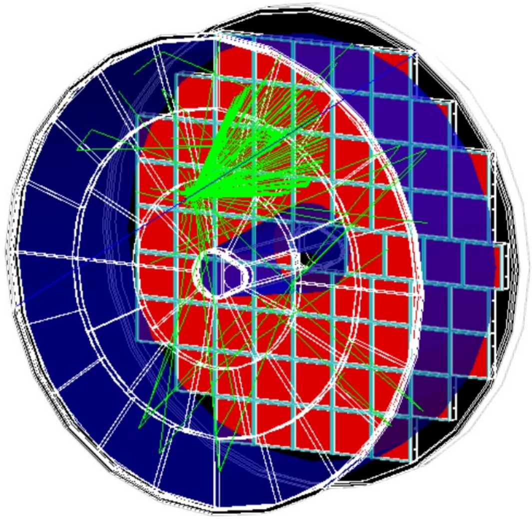
Particle identification performance studies with pfRICH simulations

Youqi Song (youqi.song@yale.edu)

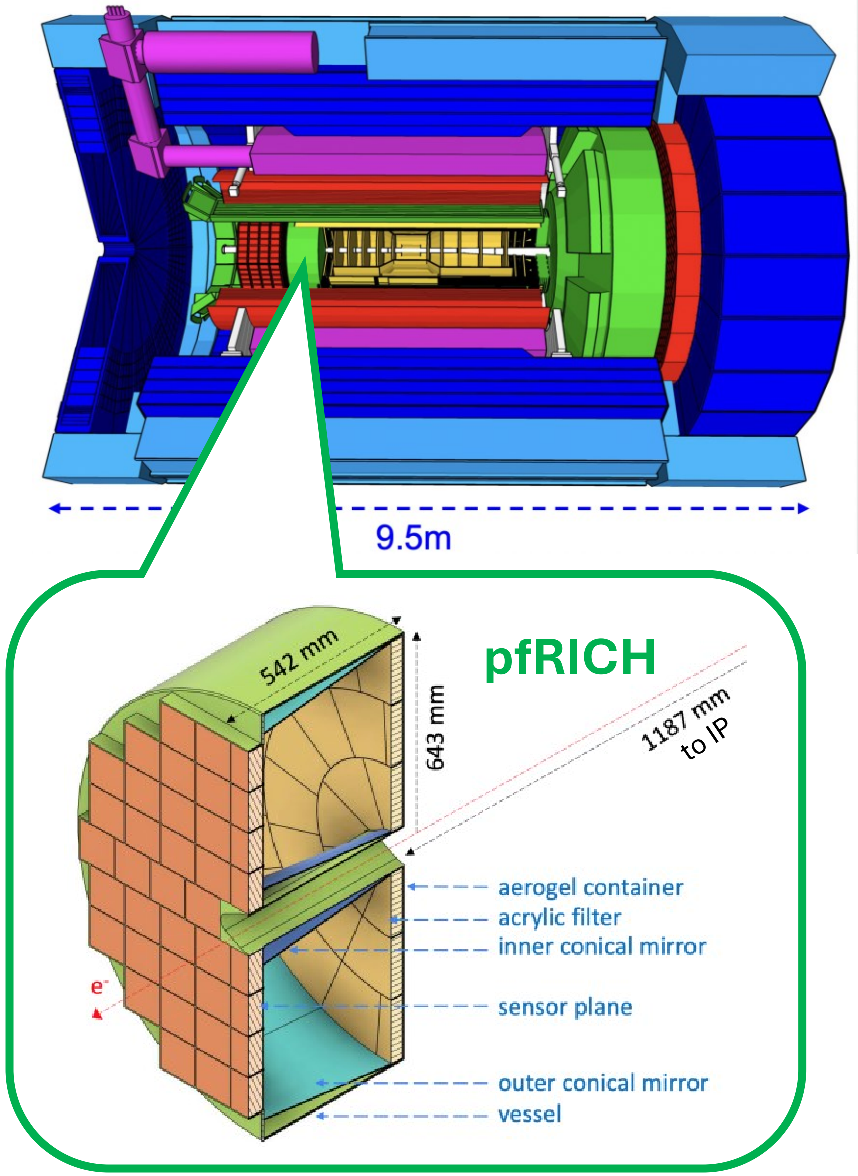
07/22/2024

EIC User Group Early Career Workshop



Supported in part by U.S. DEPARTMENT OF ENERGY Office of Science

Overview of pfRICH



pfRICH (proximity-focusing Ring Imaging CHerenkov)

