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Time spectrum @ CEPC ECAL

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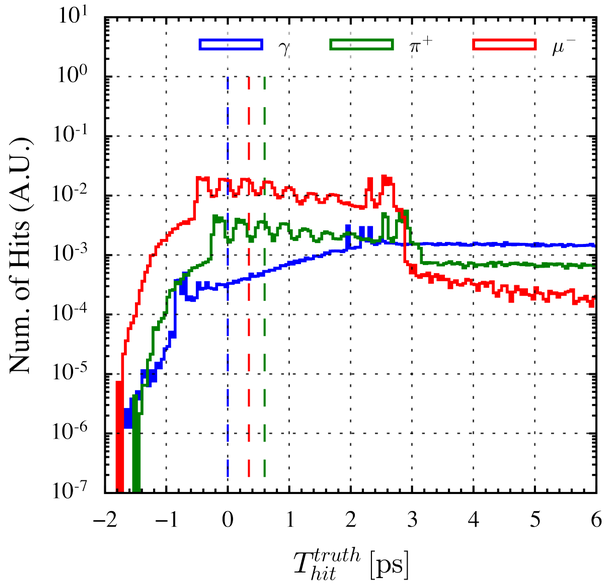
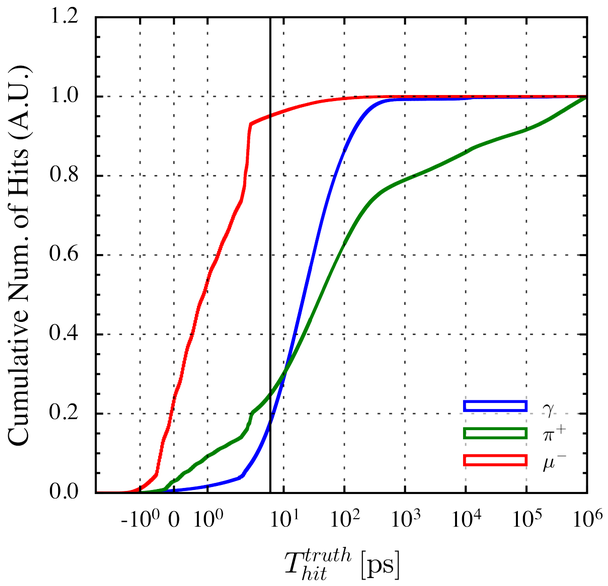
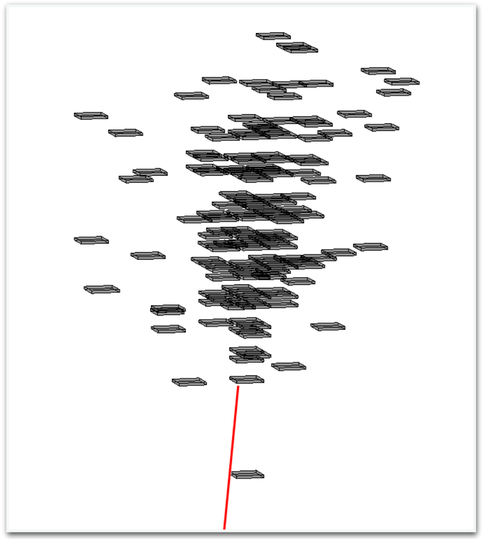
Motivation: Time spectrum @ hit level

- Simulated in CEPC baseline ECAL
- 10 GeV γ, π^+, μ^- with $\theta \sim 84^\circ, \phi = 0$
- B field: 0

