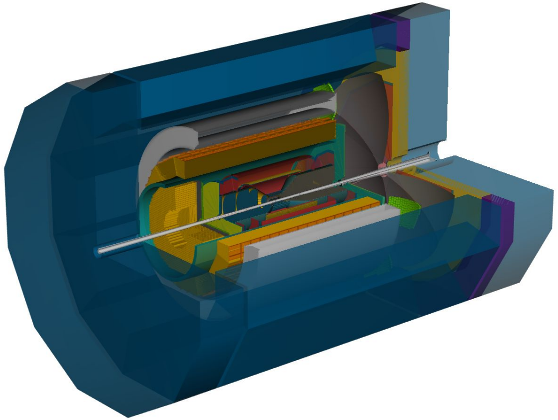
GD/I WG Meeting

Muon Detection



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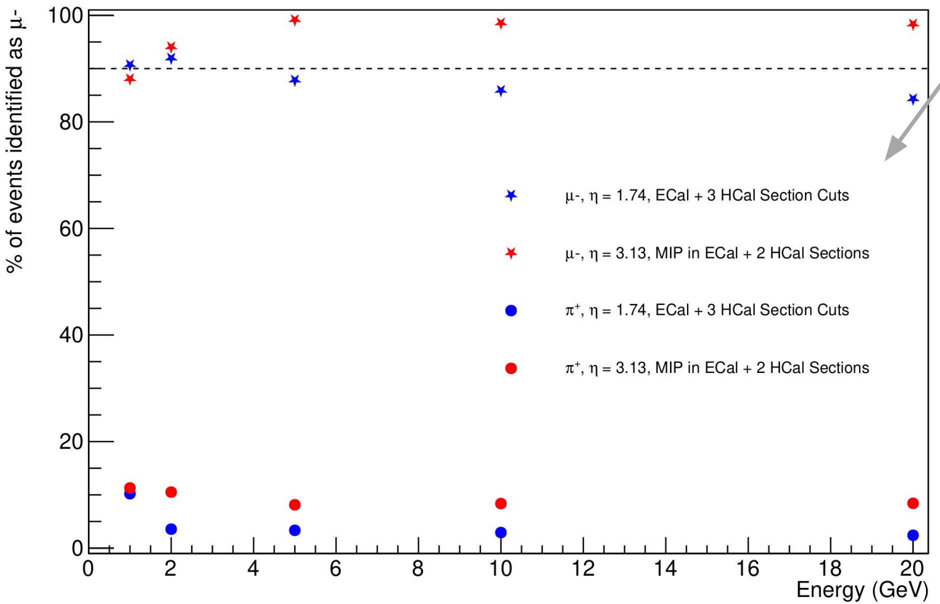
DPAP Question - muon PID

G-5 Provide estimates of the **pi/mu rejection** factor in different regions of pseudorapidity

Muons in hadron endcap region

- Muon/pion separation in **forward region** determined from **pECal** and **pHCal** responses
  - ➢ pEndCap calorimeter has five longitudinal segments: pECal + four sections in pHCal, total ~ **7 interaction lengths**



Percent of events identified as muons for generated pion sample (pion contamination, dots) and muon sample (muon efficiency, stars) at η=1.74 and η=3.13

For **~90% muon efficiency**, only **a few % of pions are misidentified as muons**

Simulation:

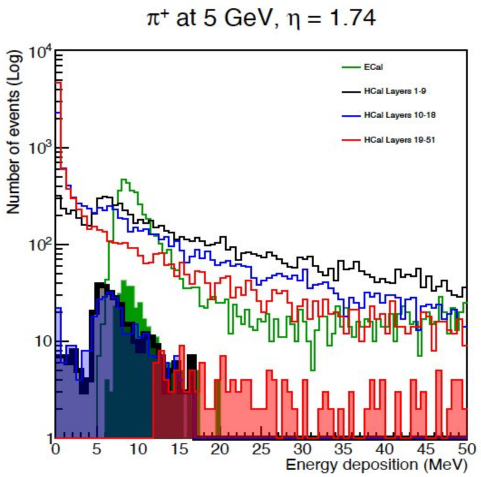
- Single particle simulation at η=1.74 and η=3.13 with stand-alone pHCal and pECal

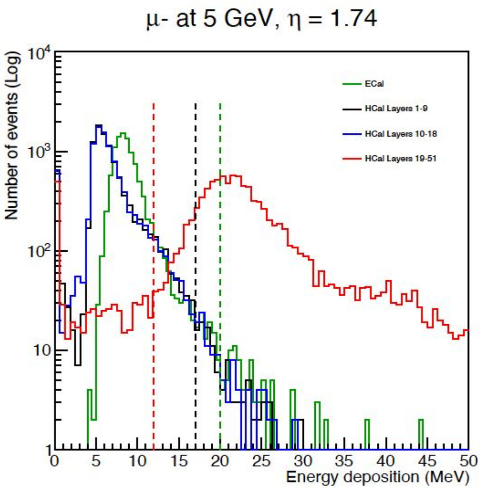
Selection Criteria:

