Simulation study for optimizing the performance of a photon pair-spectrometer

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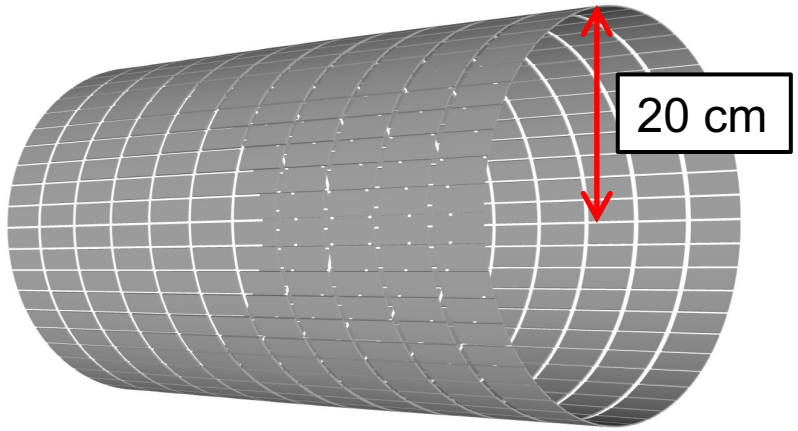
Outline

1. The overall setup of the simulation
2. Optimization of the converter design
3. Possibility of angle measurement of γ
4. θ_γ dependence of the signal efficiency

1. The overall setups and signal selection

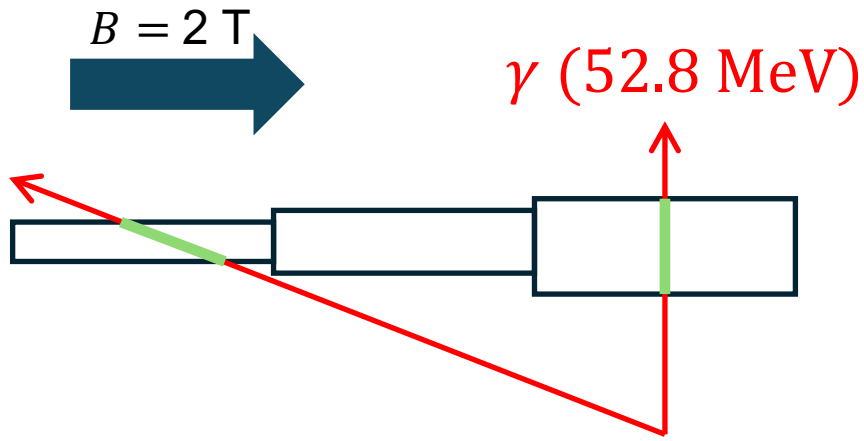
Geometry

- One converter layer (without tracker)
- Distance from the beam axis: 20 cm
- 2 T uniform magnetic field along z direction
- Converter thickness thinner in outer segment
  - In order to make the effective thickness for the γ to be uniform



Signals

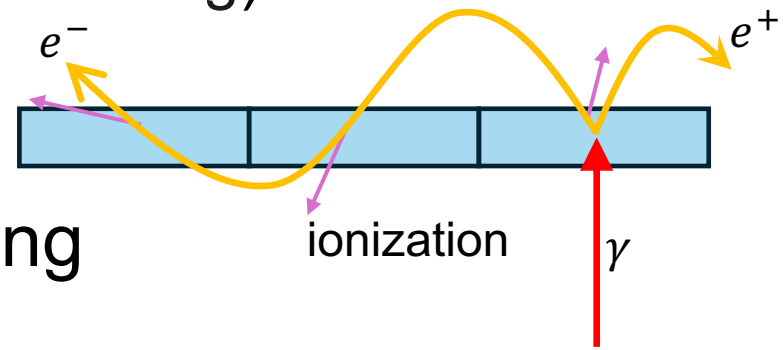
- Photon particle gun from the origin
- Monochromatic energy of 52.8 MeV



Definition of “efficient event”

- Usually, multiple electron tracks are found in one event
  - Mainly from the ionization (including Bhabha/Møller scattering)

  → Need to select one $e^{\pm}$ pair from the conversion



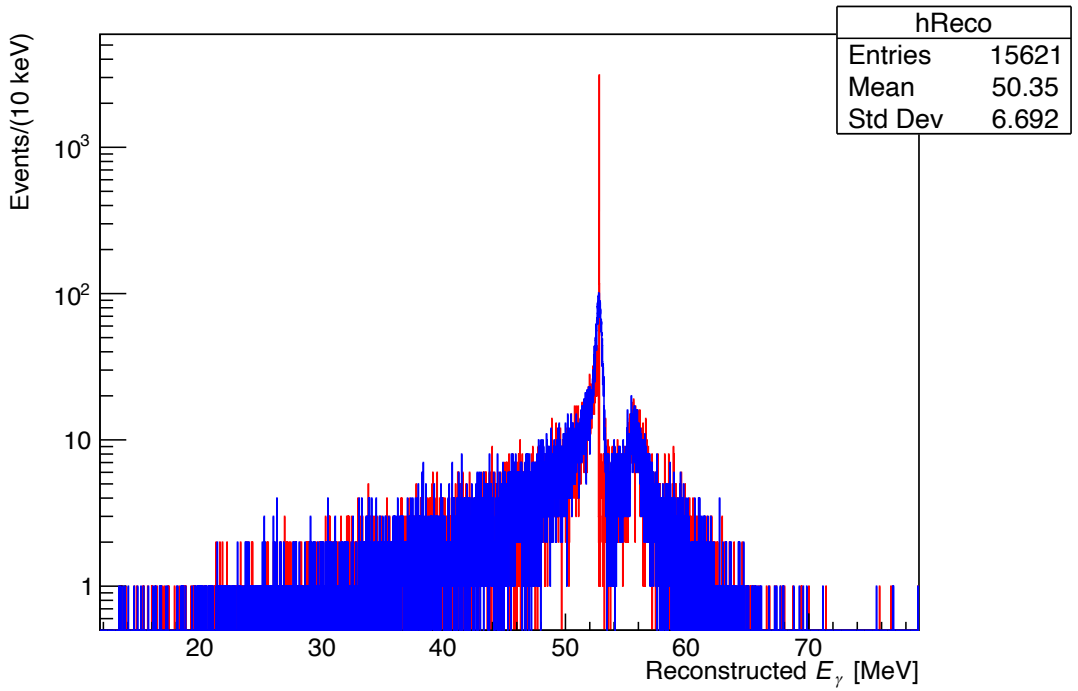
- So, pair-created e^+e^- track is selected as following
  - First, group the tracks are grouped according to their distance (2mm) and time difference (15 ns) of leaving the converter
  - The group is counted as a candidate if it contains only one electron and one positron

