8/5/25

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ILLINOIS

Muons in nHCAL

Purpose: To study muons in nHCal, muon efficiency, understand the geometry of the nHCal and how the simulation interacts with it, distinguishing from charged pions and electrons (See talk given at the EIC user group meeting
here: https://indico.jlab.org/event/934/contributions/17248/attachments/13174/21221/250716_MuIDCapabilities_CGal.pdf)

Status: Starting with particle gun (Sasha Prozorov's framework). Made a simple code based off Caroline's main analysis code.

/eic/u/kirar/eic/nHCal/nHCal_MuonAnalysis.C

Analysis Code

Information from TTree I am accessing

- Accessing MC Truth, reconstructed hit, and cluster information

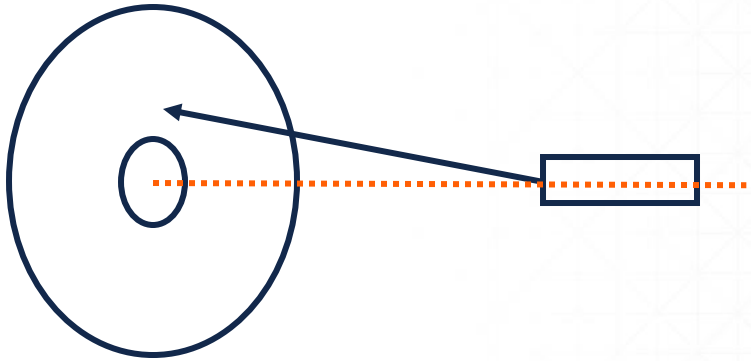
Histograms I currently have

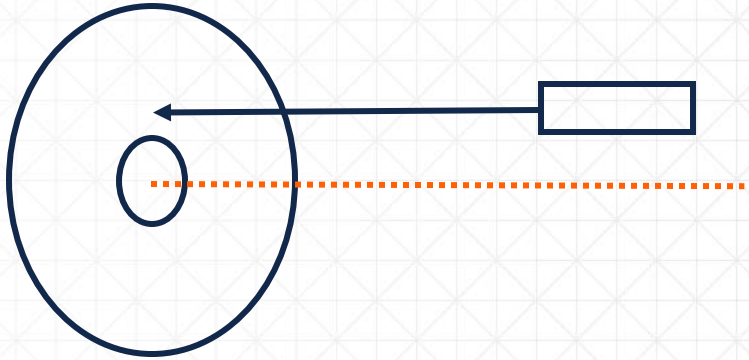
```
// MC truth
TTreeReaderArray<int> pdg(reader, "MCParticles.PDG");
TTreeReaderArray<int> status(reader, "MCParticles.generatorStatus");
TTreeReaderArray<int> simStatus(reader, "MCParticles.simulatorStatus");
TTreeReaderArray<double> momX(reader, "MCParticles.momentum.x");
TTreeReaderArray<double> momY(reader, "MCParticles.momentum.y");
TTreeReaderArray<double> momZ(reader, "MCParticles.momentum.z");

// Reco hits and clusters
TTreeReaderArray<float> recHitE(reader, "HcalEndcapNRecHits.energy");
TTreeReaderArray<float> recHitX(reader, "HcalEndcapNRecHits.position.x");
TTreeReaderArray<float> recHitY(reader, "HcalEndcapNRecHits.position.y");
TTreeReaderArray<float> recHitZ(reader, "HcalEndcapNRecHits.position.z");

TTreeReaderArray<float> clusterE(reader, "HcalEndcapNClusters.energy");
TTreeReaderArray<unsigned int> hitsBegin(reader, "HcalEndcapNClusters.hits_begin");
TTreeReaderArray<unsigned int> hitsEnd(reader, "HcalEndcapNClusters.hits_end");
TTreeReaderArray<unsigned int> clusterRecID(reader, "HcalEndcapNClusterAssociations.recID");
TTreeReaderArray<unsigned int> clusterSimID(reader, "HcalEndcapNClusterAssociations.simID");

// Histograms
TH1D* h_allEta = new TH1D("allEta", "All;#eta", 100, -6, 6);
TH1D* h_allPhi = new TH1D("allPhi", "All;#phi [rad]", 100, -3.2, 3.2);
TH1D* h_muInAcceptance = new TH1D("muInAcceptance", "Muons in nHCal Acceptance;#eta", 100, -6, 6);
TH1D* h_muNotDecayed = new TH1D("muNotDecayed", "Muons Not Decayed in Acceptance;#eta", 100, -6, 6);
TH1D* h_muEnergy = new TH1D("muEnergy", "Muon Cluster Energy;E [GeV]", 100, 0, 10);
TH1D* h_hitMultiplicity = new TH1D("hitMultiplicity", "Hits per Muon in nHCal;# hits", 50, 0, 50);
TH2D* h_layerVsEnergy = new TH2D("layerVsEnergy", "Hit Energy vs Layer;Layer;E [GeV]", 10, 0, 10, 100, 0, 1);
TH1D* h_electronEnergy = new TH1D("electronEnergy", "Electron Cluster Energy; E [GeV]", 100, 0, 10);


TH1D* h_layerE[10];
for (int i = 0; i < 10; ++i) {
  h_layerE[i] = new TH1D(Form("layerE_%d", i), Form("Layer %d Energy;E [GeV]", i), 100, 0, 1);
}

TH3D* h_hitsXYZ = new TH3D("hitsXYZ", "nHCal RecHit XYZ;X [mm];Y [mm];Z [mm]",
                           100, hx_min_nhcal, hx_max_nhcal,
                           100, hy_min_nhcal, hy_max_nhcal,
                           100, hz_min_nhcal, hz_max_nhcal);
```

