dRICH: R&D status and design in ATHENA

20/Dec/2021 – Giornata Nazionale EIC_NET

E. Cisbani (INFN-RM and ISS)

People involved (past and present):

P. Antonioli (INFN-BO), L. Barion (INFN-FE), C. Chatterjee (INFN-TS), M. Contalbrigo (INFN-FE),
F. Cossio (INFN-TO), M.D. Da Rocha Rolo (INFN-TO), A. Del Dotto (ENEA), C. Dilks (Duke),
C. Fanelli (JLab/MIT), A. Kiselev (BLN), M. Mirazita (INFN-LNF), A. Movsisyan (INFN-FE), F. Noto (INFN-CT),
R. Preghenella (INFN-BO), G.M. Urciuoli (INFN-RM), S. Vallarino (INFN-FE), Z. Zhao (Duke/JLab),
... and those I forgot to mention, and the EIC-eRD14/PID Consortium

- Origin of dRICH
- Baseline performances
- ATHENA implementation
- The other EIC/dRICHes
- Hardware Key components
- Hardware R&D

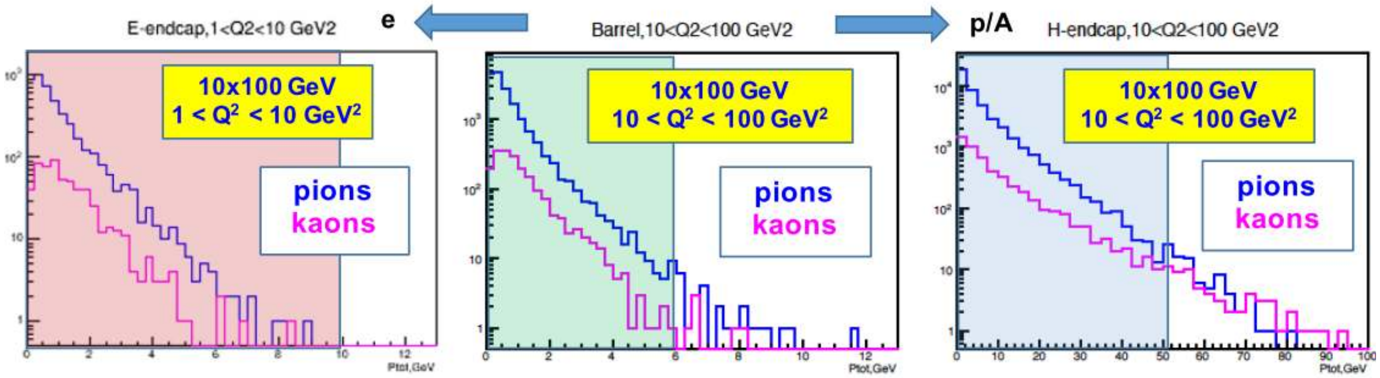
Tomorrow specific talks:

Chandra	Simulation status	9:25
Roberto	SiPM for RICH	9:45
Fabio	ALCOR ASIC	10:05
Simone	Beam tests	10:25

Hadron-ID @ EIC h-endcap (forward region)

“**Simulations show that in order to satisfy the physics goals of the EIC, it is desirable to provide π/K identification** in the central barrel up to 5-7 GeV/c, in the electron-going endcap up ~10 GeV/c, and **in the hadron-going endcap one would need to reach ~50 GeV/c**.”, from the “Electron-Ion Collider Detector Requirements and R&D Handbook”, January 10, 2019

- SIDIS
- 3D tomography
- Diffraction
- Gluon saturation
- Open charm



Luminosity ≈ 10^{34}/s/cm^2

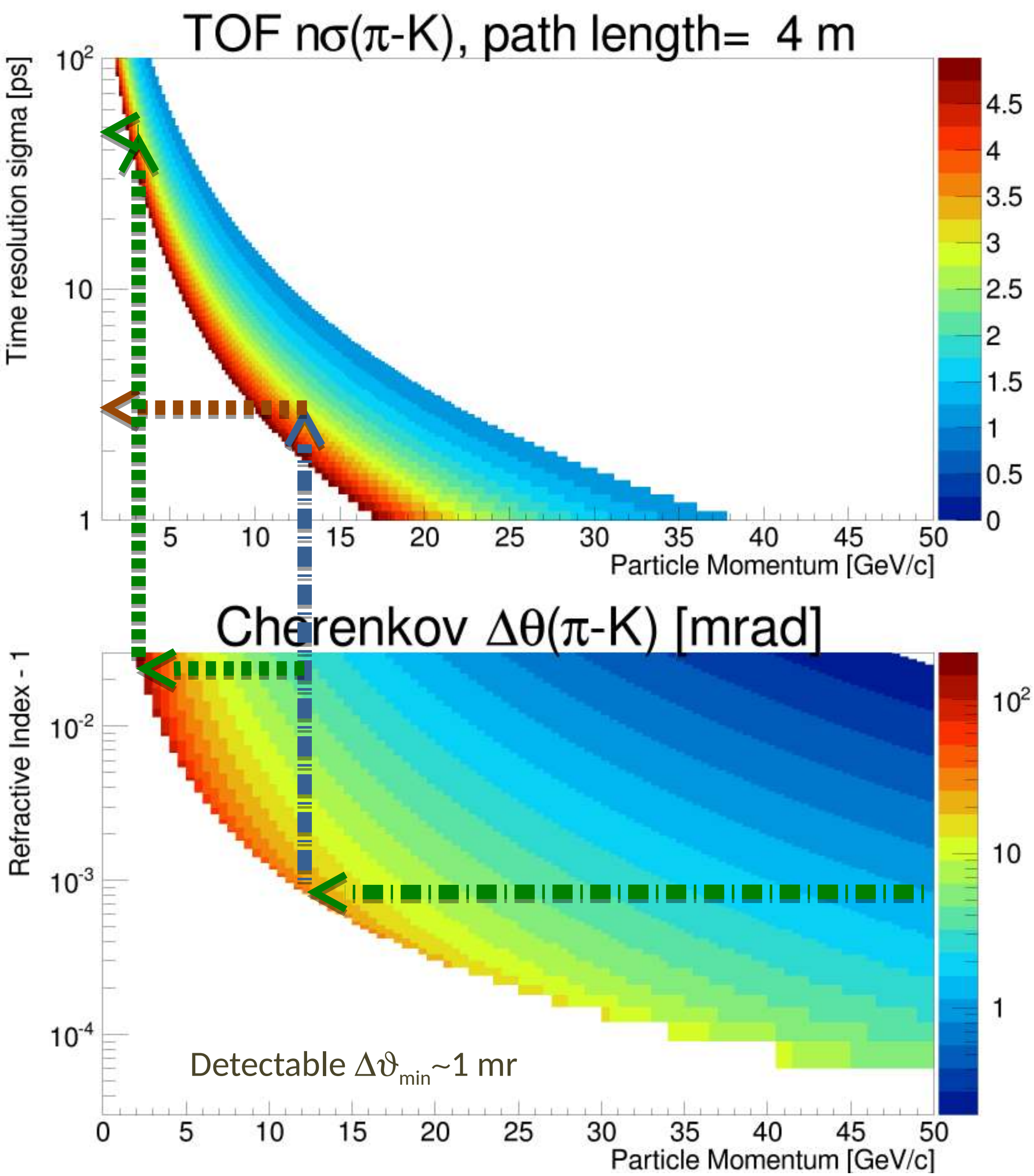
Physics Requirement:

1. **Continuous *π/K/(p) identification up to ~50 GeV/c* in hadron endcap**

Main Technological Requirements:

2. **Geometrical constraints** (relatively small longitudinal space and large transverse space)
3. **Solenoid Magnetic Field**
4. **Radiation levels**

Why a dual radiator RICH in the EIC h-endcap?



Single detector technology cannot cover the whole range up to ≈50 GeV/c with "good" separation of π-K-p

Three main options:

1) TOF+RICH(n1):

   Need challenging time resolution (≈3 ps sigma!)

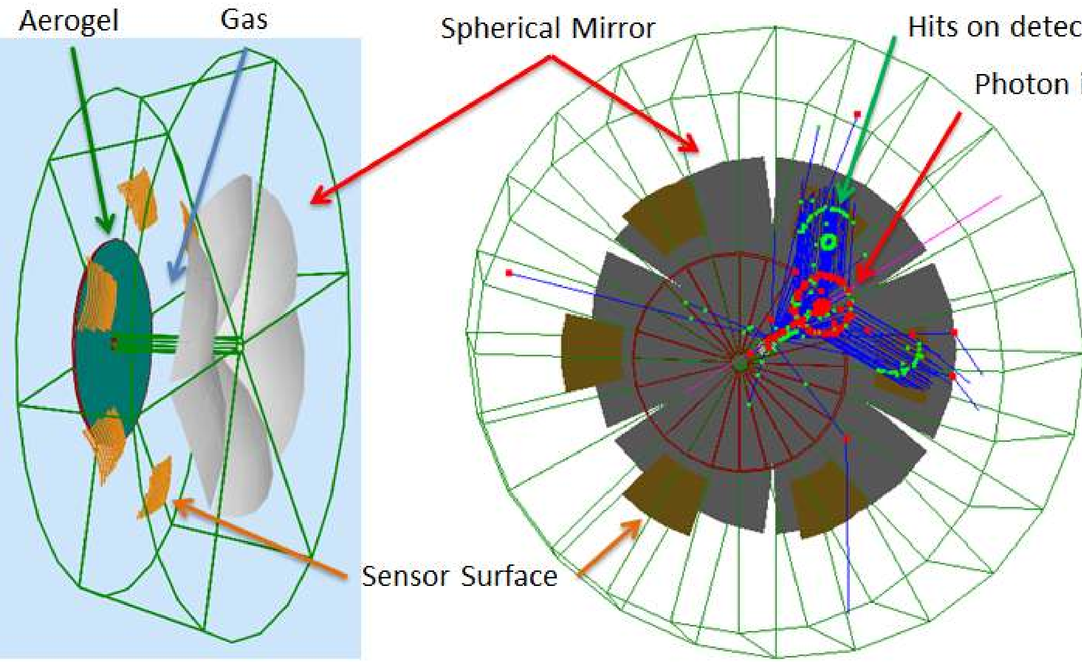
2a) TOF+RICH(n1)+RICH(n2)

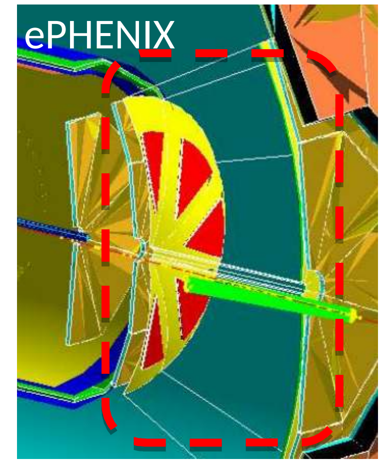
   Expected to be more expensive due to twice the sensors and electronics

