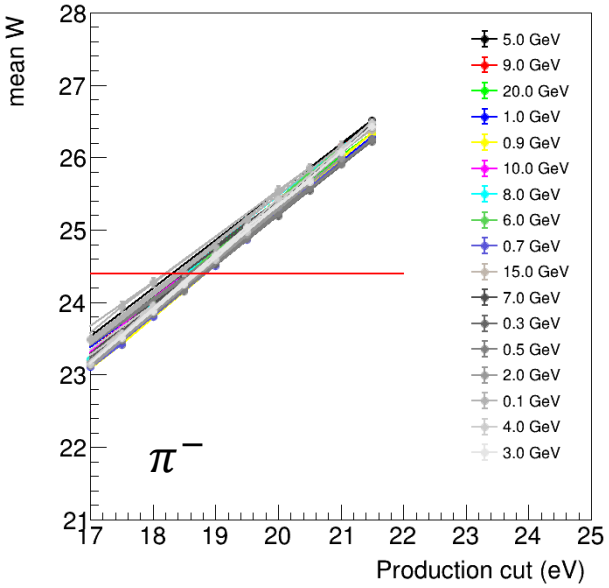
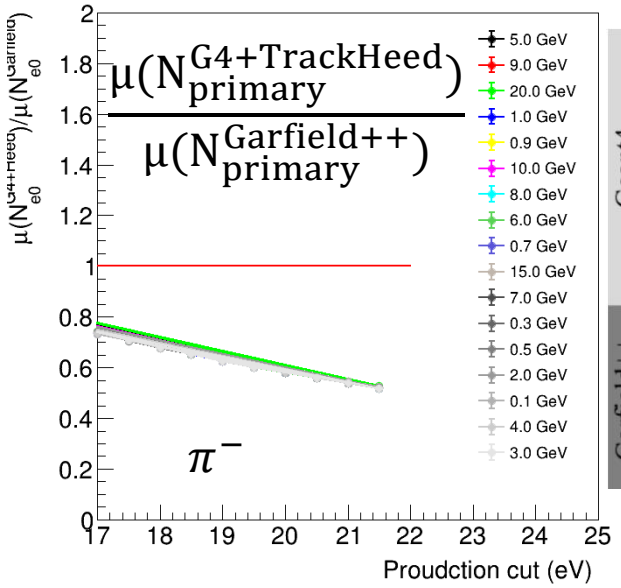
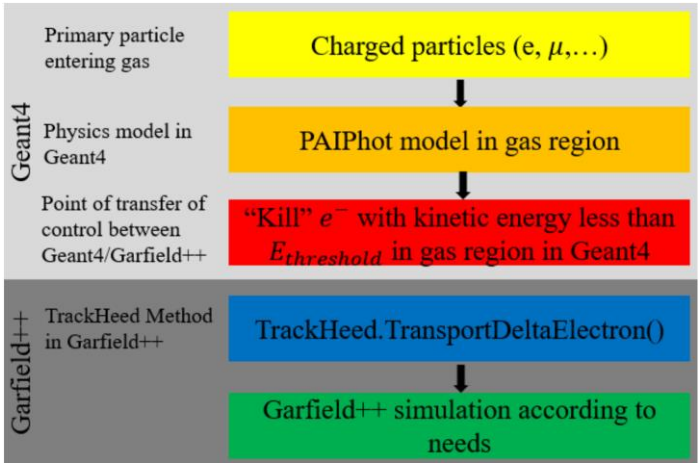
dN/dx Simulation

- Previous design:
  - Using Geant4 PAI model for ionization simulation, and transfer electron (or photon) with kinetic energy less than E_transfer (~ few keV) to TrackHeed for delta electron (or photon) simulation using TransportDeltaElectron() (or TransportPhoton())
  - However, after some studies, we find the number of primary electrons generated by Geant4 PAI model is much less than Garfield++ standalone simulation







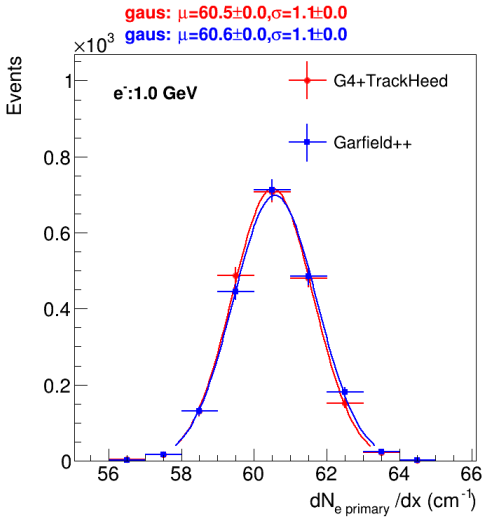
  - The author of the Geant4/Garfield++ interface said this method is designed to get correct energy deposit, but not the number of primary ionization electrons. She also see the deficit of primary ionization electrons from Geant4 PAI simulation.

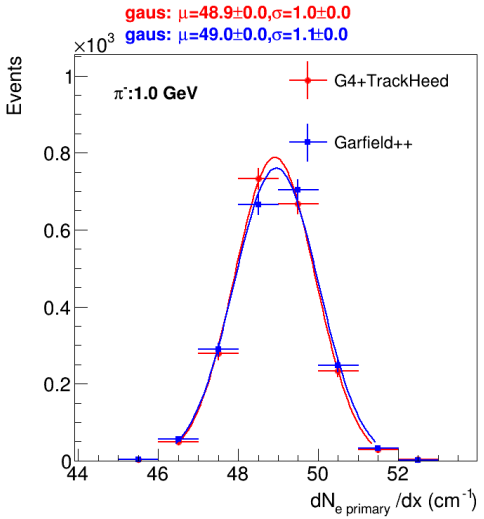
dN/dx Simulation

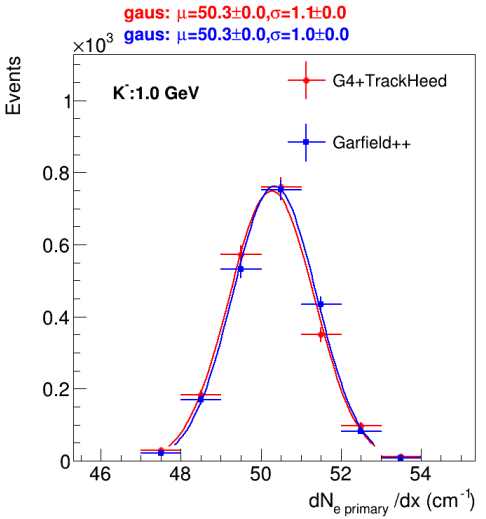
- New design:
  - Using dE/dx simulation tool interface and develop a tool for ionization simulation using G4Step information
  - For each G4Step, using TrackHeed to do ionization simulation (same as Garfield++)
  - In order to speed by this method, some G4Steps form one track can be merged and do one step ionization simulation
  - In order to use TrackHeed to do one desired step length simulation, one API is added to Heed and HeedTrack (send the change part to author of Garfield++ for comments)
  - The produced ionized electrons are saved in SimTrackerHitCollection (the m_Quality is used to distinguish primary electron (the cluster) and total ionized electron)
  - Updating the kinetic energy of G4Track considering its energy loss in TrackHeed simulation
  - Set MC Particle (just primary) to ionized electron
  - To be finished: using x,y,z of ionized electron to get cell id

