Status of LUT for PID Detectors

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TIC Meeting (Zoom)
April 15, 2024

Brookhaven National Laboratory

Reminder

- PID groups are in the process of implementing their original ‘stand-alone’ simulation and reconstruction software in EICrecon
- Process takes time and might not be fully completed (and tested) in time for the simulation needed for the TDR
- Only way out is to handle the reconstruction/simulations externally and create lookup tables for the TDR analyses

Summary of discussion among PID & S&C & many more

1. The PID lookup mechanism is a temporary patch, while the long-term goal is the job of developing a full PID reconstruction as part of EICrecon. The goal of the PID lookup mechanism to provide a first order approximation to make possible the usage of PID information in the analysis and physics studies in the short-term perspective.
2. The PID lookup mechanism will be integrated in EICrecon. The respective 'factory' and data structures are already or will be made available by the S&C group.

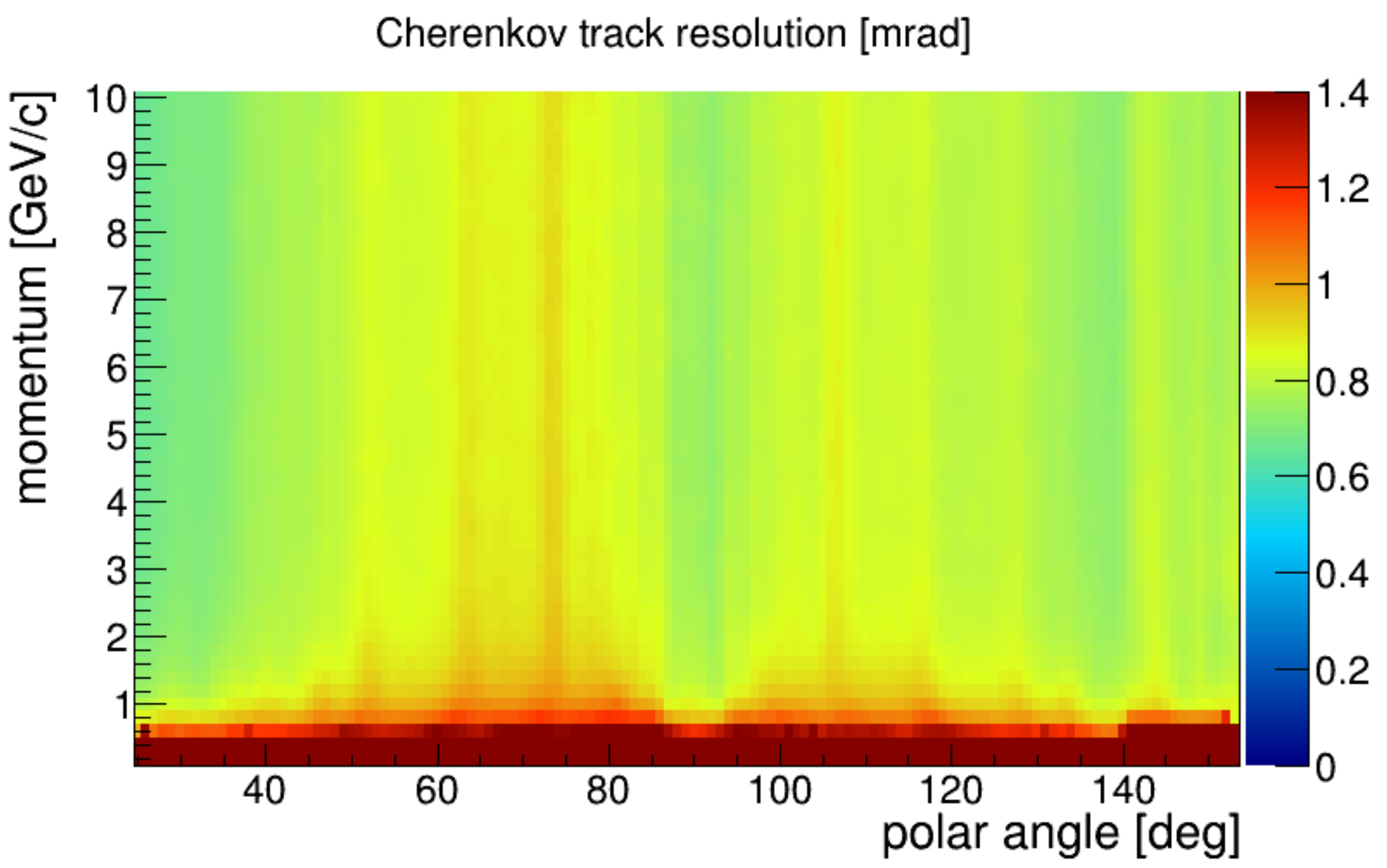
Reminder (continued)

3. The S&C group will create an example for the DSCs to guide their specific efforts
4. The PID info is to be created as a function of the following kinematic variables: p (GeV), η, φ (rad), q; with q either +1 or -1 depending on the charge of the particle. The variables are defined at the vertex.
    1. Comment: To define the kinematics at the vertex is easier to implement than at the entry point to the PID system. One would need additional xyz positions to implement the η,φ dependence.
5. The particles range to cover are: π, K, p, e, null; here 'null' means that no PID information is available; this is rather implementation specific and the easiest approach should be chosen by the implementer.
6. The DSCs have to provide weights/probabilities of the form: Pij(p, η, φ, q) where i is the generated particle type (π, K, p, e) and j is the hypothesis where j is one of π, K, p, e of course.
    1. Comments: as of now, the P is meant as a normalized probability, meaning Sum_over_j(Pij) = 1
    2. Comments: Further details to be given by the PID system. Any algorithm needs to be based on the detailed information of the detector system.
7. We will have to generate a random number according to the given Ps for a given i to make the final decision. This should be integrated into EICrecon.
8. A decision quality parameter was suggested to be provided along the PID result. While easily envisioned it is not at all straightforward to do in a statistically meaningful way. Possible addition at a later point.

hpDIRC

LUT PID for hpDIRC

Based on Cherenkov track resolution map obtained by using the full standalone Geant4 simulation and reconstruction



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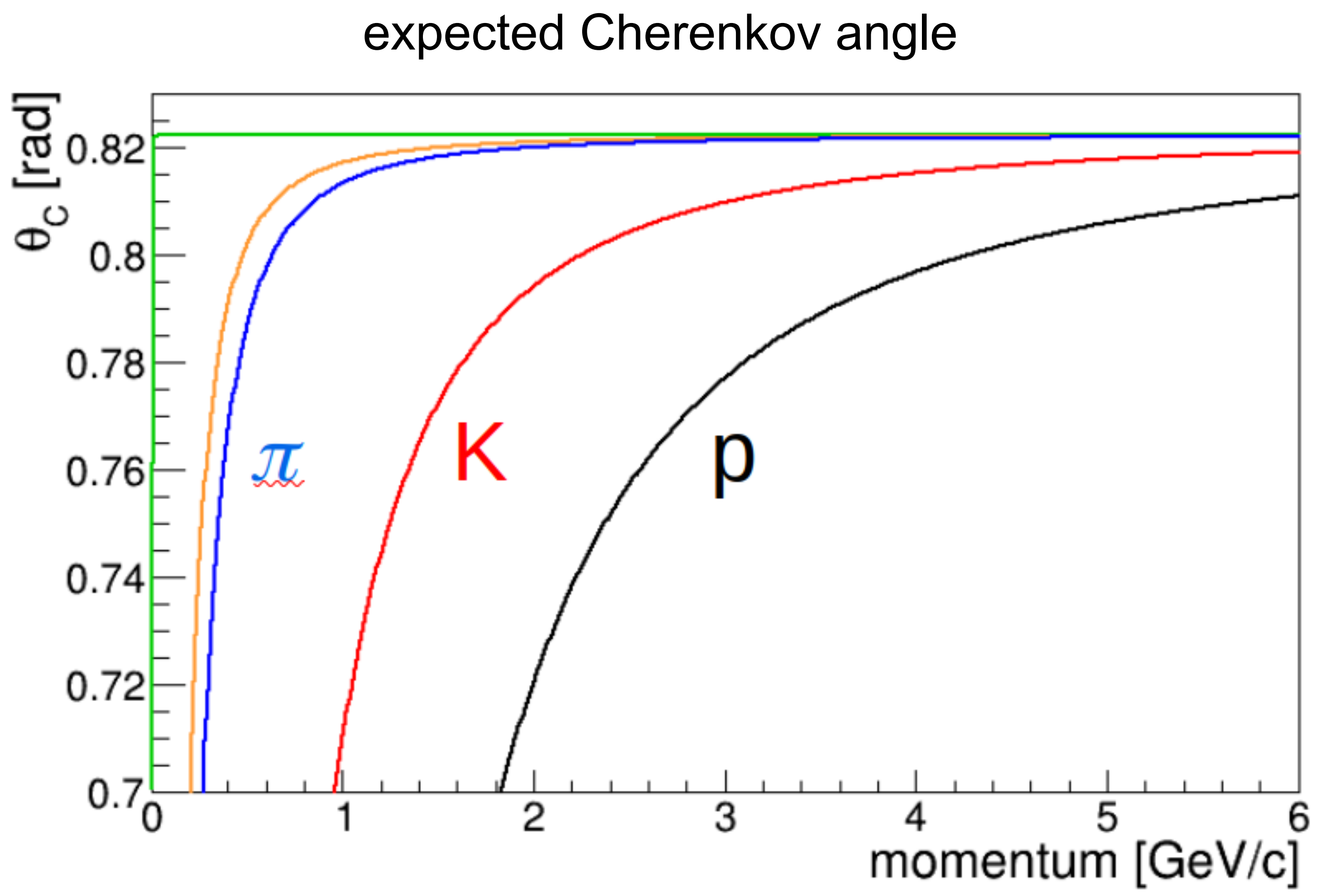
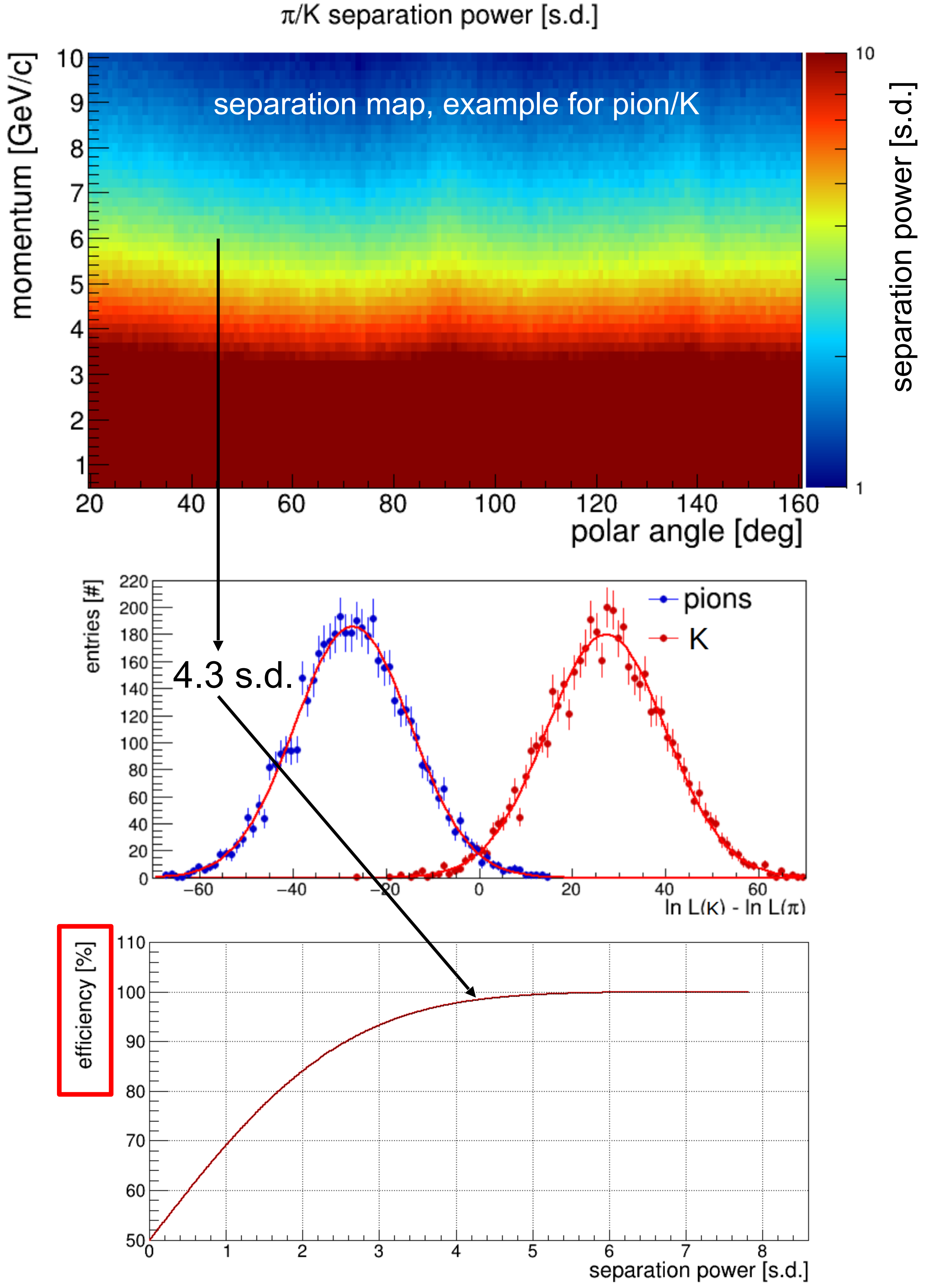
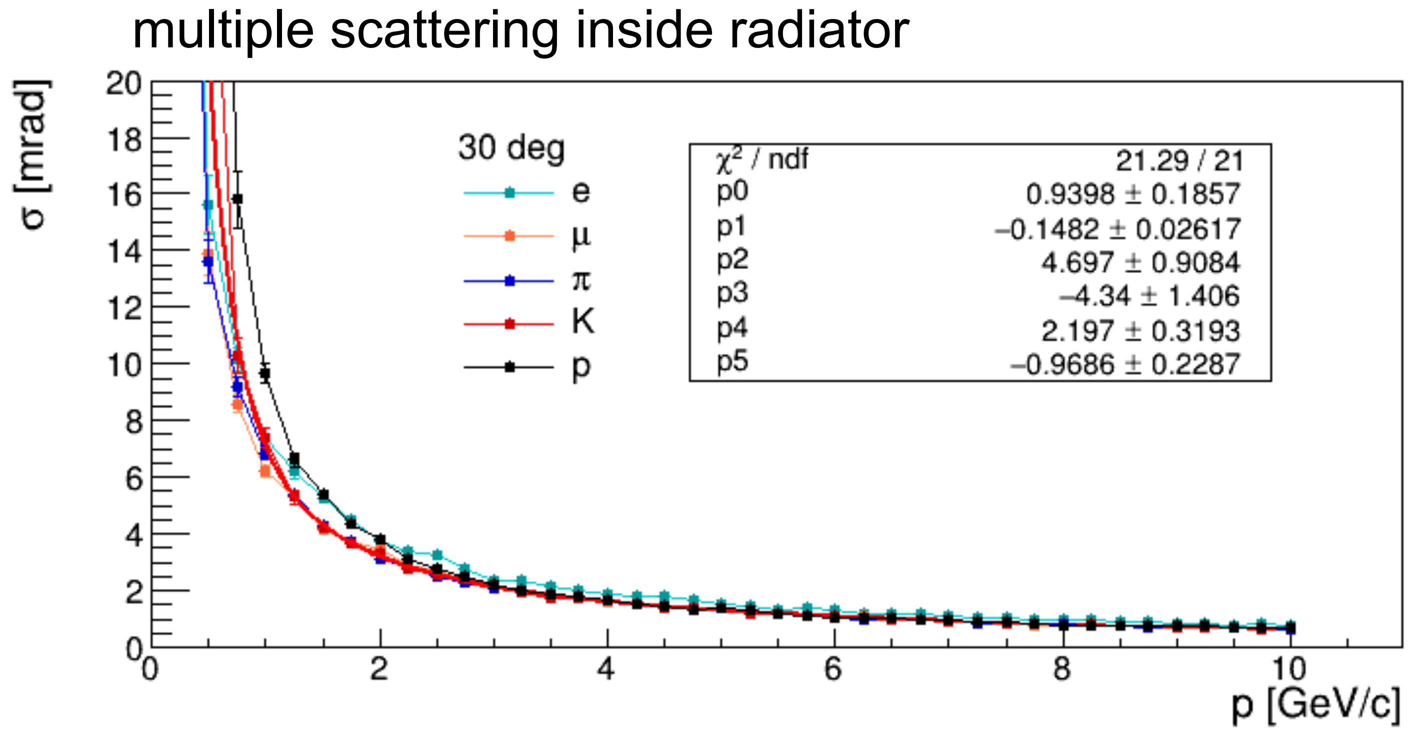
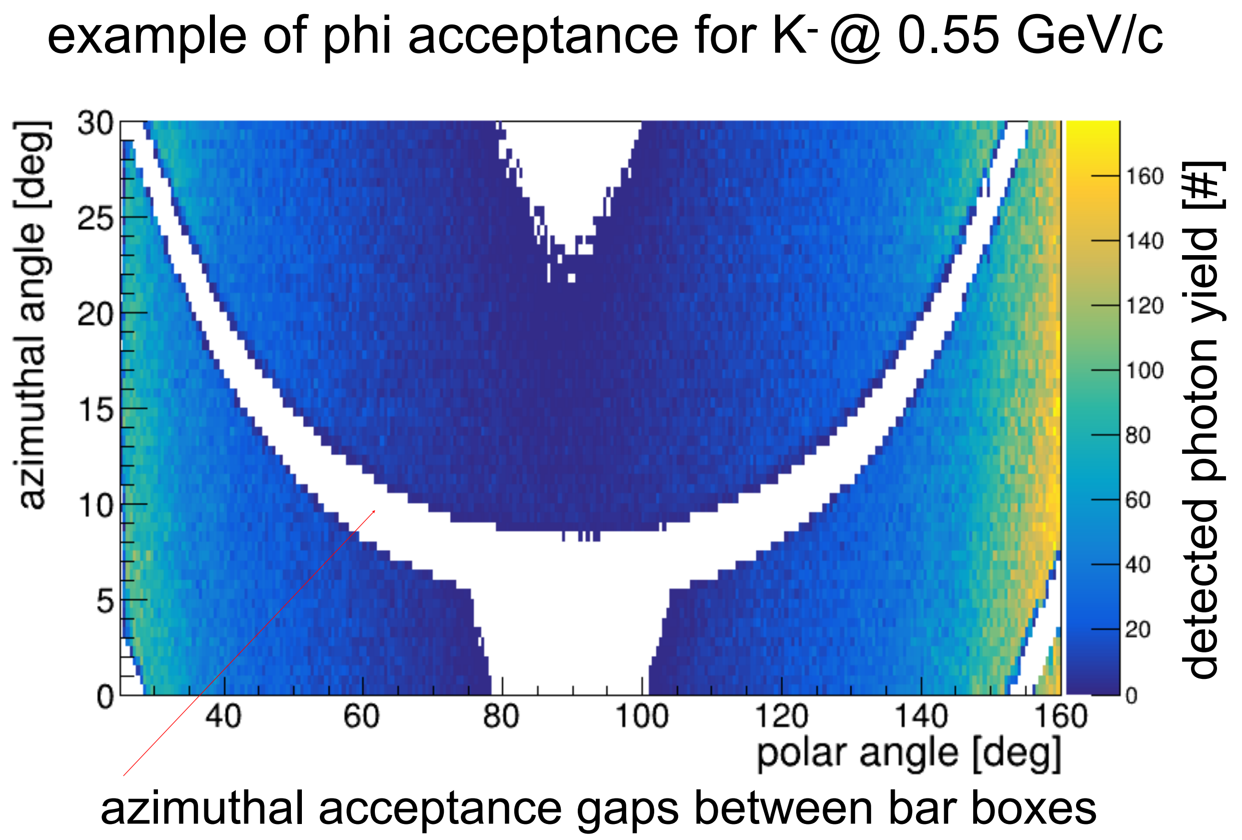




