MPD μID physics requirements

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TIFR ND workshop
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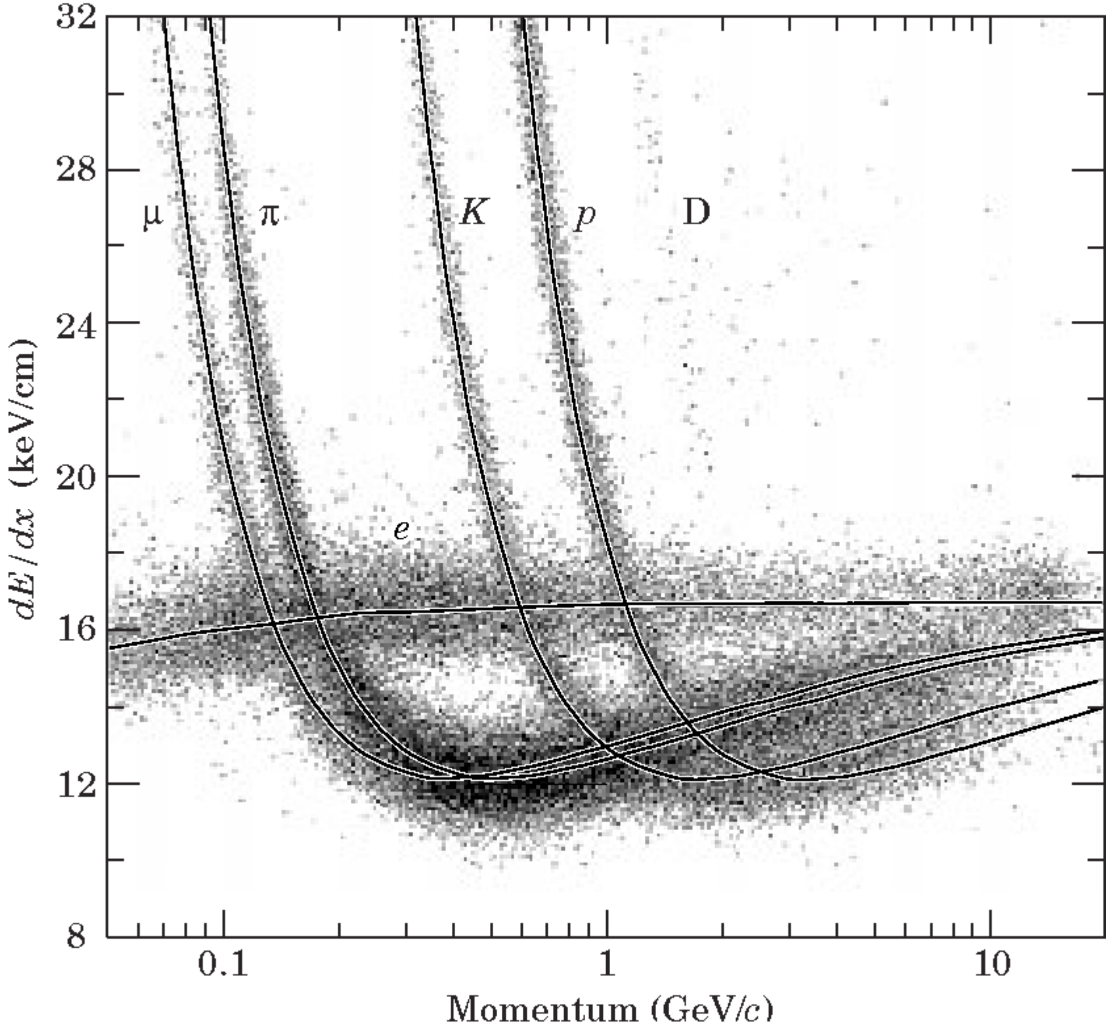
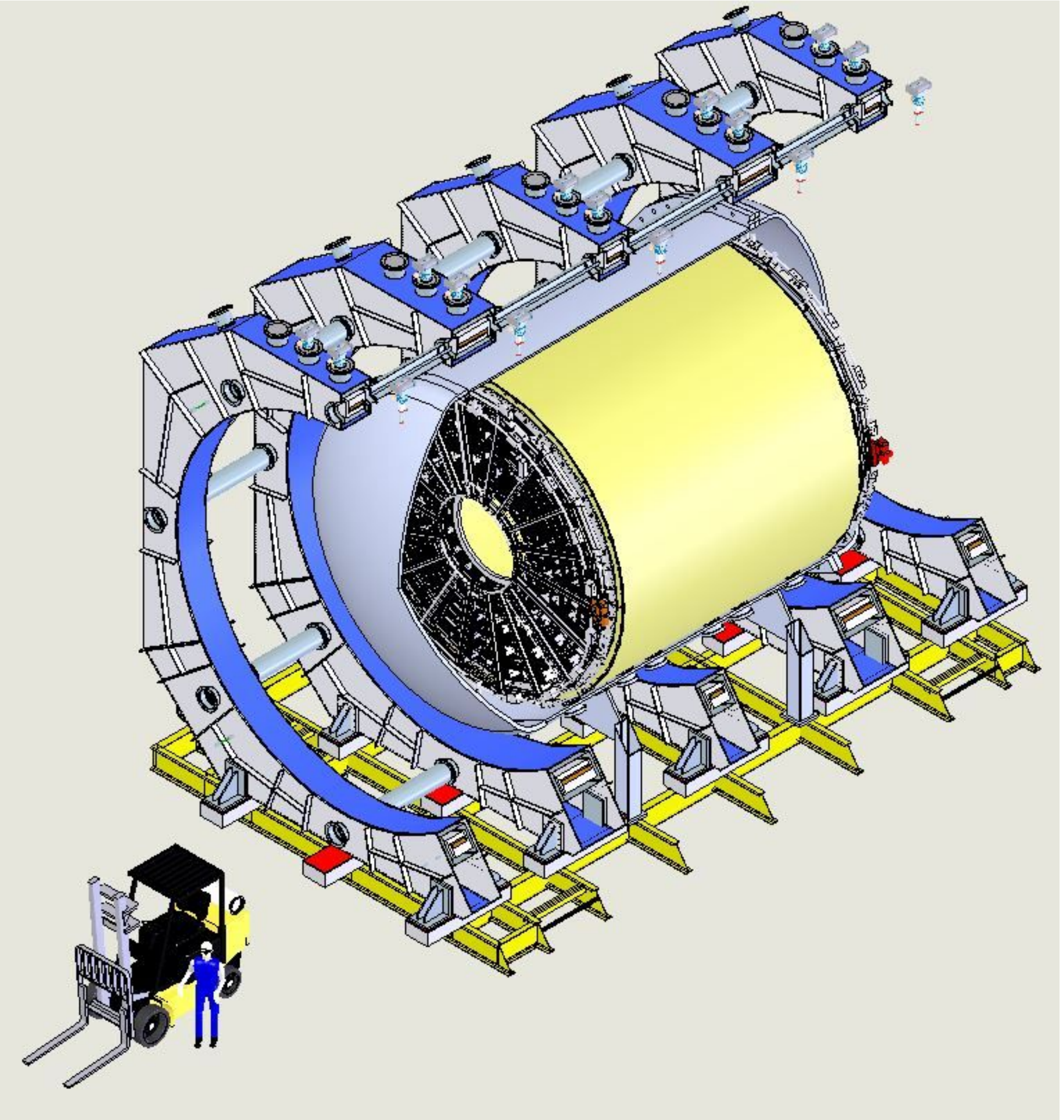
PID in HPgTPC

