dRICH R&D Status

Detector R&D Day, 25th Marh 2023

dRICH Collaboration

Compact cost-effective solution for particle identification in the high-energy endcap at EIC

dRICH

INFN: BA, BO, CS, CT, FE , GE, LNS, RM1, RM2, SA, TO, TS

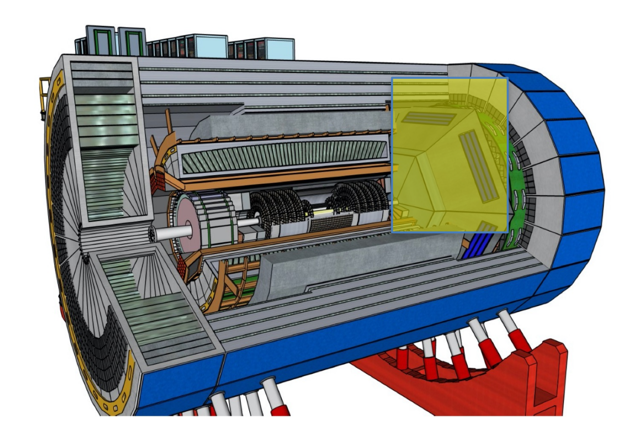
Jefferson Lab

Duke University

Ramaiah University of Applied Sciences

NISER

EPIC



EIC RICH Consortium

Brookhaven National Laboratory

Stony Brook University

Univerza v Ljubljani

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Forward particle detection

Hadron ID in the extended 3-50 GeV/c interval

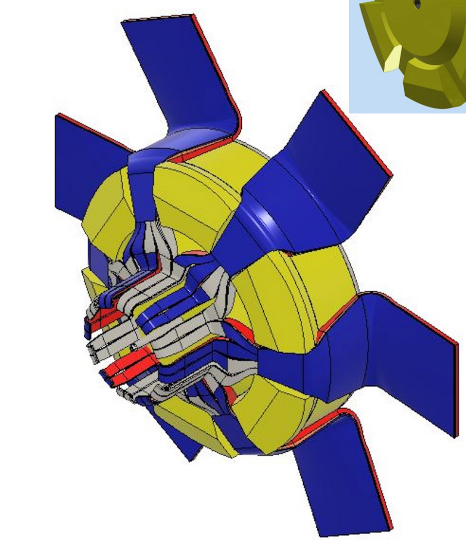
Support electron ID up to 15 GeV/c

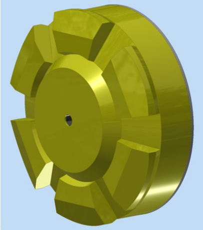
Main challenges:

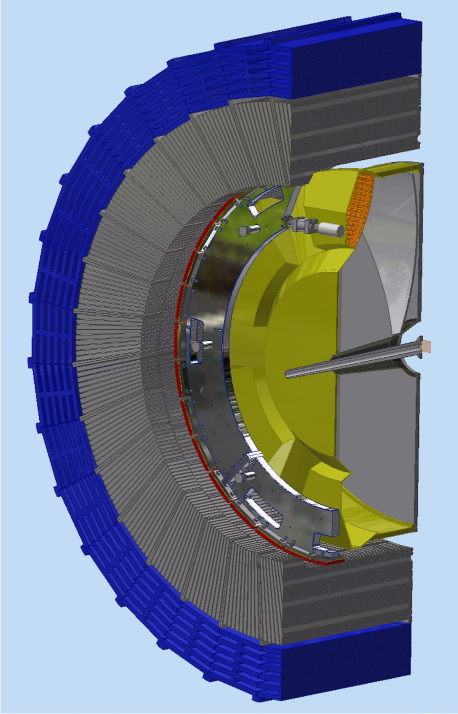
Cover wide momentum range 3 - 60 GeV/c -> **dual radiator**
Work in high (~ 1T) magnetic field -> **SiPM**
Fit in a quite limited (for a gas RICH) space -> **curved detector**

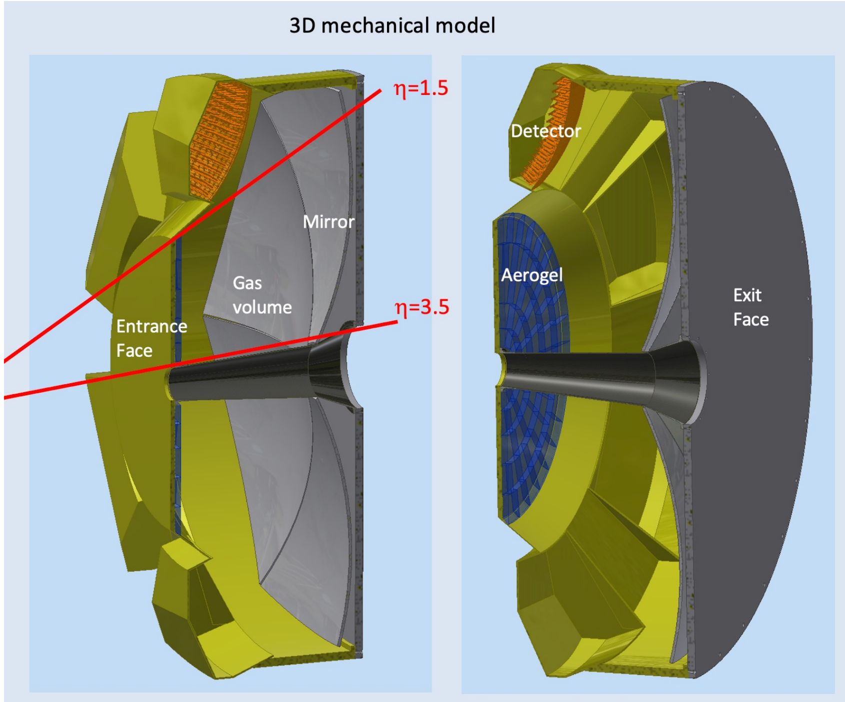
ePIC dRICH

- Φ3600 mm x L1200 mm
- Operating pressure up to 200 Pa
- Operating temperature of 22 °C



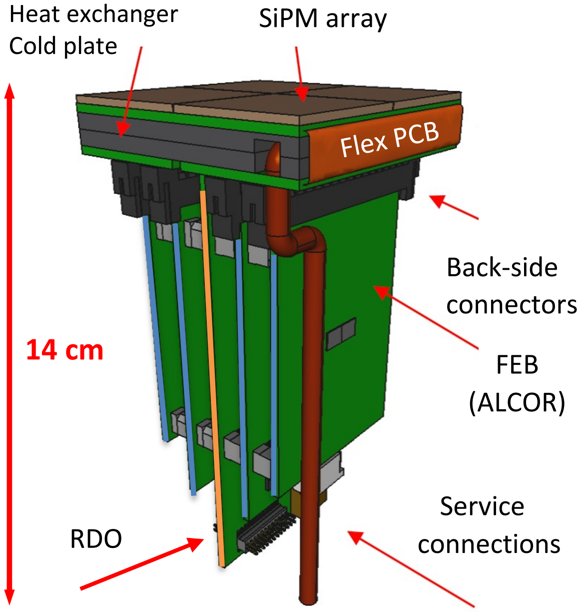


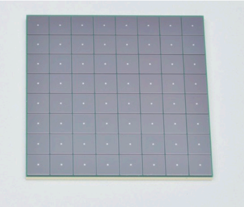




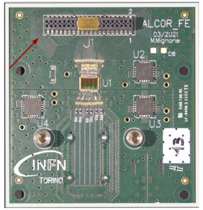
Interferences: material budget concentrated beheind the barrel ecal and its support ring
readout electronics design in order to minimize the detector box volume

Acceptance: defined by pipe and barrel ecal
minimize material budget with the use of composite materials





SiPM array



ALCOR chip

Photon Detector Unit (PDU):

Compact to minimize space

4x Hamamatsu S13361-3050HS SiPM arrays

4x Front-End Boards (FEB)

4x ALCOR chip (ToT discrimination)

4 x Annealing Circuitry

1x Read-Out Board (RDO)

1x Cooling plate (< -30 C)

Active area is shaped to resemble the focal surface and best exploits the focalization

Detector box:

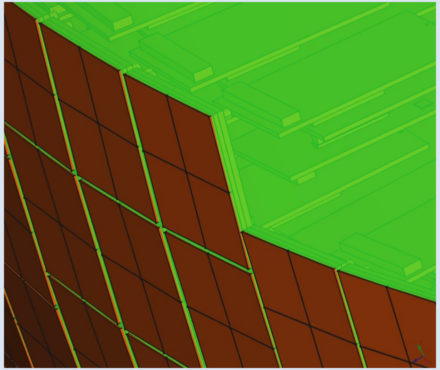
Shaped to fit the space

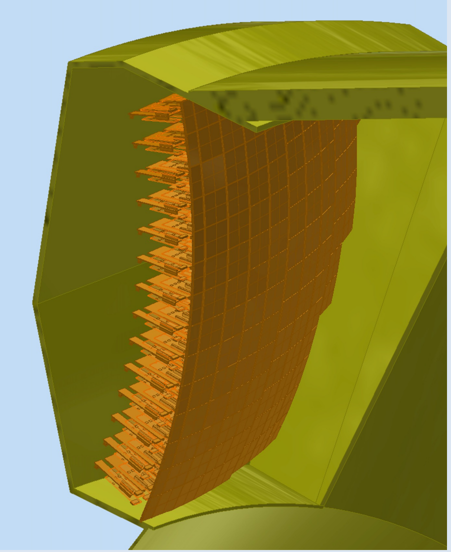
Quartz window

Cooling for sensors and electronics

Power distributing patch panel

Heat insulation



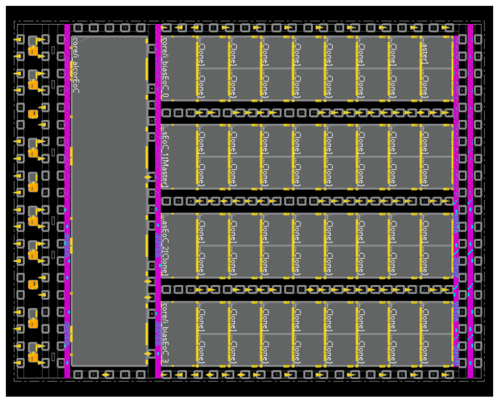


ALCOR Front-End Chip

ALCOR features

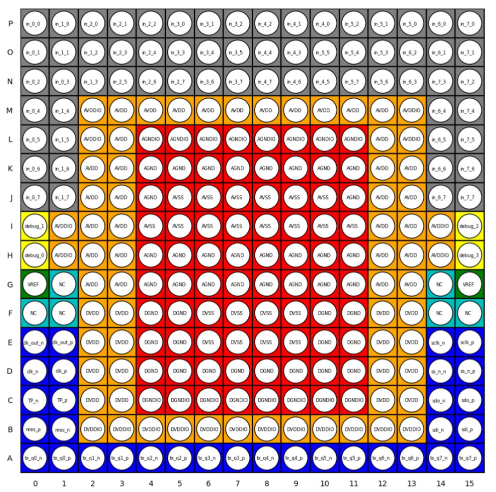
ToT architecture, streaming mode ready

- 50 ps time bin
- 500 kHz rate per channel
- cryogenic compatible



8x8 pixel matrix

- **ALCOR v2.0 – v2.1**: 32ch *chip available or produced*
- ***ALCOR Board****: 2x32 ch routinely used (lab and beam tests)*
- ***Irradiation****: no evident issue*
- **ALCORv3 64**: 64 ch *being designed (AC vs DC)*
- ***BGA Packaging****: being investigated*
- ***ALCOR64 Board****: to be evolved from existing one*



