Study of the Cluster Splitting Algorithm In PANDA EMC Reconstruction

Ziyu Zhang[1,2], Qing Pu[1,2] , Guang Zhao[2] , Chunxu Yu[1], Shengsen Sun[2]

[1]Nankai University

[2]Institute of High Energy Physics

PANDA Collaboration Meeting

10/09/2021

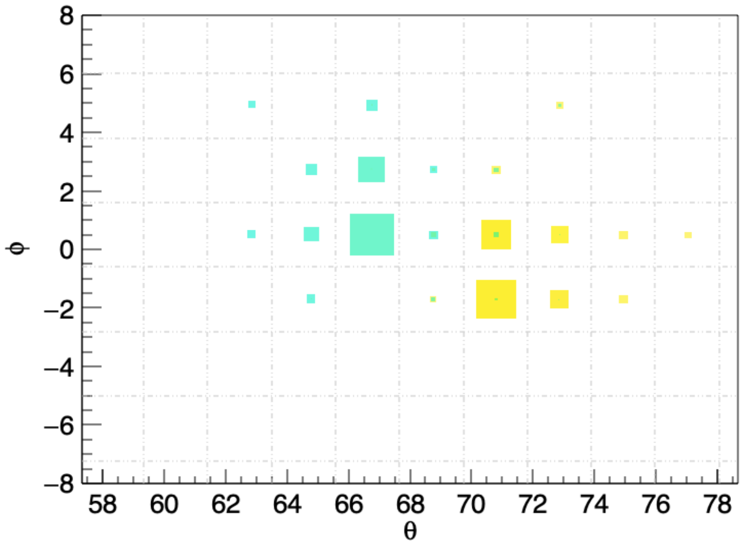
Outline

- Introduction
- Study of the cluster-splitting algorithm
  - Lateral development measurement
  - Seed energy correction
  - Reconstruction checks
- Summary

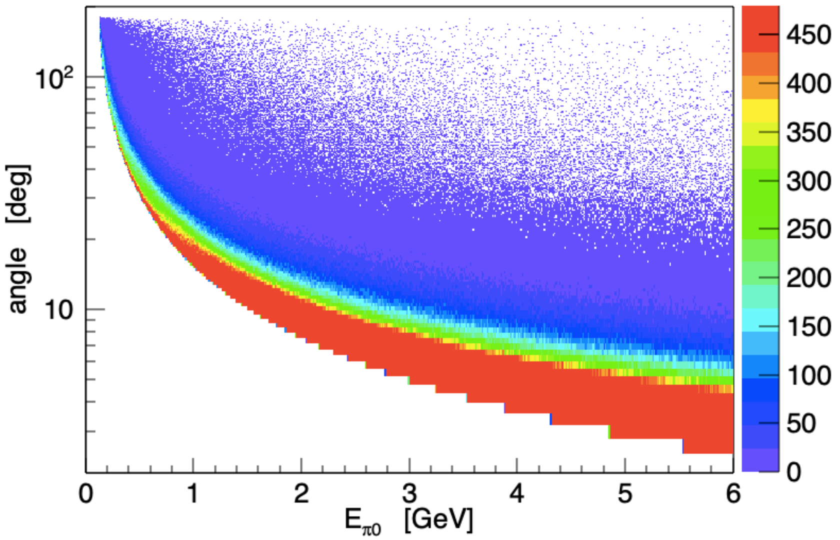
Introduction

- Cluster-splitting is an important algorithm in EMC reconstruction.
- The purpose of the cluster-splitting is to separate clusters that are close to each other.
- In this presentation, we improve the cluster-splitting algorithm in the following ways:
  - Update the lateral development formula
  - Correct the seed energy

Cluster-splitting for a EmcCluster



Angles between the 2γ from pi0



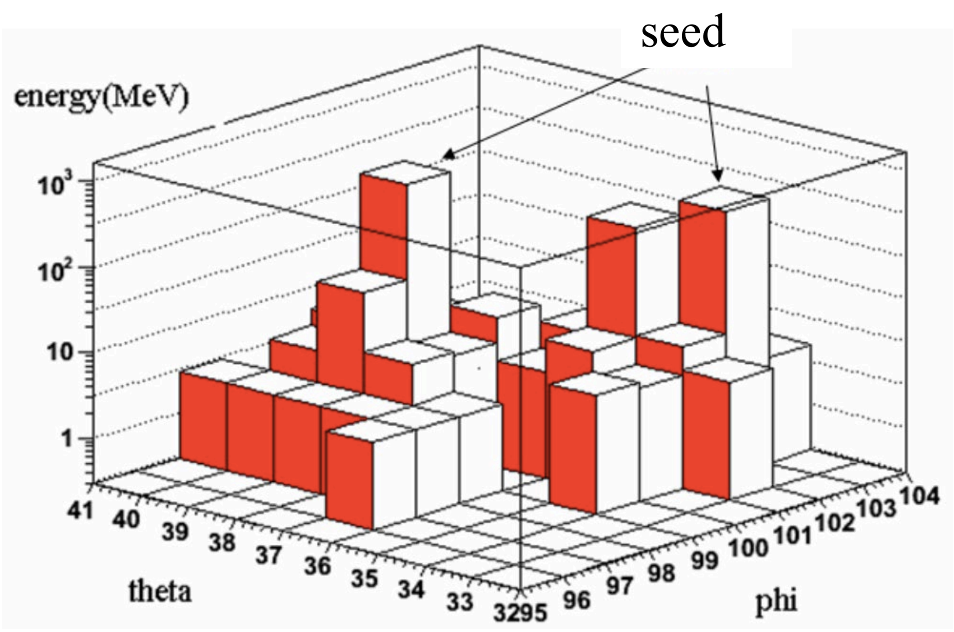
Cluster splitting is important for high energy pi0

EMC reconstruction overview

1. Cluster finding: a contiguous area of crystals with energy deposit.

2. The bump splitting
   - Find the local maximum: Preliminary split into seed crystal information

   - Update energy/position iteratively
     - The spatial position of a bump is calculated via a center-of-gravity method
     - Lateral development of cluster:
       $E_{\text{target}} = E_{seed}\exp(-2.5\, r/R_M)$
     - The crystal weight for each bump is calculated by a formula



The Cluster splitting algorithm

- Initialization:
  Place the bump center at the seed crystal.

- Iteration:
  1.Traverse all digis to calculate w_i.

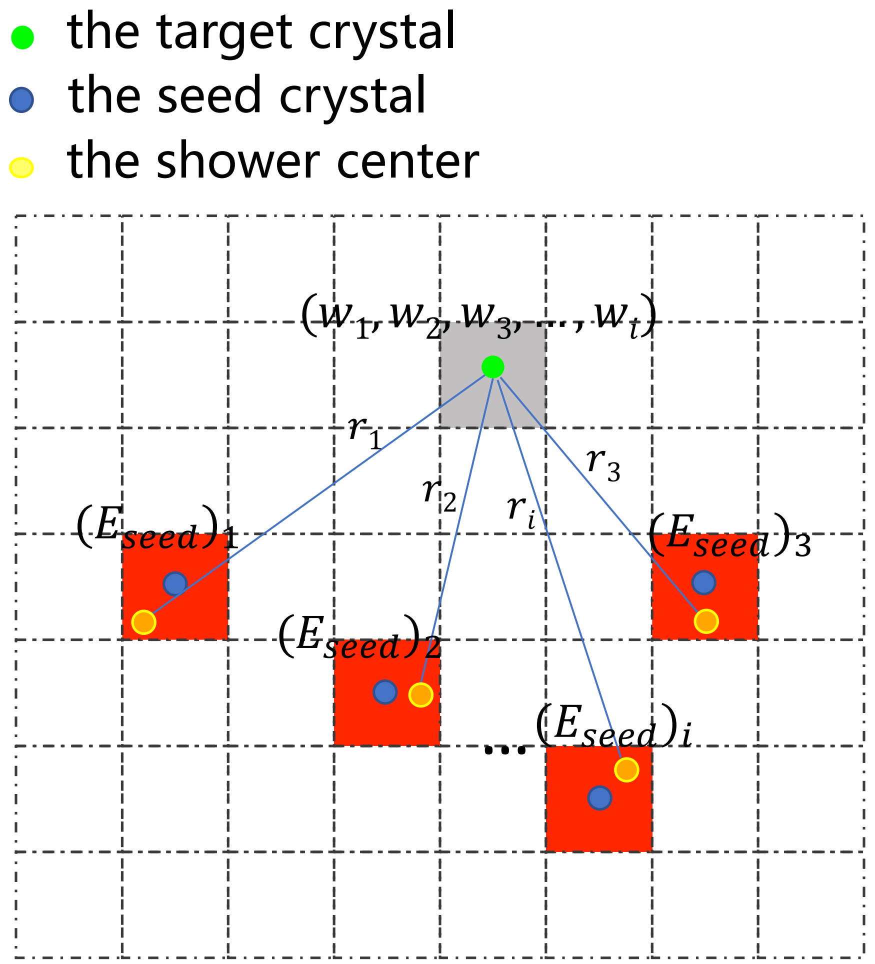
$$w_i = \frac{(E_{seed})_i \exp(-2.5 r_i / R_m)}{\sum_j (E_{seed})_j \exp(-2.5 r_j / R_m)}$$

Energy for the target crystal: E_{target}

i or j : different seed crystals
R_m: Moliere radius
r_i: distance from the shower center to the target crystal

2. Update the position of the bump center.

3. Loop over 1 & 2 until the bump center stays stable within a tolerance of 1 mm or the number of iterations exceeds the maximum number of iterations.

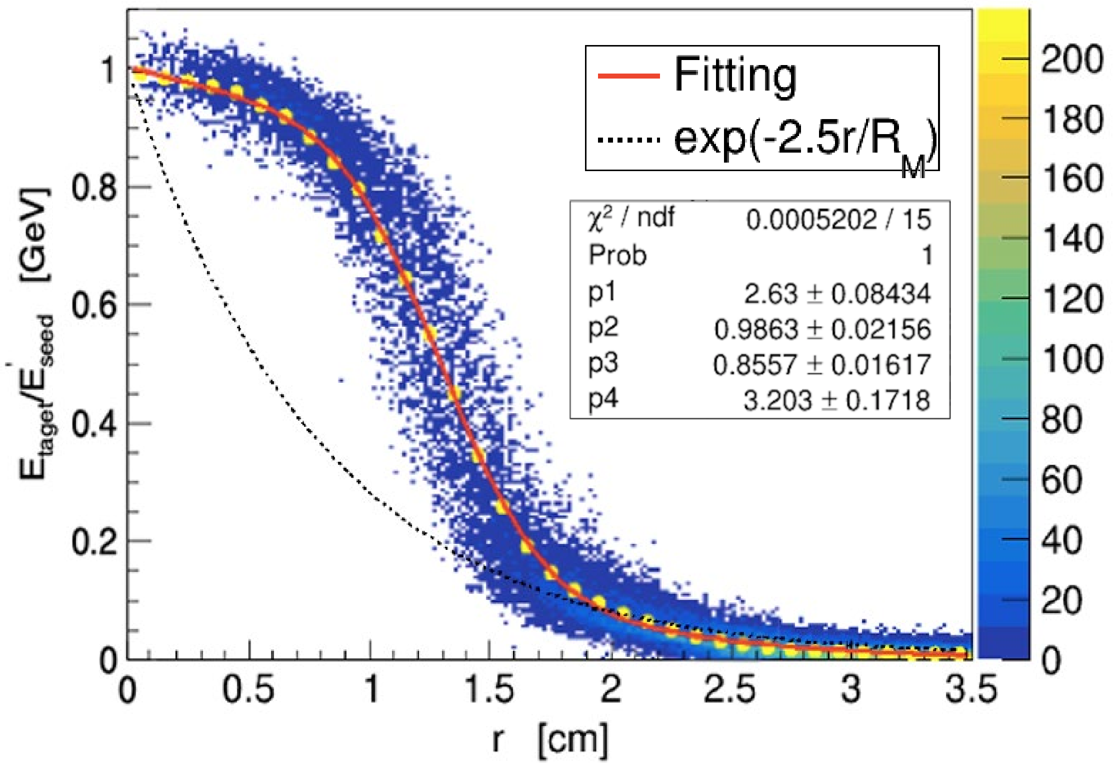


The E_{target} is calculated using the lateral development formula

The lateral development

The previous lateral development formula $\frac{E_{target}}{E_{seed}} = \exp(-2.5\, r/R_M)$ has no consideration of crystal granularity, detector geometry and energy of particles.

