Status and beam test results of the ePIC-dRICH detector at EIC

Davide Giordano

13th Beam Telescopes and Test Beams Workshops

Valencia, Spain

20.05.2025

Istituto Nazionale di Fisica Nucleare

The Electron Ion Collider

The Electron-Ion Collider (EIC) is a large scale innovative particle accelerator that is planned to be built at Brookhaven National Laboratories (BNL) at Long Island, New York (USA).

Hadrons (up to 275 GeV)

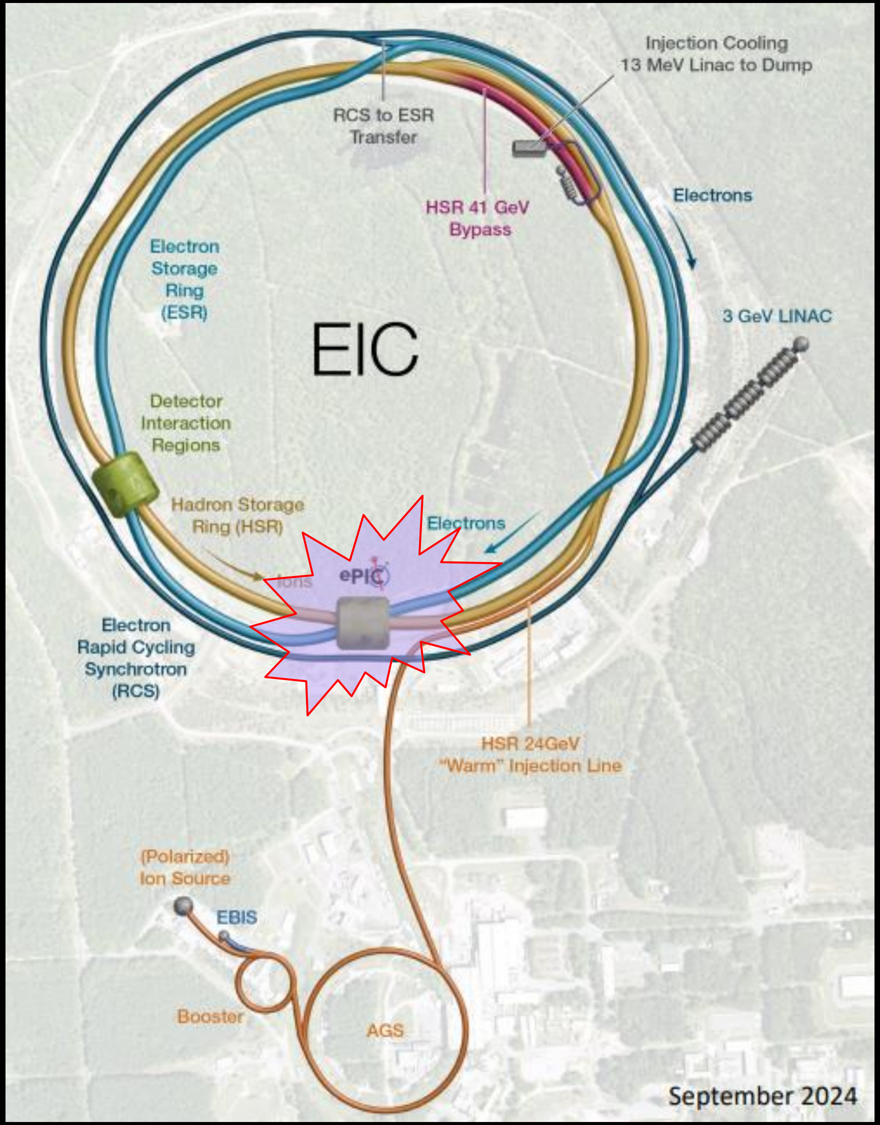
Existing RHIC complex includes:

- Storage Ring (Yellow)
- Injectors: Source, Booster, AGS

- RHIC beam parameters are close to those required for **EIC@BNL**

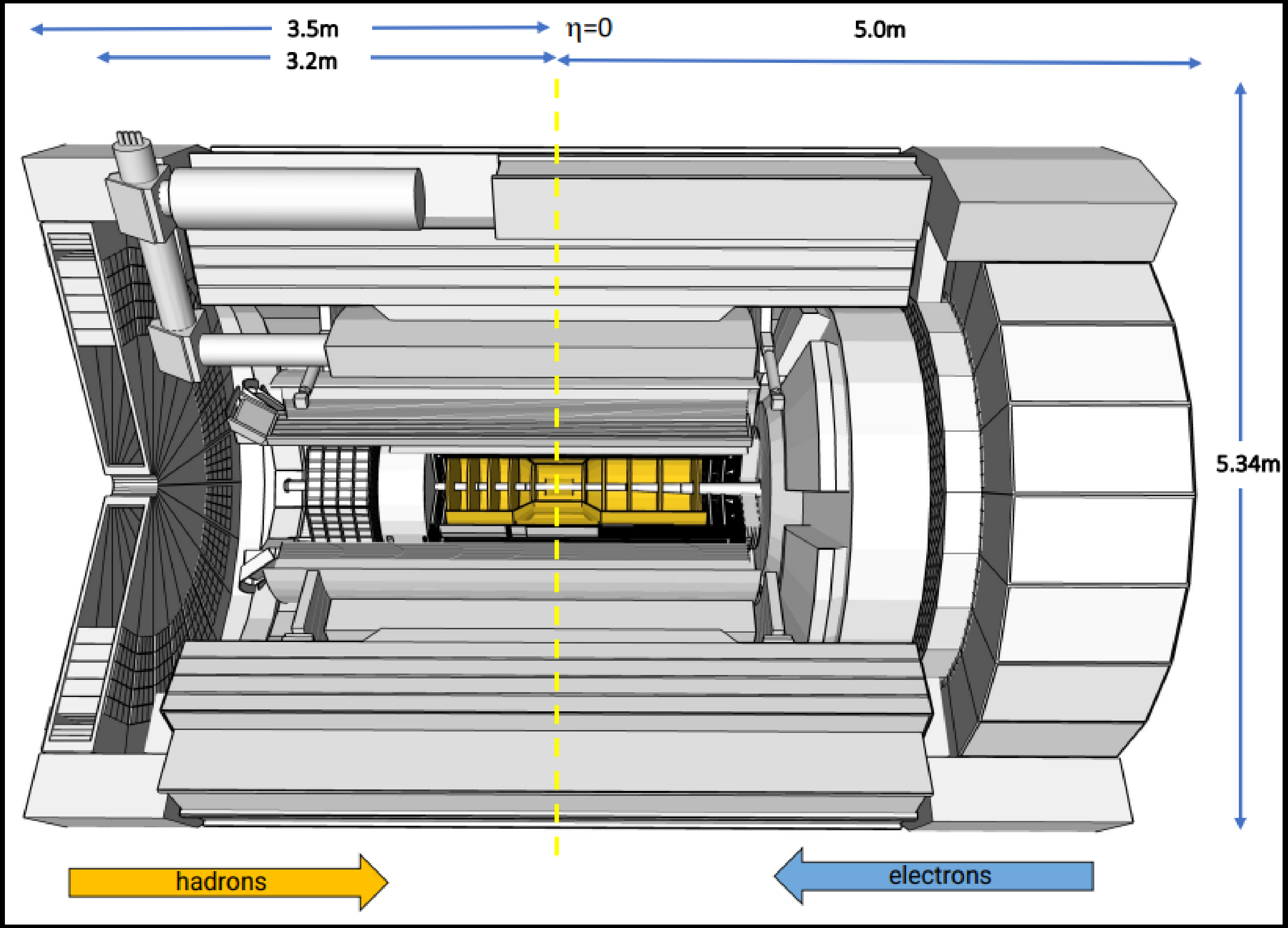
Electrons (up to 18 GeV)

- Storage ring provides a range of √s = **20–140 GeV**
- Electron beam:
  - Variable spin pattern (s)
  - Accelerated in an on-energy, spin-transparent injector:



Slide from
A. Deshpande
@IWHSS2024

ePIC Detector Design



Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

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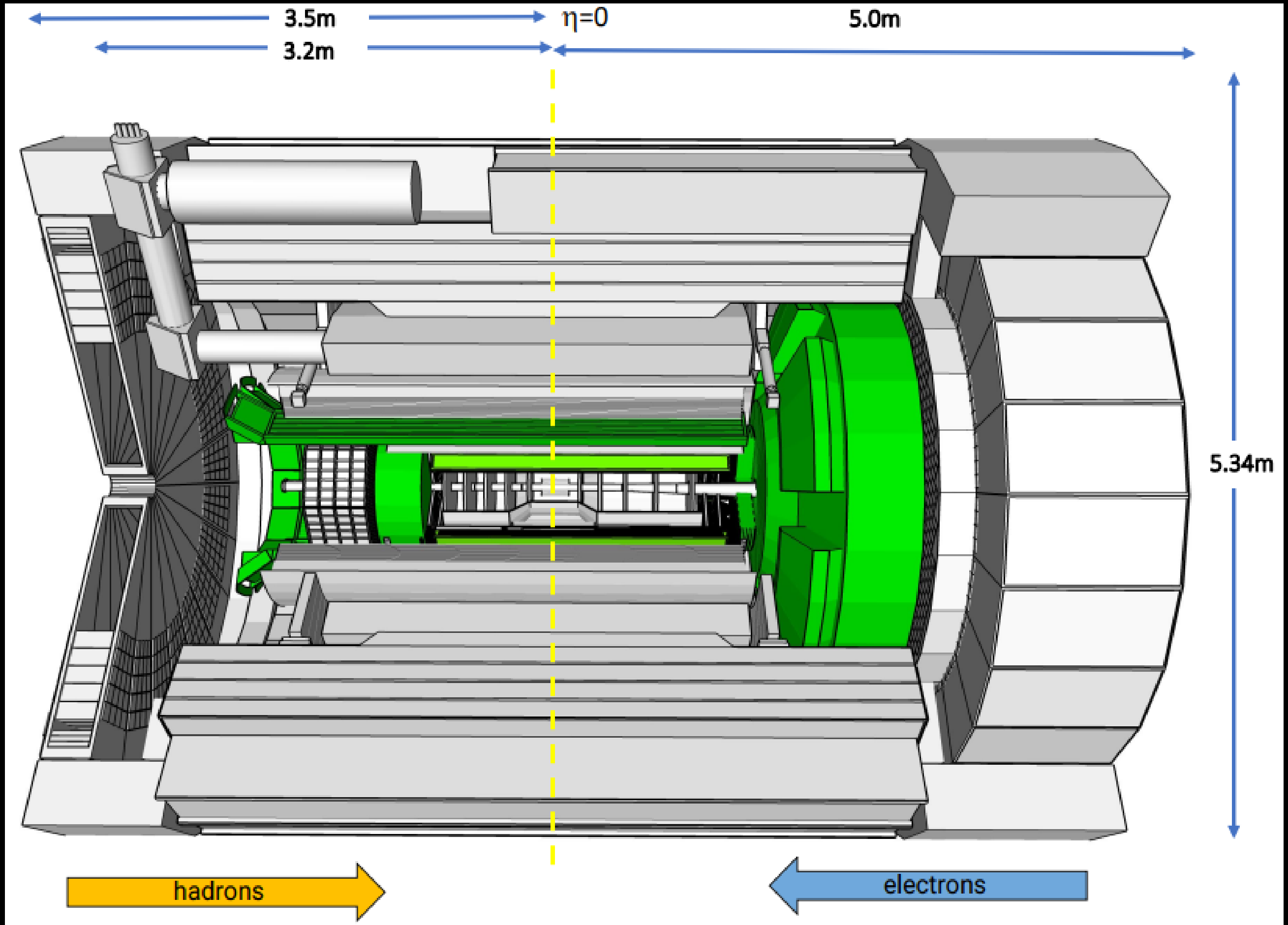

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PID:
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

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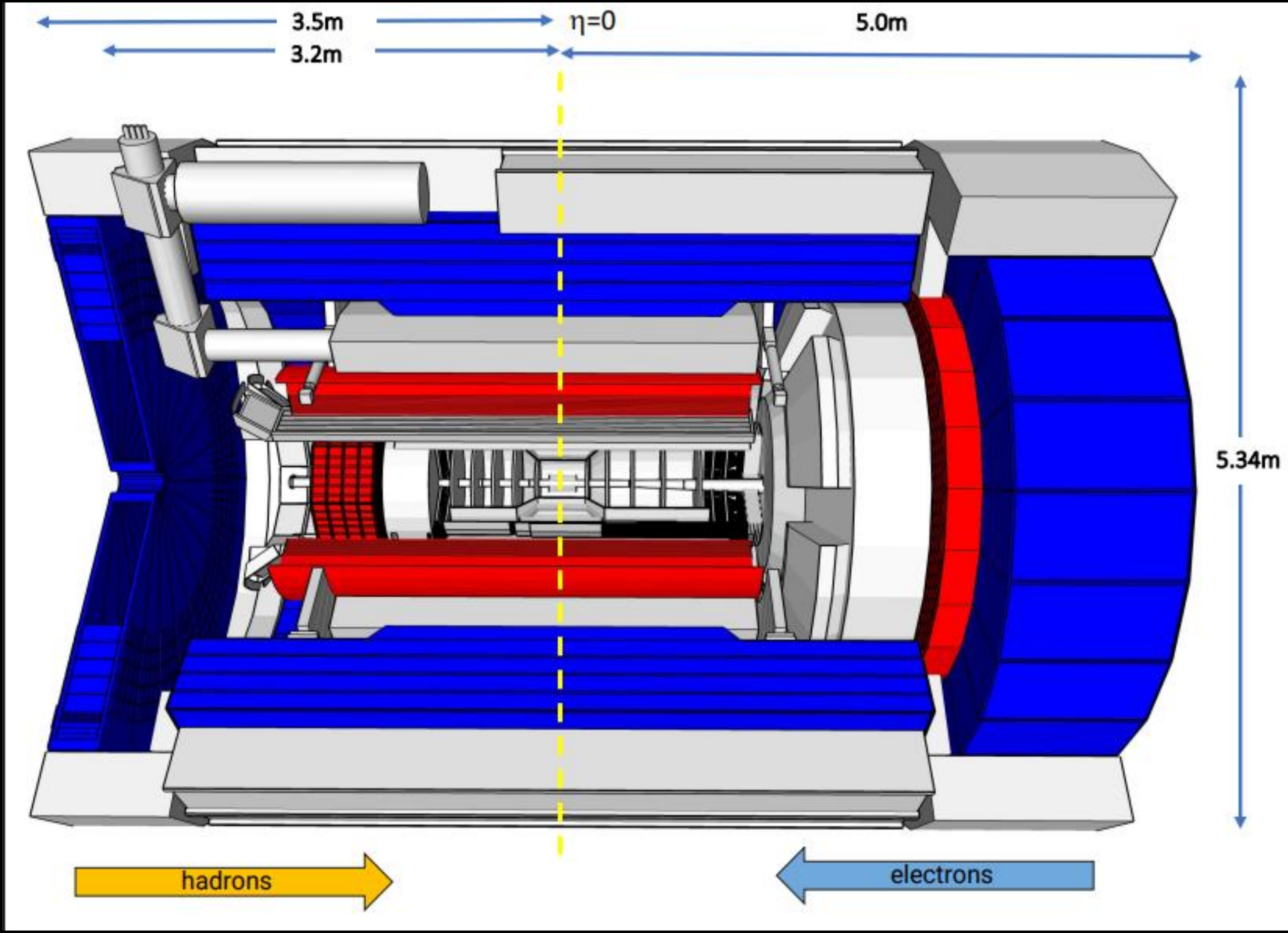
ePIC Detector Design



