDE (%)	DCR (kHz/mm^2)	window	notes
HAMA1	S13360 3050VS	50	53	40	55	silicone	legacy model Calvi et. al
	S13360 3025VS	25	53	25	44	silicone	legacy model smaller SPAD
HAMA2	S14160 3050HS	50	38	50		silicone	newer model lower V_{bd}
	S14160 3015PS	15	38	32	78	silicone	smaller SPADs radiation hardness
SENSL	MICROFJ 30035	35	24.5	38	50	glass	different producer and lower V_{bd}
	MICROFJ 30020	20	24.5	30	50	glass	the smaller SPAD version
BCOM	AFBR S4N33C013	30	27	43	111	glass	commercially available FBK-NUVHD

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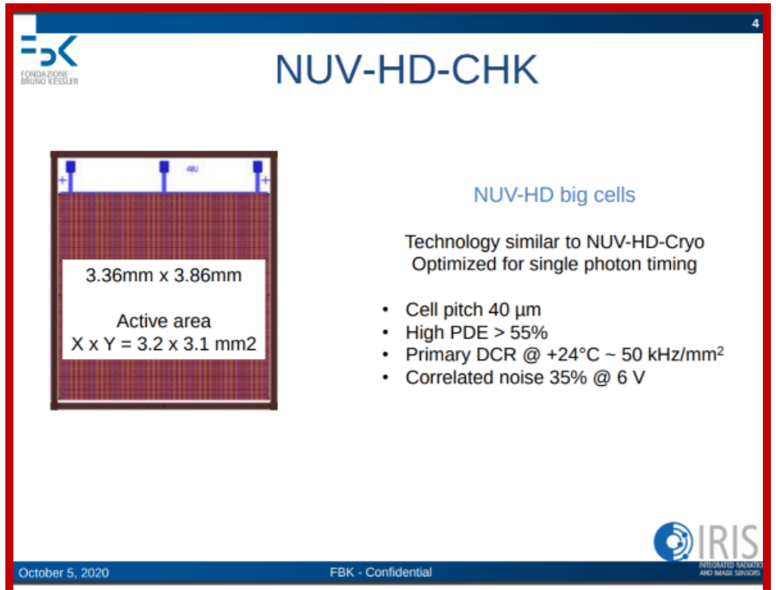
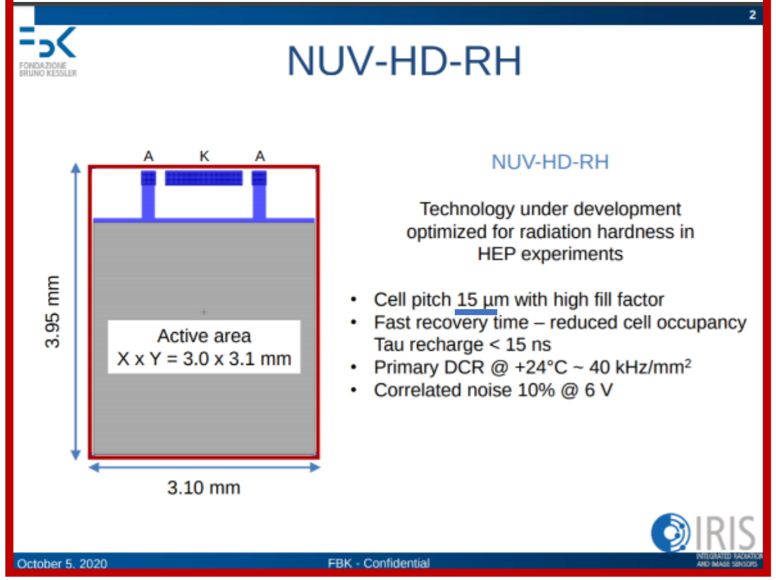
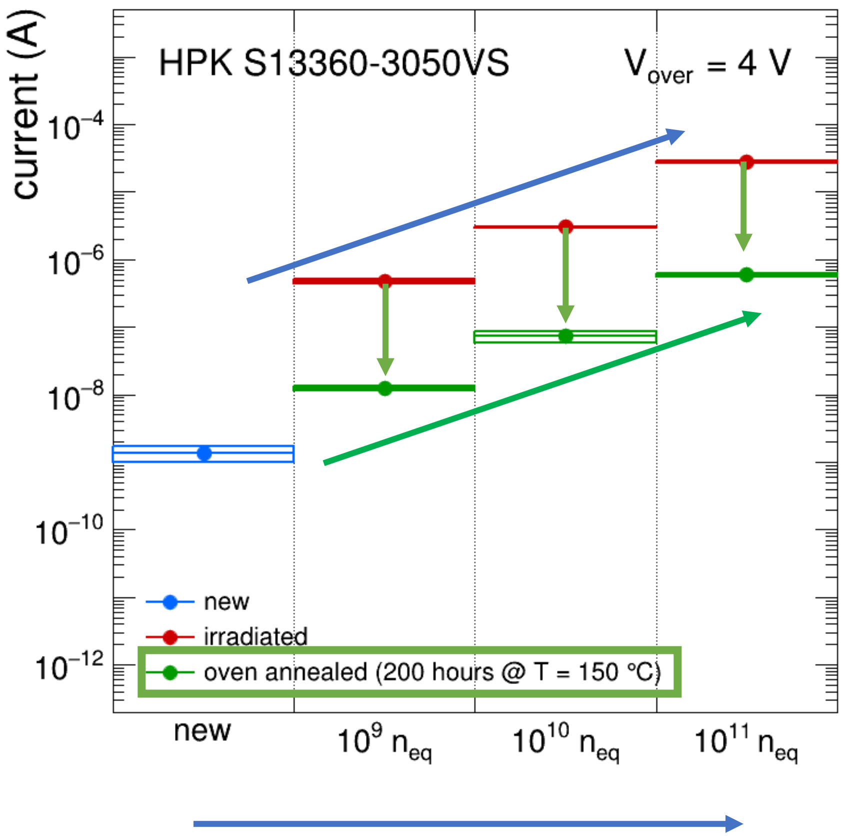




Irradiation-annealing campaigns findings

4 irradiation campaigns with protons and neutrons at TIFPA (TN) and LNL (PD)

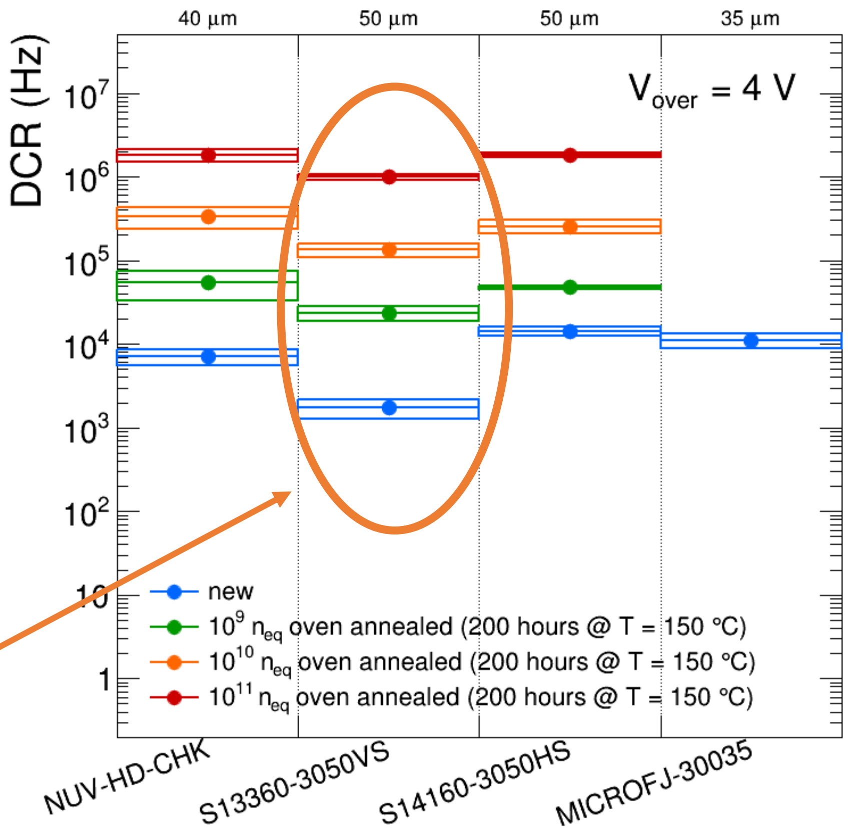


Linear **increase** of dark current/**DCR** with the dose

~40x reduction of dark current/**DCR** with **150° C** oven **annealing**

Residual increase in **DCR** is **proportional** to the dose

All sensors behave similarly but **HAMATSU s13-50 um** shows the **lowest DCR**

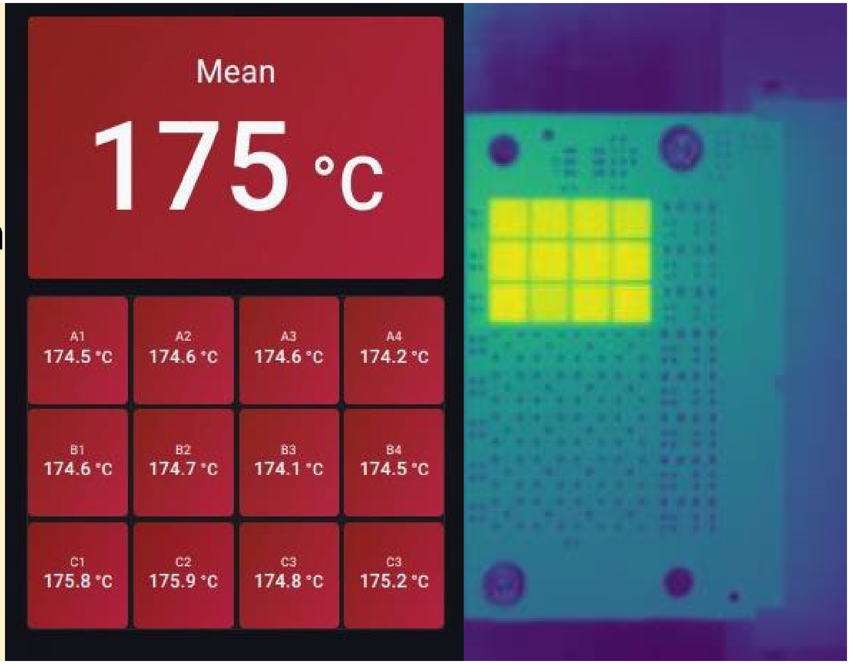


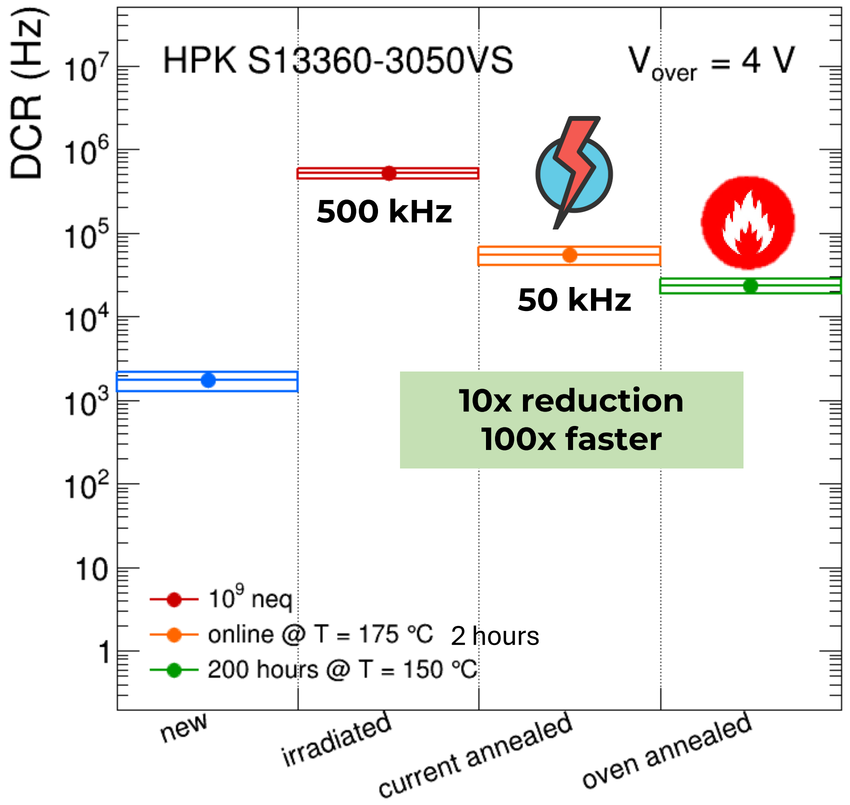
Measurements taken @ -30° C

Current annealing

Another way to heat up the sensors is by directly polarization. Current flowing into the SiPM, generates heat resulting in annealing.
175° C can be obtained providing 10 V and ~100 mA (**~ 1 W**) per sensor @ room temperature

