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

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on behalf of the dRICH collaboration

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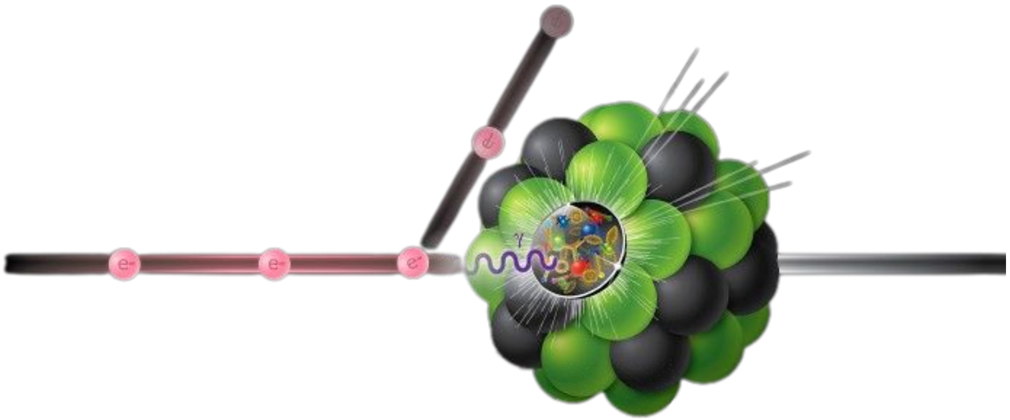
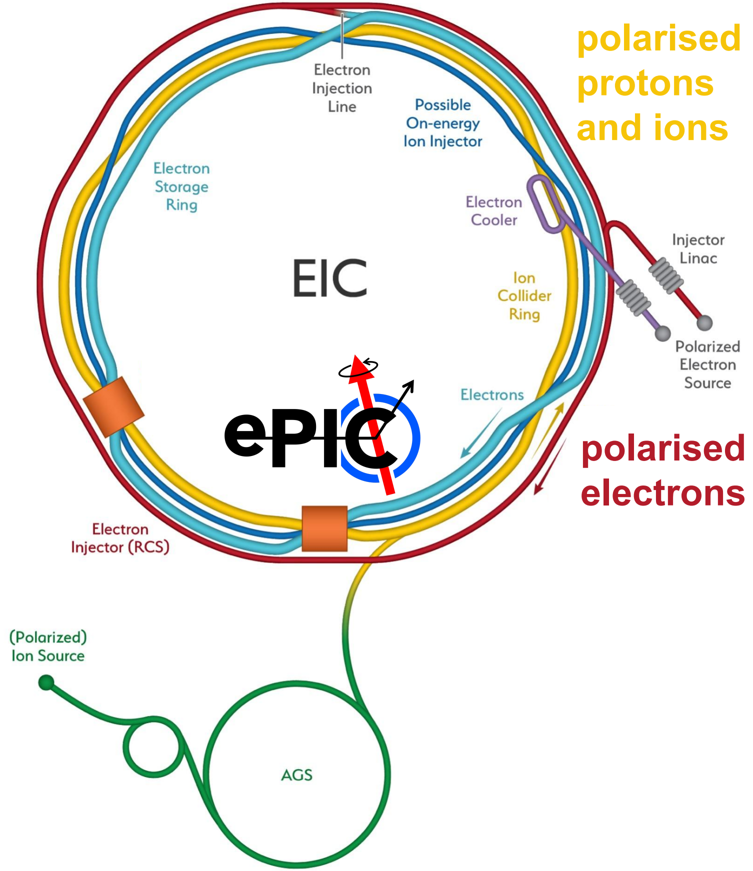
Electron-ion collider

A future accelerator that will for the first time collide polarised electrons and polarised ions or protons

A major US facility that will be the frontier of nuclear and subnuclear physics in the early 2030s

Will provide an extraordinary 3D imaging of the proton and nucleus structure, together with providing insights on the origin of the proton mass and spin