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Calorimetry:
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

PID in ePIC

Physics requirements:

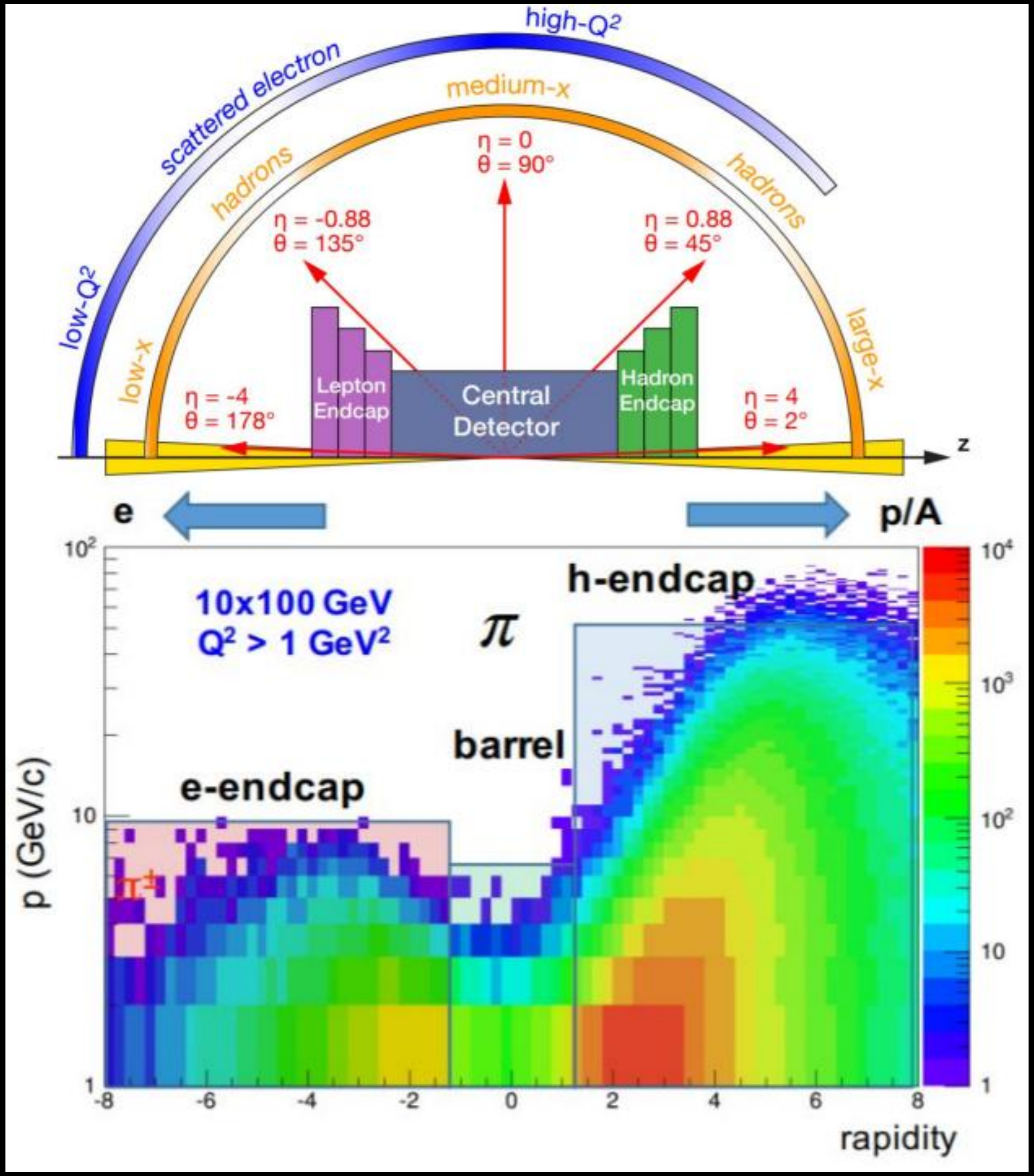
+ 3sigma π/K/p separation in $|\eta| < 3.5$
+ Pion/electron suppression

Momentum ranges

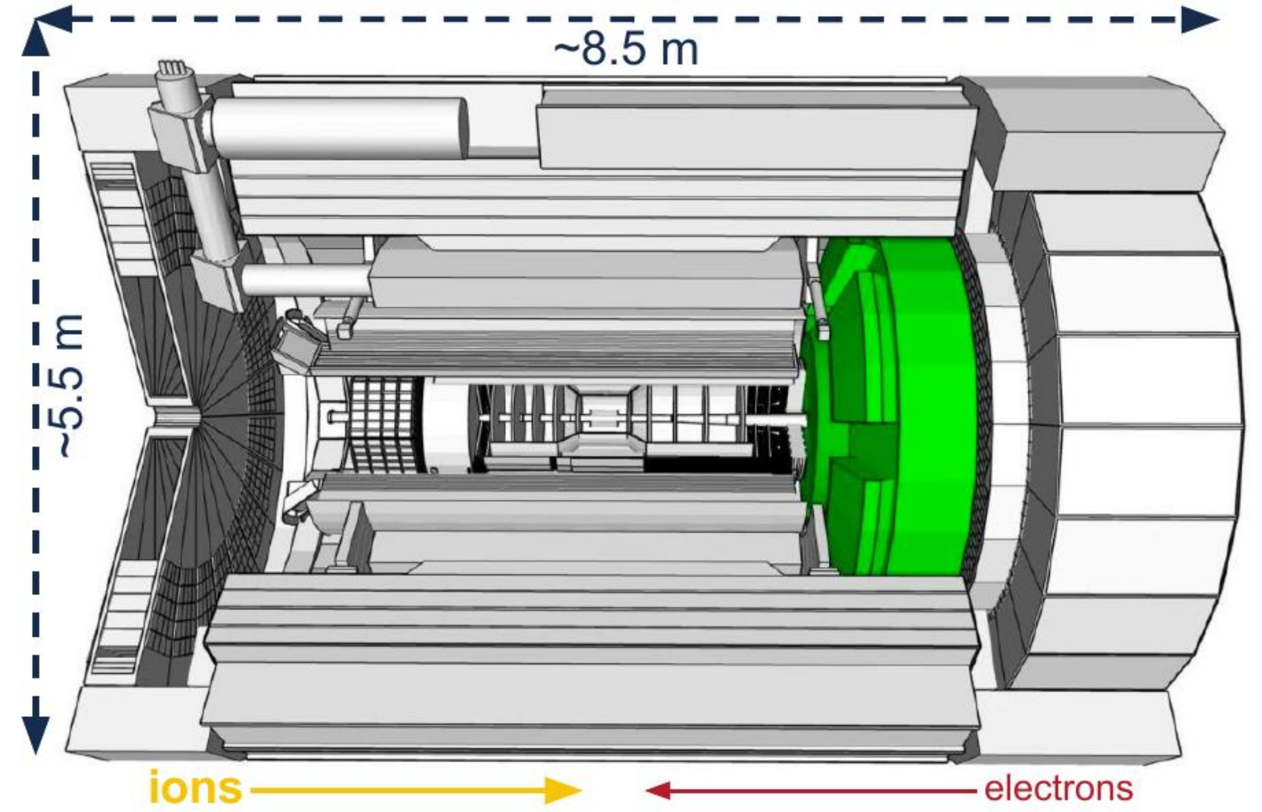
+ Forward: up to 50 GeV/c
+ Central up to 6 GeV/c
+ Backward: up to 10 GeV/c

→Operation in high magnetic field

→compact and cost-effective solution for broad momentum coverage at forward rapidity



Forward PID: dual radiator RICH (dRICH)



Aerogel (n ~ 1.02)
C_2F_6 (n ~ 1.0008)

6 open sectors mirrors

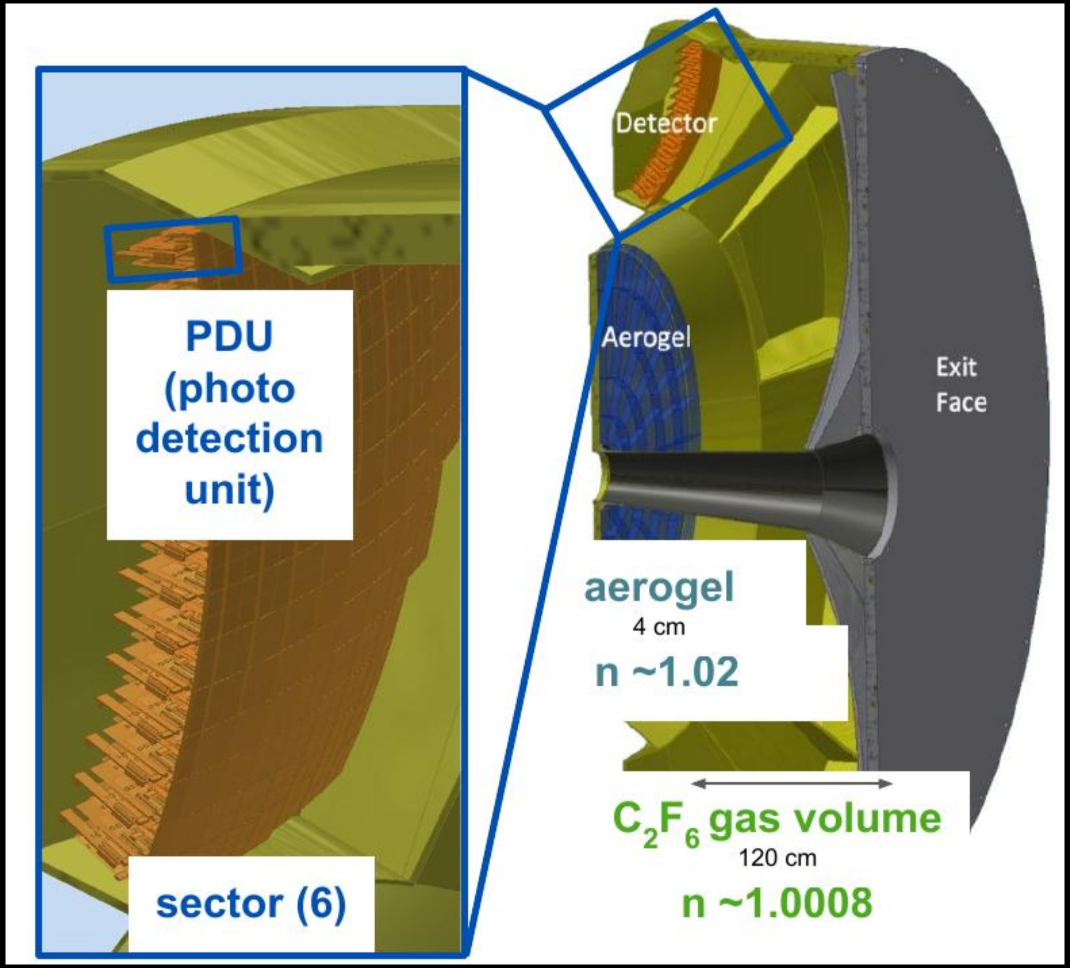
~3 m^2 photosensors surface:

- 3x3 mm^2 pixel
- Single photon detection in high B field (~ 1 T)
- Outside acceptance
- $10^{10} - 10^{11}\ n_{EQ}/cm^2$ total exposure 12 y operation

PID momentum ~ 3-50 GeV/c

Forward PID: dual radiator RICH (dRICH)

N. Rubini @VCI2025



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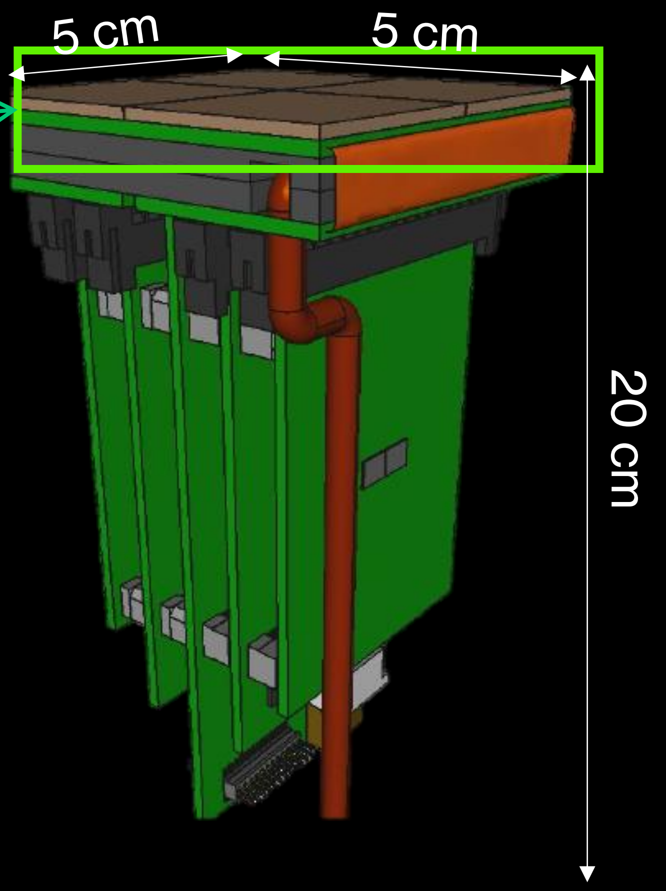
PID momentum ~ 3-50 GeV/c

PDU layout

SiPM
4 matrices
8x8 sensors
3x3 mm^2 pixels
256 channels

- cheap
- high photon efficiency
- excellent time resolution
- insensitive to magnetic field

