Digitization in the IDEA Drift Chamber FCC-ee

Name: **Muhammad Saiel**

University: **Politecnico di Bari and INFN Bari-Section**

Department: **Engineering and Aerospace Sciences**

Supervisor: **Prof. Nicola De Filippis**

Dr. Guang Zhao

FCC Group

Simulation Steps Performed

1. Track-Cell Interaction:

- **The simulated particle track (from Geant4) is intersected with the active gas volume of the drift cell.**
- **This defines the segment length (ℓ) of the track inside the cell — the region where ionization occurs.**

2. Ionization Length:

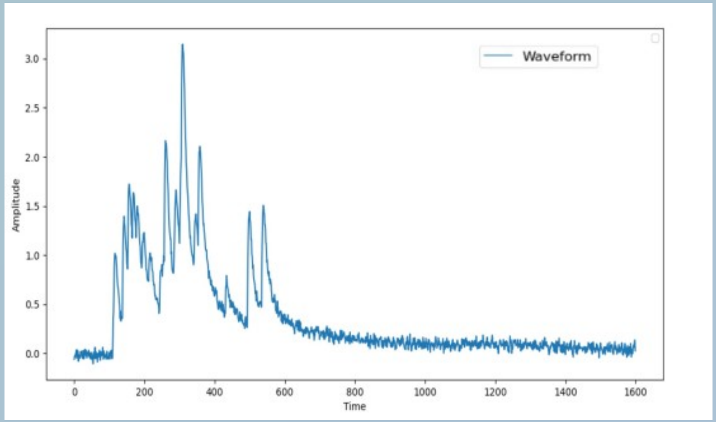
- **The ionization length ℓ represents how far the charged particle travels within the cell gas (He–Isobutane 90:10).**

3. Cluster Generation:

- **Along ℓ, clusters are randomly generated following:**
  1. **Poisson distribution for the number of clusters**
  2. **dNcl/dx from Bethe–Bloch-like parameterizatio**

4. Number of Electrons:

- Extract the number of electrons
  -
  -
  -
  -



Digitization

Reproduced the simulated Hit:

- **Gun Particle:** Muon, Proton, Pion, Kaon
- **Number of muons:** 1, 10, 100 (the number increased to increase the statistics)
- **Coordinates:** The gun particle fired from (0,0,0) $\rightarrow$ (1,1,1)
- **Momentum:** 10 GeV
- **GEANT4 steps:** Geant4TrackerWeightedAction

Note: All this setting can be done in the steering file.

Mathematical Formulae

1. Bethe-Bloch Formula:

$$\frac{dE}{dx} = K \cdot \frac{z^2 Z}{A} \cdot \frac{1}{\beta^2} \left[\frac{1}{2} \ln \left(\frac{2 m_e \beta^2 \gamma^2 T_{\max}}{I^2} \right) - \beta^2 - \frac{\delta}{2} \right]$$ (MeV cm^2 / g)

2. Multiply with Density of the gas:

$$\frac{dE}{dx} = \rho \cdot \left(\frac{dE}{dx} \right)_{\text{mass}}$$ (MeV / cm), $\rho = 0.0003984$ g/cm3

