The chain of the dN/dx study based on CEPCSW

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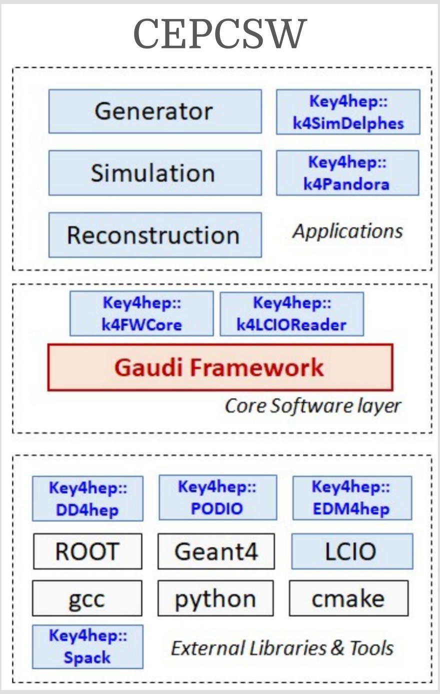
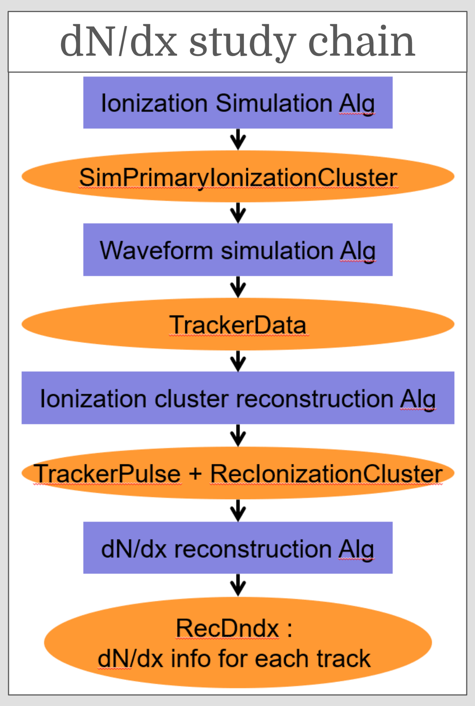
Introduction

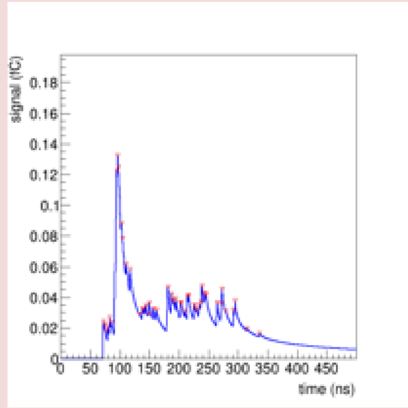
- The CEPC [1] aims to precisely measure the Higgs boson's properties. The PID is essential
- The dN/dx [2] method has great potential for the PID, while needs careful checks using a full simulation of the CEPC detector
- The CEPCSW [3] is the software for the CEPC experiment