- Gamma (0~6GeV)
- Events 10000
- Geant4
- Generator: Box
- Phi(0, 360)
- Theta(22, 140)



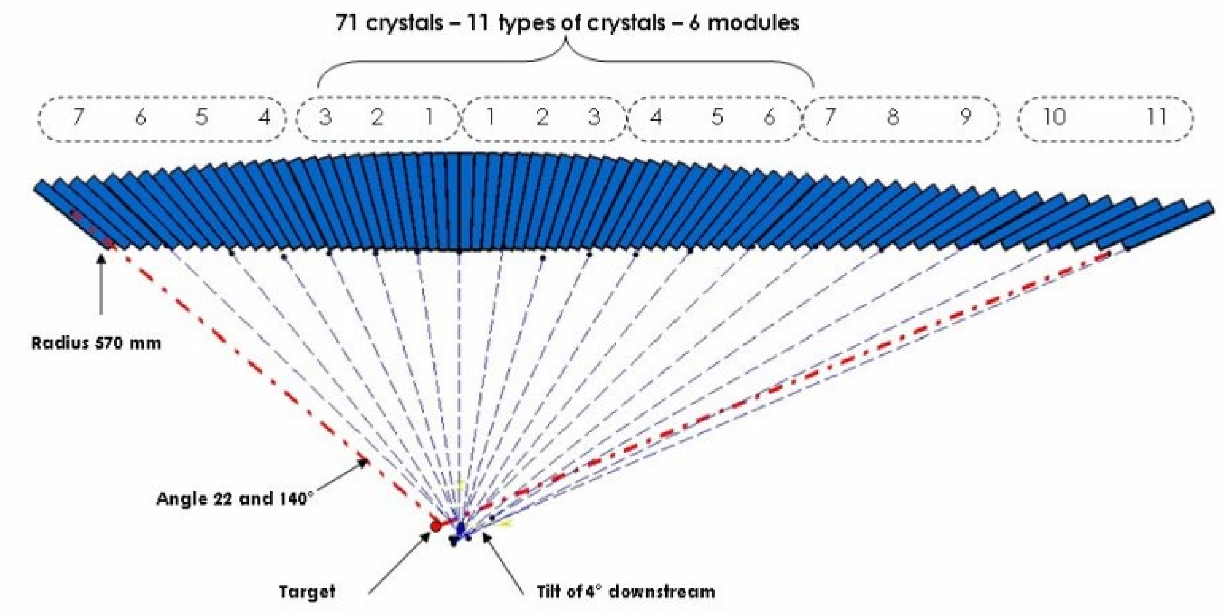
Since exp does not fit the data well, we try to improve the formula.

Parametrization

The function form used for fitting:

$$f(r) = \frac{E_{target}}{E_{seed}} = \exp\left[-\frac{p_1}{R_M}\xi(r)\right], \qquad \xi(r) = r - p_2 r \exp[-\left(\frac{r}{p_3 R_M}\right)^{p_4}]$$

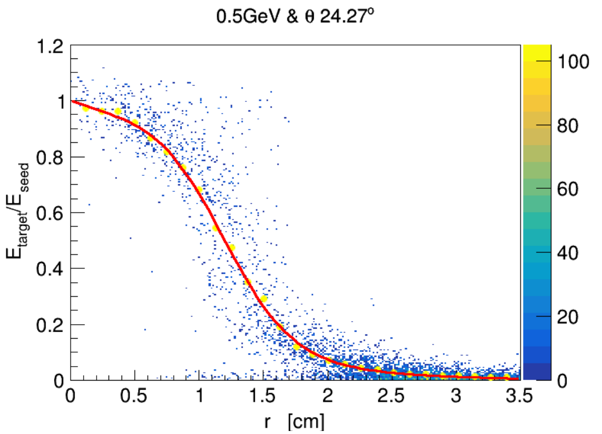
Where p_1, p_2, p_3 and p_4 are parameters.

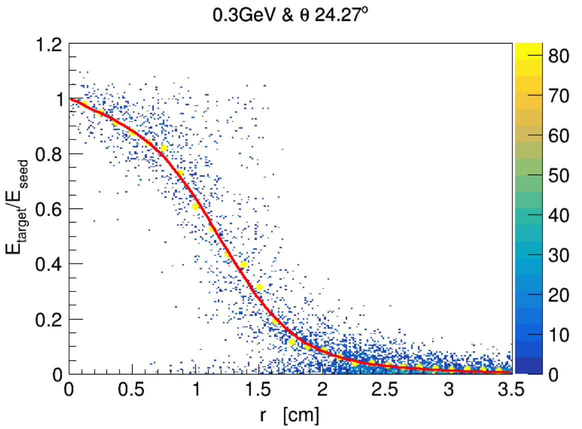


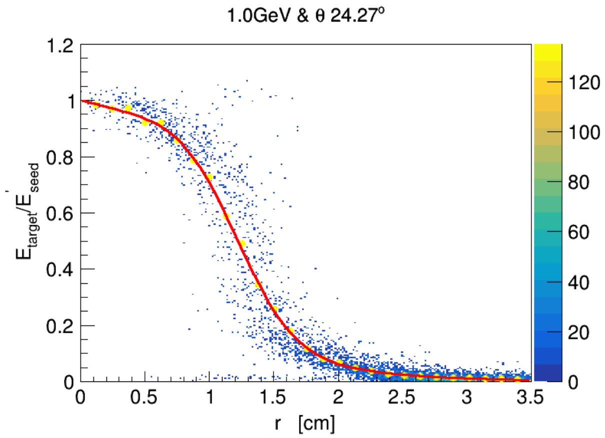
- We consider the dependency of the parameters on energy and polar angle.

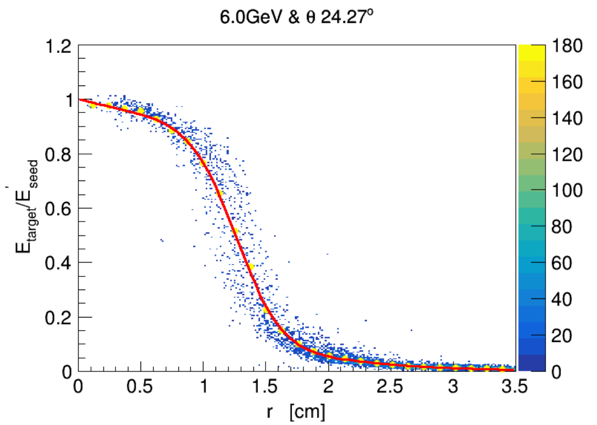
$p_1(E_\gamma, \theta)$ $\quad p_2(E_\gamma, \theta)$ $\quad p_3(E_\gamma, \theta)$ $\quad p_4(E_\gamma, \theta)$

Fitted parameters of the lateral developmen









Fitting Result:

$$\frac{E_{target}}{E_{seed}} = \exp\{-\frac{p_1}{R_M}\xi(r, p_2, p_3, p_4)\}$$

$$\xi(r) = r - p_2 r\exp[-\left(\frac{r}{p_3 R_M}\right)^{p_4}] \quad (R_M = 2.00\ cm)$$

$$p_1(E_\gamma, \theta) = -0.384 * exp(3.88 * E_\gamma) + 5.44 * 10^{-5} * (\theta - 97.7)^2 + 2.6$$

$$p_2(E_\gamma, \theta) = -0.352 * exp(4.21 * E_\gamma) + (-3.94) * 10^{-6} * (\theta - 69)^2 + 0.932$$

$$p_3(E_\gamma, \theta) = 0.151 * \exp(4.52 * E_\gamma) + (-2.14) * 10^{-5} * (\theta - 91)^2 + 0.841$$

$$p_4(E_\gamma, \theta) = -3.51 * exp(1.15 * E_\gamma) + 2.26 * 10^{-4} * (\theta - 80.3)^2 + 4.96$$

Energy dependency

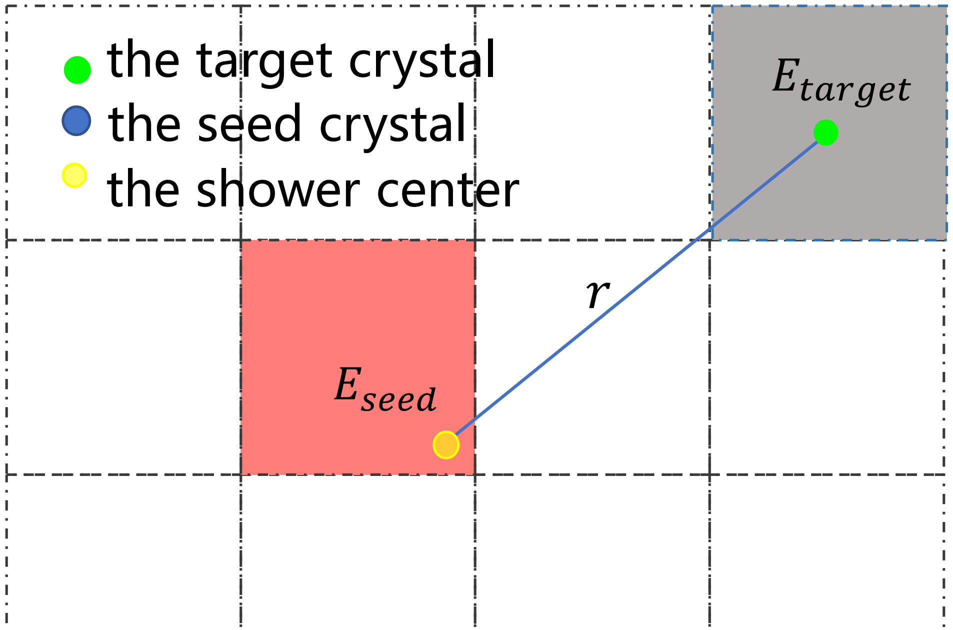
Angle dependency

Seed energy correction

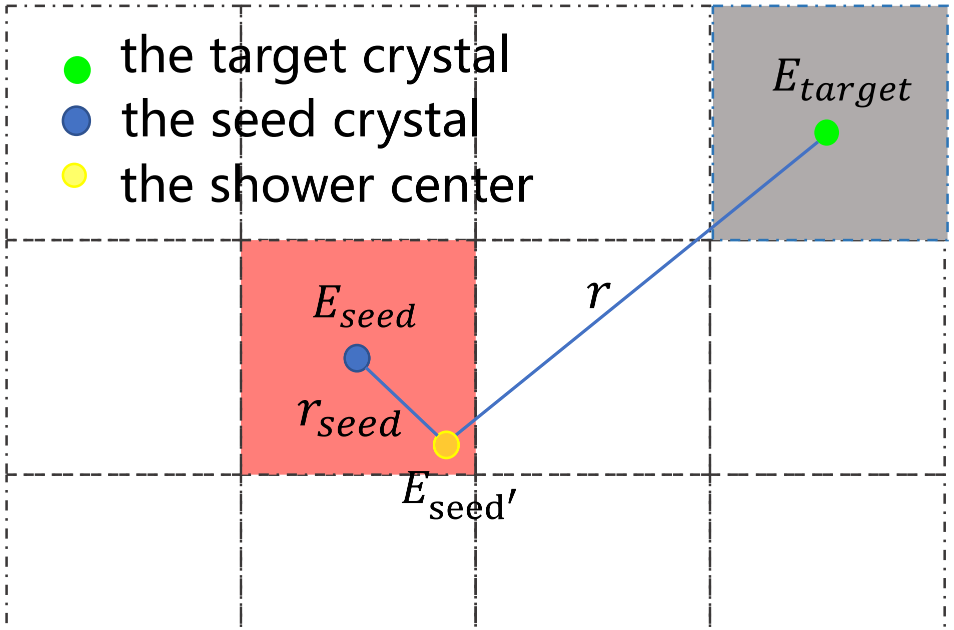
- In the old PandaRoot, the seed energy is used to calculate the $E_{target} = E_{seed} \times f(r)$
- If the shower center does not coincide with the crystal center, E_{seed} needs to be corrected

r or r_{seed}:
the distance from the center of the Bump to the geometric center of the crystal.