Efficiency

Main Goal is to study muon efficiency in the nHCal

To do this, we want to "raise" the gun, so we are only shooting into one module at a time



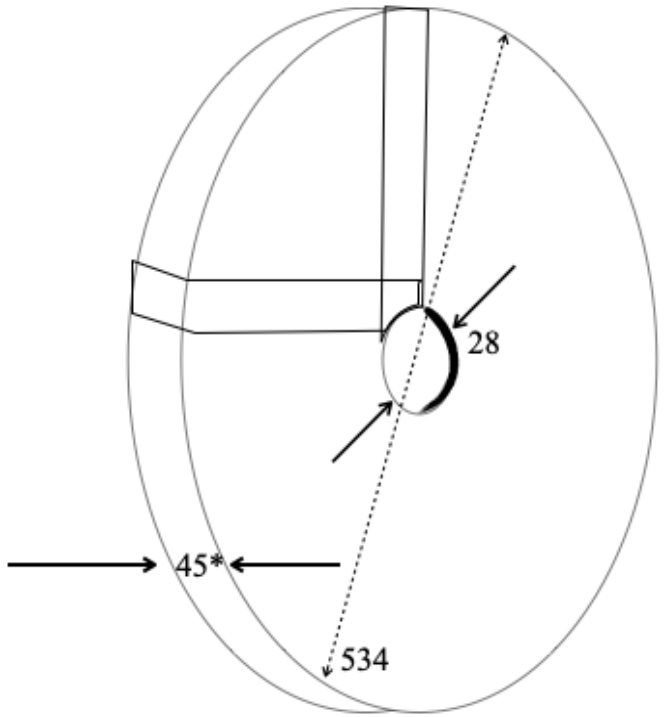


Raising the Particle Gun

Attempted to "raise" the particle gun so we could shoot straight into the detector.