BGA pinout

SiPM technical specs

SiPM LLP Review September 2023

baseline sensor device
64 (8x8) channel SiPM array
3x3 mm^2 / channel

Parameters	Value	Notes (all parameters at the recommended operating voltage and T = 25 C, unless specified)
Device type	SiPM array	
Number of channels	64	8 x 8 matrix
Active Area	3 x 3 mm^2	active area of one channel, total active area is 64 x 3 x 3 mm^2
Device Area	< 28 x 28 mm^2	device area should be small such as to have > 75% fraction of active area over device total area
Pixel Size	40 - 80 um	pitch of the microcell SPAD
Package Type	surface mount	
Operating voltage	< 64 V	
Peak Sensitivity	400 - 450 nm	
PDE	> 35%	at peak sensitivity wavelength
Gain	> 1.5 10^6	
DCR	< 1.5 MHz	
Temperature coefficient of Vop	< 60 mV / C	
Direct crosstalk probability	< 10%	
Terminal capacity	< 600 pF	
Packing granularity		
Vop variation within a tray	< 300 mV	Vop variation between channels in one device
Recharge Time	< 100 ns	ctau recharge time constant
Fill Factor	> 70%	
Protective Layer	silicone resin (n = 1.5 - 1.6)	radiation resistant, heat resistant (up to T = 180 C)
DCR at low temperature	< 10 kHz	at T = -30 C
DCR increase with radiation damage	< 1 MHz / 10^9 neq	at T = -30 C, after a radiation damage corresponding to 10^9 1-MeV neutron equivalent / cm^2 (neq)
Residual DCR after annealing	< 25 kHz / 10^9 neq	at T = -30 C, after a radiation damage of 10^9 neq and a 150 hours annealing cycle at T = 150 C
Single photon time resolution	< 200 ps FWHM	corresponding to < 85 ps RMS

Optimization on:
- Size of μ-cell
- Protective layer
- Signal shape

very important parameters to ensure detector performance over the years

we will evaluate as part of QA, testing sensor samples in received batches

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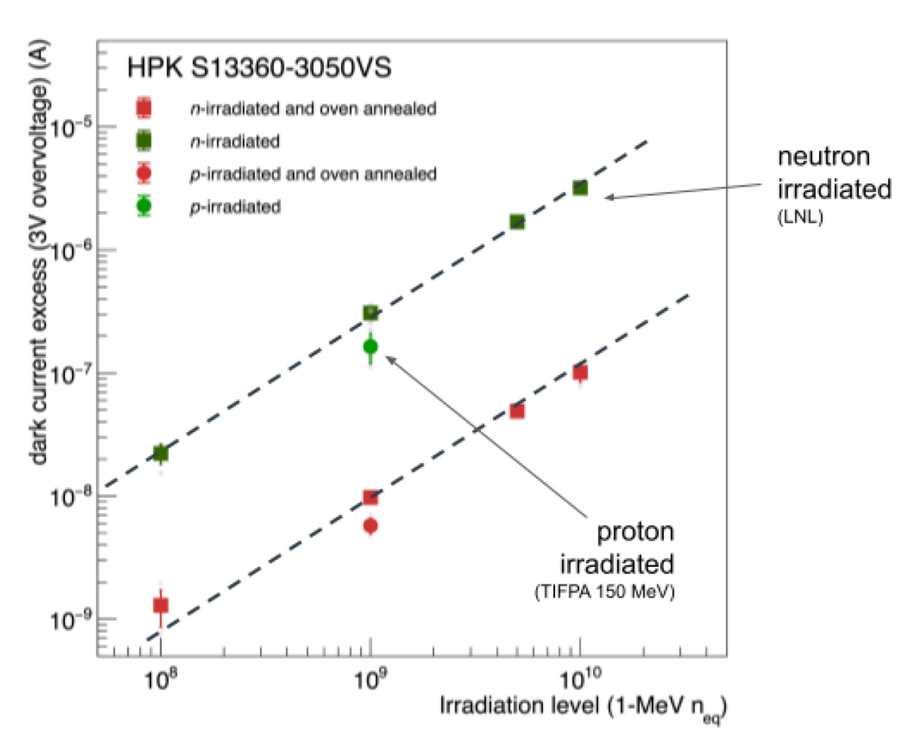
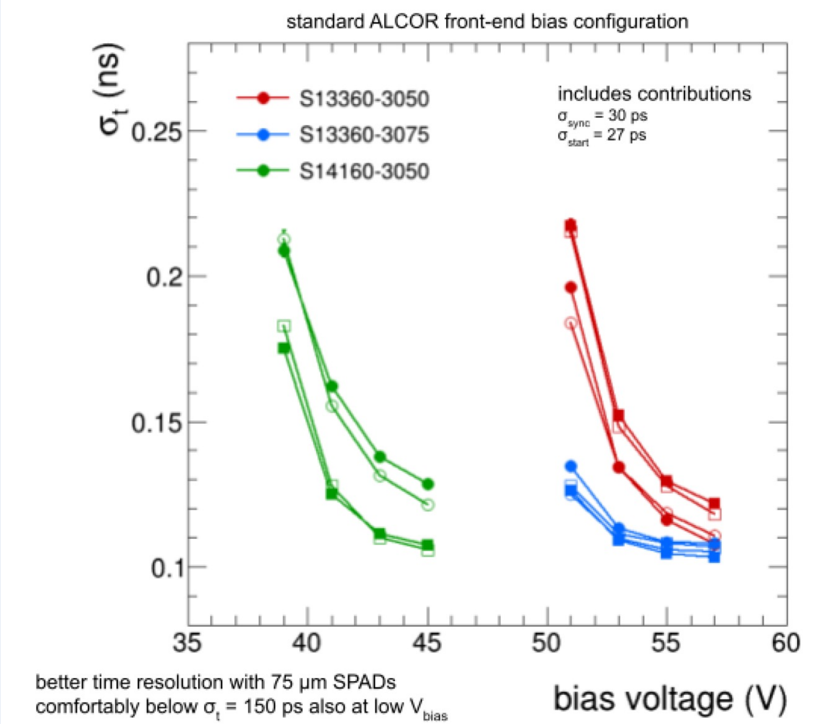
SiPM Characterization

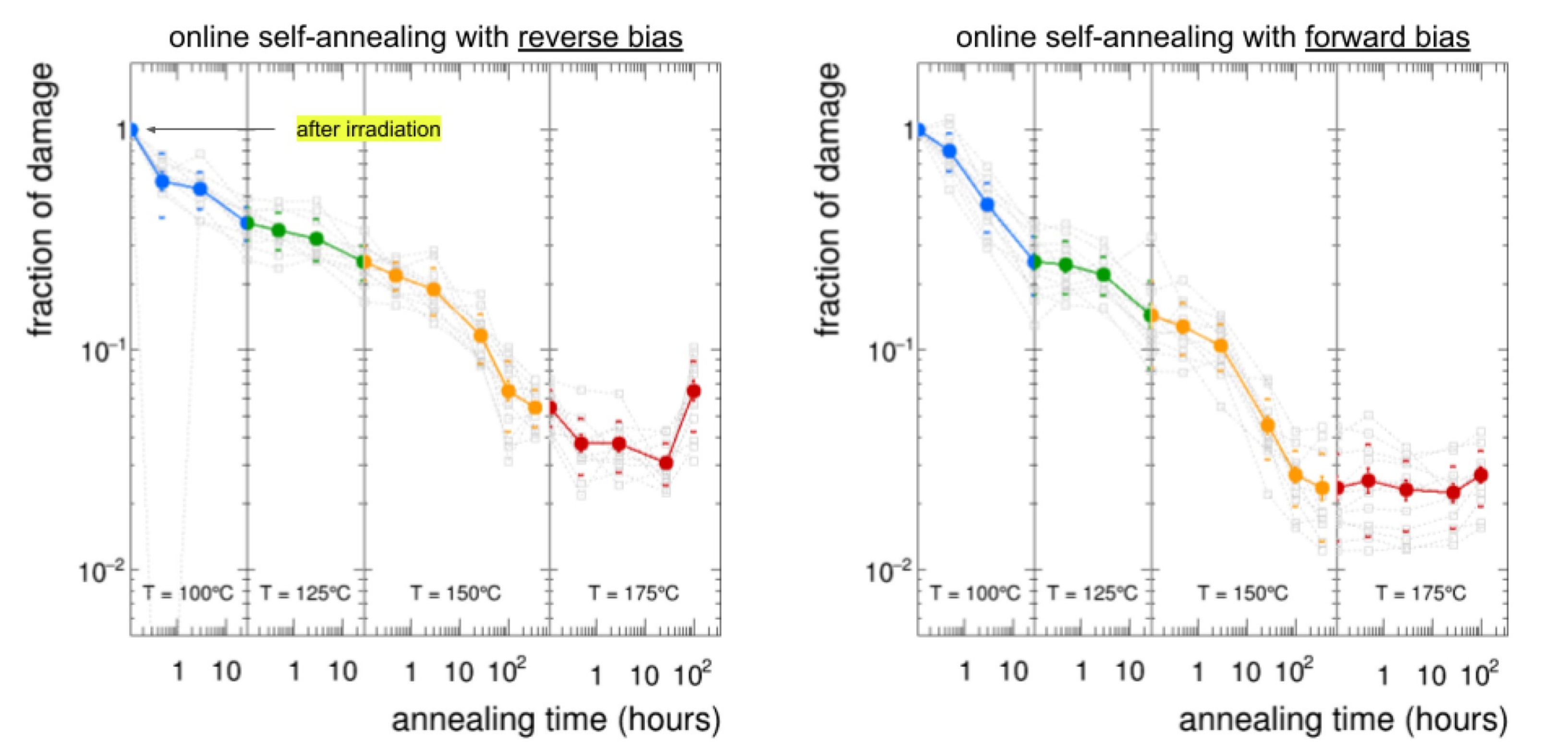
Neutron irradiation campaign



Time resolution measured with ALCOR readout chain

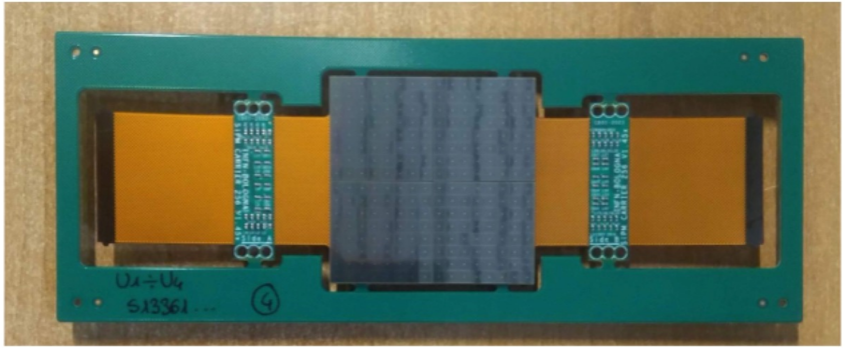


Study of the protocol for on-board annealing in conjunction with sensor irradiation cycles and consequence for the electronics layout (current sustainability & MOSFET protection)

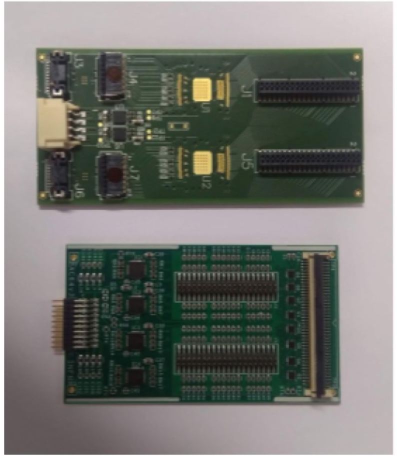


Photon Detector Unit (PDU)

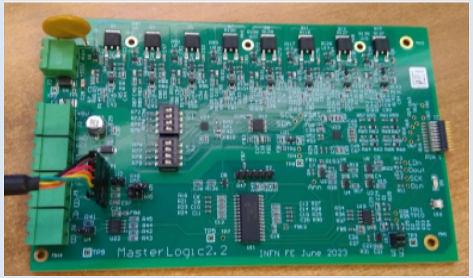
SiPM **carrier board** with 256 channels and flex connector circuits.