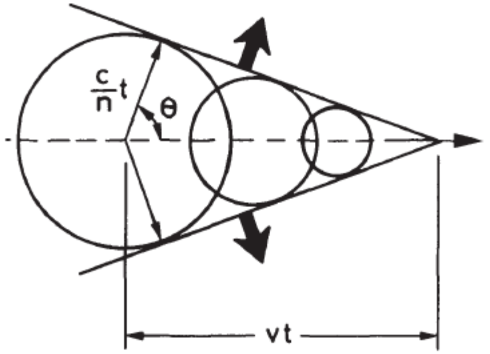
- Crucial for **PID in the e-going direction** in $-3.5 < \eta < -1.5$
  - Excellent separation power up to 9 GeV:

competing particle species	separation range (GeV/c)
e *vs* π/K/p	∼0.2 ÷ ∼2.5
K *vs* π/p	∼ 2.0 ÷ ∼9.0

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

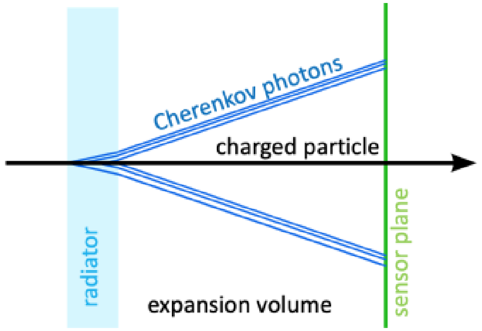
$$\cos \theta_C = \frac{1}{\beta n(\omega)}$$

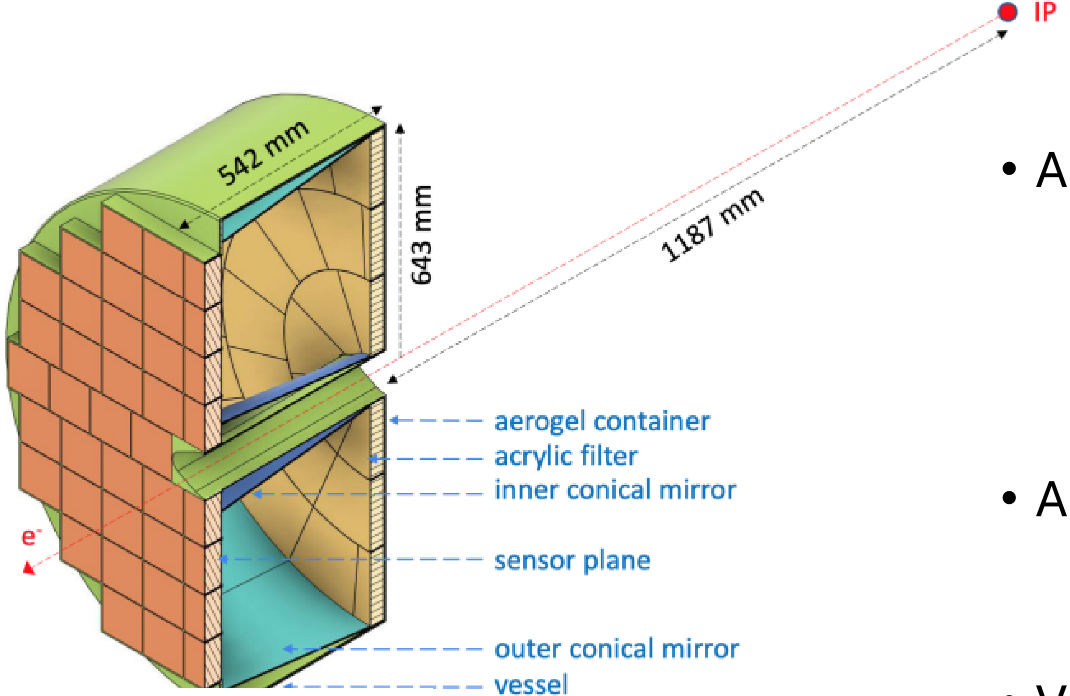
"electromagnetic shock wave"

