# dRICH development toward prototyping

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EIC-PID Workshop

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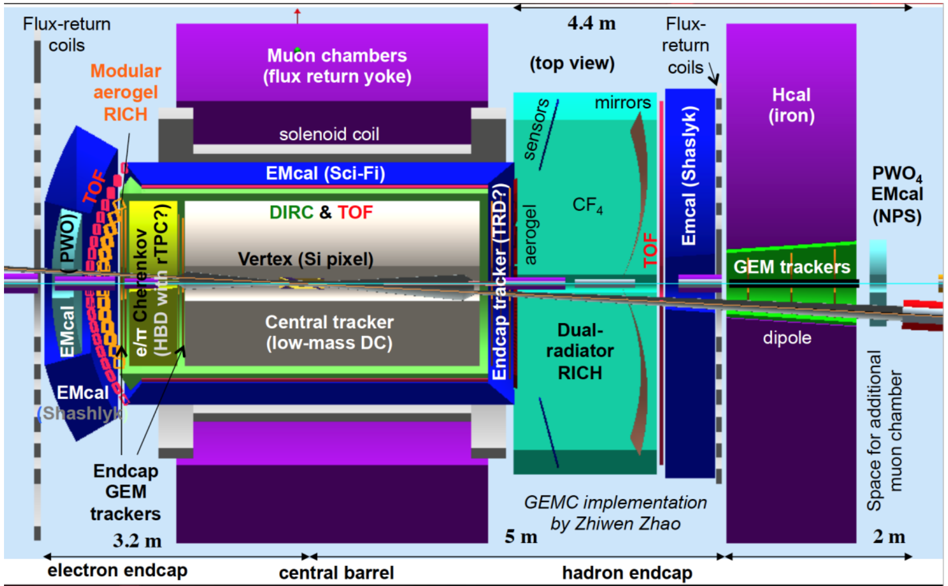
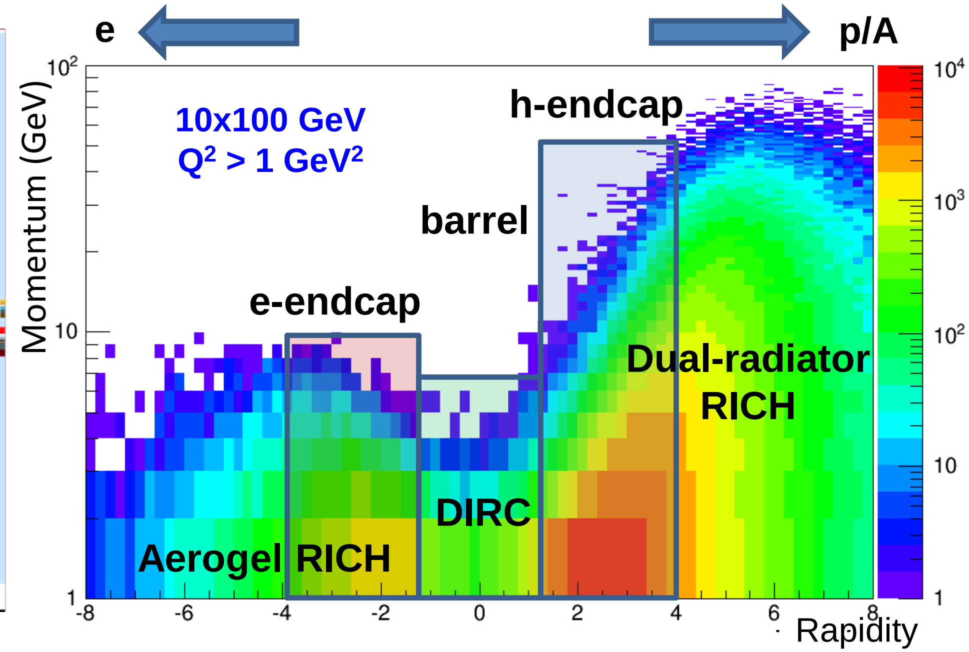
- **dRICH design and performance**
- **Recent design optimization**
- **Event based particle Identification**
- **Prototype definition and MonteCarlo analysis**

