MEG II実験：液体キセノン検出器の物理ラン開始に向けたコミッショニング(2)

MEG II experiment: Commissioning of Liquid Xenon Detector towards Start of Physics Run (2)

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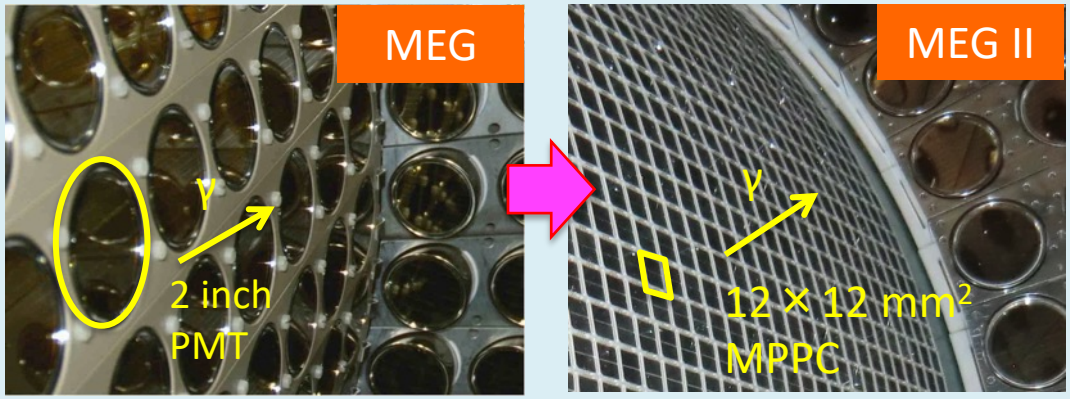
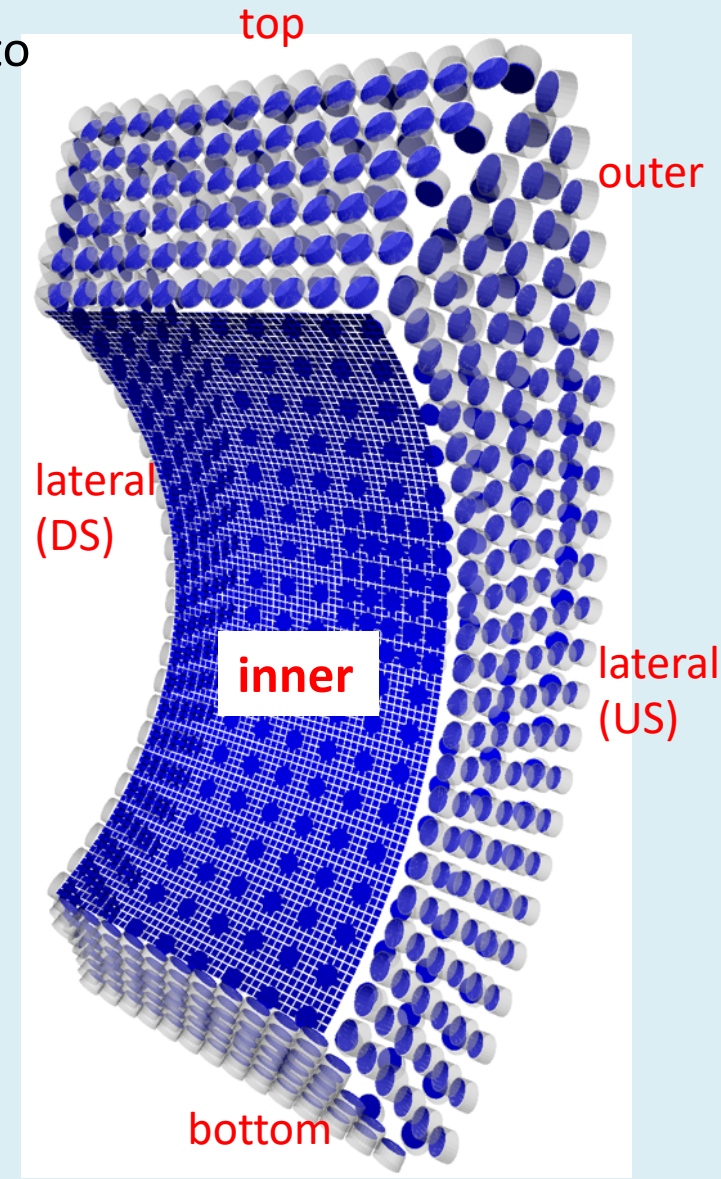
LXe detector in MEG II

- LXe γ-ray detector has been upgraded for MEG II to significantly improve the performance.
  - measure energy, hit position, and timing of 52.8MeV γ from $\mu \rightarrow e\gamma$.

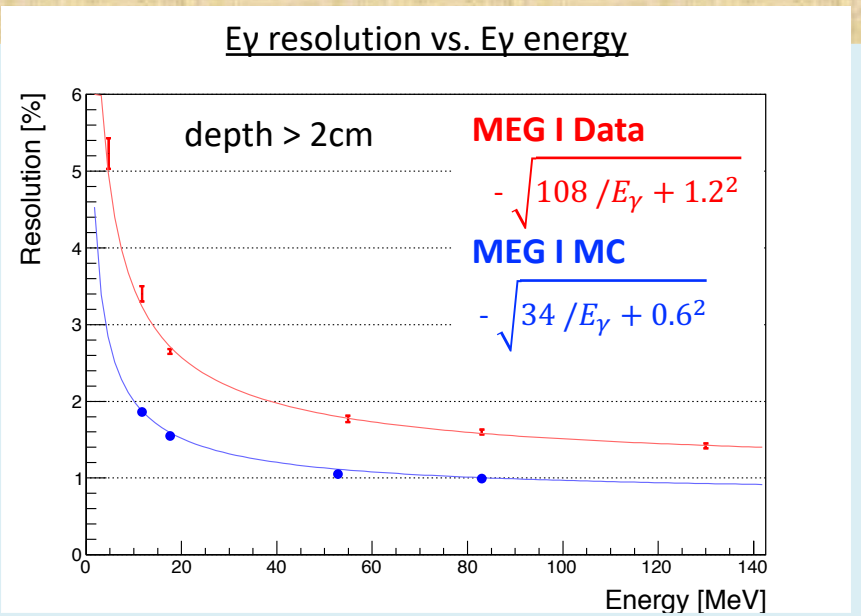


216 2-inch PMTs **4092 12 × 12 mm² MPPCs**

- Detector commissioning on going.
- On 2018 Dec., Pre-Engineering run 2018 was conducted.
  - Monochromatic γ-source for calibration.
  - BG γ-ray from muon beam.



Energy resolution of MEG LXe detector



- In MEG (I), measured energy resolution for signal 52.8 MeV γ was worse than expected in MC.

Energy resolution (σ) for signal 52.8MeV	MEG (MC)	MEG (Data)
depth < 2cm	~2%	2.4%
depth > 2cm	1.0%	1.7%

- The reason of this degradation is not understood.
- Degradation has an energy dependence, and it is obvious in low energy.
- For MEG II, the uniformity of readout is improved. This leads to better resolution for the shallower region.
- This unsolved degradation is limiting the precision of expected energy resolution (0.7-1.5%) , and that of the expected sensitivity of MEG II.

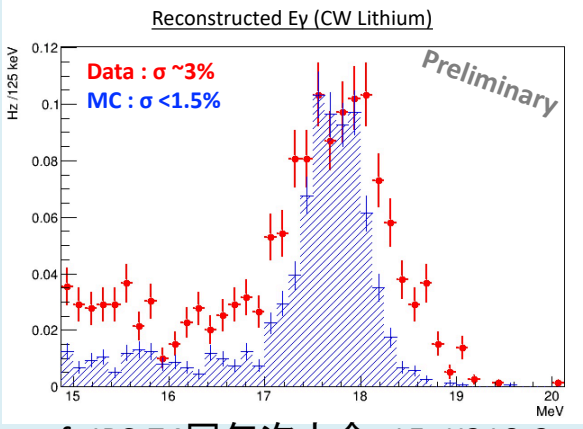
Energy resolution (σ) for signal 52.8MeV	MEG II (MC)	MEG II (Data)
depth < 2cm	0.8%	???
depth > 2cm	0.8%	???

