MEG II実験液体キセノンガンマ線検出器の位置分解能およびその位置依存性の評価

Evaluation of position resolution and its position dependence of the MEG II liquid xenon gamma-ray detector

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日本物理学会
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(オンライン開催)
15aSE-9

MEG II
Mu - E - Gamma collaboration

THE UNIVERSITY OF TOKYO

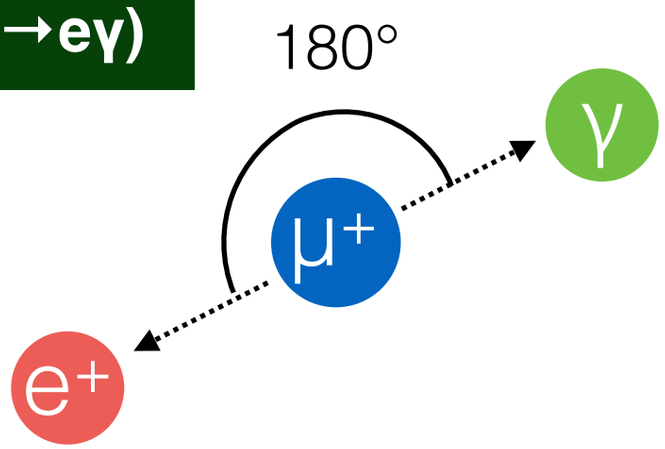
Core-to-Core Program

Outline

- Introduction
  - MEG II experiment
  - Liquid Xenon Gamma-ray Detector Upgrade
- Position resolution measurement
  - Measurement setup
  - Evaluation method
  - Measured position resolution
- Summary & Prospects

μ→eγ search

Signal (μ→eγ)



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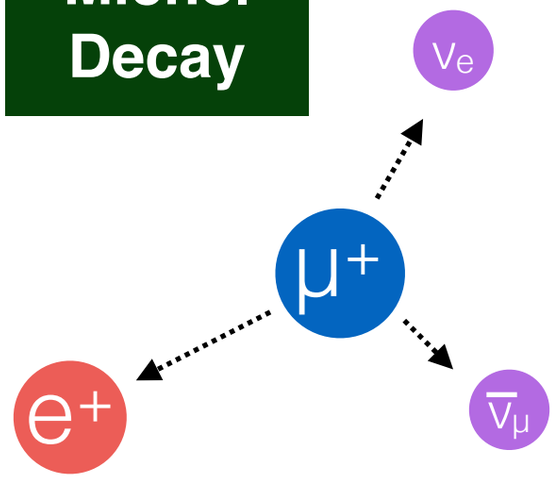
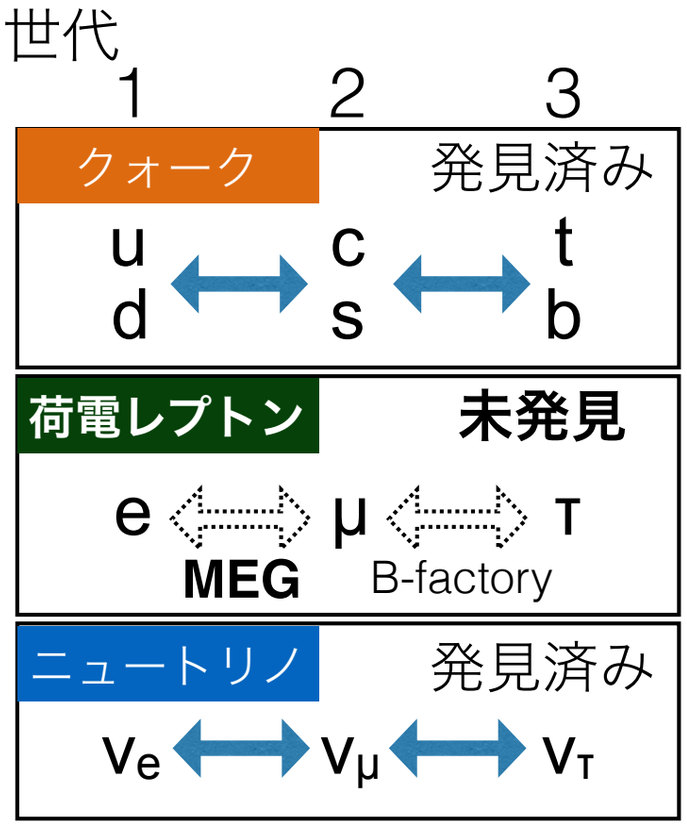
Michel Decay



- 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

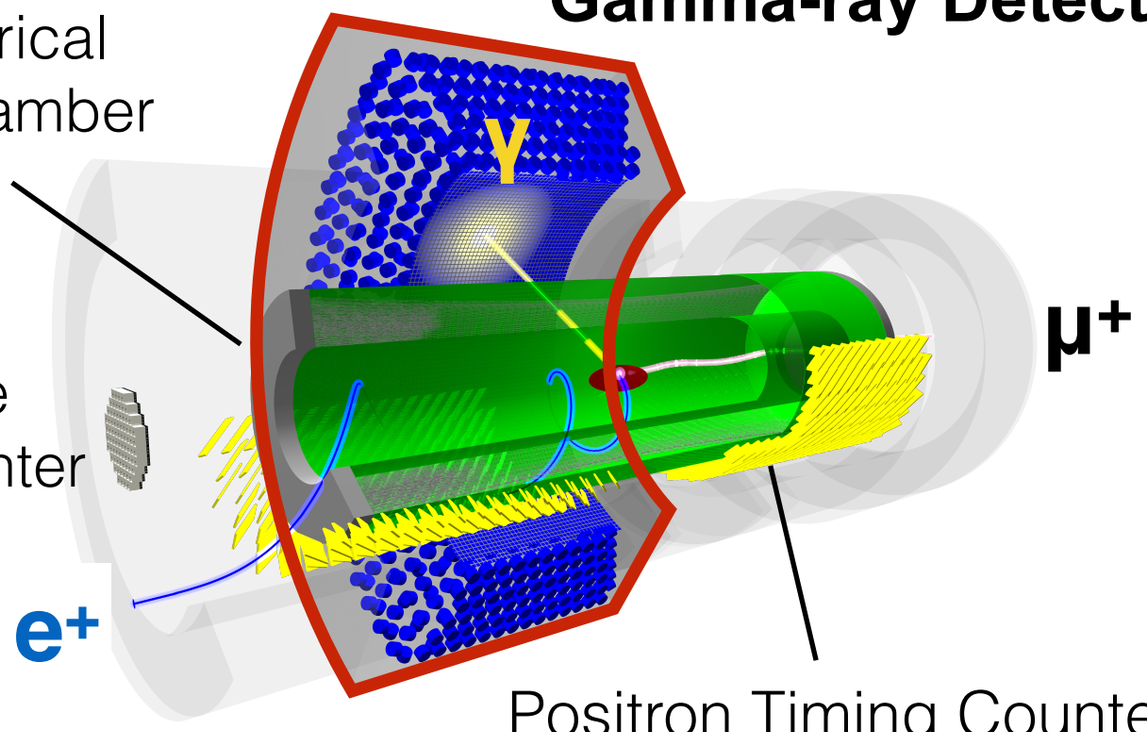
MEG II Setup

14aSE-4(宇佐見)

Cylindrical
Drift Chamber

14aSE-2(恩田)

Radiative
Decay Counter



Liquid Xenon Gamma-ray Detector

Positron Timing Counter

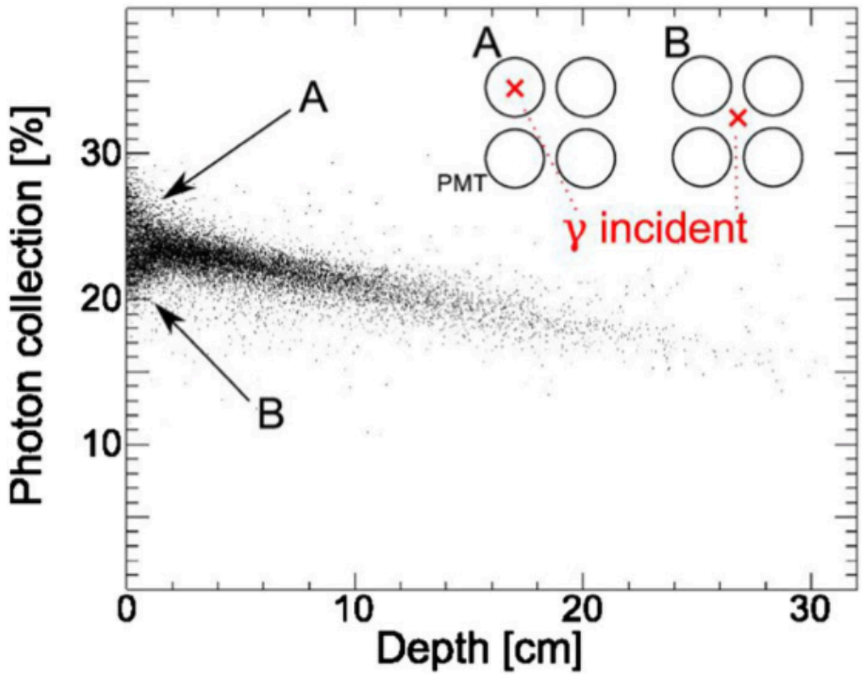
Related talk:
14aSE-1(家城)
14aSE-3(小川)
15pSF-5(島田)

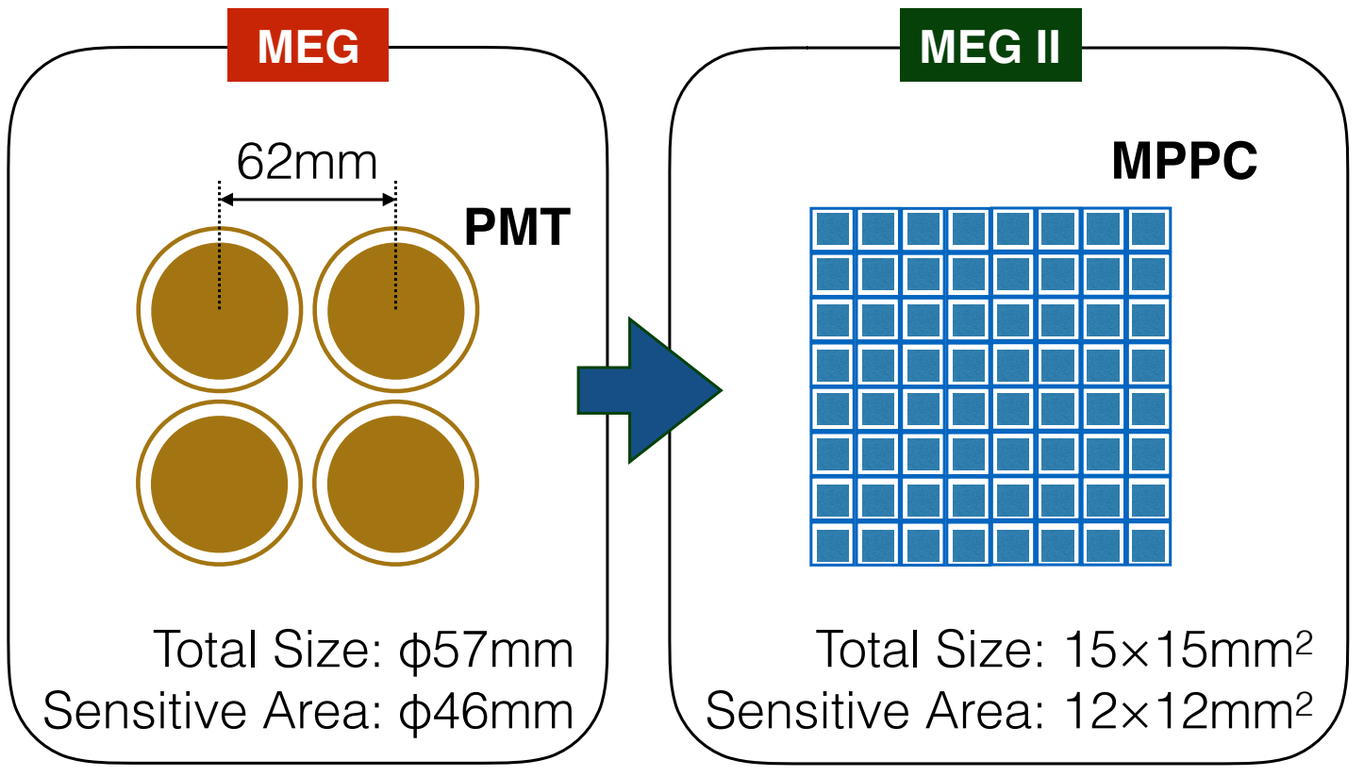
15pSF-4(米本)

