Muon Detection Study in the forward region at ePIC (for 2nd Detector)

Jihee Kim (jkim11@bnl.gov)

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Approach

- Pass-0
  - Two layers: Ecal and Hcal as a whole
  - Focus on energy
    - Reconstructed hit level (calibrated and sampling fraction applied)

- Information on Calorimeters in the forward
  - fEMCal - WScFi ($1.4 \leq \eta \leq 3.9$) coverage with $12\%/\sqrt{E} \oplus 2\%$
    - 23 X_0 (ref. X_0 = 7 mm) and 2.5 cm × 2.5 cm in transverse direction
  - LFHCal – steel-plastic scintillator sandwich ($1.2 < \eta < 3.5$) coverage
    - 6.5 λ/λ_0 and 5 cm × 5 cm in transverse direction
    - SiPM signals from tiles in 5-10 consecutive layers are summed up before digitization

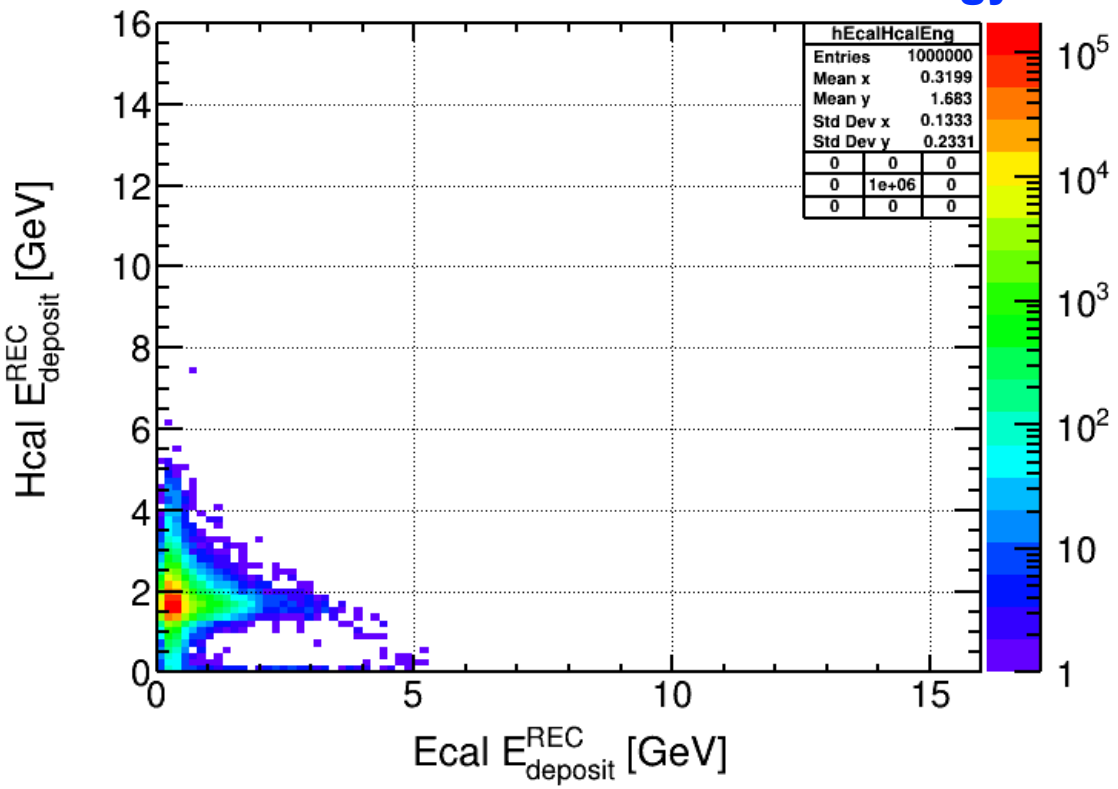
ePIC Simulation – μ^+ and π^+

ex) 5 GeV at η = 1.74 (θ = 20°)

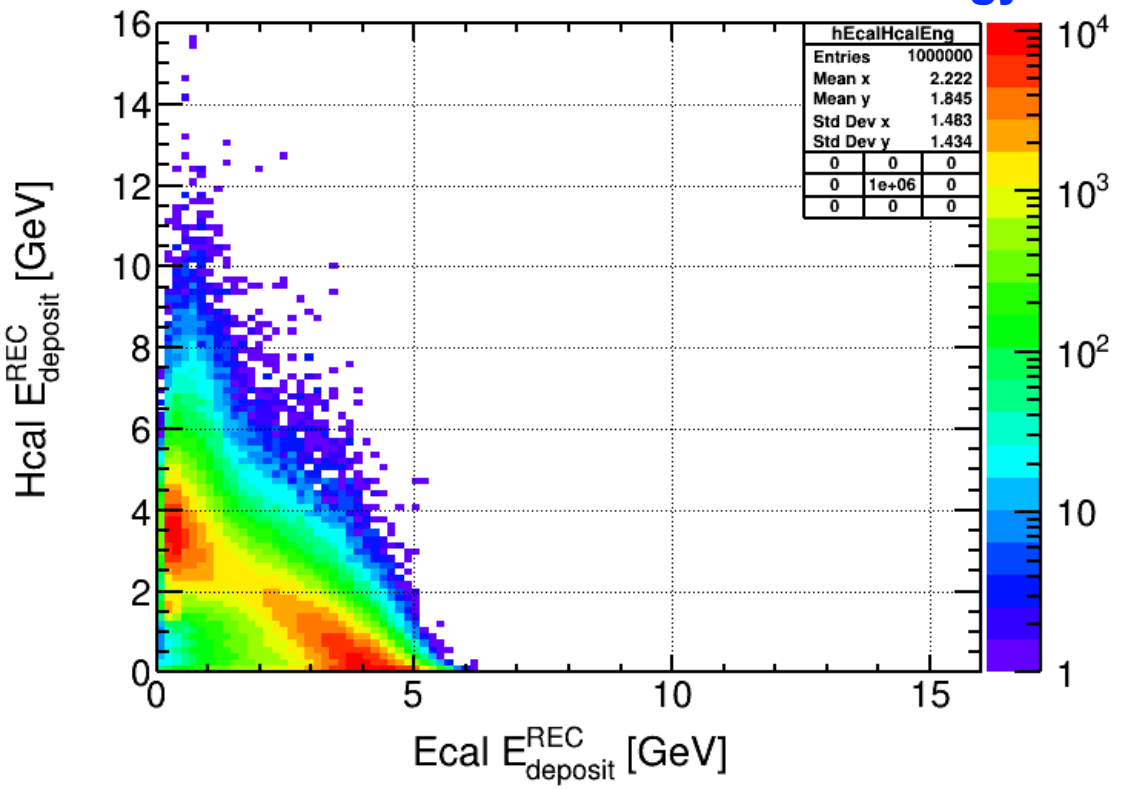
p = 5 GeV and η = 1.74

Reconstructed Energy in Forward

Muon
Σ Energy



Pion
Σ Energy

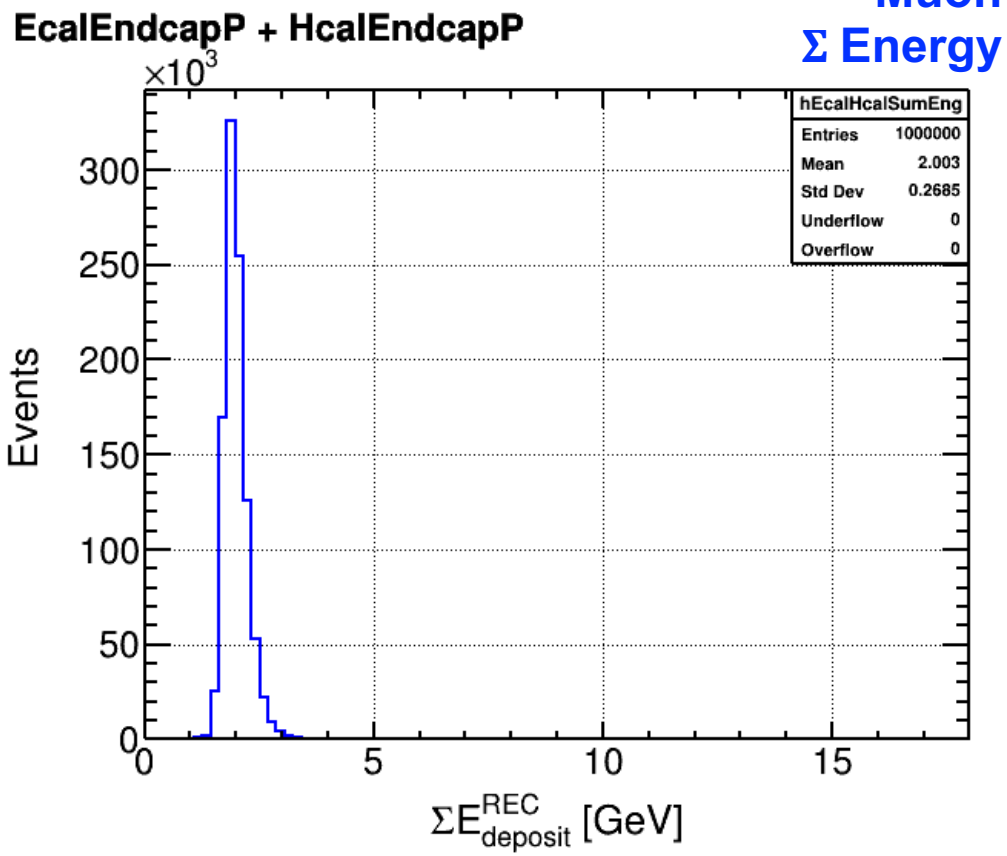


While muon sample has one hot spot, pion sample has three groups;
pions showering from ECAL, pions showering from HCAL, and pions not showering at all (MIP-like)

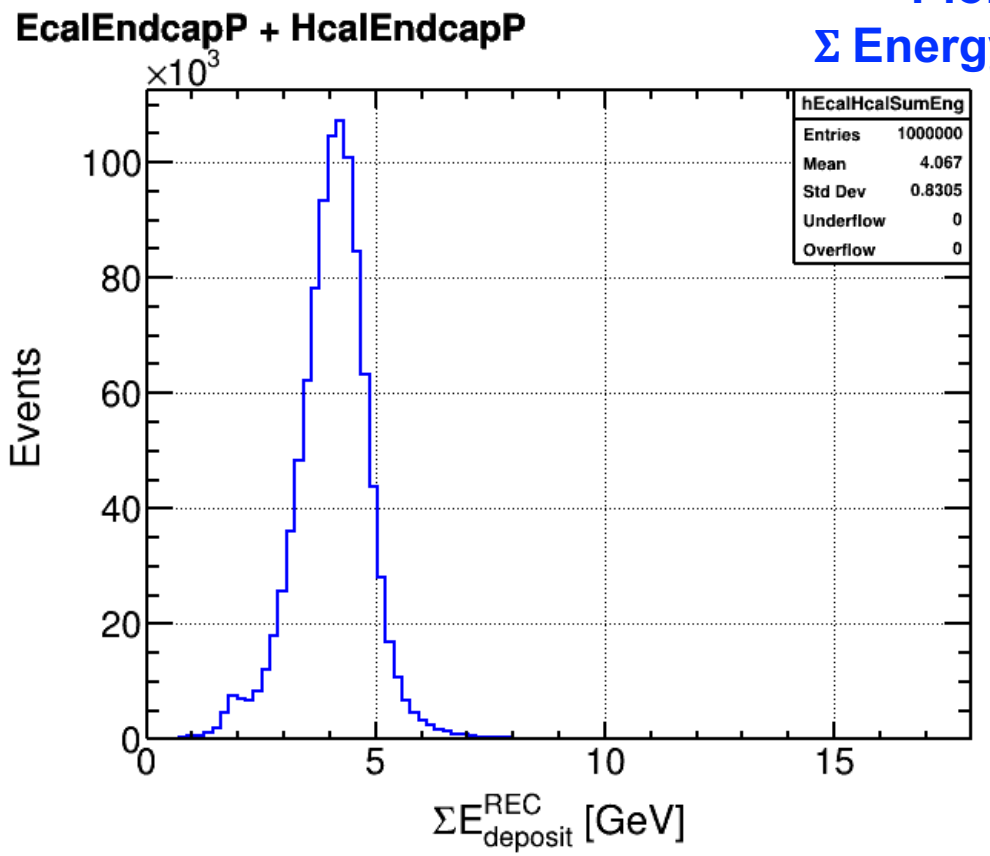
p = 5 GeV and η = 1.74

Reconstructed Energy in Forward

Muon
Σ Energy



Pion
Σ Energy

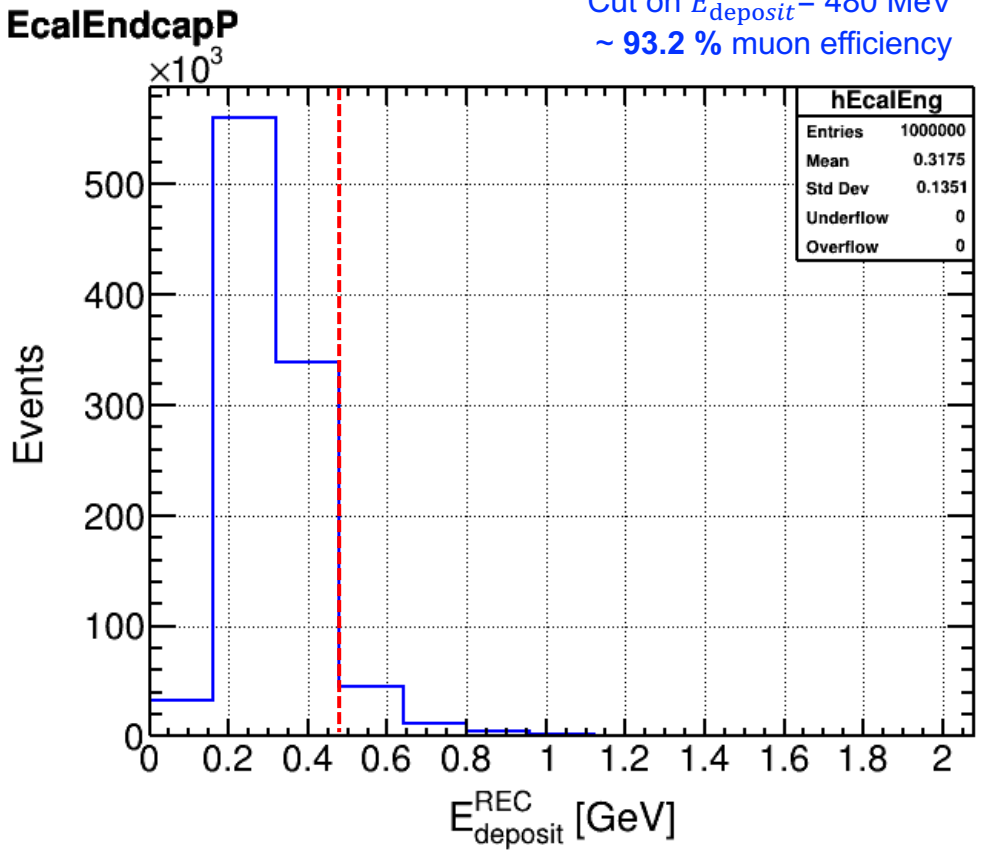


Little bump around 2 GeV where muon sample is at peak (MIP-like)

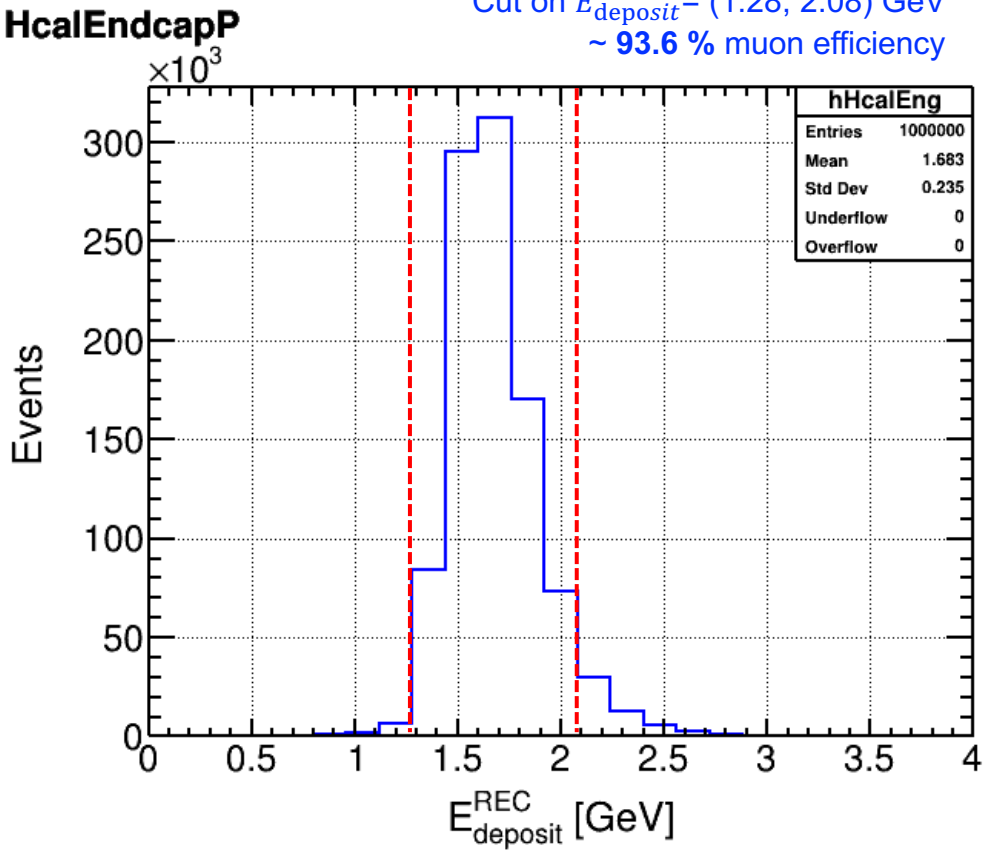
p = 5 GeV and η = 1.74

Muon Sample – Σ Energy

Cut on $E^{REC}_{deposit}$= 480 MeV
~ **93.2 %** muon efficiency



Cut on $E^{REC}_{deposit}$= (1.28, 2.08) GeV
~ **93.6 %** muon efficiency

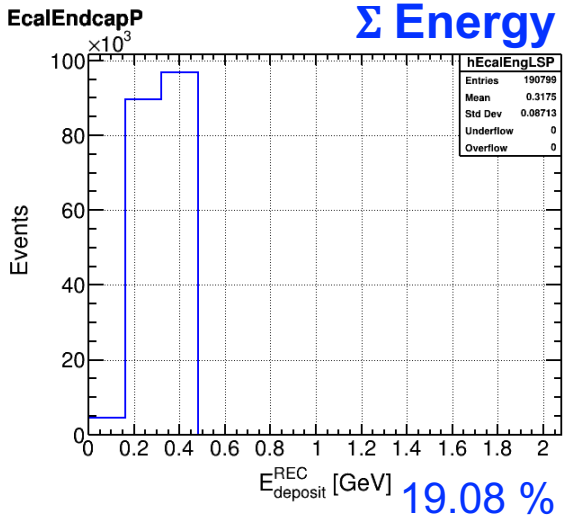


Based on muon sample,
MIP event leave energy **480 MeV** in EMCAL and energy between **1.28 and 2.08 GeV** in HCAL