- MIP-like signal in pEndCap calorimeter sections (cut on energy deposit)
- Number of hits along the tracks consistent with no shower (at higher energy/rapidities)

Muons in hadron endcap region - methods

Example energy deposit of 5 GeV pions (left) and muons (right) in ECal, and section-1, section-2, and section-3+4 of HCal





Filled histograms: pions misidentified as muons

Lines: cut on energy losses for muon ID

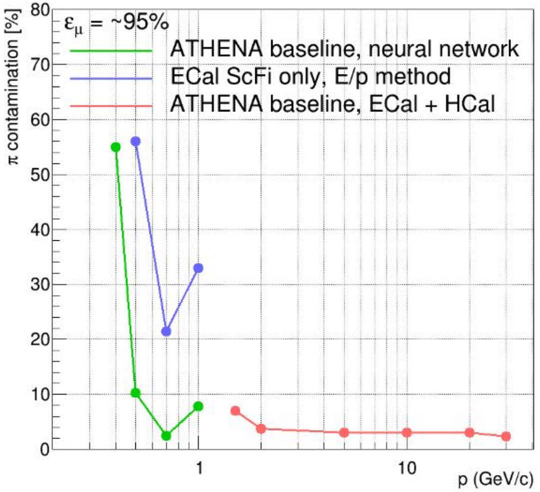
- dE > 12 MeV for section-3+4
- dE < 17 MeV for section-2 and 1
- dE < 20 MeV for ECAL

- Pions passing calorimeter without showering are misidentified as muons (filled histograms in pion plot)
- First three sections of pEndCap shield low/medium energy pions, i.e. **energy deposition from muons is larger** in last two sections **of pHcal than that from pions**, which provides clean muon ID
  - Compare the red histograms in the muon and pion plots

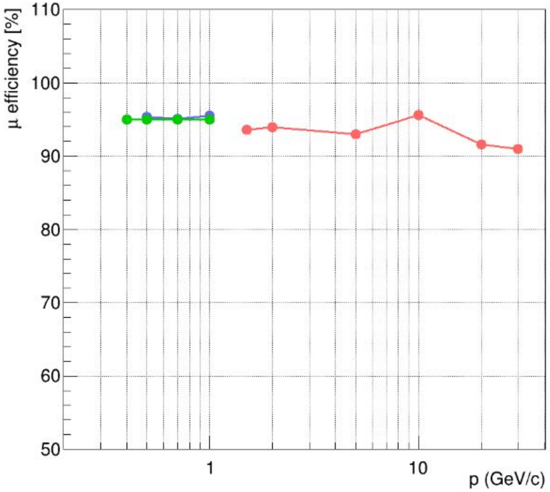
Muons in barrel region at 3T

- Muon/pion separation in **central region** determined from information from the **Barrel ECal** and **HCal**
- Results for single particle simulation, **see details in the following slides**

