Progress on the Digitization of TPC of CEE Experiment

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Outline

- Basics of Detector Simulations
- Study of Momentum Resolution
- TPC Digitization
- Future work

Reference taken from MPD, PANDA and ALICE Experiment

Questions, comment, suggestion always welcome!!

Basics of Detector Simulations

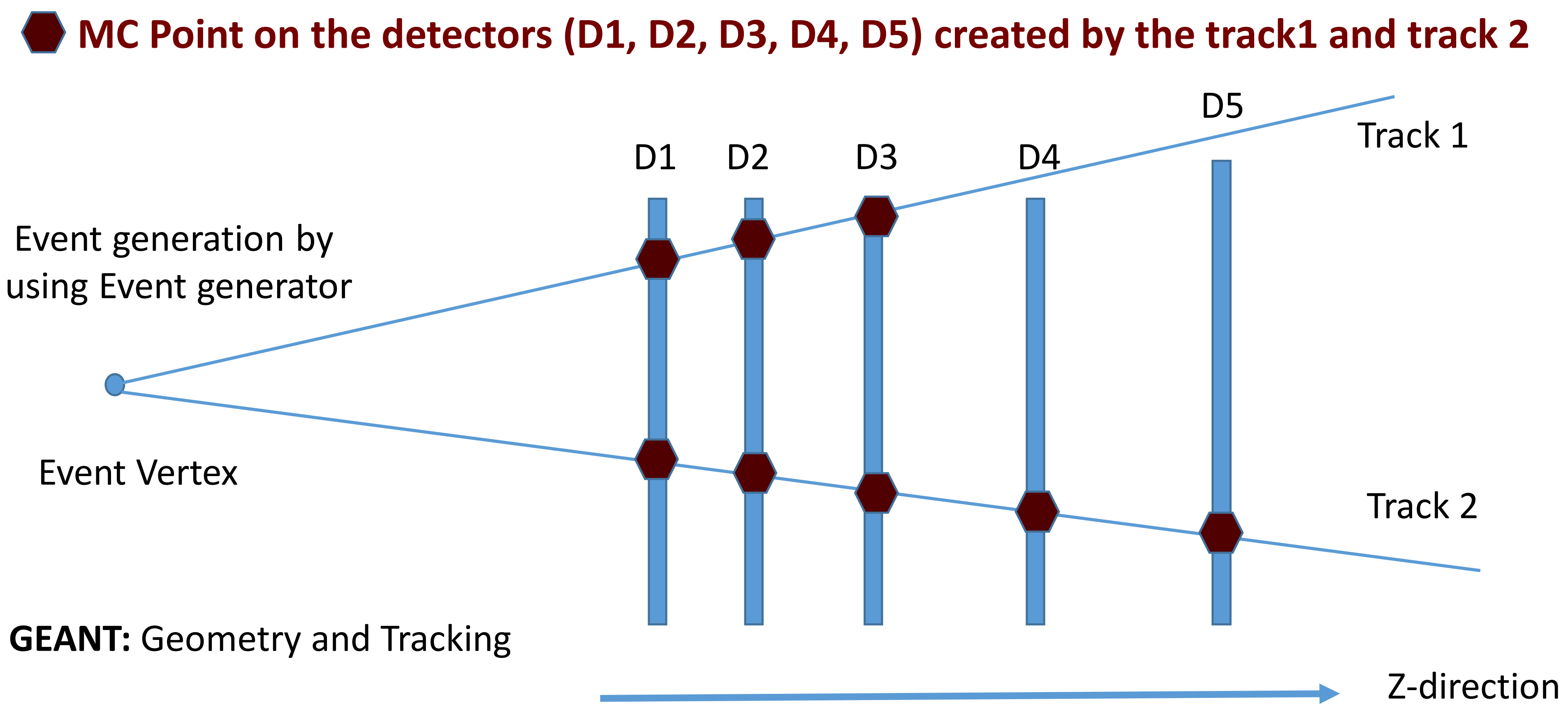
❖ Main five steps for detector simulations

- **Simulation**
- **Digitization**
- **Reconstruction**
- **Particle Identification**
- **Event Display**
- **Physics Analysis**

Simulation

- Generation of Events using event generator e.g. Box Generator, PYTHIA, HIJING etc.
- Event consists many particles, these particles are propagated to the detector material by using the transport model e.g. GEANT3, GEANT4, FLUKA.
- The particle interact with the detector material gives the MC Point on the detector material

MC Point on the detectors (D1, D2, D3, D4, D5) created by the track1 and track 2



GEANT: Geometry and Tracking

Example:

- Assume in the above case in an event two tracks are created Track1, Track2.
- In the simulation step in the root file, we will get the branches e.g. MCTrack, D1Points, D2Points, D3Points, D4Points, D5Points

❖ MCTrack:

- In the above case, It will register two entries corresponds to track 1, track 2.
- Each track has a unique Id know as Track Index (Track ID starts from 0), Mother ID (=-1 for primary tracks), PDG Code etc.

❖ MC Points on Detectors:

- Each track when it hits the detectors registered as the MC Point on the detector plane.
- For each point you can get, Track ID, Mother ID, PDG Code, Px, Py, Pz, X, Y, Z, Energy loss etc.
- In the above example D1, D2, D3 will show 2 entries while D4, D5 only one entry.

In general, we can access any information about the track and MC Points, means we know every thing!!!!

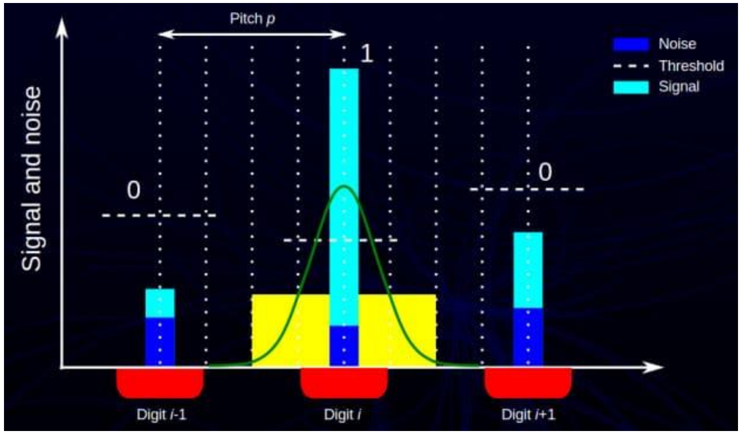
Digitization

I am handling it

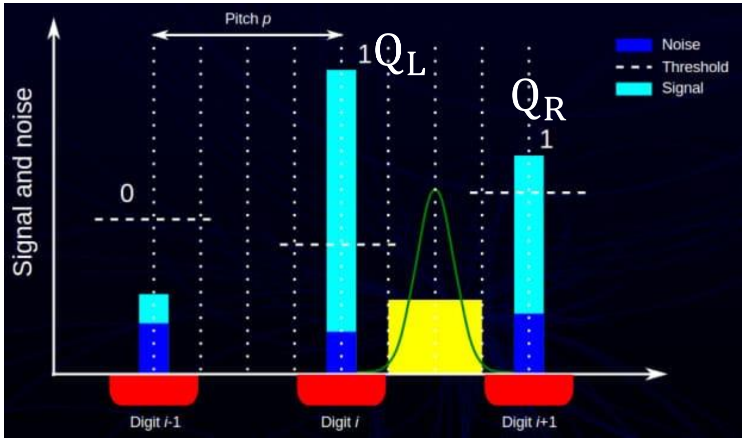
❖ We have thrown a known particle (everything is known), we will try to reconstruct the position of particle (X, Y, Z) with the help of the signal created (due to energy loss) on the detector planes

$$\text{Charge Created (Q)} = \frac{\text{Energy Deposited}}{\text{Mean Energy required to create e}-\text{hole pair}}$$

Example of Strip detector (1D)



Single Strip Cluster



Two Strip Cluster

Q_L and Q_R: Charge on left and right strips

$$Q = Q_L + Q_R$$

ENC: Equivalent Noise Charge

Left (Digital and Analog readout): $\text{X Position} = X_i$

$$\sigma_x = \text{Pitch}/\sqrt{12}$$

Right: (Digital): $\text{X Position} = \frac{X_i + X_{i+1}}{2}$

$$\sigma_x = \text{Pitch}/(2 * \sqrt{12})$$

Right: (Analog): $\text{X Position} = X_i + \frac{Q_R}{Q_L + Q_R} * \text{Pitch}/2$

COG: Center of Gravity

$$\sigma_x \propto \frac{\text{Pitch}}{\frac{\text{Signal}}{\text{ENC}}}$$

Ref: Manfred Valentan. Eta correction for silicon sensors. Connecting the Dots, Vienna:1–13, 2016.

- In the digitization, we take many effects in to accounts electronics etc. to reconstruct x, y, z and also on the resolution.

- After hit reconstruction, we can always check, how close the reconstructed x, y, z (in digitization) to the x, y, z in the simulation.

- The output of reconstructed hit position and resolution is used for the pattern recognition which is used as the input for the Kalman filter to reconstruct the whole trajectory.

- The multiple scattering, inhomogeneous magnetic field are taken in to account in the covariance matrix.

Reconstruction

- This includes the tracking and reconstruction of full particle trajectory to the primary vertex to get the momentum of particles.

- Two cases:

✓ In the homogenous magnetic field with no multiple scattering effect: Helix fit for the track

  - Simply fit a circle in X-Y plane and fit and straight line in r-z plane.

✓ In the non-homogenous magnetic field and multiple scattering effect: More general case fit the track by using Kalman filter algorithm (Covariance Matrix)

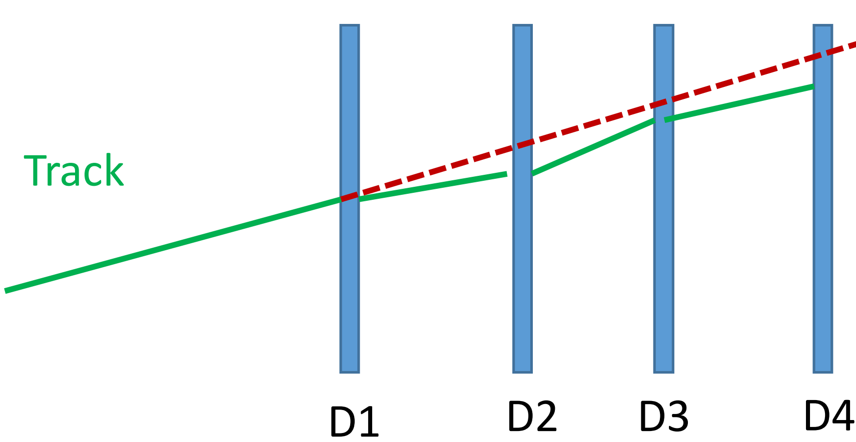
- The output of pattern recognition is used as the input for the Kalman filter algorithm which fits the tracks iteratively until convergence criteria are met (e.g. Chi2 for the fit <1).

- One track is reconstructed we can reconstruct x, y, z, and px, py, and pz.

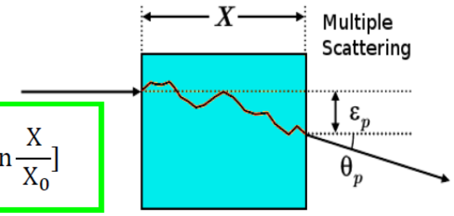
$\mathrm{p_{rec}}$: Reconstructed Momentum
$\mathrm{p_{MC}}$: True Momentum

$$\text{Momentum resolution} = \frac{(\mathrm{p_{rec}} - \mathrm{p_{MC}})}{\mathrm{p_{MC}}}$$

Aim: To achieve $\mathbf{p_{rec}}$ as close as $\mathbf{p_{MC}}$ typically around < 1 %



$$\theta_p = 13.6\frac{\mathrm{MeVz}}{\beta cp}\sqrt{\frac{X}{X_0}}\left[1 + 0.038\ln\frac{X}{X_0}\right]$$

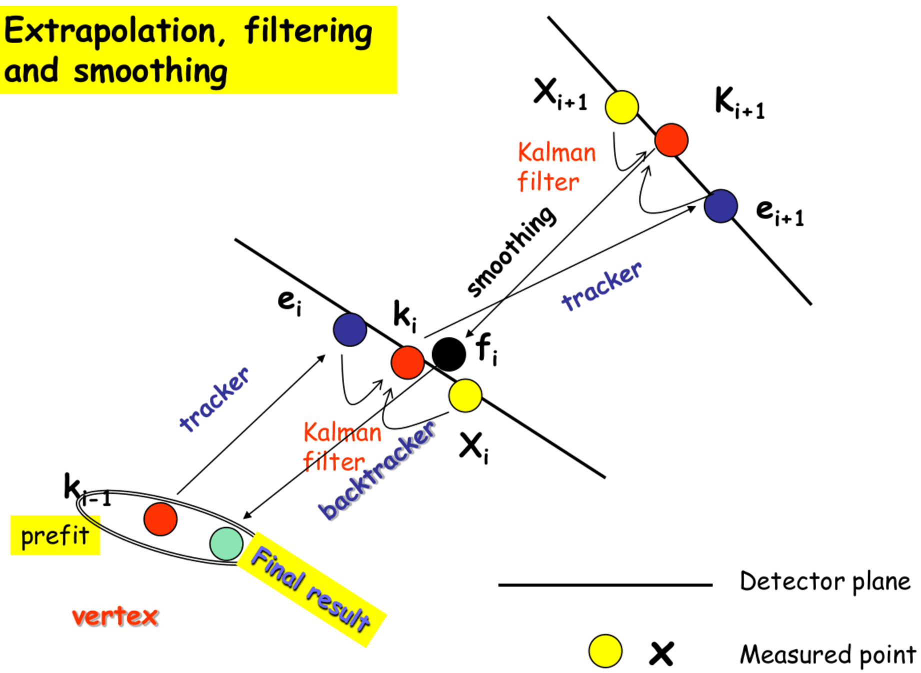


$$\epsilon_p \approx \frac{1}{\sqrt{3}}\theta_p X$$

Ref: "Particle Detectors", C. Grupen and B. A. Shwartz

At low p: $\mathrm{m.s.\,dominated\ by} \propto \frac{1}{p}$

At high p: $\mathrm{m.s.\,dominated\ by} \propto \sqrt{\frac{X}{X_0}}$



Track passing from multiple detector planes: multiple scattering can effect direction (Effect very large at low momentum)

Kalman Filter (Three Steps):

- **Extrapolation:** Theoretical predication of a track on a detector plane with M.S.
- **Filtering:** Weighted average of measured position and extrapolated position
- **Smoothening :** Smoothening of track

If Mag field = 0: Linear extrapolation

If Mag field $\neq$ 0 : Non linear extrapolation (Parabolic)

Ref:Alberto Rotondi. A fast introduction to the tracking and to the Kalman filter. Alghero, 2009.