- ○ large dark count rates
- ○ not radiation tolerant



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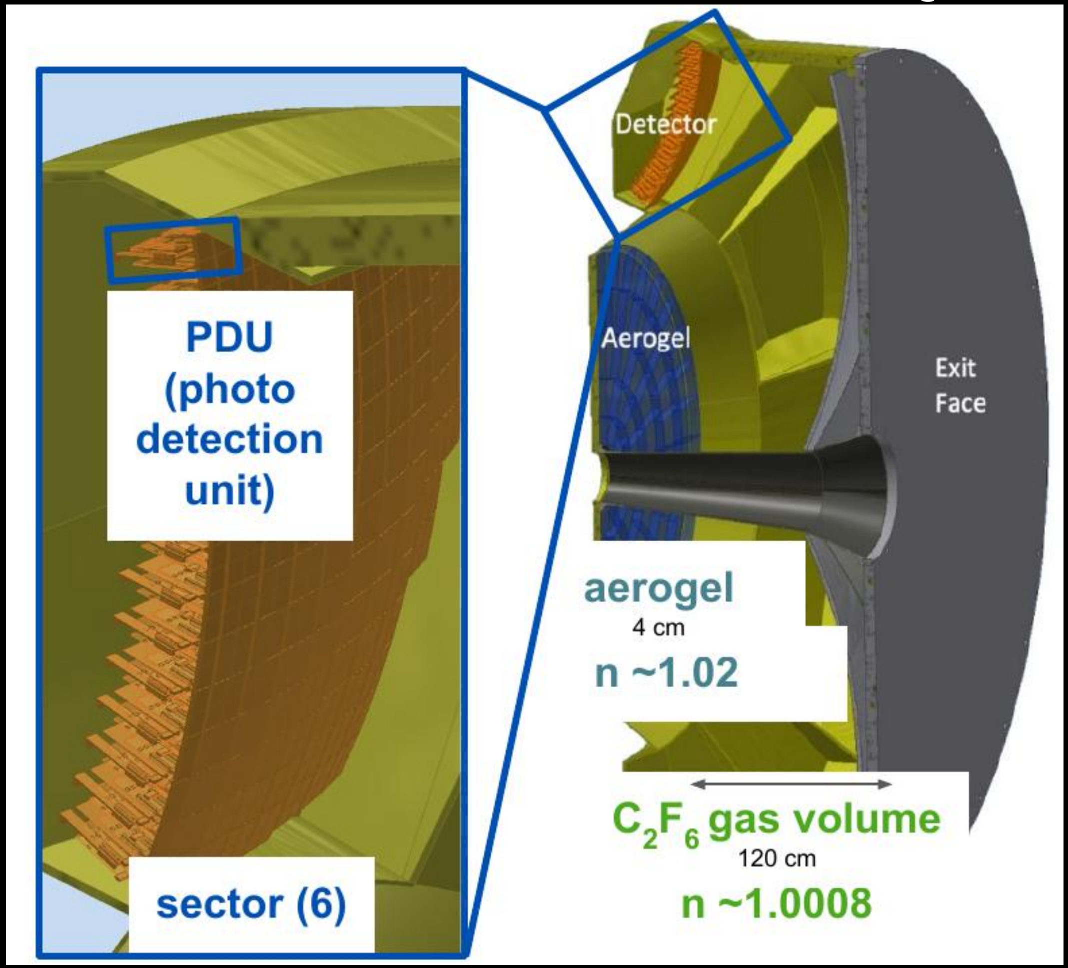
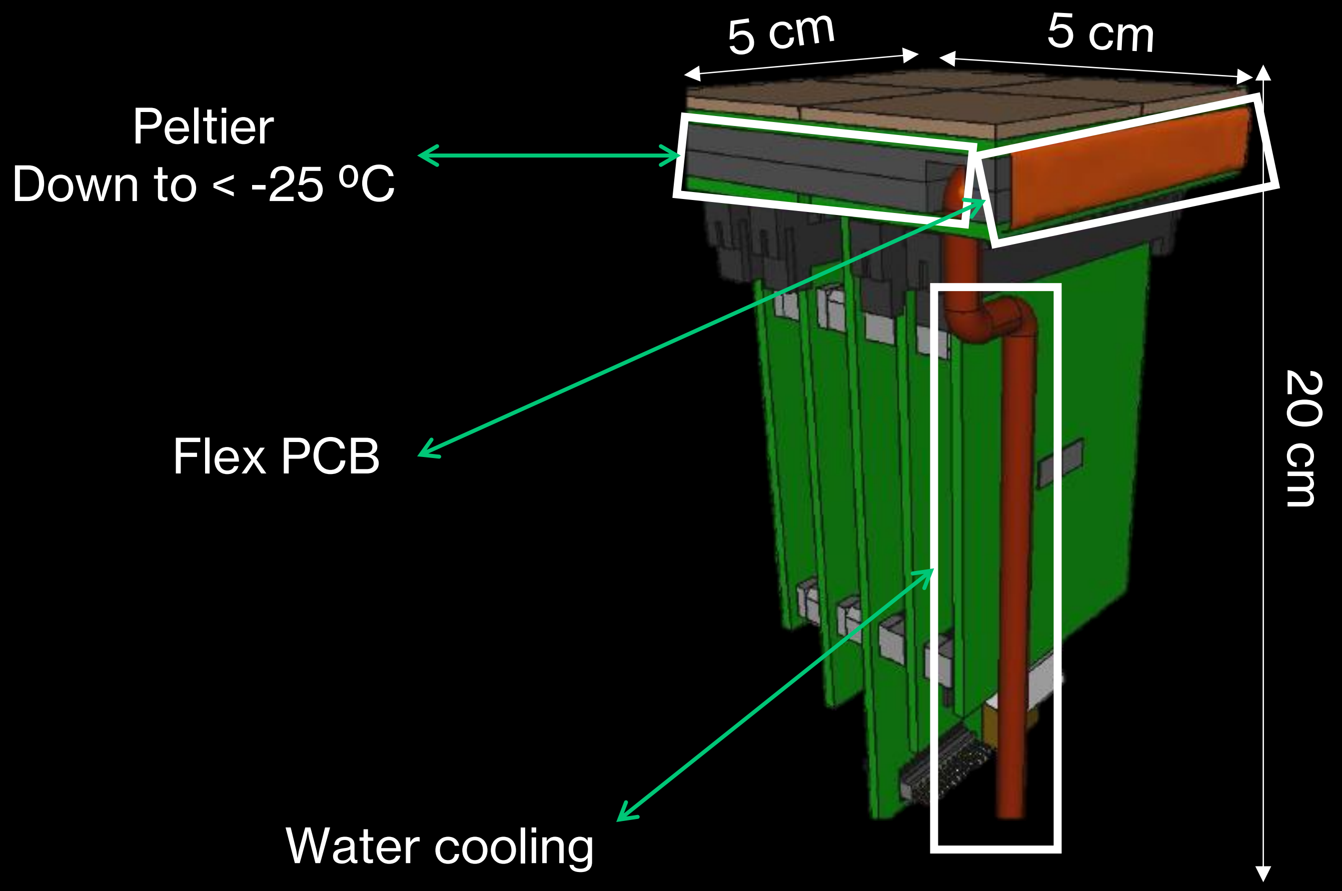


PDU layout



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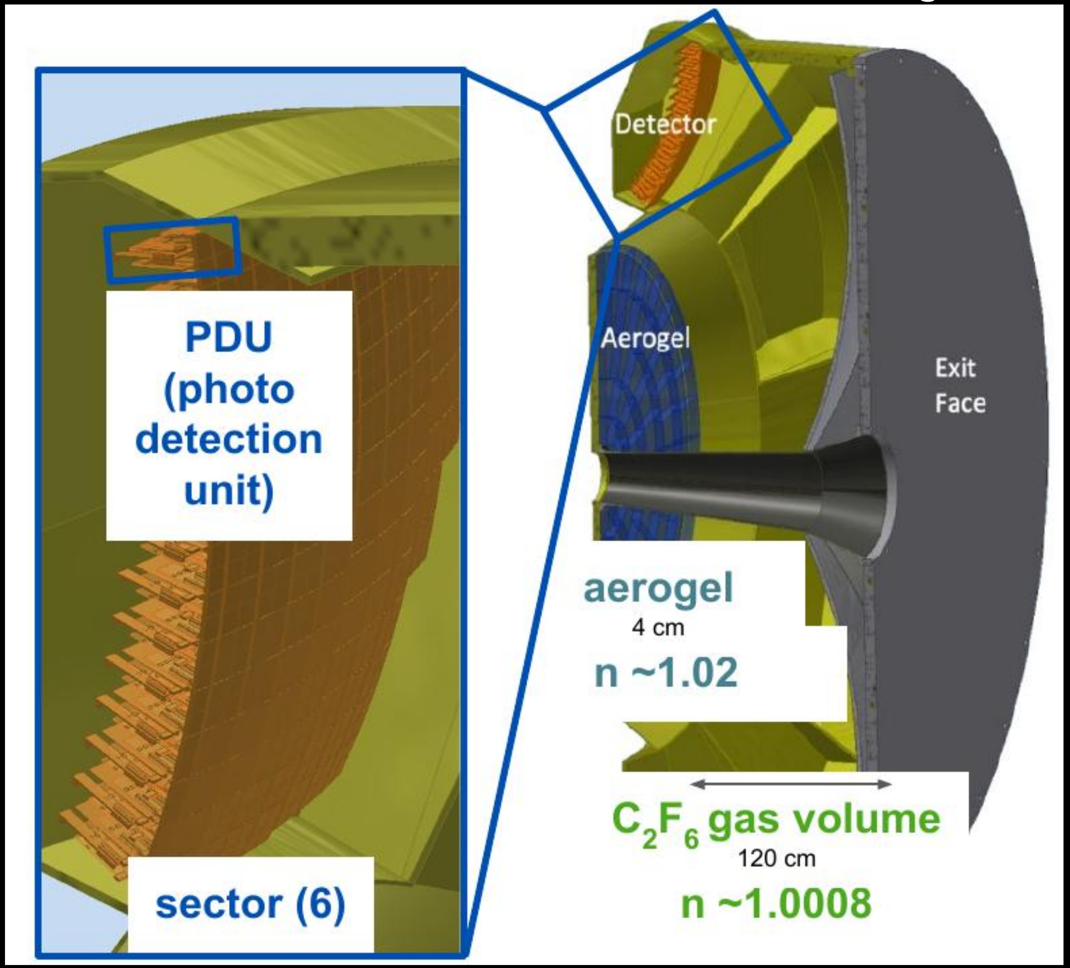


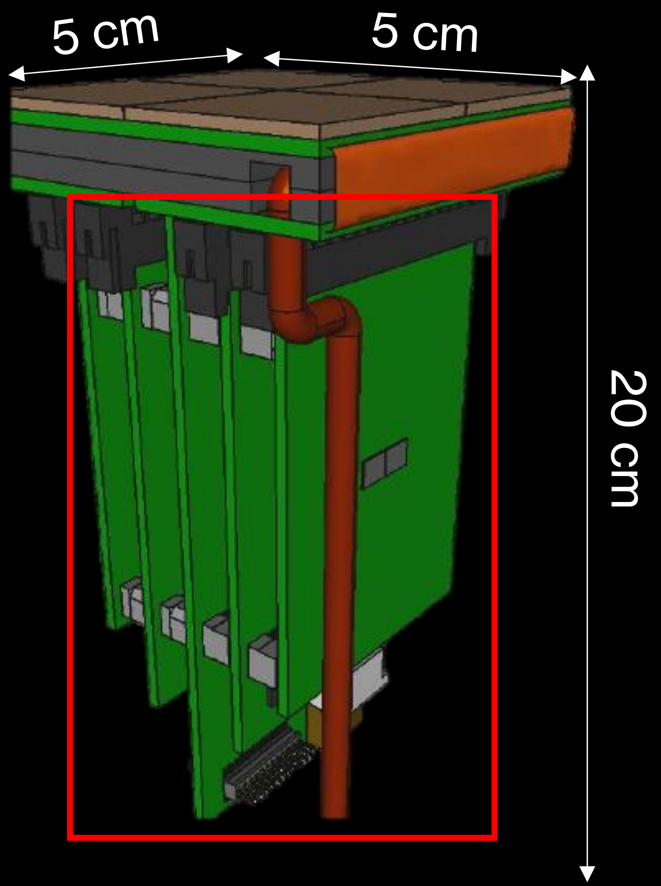
PDU layout - A Low Power Chip for Optical Sensor Readout

ALCOR ASIC FEB v3.0

Developed by INFN Torino
BGA bonded
64-pixel matrix mixed-signal ASIC

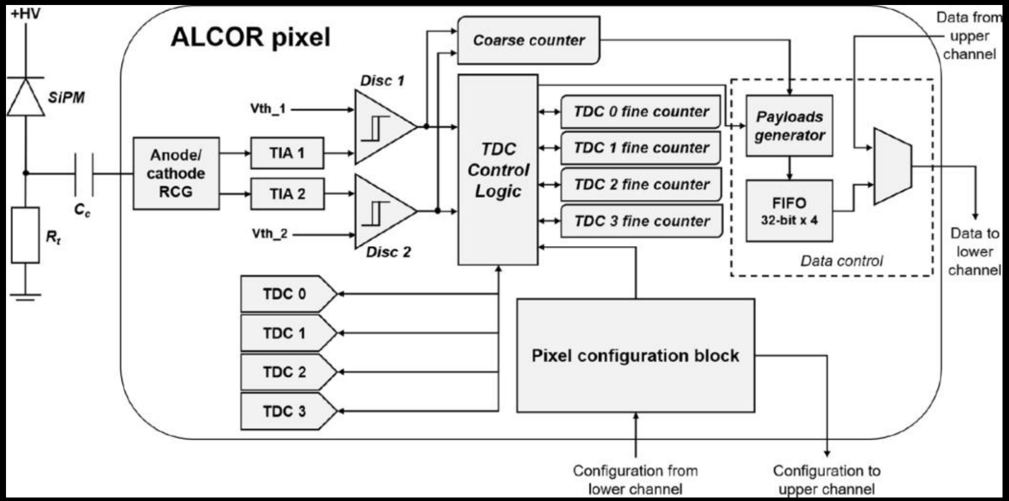
1. Amplification
2. Conditioning and event digitization

