Status and Plans for dRICH Development and Integration

ePIC General Meeting, 5th April 2024

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

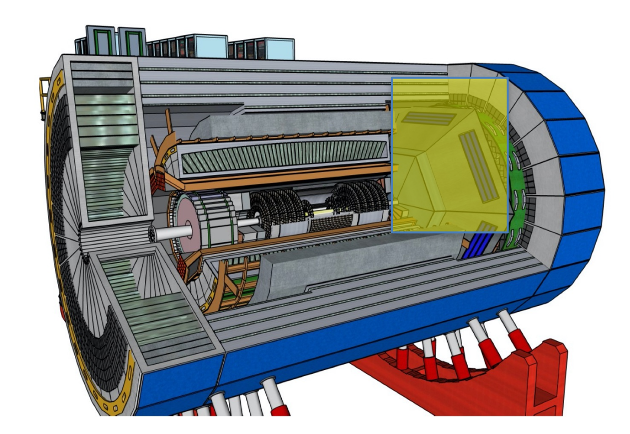
Jefferson Lab

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

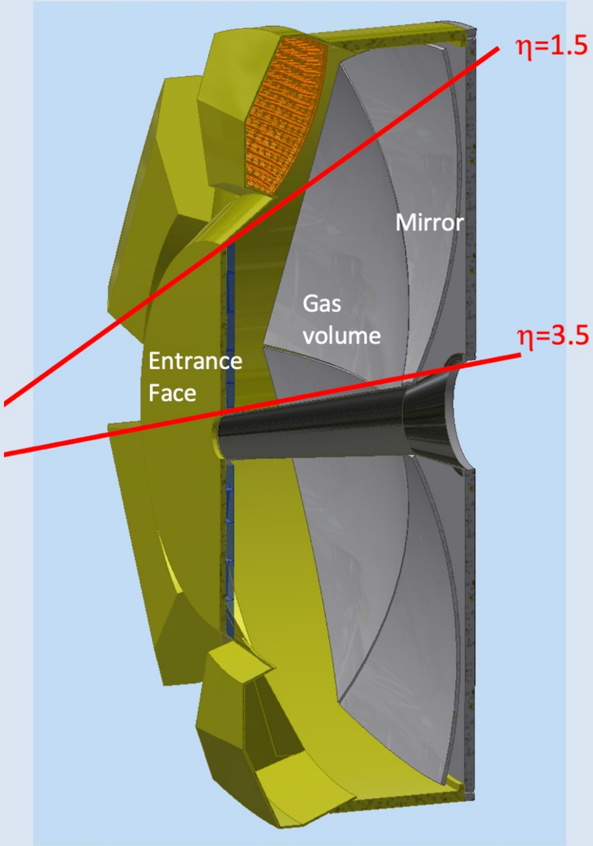
Main challenges:

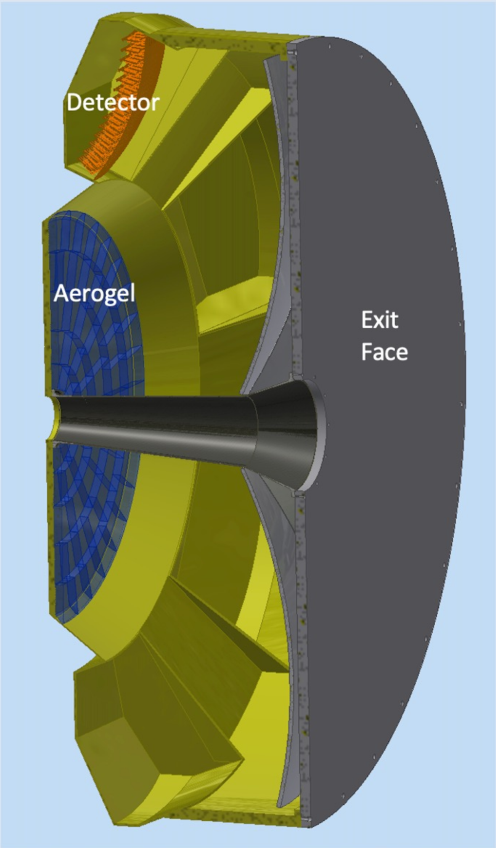
Cover wide momentum range 3 - 60 GeV/c -> dual radiator

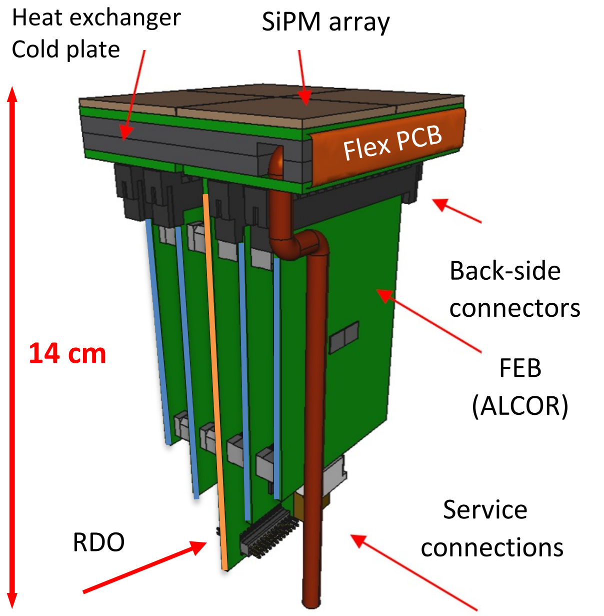
Work in high (~ 1T) magnetic field -> SiPM

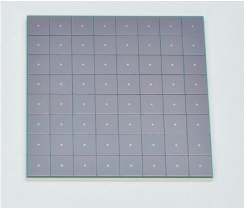
Fit in a quite limited (for a gas RICH) space -> curved detector

ePIC dRICH

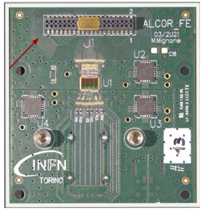








SiPM array



ALCOR chip

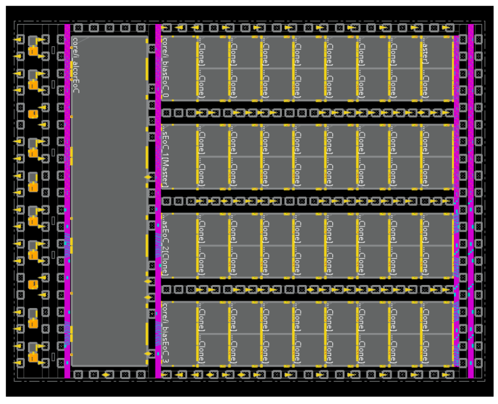
ALCOR Front-End Chip

ALCOR features

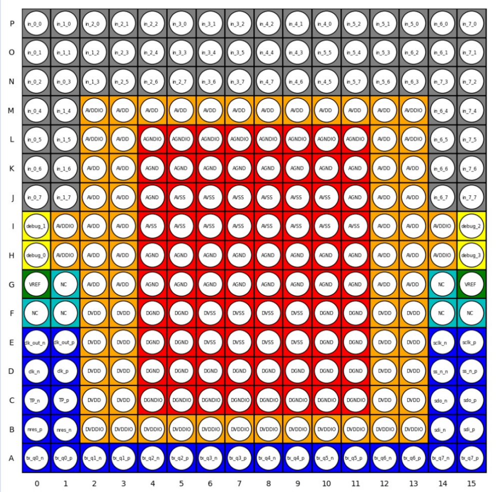
ToT architecture, streaming mode ready

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

- **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*



8x8 pixel matrix



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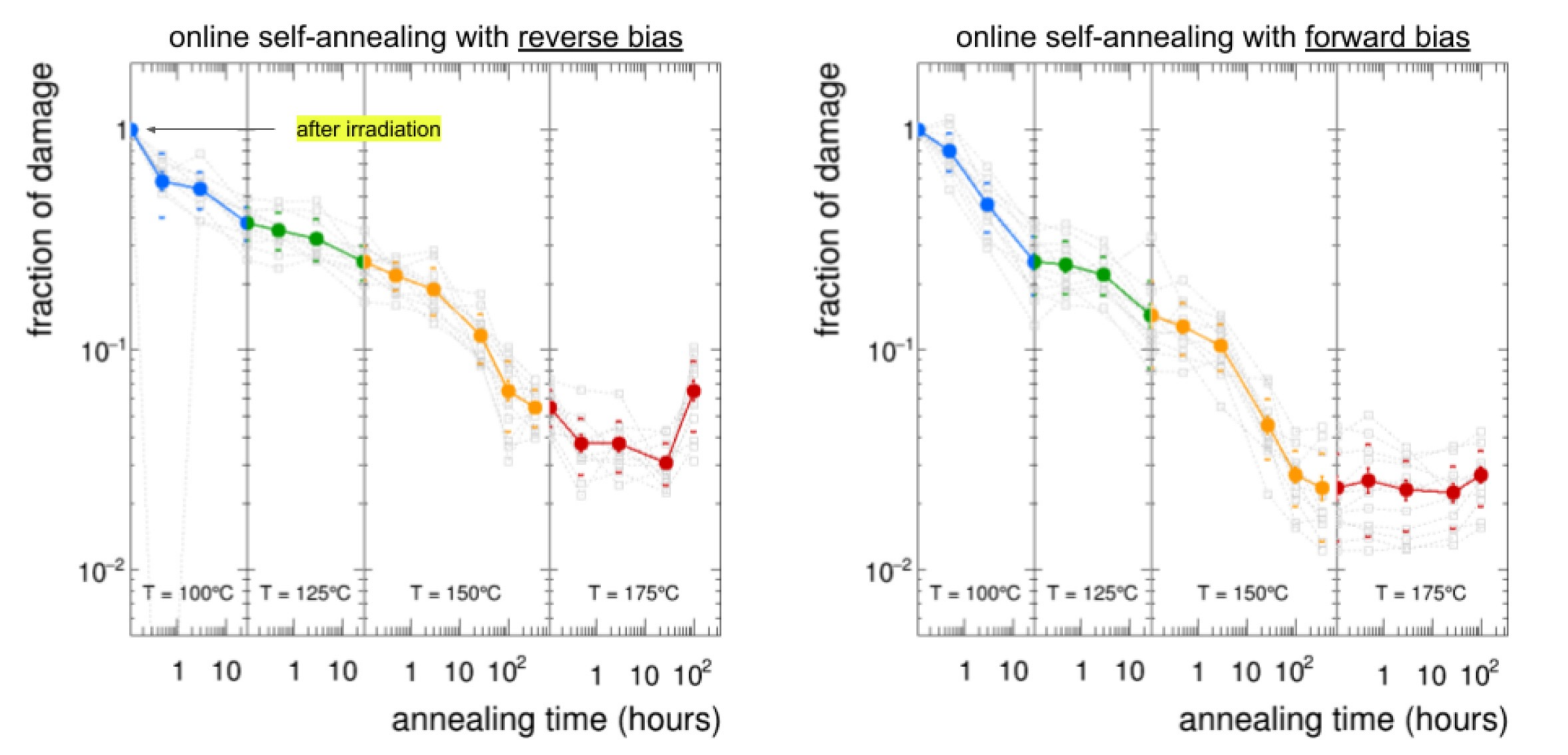
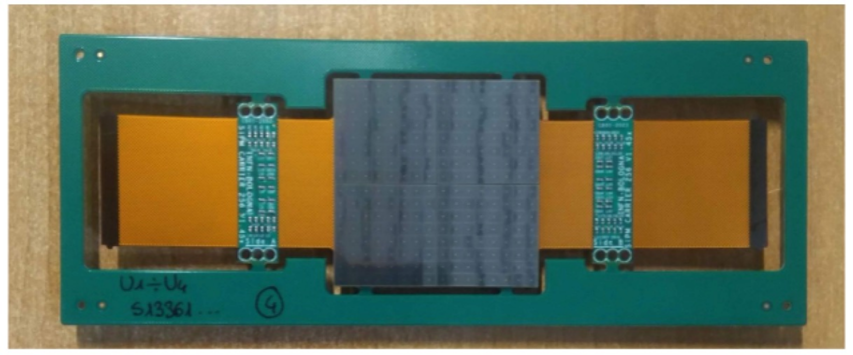
Study of the protocol for on-board annealing in conjunction with sensor irradiation cycles and consequence for the electronics layout (current sustainability & MOSFET protection)

