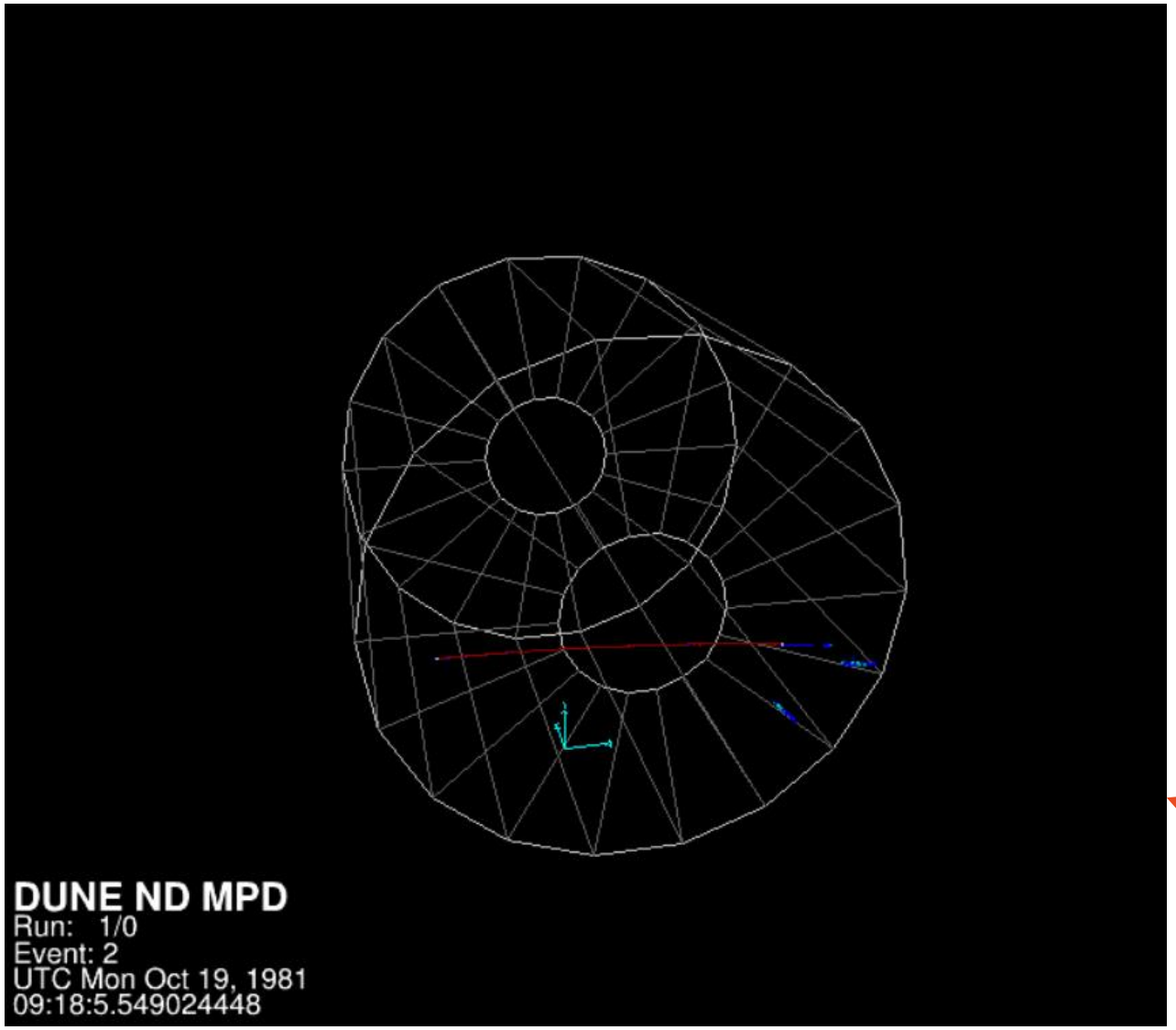
IMMIDIATE GOALS

- The ND-GAr tracking capabilities need to be carefully studied and benchmarked
- Specifically the momentum reconstruction algorithms, involving extended Kalman filter, need to be evaluated in their efficacy and potentially improved
- The easiest sample to study for this purpose is the sample of muons produced in $\nu_\mu(CC)$ interactions in the ArgonCube that then reach the Gas Argon TPC
- In order to correctly evaluate ND-GAr's capability as a muon spectrometer of ND-LAr, the L-to-G propagation of tracks needs to be understood
- One of the first step in this endeavor would be to learn how these samples are produced by the experts and being able to reproduce them

THE SIMULATION EXERCISE

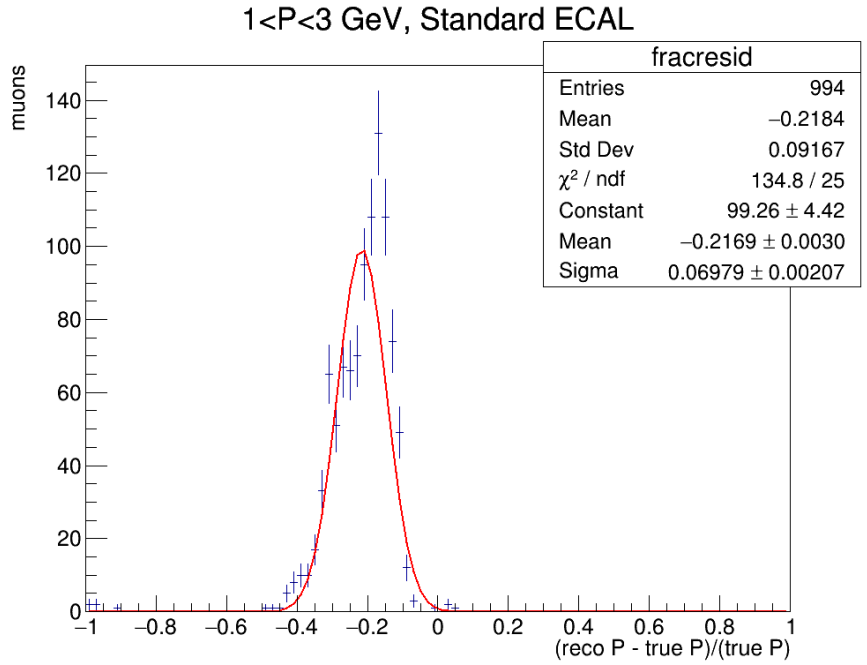


- To familiarise with the software I started working on a previously existing Garsoft simulation:
  1. Produce low energy (1GeV<p<3GeV) and high energy (3GeV<p<5GeV) upstream muon samples from a randomly generated text file, all muons starting outside the Gas Argon detector at z =-500cm, and having x and y coordinate that vary between -200 and 200 cm and -200 and 0 cm respectively
  2. Execute readout simulation, reconstruction and convert into analysis tree
  3. Produce resolution plot: $(p_{reco} - p_{true})/p_{true}$