Added this line to the code --gun.position "0.0 100.0 0.0" \ (We figured out it is in cm, not mm)

```
if ! ddsim \
        --compactFile "$DETECTOR_PATH/DETECTOR_CONFIG_PLACEHOLDER" \
        --numberOfEvents "$NUMBER_OF_EVENTS" \
        --random.seed "$(date +%N)" \
        --enableGun \
        --gun.particle "$PARTICLE" \
        --gun.thetaMin "${GUN_THETA_MIN}*degree" \
        --gun.thetaMax "${GUN_THETA_MAX}*degree" \
        --gun.phiMin "${GUN_PHI_MIN}*degree" \
        --gun.phiMax "${GUN_PHI_MAX}*degree" \
        --gun.distribution uniform \
        --gun.momentumMin "${GUN_MOMENTUM_MIN}*GeV" \
        --gun.momentumMax "${GUN_MOMENTUM_MAX}*GeV" \
        --gun.position "0.0 1000.0 0.0" \
        --outputFile "$DDSIM_FILE"; then
        echo "DDSIM simulation failed"
        exit 1
```

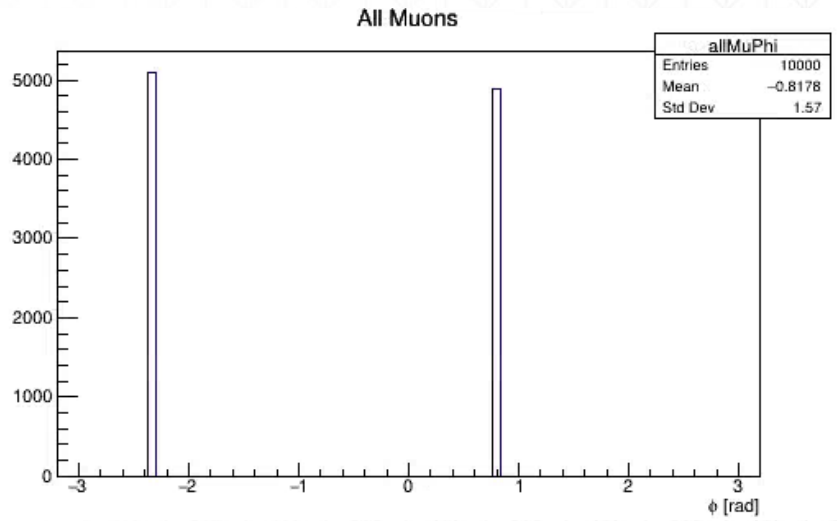


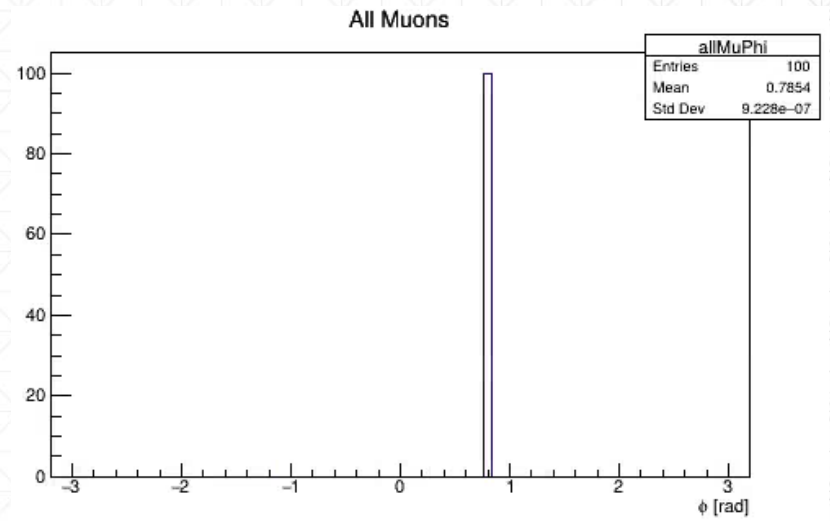
Raising the Particle Gun

My histograms were empty every single time I attempted to run this, except phi.

env MOMENTUM=1 PHI=45 THETA=180 PARTICLE=mu- NUMBER_OF_EVENTS=1000
./run_submit_movedup.sh