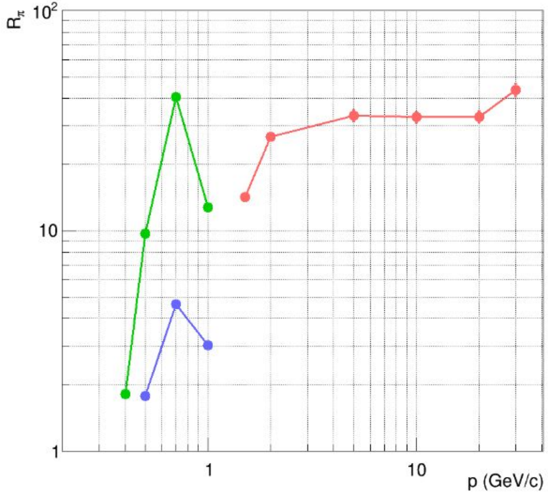
π contamination



μ efficiency



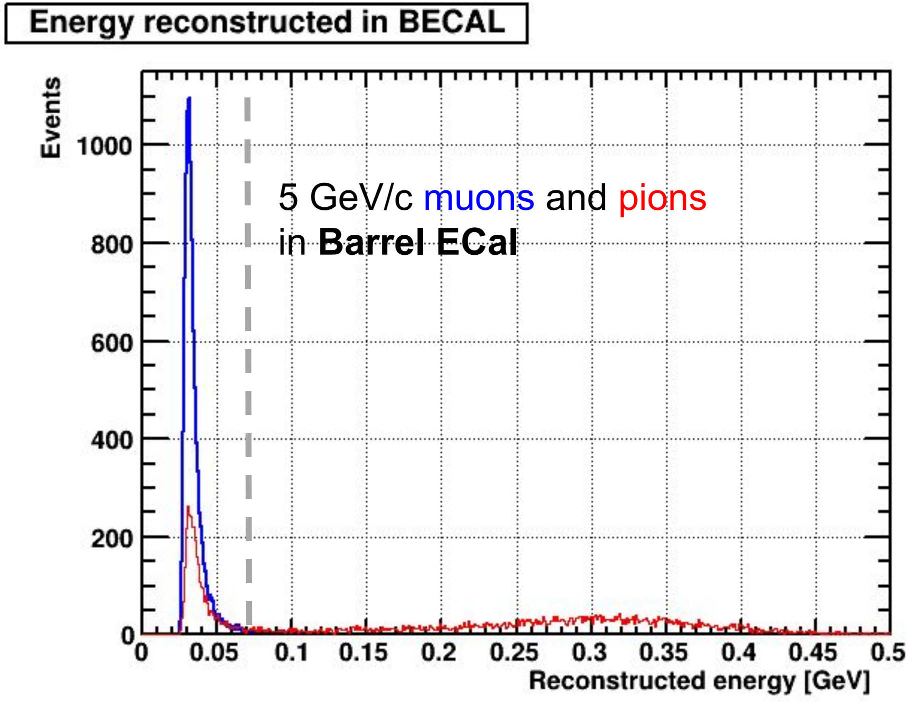
π suppression



- **At η = 0: muons >~1.5 GeV/c reach HCal, and <~1.5 GeV/c curl inside the BCal** (different approach to analysis)
  - ➢ This discontinuity (in reaching HCal) is rapidity dependent
- Neural Network studies in ECal done for η = (-1,1), ECal+HCal studies and E/p studies in ECal done for η = 0
- Further improvements to muon/pion separation from PID detectors expected (DIRC)

Muons in barrel region - methods

- For energies **above ~1.5 GeV/c** muons **punch through the Barrel ECal** leaving MIPs signal and **reach HCal**



Simulation:

- Muons and pions generated at **η = 0** with different energies **with full simulation and 3T field**

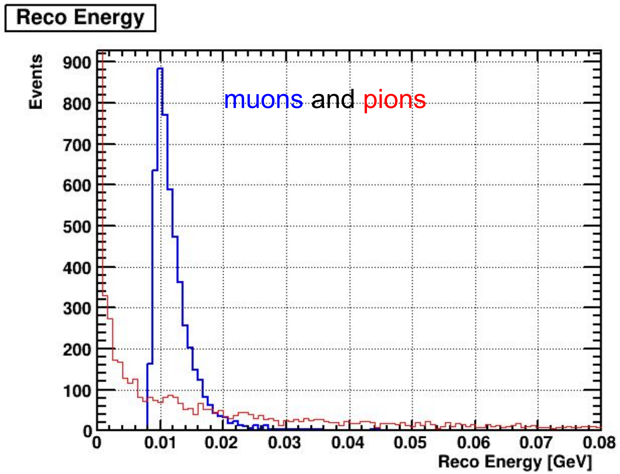
Muon selection cut:

- Energy deposit in Barrel ECal within MIP region (~95% muon efficiency)
- One or two hit tiles required in each of the first 10 layers of HCal

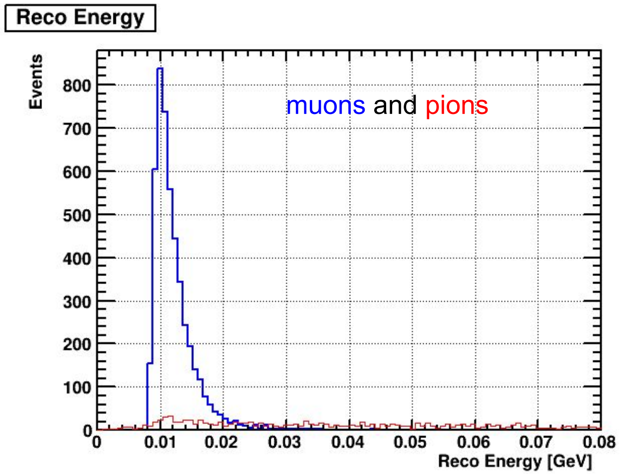
Muons in barrel region - methods

- **Energy deposit in the Barrel HCal** for muons and pions - example at **5 GeV/c**

