PANDA EMC and Energy Calibration

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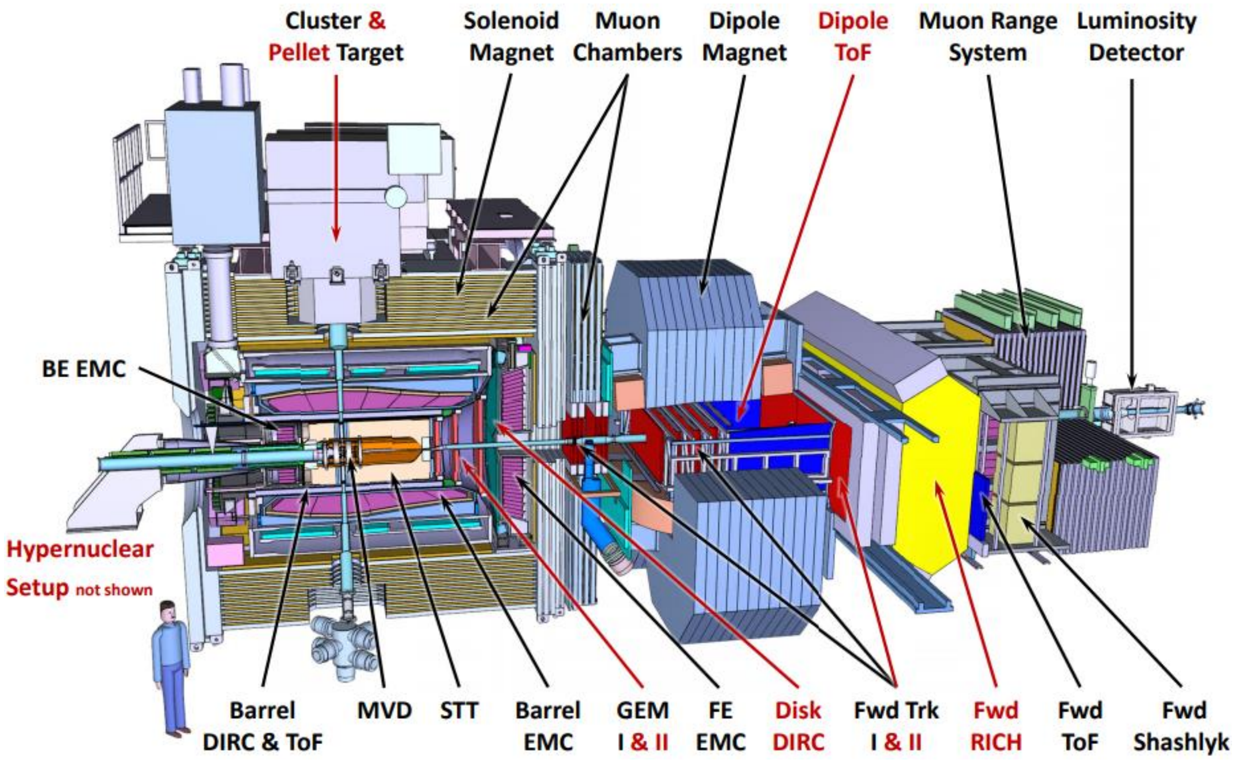
2021.7 - NKU

Outline

- PANDA Experiment
- PANDA EMC
- Energy Reconstruction
- Energy Calibration
- Energy Leakage
- Summary and outlook

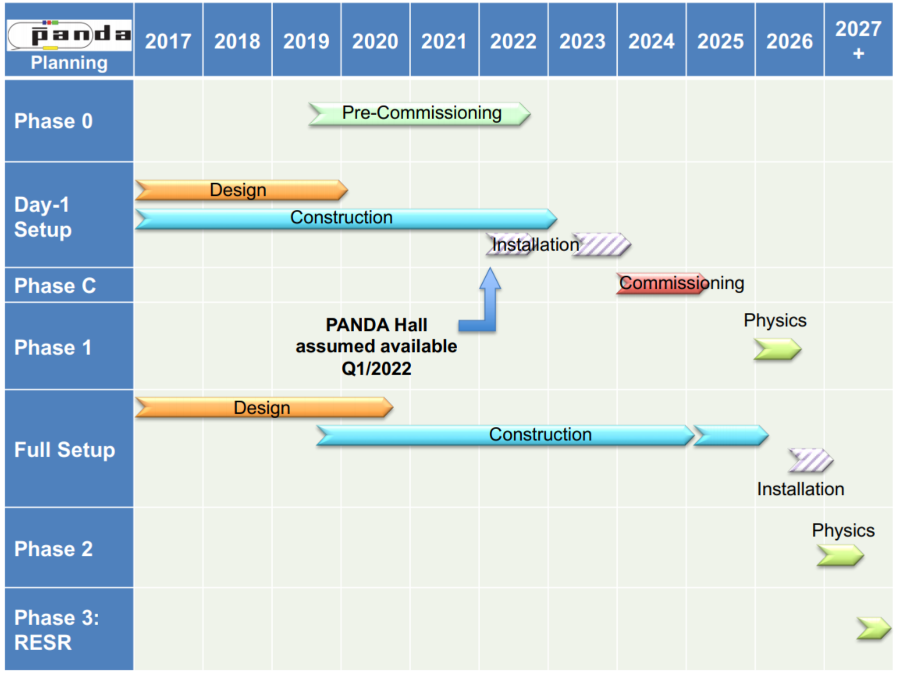


PANDA Experiment

- The Antiproton Annihilations at Darmstadt experiment
- Beam momentum: $1.5 - 15\mathrm{GeV}/c \ \left(\sqrt{s} = 2.14 - 5.47\mathrm{GeV}\right)$
- Peak luminosity: $2 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Spectrometer:
  - Target + Forward
  - Tracking detector, PID, Calorimeter …
- Physics topics:
  - Strong interaction

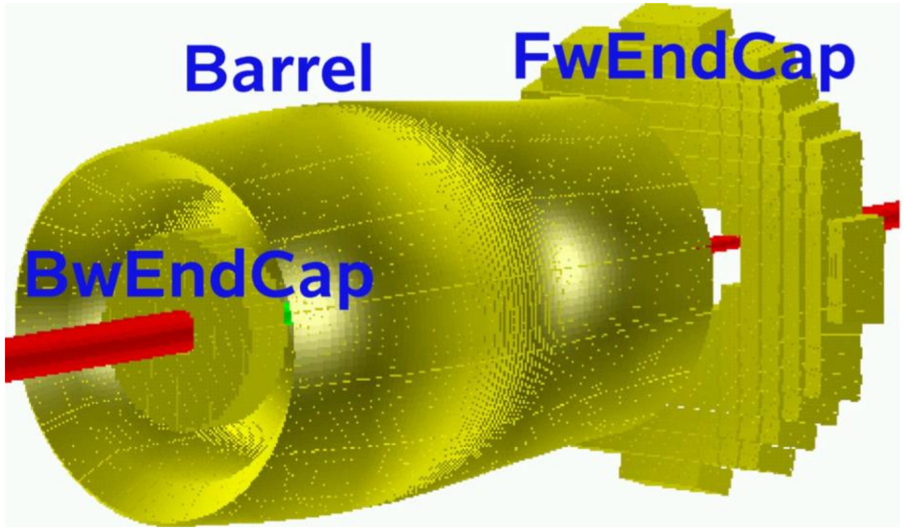
hadron spectroscopy, charmed hadrons,

double-hypernuclei; nucleon structure …



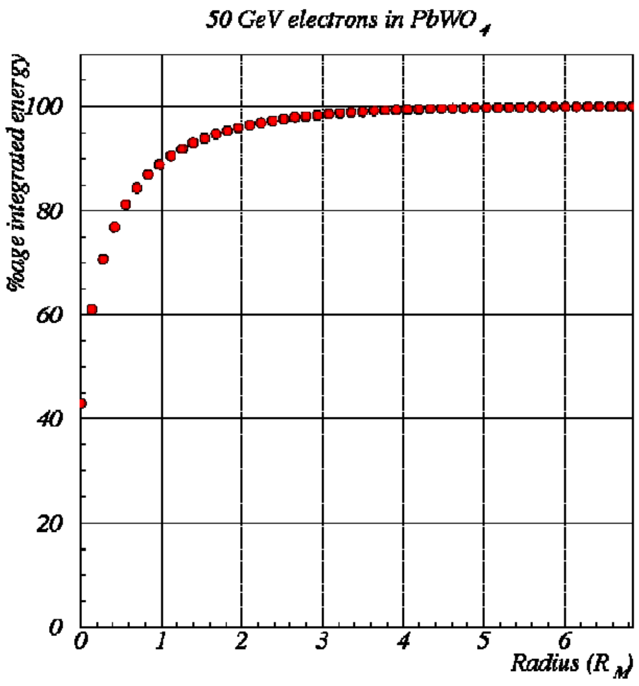
PANDA EMC

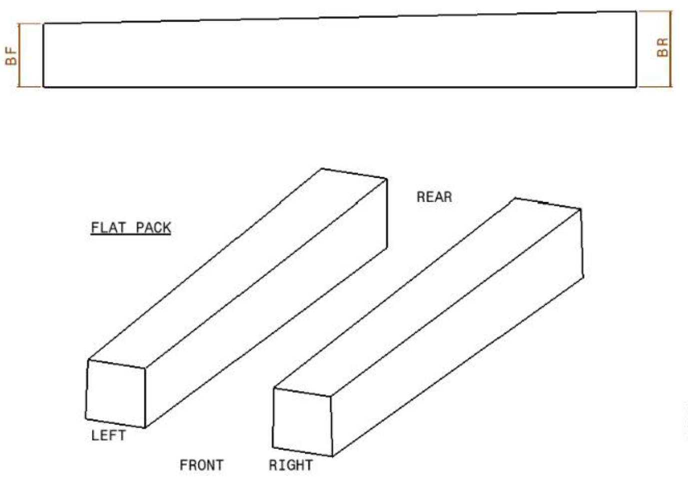
- Good identification and reconstruction of multi-photon and lepton pair channels are of utmost importance for the success of PANDA
- PWO-II: good energy and spatial resolution, fast response, radiation hardness, improved light yield for low energy threshold

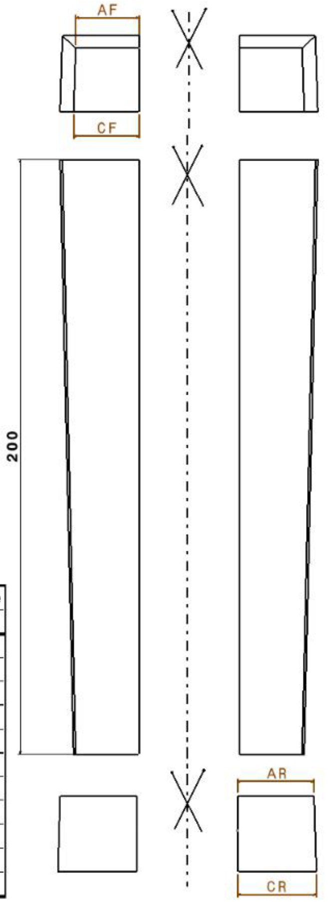


PANDA EMC (PWO-II)

- Width ~ 2-3 cm (r_m = 2 cm)
- Length ~ 20 cm (~ 22 X_0)





