Upstream energy losses

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ProtoDUNE analysis workshop

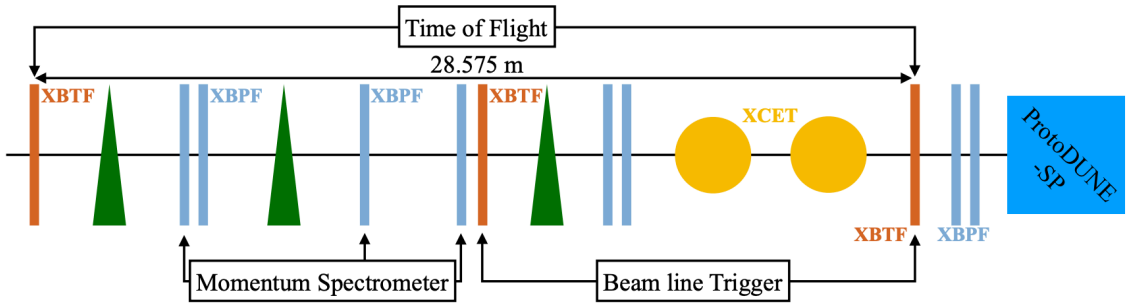
1/26/2020

BERKELEY LAB

ProtoDUNE beamline material

Three primary components:

- Beamline instrumentation
- Cryostat beam window
- Beam plug



Dominant unknown is LAr layer thicknesses (~1cm, ~3MeV MIP eq.)

Total beamline material:
9g/cm2 (18 MeV MIP eq.)

Beamline instrumentation:

- 11 scintillating fiber arrays
- 2 pressurized CO_2 Cherenkov detectors
- expected to contribute ~2g/cm2 (4MeV MIP eq.)

Cryostat beam window:

- Nitrogen back-filled volume
- Foam + glass wool insulation
- 1.2cm SS primary membrane
- contributes ~2.5g/cm2 (5MeV MIP eq.)

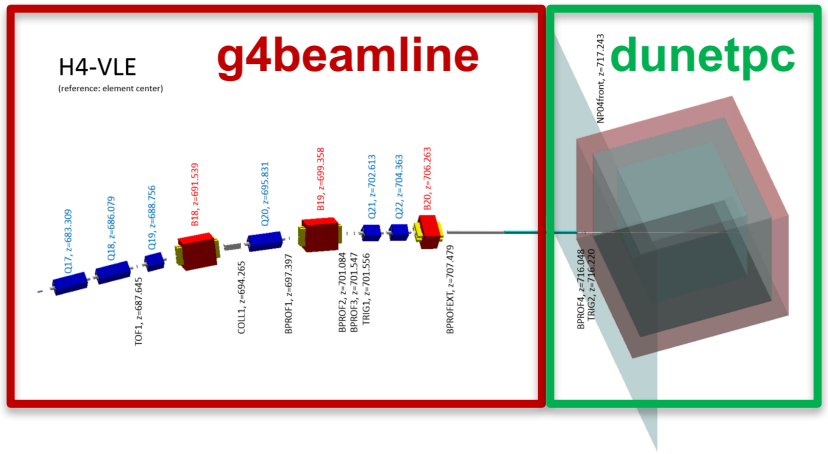
Beam plug:

- Cold nitrogen back-filled volume
- G10 windows
- Small LAr layers due to mating tolerances
- contributes 4-5g/cm2 (~8-10MeV MIP eq.)

ProtoDUNE simulation of material

Split into two:

- G4beamline simulation of beamline instrumentation and optics
- LArSoft (dunetpc) simulation



Full expected beamline material budget is included in the simulation, accurate to ~2g/cm^2

dunetpc starts with particles that have lost small amount of energy to beamline instrumentation

G4beamline simulation:

- Propagates particles from production at target, through instrumentation, to near cryostat face
- files exist at /pnfs/dune/persistent/dunepro/beam_data/simulation/mcc10

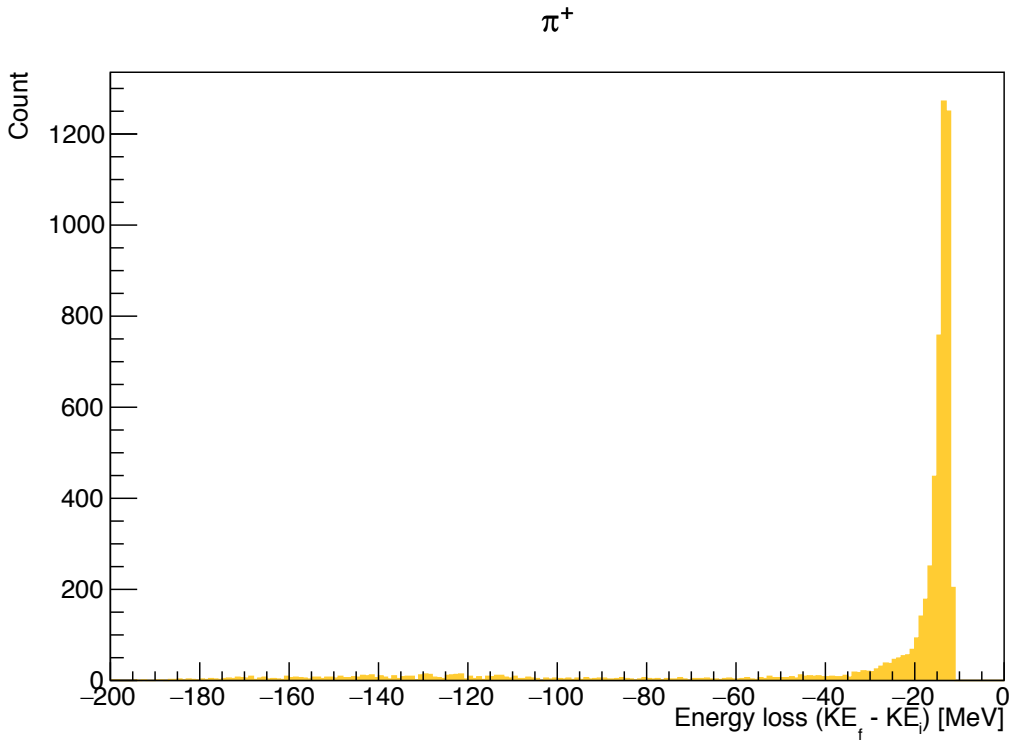
dunetpc simulation:

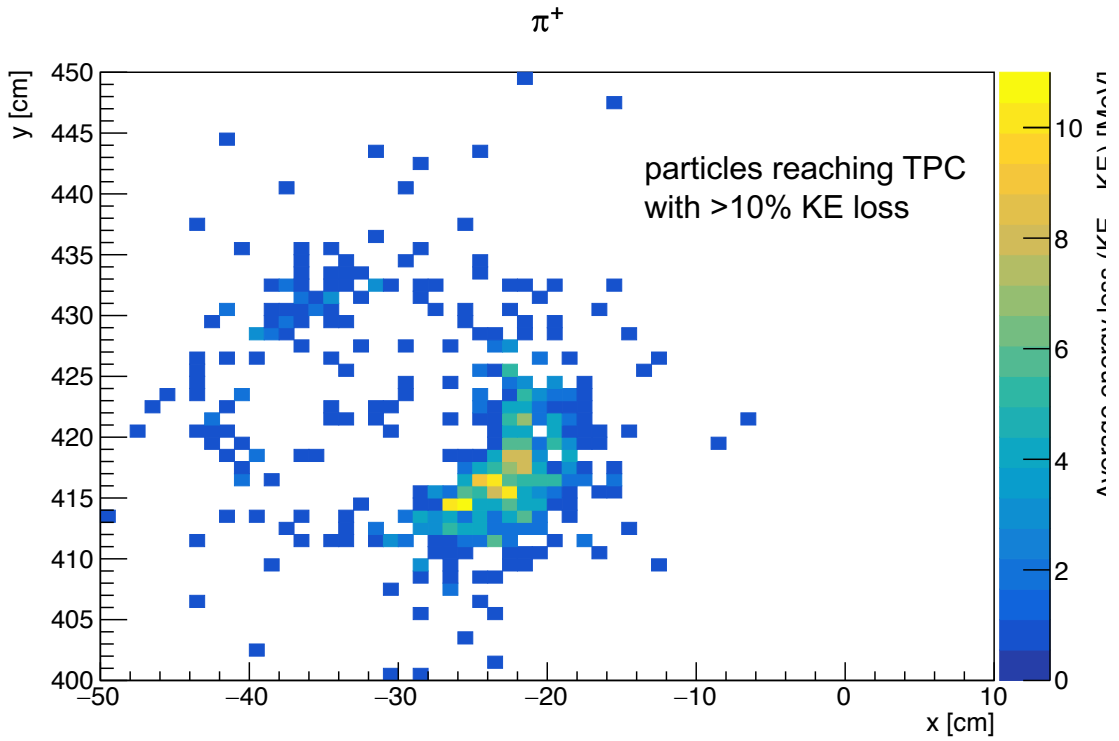
- Grabs from g4beamline ntuples
- Simulates from near cryostat face, through cryostat window and beam plug

Not much g4beamline information is available in dunetpc (currently)

Requires painstakingly searching through g4beamline files to lookup spectrometer momentum for each dunetpc particle

Total energy losses pi+ @ 1GeV (MC)





