Performance Study of a New Cluster Splitting Algorithm for the Reconstruction of $\overline{\text{P}}$ANDA EMC Data

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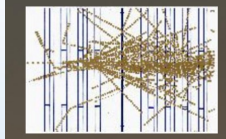
On behalf of the PANDA Collaboration



CALOR 2022

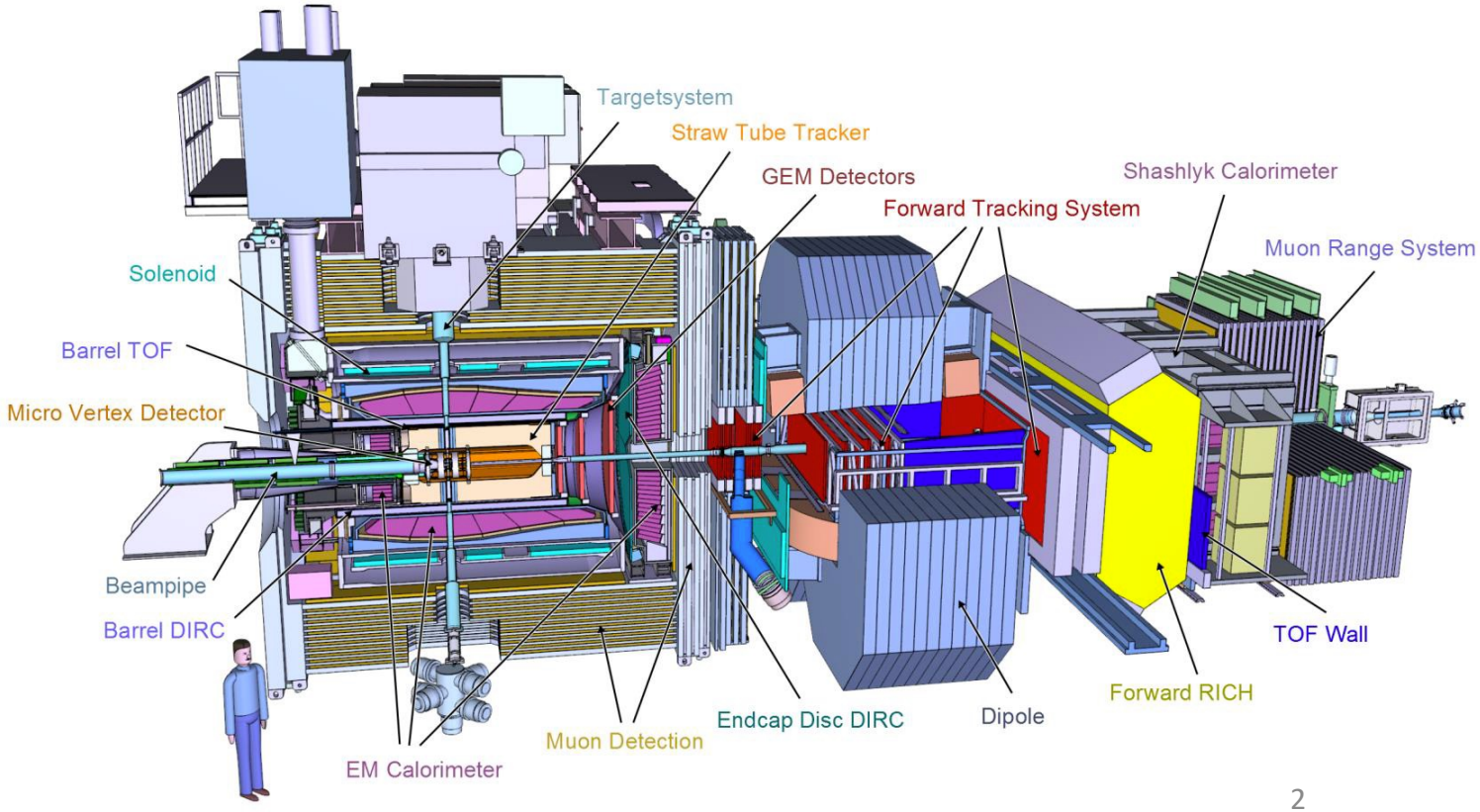
19th International Conference on Calorimetry for High Energy Physics