※ w/ limited # of readout ch

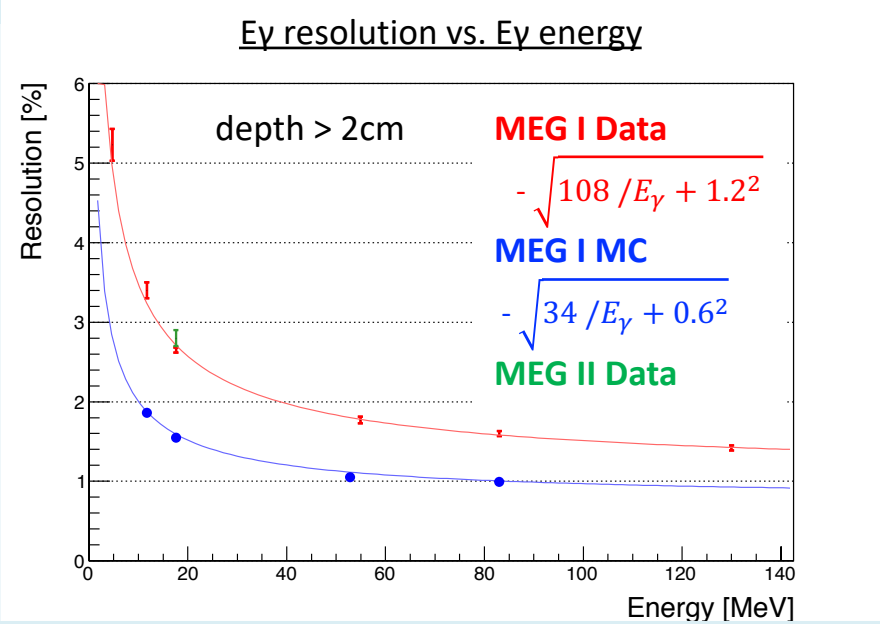
Energy resolution in MEG II

- We observed worse energy resolution in 17.6MeV.
  - MC: 1.5 %, Data : 2.8%. (for depth > 2cm)
  - 17.6MeV γ-ray from $^{7}_{3}\mathrm{Li}(\mathrm{p},\gamma)^{8}_{4}\mathrm{Be}$.

- How to investigate the situation.
  - Try to check measured energy resolution @ high energy region.
    → Access to constant term.
    This talk.
  - Try to understand MC/Data difference observed @ 17.6 MeV.
    → Access to energy dependent term.
    Next talk.

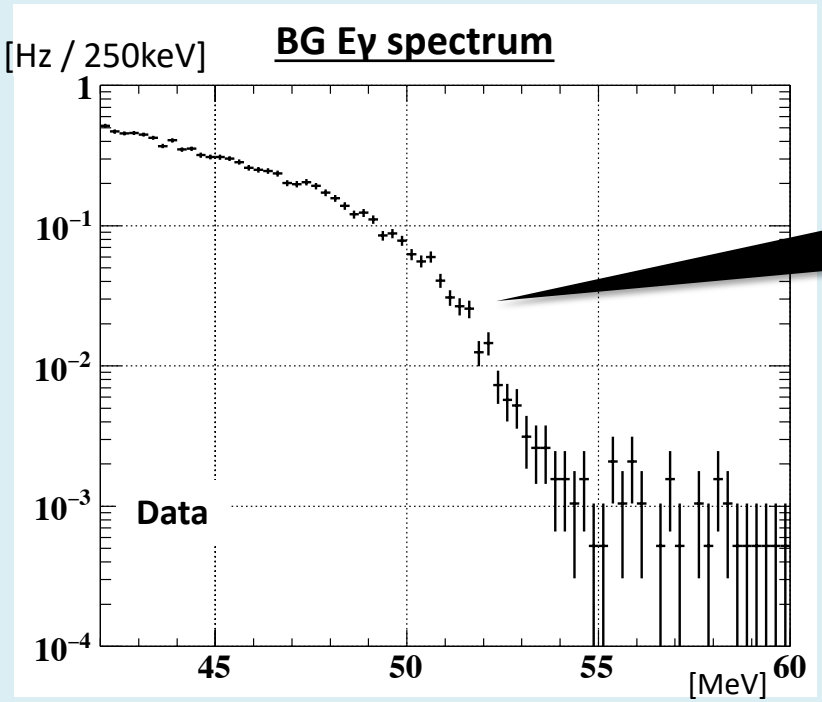


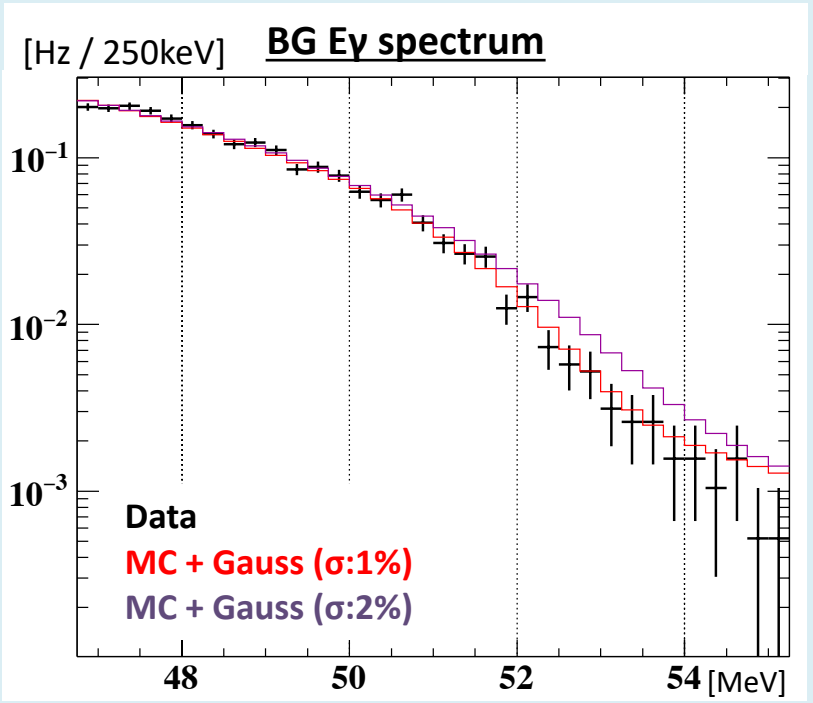
ref: JPS,74回年次大会, 15aK210-2



Energy resolution estimation from BG spectrum

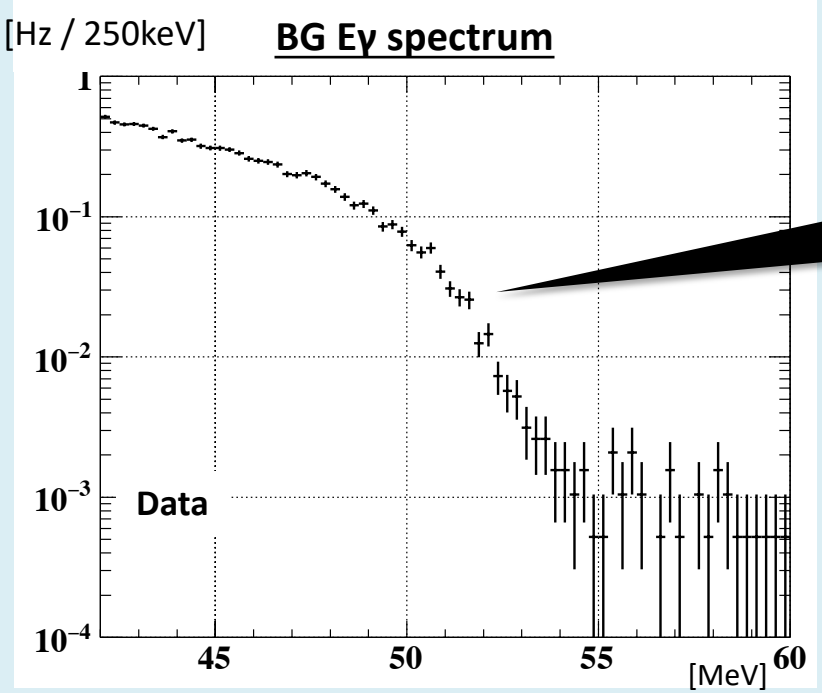
- In MEG, energy resolution at 55MeV was measured by $p\pi^- \rightarrow n\pi^0, \pi^0 \rightarrow 2\gamma$.
- This was not possible due to the delayed schedule of the experiment.
- In this study, γ-ray spectrum from muon beam was used.
  - Mainly coming from radiative decay of muon stopped on target ($\mu \rightarrow e\nu\nu\gamma$) .
  - Background of gamma in the physics search.
  - Data at reduce muon beam intensity is used to reduce the effect of pileup.
- Energy resolution can be estimated from the edge of the spectrum.