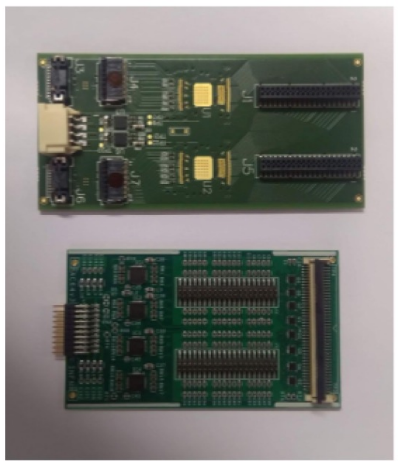


Photon Detector Unit (PDU)

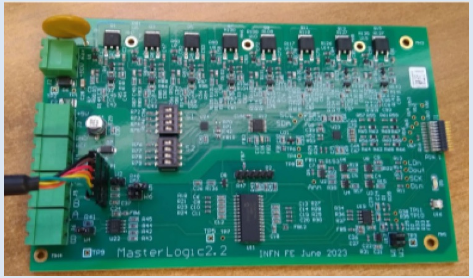
SiPM **carrier board** with 256 channels and flex connector circuits.

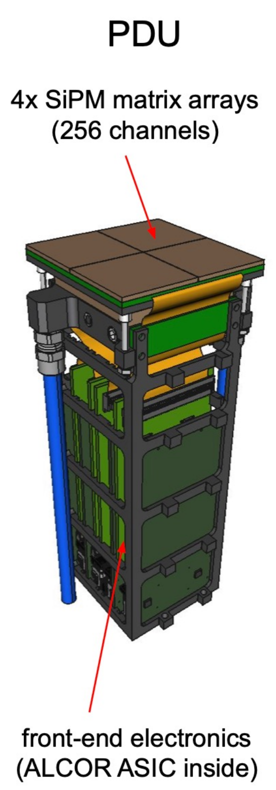


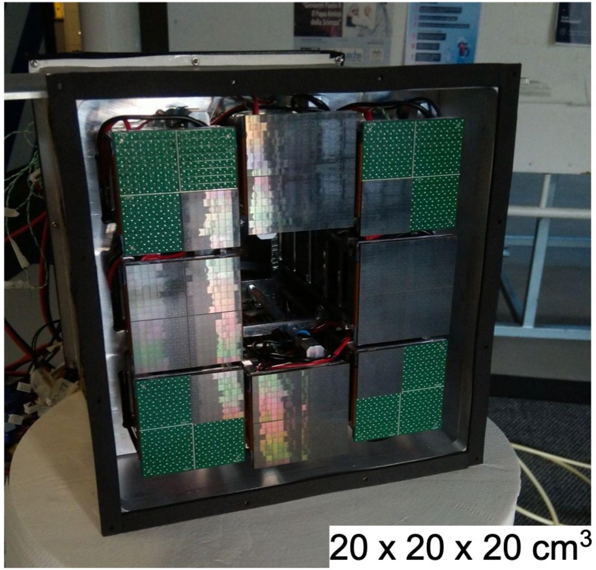
2x **ALCOR front-end card** and the **adapter board**



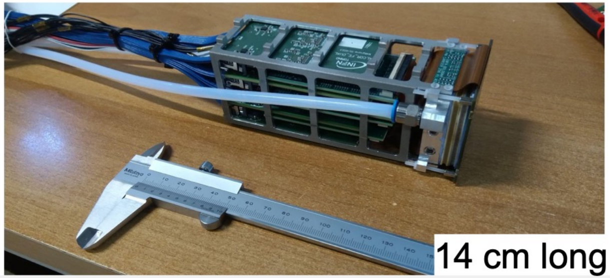
MasterLogic card to control SiPM bias voltage & monitoring service







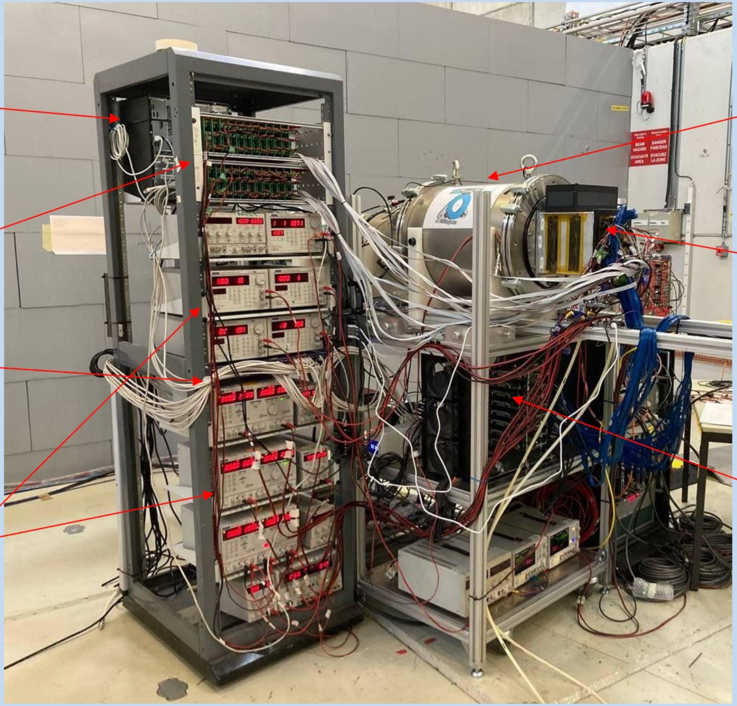
20 x 20 x 20 cm^3



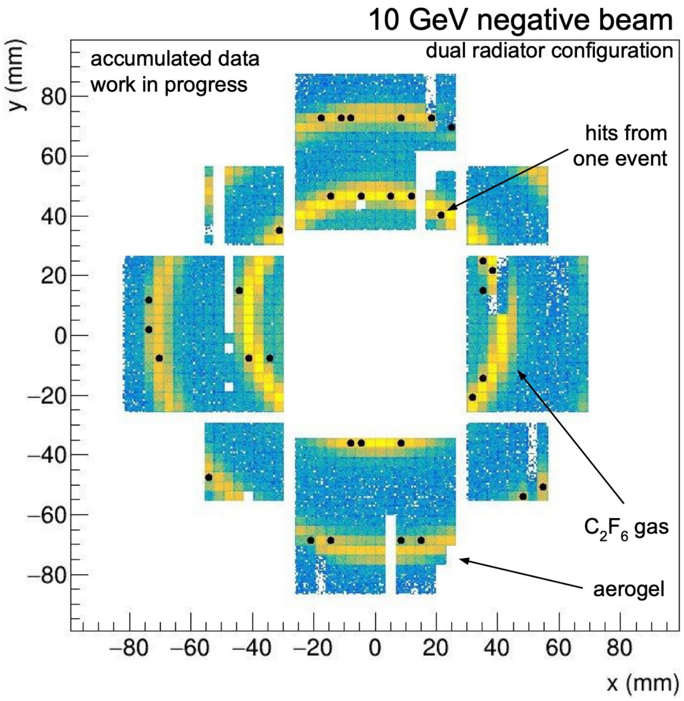
14 cm long

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

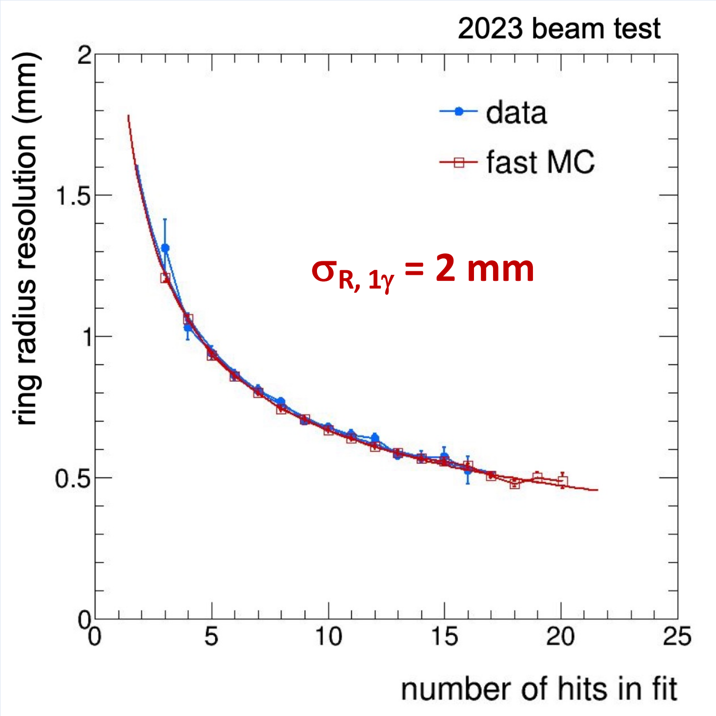
Beam test at CERN PS-T10 beam line: October 2023

