EIC Dual-Radiator RICH

EPIC PID Review

Contalbrigo Marco – INFN Ferrara

1. Title
2. dRICH Collaboration
3. EIC forward RICH
4. dRICH Baseline Design
5. dRICH Organization
6. dRICH Layout
7. dRICH Vessel
8. dRICH Gas Radiator
9. dRICH Aerogel Radiator
10. dRICH Mirrors
11. EPIC Environment
12. dRICH Photo-detector
13. dRICH Readout Scheme
14. dRICH Services
15. dRICH Simulation: Sensors Model
16. dRICH Simulation: Aerogel Model
17. dRICH Simulation: Resolution
18. dRICH Simulation: Momentum Reach
19. R&D: Status
20. R&D: Highlight
21. R&D: Milestones
22. dRICH Construction Schedule
23. Optimization & Risk Mitigation
24. Environment, Safety & Healt
25. Quality Assurance
26. Calibration & Commissioning
27. Executive Summary

Charge 1

Charge 2

Charge 3

Charge 5

Charge 6

dRICH Collaboration

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

dRICH

INFN

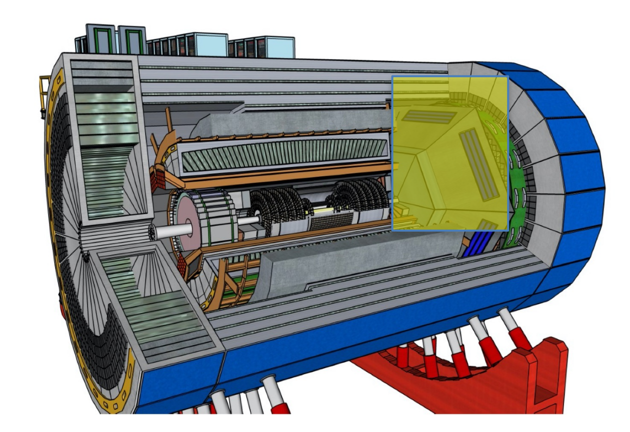
BA, BO, CS, CT, FE ,
GE, LNF, LNS, RM2,
SA, TO, TS

Duke University

NISER

Jefferson Lab

EPIC



EIC RICH Consortium

Brookhaven National Laboratory

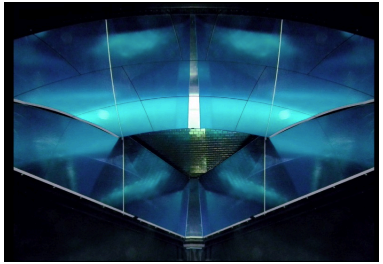
Stony Brook University

Univerza v Ljubljani

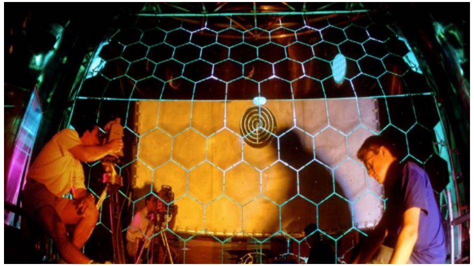
.....

Background Expertise:

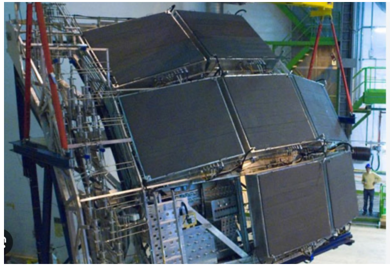
CLAS12 RICH



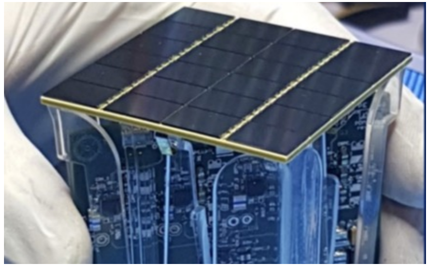
COMPASS RICH



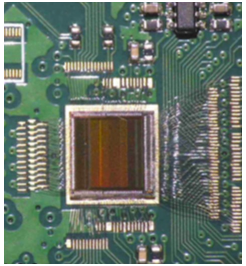
ALICE HMPID



DARKSIDE



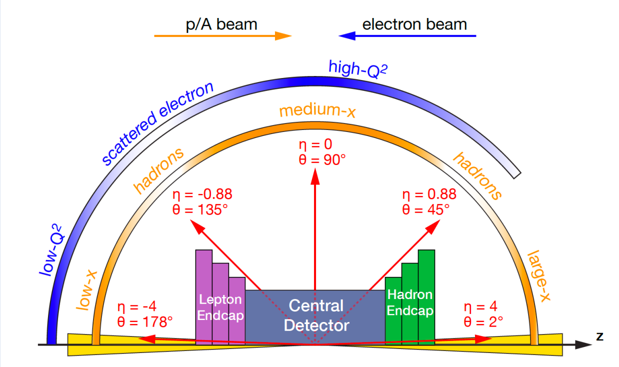
ALCOR

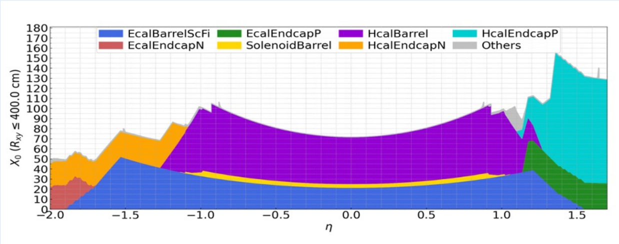


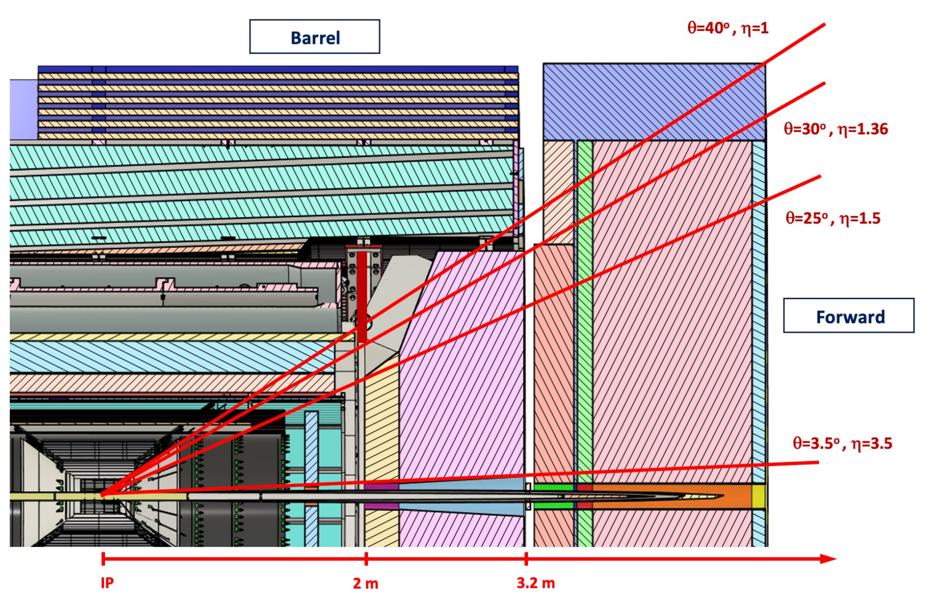
EIC Forward RICH

- Forward particle detection
- Hadron ID in the extended 3-50 GeV/c interval
- Support electron ID up to 15 GeV/c

η	Nomenclature	Electrons and Photons			π/K/p	
		Resolution σ_E/E	PID	Min E Photon	p-Range	Separation
1.0 to 1.5	Forward Detectors	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c	≥ 3σ
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0						
3.0 to 3.5						



