Dual Ring Imaging Cherenkov Status

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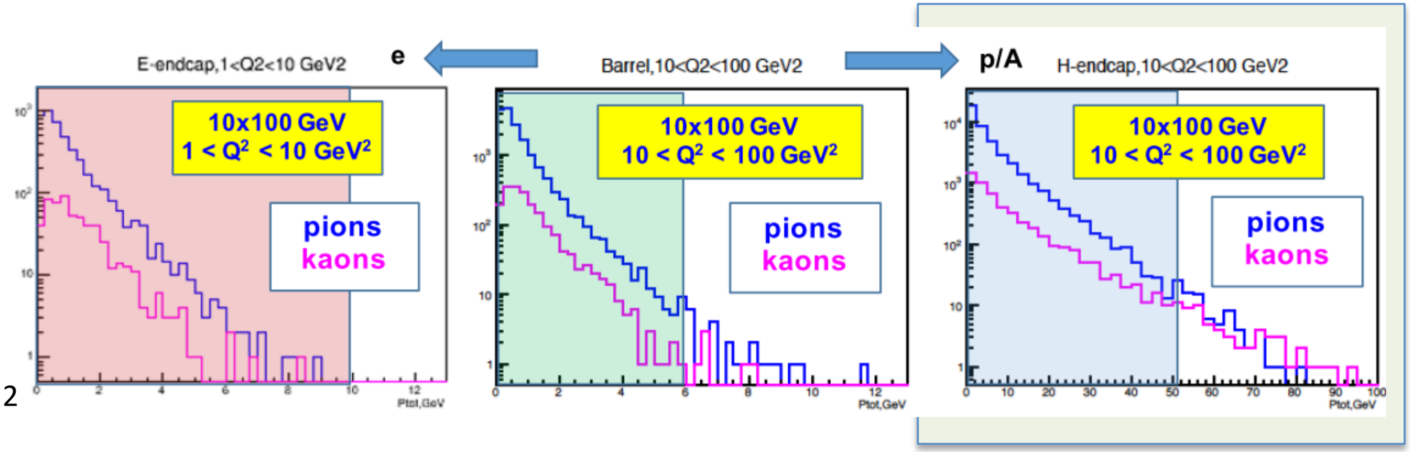
Hadron ID @ EIC h-endcap

