パイ粒子の反応由来の単色ガンマ線を用いた MEG II実験液体キセノンガンマ線検出器のエネルギー分解能評価

Measurement of the energy resolution of MEG II liquid xenon gamma-ray detector with monochromatic gamma-rays from reactions of the pion

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The University of Tokyo

日本物理学会
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(オンライン開催)
14aT2-2

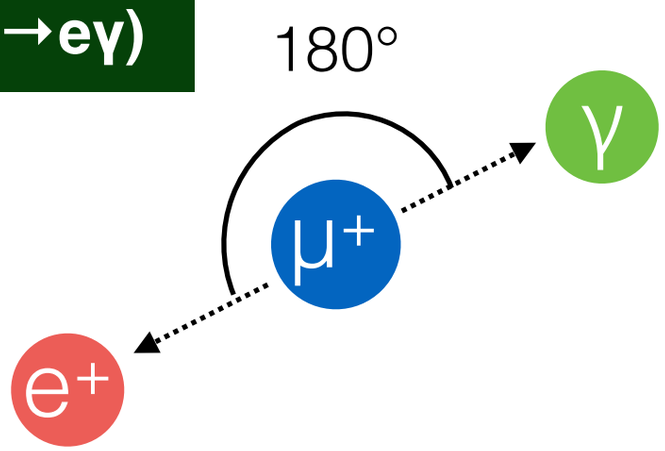
Core-to-Core Program

Outline

- Introduction
  - MEG II experiment
  - Liquid Xenon Gamma-ray Detector Upgrade
- Energy Resolution Measurement
  - Previous measurement
  - Measurement setup
  - Energy resolution
- Summary & Prospects

μ→eγ search

Signal (μ→eγ)



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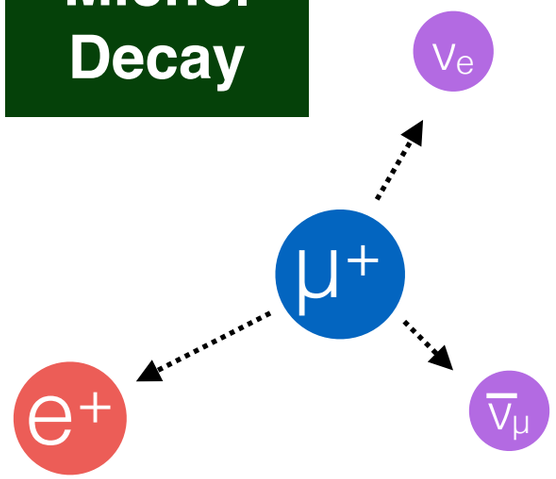
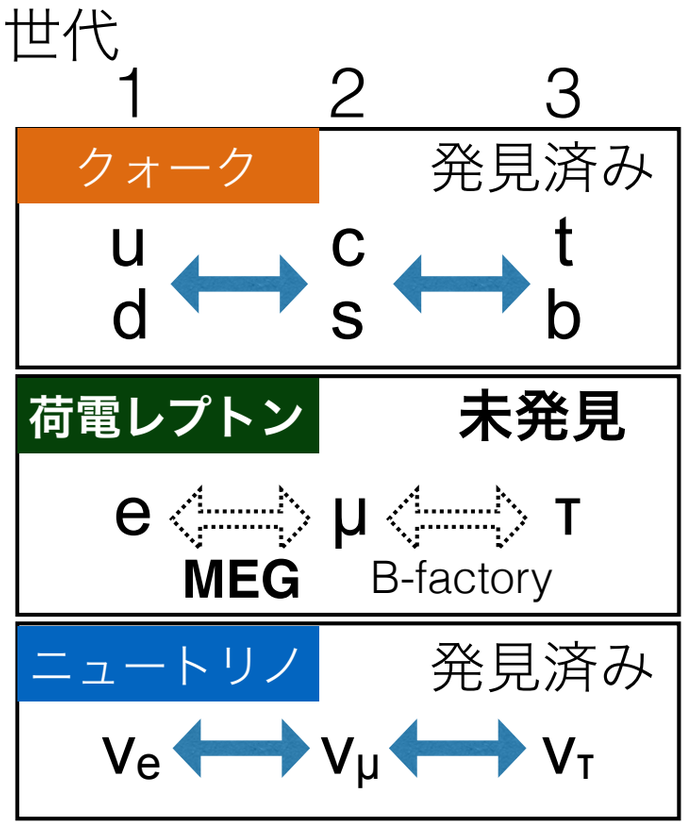
Michel Decay



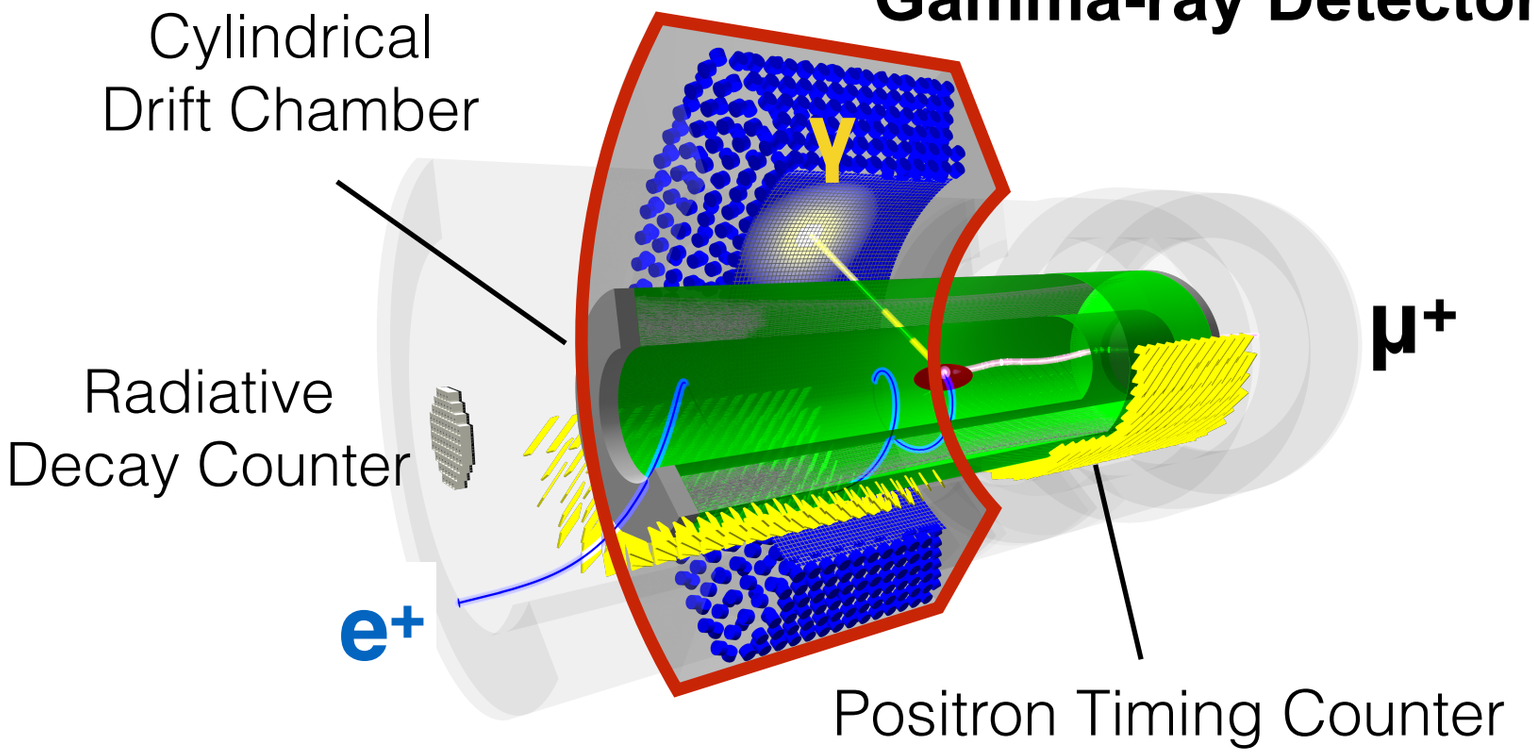
- Simultaneously emitted
- Back-to-back
- Same energy(52.8MeV)



- μ→eγ decay is a charged lepton flavor violating(**cLFV**) decay.
  - **Almost forbidden** in SM+ν. oscillation(Br(μ→eγ)~10^{-54})
  - **Predicted** in some theories(Br(μ→eγ):10^{-11}~10^{-14})
- The MEG experiment gives the current upper limit of Br(μ→eγ).
  - Br($\mu^+ \to e^+\gamma$) < **4.2×10^{-13}** (90% C.L.)