We start seed position for the fit from the outwards (low track density)

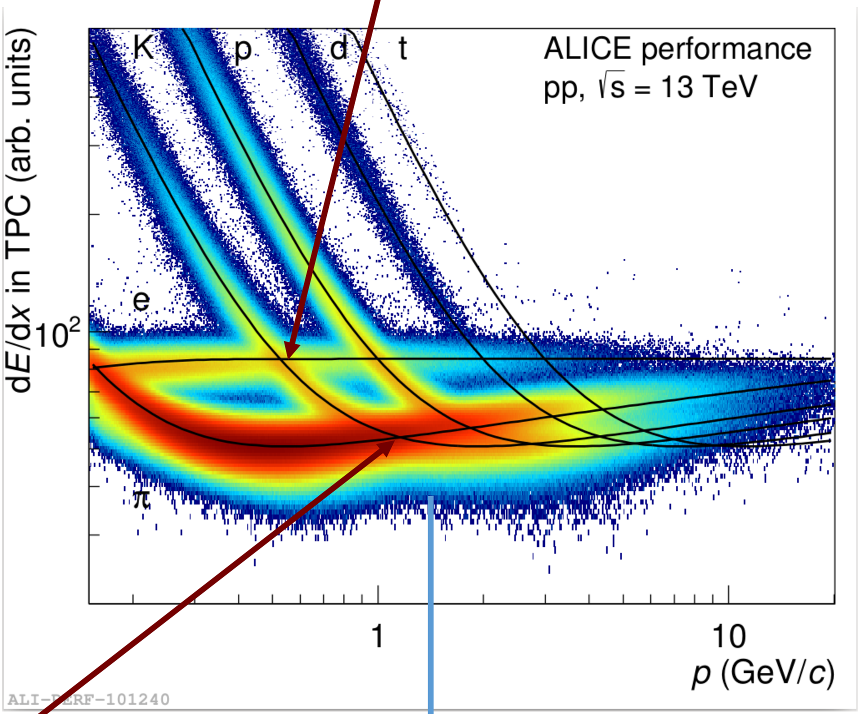
Particle Identification

Different Particle Identification Methods:

❖ **Energy loss vs Momentum:**

- Low momentum range (< 1 GeV/c) after a certain momentum particle becomes Minimum Ionizing particle so no track by track PID possible. In the large momentum range we can use statistical method by using relativistic rise.
- One more issue of band crossing at which no separation of particles we have to use other method

Band crossing: no separation

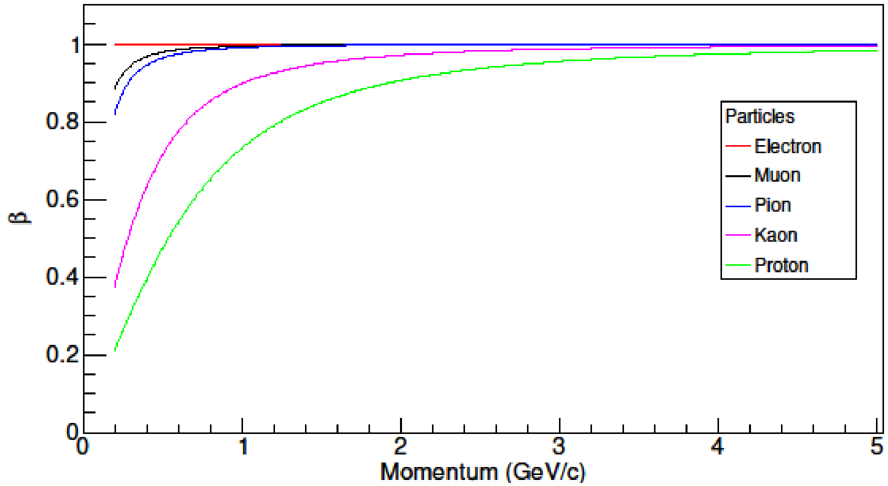


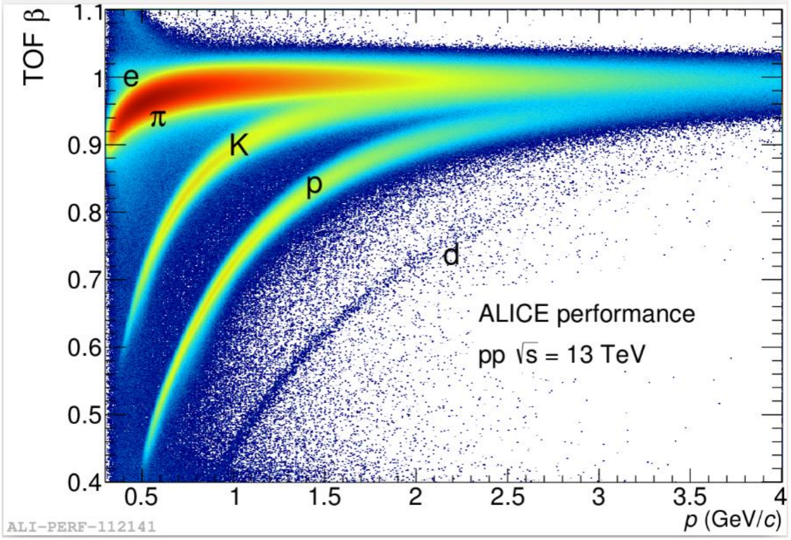
Band crossing: no separation

Band merging due to MIP and Gaussian distribution of energy loss

❖ Time of flight (Beta vs Momentum):

- The method is used in the middle momentum range
- In the right plot, as we go at high momentum beta is close to 1.
- The particle bands can be separated of we have good detector time resolution (small) adapted detector in CEE is MRPC (Multi-Gap Resistive Plate Chamber)
- Electron has lowest mass so beta close to 1.
- At a fixed momentum time distribution of particle follows the Gaussian distribution



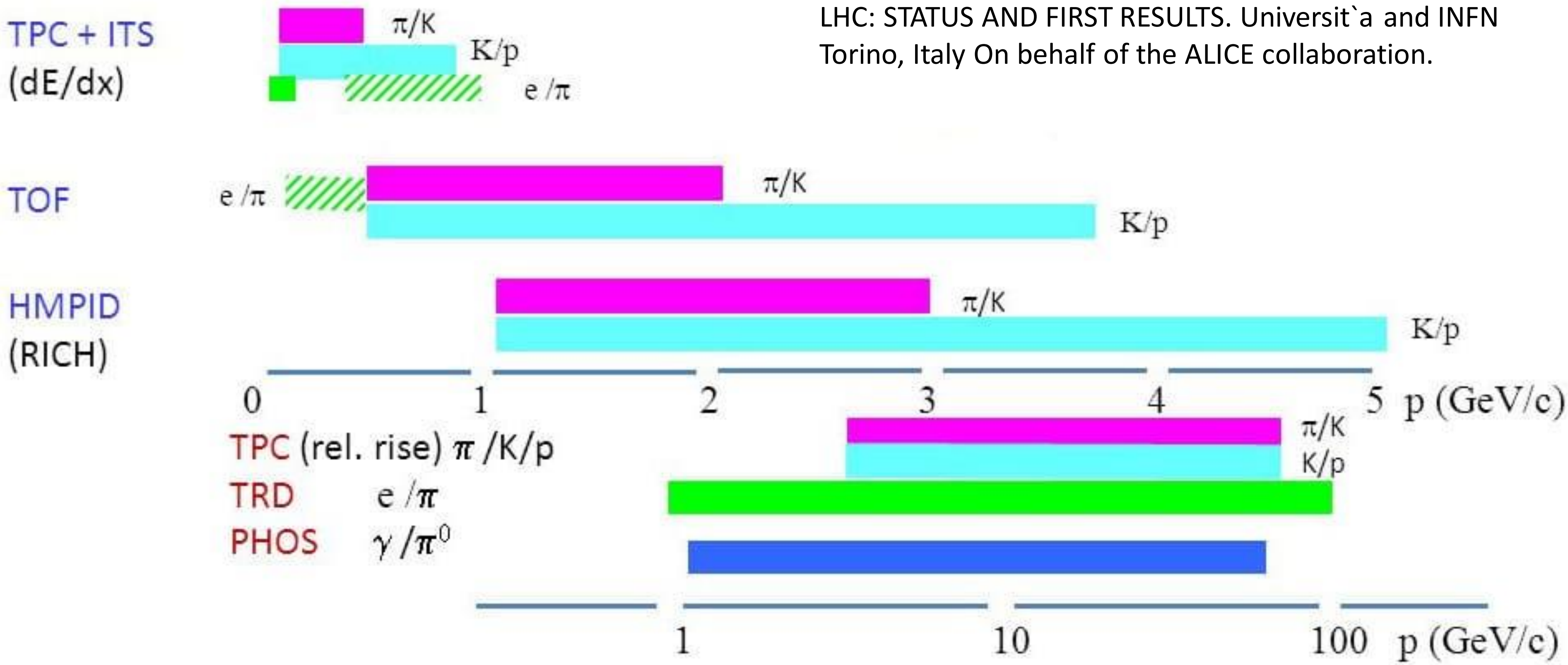


❖ Cherenkov Method: (Cherenkov angle vs Momentum)

- High momentum particle emits Cherenkov radiation which is used to identification of particles in large momentum range. (Not used in CEE)

Different Methods of Particle Identification in different ranges

Ref: Ermanno Vercellin. THE ALICE EXPERIMENT AT CERN LHC: STATUS AND FIRST RESULTS. Universit`a and INFN Torino, Italy On behalf of the ALICE collaboration.



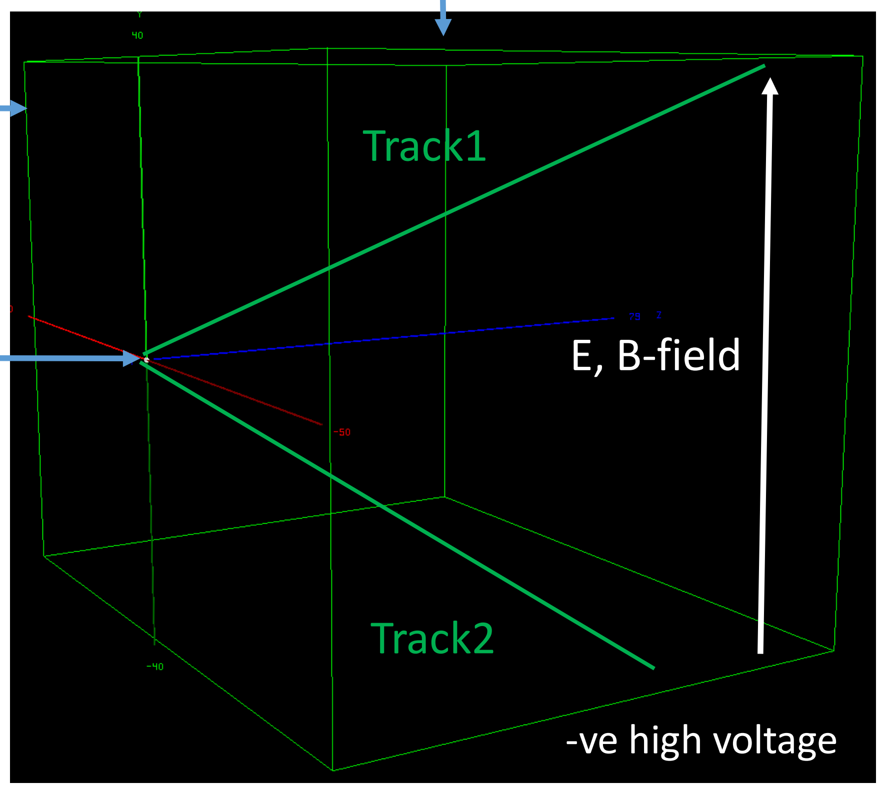
❖ Event Display:

❖ Graphic use interface which can be used to visualize the tracks, MC Points, Hits, Geometry etc.

