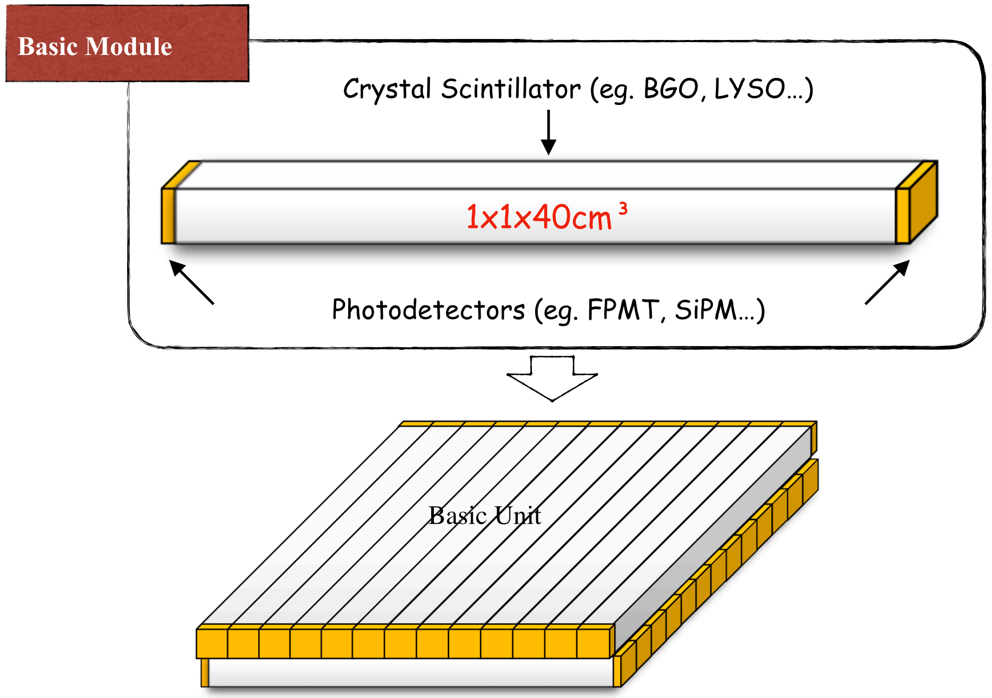
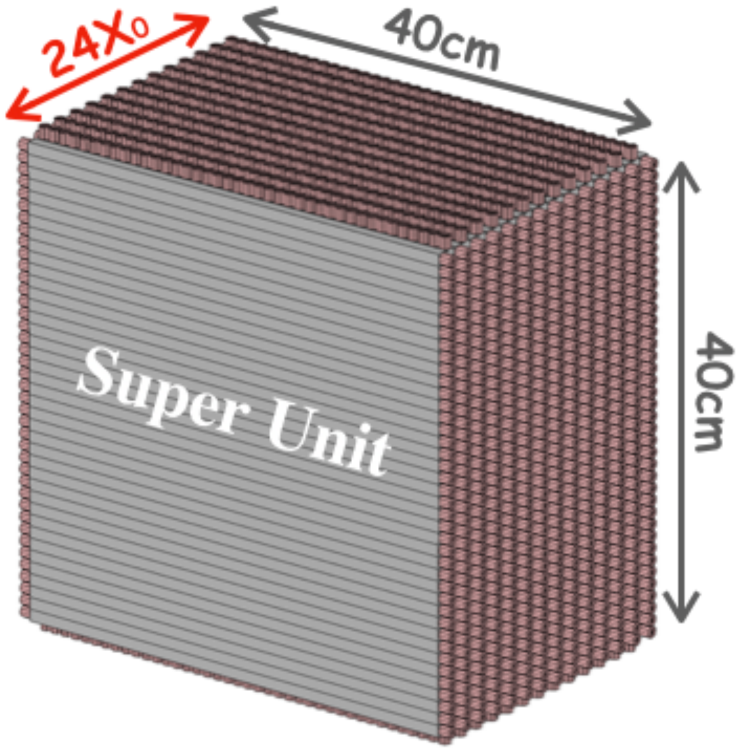
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC

Preliminary reconstruction of diphoton on ECAL Tower

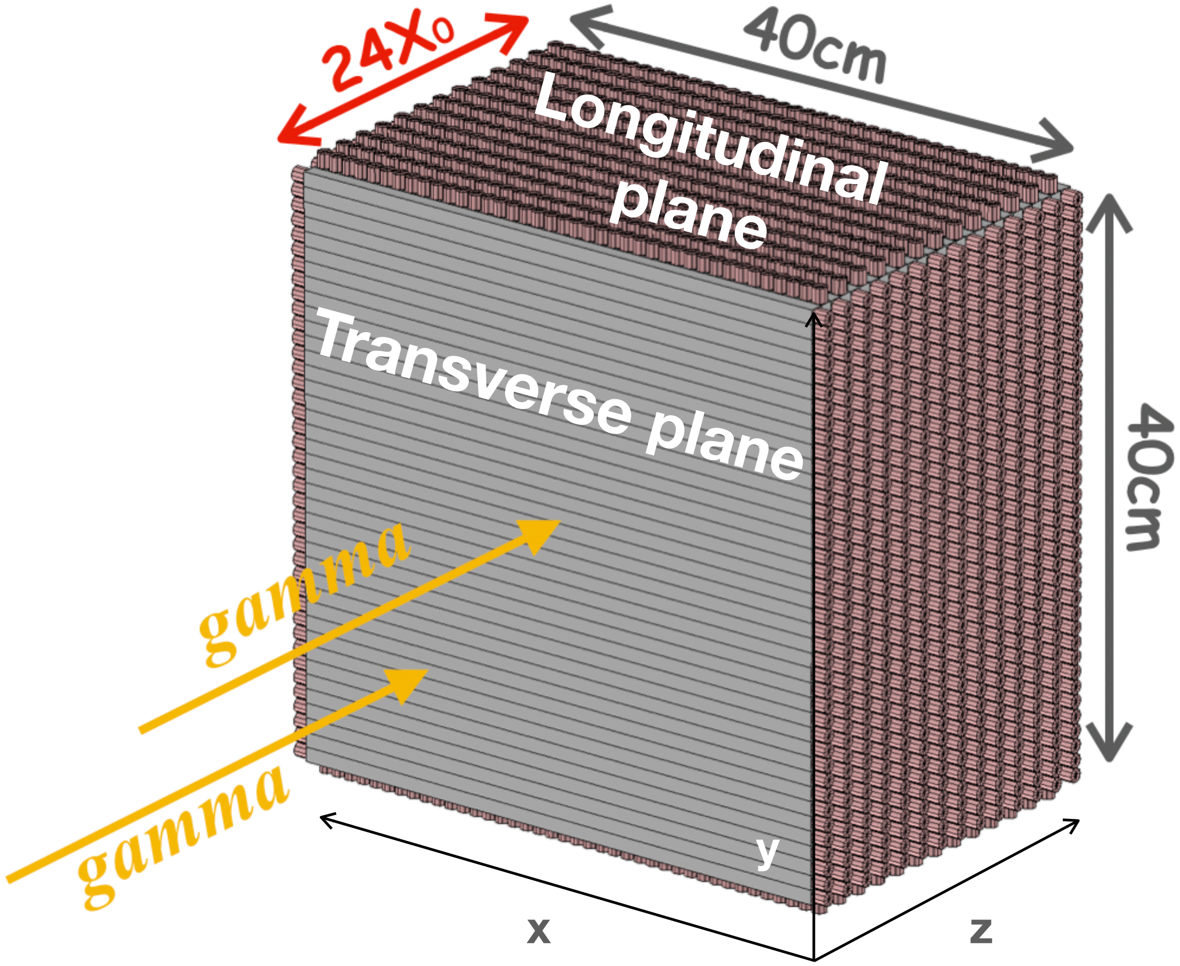
Yuexin Wang



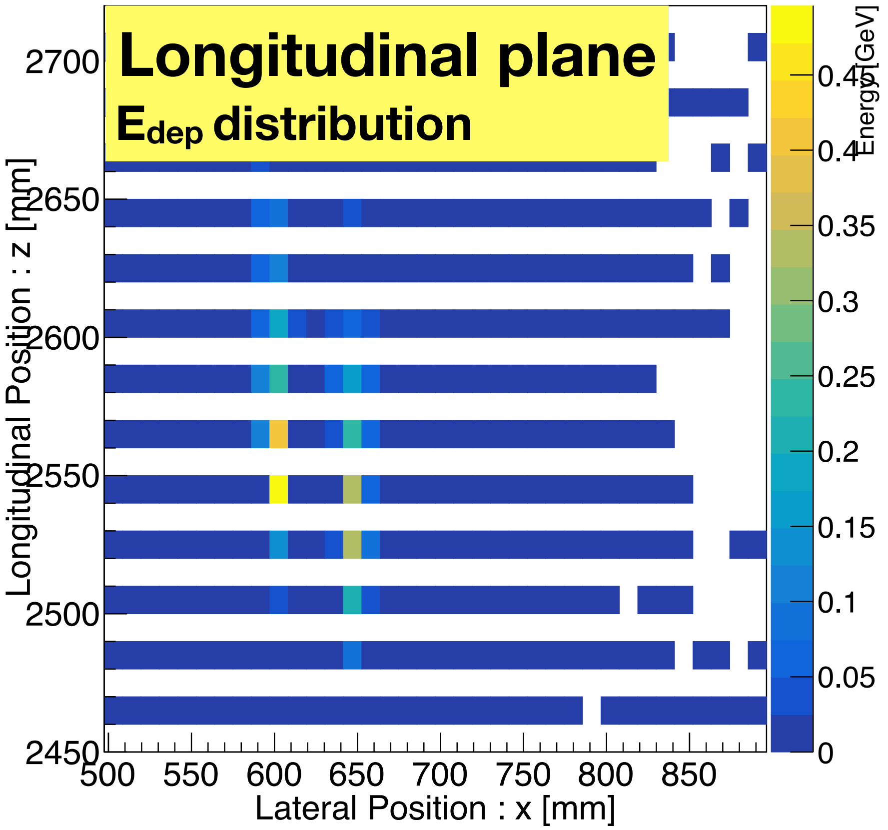


Setup of diphoton event

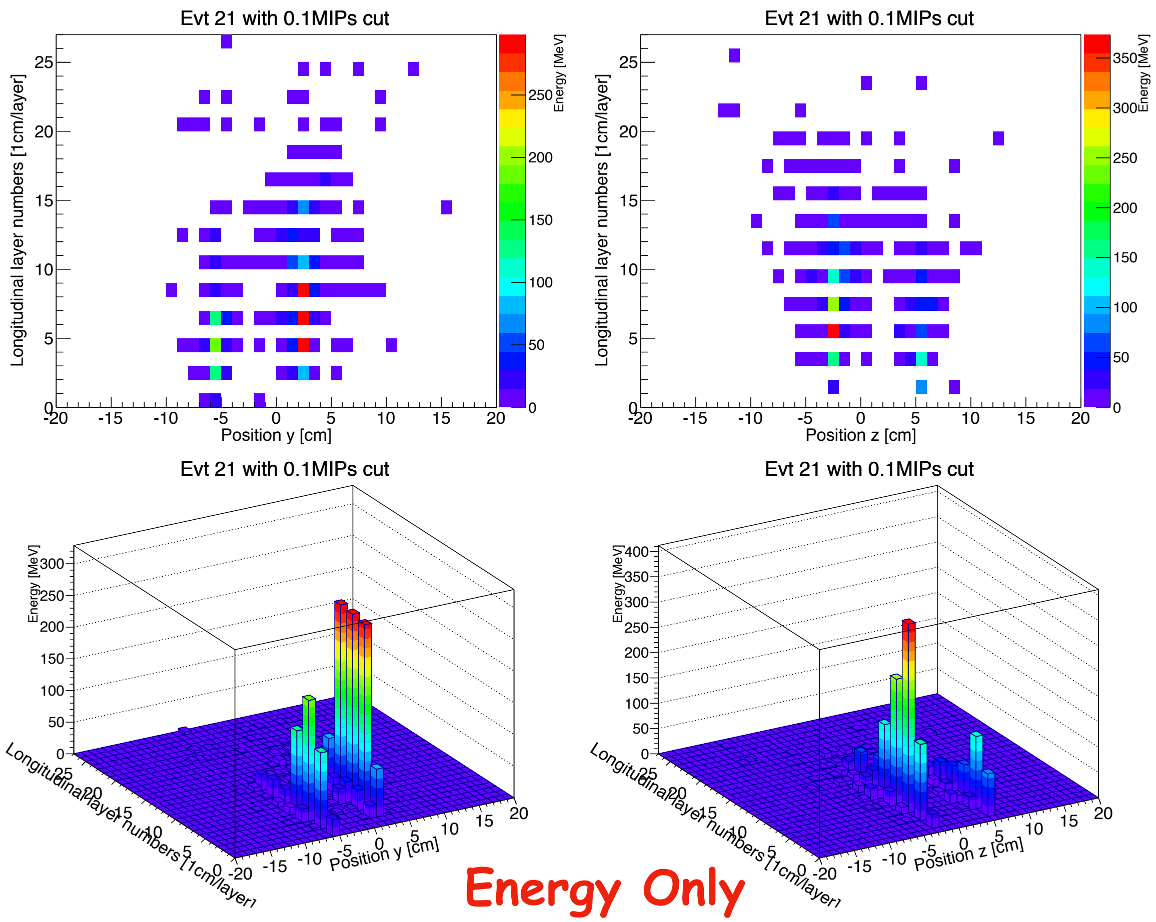
2 parallel 5GeV γ along the diagonal



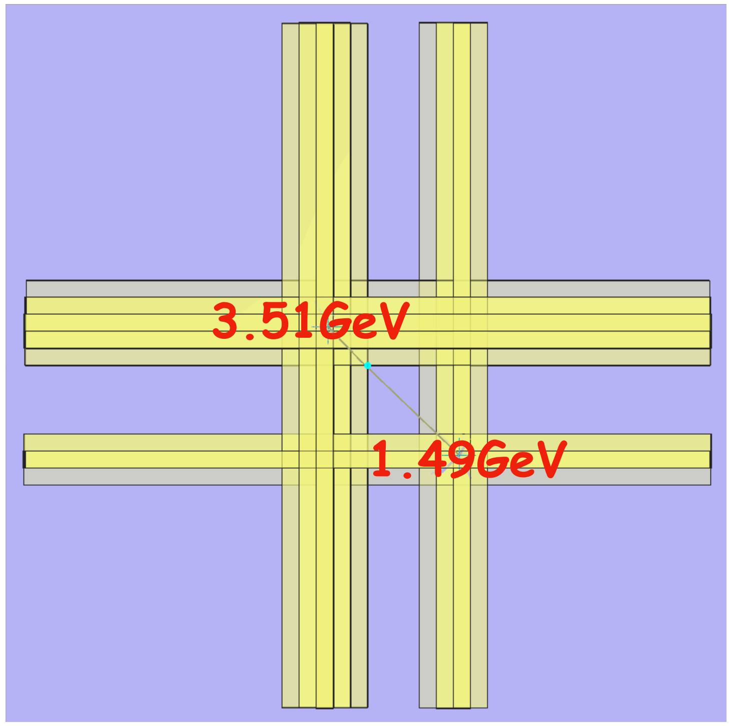
5cm ~ $2R_M$ for BGO (R_M=2.26cm)



$\pi^0 \rightarrow \gamma\gamma$ at 5GeV



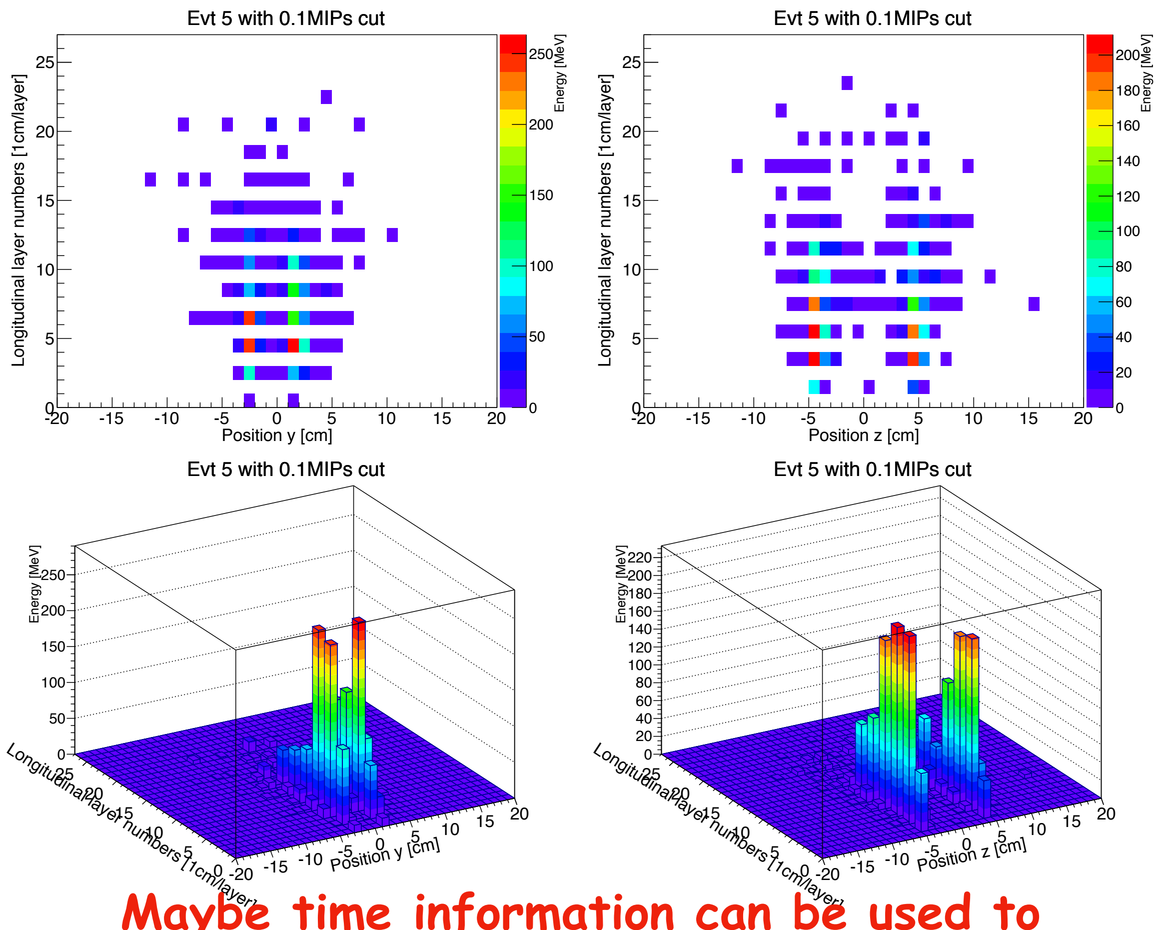
Energy Only



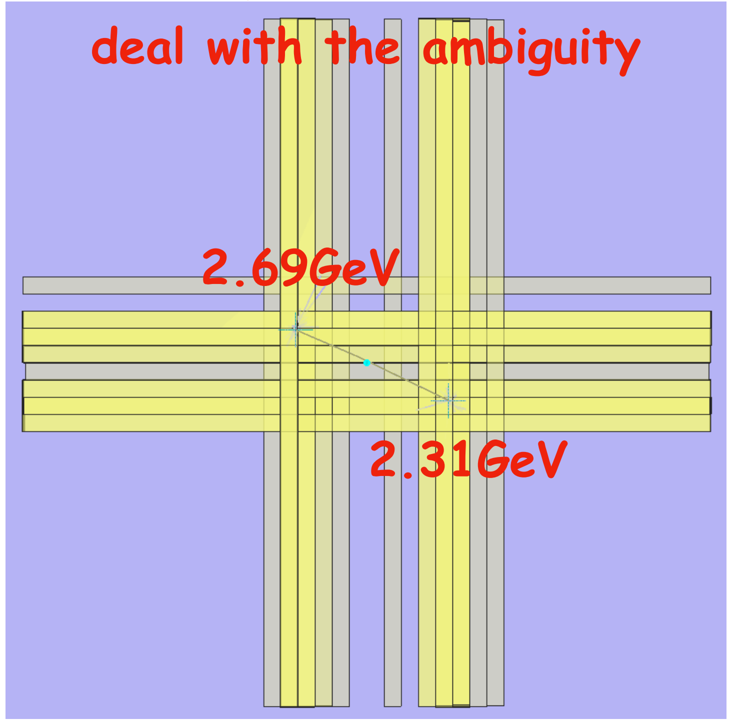
3.51GeV

1.49GeV

VS



Maybe time information can be used to deal with the ambiguity



2.69GeV

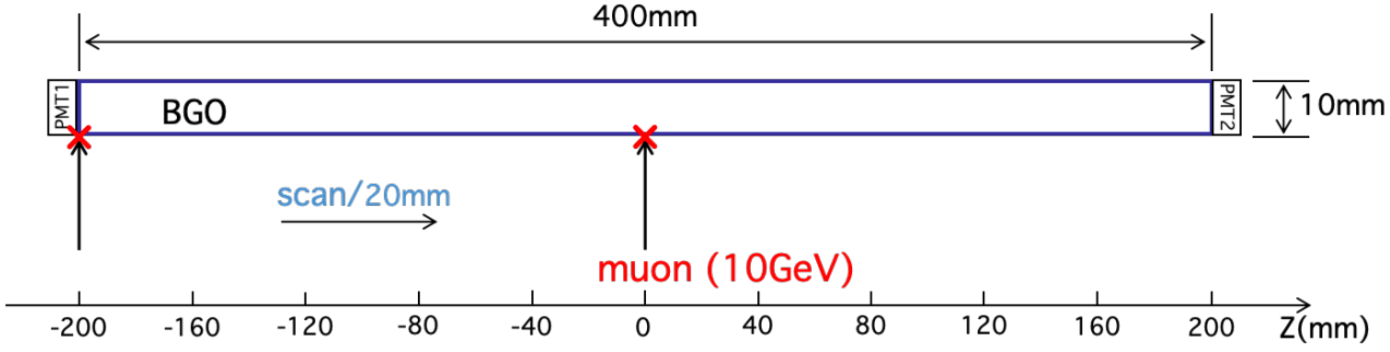
2.31GeV

Simplified Digitization of Time

$$\sigma_t = \sigma_{intrinsic} \oplus \sigma_{PMT} \oplus \sigma_{electronics}$$

