Particle identification performance studies with pfRICH simulations

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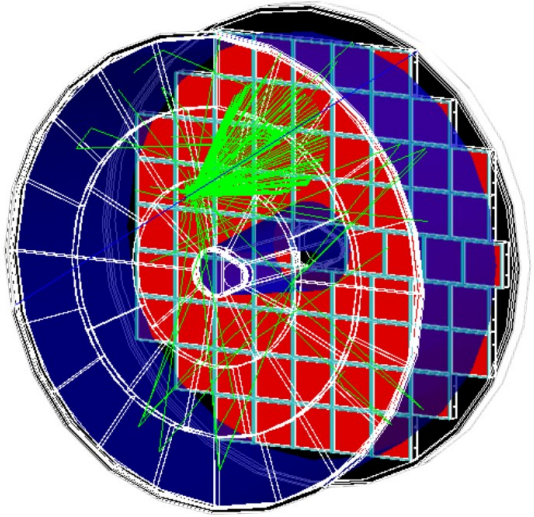

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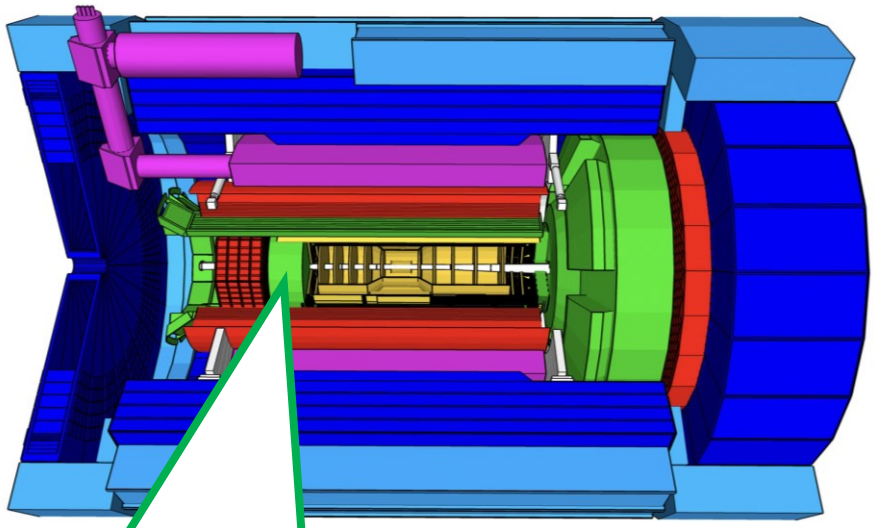
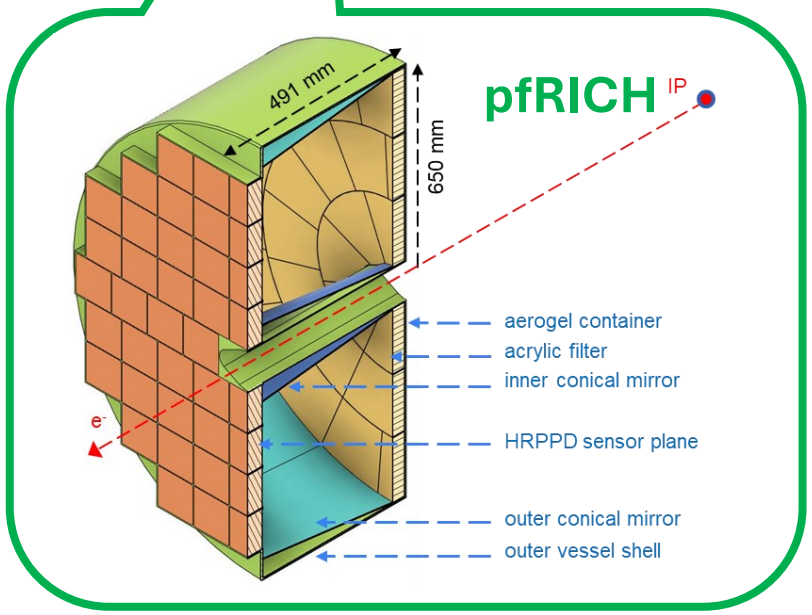
Overview of pfRICH





pfRICH (**p**roximity-**f**ocusing **R**ing **I**maging **CH**erenkov)

- Crucial for **PID in e-going direction** in $-3.5 < \eta < -1.5$
  - Excellent separation power up to 7 GeV:

Competing species	Separation range [GeV]
e vs hadrons ($\pi/K/p$)	~0.2 to ~2.5
K vs π/p	~2.0 to ~7.0

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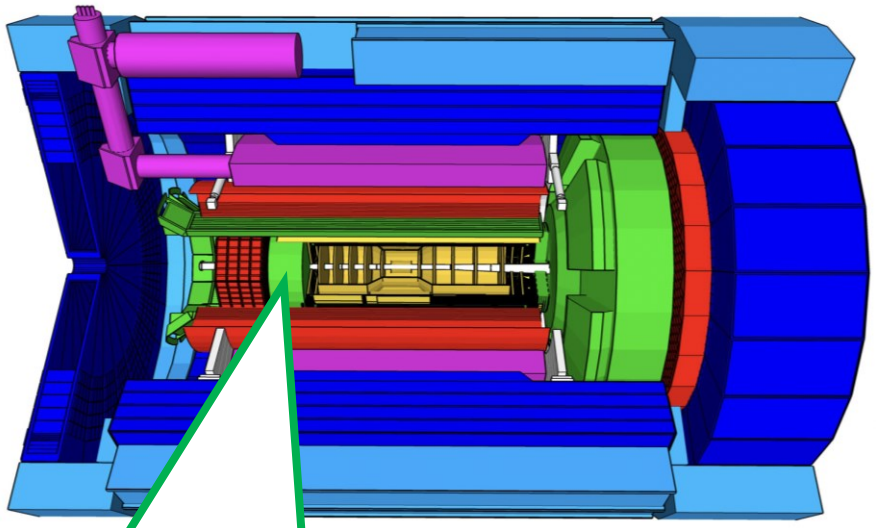

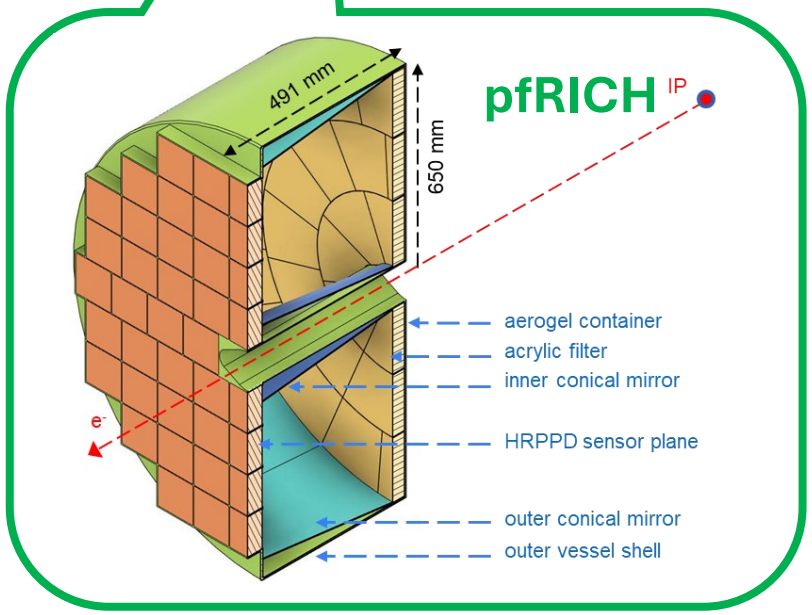

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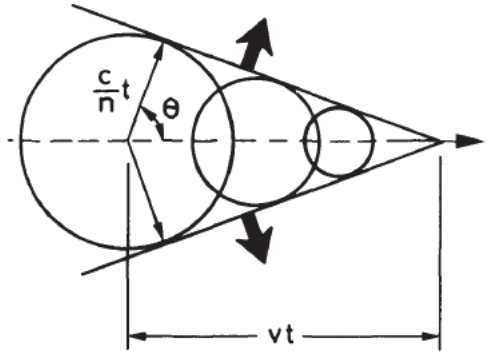
  - Cherenkov radiation angle θ_c, is related to particle's speed $\beta = v/c$ and medium's refractive index n

$$\cos\theta_C = \frac{1}{\beta n(\omega)}$$

"electromagnetic shock wave"



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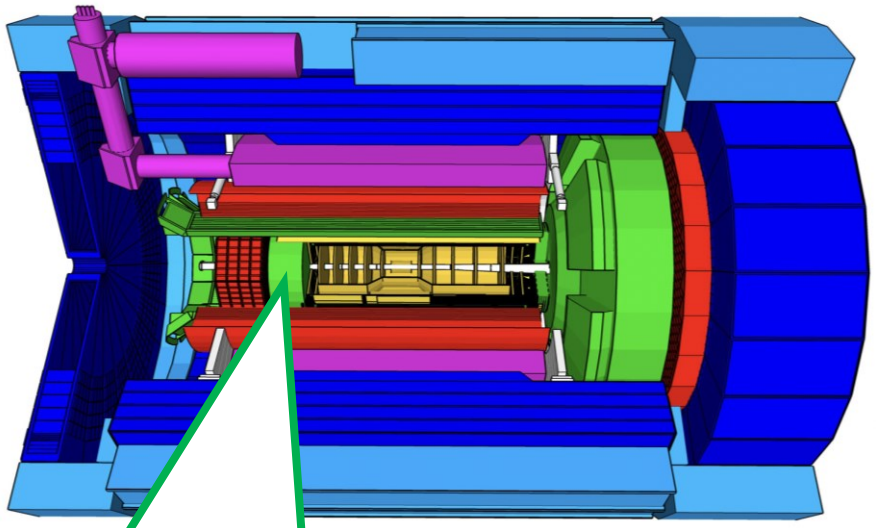

