

COSENZA

UNIVERSITÀ DELLA CALABRIA

Simulation of Aerogel for the dRICH detector

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Annalisa De Caro, Salvatore Fazio

On behalf of the ePIC dRICH simulation team

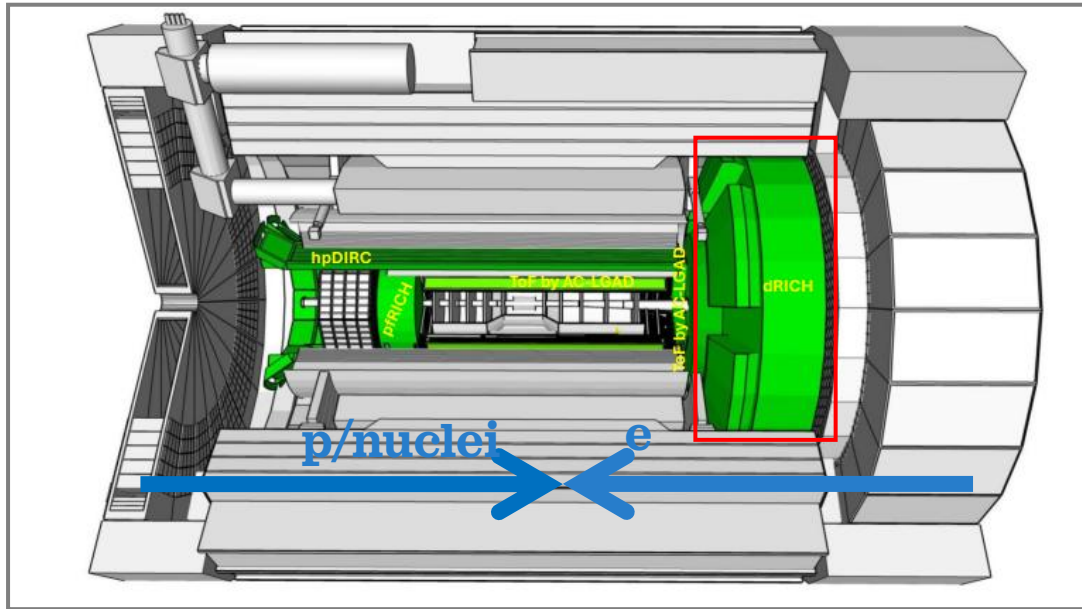


ePIC and EIC Physics Readiness Workshop, Cosenza 17-19 March
2026

Outline

- Particle ID and the dRICH detector
- Performance simulation studies (Phase I)
 - Aerogel laboratory characterization
- Performance simulation studies (Phase II)
- Geometry optimization
- Multiplicity studies

Particle ID: a key challenge



π/K separation requirements:

Backward → pfRICH

- Up to 9 GeV/c

Central → hpDIRC + ToF

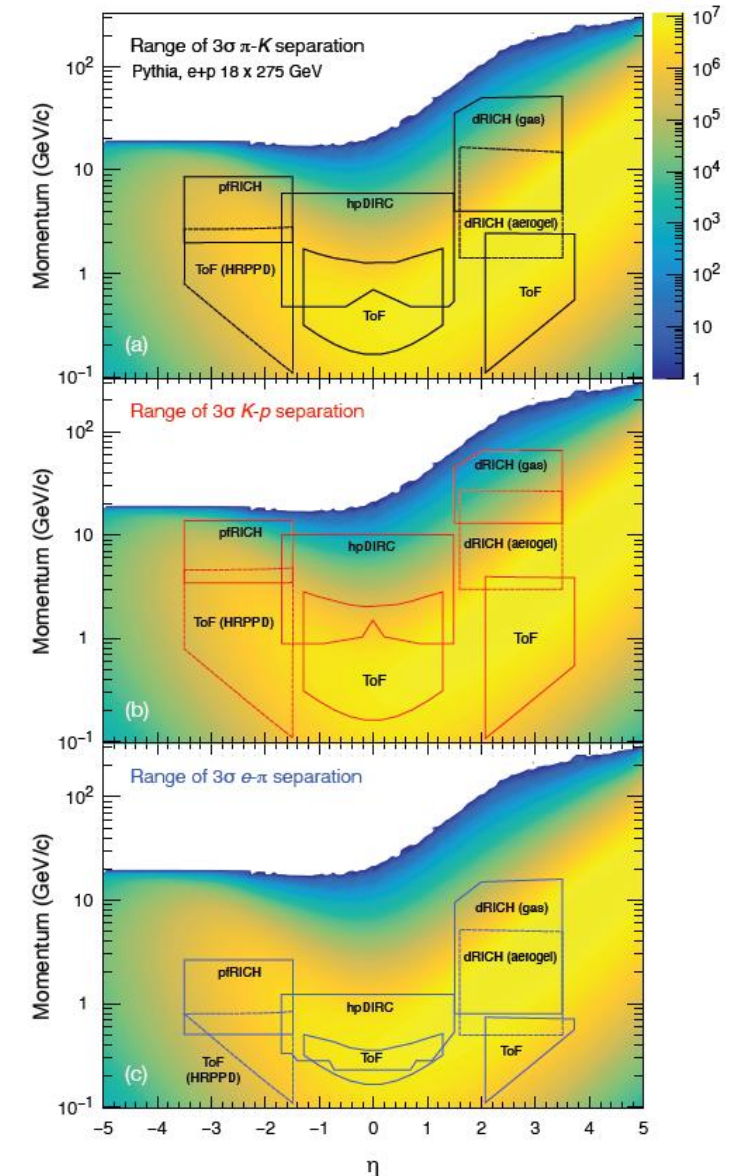
- Up to 6 GeV/c

Forward → dRICH + ToF

- Up to 50 GeV/c

Key Detector Requirement:

- ✓ Essential for identifying particles from **e+p/nuclei collisions**
- ✓ Compact design with high performance in the **forward region**
- ✓ Critical for physics goals: **e/ π separation up to 50 GeV/c**



The dRICH detector

Radiators:

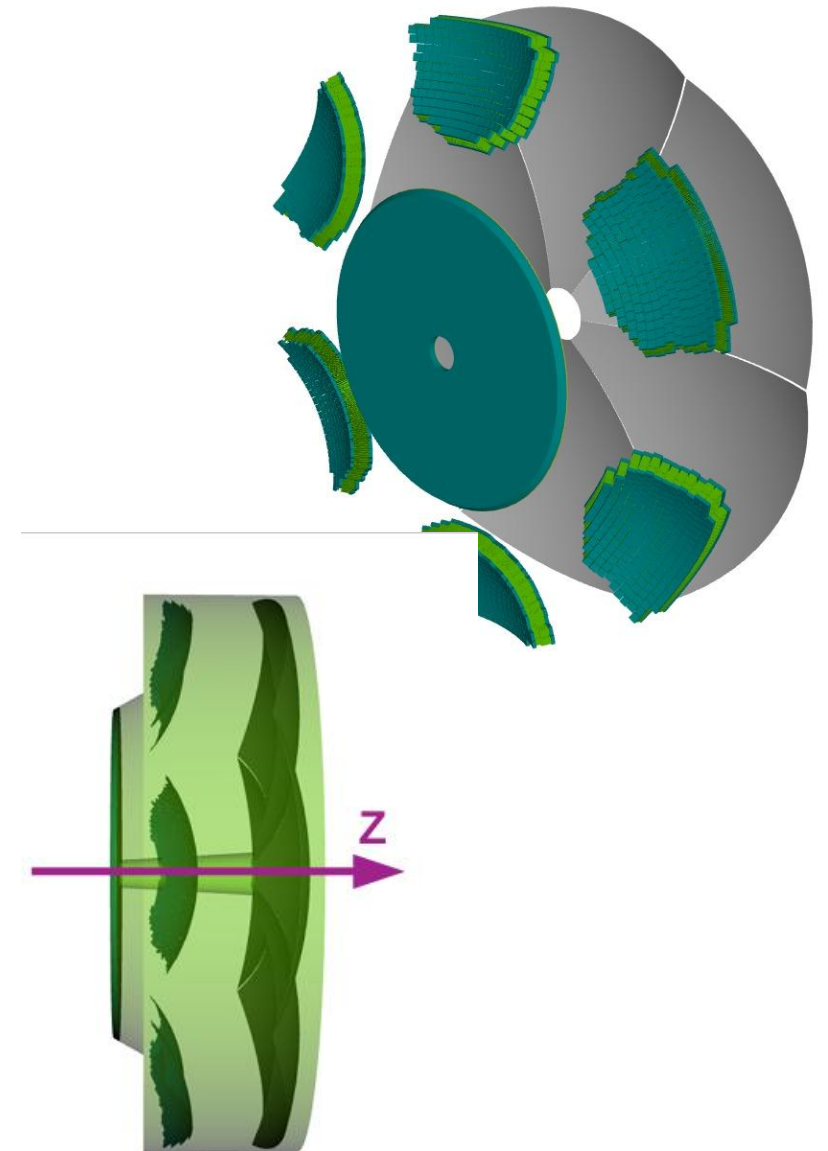
- Aerogel ($n \sim 1.026$): changed from baseline $n \sim 1.019$
- C_2F_6 ($n \sim 1.0008$)

Mirrors

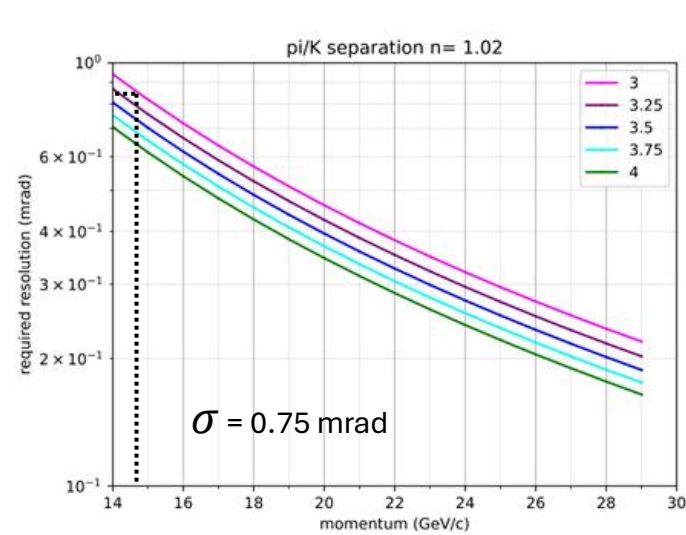
- Large outward-reflecting, 6 open sectors

Sensors

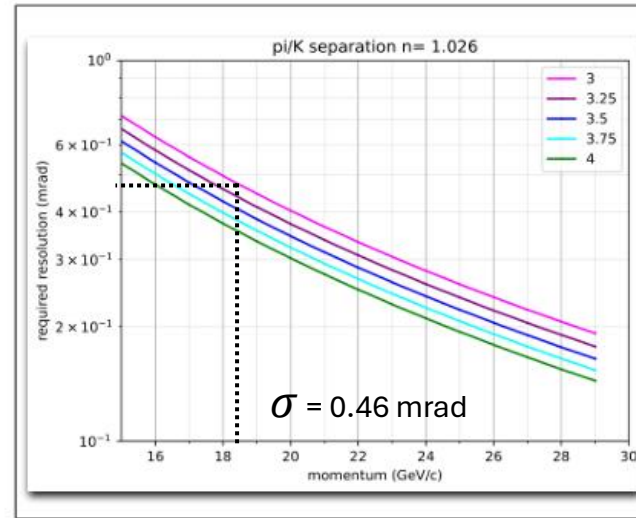
- Single-photon detection
- High photon detection efficiency
- Insensitive to the magnetic field
- SiPM as a cost effective solution



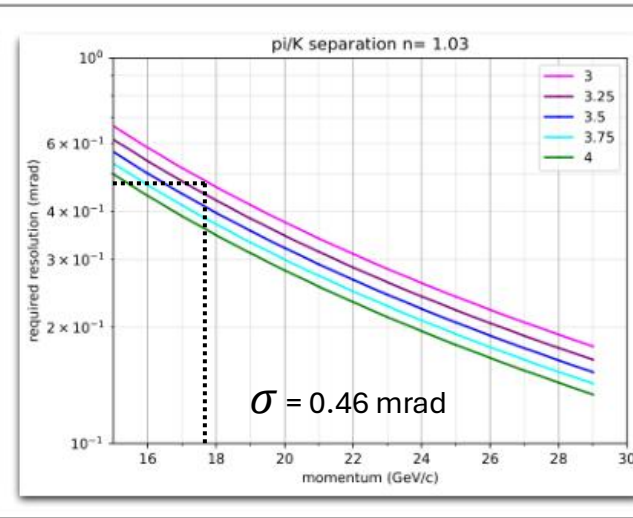
Requirements for radiators



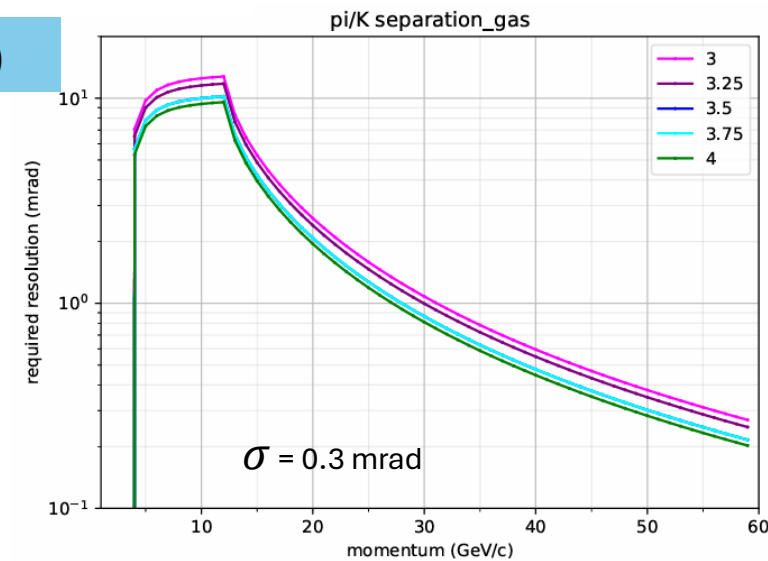
Nominal ($n \sim 1.019$)