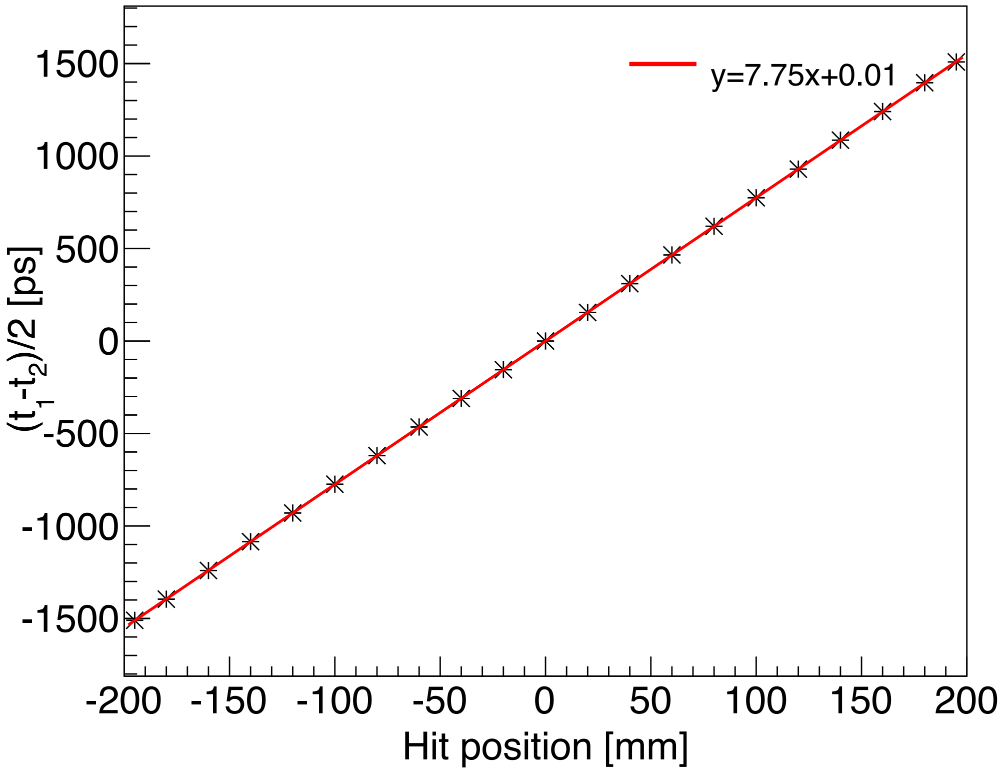
σ_{PMT}: 30ps

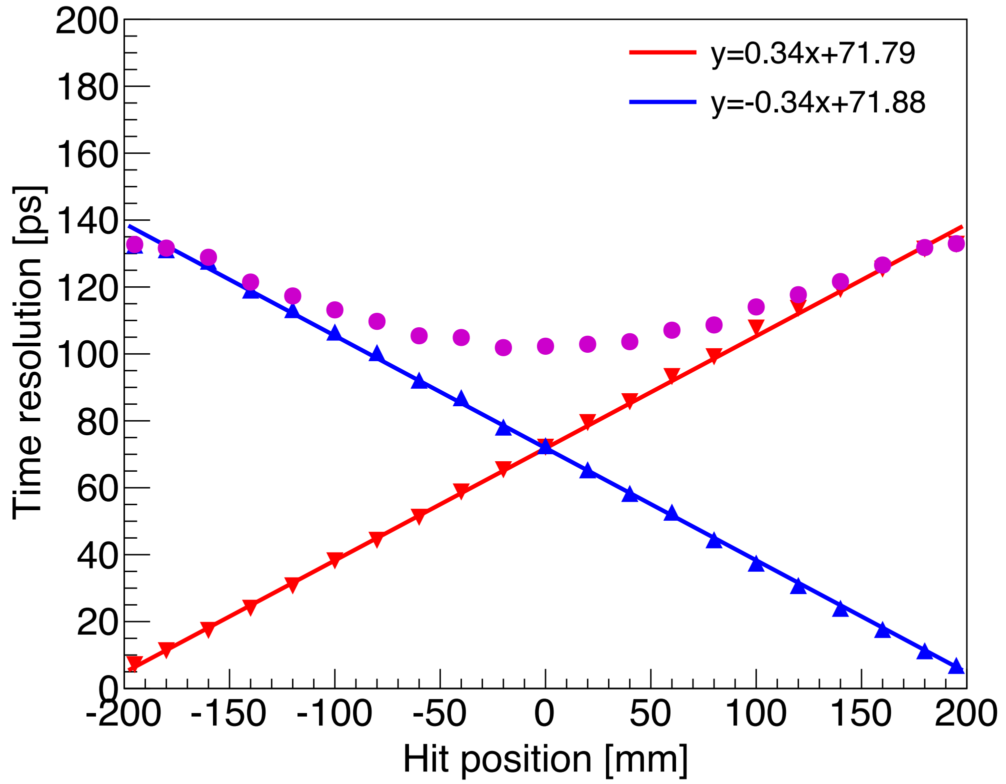
$\sigma_{electronics}$: 20ps



Parameter	Value
发光光谱峰位能量 Photon Energy	2.59eV (480nm)
发光光谱半峰宽 Photon Energy Width	0.6987eV (420-550nm)
快成分时间常数 FastTime Constant	60ns
慢成分时间常数 SlowTime Constant	300ns
光衰减长度 Absorption Length	7-15m
光产额 Scintillation Yeild	9000-10000/MeV
折射率 Refractive Index	2.15

表面反射率 reflectivity： 0.99



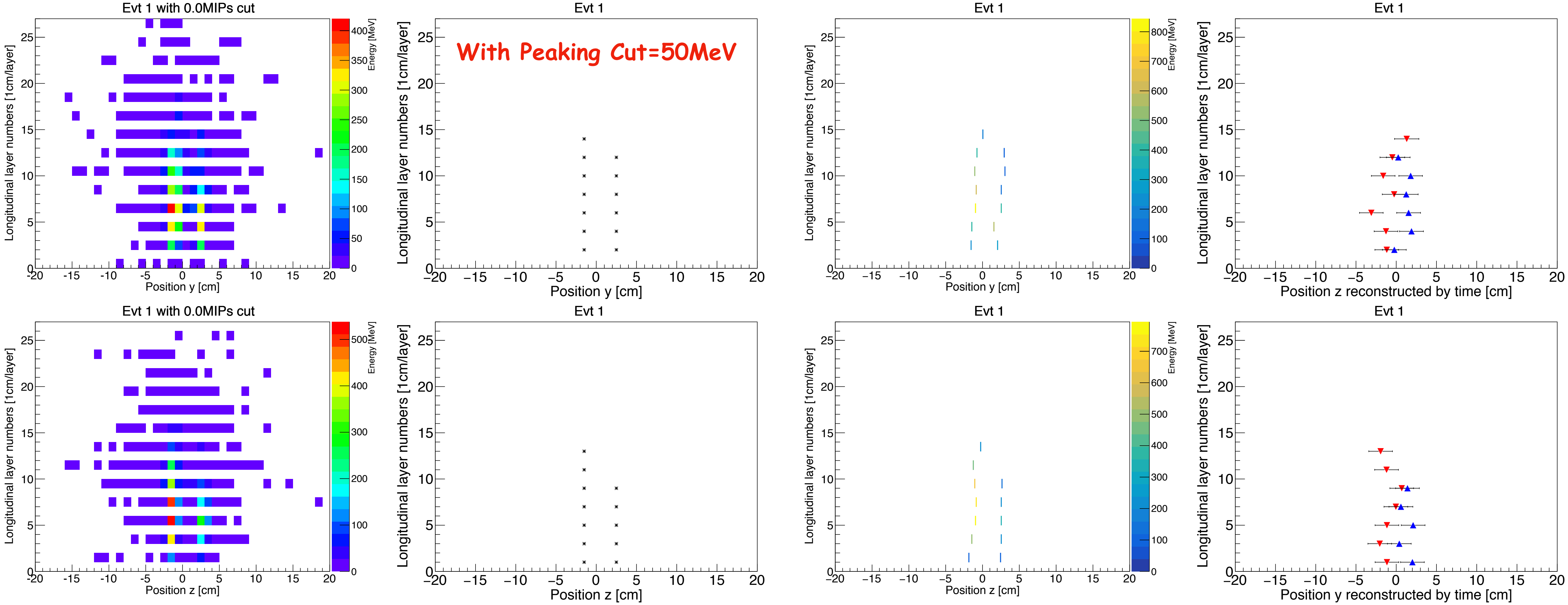


Idea on reconstruction of di-photon event

Note: current reconstruction only use truth energy and digitized time in order to evaluate the effect of time performance. Digitized energy will be considered next.

Truth energy distribution on two longitudinal planes

Share energy according to the number and energy of seeds to get sub-clusters. Connect sub-clusters layer by layer to get information of shower, Energy & Position, in two longitudinal dimensions.



Find peak layer by layer; local maximum of energy deposition; seed crystal.

Position of shower core can also be calculated by the time information of seed crystals. Combine these two positions, one based on energy while the other based on time, to match showers in two dimensions to get a complete particle shower.

Transverse Energy Distribution

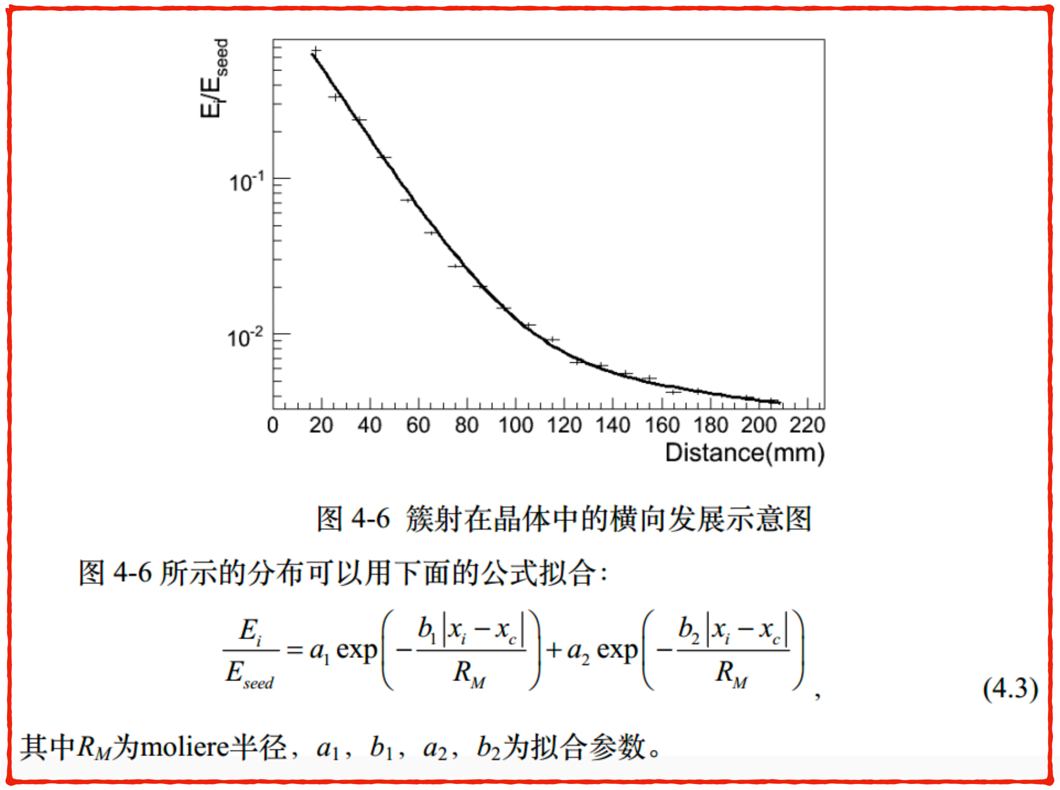
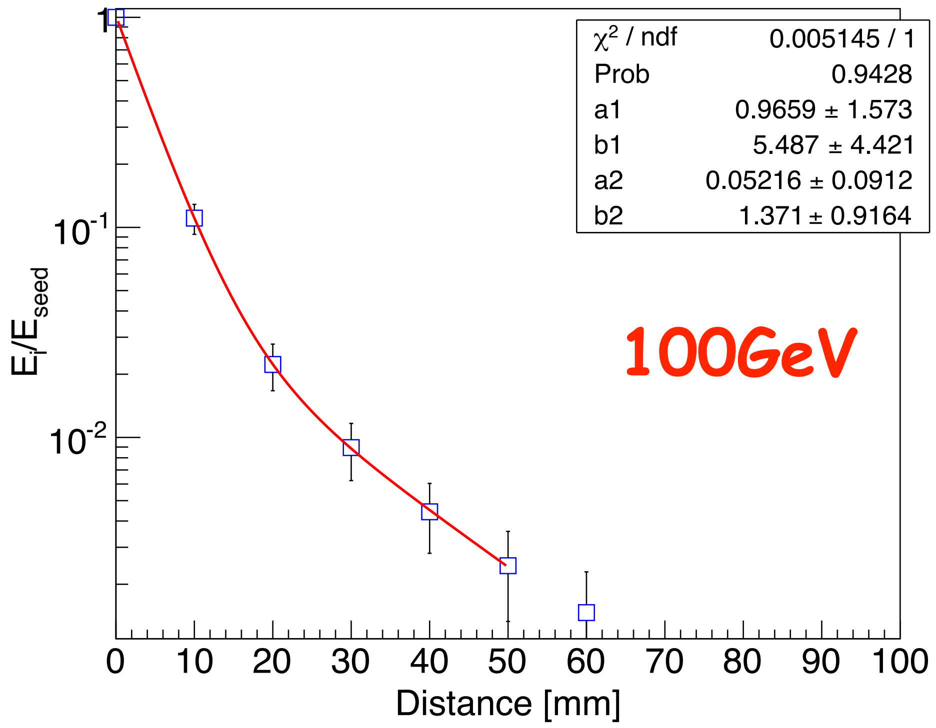


图 4-6 簇射在晶体中的横向发展示意图

图 4-6 所示的分布可以用下面的公式拟合：

$$\frac{E_i}{E_{seed}} = a_1 \exp\left(-\frac{b_1|x_i - x_c|}{R_M}\right) + a_2 \exp\left(-\frac{b_2|x_i - x_c|}{R_M}\right), \qquad (4.3)$$

其中R_M为moliere半径，a_1，b_1，a_2，b_2为拟合参数。



Longitudinal layer with max E

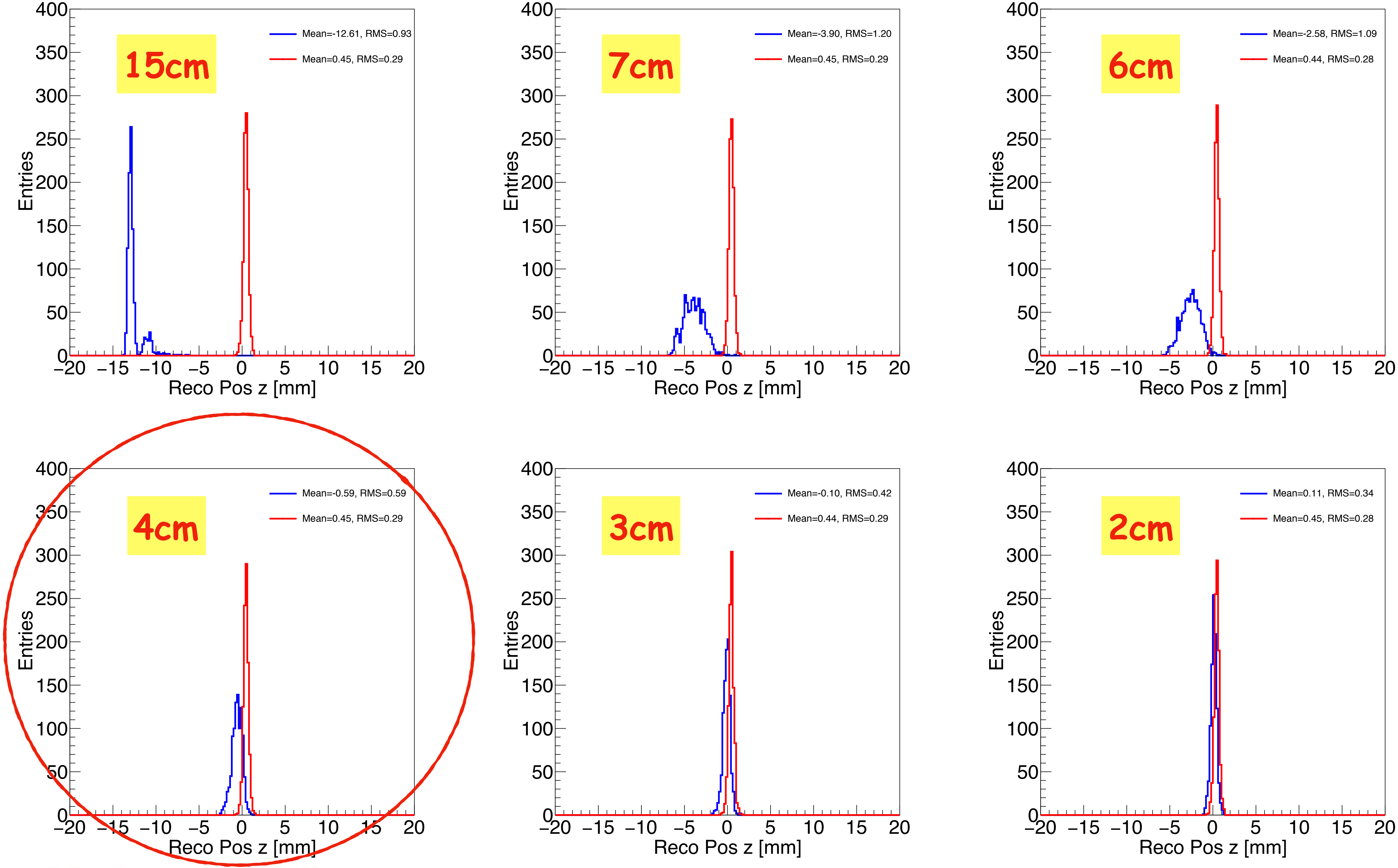
Fitting parameters

Photon Energy	a1	b1	a2	b2	χ²/ndf
1	0.9664	6.341	0.03005	1.404	6.283e-5
5	0.9579	5.939	0.0387	1.389	2.497e-4
10	0.9617	5.814	0.04305	1.394	3.824e-4
25	0.9479	5.595	0.04557	1.367	1.322e-3
50	0.9456	5.498	0.04834	1.358	3.189e-3
75	0.9762	5.545	0.05199	1.38	3.321e-3
100	0.9659	5.487	0.05216	1.371	5.145e-3
120	0.9704	5.456	0.05197	1.357	4.426e-3
125	0.9677	5.461	0.05276	1.366	7.21e-3
150	0.9628	5.438	0.05333	1.363	6.757e-3
175	0.9757	5.457	0.05448	1.367	5.341e-3
200	0.9736	5.437	0.05471	1.367	5.526e-3
	0.96	5.8	0.04	1.38	