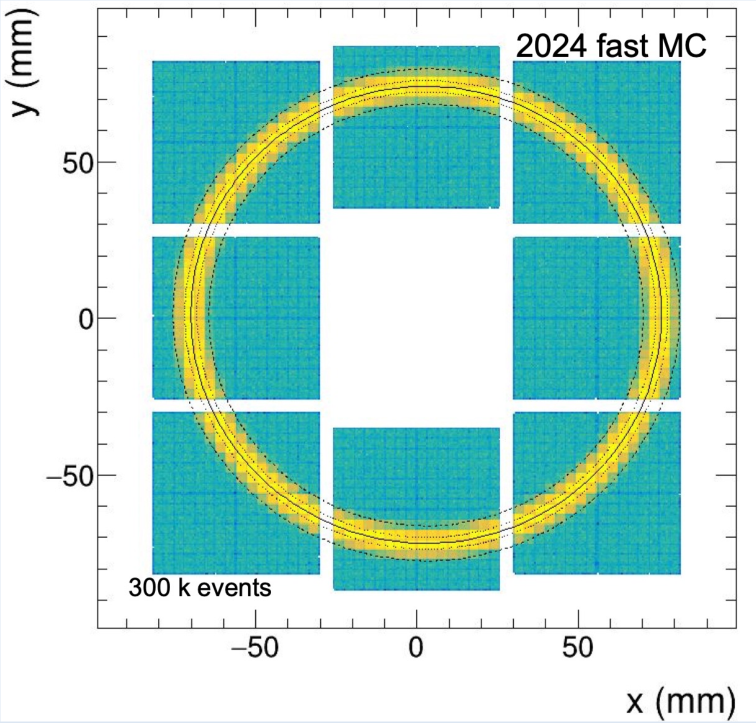


<N> = 9 p.e. per aerogel ring



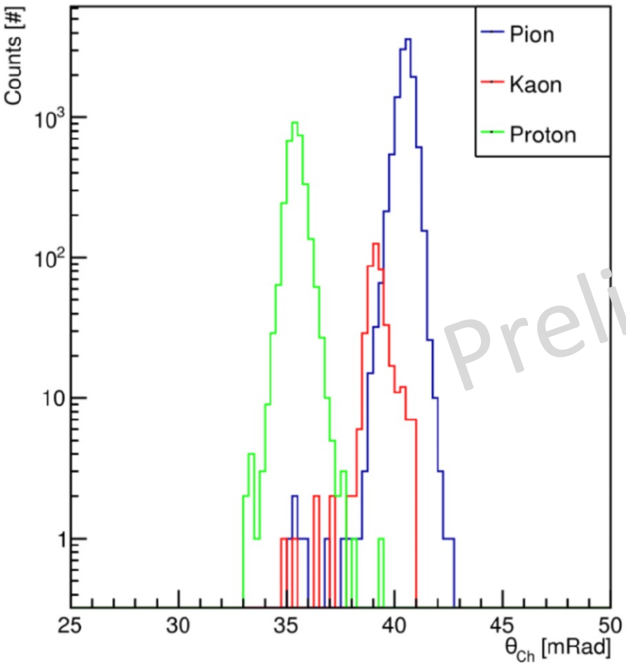
2024 Test-beam: May 22th – June 5th at PS T10 beam line of CERN
Goal: detailed study of the performance (timing, background, photon yield, resolution, particle ID)



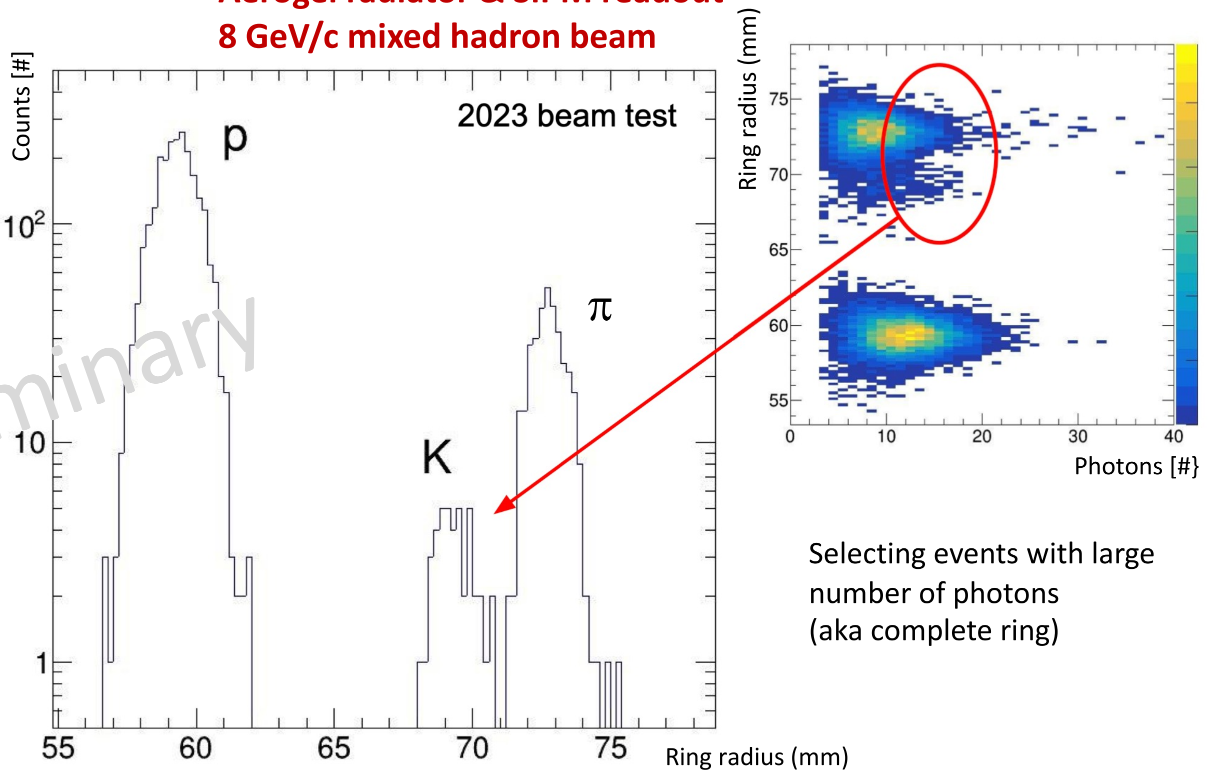


Particle identification tests with beam gas Cherenkov tagging

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

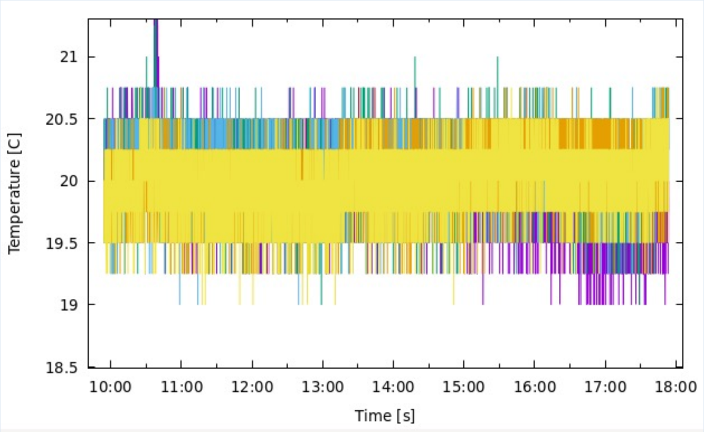


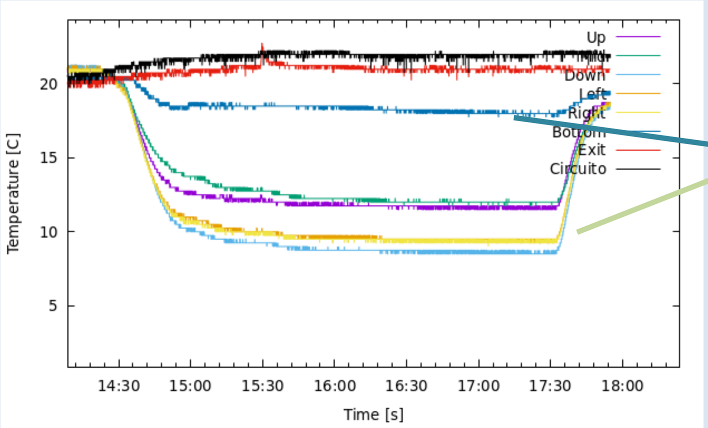
Aerogel radiator & SiPM readout
8 GeV/c mixed hadron beam



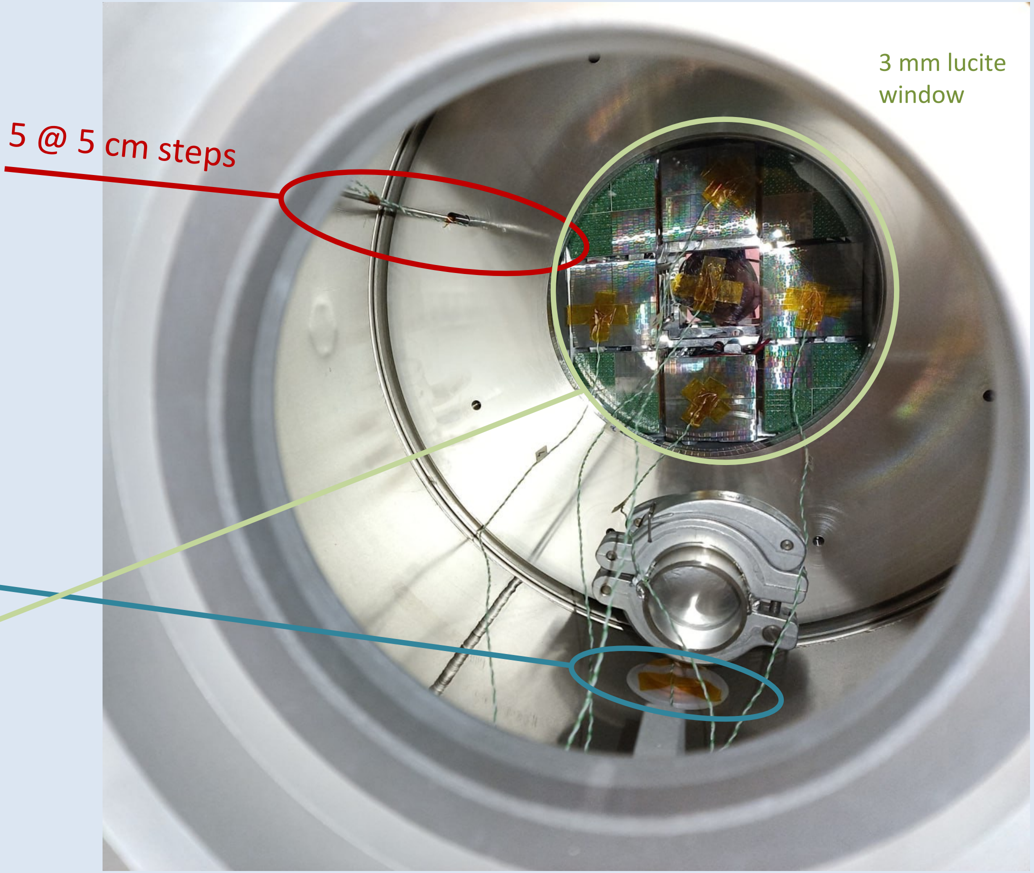
Selecting events with large number of photons (aka complete ring)

Temperature profile with SiPM at -30º



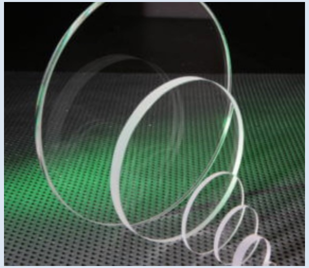


Gas volume with termocoupes



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*
- ***Quartz window**: to be tested*



Quartz windows have been procured
(various type, dimension, thickness)

PID Review July 5-6, 2023

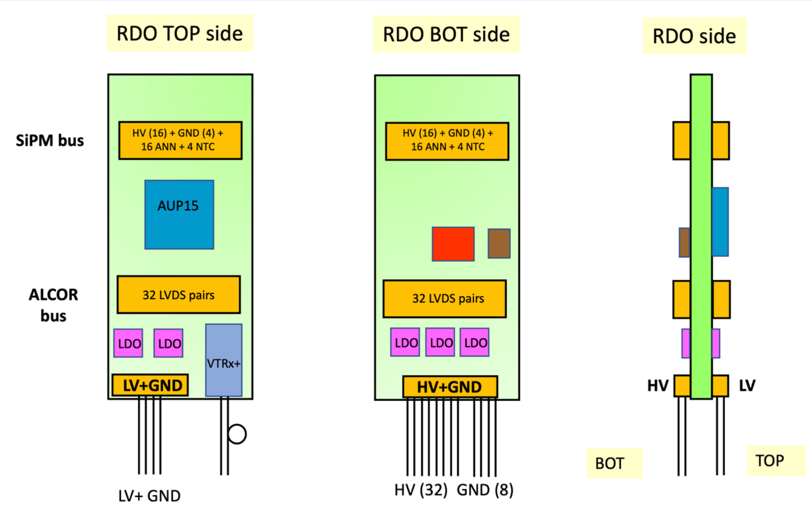
- To reduce dark current, heavy annealing is planned. It is required to check that the charge collection efficiency is not reduced due to over-annealing. The reviewers understand that this is part of the ongoing R&D campaign and that encouraging first results have been obtained.
- We advise exploring 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.