Type-1 ($n \sim 1.026$)

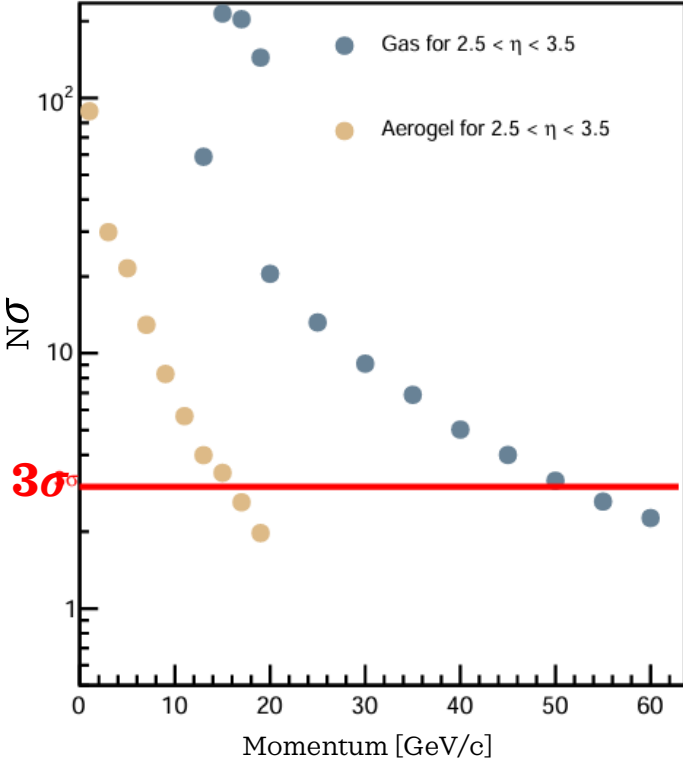
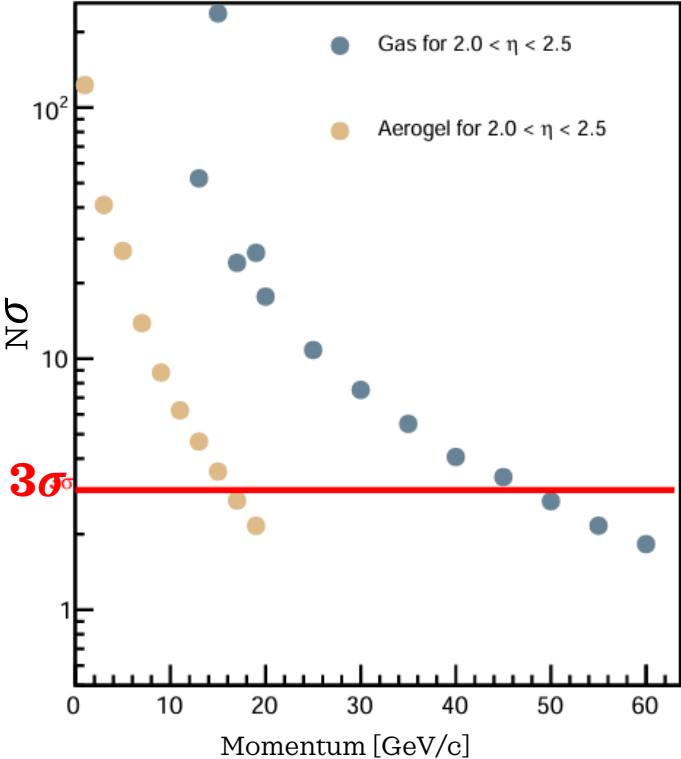
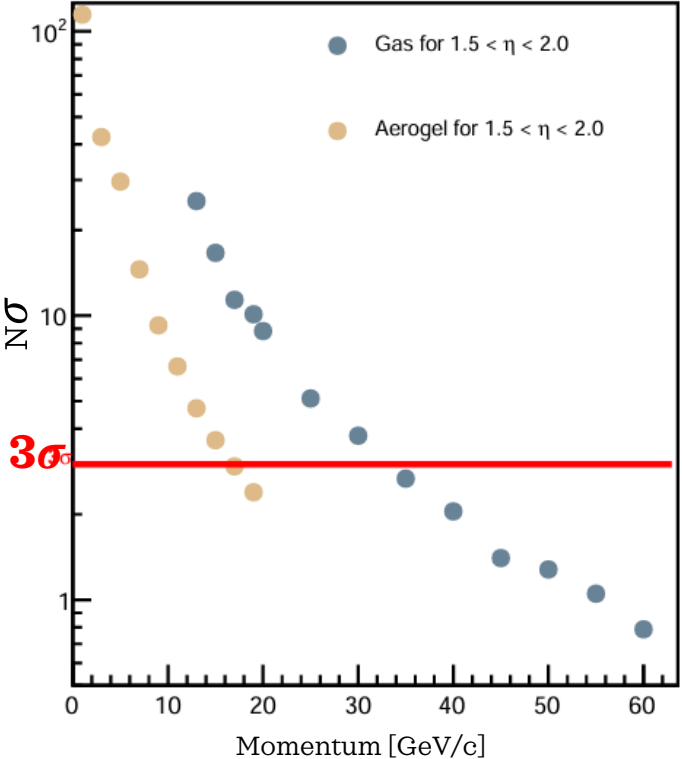


Type-2 ($n \sim 1.03$)



- ✓ In order to achieve at least a 3σ pion/Kaon separation up to 15 GeV/c in Aerogel we need a ring resolution better than 0.75 mrad with nominal refractive index $n=1.019$.
- ✓ In order to achieve at least a 3σ pion/Kaon separation above 50 GeV/c we need a *ring resolution* ($\frac{\sigma_{PE}}{\sqrt{NPE}}$) around 0.3 mrad.

Simulation results for Gas and Nominal Aerogel (n=1.019)

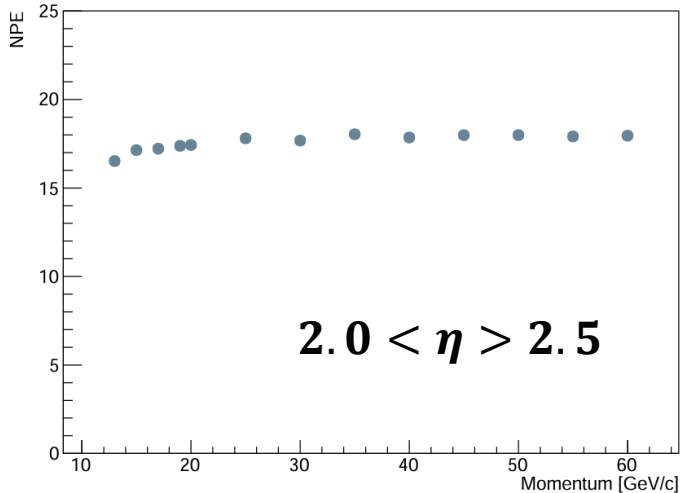
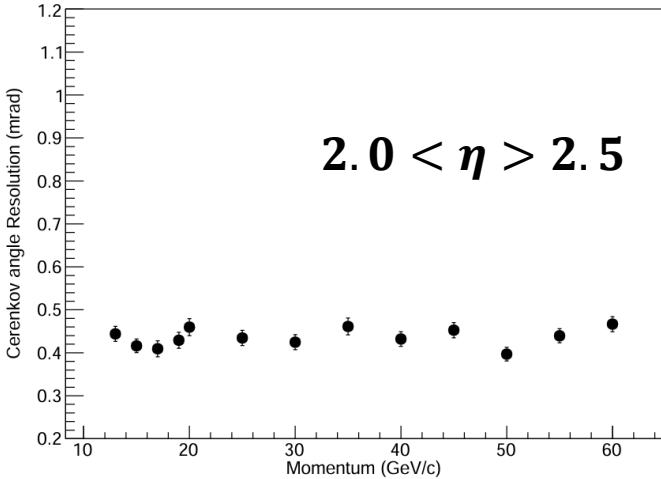


@ $\eta > 2.5$ we achieve 3σ with ~ 15 GeV/c of momentum for the aerogel and ~ 50 GeV/c for the gas.

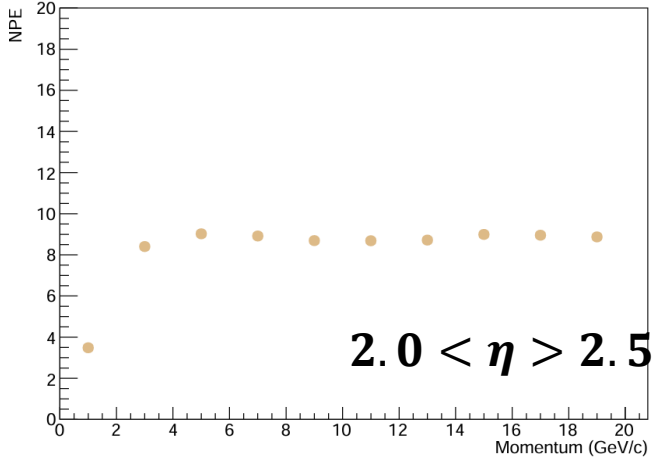
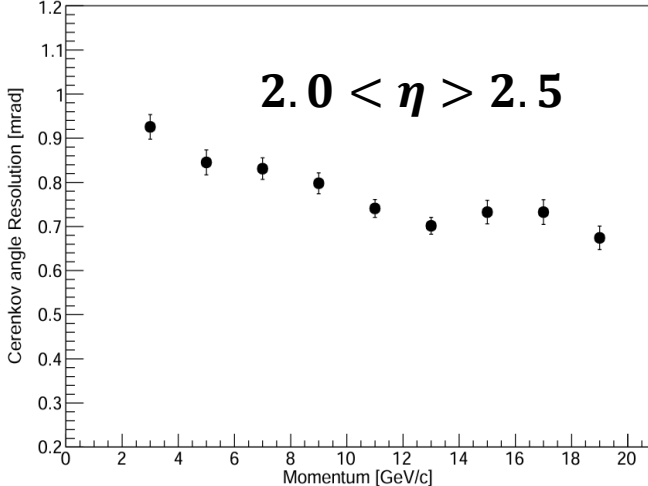
No discontinuity in PID

Simulation results for Gas and Nominal Aerogel (n=1.019)

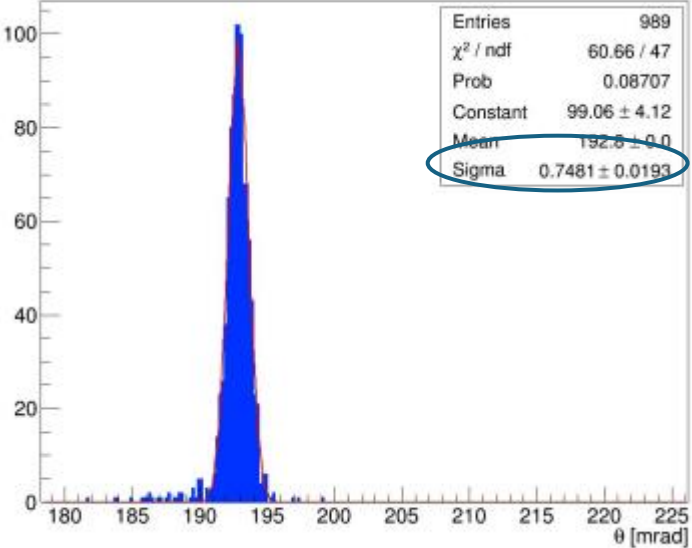
GAS



Aerogel



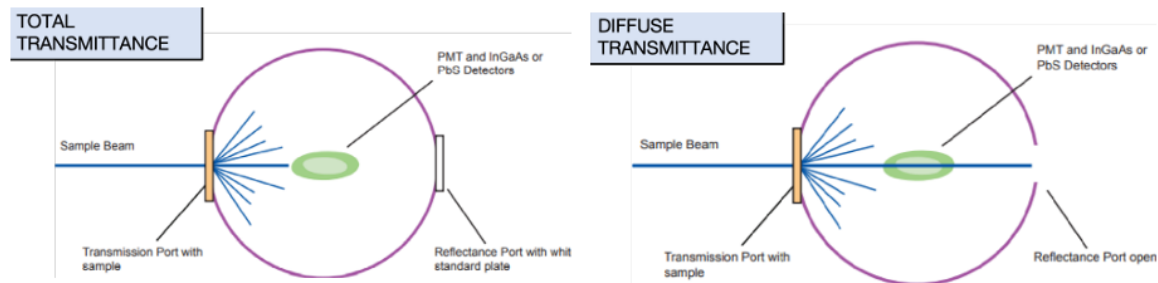
Cherenkov angle resolution compatible with the expectations



Potential issues:
 Availability
 Hydrophobic aerogel available from Chiba Aerogel Factory Japan.
 Better optical quality.

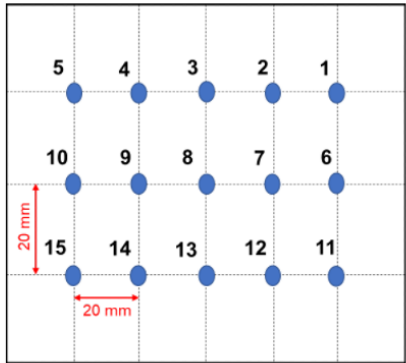
Aerogel characterization @ INFN Bari (A. Altamura et al)

Measurements performed with a Perkin Elmer spectrometer at CERN, using an integrating sphere and a light source to cover the range 250- 800 nm to map the Linear Transmittance.

