BNL LDRD Detector-II Weekly Meeting

Update on Muon ID Study in Forward Region at ePIC

Jihee Kim (jkim11@bnl.gov)
Brookhaven National Laboratory

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What We Learned So Far

Some beneficial aspects for muon detection:

- Eliminate ambiguity since incoming/scattered and decay leptons are distinguishable and reduce combinatorial background (less radiative effects – better invariant mass resolution)
- In order to accommodate very small cross sections of both processes (double-statistics)

With muon and pion samples assuming the same kinematics (single sim):

Based on results incorporated the flux in the forward region (hadron-going),

- Smaller scattering angle (higher pseudo-rapidity) tends to have larger pion background
- Single muon detection might be challenging by just using fECAL and fHCAL

Here, assuming muon and pion have the same kinematic

What We Learned So Far

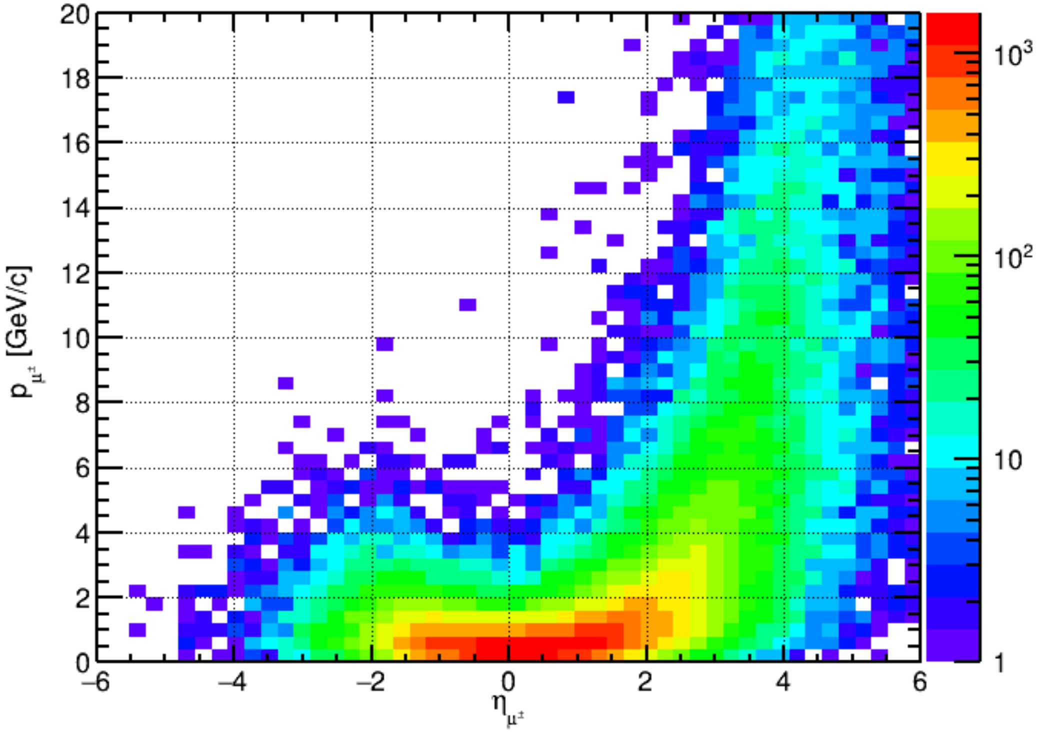
▼For same sample size (η = 1.74 or θ = 20°)

Momentum [GeV/c]	Muon Efficiency ($\frac{N_{\mu\to\mu}}{N_{\mu}}$)	Background Rejection Efficiency ($\frac{N_{\pi\to\pi}}{N_{\pi}}$)	Mis-ID Efficiency ($\frac{N_{\pi\to\mu}}{N_{\pi}}$)
1	0.752747	0.962042	**0.037958**
2	0.987315	0.987468	**0.012532**
5	0.997934	0.984391	**0.015609**
10	0.997733	0.990938	**0.009062**