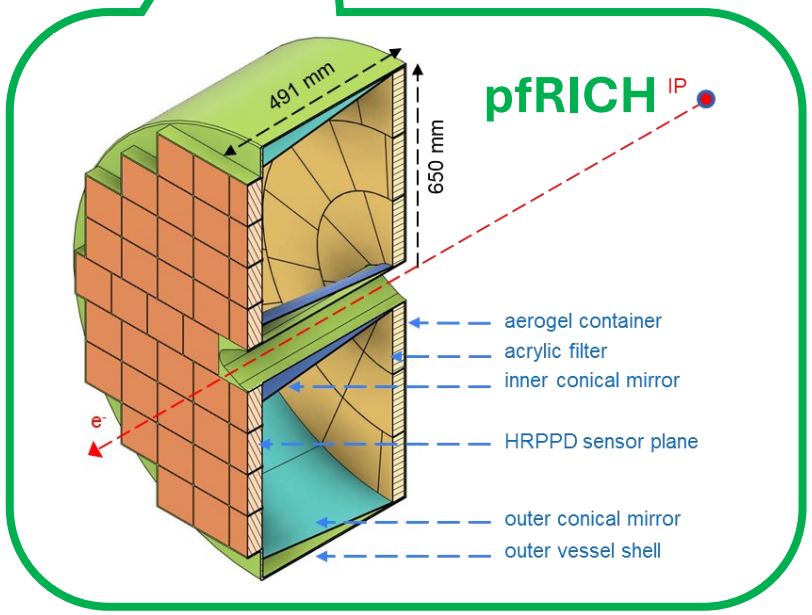

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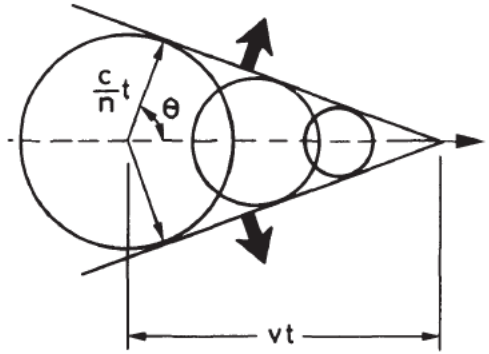
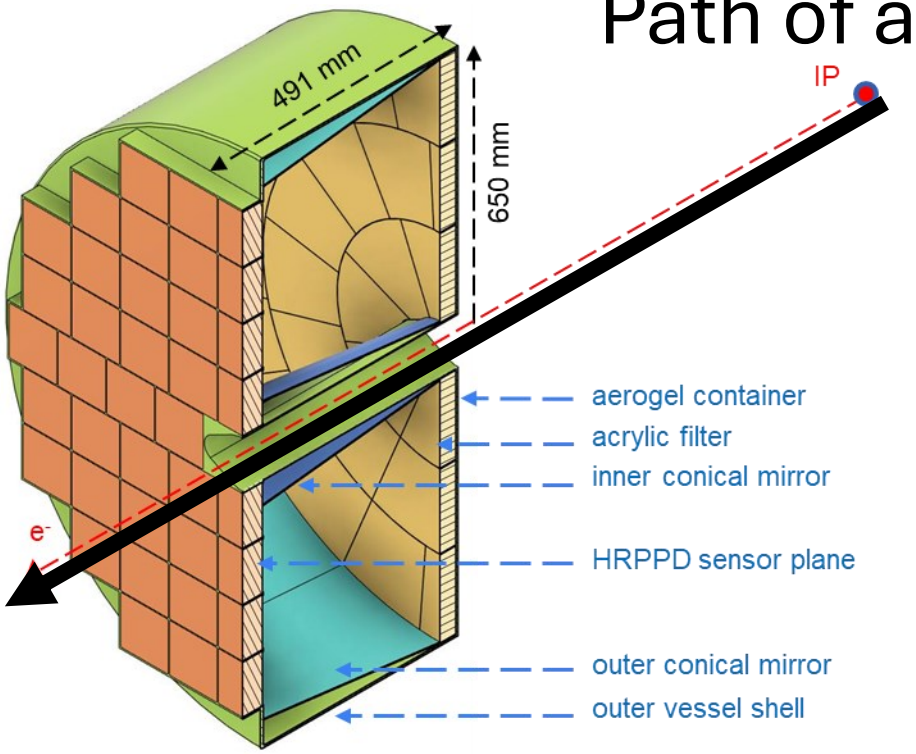
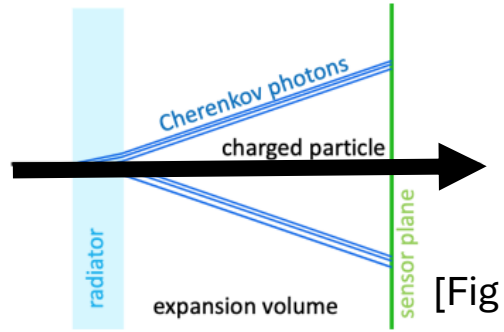


- pfRICH also has potential application for **global timing**

Path of a Cherenkov photon

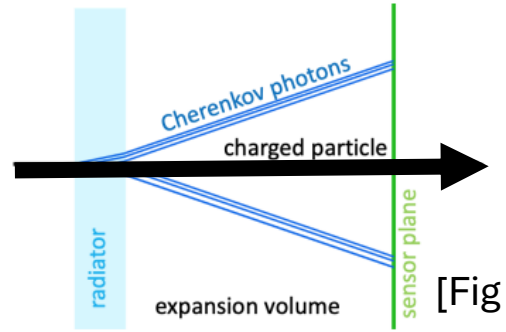




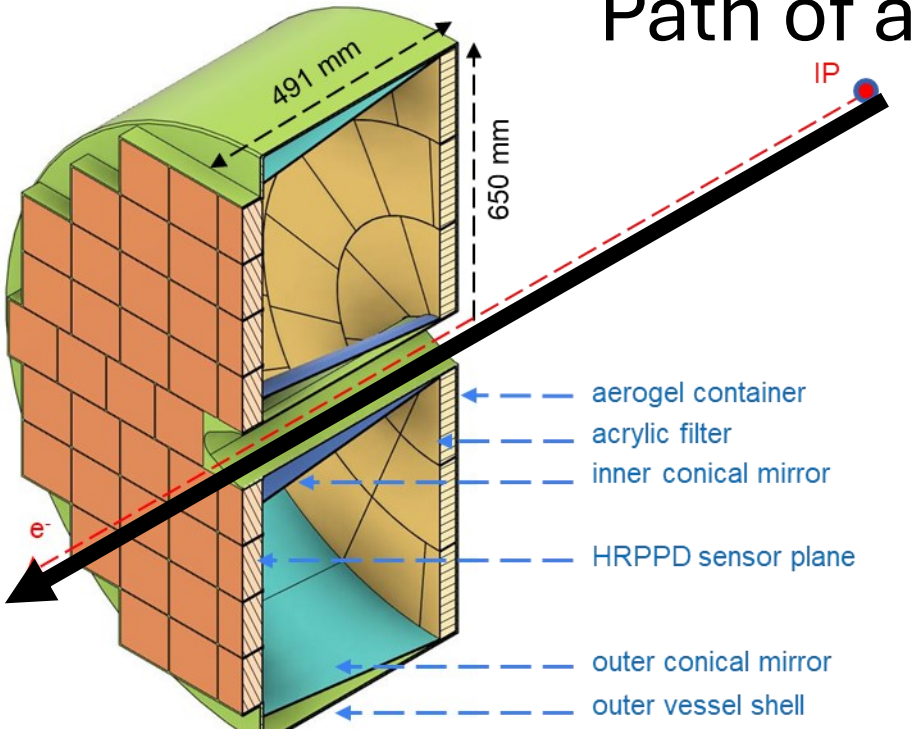
[Fig 1.3, CDR]

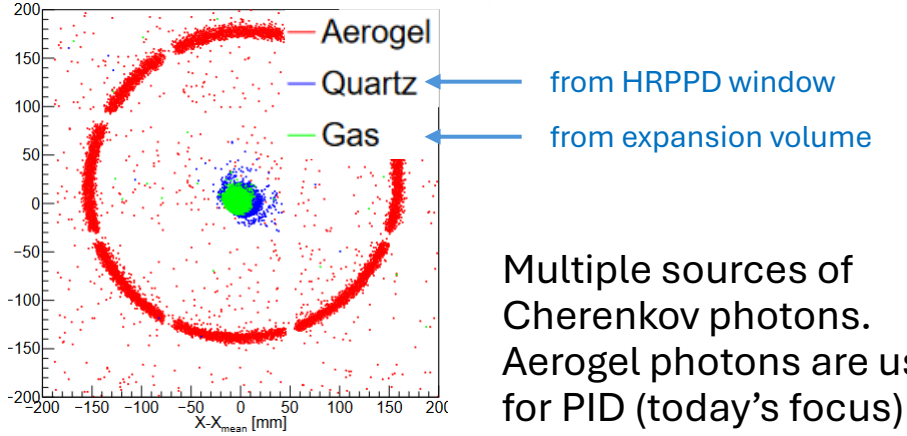
- Aerogel
  - "**Radiator**": Cherenkov photons produced here
  - $\langle n \rangle = 1.045$, 2.5 cm thick, 42 tiles
    - Optimize angle resolution & number of photons
- Acrylic layer
  - **Filters** out photons with wavelength < 300 nm
    - Minimize dependency on $n(\omega)$
- Vessel
  - Encloses a 40 cm long "**expansion volume**": Photons travel through here
    - Large gap improves angle resolution
- Sensor plane
  - **Detects** the photons and amplifies the signals
  - 68 HRPPD (High Rate Picosecond Photo Detector) sensors

Path of a Cherenkov photon



[Fig 1.3, CDR]





Multiple sources of Cherenkov photons. Aerogel photons are used for PID (today's focus)

[Fig 7.3 (a), CDR]