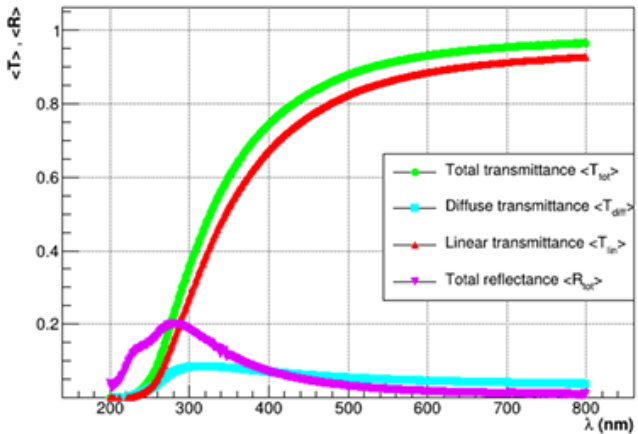
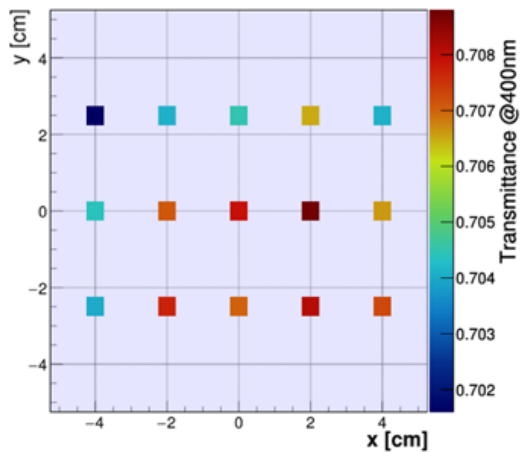
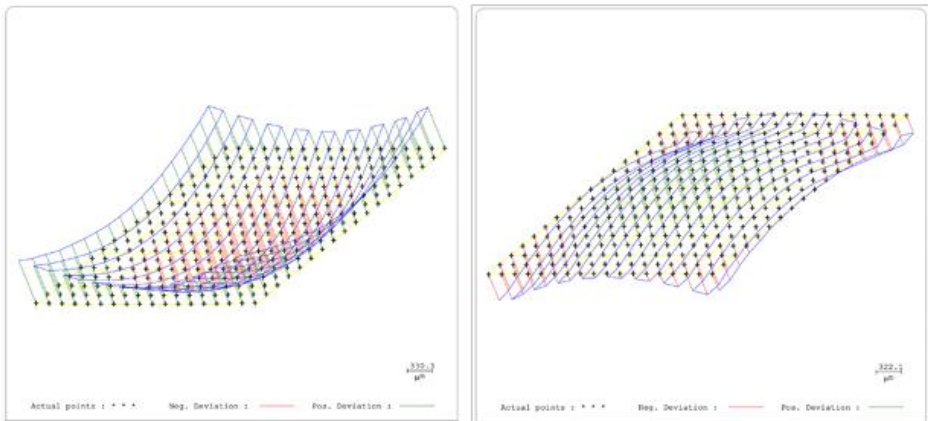


LINEAR TRANSMITTANCE

$$T_{LIN} = T_{TOT} - T_{DIFF}$$



The transmittance is not uniform: thinner areas transmit light better. Non-planarity (up to 1.27 mm) can distort the Cherenkov angle reconstruction.



For more details
 look at
<https://pos.sissa.it/476/1116/>

Aerogel characterization @ INFN Bari (A. Altamura et al)

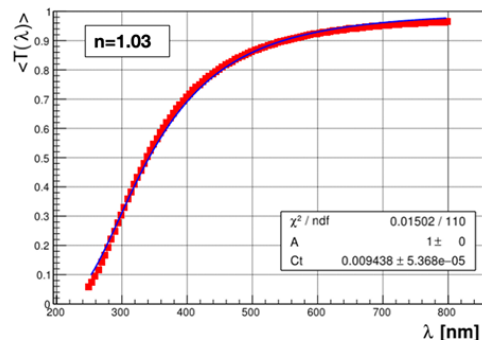
2-parameters **Hunt-basic formula**

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}} = Ae^{-\frac{Ct}{\lambda^4}}$$

ASSUMPTIONS

Λ_A constant

$\Lambda_S \sim \lambda^4$



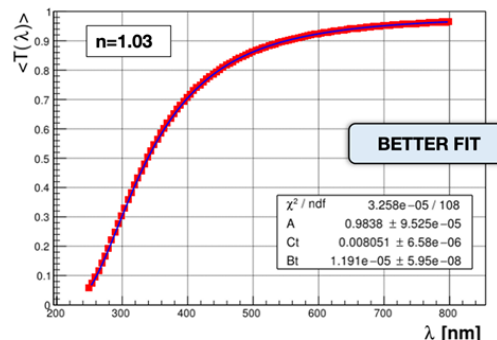
3-parameters **Hunt-extended formula**

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}} = Ae^{-\frac{Bt}{\lambda^8}} e^{-\frac{Ct}{\lambda^4}}$$

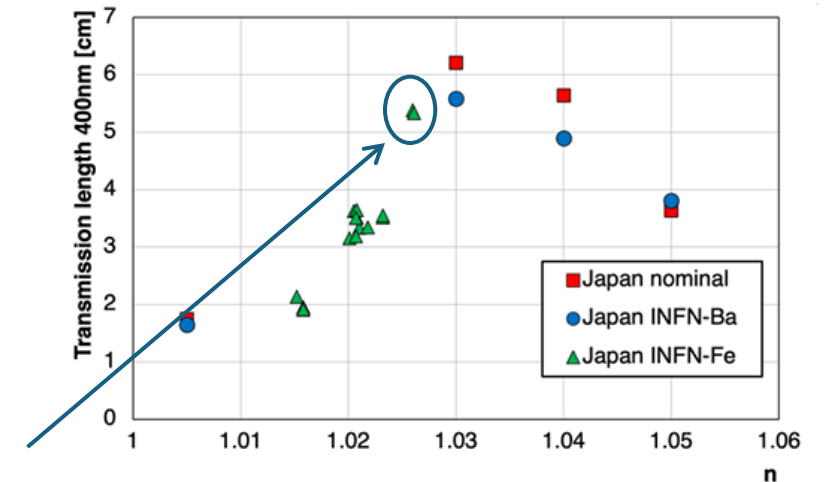
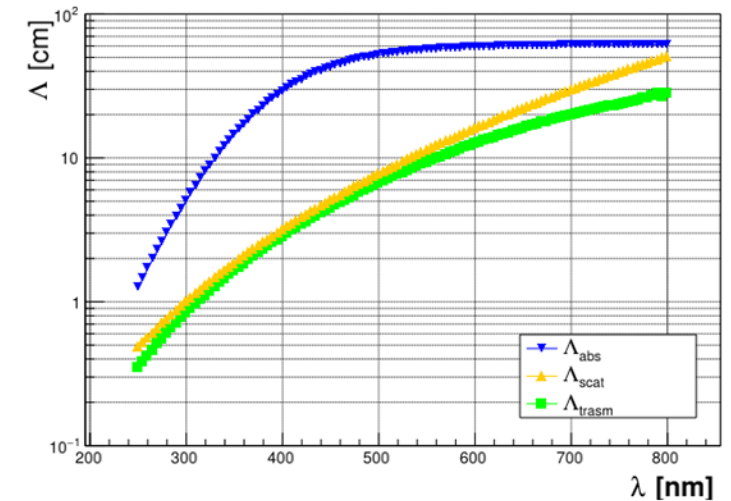
ASSUMPTIONS[3]

$\Lambda_A \sim \lambda^8$

$\Lambda_S \sim \lambda^4$



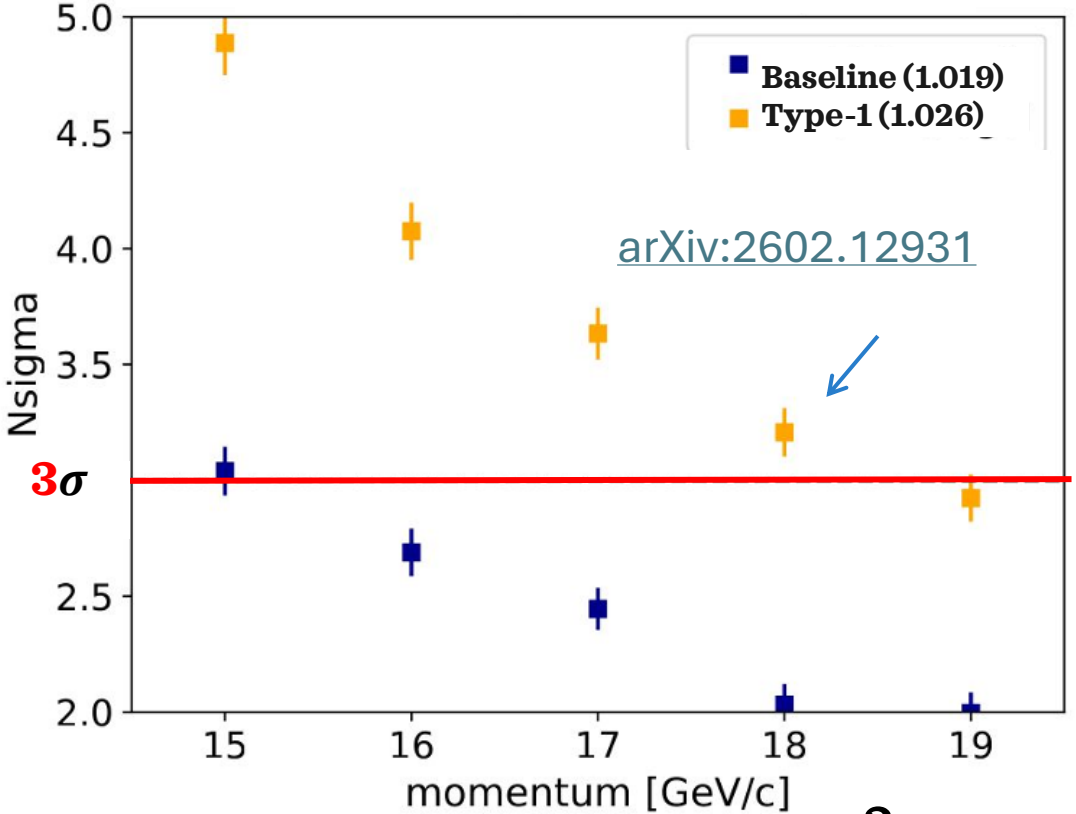
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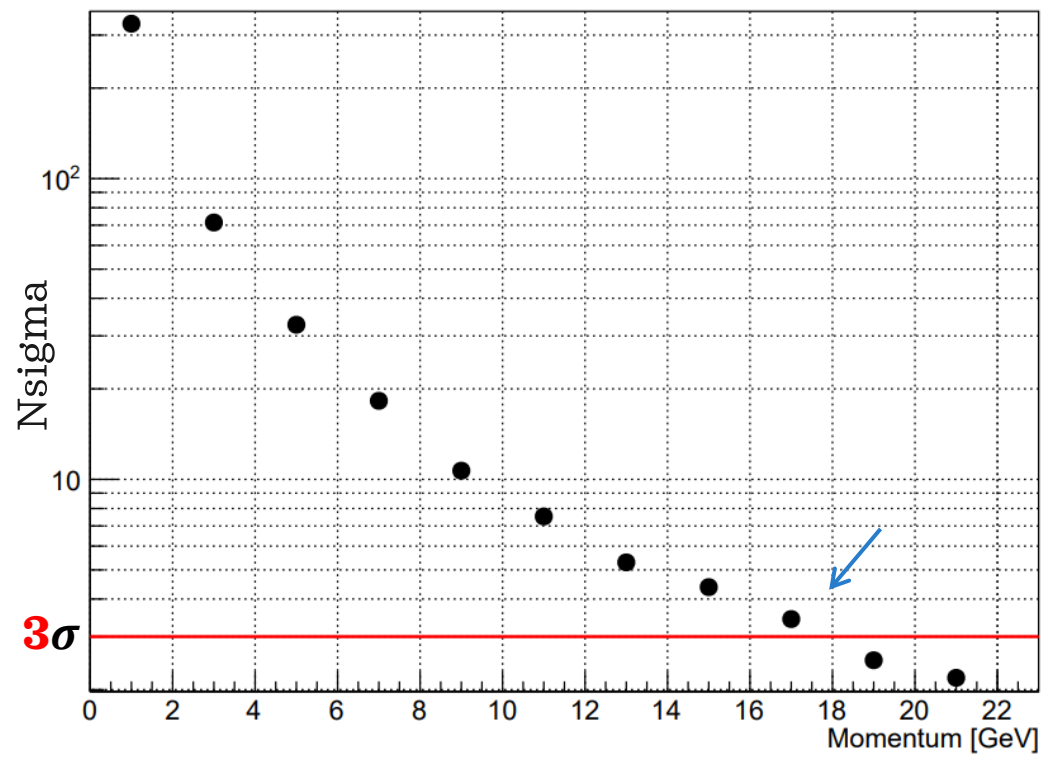
- ✓ Adding a third parameter λ^8 allows for better modeling of the absorption, resulting in higher statistical precision.
- ✓ Absorption negligible; the loss of transparency was dominated almost entirely by Rayleigh scattering.
- ✓ **$n=1.026$: the best compromise between optical performance and spatial constraints.**