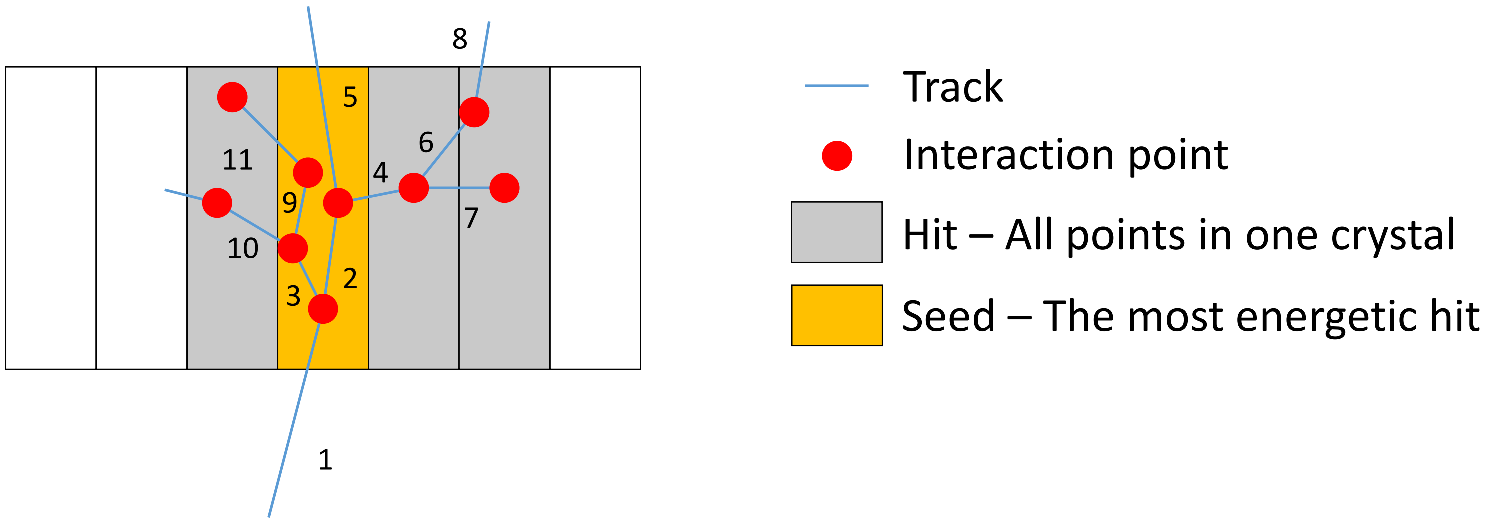


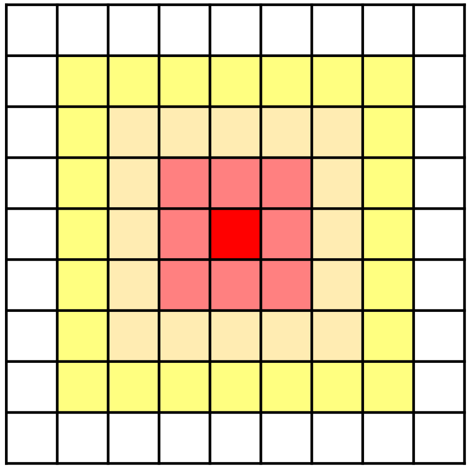
T = −25°C

Type	Volume (cm3)	AF (mm)	BF (mm)	CF (mm)	AR (mm)	BR (mm)	CR (mm)	Quantity / slice Left	Right
1	126,86	21,21	21,28	21,27	29,04	28,75	29,12	40	40
2	126,56	21,18	21,28	21,39	28,78	28,75	29,07	40	40
3	125,79	21,17	21,28	21,51	28,36	28,75	28,81	40	40
4	120,85	21,17	21,28	21,60	27,90	27,22	28,45	40	40
5	119,69	21,17	21,28	21,69	27,35	27,22	28,01	40	40
6	118,35	21,19	21,28	21,78	26,72	27,22	27,47	40	40
7	112,9	21,22	21,28	21,86	26,23	25,47	26,99	40	40
8	111,75	21,23	21,28	21,91	25,70	25,47	26,51	20	20
9	110,52	21,23	21,28	21,95	25,14	25,47	26,00	20	20
10	107,01	21,25	21,28	22,00	24,70	24,42	25,56	20	20
11	106,25	21,25	21,28	22,02	24,35	24,42	25,23	15	15

Energy Reconstruction

- **Cluster:** a series of neighbored crystals with energy above the designed threshold;
- **Seed crystal:** the one with the largest deposited energy;
- **$E(7 \times 7)$:** energy deposited in 49 crystals around the seed crystal.



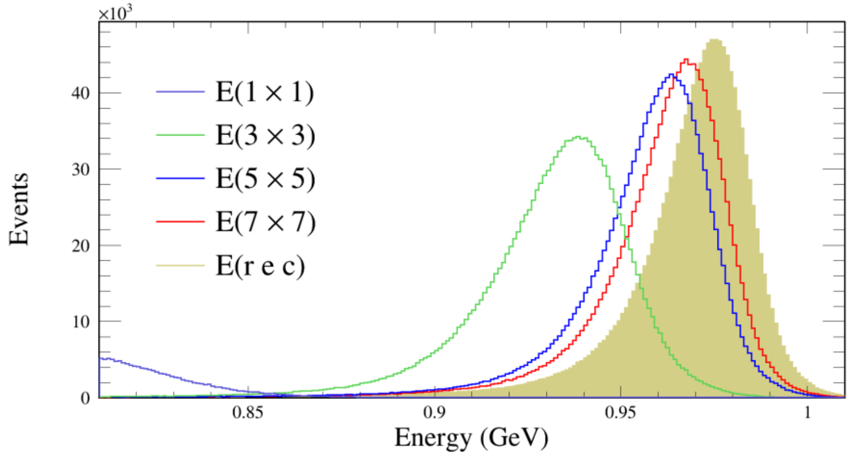


Energy Distribution

- **Asymmetric distribution:**

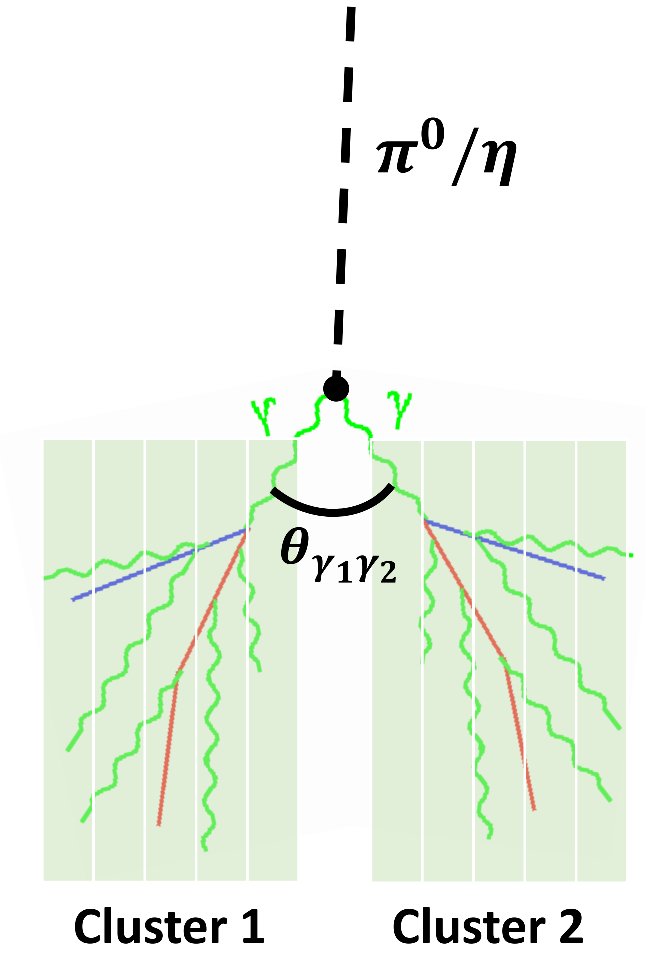
$$f_{Nov}(E) = A \cdot \exp\left(\frac{-\ln^2\left(1 + \boldsymbol{t}\frac{\sinh(\boldsymbol{t}\sqrt{\ln 4})}{\boldsymbol{t}\sqrt{\ln 4}} \cdot \frac{E - \boldsymbol{E_0}}{\boldsymbol{\sigma}}\right)}{2\boldsymbol{t}^2} - \frac{\boldsymbol{t}^2}{2} \right)$$

$\boldsymbol{\sigma}$ is resolution, $\boldsymbol{E_0}$ is mean value, $\boldsymbol{t}$ parameterizes the asymmetric tail due to the energy lost before EMC and energy leakage.



Energy Calibration

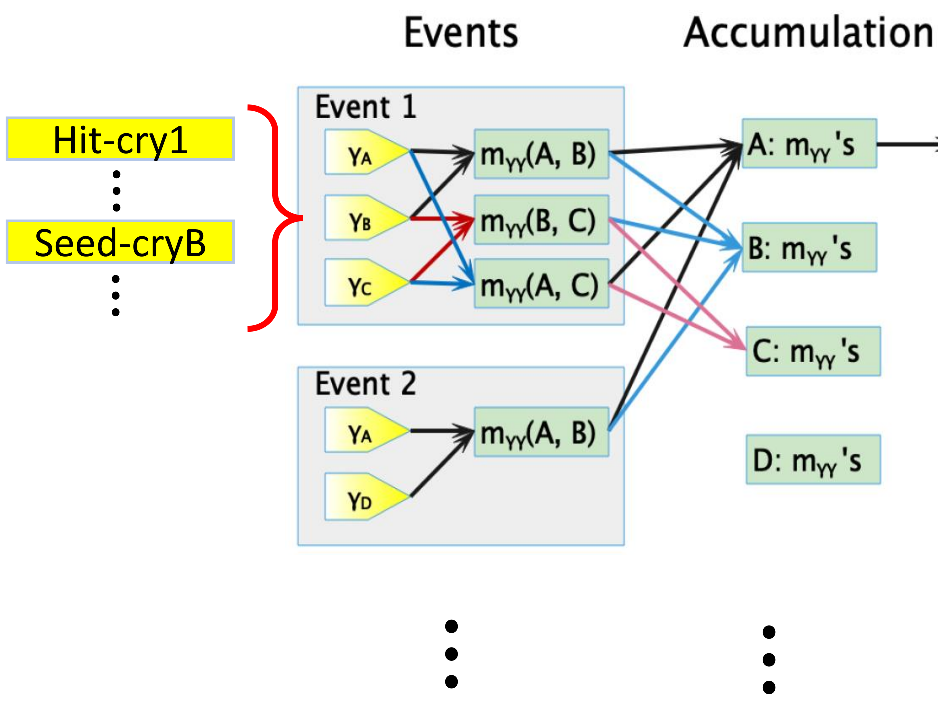
- **Absolute energy correction**
  - ADC → E_{dep} → E_{truth}
- **Correct the variations of detector response**
  - Light yield non-uniformity
  - Detection unit uniformity
  - Energy leakage
  - Electronics
- **Calibration sample**
  - Physics event: $\pi^0(\eta) \to \gamma\gamma$



Energy Calibration ($\pi^0 \rightarrow \gamma\gamma$)

- **Invariant mass of π^0:**
  - $m_{\pi^0}^2 = 2E_{\gamma_1}E_{\gamma_2}(1 - cos\theta_{\gamma_1\gamma_2})$
- **Dedicated data sets for Calibration:**
  - Hit - Crystal ID information
  - Cluster - Hits information
  - Cluster ID - Seed ID information
  - $m_{\pi^0} = m(\gamma_j\gamma_i) = m_{ij}$

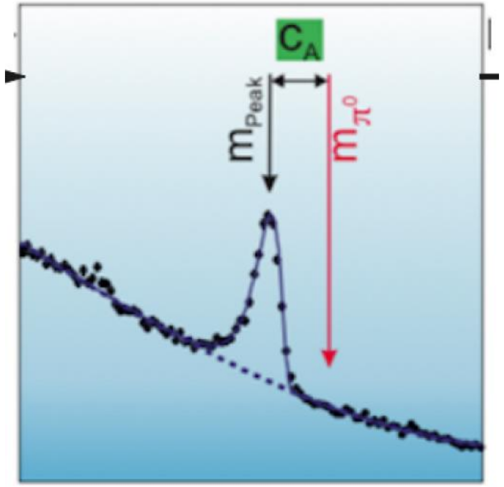
  (γ_i is the cluster with seed crystal i)
  - m_{ij} is assigned to crystal i and j



Energy Calibration ($\pi^0 \to \gamma\gamma$)

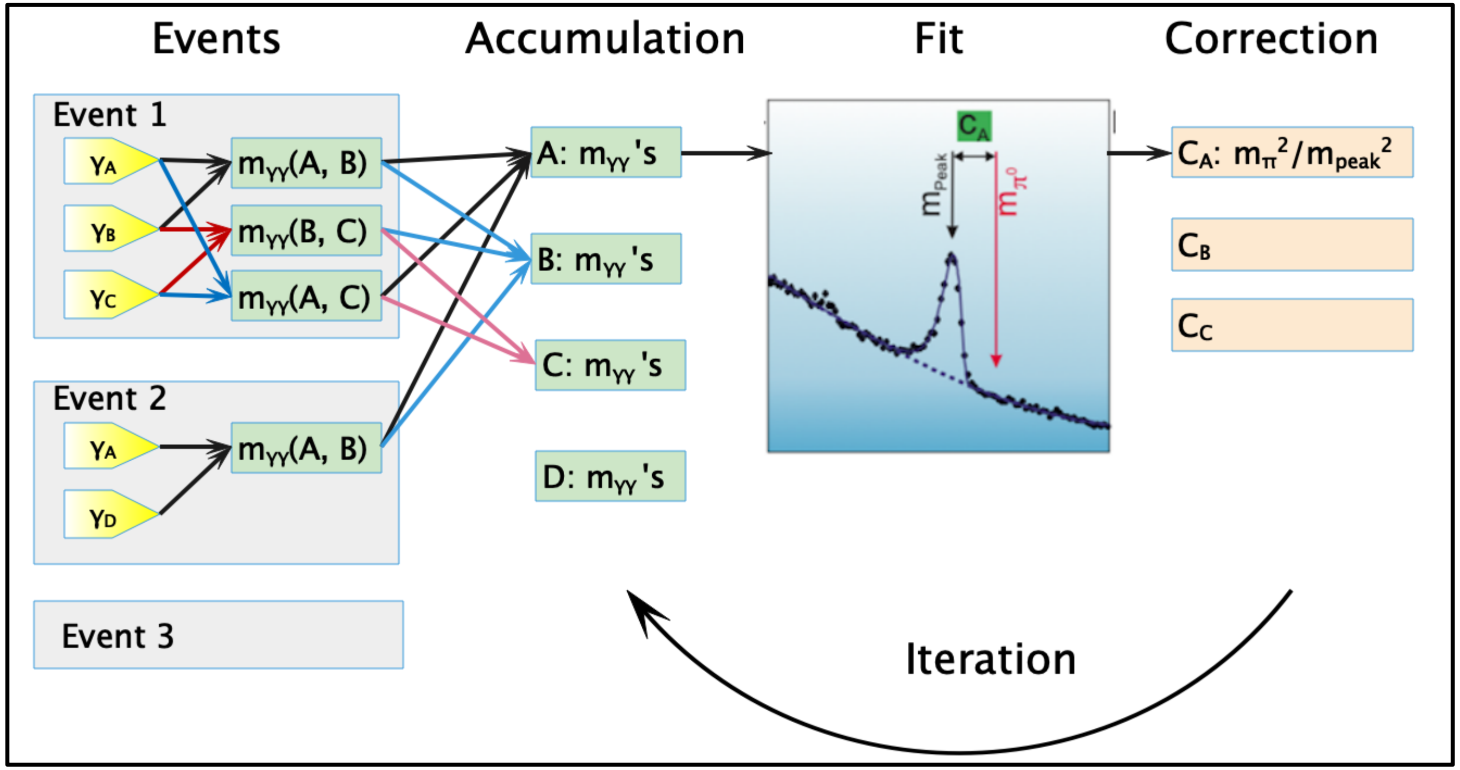
- **Fit:**
  - Fit the invariant mass distribution of π^0 candidates from the prepared date set for each crystal
  - m_{peak} is the MPV from fit
- **Correction:**
  - Calibration constant: $C_0 = \left(m_{\pi^0}^{PDG} / m_{peak}\right)^2$
  - Damping factor: $C_1 = D \cdot (C_0 - 1) + 1$
  - Re-clustering: $E_\gamma = \sum C_1^i \cdot E_{hit}^i$