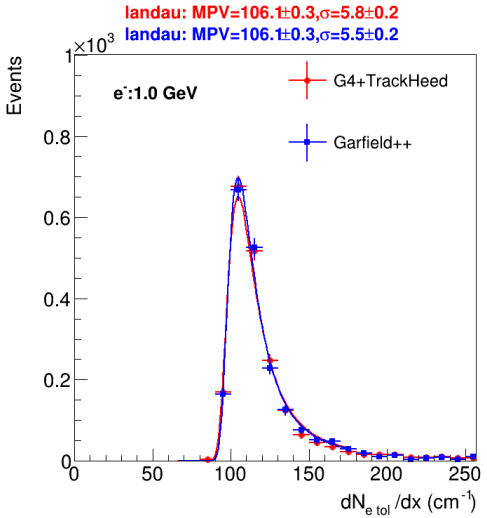
dN/dx Simulation

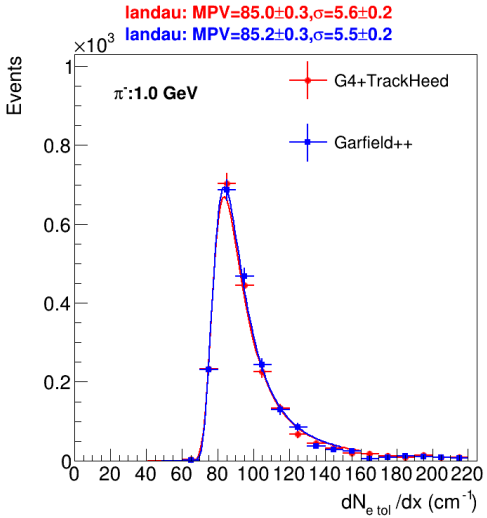
- Gas: 50% He + 50 % C_4H_{10}
- Length: 0.5 m