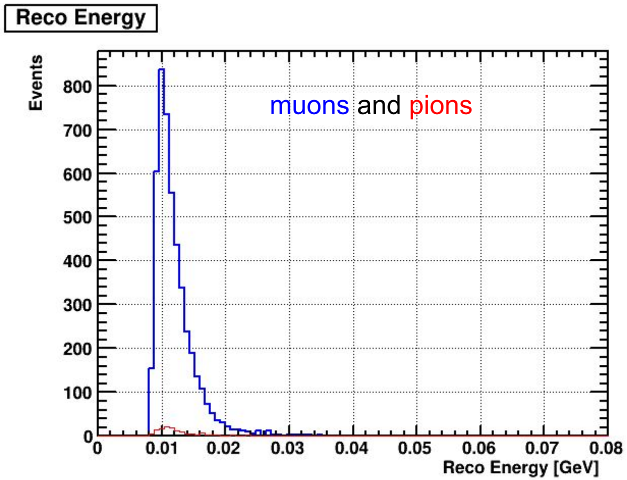
No cuts



Cut on MIPs from ECal

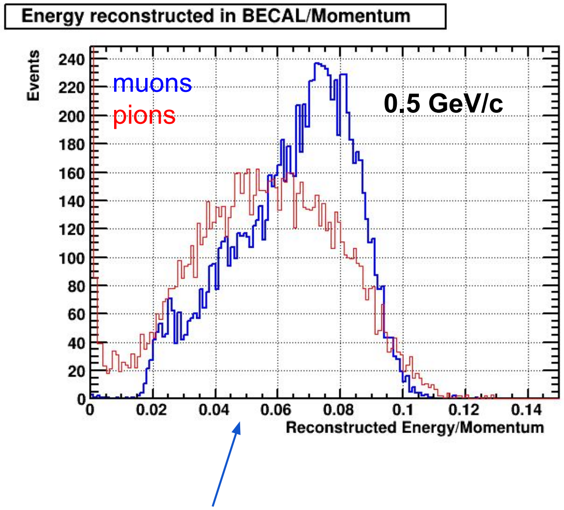


Cut on nb of hit tiles in HCAL

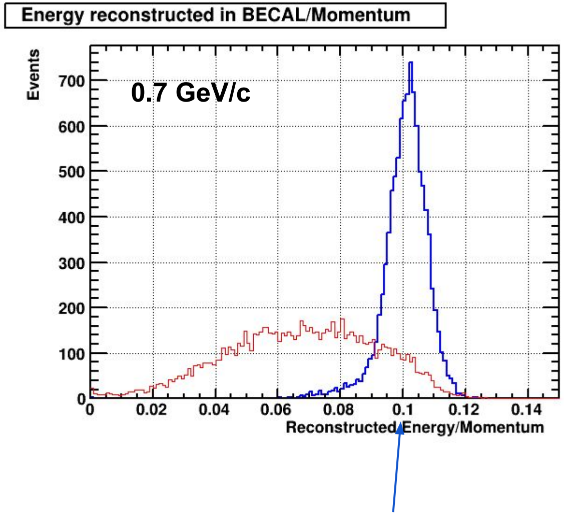


Muons in barrel region at 3T - methods

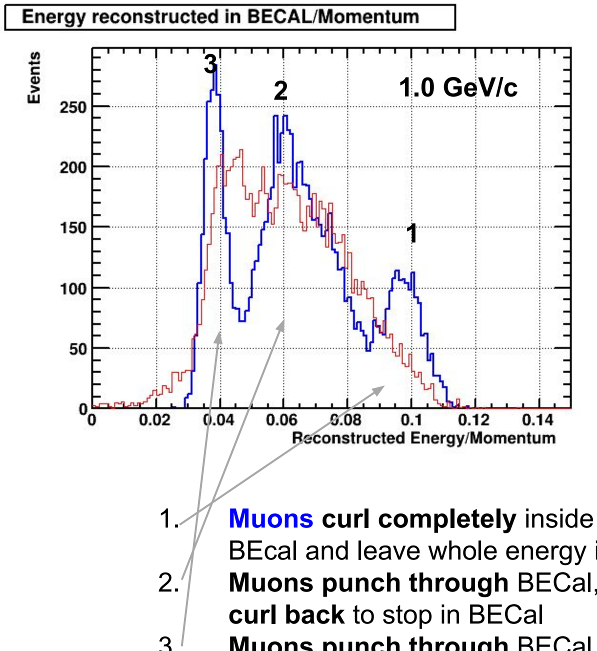
- For energies **below ~1.5 GeV/c** muons **curl inside the Barrel ECal**



Muons reach only a few first layers of BEcal; deposit partial energy inside the BECal and **curl back**



Muons curl completely inside the BEcal and leave whole energy inside



1. **Muons curl completely** inside the BEcal and leave whole energy inside
2. **Muons punch through** BECal, and **curl back** to stop in BECal
3. **Muons punch through** BECal, and **don't curl back** (MIPs signal)

Sampling fraction of Barrel ECal = ~**0.1**

For 1.5 T field the p ~ 0.2 GeV/c (case I), p ~ 0.3 GeV/c (case II), p ~ 0.5 GeV/c (case 3)

Muons in barrel region - methods

- For energies below ~1.5 GeV/c muons **curl inside the Barrel ECal**
- **Barrel ECal with 3T field "serves as" an HCal**