- uses 0.5 mrad tracking resolution combined with multiple scattering inside radiator
- accounts for azimuthal acceptance gaps
- includes threshold mode PID
- no backgrounds other than effects caused by primary particle





LUT PID for hpDIRC

The LUT in ASCII:

```
...
11 1 9.80 69.00 21.50 0.3932 0.3792 0.2150 0.0125
11 1 9.80 69.00 22.00 0.3894 0.3757 0.2202 0.0147
11 1 9.80 69.00 22.50 0.3945 0.3764 0.2170 0.0121
11 1 9.80 69.00 23.00 0.3933 0.3803 0.2146 0.0118
11 1 9.80 69.00 23.50 0.3929 0.3747 0.2186 0.0139
11 1 9.80 69.00 24.00 0.3919 0.3760 0.2185 0.0136
...
```

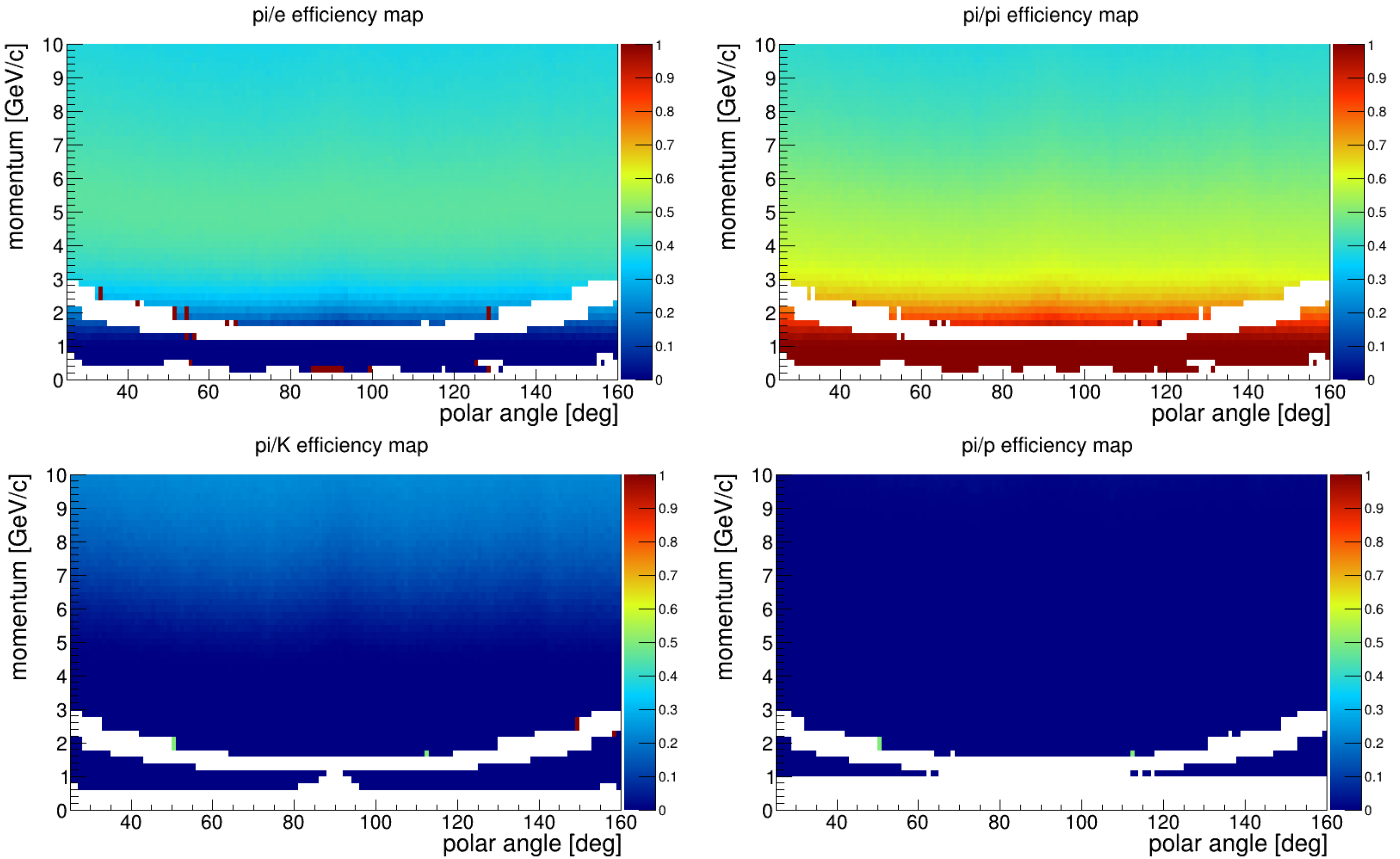
Full version is here:
https://github.com/rdom/fastpid/blob/master/hpdirc_fastpid.tar.gz

Description of PID LUT's columns:

1) PDG code of the particle (e 11, pi 211, K 321, p 2212)
2) charge (-1,1)
3) momentum, [0.2,10] with 0.2 GeV/c step, for higher momenta one should use 10 GeV/c
4) polar angle, [25,160] with 1 degree step
5) azimuthal angle [0,30] with 0.5 degree step, there is 12x azimuthal symmetry
6) probability for electron
7) probability for pion
8) probability for kaon
9) probability for proton

Probabilities are normalized to 1 (for e,pi,K,p).
If all probabilities = 0 then PID is not possible.

Example of probabilities for π^+ at 5.5^o azimuthal angle:



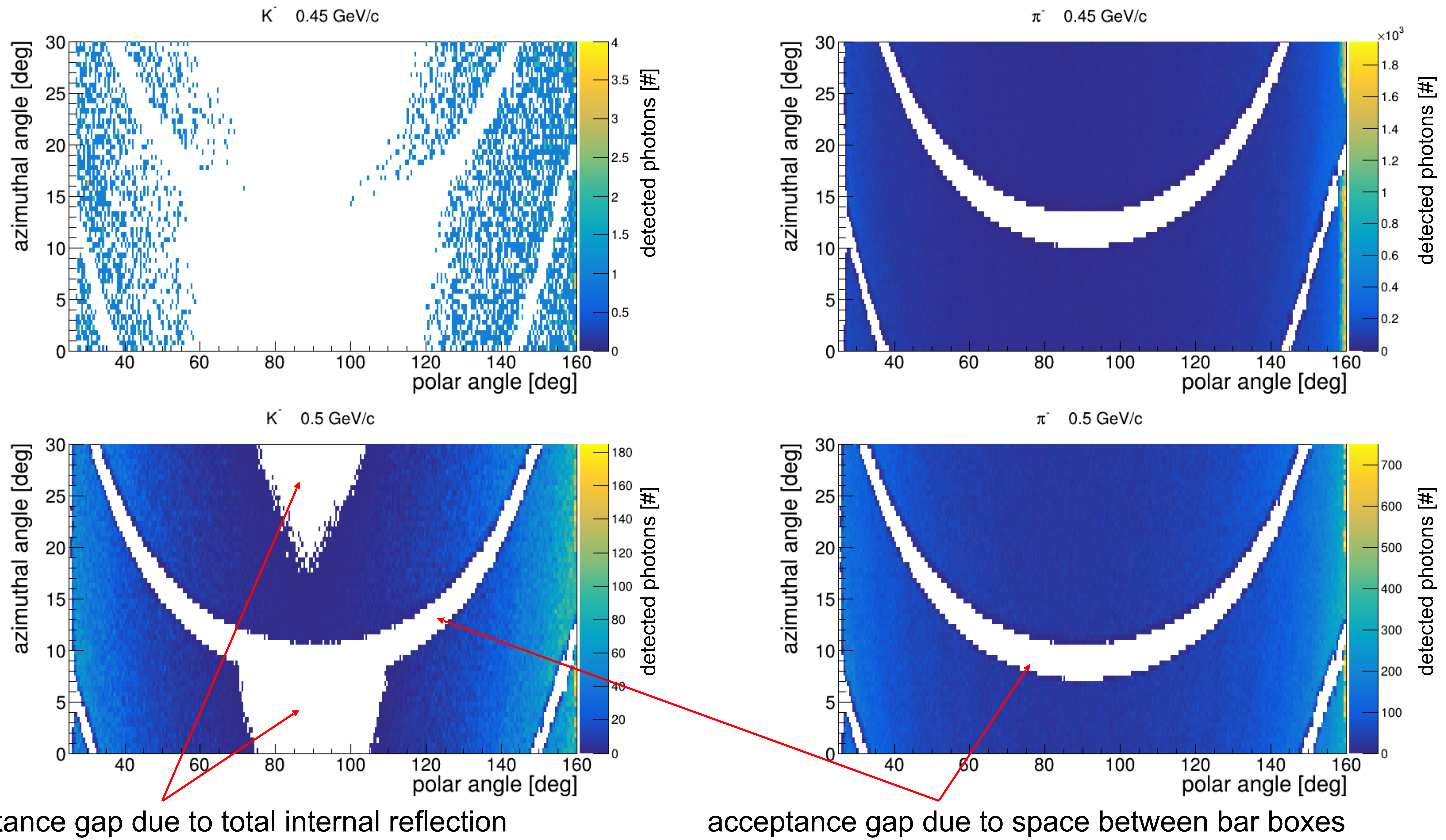
LUT PID for hpDIRC

Example of threshold mode

Require more than 5 detected photons for robust PID

➡ positive ID for pions over whole phase space @ 0.45 GeV/c

➡ positive ID for pions over large part of phase space @ 0.5 GeV/c

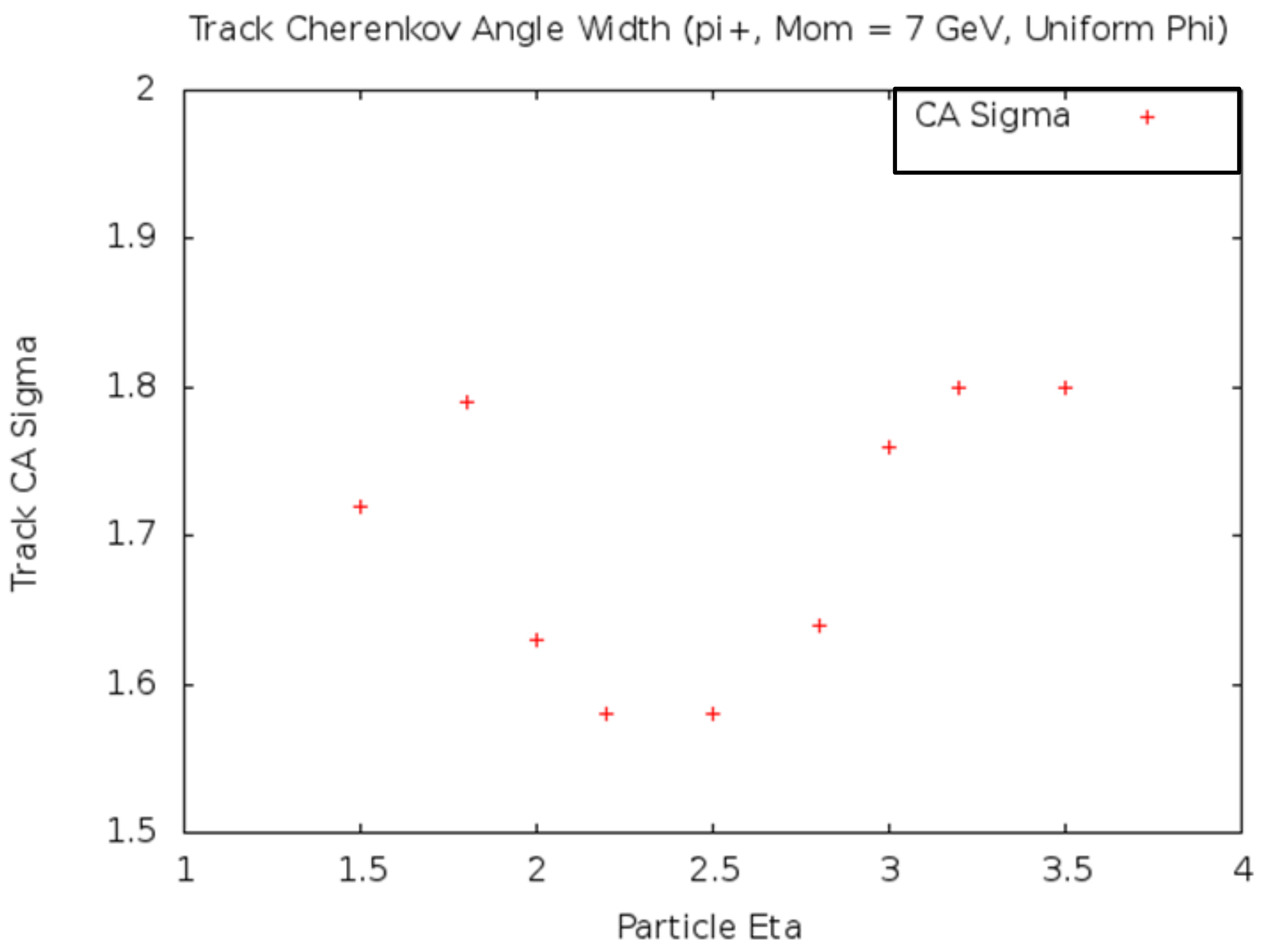


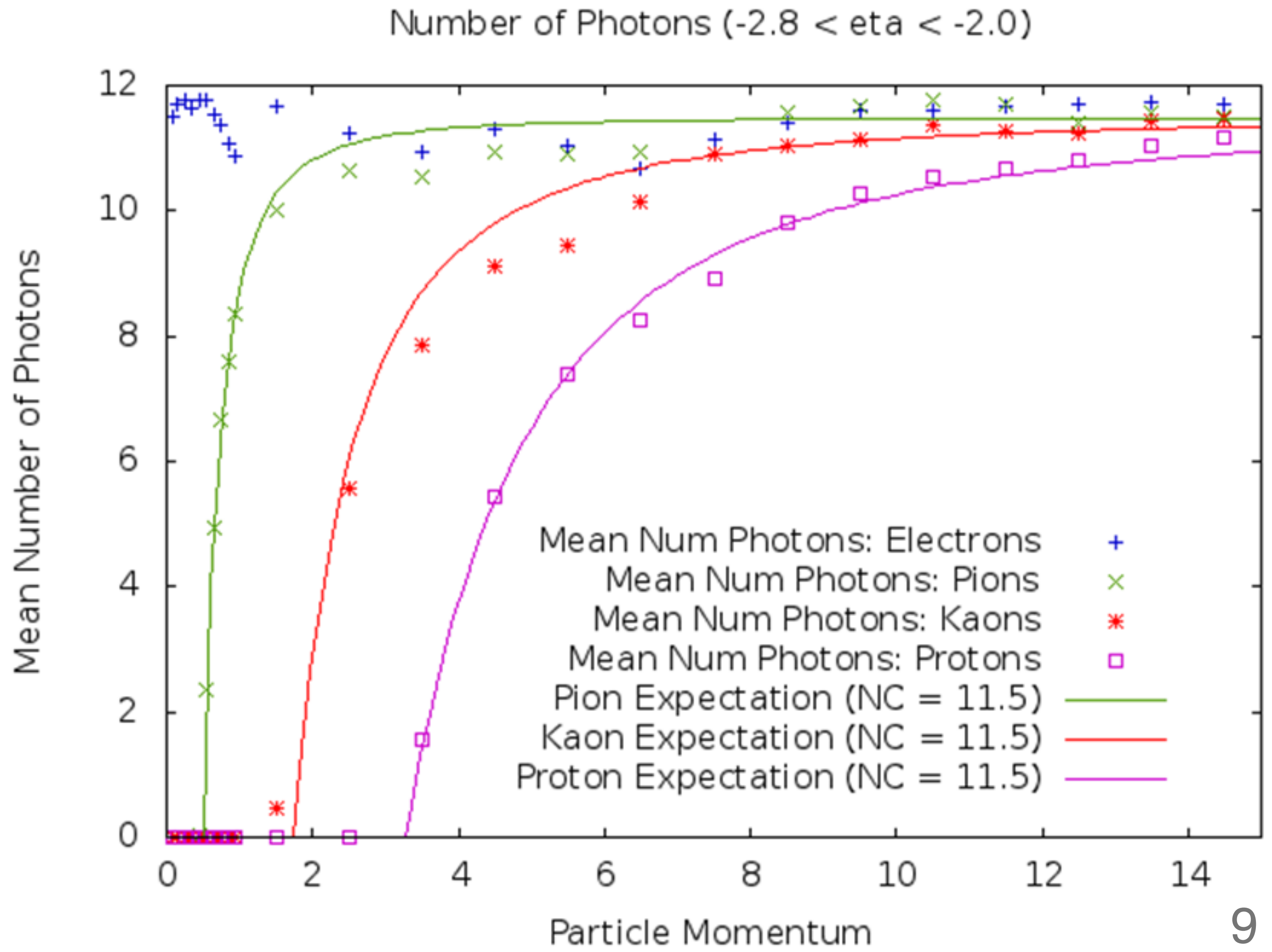
Fine binning in angle and momentum needed to deal with rapid changes in photon yield

pfRICH

pfRICH LUT Status

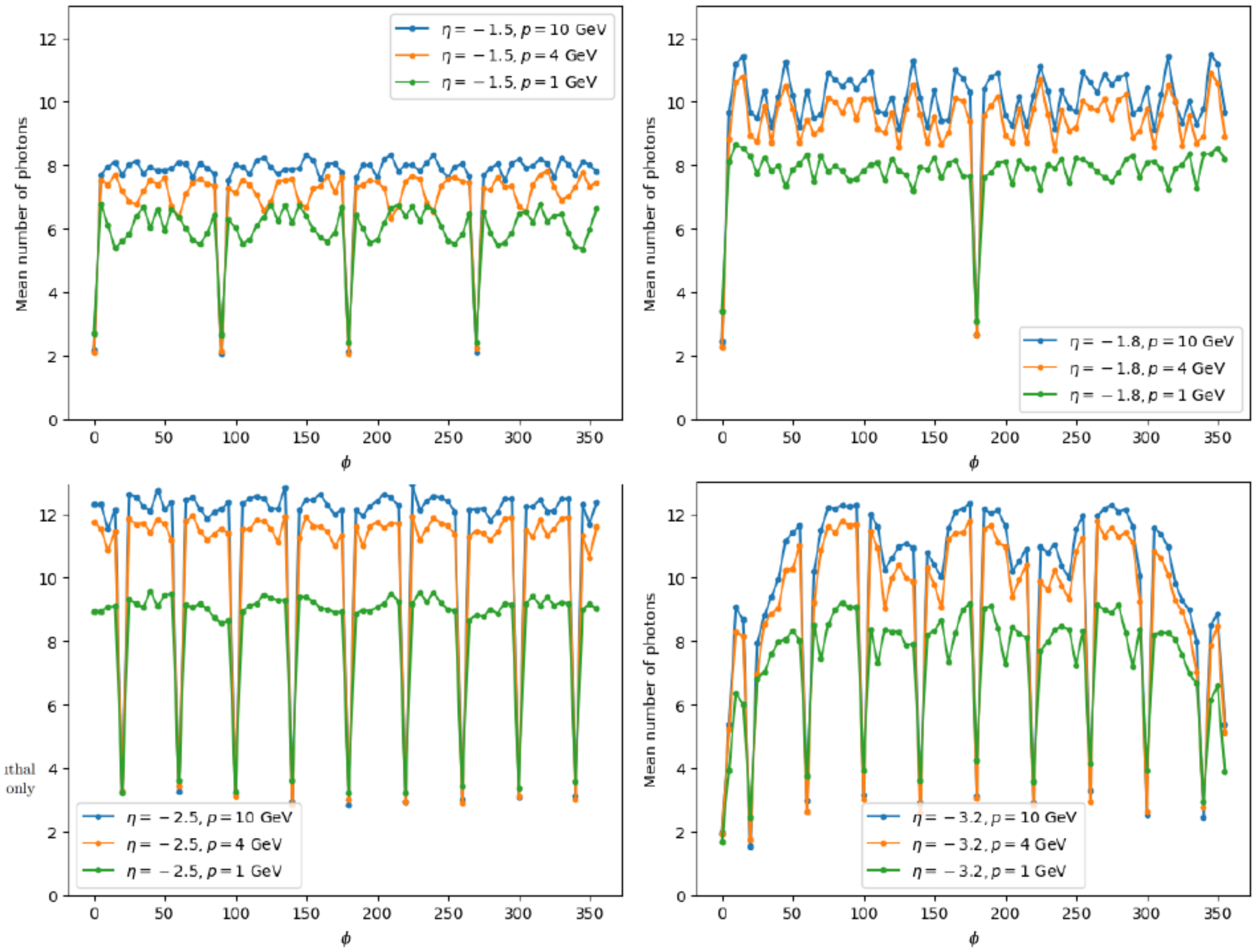
- Initial set of pfRICH tables (π/K/p and e/π/K/p) submitted on 3/12
  - 4 η bins [-3.5,-3.0], [-3.0,-2.8], [-2.8,-2.0], [-2.0,-1.5]
  - 25 momentum bins [0.05, 0.1], [0.1, 1.0] in 0.1 steps, and [1.0, 15.0] in 1.0 steps
  - Require > 5 Cherenkov photons to report a PID determination (p > 0.7, 3.0, and 5.0 for pions, kaons, and protons, respectively)
- Strategy: start simple and then refine
  - For March: provide probabilities based on track level Cherenkov angle resolutions (a la ATHENA)
  - Neglect B-field, charge dependence, φ dependence, vertex smearing, and track resolution (do spot checks of B-field and track resolution to get an idea of importance)
  - Add these effects in subsequent iterations
- Next Steps:
  - Add neglected effects
  - Estimate background effects
  - Obtain probabilities directly from reconstruction





Next Steps

- For the next iteration of LUTs, we want to move away from track level Cherenkov angle resolutions and utilize the full (stand alone) reco machinery
  - More robust migration matrix
  - More control over detected photon count and sub-threshold cases
- Next iterations will include B-Field, charge dependence, vertex and momentum smearing, and phi dependence
- Need to decide on phi binning scheme
  - Mostly constant response in phi with localized regions of inefficiency
  - What is easier for software and infrastructure to handle – variable sized phi bins, or large number of bins?