Sharply peaked, long tail due to particle skimming

MVP: 13MeV FWHM: 2MeV

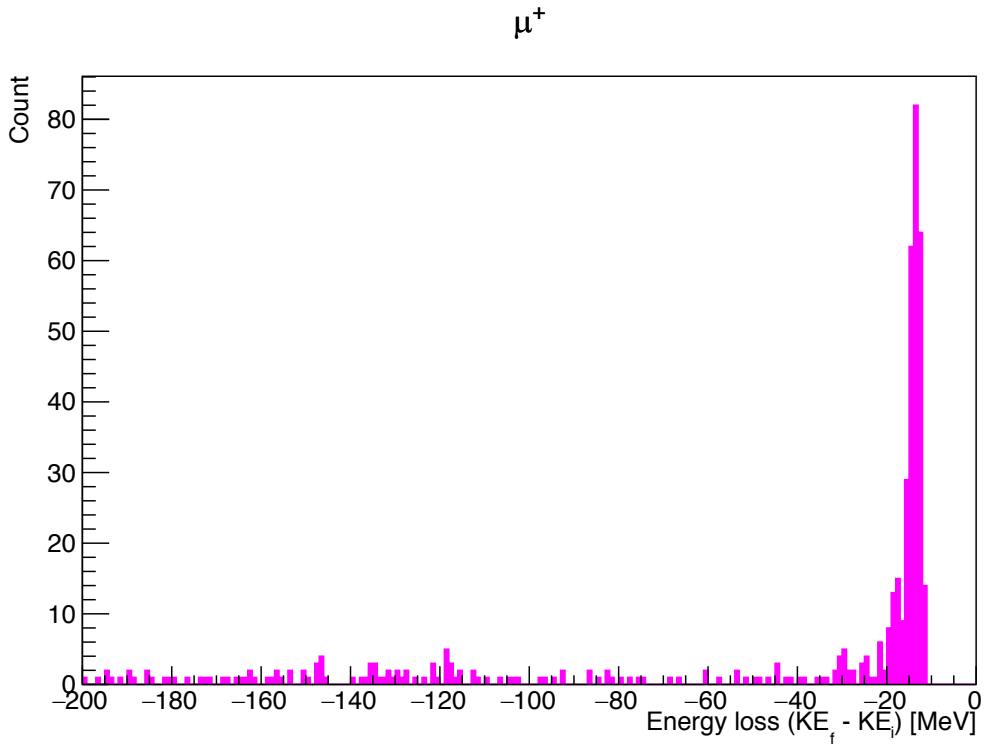
Mean: 30MeV Std. dev: 40MeV

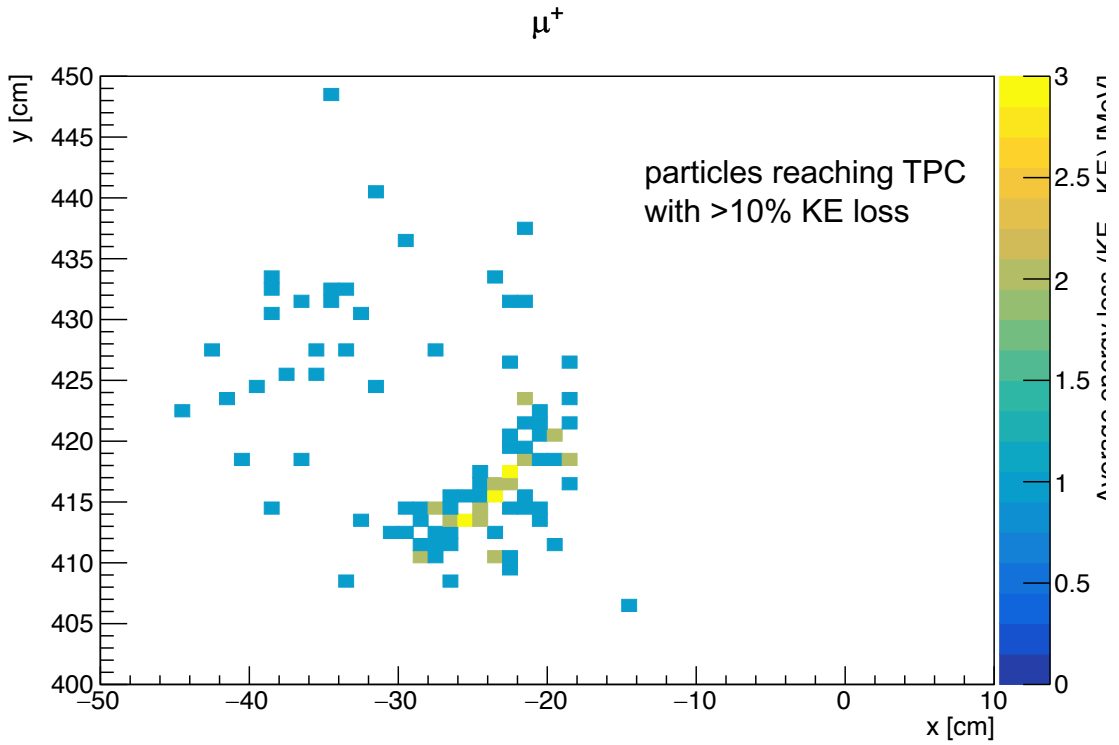
Known issue with geometry misalignment contributes to skimming particles: 10% (593/5970)

Uncertain how much skimming occurs in data

-> Heavily impacts mean+std dev, does not impact MVP or FWHM

Total energy losses mu+ @ 1GeV (MC)





Sharply peaked, long tail due to particle skimming

MVP: 13MeV FWHM: 2MeV

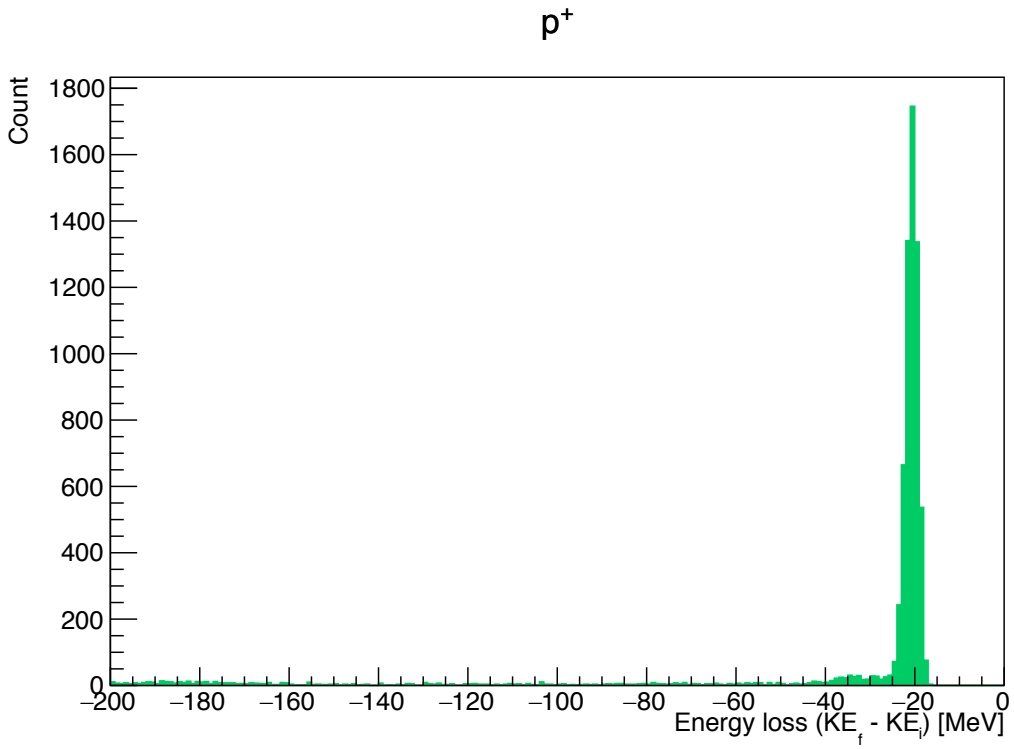
Mean: 50MeV Std. dev: 40MeV

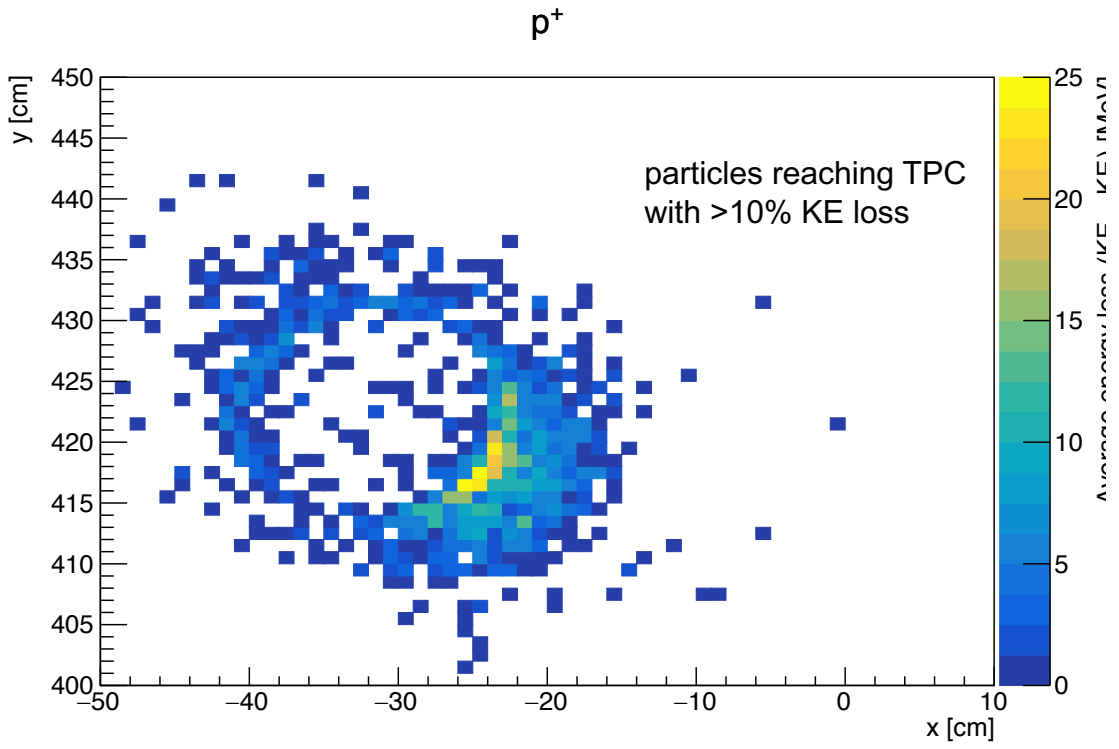
Larger fraction of particle skimming: 23% (105/464)

