Simulation studies for the RICH detectors in ATHENA

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ATHENA

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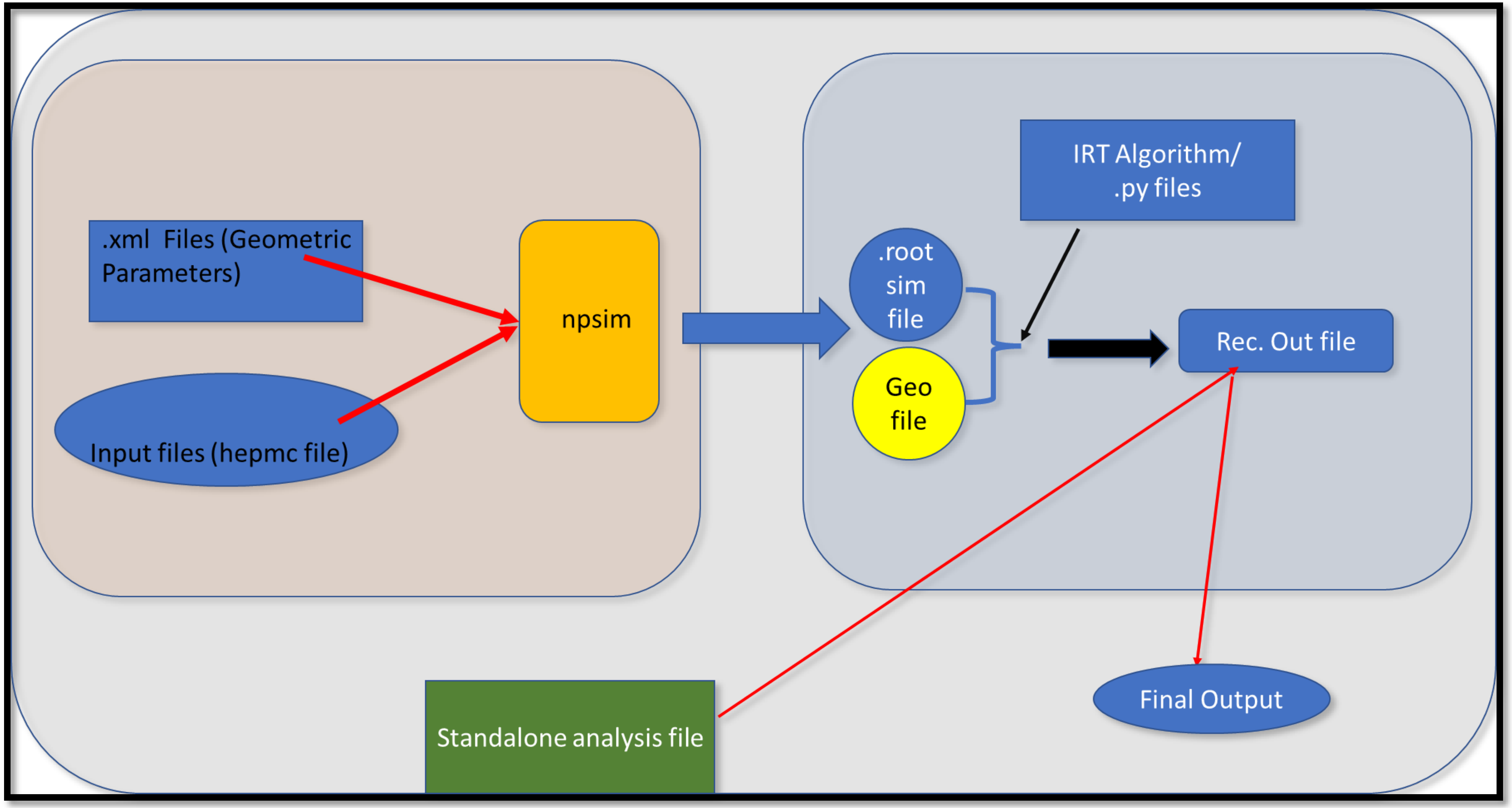
The Workflow



- The Workflow is same for both pfRICH and dRICH
- Specific geometry is inserted according to the RICH of interest.
- The IRT algorithm is the same.

https://eicweb.phy.anl.gov/EIC/irt.git

Inverse Ray Tracing Algorithm

NEW Inverse Ray Tracing code (IRT): **equally applicable in standalone GEANT4** environment and in the **ATHENA software framework**.

→ Last months were dedicated to this development

→ Complicated dRICH environment is the main application.

Substantial generalization as compared to HERMES.

→ Reconstruction of Cherenkov photon angle from 3D detected point and expected point of emission Range over the charged particle trajectory.

2D iterative Newton-Gauss minimization procedure is applied.

IRT algorithm implementation in the **ATHENA Juggler PID** plugin is complemented by a sophisticated logic**, performing sampling along the charged particle trajectory**, which allows one to estimate **average Cherenkov angle** in the same way for **both straight tracks and in presence** of a **relatively strong bending component of the ATHENA solenoid magnetic field.**