Physics Analysis

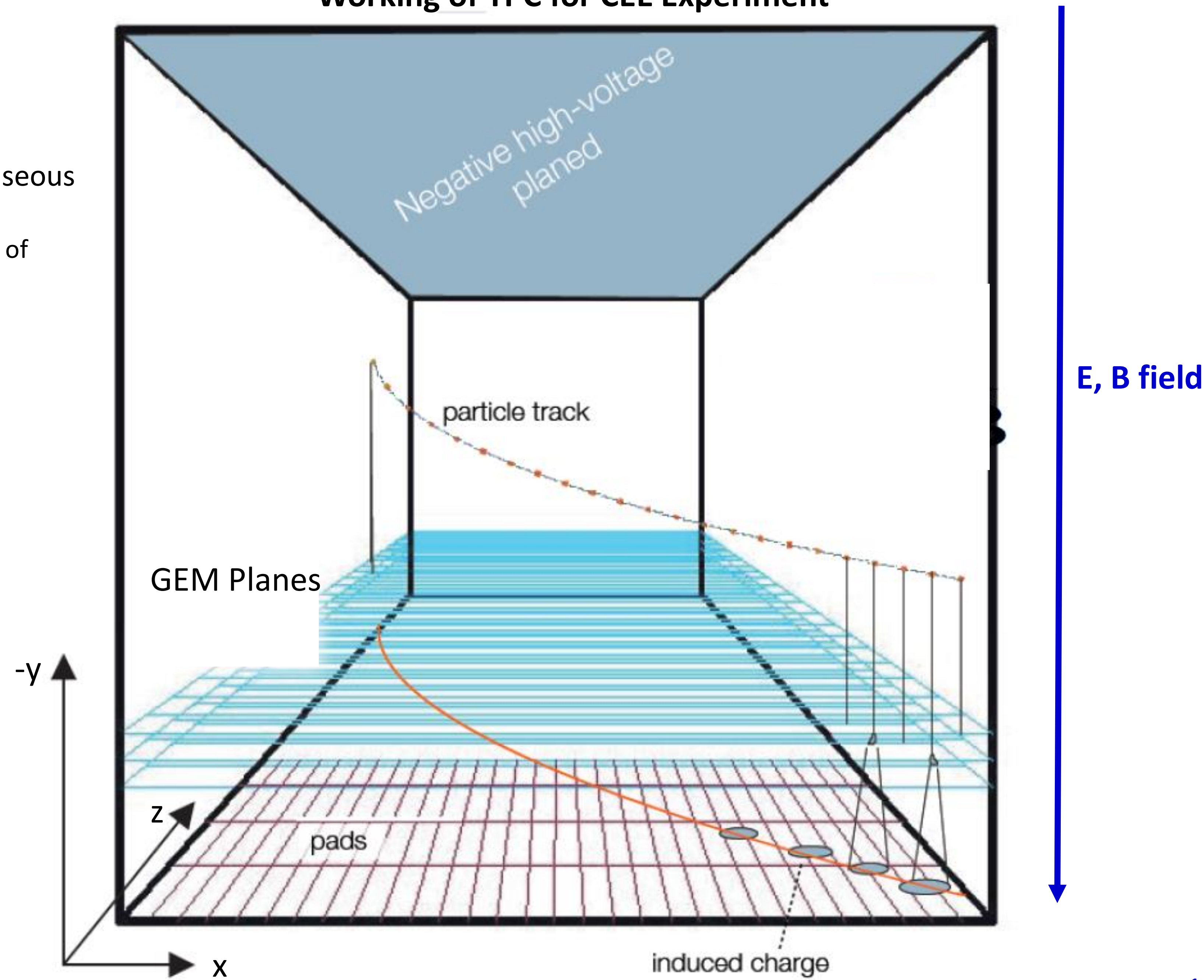
- Once we reconstruct the particles we reconstructed short lived particles (Heavy-Flavour) using invariant mass reconstruction techniques: Heavy-flavor Physics
- Once we reconstruction Proton and Antiproton in an event: Study of critical point

TPC Geometry



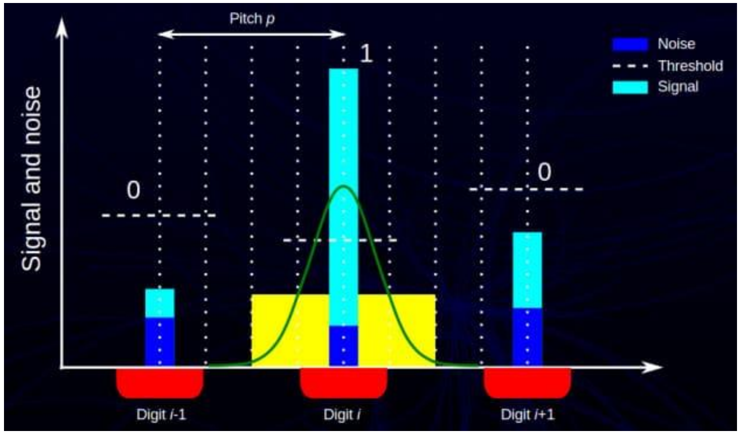
Working of TPC for CEE Experiment

Ref (PPT):Gaseous detectors:
measurement of ionization
position determination



Intrinsic Spatial Resolution

Single Strip Cluster



Digital and Analog algorithm:

Ref: My thesis

$$f(x) = \begin{cases} \frac{1}{p}, & \text{if } \bar{x} - \frac{p}{2} \leq x \leq \bar{x} + \frac{p}{2} \\ 0, & \text{otherwise} \end{cases}$$

$$\int_{\bar{x}-\frac{p}{2}}^{\bar{x}+\frac{p}{2}} f(x)\, dx = 1$$

If we assume $\bar{x}$ as mean position and p as the pitch then the spatial resolution can be written as

$$\sigma_x^2 = < x^2 > - < x >^2$$

Since $< x > = 0$ because of odd function.

$$\sigma_x^2 = \frac{\int_{-\frac{p}{2}}^{+\frac{p}{2}} x^2 f(x) dx}{\int_{-\frac{p}{2}}^{+\frac{p}{2}} f(x) dx}$$

solving the above integral we get the expression for the spatial resolution given below.

$$\sigma_x = \frac{p}{\sqrt{12}}$$

The error in the measurement of the position x is given by σ_x, which is limited by $\frac{p}{\sqrt{12}}$.

Two Strip Cluster [Digital Algorithm]

In the case of a two strip cluster, as shown in the right panel of Fig.2.18, the position of hit is given by the mid position of two strips. The spatial resolution can be determined again by considering the uniform distribution of charge using the method below [46].

$$f(x) = \begin{cases} \frac{2}{p}, & \text{if } \bar{x} - \frac{p}{4} \leq x \leq \bar{x} + \frac{p}{4} \\ 0, & \text{otherwise} \end{cases}$$

$$\int_{\bar{x}-\frac{p}{4}}^{\bar{x}+\frac{p}{4}} f(x)dx = 1$$

If we assume $\bar{x}$ as the mean then the spatial resolution can be written as

$$\sigma_x^2 = < x^2 > - < x >^2$$

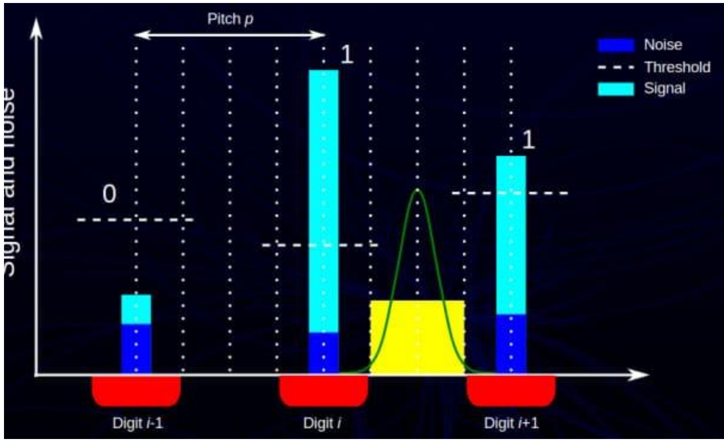
Since $< x > = 0$ because of odd function.

$$\sigma_x^2 = \frac{\int_{-\frac{p}{4}}^{+\frac{p}{4}} x^2 f(x)dx}{\int_{-\frac{p}{4}}^{+\frac{p}{4}} f(x)dx}$$

solving the above integral, the spatial resolution can be written as

$$\sigma_x = \frac{p}{2\sqrt{12}}$$

The error in the measurement of the position x is given by σ_x, which is limited by $\frac{p}{2\sqrt{12}}$.



Ref: My thesis

Two Strip Cluster [Analog Algorithm]

$$X = X_i + \frac{Q_R}{Q_L + Q_R} * p/2$$

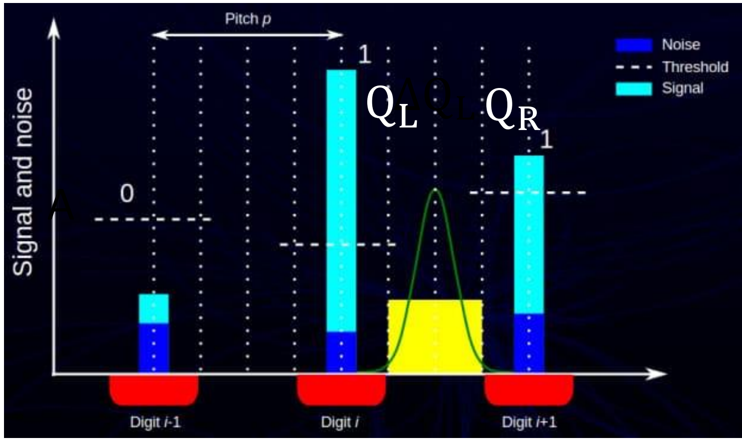
p: Pitch

Assume $X_i = 0$

$$Q = Q_L + Q_R = \text{Signal Created}$$

This is used when we also want to measure the signal (Energy loss e.g. TPC) dEdX vs momentum PID

Q_L and Q_R are negatively correlated



$$u = u(x, y)$$

$$\sigma_u^2 = \left(\frac{\partial u}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2 \sigma_y^2 + 2 * r_{xy} * \sigma_x \sigma_y \left(\frac{\partial u}{\partial x}\right)\left(\frac{\partial u}{\partial y}\right)$$

$$\Delta x = \left(\frac{\partial X}{\partial Q_L}\right)\Delta Q_L + \left(\frac{\partial X}{\partial Q_R}\right)\Delta Q_R$$

$$\frac{\partial X}{\partial Q_R} = \frac{p}{2}\left[Q_R * \left(-\frac{1}{(Q_L + Q_R)^2}\right) + \frac{1}{Q_L + Q_R}\right]$$

$$\frac{\partial X}{\partial Q_L} = \frac{p}{2}\left[Q_R * \left(-\frac{1}{(Q_L + Q_R)^2}\right)\right]$$

$$\Delta x = \frac{p}{2}\left[Q_R * \left(-\frac{1}{(Q_L + Q_R)^2}\right)\right]\Delta Q_L + \frac{p}{2}\left[Q_R * \left(-\frac{1}{(Q_L + Q_R)^2}\right) + \frac{1}{Q_L + Q_R}\right]\Delta Q_R$$

Ref: Semiconductor Radiation Detectors: Gerhard Lutz

$$\Delta x = -\left[\left(\frac{X}{Q_L + Q_R}\right)\right]\Delta Q_L + \left(\frac{p}{2} - X\right) * \left[\frac{1}{Q_L + Q_R}\right]\Delta Q_R$$

$$\Delta x = \frac{1}{Q} * \left[\left(\frac{p}{2} - X\right) * \Delta Q_R - X * \Delta Q_L\right]$$

$$\boxed{< \Delta x^2 >= \frac{1}{Q^2} * \left[\left(\frac{p}{2} - X\right)^2 *< \Delta Q_R^2 > +X^2 *< \Delta Q_L^2> - 2 * X * \left(\frac{p}{2} - X\right) < \Delta Q_L \Delta Q_R >\right]}$$

$\Delta Q_L, \Delta Q_R$ are the error in the left and right signals due to the noise.

Note: The dominant noise in much of the cases is amplifier noise and resistor noise which are uncorrelated for left and right signals $< \Delta Q_L \Delta Q_R >$ = 0

$$\boxed{< \Delta x^2 >= \frac{1}{Q^2} * \left[\left(\frac{p}{2} - X\right)^2 *< \Delta Q_R^2 > +X^2 *< \Delta Q_L^2>\right]}$$

$$\boxed{\Delta x \propto \frac{\text{pitch}}{\frac{\text{Signal}}{\text{Noise}}}}$$

Noise has different contributions

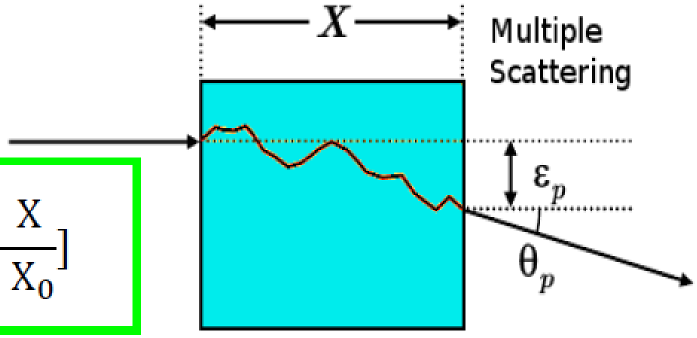
Fundamental Limit for Space Point Resolution

- Many effects will have an impact on the accuracy of the coordinate measurements
  - Electronic noise
  - Diffusion
  - Gas gain fluctuation
  - Angular pad effect
  - Landau fluctuation
  - E x B effect

Ref: Diffusion and space point resolution in a TPC: Michael Ciupek

$$\boxed{\sigma_{total}^2 = \sigma_0^2 + \sigma_{Drift}^2 + \sigma_{ang.}^2 + \sigma_{E\times B}^2}$$