Phi histogram from moved up simulation vs not moved up





Particle Gun

Decided to run without changing gun position as it was not working

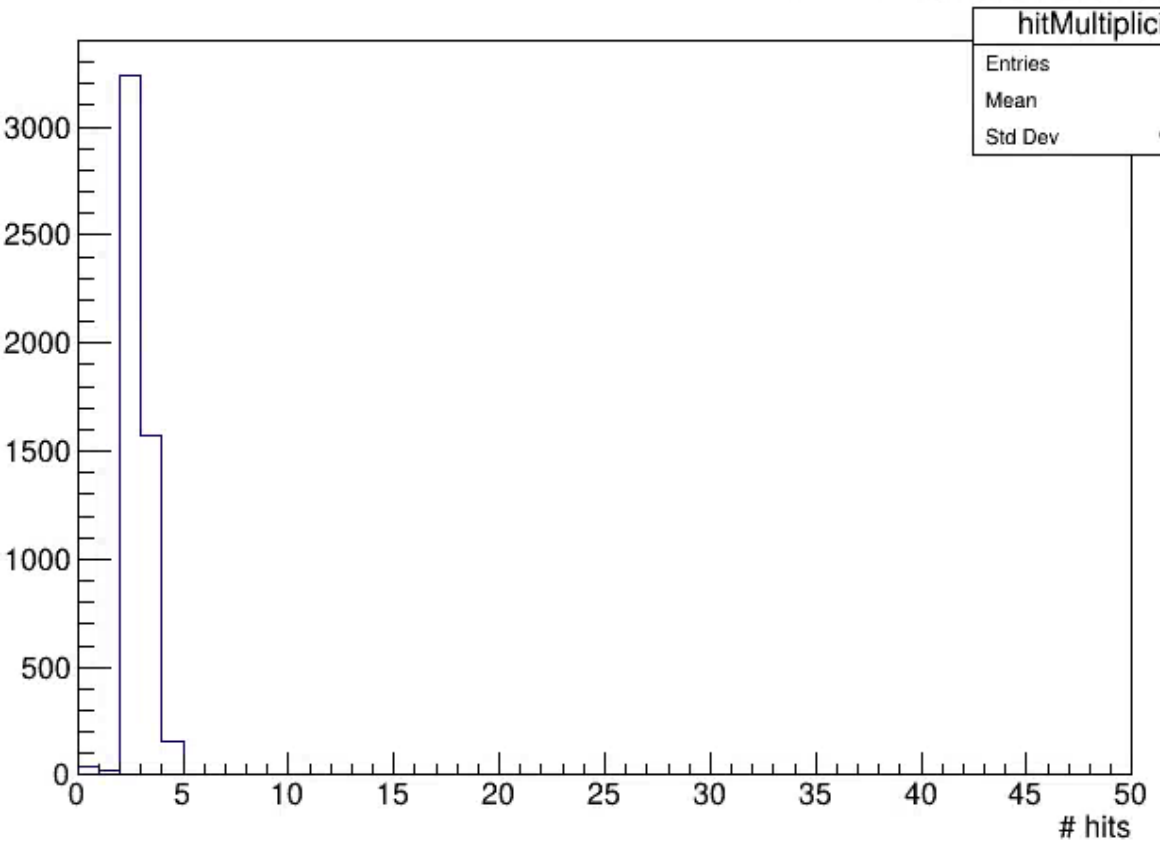
Default Geometry, env MOMENTUM=1 PHI=45 THETA=170 PARTICLE=mu- NUMBER_OF_EVENTS=1000 ./run_submit.sh

