MEG II実験における陽電子タイミングカウンターの運用・較正手法の改善

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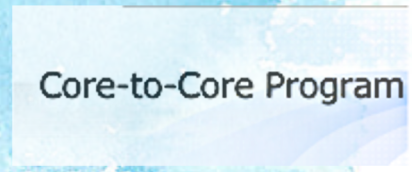

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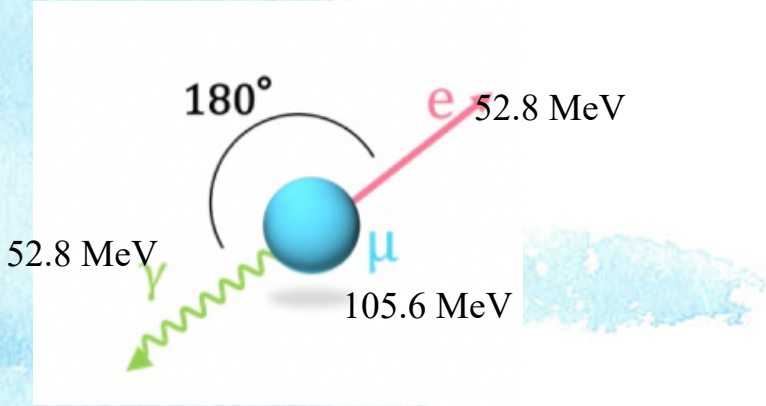
$\mu \rightarrow e\,\gamma$ process



- One of charged lepton flavor violating (cLFV) decays, which is forbidden in the Standard Model.

- Many of the new physics beyond the Standard Model (BSM) predict that the branching ratio is $\mathcal{O}$ (10^{-13}) – $\mathcal{O}(10^{-14}$) where an undiscovered particle in $\mathcal{O}(10)$ TeV mediates the process.

- Upper limit on the branching ratio was obtained by the MEG experiment: $\mathcal{B}(\mu \rightarrow e\,\gamma) < 4.2 \times 10^{-13}$ (90% C.L.)