3. Cluster Density (Number of clusters per cm)

$$\frac{dN}{dx} = \frac{1}{W} \frac{dE}{dx}$$ (N/ cm) W = 110 eV

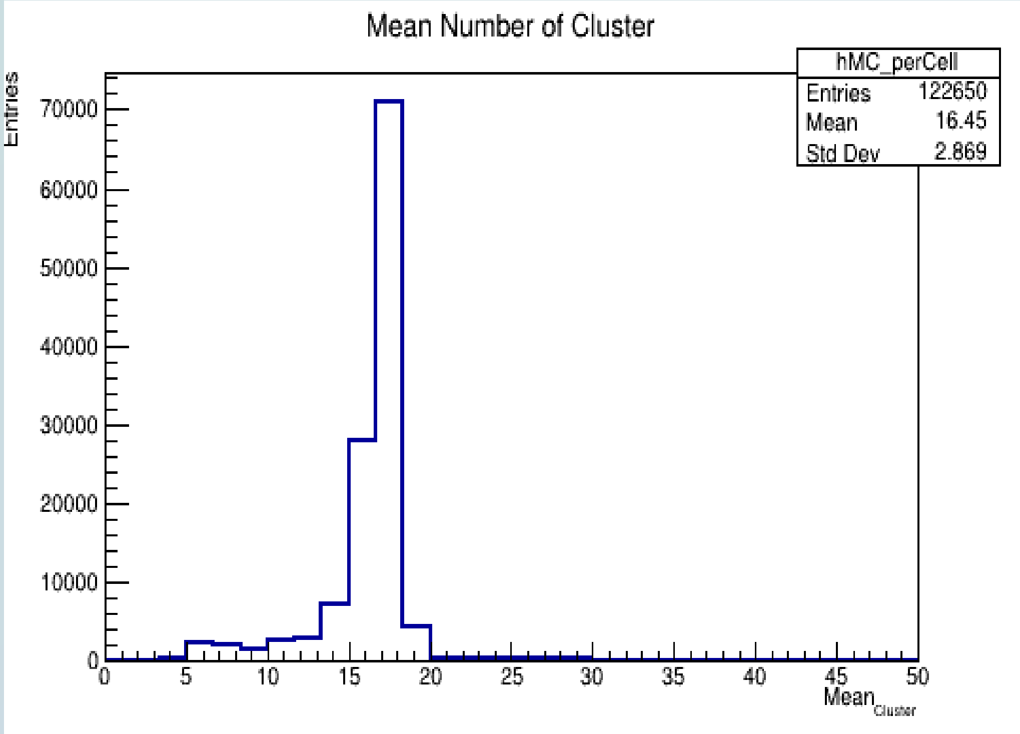
Ref: Average energy required to produce an ion pair. ICRU Report 31. Washington, DC: International Commission on Radiation Units and Measurements, 1979.

Mean Number of Clusters

Mean Number of Clusters:

$$\mu = \lambda \times l_{cm}$$

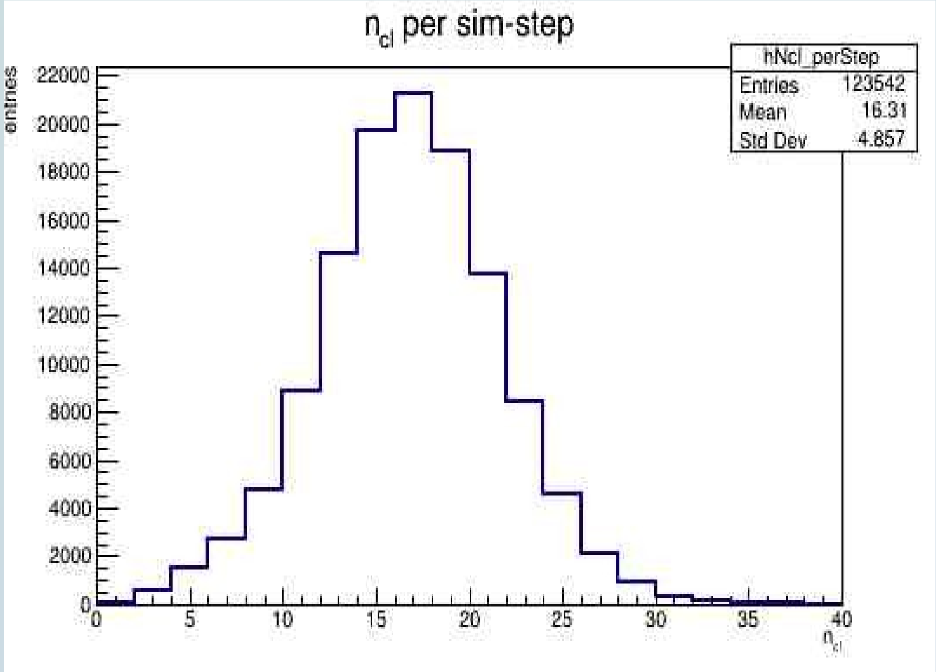
$\lambda = dN/dx$



Number of Clusters

Point 1: The number of Clusters can be Calculated using Poisson distribution:

$n_{cl} = pois(\mu)$

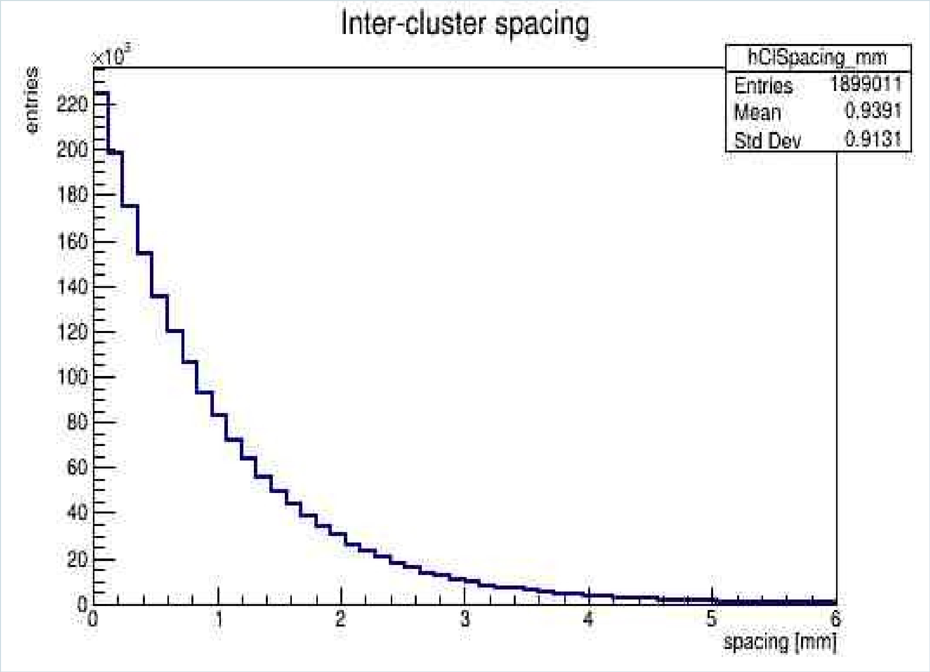


Cluster Spacing

Distribution of the Inter Spacing between clusters:

Logic:

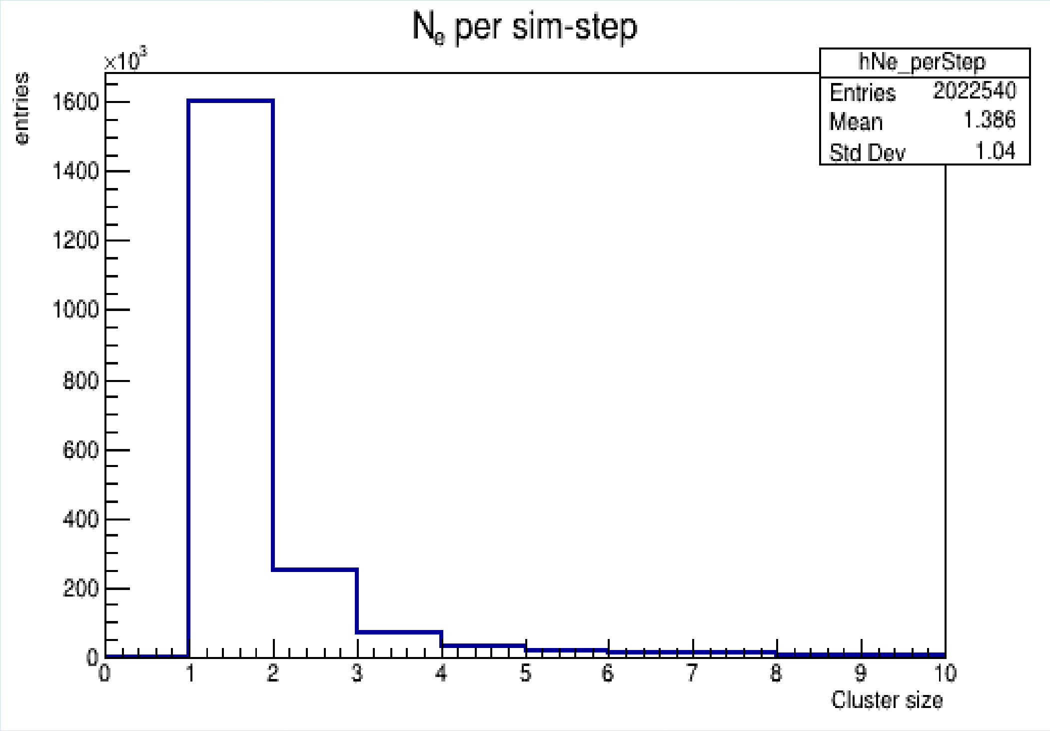
The cluster spacing is calculated from the difference between the next cluster's position and the previous one's.