Fit



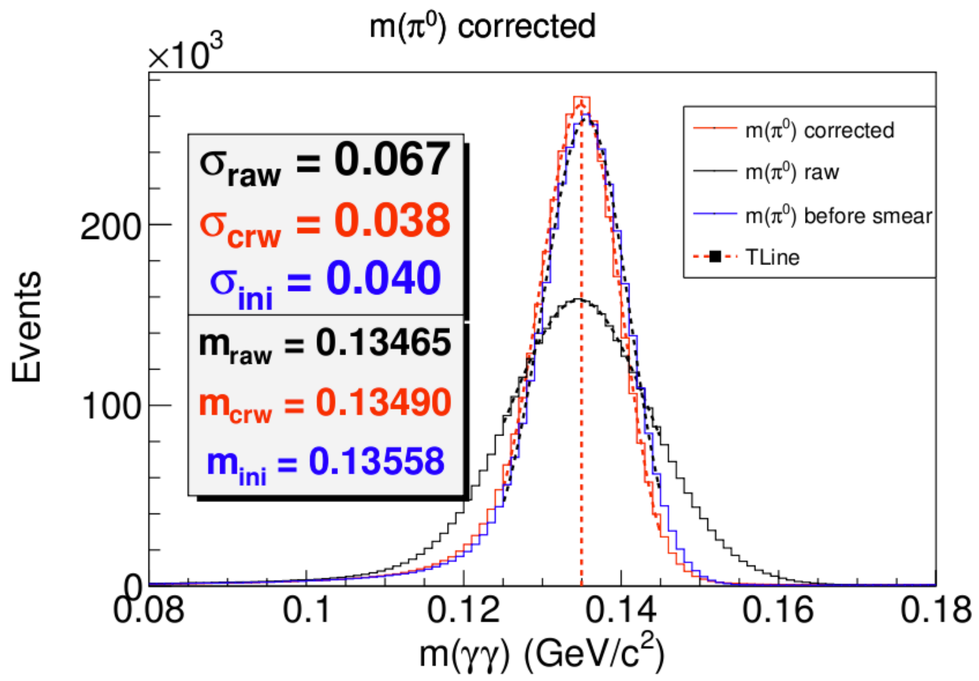
Energy Calibration ($\pi^0 \rightarrow \gamma\gamma$)

- Iteration:

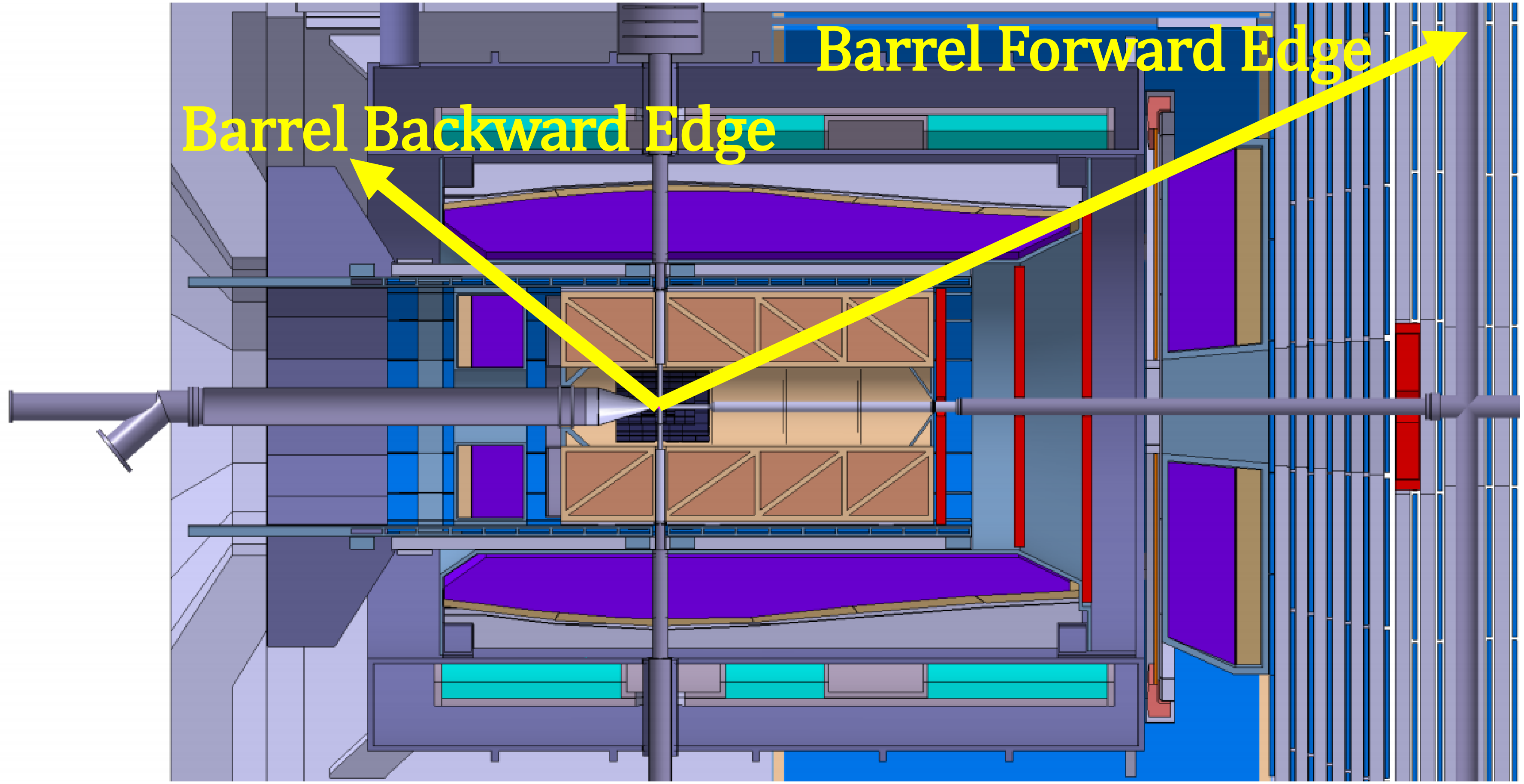


Energy Calibration ($\pi^0 \rightarrow \gamma\gamma$)

- The calibration algorithm can be applied to those inner crystals to avoid the energy leakage at the edge of the EMC.
- Test with multi-threads mode:

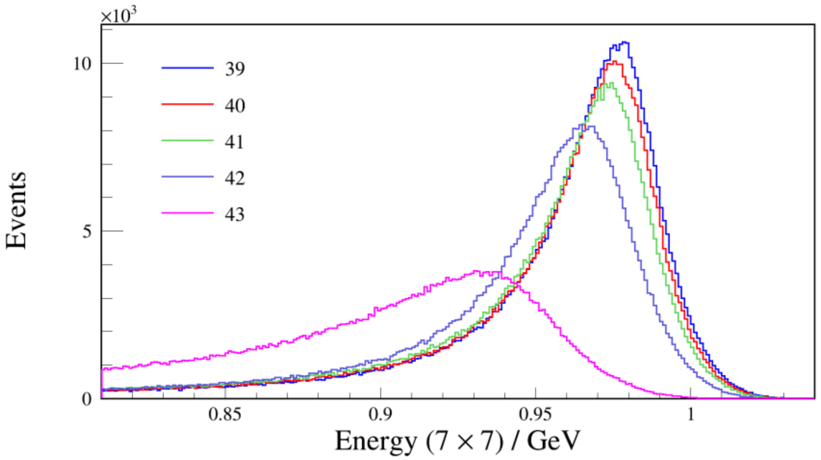


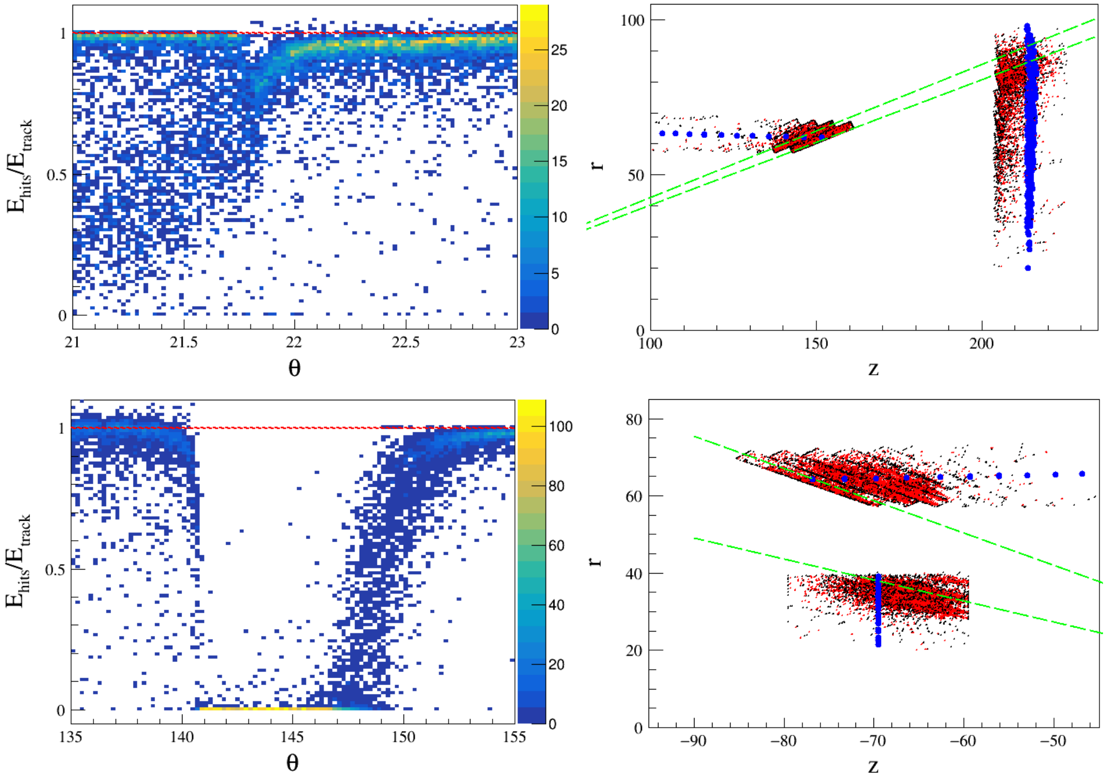
Energy Leakage



Energy Leakage

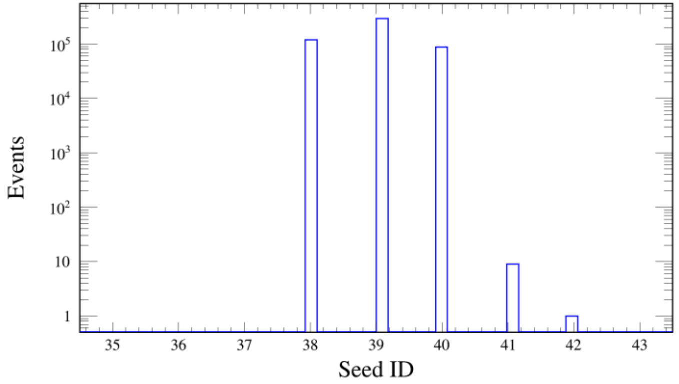
- Energy leakage at edge crystal
  - Statistics lost – bad resolution
  - Shower lost – MPV shift