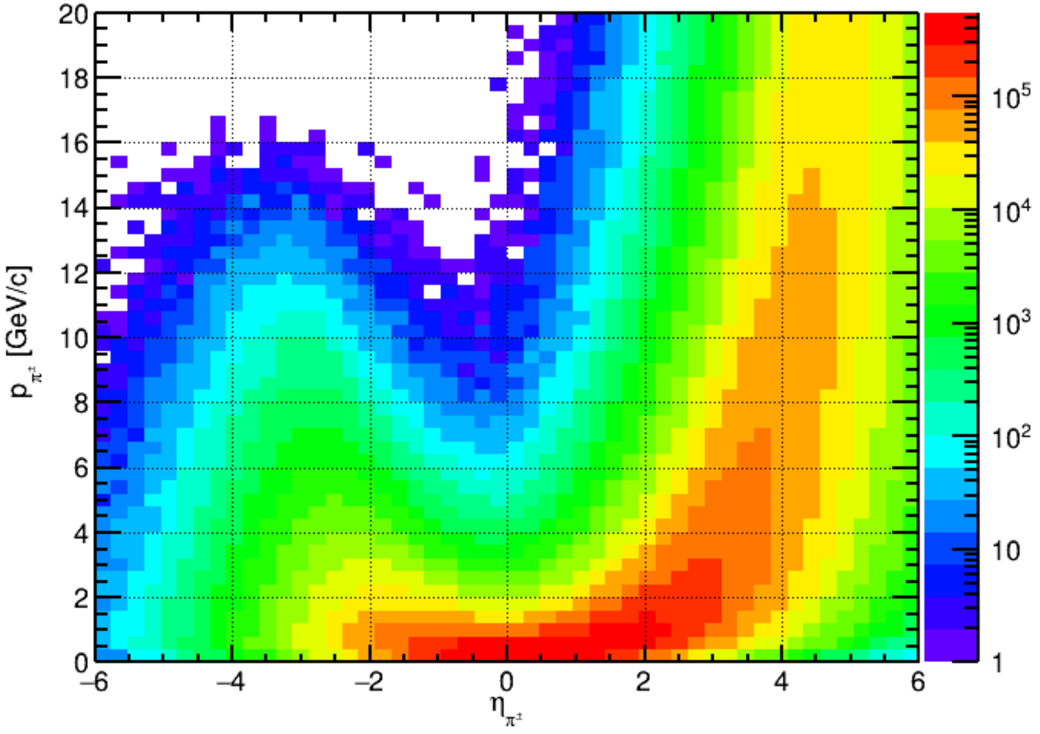
ep 18×275 GeV² 10M in high divergence mode (EIC CDR Table 3.3)

Cross Section from PYTHIA Sample

$\mu^{\pm}$



$\pi^{\pm}$



ep 18×275 GeV^2 10M in high divergence mode (EIC CDR Table 3.3)

Cross Section from PYTHIA Sample

η = 2.44	1 GeV/c	2 GeV/c	5 GeV/c	10 GeV/c
N_μ	254	283	76	4
N_π	226983	196246	41073	3311
N_π/N_μ	**~ 893.63**	**~ 693.45**	**~ 540.43**	**~ 827.75**

η = 2.02	1 GeV/c	2 GeV/c	5 GeV/c	10 GeV/c
N_μ	506	308	38	1
N_π	338213	153524	12806	981
N_π/N_μ	**~ 668.41**	**~ 498.45**	**~ 337**	**~ 981**

η = 1.74	1 GeV/c	2 GeV/c	5 GeV/c	10 GeV/c
N_μ	736	271	22	2
N_π	368039	109691	7507	492
N_π/N_μ	**~ 500**	**~ 405**	**~ 342**	**~ 246**

η = 1.51	1 GeV/c	2 GeV/c	5 GeV/c	10 GeV/c
N_μ	793	233	14	2
N_π	364095	68969	4248	278
N_π/N_μ	**~ 459.14**	**~ 296.00**	**~ 303.43**	**~ 139**

Here, assuming muon and pion have the same kinematic

What We Learned So Far

▼For same sample size (η = 1.74 or θ = 20°)

Momentum [GeV/c]	Muon Efficiency ($\frac{N_{\mu\to\mu}}{N_{\mu}}$)	Background Rejection Efficiency ($\frac{N_{\pi\to\pi}}{N_{\pi}}$)	Mis-ID Efficiency ($\frac{N_{\pi\to\mu}}{N_{\pi}}$)
1	0.752747	0.962042	**0.037958**
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5	0.997934	0.984391	**0.015609**
10	0.997733	0.990938	**0.009062**

▼ Taking muon and pion flux into account based on PYTHIA8 ep 18×275 GeV^2 10M in high divergence mode

Momentum [GeV/c]	Muon Efficiency	Mis-ID Rate ($\frac{\{(N_{\pi\to\mu})*(\text{cross section})\}}{N_{\mu\to\mu}+\{(N_{\pi\to\mu})*(\text{cross section})\}}$)	Signal-to-Background ($\frac{N_{\mu\to\mu}}{\{(N_{\pi\to\mu})*(\text{cross section})\}}$)
1	0.752747	**0.96185097**	**0.03966210**
2	0.987315	**0.83715130**	**0.19452720**
5	0.997934	**0.84250306**	**0.18693931**
10	0.997733	**0.69081573**	**0.44756403**