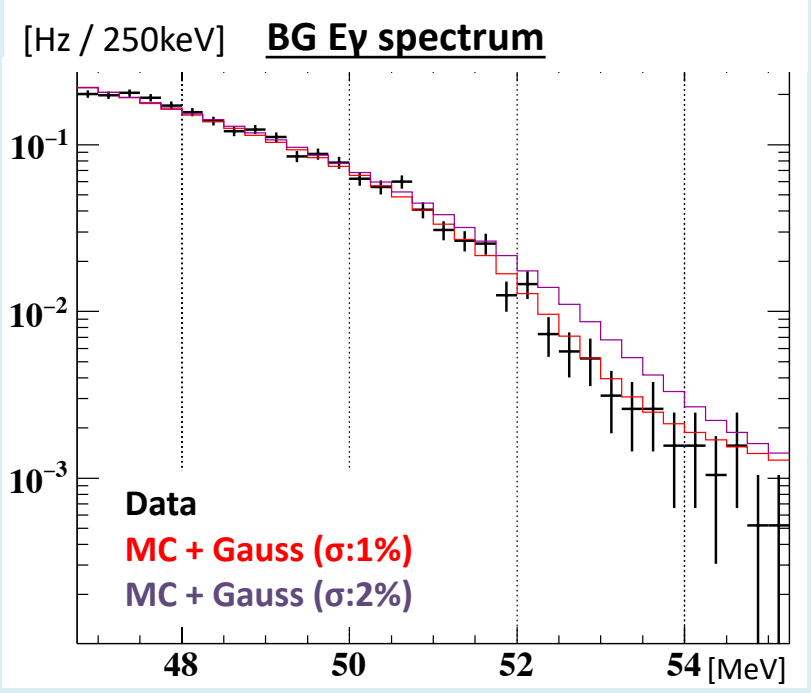




Fit method

- Energy spectrum of data is fitted by that of MC convoluted by gauss.
  - Minimizing chi square between reconstructed energy distribution of MC and Data.
  - Fit region : 45-54MeV.
- Fit parameter:
  - Energy scale of data. (i.e. scale of x-axis)
  - Beam rate of data. (i.e. scale of y-axis)
  - Sigma of convoluted gauss.
    - (Resolution of Data) = (Resolution in MC. 0.8%) ⊕ σ of convoluted gauss.





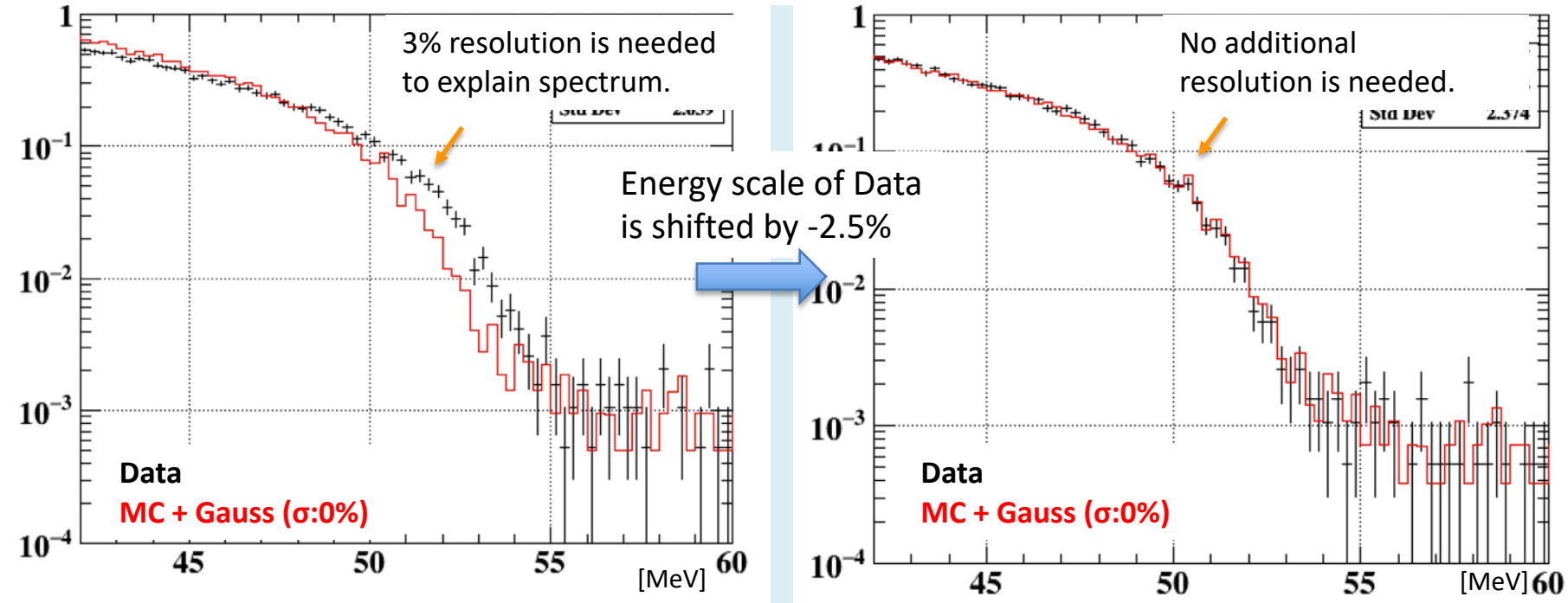
Energy scale

- Energy scale has to be fixed,
  to get resolution with reasonable uncertainty.
- In MEG, energy scale is monitored
  by monochromatic γ-ray from calibration source.
- Due to unexpected change of MPPC PDE/PMT Gain in 2018,
  energy scale cannot be fixed by this issue.
- We tried to estimate energy scale from the spectrum itself.

Energy reconstruction

$$E_\gamma = Const. \times \sum_{sensor} \frac{charge \times weight}{gain \times ECF \times PDE}$$

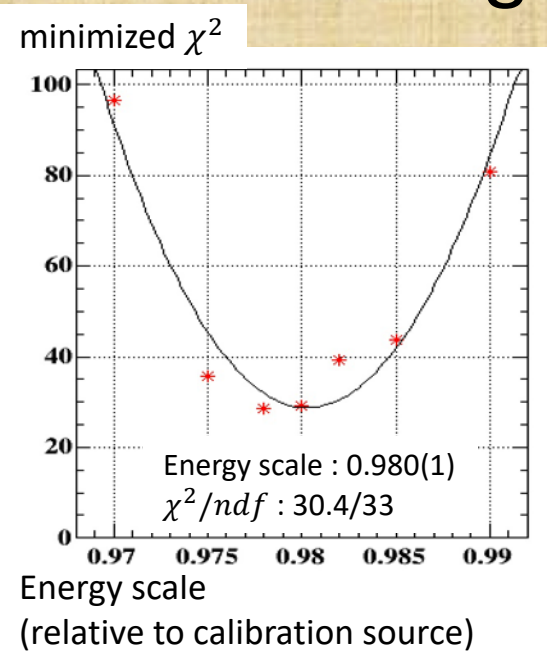
BG Eγ spectrum

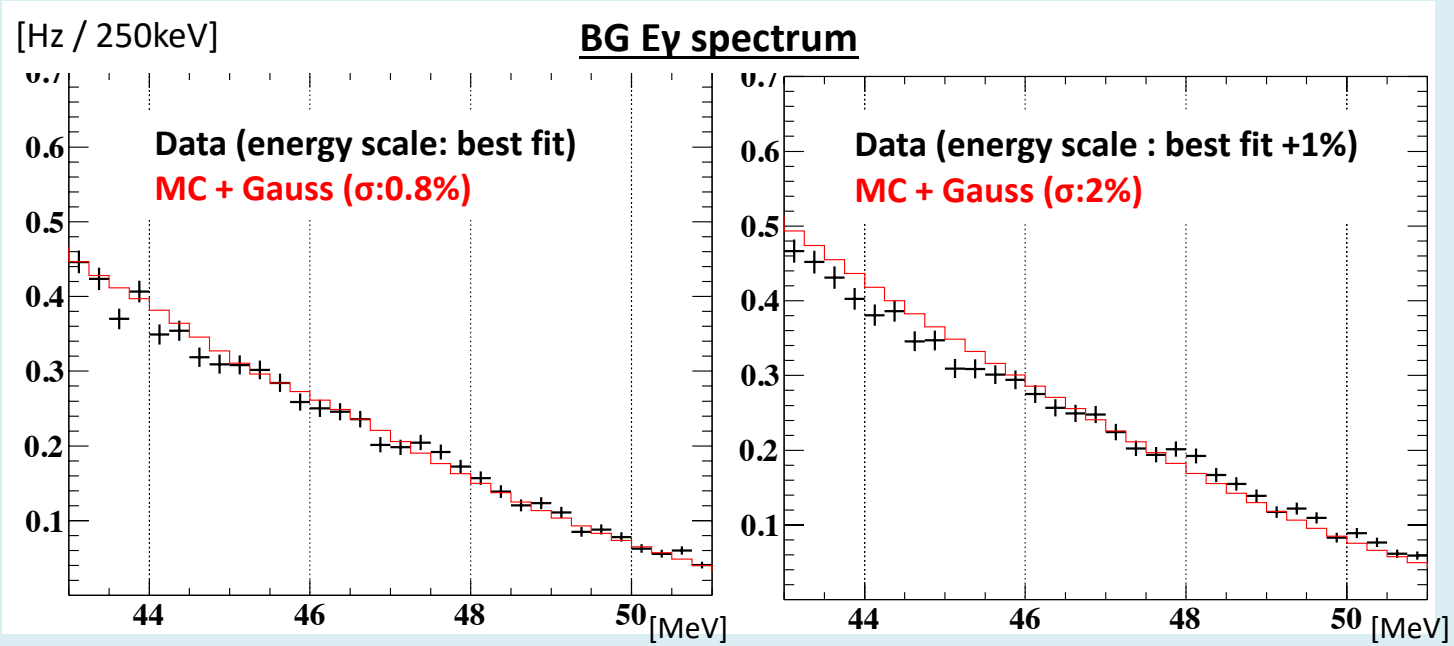


Fit result -energy scale-

- Minimization of chi square are performed at each energy scale.
- Best fit : at energy scale of -2.0(1) % from calibration source.