PID Cuts

1) **Method 1:** Using only information from ScFi in Barrel ECal (Energy losses in layers)
    a) Cut on E/p from single ScFi/Pb Calo Layer or sum of all ScFi/Pb Calo Layers

2) **Method 2 (showing impact of imaging layers):** ML supported, using information from **ScFi/Pb and Imaging layers**
    a) Input which encodes the energy and spatial distribution of the particle's shower
        - **Four features** for each hit: η, φ, E, $R = \sqrt{(x^2 + y^2)}$; (no η for ScFi/Pb)
        - Values normalized to [0,1]
        - Three-layers convolutional neural network and three-layers perceptron network
        - Network outputs: **likelihoods** of the input particle to be **identified as a muon or a pion**. Likelihood **cut: 95% of muon efficiency**

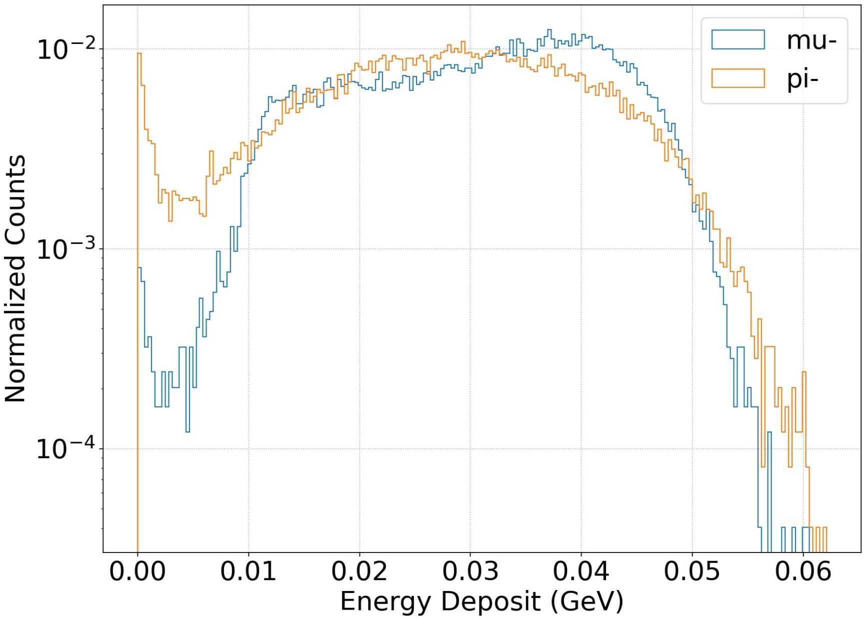
Muons in barrel region - methods

Example of **muons** and **pions** at **p = 0.5 GeV/c** at η = (-1,1)

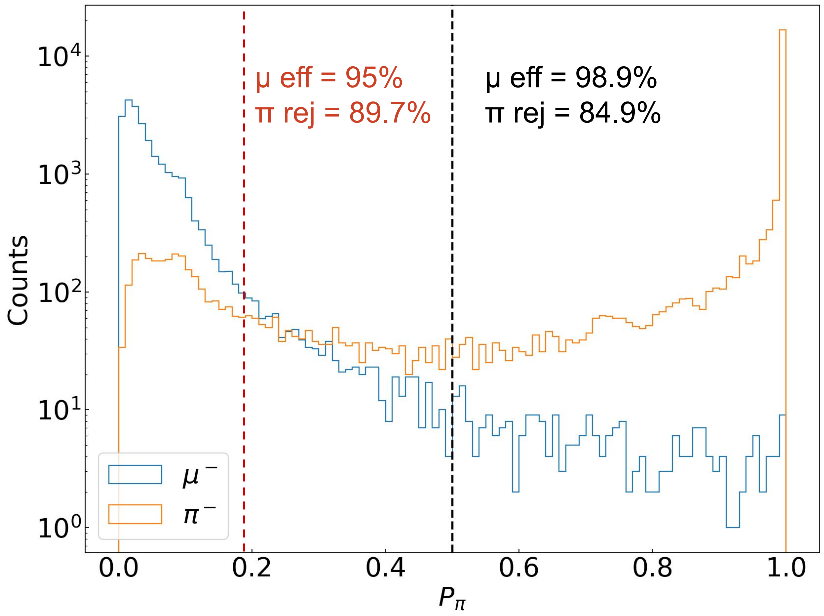
Efficiency: 98.9% → Rejection Power: 6.6

