Muon ID Study in the Forward region for EIC 2nd Detector

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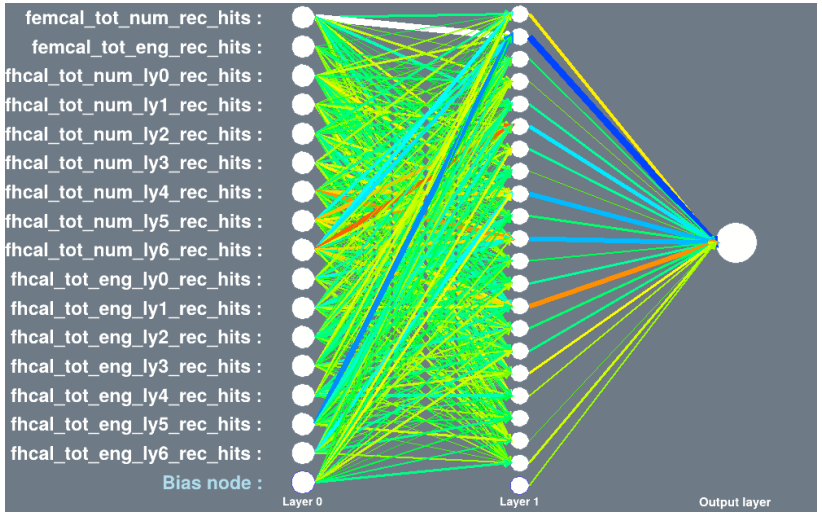
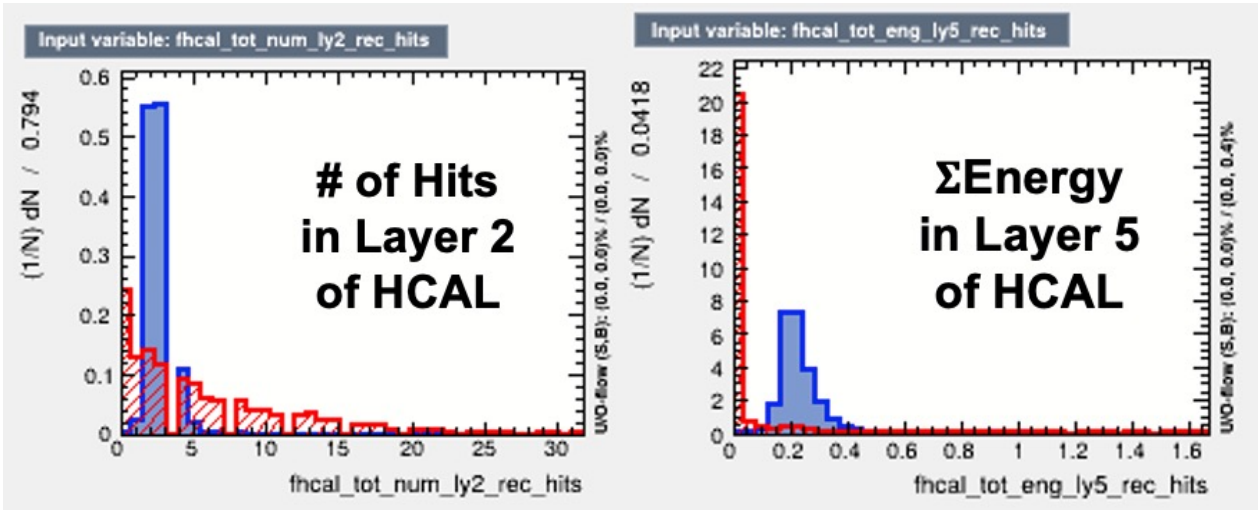
Hcal Muon ID Discussion

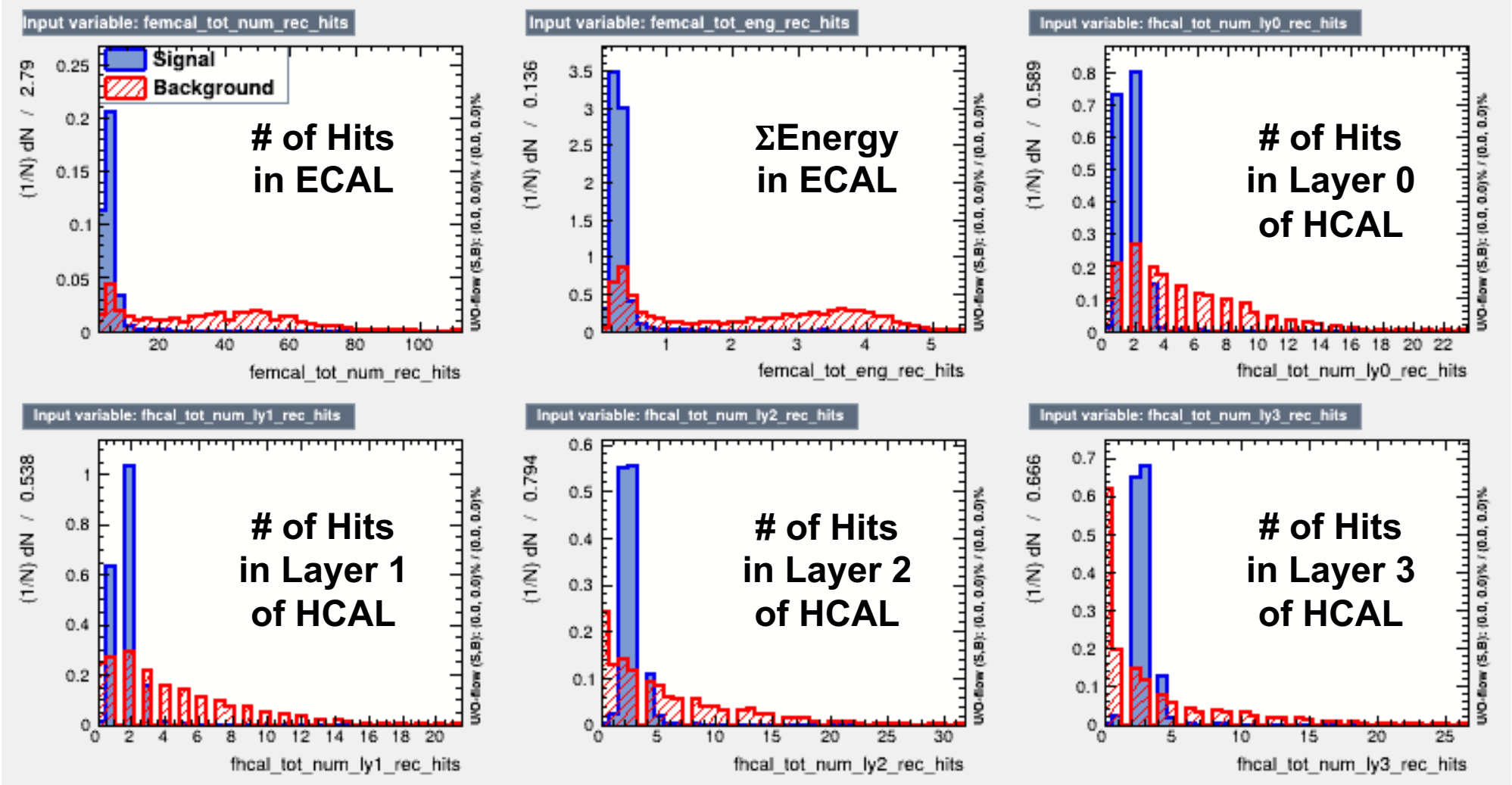
Approach – Evaluate Capabilities on μID

- Evaluate muon ID performance in the **forward** region at ePIC (CAL and PID)
- This study serves as a good example for applying Machine Learning with ROOT TMVA module
- Inputs – Use EMCAL and HCAL information to identify MIP-like events
  - EMCAL: Use energy and # of hits from the entire detector
  - HCAL: Use energy and # of hits from each individual layer





Input Distribution for 5 GeV μ^+ and π^+



Figures are normalized to show 1/N*dN/dx. So integral of histogram equals to 1.