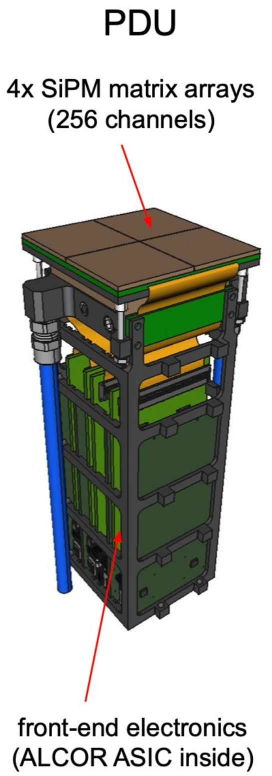


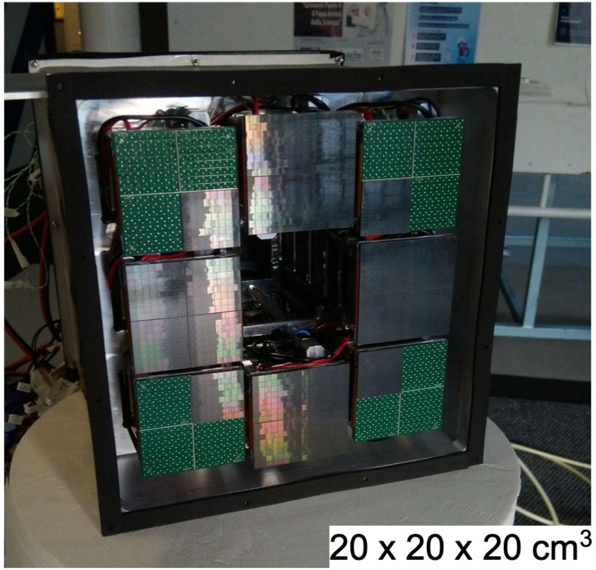
2x **ALCOR front-end card** and the **adapter board**

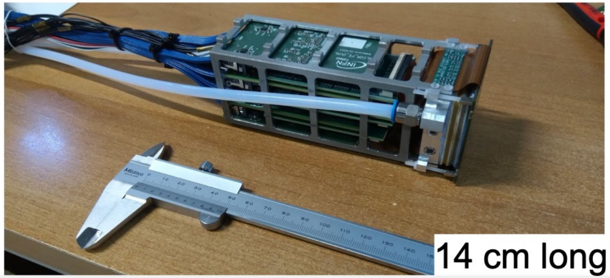


MasterLogic card to control SiPM bias voltage & monitoring service









dRICH Prototype

Dual radiator prototype is operative.
Performance with reference readout (MAPMT+MAROC) in line with expectations (gas + n=1.026 aerogel).
EIC-driven PDU commissioned at the last test-beam in October 2023

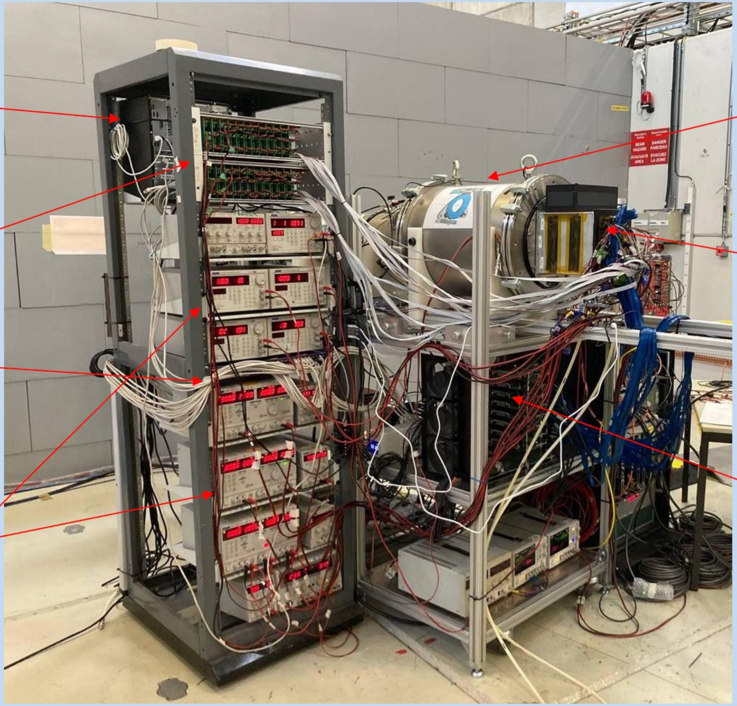
Beam test at CERN PS-T10 beam line: October 2023

DAQ and DCS computers

auxiliary control electronics crates

gigabit ETH switch for DAQ and DCS

low voltage and high voltage power supplies

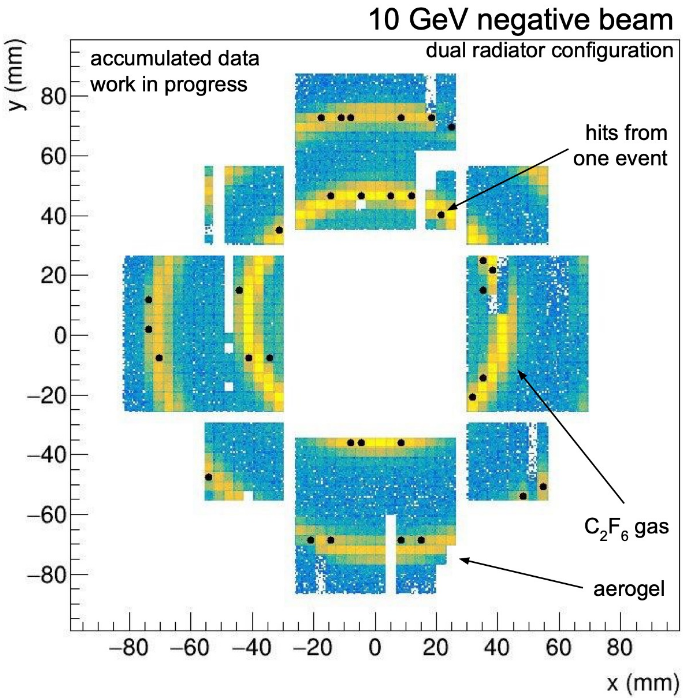


dRICH prototype

SiPM photodetector readout box

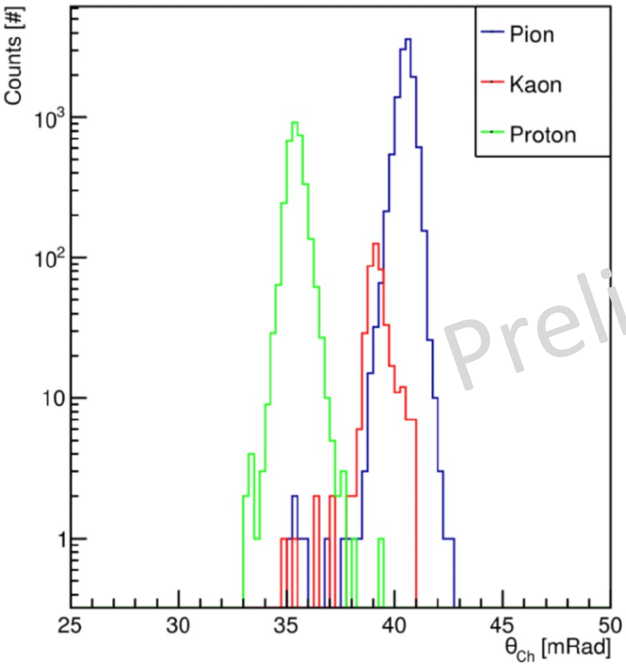
DAQ FPGAs and clock distribution

<N> = 9 p.e. per aerogel ring

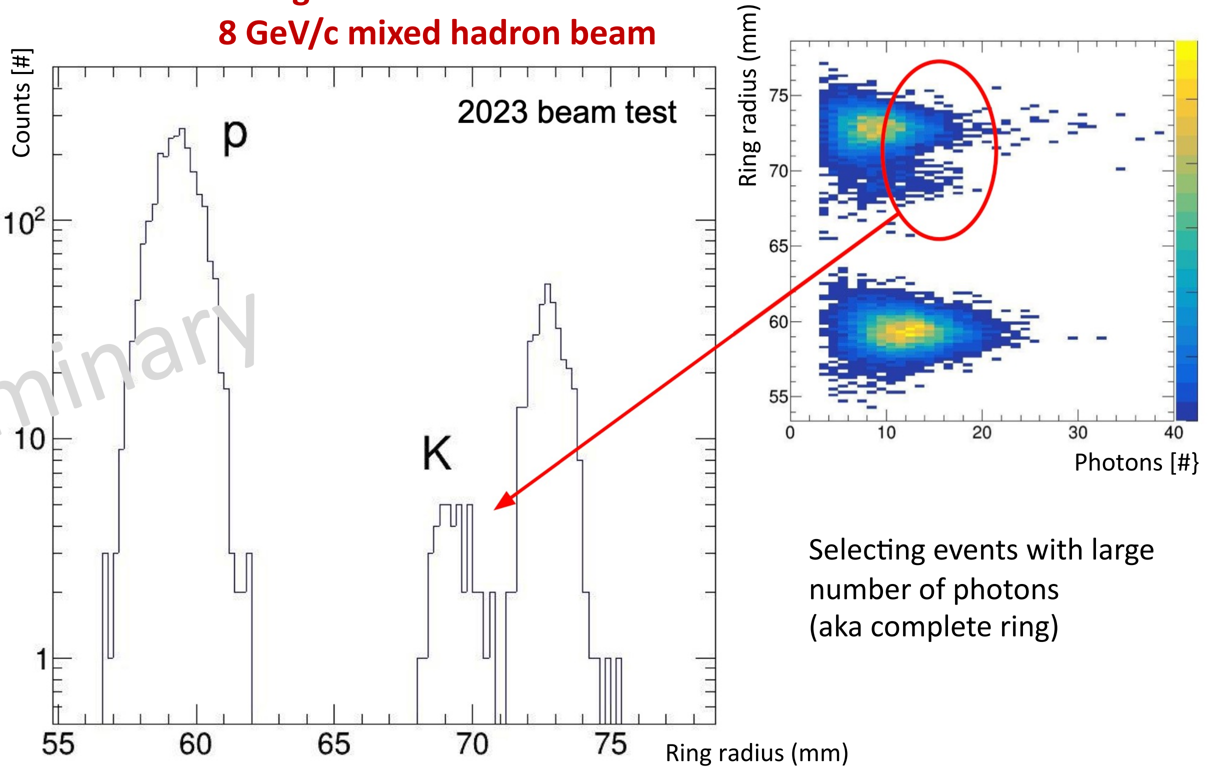


Particle identification tests with beam gas Cherenkov tagging

Gas radiator & MAPMT readout
50 GeV/c mixed hadron beam

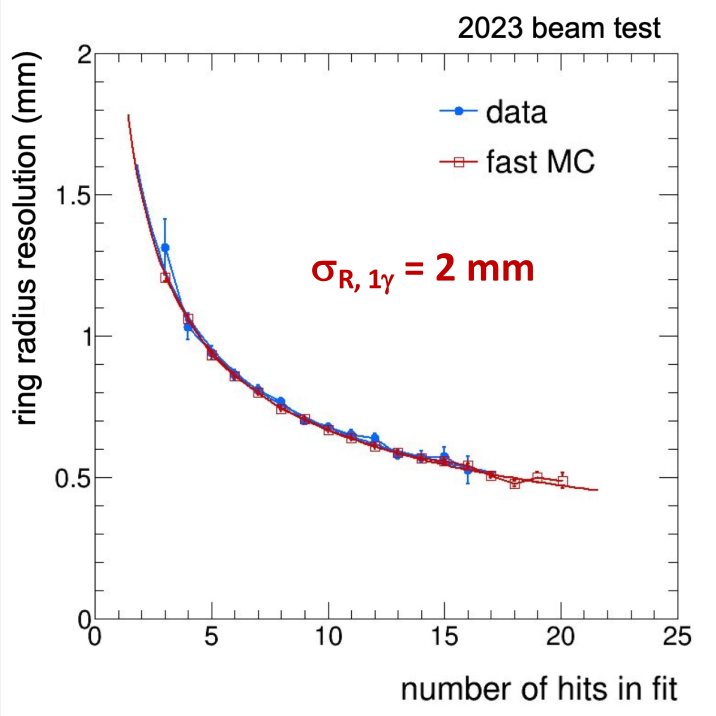


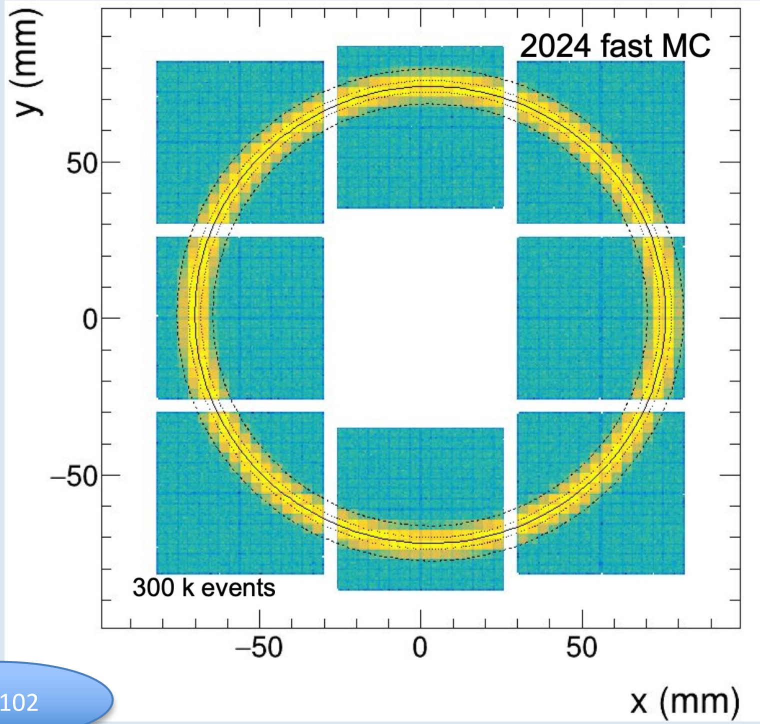
Aerogel radiator & SiPM readout
8 GeV/c mixed hadron beam



