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dN/dx simulation software in CEPCSW

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On behalf of drift chamber working group

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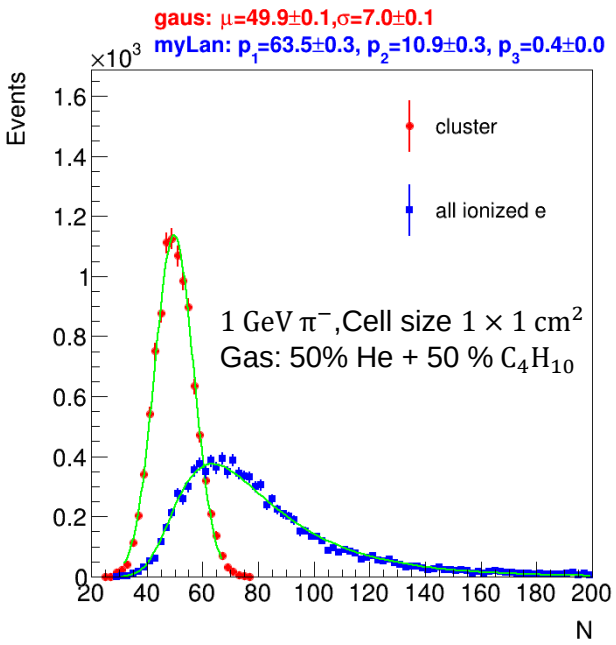
Motivation

- The particle identification is very important for CEPC flavor physics study. Good hadron separation up to 20 GeV is essential
- Traditionally: using dE/dx method
  - Due to the production of delta electron, the deposited energy follows Landau distribution
  - Resolution is ~6%
- New technique: using dN/dx (cluster counting) method
  - The number of primary ionization follows Poisson distribution
  - Resolution could reaches <3%
- The dN/dx technique will be widely explored in CEPC drift chamber detector

