ProtoDUNE-SP:
Upstream beam energy losses

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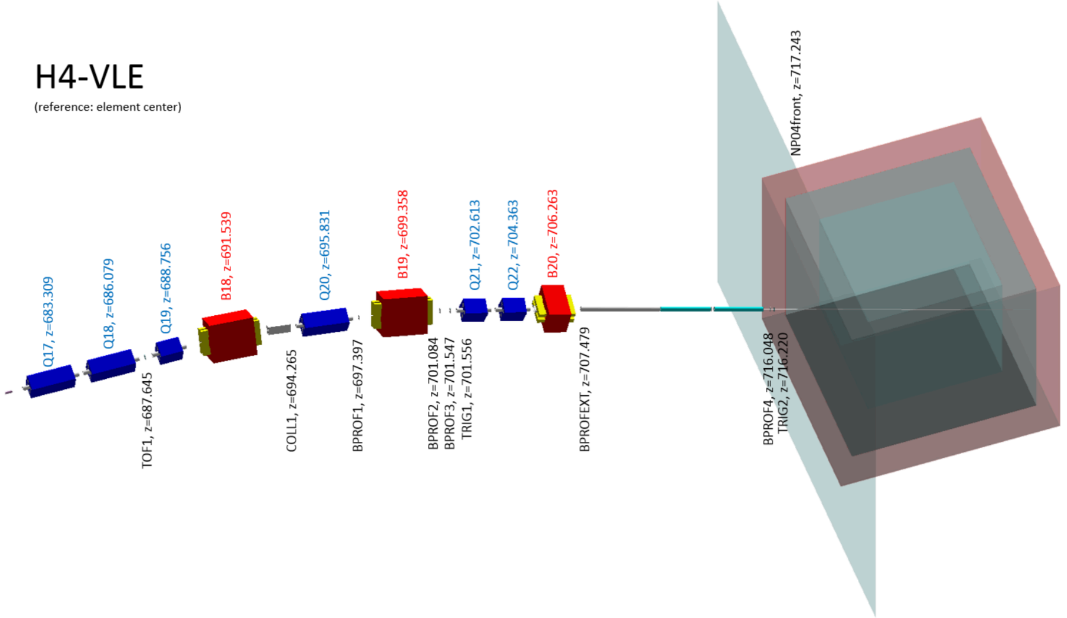
ProtoDUNE-SP DRA weekly meeting

5/14/2019

BERKELEY LAB

This study

- Re-evaluate implemented geometry with ‘as-built’ information
- Combine beamline MC and detector MC to determine expected energy loss between upstream spectrometer and TPC face
- Validate this expectation with data (or at least show it is too small to reasonably measured)



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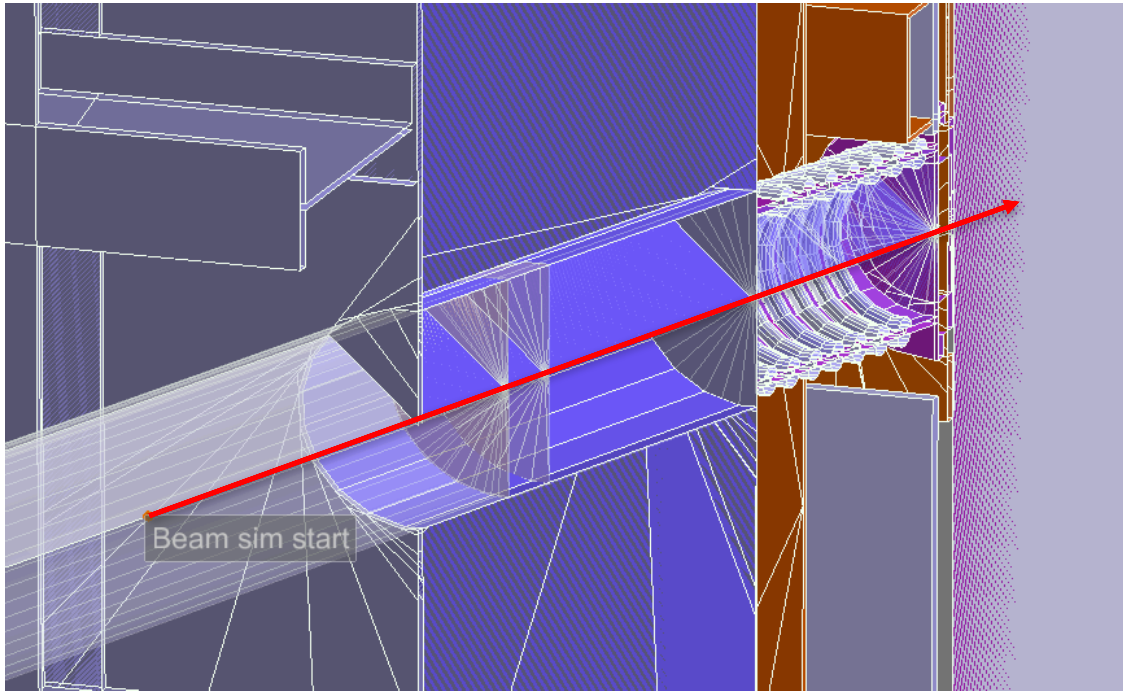
Differences between ’as-built’ and GDML

Performed a ray trace through the protodune_v5_nowires.gdml geometry

- 10.00cm of glass wool
- 52.00cm of beam window foam
- 0.138cm of stainless steel
- 0.60cm of liquid argon
- 49.17cm of nitrogen gas
- 0.41cm of G10
- 0.10cm of liquid argon

Total: 4.45g/cm^2



Note:

I am using the beam direction according to the GDML – this appears to be slightly different than the direction I find in the beamline MC

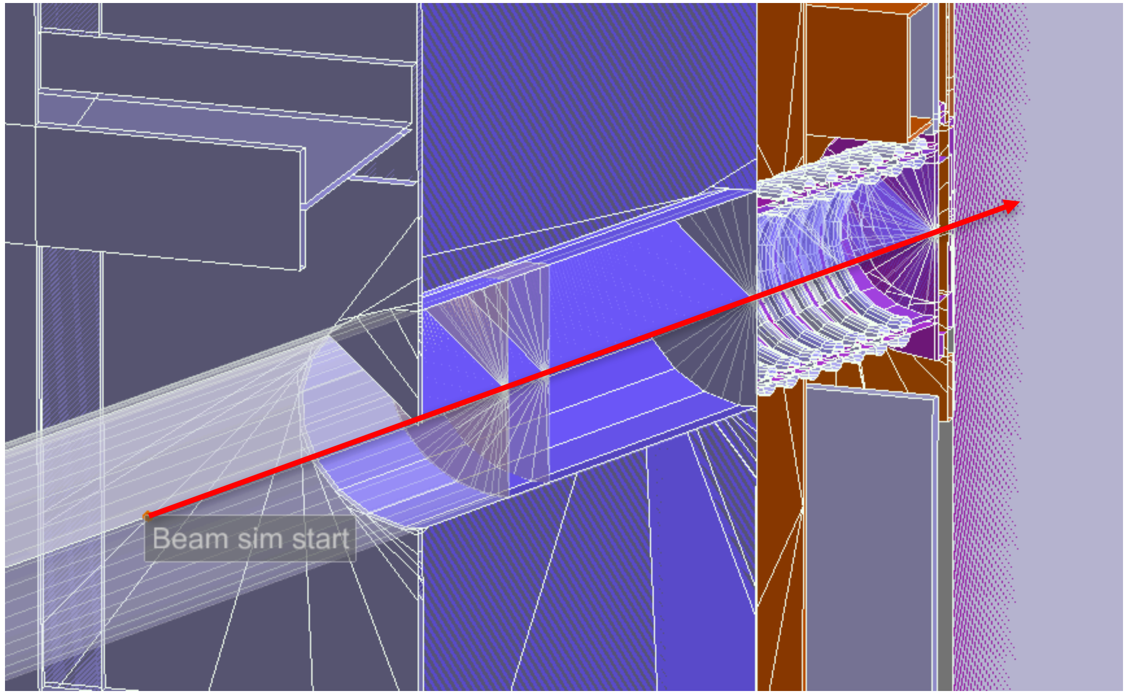
(-0.201, -0.193, 0.960) vs. (-0.179, -0.199, 0.964)

Differences between ’as-built’ and GDML

Performed a ray trace through the protodune_v5_nowires.gdml geometry

- 9.97cm of glass wool
- 51.85cm of beam window foam
- 0.121cm of stainless steel
- 0.62cm of liquid argon
- 49.01cm of nitrogen gas
- 0.42cm of G10
- 0.12cm of liquid argon