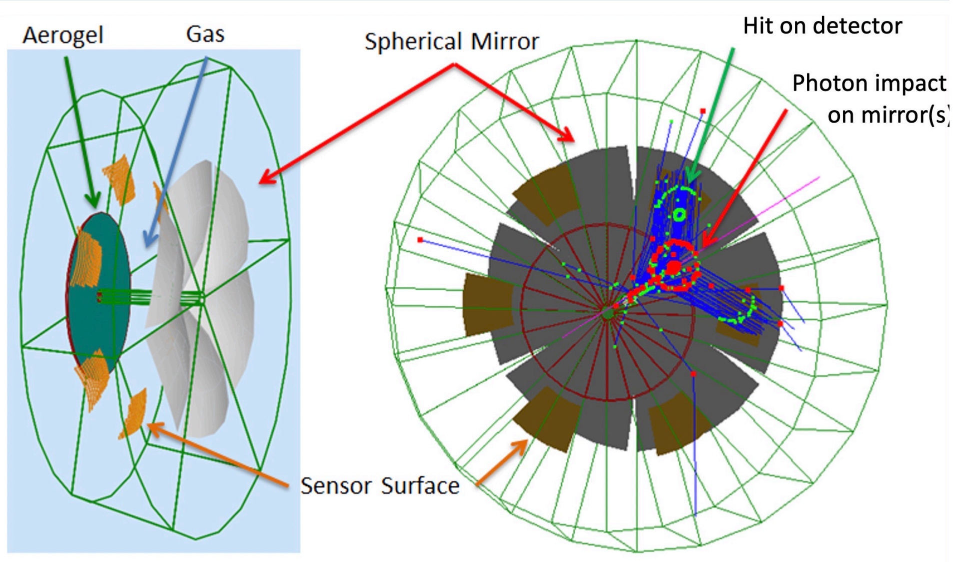


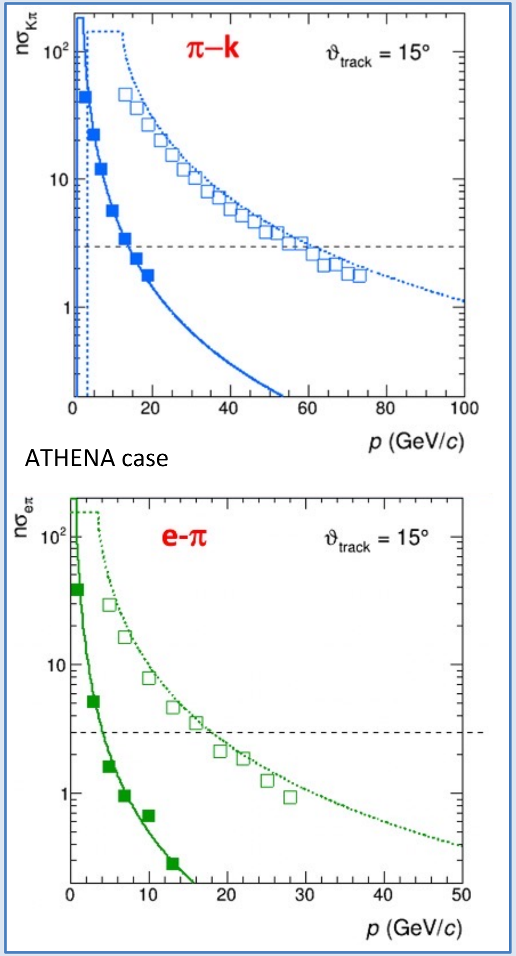


Essential for semi-inclusive physics due to absence of kinematics constraints

dRICH Baseline Design

Main features
- **cover wide momentum range 3 - 60 GeV/c**
- **work in high (~ 1T) magnetic field**
- **fit in a quite limited (for a gas RICH) space**





dRICH: cost-effective compact solution

Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

Detector: 0.5 m^2/sector, 3x3 mm^2 pixel → SiPM option

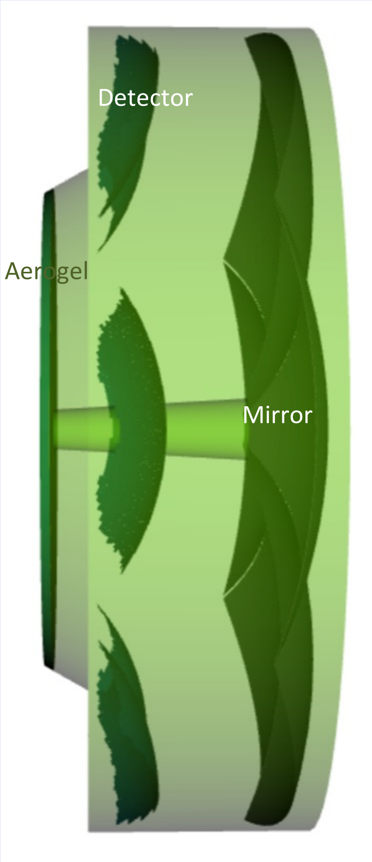
dRICH Organization

6.10.04 Particle Identification Level-3	CAM from Project
6.10.04.03 dRICH Level-4	CAM from Project + DSTC from EPIC (**M. Contalbrigo**)

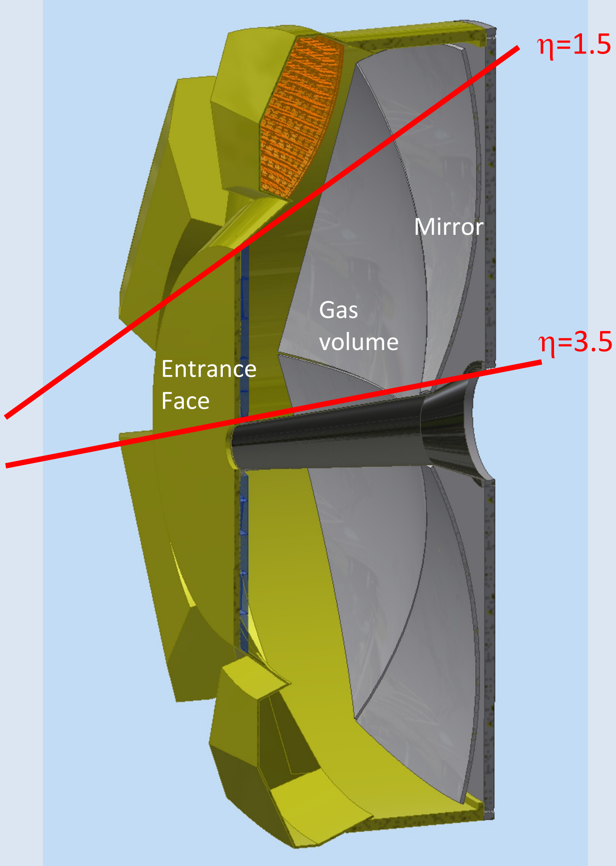
	Work packages lead from EPIC	Work packages not yet active
Photo-Detector Level-5	**R. Preghenella**, INFN-BO, INFN-FE, INFN-CS, INFN-SA, INFN-LNF, INFN-CT, NISER	
Front-end Asics Level-5	**F. Cossio**, INFN-TO, INFN-BO	Interlock Level-5
Data-acquisition Level-5	**P. Antonioli**, INFN-BO, INFN-FE	Slow Control Level-5
Mechanics Level-5	**A. Saputi**, INFN-FE, INFN-CT, INFN-GE, JLAB, BNL	Cooling Level-5
Gas radiator Level-5	**F. Tessarotto**, INFN-TS, BNL	Vessel Level-5
Mirror Level-5	**A. Vossen**, DUKE, INFN-FE	Detector box Level-5
Aerogel Radiator Level-5	**G. Volpe**, INFN-BA, INFN-FE, RICH Consortium	Mirror Alignment Level-5
Simulation	INFN-TS, DUKE, INFN-FE	Power Supply Level-5