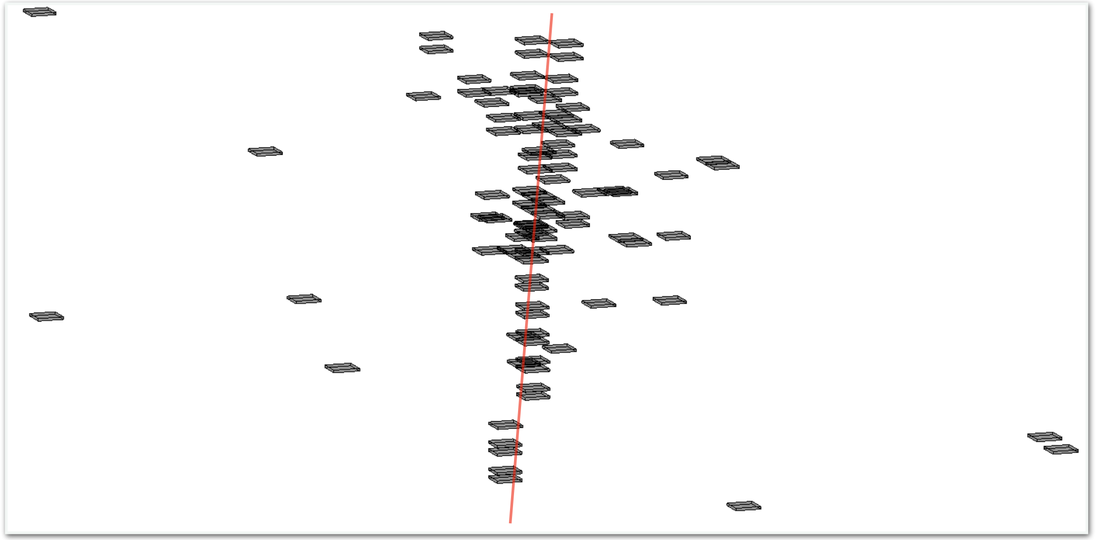




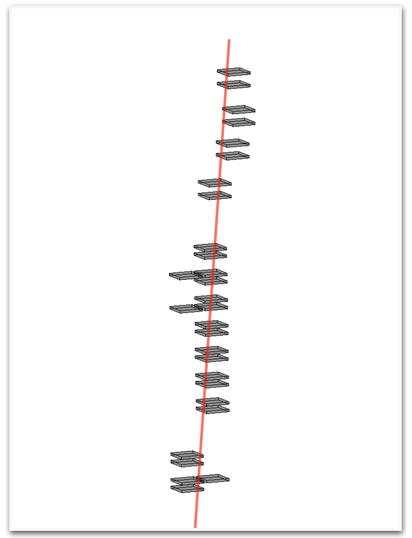
10 GeV γ



10 GeV π^+



10 GeV μ^-



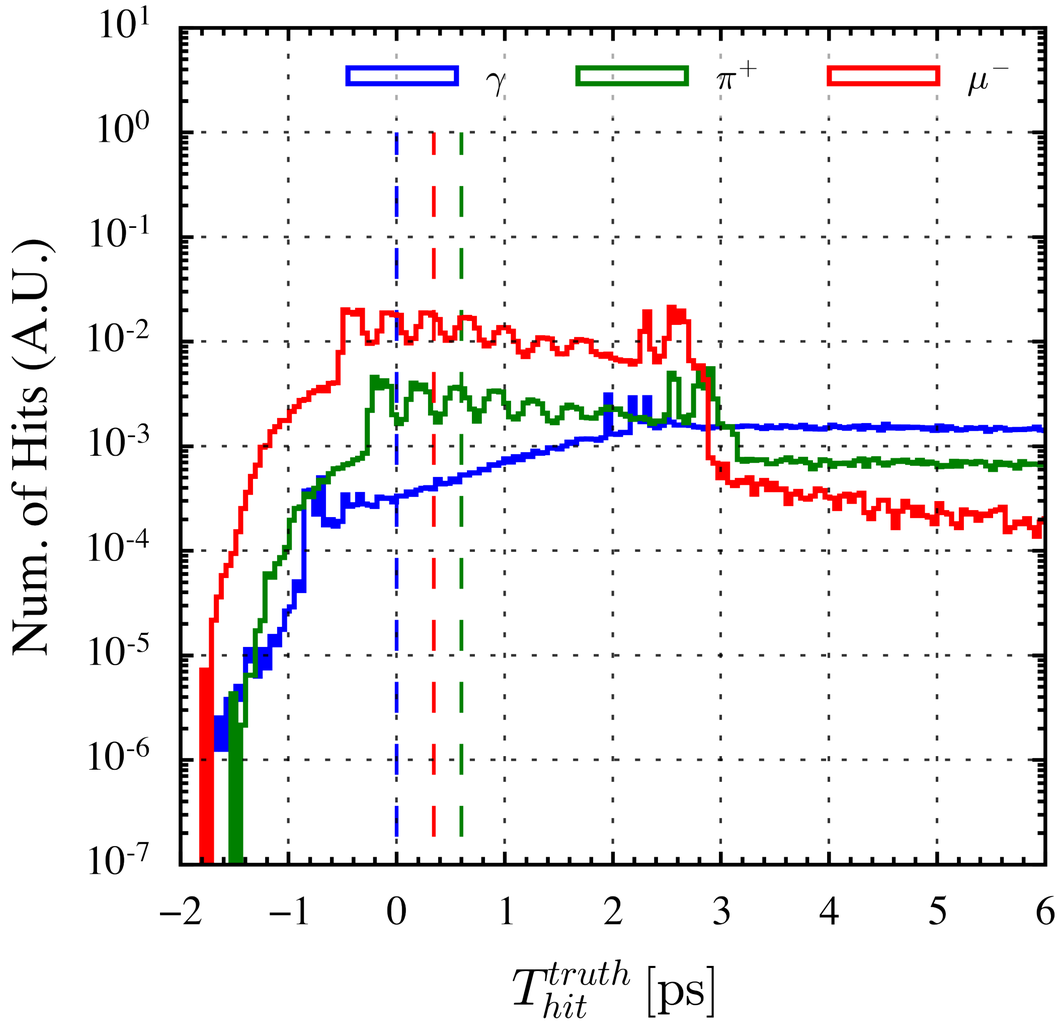
Motivation: Time spectrum @ hit level

Conventions:

- **Hit time (t_{hit})**: time of the **most energetic** sub-hit in the cell
- **Hit position**: **center** of the cell
- **Shifted time**: $T_{\text{shift}} = t_{\text{hit}} - L_{\text{IP}\to\text{hit}}/c$
  $L_{\text{IP}\to\text{hit}}$: distance from the IP to hit position.

Interesting phenomenons:

1. Zigzagging structure (0 ~ 3 ps)
2. Frontier < 0 (seems like faster than light)



The time of a sub-hit is defined by the Geant4 step: `G4double time = aStep->GetTrack()->GetGlobalTime();`

Understand the hits *faster than light*

The position uncertainty causes bias on the shifted time.

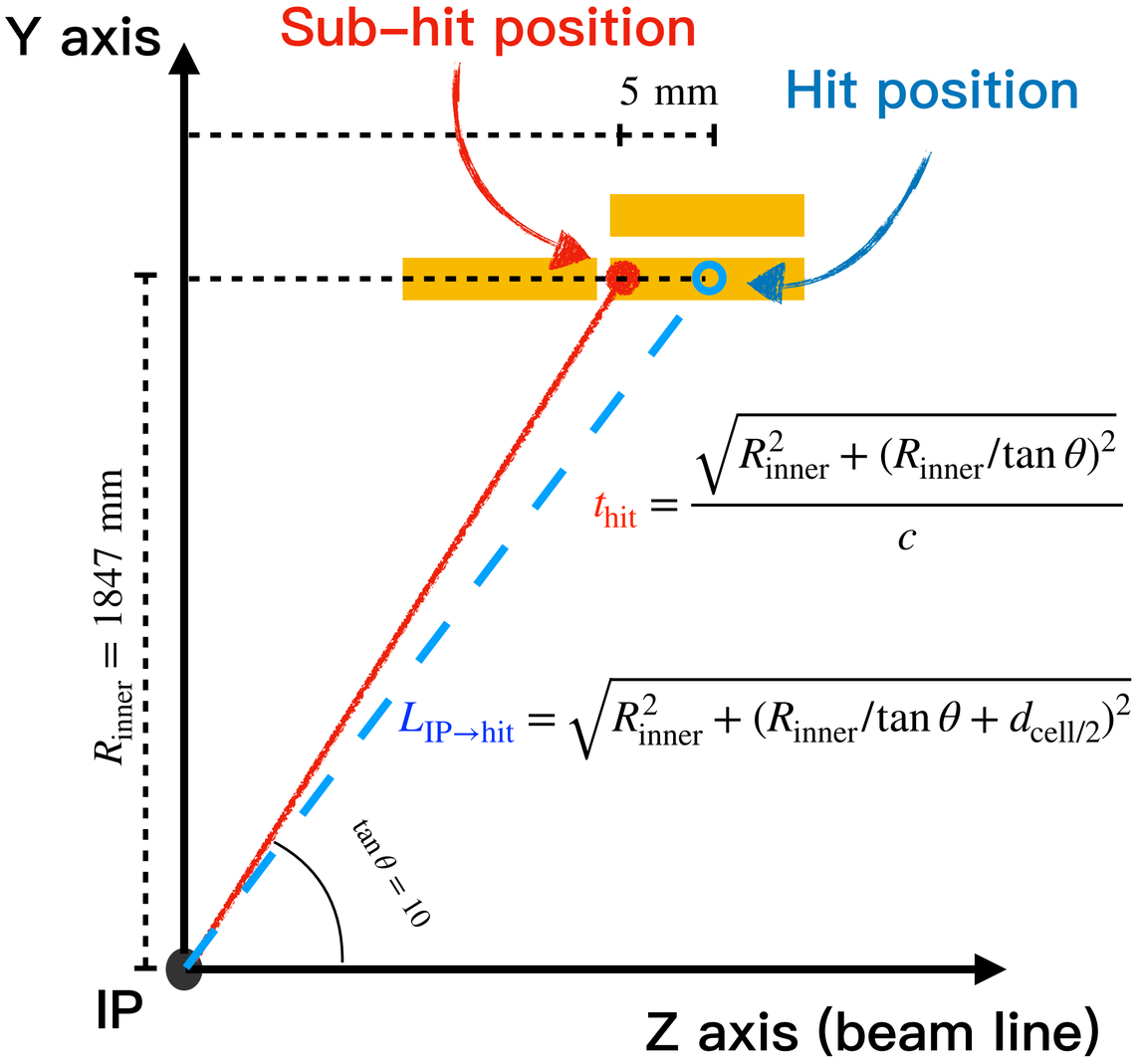
$$T_{\text{shift}} = t_{\text{hit}} - L_{\text{IP}\to\text{hit}}/c$$

$$= \frac{1}{c}\left(\sqrt{R_{\text{inner}}^2 + (R_{\text{inner}}/\tan\theta)^2} - \sqrt{R_{\text{inner}}^2 + (R_{\text{inner}}/\tan\theta + d_{\text{cell}}/2)^2}\right)$$

$$= \frac{R_{\text{inner}}}{c}\left(\sqrt{1+\frac{1}{\tan^2\theta}} - \sqrt{1+(\frac{1}{\tan\theta}+\frac{d_{\text{cell}}}{2R_{\text{inner}}})^2}\right)$$

$$\sim -\left(\frac{\cancel{R_{\text{inner}}}}{c}\frac{\mathrm{d}\sqrt{1+\mathrm{x}^2}}{\mathrm{dx}}\Big|_{x=\frac{1}{\tan\theta}}\right)\cdot\frac{d_{\text{cell}}}{2\cancel{R_{\text{inner}}}}$$

$$= -\frac{1}{0.299792\ \text{mm/ps}} \times 0.0995 \times 5\ \text{mm} \sim -1.7\ \text{ps}$$



Understand the zigzag structure

The position uncertainty causes bias on the shifted time, which is **proportional to the position error(to first order)**:

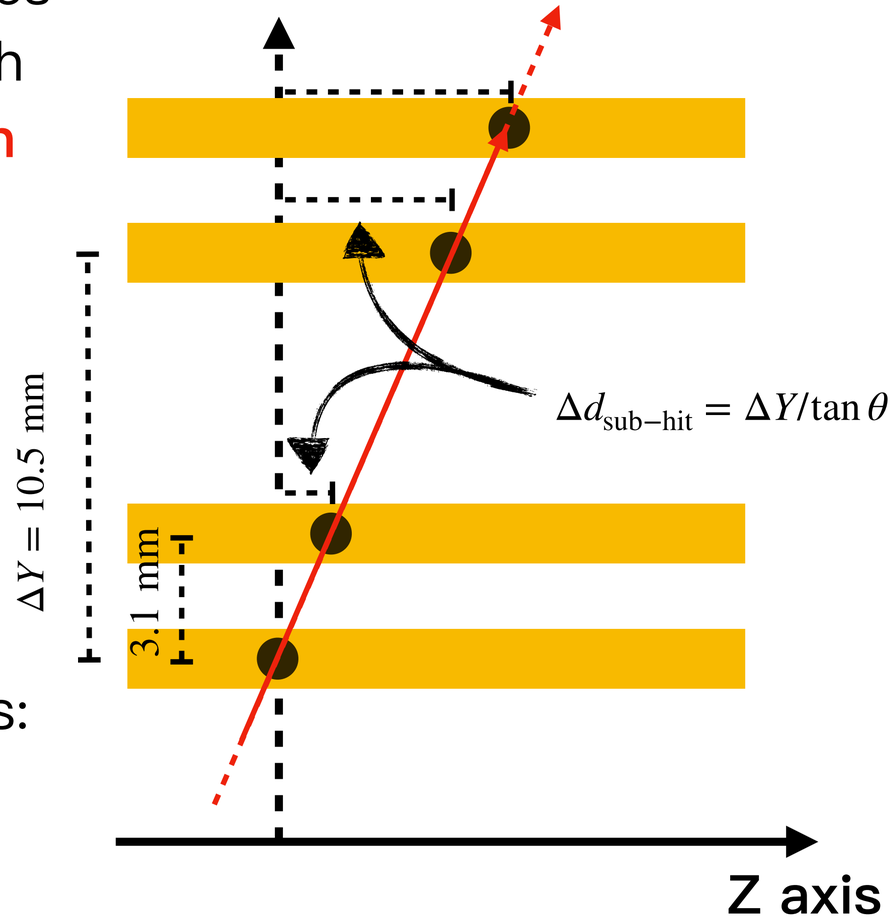
$$T_{\text{shift}} = K \cdot d_{\text{sub-hit}}$$

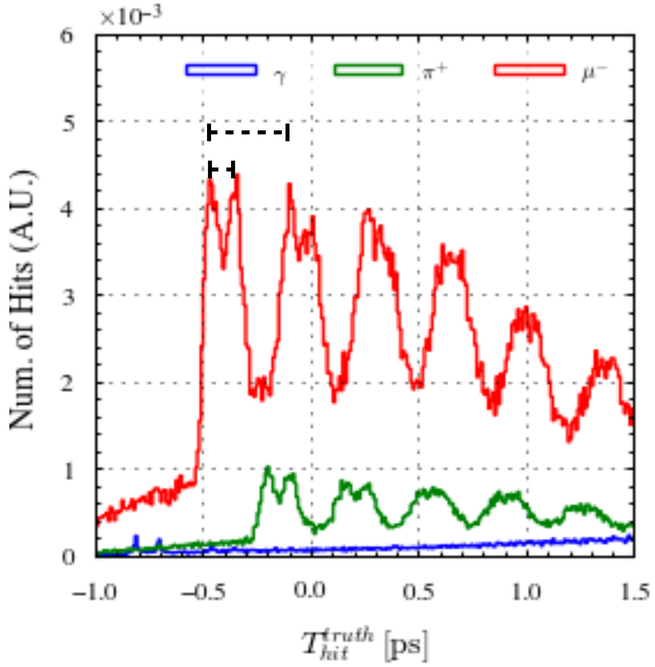
where, $K = \frac{1}{c}\frac{\mathrm{d}\sqrt{1+\mathrm{x}^2}}{\mathrm{dx}}\Big|_{x=\tan\theta}$

The space between two peaks:

$$\Delta T_{\text{shift}} \sim K \cdot \Delta d_{\text{sub-hit}}$$

$$= K \cdot \Delta Y/\tan\theta \sim 0.10,\ 0.35\ \text{ps}$$

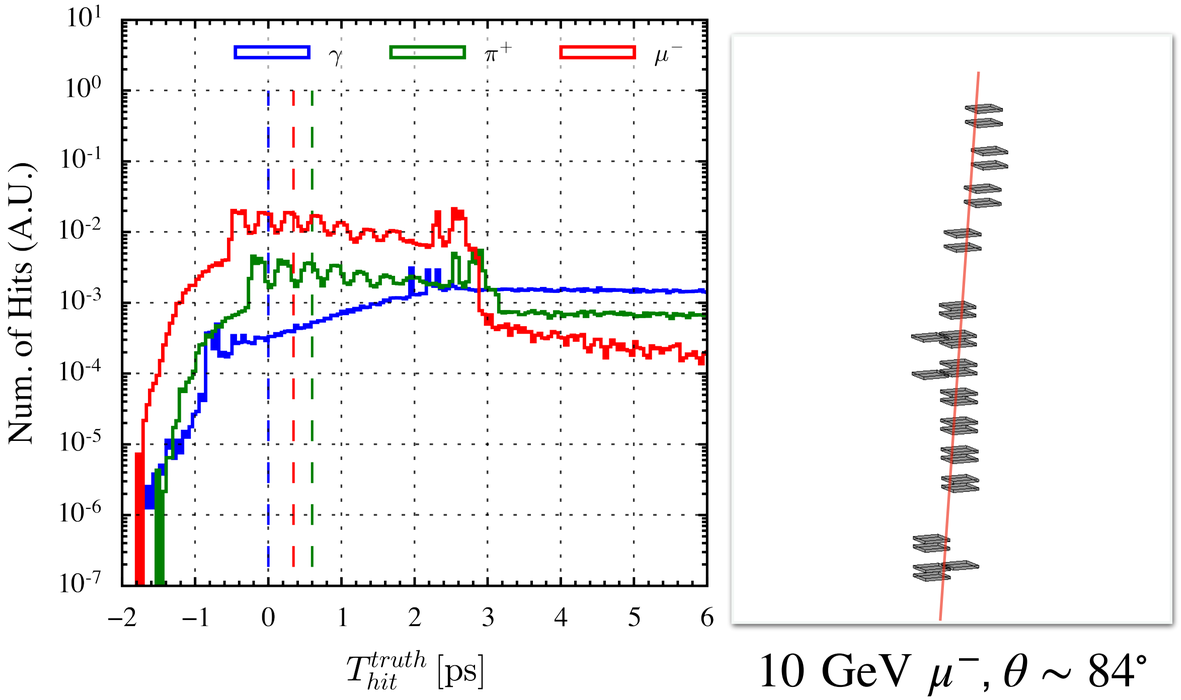




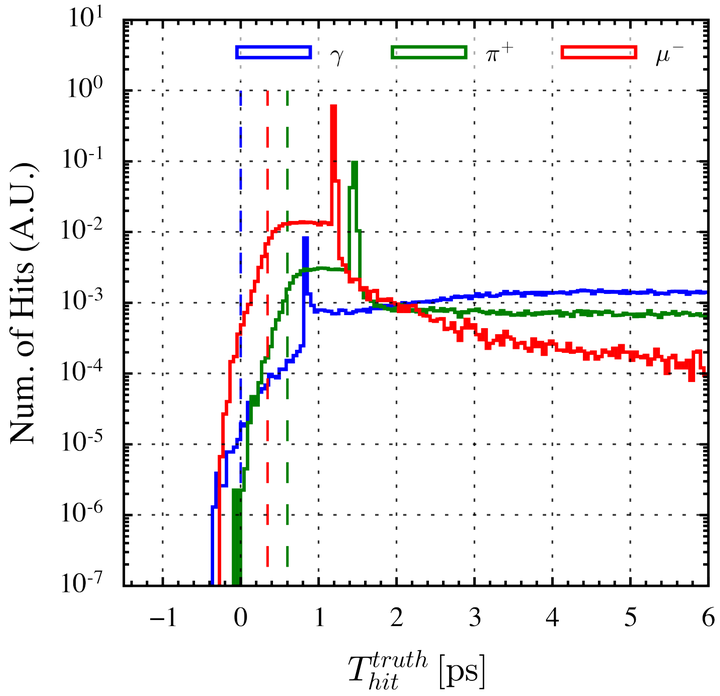
Demonstration: shot particles perpendicular to ECAL

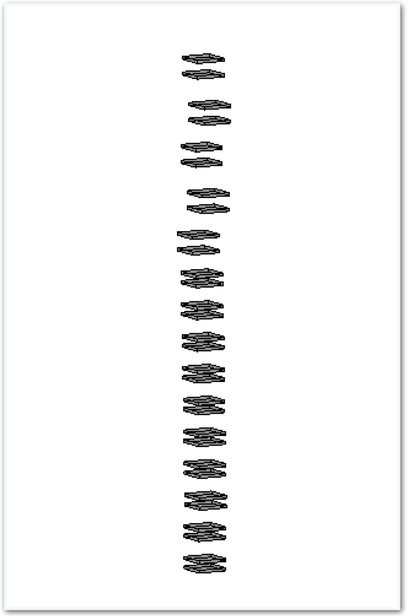
Generate single particle with $\theta = 90°$,

1) the zigzagging structure disappears, and **2)** the frontier shifts latter.