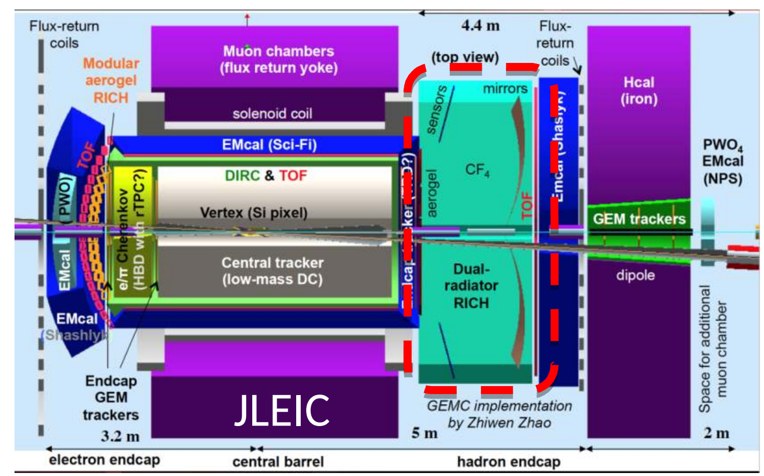
2b) TOF+RICH(n1,n2)

   ... next slides

EIC-eRD14/PID dRICH→YR baseline







Radiators:

- Aerogel: 4 cm, $n_{(400nm)}$~1.02 + 0.3 mm acrylic filter
- Gas: 1.6m (1.1m ePHENIX), n_{C2F6}~1.0008

6 Identical Open Sectors (Petals):

- Large Focusing Mirror with R ~2.9m (~2.0 m ePHENIX)
- Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

Phase Space:
- Polar angle: 5–25 deg (1.5–3.5 eta)
- Momentum: 3–50 GeV/c

A. Del Dotto et al., “Design and R&D of RICH detectors for EIC experiment”, NIM A876 (2017) 237-240

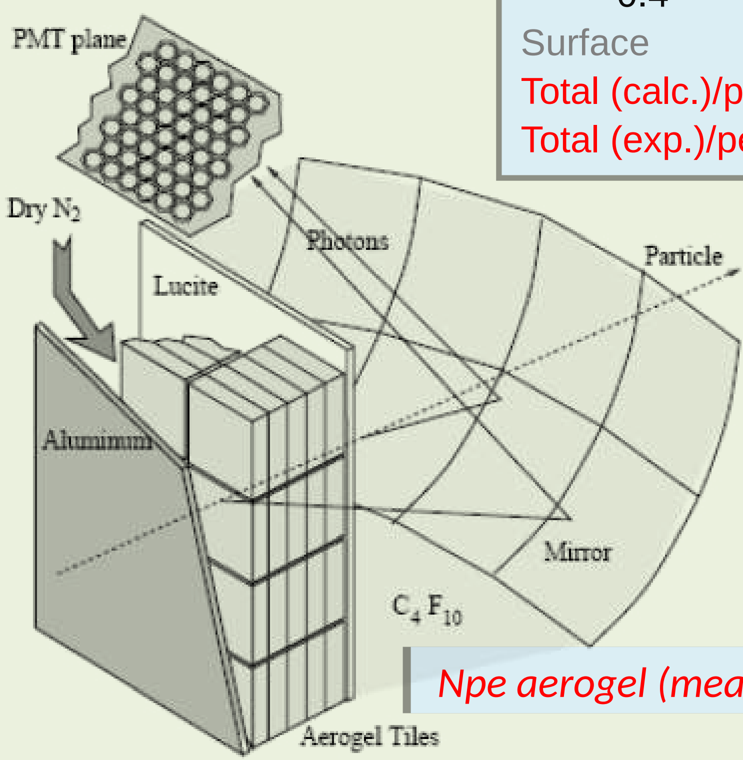
dual-radiator RICH PROs and CONs

- ✔ **>3σ π-K separation in ~3–50+ GeV/c** whole range in RICH mode – as well as large coverage for K-p (and π-e) PID
- ✔ **Photon detector out of acceptance** and far from the beam pipe in moderate magnetic field; less constraints on material budget (e.g. mechanical supports, shielding, cooling); neutron flux is also reduced
- ✔ Expected to be **cheaper and more compact** (also in terms of services) than 2 (or more) detectors solution (sparing on photosensors and related electronics)
- ✔ **Material budget** likely smaller than 2 detectors solution: from CLAS12/RICH-LTCC: $X_0 \approx 1\%$ vessel (no pressurization) + 1% mirror + aerogel, acrylic filter and gas

- ✗ **More demanding PID** respect to single radiator RICH
- ✗ **Aerogel chromatic** performances are critical and need to be well investigated in terms of stability and interference with gases
- ✗ **Gas Procurement** potential issue due to possible ecological restrictions and costs (common to other EIC detectors)

Dual radiator aerogel-gas RICHes so far

HERMES RICH

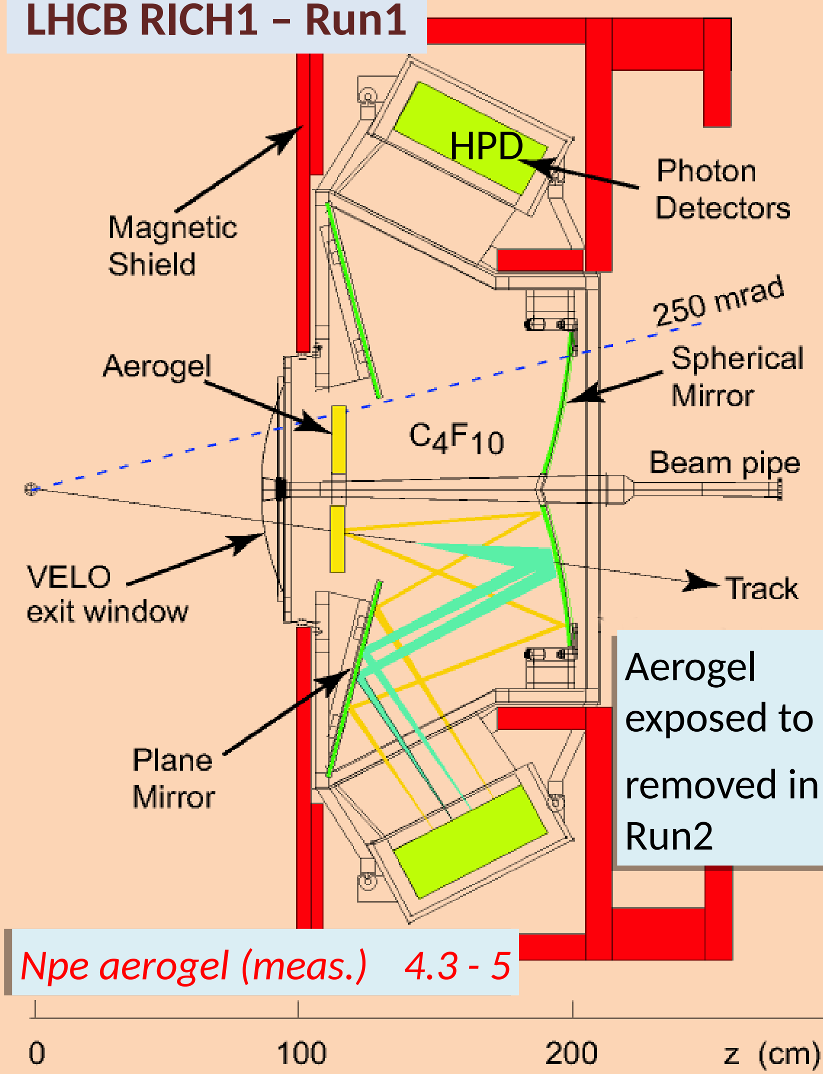


Angular resolution

Pixel	**2.3**
Chromatic	**1.3**
Point emiss.	0.7
Mirror	0.6
n spatial disp.	0.5
Forw. scatt.	0.4
Surface	0.4
Total (calc.)/pe	2.9
Total (exp.)/pe	3.3

Npe aerogel (meas.) ~10

LHCB RICH1 – Run1



Aerogel exposed to gas;

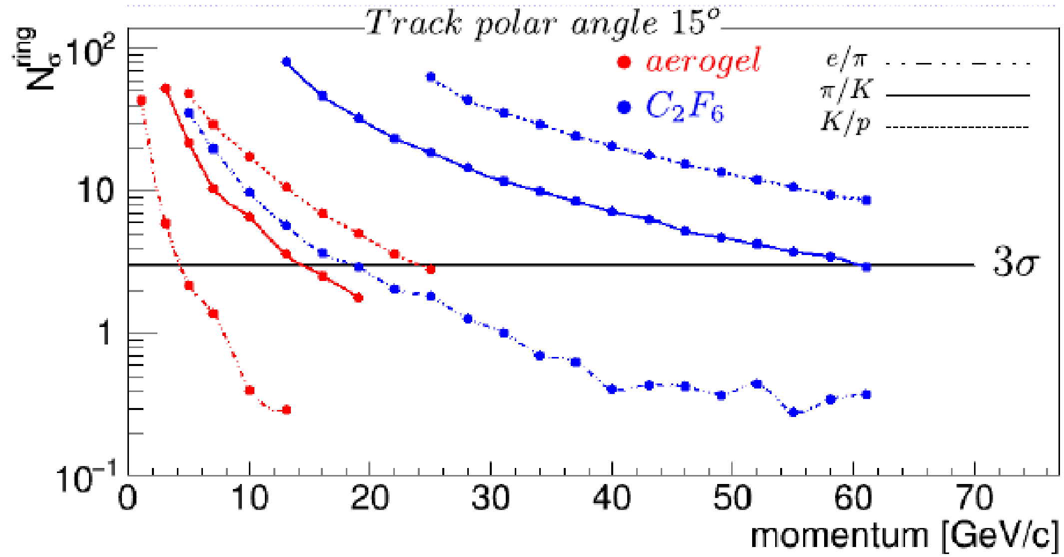
removed in Run2

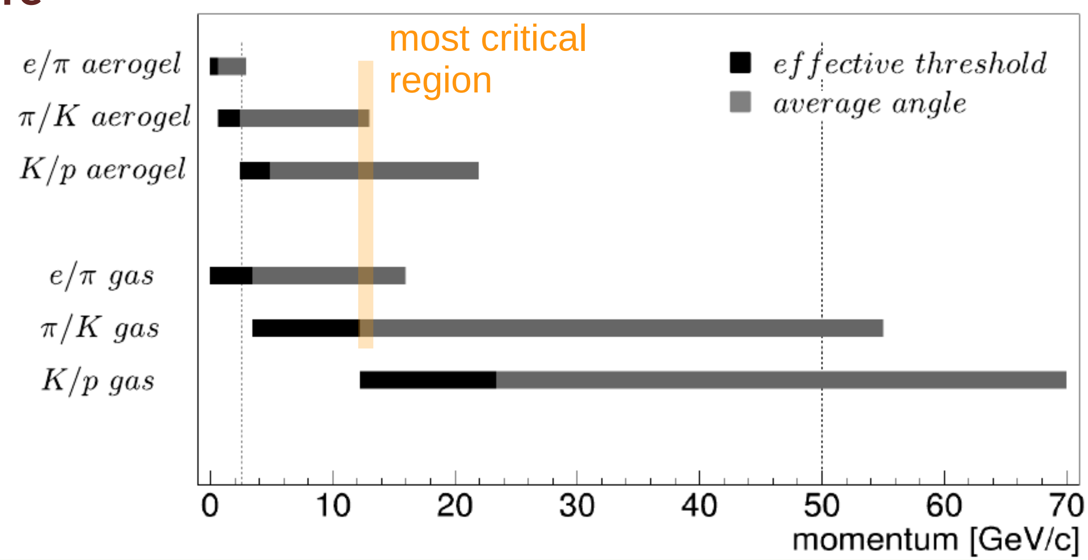
Npe aerogel (meas.) 4.3 - 5

Underestimation of aerogel stability in freon gas?
Large multiplicity and relative large background?