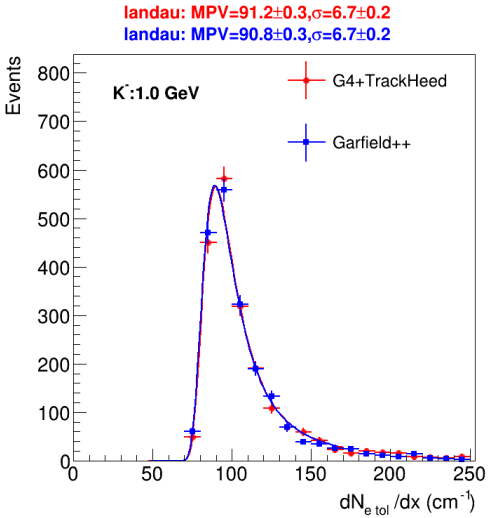




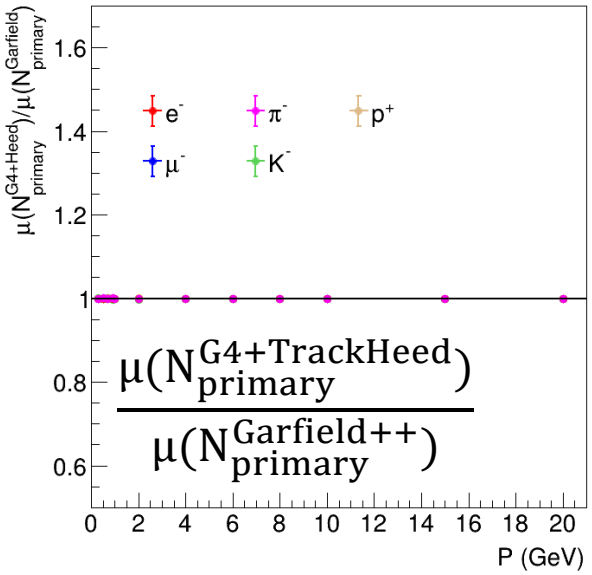


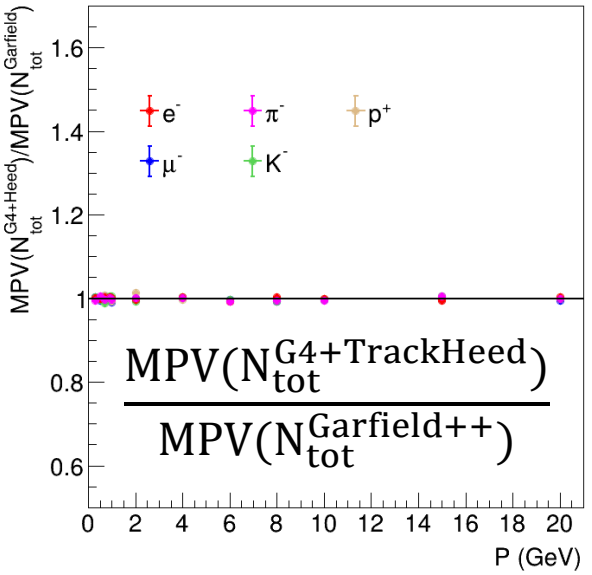


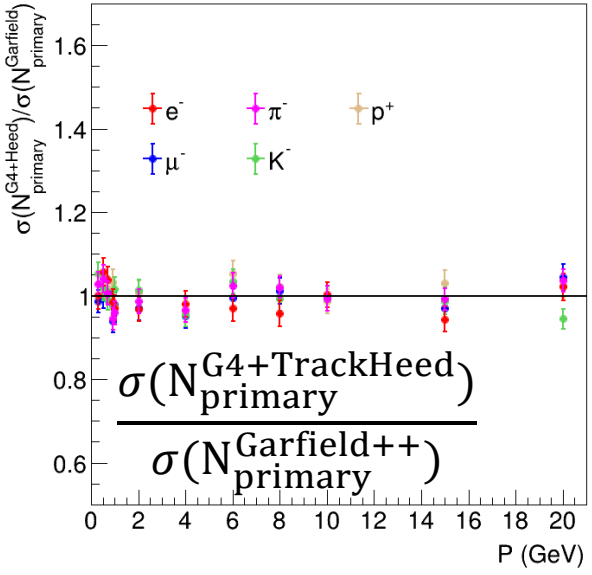


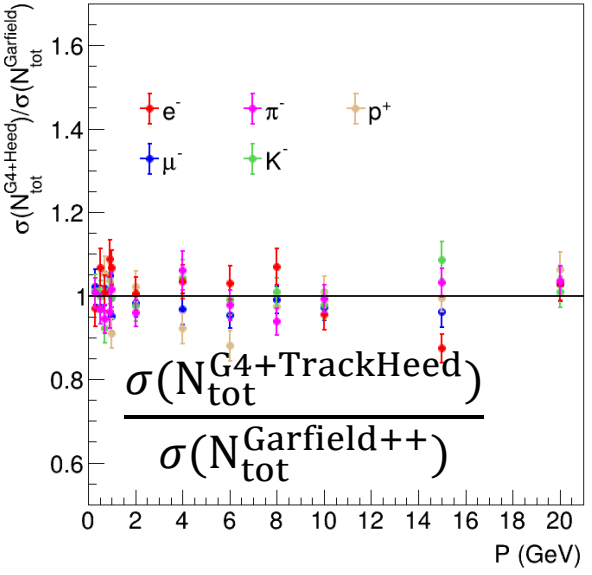


dN/dx Simulation









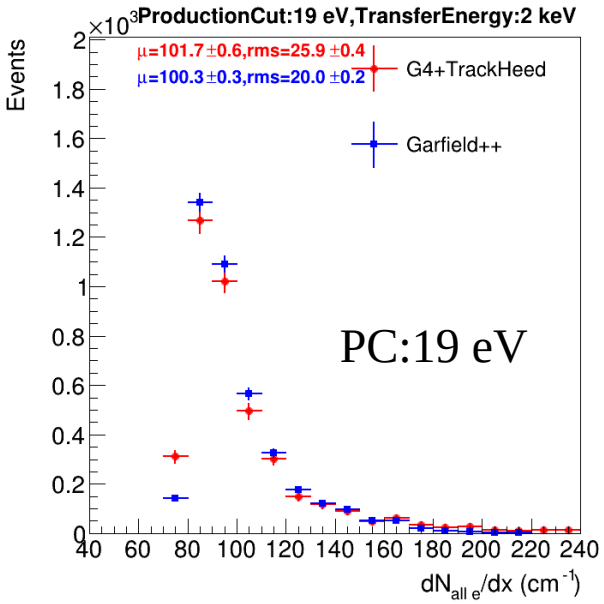
Back up

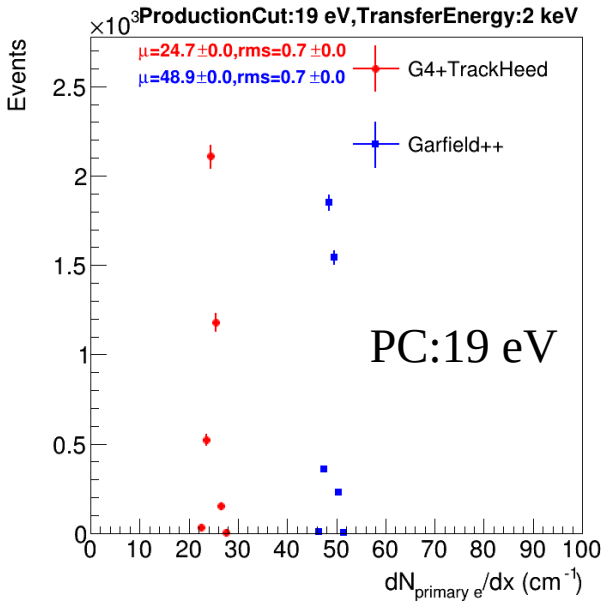
dN/dx Simulation

- In DCHFastSimG4Model:
  - "kill" electron and photon when its KineticEnergy < E_transfer (few keV)
  - The information of "killed" electron and photon is saved in SimTrackerHitCollection (the m_Quality is used to distinguish electron or photon)
- In DigiGarfieldAlg:
  - Using TrackHeed.TransportDeltaElectron() to simulate "killed" electron
  - Using TrackHeed.TransportPhoton() to simulate "killed" photon
  - Should the simulation of induced current be done in this algorithm ?
    - Using Garfield++:
      - Slow
      - GaudiHive: need support EDM4HEP read and write
    - Parameterization or sampling:
      - Fast
      - For each ionized electron, parameterizing (or sampling) induced current wave form
  - Is it possible to get cell id (or signal wire position) from (x,y,z) ?

- Event data model:
  - Wave from: collection of TPC hit (m_CellID, m_Quality, m_Time, m_Charge) ?
  - Peaks: collection of TPC hit ?