PEP-4 TPC



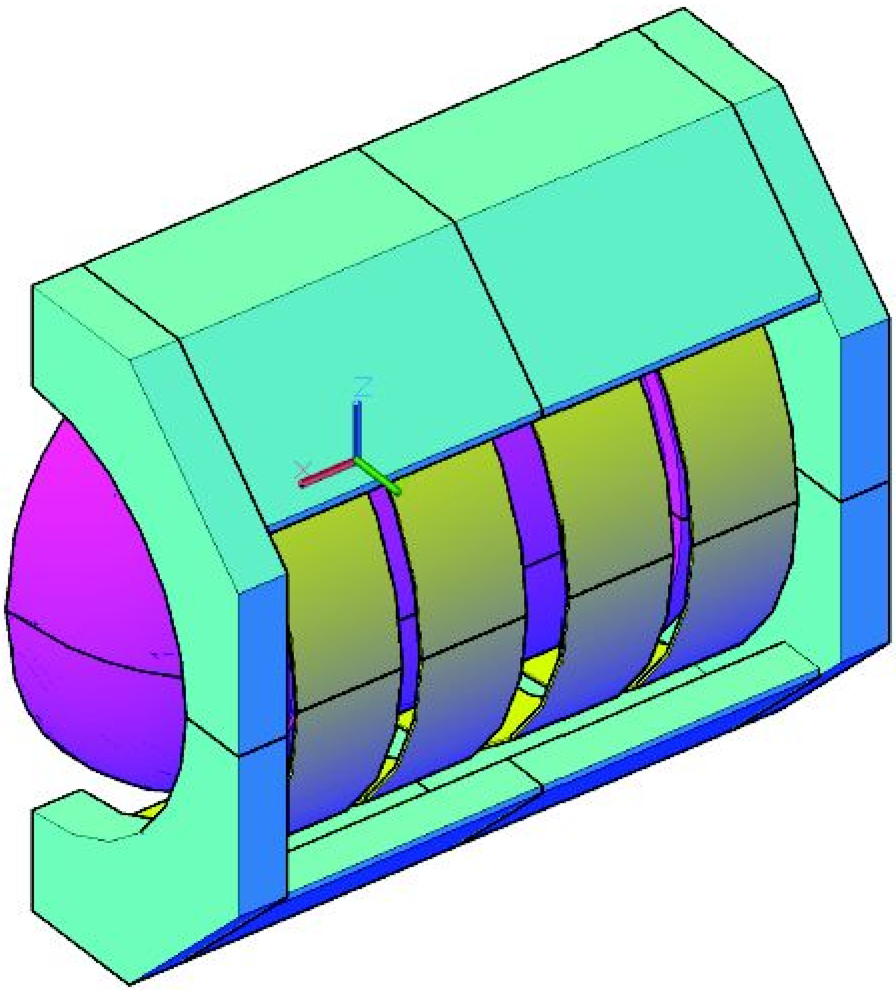
- Measure momentum from curvature
- Measure dE/dx from ionization
- Nice π/K/p separation out to ~1 GeV/c
- But no π/μ separation above ~0.2 GeV/c

MPD muon identification



- 60 layers ECAL (2mm Cu + 5mm CH) will range out a ~270 MeV (KE) muon or pion
- ECAL is ~1 pion collision length → ~2/3 of pions will scatter
- But ~1/3 of pions will track through ECAL and look like muons
- Instrumenting an iron return yoke could serve as μID

Solenoid with partial return yoke



- Magnetic flux return yoke is cut out in ±60º region to facilitate muon tracking into the HPgTPC
- Downstream side of yoke could be instrumented to measure muons
- Don't need momentum resolution, just μ/π separation

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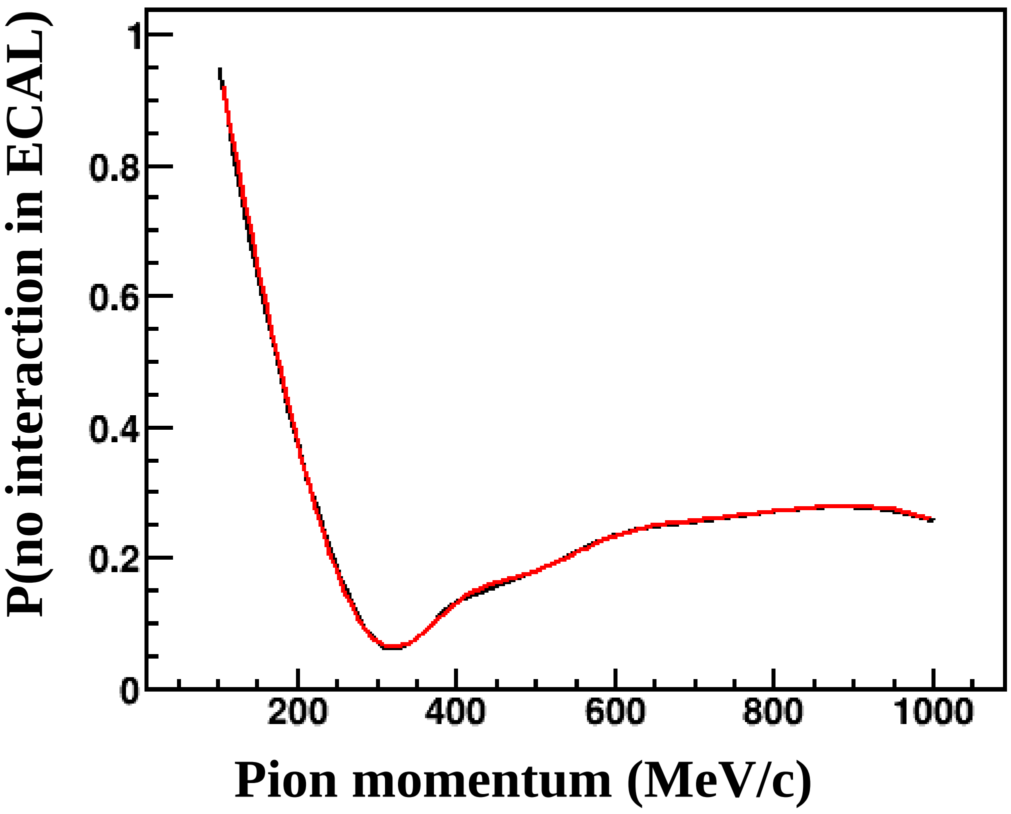
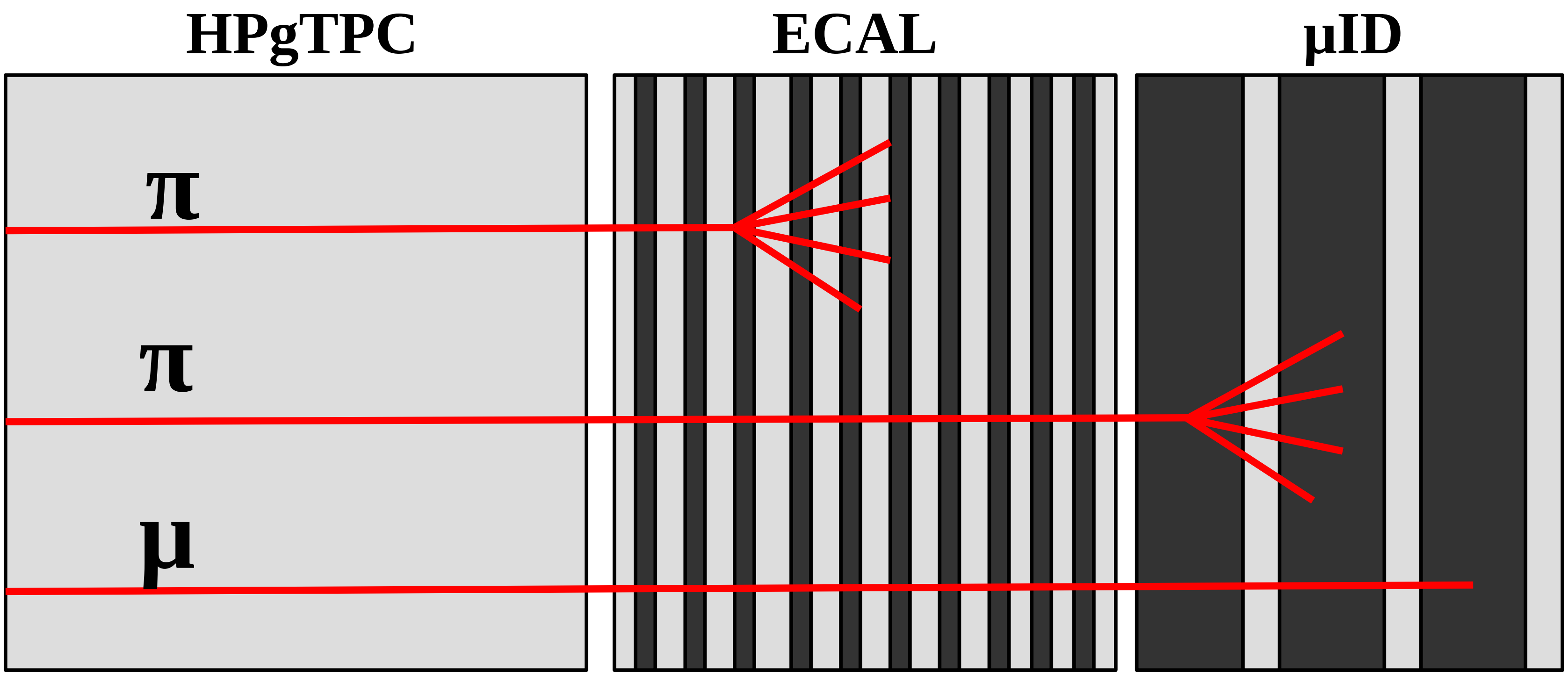
Pion interactions in the ECAL