Position reconstructed by time

σ_t ~145ps

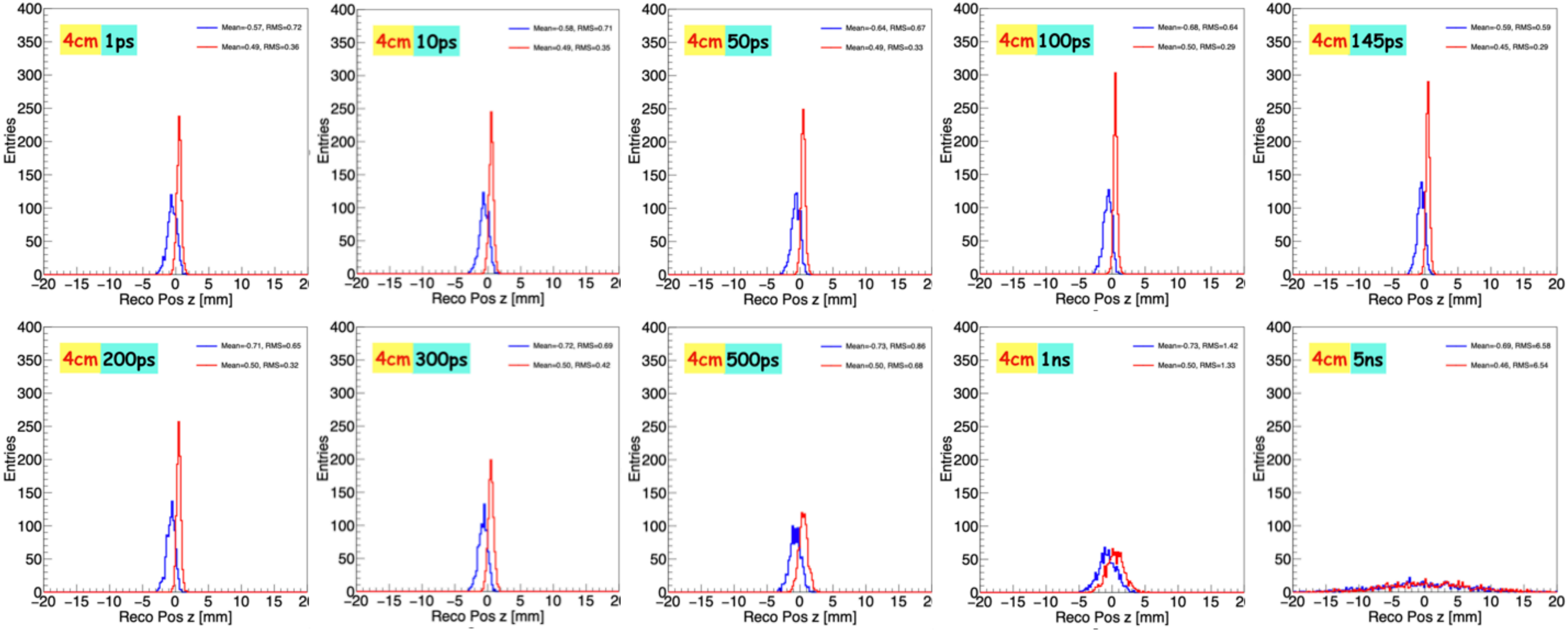
at different distances



Maybe critical distance

Position reconstructed by time

varying the time resolution artificially



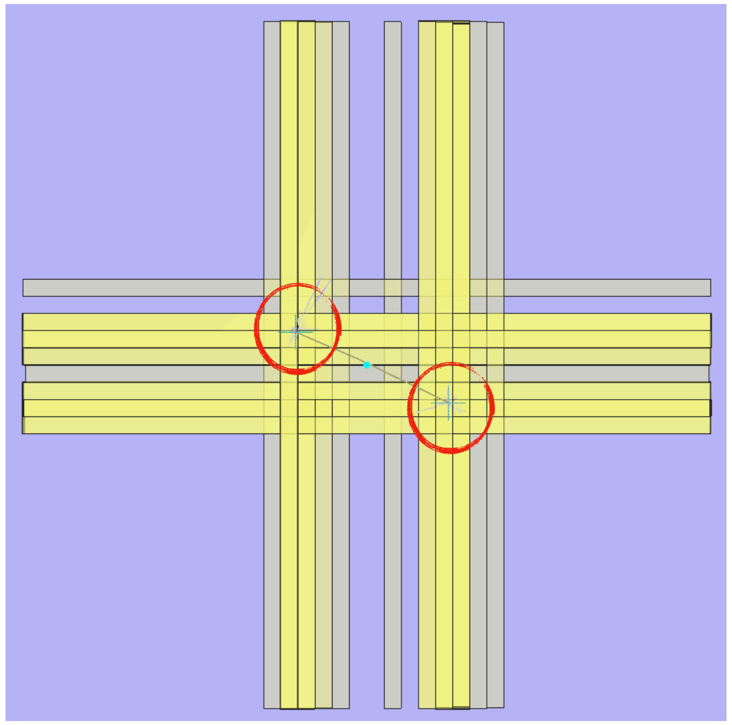
Improvement of time resolution don’t improve the separation power?!
→ need further check of the time digitization?

Reconstruction efficiency

Reconstruction considering both energy and time
Reconstruction Efficiency (Preliminary results)

Distance (cm)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
γγ	98.80%	98.30%	98.60%	99.20%	97.70%	98.10%	97.80%	98.10%	98.40%	98.60%	99.10%	97.70%	98.60%	98.70%	22%
Position Matching	98.80%	98.30%	98.60%	99.20%	97.70%	98.10%	97.80%	98.10%	98.20%	97.40%	93.10%	81.20%	79.90%	76.60%	12%
Energy Sharing	98.70%	98.20%	98.50%	99.10%	97.60%	98%	97.70%	98%	98.30%	98.50%	99%	97.60%	98.50%	98.60%	0%
All 3 conditions	98.70%	98.20%	98.50%	99.10%	97.60%	98%	97.70%	98%	98.10%	97.30%	93%	81.10%	79.80%	76.50%	0%

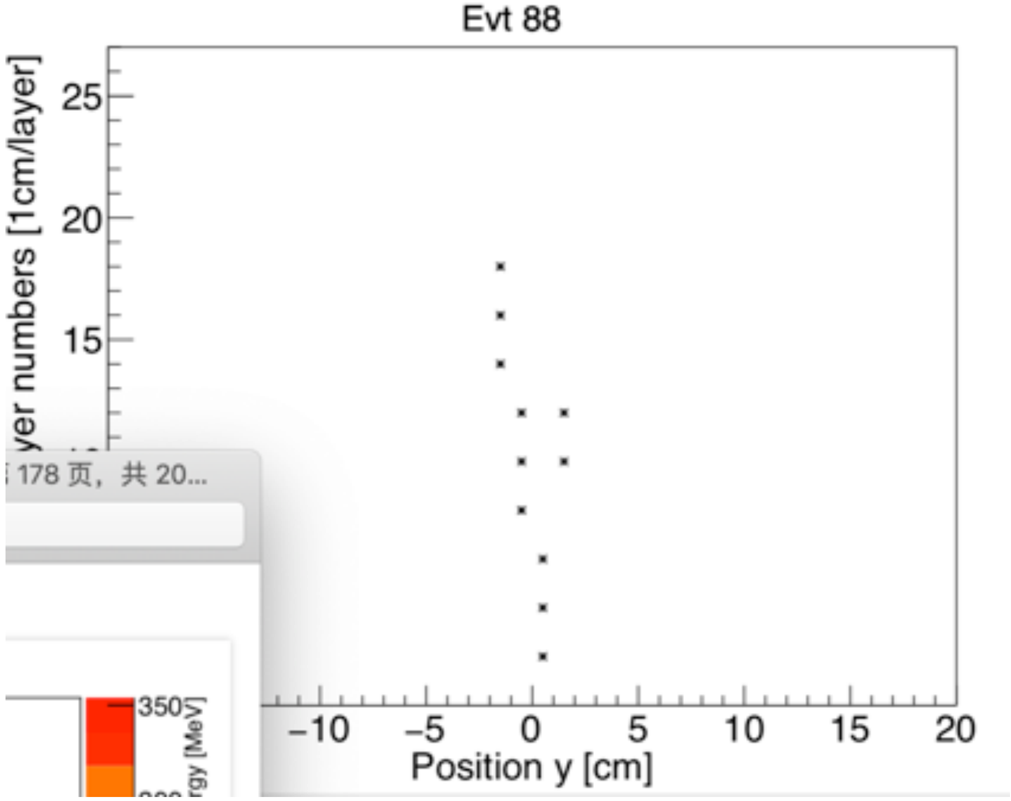
Position matching



Energy sharing

$$\frac{1}{3}E_{Sum} < E_{photon1} < \frac{2}{3}E_{Sum}$$
&&
$$\frac{1}{3}E_{Sum} < E_{photon2} < \frac{2}{3}E_{Sum}$$

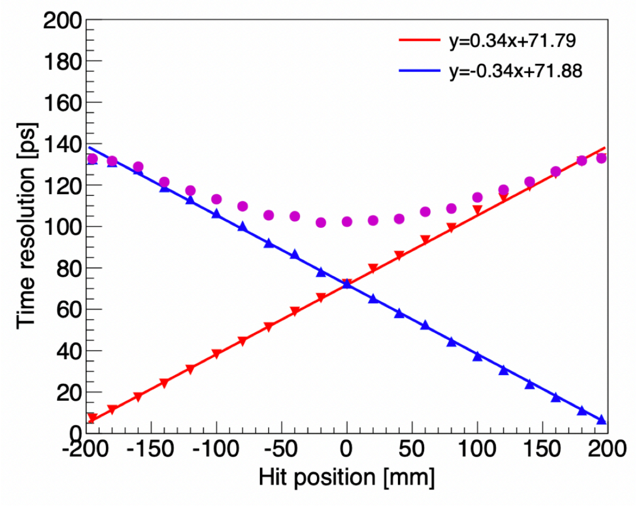
Far distances are expected to achieve 100% reconstructed successfully.
Optimization of the algorithm to connect sub-clusters into complete shower is needed.



Preliminary Study of di-photon separation

Vary the time resolution artificially:

- *Maintain the dependence on hit position, change the slope to get worst time resolution of single end from 10ps to 500ps.*

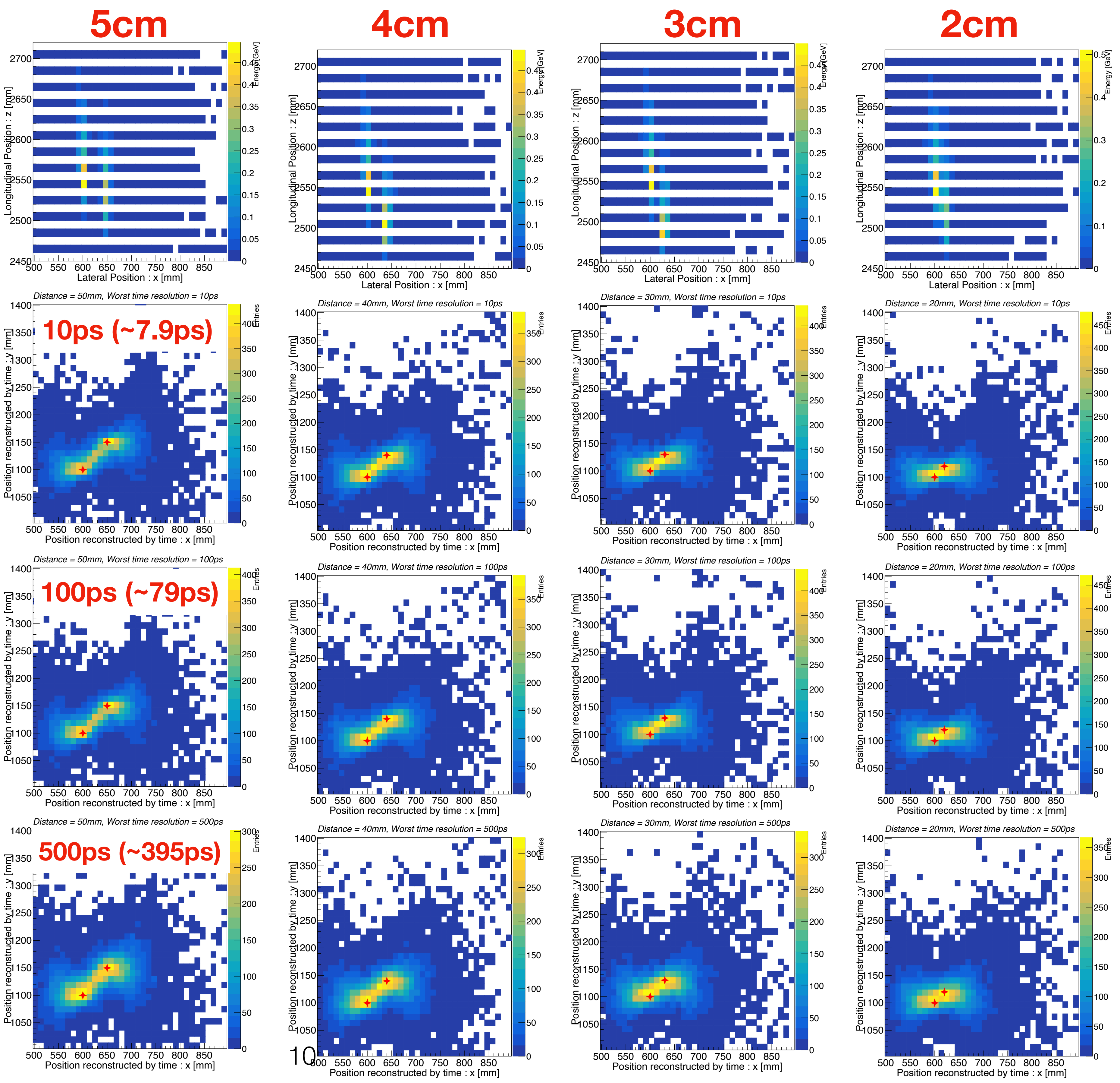


Critical separation distance (with the help of energy info.):

~ 3cm (~4cm along the diagonal), mainly limited by R_M.

Separation power is not so sensitive to time resolution.

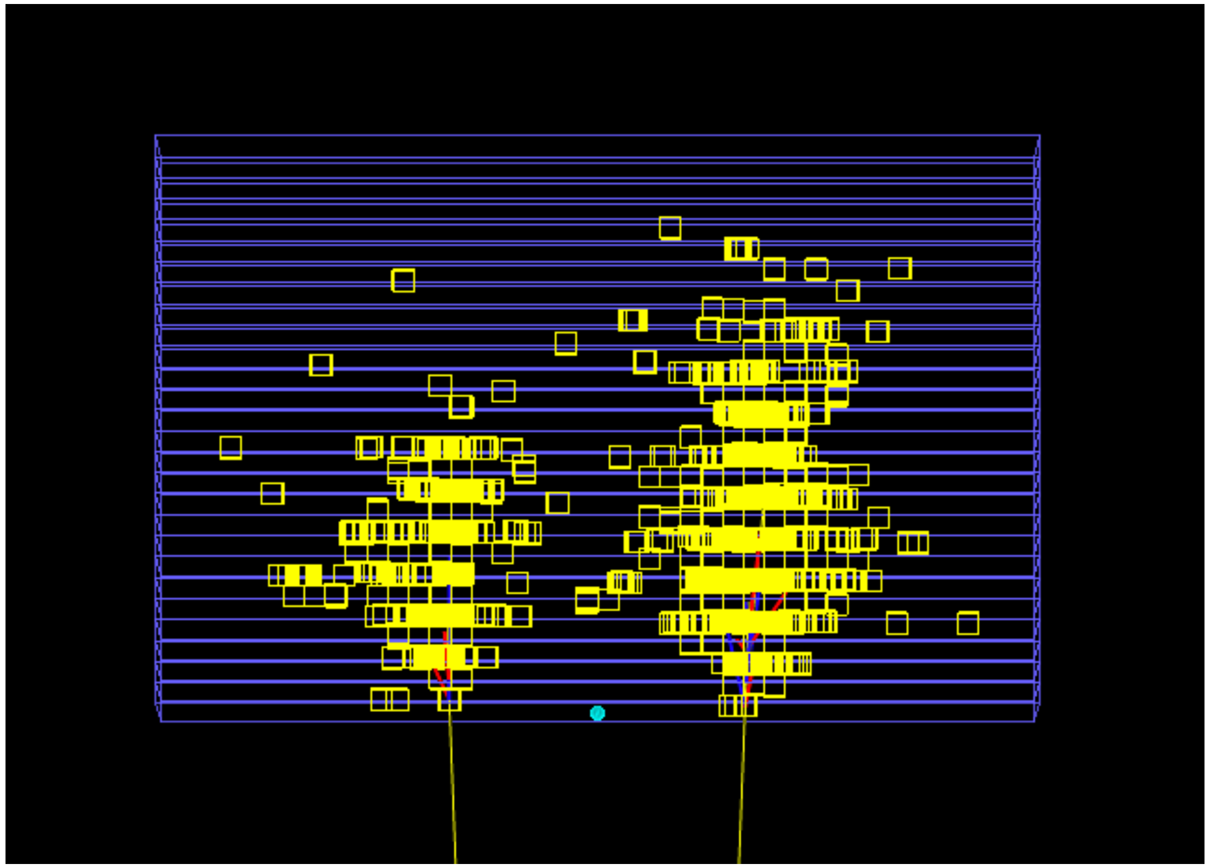
(Only preliminary results of current simple digitization, need to check and understand further…)