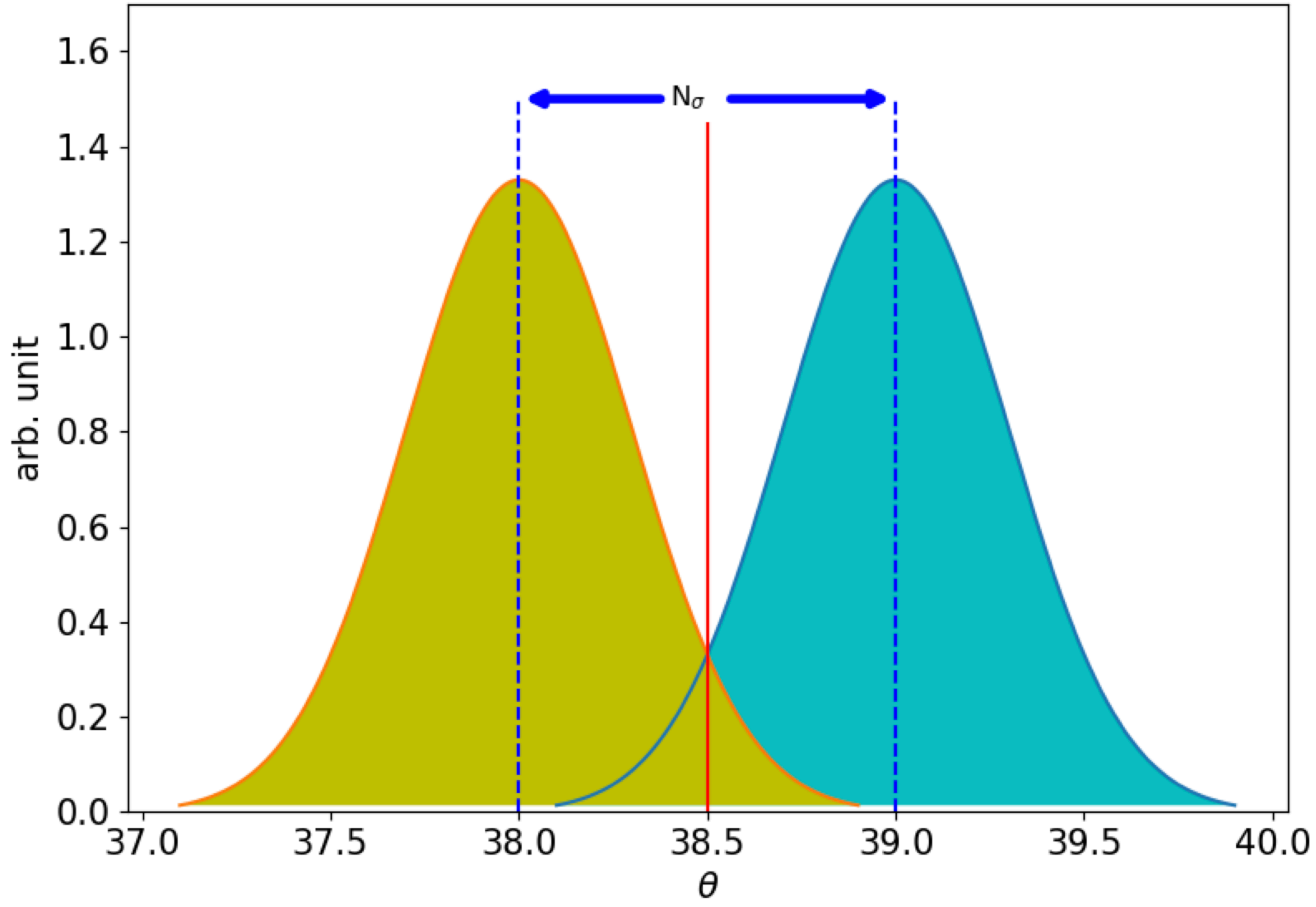


dRICH

dRICH LUTs

- dRICH simulations are running within ePIC framework
- LUT still needed since EICrecon is not able to handle all complex event structure yet
- Generation of LUTs is therefore more time consuming than stand-alone app
- Present LUTs are preliminary tables
  - Nominal aerogel (not yet optimized)
  - Nominal dRICH geometry
  - No noise (expected negligible at beginning of ePIC and for gas)
  - Only 3 eta bins
  - Averaged on phi (azimuth)
  - One file for e/π and one for π/k/p
- LUTs will be refined while the full epIC simulation/analysis chain is commissioned

Using Delphes to create LUTs (thanks to Brian)

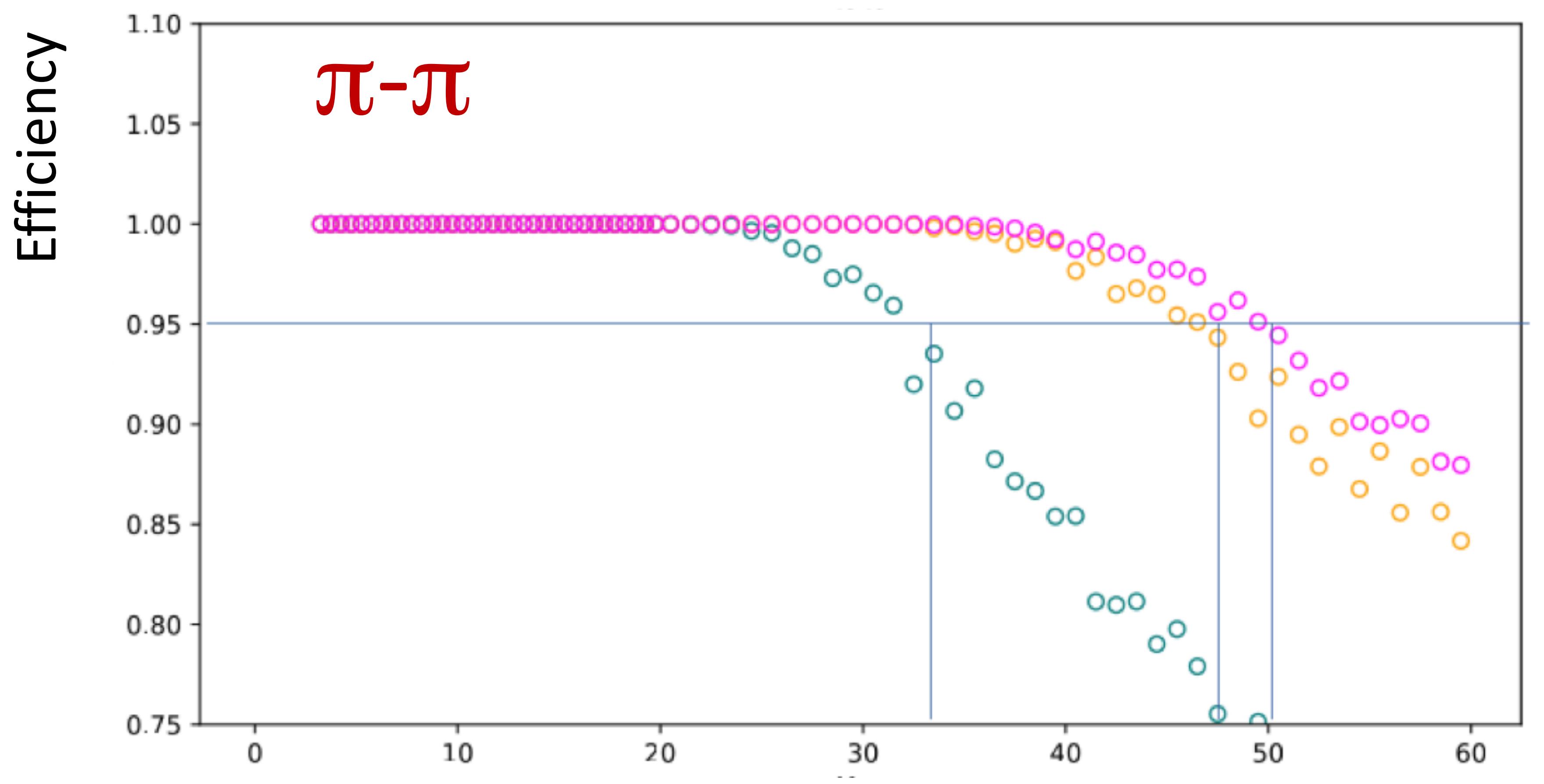


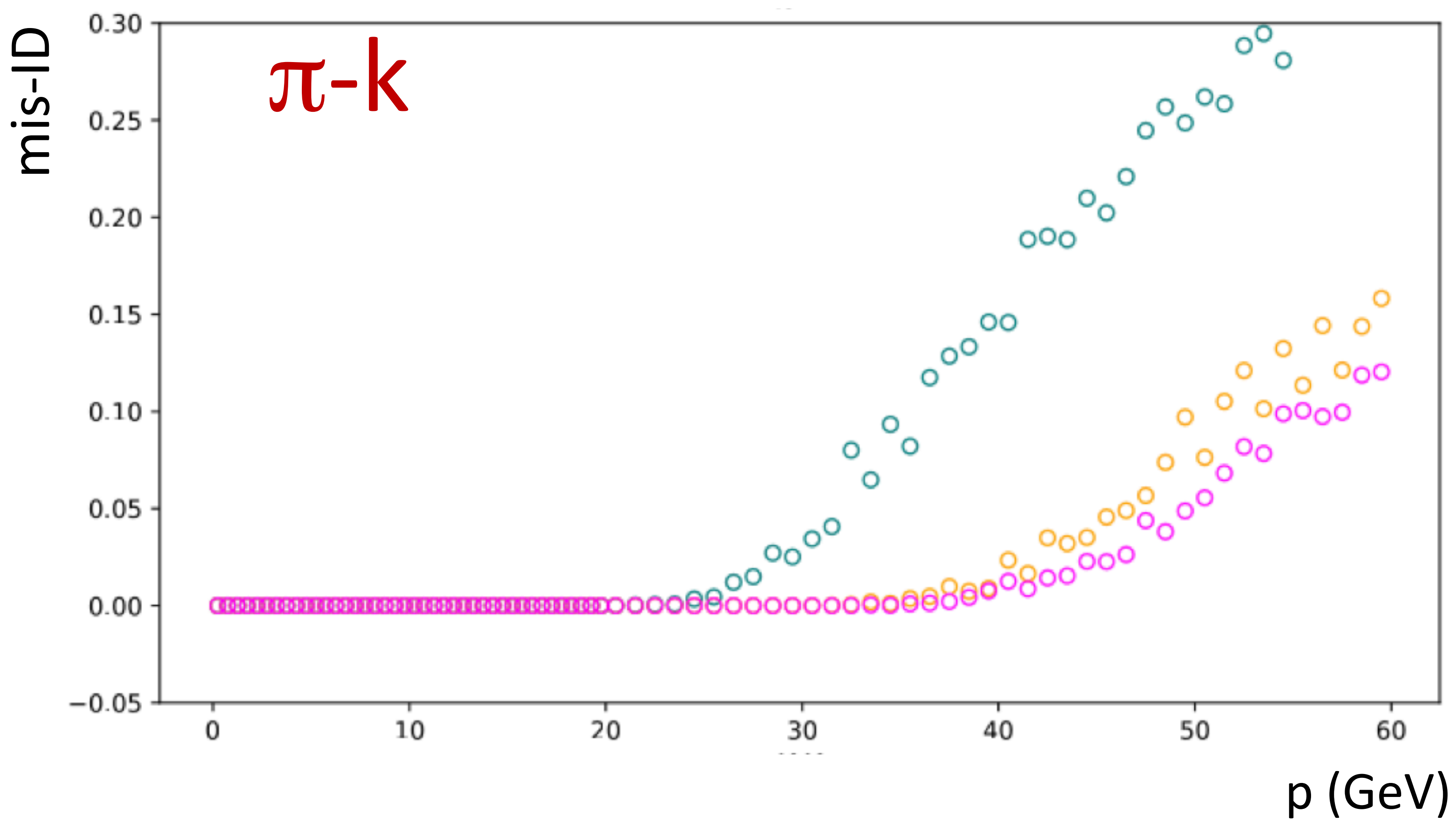
From ePIC simulations: refractive index
sigma values