dRICH baseline MC performance

- Montecarlo: GEMC (Geant4)
- Aerogel Optical properties from CLAS12 RICH data, scaled to 1.02
- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh
- Gas number of photons normalized by 0.7 factor from «poor» literature
- Include 3T central magnetic field
- Mirror quality from CLAS12
- QE from realistic CLAS12/PMT measurements (200-500 nm)
- Cherenkov Angle reconstruction based on Inverse Ray Tracing

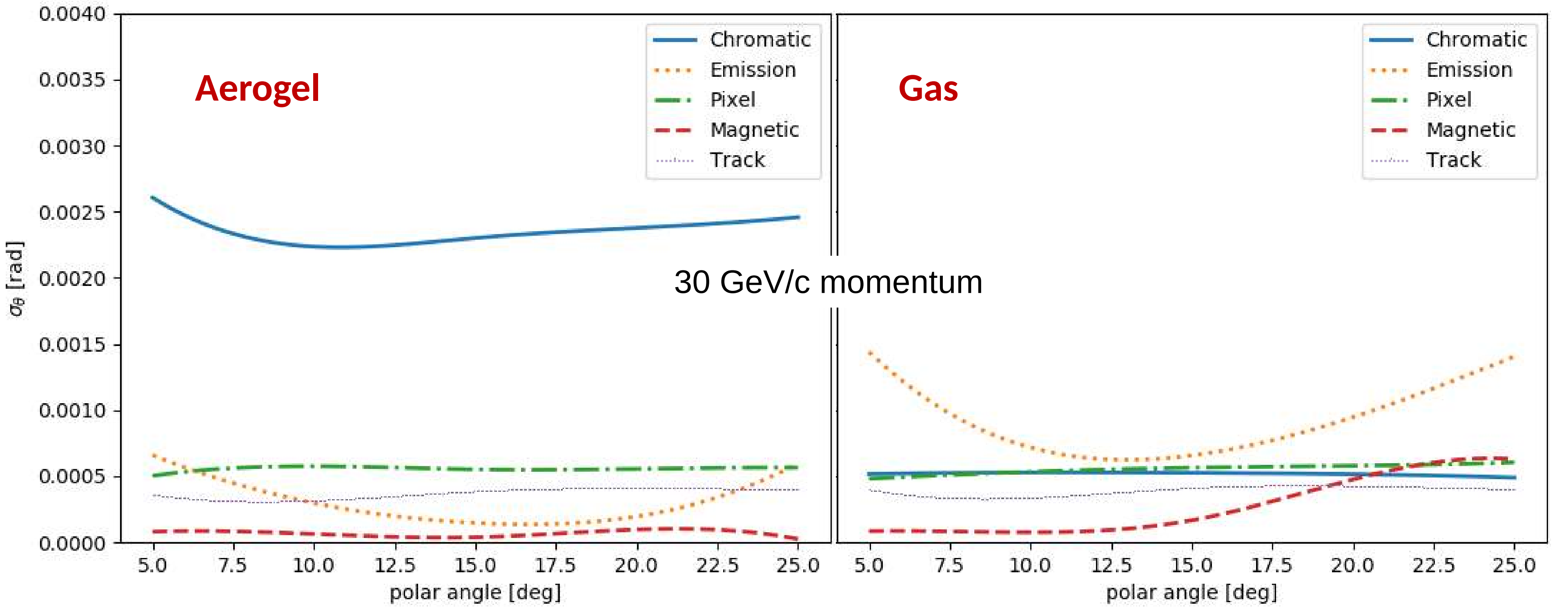




Hadron identification (π/K/p, better than 3 sigma apart); continuous coverage from ~3 up to ~50 GeV/c for π/K and up to ~15 GeV/c for e/π

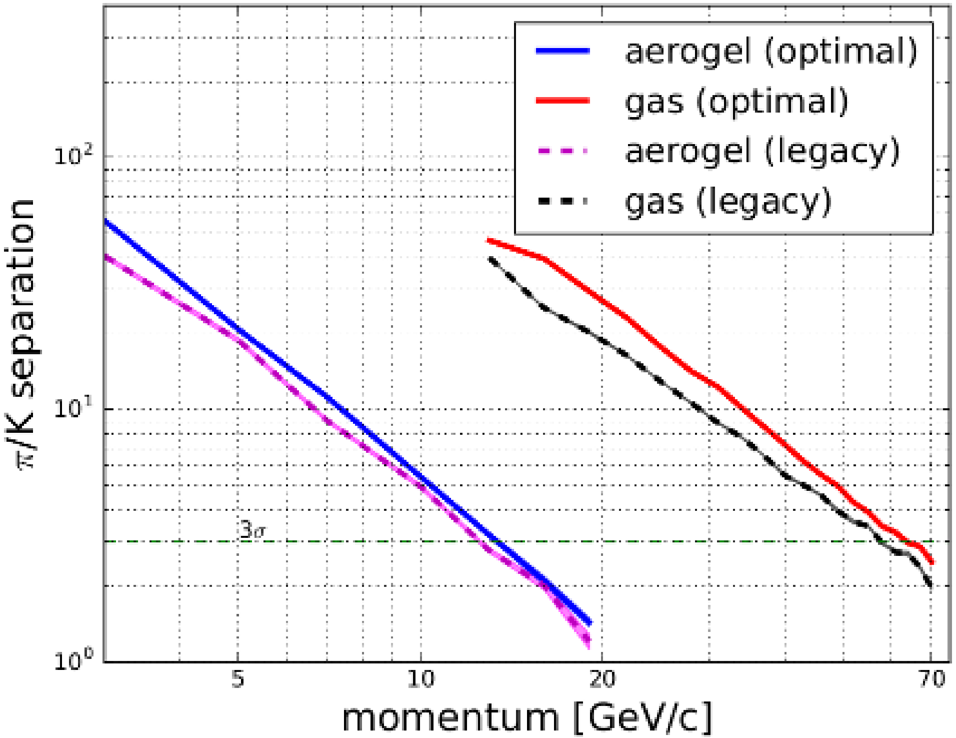
Contributions to Cherenkov Angle Resolution

- Tracking accuracy 0.5 mrad
- Photo sensor (CLAS12/PMT) surface "optimized" (slightly curved)
- 3T central Magnetic Field (in JLEIC)
- 1.6 m gas (similar results down to about ~1 m)



Bayesian Optimizer in dRICH design

Use Bayesian Inference to efficiently maximize proper Figure of Merit:
π-K Cherenkov angles separation in critical phase space regions
(e.g. TOF-aerogel, aerogel-gas transitions, high momentum limit ...)



Full π/K/p separation from ~3 to 60 GeV/c

parameter	**description**	**range** [units]
R	mirror radius	[290.0,300.0] [cm]
pos r	radial position of mirror center	[125.,140.] [cm]
pos l	longitudinal position of mirror center	[-305.,-295.] [cm]
tiles y	shift along y of tiles center	[-5,5] [cm]
tiles z	shift along z of tiles center	[-105,-95] [cm]
tiles x	shift along x of tiles center	[-5,5] [cm]
$n_{aer.}$	refraction index of aerogel	[1.015,1.03]
$t_{aer.}$	aerogel thickness	[3.0,6.0] cm

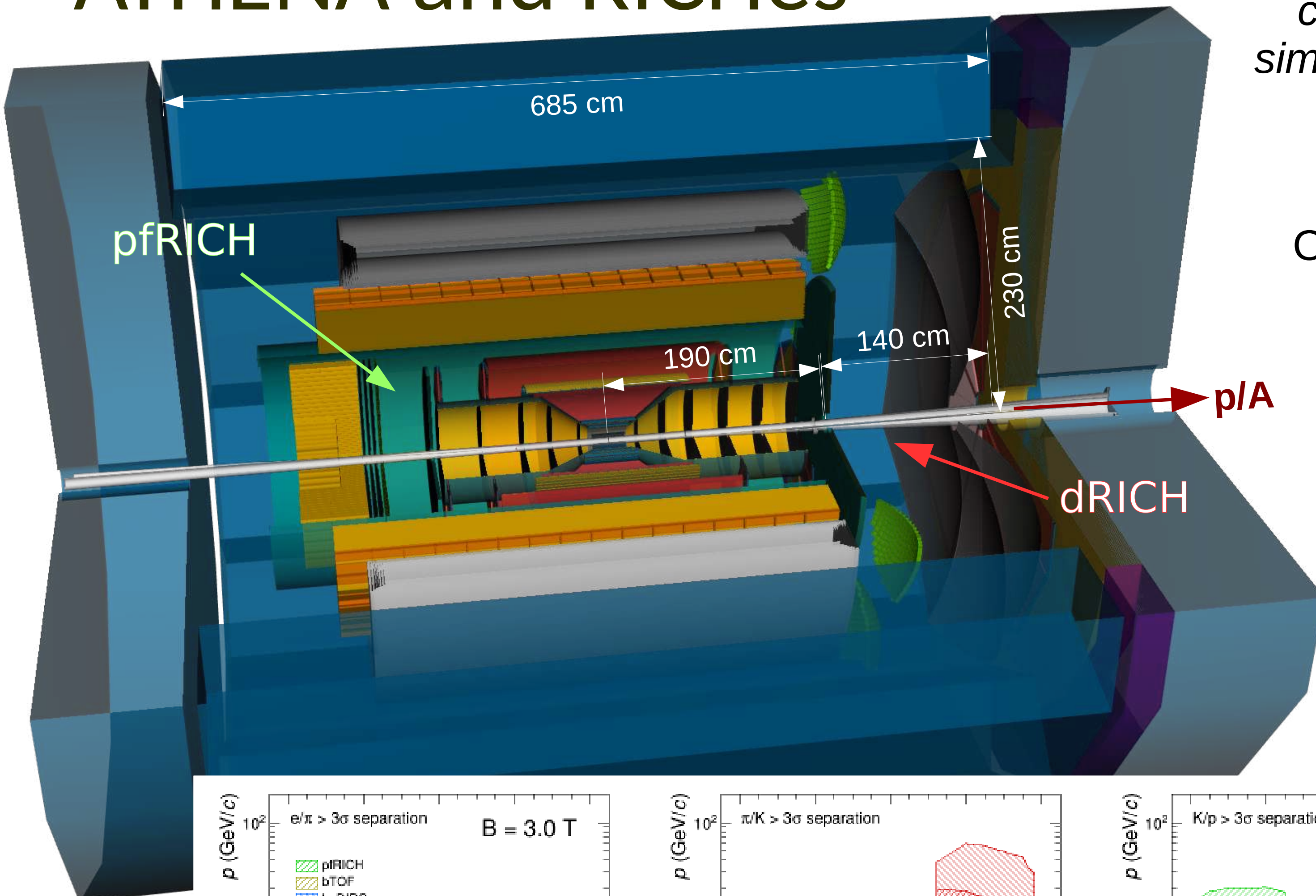
First implementation used 8 “free” parameters, but is not limited to them.