Selecting events with large number of photons (aka complete ring)

2024 Test-beam: May 22th – June 5th at PS T10 beam line of CERN
Goal: detailed study of the performance (timing, background, photon yield, resolution, particle ID)

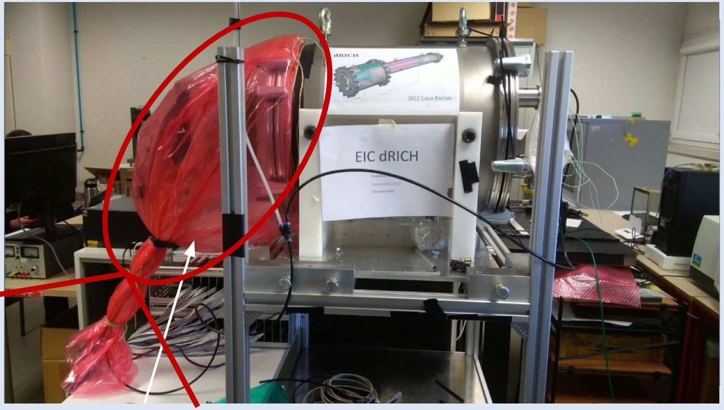




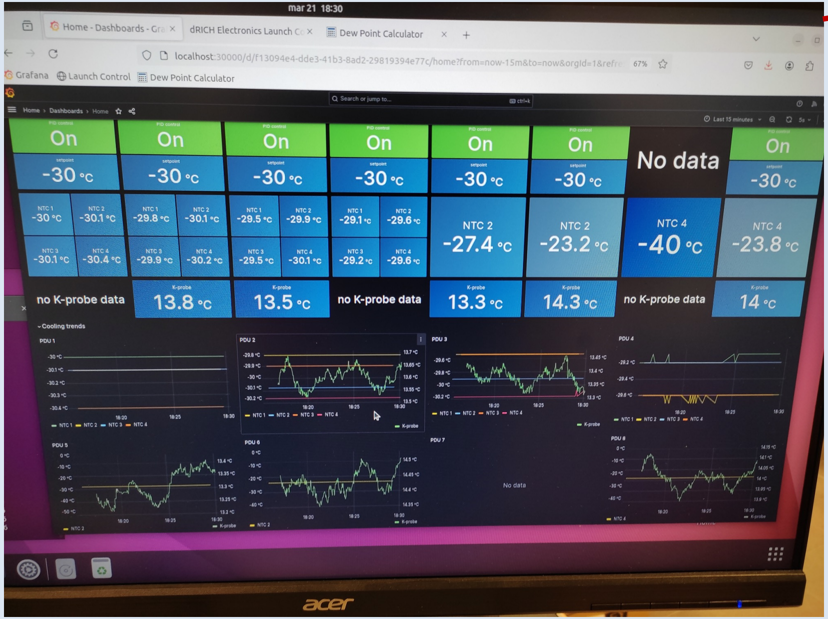
eRD102

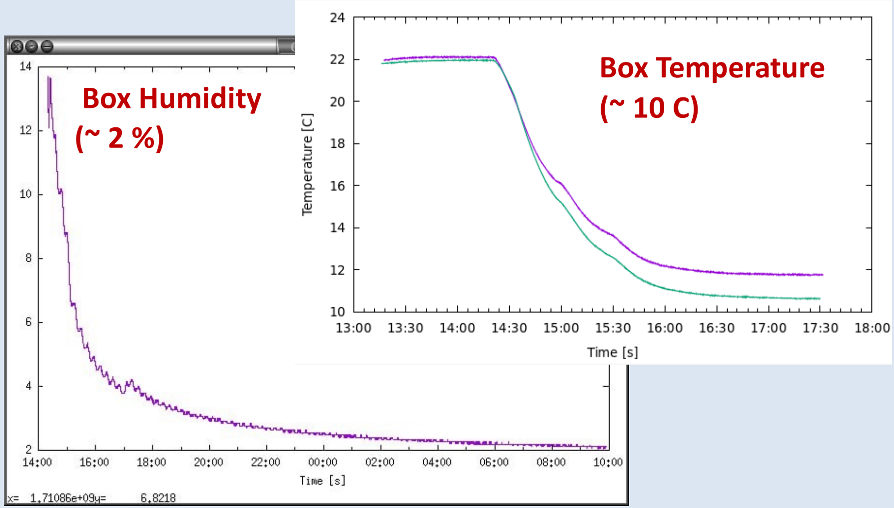
Cooling and insulation tests started with the existing dRICH prototype & SiPM detector box

Plan to optimize humidity control and verify the induced temperature gradients in the gas volume by the cool SiPM plane

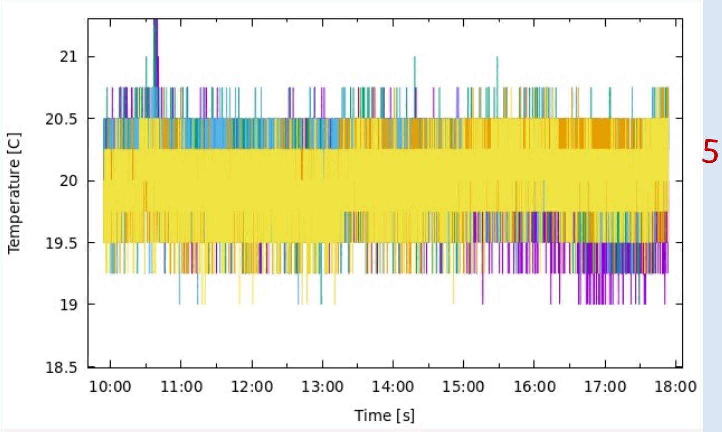


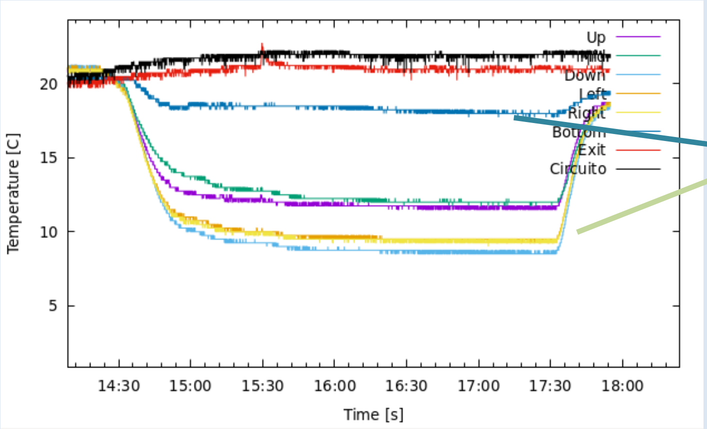
SiPM setpoint at -30 C





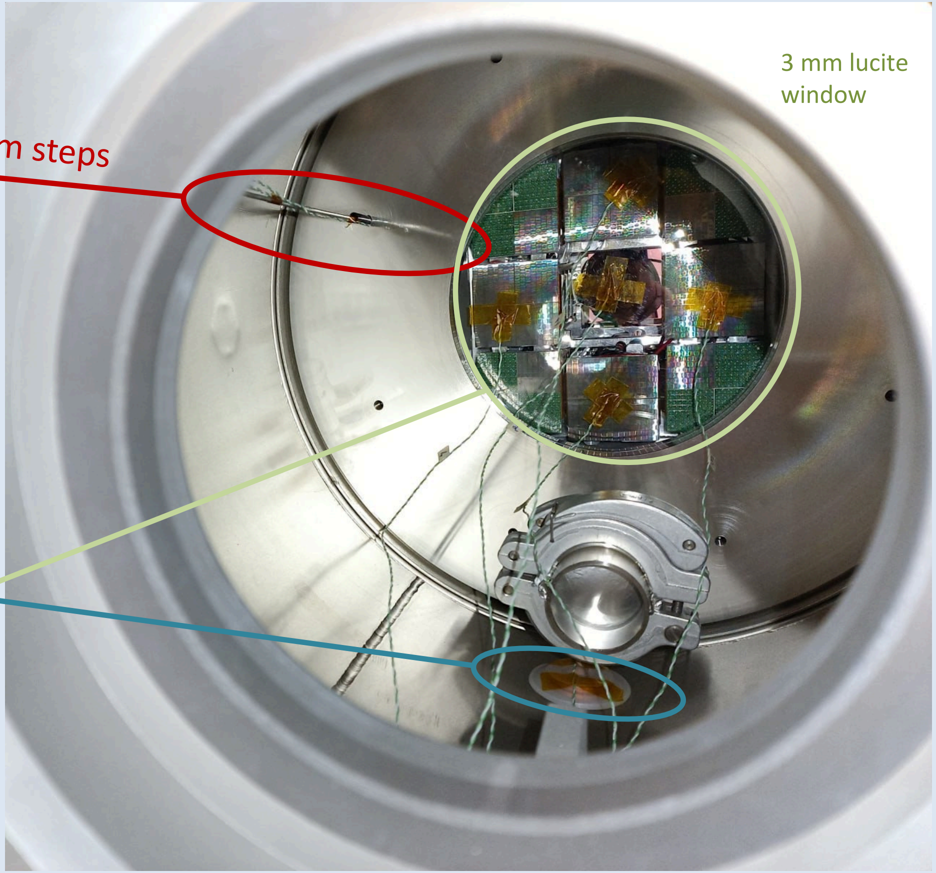
Temperature profile





Gas volume with termocoupes

5 @ 5 cm steps



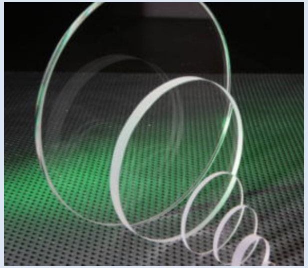
3 mm lucite window

dRICH Photon-Detector

- ***PDU**: baseline basically validated*
  moving to performance optimization
- ***Carrier board**: baseline is fine*
- **SiPM specs**: *largely defined with LLP review*
- **Irradiation**: *now intrumental to annealing study*
- **Online annealing protocol and materials**: *ongoing*
- **Cooling & Insulation**: *test with dRICH prototype in March*