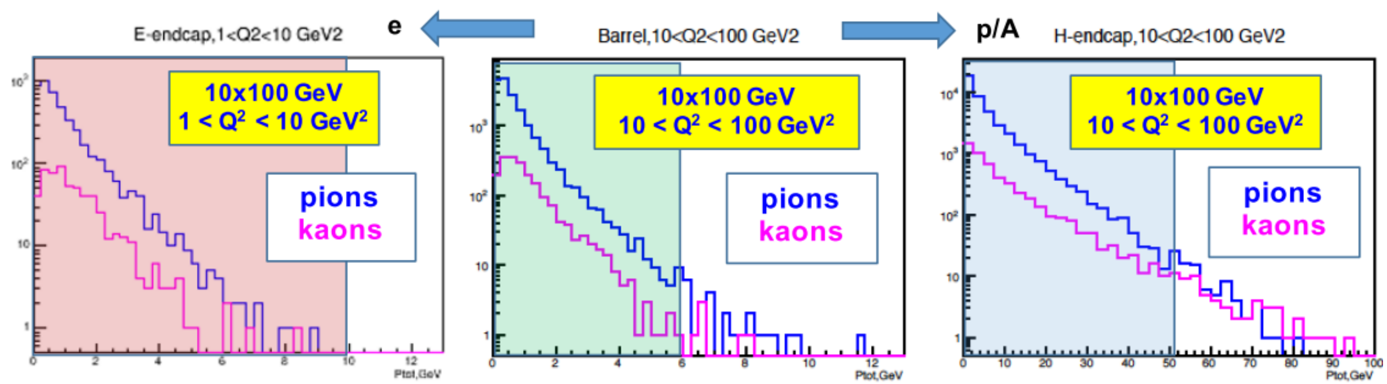
# Hadron-ID in JLeic



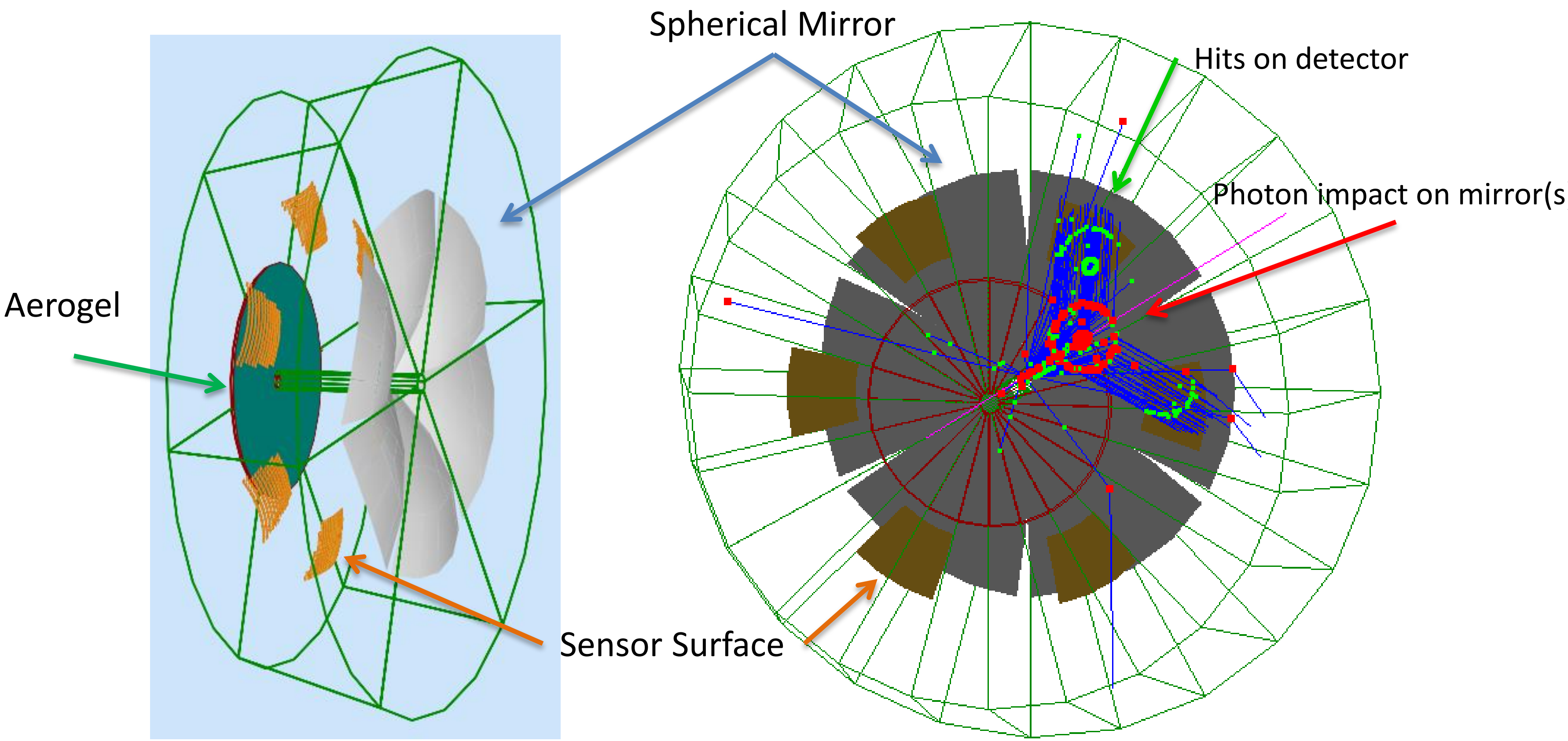

Hadron ID beneficial for many physics cases, expecially in the high-momentum tails:

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




Hadron endcap: *need π/K separation up to ~50 GeV/c*

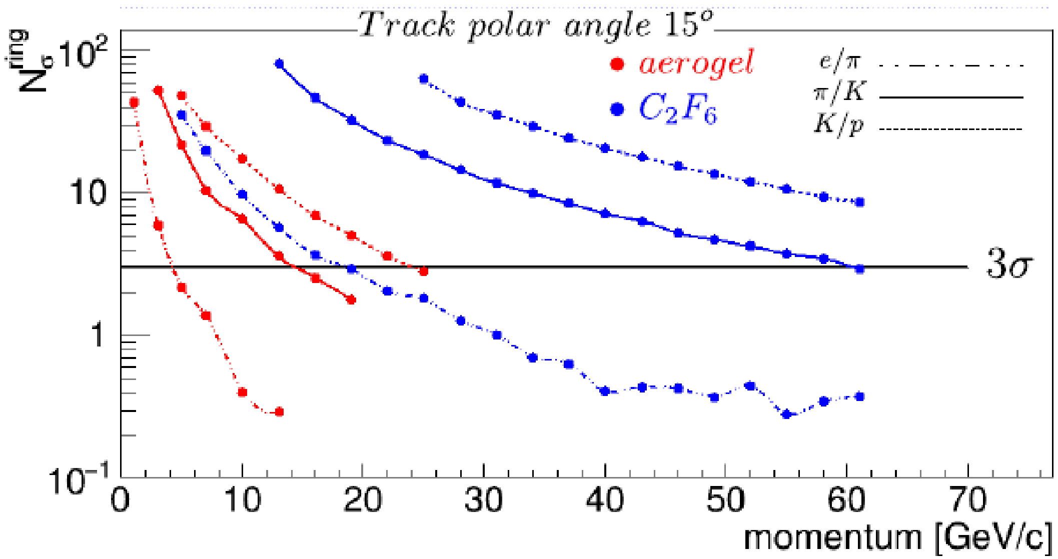
# dRICH baseline model

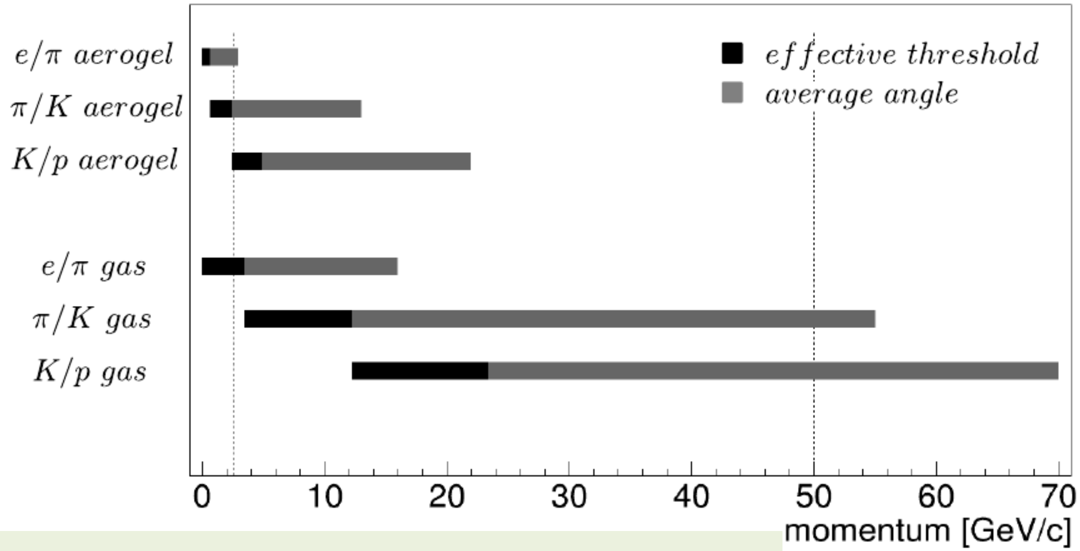



- Radiators: Aerogel (4 cm, $n_{(400nm)}$~1.02) + 3 mm acrylic filter,
  Gas (1.6 m, $n_{C2F6}$~1.008)
- 6 Identical Open Sectors (Petals):
  - Large Focusing Mirror with R ~2.9 m
  - Optical sensor elements: ~4500 cm$^2$/sector, 3 mm pixel size, UV sensitive, out of charged particle acceptance

# 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 as for $CF_4$ data**
- **Include 3T central magnetic field**
- **PMT H12700 (200-500 nm)**
- **Cherenkov Angle reconstruction based on Inverse Ray Tracing**

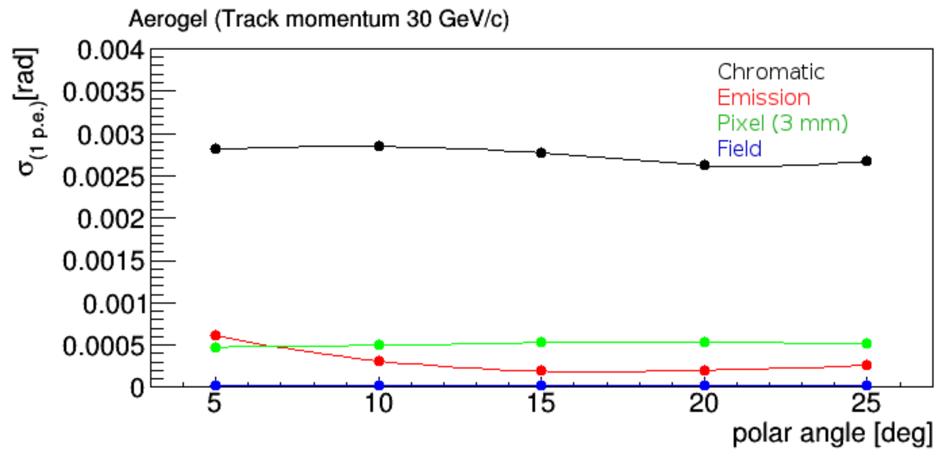



Hadron identification (π/K/p, better than 3 sigma apart); continuous coverage from 3 GeV/c up to ~50 GeV for π/K and ~15 GeV for e/π