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ePIC detector layout

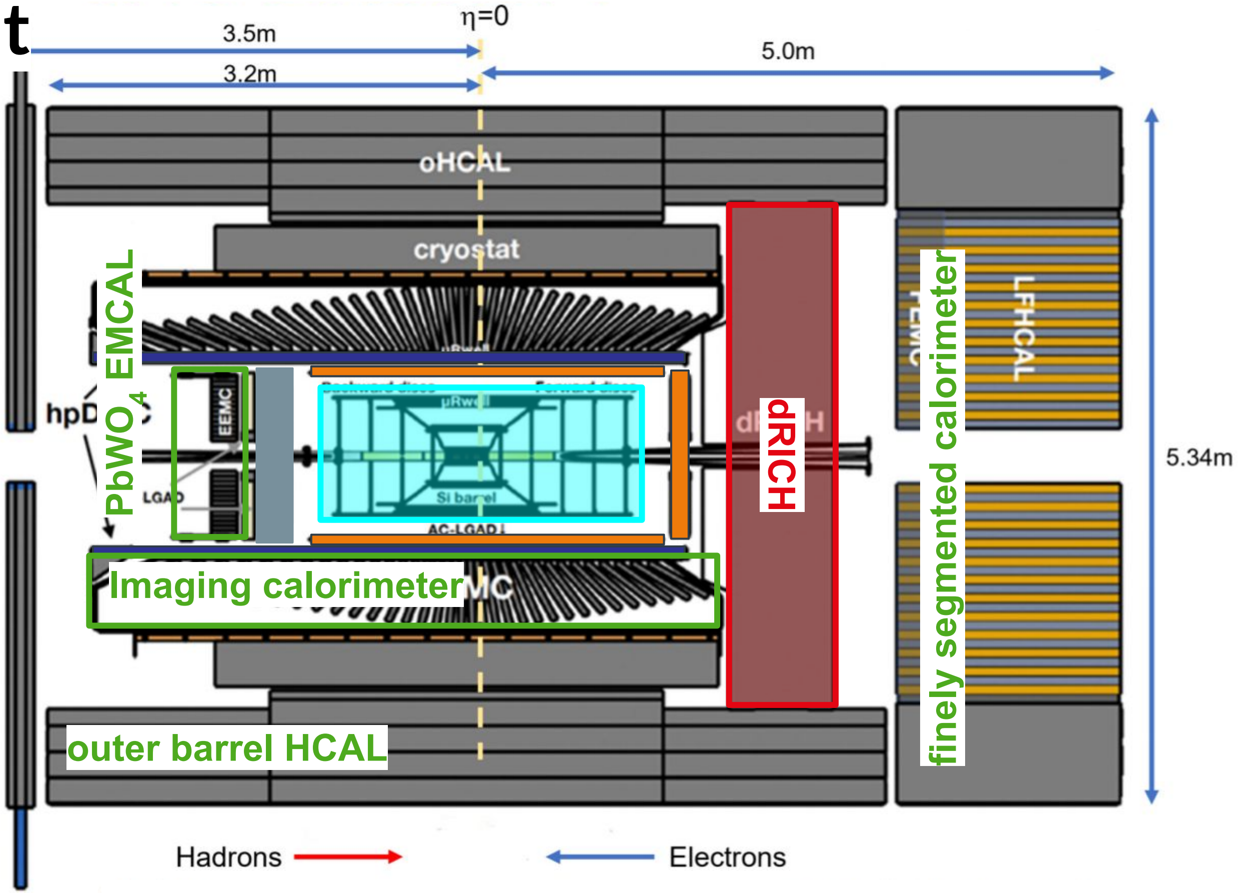
Particle ID

dRICH	**hpDIRC**
p ~3-50 GeV/c	**p ~0.5-6 GeV/c**
LGADs TOF	**pfRICH**
p ~0.5-4.5 GeV/c	**p ~0.5-9 GeV/c**

Tracking

Si-MAPS

MPGDs



The dual-radiator (dRICH) for forward PID at ePIC

Particle ID

dRICH
p ~3-50 GeV/c
η ~1.5-3.5
e-ID up to 15GeV/c

Broad momentum coverage thanks to dual refractive index:
gas ~ 1.0008
aerogel ~ 1.02

Photosensors:

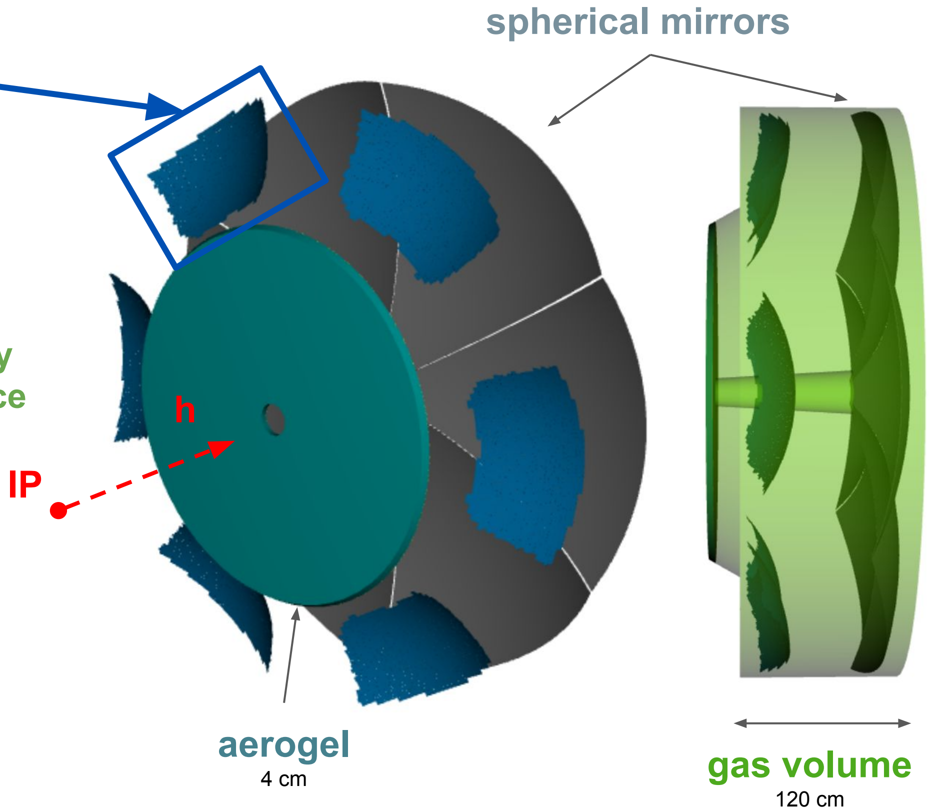
- $3x3mm^2$ pixels
- $0.5m^2$ per sector
- SiPM chosen

Pros

1. Single photon sensitivity
2. Good timing performance
3. Insensitive to magnetic fields
4. Cheap

Cons

1. High dark count rate at room temperature
2. High radiation sensitivity



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The SiPM option and neutron fluence for dRICH sensors

Cons

1. **High dark count rate at room temperature**
2. **High radiation sensitivity**

What can be done?

1. Cooling can lower DCR of a factor ~2 every ~8°C
2. Timing can discard background
3. Annealing can recover DCR resulted from radiation damage

10^9 n_{eq}/cm^2 fluence:

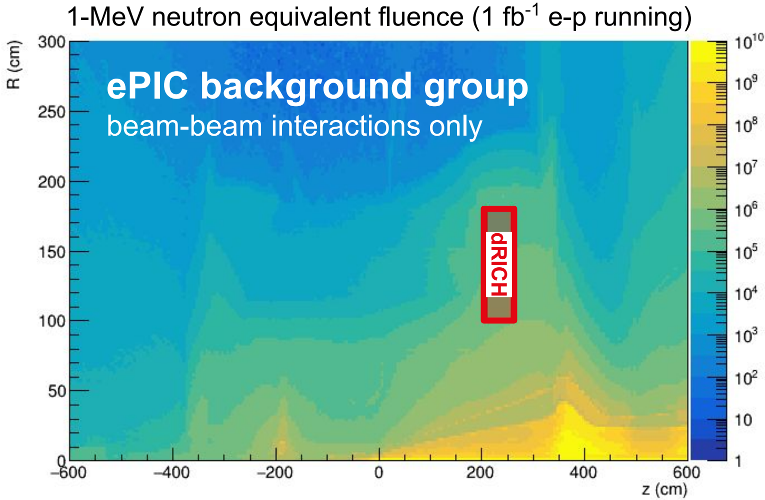
Requirement for the key physics goals is 10 fb^{-1} per center of mass energy and polarization setting

10^{10} n_{eq}/cm^2 fluence:

Requirement for the nucleon imaging programme is 100 fb^{-1} per center of mass energy and polarization setting

10^{11} n_{eq}/cm^2 fluence:

Expected fluence over 10-12 years of operation, might never be reached



Expected fluence:

average: ~4 10^5 n_{eq} / cm^2 fb^{-1}

maximum: ~ 10^6 n_{eq} / cm^2 fb^{-1}

assumed: ~ 10^7 n_{eq} / cm^2 fb^{-1}

x10 safety factor

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We need to study the SiPM response to this moderately irradiated environment

We started setting up these three levels of irradiation

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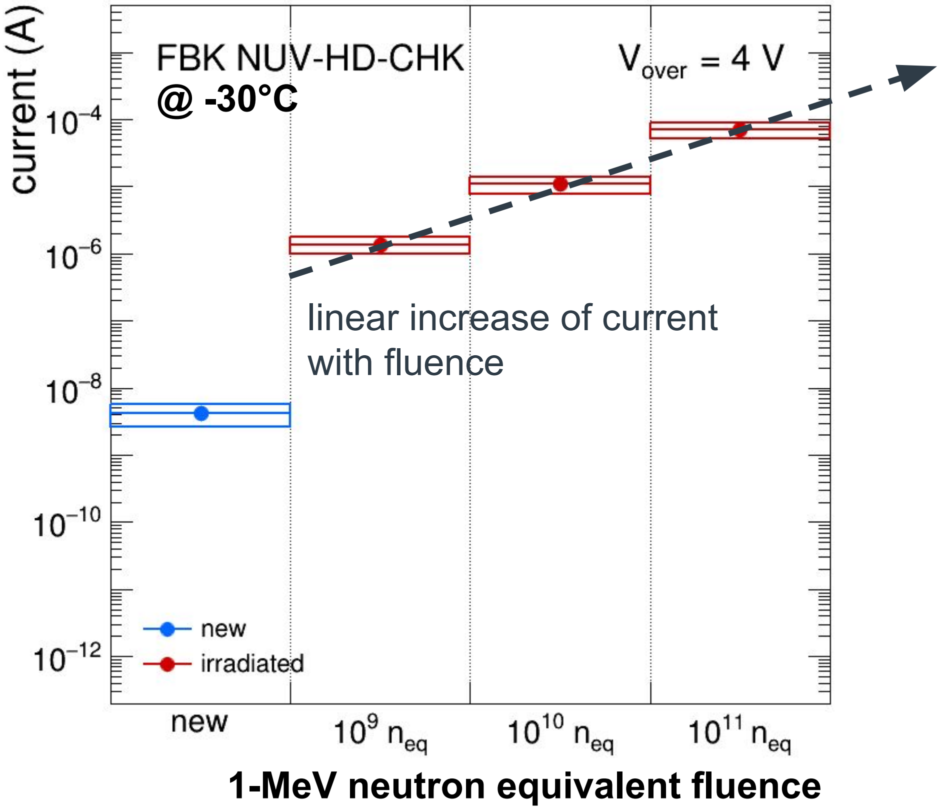
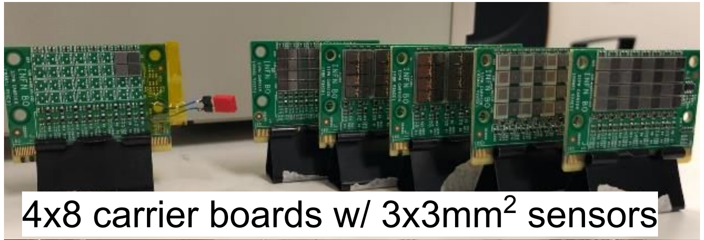
Radiation damage of SiPMs with protons at TIFPA





4x8 carrier boards w/ 3x3mm^2 sensors

2021, 2022, 2023 campaigns set-up

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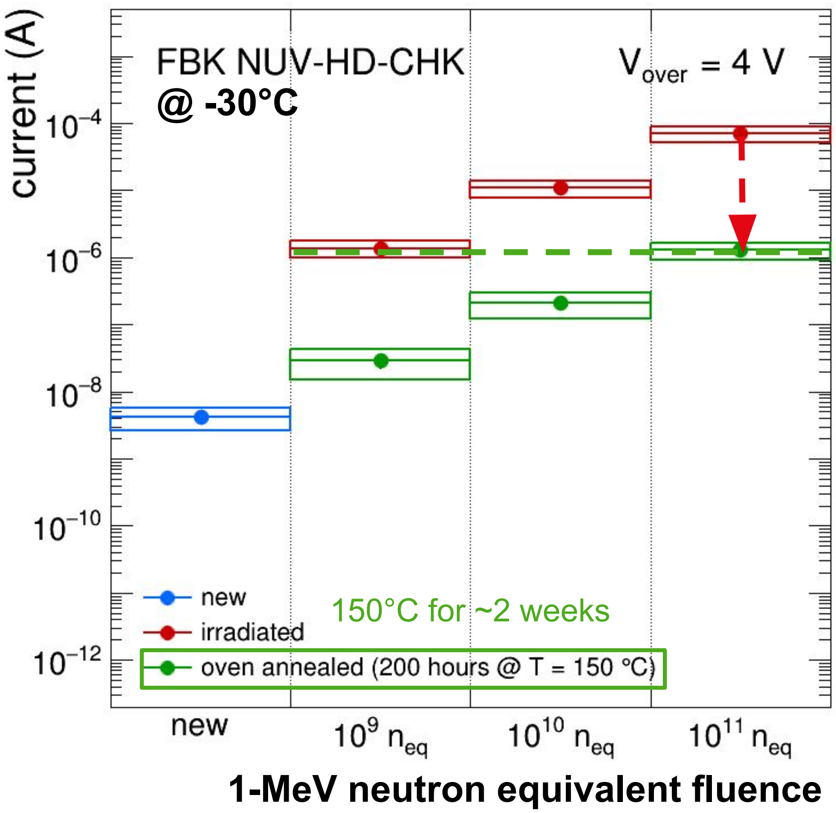
Radiation damage recovery of SiPMs with offline annealing