p = 5 GeV and η = 1.74

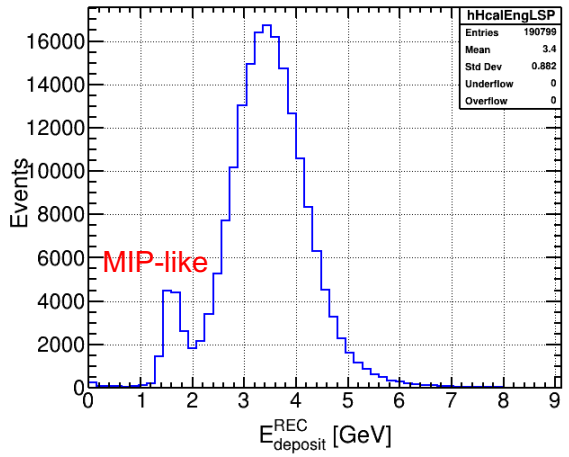
Pion Sample – Σ Energy

MIP-like in ECAL

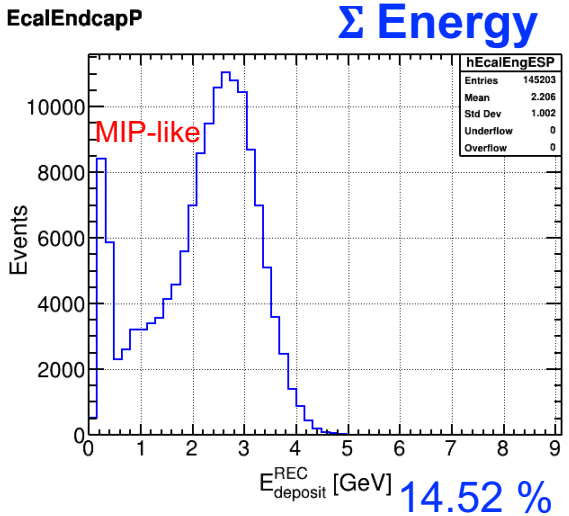


19.08 %

fake-ID efficiency

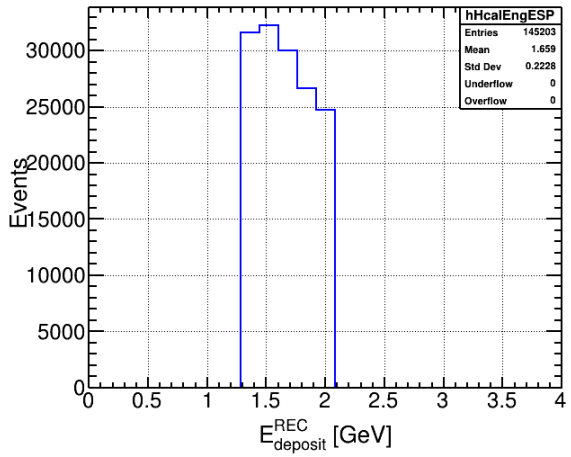


MIP-like in HCAL

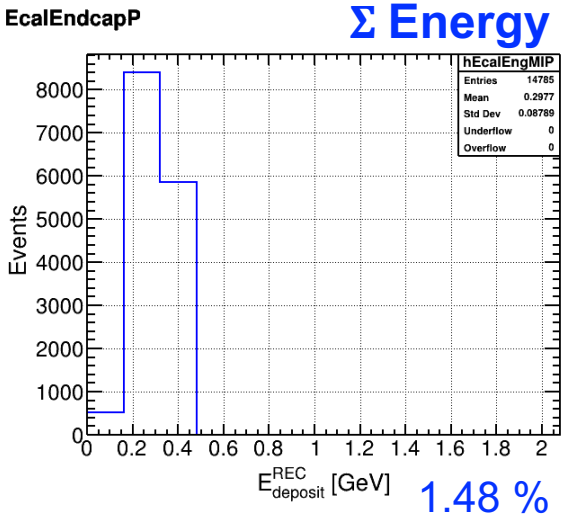


14.52 %

fake-ID efficiency

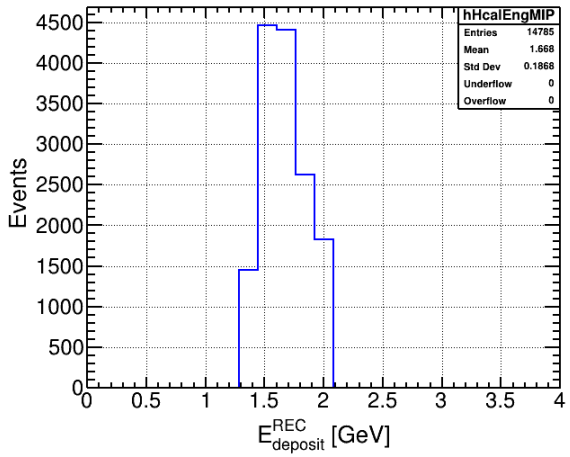


MIP-like in ECAL **&** HCAL



1.48 %

fake-ID efficiency

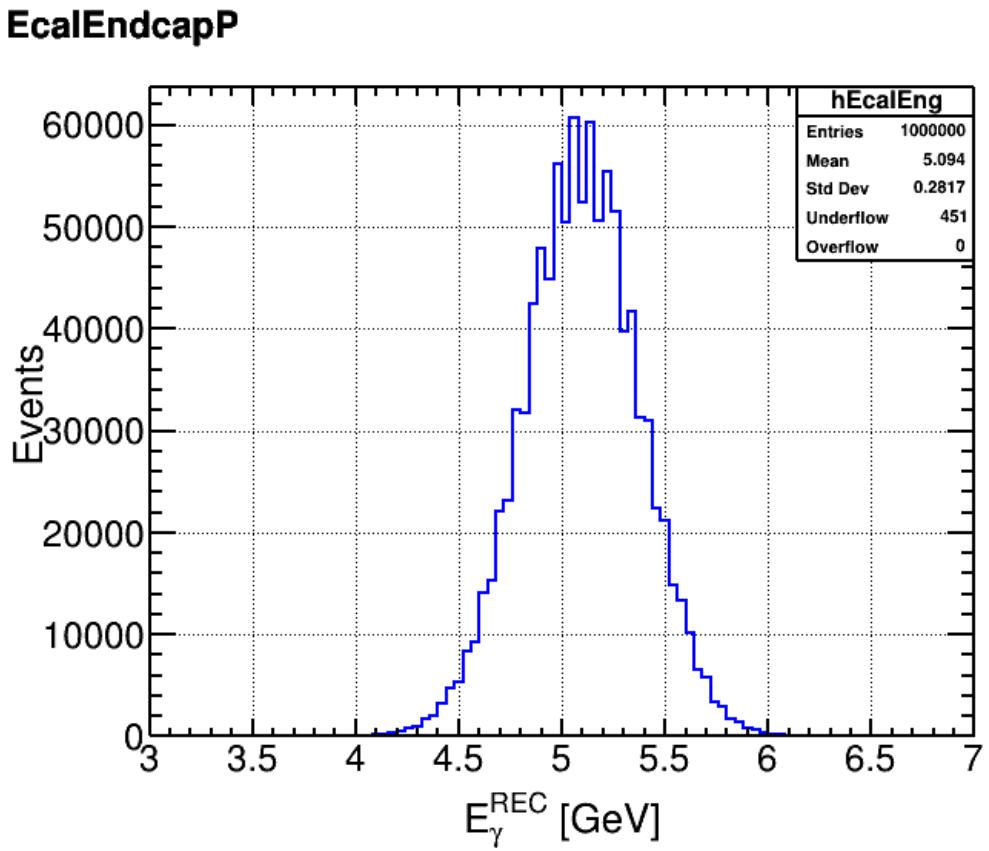


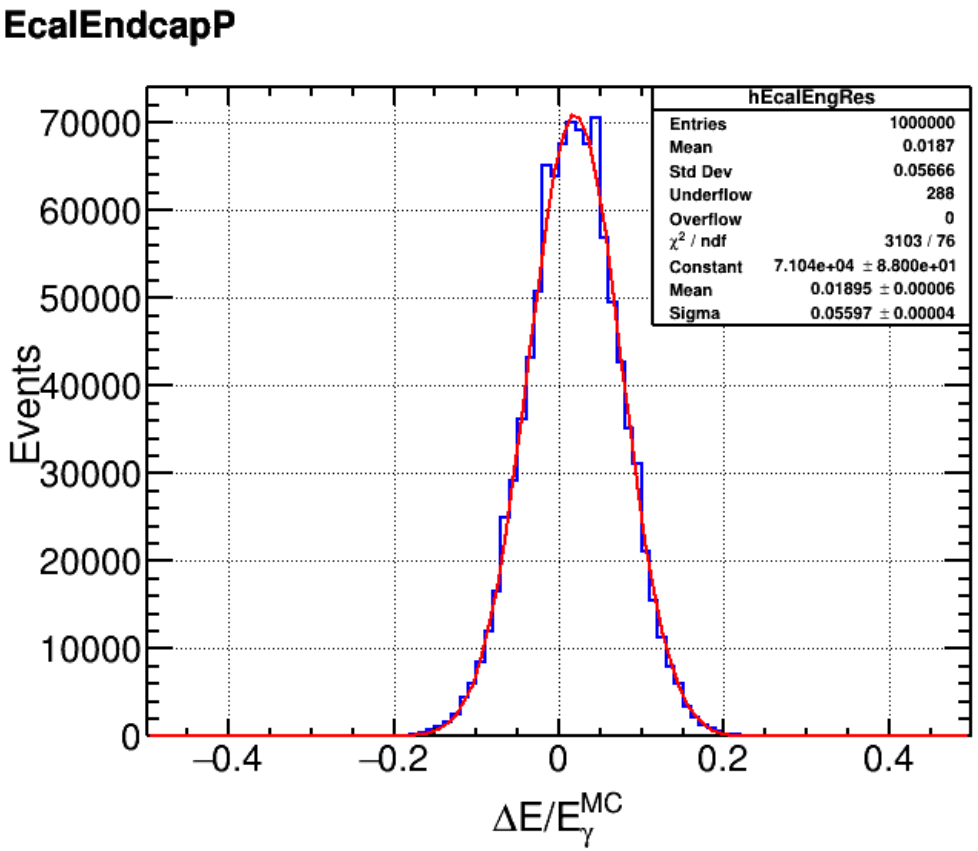
ePIC Simulation – γ

ex) 5 GeV at η = 1.74 (θ = 20°)

per Sasha's request

Gamma Sample – Σ Energy





ePIC Simulation – μ^+ and π^+

ex) 10 GeV at η = 1.74 (θ = 20°)

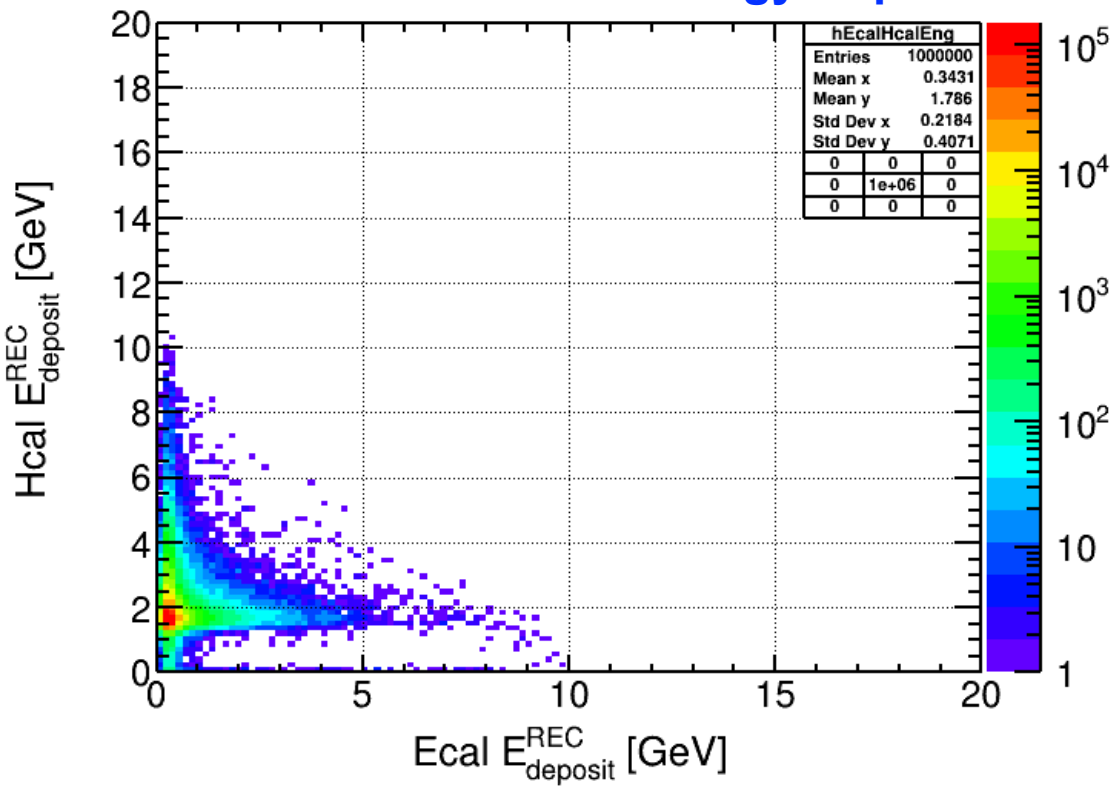
p = 10 GeV and η = 1.74

Reconstructed Energy in Forward

Muon

EcalEndcapP vs HcalEndcapP

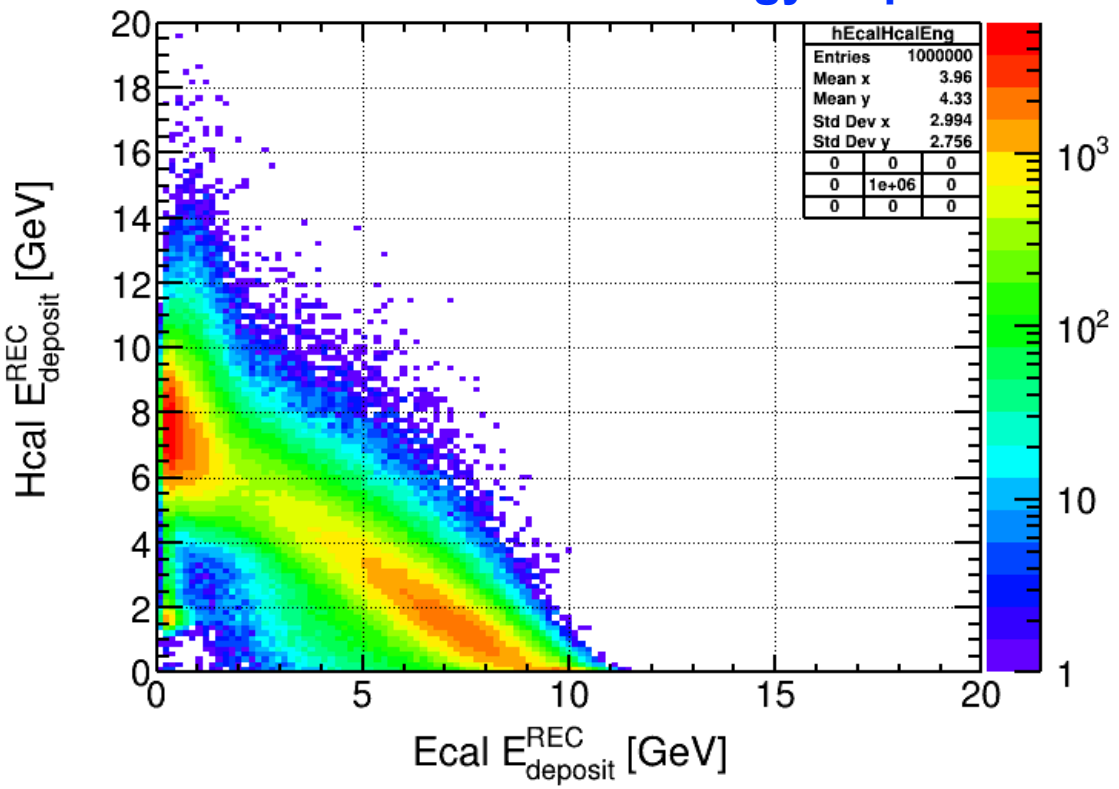
Σ Energy Deposits



Pion

EcalEndcapP vs HcalEndcapP

Σ Energy Deposits



While muon sample has one hot spot, pion sample has three groups;
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p = 10 GeV and η = 1.74

Reconstructed Energy in Forward

Muon

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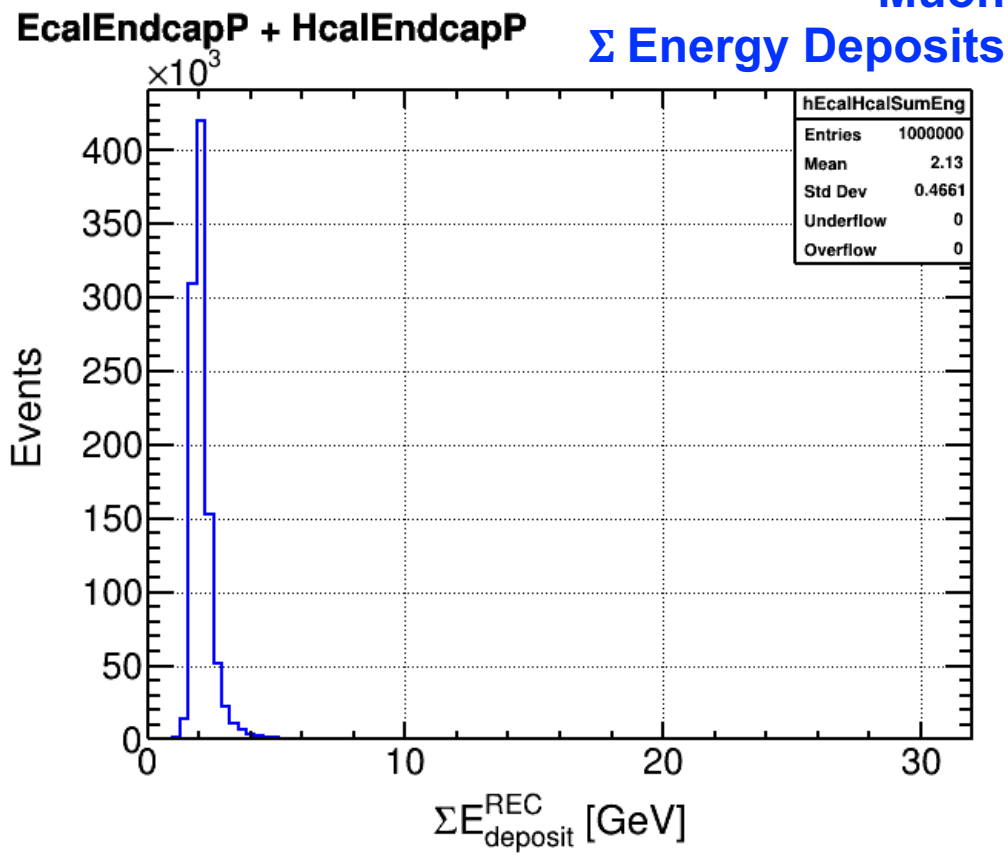
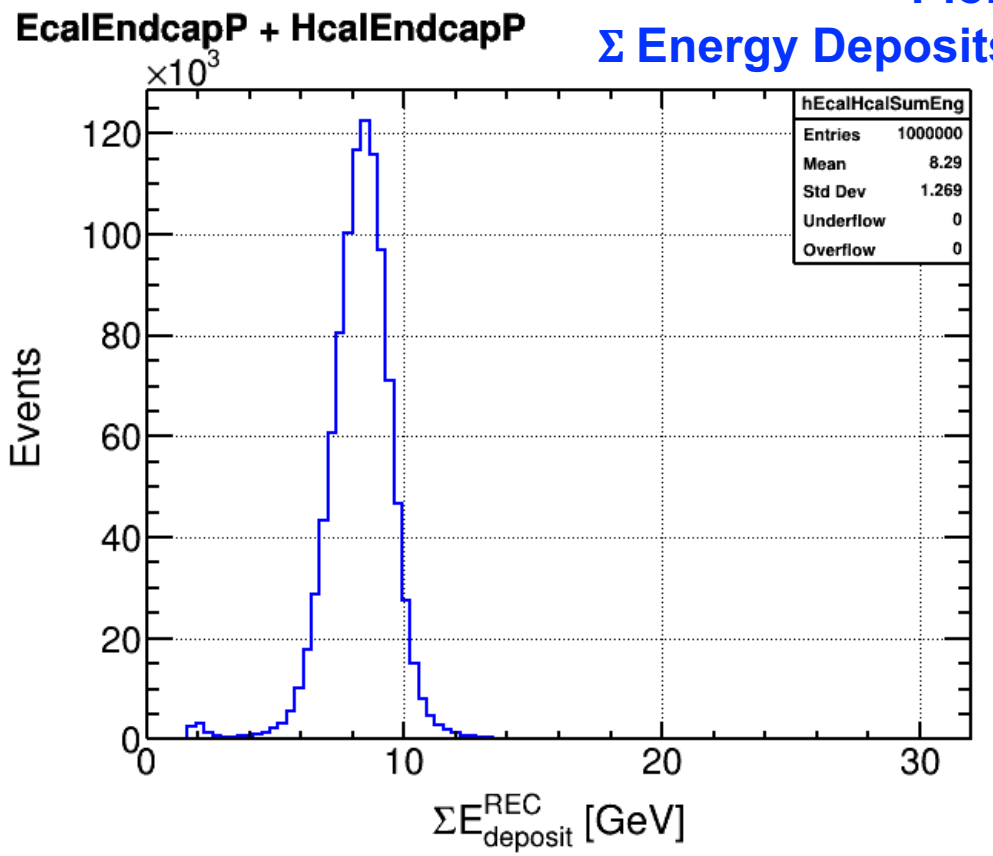