Momentum Resolution



$$\theta_p = 13.6\frac{\mathrm{MeVz}}{\beta cp}\sqrt{\frac{X}{X_0}}[1 + 0.038\ln\frac{X}{X_0}]$$

$$\epsilon_p \approx \frac{1}{\sqrt{3}}\theta_p X$$

Ref: “Particle Detectors”, C. Grupen and B. A. Shwartz

At low p: $\mathrm{m.s.\,dominated\ by} \ \propto \frac{1}{p}$

At high p: $\mathrm{m.s.\,dominated\ by} \ \propto \sqrt{\frac{X}{X_0}}$

Momentum resolution can be affected by multiple scattering

Momentum Measurement: Sagitta

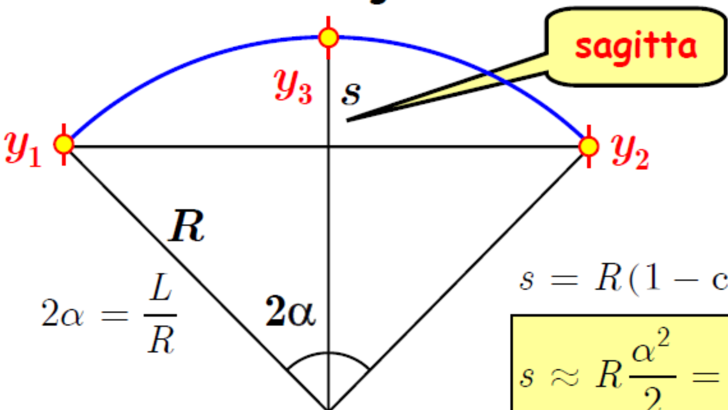
Consider: **p** = p_T

To introduce the problem of momentum measurement let's go back to the sagitta

a particle moving in a plane perpendicular to a uniform magnetic field B

$$\boxed{R = \frac{p}{0.3B} \qquad \frac{\delta p}{p} = \frac{\delta R}{R}}$$

the trajectory of the particle is an arc of radius R of length L



$$2\alpha = \frac{L}{R}$$

$$s = R(1 - \cos\alpha)$$

$$\boxed{s \approx R\frac{\alpha^2}{2} = \frac{L^2}{8R}}$$

assume we have 3 measurements: y_1, y_2, y_3

$$s = y_3 - \frac{y_1 + y_2}{2} \qquad \delta s = \sqrt{\frac{3}{2}}\delta y \sim \delta y$$

the error on the radius is related to the sagitta error by

$$|\delta s| = \frac{L^2}{8R}\frac{\delta R}{R} \sim \delta y \qquad \frac{L^2}{8R}\frac{\delta p}{p} = \delta y$$

$$\frac{\delta p}{p} = \frac{8R}{L^2}\delta y \qquad \frac{\delta p}{p} = \frac{8p}{0.3BL^2}\delta y$$

$$\boxed{\frac{\delta p}{p^2} = \frac{8\delta y}{0.3BL^2}}$$

important features

- the percentage error on the momentum is proportional to the momentum itself
- the error on the momentum is inversely proportional to B
- the error on the momentum is inversely proportional to $1/L^2$
- the error on the momentum is proportional to coordinate measurement error

Momentum Resolution

The covariance matrix is

$$\mathbf{V_p} = \frac{1}{F_0F_4 - F_2F_2}\begin{pmatrix} F_4 & 0 & -F_2 \\ 0 & \dfrac{F_0F_4 - F_2F_2}{F_2} & 0 \\ -F_2 & 0 & F_0 \end{pmatrix}$$

we are mostly interested on the error on the curvature

$$\boxed{\sigma_c^2 = \frac{F_0}{F_0F_4 - F_2F_2} = \frac{\sigma^2}{L^4}C_N}$$

$$C_N = \frac{180N^3}{(N-1)(N+1)(N+2)(N+3)}$$

it can be shown that the error on the curvature do not depend on the position of the origin along the track

Let's recall from the discussion on the sagitta

$$\boxed{R = \frac{p}{0.3B} \qquad \frac{\delta p}{p} = \frac{\delta R}{R}}$$

also recall that

$$c = \frac{1}{2R} \qquad \sigma_c = \frac{1}{2R^2}\delta R$$

and finally the momentum error

$$\boxed{\frac{\delta p}{p^2} = \frac{\sigma}{0.3BL^2}\sqrt{4C_N}}$$

the formula shows the same basic features we noticed in the sagitta discussion

we have also found the dependence on the number of measurements (weak)

Track Fit With Multiple Scattering Consider: p = p_T

The methods developed to fit a track to the measured points can be used to perform a fit taking into account M.S.

- the covariance matrix is computed
- the same fit procedure is applied

Let's now try to understand qualitatively the effect of multiple scattering on the determination of tracks parameters:

- the size of the effect goes as $1/p$
- then the effect is important for low momentum track

Assume we are dominated by multiple scattering

- the momentum resolution is given by

$$\boxed{\frac{\delta p}{p^2} = \frac{\sigma}{0.3BL^2}\sqrt{4A_N}}$$

the coordinate error due to M.S. is

$$\boxed{\sigma \sim \frac{L}{N}\delta\theta = \frac{L}{N}\frac{0.0136}{p\beta}\sqrt{\frac{X}{X_o}}}$$

we have then

$$\boxed{\frac{\delta p}{p} \sim \frac{0.0136}{\beta}\sqrt{\frac{X}{X_0}}\frac{1}{0.3BL}\frac{\sqrt{4A_N}}{N}}$$

We conclude:

- for low momentum the percentage momentum resolution reach a almost constant value (still dependent on β)

$$\boxed{\frac{\delta p}{p} \rightarrow \text{constant}}$$

- The momentum resolution only improves as $1/L$
- The additional factor $1/N$ can help but in this case uniform spacing is essential

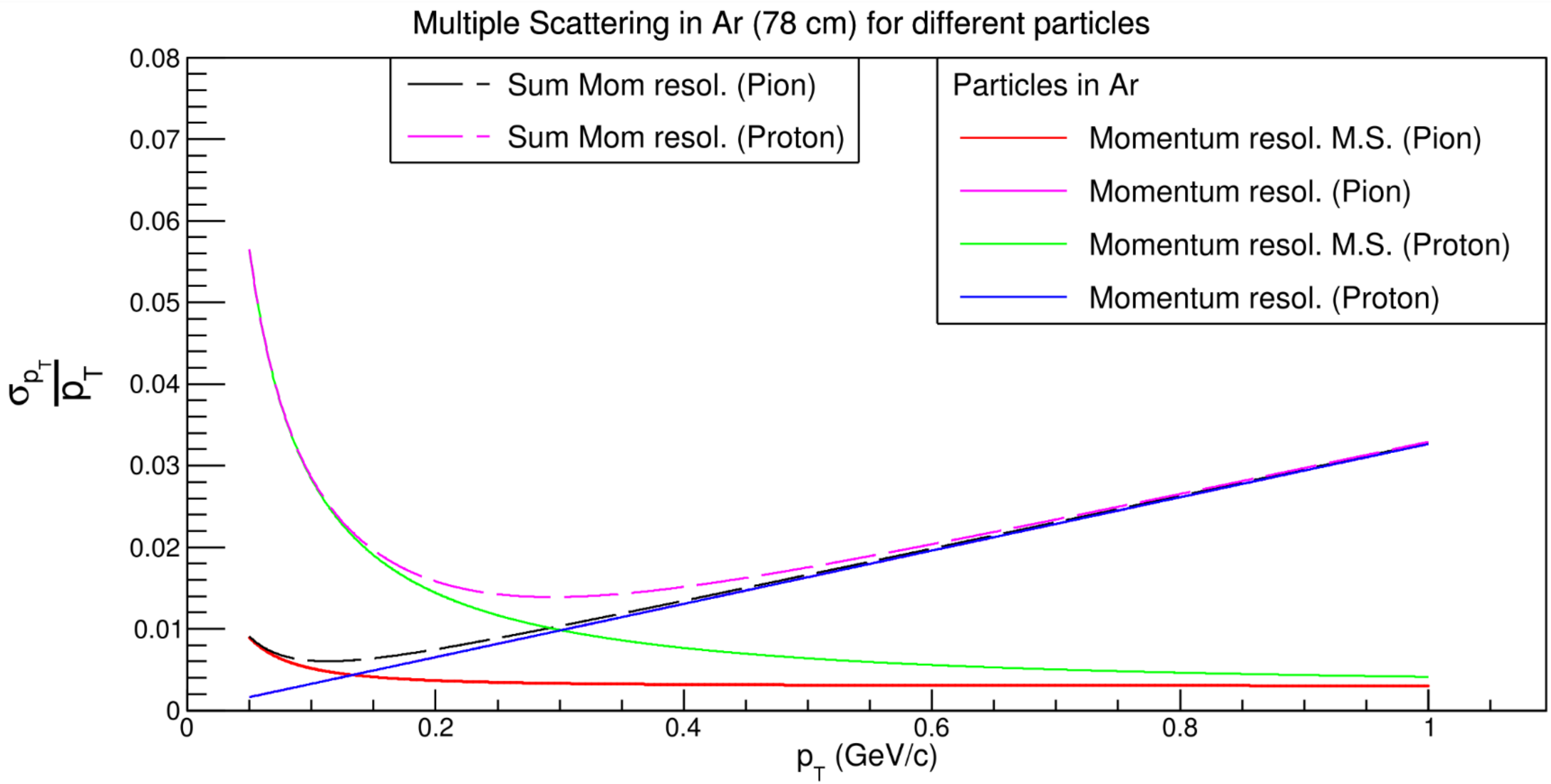
TPC Parameters used for the calculation:

No of points (N) = 76

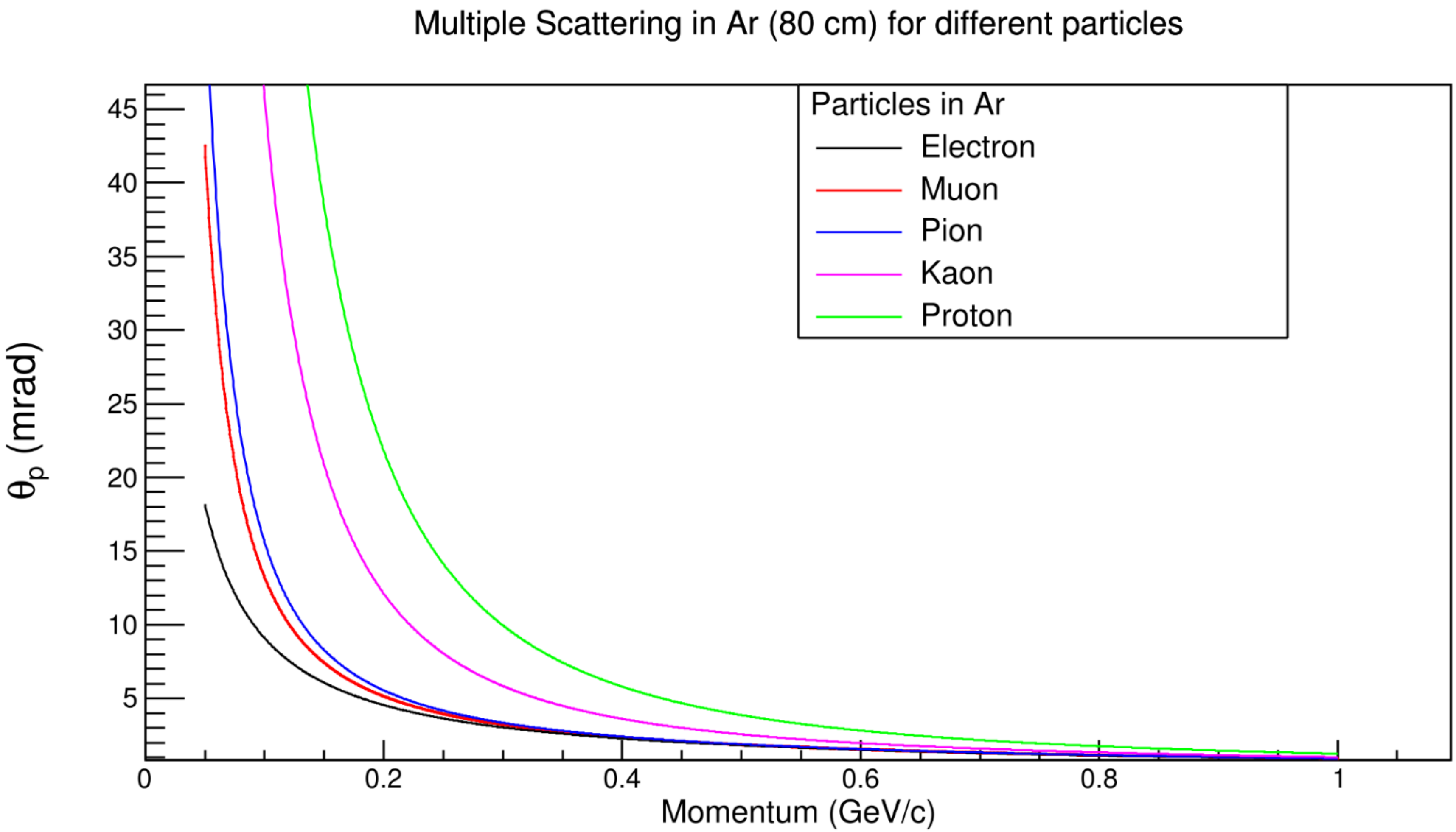
Length = 78 cm

Radiation length of Ar gas

Resolution of Pad for cluster = 1 mm



Momentum resol: Due to the error in curvature measurement and Multiple scattering


Multiple Scattering in Ar (80 cm) for different particles
Particles in Ar
Electron
Muon
Pion
Kaon
Proton
θ_p (mrad)
45
40
35
30
25
20
15
10
5
0
0.2
0.4
0.6
0.8
1
Momentum (GeV/c)

Lorentz force in electric and magnetic field: Steady state:

$$\frac{d\vec{v}}{dt} = 0 = \frac{e}{m}\vec{E} + \frac{e}{m}[\vec{v}x\ \vec{B}] - \frac{K}{m}\vec{v}$$

$$\frac{e}{m}\vec{E} = \frac{1}{\tau}\vec{v} - \frac{e}{m}[\vec{v}x\ \vec{B}]$$

$$\vec{\omega} = \frac{e}{m}\vec{B}, \quad \vec{\varepsilon} = \frac{e}{m}\vec{E}, \quad \mu = \frac{e}{m}\tau$$

$$\boxed{\vec{v} = \frac{\mu}{1+(\omega\ \tau)^2}[\vec{E} + \frac{\omega\ \tau}{B}[\vec{E}\times\vec{B}] + (\omega\ \tau)^2\frac{\vec{E}\cdot\vec{B}}{B^2}\vec{B}]}$$

Ref: J.Va’vra, Detector Lecture in Rome, January 25, 2002: **The drift of electrons and ions in gases or, how to design a good TPC**

For $\omega\,\tau = 0$ ==> $\vec{v} = \mu\,\vec{E}$, **i.e.** $\vec{v}$ **is aligned with** $\vec{E}$,

$\omega\,\tau$ **large** ==> $\vec{v}$ **tends to be aligned along** $\vec{B}$,

$\omega\,\tau$ **large &** $\vec{E}.\vec{B} = 0$ ==> $\vec{v}$ **tends to be aligned along** $\vec{E}\text{x}\ \vec{B}$.