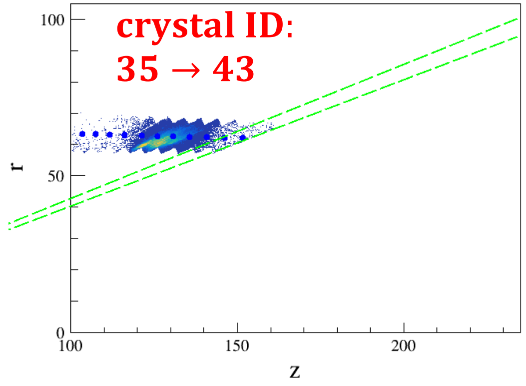


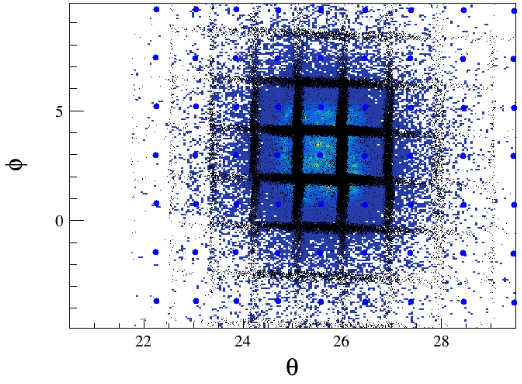


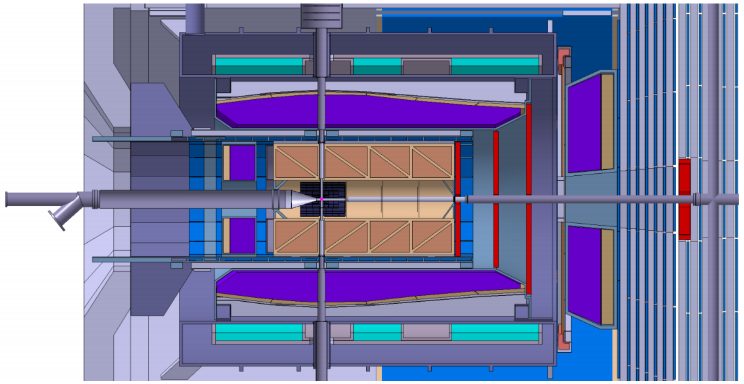
Energy Leakage

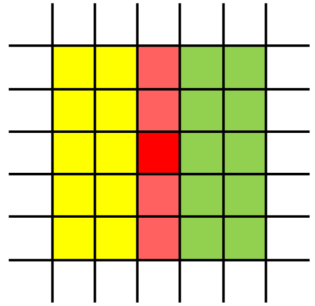
- Data set: single γ



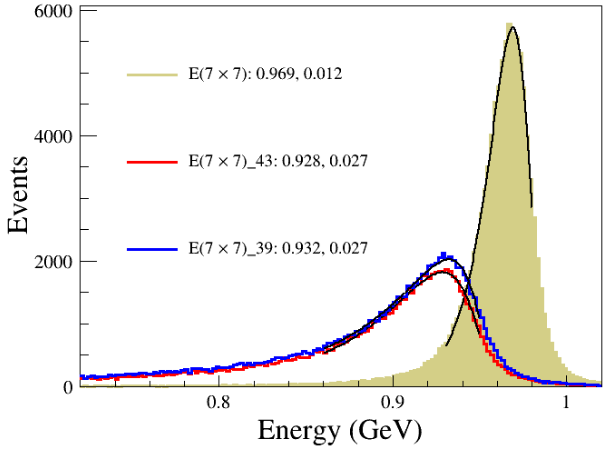






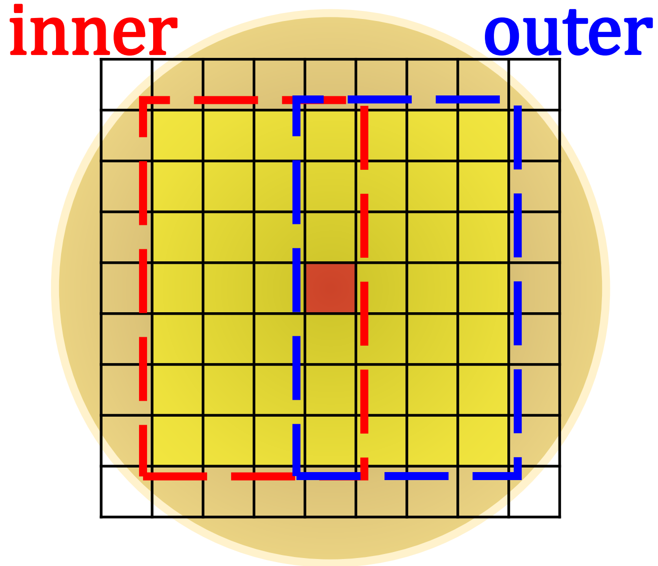


← inner side | seed | outer side →

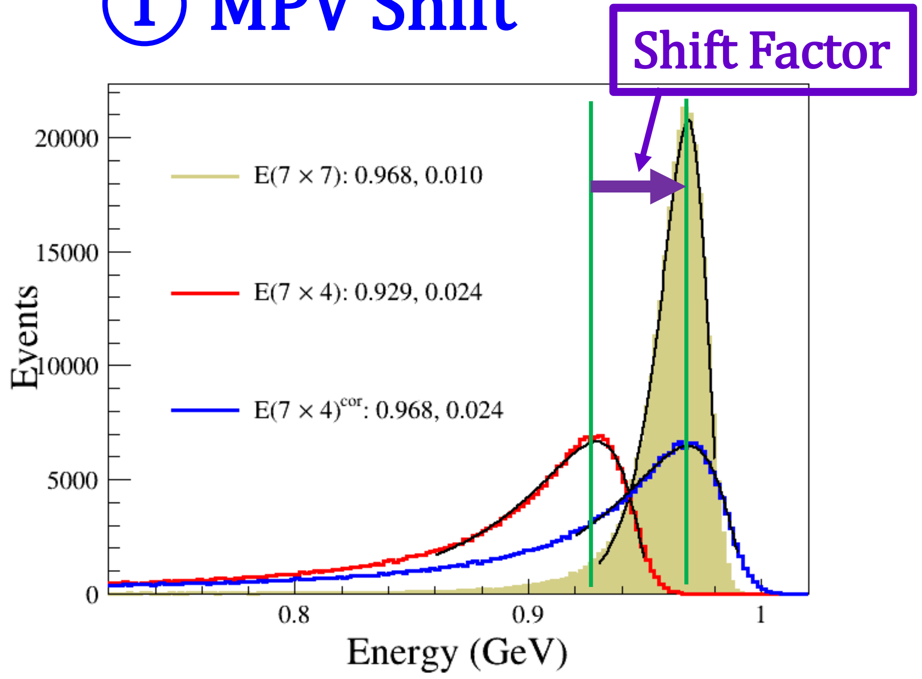


Energy Leakage

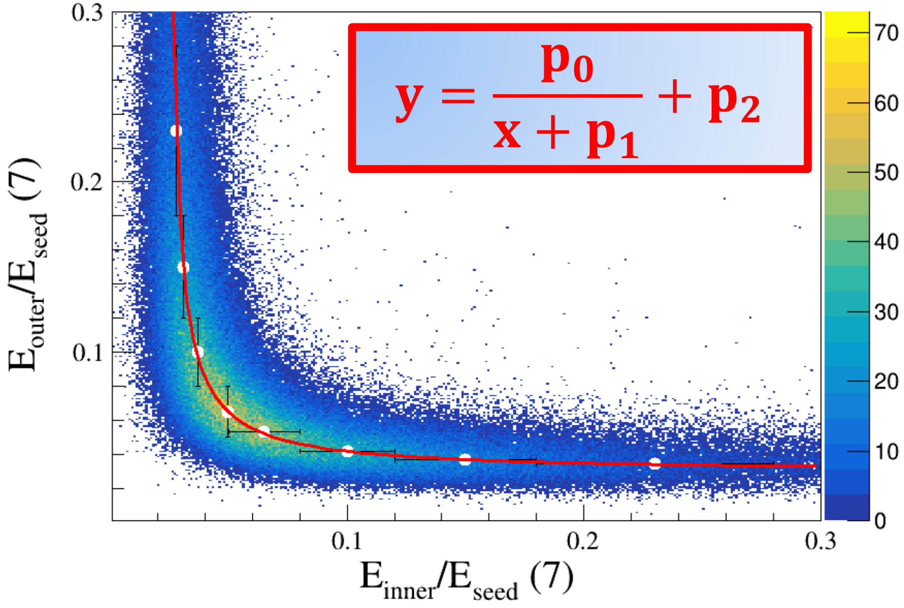
- Correction methods (single γ 5GeV):



① MPV Shift

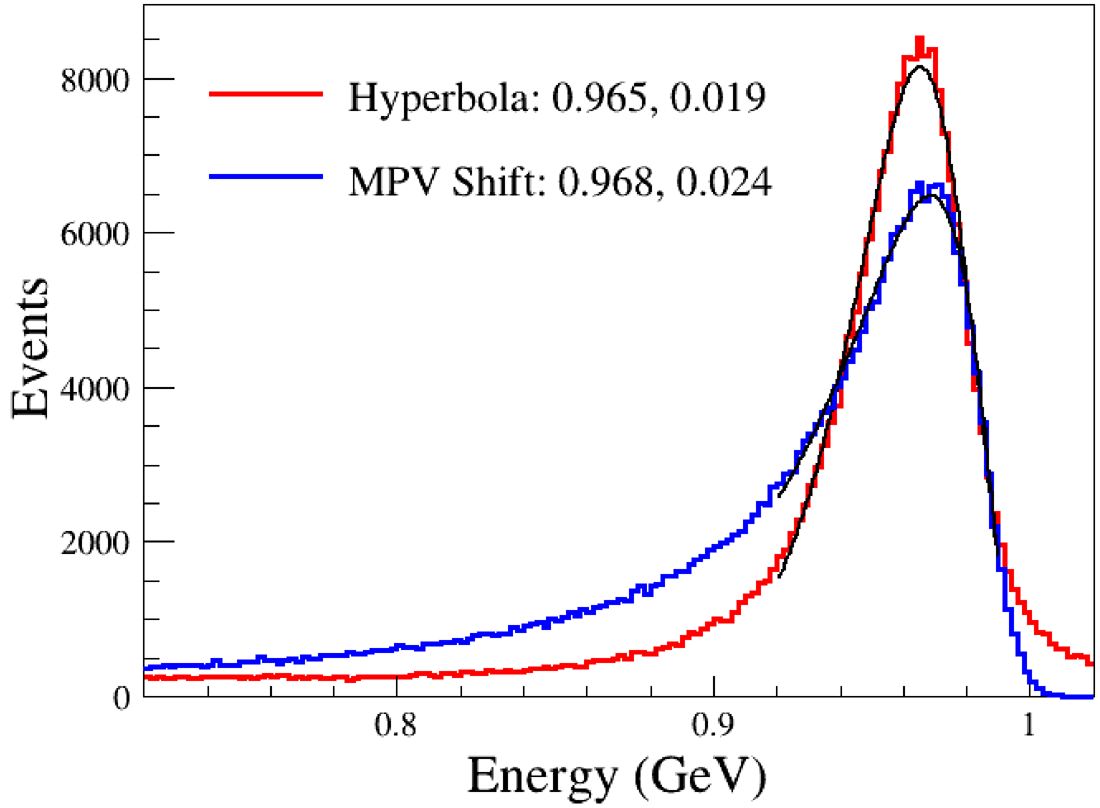


② Hyperbola



Energy Leakage

- Preliminary result (single γ 5GeV):

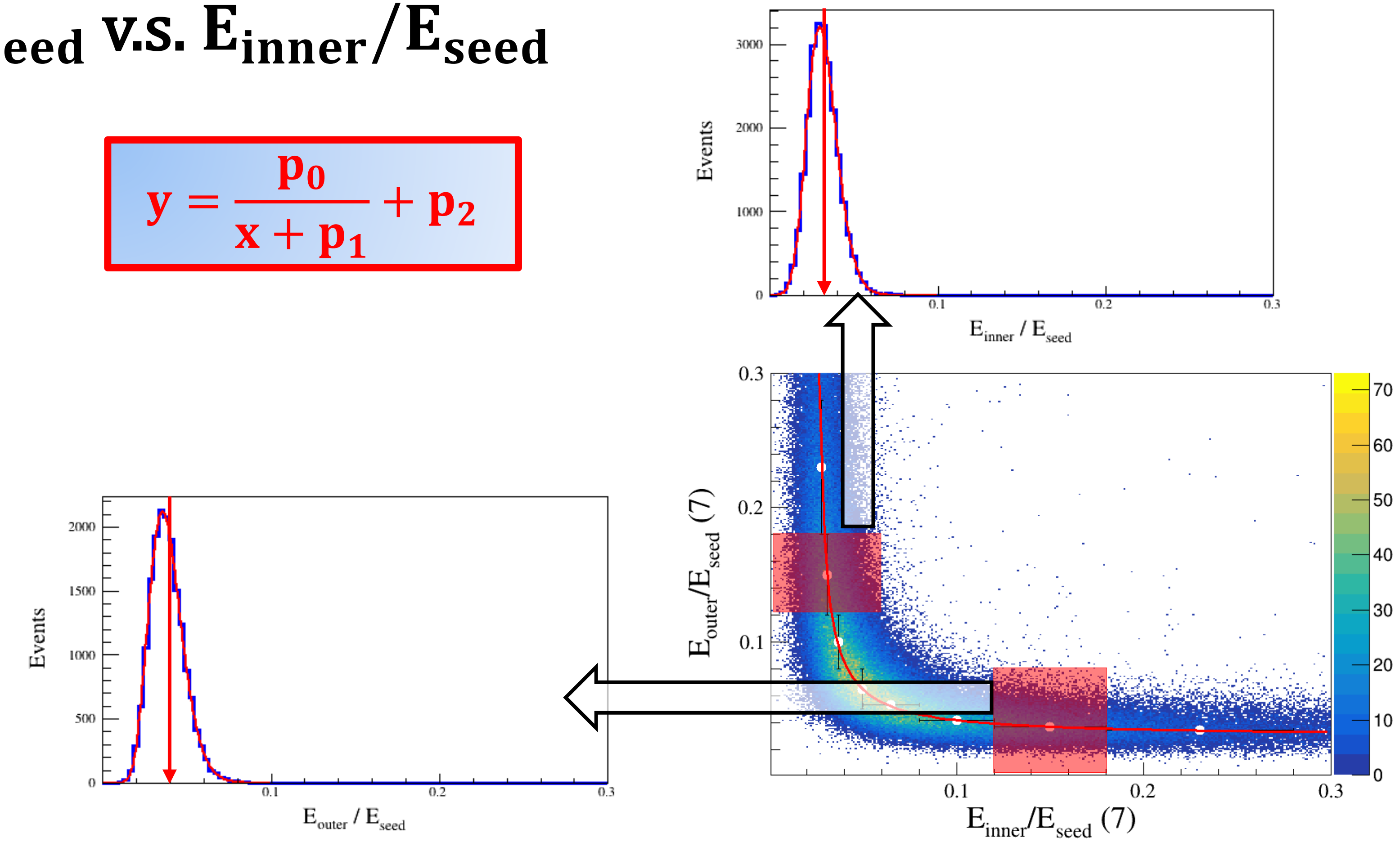


Hyperbola method is applied due to its better resolution

Energy Leakage (Hyperbola method)