Old PandaRoot version



Updated version



Seed energy correction

In the new update, E_{target} can be calculated by the lateral development f(r):

$$E_{target} = E_{seed'} \times f(r)$$

$E_{seed'}$, which is not available in the reconstruction algorithm, can be related to the E_{seed} :

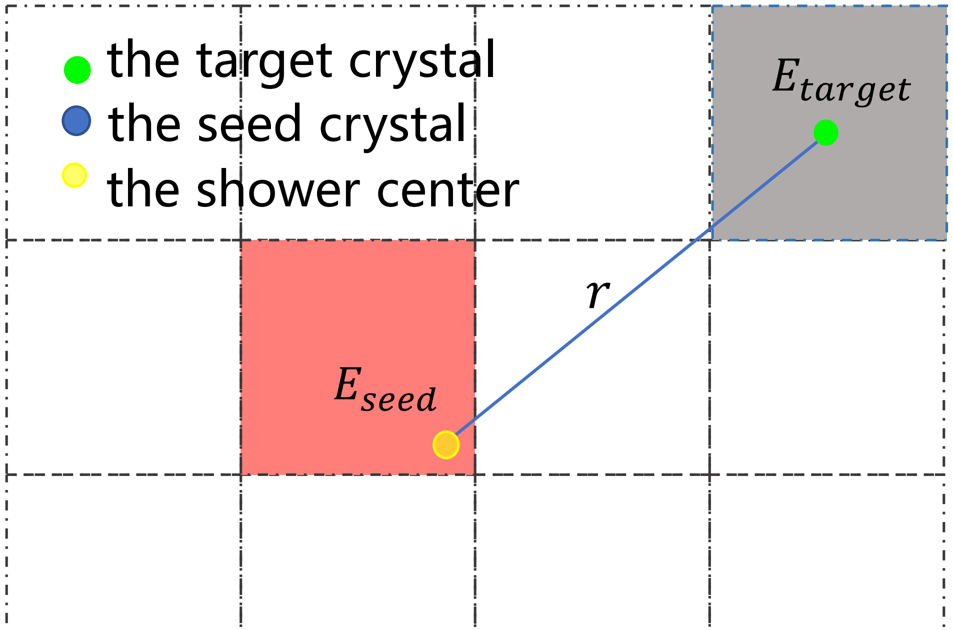
$$E_{seed'} = \frac{E_{seed}}{f(r_{seed})}$$

In the end, E_{target} can be calculated as ($\frac{1}{f(r_{seed})}$ as the correction factor) :

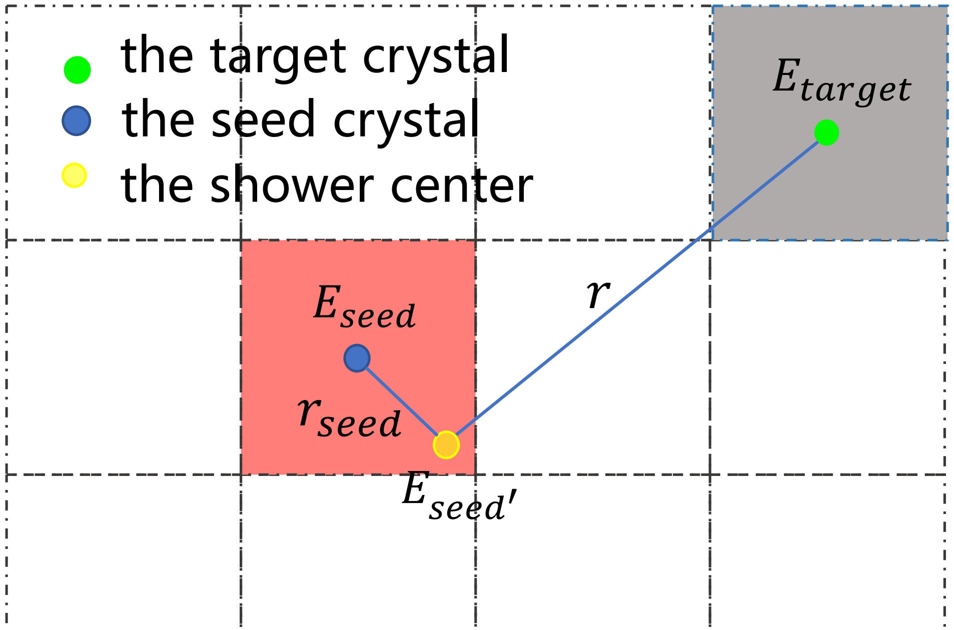
$$E_{target} = \frac{E_{seed}}{f(r_{seed})} \times f(r)$$

r or r_{seed}:
the distance from the center of the Bump to the geometric center of the crystal.

Old PandaRoot version



Updated version



Fitted parameters of the lateral developmen

Seed energy correction

Fitting Result:

$$\frac{E_{digi}}{E_{seed}} = \exp\{-\frac{p_1}{R_M}[\xi(r,p_2,p_3,p_4) - \xi(r_{seed},p_2,p_3,p_4)]\} \quad \xi(r) = r - p_2 r\exp[-\left(\frac{r}{p_3 R_M}\right)^{p_4}] \quad (R_M = 2.00\ cm)$$

$$p_1(E_\gamma,\theta) = -0.384 * exp(3.88 * E_\gamma) + 5.44 * 10^{-5} * (\theta - 97.7)^2 + 2.6$$

$$p_2(E_\gamma,\theta) = -0.352 * exp(4.21 * E_\gamma) + (-3.94) * 10^{-6} * (\theta - 69)^2 + 0.932$$

$$p_3(E_\gamma,\theta) = 0.151 * \exp(4.52 * E_\gamma) + (-2.14) * 10^{-5} * (\theta - 91)^2 + 0.841$$

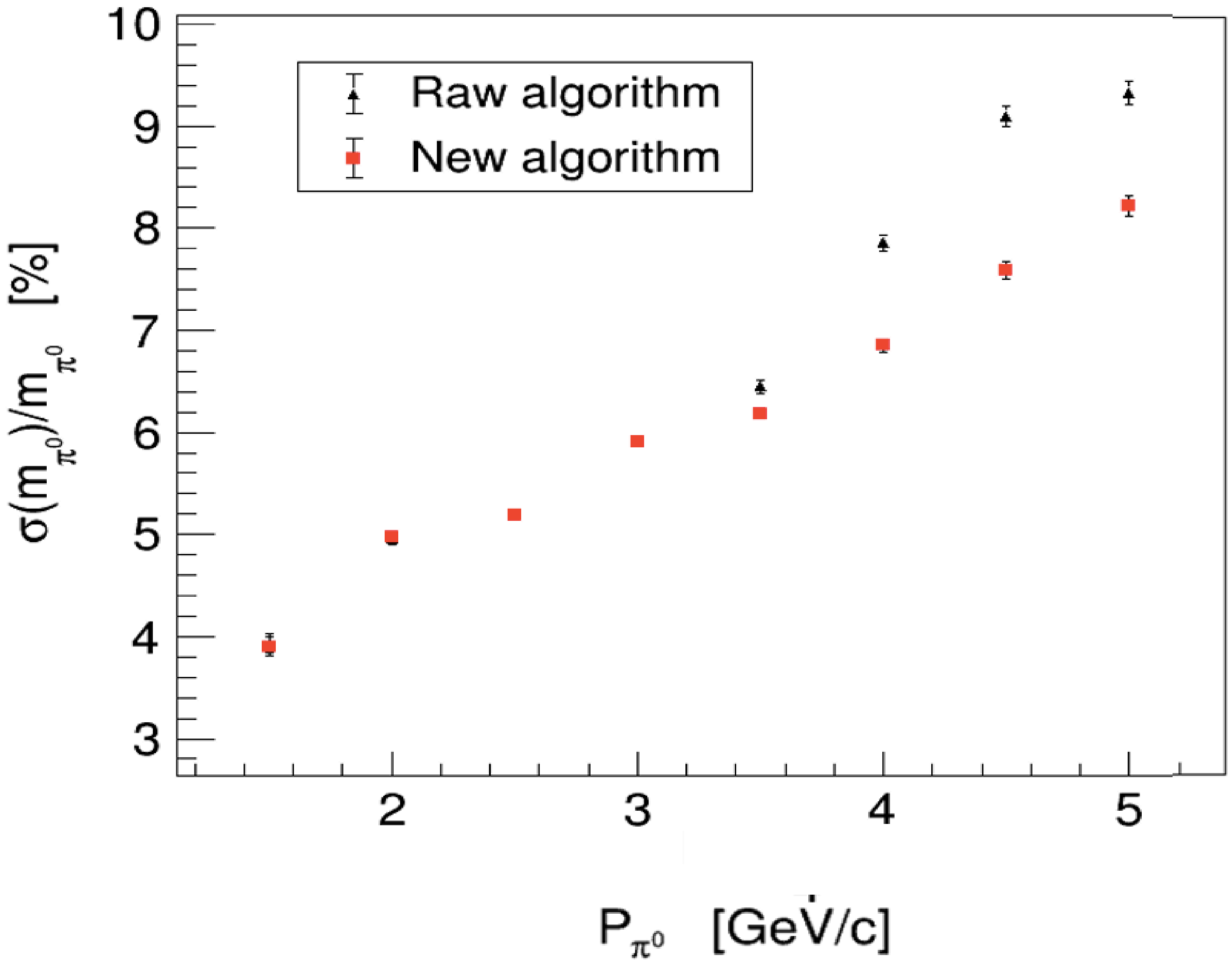
$$p_4(E_\gamma,\theta) = -3.51 * exp(1.15 * E_\gamma) + 2.26 * 10^{-4} * (\theta - 80.3)^2 + 4.96$$

Energy dependency

Angle dependency

Mass resolution (pi0)

pi0 mass resolution



Range of simulated samples:

- Energy

0.5~5 GeV

- Theta

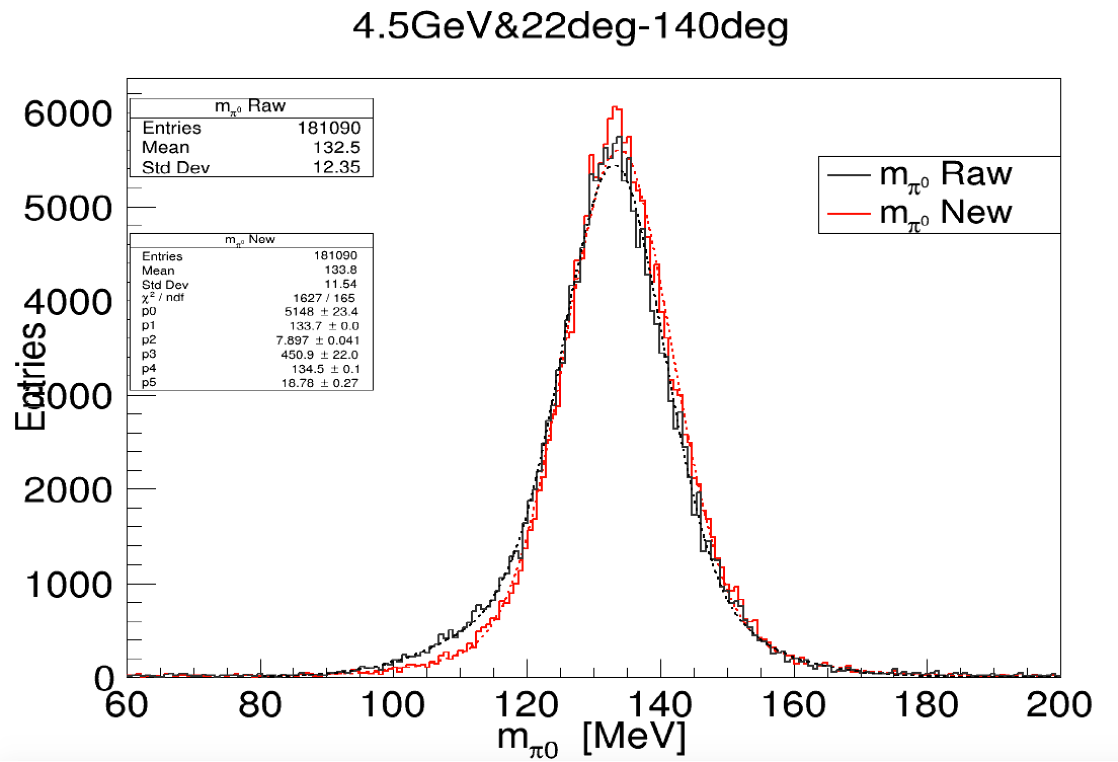
22~140 (deg)