Pion

Σ Energy Deposits

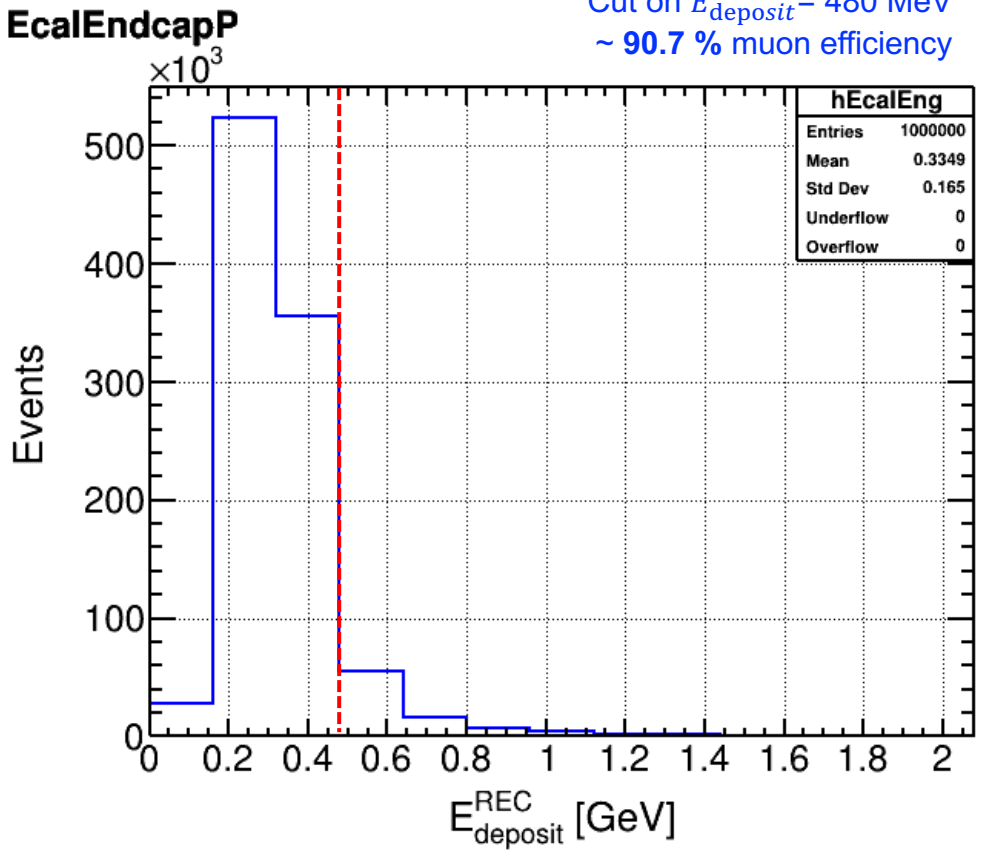


Little bump around 2 GeV where muon sample is at peak (MIP-like)

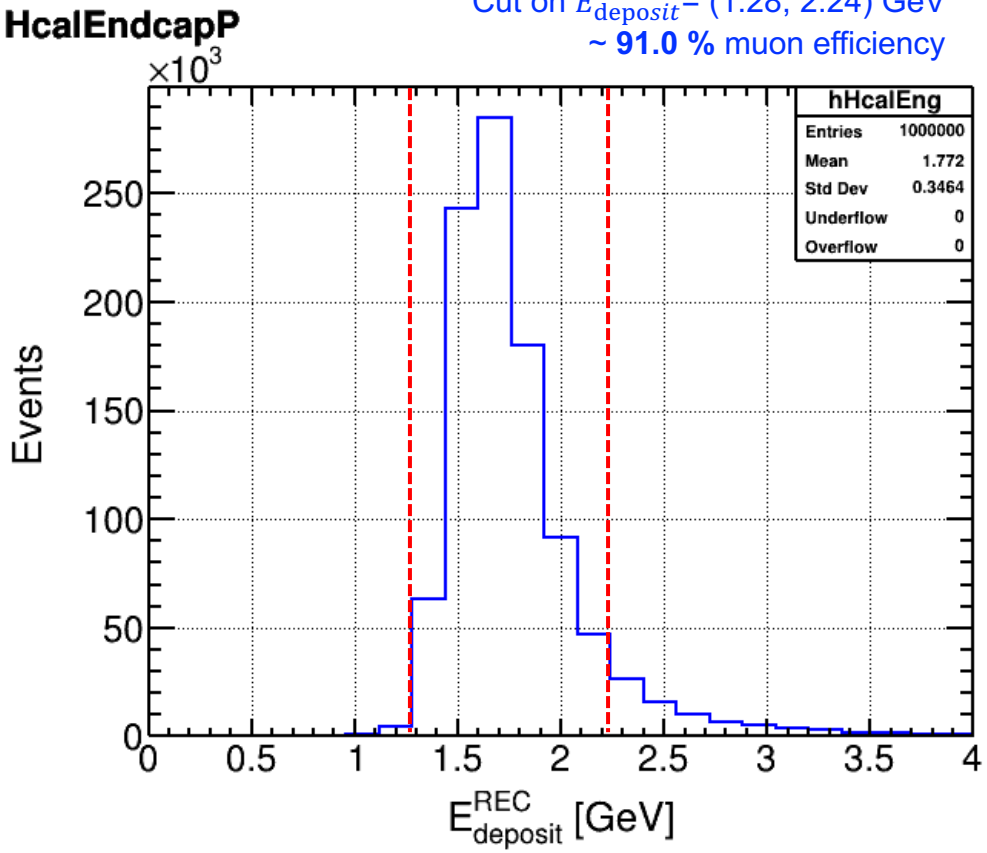
p = 10 GeV and η = 1.74

Muon Sample – Σ Energy

Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= 480 MeV
~ **90.7 %** muon efficiency



Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= (1.28, 2.24) GeV
~ **91.0 %** muon efficiency



Based on muon sample,
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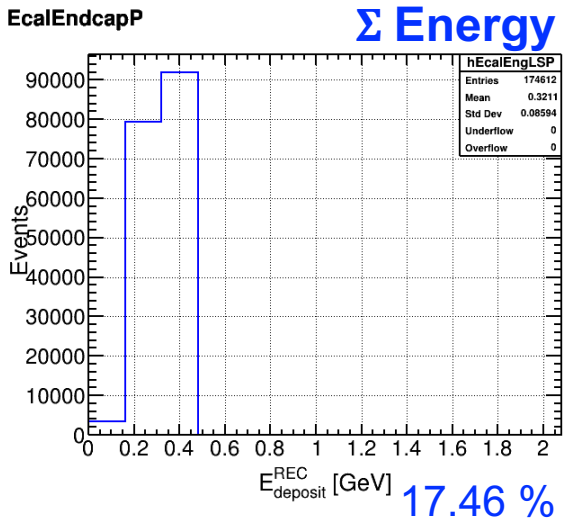
p = 10 GeV and η = 1.74

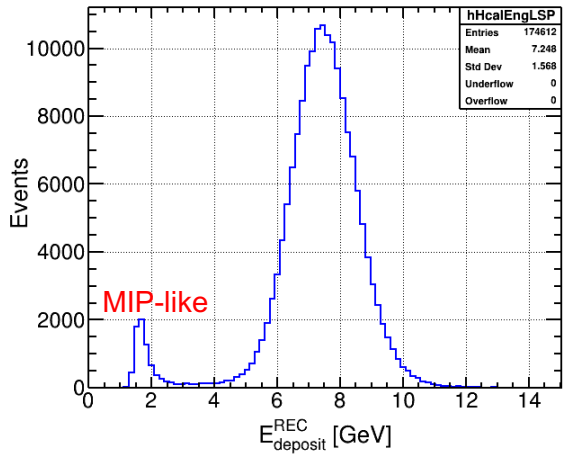
Pion Sample – Σ Energy

MIP-like in ECAL

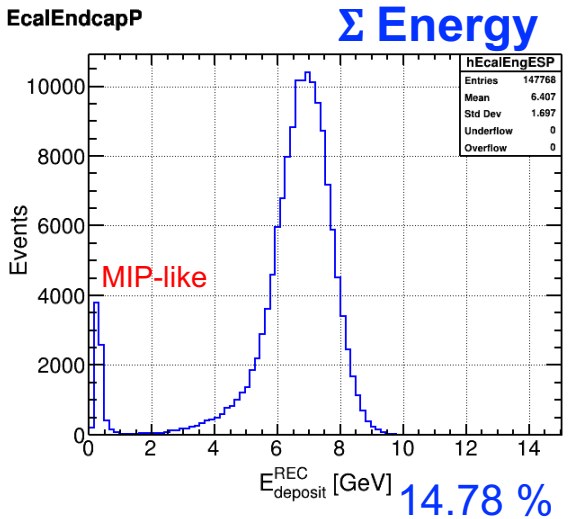


17.46 %

fake-ID efficiency

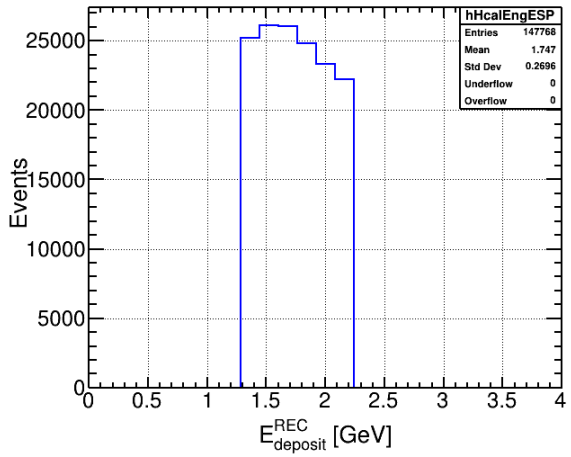


MIP-like in HCAL

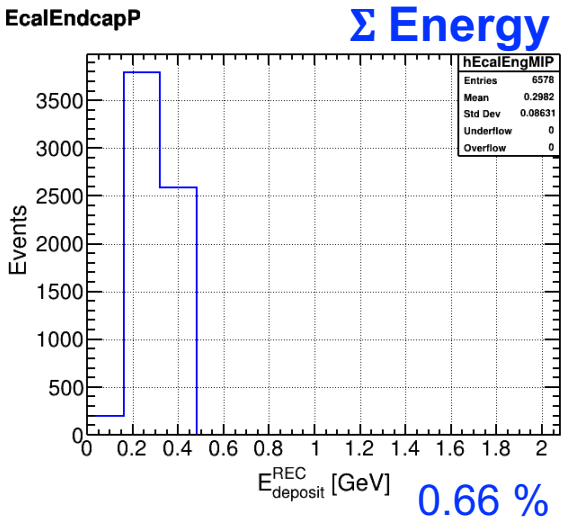


14.78 %

fake-ID efficiency

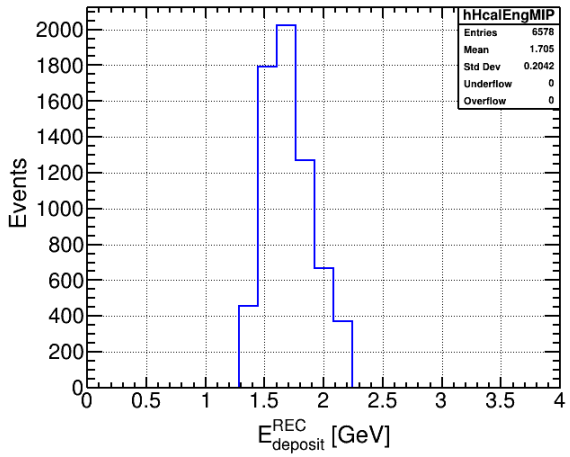


MIP-like in ECAL **&** HCAL



0.66 %

fake-ID efficiency



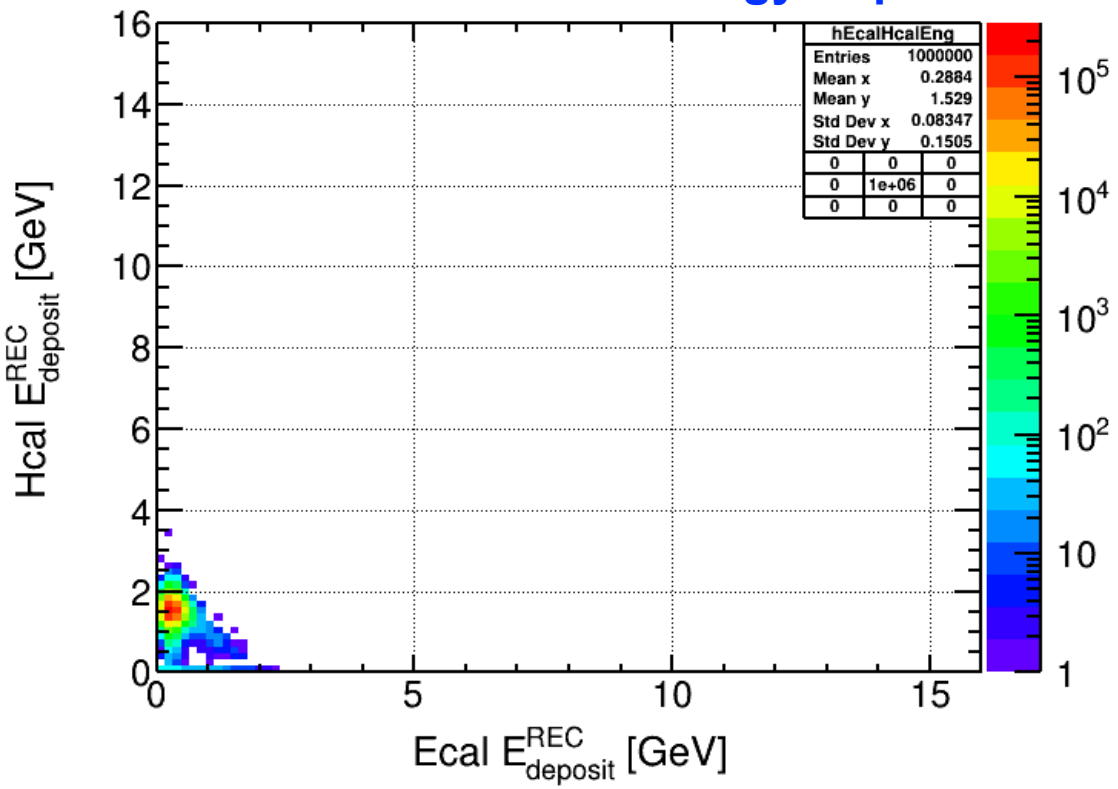
ePIC Simulation – μ^+ and π^+

ex) 2 GeV at η = 1.74 (θ = 20°)

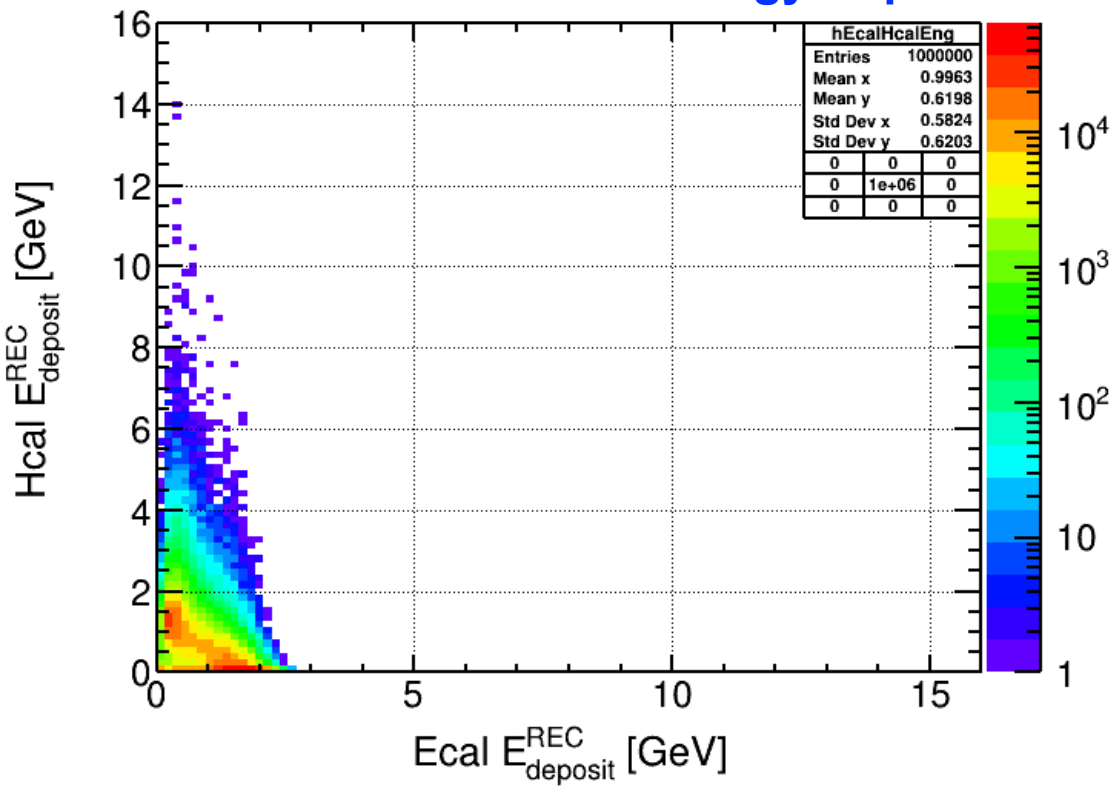
p = 2 GeV and η = 1.74

Reconstructed Energy in Forward

Muon



Pion



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Reconstructed Energy in Forward

Muon

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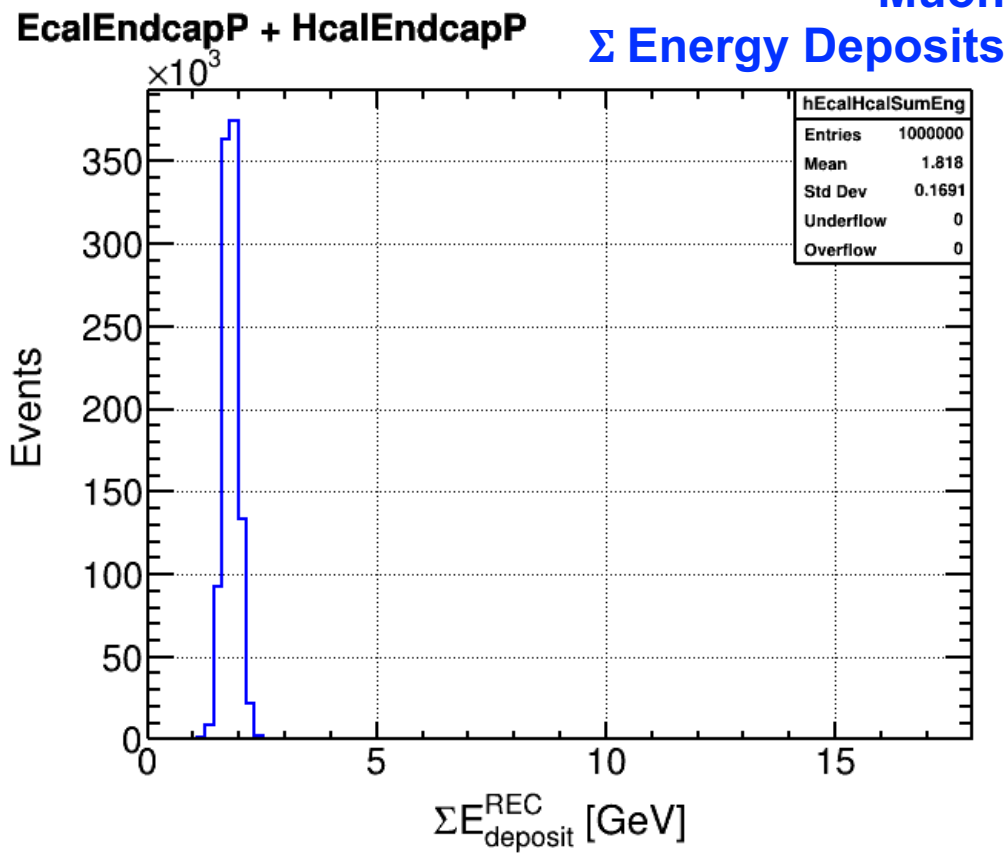
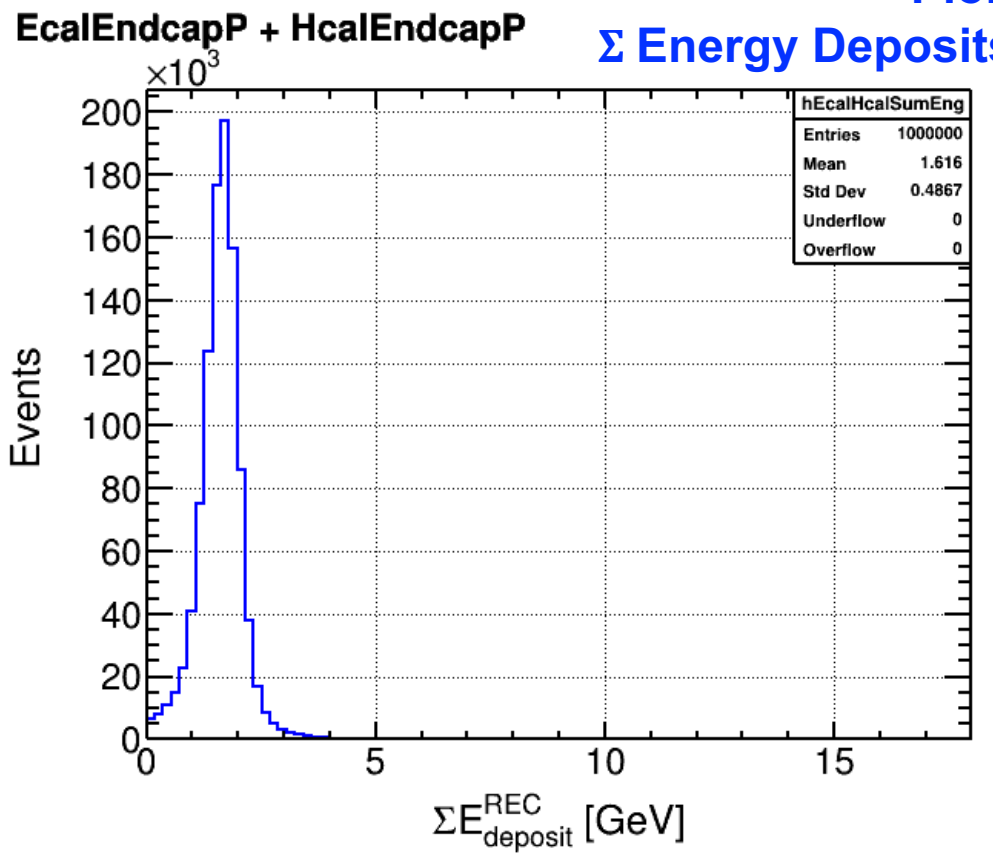