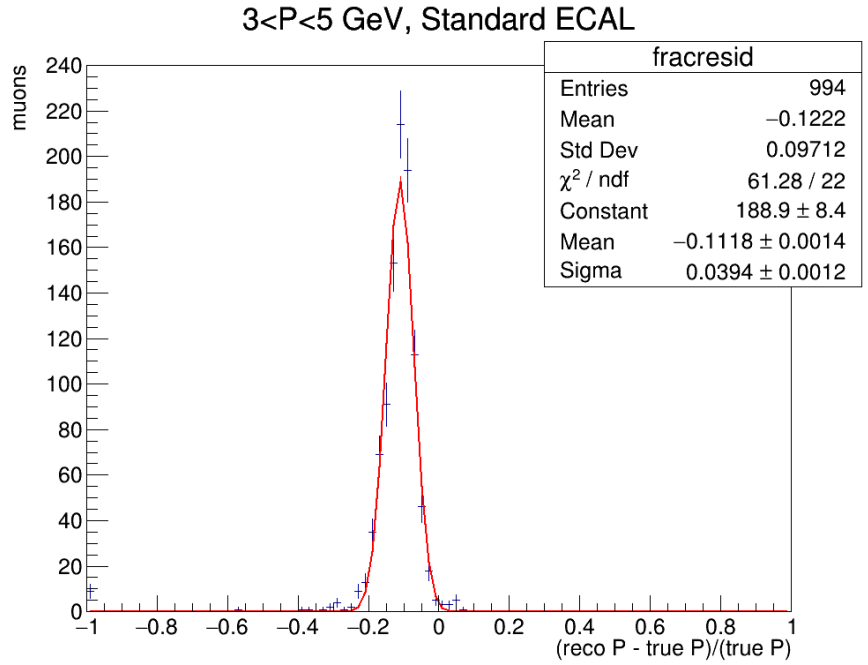
Graphical representation of one of the muons, produced with evl.fcl

RESOLUTION (MUONS FROM OUTSIDE THE DETECTOR)

- The resolution plots show a resolution degradation probably due to energy loss in ECAL



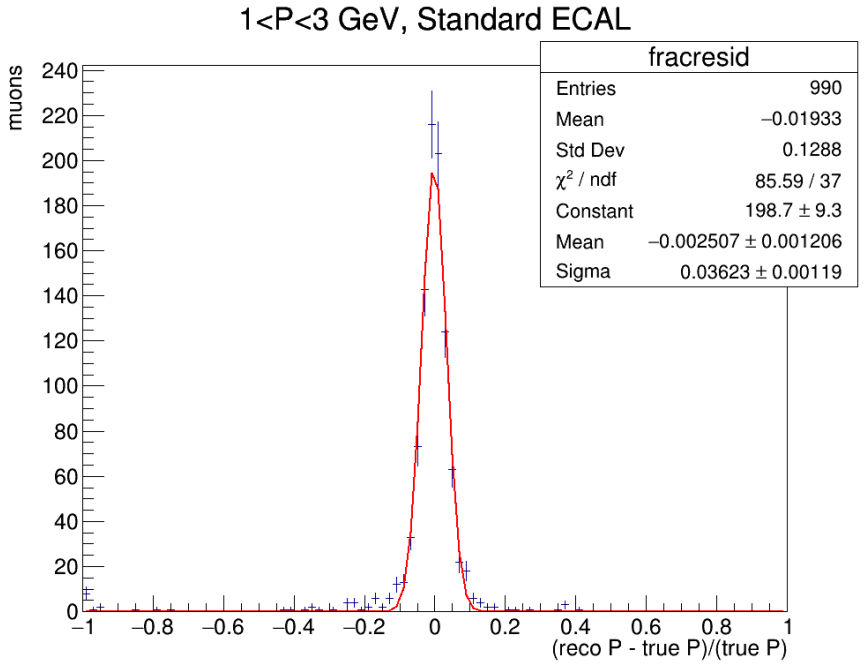
Resolution plot for low momentum $(1 < p < 3)$ GeV/c muon sample generated upstream outside the detector ($z = -500$cm)



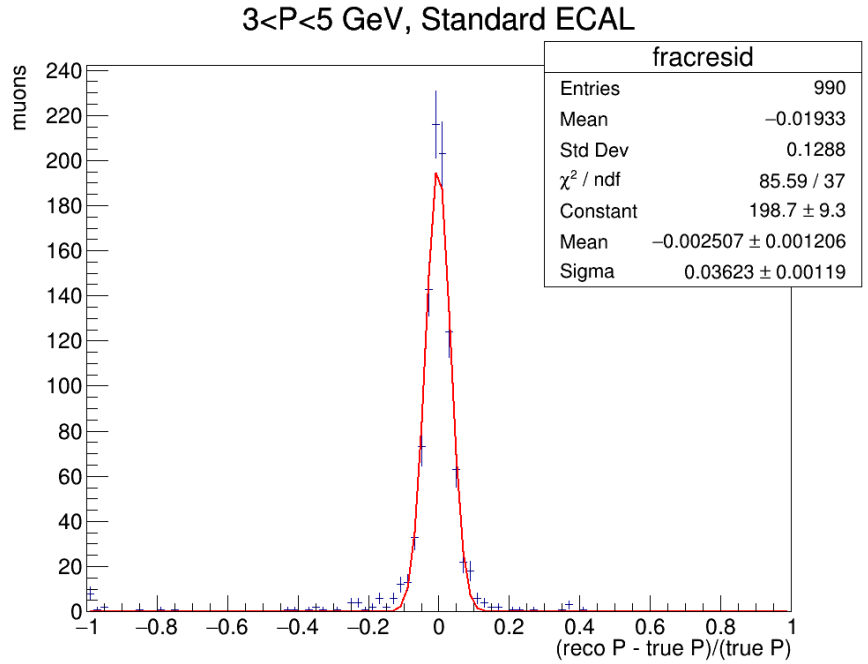
Resolution plot for high momentum $(3 < p < 5)$ GeV/c muon sample generated upstream outside the detector ($z = -500$cm)