Here, assuming muon and pion have the same kinematic

Results

▼For same sample size (η = 2.44 or θ = 10°)

Momentum [GeV/c]	Muon Efficiency ($\frac{N_{\mu\to\mu}}{N_\mu}$)	Background Rejection Efficiency ($\frac{N_{\pi\to\pi}}{N_\pi}$)	Mis-ID Efficiency ($\frac{N_{\pi\to\mu}}{N_\pi}$)
1	0.988104	0.941976	**0.058024**
2	0.994872	0.973376	**0.026624**
5	0.999282	0.981273	**0.018727**
10	0.998664	0.988116	**0.011884**

▼ Taking muon and pion flux into account based on PYTHIA8 ep 18×275 GeV^2 10M in high divergence mode

Momentum [GeV/c]	Muon Efficiency	Mis-ID Rate ($\frac{\{(N_{\pi\to\mu})*(\text{cross section})\}}{N_{\mu\to\mu}+\{(N_{\pi\to\mu})*(\text{cross section})\}}$)	Signal-to-Background ($\frac{N_{\mu\to\mu}}{\{(N_{\pi\to\mu})*(\text{cross section})\}}$)
1	0.988104	**0.98130770**	**0.019048355**
2	0.994872	**0.94883742**	**0.053921339**
5	0.999282	**0.91007070**	**0.098815732**
10	0.998664	**0.90786056**	**0.10149074**

Here, assuming muon and pion have the same kinematic

Results

▼For same sample size (η = 2.02 or θ = 15°)

Momentum [GeV/c]	Muon Efficiency ($\frac{N_{\mu\to\mu}}{N_\mu}$)	Background Rejection Efficiency ($\frac{N_{\pi\to\pi}}{N_\pi}$)	Mis-ID Efficiency ($\frac{N_{\pi\to\mu}}{N_\pi}$)
1	0.990663	0.942297	**0.057703**
2	0.994655	0.975953	**0.024047**
5	0.998992	0.982516	**0.017484**
10	0.998665	0.98817	**0.01183**

▼ Taking muon and pion flux into account based on PYTHIA8 ep 18×275 GeV^2 10M in high divergence mode

Momentum [GeV/c]	Muon Efficiency	Mis-ID Rate ($\frac{\{(N_{\pi\to\mu})*(\text{cross section})\}}{N_{\mu\to\mu}+\{(N_{\pi\to\mu})*(\text{cross section})\}}$)	Signal-to-Background ($\frac{N_{\mu\to\mu}}{\{(N_{\pi\to\mu})*(\text{cross section})\}}$)
1	0.990663	**0.97494293**	**0.025701063**
2	0.994655	**0.92331146**	**0.083058144**
5	0.998992	**0.85503156**	**0.16954747**
10	0.998665	**0.92076537**	**0.086053012**

Here, assuming muon and pion have the same kinematic

Results

▼For same sample size (η = 1.51 or θ = 25°)

Momentum [GeV/c]	Muon Efficiency ($\frac{N_{\mu\to\mu}}{N_\mu}$)	Background Rejection Efficiency ($\frac{N_{\pi\to\pi}}{N_\pi}$)	Mis-ID Efficiency ($\frac{N_{\pi\to\mu}}{N_\pi}$)
1	**0.00057**	0.879435	**0.120565**
2	0.998268	0.940588	**0.059412**
5	0.998201	0.982762	**0.017238**
10	0.998999	0.990299	**0.009701**

▼ Taking muon and pion flux into account based on PYTHIA8 ep 18×275 GeV^2 10M in high divergence mode

Momentum [GeV/c]	Muon Efficiency	Mis-ID Rate ($\frac{\{(N_{\pi\to\mu})*(\text{cross section})\}}{N_{\mu\to\mu}+\{(N_{\pi\to\mu})*(\text{cross section})\}}$)	Signal-to-Background ($\frac{N_{\mu\to\mu}}{\{(N_{\pi\to\mu})*(\text{cross section})\}}$)
1	0.00057	**0.99998970**	**0.00001030**
2	0.998268	**0.94628411**	**0.056765082**
5	0.998201	**0.83955145**	**0.19111224**
10	0.998999	**0.57443008**	**0.74085591**

Path Forward for Muon ID Study

There might be another suppression factor to muon identification

In case of Hard Exclusive Meson Productions

- Pair reconstruction such as $J/\psi \rightarrow \mu^{+}\mu^{-}$ may have better chance on reducing background (invariant mass)