Likely due to production from pion decays in flight

=> larger divergence

Total energy losses p+ @ 1GeV (MC)





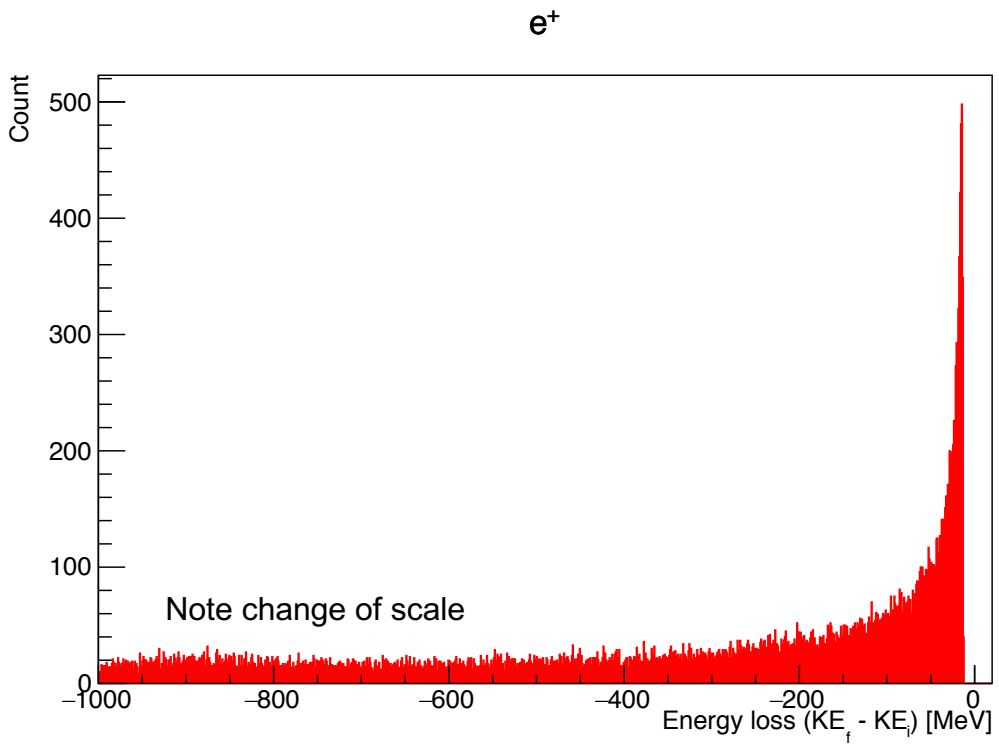
Sharply peaked, long tail due to particle skimming

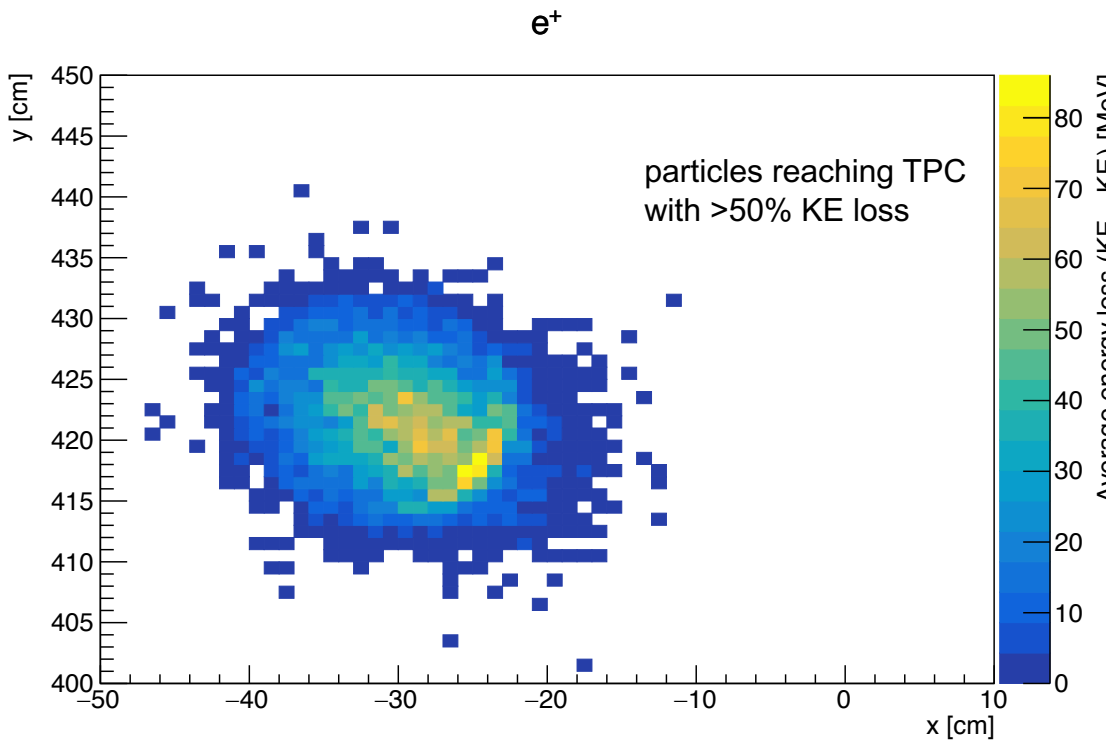
MVP: 21MeV FWHM: 2MeV

Mean: 52MeV Std. dev: 73MeV

Skimming: 19% (1489/7896)

Total energy losses e+ @1GeV (MC)





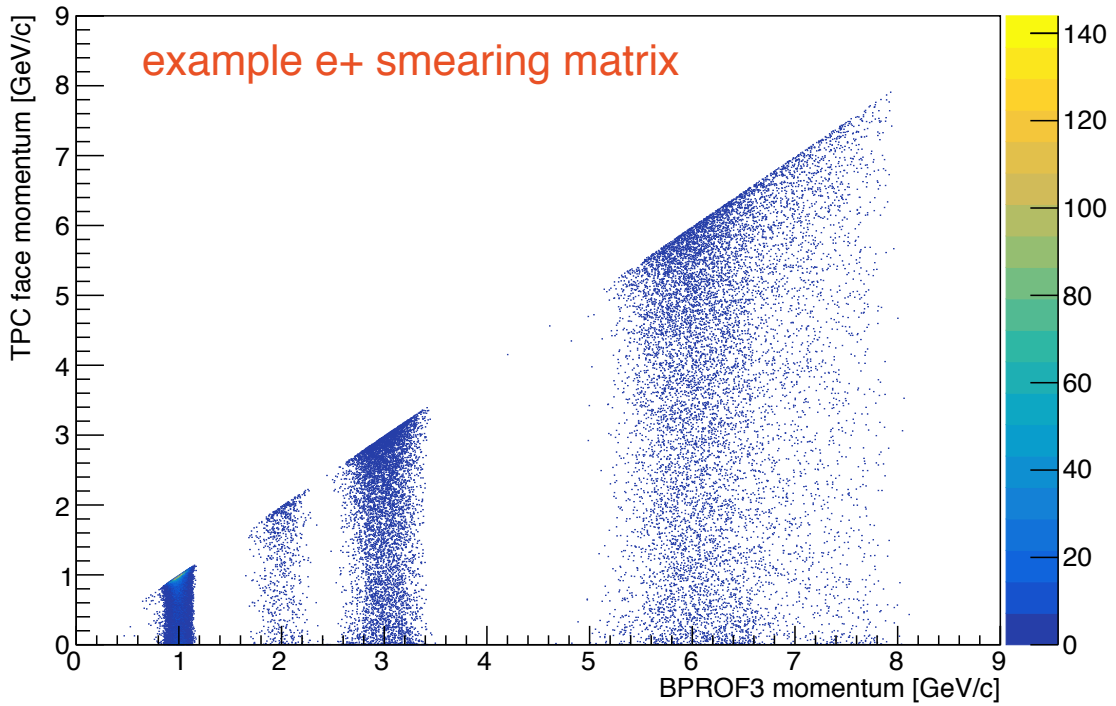
Broader distribution, significant tail

MVP: 15MeV FWHM: 8MeV

Mean: 315MeV Std. dev: 300MeV

Substantial fraction of electrons loose >50% of energy regardless of skimming: 29% (9062/31705)

Smearing matrices



- Can use this to create expected particle momentum at TPC
- Verification of skimming particle fraction is necessary before deploying
- Ask me if you want these, or I will think about putting them in a DUNE accessible place

$$pdf\left(p_{\mathrm{TPC},i} \middle| p_{\mathrm{BPROF3},j}\right) = M_{i,j} \Big/ \sum_i M_{i,j}$$

Channels sensitive to energy loss in data

Protons

Beam-muons

Pions

Electrons

…that's all of them!

But requires very accurate measurement of energy scale in the detector, O(1%)!