Number of Electron

Point 2: Distribution of the number of electrons:

Sampled from the experimental probability distribution



$$P(n_e = 1) \approx 0.78$$
$$P(n_e = 2) \approx 0.12$$
$$P(n_e = 3) \approx 0.034$$

.

.

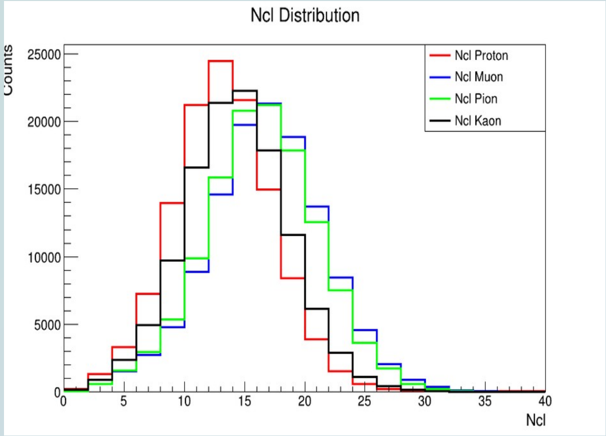
.

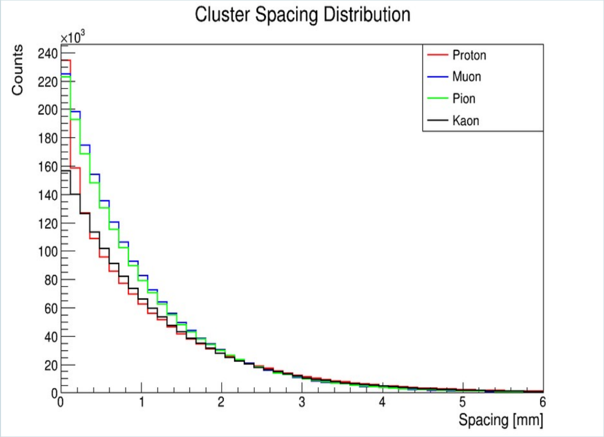
Ref: H. Fischle, J.Heintze and B. Schmidt, Experimental determination of ionization clustersize distributions in counting gases, NIMA 301 (1991)

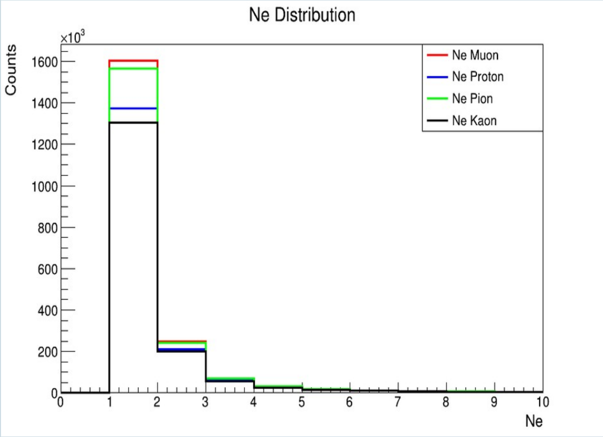
Extending Simulation

The simulation is further extended to more particles Proton, Pion, and Kaon.

- For different Particles, λ(βγ) is different







Normalized Number of Cluster

Problem: Different path lengths each drift cell.

$$\mu_i = dN/dx \times l_i \quad \longrightarrow \quad n_{cl} = \text{Poisson}(\mu_i)$$

If we histogram raw cluster counts from all the cells, we mix many Poisson distributions

Normalization: Divide the cluster count by the path length to obtain clusters per length