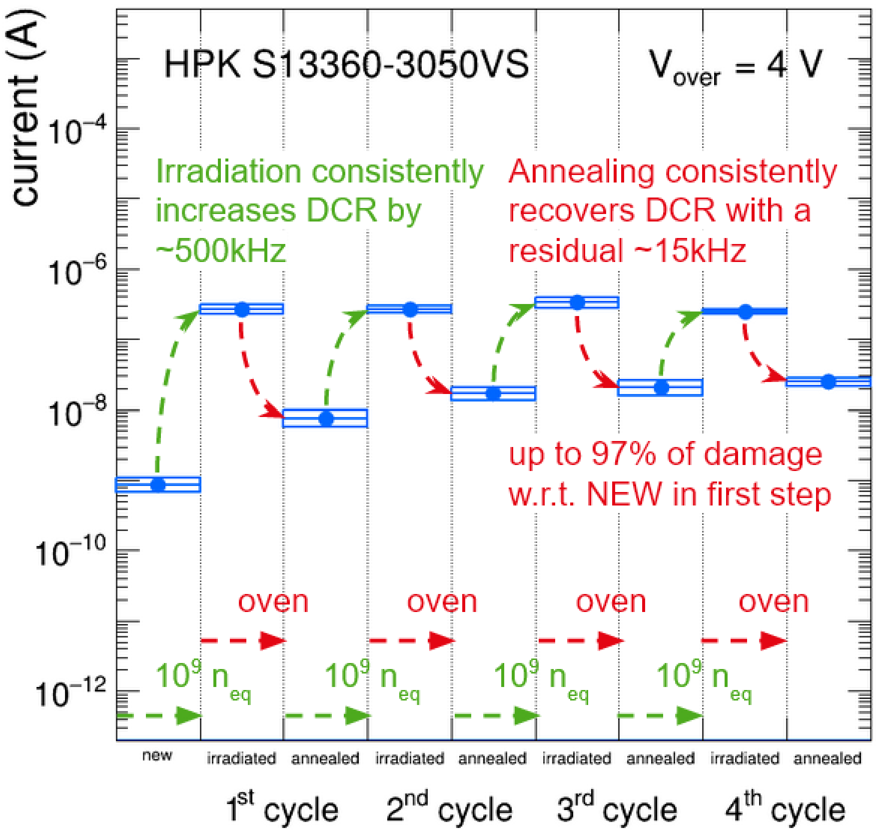
An **IR thermal camera** provides **feedback** to a **PWM** system able to set each **SiPM temperature**





Measurements taken @ -30° C

Damage recovery of SiPMs with multiple annealing cycles



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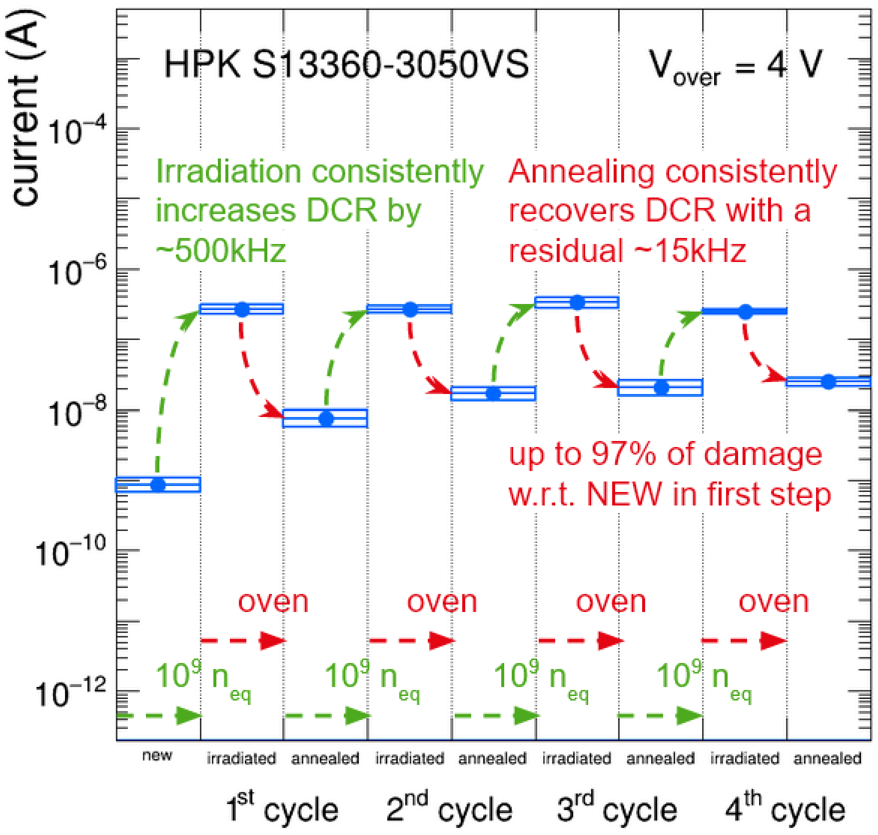
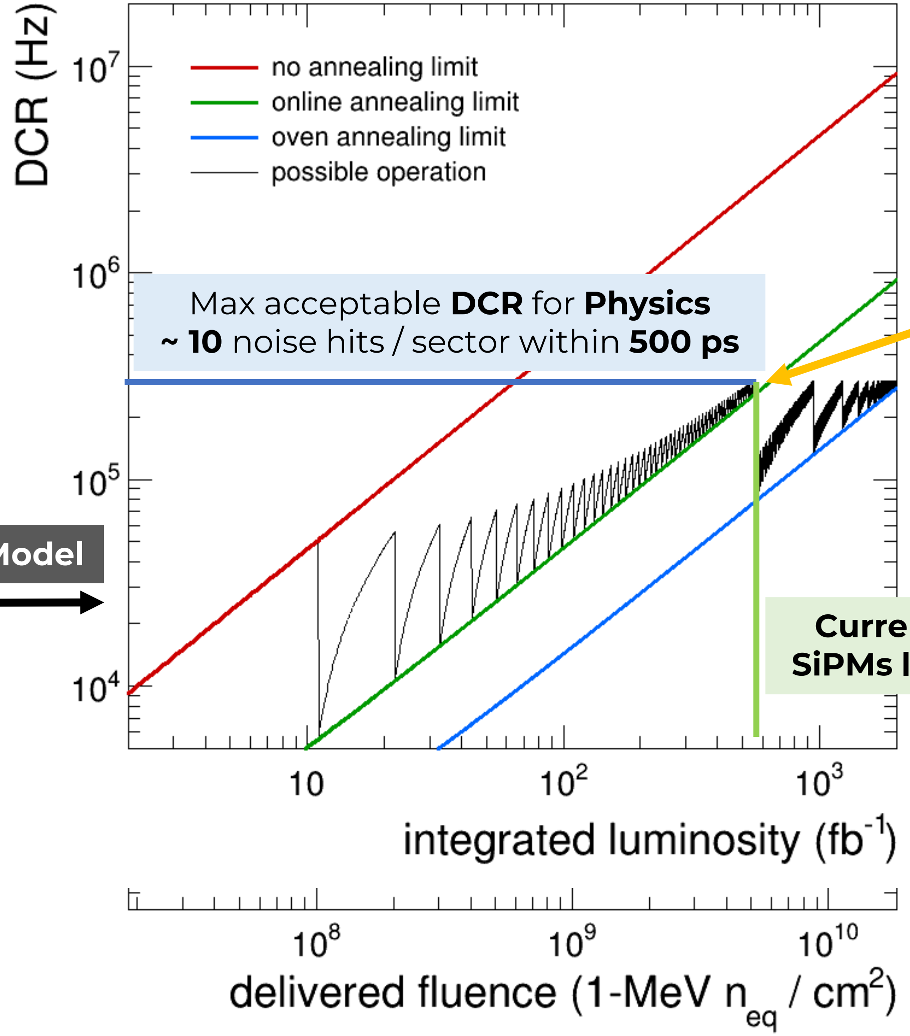


