Simulation of dN/dx with TPC

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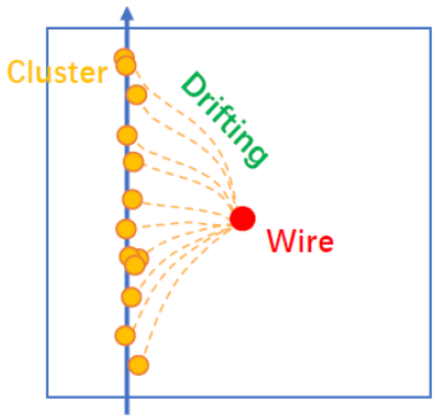
dN/dx in gaseous detectors

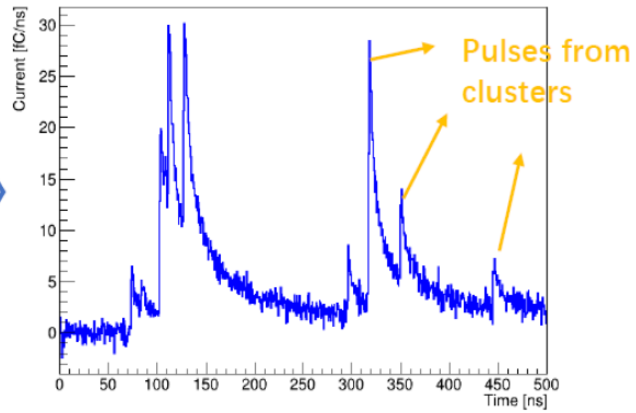
- **In time**
  - **Time measurement in small drift cells of DC**
  - Challenging of fast-shaping electronics (~ns needed)
  - De-couple the charge collection from the cluster counting altogether
  - →optical, with ~(sub) ns continuous readout sensors
- **In space**
  - **Resolve clusters in space by high granularity TPC**
  - Challenging of the low power consumption electronics (>40 mV/fC needed at 2000 of gas gain)
  - Pixelated readout – high granularity
  - →the reasonable pixilation reveals the underlying cluster structure in 3D chamber

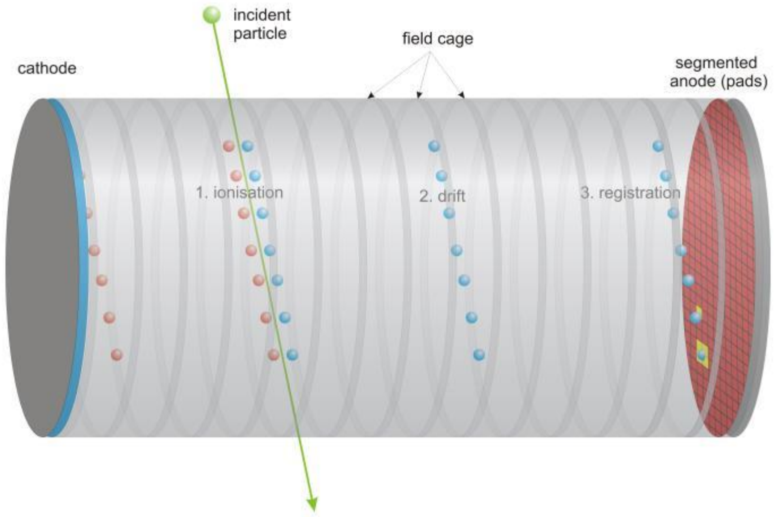
DC cell



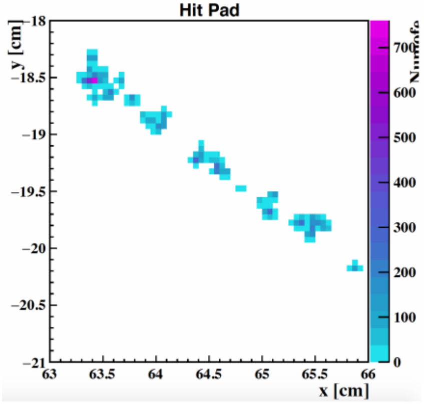
(for demonstration)