Efficiency: 95% → Rejection Power: 9.7

Total Energy deposit in ScFi/Pb

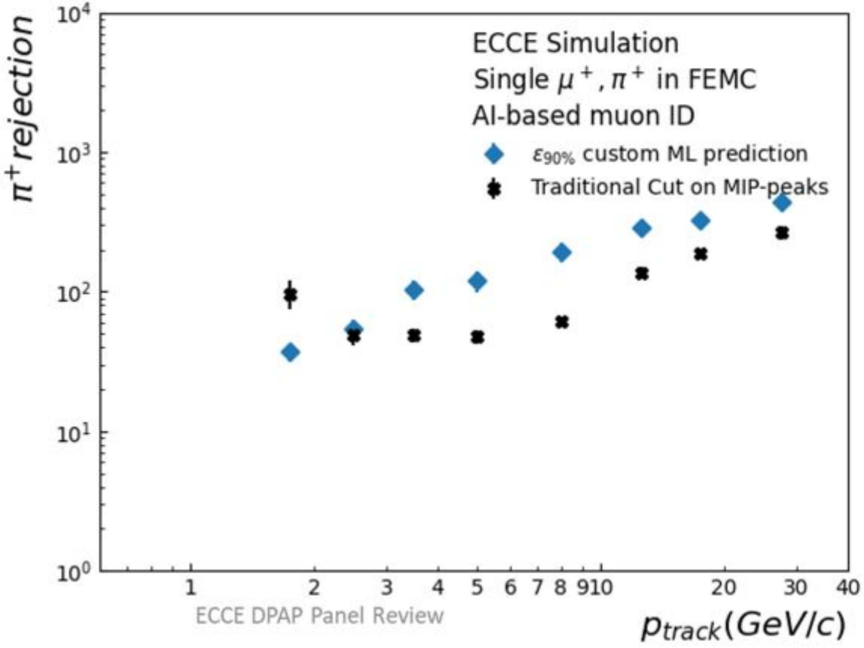


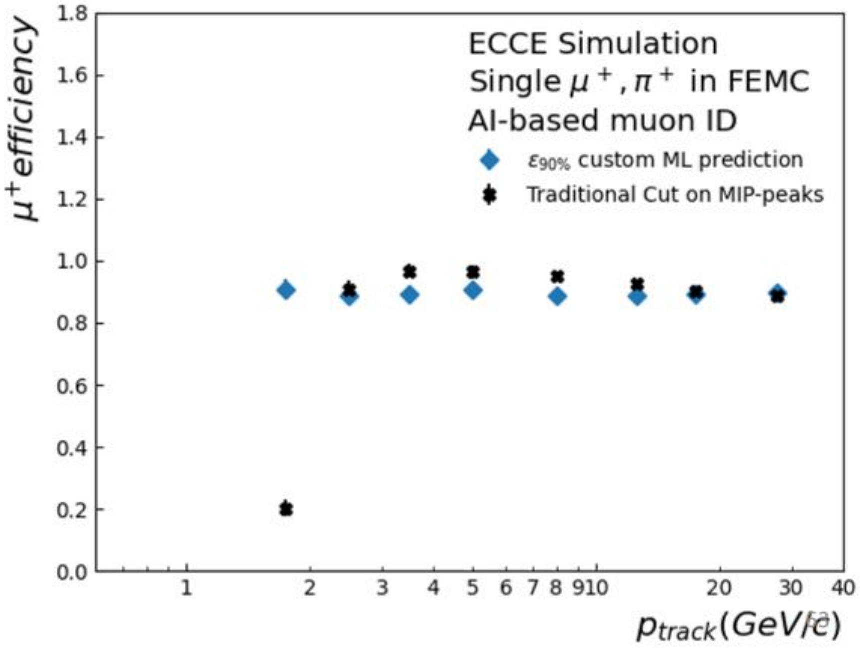
NN output likelihood



G-5: pion rejection/muon eff. - forward

- Utilizing tracking, forward EMCal, and six layers of forward HCal
- Pion rejection starting at few 10s:1 at low p and increase to a few 100:1 above a few GeV/c