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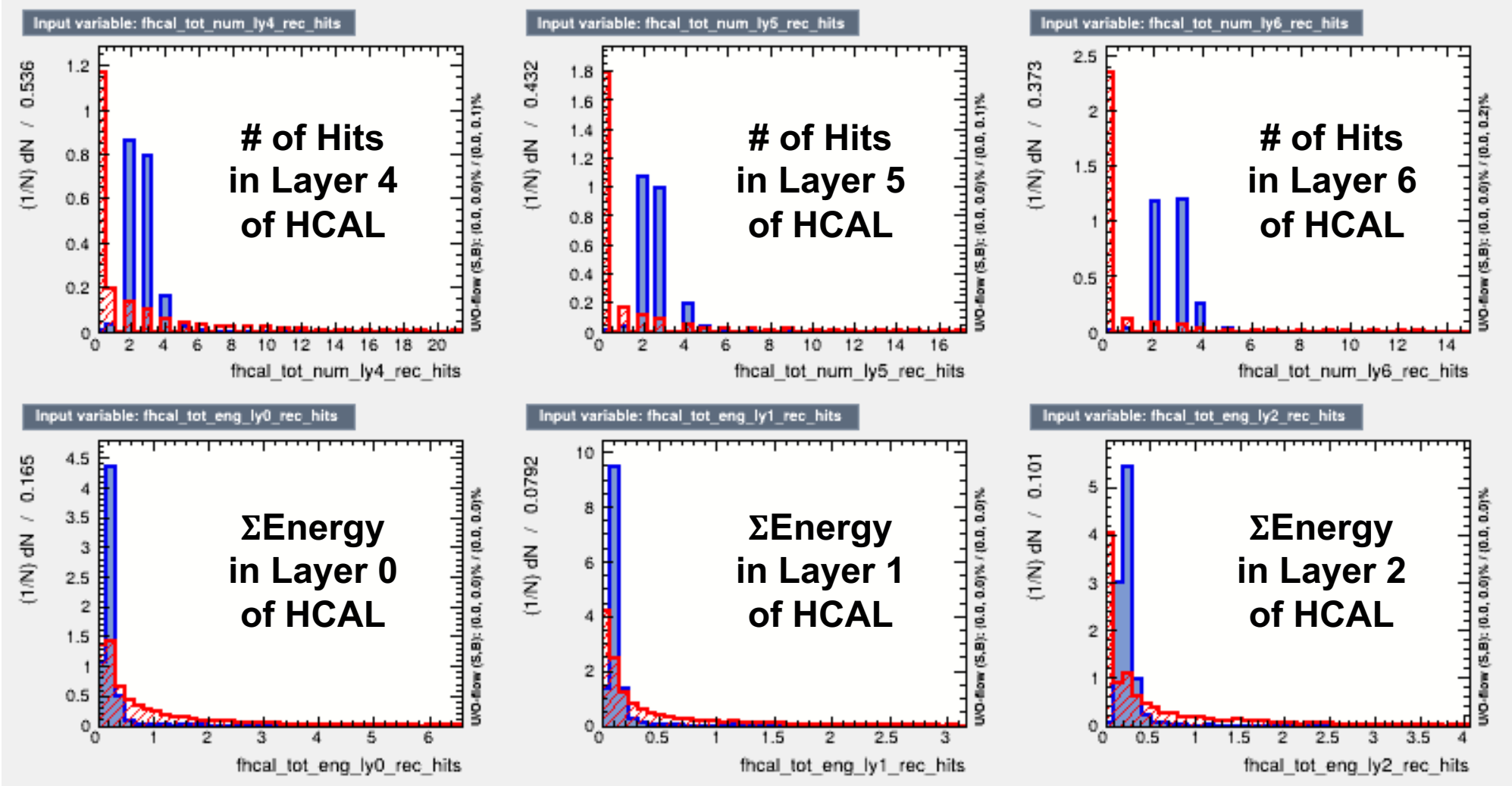

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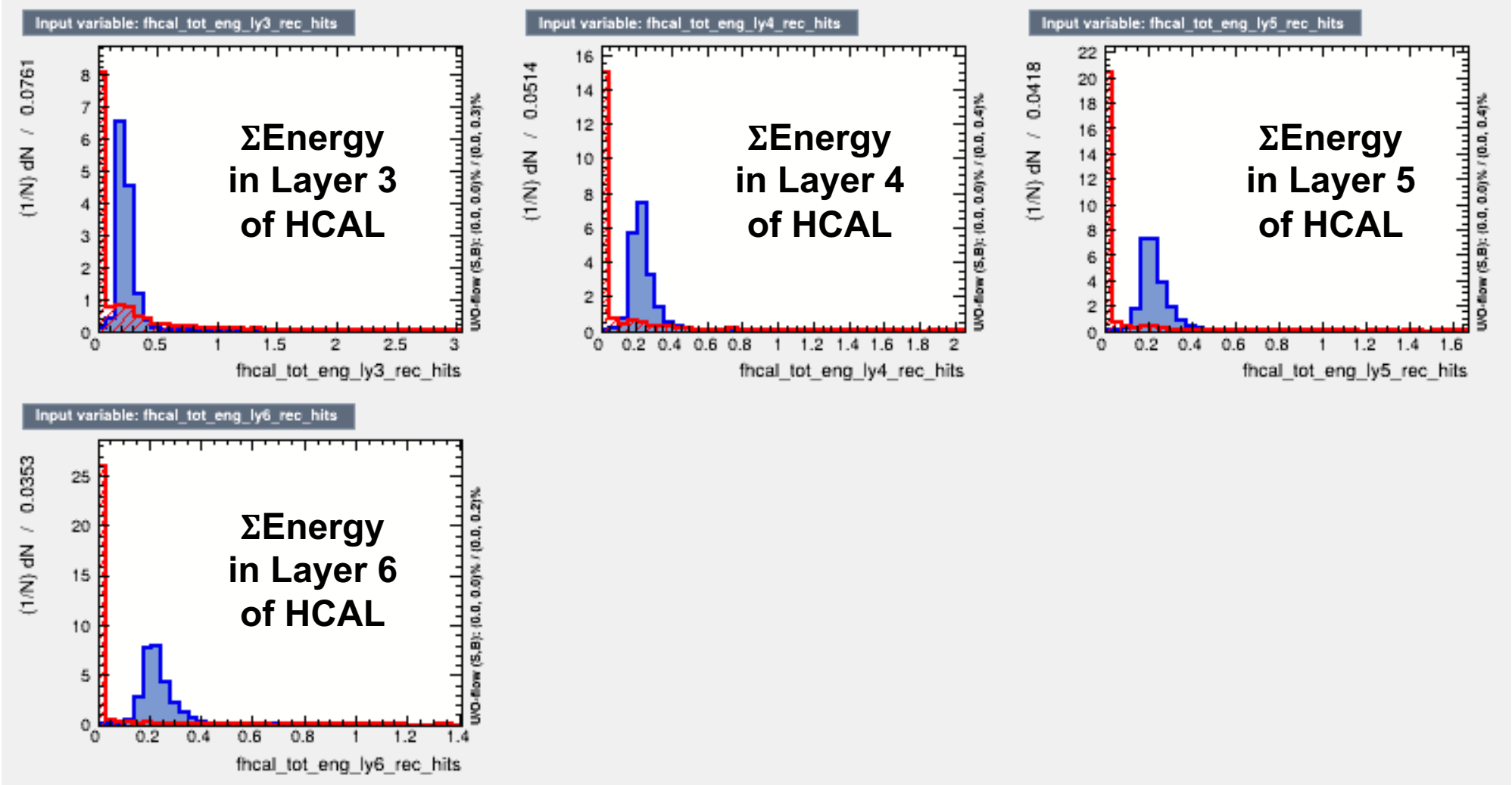