Simulation result for new Aerogel

n=1.019 vs n=1.026



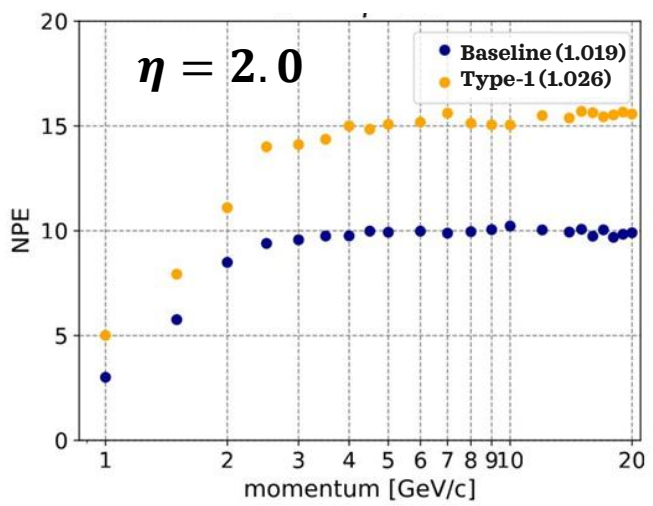
n=1.03



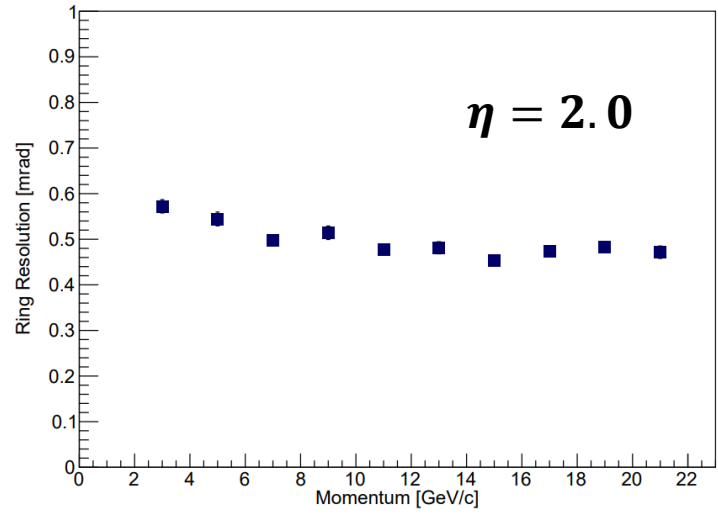
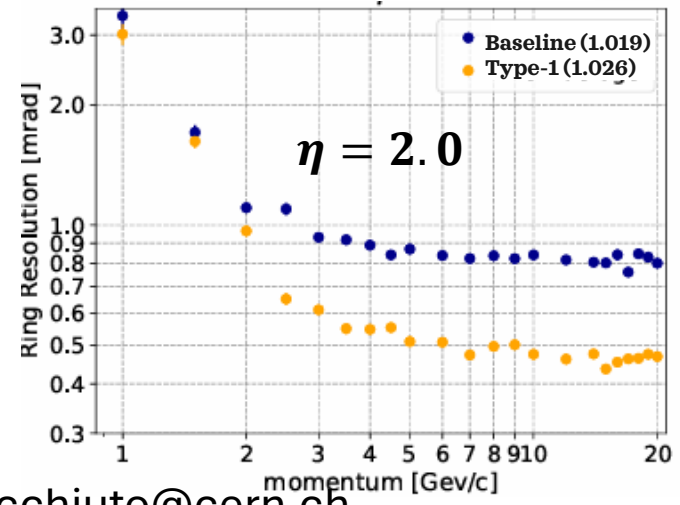
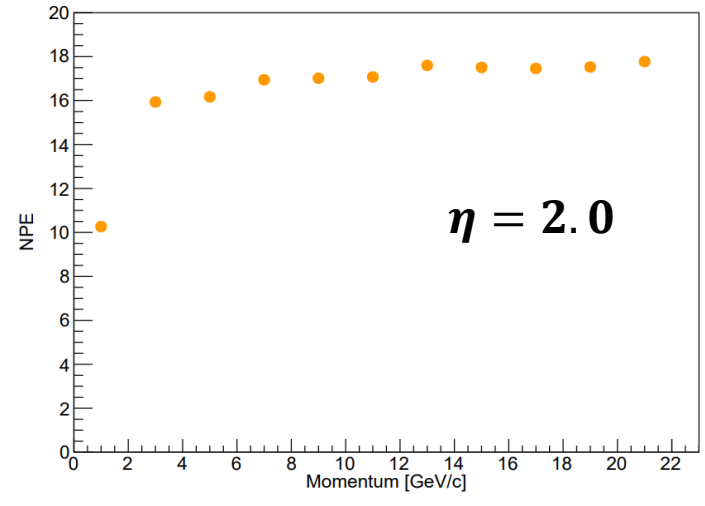
3σ separation at ~ 17/18 GeV/c of momentum!

Simulation results for new Aerogel

n=1.019 vs n=1.026



n=1.03



Also the NPE increase (~50%) and the Cherenkov angle resolution improves (>30%)!

Chromatic aberration

<https://zenodo.org/records/14328280>

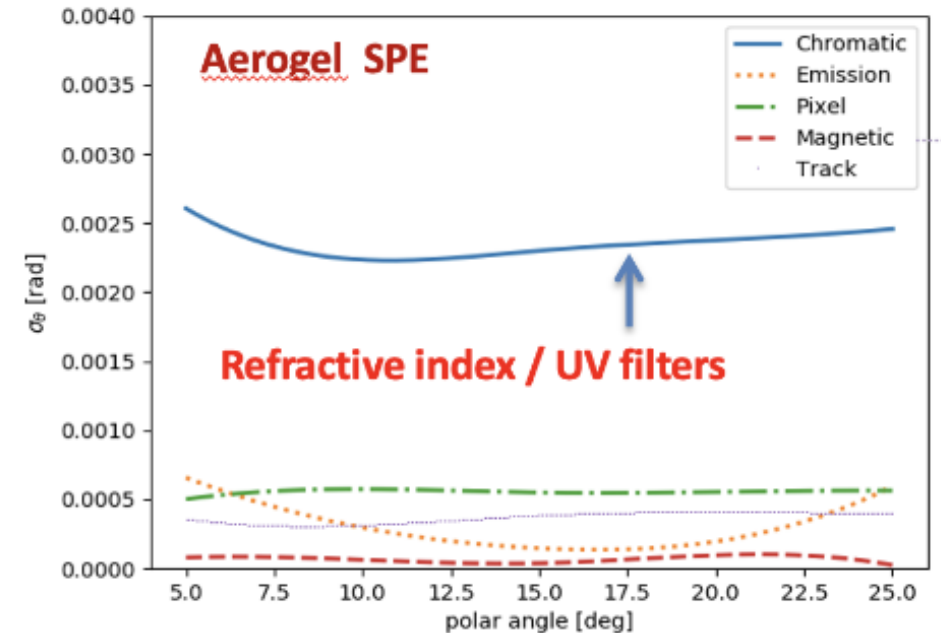
What is Chromatic aberration?

- ✓ Optical effect limiting the **precision of Cherenkov angle measurements**
- ✓ Caused by **wavelength-dependent refractive index** (of aerogel or gas)

How is its impact estimated?

Simulation with and without λ – **dependence** of refractive index

- ✓ 1000 events.
- ✓ PID: 211
- ✓ Momentum fixed @ 15 GeV/c.
- ✓ Different bins of η .



Chromatic term dominates the angular uncertainty!

Studied at two refractive index values!

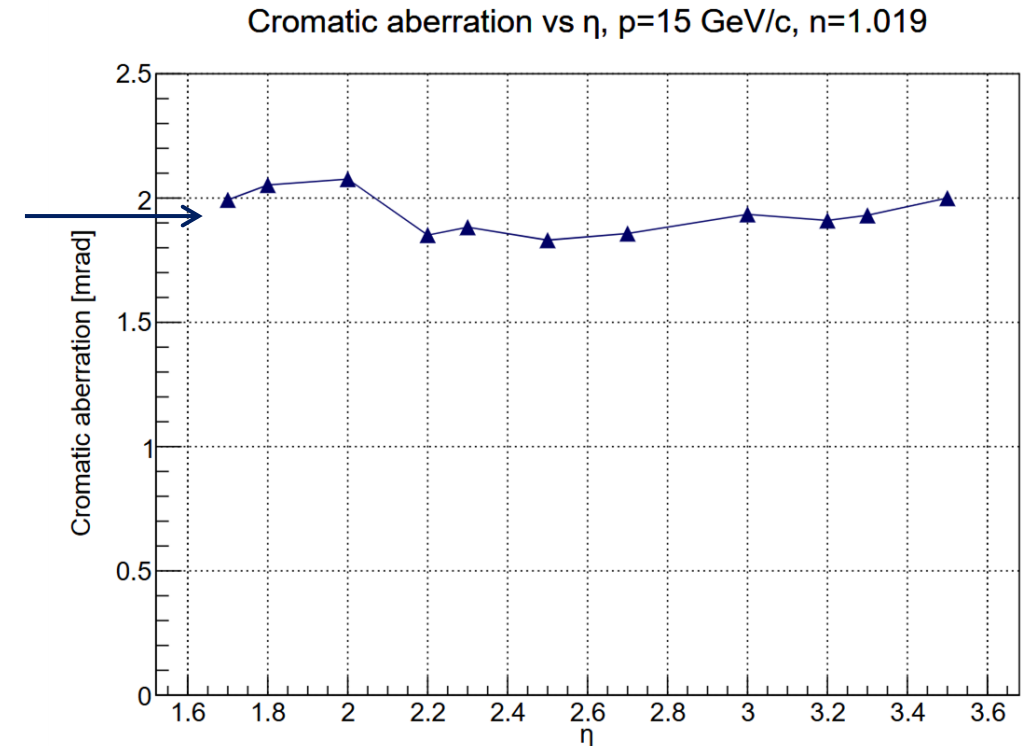
Chromatic aberration in Aerogel

n=1.019

Chromatic aberration as a function of η , fixing momentum @ 15 GeV/c.

$$\sigma_{\{chromatic\ aberration\}} = \sqrt{\sigma_{tot}^2 - \sigma_{w/o\ \lambda\ dep.}^2}$$

Where σ_{tot}^2 is σ with λ dependency and $\sigma_{w/o\ \lambda\ dep.}^2$ is σ with n fixed (w/o λ dependency).



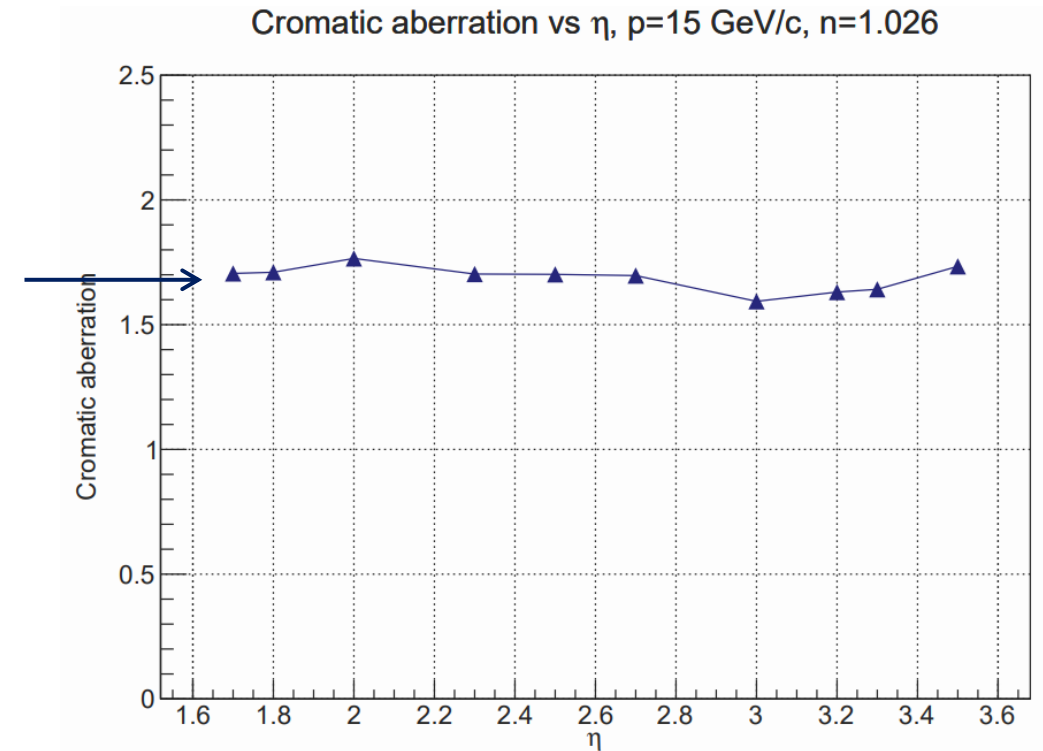
Chromatic aberration in Aerogel

n=1.026

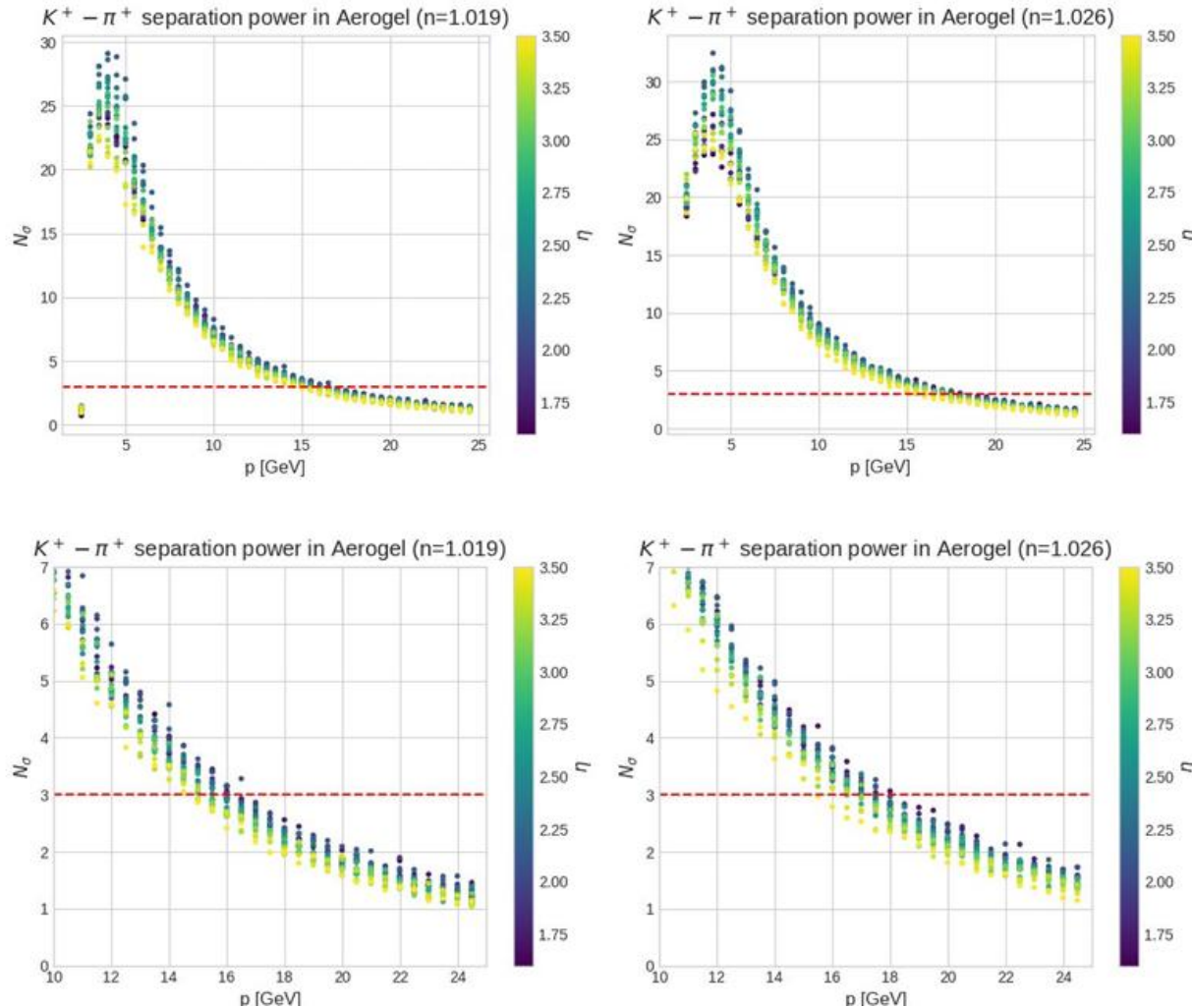
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Aerogel validation @ CUK (J.Agarwala et al.)