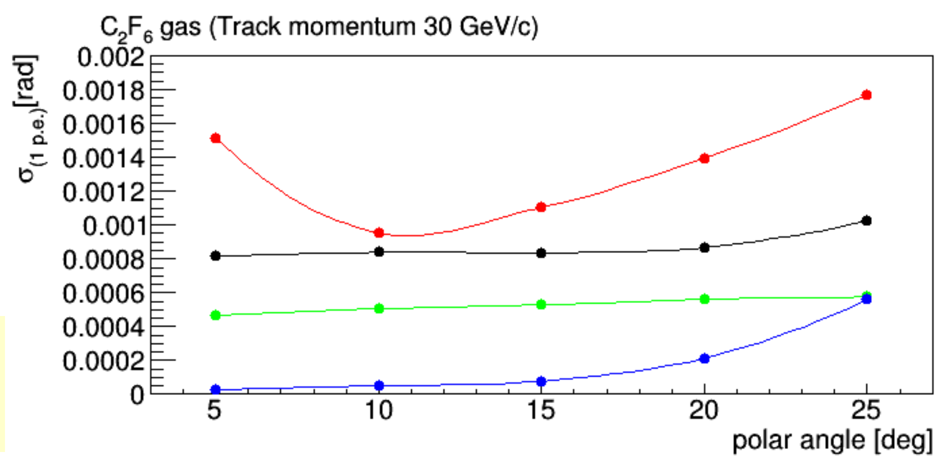
# Angular resolution

All the main contributions to the Cherenkov angle resolution have been evaluated by MC




Largest effects from

- Aerogel chromatic (variation of refractive index with wavelength)
- Gas emission (unknow emission position of the photons)

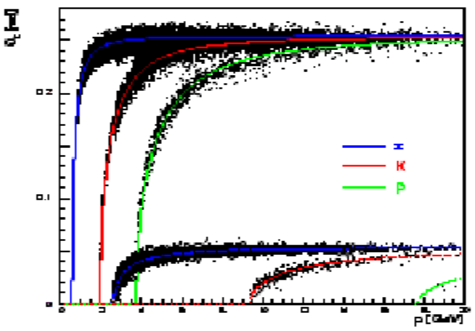



***dRICH demands excellent performance from aerogel radiator!***

Prototype needed to validate (or reject) these results

Aerogel optical characterization needed to test long term stability

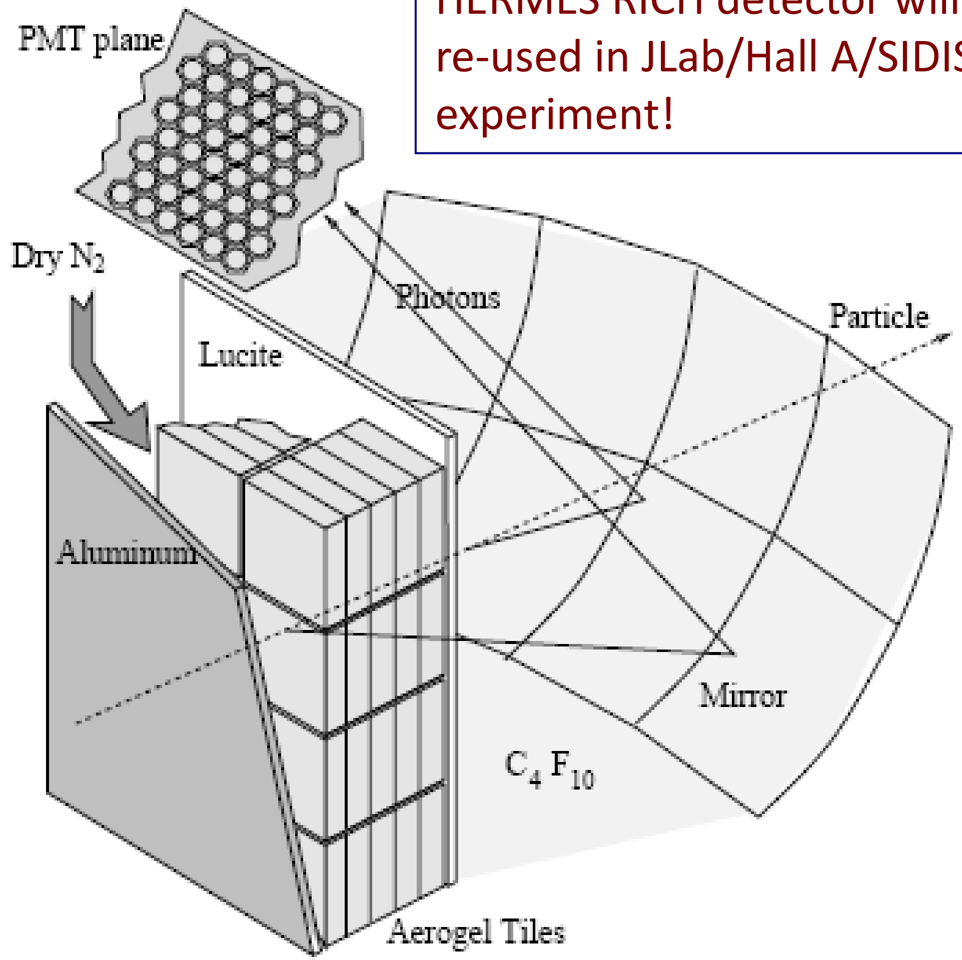
# dual RICH: successful in HERMES but …




| | |
|---|---|
| **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 (exp.)* *10*

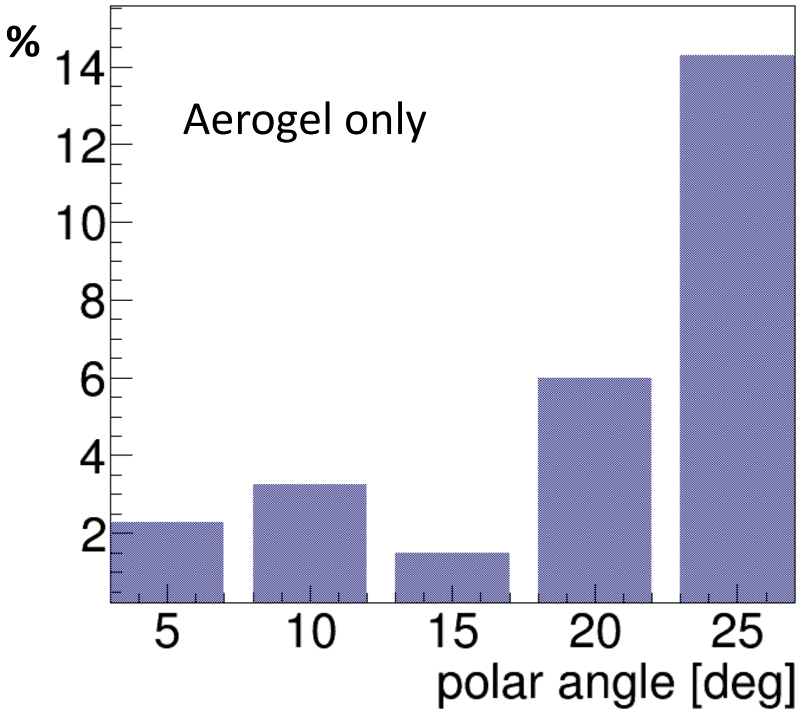
HERMES RICH detector will be re-used in JLab/Hall A/SIDIS experiment!