- 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

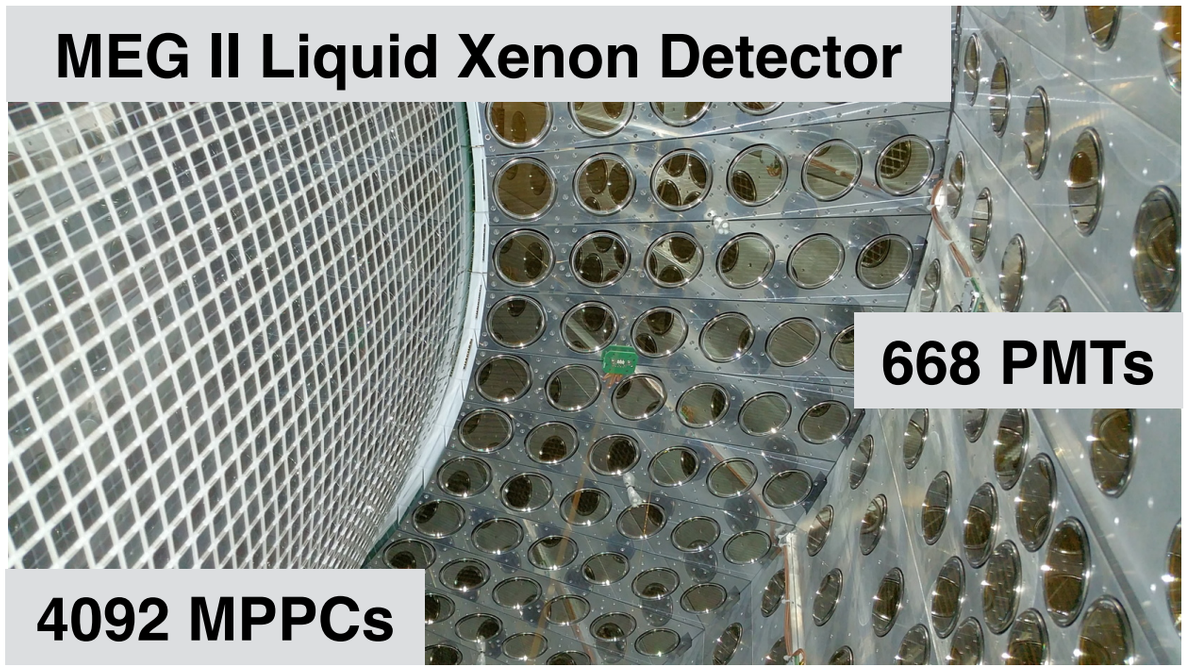
Light Collection Efficiency @MEG

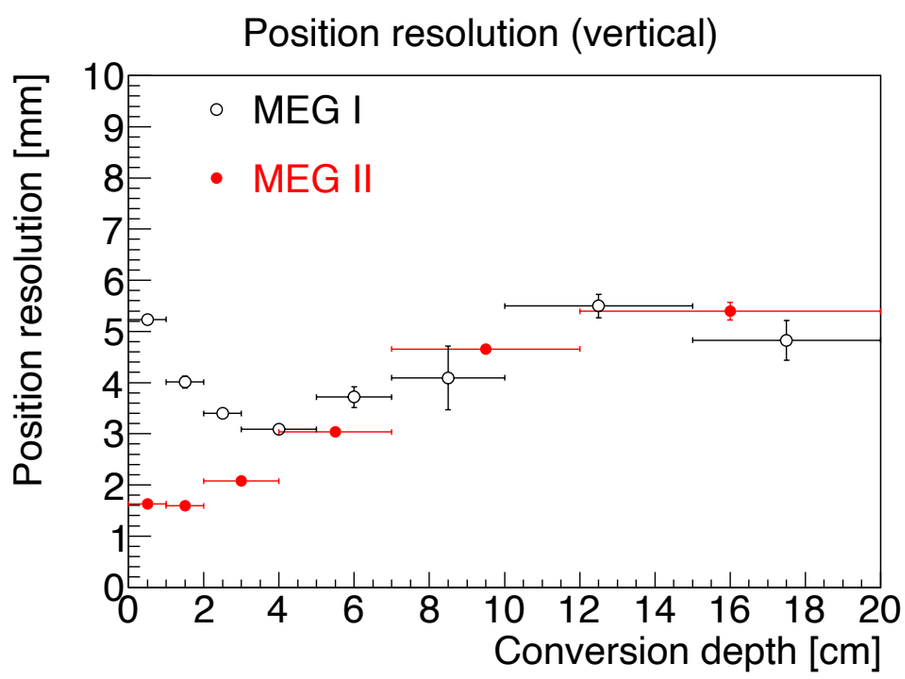




- MEG gamma-ray detector used 2-inch PMTs to detect scintillation light of liquid xenon in the VUV range($\lambda \sim 175$ nm).
- Non-uniformity of light collection efficiency limited the resolution.
  - A small and square-shaped photosensor is desirable.
- We use **VUV-sensitive MPPCs** in MEG II.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

Liquid Xenon Detector Upgrade

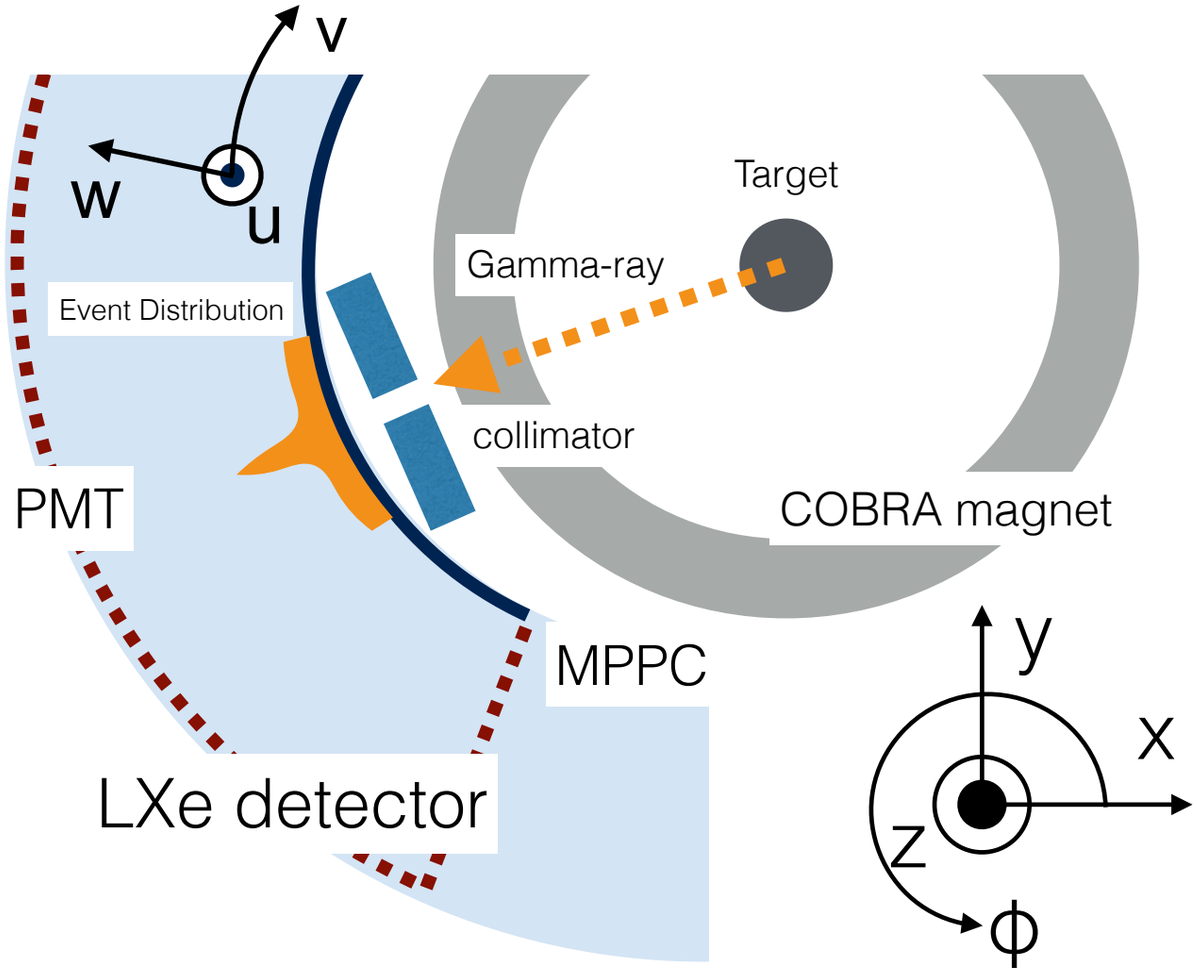


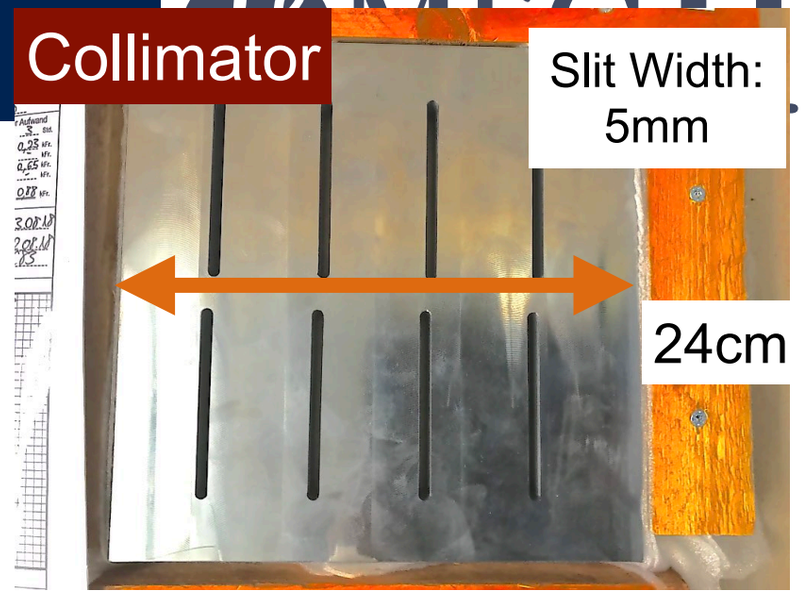


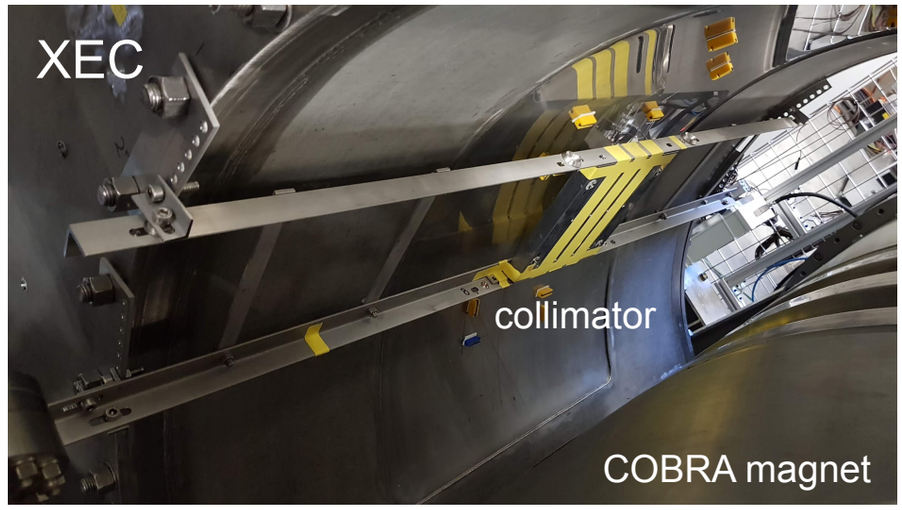
from “The design of the MEG II experiment”

- Thanks to the granular readout by MPPCs, the resolution is expected to be improved by a factor of two.
  - Position resolution: 5 mm → **2.5 mm**
  - Energy resolution: 2% → **1%**
- The commissioning is in progress with the limited number of readout electronics from 2017.
- Today’s theme:
  - **Measured improvement of the position resolution**

Position Resolution Measurement







- Measure the position distribution of gamma-ray with a lead collimator.
  - The width of peaks in the distribution corresponds to the resolution.
  - Rotate by 90° to measure the horizontal(u) & vertical(v) resolution.
- Gamma-ray source: 17.6 MeV from $^{7}_{3}\mathrm{Li}(\mathrm{p},\gamma)^{8}_{4}\mathrm{Be}$ reaction
- The geometry of the setup was precisely aligned by optical instruments.
  - Collimator: <50 μm / MPPC: <500 μm precision