Pion

Σ Energy Deposits

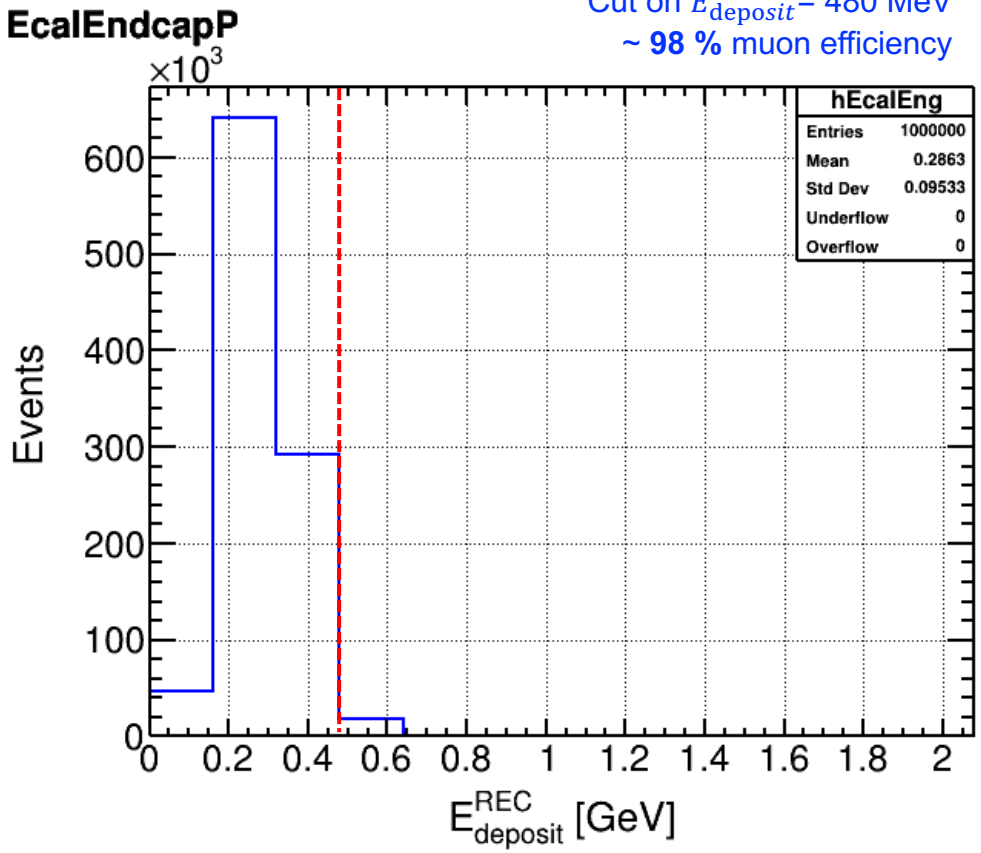


MIP-like signal is buried under pion tail

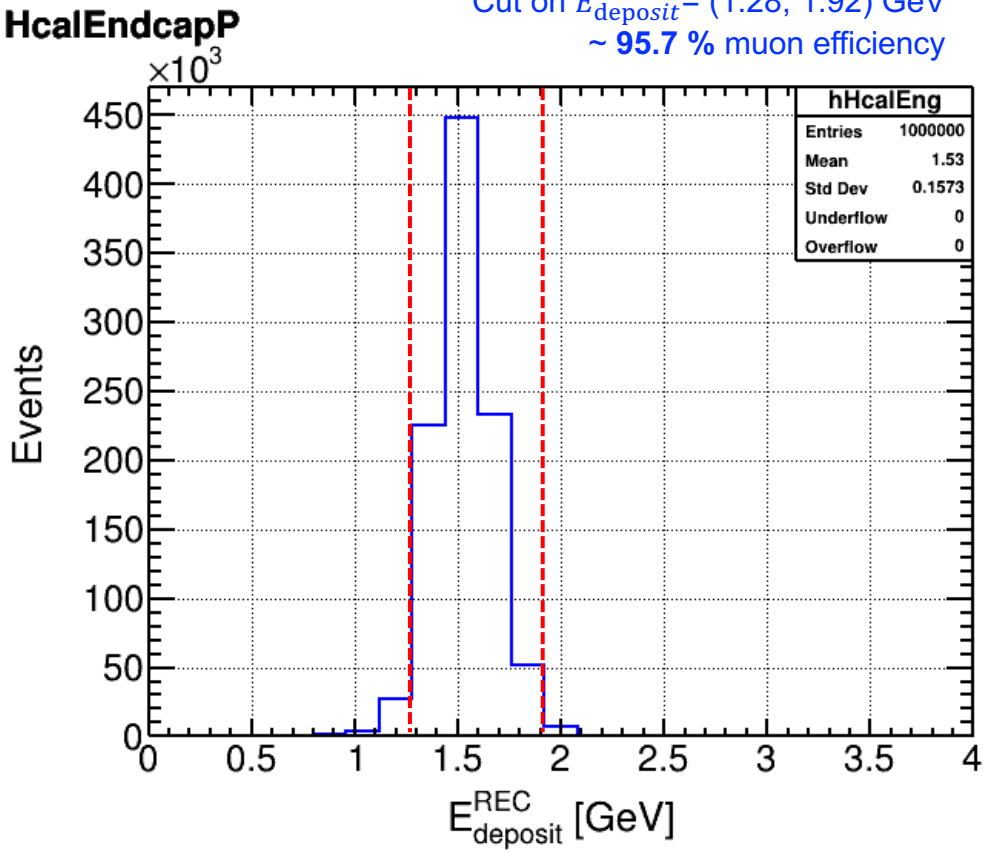
p = 2 GeV and η = 1.74

Muon Sample – Σ Energy

Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= 480 MeV
~ **98 %** muon efficiency



Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= (1.28, 1.92) GeV
~ **95.7 %** muon efficiency



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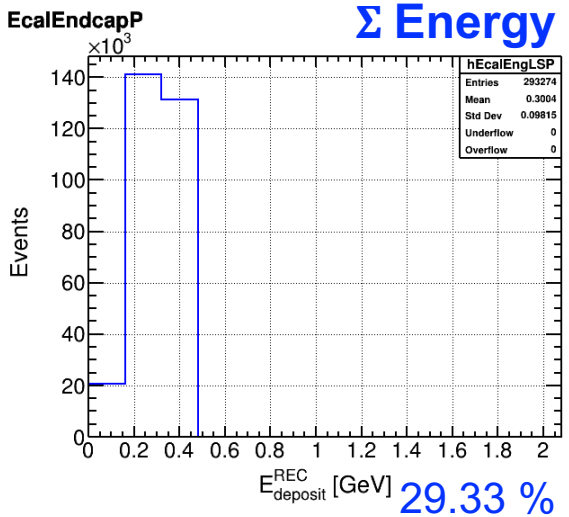
MIP event leave energy **480 MeV** in EMCAL and energy between **1.28 and 1.92 GeV** in HCAL

p = 2 GeV and η = 1.74

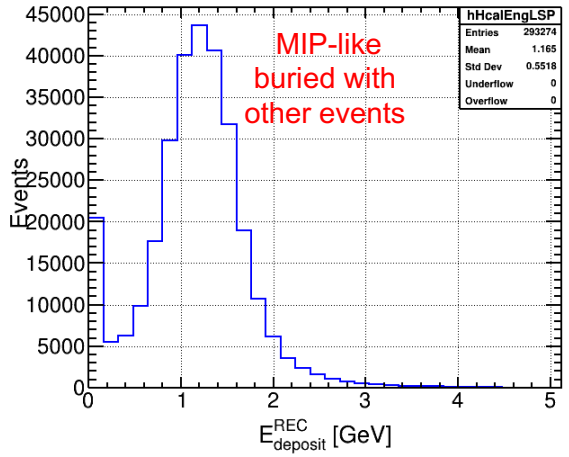
Pion Sample – Σ Energy

MIP-like in ECAL

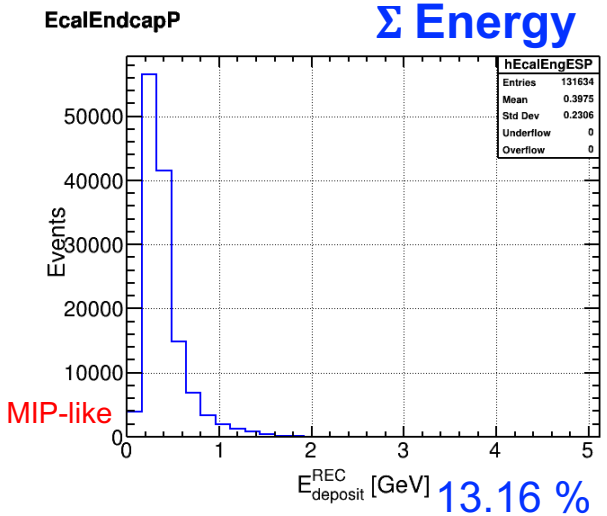


29.33 %

fake-ID efficiency

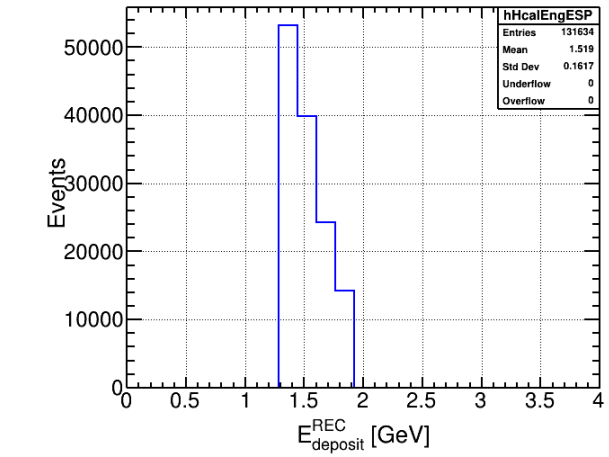


MIP-like in HCAL

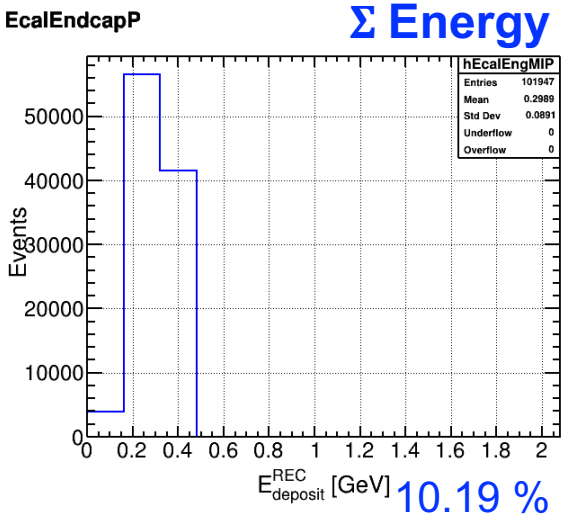


13.16 %

fake-ID efficiency

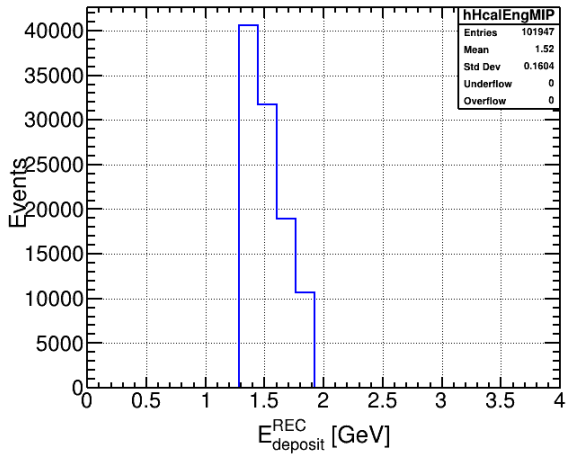


MIP-like in ECAL **&** HCAL



10.19 %

fake-ID efficiency



ePIC Simulation – μ^+ and π^+

ex) 1 GeV at η = 1.74 (θ = 20°)

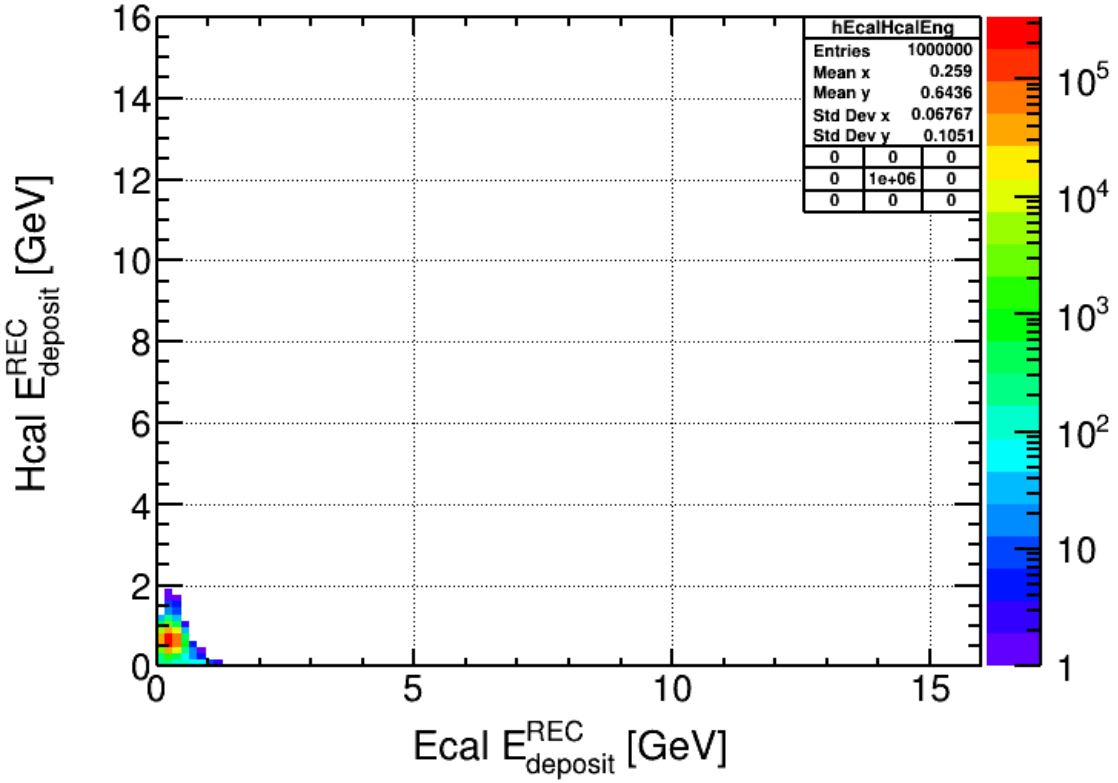
p = 1 GeV and η = 1.74

Reconstructed Energy in Forward

Muon

EcalEndcapP vs HcalEndcapP

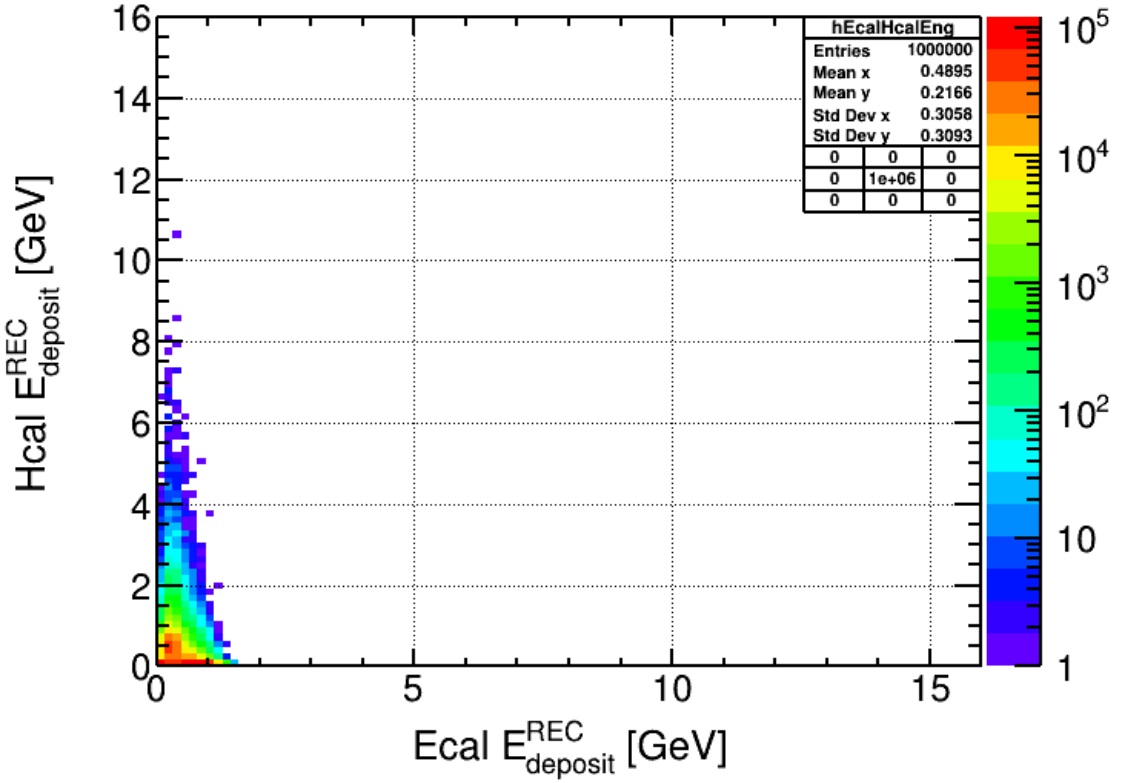
Σ Energy Deposits



Pion

EcalEndcapP vs HcalEndcapP

Σ Energy Deposits



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Reconstructed Energy in Forward