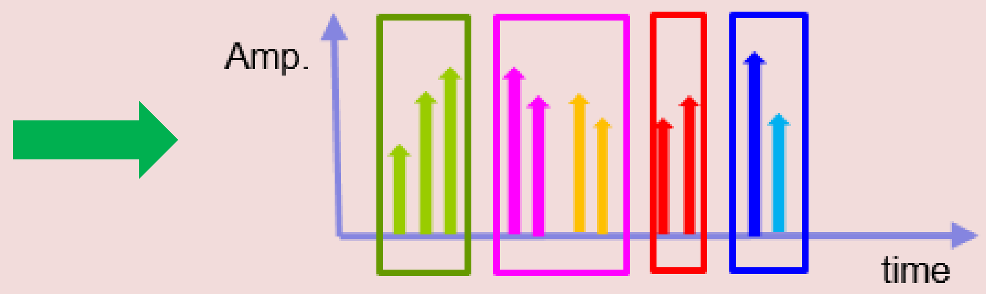




Ionization cluster reconstruction

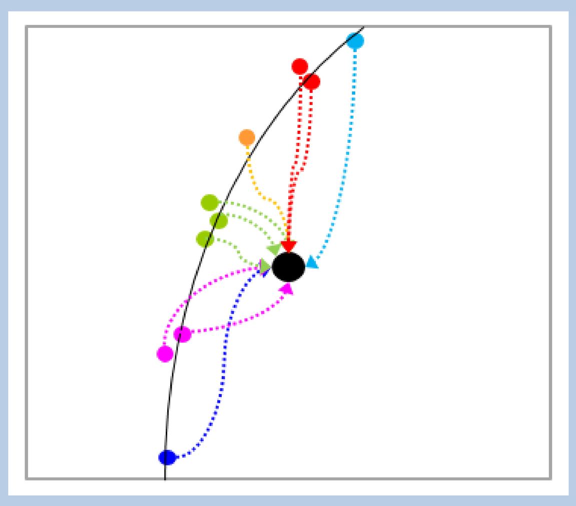
- Using simulated waveform as input
- 1, reconstructing pulses using peak finding, derivative, deconvolution, or NN, ...
- 2, clustering the reconstructed pulses into several ionization clusters. Using simple time window merge or machine learning, ...
- Outputs: reconstructed pulses and ionization clusters





Ionization simulation

- The ionization simulation is done by combining Geant4 and Garfield++ simulation [4]
- Garfield++ [5] used for ionization process simulation
- Geant4 for particle propagation (decay) in the detector, interaction with detector material, ...
- The simulation will produce the primary ionization cluster and the ionized electrons in the cluster.
- The right cartoon shows the simulation of a charged particle passing through one drift chamber cell, each point represents one ionization electron, and electrons with the same color are from the same primary ionization cluster



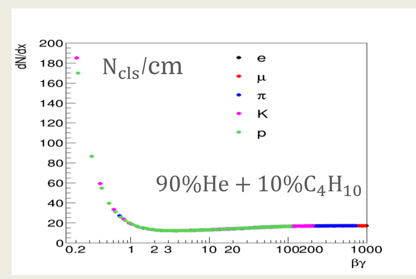
dN/dx reconstruction

- Separated into hit level and track level
- Hit level: the track length in each cell is calculated from the reconstructed track. The dN/dx measurement equals the number of reconstructed ionization clusters divided by the track length
- Track level: due to the production of delta electrons and secondary particles, the dN/dx measurements can be quite large for some cells. The truncated mean method can be used to get the unbiased dN/dx measurement
- Output: RecDndx object includes the dN/dx, particle type, chi for different particle hypotheses, ...

```
edm4dc::RecDndx:
  Description : "dN/dx info of Track."
  Author : "Wenxing Fang, IHEP"
  Members :
    - float dNdx
    - float dNdxError
    - int16_t particleType
    - int16_t type
    - std::array<edm4dc::Hypothesis, 5> hypotheses
  VectorMembers:
    - edm4dc::HitLevelData hitData
  OneToOneRelations:
    - edm4hep::Track track
```