Total: 4.38g/cm^2 = ~2% difference

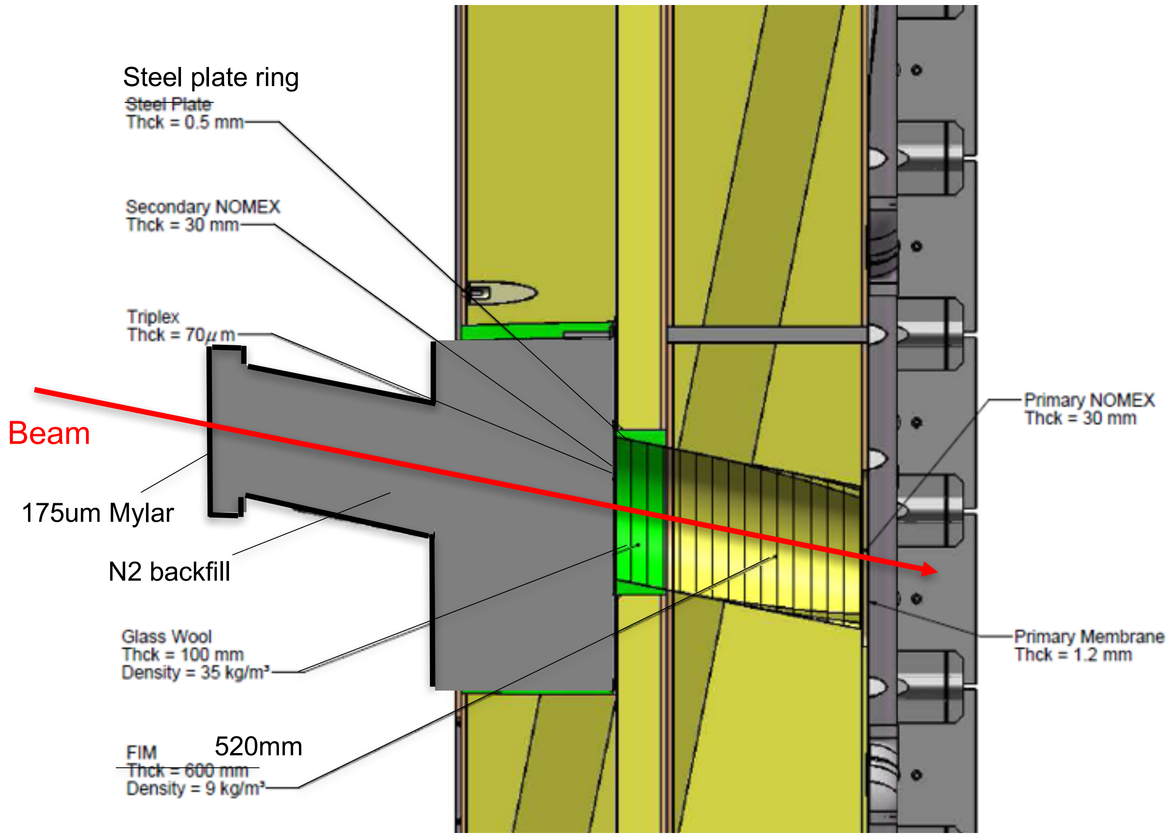


Note:
Here I use the beam direction I find in the beamline MC
This is the path the beam takes in both simulations
(-0.201, -0.193, 0.960) vs. **(-0.179, -0.199, 0.964)**

Cryostat penetration geometry

According to the drawing supplied to Martin T.
The cryostat penetration contains (in order):

- 0.0002cm Mylar
- 62.4cm N2 backfill (~1atm)
- 3.1cm NOMEX
- 0.007cm Triplex
- 10.4cm glass wool
- 54.1cm FIM (foam)
- 3.1cm NOMEX
- 0.125cm SS (inner membrane)



total:
~ 2.5g/cm^2

*includes 1.04 factor from 16.2º beam angle
beam vector: (-0.201, -0.193, 0.960)

Beam plug geometry

Received detailed drawings and description from Tim L. and details of installation from Rob A. Actual geometry contains

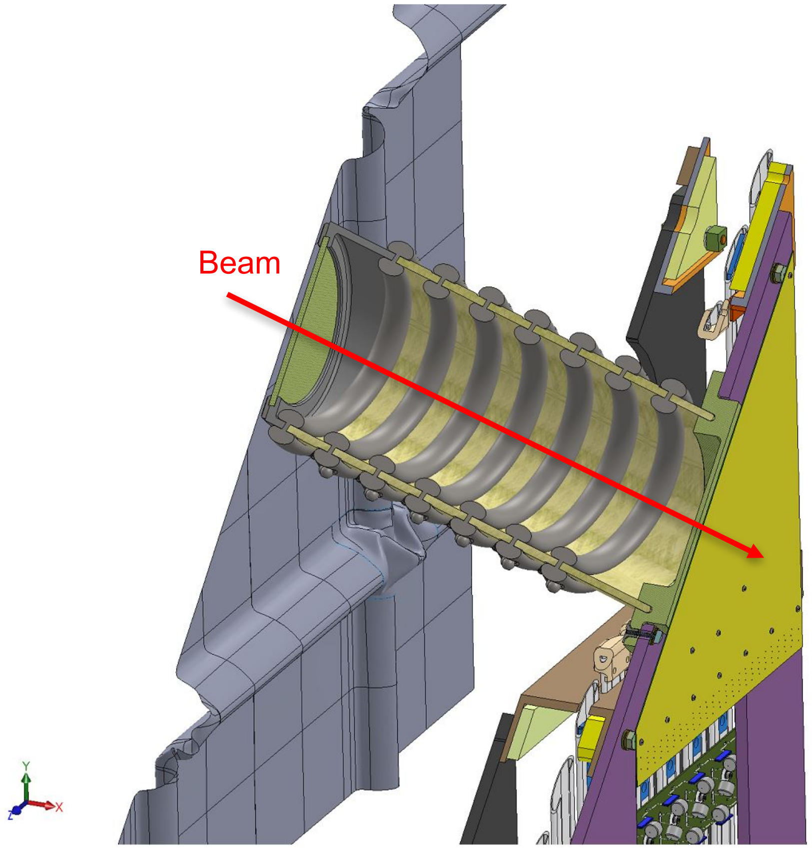
- ~ 1.2cm of liquid argon
- 0.66cm of G10 (BP entry window)
- 50.00cm of nitrogen gas
- 0.52cm of G10 (BP exit window)
- ~ 0.1-0.5cm of liquid argon (between exit window and field shaping plane)
- ~ 0.10cm of G10 (field shaping plane)

total:

~ 4.3 to 4.9g/cm^2 of material

total (penetration + BP):

~ 6.9 to 7.4g/cm^2



*includes 1.04 factor from 16.2º beam angle

beam vector: (-0.201, -0.193, 0.960)

Beam plug geometry

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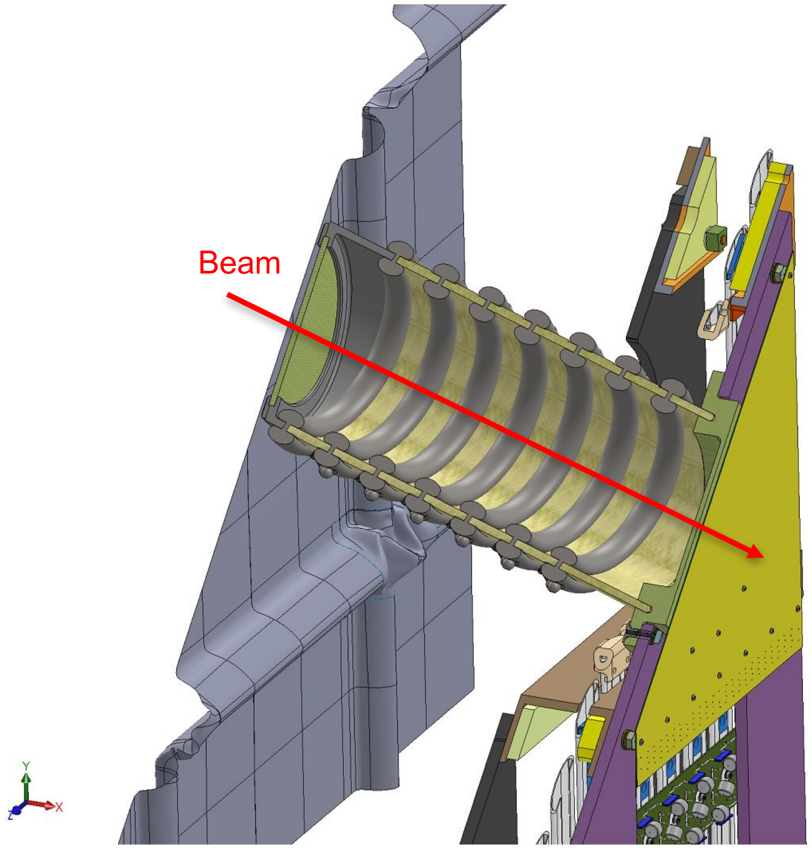
- ~ 1.2cm of liquid argon
- 0.66cm of G10 (BP entry window)
- 50.00cm of nitrogen gas
- 0.52cm of G10 (BP exit window)
- ~ 0.1-0.5cm of liquid argon (between exit window and field shaping plane)
- ~ 0.10cm of G10 (field shaping plane)

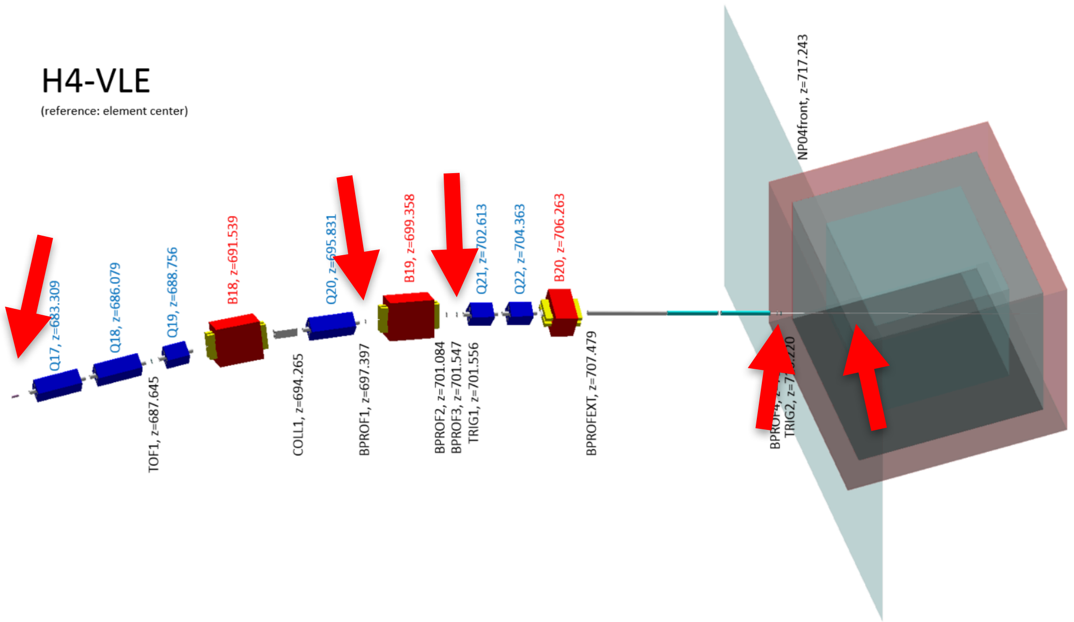


total difference from simulation (penetration + BP):
~ +2.4 to ~ +3.0g/cm^2 of material