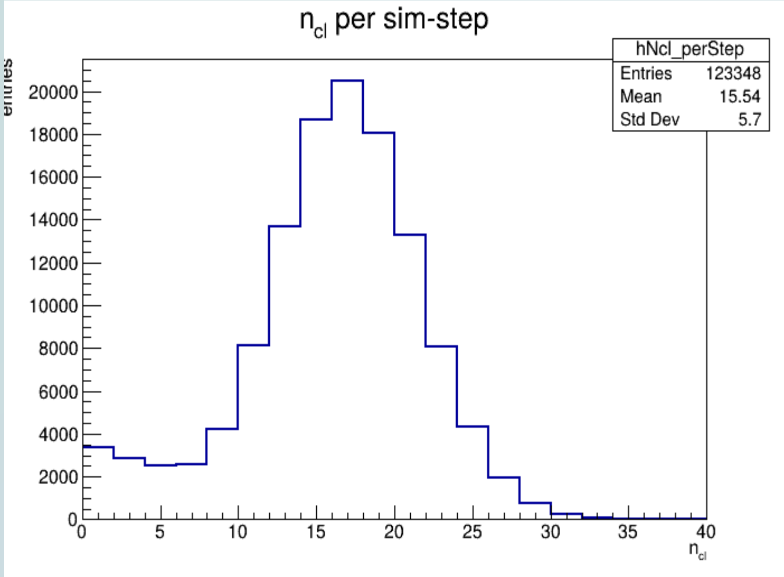
$$\mathbf{Ncl = n_{cl} \,/\, pathLength}$$

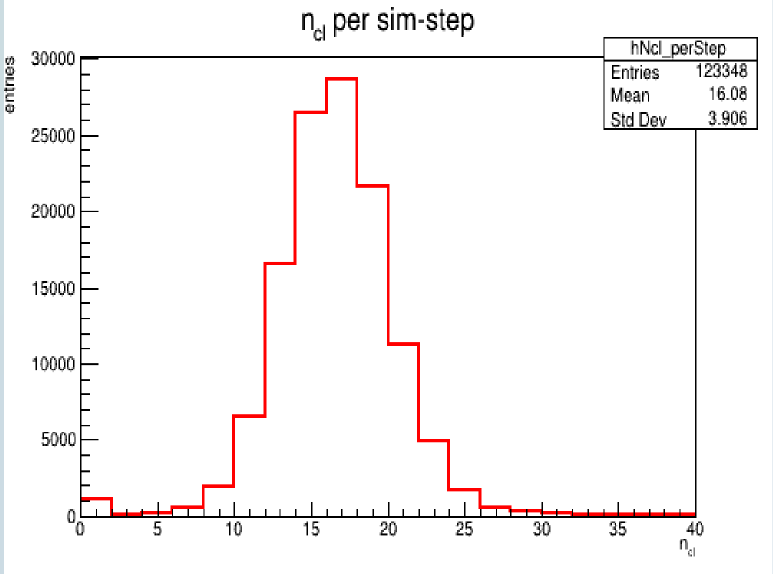
```
Layer: 1      Cell Number: 23 pathLength: 14.5349 mm
Layer: 2      Cell Number: 25 pathLength: 15.0203 mm
Layer: 3      Cell Number: 23 pathLength: 15.522 mm
Layer: 4      Cell Number: 25 pathLength: 16.0406 mm
Layer: 5      Cell Number: 23 pathLength: 16.5767 mm
Layer: 6      Cell Number: 25 pathLength: 17.1309 mm
Layer: 7      Cell Number: 22 pathLength: 17.7038 mm
Layer: 8      Cell Number: 25 pathLength: 18.296 mm
Layer: 9      Cell Number: 28 pathLength: 15.0762 mm
Layer: 10     Cell Number: 32 pathLength: 15.4785 mm
Layer: 11     Cell Number: 28 pathLength: 15.8918 mm
Layer: 12     Cell Number: 32 pathLength: 16.3163 mm
Layer: 13     Cell Number: 28 pathLength: 16.7522 mm
Layer: 14     Cell Number: 32 pathLength: 17.2 mm
Layer: 15     Cell Number: 28 pathLength: 17.6599 mm
Layer: 16     Cell Number: 32 pathLength: 18.1323 mm
Layer: 17     Cell Number: 33 pathLength: 15.4801 mm
Layer: 18     Cell Number: 39 pathLength: 15.8247 mm
Layer: 19     Cell Number: 33 pathLength: 16.1772 mm
Layer: 20     Cell Number: 39 pathLength: 16.5376 mm
Layer: 21     Cell Number: 33 pathLength: 16.9063 mm
```

Number of Clusters

Normalized Number of Cluster: $\mathrm{Ncl} = n_{cl}/\mathrm{pathLength}$

W = 110 eV → 56 eV





Thank you

Questions