University of Sussex, Brighton, 16-20 May 2022

May 17, 2022

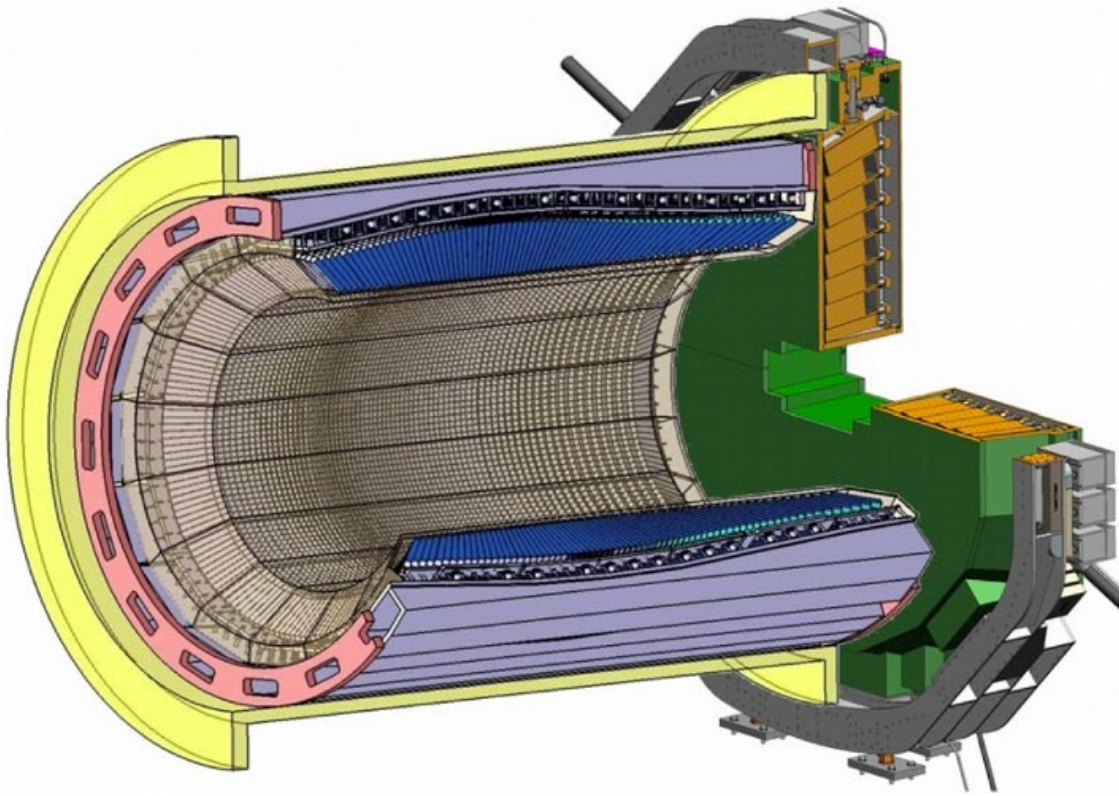
$\overline{\text{P}}$ANDA Experiment

- Anti**P**roton **AN**nihilations at **DA**rmstadt
- Cooled antiproton beams between 1.5 GeV/c to 15 GeV/c
- Fixed target experiment : Hydrogen and other
- $\sqrt{s}$: 2.3 GeV ~ 5.5 GeV
- High luminosity: 10^{32} cm^{-2} s^{-2}
- Hadron spectroscopy
  - Exotic states
  - Baryons
- Nucleon structure
- Mesons in nuclear
- Hypernuclei



$\overline{\text{P}}$ANDA Electromagnetic Calorimeter

- $\overline{\text{P}}$ANDA physics: Full reconstruction of multi-photon and lepton-pair channels of utmost importance
- Target Spectrometer:
  - Barrel part and two endcaps
  - 16,000 crystals, improved PbWO4
  - X_0 = 0.89 cm, R_M = 2.00 cm
  - For barrel EMC, 11360 crystals, the average lateral size of crystal is 21.3mm
- Forward Spectrometer:
  - Shashlik type sampling calorimeter
- Good energy and spatial resolution for photons
  - $\leq 1\% \oplus \frac{\leq 2\%}{\sqrt{E/GeV}}$
  - $\leq 0.5°$(backward), $\leq 0.3°$(barrel), $\leq 0.1°$(forward)

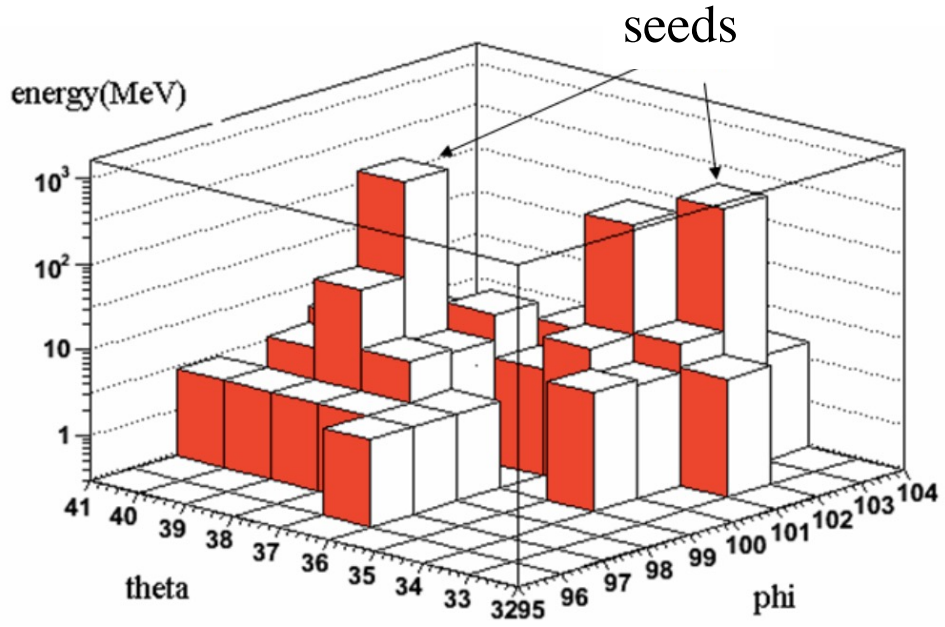


- For barrel EMC : 22 ˚< θ < 140 ˚

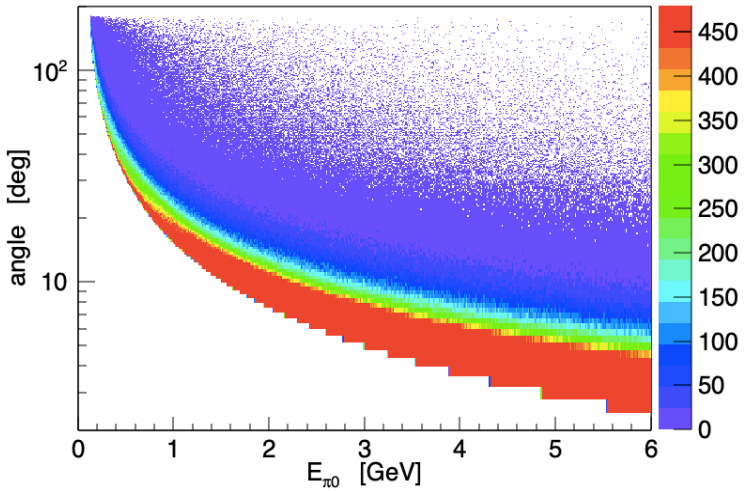
EMC Reconstruction

- Cluster Finding
  - A contiguous area of crystals with energy deposition
  - Local maximum as the seed of shower

- Cluster Splitting
  - Several local maxima due in general to overlapping showers
  - Especially important for high momentum π^0, significance of π^0 depends on mass resolution, and performance of cluster splitting algorithm



Angles between the 2γ from pi0



Cluster Splitting in Reconstruction

- The purpose of the cluster splitting is to precisely assign energy deposits to the correct particles

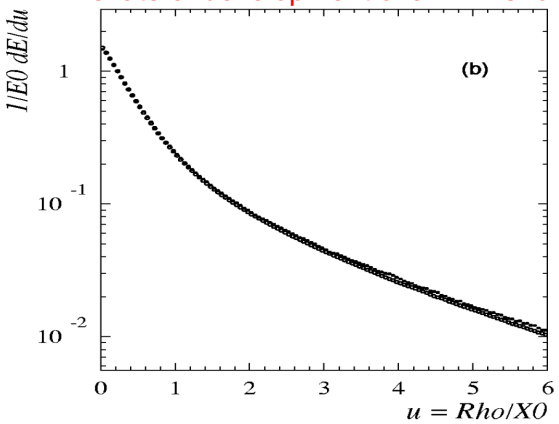
- Update energy/position iteratively
  - EM lateral development of a shower:

    $\mathrm{E}_{\mathrm{target}} = \mathrm{E}_{\mathrm{seed}} \cdot \exp(-2.5\, r/R_M)$

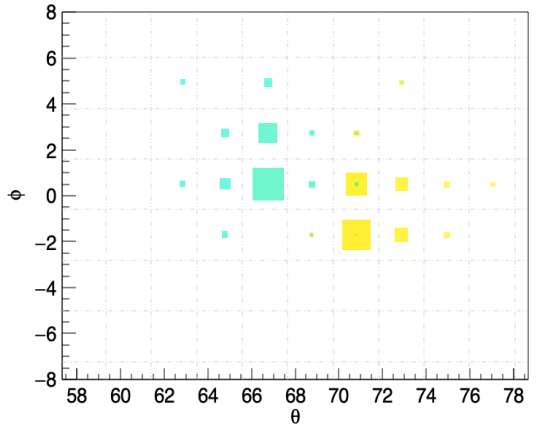
  - The fraction of energy for each shower deposited in same crystal is calculated
  - Estimated energies and positions of the single showers involved as input parameters

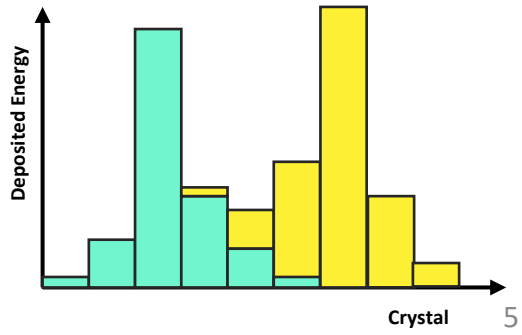
- In this presentation, the cluster splitting algorithm is improved:
  - Update the lateral development description function based on crystal granularity
  - Correct the seed energy

The lateral development of an EM shower



Cluster splitting for an EMC Cluster





Cluster Splitting Algorithm*

- Initialization:

Place the shower center at the center of seed crystal, the total energy of seed crystal as E_{seed}.

- Iteration:

1.Traverse all crystals to calculate fraction f_i of shower i.

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

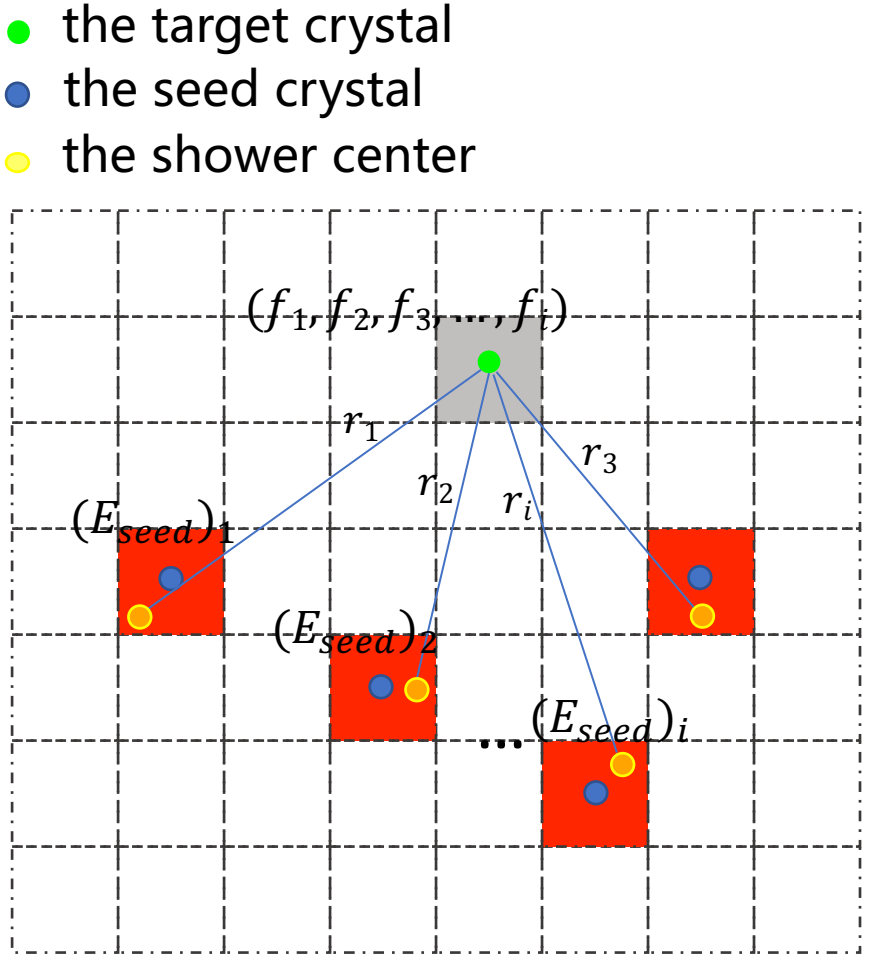
i or j : different showers

R_m: Moliere radius

r_i: distance from the shower center to the center of target crystal

2. Update the position of the shower center and E_{seed}.

3. Loop over 1 & 2 until the shower center convergent.



*Similiar as BESIII and BaBar: [1] BESIII Collaboration, Nucl. Inst. Meth. A Volumn 614, Issue 3, 11 March 2010. [2] BABAR Collaboration, B. Aubert *et al.*, Nucl. Instr. and Methods A **479**, 1 (2002).