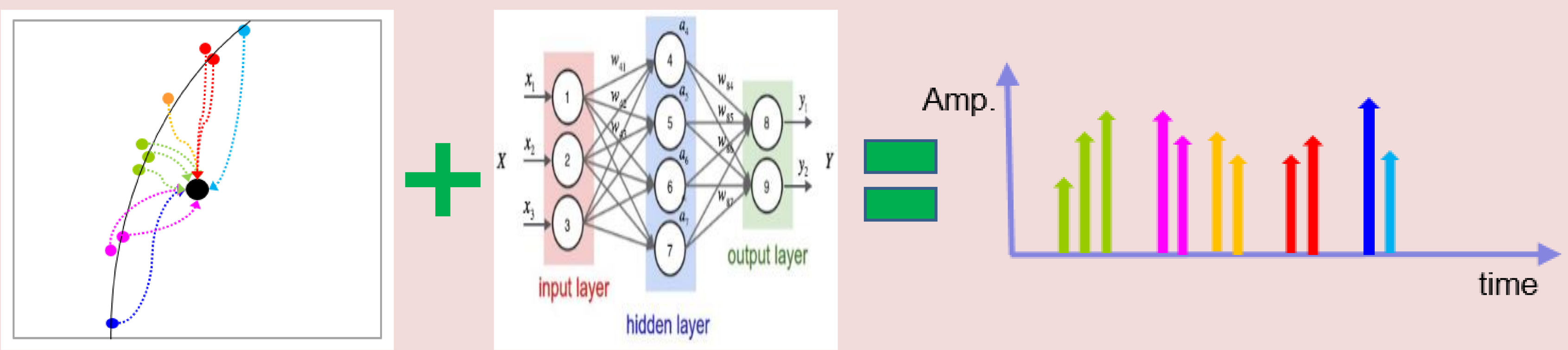
```
components:
    #---------- Hypothesis for 5 particle types
    edm4dc::Hypothesis:
      Members:
        - float chi2       // chi2
        - float expected   // expected value
        - float sigma      // sigma value

    #---------- hit level data
    edm4dc::HitLevelData:
      Members:
        - uint64_t cellID    // cell id
        - uint32_t N         // number of reconstructed ionization cluster.
        - float  eDep        // energy deposit.
        - float  pathLength  // track path length in [mm].
```



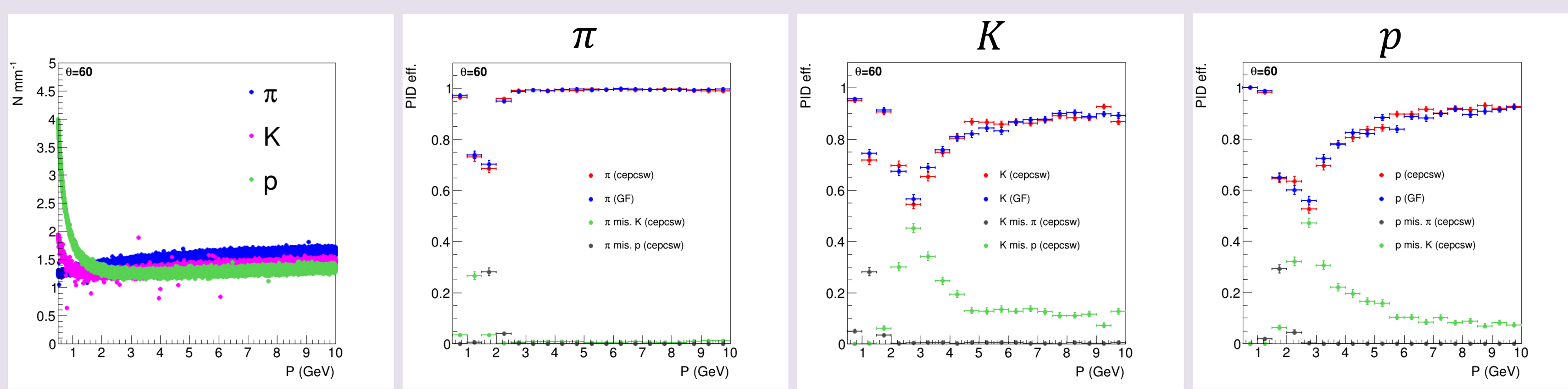
Pulse simulation

- The drift chamber contains an electromagnetic field, the produced ionized electrons and ions will drift in the cell, when the ionized electrons are close enough to the signal wire, the avalanche process will happen.
- Each ionized electron will contribute a pulse in the signal wire
- Extremely time-consuming by using Garfield++ simulation 😟
- A fast pulse simulation based on deep learning has been developed [4]: 🙂 The network learns the relation shape between the position of the ionized electron and the pulse's time and amplitude it produced



