Dual-radiator Ring Imaging Cherenkov – dRICh

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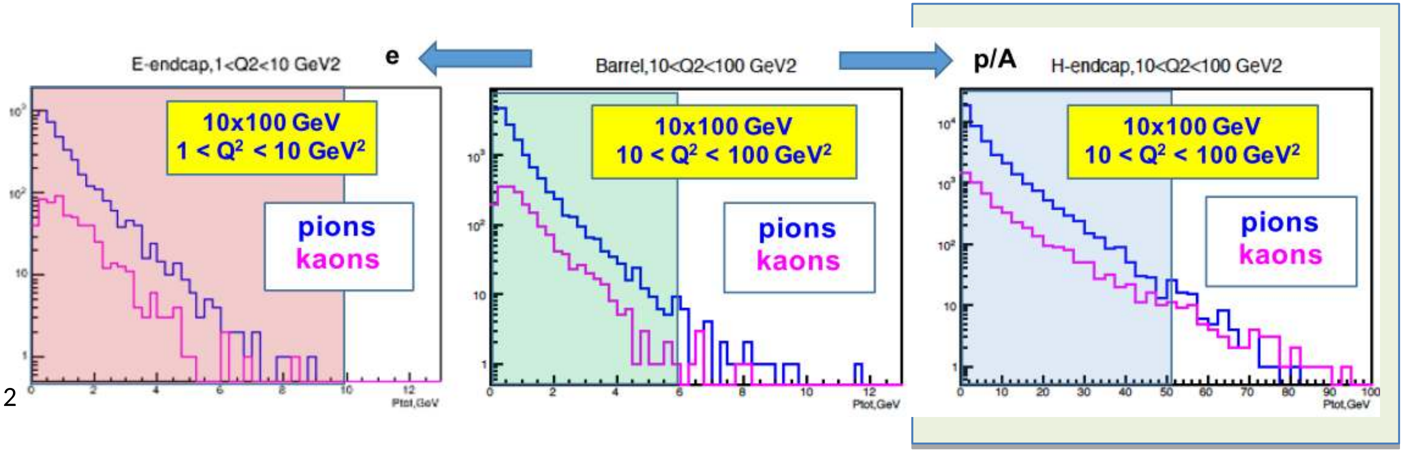
Hadron ID @ EIC h-endcap

“**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



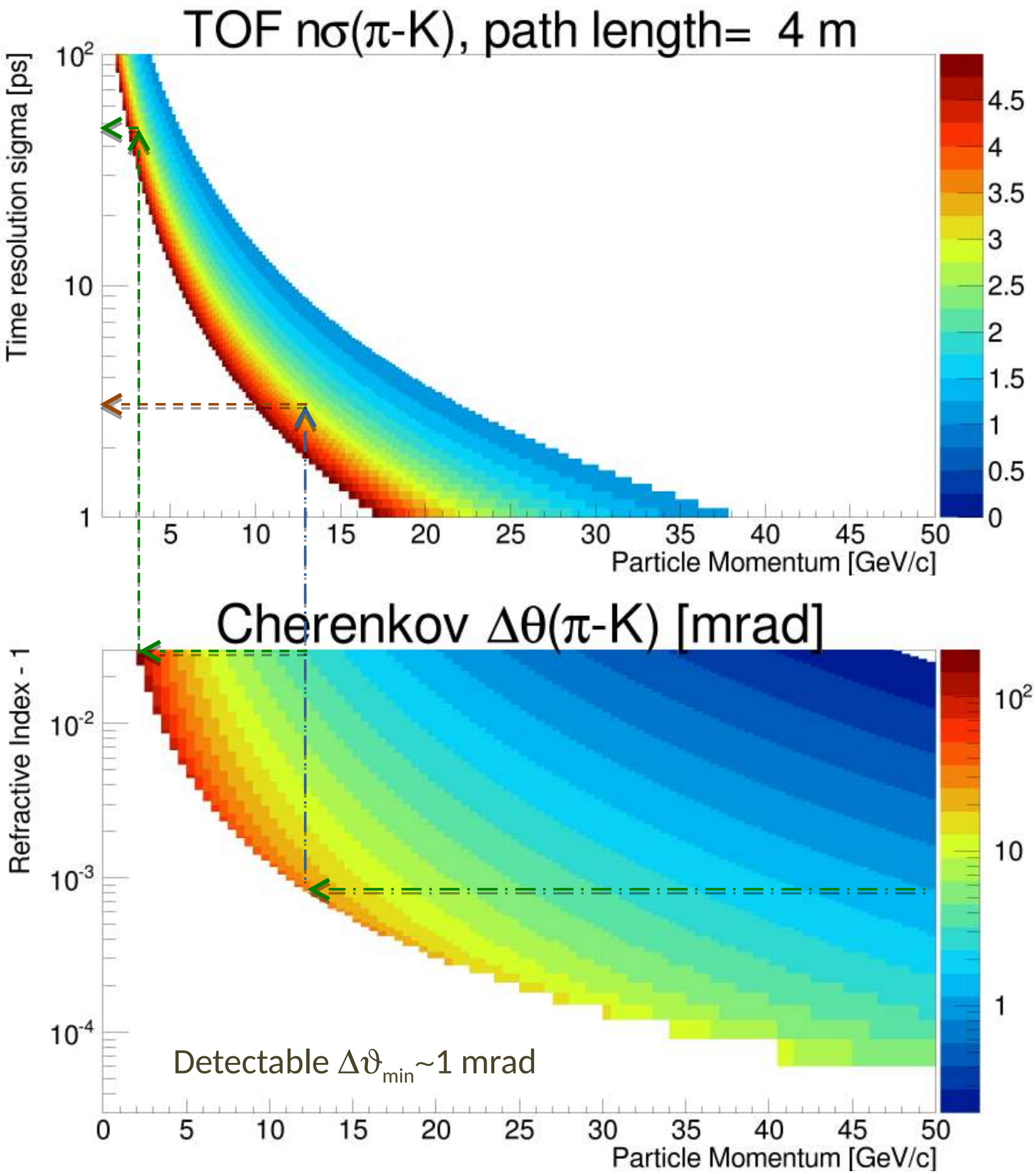
Physics Requirement:

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

Main Technological Challenges:

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

Extended momentum PID in the EIC hadron-endcap



Single detector technology cannot cover the whole range from few GeV/c up to ≈50 GeV/c with "good" separation of pi-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