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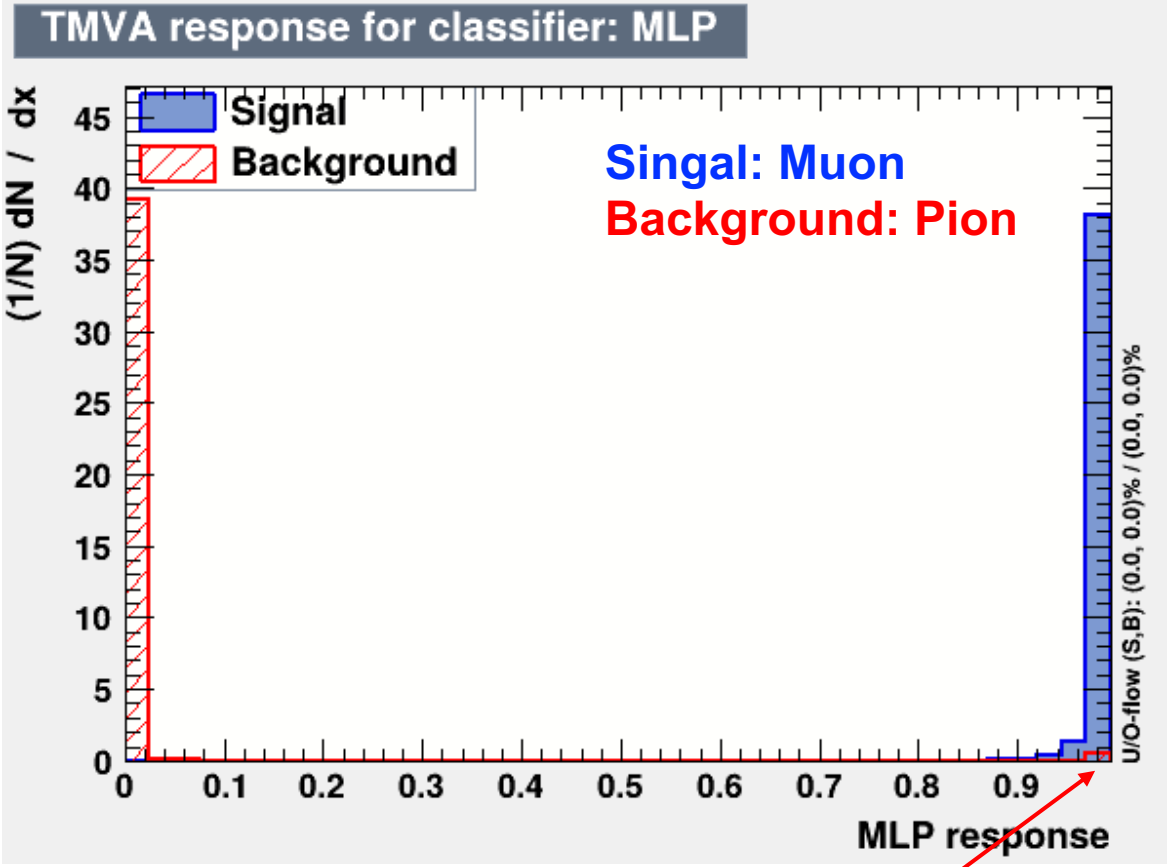
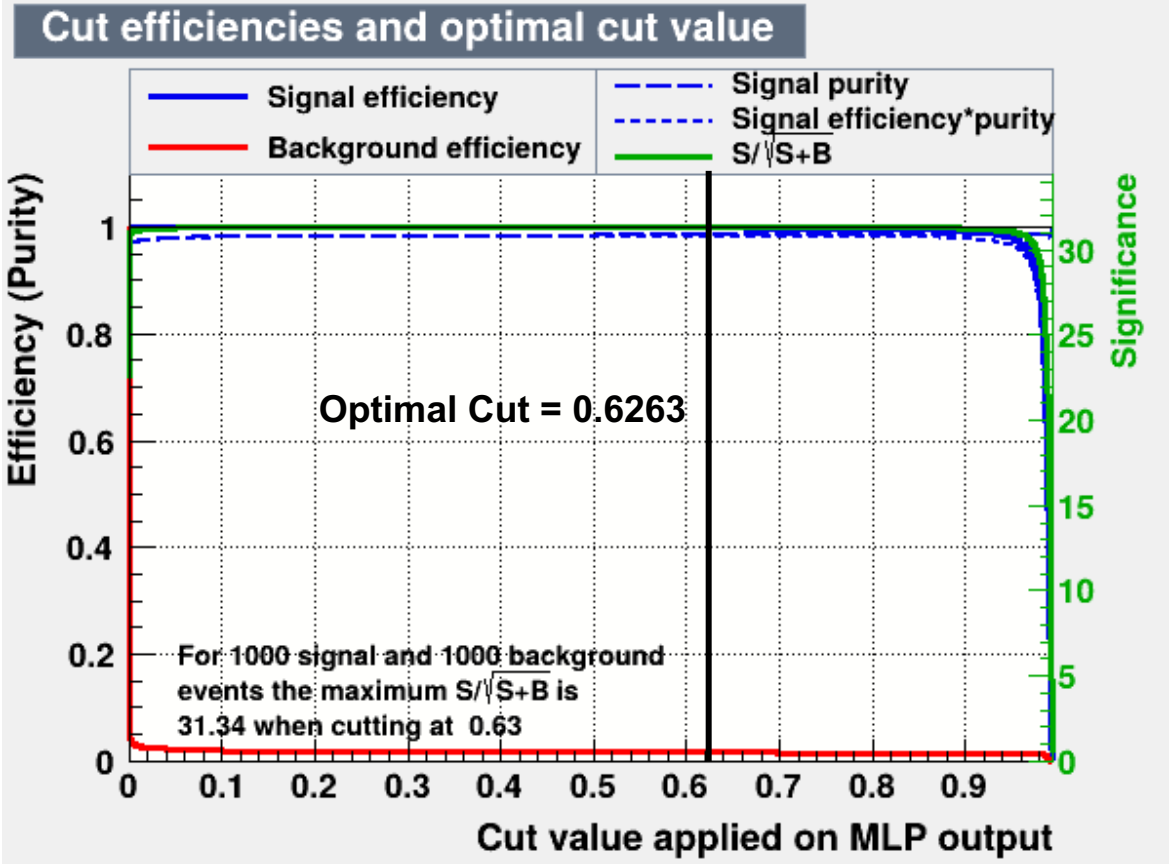
Singal/Background Efficiency for 5 GeV