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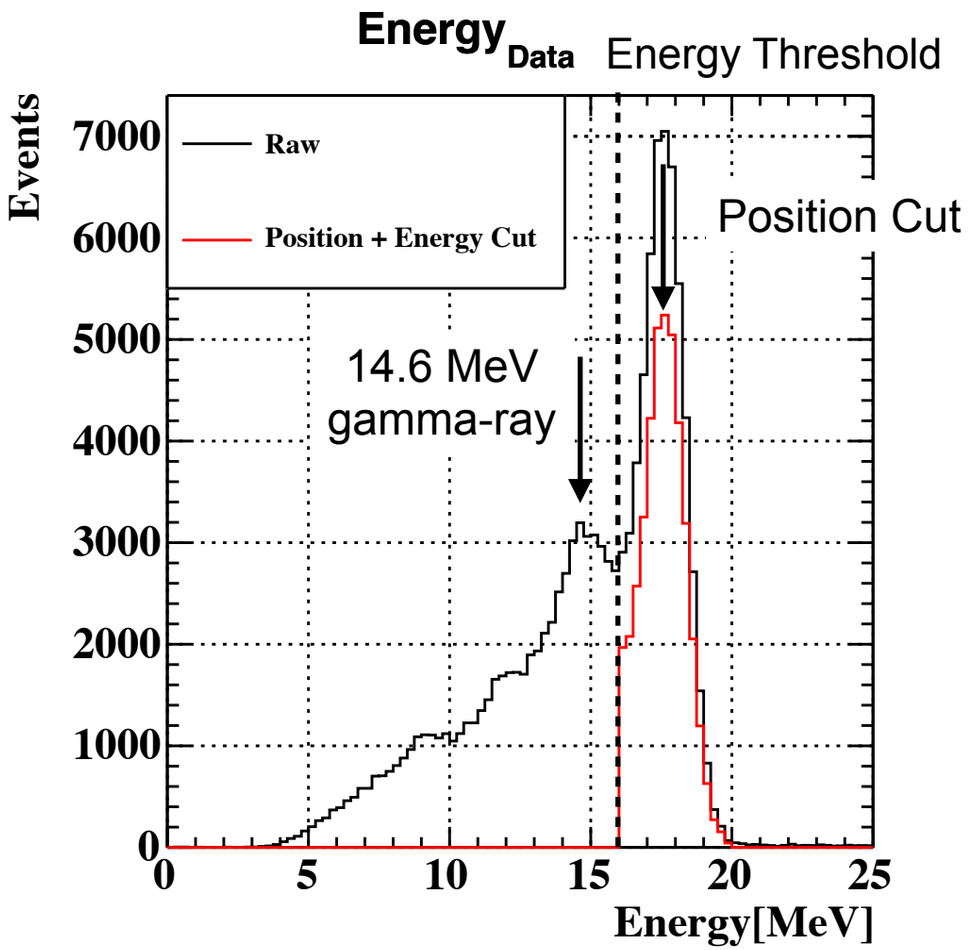
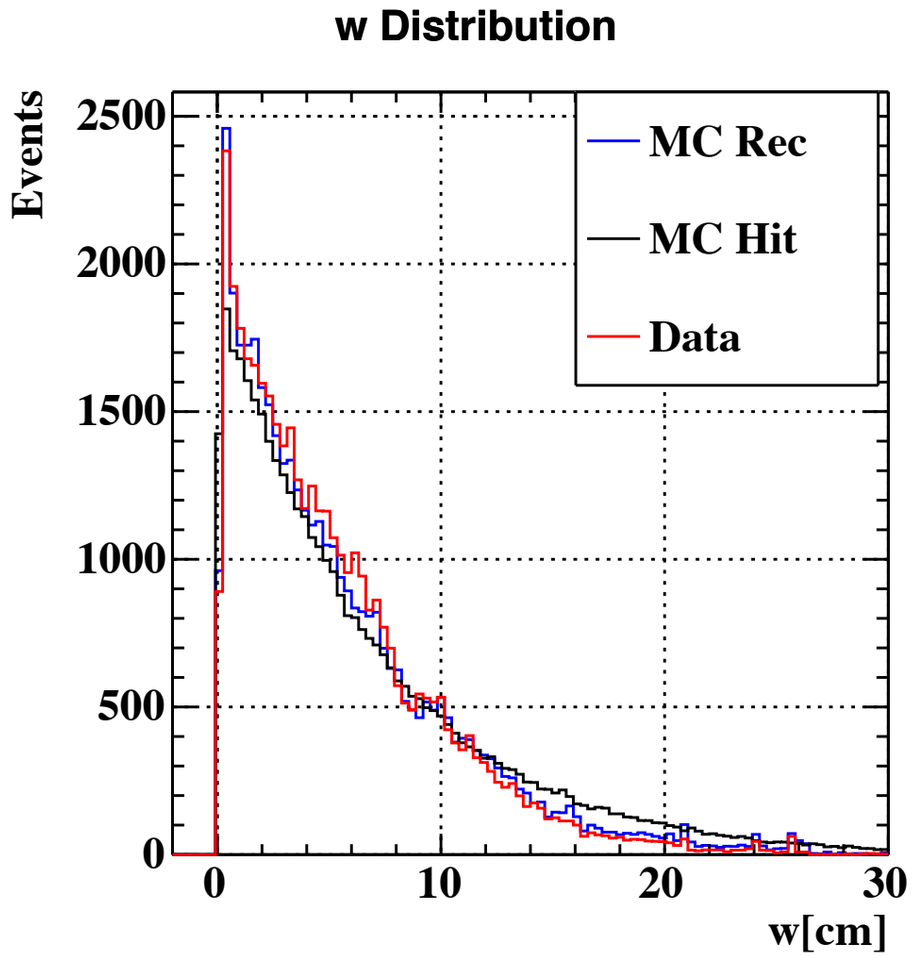
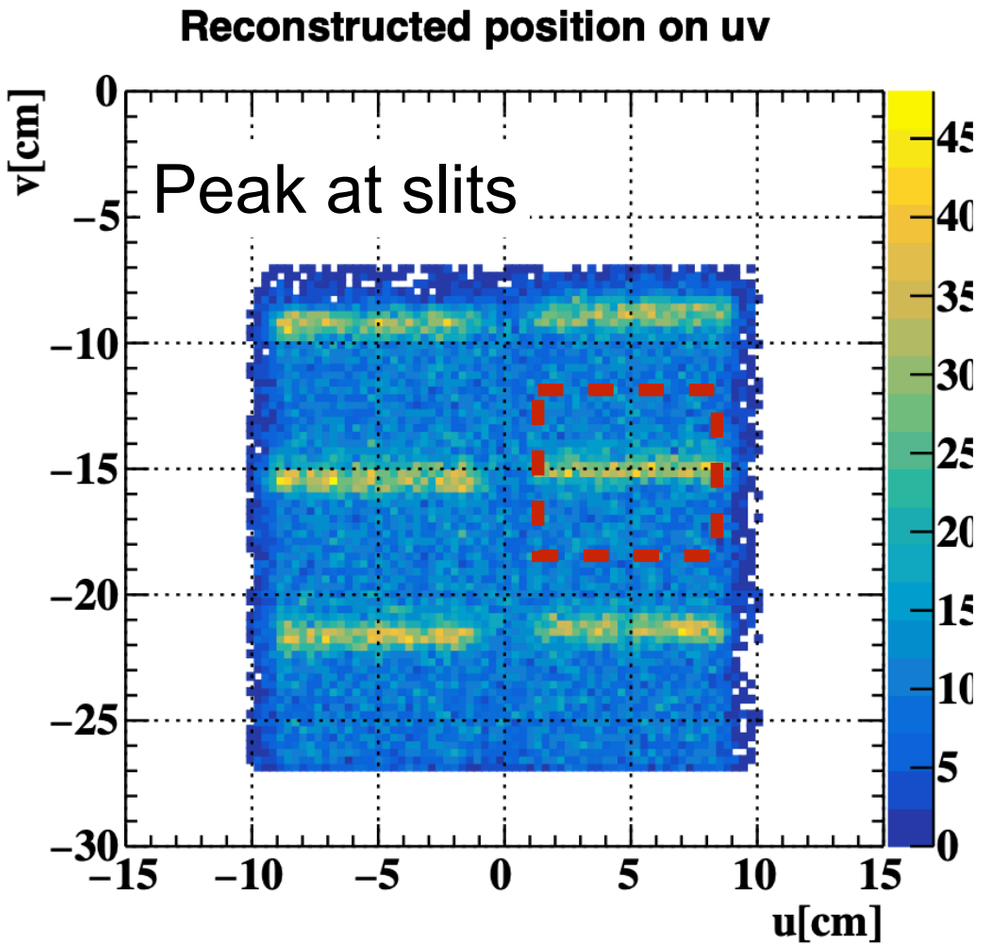
Event Selection



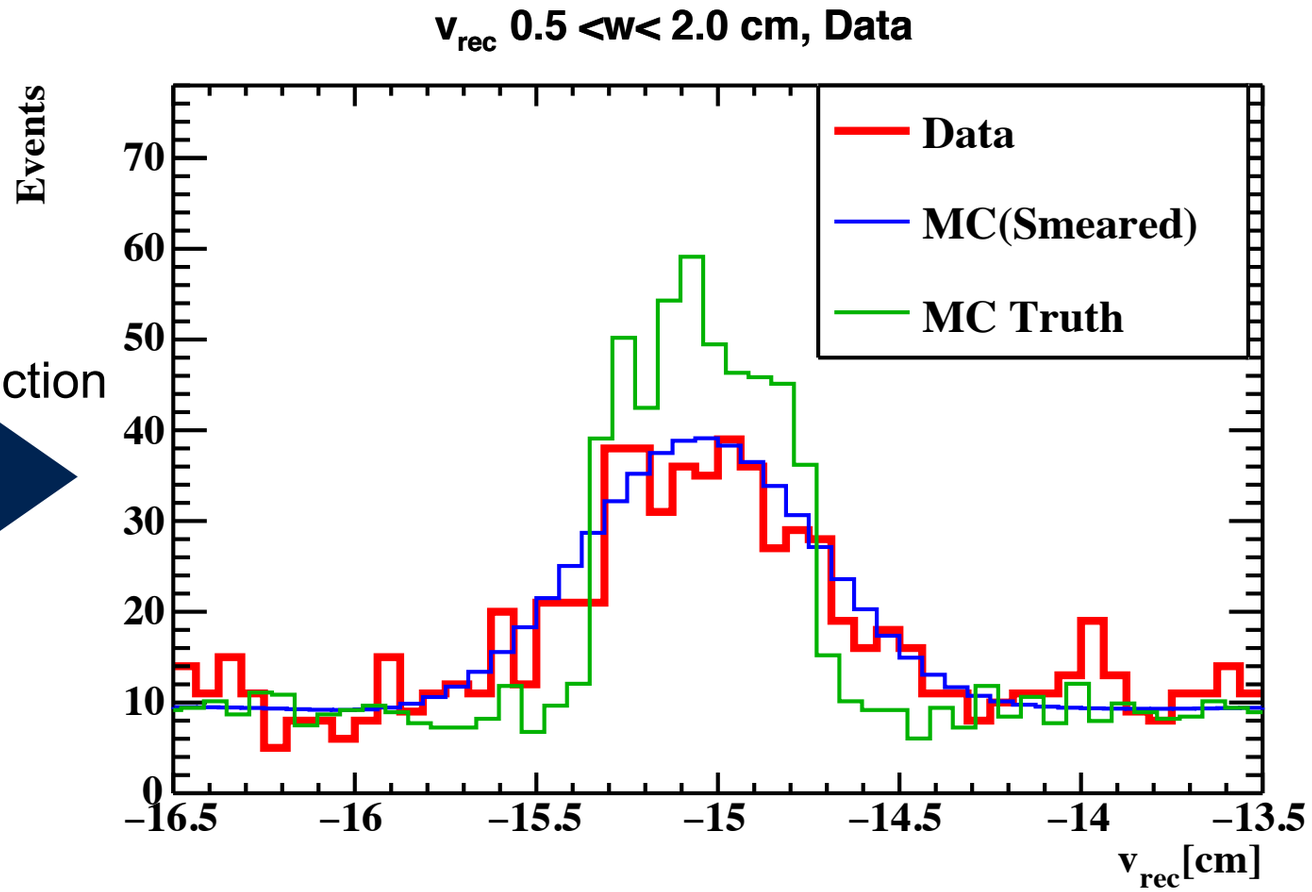


- The position is reconstructed by the fitting of light distribution.
- Energy cut and position cut were applied both for MC and for data.
  - Energy: $16\ \mathrm{MeV} < E_\gamma < 20\ \mathrm{MeV}$: around energy peak(17.6 MeV)
  - Position: $\begin{cases} -10\ \mathrm{cm} < u < 10\ \mathrm{cm} \\ -27\ \mathrm{cm} < v < -7\ \mathrm{cm} \end{cases}$: around the collimator
- With these selections, the distribution of reconstructed depth(w) in data and MC was consistent with each other.

