FCAL energy calibration

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for the GlueX and PrimEX-D experiments

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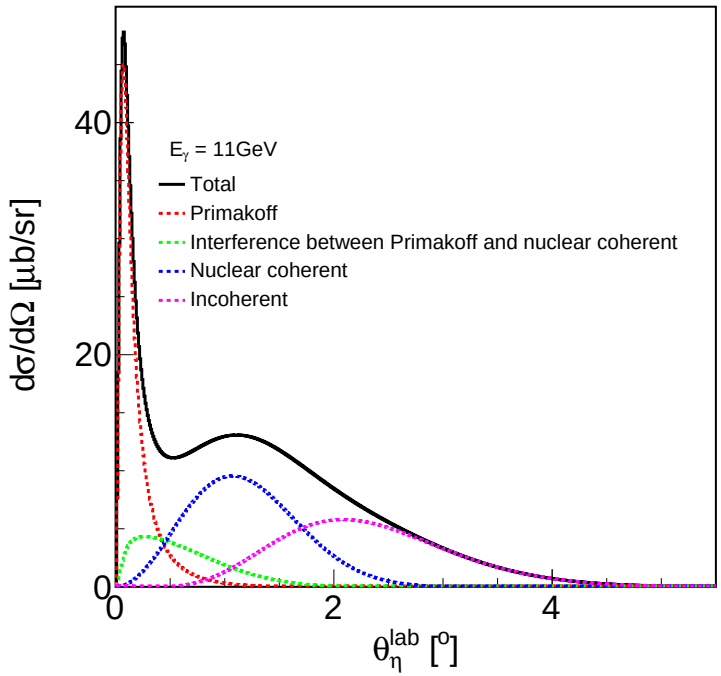
Introduction

PRIMEXD or η decay width measurements via the Primakoff process is measured by FCAL

- Expected differential cross-section



$$\gamma^4He \rightarrow \eta(\rightarrow \gamma\gamma)^4He$$

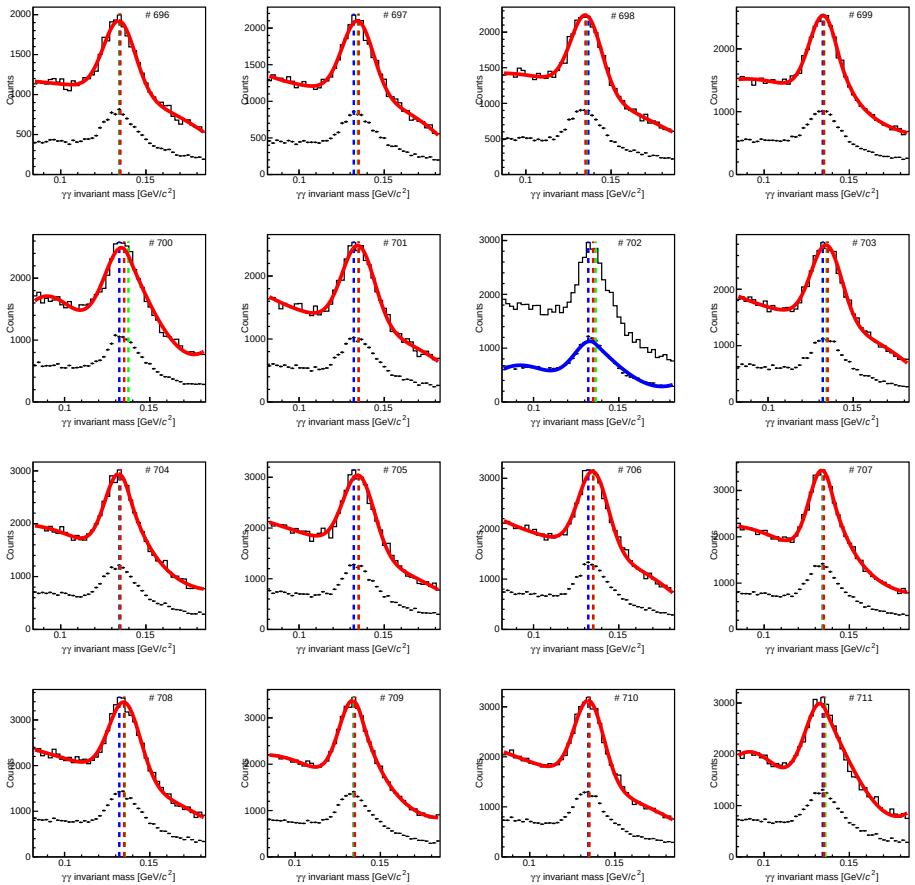
- PDG average: $\Gamma(\eta \rightarrow \gamma\gamma) = 0.51\ keV \pm 0.018\ keV$
- PRIMEXD expected precision for decay width: 3.2 %

- Require 1% energy calibration precision for all η momenta and polar angles (below 7^o)
- => Implementation of a "new" calibration procedure for data and simulation
  - Find bad channels for each run and determined if can still be used or removed in clustering (Chandra)
  - Gains calibration done without energy dependence correction applied
  - Energy dependence correction per ring

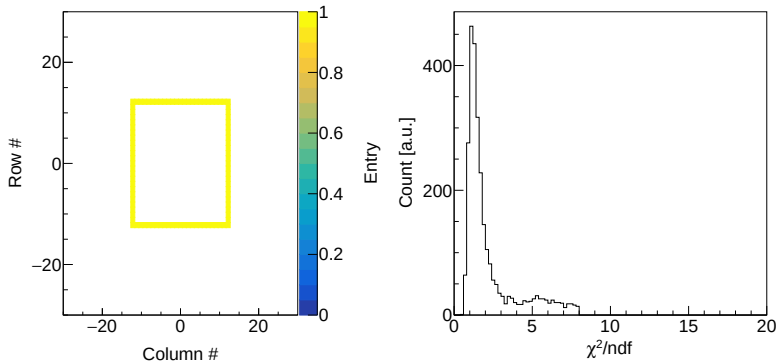
PRIMEXD runs

No magnetic field but some runs have CDC and/or FDC turn on

- New π^0 skim/plugin that includes TOF, trigger bit, and tagged photon-beam
- New macros developped with enhanced visualization
  $=>$ e.g. square 10, first batch of 16 channels



- All possible di-photon combinations out of 12 photons
- $|t_{\mathrm{cluster\ 1}} - t_{\mathrm{cluster\ 2}}| \leq 1$ ns
- Random background subtracted
- Trigger bit checked

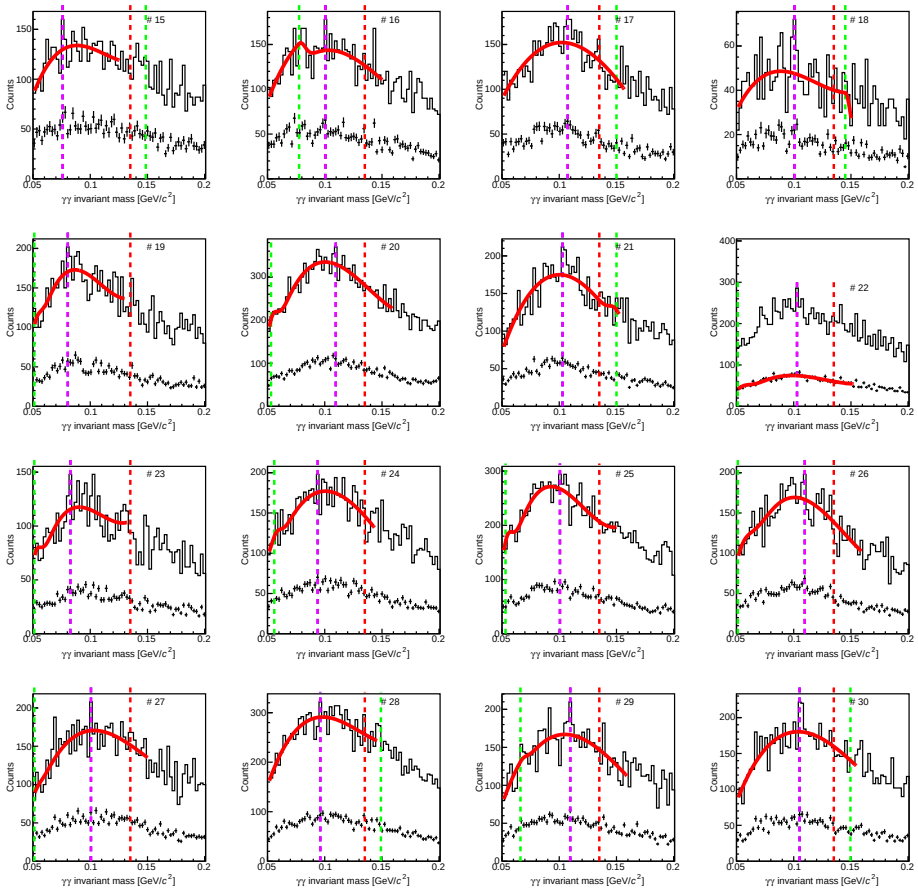


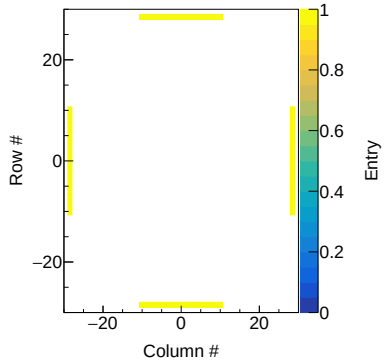
- Fit function: crystalball + exp(pol3 or 5)
- Results accepted if $\chi^2 \leq 8$
- If bad channels gain set to 1

FCAL gains calibration

Of all channels

- Ilya's method for outer rings: distribution expected to peak around 100 MeV/c^2 $=>$ e.g. square 26, first batch of 16 channels

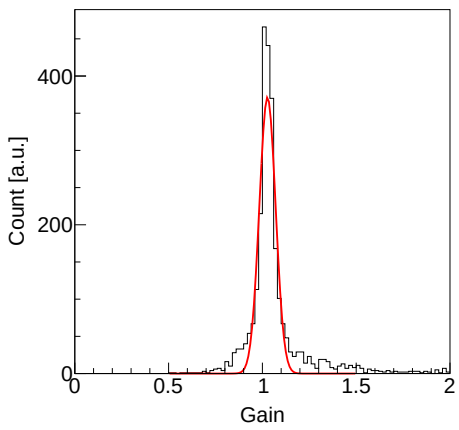


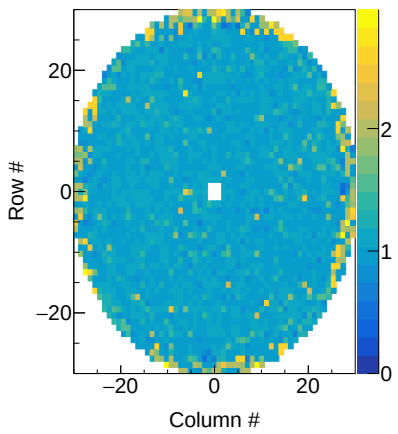


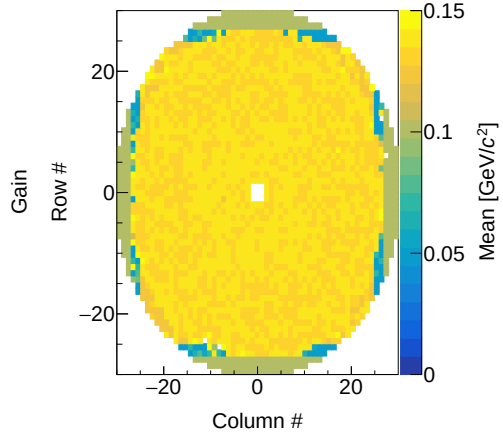
- Fit function: Gaus + pol3 or 5
- Results accepted if $\chi^2 \leq 8$
- If bad channels gain set to 1