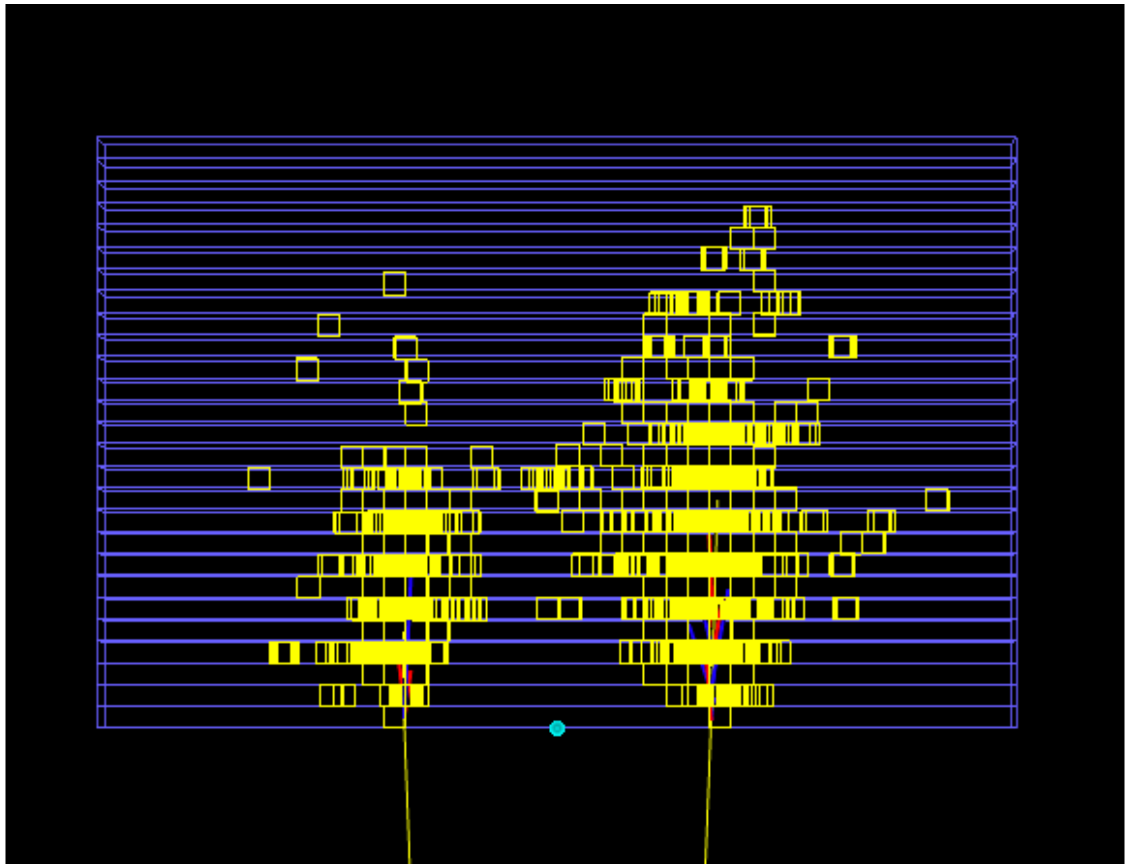


Backup

Shower shape in ECAL

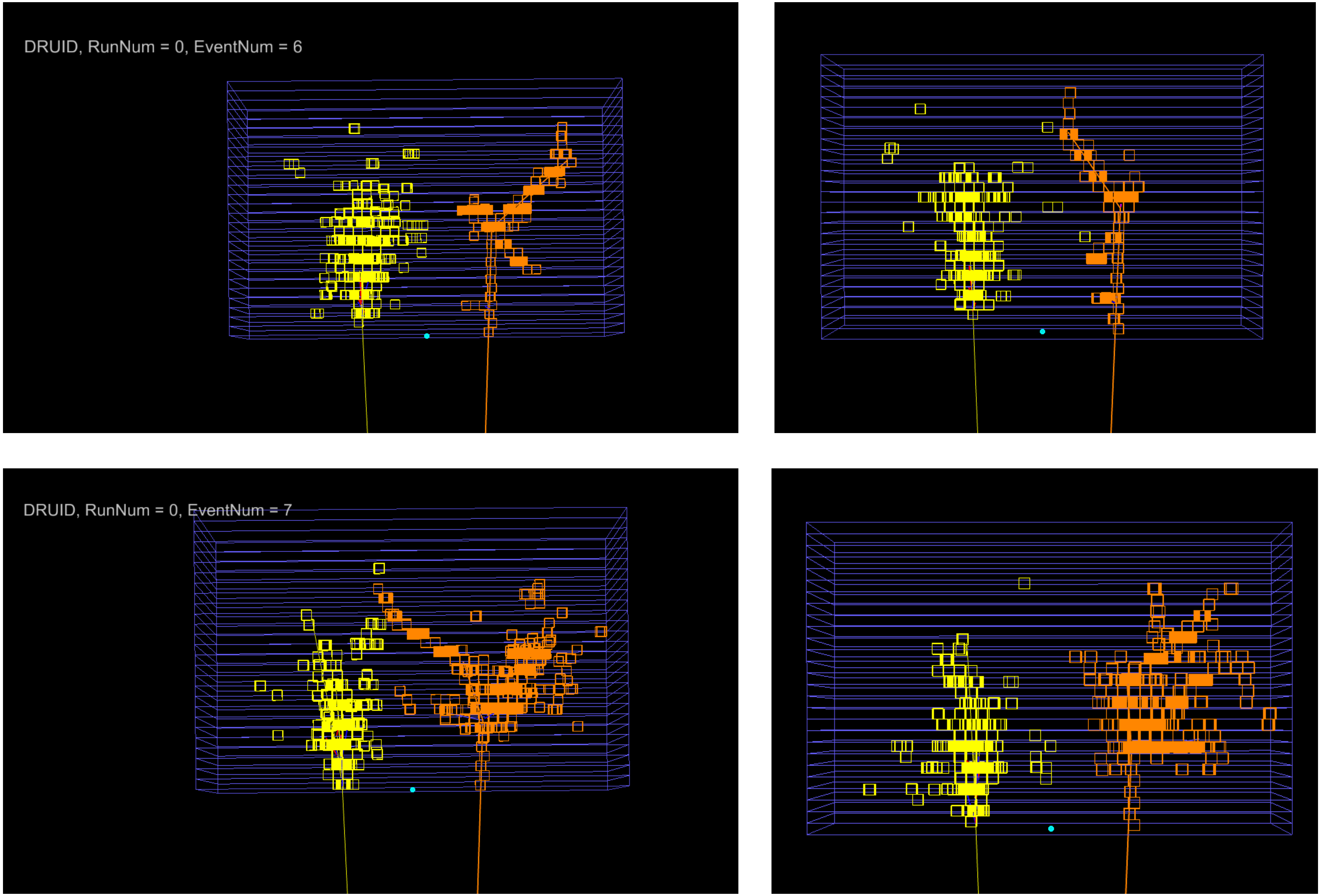
1GeV γ + 2.5GeV γ





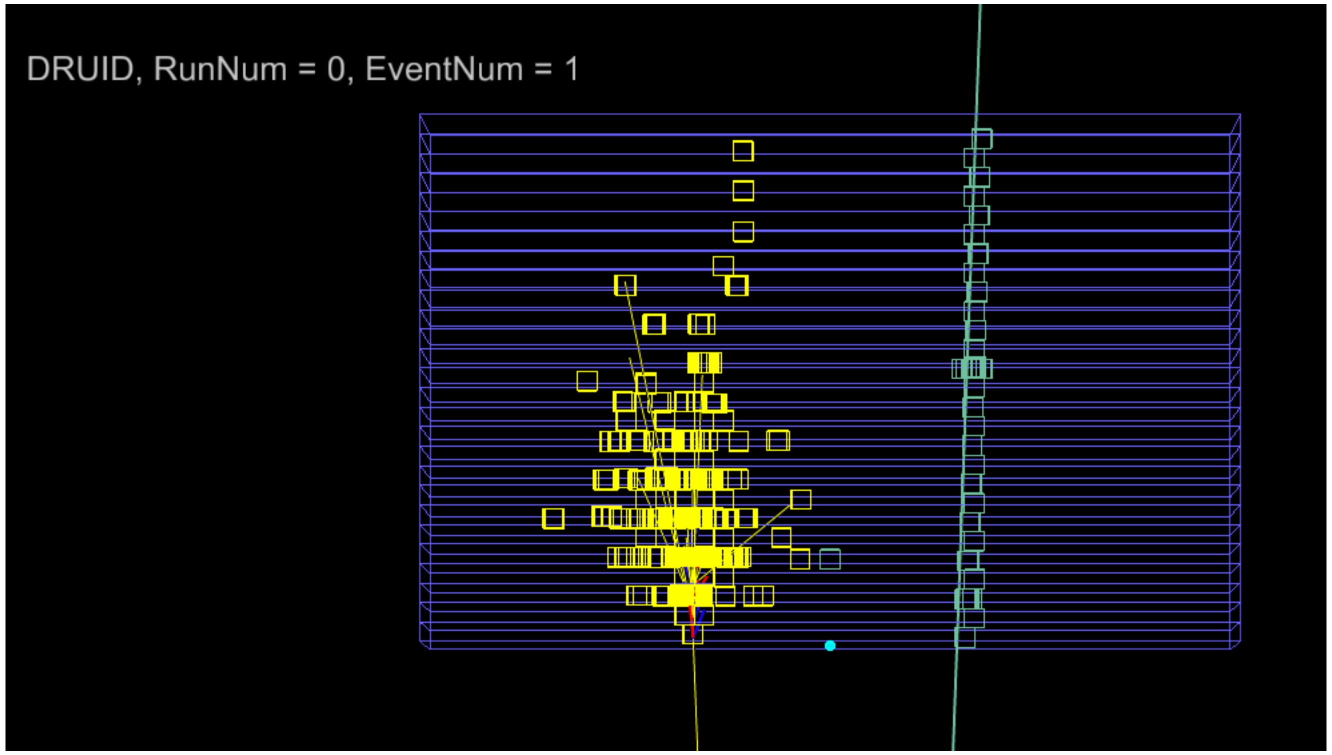
Shower shape in ECAL

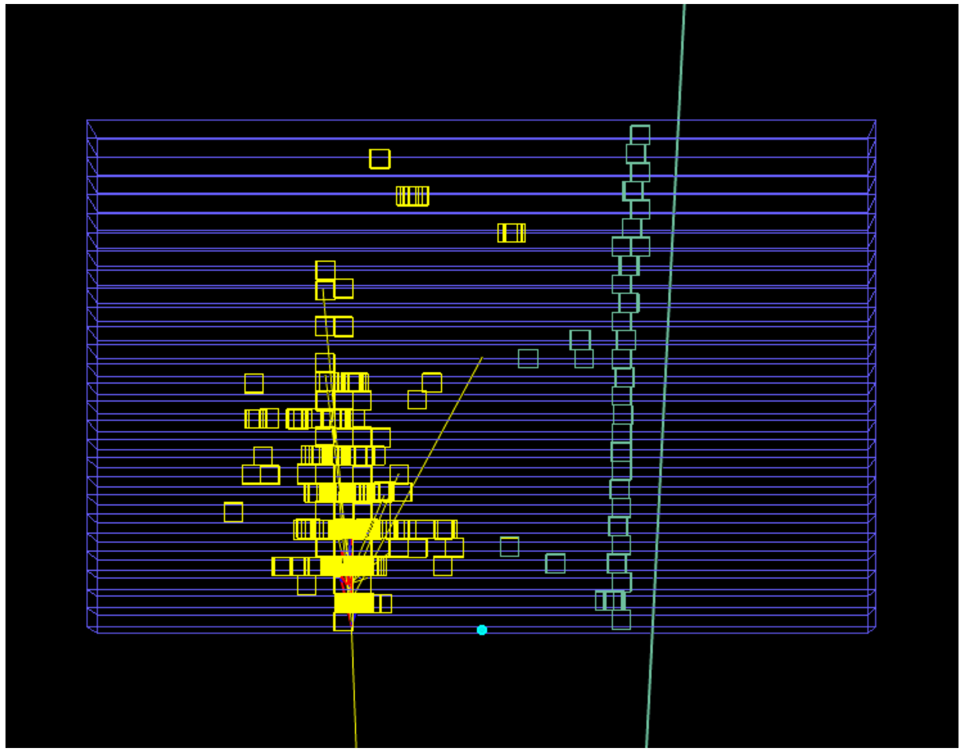
1GeV γ + 3GeV π+

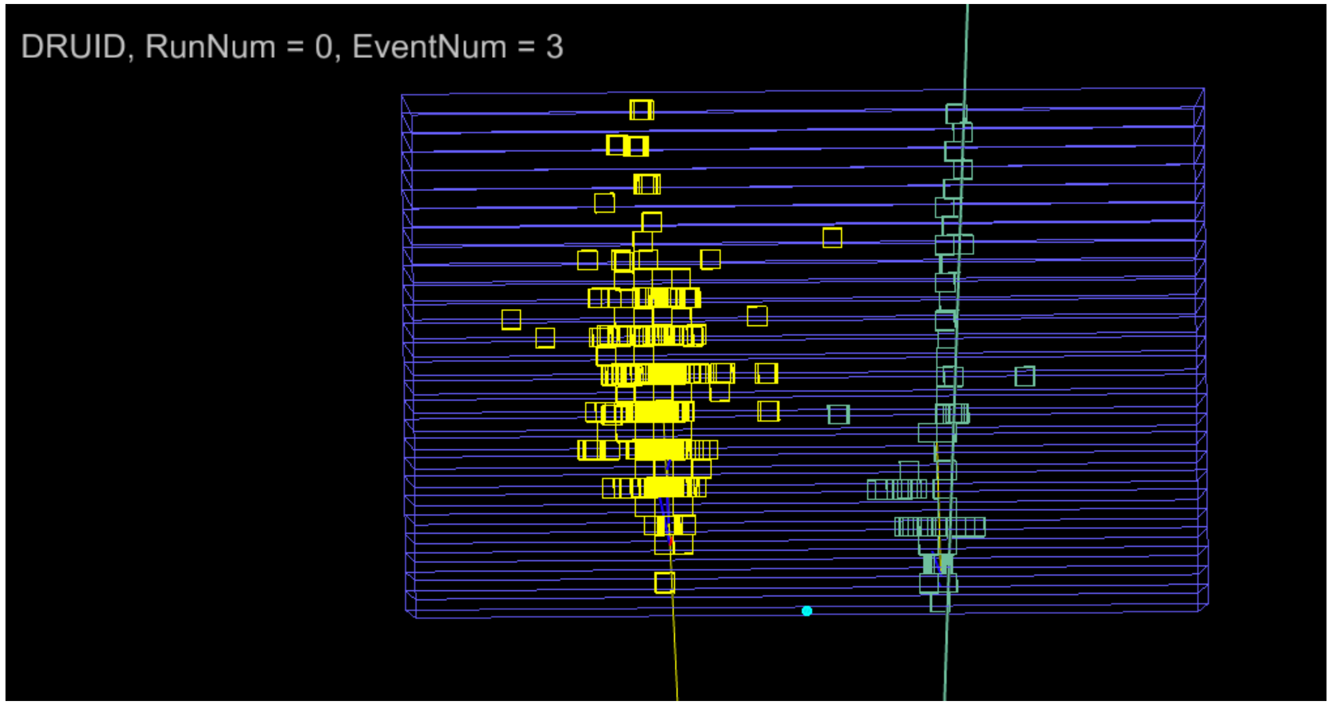


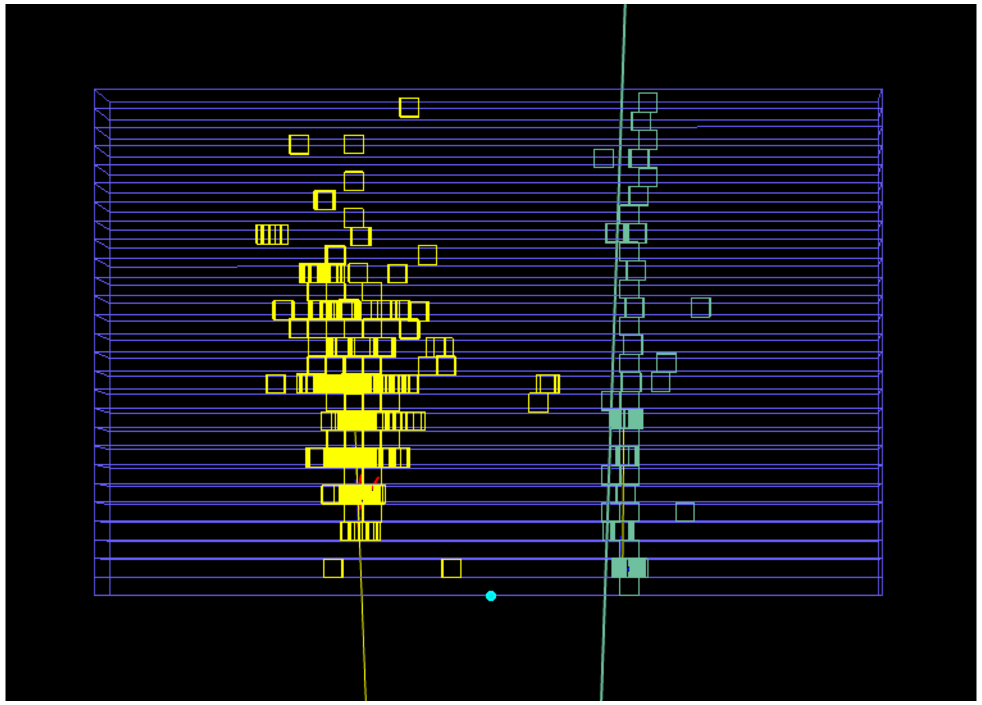
Shower shape in ECAL

1GeV γ + 6GeV K+



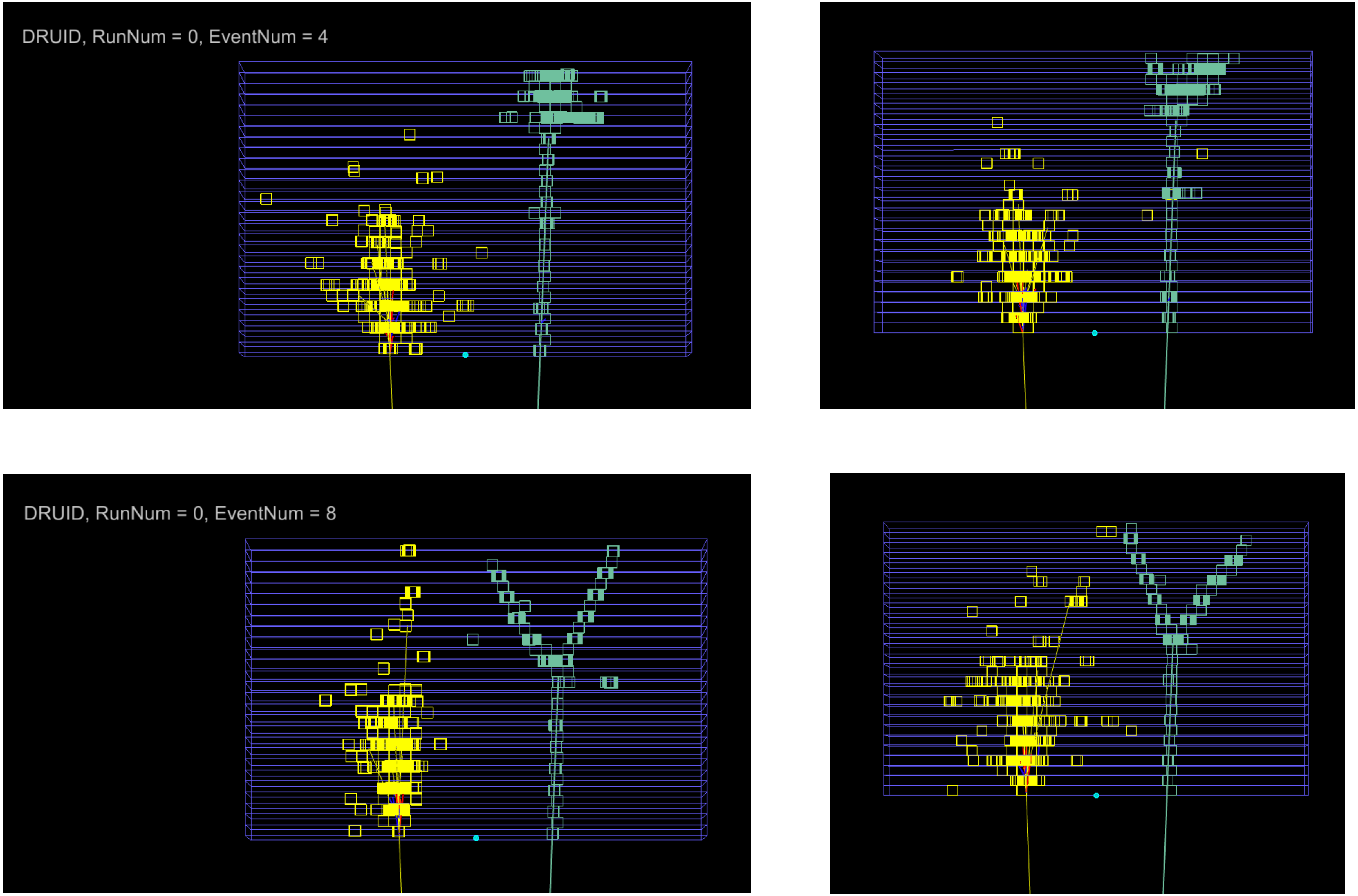




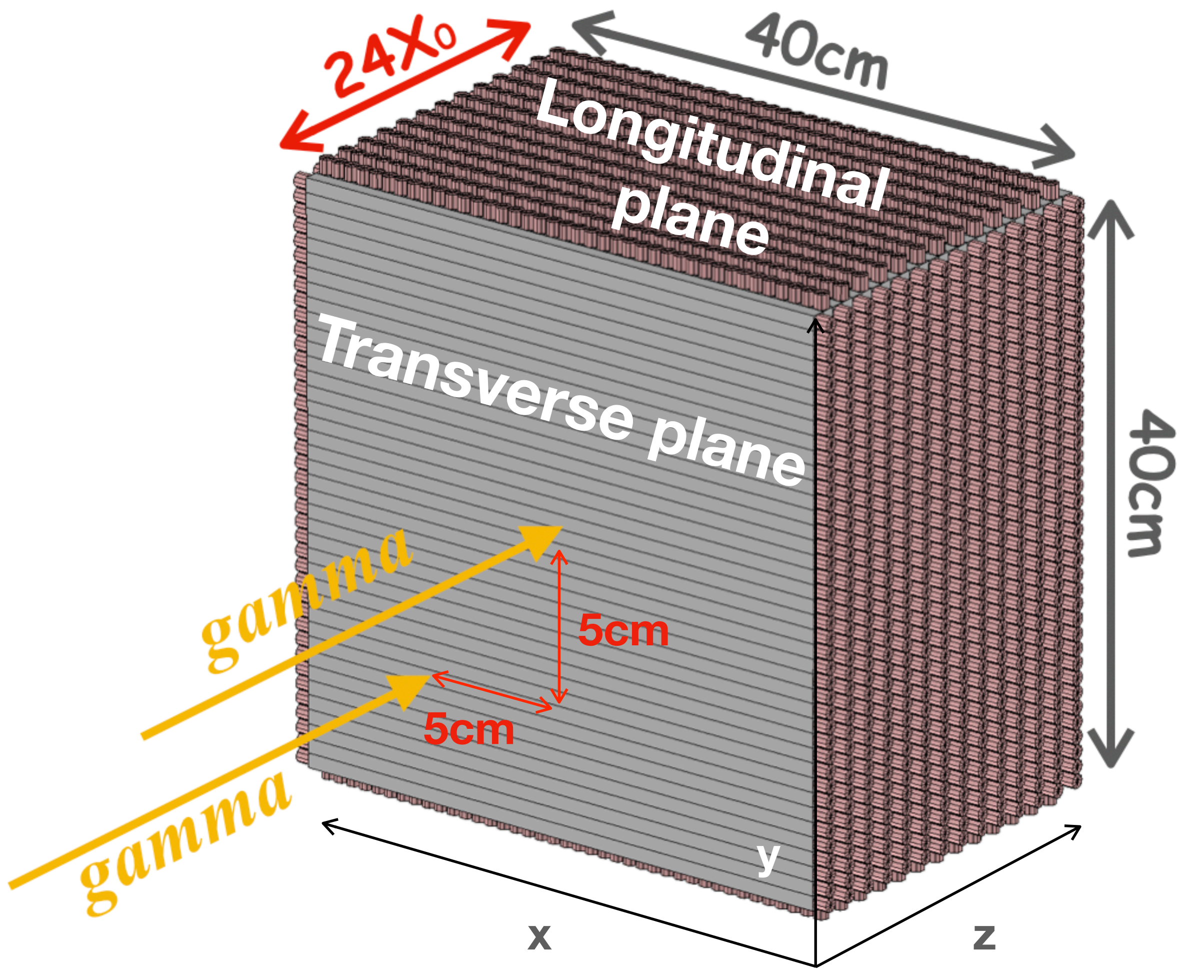


Shower shape in ECAL

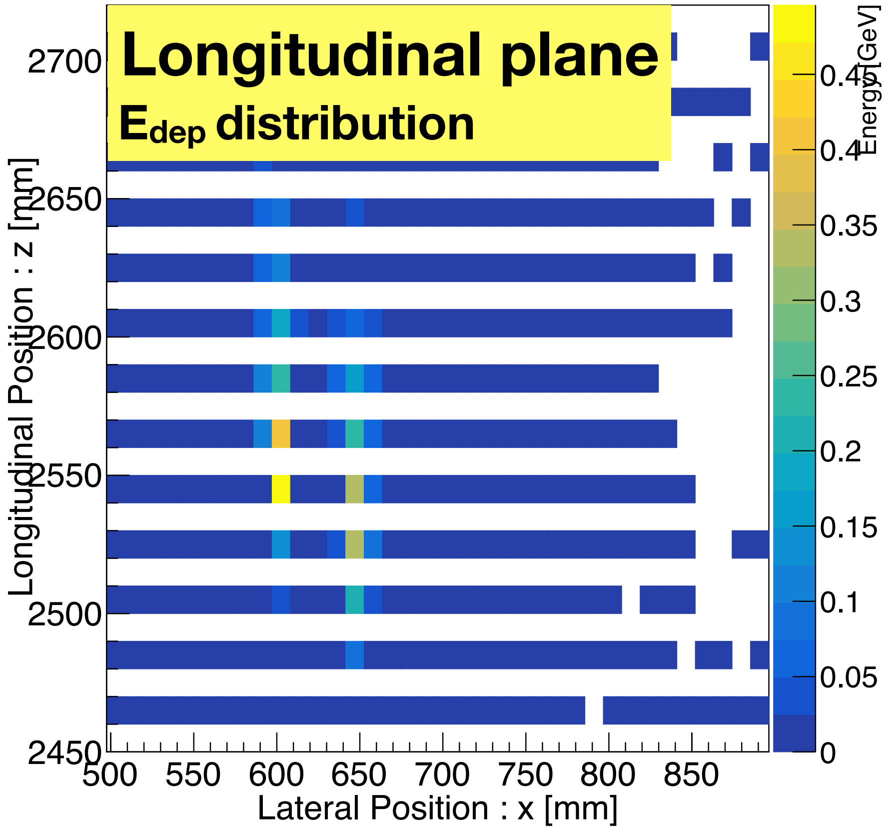