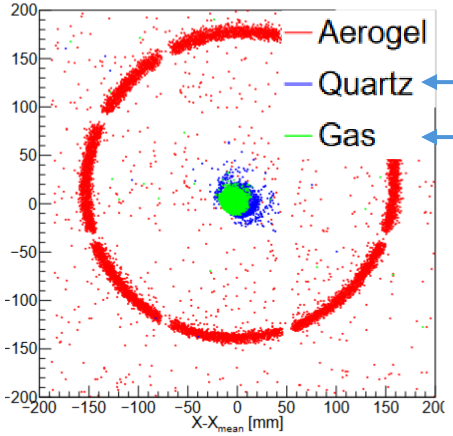


- pfRICH also has potential application as a timing detector

Path of a Cherenkov photon







from HRPPD window

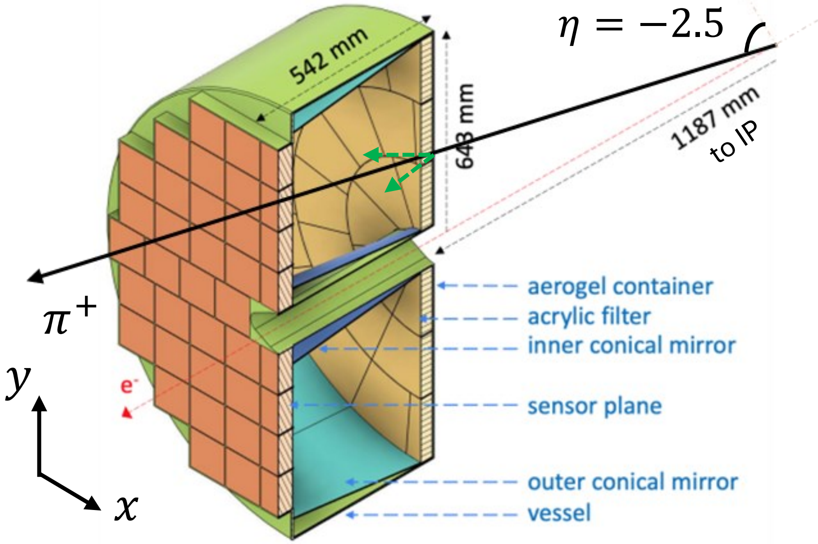
from expansion volume

[Fig 7.3 (a), CDR]

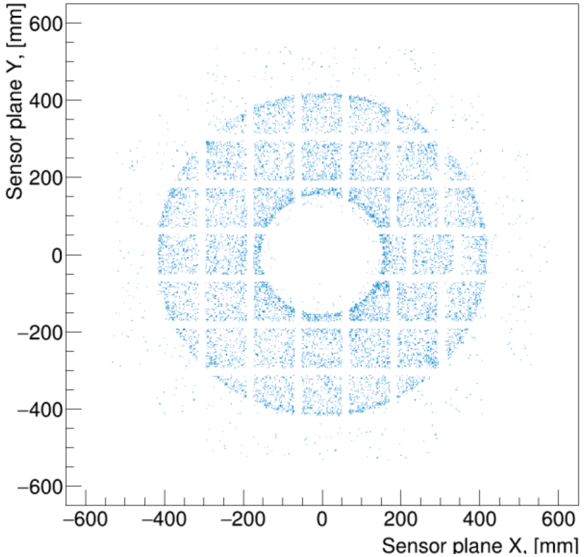
Multiple sources of Cherenkov photons. Aerogel photons are used for PID (today's focus)

- Aerogel
  - "**Radiator**": Cherenkov photons produced here
  - 2.5 cm thick, 42 tiles
    - Thinner aerogel improves angle resolution
    - Thicker aerogel increases number of photons
- Acrylic layer
  - **Filters** out photons with wavelength > 300 nm
    - Minimize dependency on $n(\omega)$
- Vessel
  - Encloses the 45 cm long "**expansion volume**": Cherenkov photons travel through here
    - Large gap improves angle resolution
- Sensor plane
  - **Detects** the photons and amplifies the signals
  - 68 HRPPD (High Rate Picosecond Photo Detectors) sensors

“Imaging” sensor plane

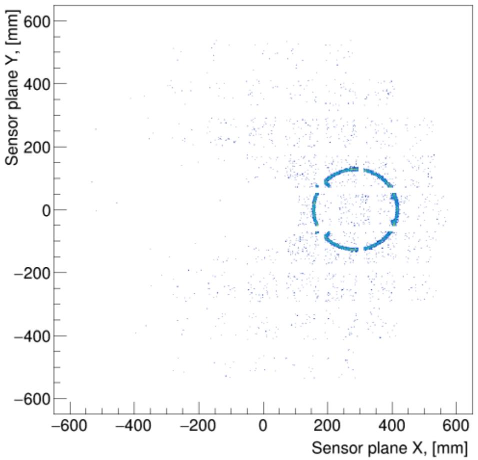


- Study pfRICH performance with standalone software https://github.com/eic/pfRICH
- E.g., “imaging” part of the HRPPD sensor plane

