PLANS FOR IMPROVING HPGTPC TRACKING:
REVISITING LAR-TO-GAR MUON MOMENTUM RECONSTRUCTION

UNIVERSITY OF OXFORD

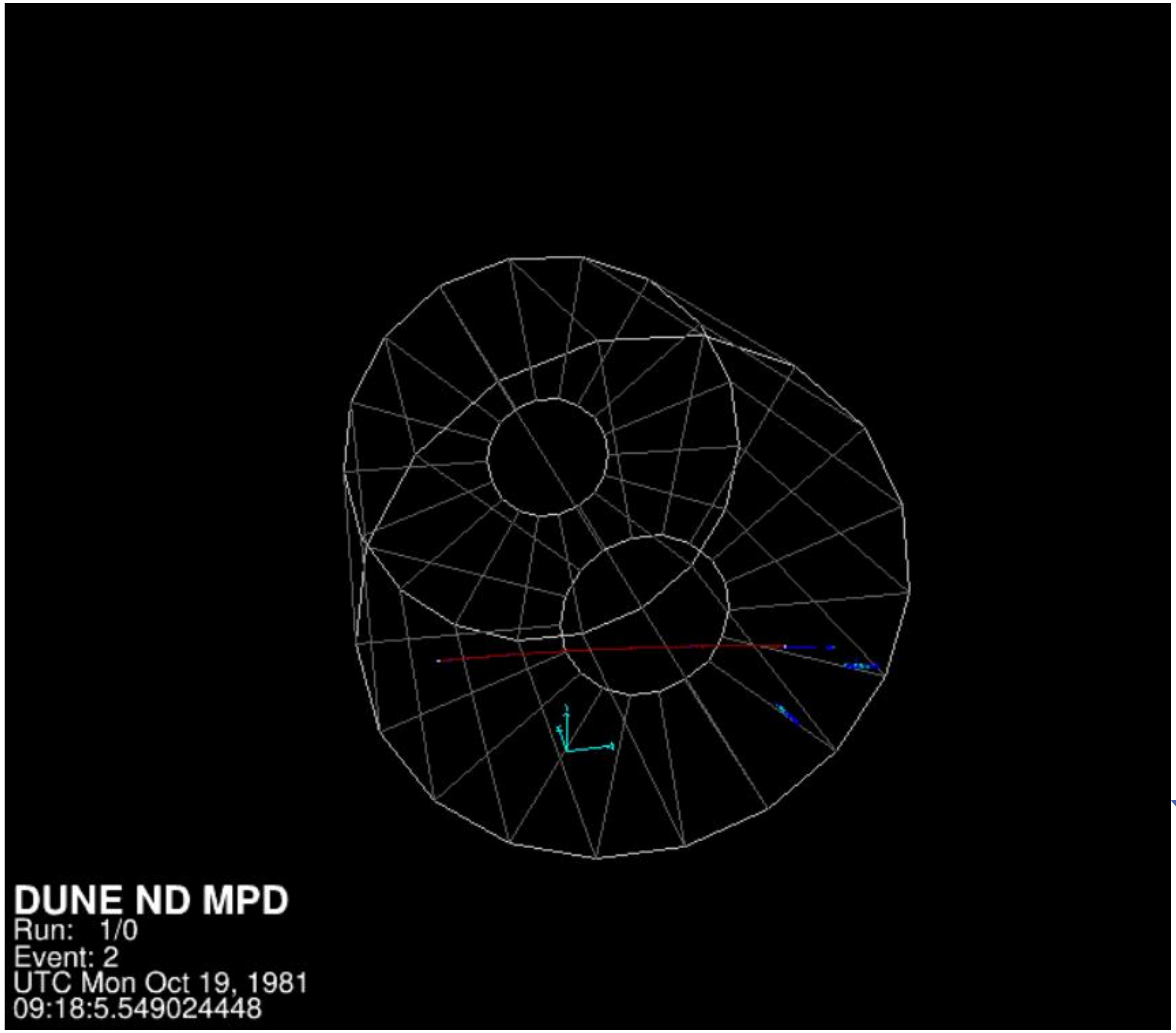
Presents:
Federico Battisti

IMMIDIATE AND FUTURE GOALS

- The ND-GAr tracking capabilities need to be carefully studied and benchmarked
- Specifically the momentum reconstruction algorithms, involving Kalman filter, need to be evaluated in their efficacy and potentially improved
    - Tracking in ND GAr will have to take into account dEdx , multiple scattering and field inhomogeneity in high pressure gasses if performances at the levels of ALICE or better want to be achieved
- An important role of ND-GAr will be to function as a muon spectrometer of ND-LAr: to evaluate its capabilities in that sense the LAr $\rightarrow$ GAr propagation of tracks needs to be understood

- Easiest sample to study consists of muons produced in $\nu_\mu(CC)$ interactions in the ArgonCube that reach the Gas Argon TPC
    - Learn how these samples are produced by the experts and be able to reproduce them

THE SIMULATION EXERCISE

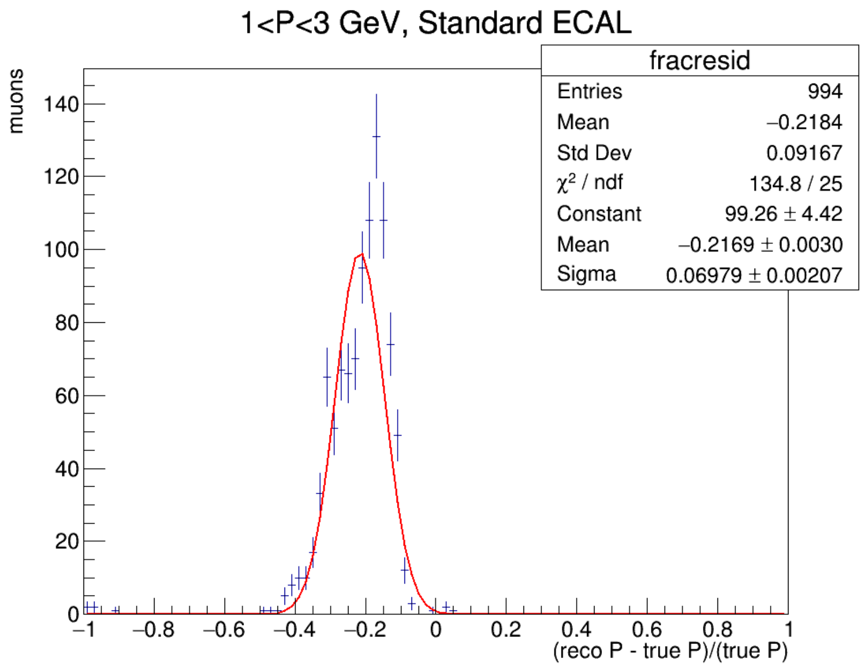


- Started working on previously existing Garsoft simulation to familiarise with the software:
  1. Produce low energy (1GeV<p<3GeV) and high energy (3GeV<p<5GeV) upstream muon samples from a randomly generated text file, all muons starting outside the Gas Argon detector at $z = -500$cm , and having x 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: $(p_{reco} - p_{true})/p_{true}$