1GeV γ + 6GeV K+

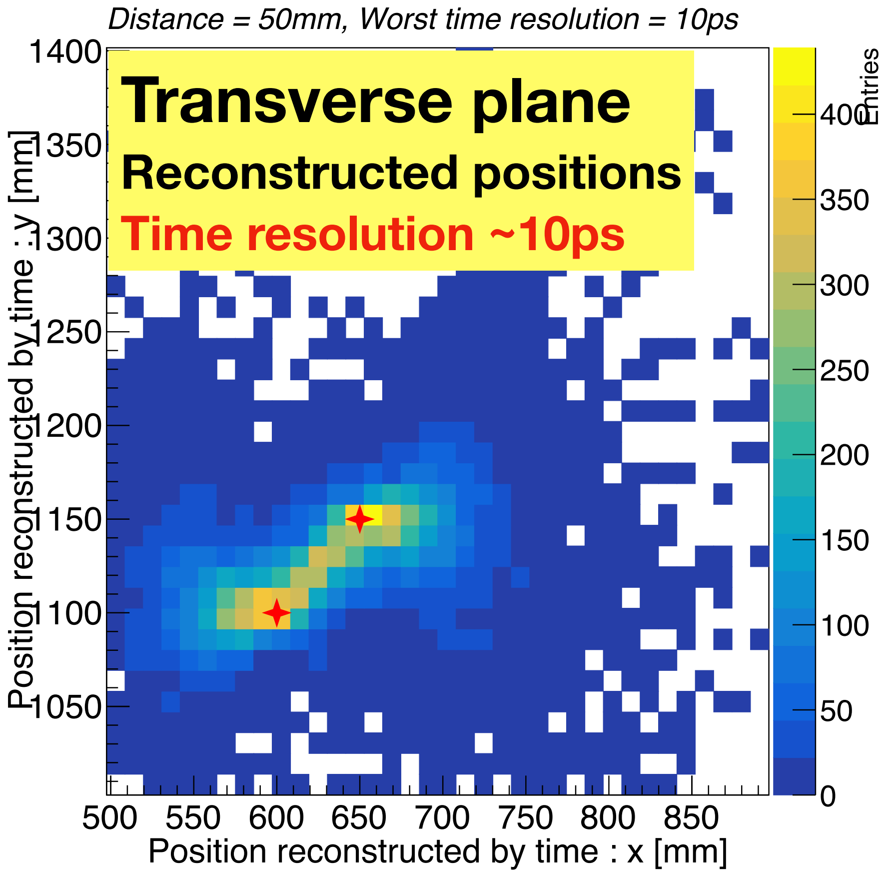


Preliminary Study of di-photon separation

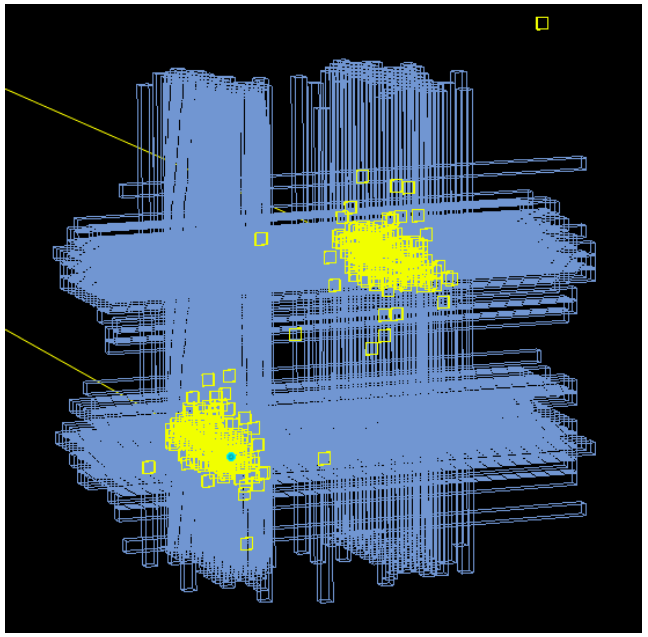


5cm ~ $2R_M$ for BGO (R_M=2.26cm)





Reconstruction: pattern study using Event Display

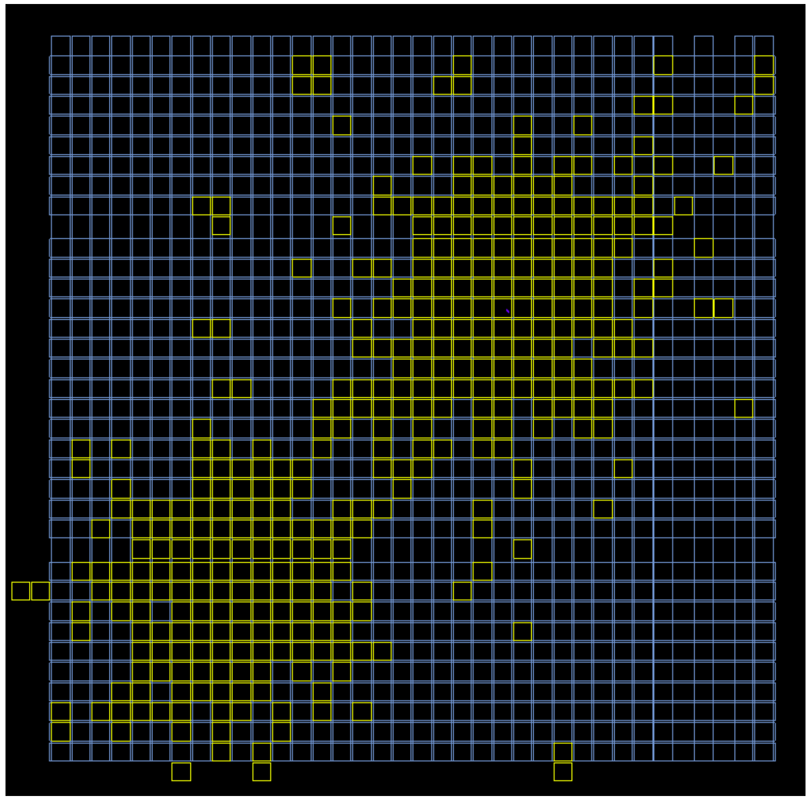


2 parallel 5GeV γ

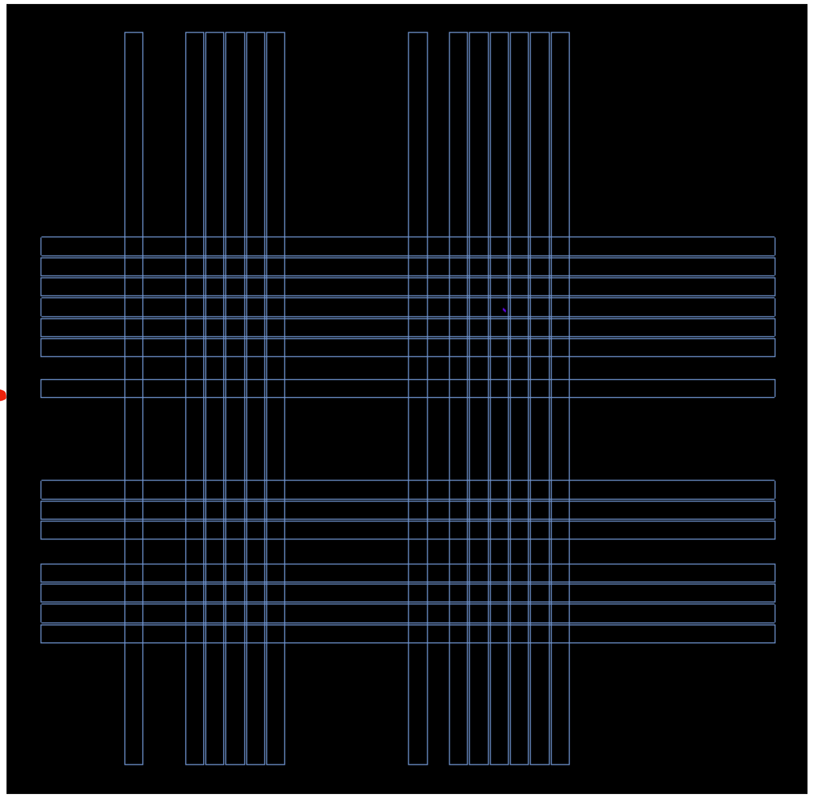
distance ~20cm along the diagonal

→ can be separated.

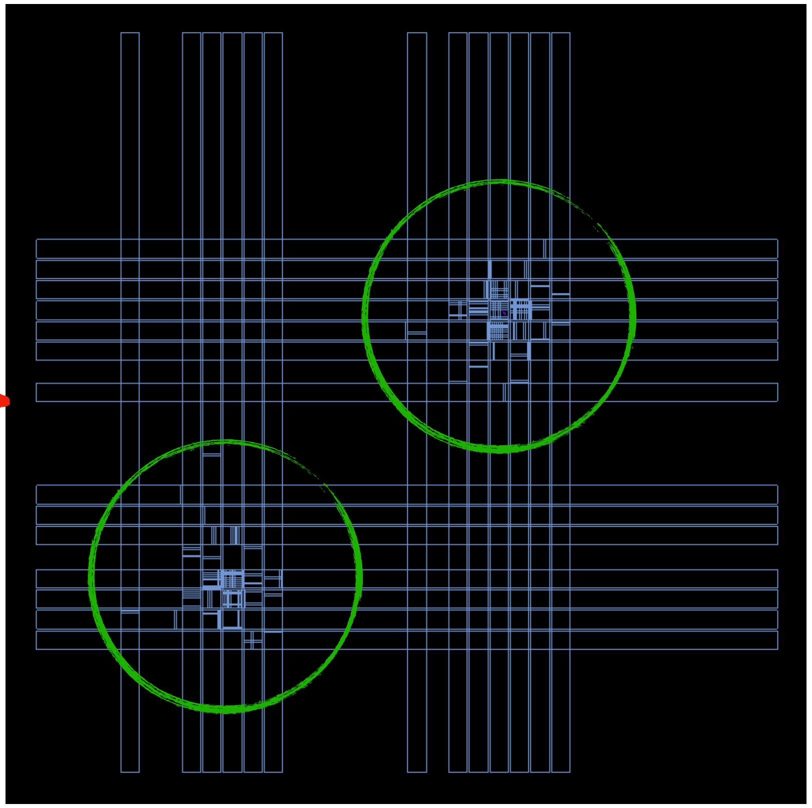
Simulated Hits (yellow cells)



Digitized Long Bar Hits (E_{dep} > 1 MIP)

