東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo

次世代$\mu^+ \to e^+\gamma$崩壊探索実験のための光子ペアスペクトロメーターの開発

-シミュレーションによる測定器設計の最適化-

横田凛太郎

池田史，岩本敏幸[A]，内山雄祐[A]，大谷航[A]，潘晟[A]，松下彩華，森俊則[A]，山本健介
(東大理，東大素セ[A])

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Outline

- Introduction
  - MEG II & New $\mu \rightarrow e\,\gamma$ experiment
  - Pair spectrometer with active convertor
- Current status and considerations
- Performance study with simulation
- Summary and prospect

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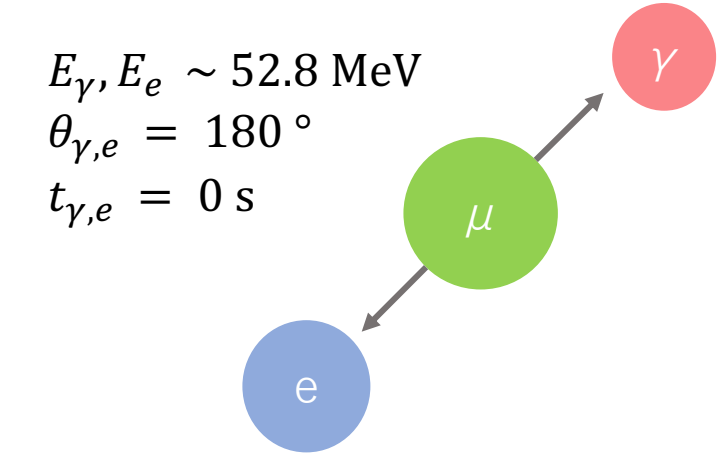
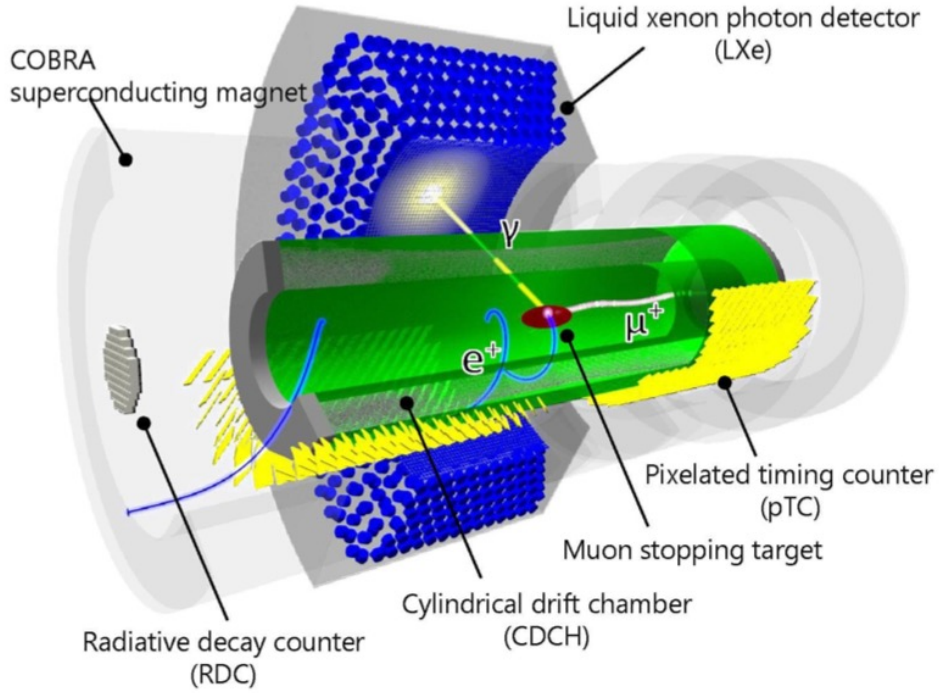
$\mu \rightarrow e\,\gamma$ Decay

- Charged lepton flavor violation
  → strong evidence for BSM
- Characteristics of decay
  - same energy: $E_\gamma, E_e \sim 52.8\ \mathrm{MeV}$
  - back-to-back
  - same timing

- MEGII is searching for $\mu \rightarrow e\,\gamma$ decay at Paul Scherrer institute (PSI)

  Target sensitivity : $\mathrm{Br}\ (6\times10^{-14})$

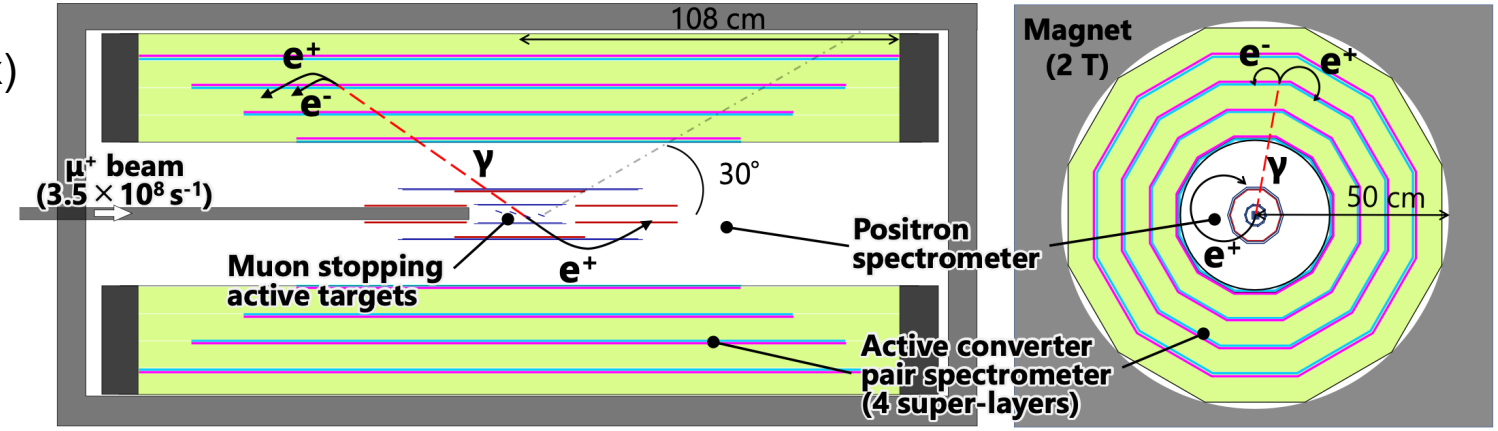




New experiment for $\mu \rightarrow e\,\gamma$

- High intensity muon beam is planed at PSI (2027-2028)
  → 100 times higher intensity ~ 10^{10} μ/s
  → New concept experiment
    - requirement for high resolution and high rate capability

1. **Photon pair spectrometer**
   → higher resolutions (Δ E, Δ t, Δ x)
   angle measurement
2. **Positron spectrometer**
   → high rate capability
3. **Separate active targets**
   → higher vertex resolution, further BG suppression



⇒**Target sensitivity:** $\mathbf{Br}_{\mu \rightarrow e\,\gamma}\left(\mathcal{O}\left(10^{-15}\right)\right)$

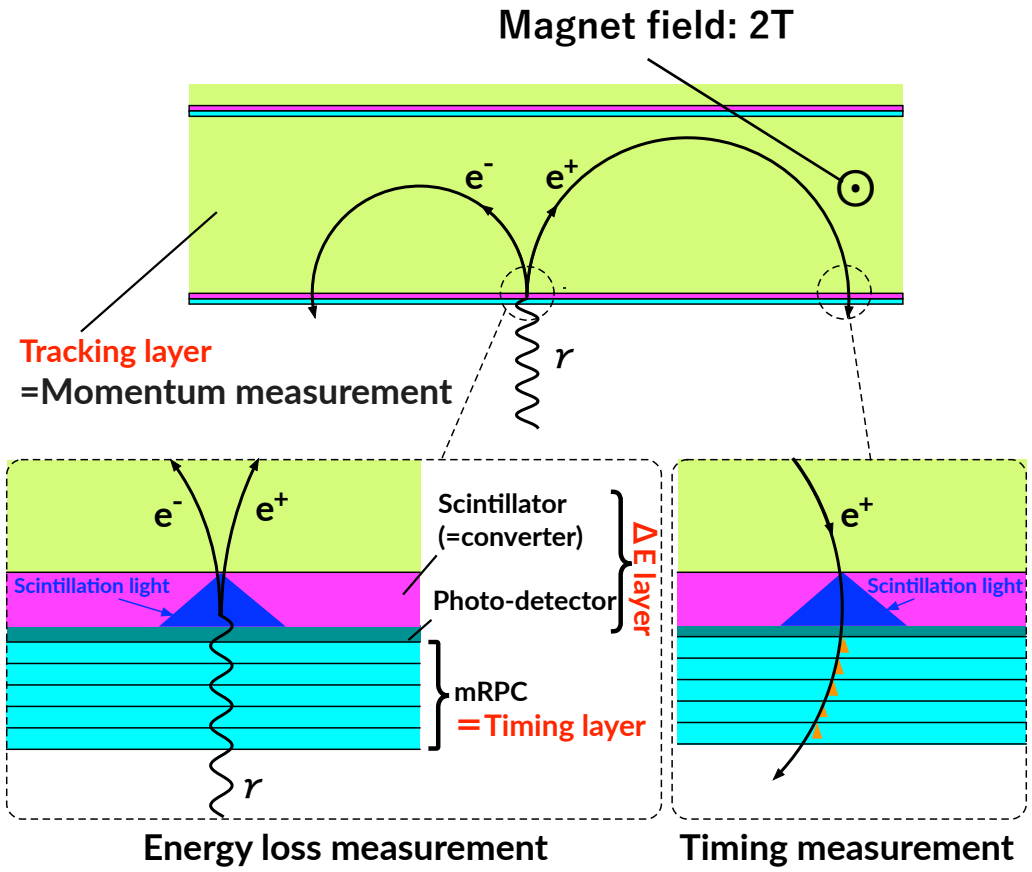
Pair spectrometer with active converter

- Pair spectrometer for γ-ray measurement
  - **Advantages**

    high resolutions (energy, position)
    angle measurable
  - **difficulty**

    energy loss in convertor : invisible

- Possible performance improvement with active converter
  - γ ray converts in scintillator
  - can measure energy deposit in convertor
  - can measure timing



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Considerations for active converter

- Material

evaluation : conversion prob.