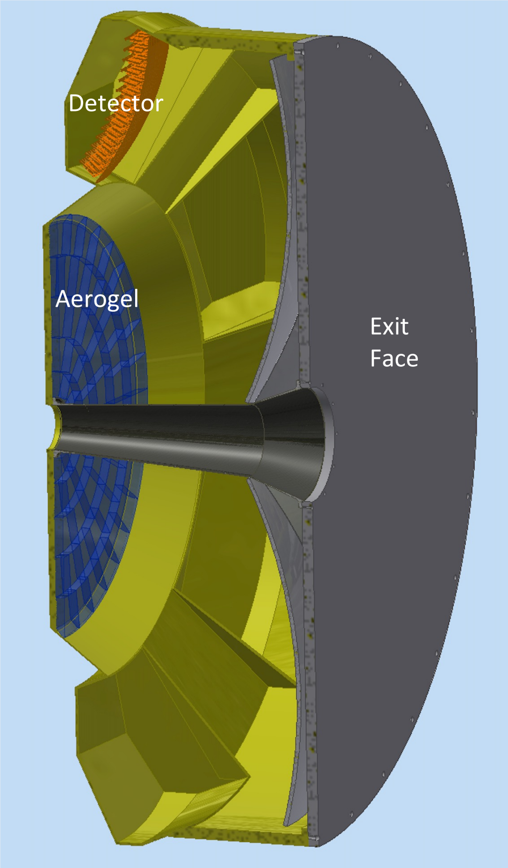
dRICH Layout

Simplified representation



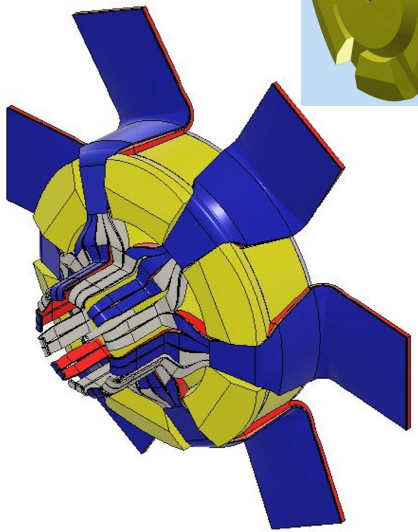
3D mechanical model

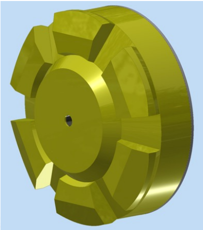


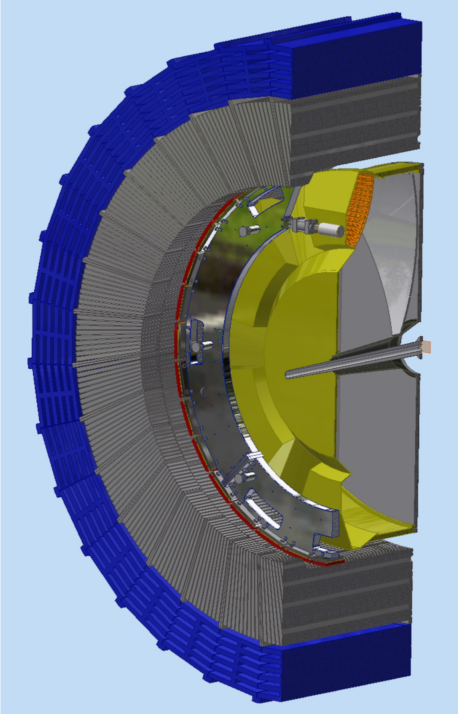


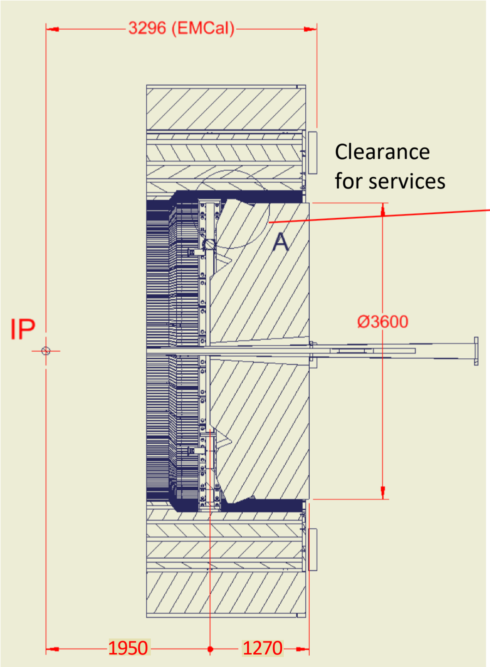
dRICH Vessel

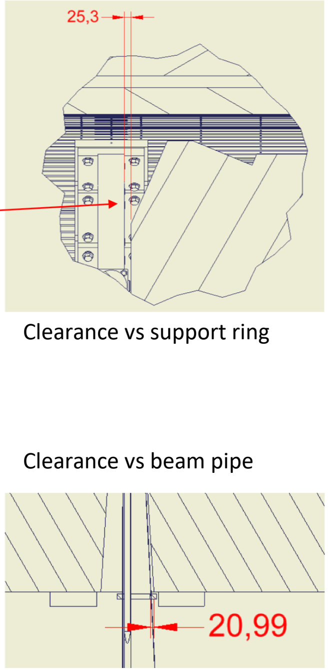
- Φ3600 mm x L1200 mm
- Operating pressure up to 200 Pa
- Operating temperature of 22 °C











Clearance vs support ring

Clearance vs beam pipe

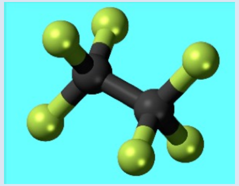
Windows: sandwich panel made of two ~1 mm carbon fiber reinforced epoxy skins separated by 30 mm PMI foam or Al honeycomb (~ 1% X_0)

Shells: 3 mm (inner tube) to 8 mm (outer tube) thick carbon fiber epoxy composite (~ 4% X_0)

Skins formed with two layers of balanced weave laminate with fibers at 0°/90° and +/- 45° for uniform stiffness

dRICH Gas Radiator

C_2F_6



50 GeV/c pions and kaons shot at eta 2.5

Gas	Npe(pi /K)	Th_pi	Th_K	Sig_pi	Sig_K	N_Sig
C2F6	16.03/ 14.94	36.8	35.67	0.32	0.33	3.5
C4F10	24.8/2 3.8	48.63	47.8	0.29	0.30	2.8

Chromaticity

$$\Delta\theta = \theta_{\check{c}}(\lambda=300nm) - \theta_{\check{c}}(\lambda=600nm)$$

$$\rho = \Delta\theta/\theta_{\check{c}}(\lambda=300nm)$$

$\rho_{C2F6} = 1.8\%$; $\rho_{C4F10} = 2.4\%$;

Assume dRICH volume ~ 20 m^3

C_2F_6 density 5.73 Kg/m3 → 114 kg

Initial minimal quantity ~ 200 kg

~ 500 kg could be enough for 10 yr of operation

Initial survey:

Several distributors contacted: availability confirmed by two:

- SIAD S.p.A.
- Resonac Europe GmbH

Yearly leaks are difficult to estimate:

- Filling and recovery operations	6%
- Filtering and maintenance	3%
- Leaks	10%
- Sampling, analysis, etc.	2%

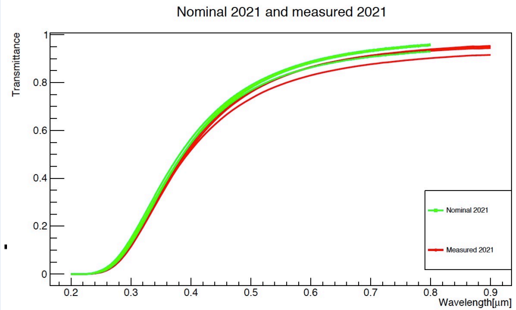
30 kg /yr emission → 300 tCO_2 /yr
comparable to one intercontinental flight /yr

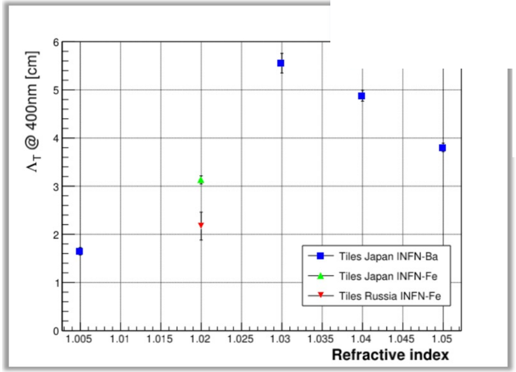
CERN new gas systems qualification standard:	
Target Leak flow at reference conditions	<1*10-3 STD cc/s

New standards should reduce significantly the losses and environmental impact

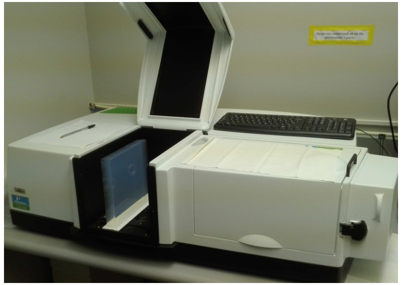
Aerogel Factory (BELLE-II)
Initial evaluation & Reproducibility
on small samples in sinergy with ALICE

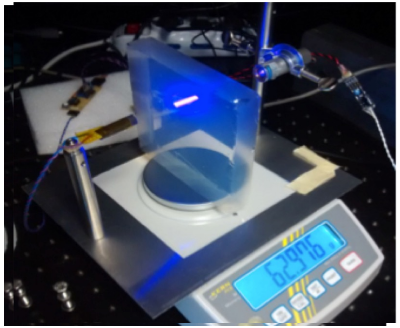
Transmittance & Transflectance



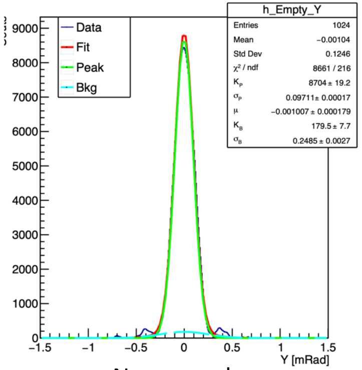


Density & refractive index

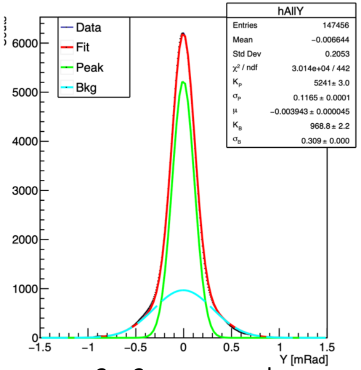




Laser spot bradening: Y profile



No aerogel



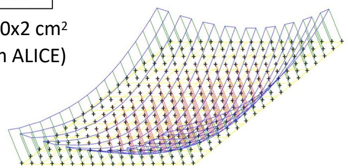
3 x 2 cm aerogel

Touch Probe: planarity and thickness

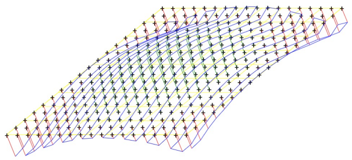
n = 1.03

10x10x2 cm^2
(from ALICE)

Y -



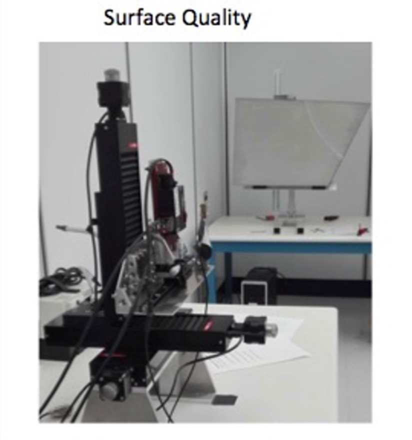
Y +

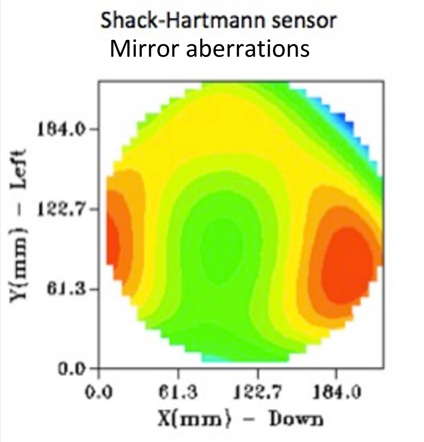


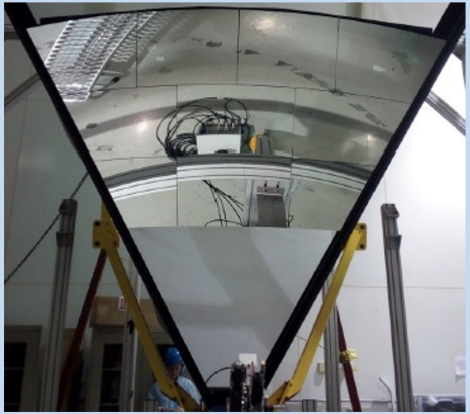
CMA Carbon fiber mirrors (HERMES, AMS, LHCb, CLAS12)