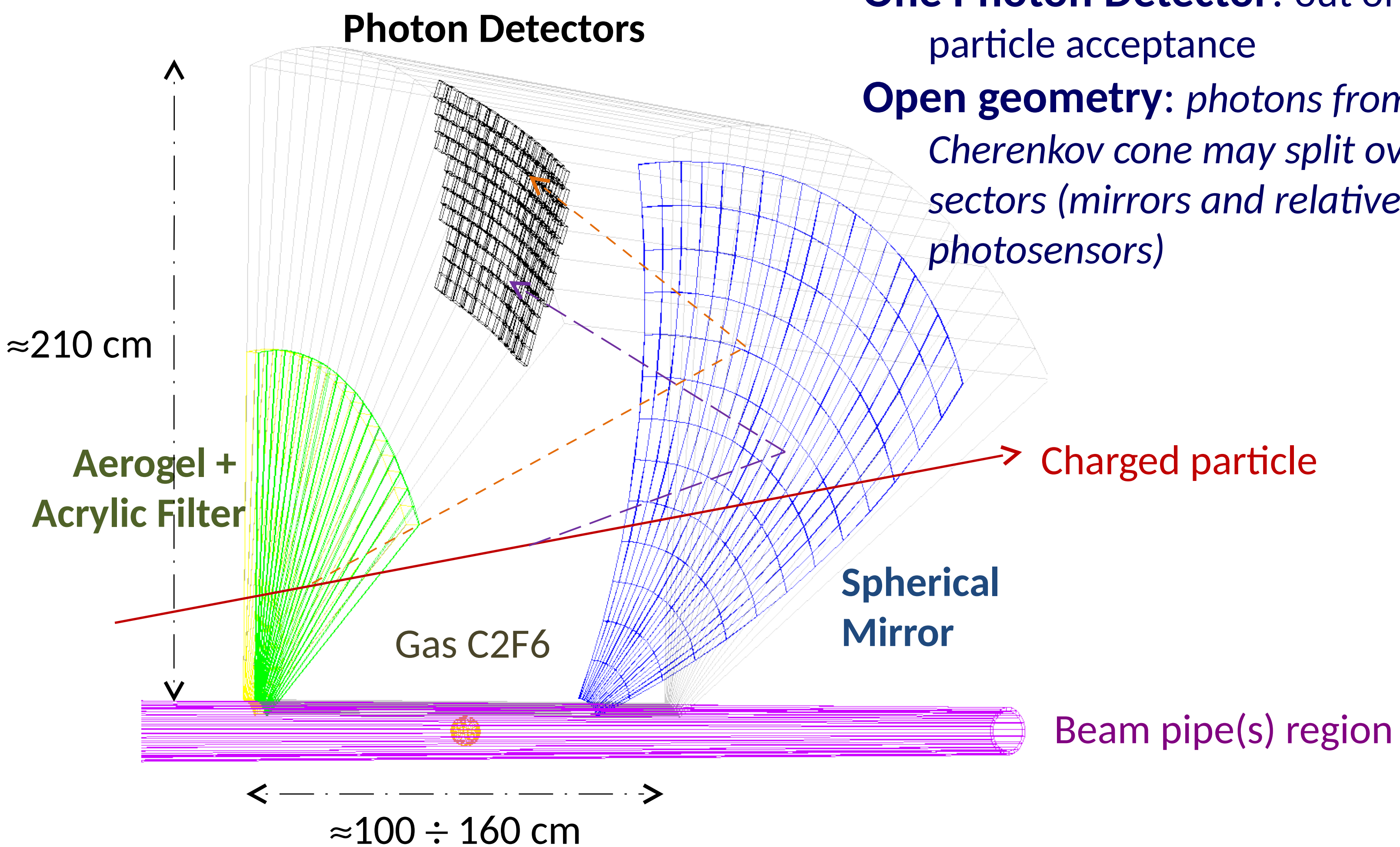
dRICh single sector - working principle

Two radiators: aerogel and gas

Focusing Optics: essential for gas

One Photon Detector: out of charged particle acceptance

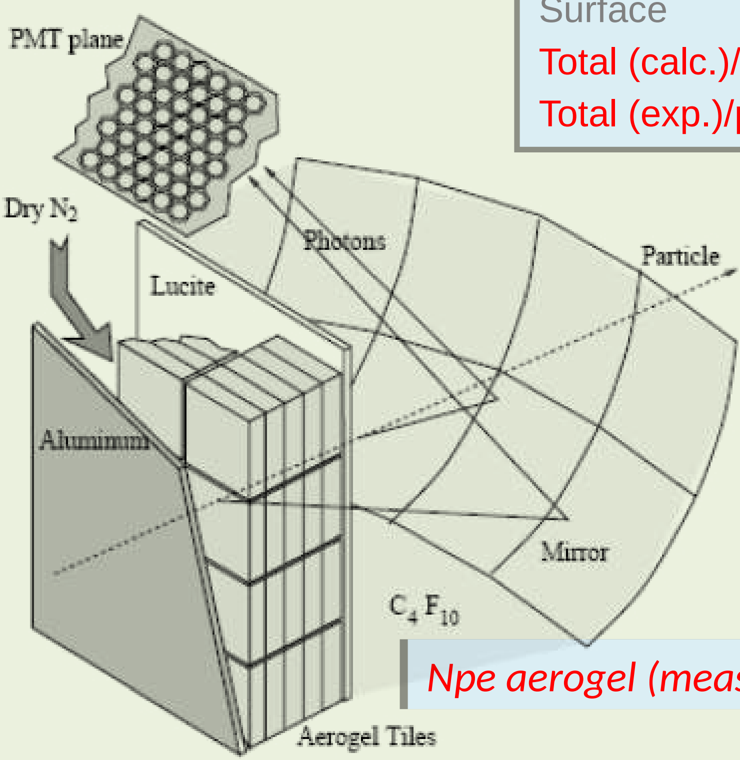
Open geometry: *photons from a Cherenkov cone may split over 2 or more sectors (mirrors and relative photosensors)*