*includes 1.04 factor from 16.2° beam angle
beam vector: (-0.201, -0.193, 0.960)

Combining beamline and TPC MC

- Event number of particles in detector MC corresponds to the row in the beamline tuple
- Verify good match by comparing particle (px, py, pz) at end of beamline sim matches (px, py, pz) at start of TPC sim to <1MeV in each value
- Extract particle momentum (or energy) at key locations along beamline
  1. After the target
  2. In BPROF1
  3. In BPROF3
  4. At point between simulations (in beampipe just upstream of cryostat)
  5. At transition to active TPC



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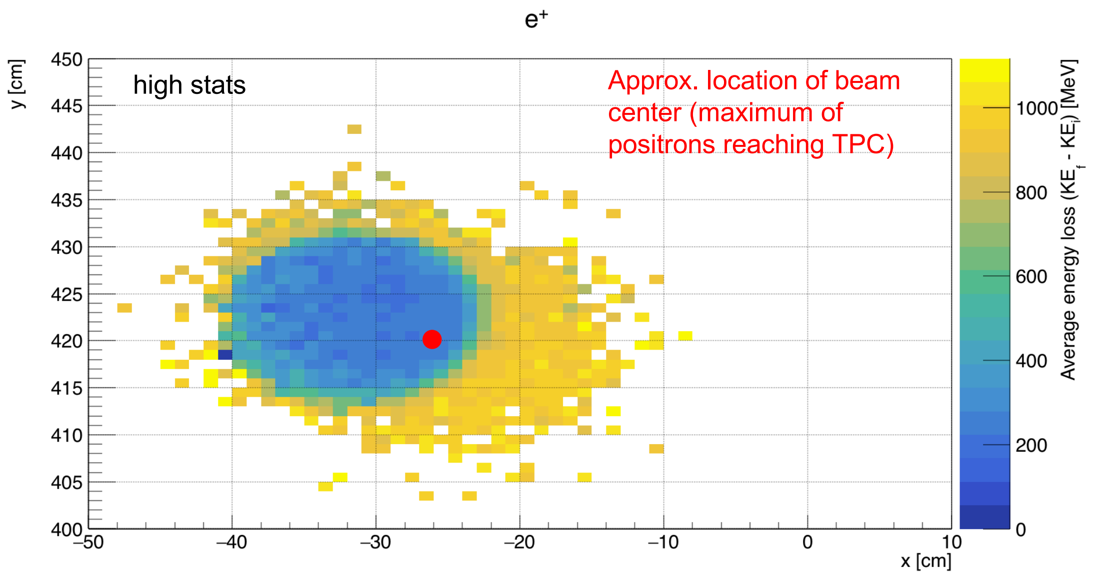
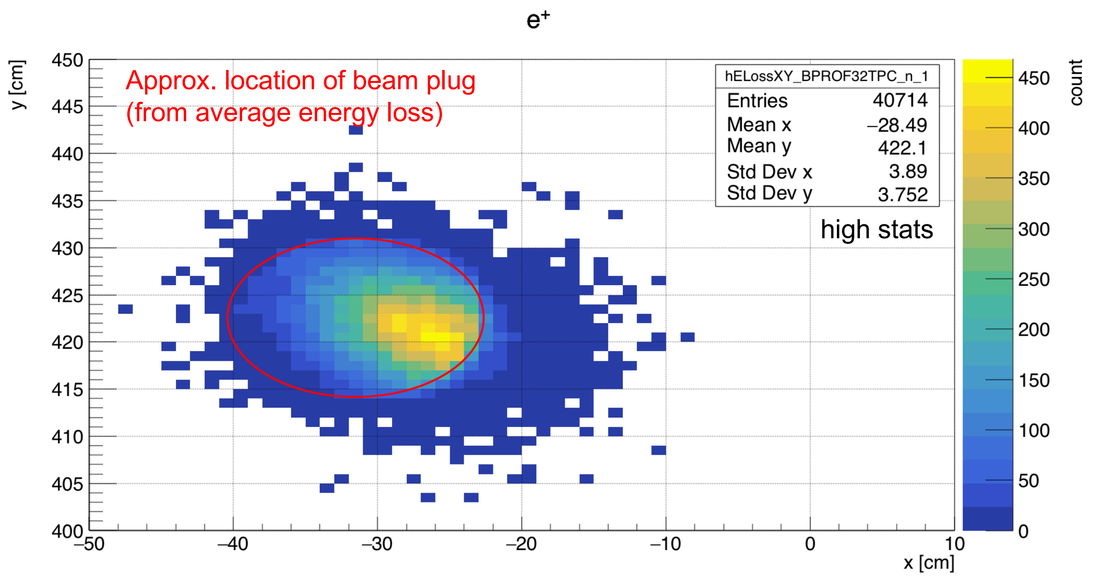
MC results (beam spot)

Average energy loss between BPROF3 and TPC



Number of particles reaching TPC

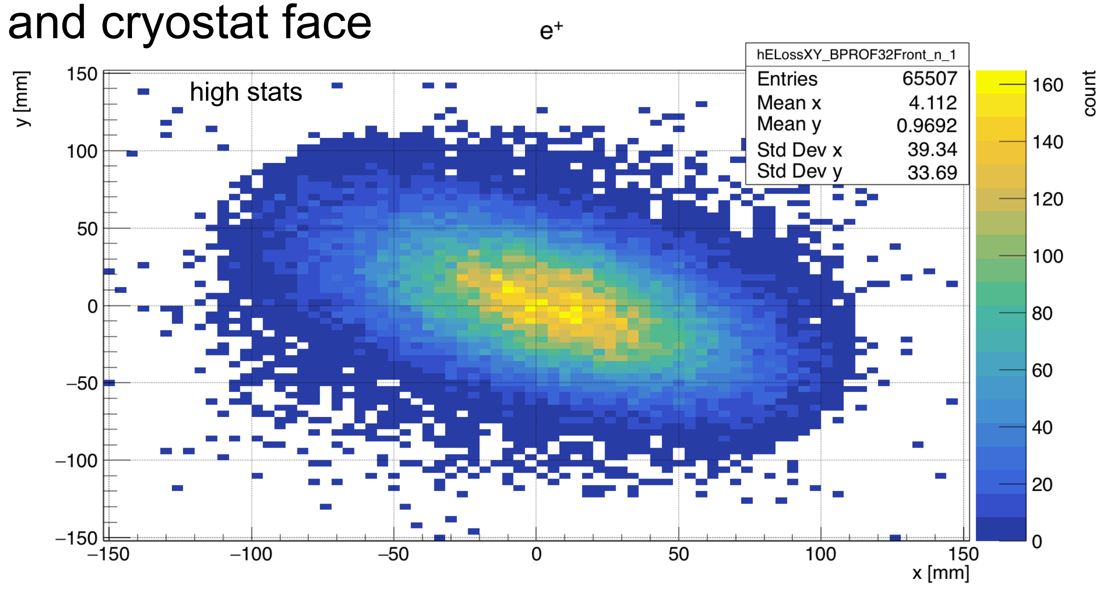


1GeV/c electrons (for statistical reasons only)

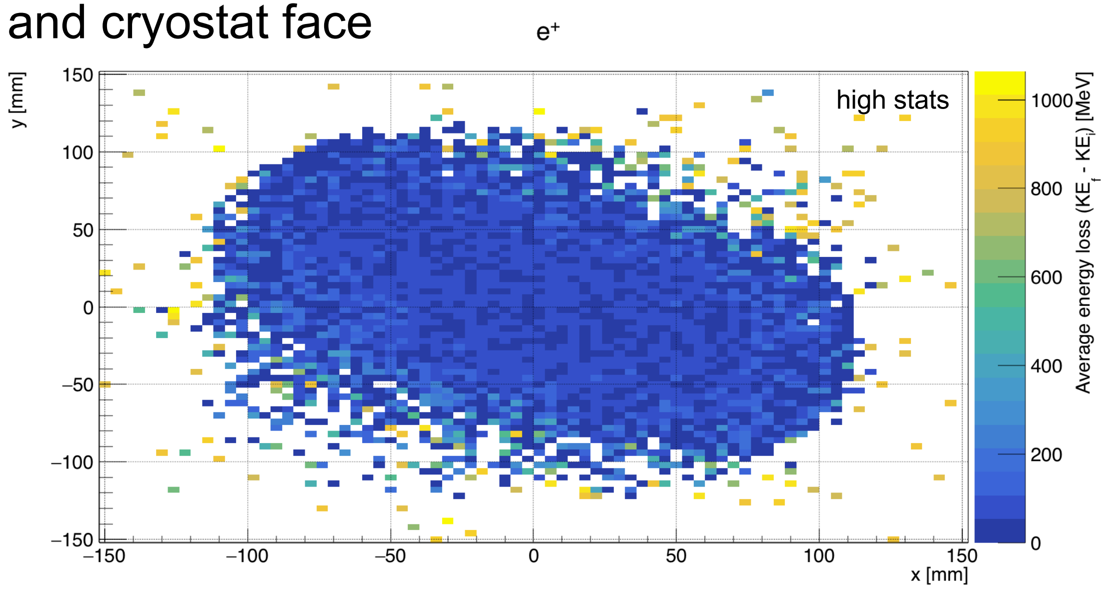
- Beam plug center is located at ~(-32cm, 423cm)
- Beam spot center is located at ~(-25cm, 420cm)

MC results (beam spot)