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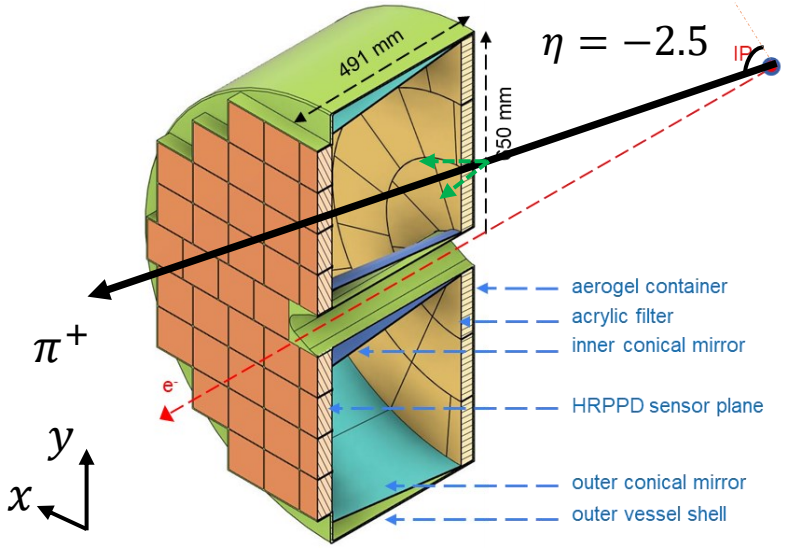
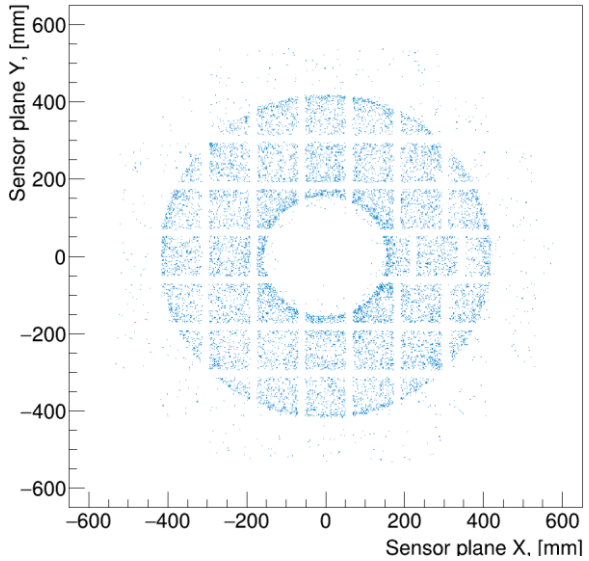
“Imaging” sensor plane



- Study pfRICH performance with standalone software https://github.com/eic/pfRICH

- E.g., “imaging” part of the HRPPD sensor plane



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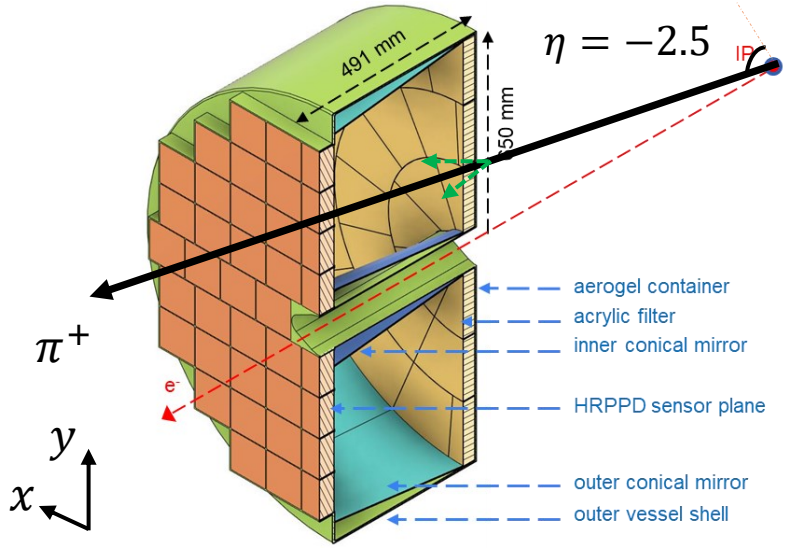

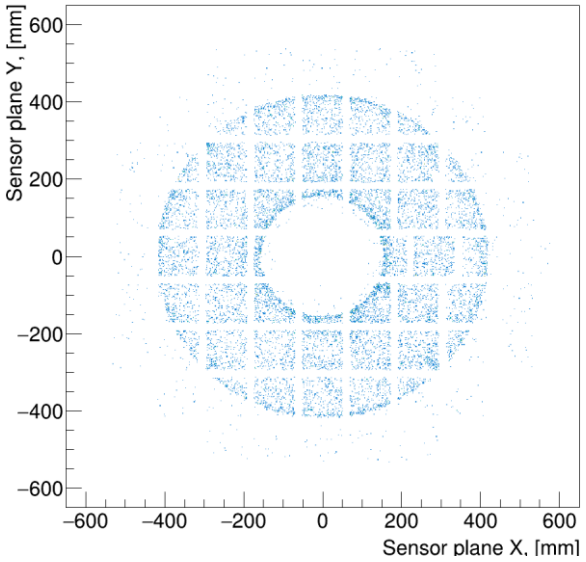

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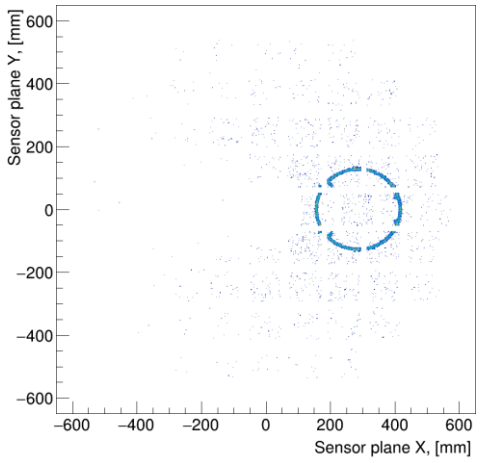
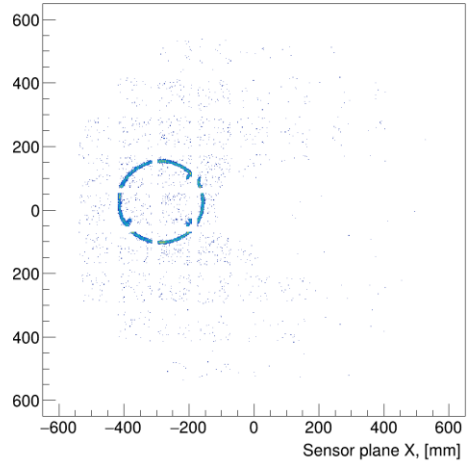
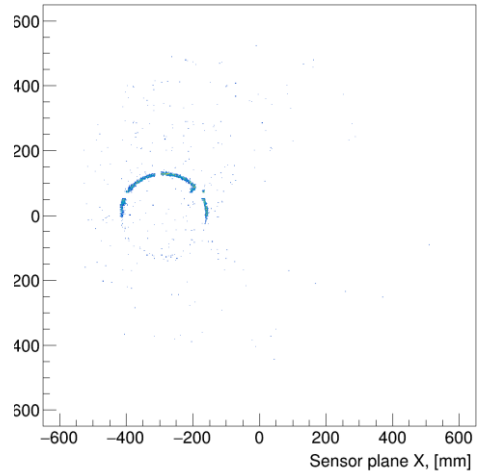
$\phi \in (0,360)$



$\phi = 0$



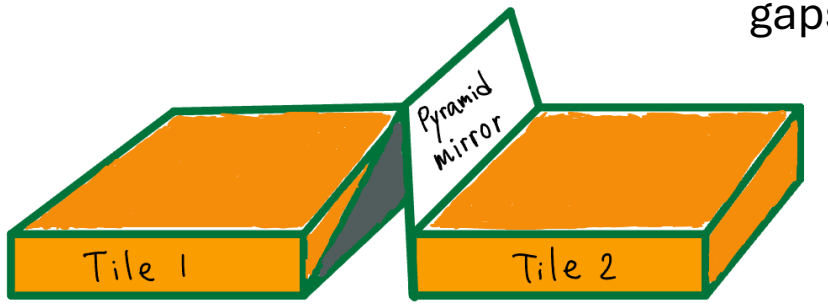
$\phi = 175$

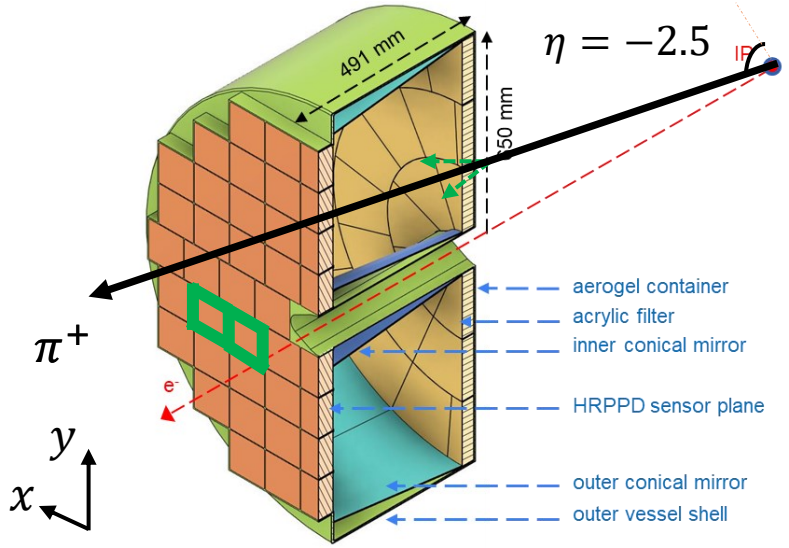


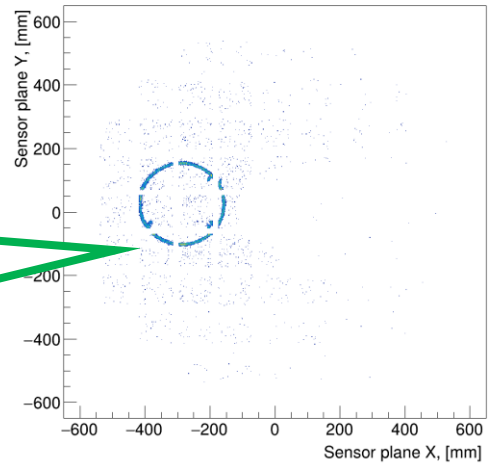
$\phi = 180$

“Imaging” sensor plane

- Study pfRICH performance with standalone software https://github.com/eic/pfRICH
- Check other features of setup
  - “Pyramid” mirrors help reconstruct photons lost in gaps between HRPPD tiles