- 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



Power consumption ~10-12 mW/channel
0.11 µm CMOS technology

https://doi.org/10.1016/j.nima.2024.169817



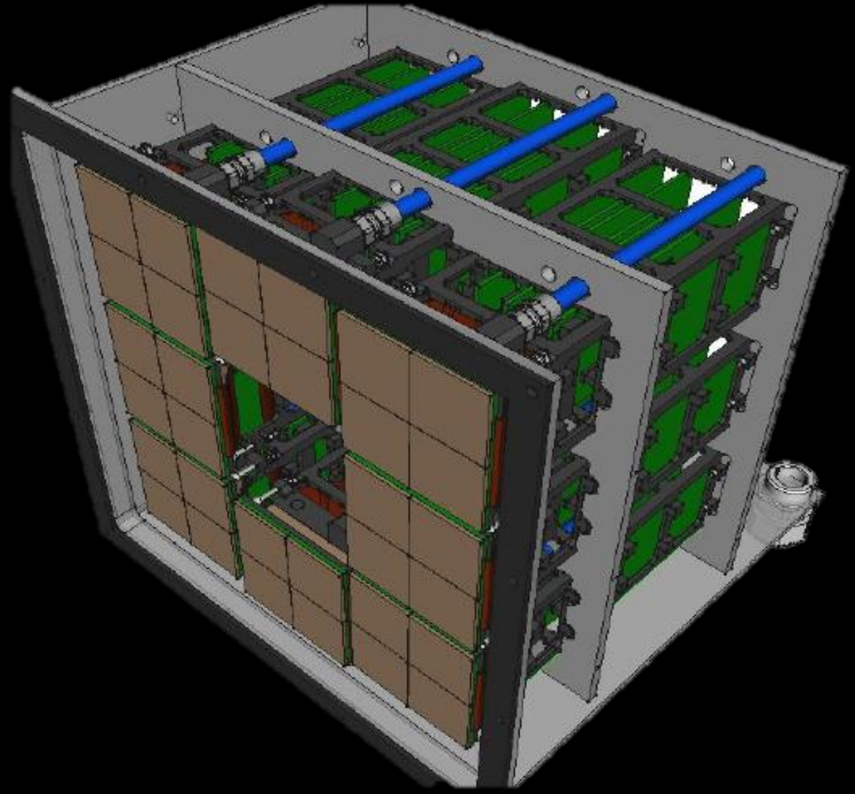
Single photon time-tagging mode:
- **continuous readout**
- possible time-over-threshold mode

Fully digital output with 8LVDS TX Data Links

PDU & detector prototype

2 peltier cells for subzero operating temperatures
Temperature sensors both under the sensors and on the peltiers

x8



Externally provided:
High voltage bias for sensors, low voltage power supply for electronics, T sensors piloting and read-out

~18 cm2 active area
2048 channels

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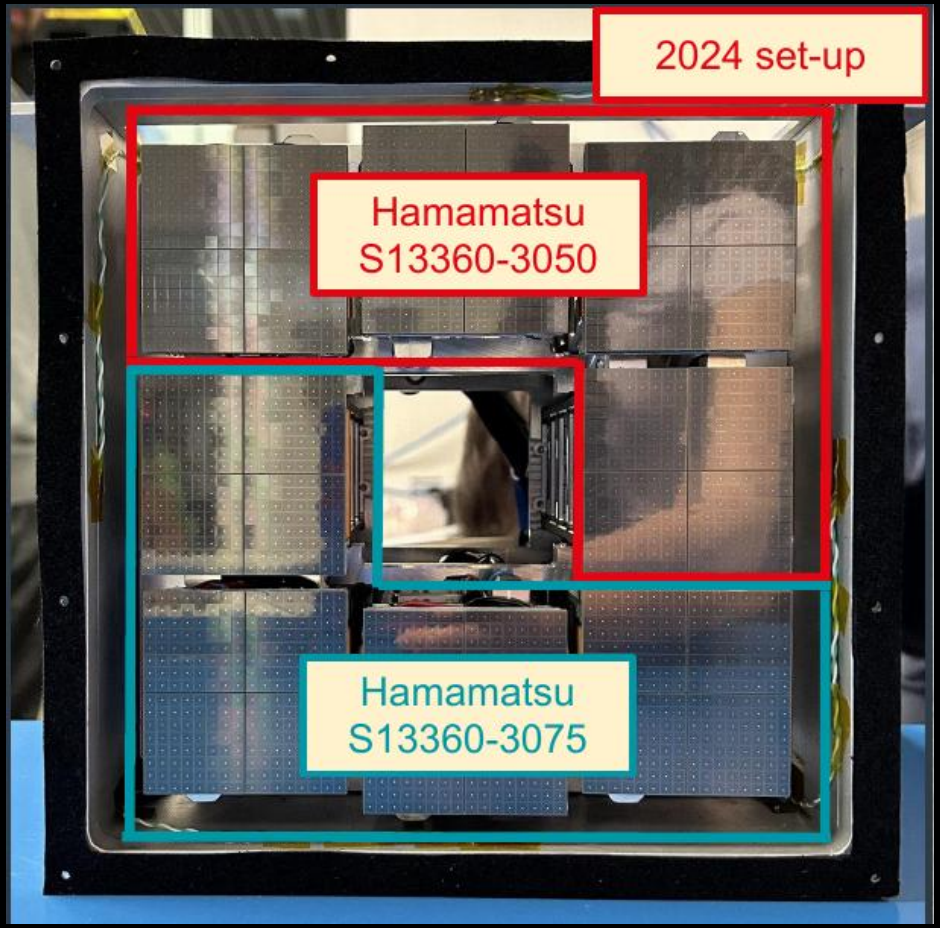

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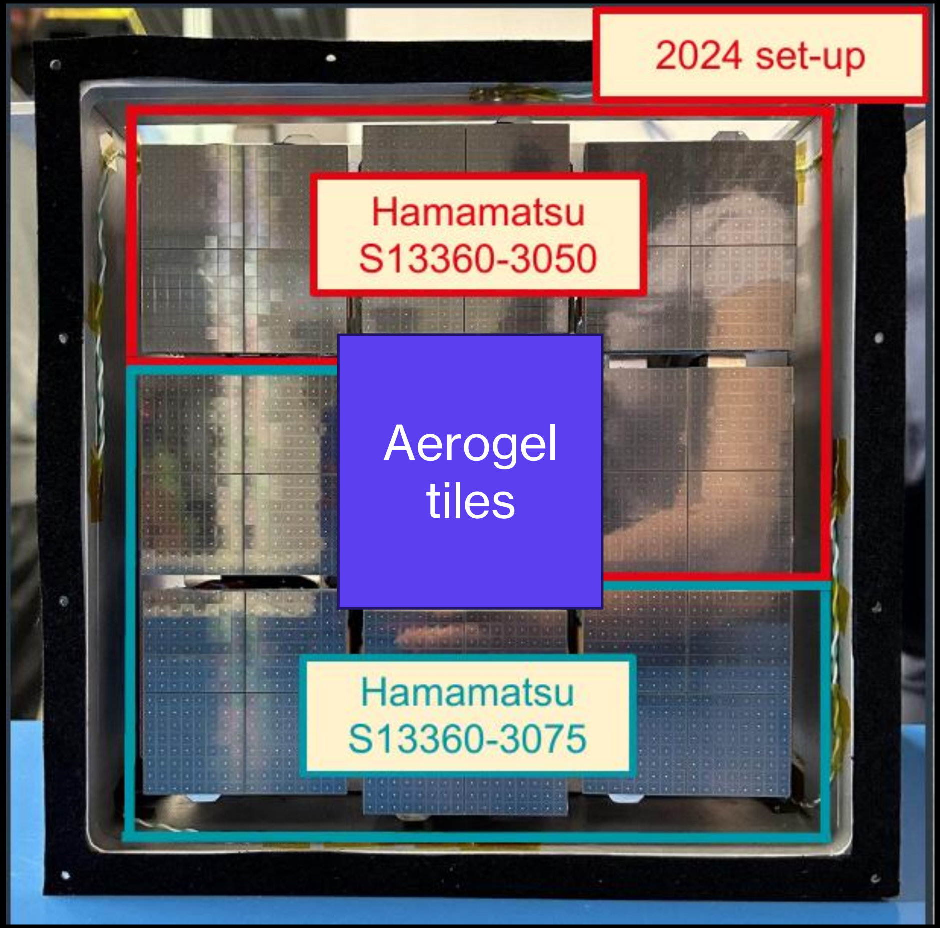
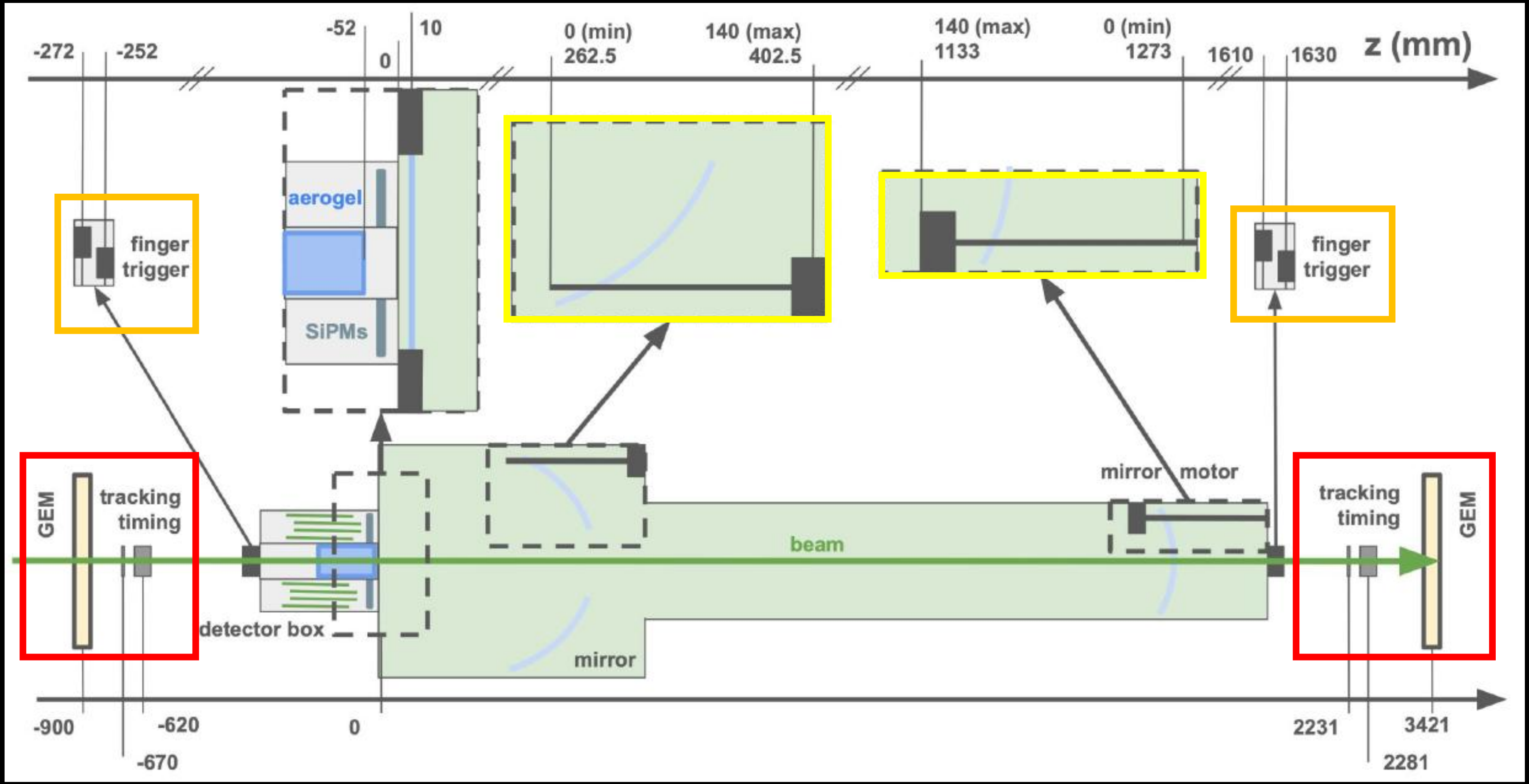