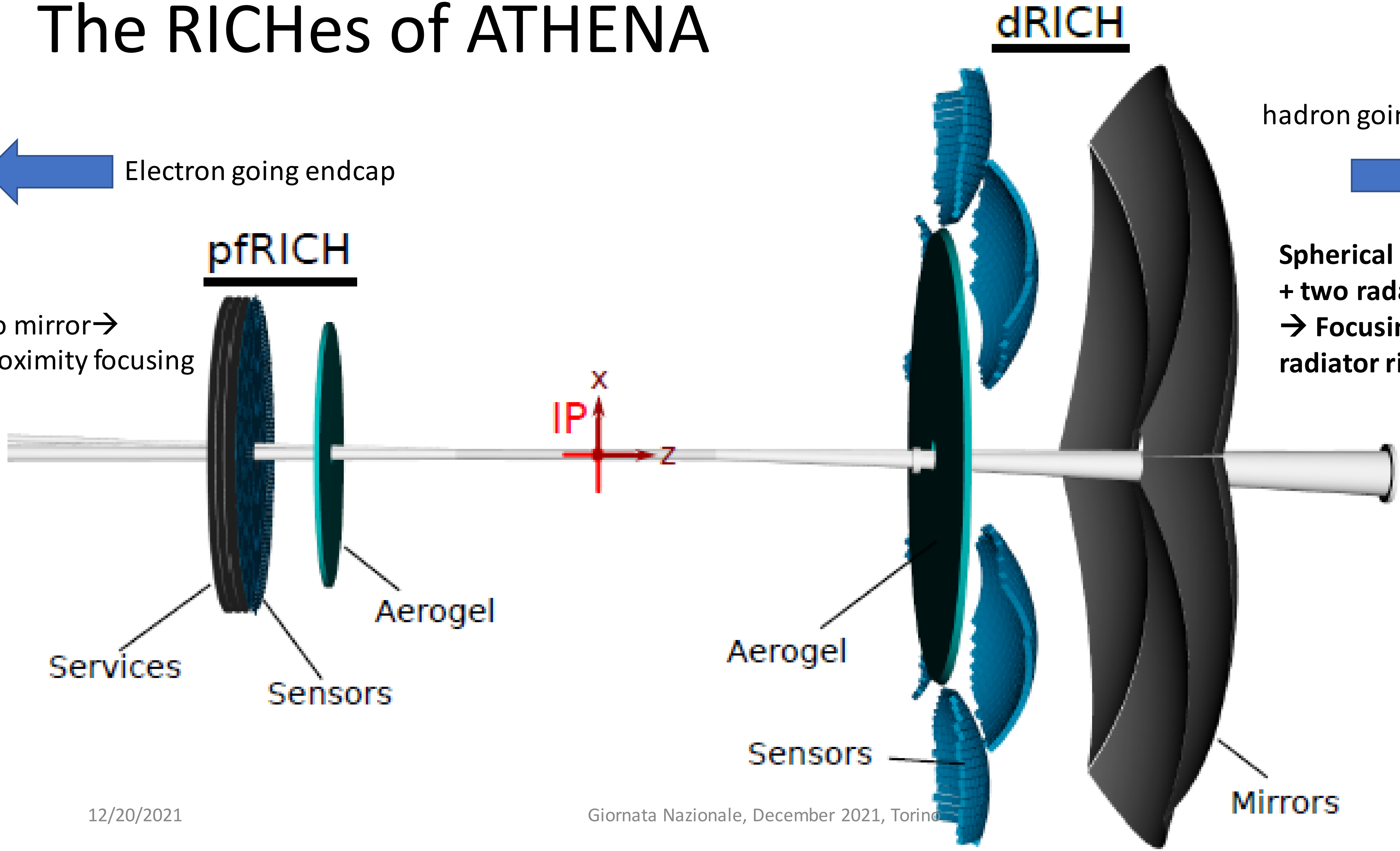
The RICHes of ATHENA

Electron going endcap

hadron going endcap

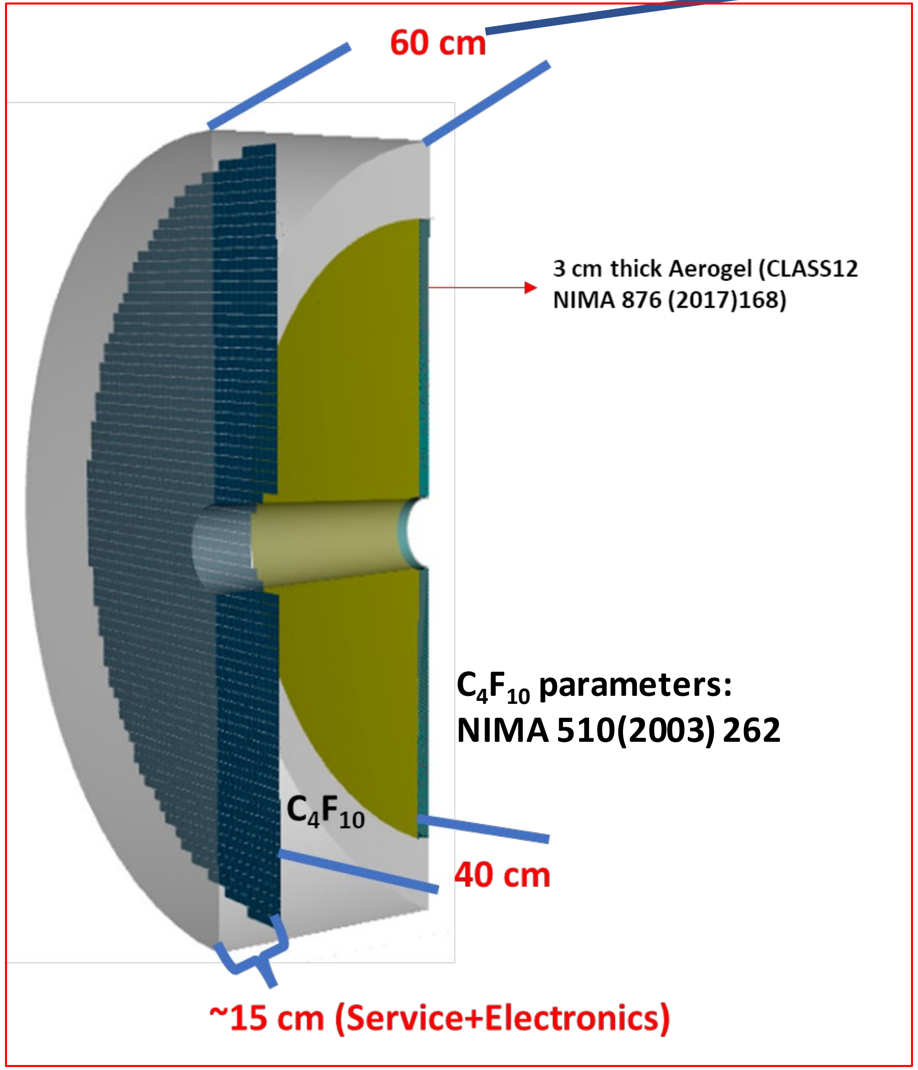
No mirror→ proximity focusing

Spherical mirrors + two radaitors → Focusing dual radiator rich



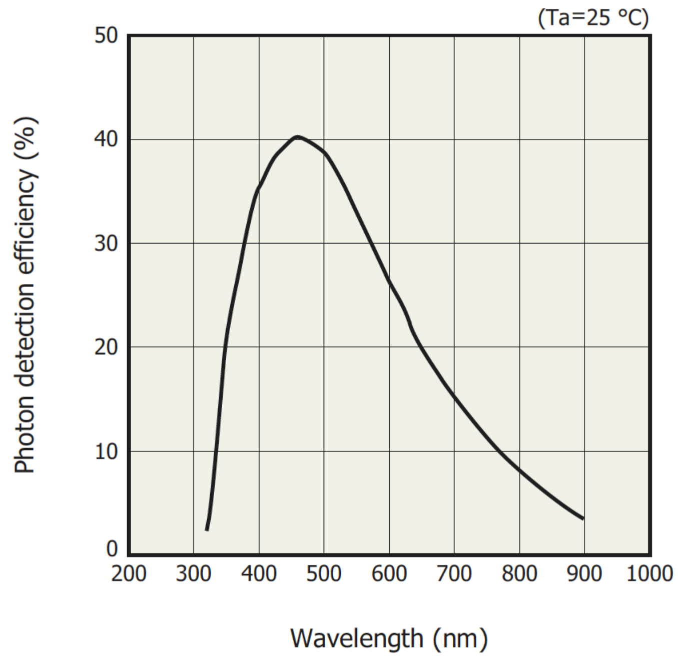
pfRICH Geometric description

Geometric description of pfRICH

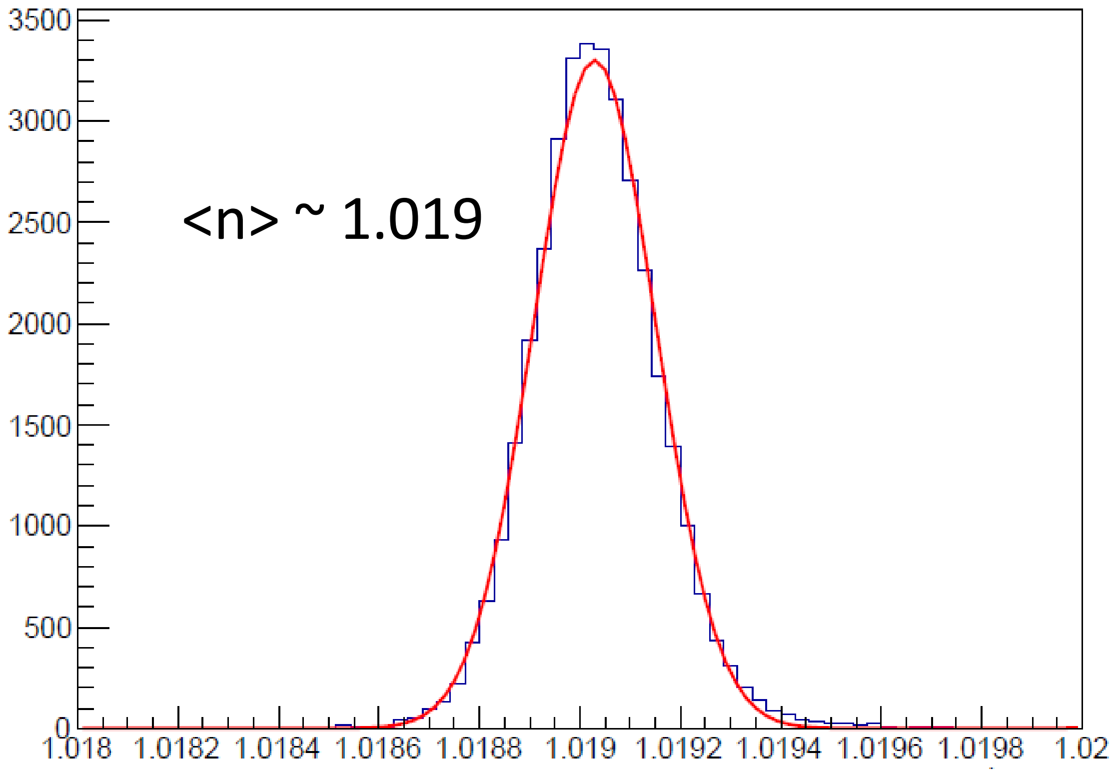


Vessel occupation space: -150 cm to -210 cm
→ Includes proximity gap (Filled with C_4F_{10} : threshold mode)+ Sensors + Filter (Acrylic: Filters photon below ~350 nm) + Aerogel + Services

Sensors:
a) Hamamatsu S13361-3050AE-08 8x8 SiPM panels (*https://www.hamamatsu.com/us/en/product/type/S13361-3050AE-08/index.html*)
b) 3 mm X 3 mm single SiPM with 8X8 pixels in each sensor.
Sensor full size = 25.8 mm X 25.8 mm.
→ 0.85 geometric efficiency.
c) Additional safety factor of 0.7 on top of Photo Detection Efficiency provided by Hamamatsu.



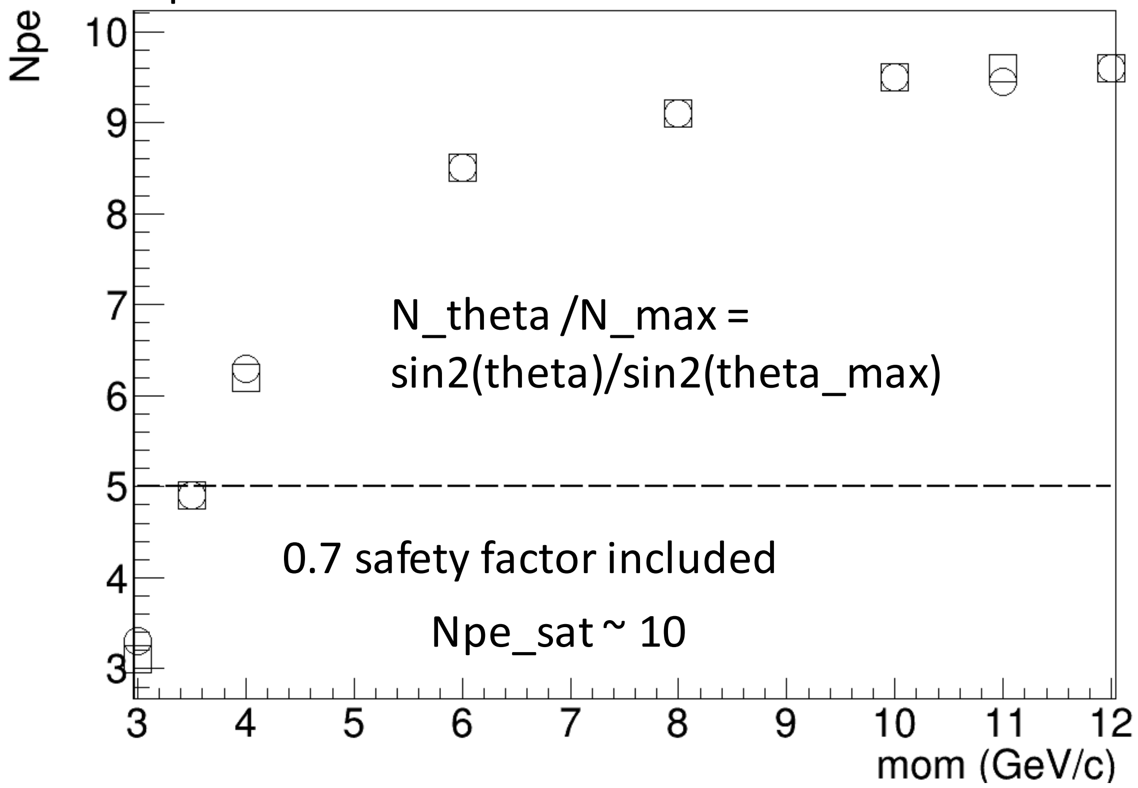
First Consistency Check → Validation of Rec. algorithm



<n> ~ 1.019

Refractive Index

Example pions at eta -1.7; open box exp.
Open circle reconstructed



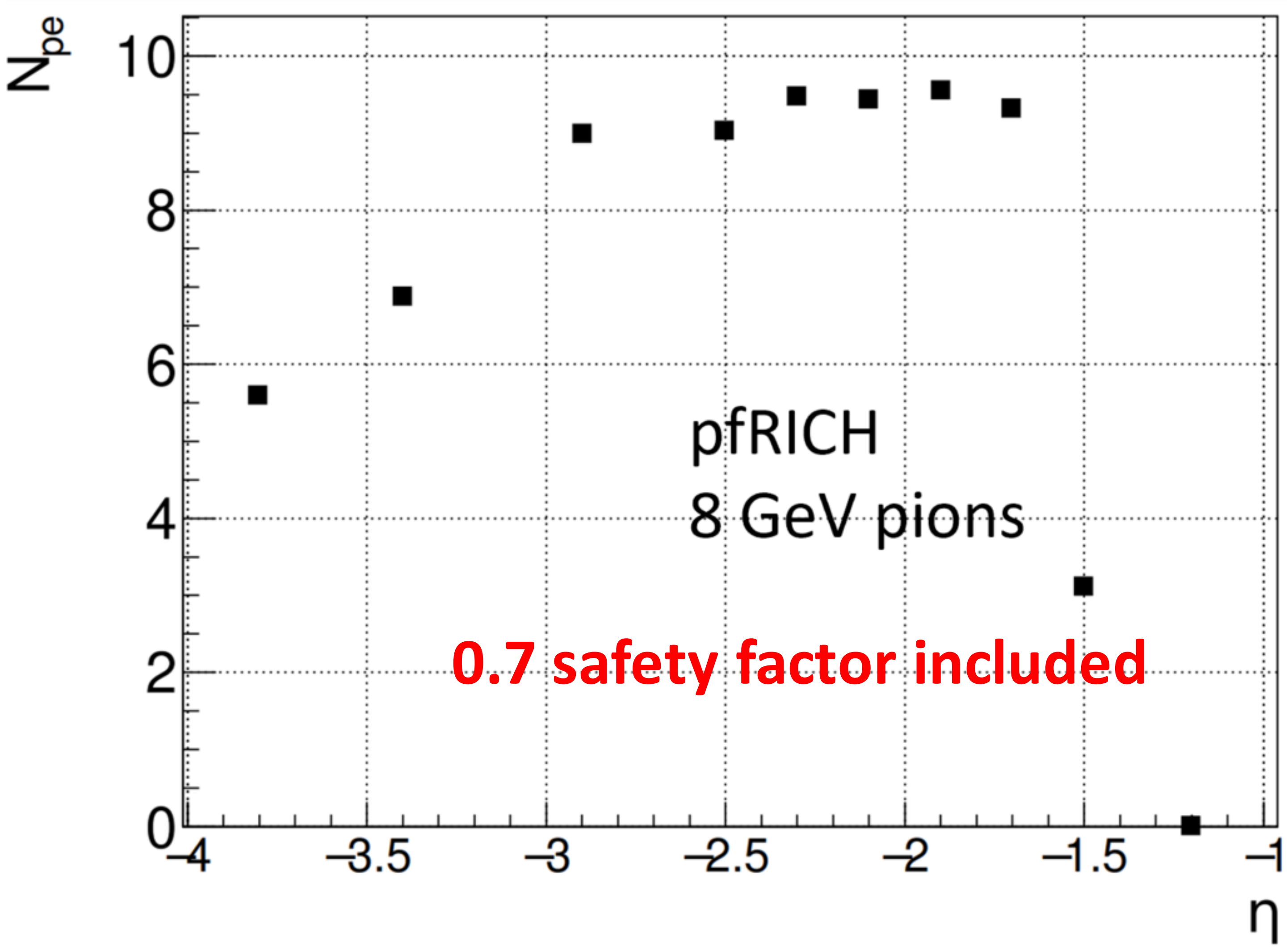
N_theta /N_max =
sin2(theta)/sin2(theta_max)