- PDS and TPC provide largely independent measurements
  - Range can be biased due to non-uniformity of bulk charge distribution
  - Calorimetry can be biased due to reconstruction and SCE non-uniformities

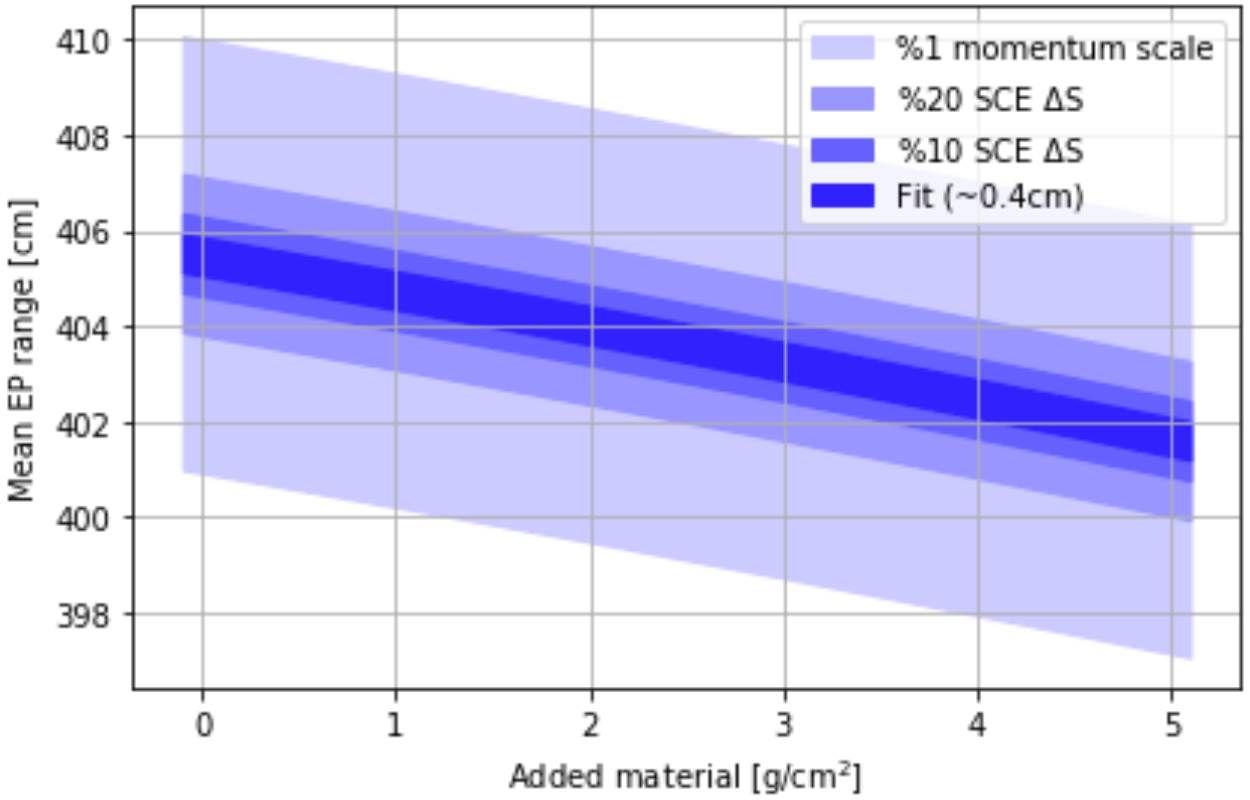
Challenges:

- SCE bias
  - Recombination and range effected by SCE
  - Position dependent effect
  - Up to 10-20% rough uncertainty according to Mike Mooney
- Spectrometer bias
  - Calibration technique used by beamline group relies on known magnetic field
  - Proportional to momentum
  - Magnetic field uncertainty is 1%

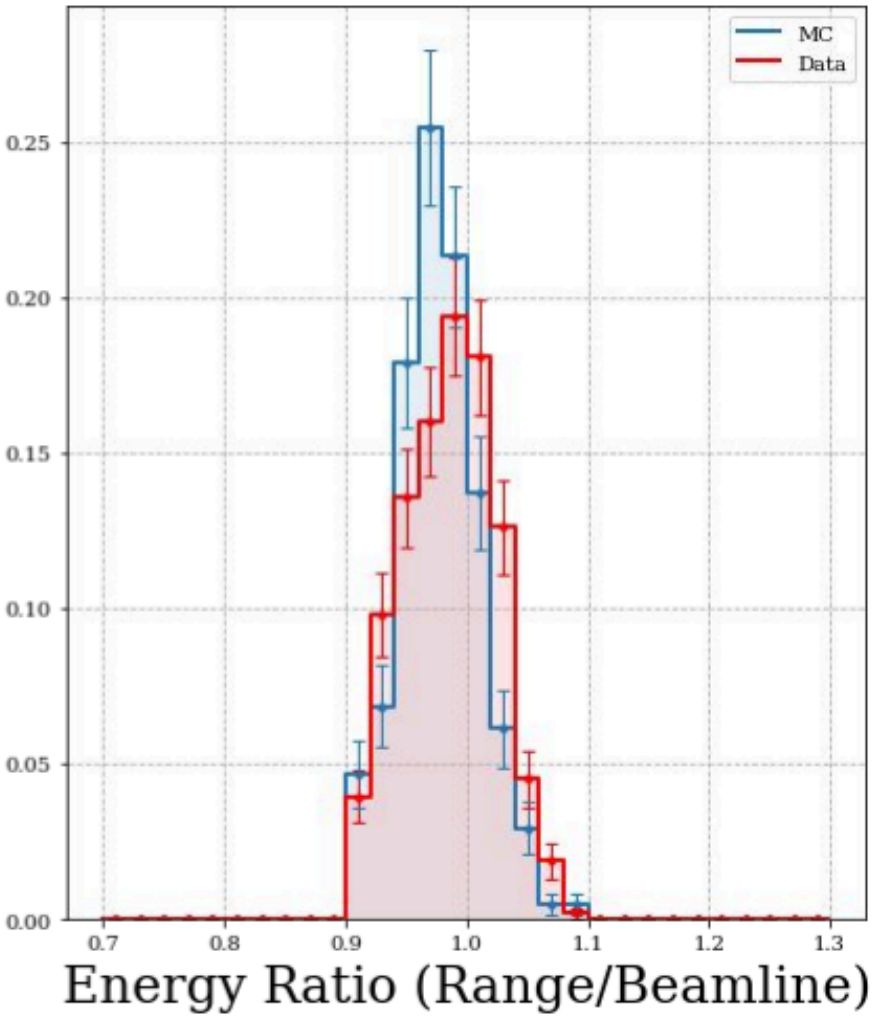
Sensitivity of stopping beam muons

- Studied how sensitive stopping beam muons would be to increased material in beamline
- Focused on potential ~10% SCE and 1% momentum scale biases on a range-based measurement
  - 8cm SCE correction => potential 0.8cm bias
  - 1% momentum => potential ~5cm bias (correlated between different beam particles)
- Can reach only reach ~6g/cm^2 sensitivity without spectrometer bias measurement
- Can reach ~1g/cm^2 sensitivity with spectrometer bias measurement

Other channels are more affected by SCE and will likely have a larger bias



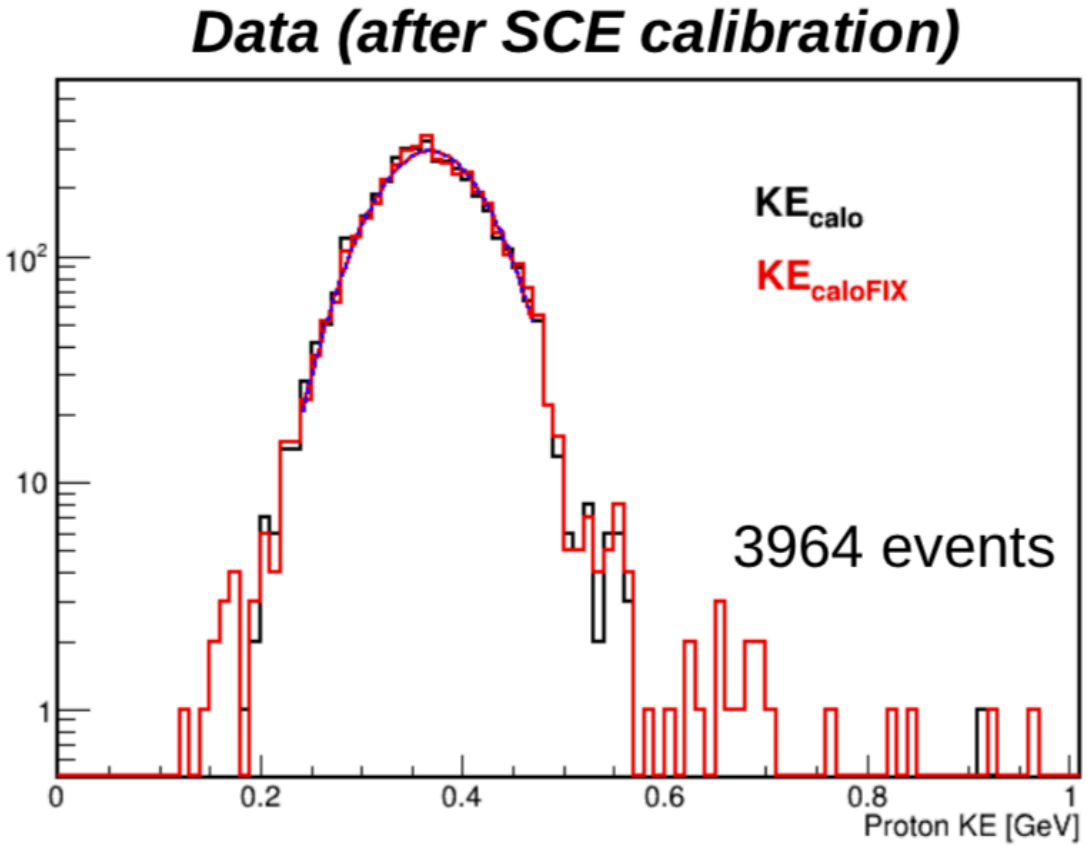
Energy losses for muons (TPC calorimetry)