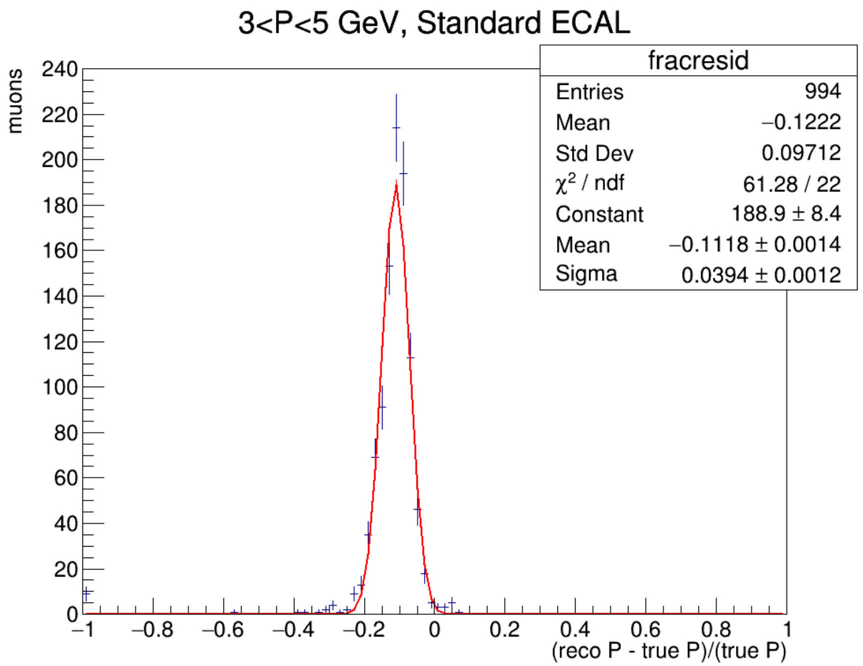
Graphical representation of one of the muons, produced with evl.fcl

RESOLUTION (MUONS FROM OUTSIDE THE DETECTOR)

- The resolution plots show a degradation probably due to energy loss in ECAL: the momentum reconstruction bias needs to be corrected



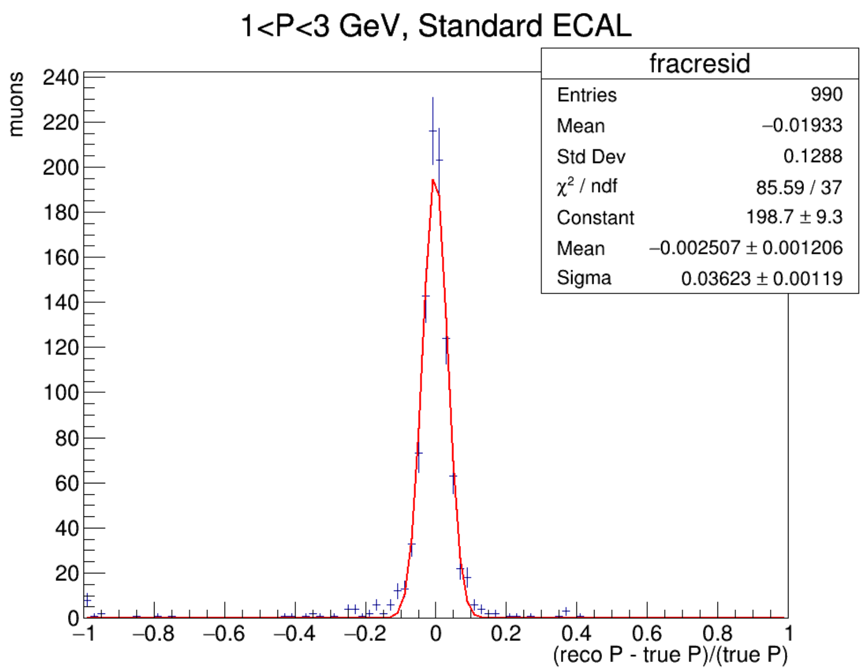
Resolution plot for low momentum $(1 < p < 3)$ GeV$/c$ muon sample generated upstream outside the detector ($z = -500$cm)



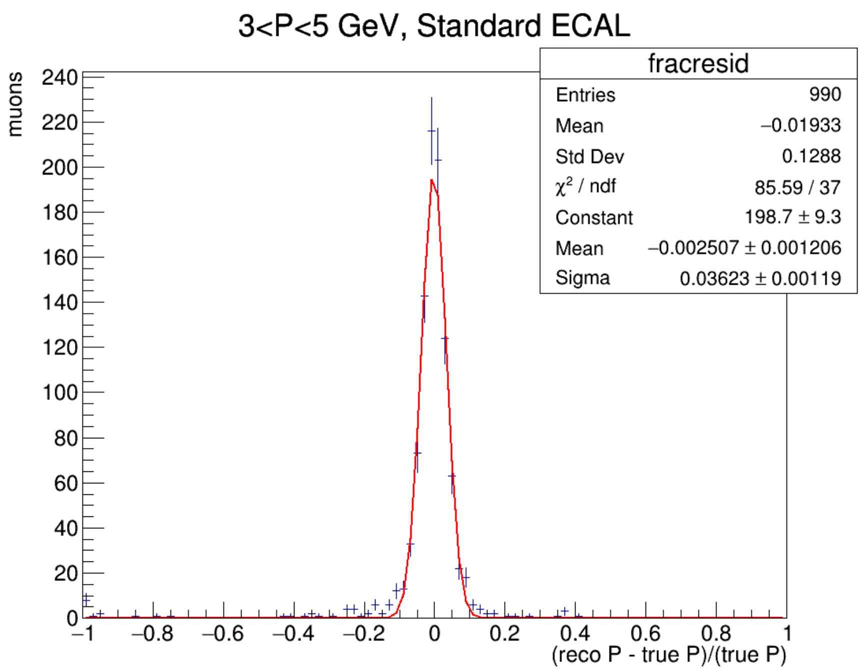
Resolution plot for high momentum $(3 < p < 5)$ GeV$/c$ muon sample generated upstream outside the detector ($z = -500$cm)

RESOLUTION (MUONS FROM INSIDE THE DETECTOR)