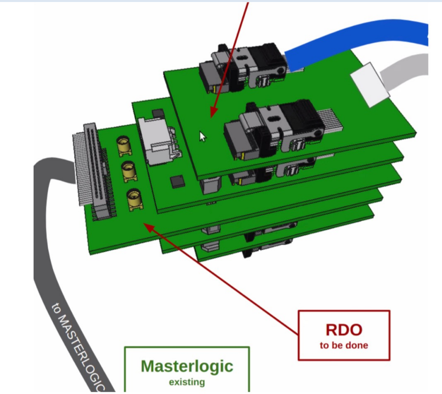
- The quartz window to separate the photodetector box from the gas radiator was identified as a point of attention. A thermal simulation is required with the SiPM array at the foreseen operating temperature of -30 C and the approach to avoid condensation or convection of the C2F6 gas radiator should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

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 (contribution from the Project)*
- ***L2-filter****: ML patter recognition study (contribution from other INFN projects)*

Target: RDO demo before the end of the year





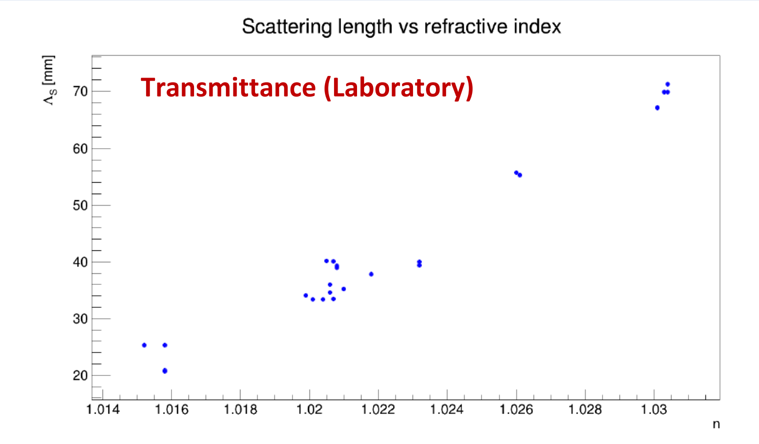
Integration of new RDO with existing PDU

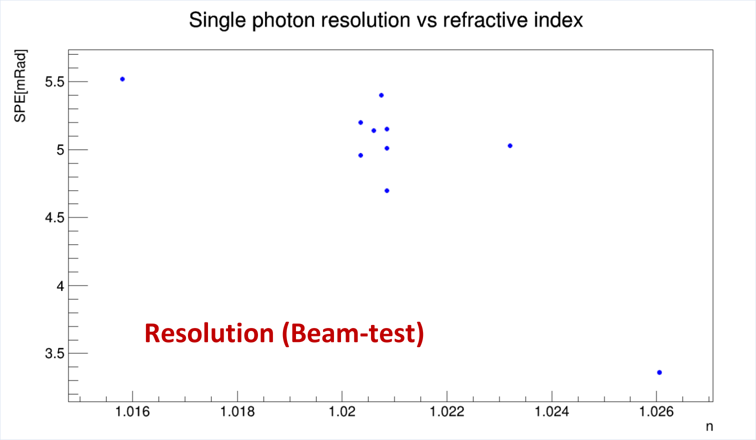
- **Test-beam data analysis:** *preliminary result available*
- **Characterization:** *preliminary study done*
  transmittance, forward scattering, planarity, chromaticity
- **Reproducibility**: *under study*
  new n=1.020 samples close to delivery
  new n=1.026 sample being ordered
- ***Optimization****: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

Test-station under development @ Temple University

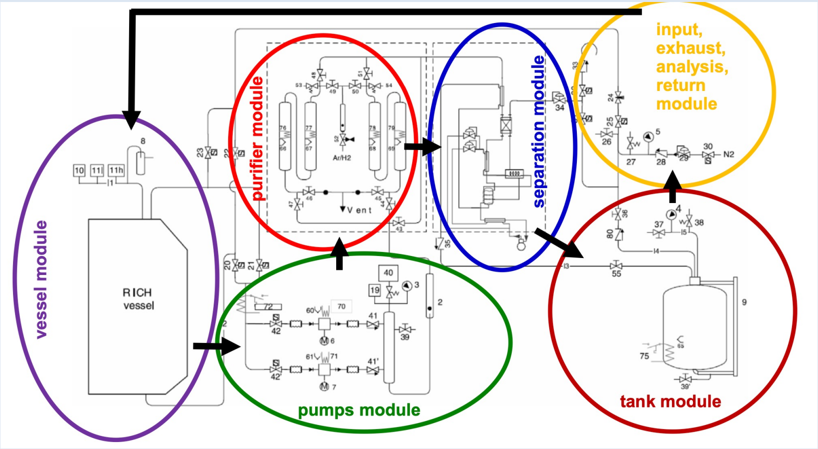
DAC Review August 28-31, 2023

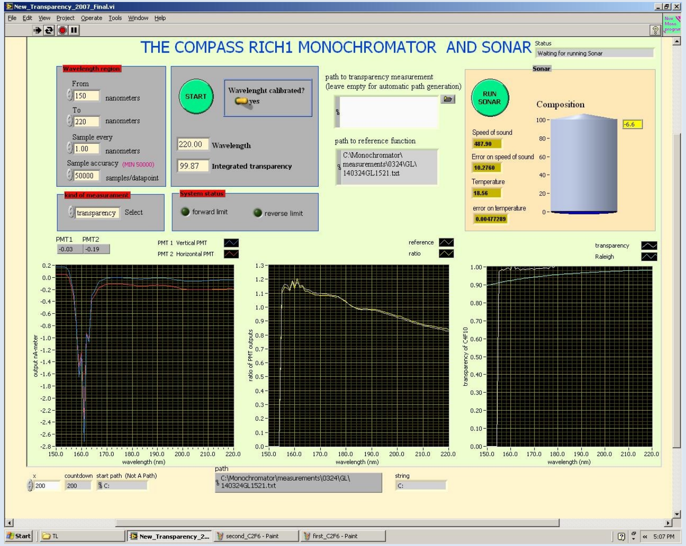
3) It is important to understand the aerogel quality issues and give feedback to this manufacturer in order to allow time for the production of aerogel which meets the requirements of the detector.





- **Test-beam data analysis:** *preliminary result available*
- **Characterization:** *Preliminary measurement done*
  being extended to the visible range
- **Purging & fast-recirculation systems**:
  basic scheme to define services
  comparison with well known C_4F_{10}
- ***Long-term tests with composite materials***: *in preparation*

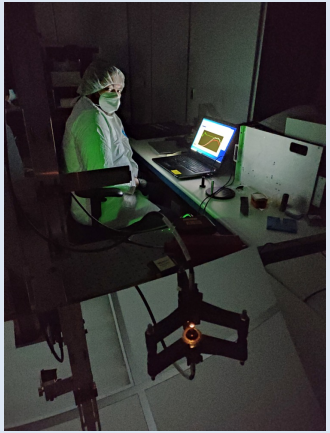


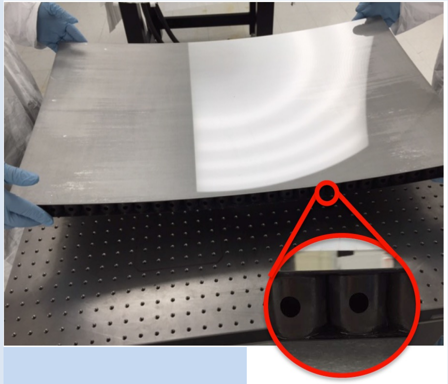


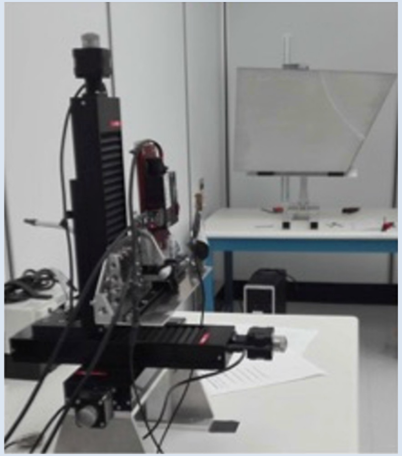
dRICH Mirrors

- **Specs:** *derived from CLAS12 / LHCB*
- ***Samples***: *ordered*
- **Small demo:** *compatible with present prototype suitable for long-term test with gas*
- **Medium-size proto**: *core structure optimized*
- ***Characterization (JLab, DUKE)***
- ***Alignment/Support***: *aka NA62, piezo-motor acquired*

Delivered at JLab (applies to Samples and Small demo)