- Below ~300 MeV/c: pions range out in ECAL, are less likely to interact when expected range is short
- ~300 MeV/c: resonance in pion scattering cross section, very high probability to scatter
- High momentum: entire ECAL traversed by pion above resonance region, plateaus at ~1.2 pion collision lengths

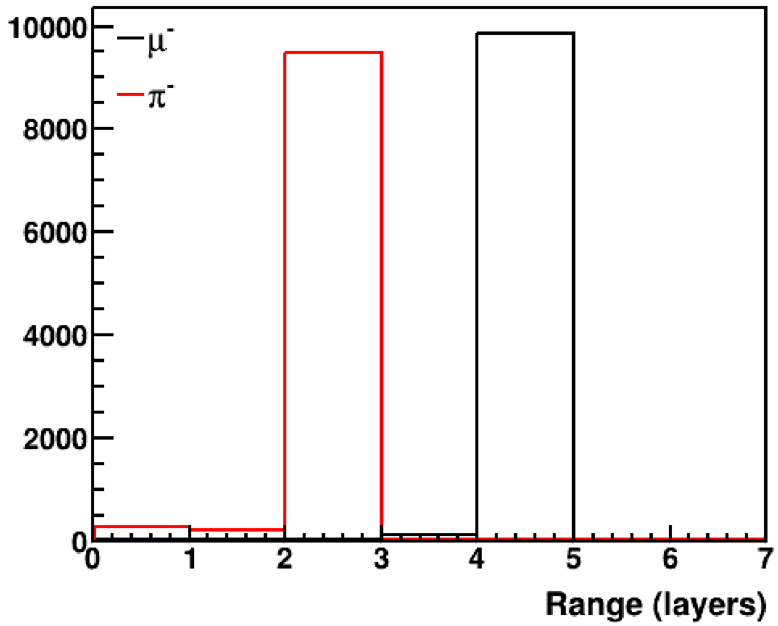
Basic idea of μID system



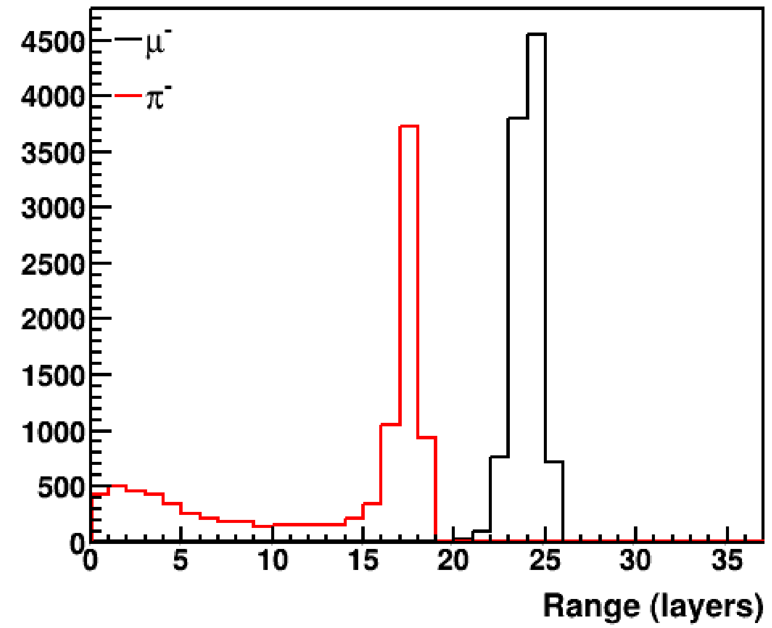
- Pion interactions will produce wider energy distribution in the active regions, even if individual products can't be measured
- 3 total interaction lengths gives ~95% pion rejection

ECAL stoppers can be selected by range & momentum

p = 100 MeV/c



p = 200 MeV/c



- Muons and pions of the same momentum have different kinetic energy and different range in ECAL, even for tracks that range out

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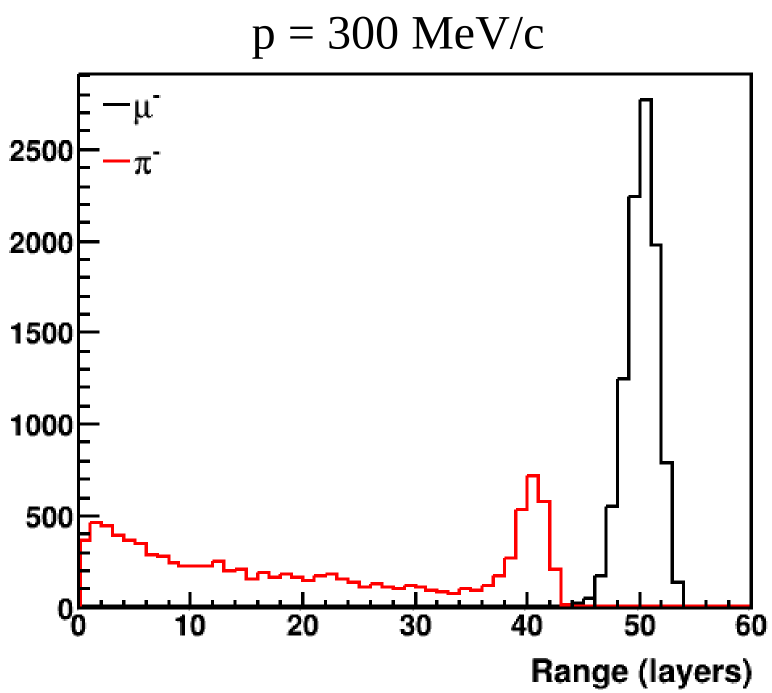
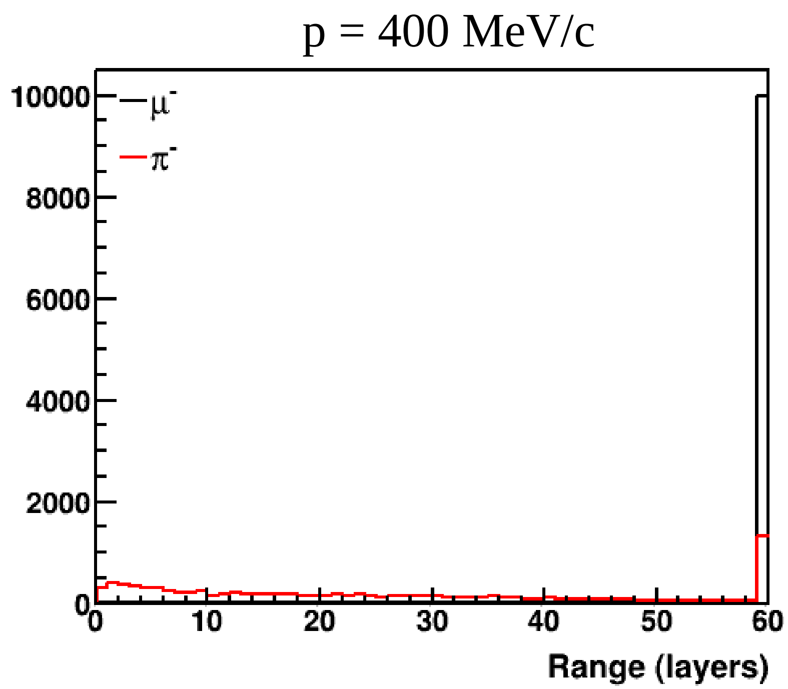
ECAL stoppers can be selected by range & momentum



