ToF Measurement with Calorimeter Cluster

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The 2021 international workshop on the high energy Circular Electron-Positron Collider
November 8-12, 2021

Contents

What could cluster TOF resolution be reached in the CEPC baseline?

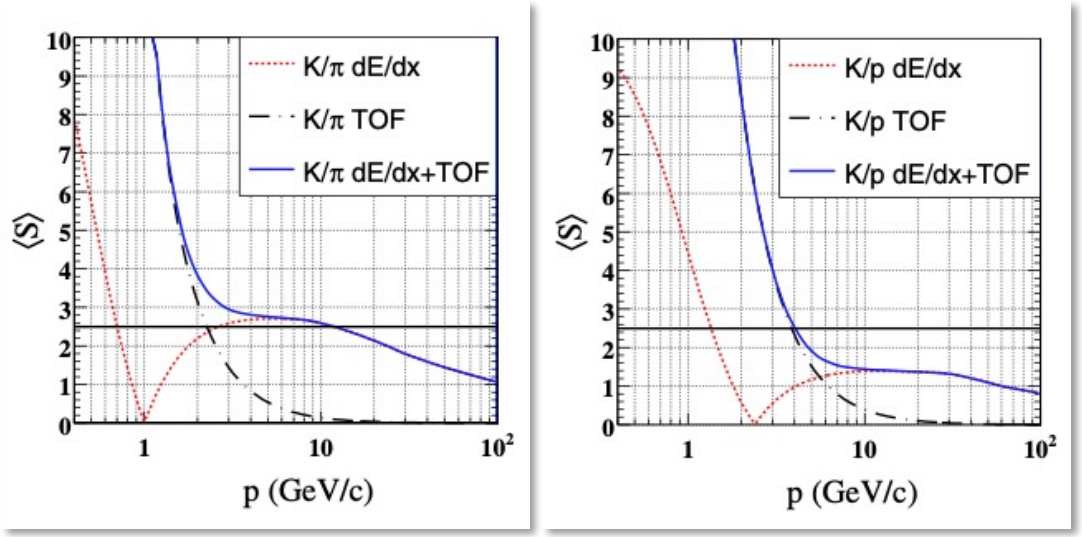
Motivation

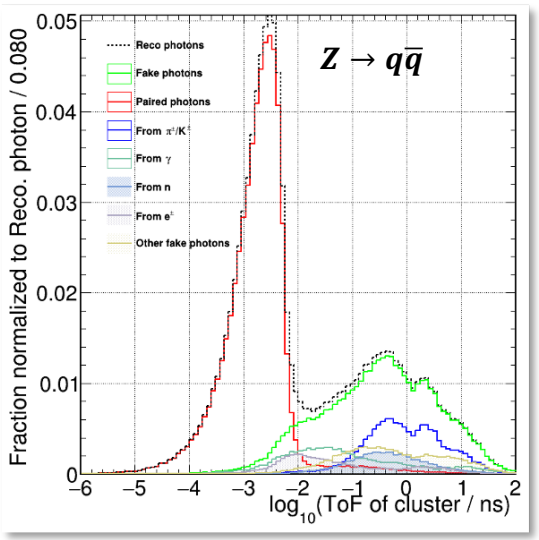
- Precise Cluster TOF information produces,
  - higher separation power
  - better PFO clustering.

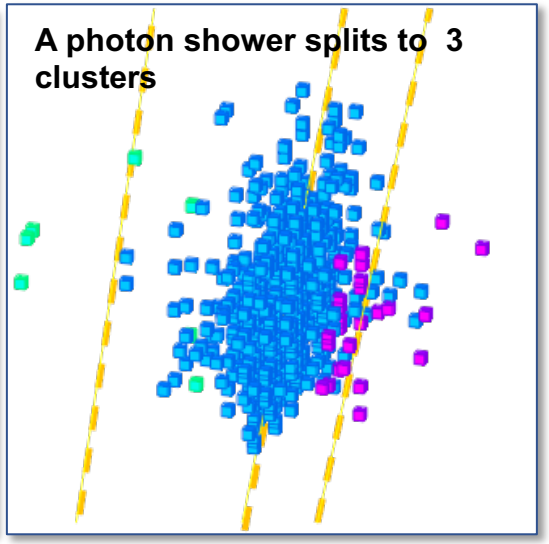
TOF measurement improves the reconstruction of basic level objects

- **An effective $k^{\pm}/\pi^{\pm}/p^{\pm}$ identification** can be achieved with the combined information of **dE/dx** and **TOF** (assumed with a 50 ps time resolution).

- **Better PFO clustering** (cluster fragments identification) can be achieved with the **cluster TOF** information.







F. An, S. Prell, C. Chen, J. Cochran, X. Lou, and M. Ruan, *Monte Carlo Study of Particle Identification at the CEPC Using TPC dE / Dx Information*, Eur. Phys. J. C **78**, 6 (2018).

Introduction of showers, clusters & hits

The fundamental information: calorimeter hits

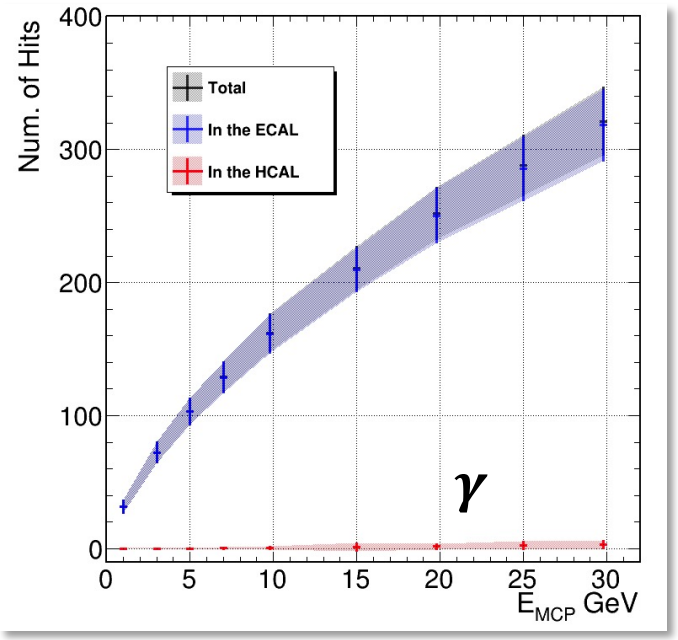
- energy & time distribution at truth level
- Clustering process