MEG II Experiment

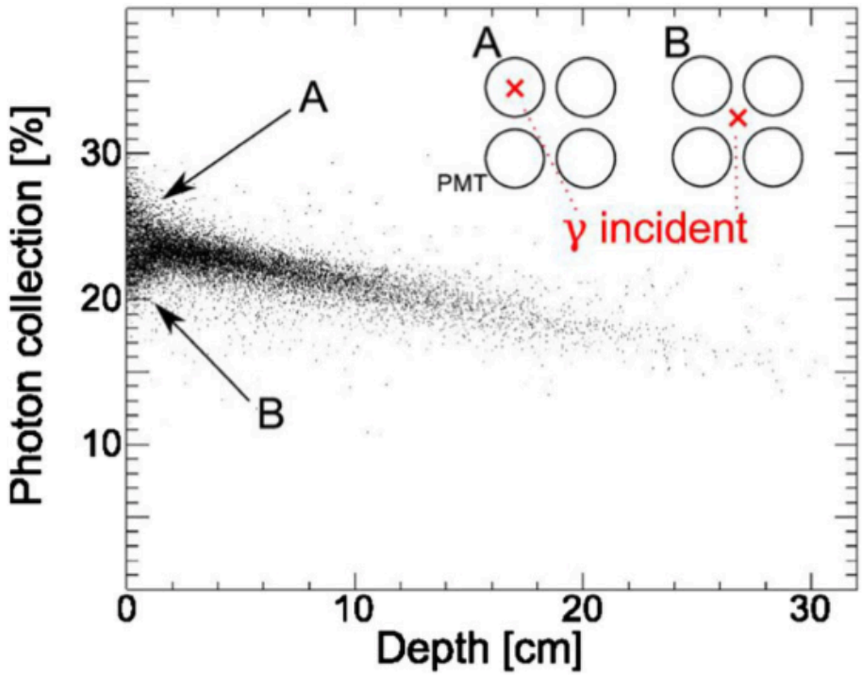
MEG II Setup

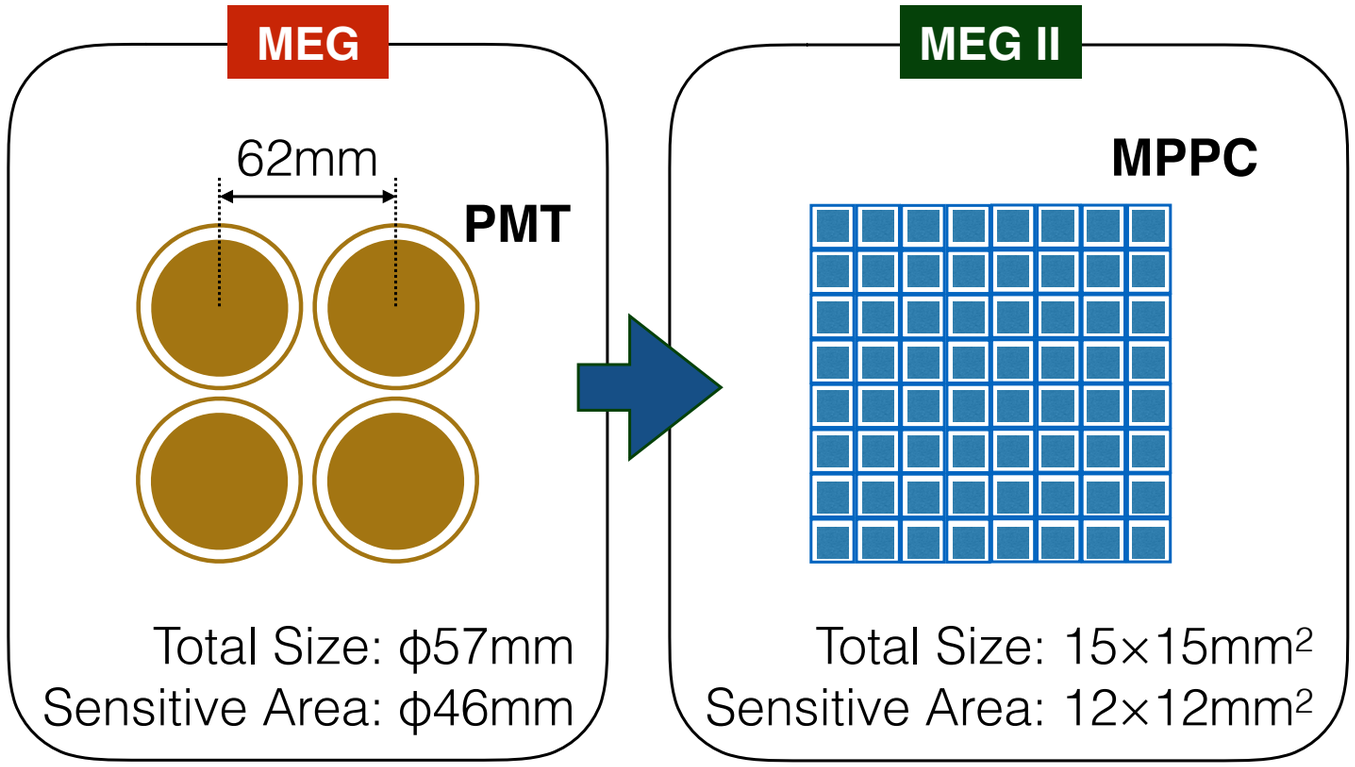


- MEG II will search for the μ→eγ decay with unprecedented sensitivity.
  - Goal: **Br(μ→eγ)~6×10^{-14}** in 3 years of data acquisition.
  - Even **higher intensity muon beam**($3 \times 10^7 \mu/s \rightarrow 7 \times 10^7 \mu/s$)
  - **Detector upgrade**($\times 2$ improvement for each detector)
- Liquid Xenon gamma-ray detector measures the position, energy, and timing of the incident gamma-ray.
  - 900 L liquid xenon + VUV-sensitive photosensor.