- Energy scale of reasonable uncertainty is obtained from the gradient of the spectrum.

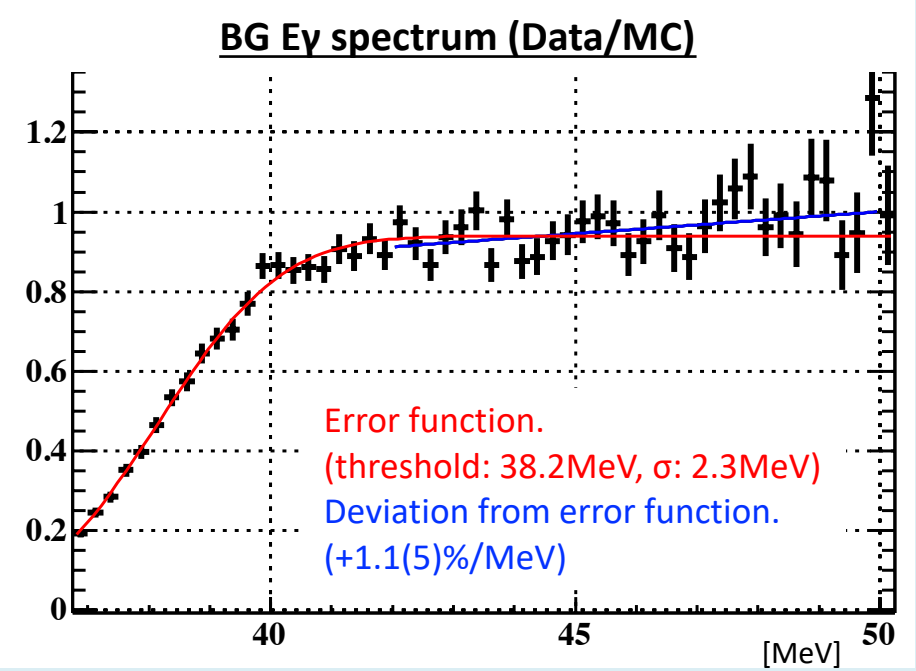




Uncertainty of energy scale

- If there is some systematic uncertainty in the spectrum shape of background gamma, it can bias fit result of energy scale.
  - Spectrum of this region is defined by RMD decay of stopped muon on target, little uncertainty from physics.
- Still there may be some effect which is not correctly included in simulation.

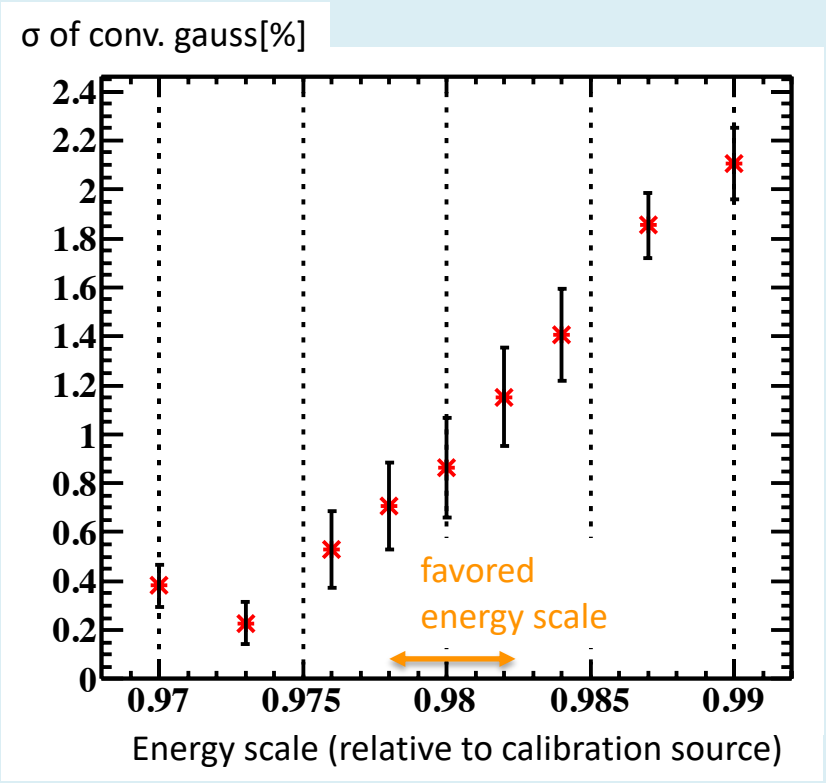
- Example : trigger efficiency
  - DAQ by self trigger of γ energy
  - If trigger efficiency follows error function, efficiency > 99.7% in fit region, and no effect to the fit .
  - It there is long tail component, it may bias spectrum shape.
  - Some deviation of +1[%/MeV] may be observed. → Corresponds to 0.2% uncertainty to energy scale.

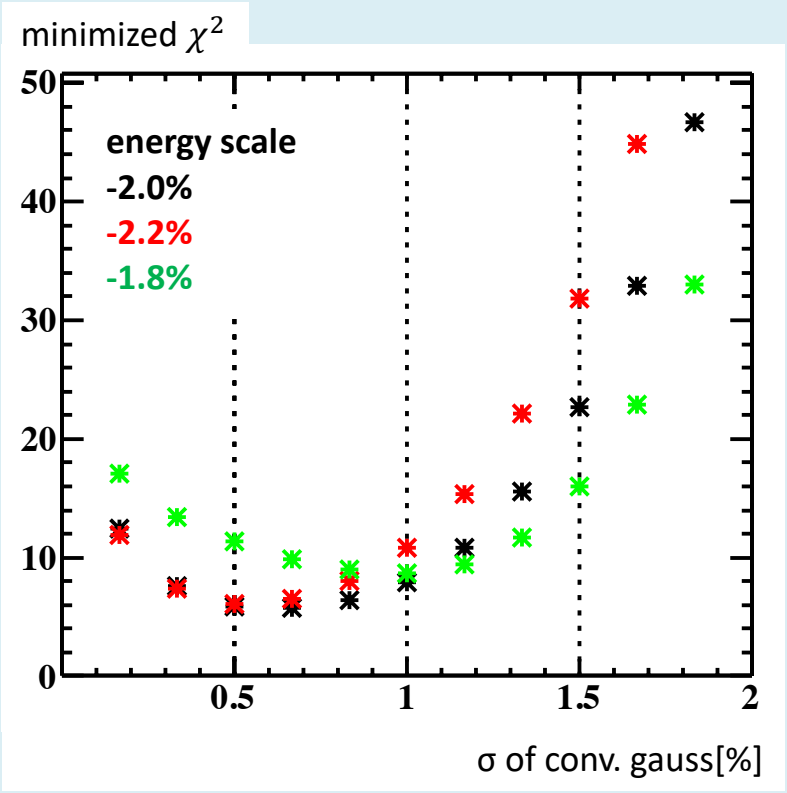


Fit result -energy resolution-

- Best fit of resolution at each energy scale.
- Optimal resolution largely depends on the assumed energy scale.

- σ is fitted to be 0.5-1.4 %, in the favored energy scale (-2.0(2)%).