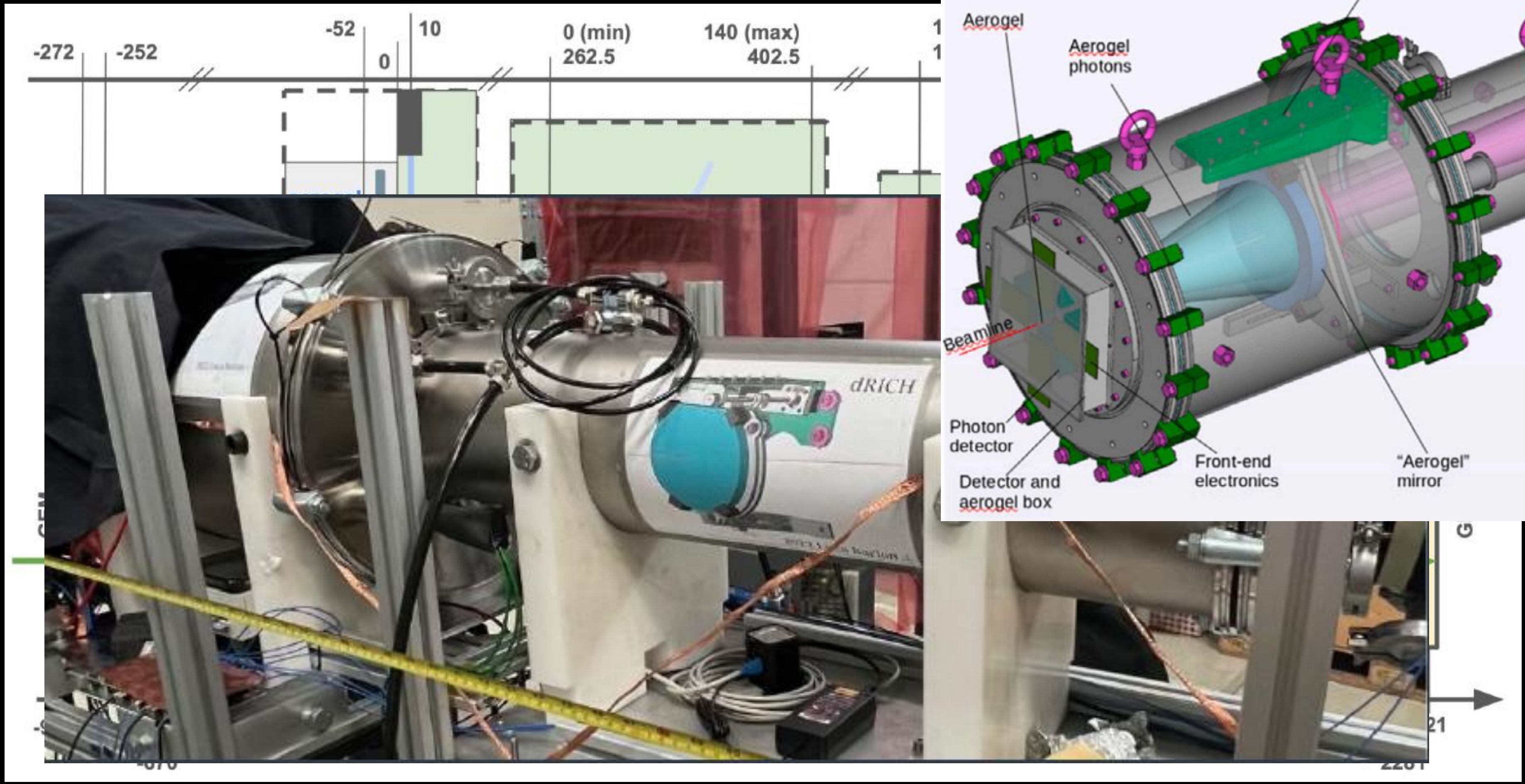
Beam test setup

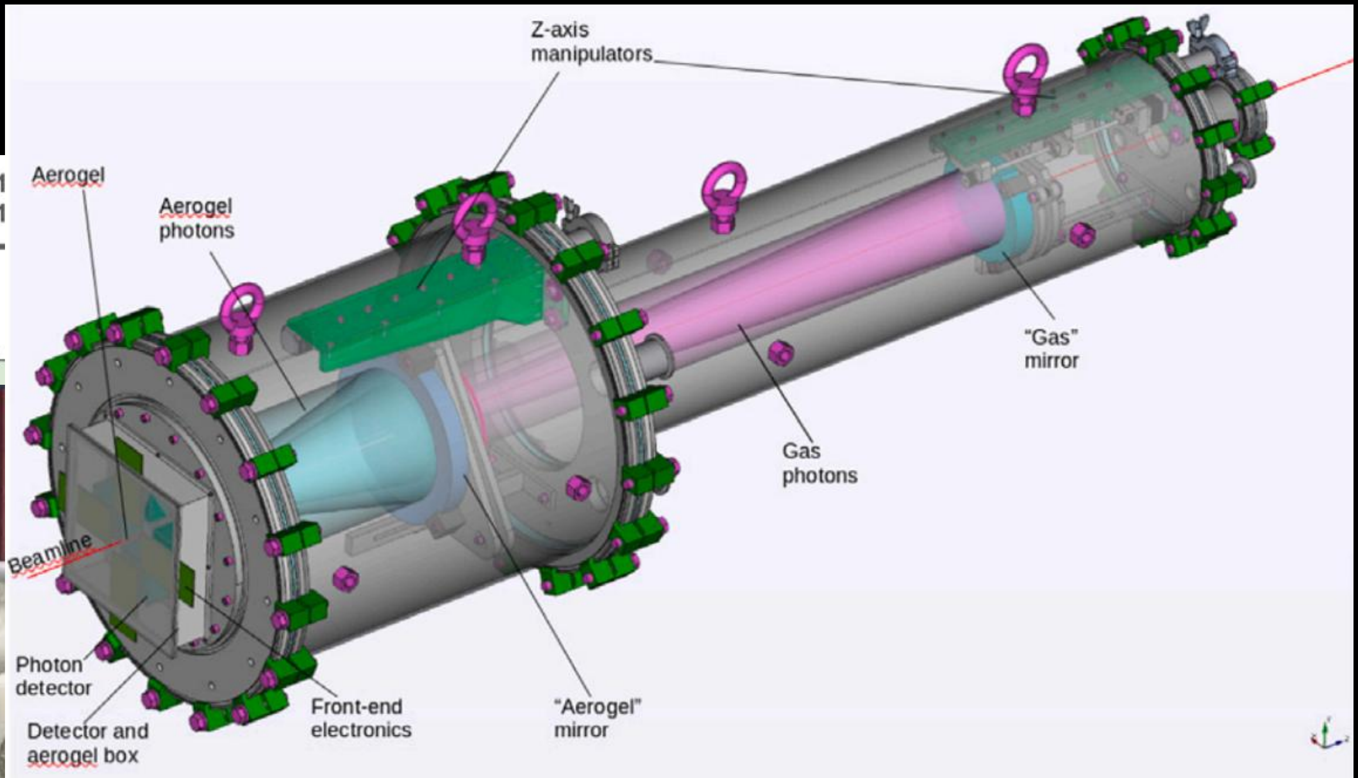


- Motorized mirrors for focusing
- Tracking and timing based on ALCOR and SiPM
- Finger trigger for beam particles crossing
- Swappable aerogel tiles

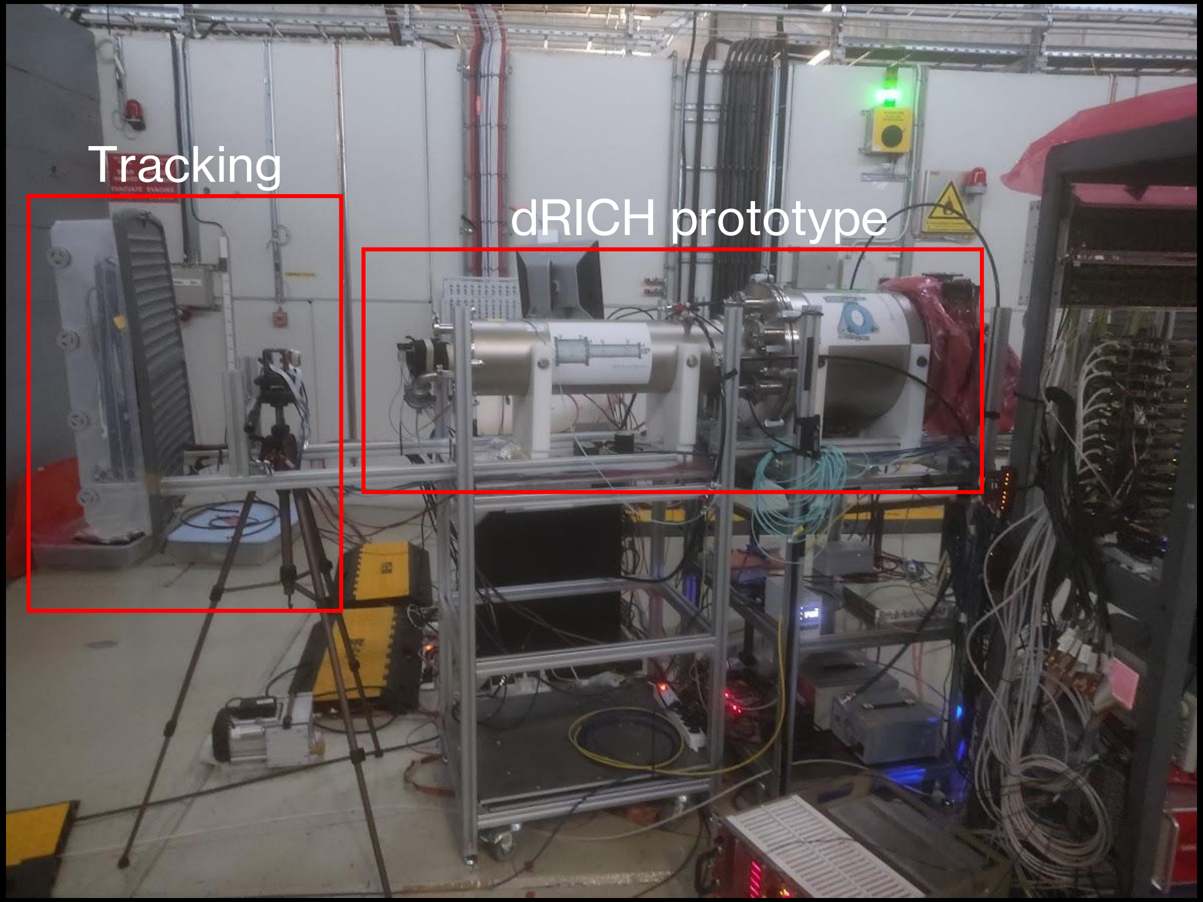
Beam test setup

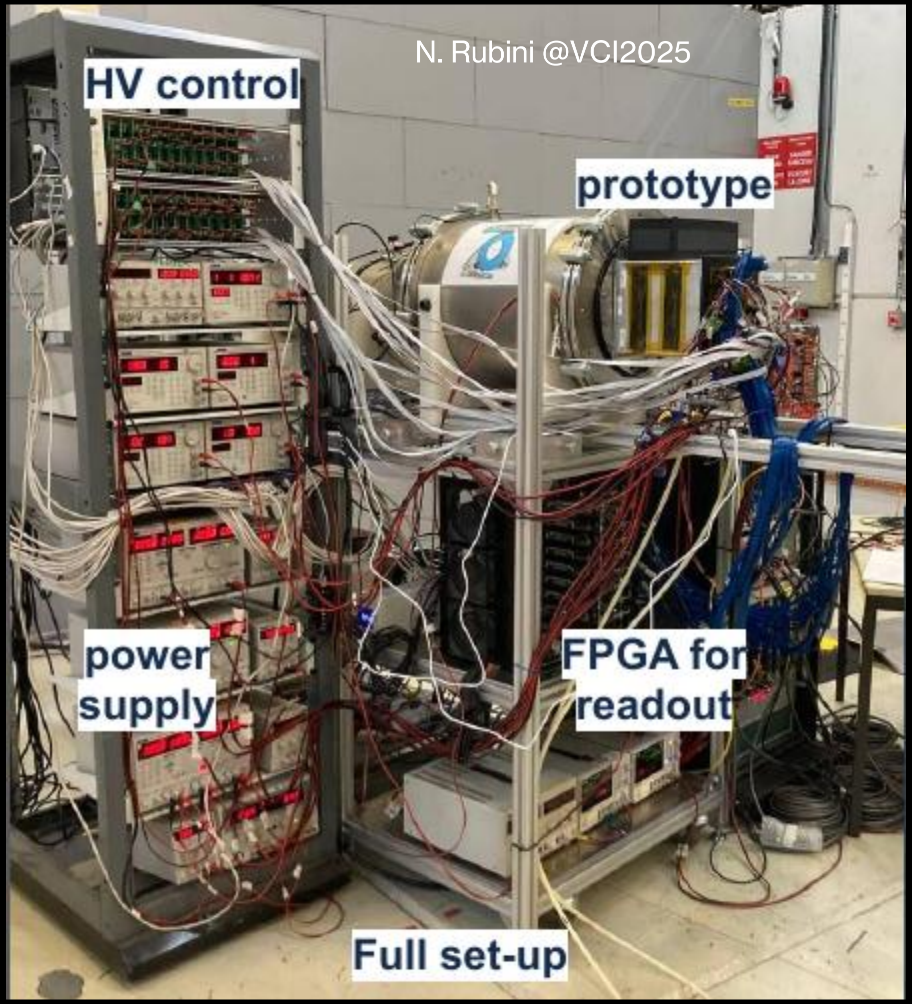
https://doi.org/10.1016/j.nima.2023.168834