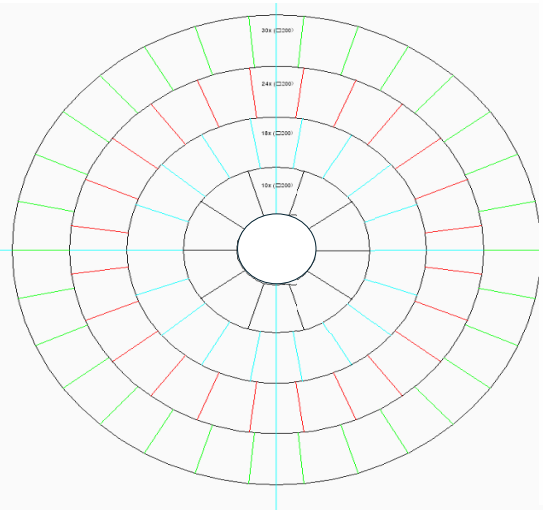


- ✓ **Infrastructure:** GPU facility at Central University of Karnataka (CUK) for dRICH parallel processing.
- ✓ **Fine Granularity:** 74 momentum bins (0.5-60 GeV/c) and 0.1 η steps.
- ✓ **Efficiency:** Large-scale simulations completed in 5 days (using 25 GPU cores)
- ✓ **Significant Nsigma boost with $n=1.026$ and π/K separation up to 20 GeV/c**

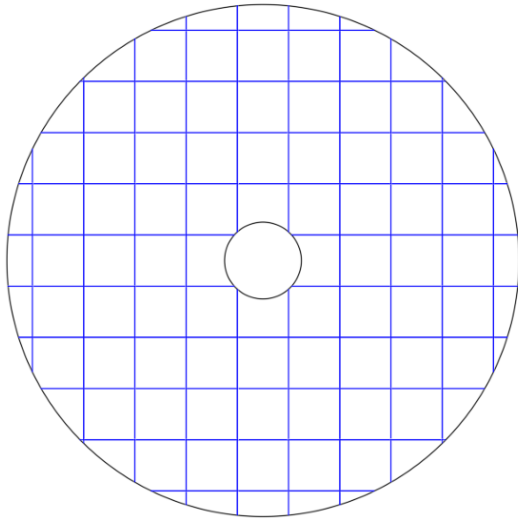
For more details look @ https://doi.org/10.1007/978-981-95-1513-4_352

Geometry evolution: From mechanics to simulation

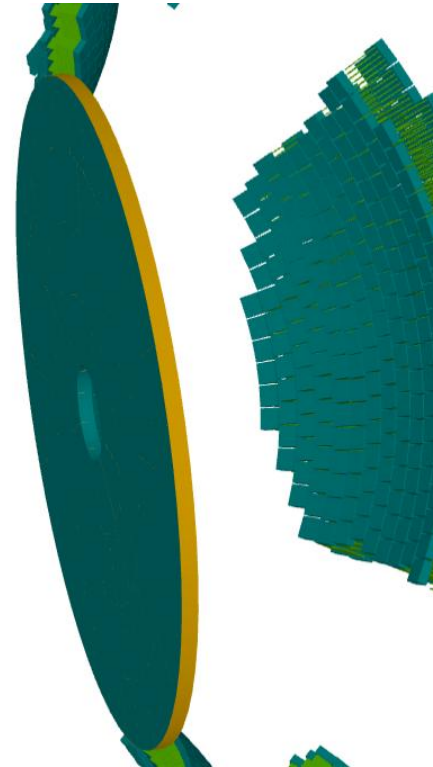
From mechanics



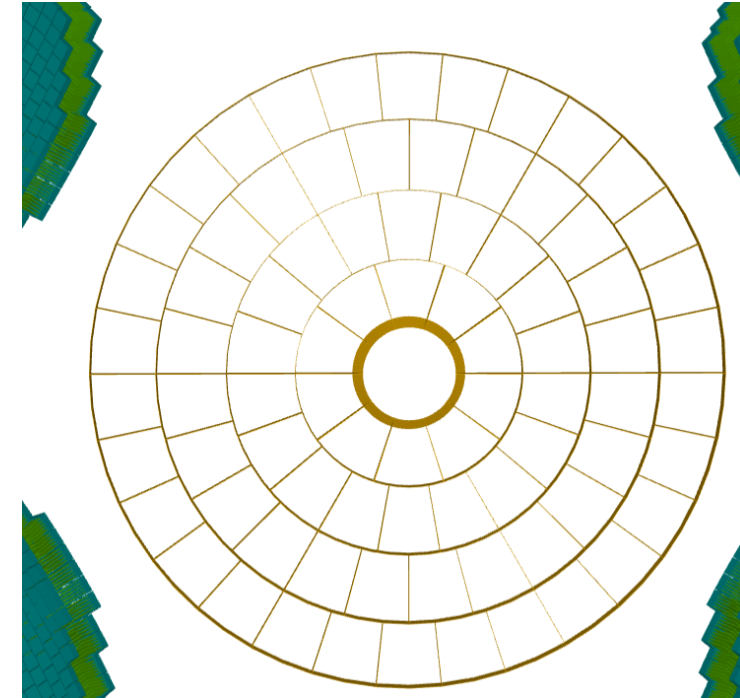
Option A



Option B

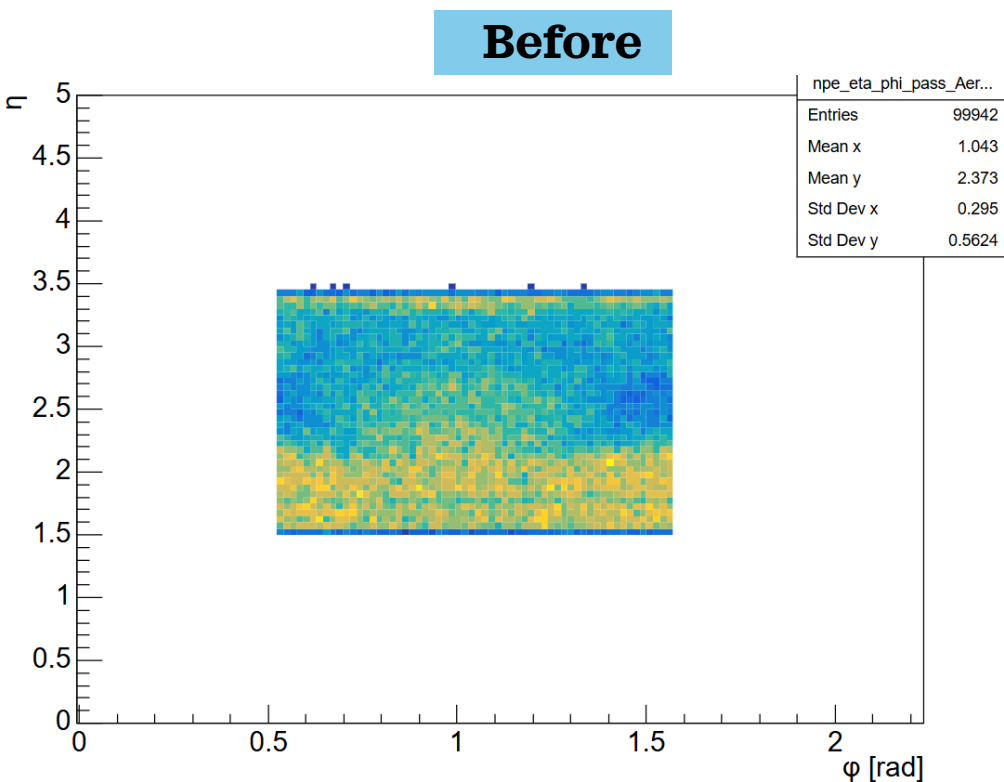


+

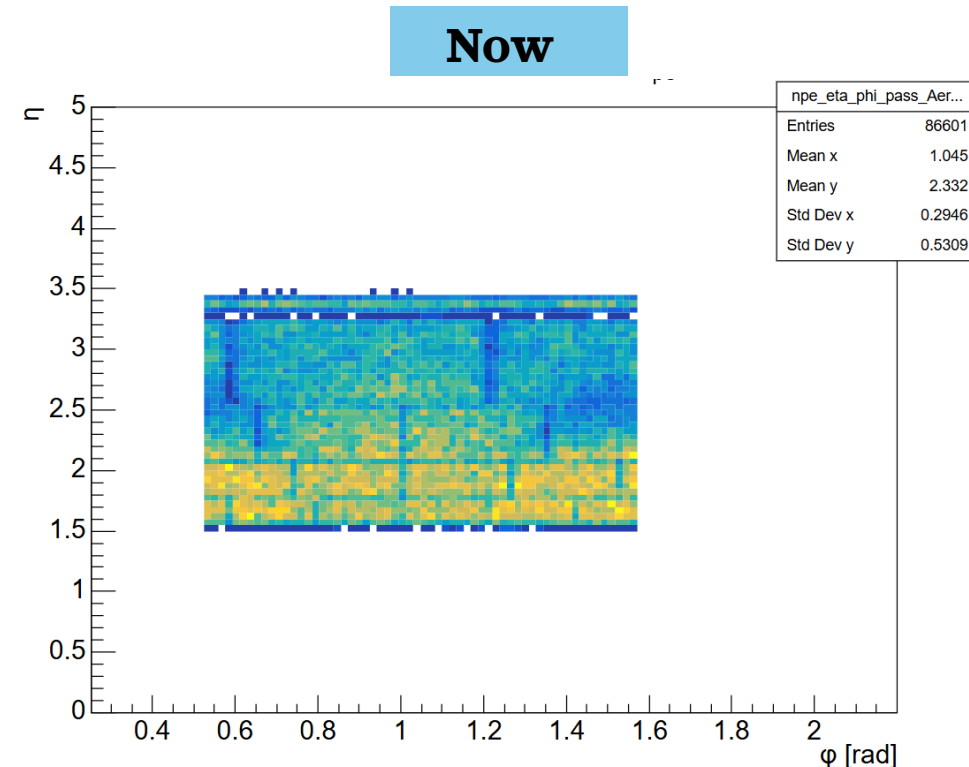


- ✓ From conical aerogel to cylindrical aerogel.
- ✓ Carbon fiber support structure added.
- ✓ Crowns and segments implemented as easily editable parameters via xml file.