MEG II experiment

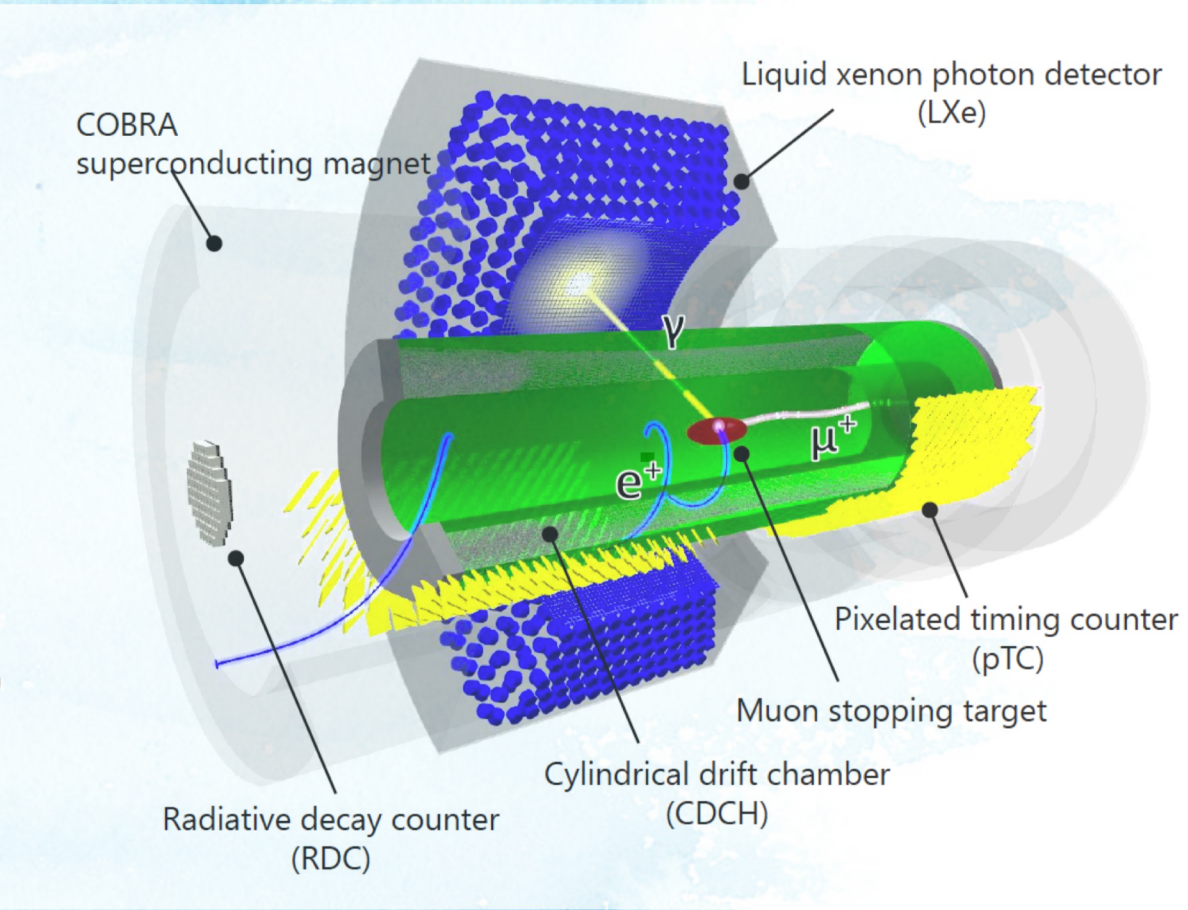
- Upgrade of the MEG experiment to aim for the most sensitive $\mu \rightarrow e\,\gamma$ search at:

$$\mathcal{B}(\mu \rightarrow e\,\gamma) \sim 6 \times 10^{-14}$$

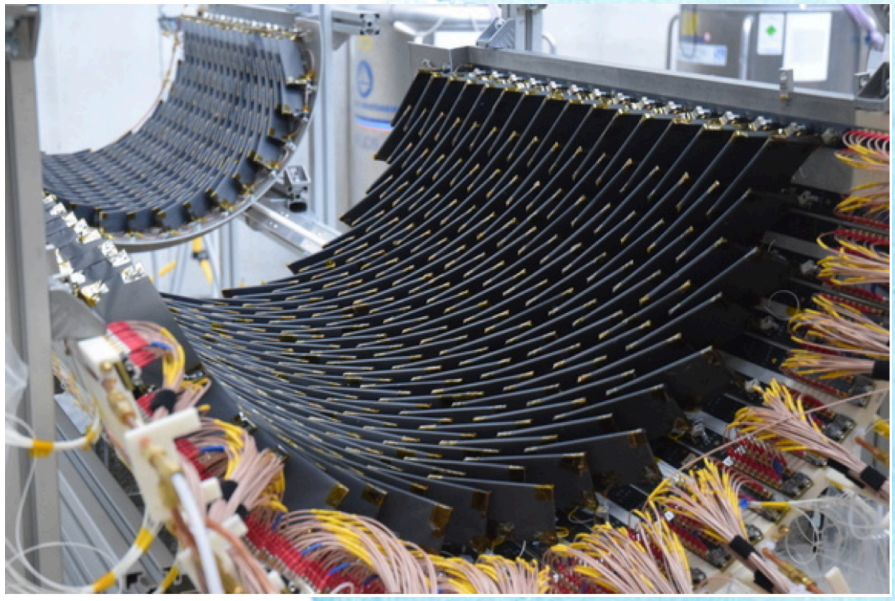
- μ : most intense μ^+ DC beam at Paul Scherrer Institute ($\sim 10^8\ \mu^+$/s)