Dual radiator aerogel-gas RICHes so far

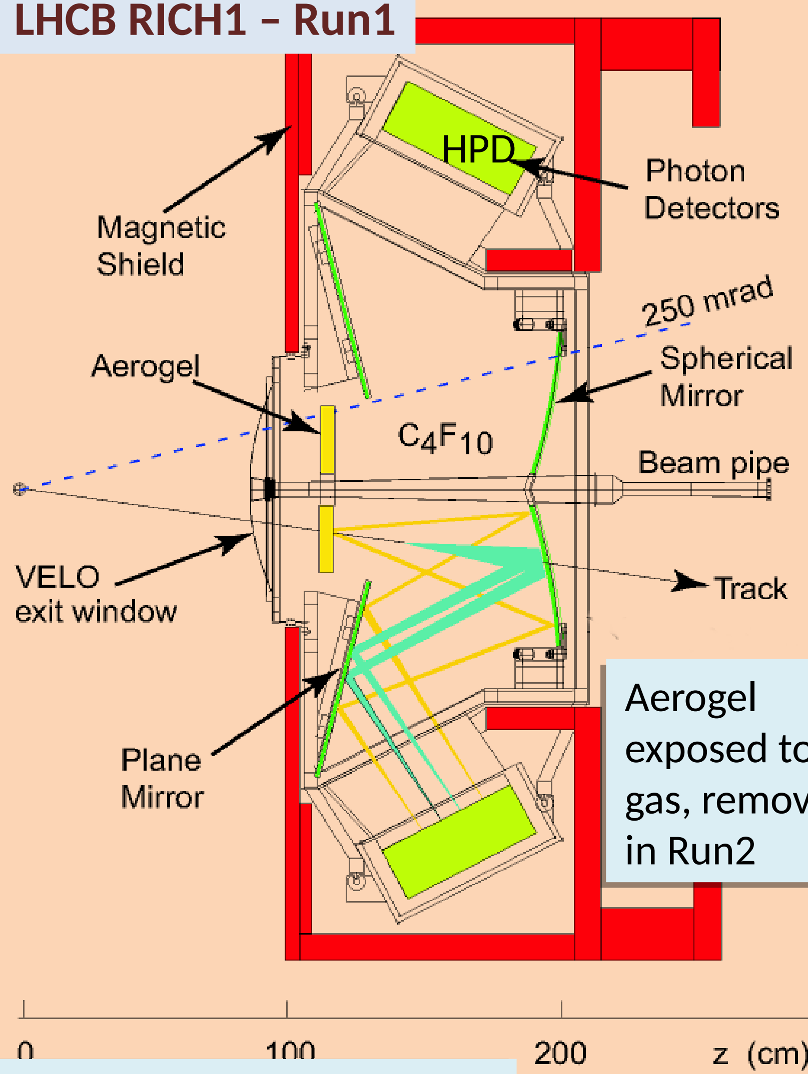
HERMES RICH

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



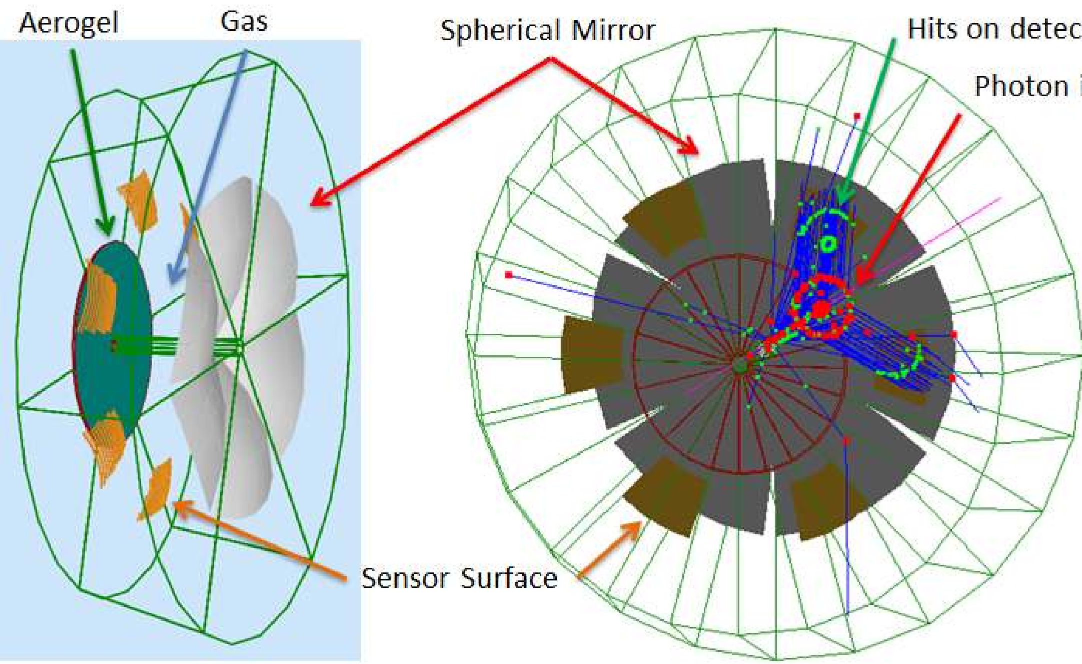
Npe aerogel (meas.) ~10

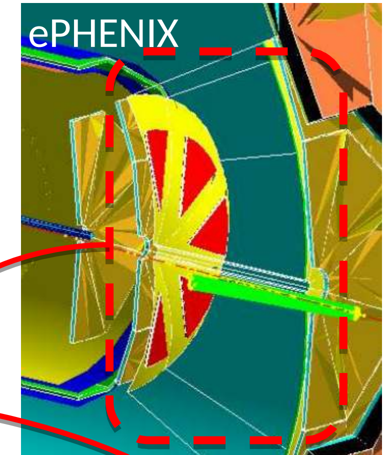
LHCB RICH1 – Run1

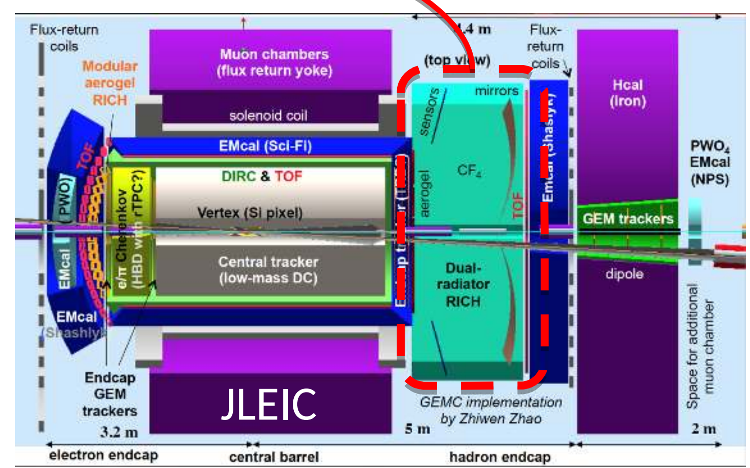


Aerogel exposed to gas, removed in Run2

Npe aerogel (meas.) 4.3 - 5







Radiators:

- Aerogel: 4 cm, $n_{(400nm)}$~1.02 + 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 (~2.0m ePHENIX)
- Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

Optimized for JLEIC, preliminary implementation in ePHENIX

Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c

dRICh - MC External Assumptions

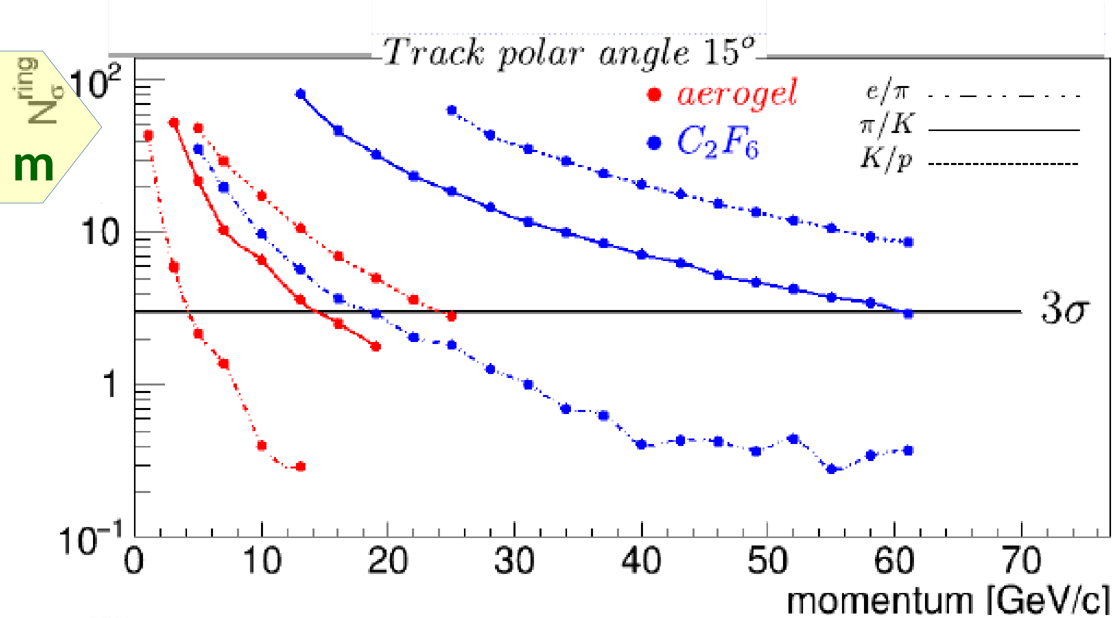
Tracking	
Angular resolution	σ = 0.5 mrad (1 mm over 2 m) – whole momentum range
Impact point resolution	σ = 0.3 mm
Momentum resolution *dP/P*	+/- few percent negligible effects in Cherenkov angle reconstruction
Magnetic Field	3 Tesla Central Field in JL-MEIC spectrometer
Space Requirement	(based on original spectrometer constraints)
longitudinal length	JLEIC: ≈1.6 m, ePHENIX: ≈1.0 m
transverse radius	JLEIC: ≈2.5 m, ePHENIX: ≈2 m
beam pipe radius	<10 cm
Background	no direct external background only backrground produced by the simulated charged particle: Delta rays, Rayleigh scattering …