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



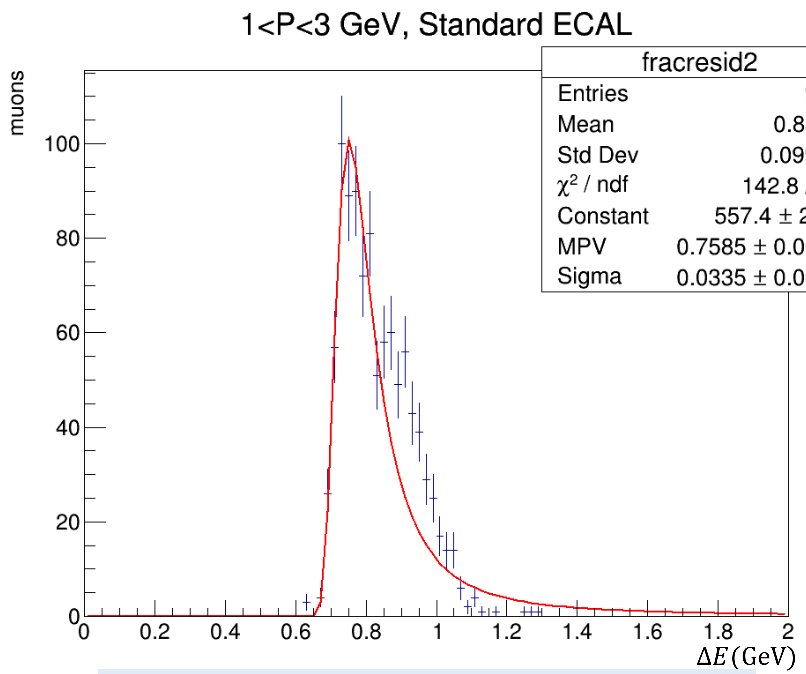
Resolution plot for low momentum $(1 < p < 3)$ GeV/c muon sample generated upstream inside the detector $(z = -190\text{cm})$



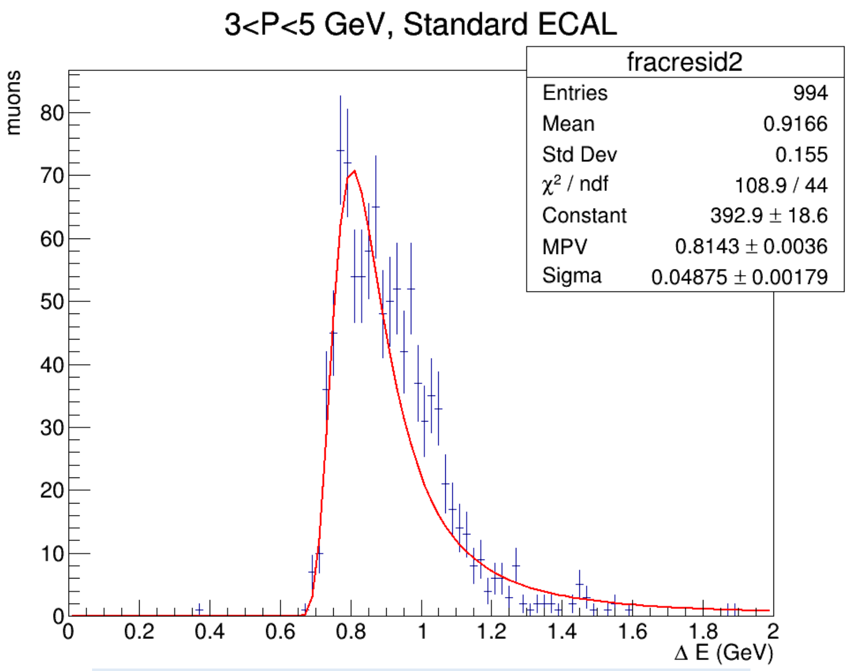
Resolution plot for high momentum $(3 < p < 5)$ GeV/c muon sample generated upstream inside the detector $(z = -190\text{cm})$

ENERGY LOSS PLOTS

- Energy loss $\Delta E = E_{start} - E_{end}$ (E_{start} and E_{end} are muon true energy at the end and start of its trajectory) is a better parameter to understand the momentum reconstruction bias



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



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

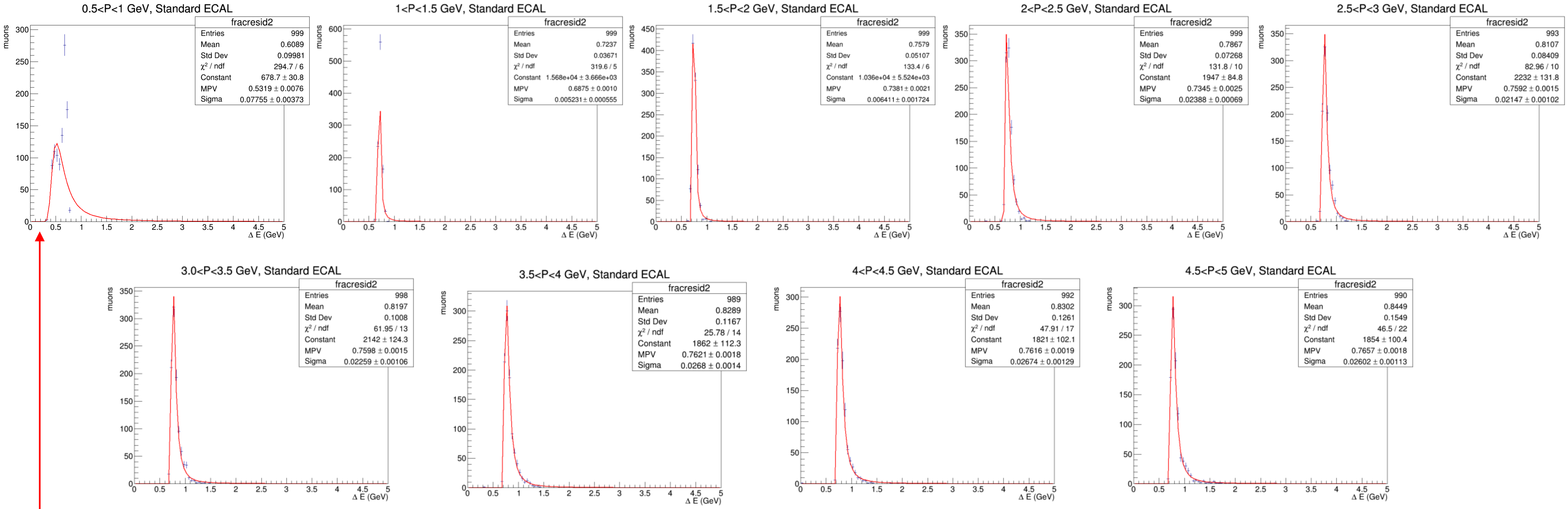
Note: the muons start upstream of the ECAL material and they pass through the entire detector (i.e. they go through the ECAL two times). The muon trajectory ends when it reaches the edge of the geometry world at $z = 20000$cm