"**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

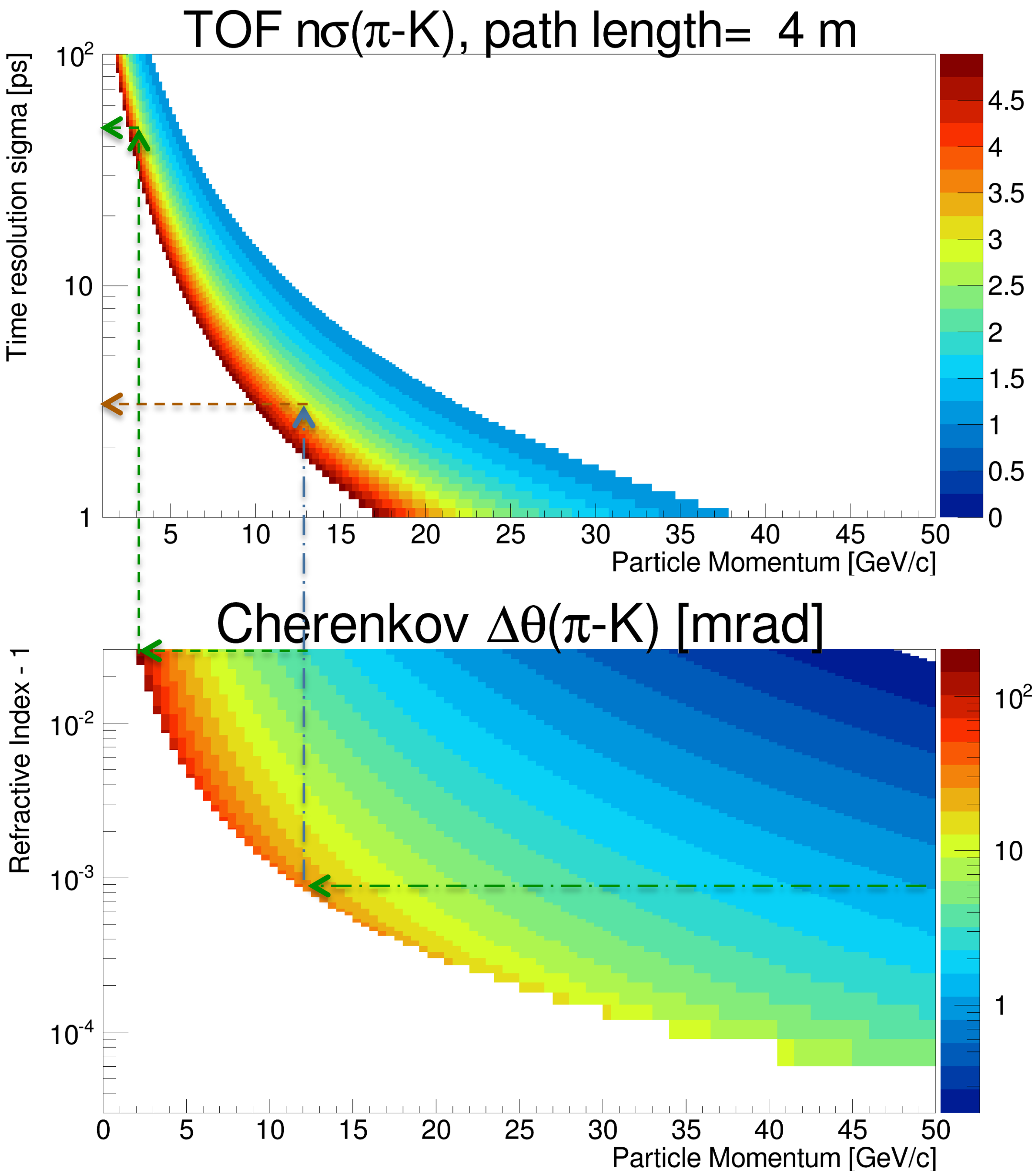


Physics Requirement:

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**



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

Three main options:

1) TOF+RICH:

Need challenging time resolution (≈3 ps sigma!)

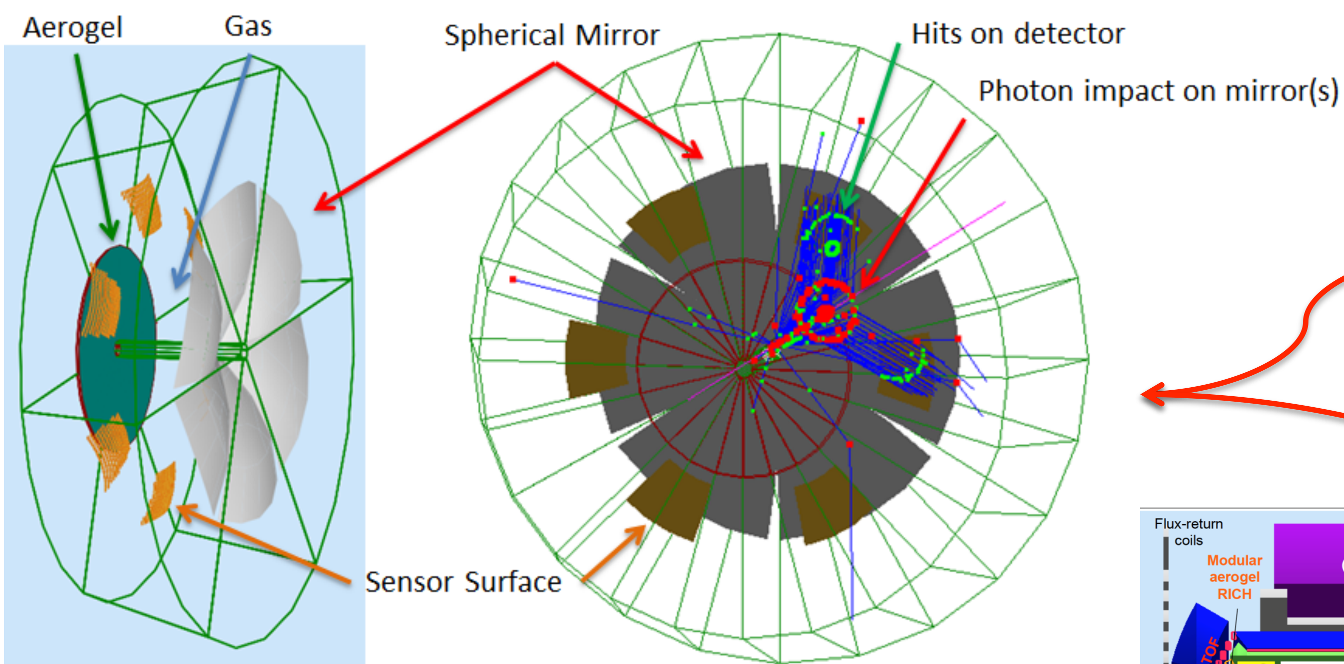
2a) TOF+RICH(n1)+RICH(n2)