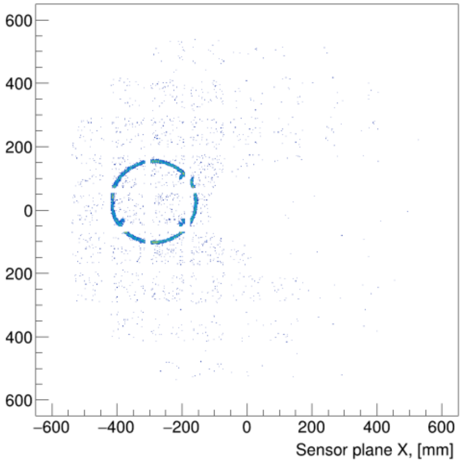


1000 single-particle events, $\pi^+, p = 10\ \mathrm{GeV}, \eta = -2.5$

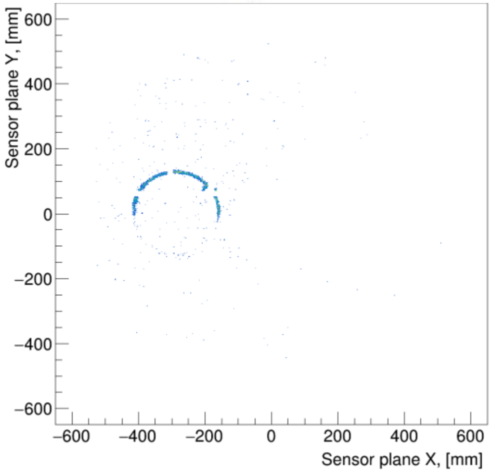
$\phi \in [0{,}360)$



$\phi = 0$



$\phi = 175$



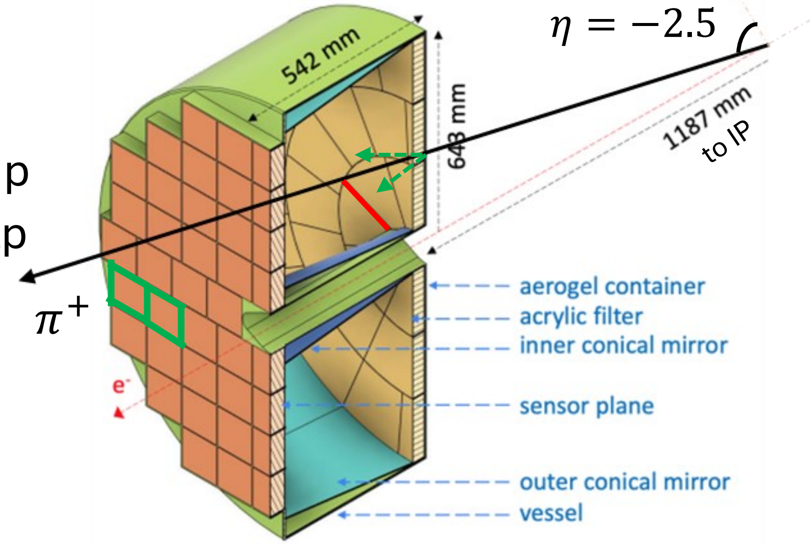
$\phi = 180$

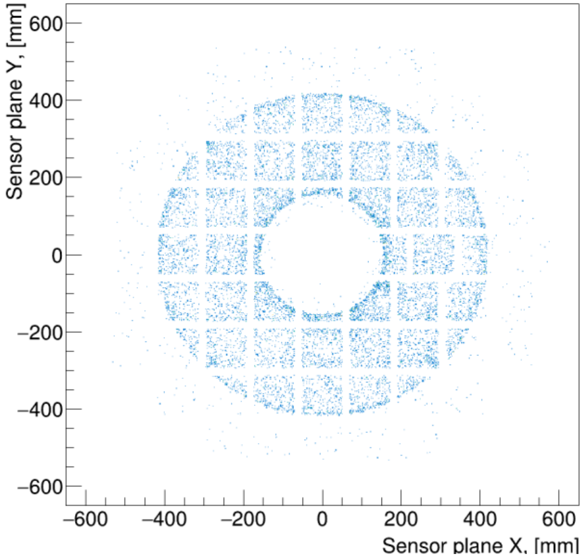
“Imaging” sensor plane

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

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

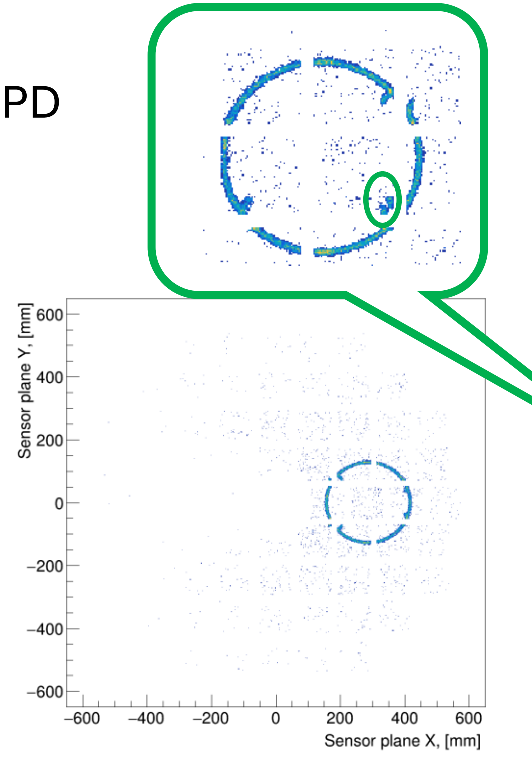
- Check other features of the setup
  - “Pyramid” mirrors help reconstruct photons lost in gaps between HRPPD tiles