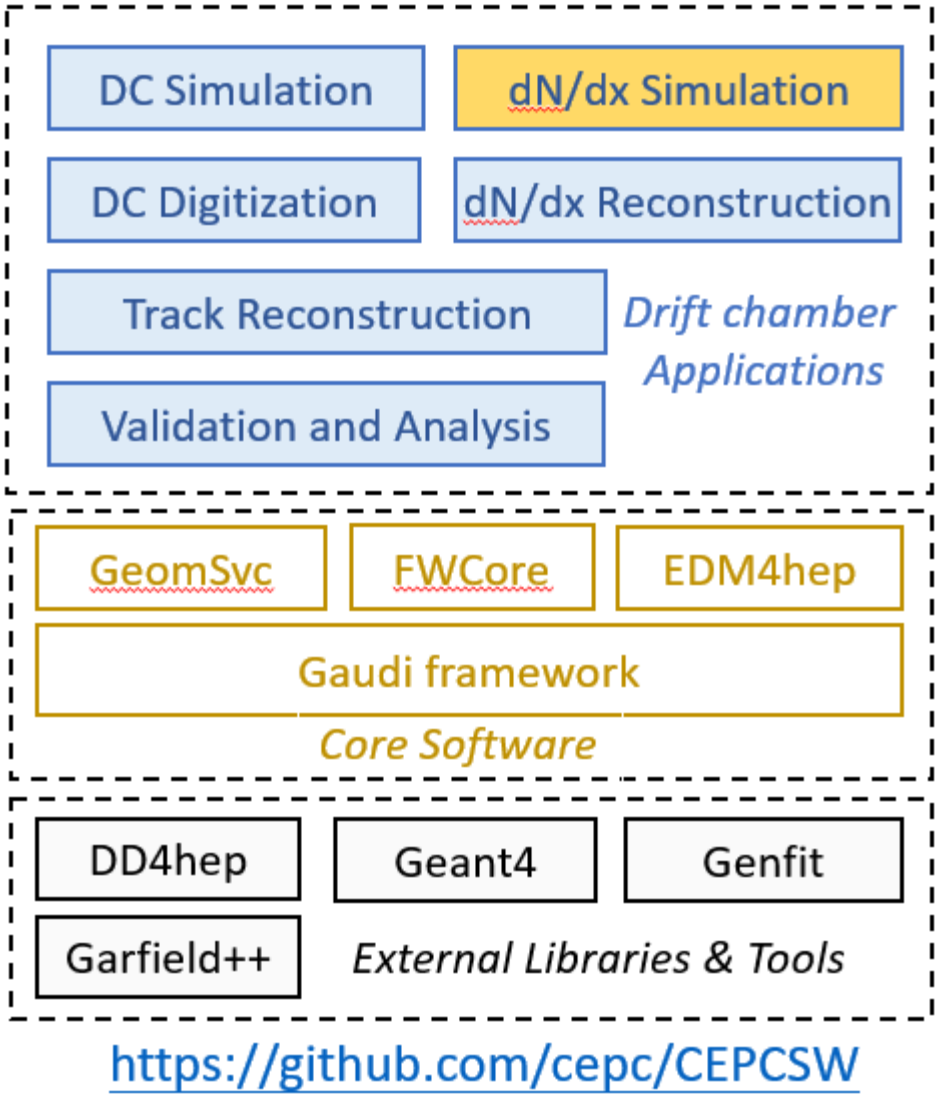


Ionization simulation in gas

- Garfield++
  - Using Heed PAI model to simulate the ionization in gas precisely
  - Can simulate the drift and avalanche of electrons in gas
  - The drift of ions to cathode can be simulated
  - The induced current can be given
  - It is useful to study and characterize the properties of gas detector with simple geometry but not for full drift chamber detector
- Geant4
  - Can simulate collider events and the interaction between particles and materials in full detector
  - It does not simulate the ionization process properly, neither the drift and avalanche processes
- In order to simulate including particle interaction will detector materials, ionization in gas, drift and avalanche processes in full detector, we try to combined Geant4 and Garfield++ in CEPCSW3

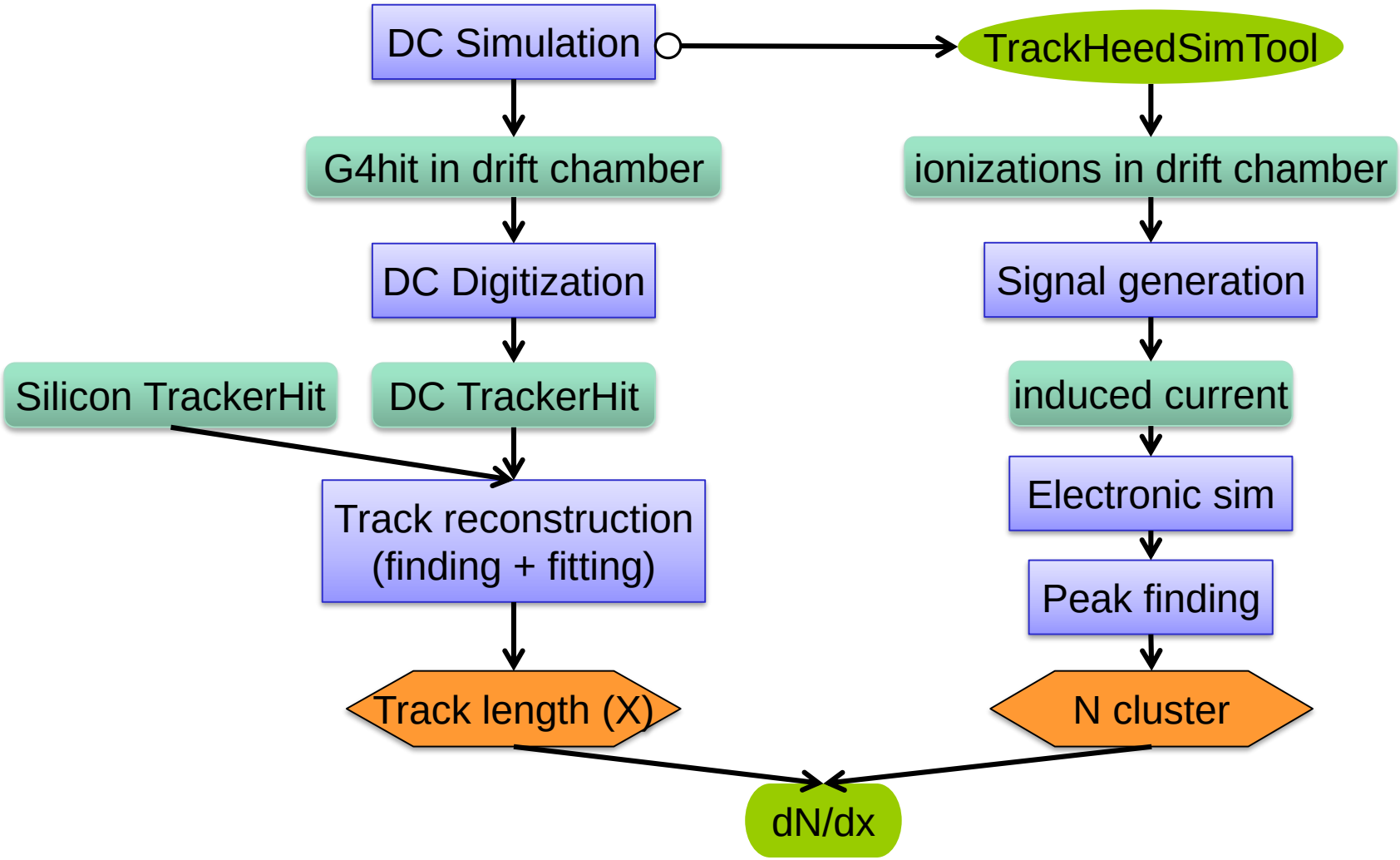
CEPCSW for drift chamber study

- Framework:
  - Gaudi
- EDM:
  - EDM4hep
  - FWCore
- Detector geometry and B field:
  - DD4hep
  - GeomSvc
- Drift chamber:
  - DC simulation (Geant4)
  - DC digitization
  - Track reconstruction (Genfit)
  - dN/dx simulation (Garfield++)
  - dN/dx reconstruction