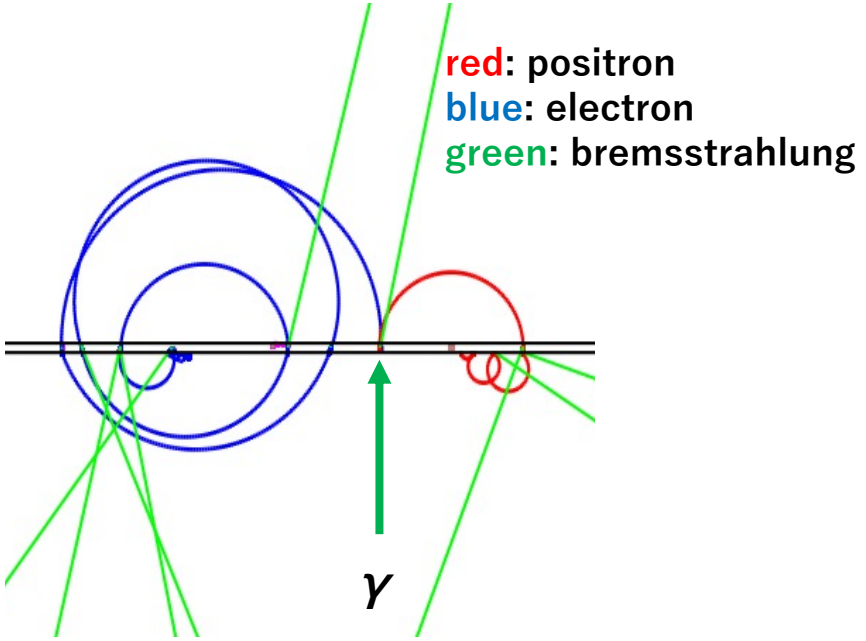
energy resolution

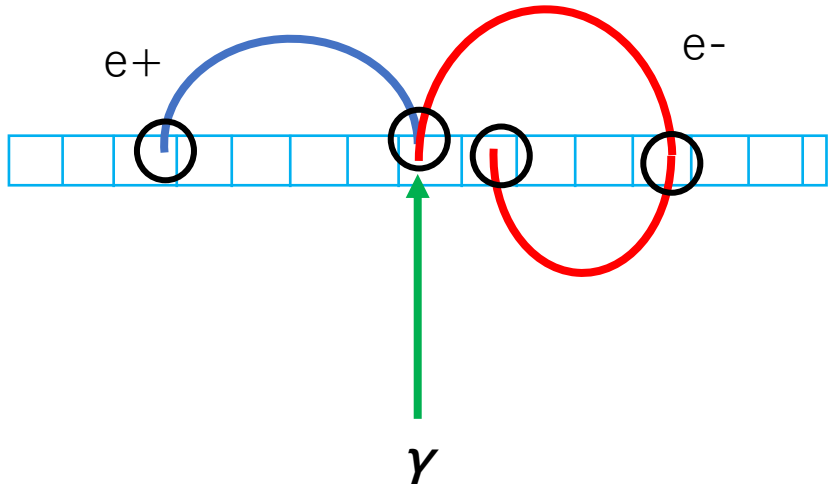
- Convertor's thickness

- Pileup hit by returning conversion pairs

→ incorrect deposit energy

・ can be mitigated by "segmentation"





Material & Thickness study by S. Ban

- Current status
  - Material and thickness were studied by MC

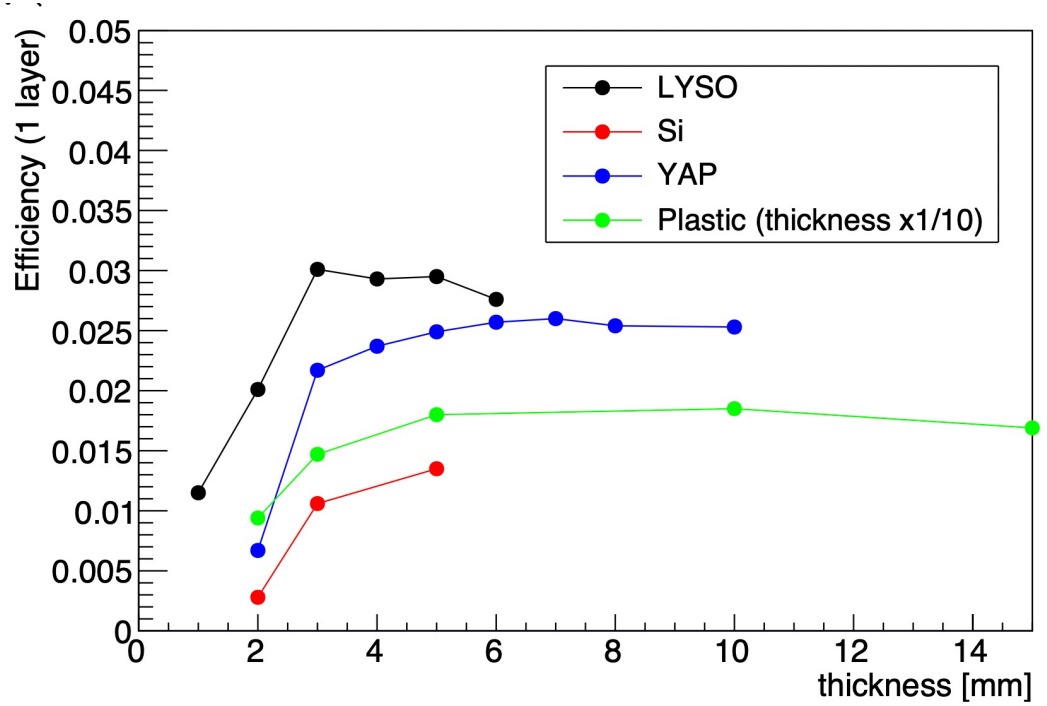
→LYSO (thickness: 3 mm) seems to be preferred

- No magnetic field implemented

→ effect of pileup was not studied

- This study

Optimize segmentation taking into account pileup hit



Efficiency calculation

Input E_γ : 52.8 MeV

- loss 1.022 MeV (pair creation)
- δE = 100 keV (ideal γ detector's resolution)

→selection range [51.7 MeV~51.8 MeV]

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Simulation method

MC simulation “Geant4”

・physics model : Livemore

Configuration

<Fix>

・Scintillator: LYSO

・ Magnet field: 2 T

・γ ray(52.8MeV) : Injection to scintillator
(vertical, uniform to the position)

<Parameter>

・thickness:1, 2, 3, 4, 5, 6 mm

・segmentation

x (parallel to magnet field) : 25, 50, 100, 125 mm

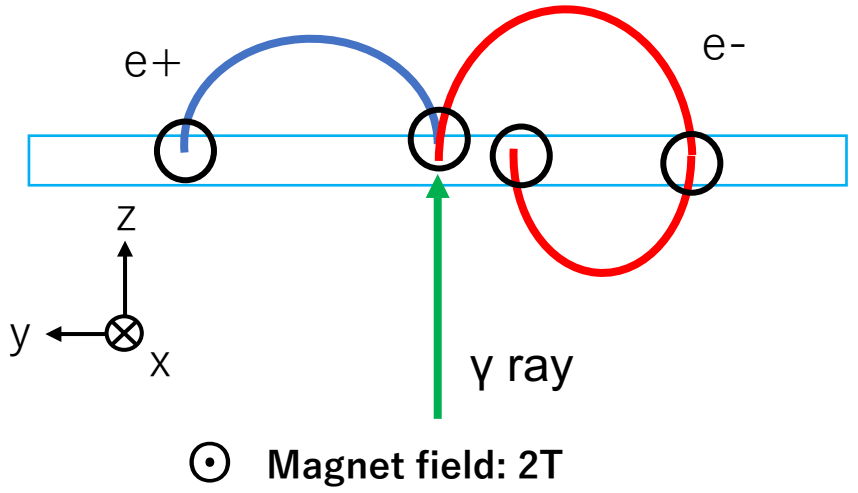
y (vertical to magnet field) : 2.5, 5, 10, 12.5 mm