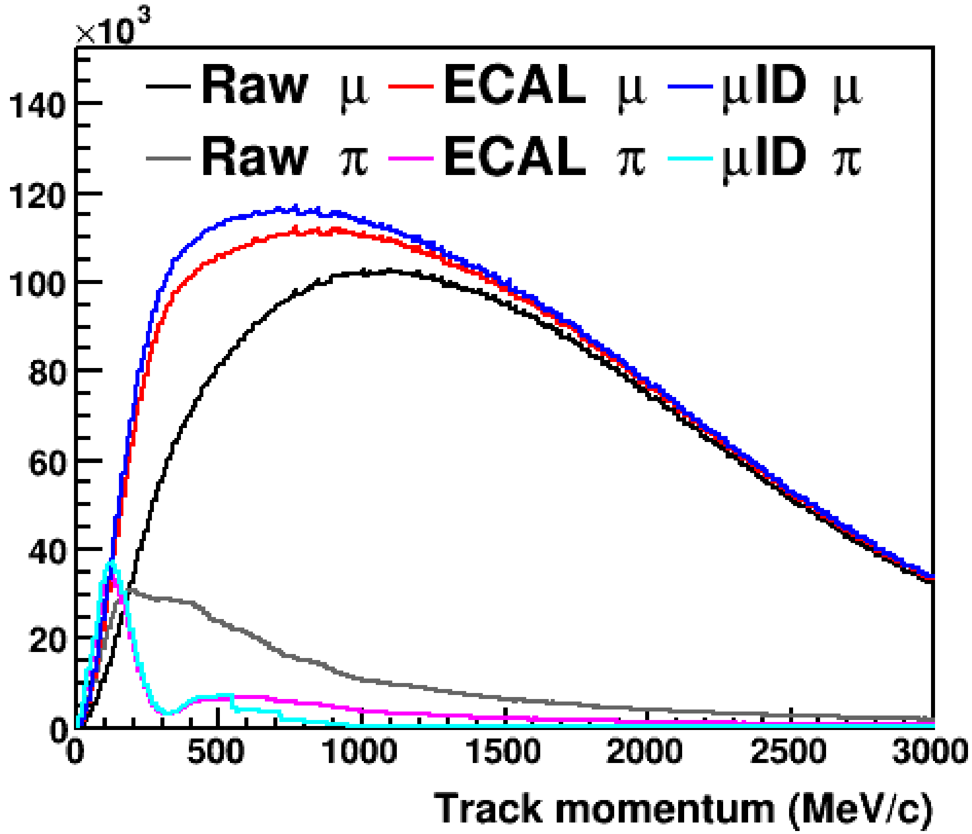


- There is basically zero overlap in ECAL traversed layers for muons and pions, up to where the pions start going all the way through, which is ~380 MeV/c

This study

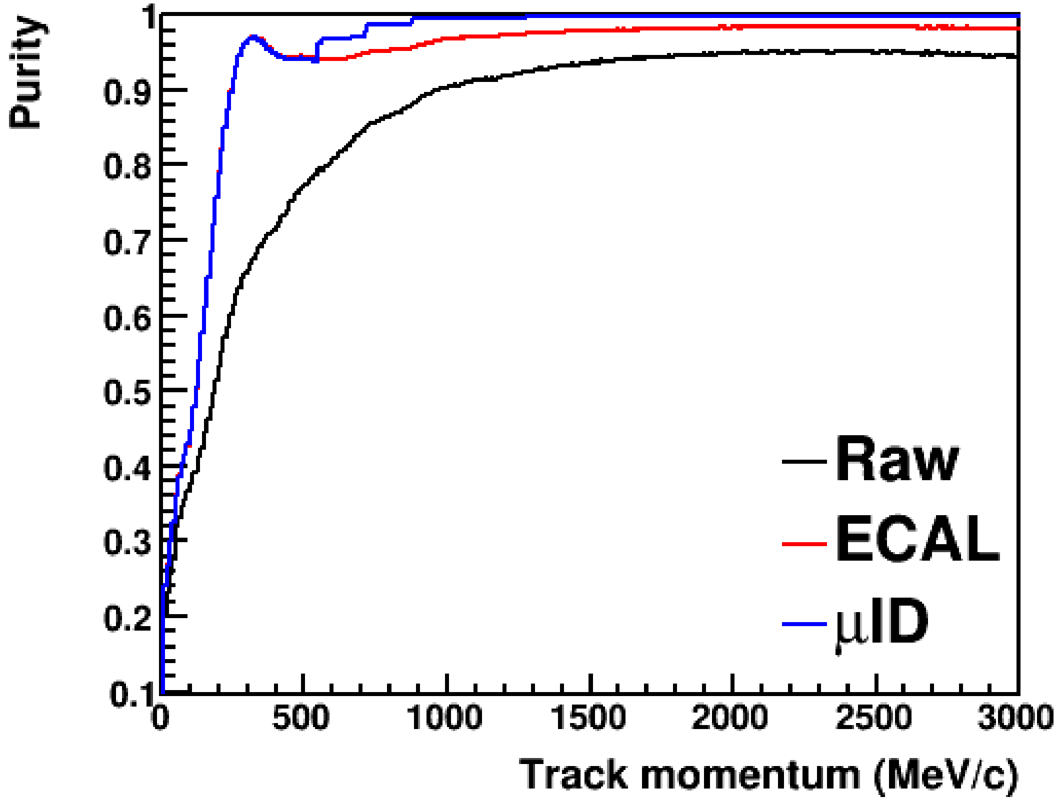
- Simulate neutrino interactions on Argon with GENIE
- Try to find the muon:
  - Select the highest-momentum right-sign μ or π track from HPgTPC (can't distinguish μ/π)
  - Determine if it interacts in the ECAL or μID system
  - If it does, then reject it as a pion, and proceed to the next track
- Goal: select high-purity charged-current samples – underlying pion and muon spectra set the bar for what rejection fraction is required
- Initial assumption for μID is 3 layers of 10cm steel

FHC CC ν_μ selection (μ^-/π^-)



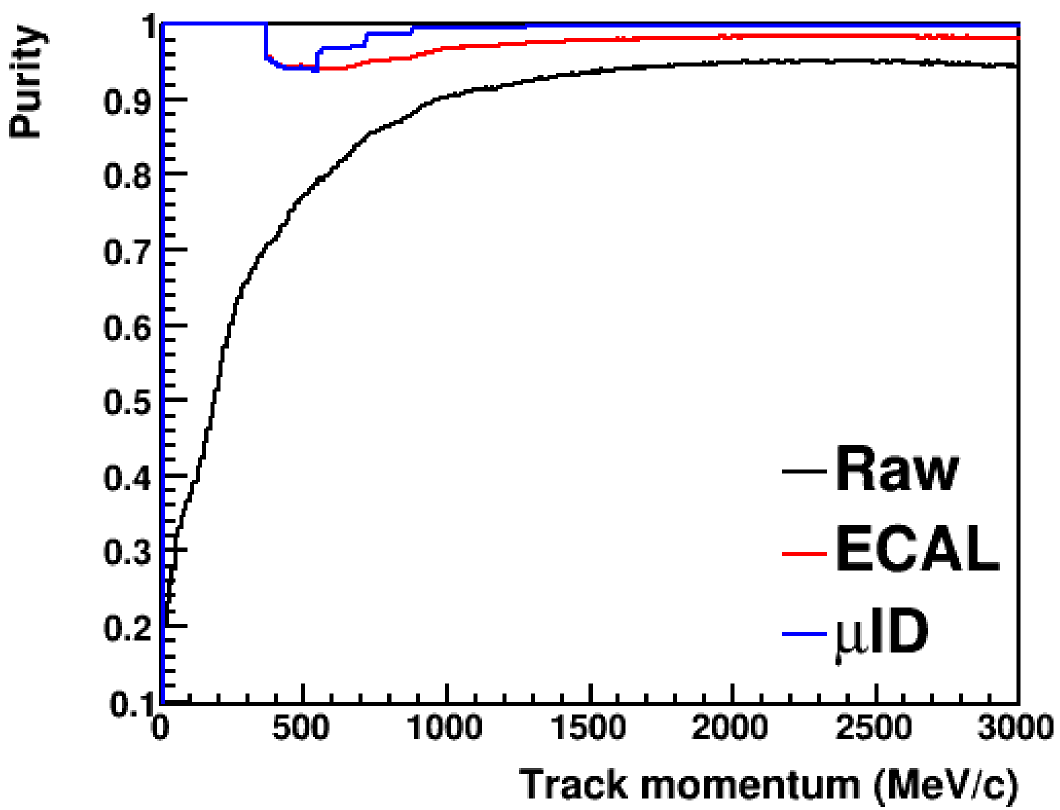
- Raw = select the highest-momentum muon/pion track no matter what
- ECAL = Select the highest-momentum track that does not interact in the ECAL
- μID = Select the highest-momentum track that does not interact in the ECAL or μID

FHC CC ν_μ purity (μ^-/π^-)