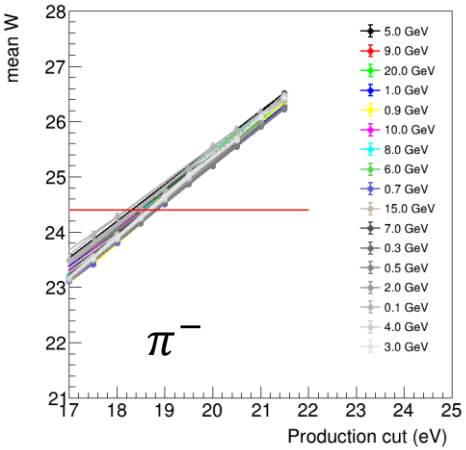
https://github.com/cepc/CEPCSW

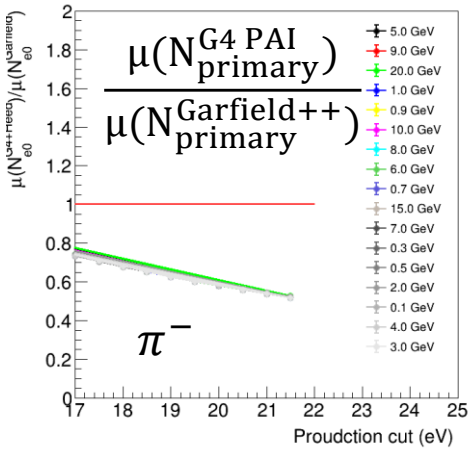
Scheme of dN/dx study in CEPCSW

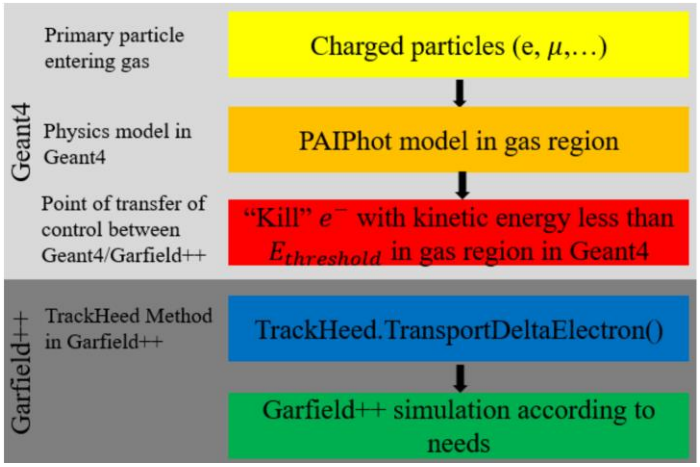


Ionization simulation in CEPCSW (G4 PAI)

- First try: according to paper "Interfacing Geant4, Garfield++ and Degrad for the Simulation of Gaseous Detectors" :
  - Geant4 PAI model to simulate primary or secondary ionization
  - TrackHeed to simulate ionization from residual delta electron
- However, it was found that the primary ionization produced by this method is much less than Garfield++.







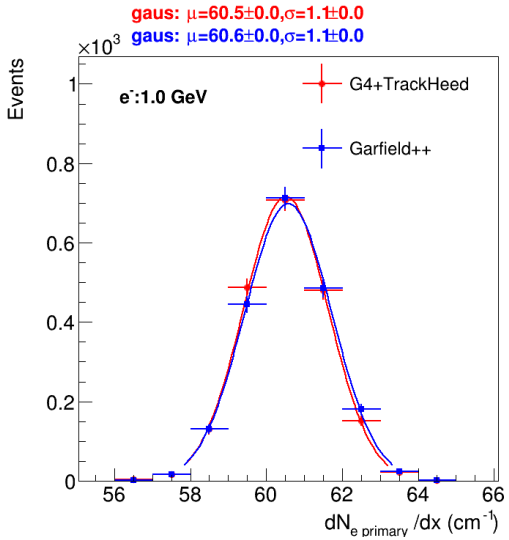
- Checking with authors:
  - This method designed to obtain correct energy deposition (or total ionizations)
  - It is true that this method will give less primary ionizations, so this method is obsoleted