dN/dx Simulation





arXiv:1806.05880v1

Table 1: Optimal lower production cut values for different ratios

	production cut (eV)	
f	He/isoButane (He)	Ar/CO_2 (CO_2)
0	18.71 ± 0.01	20.7 ± 0.01
0.1	18.74 ± 0.01	20.89 ± 0.01
0.2	18.79 ± 0.01	21.11 ± 0.01
0.3	18.84 ± 0.01	21.35 ± 0.01
0.4	18.92 ± 0.01	21.62 ± 0.01
0.5	19.01 ± 0.01	21.88 ± 0.01
0.6	19.17 ± 0.01	22.16 ± 0.01
0.7	19.45 ± 0.01	22.48 ± 0.01
0.8	20.07 ± 0.01	22.75 ± 0.01
0.85	20.86 ± 0.01	-
0.9	21.95 ± 0.01	23.12 ± 0.01
0.95	25.19 ± 0.01	-
1	30.54 ± 0.01	23.48 ± 0.01

Optimized production cut for **2 keV** energy threshold

- Simulate 1 GeV π^-
- Gas: 50% He + 50 % C_4H_{10}
- TrackHeed:
  - Cluster density: 47.403 cm-1
  - Stopping power (restricted): 2.33135 keV/cm
  - Stopping power (incl. tail): 2.46105 keV/cm
  - W value: 24.3944 eV
  - Fano factor: 0.19
  - Min. ionization potential: 10.55 eV

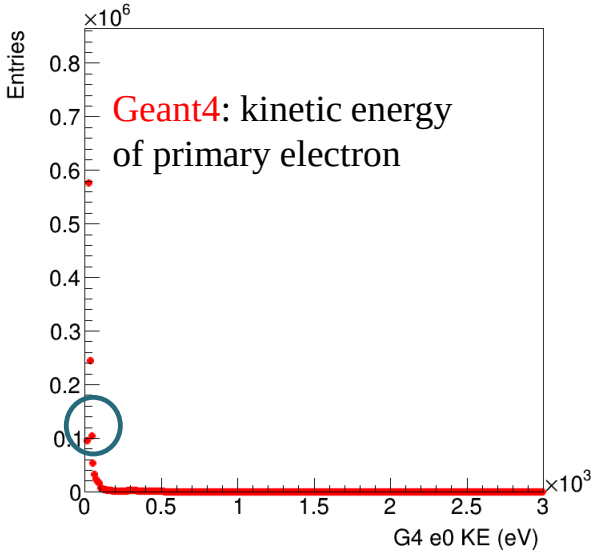
- The number of all ionized electron looks similar. Try to tune the production cut and transfer energy to see if one can get better agreement
- Number of primary ionized electron has large difference:
  - G4: $N_{primary\ e}$ is number of electrons whose mother particle is injected particle
  - Garfiled++: $N_{primary\ e}$ equals number of cluster