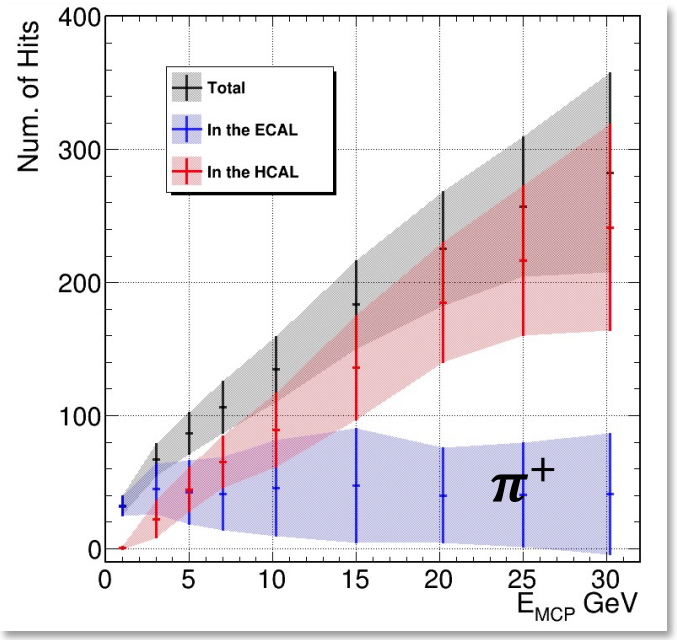
Arbor

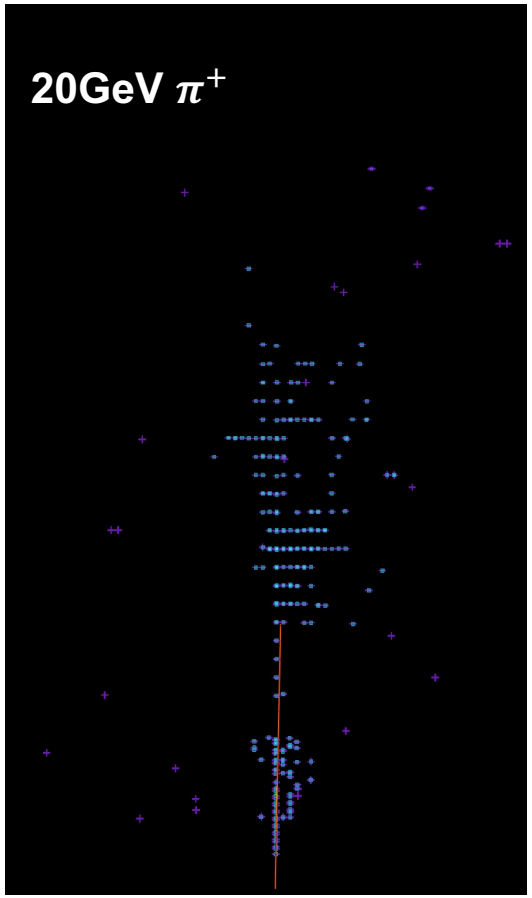
- Hit collection efficiency
- Detector response: the hit time resolution

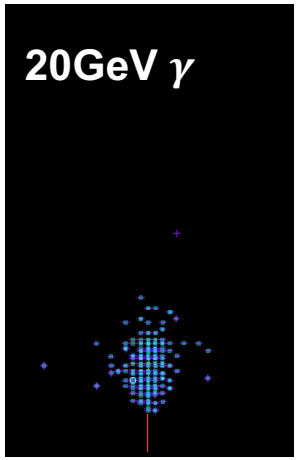
The fundamental information: calorimeter hits

Single photon/pion samples with a set of energy points, in the CEPC baseline setup.
Choose the 1-1 reconstruction events (where only 1 cluster is reconstructed).









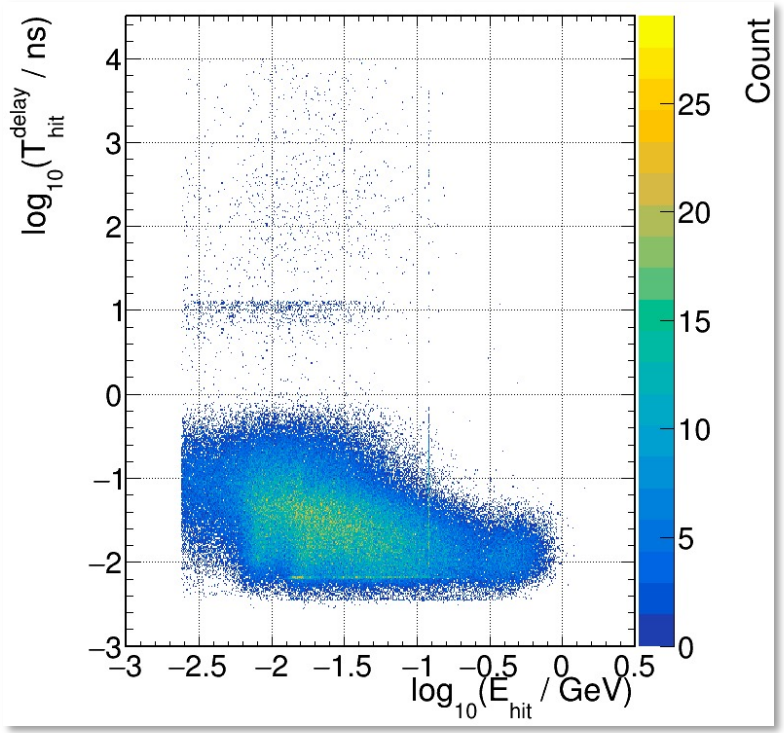
Number of hits in ECAL/HCAL versus MC particle energy.
The error bar represents the standard deviation of the hit num. distribution in the corresponding sample.

Calorimeter provides many hits for a particle shower

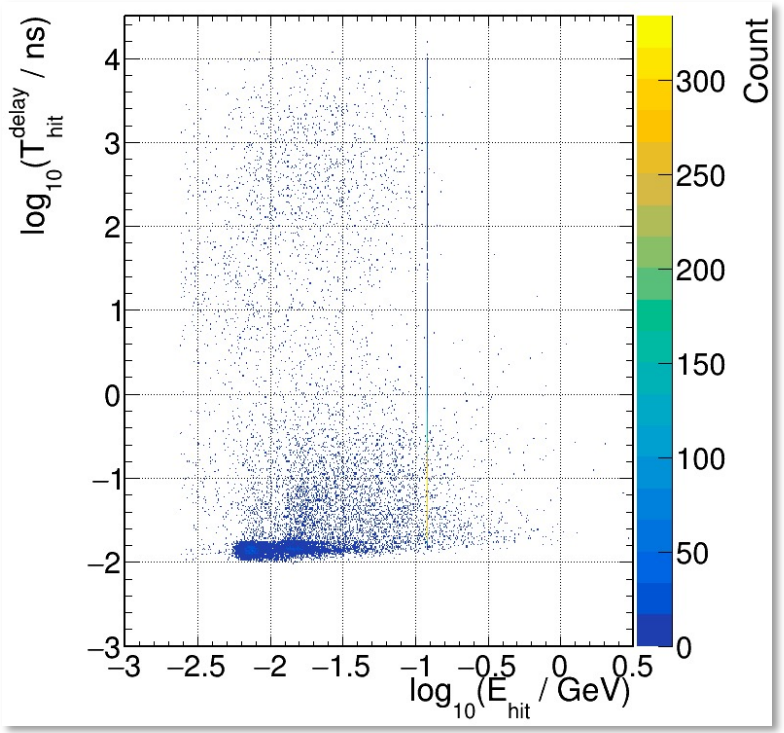
Hits time & energy distribution in single **10 GeV** photon/pion samples.

The Y axis:

$$T_{hit}^{delay} = T_{hit}^{truth} - \frac{L_{IP \to hit}}{c},$$



Time vs. energy of **photon** shower hits



Time vs. energy of **pi+** shower hits

Compared to the EM shower, the ECAL hits in the hadronic shower have lower energy and more compact and faster time.