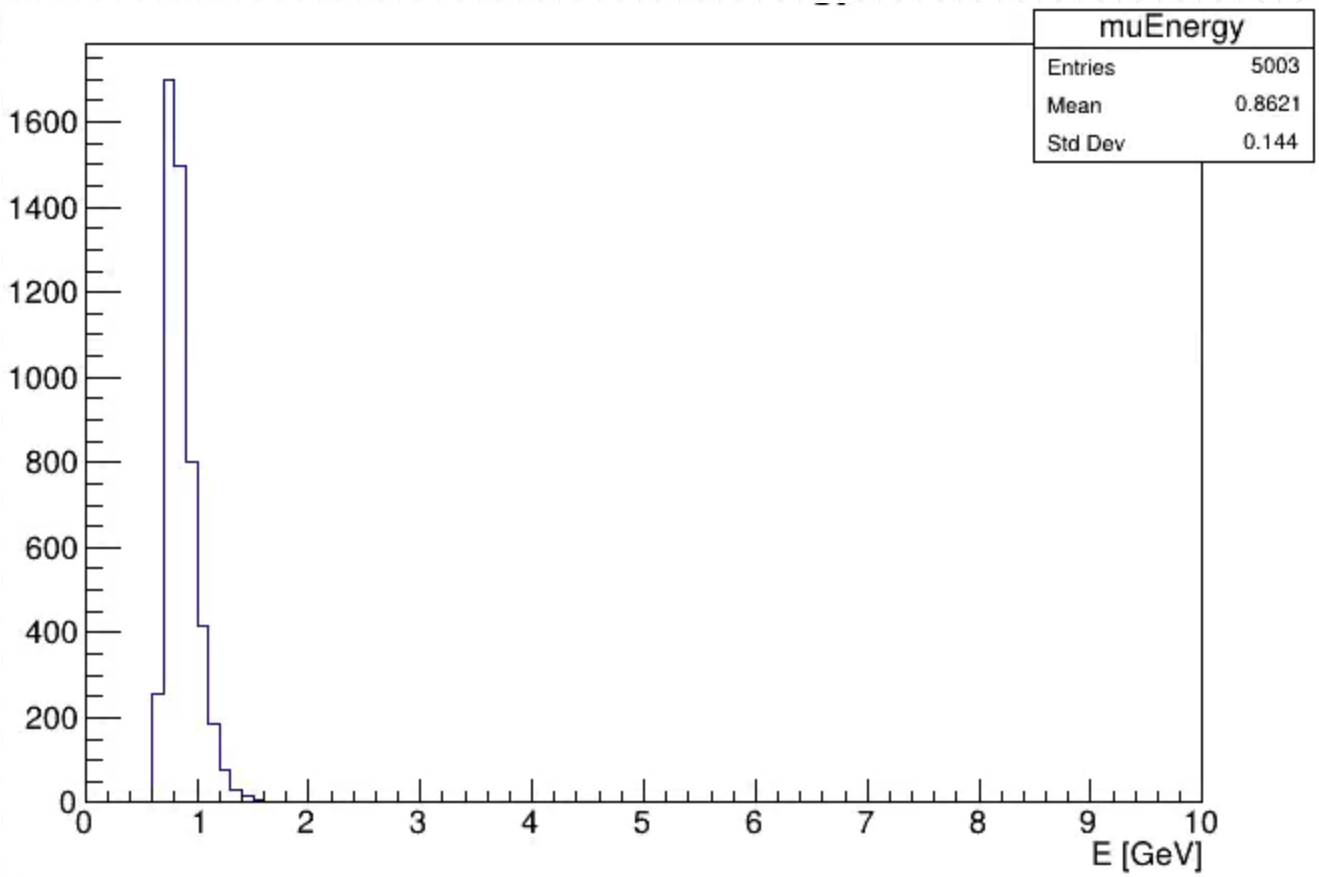
Output files will be saved in /gpfs02/eic/kirar/output/nhcal_only_tile10cm_absorber4cm_scintillator0.4cm_10layers/mu-_p1gev_phi45_theta170_1000events

Followed this framework to create files ranging from 1-10 GeV. Not every file turns into an eicrecon file?

P=1 GeV Data

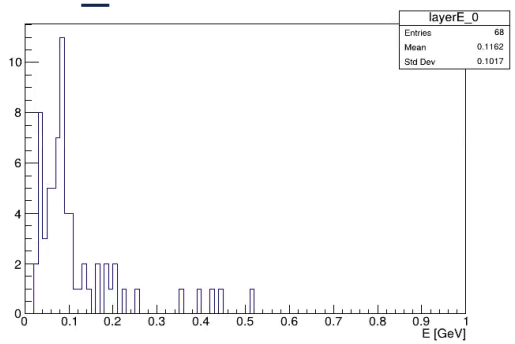
Default Geometry, env MOMENTUM=1 PHI=45 THETA=170 PARTICLE=mu- NUMBER_OF_EVENTS=1000
./run_submit.sh