Production cut

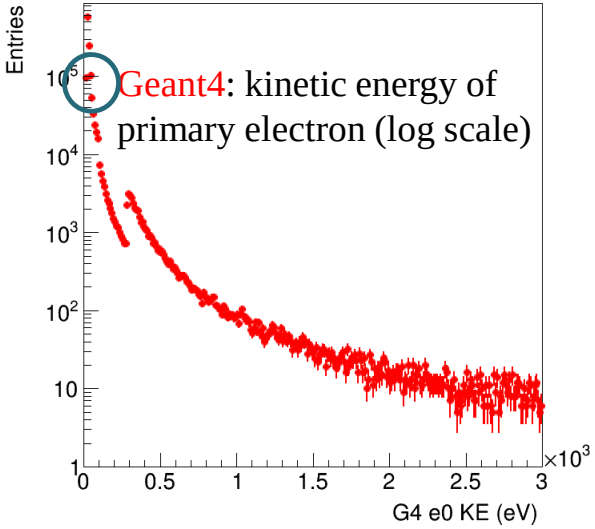

```
G4ProductionCutsTable::GetProductionCutsTable()->SetEnergyRange(fPAIEnergyCut,100*unit::GeV);
G4Region *region = G4RegionStore::GetInstance()->GetRegion("RegionGarfield");
G4ProductionCuts * cuts = new G4ProductionCuts();

// By setting the range to 0 * mm, the actual production cut in RegionGarfield will be same w
cuts->SetProductionCut(0., G4ProductionCuts::GetIndex("gamma"));
cuts->SetProductionCut(0., G4ProductionCuts::GetIndex("e-"));
cuts->SetProductionCut(0., G4ProductionCuts::GetIndex("e+"));

if (region) {
  region->SetProductionCuts(cuts);
}
```

From COMET

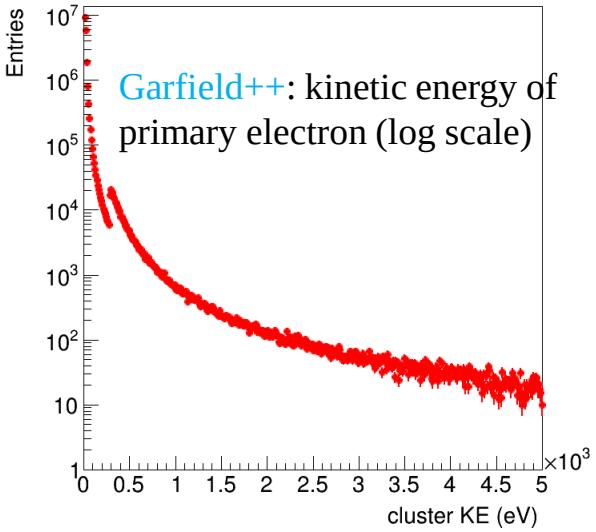
dN/dx Simulation



Geant4: kinetic energy of primary electron



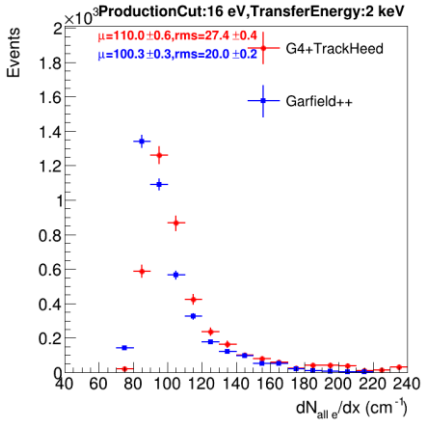
Geant4: kinetic energy of primary electron (log scale)

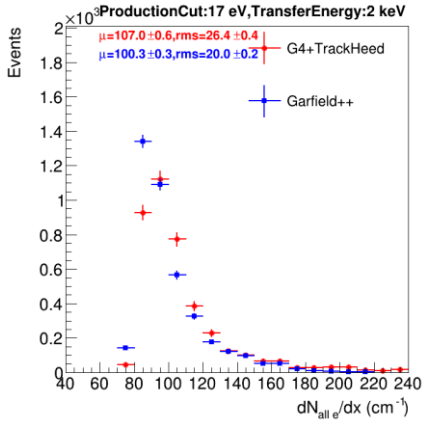


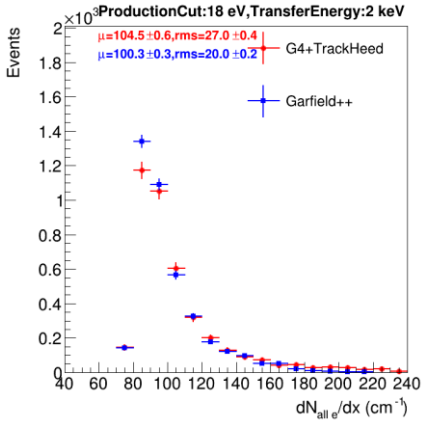
Garfield++: kinetic energy of primary electron (log scale)

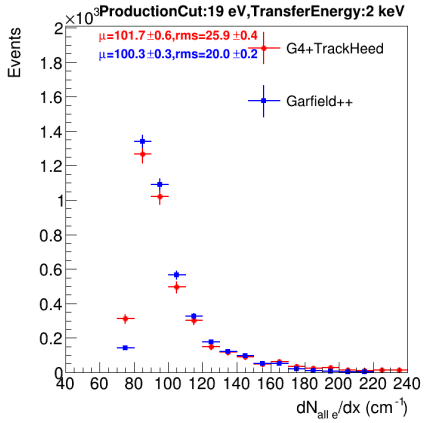
- Comparing with Garfield++, the first bin (0-10 eV) for Geant4 one seems abnormal !