MIP-like background (pions)



$\varepsilon_{Bg} = 0.016$ for $\varepsilon_{Sg} = 0.9982$

Results – Efficiency

Events with angle η = 1.74 or θ = 20°
Given 1M muon and 1M pion simulation samples

Muon Efficiency: Muon to Muon = $\frac{N_{\mu\to\mu}}{N_{\mu}}$

Background Rejection Efficiency: Pion to Pion = $\frac{N_{\pi\to\pi}}{N_{\pi}}$

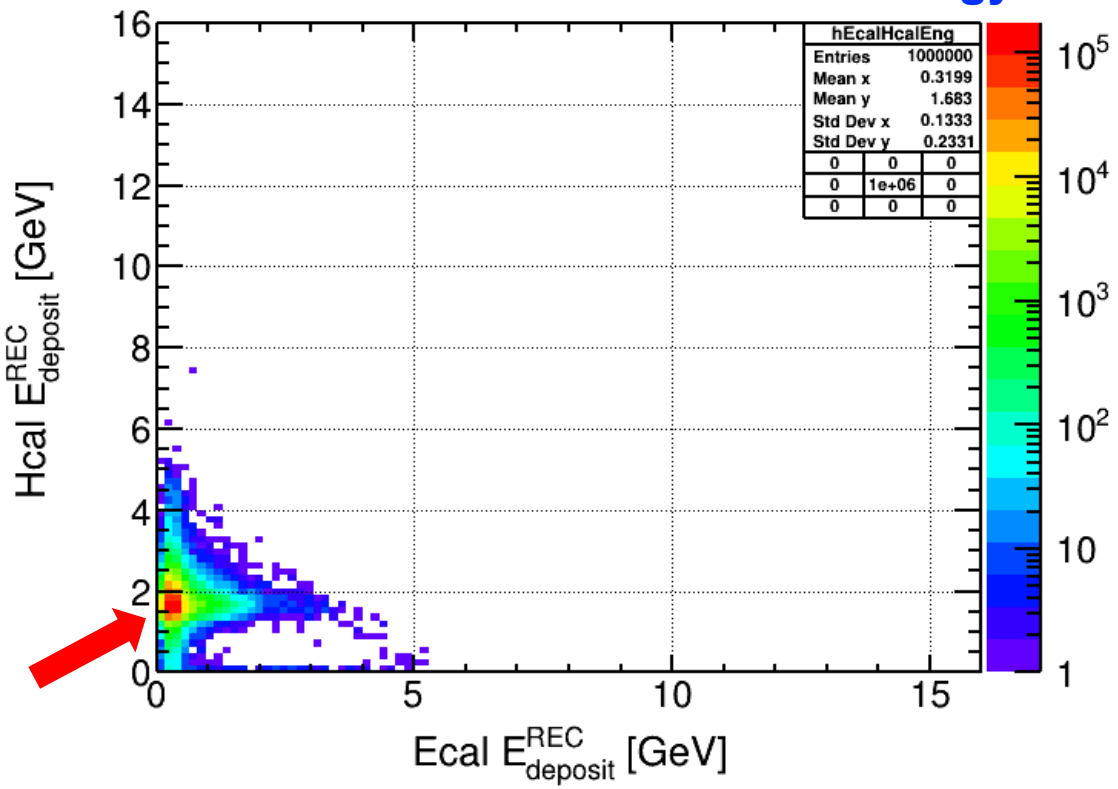
Mis-ID Efficiency: Pion to Muon = $\frac{N_{\pi\to\mu}}{N_{\pi}}$

Momentum [GeV/c]	Muon Efficiency	Background Rejection Efficiency	Mis-ID Efficiency
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**