The Lateral Development of Electromagnetic Shower

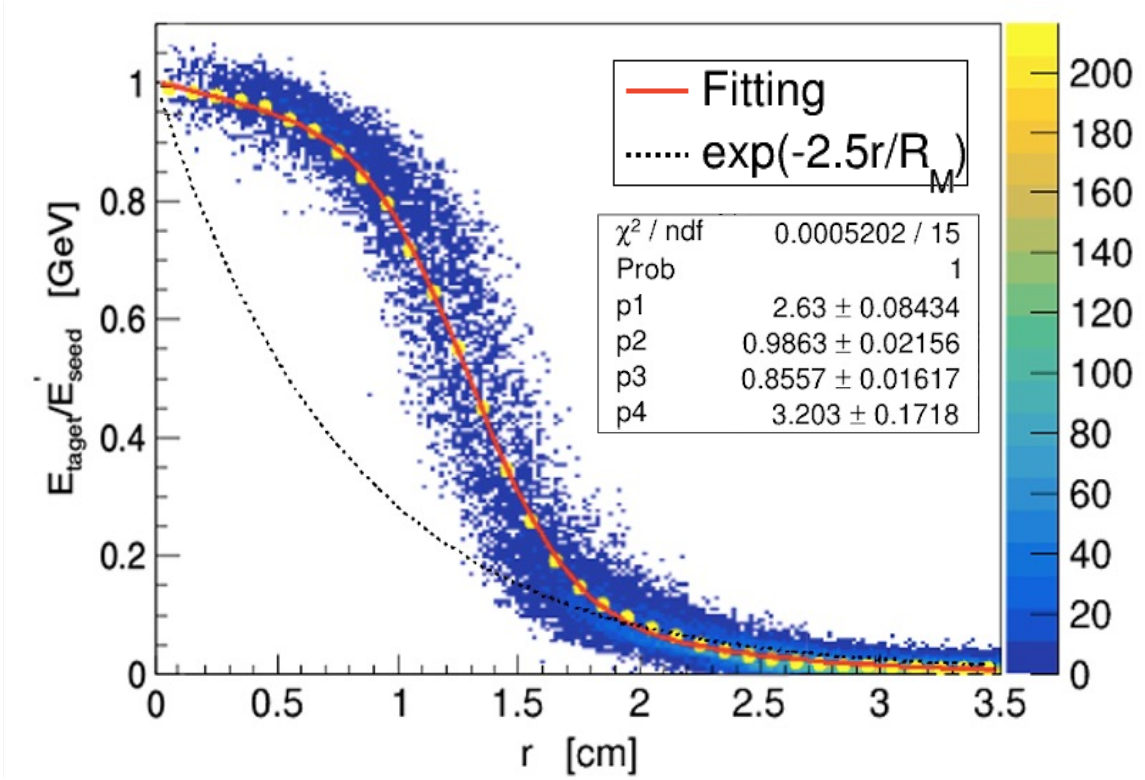
- The conventional lateral development formula $\frac{E_{\text{target}}}{E_{\text{seed}}} = \exp(-2.5\, r/R_M)$ has no consideration of crystal granularity.

- The function form used for fitting:

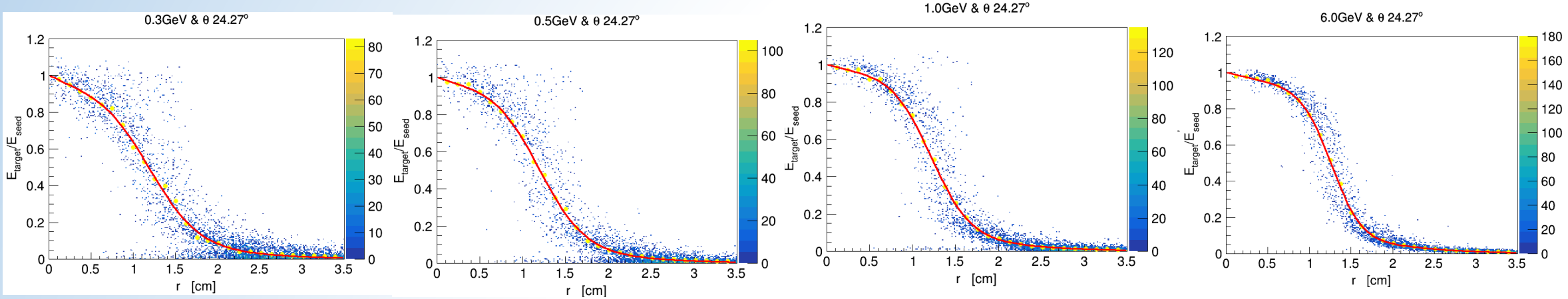
$$f(r) = \frac{E_{\text{target}}}{E_{\text{seed}}} = \exp\left[-\frac{p_1}{R_M}\cdot\xi(r)\right],$$

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

here p_1, p_2, p_3 and p_4 are parameters.



Parametrization



Fit the distribution of different detector polar angle and energy regions for barrel EMC to get the parameters.