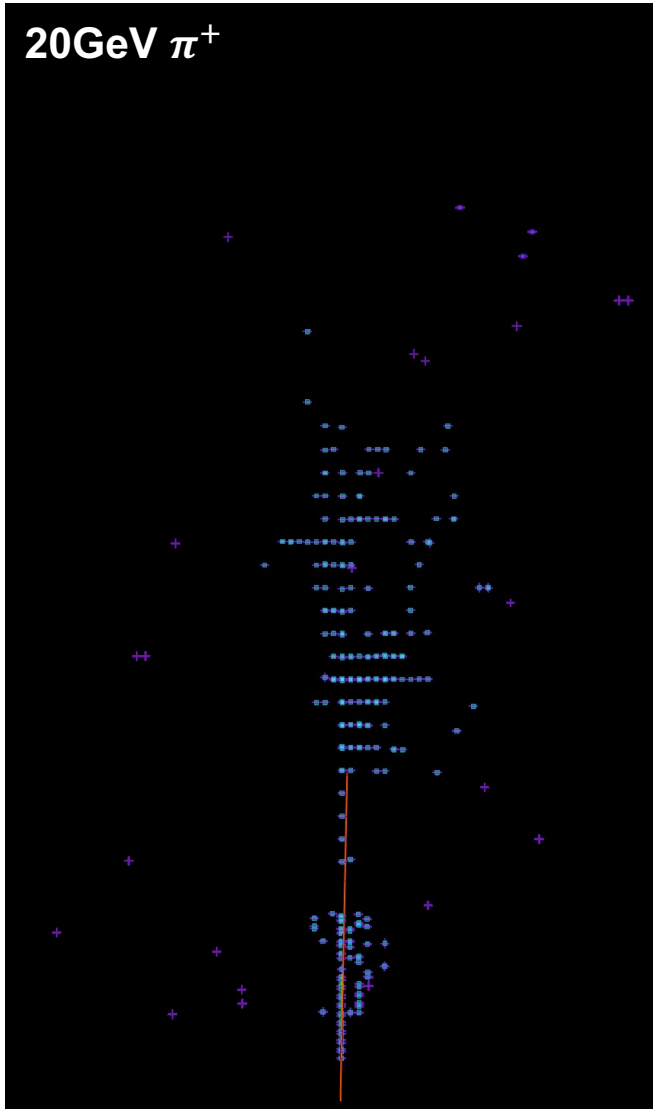
Clustering algorithm: Arbor

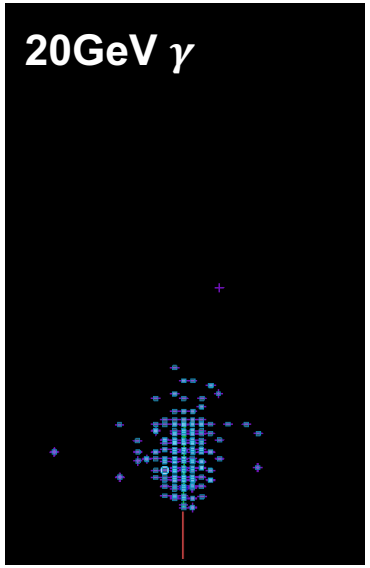
The PFA Clustering module collects a part of the shower hits into clusters, only which can be used in TOF reconstruction.

On the CEPC, the Arbor algorithm are used to perform the clustering process.

- **Clustering (Calo hit -> Clusters)**
  - Links between hits and hits
  - Bushes (Sub-clusters), clusters
- **Cluster identification (charged/neutral particle)**
  - Cluster & trajectory matching
  - PID

Because of the correlation of the hits time, energy and position, Arbor tends to collect more calorimeter hits with **higher energy** and **faster time.**



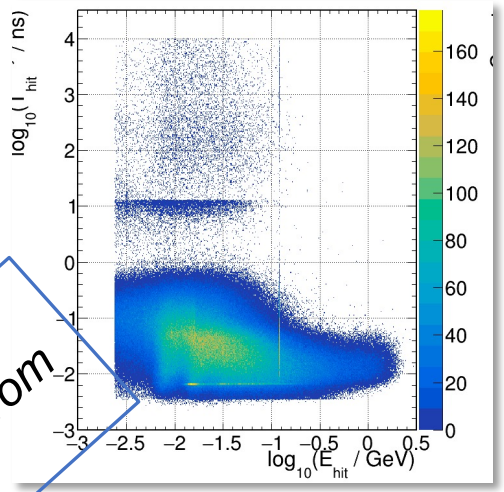


M. Ruan, *Arbor, a New Approach of the Particle Flow Algorithm*, ArXiv:1403.4784 [Hep-Ex, Physics:Physics] (2014). https://arxiv.org/abs/1403.4784

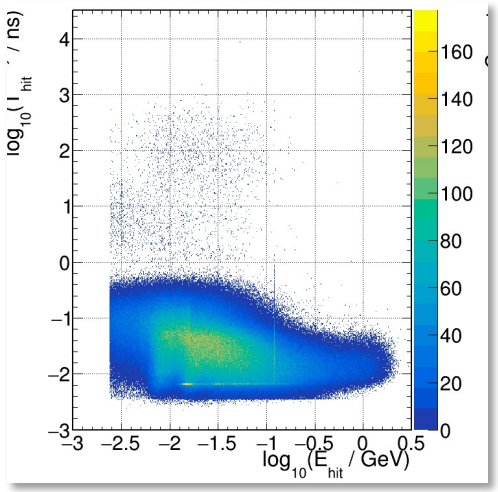
Cluster TOF measurement is depends on the clustering algorithm

photon showers

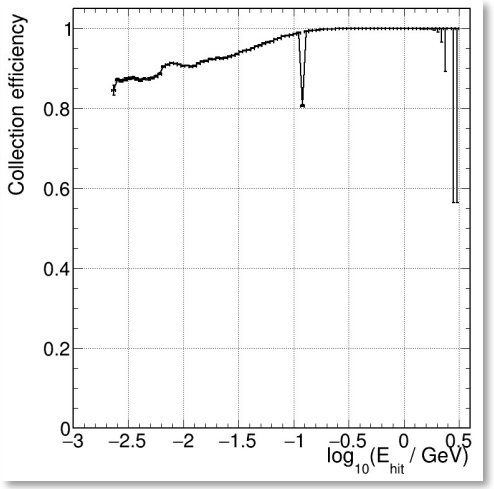
All samples with energy points from 1 to 30 GeV