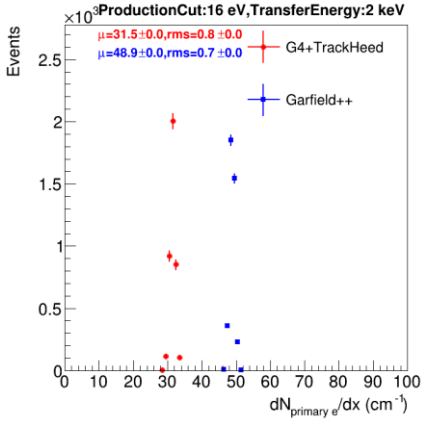
dN/dx Simulation

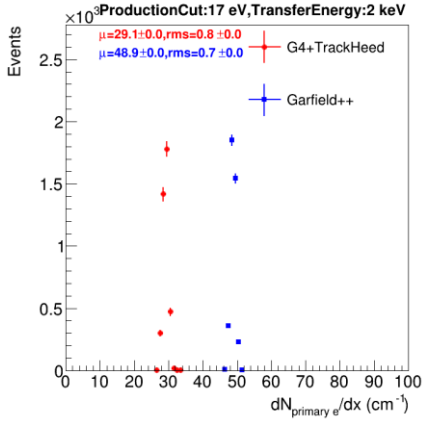


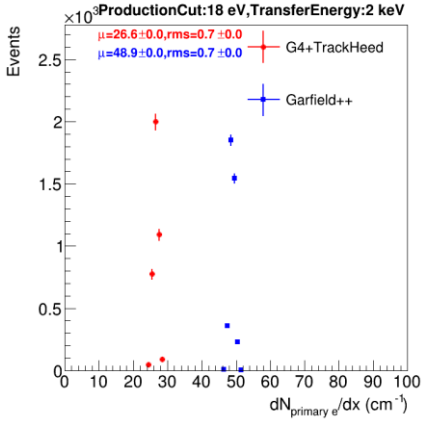


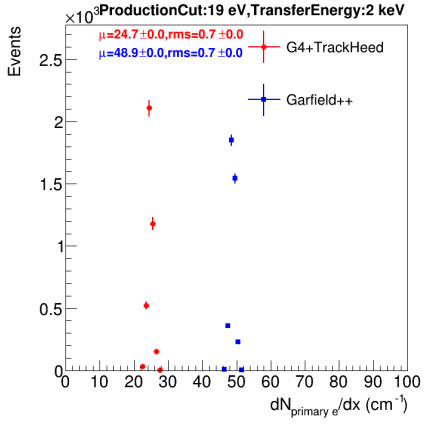




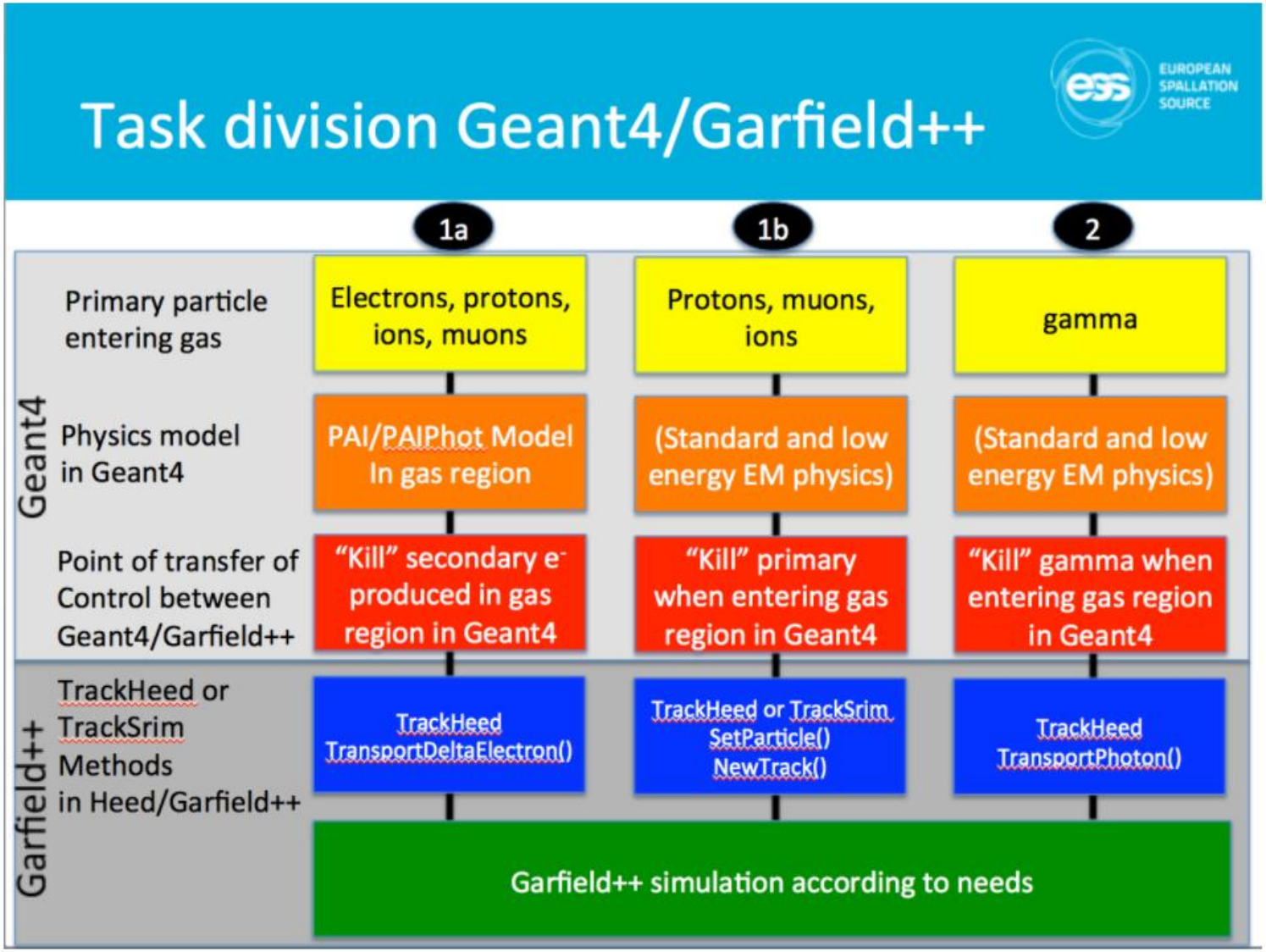






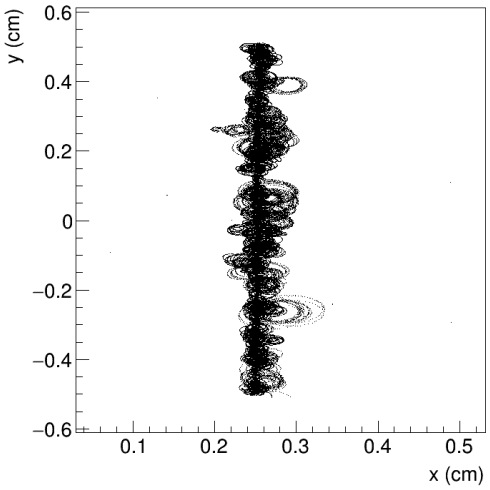


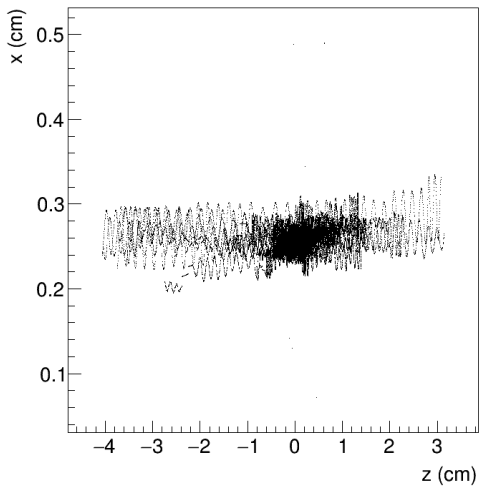
Geant4 + Garfield++

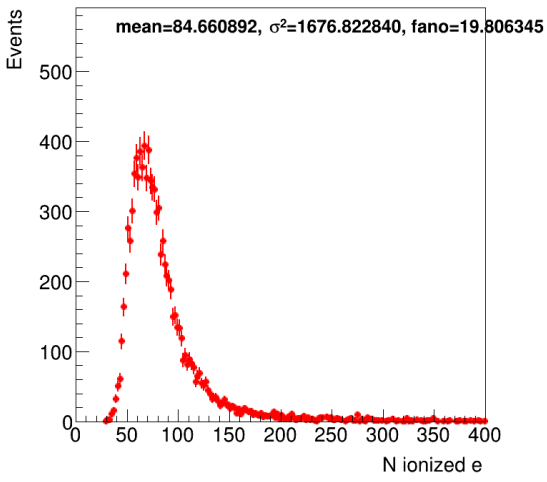


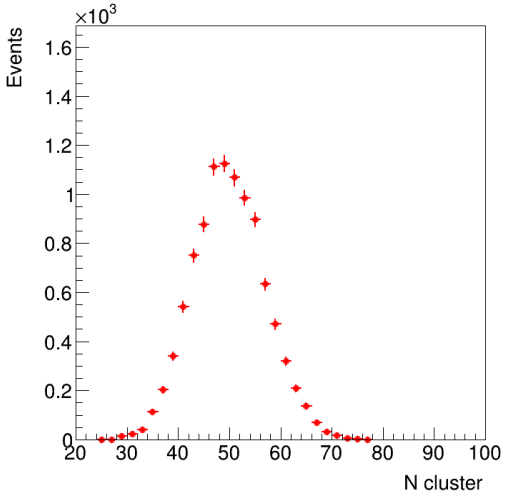
Garfield++ alone

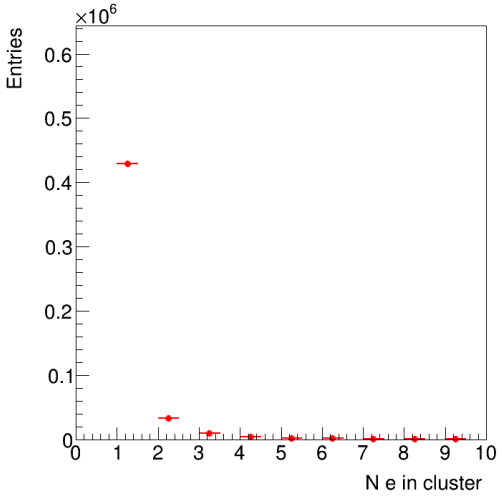
- Cell size 1 × 1 cm (1 signal wire around by 8 field wires)
- π^- momentum 1 GeV