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

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

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

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

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

Energy dependency

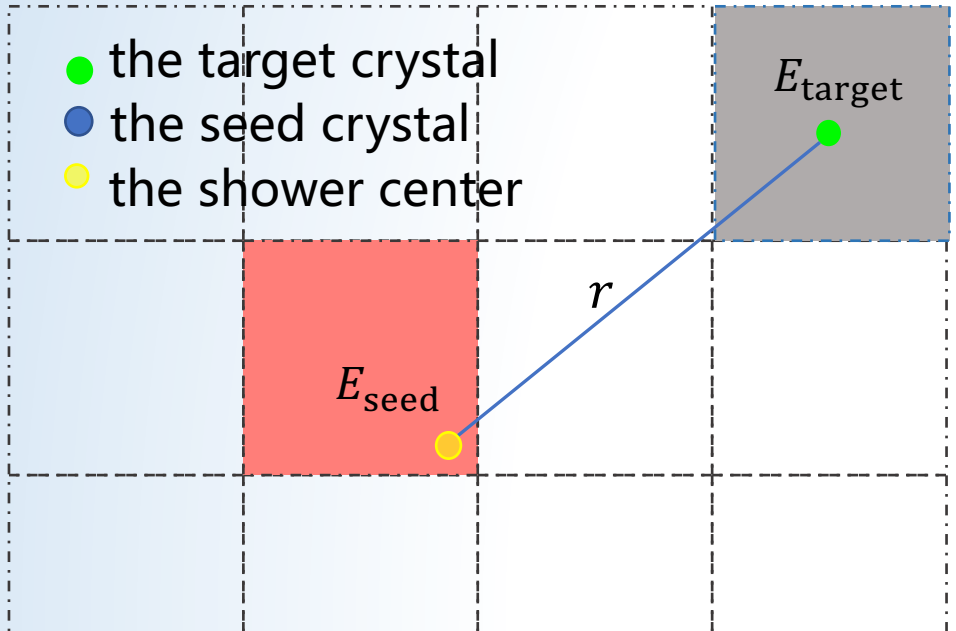
Angle dependency

Seed Energy Correction

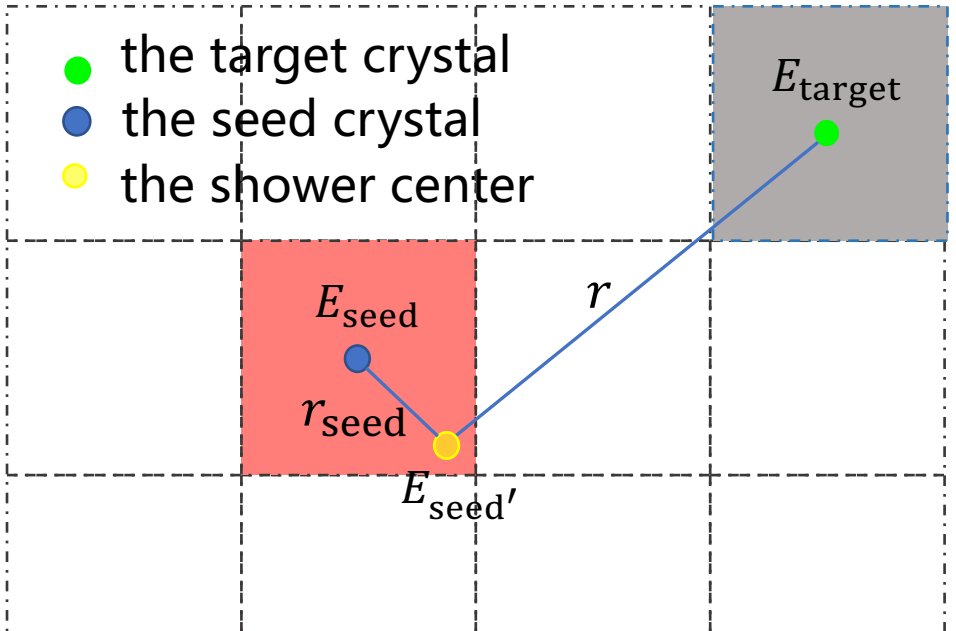
- In the default algorithm, the seed energy is used to calculate the $E_{\text{target}} = E_{\text{seed}} \cdot f(r)$
- If the shower center not coincide with the crystal center, E_{seed} needs to be corrected

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

Default algorithm



New algorithm



Seed Energy Correction

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

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

- $E_{\text{seed}'}$ can be related to the E_{seed} :

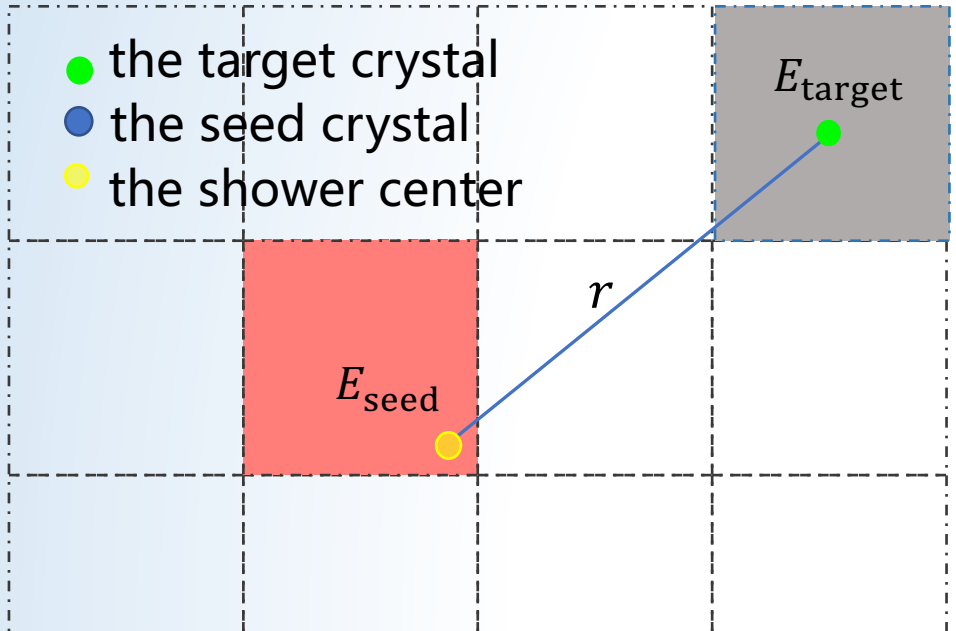
$$E_{\text{seed}'} = \frac{E_{\text{seed}}}{f(r_{\text{seed}})}$$

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

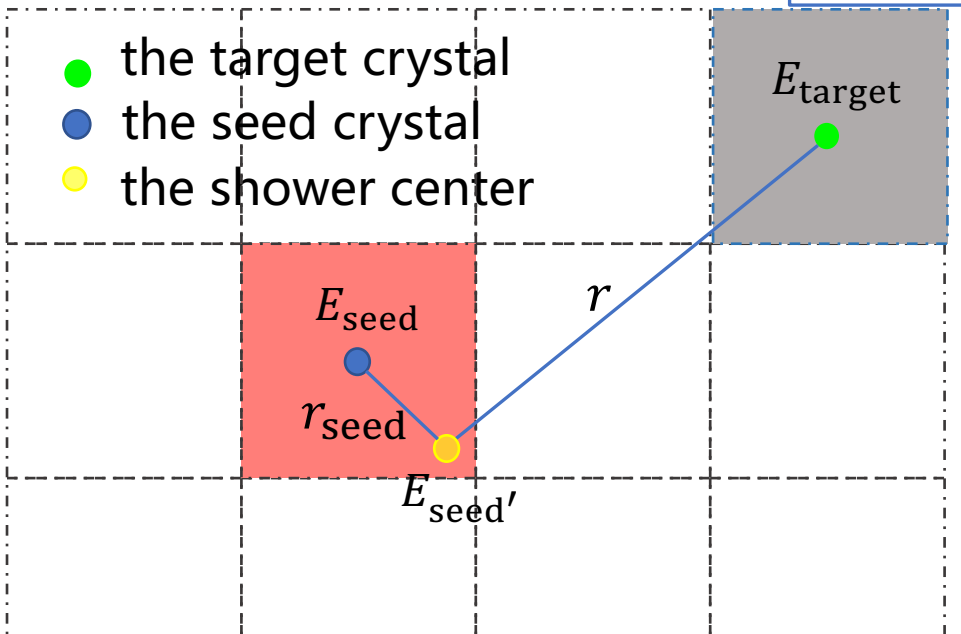
$$E_{\text{target}} = \frac{E_{\text{seed}}}{f(r_{seed})} \cdot f(r)$$