- Next, the energy of γ is reconstructed from the pair
  - $E_\gamma = E_{e^+} + E_{e^-} + E_{dep}$ E_{dep} = total energy deposition in the cell
  - If $52.7\ \mathrm{MeV} < E_\gamma < 52.9\ \mathrm{MeV}$, count as efficient

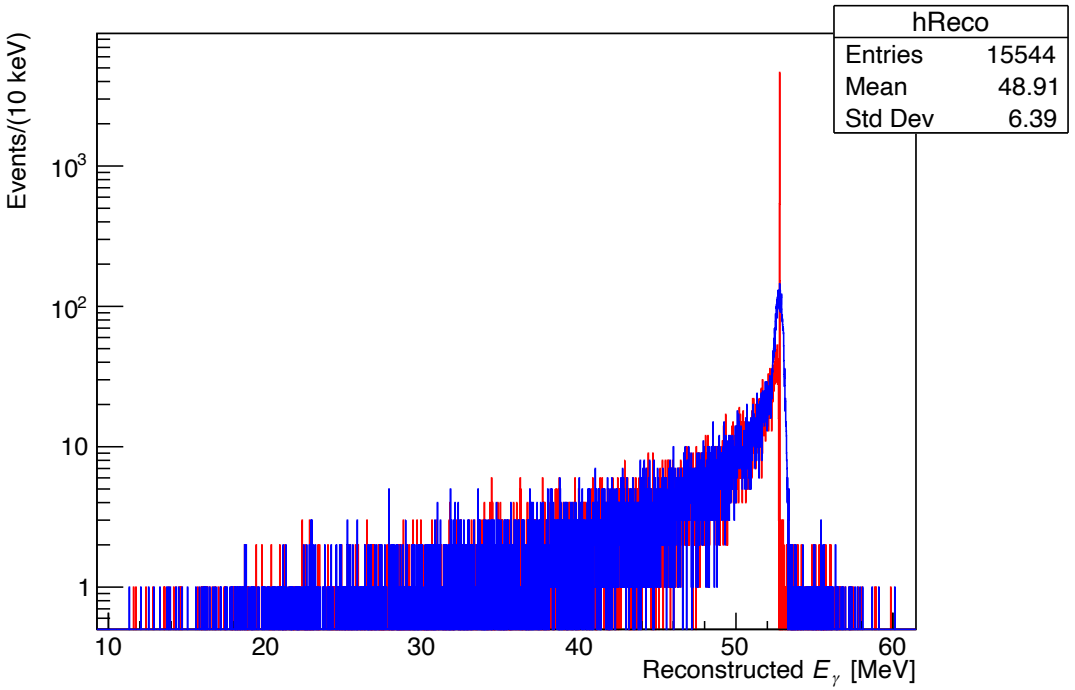
2. Optimization of the converter design

Consideration of the cell size

- Cell size is important to reduce ‘boomerang’ events and to obtain a good energy spectrum



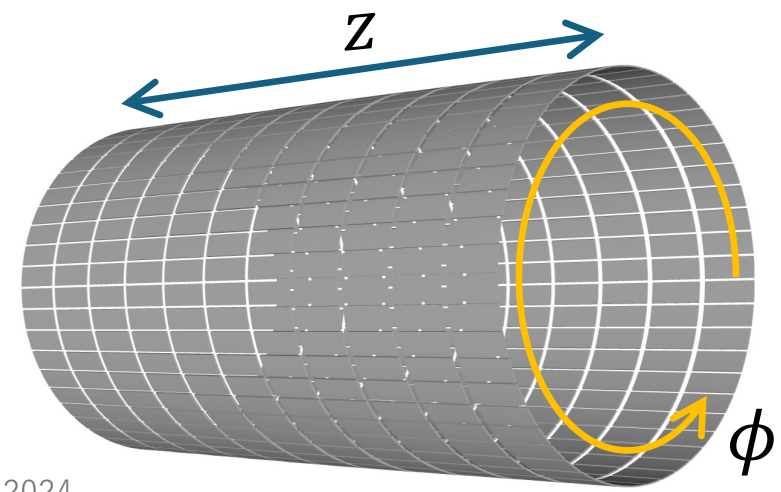
Cell size: 25mm × 150 mm
Events with track pair candidates: 7.8%
Events with $52.7\ \mathrm{MeV} < E_{rec} < 52.9\ \mathrm{MeV}$: 1.8 %