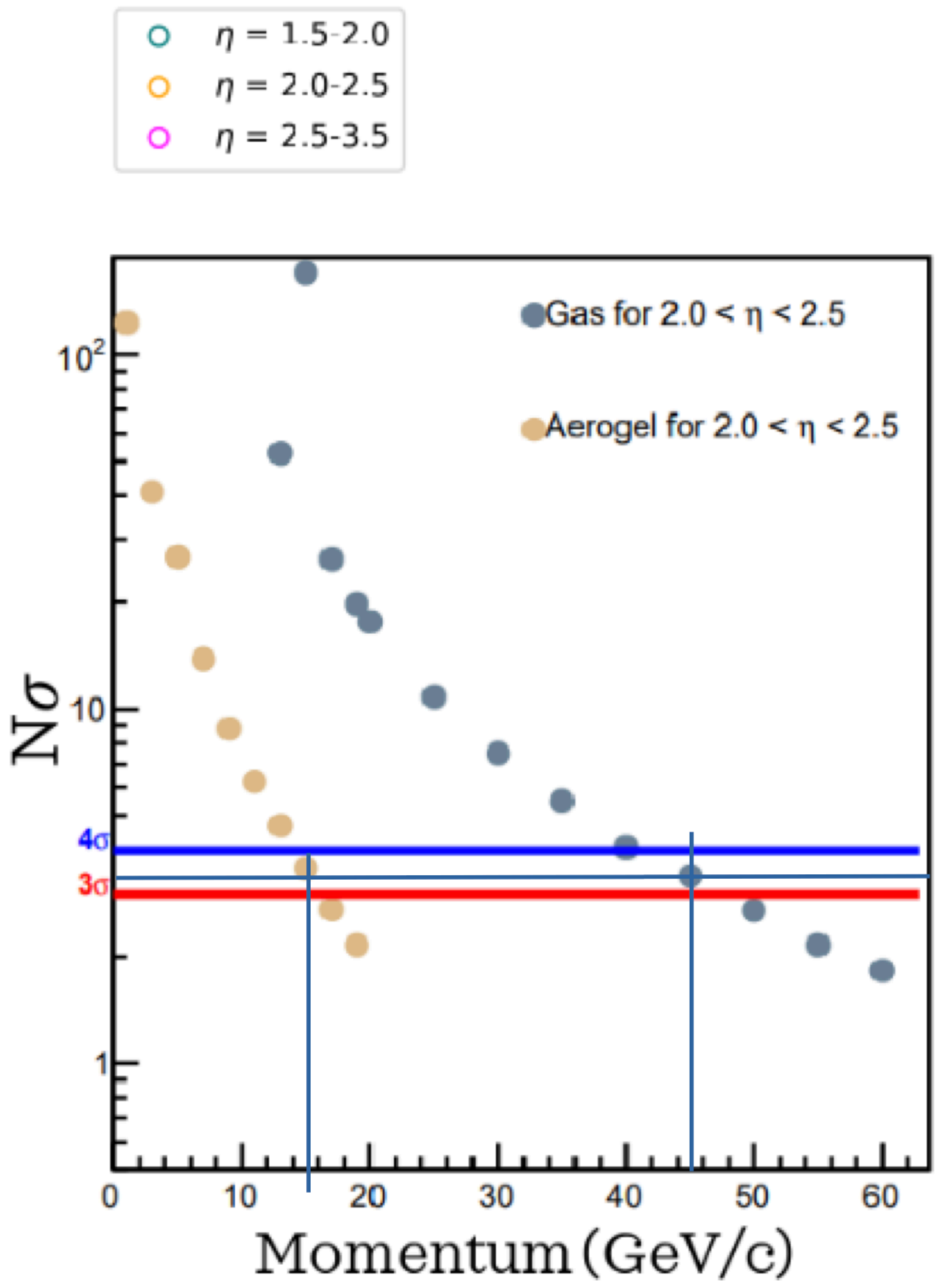
Delphes: separation at mid-point
efficiency & mis-ID probabilities