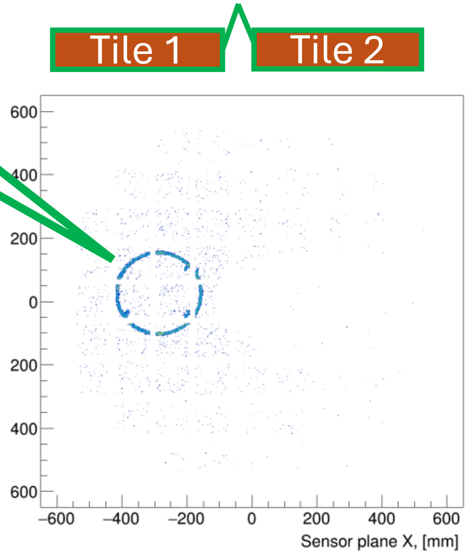


1000 single-particle events,
$\pi^+, p = 10\text{ GeV}, \eta = -2.5$

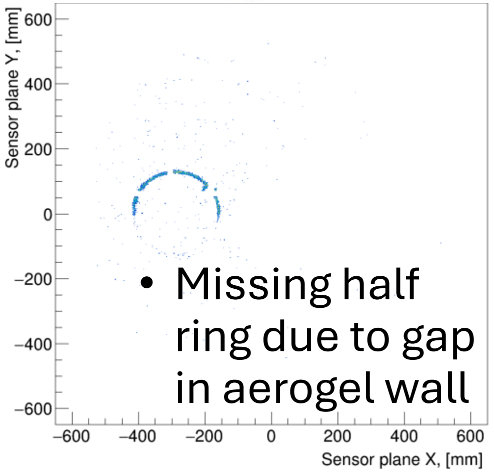
$\phi \in [0{,}360)$



$\phi = 0$



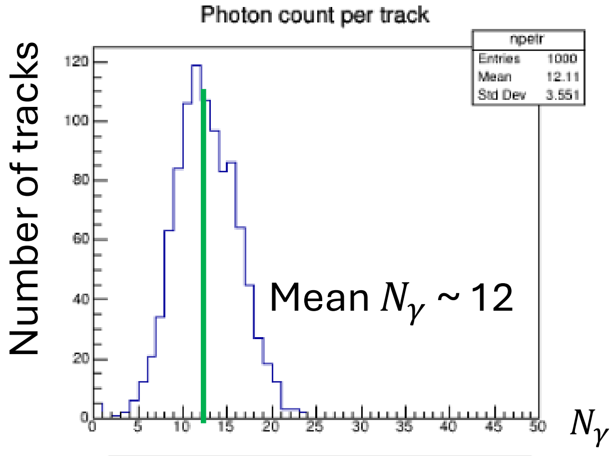
$\phi = 175$

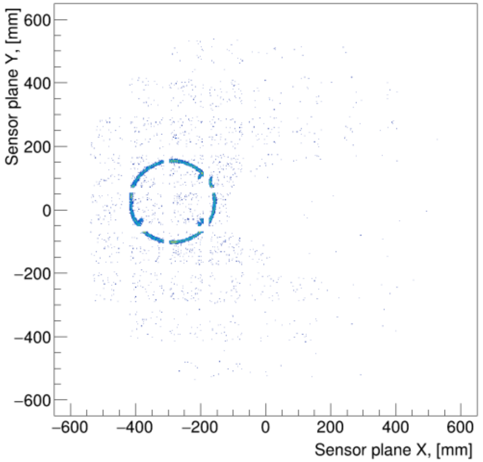


- Missing half ring due to gap in aerogel wall

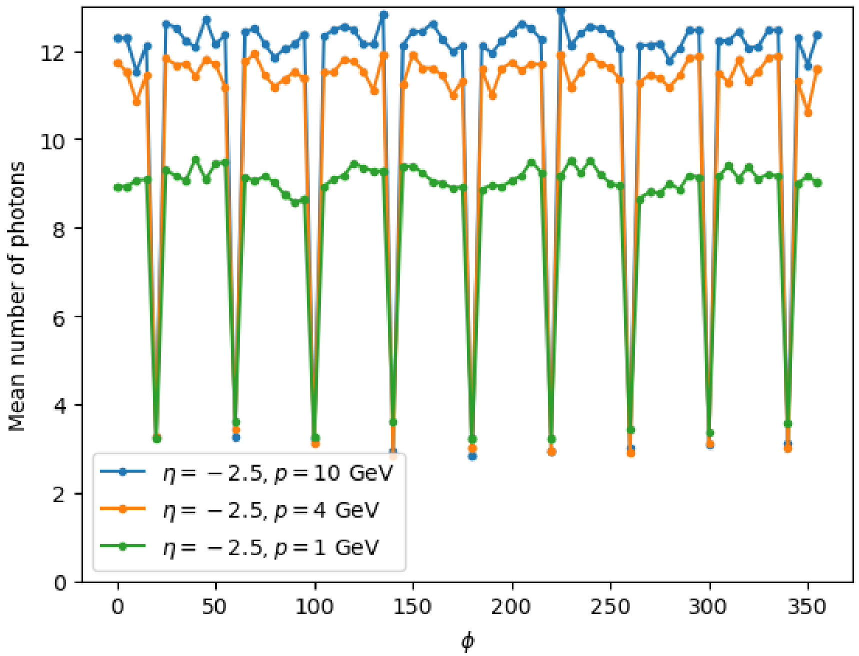
$\phi = 180$

Efficiency vs azimuthal angle





$\phi = 175$



1000 single-particle events for each ϕ value, $\pi^+, p = 10\ \mathrm{GeV}, \eta = -2.5$