… aerogel errors were not dominant !!!

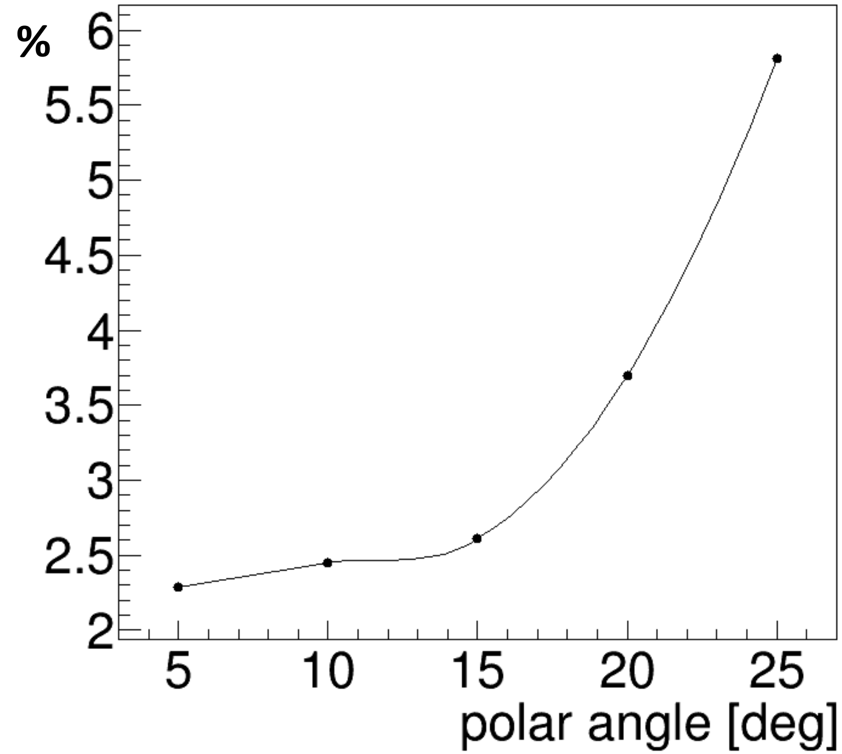
# Other Montecarlo predictions

**Inefficiency**




Probability of Nph < 3 / track
Poissonian distribution
300 nm filter in

**Background / Direct Cherenkov Photons**

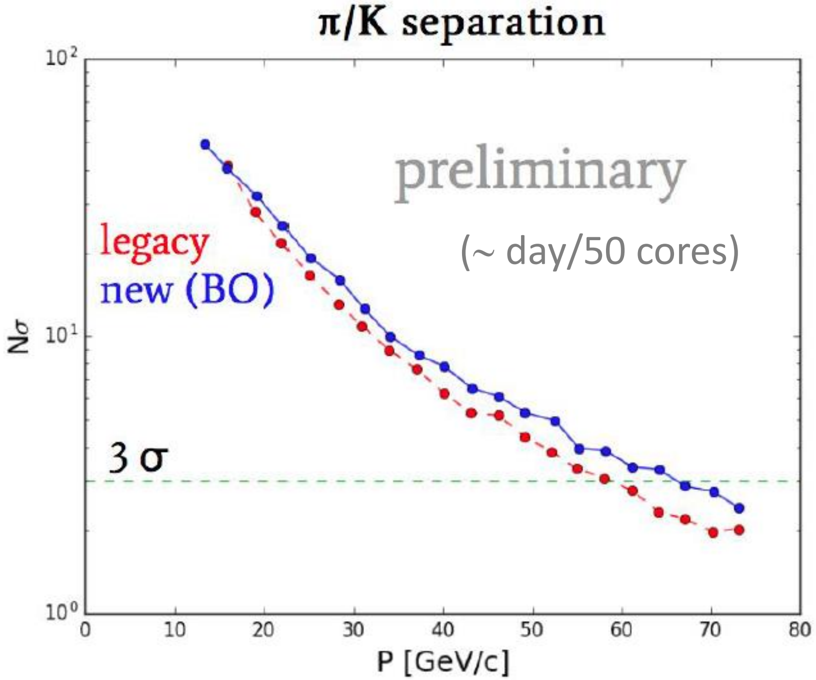



Assuming track multiplicity = 1

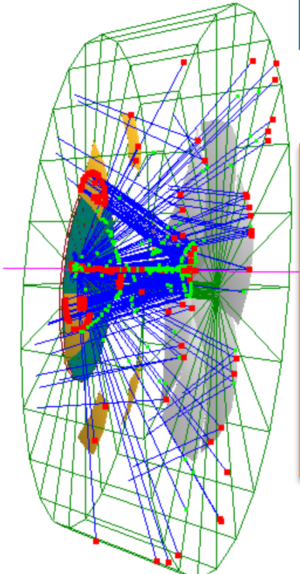
Need prototyping to get realistic results

# dRICH Performance Optimization by Bayesian Approach

- Combine detailed MonteCarlo simulations with Bayesian Approach to efficienty maximize a proper Figure of Merit (π-K Cherenkov angles separation in critical phase spaces regions, e.g. TOF-aerogel and aerogel-gas transitions, high momentum limit)
- Current implementation use 7 independent parameters: aerogel refractive index, mirror radius and position, sensor position and orientation




- Number of free parameters can be extended (e.g. aerogel thickness, gas refractive index …)
- The optimization approach can be ported to any detector development where a detailed MonteCarlo exists (or there are significant amount of real data)
- Validated MonteCarlo is essential to get realistic results → prototype needed



Inverse Ray-Tracing

# IRT Event Based Reconstruction

**Nt : tracks (+ background «dummy track»)**

**Nh : photon hits (photoelectrons)**

**Nr : radiators (aerogel and gas)**

**Np : potential particle types (e,pi,K,p)**

*~40% of PYTHIA events have multiple tracks in dRICH*
*~50% of them overlapping rings;*
***Simple track based IRT → π/K contamination>10%***

Global naive «brute force» approach: explore all possible combinations of

Track ∈ Particle type hypothesis: Np^Nt

Photon hits ∈ (Track ⊗ Radiator + Background) : **(Nt*Nr+1)^Nh**

Each combination has an associated Likelihood; take the maximum

Our approach:

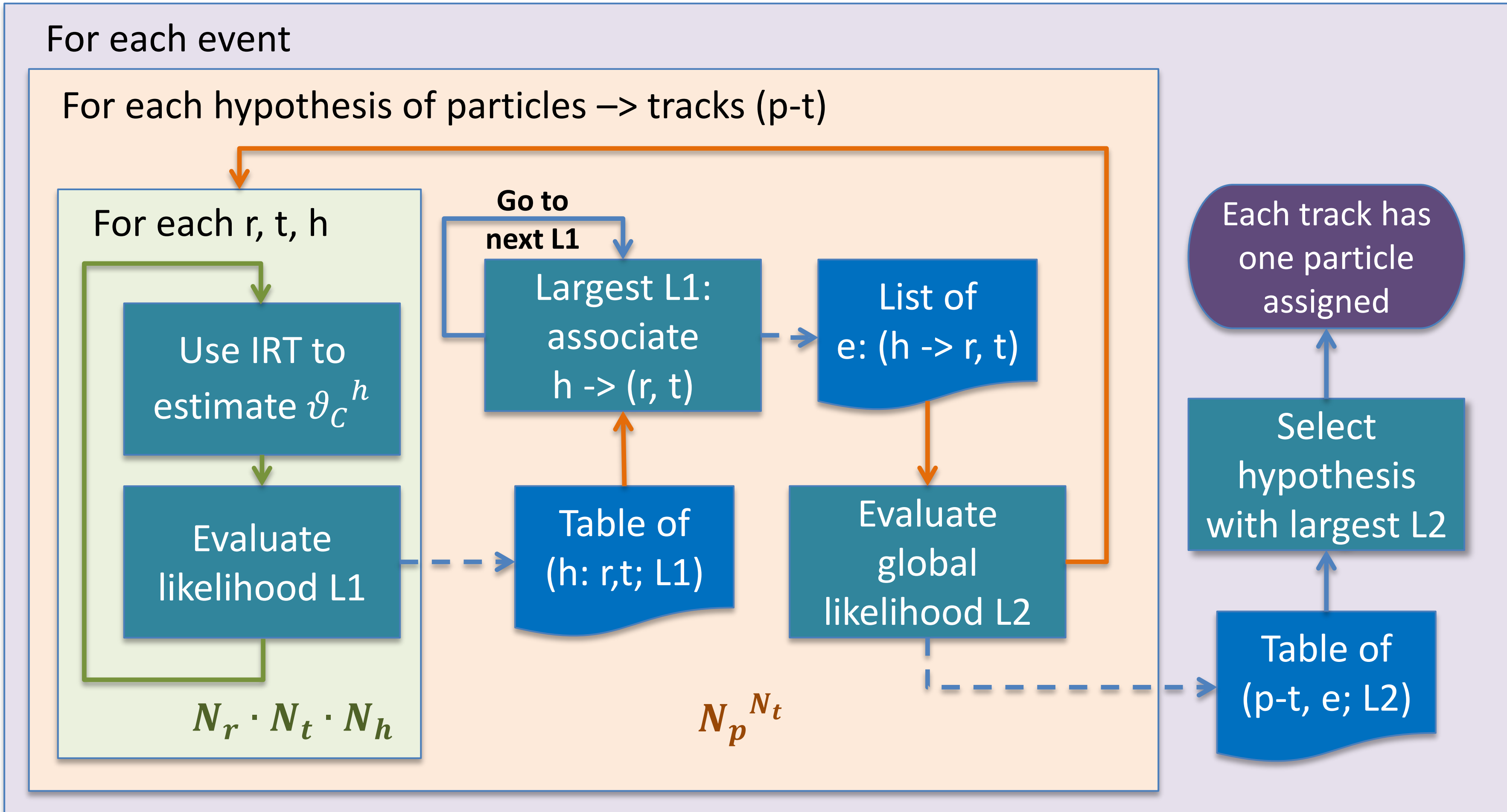
- Determine (by IRT) the potential emission angles corresponding to each photon hit
- Split the problem in two steps (for each event):
  1) Sequential hits association to tracks/radiators using a first likelihood L1 (combinations drop to **(Nt*Nr+1)*Nh**)
  2) Once all hits are associated, estimate a global Likelihood (L2) for each (track ∈ particle) combination; choose the combination with max L2

Example: event with 2 tracks and 15 hits

Brute Force: up to **~488 billion** combinations
Our approach: **1200** combinations

# Based Global Reconstruction

Particle Type (p), Radiator (r), Track (t), Hit (h)




L1: Function of distance between estimated and expected $\vartheta_C$ normalized to $\sigma_\vartheta$

L2: $\sum_{(t,r)} Gaus(\langle\vartheta_C\rangle) \times Poisson(N_{pe})$

# Detailed analysis on L1

$$L_1(p,t,r;h) \equiv G(\theta_h^{t,r} | \theta^{c,r}, \sigma_{\theta^{c,r}}) \cdot P_S(N_a^{c,r} + 1; N^{c,r})$$

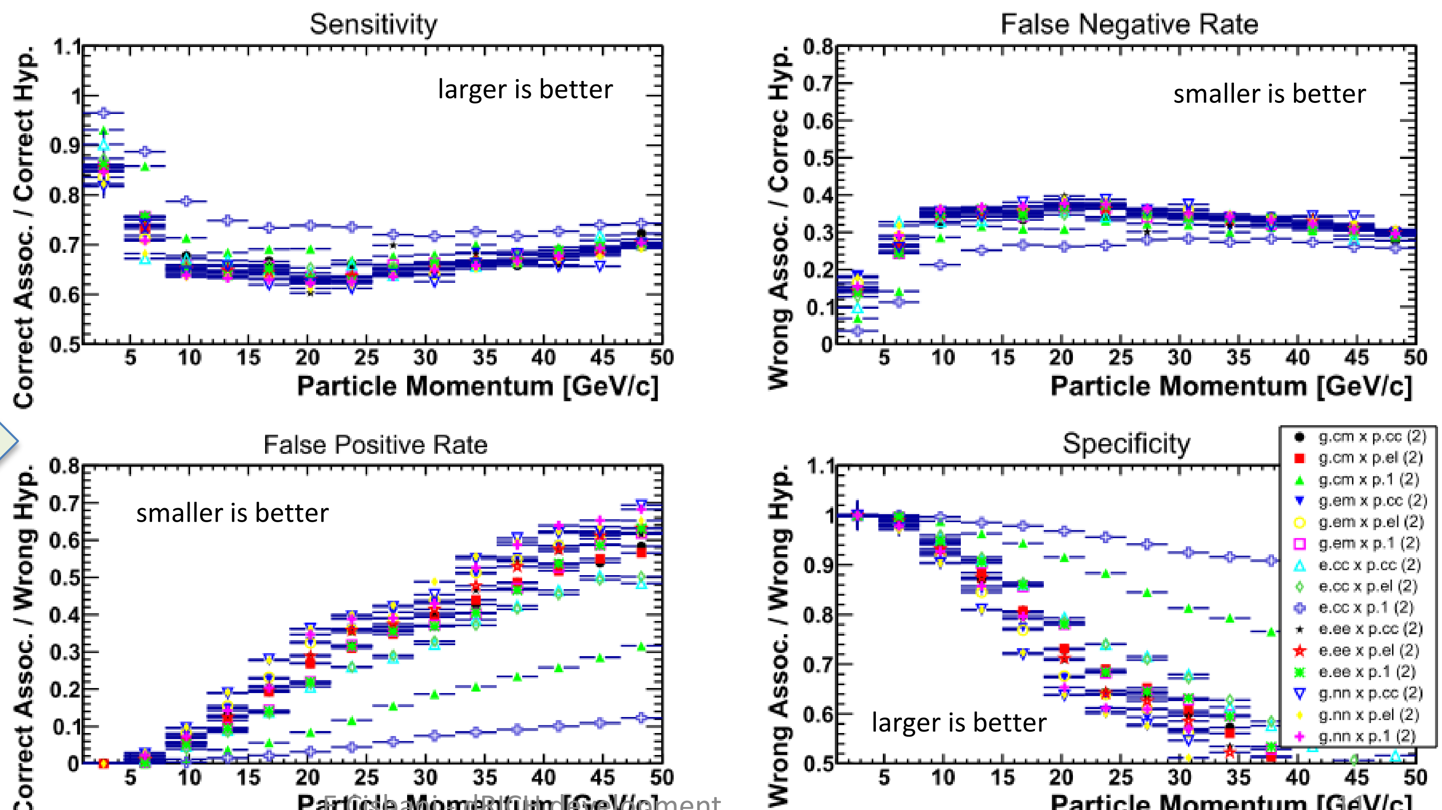
Degree of correlation of estimated and expected angle

- Gaussian distribution with max=1
- Normalized gaussian (integral = 1)
- ERF function
- =1 (no contribution)
- Combine correlation and anti-correlation