- Phi

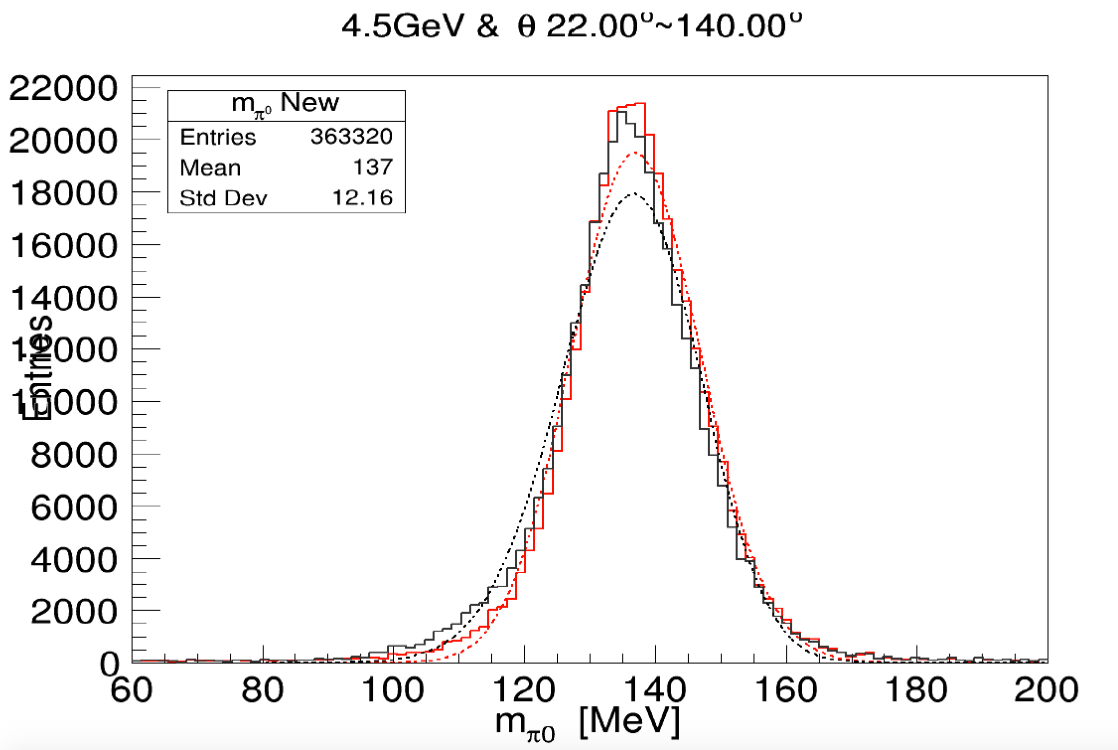
0~360 (deg)

- This is the result shown in the last report.

Mass resolution (pi0)



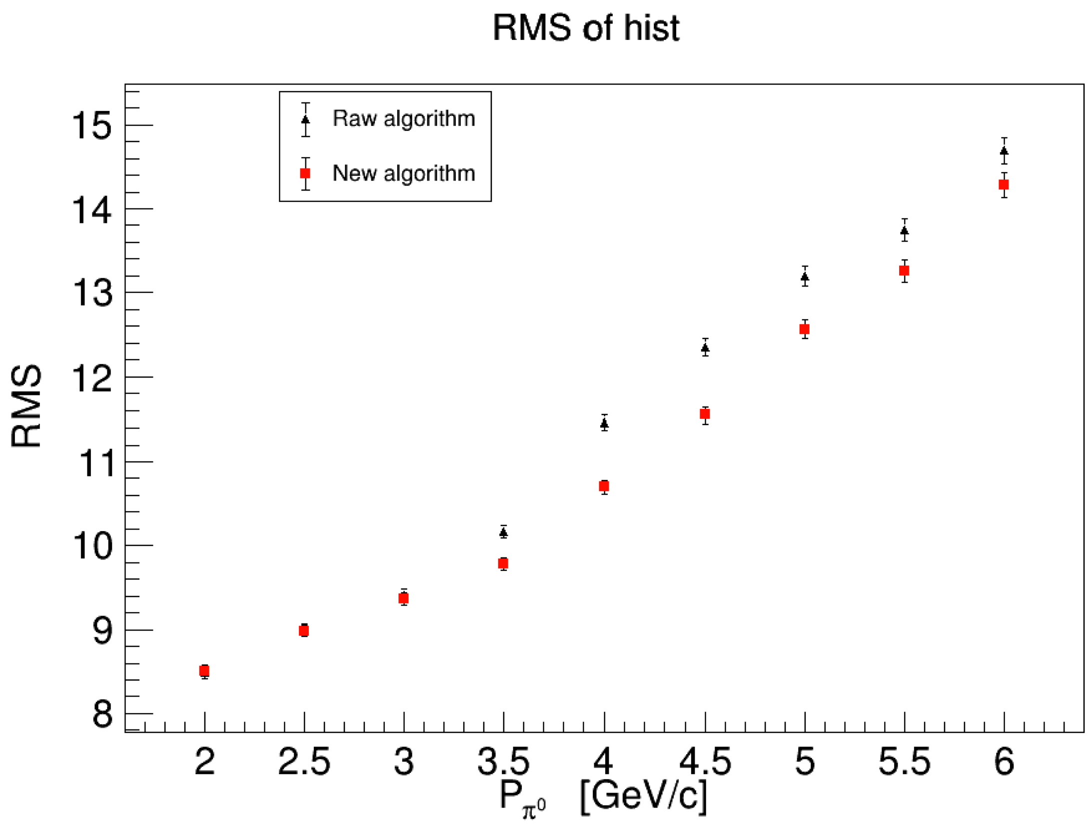
My result



Qing's result

- There are some problem when fitting to the distribution of pi0 mass, and we are working over it.

Mass resolution (pi0)



Range of simulated samples:

- Energy

6GeV

- Theta

22~140 (deg)

- Phi

0~360 (deg)

- We initially checked the results through the standard deviation of the distribution of pi0 mass.
- The standard deviation of new method is reduced, indicating that the new method has improved the performance of cluster splitting algorithm.

Summary

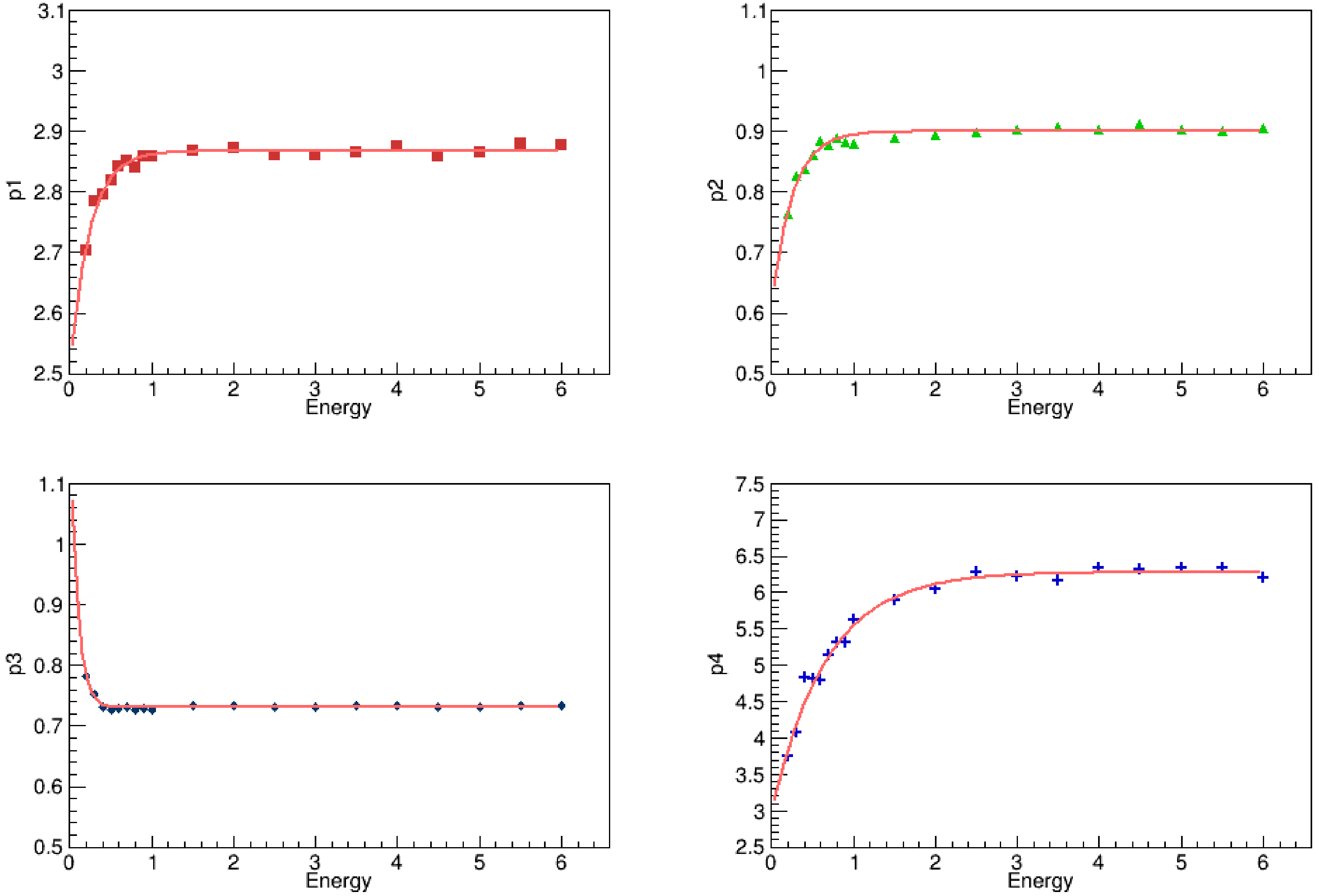
- The lateral development of the cluster is measured
  - Lateral development with the crystal granularity is considered
  - Energy and angle dependent is considered
- Seed energy is corrected while applying the lateral development in cluster-splitting
- Mass resolution for pi0 samples are doing, and improvements are seen with the new algorithm

- To do list:
  - Fully check the energy resolution of small-cross-angle photons and mass resolution of pi0
  - Check in to PandaRoot repository

Thank you for your attention!