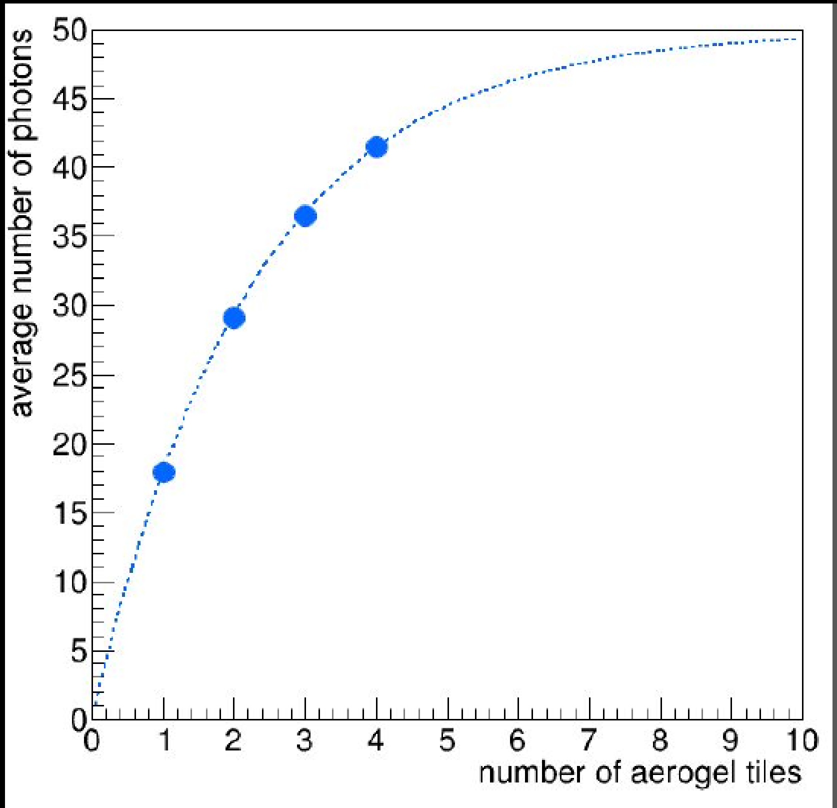


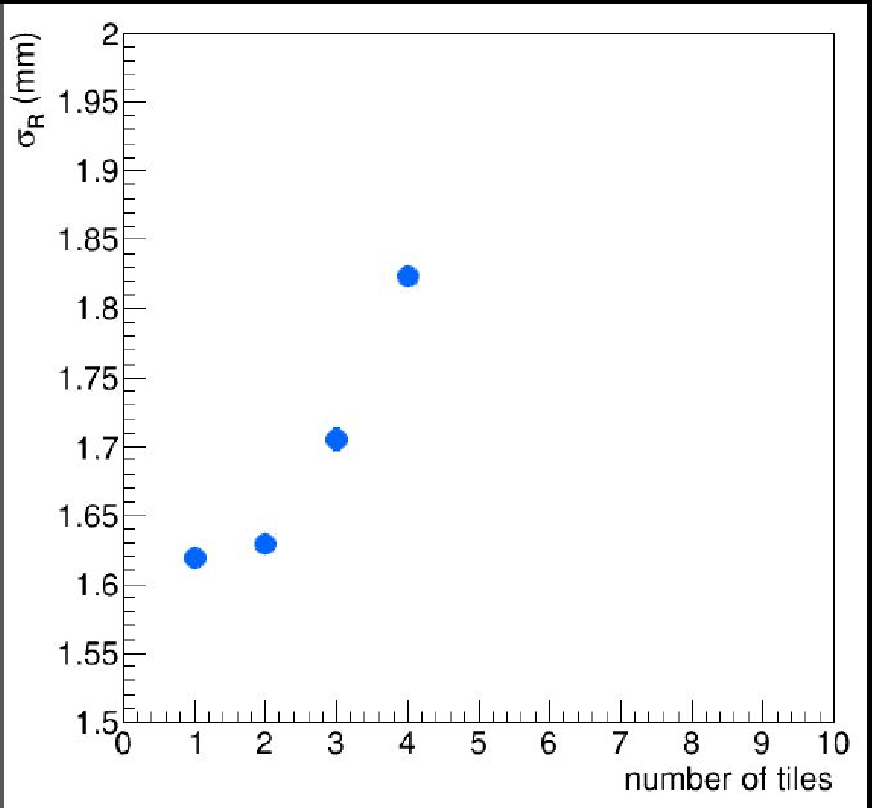
Experimental set-up @T10 CERN PS





Aerogel performances



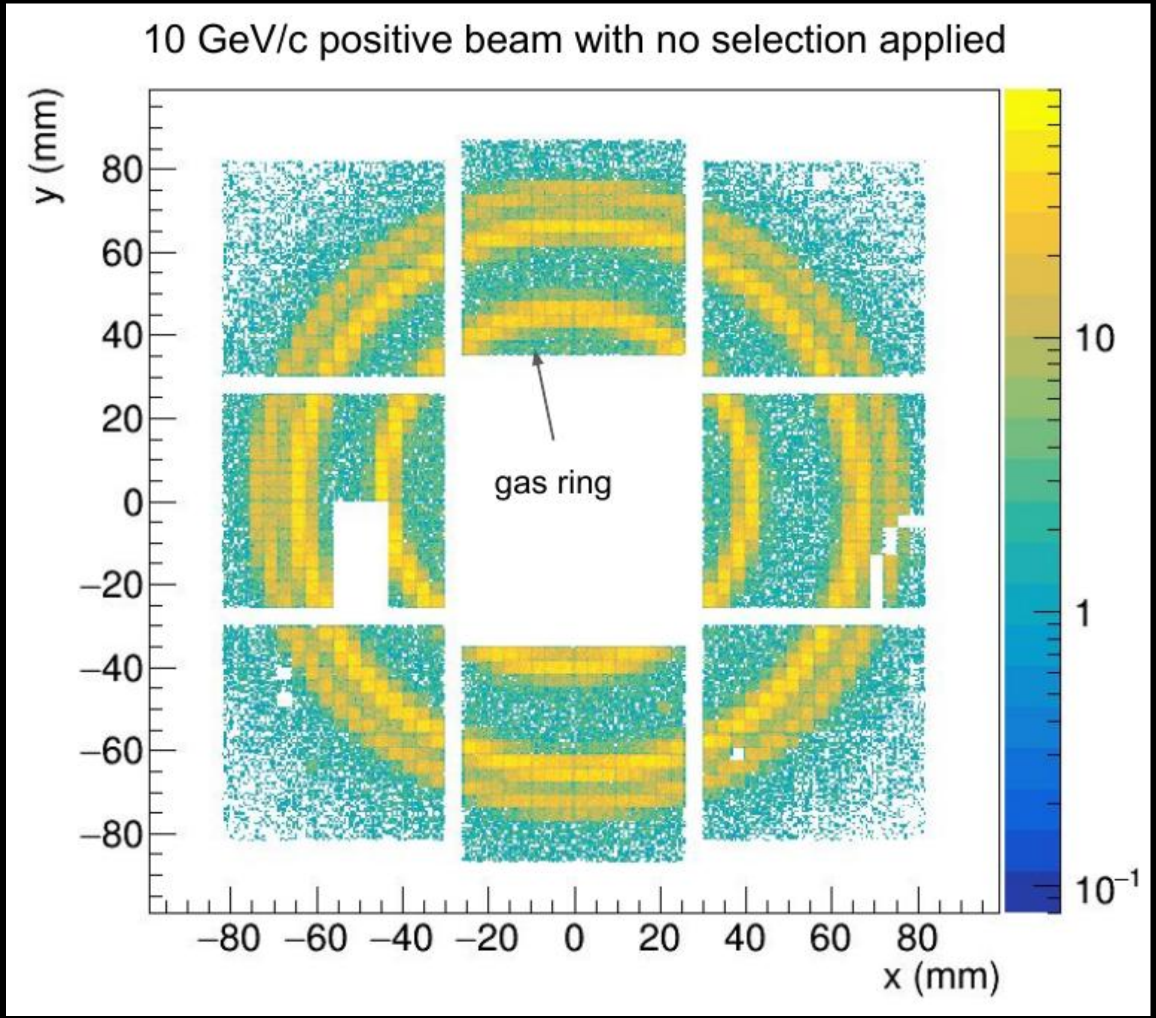


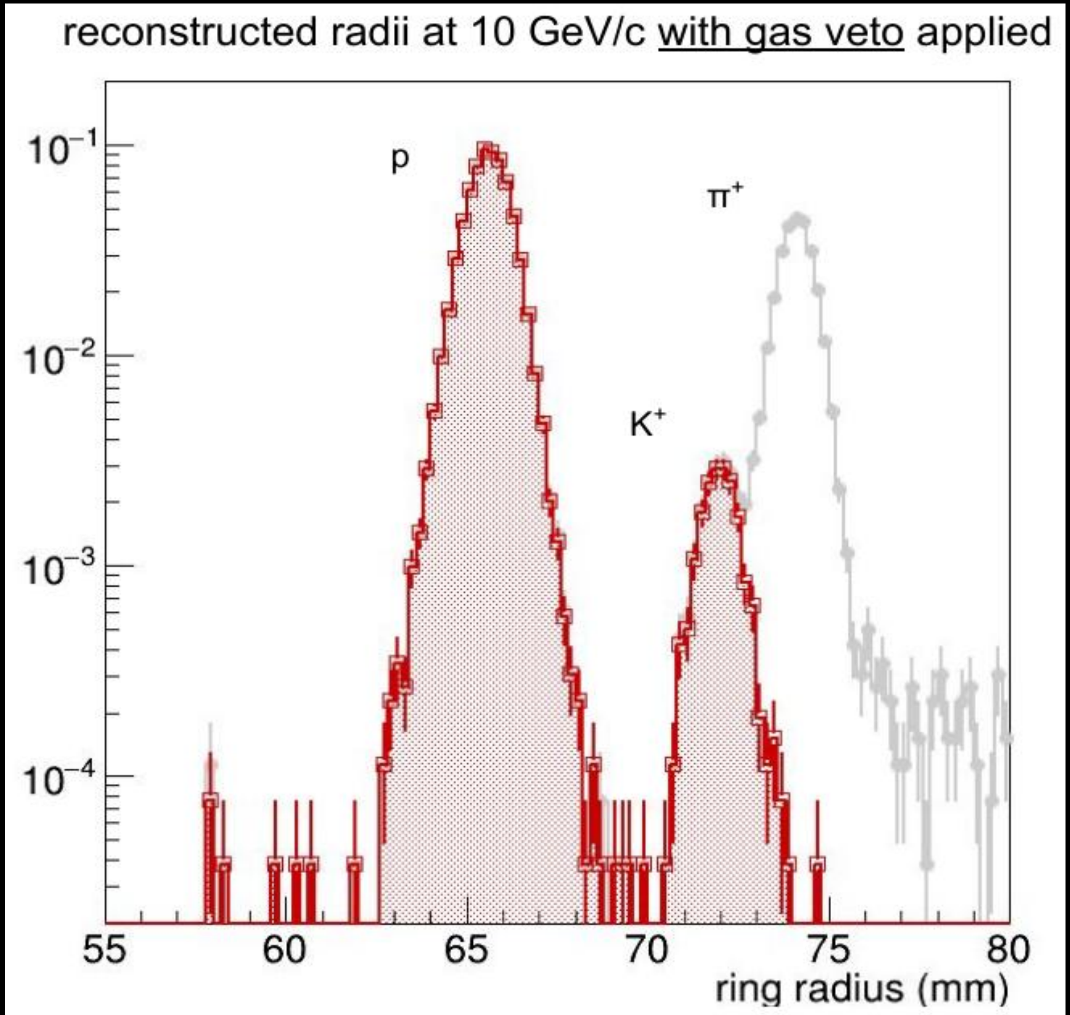
Data taking with different aerogel configurarions

Each tile is ~ 2 cm long and have roughly the same refractive index

Single photon resolution worsen as more tiles are introduced

PID with gas & aerogel





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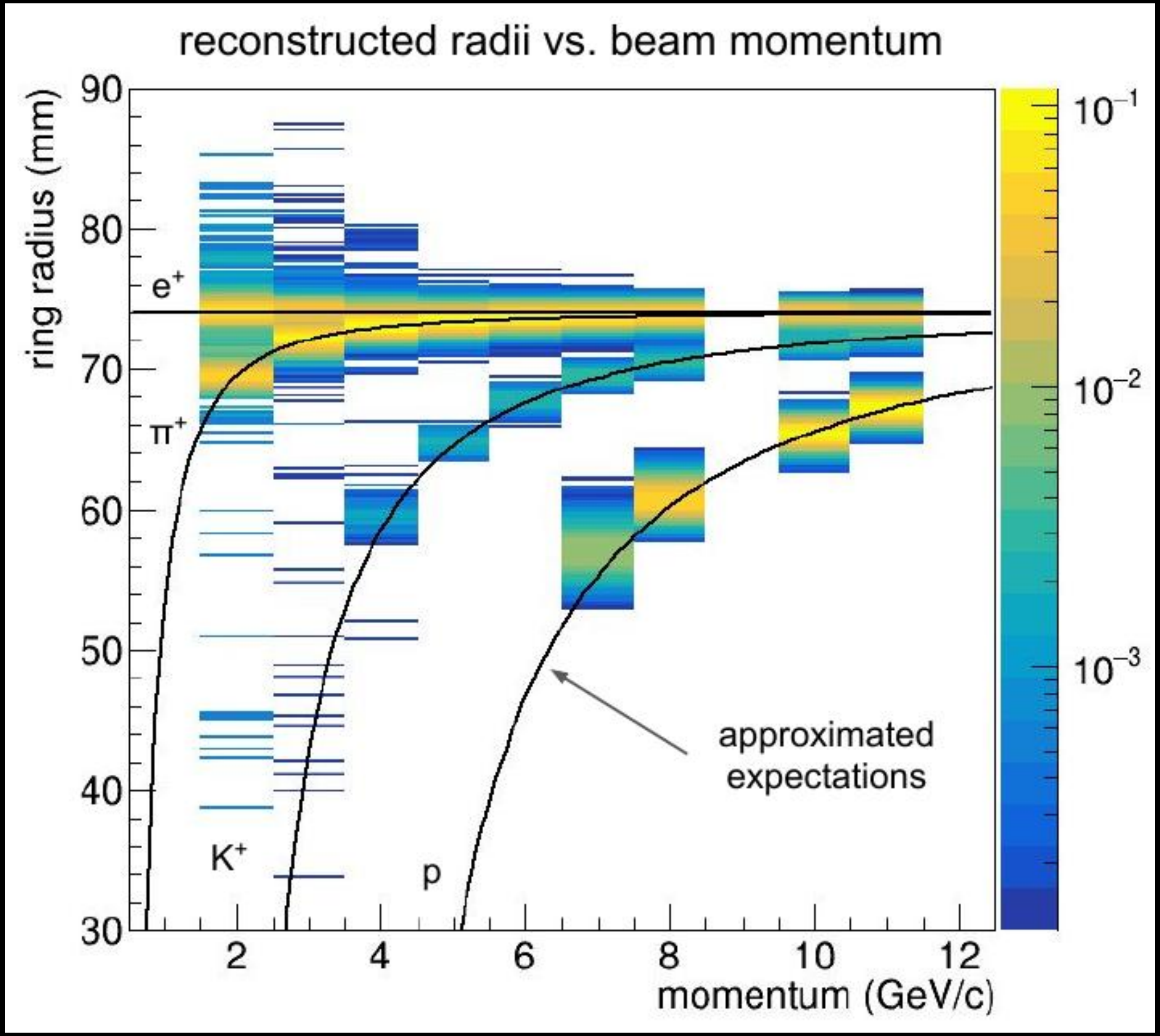


As main user in the 2024 test beam campaign , we could perform a beam momenta scan from 2 to 11 GeV/c:

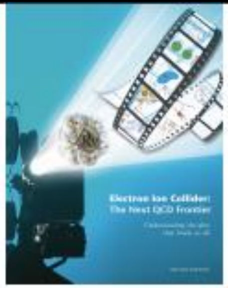
→ reconstructed aerogel Cherenkov ring radii across different particle types (positrons, pions, kaons, and protons) well align with theoretical expectations!

Summary

- The ePIC-dRICH detector prototype features a modular SiPM readout coupled with ALCOR ASIC FEB into a novel PDU architecture developed by INFN
- The performances are in line with the expected experiment requirements
- Extensive irradiation campaigns have been carried out to study the Dark Count Rate and the radiation hardness of the photodetectors and FEE
- Final engineering is planned by 2026, with mass production between 2027 and 2029 and full-scale integration in 2030.
- New UV-enhanced SiPM possibility is under investigation! → possibly tested at new test beam with ALCOR v3

→These results mark a major milestone in the ePIC-dRICH development, validating its modular SiPM-based approach for the final detector design.

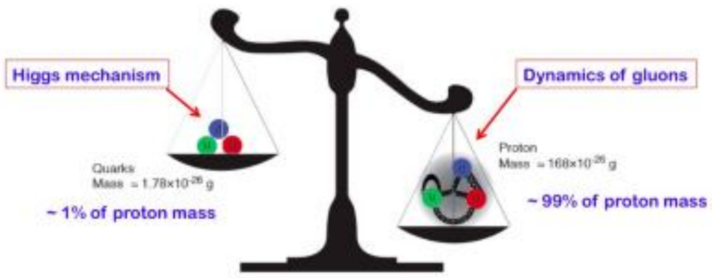
Backup



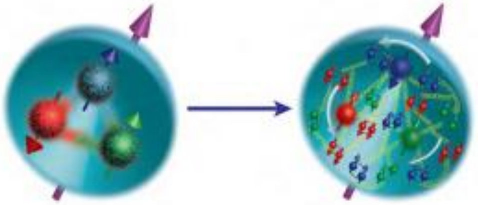
EIC Physics at-a-Glance

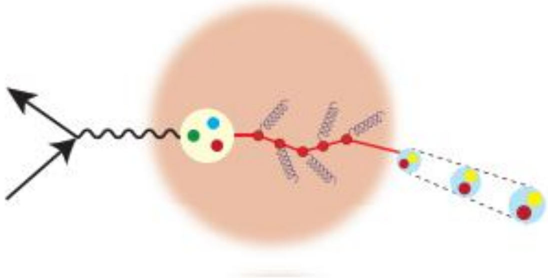
Eur. Phys. J. A 52 (2016) 9, 268 arXiv:1212.1701 (nucl-ex)

Slide from A. Deshpande @IWHSS2024



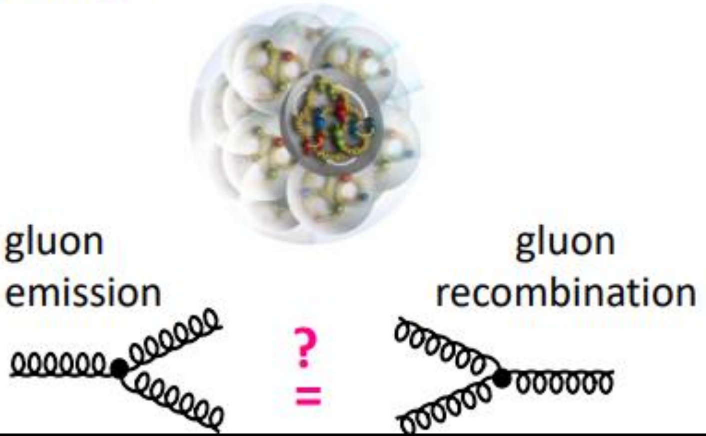
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?