Reconstructed position distribution

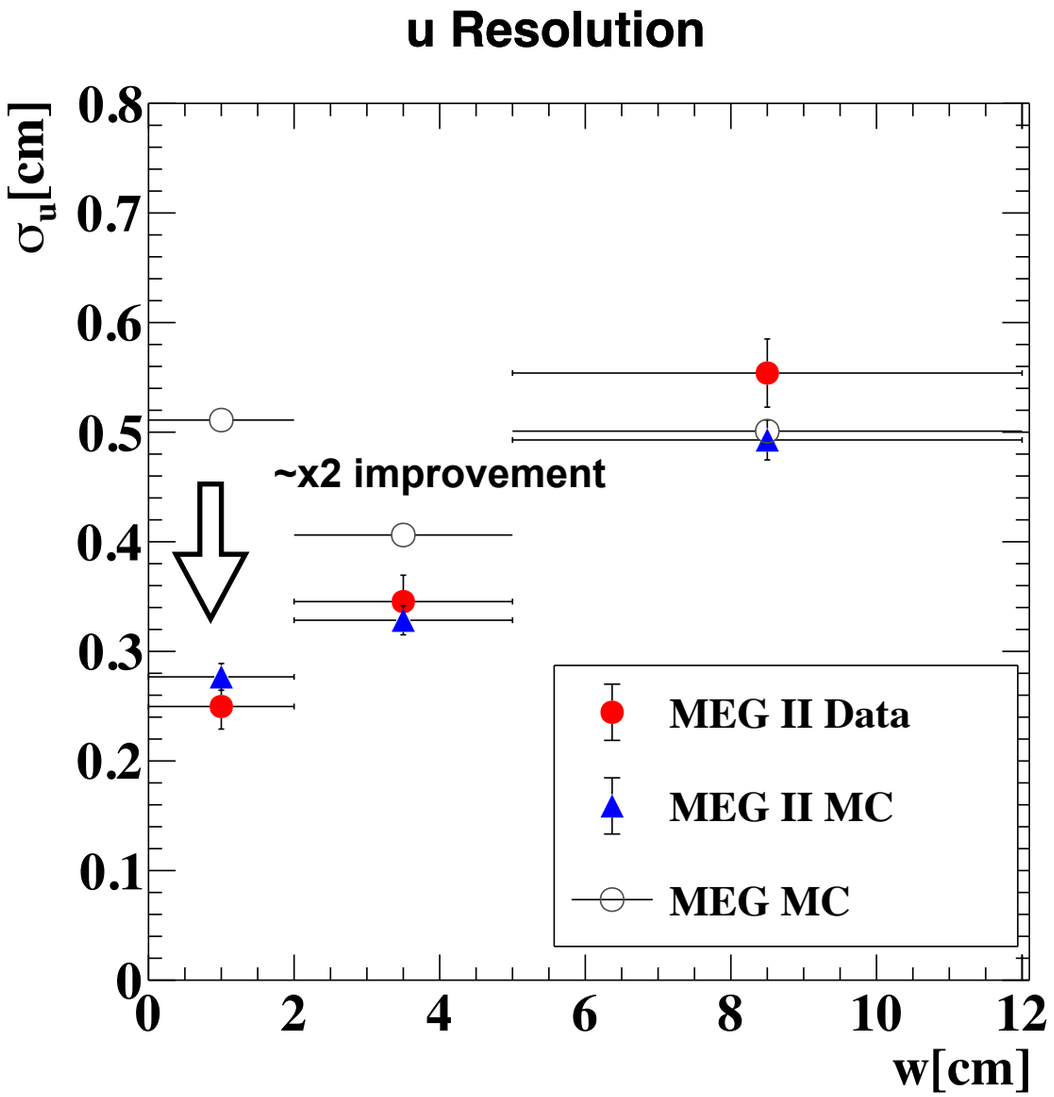


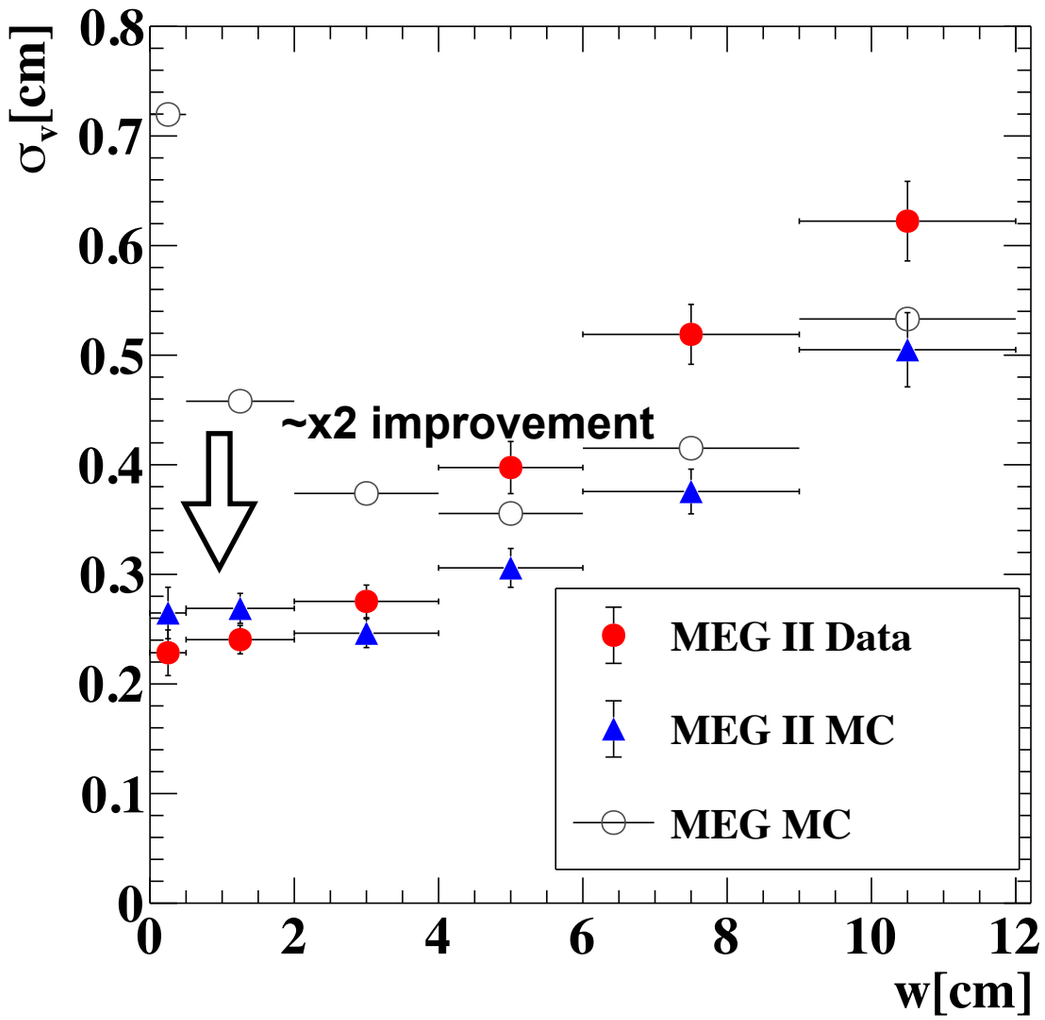
Projection



- We smeared MC truth position distribution with a Gaussian function to fit the reconstructed position distribution.
  - We regard σ of the Gaussian as the resolution.
- Measured geometry is reflected in the MC simulation.
- Four slits were used to evaluate the position resolution.

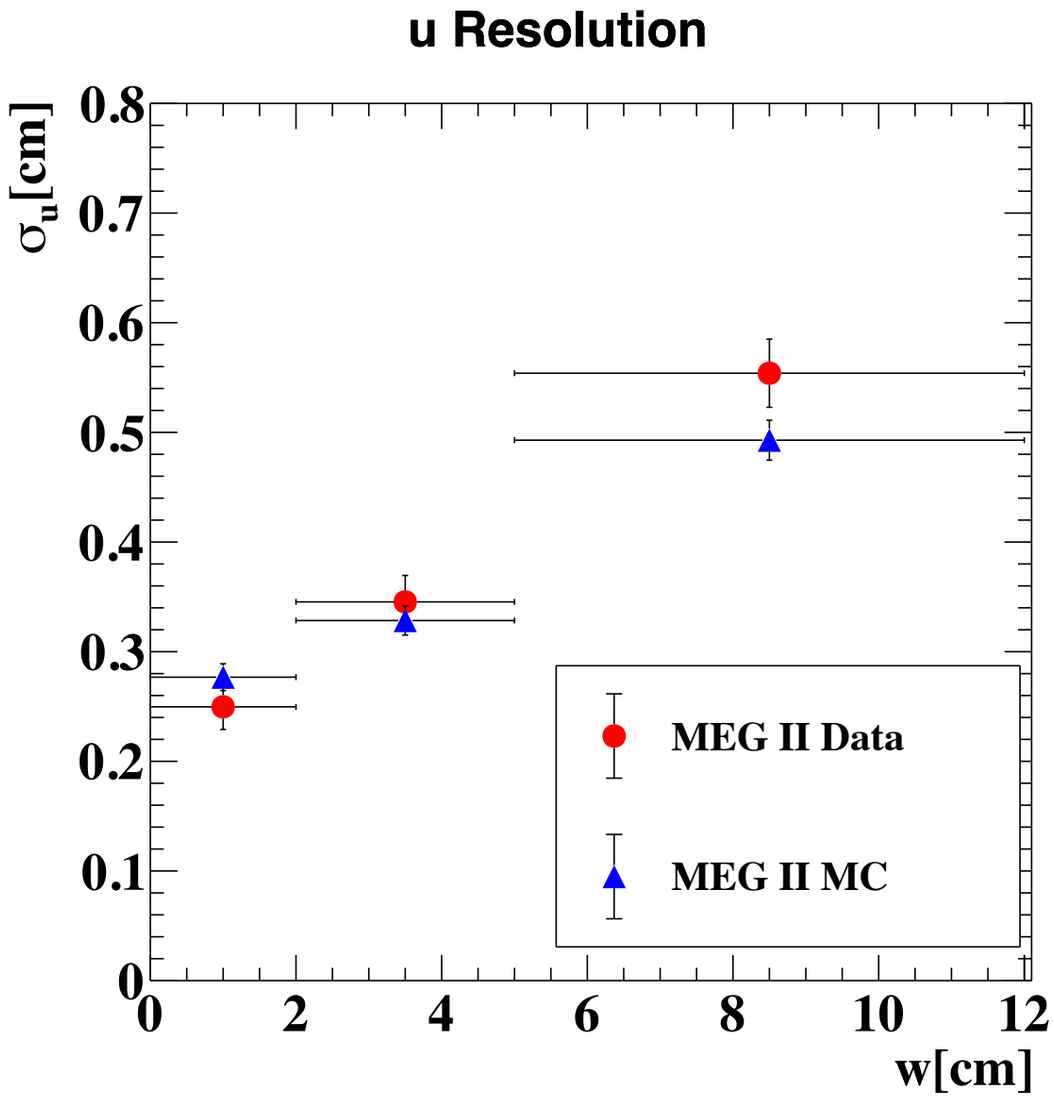
Position Resolution

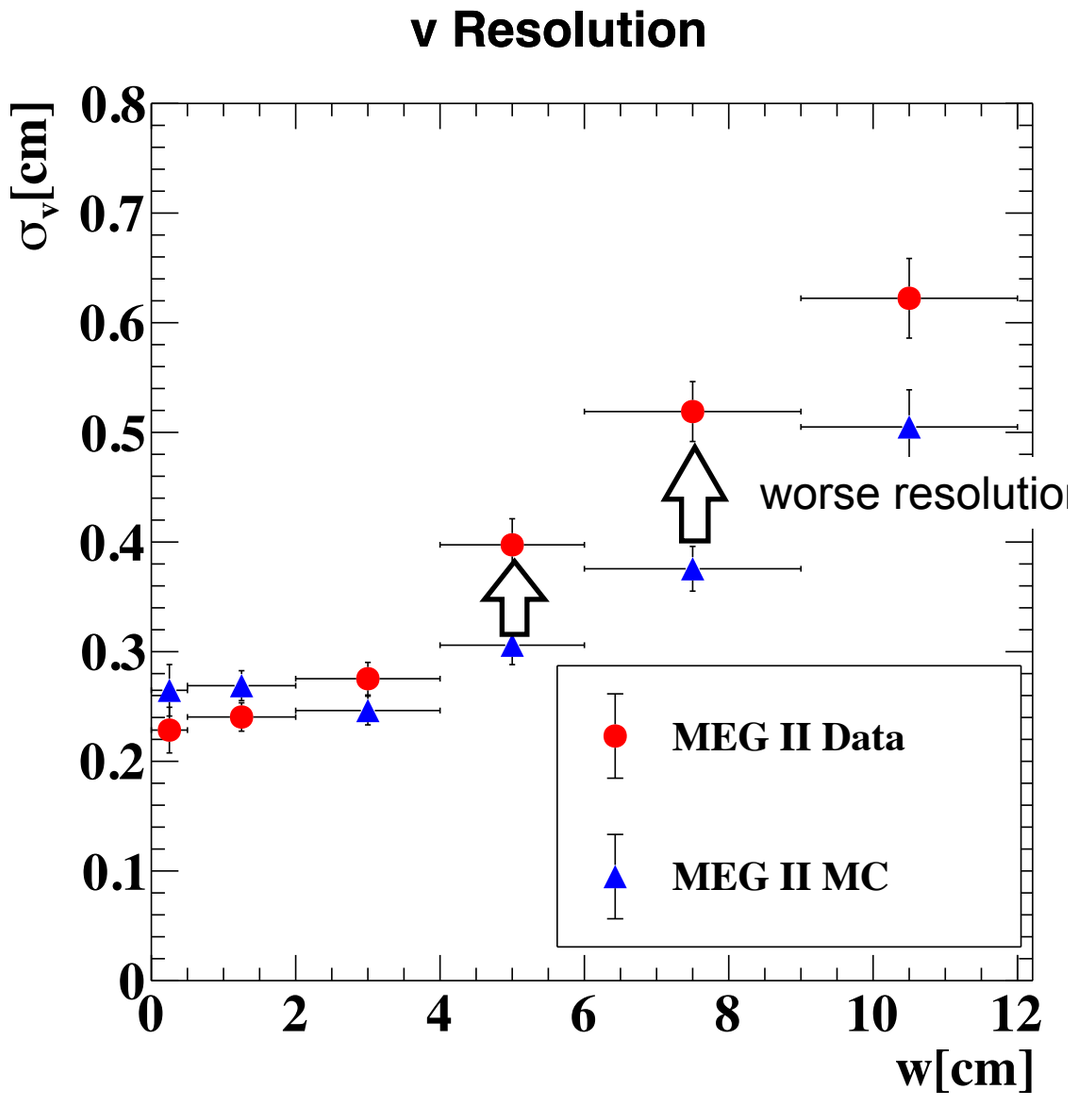




- The average resolution of four slits.
- **We observed an expected improvement of the position resolution.**
  - u(horizontal) resolution: $\sigma_u = 2.5 \pm 0.2$ mm(w < 2 cm)
  - v(vertical) resolution: $\sigma_v = 2.4 \pm 0.2$ mm(w < 2 cm)
- W binning is sparse for u direction because of the statistics.

Position Resolution



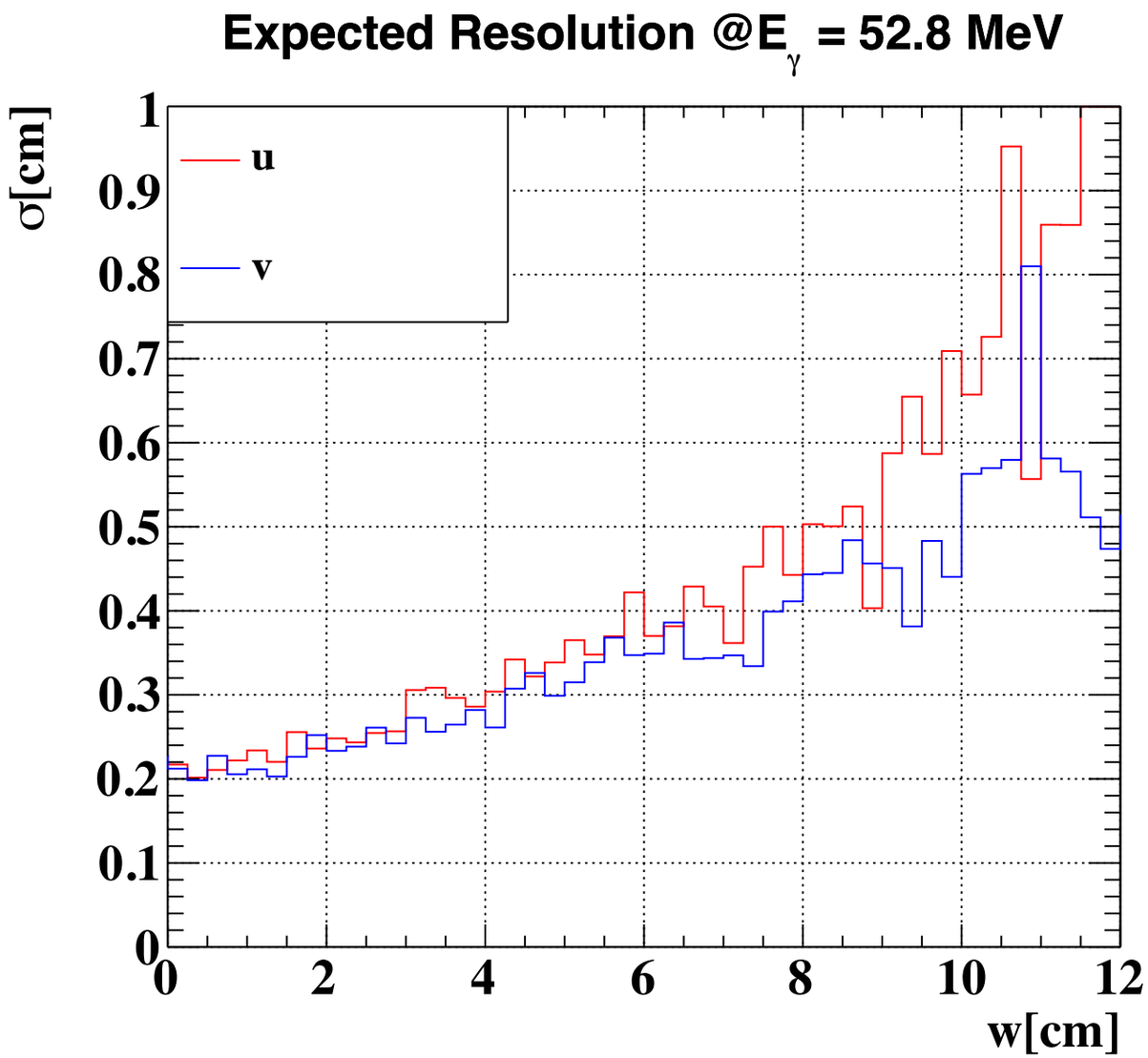


- The resolution for deep events was worse than the expectation.
  - Not critical because the fraction of deep events is small.
- We have several candidates of this discrepancy.
  - Noise on readout electronics, S/N.
  - Correlated noise(cross-talk and after-pulsing) of MPPC.
- We are investigating their impact on the position resolution using MC.

Summary

- The commissioning of the liquid xenon gamma-ray detector for the MEG II experiment is in progress.
- We evaluated the position resolution using a well-aligned lead collimator with slits.
- **We achieved a 2.5 mm resolution for shallow events(w < 2 cm).**
  - **Twice better than ~5 mm in MEG as expected**.
  - Thanks to the high-granularity readout with VUV-sensitive MPPCs.