dRICh - MC Internal Assumptions

Aerogel radiator	n=1.02, 4 cm Characteristics scaled from CLAS12/RICH measurements
Gas radiator	n=1.0008, 160/100 cm - C2F6 yield scaled from CF4 data (x0.7); chromaticity from literature (NIMA 354(1995)417); constant absorption length
Mirror	Reflectivity from CLAS12/RICH measurement; Roughness not included
Photon Detector	3 mm pixel size; 200-500 nm MAPMT characteristics from CLAS12 measurements
Vessel	no thickness assumption so far
Background	
Sensor Electronics	Random - spatially uniform on photosensor, poissonian with 30 hits/event mean (assuming 1kHz/pixel dark count x 100 ns) Note: uniform background hits do not influence noticeably the angular resolution; they influence the PID and therefore the migration matrix
Acrylic filter	3.2 mm (from HERMES and LHCb), remove aerogel photons (Rayleigh scattering) below 300 nm impact on ≈1% of signal photons
Particle Generation	All charged particles originate from the vertex and are uniformly distributed in the angular phase space

dRICh MC separations in JLeic and ePHENIX

dRICh in JLEIC spectrometer
Optics manually optimized for 1.6 m

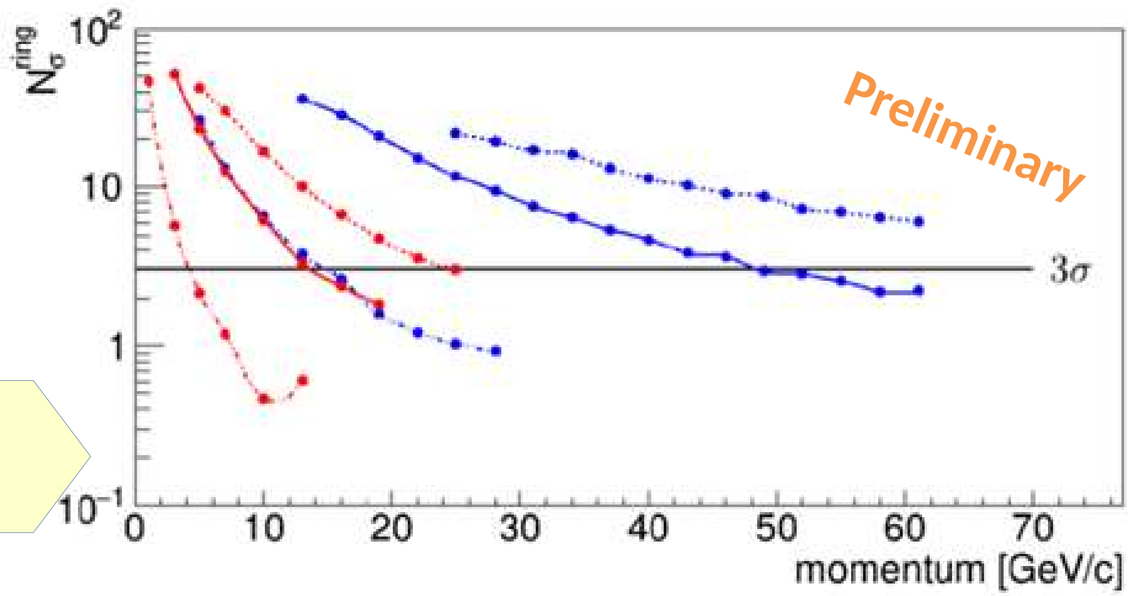


GEANT4 (GEMC) simulation includes:

- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh scattering
- Mirror quality from CLAS12
- PMT 3x3 mm pixel, QE from real CLAS12/PMT data (200-500 nm)
- **Tracking accuracy 0.5 mrad**
- **3T central magnetic field**

Cherenkov Angle reconstruction based on Inverse Ray Tracing

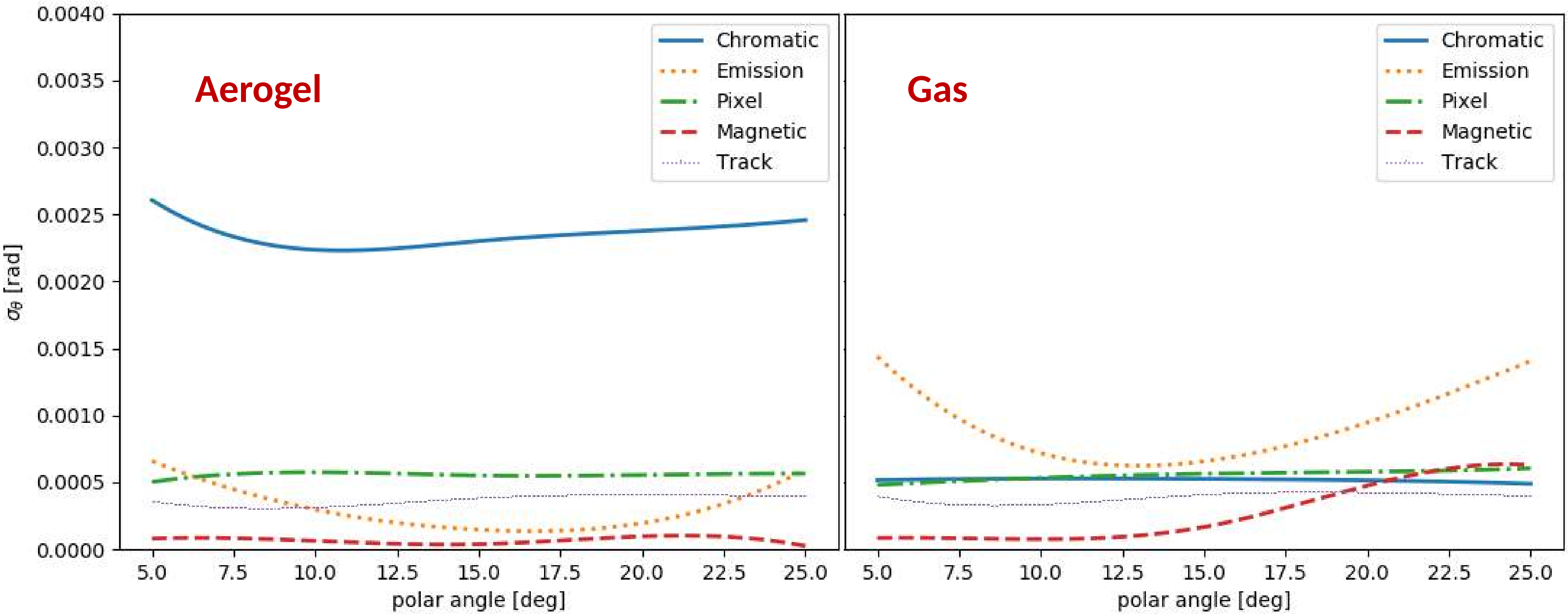
dRICh in ePHENIX spectrometer
Optics barely adapted to 1.0 m