10 GeV $\mu^-, \theta \sim 84°$

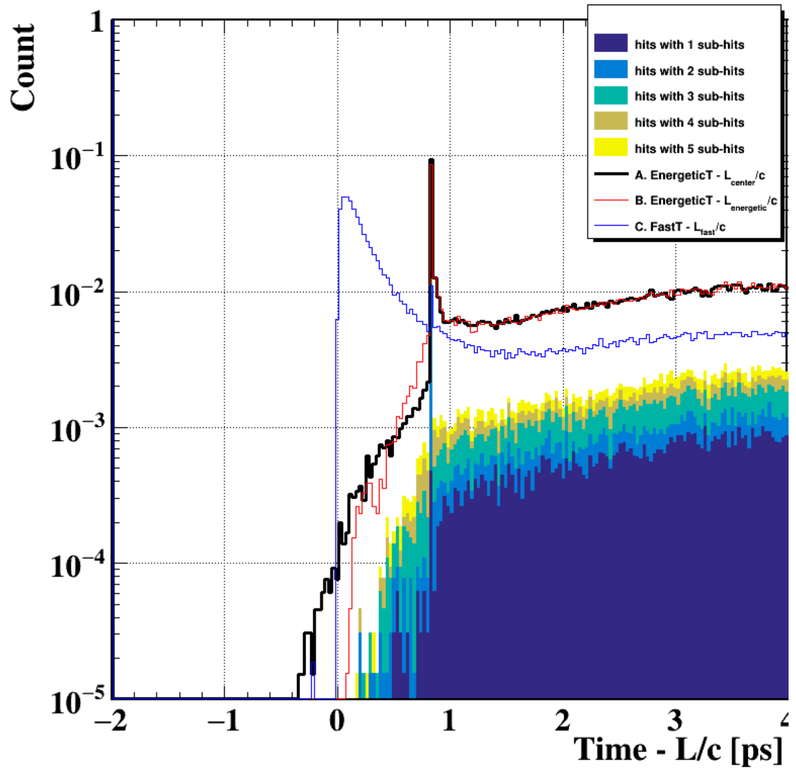




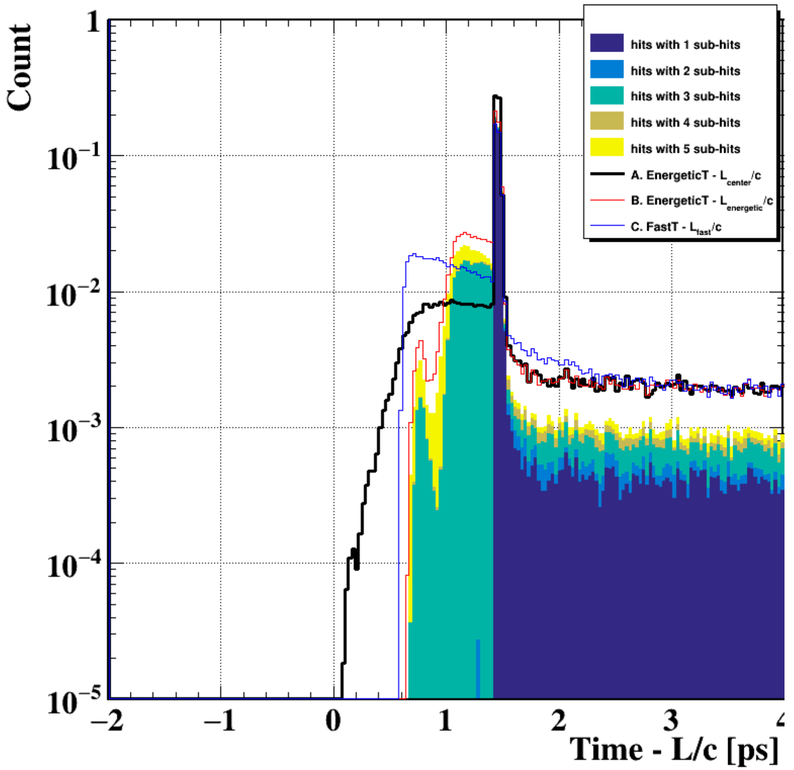
10 GeV $\mu^-, \theta = 90°$

Try other definitions of hit time and position

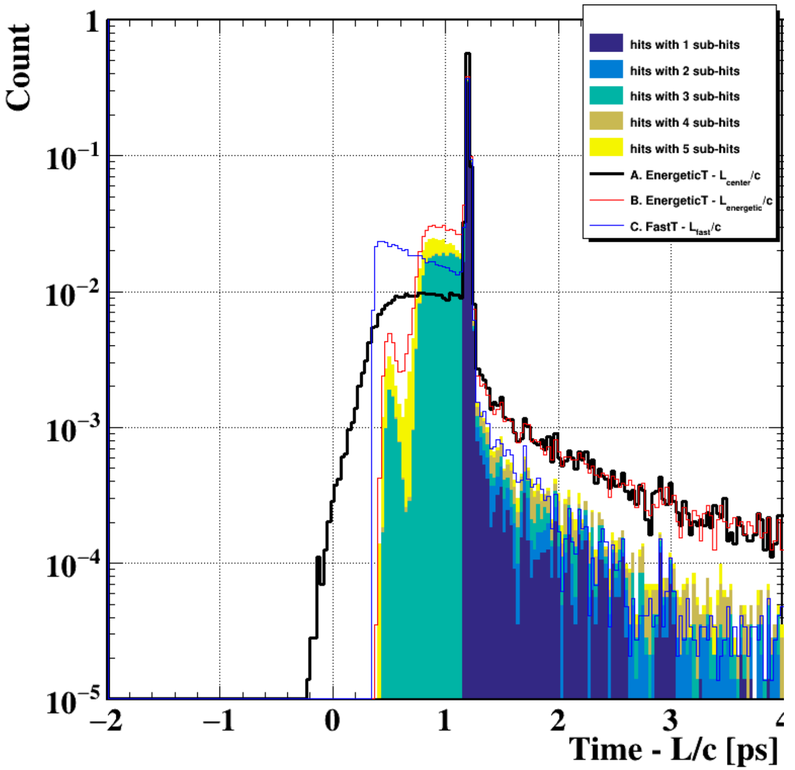
	Hit time	Hit position
1 (black line)	energetic sub-hit	cell center
2 (red line)	energetic sub-hit	(start + end) / 2 of (energetic) sub-hit (step)
3 (blueline)	fastest sub-hit	(start + end) / 2 of (fastest) sub-hit (step)