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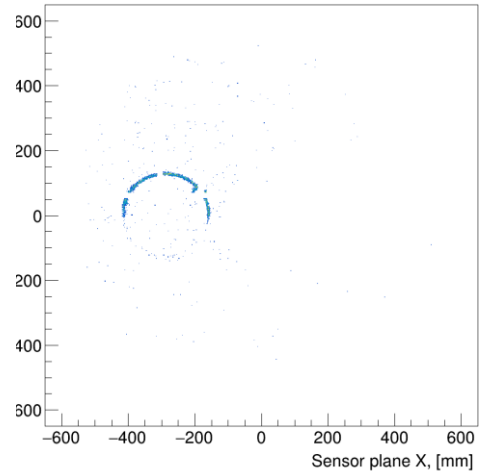

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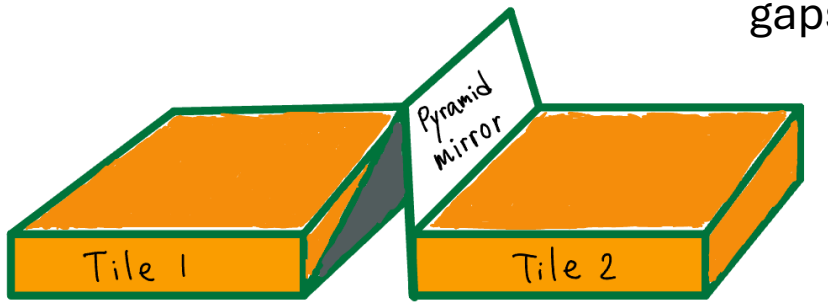

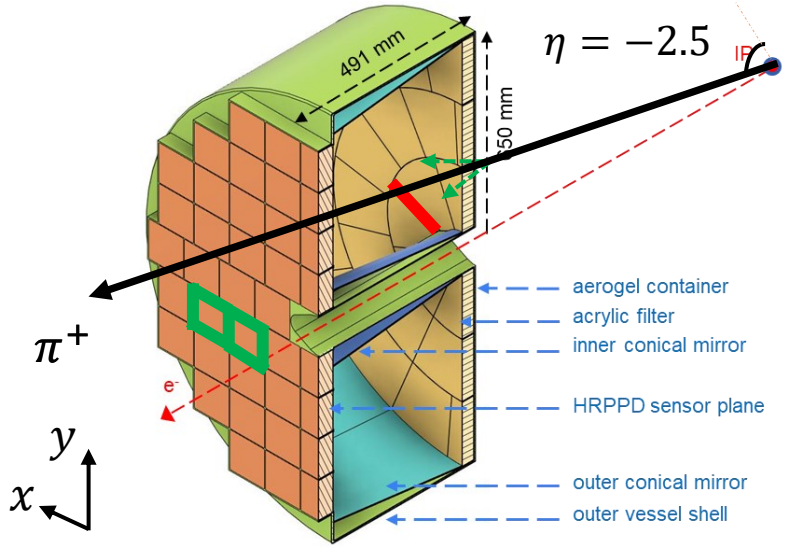

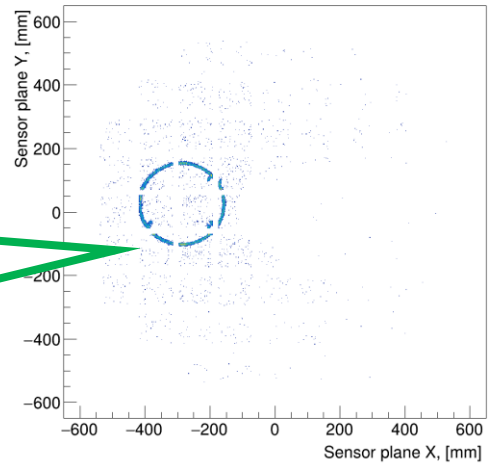

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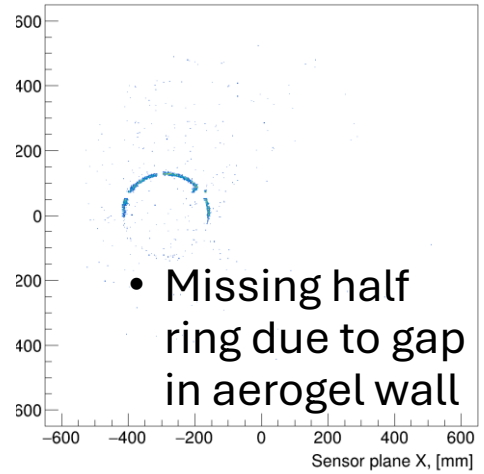
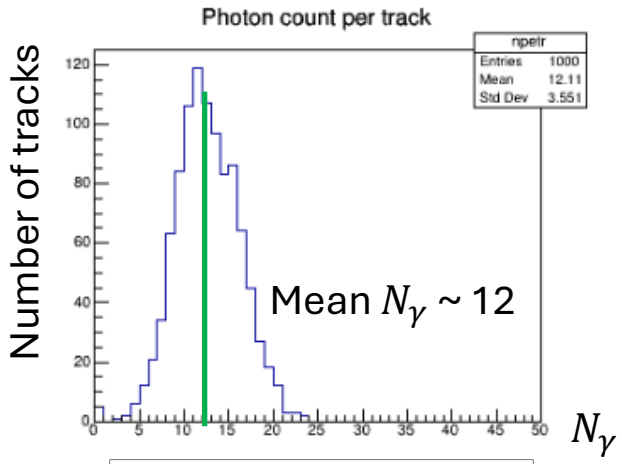
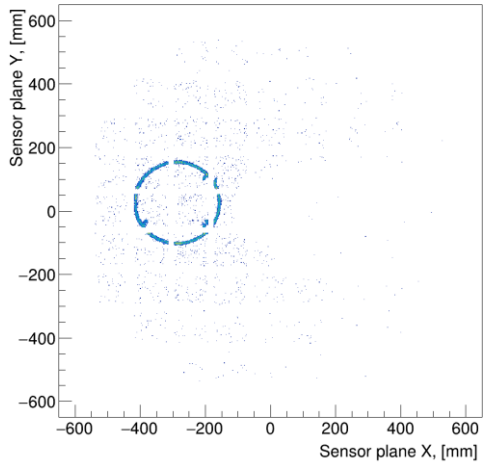


- Missing half ring due to gap in aerogel wall

$\phi = 180$

Efficiency vs azimuthal angle





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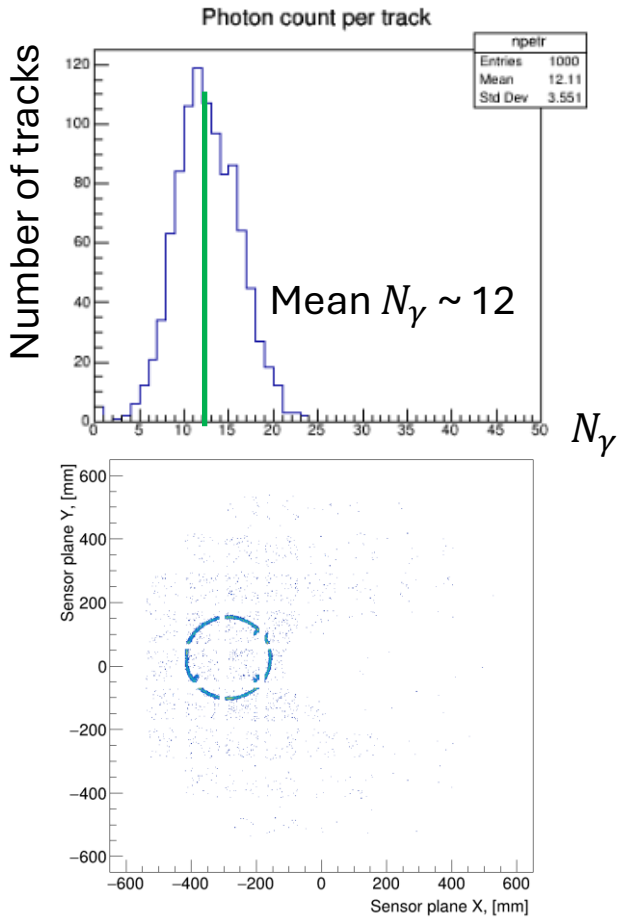

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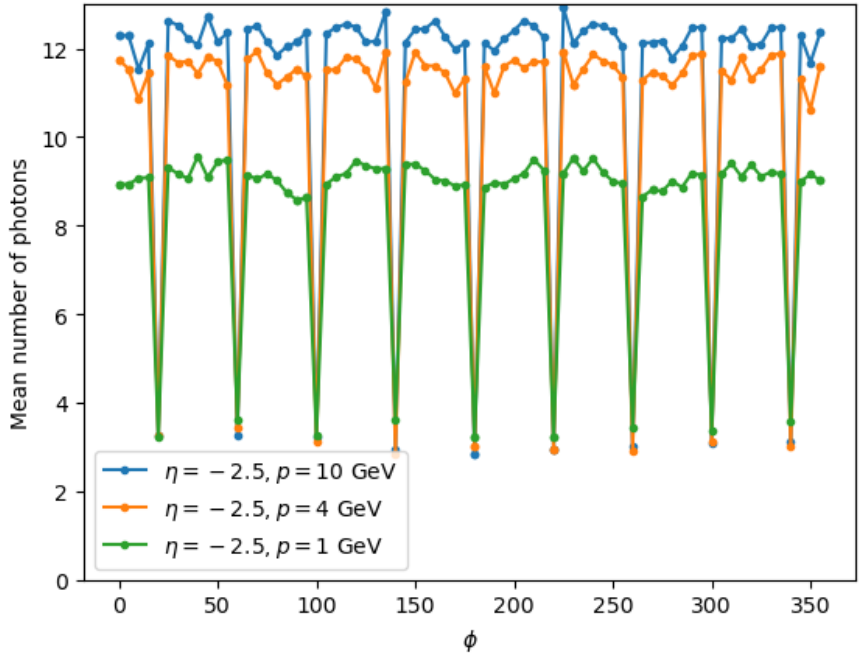