Backup

Parameters (energy dependency)



Range of simulated samples:

- Theta

Range4: 32.6536 ~ 33.7759

- Phi

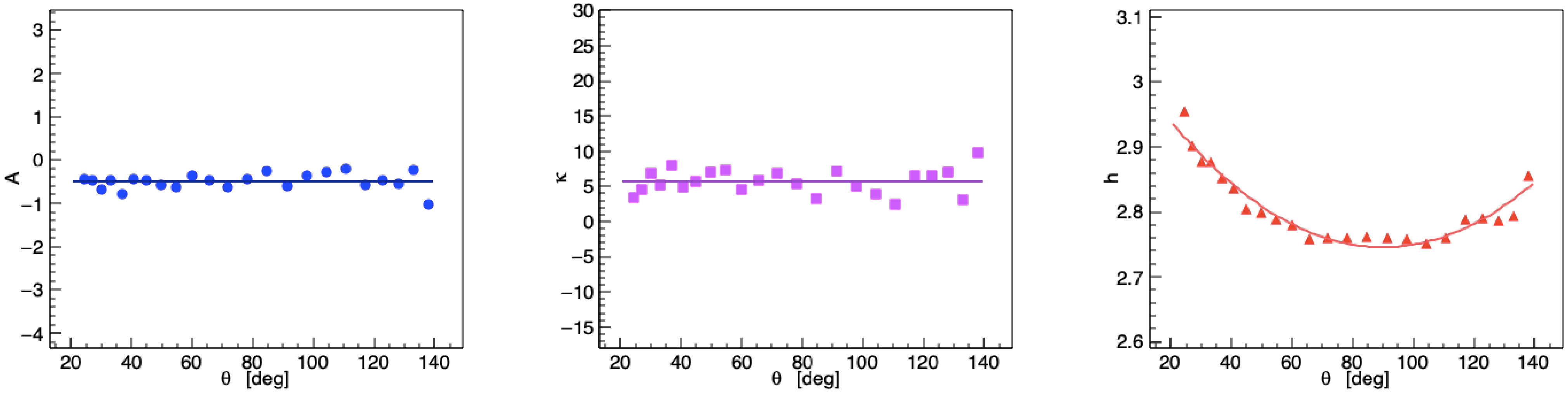
0~360

Fitting function:

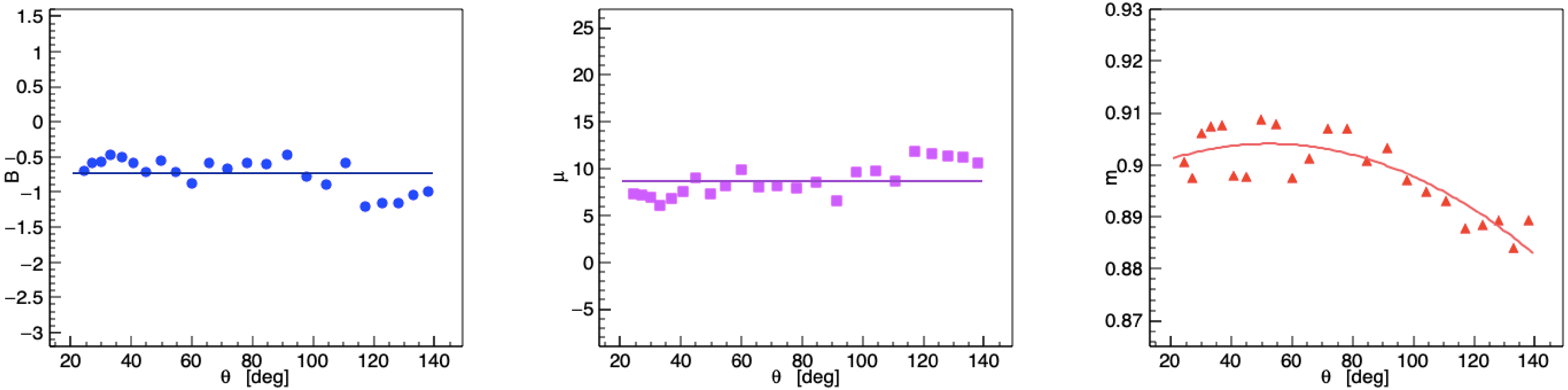
$$p_1 = A\exp(-\kappa E_\gamma) + h$$
$$p_2 = B\exp(-\mu E_\gamma) + m$$
$$p_3 = C\exp(-\tau E_\gamma) + n$$
$$p_4 = D\exp(-\lambda E_\gamma) + q$$

Parameters (angle dependency)

$$p_1 = A\exp\left(-\kappa E_\gamma\right) + h$$

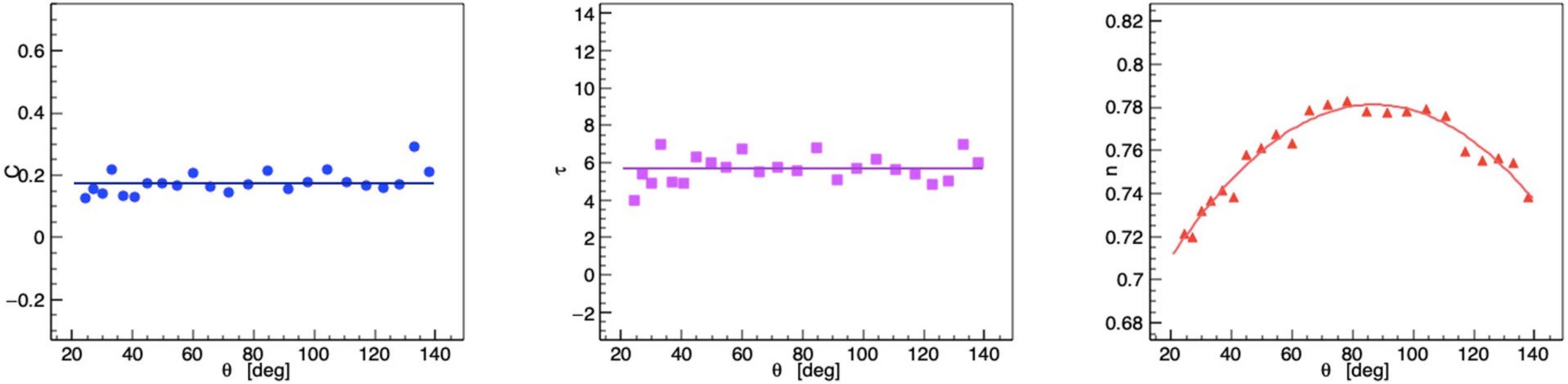


$$p_2 = B\exp\left(-\mu E_\gamma\right) + m$$

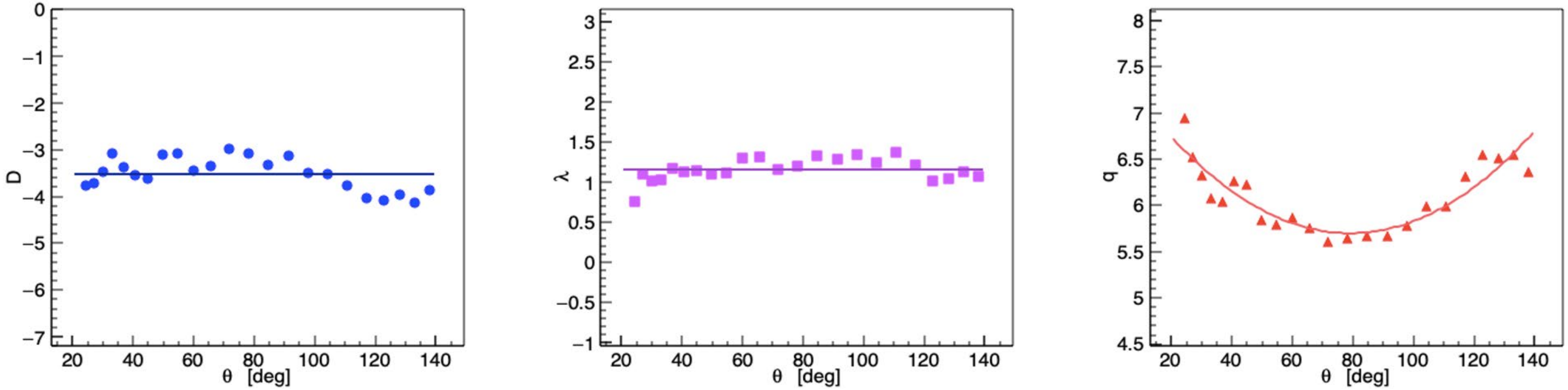


Angle dependency of parameters

$$p_3 = C\exp(-\tau E_\gamma) + n$$



$$p_4 = D\exp(-\lambda E_\gamma) + q$$



The lateral development (new measurement

Define the lateral development:

$$f(r) = \frac{E_{target}}{E_{shower}}$$

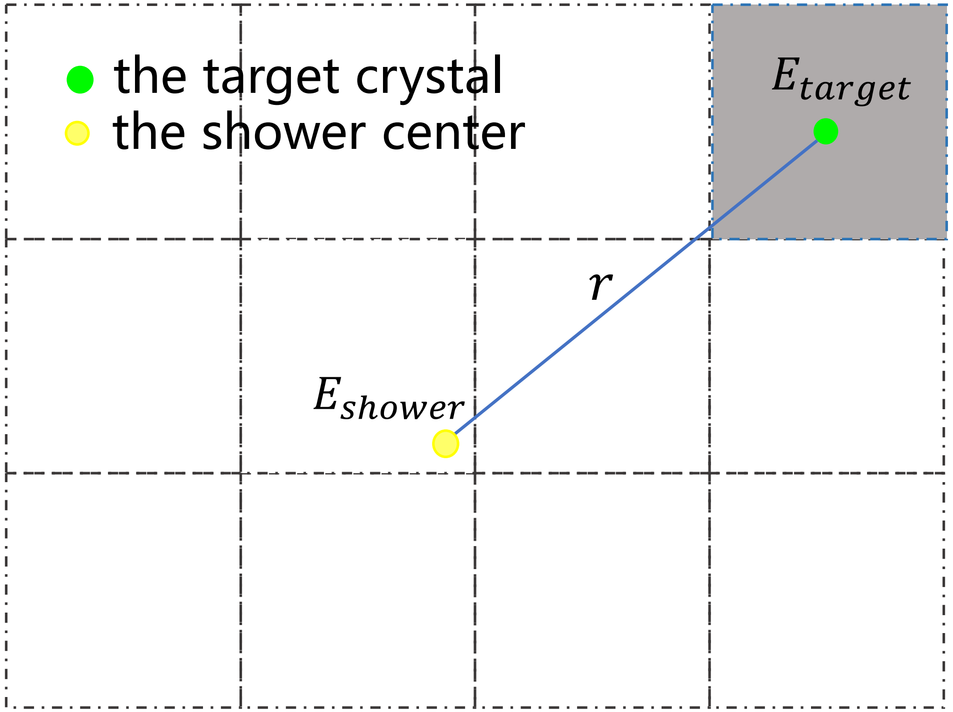
E_{shower} is the total energy of the single-particle shower.

The lateral development $f(r)$ can from obtained Geant4 simulation.