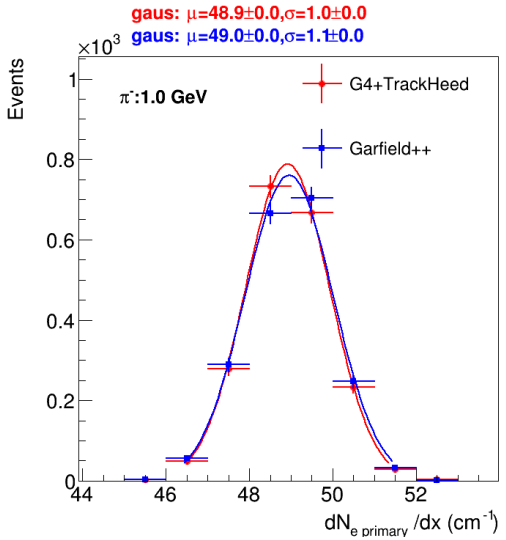
Ionization simulation in CEPCSW (TrackHeed)

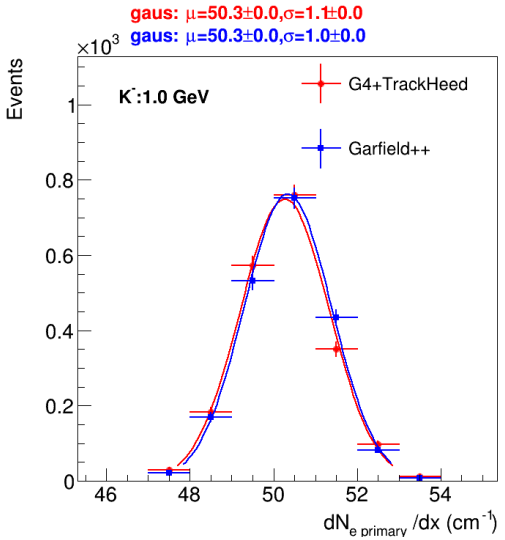
- Current method:
  - The simulation of ionization is done by TrackHeed same as Garfield++
  - The particle related information is provided by Geant4, e.g. particle type, initial position and momenta, ionization path length
- TrackHeedSimTool is created for this task
  - Input: G4Step
  - Use TrackHeed to simulate one step length (or multi-step length for speed up) ionization (new API added to Garfield++ PR)
  - Output: cluster and total ionization information (contains position, time, cell id), saved in SimTrackerHit collection
  - The kinetic energy of G4Track will be updated according to the energy loss in the ionization
  - Non-uniform magnetic field can be handled easily