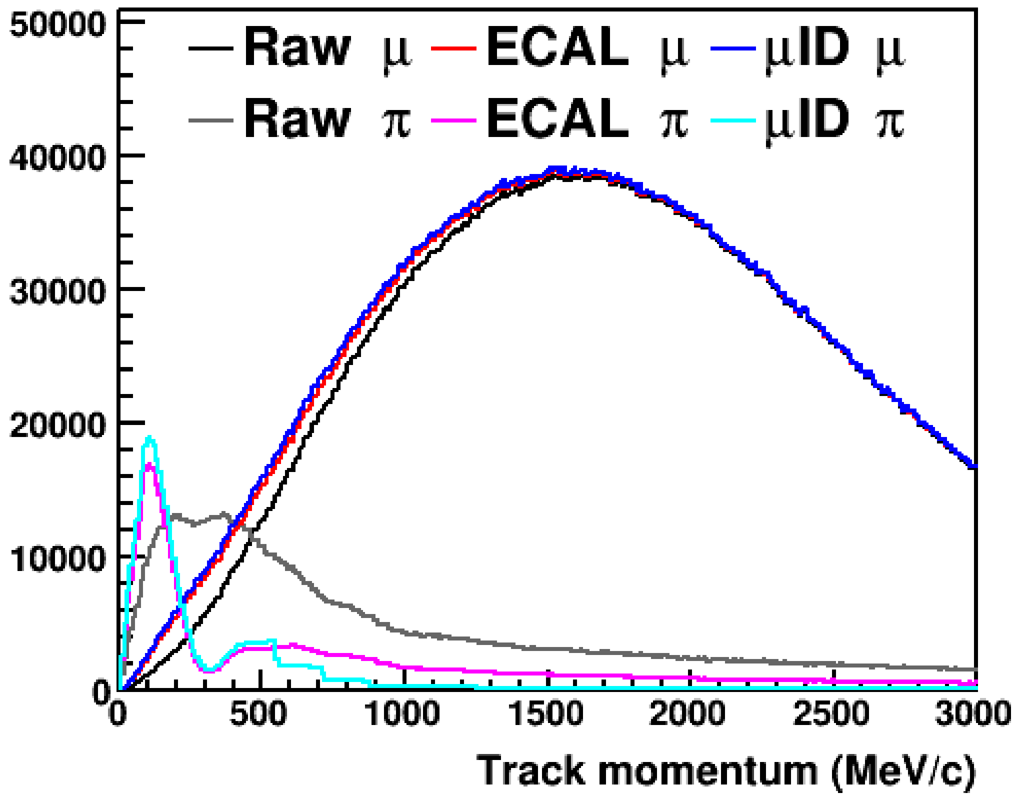
- With no reduction, purity reaches ~90% at high momentum
- With ECAL only (no μID) gets to ~96%
- With μID → 100%
- In region where tracks stop in μID (500-1000 MeV/c) purity is 94-100%

FHC CC ν_μ purity (μ^-/π^-)



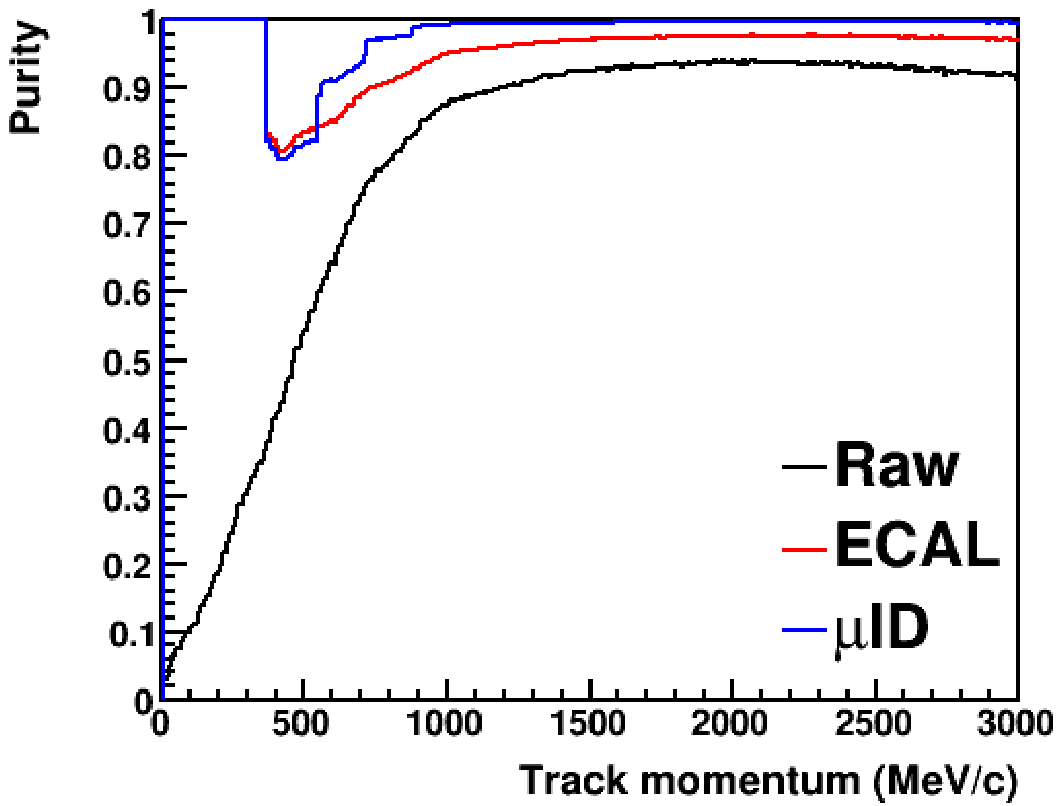
- Including the near-perfect selection by range for ECAL stoppers
- Dip region in purity is where pions go through the ECAL and stop in the first μID layers
- 80-layer ECAL would increase the cutoff from 380 → 480 MeV/c
- More granular μID would smooth the rise between 380 and 1000

RHC CC $\bar{\nu}_\mu$ selection (μ^+/π^+)



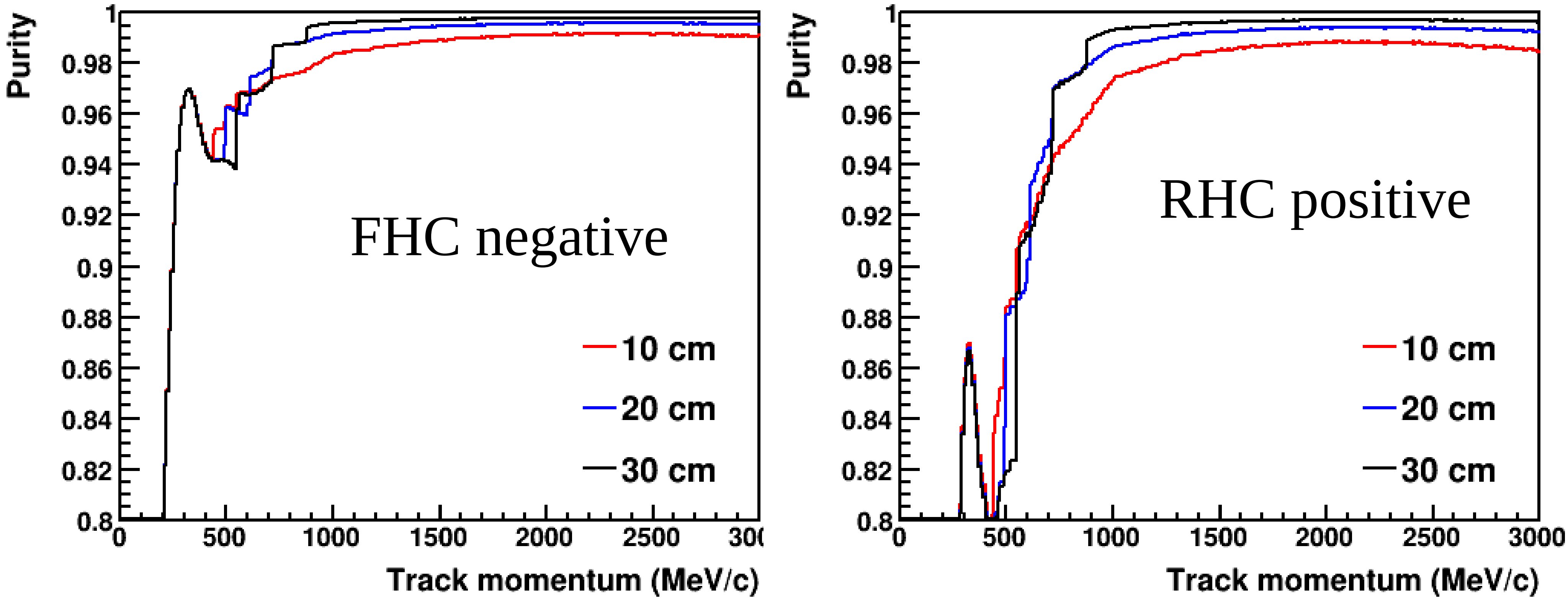
- RHC antineutrinos produce somewhat higher energy muons on average
- Pion background is worse due to larger wrong-sign NC contribution

RHC CC $\bar{\nu}_\mu$ purity (μ^+/π^+)