The optimization approach can be ported to any detector (or combination of detectors) development where a detailed MonteCarlo exists and is parameterizable

J. Inst., vol.15, P05009 - May 2020 doi: 10.1088/1748-0221/15/05/P05009

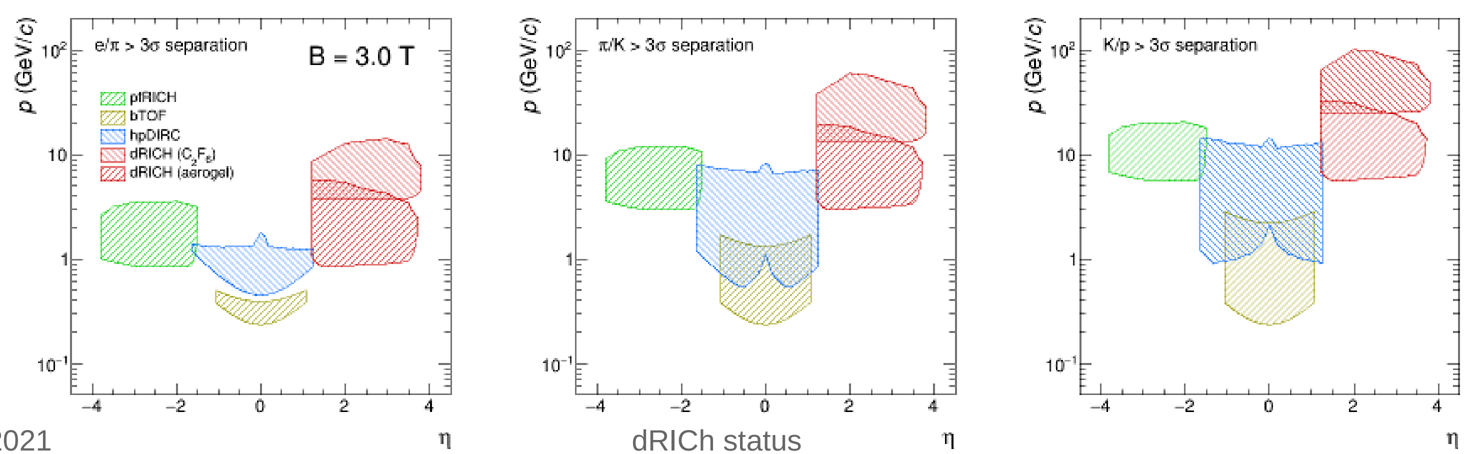
ATHENA and RICHes

"In general, the dRICH configuration is very similar to the one from the Yellow Report"

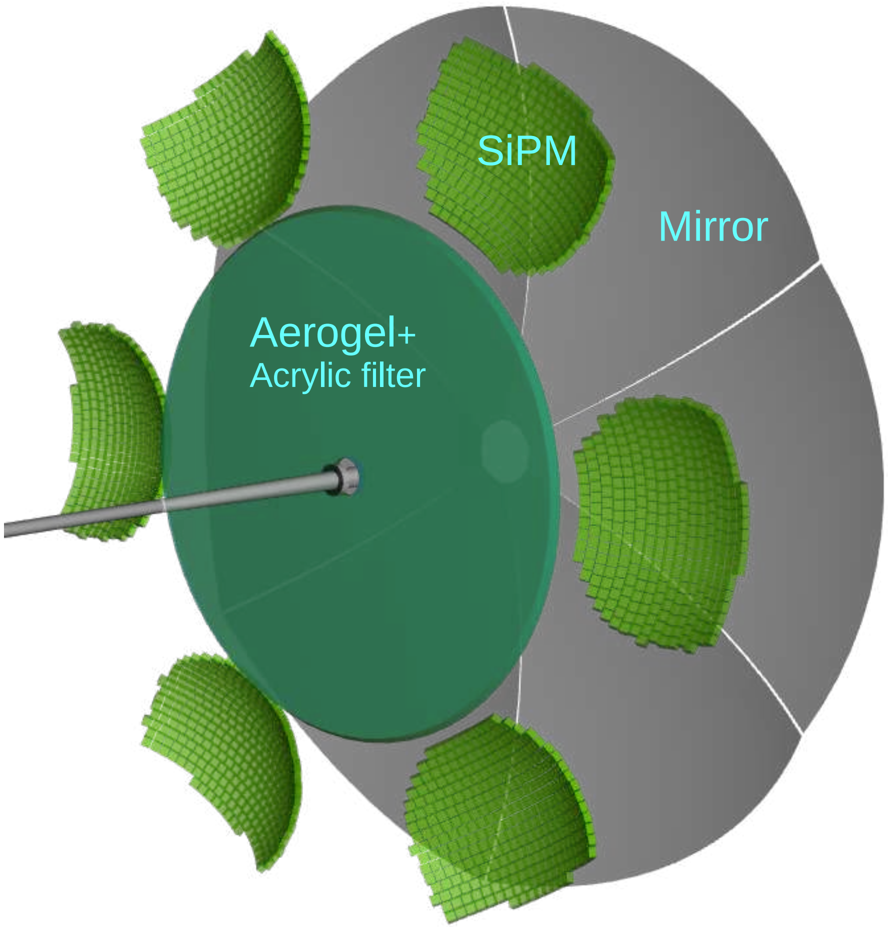


Optics and *solenoid fringe field* mainly constrained size and position

C. Chatterjee tomorrow Talk



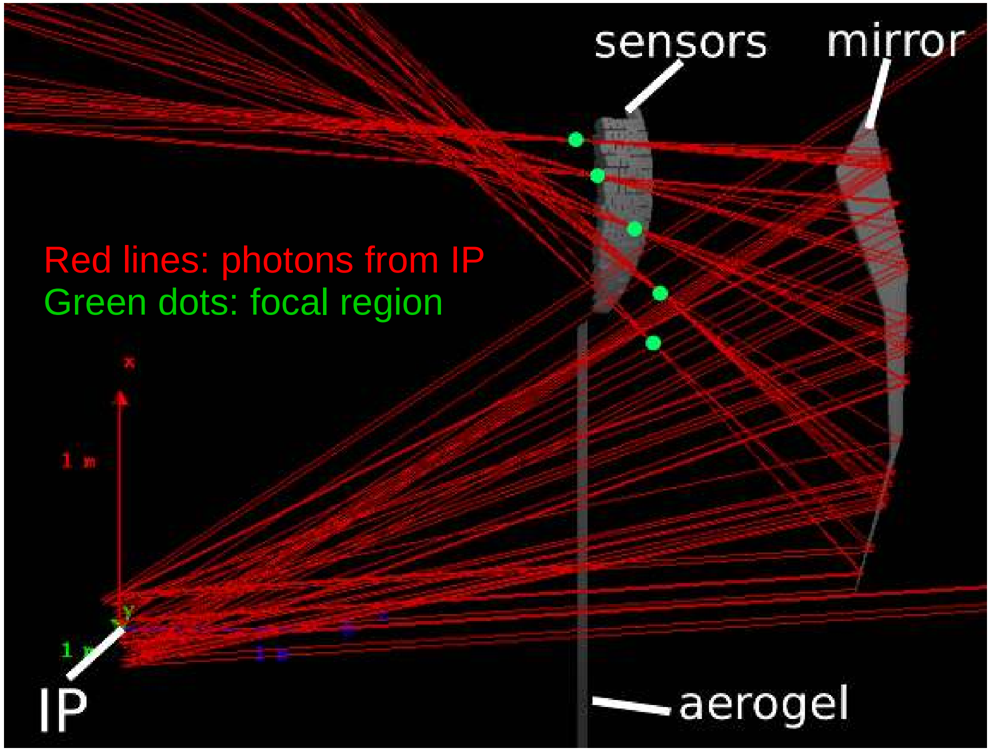
ATHENA dRICH – geometry and optics



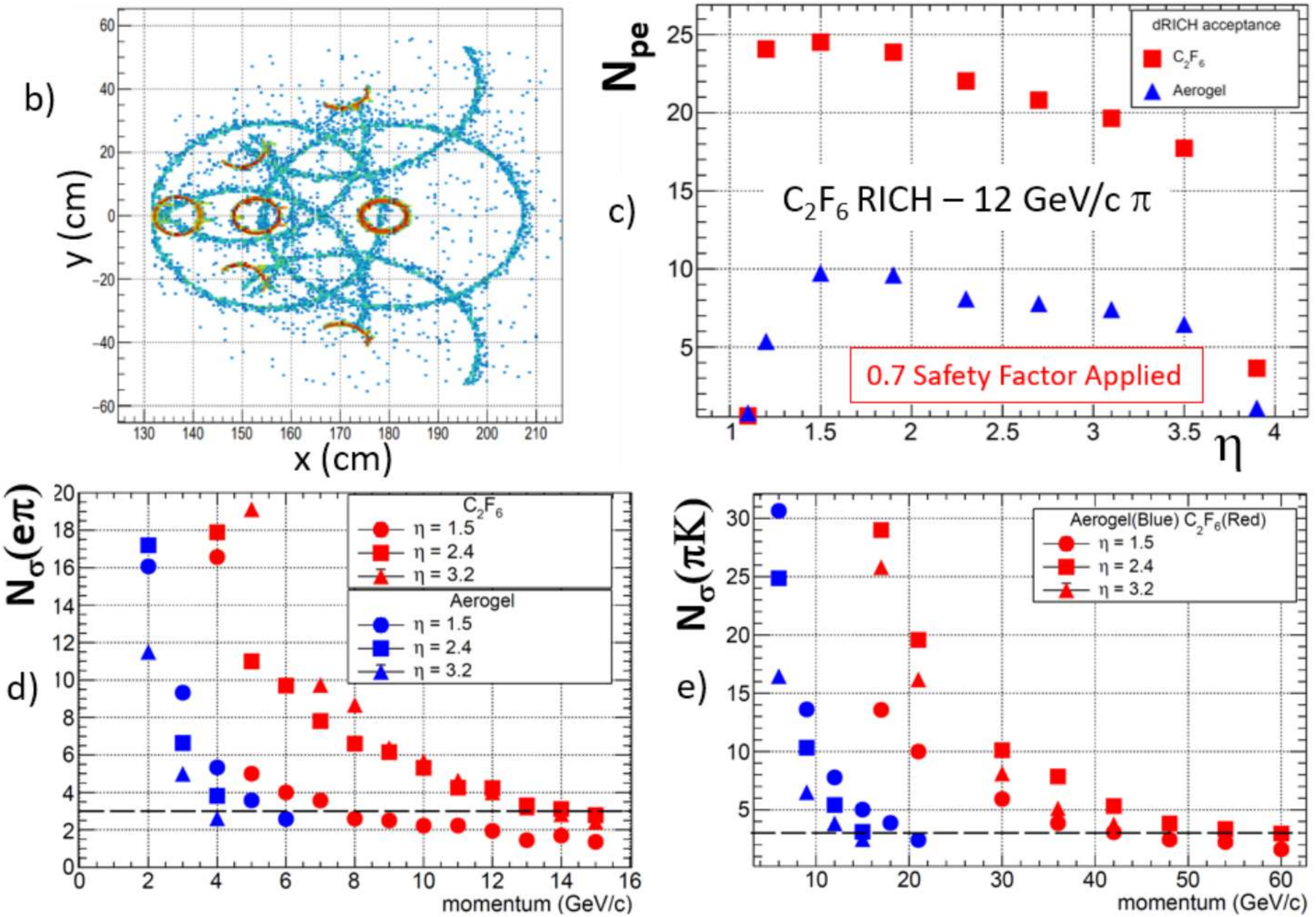
C2F6 gas fill the ~140 cm aerogel-mirror gap

dd4hep simulation and optimization by C. Dilks and A. Kiselev

- SiPMs (3 mm pixel) on spherical surface, above the aerogel
- Mirror “points” photosensor centroid shifted by two focusing parameters to maximize focal region to sensor surface