・Evaluating efficiency

・E selection is same to the previous research

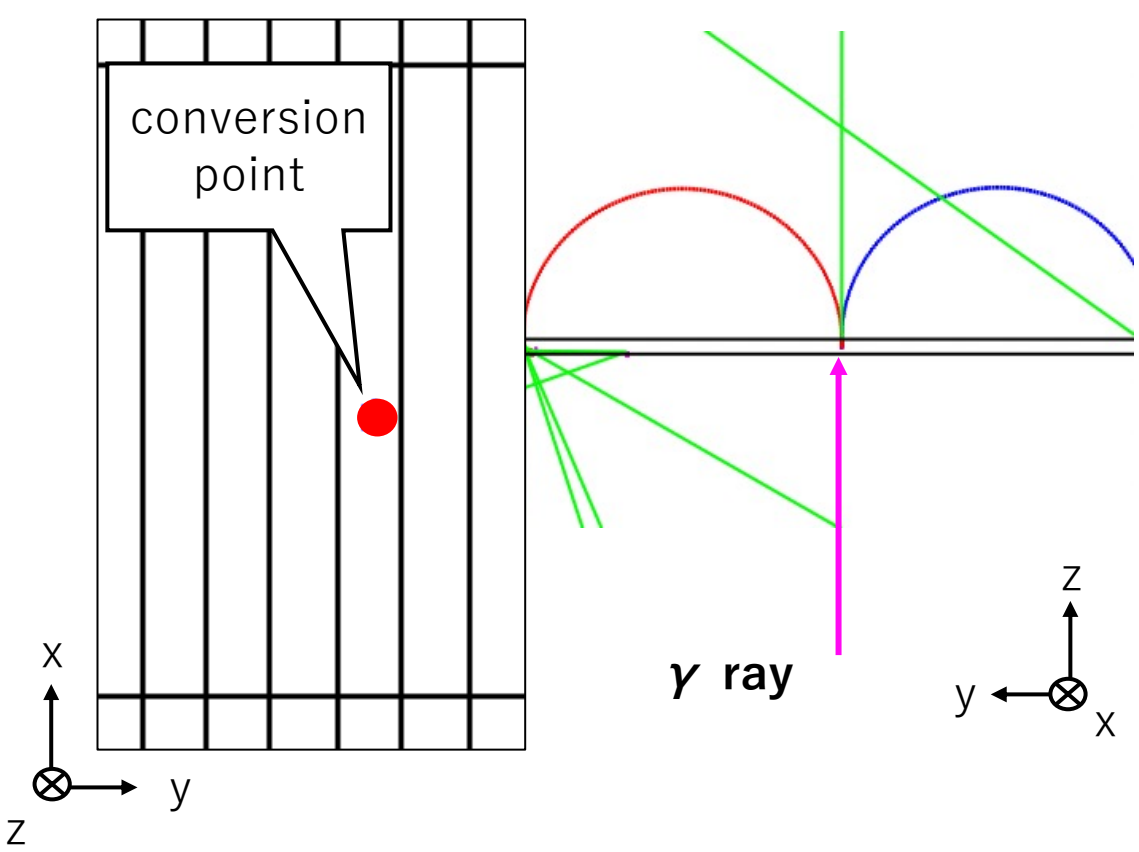
・considering pileup

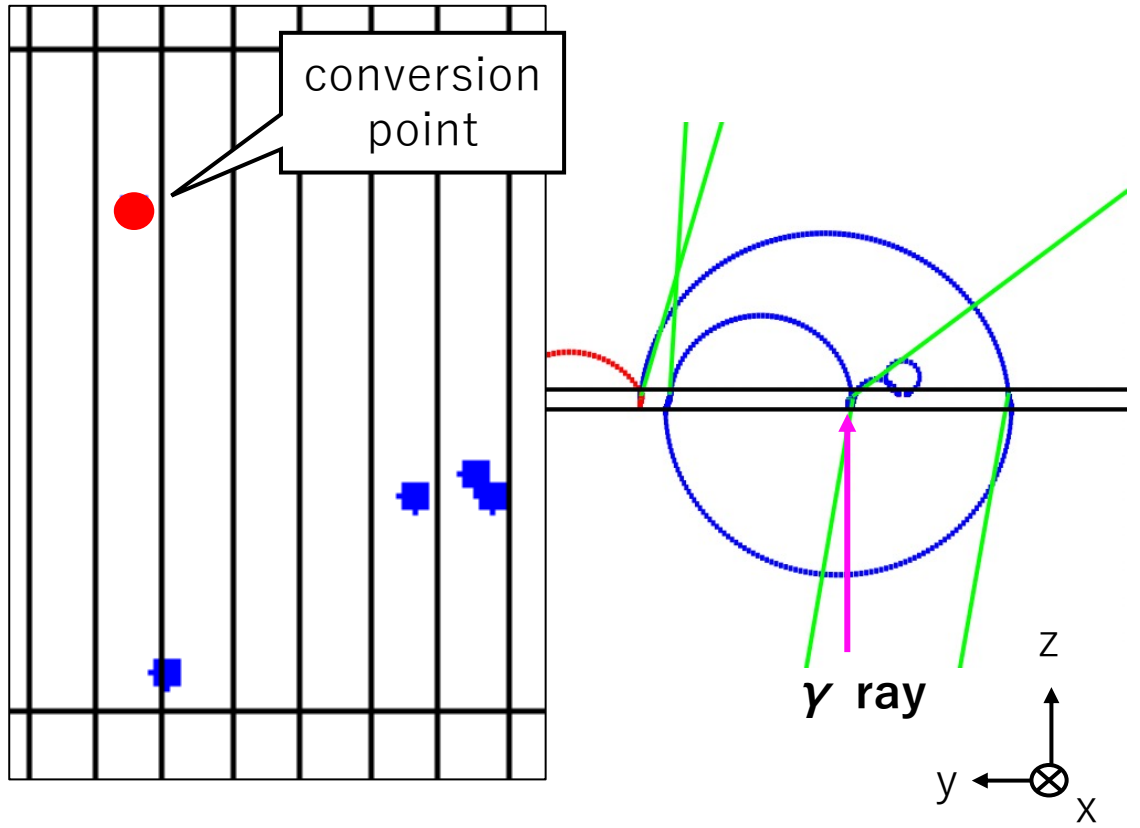
→ Optimize segment size



Examples of event display (non-pileup)