In practical chambers we have these conditions typically:

$\mu \sim 10^4\ \text{cm}^2\ \text{V}^{-1}\ \text{s}^{-1}$ **for electrons,**

$\mu \sim 1\ \text{cm}^2\ \text{V}^{-1}\ \text{s}^{-1}$ **for ions,**

$B \leq\ 1\ \text{T} = 10^{-4}\ \text{V s cm}^{-2}$,

$\omega\,\tau = B\,\mu \approx\ 10^{-4}$ **for ions,**

$\omega\,\tau = B\,\mu \approx\ 1$ **for electrons.**

$\tau \approx 2\text{-}5$ psec **for electrons,**

$\frac{1}{\tau} \approx (2\text{-}5) \times 10^{11}$ Hz **collision rate for electrons,**

The effect of typical magnetic fields on ion drift is negligible.

Ref: J.Va'vra, Detector Lecture in Rome, January 25, 2002: **The drift of electrons and ions in gases or, how to design a good TPC**

Example #2 ($\vec{E}$ is parallel to $\vec{B}$):

We assume:

$$\vec{E} \times \vec{B} = 0,\ \vec{E} = (0,0,E_z),\ \vec{B} = (0,0,B_z)$$

From equation (12) we obtain:

$$\begin{aligned} v_x &= 0 \\ v_y &= 0 \\ v_z &= \frac{\mu}{1+(\omega\tau)^2}\left[E_z + (\omega\tau)^2 \frac{E_z \cdot B_z}{B^2} B_z\right] \equiv \mu\left|\vec{E}\right| \end{aligned} \qquad \textbf{(18)}$$

Example #3 ($\vec{E}$ is nearly parallel to $\vec{B}$):

Realistic case

We assume:

$$\left|\vec{B}\right| \approx B_z,\ \vec{E} = (0,0,E_z),\ \vec{B} = (0,B_y,B_z),\ B_y << B_z$$

Ref: J.Va'vra, Detector Lecture in Rome, January 25, 2002: **The drift of electrons and ions in gases or, how to design a good TPC**

$$v_x = \frac{\mu}{1+(\omega\tau)^2}\frac{\omega\tau}{B}E_z B_y \approx \frac{\omega\tau}{1+(\omega\tau)^2}\frac{B_y}{B_z}\,v(B=0)$$

$$v_y = \frac{\mu}{1+(\omega\tau)^2}(\omega\tau)^2\frac{E_z \cdot B_z}{B^2}B_y \approx \frac{(\omega\tau)^2}{1+(\omega\tau)^2}\frac{B_y}{B_z}\,v(B=0)$$

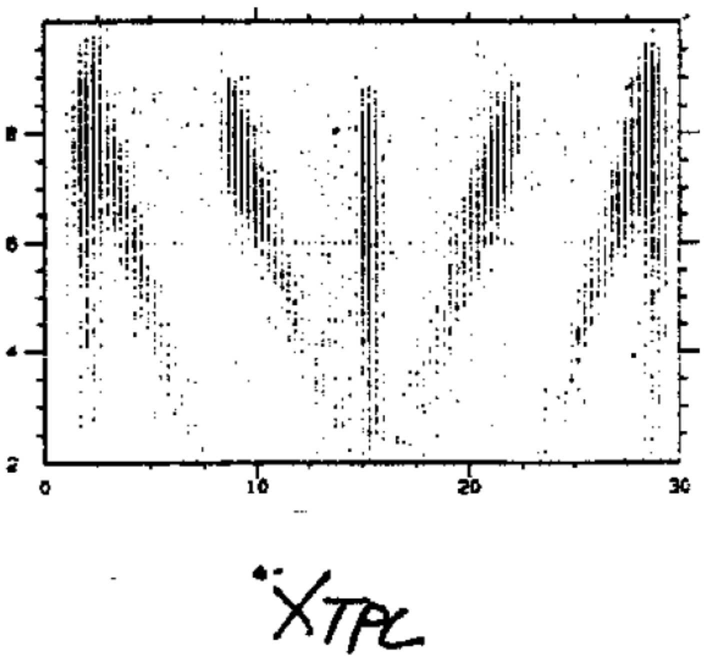
$$v_z = \frac{\mu}{1+(\omega\tau)^2}\left[E_z + (\omega\tau)^2\frac{E_z \cdot B_z}{B^2}B_z\right] \approx \mu E_z = v(B=0)$$

If we have some component of magnetic field other than one direction, we have all the velocity component so the track will shift in x and y direction: Distortion

Ref: J.Va'vra, Detector Lecture in Rome, January 25, 2002: **The drift of electrons and ions in gases or, how to design a good TPC**

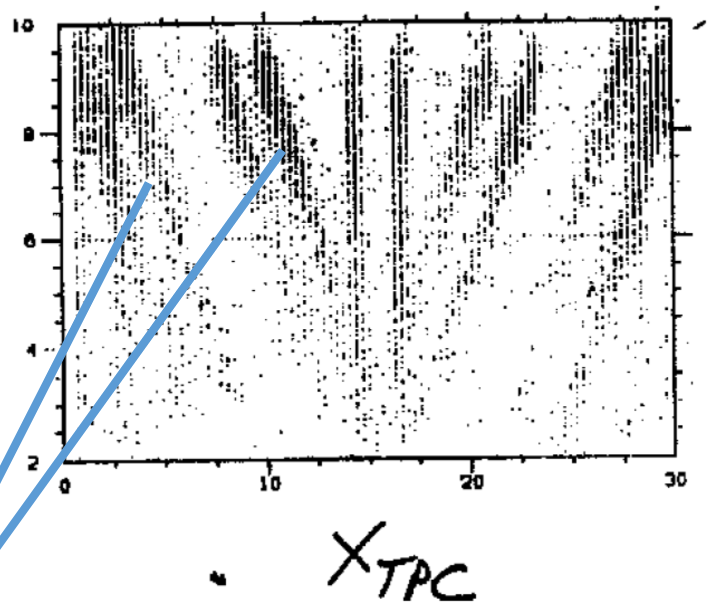
1) Magnet off

d) High voltage end



2) Magnet on

b) High voltage end



Shifting of tracks due to magnetic field: Distortions

Diffusion

Diffusion Equation:

D: diffusion coefficient

T: time

$$\boxed{\frac{\partial N(x,t)}{\partial t} = D * \nabla^2 N(x,t)}$$

In 1 dimension:

$$\frac{\partial N(x,t)}{\partial t} = D * \frac{\partial^2 N(x,t)}{\partial x^2}$$

I solved the equation in Mathematica with the condition: $N(x,0) = N_0\,\delta(x)$

Solution of the equation is:

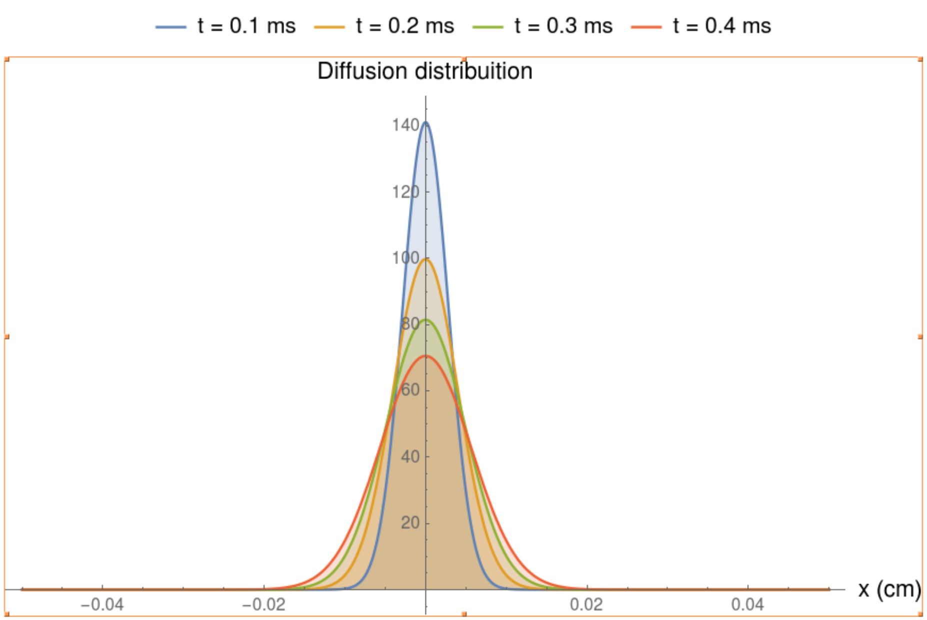
$$\boxed{N(x,t) = \frac{N_0}{\sqrt{4\pi Dt}} e^{-\frac{x^2}{4\,Dt}}}$$

Comparing with Gaussian with of charge cloud: $\sigma = \sqrt{2\,Dt}$

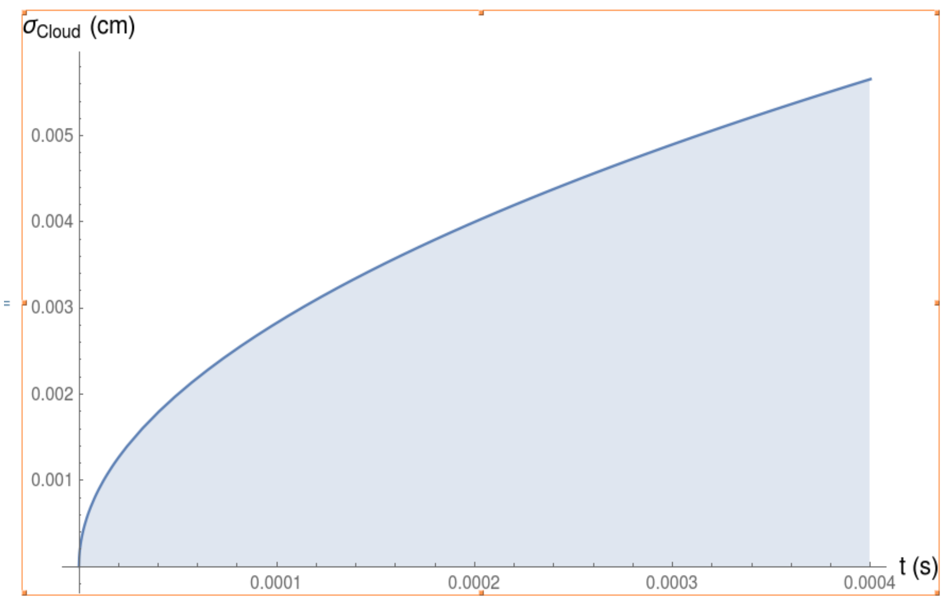
Mathematica code and Plots

```
heqn = D[n[x, t], t] == Dd * D[n[x, t], {x, 2}];

ic = n[x, 0] == N0 * DiracDelta[x];
sol = DSolveValue[{heqn, ic}, n[x, t], {x, t}];
Echo[Simplify[sol] // MatrixForm, "N(x,t) ="];
Plot[Evaluate[Table[sol /. {Dd → 0.04, N0 → 1}, {t, 0.0001, 0.0004, 0.0001}]], {x, -0.05, 0.05}, PlotRange → All, Filling → Axis,
 PlotLegends → Placed[{"t = 0.1 ms", "t = 0.2 ms", "t = 0.3 ms", "t = 0.4 ms"}, Above],
 AxesLabel → {Style["x (cm)", 14, Black], Style["Diffusion distribuition", 14, Black]}, ImageSize → Large]

Plot[Sqrt[2 * 0.04 * t], {t, 0.000, 0.0004}, PlotRange → All, Filling → Axis,
 AxesLabel → {Style["t (ms)", 14, Black], Style["σCloud (cm)", 14, Black]}, ImageSize → Large]
```

Diffusion distribution at different times



Sigma with time follows parabolic shape



Digitization of CEE TPC

- Ar 90%, CH2 10%,
- Temperature in K: 293
- Pressure in hPa: 1013
- B field in T: 0.5
- Calculations done at these E-Fields (in V/cm): 130
- Drift velocity in cm/ns: 0.0055
- Transverse Diffusion in cm/sqrt(cm): 0.0185
- Longitudinal Diffusion in cm/sqrt(cm): 0.032
- Attachment coefficient in 1/cm: 0
- Ion mobility in cm2/(s*V): 4.41307
- Ion mobility in cm2/(s*V): 19155
- Average energy for the creation of one

electron in eV: 35.2394

$$\mathbf{D_q = \frac{kT}{q}\,\mu_q}$$

kT = 25 meV at room temperature, μ depends on Electric field

Considering these parameters: Drift task is written for the digitization: Much more work is required

Mobility (μ) of Charge carriers

$$\mu\,(P,T) = \mu(P_0,T_0)\left(\frac{T}{T_0}\right)\left(\frac{P_0}{P}\right)$$

P_0, T_0: standard pressure and temperature

$$\vec{v_d} = \mu\,(P,T)\,\vec{E}$$

If $\vec{B} = (0, By, 0)$:

$$\omega = \frac{qB_y}{m}$$

$$D_y = D$$

$$D_x = D_z = \frac{D}{(1+(\omega t)^2)}$$

Magnetic field reduces diffusion in Transverse direction !!!!

The main classes for digitization are in tpc/DigiTpc

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master ▾ **CeeRoot / tpc / DigiTpc** Clone or download ▾

shyam authored a day ago Minor modification

...