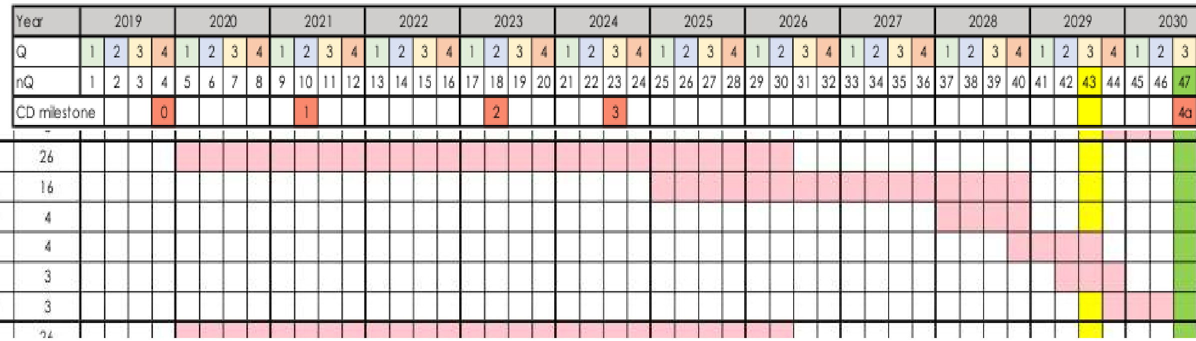


ATHENA dRICH – Performances



- **YR forward region PID requirements generally fulfilled**
- Eta lower bound slightly larger than goal of 1 (not an issue due to DIRC overlap)
- $e\pi$ PID momentum limit lower than desired 15 GeV/c (further magnetic field tuning may helps)

ATHENA dRICH – Timeline and Estimated Costs



81	dRICH R&D	1/1/20	2020	6/30/26	2026	26
82	dRICH: Procurement	1/1/25	2025	12/31/28	2028	16
83	dRICH: Assembly (In-House)	1/1/28	2028	12/31/28	2028	4
84	dRICH: Assembly (in-situ)	10/1/28	2028	9/30/29	2029	4
85	dRICH: Test (in situ)	6/1/29	2029	12/31/29	2029	3
86	dRICH: Installation	12/1/29	2029	6/30/30	2030	3

Estimated R&D costs:

Materials: 0.47 MUSD, in kind: 54%
Labor: 1.9 MUSD, in kind: 79%

Estimated Construction costs:

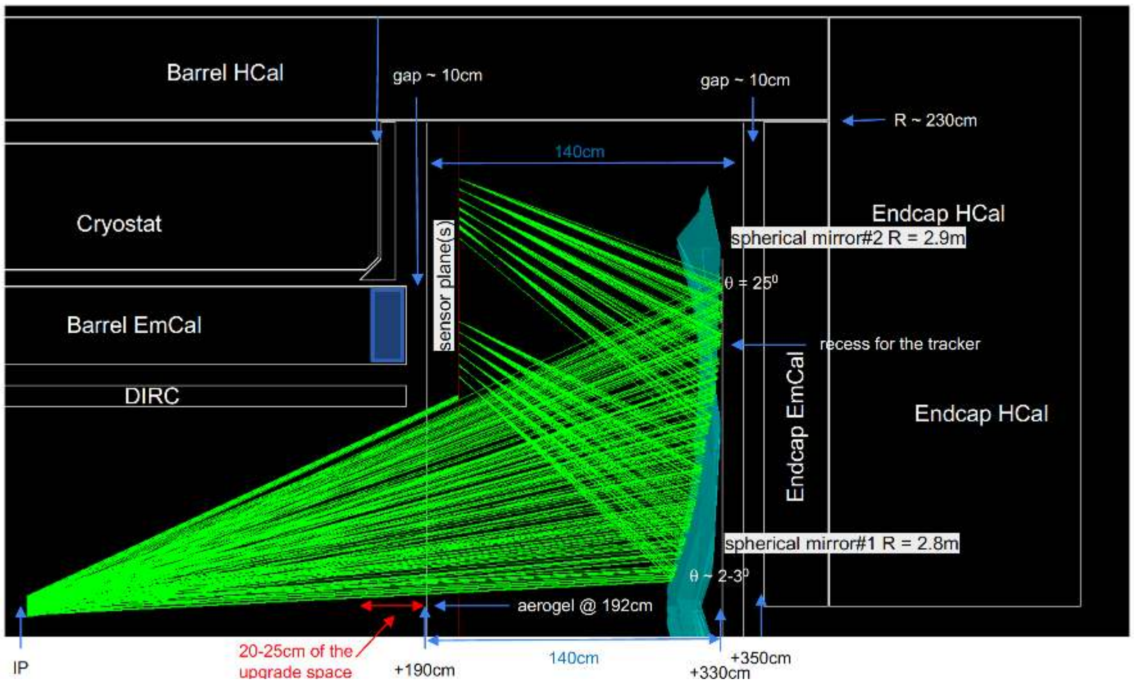
Materials: 8.8 MUSD, in kind: 61%
Labor: 3.2 MUSD, in kind: 69%

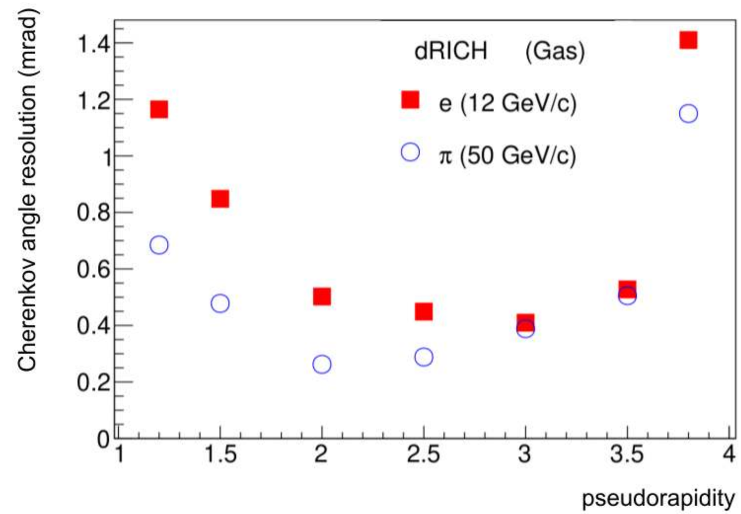
Estimated construction material costs	
Component	%
Sensors (SiPM)	18
Power Supply for Sensors (SiPM)	5
Electronics, PS, services	30
Aerogel Radiator	5
Gas assume C2F6 (with 0.2 M$ for recollection system)	4
Mirrors (with coating) fiber reinforced polymer	12
Mechanics (vessel, mirror and readout supports, etc.)	13
Mirror alignment system	7
Cooling system	6

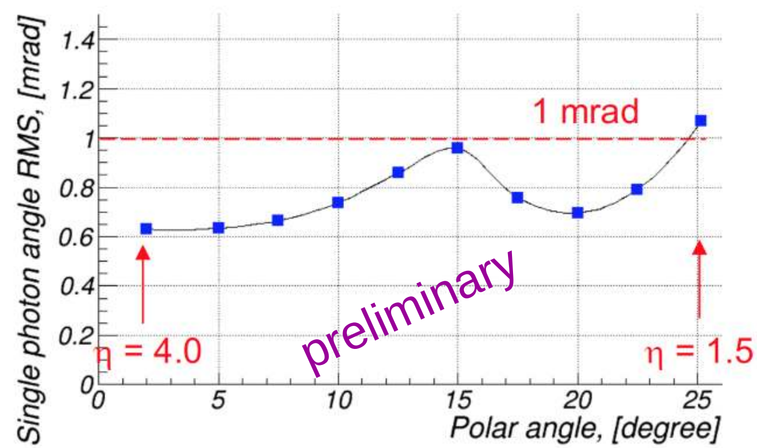
(material costs breakdown from 15/Oct/21)

ATHENA dRICH – toward further improvements

- Segmented single sector mirror with different radii to better match focal region with sensor region







C. Chatterjee et al. “Supplemental Material for ATHENA detectors”

wiki.bnl.gov/athena/index.php/Particle_Identification

… further development steps

Physics Event Reconstruction

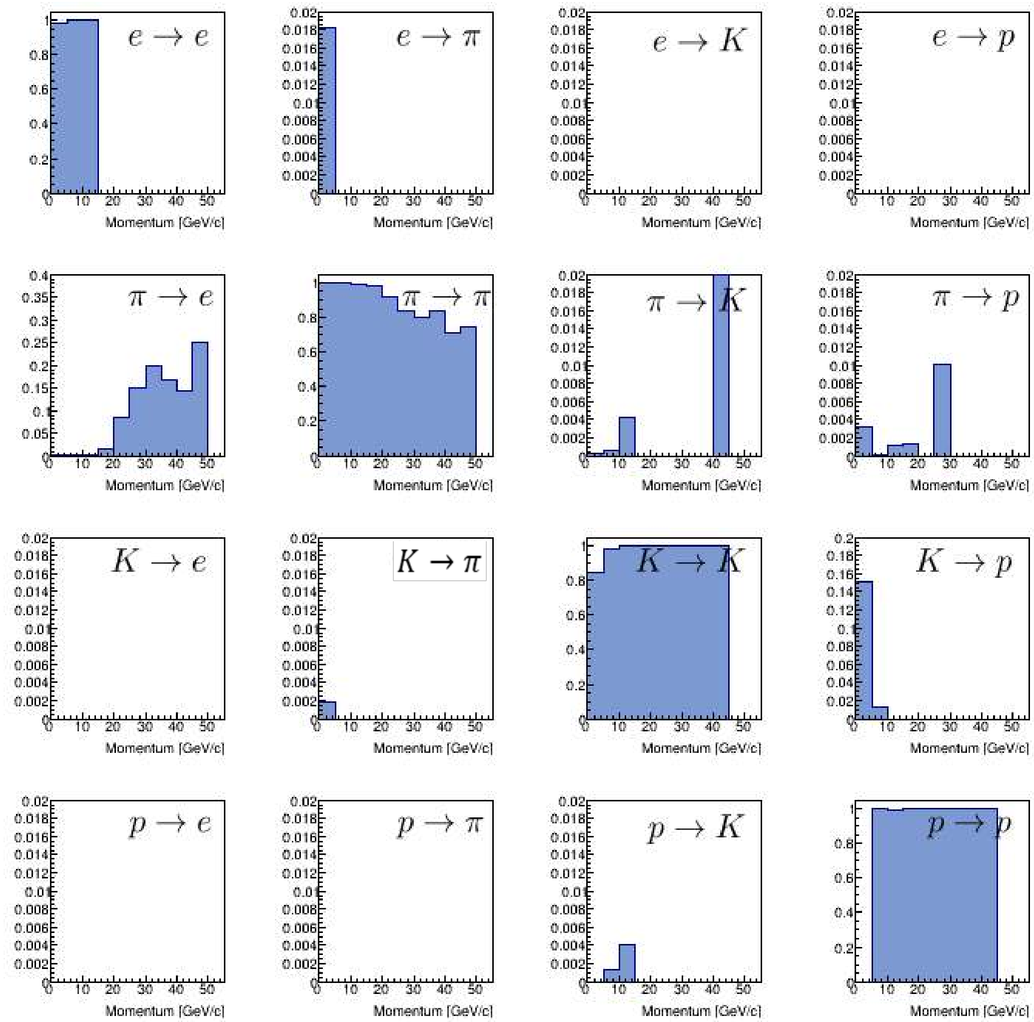
JLEIC attempt based on Inverse Ray Tracing