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

Default algorithm



New algorithm



Parametrization after Seed Correction

Seed energy correction

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

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

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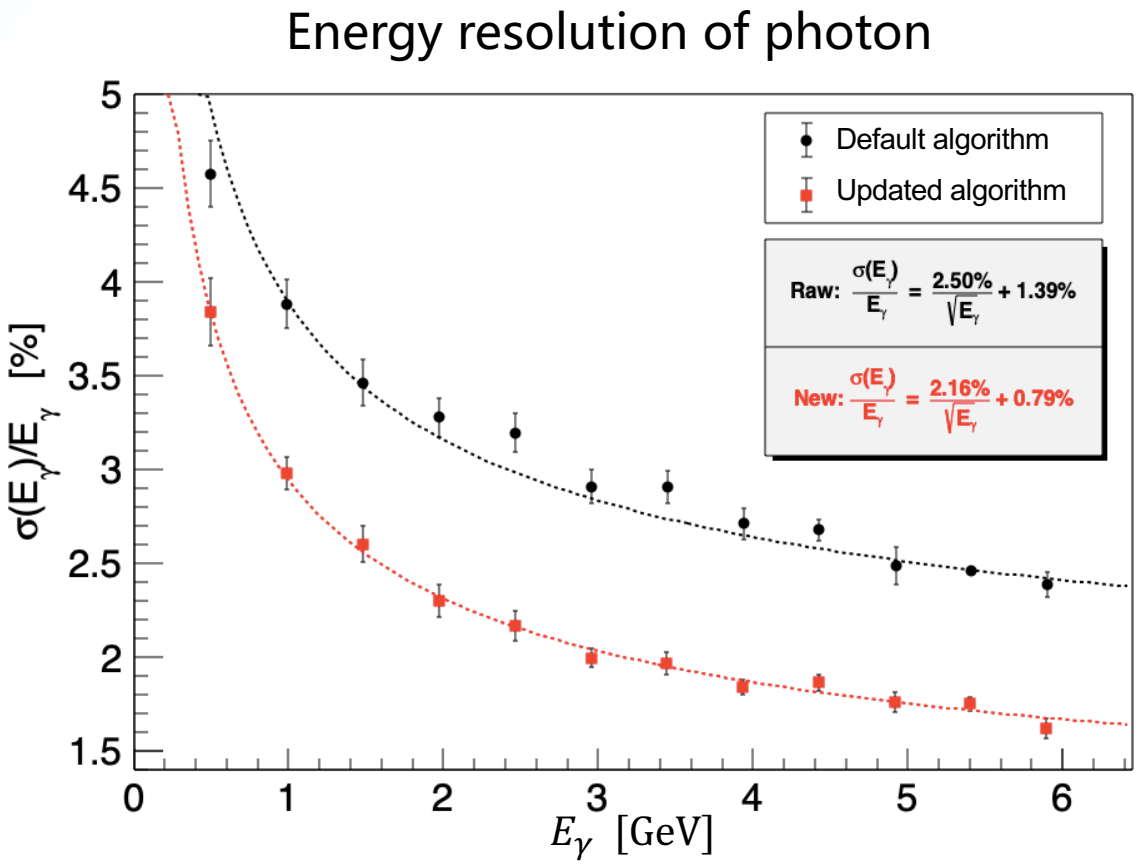
Energy dependency