Next Step

Use PYTHIA events (electroproduction Q^2 > 1 GeV) with 3 tracks in main detector

**J/ψ di-muon (J/ψ, ϕ, ρ, Υ, etc) and photoproduction Q^2 < 1 GeV

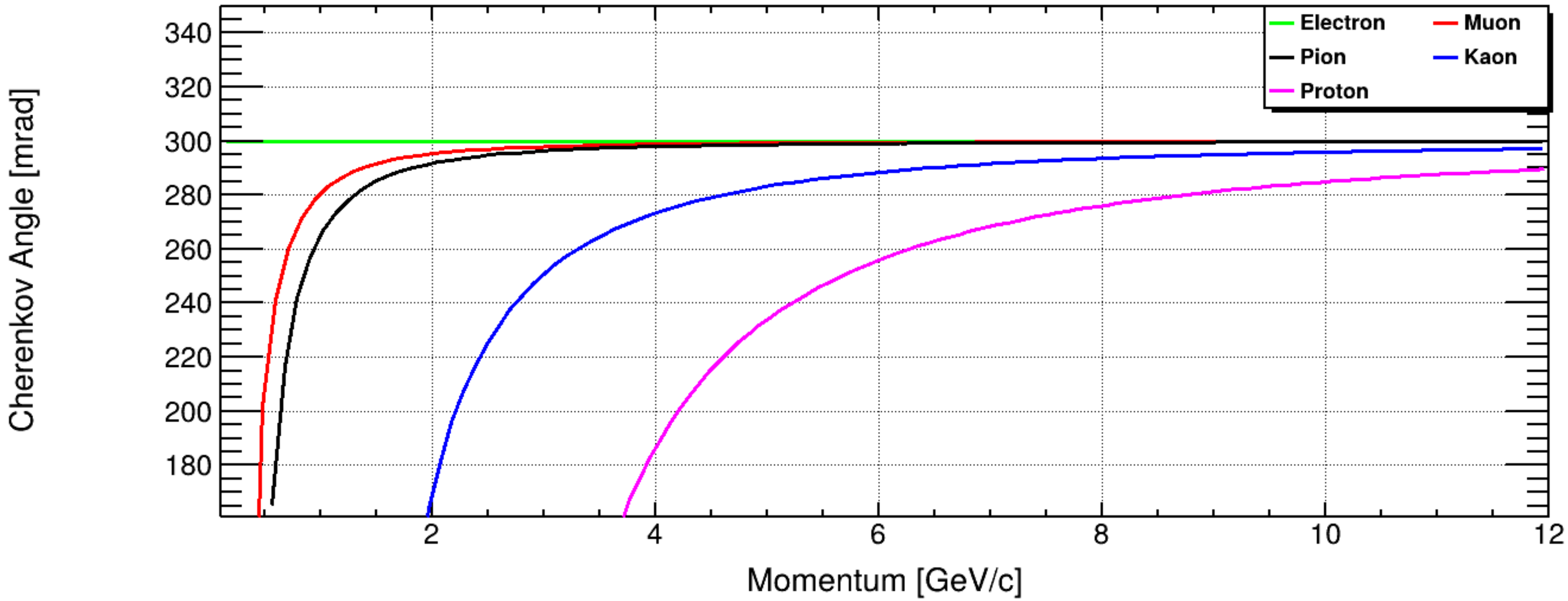
Match tracks to calorimeter clusters, Look at calorimeter information, and Select events have MIP-like response (exclude shower-like in calorimeter)

Do invariant mass reconstruction to check

What about Adding PID Detector Information?

Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.045 (pfRICH)