Muon

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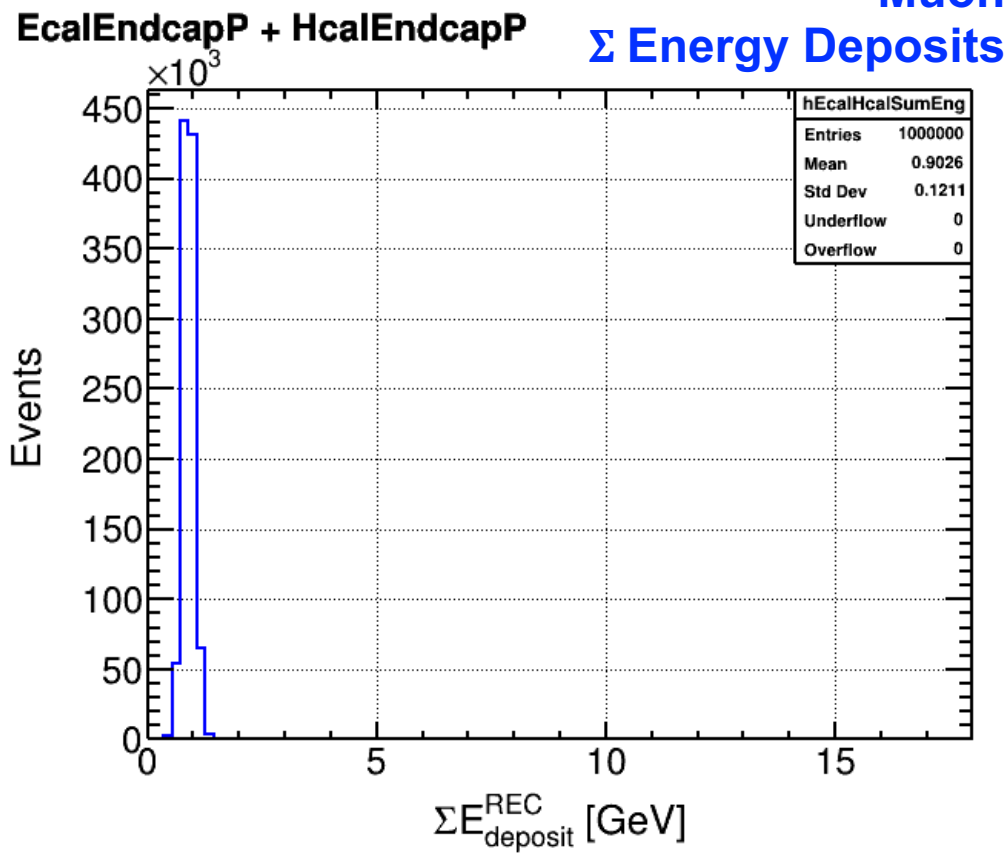
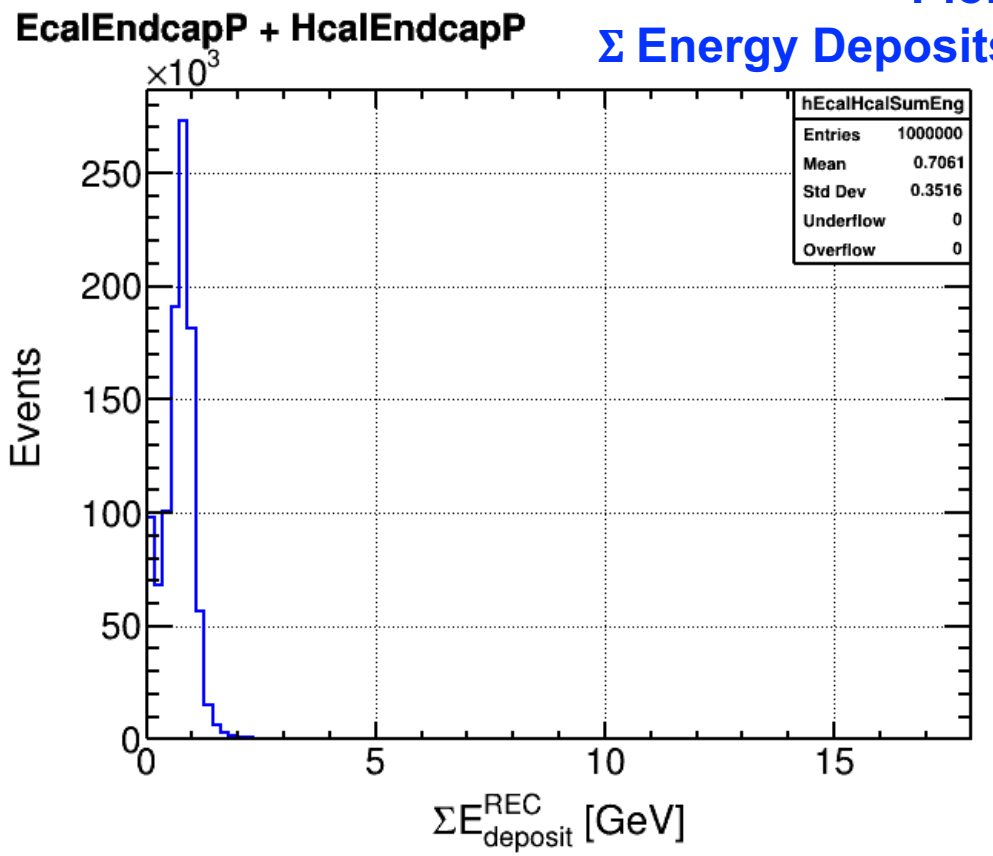


Pion

Σ Energy Deposits

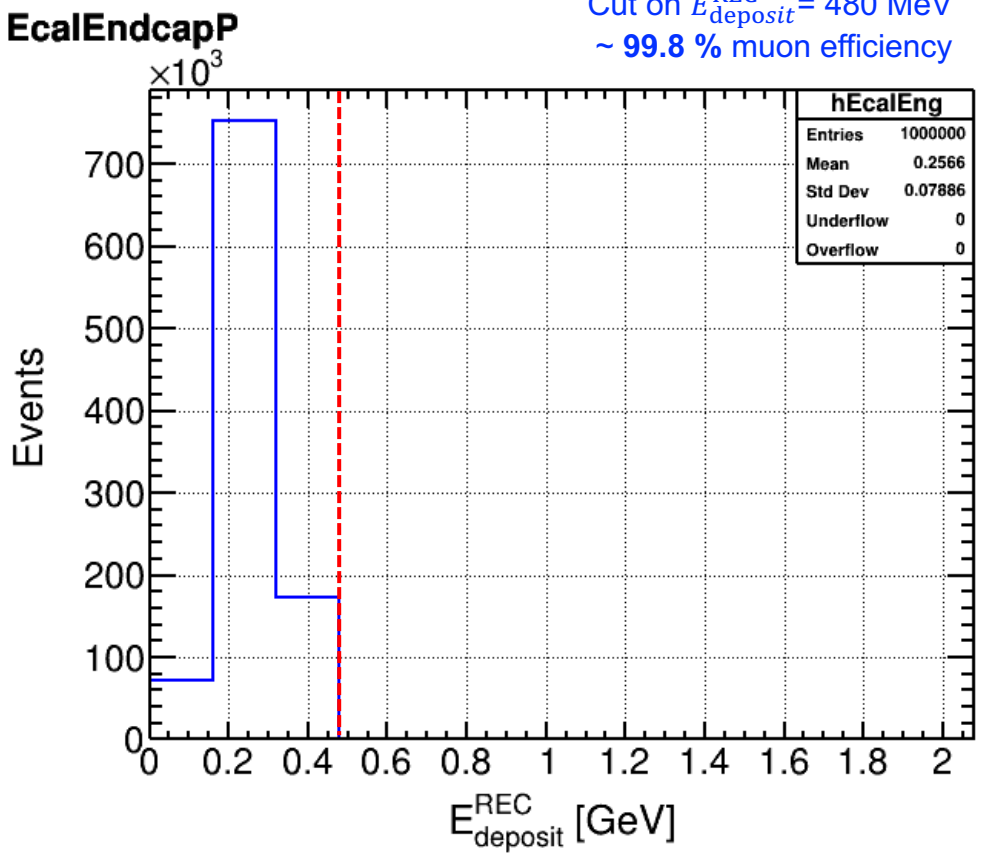


MIP-like signal is buried under pion tail

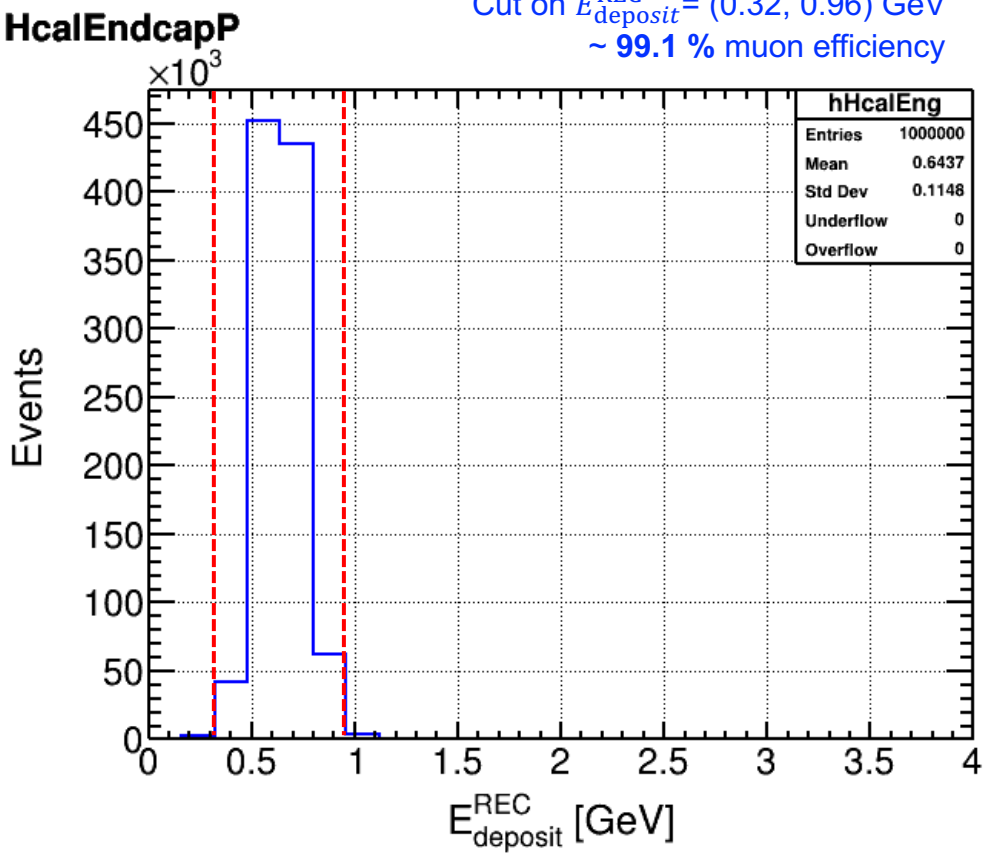
p = 1 GeV and η = 1.74

Muon Sample – Σ Energy

Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= 480 MeV
~ **99.8 %** muon efficiency



Cut on $E^{\mathrm{REC}}_{\mathrm{deposit}}$= (0.32, 0.96) GeV
~ **99.1 %** muon efficiency



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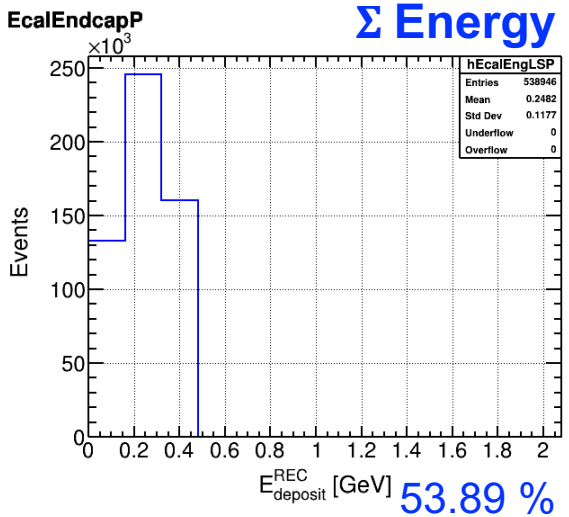
MIP event leave energy **480 MeV** in EMCAL and energy between **0.32 and 0.96 GeV** in HCAL

p = 1 GeV and η = 1.74

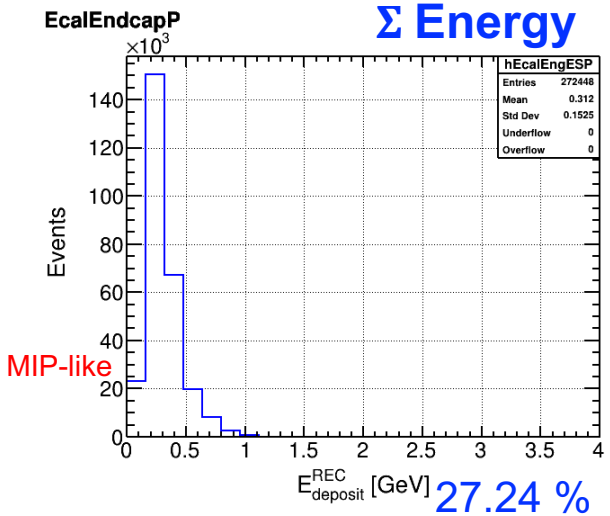
Pion Sample – Σ Energy

MIP-like in ECAL



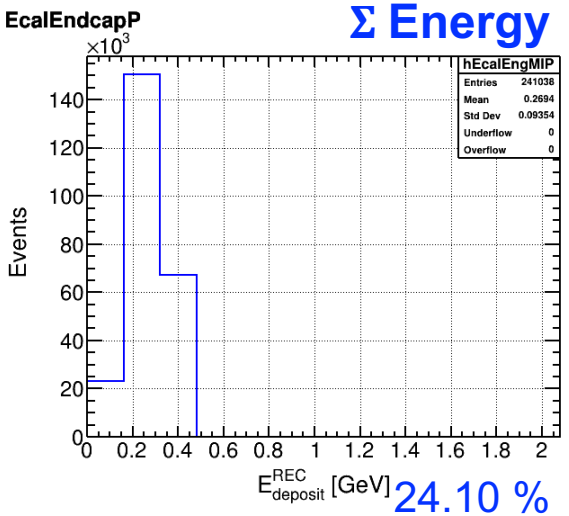
53.89 %

MIP-like in HCAL

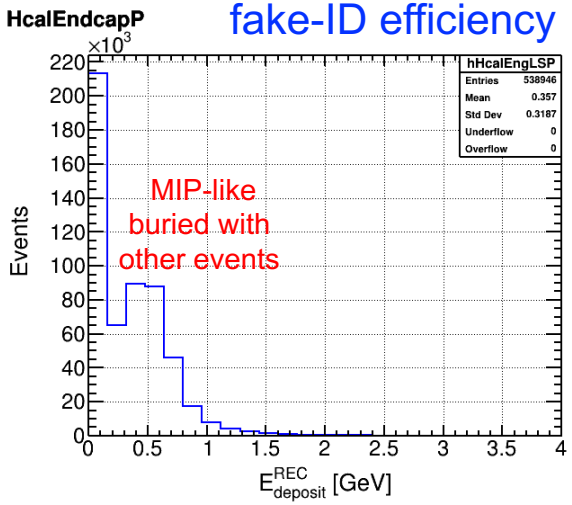


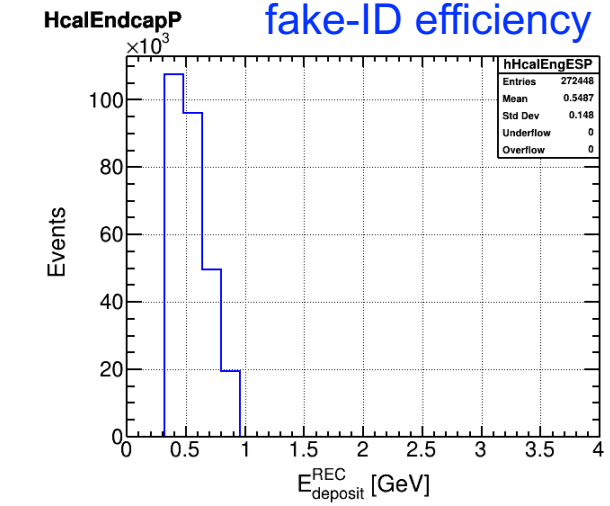
27.24 %

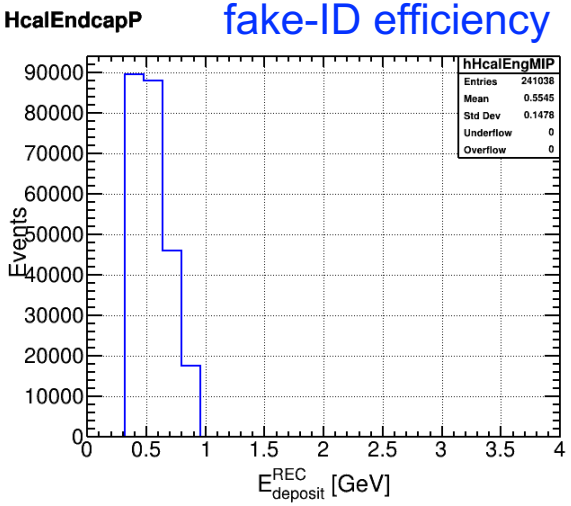
MIP-like in ECAL **&** HCAL



24.10 %







Muon Cut and Muon/Fake-ID Efficiency

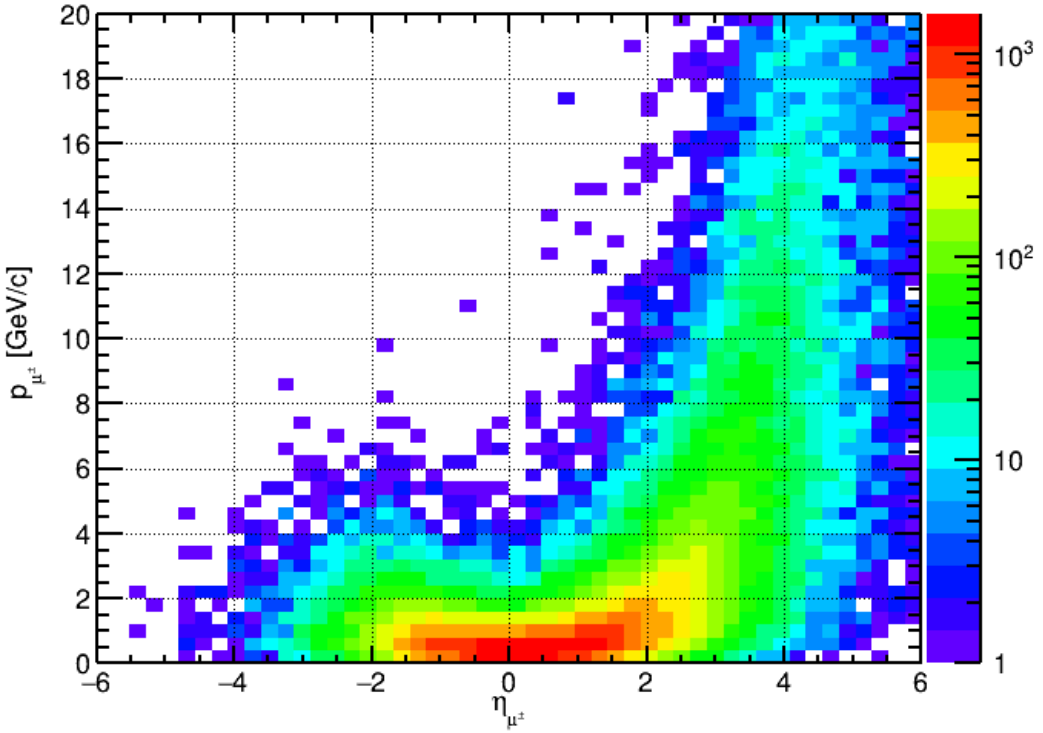
Angle	Momentum	ECAL & HCAL		Muon Efficiency	Fake-ID Efficiency	N_μ/N_π
η = 1.74 (θ = 20°)	1 [GeV/c]	0 < ΣE < 0.48 [GeV]	0.32 < ΣE < 0.96 [GeV]	99.06%	24.10 %	~ 4.1
	2 [GeV/c]		1.28 < ΣE < 1.92 [GeV]	93.85 %	10.19 %	~ 9.2
	5 [GeV/c]		1.28 < ΣE < 2.08 [GeV]	87.32 %	1.48 %	~ 59.1
	10 [GeV/c]		1.28 < ΣE < 2.24 [GeV]	82.75 %	0.66 %	~ 125.8

There might be room for improvement on using layer information instead of whole HCAL
Consistent energy deposit and number of hits each layer throughout HCAL layers for muons