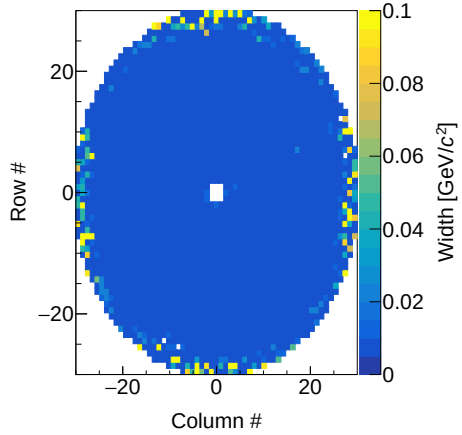
Gain definition

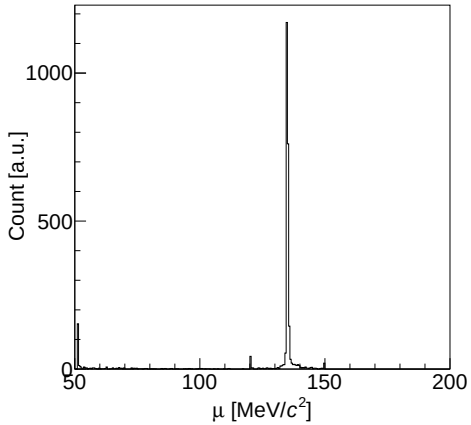
$$\text{New gain} = \text{old gain} \times \frac{\pi^0 \text{ PDG mass}}{\text{Fitted mean}}$$

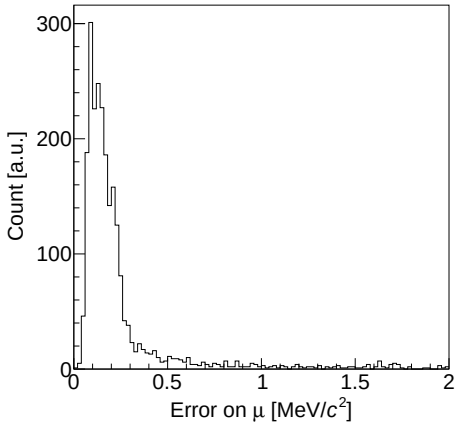


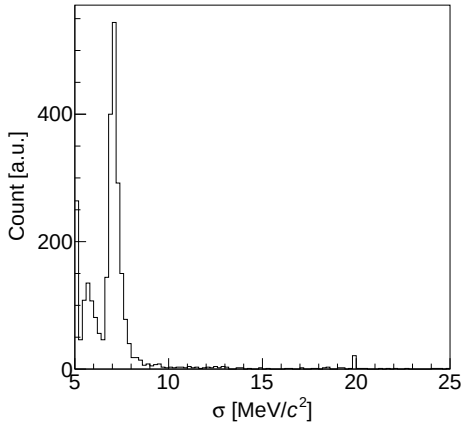


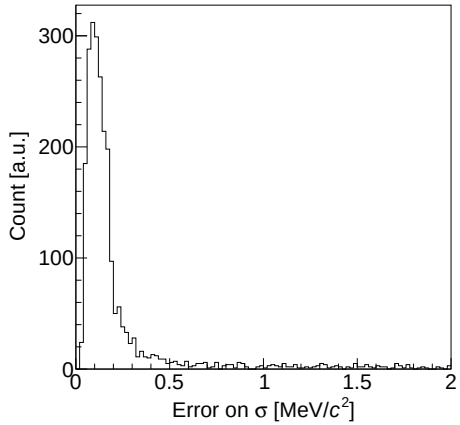








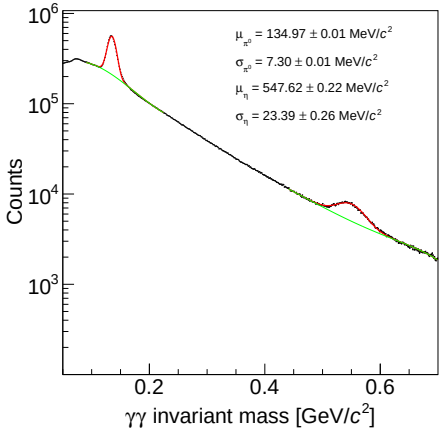




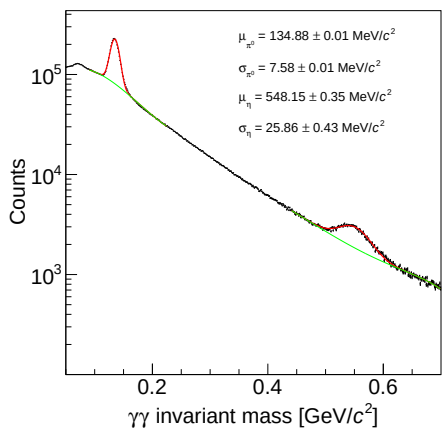
Quality assurance

- Fitted π^0 mean within $\pm$ 1 % of the PDG mass (101 MeV/c^2 for outer rings) for all channels
- PRIMEXD phase I divided into 7 periods

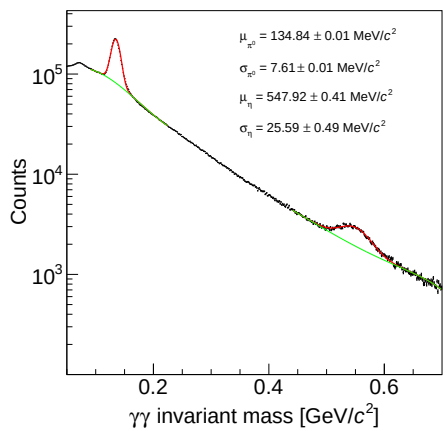
- Be runs



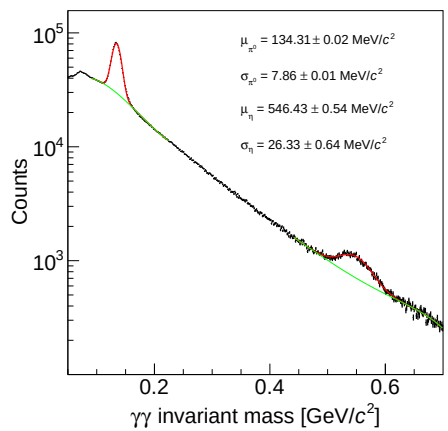
- He runs, first 1/6



- He runs, second 1/6



- He runs, last 1/6

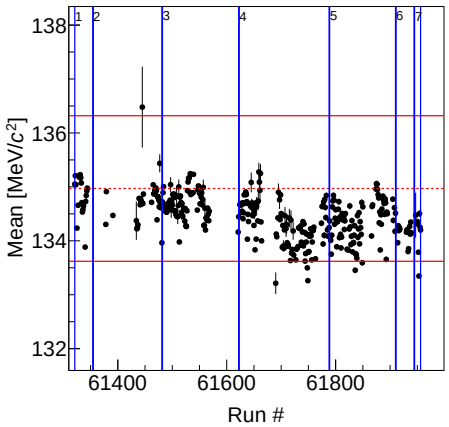


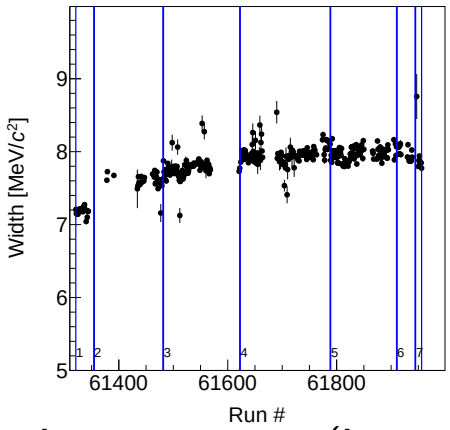
Target	run range	μ_{π^0} [MeV/c^2]	σ_{π^0} [MeV/c^2]	μ_η [MeV/c^2]	σ_η [MeV/c^2]
Be	61321-61332	134.97	7.3	547.62	23.39
He	61437-61479	134.99	7.58	548.15	25.86
He	61510-61519	134.84	7.61	547.92	25.59
He	61700-61709	134.61	7.65	547.33	26.64
He	61810-61818	134.42	7.78	546.72	23.83
He	61930-61939	134.31	7.86	546.43	26.33
He	61947-61956	134.35	7.82	547.09	26.82

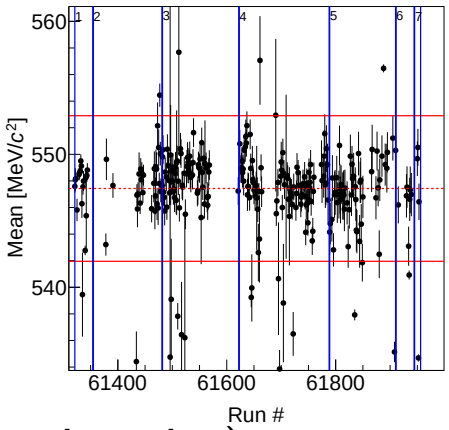
Quality check

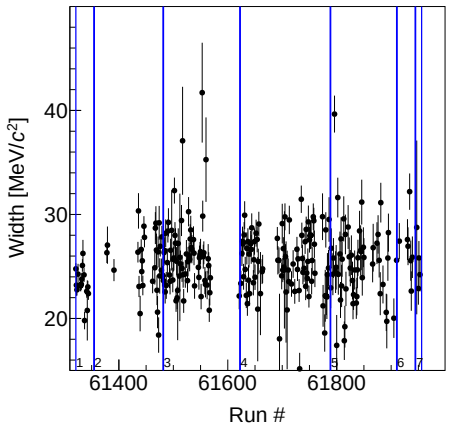
Without energy dependence correction applied