Prospects



- Investigation of the discrepancy of the resolution for deep events.
- Measurement of the position resolution for gamma-rays with $E_\gamma \sim 52.8$ MeV(signal event)
  - As in MEG, we are planning to use 55 MeV gamma-ray from charge exchange reaction($\pi^0 \to \gamma\gamma$).

Thank you for listening!!

Backup

- Evaluation in MEG
- DAQ configuration
- 2017 Measurement
- Alignment of the setup
- Position Reconstruction Algorithm
- etc…

Evaluation in MEG

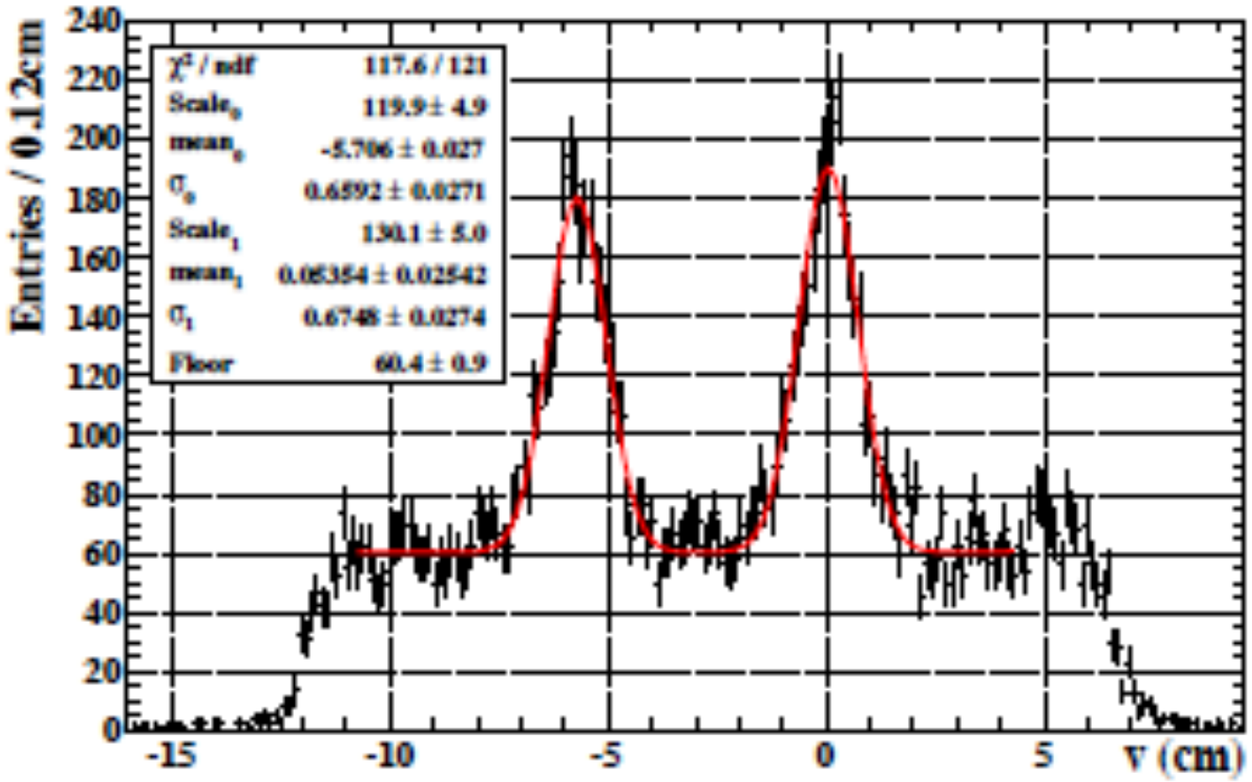


Figure 7.5: Cross section along vertical v ($w > 2$ cm).

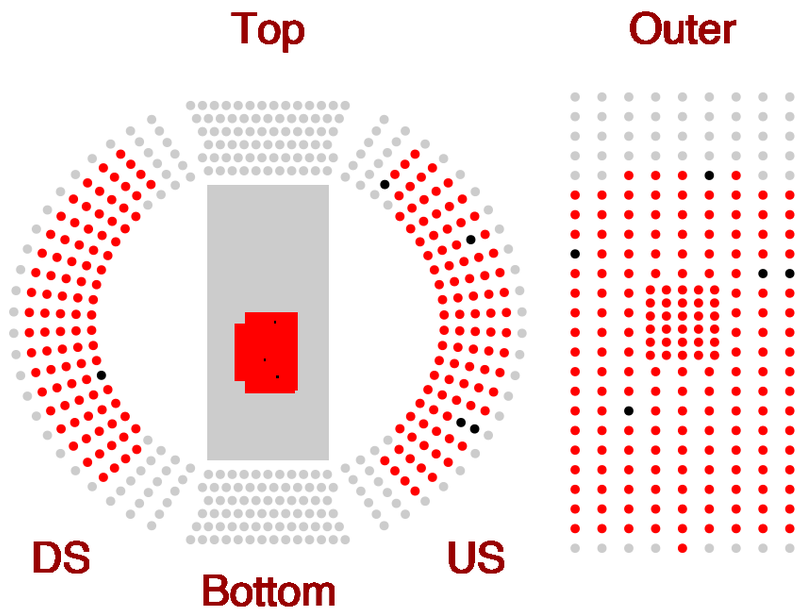
Table 12: Sigmas fitted in slits and edges along v (w >2 cm). Central slit in MC is omitted due to a difference of the geometry between data and MC.

	slit1	slit2	slit3	edge1	edge2
σ_v in 2008 Data (mm)	7.2	6.8	6.7	4.7	4.2
σ_v in MC (mm)	6.8	-	6.5	3.9	4.2
σ_v in MC truth (mm)	4.7	-	4.9	2.3	2.8

- The position distribution was fitted by Gaussian function(+offset).
- The hit position distribution of MC truth was approximated to Gaussian.

DAQ Configuration

Orientation	u	v
Date	2018/12/12	2018/12/13
# of runs	80	142
# of events	78681	141441
# of used events	9609	41208



- TRG: sum of 256 MPPCs are used.
- DAQ rate: ~5 Hz
- The number of used channels was limited to ~1000 because the mass production was not yet started.
  - ~360 PMTs and ~640 MPPCs.

First Measurement in 2017 - Set up

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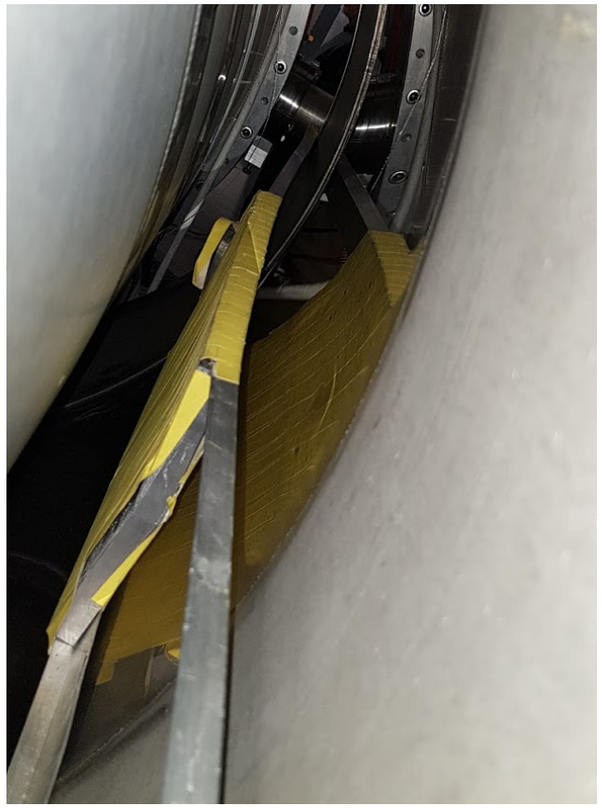
Installed collimator (v direction)



Collimator (u direction)

- We tried to estimate the resolution using BG gamma-ray from muon decay.
- We reused MEG lead collimators.
  - Along with their support structure.

First Measurement in 2017 - Result

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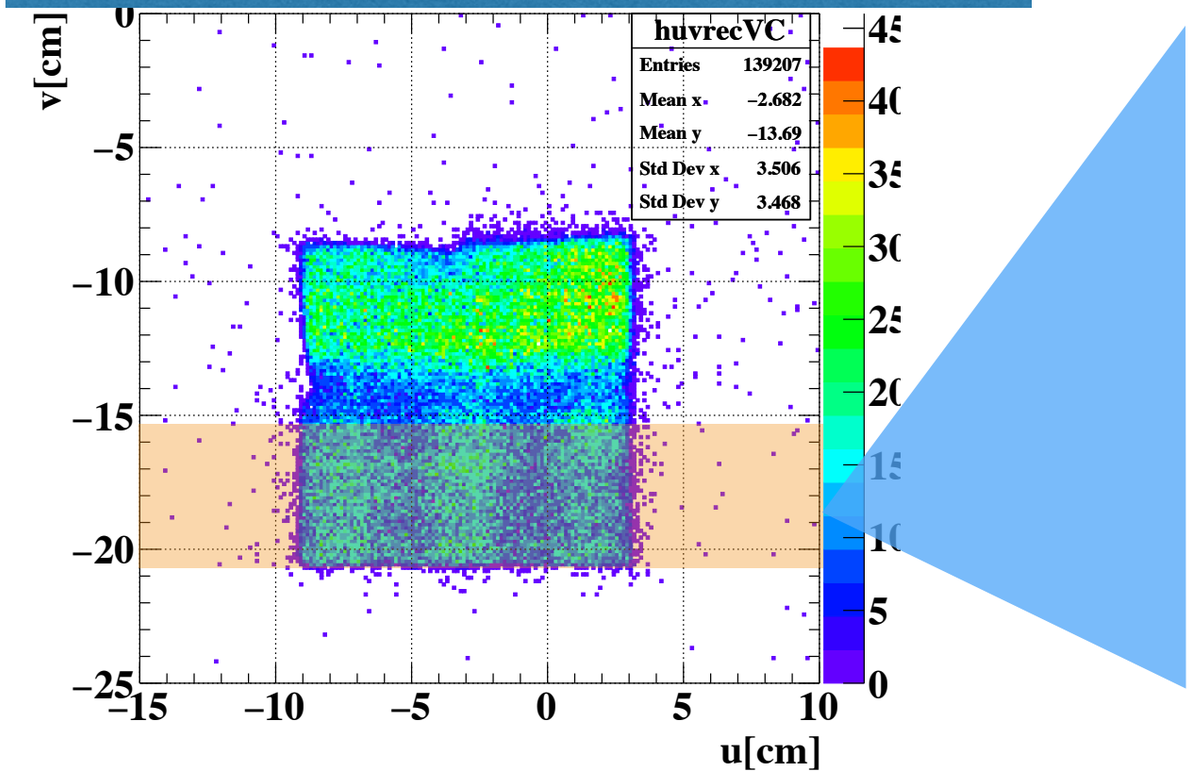
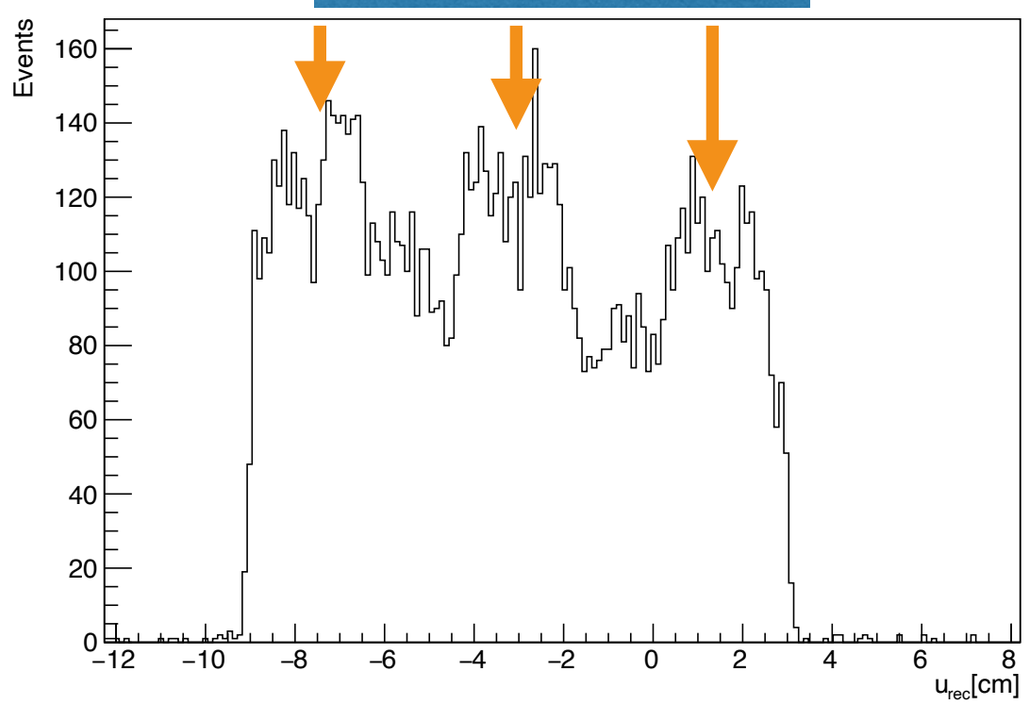
Reconstructed position in uv plane