RESOLUTION (MUONS FROM INSIDE THE DETECTOR)

- To verify resolution degradation is due to the muon transversing the calorimeter I redid the simulation with a new muon sample generated inside the gas detector



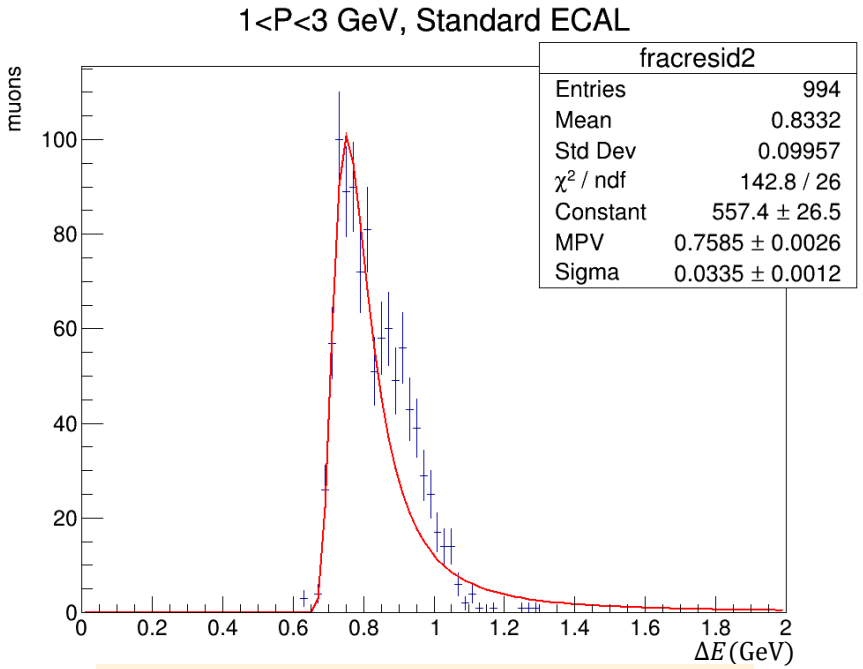
Resolution plot for low momentum $(1 < p < 3)$ GeV/c muon sample generated upstream inside the detector ($z = -190$cm)



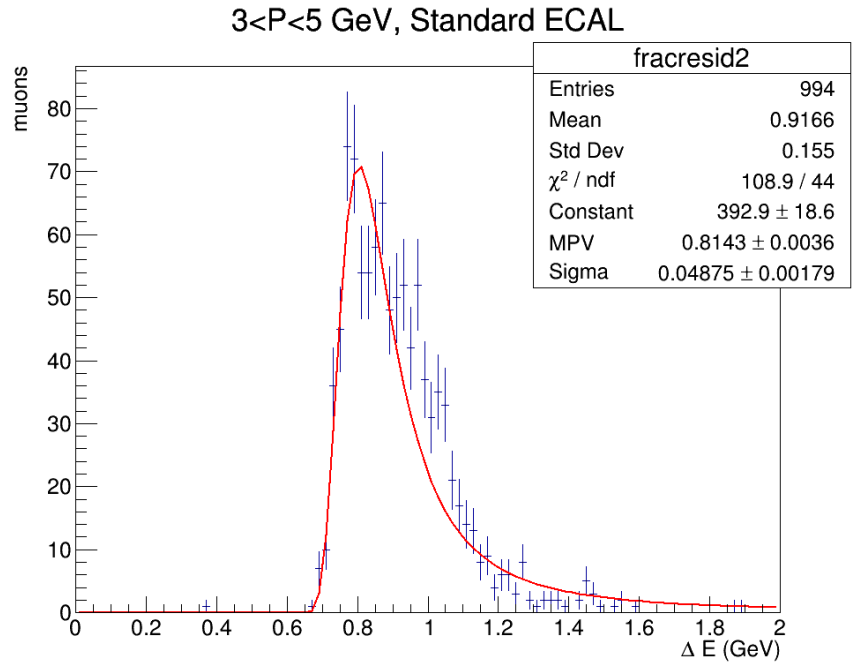
Resolution plot for high momentum $(3 < p < 5)$ GeV/c muon sample generated upstream inside the detector ($z = -190$cm)

ENERGY LOSS PLOTS

- We also did energy loss plots with $\Delta E = E_{fin} - E_{in}$ where E_{fin} and E_{in} are the true energy of the muon at the beginning and end of its track



Energy loss $\Delta E\,(\mathrm{GeV})$ for low momentum $(1 < p < 3)\ \mathrm{GeV}/c$ muon sample generated upstream outside the detector $(z = -500\mathrm{cm})$