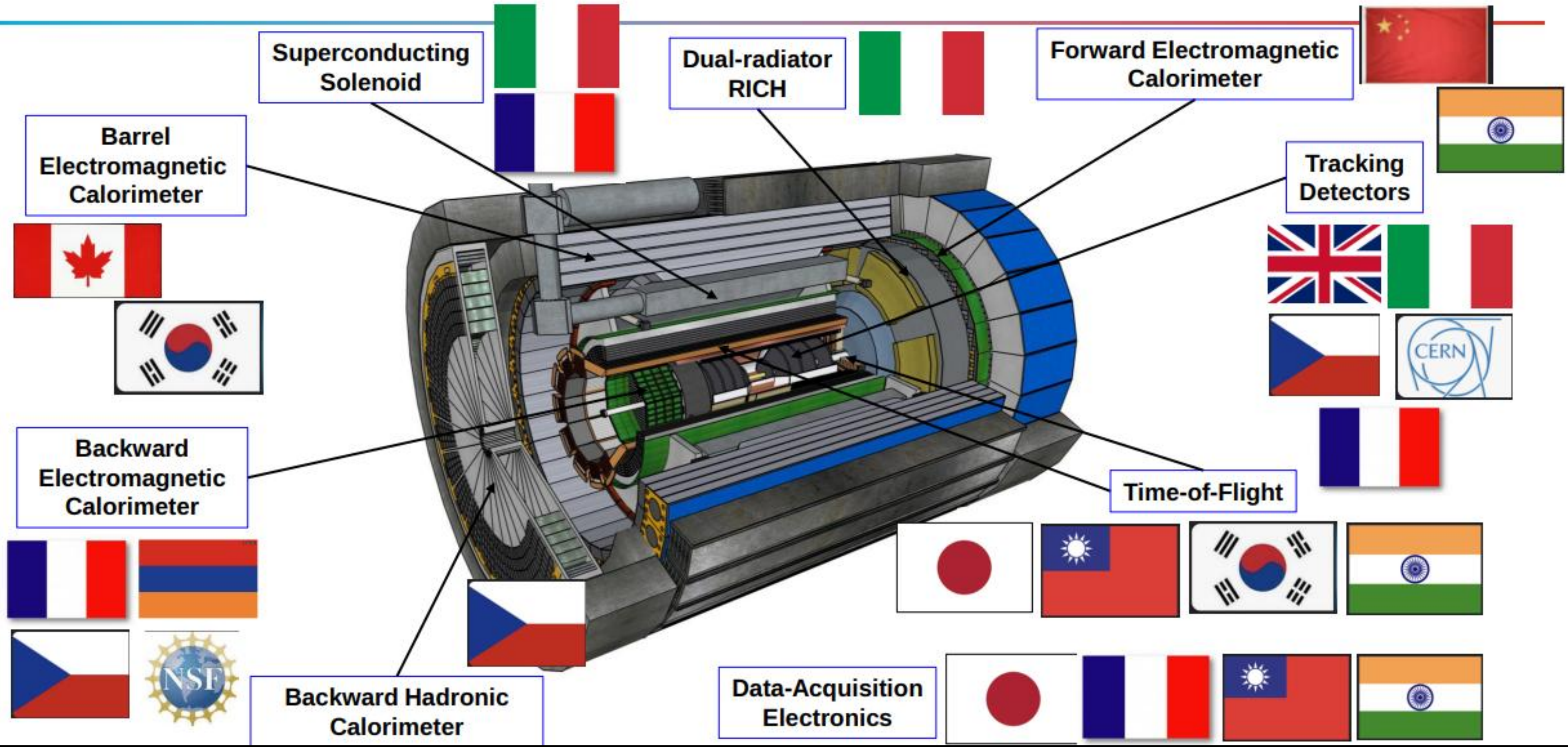
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



ePIC detector collaboration

Slide of S. Nagaitsev @FCC Week 2024

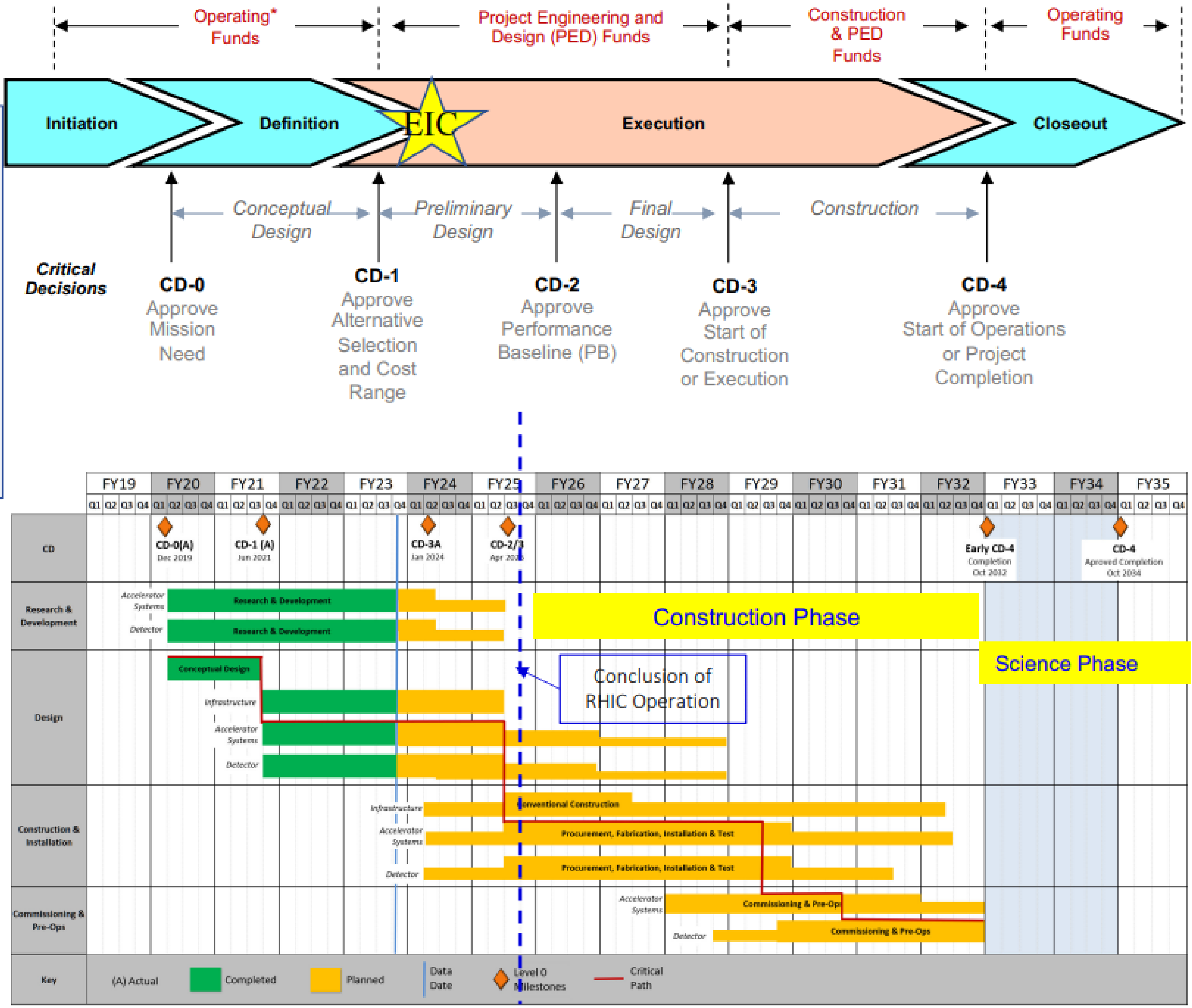


Timeline:

Slide from
A. Deshpande
@IWHSS2024

EIC Critical Decision Plan

CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	March 2024 ✅
CD-3B	**March 2025**
CD-2/3	**End of 2025**
CD-4A	October 2032
CD-4	**October 2034**



CD-3A: (Approved)

Define Baseline:

technologies, Scope, Cost & Schedule

Long Lead Procurement (LLP) items

Design Maturity: ~90%

Plan is tracked through EVMS

& Change control process

Start of construction for LLPs

ALCOR v3

F. Cossio @ PM2024

ALCOR v3

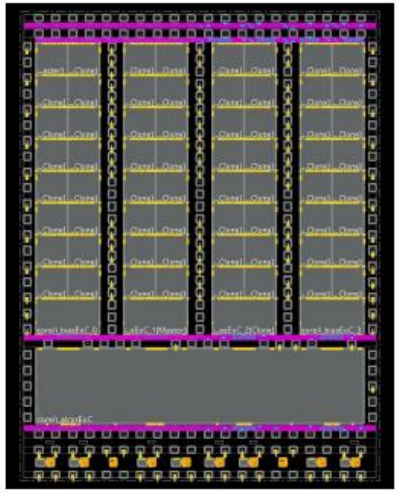
ALCOR v2: 32-channel wire bonded ASIC
ALCOR v3: 64-channel ASIC (8x8 matrix) inside BGA package (256 balls)

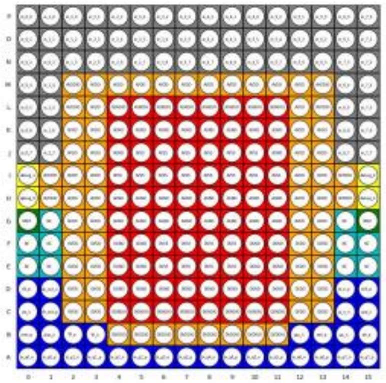
Operation of ALCOR at multiple of **EIC clock frequency** (98.52 MHz): digital logic, TDCs and serializers/drivers re-implemented and verified at **394.08 MHz**

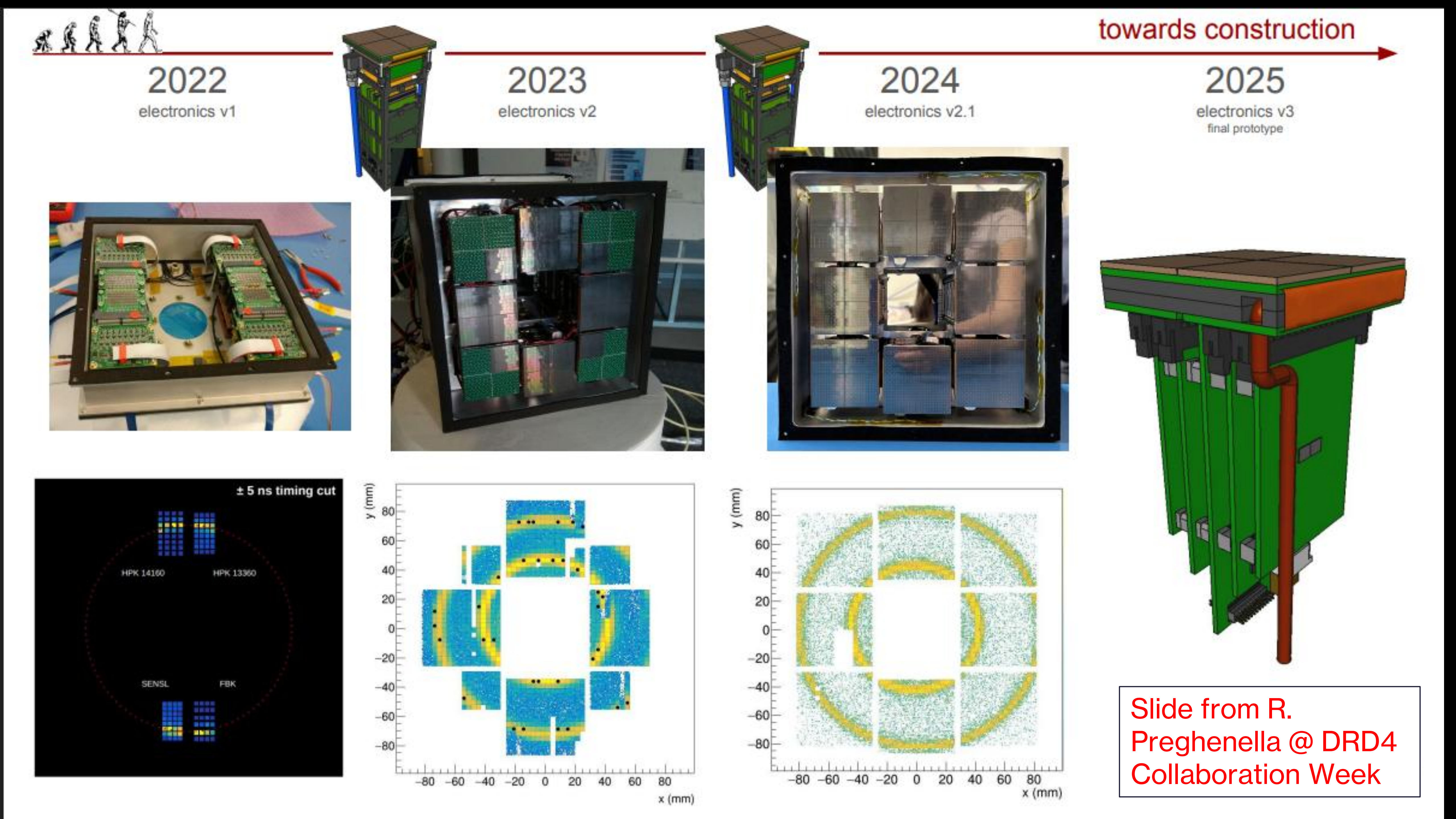
The ePIC detector will take data using a **streaming data acquisition system** with no traditional hardware trigger

Digital shutter: “inhibit” pixel digital logic to reduce data throughput

- ~10.2 ns bunch crossing, ~300 ps bunch length, select 2-3 ns → 3x-5x data reduction before ALCOR digitization
- Asynchronous digital shutter implemented in ALCOR v3 pixel logic with programmable delay to compensate offsets between the channels