PYTHIA-DIS events: ≈ 20% with multiple tracks & overlapping rings

Implemented efficient event based reconstruction method:

it maximizes 2 likelihood functions in sequence to reduce significantly the computational efforts

L. Barion et al., 2020 JINST 15 C02040



Example: event with 2 tracks and 15 hits

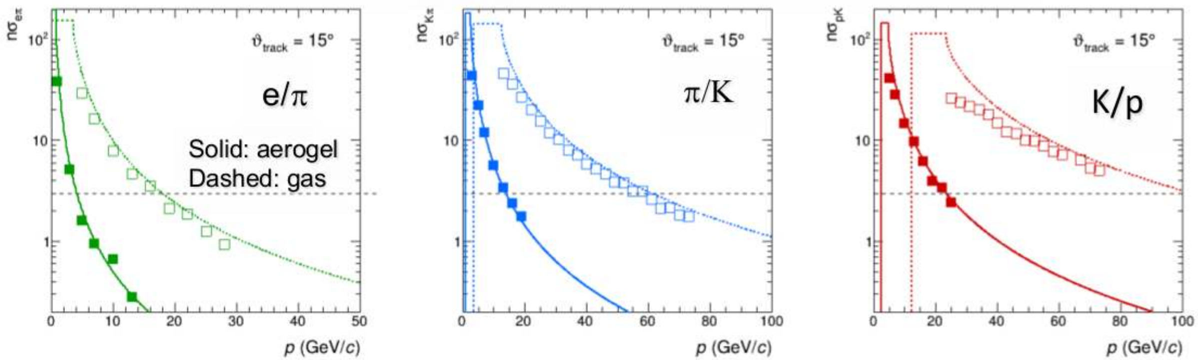
Brute Force: up to **~488 billion** combinations
Our approach: **1200** combinations
… and it seems to perform pretty well (see above)

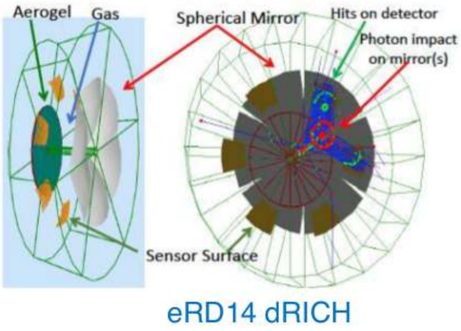
dRICH in CORE Proposal

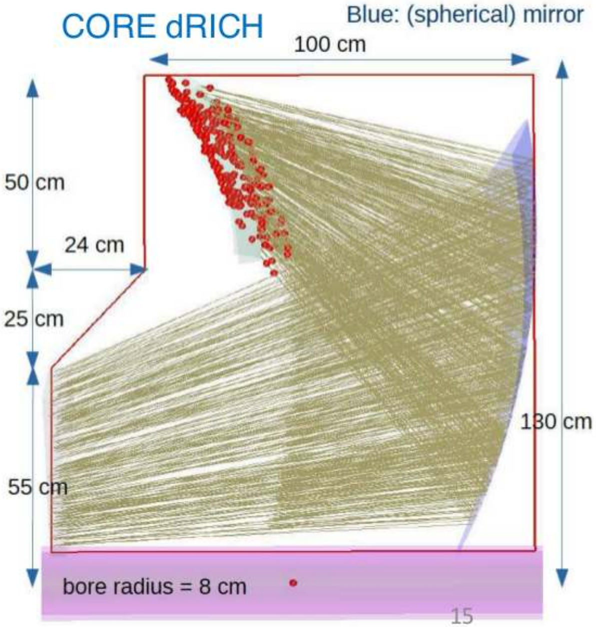
From Pawel Nadel-Turonski and Charles Hyde presentations (13-14/Dec/2021 EIC Detector Proposal Advisory Panel Meeting)

PID in the hadron endcap – dual-radiator RICH

Performance of the dRICH developed by the EIC PID consortium (eRD14)







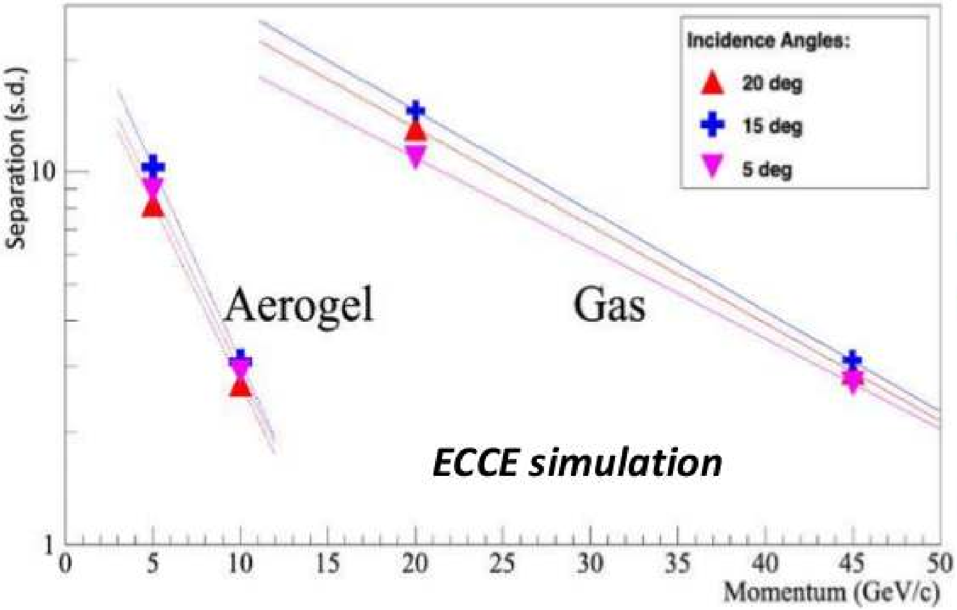
- The CORE dRICH is a smaller version of the eRD14 design
  - Most dimensions were scaled by a factor 2, but the length of the gas along the beam was only reduced from 1.6 m to 1.2 m (25%).
  - The resulting geometry provides a good match to the photosensor plane and a photon yield almost as high as the eRD14 dRICH
  - The 55 cm aperture matches the inner radius of the barrel EMcal
- The CORE dRICH performance should be close to that of the original eRD14 dRICH, with continuous π/K coverage in RICH mode for 2-50 GeV/c, and positive pion ID below kaon threshold.

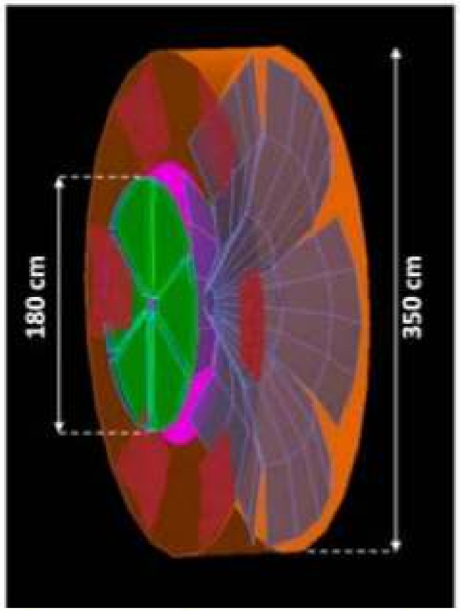
Sub-system	Primary Responsibility	Key Participants	Potential Source of Support
Solenoid	P. Brindza (ODU/JLab)		JLab/BNL Magnet Groups
Silicon tracker	S. Bueltmann (ODU)		EIC Silicon consortium
MPGD	M. Hohlmann (FIT)	K. Gnanvo (JLab)	JLab Detector Group
DIRC	G. Kalicy (CUA)	J. Schwiening (GSI)	PANDA DIRC Group (GSI)
dRICH	K. Joo (UConn)		CFNS @ Stony Brook, PID consortium

dRICH in ECCE Proposal

From Tanja Horn and Or Hen presentations (13-14/Dec/2021 EIC Detector Proposal Advisory Panel Meeting)

Use a combination of aerogel and C_mF_n with indices of refraction matching EIC momentum range in the forward endcap. Similar to LHC-b, HERMES, JLAB/Hall-B, …





Region	System	Technology	Institutions	Experience / Comments
Forward Endcap (Hadron direction)	Tracking	ITS-3 Si Disks	LANL, LBL, ORNL, MIT/BATES, EIC-China, EIC-Taiwan, EIC-Korea, Brunel (UK), Regina (Canada), Czech. Tech. Univ., BNL	Experience constructing previous Si trackers, most recently for sPhenix.
		AC-LGAD	RICE, ORNL, BNL, UTSM	Experience in CMS
	PID	dRICH	UConn, Duquesne, Duke, JLab, Tsinghua/China	E&D (strong engineering) Simulations (Hall B RICH, Hall A/SBS RICH), HERMES RICH refurbishment
	EM Calorimetry	Longitudinally segmented, scintillating tile	ORNL, ISU, Ohio U., EIC-Japan, EIC-Korea, EIC-China, BNL	Experience with calorimeters in sPHENIX and ALICE
	Hadron Calorimetry			

dRICH Key Hardware Components

Component	Function	Specs/Requirements	Critical Issues / Comments
Mechanics	Support all other components and services Keep in position and aligned	Large volume gas and light tightness; alignment of components	Technically demanding but feasible; no major challenges expected
Optics (Mirrors)	Focus (expecially for gas) and deflect photons out of particle acceptance and reduce sensor surface	sub-mrad precision reflectivity ≥ 90% low material budget	Spherical mirrors technology of CLAS12 suitable (optical fiber and/or glass skin); similar geometry; **Development for cost reduction**
Aerogel Radiator	Cover Low Mom. Range between TOF and Gas	≥3σ π-K separation up to Gas region (~13 GeV)	Procurement: currently 1 active provider (2 main producers + 1 potential) **Long term stability assessment in conjunction with gas**
Gas Radiator	Cover High Mom. Range above Aerogel	≥3σ π-K separation up to ~50 GeV and overlap to aerogel	Greenhouse gas: potential procurement issue **Search for alternatives, e.g. Pressurized Argon**
Photon Detector	Single photon spatial detection	Magnetic field tolerant and radiation hardness; ~ few mm spatial resolution	MCP-PMT is likely doable, but expensive. LAPPD may represent an alternative. **R&D on SiPM:** a promising, quicky improving, wordwide pursued, and cheap technology.
Electronics	Amplify and shape single photon analog signal, convert to digital, transfer to DAQ nodes	Low noise Time res. < 0.5 ns μs signal latency	MAROC3 based readout available for prototyping; final choice will depend on sensor. **ASIC development for optimised streaming readout (discrimination vs sampling)**

dedicated R&D in progress on:

detector prototyping, photon sensor selection and characterization, electronics

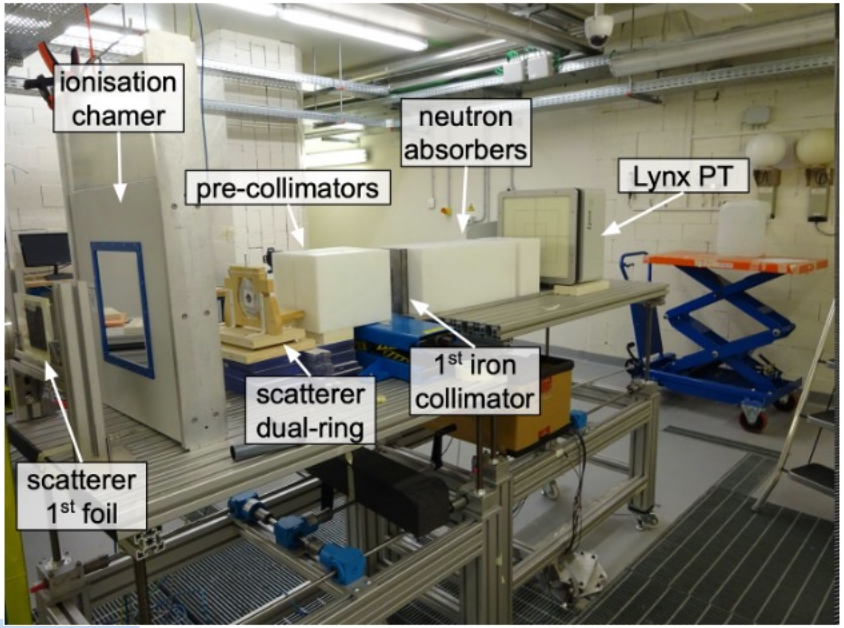
(aerogel, photon sensor and electronics R&D essentially shared with pfRICH)