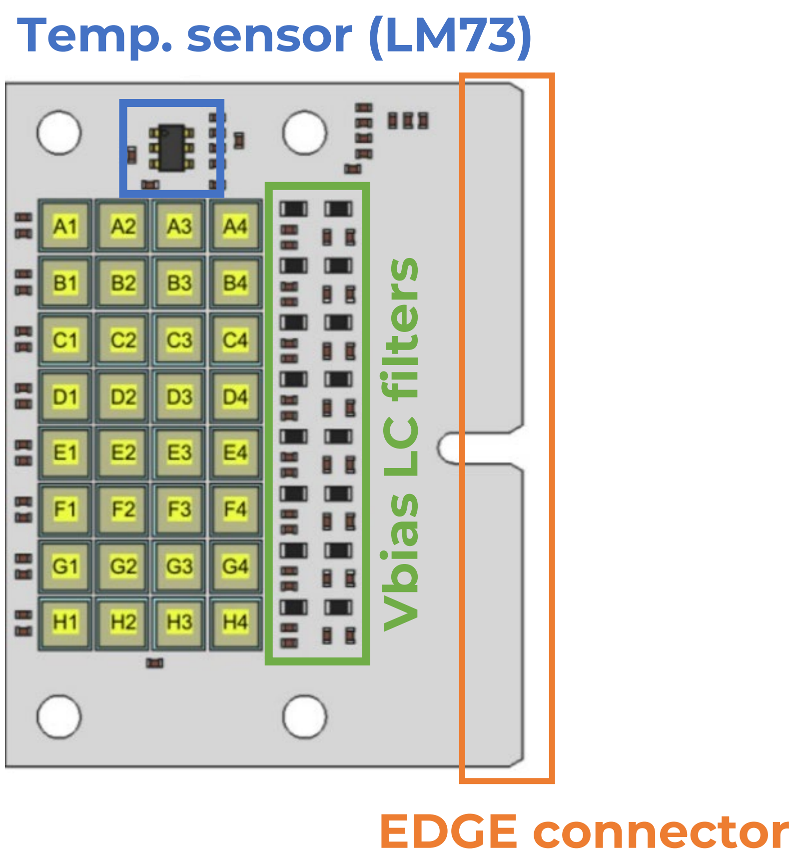
Ageing Model

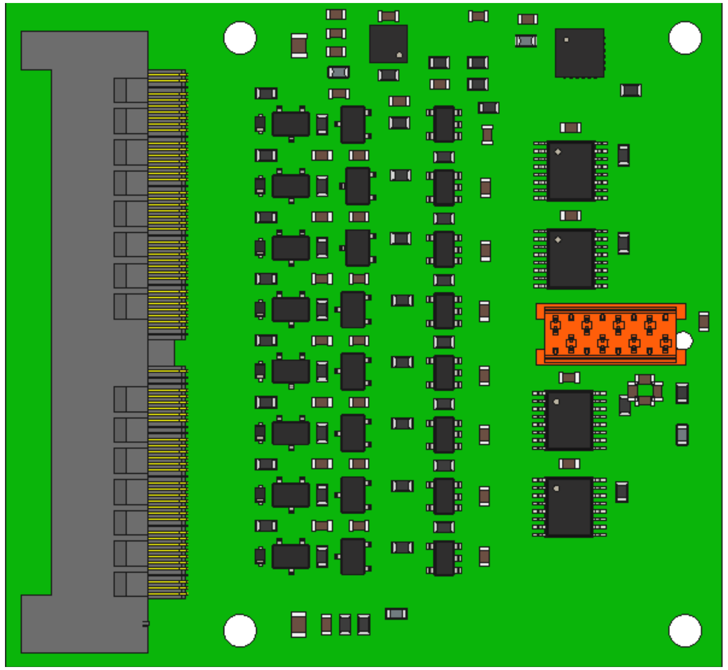


More **aggressive** annealing is needed: **oven**

Current annealing extends **SiPMs lifetime** by a factor **~ 10**

First prototype concept: flexibility





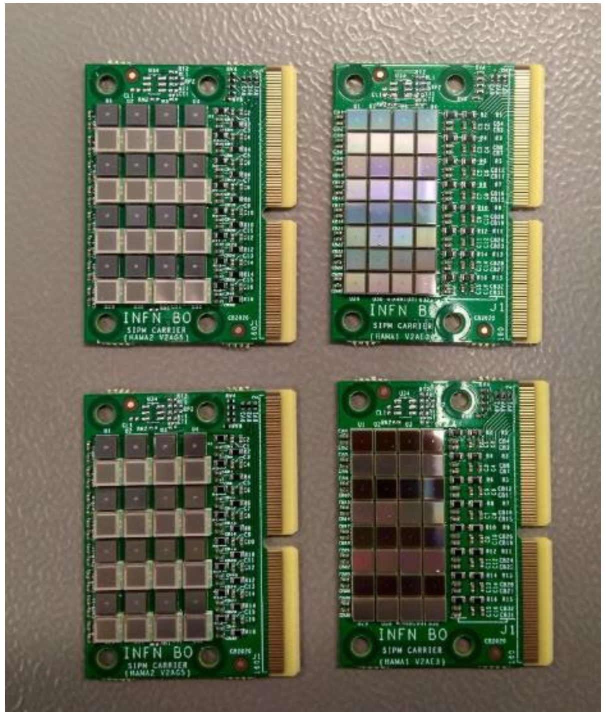
SIPMs matrix

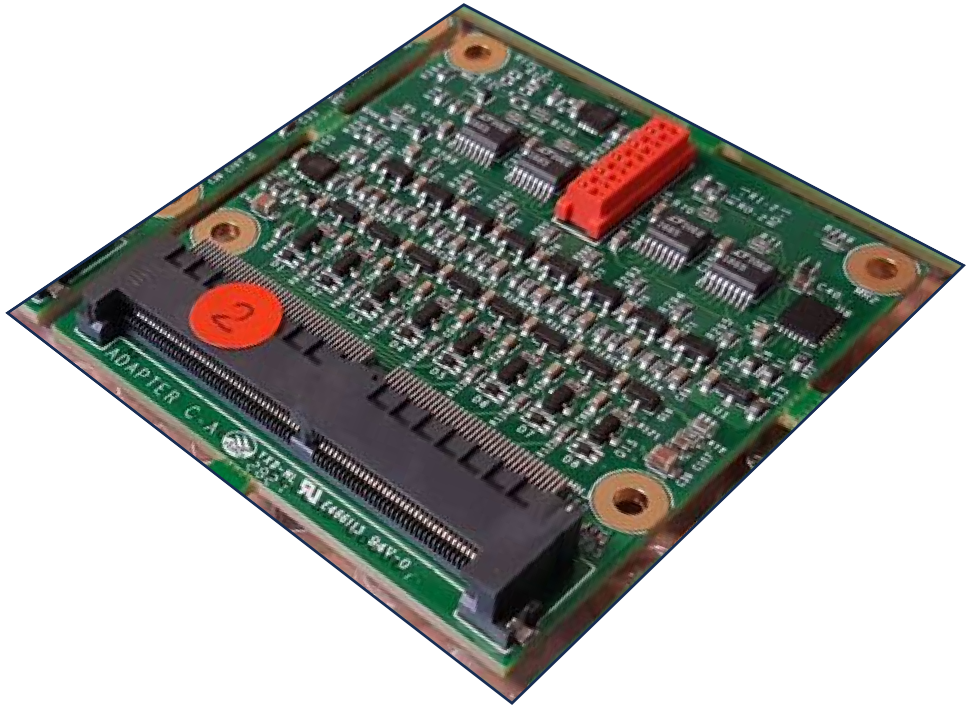
- Different sensors
- No plastic

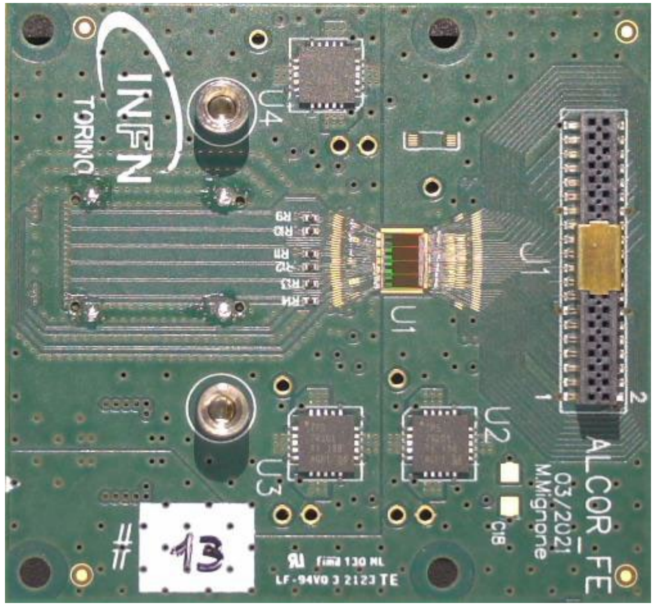
Adapter (INFN FE)

- VBias fine tuning
- AC connection to the FE

First prototype







SIPMs matrix
- Different sensors
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Adapter (INFN FE)
- AC connection to the FE
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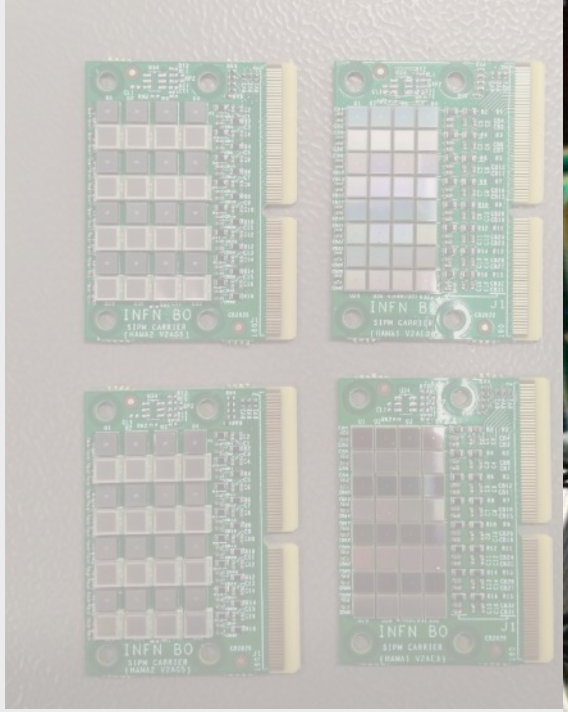
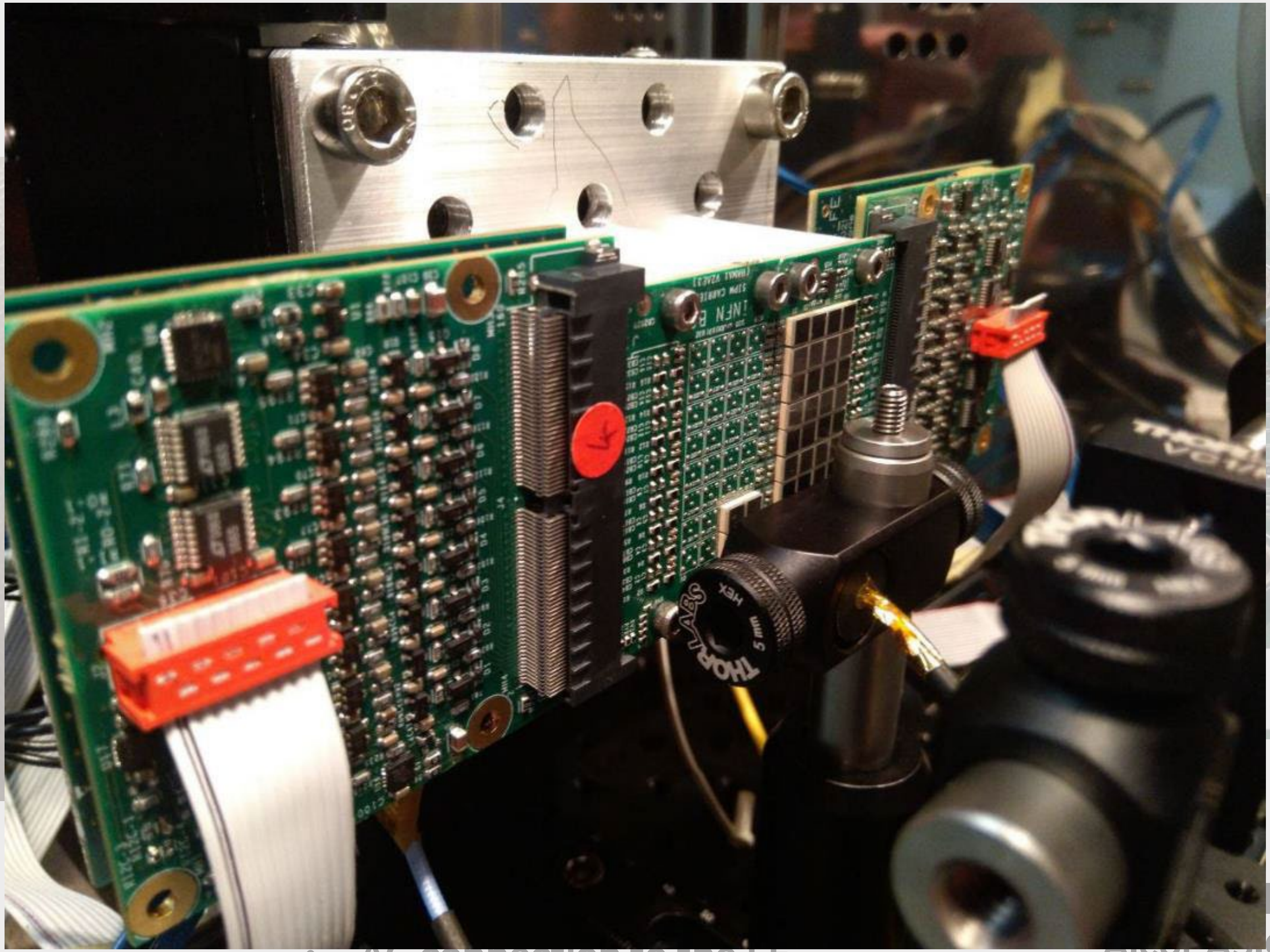
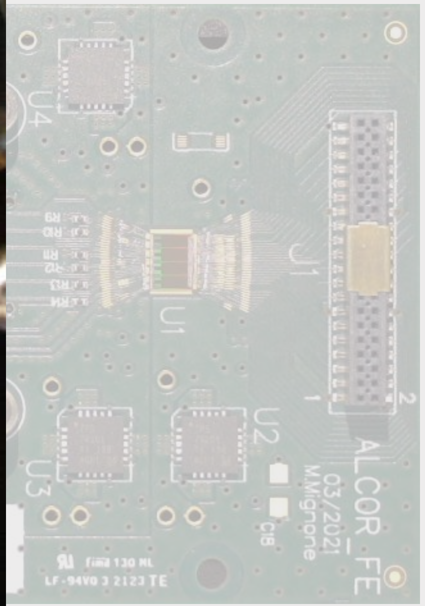
Front-End board (INFN TO)
- Alcor ASIC
- Voltage regulators
- Samtec Firefly 8x pairs to FPGA

First prototype







SIPMs matrix

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INFN TO)

- Alcor ASIC
- Voltage regulators
- Samtec Firefly 8x LVDS pairs

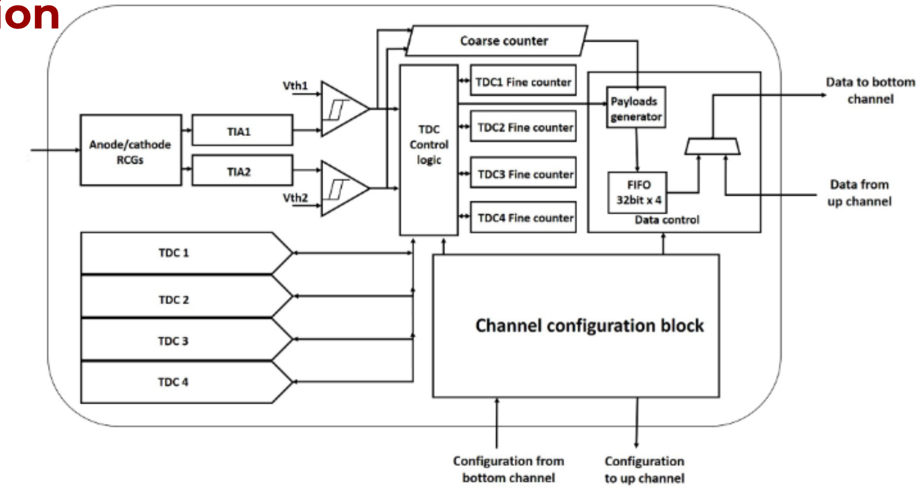
ALCOR ASIC by INFN-To

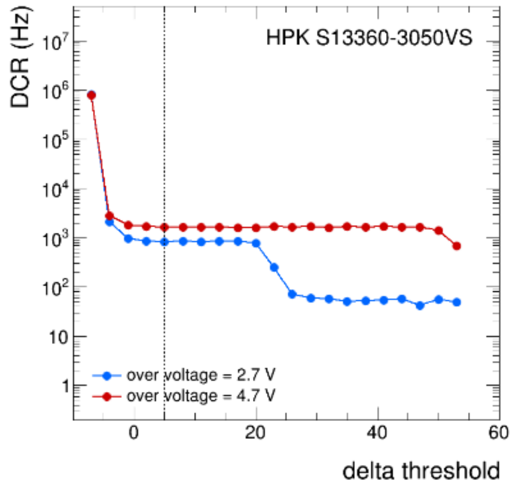
32-pixel matrix mixed signal **ASIC** initially foreseen for **SiPMs** in **cryogenics**