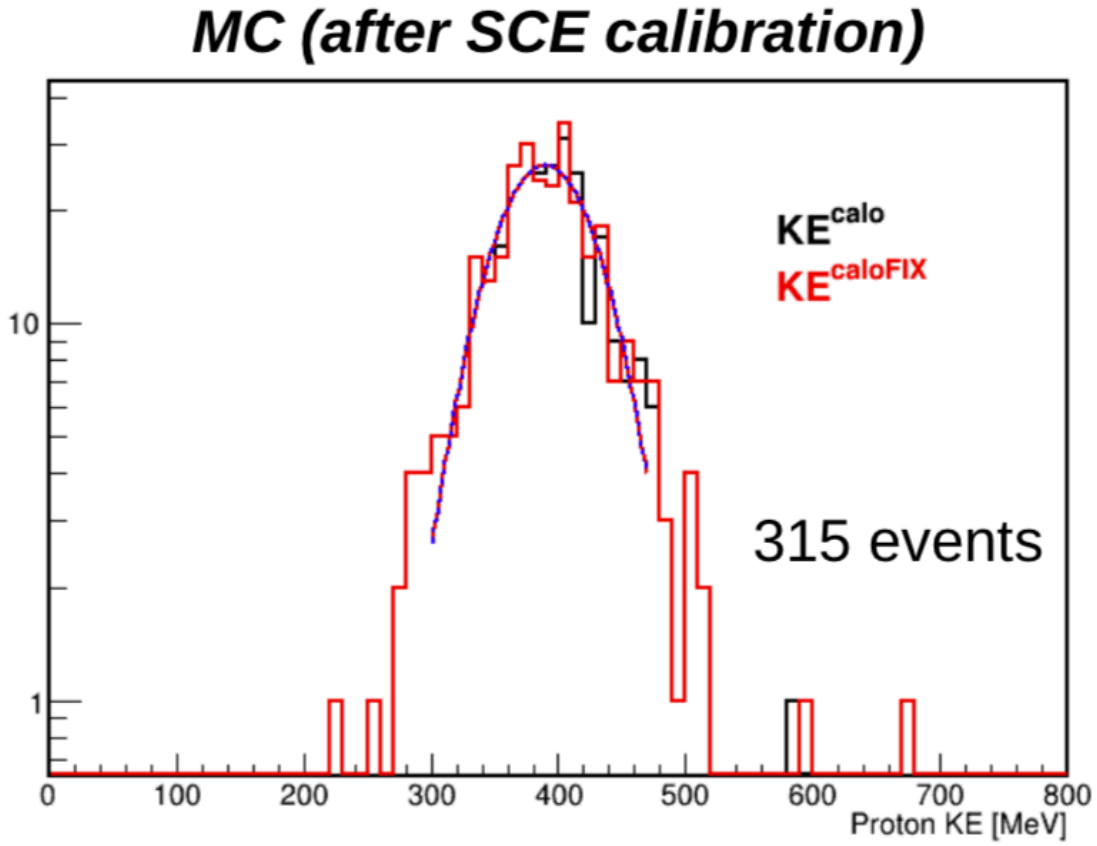


1 GeV stopping muons (Owen G's anaylsis):

- MC reco energy loss ~21MeV (+~4MeV)
- Data reco energy loss ~14MeV
- Consistent with expectations
  - Data/MC disagreement of ~11MeV is reasonable based on expected biases from SCE uncertainty and spectrometer (~1%)
  - Unclear why MC reco energy loss is 12MeV larger than MC true energy loss

Energy losses for protons (TPC calorimetry)





1 GeV stopping protons (Heng-Ye L's analysis):

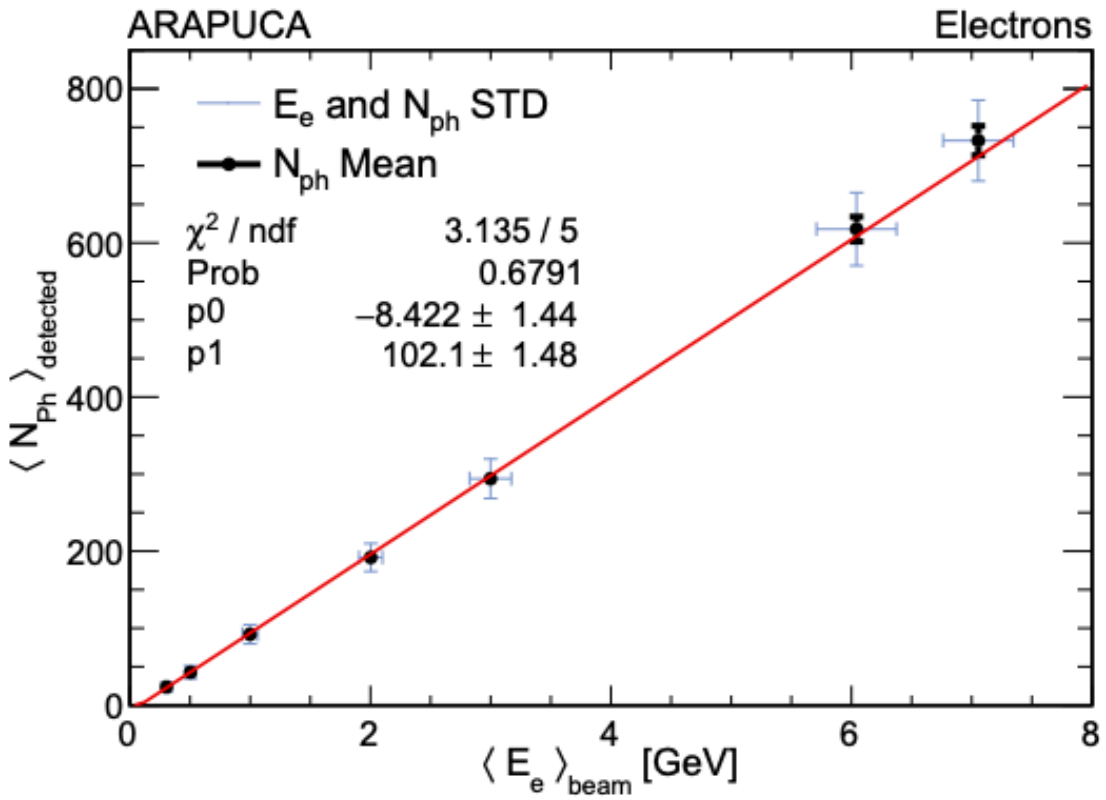
MC energy loss (peak mean): 18MeV, 45MeV (+~6MeV)

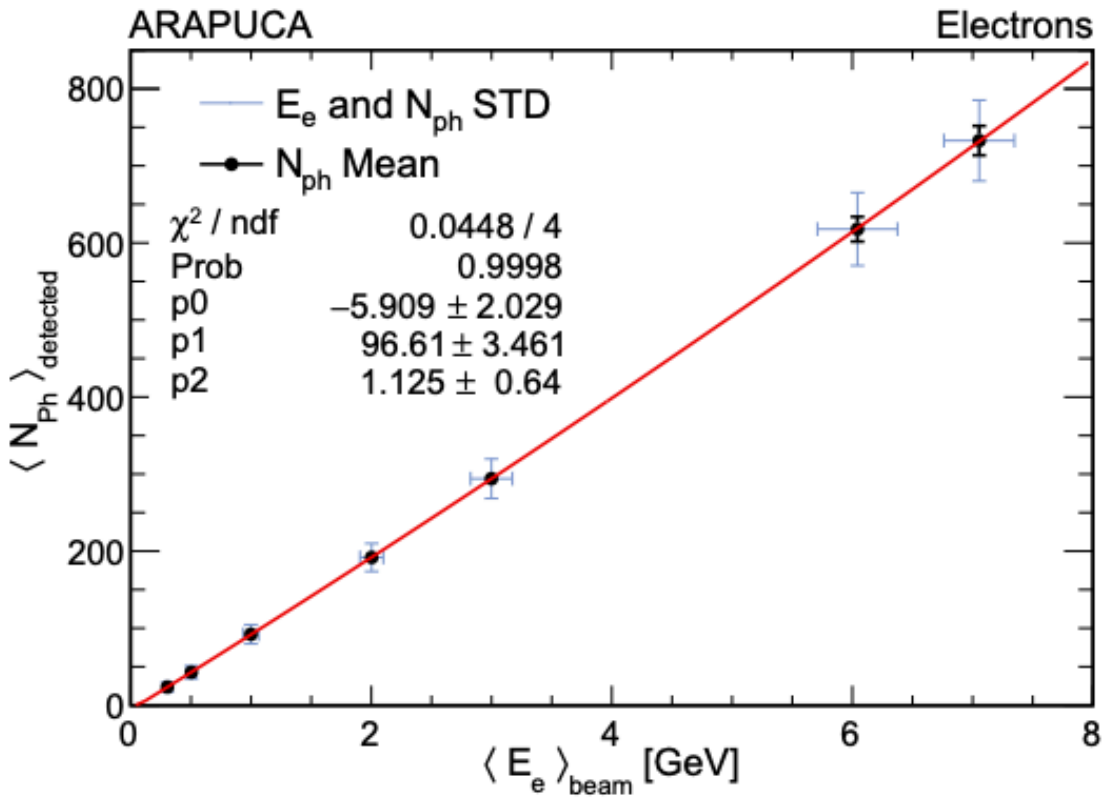
Data energy loss (peak mean): 34MeV, 68MeV (range, calo)

Range-based reconstruction is consistent with MC truth to 3MeV

Data/MC discrepancy can be accounted for by 1% spectrometer bias + 3MeV SCE bias

Energy losses for positrons (ARAPUCA)