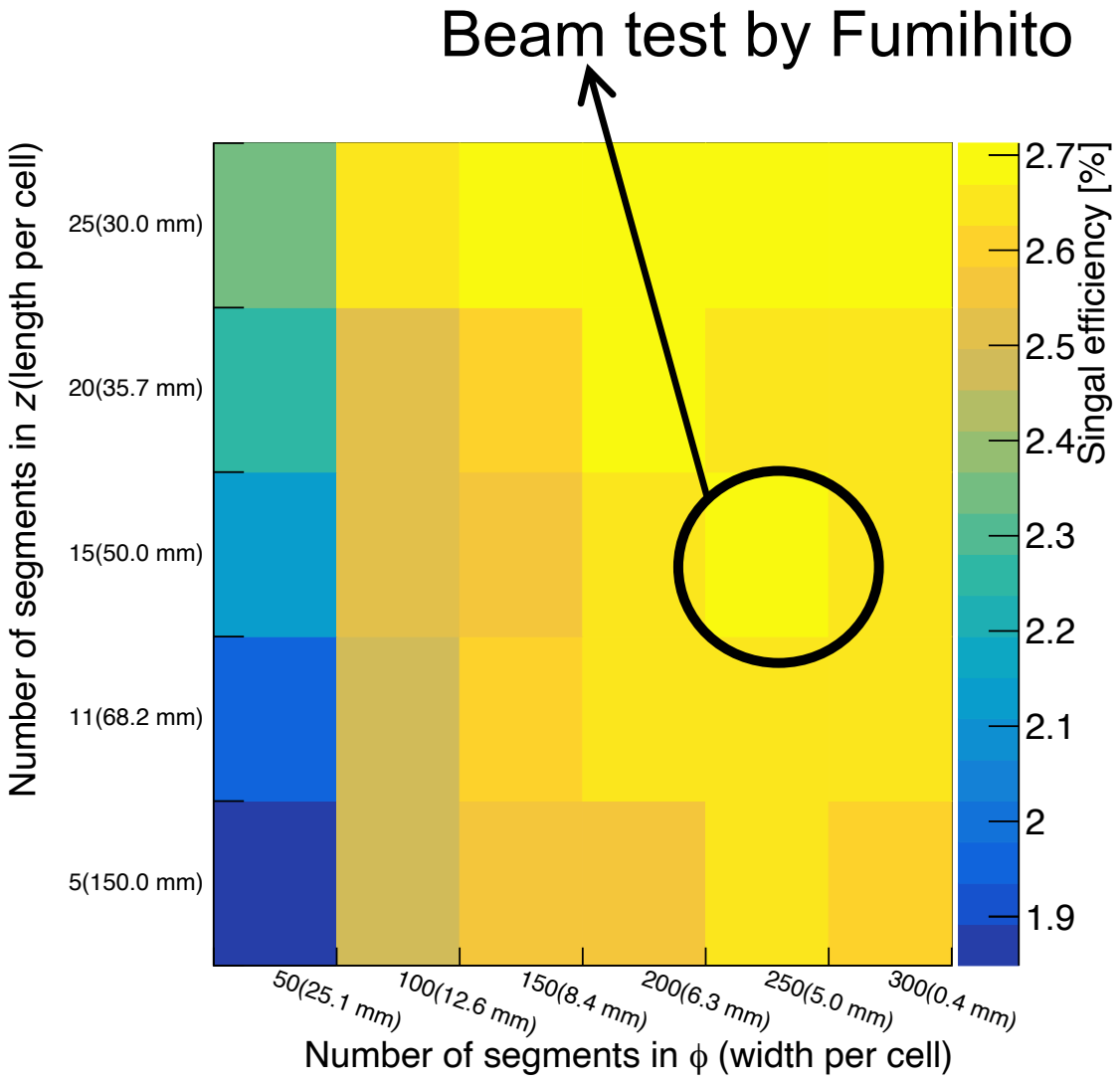


Cell size: 5mm × 50 mm
Events with track pair candidates: 7.7%
Events with $52.7\ \mathrm{MeV} < E_{rec} < 52.9\ \mathrm{MeV}$: 2.7 %

Comparison of different segmentation

- Investigated signal efficiency in several converter cell size
- Finer segment improves the efficiency
- efficiency depends strongly on ϕ segment

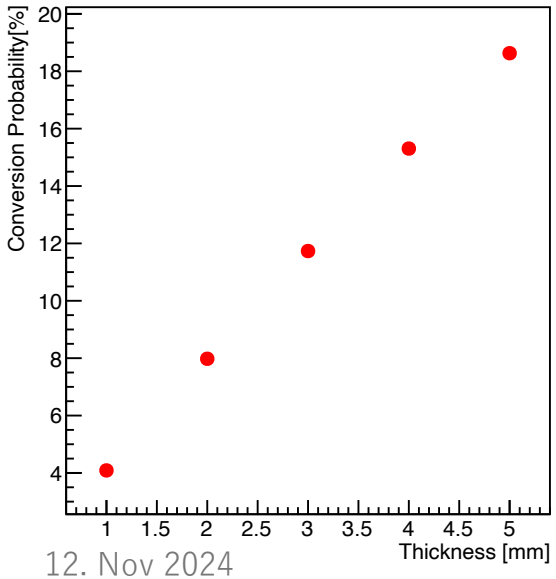




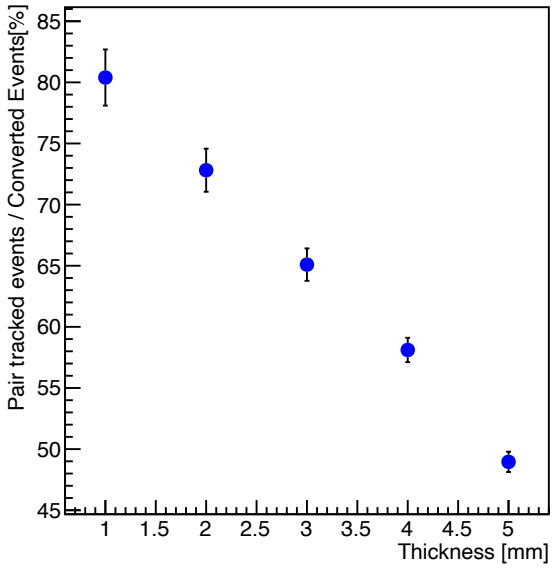
Converter Thickness

- Increase with thickness …Conversion probability
- Decrease with thickness
  - Events with trackable pair e^+e^- ...Low energy tracks cannot leave a thick converter
  - Events with good reconstructed energy. …Energy escape by bremsstrahlung