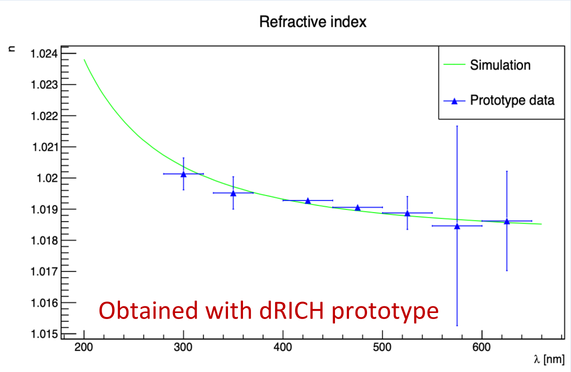




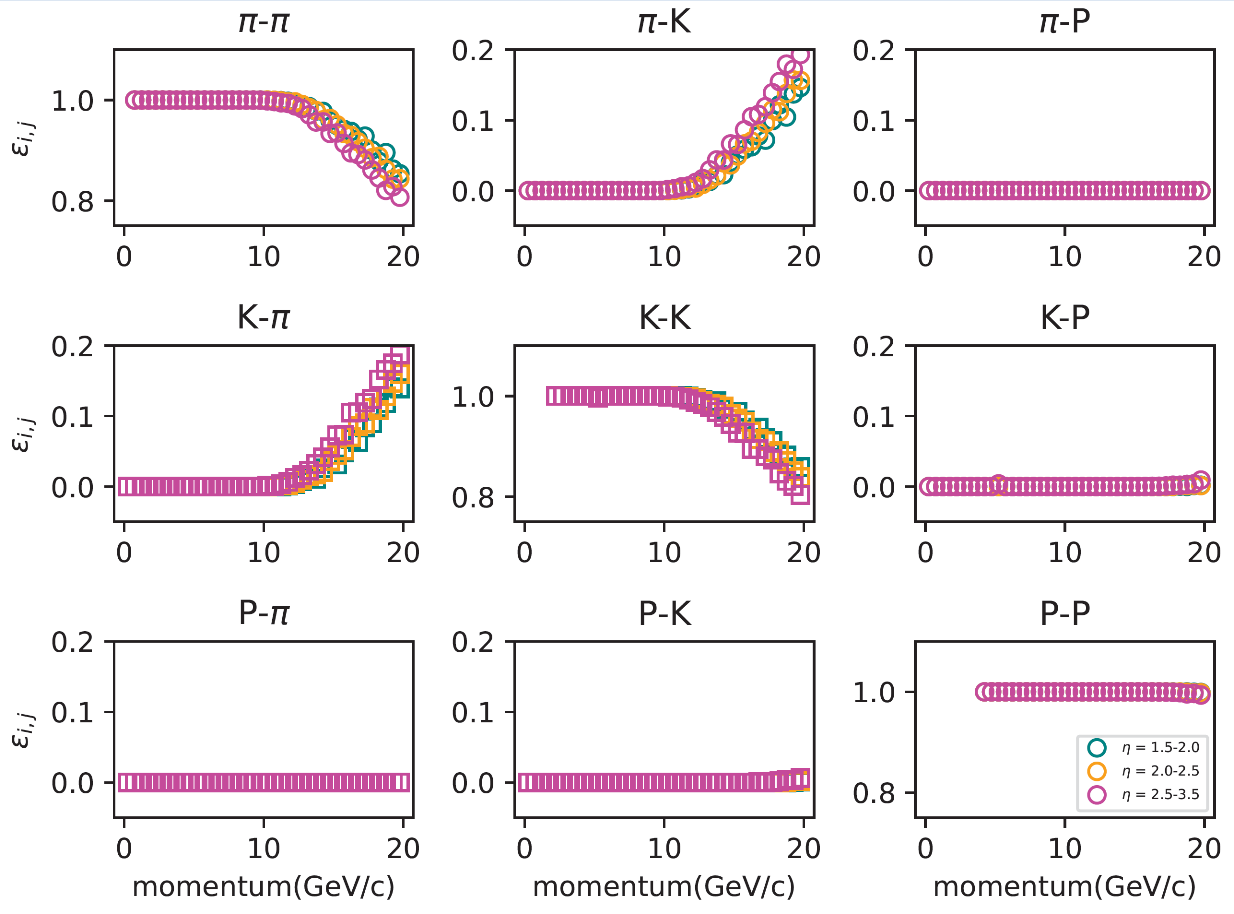
dRICH Simulations

dRICH simulation is already performed within ePIC framework

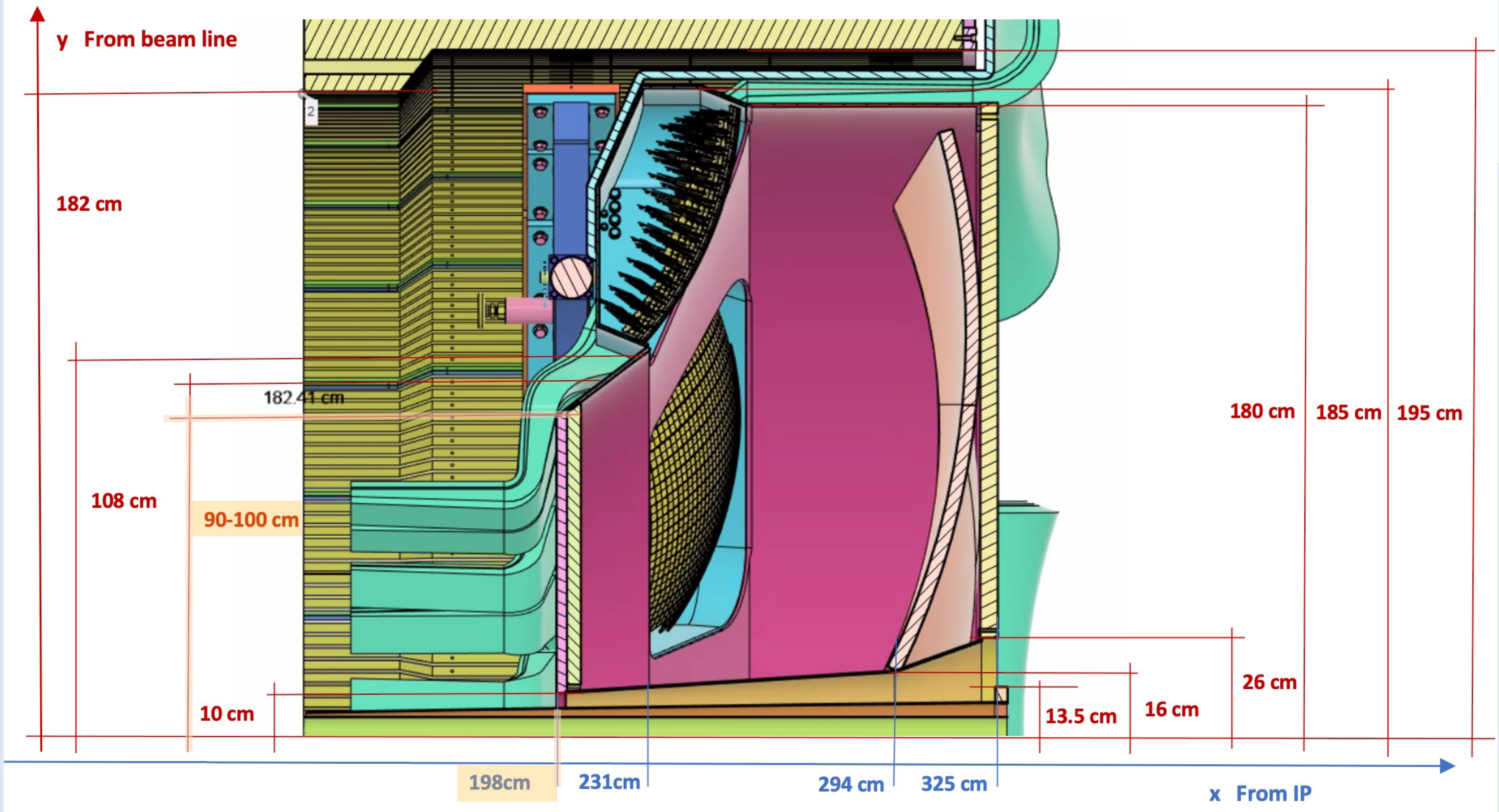
Implements measured features



LUTs being generated for PID simulation and physics analysis

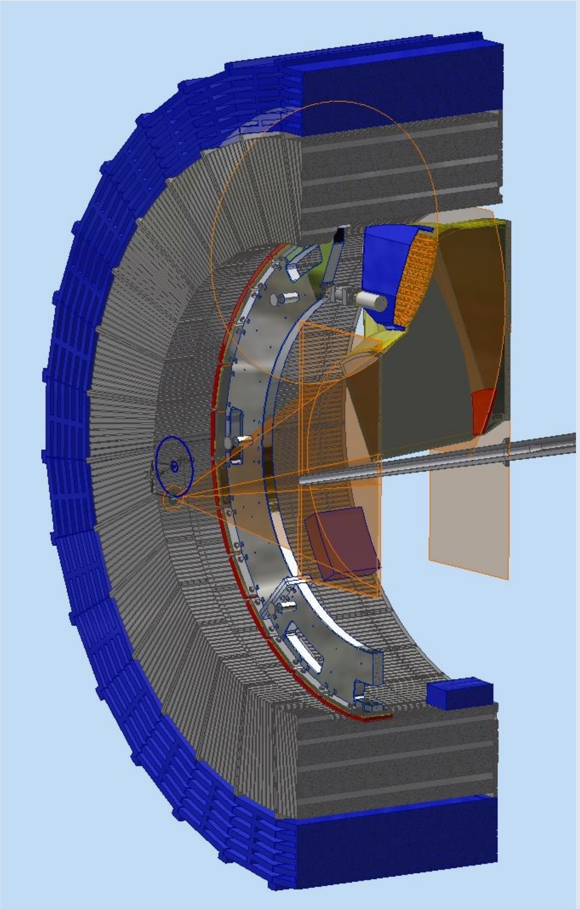


News: +3 cm downstream shift with respect the IP, O(10 cm) tolerance in aerogel disk radius