The chip performs **amplification**, **signal conditioning** and **event digitization** with a fully **digital I/O**

Each **pixel** features

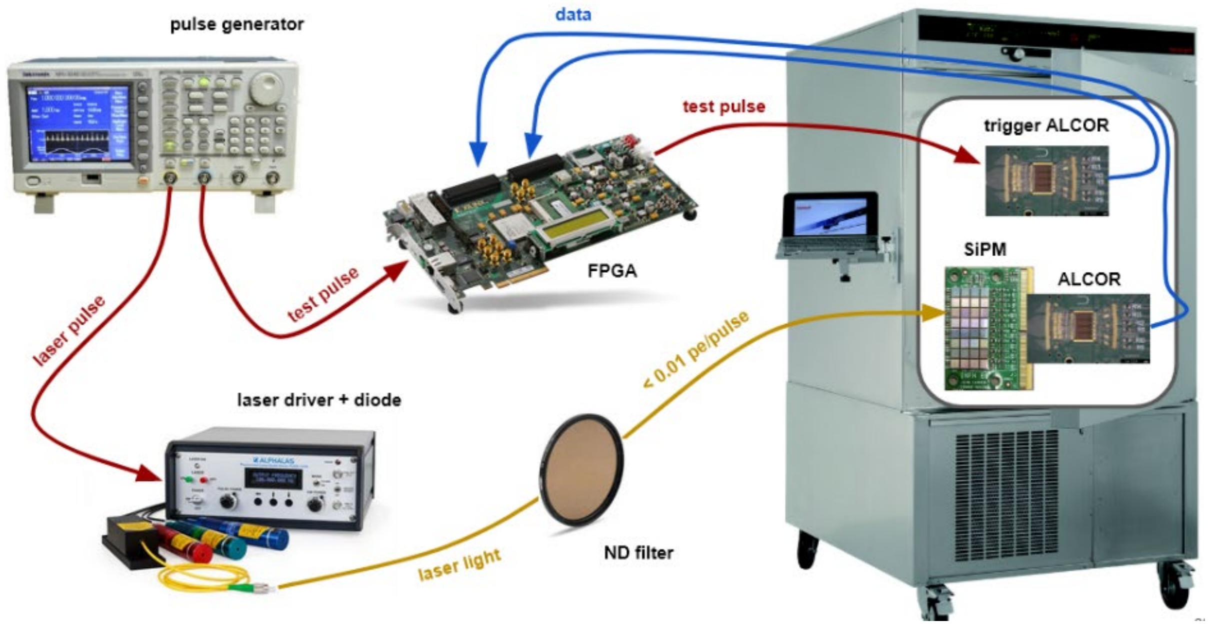
- Regulated common gate **amplifier** (10 ohm impedance)
- Post amp TIA for **4 gain settings**
- 2 **leading-edge discriminators** with independent **threshold** settings
- 4 **TDCs** based on analogue interpolation with **50 ps LSB** (@ 320 MHz)
- 3 **triggerless operation** modes:
    - **LET** leading edge threshold measurement, high-rate time-stamp
    - **ToT** Time-over-Threshold
    - **Slew rate** measurements for signal characterization



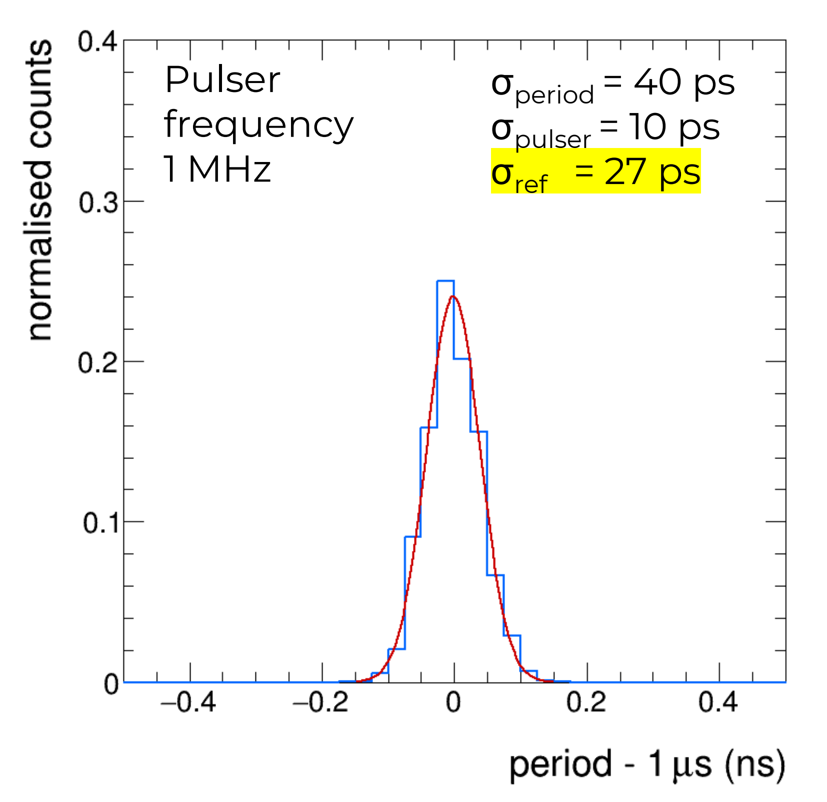


Fully **digital output** on **4 LVDS TX** data links
SPI-based chip configuration
64-bit event and **status** data

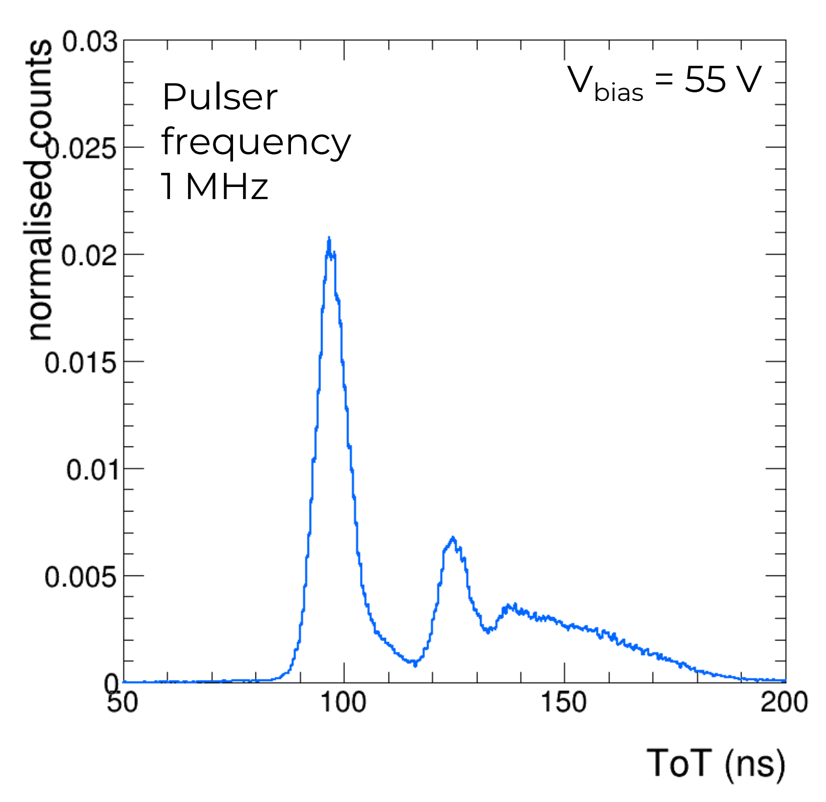
Timing performance



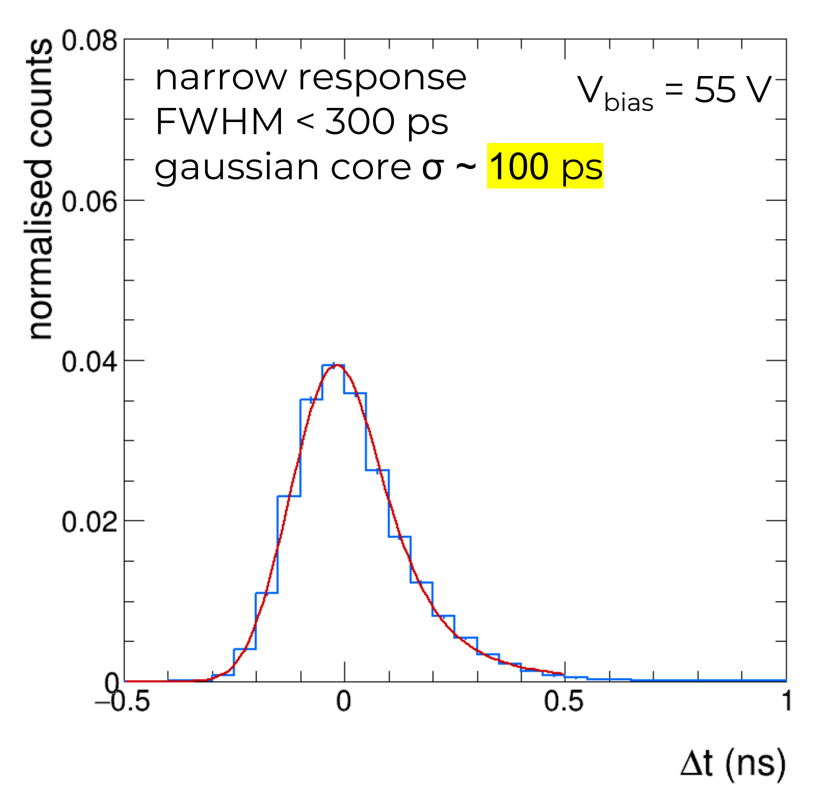
The setup
Climatic chamber **@ -30° C** hosting the readout system with **SiPMs** and one without used as reference.
< 4 ps laser pulse filtered down to single photon by ND filters.
Laser-SiPM signal **synchronization** by sending test **pulse** to **reference ALCOR** to measure laser pulse start (50 ps LSB TDC) in synch with ALCOR readout.
Δt is measured as the time difference between reference and ALCOR reading SiPM