Number of beam particles between BPROF3 and cryostat face



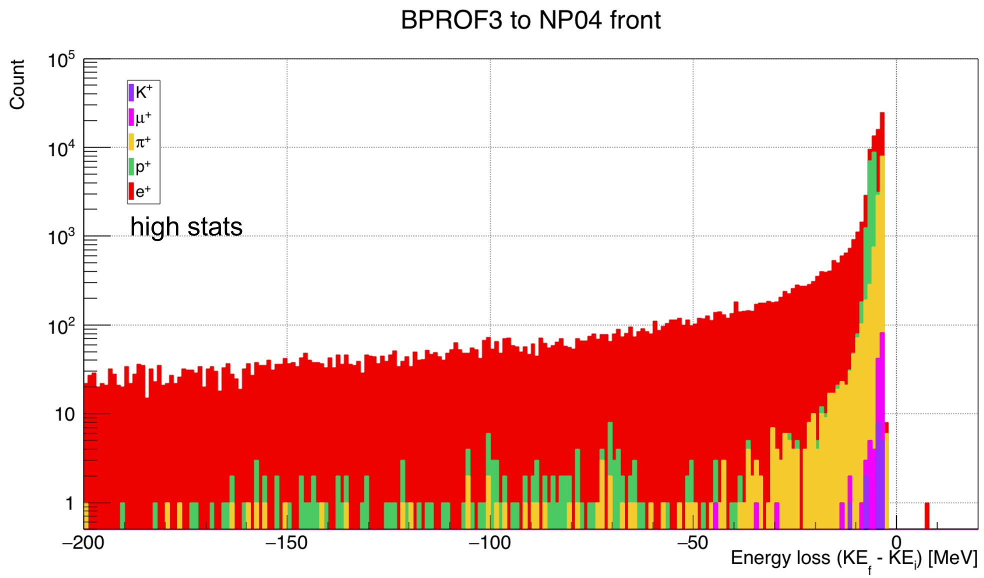
Average energy loss of particle between BPROF3 and cryostat face

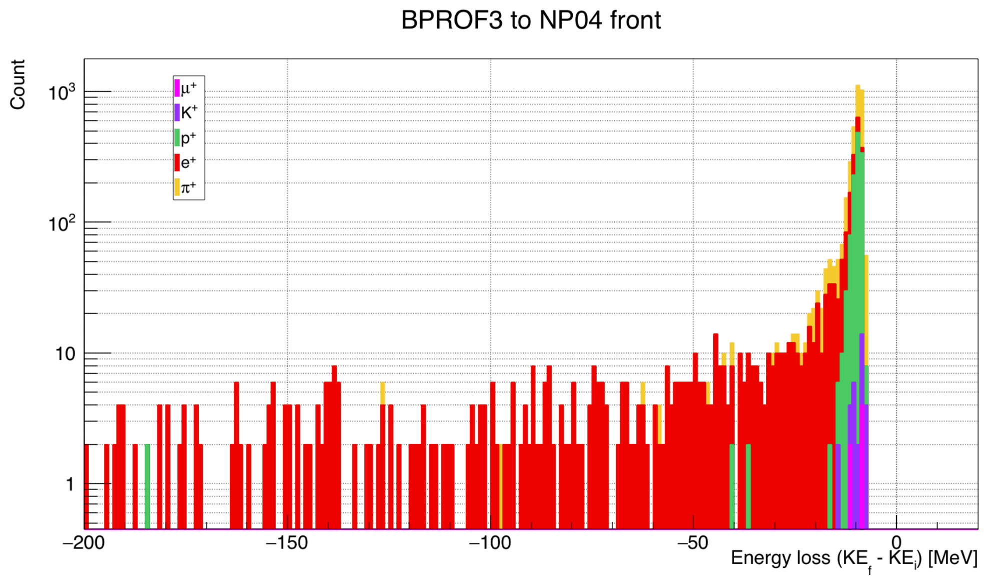


1GeV/c electrons (for statistical reasons only)

- Offset of ~4mm in X, ~1mm in Y
- Beam appears well-centered in beamline simulation

MC results (ΔE before cryostat)





Beamline losses by species @ 1GeV/c:

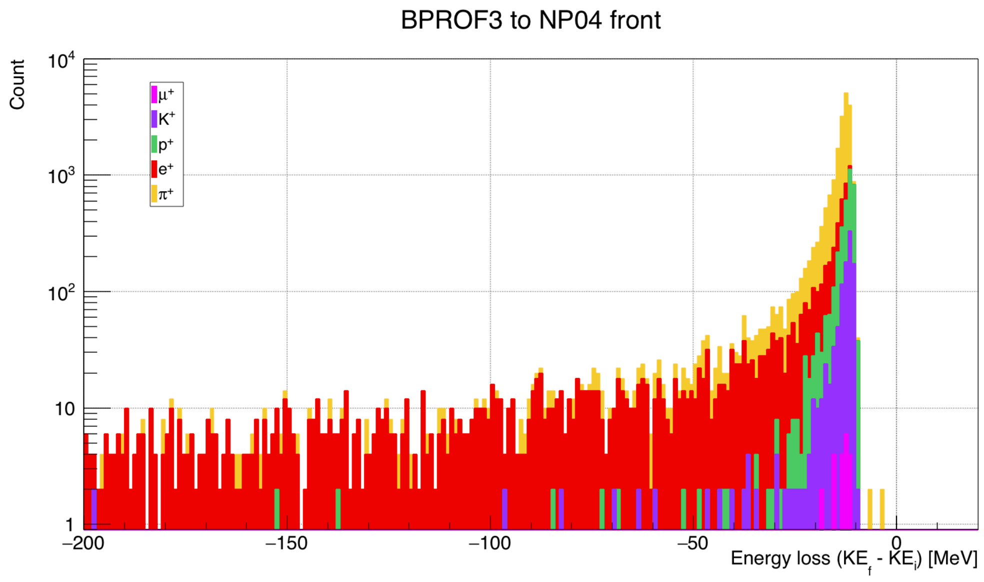
- positron : 4MeV (MPV)
- muon : 4MeV (MPV)
- pion : 4MeV (MPV)
- proton : 6MeV (MPV)
- kaon : 5MeV (MPV)

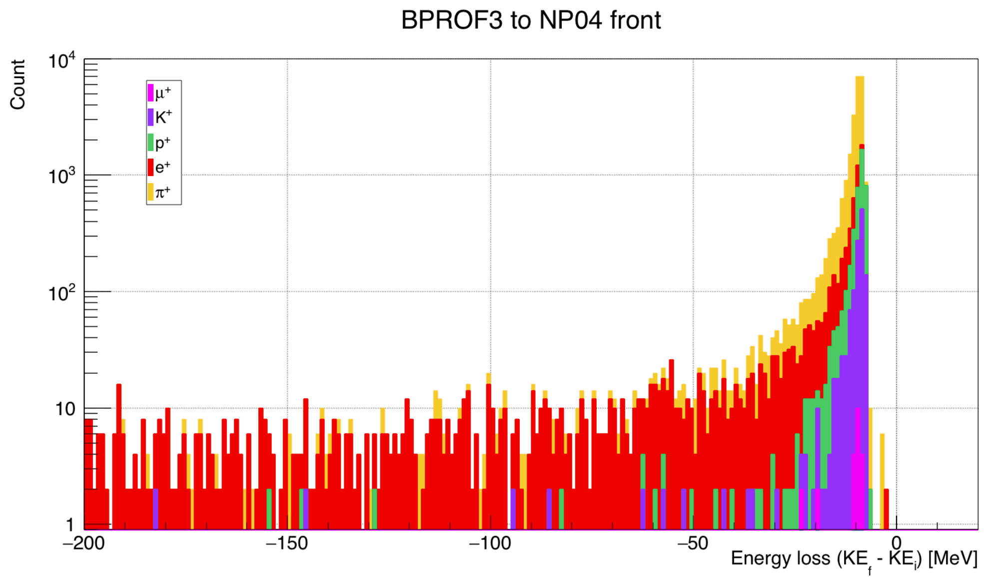
Beamline losses by species @ 2GeV/c:

- positron : 10MeV (MPV)
- muon : 9MeV (MPV)
- pion : 9MeV (MPV)
- proton : 10MeV (MPV)
- kaon : 9MeV (MPV)

MPV = Most probable value (maximum bin)

MC results (ΔE before cryostat)





Beamline losses by species @ 6GeV/c:

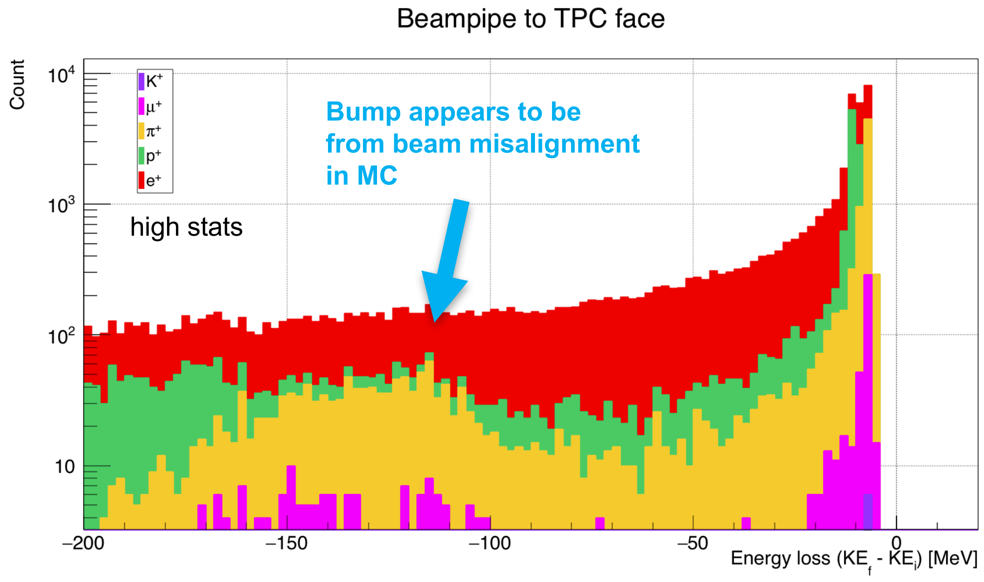
- positron : 14MeV (MPV)
- muon : 13MeV (MPV)
- pion : 13MeV (MPV)
- proton : 12MeV (MPV)
- kaon : 12MeV (MPV)