0.7 safety factor included

Npe_sat ~ 10

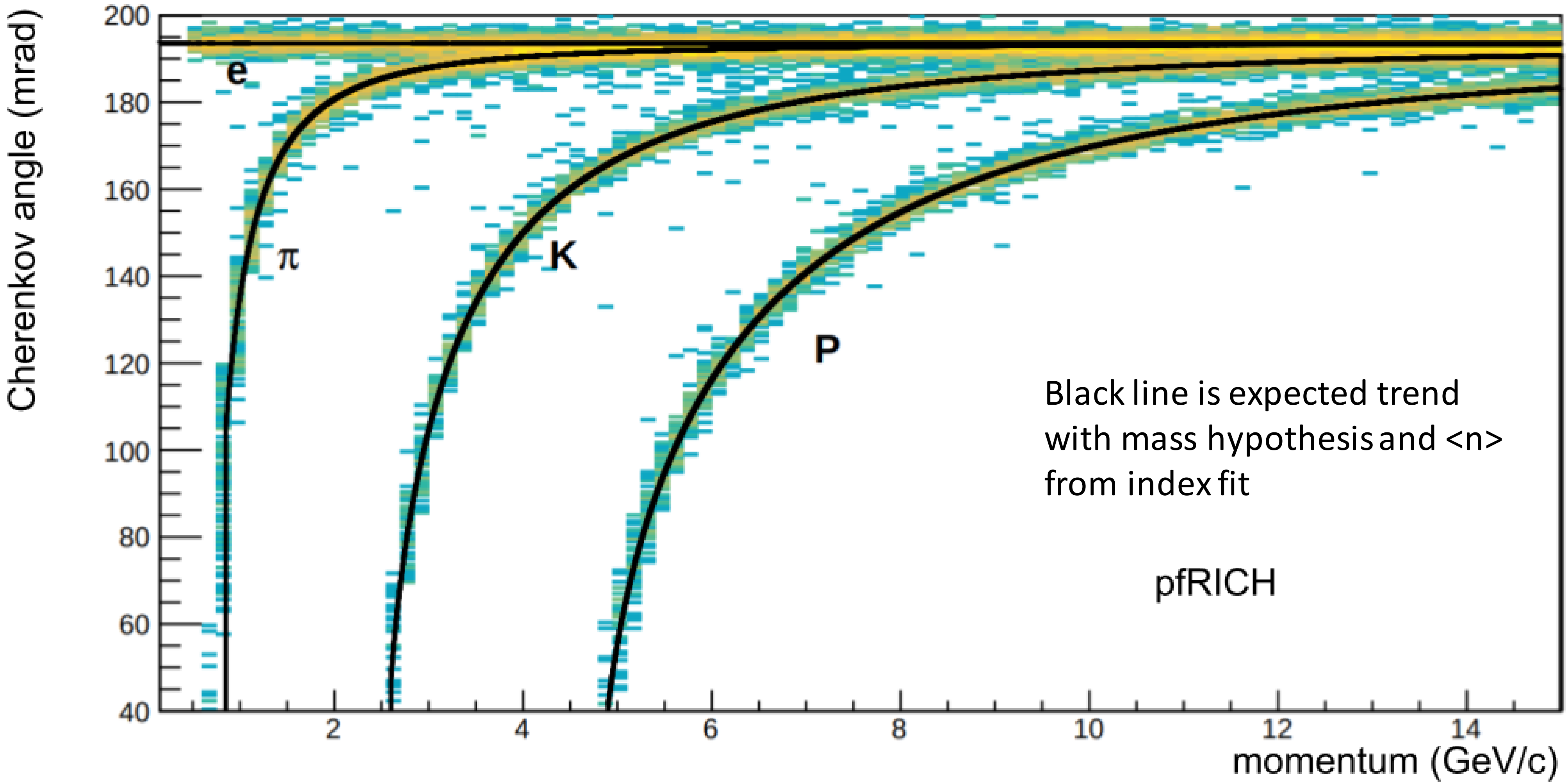
pfRICH Results

Acceptance

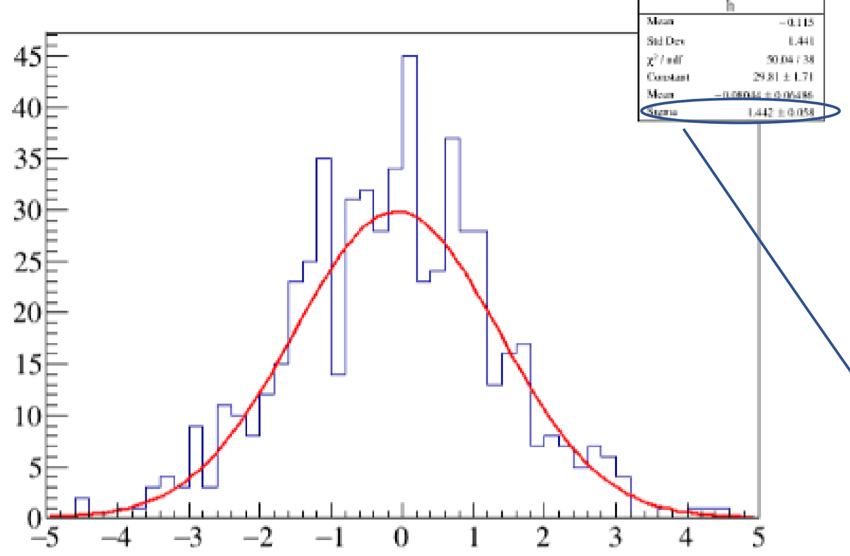


Npe are as expected from estimations.
Acceptance is consonant with YR requirements