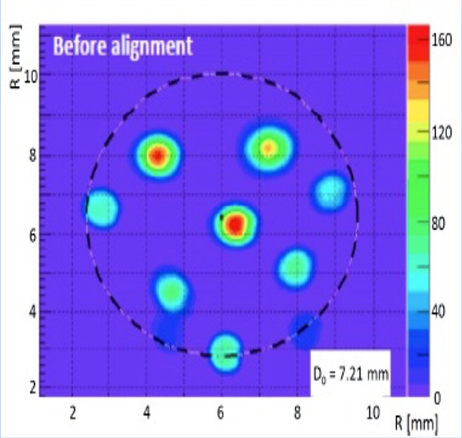
cost-effective light & stiff solution:

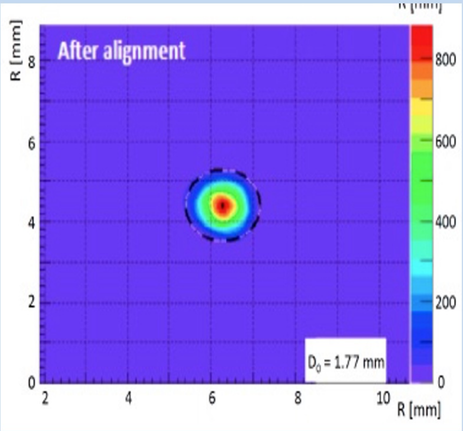
- roughness driven by mandrel 1-2 nm rms
- surface accuracy better than 0.2 mrad
- radius reproducibility better than 1 %





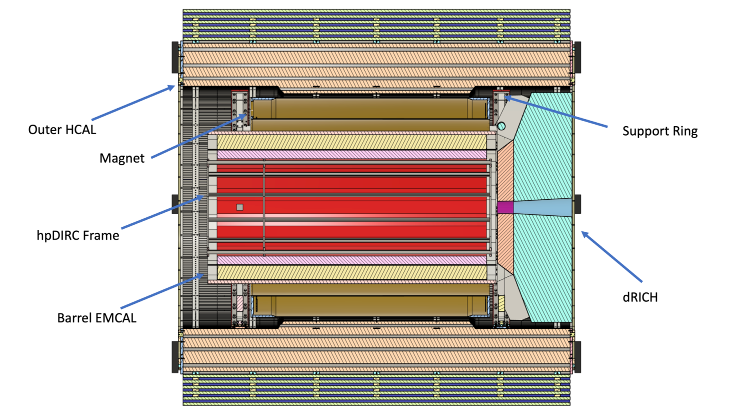


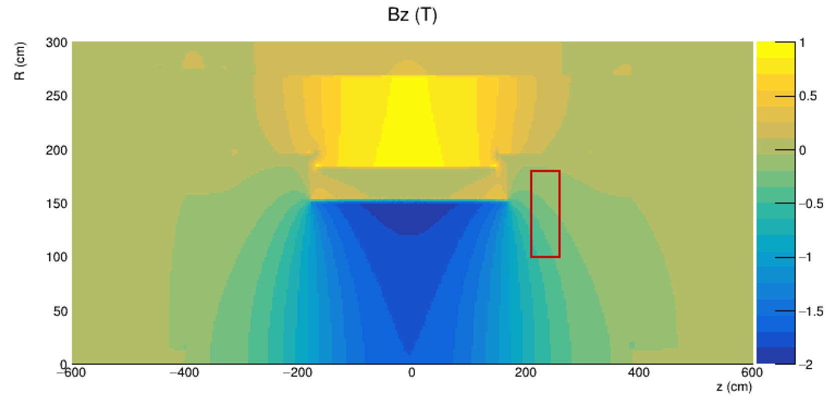




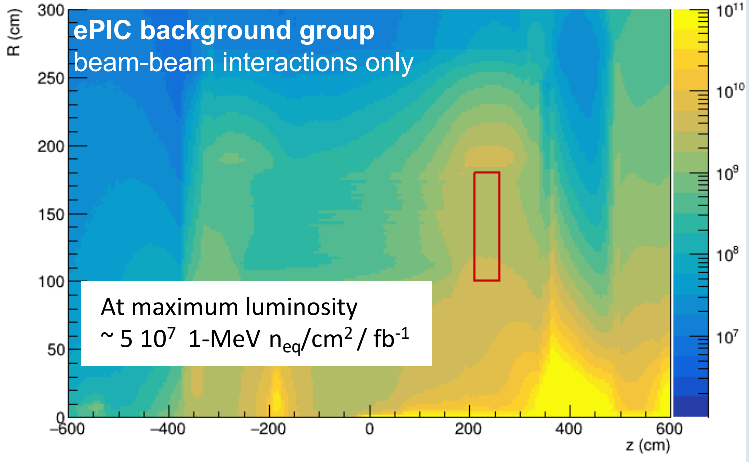
CLAS12 RICH QA laboratory @ JLab being refurnished

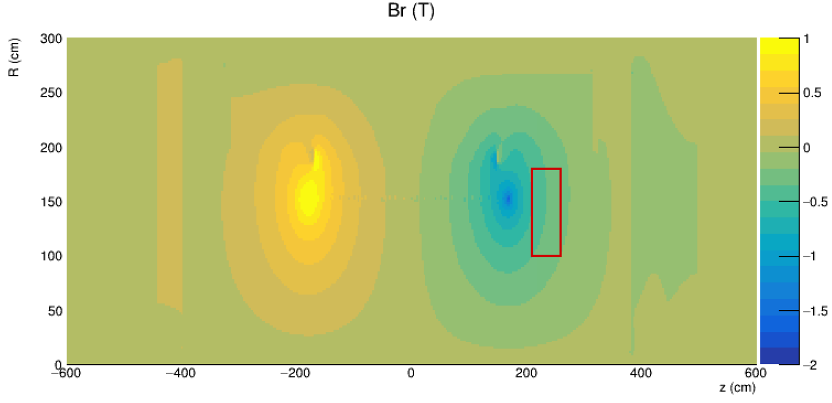
EPIC Environment



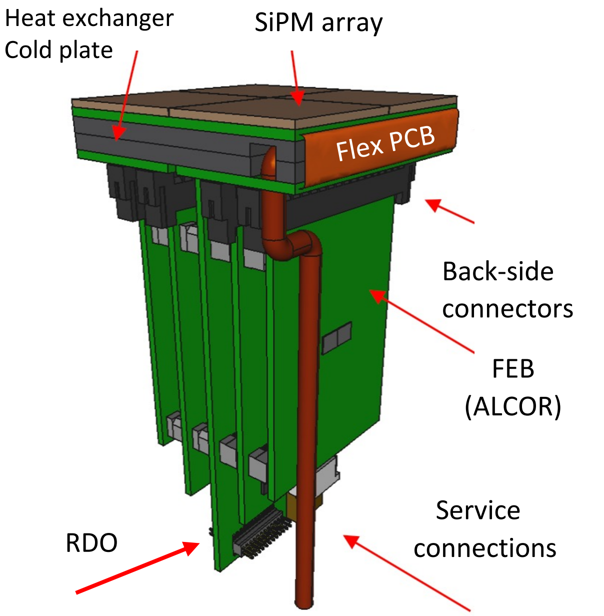


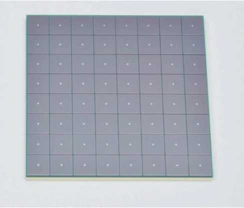
neutron (> 100 keV) fluence for 6 months at 500 kHz



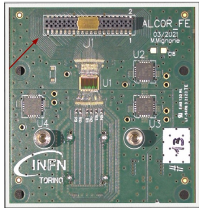


Strong (~ 0.7 T) magnetic field, not uniform





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)

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:

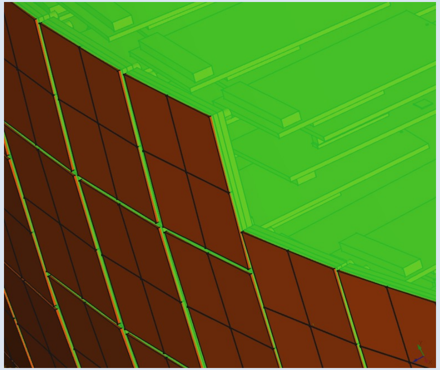
Shaped to fit the space

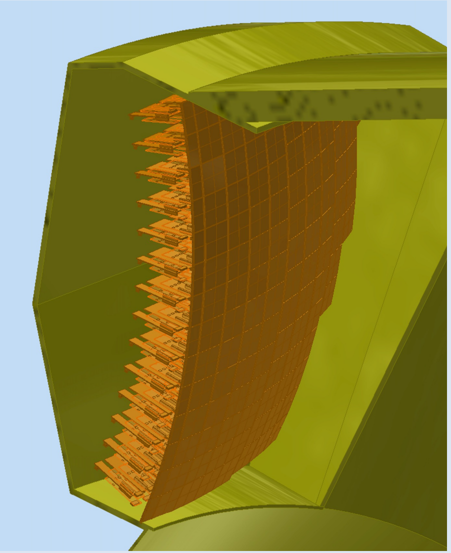
Quartz window

Cooling for sensors and electronics

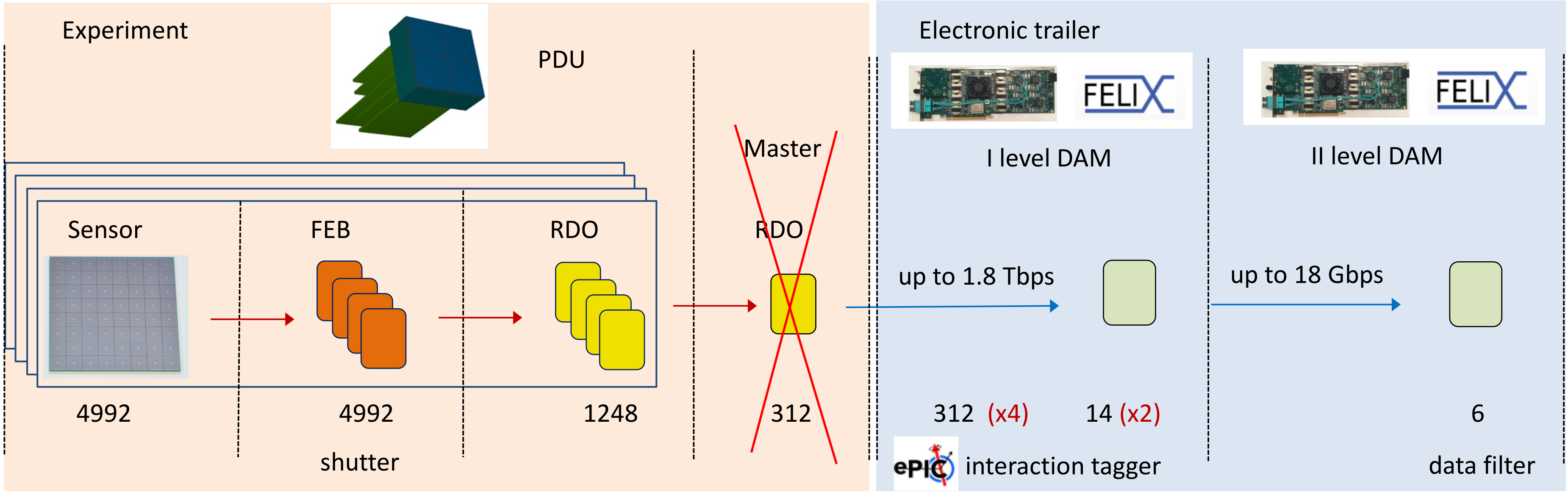
Power distributing patch panel

Heat insulation





dRICH Readout Scheme



Reduce complexity at the detector level (spare space, custom boards, FPGA/SEU)

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

DAM-L1 might be eventually stored in the experimental Hall (rack enclosure)

dRICH Services

Commercial Examples:

Power supply

Cooling plants

huber

General & Temperature Control

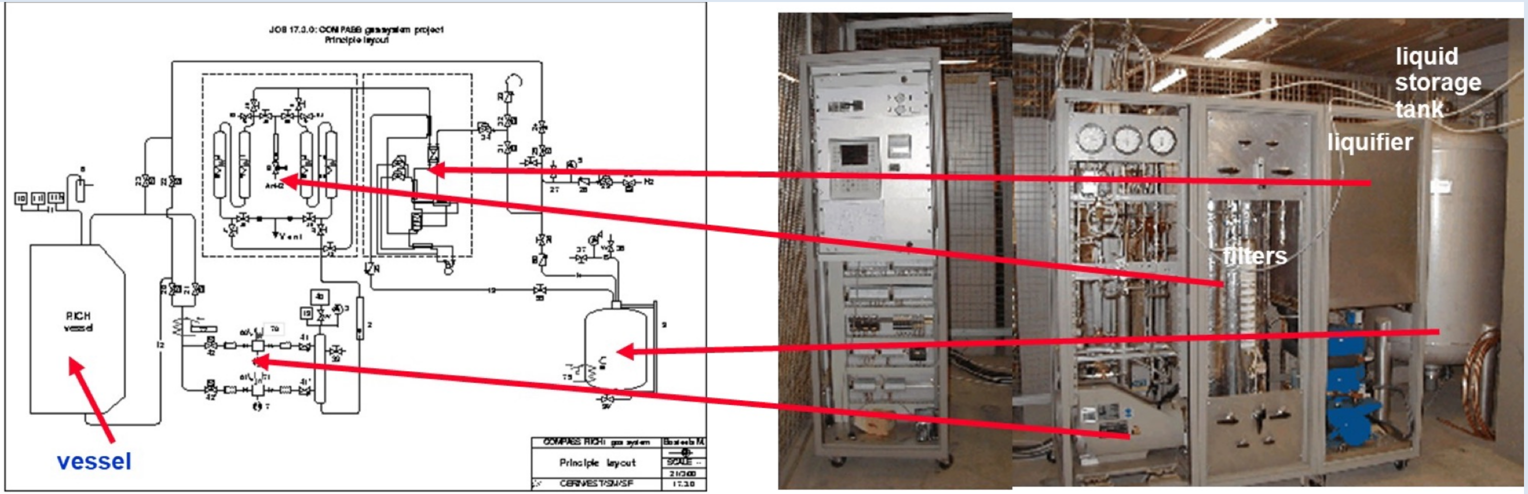
Temperature range	-55...250 °C
Temperature stability	±0,01 K

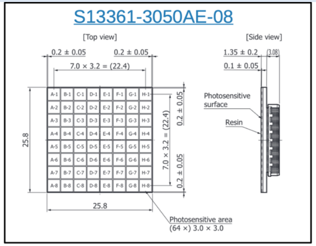
Heating / cooling capacity

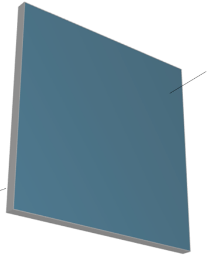
Heating capacity	6 kW								
Cooling capacity	250	200	100	20	0	-20	-40	-50	°C
	6	6	6	6	6	4,2	1,5	0,65	kW

Existing systems & standards:

COMPASS C_4F_{10} recirculating and purgingn system



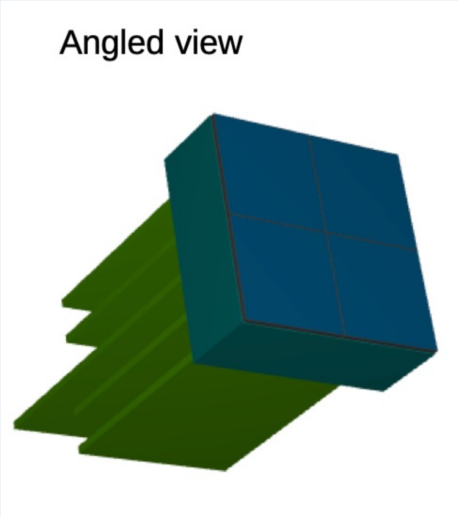


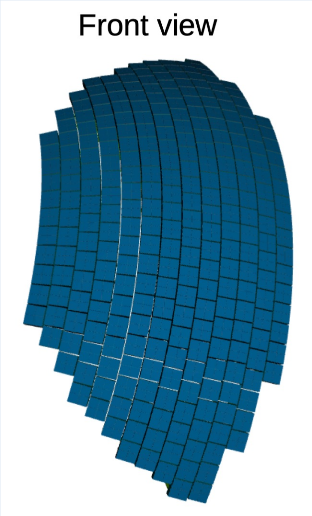


- Photosensitive Surface (PSS)
- 25.6 x 25.6 x 0.1 mm
- Material: 'AirOptical'
- 3.2 x 3.2 mm pixels (includes gaps) implemented as DD4hep Cartesian Segmentation
  - 8 x 8 pixel matrix
- 0.2 mm gaps between pixels masked in the reconstruction, so effective pixel is 3x3 mm

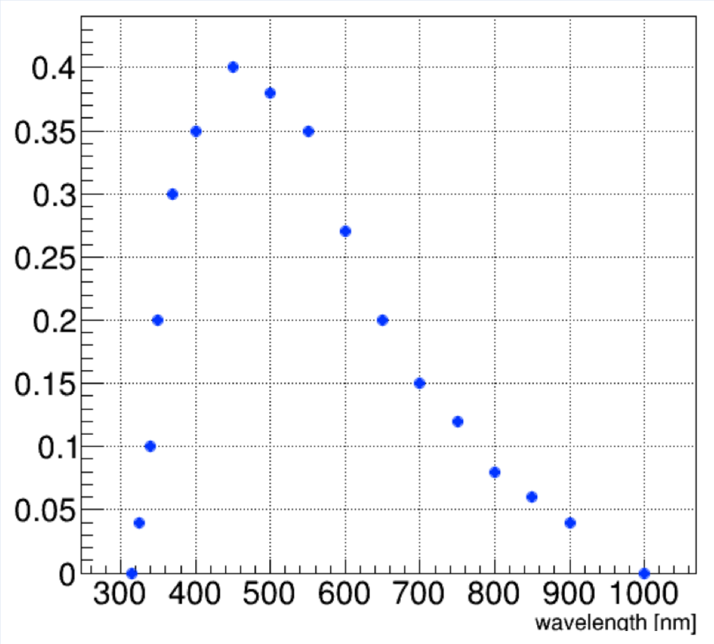
- Resin
- 25.8 x 25.8 x 1.35 mm
- Material: 'Epoxy'