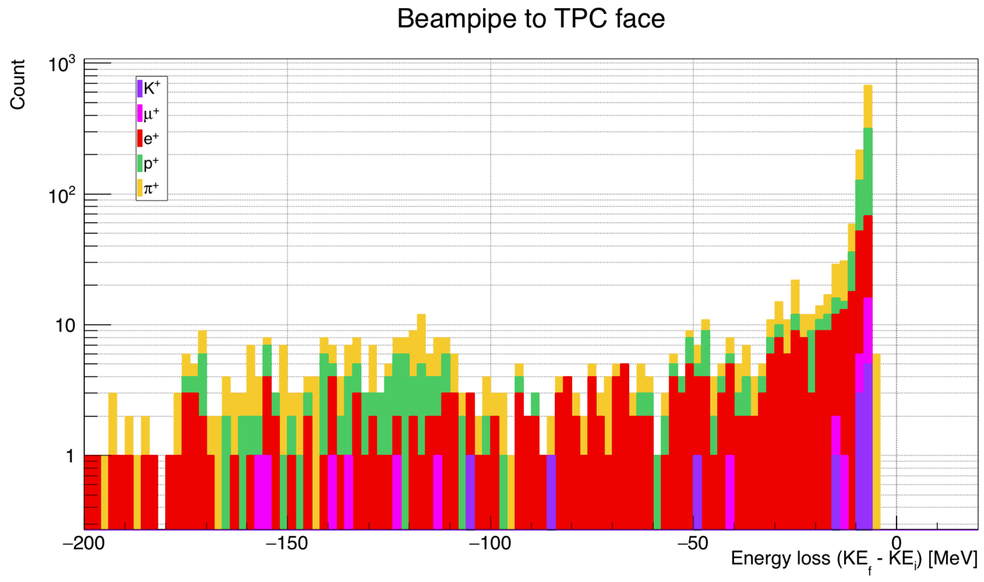
Beamline losses by species @ 7GeV/c:

- positron : 10MeV (MPV)
- muon : 10MeV (MPV)
- pion : 10MeV (MPV)
- proton : 12MeV (MPV)
- kaon : 9MeV (MPV)

MPV = Most probable value (maximum bin)

MC results (ΔE through penetration/BP)





Beam window losses by species @ 1GeV/c:

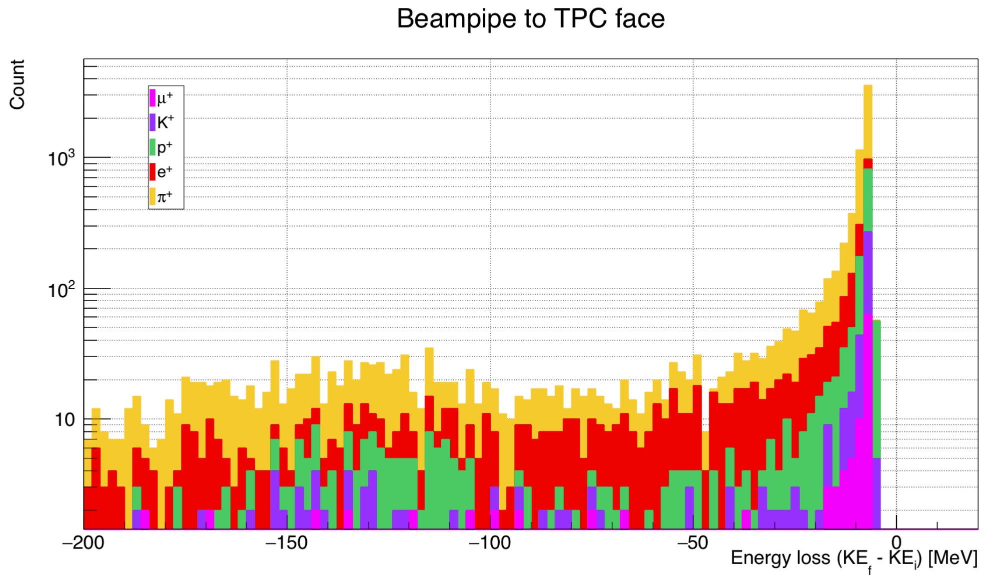
- positron : 8MeV (MPV)
- muon : 8MeV (MPV)
- pion : 8MeV (MPV)
- proton : 12MeV (MPV)
- kaon : 8MeV (MPV)

Beam window losses by species @ 2GeV/c:

- positron : 8MeV (MPV)
- muon : 8MeV (MPV)
- pion : 8MeV (MPV)
- proton : 8MeV (MPV)
- kaon : 8MeV (MPV)

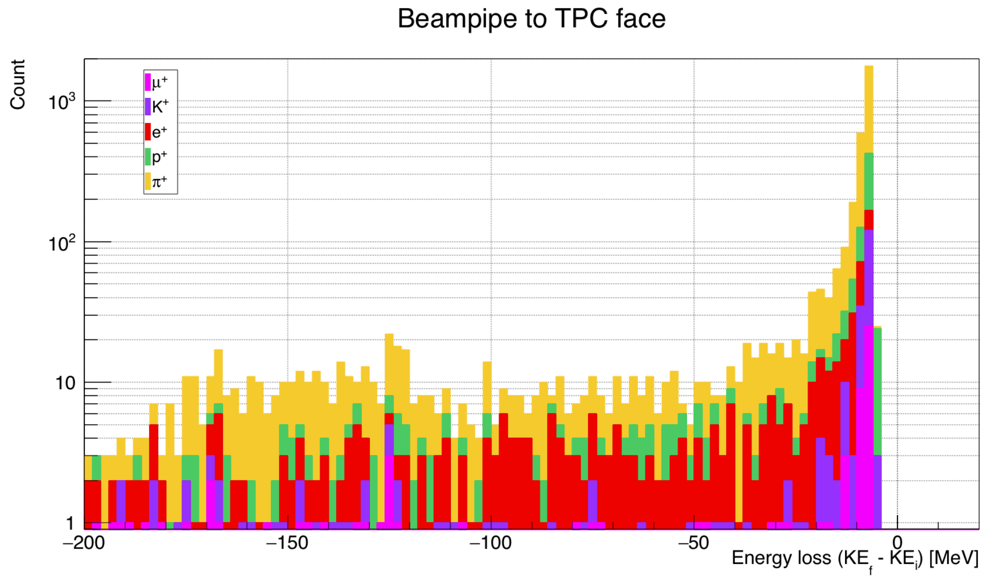
MPV = Most probable value (maximum bin)

MC results (ΔE through penetration/BP)



Beam window losses by species @ 6GeV/c:

- positron : 8MeV (MPV)
- muon : 8MeV (MPV)
- pion : 8MeV (MPV)
- proton : 8MeV (MPV)
- kaon : 8MeV (MPV)

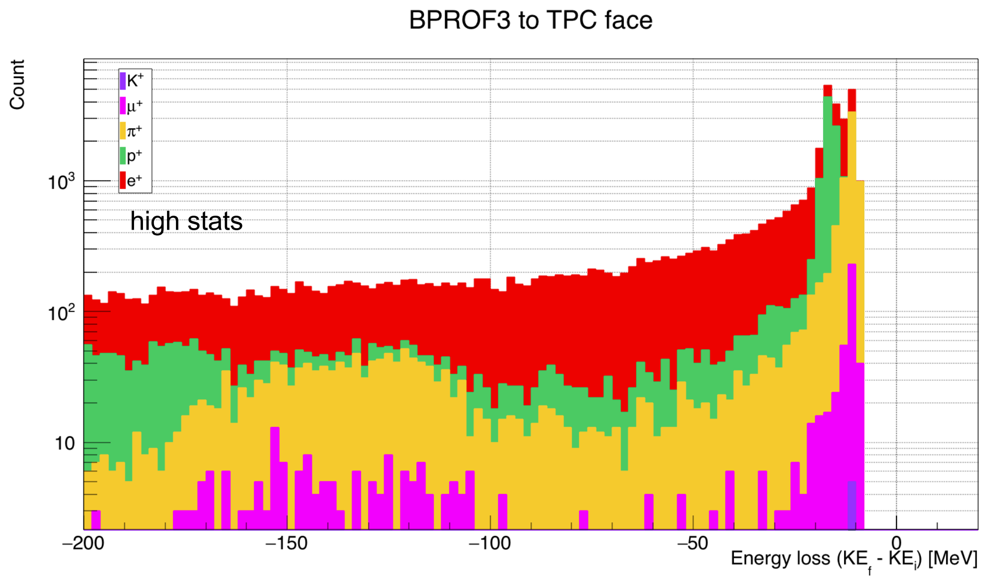


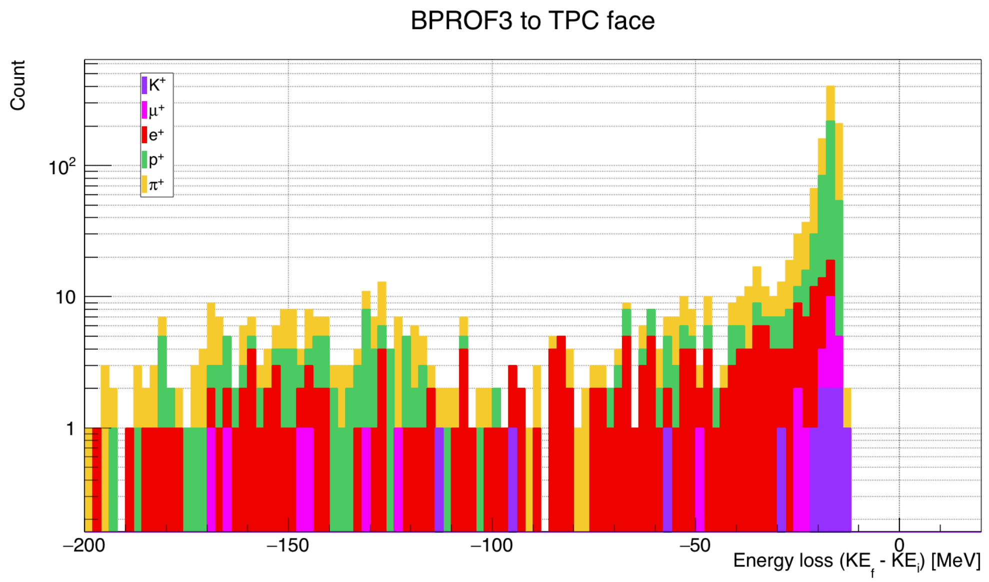
Beam window losses by species @ 7GeV/c:

- positron : 8MeV (MPV)
- muon : 8MeV (MPV)
- pion : 8MeV (MPV)
- proton : 8MeV (MPV)
- kaon : 8MeV (MPV)

MPV = Most probable value (maximum bin)

MC results (combined)





Upstream energy loss by species @ 1GeV/c:

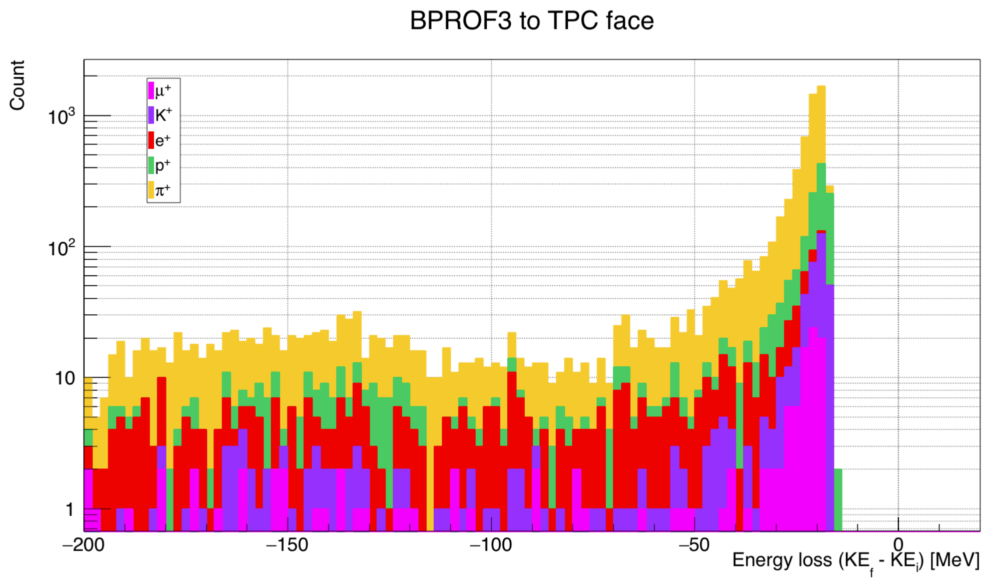
- positron : 14MeV (MPV)
- muon : 12MeV (MPV)
- pion : 12MeV (MPV)
- proton : 18MeV (MPV)
- kaon : 12MeV (MPV)

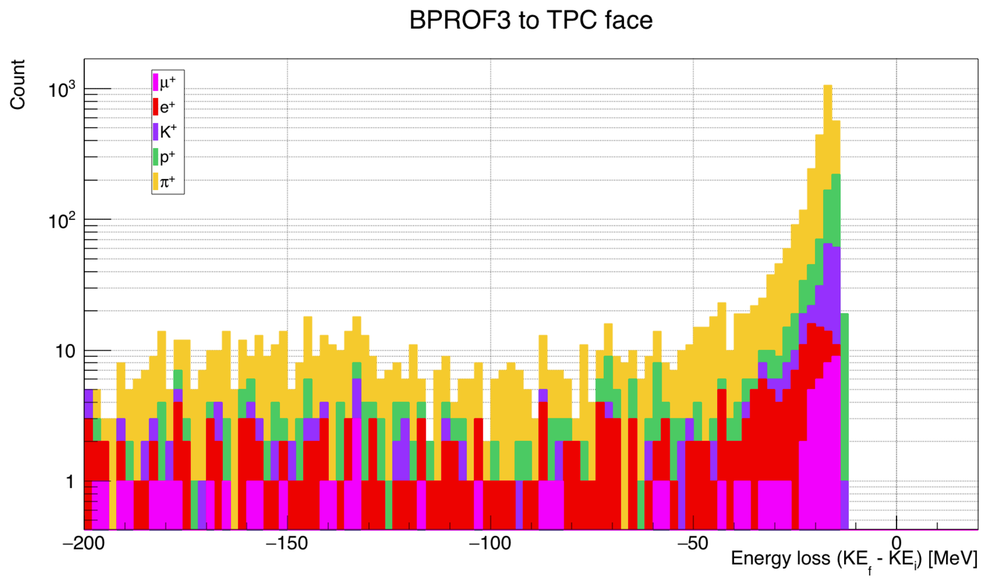
Upstream energy loss by species @ 2GeV/c:

- positron : 22MeV (MPV)
- muon : 18MeV (MPV)
- pion : 18MeV (MPV)
- proton : 18MeV (MPV)
- kaon : 20MeV (MPV)

MPV = Most probable value (maximum bin)

MC results (combined)





Upstream energy loss by species @ 6GeV/c:

- positron : 24MeV (MPV)
- muon : 22MeV (MPV)
- pion : 20MeV (MPV)
- proton : 20MeV (MPV)
- kaon : 20MeV (MPV)

Upstream energy loss by species @ 7GeV/c:

- positron : 22MeV (MPV)
- muon : 16MeV (MPV)
- pion : 18MeV (MPV)
- proton : 16MeV (MPV)
- kaon : 18MeV (MPV)

MPV = Most probable value (maximum bin)

Validation/measurement(?) in data

- Very small effect (< few % fractional KE)

Potential measurement approaches:

  - LE protons -> 1GeV/c and 2GeV/c will stop in detector
  - electrons -> shower energy reconstruction is not very good
  - pions -> interactions and decay in flight makes this more complicated, but 1GeV/c will stop in detector
  - LE muons -> 1GeV/c muons will range out near middle of TPC

- I've opted to start by looking at 1GeV muons which I expect be the easiest to perform this measurement
- End goal is to look at each particle species at contained energies (maybe not a solo task)

Open to suggestions or comments!

Event selection

Preliminary stopping muon selection from Anselmo / Francisco:

- 145ns < TOF < 170ns
- $\cos(\theta_{beam,\ tpc}) > 0.93$
- $0.69 < range/CSDA_{range} < 1.05$

Added some additional selections for this analysis:

- 90% nominal < beamline momentum < 110% nominal
- 320cm < track end z < 520cm

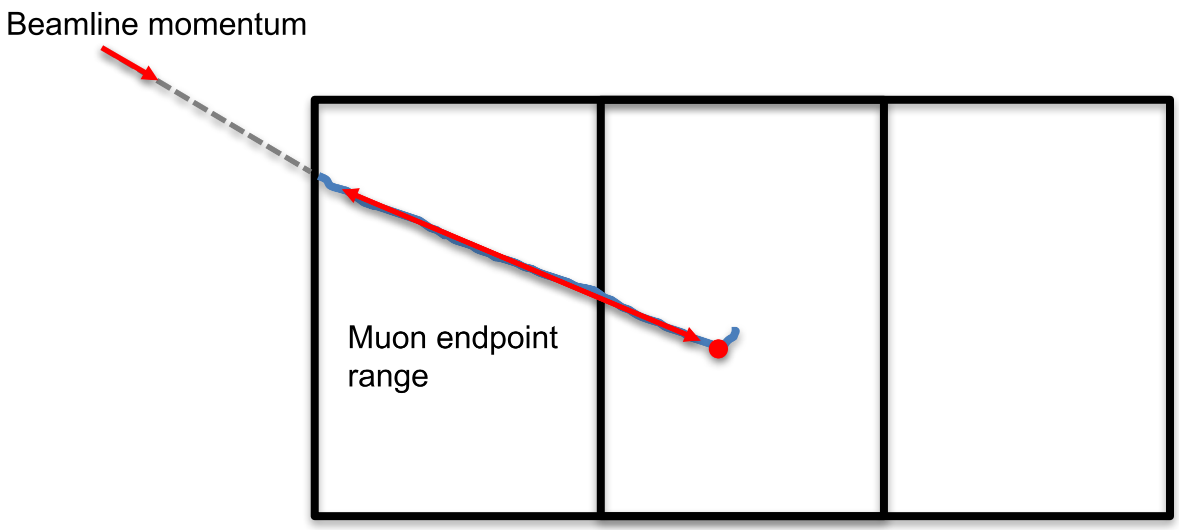
Purity (sce MC sample): 71% (353/497)
Efficiency (sce MC sample): 52% (353/684)

Energy estimation

Endpoint range:

- distance between the TPC face (z=0) given by beamline instrumentation and muon tracking endpoint

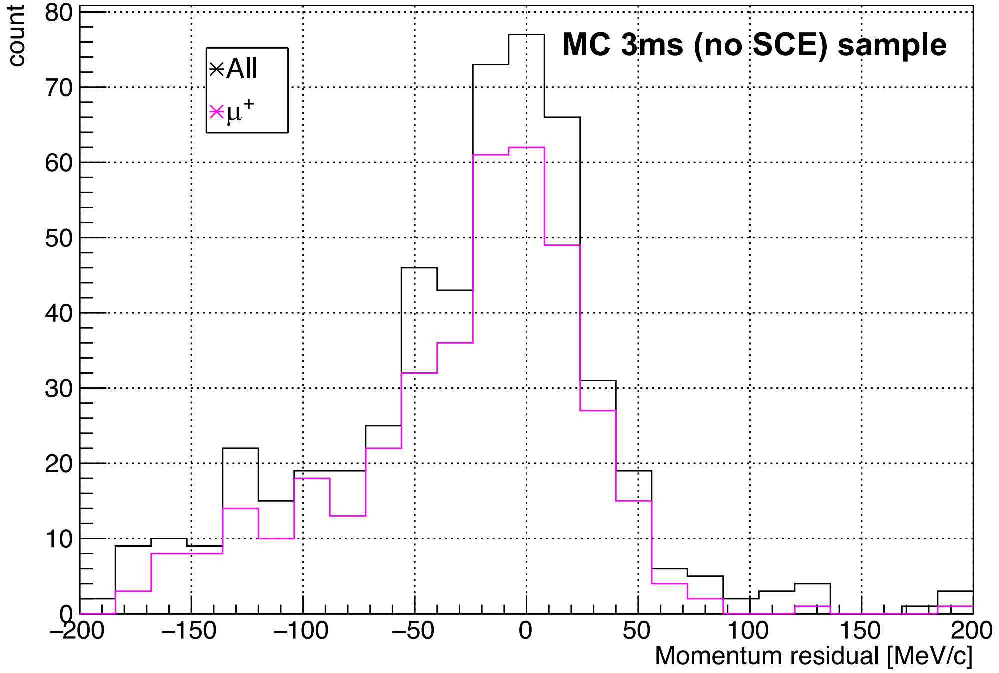
- "calibrate" to the CSDA range to account for MCS (using MC)