Reconstructed Cherenkov Angle Vs momentum

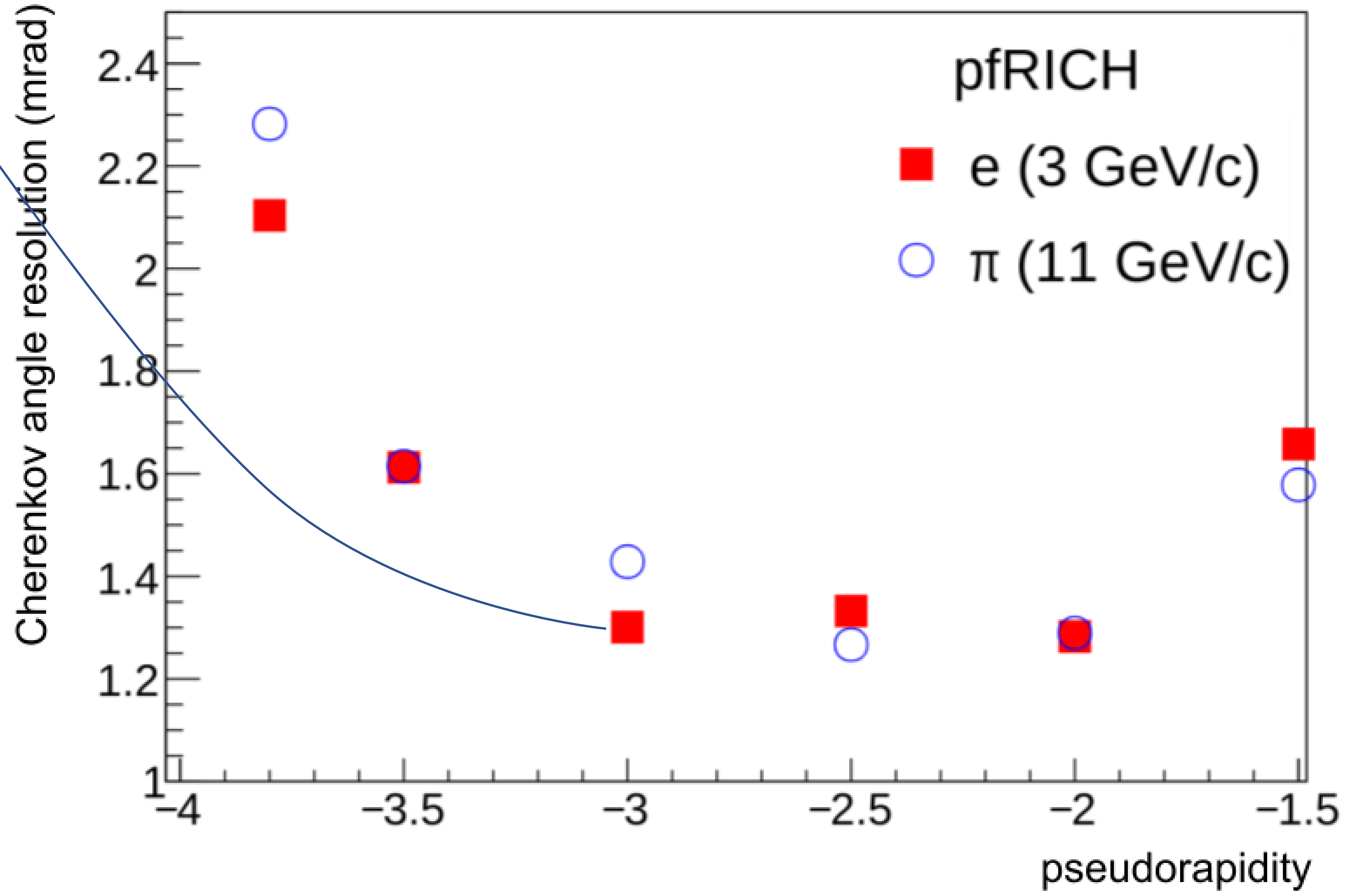


Dependence of ring resolution with pseudo rapidity

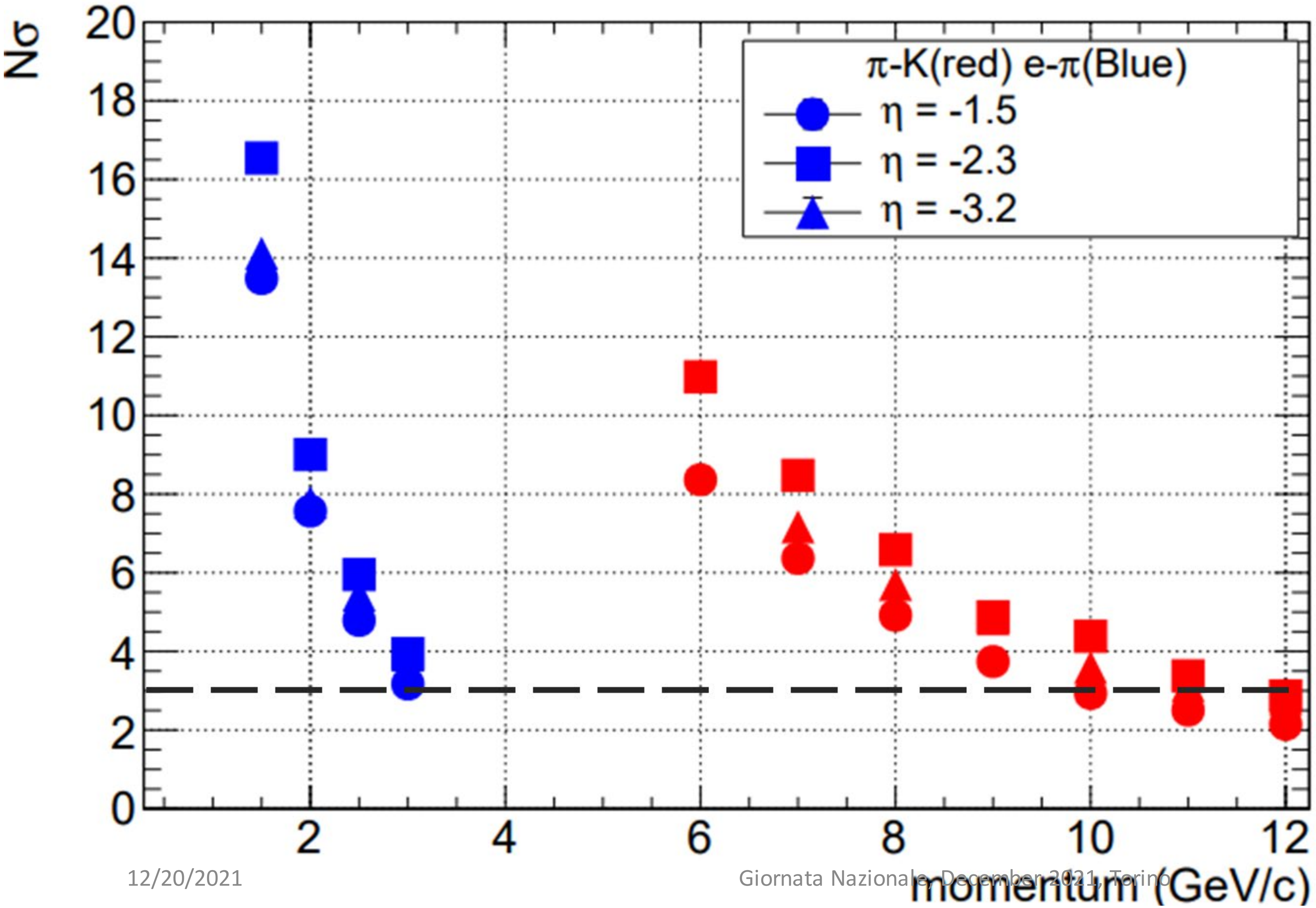


Track level resolution:
pixel size, emission point uncertainty, and chromaticity to the track-level
Cherenkov photon angle resolution were taken together to estimate ~1.5 mrad.

[agRICH-bi-weekly-meeting-2021-09-30.v00.pdf (bnl.gov)]
Slide 13



N Sigma Separation

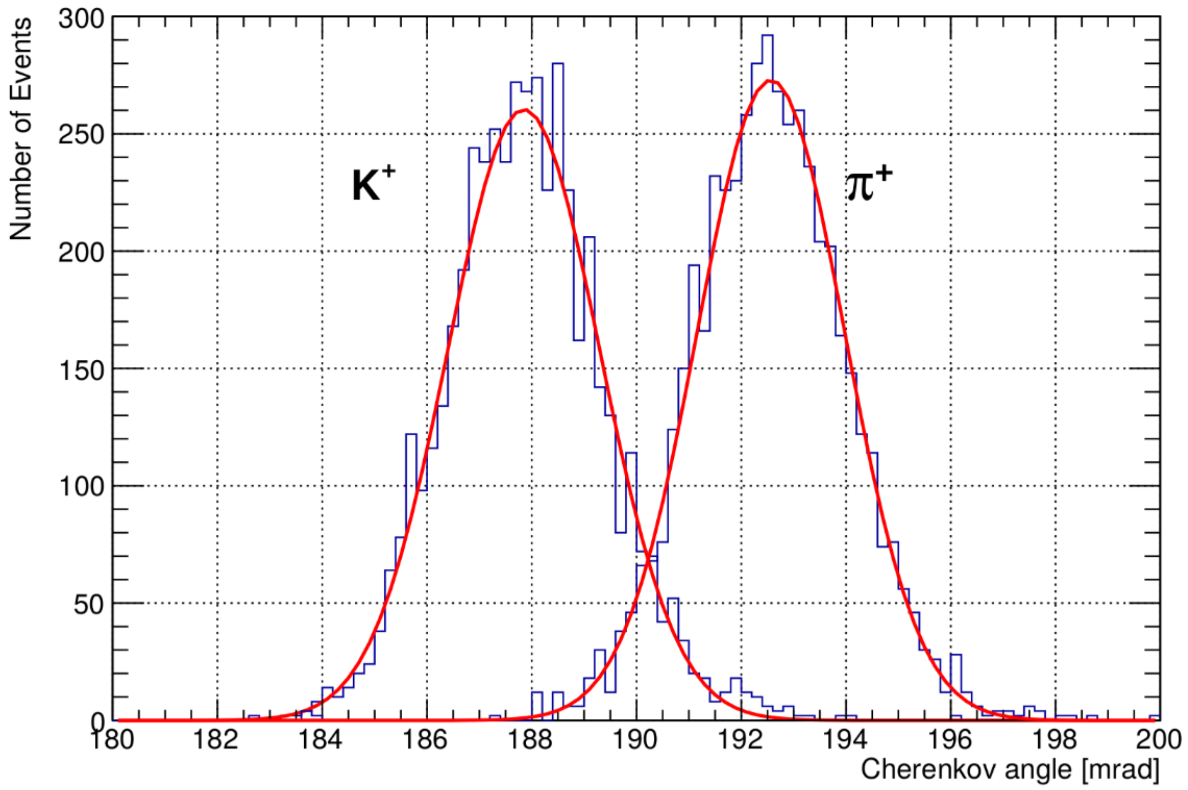


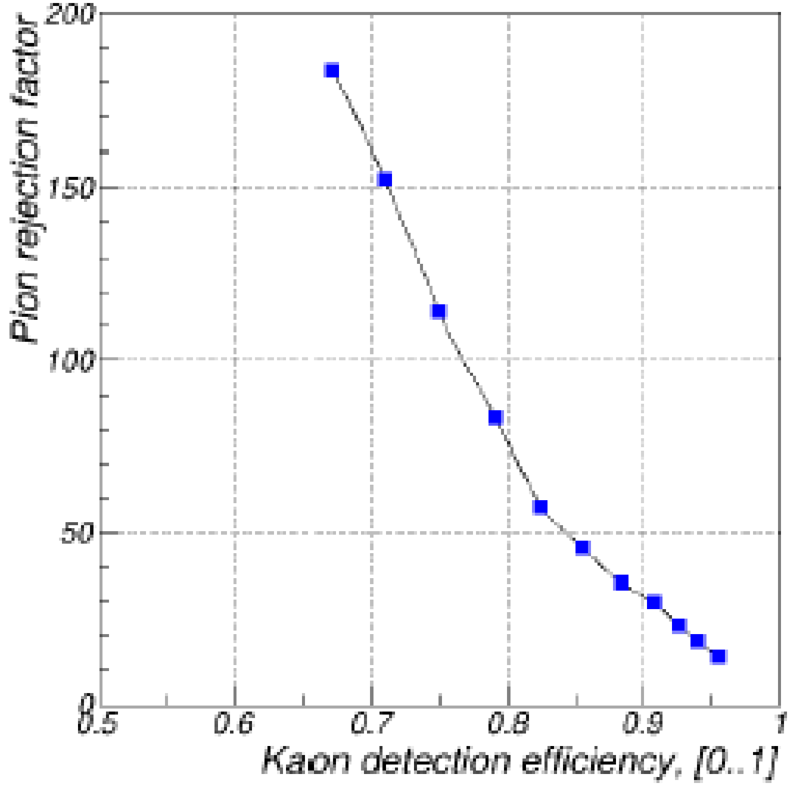
Yellow Report requirement: hadron
PID in the electron-going endcap: better than 3σ π/K separation either
(1) to 7 GeV/c (pp. 21)
(2) up to 10 GeV/c [table 3.1]

We consider the later as a reference!

YR requirement achieveable

Performance plot





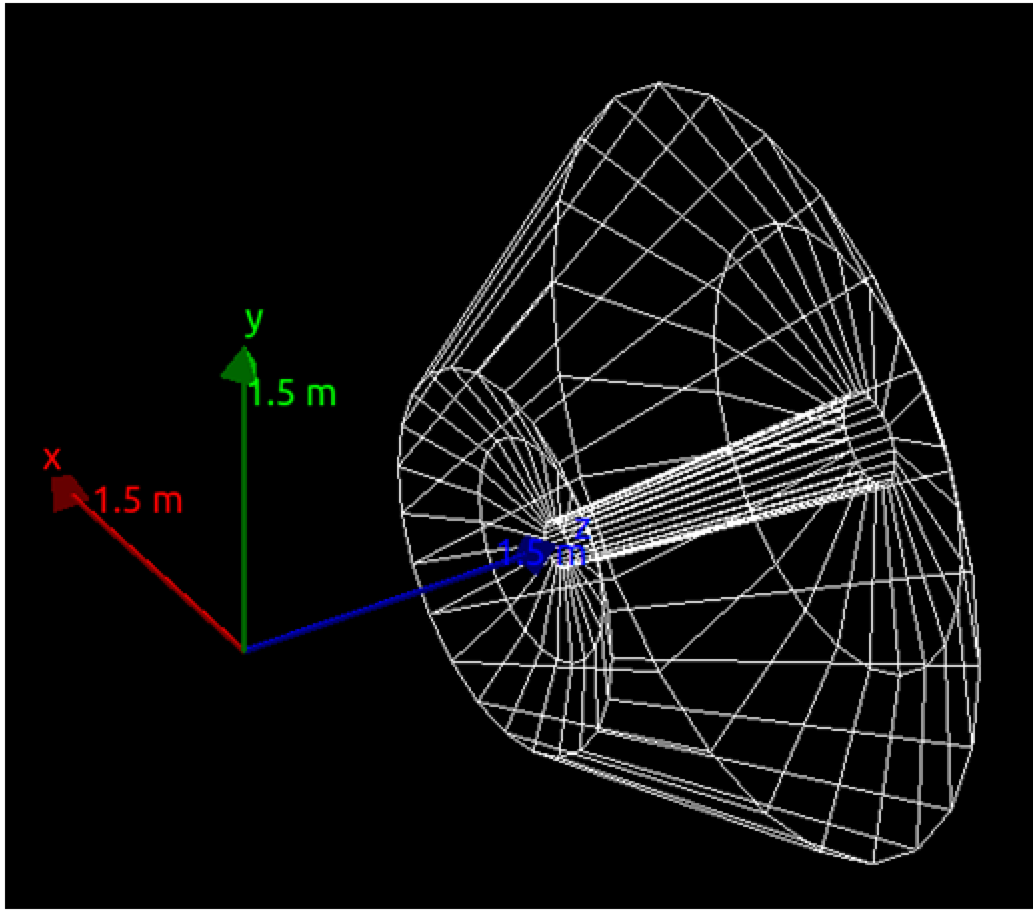
Expected pfRICH preformance in π/K separation.
Left: Reconstructed Cherenkov angle peaks for a **50:50 mix of 10 GeV/c pions and kaons** at **η = -1.7**.
Right: Dependency of pion rejection factor as a function of kaon identification efficiency with the reconstructed track-by-track Cherenkov ring angle cut varying between 187.8 mrad and 190.2 mrad.