Acceptance performance



- ✓ 200k events.
- ✓ $n = 1.019$
- ✓ Particles 10 GeV/c momentum
- ✓ **$N_{pe} > 5$**
- ✓ $\phi \in [\pi/6, \pi/2]$
- ✓ $\eta \in [1.5, 3.5]$

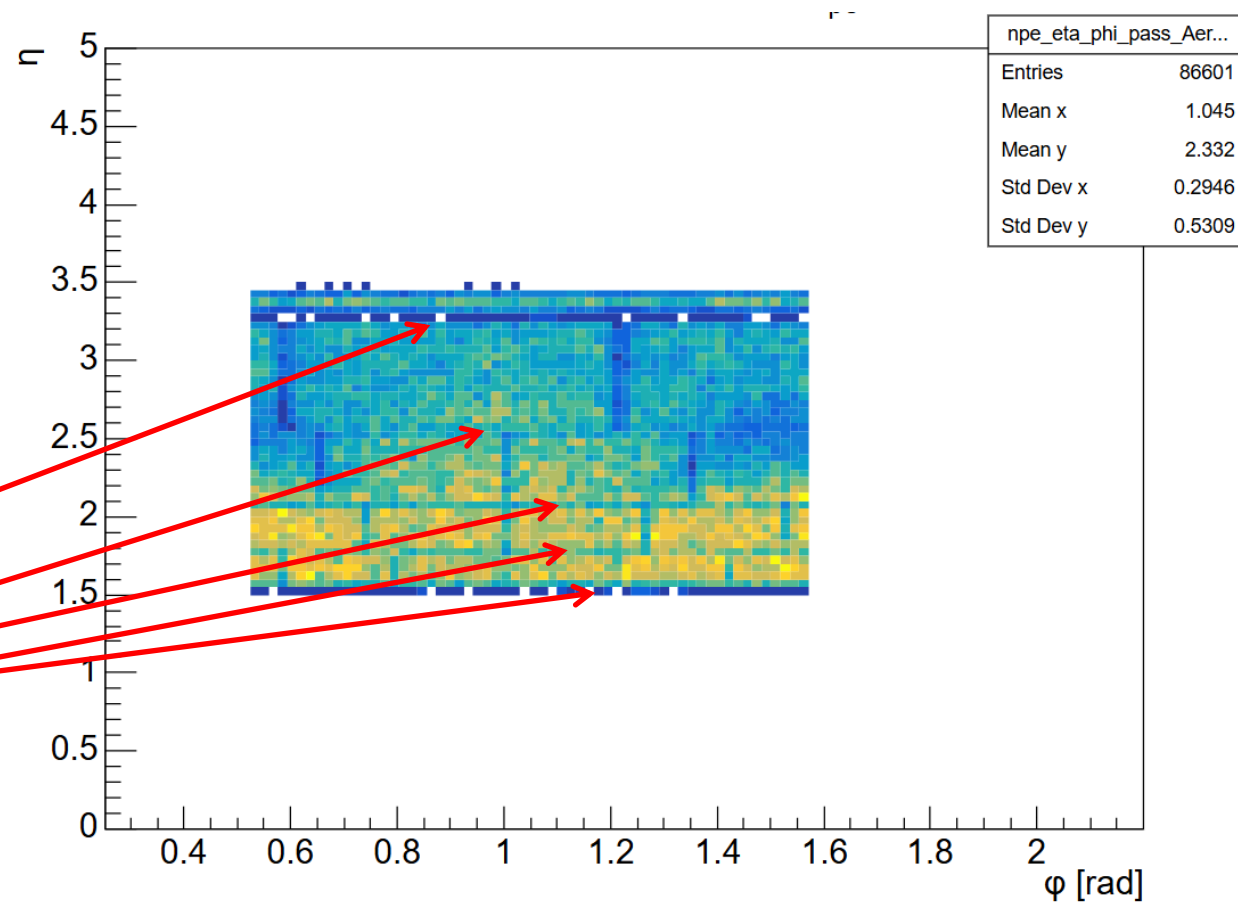
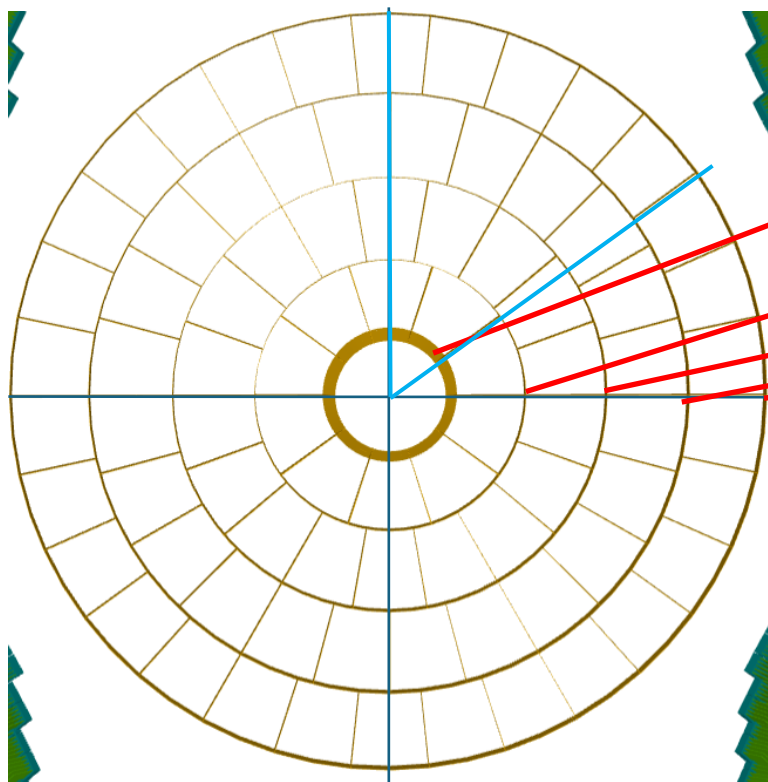


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Acceptance performance

Looking into more details....

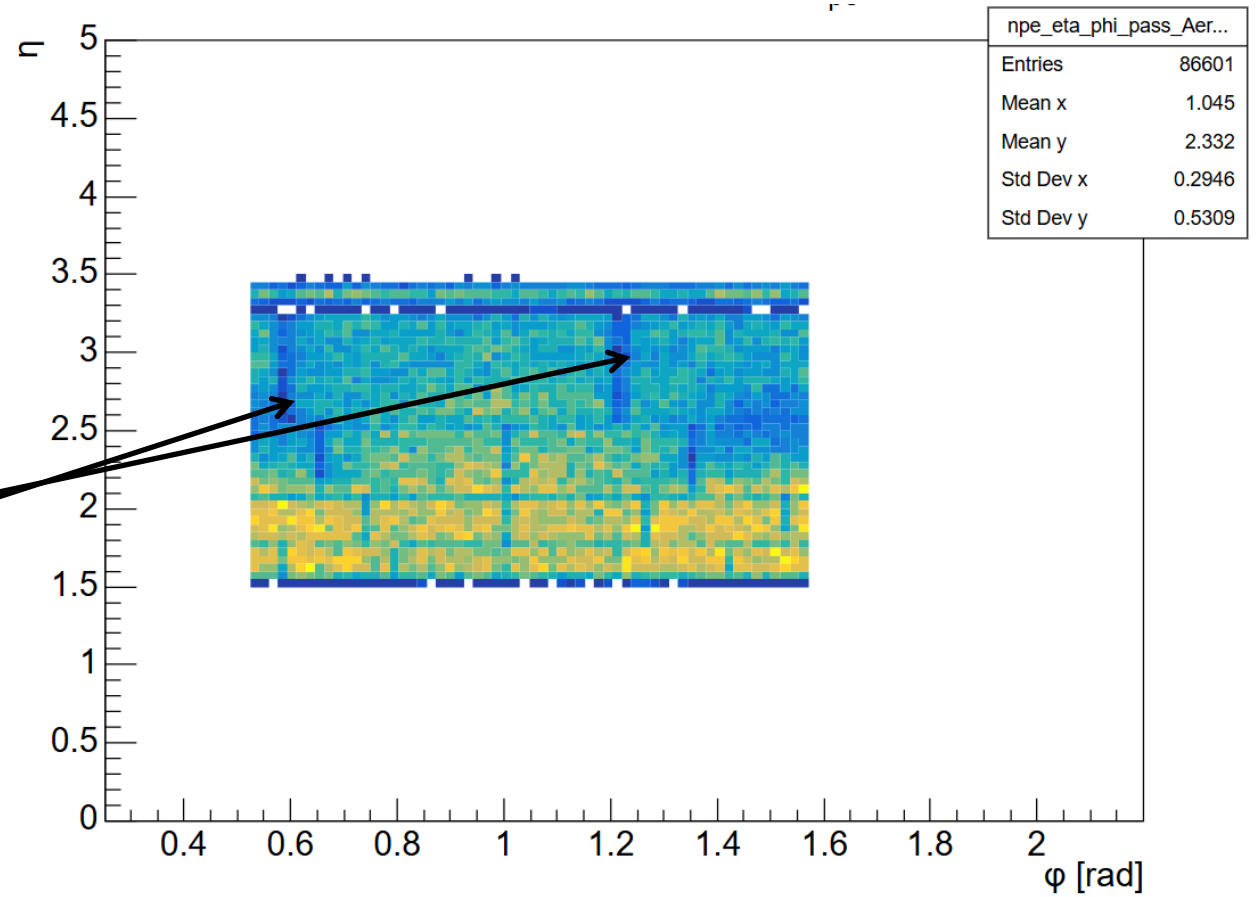
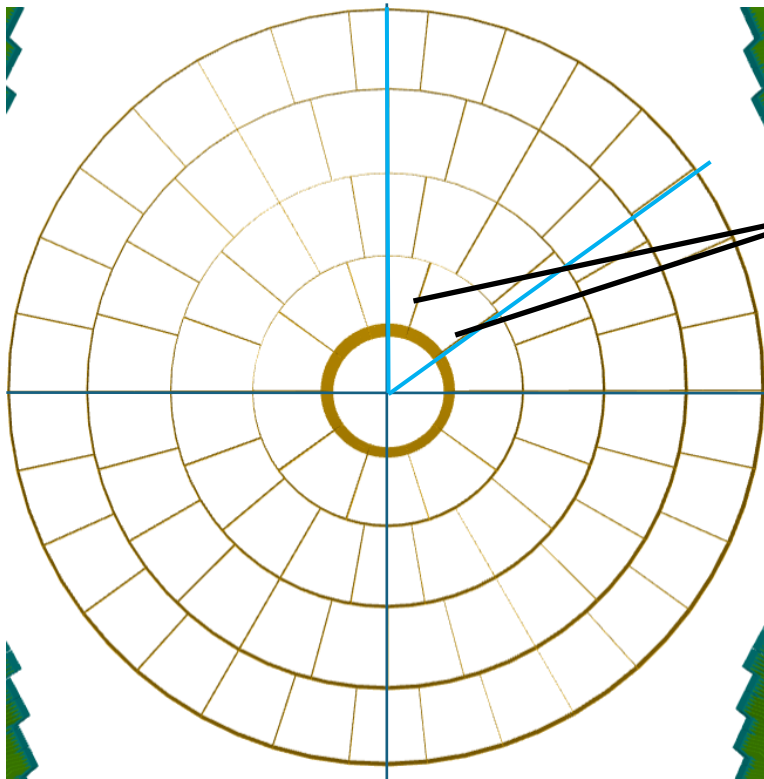
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Acceptance performance

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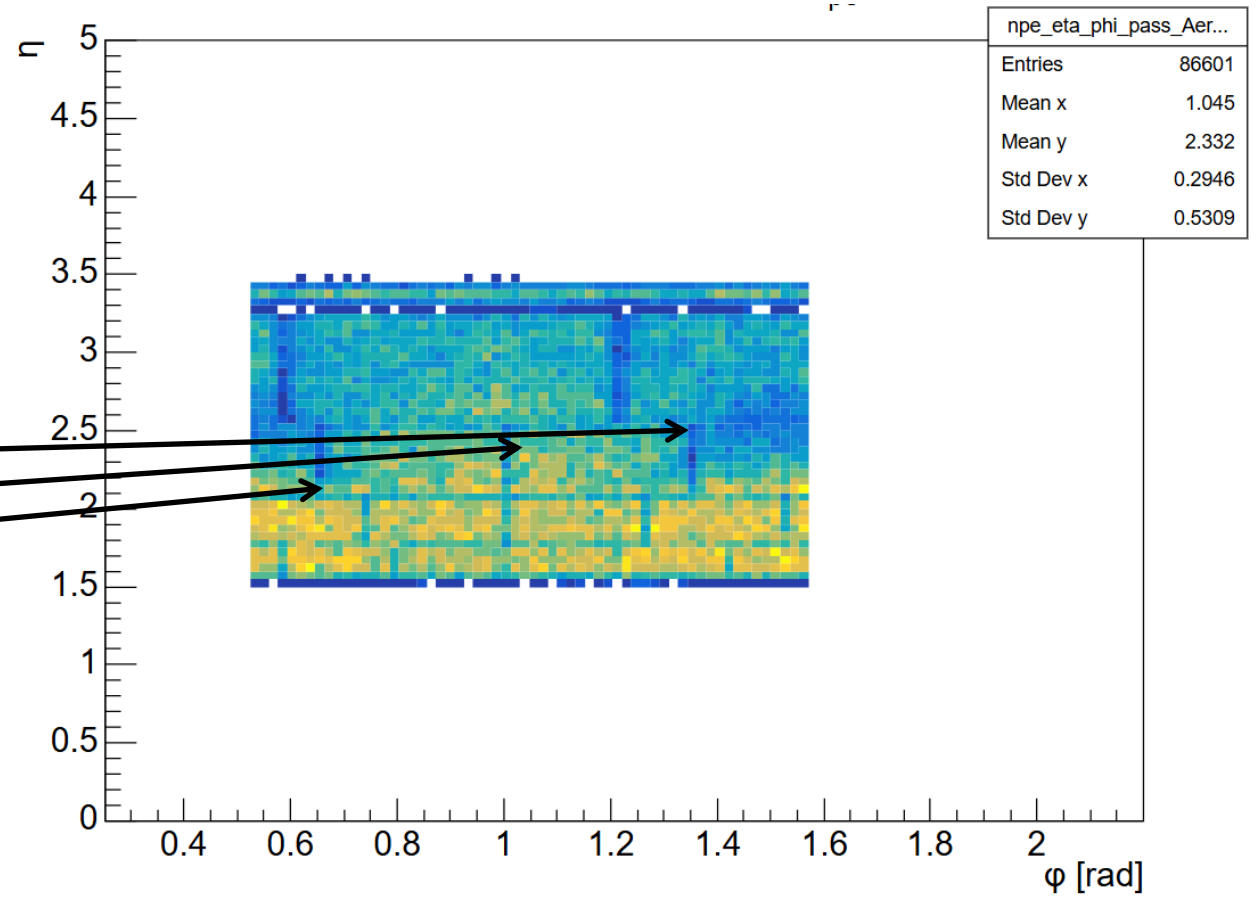
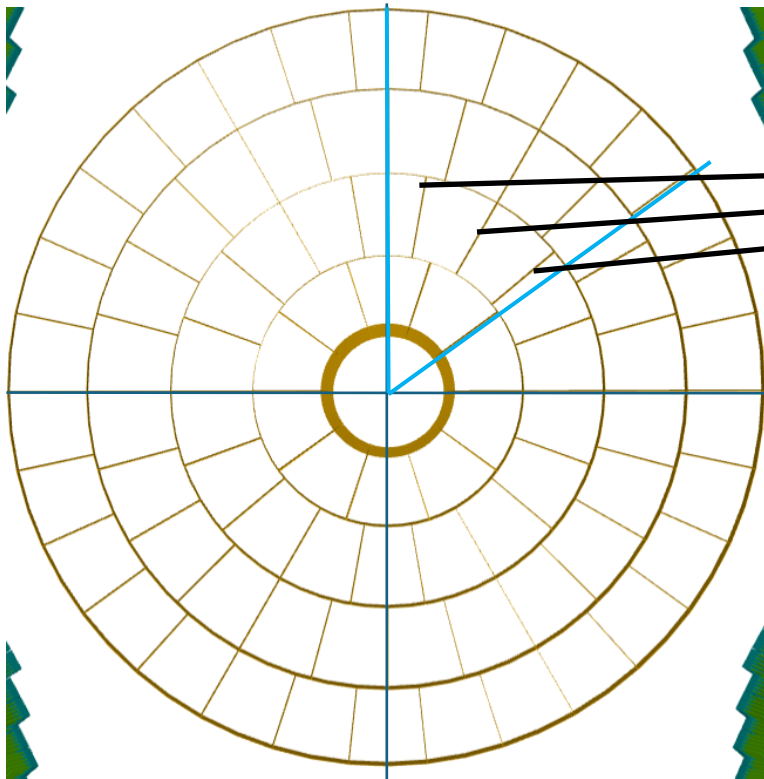
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Acceptance performance