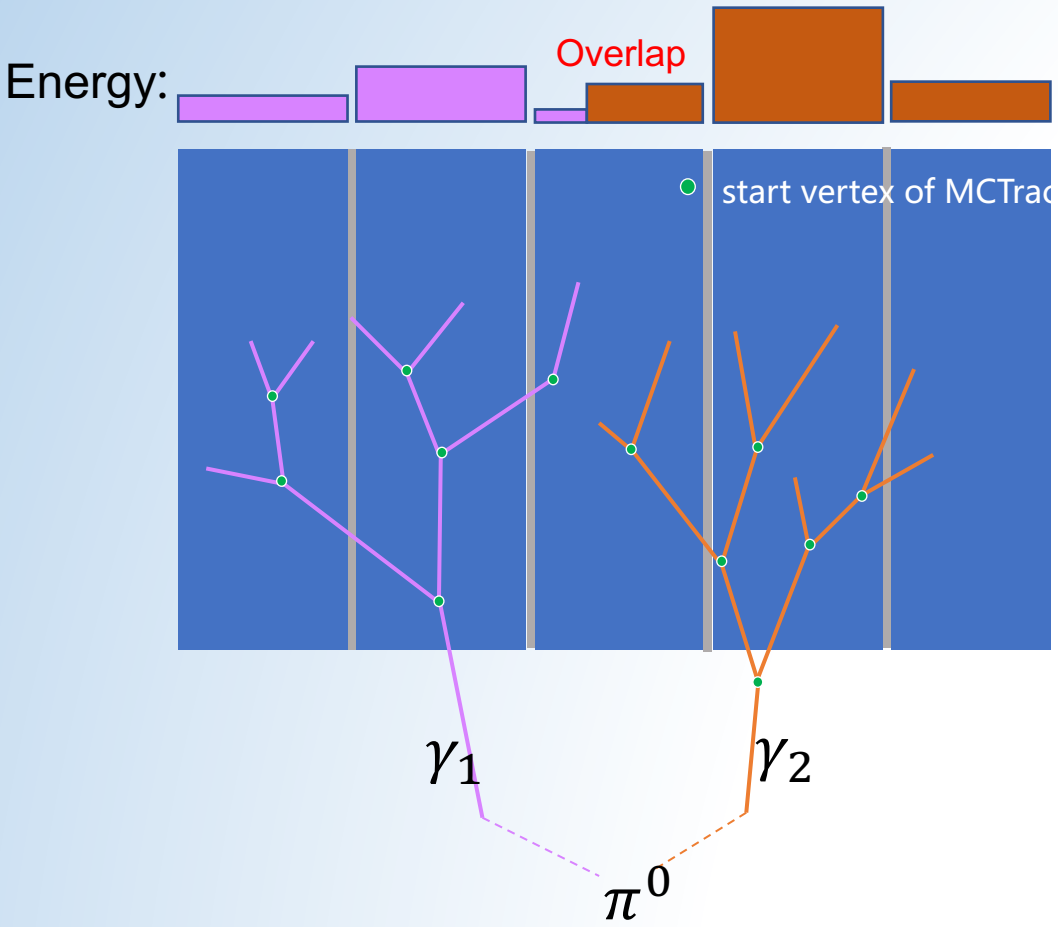
Angle dependency

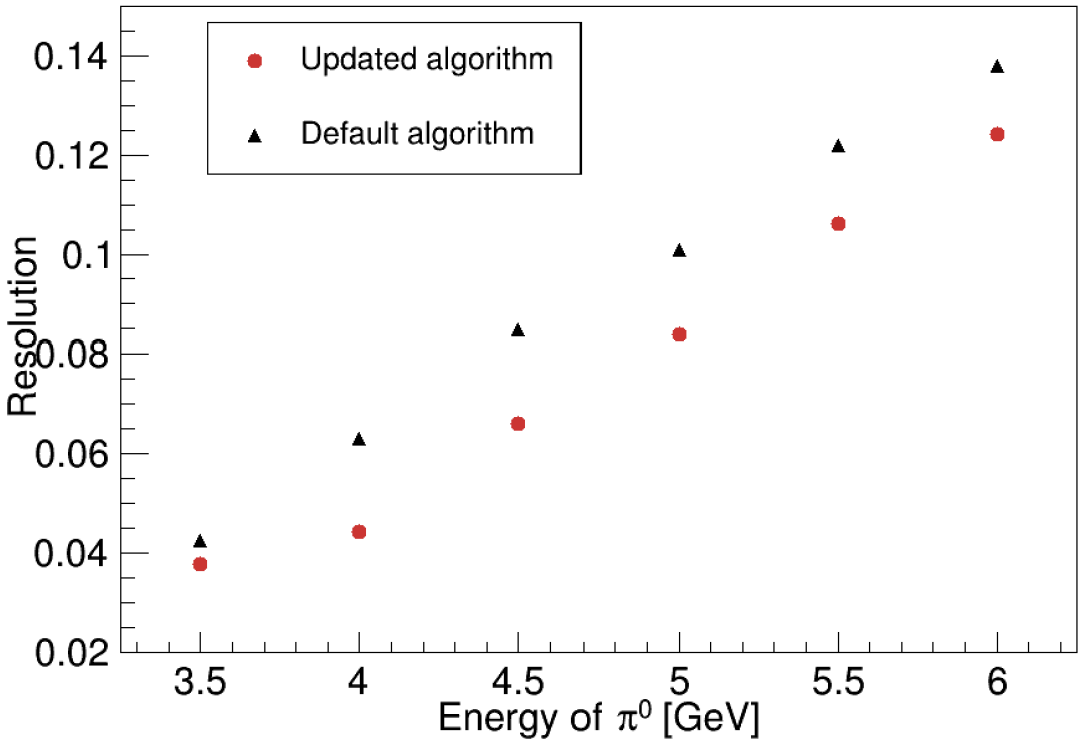
Photon Resolution from Small-cross-angle Photon Samples