ENERGY LOSS AS A FUNCTION OF INITIAL MOMENTUM

- Previous integrated energy loss is not accurate enough, many effects are convoluted
- We want to study the difference in muon energy loss ΔE(GeV) as a function of their initial momenta
- Muon samples considered: initial coordinates $(x, y, z) = (0,0,-500)$cm, null initial p_x and p_y momentum components and p_z uniformly distributed over multiple 0.5 Gev/c momentum spans.
- Simulated 9 samples in total (1000 muons each) with p_z ranging from 0.5 GeV/c to 5 GeV/c

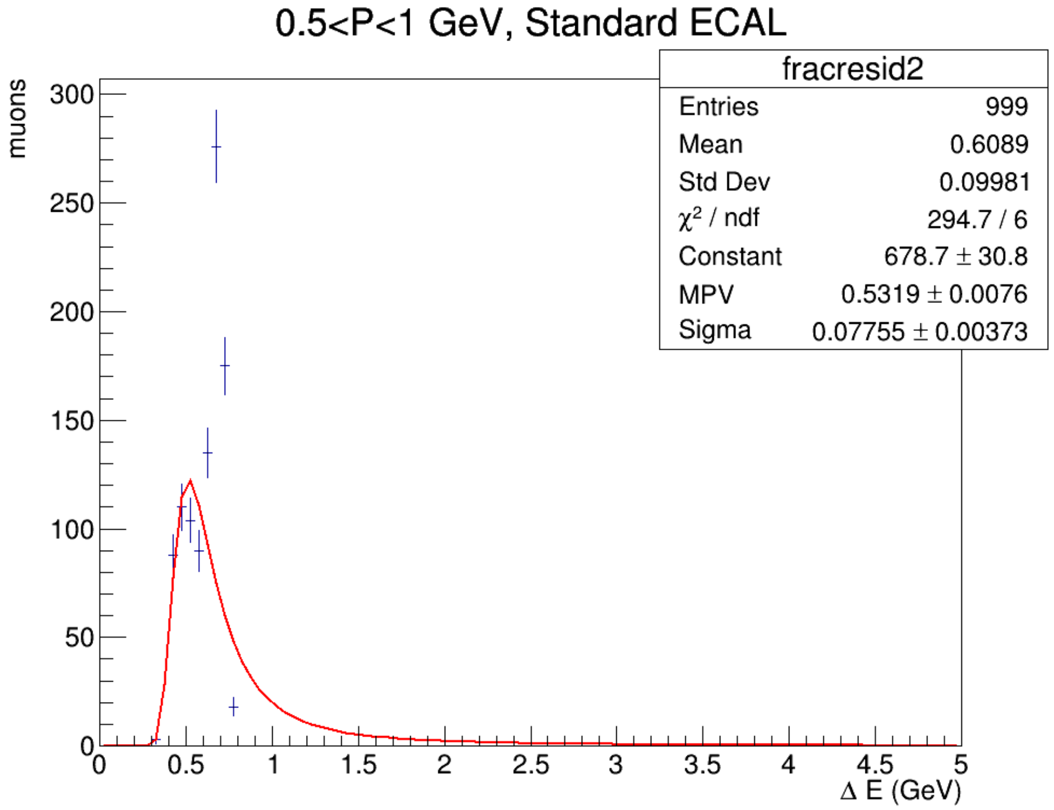
ENERGY LOSS AS A FUNCTION OF INITIAL MOMENTUM

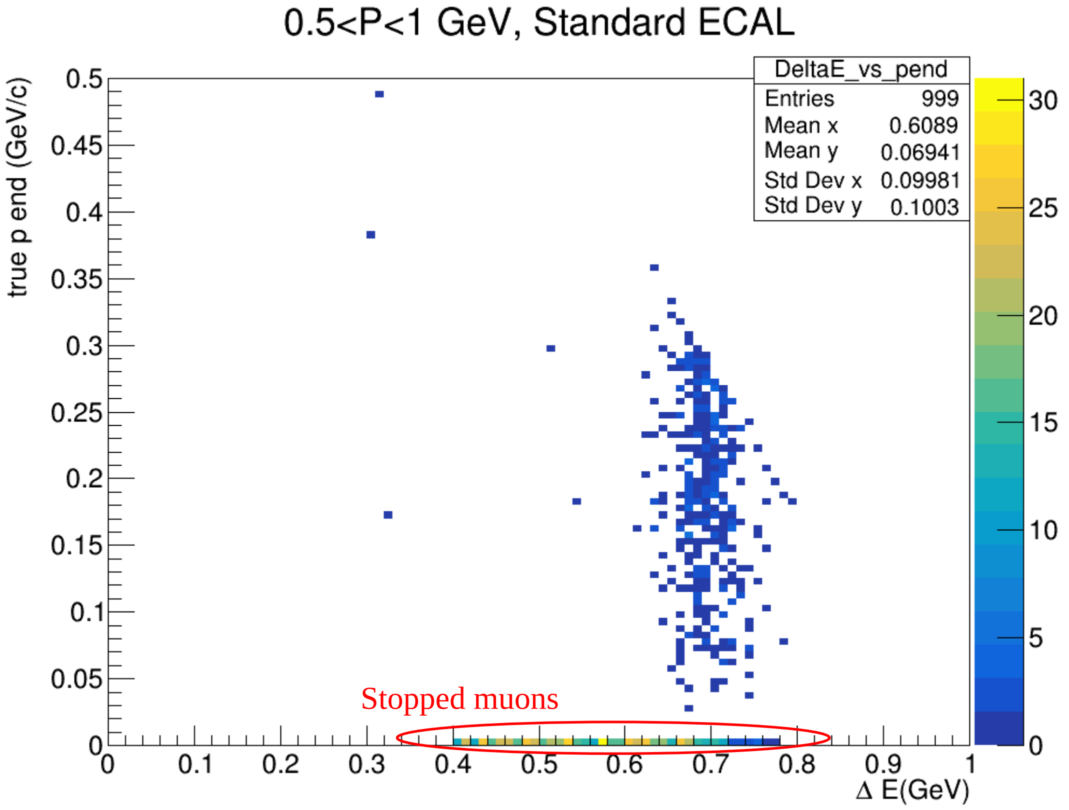
- I then plotted the Energy loss distributions, fitting with a Landau and obtaining the MPV for $\Delta E\,(\mathrm{GeV})$



Note anomalous double peak feature in very low momentum sample $(0.5 < p < 1)\mathrm{GeV}/c$