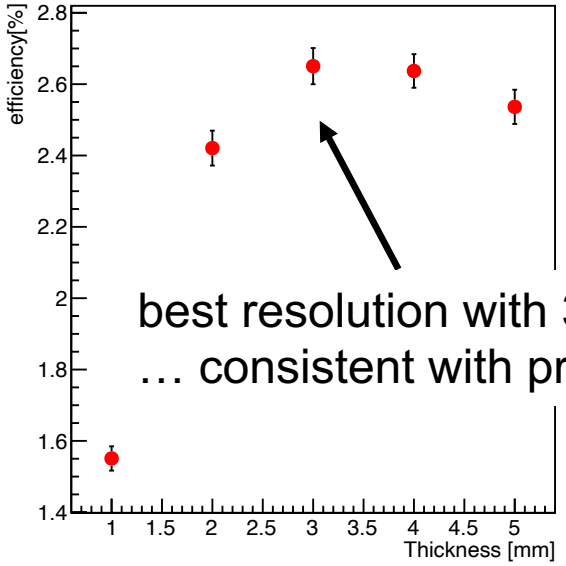
converted events /all events



events with trackable pair /converted events



events with $52.7\ \mathrm{MeV} < E_{rec} < 52.9\ MeV$ /all events



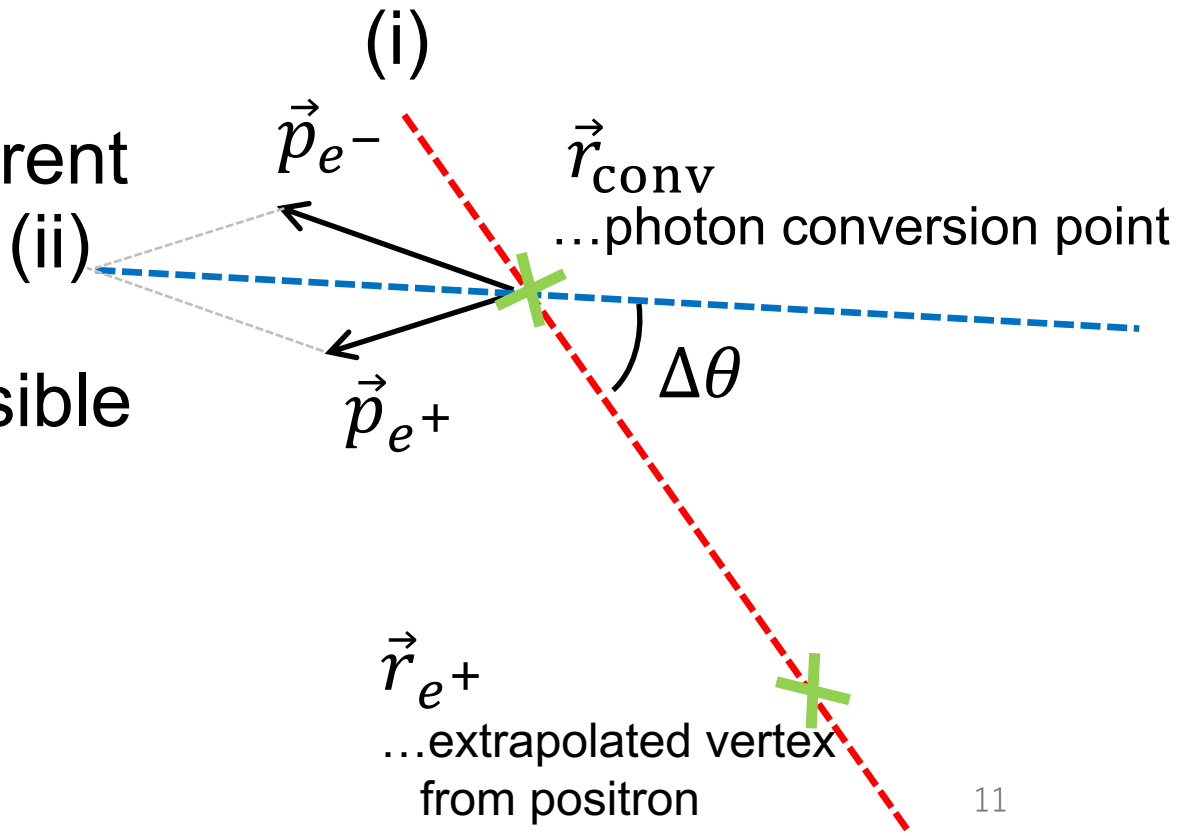
best resolution with 3mm thickness … consistent with previous studies

3. Angle measurement of γ

Possibility of angle cut

- The angle of the gamma can be estimated in two ways:
  (i) Direction of $\vec{r}_{\mathrm{conv}} - \vec{r}_{e^+}$ …used in MEG II
  (ii) Direction of $\vec{p}_{e^+} + \vec{p}_{e^-}$ …becomes possible with pair spectrometer