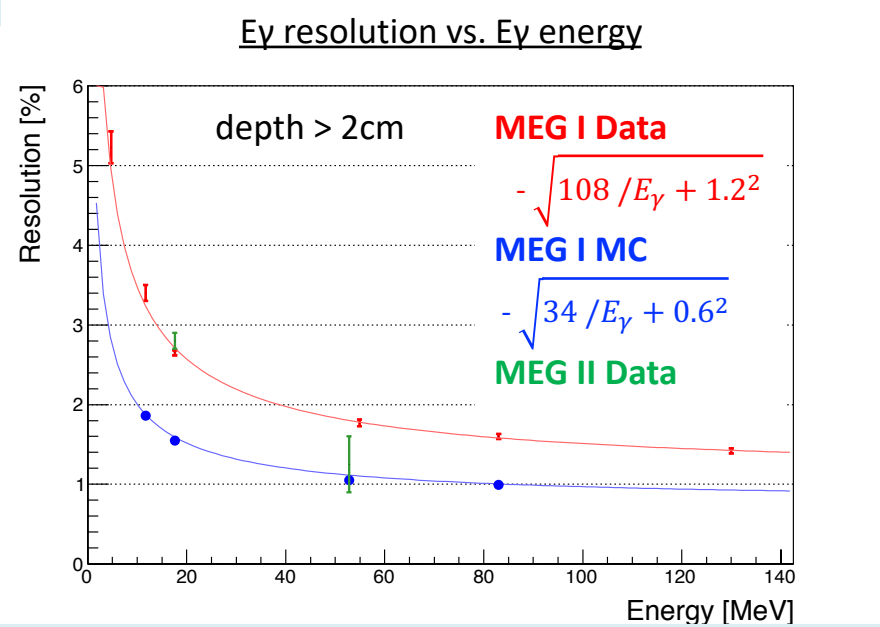




Summary

- Energy resolution for 52.8 MeV signal γ-ray is one important parameter for MEG II experiment.
- Worse resolution than simulation is observed both in MEG and at 17.6 MeV in MEG II.
- We are trying to understand the reason of this.

- We tried to estimate energy resolution at 52.8MeV from the edge of the BG gamma spectrum.
  - Resolution is fitted to be 0.9-1.6%.
  - This is not fully reliable due to the hidden systematics of the energy scale of data.



Prospect

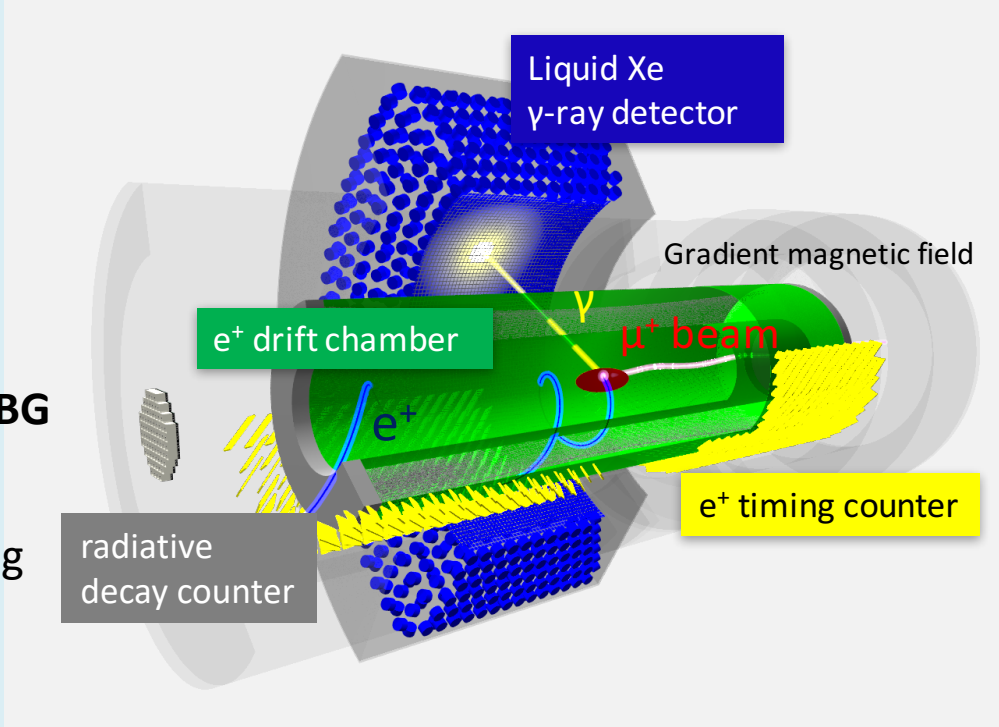
- In 2019 Oct-Dec, Pre-Engineering run 2019 is planned.
  - Stable and frequent DAQ of calibration data in MEG II beam environment.
    - Mainly to study in-beam degradation of sensor performance.
    - This will enable us to understand and track energy scale fluctuation.
  - DAQ of monochromatic 55MeV γ-ray from $p\pi^- \rightarrow n\pi^0, \pi^0 \rightarrow 2\gamma$.
    - Direct measurement of energy resolution at 55MeV.
    - Energy scale measurement at 55MeV.

BACKUP

MEG II experiment

Upgrade of MEG experiment

- Searches for $\mu \to e\gamma$.
- Dominant BG : accidental BG
- **More statistics**
  - x2.3 muon beam rate
  - x2 positron efficiency
- **Better separation of signal event from BG**
  - x2 for all detector resolutions
  - New detector for background tagging will be introduced



Expected sensitivity: 6×10^{-14}

- One order of magnitude better than MEG

Engineering run from 2020

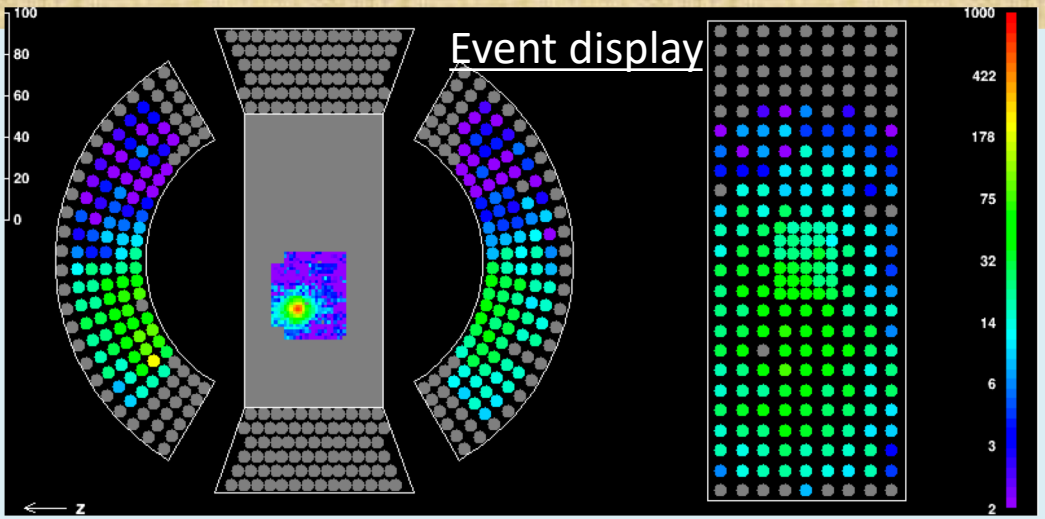
- Followed by physics data taking.

Reference :
"The design of the MEG II experiment",
Eur. Phys. J. C (2018) 78:38

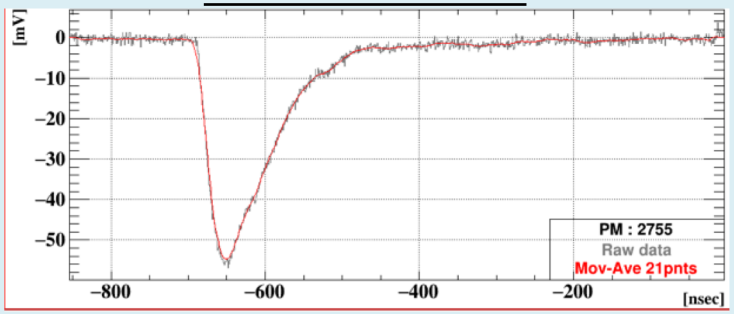
Energy resolution in MEG II

- Study of energy resolution with 2018 data is ongoing.
- Use WaveDREAM (electronics for MEG II) for waveform readout.
  - Read out 25% of detector.