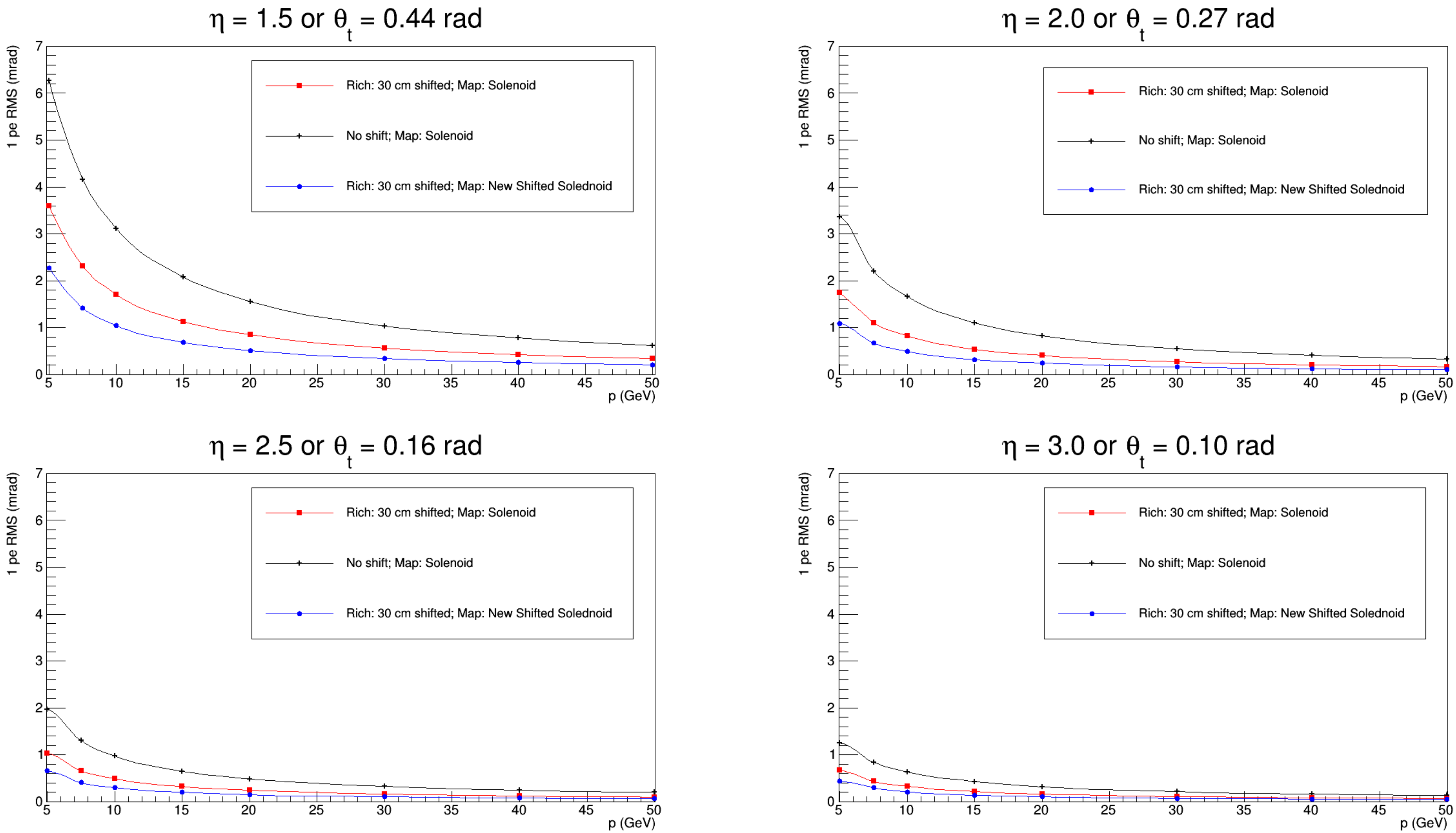
dRICH

1. Optimization of dRICH location
2. Geometric description.
3. Results.

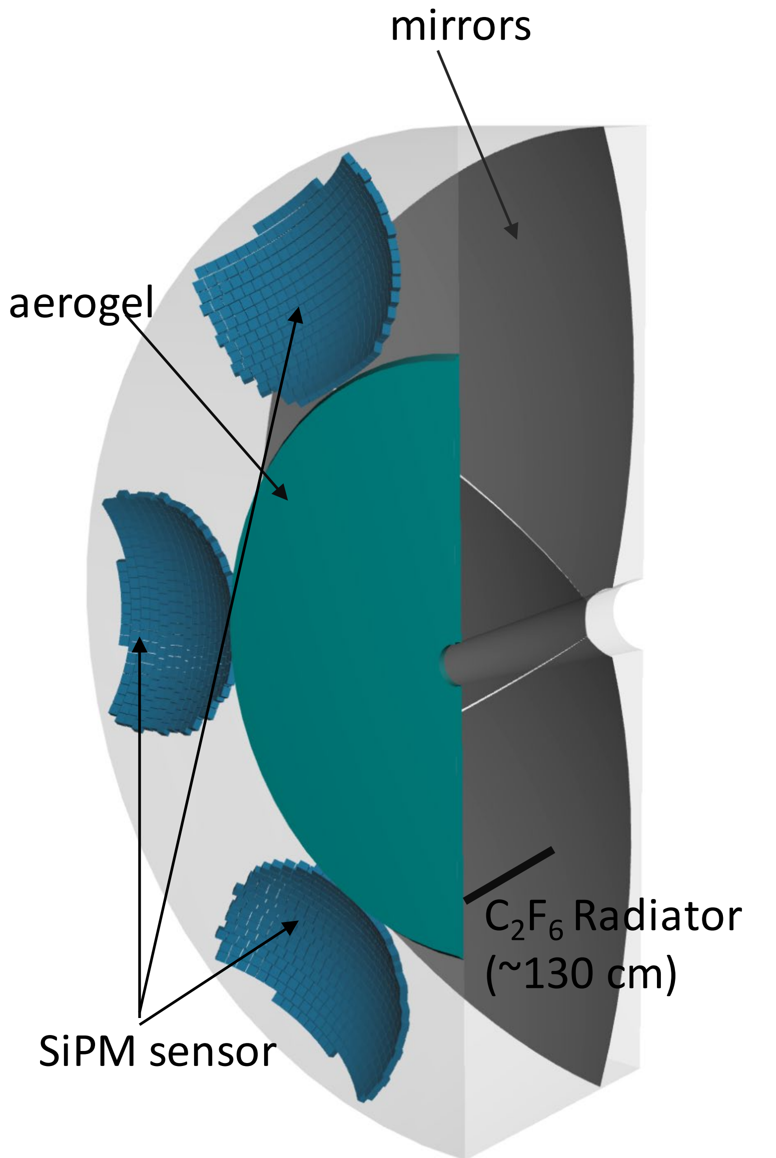
Stand alone Geant4 model : Optimisation of position

- **C2F6 refractive index for the radiator**
  - with chromatic dispersion
  - realistic C_2F_6 material
- **spherical mirror with perfect reflection**
  - R = 300 cm
- **spherical sensor surface**
  - R = 150 cm
- **basically an ideal RICH detector**
- **inverse ray-tracing reconstruction**
  - from HERMES papers
  - fix emission at mid-point of the radiator
  - assumes perfect tracking information
    - namely the actual track position / direction at the emission point




η = 1.5 or θ_t = 0.44 rad
η = 2.0 or θ_t = 0.27 rad
η = 2.5 or θ_t = 0.16 rad
η = 3.0 or θ_t = 0.10 rad
1 pe RMS (mrad)
p (GeV)
Rich: 30 cm shifted; Map: Solenoid
No shift; Map: Solenoid
Rich: 30 cm shifted; Map: New Shifted Solednoid

Geometric description of dRICH

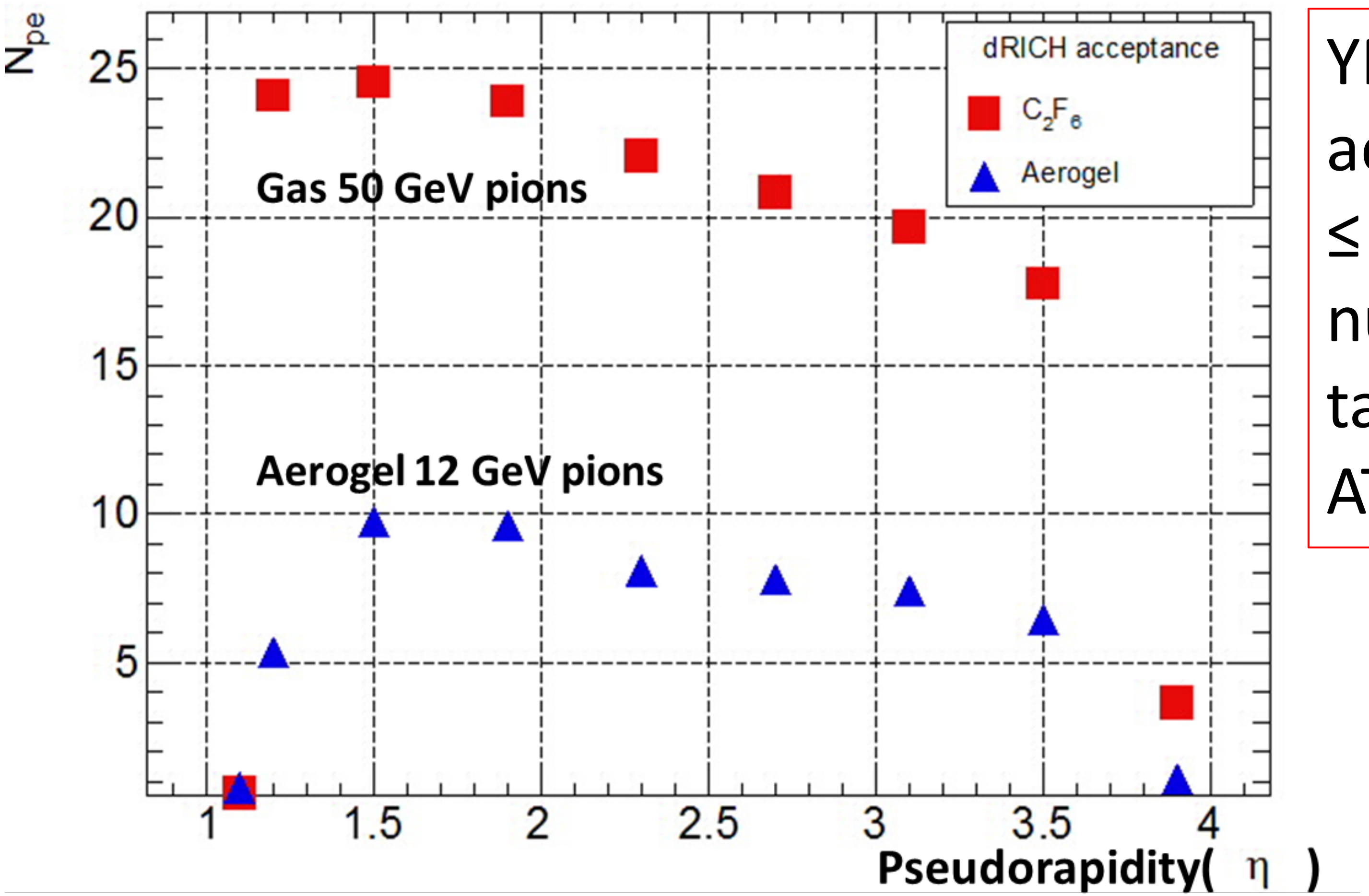


1. 140 cm of total length. Occupying space +190 cm to +330 cm from the IP.
2. Detector will have six 60° sectors, each equipped with its own spherical mirror segment and a sensor plane.
3. Sensors are like pfRICH
4. Focusing mirrors → 6 individual elements (single mirror configuration)
5. More complicated beam pipe geometry.
6. C_2F_6 radiator. Fully parameterized (The Journal of Chemical Physics 73.2 (1980), p. 990., NIMA 354.2 (1995), pp. 417). Conservative absorption length (10 m).
7. Aerogel properties are similar to pfRICH. → 4 cm thick
8. Similar Sensors.