- π^0 mean
- π^0 *width*
- η mean
- η width



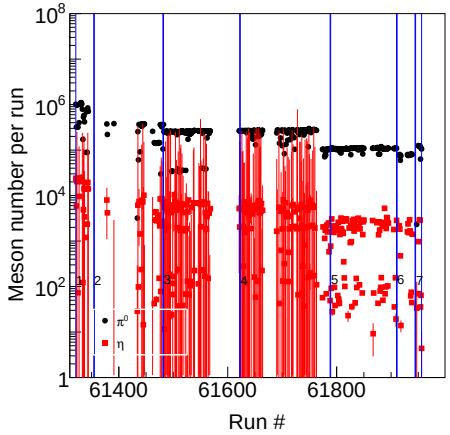


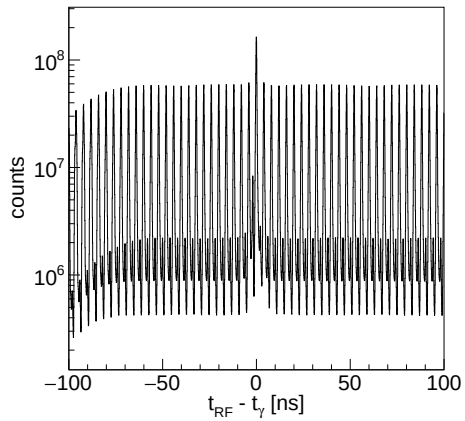




- Still some room for improvements (i.e. more iteration)
- All fitted mean for π^0 and η within $\pm$ 1 % for all physics runs

- Counting per run
- RF - tagger time

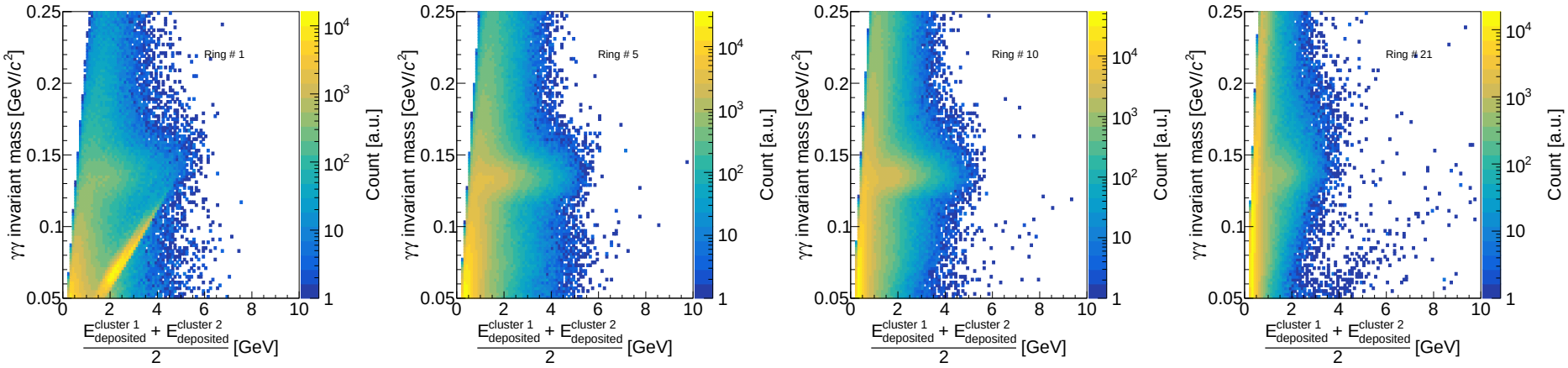


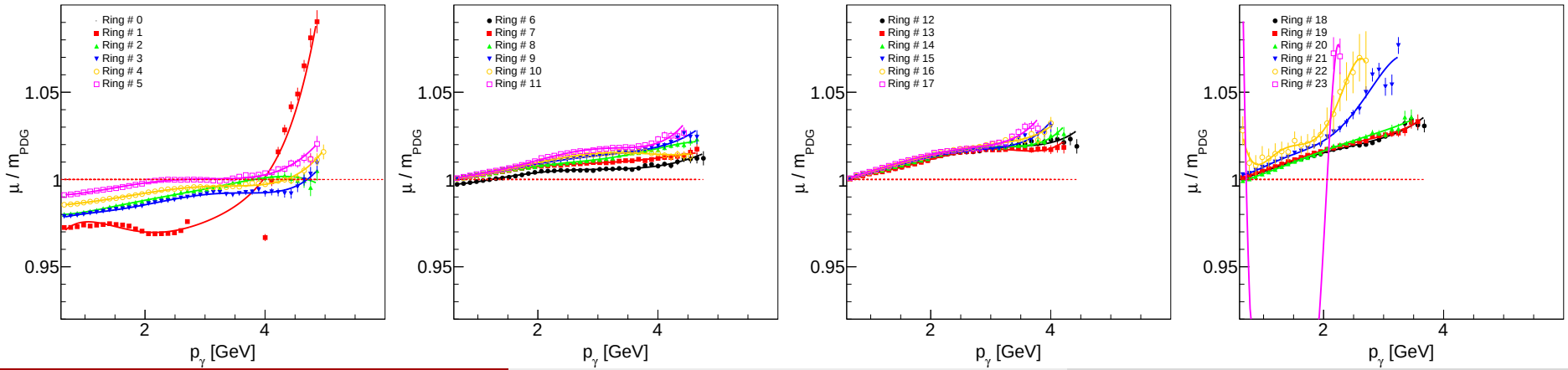


Energy dependence correction

Per "ring" for all physics runs combined, cell with max. energy face radius divided by 5 cm

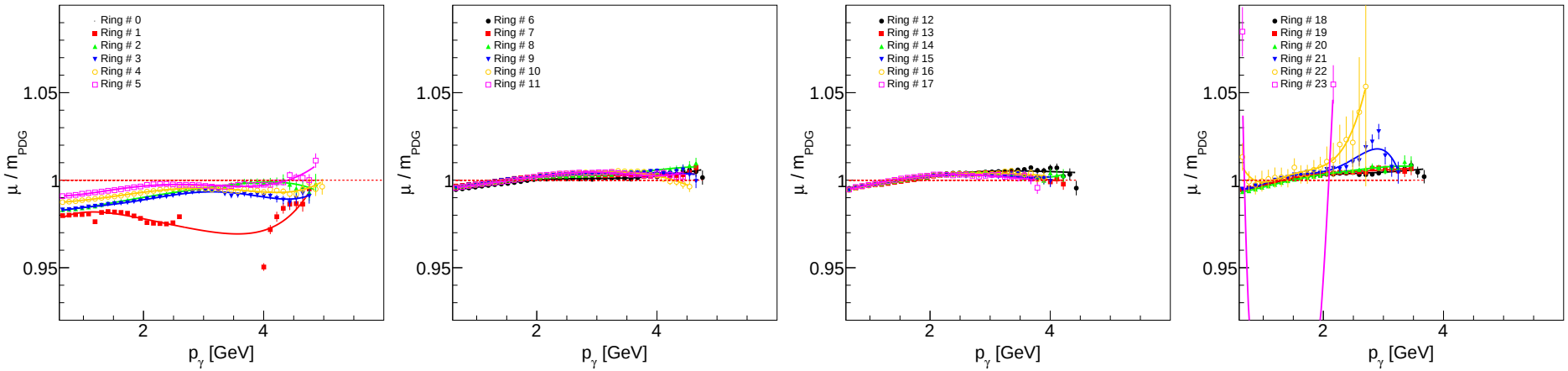
- 25 "rings"
- $|\mathrm{E}^{\mathrm{cluster\ 1}}_{\mathrm{deposited}} - \mathrm{E}^{\mathrm{cluster\ 2}}_{\mathrm{deposited}}| < 100$ MeV
- Find π^0 fitted mean vs. photon momentum
- Correction: $E_\gamma = \frac{E_{\mathrm{cluster}}}{A+BE_{\mathrm{cluster}}+CE^2_{\mathrm{cluster}}+CE^3_{\mathrm{cluster}}+CE^4_{\mathrm{cluster}}+CE^5_{\mathrm{cluster}}}$
- (No correction applied to figures below)