10 GeV photon



10 GeV charged pion

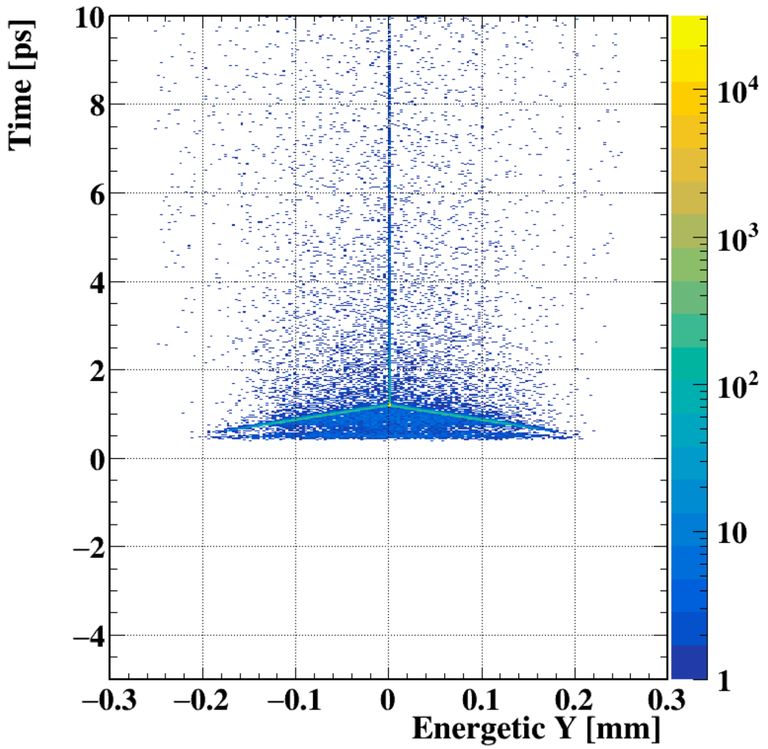


10 GeV muon

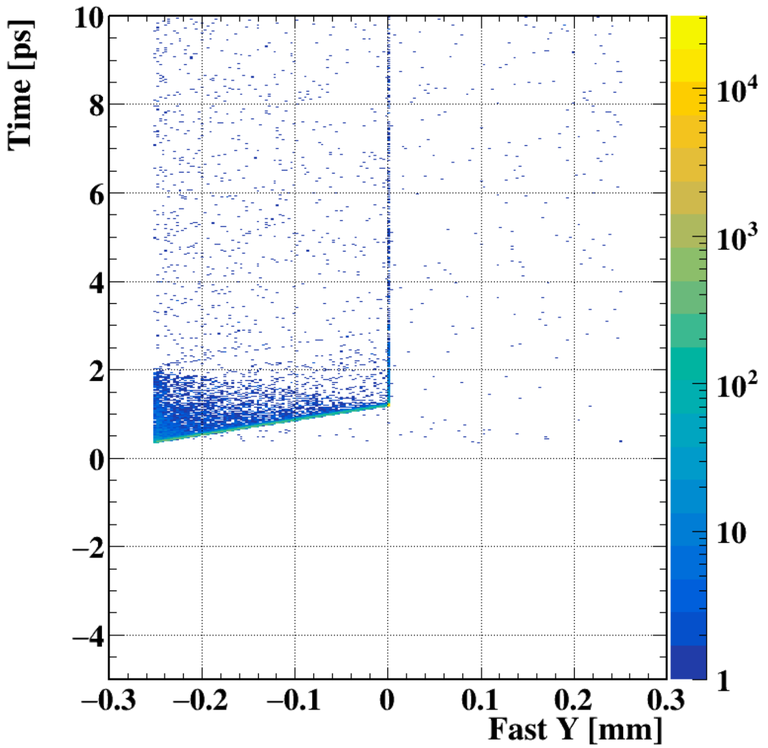
Sub–hit distribution inside cell

Shifted time versus relative position of the corresponding sub–hits.

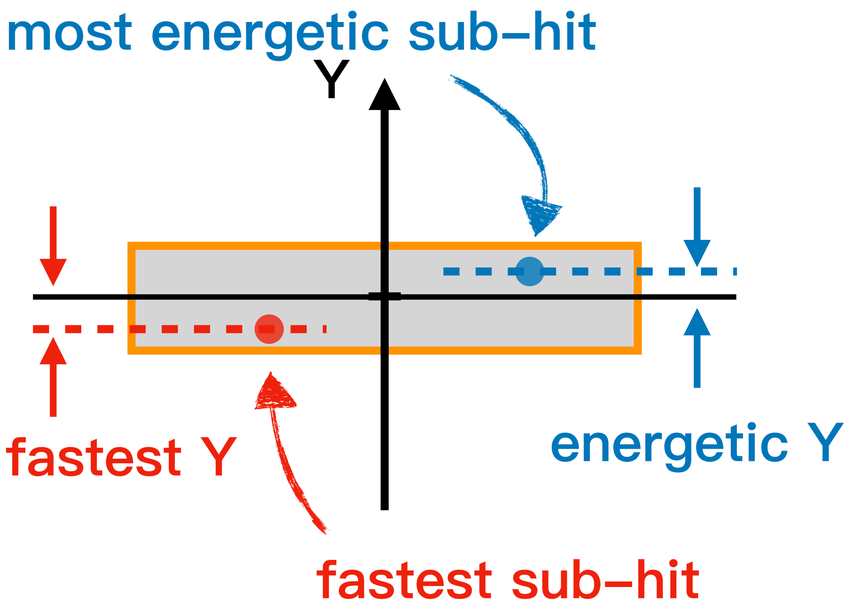
Some artificial structures …



The most energetic sub-hit



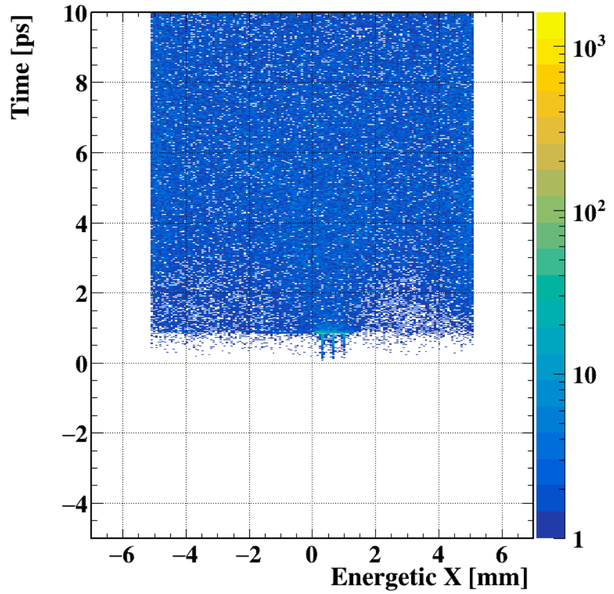
The fastest sub-hit

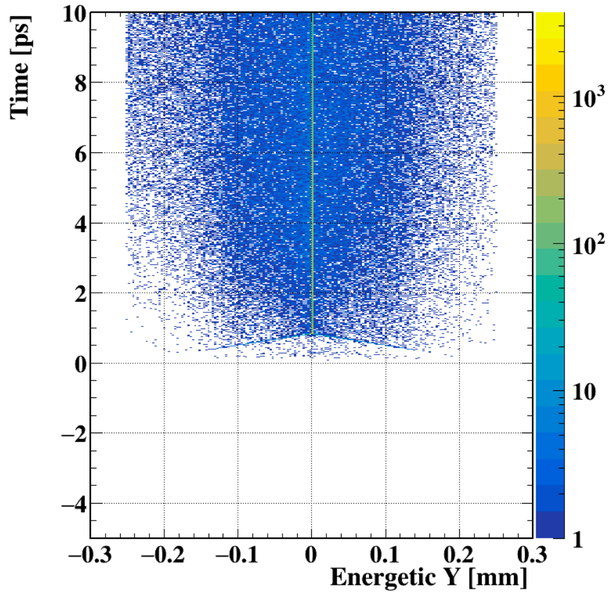


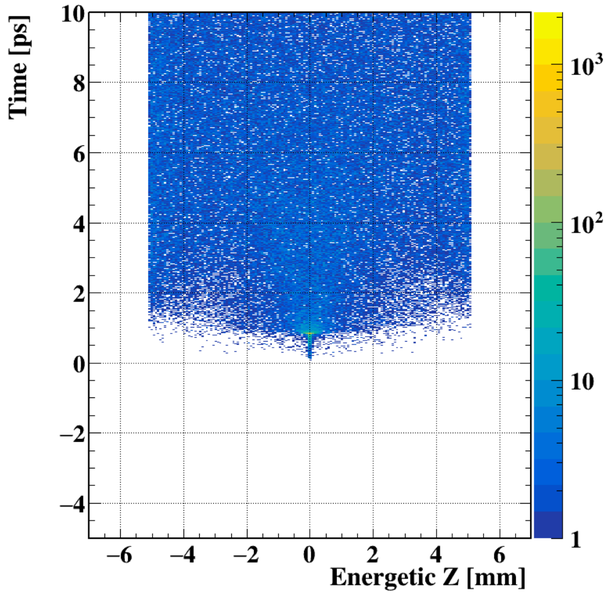
Only 10 GeV Muon sample.