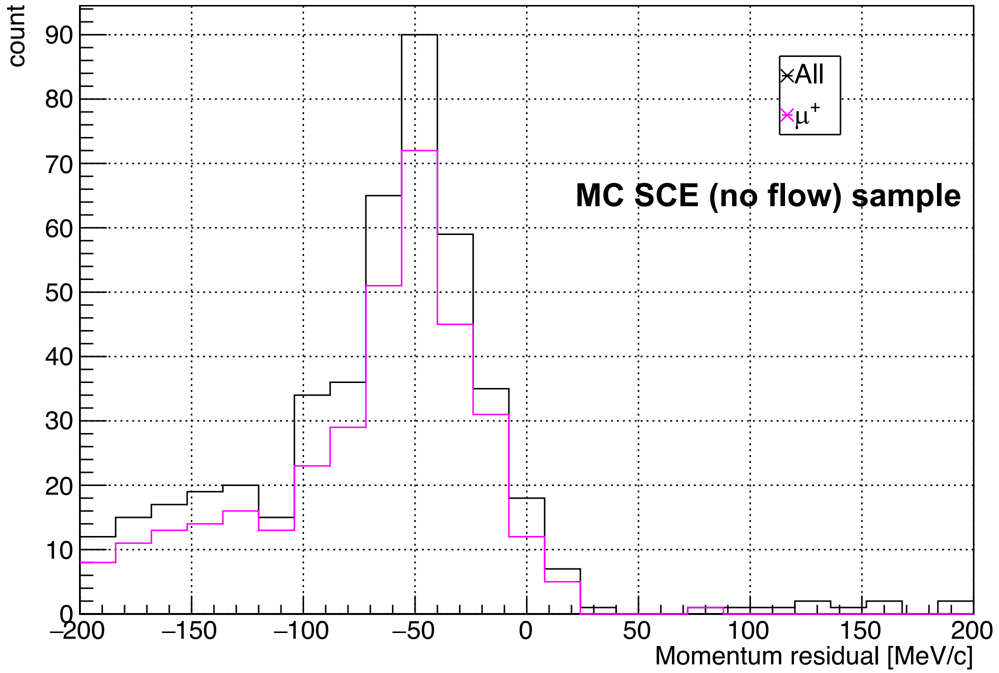
Only uses a single reconstructed point in central region of TPC
-> minimize bias due to SCE

SCE bias (CSDA range)

CSDA momentum residual
CSDA – true (no SCE)



CSDA momentum residual
CSDA – true (SCE)



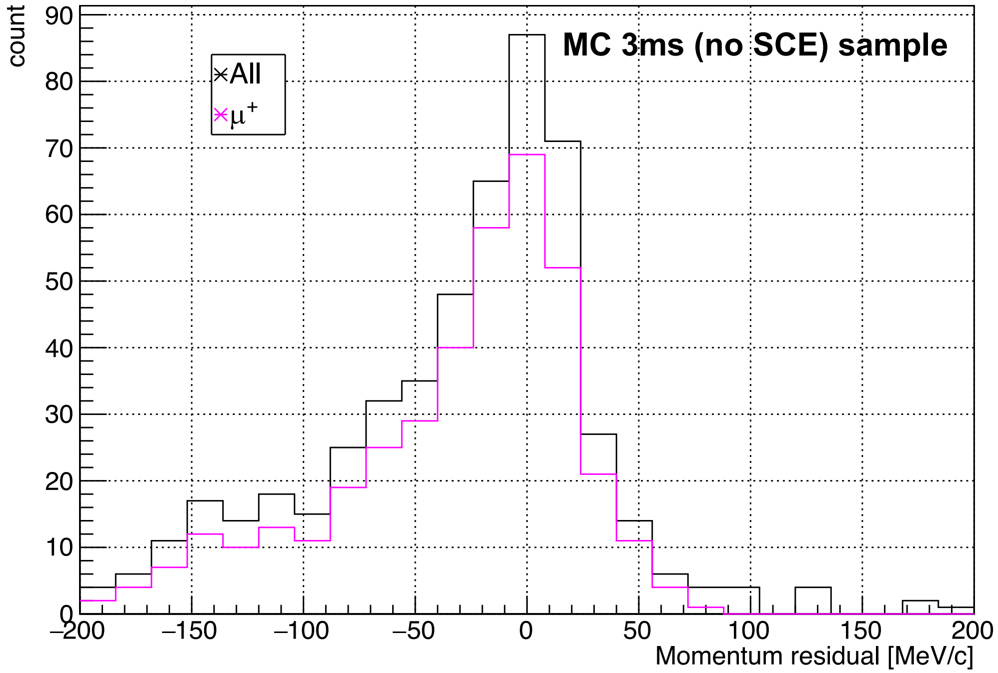
Apparent resolution ~50MeV/c / sqrt(N)

Introduces bias ~50MeV

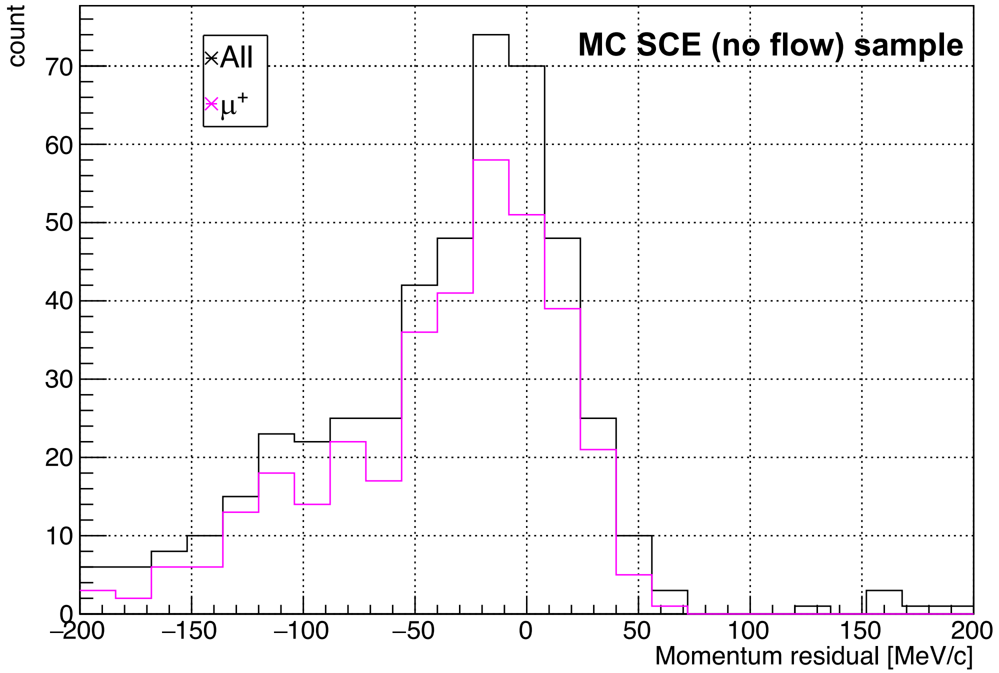
Resolution is similar as no SCE

SCE bias (endpoint range)

Endpoint momentum residual endpoint – true (no SCE)



Endpoint momentum residual endpoint – true (SCE)