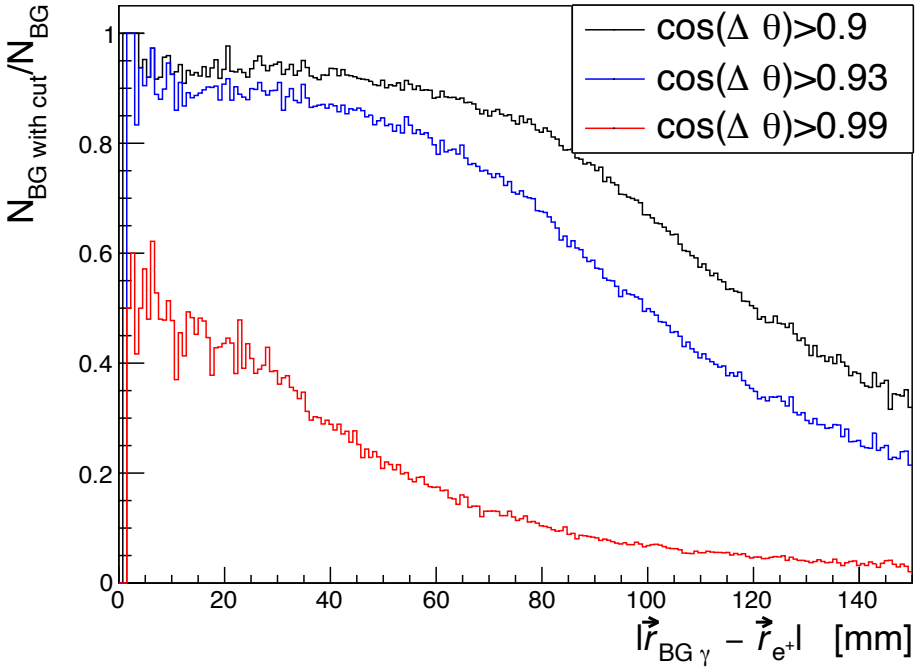
- (i) = (ii) for signal events
- (i) ≠ (ii) for BG events which have different emission point of γ and e^+



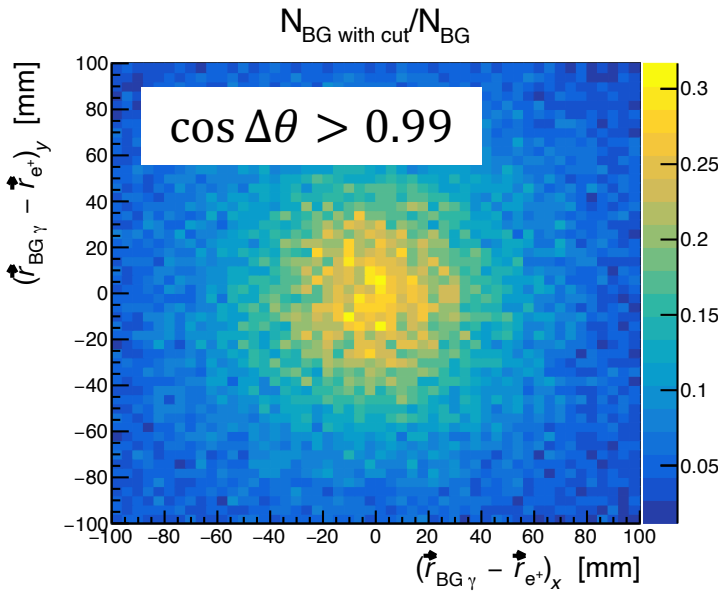
Background rejection will be possible by applying cut on $\Delta\theta$

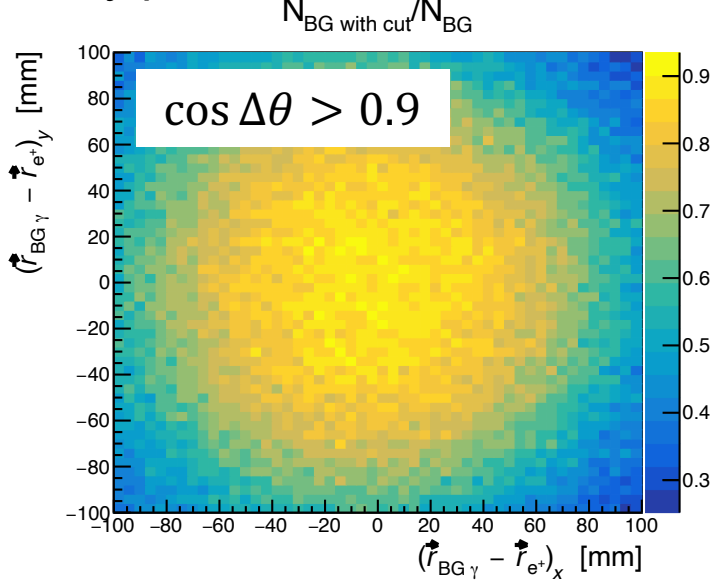
BG rejection with angle cut

- Injected RMD γ from various positions ($\vec{r}_{BG\,\gamma}$)
- Assuming that positron vertex is $\vec{r}_{e+} = (0,0,0)$, applied cut on $\cos\Delta\theta$
- Investigated rejection efficiency depending on the relative position of γ emission to positron vertex