CeeTpcDriftTask.cxx	Minor modification	a day ago
CeeTpcDriftTask.h	Separate diectory created for Digi classes	2 days ago
CeeTpcDriftedElectron.cxx	Separate diectory created for Digi classes	2 days ago
CeeTpcDriftedElectron.h	Separate diectory created for Digi classes	2 days ago
CeeTpcGas.cxx	Separate diectory created for Digi classes	2 days ago
CeeTpcGas.h	Separate diectory created for Digi classes	2 days ago
CeeTpcGem.cxx	Separate diectory created for Digi classes	2 days ago
CeeTpcGem.h	Separate diectory created for Digi classes	2 days ago
LinearInterpolPolicy.cxx	Separate diectory created for Digi classes	2 days ago
LinearInterpolPolicy.h	Separate diectory created for Digi classes	2 days ago
QAPlotCollection.cxx	Separate diectory created for Digi classes	2 days ago
QAPlotCollection.h	Separate diectory created for Digi classes	2 days ago

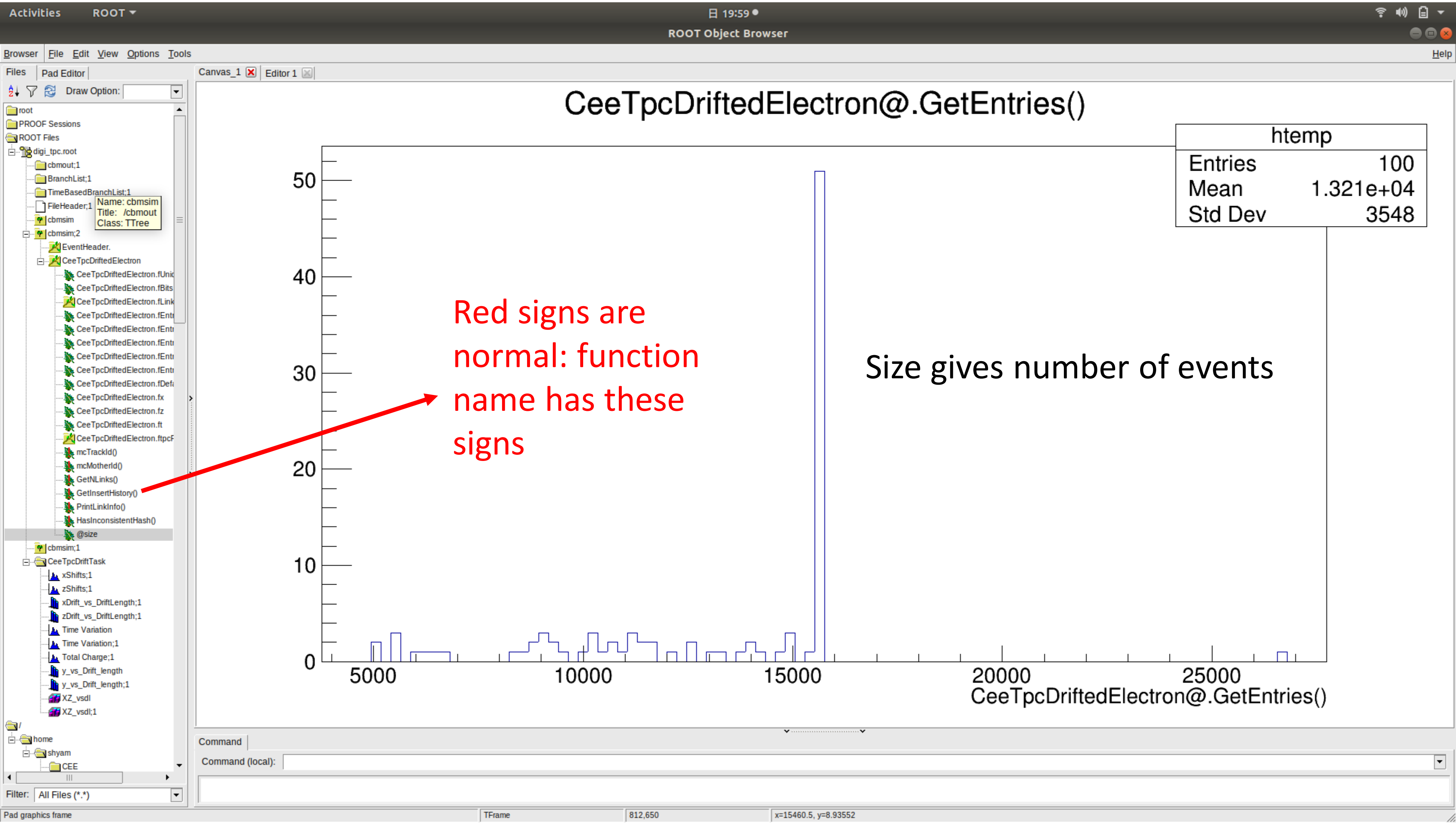
```
for(int ic=0;ic<nc;++ic){

CeeTpcPoint *mcpoint = (CeeTpcPoint*)fPrimArray->At(ic);
//create single electrons
Double_t dE = mcpoint->GetEnergyLoss() * 1E9; //convert from GeV to eV
Int_t q =10;
//Int_t q = (Int_t) TMath::Abs(dE / fGas->W());

for(Int_t ie = 0; ie < q; ++ie) {

driftl = fyGem - y_length;
// attachment
if (fAttach) {

if ( exp(-driftl * fGas->k()) < gRandom->Uniform() ) continue;
}
// diffusion
if (fDiffuse) {

Double_t sqrtDrift = sqrt(driftl);

Double_t sigmat = fGas->Dt() * sqrtDrift;

Double_t sigmal = fGas->Dl() * sqrtDrift;

dt = (driftl+gRandom->Gaus(0,sigmal)) / fGas->VDrift();

dx = gRandom->Gaus(0,sigmat);

dz = gRandom->Gaus(0,sigmat);

dt1 = (gRandom->Gaus(0,sigmal)) / fGas->VDrift();
}
// drift distortions
if (fDistort) {
// TODO: to be implemented
}
```

- **For each MC Point**:
- Calculate charge = Energy loss/W;
- Drift each electron till the GEM Plane starts considering transverse and longitudinal diffusion
- Make the distribution Gaussian for the electrons

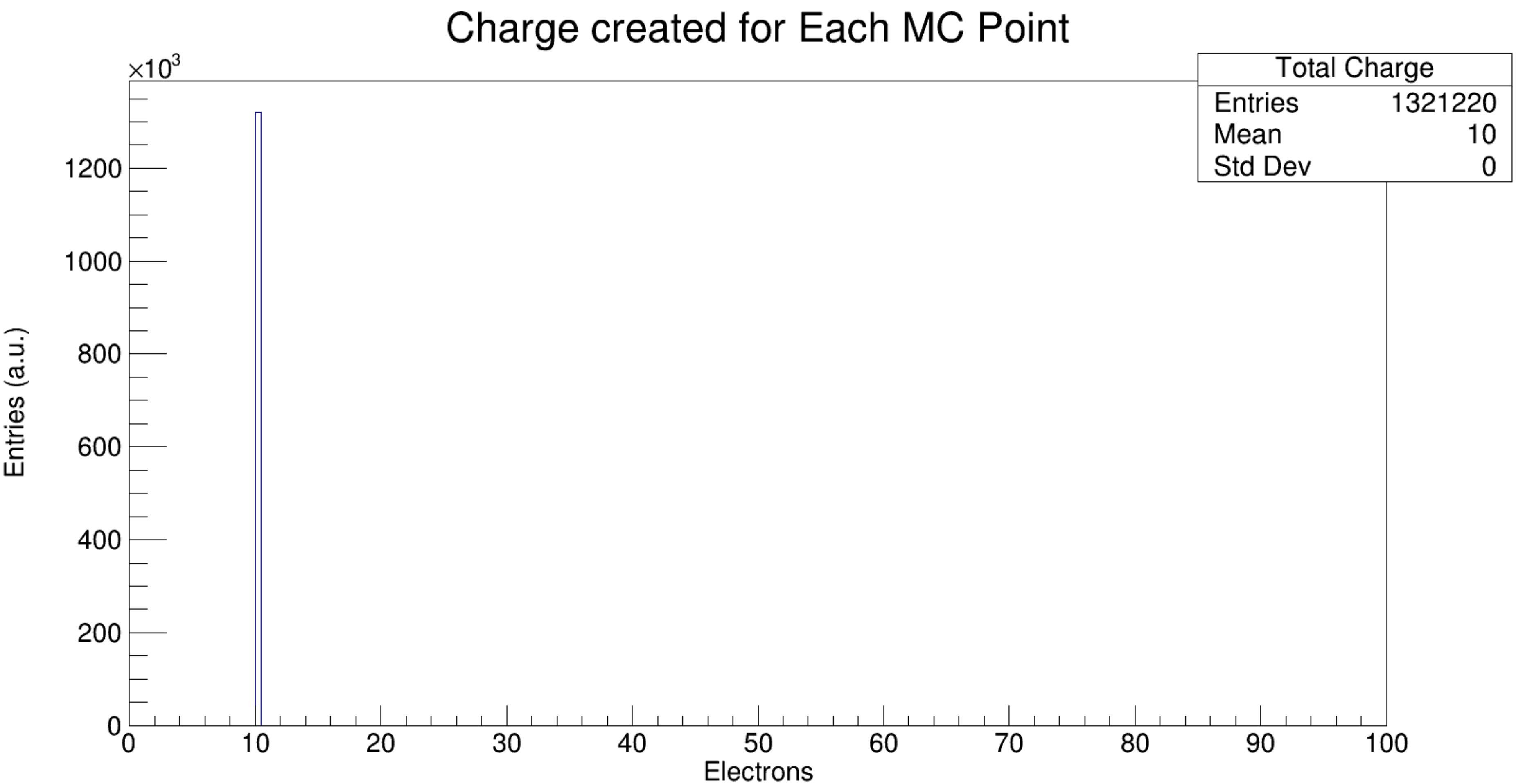
Distortion Not implemented required B-field file !!!

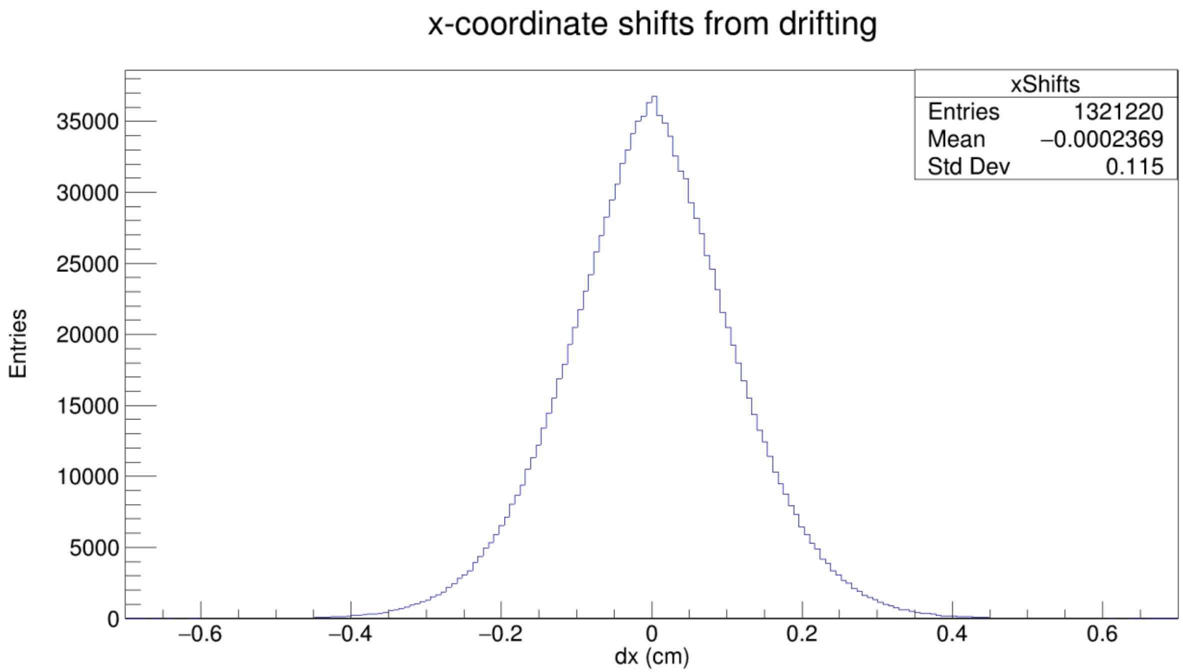
Results

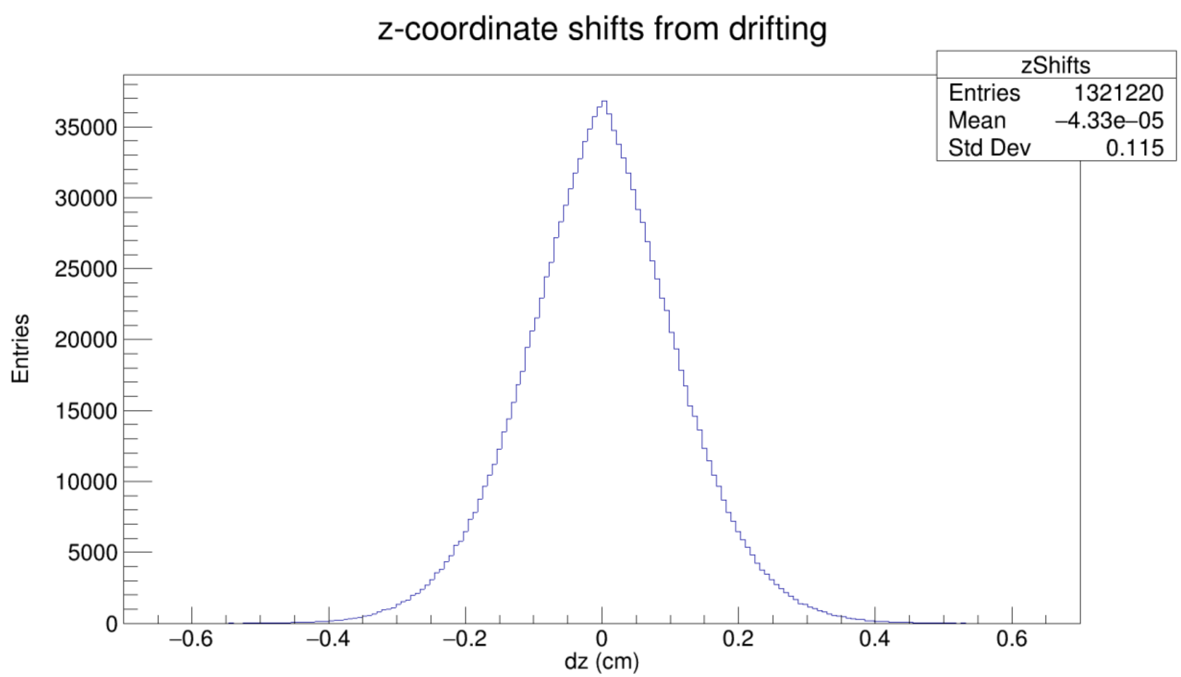
Simulation of 100 Protons with multiplicity 1 of momentum 0.5 GeV/c