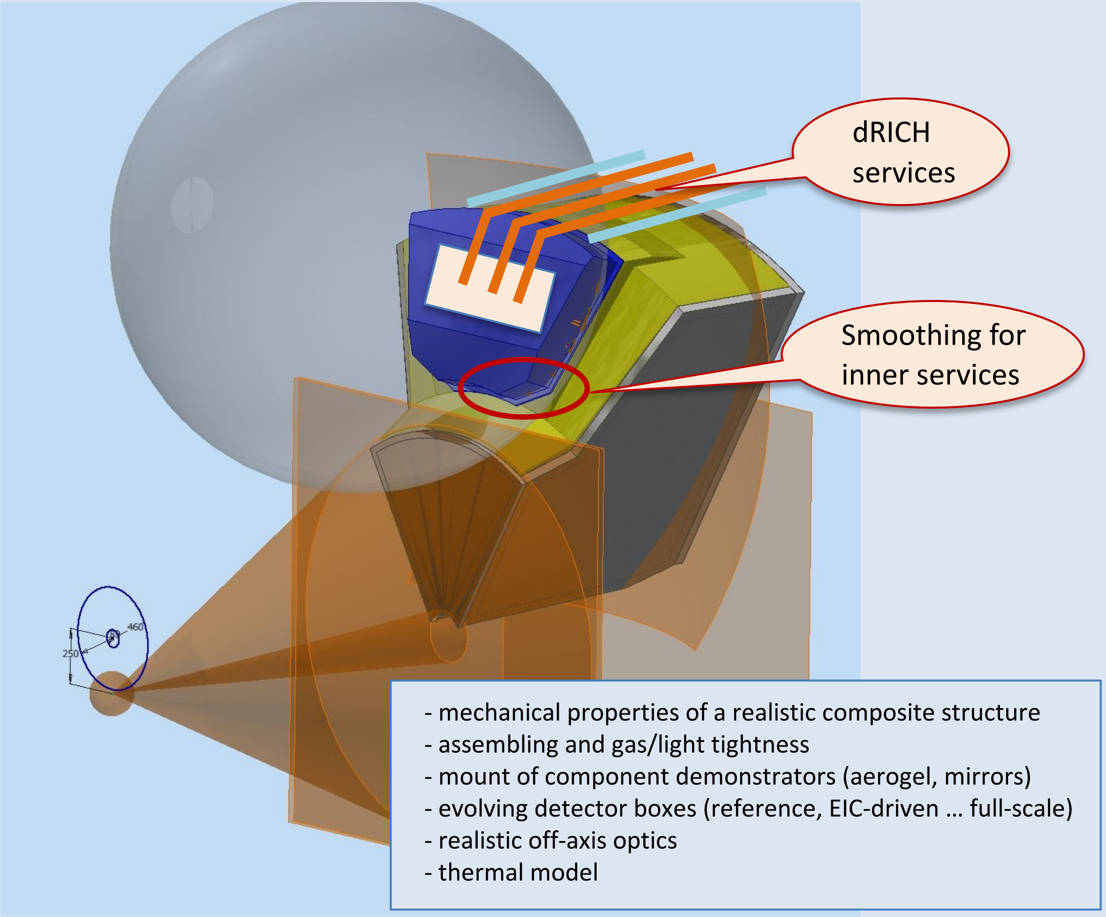


dRICH Basic Module

Scalable to the wanted shape



Baseline for the real-scale prototype



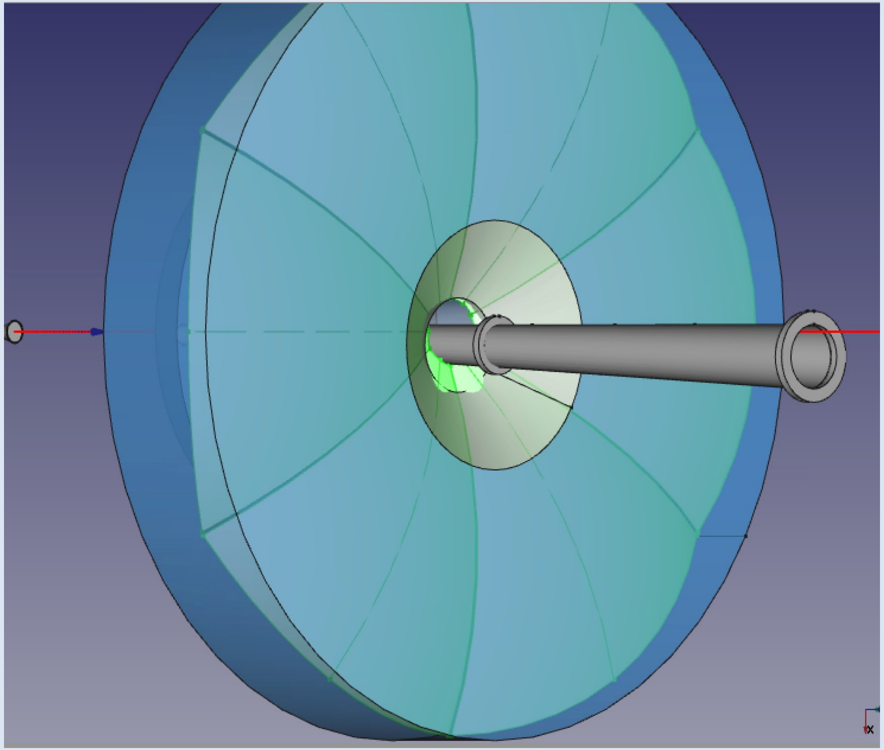
- mechanical properties of a realistic composite structure
- assembling and gas/light tightness
- mount of component demonstrators (aerogel, mirrors)
- evolving detector boxes (reference, EIC-driven … full-scale)
- realistic off-axis optics
- thermal model

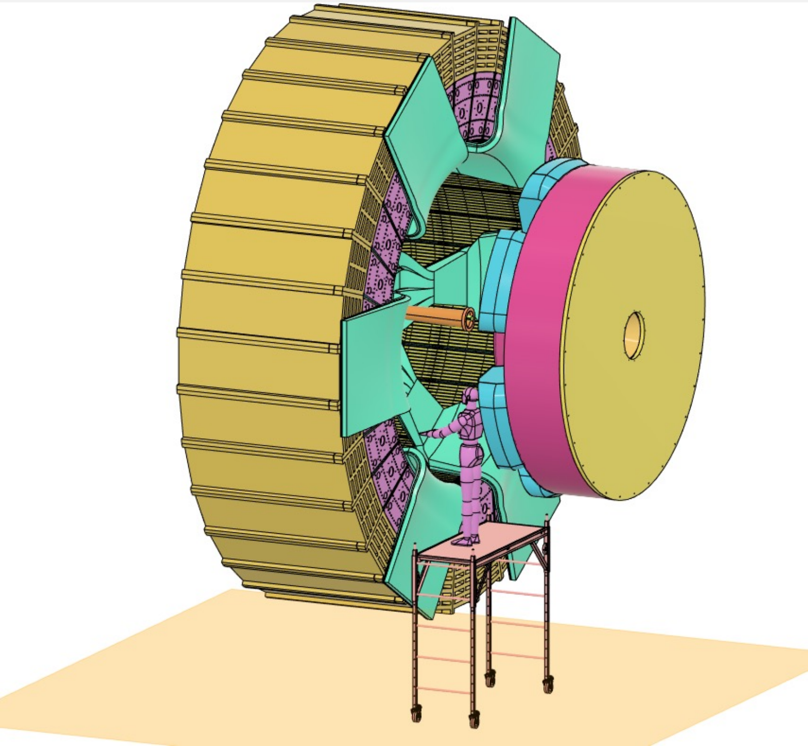
dRICH Bore

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



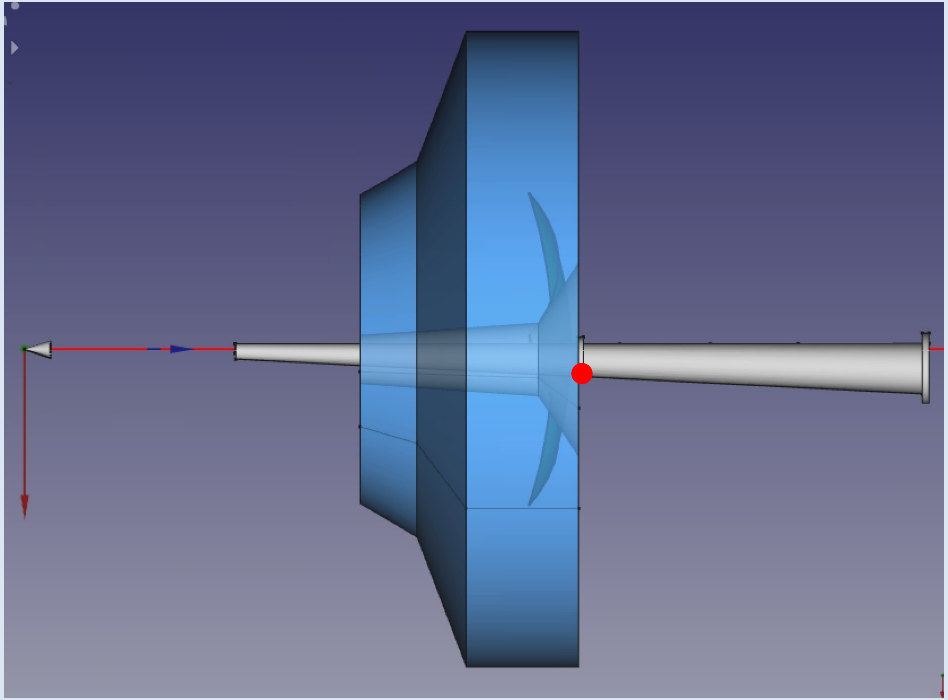


Case 1: single dRICH volume rolling in and out along the beam pipe

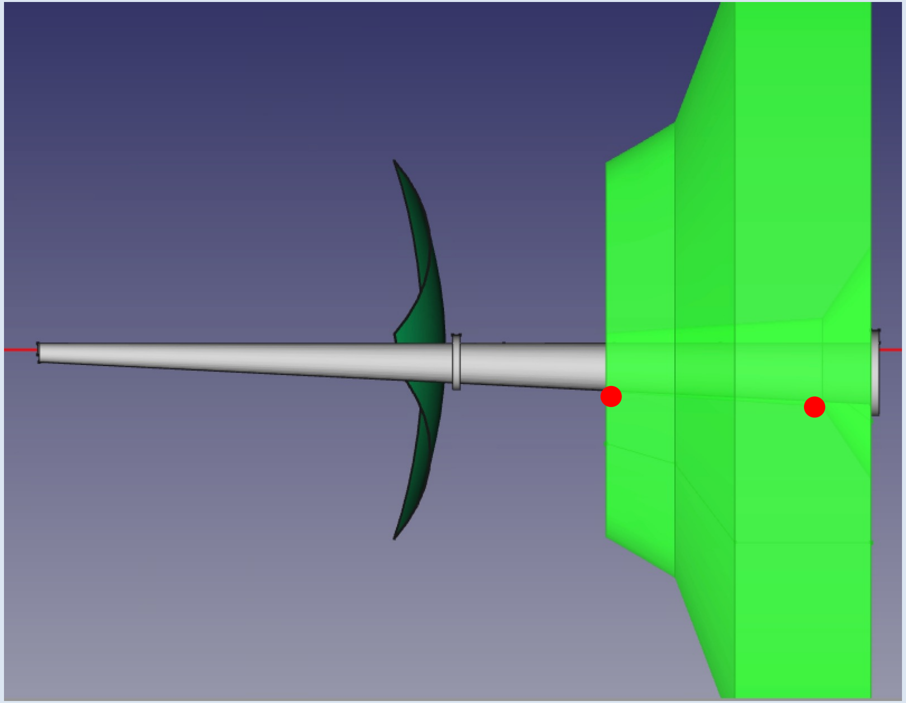
dRICH bore should be enlarged to remove all interferences along the pipe, final clearance should be sufficient

Mid-flange and pipe cross-section at the parking position provide similar constraint