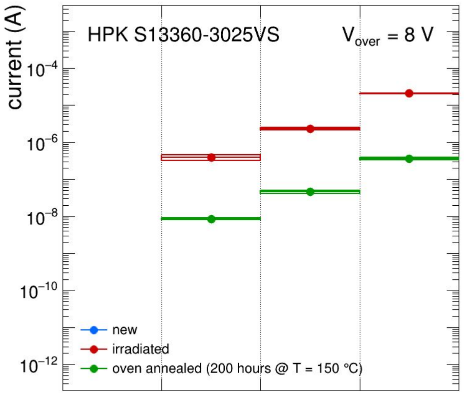


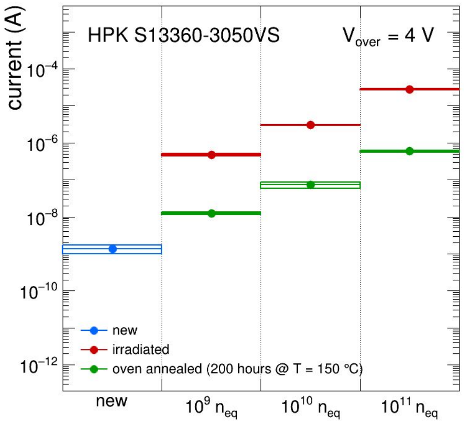
~ 100x reduction of dark current

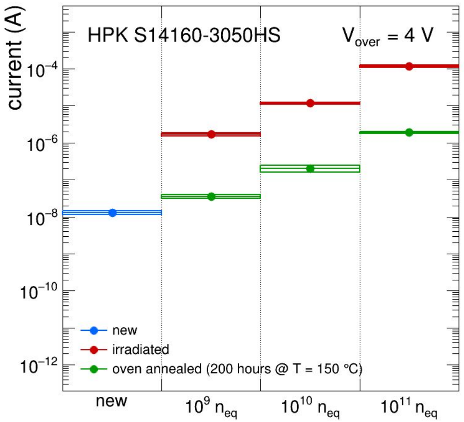
behaves as if it had received ~100x less fluence

Offline annealing done with sensors in oven

Hamamatsu sensors show very similar behaviours







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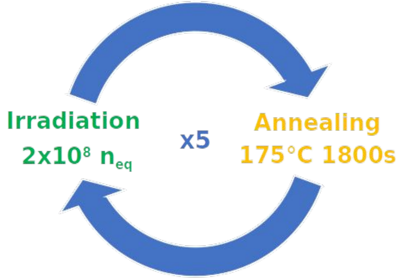
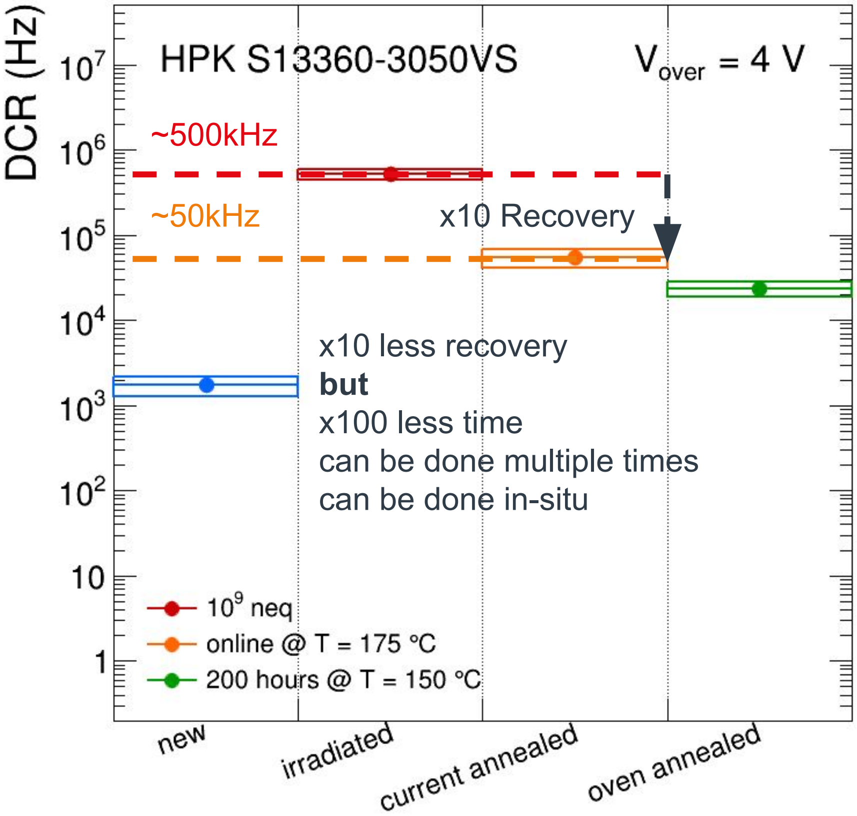
Radiation damage recovery of SiPMs with online anneling

Online annealing done with sensor in forward bias, delivering ~1W/sensor



Exposure to radiation is interleaved with annealing cycles as could be the case in the experiment



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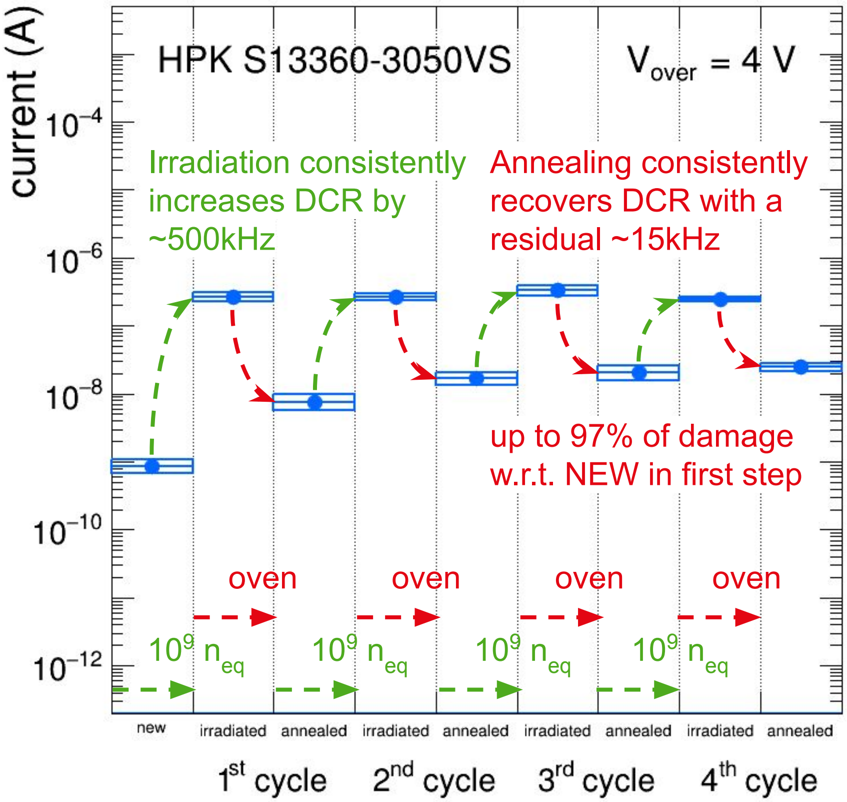
Damage recovery of SiPMs with multiple annealing cycles