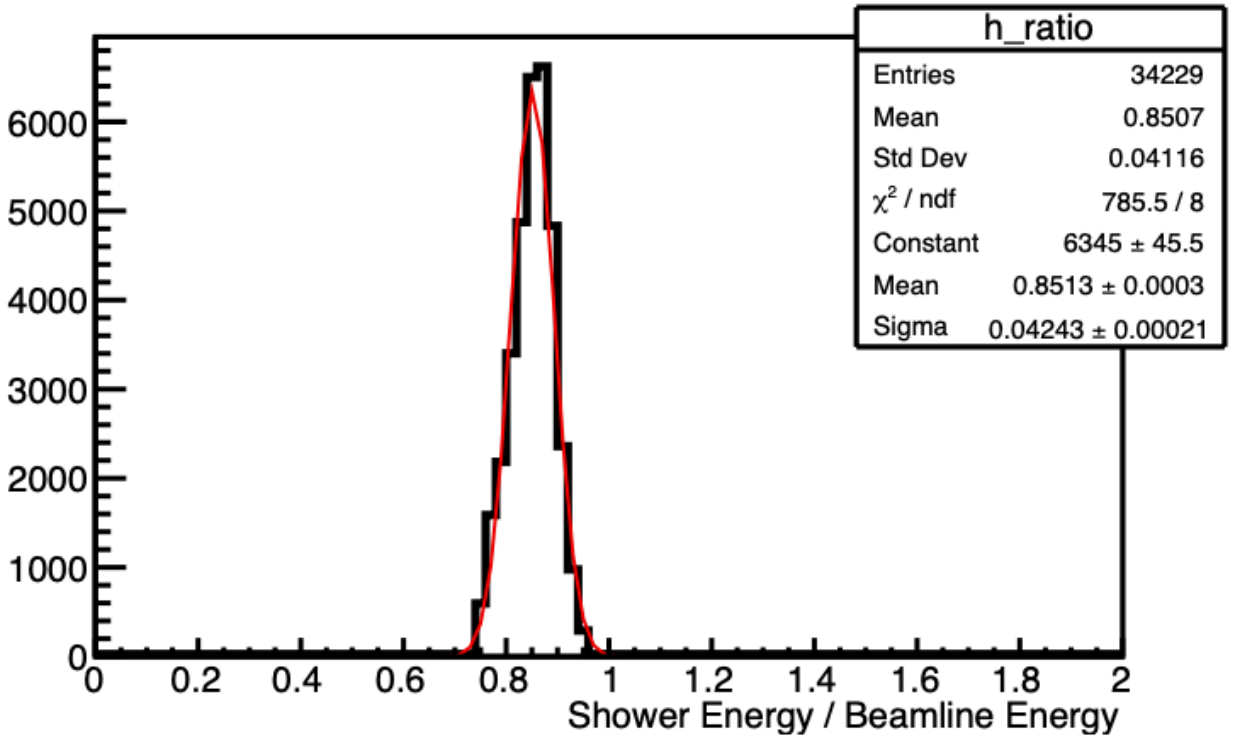


Measures average energy loss:

- sensitive to skimming particles
- average energy loss changes with momentum (roughly linearly @GeV) and so is reflected in slope of fit

Very difficult to disentangle from geometric/acceptance effects

Energy losses for electrons (TPC calorimetry)



Aaron H's analysis (1GeV electrons)

- ~150MeV bias in reco energy (both MC and data)

  => not due to upstream energy loss, since energy loss is simulated

  - ~100MeV accounted for in reconstruction
  - ~50MeV remaining
- Reconstruction challenges limit the sensitivity to positron energy loss in the beamline

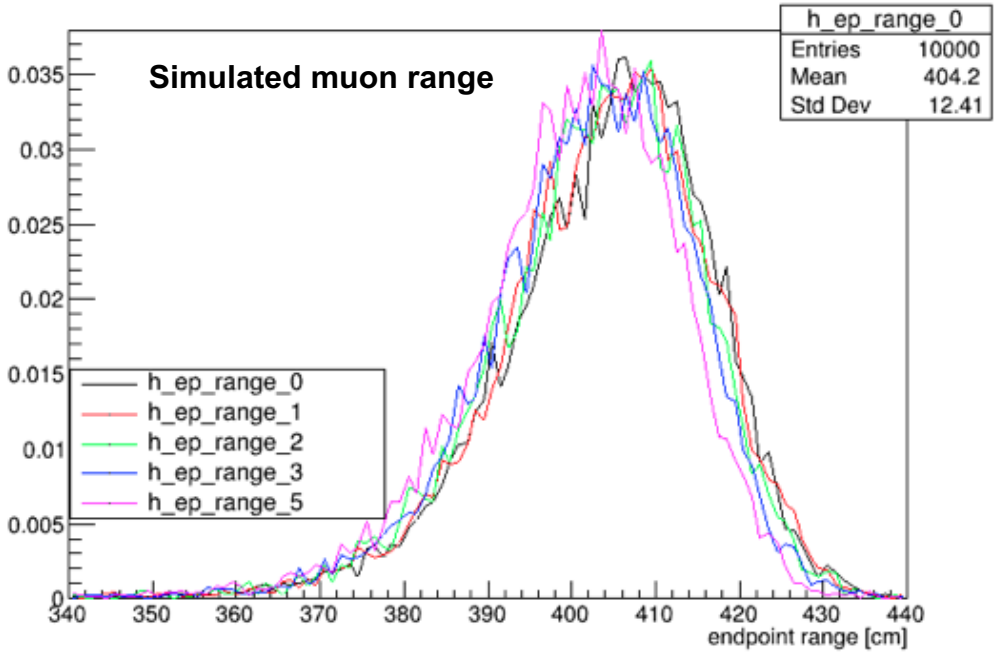
Conclusions

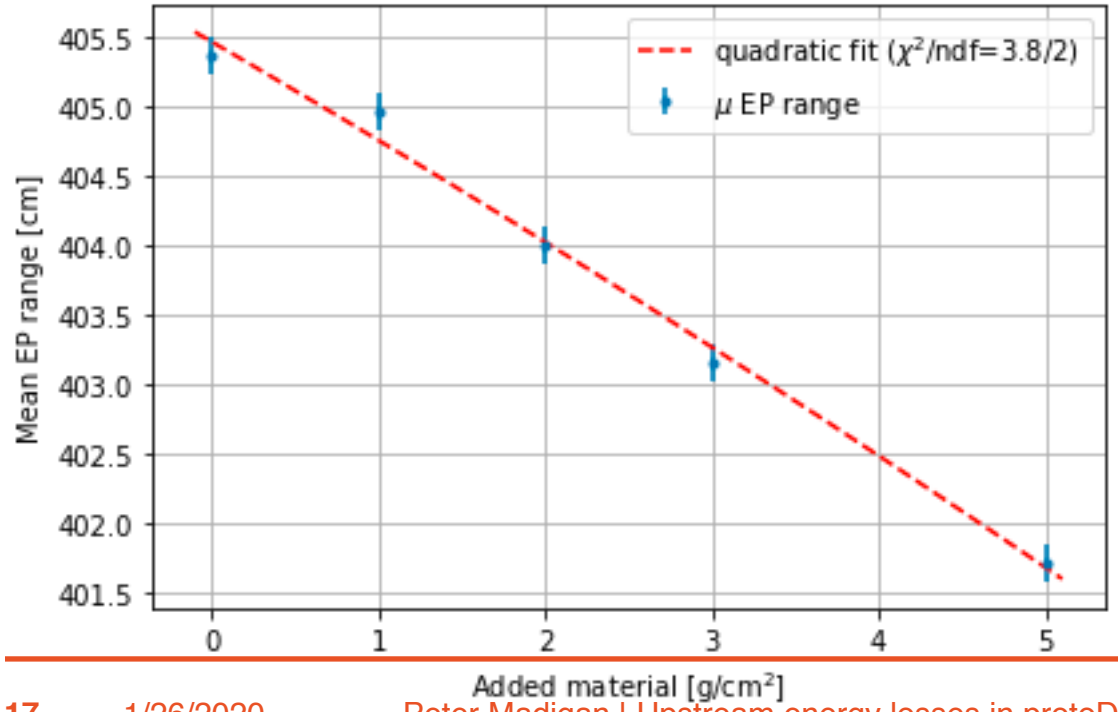
- On-axis beamline material is expected to be 9±1g/cm2
- Dunetpc simulation includes all but up to 2g/cm2 of material
  - However, spectrometer momentum is not currently accessible
- Measurements of the proton and muon energy loss seem consistent with expectations
  - Must consider spectrometer and SCE biases
- Electron energy loss is much more difficult due to reconstruction challenges