Contributions to Cherenkov Angle Resolution

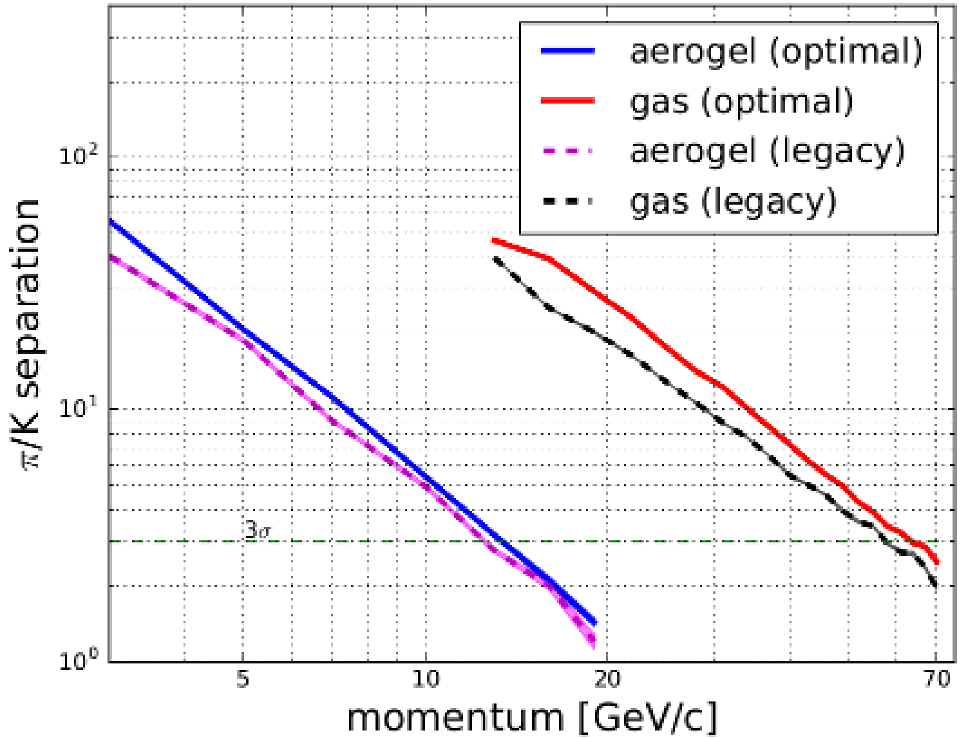
dRICh Single Photon Cherenkov Angle Resolution

- Charged particle momentum 30 GeV/c
- Photo sensor surface "optimized" (slightly curved)
- 3T central Magnetic Field
- 1.6 m gas



dRICh Model Integrated in Bayesian Optimizer

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

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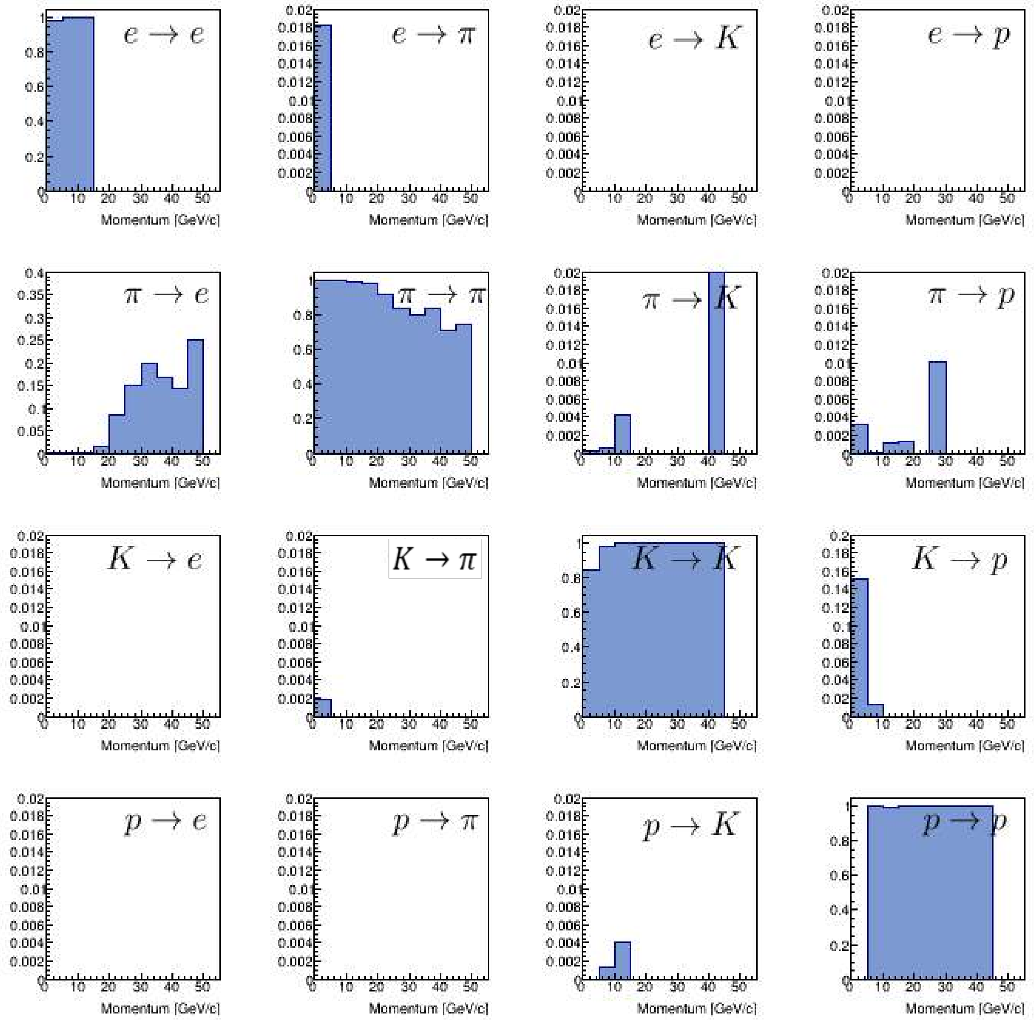
Inverse Ray-Tracing