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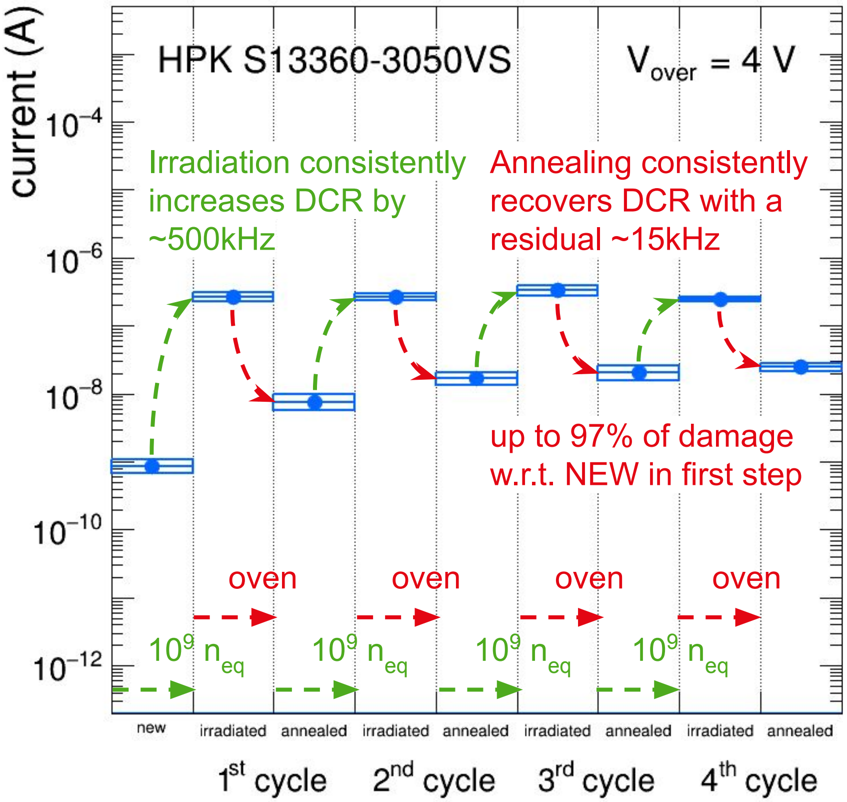

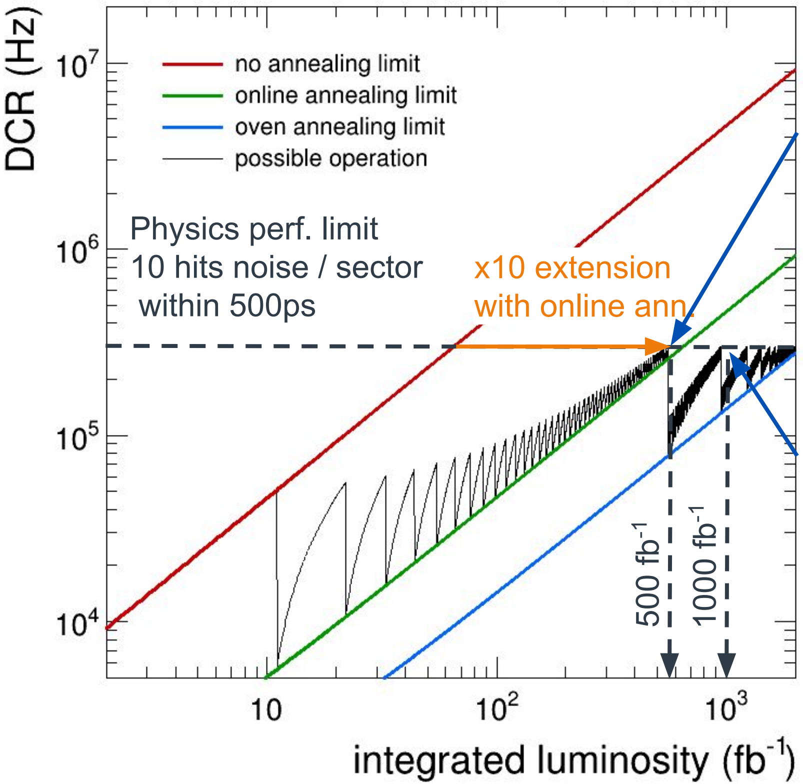

At the 500fb^{-1} mark a more aggressive annealing is required (oven)

It makes it possible to stay within the limit with 1000fb^{-1} luminosities

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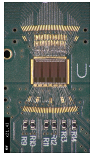
Photodetector unit