Sub-hit time vs. relative X, Y, Z: photon

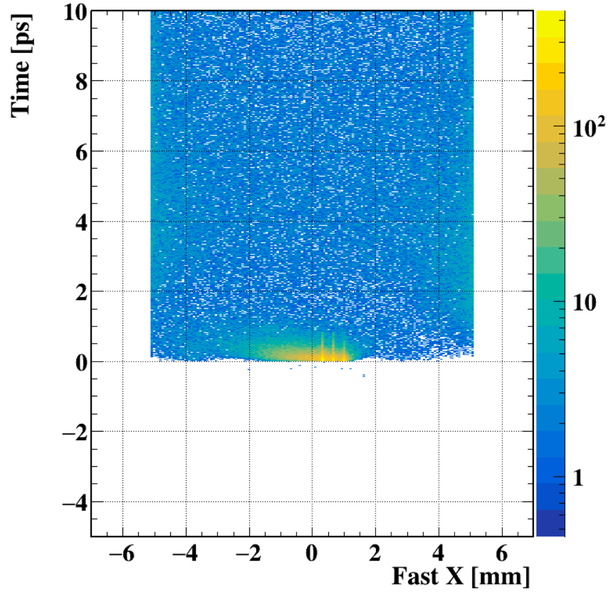
Most energetic sub-hit

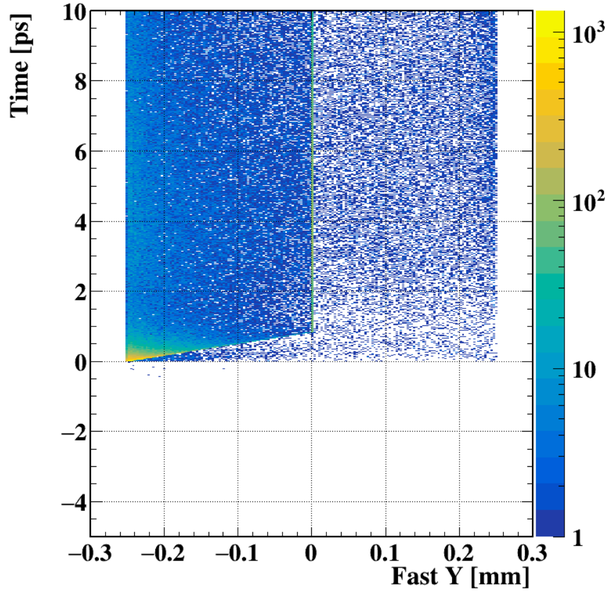


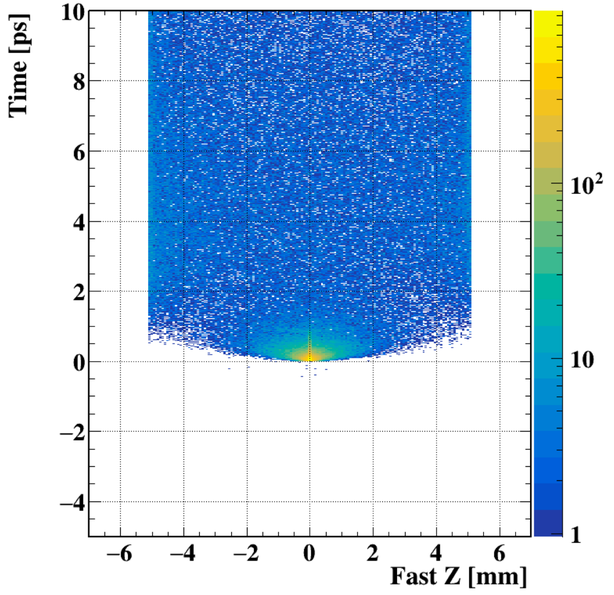




Fastest sub-hit

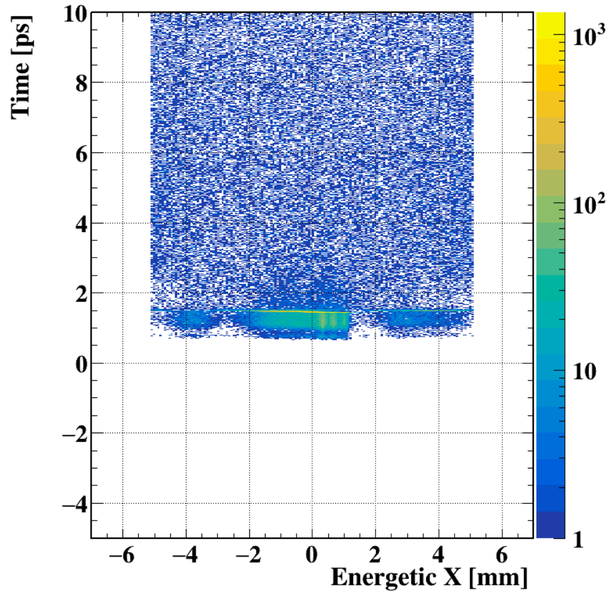


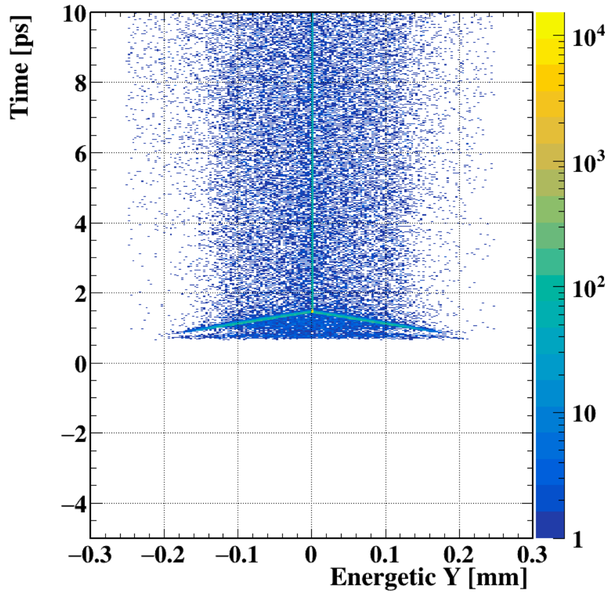


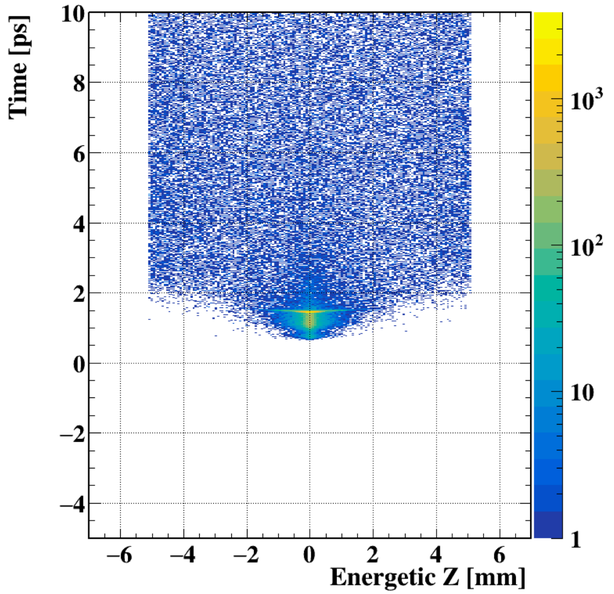


Sub-hit time vs. relative X, Y, Z: charged pion

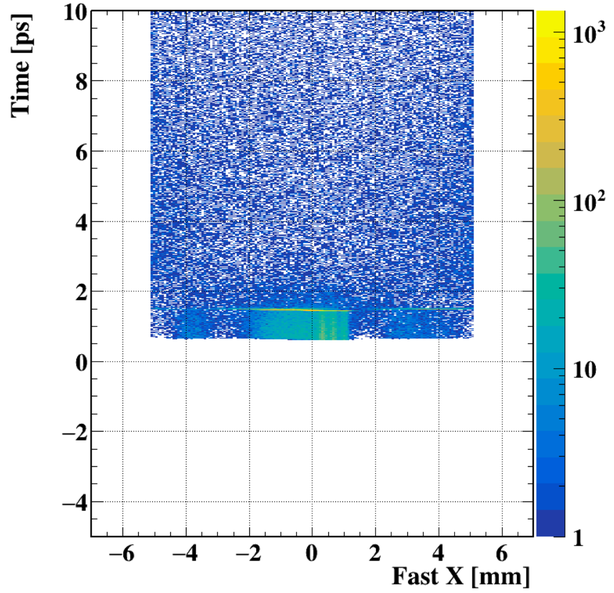
Most energetic sub-hit

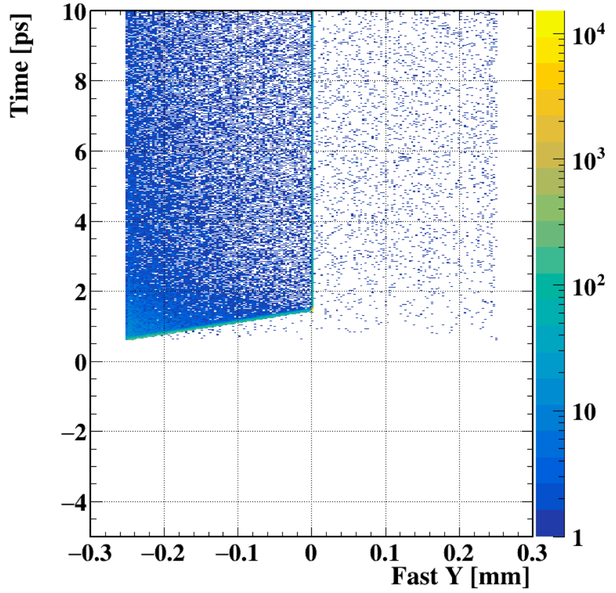


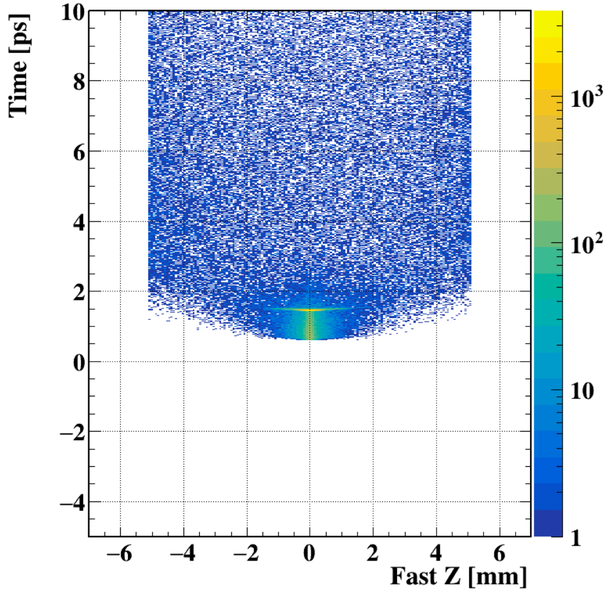




Fastest sub-hit

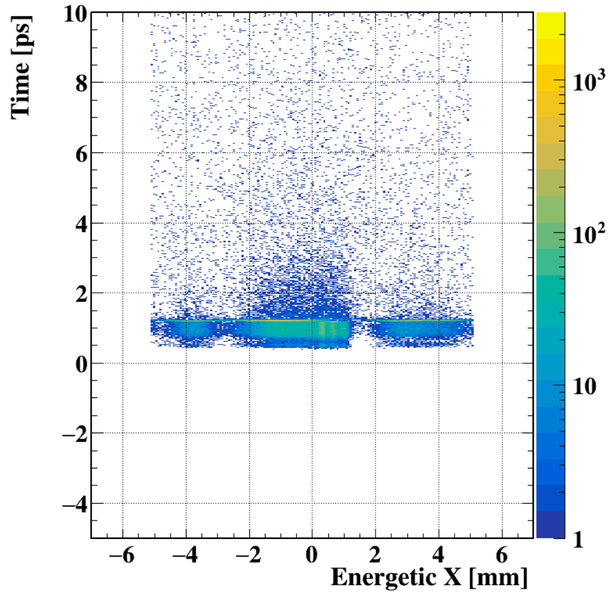


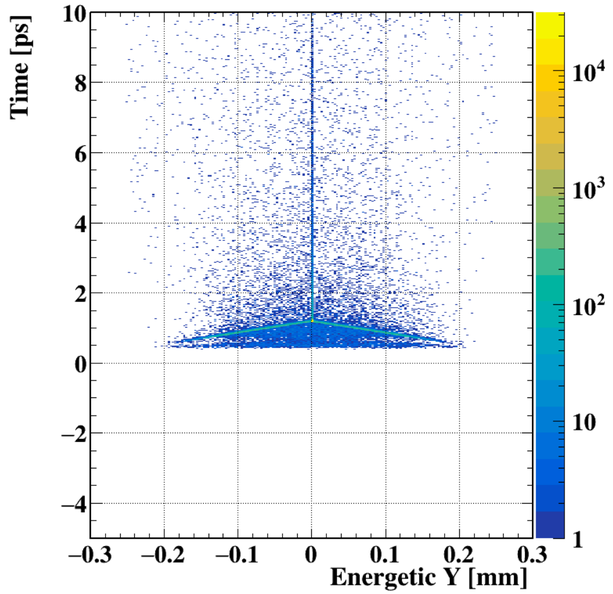


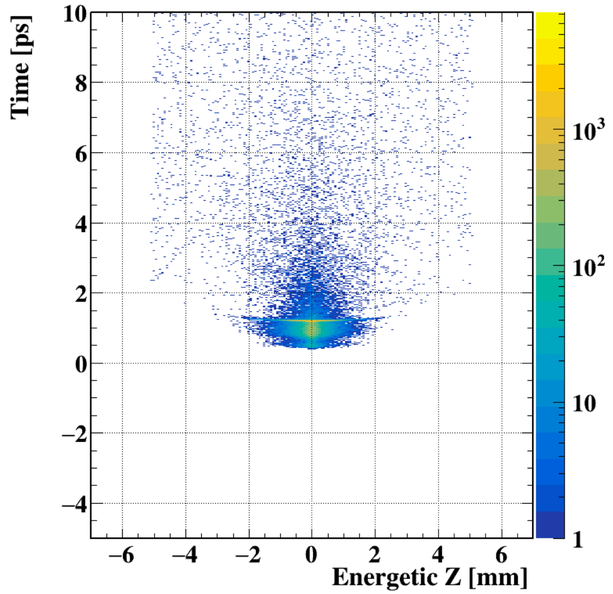


Sub-hit time vs. relative X, Y, Z: muon