Event display



MPPC waveform

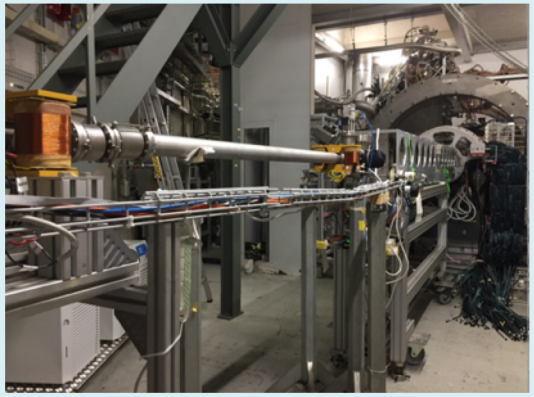


- Energy is reconstructed based on sum of detected # of photon.
  - $E_\gamma = Const. \times \sum_{sensor} \frac{charge \times weight}{gain \times ECF \times PDE}$
  - Elimination of pileup gamma is applied.
    - ref: JPS, 2018年秋季大会, 16aS41-8

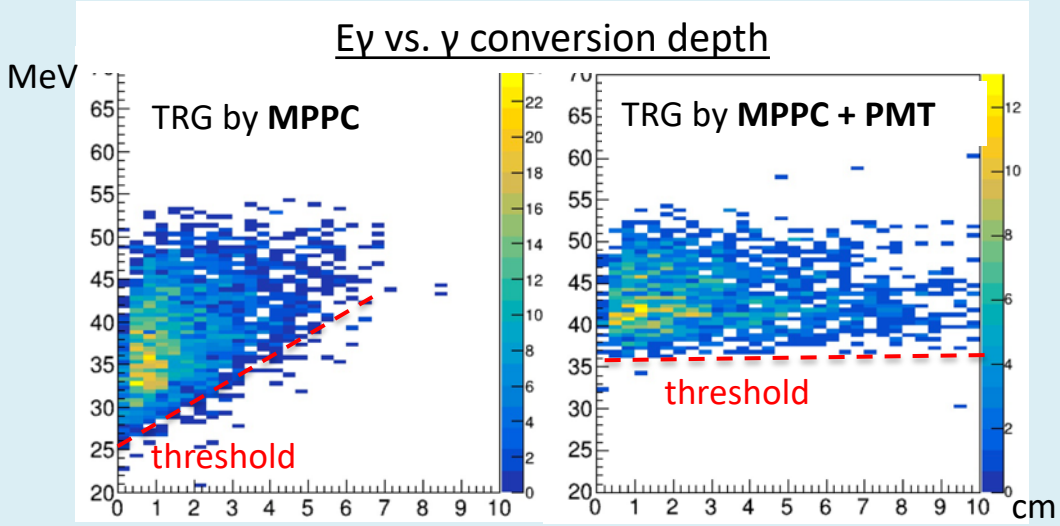
Pre-engineering run 2018

- Pilot run of LXe detector was carried out with MEG II muon beam.
- Similar beam time was also performed in 2017.
  → Several improvements in 2018.

1. Monochromatic γ from calibration source.
   - Not available in 2017.



2. Unbiased TRG thanks to better sensor calibration.
   - In 2017, trigger by sum of MPPC waveform
   - In 2018, trigger by sum of MPPC + PMT waveform



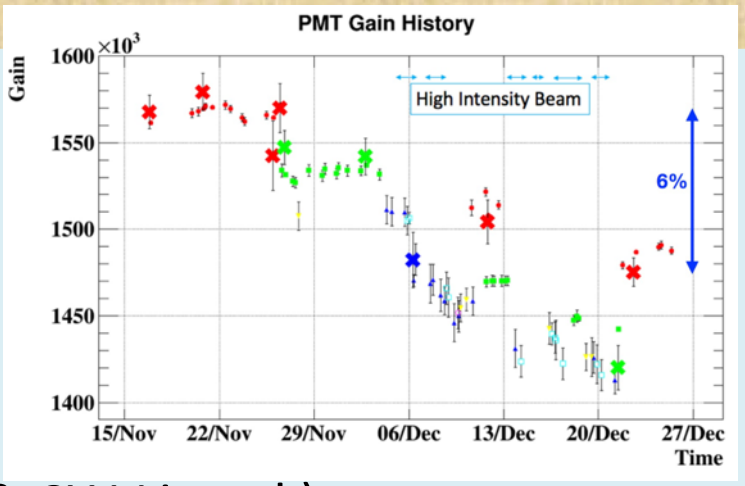
Sec. 2

Detector performance study.
Detector response calibration.

Sec. 3

Beam background γ spectrum study with calibrated detector.

Energy scale stability

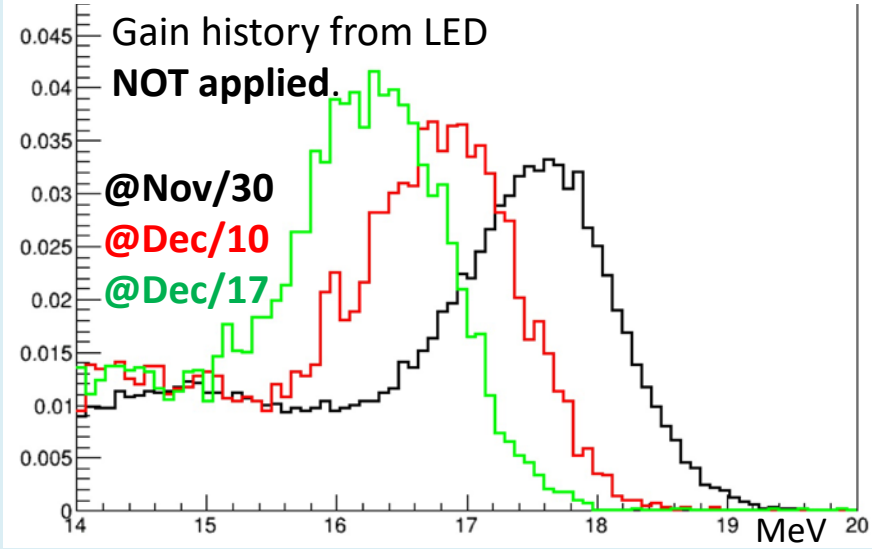


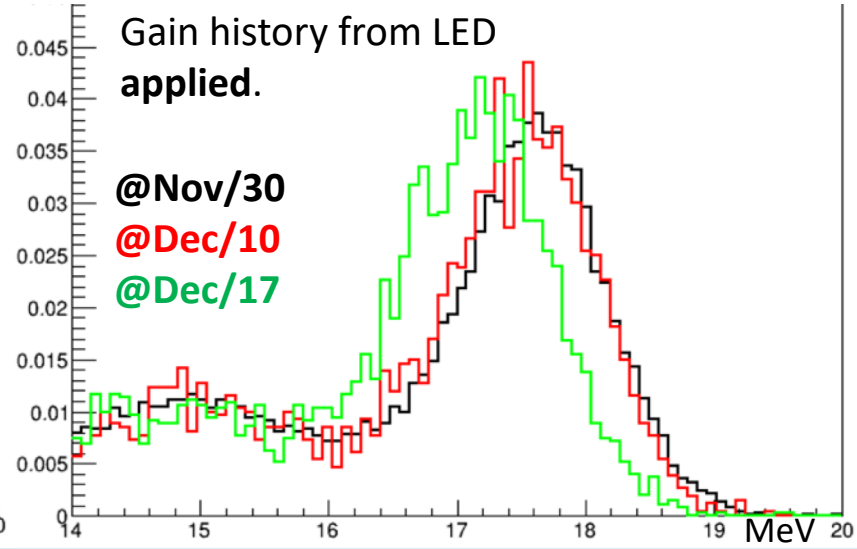
- Photo sensor response changes.
  - PMT gain shift by
    Magnetic field, beam charge-up.
  - PMT gain aging by beam.

→ Needs to be monitored.

- Monitor by 2 independent methods (LED & CW-Li peak).
  → Gain shift by ~10% observed. Still ~2% inconsistency left.

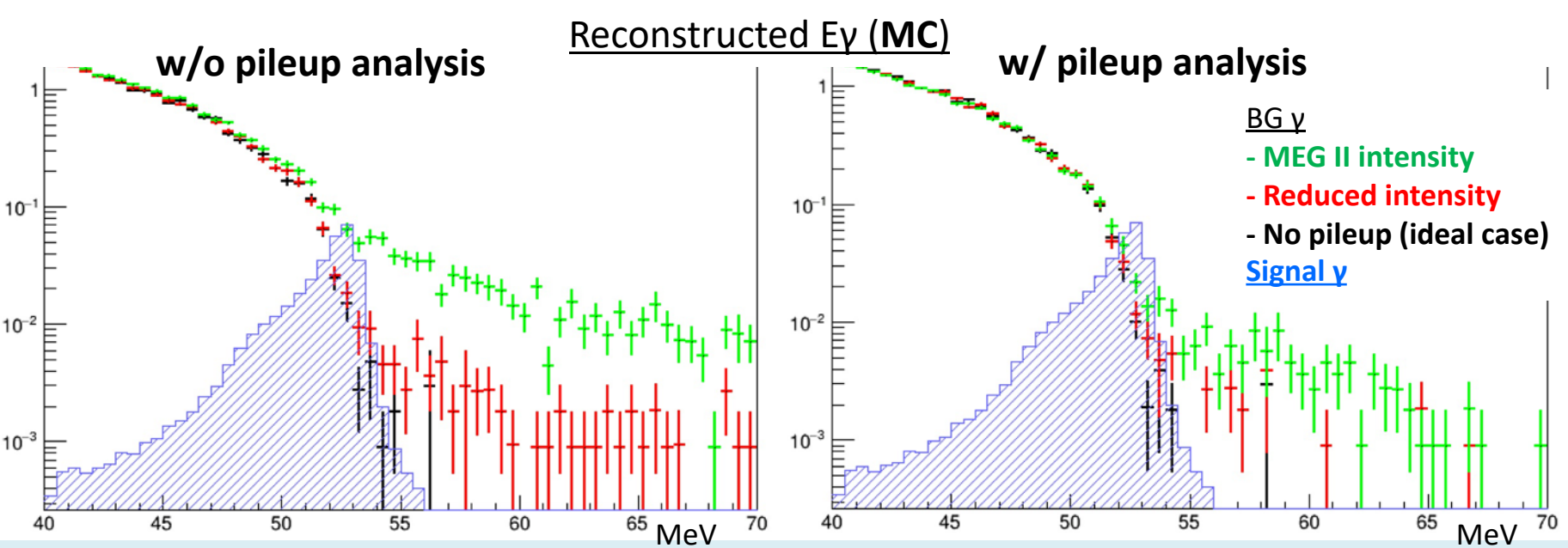
Reconstructed Eγ (CW Lithium)