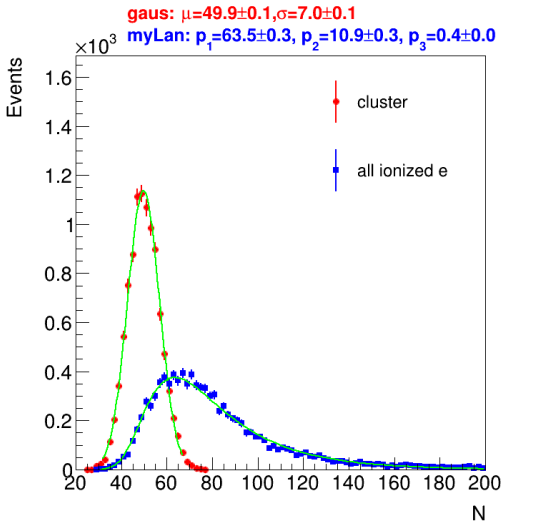






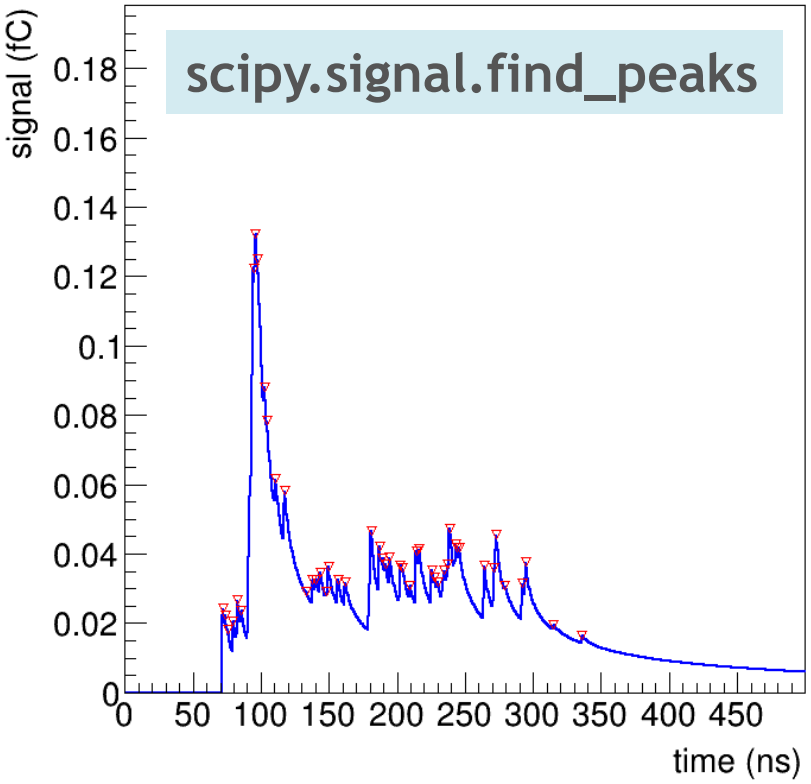


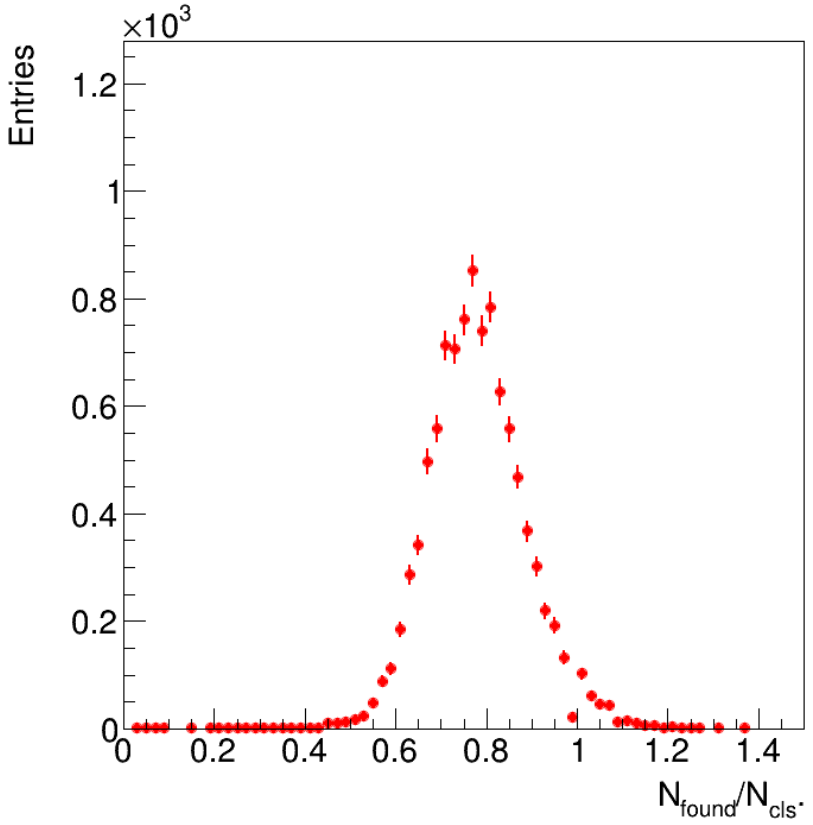




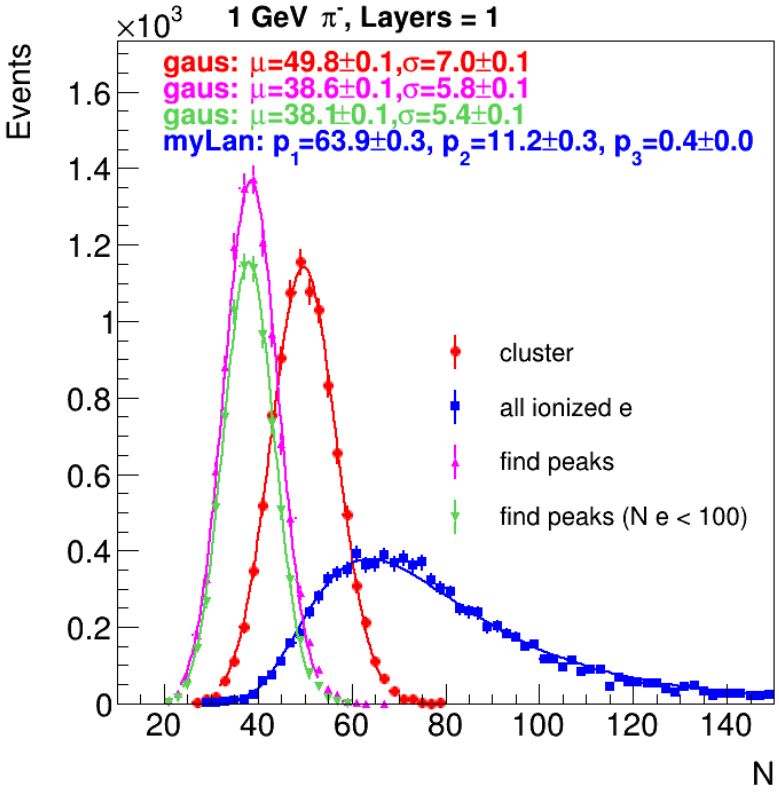
Garfield++ alone

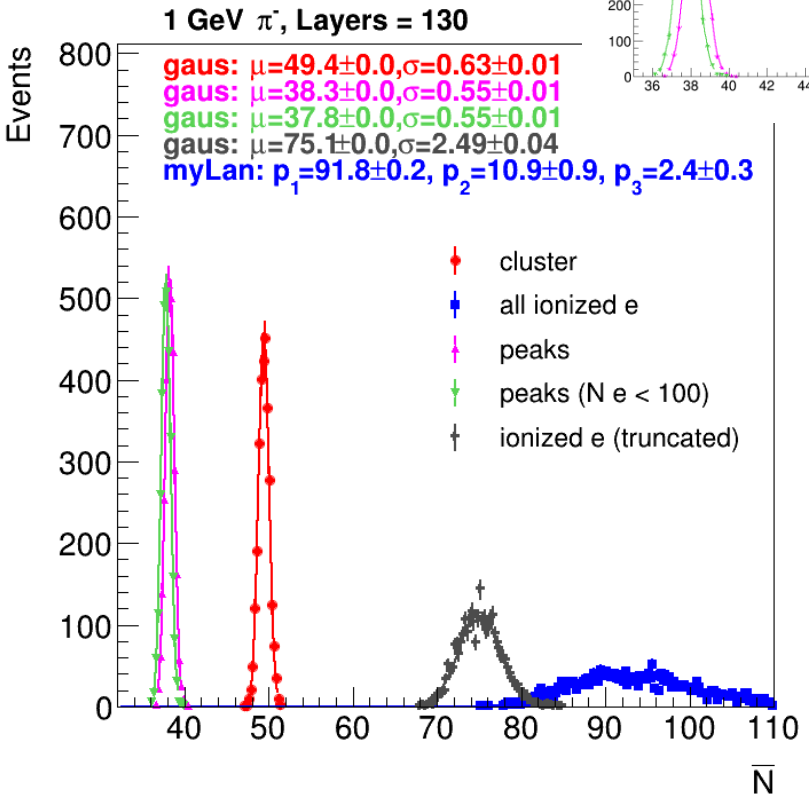
- Simulate drift and avalanche of ionized electrons using Garfield++
- Do peak finding