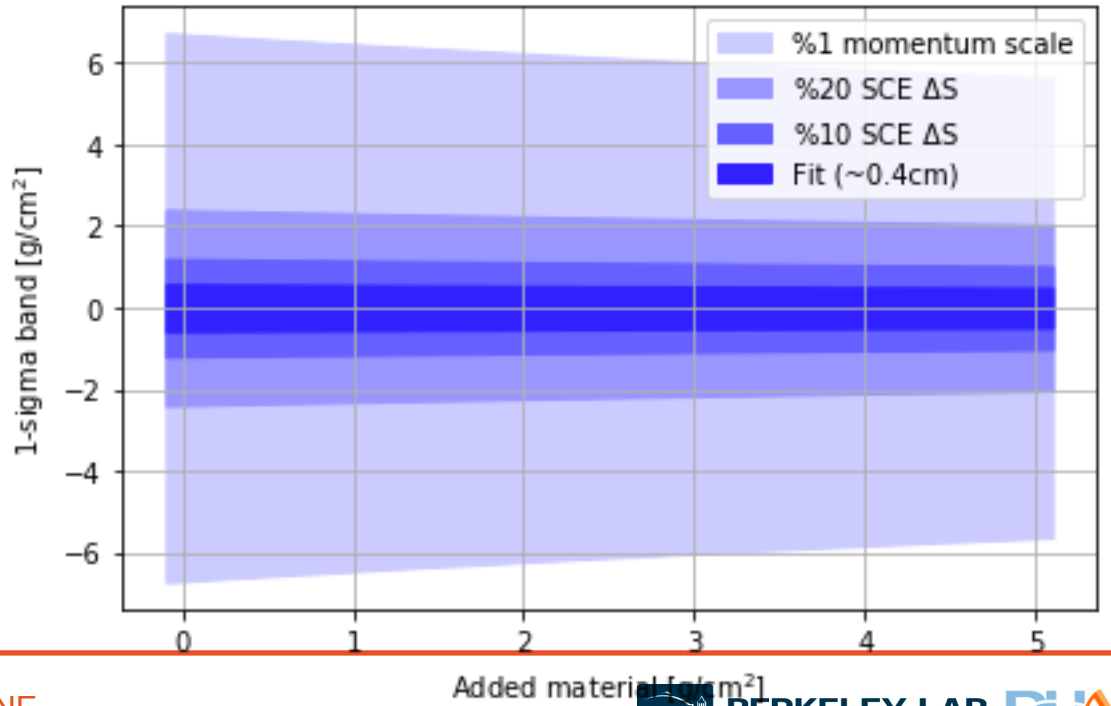
Backup

Sensitivity study

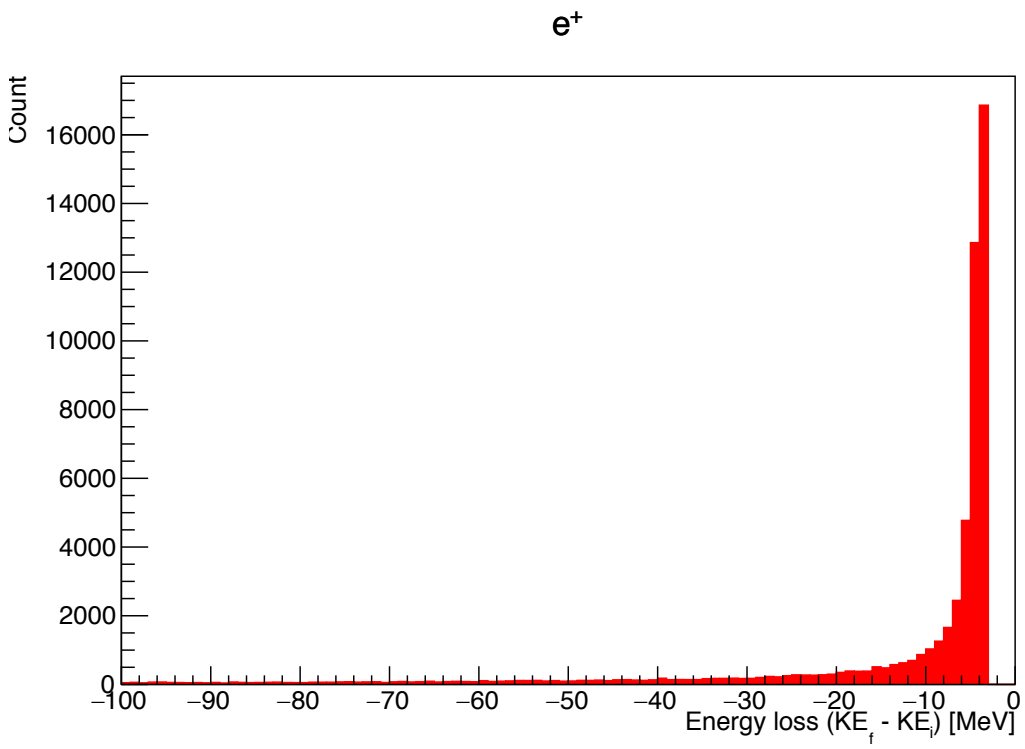
- Simulate 10k 1 GeV muons in protodune geometry with increased beam plug gas density
- Offset stopping position by ±10-20% of SCE correction, or approximate change in range due to 1% momentum scale bias (dE * <dE/dx>)
- Use band to estimate sensitivity, ~±6g/cm2 for momentum scale, ~±1-2g/cm^2 for SCE

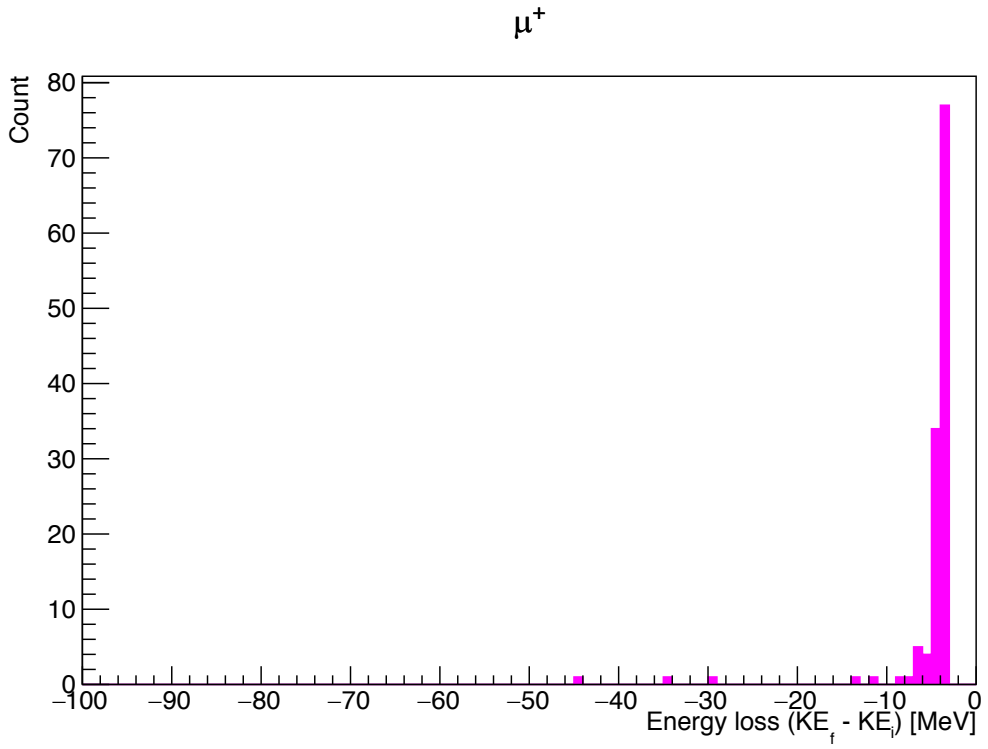




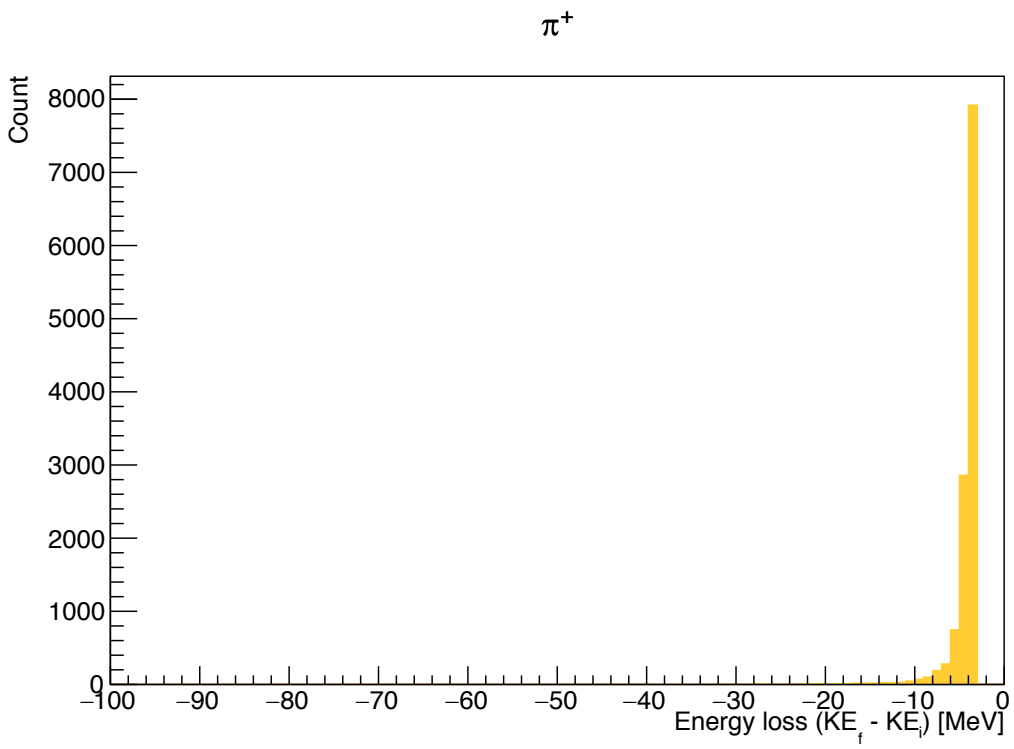


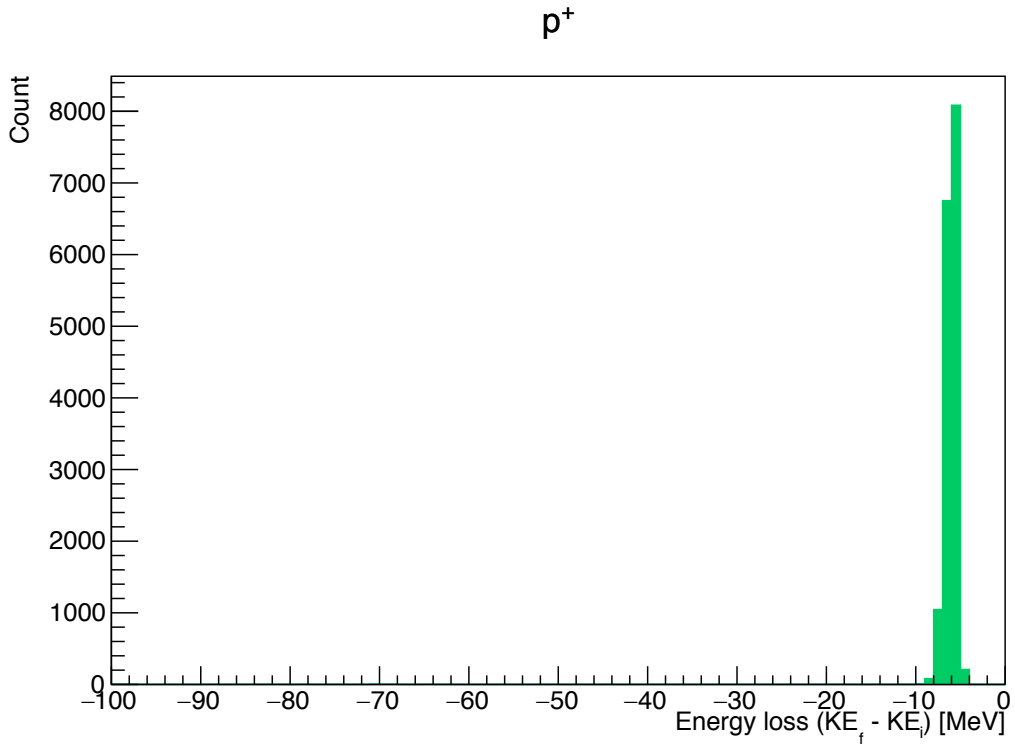
G4 beamline losses (1GeV)