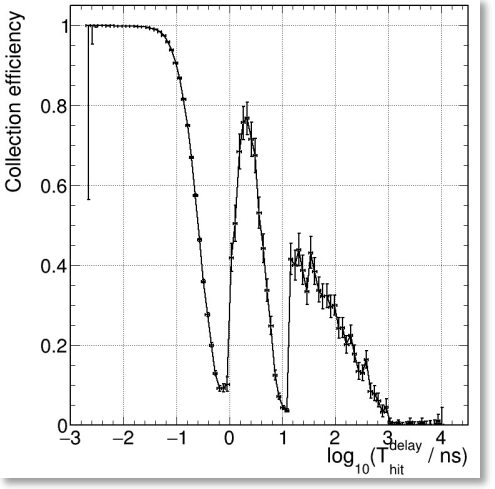
Before clustering



After clustering

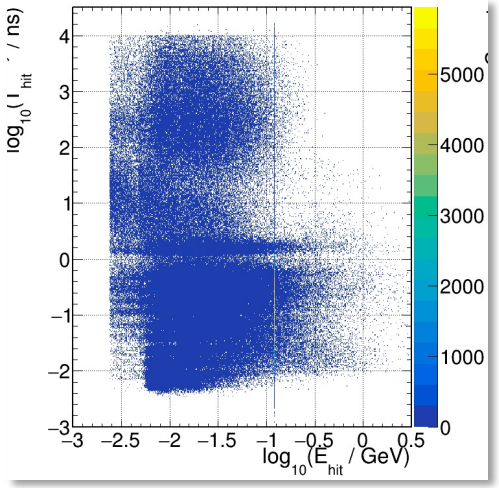


Collection efficiency vs. hit energy

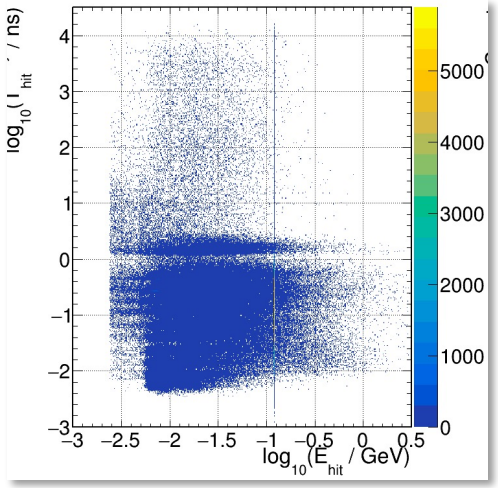


Collection efficiency vs. hit time

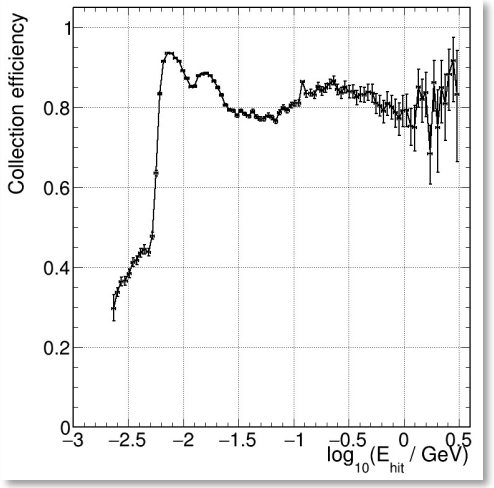
pion showers



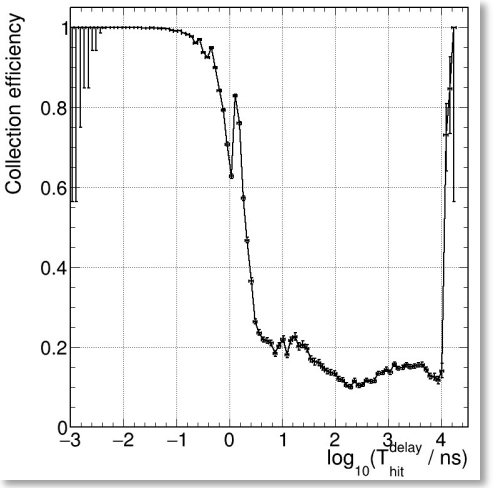
Before clustering



After clustering

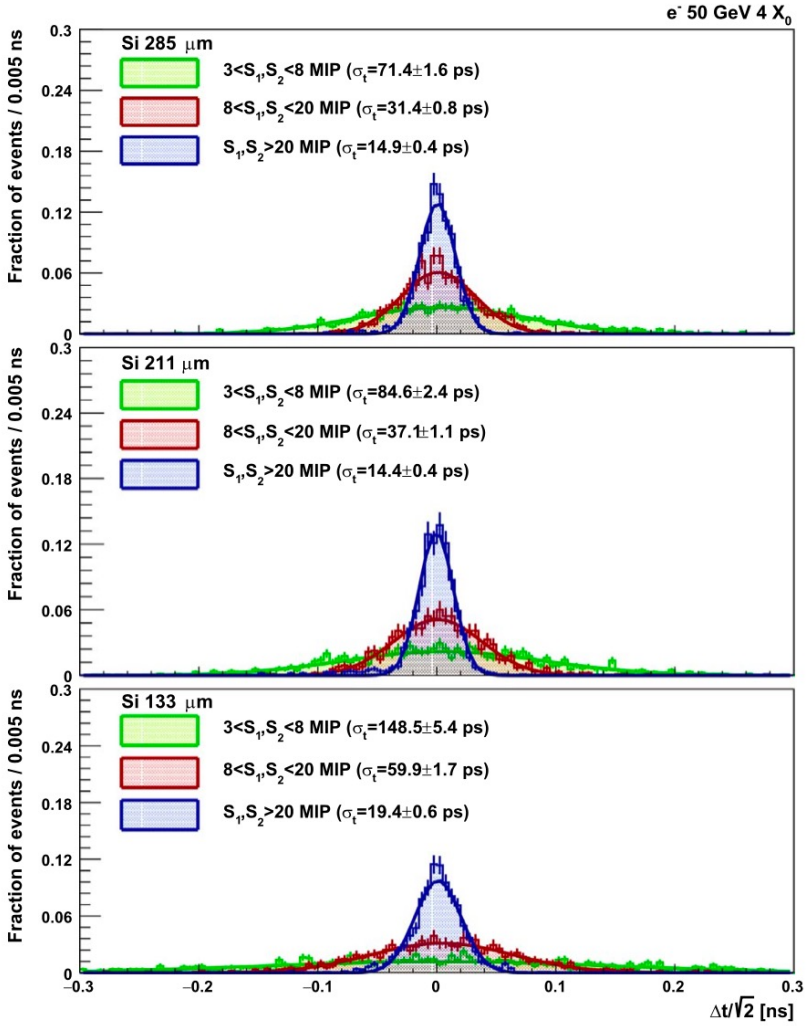


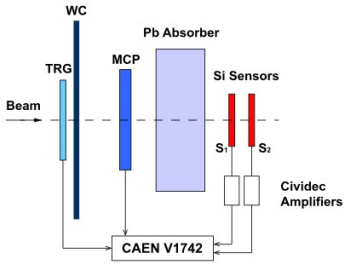
Collection efficiency vs. hit energy



Collection efficiency vs. hit time

Intrinsic time resolution at Hit level





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On the timing performance of thin planar silicon sensors

N. Akchurin[b,*], V. Ciriolo[g], E. Currás[a,b], J. Damgov[b], M. Fernández[b], C. Gallrapp[a], L. Gray[f], A. Junkes[c], M. Mannelli[a], K.H. Martin Kwok[i], P. Meridiani[e], M. Moll[a], S. Nourbakhsh[d], S. Pigazzini[g], C. Scharf[c], P. Silva[a], G. Steinbrueck[c], T. Tabarelli de Fatis[g], I. Vila[b]
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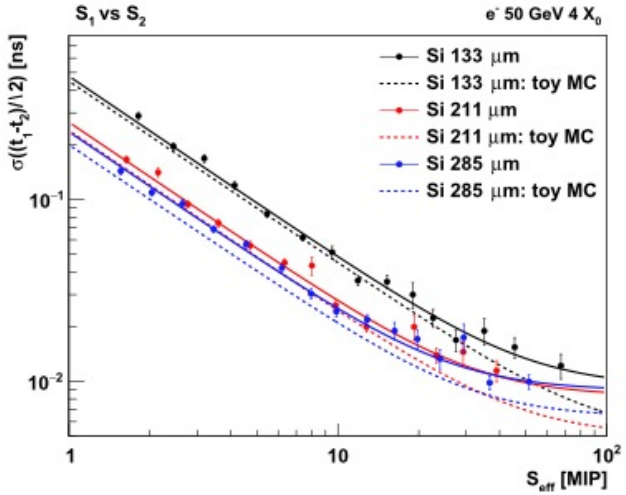
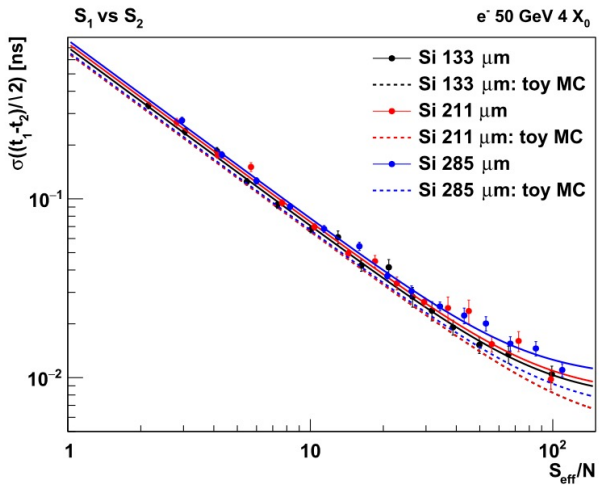