Hadron Identification

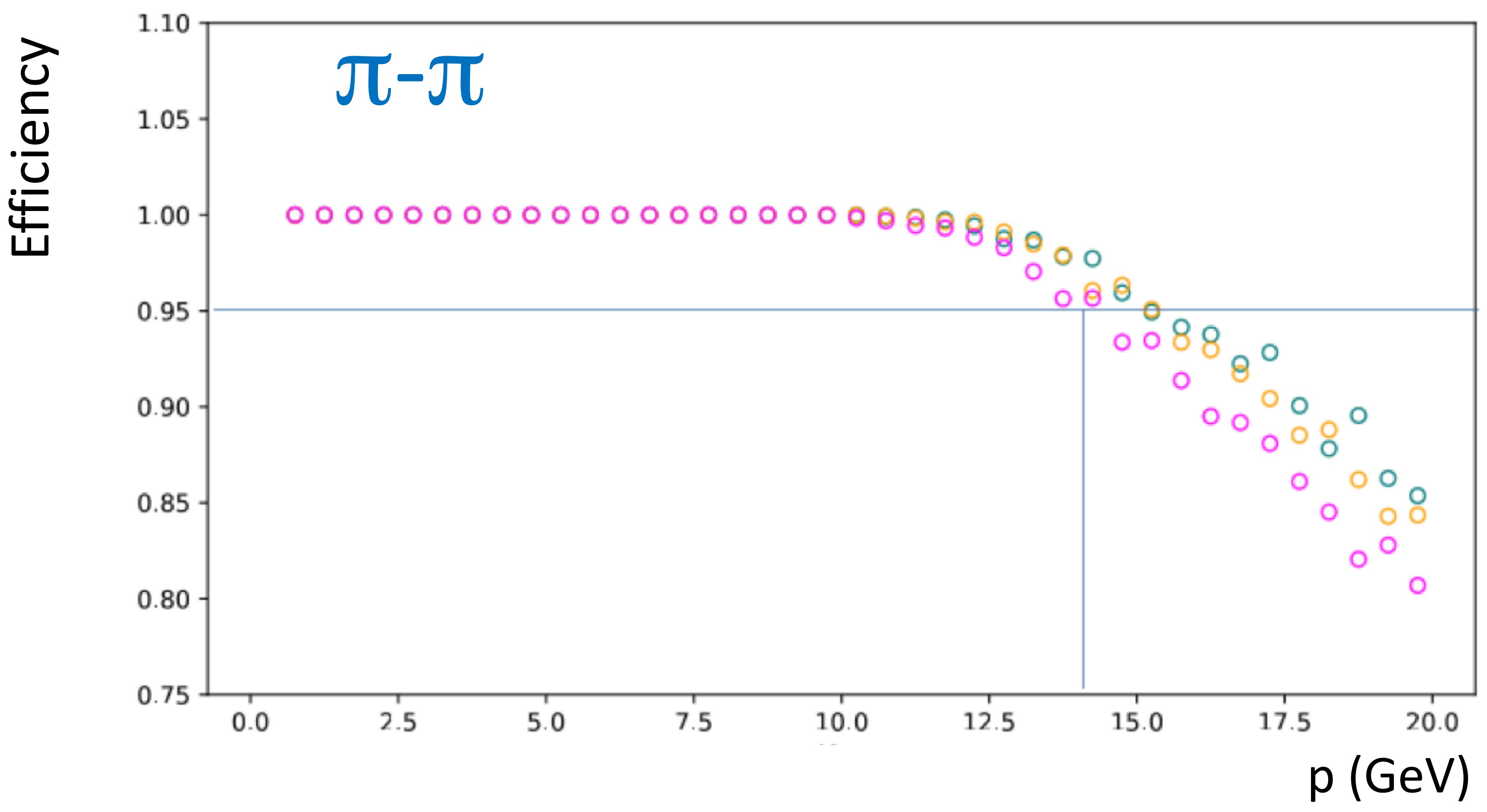
Aerogel

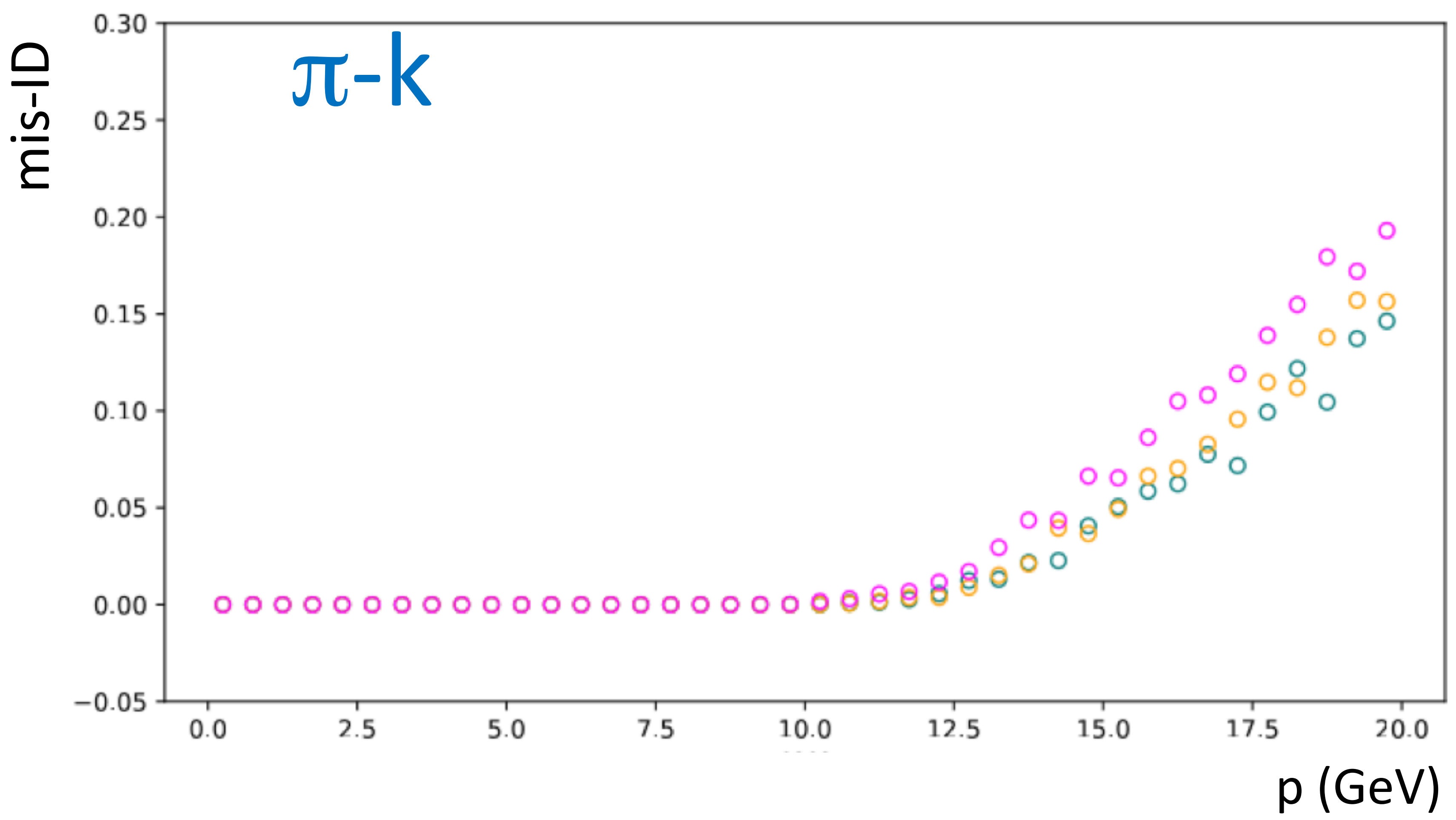






Gas



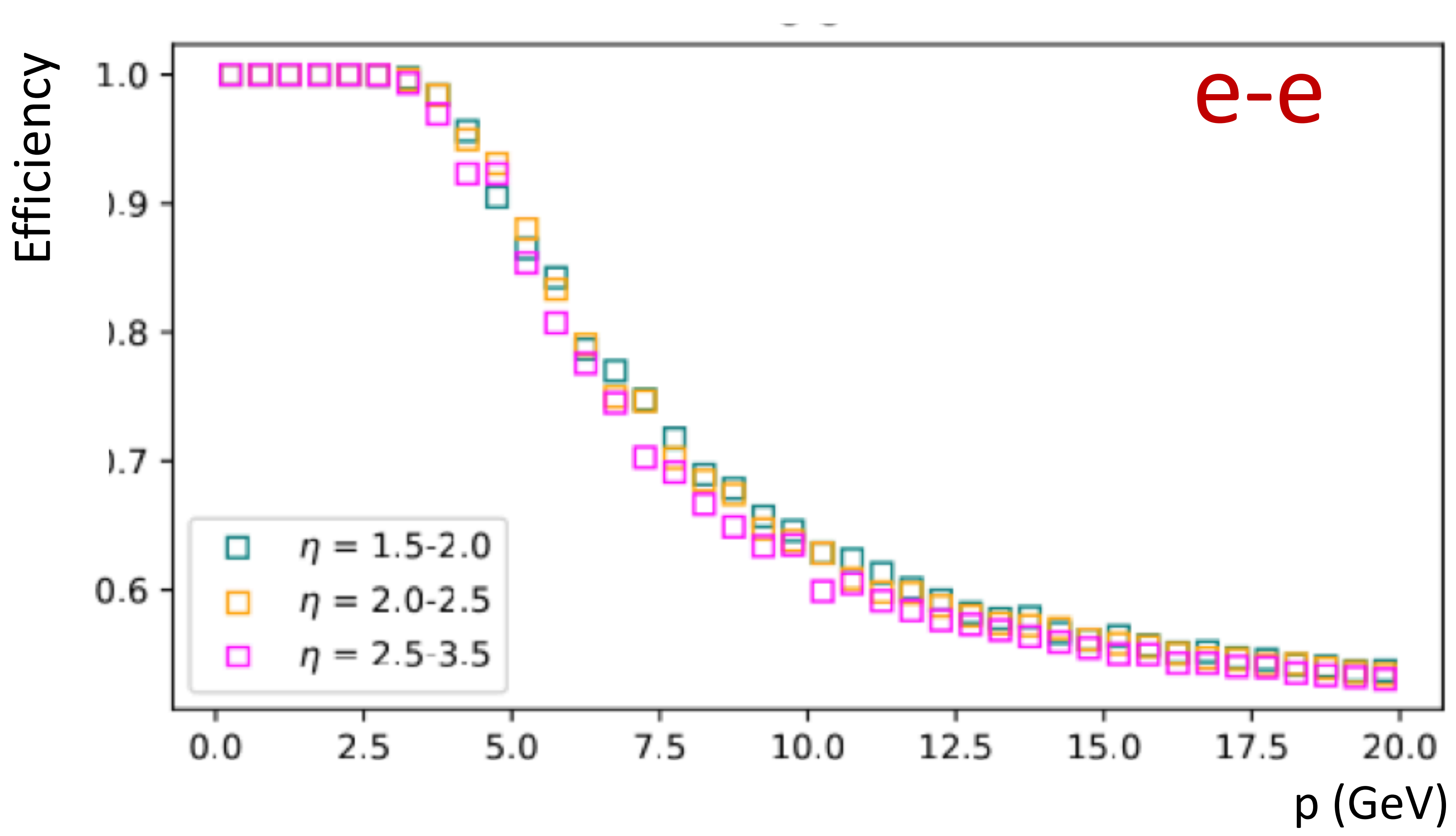


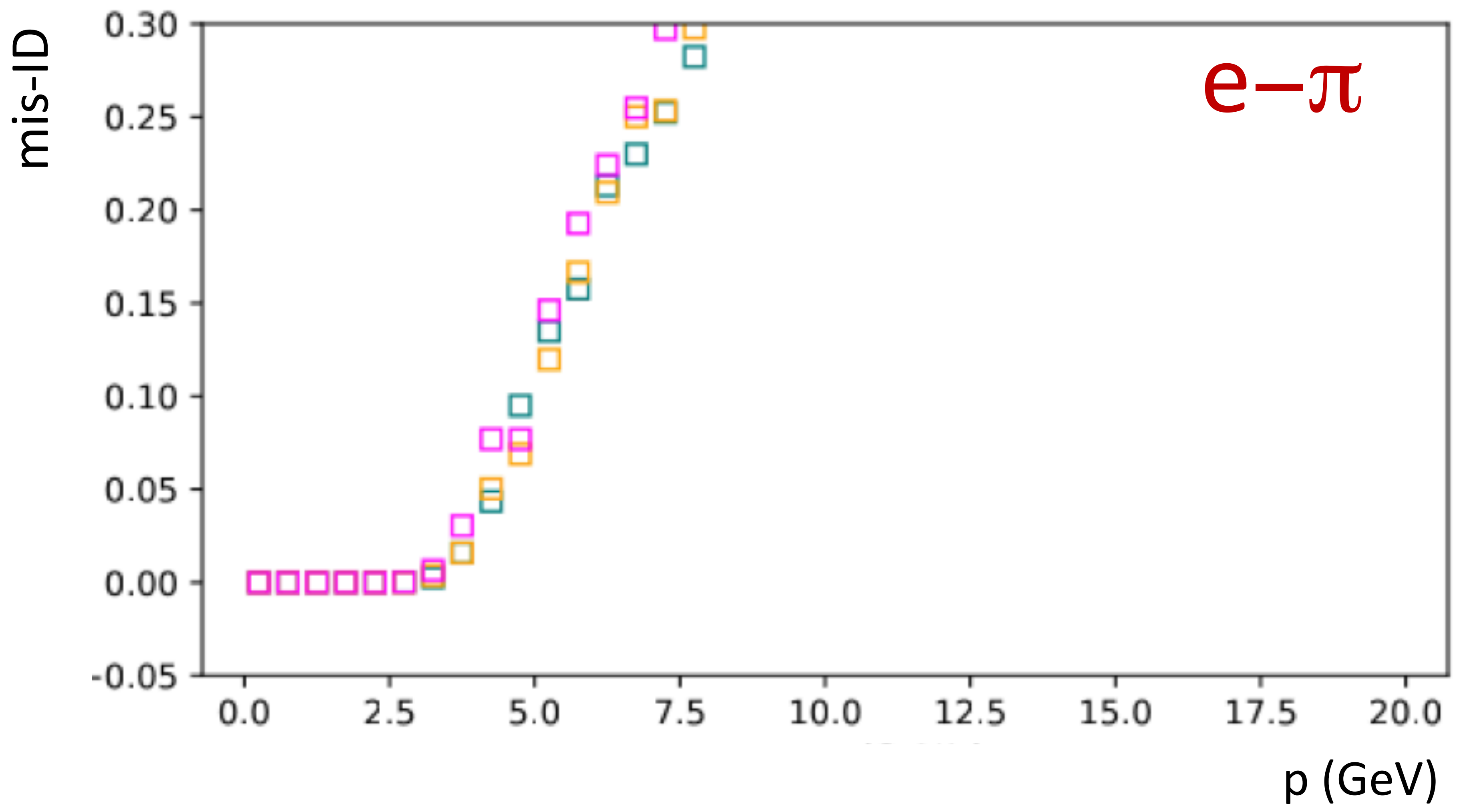
Currently: gas and aerogel are different LUTs - might merge soon

Electron Separation

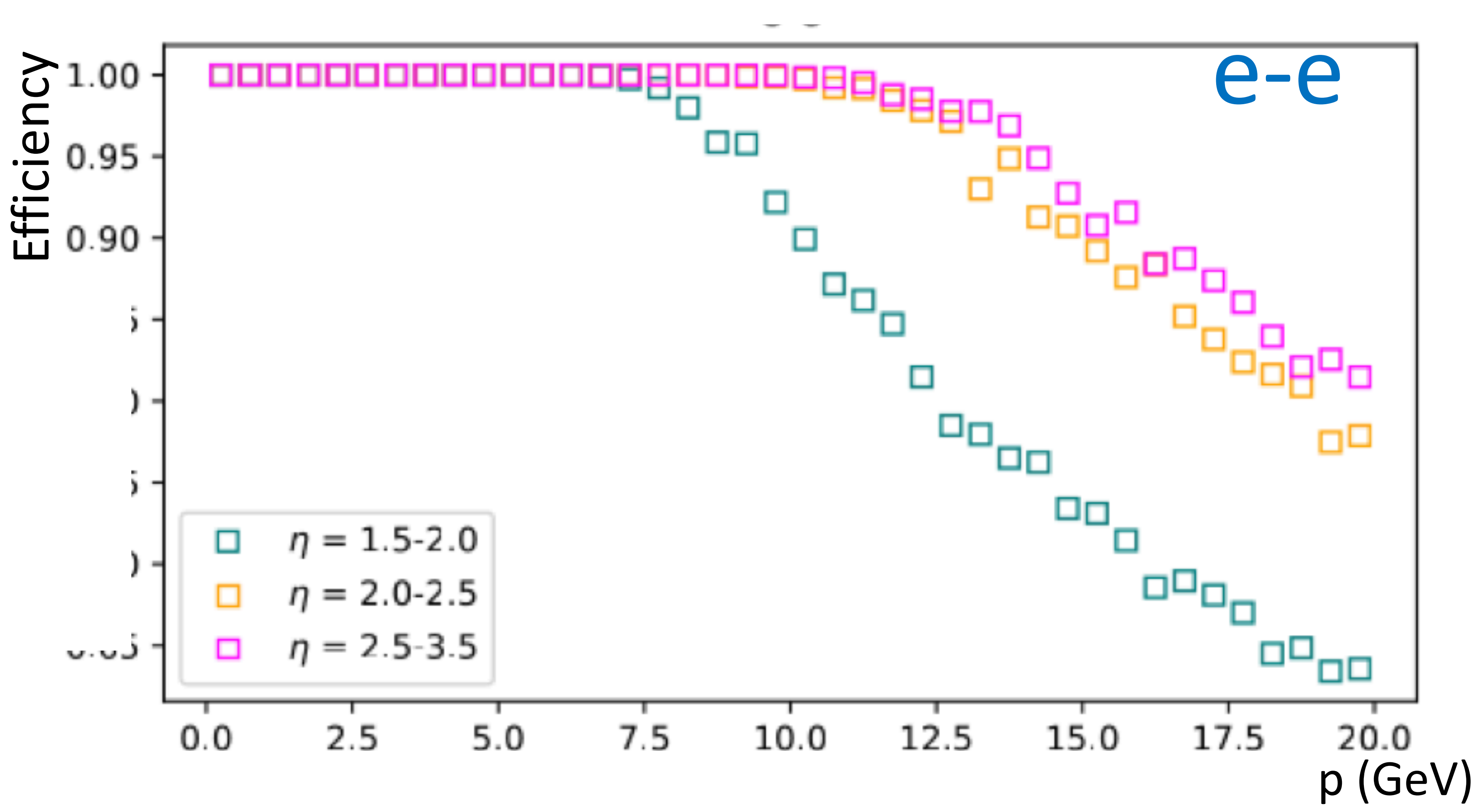
Right now PID info is not used in the electron finder!