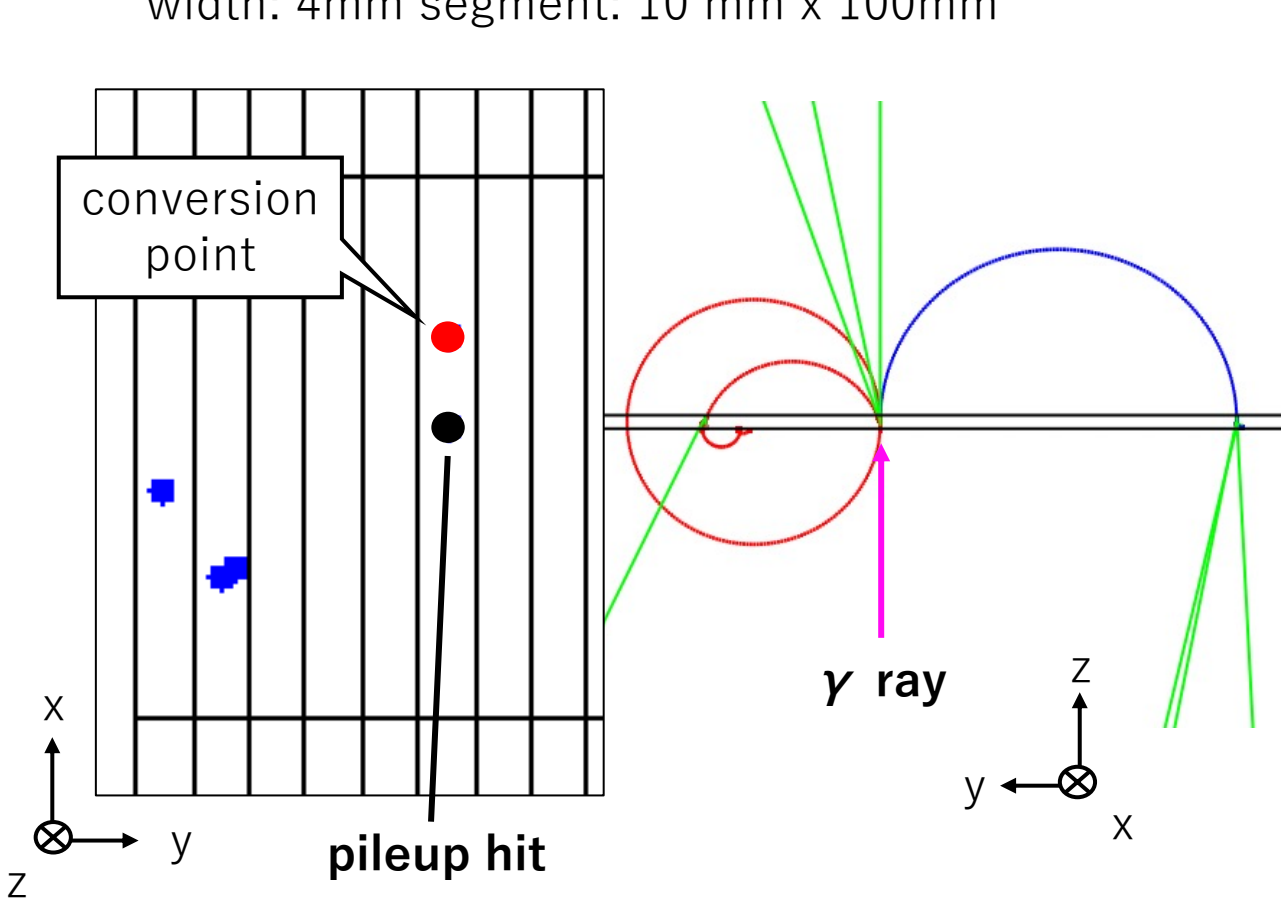
width: 4mm segment: 10 mm x 100mm

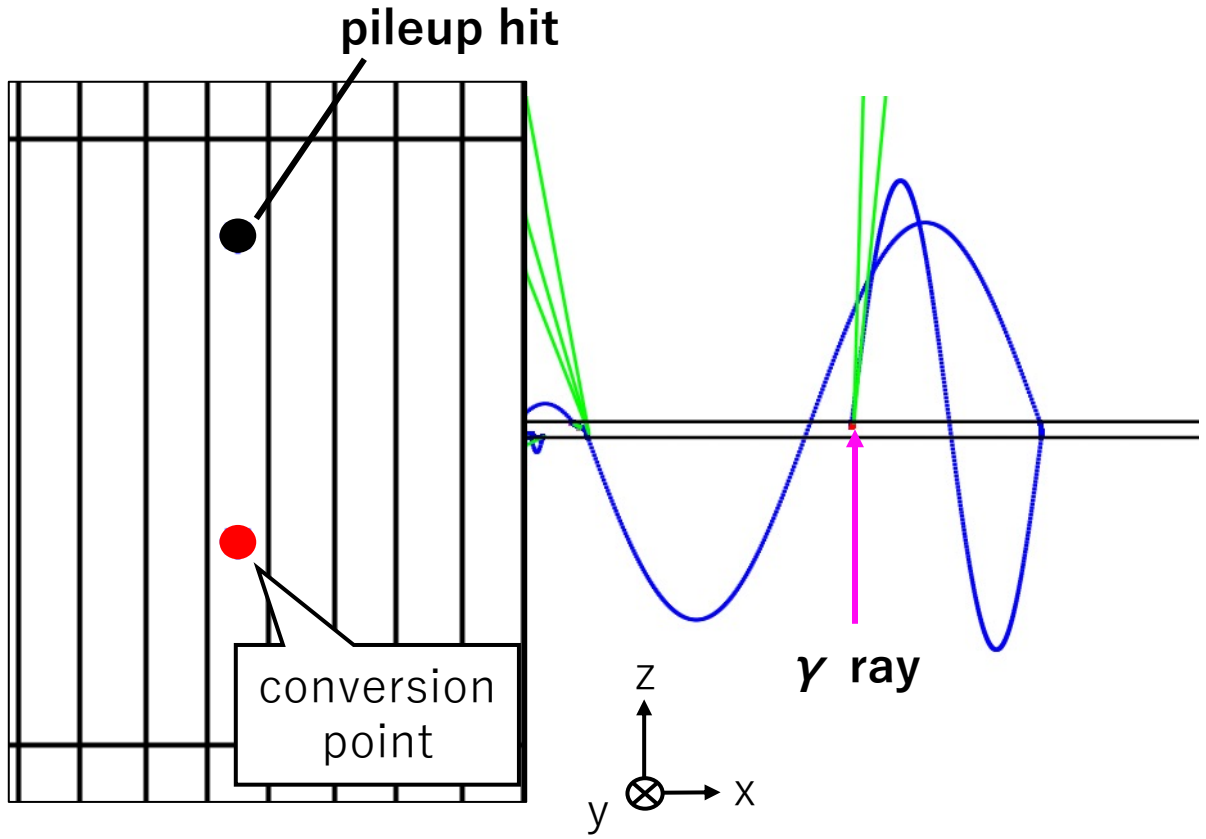




Examples of event display (pileup)

width: 4mm segment: 10 mm x 100mm





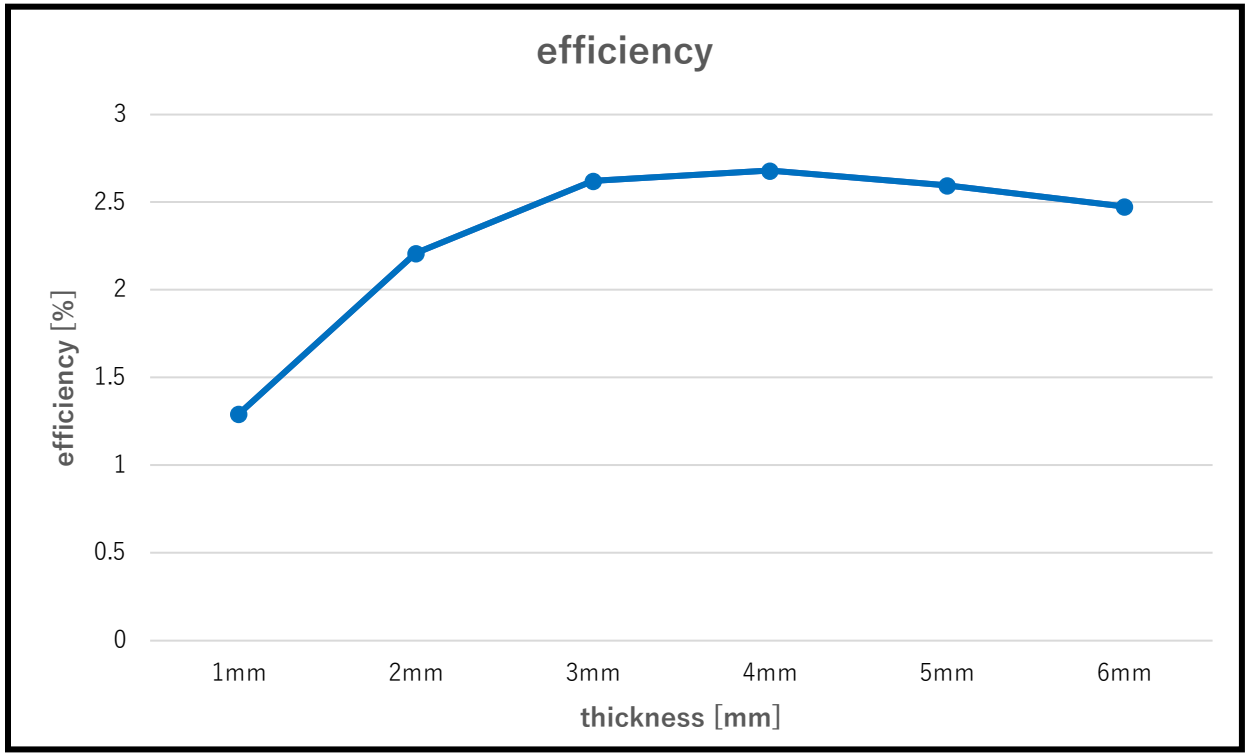
x

Efficiency

Efficiency is evaluated

by counting the number of events meeting the following conditions.

- conversion event
- reconstruct Energy
  = (deposit E in converter) + (kinematic E of e-e+)
  ~ 51.8 MeV
- no pileup



Input E_γ : 52.8 MeV

- loss 1.022 MeV (pair creation)
- δE = 100 keV (from ideal γ detector's resolution)

※ tracker's resolution is not considered

→selection range [51.7 MeV~51.8 MeV]

example: segment: width: 12.5 mm length: 25 mm

⟹ Thickness 4 mm has the highest efficient in this segmentation.

Efficiency

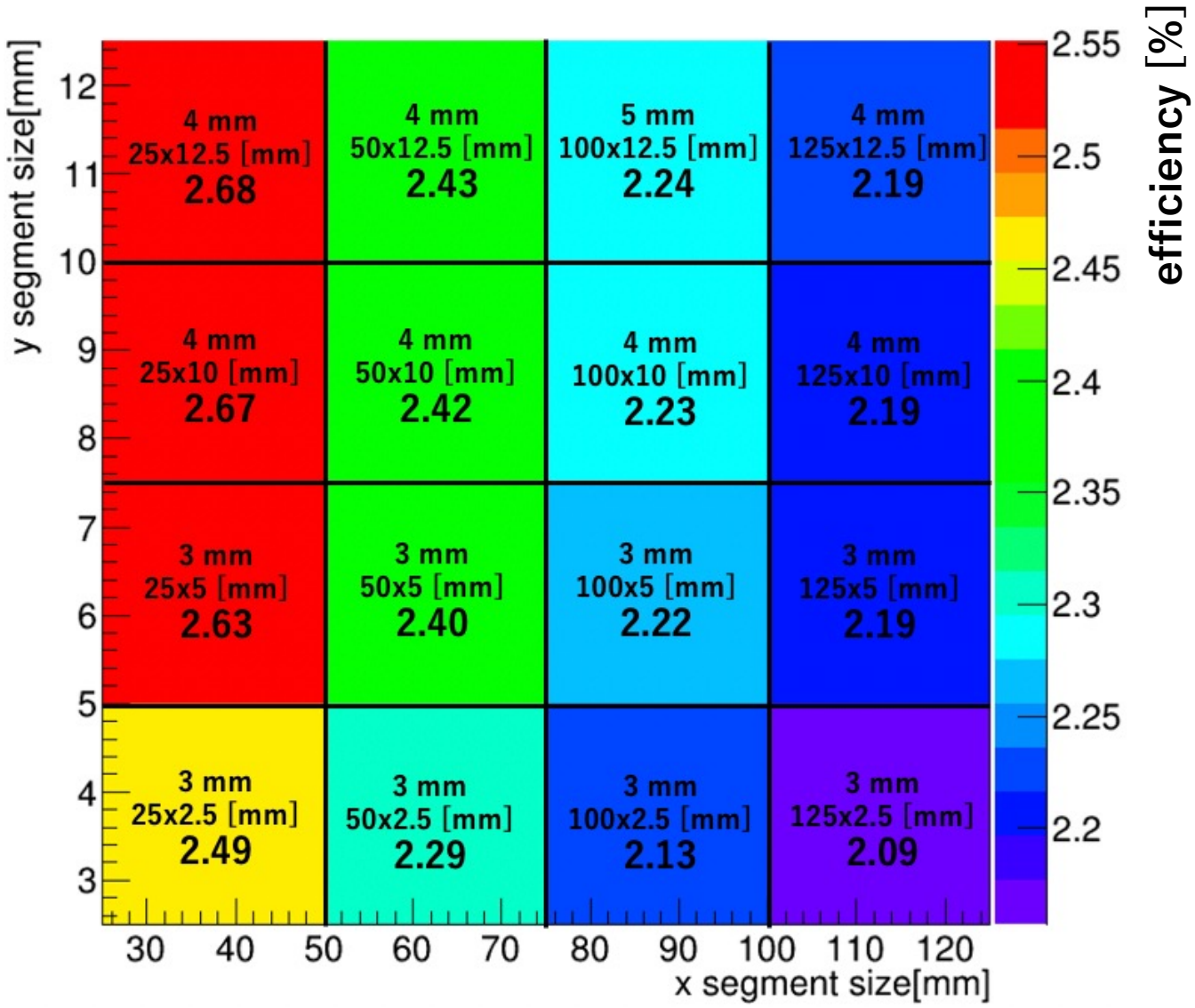
・segment
width: 12.5mm length: 25mm thickness: 4mm
is optimal efficiency 2.68% for 1 layer

・The efficiency decreases as the y-direction segment becomes smaller

← This seems to be due to the lack of accurate measurement of the deposit energy for events that cross between the segments.