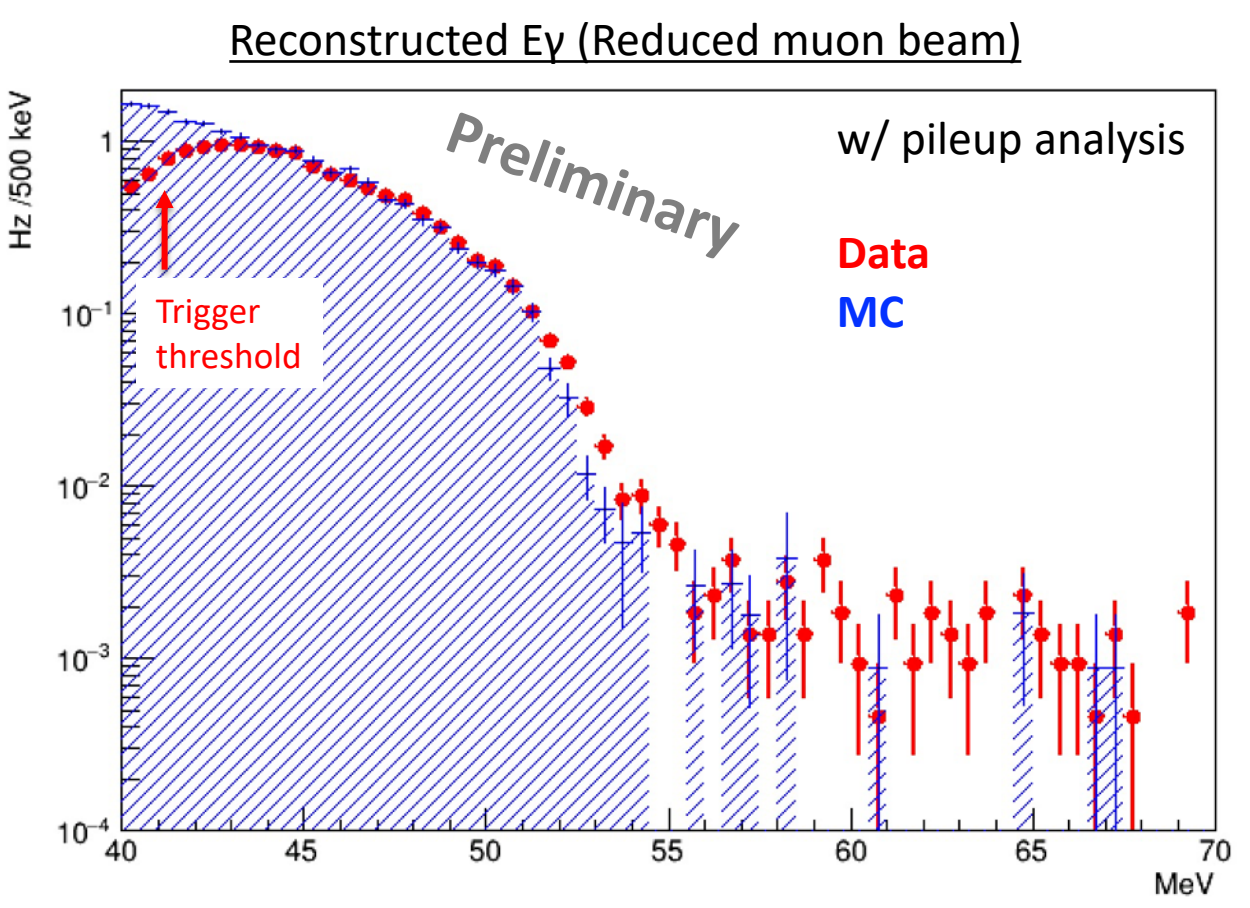
γ-ray DAQ with muon beam

- γ-ray DAQ with muon beam.
  (i.e. background γ spectrum in $\mu \to e\gamma$ search)
  - γ-ray from radiative muon decay + converted γ from Michel muon decay.
- DAQ performed at 2 types of beam rate.
  - MEG II intensity rate (7×10^7 μ/s) → To check pileup effect.
  - Reduced beam rate (8×10^6 μ/s) → To check detector response w/o pileup.
- Pileup identification and unfold is applied in offline analysis.



Eγ spectrum (@ reduced muon beam rate)

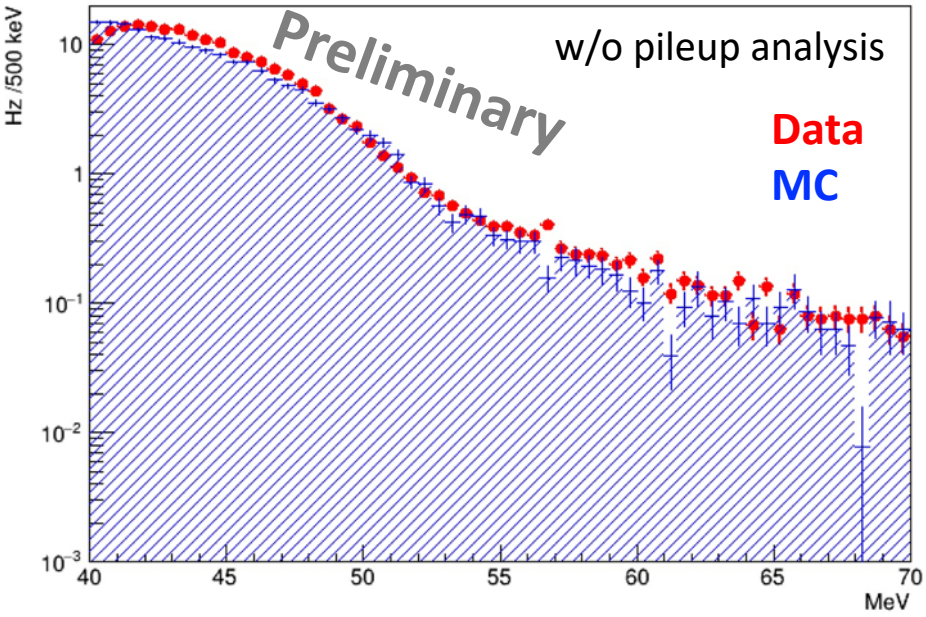
- Energy spectrum is well consistent up to ~51 MeV.
- Inconsistency observed in high energy region.
  - maybe due to BG events not coming from muon beam.

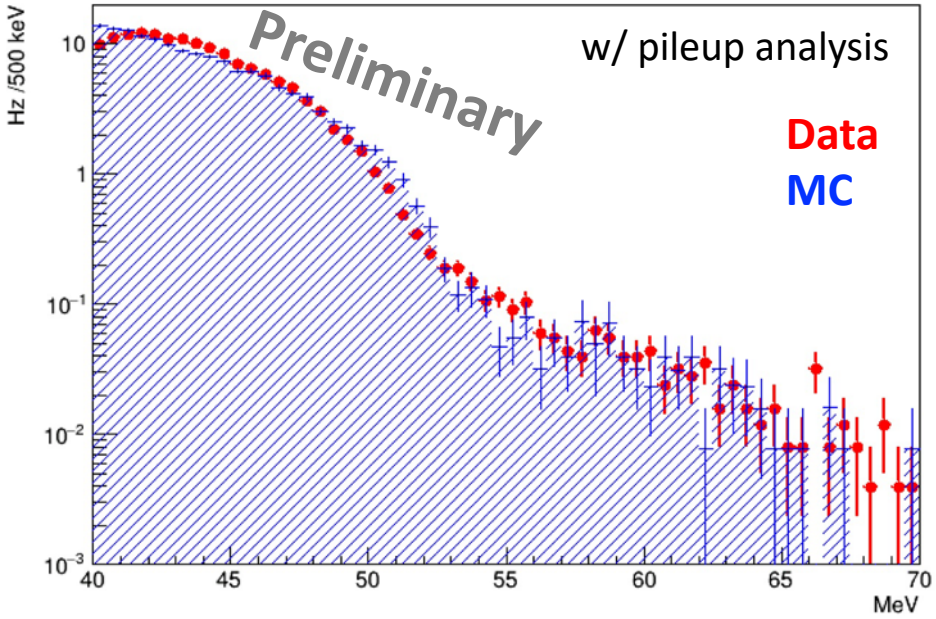


Eγ spectrum (@ MEG II nominal muon beam)

- Energy spectrum has similar shape, but not consistent with MC.
  - Large number of events in high energy region.
    This is due to larger number of pileup γ than expected.
  - Some inconsistency also in low energy region.
- Pileup subtraction in offline analysis works.