The sensors are positioned on a sphere, with a square tiling algorithm. The spherical mirrors are parameterized by three variables: the z position of the back plane, which is the maximum z the spherical mirror will reach, along with two focus tune parameters f_x and f_z.

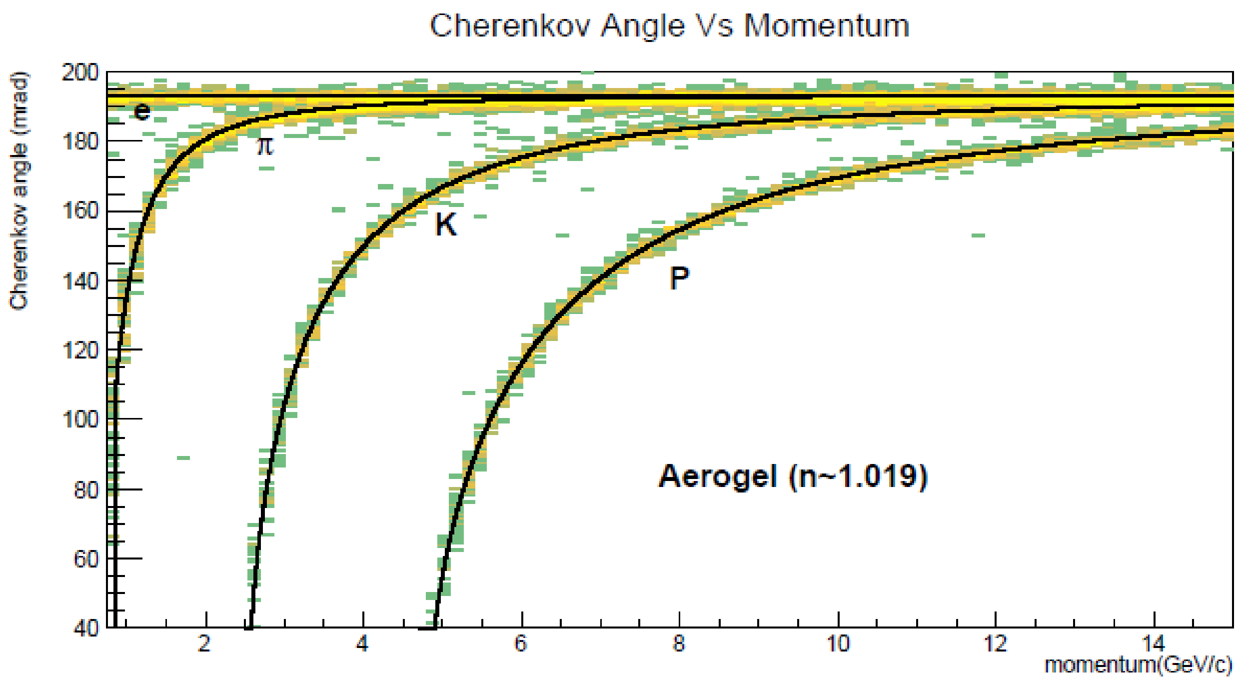
Different placement geometries of the sensors, as well as a dual or multi-mirror configuration are under consideration → IMPROVE OPTIMIZATION!

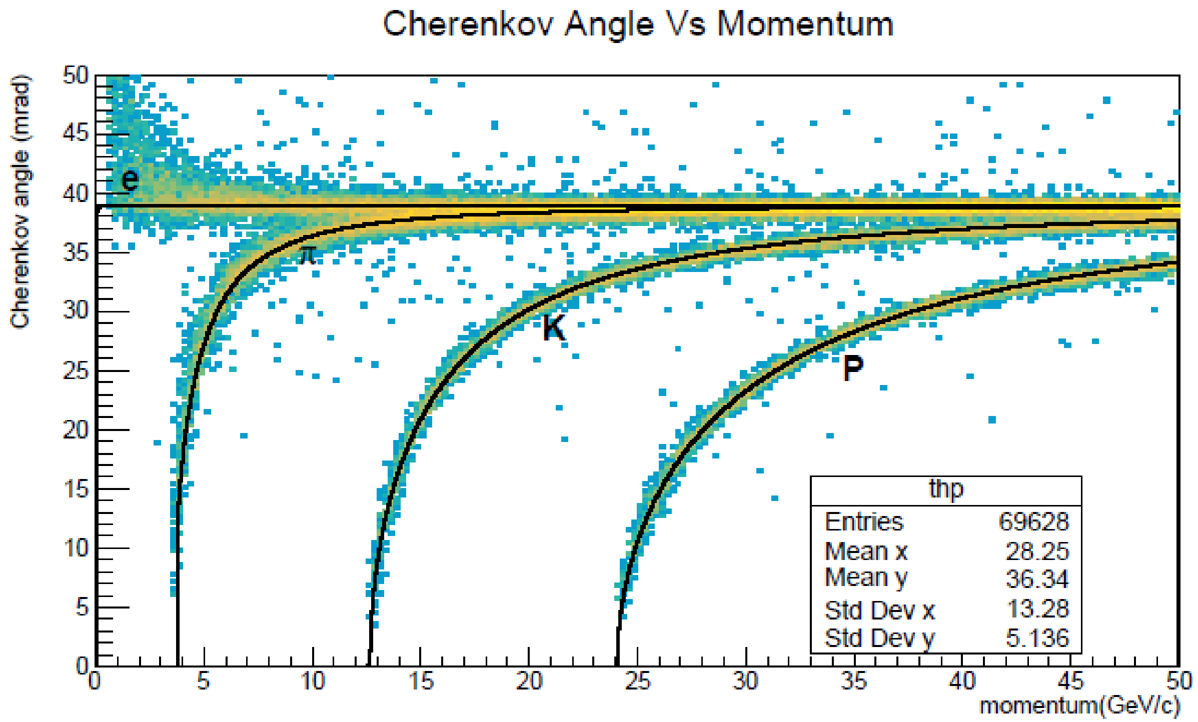
dRICH acceptance as a function of pseudorapidity



YR requirement:
acceptance for the dRICH is $1.0 \le \eta \le 3.5$. These reference numbers were
taken as a guidance for the ATHENA implementation.

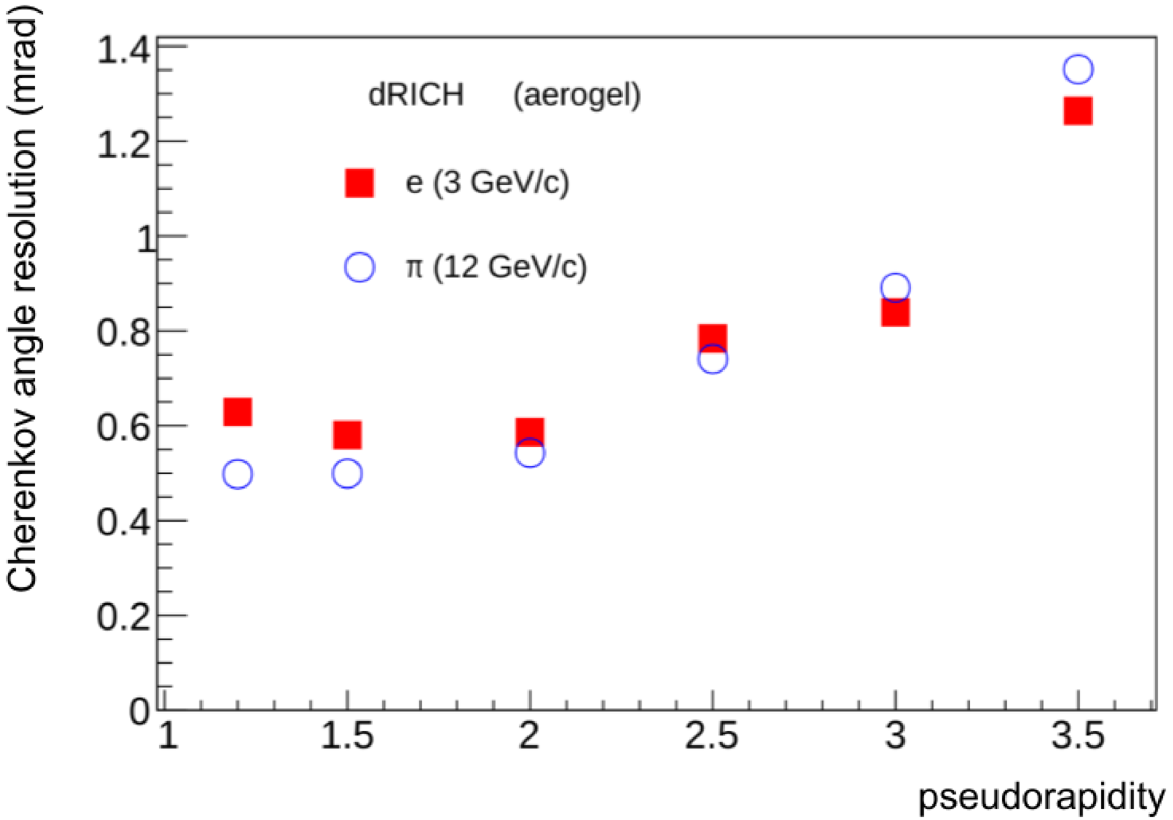
Reconstructed Cherenkov Angle Vs momentum