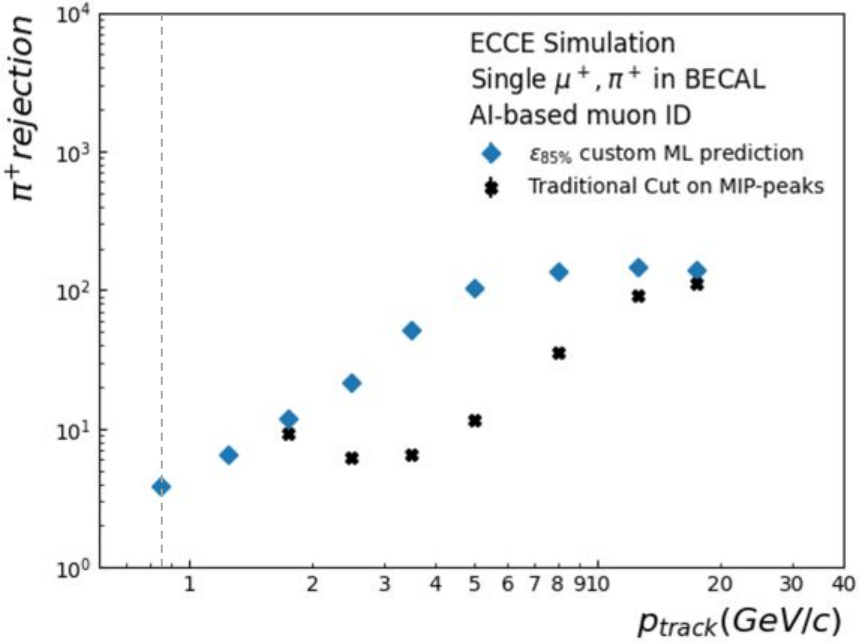


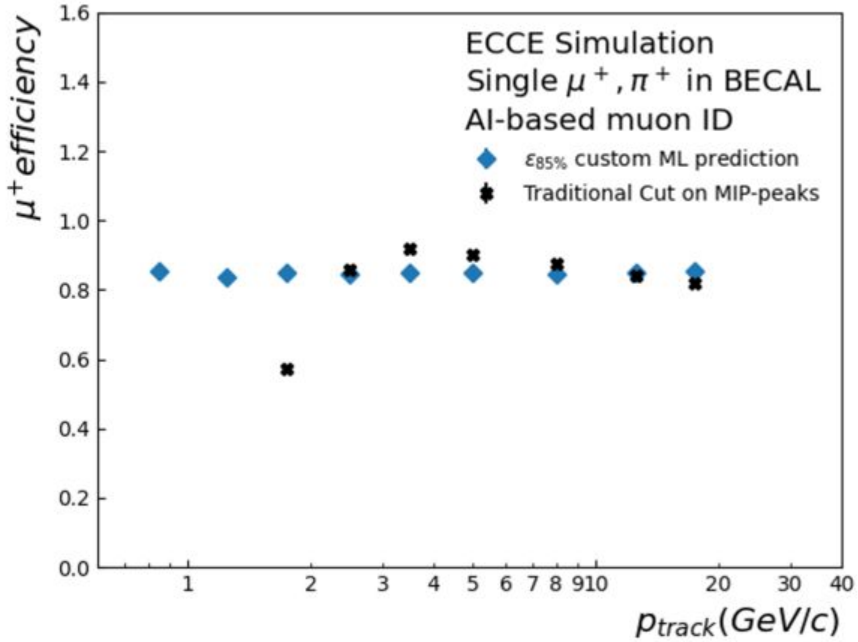


Source: DPAP Homework Responses

G-5: pion rejection/muon eff. - central

- Utilizing central track, barrel EMCal, EMCal active support and barrel HCal
- Pion rejection starting at 10^{-1} at low p and saturate above 100:1 above a few GeV/c





Muons in barrel region at 3T

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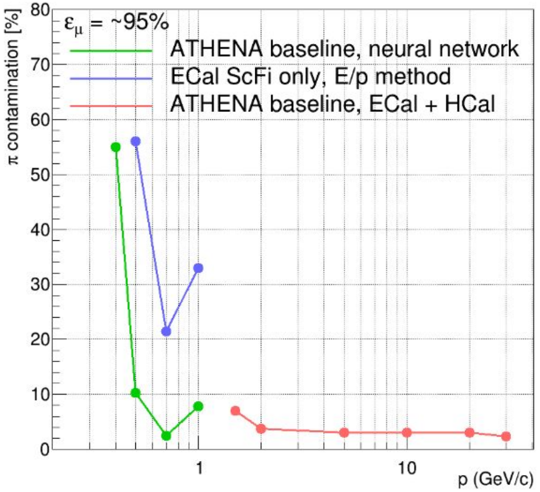

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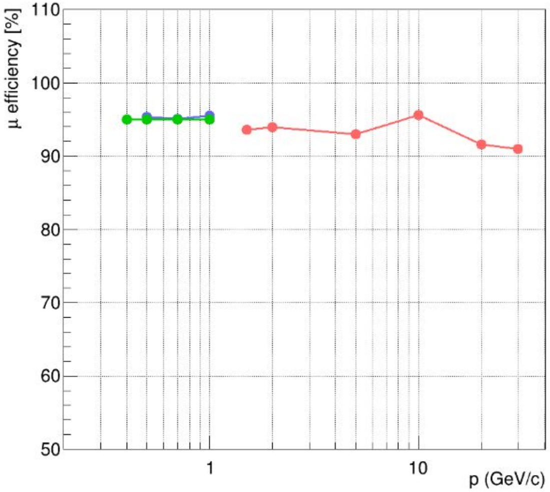