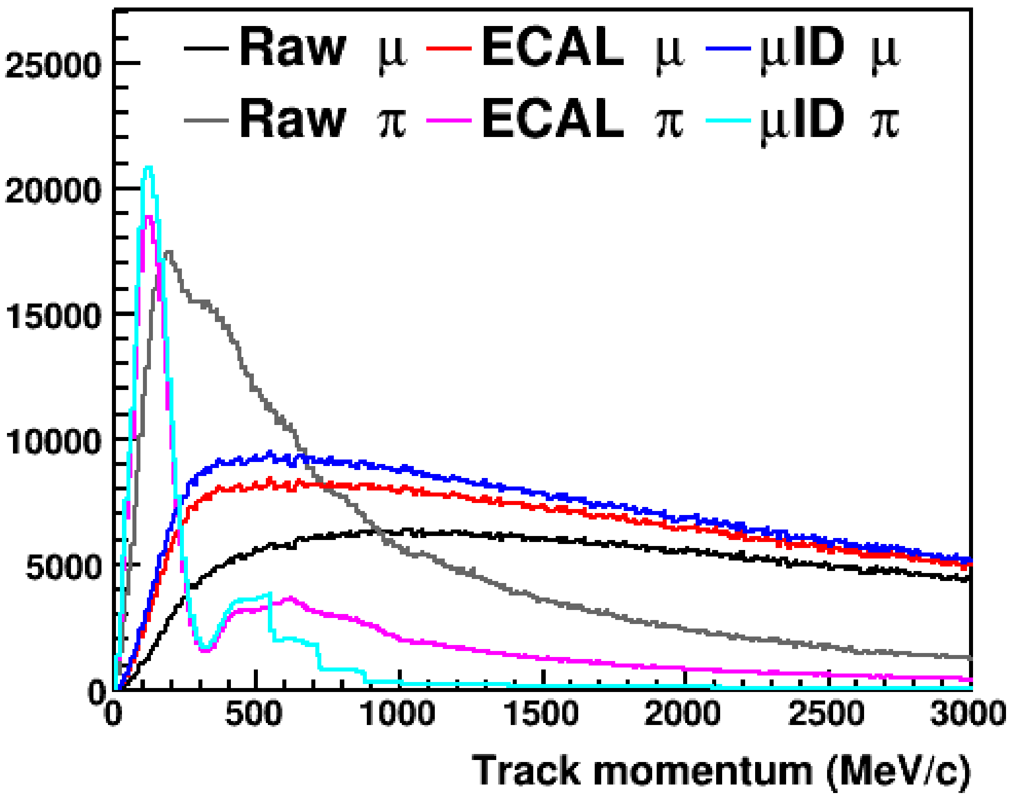
- Dip is worse – purity around 500 MeV/c muon is only ~80%
- But still reaches nearly 100% purity by 800 MeV/c

μID thickness requirement



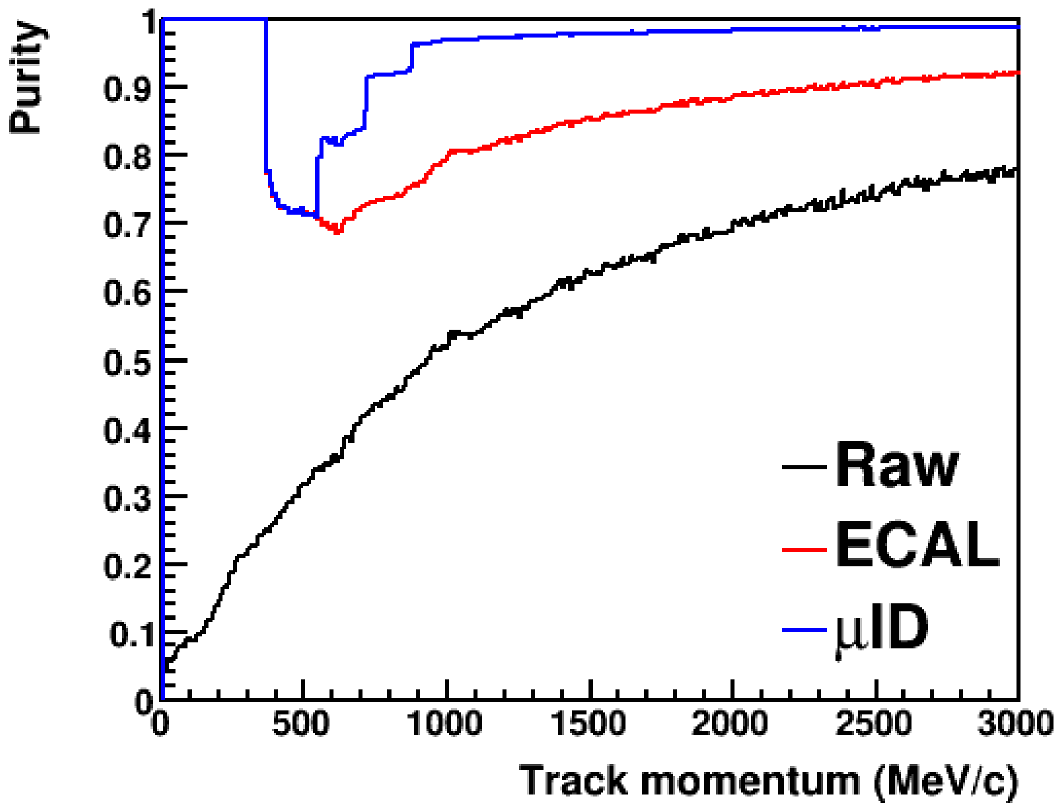
- Assuming three identical layers, with total thickness of 10, 20, or 30 cm
- ~15 cm total gives >99% purity for CC selection in both FHC and RHC modes

RHC CC ν_μ selection (μ^-/π^-) (wrong sign)



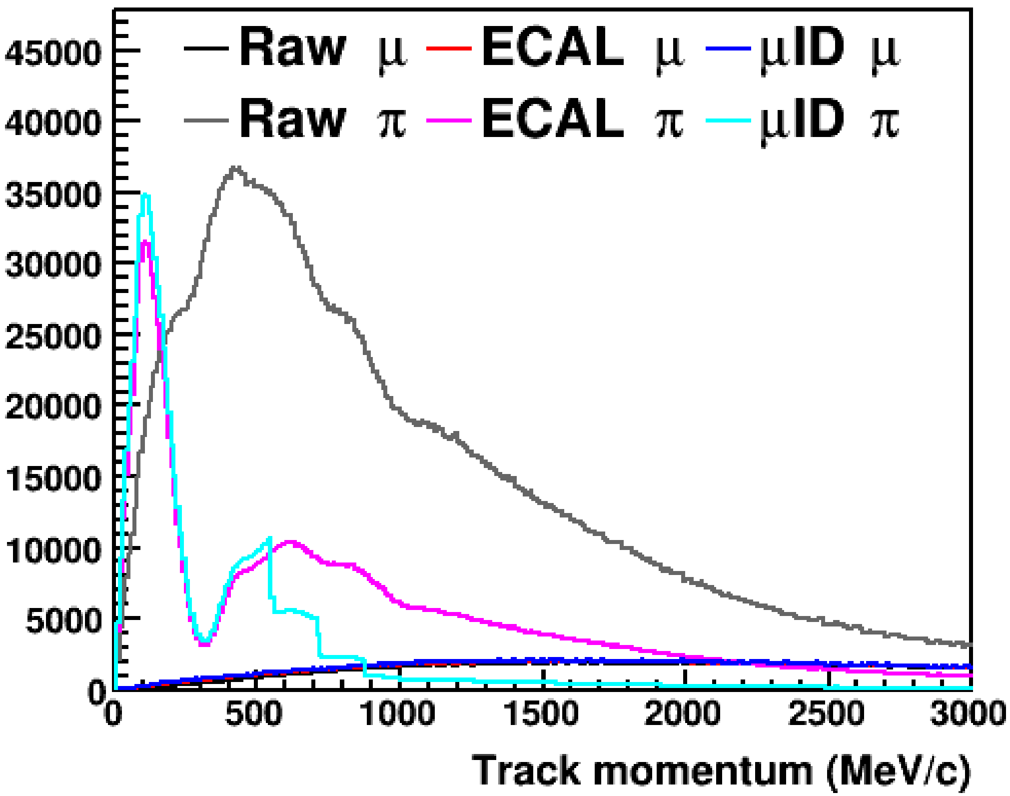
- Very low wrong sign contamination in the flux peak makes selecting wrong-sing sample challenging
- Not clear if this is needed at low energy
- Very clean at high energy with μID

RHC CC ν_μ purity (μ^-/π^-) (wrong sign)