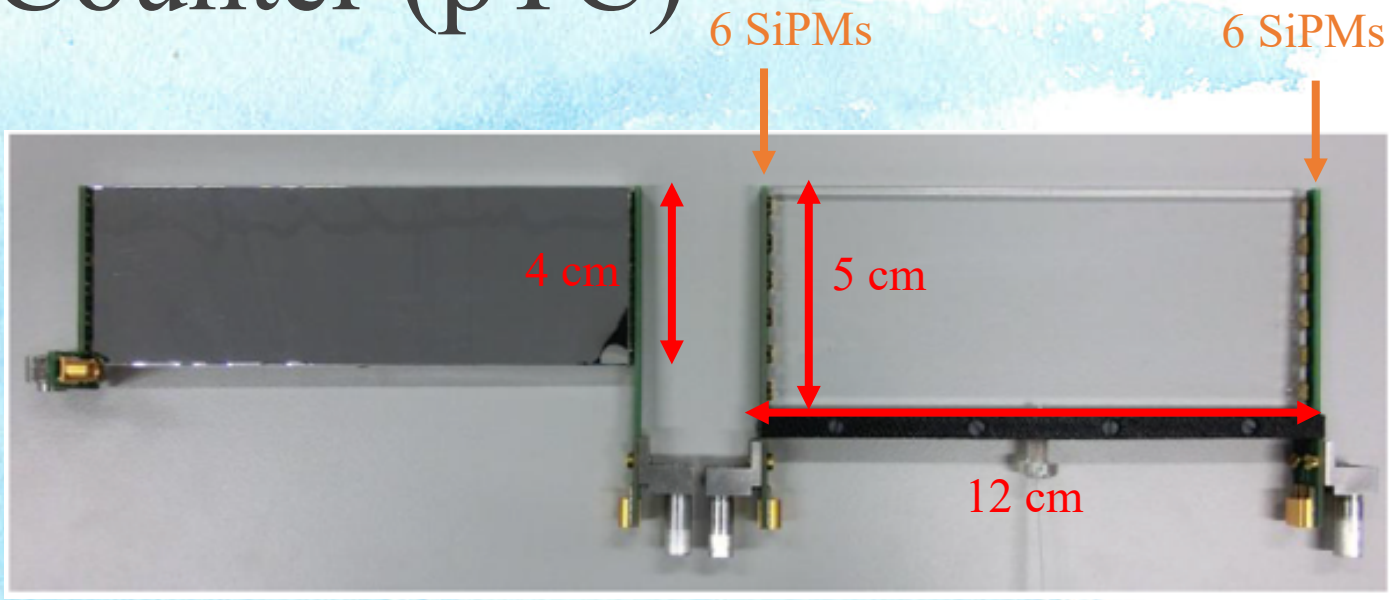
  γ : detected by LXe

  e^+ : detected by pTC & CDCH



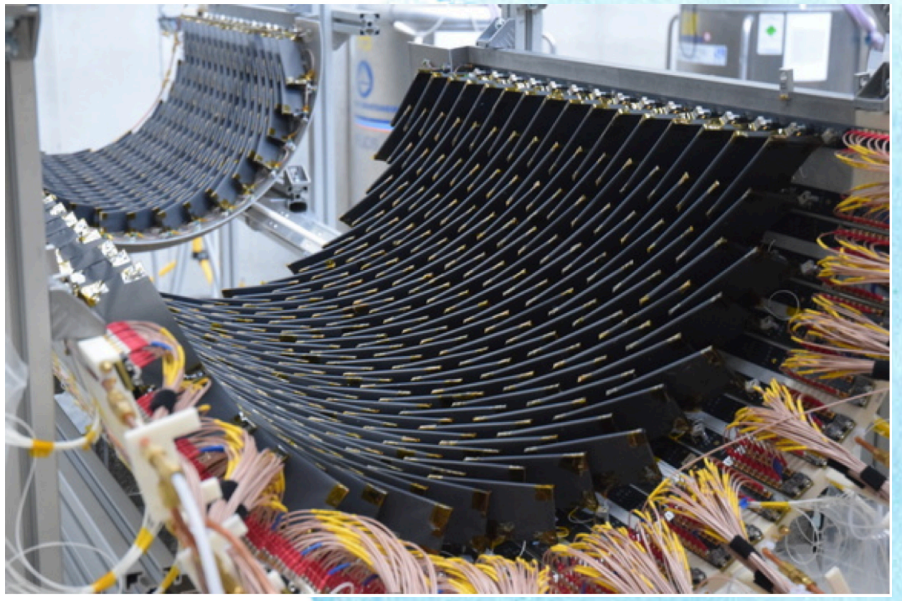
pixelated Timing Counter (pTC)