Liquid Xenon Detector Upgrade

Light Collection Efficiency @MEG

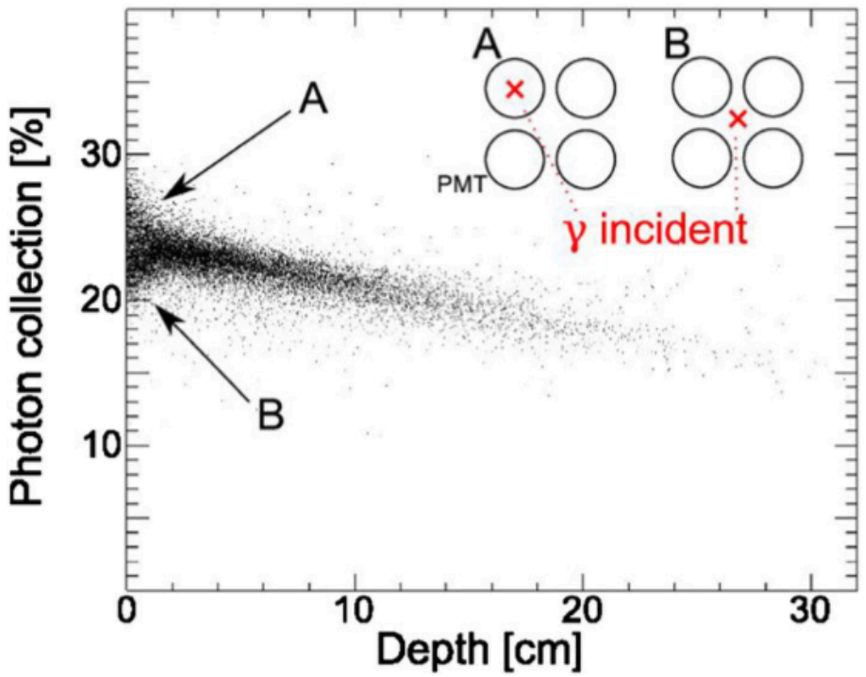




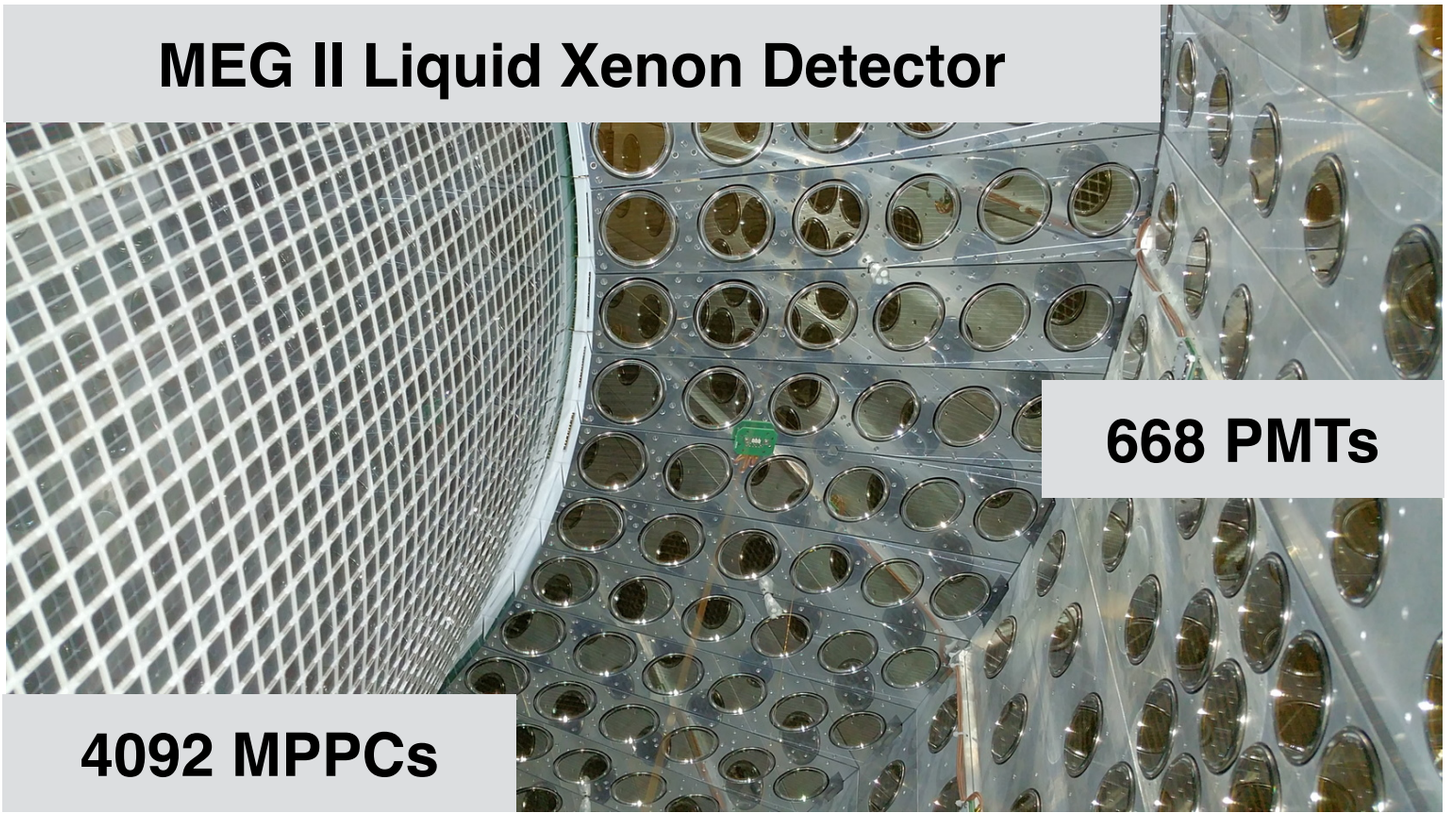
- MEG gamma-ray detector used 2-inch PMTs to detect scintillation light of liquid xenon in the VUV range($\lambda \sim 175$ nm).
- Non-uniformity of light collection efficiency limited the resolution.
  - A small and square-shaped photosensor is desirable.
- We use **VUV-sensitive MPPCs** in MEG II.
  - Developed for MEG II in collaboration with Hamamatsu K.K.
  - Entrance face: 216 PMTs → **4092 MPPCs(**12×12 mm^2**)**

Liquid Xenon Detector Upgrade

Light Collection Efficiency @MEG



MEG II Liquid Xenon Detector



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Liquid Xenon Detector Upgrade

Detector Resolution	MEG (measured)	MEG II (design)	MEG II (measured)
Position(mm)	5 - 6	2.5	✓ 2.5
Energy(%)	1.7 - 2.4	1.0 - 1.1	(1.7)
Timing(ps)	62	50 - 70	(40: intrinsic)
Efficiency(%)	63	69	-

2020 Autumn JPS / 15aSE-9

2019 Autum JPS(小川) / **This talk**

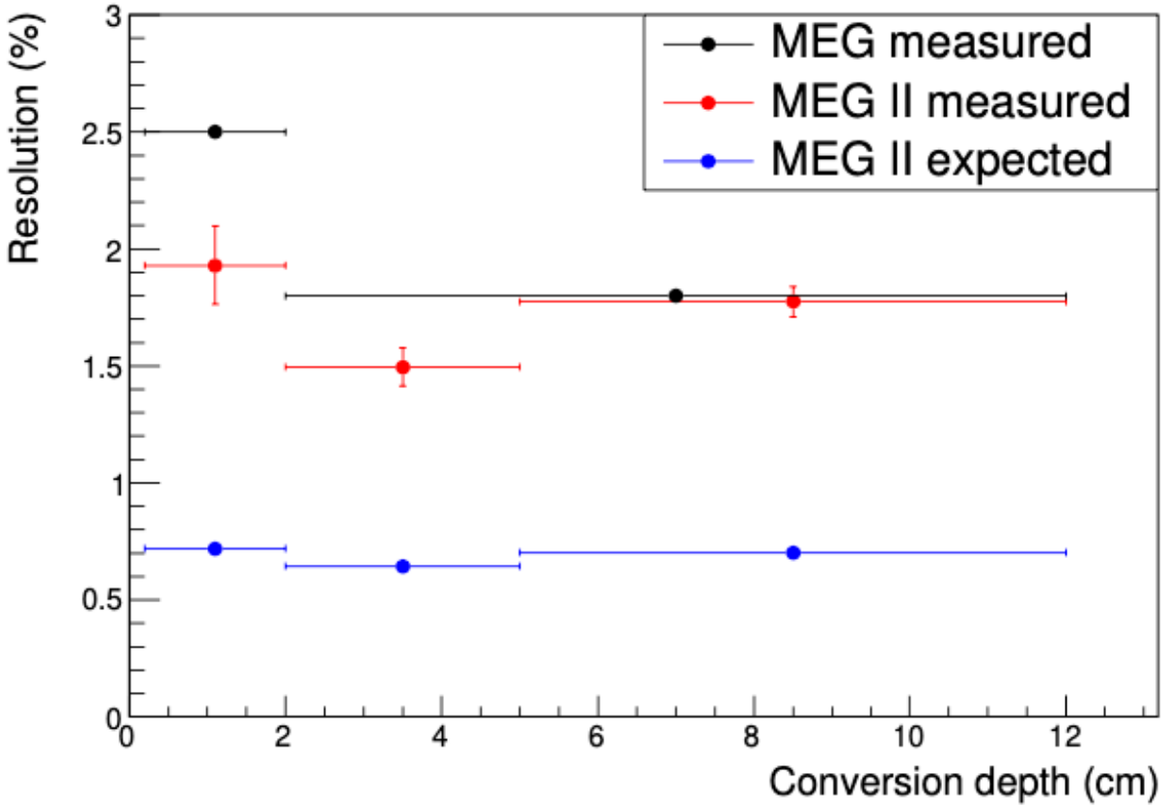
2018 Spring JPS(小川) / **Next talk**(恩田)