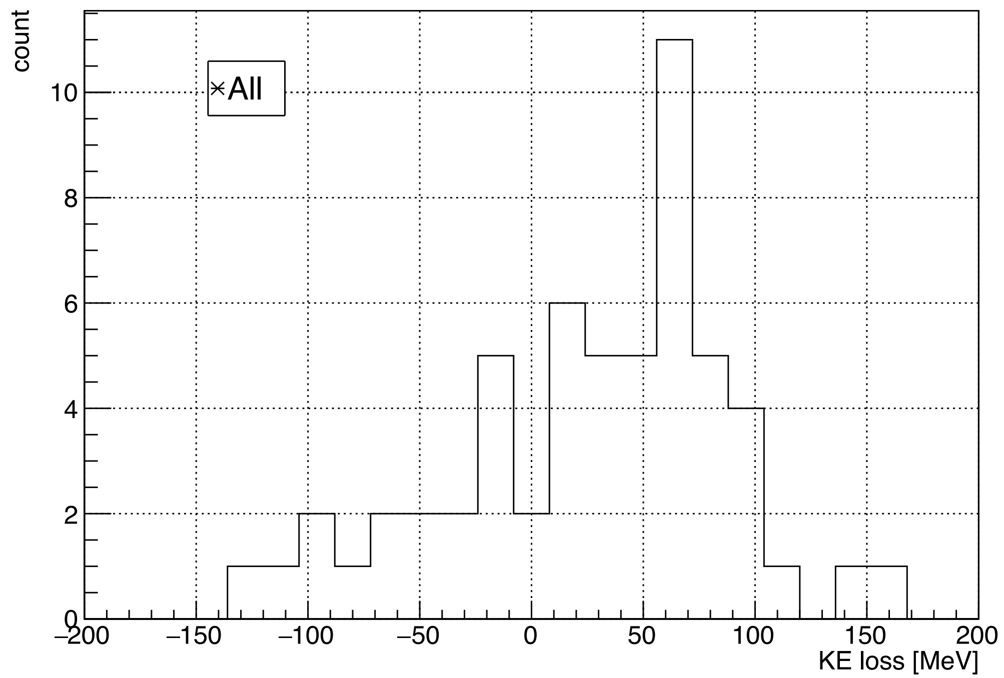
Very little change to resolution

Bias due to SCE is much smaller than CSDA estimate

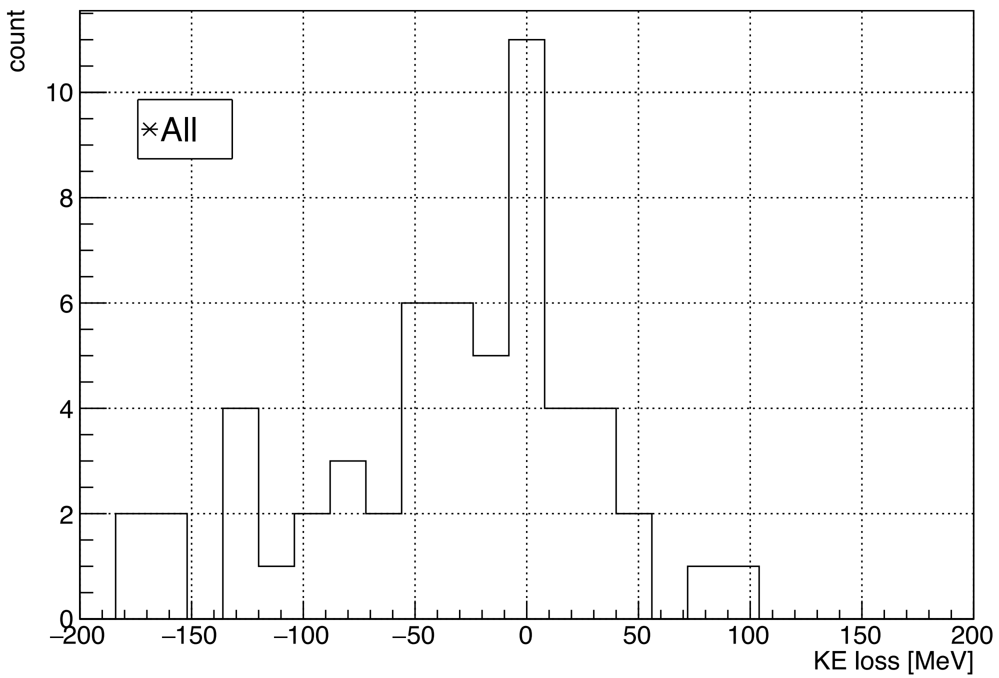
Still significant -> still will probably need to utilize a SCE correction

Run 5809

Energy loss
endpoint KE – beamline KE



Energy loss
CSDA KE – beamline KE



Observe an enhancement of the estimated energy within detector (~50-60MeV)

Statistics are low

Suggests significant space charge calibration or modified drift velocity is needed

Summary and next steps

Summary

- Identified some small differences in simulated and actual geometry
  - Total material difference is only ~3g/cm^2
- Combined beamline and detector MC to determine the expected energy loss of each particle species between the spectrometer and TPC
  - ~15-20MeV from both beamline instrumentation and beam window
- Started looking into using particle range for validating / measuring energy loss
  - SCE calibration is necessary

Next

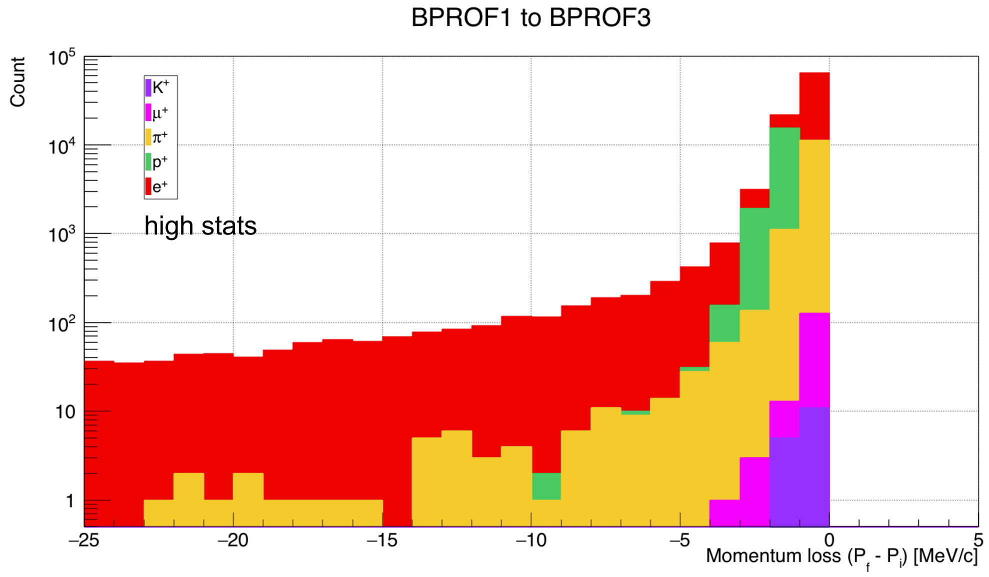
- Implement SCE correction on stopping muons
- Use a larger sample of muons
- Repeat for stopping protons (1 + 2 GeV/c)

Backup

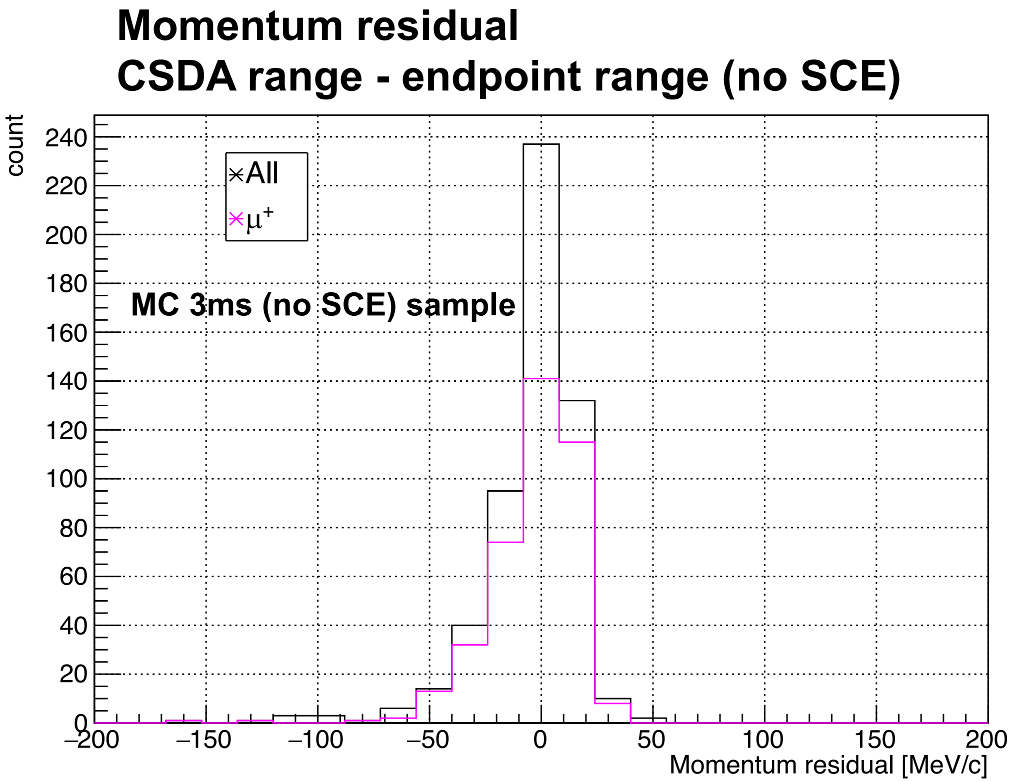
MC results (ΔP in spectrometer)

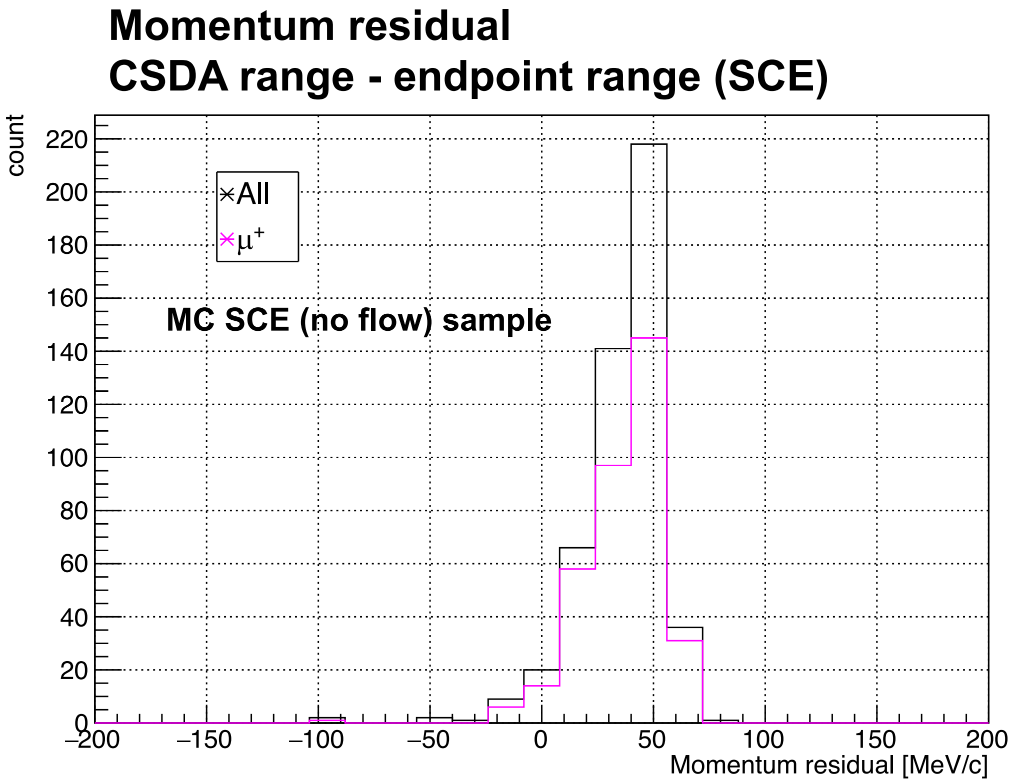
1 GeV/c

- Material in spectrometer contributes <0.2% change in measured momentum
- This gets better for higher momentum
- Probably worse for lower momentum



MC comparison (CSDA v. endpoint)





Observe ~50MeV relative shift when including SCE