Det 1	Det 2	Fit Function	*A* [ns×ADC]	*C* [ns]
Measurement I				
S_1(133-μm)	S_2(133-μm)	$\frac{\sigma(t_1-t_2)}{\sqrt{2}} = \frac{A}{\sqrt{2}S_{\text{eff}}} \oplus C$	0.69 ± 0.01	0.010 ± 0.001
S_1(211-μm)	S_2(211-μm)		0.38 ± 0.01	0.009 ± 0.001
S_1(285-μm)	S_2(285-μm)		0.34 ± 0.01	0.010 ± 0.001

N. Akchurin, V. Ciriolo, E. Currás, J. Damgov, M. Fernández, C. Gallrapp, L. Gray, A. Junkes, M. Mannelli, K. H. Martin Kwok, P. Meridiani, M. Moll, S. Nourbakhsh, S. Pigazzini, C. Scharf, P. Silva, G. Steinbrueck, T. T. de Fatis, and I. Vila, *On the Timing Performance of Thin Planar Silicon Sensors*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **859**, 31 (2017).

A basic TOF reconstruction algorithm

Mimic the intrinsic hit resolution in CEPC software

A basic algorithm

- Select the enough fast hits by delay time
- Take an average as the cluster TOF

Performance parameters: bias & resolution

Mimic the detector time response at hit level

- Record the truth level ECAL hits time.
- Smear the hits time with a Gaussian distribution,

$$T_{hit}^{reco} = Gaus(\mu, \sigma),$$
$$\mu = T_{hit}^{truth},$$

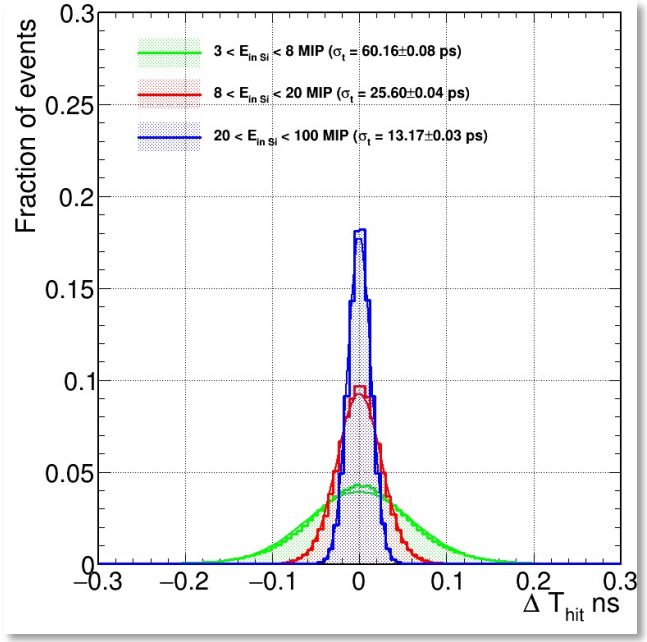
$$\sigma = \sqrt{\left(\frac{A}{\sqrt{2}S}\right)^2 + C^2}$$

where,

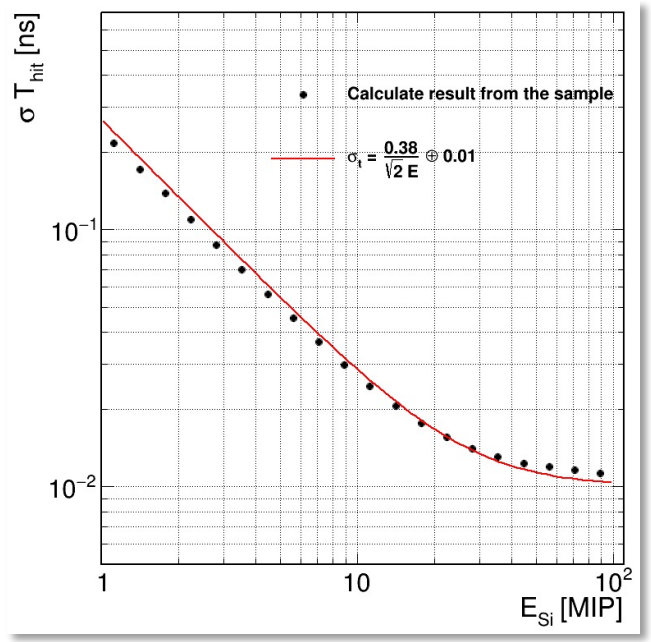
S = the energy deposition in the Si diodes, converted to the unit of MIP,

A = the noise terms, assumed to be $0.38\ ns \times MIP$,

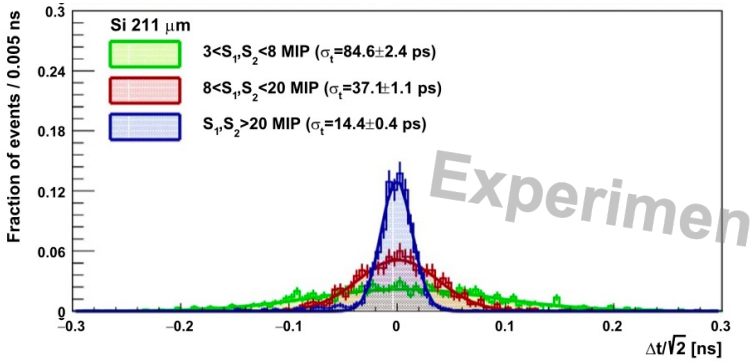
C = the constant terms, assumed to be $0.01\ ns$.

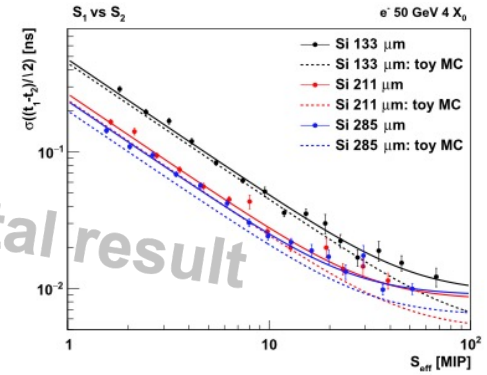


(a) The bias of smeared hit time in different energy deposition bins.



(b) The smeared hit time resolution versus energy deposition on Si diodes.