Design values : “The design of the MEG II experiment”,

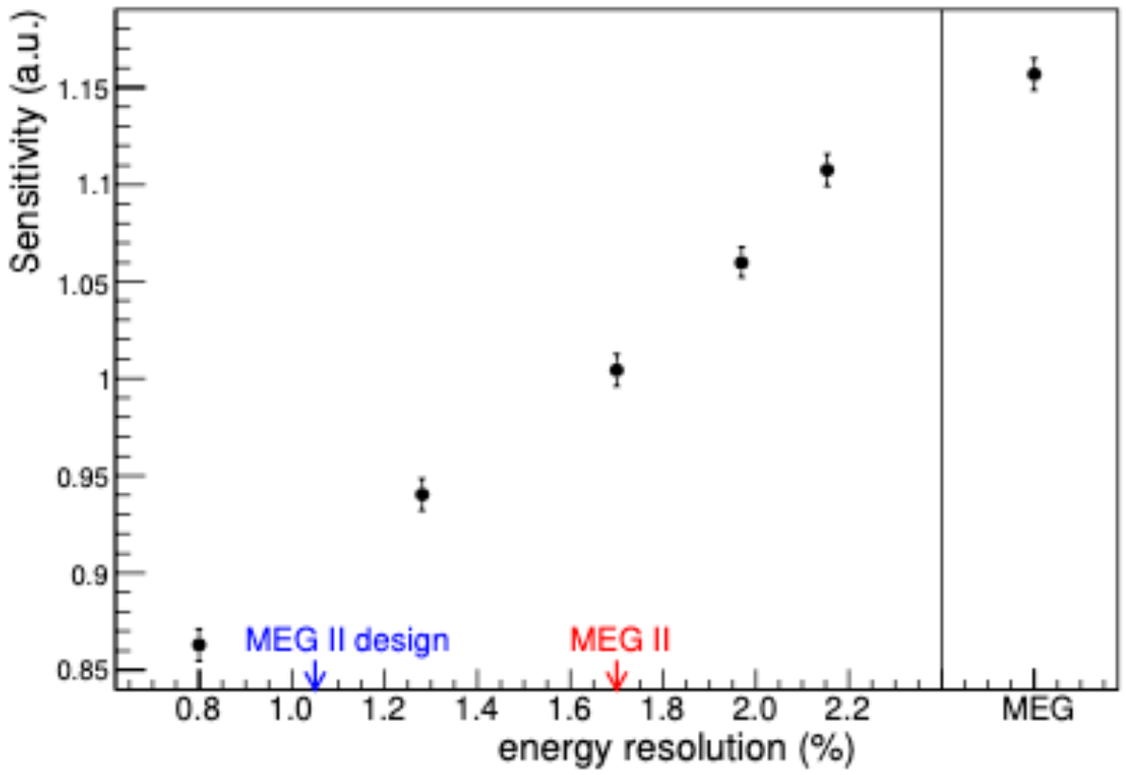
- We need to measure energy and time resolution whereas **improvement of position resolution was already confirmed**.
- The number of readout electronics is limited(~1000/4760) in 2020.
  - Installation and commissioning of full system is now in progress.
- Today’s theme:
  - **Energy resolution measurement using pion decay $\pi^0 \to \gamma\gamma$**

Previous measurement of energy resolution

Energy resolution with muon BG gamma-ray spectrum



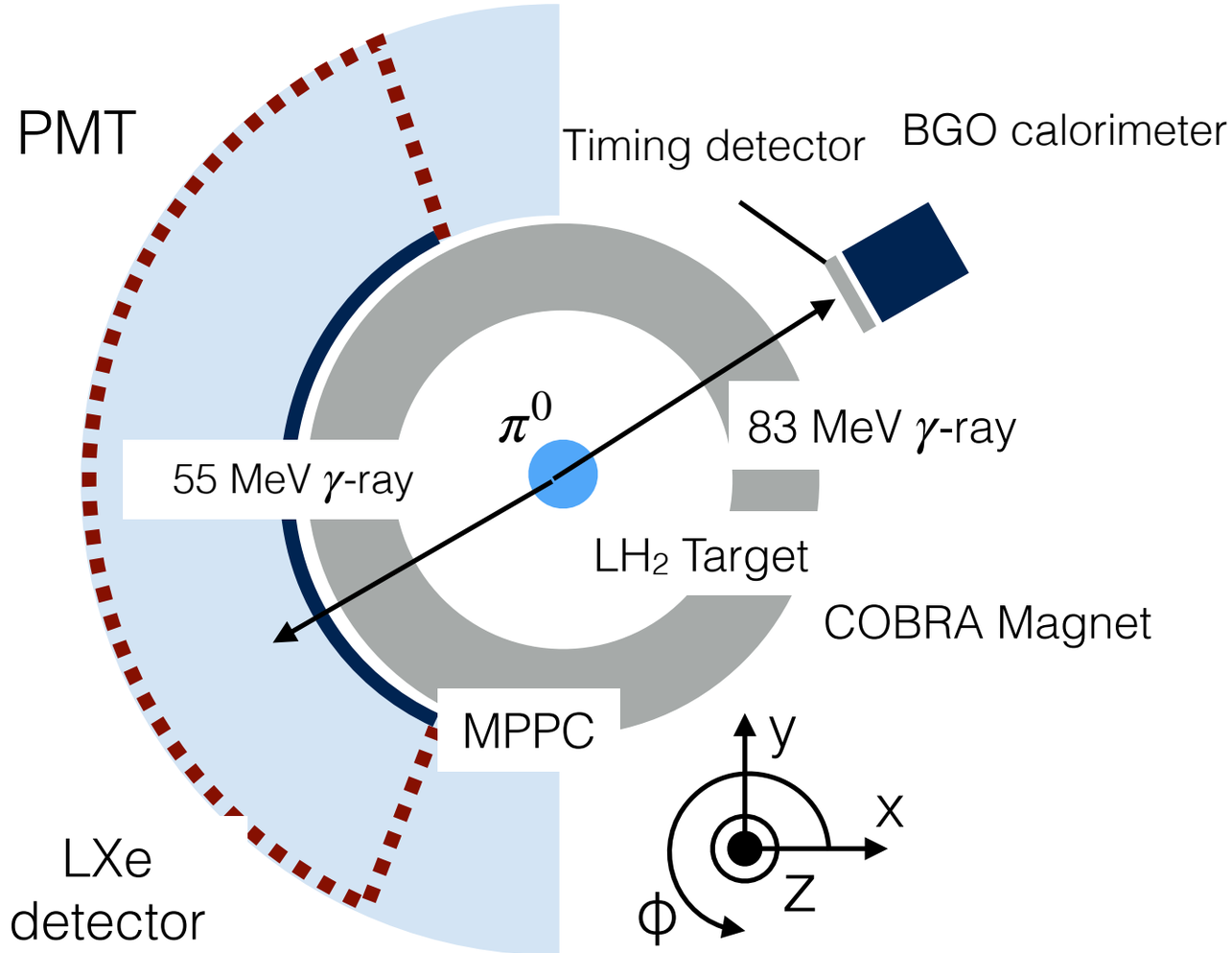
Sensitivity vs Energy resolution



from Shinji Ogawa's Ph.D. thesis

- Energy resolution @$E_\gamma \sim 52.8$ MeV was measured with the BG gamma-ray energy spectrum from muon decay.
  - $\sigma_E = 1.7 \pm 0.1$ % : limited by an unknown term.
- Sensitivity improves by ~15% from MEG with energy resolution 1.7%, but ~10% worse than the design.

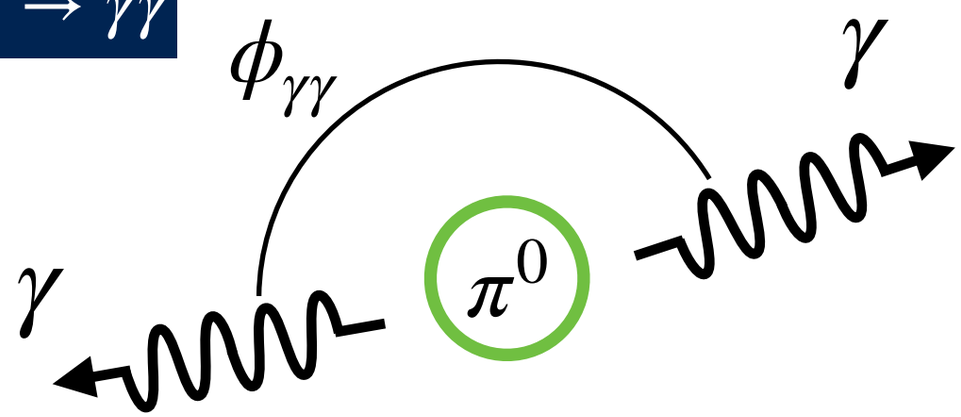
Measurement setup - Instruments -



- π^- beam (70.5 MeV/c) is introduced to a liquid hydrogen(LH_2) target.
- Gamma-ray pair from neutral pion decay is used for the measurement.
  - $\pi^- + p \rightarrow \pi^0 + n$: charge exchange (CEX) process
  - $\pi^0 \rightarrow \gamma\gamma$: two-body decay from boosted neutral pion
- The other gamma-ray is detected with a tag detector in the opposite side.
  - Timing detector: plastic scintillator plates + MPPCs
  - Calorimeter: BGO crystals + PMTs