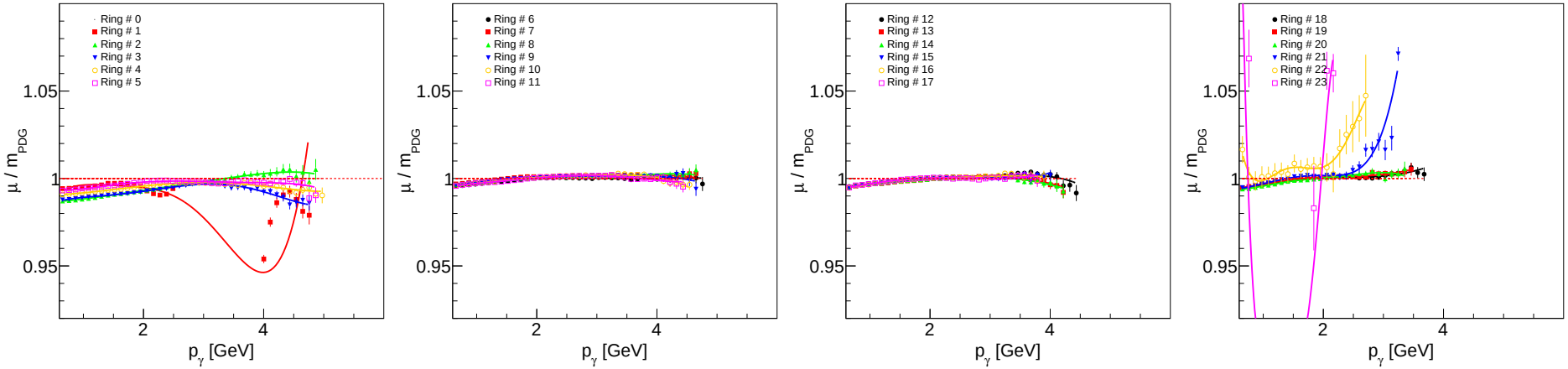


Energy dependence correction applied

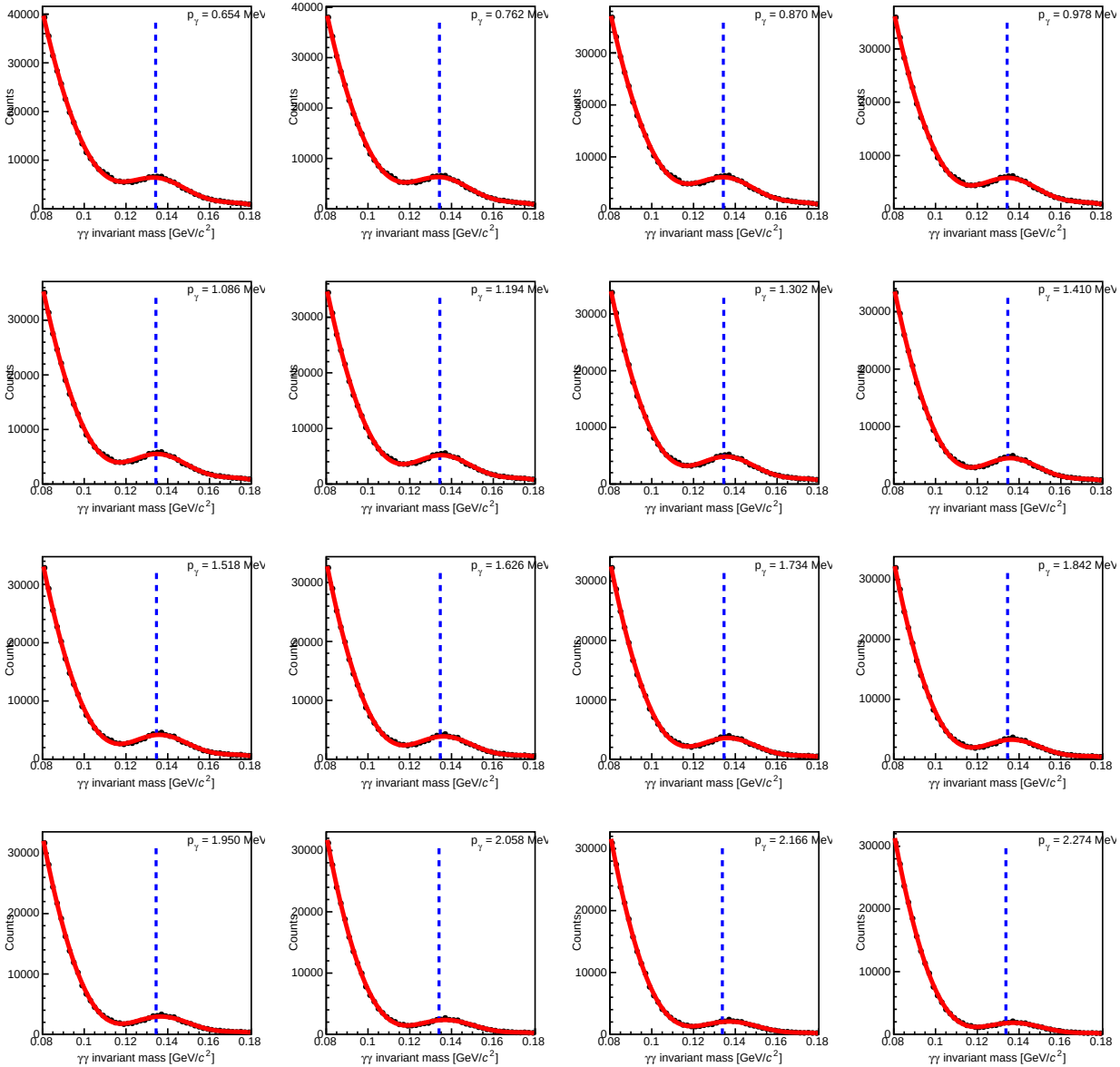
- First iteration



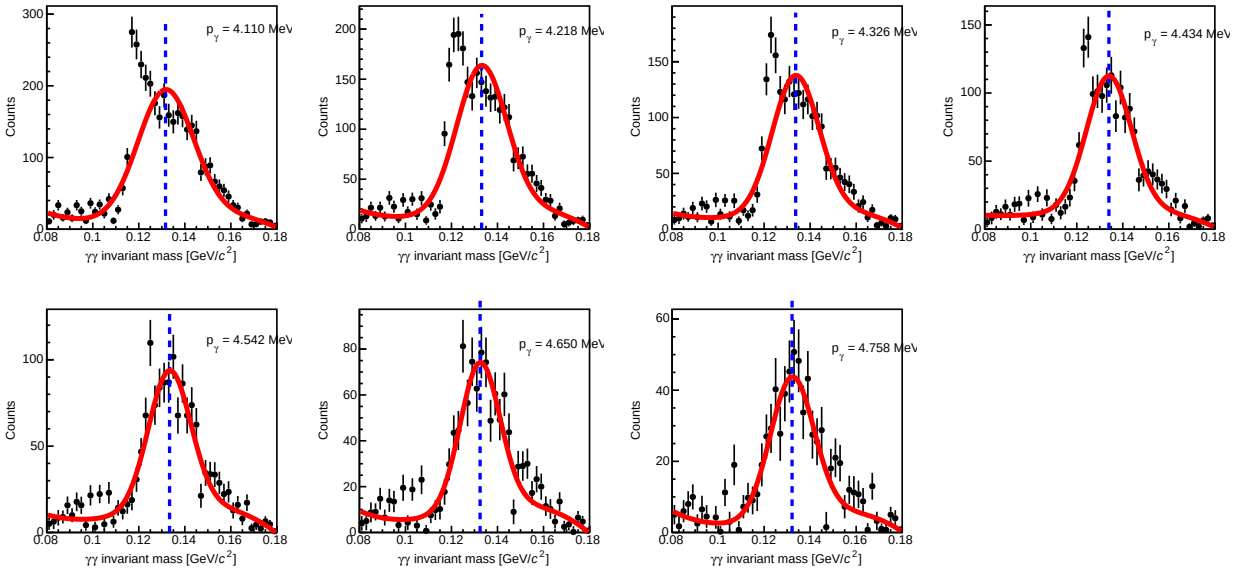
- Second iteration



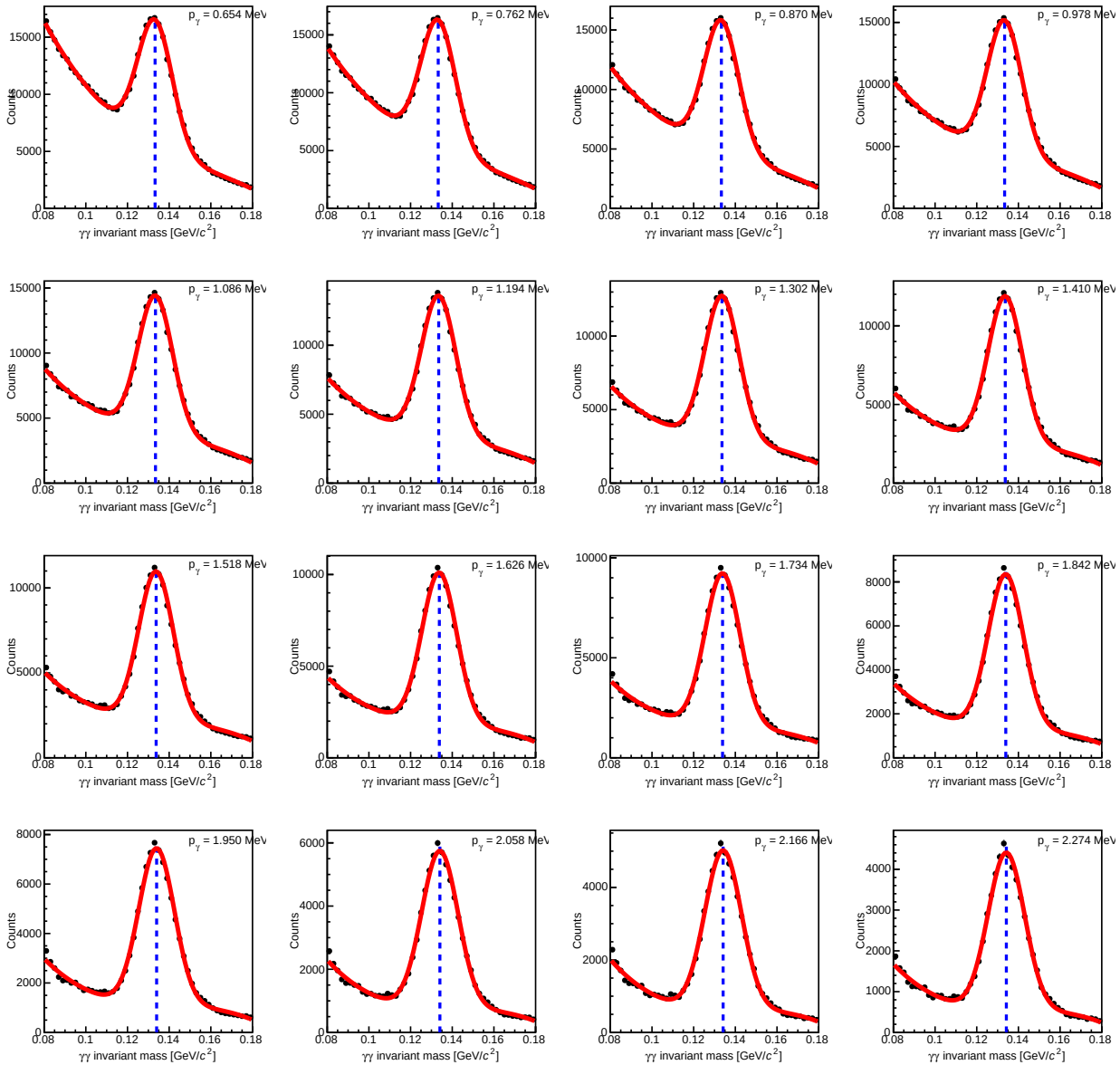
Inner ring (1) low momentum photon



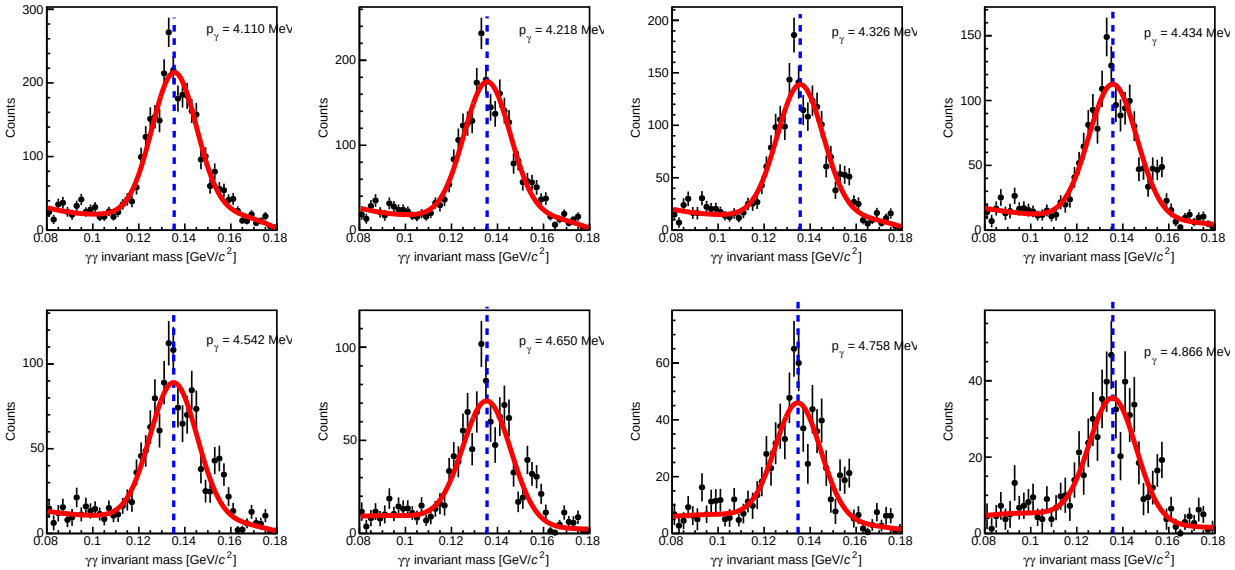
Inner ring (1) high momentum photon



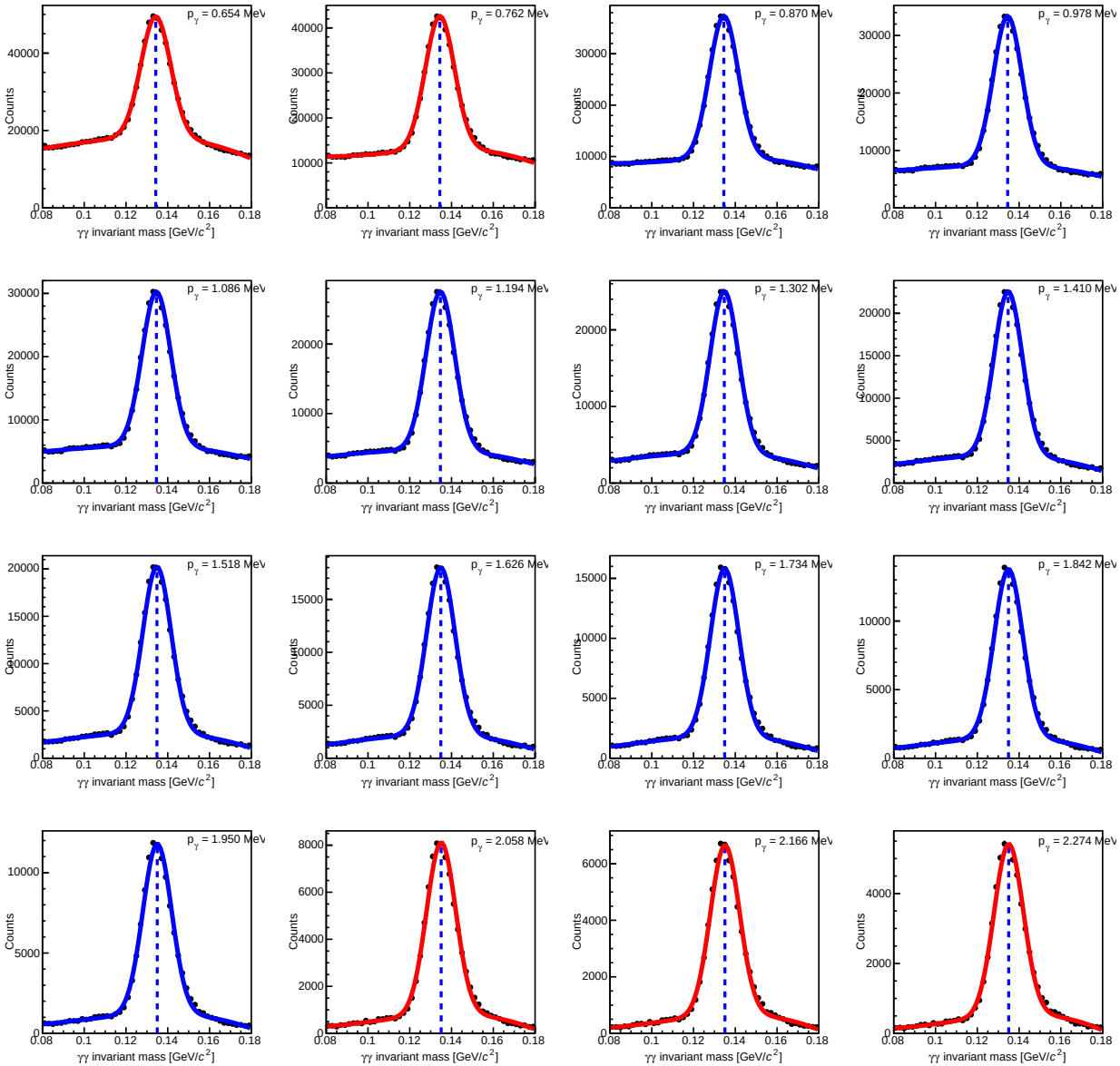