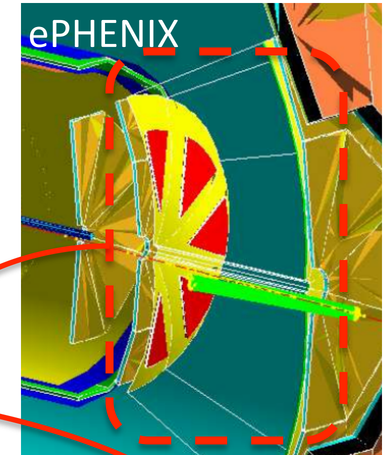
Expected to be more expensive due to twice the sensors and electronics

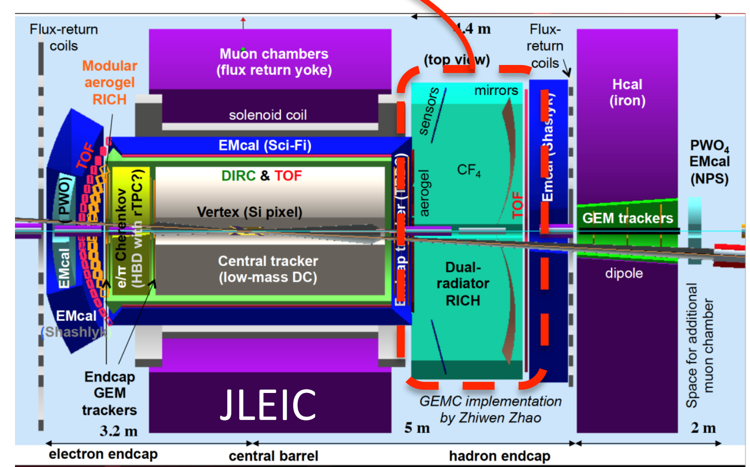
2b) TOF+RICH(n1,n2)

… next slides

Dual Radiator RICH in EIC Hadron-endcap







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):

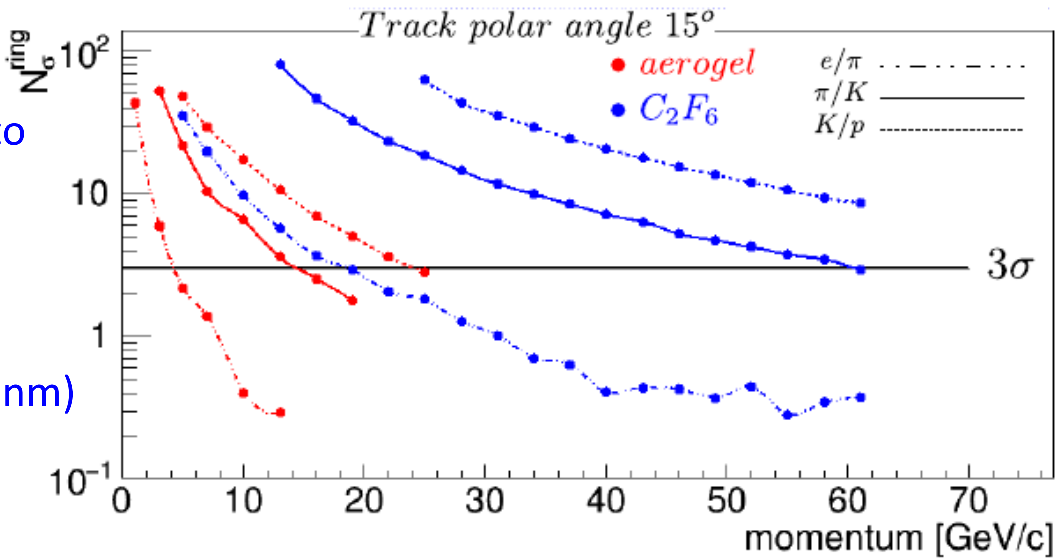
- Large Focusing Mirror with R ~2.9m (~2.0m ePHENIX)
- Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