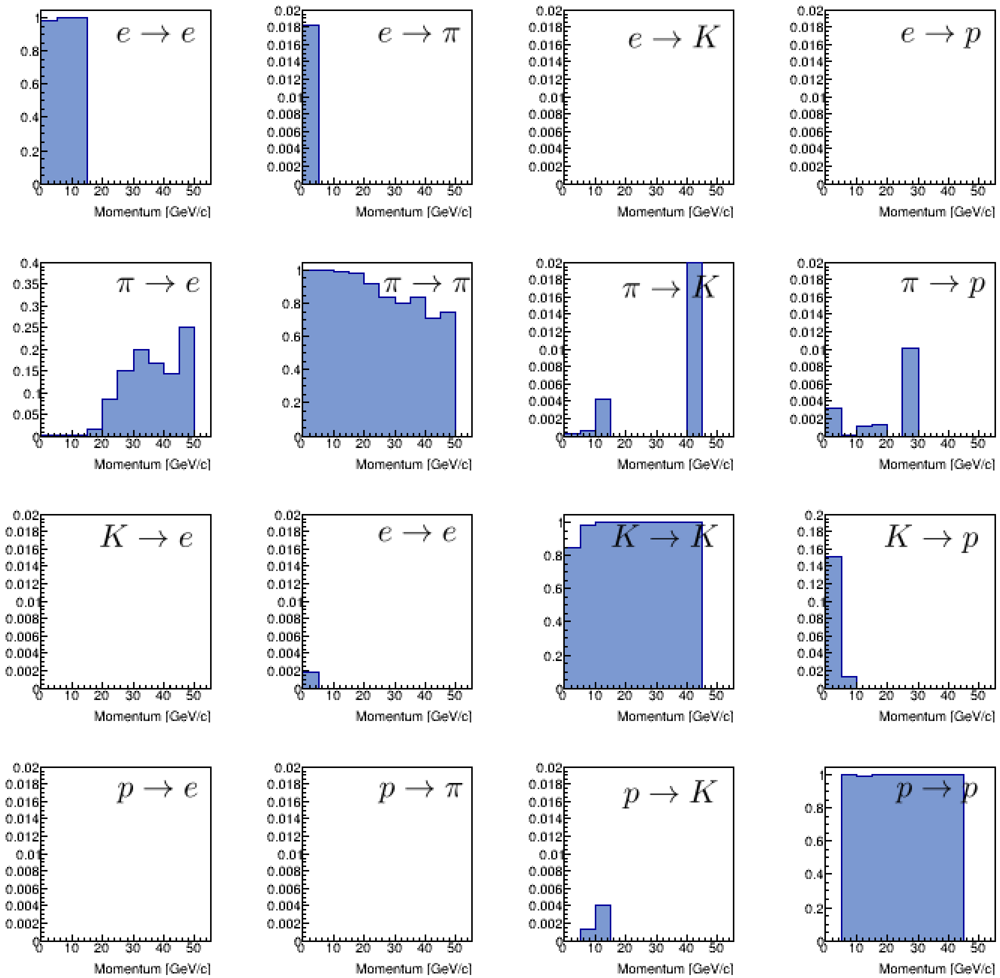
Probability to assign a new photon to the track/rad/part by random choice

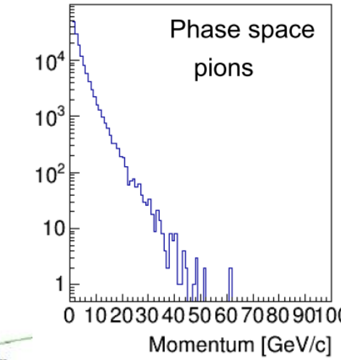
- Cumulated Poisson: prob. assign one or more photon to a given track/rad...)
- Partitioning: enumerate all combinations on “n” photons into “m” partitions (track/rad..);
- =1 (no contribution)

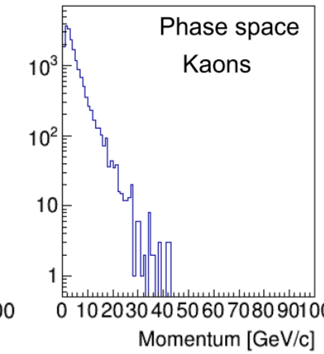
L1=(1-ERF) provides best predictions

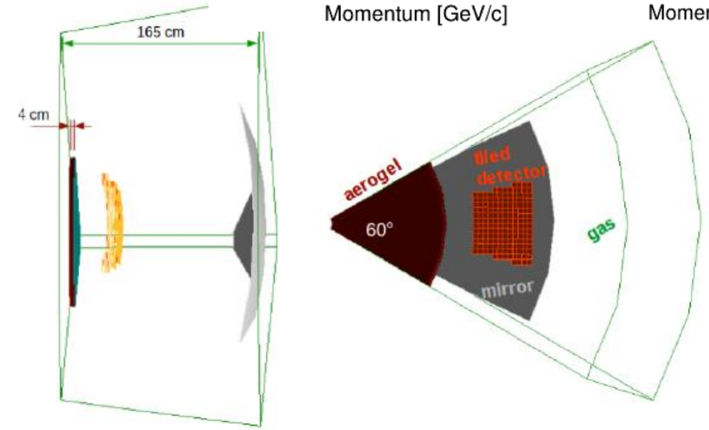


# dRICH performance for a key process (PYTHIA DIS simulation)




one of the six dRICH sectors

| Momentum Threshold (GeV/c) | | |
|---|---|---|
| Particle | Aerogel (1.02) | C2F6 (1.0008) |
| e | 0.003 | 0.013 |
| pi | 0.694 | 3.49 |
| K | 2.46 | 12.3 |
| p | 4.67 | 23.5 |

**The PID capability fulfills the design goals**

# Toward dRICH prototype

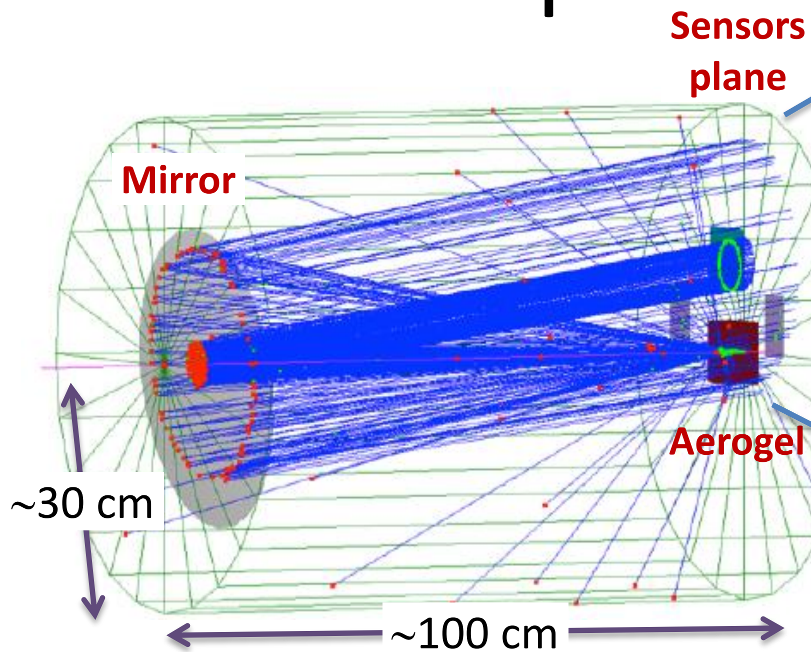
Why: **Validate main design choices, consolidate the estimated performances, identify potential technical issues that are hard to model**