VERY LOW MOMENTUM SAMPLE

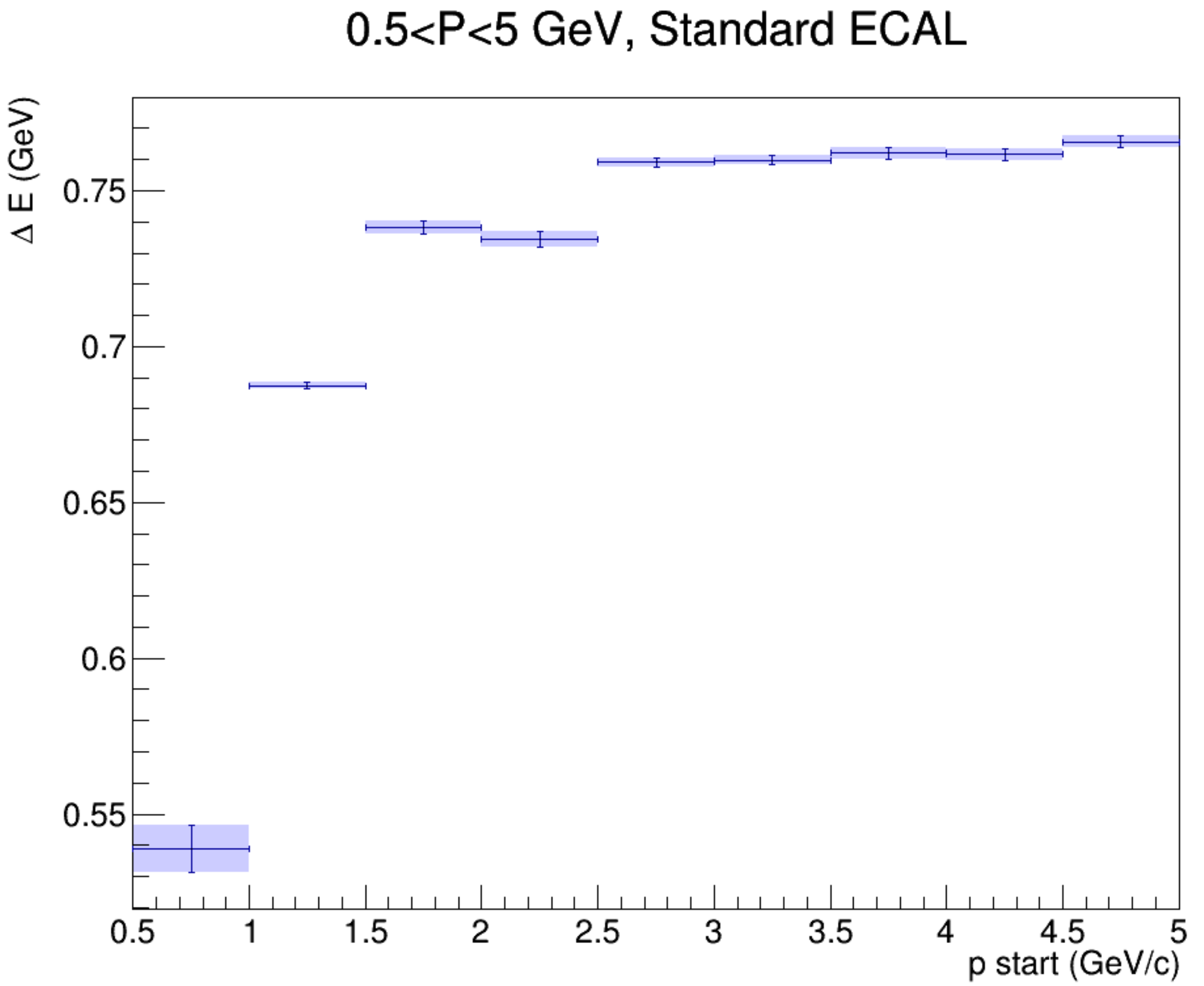




- A double peak structure can be noticed in the very low momentum sample $(0 < p_z < 0.5)$ GeV/c
- Most muons in the sample traverse the barrel ECAL, are bent by the magnetic field and re-enter the barrel calorimeter.
- Overall muons that traverse the ECAL two times are expected to lose about $\Delta E \simeq 0.7$ GeV
- The lower peak probably consists of particles that have an initial energy lower than 0.7 GeV and that are expected to be stopped in the ECAL $(p_{end} = 0\text{GeV}/c)$ the second time they pass through it