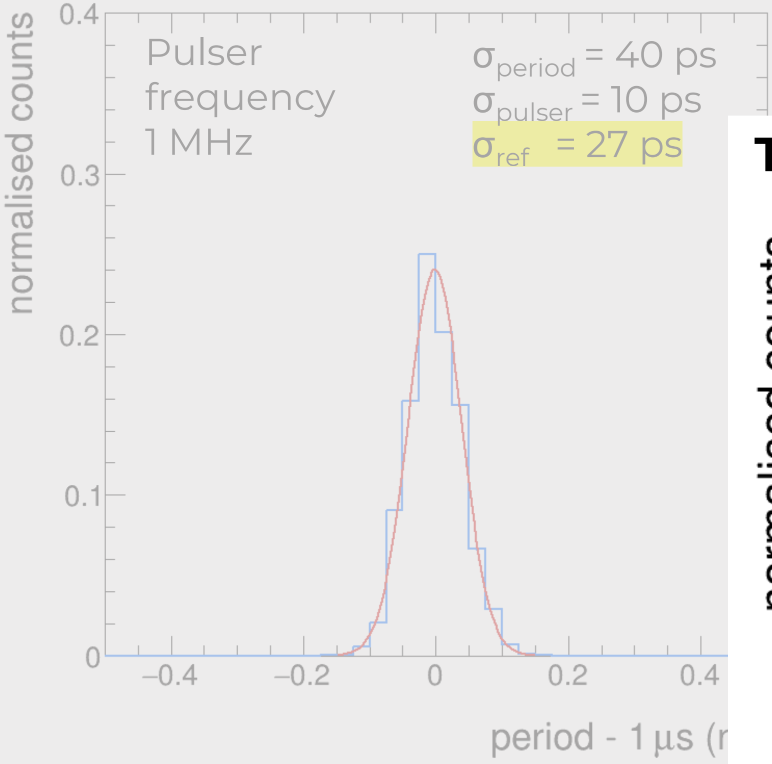
Reference ALCOR pulse period



Time-over-Threshold values

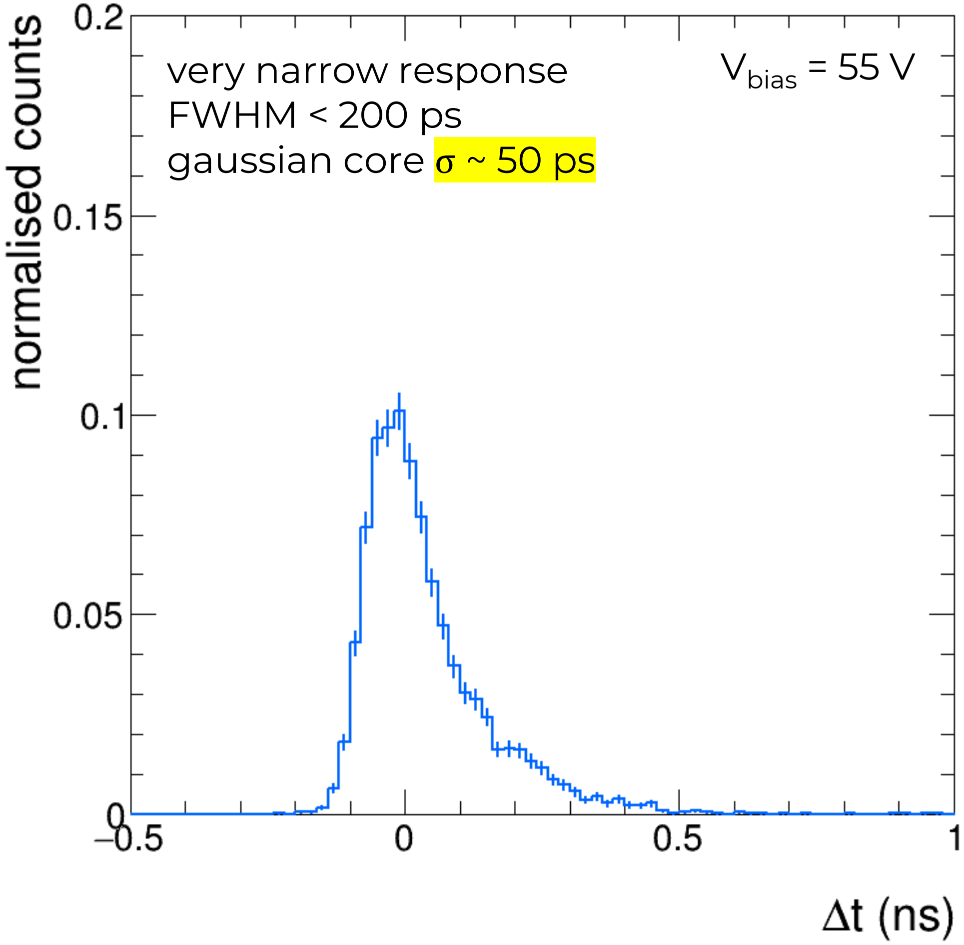


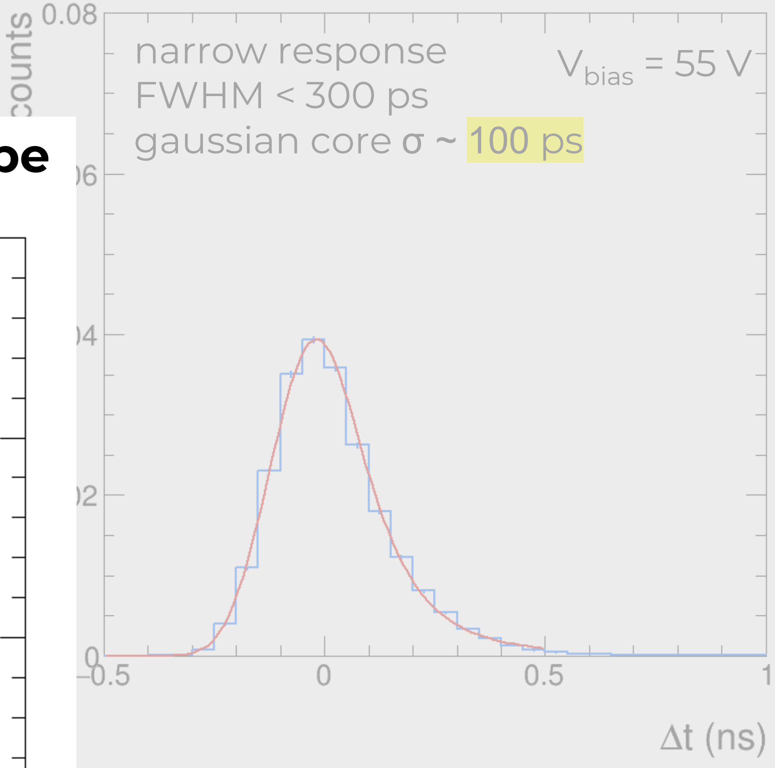
Laser-SiPM correlations (time-walk corrected)



Reference ALCOR pulse perio

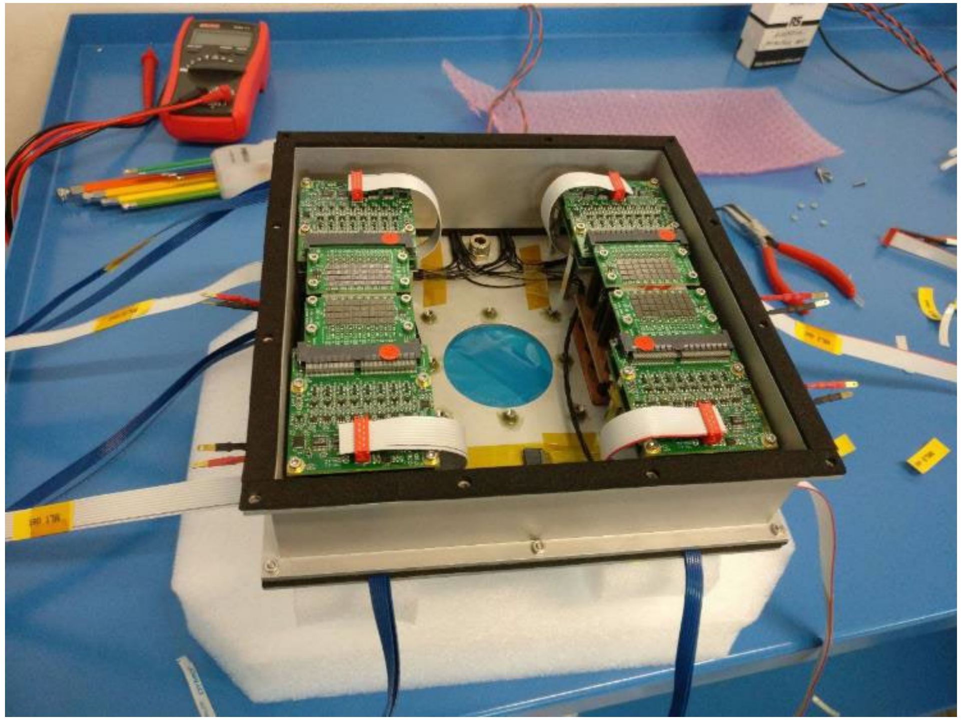
Time jitter measured with oscilloscope





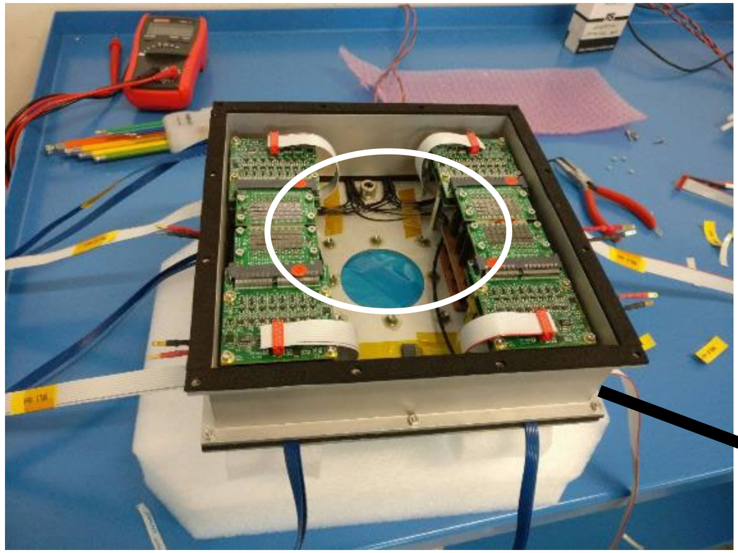
Laser-SiPM correlations (time-walk corrected)

2022 test beam prototype at CERN-PS

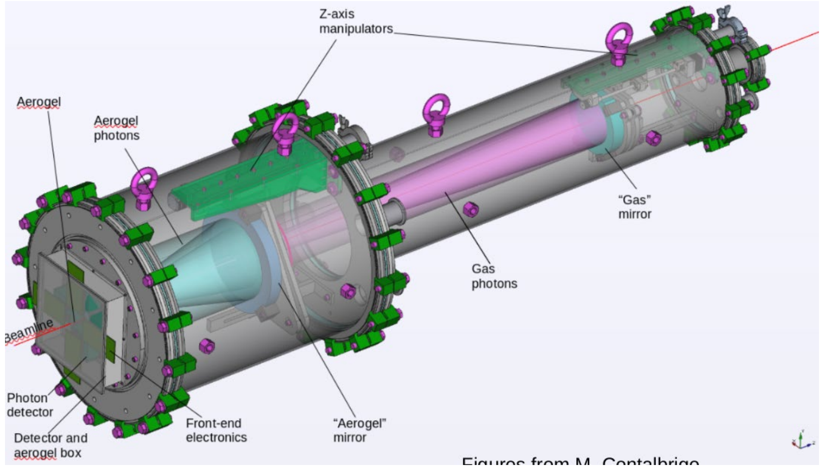


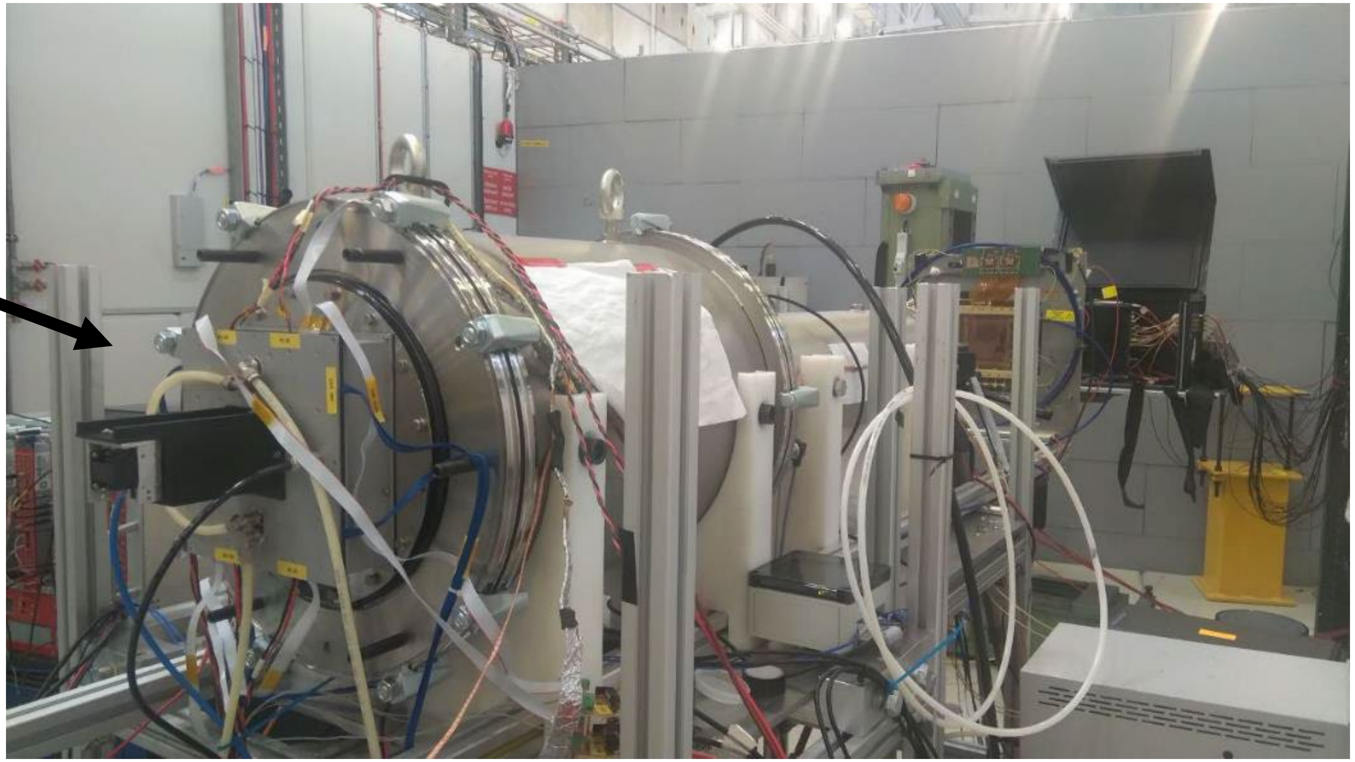
First prototype readout
4 matrixes with different **SiPMs irradiated** at **10^{10} n_{eq}/cm^2**
annealed in the oven (200 h @150° C)
- 30° C operation with peltier cells
Nitrogen gas circulation in the box to **avoid moisture** and **frost**
Neoprene on the edges to isolate the sensors from light