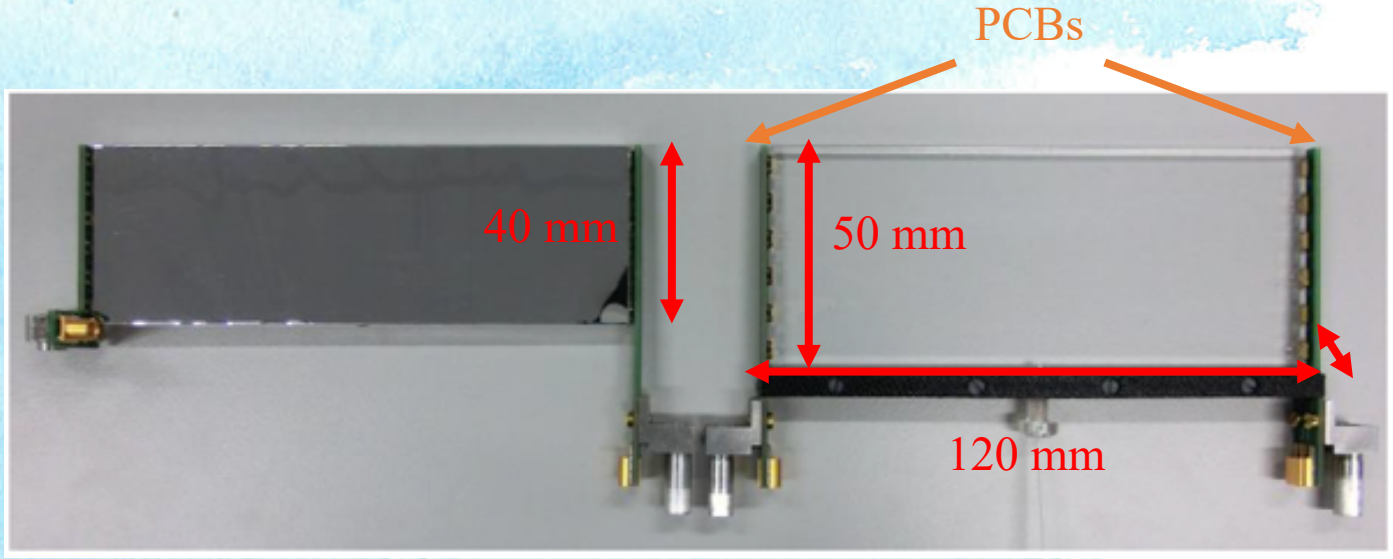




- A highly segmented (256 pixels ×2) scintillation detector on two semi-cylindrical super modules.
- Each pixel consists of a 12 cm × 4 cm (5 cm) × 5mm plastic scintillator read by series connection of 6 SiPMs attached to both side.

pixelated Timing Counter (pTC)