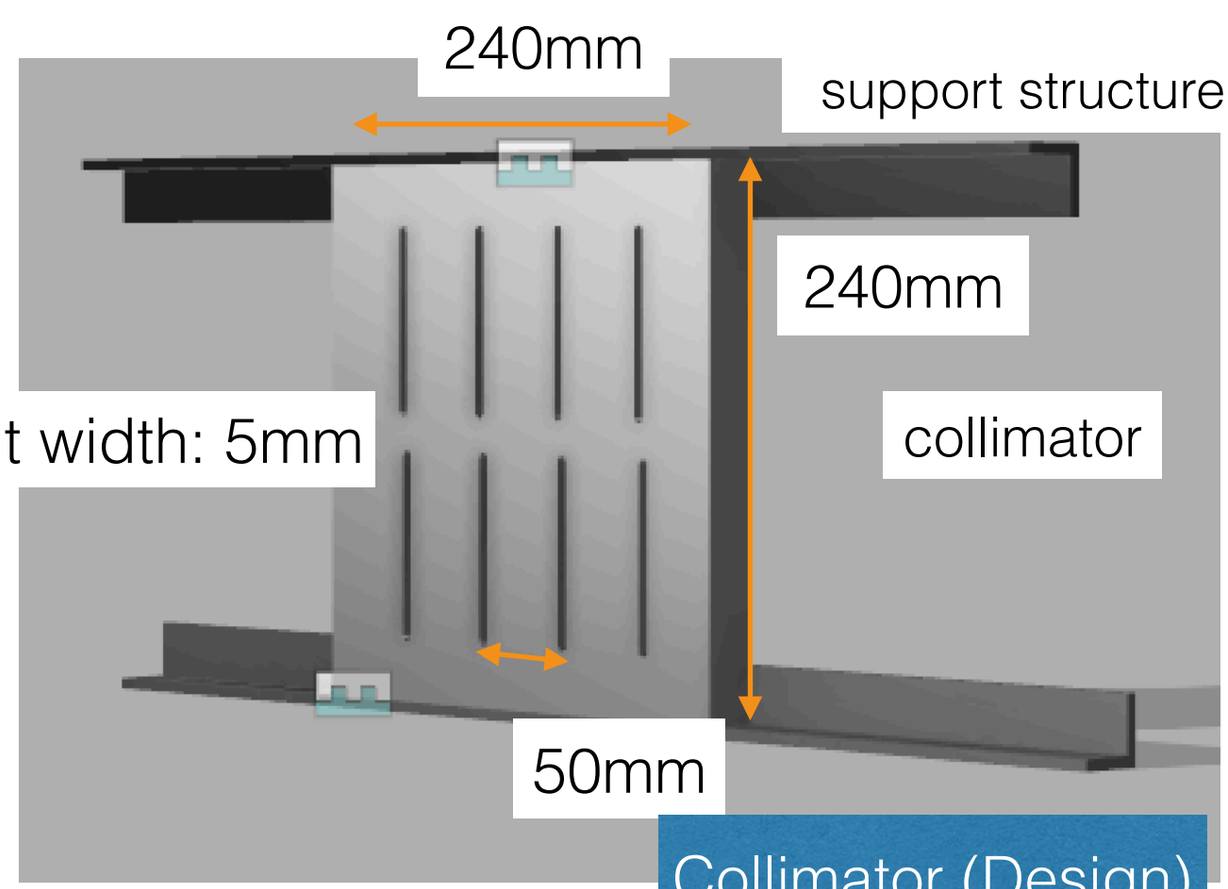
Reconstructed u



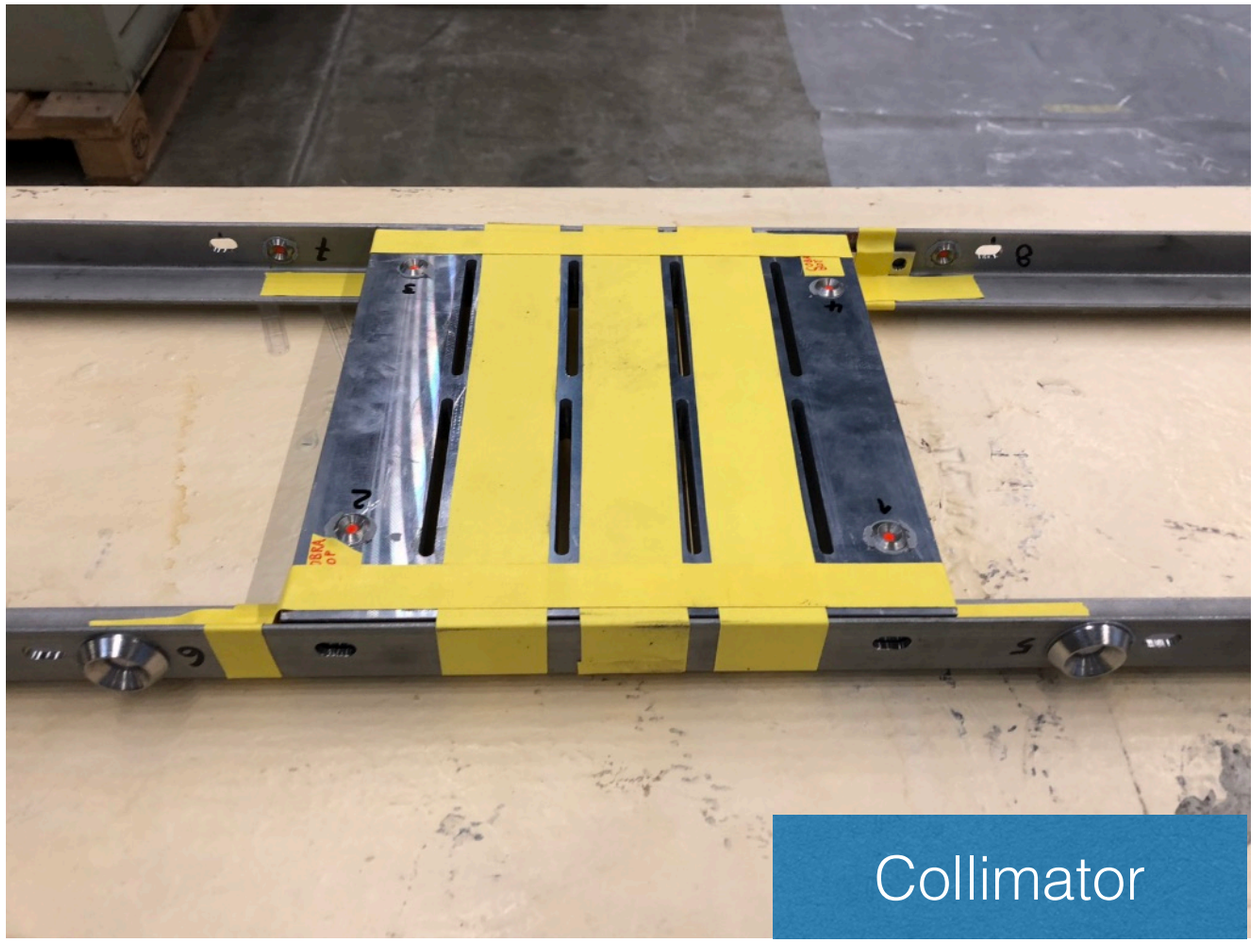
- Vague position distribution.
  - **The slit of the collimator was too wide.**
  - The spread of the vertex of gamma-ray was too wide(a few cm).
- Furthermore, following issues make it difficult to compare data with MC.
  - **Neither detector nor collimator were aligned.**
  - Support structure for the collimator was not robust enough.

We needed to optimize the collimator and align it.

Redesign of collimator



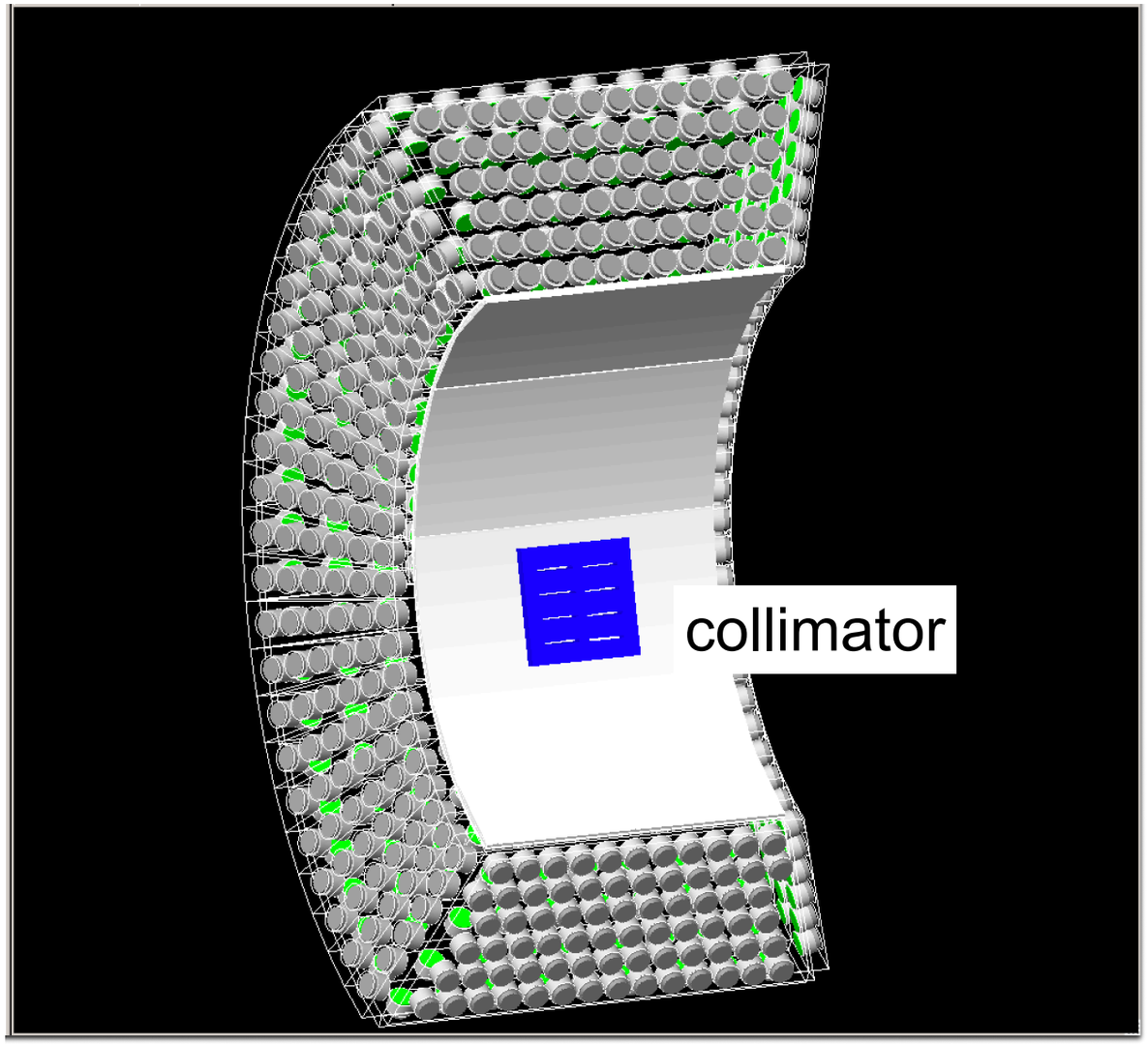
Collimator (Design)



Collimator

- A new collimator with narrow slits was produced.
  - Slit width: 10mm→5mm: narrow peak
  - Thickness: 18mm→25mm: better S/N
- Rigid support structure was produced.
  - Supports 15kg lead collimator with little deformation.

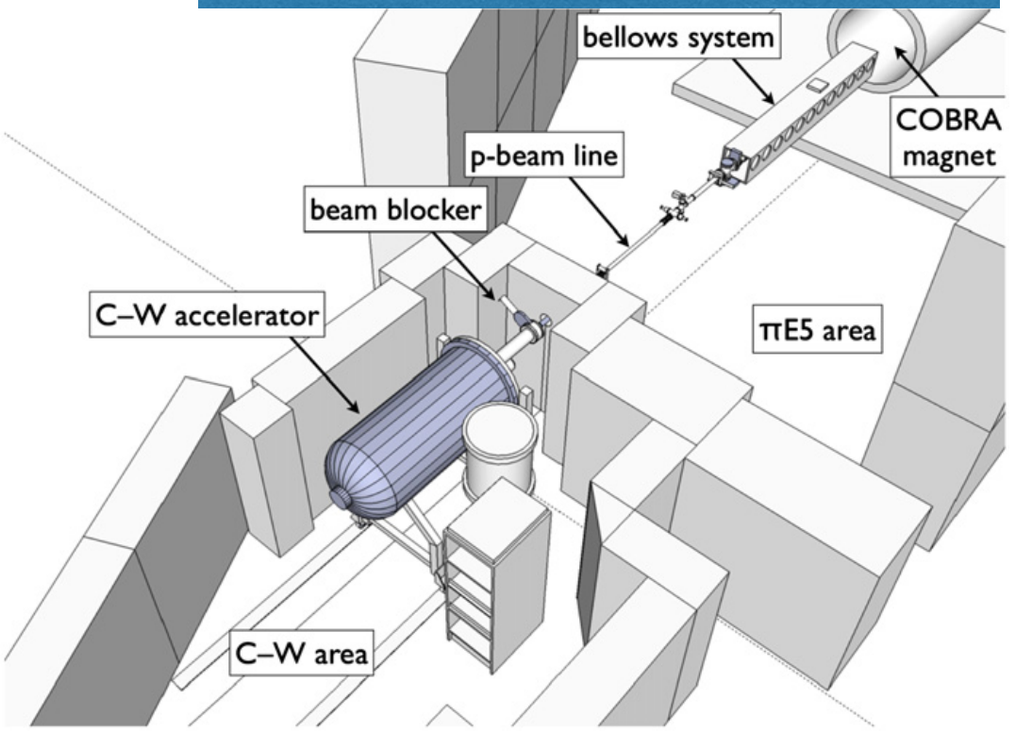
MC Configuration

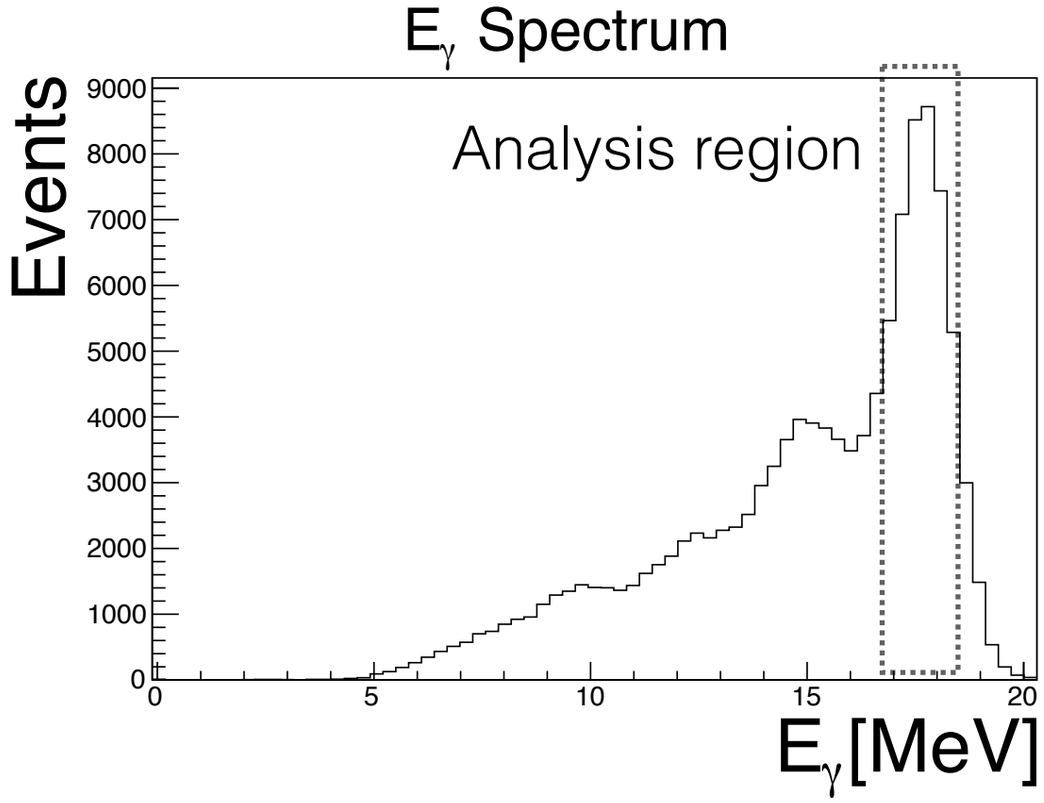


- Geant4 MC simulation + Waveform Digitization
- Measured geometry of MPPC, collimator, vertex is reflected.
- PDE: 8% = Measured PDE in PreEng2018