This problem will need to be corrected

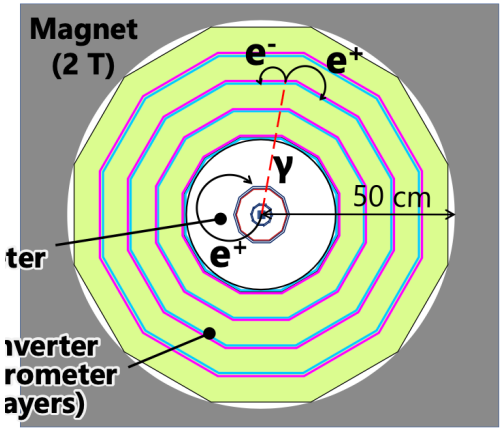
Efficiency by segment

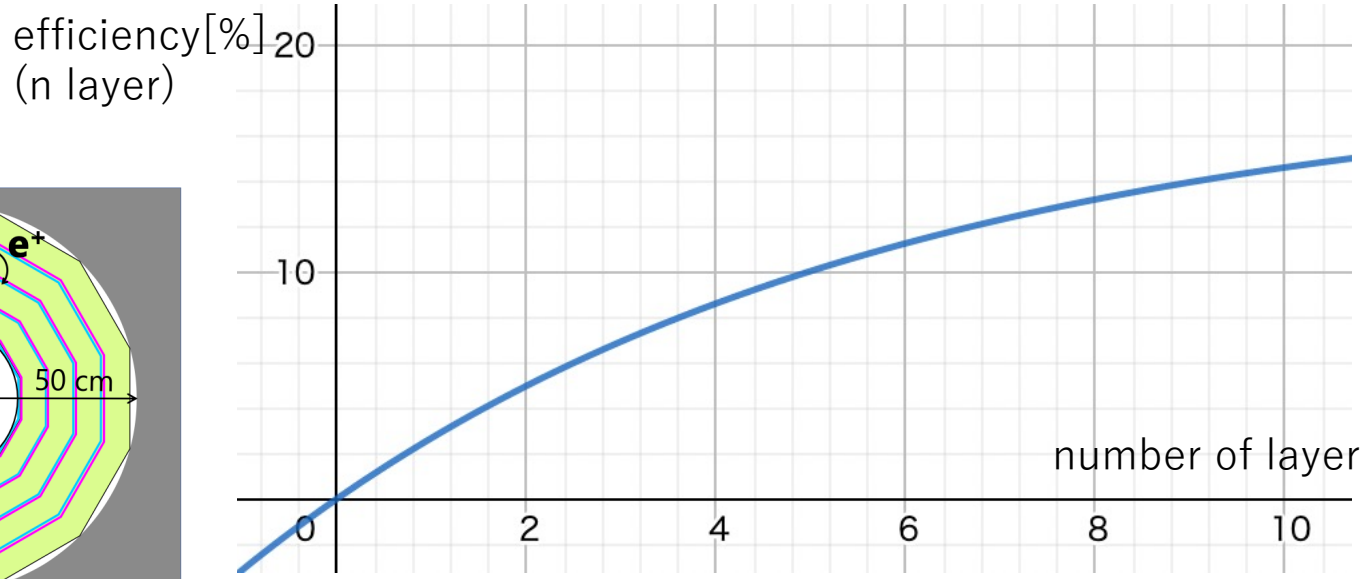


Efficiency for the number of Layer

Best geometry: LYSO, 12.5 mm × 25 mm × 4mm (width × length × thickness)

considering multi layers $\boldsymbol{eff.(n_{layer}) = \frac{eff_{\cdot 1\ layer}}{p_c}(1-(1-p_c)^{n_{layer}})}$, $\mathbf{p_c = conversion\ prob.}$





1 layer: efficiency = 2.7%
5 layer: efficiency = 10%
10 layer: efficiency = 15%

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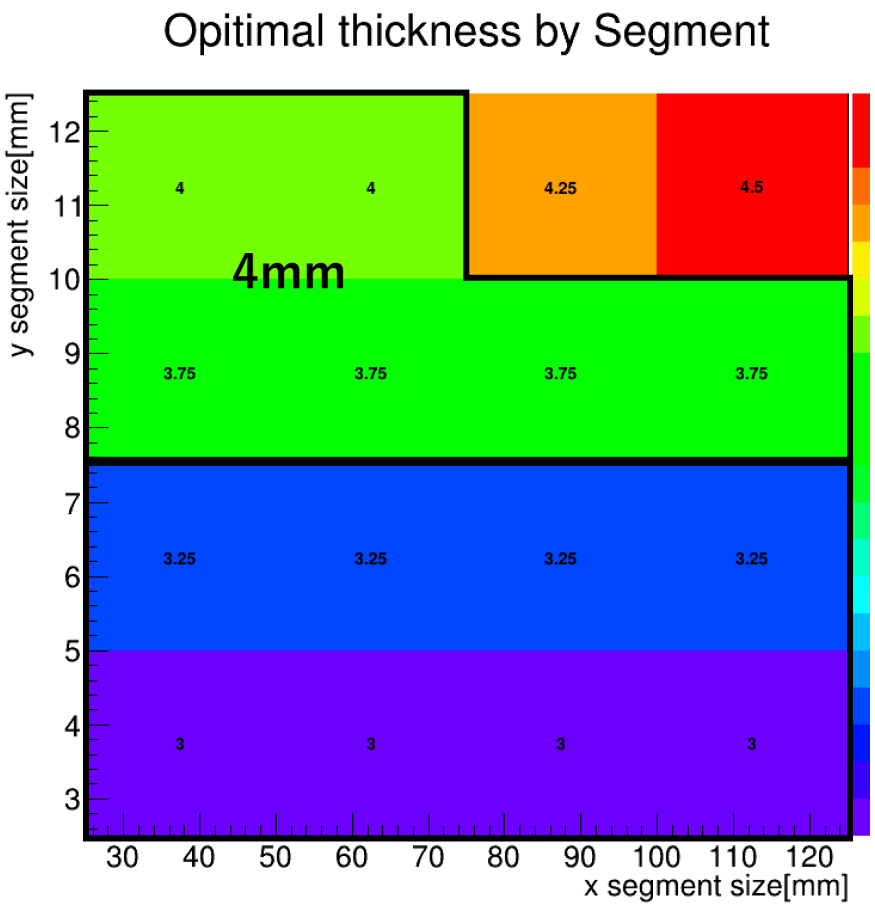
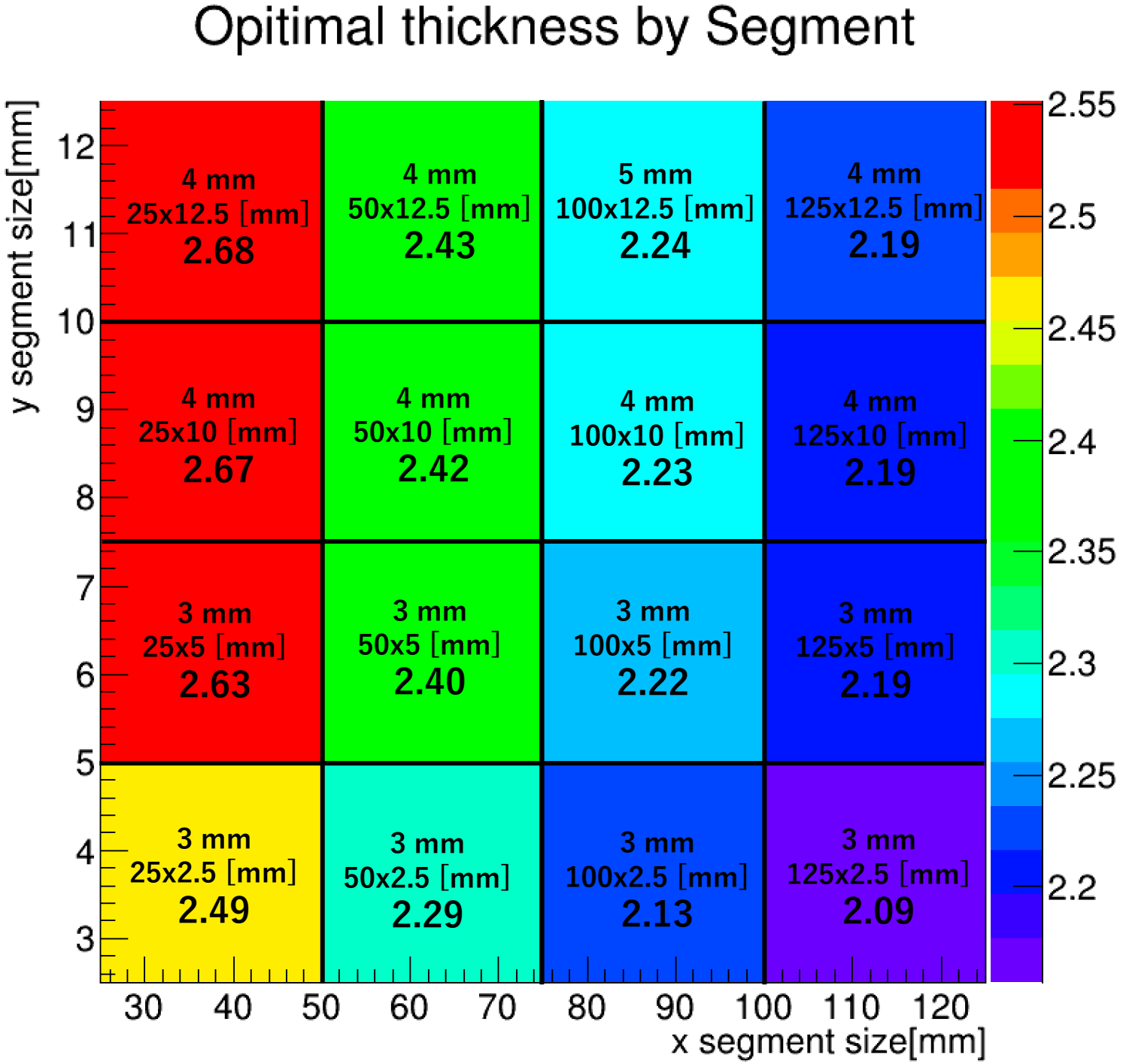
Summary & prospect

- New concept of $\mu \rightarrow e\,\gamma$ experiment is planned now
- Consider the best material as active converter
- Optimize segment size considering magnetic field
- High efficiency for each parameters
  - thickness → 4mm
  - segmentation → width: 25mm, length: 12.5mm
- Prospect
  - Need estimate for angle measurement
  - Introduce tube type convertor