Reconstruct the cluster time

Body content of the basic algorithm:

- Define a ***Delay time*** for every hit,

$$T_{delay}^{reco} = T_{hit}^{reco} - \frac{L_{IP \to hit}}{c},$$

- Sort all of the cluster hits according to the T_{delay}
- Define a hits number fraction, R
- Take the fastest R of the hits, calculate the average time,

$$T_{cluster}^{reco} = \frac{1}{N \cdot R} \sum_{N \cdot R} T_{delay}^{reco} \cdot W$$

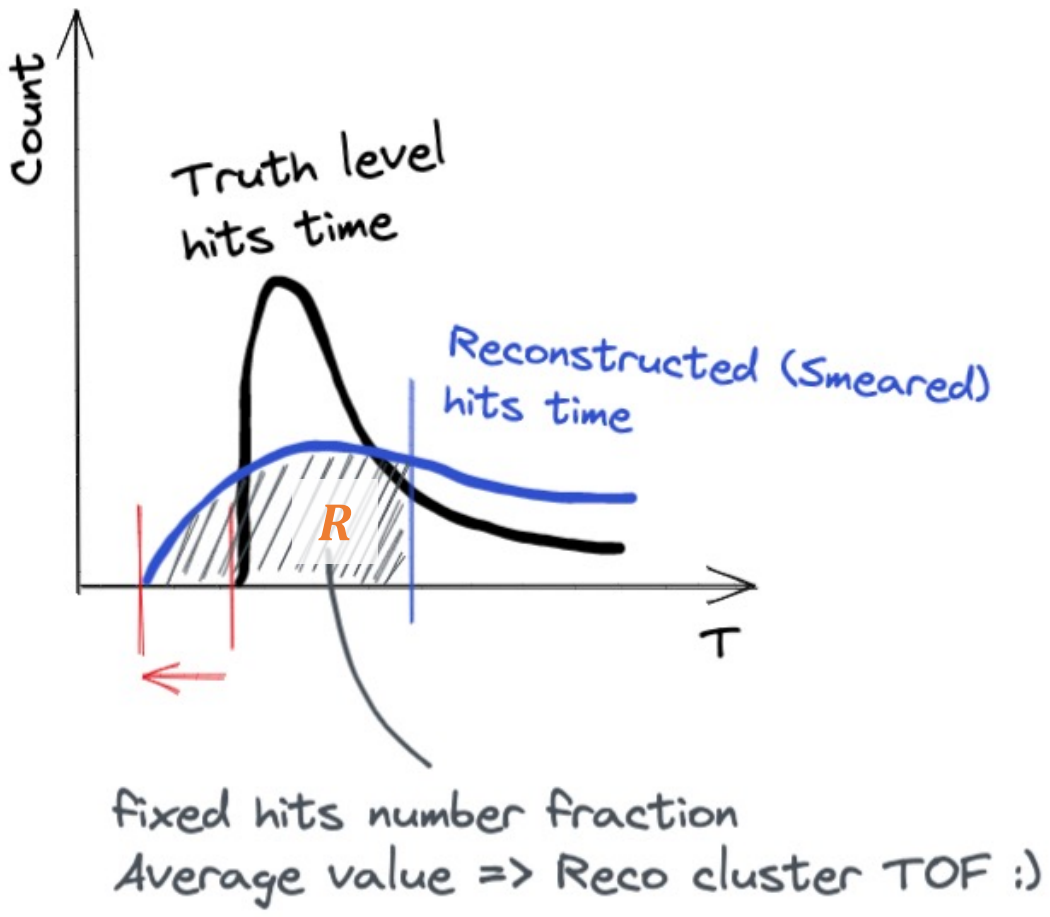
where,

$T_{cluster}^{reco}$ = the reconstructed cluster time,

N = Number of all hits in the cluster,

R = hits number ratio defined previously,

W = weight value, fixed to 1 currently.



Performance evaluation

- Cluster **truth TOF**,

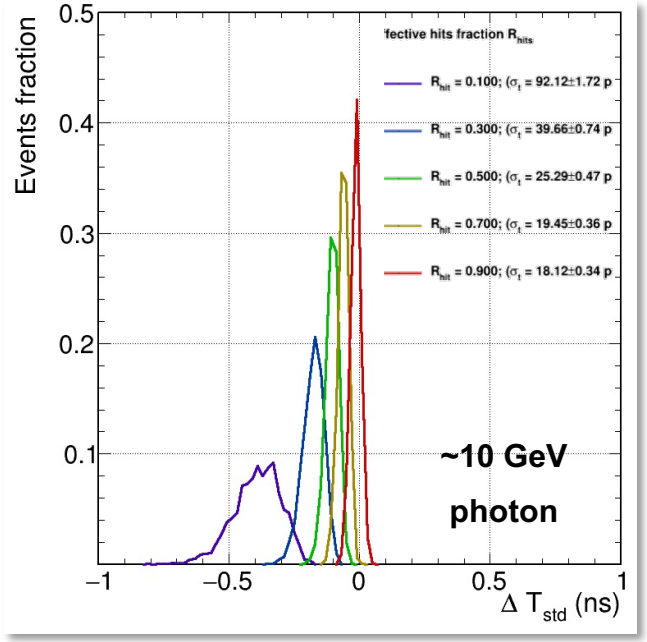
$$T_{cluster}^{truth} = \min\left\{T_{hit}^{truth} - \frac{L_{IP\to hit}}{c}\right\}$$

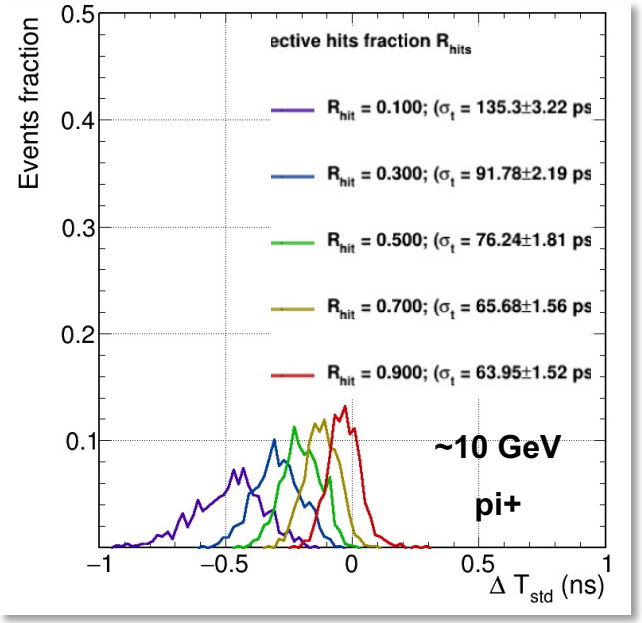
- Time reconstruction **bias**,

$$\Delta T = Mean\{T_{cluster}^{reco} - T_{cluster}^{truth}\}$$

- Time **resolution**,

$$\sigma T = StdDev\{T_{cluster}^{reco} - T_{cluster}^{truth}\}$$





- The performance **depends on**,
  - hits number fraction, ***R***,
  - incident particle type and momentum,
  - intrinsic time resolution at hit level… …

Different between the truth cluster TOF and the reconstructed cluster TOF, in the (left) photon clusters sample, and (right) pi+ clusters sample.

The mean value of the above distribution is defined as the **bias**, and the standard deviation is defined as the time **resolution**.