ENERGY LOSS AS A FUNCTION OF INITIAL MOMENTUM

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

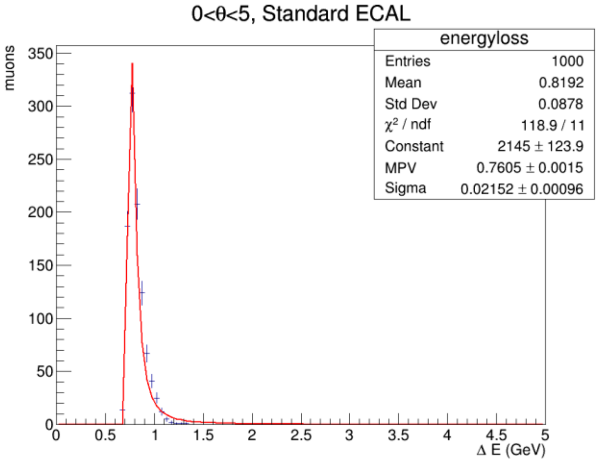


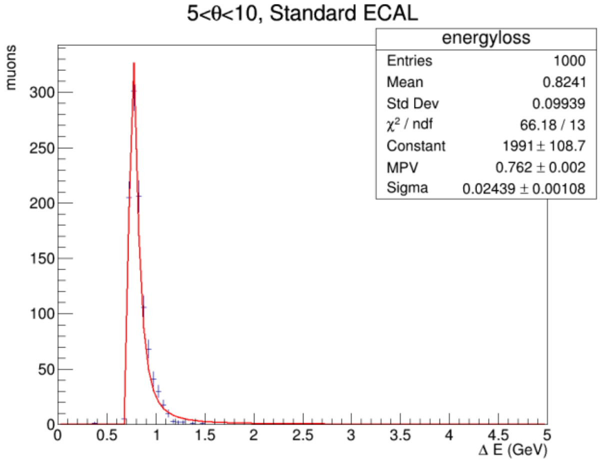
ENERGY LOSS AS A FUNCTION OF TRAVERSED MATERIAL

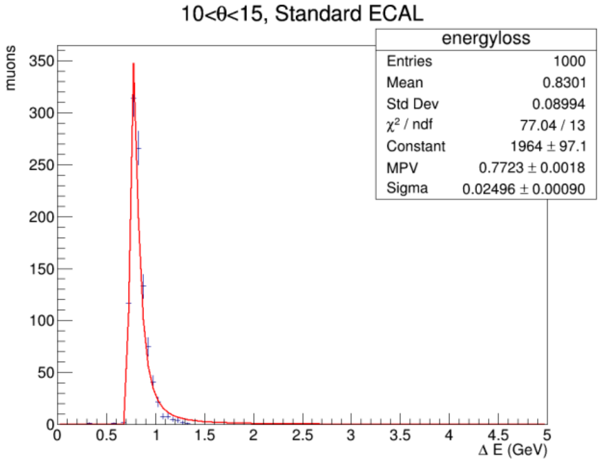
- We then wanted to study the difference in muon energy loss $\Delta E\,(\mathrm{GeV})$ as a function of the amount of traversed ECAL material.
- The most immidiate way to do it was to produce upstream muon samples (z=-500cm), whose initial momentum formed an increasingly larger angle with the z axis.
- 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

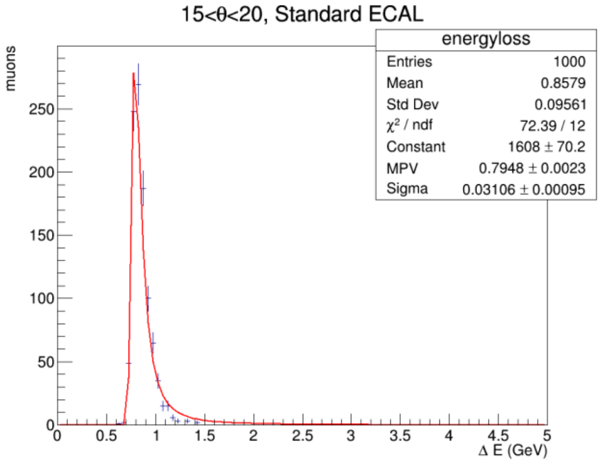
ENERGY LOSS AS A FUNCTION OF TRAVERSED MATERIAL

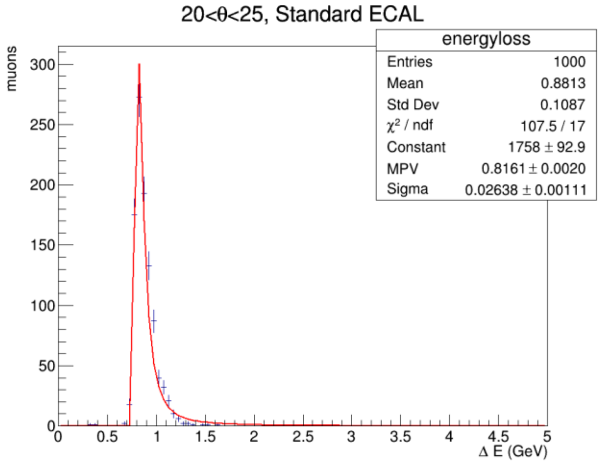
- I then plotted the Energy loss distributions, fitting with a Landau and obtaining the MPV for $\Delta E\,(\mathrm{GeV})$





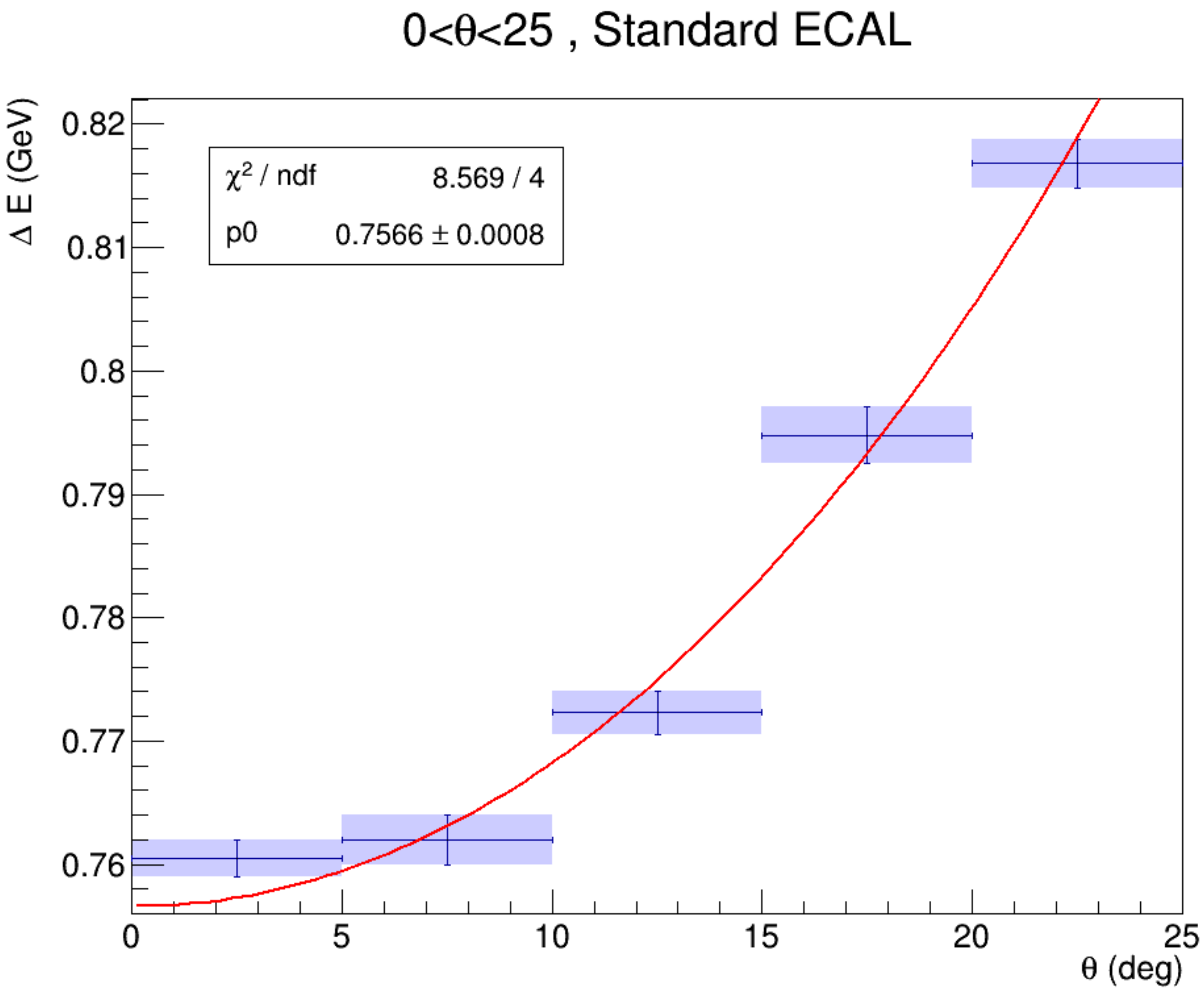






ENERGY LOSS AS A FUNCTION OF TRAVERSED MATERIAL

- 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 $\Delta E = f(\theta) = \frac{dE}{dx}\left(\frac{\Delta x}{\cos\theta}\right) = \frac{p_0}{\cos\theta}$ 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 $f(\theta)$