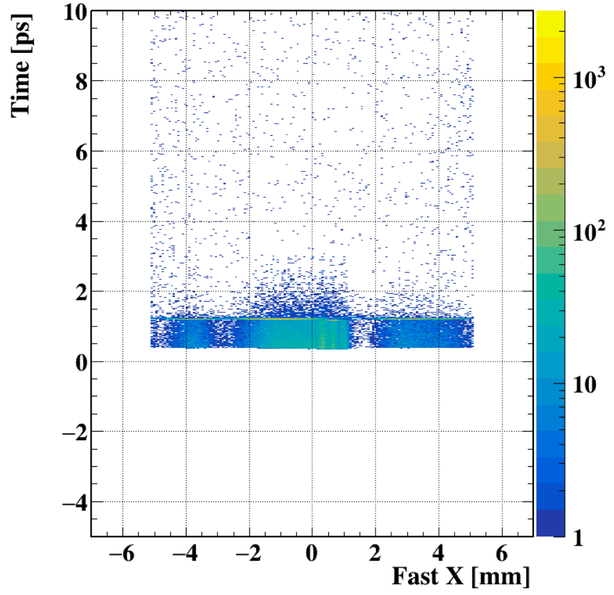
Most energetic sub-hit

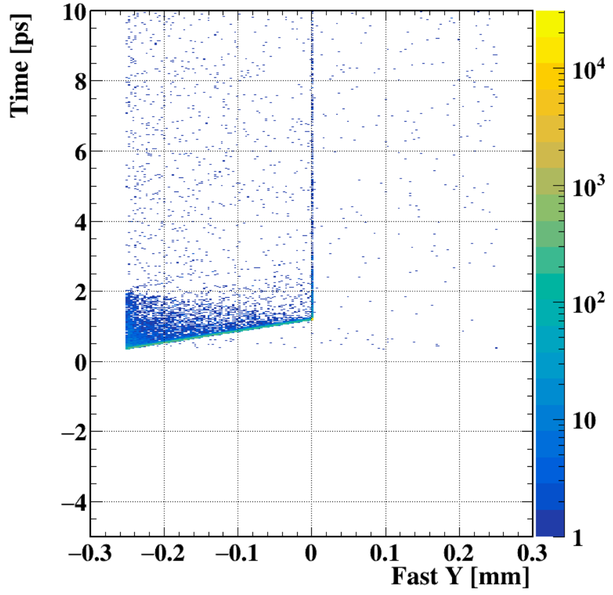


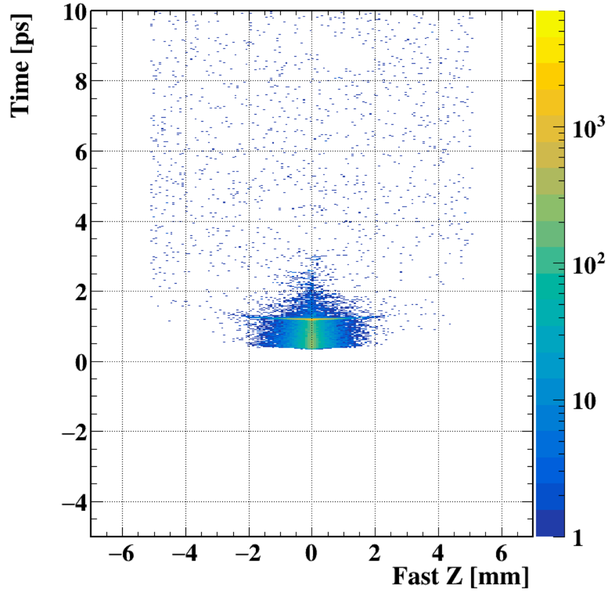




Fastest sub-hit







Summary

1. Several conventions make difference on the time spectrum:

    1.1. Definition of hit time

        1.1.1. the time of the most energetic sub-hit

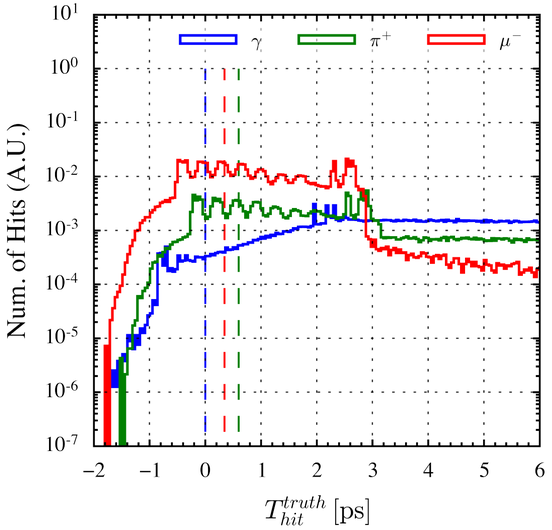
        1.1.2. the time of the fastest sub-hit

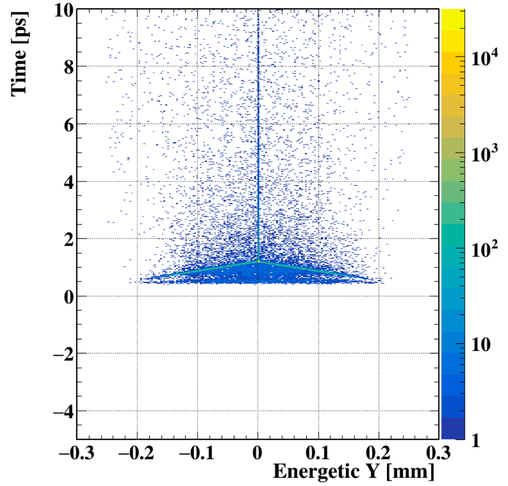
    1.2. Definition of hit position

        1.2.1. center of the cell

        1.2.2. position of the corresponding sub-hit

    1.3. Normalization (or shift) of the hit time