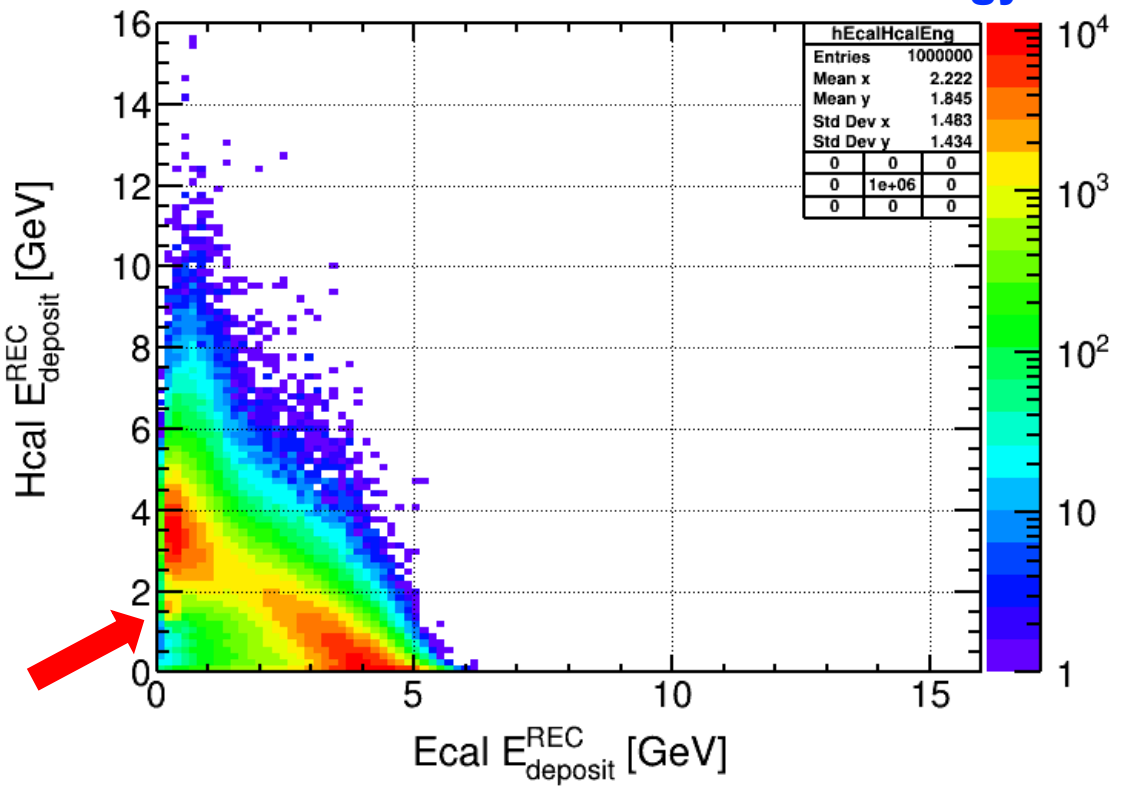
p = 5 GeV and η = 1.74

Reconstructed ΣEnergy in Forward

Muon
Σ Energy



Pion
Σ Energy



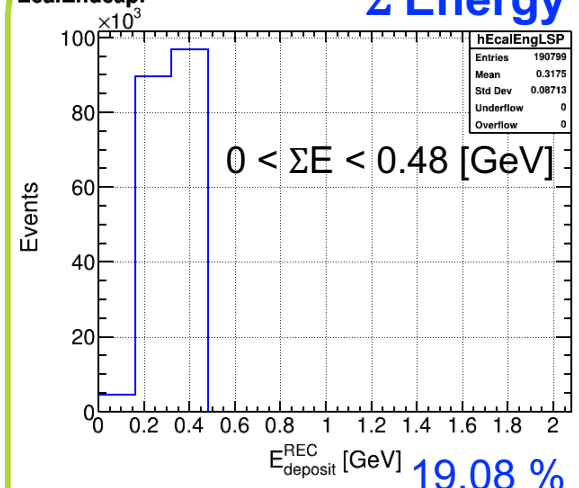
While muon sample has one hot spot, pion sample has three groups;
pions showering from ECAL, pions showering from HCAL, and pions not showering at all (MIP-like)