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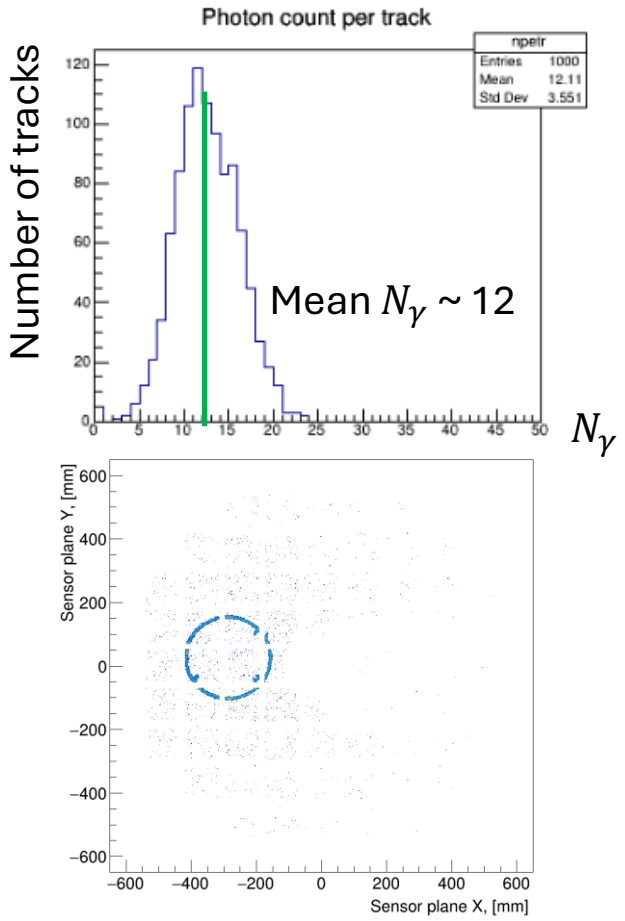

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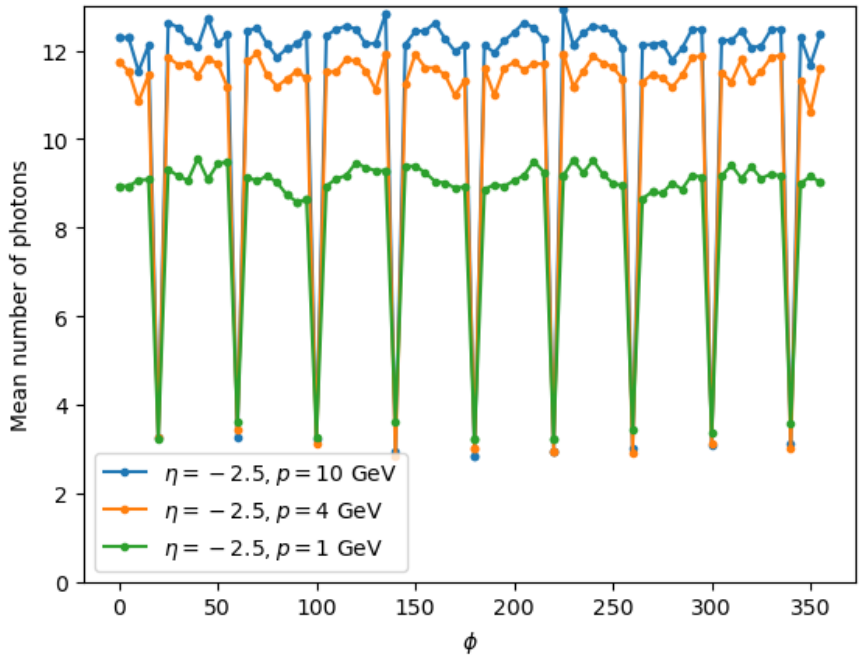

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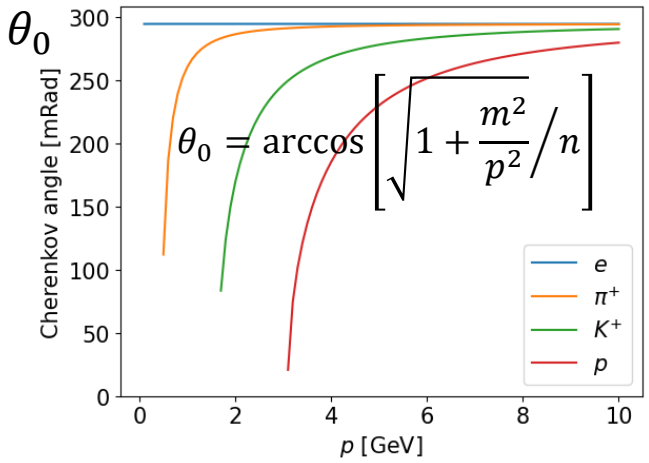
- Periodic efficiency drops due to aerogel support structure
- Mean N_γ higher for higher p
  - Expected from $N_\gamma = \frac{N_c(1-\frac{1}{\beta^2 n^2})}{1-\frac{1}{n^2}}$, where N_c is a constant dependent on detector geometry

From Cherenkov angle to PID

Theoretical expectation



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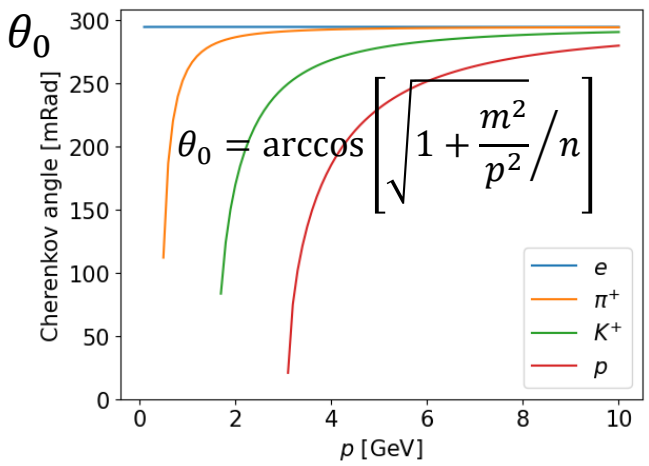
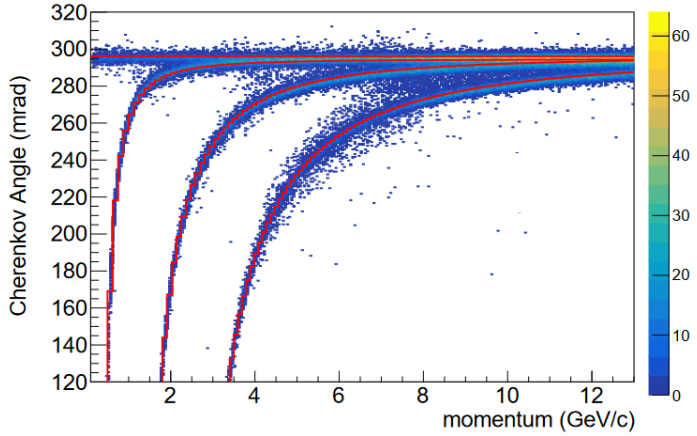


Reconstruction result from simulation



[Fig 4.8 (a), CDR]

→ Systematically determine particle type through a χ^2 analysis, with framework integrated in standalone software

From Cherenkov angle to PID

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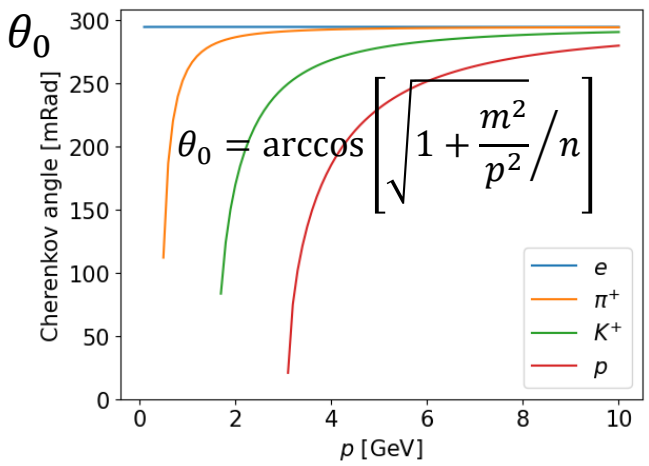

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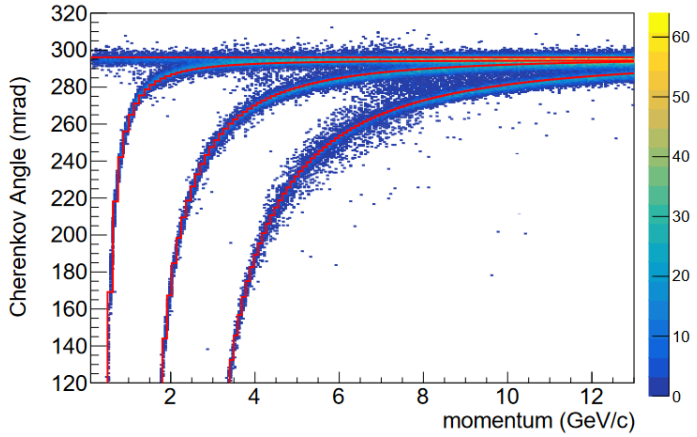
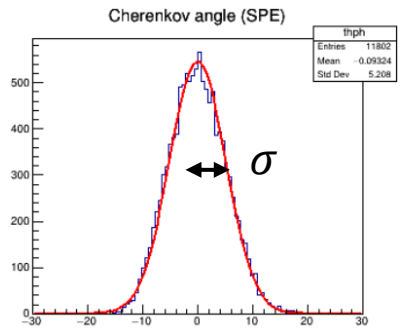


[Fig 4.8 (a), CDR]

→ Systematically determine particle type through a χ^2 analysis, with framework integrated in standalone software