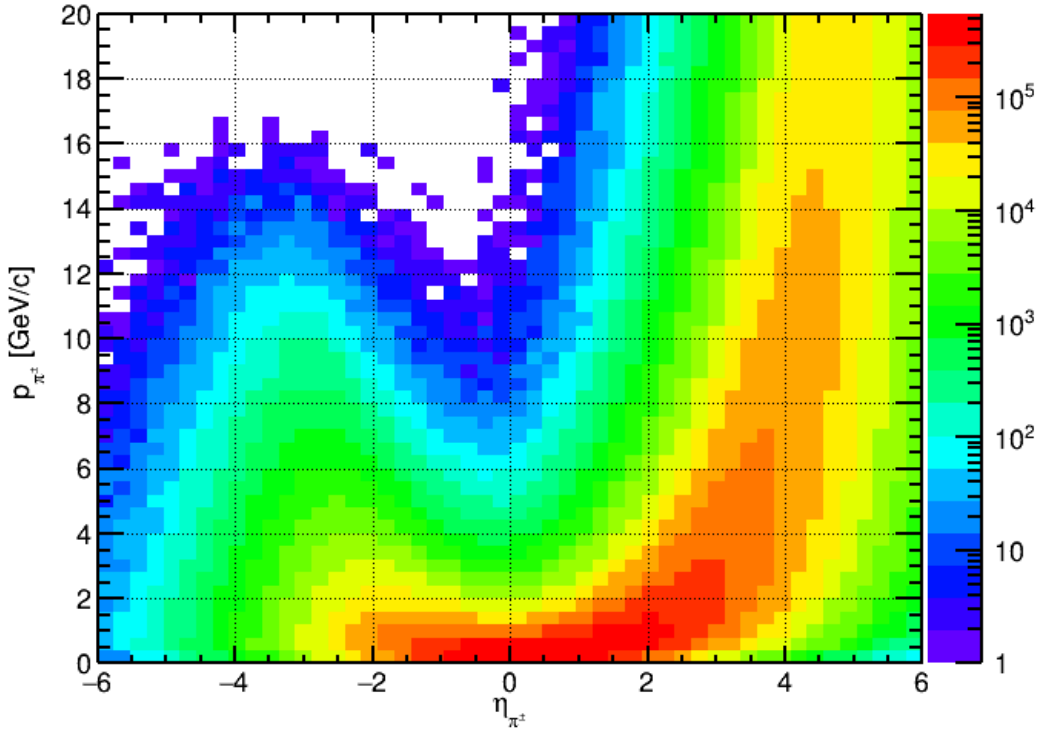
Pythia8 sample

Muon and Pion Kinematics – 18×275 GeV²

$\mu^{\pm}$



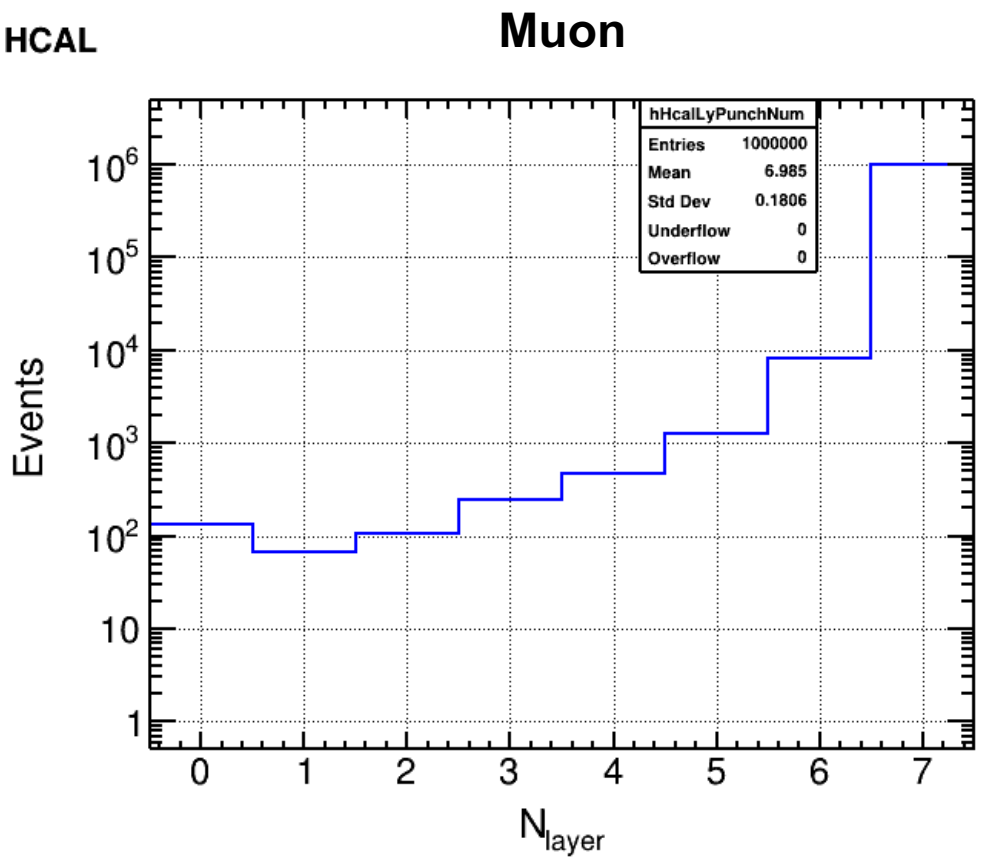
$\pi^{\pm}$

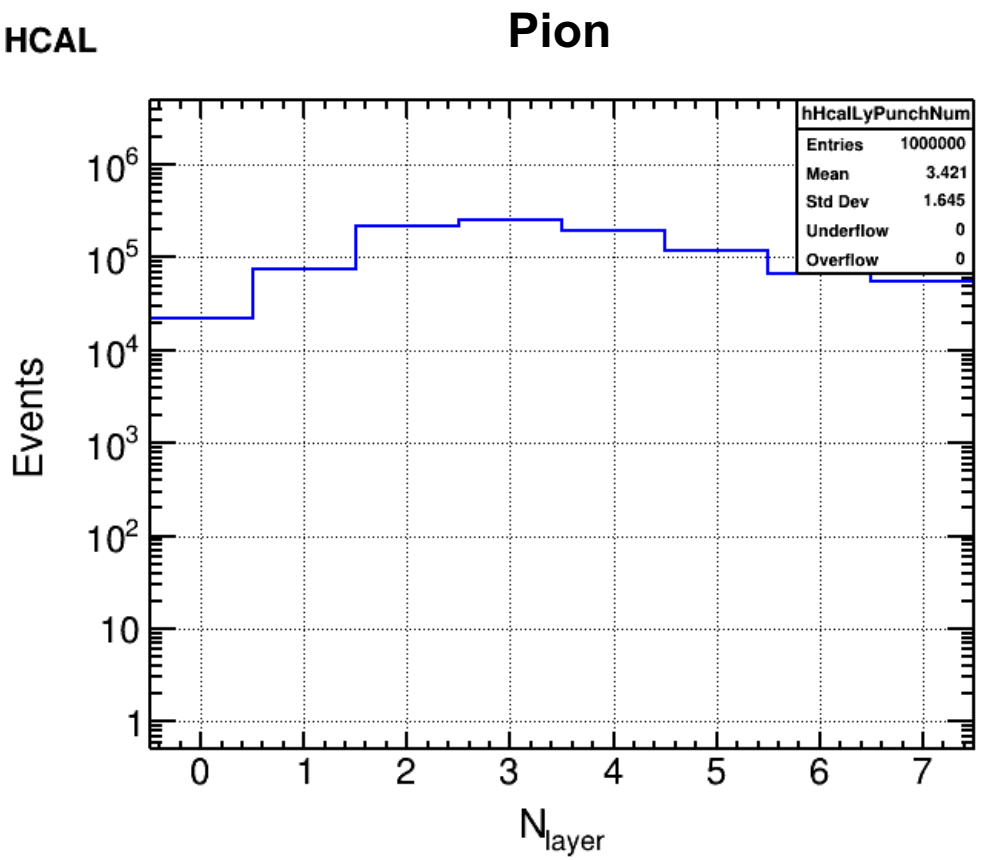


η = 1.74	1 GeV/c	2 GeV/c	5 GeV/c	10 GeV/c
Muons	736	271	22	2
Pions	368039	109691	7507	492
Ratio (Pions/Muons)	~ 500	~ 405	~ 342	~ 246

p = 5 GeV and η = 1.74

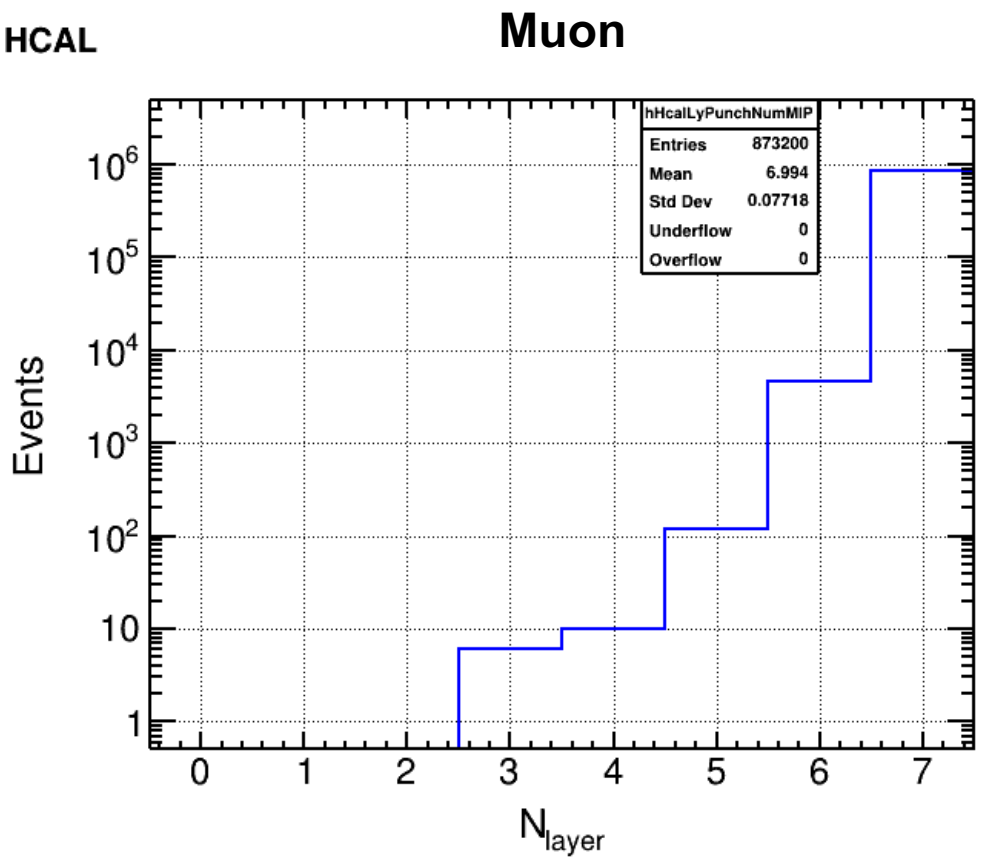
HCAL – How Many Layers Has RecHits

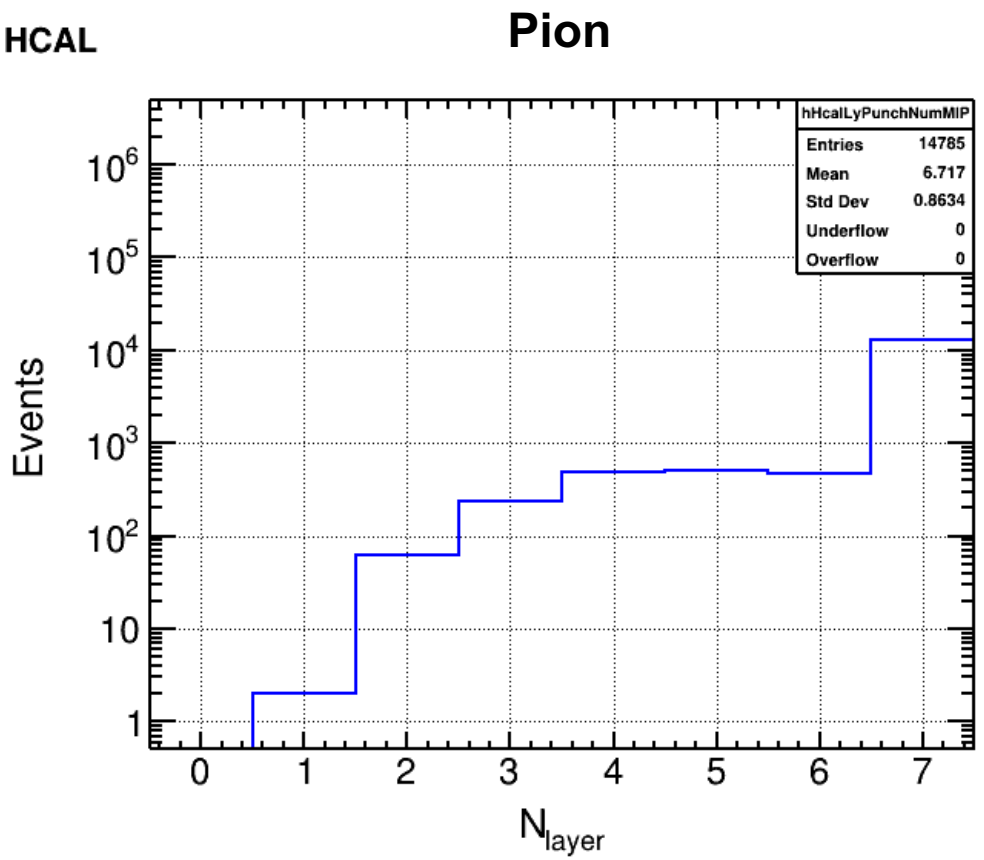




p = 5 GeV and η = 1.74 **MIP-like Events Only based on Whole ECAL+HCAL cut**

HCAL – How Many Layers Has RecHits

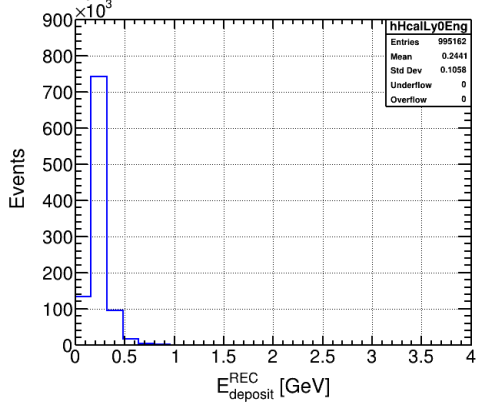




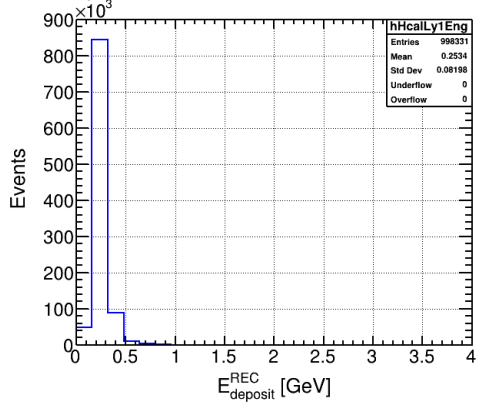
p = 5 GeV and η = 1.74

All Muon Sample – Each HCAL Layer

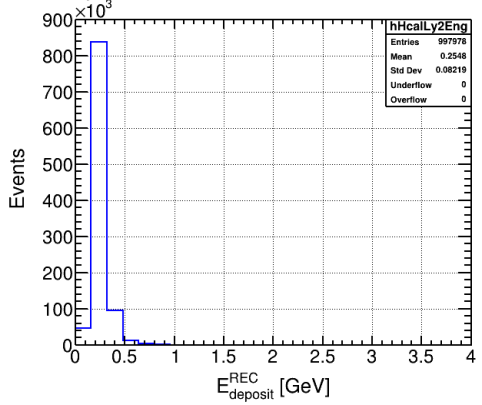
HCAL Layer=0



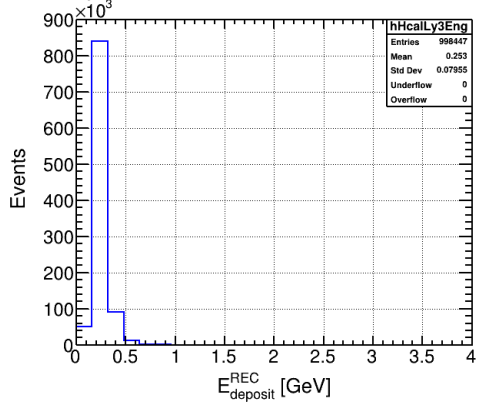
HCAL Layer=1



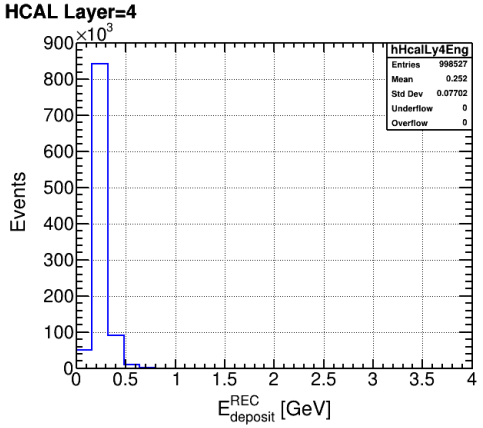
HCAL Layer=2



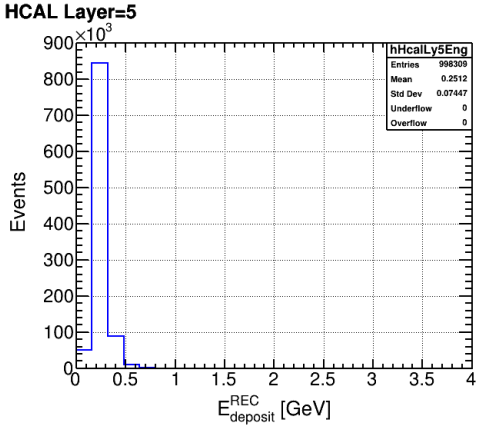
HCAL Layer=3



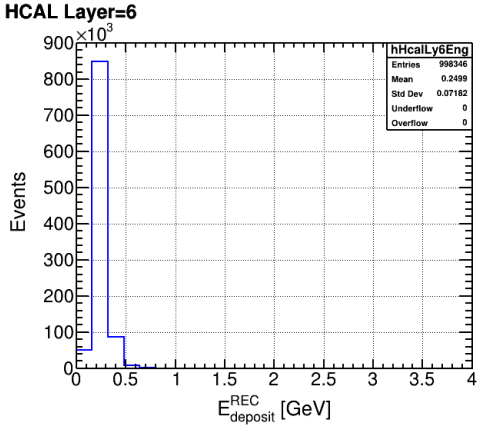
HCAL Layer=4



HCAL Layer=5



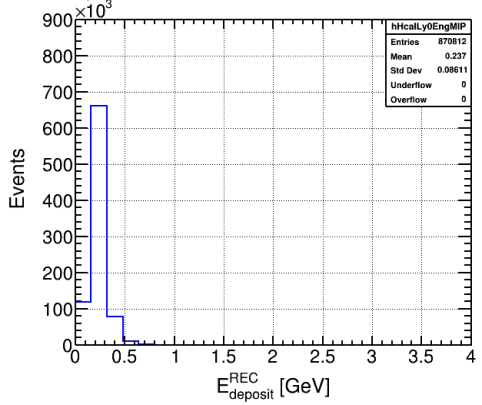
HCAL Layer=6



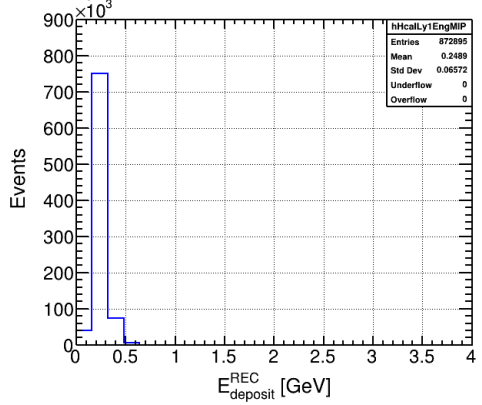
p = 5 GeV and η = 1.74 **MIP-like Events Only based on Whole ECAL+HCAL cut**