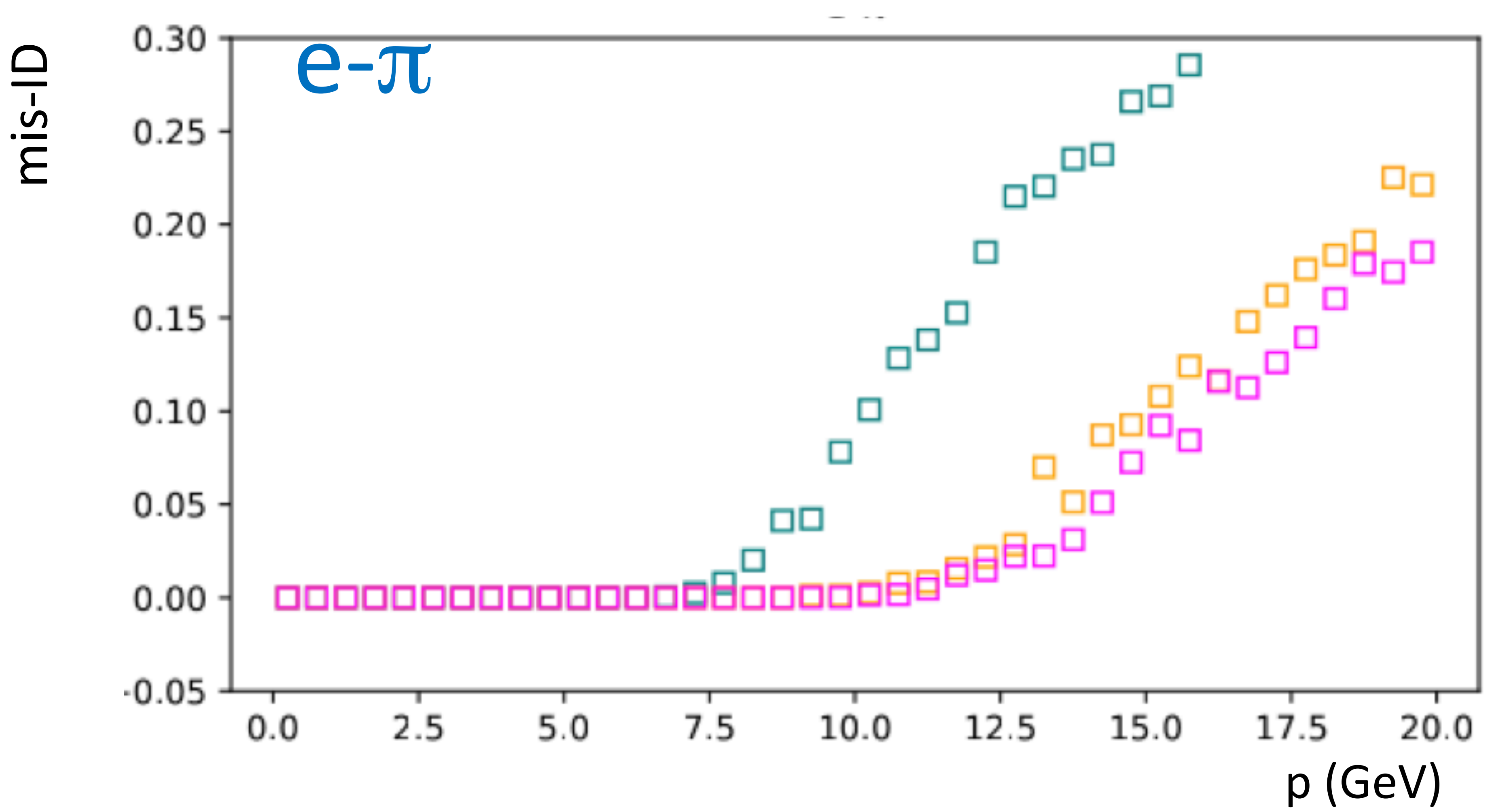
Aerogel





Gas

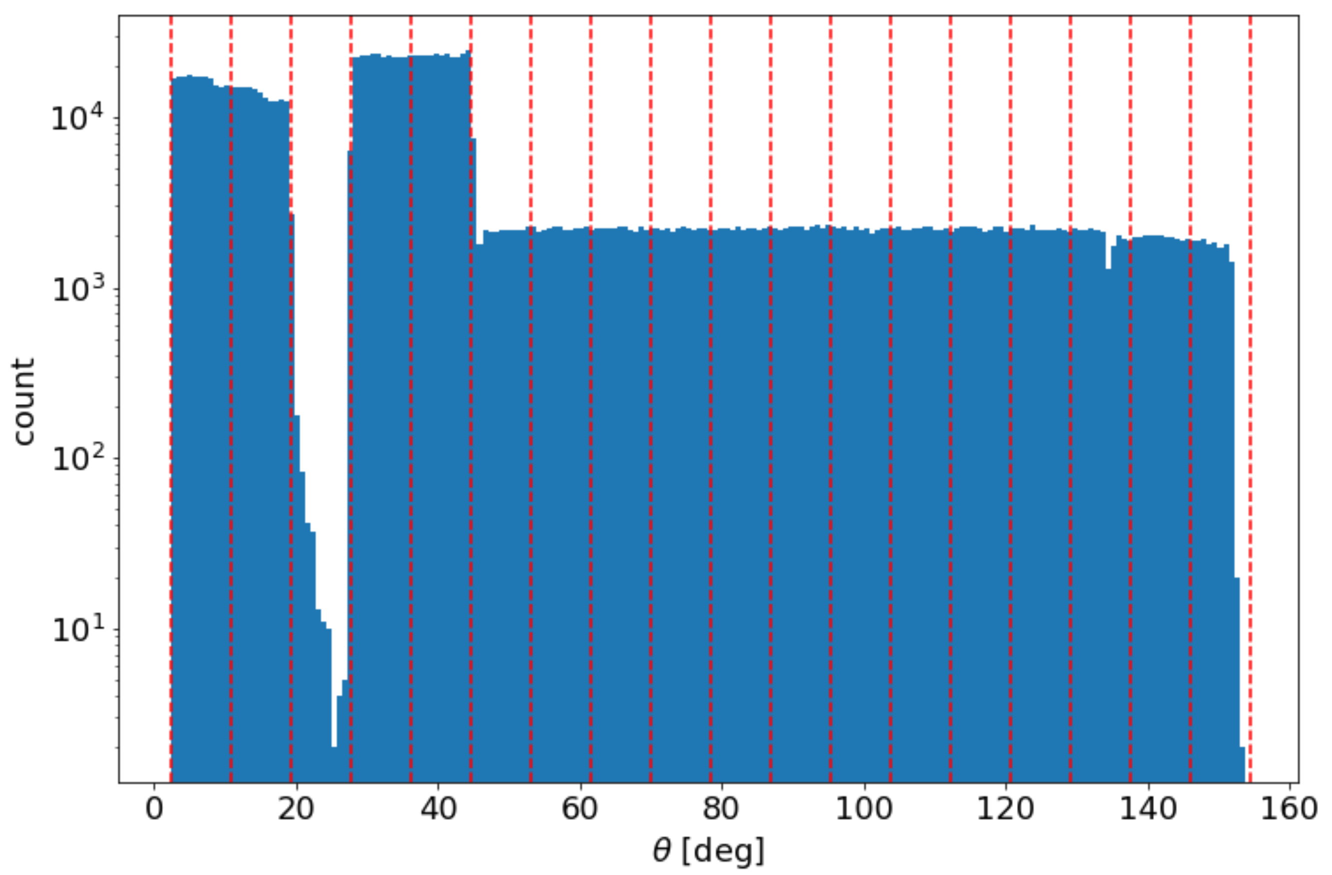


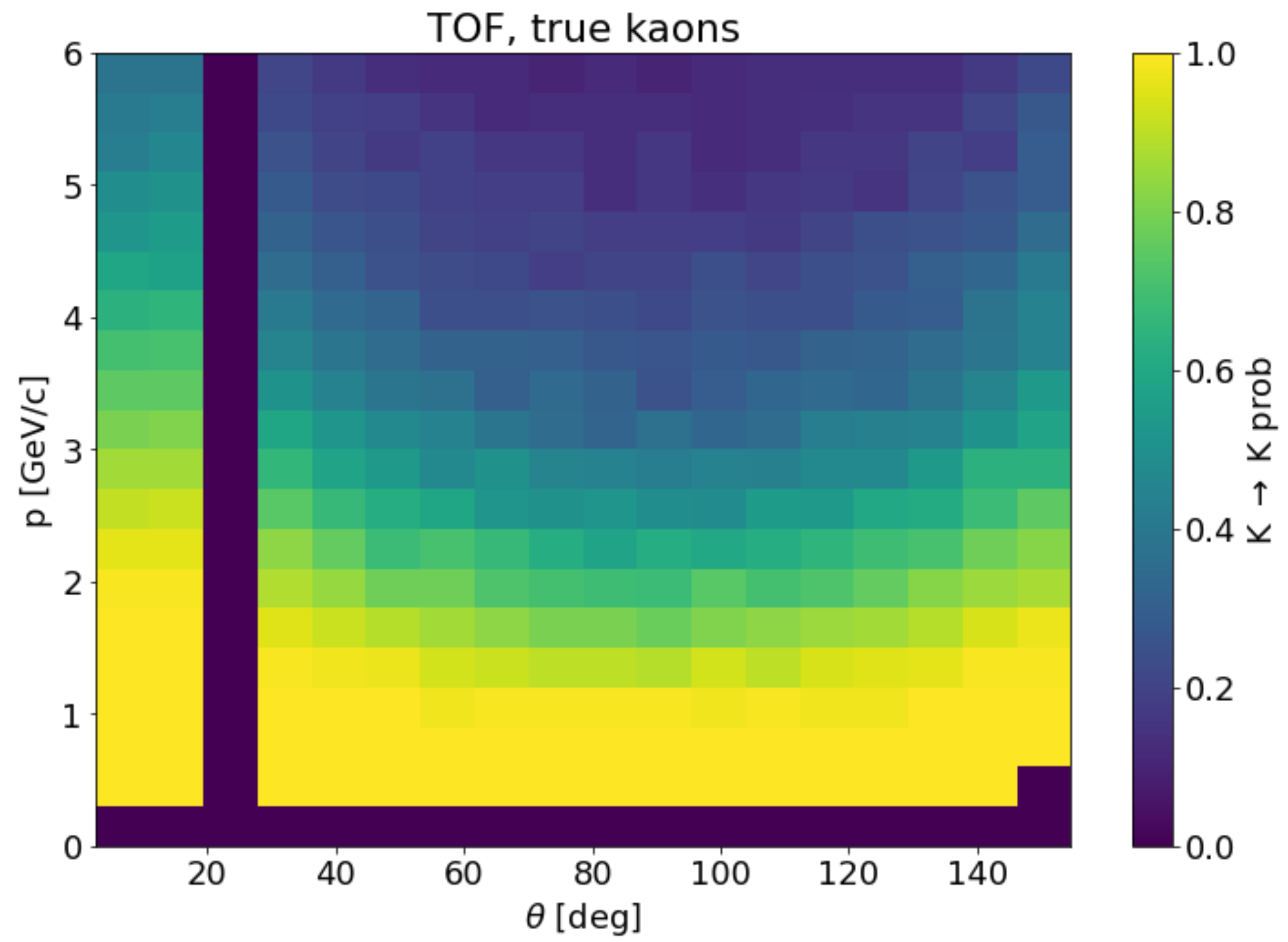


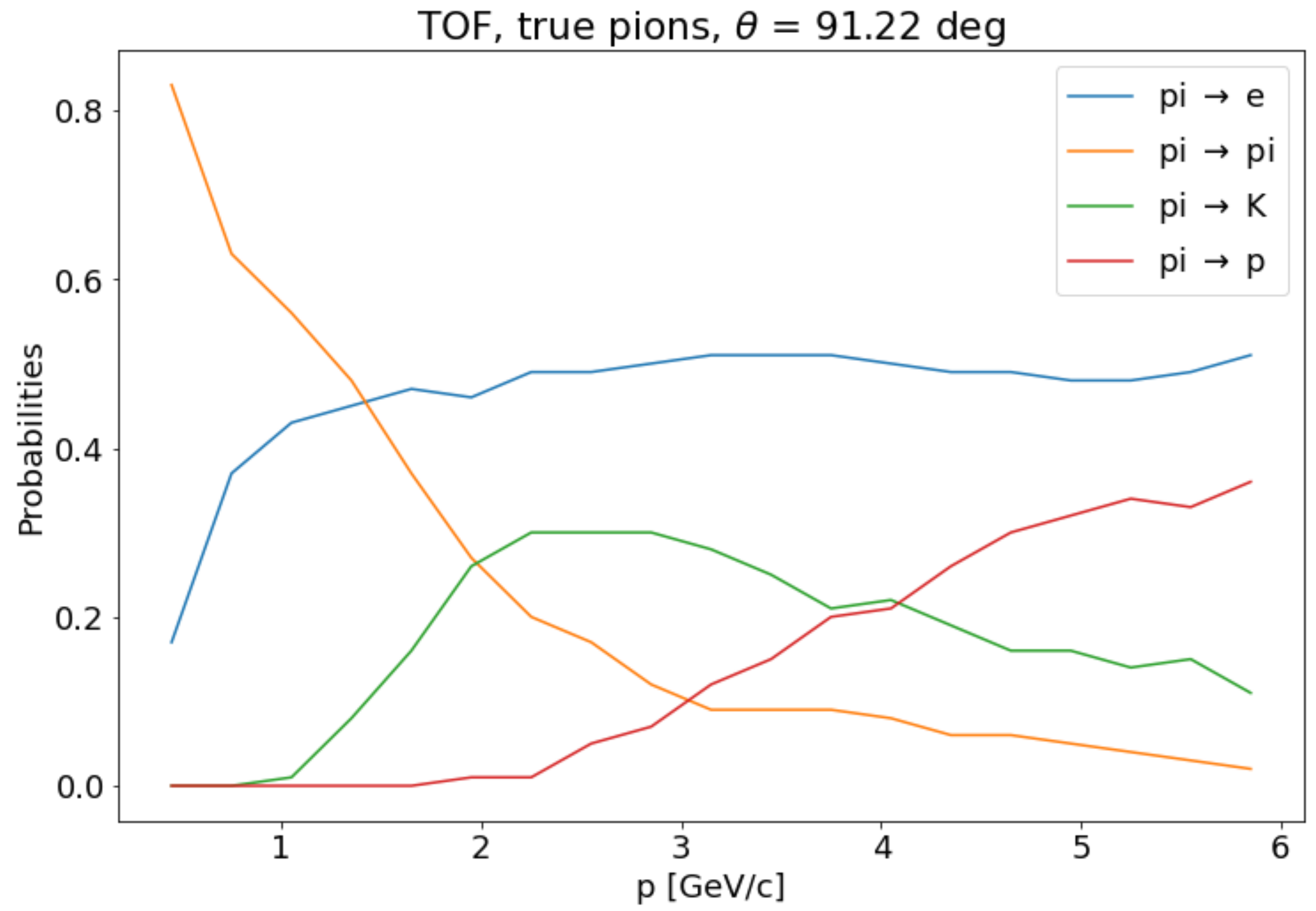
ToF

TOF Lookup Table

- Assume 35ps (25ps) sensor + R/O resolution in barrel (endcap)
  - Additional 20ps t_0 resolution added in quadrature (conservative)
- TOF is symmetric (enough) in φ, charge
- 17 bins in θ [2.5, 154.6] deg
  - Nicely covers gap between forward and barrel with single empty bin
- 20 bins in p: [0, 6] GeV/c
  - Covers most relevant momentum range
  - Omits slight curve in lower momentum acceptance in TOF barrel, but good enough for now







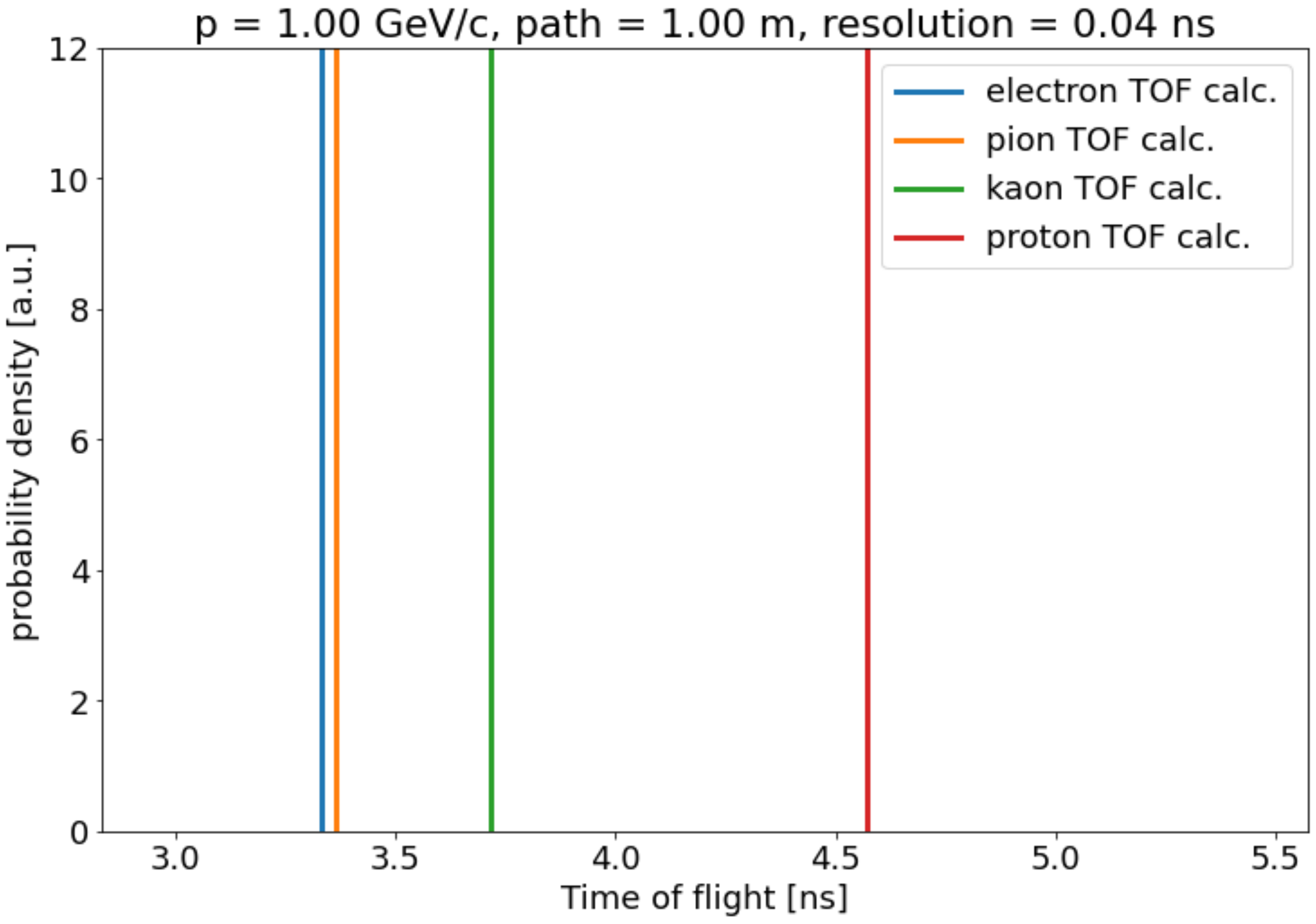
Summary

- All PID DSCs have LUT submitted
  - hpDIRC has also threshold mode included
  - pfRICH submitted initial set of LUT but will continue to add more effects
  - dRICH has very basic LUTs produced that will be refined while the full ePIC physics analysis chain becomes more realistic with more features added
  - ToF submitted LUTs, room for improvements
- Next
  - Next simulation campaign will only use LUT partially
  - Looking forward to feedback from Physics PWG (important)
  - PID DSCs plan to further refine tables also depends on the level of implementation in EICrecon