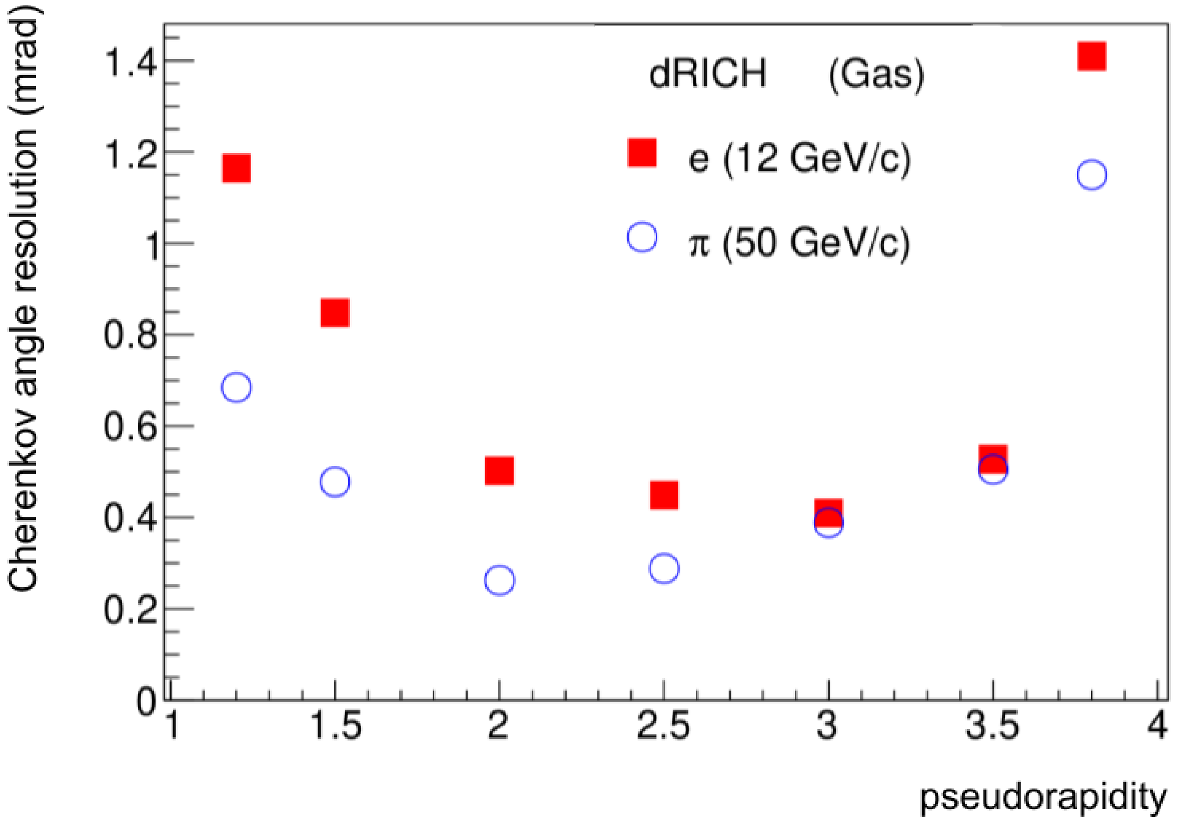




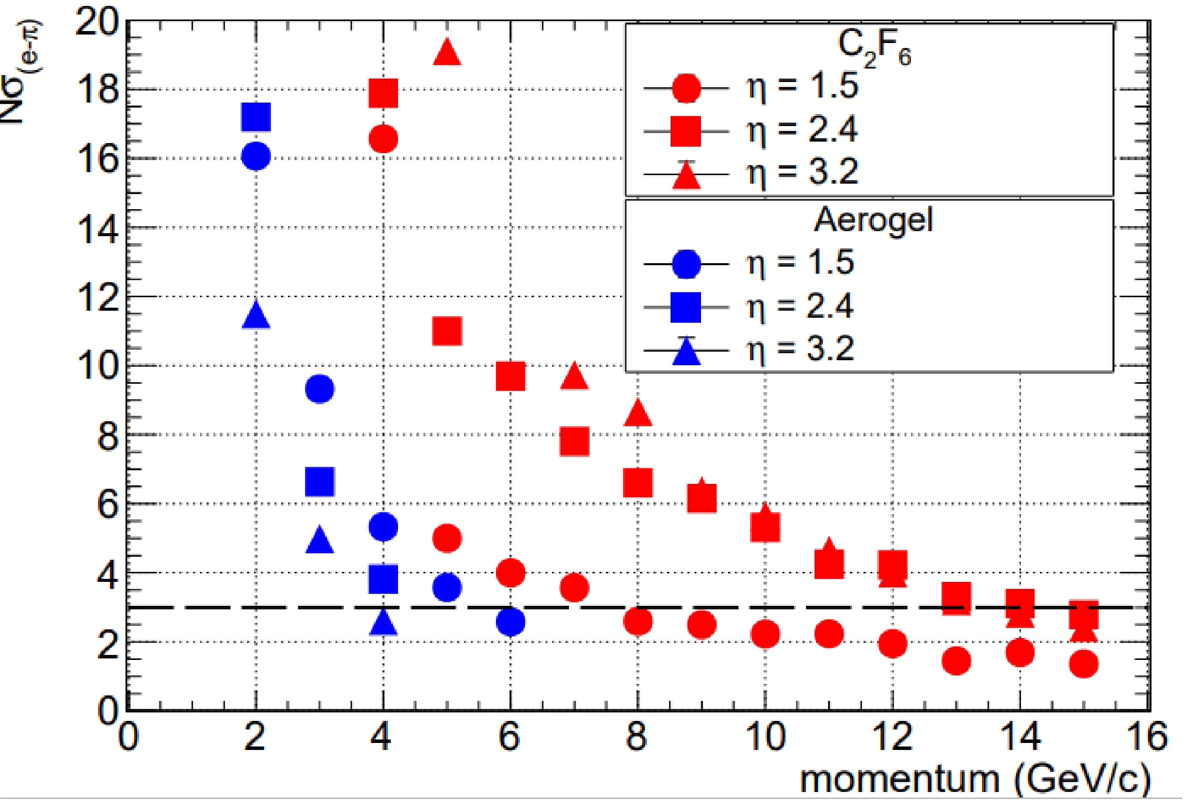
@ pseudo rapidity = 2.4

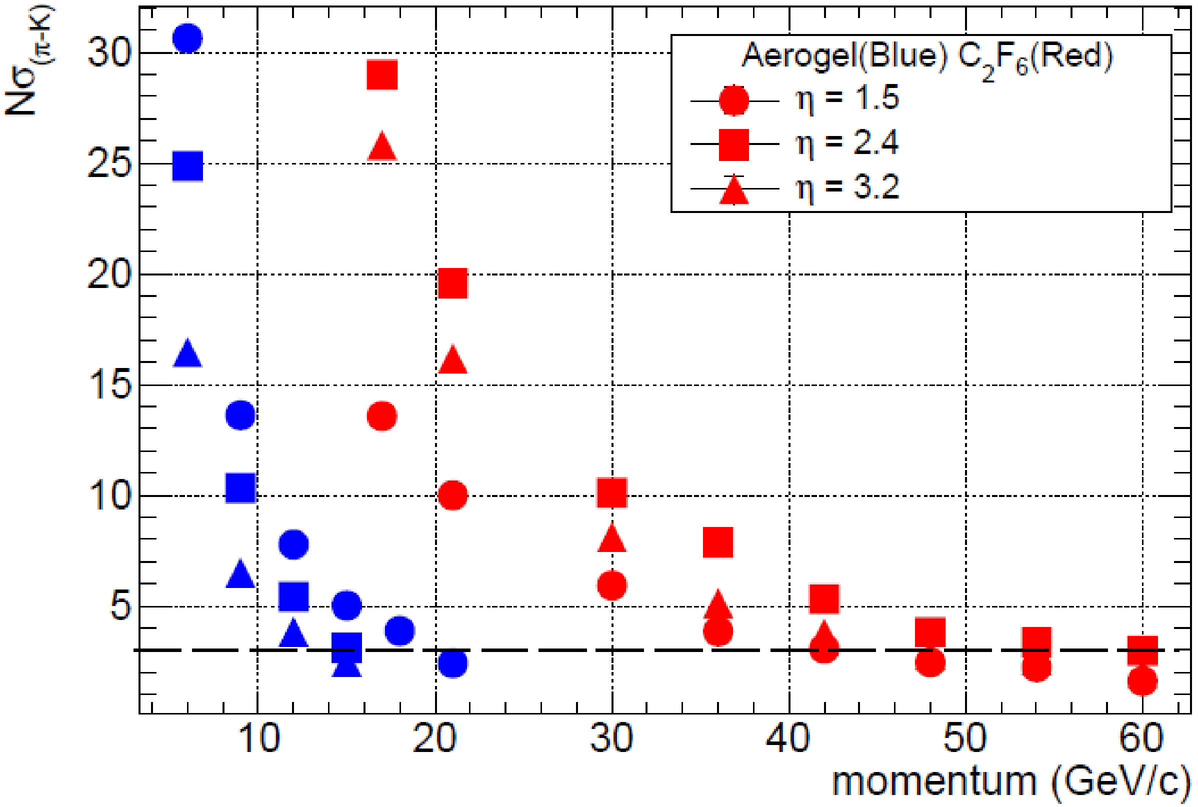
Dependence of ring resolution with pseudorapidity