Optimized for JLEIC, preliminary implementation in ePHENIX

Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-50 GeV/c

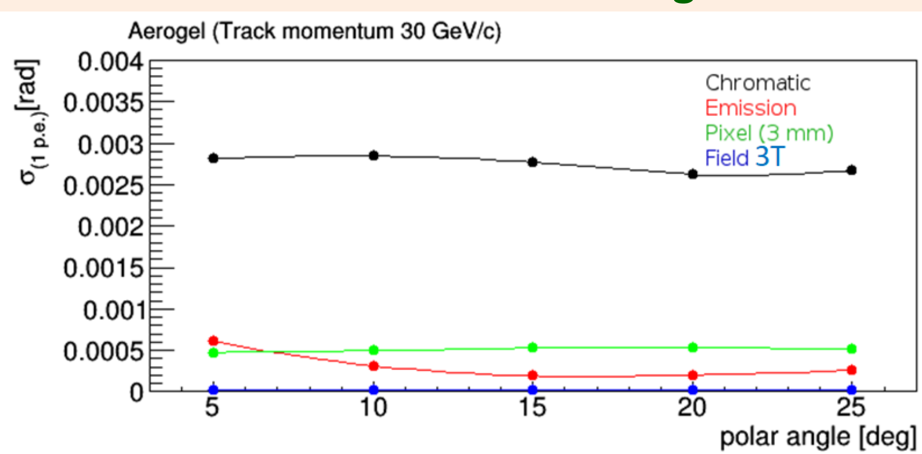
dRICH MonteCarlo Expected Performance

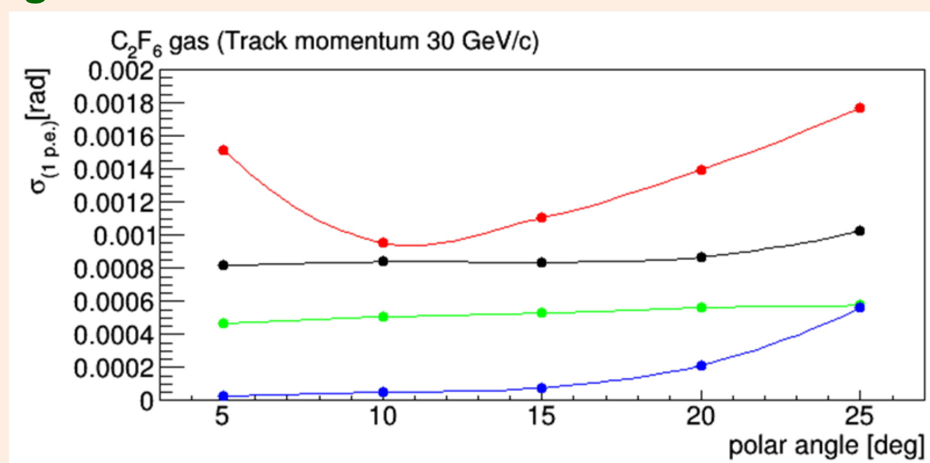
- **Montecarlo: GEMC (Geant4)**
- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh scattering
- Mirror quality from CLAS12
- PMT 3x3 mm pixel
- QE from real CLAS12/PMT data (200-500 nm)
- **Tracking accuracy 0.5 mrad**
- **Include 3T central magnetic field**
- **Cherenkov Angle reconstruction based on Inverse Ray Tracing**



Hadron identification (π/K/p): provides better than 3 sigma from ~3 up to ~50 GeV/c for π/K