2022 test beam prototype at CERN-PS



Readout box mounted onto the dRICH prototipe on PS beamline





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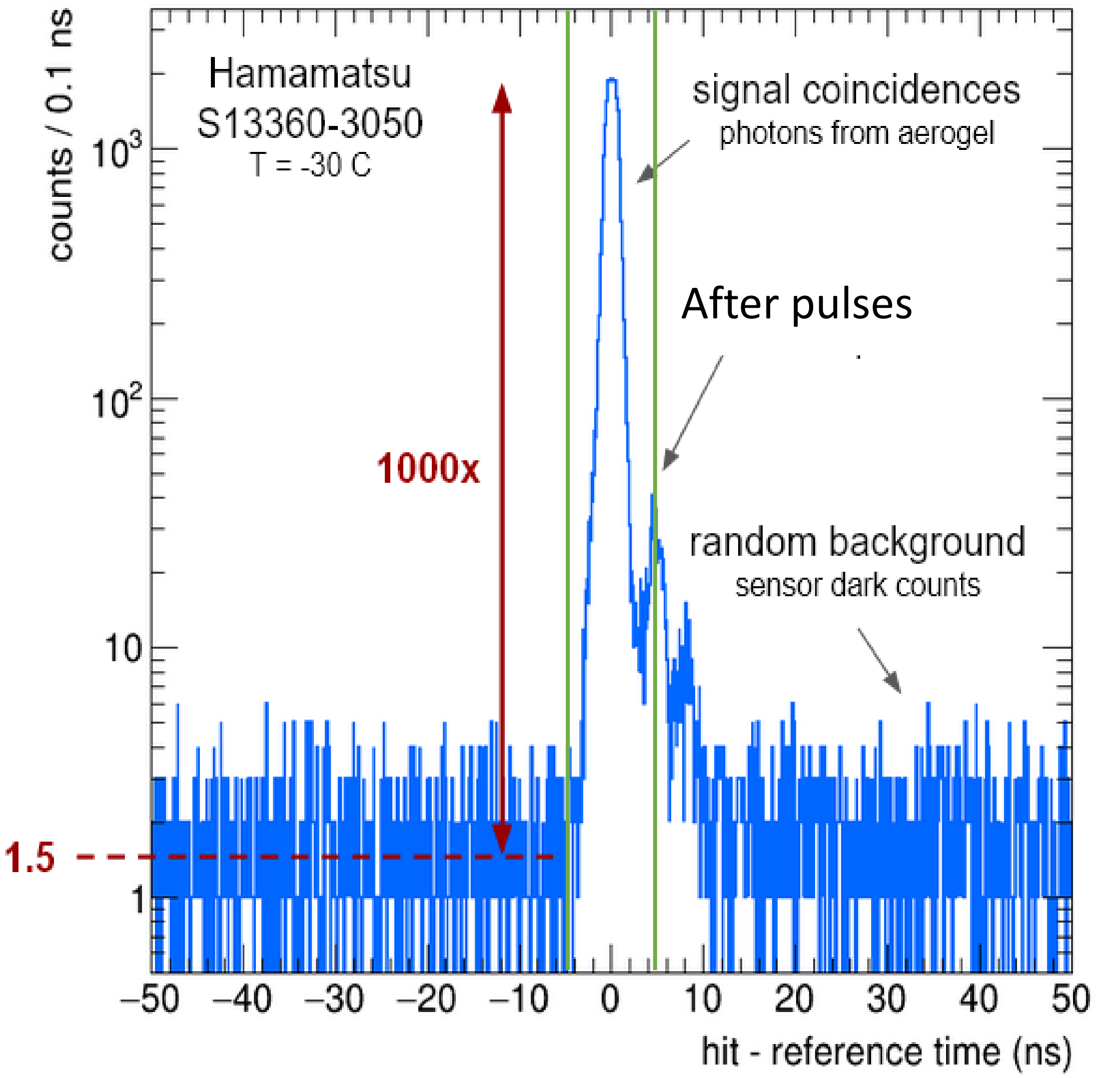
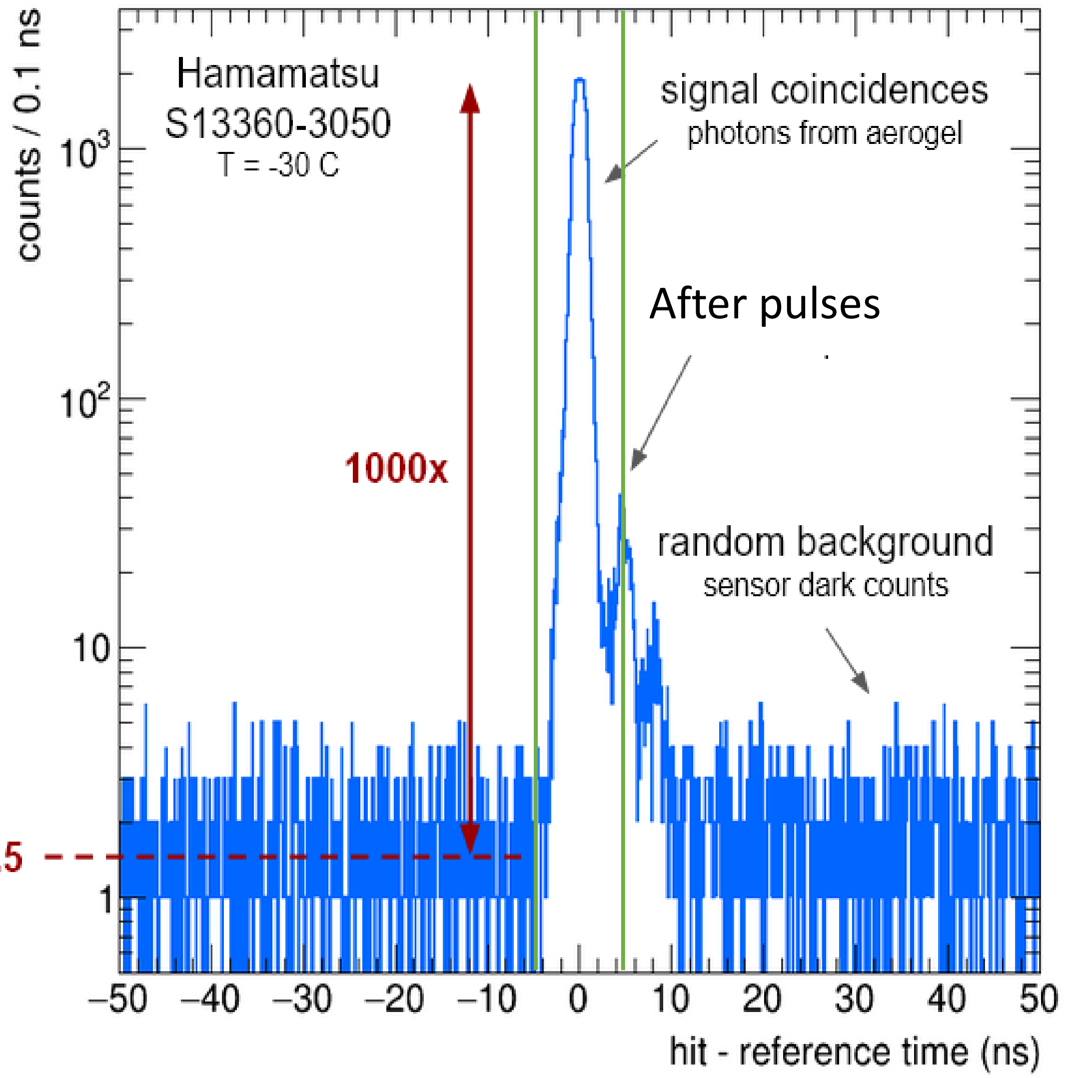


sensor DCR ~ 15 kHz

2022 test beam prototype at CERN-PS



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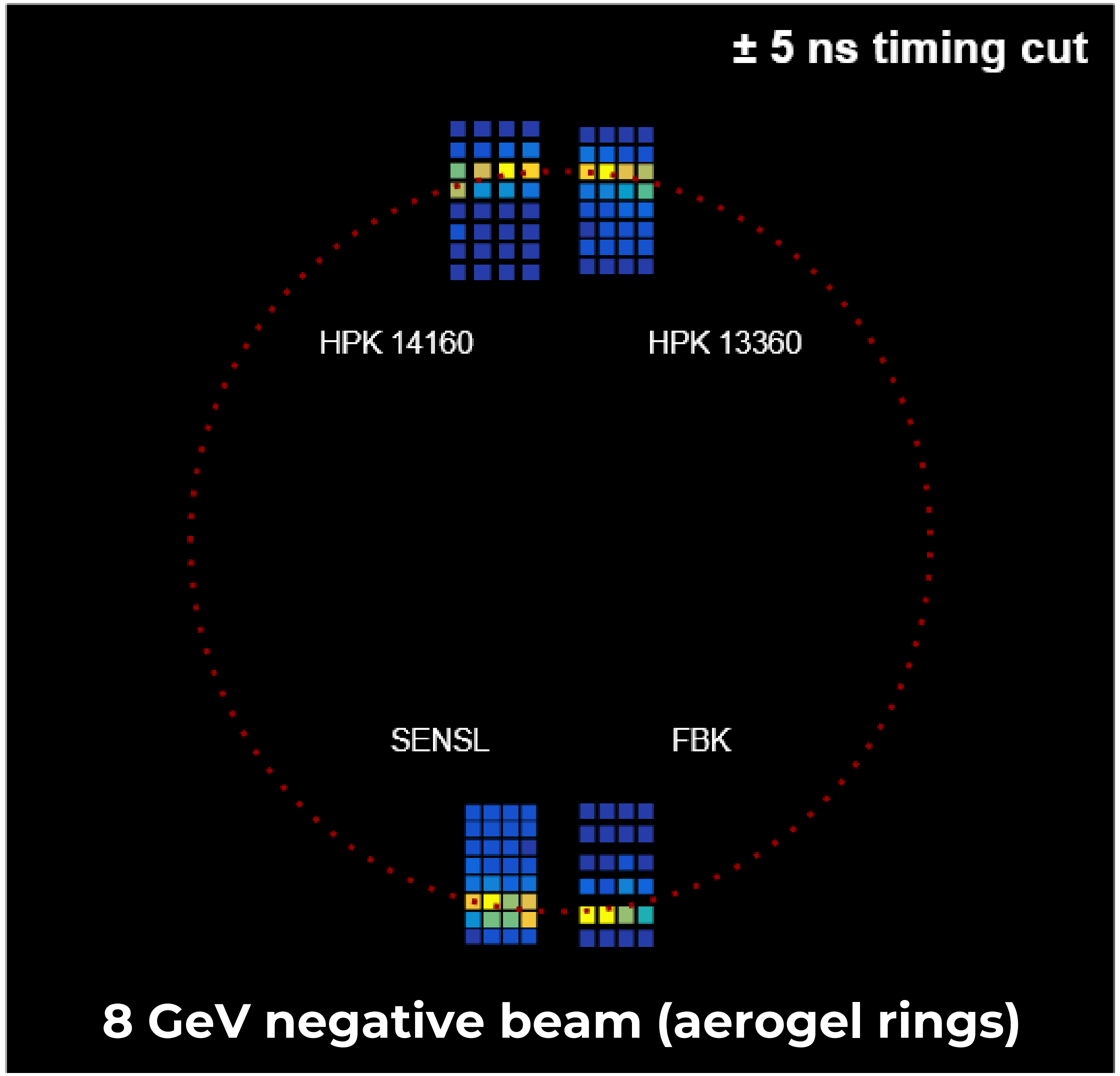
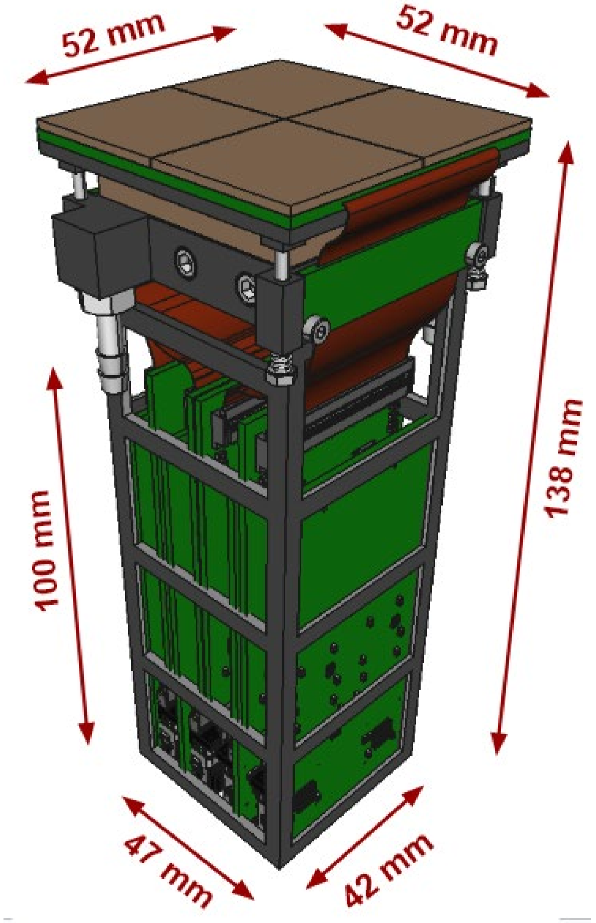