conceptual design

ALCOR ASIC



SiPMs

flex PCB

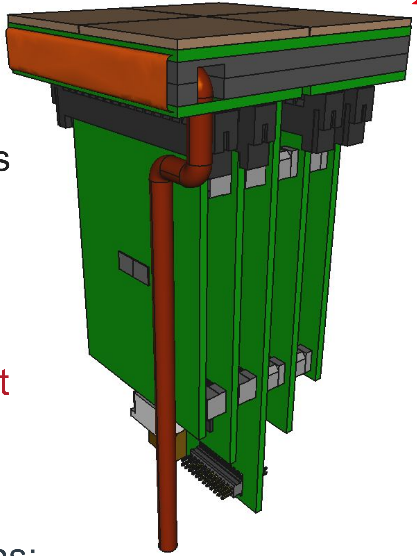
cold plate

back-side connectors

front-end board

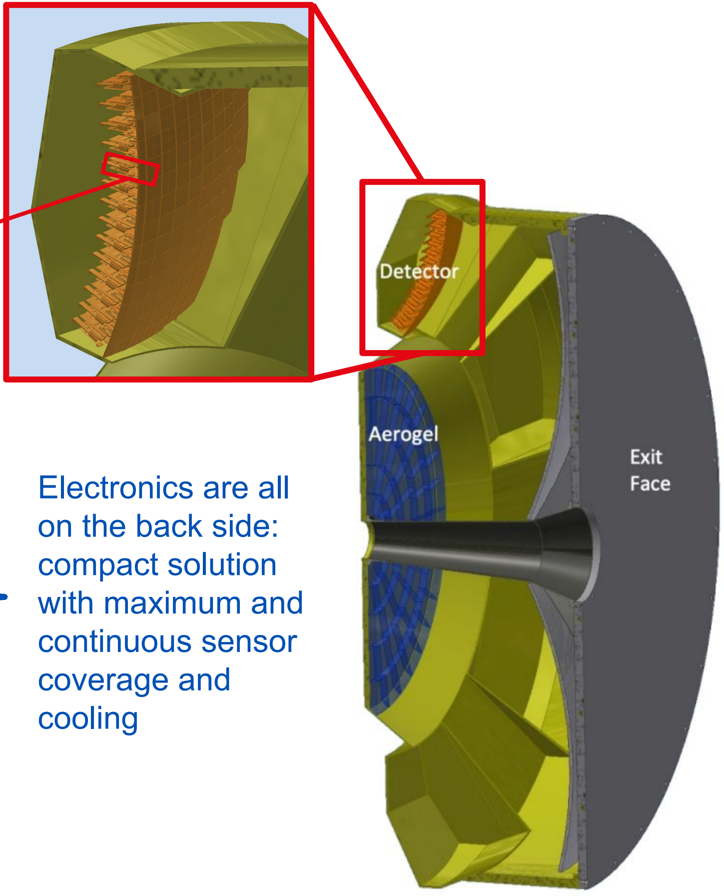
Water heat exchange

Services connections: LV, HV, DAQ



~ 15-20 cm

Electronics are all on the back side: compact solution with maximum and continuous sensor coverage and cooling



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ALCOR ASIC as front-end

developed by INFN Torino, 64-matrix mixed signal

The chip takes care of:

- Signal amplification
- Conditioning and event digitisation

Each pixel features:

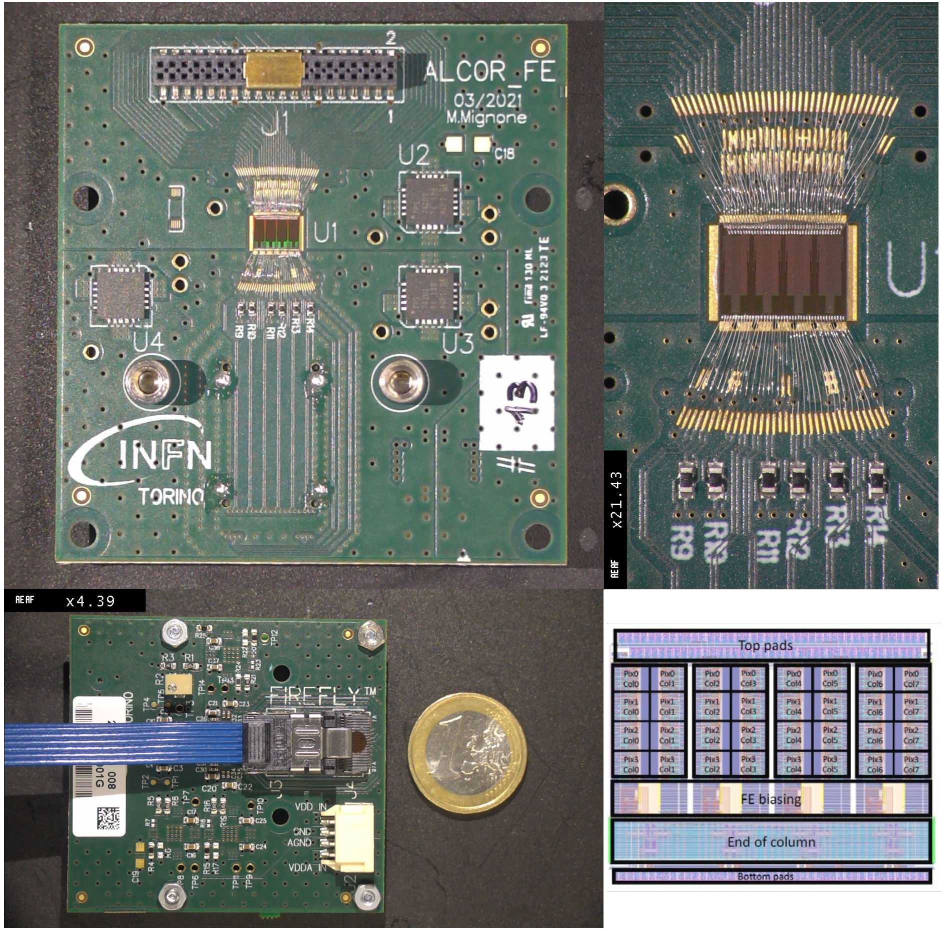
- 2 leading-edge discriminators
- 4 TDCs w/ analog interpolation
    - 20 or 40ps LSB @394MHz
- Digital shutter to allow TDC digitisation
    - Suppress out-of-gate DCR hits
    - 1 - 2ns timing window
    - programmable delay, sub ns accuracy

Single photon time-tagging mode:

- continuous readout
- possible time-over-threshold mode

Fully digital output:

- 8LVDS TX Data Links



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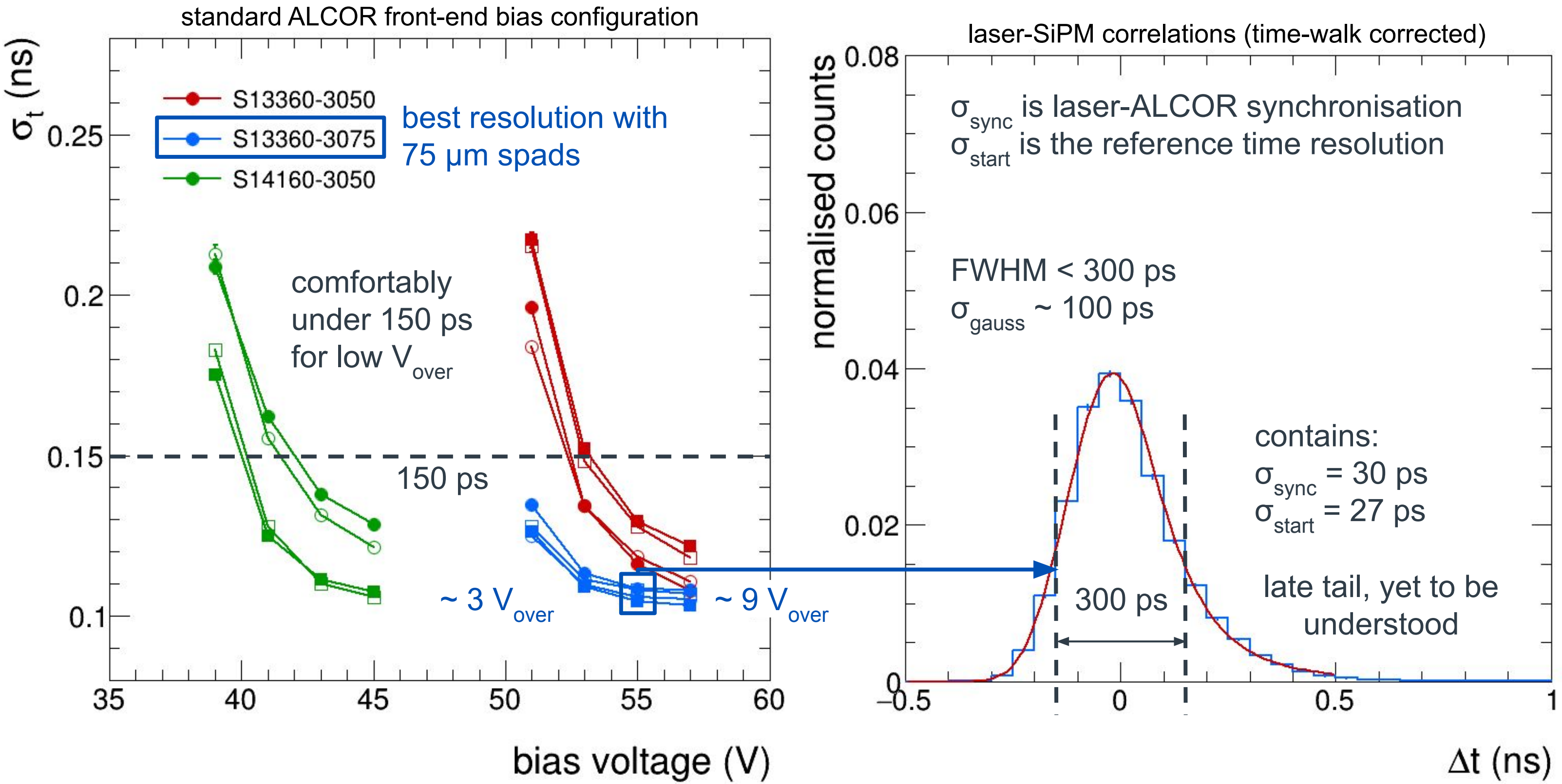
Laser timing w/ ALCOR



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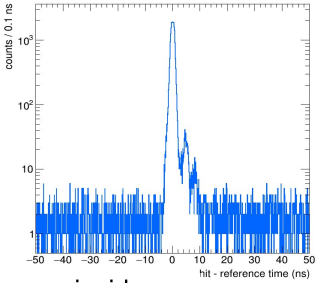
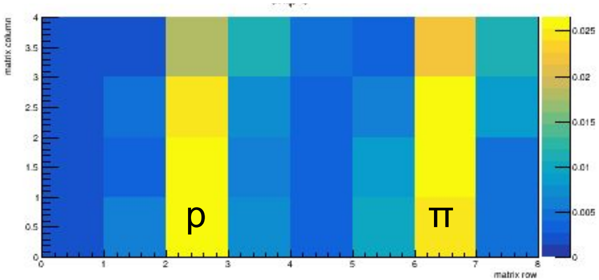
2022 Test beam at CERN-PS

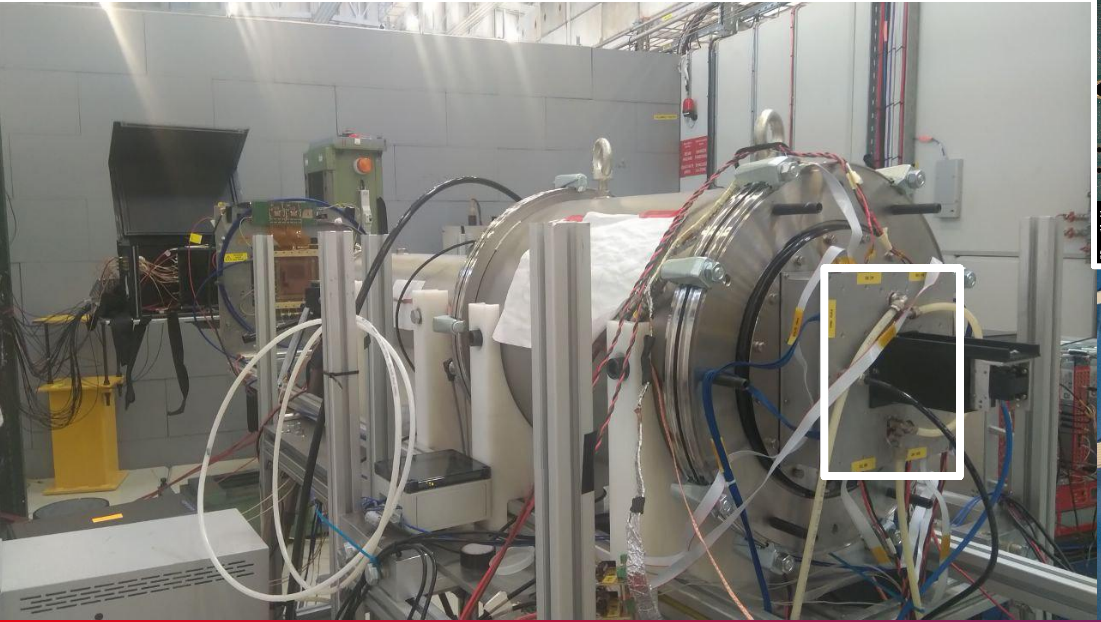
Successful operation of SiPMs readout

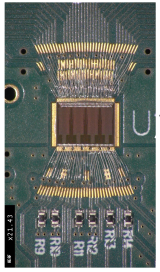
Tests made with sensors both
irradiated (10^{10} n_{eq}) and annealed (@150 C)