In this measurement the crystal dimension is considered

Control sample:

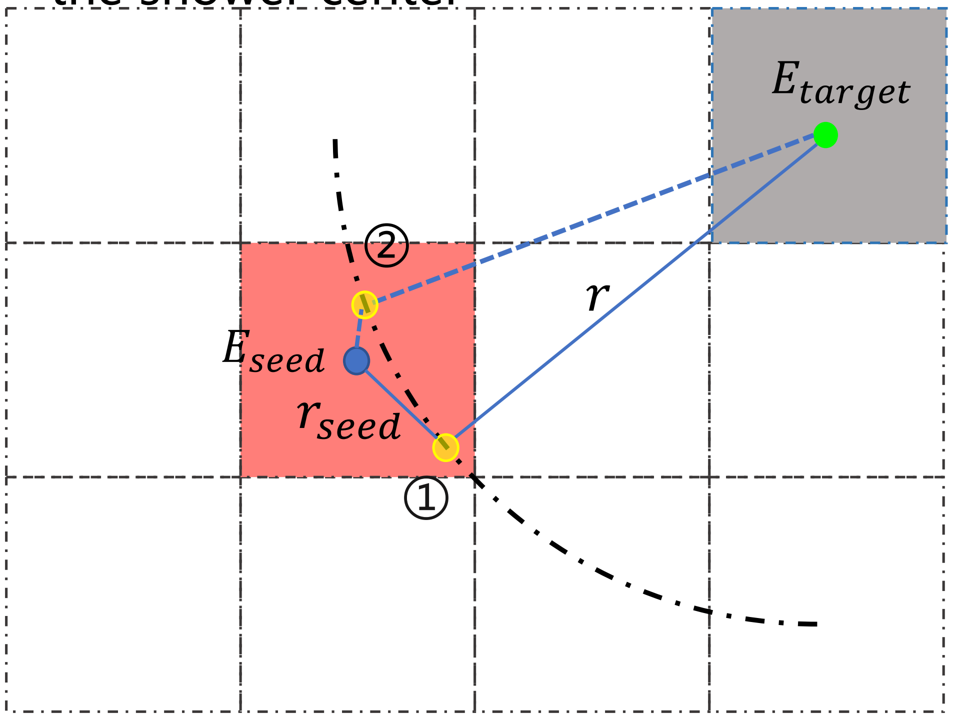
- Gamma (0 ~ 6GeV)
- Geant4
- Phi(0, 360)
- Events 10000
- Generator: Box
- Theta(22, 140)



The seed energy dependency

Consider two cases where the photon hits the seed at different positions:

- the target crystal (green dot)
- the seed crystal (blue dot)
- the shower center (yellow dot)



$$E_{target} = E_{seed} \exp(-2.5\, r/R_M)$$

$case1$:	r	E_{target}	E_{seed}
	||	||	X
$case2$:	r	E_{target}	E_{seed}

- For the same r, $\frac{E_{target}}{E_{seed}}$ depends on r_{seed}.

The detector geometry dependency

According to the definition of $f(r)$:

$$f(r) = p_0 \exp[-\frac{p_1}{R_M}\xi(r)] \qquad \xi(r) = r - p_2 r \exp[-\left(\frac{r}{p_3 R_M}\right)^{p_4}] \qquad (R_M = 2.00\ cm)$$

$$f(r)/ f(r_{seed}) = p_0 \exp[-\frac{p_1}{R_M}\xi(r)]/ p_0 \exp[-\frac{p_1}{R_M}\xi(r_{seed})] = \exp\{-\frac{p_1}{R_M}[\xi(r) - \xi(r_{seed})]\}$$

$$\frac{E_{target}}{E_{seed}} = \exp\{-\frac{p_1}{R_M}[\xi(r, p_2, p_3, p_4) - \xi(r_{seed}, p_2, p_3, p_4)]\}$$

$$Raw: \quad \frac{E_{target}}{E_{seed}} = \exp(-\frac{\varepsilon}{R_M} r)$$

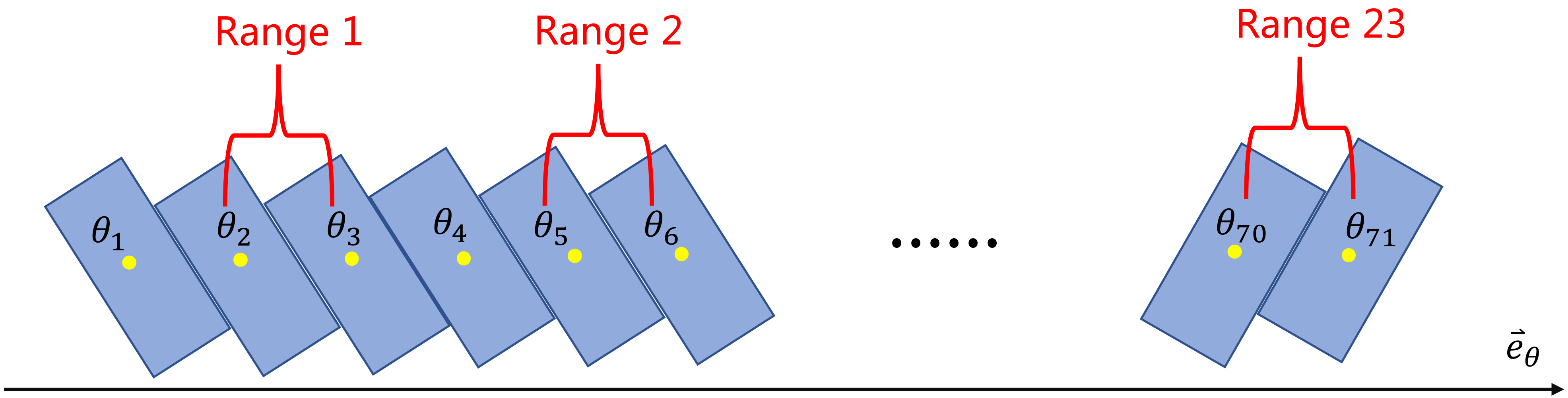
Control sample

$< 1GeV$

- Gamma (0.2, 0.3, 0.4…0.9 GeV)
- Events 10000
- Geant4
- Generator: Box
- Phi(0, 360)
- Theta(Range1, Range2,… ,Range23)

$\geq 1GeV$

- Gamma (1, 1.5, 2, 2.5…6 GeV)
- Events 10000
- Geant4
- Generator: Box
- Phi(0, 360)
- Theta(Range1, Range2,… ,Range23)



Control sample

Phi: 0~360

Theta(deg):

Range1: 23.8514 ~ 24.6978
Range2: 26.4557 ~ 27.3781
Range3: 29.4579 ~ 30.4916
Range4: 32.6536 ~ 33.7759
Range5: 36.1172 ~ 37.3507
Range6: 39.9051 ~ 41.2390
Range7: 44.2385 ~ 45.7355
Range8: 48.8451 ~ 50.4459
Range9: 53.7548 ~ 55.4790
Range10: 59.0059 ~ 60.8229
Range11: 64.7855 ~ 66.7591
Range12: 70.8088 ~ 72.8652
Range13: 77.0506 ~ 79.1942
Range14: 83.4997 ~ 85.6749
Range15: 90.2068 ~ 92.4062
Range16: 96.8200 ~ 99.0099
Range17: 103.361 ~ 105.534
Range18: 109.793 ~ 111.893
Range19: 116.067 ~ 118.019
Range20: 121.838 ~ 123.686
Range21: 127.273 ~ 129.033
Range22: 132.400 ~ 134.031
Range23: 137.230 ~ 138.679

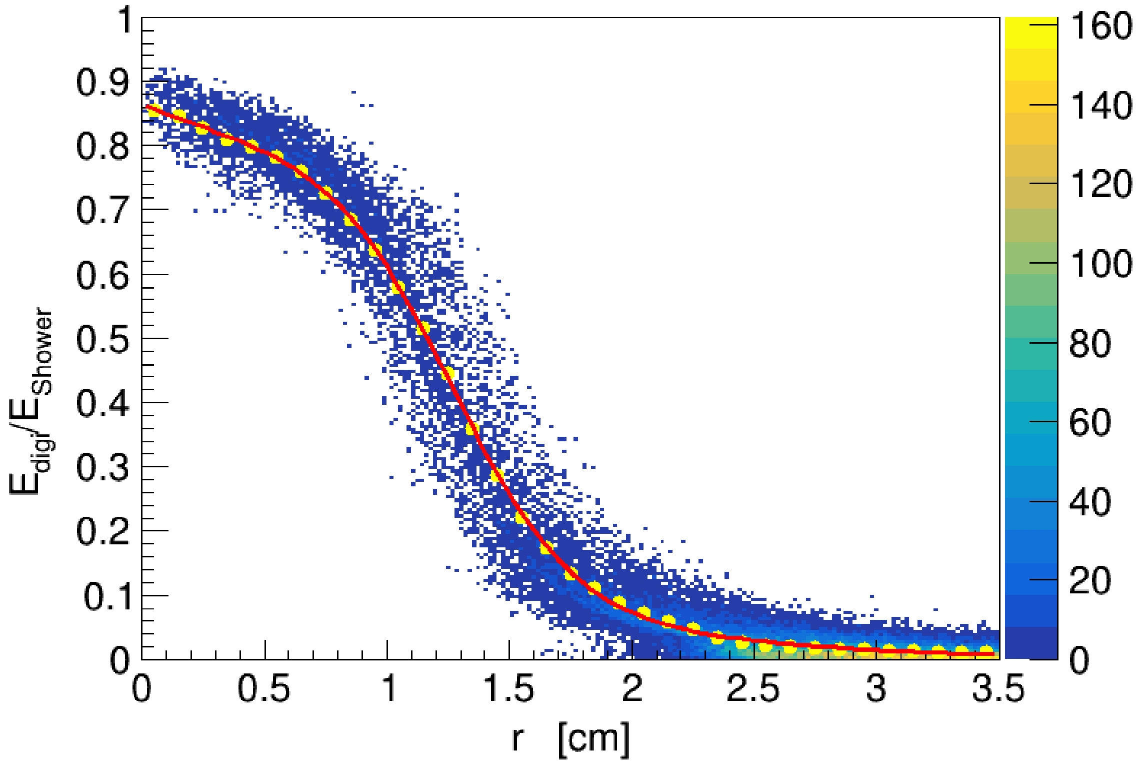
Fitting results

Fitting function:

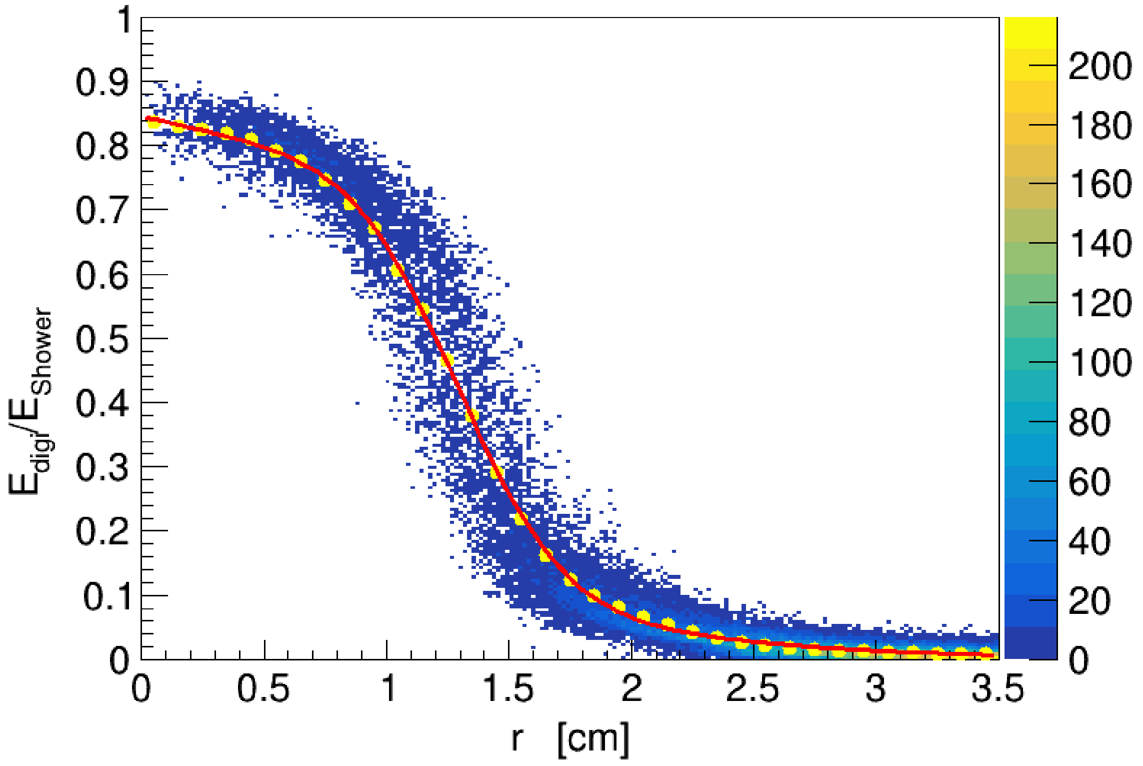
$$f(r) = p_0 \exp\left[-\frac{p_1}{R_M}\xi(r, p_2, p_3, p_4)\right],$$

$$\xi(r, p_2, p_3, p_4) = r - p_2 r \exp\left[-\left(\frac{r}{p_3 R_M}\right)^{p_4}\right]$$