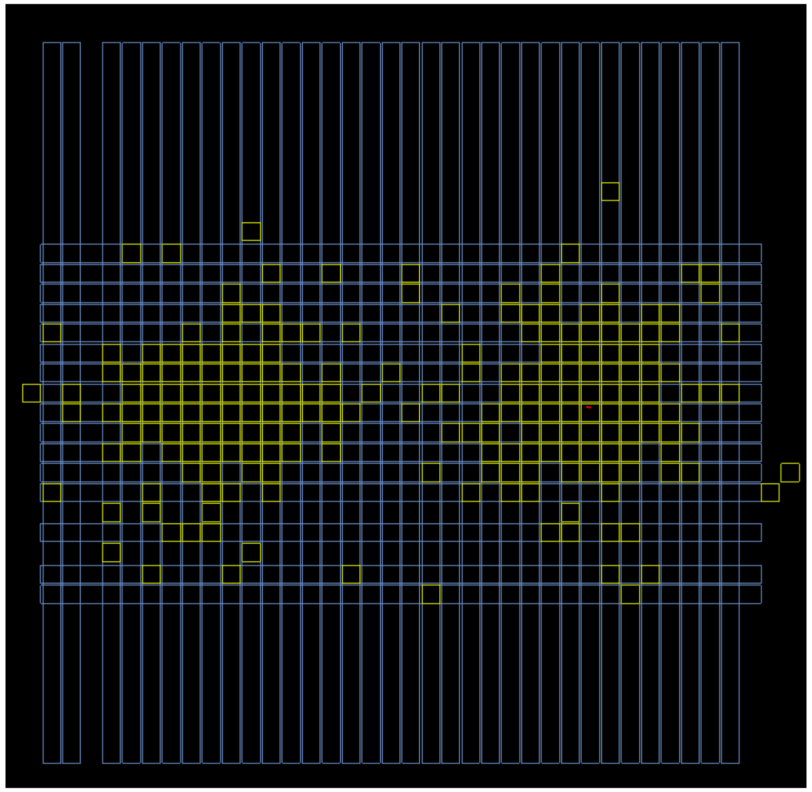


Reconstructed positions using time difference of 2 ends

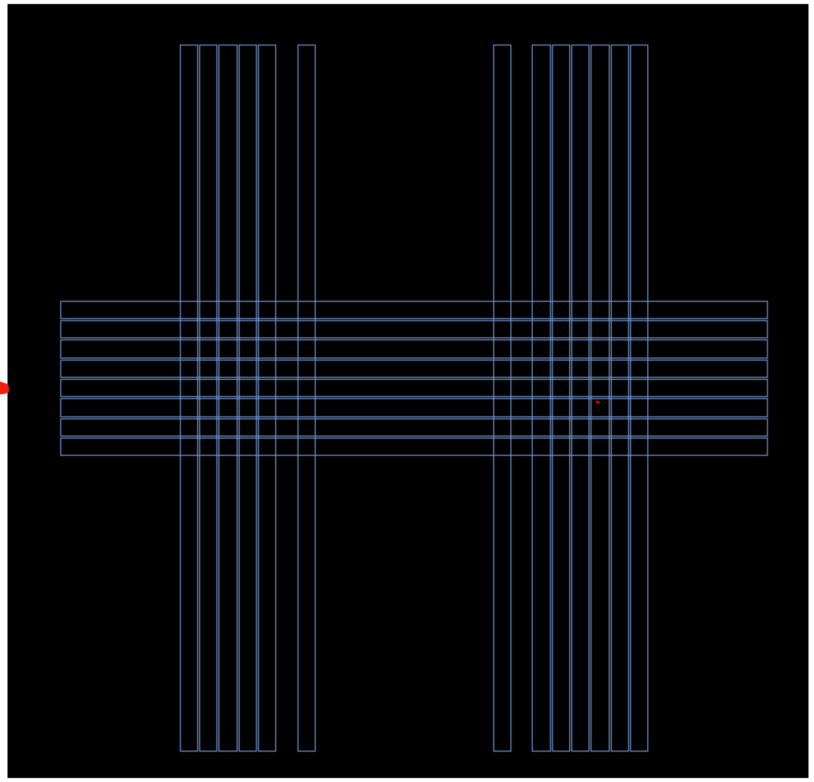


MIP energy = 8.77MeV for 1cm thick BGO

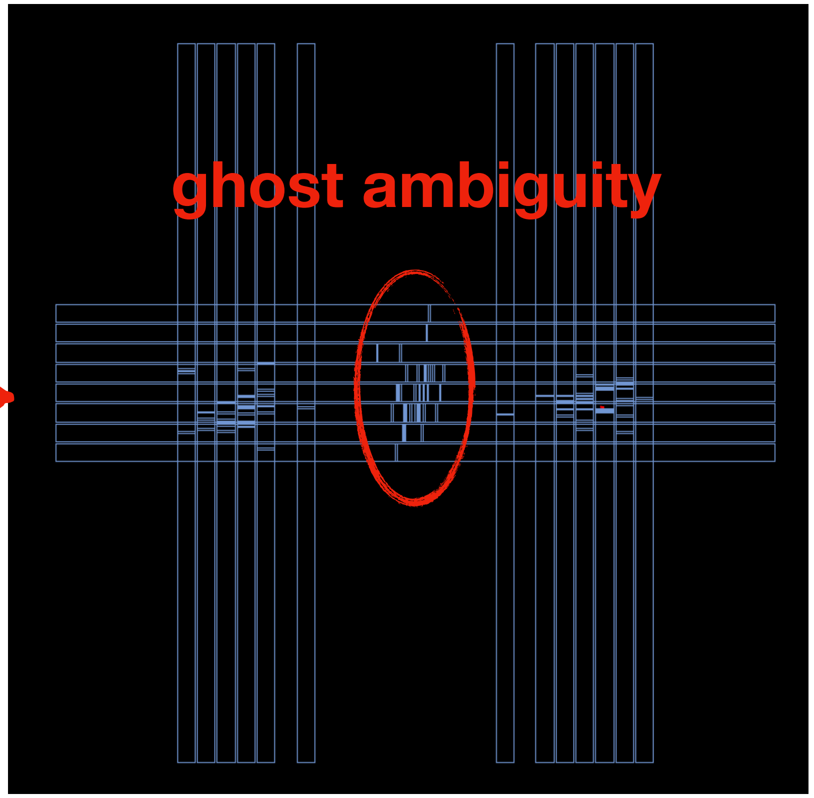
Reconstruction: pattern study using Event Display



Simulated Hits (yellow cells)



Digitized Long Bar Hits (E_{dep} > 1 MIP)



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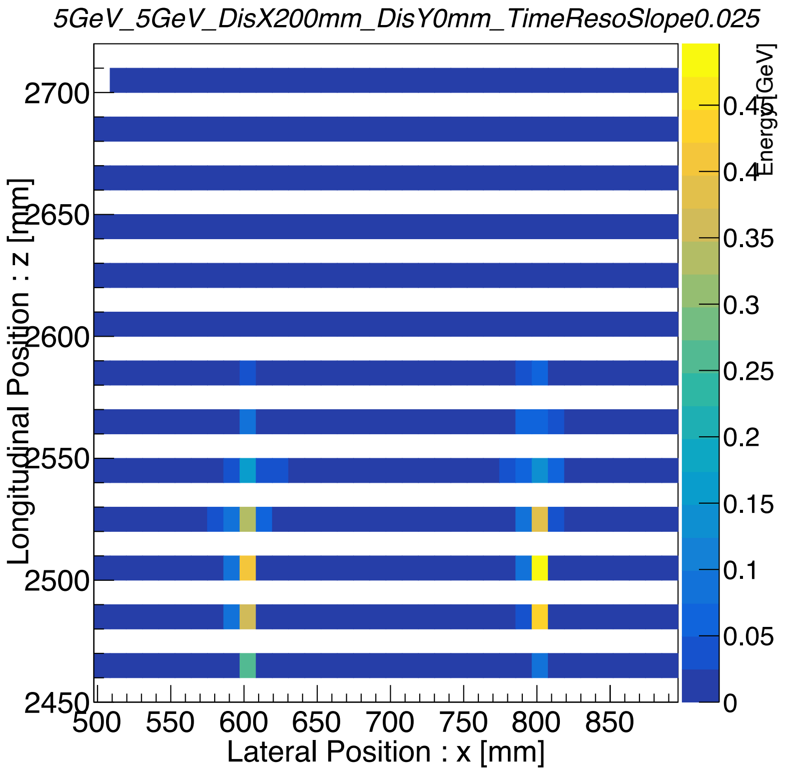


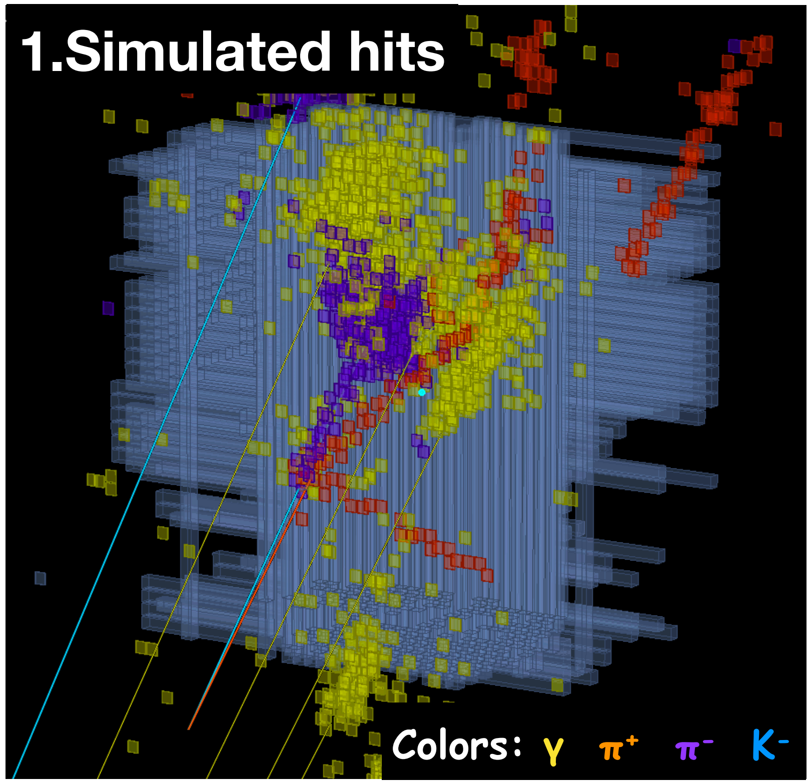
2 parallel 5GeV γ, hit the same bar, 20cm away

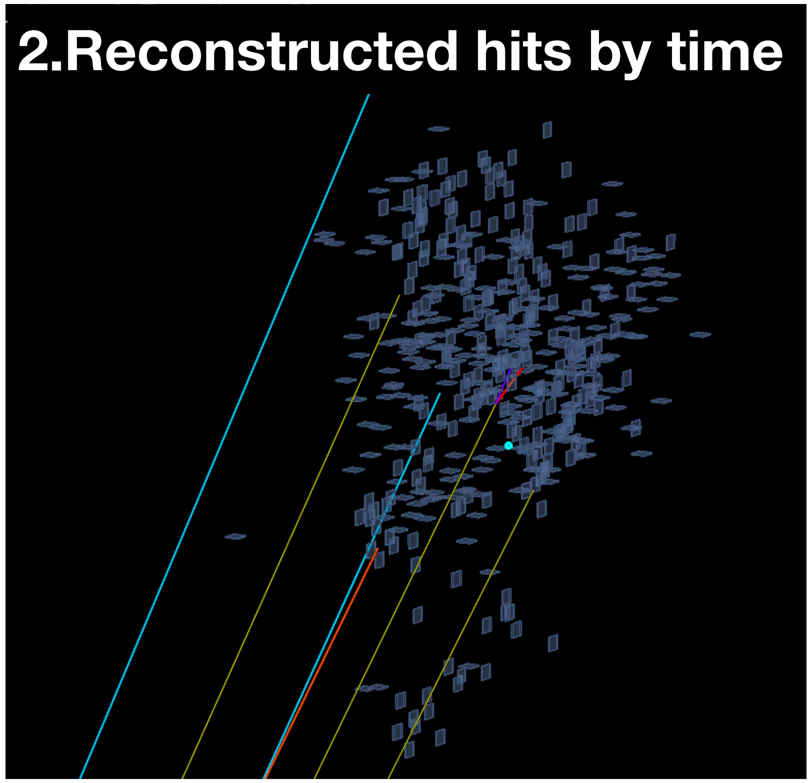
- *If one crystal bar has >1 particles with E_{dep} > 1MIP, position reconstructed will be biased.*
- *Ambiguity can be removed by longitudinal position and energy*

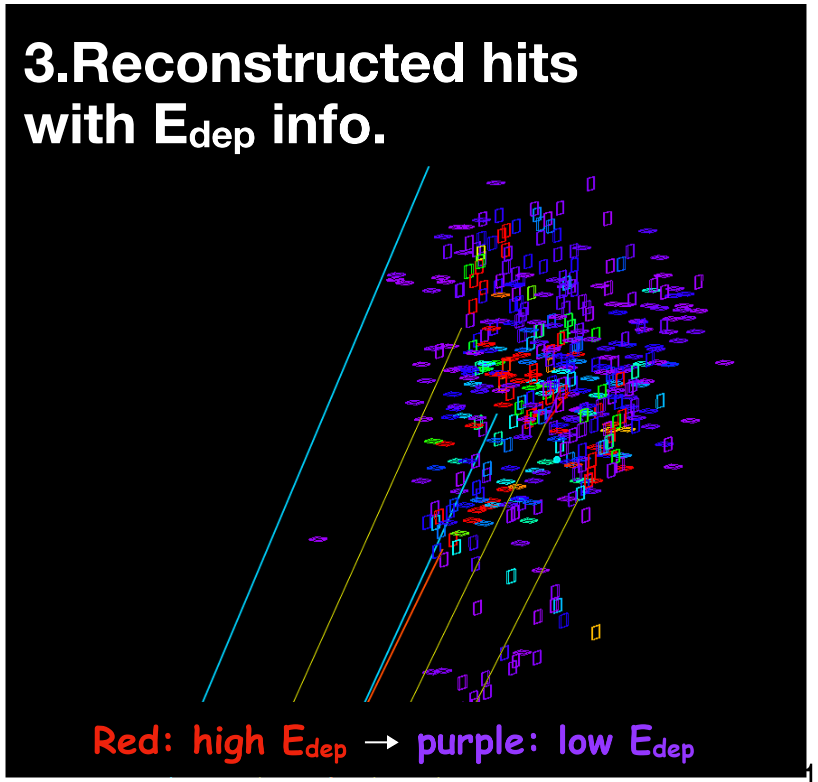
MIP energy = 8.77MeV for 1cm thick BGO

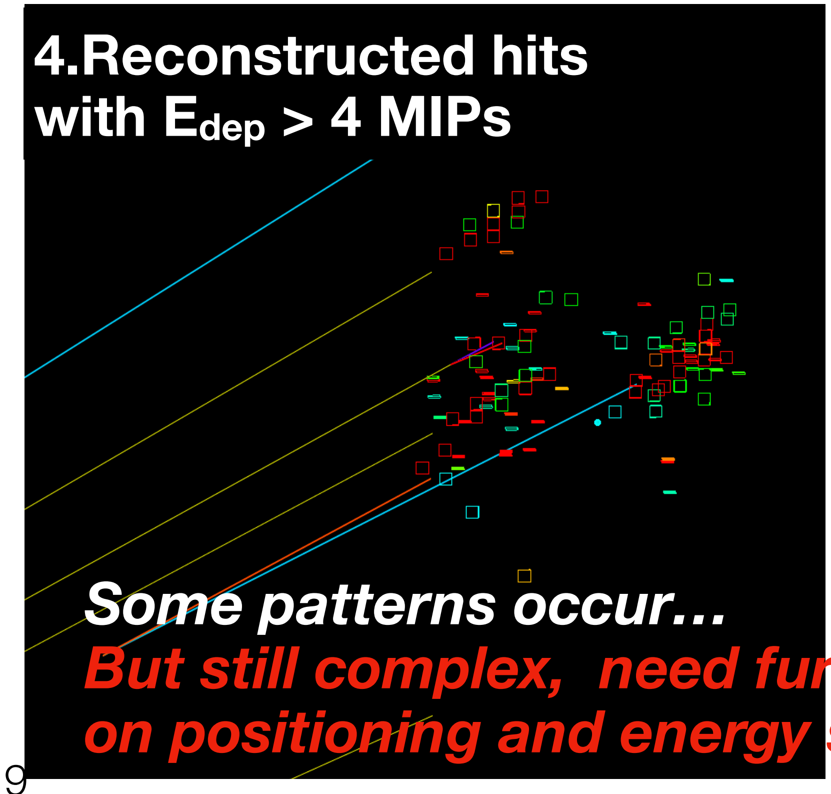
Pattern study using Event Display

Jet event, with increasing multiplicity and combinations


1.Simulated hits


2.Reconstructed hits by time


3.Reconstructed hits with E_{dep} info.


4.Reconstructed hits with E_{dep} > 4 MIPs

Some patterns occur…

But still complex, need further study on positioning and energy sharing.