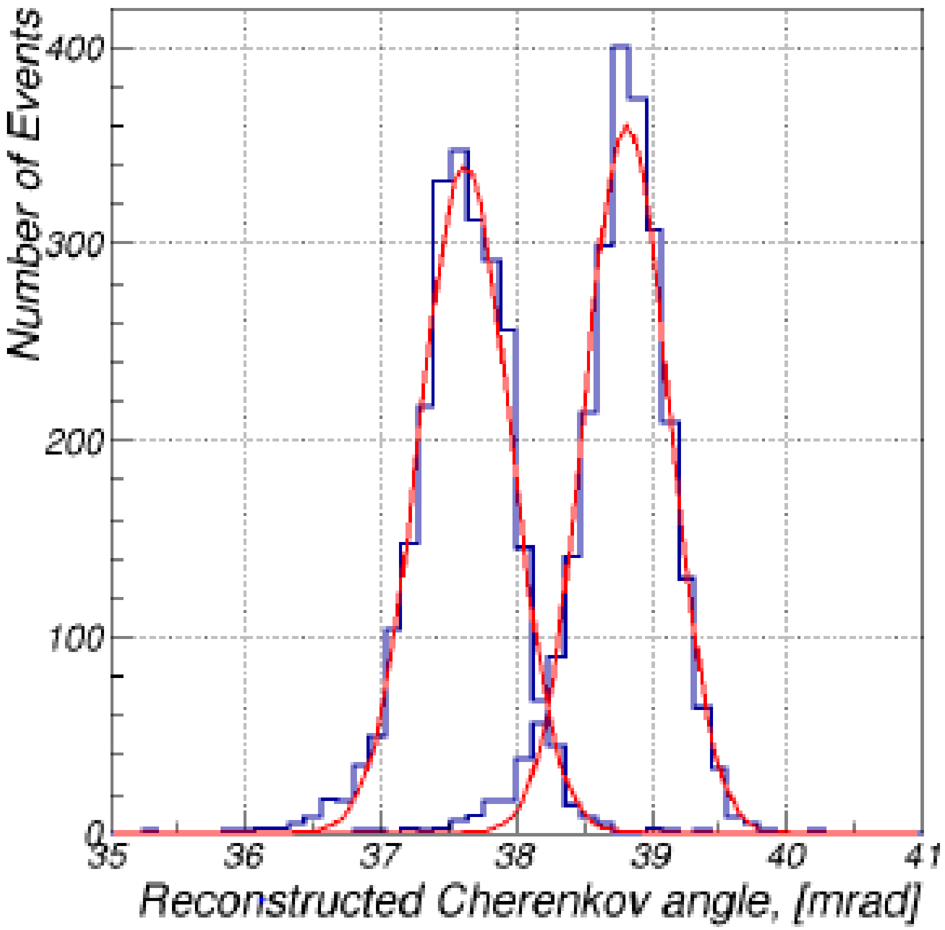


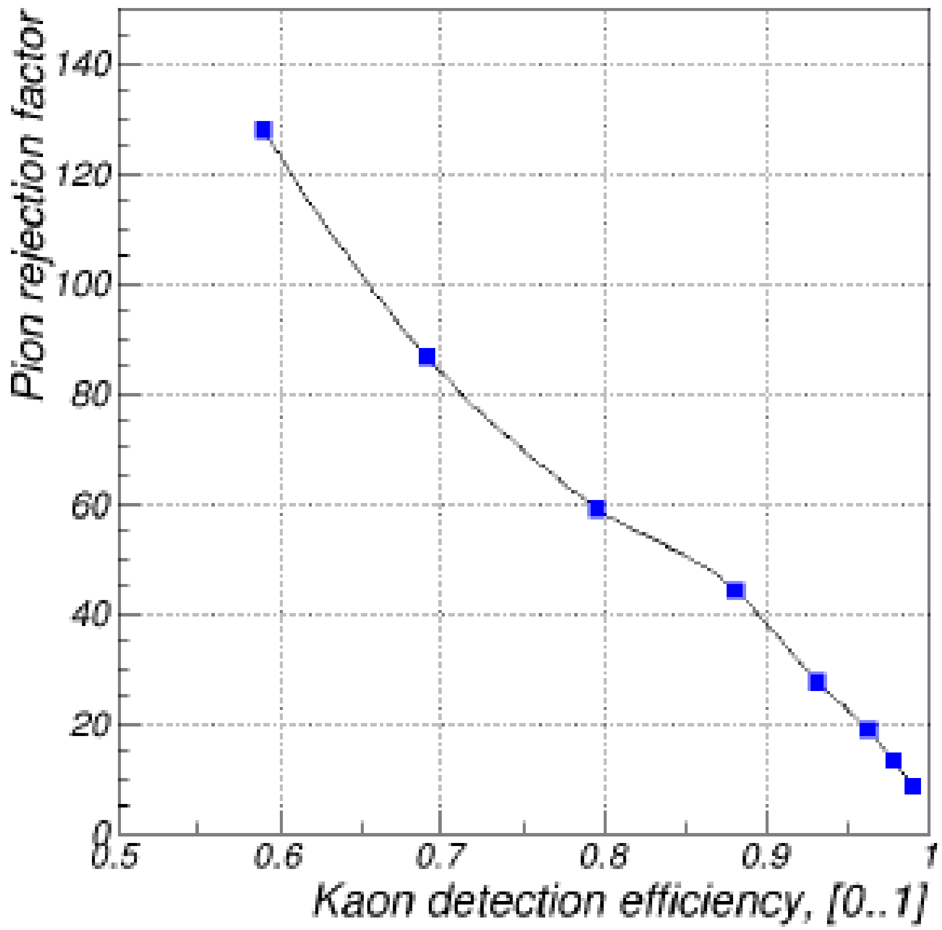
N Sigma Separation



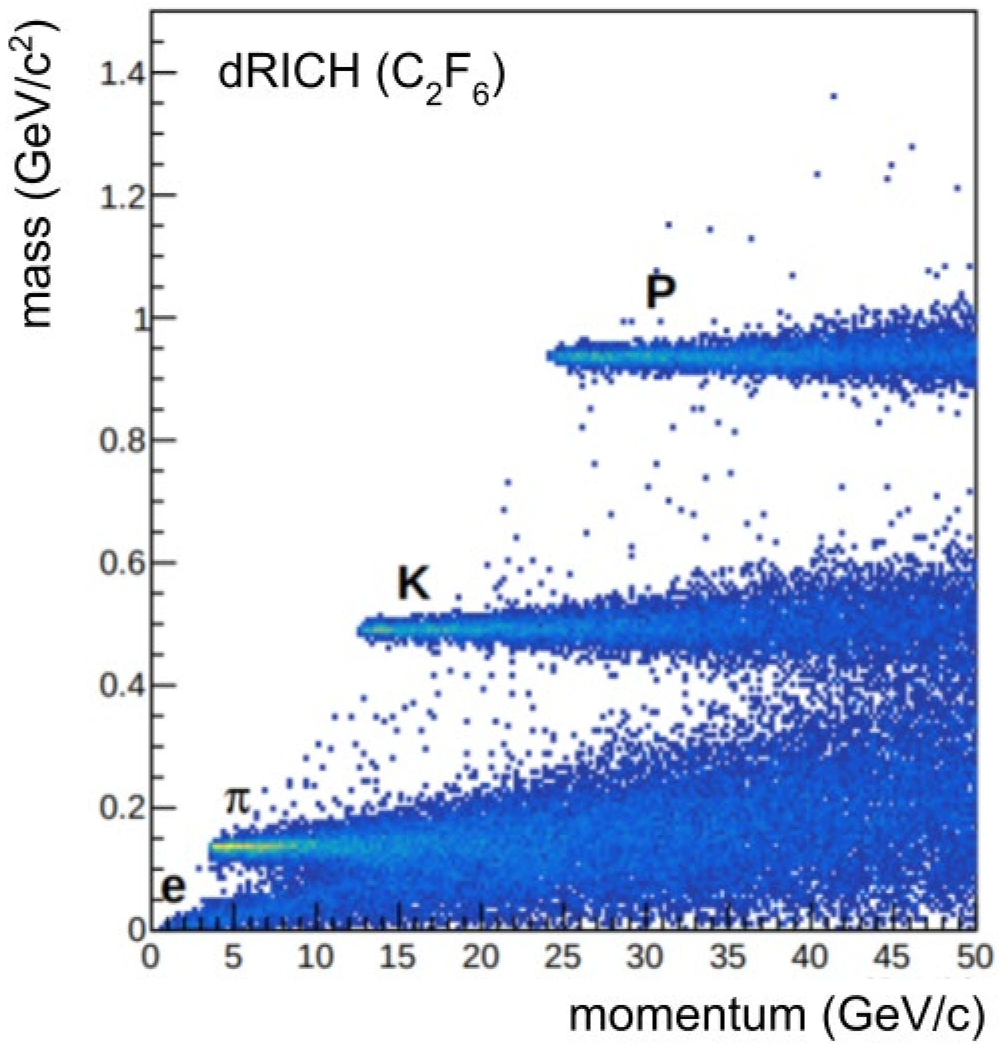


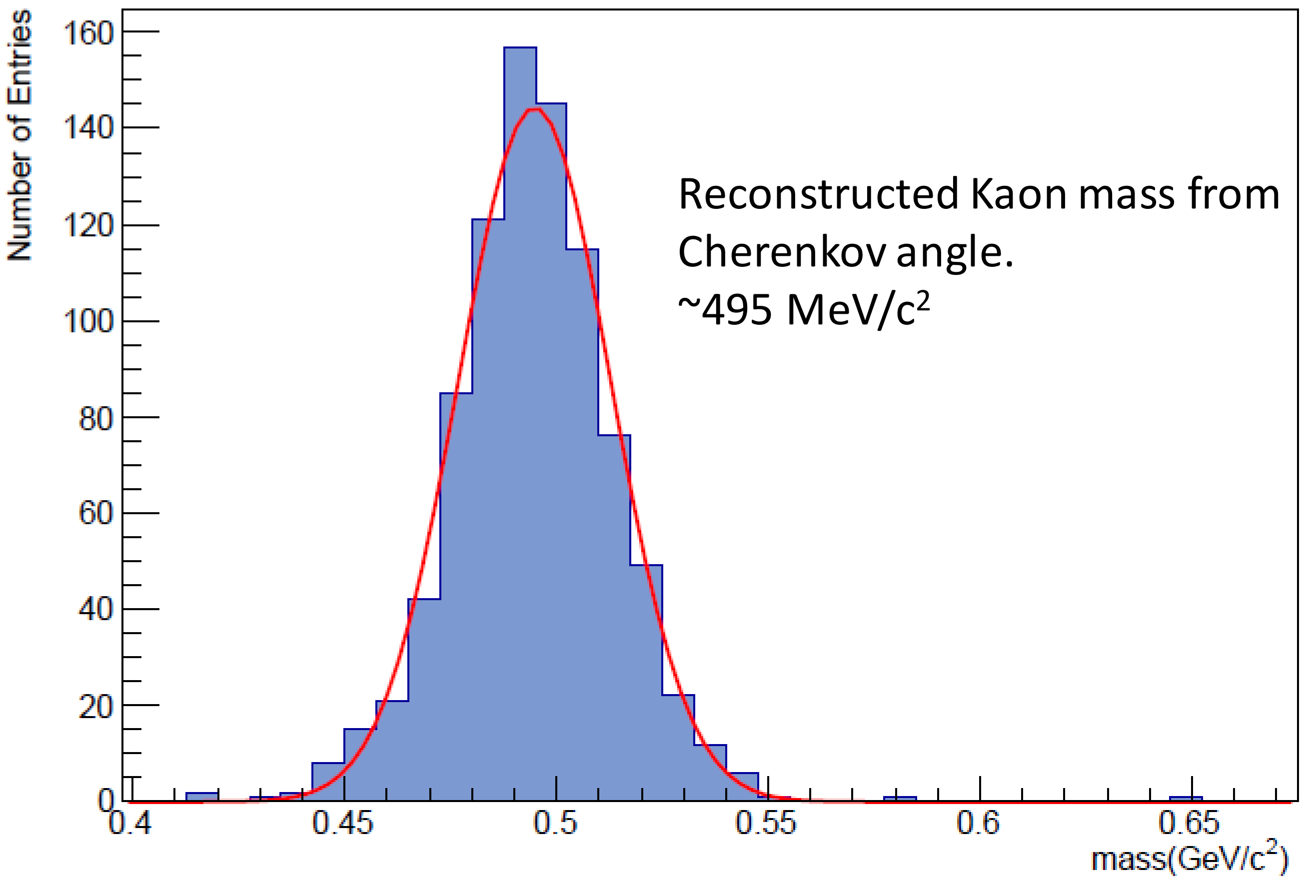
Performance plots





Left: reconstructed Cherenkov angle peaks for a 50:50 mix of 50 GeV/c kaon and pion tracks at η = 2.4 are ~3σ apart (C_2F_6 radiator). Right: dependency of pion rejection factor on kaon detection efficiency with the selection cu varying between 37.6 mrad and 38.4 mrad applied to the left hand side plot.





Particle Mass as a function of momentum retrieved from reconstructed Cherenkov angle

Future modifications and tasks in pipeline

- The exercises show that for single particle scenario the algorithm works and YR dictated performances can be achieved. In the next days multi particle systems will be added and more realistic physics hepmc files will be feed to see the limit of the performance.
- More sophisticated algorithm will be implemented in near future.
- Right now, no NOISE is added. Performances will be studied with added noise.
- The dRICH foreseen to be having dual mirror configuration to contain the focalization along the sensor plane.

  → Caveat: Multi solution of a single detected hit point… Complicated PID algorithm.
  Rigorous tests are to be done.

Right now the pfRICH has flat aerogel, it can be tilted also it can be considered making the sensor arrangement rather hemispheric than flat, at least at the large radii. This can allow to reach a full detector efficiency up to
$\eta \sim -1.5$ and consequently provide a better overlap in PID with the barrel DIRC.

The works had been done with:
A. Kiselev (BNL), C. Dilks (Duke University), R. Preghenella (INFN BO)

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Thanks a lot!!!

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Some links:

- *https://eicweb.phy.anl.gov/EIC/detectors/athena/-/blob/irt-init-v01/compact/erich.xml* *pfRICH xml*
- *https://eicweb.phy.anl.gov/EIC/detectors/athena/-/blob/irt-init-v01/src/ERich_geo.cpp* *pfRICH geo parser*
- *https://wiki.bnl.gov/athena/index.php/Particle_Identification* *PID supplemental*
- *https://indico.bnl.gov/event/12711/contributions/53072/attachments/36449/59891/chchatte20210809.pptx* *dRICH position optimization*
- *https://indico.bnl.gov/event/12875/contributions/53838/attachments/36885/60713/Drich-optics.pdf* *dRICH optics tuning*