Inner ring (2) low momentum photon



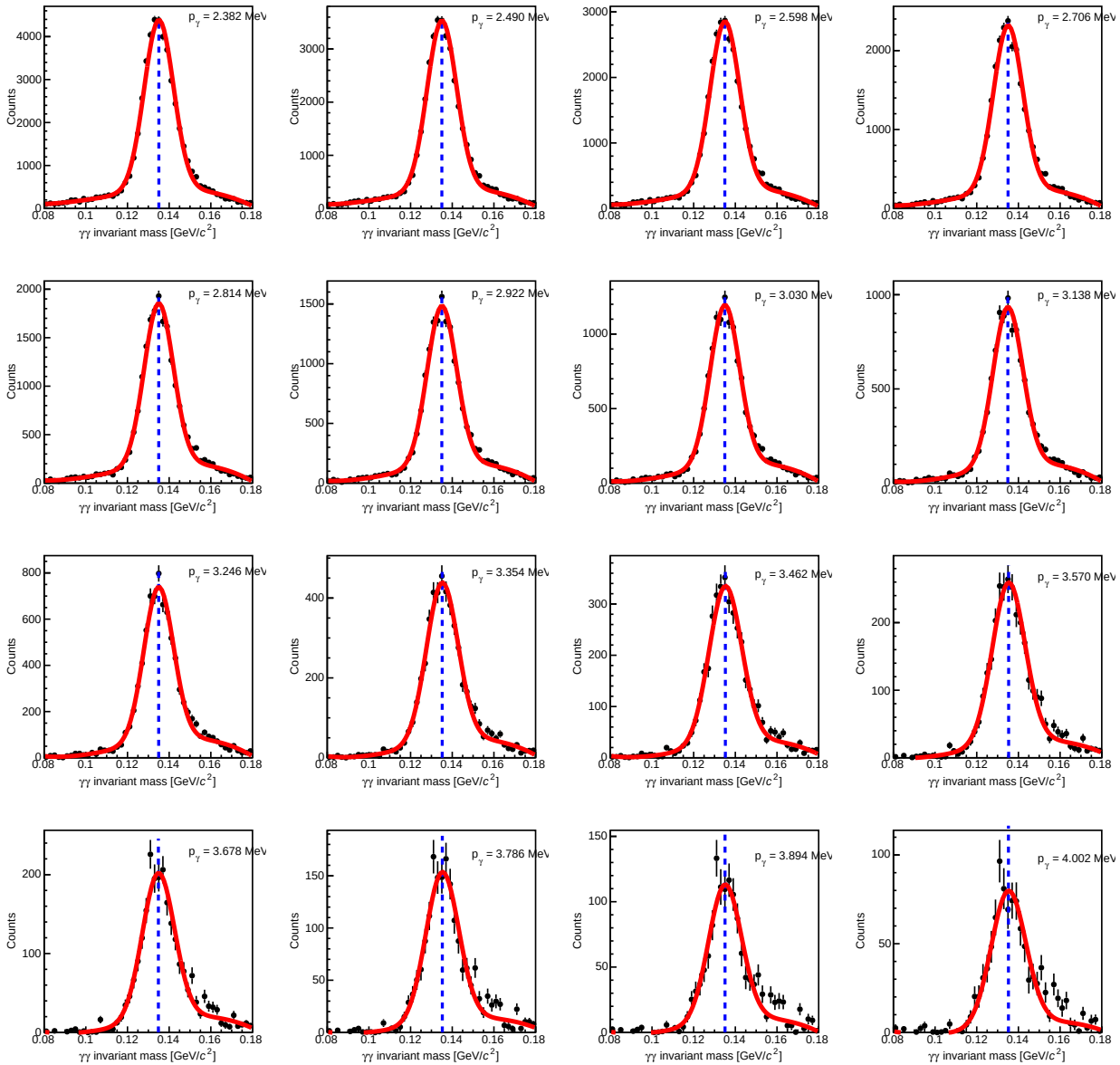
Inner ring (2) high momentum photon



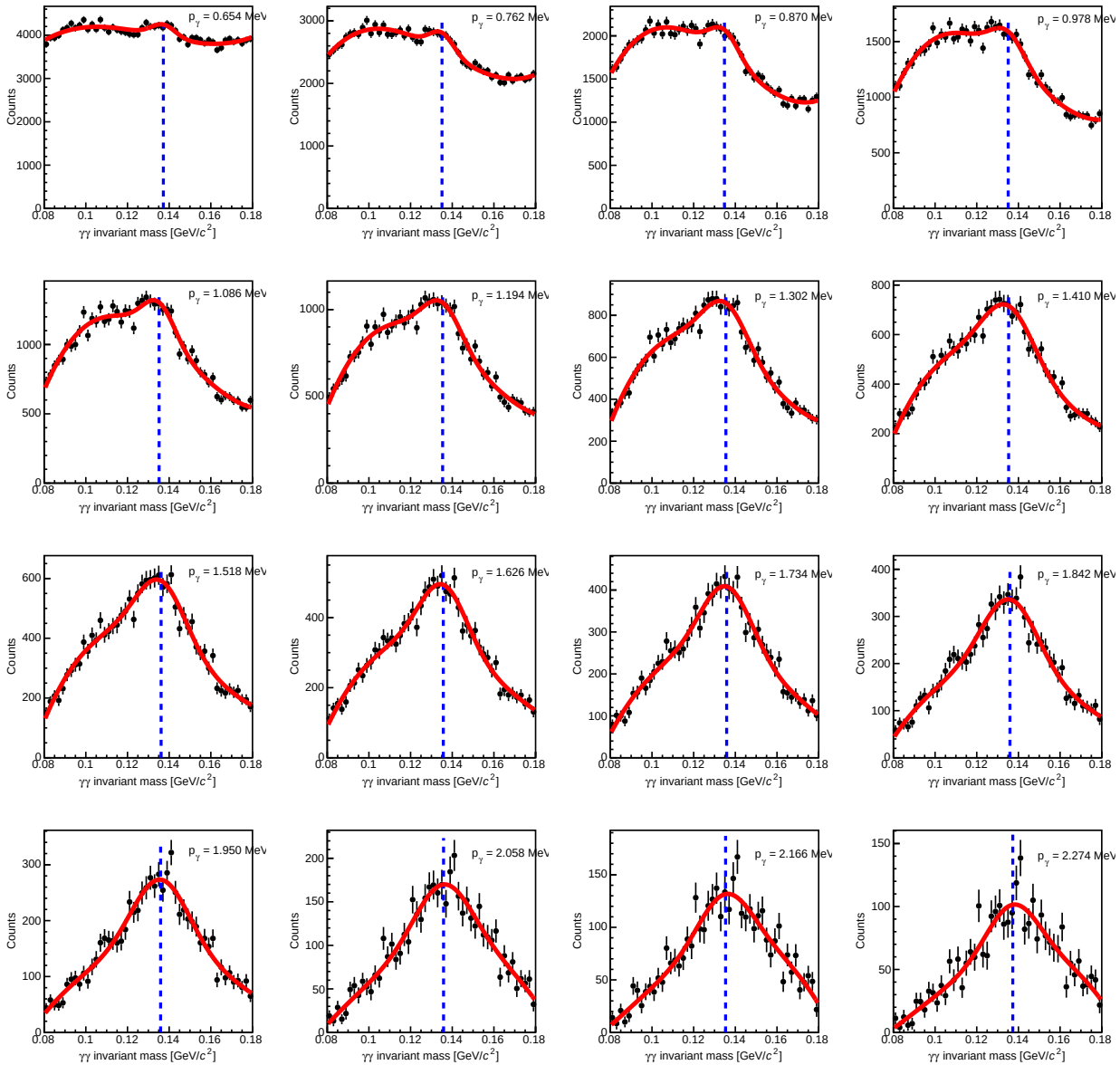
Middle ring (15) low momentum photon



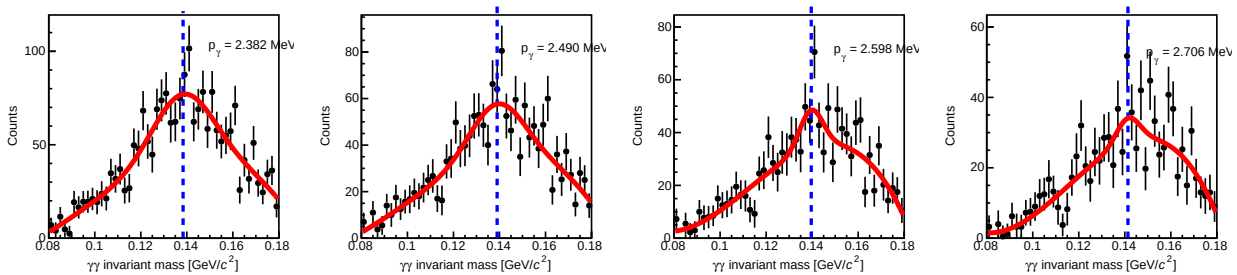
Middle ring (15) high momentum photon



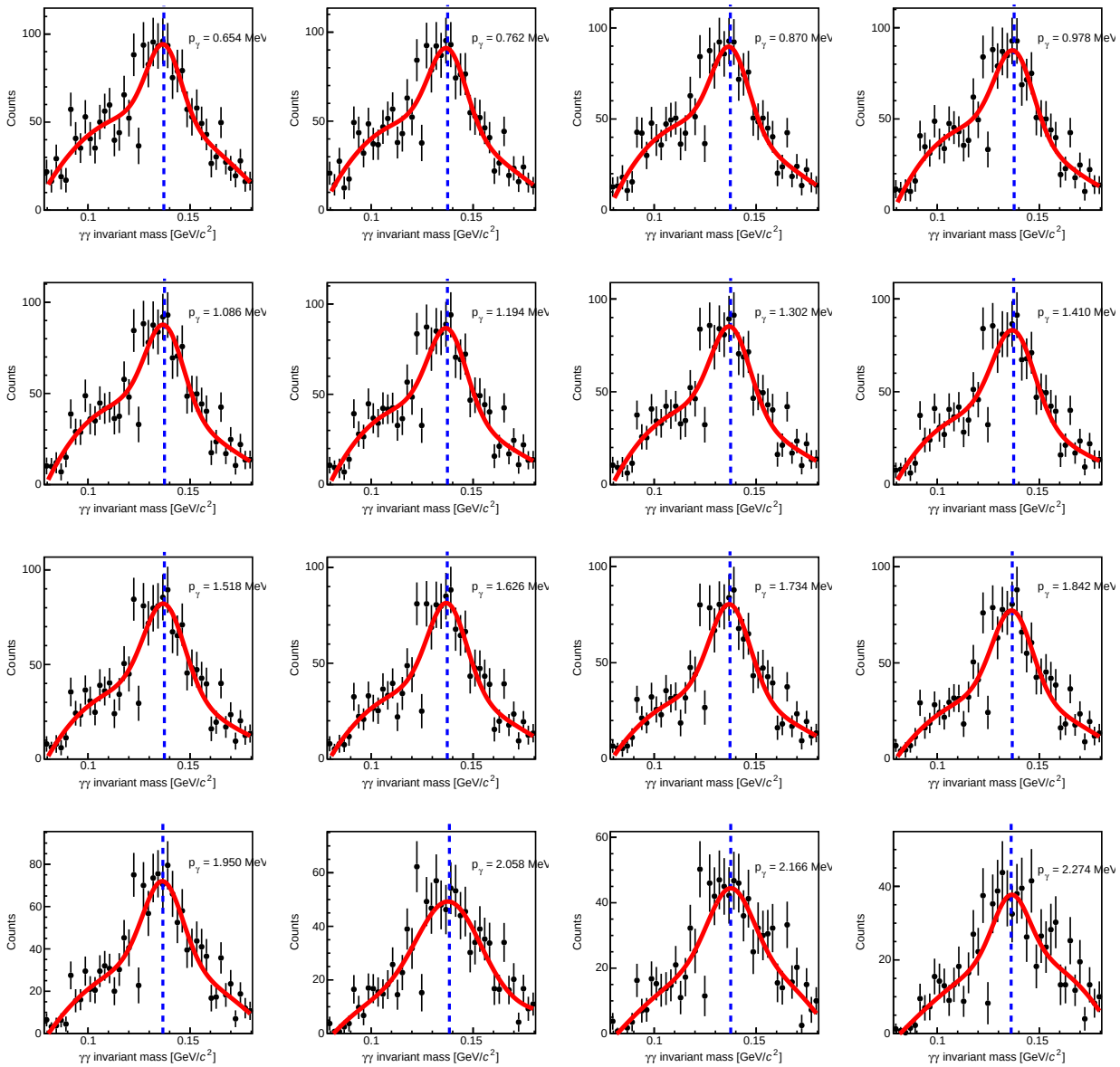
Outer ring (22) low momentum photon



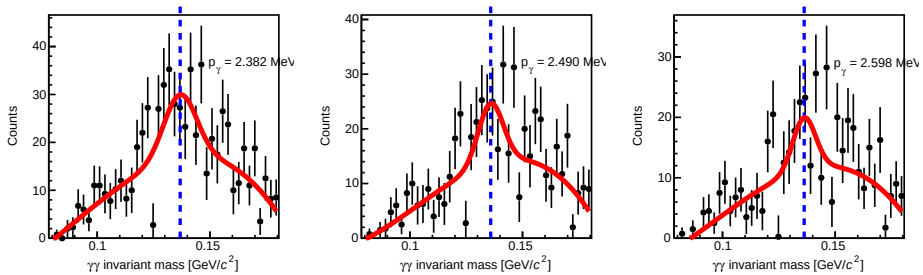
Outer ring (22) high momentum photon