两种时间数字化方案的对比

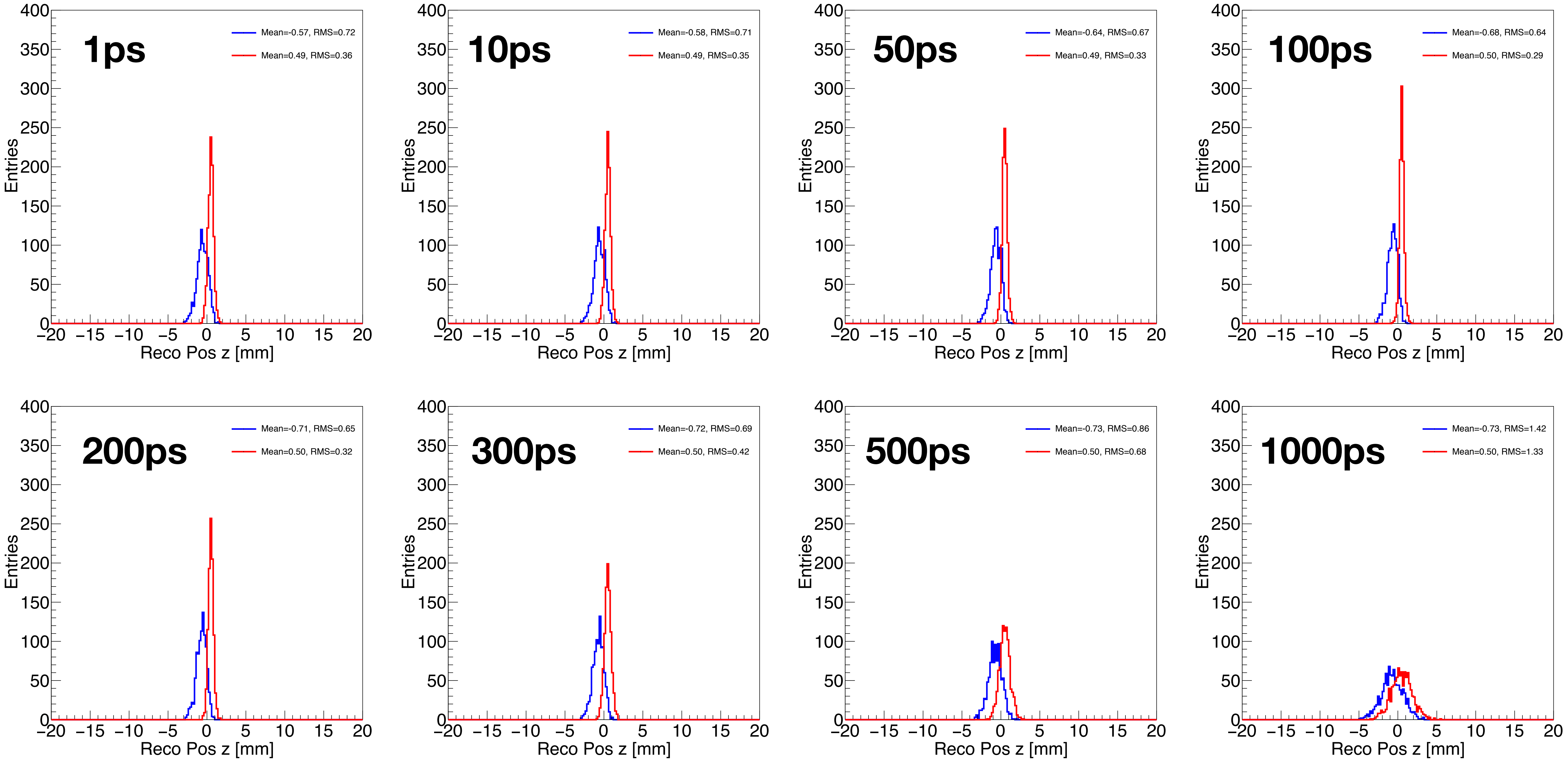
两种数字化方案：

1. 经过*smear*之后得到的时间谱的最快时间
2. 对能量沉积最大的那一个*step*的时间做*smear*

待评估的物理量：

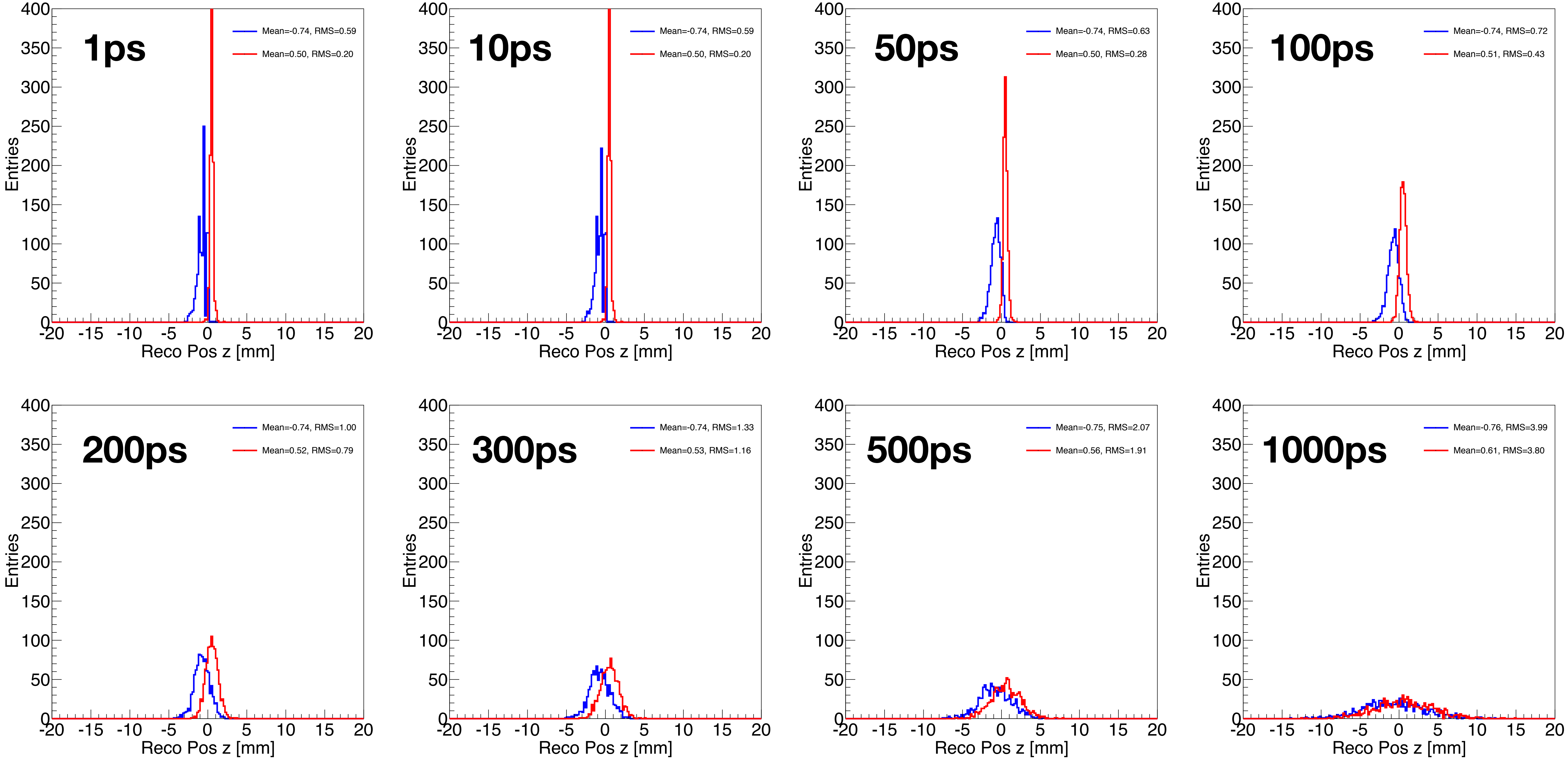
双光子事例，仅通过时间信息重建出来两个光子的位置分辨随时间分辨的变化

经过*smear*之后得到的时间谱的最快时间



时间分辨在*300ps*以下，对位置分辨基本没有影响，不太让人理解

对能量沉积最大的那一个*step*的时间做*smear*



可以看到对时间分辨的明显依赖

但对于一根晶体上有多粒子击中的情况，这种数字化方式似乎又不是那么符合物理过程?

三种“时间数字化”方法的对比

三种时间数字化方案：

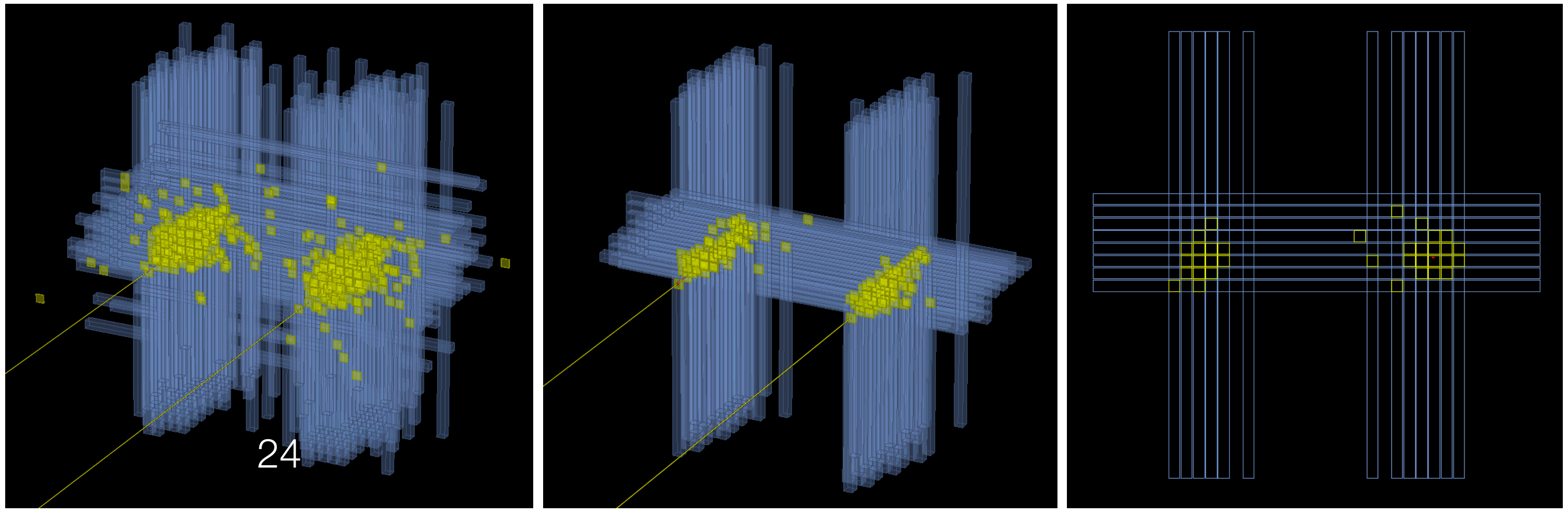
1. 将一根晶体条上每一个小*cell*的时间都根据其位置得到经过相应时间分辨*smear*之后到达两端的时间，再针对每一端选出最快的时间；
2. 先挑出能量沉积最大的一个小*cell*，只用这一个*cell*的时间和位置来做数字化。