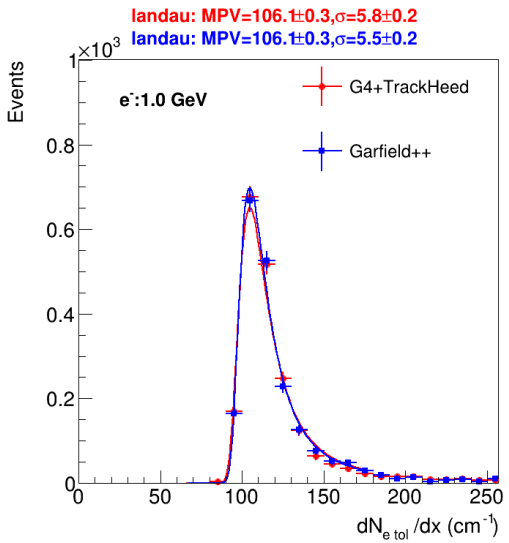
Ionization simulation performance

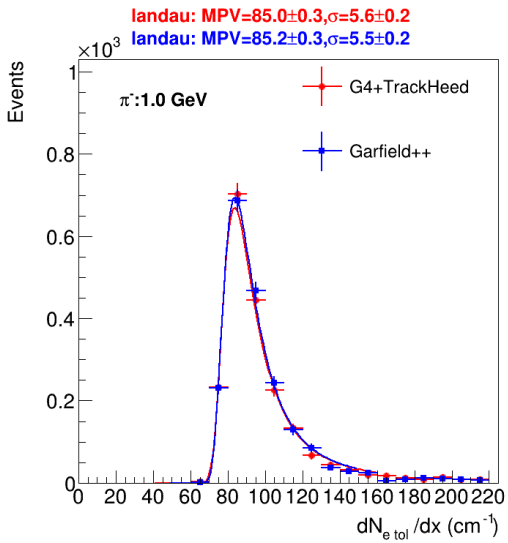
- Gas: 50% He + 50 % C_4H_{10}

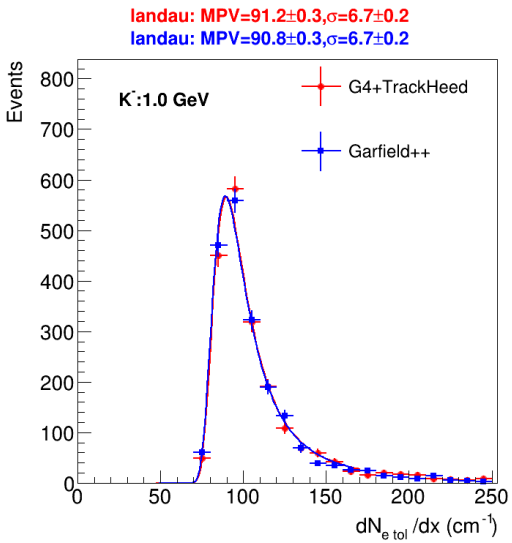








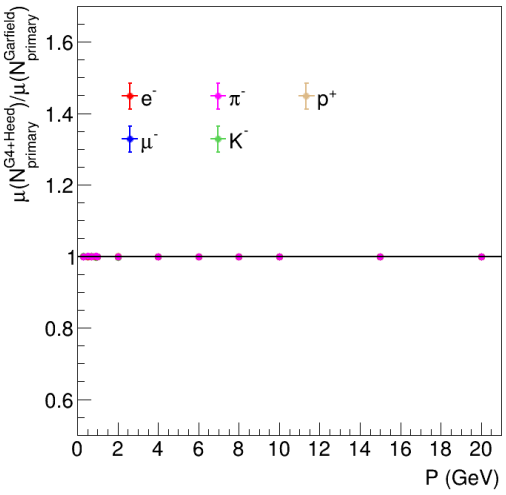


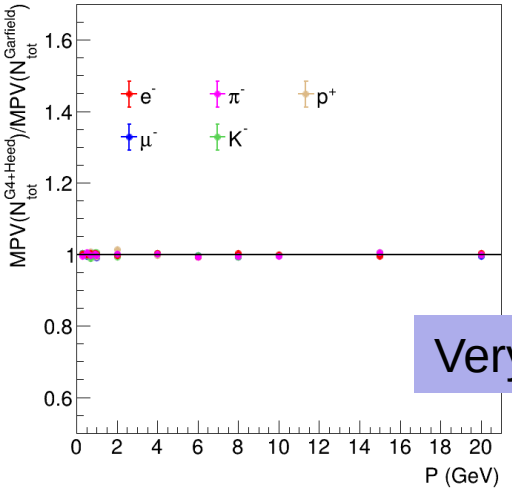


Ionization simulation performance

- Gas: 50% He + 50 % C_4H_{10}

$$\frac{\mu(N_{primary}^{G4+TrackHeed})}{\mu(N_{primary}^{Garfield++})}$$

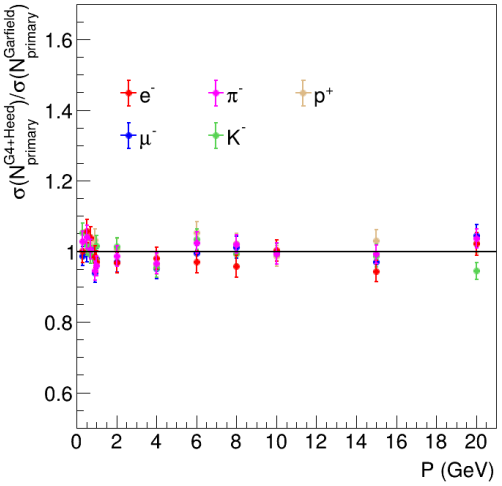


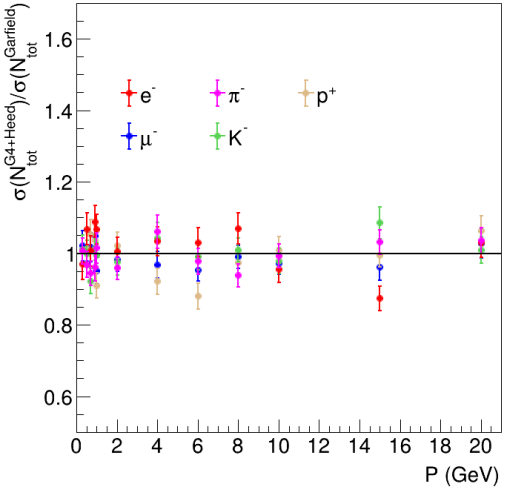


$$\frac{MPV(N_{tot}^{G4+TrackHeed})}{MPV(N_{tot}^{Garfield++})}$$

Very good agreement

$$\frac{\sigma(N_{primary}^{G4+TrackHeed})}{\sigma(N_{primary}^{Garfield++})}$$

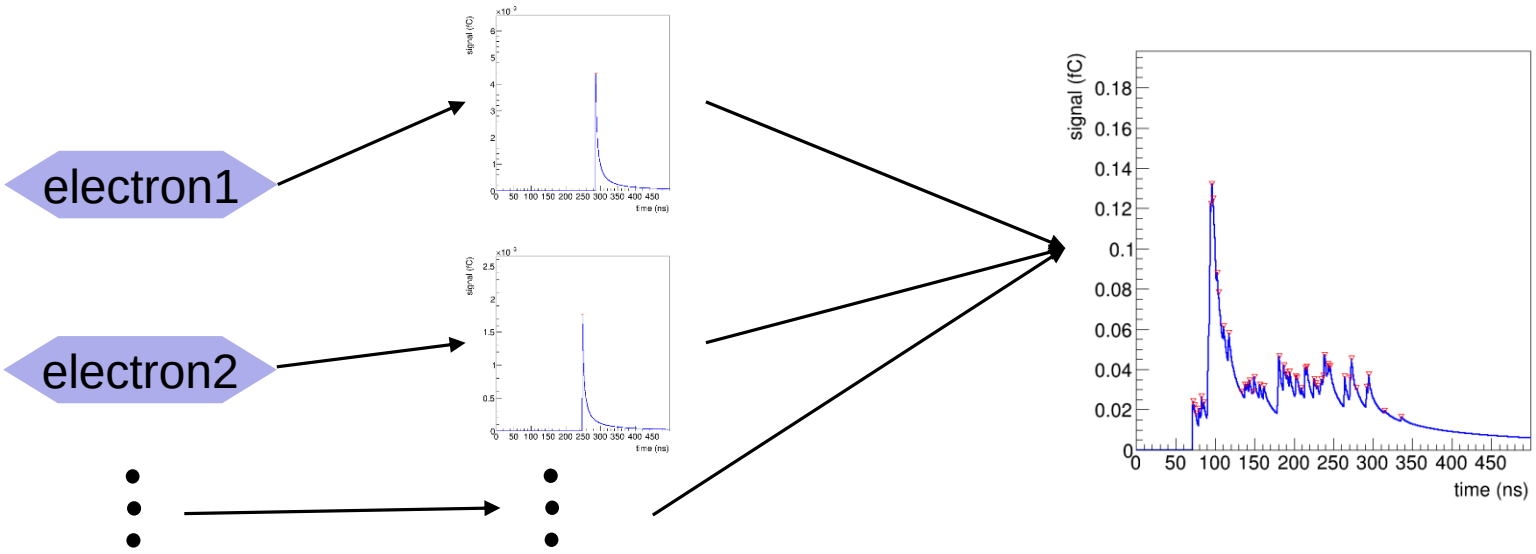