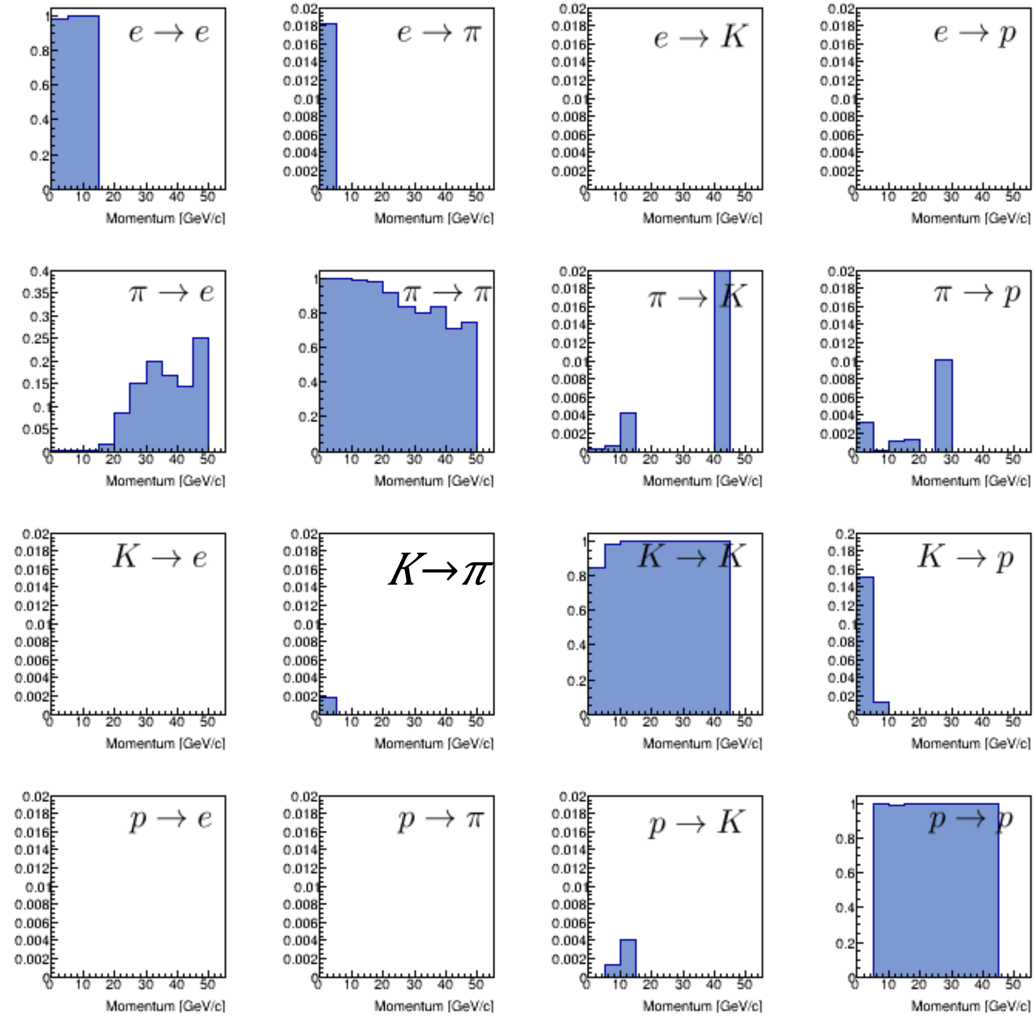
Single Photon Angular resolution





Inverse Ray-Tracing

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



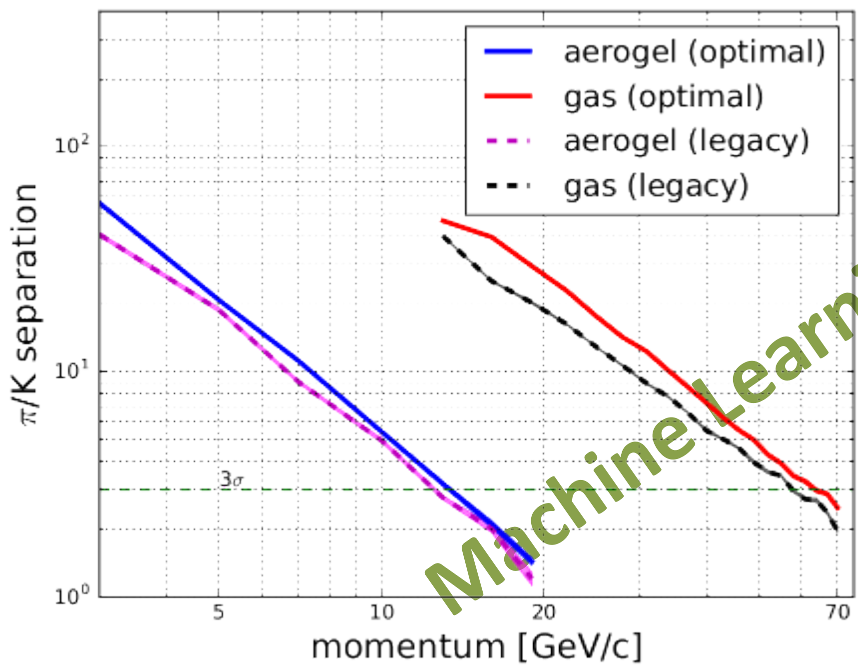
Implemented efficient event based reconstruction method:
it maximizes 2 likelihood functions in sequence to reduce significantly the computational efforts

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 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 …)