Induced current

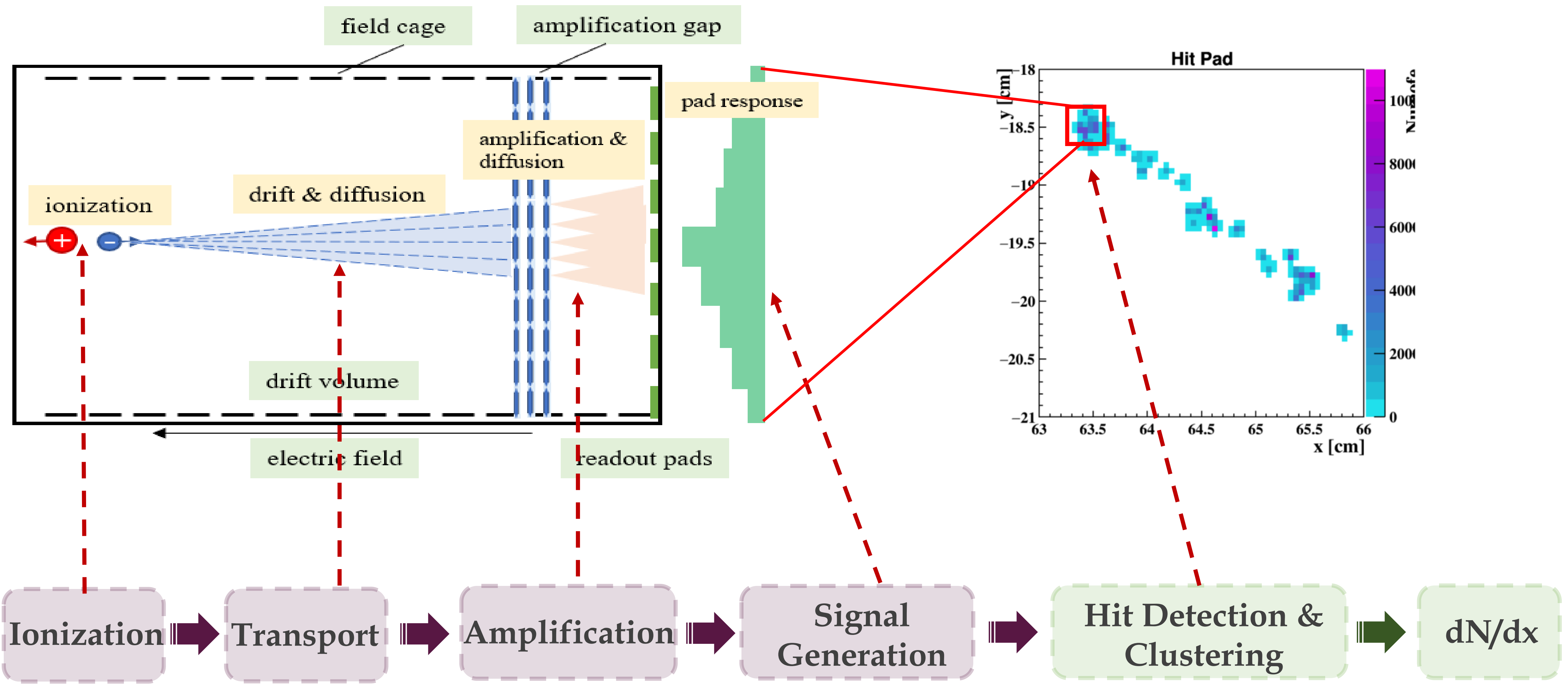




Readout



Simulation framework



Garfield++

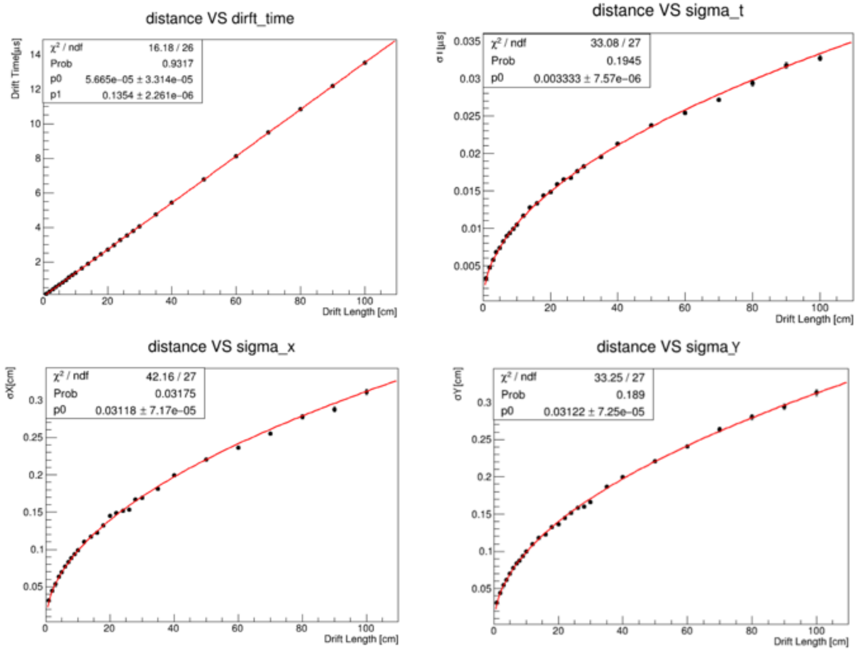
Simulation/Digitization

Reconstruction

Parametrizations

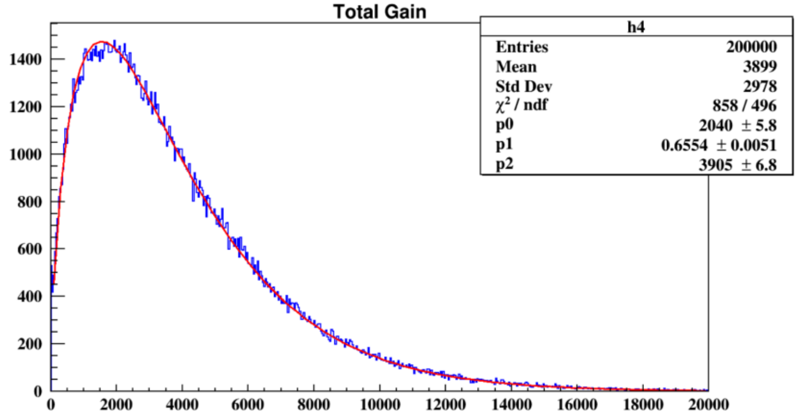
- **Diffusion:**
  - σ_T vs drift distance
  - σ_X vs drift distance
  - σ_Y vs drift distance
- **Amplification:**
  - Particle number: Polya function sampling with 2000 gain
  - Space resolution: 120 μm
- **Electronics noise:**
  - 100 e^-/pad