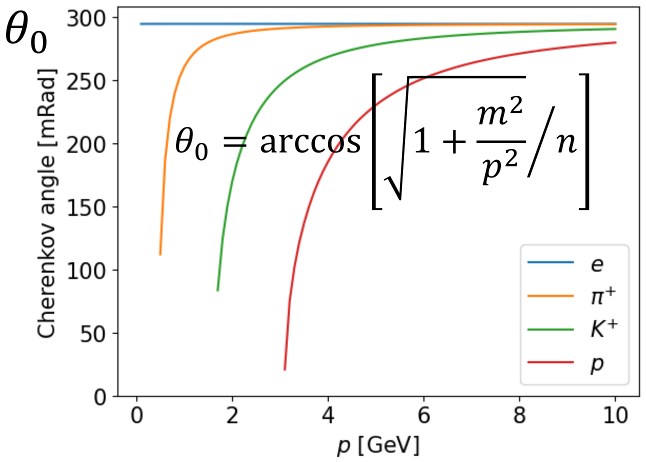
- Periodic efficiency drops due to aerogel support structure
- Mean N_γ higher for higher p
  - Expected from

$$N_\gamma = \frac{N_c\left(1 - \frac{1}{\beta^2 n^2}\right)}{1 - \frac{1}{n^2}},$$

where N_c is a constant dependent on detector geometry

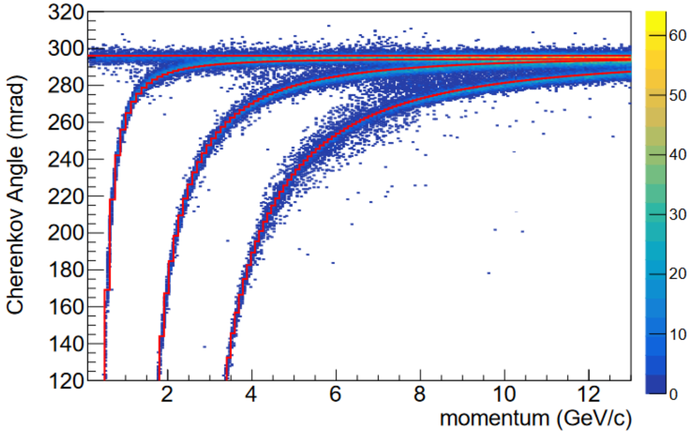
From Cherenkov angle to PID

Theoretical expectation



$$\theta_0 = \arccos\left[\sqrt{1+\frac{m^2}{p^2}}\Big/n\right]$$

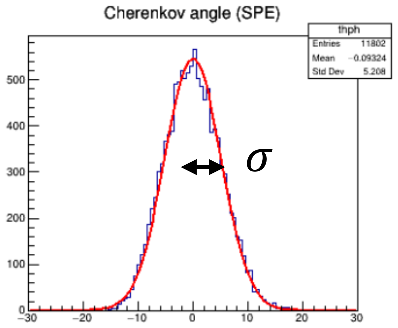
Reconstruction result from simulation



[Fig 4.8 (a), CDR]