p = 5 GeV and η = 1.74

Pion Sample – Σ Energy

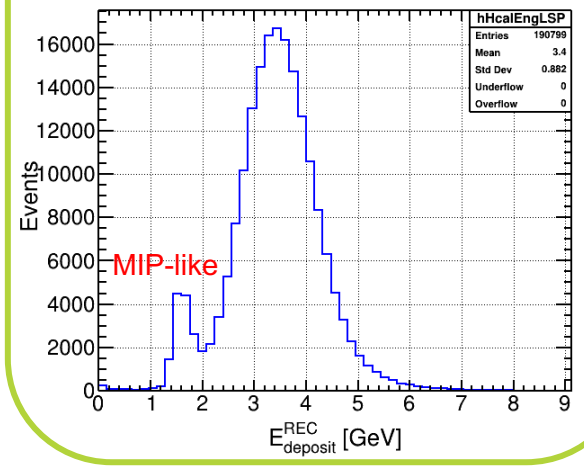
MIP-like in ECAL

Σ Energy



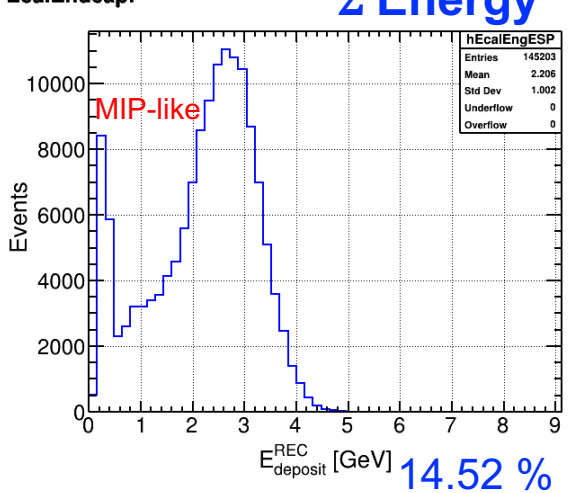
19.08 %

mis-ID efficiency



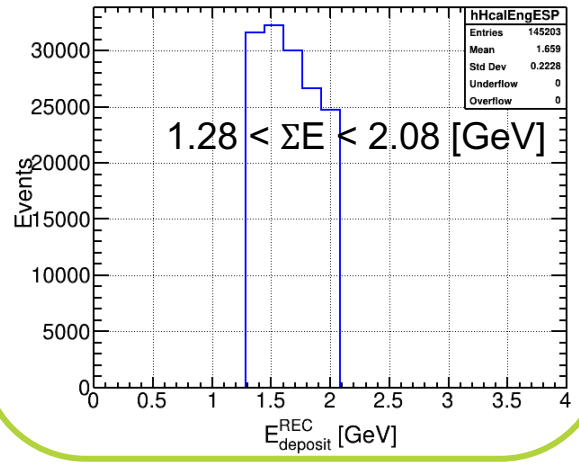
MIP-like in HCAL

Σ Energy



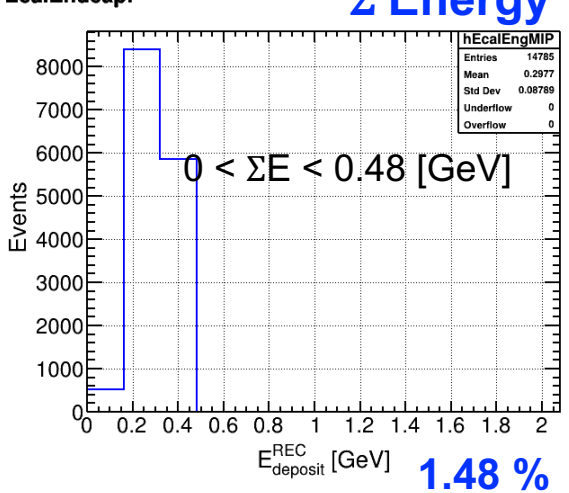
14.52 %

mis-ID efficiency



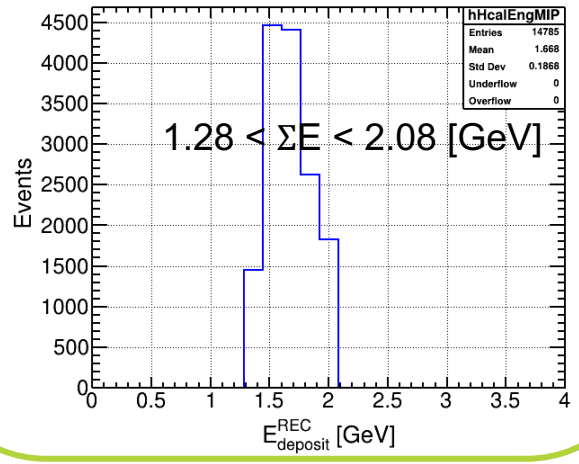
MIP-like in ECAL **&** HCAL

Σ Energy



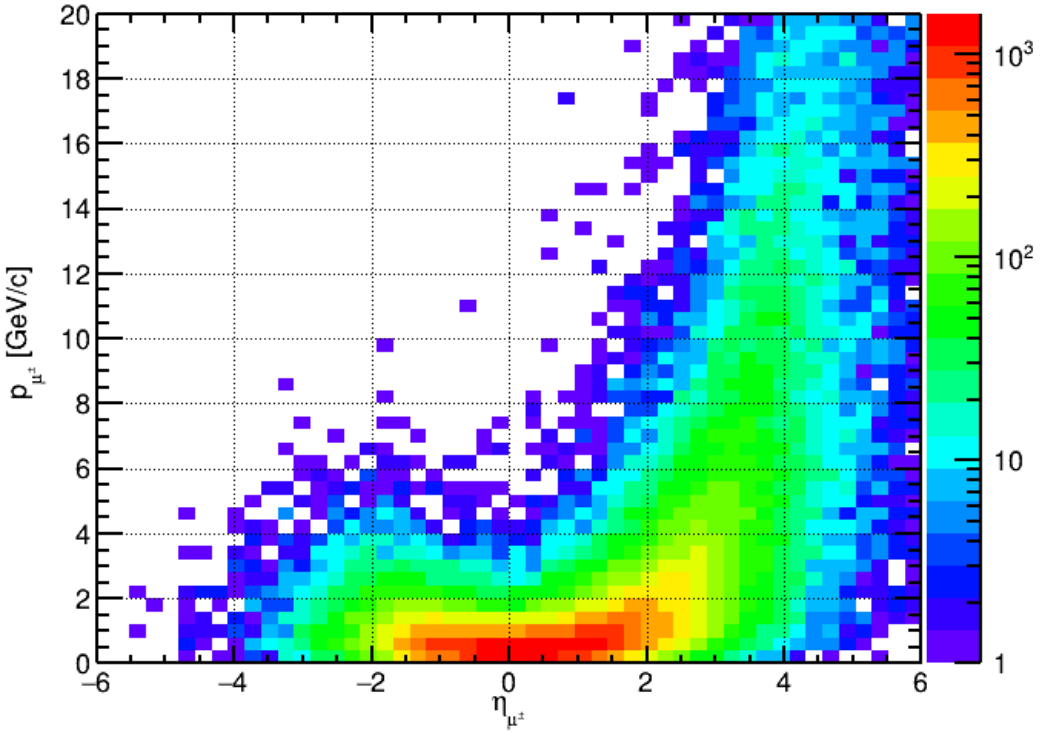
1.48 %

mis-ID efficiency

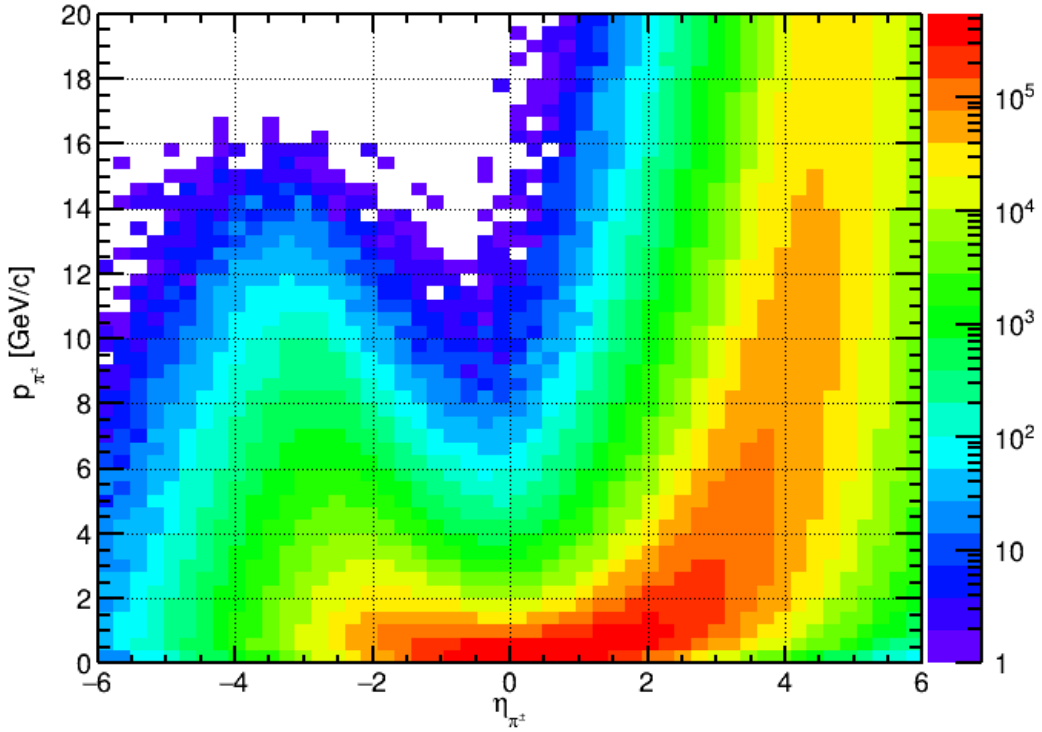


Cross Section from PYTHIA Sample

$\mu^{\pm}$



$\pi^{\pm}$



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

Results – With Cross Section

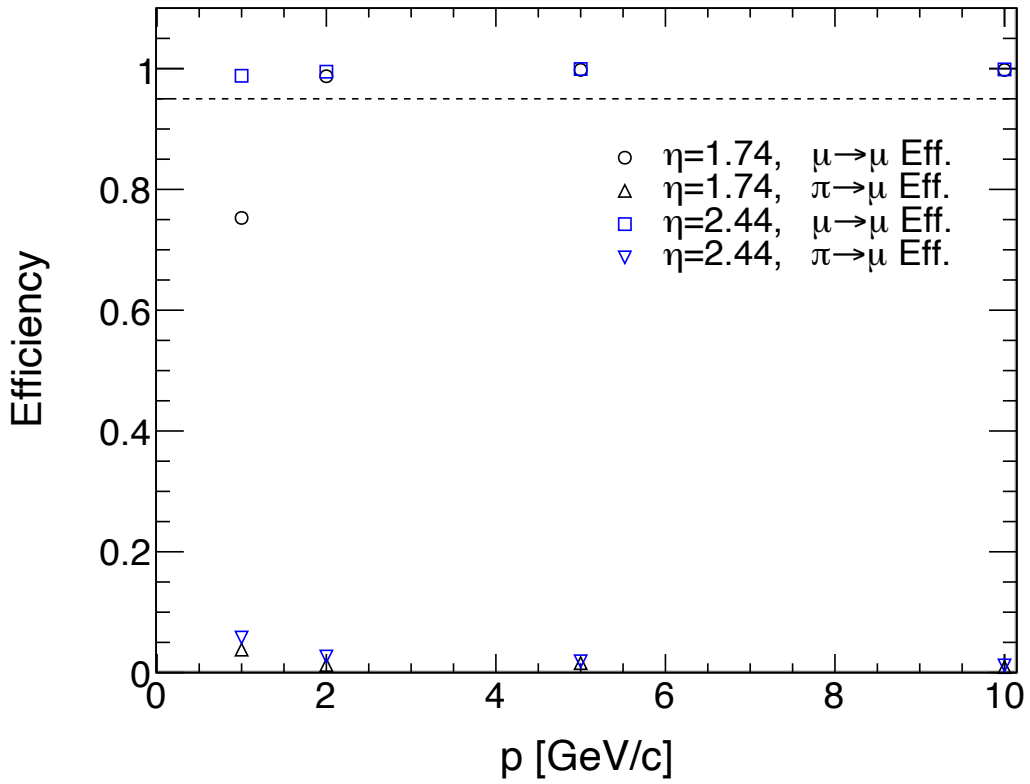
Events with angle η = 1.74 or θ = 20°
Given cross section from PYTHIA