Running position within ePIC



Parking position for maintenance

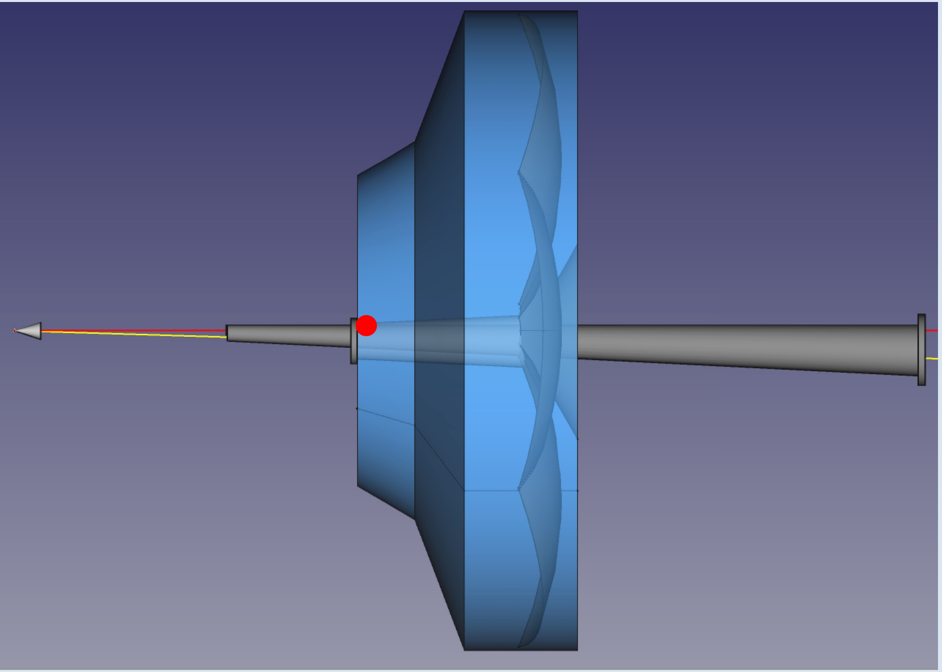


Case 2: two dRICH halves to be divided as soon as outside ePIC

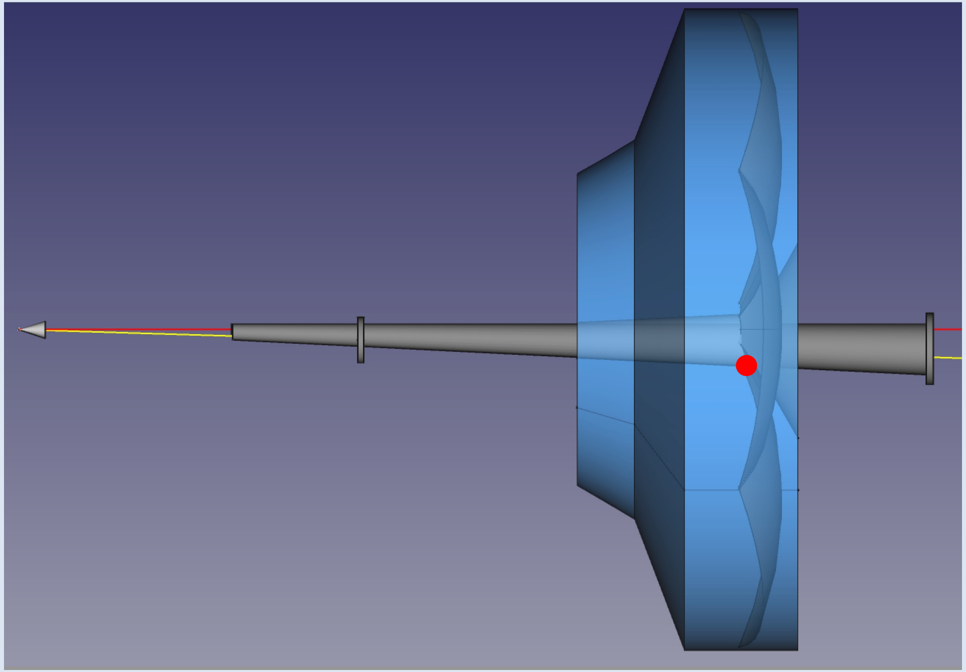
dRICH bore could be minimized if the mid-flange is moved in front of dRICH

The septum will obstruct inter-sector photon propagation.

Running position within ePIC

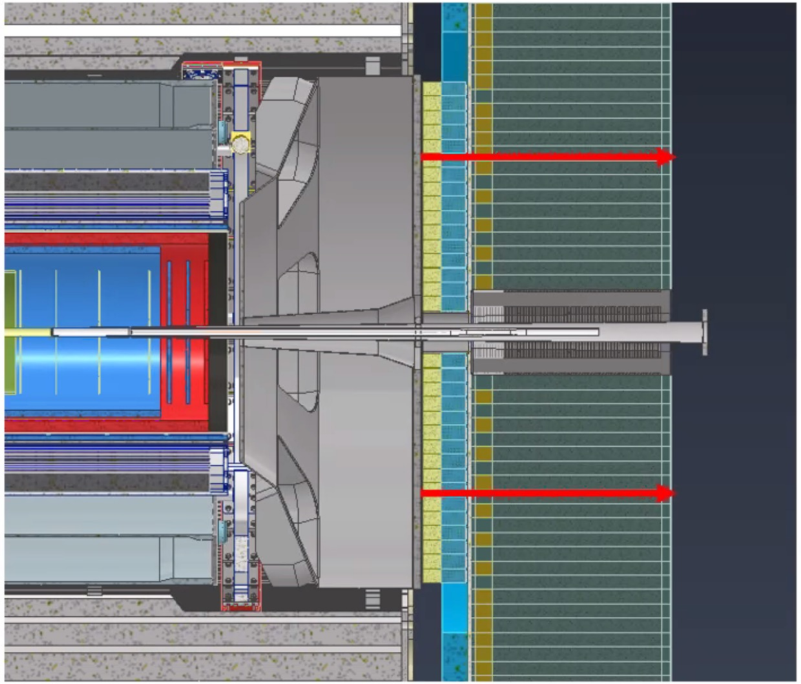


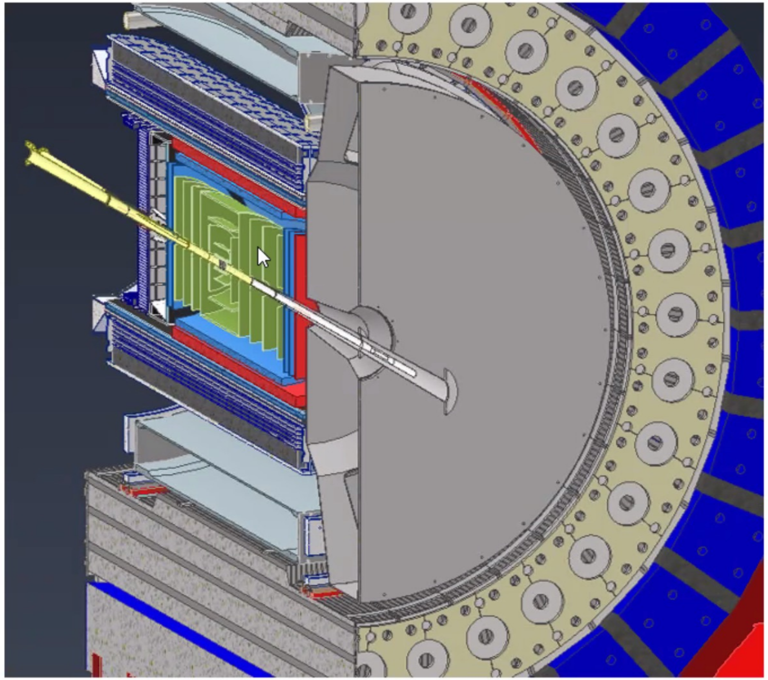
Extraction position

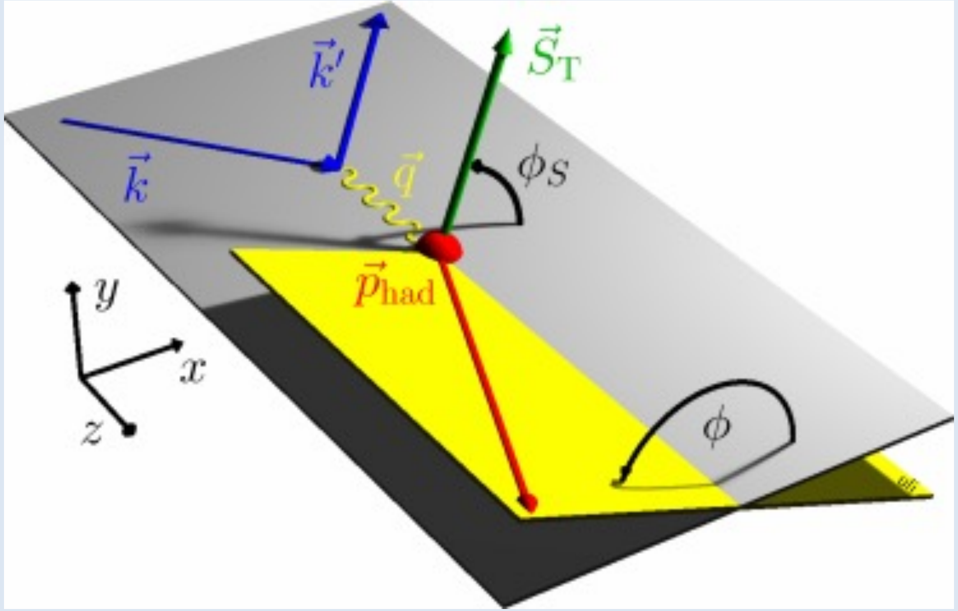


Case 1: Large bore will reduce forward acceptance

Case 2: Large ($2x4\ m^2$) septum would be inside the acceptance with implications for the mechanical stability vs pressure gradients we need to explore







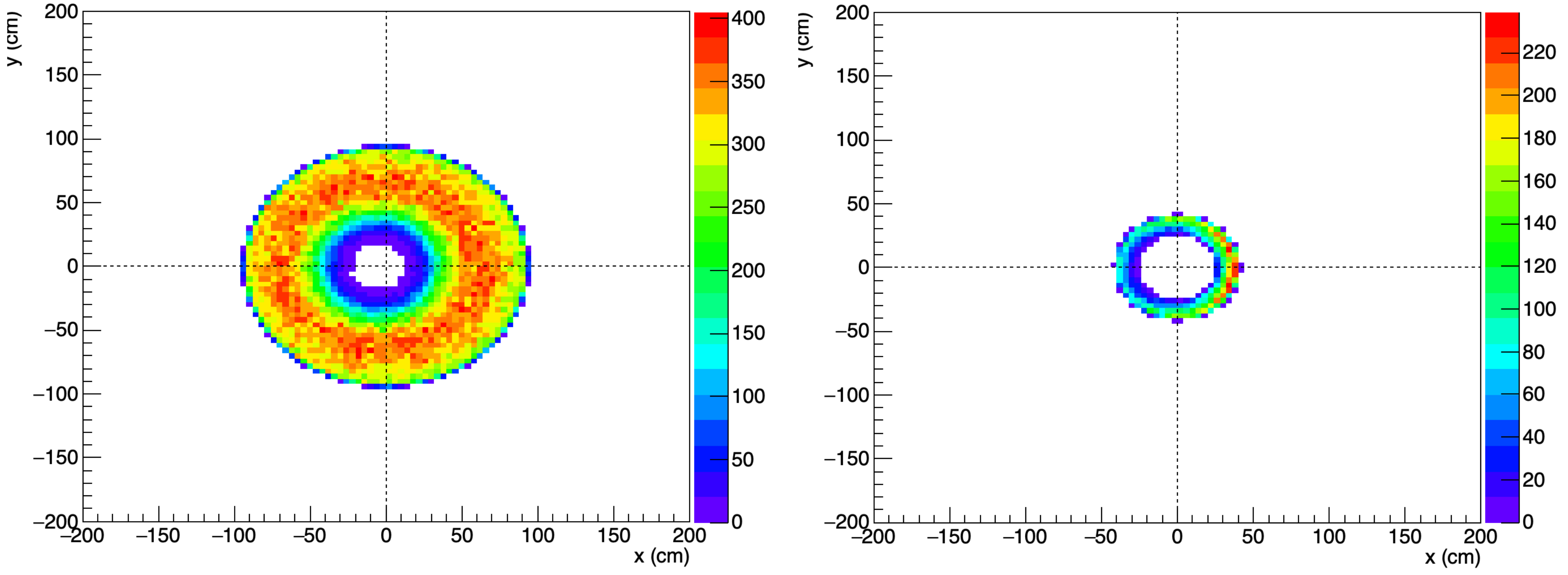
Notes (provisional):