$$\frac{\sigma(N_{tot}^{G4+TrackHeed})}{\sigma(N_{tot}^{Garfield++})}$$

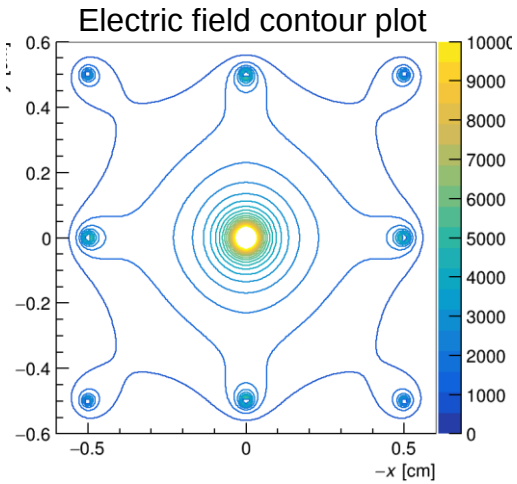
Signal simulation in CEPCSW

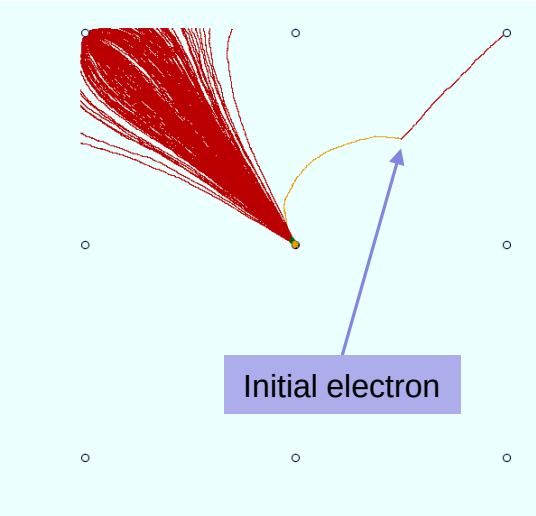
- From ionized electrons to induced currents
  - Using Garfield++, simulate the drift and avalanche of electron and drift of ions. It is slow, $\mathcal{O}(1)$ to $\mathcal{O}(10)$ seconds for different gas for one electron
  - Going to use parameterization method (parameters are based on Garfield++ simulation results), will be much faster
    - For each electron, give one induced current spectrum
    - As done by Garfield++, stacking all spectrums which come from same drift chamber cell gives final induced current for this cell