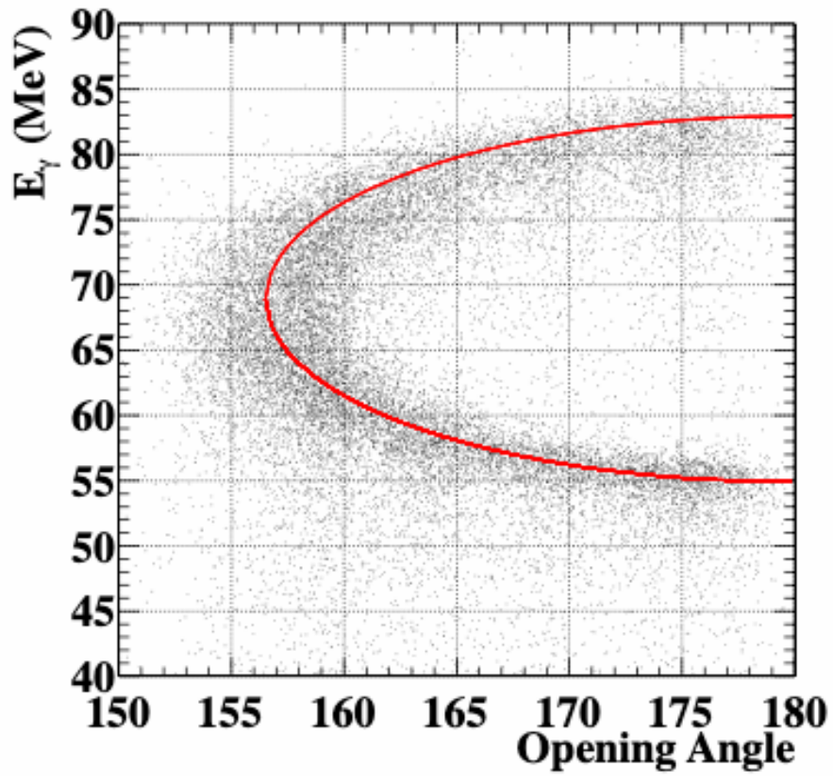
Measurement setup - Kinematics -

$\pi^0 \to \gamma\gamma$



$$\cos\phi_{\gamma\gamma} = \frac{m_{\pi^0}^2}{2E_\gamma\left(E_{\pi^0} - E_\gamma\right)}$$