Diffusion



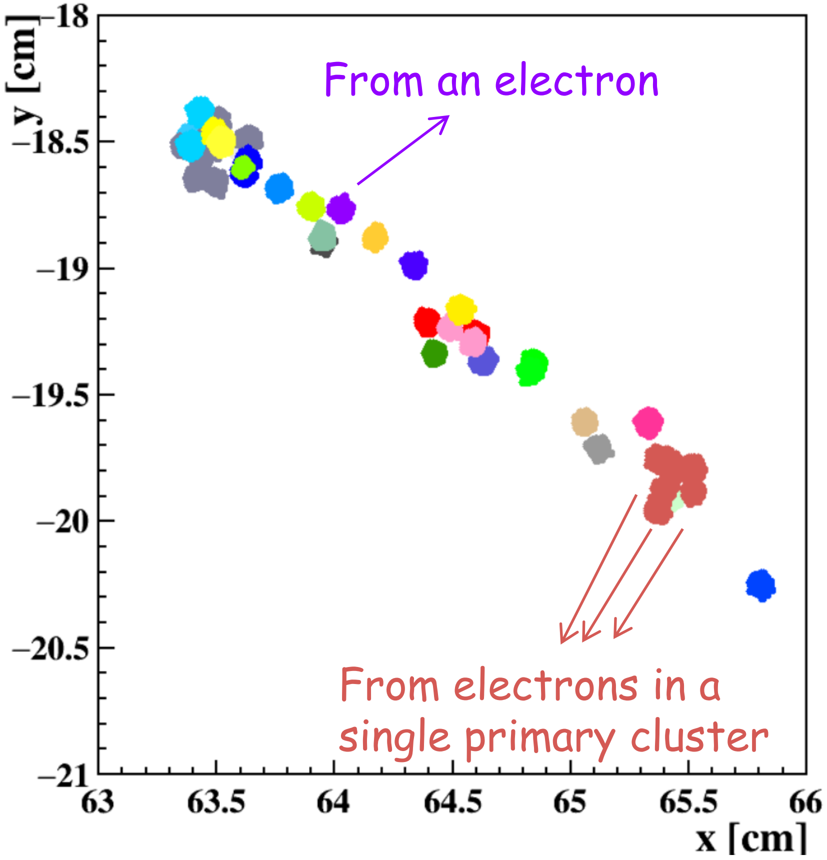
Input from Garfield++

Amplification



Micromegas

MC-truth-level readout

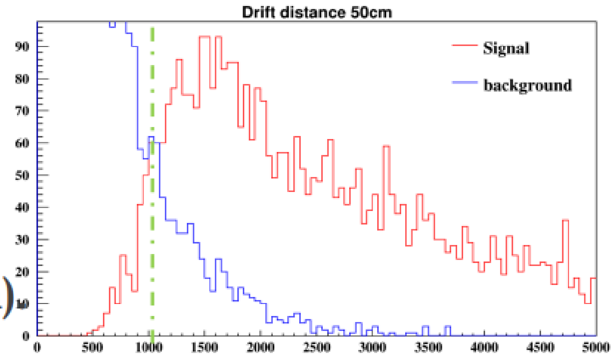


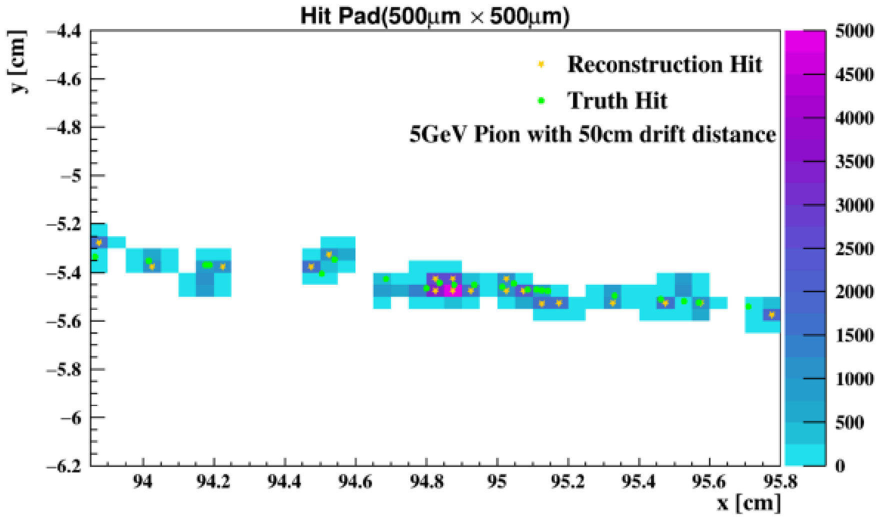
Drift distance: ~160 cm
Magnetic field: 2T