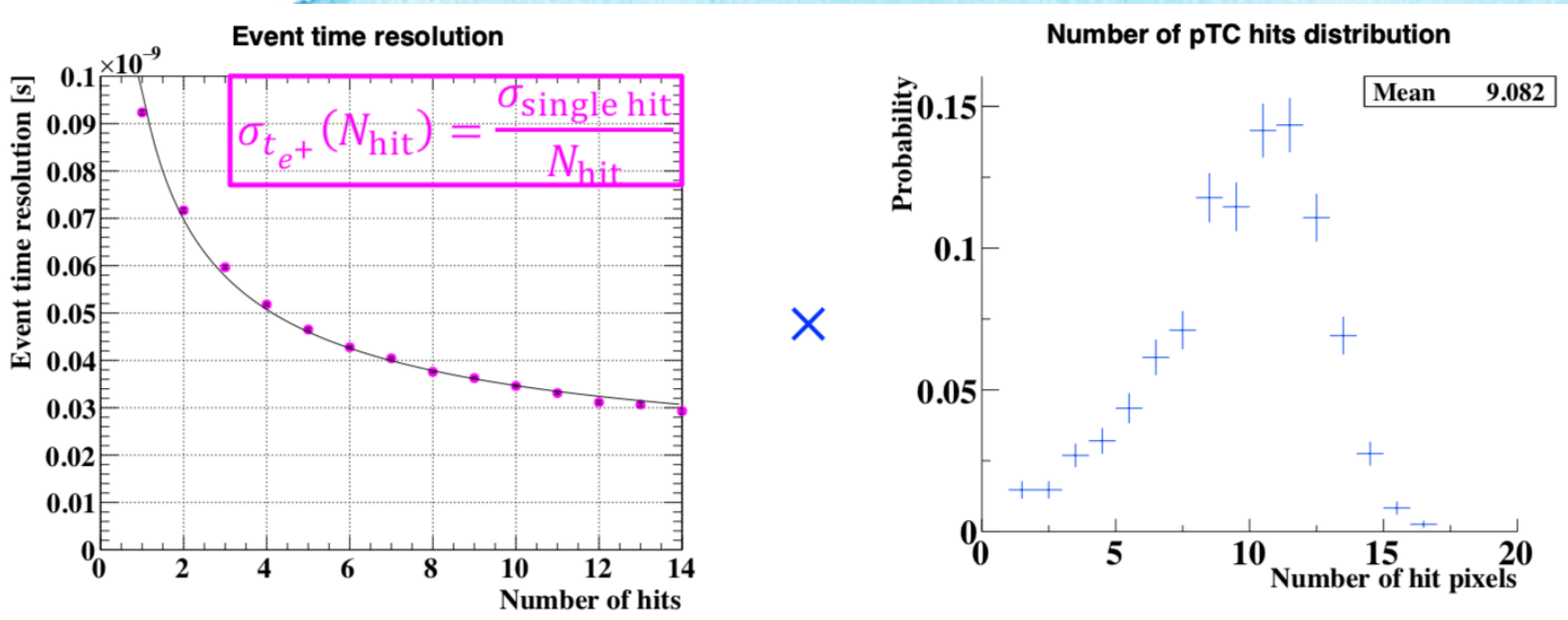




- Aims to achieve the precise decay time of muons and efficient trigger information on the positron side.
- Multiple hit scheme significantly improves the overall time resolution.

pixelated Timing Counter (pTC)

- Overall time resolution ~38 ps (expectation value) whereas 90-100 ps for a single hit.
- An average number of hits for signal e^{+} is ~9.



Improvement idea for pTC analysis

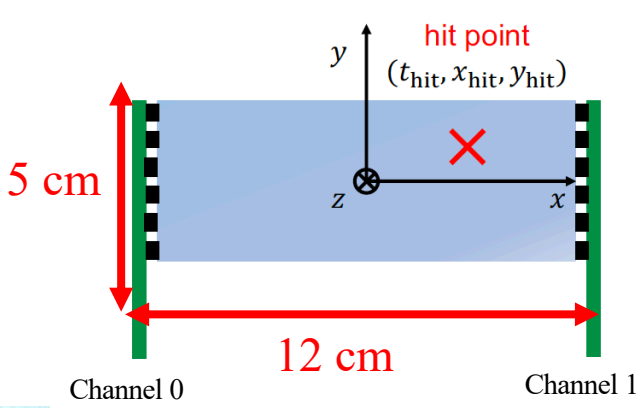
- In the original pTC analysis, the hit time in a single pixel is obtained as the simple mean of the constant fraction times of the 2 channels.