Backup Slides

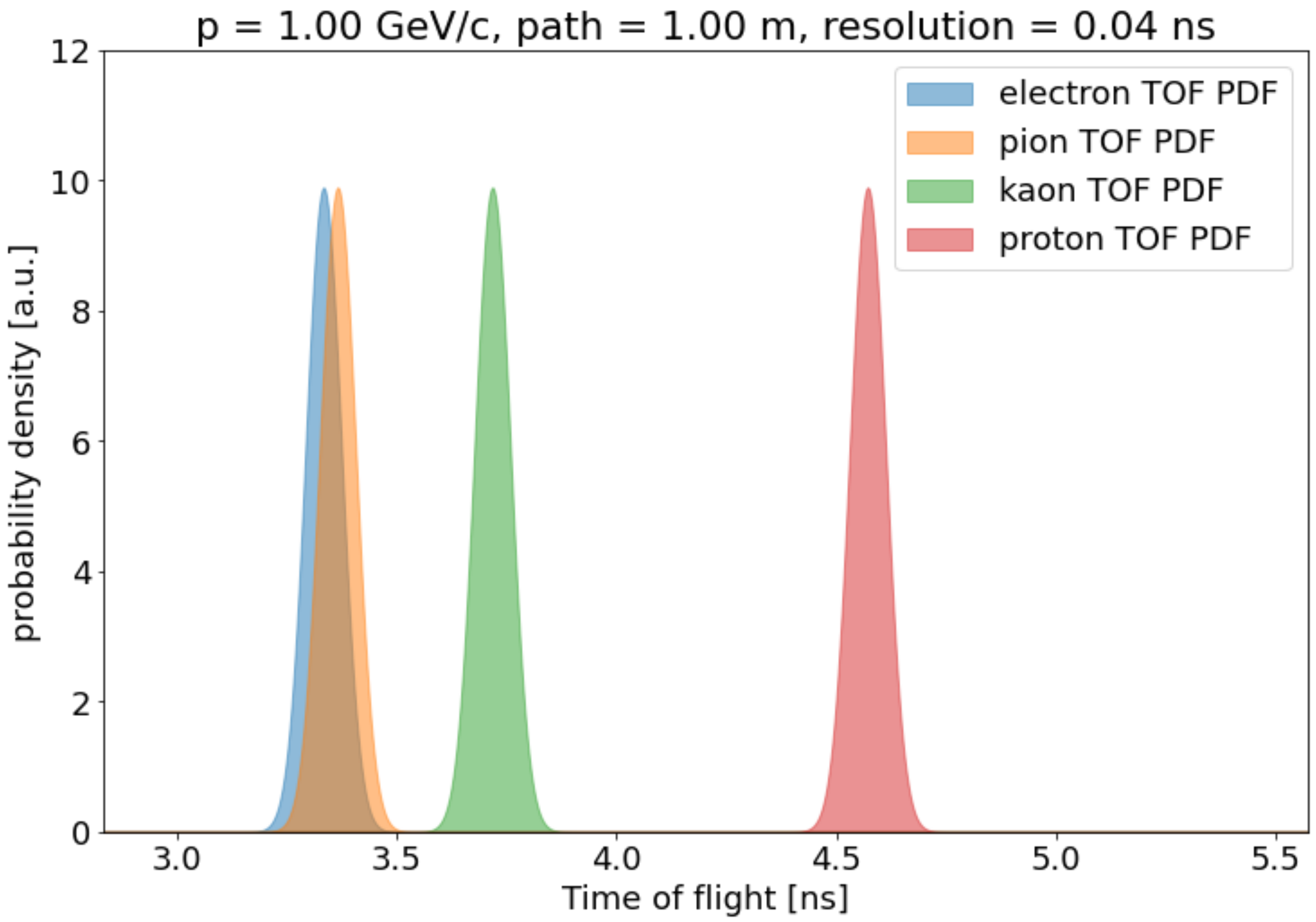
TOF Reconstruction Recap I

- ePIC tracking measures momentum and track length
  - Enables calculation of expected mean hit times of various particle species



TOF Reconstruction Recap II

- ePIC tracking measures momentum and track length
  - Enables calculation of expected mean hit times of various particle species
- Apply expected distribution based on resolutions: yields PDF for each species



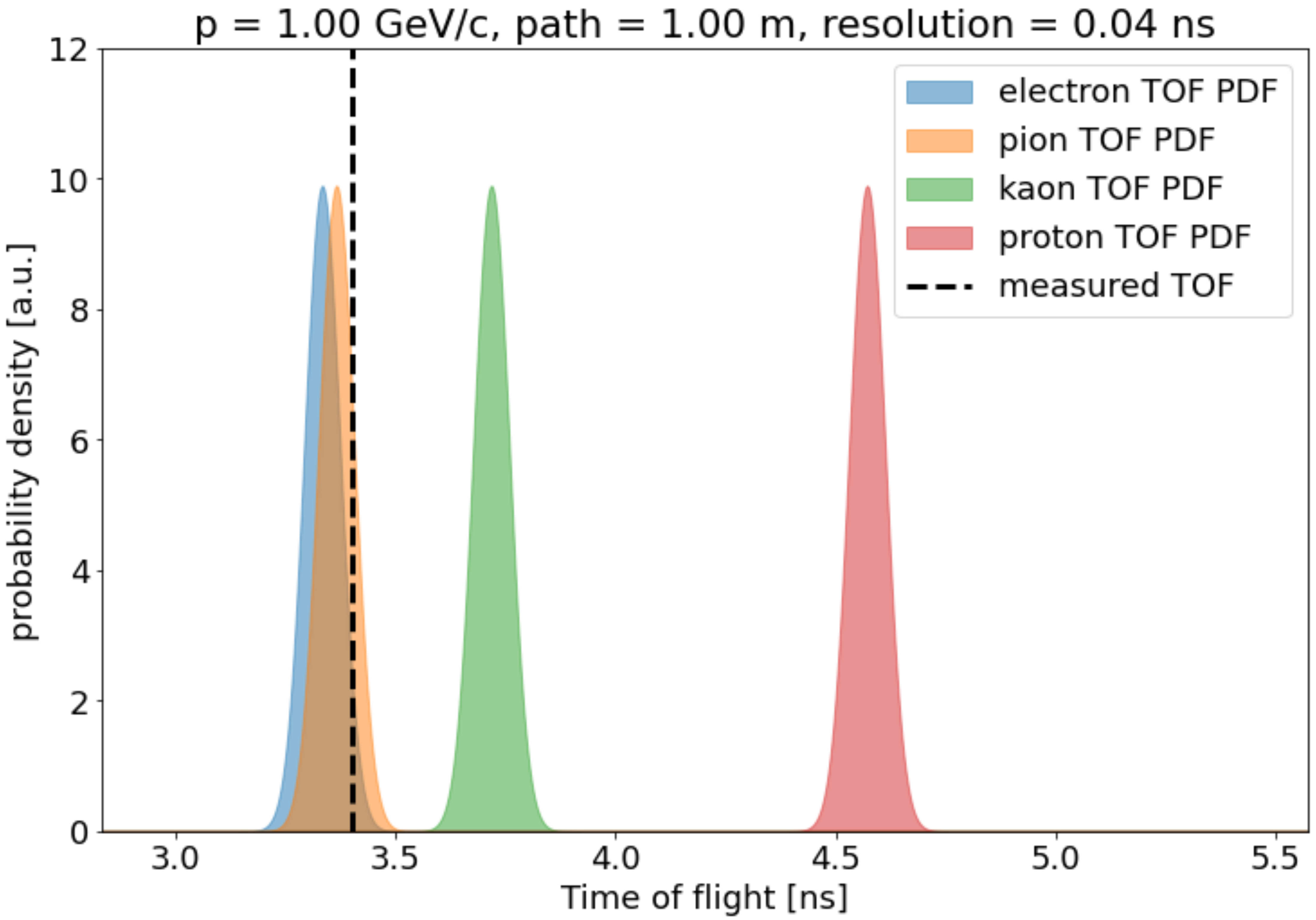
TOF Reconstruction Recap III

ePIC tracking measures **momentum** and **track length**

- Enables calculation of expected mean hit times of various particle species
- Apply expected distribution based on resolutions: yields PDF for each species

TOF system measures **hit time**

- Comparison with PDFs yields likelihood and thus reconstruction probability



- L(e): 2.52
  - LL(e): 0.92
- L(pi): 6.88
  - LL(pi): 1.93
- L(K): 0.00
  - LL(K): -28.7
- L(p): 0.00
  - LL(p): -419
- **Prob(pi)** = L(pi)/ (sum(L)) = **72.3%**

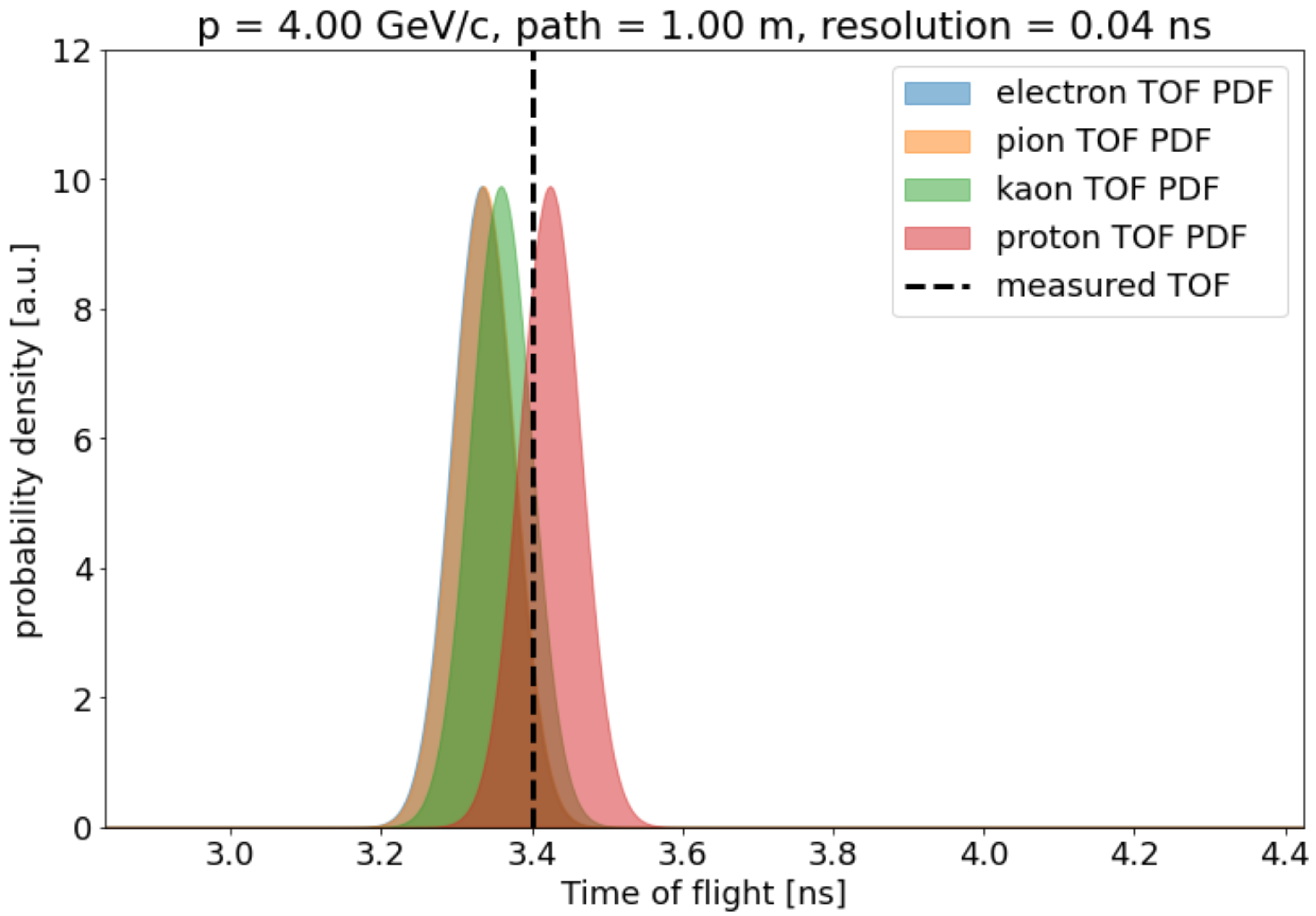
TOF Reconstruction Recap IV

ePIC tracking measures momentum and track length

- Enables calculation of expected mean hit times of various particle species
- Apply expected distribution based on resolutions: yields PDF for each species

TOF system measures hit time

- Comparison with PDFs yields likelihood and thus reconstruction probability



- L(e): 2.52
  - LL(e): 0.92
- L(pi): 2.74
  - LL(pi): 1.01
- L(K): 5.84
  - LL(K): 1.77
- L(p): 8.31
  - LL(p): 2.12
- Prob(pi) = L(pi)/ (sum(L)) = 14.1%

TOF pi/K Standalone Separation