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

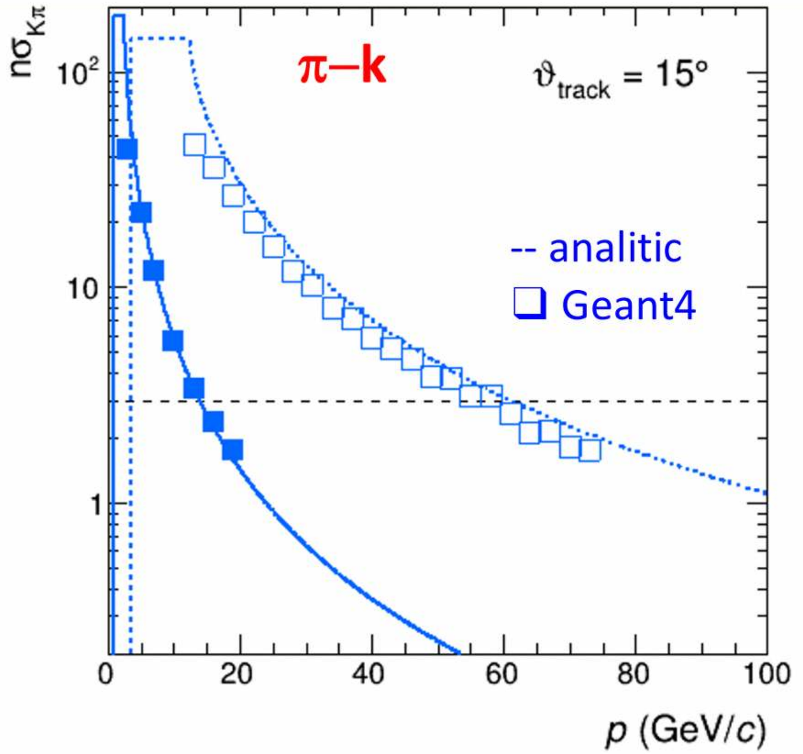
Implemented efficient event based reconstruction method:
it maximizes 2 likelihood functions in sequence to reduce significantly the computational efforts

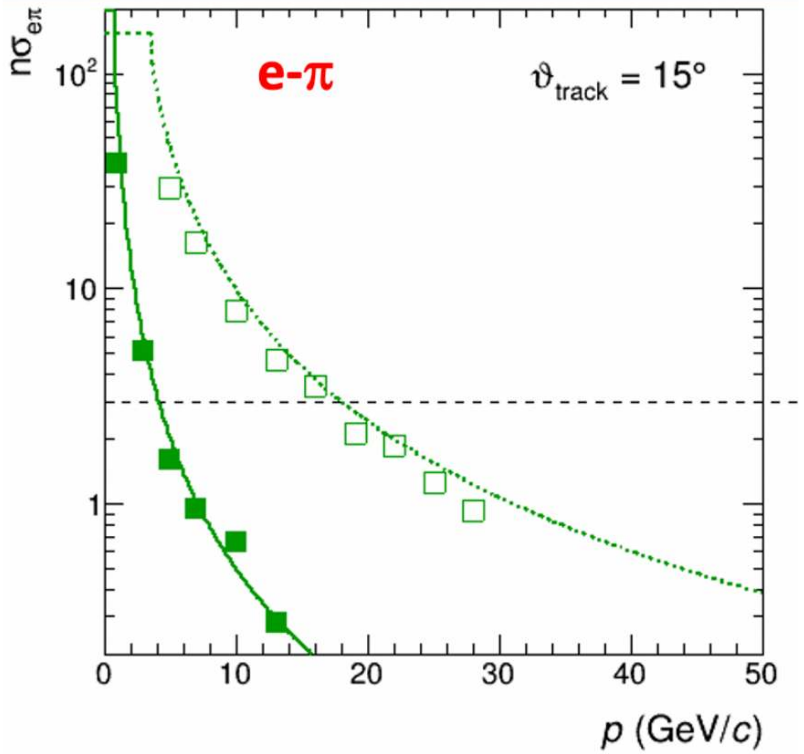


Example: event with 2 tracks and 15 hits

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

dRICh PID *baseline* performance





Evaluated in detail on JLEIC (and preliminarily on ePHENIX)

Need customization, optimization and tuning on the current spectrometer candidates

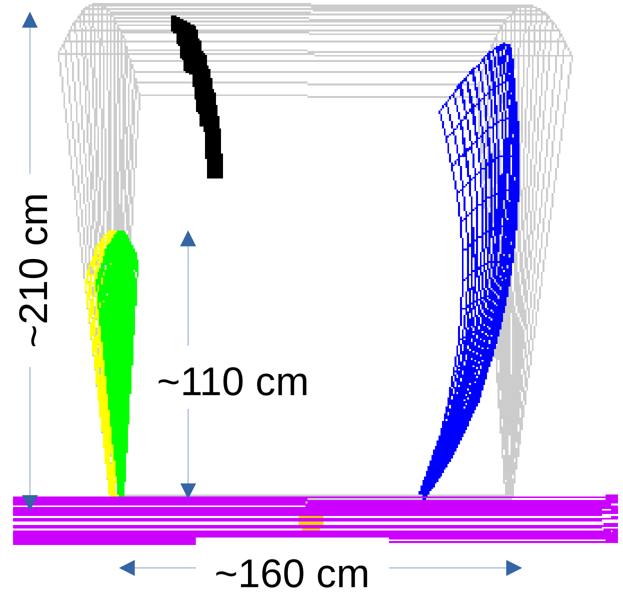
dRICh porting

- Full simulation available on GEMC
- Fast simulation on C++
- Analysis and reconstruction software on ROOT
- Optimization uses Python