- In addition, the positron time is obtained as the simple mean of all the hit times in its track.

- For a better time reconstruction, appropriate weights from timing resolution which depend on each hit position and energy deposit are considered to be implemented.

- K.Yanai, “Research on Long-term Operation and Analysis Method of Positron Timing Counter in MEG II Experiment“. Master thesis. 2020.

Setup



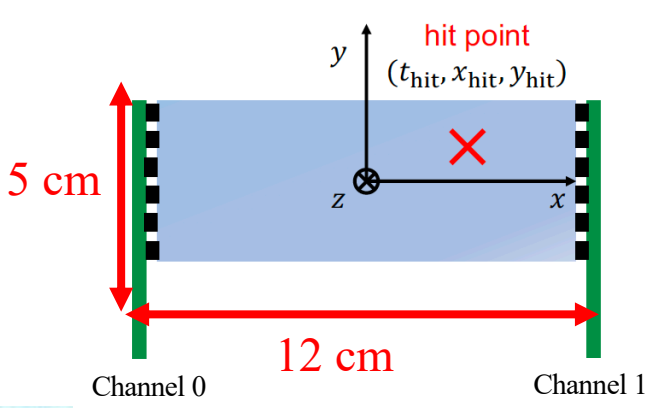
- Using 2019 commissioning data, where only a part of Upstream pTC was operated.

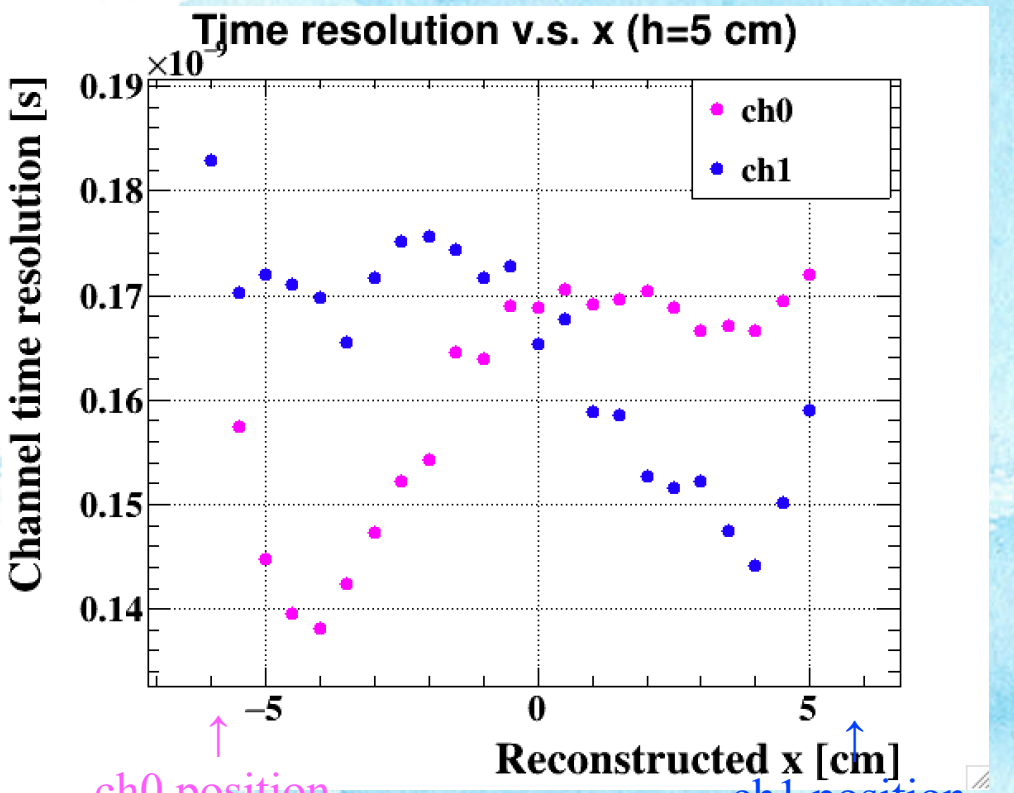
- 1.4 million Michel decay events.