Realistic description accounting for material budget





Photon detection efficiency



dRICH Simulation: Aerogel Model

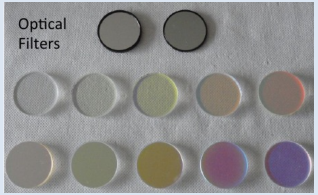
Comparison DATA vs MC model

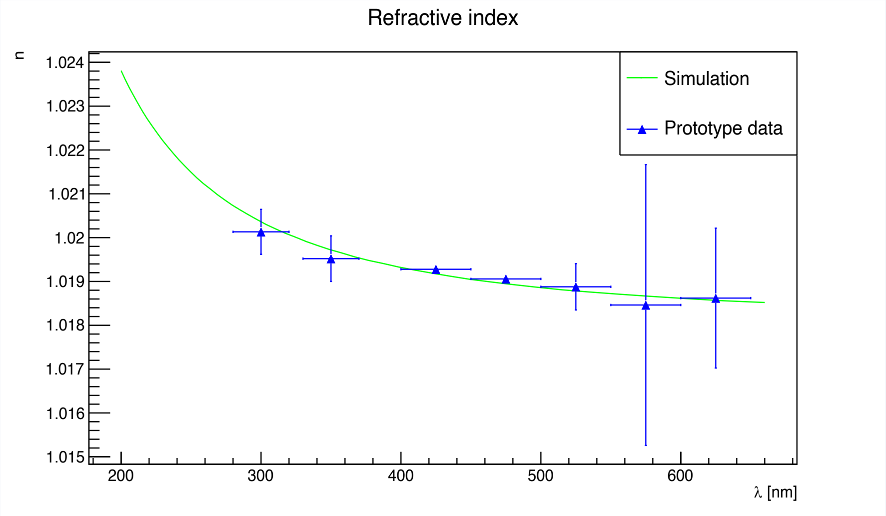
DATA: Aerogel Factory samples

MC: EPIC parameterizaion

Chromatic dispersion
(major expected contribution to resolution)

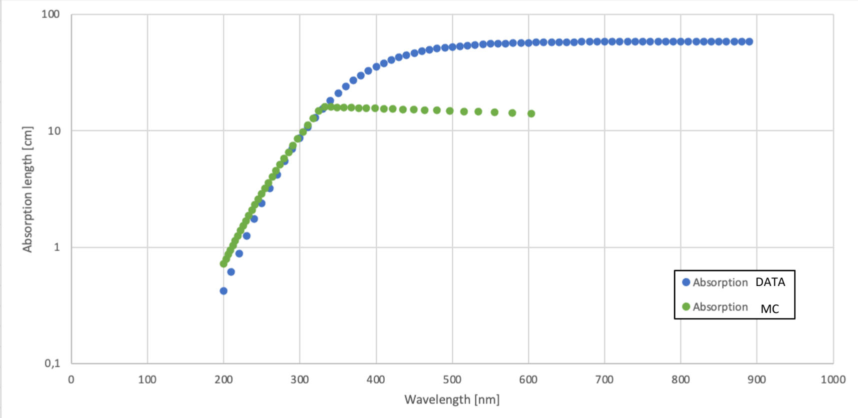
Data from dRICH prototype





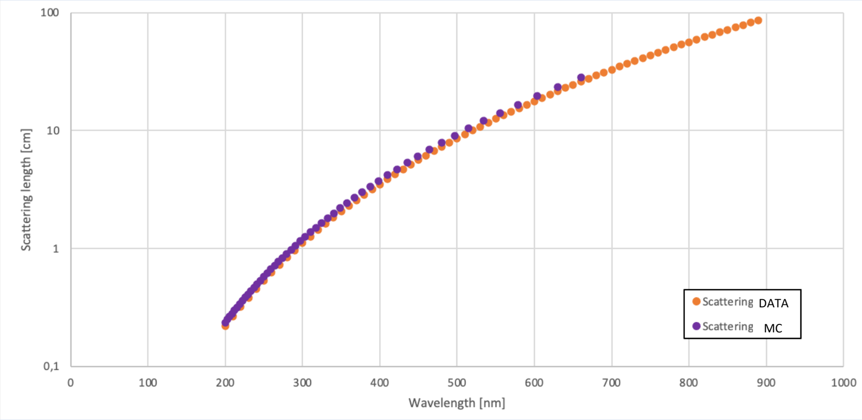
Absorption length

Data from INFN characterization



Scattering length

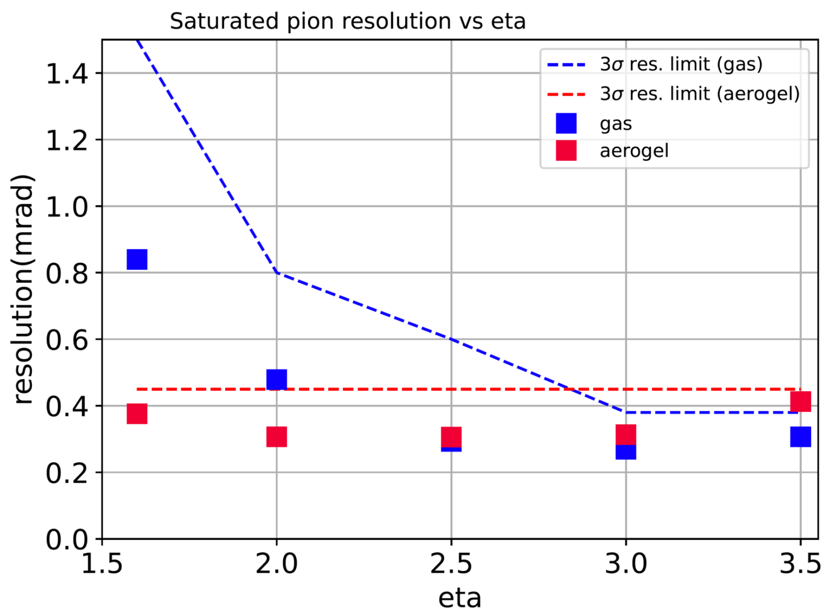
Data from INFN characterization

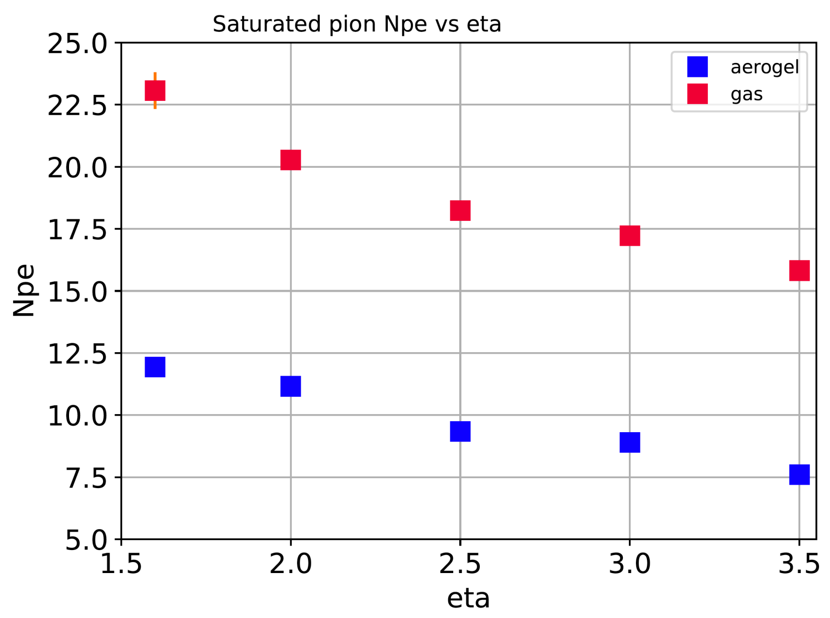


Preliminary optimization of the dRICH optics inside EPIC
Magnetic field and track resolution accounted for, results averaged over azimuthal angle (ϕ)

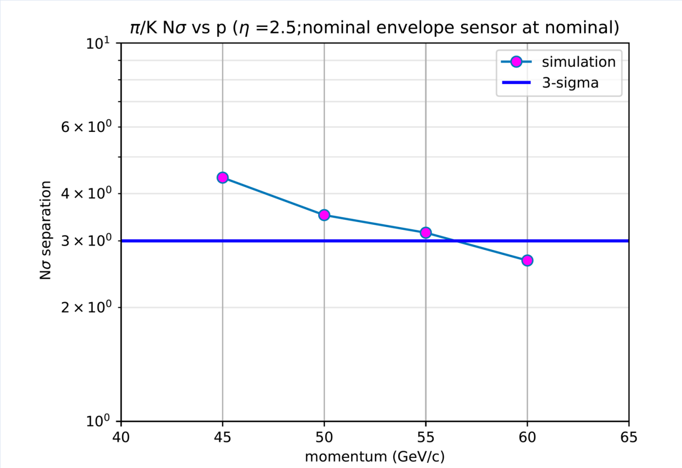
With single mirror, best focalization in the most demandig 2.5-3.5 pseudo-rapidity range to get ~ 0.3 mrad resolution

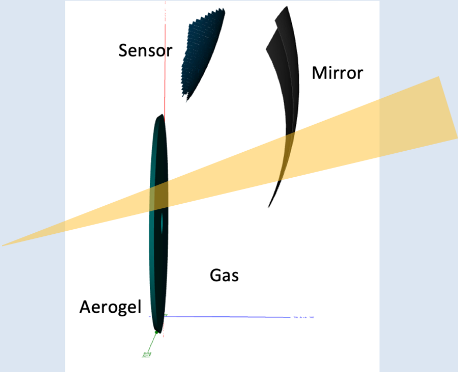
> 3σ separation in the wanted momentum range (i.e. at maximum momentum)