- E_{outer}/E_{seed} v.s. E_{inner}/E_{seed}
- MPV
- Median

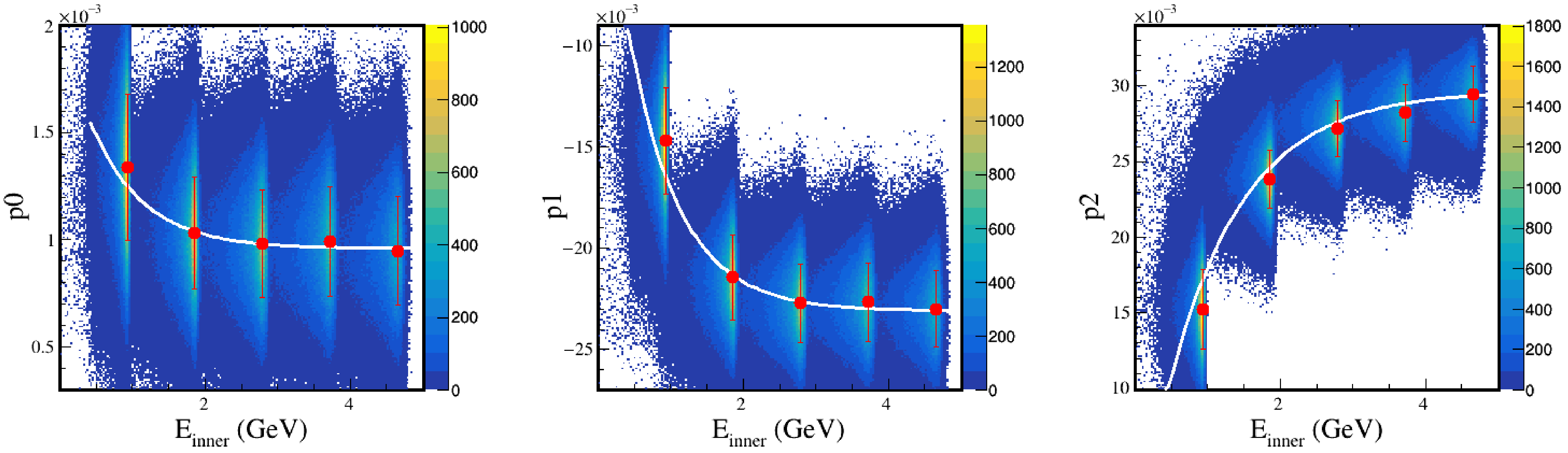
$$y = \frac{p_0}{x + p_1} + p_2$$



Energy Leakage (Hyperbola method)

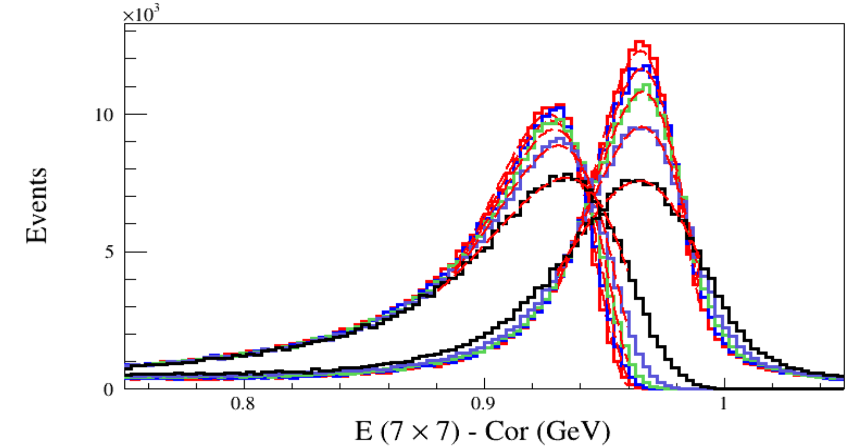
$$y = \frac{p_0}{x + p_1} + p_2$$

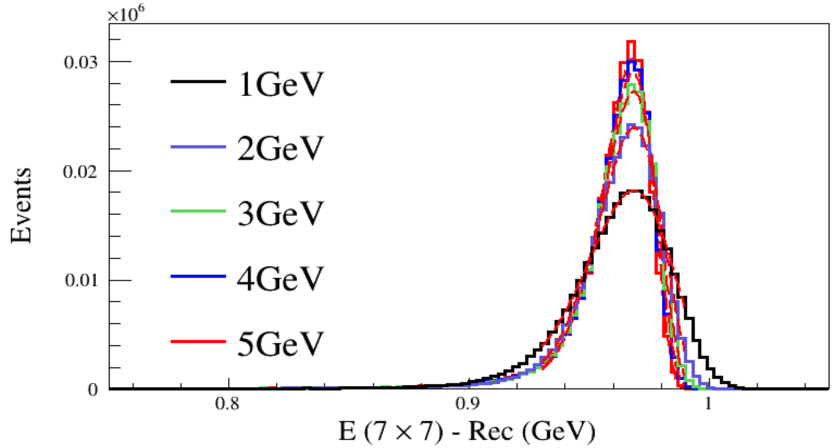
Hyperbola parameters vs. E_{inner}



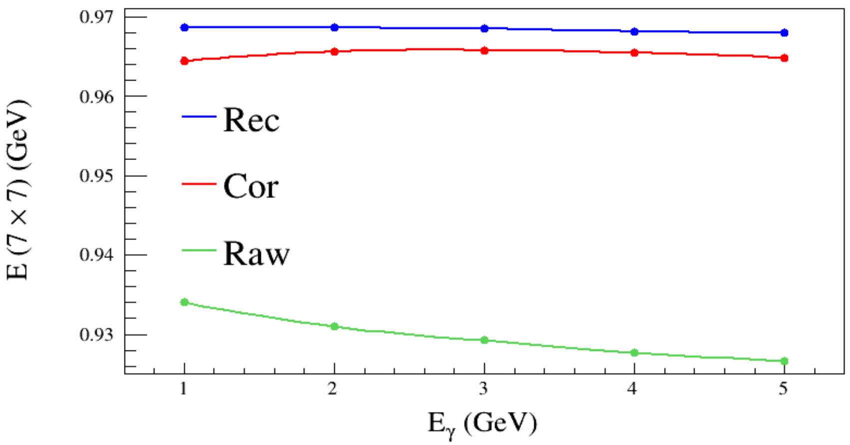
$$y = c1 \cdot exp(c2 \cdot x) + c3$$

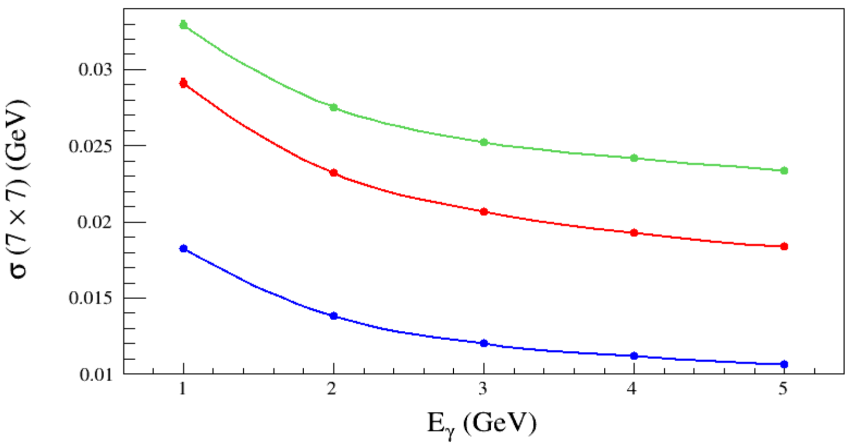
Energy Leakage (Hyperbola method)