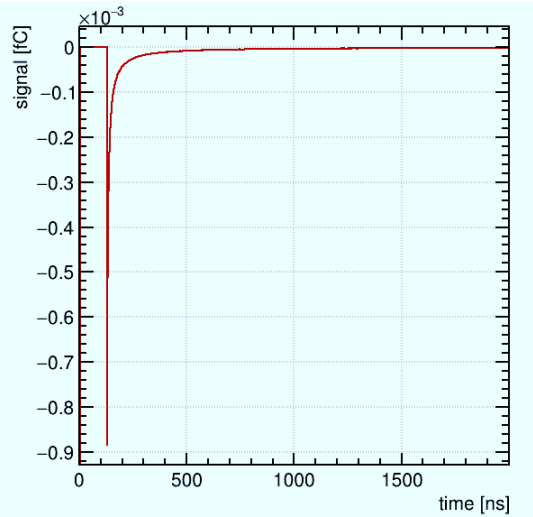


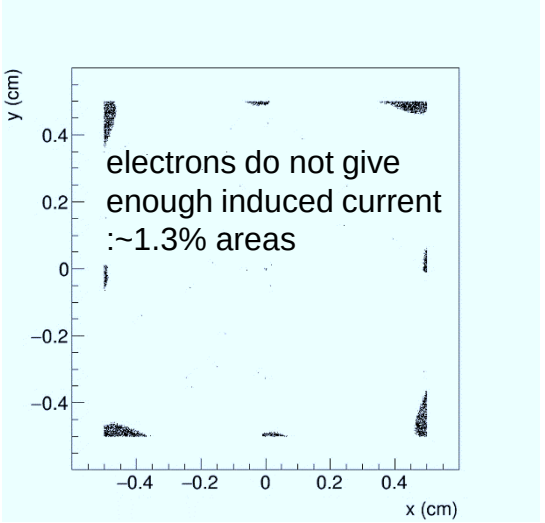
Getting parameters from Garfield++

- Garfield++ simulation:
  - 500k electrons uniformly distributed $1 \times 1\ \mathrm{cm}^2$ drift chamber cell
  - Gas: 50% He + 50 % C_4H_{10}
  - Center signal wire (2000 V), eight field wires (0 V)







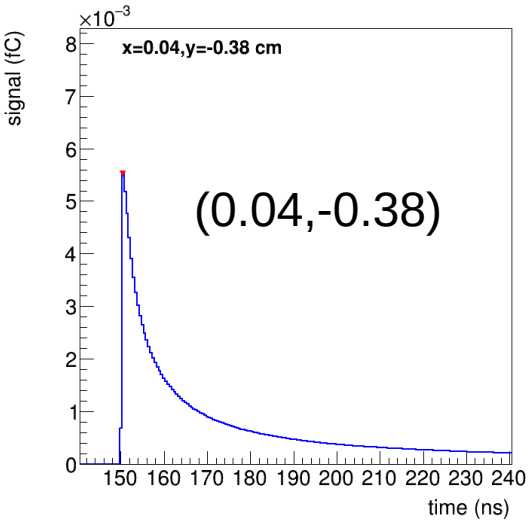


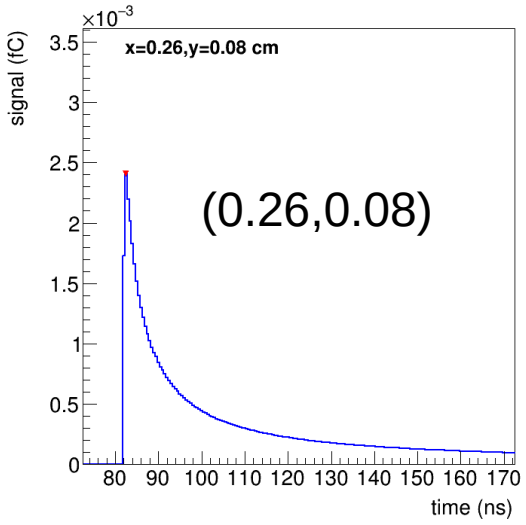
- One electron drift and avalanche
- Ions drift

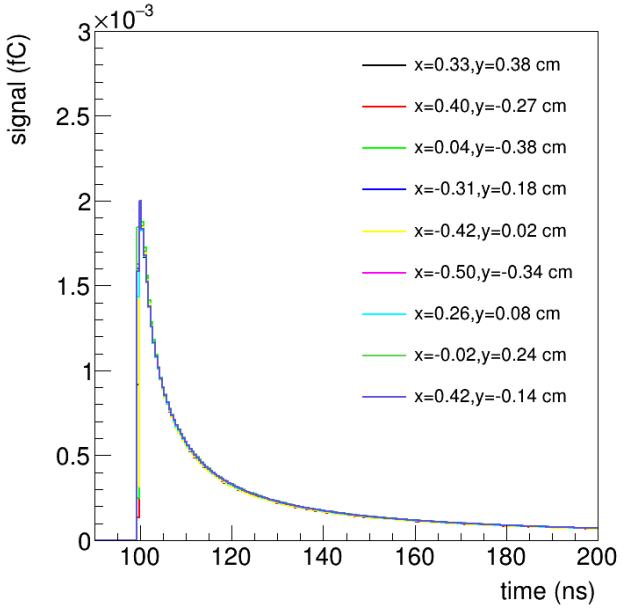
Induced current

Getting parameters from Garfield++

- After some studies, it is shown that if we shift the peak position of induced current spectrum to same value (e.g. 100 ns) and scale the peak value to same value (e.g. 2×10^{-3}), the spectrums are similar