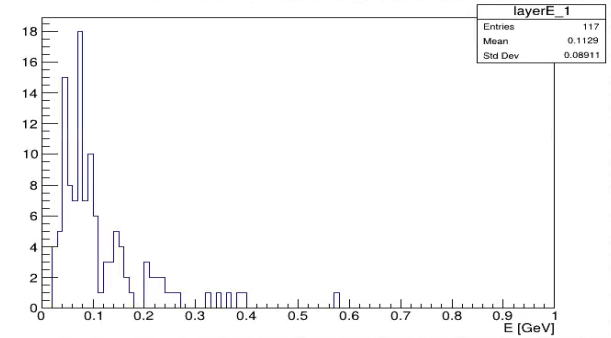


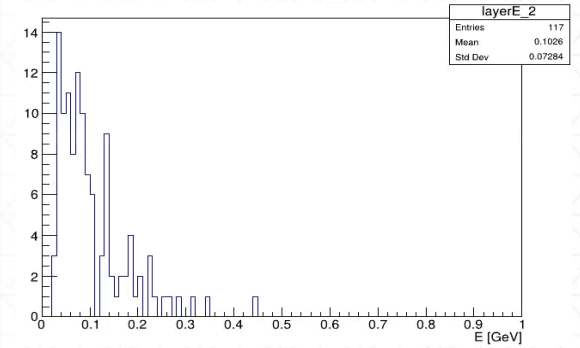


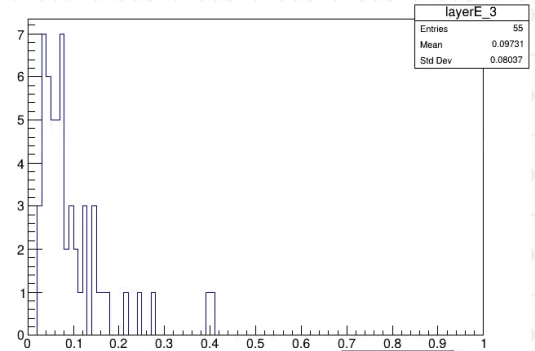
P=1 GeV Data

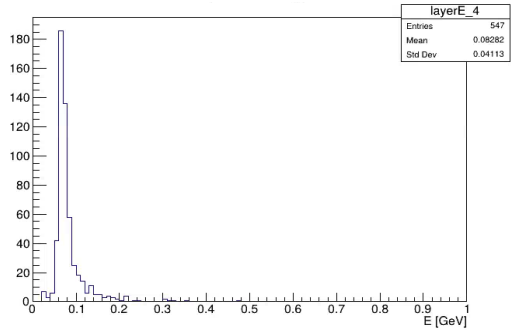
Default Geometry, env MOMENTUM=1 PHI=45 THETA=170 PARTICLE=mu- NUMBER_OF_EVENTS=1000 ./run_submit.sh