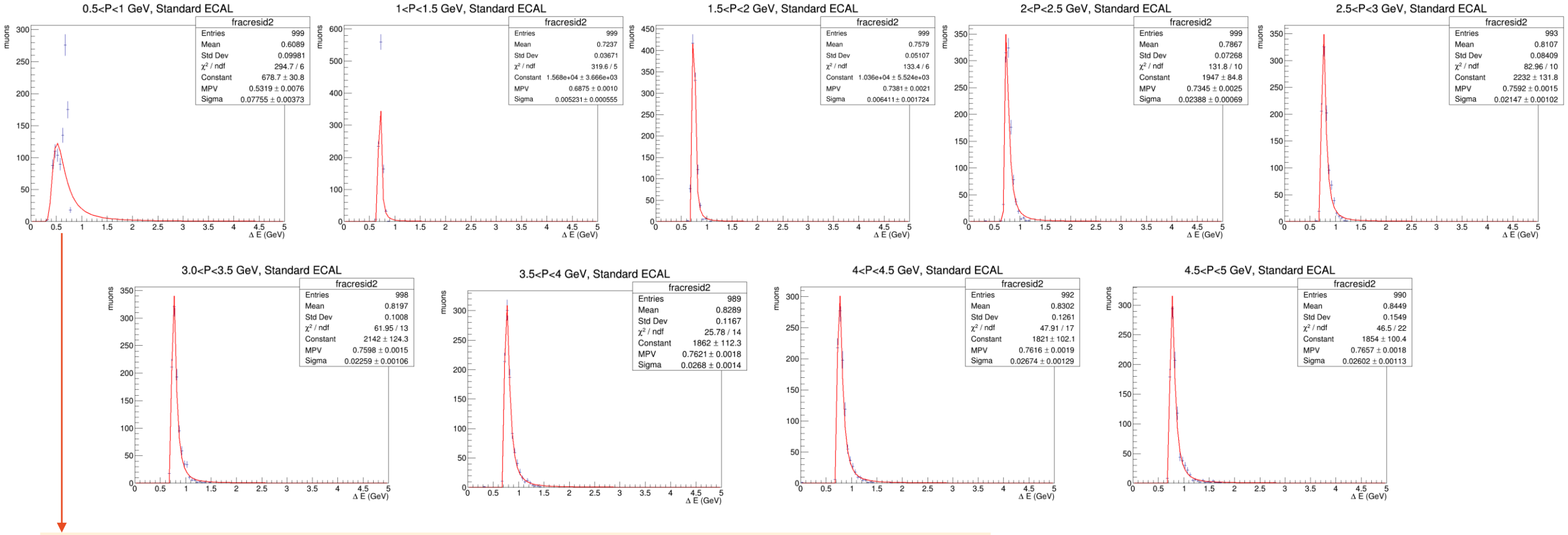
Energy loss $\Delta E\,(\mathrm{GeV})$ for high momentum $(3 < p < 5)\ \mathrm{GeV}/c$ muon sample generated upstream outside the detector $(z = -500\mathrm{cm})$

ENERGY LOSS AS A FUNCTION OF INITIAL MOMENTUM

- We wanted to study the difference in muon energy loss $\Delta E\,(\mathrm{GeV})$ as a function of their initial momenta
- I produced upstream muon samples with initial coordinates $(x, y, z) = (0,0,-500)\mathrm{cm}$, null initial p_x and p_y momentum components and p_z uniformly distributed over multiple 0.5 Gev/c momentum spans.
- Specifically I considered 9 samples in total with p_z ranging from 0.5 GeV/c to 5GeV/c
- Each sample contains a total of 1000 particles

ENERGY LOSS AS A FUNCTION OFINITIAL MOMENTUM

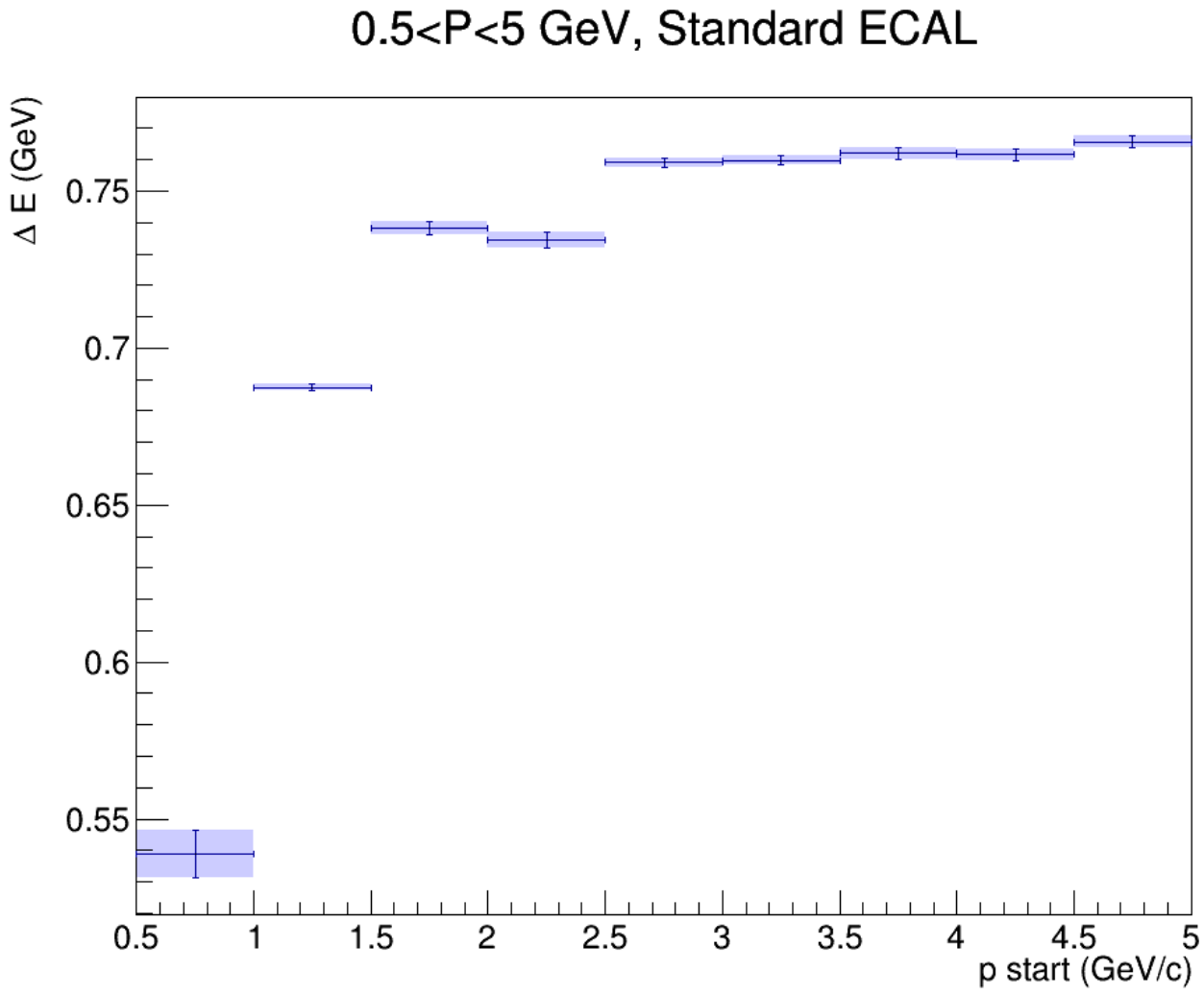
- I then plotted the Energy loss distributions, fitting with a Landau and obtaining the MPV for ΔE(GeV)