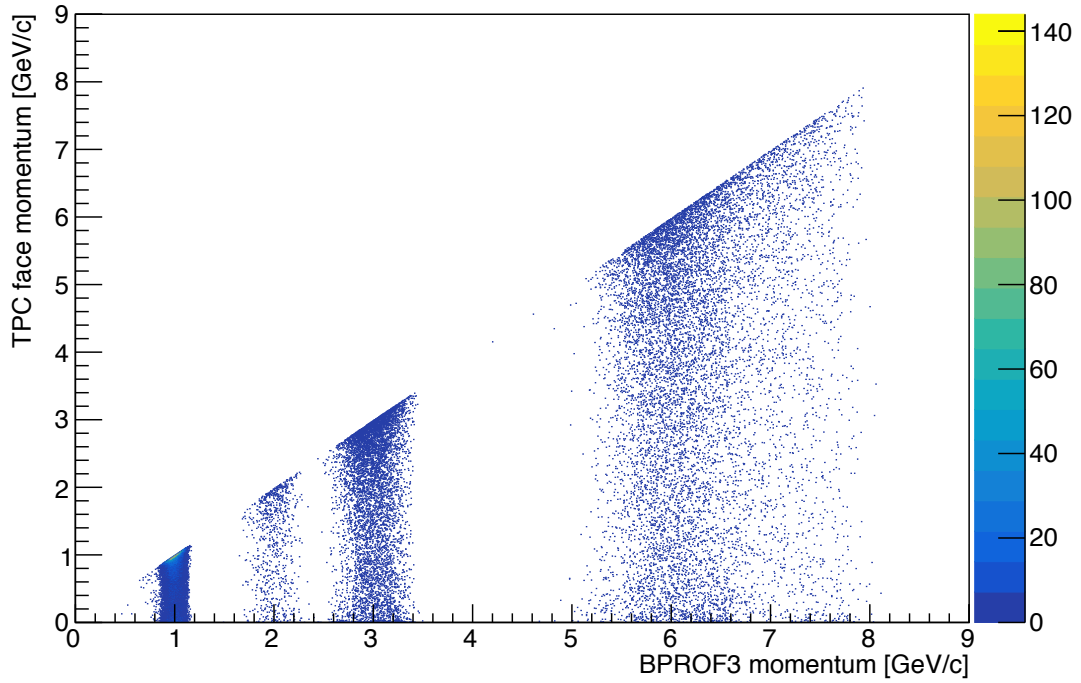


G4 beamline losses (1GeV)

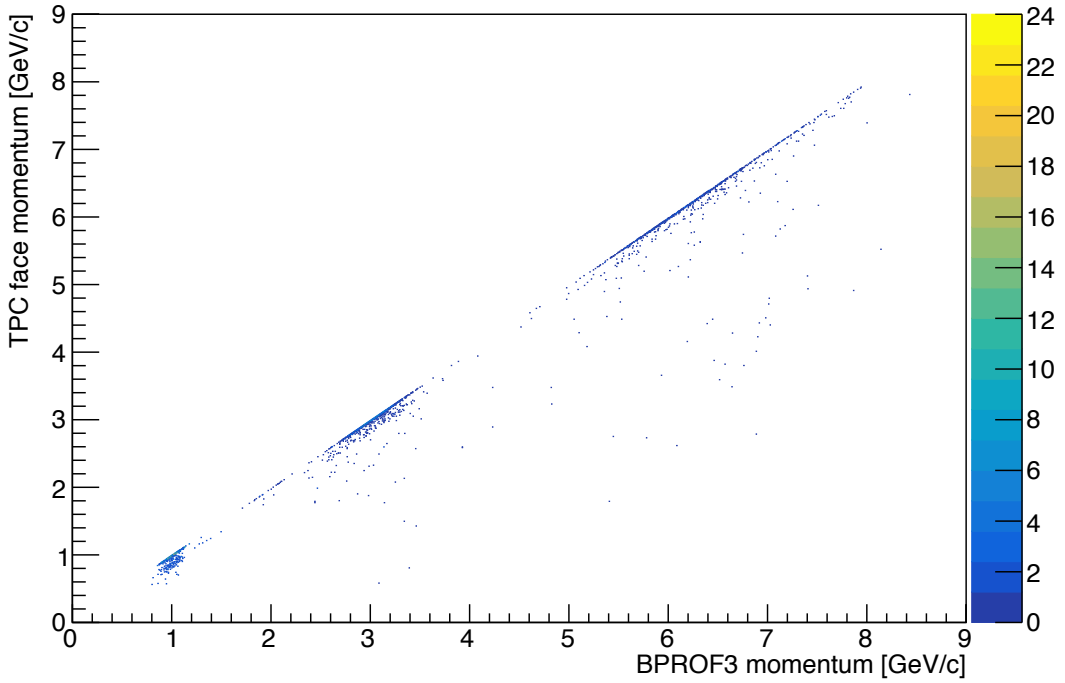




Smearing matrices

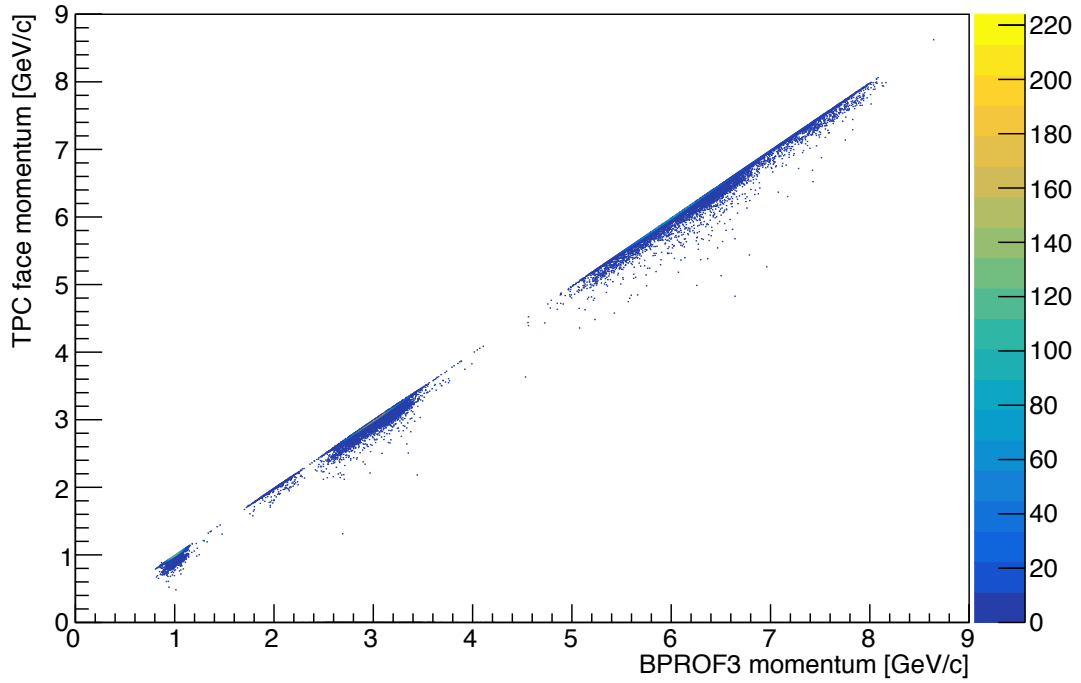


positrons

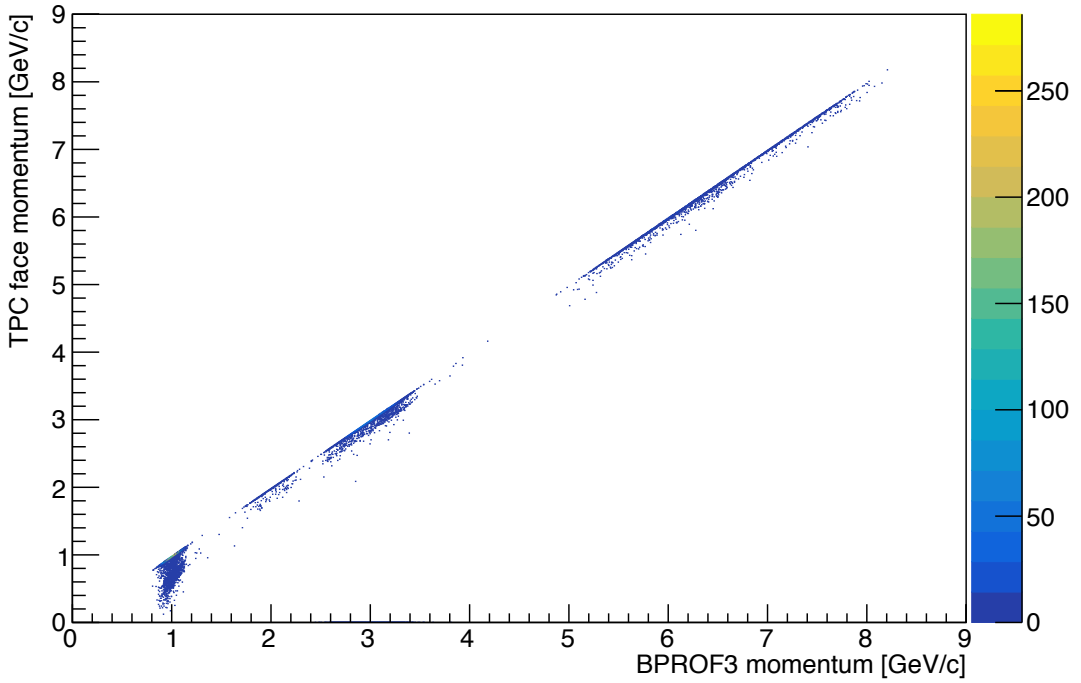


muons

Smearing matrices



pions



protons