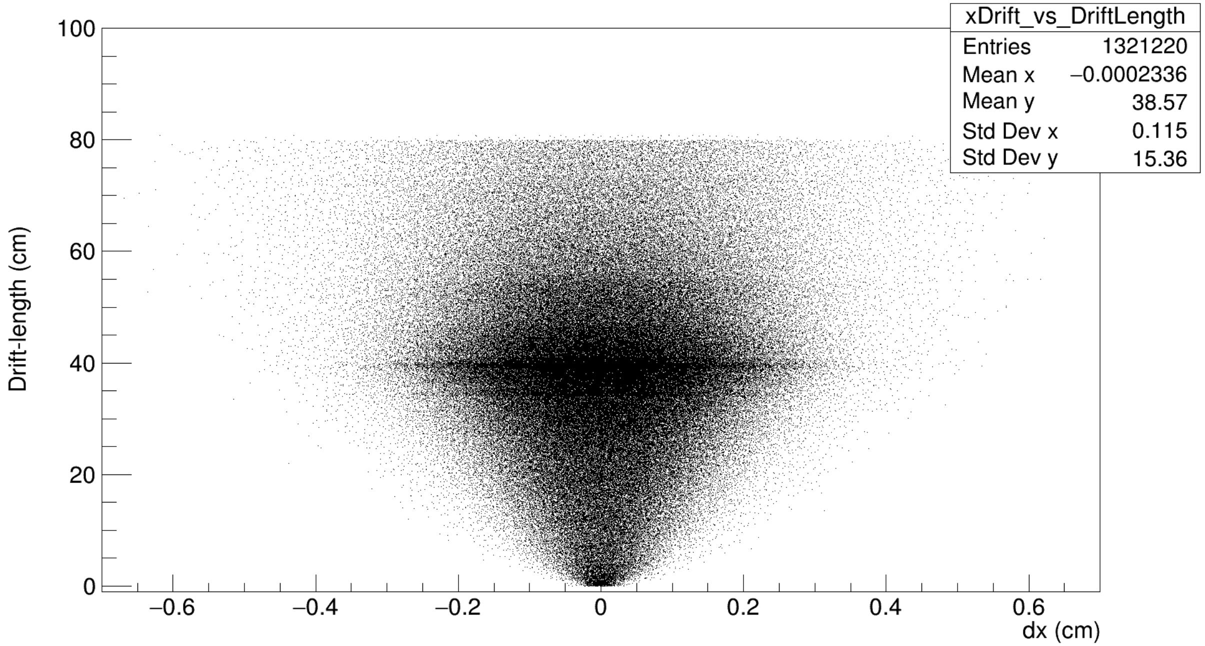
Charge has some issues I taken fixed charge 10 electrons for each MC Point
Minor issue, will be fixed soon

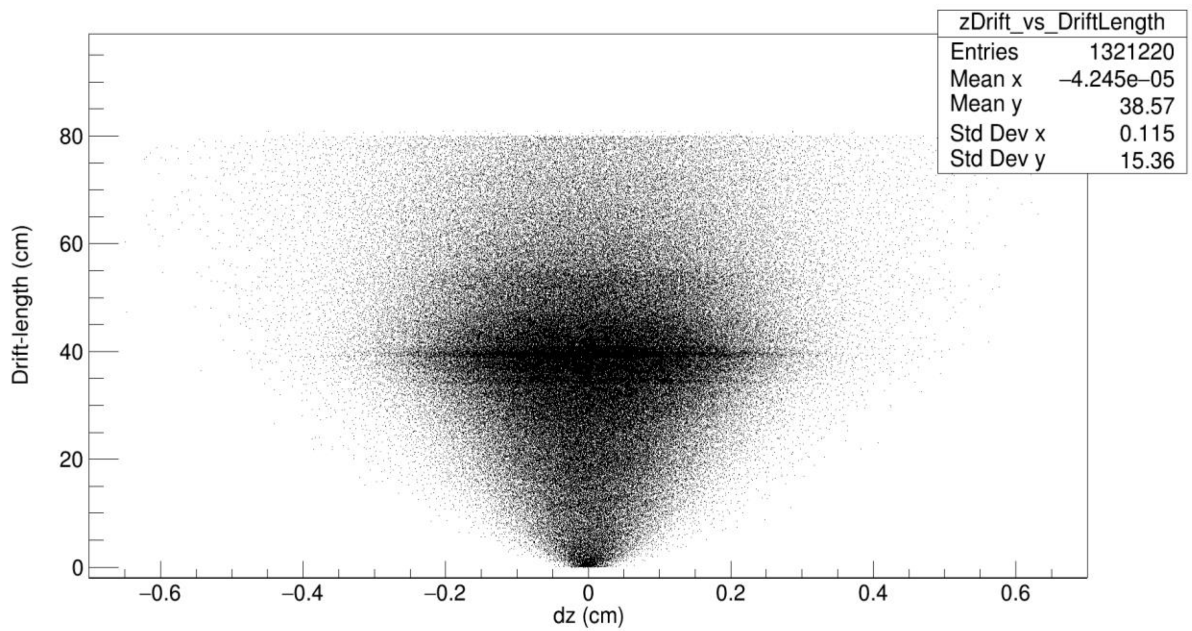


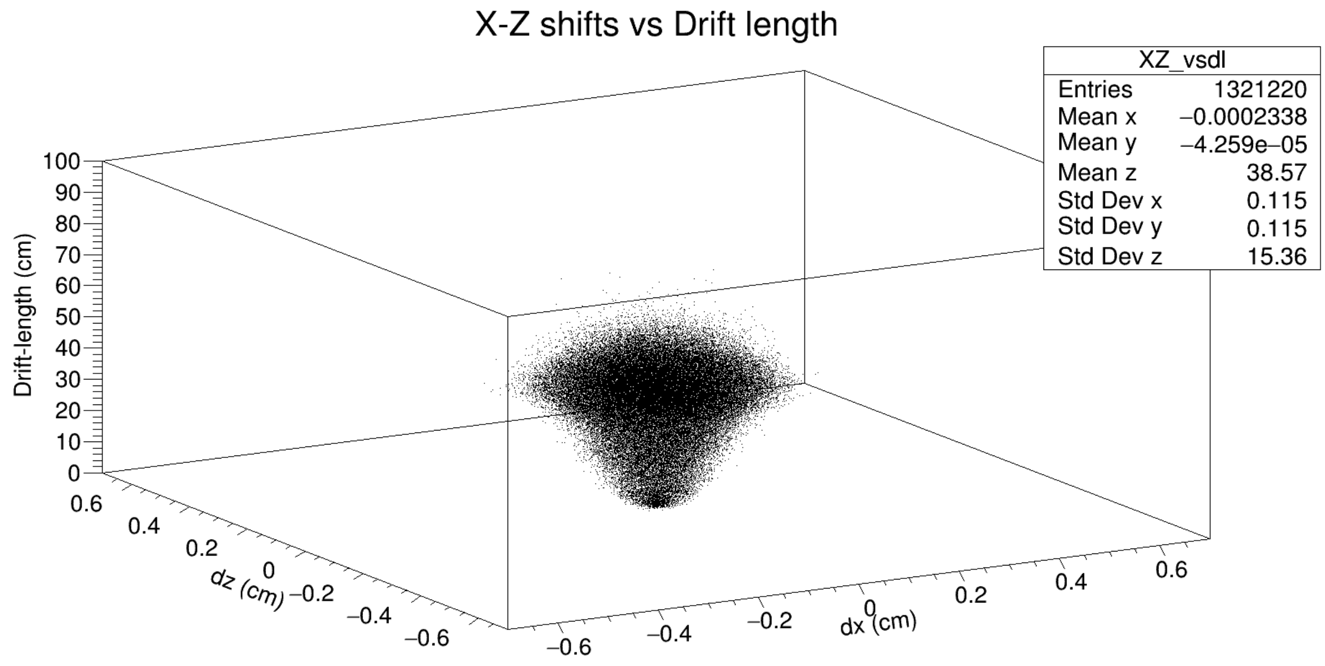

x-coordinate shifts from drifting
xShifts
Entries 1321220
Mean −0.0002369
Std Dev 0.115
Entries
35000
30000
25000
20000
15000
10000
5000
0
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
dx (cm)

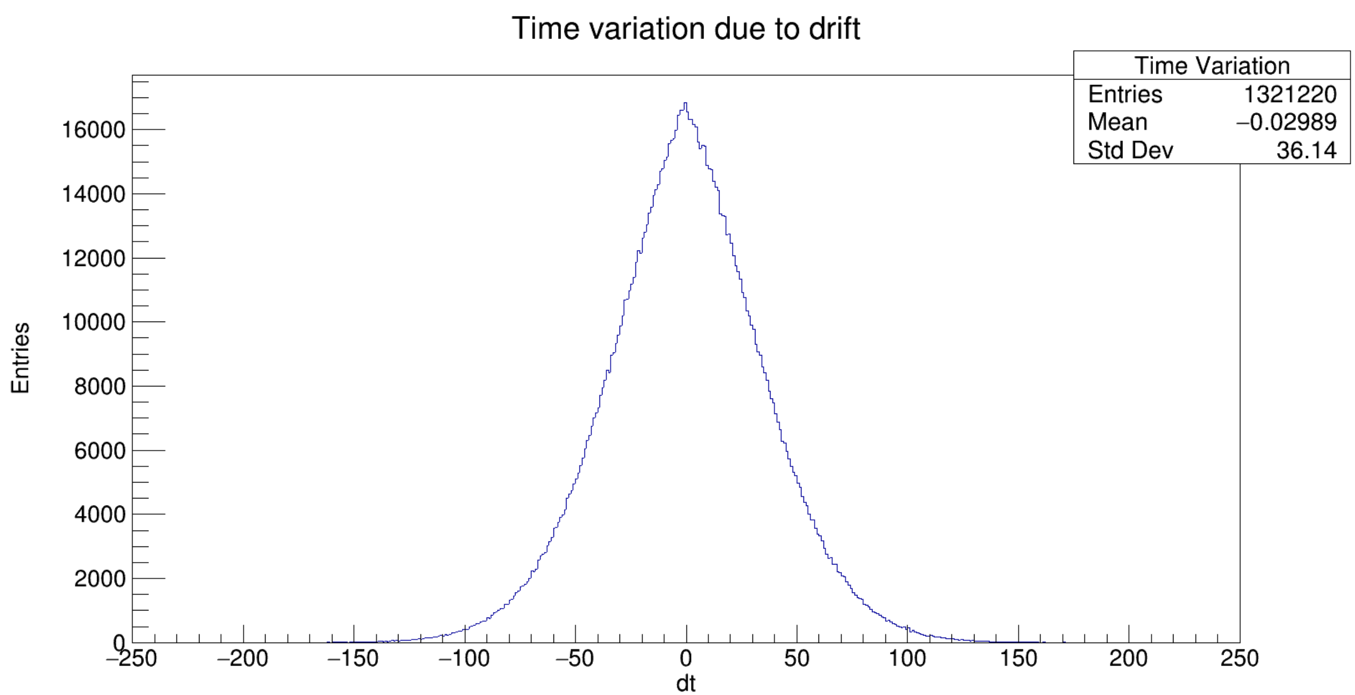

z-coordinate shifts from drifting
zShifts
Entries 1321220
Mean −4.33e−05
Std Dev 0.115
Entries
35000
30000
25000
20000
15000
10000
5000
0
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
dz (cm)

x-shifts vs. DriftLength






X-Z shifts vs Drift length
XZ_vsdl
Entries 1321220
Mean x −0.0002338
Mean y −4.259e−05
Mean z 38.57
Std Dev x 0.115
Std Dev y 0.115
Std Dev z 15.36
Drift-length (cm)
dz (cm)
dx (cm)


Time variation due to drift
Time Variation
Entries 1321220
Mean −0.02989
Std Dev 36.14
Entries
dt

Future work

- ❖ Final aim is to reconstruct the hit position x, y, z corresponding to MC points
- ❖ Started working on the implementation: will take time to reach to final goal
- ❖ Next aim is to implement Avalanche task for the GEM introducing Gain

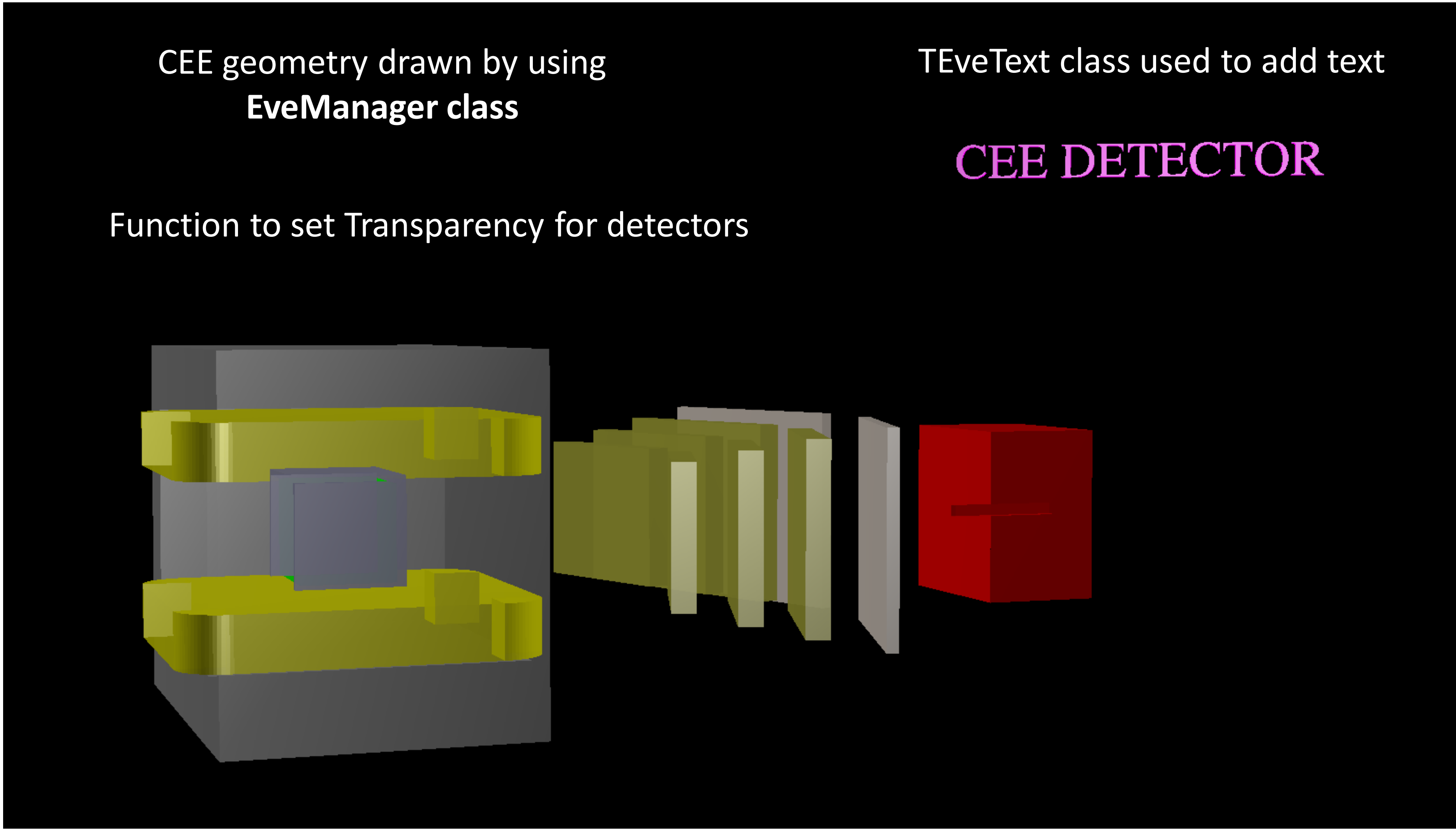
Thank you !!!