Note: The double peak structure in the very low momentum sample ($0<p_z<0.5$) GeV/c might be due to muons whose initial momentum is low enough that they lose all of it and are stopped in the front ECAL

ENERGY LOSS AS A FUNCTION OFINITIAL MOMENTUM

- We then take the MPV for each distribution and plot them them as a function of initial momentum

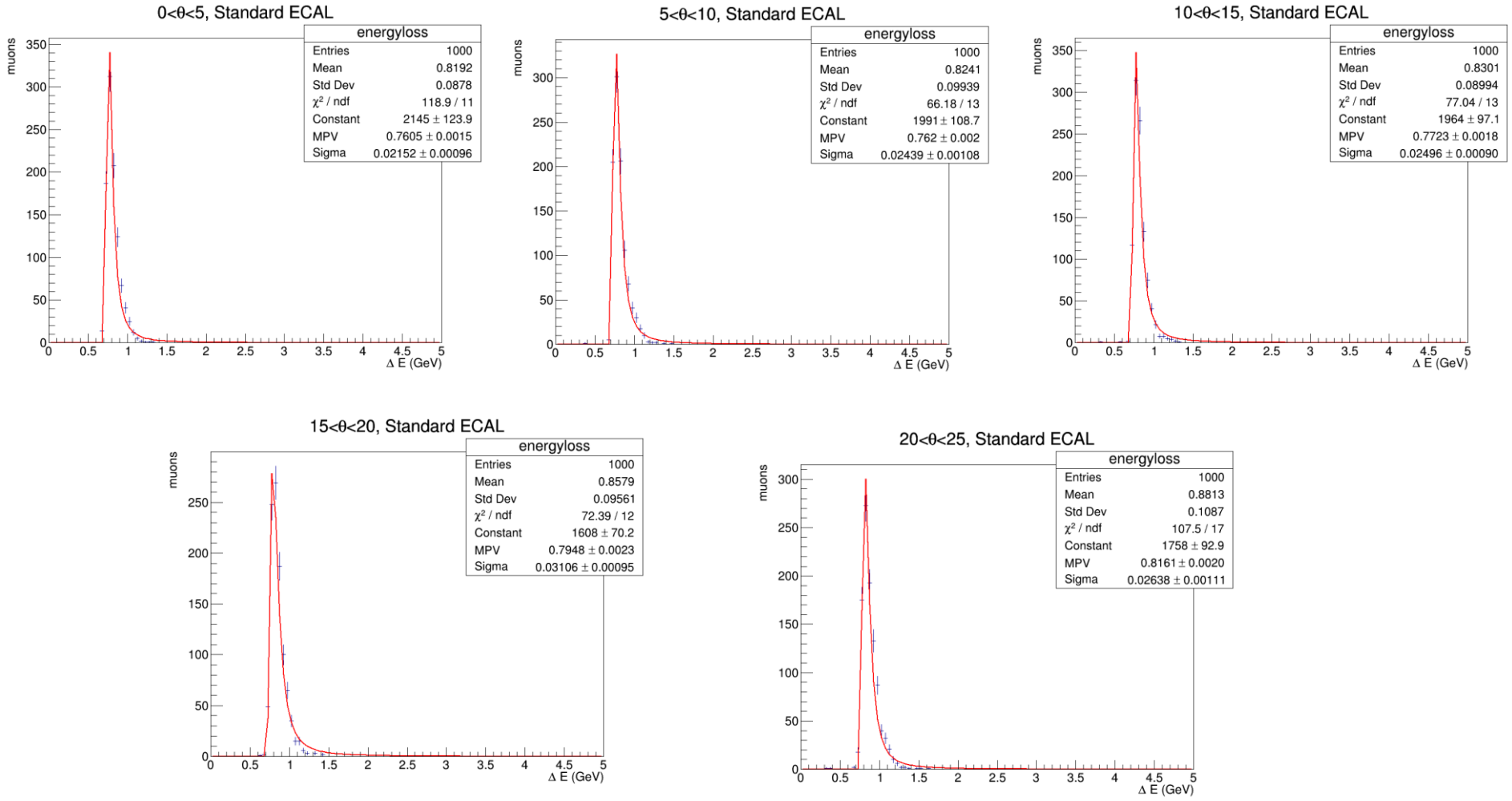


ENERGY LOSS AS A FUNCTION OFINITIAL MOMENTUM

- We then wanted to study the difference in muon energy loss $\Delta E\,(\mathrm{GeV})$ as a function of the amount of transversed ECAL material.
- The most immidiate way to do it was to produce upstream muon samples (z=-500cm), whose initial momentum formed an increasingly larger angle with the z axis.
- Specifically I added a small px component, so that the particles formed angles uniformily distributed in spans of $5°$ from $0°$ to $25°$
- Each sample contained 1000 muons having a total initial momentum of 3 GeV