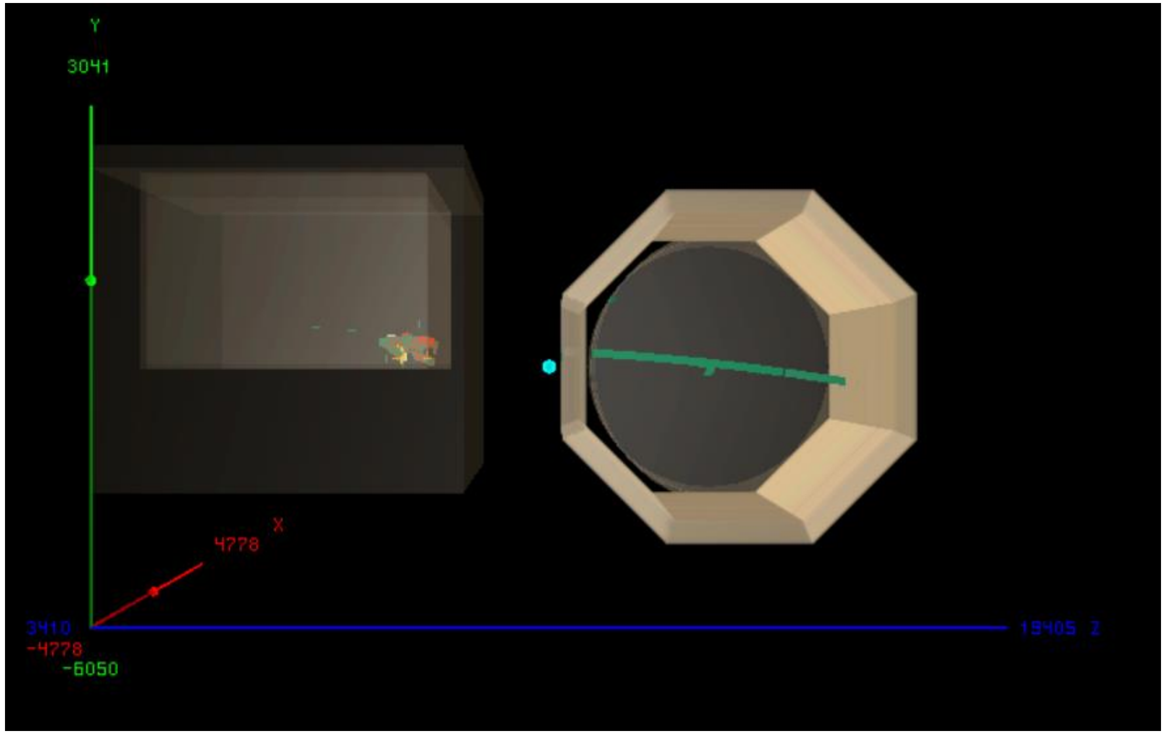
NEXT STEP IN THE SIMULATION

- 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)

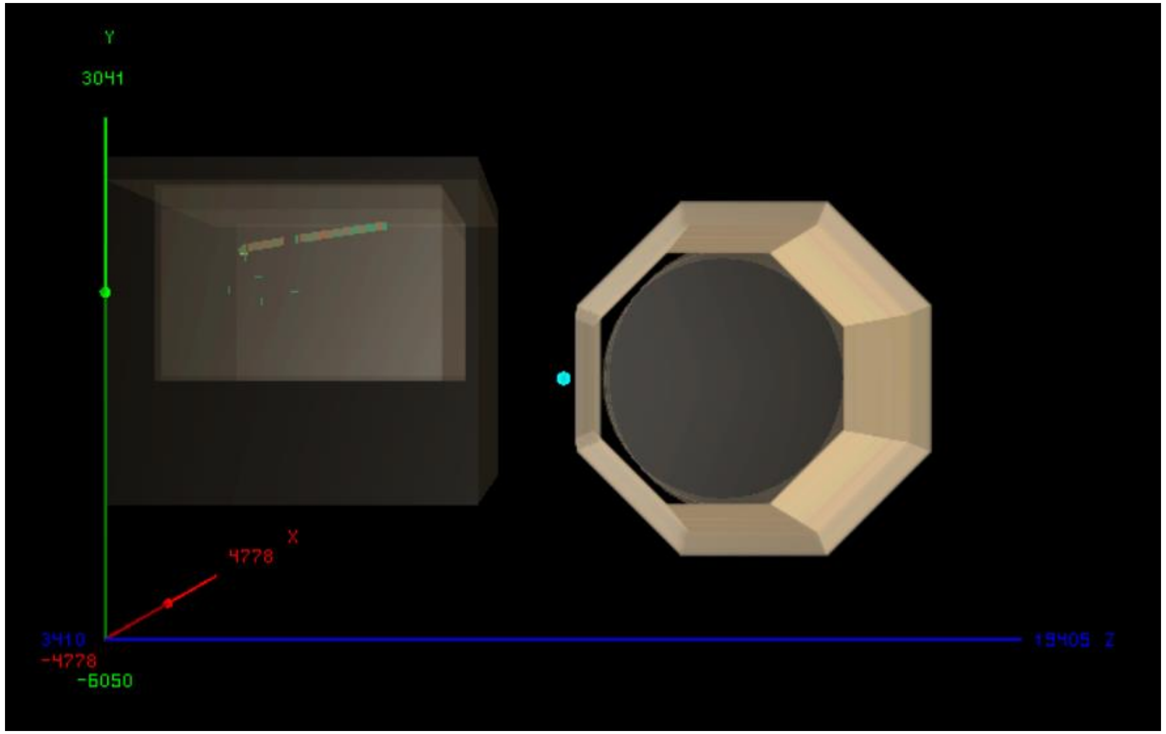
- ND simulation chain:
  1. Simulate neutrino interactions with GENIE in a ND hall geometry file containing only the liquid Argon detector
  2. Propagate particles using edep-sim in a ND hall geometry file containing both ArgonCube and HPgTPC
  3. Convert edep-sim file to root file readable by GarSoft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