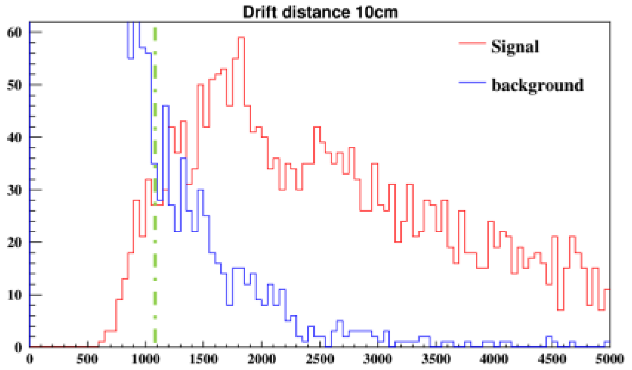
- MC-truth-level readout with simplified amplification and shaping model
- Color code indicates the cluster ID
- **Note:**
  - **Most electrons are separatable**
  - **Electrons from the same cluster are spatially localized**

Reconstruction by threshold passing

- By using a threshold-based method, preliminary reconstruction of clusters can be achieved
- The drift distance does not affect the threshold setting
- The reconstruction efficiency is related to the particle drift distance and requires calibration. (The reconstruction efficiency is 90% when the drift distance is 100 cm, and 60% when the drift distance is 50 cm).







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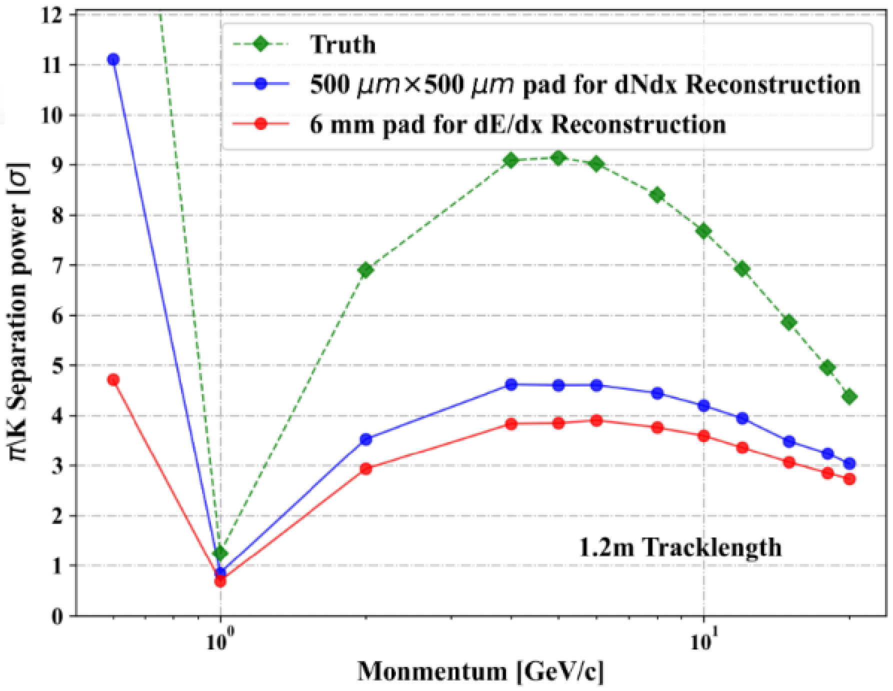
dN/dx performance