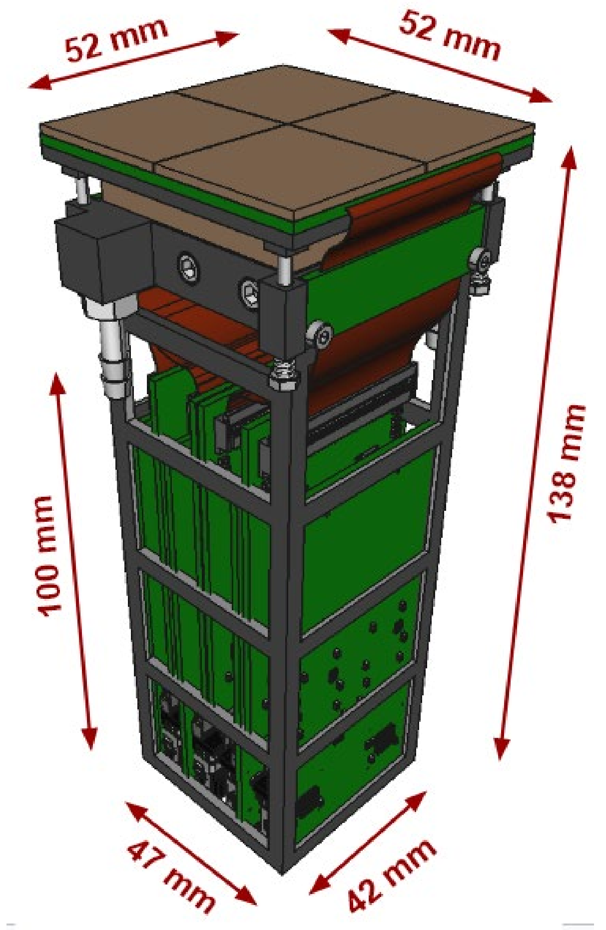
2023 readout system prototype

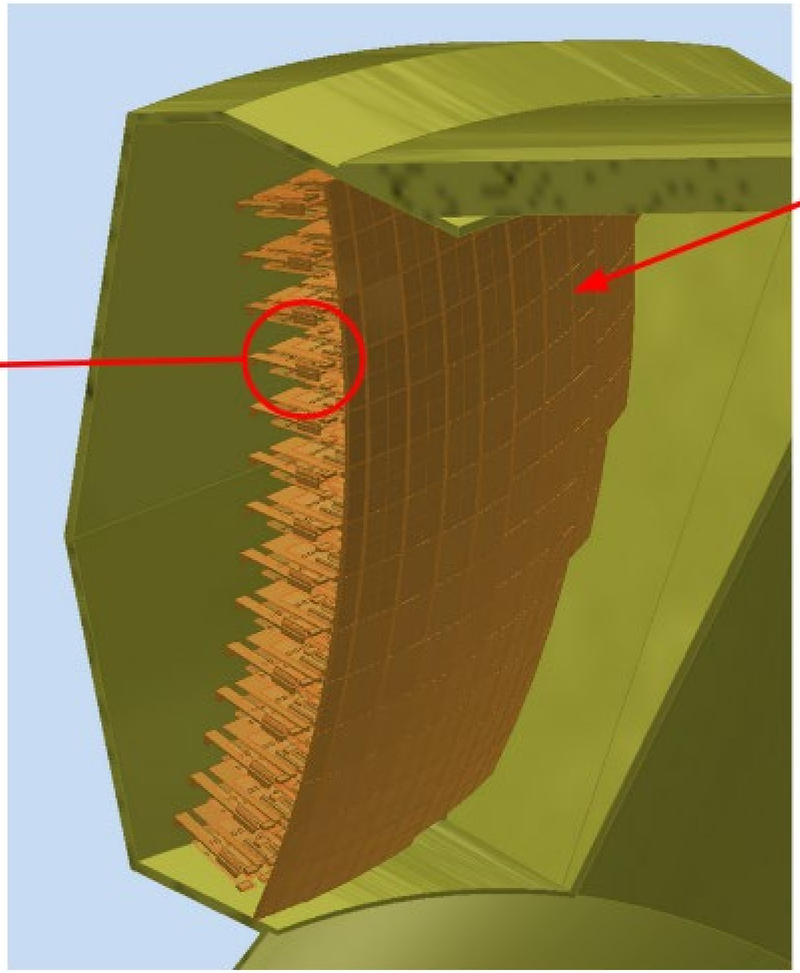


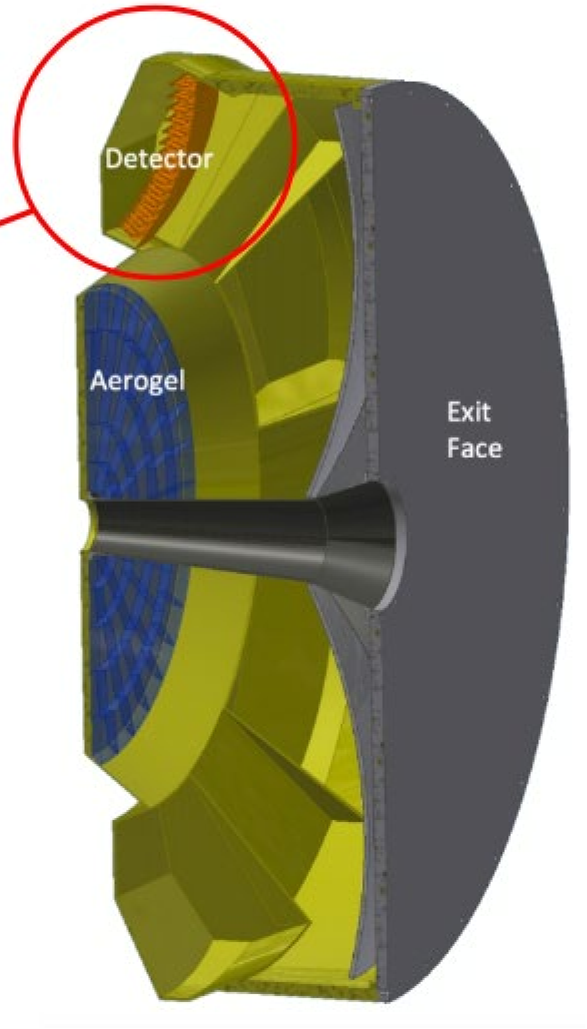
Towards the final design looking for **Compactness** and **Integration**

4 matrixes of **8x8** Hamamtsu S13650 **SiPMs** (256) hosted by a **Rigid flex** matrix board with **no plastic** connectors (can be annealed in the oven)
Integrated cooling with peltier cells and liquid cooling
4 stackable **adapters+frontened** boards placed perpendicularly to save space.

2023 readout system prototype

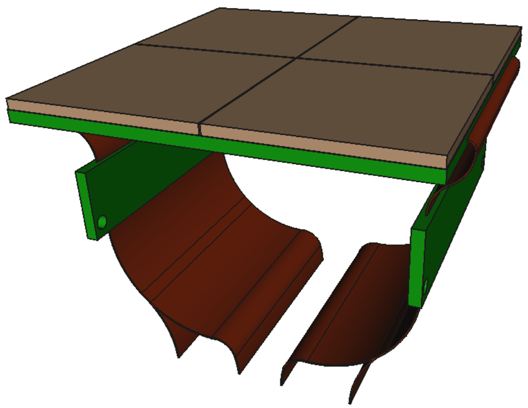






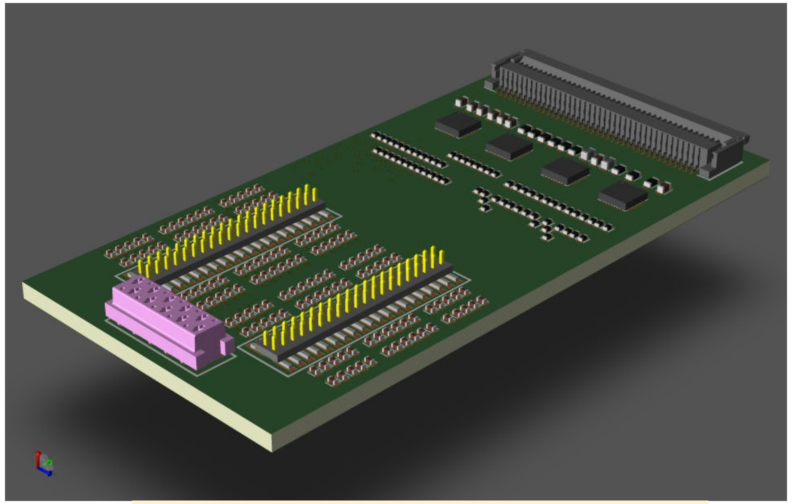
2023 readout system prototype

Matrix board



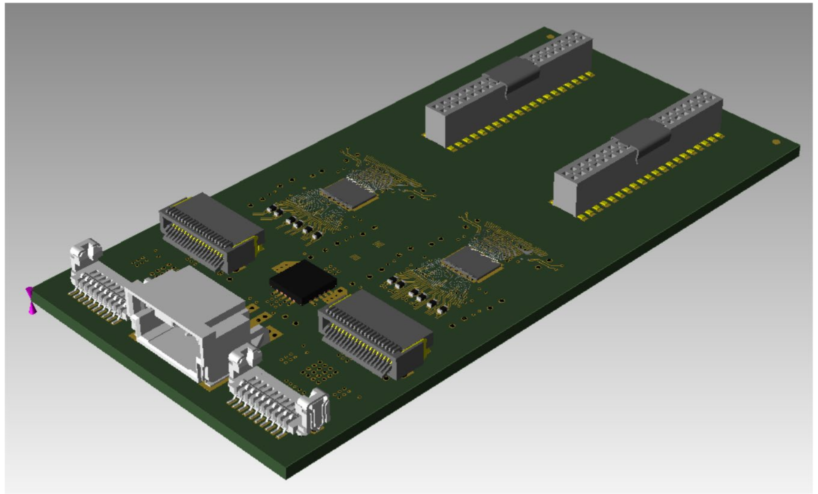
HV and signals via **flex** pcb with 1 mm bending radius
Rigid flex design to host HV LC-filters
Back-side temperature sensors