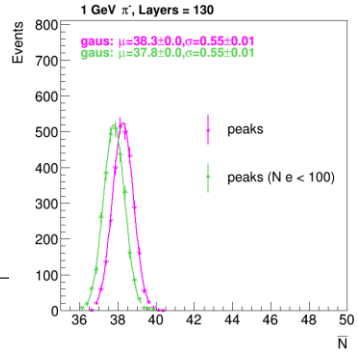




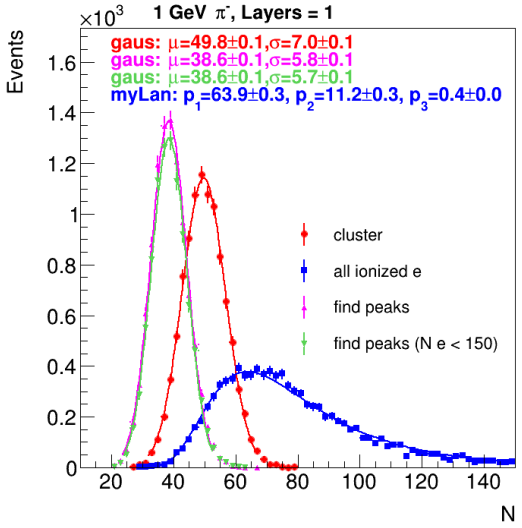
Garfield++ alone

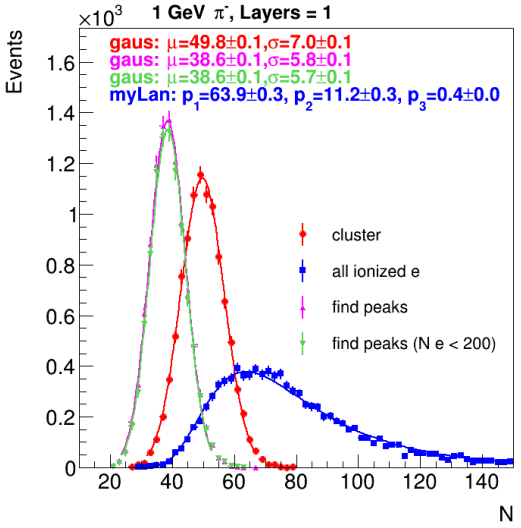


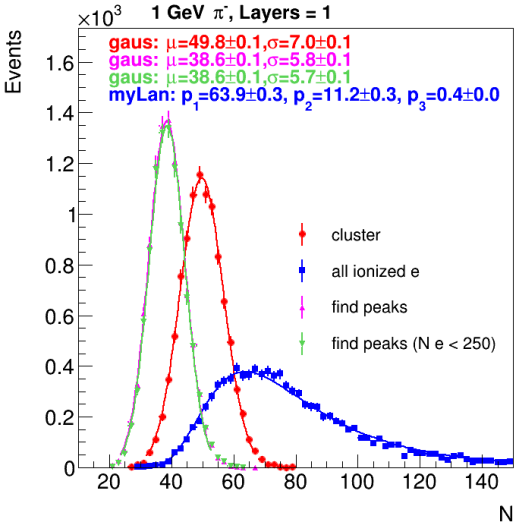


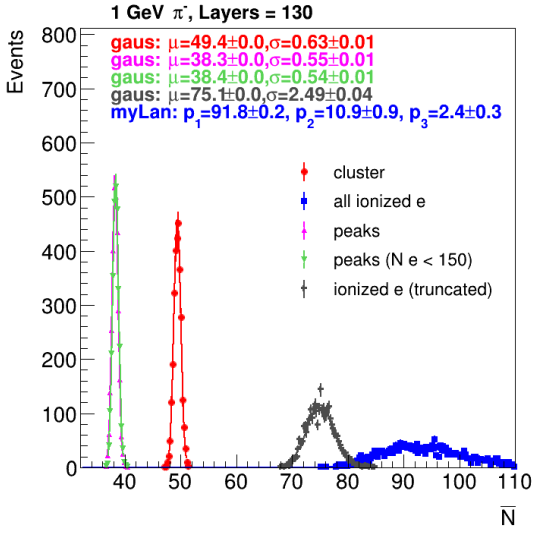


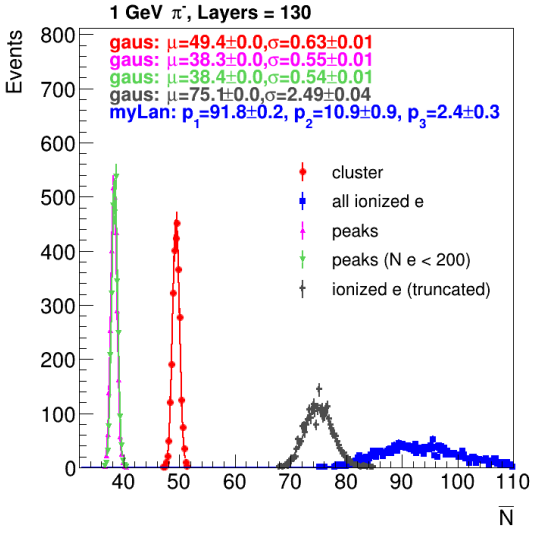
Garfield++ alone

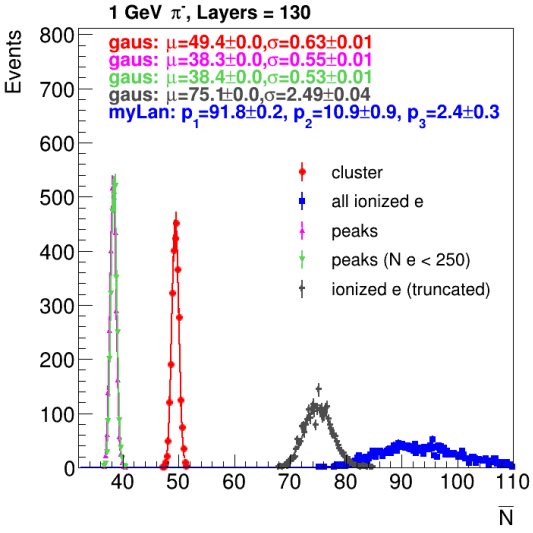






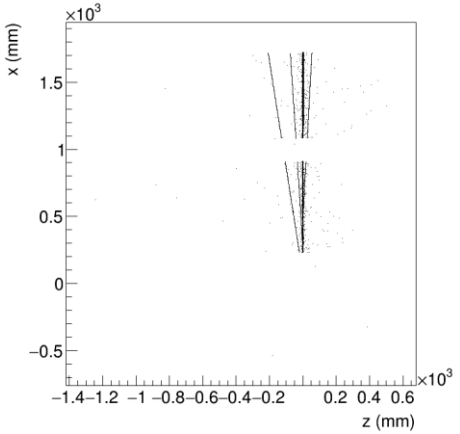




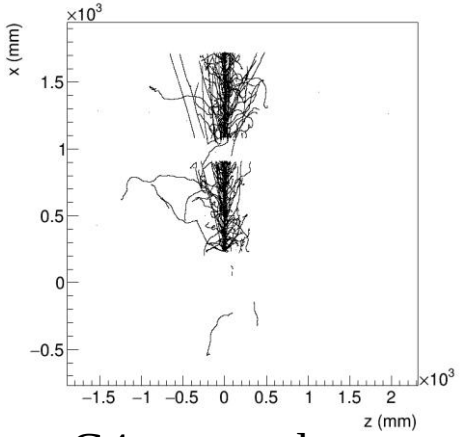


Geant4 + Garfield++

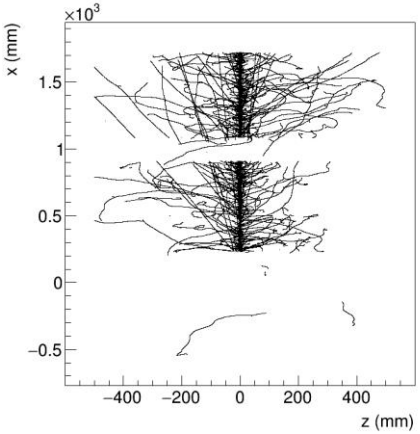
- Production cut: 19.01 eV
- Transfer energy threshold: 500 eV
- π^- momentum 1 GeV



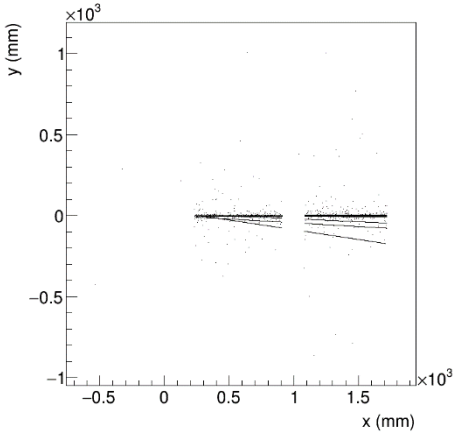
G4 e primary

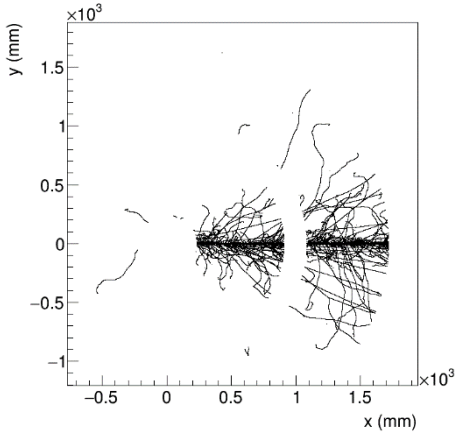


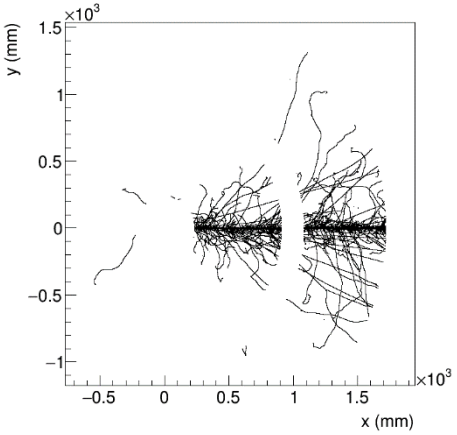
G4 e secondary



All electrons







Geant4 + Garfield++

- Production cut: 19.01 eV
- Transfer energy threshold: 500 eV
- 1 GeV π^-