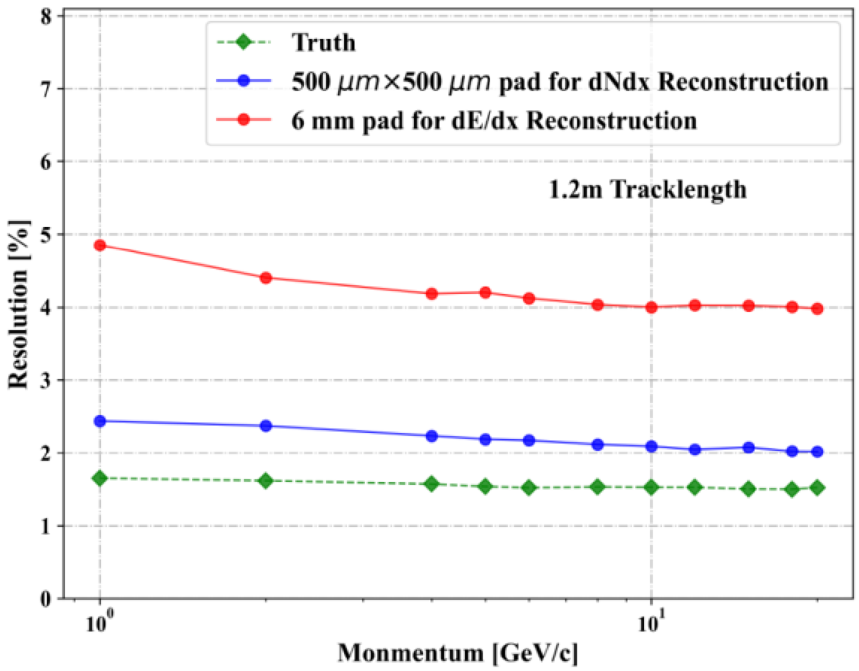
- Investigating the π/K discrimination capability using reconstructed clusters, a 3σ separation at 20GeV with a 50cm drift distance can be achieved
- dN/dx has significant potential for improving resolution

$$S = \frac{\left|\left(\frac{dN}{dx}\right)_{\pi} - \left(\frac{dN}{dx}\right)_{K}\right|}{(\sigma_{\pi} + \sigma_{K})/2}$$

Pion/kaon separation



Pion resolution



To do (I): Pad size optimization

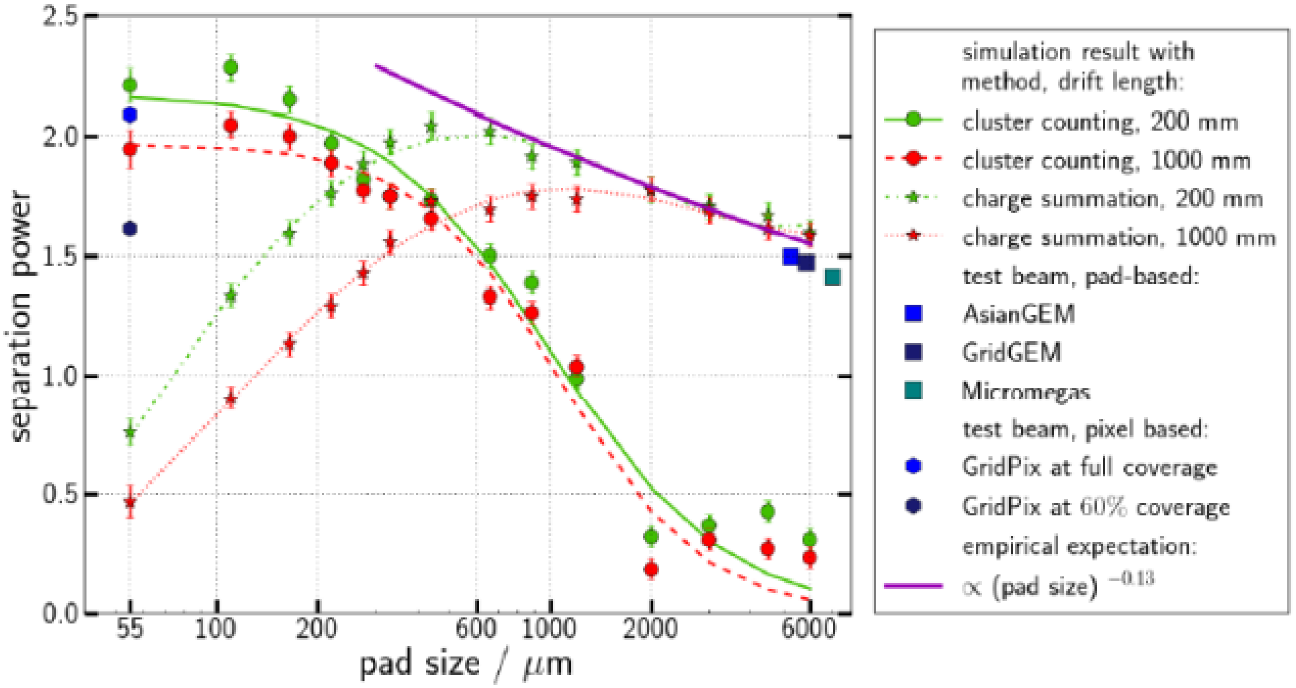
- **dN/dx (and tracking) can be beneficial from smaller pad size**