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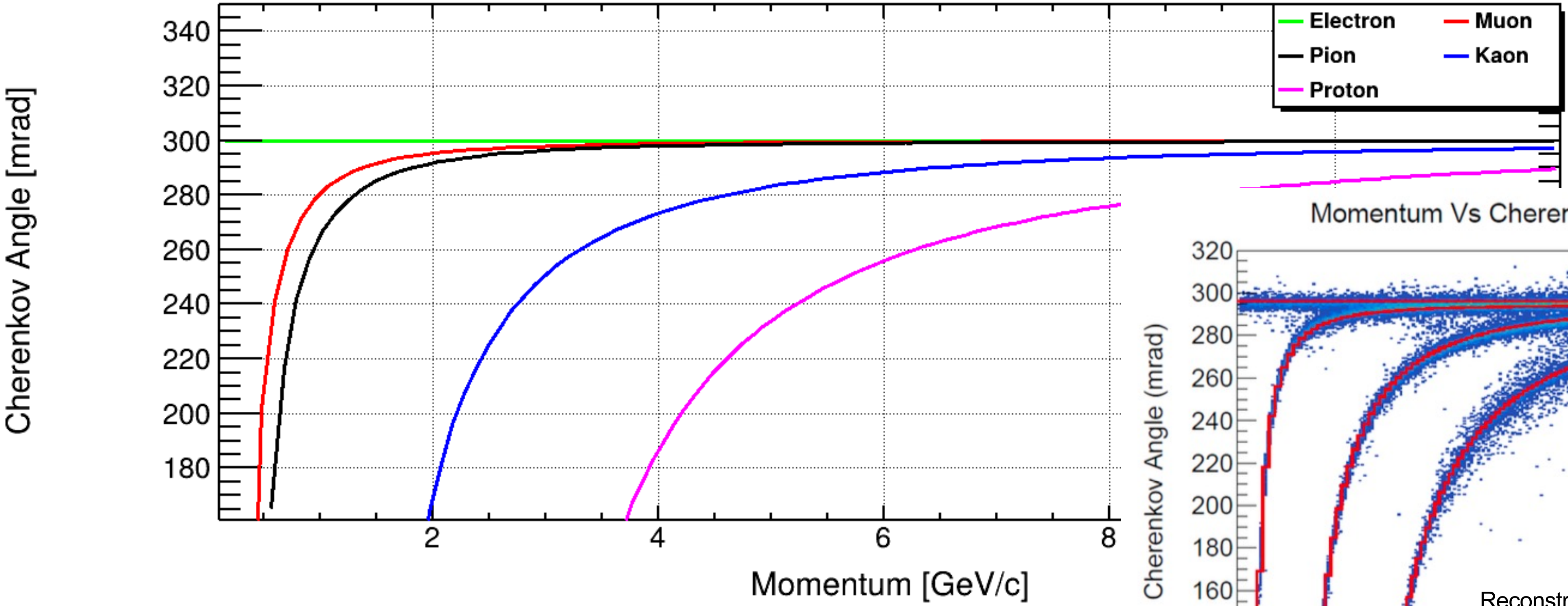
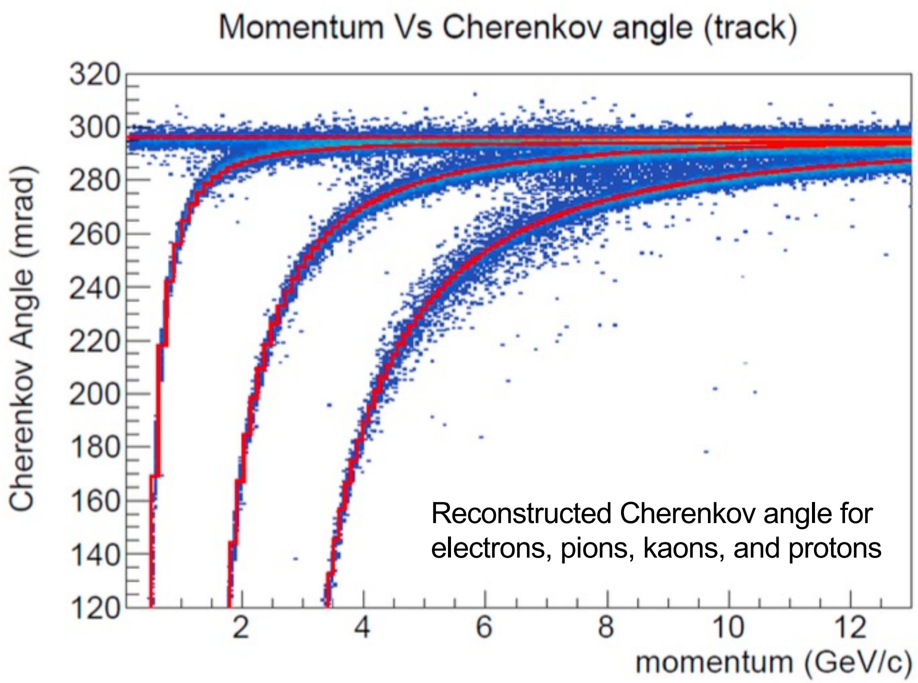
Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.045 (pfRICH)