2. Local geometry & the Geant4 modeling will induce artificial patterns in shower time spectrum on the ps level.

Back Up

Geometry of the CEPC baseline ECAL

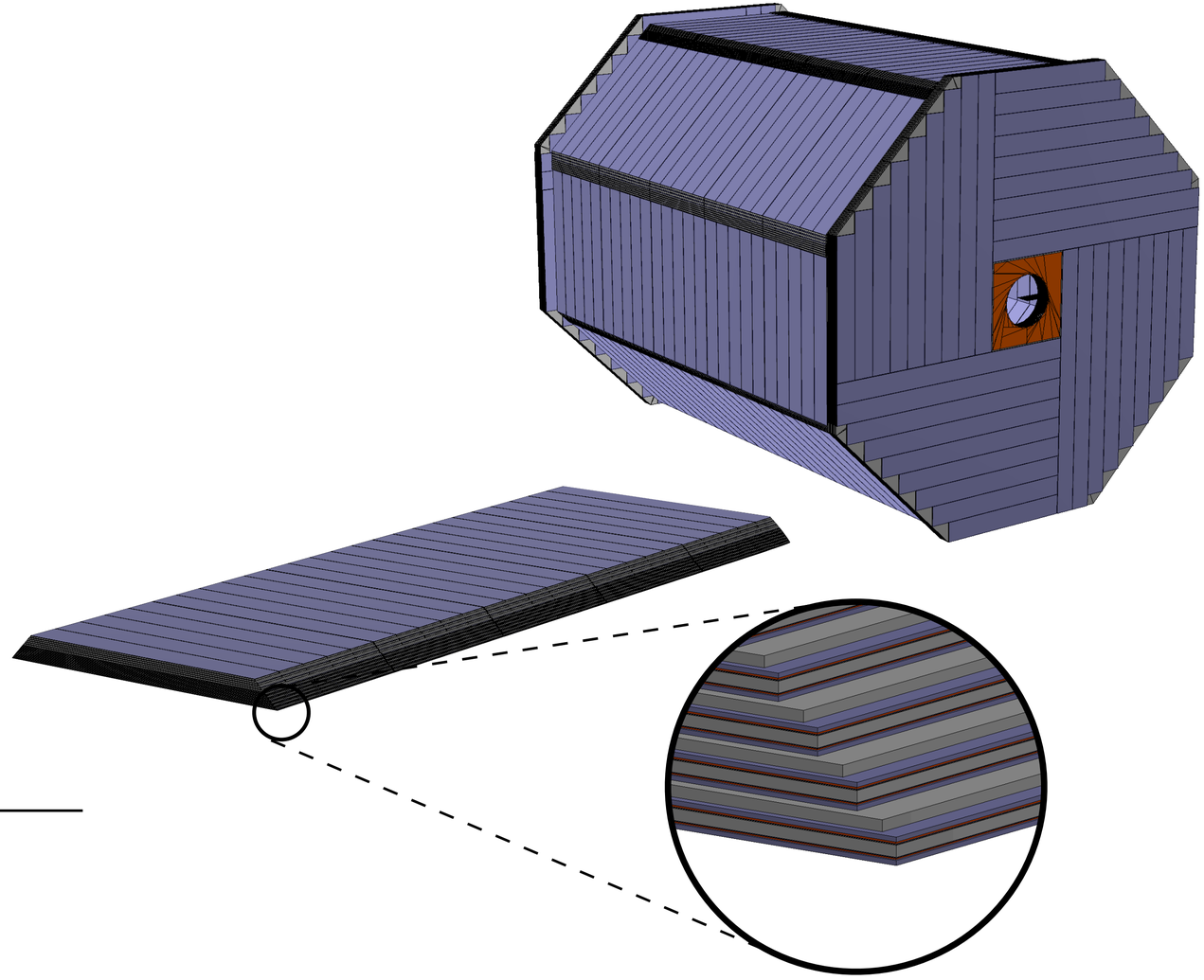
The baseline electromagnetic calorimeter (ECAL) optimized for the CEPC:

longitudinal direction: 30 (= 20 + 10) Layers

- First section: **20 layers**
  - tungsten plate $(2.1\,mm)$ + silicon sensor $(0.5\,mm \times (10 \times 10)\,mm^2)$
- Second section: **10 layers**
  - tungsten plate $(4.2\,mm)$ + silicon sensor $(0.5\,mm \times (10 \times 10)\,mm^2)$

ECAL inner radius: 1847 mm

B Field: 3 T (set to 0 in this research)



The CEPC Study Group, CEPC Conceptual Design Report: Volume 2-Physics & Detector, ArXiv Preprint ArXiv:1811.10545 **2**, (2018).