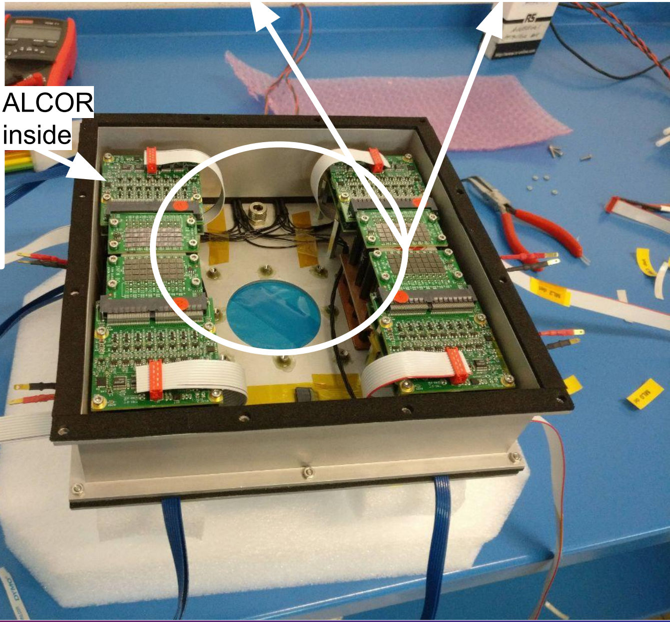


time coincidences









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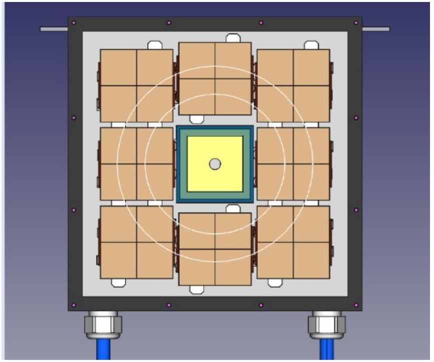
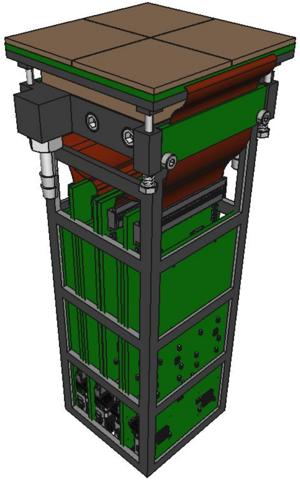
2023 Test beam at CERN-PS

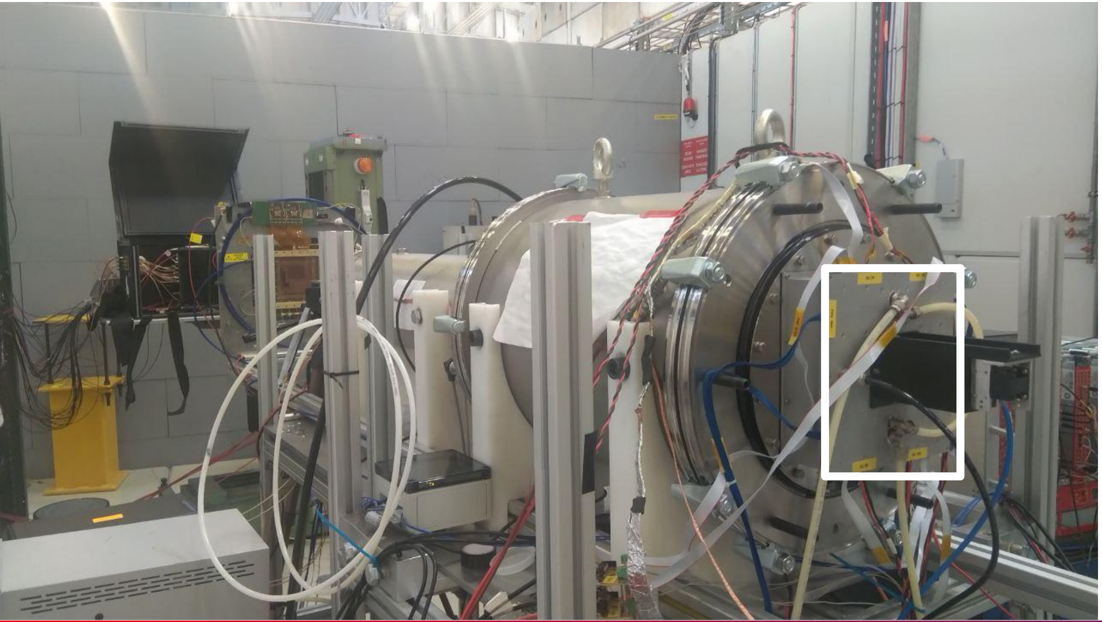
Is foreseen at the start of October

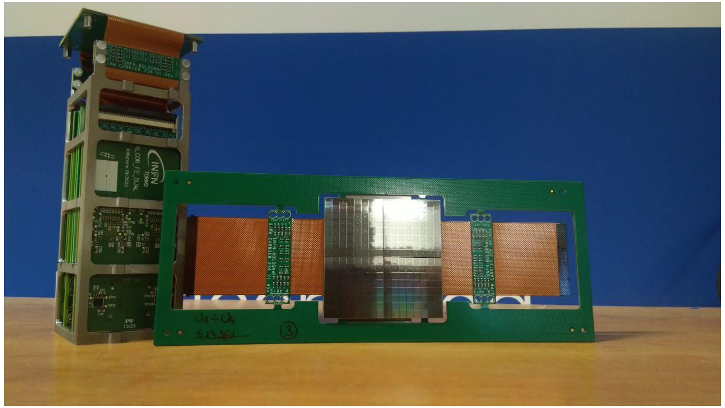
New sensors set-up with photodetector units prototypes

prototype EIC-driven
readout unit and readout box









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Summary

SiPMs fulfill all requirements for the forward dRICH of ePIC

- magnetic field limitations
- excellent timing and efficiency

Exploring solutions to mitigate the radiation damage

- low temperature operation
- online “in-situ” self-annealing
- extend lifetime of good detector performance for Physics
  - present solutions can be optimised/improved to extend it further

Full readout chain tested

- based on ALCOR ASIC
- successful beam test at CERN-PS in 2022
- overall 1-pe time resolution approaching 100 ps

Onward with development and optimisation for the TDR

- EIC-driven prototype readout units to be tested soon
- developments for the first prototype readout boards
- final optimisations and packaging of the ALCOR ASIC chip

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Thank you!

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