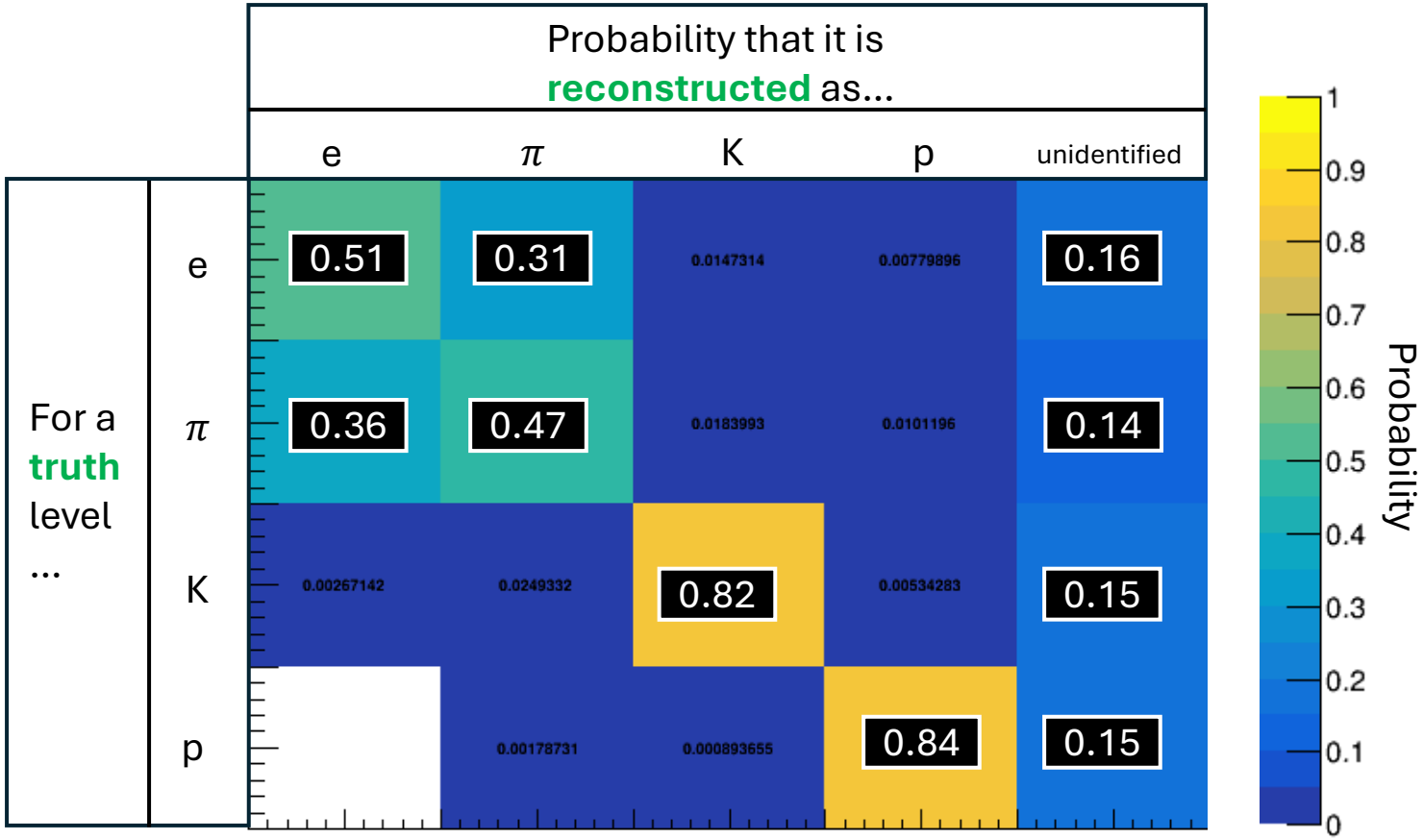
- Roughly, for single-particle events…
- Step 1. Determine if a photon hit is associated with the track, or is "background"
- Step 2. For each track, calculate for each PID hypothesis, $\chi^2 = \sum_{i\in\{hits\}}\left(\theta_{measured,i} - \theta_0\right)^2/\sigma^2$
  - θ_0 is the expected angle for the given PID hypothesis
  - σ is the single photon Cherenkov angle resolution
- Step 3. Find the PID hypothesis that **minimizes χ^2**



Quantifying PID performance: Look-up tables

For a given kinematic selection, what is the probability of correctly identifying PID?

E.g., $p \in (5.4, 5.8)$ GeV, $\eta \in (-2.10, -2.01)$, $\phi \in (0, 3)$ degrees



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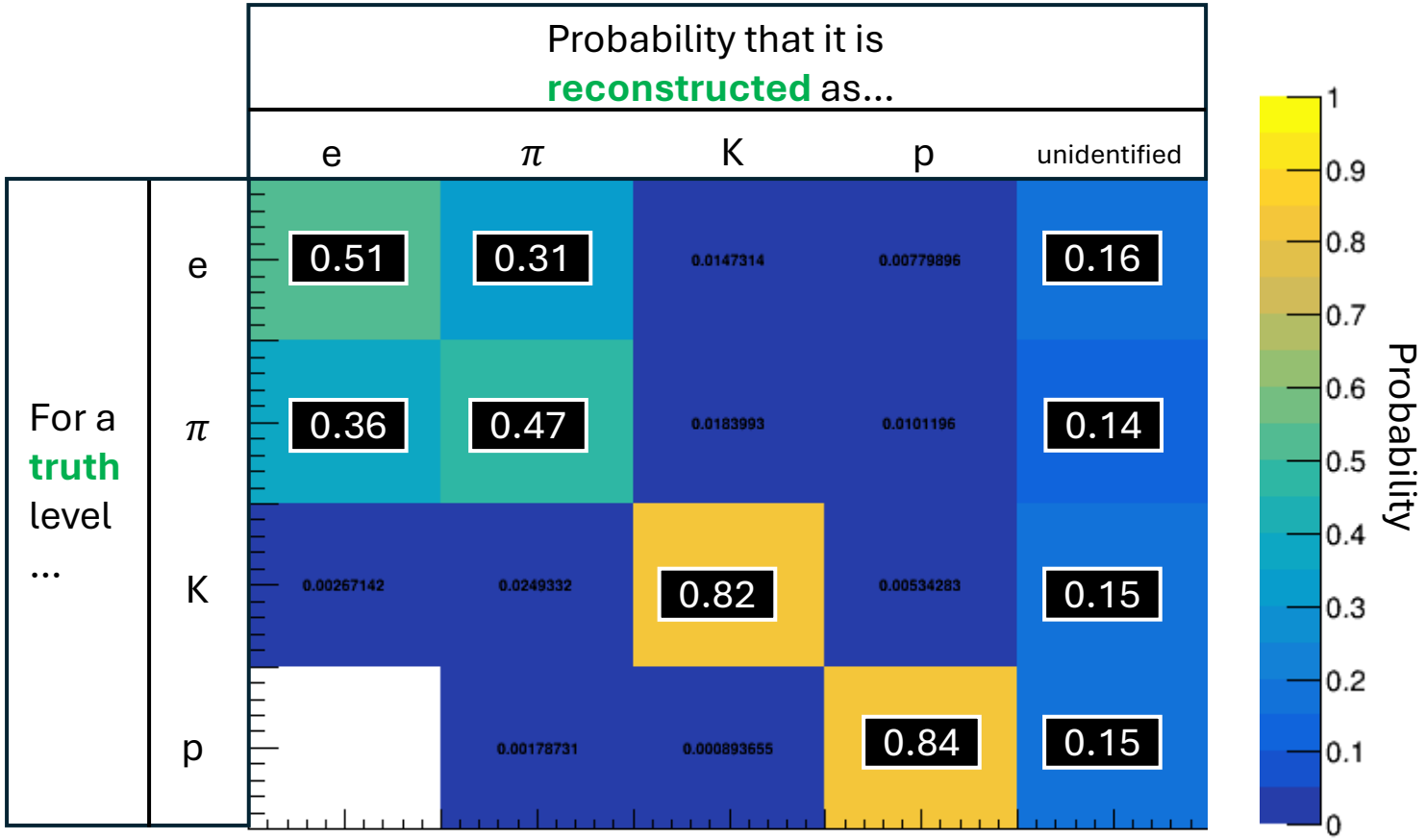

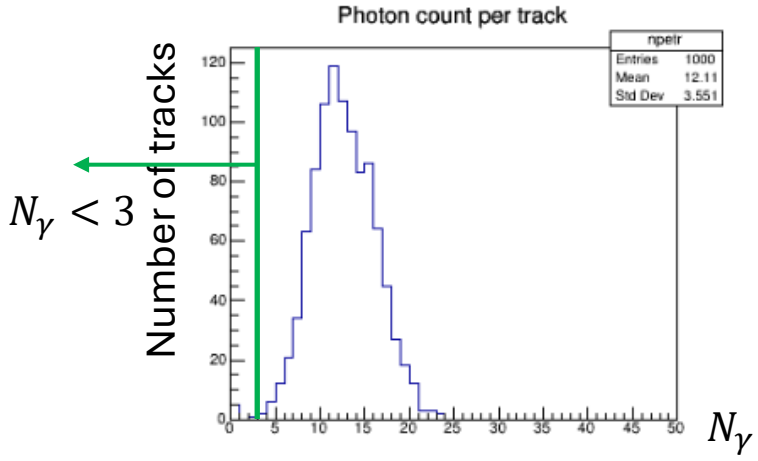

Note:

- Unidentified column for $N_\gamma < 3$, mostly from detector geometry
- $p > 3$ GeV, worse e/π separation