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

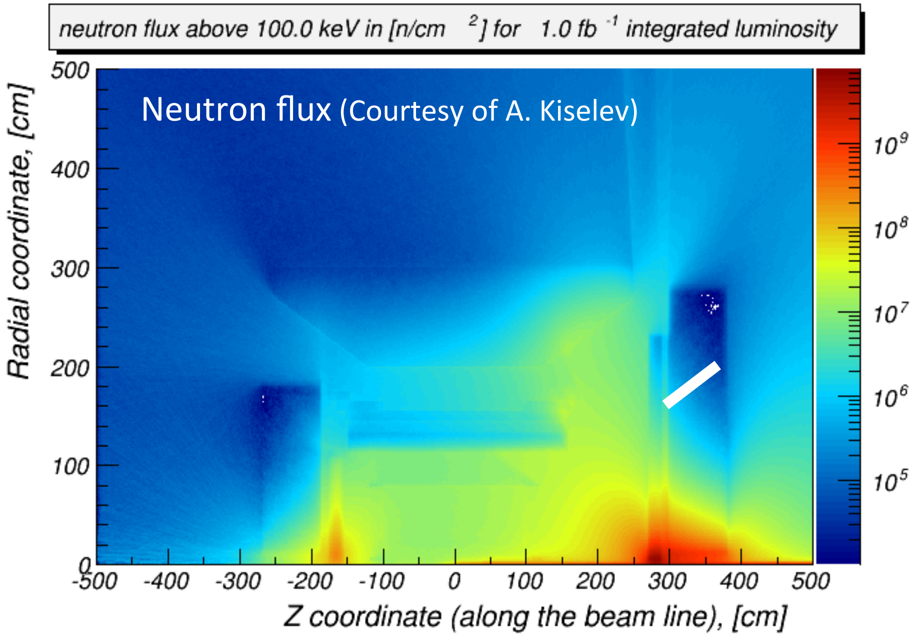
Machine Learning Approach

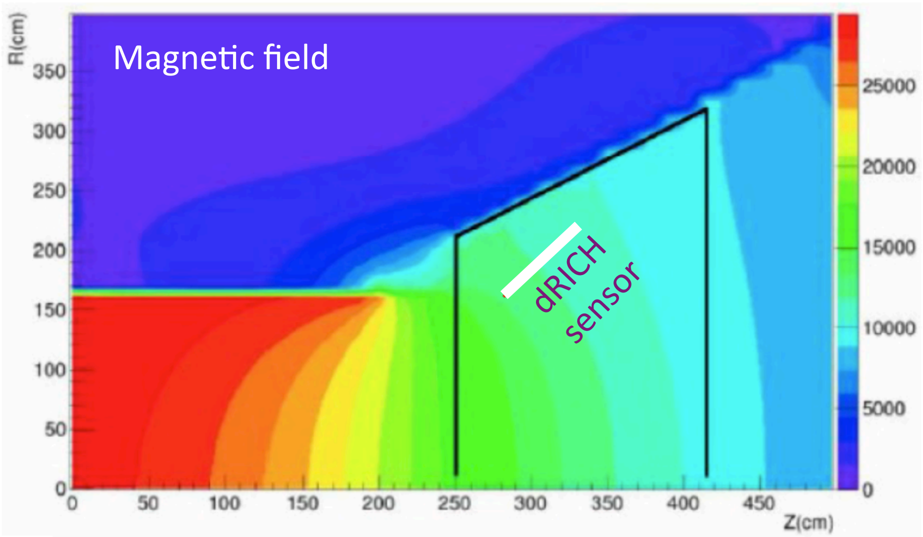
Corrent implementation uses 8 parameters, but is not limited to them.

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

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)**





dRICH sensor location relaxes requirements on neutron dose and material budget

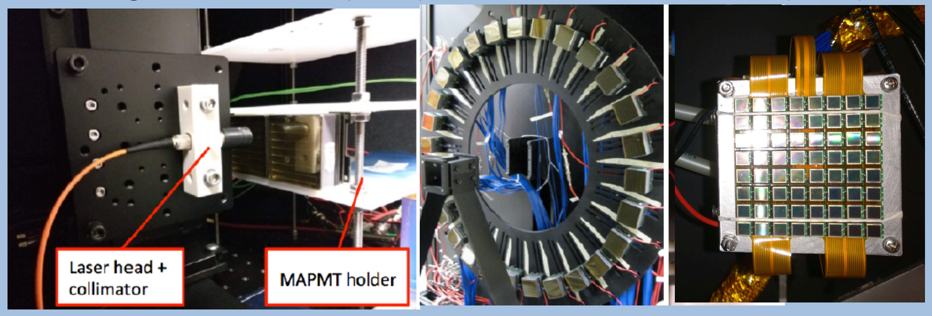
Neutron Fluence
Moderate except for very forward regions
Reference value ~ 10^{11} n_{eq}/cm^2
for several years at max lumi (10^{34})

SiPM: radiation mitigation for SPE actively studied till 10^{12} n_{eq}/cm^2 and above 10.1016/j.nima.2019.01.013
10.1016/j.nima.2018.10.191

Magnetic Field
~ 1 T order of magnitude, varying orientation

SiPM: PET study up to 7 T 10.1109/NSSMIC.2008.4774097

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



Electronics and DAQ

Electronics minimum features required:

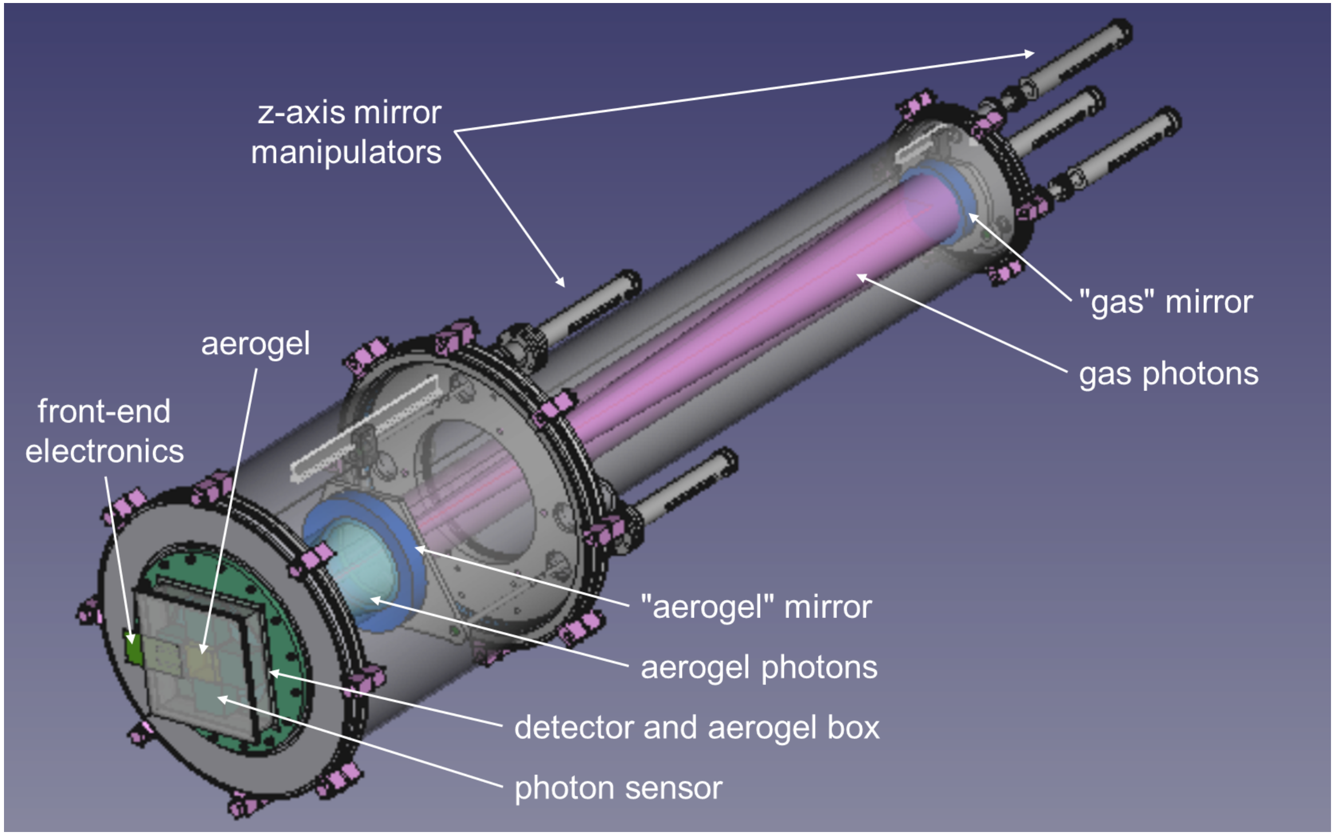
- Amplify and shape single photon analog signal
- Convert to digital: amplitude (or 0/1 at least) and timing info
- Transfer to DAQ nodes
- Time resolution: ≤0.5 ns sub-ns timestamp accuracy (?)
- Single photon sensitivity!

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*

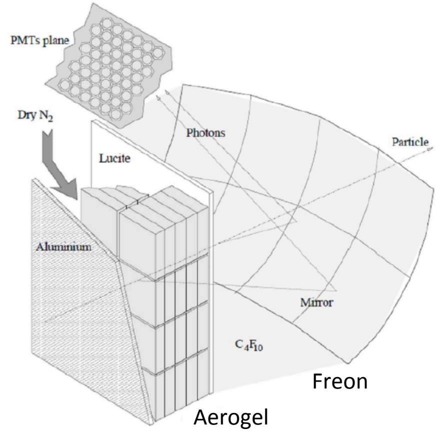
Current single JLab/SSP FPGA subsystem processor has ≈100 Gbits/s capability



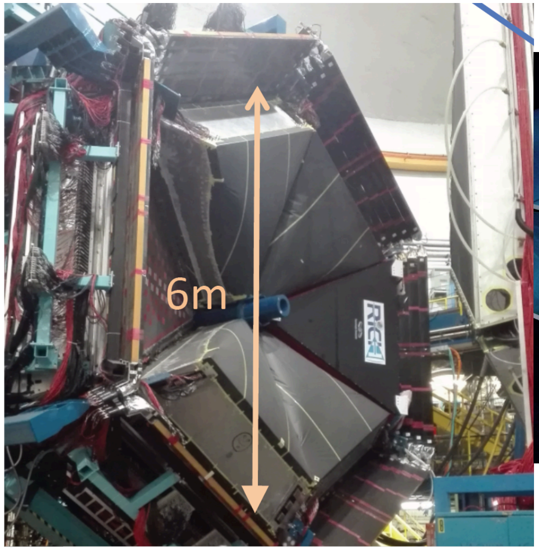
- Design in an advanced stage, mechanical details being finalized
- Standard Vacuum Technologies to optimize gas handling
- Two tuneable mirrors system for using the same detector
- Common (limited) sensitive surface for both aerogel and gas photons
- Detector and aerogel box isolated from the gas tank