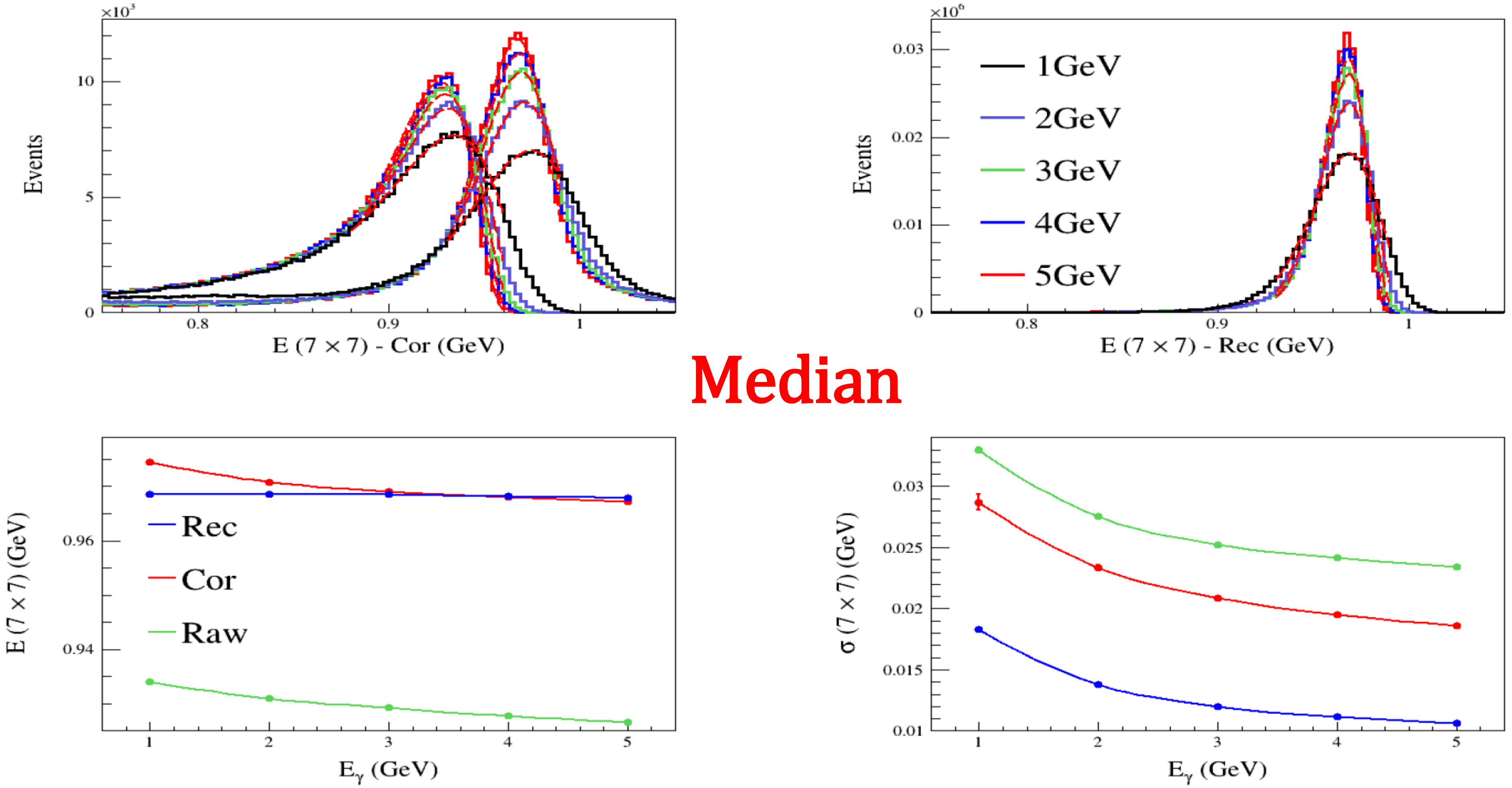


MPV





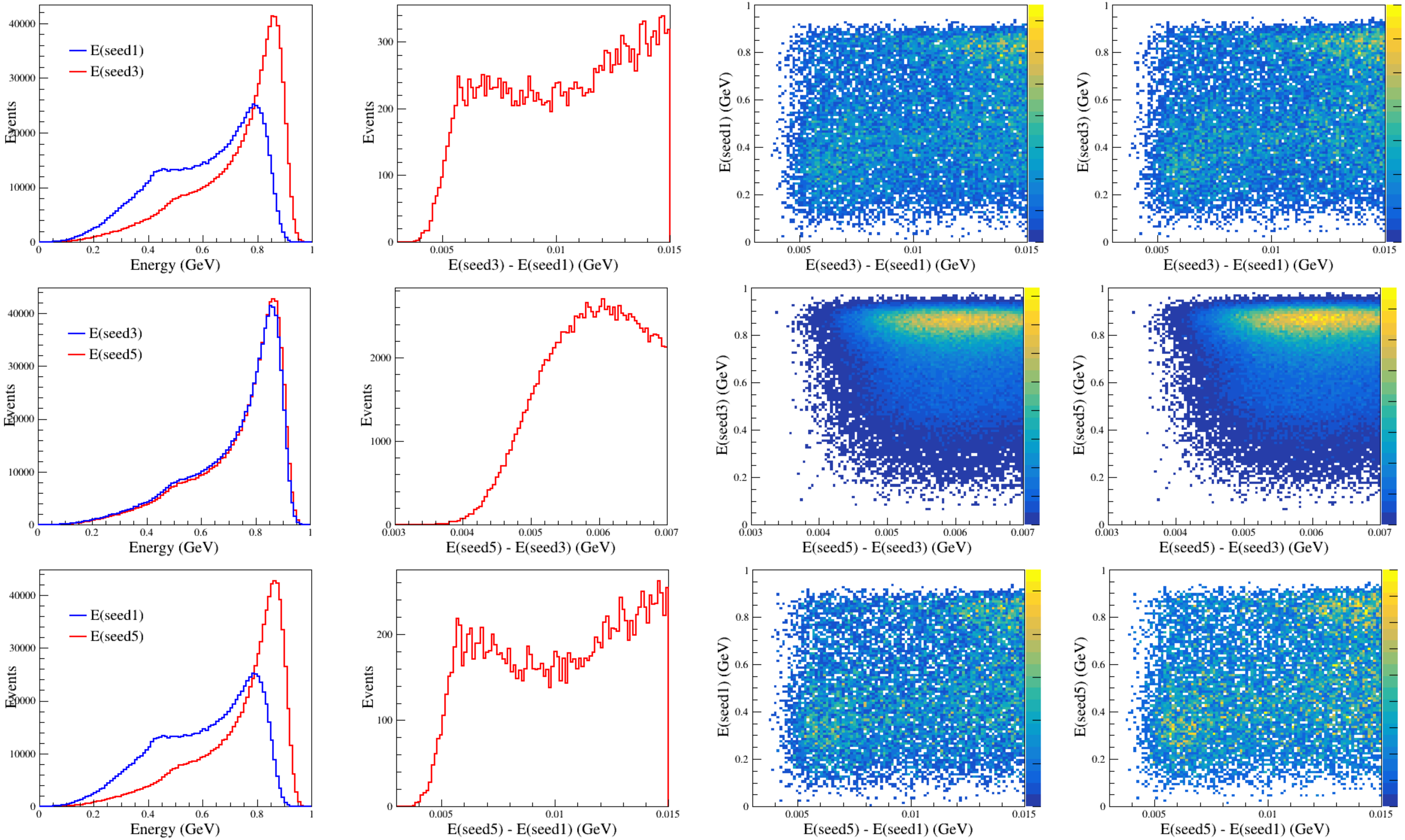
Energy Leakage (Hyperbola method)

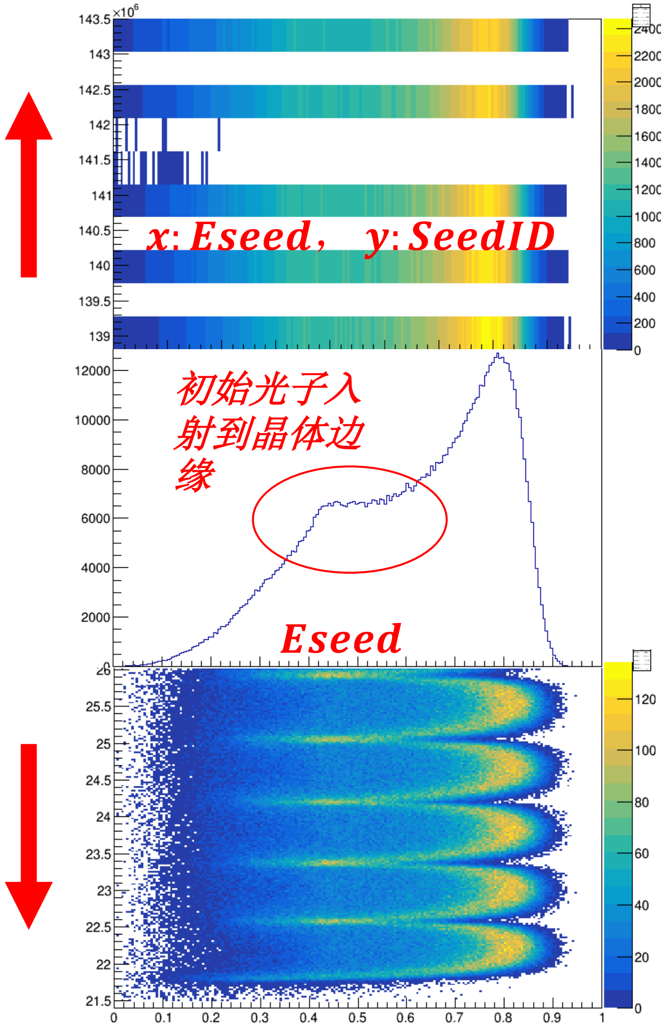


Summary and outlook

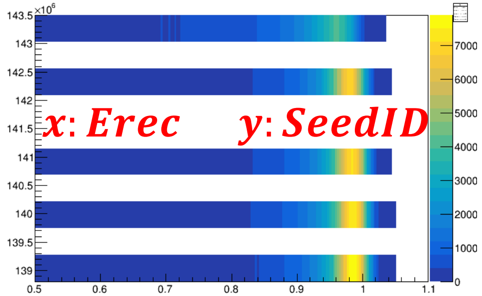
- The calibration algorithm has been built by Liu Dong and successfully applied to the barrel part of PANDA-EMC;
- A hyperbola method is developed to correct the energy leakage problem;
- The hyperbola method will be applied to higher energy;
- The hyperbola method will be applied to the calibration algorithm;
- The calibration algorithm will be applied to the full EMC in the target zone.

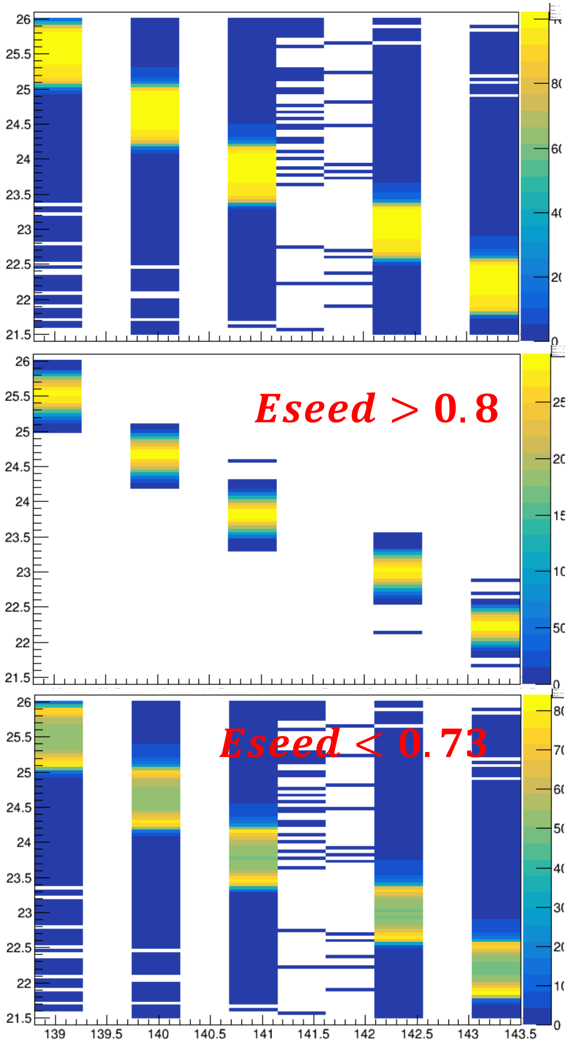
BACKUP


E(seed1)
E(seed3)
Events
Energy (GeV)
E(seed3) - E(seed1) (GeV)
E(seed1) (GeV)
E(seed3) (GeV)
E(seed3)
E(seed5)
E(seed5) - E(seed3) (GeV)
E(seed5) (GeV)
E(seed1)
E(seed5)
E(seed5) - E(seed1) (GeV)