4x Adapter boards

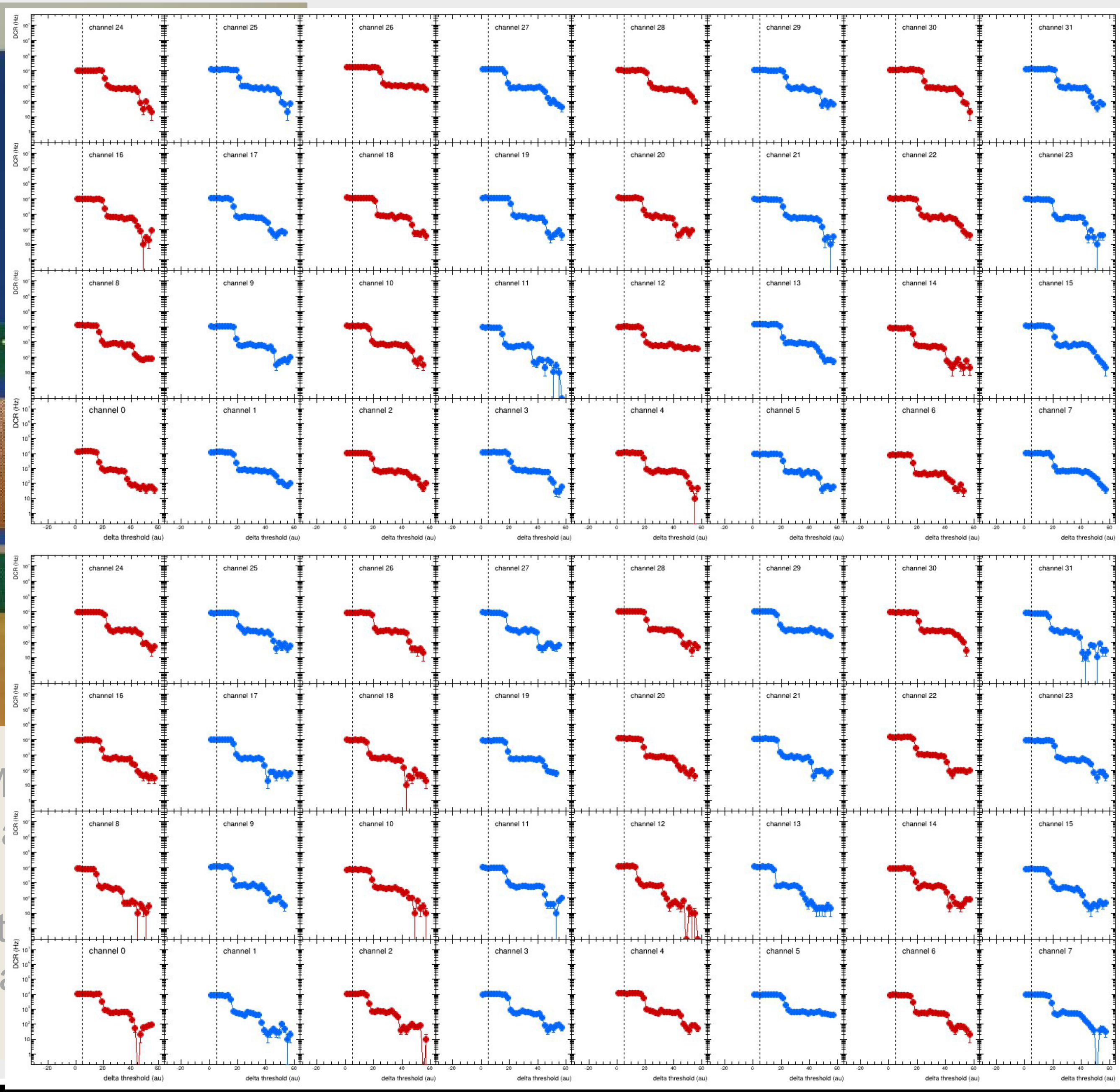


HV regulation
0-5 V per SiPM
0-80 V for 8 channels
AC coupling to ALCOR
Mosfet to isolate the anode for the “annealing mode”

4x Front-end boards



2x ALCOR-v2 ASICs (2x 32 channels)
2x Firefly connectors
Voltage regulators



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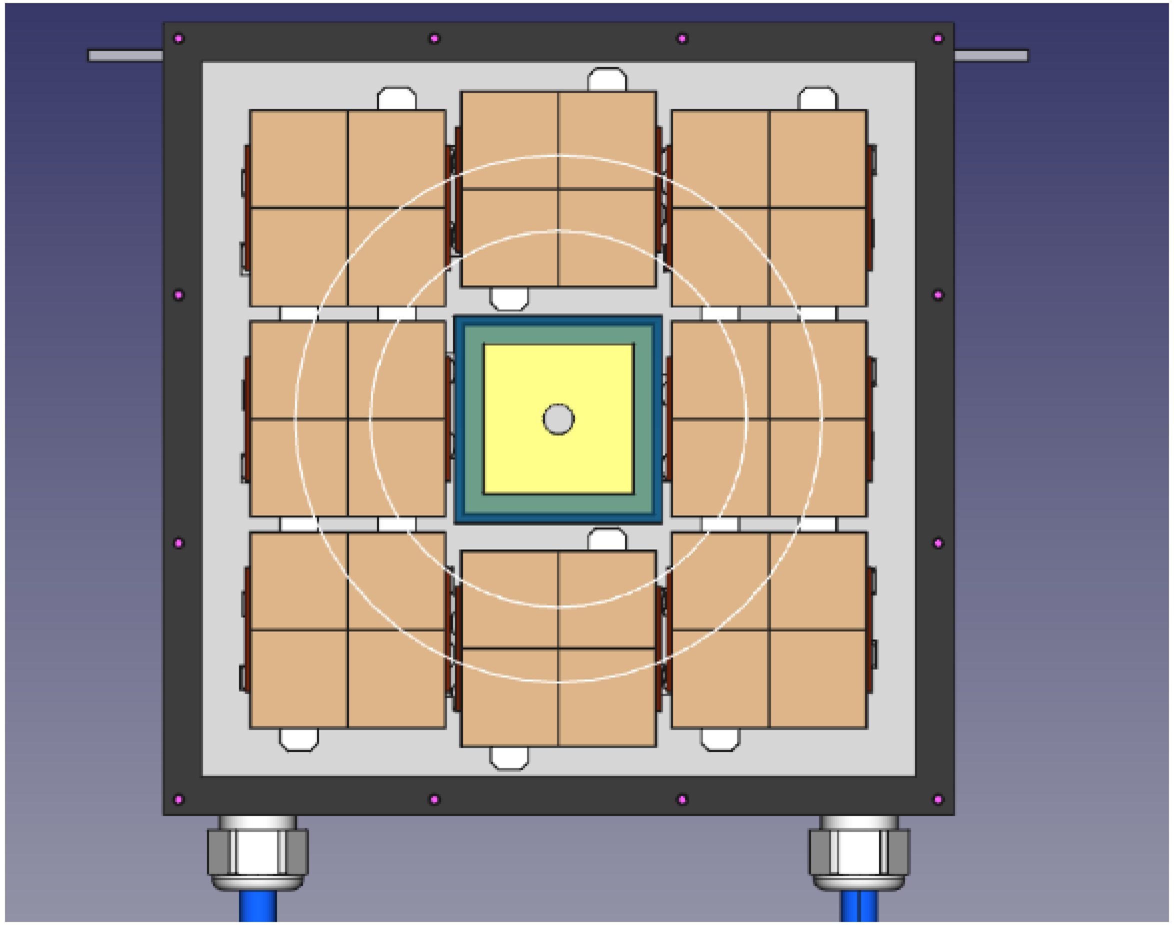
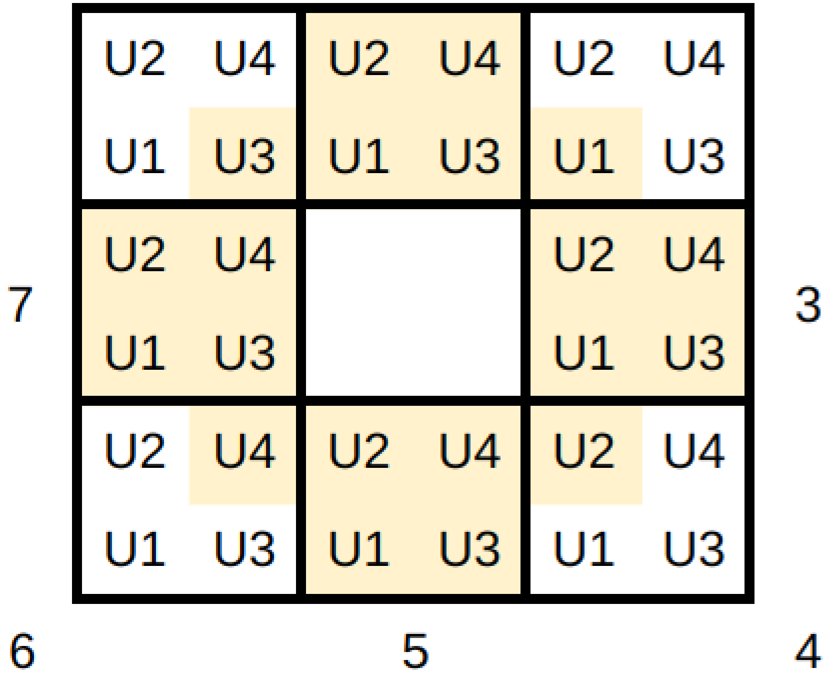
- Rigid flex design to host HV LC-filters
- Back-side temperature sensors

- HV regulation
- 0-5 V per SiPM
- 0-80 V for 8 ch
- AC coupling to
- Mosfet to isolat
- anode for the "
- mode"

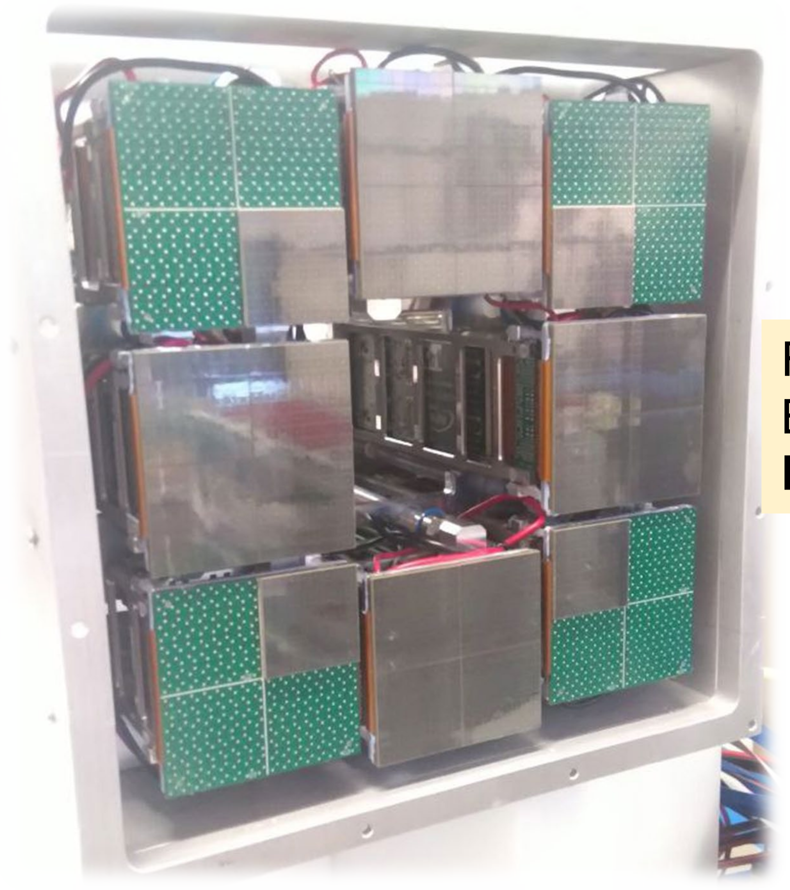
2023 test beam prototype at CERN-PS



Actual SiPM layout:
4x full matrixes
4x partial matrixes



2023 test beam prototype at CERN-PS



Full system integrated in Bologna for tests.
Now travelling to CERN!!

Conclusions

- **SiPMs are a feasible solution for the dRICH photodetection planes at EIC**
- 2 prototype of the readout system were developed and (up to be) tested in in beam operations