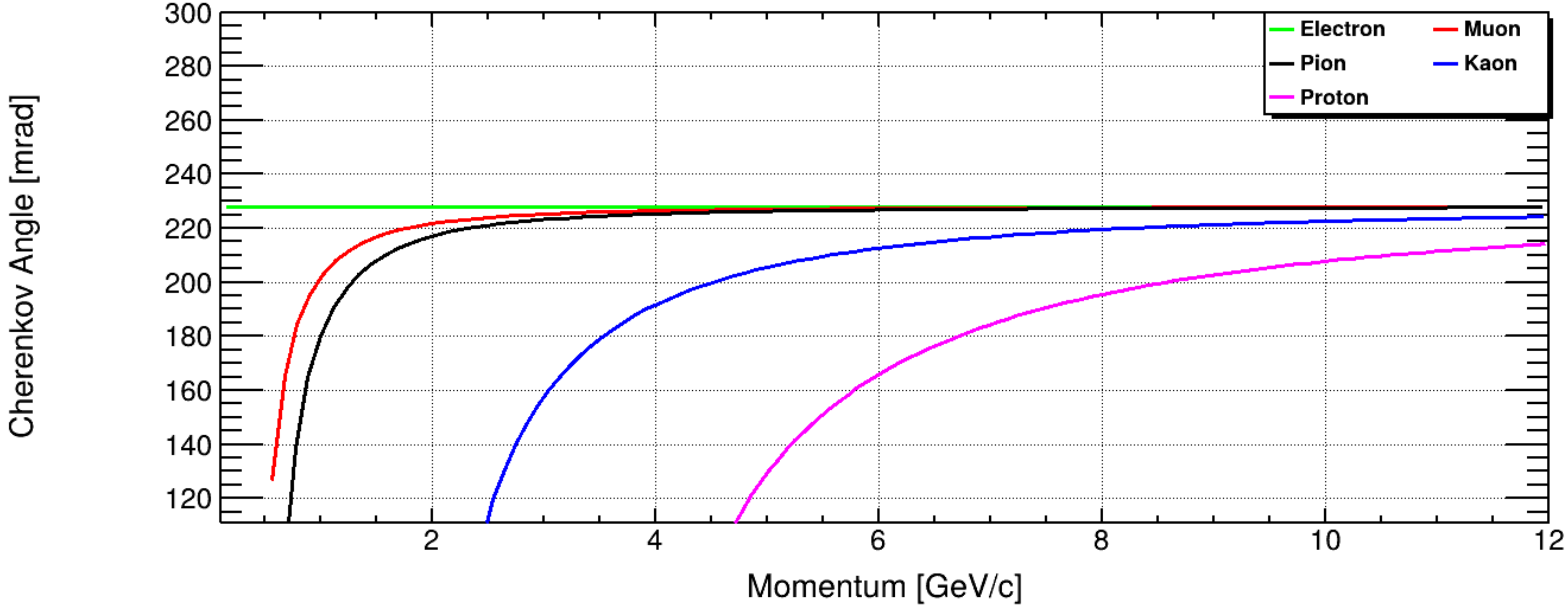




Taken from EIC PDR v.1 (Figure 8.68 on page 129)

Estimate PID Performance

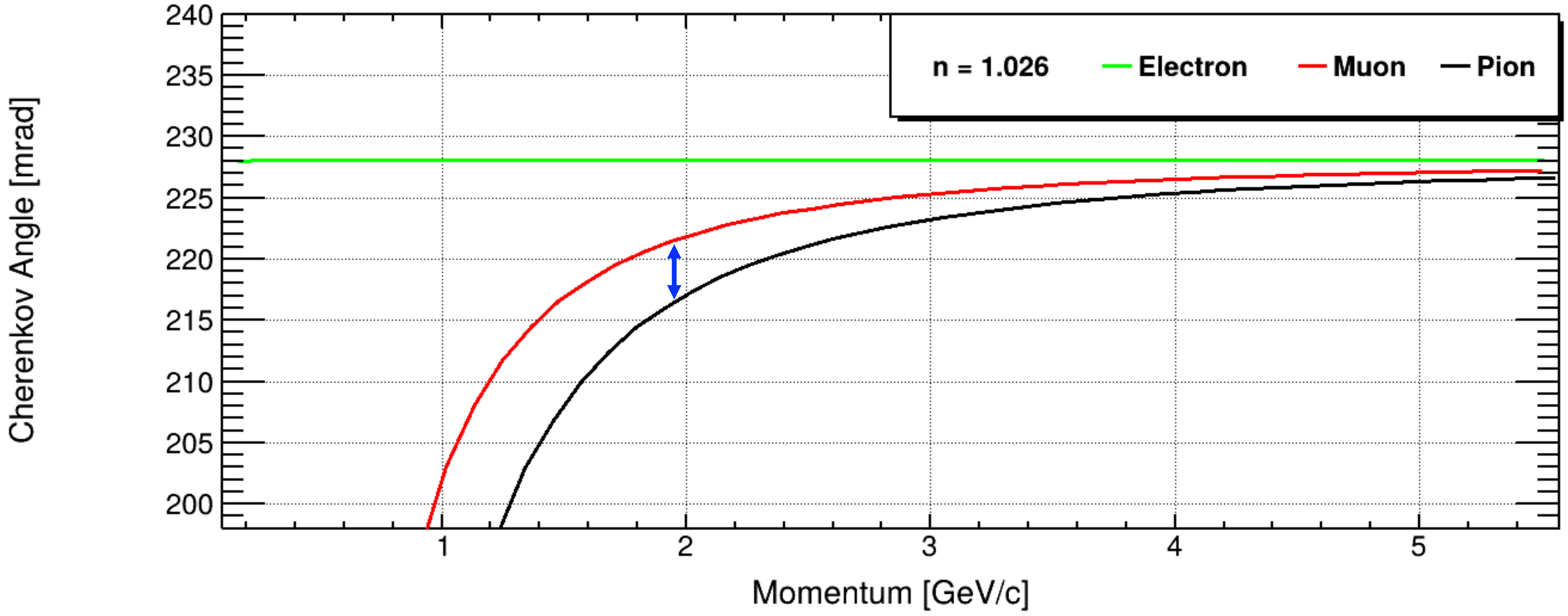
Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.026 (dRICH)