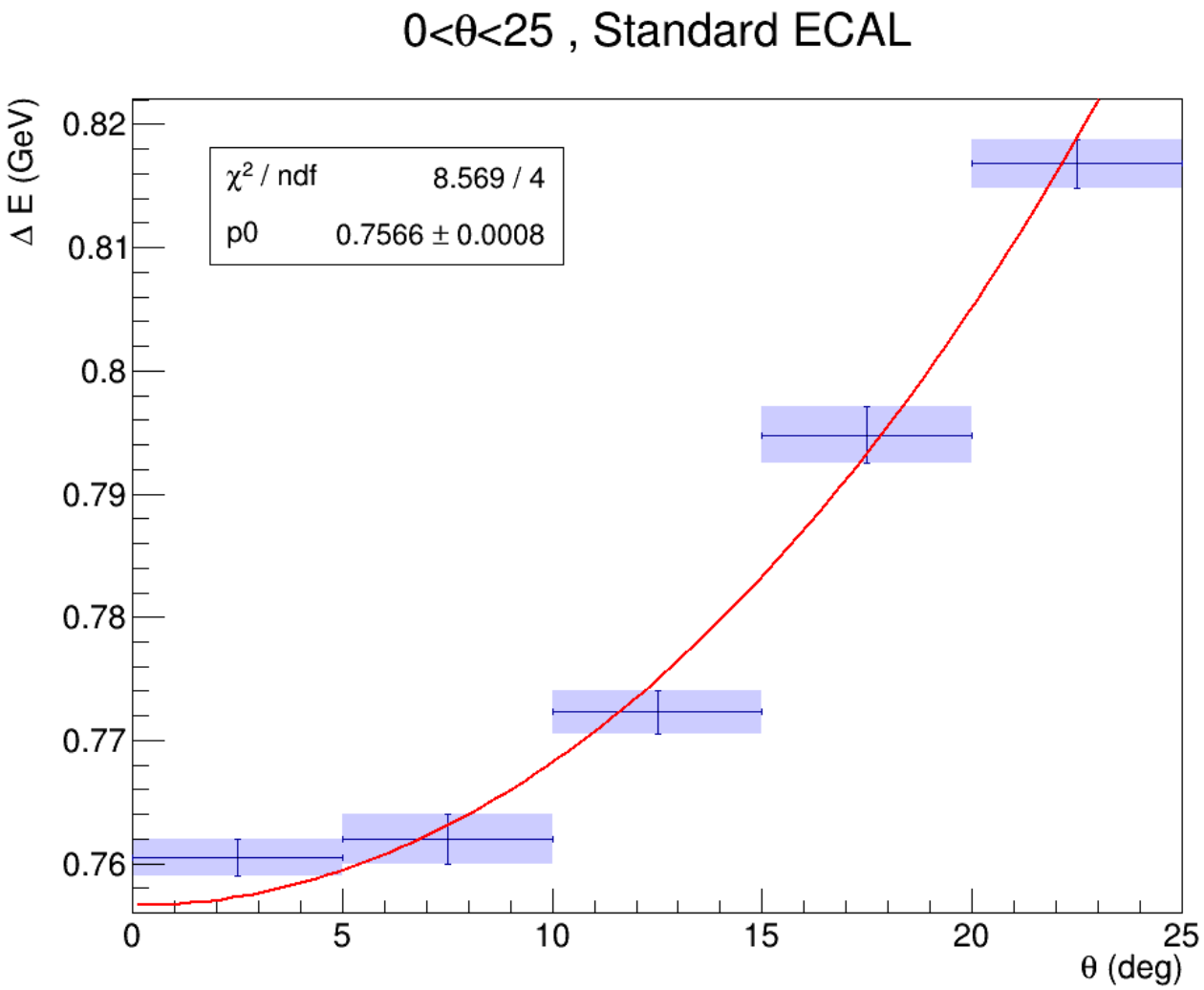
ENERGY LOSS AS A FUNCTION OFINITIAL MOMENTUM

- I then plotted the Energy loss distributions, fitting with a Landau and obtaining the MPV for $\Delta E\,(\mathrm{GeV})$



ENERGY LOSS AS A FUNCTION OFINITIAL MOMENTUM

- We then take the MPV for each distribution and plot them them as a function of initial momentum



Note: given a constant dE/dx we expect ΔE to be a function of the traversed material so that in this case we have $\Delta E = f(\theta) = \frac{dE}{dx}\left(\frac{\Delta x}{\cos\theta}\right)$ where Δx is the ECAL's thickness and $\Delta x/\cos\theta$ is the amount of material traversed by the particle . The red line in the graph is the best fit for $f(\theta)$ where $p_0 = \frac{dE}{dx} \times \Delta x$.