- The angle between two photons < 6.75(deg)
- Energy: 0.5 ~ 6 GeV



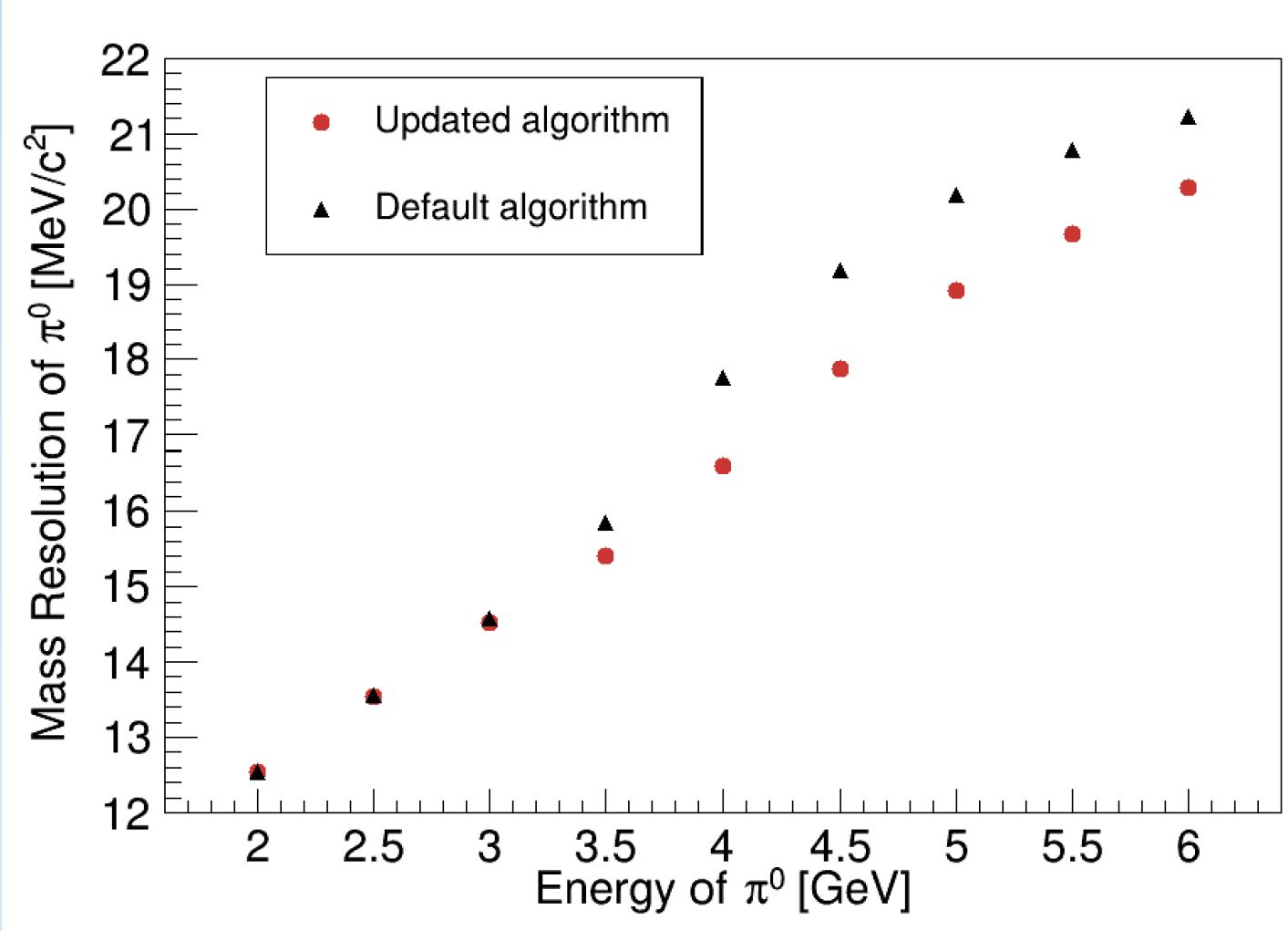
Photon Resolution from π^0 Samples





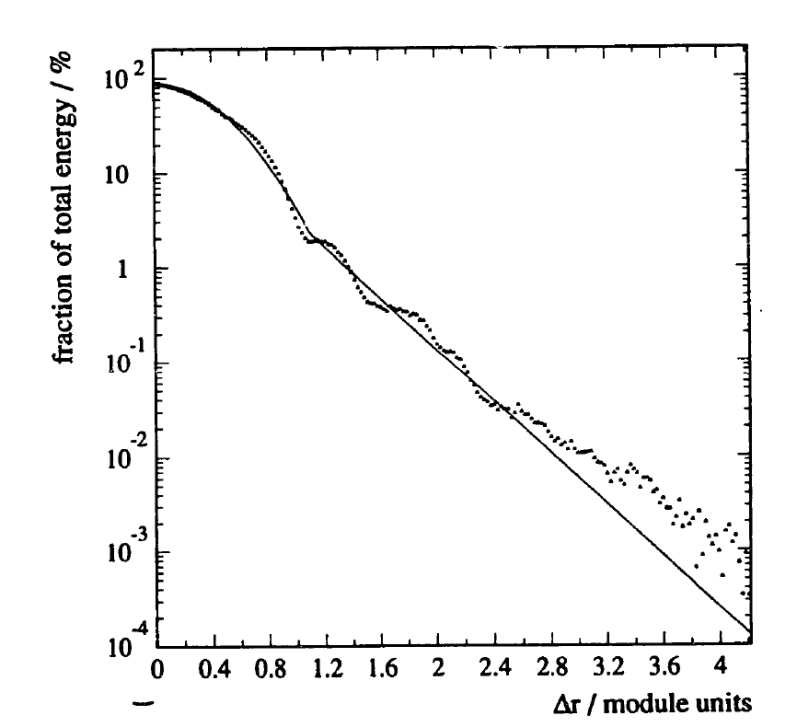
- MC Truth information stores energy deposited in calorimeter of two photons from π^0
- The deviation to MC Truth is smaller for new algorithm

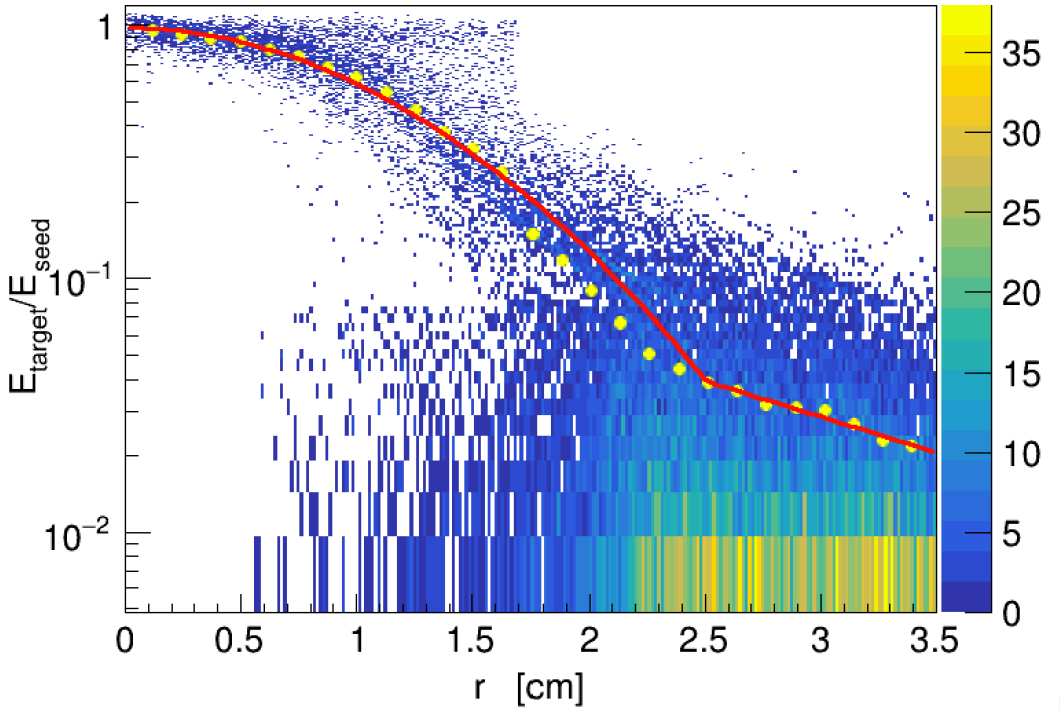
π^0 Mass Resolution



- The mass resolution of the π^0 has been improved in the high energy range compared with the conventional method.

Validation by experimental data





*The lateral development of electromagnetic showers extracted from experimental data.

$$^{*} f(r,E) = A \cdot \mathrm{Max}\left(\exp\left(-\frac{r^2}{p_1}\right), d \cdot \exp\left(\frac{-r}{s}\right)\right)$$

$$d = p_2 + p_3 \cdot E^{p_4}$$

$$s = p_5 - p_6 \cdot \ln(E)$$

[1] F. Berger et al., Nucl. Instrum. Methods A321 (1992) 152.
[2] ALICE Technology design report of the photon spectrometer.

Summary

- The cluster splitting algorithm is improved with a new lateral development description function
  - Lateral development based on the crystal granularity
  - Dependency of energy and angle of incident particle
  - Seed energy is corrected
- Good performance of new splitting algorithm
  - Energy resolution of small-cross-angle photons and daughter photons of π^0
  - Mass resolution of π^0
- Obvious improvements of mass resolution and significance of high momentum π^0

Thank you!

Backup Slides