Calculate **mis-ID rate** with **PYTHIA cross section**

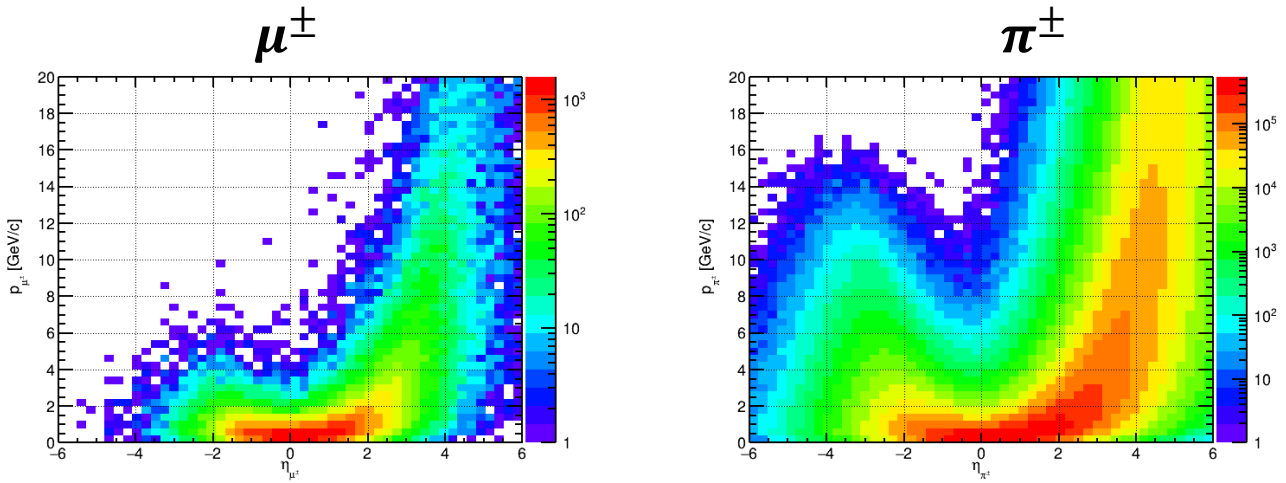
$$\textbf{Mis-ID Rate} = \frac{\{(N_{\pi\to\mu})*(\text{cross section})\}}{N_{\mu\to\mu}+\{(N_{\pi\to\mu})*(\text{cross section})\}}$$

Momentum [GeV/c]	Muon Efficiency	Background Rejection Efficiency	Mis-ID Rate
1	0.752747	0.962042	**0.96185097**
2	0.987315	0.987468	**0.83715130**
5	0.997934	0.984391	**0.84250306**
10	0.997733	0.990938	**0.69081573**

μID Efficiency with Calorimeter



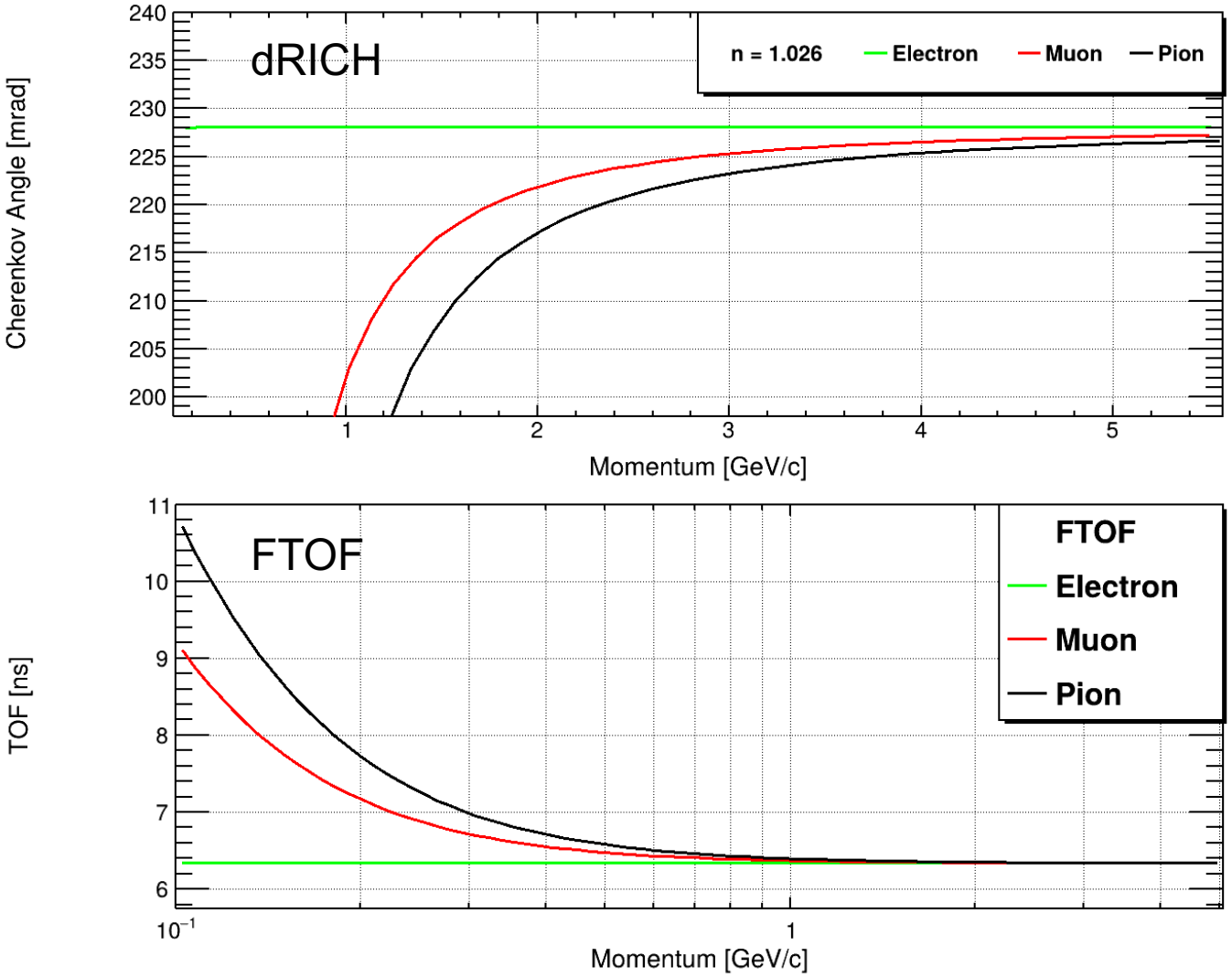
Cross Section from PYTHIA Sample



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

In forward (hadron-going) region,
muon mis-identification efficiency is less than 1 %
for given sample size of muons and pions
However,
when taking into account the cross section, **detecting single muons** using **only calorimeter (CAL)** information may still be challenging.