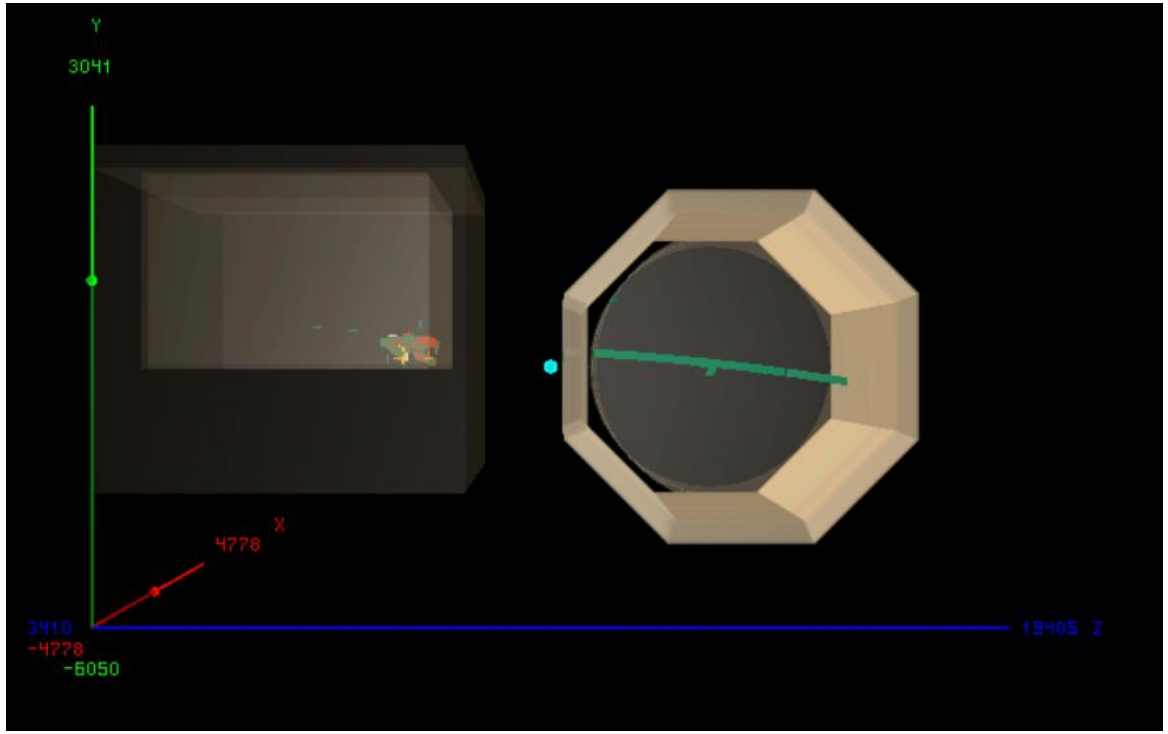
NEXT STEP IN THE SIMULATION

- The next step in the simulation is to produce a sample of muons generated in $\nu_\mu(CC)$ interactions in ArgonCube that have a trajectory such as they enter HPgTPC with a genuine Montecarlo simulation (i.e. not from randomly generated text files)

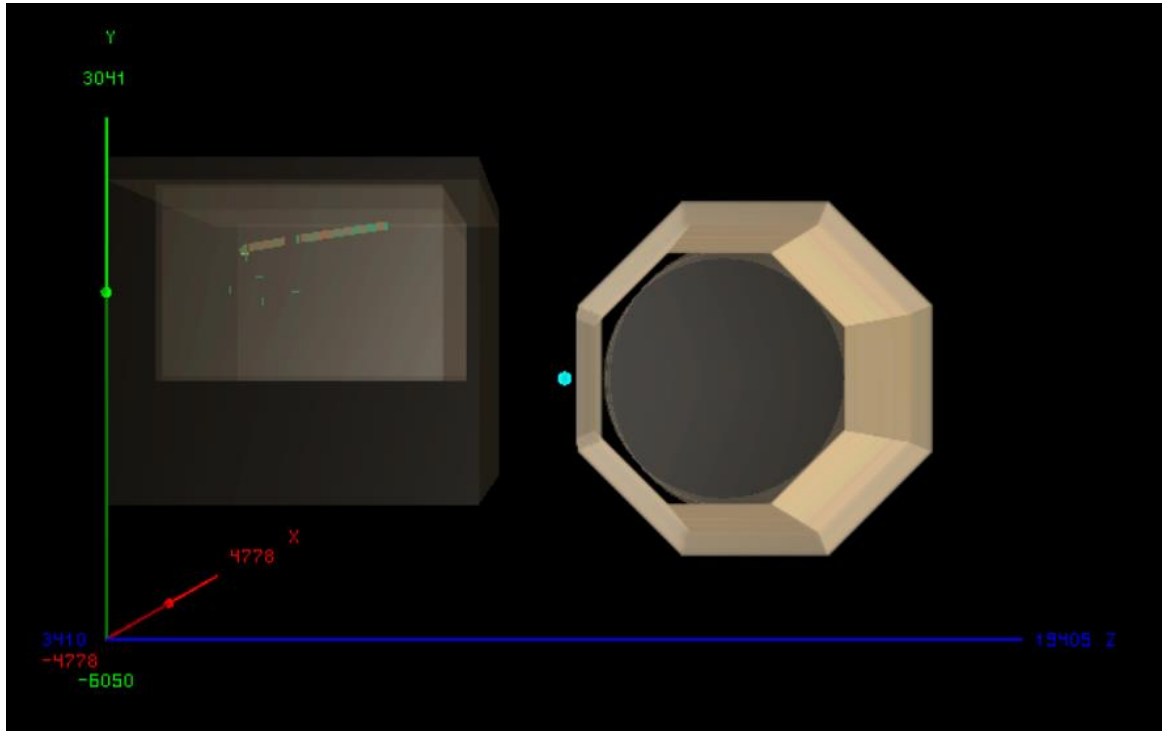
- ND simulation chain:
  1. Simulate neutrino interactions with GENIE in a ND hall geometry file containing only the liquid Argon detector
  2. Propagate particles using edep-sim in a ND hall geometry file containing both ArgonCube and HPgTPC
  3. Convert edep-sim file to root file readable by GarSoft
  4. Follow the Garsoft reconstruction chain

EDEP-DISPLAY EXAMPLES

- So far I was able to produce the sample, propagate with edep-sim and convert to GarSoft-readable format
- Here are two graphical representations of $\nu_\mu(CC)$ interactions in ArgonCube made with edep-sim event display. In one the muon enters the gas TPC, in the other it does not