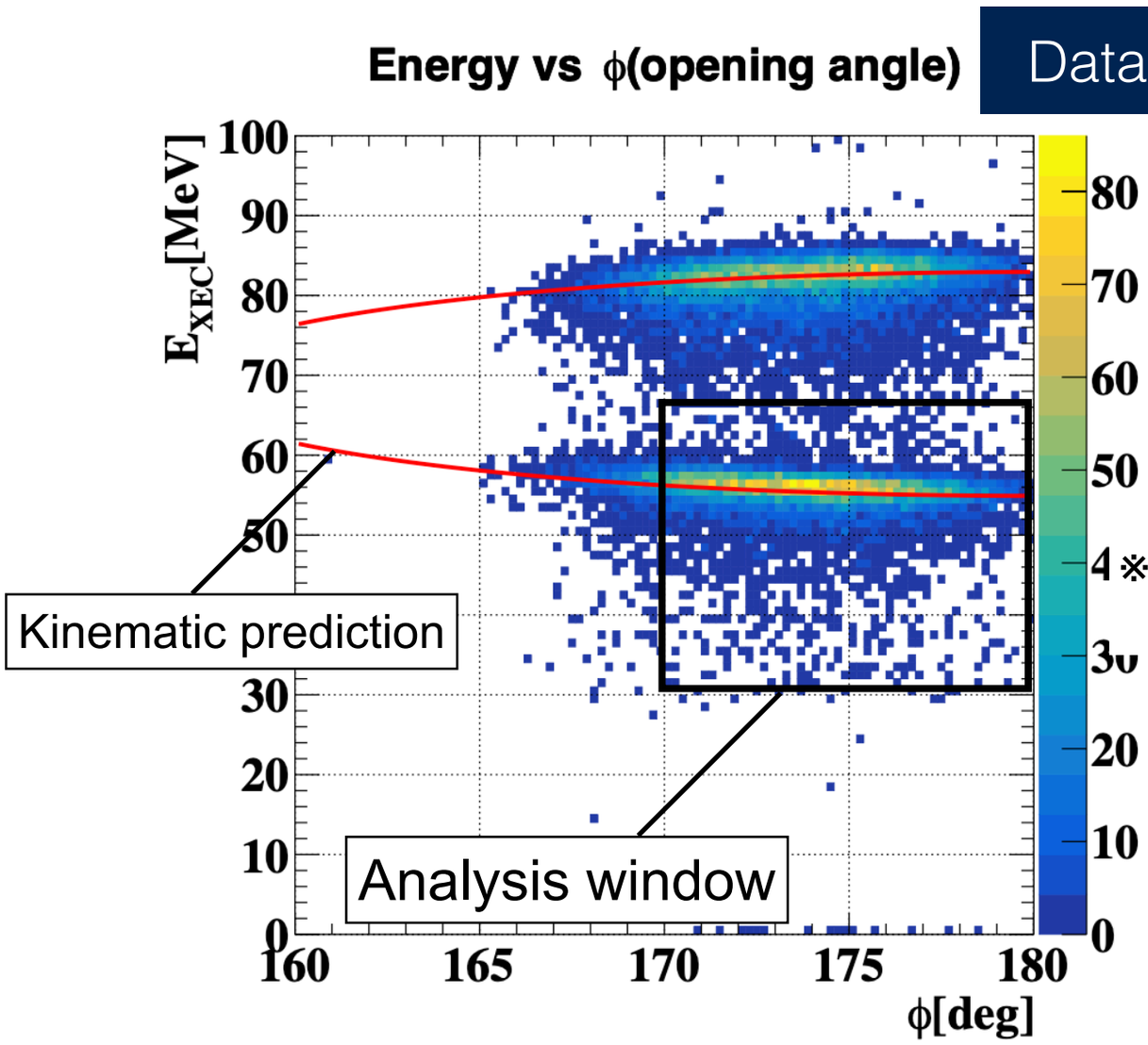
Energy vs opening angle @ MEG, data



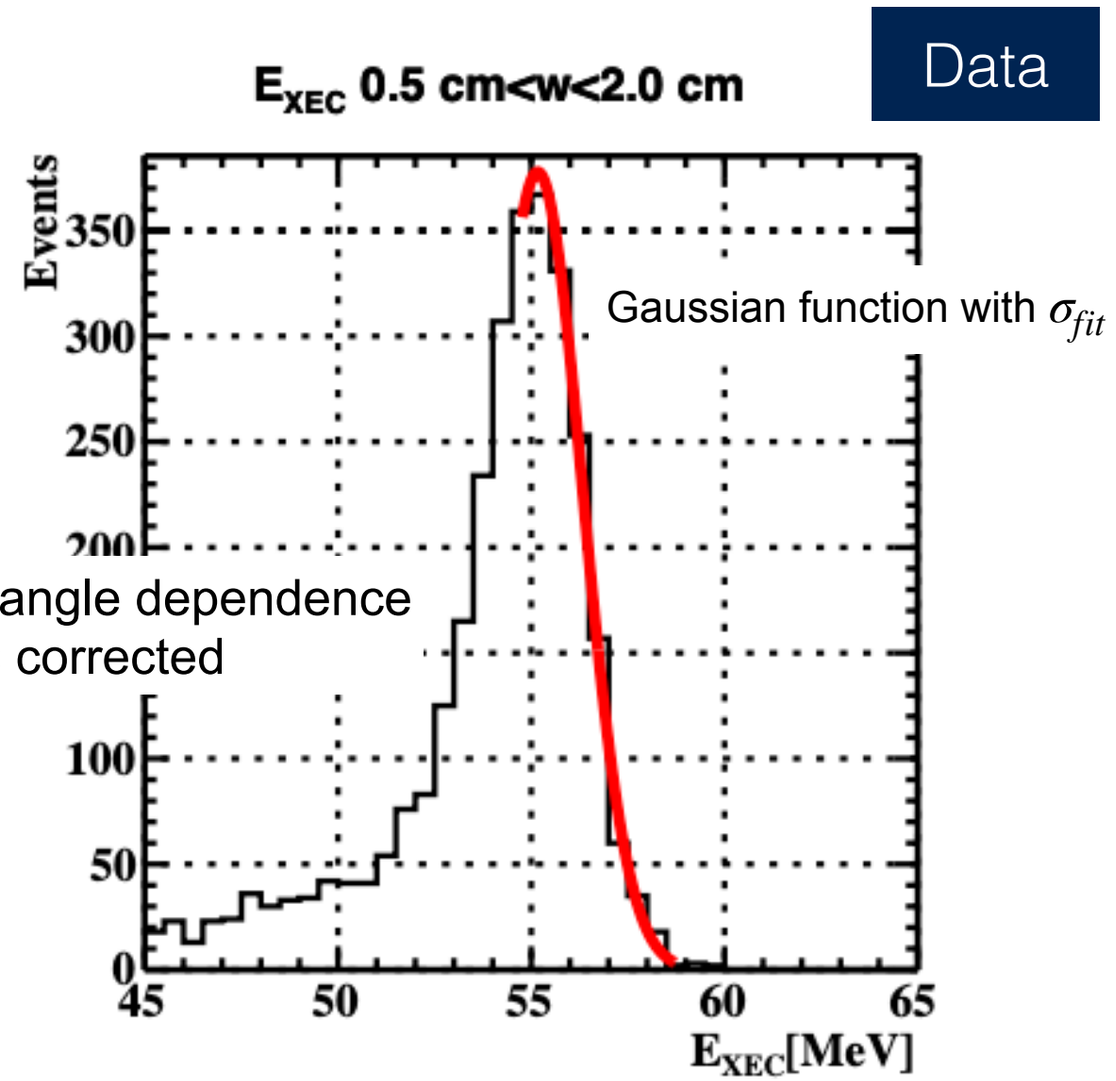
from Y. Nishimura's Ph.D. thesis

- Since $\pi^0 \to \gamma\gamma$ is a two-body decay from boosted π^0, energy deposit in the LXe calorimeter can be predicted based on the following
  - $\phi_{\gamma\gamma}$: opening angle between two gamma-rays .
  - E_{BGO}: energy measured in BGO calorimeter.
- Back-to-back gamma-ray pairs have $E_\gamma = 55{,}83\ \mathrm{MeV}$.
  - Close to $E_{signal} = 52.8\ \mathrm{MeV}$ from $\mu \to e\gamma$.
  - Energy + Time resolution can be measured.

Energy Spectrum of 55 MeV peak

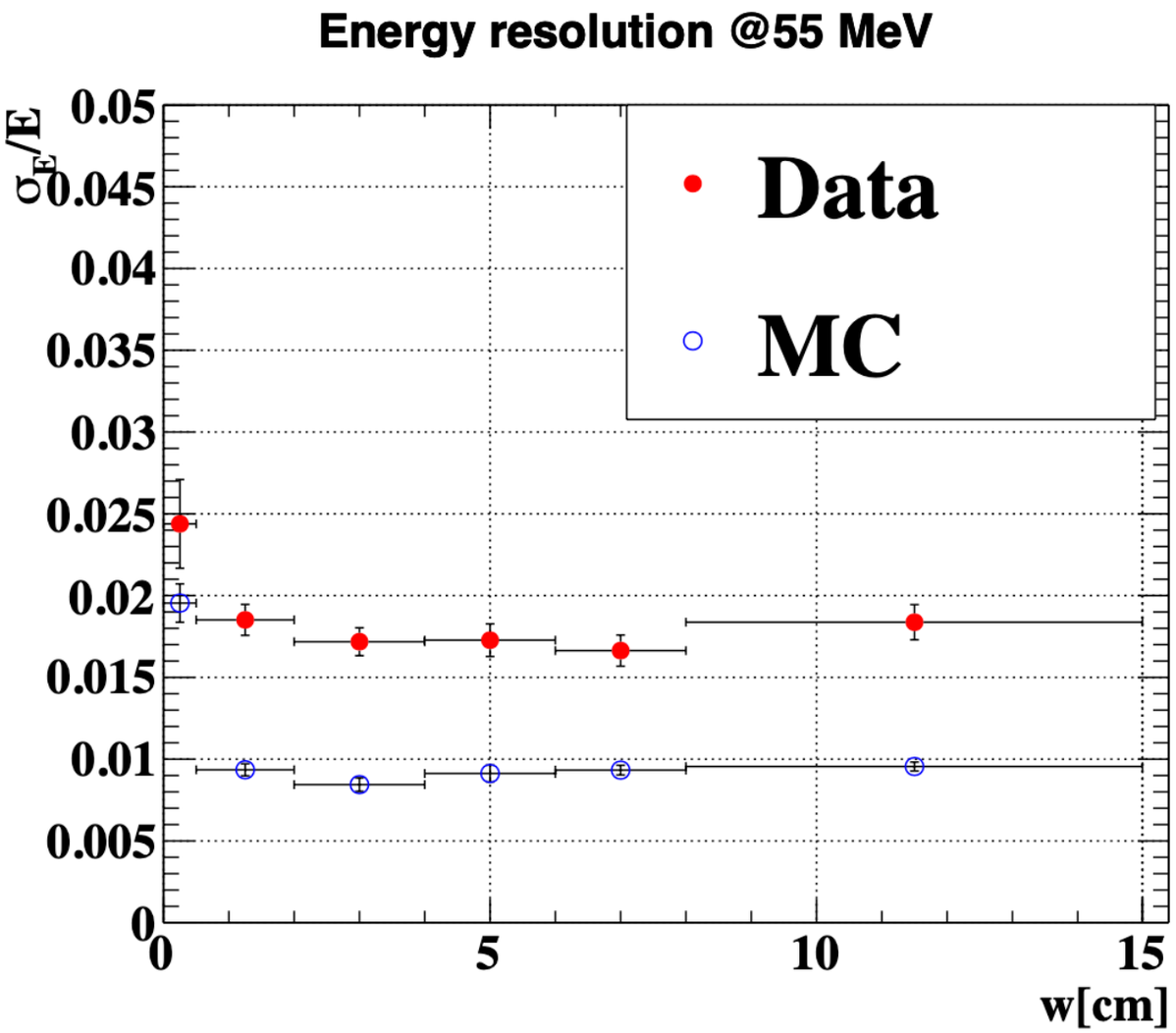


※Opening angle dependence is corrected



- Event selection:
  - Hit position is in $18 \times 18\ \mathrm{cm}^2$ (middle of readout region).
  - Energy deposit in BGO crystals $E_{BGO} > 65\ \mathrm{MeV}$.
  - Opening angle $\phi_{\gamma\gamma} > 170\ \mathrm{deg}$.
- Right side of the spectrum was fitted with gaussian function.

Energy resolution at 55 MeV



Energy resolution

$$\sigma_E^2 = \sigma_{fit}^2 - \sigma_{truth}^2$$

Sigma of fit function　　Spread of hit energy

- Energy resolution σ_E was estimated from σ_{fit}.
  - Subtracted the hit energy spread σ_{truth} using MC.
- Measured energy resolution: 1.8 ± 0.1 % (0.5 cm < depth < 10 cm).
- Unknown term(Deviation from MC) is dominant.
  - MC: identical readout configuration to data.
  - Noise term: ~0.25% / Statistical term: ~0.4%: relatively small.