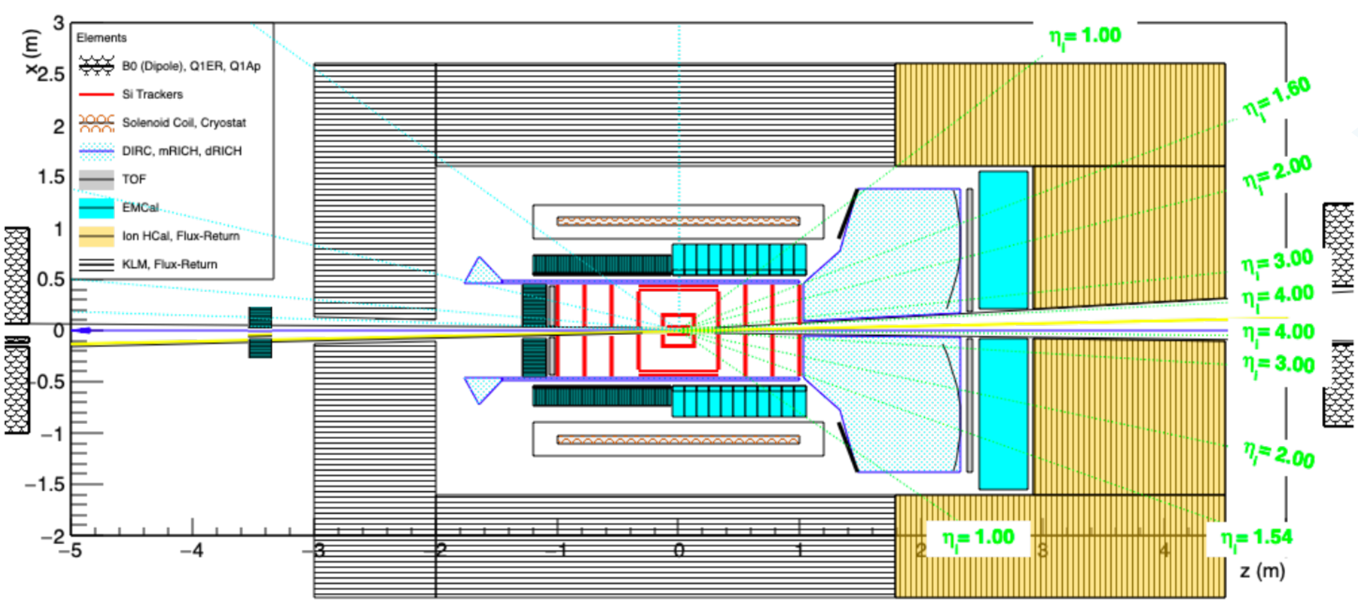
Porting on Fun4All and escalate/g4e ongoing

Already implemented:

- detailed Geant4 geometry text file
- dedicated C++/Geant4 classes for the optical description



COmpact detectoR for Eic (CORE)



In first approximation, the CORE layout requires a scaled down “baseline” dRICh

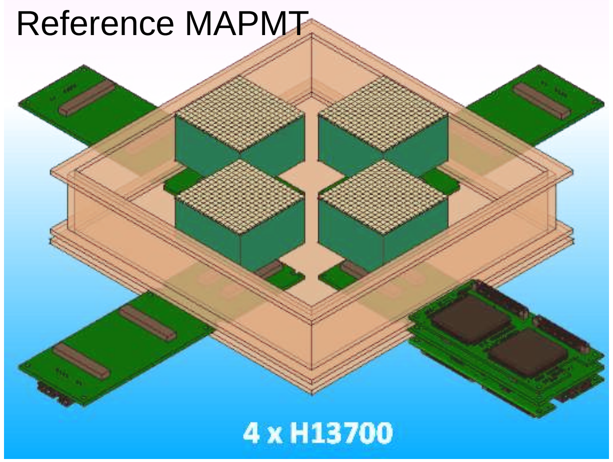
dRICh Key Hardware Components

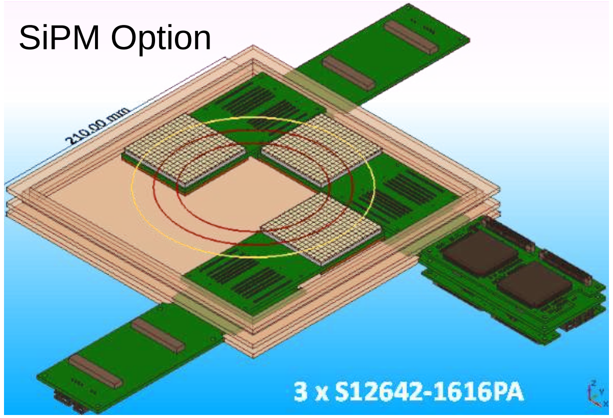
Component	Function	Specs/Requirements	Critical Issues / Comments
Mechanics	Support all other components and services Keep in position and aligned	Large volume gas and light tightness; alignment of components	Technically demanding but feasible; no major challenges expected
Optics (Mirrors)	Focus (expecially 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**
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)**

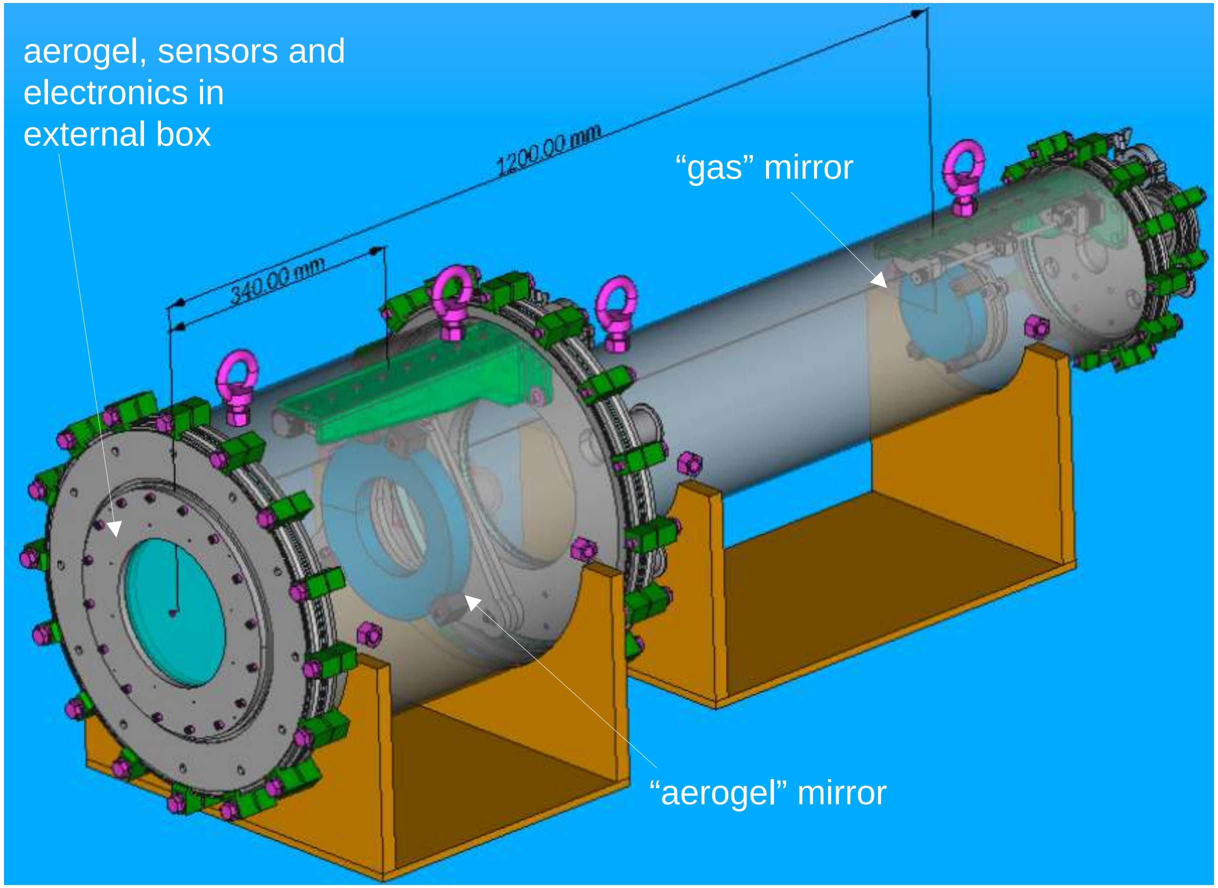
dedicated R&D in progress on:

detector prototyping, photon sensor selection and characterization, electronics

dRICh Prototype Design





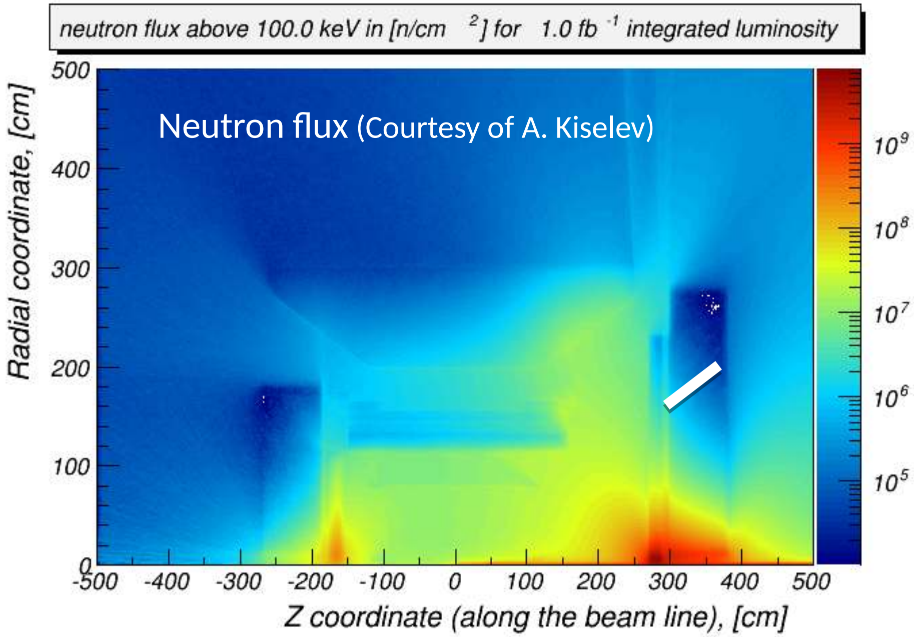


- Finalized design allows use of high pressure gases
- Photosensors and aerogel box isolated from the gas tank
- Standard vacuum components, custom flanges

Goal: validate the dRICh concept, benchmark simulation, compare components alternatives

Near term plan: First beam-test in Oct'21 @ CERN PS T10 (synergy with ALICE tests) to

dRICh sensor location relaxes requirements on magnetic field, neutron dose and material budget

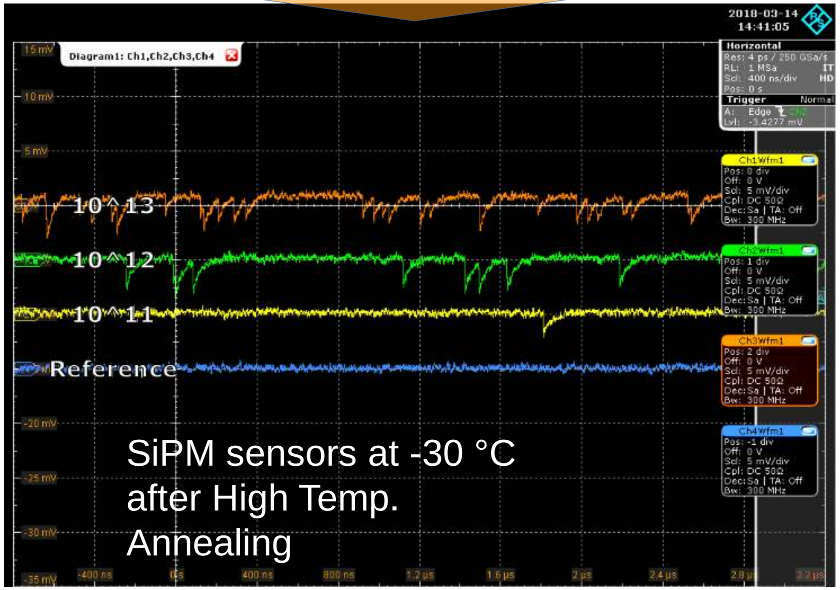


Magnetic Field
~ 1 T order of magnitude, varying orientation
SiPM: PET study up to 7 T 10.1109/NSSMIC.2008.4774097

Neutron Fluence
Moderate except for very forward regions
Reference value ~ 10^{11} n_{eq}/cm^2
for several years at max lumi (10^{34})

SiPM: radiation mitigation for SPE actively studied till 10^{14} n_{eq}/cm^2 10.1016/j.nima.2019.01.013

SiPM SPE capability under study since 2012 @ INFN
Contalbrigo++ NIMA 766 (2014) 22, Balossino ++ NIMA876 (2017) 89



dRICh - Electronics and DAQ

Electronics minimum features required:

- Amplify and shape single photon analog signal
- Convert to digital: amplitude (or 0/1 at least) and timing info
- Transfer to DAQ nodes
- Time resolution: ≤0.5 ns sub-ns timestamp accuracy
- Single photon sensitivity!

Estimated, very tentative DAQ performance requirement of Front End Electronics

		dRICh	CLAS12-RICh
Time resolution (Sampling period)	ns	0.5	1
# channels/sector		50000	25000
# bits/ch (binary info)		1	1
Data rate/sector	Gbits/s	100000	50000
Data rate/sector – zero suppression*	Gbits/s	800	375
Sort of streaming readout mode			

**Assume 1 MHz dark count/pixel as dominant contribution*
Current single JLab/SSP FPGA subsystem processor has ≈100 Gbits/s capability

Different options under evaluation (SiREAD → HDSoc, ALCOR-ToT)

dRICh - Cons

1. **More demanding PID** respect to single radiator RICH
2. **LHCb dual radiator RICH1 issues**: underestimation of aerogel stability in contact with freon gas ?
   large multiplicity and relative large background ?
3. **Aerogel chromatic** performances are critical and need to be well investigated in terms of stability and interference with gases
4. **R&D on photo sensors** needed (common to other EIC detectors)
5. **Gas Procurement** potential issue due to possible ecological restrictions and costs (common to other EIC detectors)

dRICh - Pros

1. **>3σ π-K separation in ~3 – 50+ GeV** whole range in RICH mode – as well as large coverage for K-p (and electron) PID
2. **Photon detector out of acceptance** and far from the beam pipe in moderate magnetic field (≤ 1/2 of central zone): less constraints on material budget (e.g. mechanical supports, shielding, cooling); neutron flux is also reduced
3. Expected to be **cheaper and more compact** (also in terms of services) than 2 (or more) detectors solution (sparing on photosensors and related electronics)
4. **Material budget** likely smaller than 2 detectors solution: from CLAS12/RICH-LTCC: X_0≈1% vessel (no pressurization) + 1% mirror + aerogel, acrylic filter and gas
5. Two dual radiator RICHes already operated (**lesson learned**)
6. Rather **advanced software available**: detailed Montecarlo, parameterization, full PID reconstruction, automated optimization procedure