Outer ring (22) low momentum photon for 2γ only



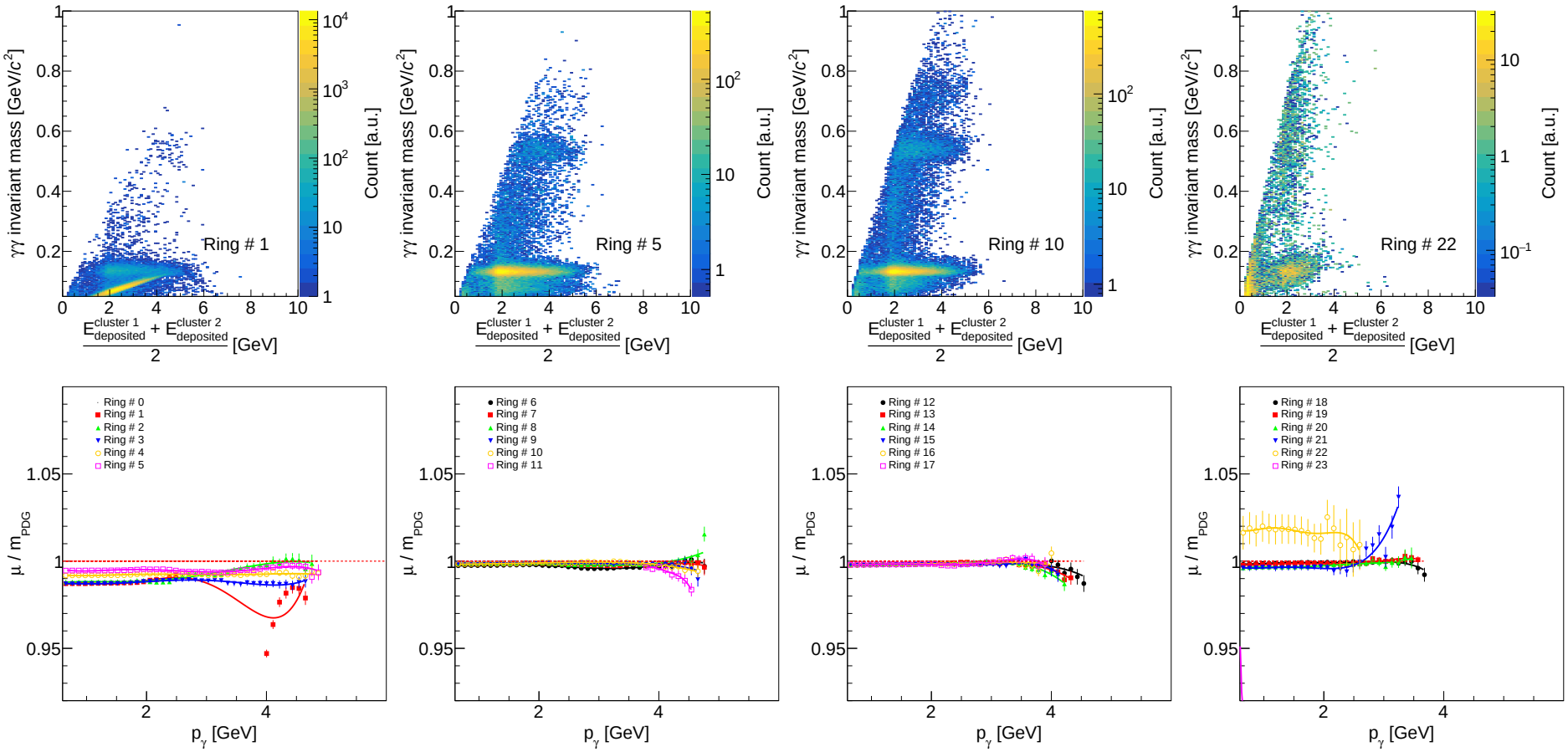
Outer ring (22) high momentum photon for 2γ only



Energy dependence correction applied

When only two photons detected

- Second iteration

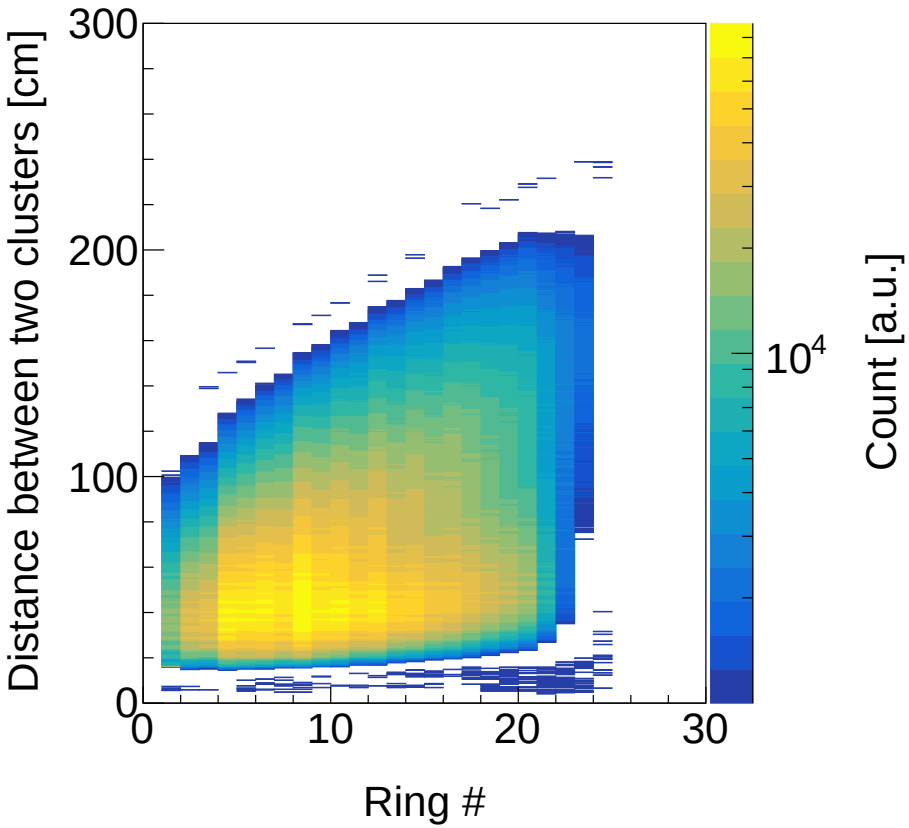


- For ring 2 to 21, procedure is working fairly well bias below 0.2% level
- For ring 1 and 22(23) some improvements are needed