Potential PID Performance at ePIC



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

Assumed distance
(straight from IP to FTOF plane;
z_{min} = 185 cm and r_{max} = 60 cm)

Potential PID for μID

dRICH n = 1.026	Difference in Cherenkov Angle [mrad]	Estimated σ Level
p = 1.5 GeV/c	8.69475	17.4σ
p = 2.0 GeV/c	4.73642	9.5σ
p = 2.5 GeV/c	2.98872	6σ
p = 3.0 GeV/c	2.05997	4.1σ
p = 3.5 GeV/c	1.50669	**3σ**
FTOF d = IP to FTOF plane	**Difference in TOF [ns]**	**Estimated σ Level**
p = 1.0 GeV/c	0.0261519	0.87σ
p = 0.8 GeV/c	0.0406902	1.36σ
p = 0.7 GeV/c	0.0529574	1.77σ
p = 0.6 GeV/c	0.07169	2.39σ
p = 0.5 GeV/c	0.10232	**3.41σ**

Upper limit (3σ separation)

- dRICH
  - μ/π up to 3.5 GeV/c
- FTOF
  - μ/π up to 0.5 GeV/c

dRICH could be helpful for low momentum (below 3.5 GeV/c)

Based on ring (track-level) resolution ~ 0.5 mrad
(given we can detect 15 photons)
Based on FTOF resolution 30 ps

A hint of μ/π separation in PID at low-momentum

For EIC 2nd Detector,

With upgrade PID detector, it can anticipate better chance

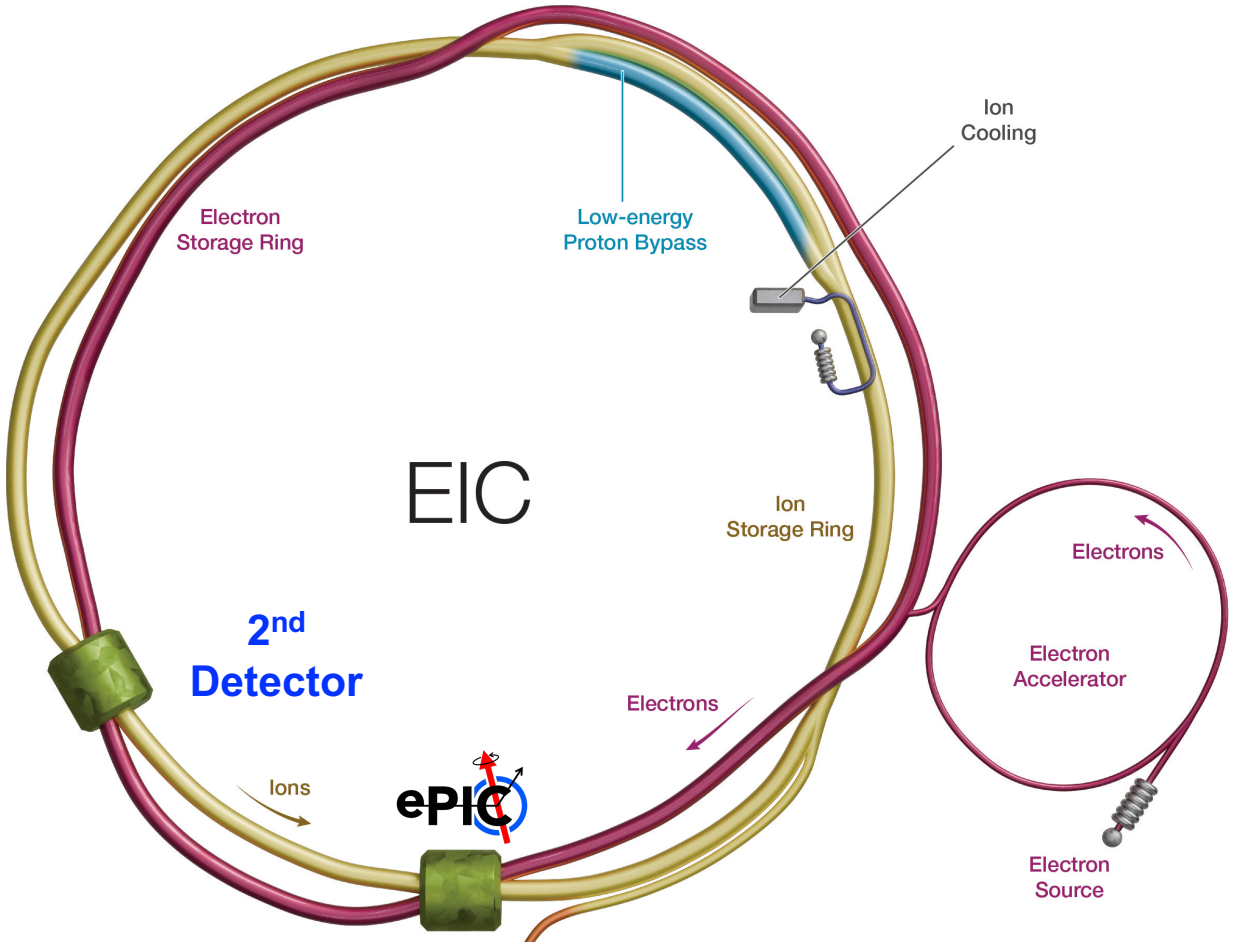
Summary

- In forward region (hadron-going),
  - Single muon detection using only calorimeter might be challenging
  - Pair reconstruction such as $J/\psi \rightarrow \mu^+\mu^-$ may have better chance on reducing background (invariant mass)
- Question: what physics needs muon detection?
  - Potential BSM Physics: Charged Lepton Flavor Violation $ep \rightarrow \tau/\mu\, X$
  - Promising ID channel: $\tau \rightarrow \mu\overline{\nu_\mu}\nu_\tau$: Larger branching ratio ~17%, suppression of SM background → Momentum or Kinematics of muons?
- There might be room for improvement
  - More inputs such as shower profile parameters, PID information
  - Low-momentum muons: Better resolution for PID detector
  - Intermediate/High-momentum muons: Deeper Calorimeter

Backup Slides

EIC 2nd Detector Motivation

- Capable of accommodate **two** detectors and **two** interaction regions (IP6 and IP8)
- **ePIC**: **One** detector and **one** interaction region supported by DOE-NP project
- Community is strongly in favor of
  - Two general purpose detectors
  - **BNL's Laboratory Directed Research and Development**
- Complementarity
  - Cross-checking, cross-calibration, **primary physics focus**, and **technology redundance**



https://www.bnl.gov/eic/