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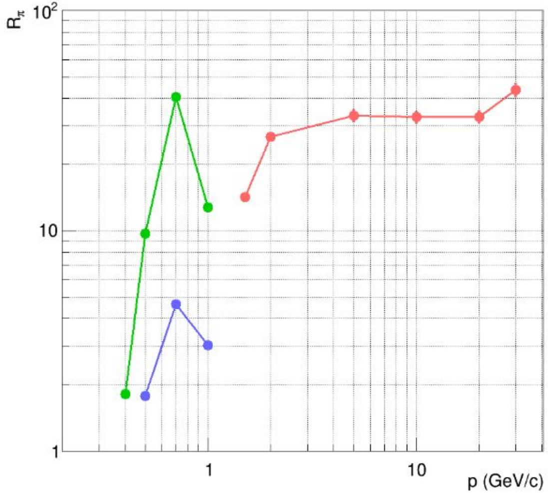

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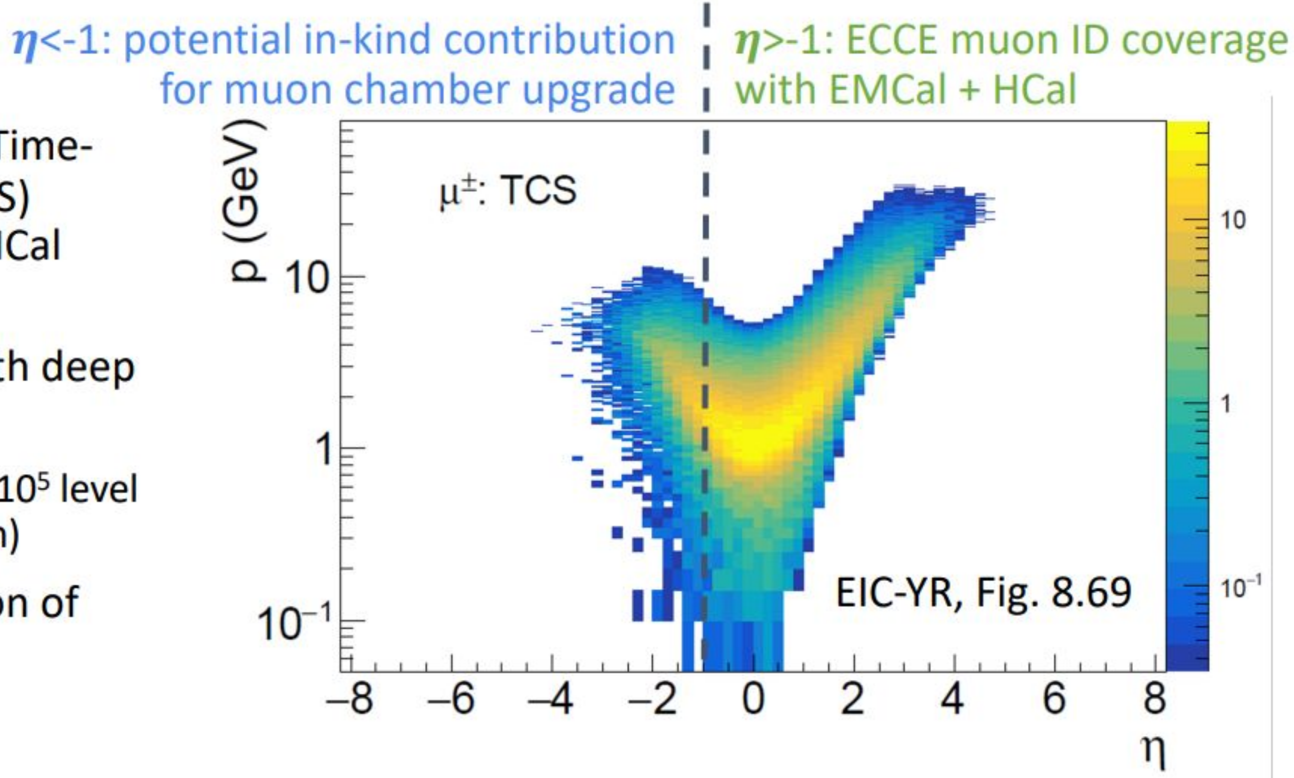
Source: DPAP Homework Responses

G-5: TCS muon-ID coverage

- ECCE cover majority of the Time-like Compton Scattering (TCS) phase space with EMCal + HCal based muon ID
- Boosted ID performance with deep learning expertise in ECCE.
- Pion-pair rejection at 10^2 to 10^5 level (square of single track rejection)
- Potential in-kind contribution of muon chamber upgrade to complete the cover for η<1



Summary

- Simulations show that for the forward region we should be able to identified muons with ~ 90% efficiency with a few % pion contamination

- For the barrel region, for high-enough pion momentum (~ 1.5 GeV/c for 3 T, and ~ 0.8 GeV/c 1.5) the muon/pion separation reaches similar level, with performance dropping close to the Solenoid-punching momentum threshold

- Rejection for the momenta below and close “punching threshold” where muons curl inside the calorimeter can be improved by imaging/tracking information ~ order of magnitude