PID Review July 5-6, 2023

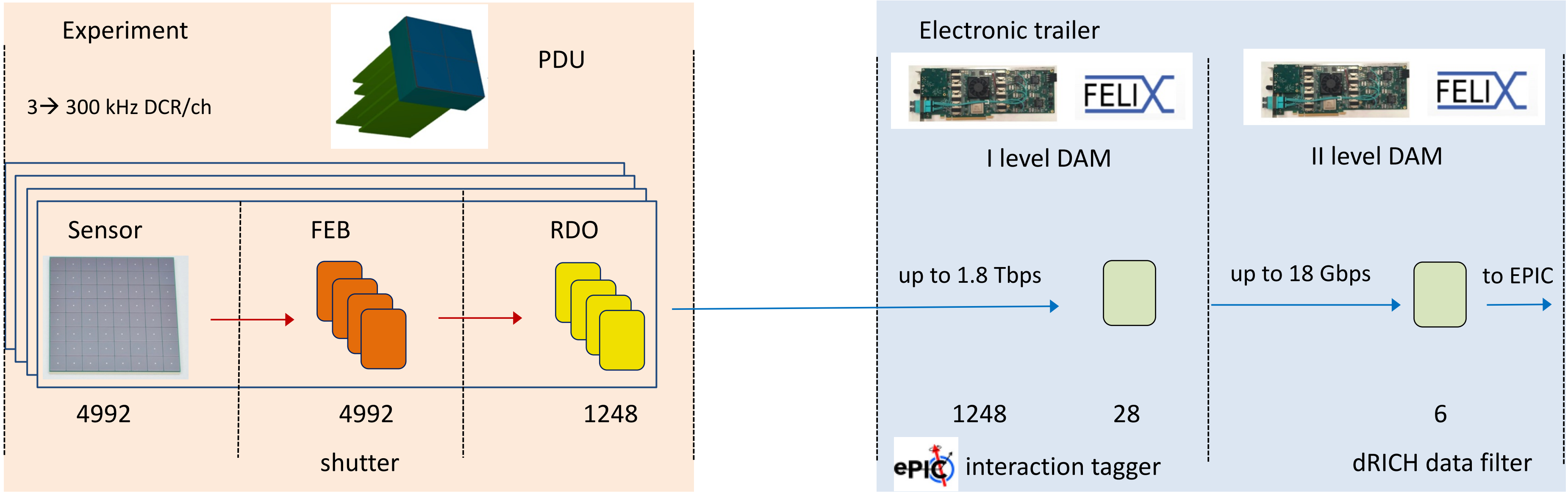
- To reduce dark current, heavy annealing is planned. It is required to check that the charge collection efficiency is not reduced due to over-annealing. The reviewers understand that this is part of the ongoing R&D campaign and that encouraging first results have been obtained.
- We advise exploring the operation of SiPMs at a lower temperature (for example -40C) to guarantee a low level of DCR.
- The online annealing procedure requires forward biasing of the sensors creating local heat generation and large current flows close to the front-end electronics. Precautions will have to be taken to avoid damage to the ASIC. It was understood that this is a part of the R&D effort, for example, through the use of MOSFETs to protect the readout.
- For online self-annealing, all materials, including glue, PCB, etc., have to be checked to see if these are tolerant to the high temperature and if the thermal cycling does not affect the components due to CTE mismatch.



Quartz windows has been procured (various type, dimension, thickness

eRD102

- The quartz window to separate the photodetector box from the gas radiator was identified as a point of attention. A thermal simulation is required with the SiPM array at the foreseen operating temperature of -30 C and the approach to avoid condensation or convection of the C2F6 gas radiator should be described. The reviewers fully recognize the importance of the foreseen small-scale system tests in the SPS test-beam facility later this year.



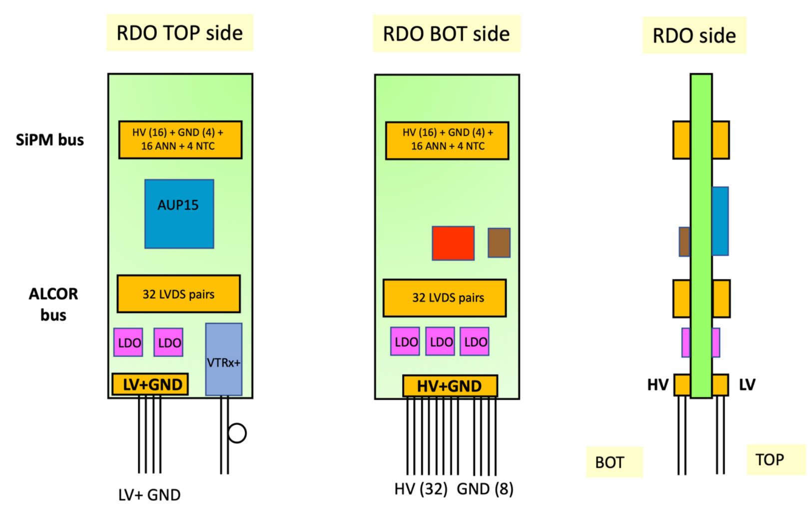
Goals: **Maximise modularity** (detector shaping) and **capability** (data stream)

DAM Hierarchy: Maximum data rate capability till DAM-L1
Big data reduction at DAM-L1 with external input (2 μs latency interaction tagger)
DAM-L2 data aggregation per sector allows for effective data-reduction algorithms

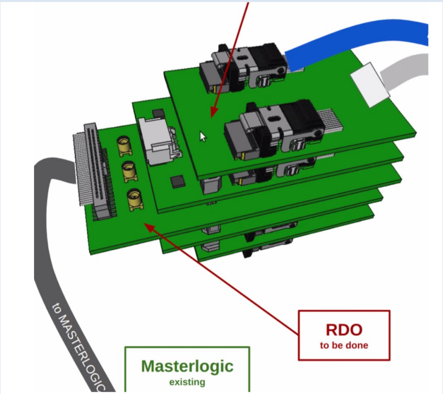
INFN experts started collaboration and are studying AI/ML solutions for L2 **(building upon APEIRON & NA62)**

dRICH DAQ

- ***General layout*** *outlined*
- ***RDO Board****: being designed*
- ***RDO FPGA****: ARTIX Ultrascale+ & Polarscale scrubber*
- **RDO Transceiver**: *VTRX+ (secured)*
- ***Fake-FEB****: adapeter to ALCORv2-FEB being designed*
- ***L1-filter:*** *interaction tagger or dRICH tagger*
- ***L2-filter****: ML patter recognition study (test-beam data)*



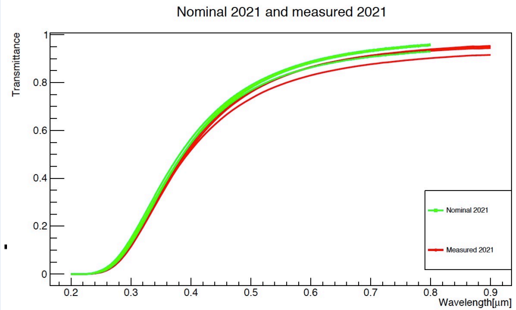
Target: RDO demo before the end of the year

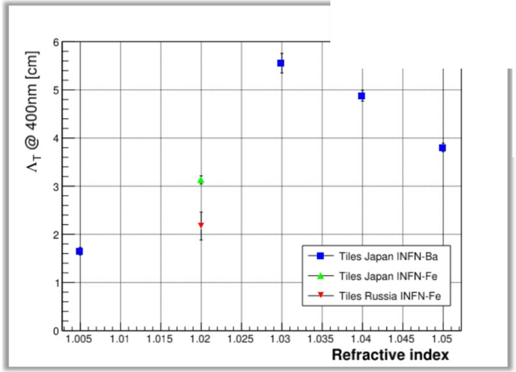


Aerogel Radiator

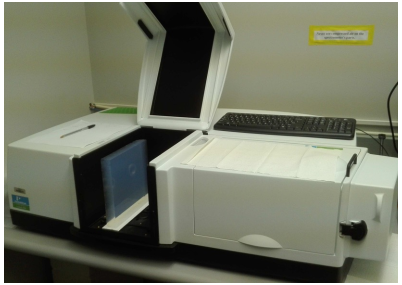
Aerogel Factory (BELLE-II)
Initial evaluation & Reproducibility
on small samples in sinergy with ALICE

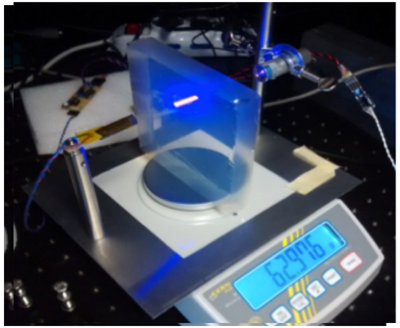
Transmittance & Transflectance



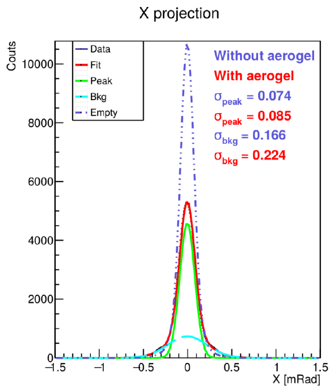


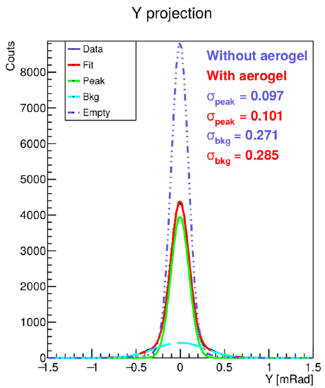
Density & refractive index





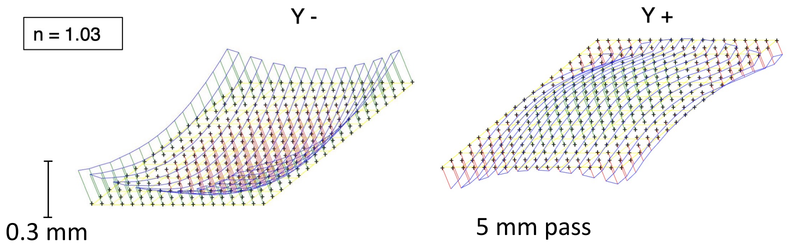
Laser spot broadening with 3 x 2 cm aerogel





Touch Probe: planarity and thickness

10x10x2 cm³ tile
(from ALICE)



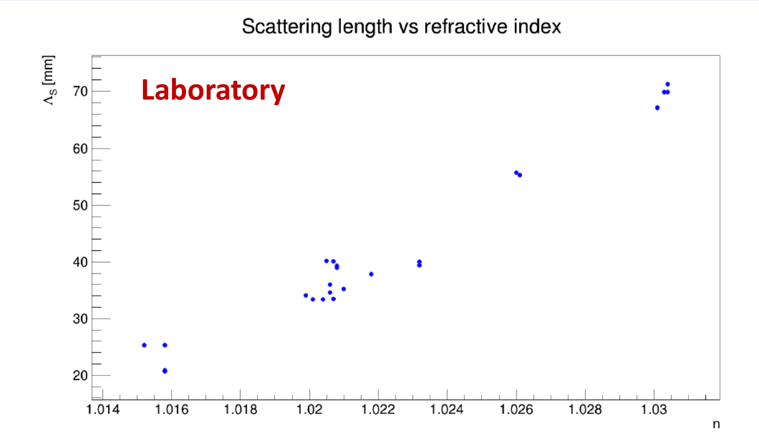
Test-station under development @ Temple University

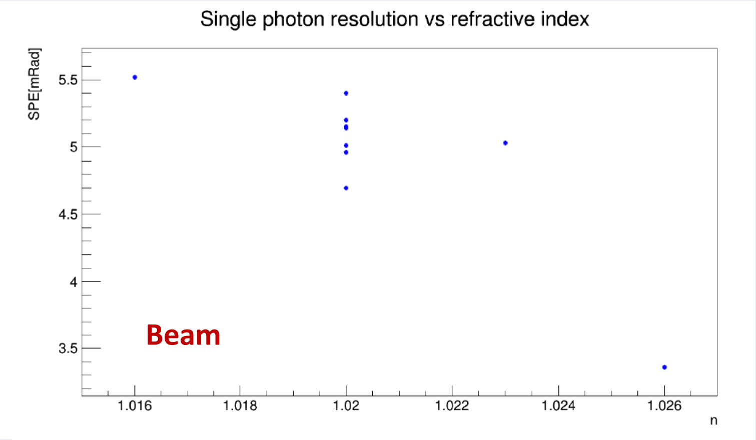
dRICH Aerogel

- **Test-beam data analysis:** *preliminary result available*
- **Characterization:** *preliminary study done*
  transmittance, forward scattering, planarity, chromaticity
- **Reproducibility**: *under study*
  new n=1.020 samples close to delivery
  new n=1.026 sample being ordered
- ***Optimization***: *unders study with test & simulation*
- ***Real-scale sample***: *under negotiationwith Aerogel Factory*
- ***Long-term tests** with C_2F_6*

DAC Review August 28-31, 2023

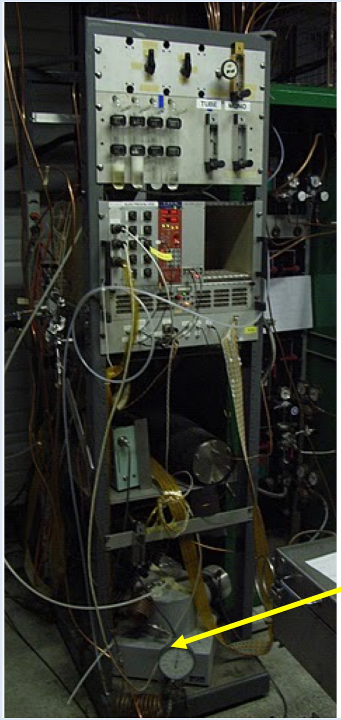
3) It is important to understand the aerogel quality issues and give feedback to this manufacturer in order to allow time for the production of aerogel which meets the requirements of the detector.