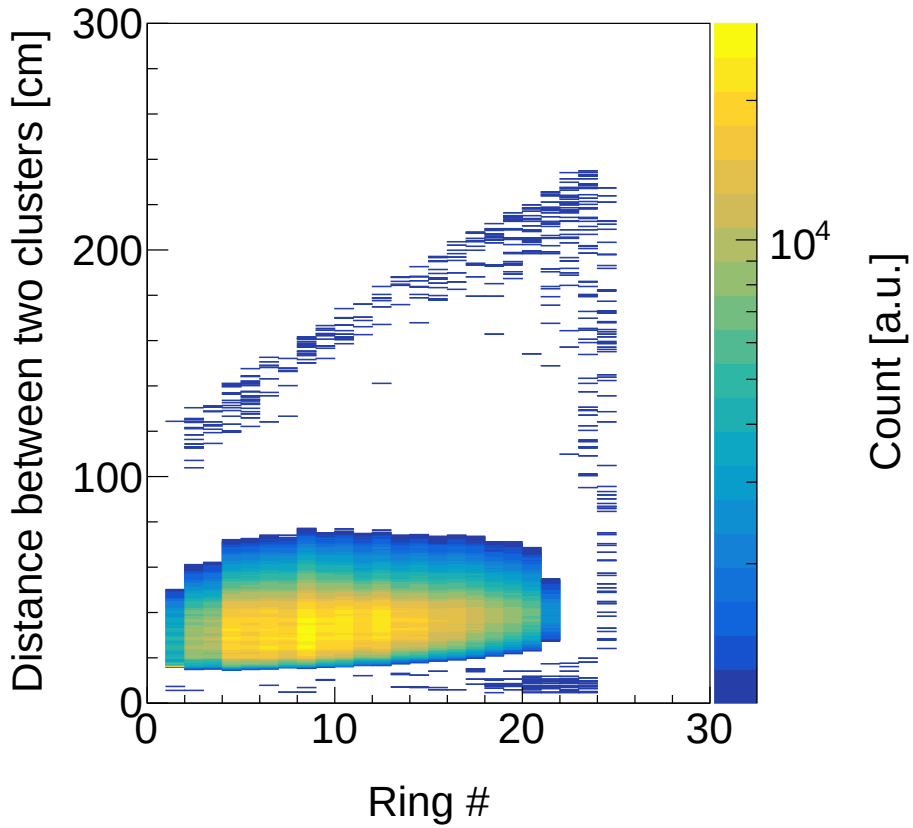
Distance between two clusters

Select events with di-photon invariant mass between 110 and 160 MeV/c^2

- For up to 12 photons



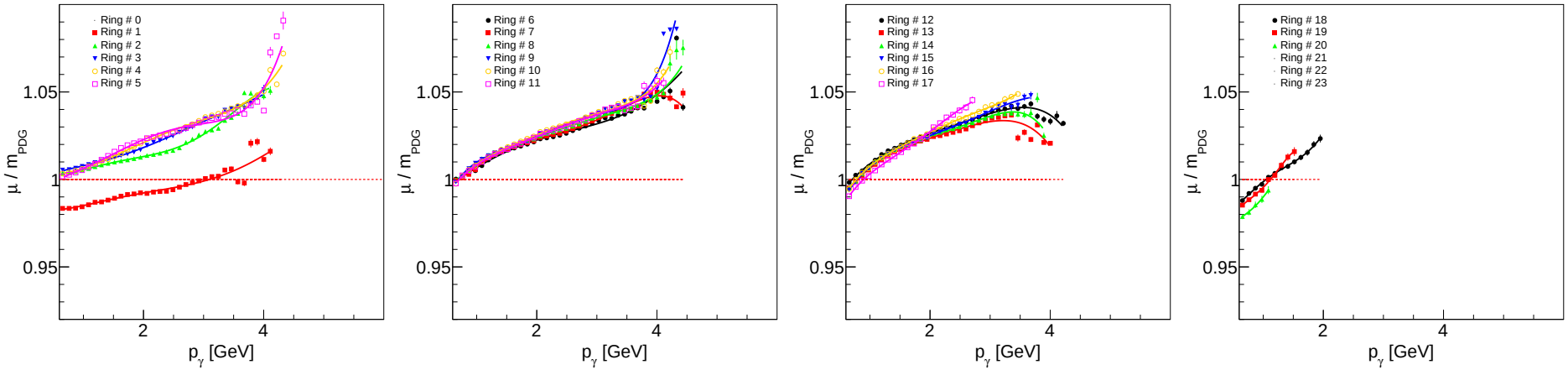
- For two photons only



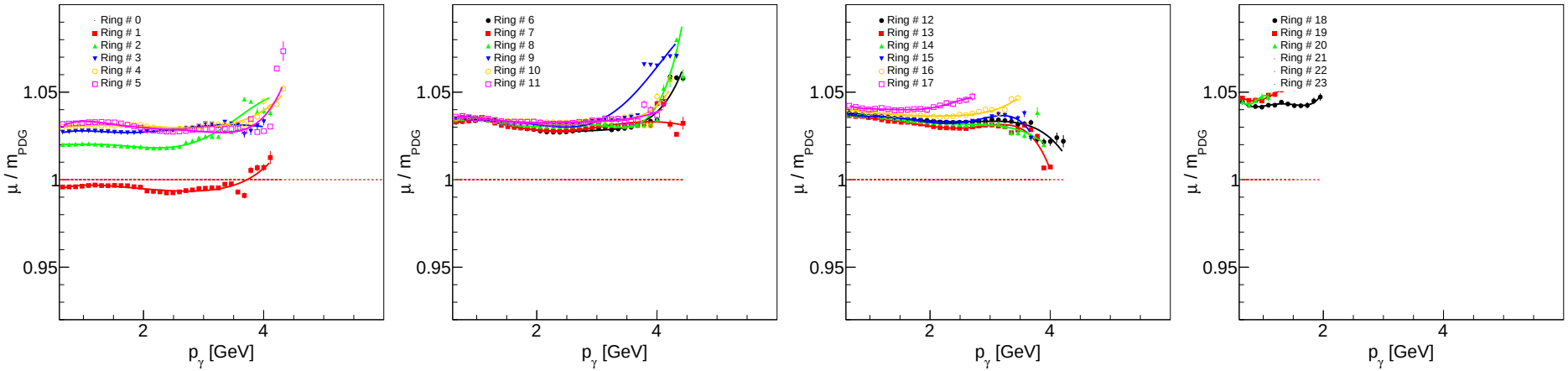
Energy dependence correction for MC simulation

Previous method used only one correction for all rings

- Correction is determined for the fiducial radius between 20 and 100 cm i.e. is ok for 8 rings (∼40% of FCAL)
- Determined with Geant4 before the fudge factor correction (JeffersonLab/HDGeant4#146)
- To be comparable to data a "gain" calibration has to be performed first
- No correction applied



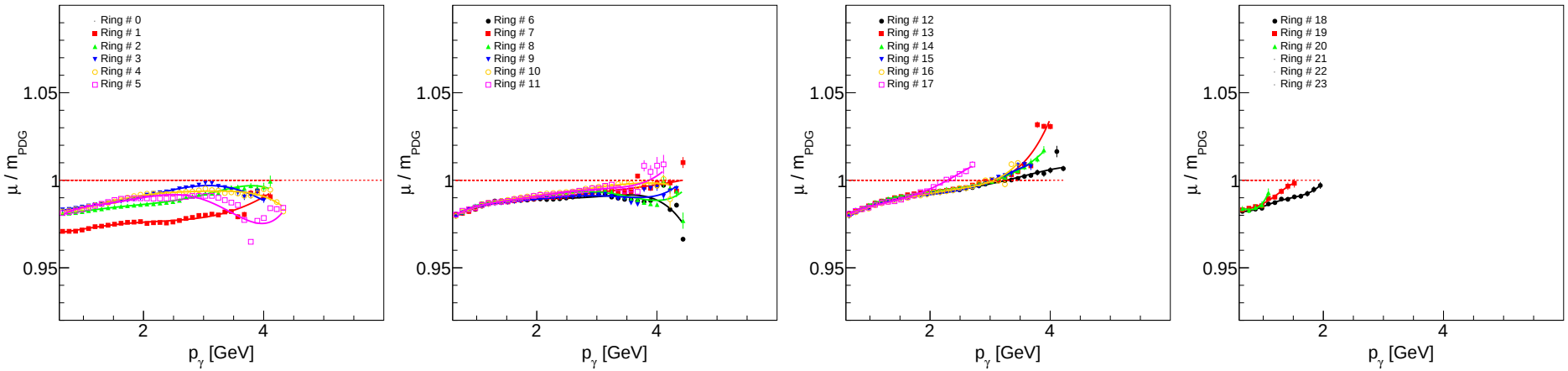
- Standard GlueX correction applied



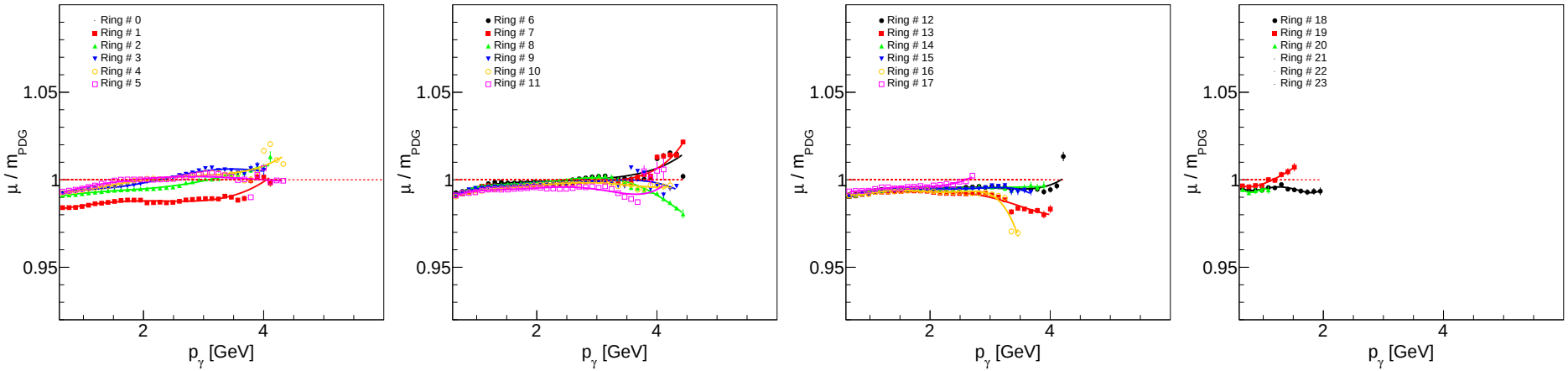
New energy dependence correction applied