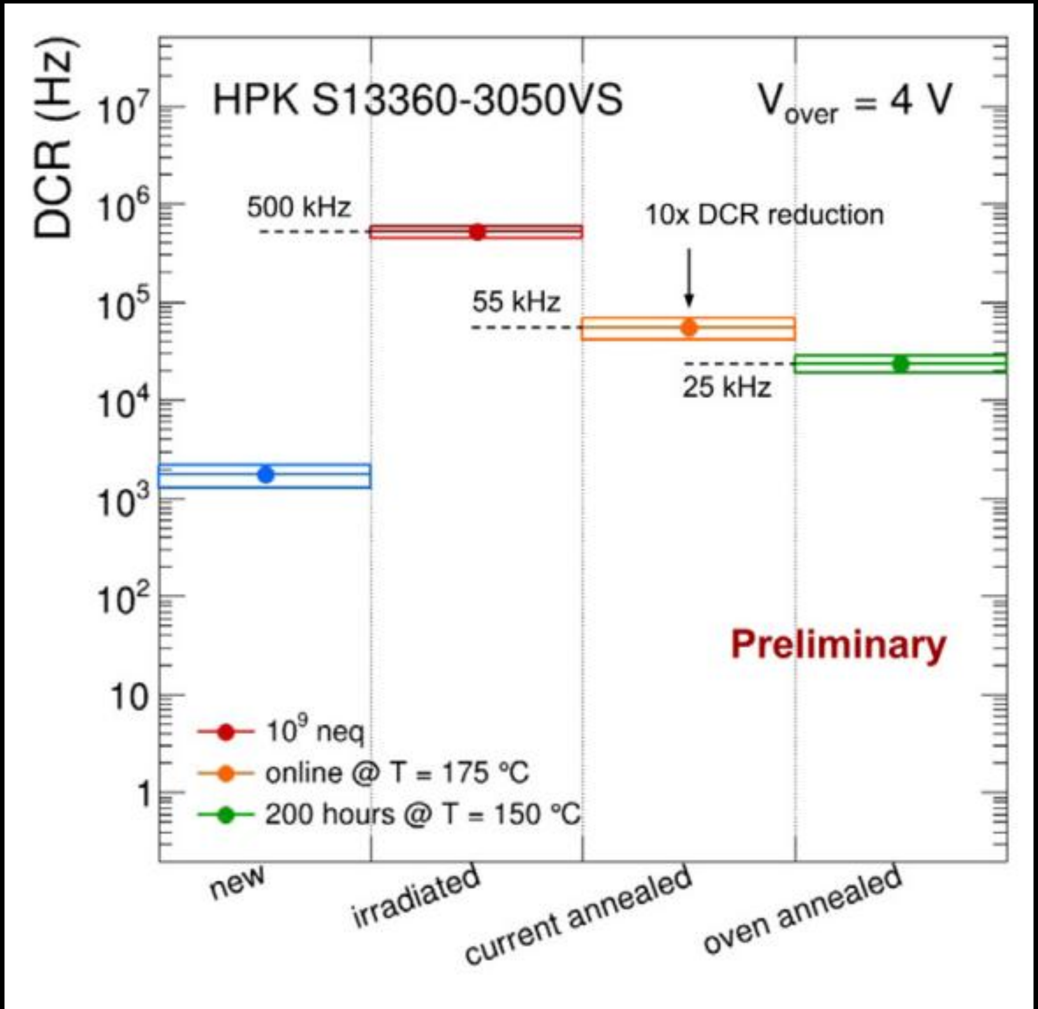


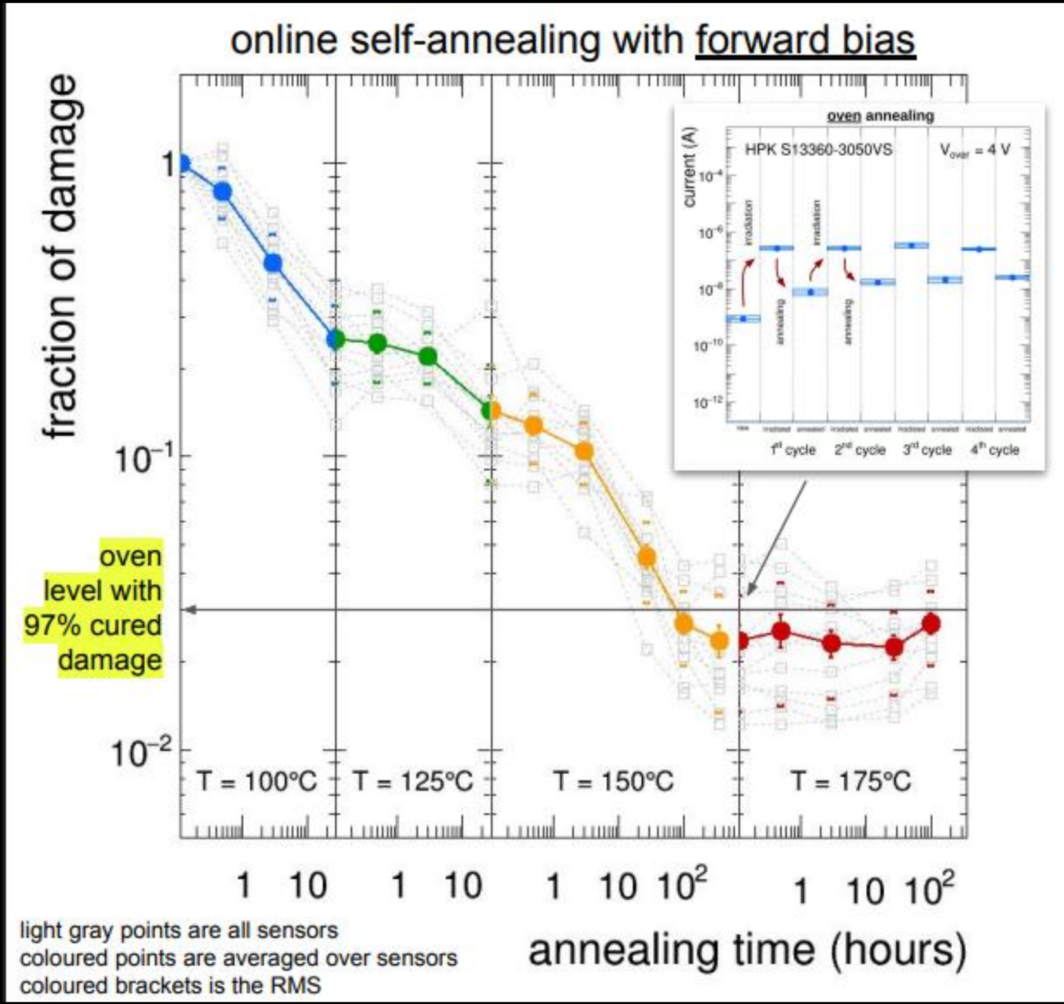


Slide from R. Preghenella @ DRD4 Collaboration Week

Irradiation studies – online annealing

https://doi.org/10.1016/j.nima.2022.167661





Irradiation studies

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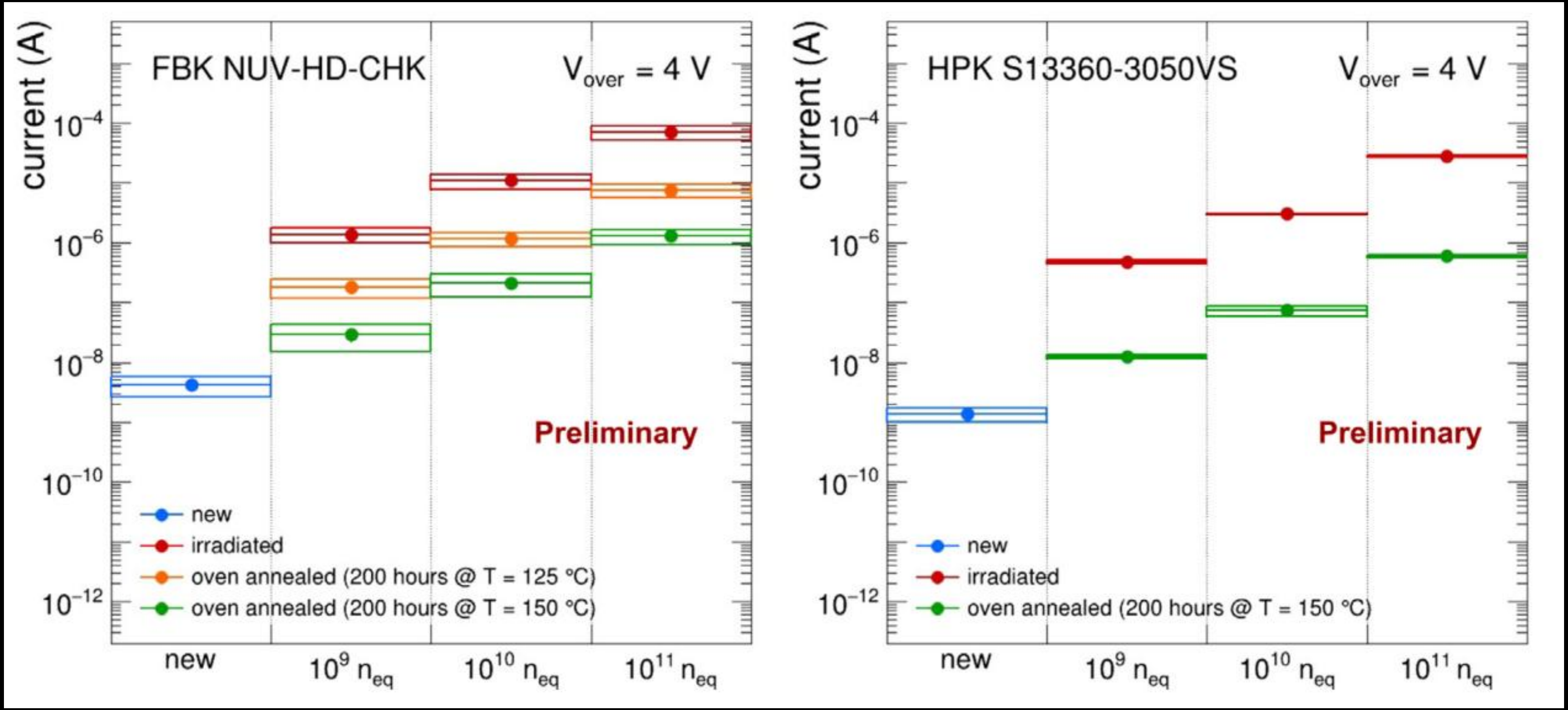


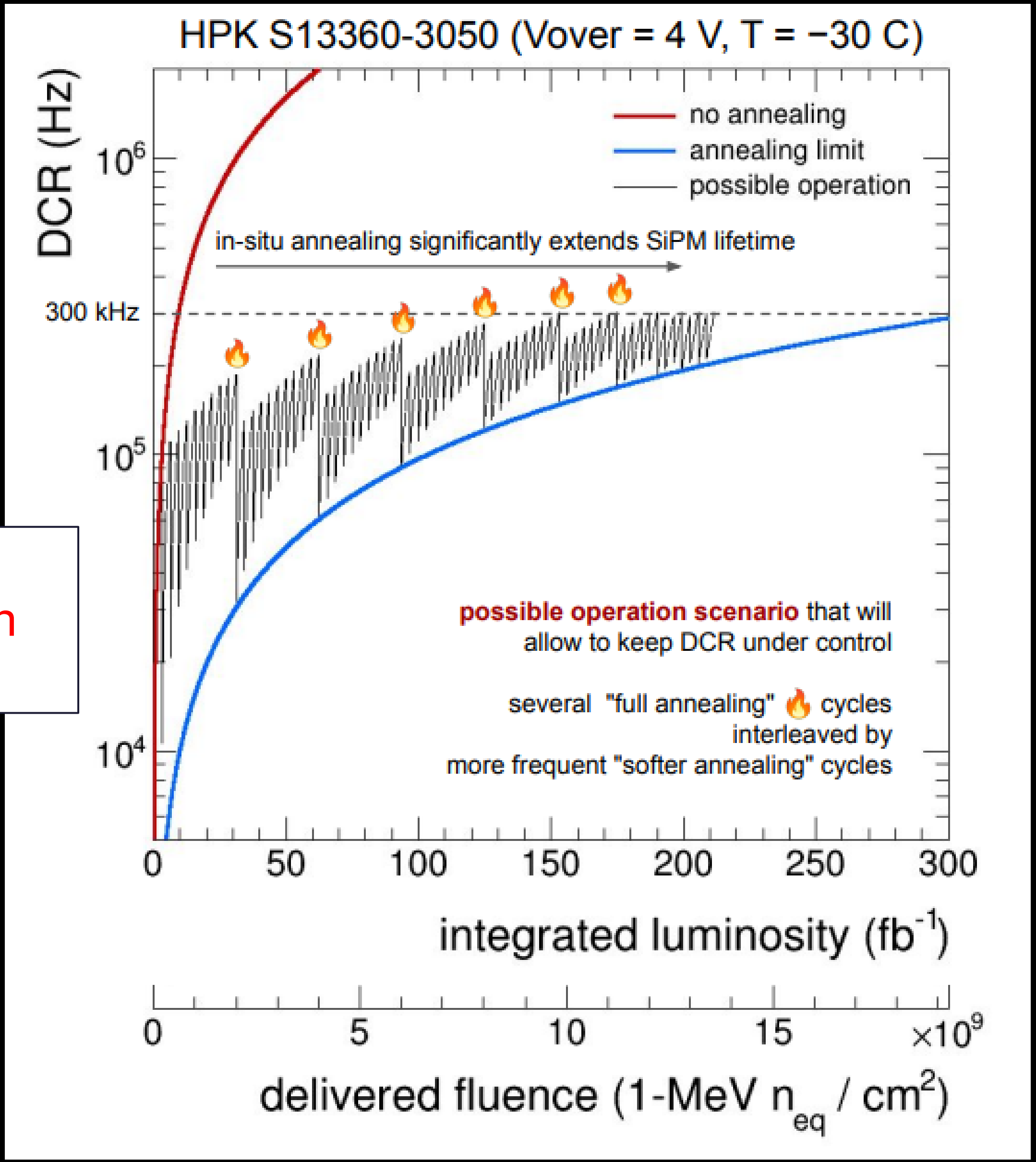
Irradiation studies

Expected Fluence:
1–5 × 10^7 neutrons/cm² (≥100 keV, 1-MeV equivalent) **per fb⁻¹** of delivered luminosity
High-Luminosity Scenario:
Up to **100 fb⁻¹** → total fluence ≈ **10^{10} neutrons/cm²**

Safety Margin:
Highest studied fluence: **10^{11} neutrons/cm²**
•Includes **5–10× safety factor**

Equivalent Runtime:
10^{11} neutrons/cm² corresponds to
2,000–10,000 fb⁻¹
→ **~6–30 years** of continuous running
at **instantaneous luminosity: 10^{34} s⁻¹ cm⁻²**

R. Preghenella @ DRD4 Collaboration Week



possible scenario for first 5 years of EIC Phase-1					
Year	**1**	**2**	**3**	**4**	**5**
Beams (GeV)	e⁻ Ru 10 x 115	e⁻ d 10 x 130	e⁻ p 10 x 130	e⁻ Au 10 x 100	e⁻ ³He 10 x 166
∫ Lumi (fb⁻¹)	0.9	11.4	5.33	0.84	8.65