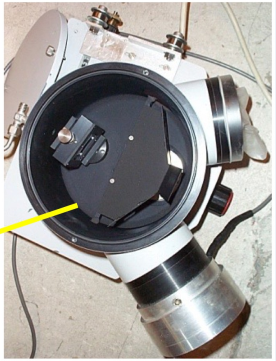


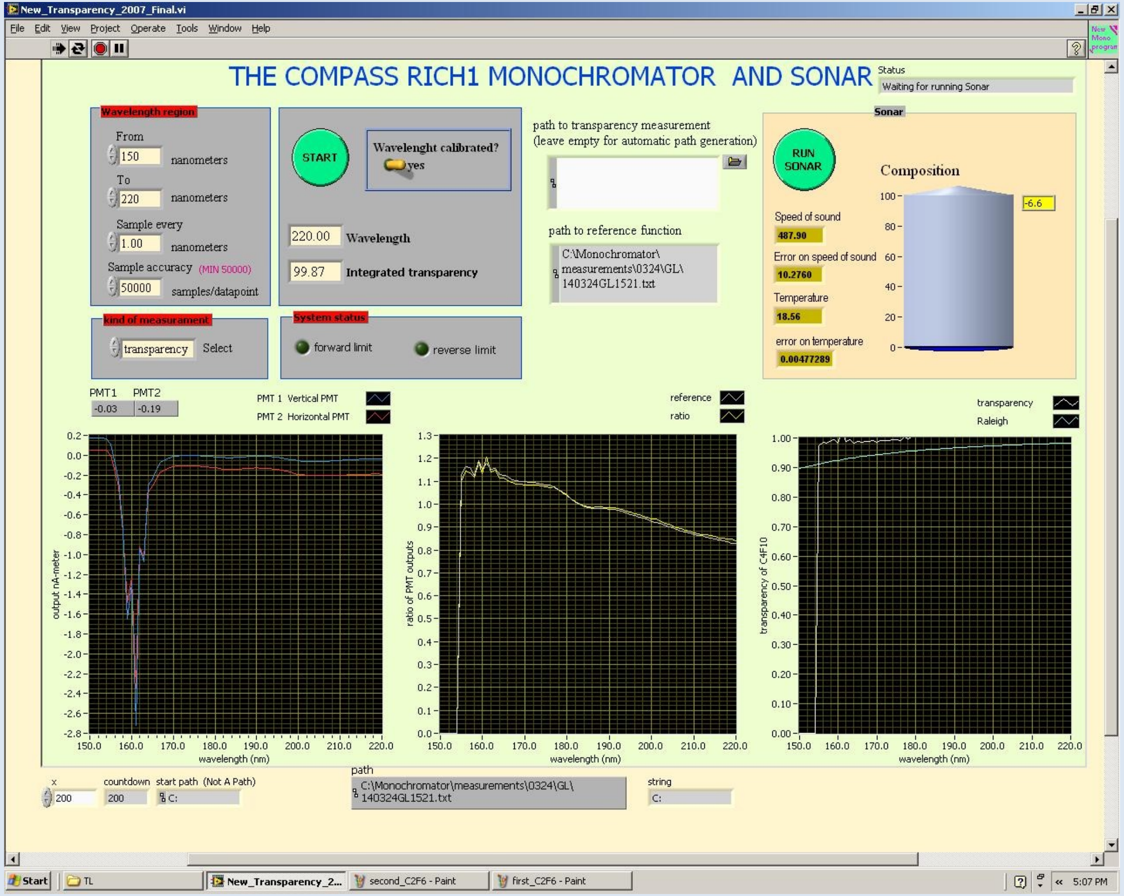
C_2F_6 Radiator

99-100% Transparency measured with instrumentation at CERN



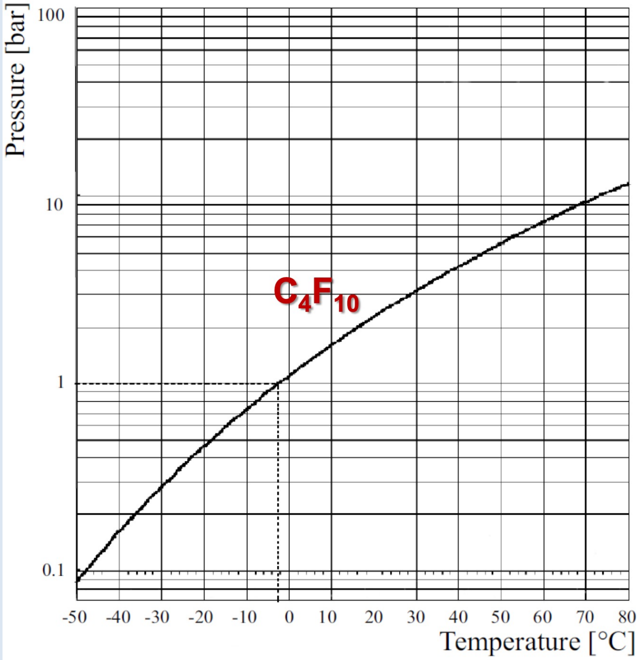
Deuterium UV lamp, Monochromator system, 1.6 m column for gas transparency measurement

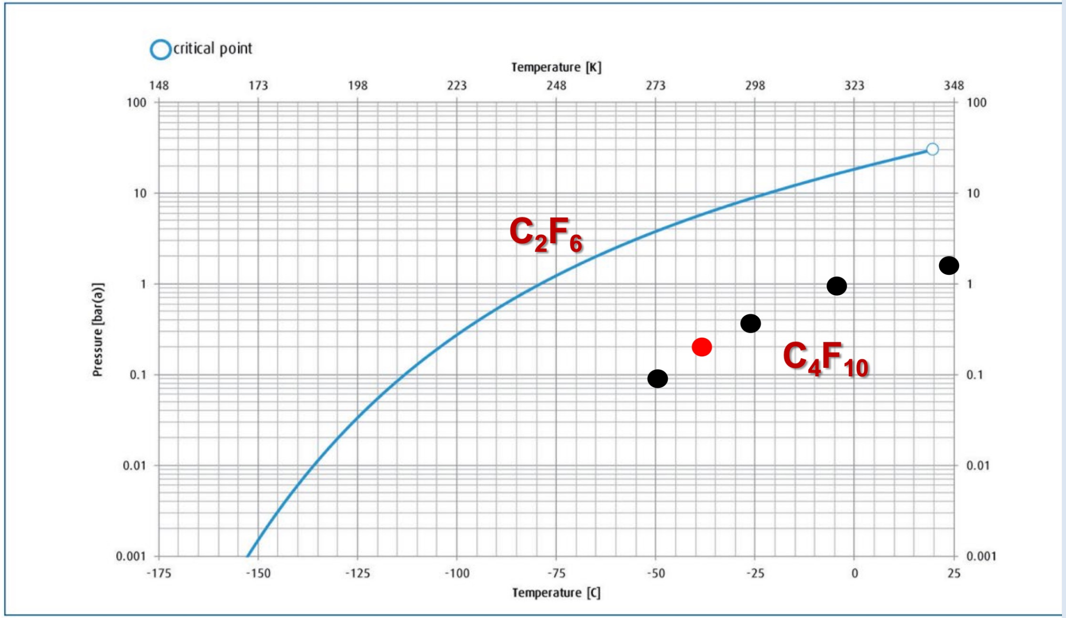




Developing the gas purging concepts from C_4F_{10} experience @ COMPASS

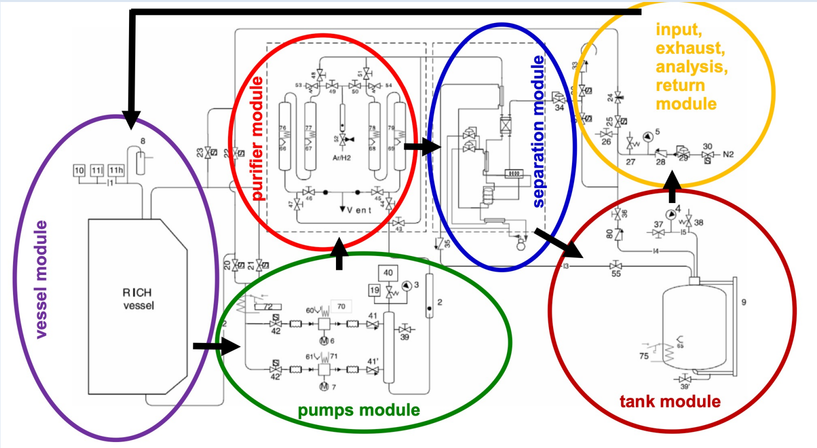
The partial pressures of C_2F_6 and C_4F_{10} are very different

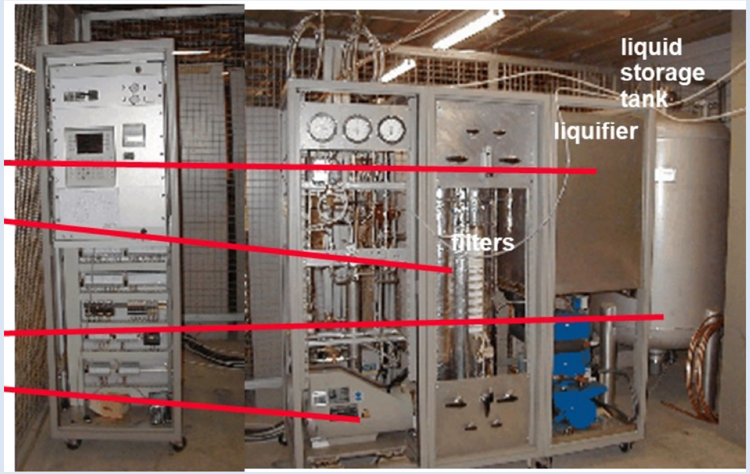




At - 36°C C_4F_{10} has 200 hPa vapor pressure. A separator working at 7 bars will purge 97% N_2 and 3% C_4F_{10}

- **Test-beam data analysis:** *preliminary result available*
- **Characterization:** *Preliminary measurement done*
  being extended to the visible range
- **Purging system**: *basic scheme to define services*
- ***Fast-recirculation system***: *basic scheme to define services*
- ***Long-term tests with composite materials***: *in preparation*



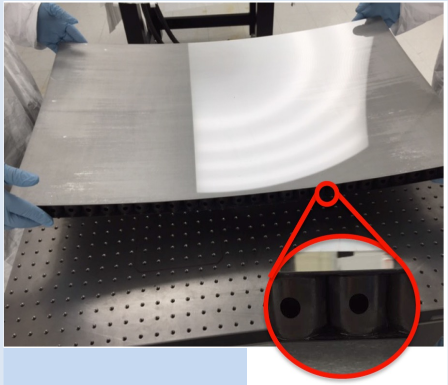


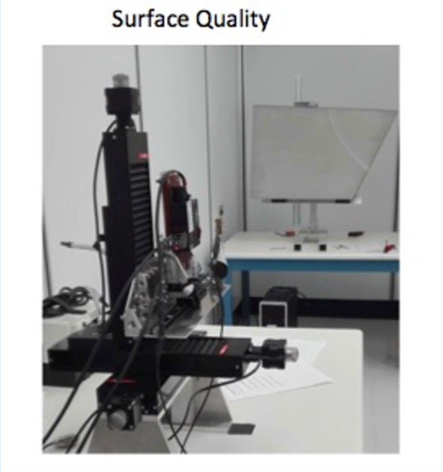
- **Specs:** *derived from CLAS12 / LHCB*
- ***Samples****: ordered*
- **Small demo:** *compatible with present prototype*
  suitable for long-term test with gas