Back Up Slides

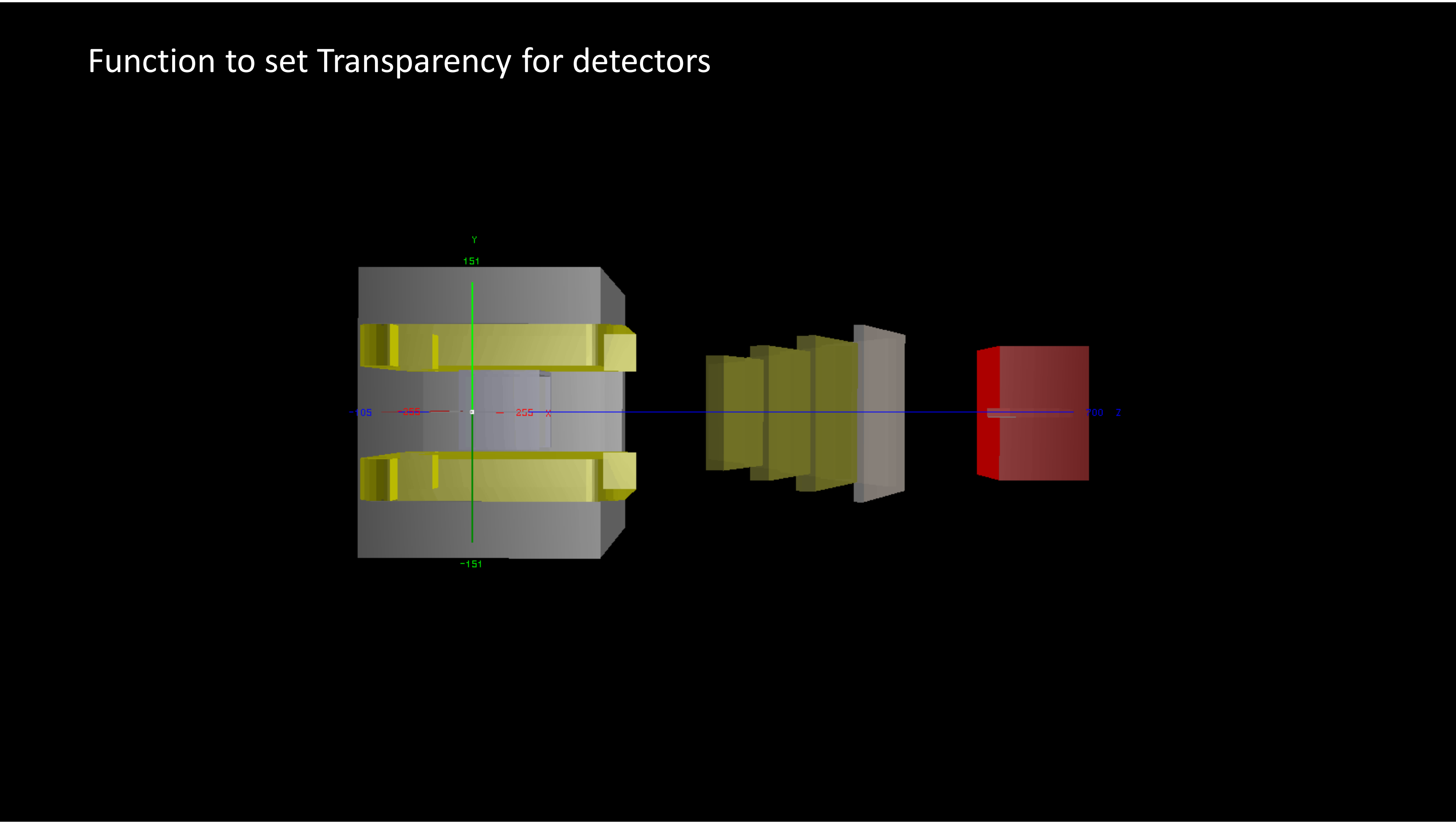
CEE Geometry

CEE geometry is stored in params.root

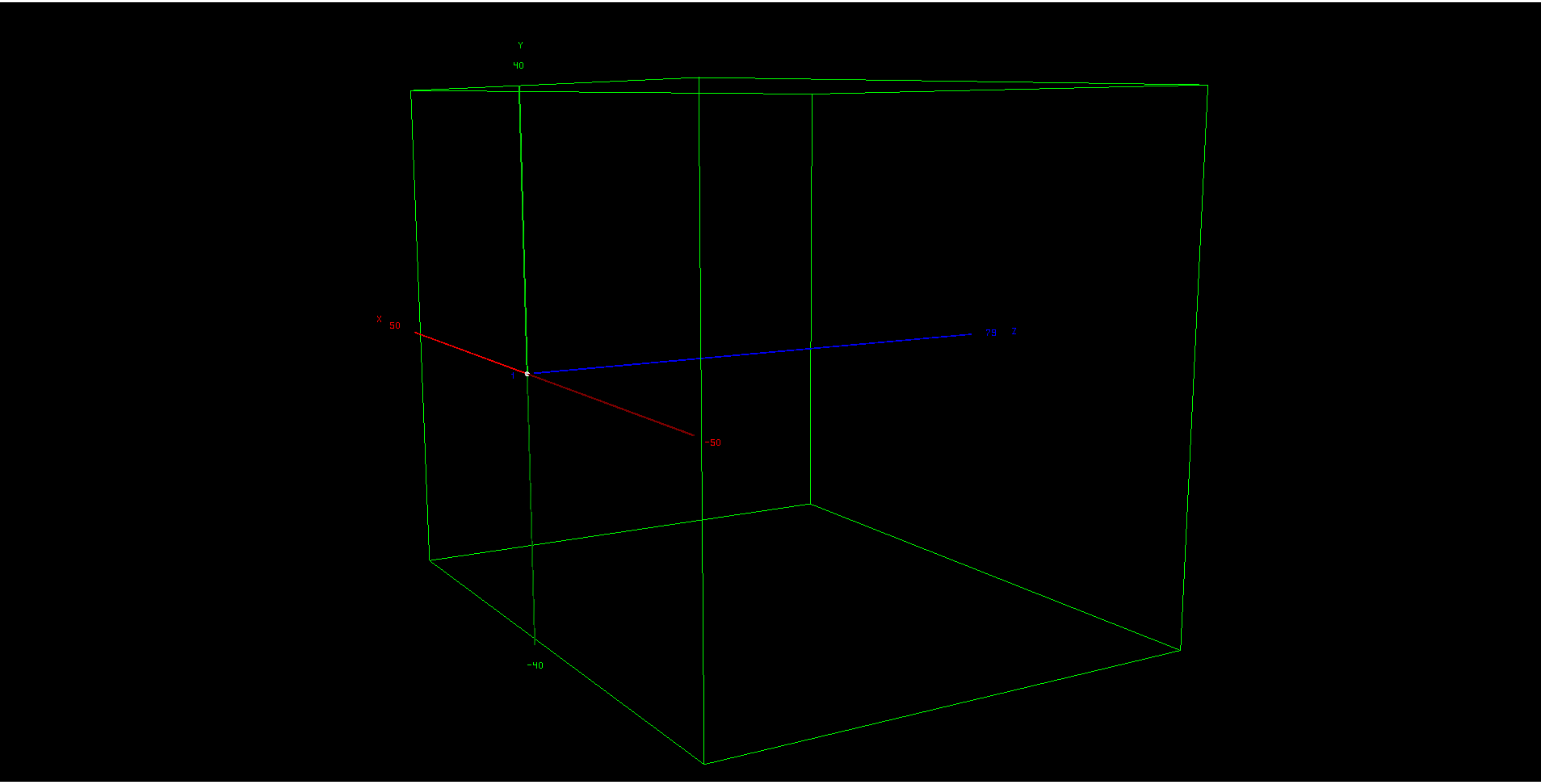
If you want to access geometry you need params.root [also event display require it]



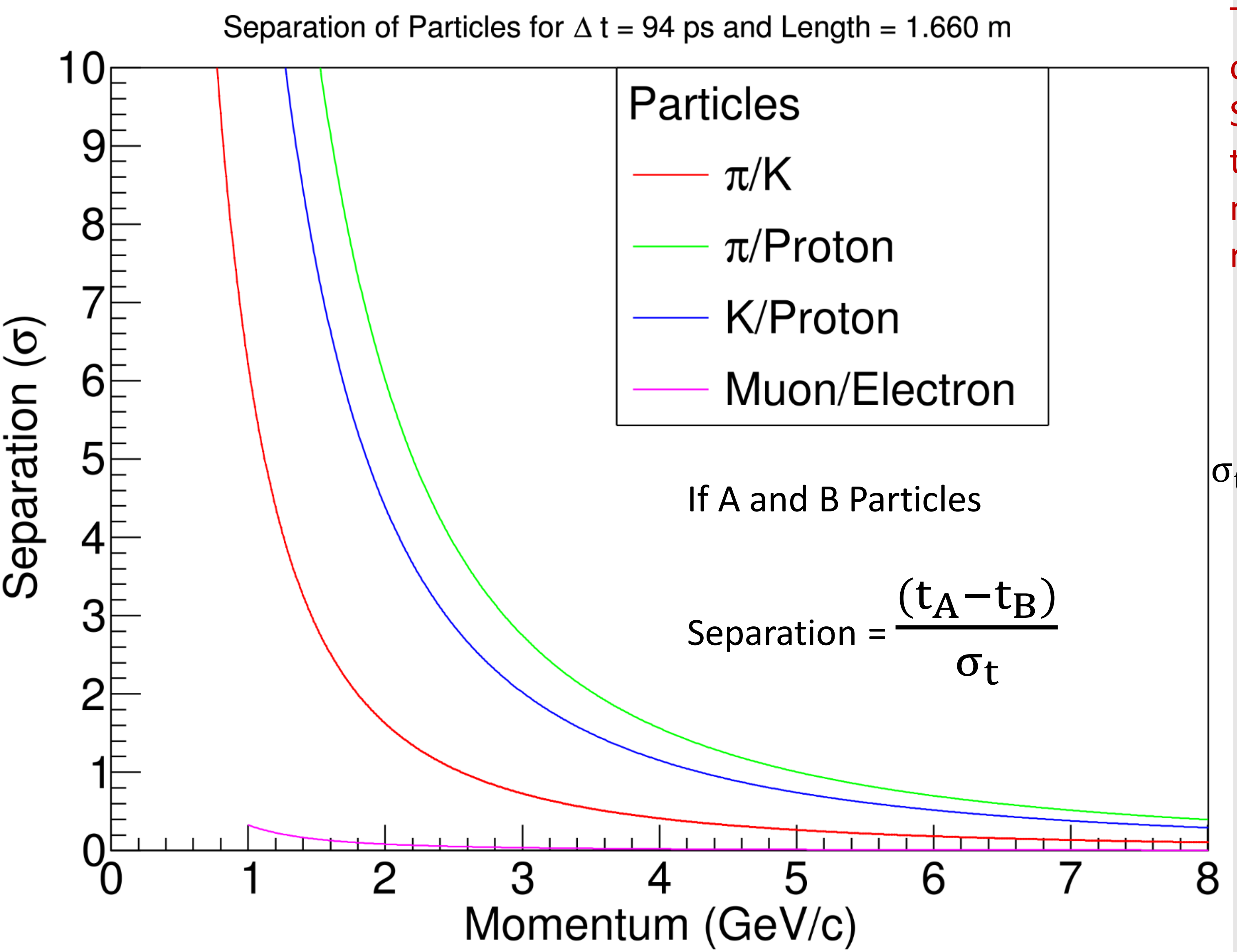
The same geometry can also be drawn by **GeoManager** class (Animation below)



TPC geometry using GeoManager (Dimensions)



Time of flight calculations



If A and B Particles

$$\text{Separation} = \frac{(t_A - t_B)}{\sigma_t}$$

Time of flight calculations: Separation for a track length of 1.66 m and time resolution = 94 ps

$$\sigma_t = \sqrt{\sigma_{start}^2 + \sigma_{stop}^2}$$