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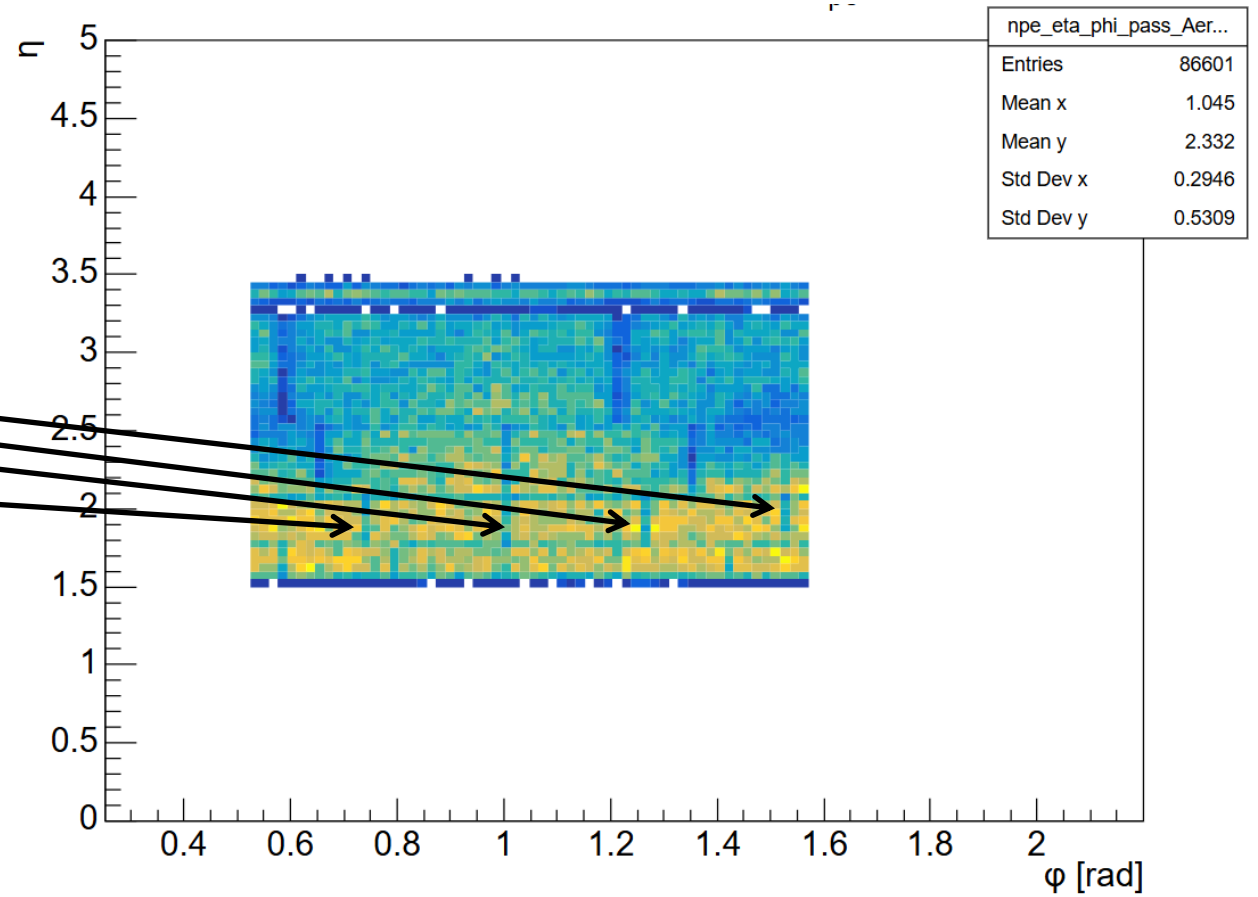
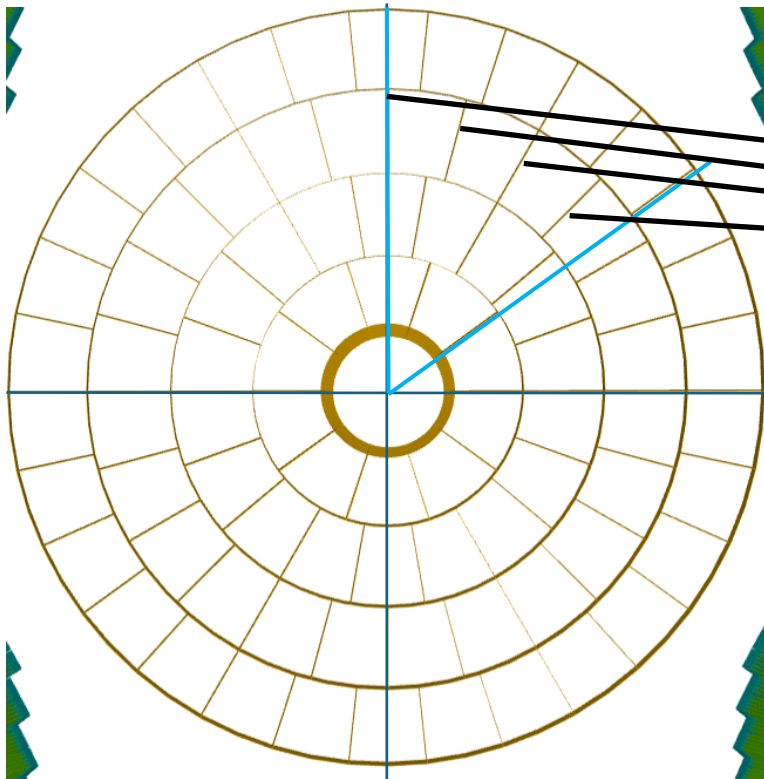
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Acceptance performance

Looking into more details....

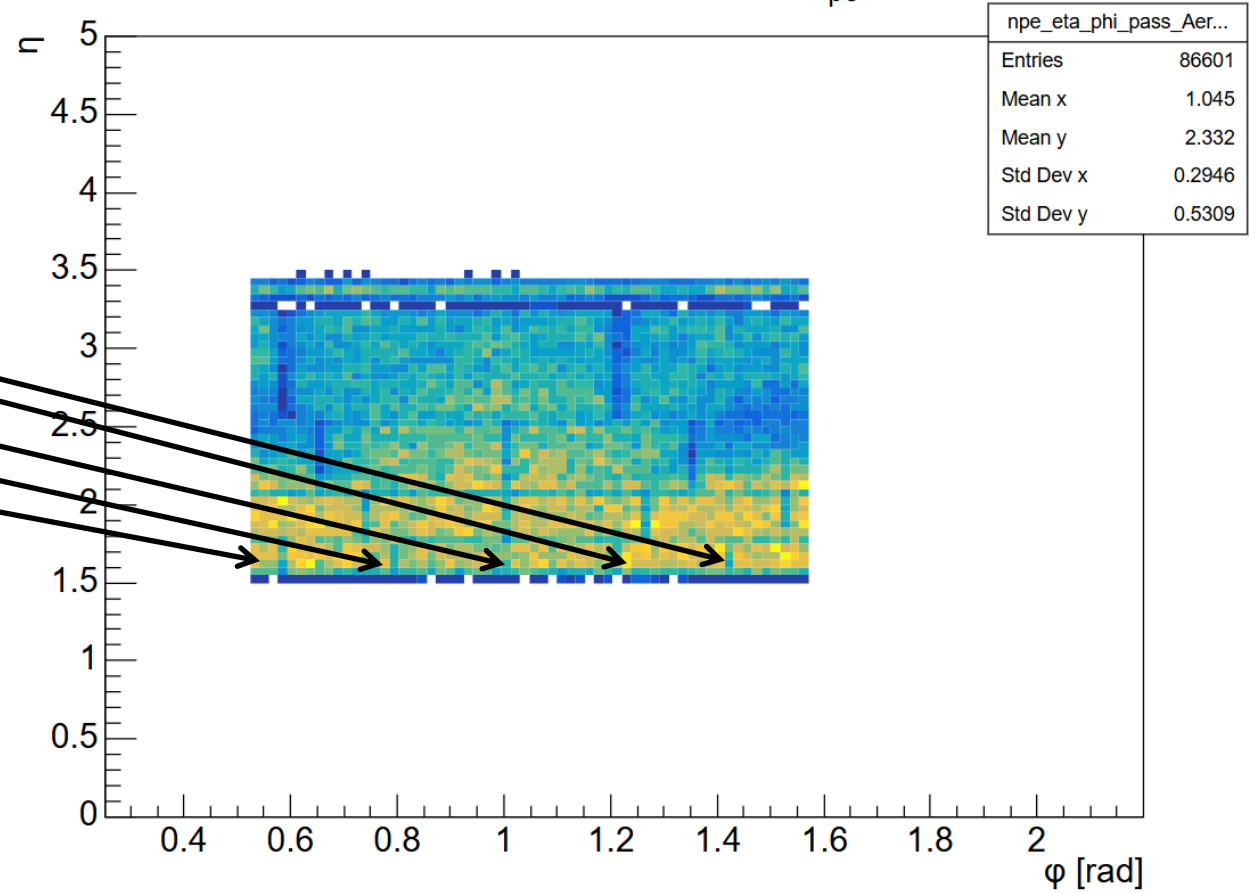
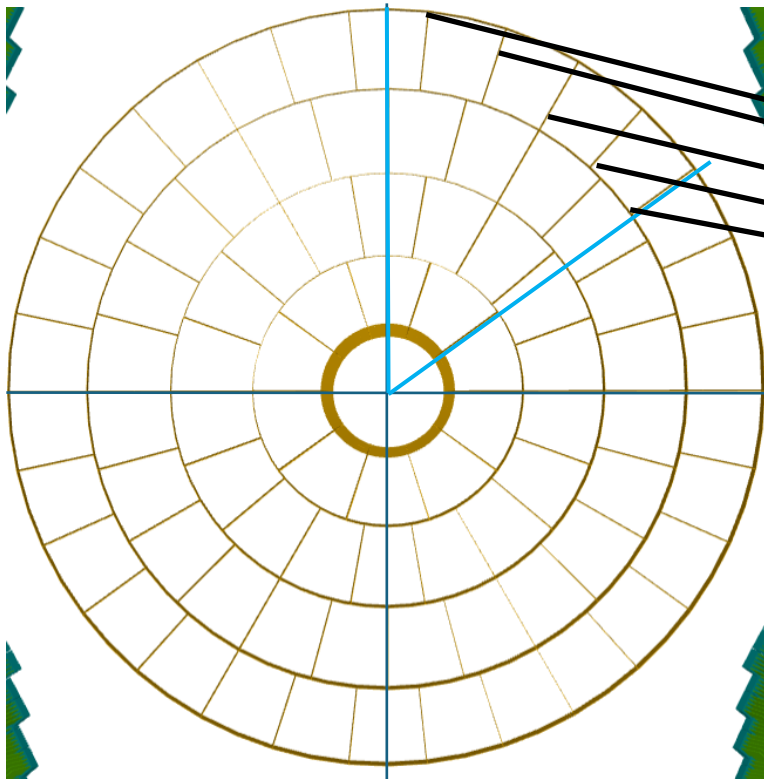
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Acceptance performance

Looking into more details....