Delivered at JLab

eRD102

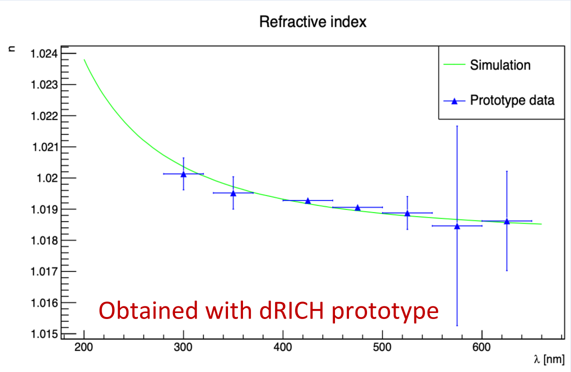
- **Medium-size proto**: *core structure optimized*
- ***Characterization (JLab, DUKE)***
- ***Alignment/Support****: aka NA62, piezo-motor acquired*



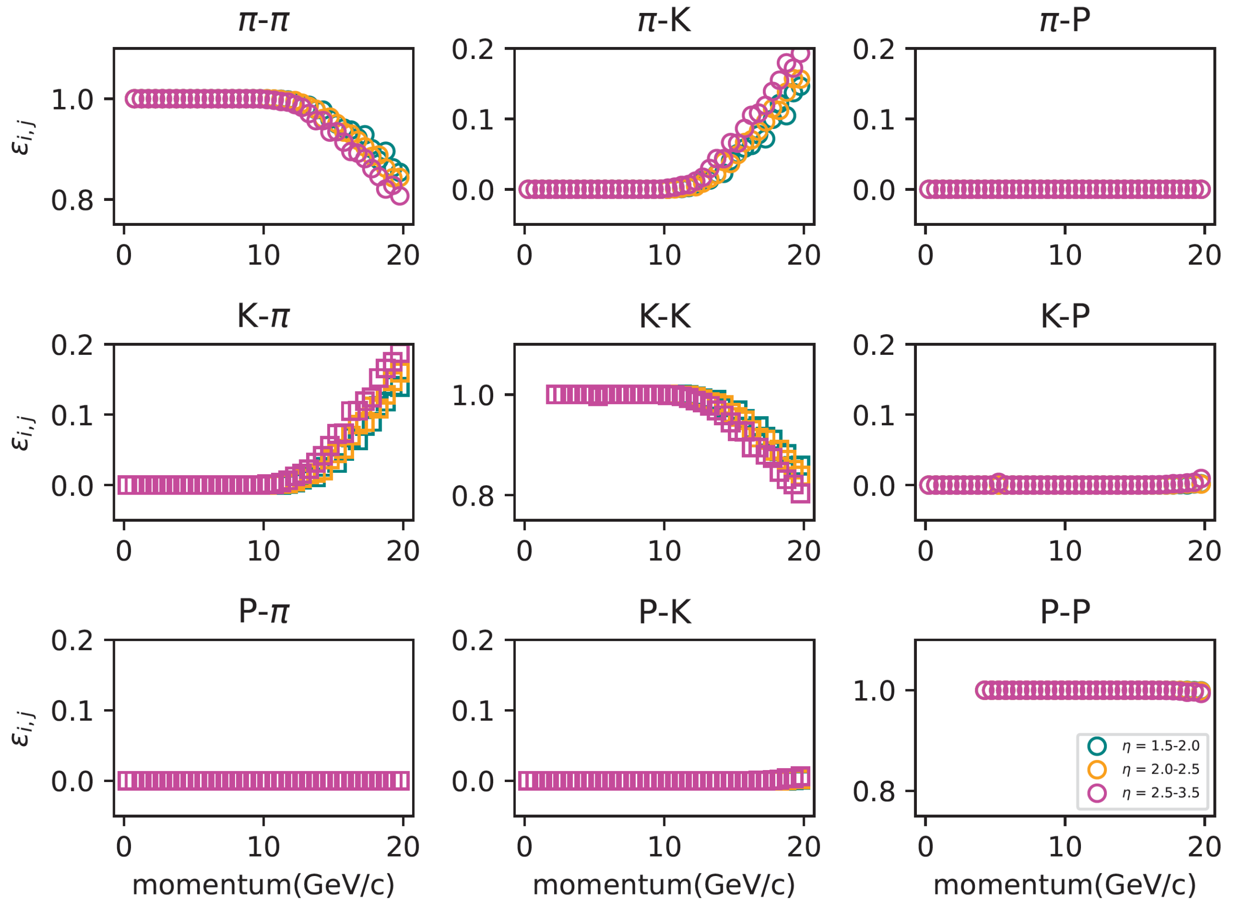


dRICH simulation is already performed within ePIC framework

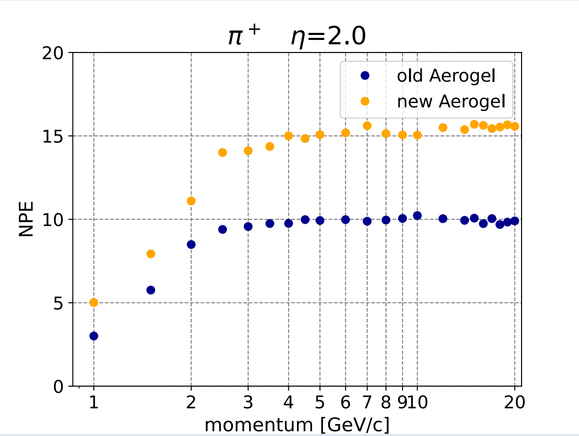
Implements measured features

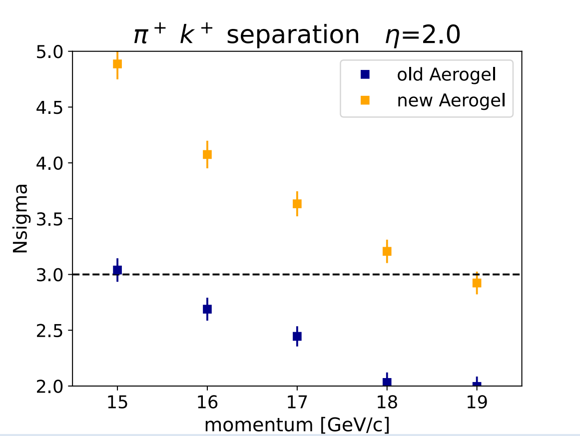


LUTs being generated for PID simulation and physics analysis

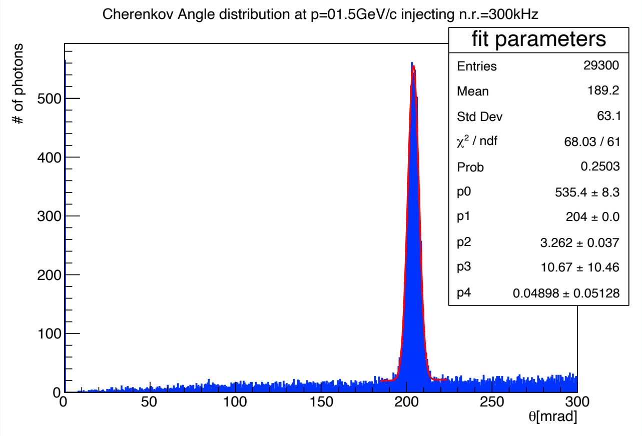


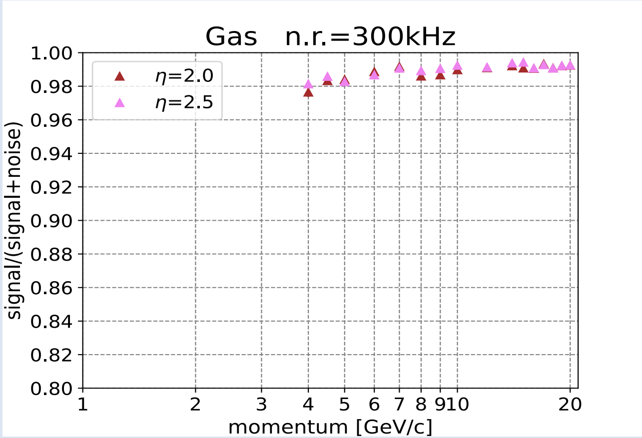
Optimization study ongoing for aerogel refractive index

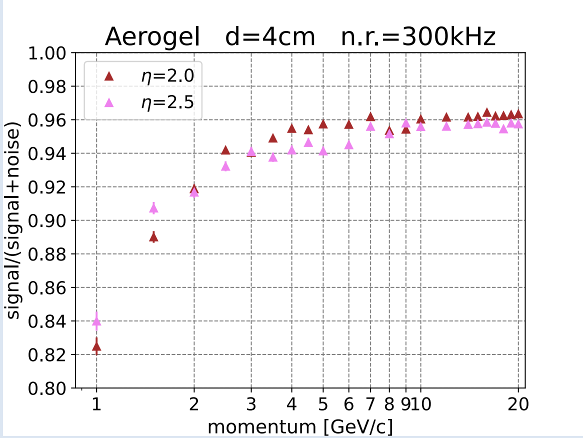




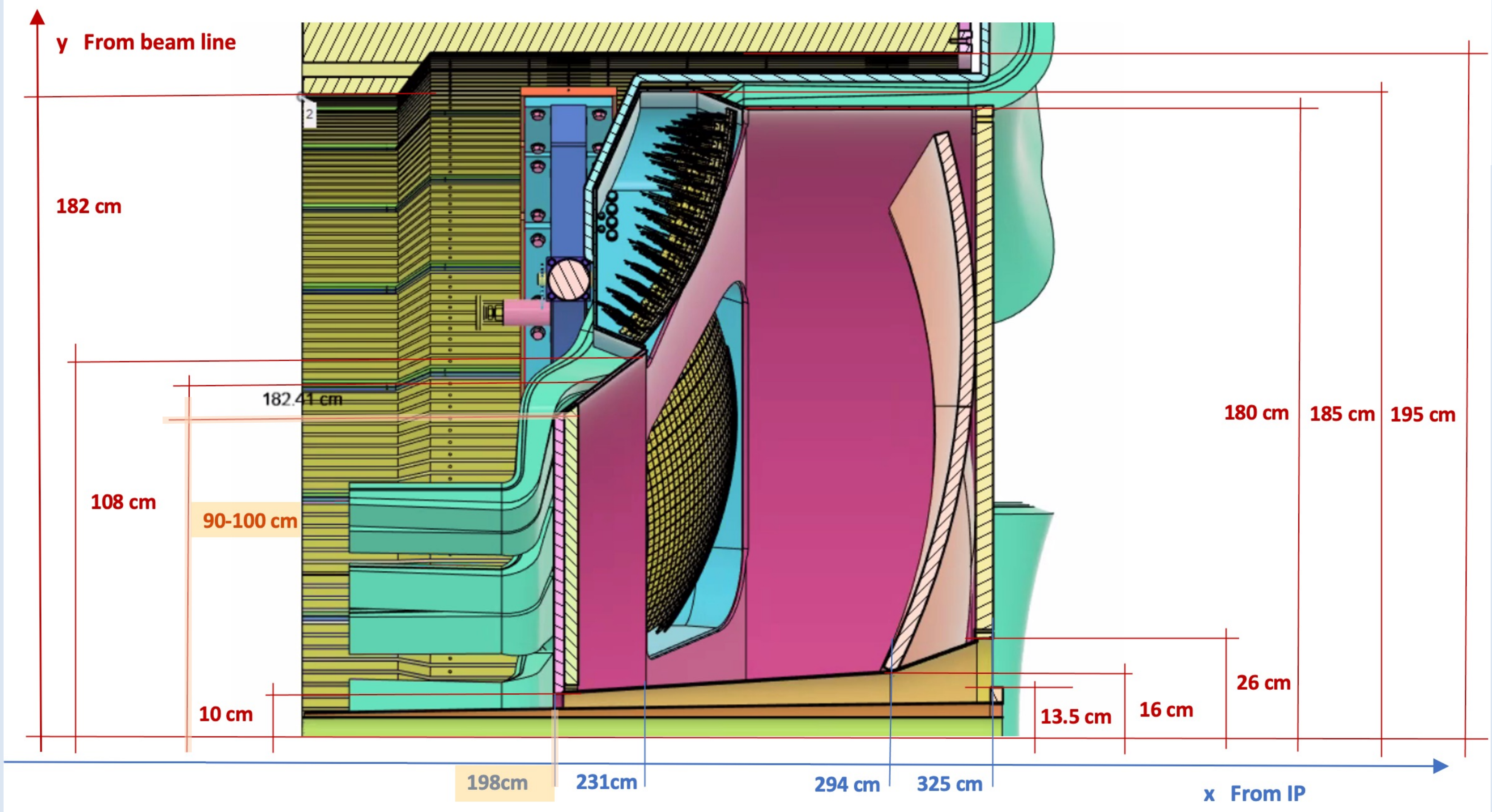
Study of “worse case” DCR background impact on resolution