→ next step: have separate tables for e/h and π/K/p

Quantifying PID performance: Look-up tables

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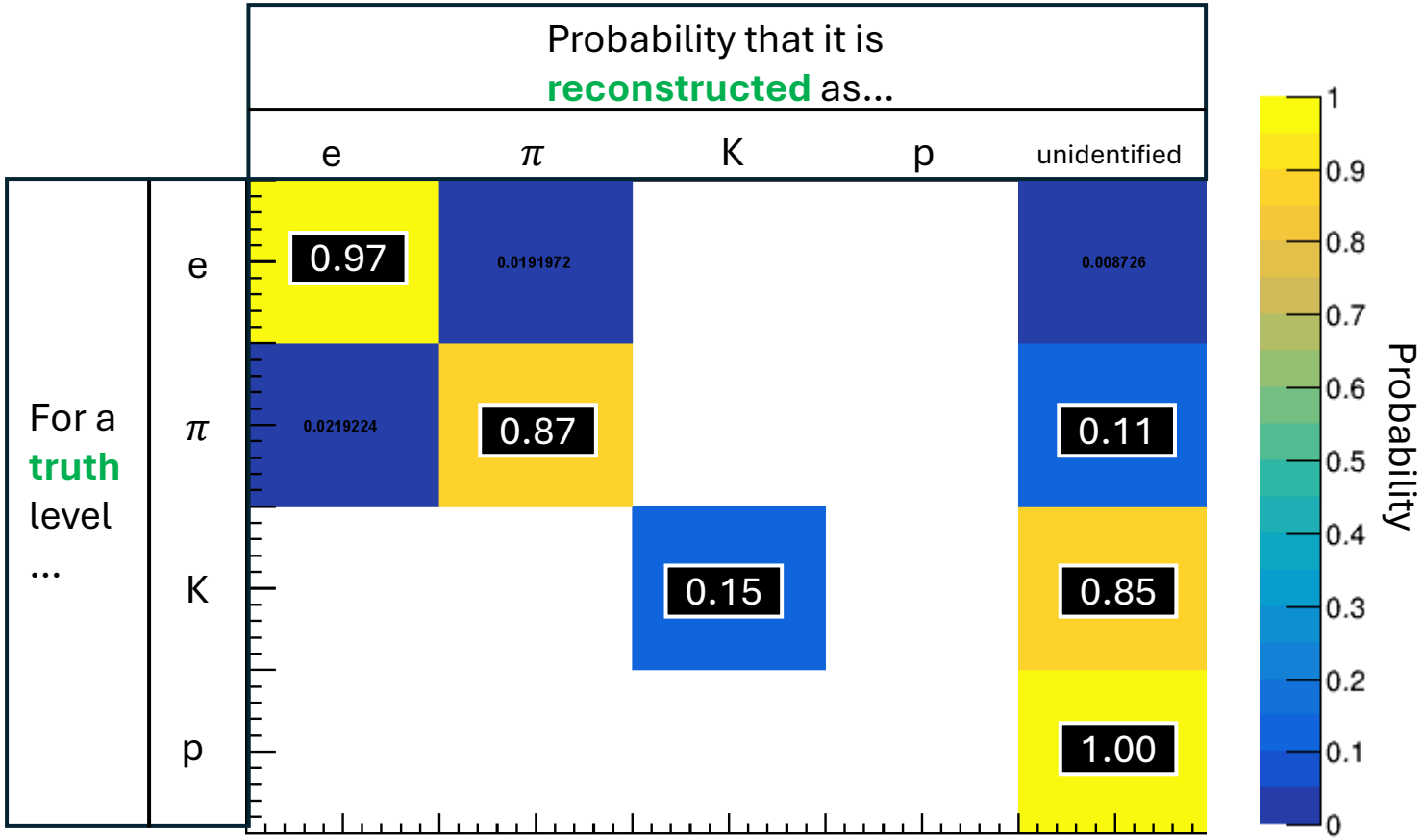

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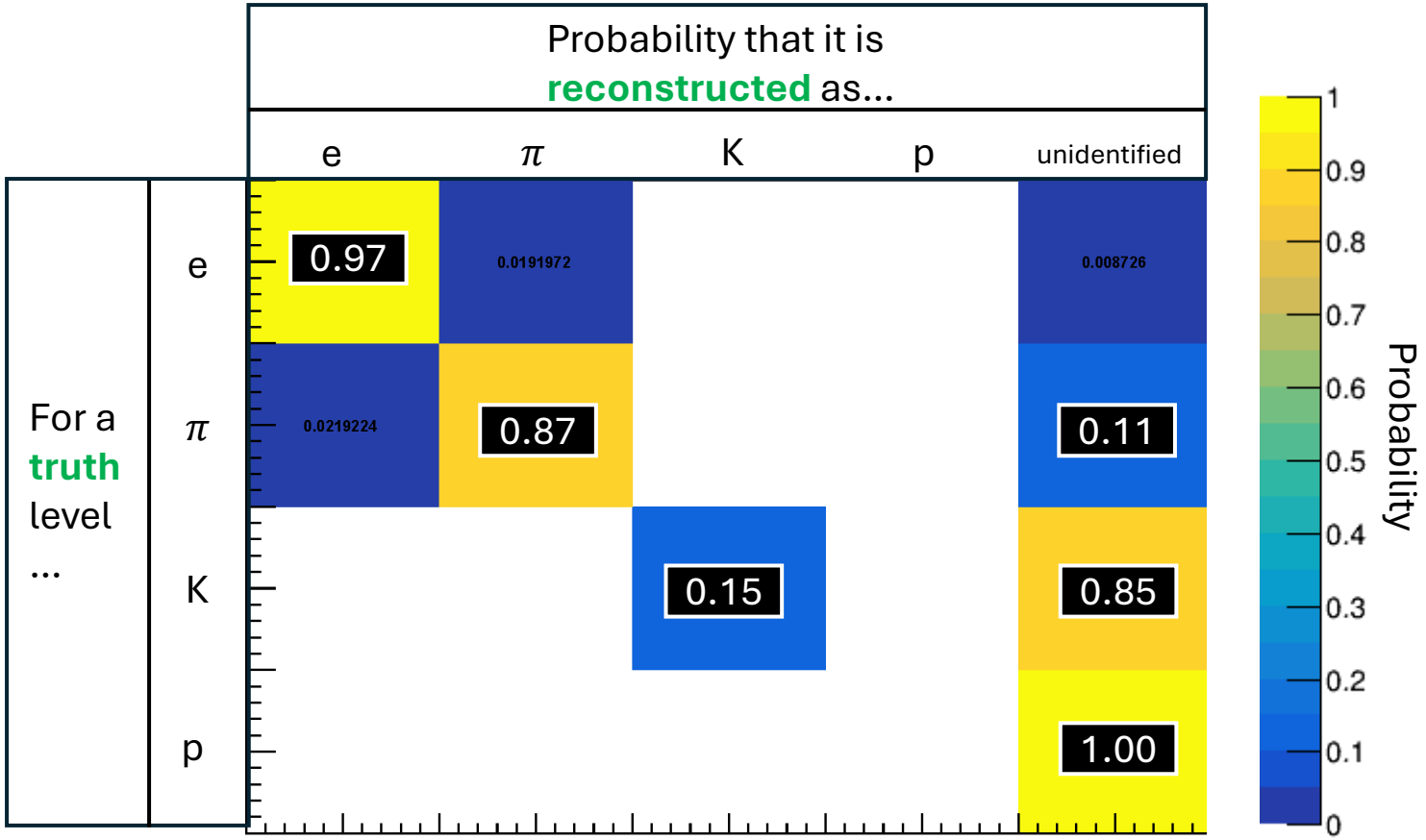


- We created 37x20x120 = 88800 histograms, covering
  - $p \in (0.1, 15)$ GeV
  - $\theta \in (2.65, 3.1) \rightarrow \eta \in (-3.87, -1.38)$
  - $\phi \in (0, 360)$ degrees

Highly differential!

- 400M single-particle events (100M e, π, K, p each)

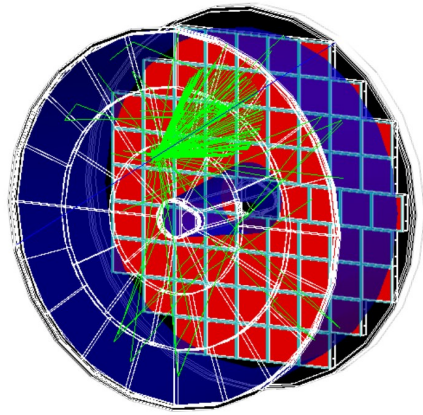
Large statistics!

- The latest tables: https://github.com/eic/epic-data/blob/main/pfrich.lut , made with the latest magnetic field map MARCO_v.7.6.2.2.11_1.7T, 2024_05_02

Conclusions

- pfRICH is **crucial for PID** in the e-going direction at ePIC
  - through detection and measurement of **Cherenkov photons** emitted by charged particles
- **Standalone software** offers flexibility for examining **detector features** and enables detailed studies of **detector performance**
- **Look-up table** with **fine binnings and large statistics** is available

Looking forward to feedback on the table from analysis teams!