Gamma-ray Source

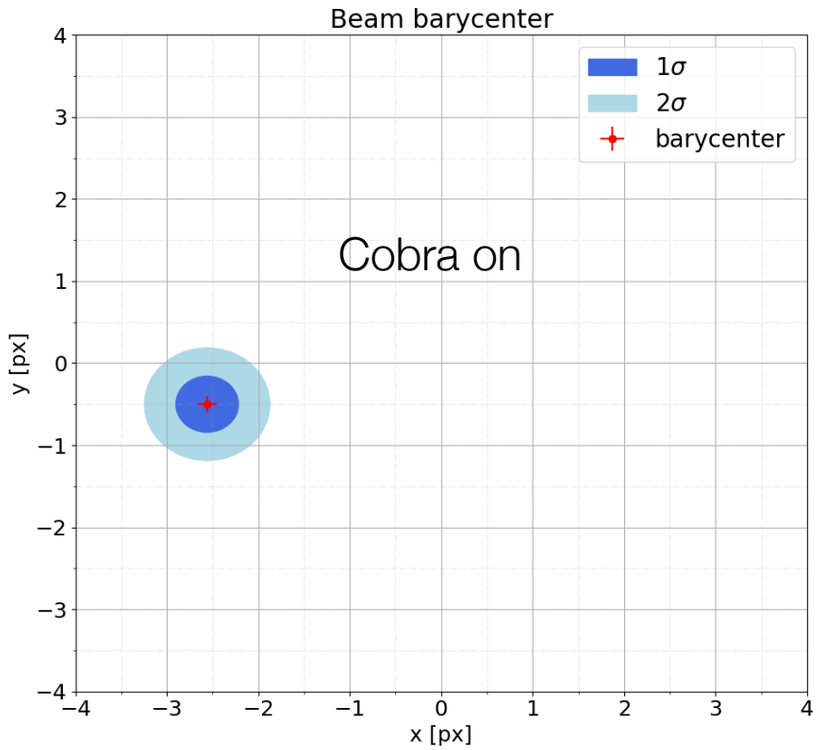
Cockcroft-Walton beamline





- Gamma-ray source: 17.6 MeV from $^{7}_{3}\mathrm{Li}(\mathrm{p},\gamma)^{8}_{4}\mathrm{Be}$
  - Proton beam from Cockcroft-Walton accelerator.
  - Beam vertex spread <1mm (2017: a few cm)
- Data taking : ~3 days in pre-engineering run.

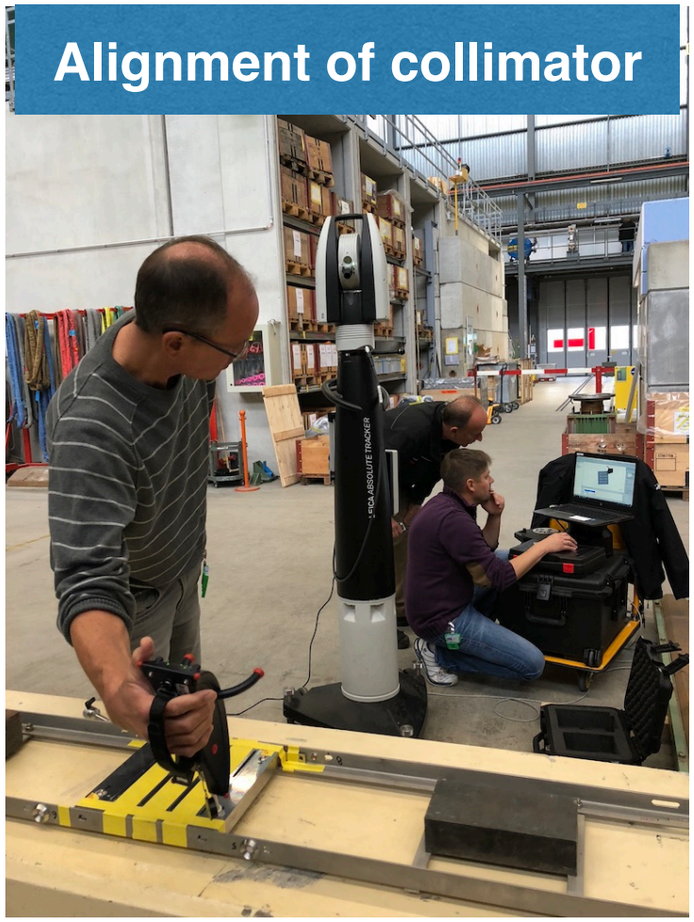
Alignment of Gamma-ray vertex



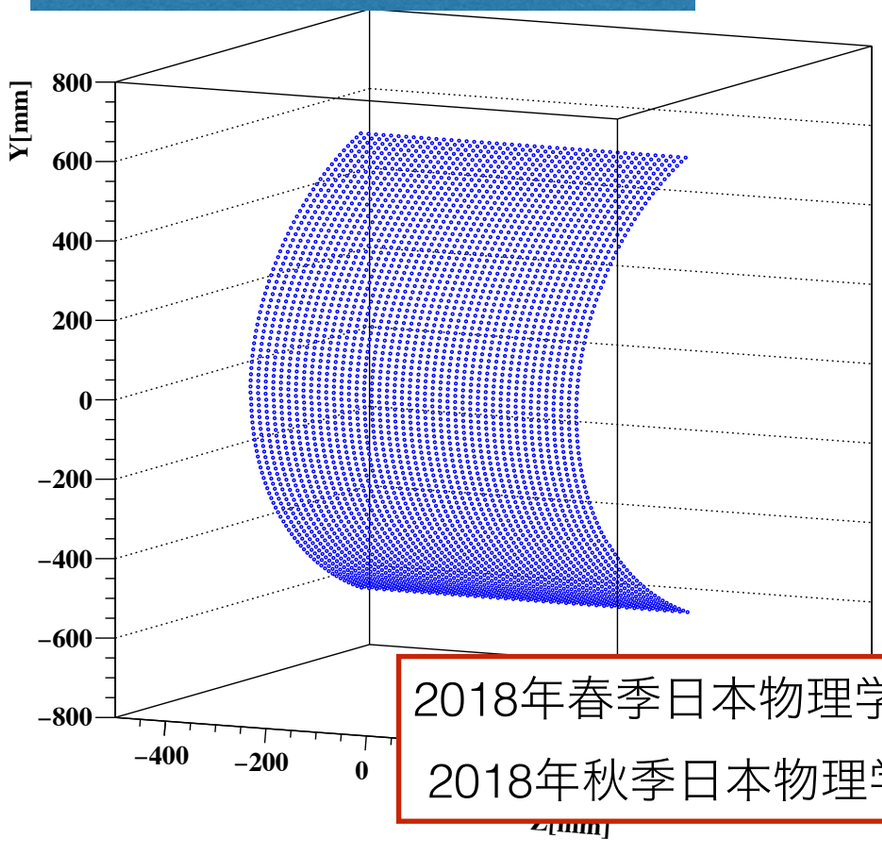
- The vertex of gamma-ray at target was aligned.
  - with and without B-field.
- The measured vertex position and its spread are reflected in MC simulation.

Alignment of collimator & detector

Alignment of collimator



Alignment of MPPCs



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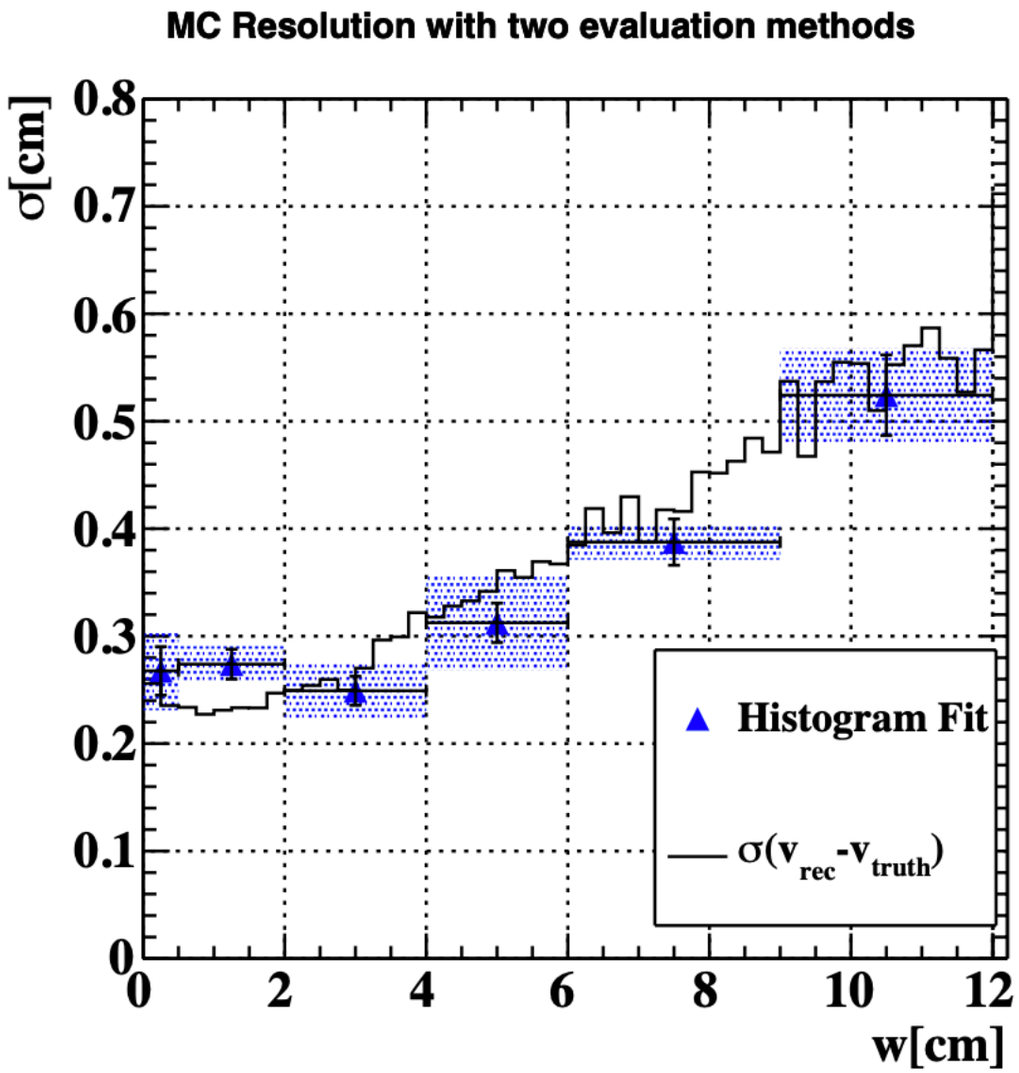
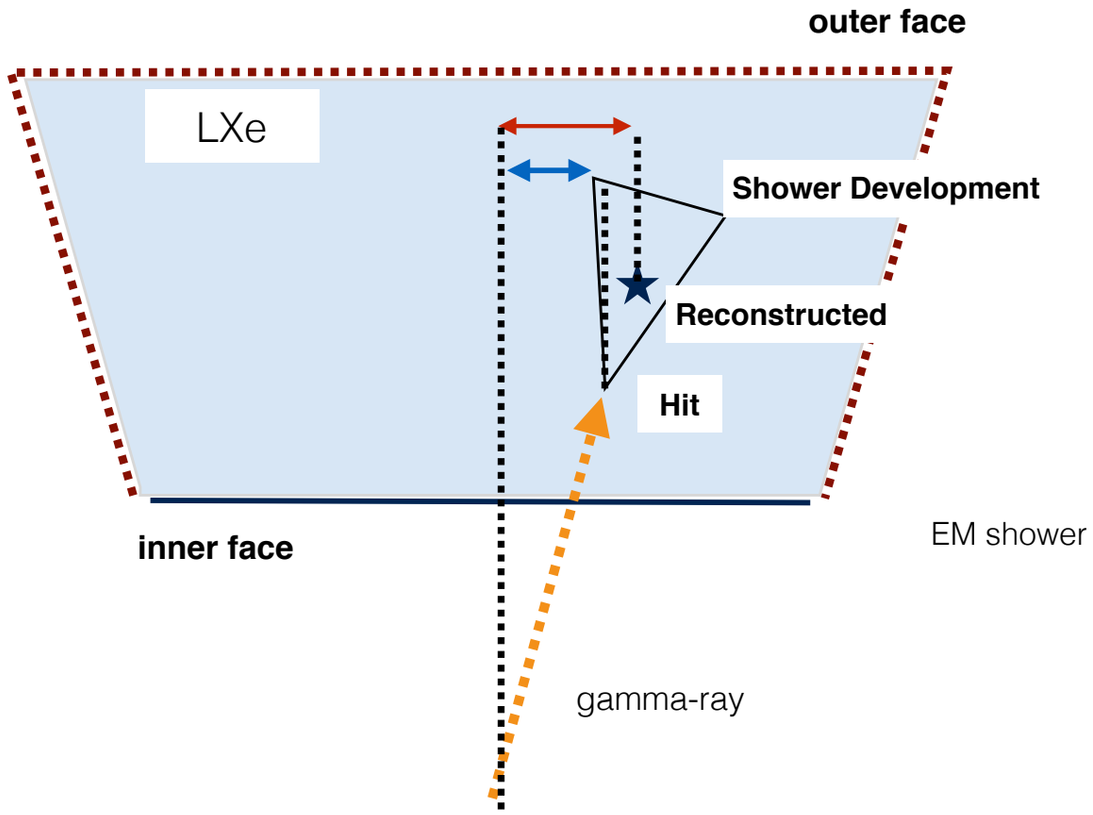
- Collimator is precisely surveyed after the installation by laser tracker.
  - Precision: ~a few 10um.
- The position of MPPCs was measured and transformed considering the position of the detector.
  - Precision: <500um.
- The measured geometry is taken into account in MC simulation.