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

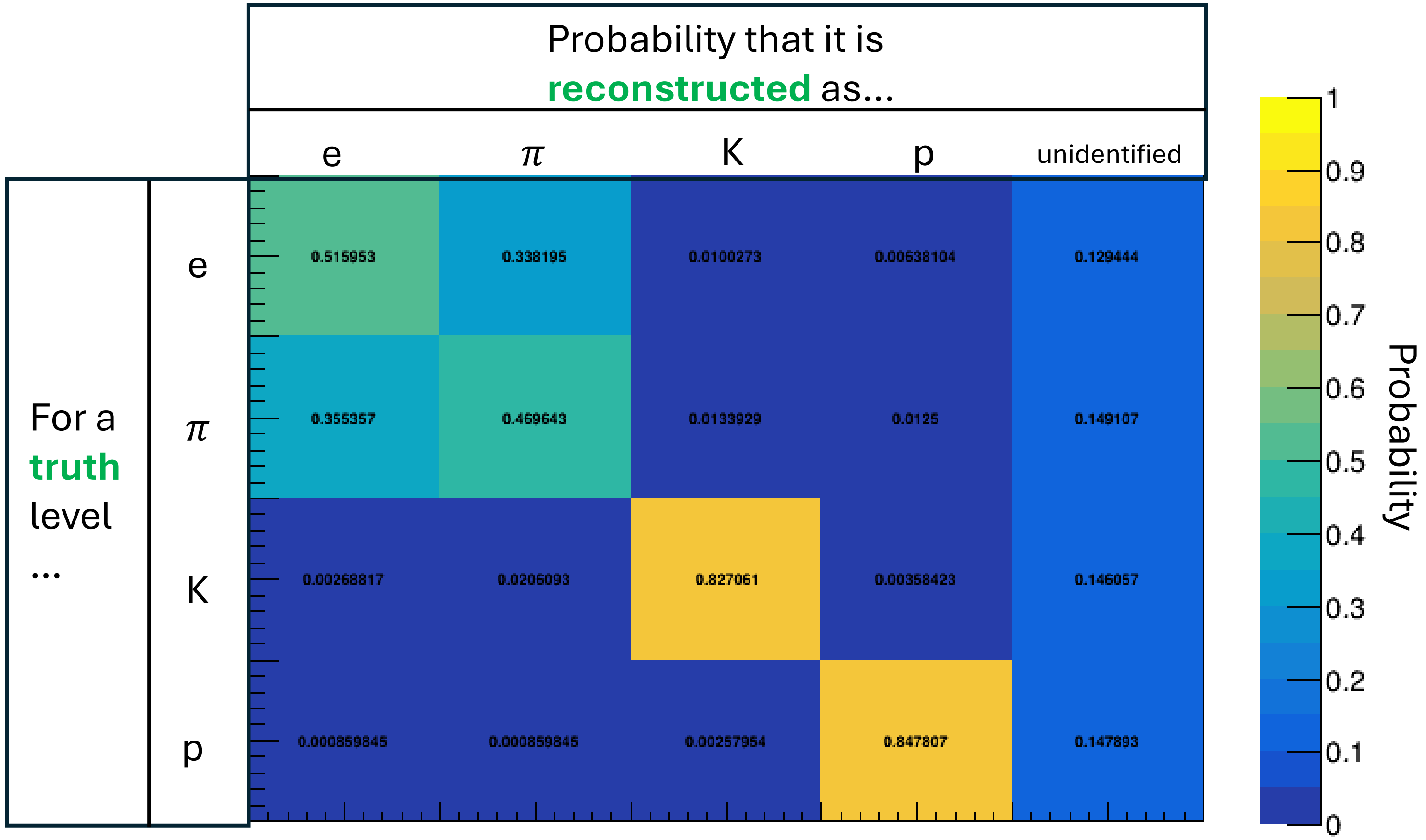
- Roughly, for single-particle events…
- Step 1. Determine if a hit is associated with the track, or is "background"
- Step 2. For each track, calculate for each PID hypothesis, $\chi^2 = \sum_{i\in\{hits\}}\left(\theta_{measured,i} - \theta_0\right)^2/\sigma^2$
  - θ_0 is the expected angle for the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



Quantifing 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


Probability that it is **reconstructed** as…

For a **truth** level …

	e	π	K	p	unidentified
e	0.515953	0.338195	0.0100273	0.00638104	0.129444
π	0.355357	0.469643	0.0133929	0.0125	0.149107
K	0.00268817	0.0206093	0.827061	0.00358423	0.146057
p	0.000859845	0.000859845	0.00257954	0.847807	0.147893