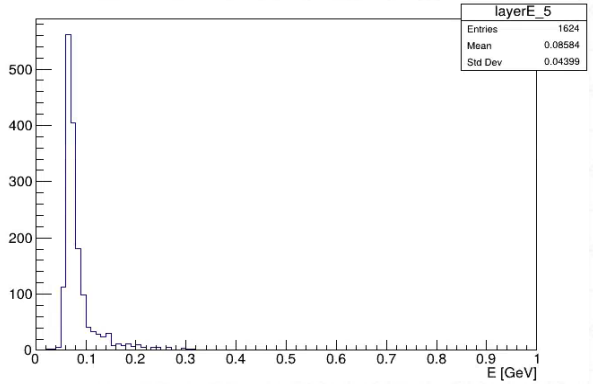


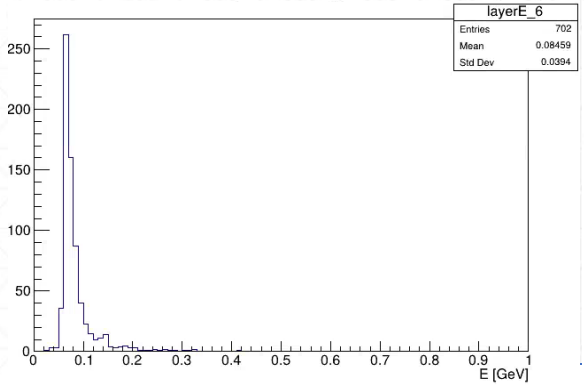


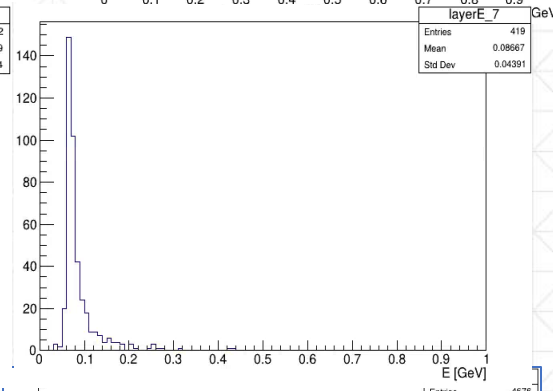


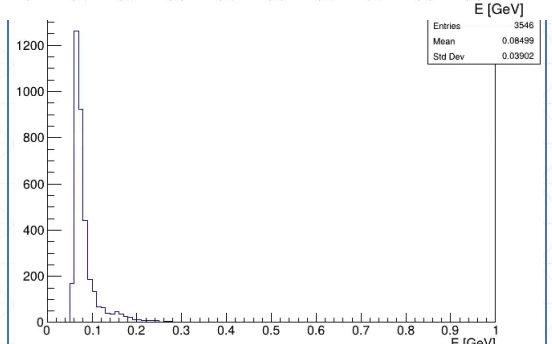


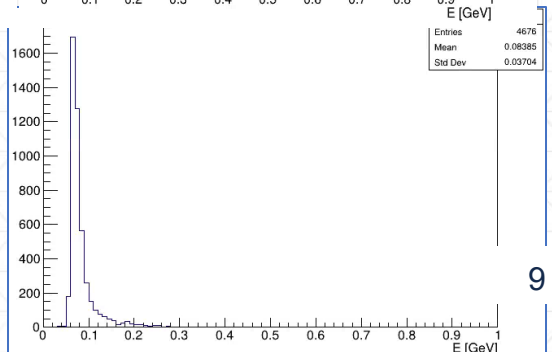








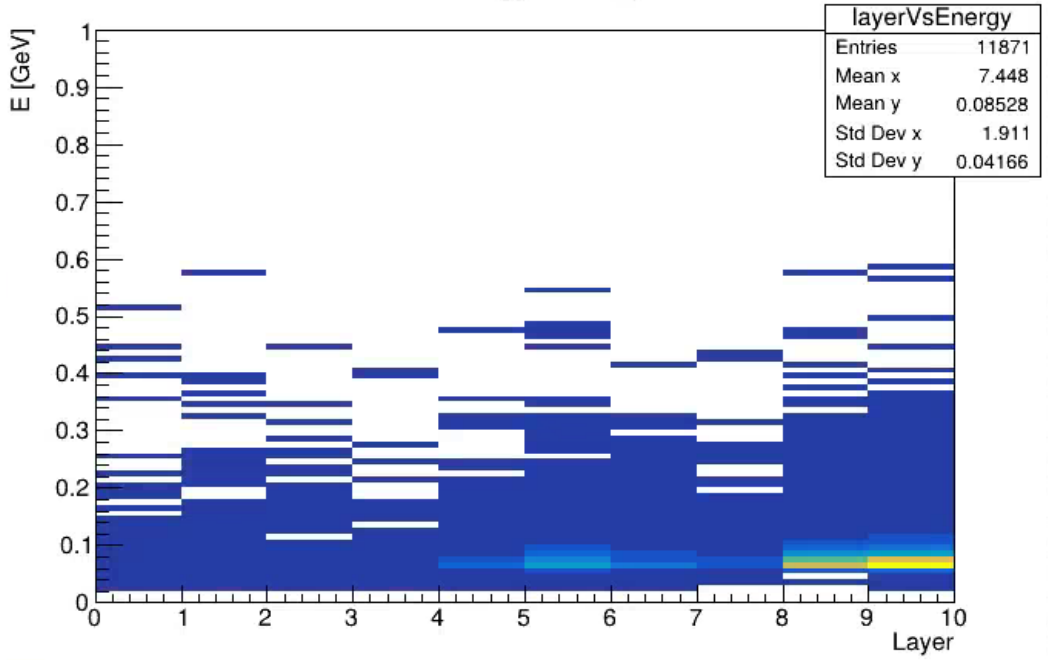




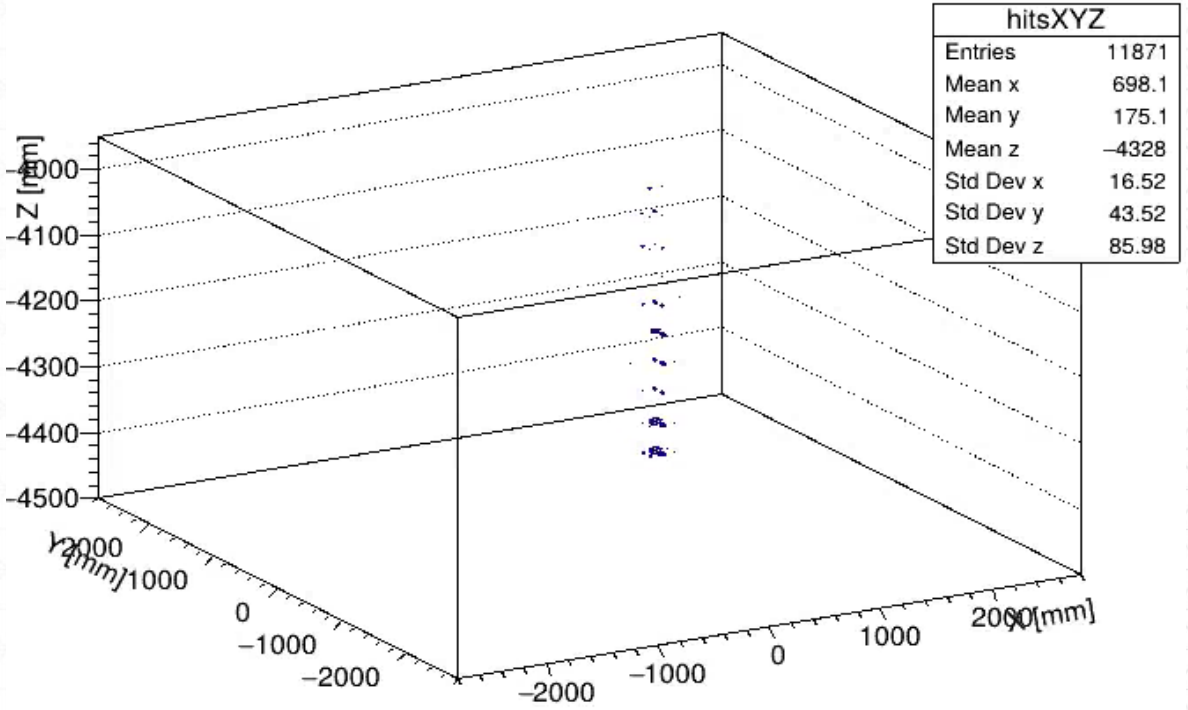
Energy in each layer

P=1 GeV Data

Default Geometry, env MOMENTUM=1 PHI=45 THETA=170 PARTICLE=mu- NUMBER_OF_EVENTS=1000
./run_submit.sh



Energy in each layer



Hits in XYZ

Next Steps

Figuring out issues with simulation

Trying to change particle gun position so I can shoot straight into the nHCal

Finishing my efficiency and e/p histograms

Making a plotting macro so I can better tune and format the histograms

Generate pion data