PASSING MUON



NON-PASSING MUON

PROBLEMS WITH GARSOFT SIMULATION LINE

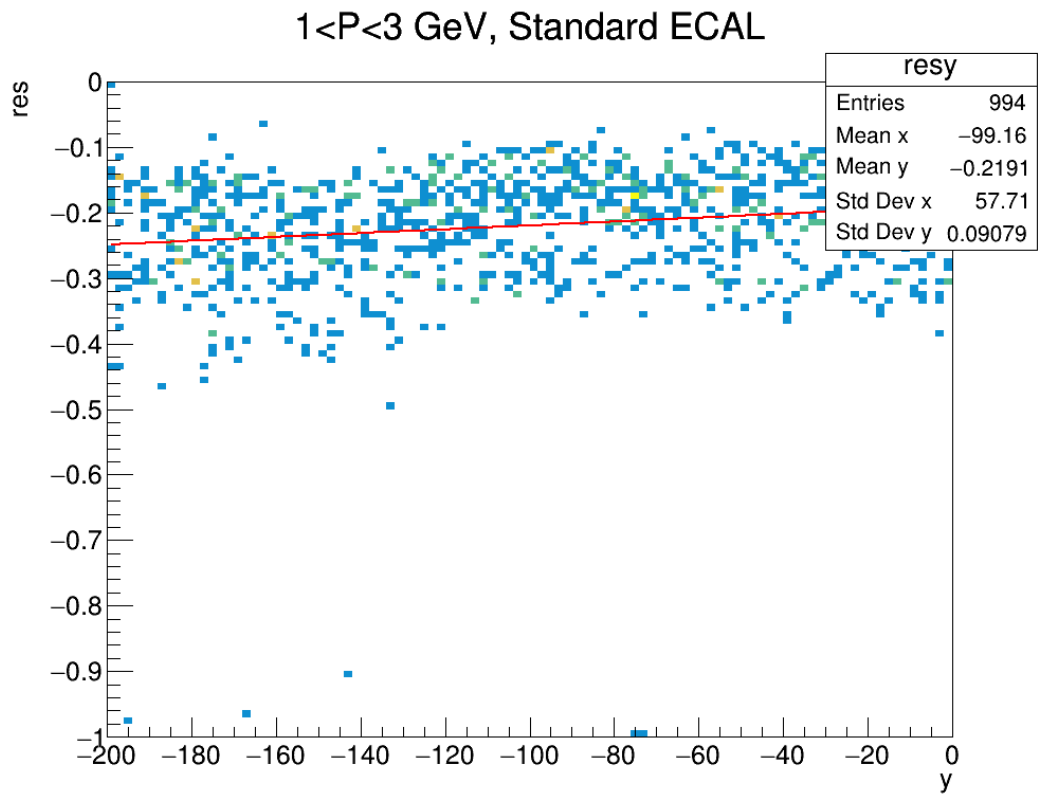
- After the edep-sim to GarSoft conversion (which exited with art status 0) I tried to follow the Garsoft simulation chain and to input the resulting file in a read-out simulation job: art -c readoutsimjob.fcl my_edepsim_converted_out.root
- Unfortunately, I get the following error as if there were a file format missmatch:

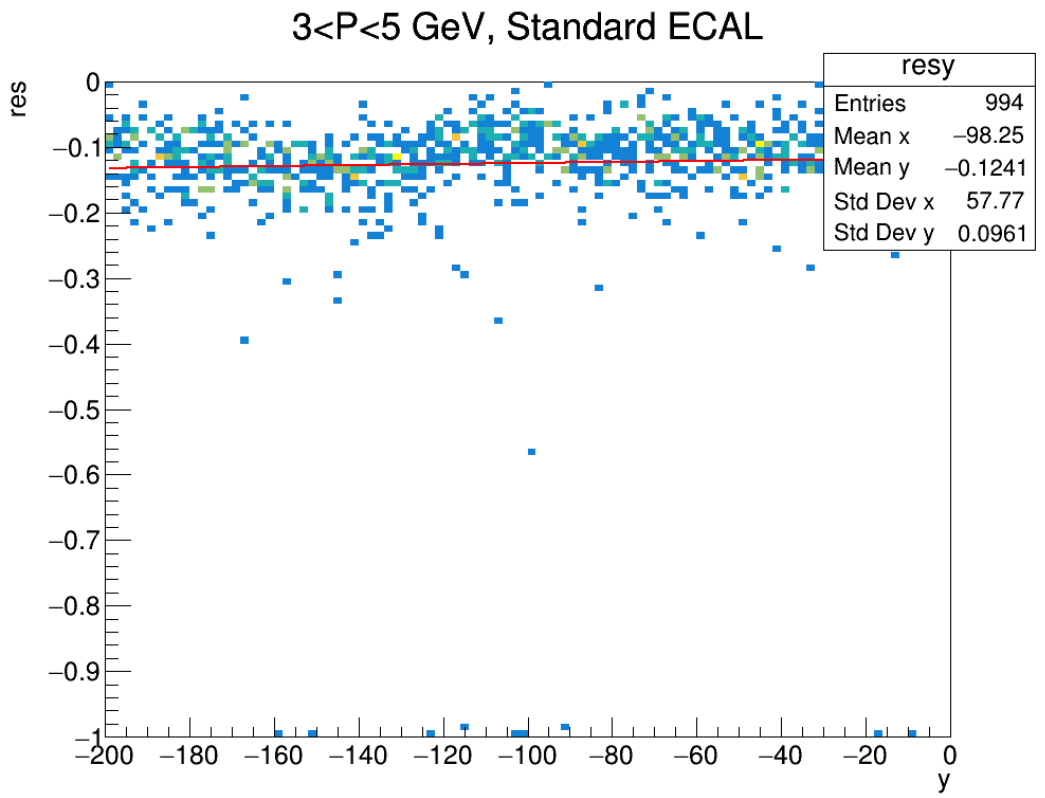
```
%MSG-s ArtException:  PostEndJob 17-Sep-2020 09:41:15 CDT ModuleEndJob
---- EventProcessorFailure BEGIN
  EventProcessor: an exception occurred during current event processing
  ---- ScheduleExecutionFailure BEGIN
    Path: ProcessingStopped.
    ---- ProductNotFound BEGIN
      getBySelector: Found zero products matching all criteria
      Looking for type: std::vector<gar::sdp::EnergyDeposit>
      The above exception was thrown while processing module IonizationReadout/daq run: 1 subRun: 0 event: 1
    ---- ProductNotFound END
    Exception going through path simulate
  ---- ScheduleExecutionFailure END
---- EventProcessorFailure END
---- FatalRootError BEGIN
  Fatal Root Error: TTree::SetEntries
  Tree branches have different numbers of entries, eg gar::raw::CaloRawDigitgar::sdp::CaloDepositvoidart::Assns_daqecal__DetReadout. has 0 entries whi
le EventAuxiliary has 100 entries.
  ROOT severity: 2000
---- FatalRootError END
%MSG
Art has completed and will exit with status 1.
```

EXTRA SLIDES

RESOLUTION AS A FUNCTION OF Y

- Plots of resolution as a function of the initial y (vertical) position of the muon (random upstream samples outside the detector -200 cm < y < 0 cm)





ENERGY LOSS AS A FUNCTION OF Y

- Plots of energy loss ΔE (GeV) as a function of the initial y (vertical) position of the muon (random upstream samples outside the detector -200 cm < y < 0 cm)