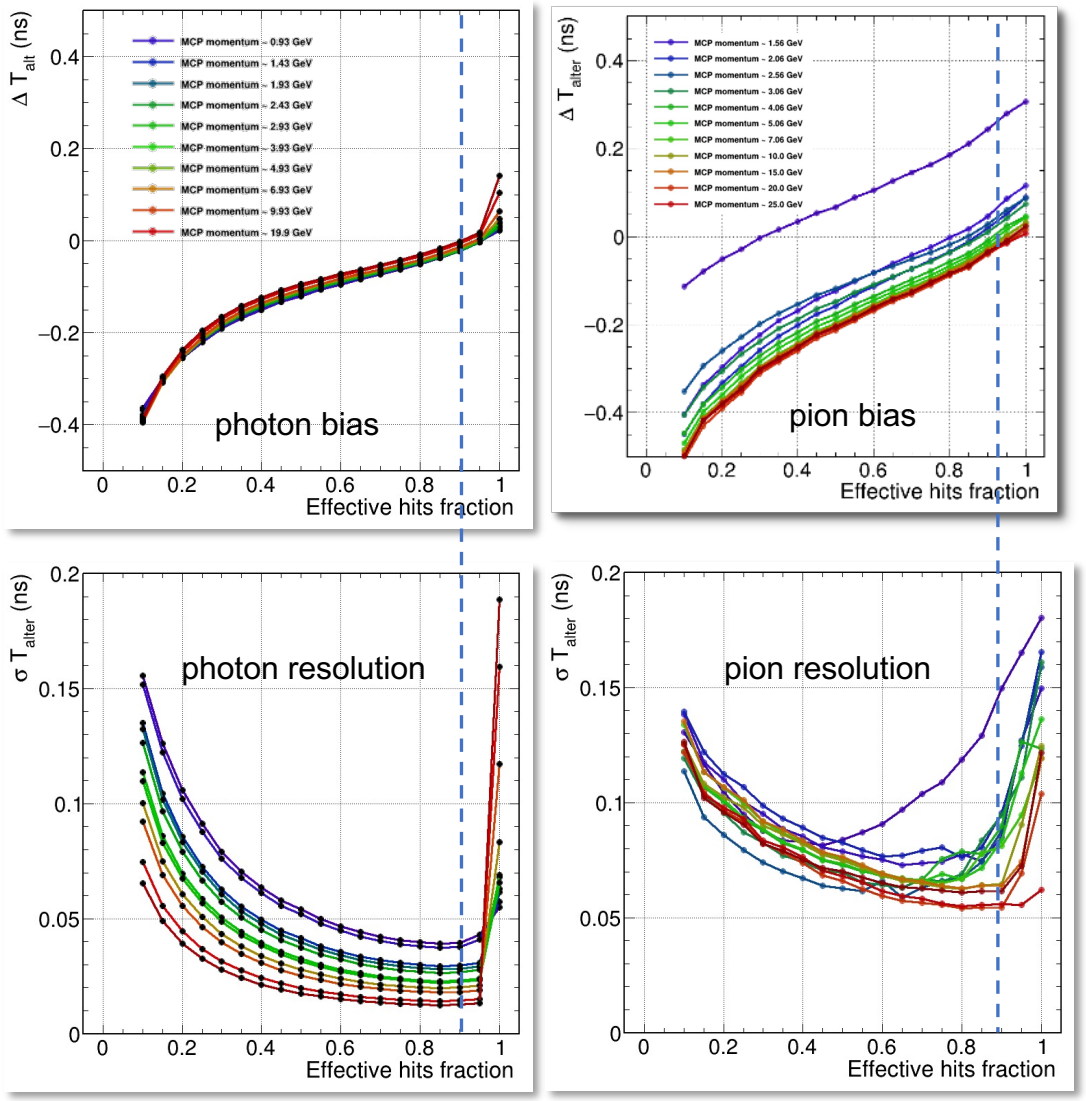
Performance @ CEPC basline

- Default configuration
- Bias & resolution
- Relationship between intrinsic resolution & cluster TOF resolution

Hits number ratio and energy dependence of cluster timing

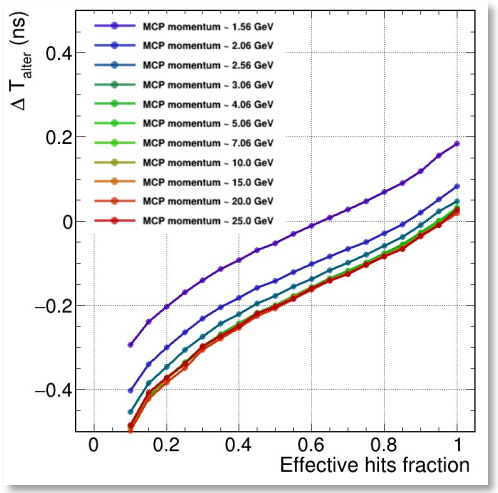
Default set up:

- CEPC baseline geometry
- Clustering algorithm, Arbor
- Experimental intrinsic hit time resolution terms
  - A = 0.38 $ns \times MIP$,
  - C = 0.01 ns.
- $e^-, \pi^+, k^+, p^+, \gamma$ with 1 ~ 30 GeV momentum.
- Select the events in which only one cluster exists.

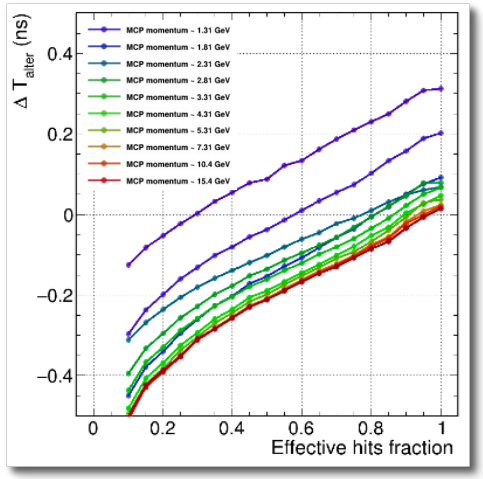


Hits number ratio and energy dependence of cluster timing

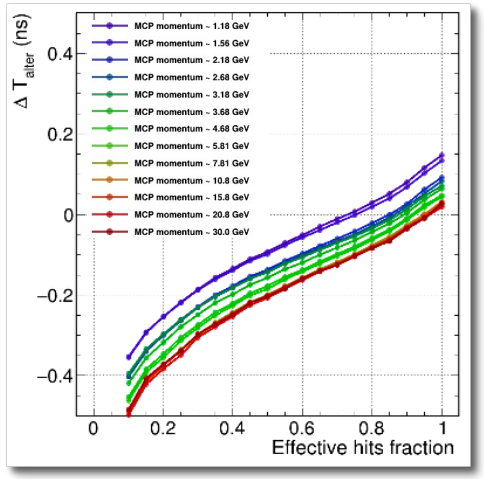
- EM shower:
  - none-bias ratio: 0.9
  - resolution: 10 ~ 40 ps
- Hadronic shower:
  - none-bias ratio: 0.9
  - resolution: ~ 60 ps