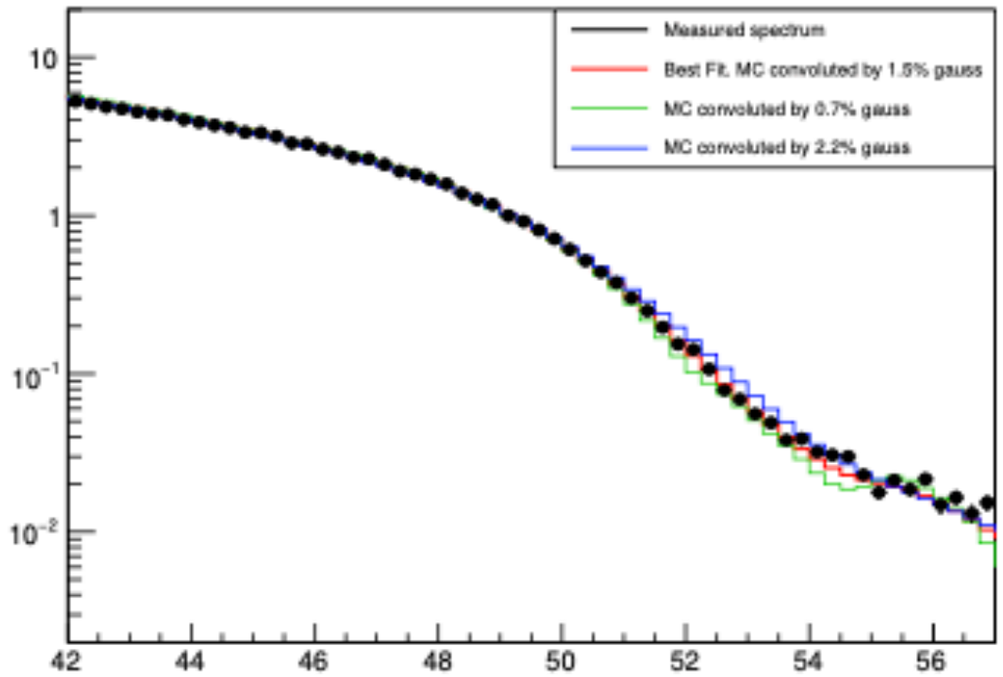
Summary & Prospects

- Summary
  - The commissioning of the liquid xenon gamma-ray detector for the MEG II experiment is in progress.
  - We measured energy resolution for 55 MeV gamma-ray from $\pi^0 \to \gamma\gamma$ decay.
    - Energy resolution was 1.8 ± 0.1 % .
      - Consistent with the previous evaluation.
      - Significantly worse than MC simulation due to an unknown term.
      - Loss of sensitivity from the design: ~10%.
- Prospects
  - Resolution evaluation at 83 MeV: in progress.
  - Measurement of energy resolution with the full electronics at the end of 2021.

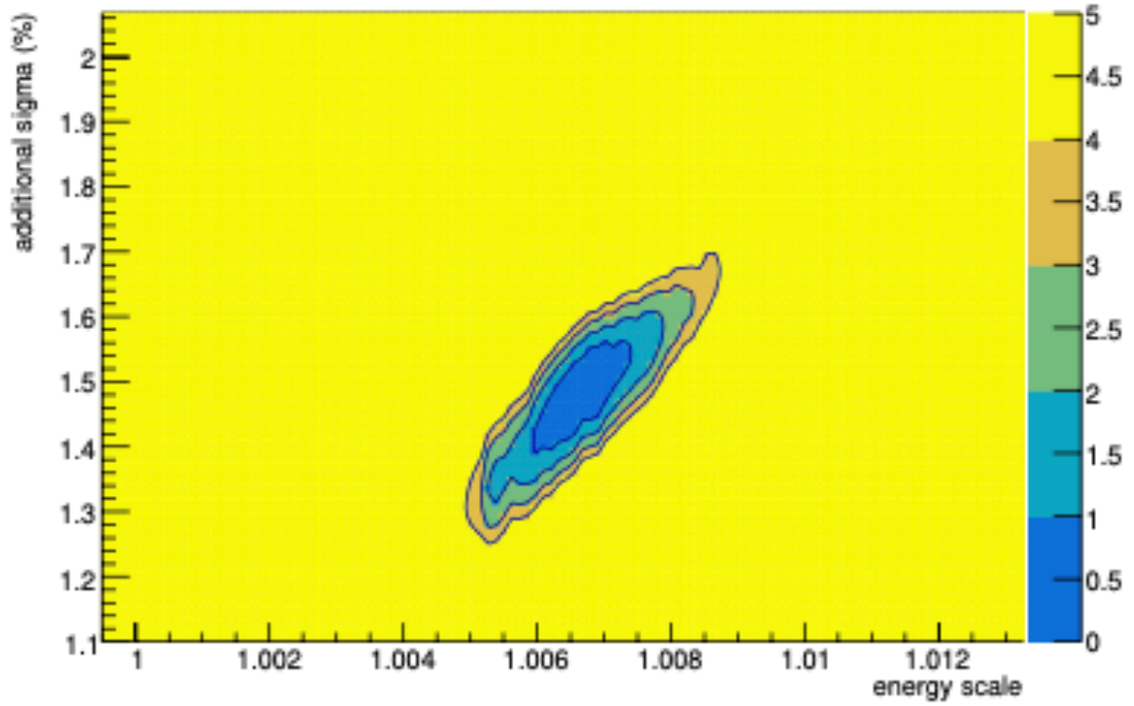
Back up

- Resolution evaluation with BG gamma
- Opening angle resolution
- Statistical contribution to resolution
- Noise contribution to resolution
- 55MeV Peak in MC
- Energy Correlation

Resolution Evaluation with BG gamma



(b)

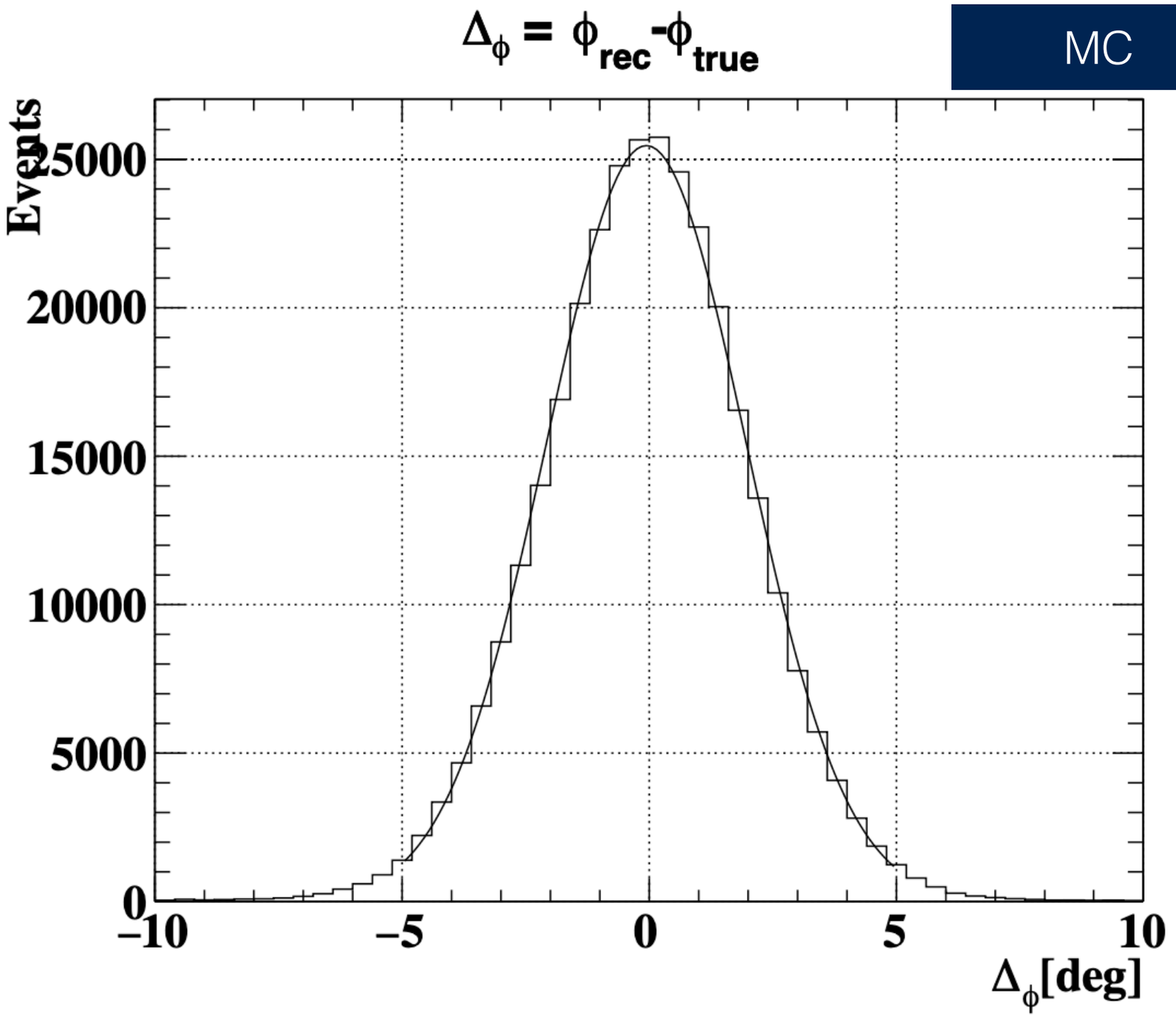


(b)