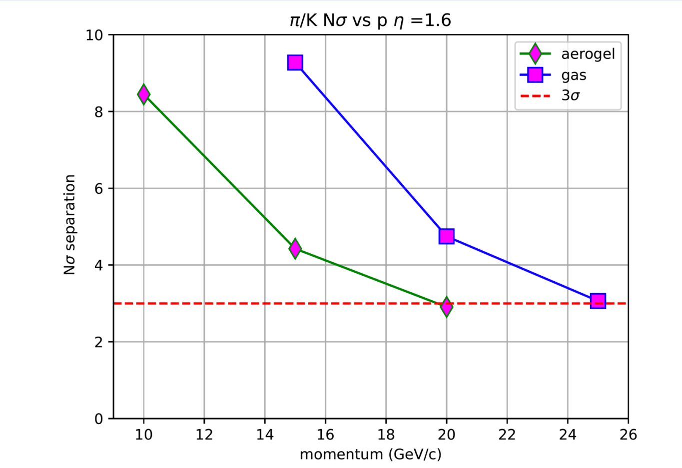


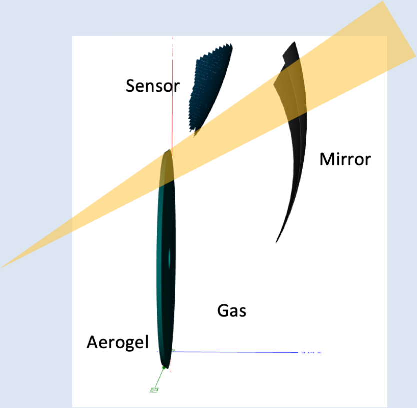
Momentum reach



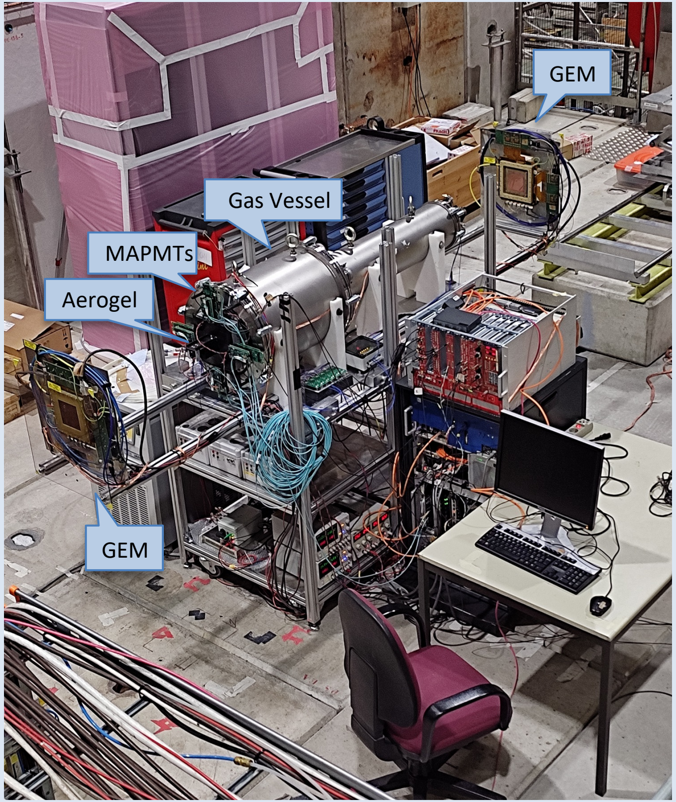


Interplay between radiators

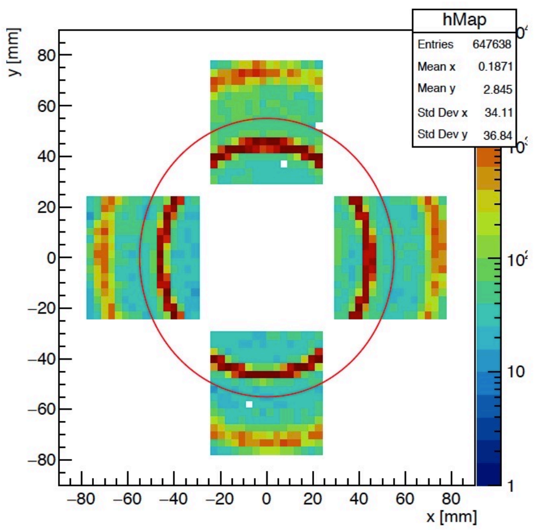




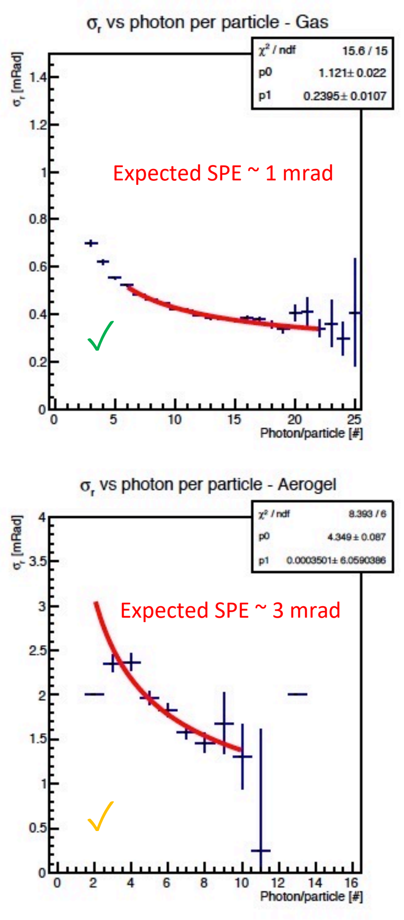
Operative prototype commissioned. Double ring imaging achieved. Performance in line with expectations except for aerogel single-photon angular resolution (worse by a factor ~ 1.5)



Reference readout from CLAS12 RICH:
H13700 MA-PMTs + ALCOR3 ToT chip



Gas ring coverage: 60%
Aerogel ring coverage: 40 %



Optics at variance with respect EIC

R&D: Highlight

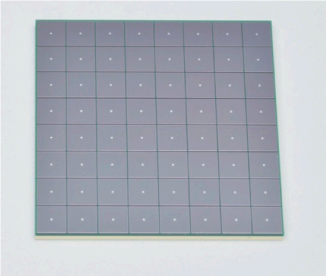
Realization of a suitable detector plane for the dRICH prototype (23/10): Design ready, procurement aligned to 2023 test-beam campaign.

Hamamatsu S13361-3050

√

8x8 array
50 μm cell
Excellent fill factor
Best DCR

S14160 alternative

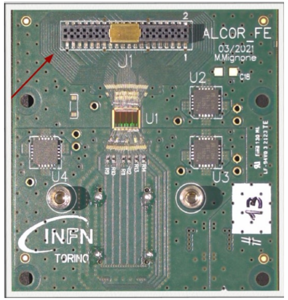


MPPC arrays selected with irradiation campaign

Front-end re-design completed

ALCOR v2 (bwetter dynamic range and rate)
ToT architecture, streaming mode ready
- 50 ps time bin
- 500 kHz rate per channel
- cryogenic compatible

ALCOR chip



√

Multi-wafer run done

Version2:
32 channels
Extended dynamic range
Improved digital time

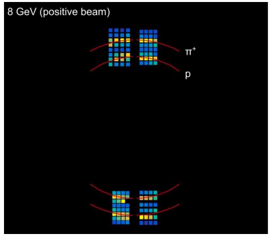
Integrated Cooling/ In-situ annealing

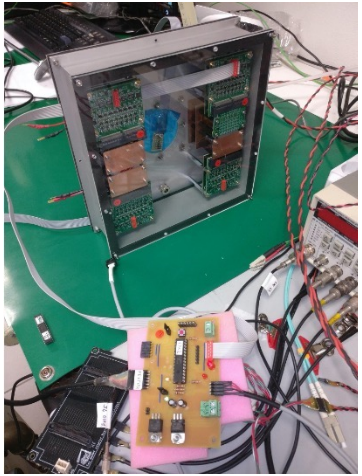
√

Cooling plate

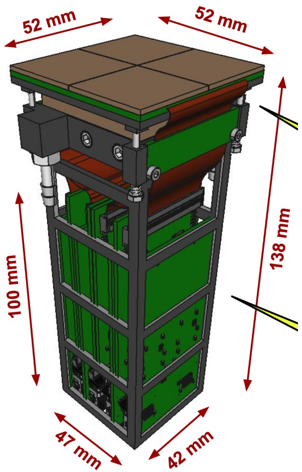
Peltier cells

Annealing circuitry

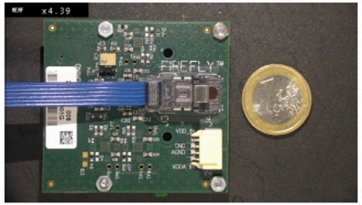




New EIC-driven readout unit



Streaming readout



√

2023:
1 RDO per chip

2024:
1 RDO per PDU

Development Kit KC705

2023: EIC-driven detector plane

✓ Initial characterization of realistic aerogel and mirror components (23/04); ⇨ Slide 10

✓ Projected performance of the baseline detector as integrated into EPIC (23/06); ⇨ Slide 16

✓ Assessment of the dRICH prototype performance with the EIC-driven detection plane (23/10). ⇨ Slide 19