Optimal thickness exists for each segment size



memo

・スライドの流れ

背景(μeγ崩壊/新実験計画/検出器設計)x3~4/現状(問題提起、先行研究)x2/手法(なにをしたか、目標)x1~2/結果x2/考察(未解決なところも)x1/まとめ、展望x1

各スライドの主張をはっきり

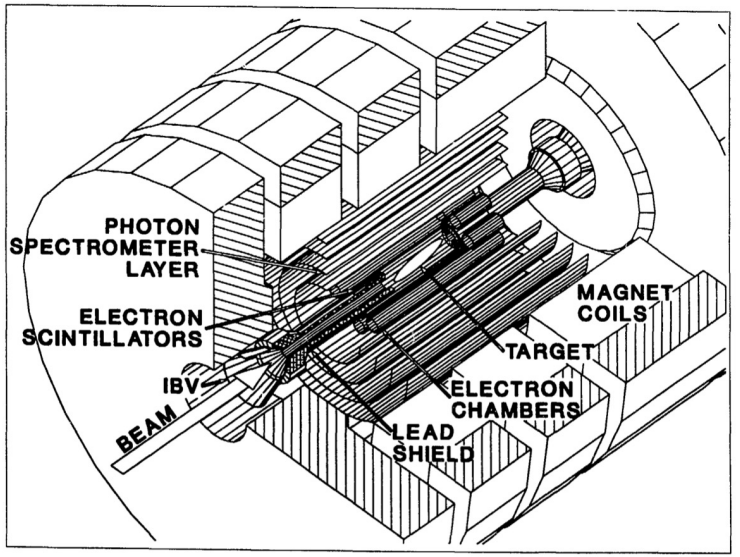
Back up

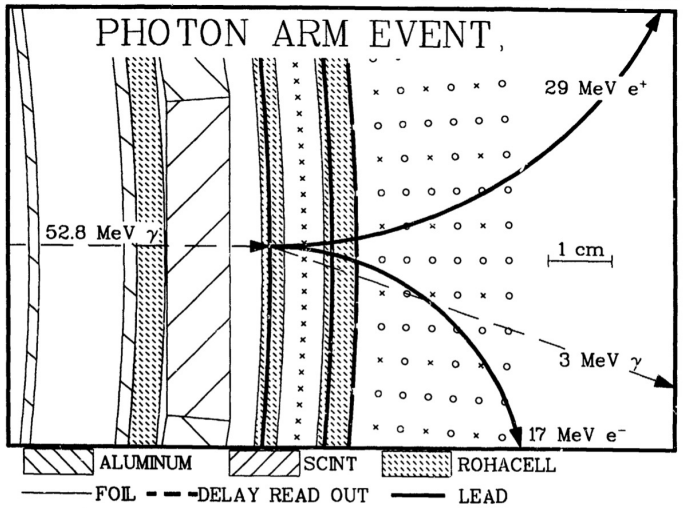
Pair Spectrometer with Active Convertor

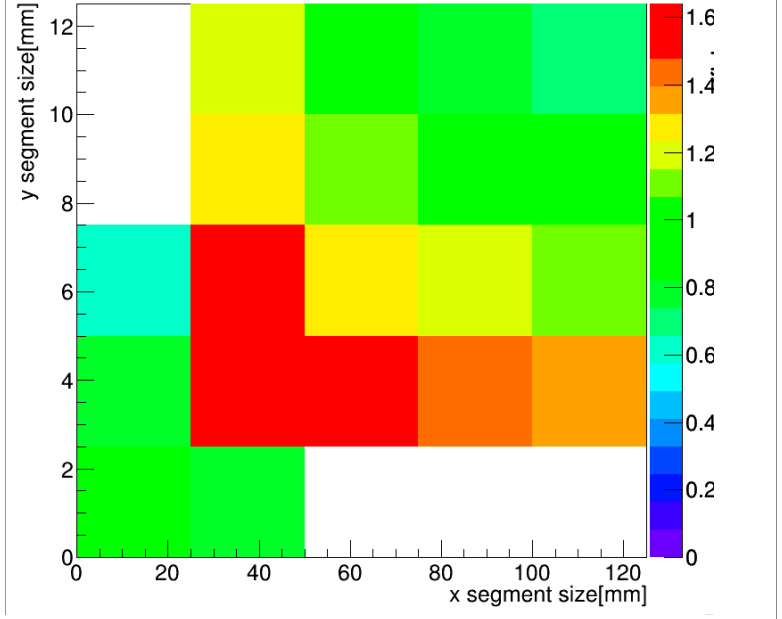
- Motivation
  - MEGA experiment at LAMPF (1985-1999)
  - Detection efficiency ~ 5%

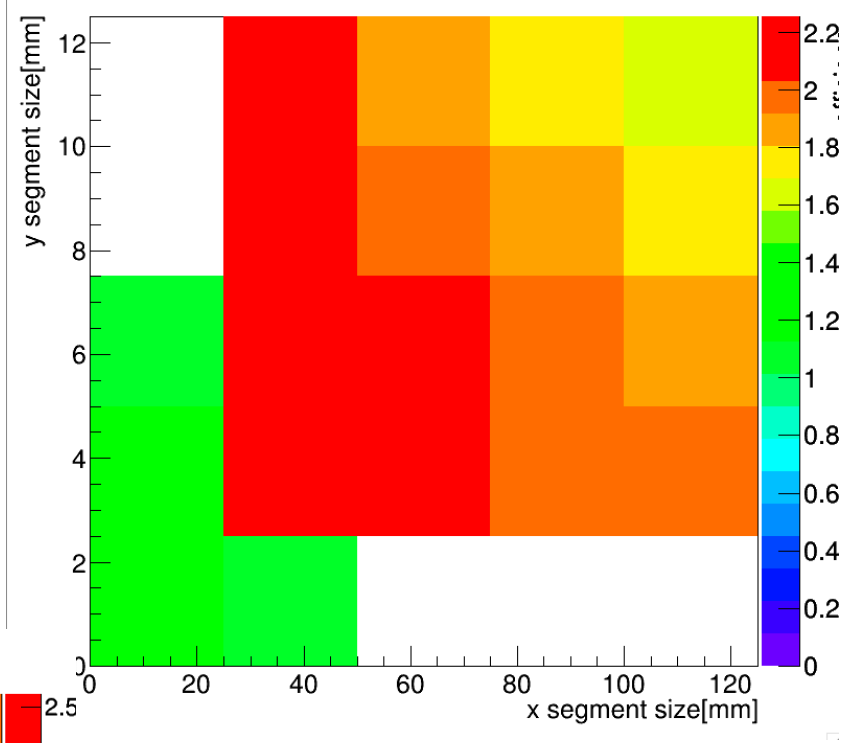
- Missing energy in Convertor & Low energy resolution