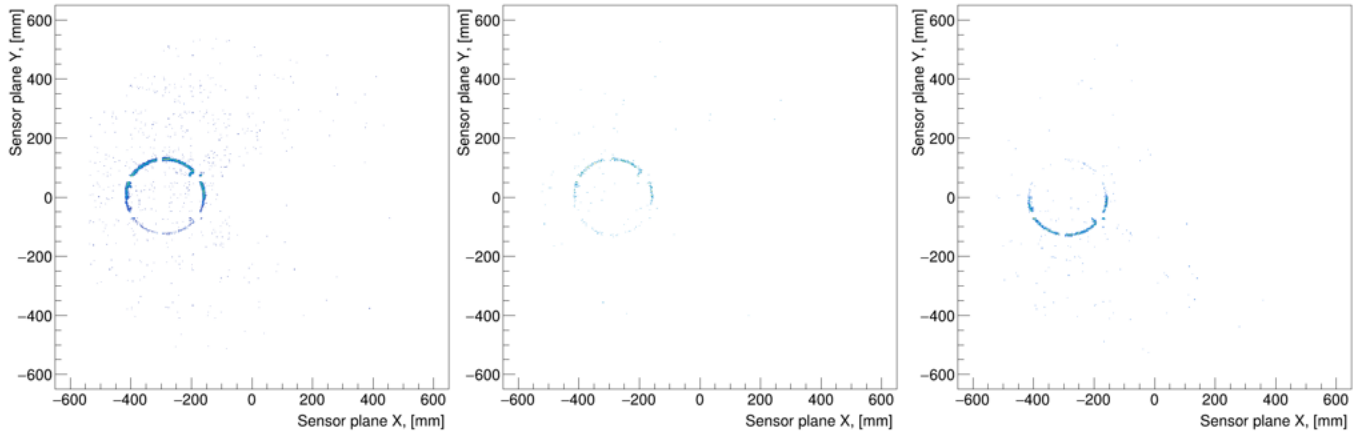
Backup

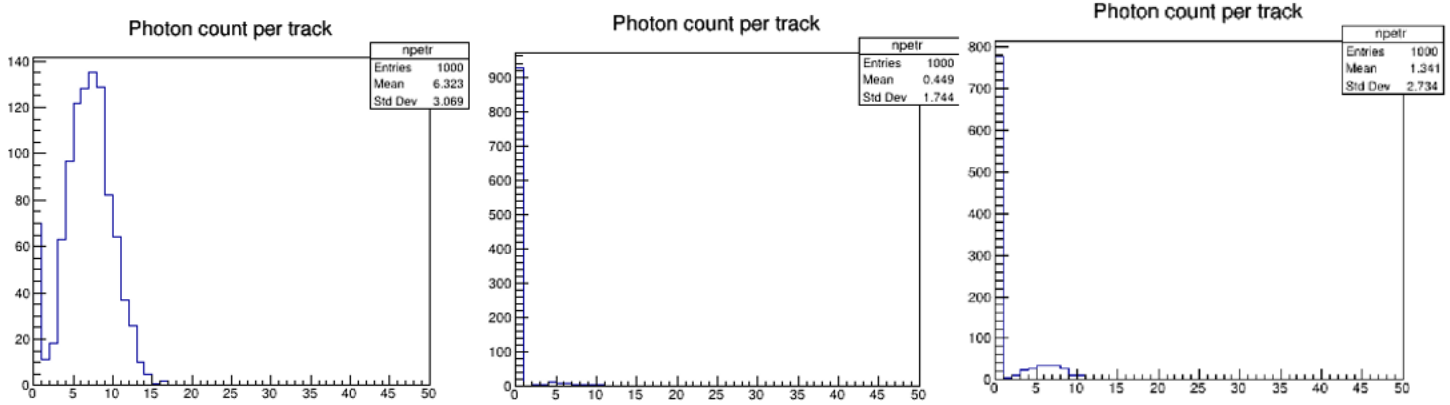
Efficiency vs azimuthal angle

E.g, $p = 10$ GeV, $\eta = -2.5$

1000 single-π^+ events for each ϕ range

$\phi \in (179.9,180)$ $\phi \in (180,180.1)$ $\phi \in (180.1,180.2)$

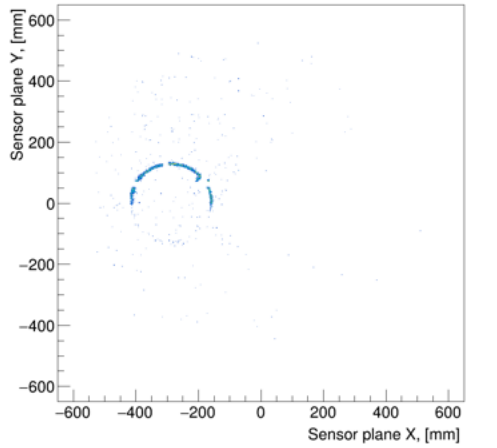


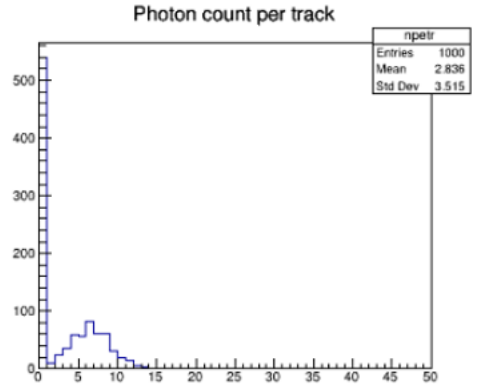


Mean = 6.3 Mean = 0.44 Mean = 1.3

From last time:

$\phi = 180$



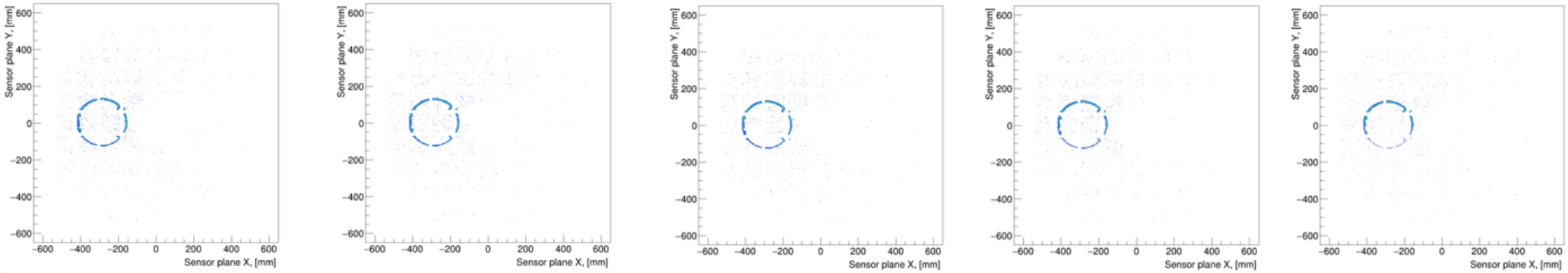


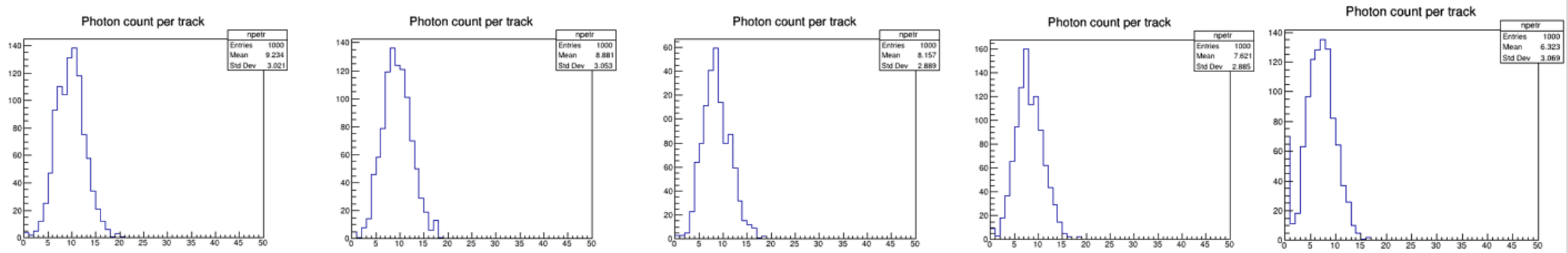
Mean = 2.8

Efficiency vs azimuthal angle

$p = 10$ GeV, $\eta = -2.5$

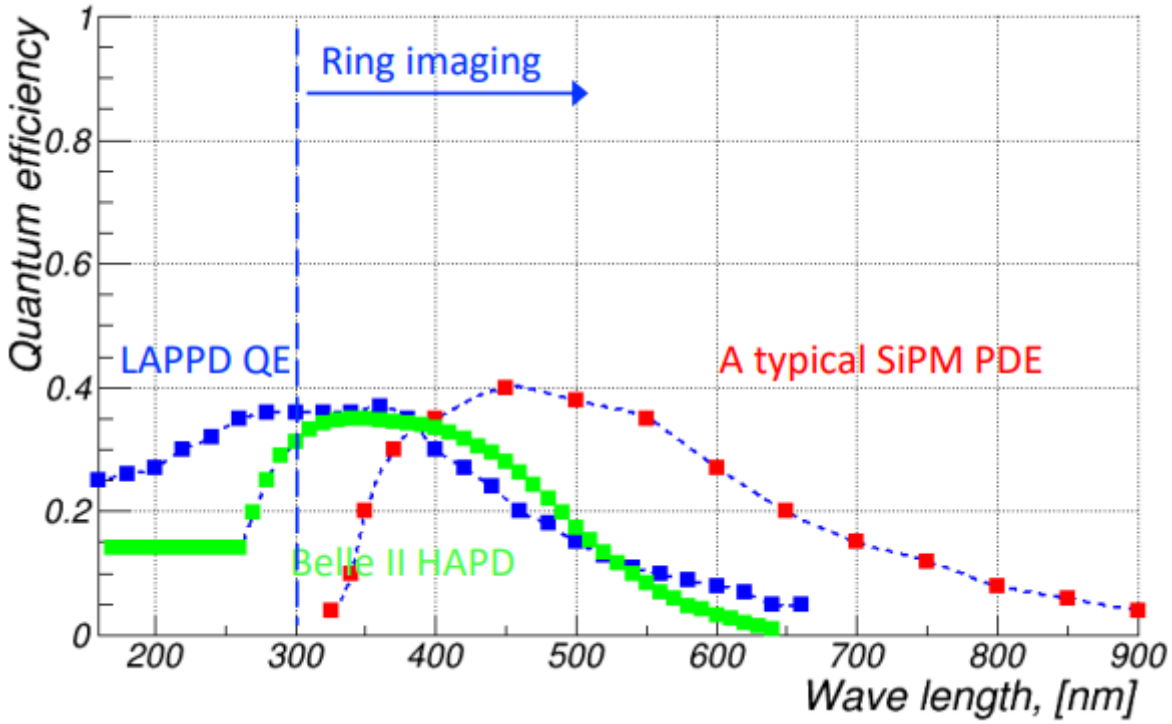
$\phi \in (179.5,179.6)$ $\phi \in (179.6,179.7)$ $\phi \in (179.7,179.8)$ $\phi \in (179.8,179.9)$ $\phi \in (179.9,180)$





Mean = 9.2 Mean = 8.8 Mean = 8.2 Mean = 7.6 Mean = 6.3

QE vs wavelength



Talk by Alexander Kiselev at HADRON 2023