from Shinji Ogawa's Ph.D. thesis

- Evaluation with MEG II intensity($R_\mu \sim 7 \times 10^7 \mu/s$) data

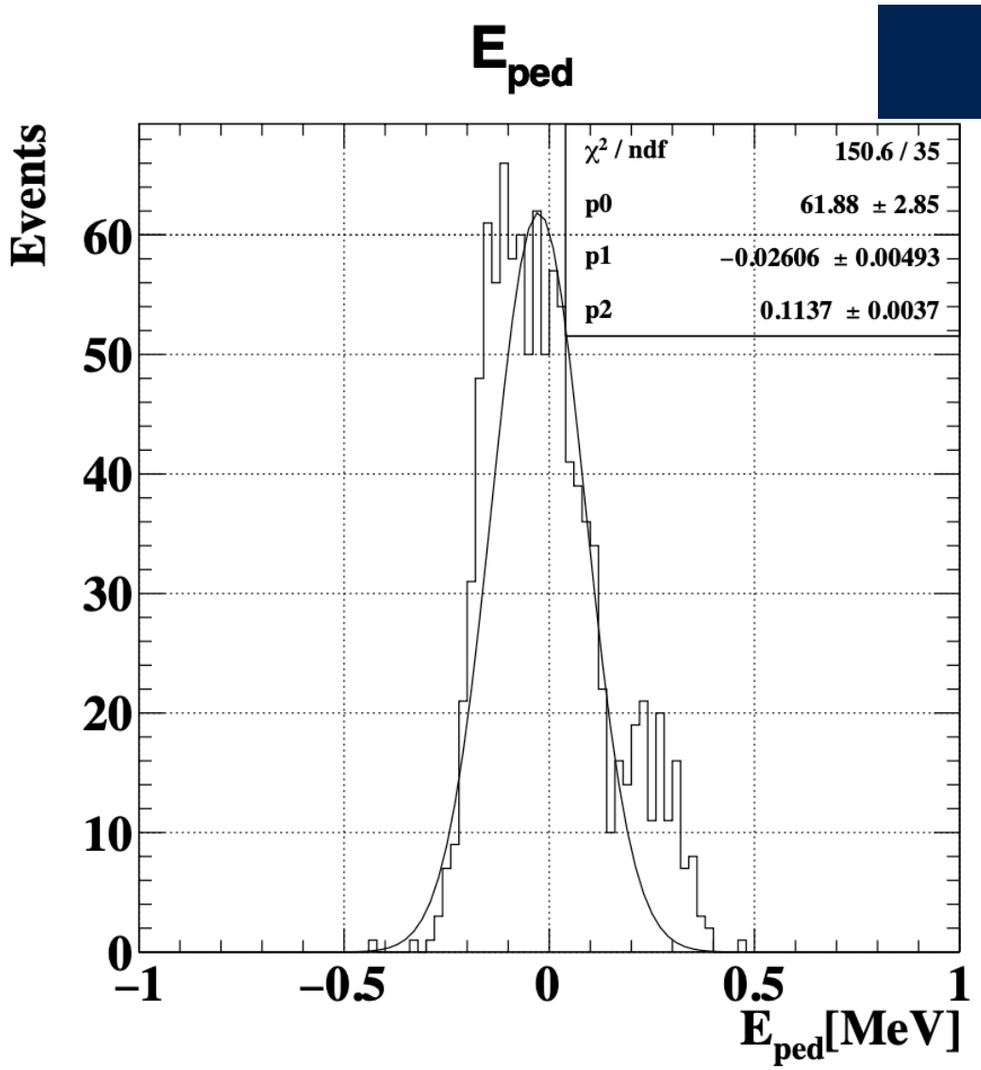
Opening angle resolution



- 2 deg resolution in MC

Noise Contribution to resolution

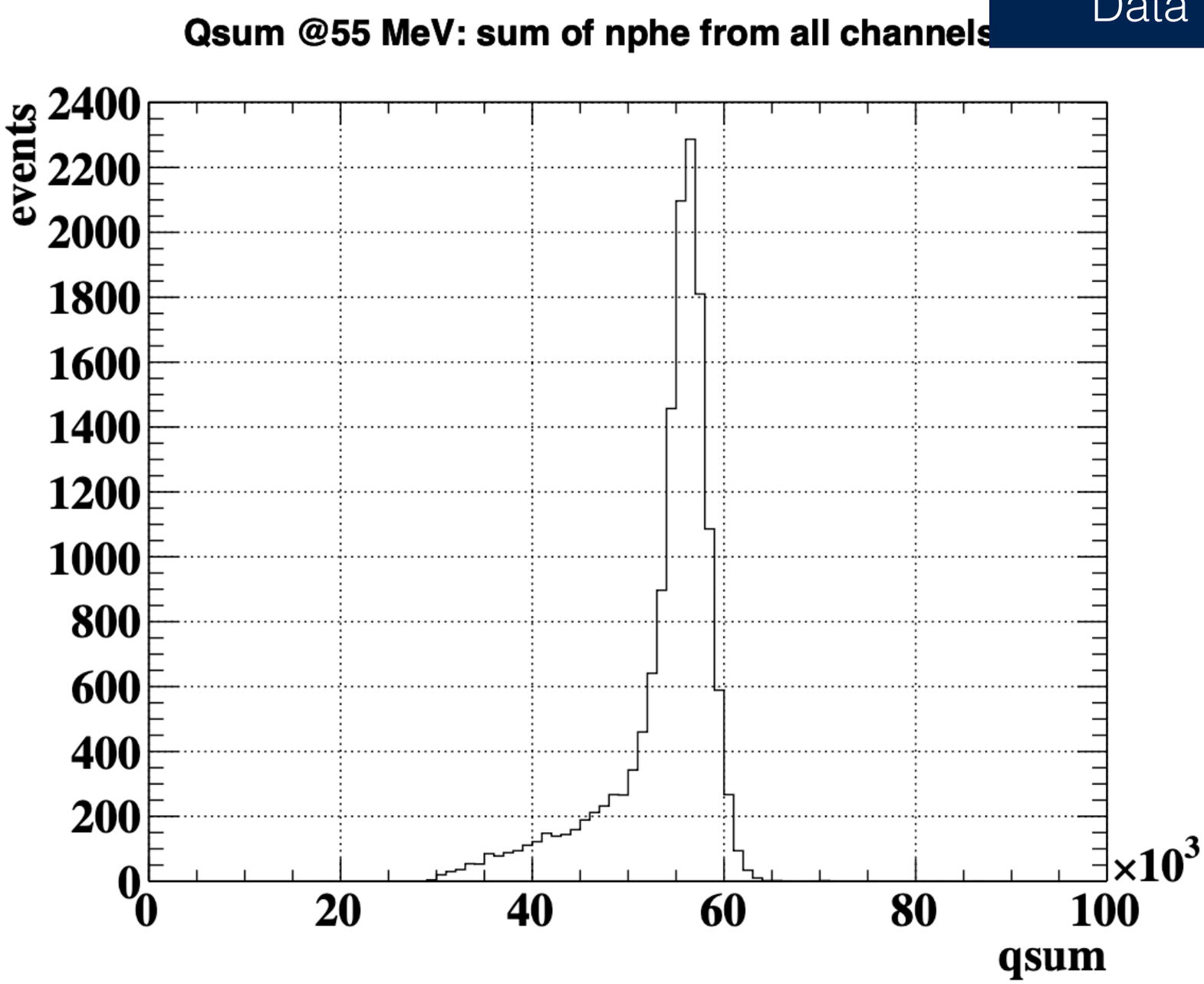
Data



- $\sigma_{pedestal}$ = 0.11 - 0.14 MeV
- ~0.25 % @ E_{signal} = 52.8 MeV

Statistical contribution

Data



- Statistical term: $1/\sqrt{N_{phe}} = 0.004(0.4\%)$

Energy Distribution in MC

MC