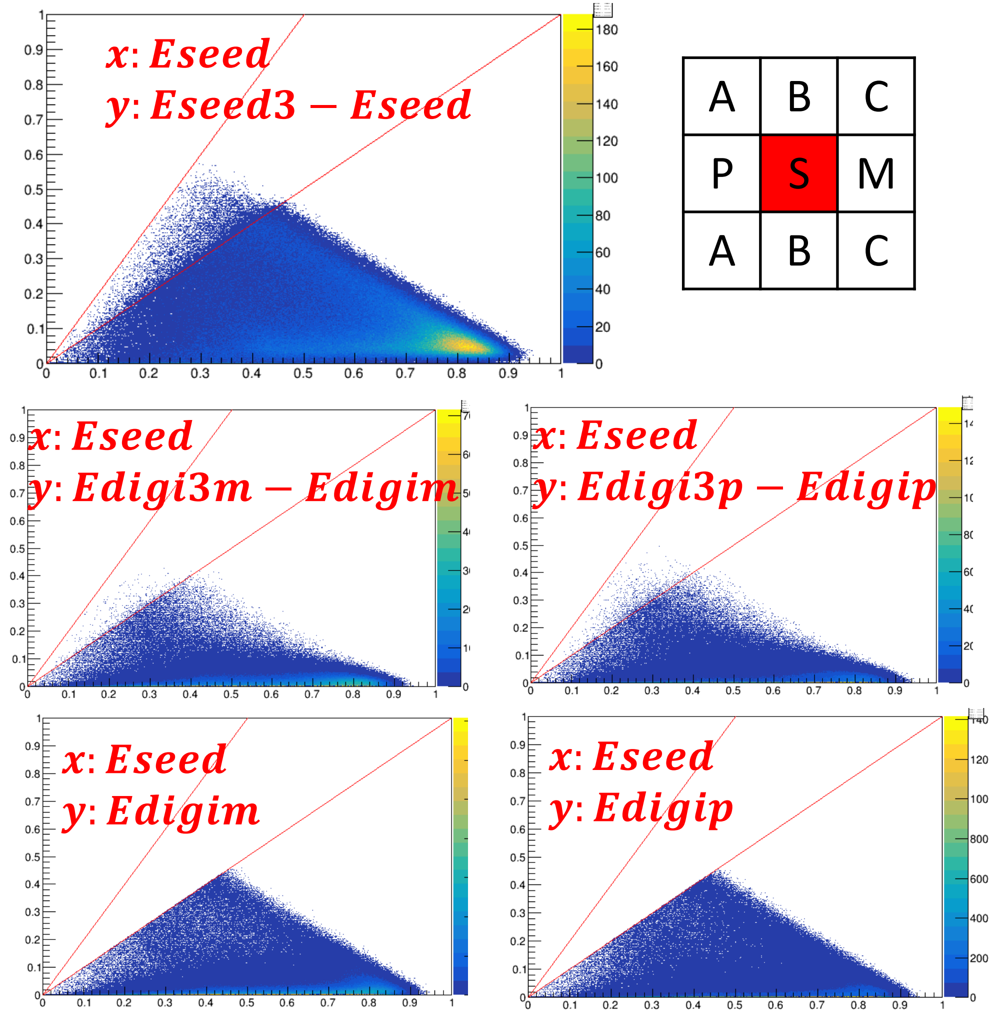
x: Eseed　y: θ_{Sim}





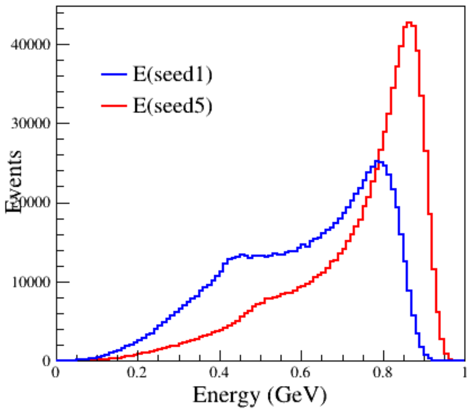
x: SeedID，$y = \theta_{Sim}$

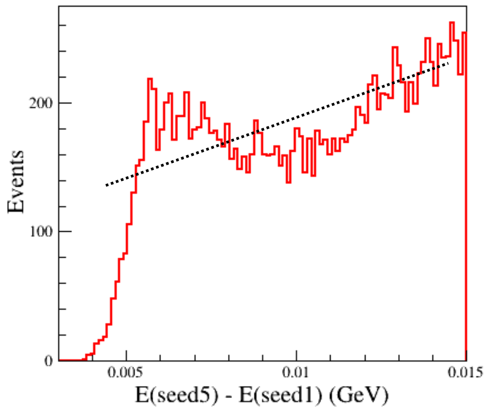
种子晶体重建的还算比较准确，基本上是初始光子入射方向上的晶体

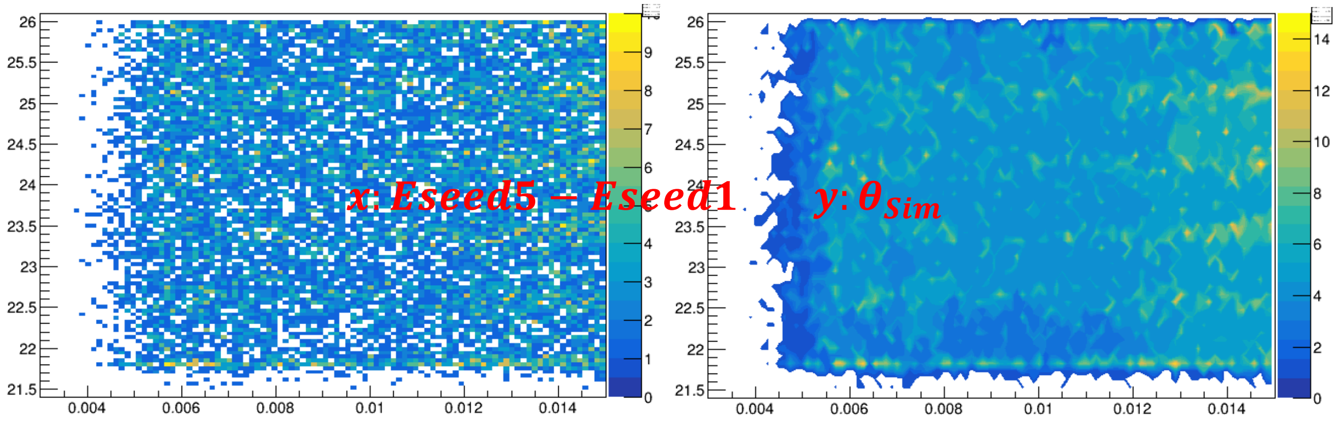


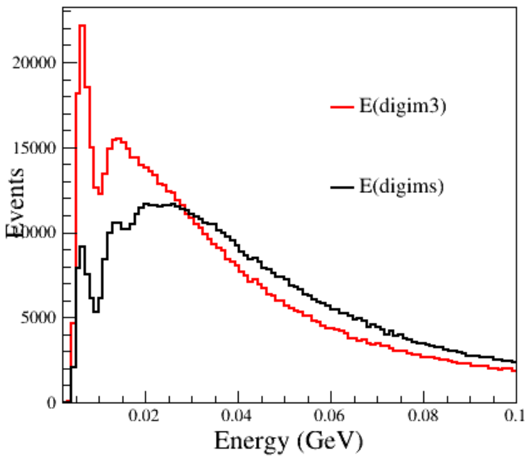
A	B	C
P	S	M
A	B	C

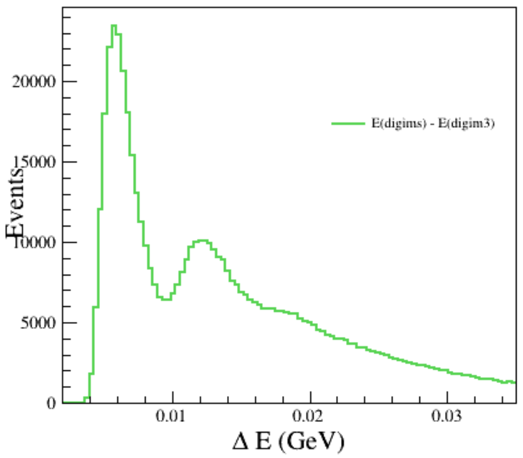
从晶体沉积能量大小来看，种子晶体重建的也还算比较准确，基本上是能量沉积最大的晶体