Range12; 0.5 GeV



Range12; 1 GeV



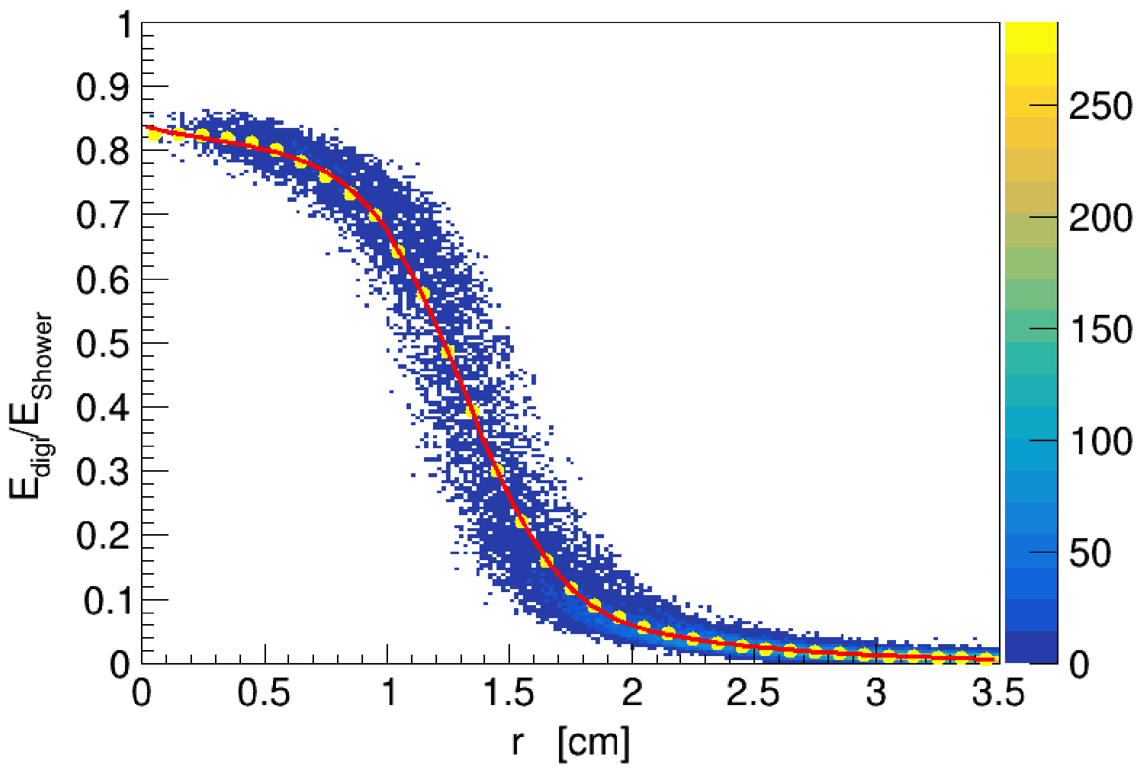
Fitting results

Fitting function:

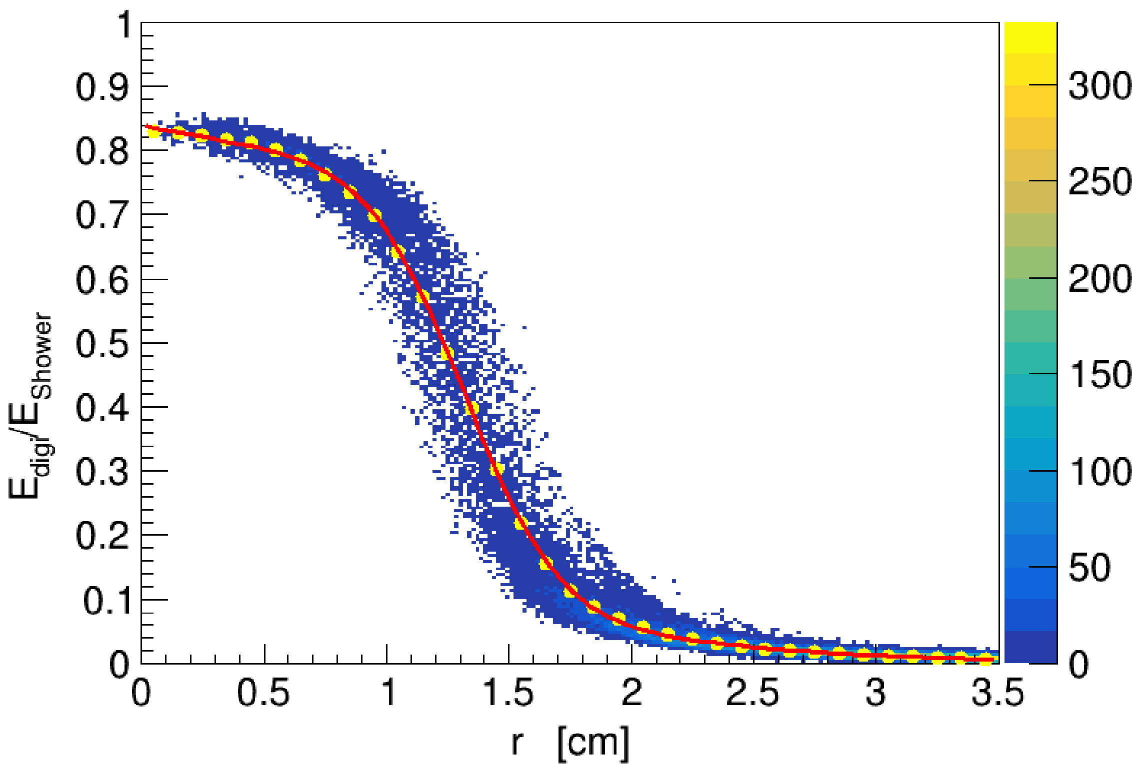
$$f(r) = p_0 \exp\left[-\frac{p_1}{R_M}\xi(r, p_2, p_3, p_4)\right],$$

$$\xi(r, p_2, p_3, p_4) = r - p_2 r \exp\left[-\left(\frac{r}{p_3 R_M}\right)^{p_4}\right]$$