- ✓ 200k events.
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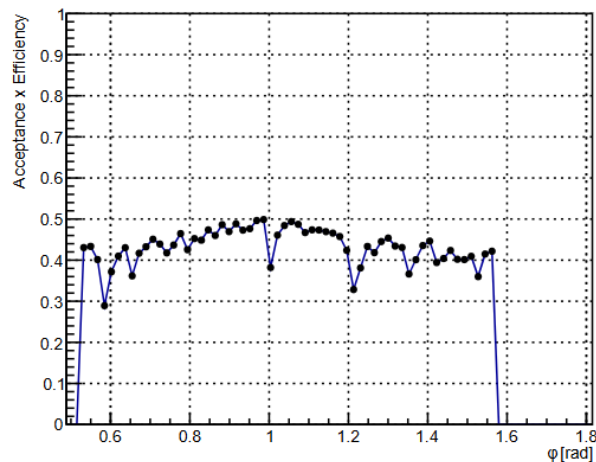


Acceptance x Efficiency performance

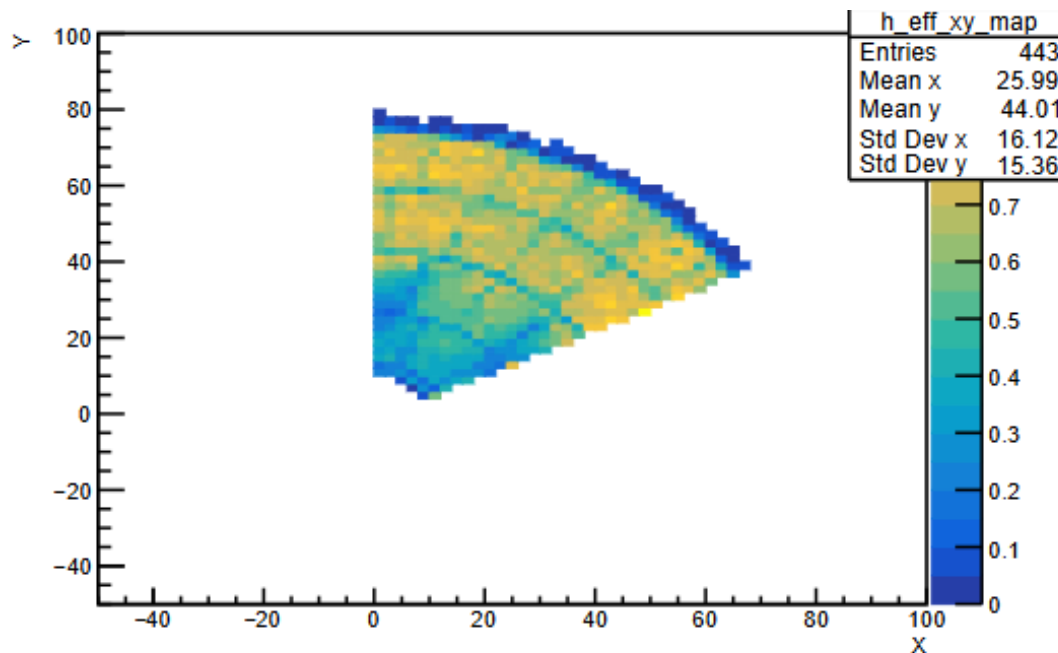
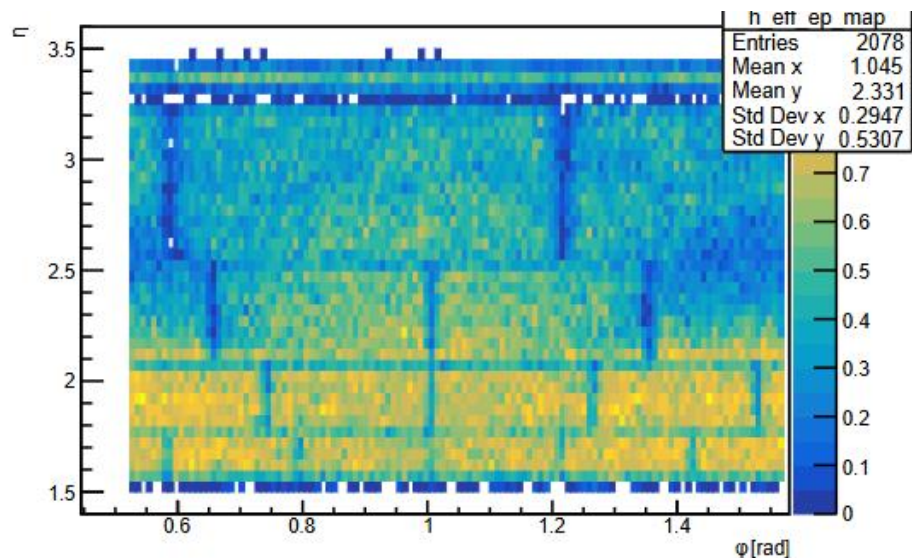
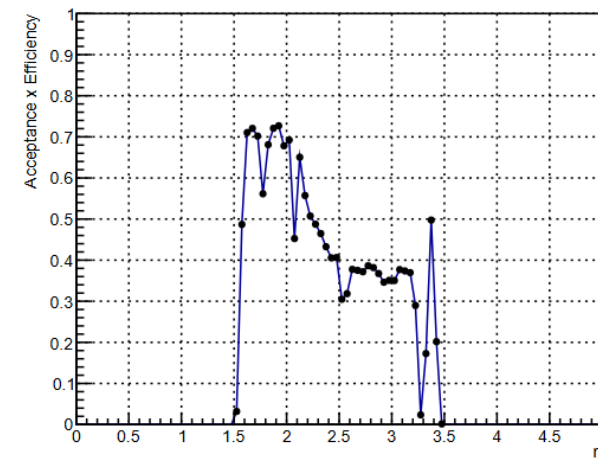
Looking into more details....

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Acceptance x Efficiency vs ϕ

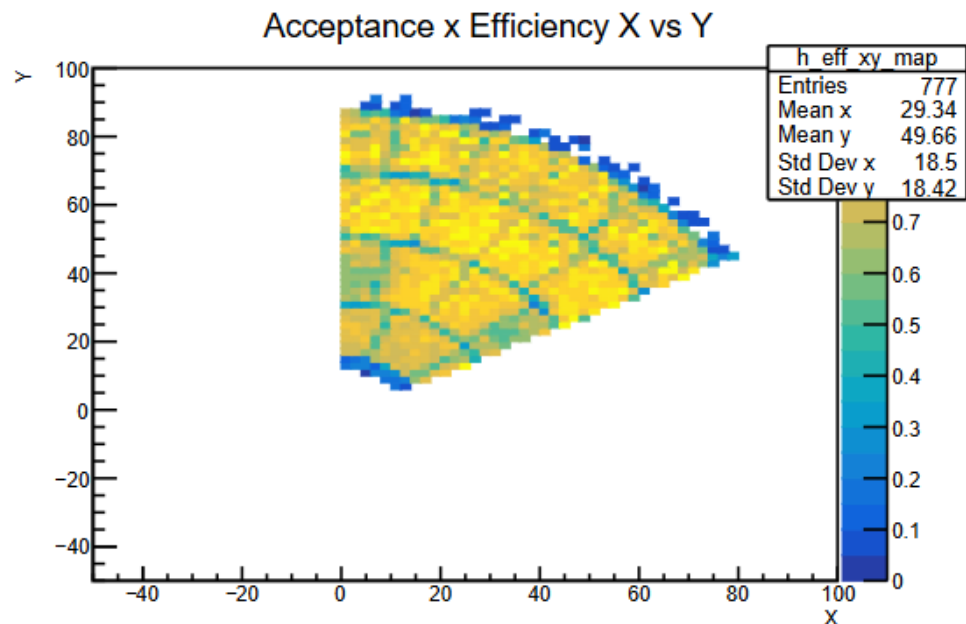
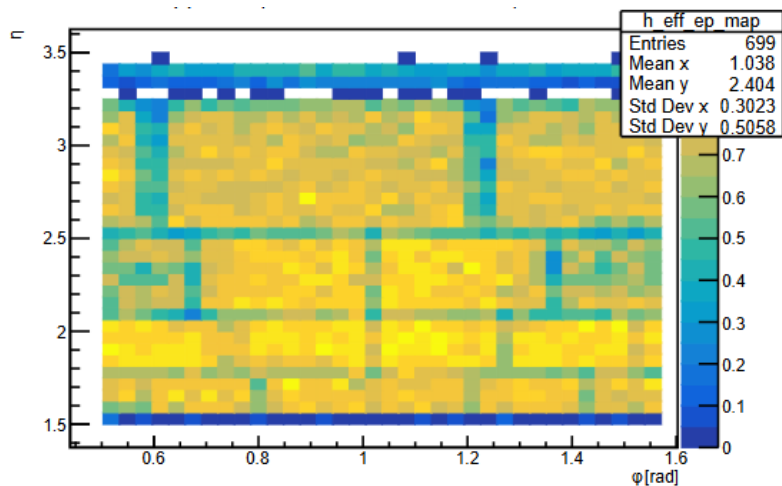
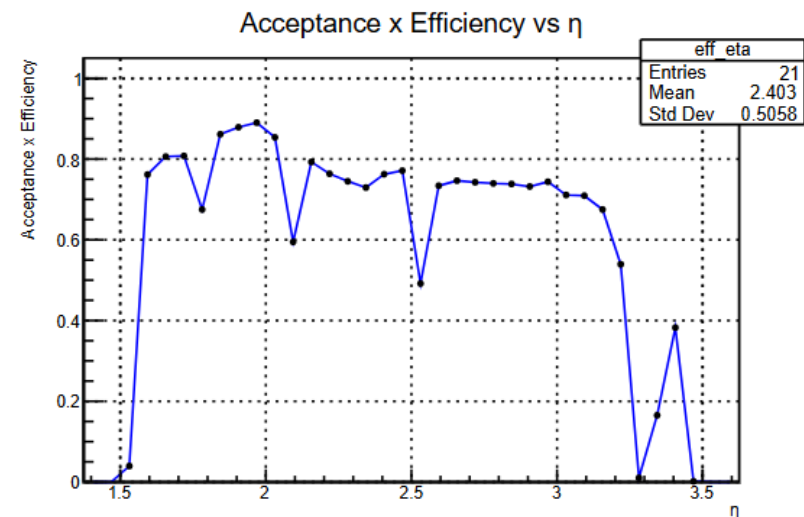
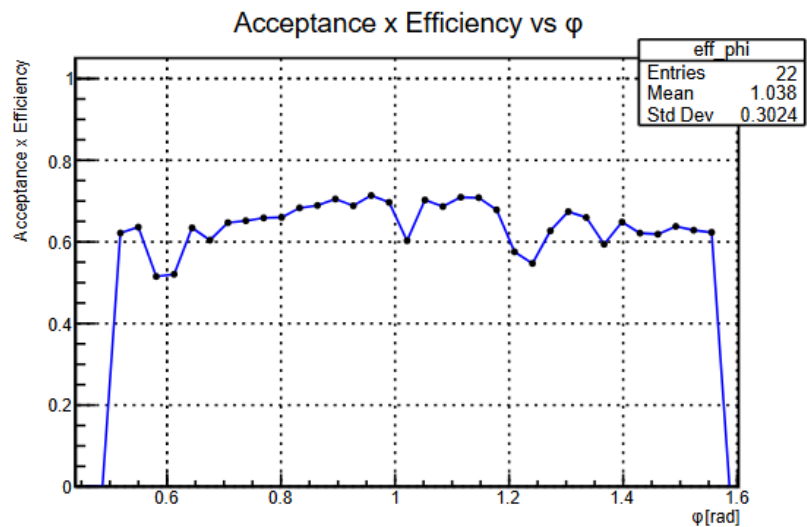


Acceptance x Efficiency vs η

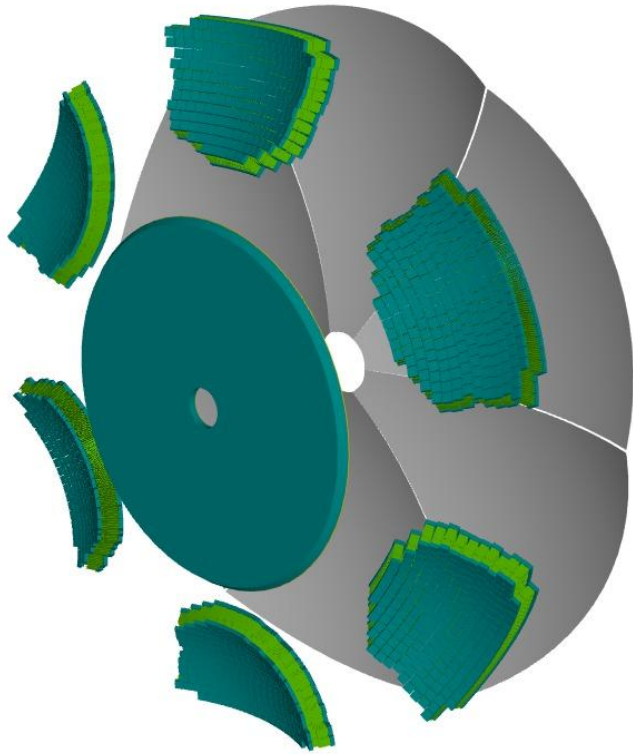


Acceptance x Efficiency performance

- ✓ 70k events.
- ✓ **n= 1.026**
- ✓ Particles 12.5 GeV/c momentum
- ✓ **N_{pe} > 7**
- ✓ $\phi \in [\pi/6, \pi/2]$
- ✓ $\eta \in [1.5, 3.5]$



Realistic Event simulation & Occupancy studies



- ✓ From **Particle Gun** to Full Events with **Pythia**
- ✓ Multiplicity studies in dRICH acceptance
- ✓ Creating **2D maps** (Pseudorapidity vs. Azimuth Angle) to track particle flux distribution
- ✓ Sector-by-sector analysis: evaluation of particle multiplicity and occupancy estimation for each optical module (petal).

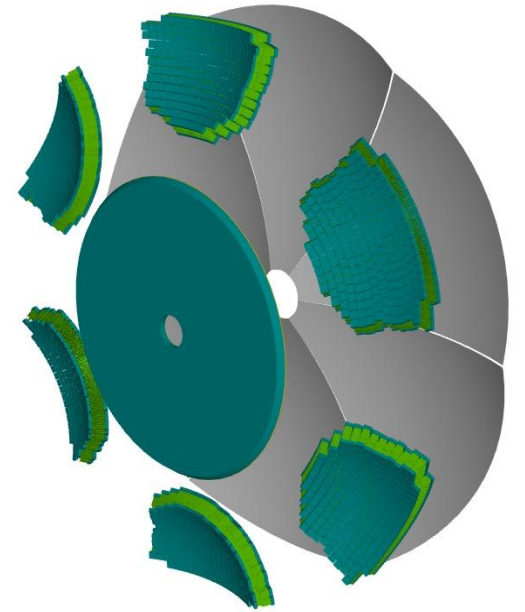


Summary

1. The aerogel with a refractive index of **$n=1.026$** produces a greater NPE compared to the aerogel with $n=1.019$ and provides better resolution at 3σ .
2. From the INFN group the aerogel characterization with $n=1.026$ is the best compromise between optical performance and spatial constraints
3. Chromatic aberration is identified as the primary source of angular resolution degradation per photon.
4. Robust code for implementing a carbon fiber structure to efficiently model the segmentation of the aerogel, with good acceptance.

Studies on going:

1. Several studies on the optimization and automatization of the code for the aerogel tiling
2. Multiplicity studies in dRICH acceptance



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THANKS!



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ePIC and EIC Physics Readiness Workshop, Cosenza 17-19 March
2026

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Backup Slides



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2026