Reconstructed Eγ (MEG II muon beam)





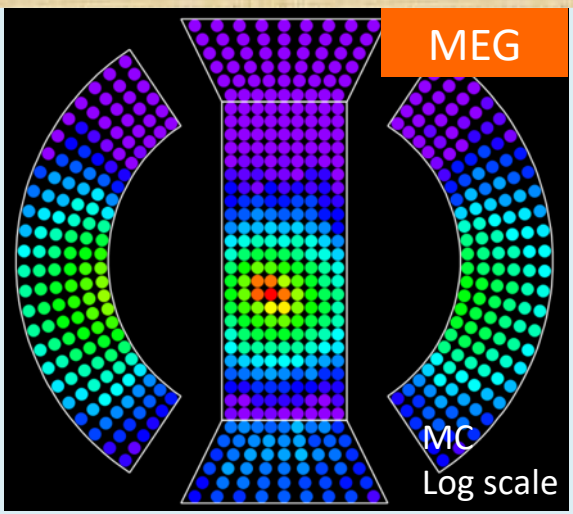
※ Energy scale of Data is shifted by -3% to match MC.

Expected performance

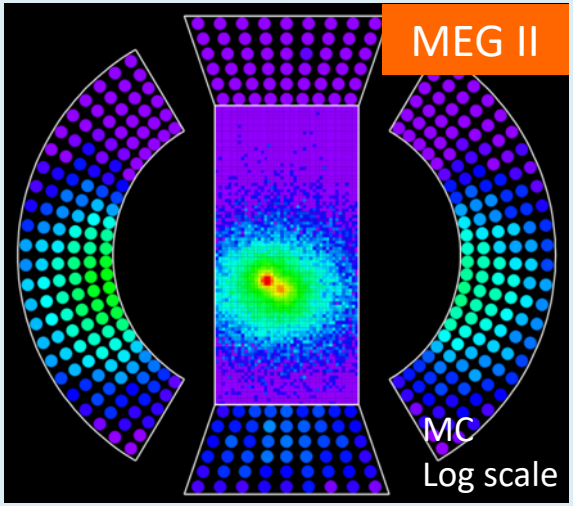
- Significant improvement of all resolutions and efficiency are expected.

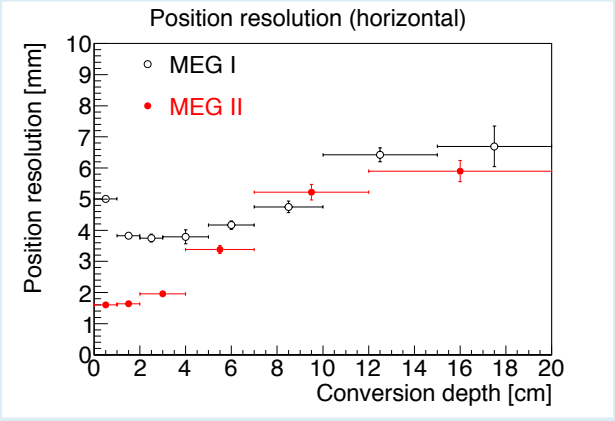
Detector performance for signal γ-ray

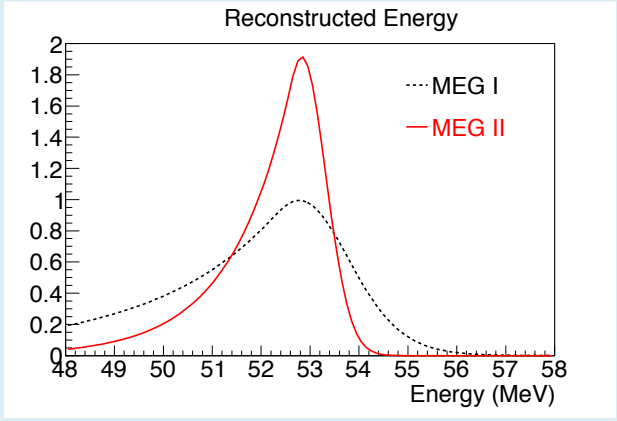
	MEG (measured)	MEG II (simulated)
Position	~5 mm	~2.5 mm
Energy	~2%	0.7 - 1.5%
Timing	62 ps	40 - 70 ps
Efficiency	65%	70%



Imaging power improves







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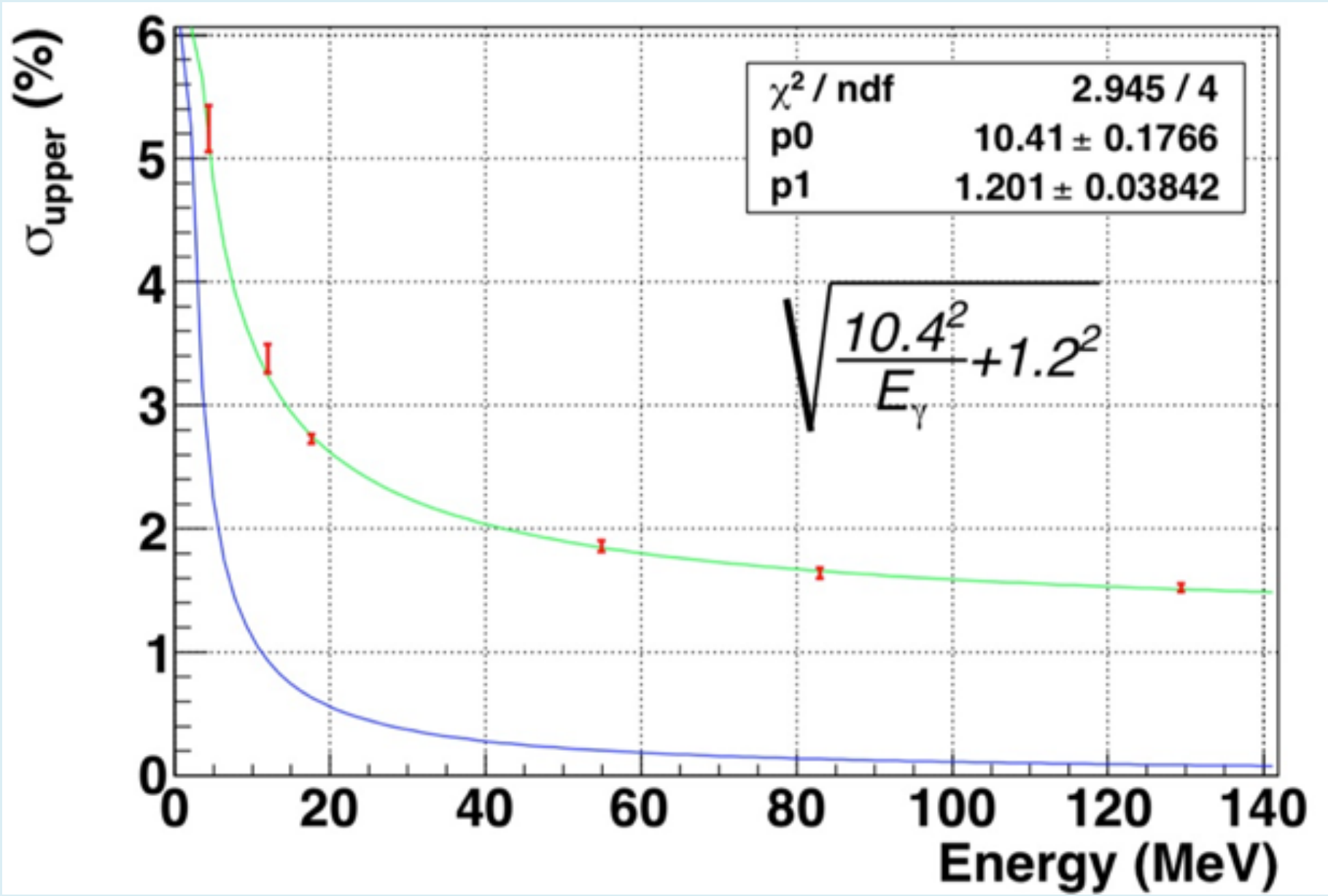
σ_{upper} (%)
χ^2 / ndf 2.945 / 4
p0 10.41 ± 0.1766
p1 1.201 ± 0.03842
$\sqrt{\frac{10.4^2}{E_\gamma}+1.2^2}$
Energy (MeV)
0
20
40
60
80
100
120
140
1
2
3
4
5
6