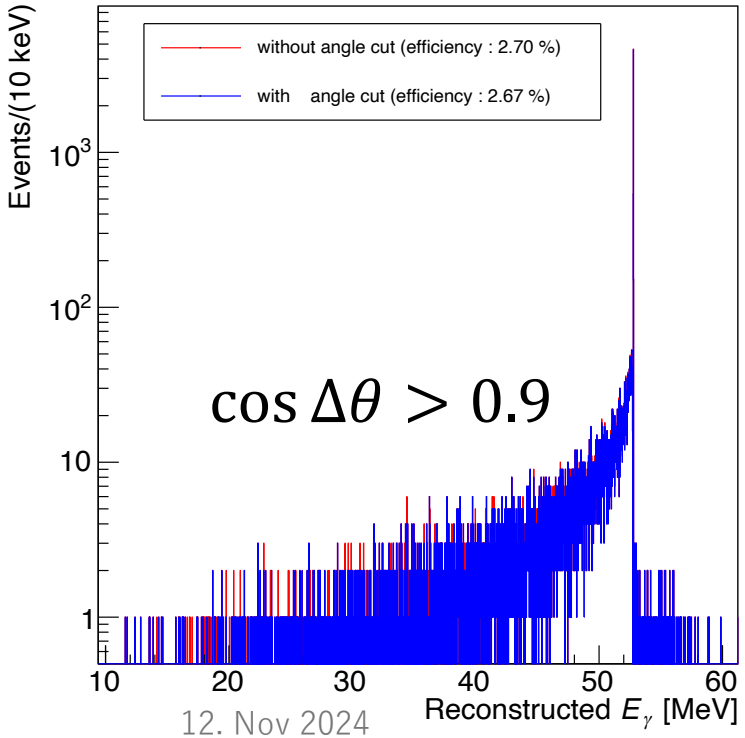
projection to the x-y plain

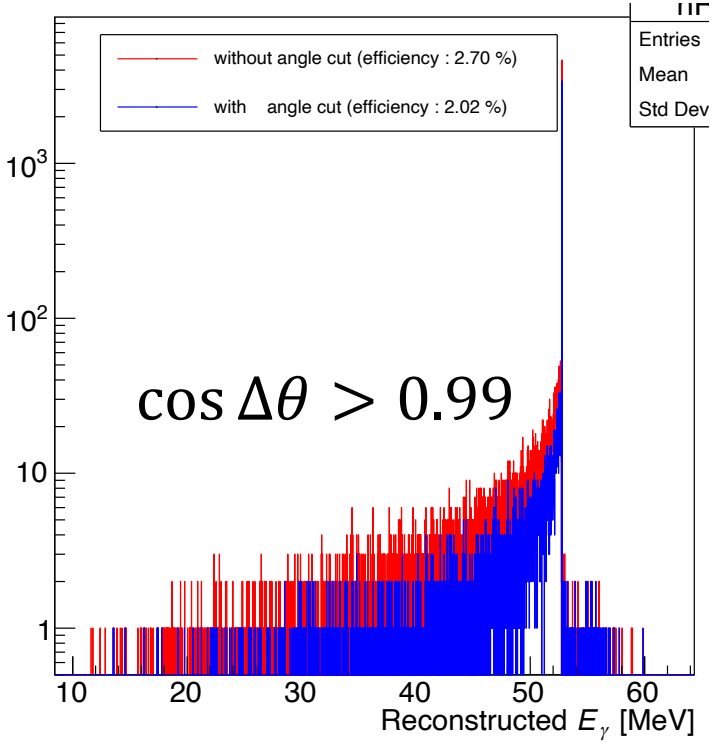


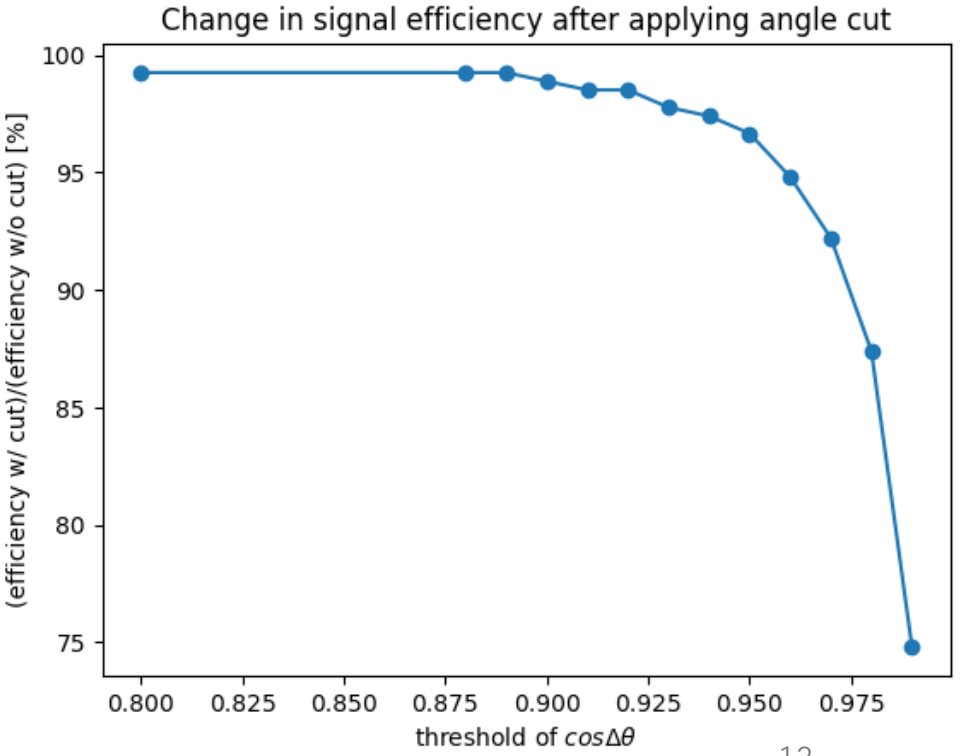


Effect of angle cut on the signal spectrum

- If we apply a too strict cut, signal efficiency will drop
  - Because of the limited angle resolution
  - When $\cos\Delta\theta$ threshold is set to 0.99, signal efficiency decreases to $\sim 75\ \%$
  - Almost 100 % until $\cos\Delta\theta = 0.9$