  →”Active Convertor” to measure missing energy

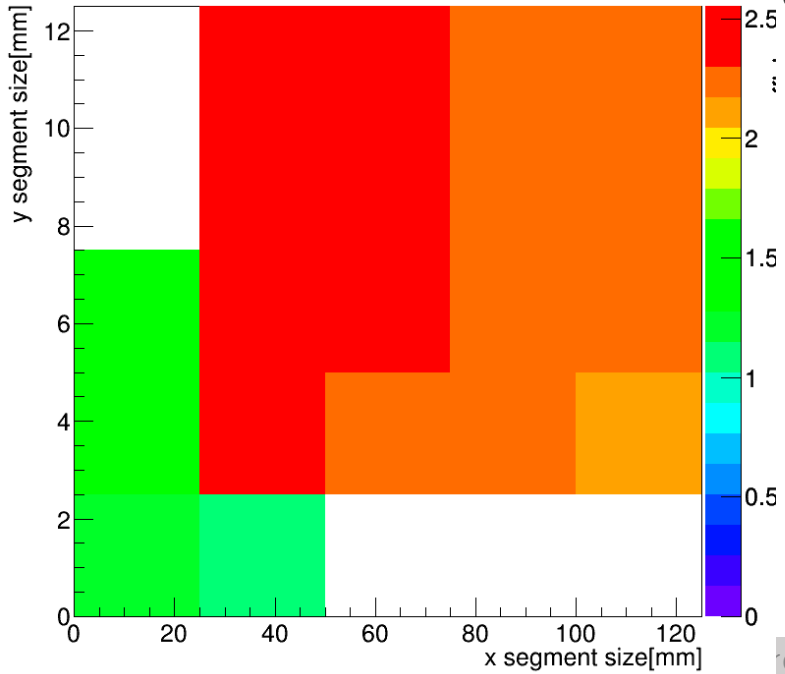


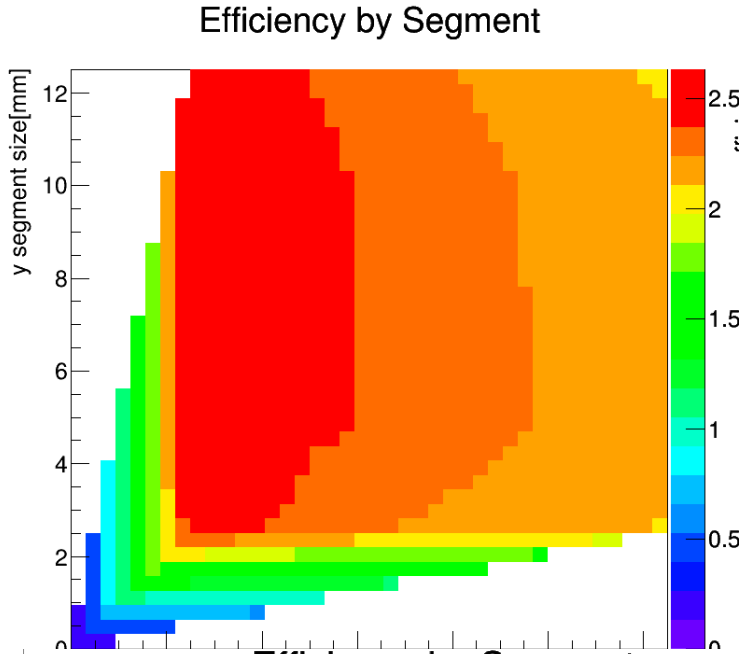


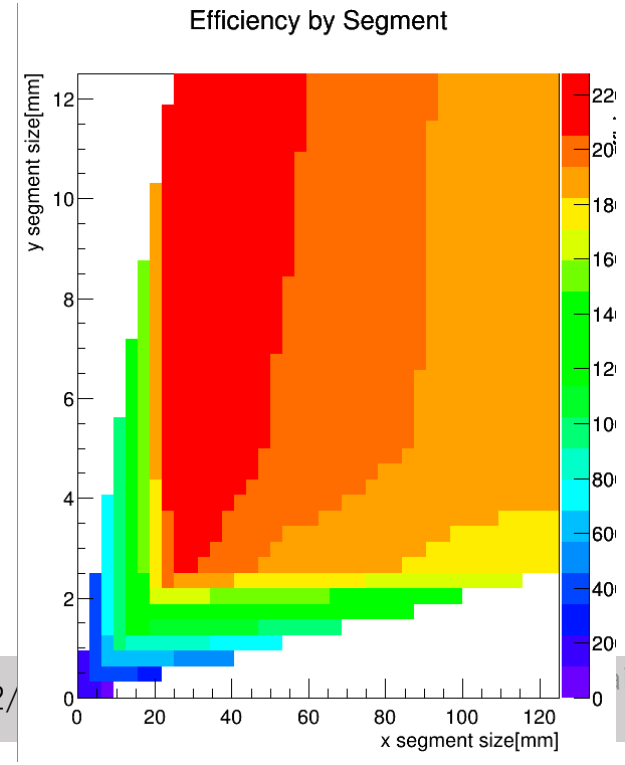




Efficiency by Segment




Efficiency by Segment
y segment size[mm]
x segment size[mm]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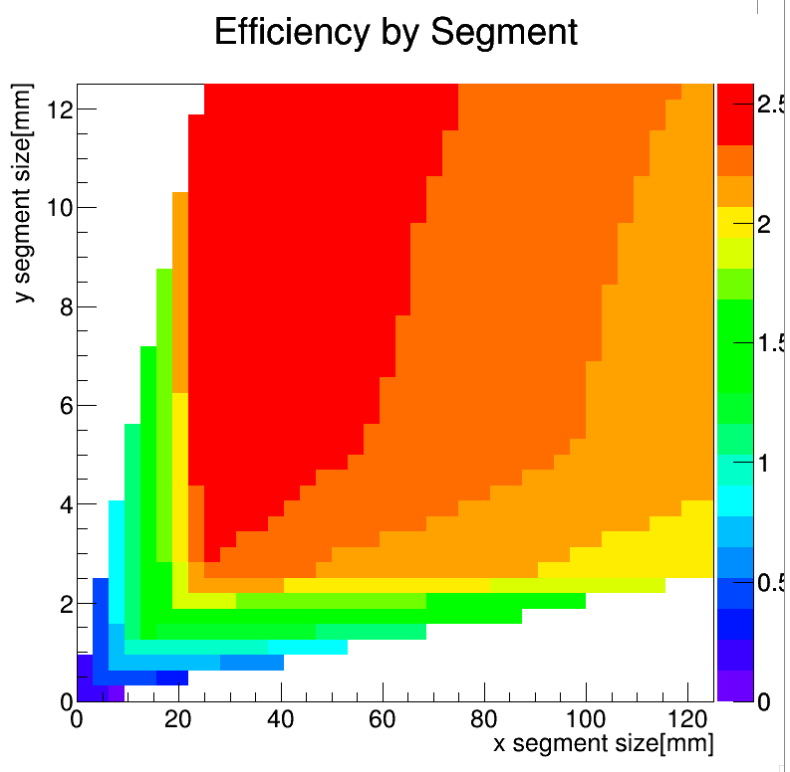
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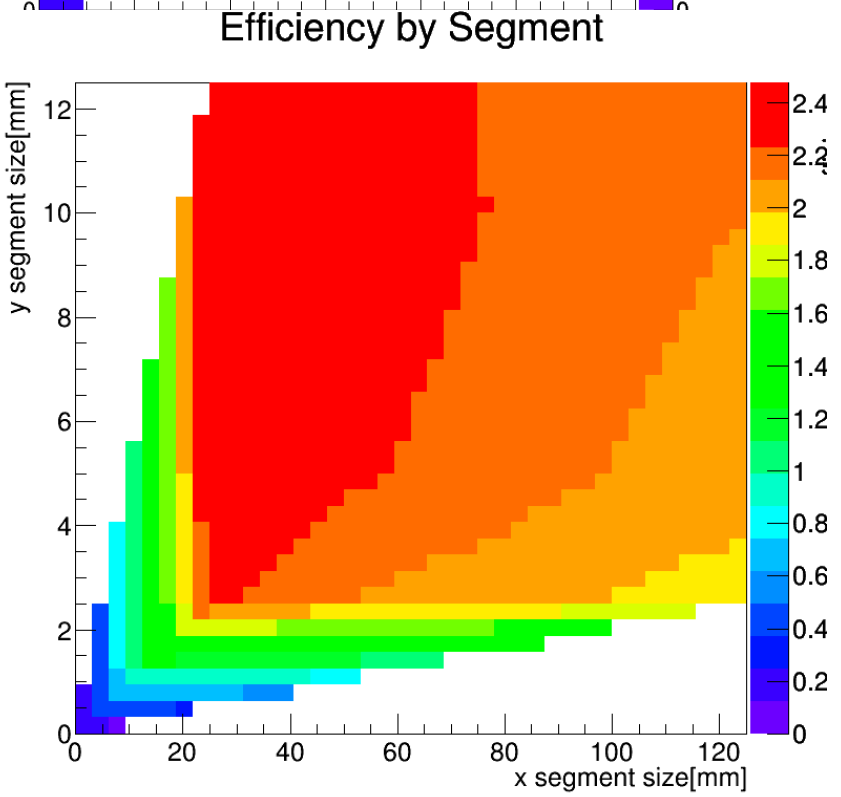
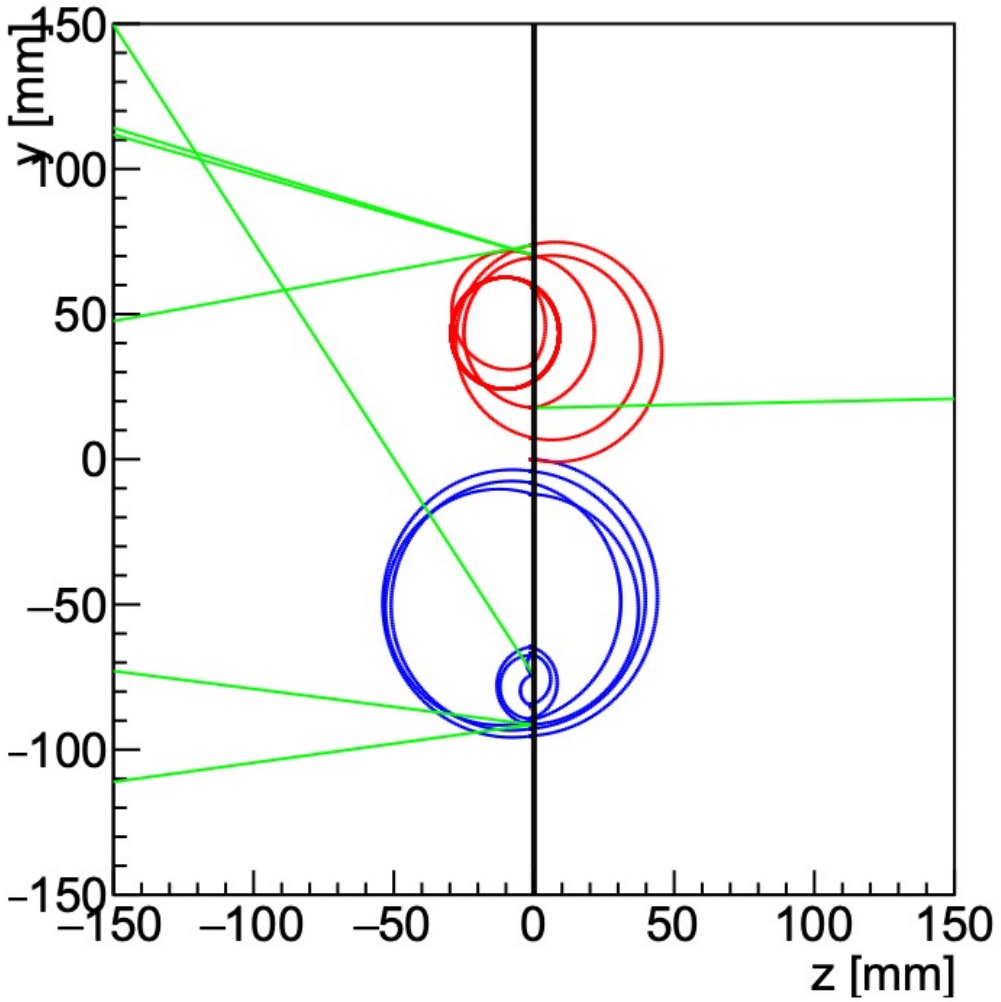
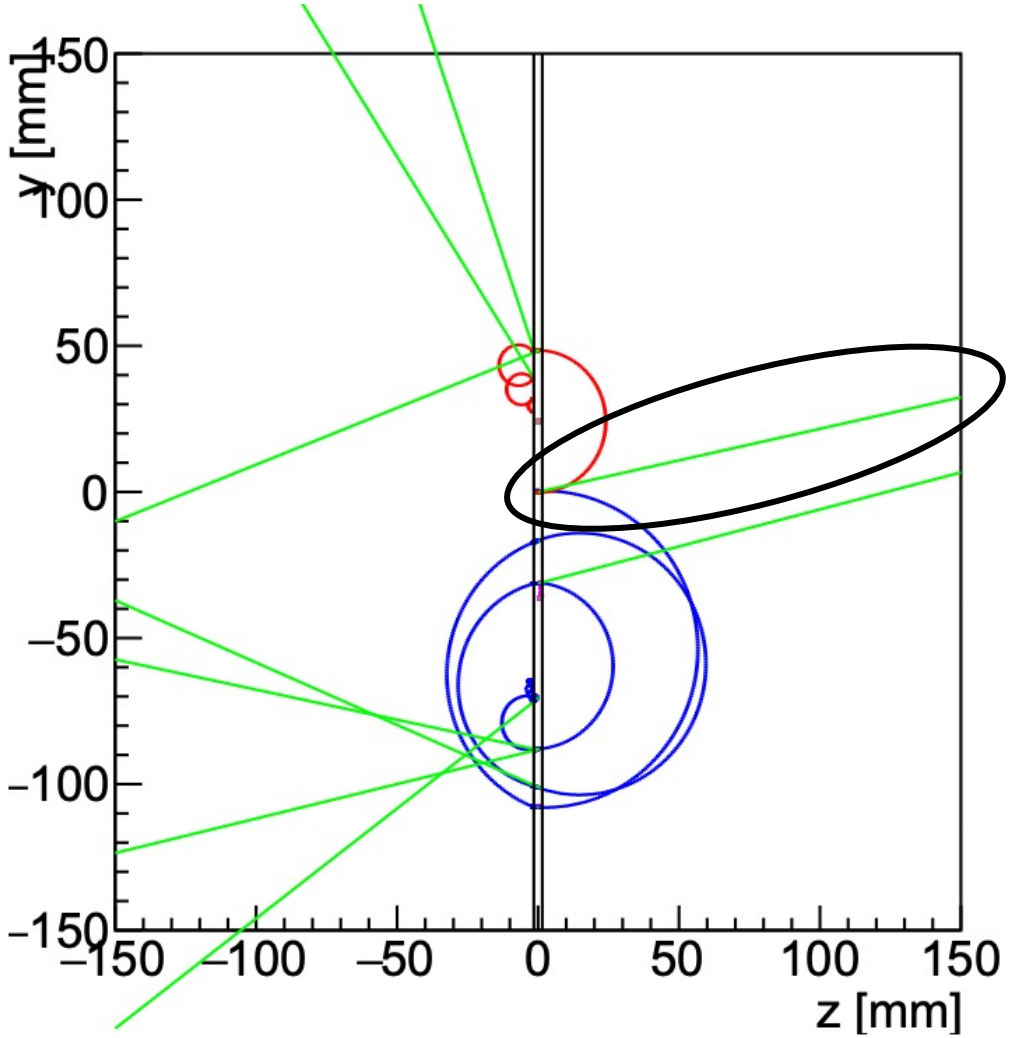