Test beam planned in August and October 2023

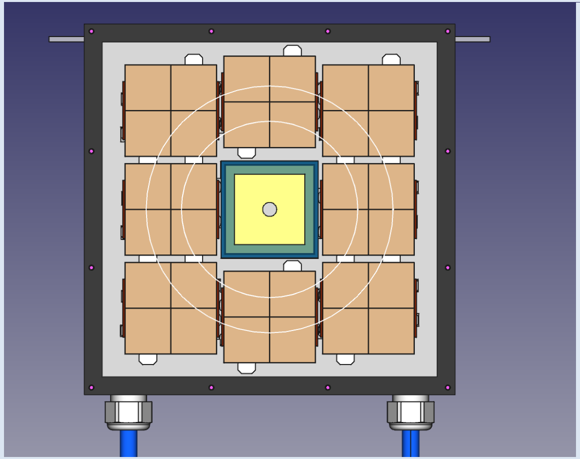
2024: Real-scale prototype for TDR

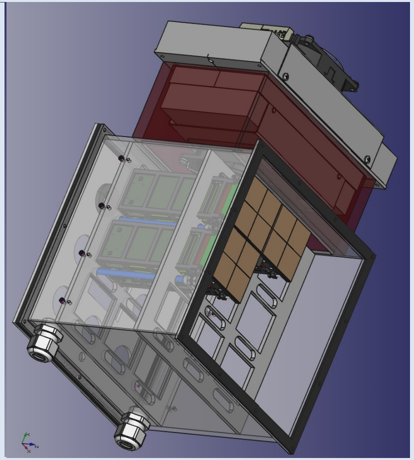
Mechanical structure

Realistic optics (off-axis)

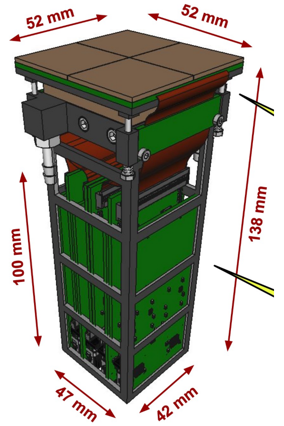
ALCOR64 FEB + RDO

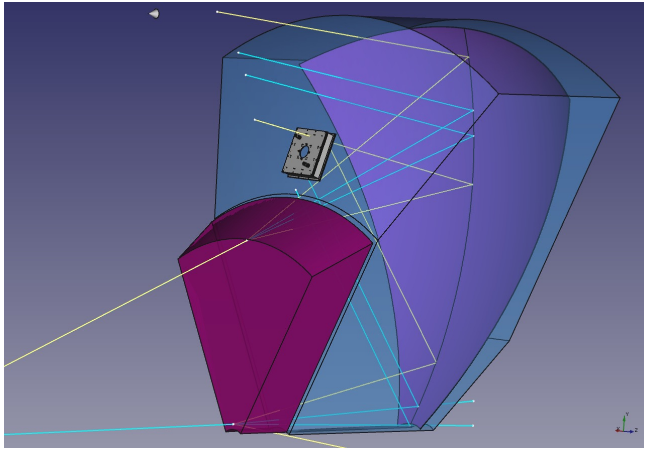
Aerogel and mirror demonstrator





New EIC-driven readout unit





dRICH Construction Schedule

EIC - Working File
Data Date: 02-Jan-20

EIC - Activities with Gantt
TASK filter: WBS Path 06.10.04.02.

WBS Path	Activity ID	Activity Name	Original Duration	Start	Finish
Project: ECE06 EIC - Working File			1797	01-Oct-21	12-Dec-28
WBS: ECE06.10 EIC Detector			1797	01-Oct-21	12-Dec-28
WBS: ECE06.10.04 Particle Identification (PID)			1797	01-Oct-21	12-Dec-28
WBS: ECE06.10.04.02 Dual Ring Imaging Cherenkov Detector (dRICH)			1797	01-Oct-21	12-Dec-28
10.04.02	EIPICH _L_FY22	6.10.04.02 - EIPICH - FY22 Labor Actuals	250	01-Oct-21	30-Sep-22
10.04.02	E1004_20000	PDR - Preliminary Design, Beam Test & Assessment (dRICH)	110	03-Oct-22	15-Mar-23
10.04.02	E1004_20010	Prototyping (dRICH)	313	03-Oct-22	05-Jan-24
10.04.02	E1004_20020	Specifications 100% Defined for 3A Procurement (dRICH)	0		31-Oct-22
10.04.02	E1004_20030	PDR _ Preliminary Design Complete (dRICH)	0		15-Mar-23
10.04.02	E1004_20040	FDR - Final Design & Finalize dRICH Design with All Required Services (dRICH)	109	16-Mar-23	17-Aug-23

SiPM may require longer engineering to reach the best performance (e.g. match temperature treatments)

WBS Path	Activity ID	Activity Name	Original Duration	Start	Finish
10.04.02	E1004_20580	AWARD: Photo Sensors (dRICH)	1	02-Oct-23	03-Oct-23
10.04.02	E1004_20660	AWARD: SiPMs Cooling System (dRICH)	1	02-Oct-23	03-Oct-23
10.04.02	E1004_20730	AWARD: Mirror Alignment System (dRICH)	1	02-Oct-23	03-Oct-23
10.04.02	E1004_20800	AWARD: Cooling System (dRICH)	1	02-Oct-23	03-Oct-23
10.04.02	E1004_20590	VENDOR EFFORT: Photo Sensors (dRICH)	360	03-Oct-23	17-Mar-25
10.04.02	E1004_20080	Write SiPMs Requisition (dRICH)	0		31-Dec-24
10.04.02	E1004_20090	SiPMs Procurement Effort with Technical Support (dRICH)	410	02-Jan-25	19-Aug-26
10.04.02	E1004_20630	RCV: Photo Sensors (dRICH)	1	17-Mar-25	18-Mar-25

Aerogel may require longer engineering to reach the best performance (e.g. mass production efficiency)

WBS Path	Activity ID	Activity Name	Original Duration	Start	Finish
10.04.02	E1004_20530	AWARD: Aerogel (dRICH)	1	02-May-25	02-May-25
10.04.02	E1004_20320	Test & Q.C. First Article Mirror (Includes Developing Test Plan) (dRICH)	115	05-May-25	16-Oct-25
10.04.02	E1004_20490	VENDOR EFFORT: C2F6 Gas Recovery System (dRICH)	180	05-May-25	23-Jan-26
10.04.02	E1004_20540	VENDOR EFFORT: Aerogel (dRICH)	500	05-May-25	04-May-27

Readiness planned 2 years before installation might result in a too aggressive schedule (see above)

WBS Path	Activity ID	Activity Name	Original Duration	Start	Finish
10.04.02	E1004_20260	Ready for Installation (dRICH) (BNL)	0		09-May-28
10.04.02	E1004_20140	SiPMT & SiPMT Test, Final Acceptance (dRICH)	20	13-Nov-28	12-Dec-28
10.04.02	E1004_20130	SiPMT & SiPMT PCBoard Vendor Delivery (dRICH)	1	12-Dec-28	12-Dec-28
10.04.02	E1004_20150	Ready for Installation (dRICH)	0		12-Dec-28

Optimization and Risk Mitigation

Component	Baseline	Optimization	Possible improvement
SiPM	Hamamatsu H13361-3050HS	75 μm cell FBK sensor	Larger PDE Better time resolution
Aerogel radiator	Aerogel Factory n=1.02	Refractive index Tile dimensions Tsinghua aerogel	Increase photon yield Reduce edge effects Risk reduction for single vendor
Gas radiator	SIAD C_2F_6	Gas mixture Early procurement	Reduced environment impact (global warming) Limit dependence on market & regulations
Mechanics	Tecnavan Carbon fiber composite	Al composite	Cost reduction
Mirrors	CMA Carbon fiber composite	Mold material Different core strucuture Tessellation	Better shape quality vs cost
Cooling	Al plate	Carbon foam plate	Reduce material budget

1 year typical C_2F_6 losses would correspond to 1 intercontinental flight CO_2 emission
requires to minimize losses in the recirculating system

About 2-2.5 kW per detector box
requires liquid cooling, air circulation + interlock

On-site annealing requires single-sensor temperature (optical) control

Low-T coolant circuit (down to -50 C) requires proper circuit and insulation

Thin transparent septa require delta-pressure control and safety diaphragm

Quality Assurance

Aerogel: Refractive index, dimensions, defects, transmittance
organized within RICH Consortium (INFN-FE, INFN-BA, CERN, Temple)
https://docs.google.com/document/d/1YpN7gx85JjoQnoB9NblD61N9B1YhRGwBh2GIKZ2ST-0/edit

Mirror: Dimensions, shape accuracy, radius, reflectivity
JLab existing test laboratory with INFN-equipment, DUKE laboratory

Sensors: Electrical connections, quench resistor, I-V characteristics, DCR, relative PDE
Test stations in Italy (INFN-BO, INFN-FE, INFN-CS)

Front-end: Electrical connections, time jitter, ToT characteristics
Test stations in Italy (INFN-BO, INFN-TO)

Gas: Performance with prototype, transparency, contaminants
CERN

Calibration and Commissioning

Detector response:

LED/laser system (sensor response and mirror alignment)

Dark count rate monitor

Single-photon time over threshold

Time calibration:

Absolute time with respect bunch crossing and Forward TOF

Time intercalibration: photons hits from the same event

Particle identification:

Control particle samples (identified by other systems)

Known meson decays (K_s, Λ, Φ)

Executive Summary

Dual-radiator RICH is a cost-effective and compact solution for the forward PID at EPIC

Baseline configuration and technology has been identified to reach the EIC requirements

- 3σ angular separation for forward hadrons up to 50 GeV/c momentum and up to 3.5 in pseudo-rapidity

dRICH Collaboration is setting up and an Executive Office has been enganged

R&D is on track to deliver the anticipated milestones towards TDR

- Working on consolidating the baseline design with further optimization of the components
- Need to integrate and validate all the progresses with a real-scale prototype prior of TDR
- Aerogel and SiPM might need longer engineering (contingency) to reach the best performance