- physics ϕ is defined vs the electron scattering plane, i.e. is not the laboratory ϕ_{LAB}
- pseudorapidity (and physics) should be defined with respect $\vec{q}$ vector ($\neq$ solenoid axis)

Impact point of the hadron track projected (w/o megnetic filed) on the dRICH entrance window
Psudorapidity defined with respect the electron axis (ePIC axis)

$\eta_e > 1.5$

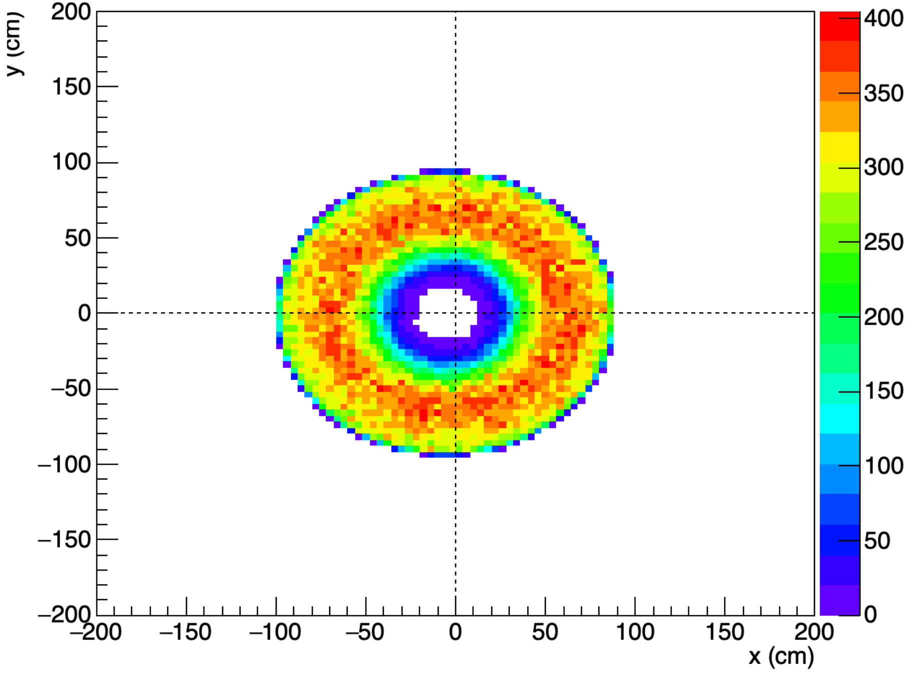
$\eta_e = 2.5 +/- 0.2$



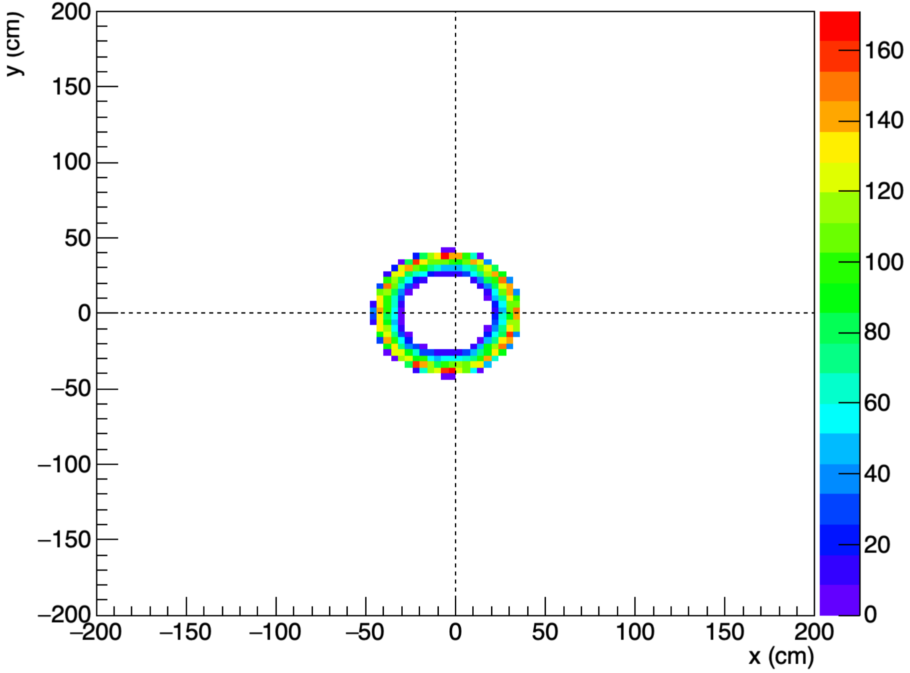
Hadron Distribution @ dRICH

Impact point of the hadron track projected (w/o megnetic filed) on the dRICH entrance window
Psudorapidity defined with respect the q axis (~ beam pipe axis)

$\eta_h > 1.5$



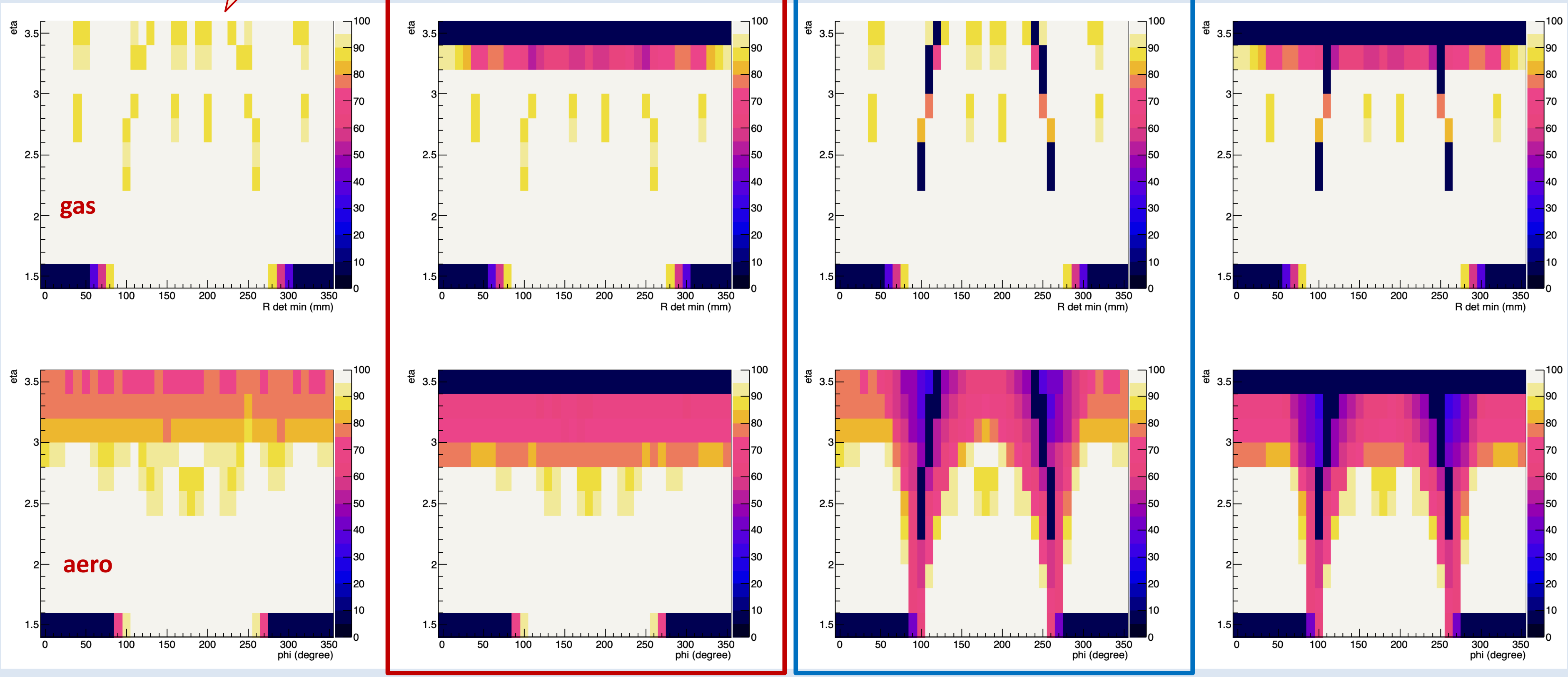
η_h = 2.5 +/- 0.2



Toy MC: Detected photon fraction

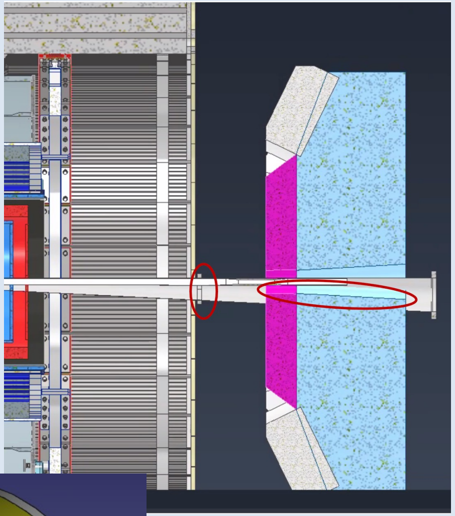
Case 1
Single piece – Large bore

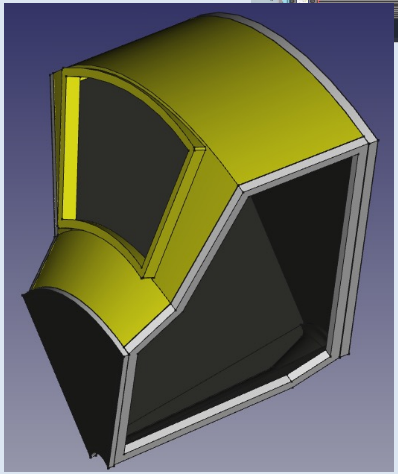
Case 2
Two halves – Optimized bore



dRICH Mechanics

- **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:*** *new prototype may be needed for a good modeling*





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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.

Conclusions

Development:

The characterization of components is on-track to define specifications and realistic inputs to simulations

The readout chain design is in an advanced state and being validated by test-beams

The design of the dRICH basic blocks (sector) is ongoing as basis for a real-scale demonstrator

Integration:

Services lines are being defined to stay in the detector box ”shadow”

The 3 cm shift downstream and the O(5 cm) tolerance in aerogel radius relax some of the constraints

Maintenance at IP6 is posing some serious constraint on the dRICH structure and performance impact:

- A large bore with “irreducible” losses in pseudorapidity
- A septum with significant impact on aerogel photon yield in 4 out of 6 sectors.
- Consequences and mitigations are being studied together with the Project