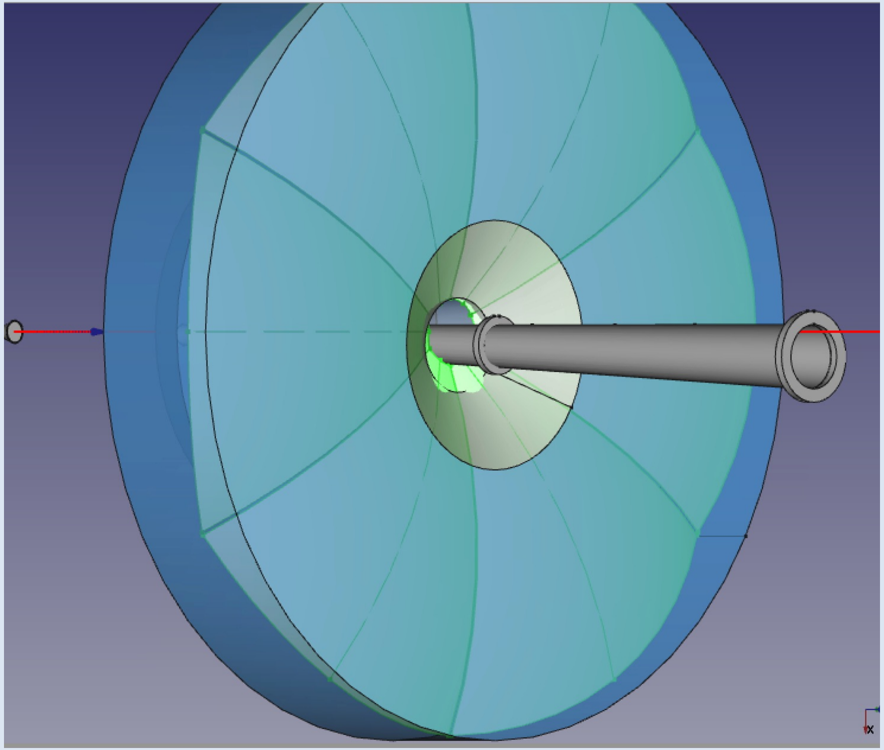


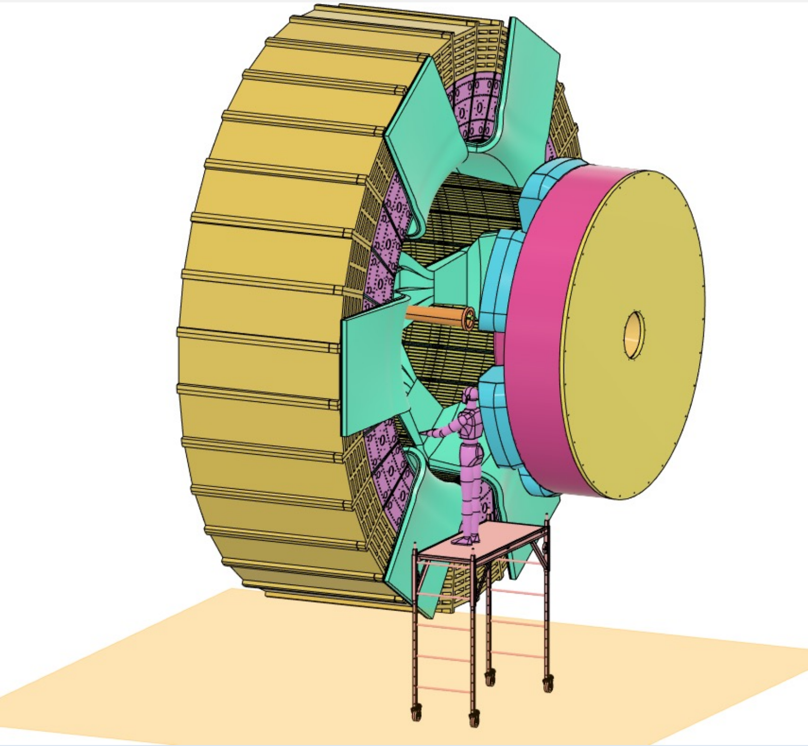
News: +3 cm downstream shift with respect the IP, O(10 cm) tolerance in aerogel disk radius



dRICH Bore

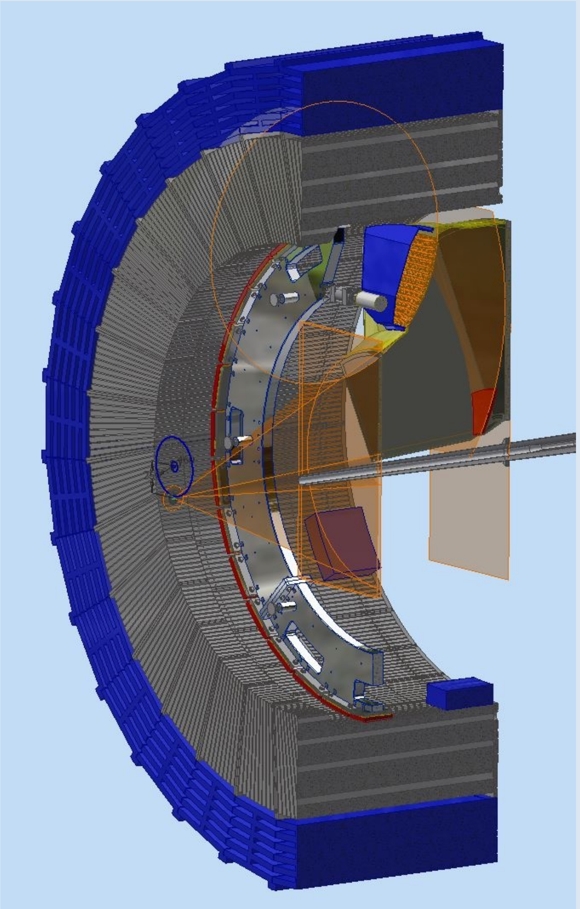
The hadron beam angle forces an expanding pipe and a off-axis dRICH bore
dRICH bore should be big enough to provide clearance for the beam pipe during maintenance operations
Working with the Project to find the best compromise





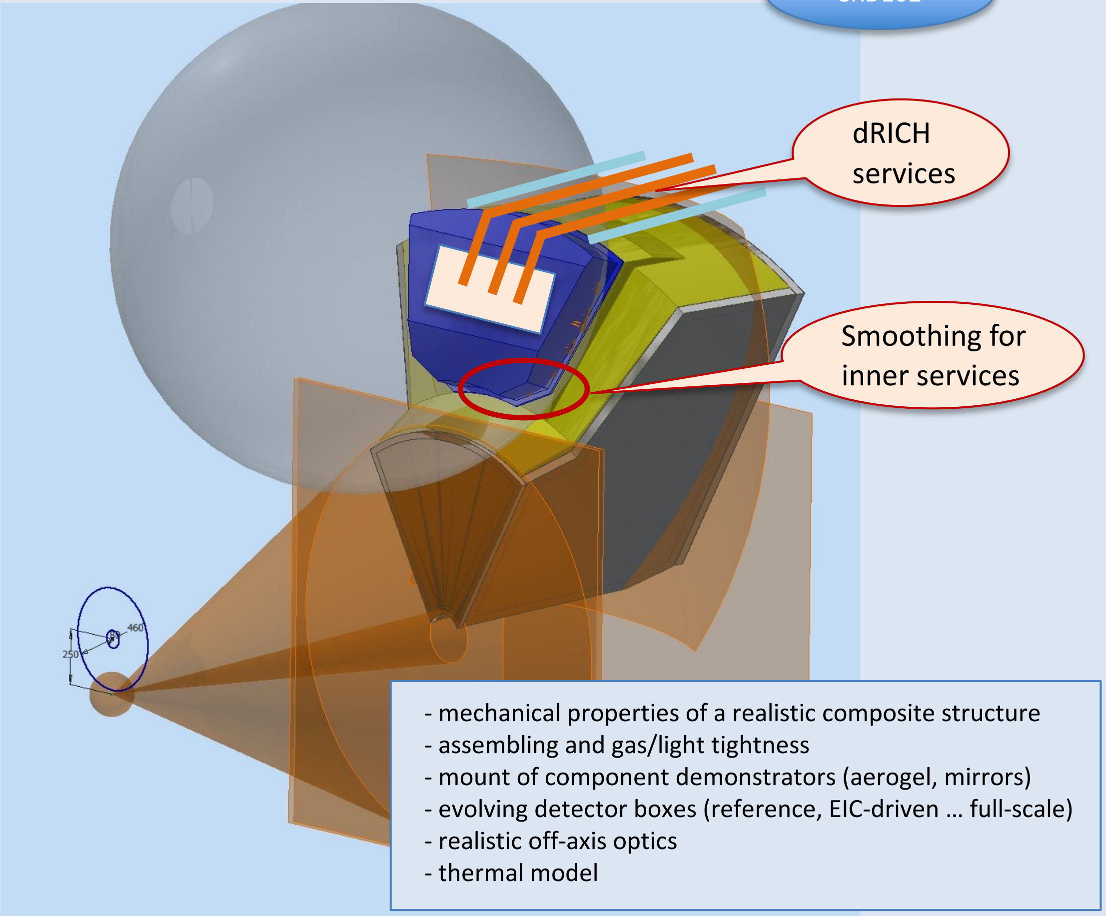
dRICH Basic Module

Scalable to the wanted shape



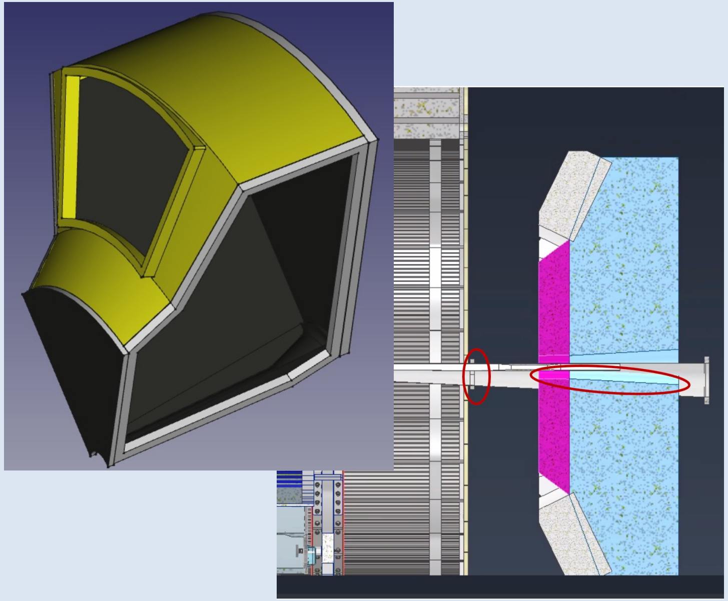
Baseline for the real-scale prototype

eRD102



- mechanical properties of a realistic composite structure
- assembling and gas/light tightness
- mount of component demonstrators (aerogel, mirrors)
- evolving detector boxes (reference, EIC-driven … full-scale)
- realistic off-axis optics
- thermal model

- **General layout** *outlined*
- **dRICH Shell**: *integration & maintenance under discussion*
- **Real-scale prototype**: *being refind (production already negotiated)*
- ***Thermal tests***: *inititated with existing prototype/detector box*
- ***Services***: *gas and cooling lines*
- ***Detector box prototype:*** *may be needed for a good modeling*



DAC Review August 28-31, 2023

4) We recommend that a detailed design of the gas box and circulation system be given high priority.
5) To address concerns with multiple track PID, we recommend the implementation in the simulation of the expected backgrounds from the accelerator and study performance in the presence of overlapping tracks.
6) We recommend the development of a detailed design of the mechanical support of the photon detectors, as the arrangement seems complex.
7) We support the development and testing of the full-scale prototype.
8) The parameters of the annealing of the SiPMs should be studied to ensure they don't affect neighbouring systems.

Milestones

2024:

Preliminary definition of the technical specifications of all the dRICH components (April ’24);

Complete mechanical design of the dRICH structure (June ’24);

Integration of the readout and optical component developments in a real-scale prototype (October ’24)

2025:

Real scale prototype completion & performance assessment

Aeorgel mass production specifications

SiPM thermal treatment protocols & on-board implementation

} Anticipated at the PID review