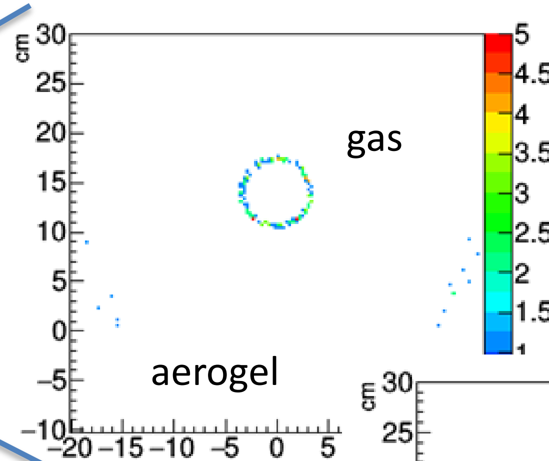
- Measure realistic number of direct Cherenkov photons coming out from both radiators
- Evaluate quality of aerogel in terms of Cherenkov photons (e.g. chromatic dispersion of refractive index)
- Estimate other effects (e.g. impact of scintillation photons in Freon gases)

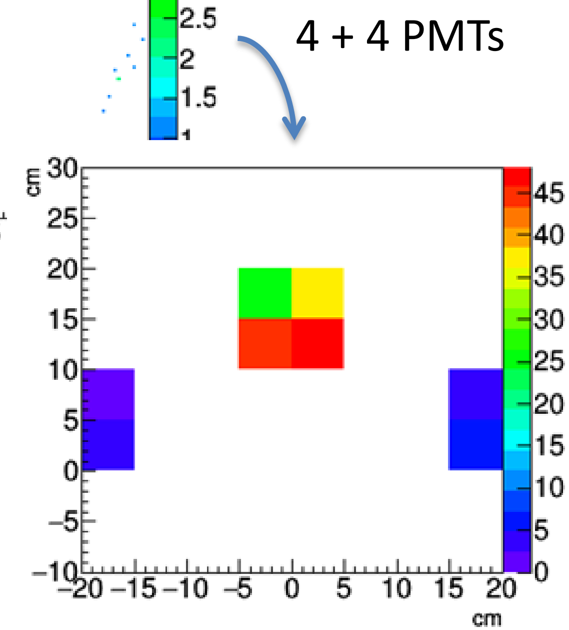
The prototype must:

- Mimic the performances of the proposed dRICH components, minimizing modeling and assumptions
- Permit to estimate the relevant quantities (e.g. chromatic effects, number of directive Cherenkov photons)
- Be cost effective (trade-off between small scale, versatility and measurable quantities); use existing components – synergy with mRICH development

# First preliminary prototype



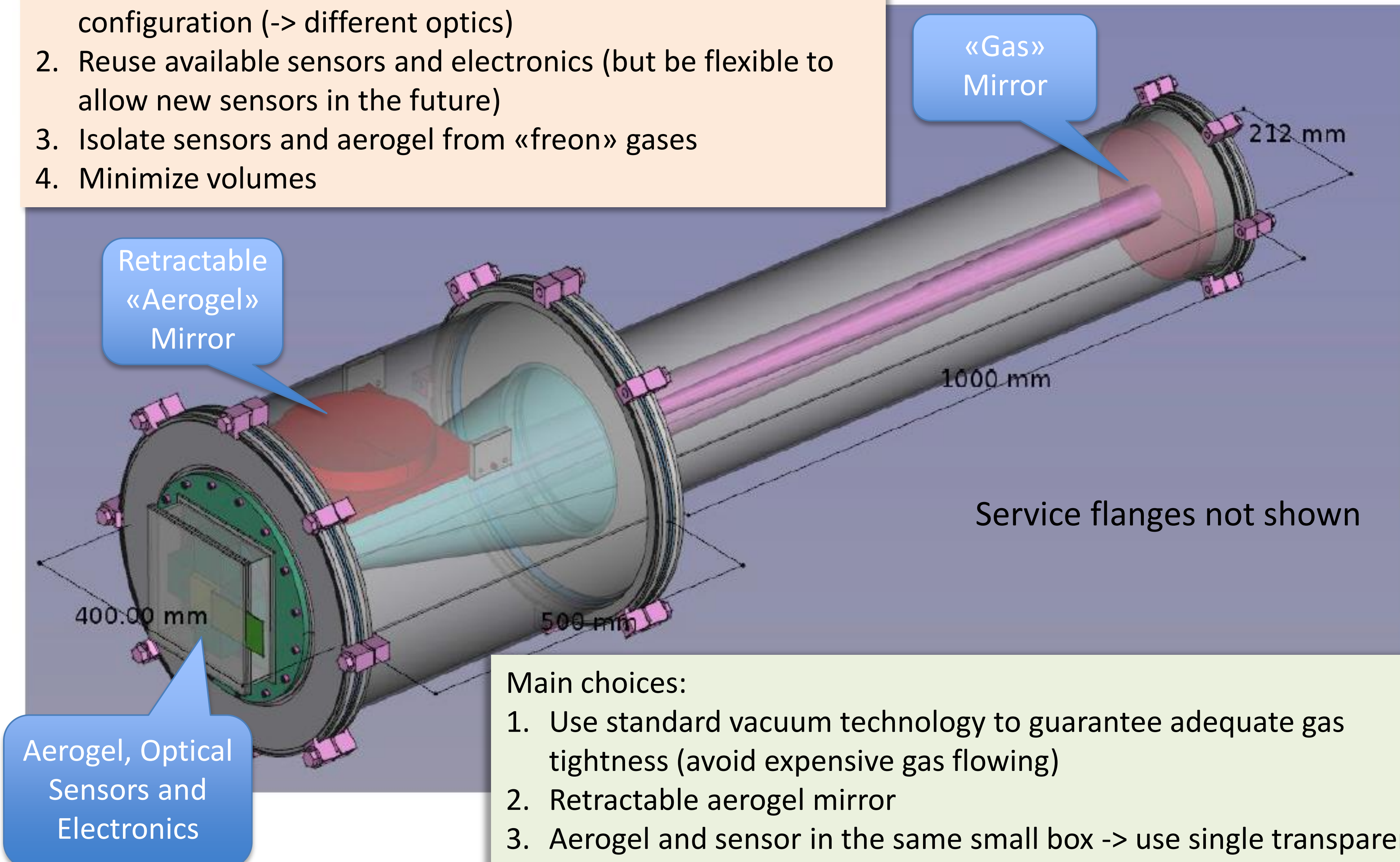

**Montecarlo prediction**

- ☺ Geometry similar to dRICH; comparable relative contributions to $\sigma_\vartheta$
- ☹ Only small fraction of aerogel ring (with available sensors/electronics)
- ☹ Switch between two different sensor/electronics setups

| 1 p.e. error (mrad) | Aerogel | Gas (C2F6) |
|---|---|---|
| Chromatic | 3.7 | 0.85 |
| Emission | 0.2 | 0.85 |
| Pixel (3 mm) | 0.9 | 1 |