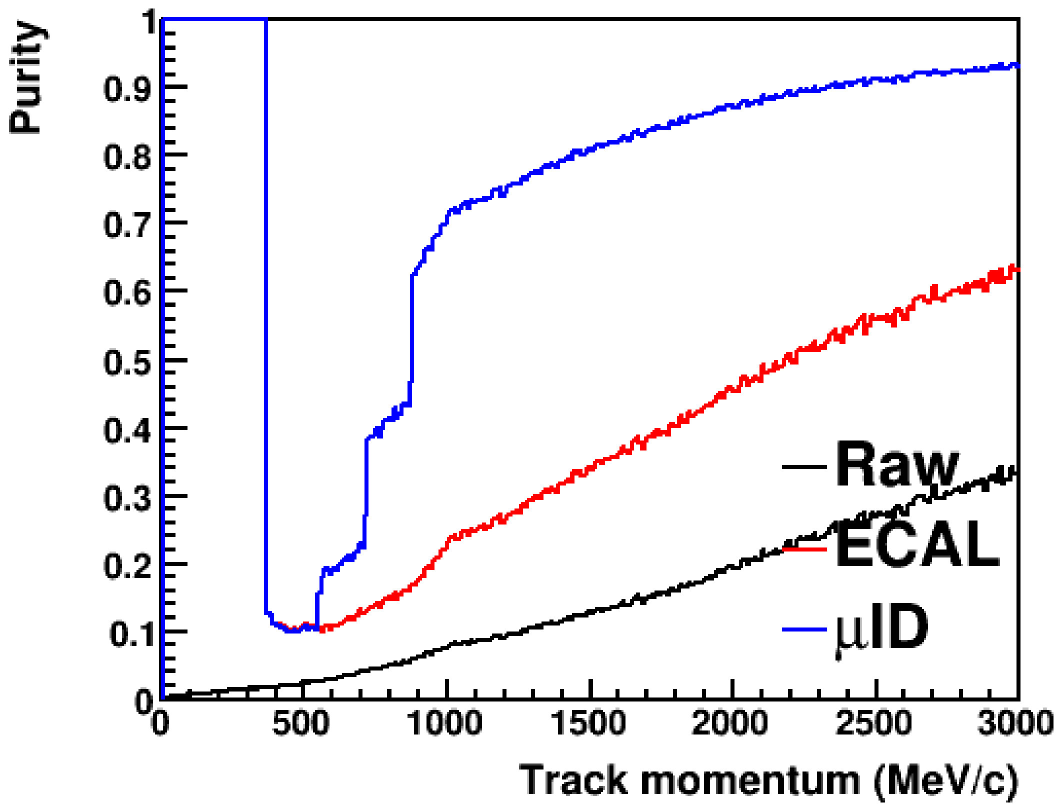
- For muons above 1 GeV/c the purity is >95% for the wrong-sign selection
- μID is necessary to achieve purity above ~80%

FHC CC $\bar{\nu}_\mu$ selection (μ^+/π^+) (wrong sign)



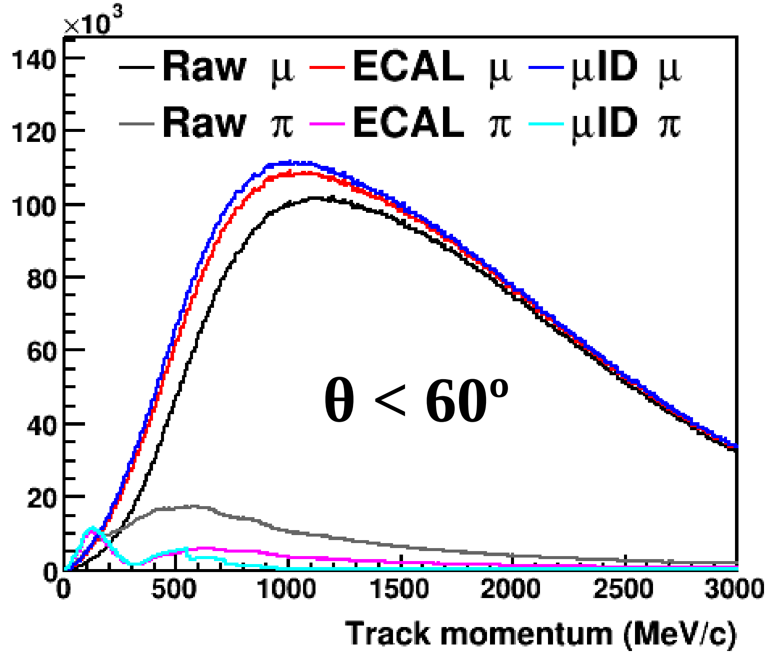
- Harder still is wrong sign events in FHC
- Huge background from pions at low momentum

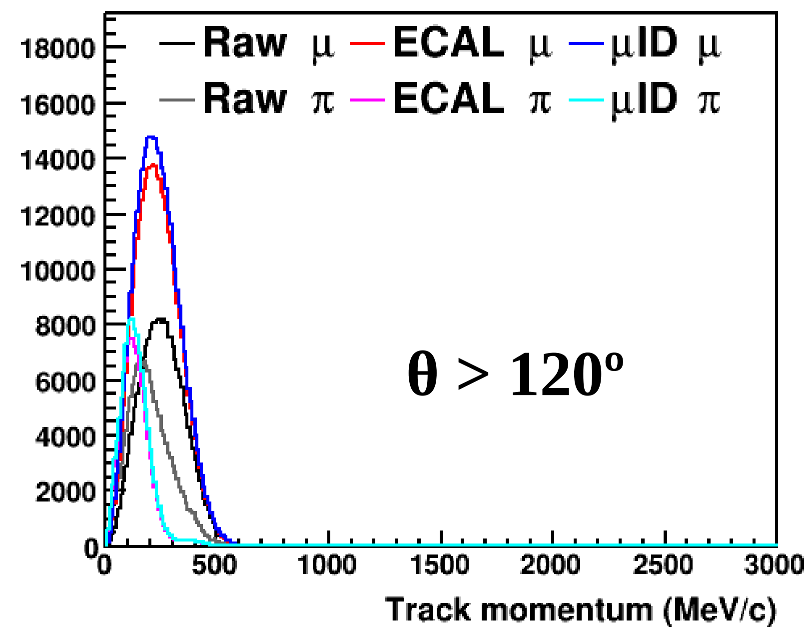
FHC CC $\bar{\nu}_\mu$ purity (μ^+/π^+) (wrong sign)



- Purity is terrible without μID, still only ~70-90% due to very low wrong sign contamination in FHC beam

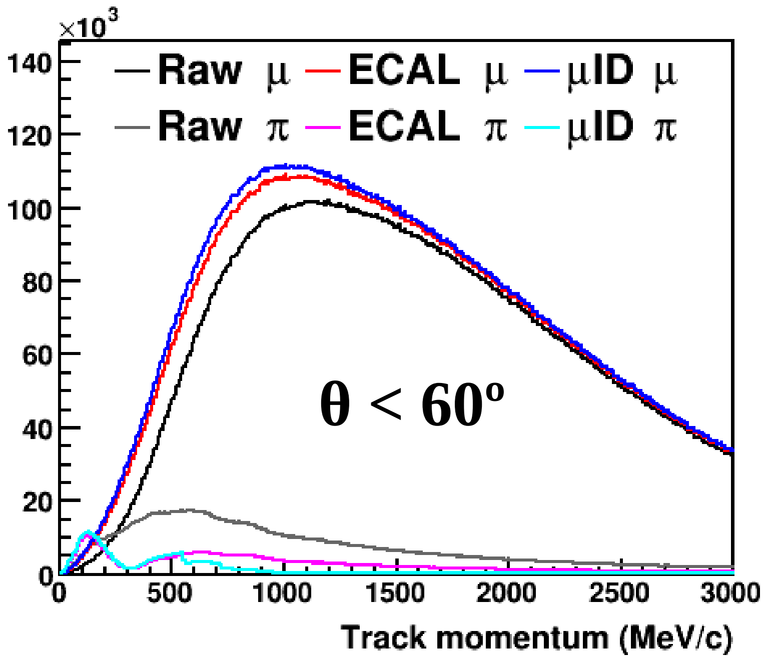
Directionality (FHC right sign)