Note:

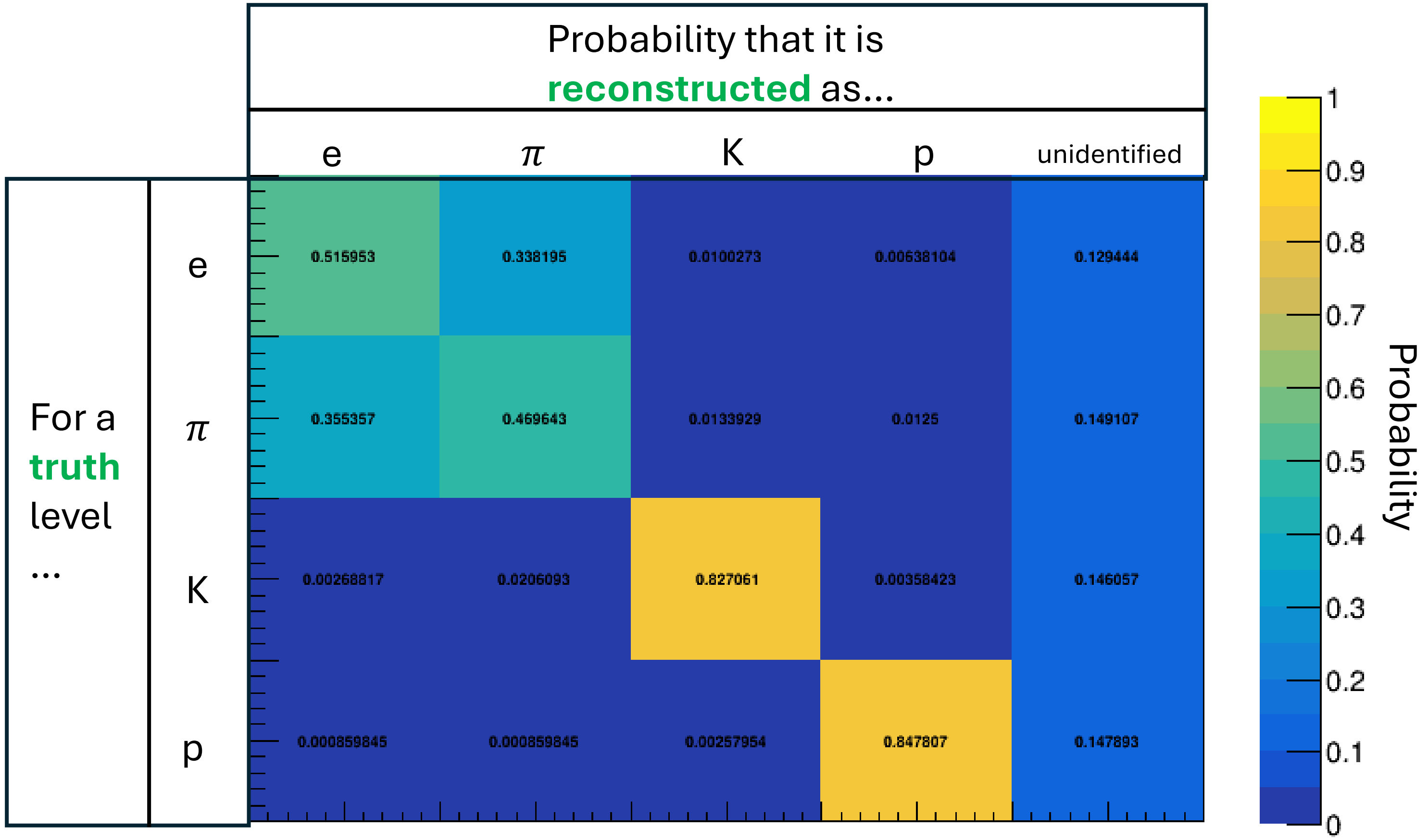
- Unidentified column for $N_\gamma < 3$, mostly from detector geometry
- For $p > 3$ GeV, combine e and π

→ next step

Quantifing 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



		Probability that it is **reconstructed** as…				
		e	π	K	p	unidentified
For a **truth** level …	e	0.515953	0.338195	0.0100273	0.00638104	0.129444
	π	0.355357	0.469643	0.0133929	0.0125	0.149107
	K	0.00268817	0.0206093	0.827061	0.00358423	0.146057
	p	0.000859845	0.000859845	0.00257954	0.847807	0.147893

- We created 37x20x120 = 88800 tables, 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 per table (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 electron-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 tables** with **fine binnings and large statistics** are available

Looking forward to feedback on the tables from analysis teams!