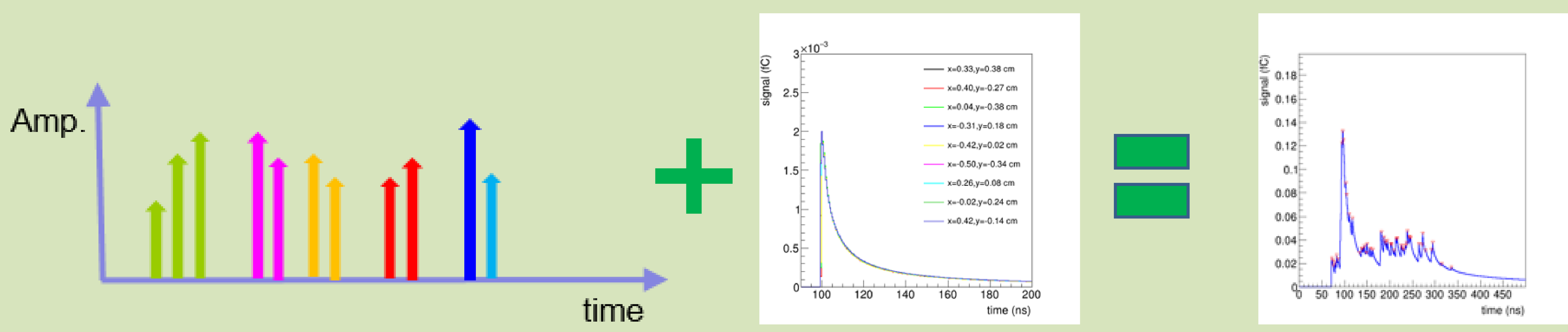
Preliminary dN/dx PID performance

- Checking the dN/dx PID performance for gas (90%He+10%C_4H_{10}) from CEPCSW and Garfield++
- By using MC truth information (number of clusters, tracker length), the PID performance obtained in CEPCSW has good agreement with the one from the standalone Garfield++ simulation



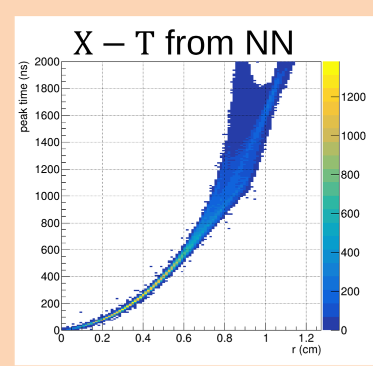
Waveform simulation

- From the Garfield++ simulation, one can find that the normalized shapes of all pulses are almost the same (independent with the ionized electron's position)
- By using a pulse shape template together with the time and amplitude properties of a pulse, one can mimic a pulse
- As done by Garfield++, piling up all pulses from the same drift chamber cell can give a final waveform
- To be more realistic, the electronic noise and response can be added to the waveform



Discussion

- More effects can be studied, such as ionizations from secondary particles, backgrounds
- Affect from track reconstruction: For example, using a more realistic drift time (X-T) simulation
- Due to the space charge effect can not be simulated by Garfield++. To workaround, extracting this effect from experimental data and applying it in the dN/dx reconstruction stage



Reference

[1] Group T C S 2018 CEPC Conceptual Design Report: Volume 2 - Physics & Detector (Preprint 1811.10545)
[2] Cuna F et al. 2021 Simulation of particle identification with the cluster counting technique (Preprint 2105.07064)
[3] CEPCSW https://github.com/cepc/CEPCSW
[4] ACAT talk: https://indico.cern.ch/event/855454/contributions/4596445/
[5] Garfield++ https://garfieldpp.web.cern.ch/garfieldpp/

Conclusion

- Performing a detailed dN/dx study is important.
- Compared with doing a dN/dx study based on standalone Garfield++ simulation, doing a dN/dx study in CEPCSW will be more realistic, such as the effects from second particles, track reconstruction and so on can be considered
- The chain of dN/dx study based on CEPCSW consists of four main steps which are ionization+ pulse simulation, waveform simulation, ionization cluster reconstruction, and the dN/dx reconstruction
- Preliminary dN/dx PID results from CEPCSW and standalone Garfield++ simulation show good agreement
- Developers can develop their own ionization cluster reconstruction and dN/dx reconstruction algorithms in CEPCSW and check the PID performance easily