$$\rho_{cl} \approx 30cm^{-1} \Rightarrow Pad\ size \approx 300\mu m$$

(To detect single e⁻)

- **Need to find out the optimal pad size considering cost/power consumption**

Simulation with 30 cm track length

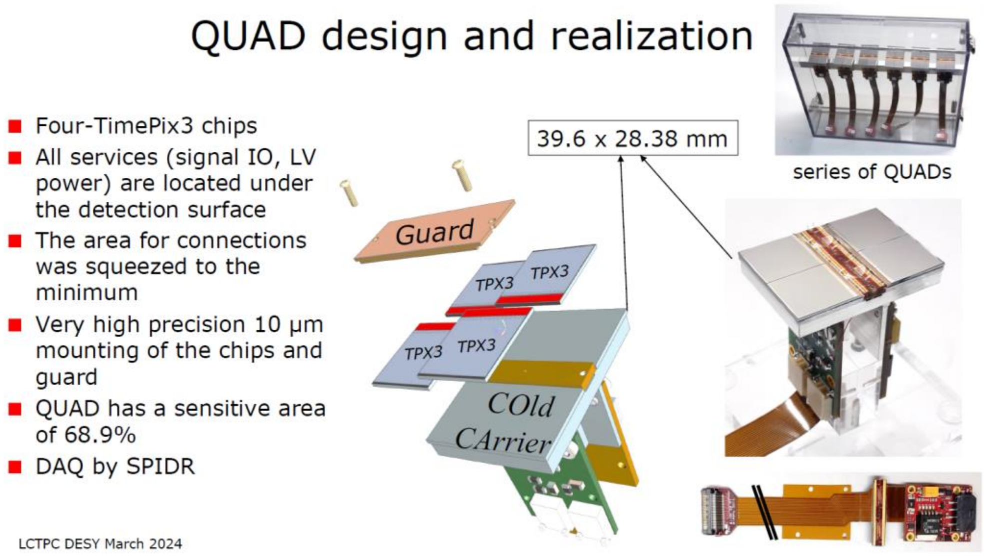


https://doi.org/10.1088/1748-0221/17/11/P11027

To do (II): Understand the 2021 DESY test beam

2021 DESY test beam:

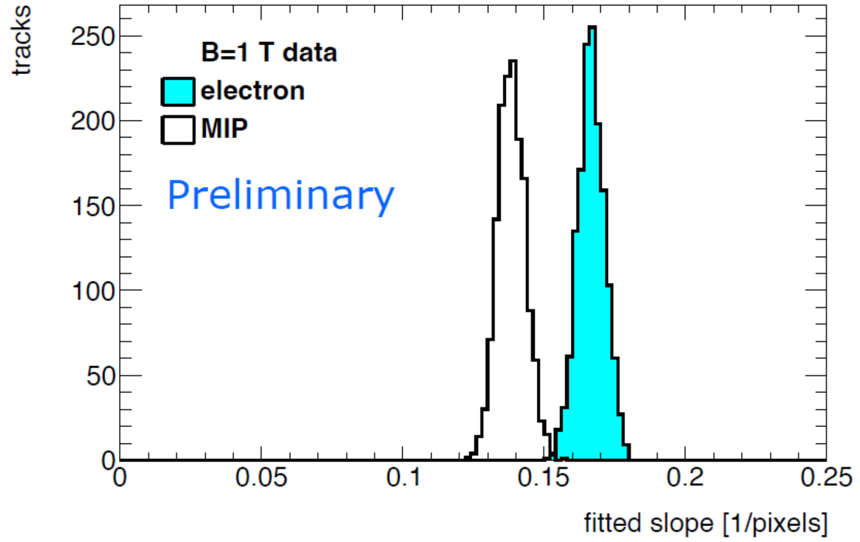
- TimePix3 Readout: 55x55 μm
- 5-6 GeV/c electron beam



dN/dx resolution

MIP scale corrected resolution 4.2% [electron has 2.9%]