用来对比的物理量：

每根晶体条通过两端时间差反解出来的位置

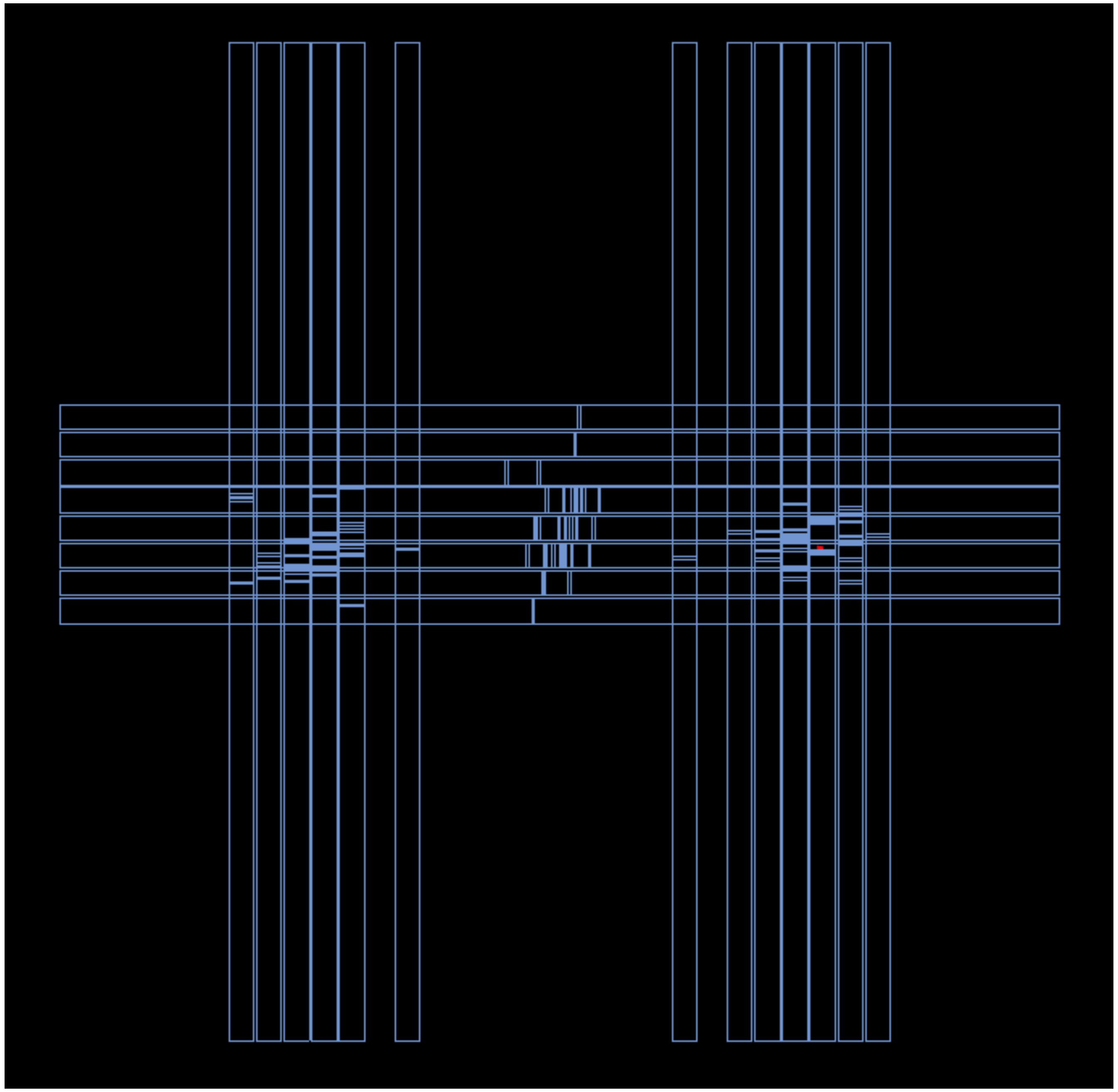
事例： *5GeV* 双光子事例

（在一个维度上打在一根晶体上）



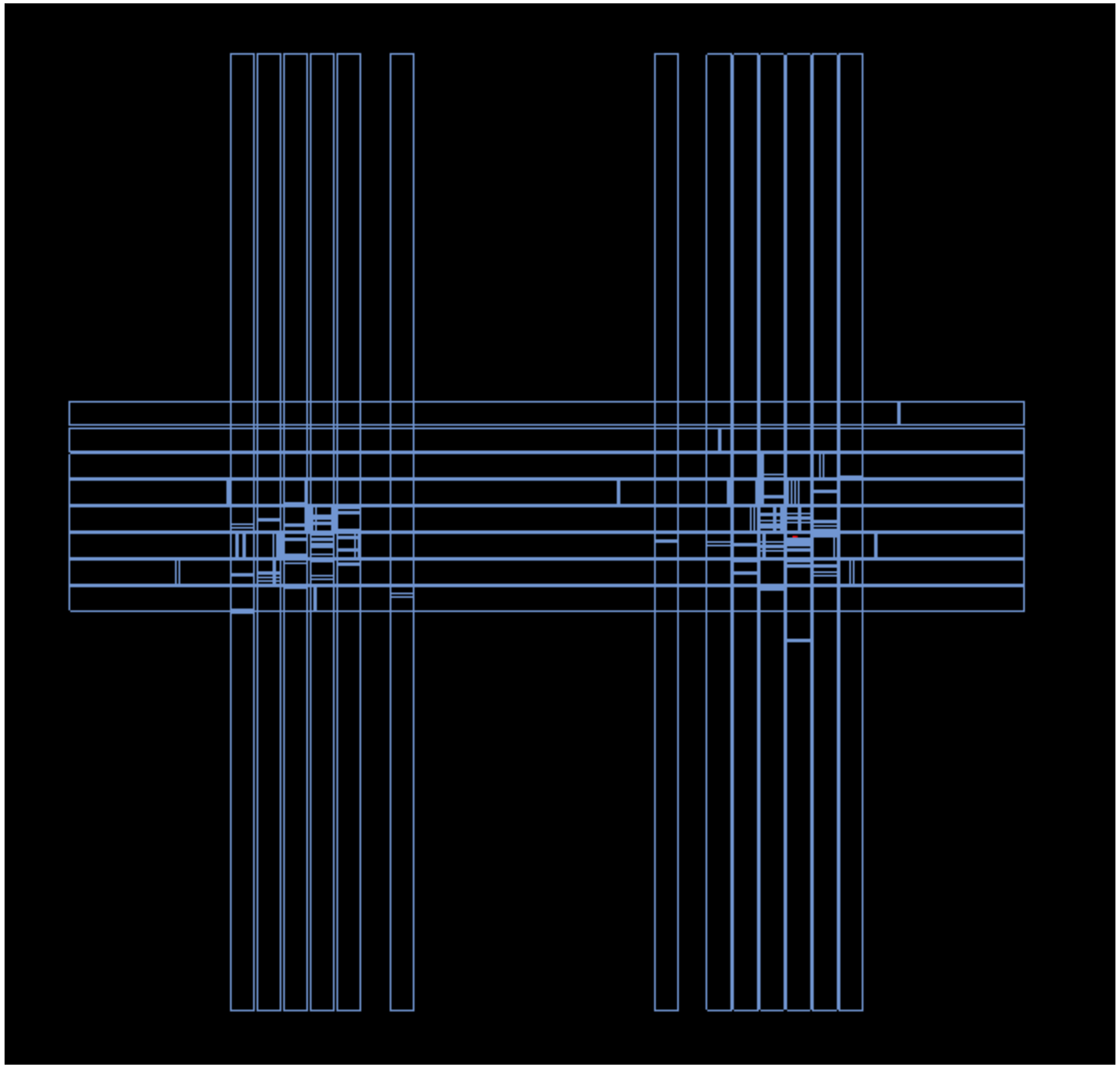
时间数字化

方法*1*：将一根晶体条上每一个小*cell*的时间都根据其位置得到经过相应时间分辨*smear*之后到达两端的时间，再针对每一端选出最快的时间。

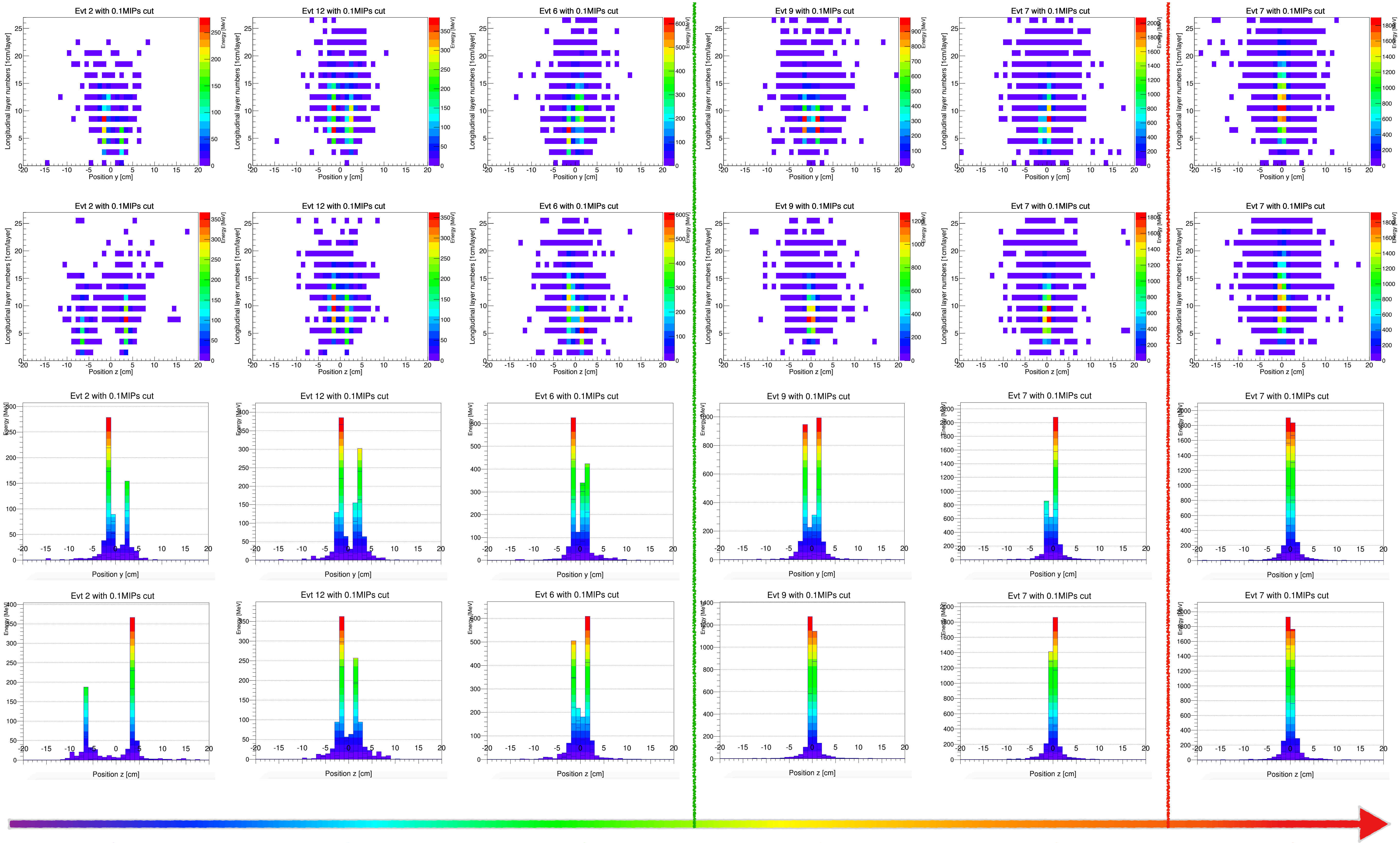


时间数字化

方法2：先挑出能量沉积最大的一个小*cell*，只用这一个*cell*的时间和位置来做数字化。



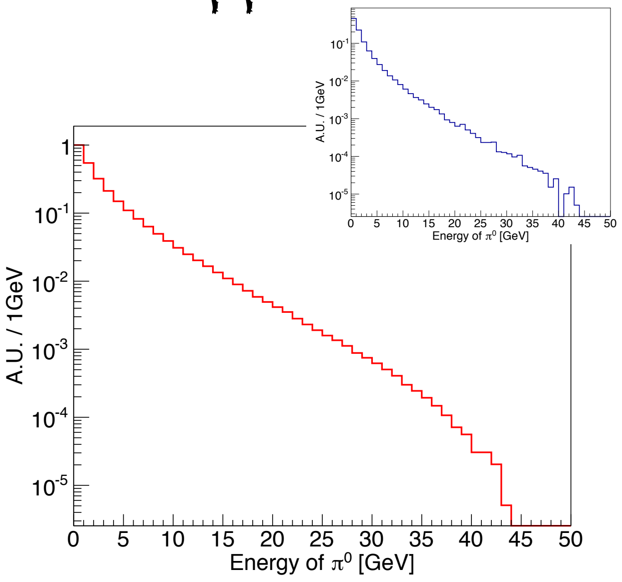
π° -> γγ at different energy

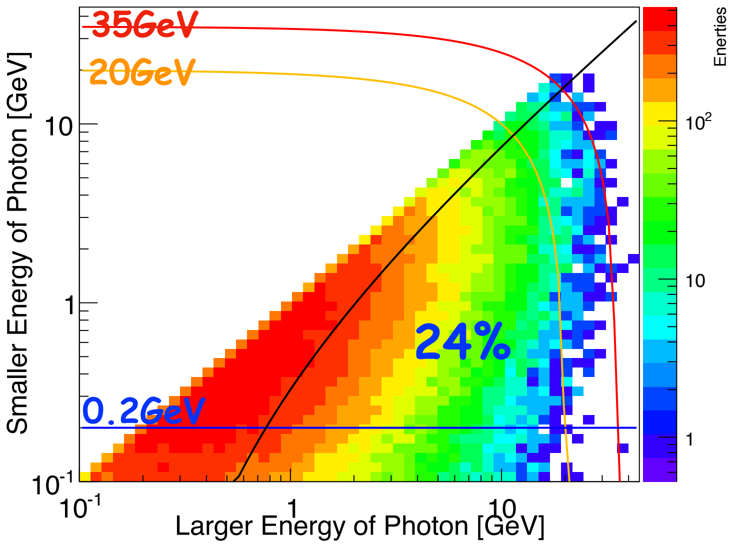


5GeV
10GeV
15GeV
20GeV
35GeV
50GeV

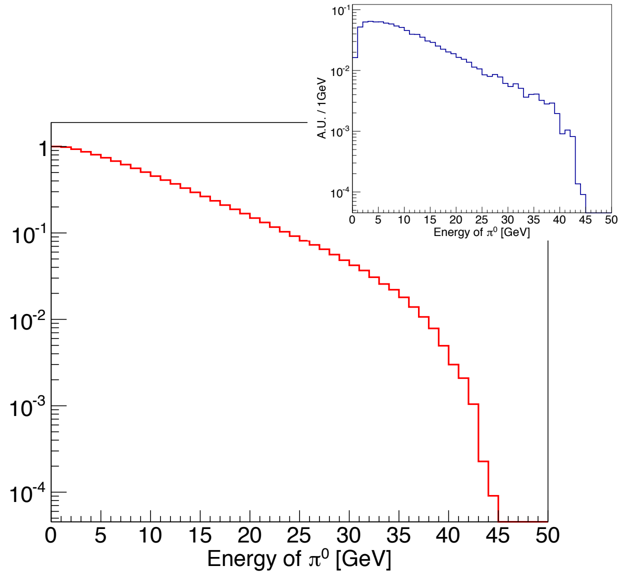
Proportion of different energy π^0

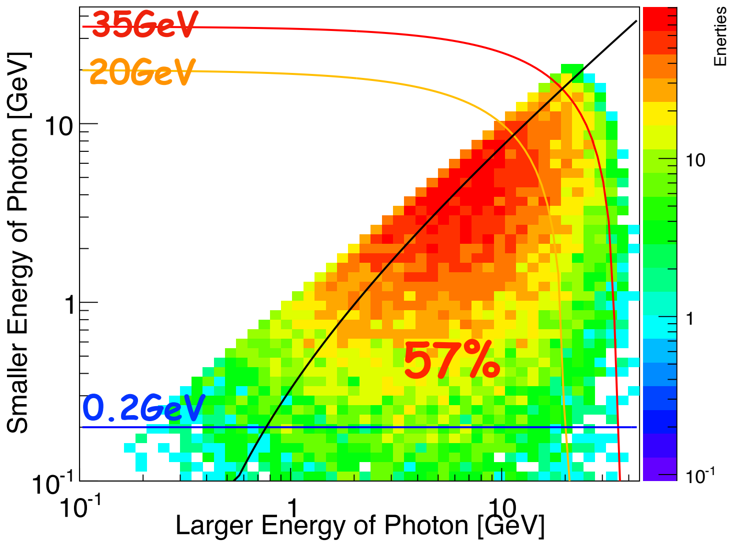
Z -> qq



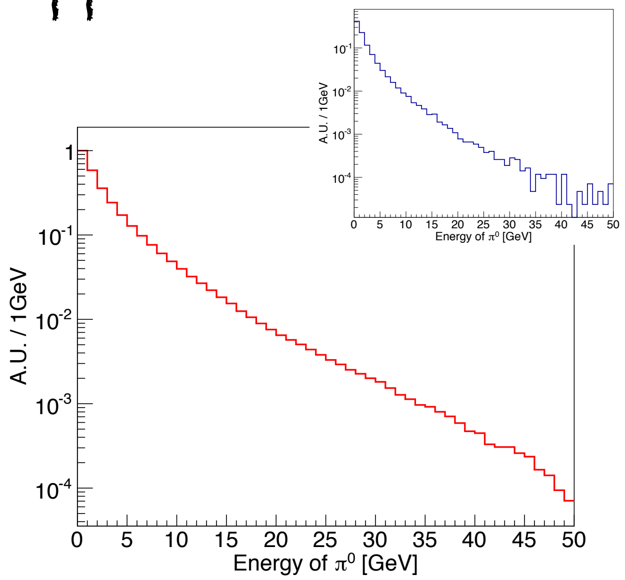


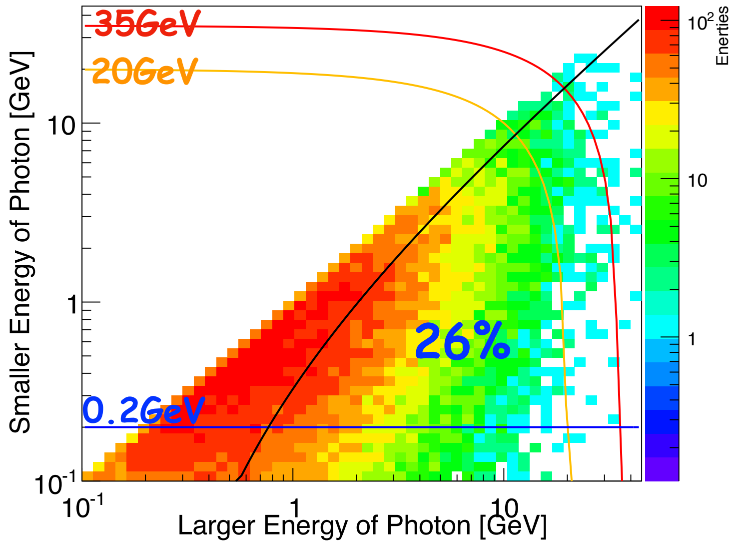
Z -> ττ





qqH -> X

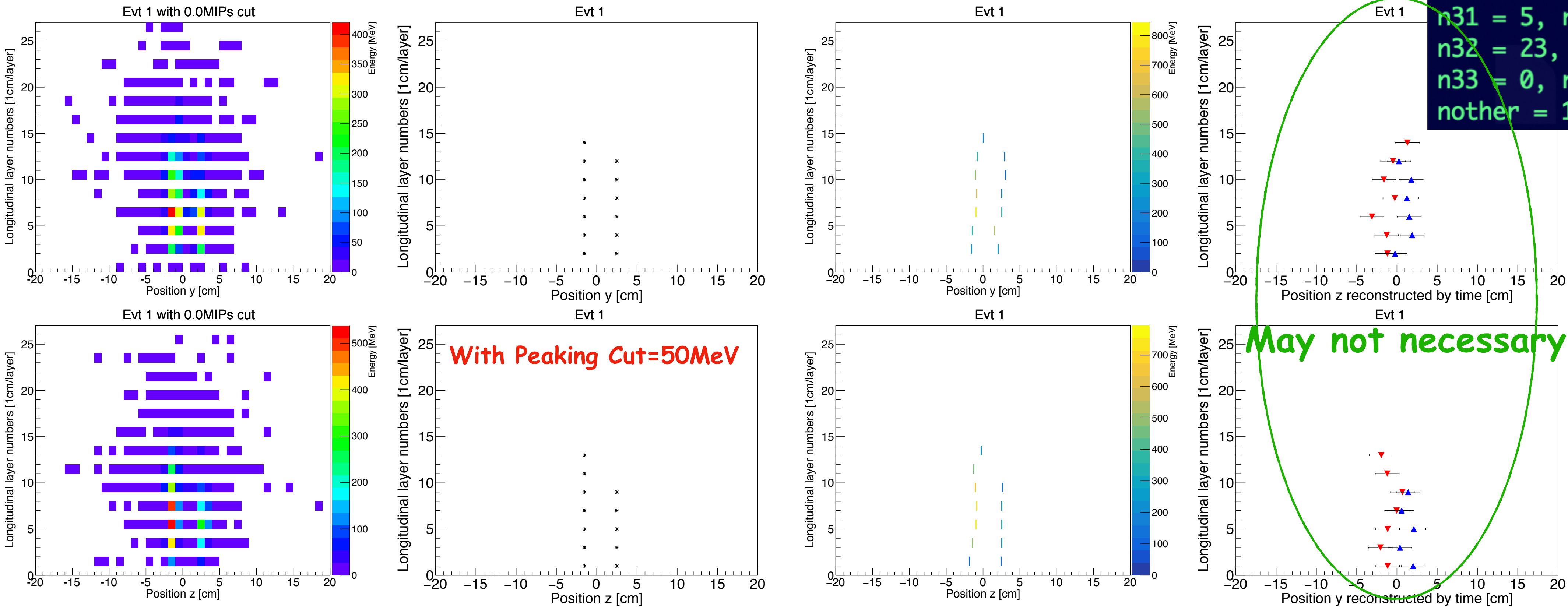




	Z->qq	qqH->X	Z->ττ
E_{π^0} > 20GeV	0.42%	0.66%	14.9%
E_{π^0} > 35GeV	0.02%	0.1%	1.8%
E_γ < 0.2GeV	45%	42%	7.5%
Confusion	57%	55%	23%

Reconstruction of 10GeV π°

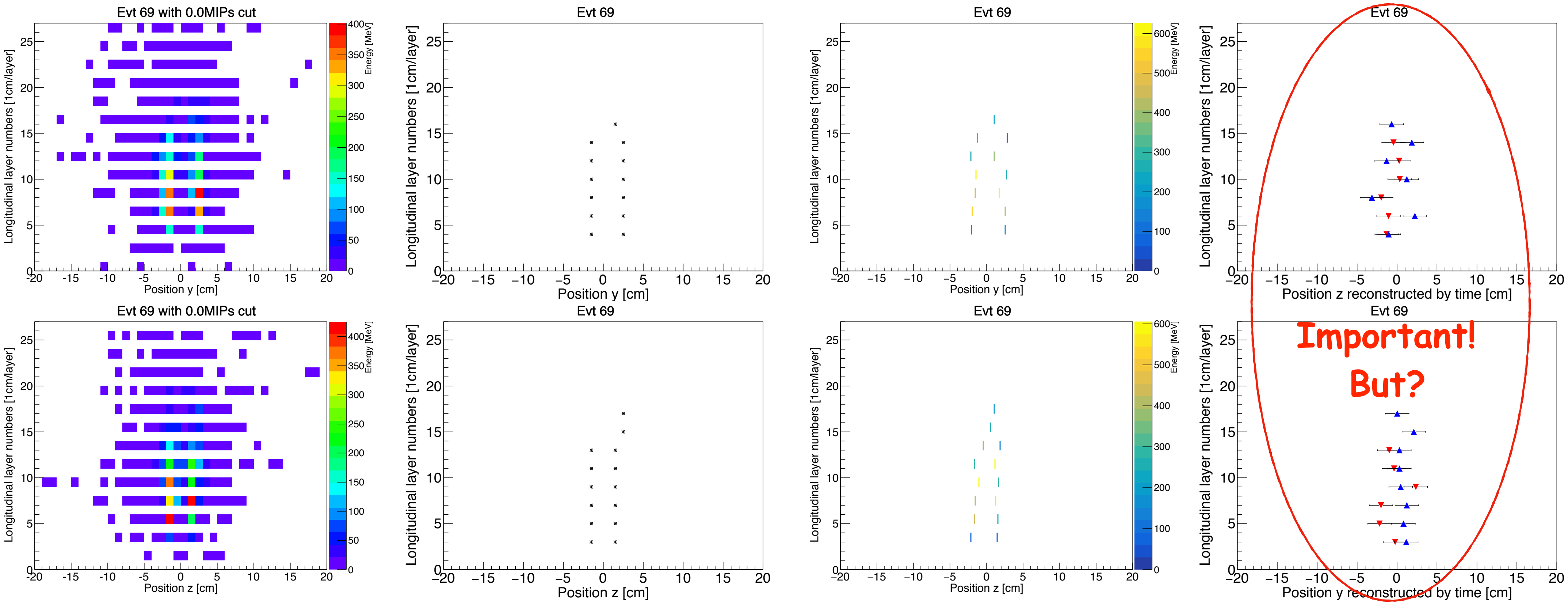
```
There are 1000 events.
n11 = 63, ratio = 6.3%
n21 = 274, ratio = 27.4%
n22 = 634, ratio = 63.4%
n31 = 5, ratio = 0.5%
n32 = 23, ratio = 2.3%
n33 = 0, ratio = 0%
nother = 1, ratio = 0.1%
```



With Peaking Cut=50MeV

May not necessary…

```
*        1 *        0 * 3231.1254 * -9.536730 *         7 * 3449.8880 * -10.44410 *       7 *
*        1 *        1 * 1565.0707 * 21.330423 *         6 * 1011.1802 * 25.473534 *       5 *
```



Important!
But?

```
*       69 *        0 * 2330.4511 * -16.73407 *         6 * 2222.0537 * -12.83199 *       6 *
*       69 *        1 * 2227.6637 * 19.448733 *         7 * 2378.6731 * 12.409615 *       8 *
```

Cluster splitting

38 BESIII 量能器的模拟与重建

$$E_k = \sum_{i=1}^{n} a_{ik} E_i \, , \tag{4.1}$$

其中n表示簇团中的晶体数，a_{ik}等于第k个簇射在第i块晶体中能量沉积期待值除以该晶体中的实际沉积能量，称为权重，满足：

$$\sum_{k=1}^{m} a_{ik} = 1 \, , \tag{4.2}$$

其中 m 为簇射数目。

权重跟簇射在晶体中的横向发展有关，可以用模拟的方法得到。图 4-6 描述了单光子能量的横向沉积，其中E_i表示第i块晶体能量，E_{seed}表示种子的能量，Distance=$|x_i-x_c|$，表示第i块晶体中心x_i到簇射中心x_c的距离。

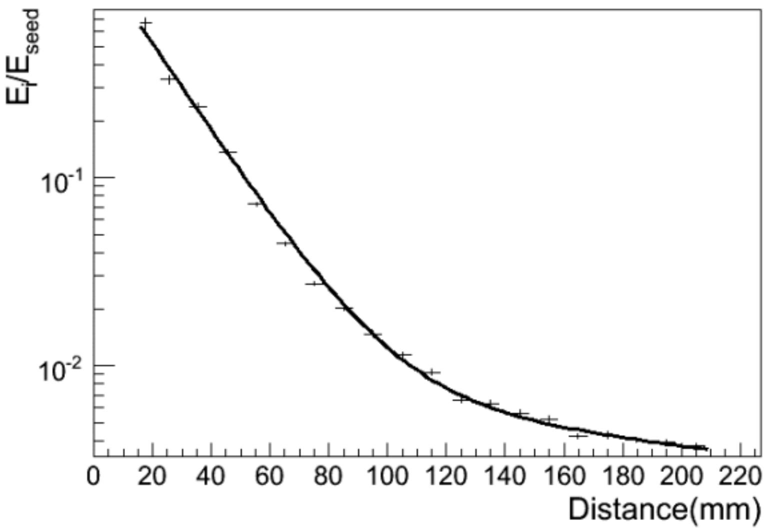


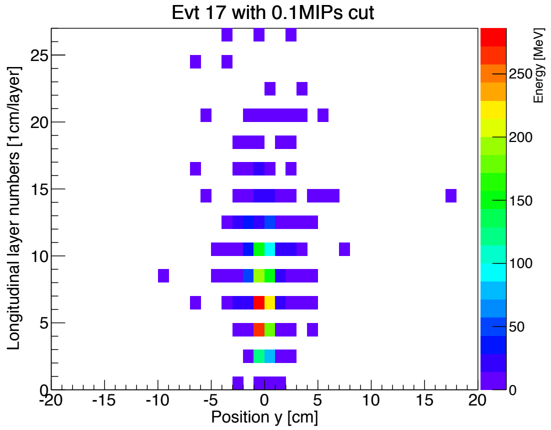
图 4-6 簇射在晶体中的横向发展示意图

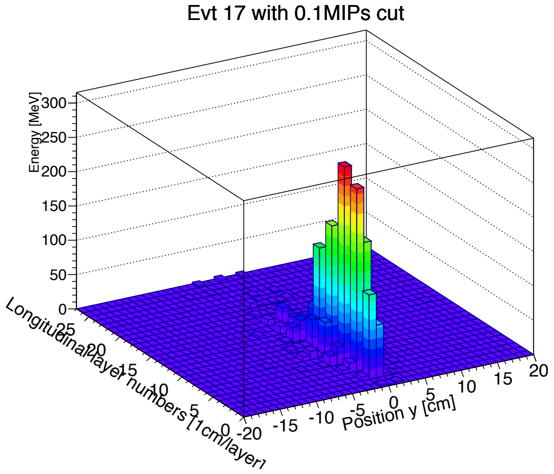
图 4-6 所示的分布可以用下面的公式拟合：

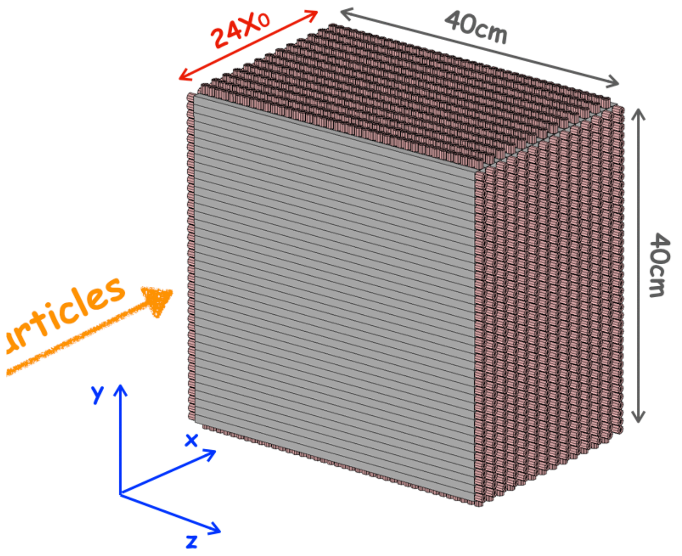
$$\frac{E_i}{E_{seed}} = a_1 \exp\left(-\frac{b_1|x_i-x_c|}{R_M}\right) + a_2 \exp\left(-\frac{b_2|x_i-x_c|}{R_M}\right) \, , \tag{4.3}$$

其中R_M为moliere半径，a_1，b_1，a_2，b_2为拟合参数。

5GeV γ







VS

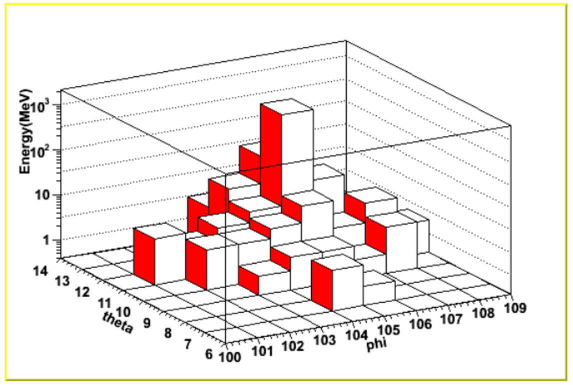


图 4-2 1GeV 光子形成的能量簇团示意图