All Muon Sample – Each HCAL Layer

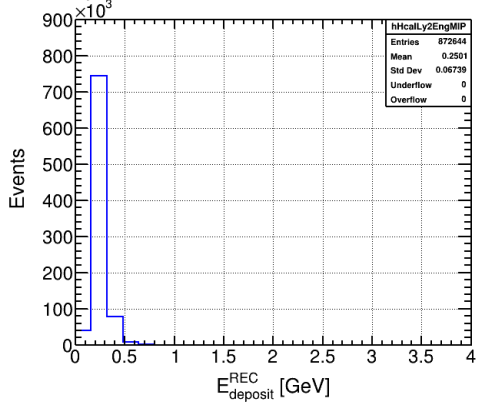
HCAL Layer=0



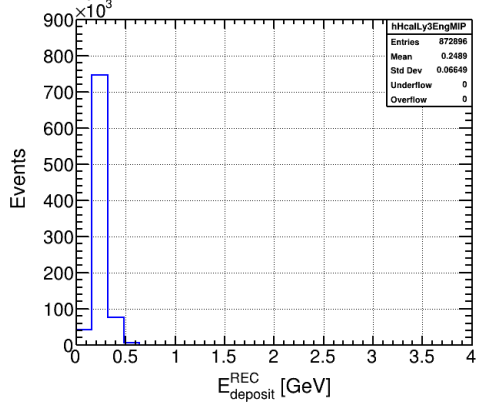
HCAL Layer=1



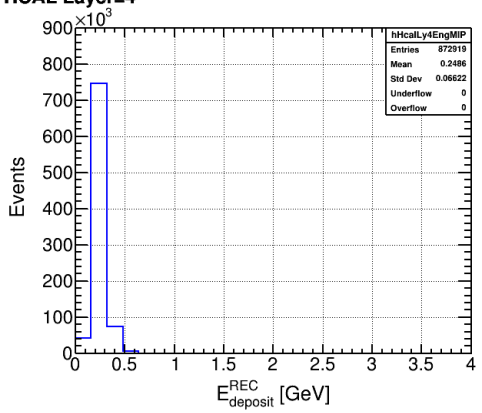
HCAL Layer=2



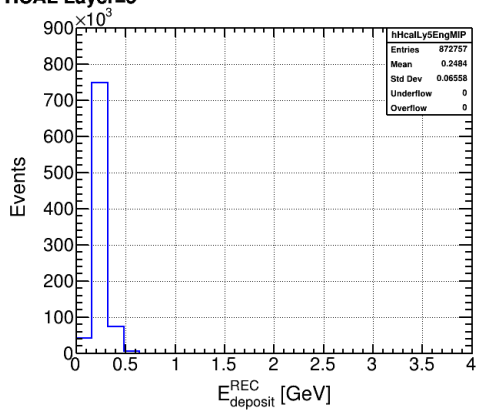
HCAL Layer=3



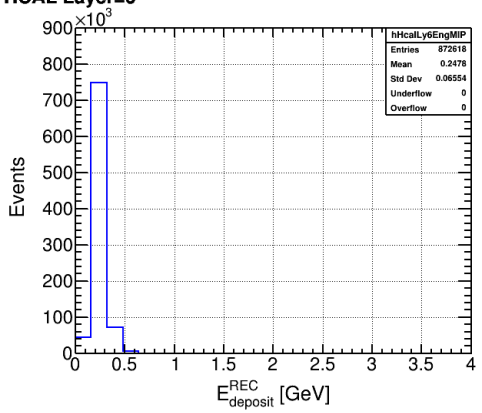
HCAL Layer=4



HCAL Layer=5



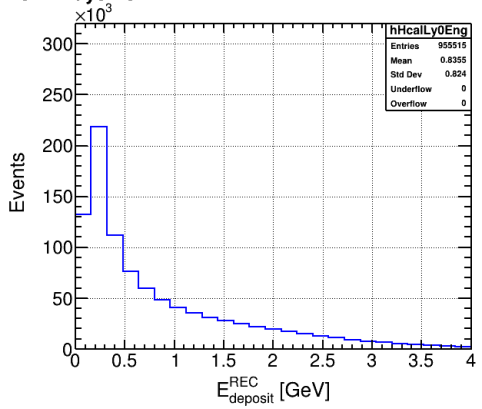
HCAL Layer=6



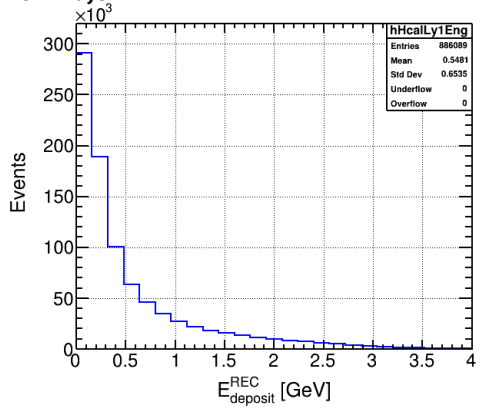
p = 5 GeV and η = 1.74

All Pion Sample – Each HCAL Layer

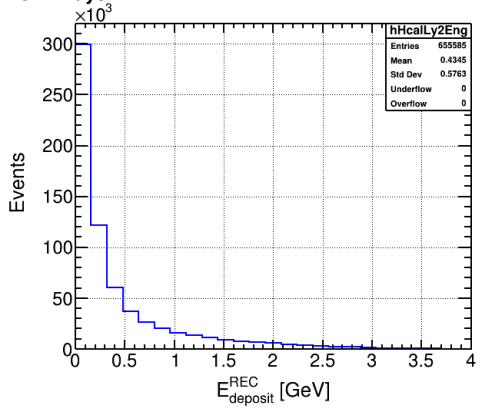
HCAL Layer=0



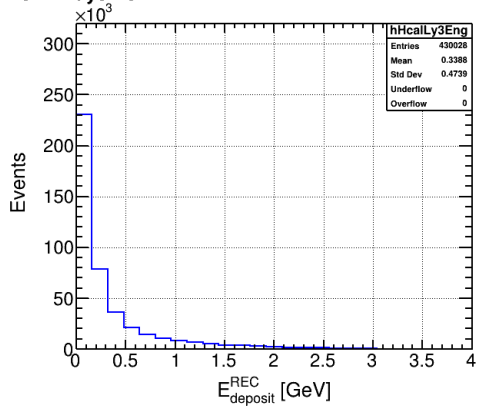
HCAL Layer=1



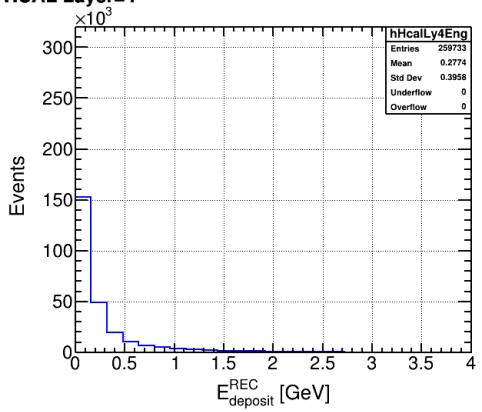
HCAL Layer=2



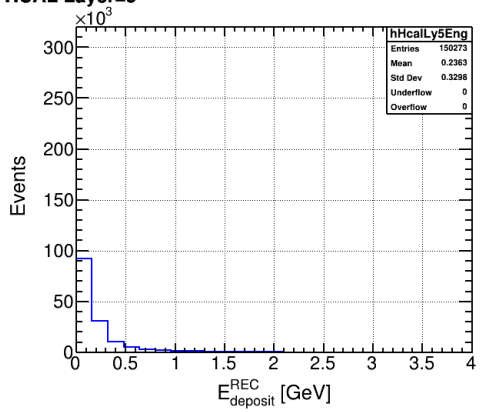
HCAL Layer=3



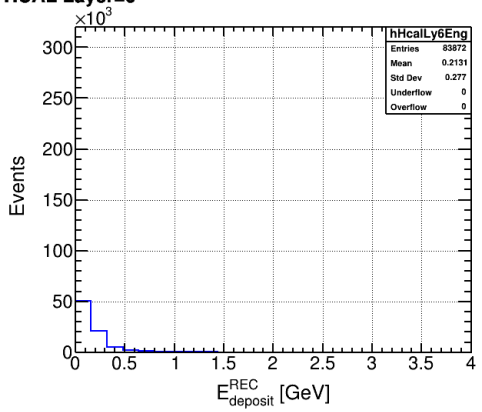
HCAL Layer=4



HCAL Layer=5



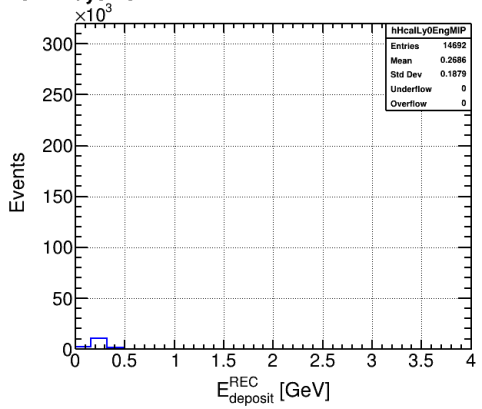
HCAL Layer=6



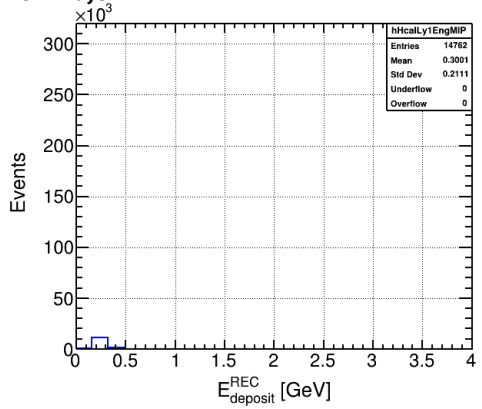
p = 5 GeV and η = 1.74 **MIP-like Events Only based on Whole ECAL+HCAL cut**

All Pion Sample – Each HCAL Layer

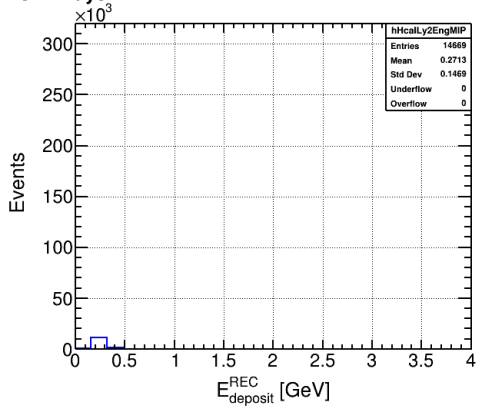
HCAL Layer=0



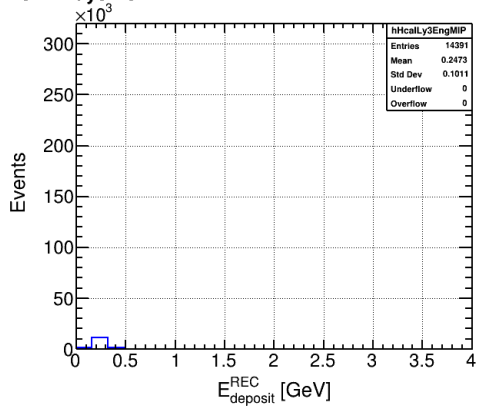
HCAL Layer=1



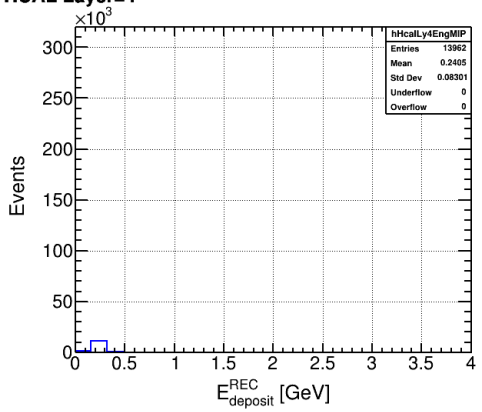
HCAL Layer=2



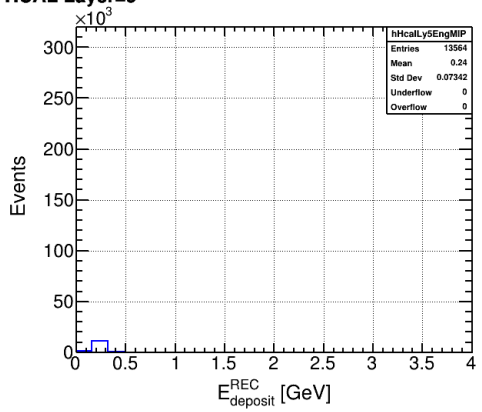
HCAL Layer=3



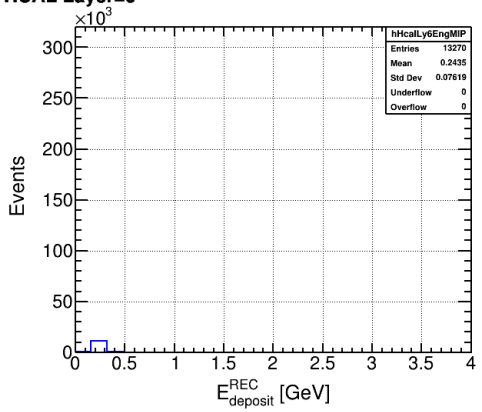
HCAL Layer=4



HCAL Layer=5



HCAL Layer=6

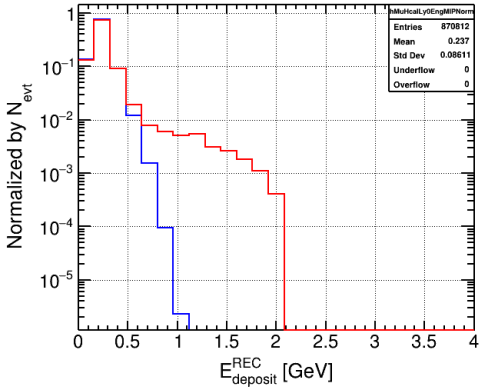


p = 5 GeV and η = 1.74 **MIP-like Events Only based on Whole ECAL+HCAL cut**

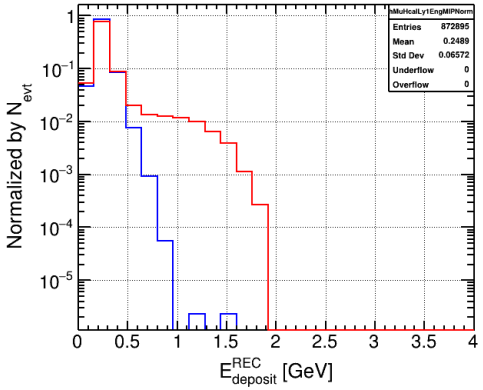
Comparison – Each HCAL Layer

Muons Pions

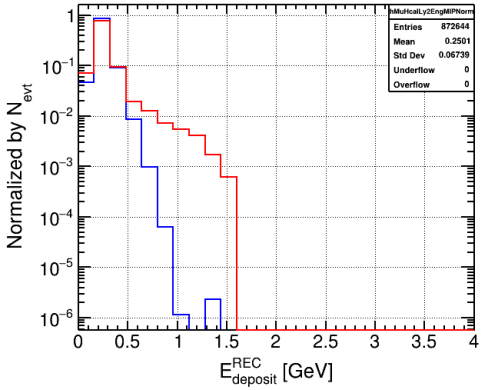
HCAL Layer=0



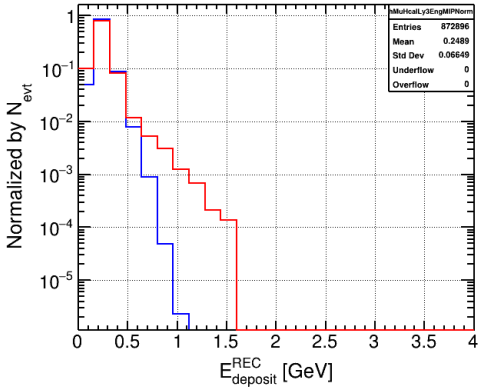
HCAL Layer=1



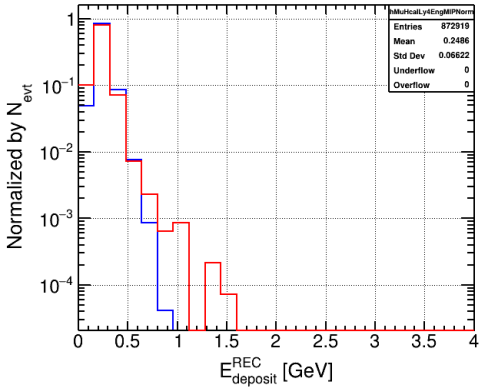
HCAL Layer=2



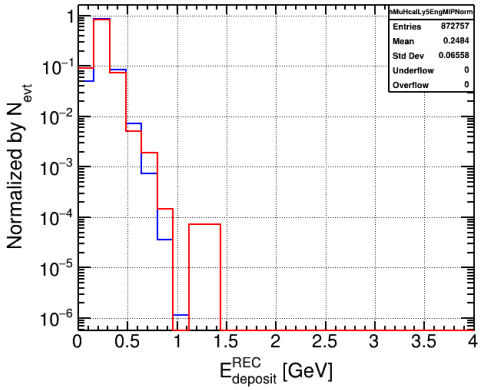
HCAL Layer=3



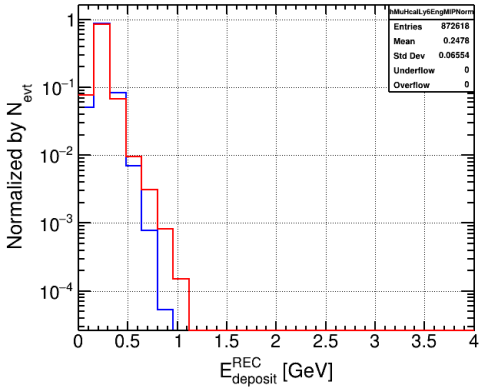
HCAL Layer=4



HCAL Layer=5



HCAL Layer=6

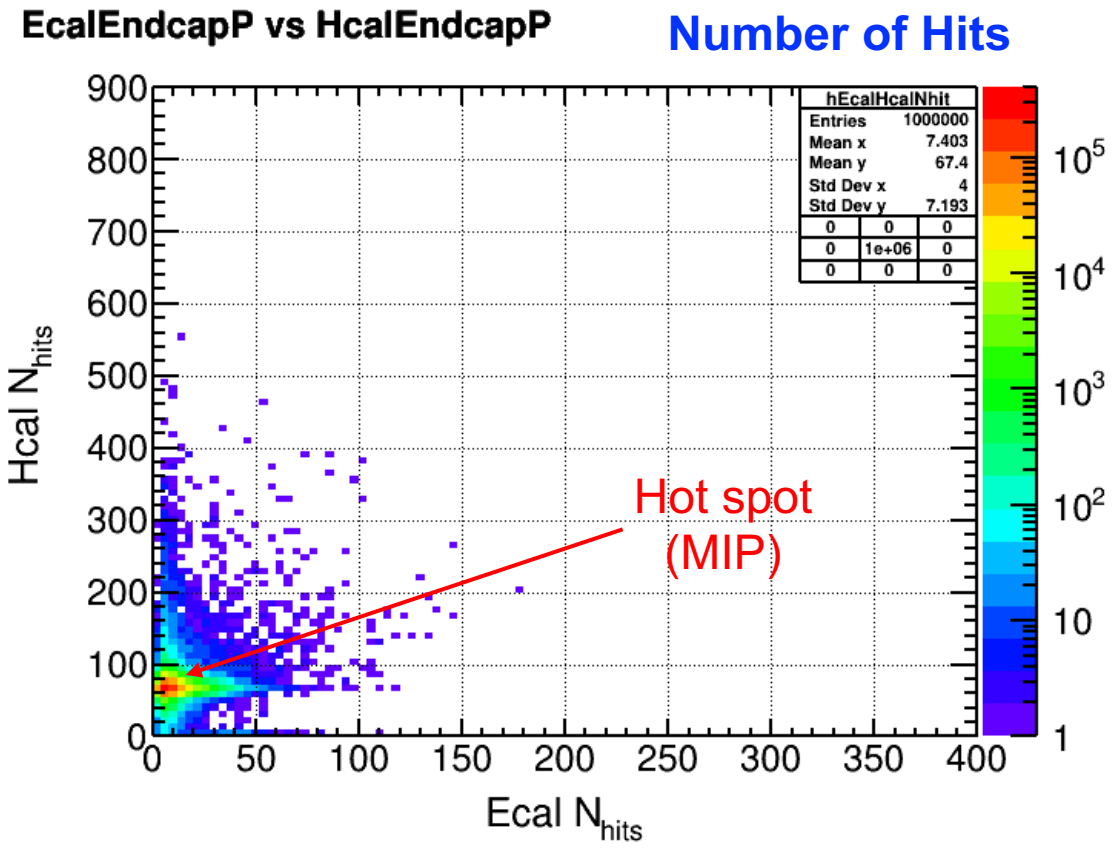


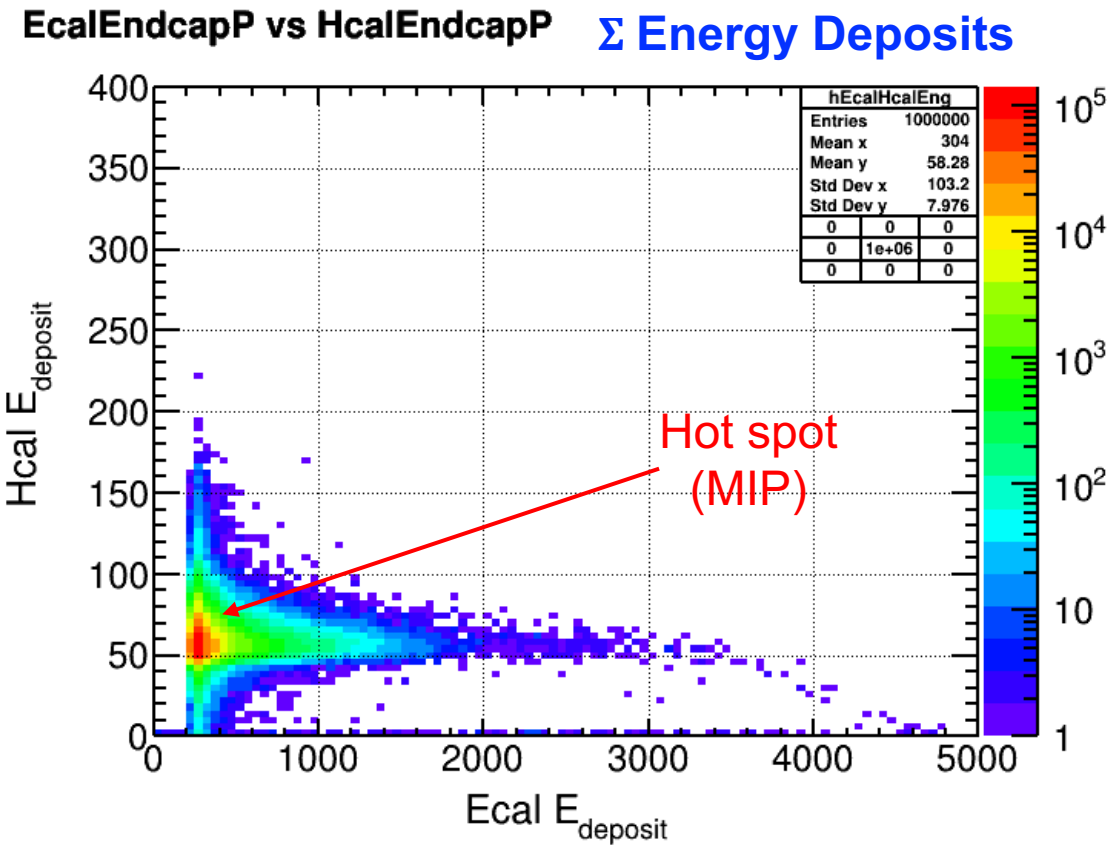
Next Step

- Pass-0
  - Two layers: Ecal and Hcal as a whole
  - Focus on energy deposit
    - Reconstructed hit level (calibrated and sampling fraction applied)
- Pass-1
  - Use information of 7 layers in HCAL
    - How many layers being punching through in HCAL
    - How munch energy being reconstructed in HCAL layer
  - Machine Learning - TMVA module