SUMMARY

- Drew momentum resolution and energy loss plots for two Garsoft samples: one with upstream muons starting outside the Gas TPC, and one inside
  - Identified a bias in momentum reconstruction due to energy loss in ECAL
- Repurposed the original simulation code to study energy loss dependency on the muon initial momentum and angle with respect to the z axis
  - Detailed dependence of the energy loss on track parameters can be tabled in the tracking code to correct the reconstruction bias
- Started simulation chain to generate samples of muons from $\nu_\mu(CC)$ interactions in ND Lar that reach ND GAr

NEXT STEPS

- Revisiting current Kalman filter with focus on point-by-point propagation of track parameters to help improve LAr $\rightarrow$ GAr global tracking
- Integrate LAr + GAr simulation with modularized interface

Thanks for your attention

Many thanks to Thomas Junk, Tanaz Mohayai, Eldwan E. Brianne, Leo Bellantoni and everyone else for their guidance and support

EXTRA SLIDES

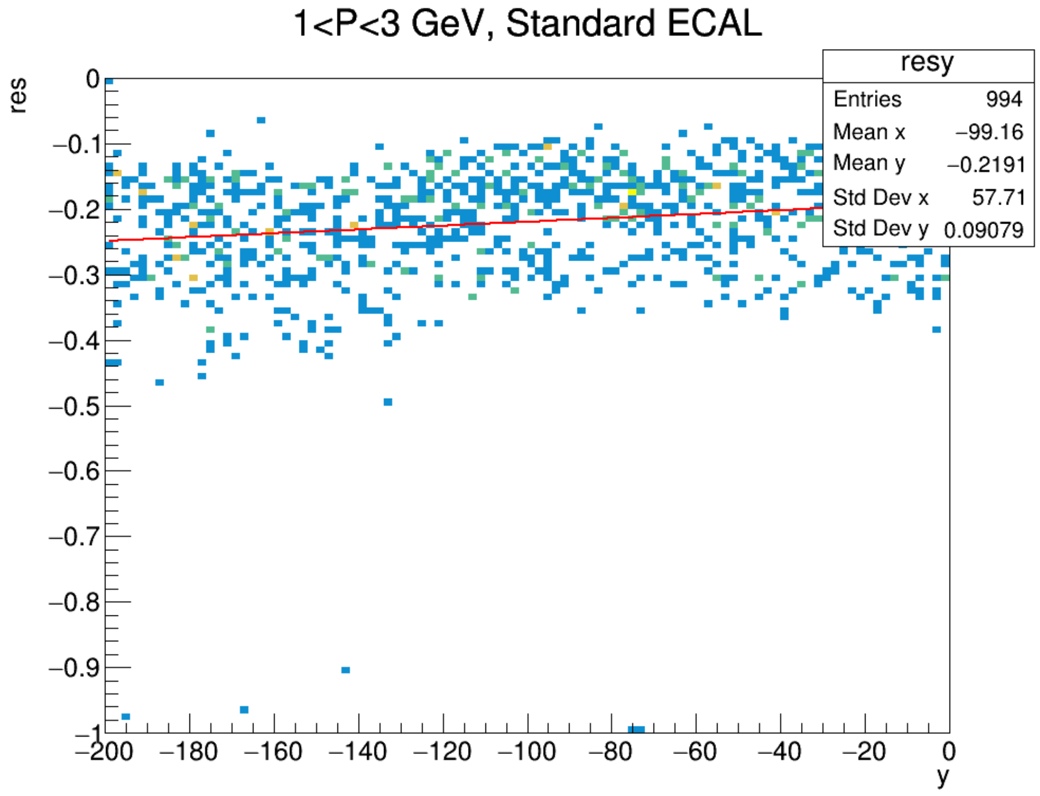
PROBLEMS WITH GARSOFT SIMULATION LINE

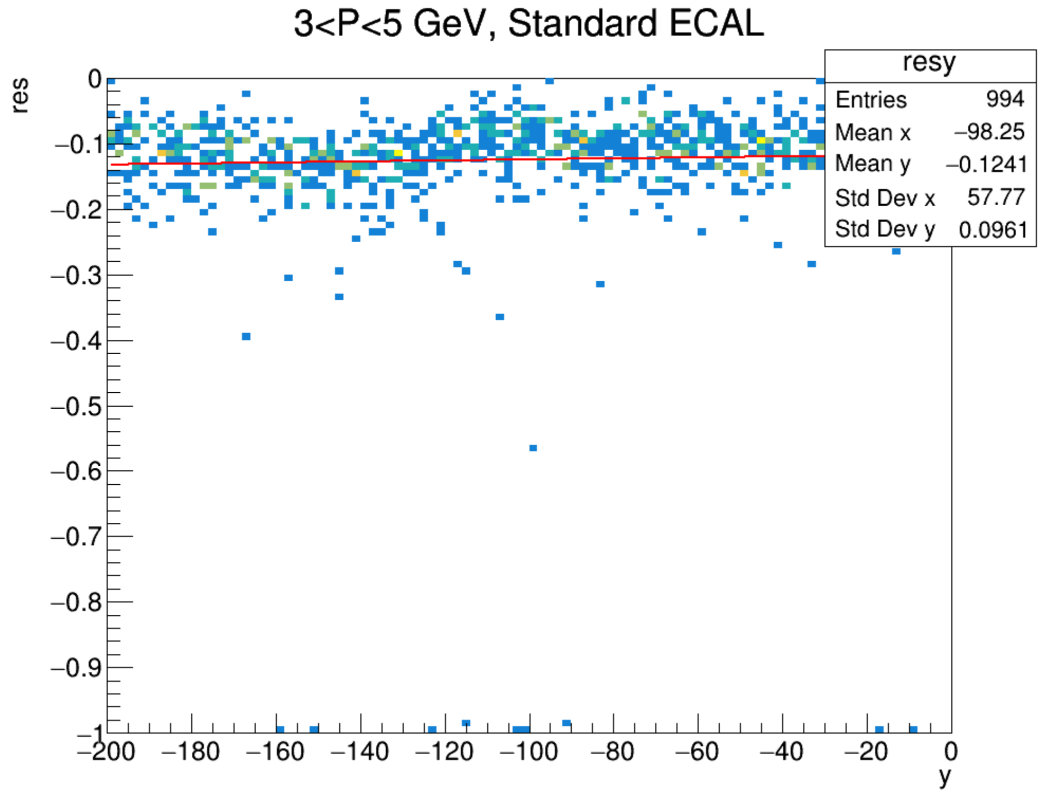
- After the edep-sim to GarSoft conversion (which exited with art status 0) I tried to follow the Garsoft simulation chain and to input the resulting file in a read-out simulation job: art -c readoutsimjob.fcl my_edepsim_converted_out.root
- Unfortunately, I get the following error as if there were a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

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)