Efficiency by Segment
y segment size[mm]
x segment size[mm]

Thin scintillator(1mm)



Thick scintillator(3mm)



E distribution each thickness (LYSO)

E=(E of e-e+) + deposit E in segment

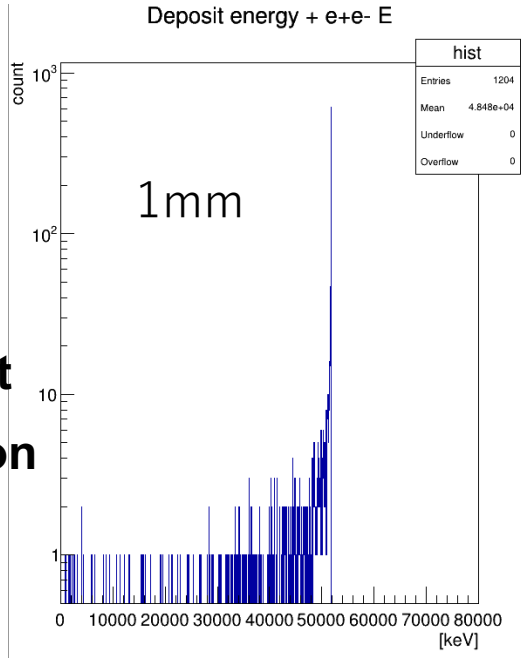
Histogram is after segment exception

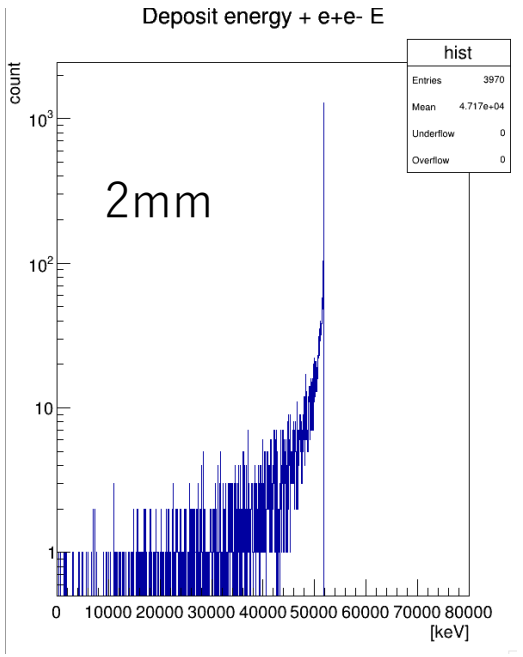
・Thin Scintillator has a lot of pileup because of many same position turn & low conversion probability

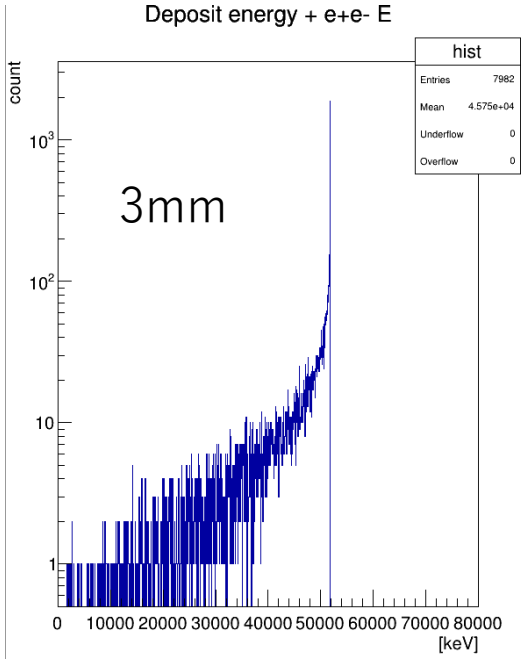
→ **Few correct events**

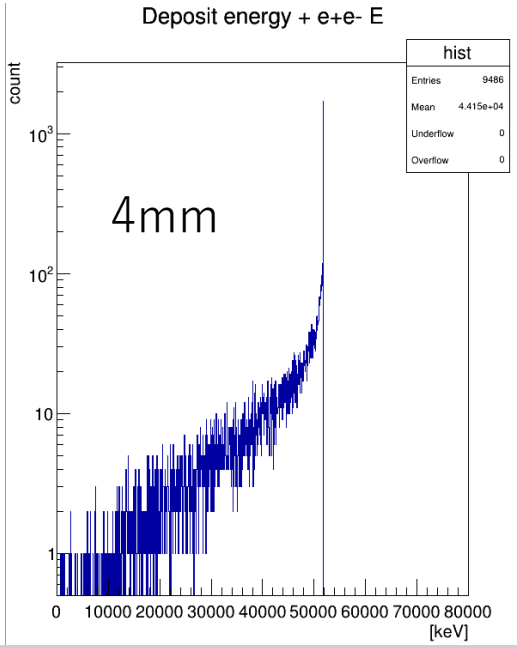
・Thick Scintillator has a lot of Bremsstrahlung

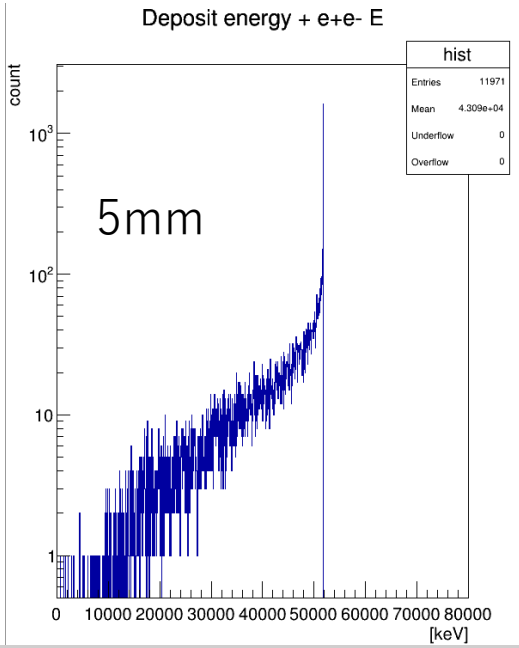
→ **E reconstruct not correct**

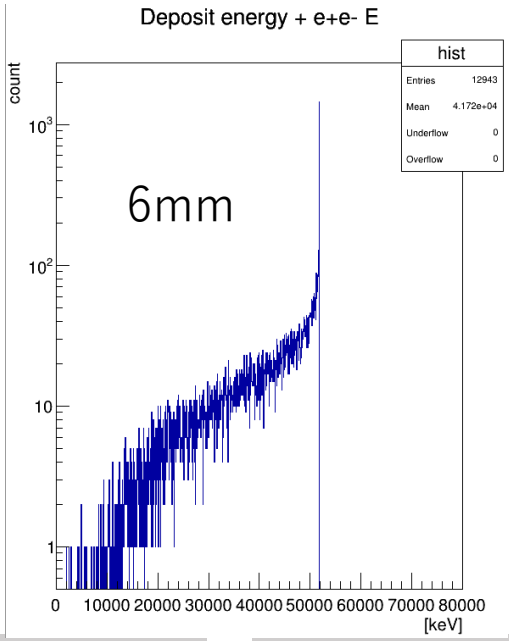












Effect of segmentation

- Y direction (vertical to B)

→ not much impact

- X direction (parallel to B)

→ much effective