Range12; 3 GeV

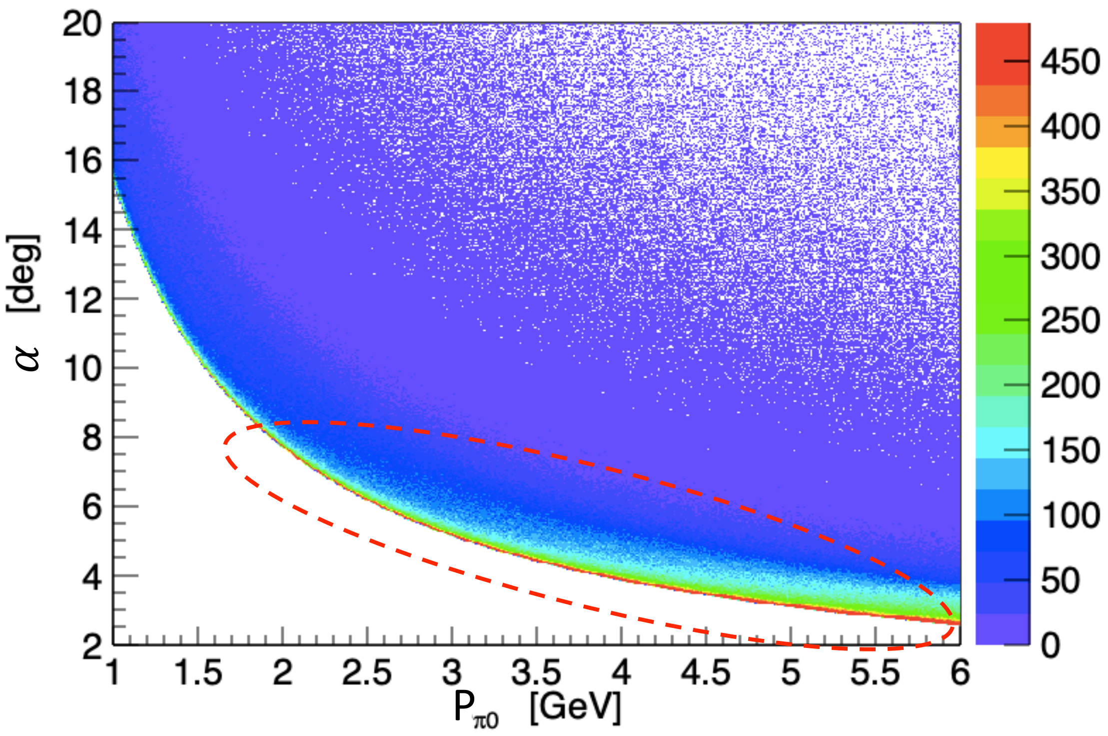


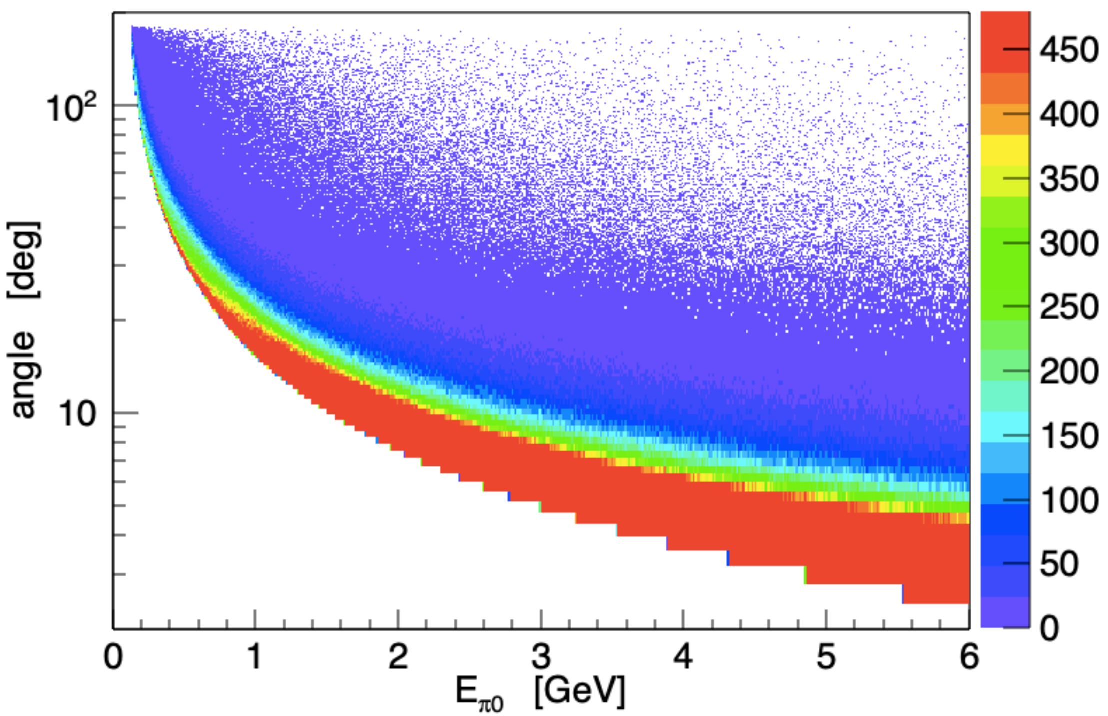
Range12; 6 GeV



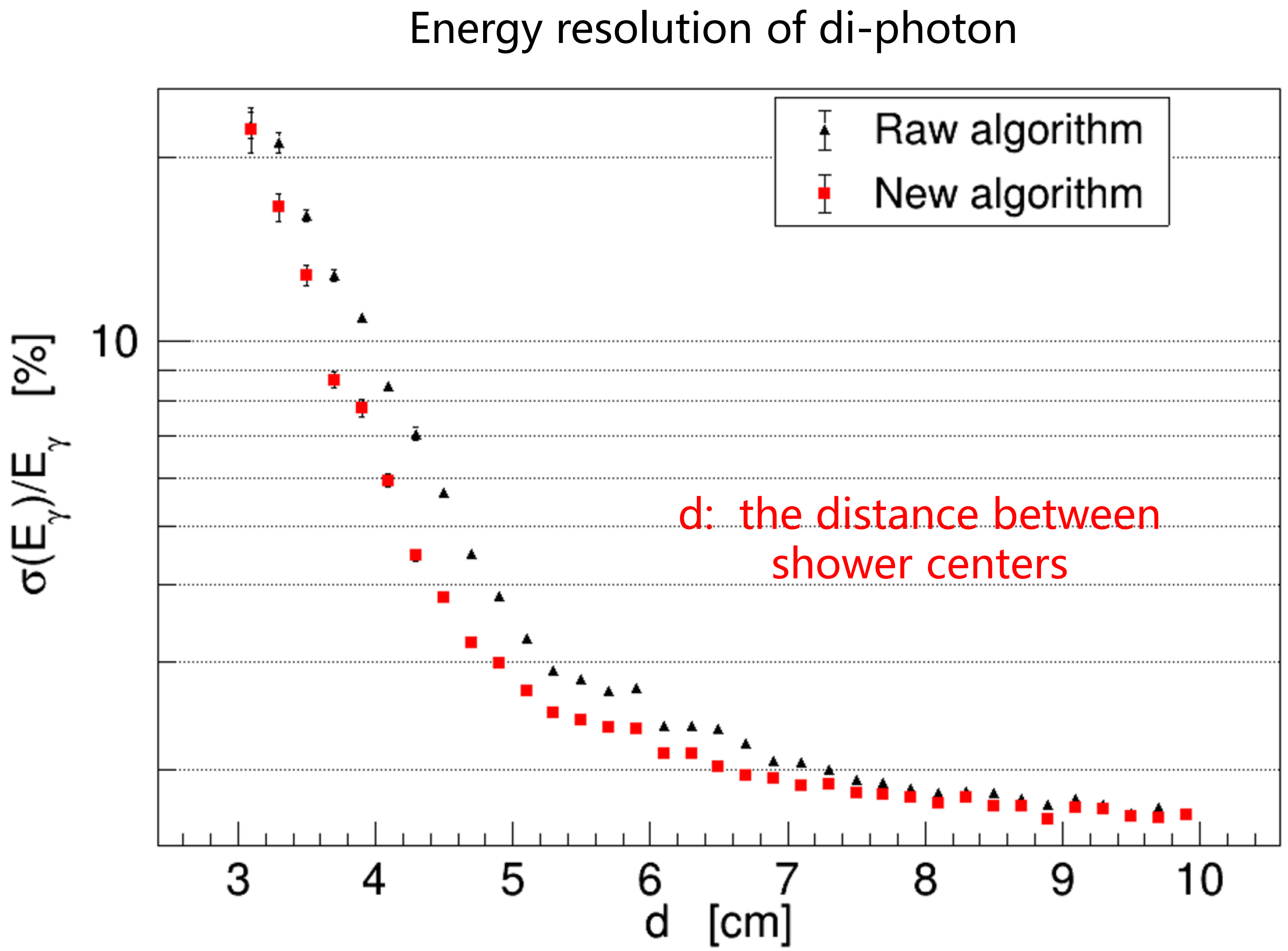
Energy resolution (pi0)

The angle between the two photons produced by the decay of pi0 changes with its momentum:





Energy resolution (di-photon)



Range of simulated samples:

- Energy

0.5~6 GeV

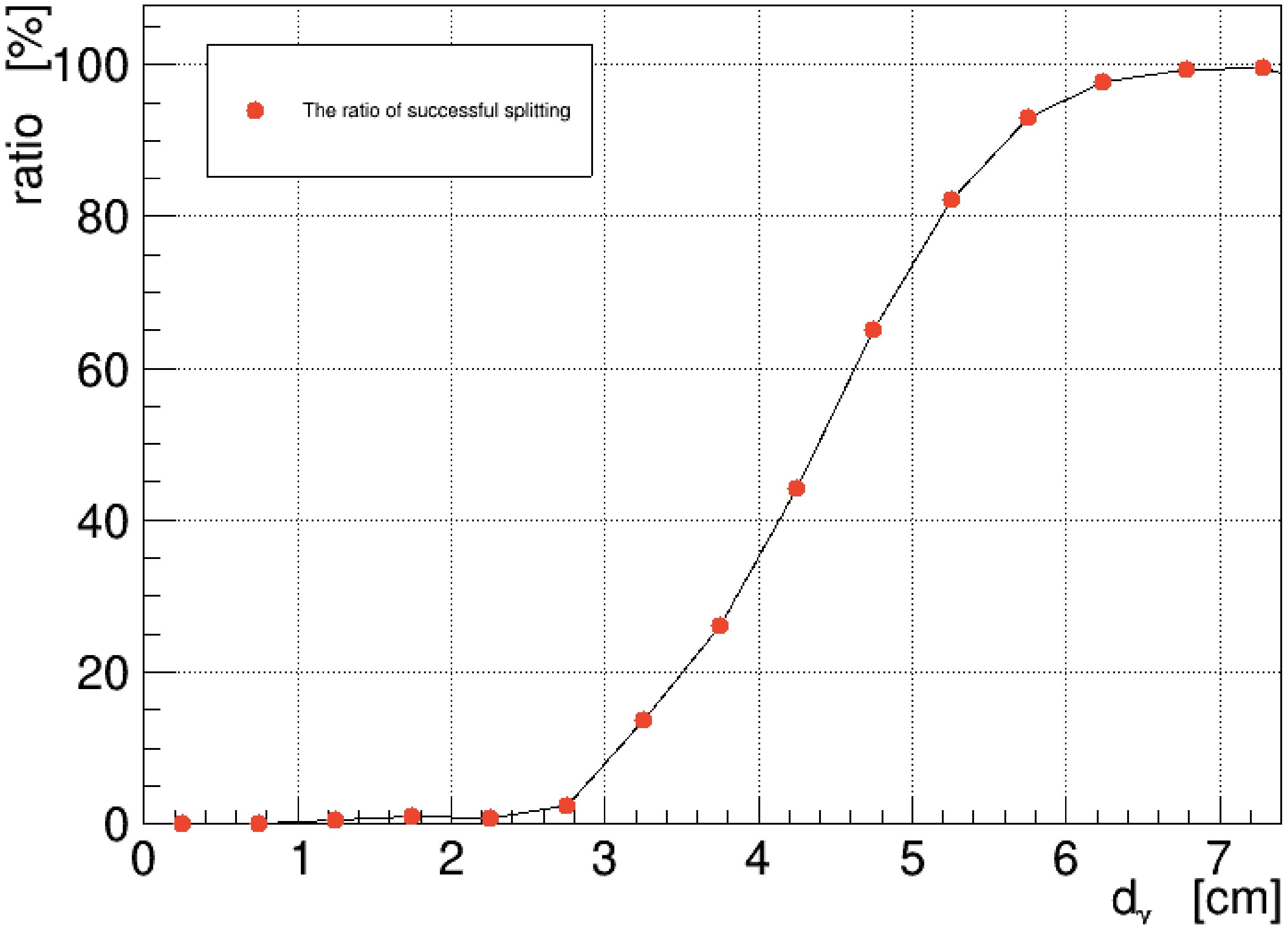
- Theta

Range12: 70.8088 ~ 72.8652

- Phi

Square area calculated according to theta

Splitting efficiency



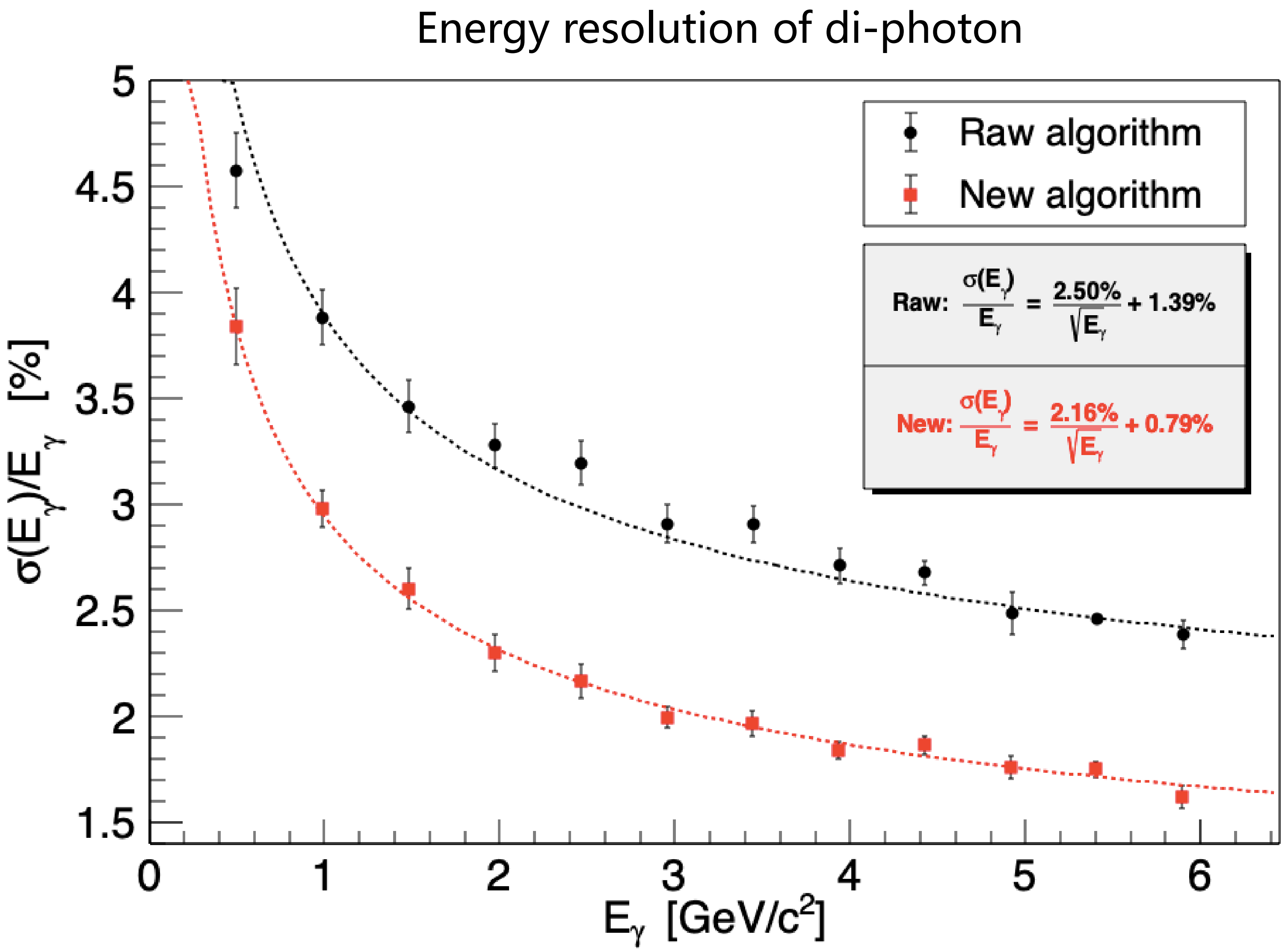
d_γ: The distance between two shower centers

$$ratio = \frac{N_{splitting}}{N_{total}} \times 100\ (\%)$$

Control sample:

- di-photon (0 ~ 6GeV)
- Events 10000
- Geant4
- Generator: Box
- Phi(0, 360)
- Theta(22, 140)

Energy resolution (di-photon)



- The angle between two photons < 6.75 (deg)

Range of simulated samples:

- Energy

0.5~6 GeV

- Theta

67.7938 ~ 73.8062 {deg}

- Phi

0.625 ~ 7.375 {deg}