To MC simulation

- After 1st iteration



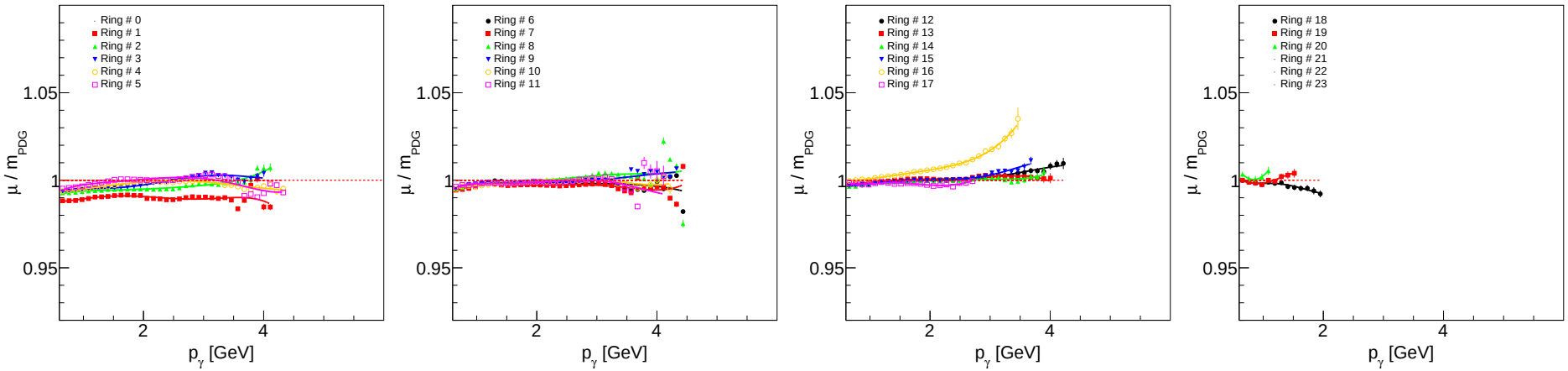
- After 2nd iteration



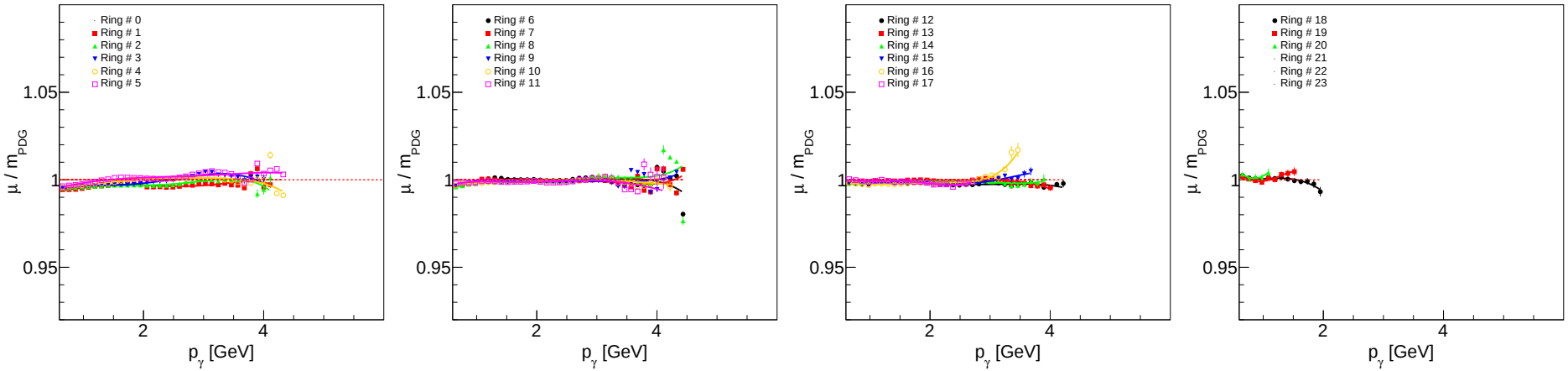
New energy dependence correction applied

To MC simulation

- After 3rd iteration



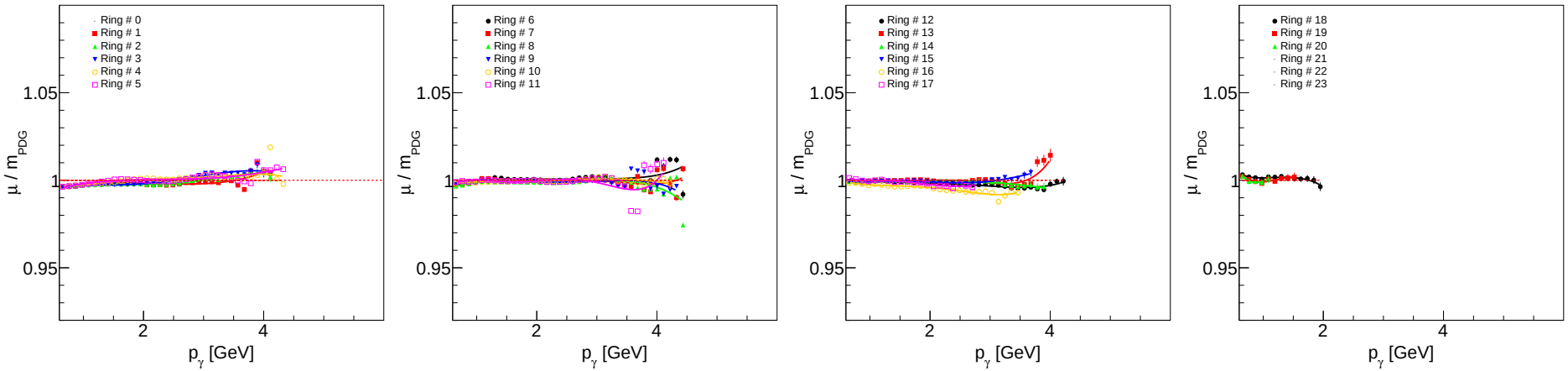
- After 4th iteration



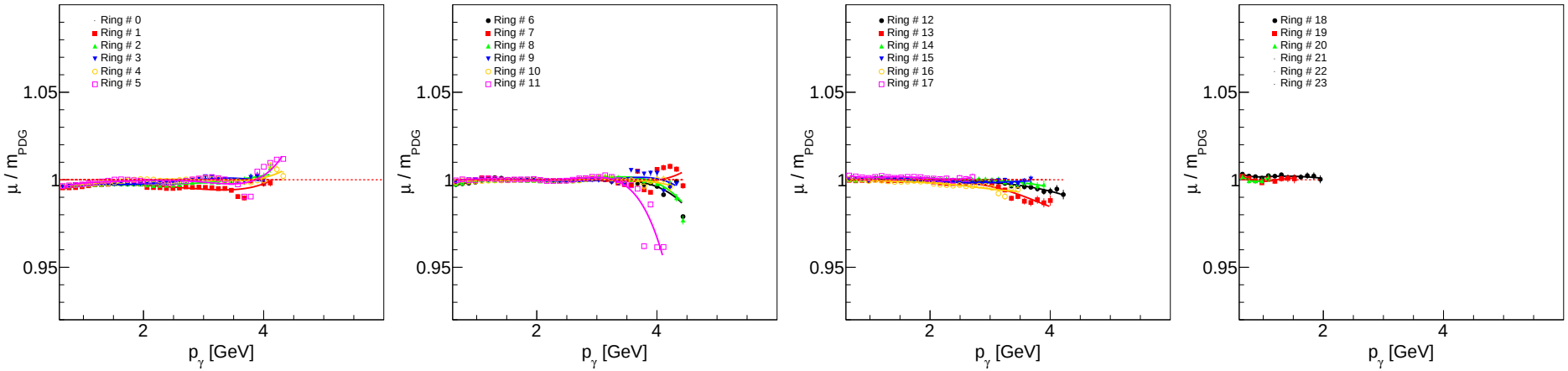
New energy dependence correction applied

To MC simulation

- After 5th iteration



- After 6th iteration



Changes in the software

By default same behavior as before only if:

- Parameters in shower_calib_piecewise set to C = 2 and A=B=D=E=0
- If energy_dependence_correction_vs_ring exists is the new correction applied

```
// Method I: IU way, one overall correction
Egamma = 0;
Ecutoff = cutoff_energy;
A = linfit_slope;
B = linfit_intercept;
C = expfit_param1;
D = expfit_param2;
E = expfit_param3;
// 06/02/2016 Shower Non-linearity Correction by Adesh.
// 29/03/2020 ijaegle@jlab.org the linear part correction is applied in (some) data/sim. backward comptability?
if ( Eclust <= Ecutoff ) {

  Egamma = Eclust / (A * Eclust + B); // Linear part

} else
  // 29/03/2020 ijaegle@jlab.org this correction is always applied if all C=2 & D=E=0 then Egamma = Eclust
  if ( Eclust > Ecutoff ) {

    Egamma = Eclust / (C - exp(-D * Eclust + E)); // Non-linear part

  }
// 29/03/2020 ijaegle@jlab.org if all C=D=E=0 by mistake then Egamma = - Eclust
// End Correction method I

// Method II: PRIMEXD way, correction per ring
if (C == 2 && D == 0 && E == 0 && energy_dependence_correction_vs_ring.size() > 0 && ring_nb < 24) {

  Egamma = 0;
  A = energy_dependence_correction_vs_ring[ring_nb][0];
  B = energy_dependence_correction_vs_ring[ring_nb][1];
  C = energy_dependence_correction_vs_ring[ring_nb][2];
  D = energy_dependence_correction_vs_ring[ring_nb][3];
  E = energy_dependence_correction_vs_ring[ring_nb][4];
  F = energy_dependence_correction_vs_ring[ring_nb][5];

  Egamma = Eclust / (A + B * Eclust + C * pow(Eclust, 2) + D * pow(Eclust, 3) + E * pow(Eclust, 4) + F * pow(Eclust, 5));
}
// End Correction method II
```

Conclusion

- New gains (but can still be improved)

Target	Table number	Preliminary run range
Be	1	61321-61354
He	2	61355-61481
He	3	61482-61622
He	4	61623-61788
He	5	61789-61910
He	6	61911-61944
He	7	61945-61956

- New energy dependence correction per rings for data and simulation (but can still be improved)
- QC, good enough for a 1st draft

To-do-list:

- Push request?
- Write a note
- Monitoring launch