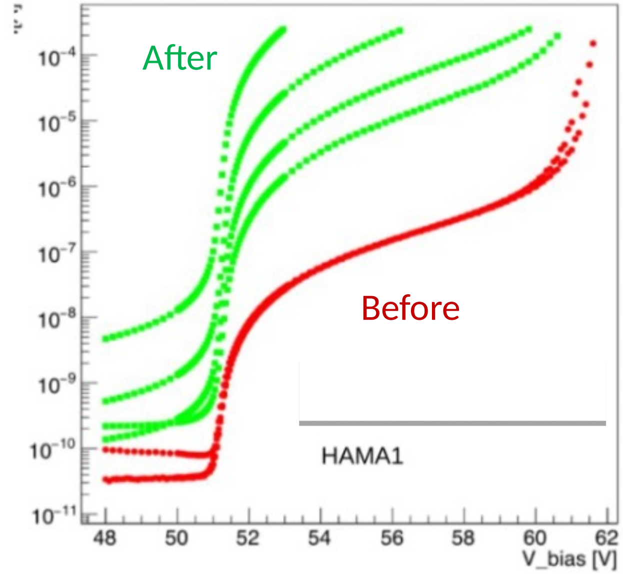
SiPM Characterization and Curing

R. Preghenella
tomorrow Talk

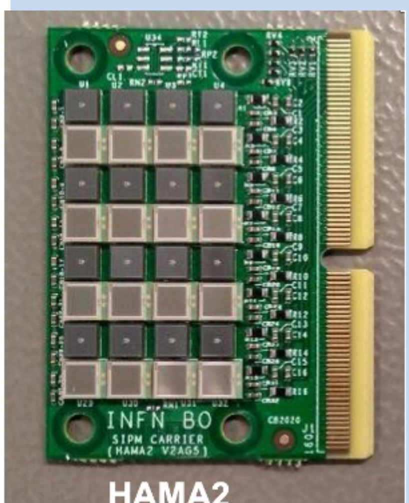
TIFPA
Proton
Beam
Facility

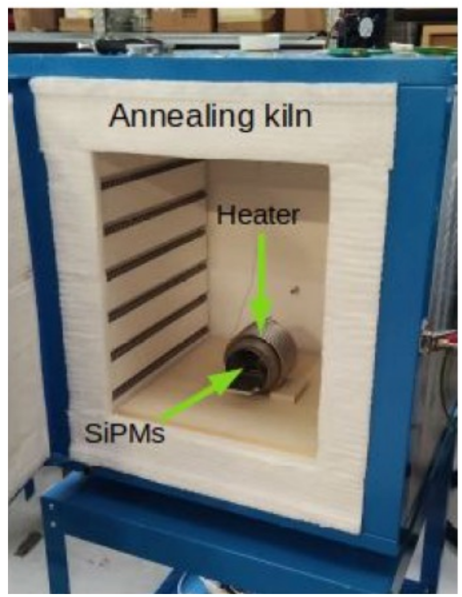
Collimated
Beam
10^9-10^{11} n_{eq}



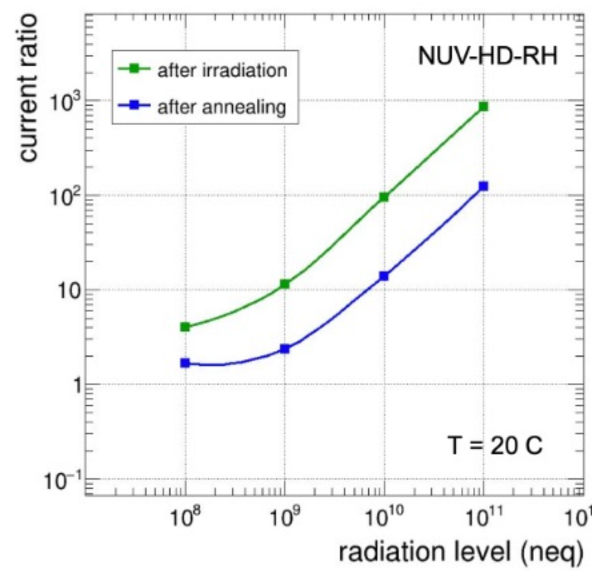


Various SiPM



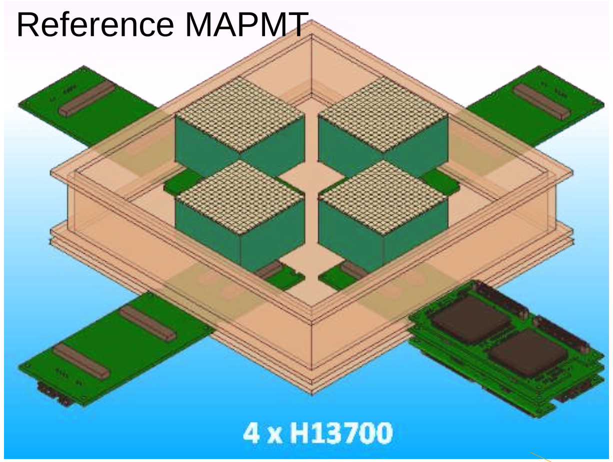


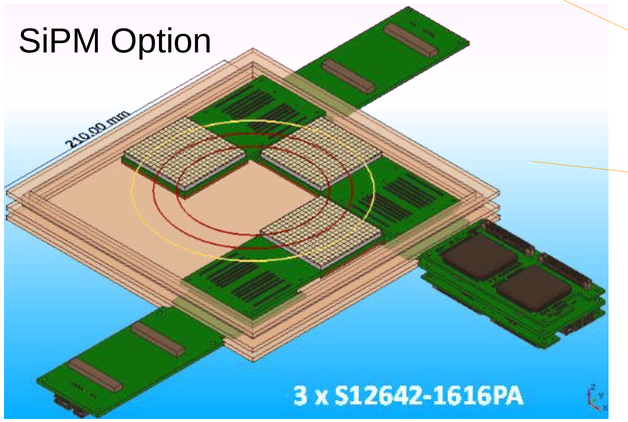
from M. Contalbrigo

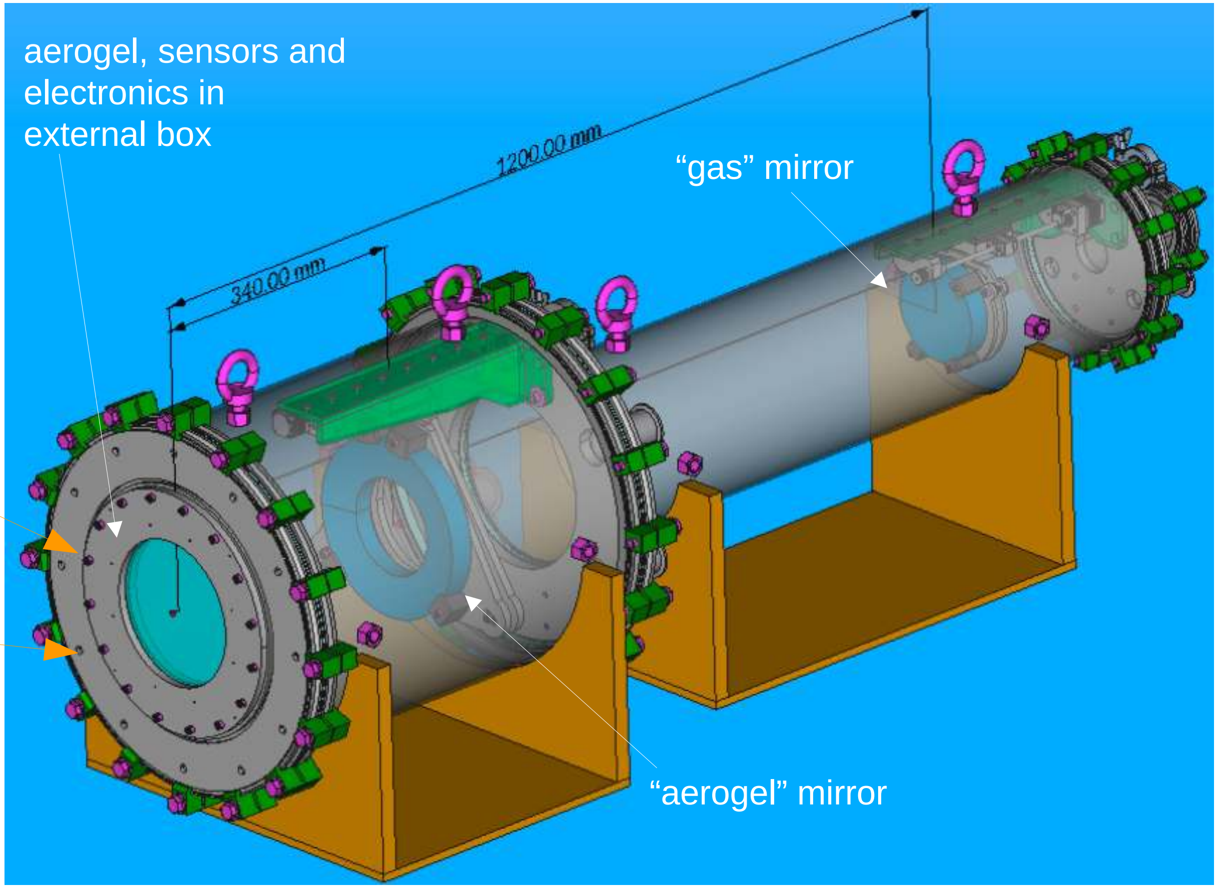


Prototyping

adapted from M. Contalbrigo







Dual radiator imaging

Pressure vessel for gas & n tune

Sensor & readout friendly

Goals:

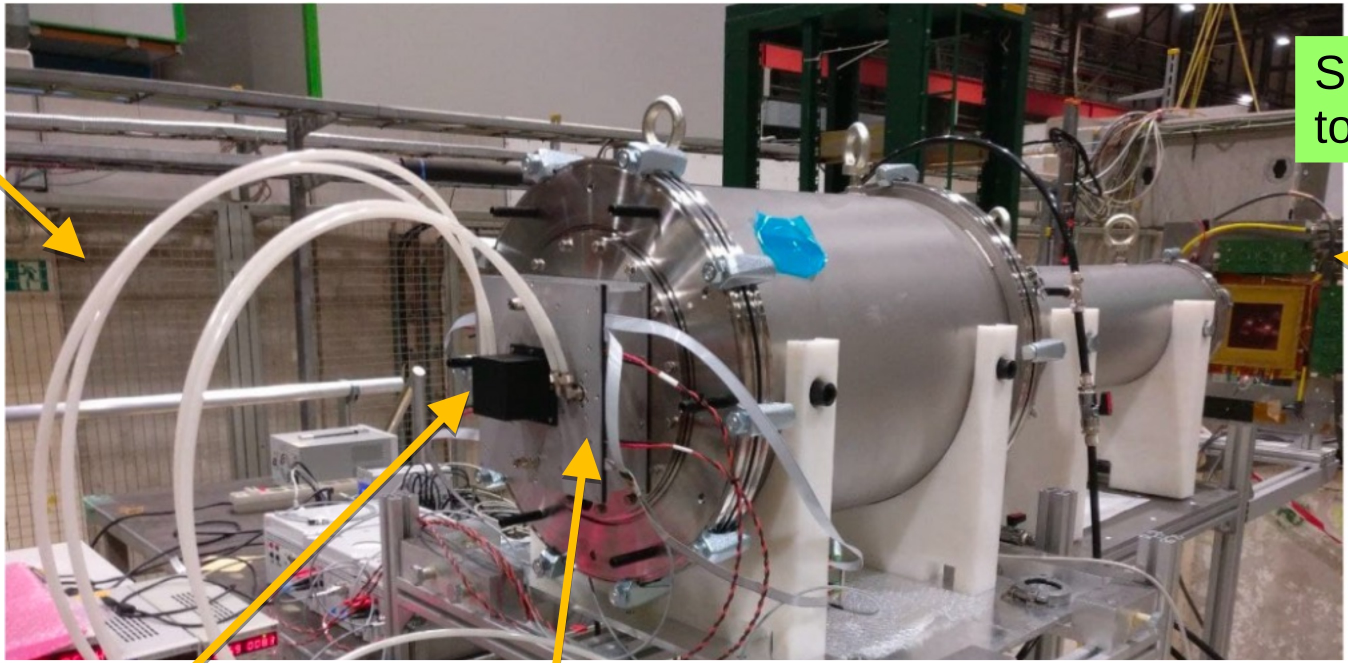
- Study dual radiator performance and interplay
- Study specifications and alternatives for optical components
- Test alternate single-photon detection systems
- First test-beams Sep. & Oct./21 at CERN (synergy with ALICE at PS T10)

Prototype Beam Tests @CERN

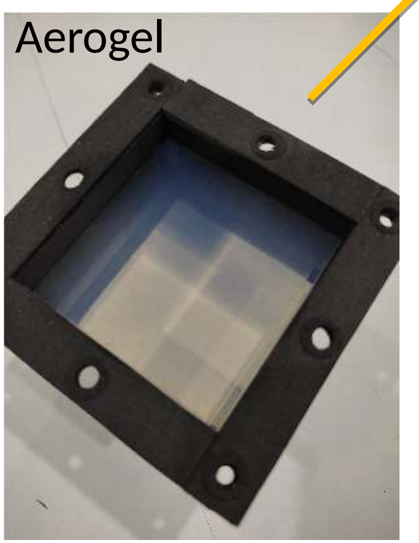
adapted from M. Contalbrigo

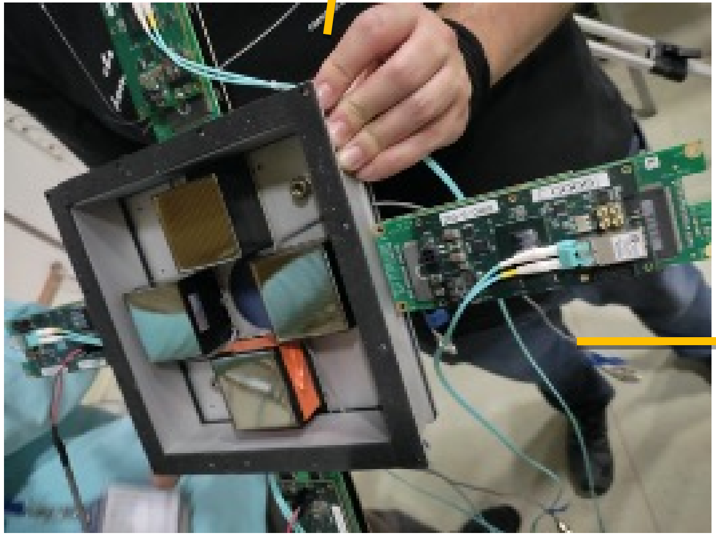
S. Vallarino tomorrow Talk

Cooling

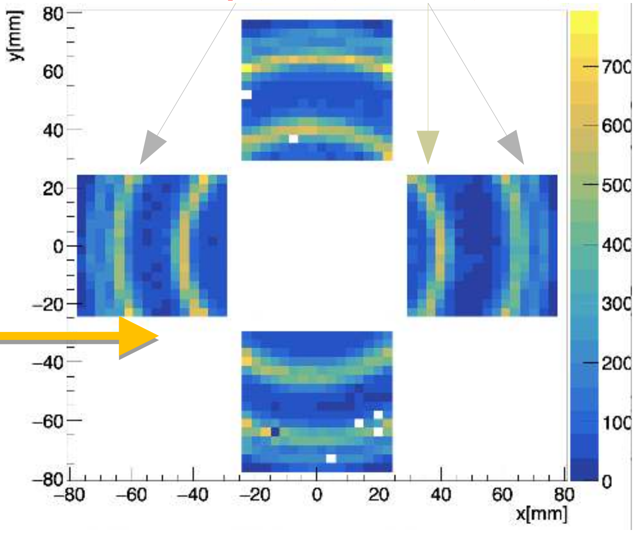


Tracking GEM (also in front)





12 GeV/c - p (70%) and π+ (30%)



Prototype Beam Test: SiPM+ALCOR Readout

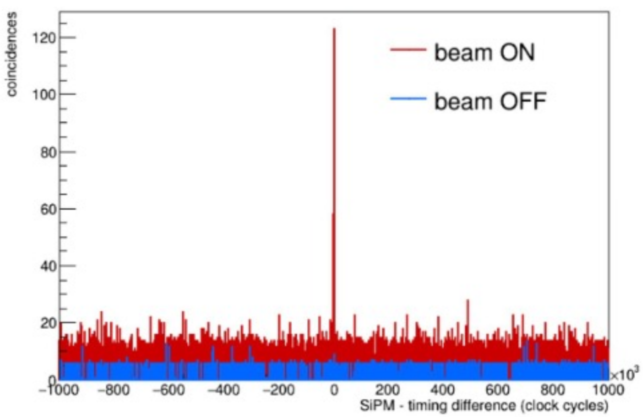
@CERN

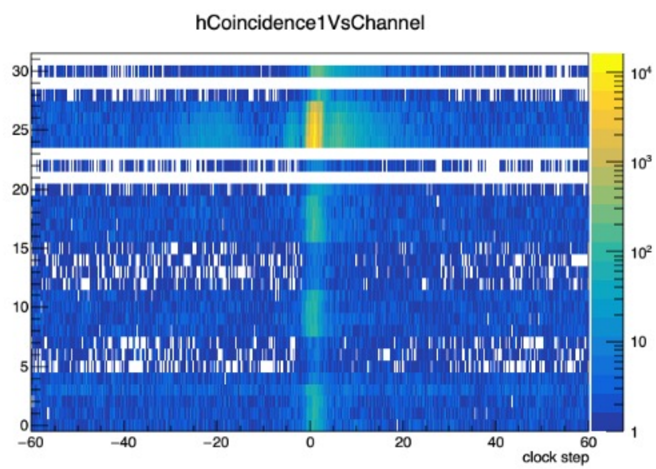
Test Cherenkov application for magnetic field insensitive sensor (SiPM)
Control SiPM high dark count to isolate single photon signal (same amplitude!)
Use a new **ALCOR chip** (high-rate ToT architecture) in streaming mode

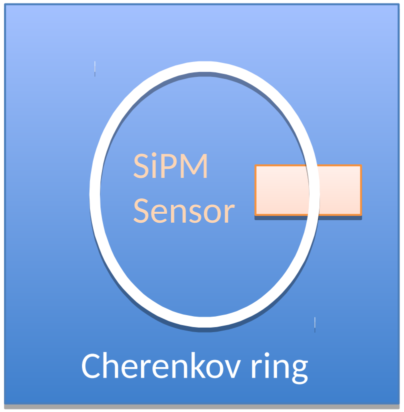
S. Vallarino tomorrow Talk

F. Cossio tomorrow Talk

Time coincidence with beam particle

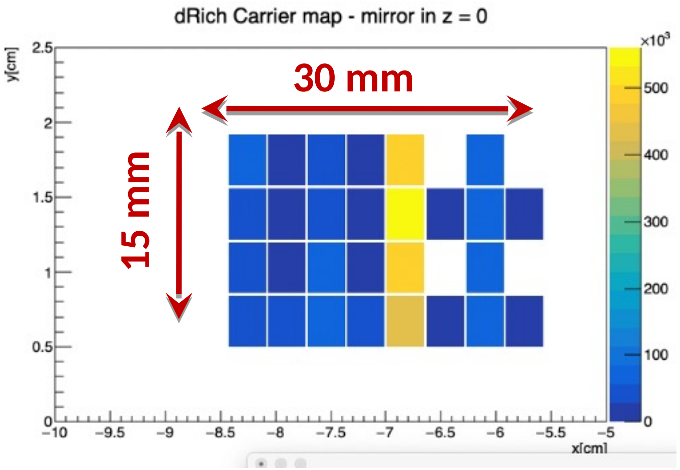


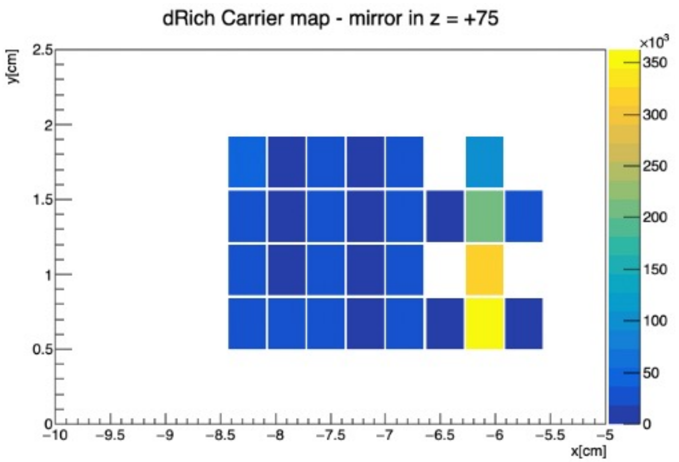




from M. Contalbrigo

Reflected signal moves with mirror





Prototyping – Status and Plan

from M. Contalbrigo

2021: MC simulations

First SiPM irradiation + annealing campaign

Basic dRICH prototype

First dRICH test-beam with hadron beams (commissioning)

2022: Extended SiPM irradiation + annealing campaign

Improved prototype

Second test-beam campaign (realistic performance)

Data analysis and technical note (D24.3)

2023: Refined data analysis and simulation

Third test-beam campaign (component optimization)

Final assessment towards TDR

Conclusions

- dRICH implementation in ATHENA shows adequate performances; there is still margin for refinement and improvements

- All proto-collaborations have included a dRICH in their proposals

- INFN is leading (and directly carrying on) the crucial R&D on dRICH