Backup Slides

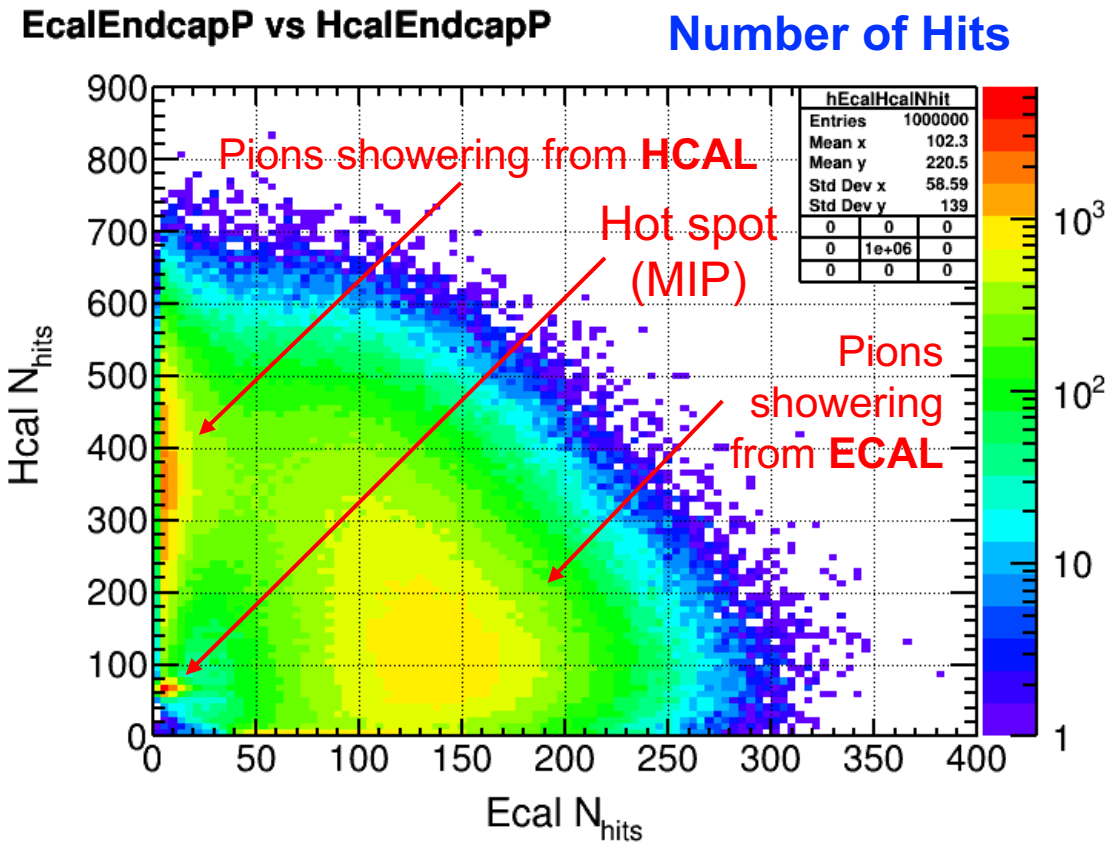
Muon – GEANT4 Response in Forward

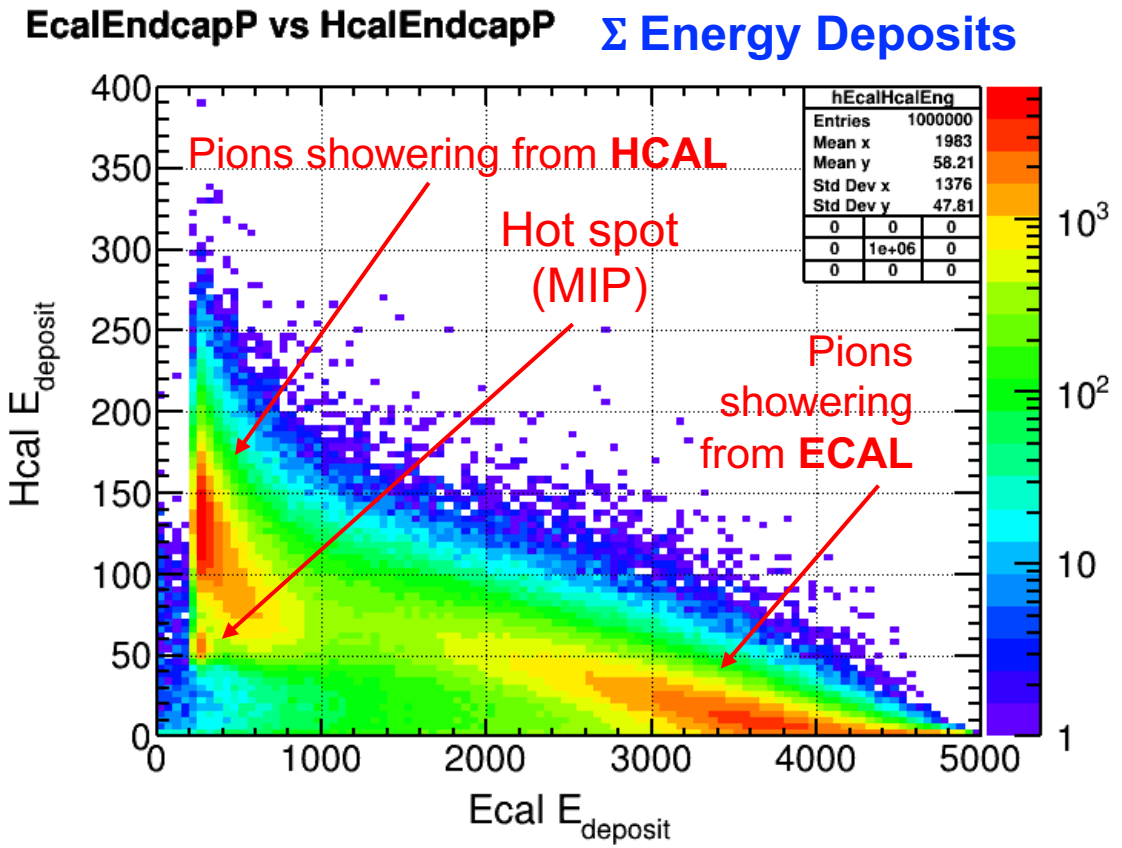




For muon sample, there is clearly a hot spot
in terms of number of hits and and energy deposit (MIP) in ECAL and HCAL respectively

Pion – GEANT4 Response in Forward



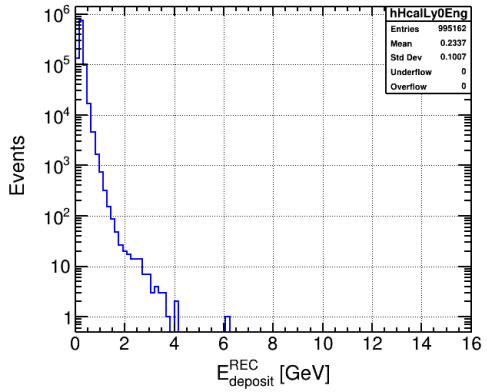


For pion sample, there are three groups;
pions showering from ECAL, pions showering from HCAL, and pions not showering at all (MIP-like)

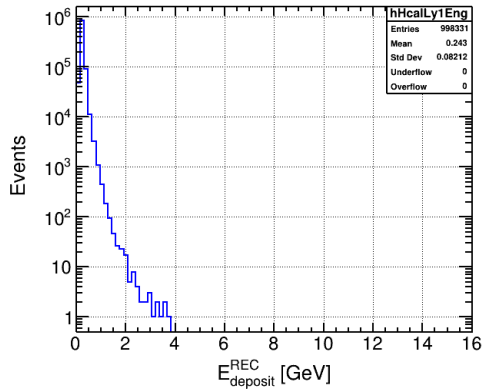
p = 5 GeV and η = 1.74

Muon Sample – HCAL Layer

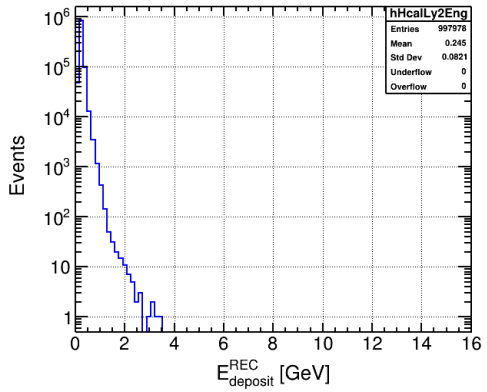
HCAL Layer=0



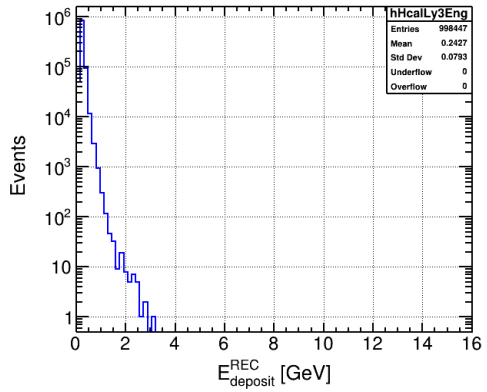
HCAL Layer=1



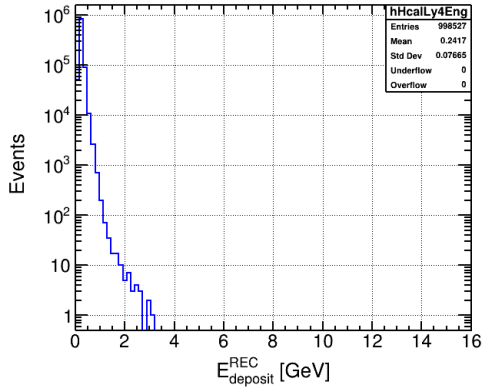
HCAL Layer=2



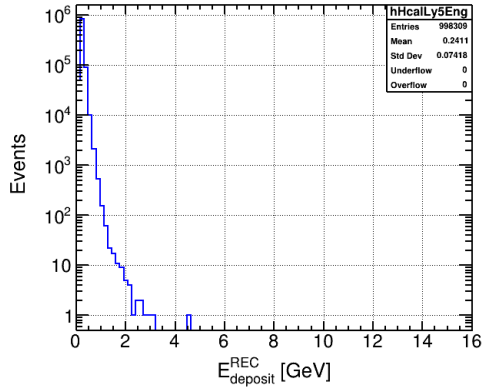
HCAL Layer=3



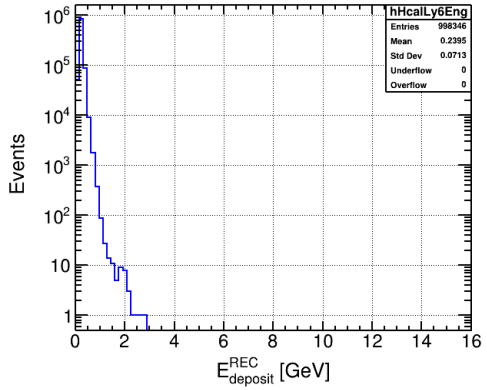
HCAL Layer=4



HCAL Layer=5



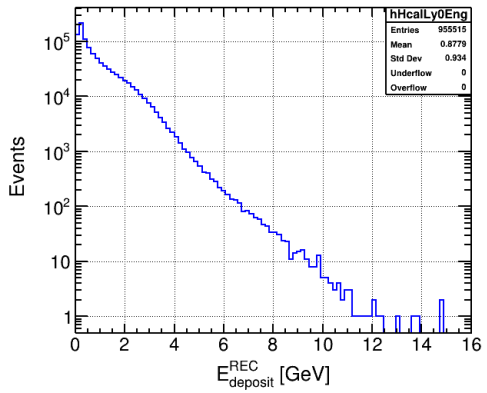
HCAL Layer=6



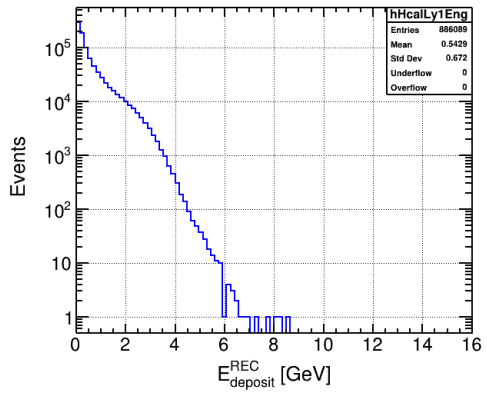
p = 5 GeV and η = 1.74

Pion Sample – HCAL Layer

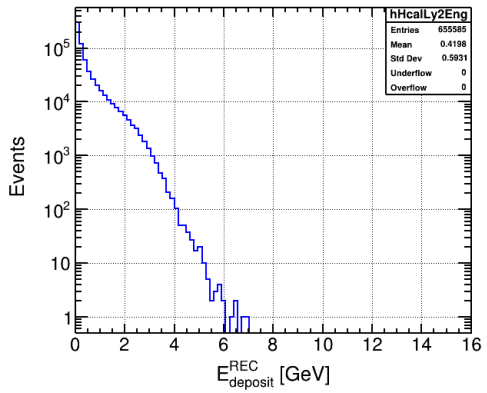
HCAL Layer=0



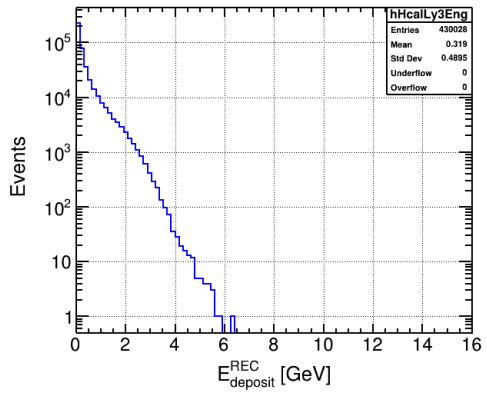
HCAL Layer=1



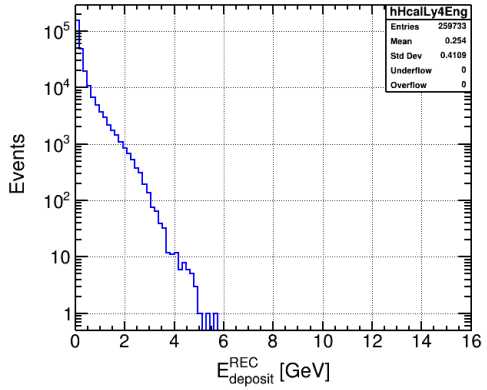
HCAL Layer=2



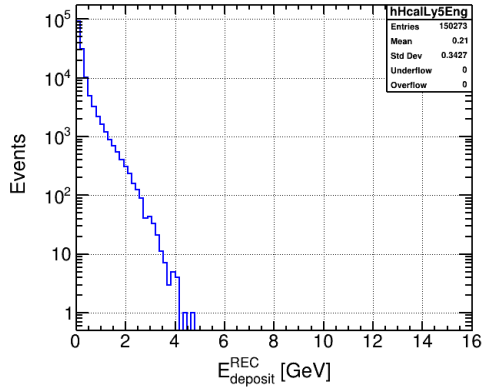
HCAL Layer=3



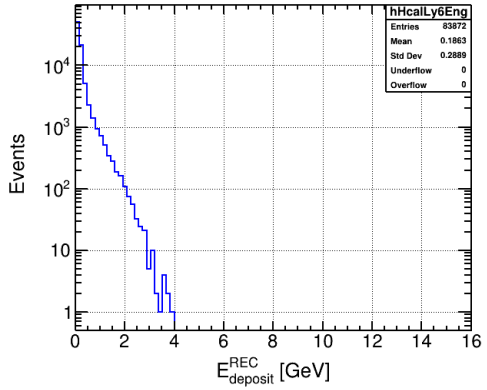
HCAL Layer=4



HCAL Layer=5



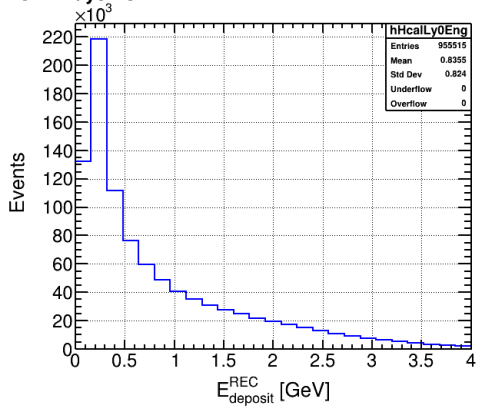
HCAL Layer=6



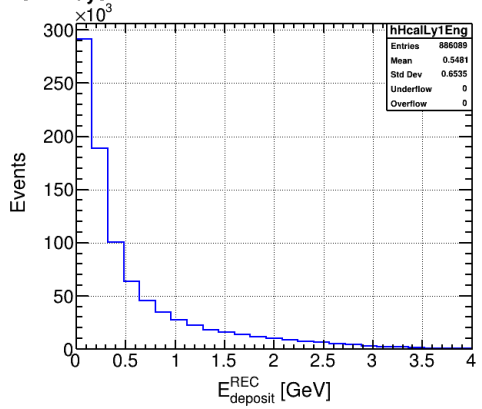
p = 5 GeV and η = 1.74

Pion Sample – Each HCAL Layer

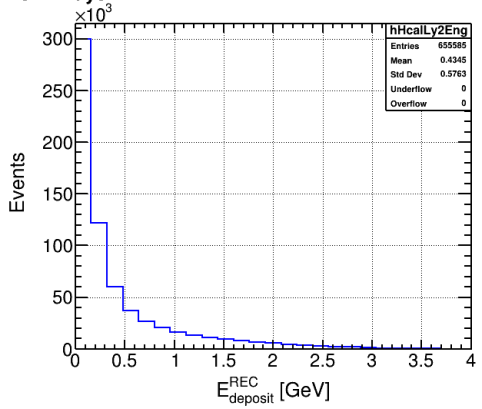
HCAL Layer=0



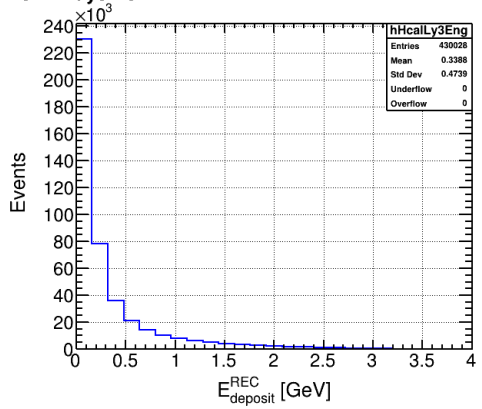
HCAL Layer=1



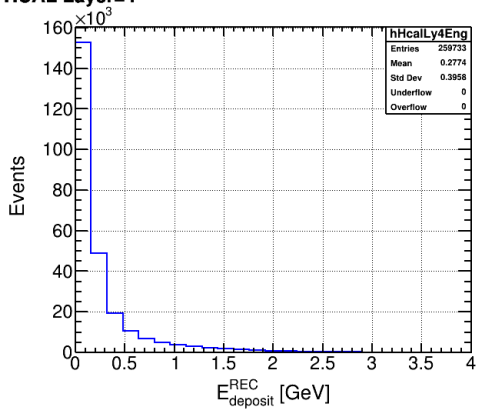
HCAL Layer=2



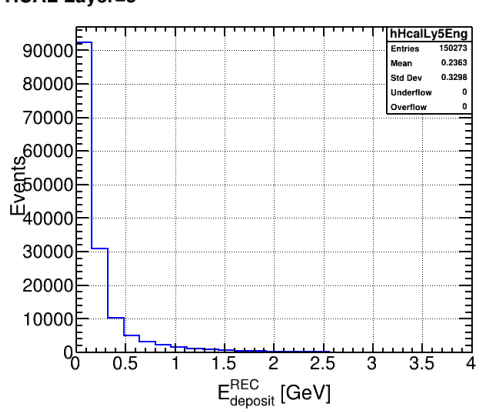
HCAL Layer=3



HCAL Layer=4



HCAL Layer=5



HCAL Layer=6