1 m track 60% and coverage



Note:

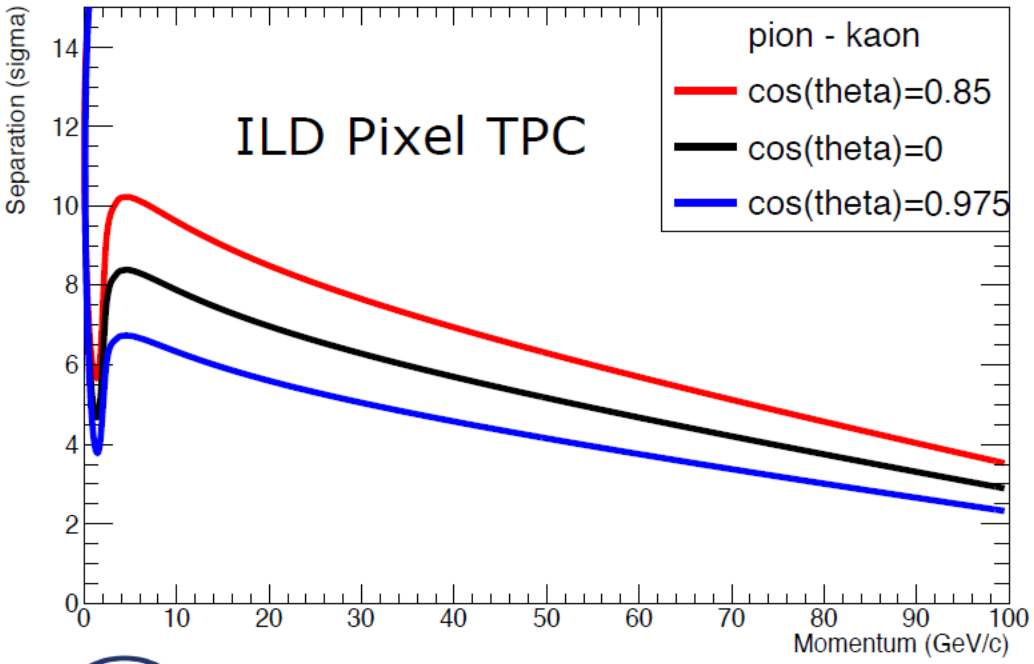
- Advance algorithm (20% better than threshold passing)
- Drift length < 4 cm, very small diffusion

To do (II): Understand the 2021 DESY test beam

Need to understand their results and tune our simulation!

Extremely powerful PID performance:

- > 6σ @ 20 GeV/c, 1.4 m track length



ILD detector

rInner = 329 rOuter = 1770 mm

MIP resolution = 3.6% at $\theta=\pi/2$

electron resolution = 2.5%

Assume Pixel TPC performance at
B = 1 T at p = 5,6 GeV/c

- Separation pion kaon
  $|\langle Eloss\ \pi \rangle - \langle Eloss\ K \rangle| / \sigma_\pi$
- Separation pion kaon for different cos(theta) values due to the track length dependence
- For cos(theta)=0 till 0.95 the separation lies between the black and red curves. Only above 0.95-0.975 the separation drops till the blue curve.
- Excellent performance over very large polar angle range

Backup

dE/dx extrapolation from test beam

- A higher granularity is also very helpful for improving dE/dx.
- According to simulation results, for a pad size of 500um, with the current 1.2-meter track length of CEPC, the dE/dx can reach 3.2%.

$$\sigma_{dE/dx} \sim L^{-0.47} \times \boxed{G^{-0.13}}$$