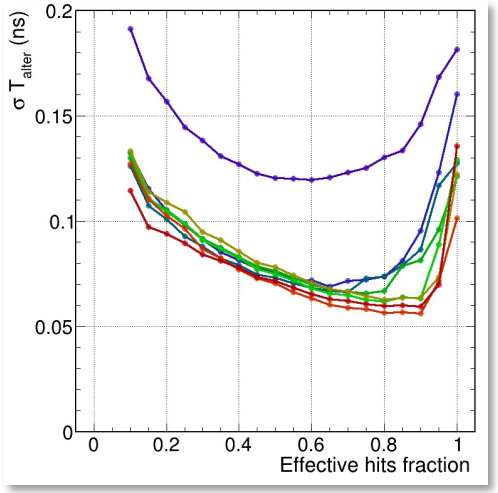
pi+ bias



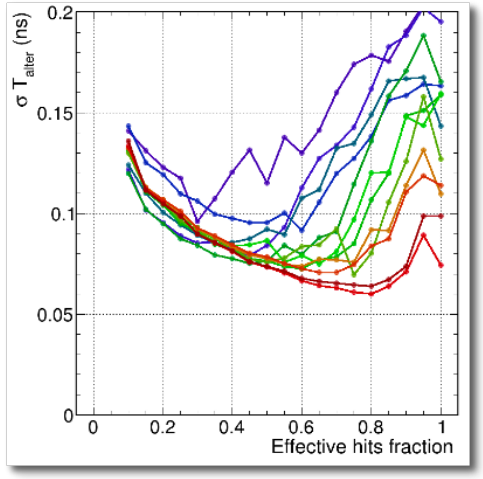
kaon



proton



pi+ resolution



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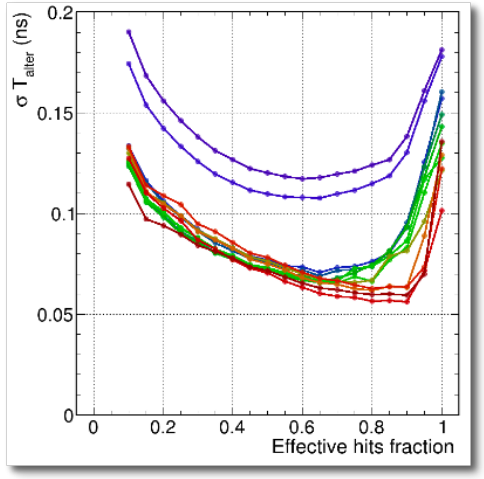
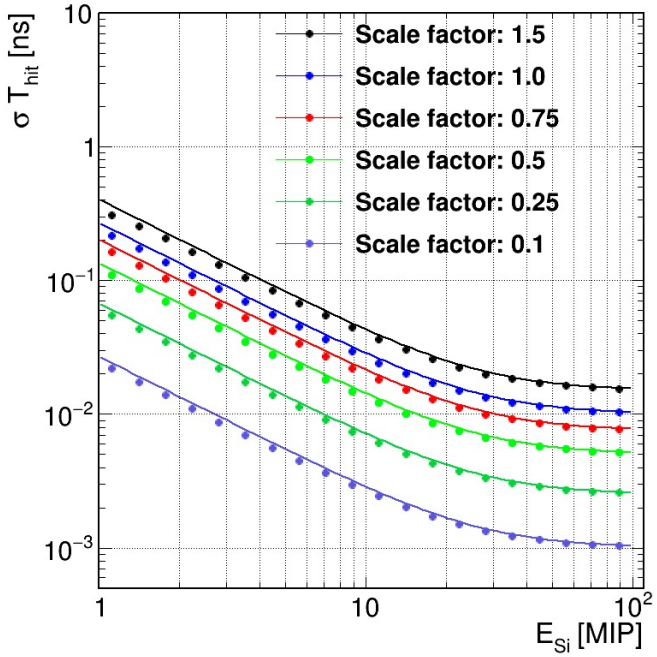
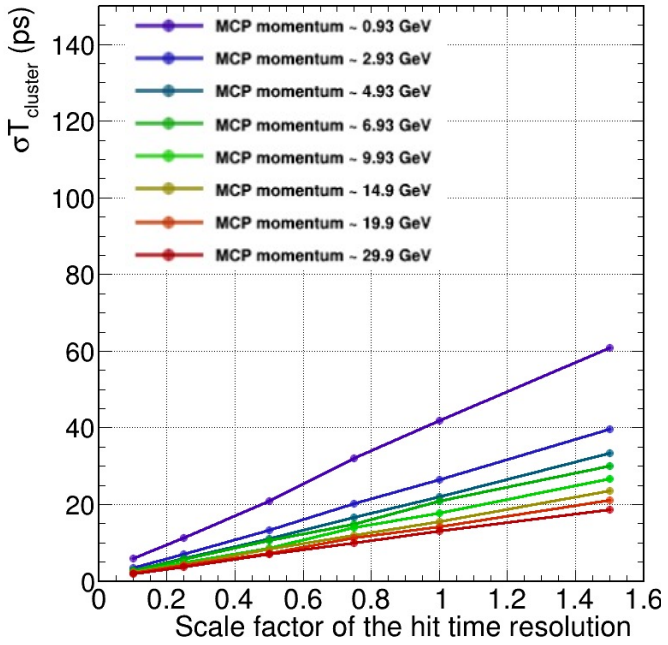


proton

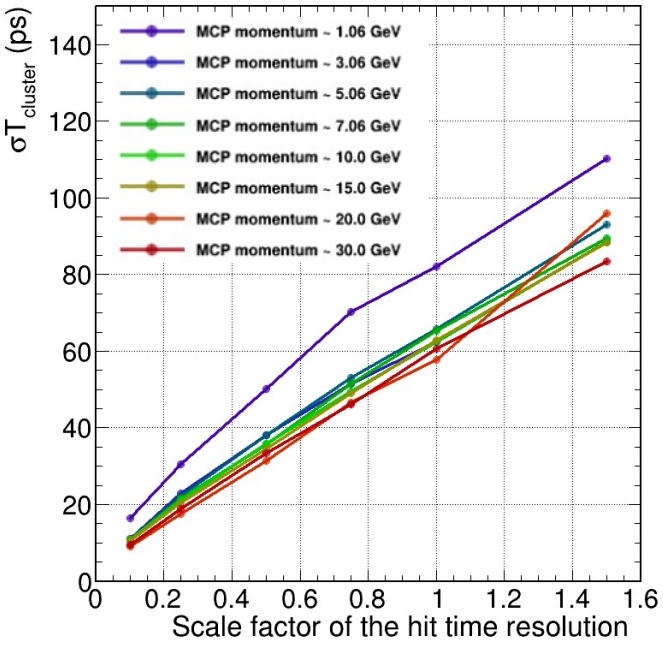
What if the detector is improved?



(a) Scaled hit time resolution



(b) Photon samples



(c) pion samples

Scale the intrinsic time resolution curve with a factor:

$$\sigma = factor \cdot \sqrt{\left(\frac{A}{\sqrt{2}S}\right)^2 + C^2}$$

When scale the intrinsic time resolution with factors from 0.1 to 1.5, the cluster TOF resolution changes with significant linearity, especially for EM showers.

Summary

- Conclusion
  - The dependent factors of cluster TOF reconstruction
  - The performance of the basic algorithm
- Future

Cluster TOF measurement by CEPC calorimeter

- A brief cluster TOF reconstruction algorithm are implemented.
- The performance of a cluster TOF algorithm depends on
  - incident particle type and energy,
  - detector geometry and PFA clustering algorithm,
  - intrinsic hit time resolution, including a noise term A and a constant term C
- At CEPC baseline set up and supported intrinsic hit time resolution (A = 0.38 ns*MIP, C = 0.01 ns), the performance of the mentioned algorithm are evaluated:
  - for EM showers with 1 to 30 GeV, optimized effective fraction R ~ 0.9, corresponding resolution ~ 10 ps,
  - for hadronic showers with 1 to 30 GeV, optimized effective fraction R ~ 0.9, corresponding resolution ~ 60 ps,
- Good linearity: when the intrinsic time resolution scale by a factor from 0.1 to 1.5, the reconstructed TOF resolution scaled by the same factor.

Future

- **Optimize** the TOF reconstruction algorithm
  - energy weight
  - use HCAL hits information
  - … …
- Research the dependence of the reconstructed TOF on the calorimeter **cell size**.
- Evaluate the separation power of **charged particles** at different momentum
- Evaluate the **cluster fragments** identification ability of the cluster TOF.
- … …

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CEPC

Thanks for your attention!

November 11, Beijing