According to Chandra Chatterjee, n = 1.026 (baseline 1.019)
Aerogel single photon resolution at n = 1.026 is ~ 2.4 mrad
Ring (track-level) resolution ~ 0.5 mrad
Given we can detect 15 photons

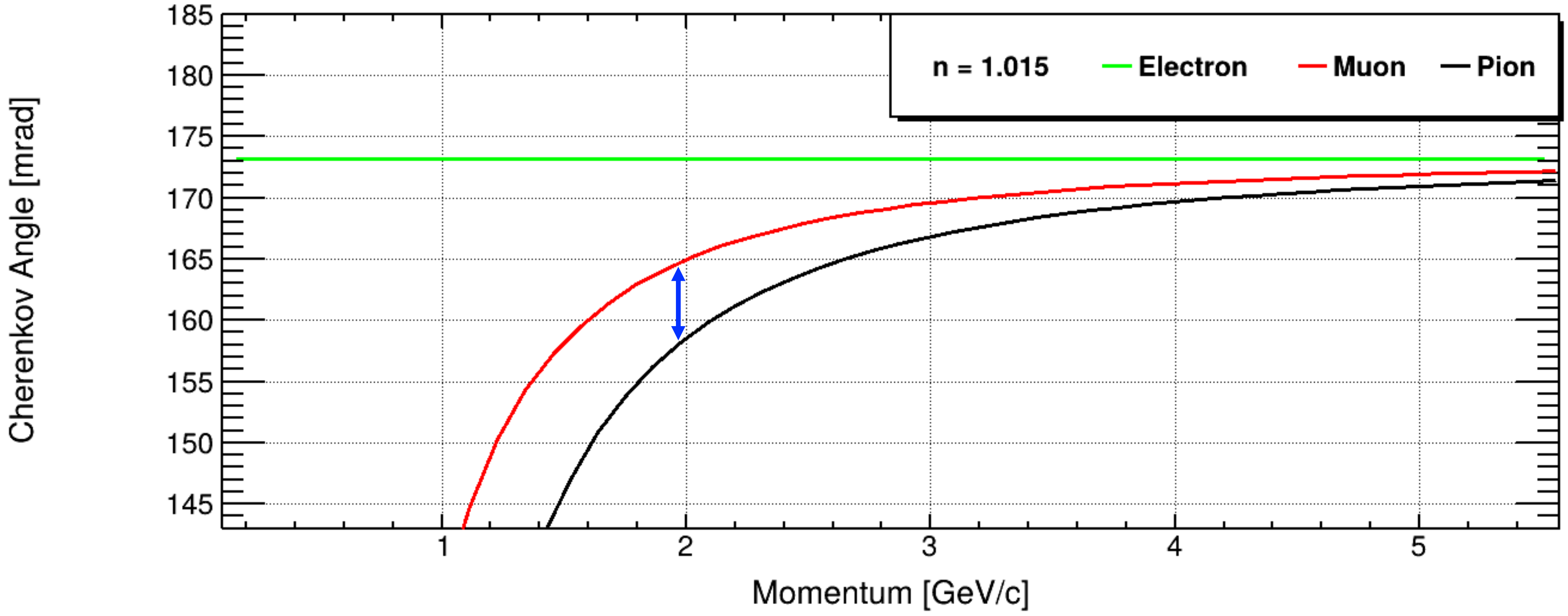
Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.026 (dRICH)