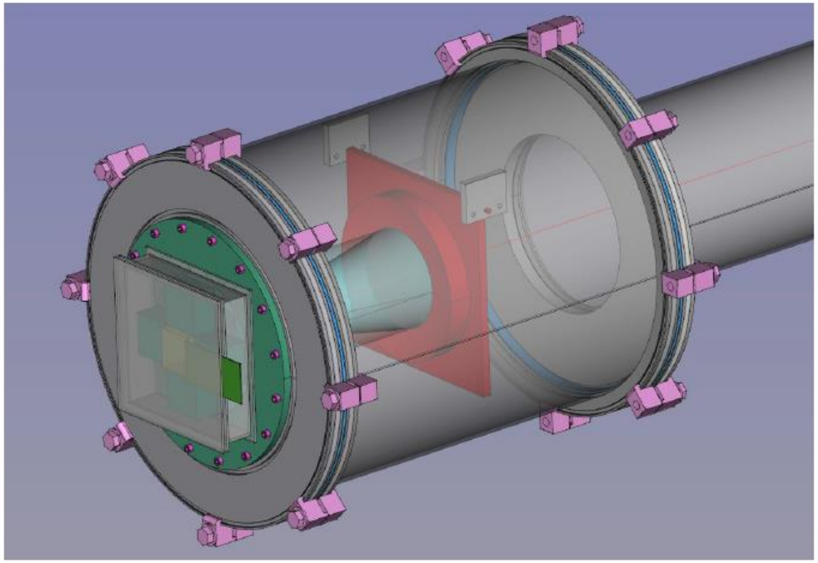
# dRICH Prototype Consolidated Design

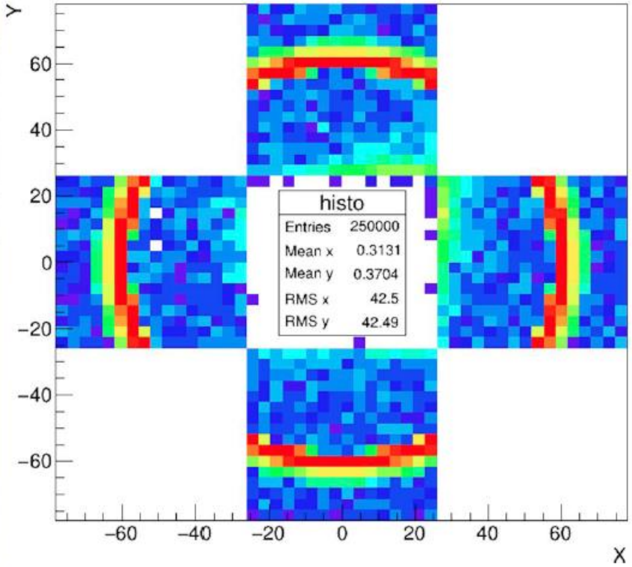
Driving items:
1. Gas and Aerogel rings need to enter the same sensors configuration (-> different optics)
2. Reuse available sensors and electronics (but be flexible to allow new sensors in the future)
3. Isolate sensors and aerogel from «freon» gases
4. Minimize volumes

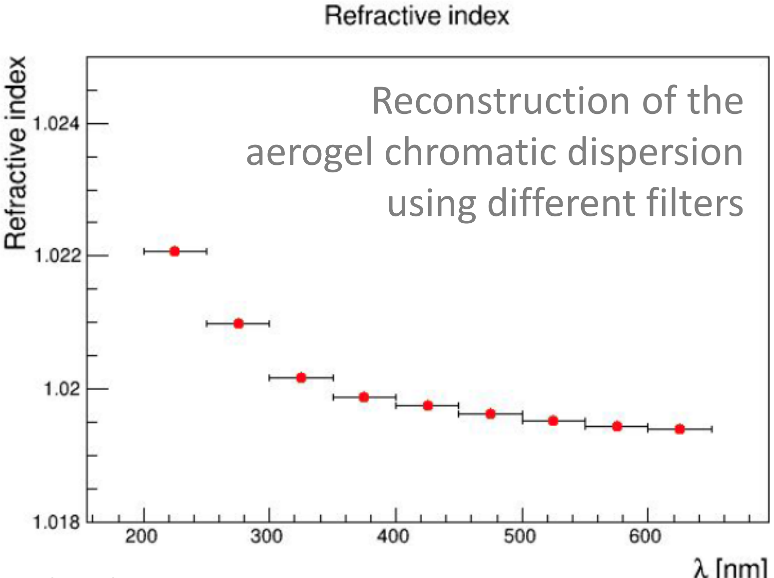



Main choices:
1. Use standard vacuum technology to guarantee adequate gas tightness (avoid expensive gas flowing)
2. Retractable aerogel mirror
3. Aerogel and sensor in the same small box -> use single transparent window (compatible with Fermilab test beam specificities)

# dRICH Consolidate Prototype “Aerogel Mode”



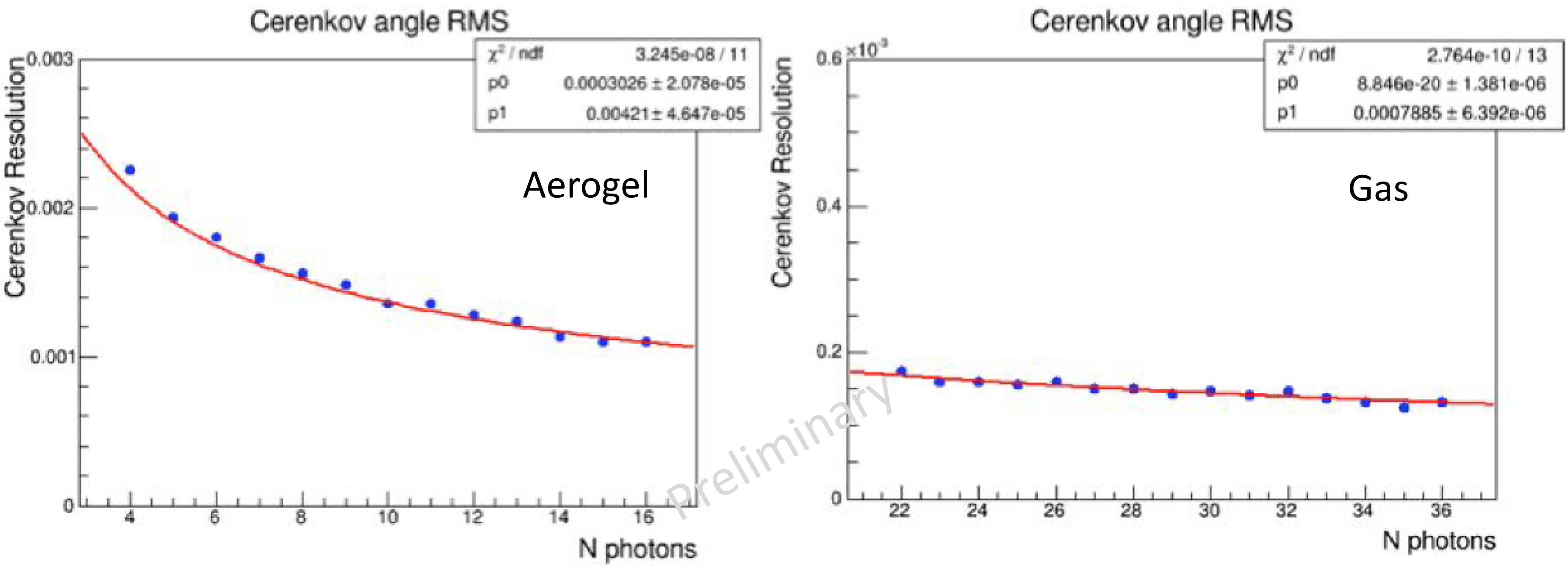



- Gas optics similar to dRICH model
- Aerogel optics is pretty different than in dRICH -> different contributions to $\sigma_{\vartheta}$

Measurement of the aerogel chromatic dispersion and UV filter optimization still possible

# dRICH Consolidated Prototype Expected Performance




| 1 p.e. Error (mrad) | Aerogel | | $C_2F_6$ Gas | |
|---|---|---|---|---|
| Chromatic error | 3.2 | (2.9) | 0.51 | (0.8) |
| Emission | 0.5 | (0.5) | 0.5 | (1.2) |
| Pixel | 2.5 | (0.5) | 0.42 | (0.5) |

Chormatic and pixel erros are comparable in prototype

# Conclusions

- Consolidate baseline dRICH design:
  - hardware (GEMC montecarlo)
  - Software (event based PID)

  → *need realistic validation*
- Further optimizations ongoing; general method can be applied to other detectors
- Prototyping design under finalization by Montecarlo analysis; need to solve few details (e.g. gas filling procedure)
- Prototype cost estimation available, construction will likely start soon