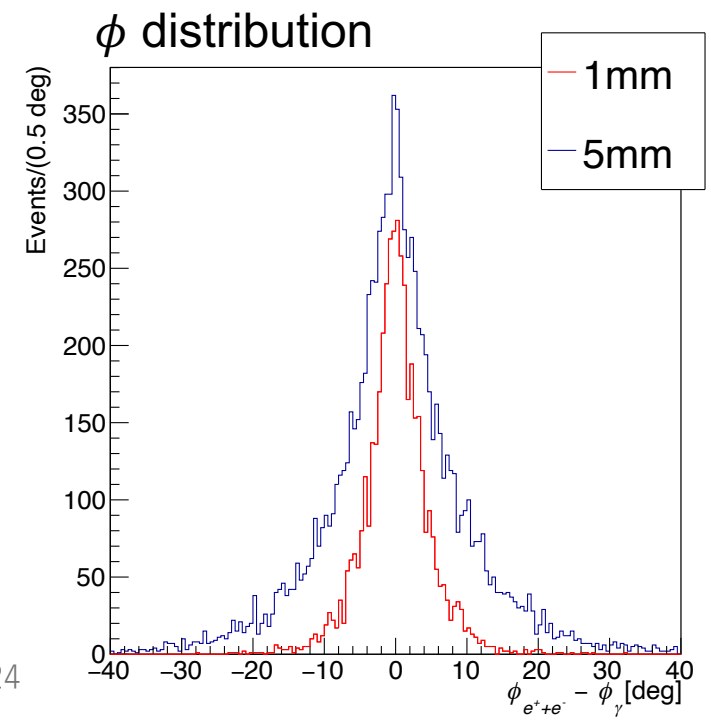


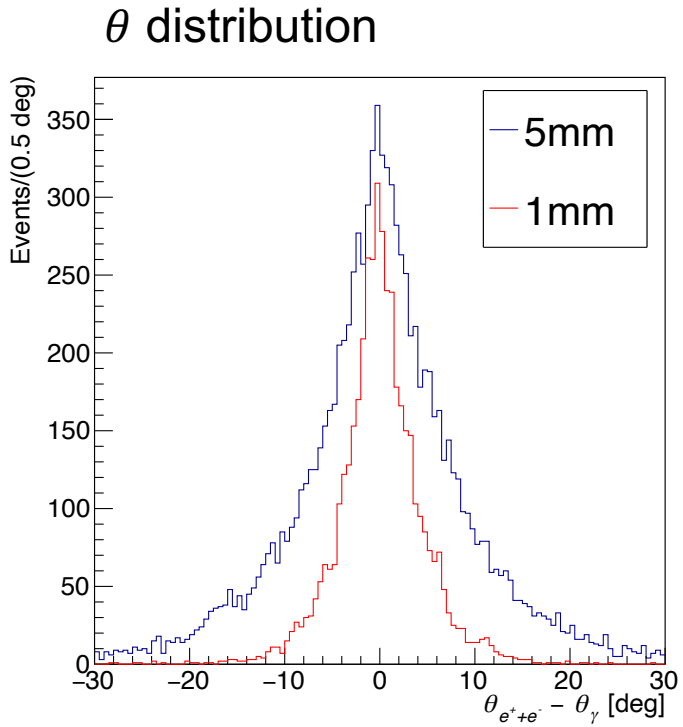


Angle resolution depending on thickness

- In terms of the signal efficiency, 3mm thickness had the best performance

- However, this may change if we think about angle measurement
  - The angle resolution is worsened with a thicker converter
  - Thinner converter may be better to maximize the sensitivity