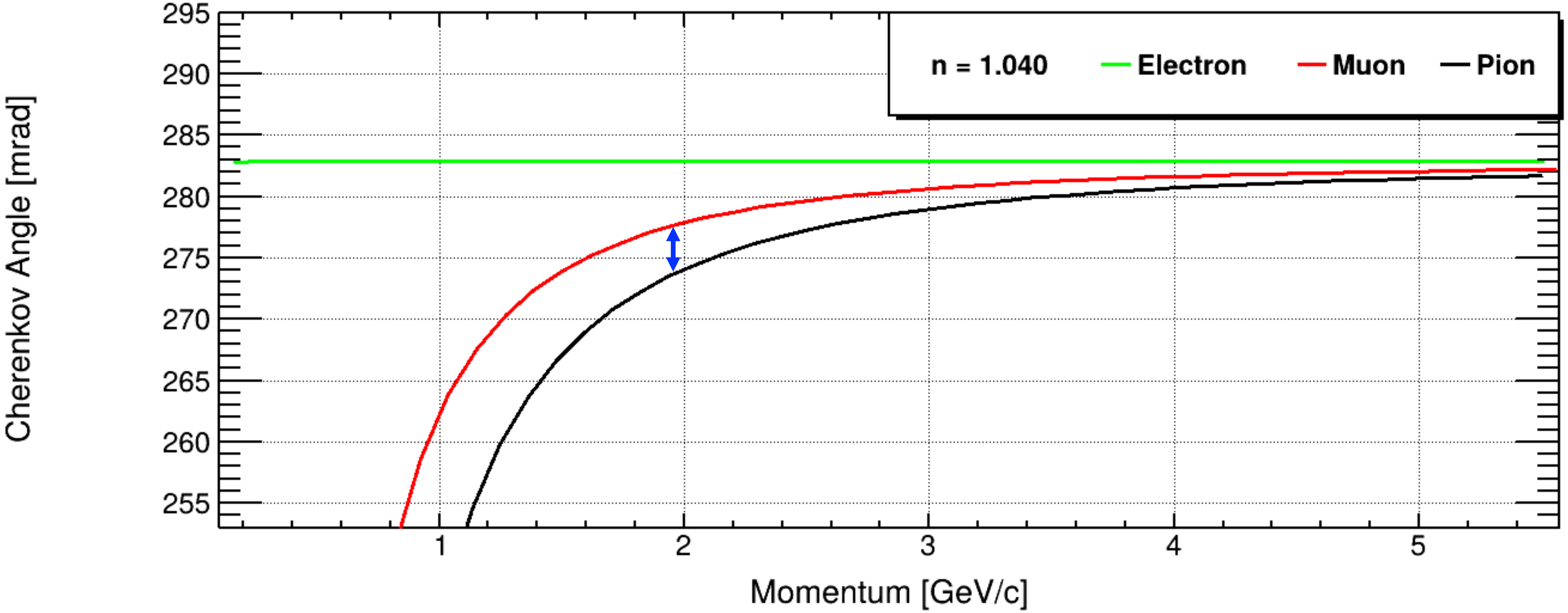
Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.015 (lower than dRICH)



Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.040 (higher than dRICH)



Estimate PID Performance

▼ Muon and pion separation in Cherenkov Angle

	n = 1.015	n = 1.026	n = 1.040
p = 1.5 GeV	12.1446 [mrad]	8.69475 [mrad]	6.83120 [mrad]
p = 2.0 GeV	6.42687 [mrad]	4.73642 [mrad]	3.76644 [mrad]
p = 2.5 GeV	4.00843 [mrad]	2.98872 [mrad]	2.38896 [mrad]
p = 3.0 GeV	2.74643 [mrad]	2.05997 [mrad]	1.65104 [mrad]
p = 3.5 GeV	2.00184 [mrad]	1.50669 [mrad]	1.20952 [mrad]

- In ePIC baseline aerogel refraction index ~ 1.019
- However, n = 1.026 performs better because of optical quality of material improvement (CLAS12 n = 1.019)
- Aerogel single photon resolution for 1.026 ~ 2.4 mrad (where for 1.019 ~ 3 mrad)
- With aerogel 1.026 we gain ~ 50 % more photons compared to 1.019
- Regarding ring (track-level) resolution, it depends on thickness optimization of aerogel (4 cm and 6 cm were studied). Resolution 0.5 mrad and given we can detect 15 photons

To-Do List

- ❑ PYTHIA events to estimate background
- ❑ PID: Time-of-Flight

Backup Slides