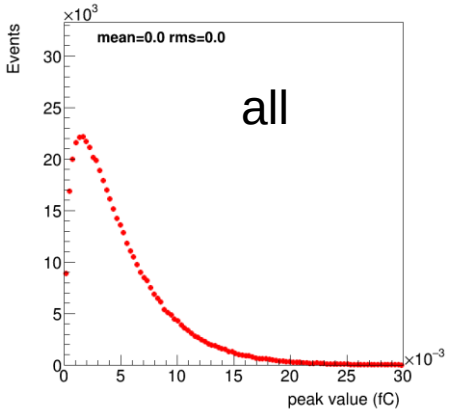


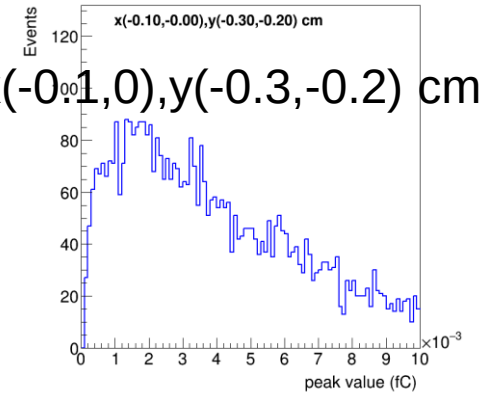


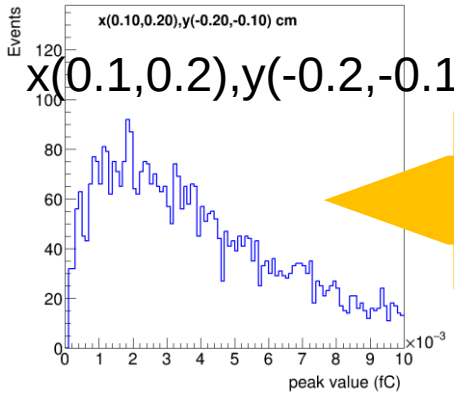


- Simulating induced current ≈ simulating (peak_time, peak_value) + using induced current template

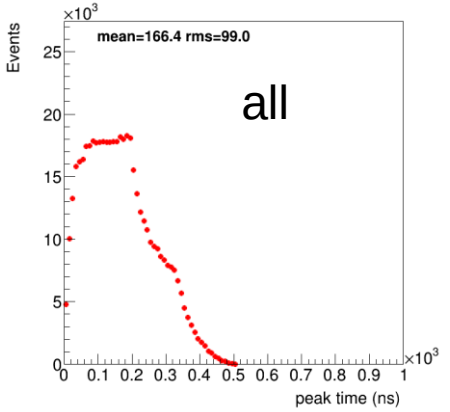
Garfield++ simulation

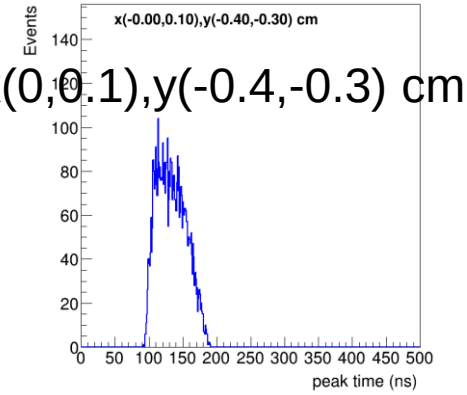


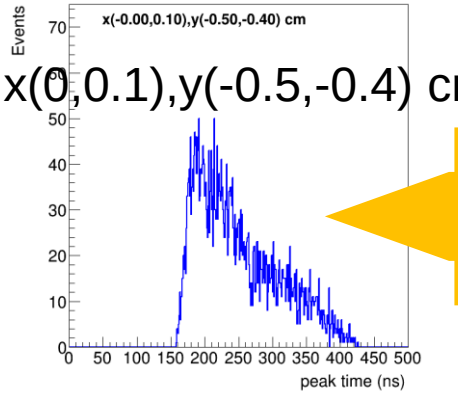




Peak value







Peak time

- Simulate (peak_time, peak_value):
  - Sampling method base on which bin the electron (x,y) is located
  - Machine learning method according electron (x, y) without binning

Summary and Plan

- A scheme of dN/dx study in CEPCSW has been presented
- The ionization simulation using Geant4 combined with TrackHeed have been implemented in CEPCSW. Results are consistent with Garfield++ simulation
- In order to speed up the avalanche simulation, a parameterized method has been studied and working in progress
- Future plan:
  - Extend EDM4hep to store waveform information (cell id, vector pairs of charge and time)
  - Electronics simulation software to be added in CEPCSW
  - Developing peak finding algorithm

Back up