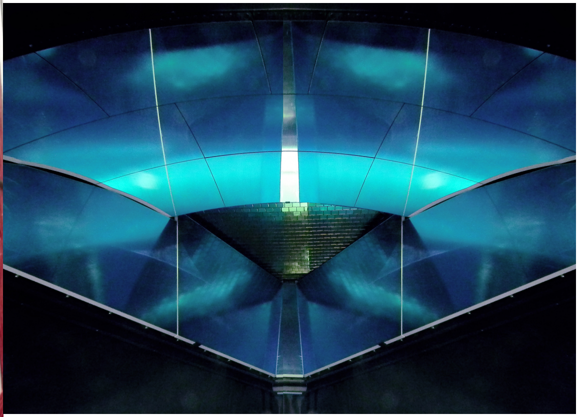
INFN/Duke > 6 staff > 4 technicians + students

HERMES RICH: successful dual-RICH

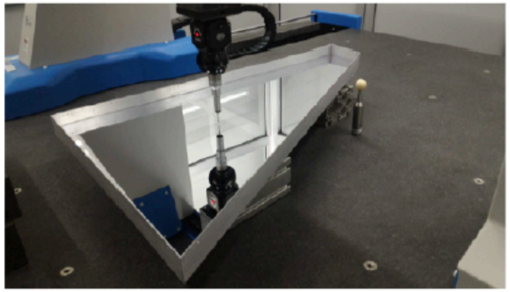


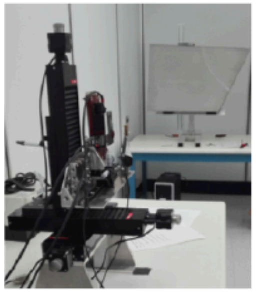
CLAS12 RICH: geometry scale similar to EIC

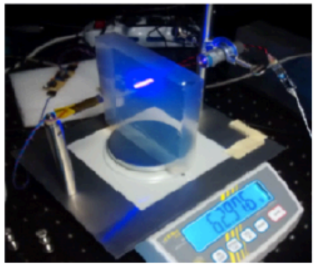


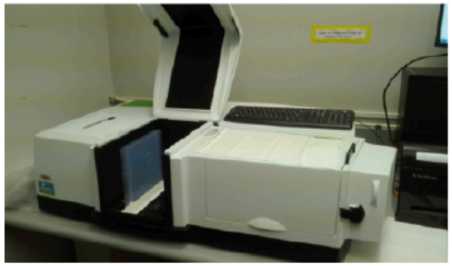


Workshops + laboratory test-benches

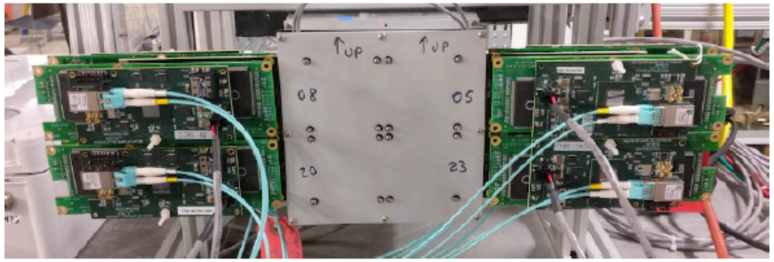


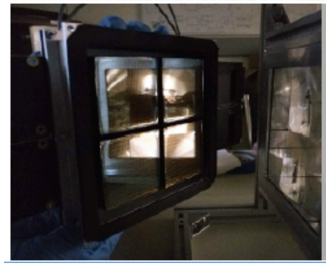






Prototyping and test-beams





Patrizia's Questions

- **Technology used: spell out clearly any risk associated, if any**
  - Consolidated baseline of the dRICH design exists
  - Can in principle be realized with standard and mature technology solutions
  - Specific Risk: availability/procurement of Freon gases
  - Common Challenge: SPE sensor in high magnetic field
- **Momentum range covered: p versus theta and Nsigma vs. p**
  - $>3\sigma$ separation in the 3-50 GeV/c momentum and 5-25 deg polar angle ranges
- **Robustness of the design (e.g. sensitivity to magnetic field) and has a prototype been built?**
  - Performance on physics (SIDIS) events simulated in high 3T field
  - Prototype design consolidated; component procurement started
- **Are the electronics considerations clear (channel count, data size, rate, background)**
  - Can be realized with available architectures
  - Details under study: depends on machine design, IP, sensor and readout
- **Time needed to complete the R&D and available workforce**
  - About 3 years
  - Experienced workforce available and increasing
  - INFN groups interested in the critical aspects: SiPM, electronics, radiators
- **Status of Simulation and Reconstruction**
  - Software: realistic Geant4/GEMC MonteCarlo
  - Bayesian optimizer and event based PID implemented