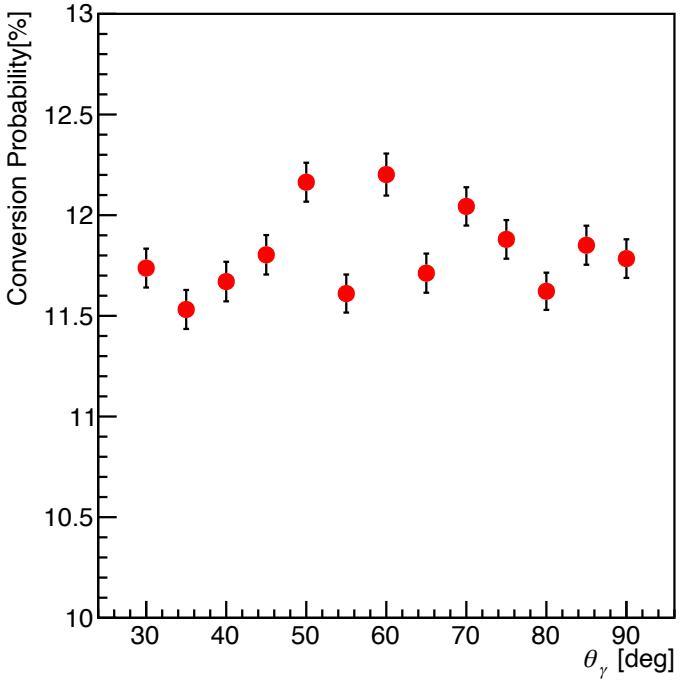


4.Efficiency dependence on θ_γ

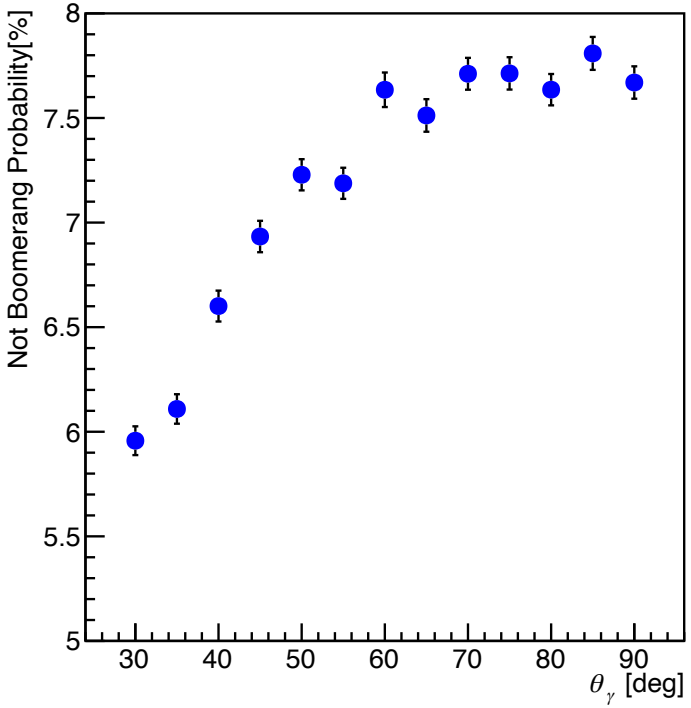
Efficiency depending on photon injection angle

- Simulation of signal gamma with various injection angle θ_γ
- This is mainly caused by higher boomerang probability in smaller θ_γ
  - Signal efficiency drops dramatically in small θ_γ
  - Conversion probability is almost constant

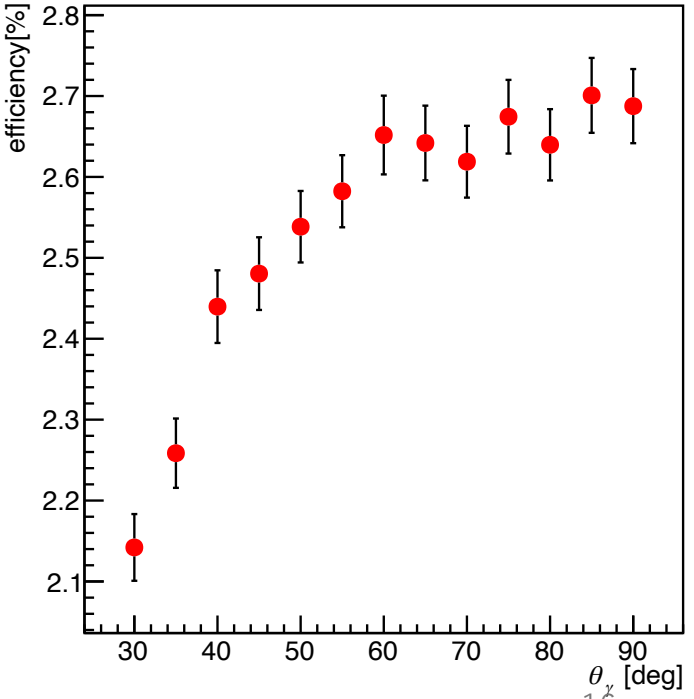
conversion probability



Events with no boomerang



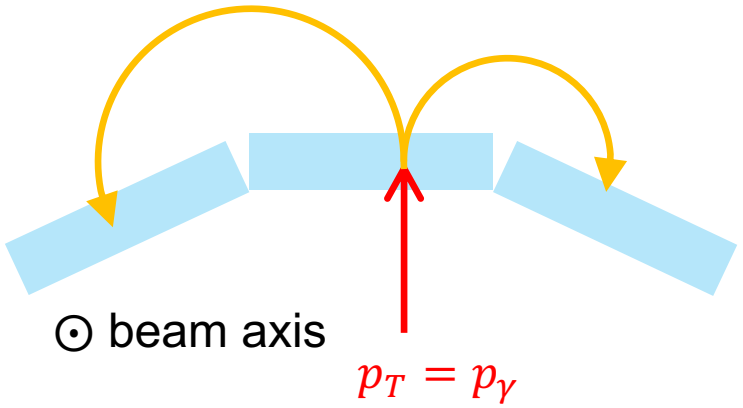
final efficiency



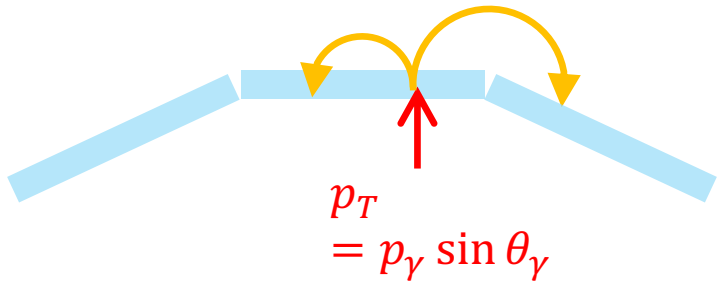
Boomerang event in outer cells

- Small θ_γ
  → Small transverse momentum,
  → Small curvature of helical trajectory
  → Higher probability of entering into the same cell

$\theta_\gamma = 90$ deg



$\theta_\gamma < 90$ deg



⇨ Finer segmentation in outer converter may be needed

Summary & Prospects

Converter thickness

- Should be thinner in larger $|z|$ region of the detector
- Need to consider following things:
  1. Maximization of the signal efficiency
     …3 mm is optimal in terms of maximizing the signal efficiency
  2. Angle resolution
     … thinner converter is better. Important for the reduction of the background.
  3. Timing & energy resolution
     …time resolution measured in the last beam test was
     36 ps(1.5 mm) and 27 ps(3.0 mm)

Converter segmentation

- $5\ \mathrm{mm} \times 50\ \mathrm{mm}$ / cell had almost maximum efficiency→ used in beam test
- In larger $|z|$, transverse momentum is small
  and thus higher probability of boomerang events
  → May need finer segmentation in this region