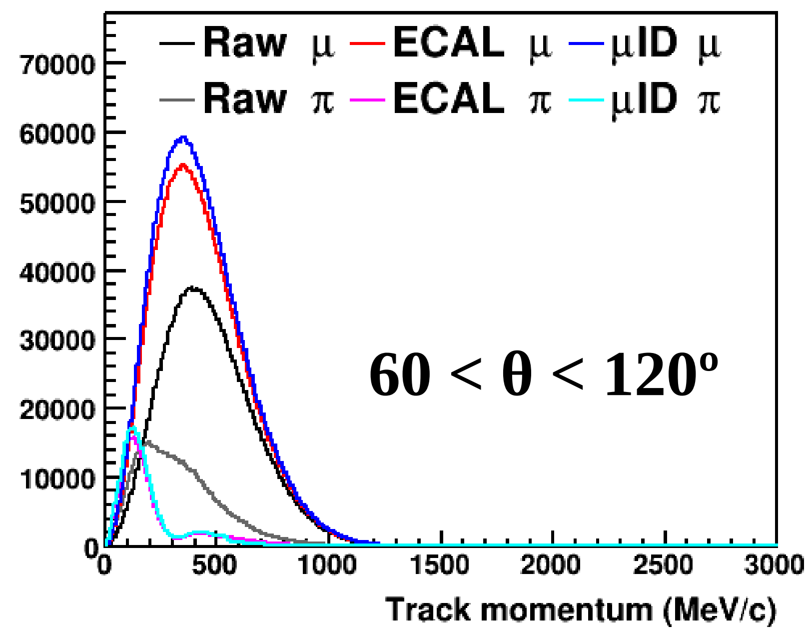




- Highest-momentum track is very rarely backward, and when it is the momentum is <500 MeV/c
- μID does almost nothing in backward sector because almost everything ranges out in the ECAL

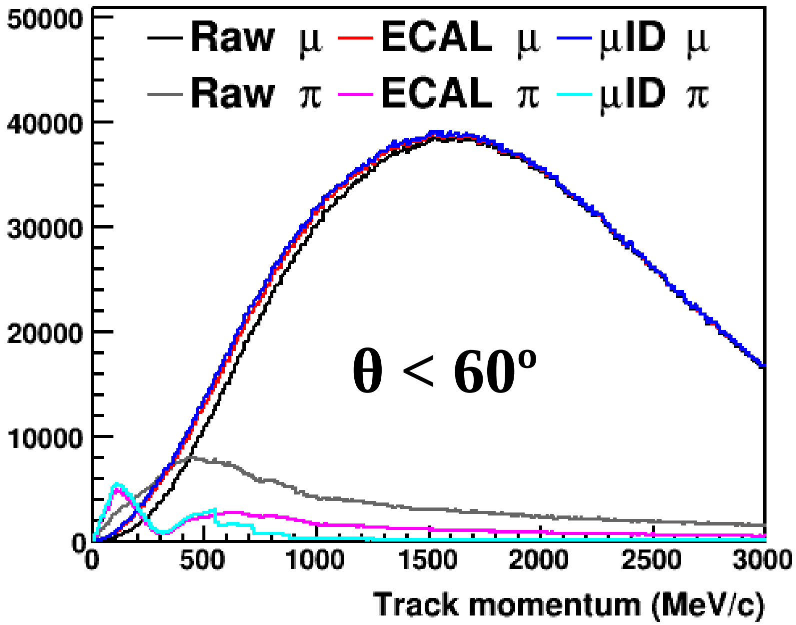
Directionality (FHC right sign)

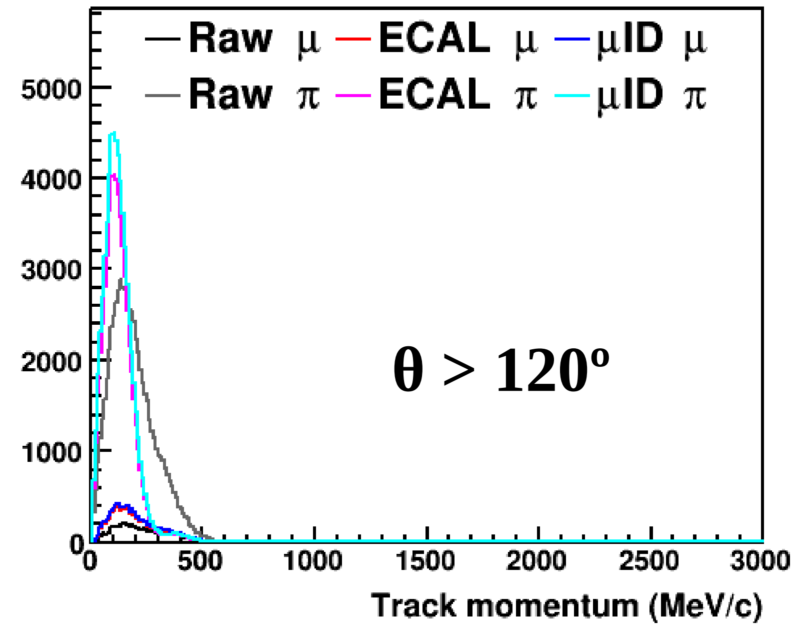




- High-angle tracks go up to ~1 GeV/c, but most pions are still soft enough to range out in ECAL

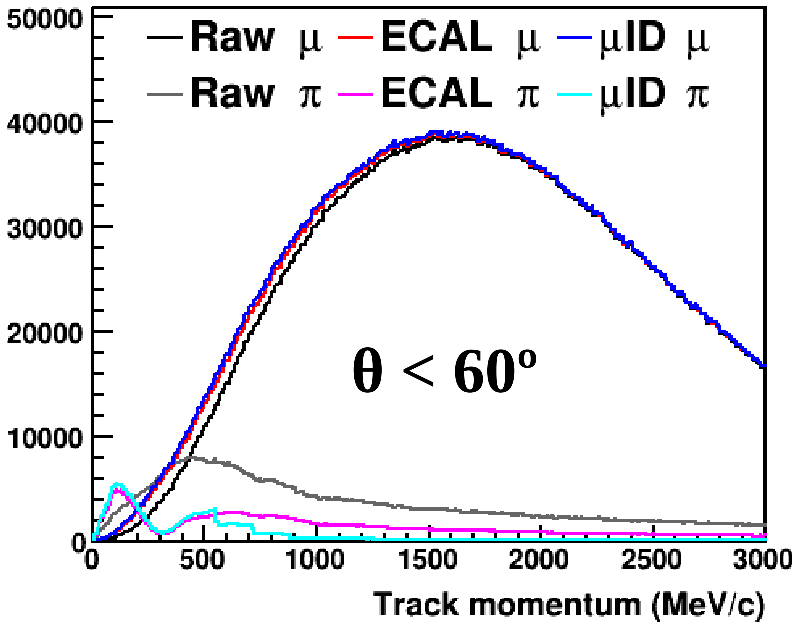
Directionality (RHC right sign)

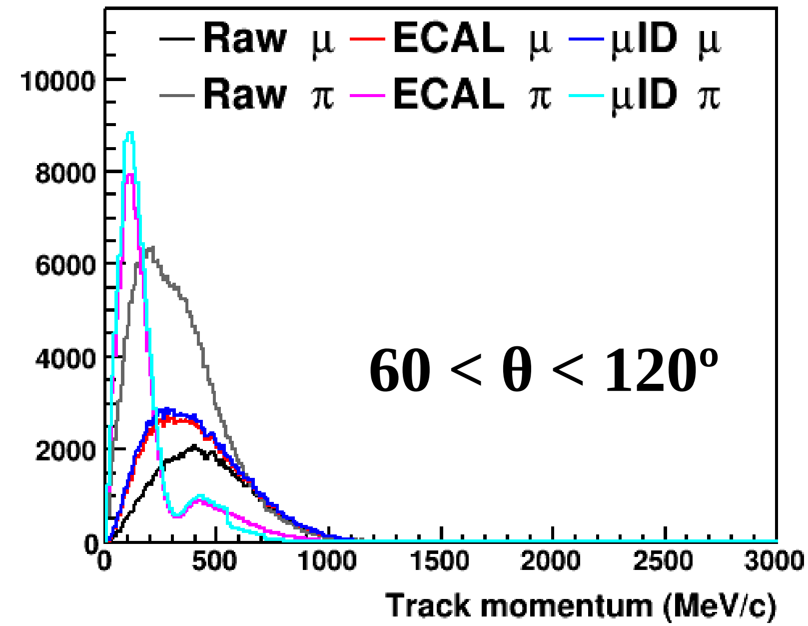




- There are very few backscattered muons in antineutrino interactions
- Almost all of them could be identified in the ECAL

Directionality (RHC right sign)





- High angle antineutrino tracks are mostly pions
- Here there is less signal than in FHC, and some improvement is obtained by including a high-angle μID

Conclusions

- Muons and pions stopping in ECAL can be separated by range with nearly 100% efficiency
- μID is required to get right-sign CC purity above 95%
- 15cm iron is required to give CC purity >99%
- In the region where tracks stop in the μID passive layers, the purity is somewhat worse
- Wrong-sign CC selection is very challenging due to large NC pion backgrounds, and even a very capable μID system will not reject all the background