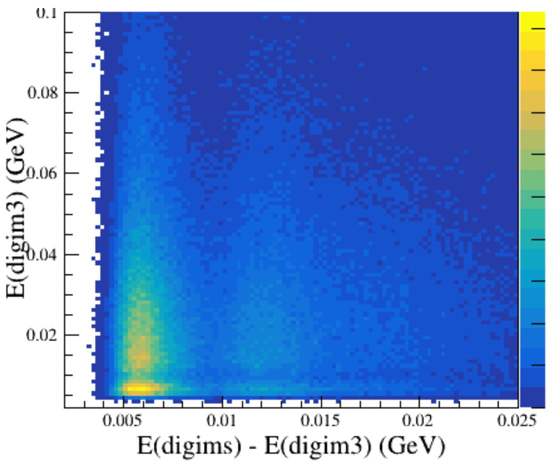


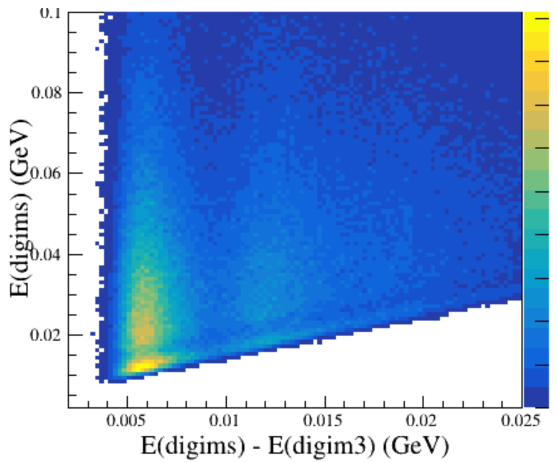


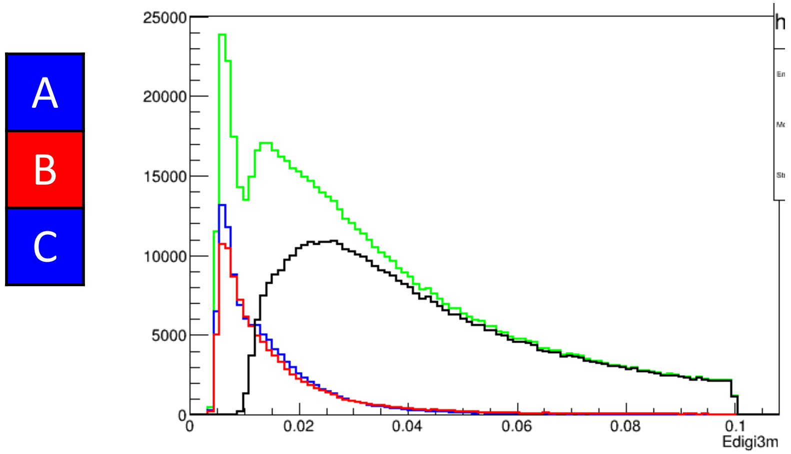


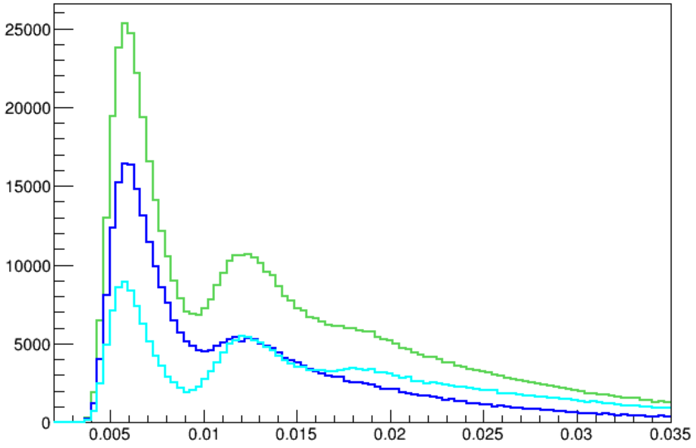




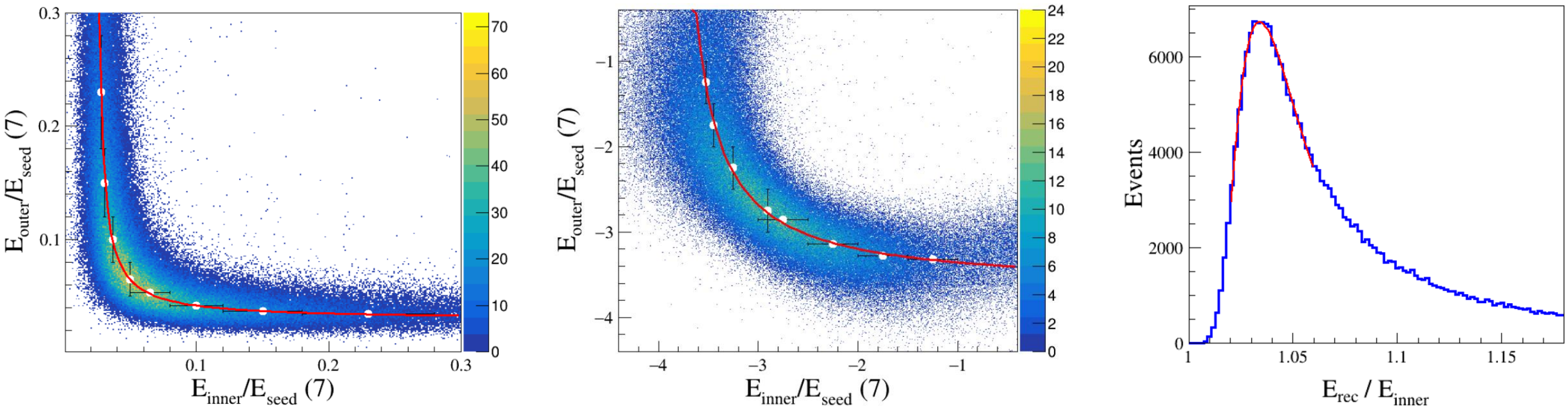




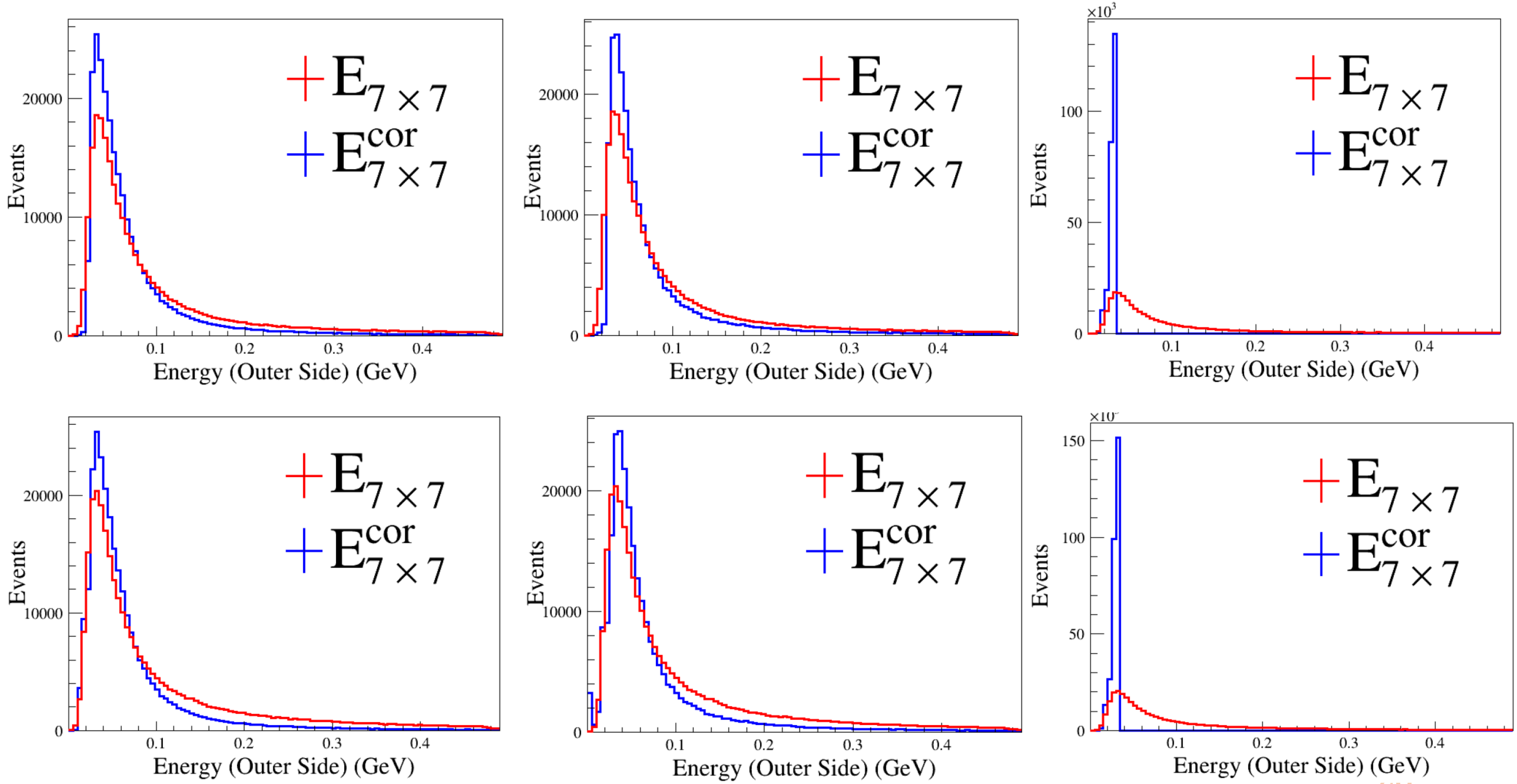




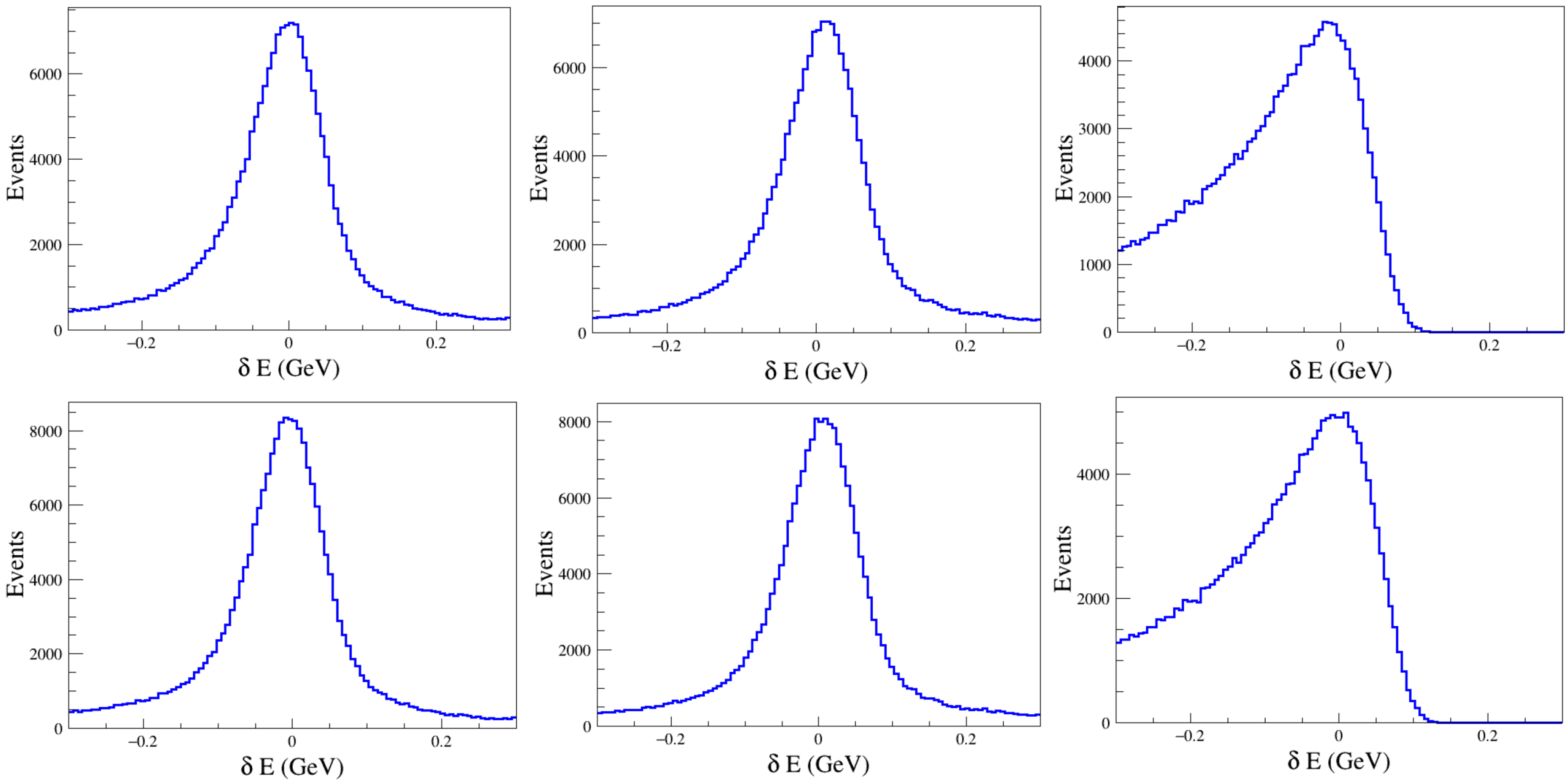
```
EXT PARAMETER
NO.   NAME        VALUE
 1   Constant     2.64451e+04
 2   Mean         5.96220e-03
 3   Sigma        9.35798e-04
FitEditor::DoFit - using funct
FCN=29.621 FROM MIGRAD    STAT
                   EDM=2.1814
EXT PARAMETER
NO.   NAME        VALUE
 1   Constant     1.07045e+04
 2   Mean         1.23352e-02
 3   Sigma        2.49873e-03
```

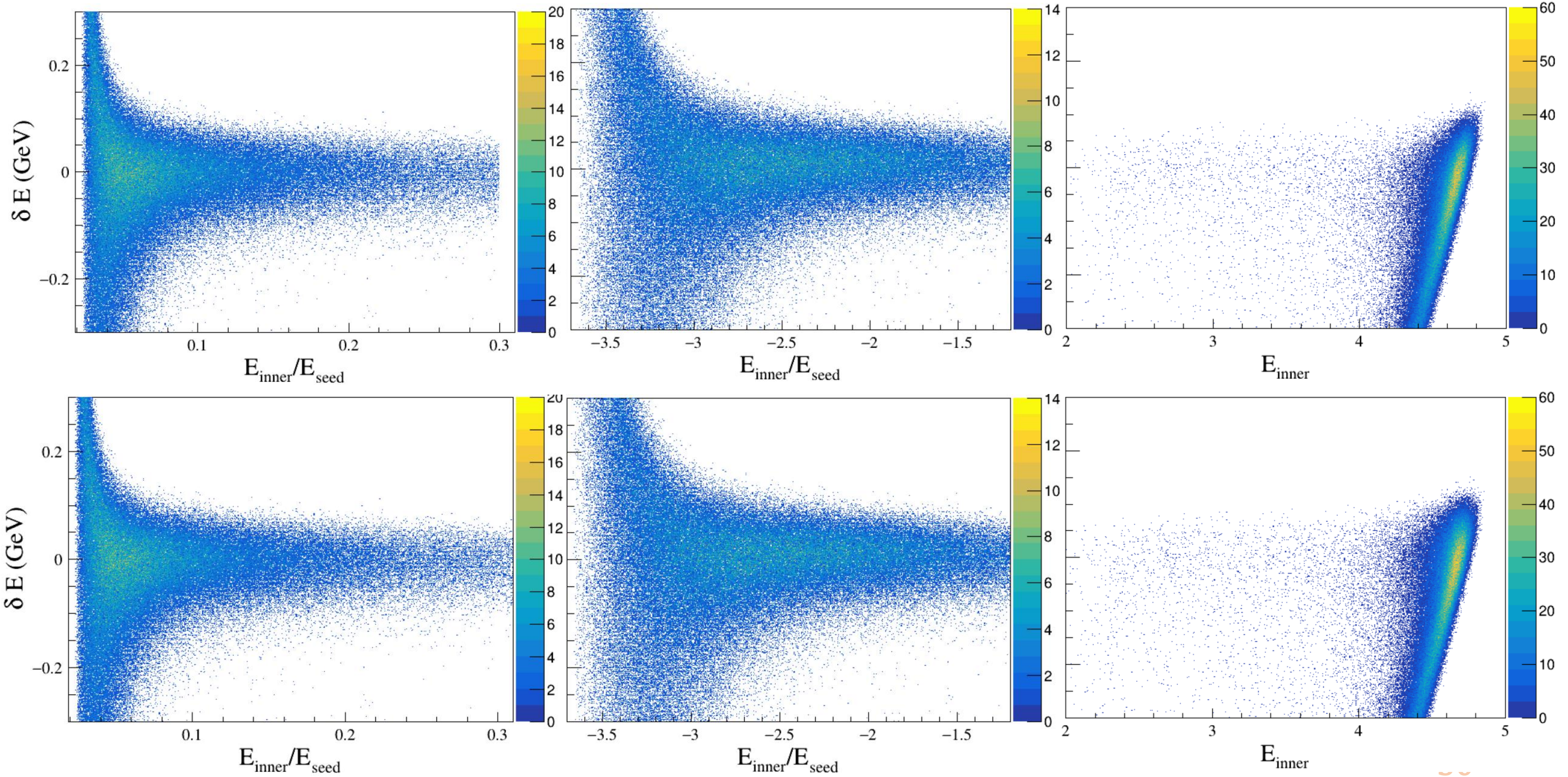


E_outer/E_seed (7)
E_inner/E_seed (7)
Events
E_rec / E_inner

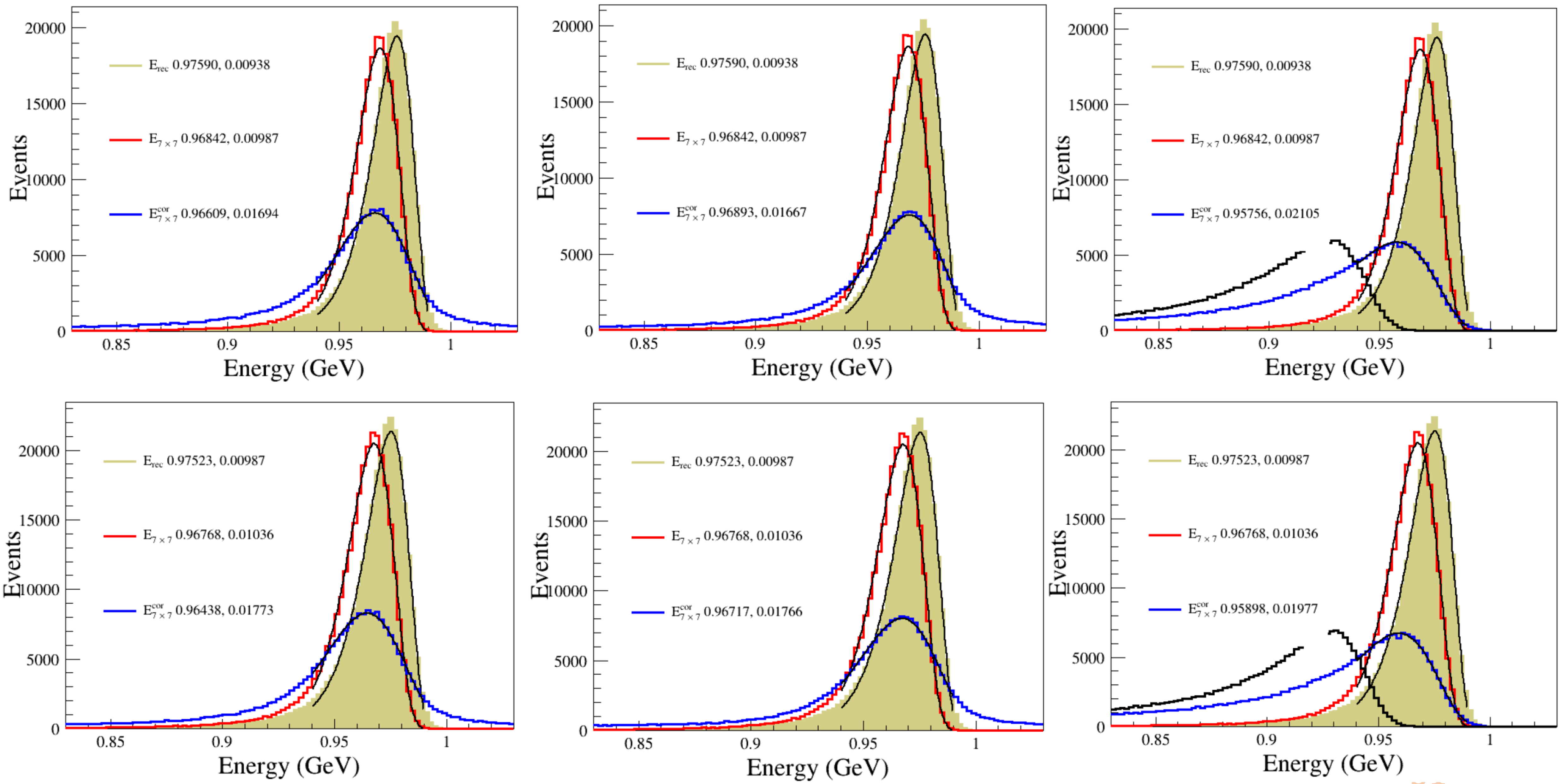


Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
10000
20000
0.1
0.2
0.3
0.4
Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
10000
20000
0.1
0.2
0.3
0.4
×10³
Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
50
100
0.1
0.2
0.3
0.4
Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
10000
20000
0.1
0.2
0.3
0.4
Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
10000
20000
0.1
0.2
0.3
0.4
×10
Events
Energy (Outer Side) (GeV)
$E_{7\times7}$
$E^{cor}_{7\times7}$
0
50
100
150
0.1
0.2
0.3
0.4


Events
δ E (GeV)
0
2000
4000
6000
8000
1000
3000
−0.2
0
0.2



δ E (GeV)
0.2
0
−0.2
0.1
0.2
0.3
E_inner/E_seed
−3.5
−3
−2.5
−2
−1.5
2
3
4
5
E_inner
0
2
4
6
8
10
12
14
16
18
20
60
50
40
30



E_rec 0.97590, 0.00938
E_7×7 0.96842, 0.00987
E^cor_7×7 0.96609, 0.01694
E_rec 0.97590, 0.00938
E_7×7 0.96842, 0.00987
E^cor_7×7 0.96893, 0.01667
E_rec 0.97590, 0.00938
E_7×7 0.96842, 0.00987
E^cor_7×7 0.95756, 0.02105
E_rec 0.97523, 0.00987
E_7×7 0.96768, 0.01036
E^cor_7×7 0.96438, 0.01773
E_rec 0.97523, 0.00987
E_7×7 0.96768, 0.01036
E^cor_7×7 0.96717, 0.01766
E_rec 0.97523, 0.00987
E_7×7 0.96768, 0.01036
E^cor_7×7 0.95898, 0.01977
Events
Energy (GeV)