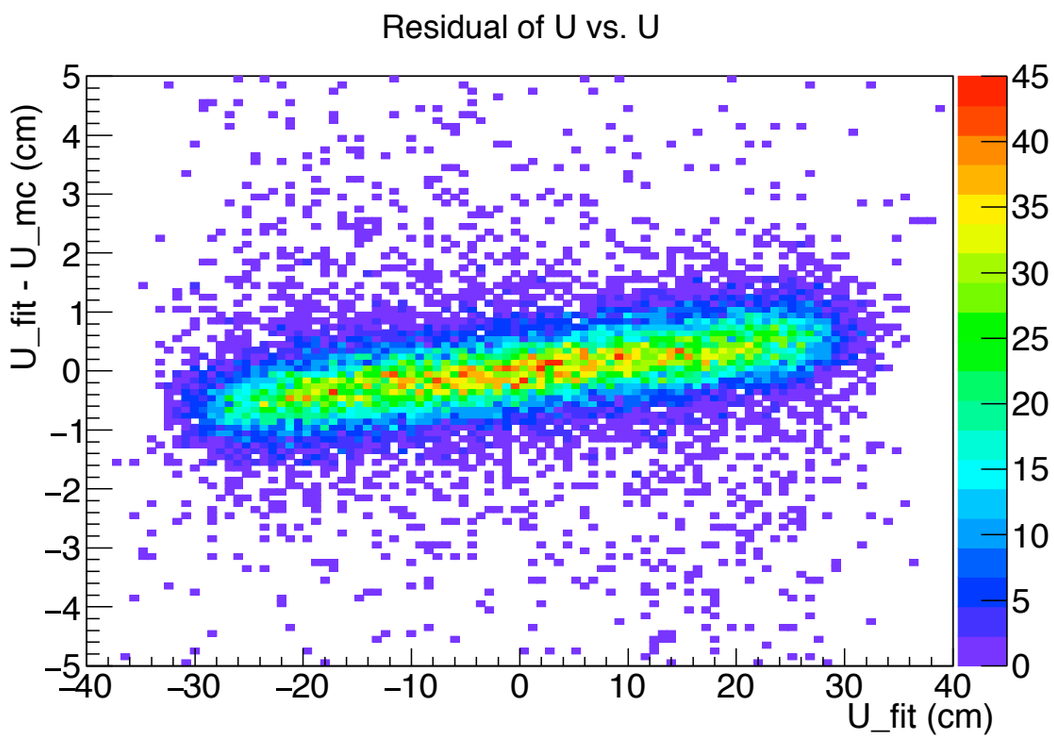
Verification of Evaluation Method



- Complementary method is to estimate the resolution from the deviation between reconstructed and true position.
  - $\sigma(x_{reconstructed} - x_{truth})$

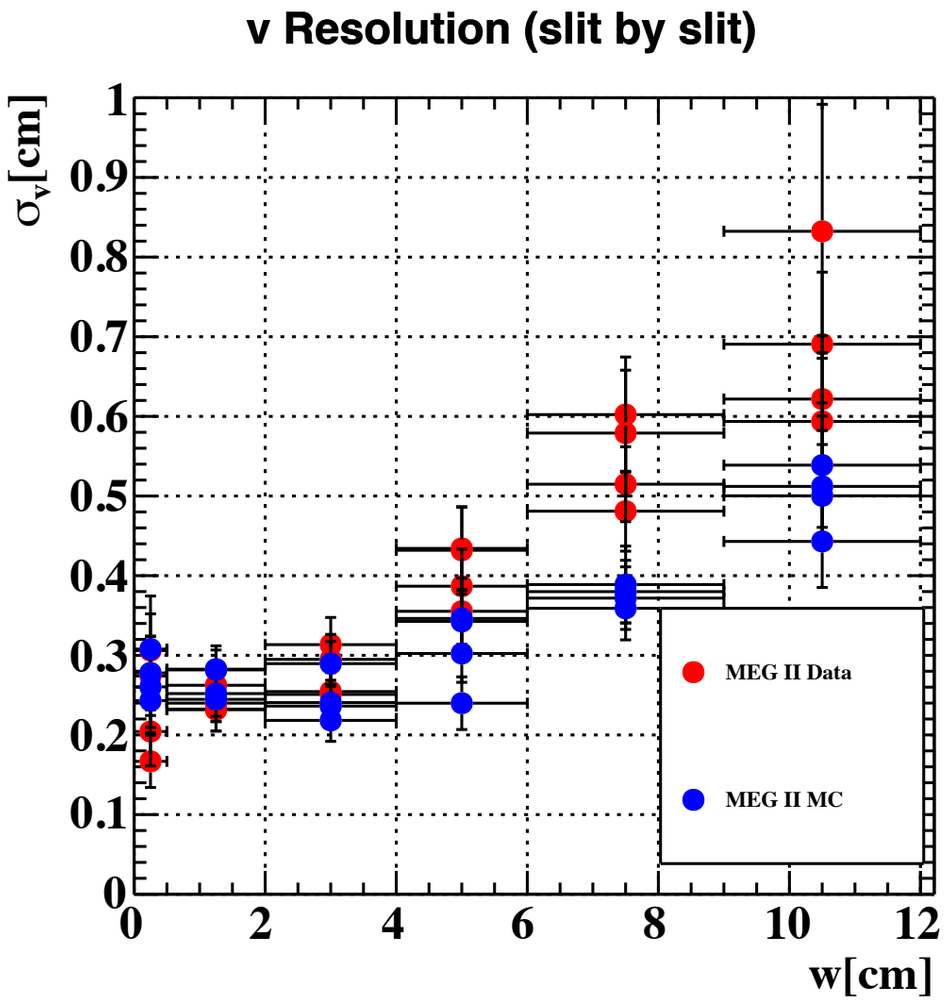
Position Reconstruction Algorithm





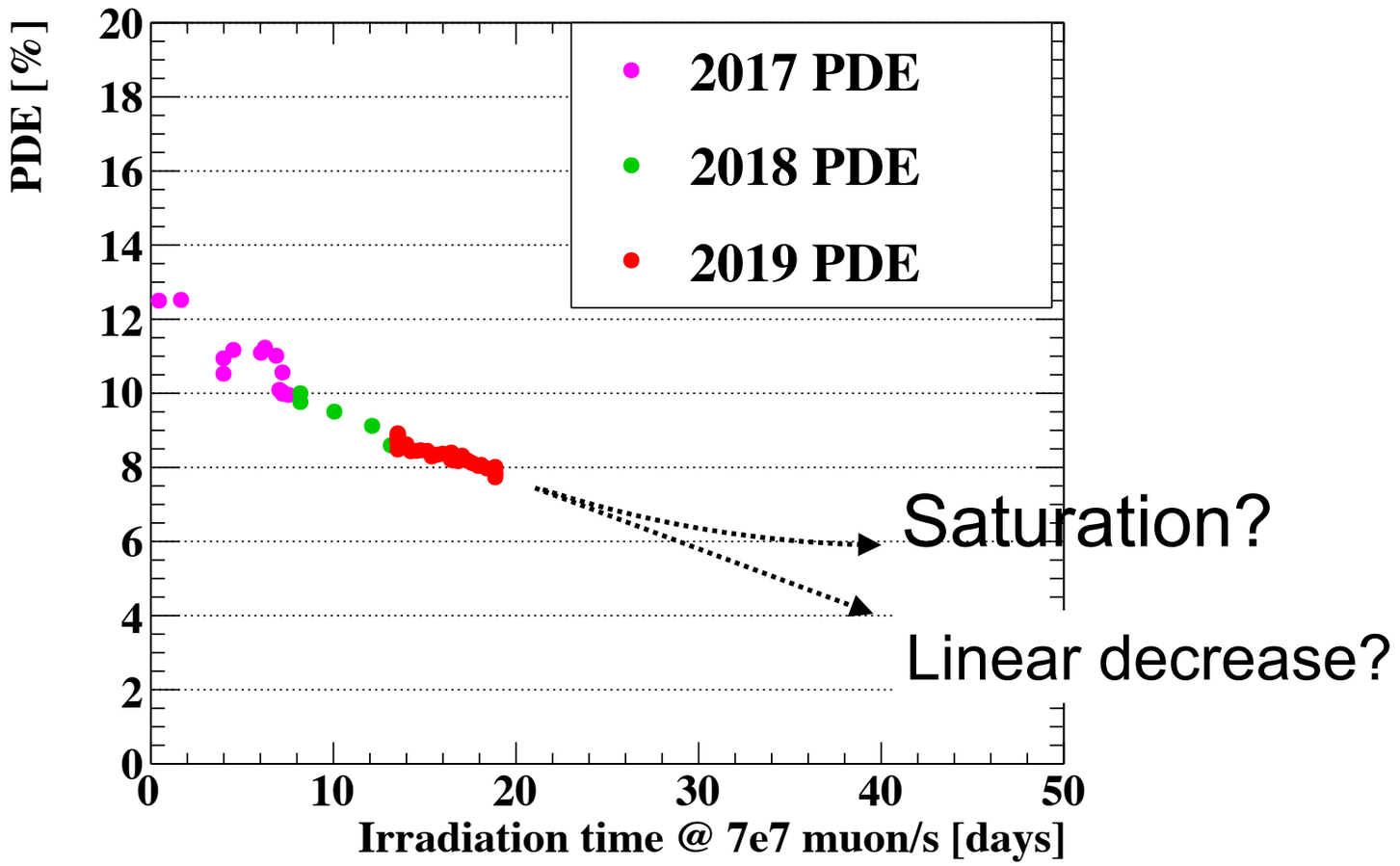
- The hit position of gamma-ray is reconstructed by the fitting of light distribution of MPPC.
- The fitted position is corrected using MC simulation.
  - Geometry and electromagnetic shower.

Uncertainty of Position Resolution



- Statistic uncertainty is dominant over the whole uncertainty.
- Uncertainty from geometry is considered to be negligible.
  - The spread of gamma-ray vertex and the position of collimator is measured.

PDE from 2017 to 2019

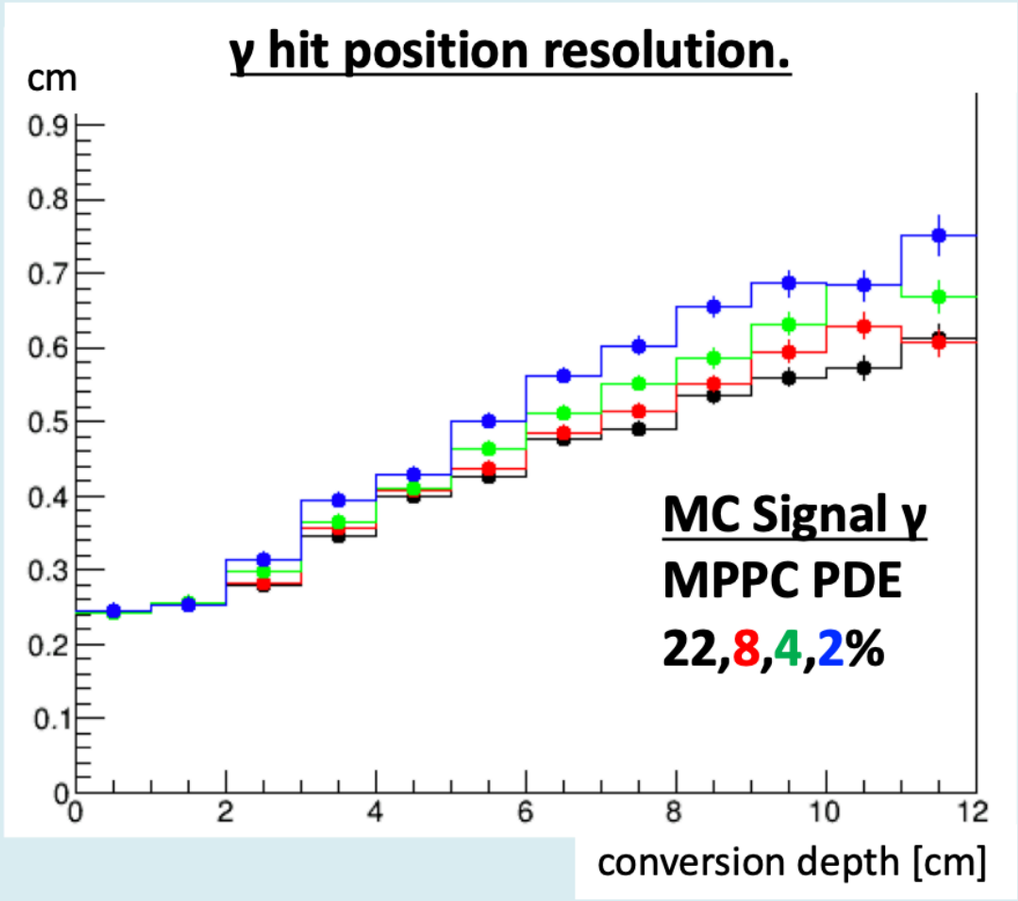


- VUV sensitivity decreased by relatively ~40% after 530 hours of beam usage.
  - **Very fast**: We were going to use μ beam for 140 days per one year.
  - MPPC PDE reaches zero in **70 days** when we assume linear decrease.
  - Lab test at room temperature indicates that PDE decrease saturates at 30%
    - (17aG22-7(R. Onda))
- A good news is that we found the annealing were able to recover PDE by 80%
  - (16pG22-13(K. Ieki)).
  - We are going to do the annealing when the PDE becomes too low to achieve a good resolution.

Position resolution

- Hit position of γ is reconstructed from the # of p.e. distribution on MPPCs.
- Worse MPPC PDE will increase statistical fluctuation of observed distribution, and leads to worse position resolution.

- Slight resolution degradation expected at smaller MPPC PDE down to 2%
  - more obvious at deep event due to their small # of p.e. statistics on inner face.



Distribution of Deviation