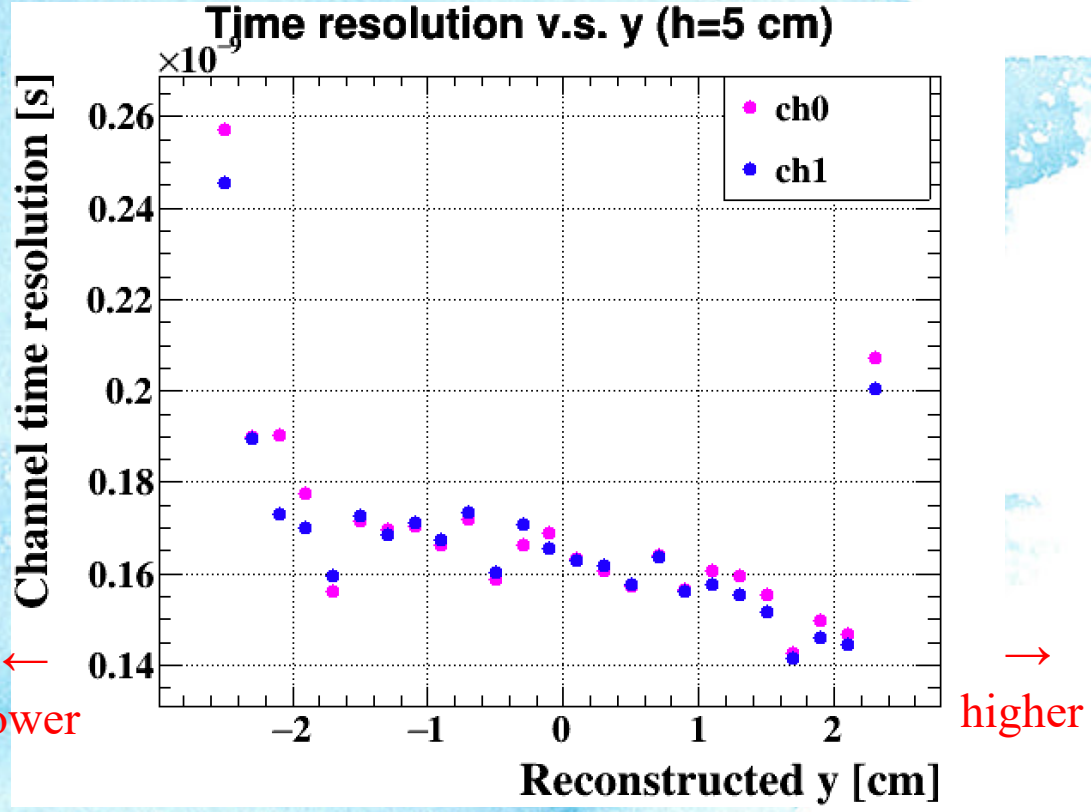
- 5mm bins for widths and heights [-6 < x < 6 cm, -2(.5) < y < 2 (.5) cm]
  0.05 MeV bins for energy deposit [0 < edep < 5 MeV]
- Hit position and reference time is reconstructed by TC self tracking.

Position dependence

- There is hit position dependence of timing resolution which is better in near side.

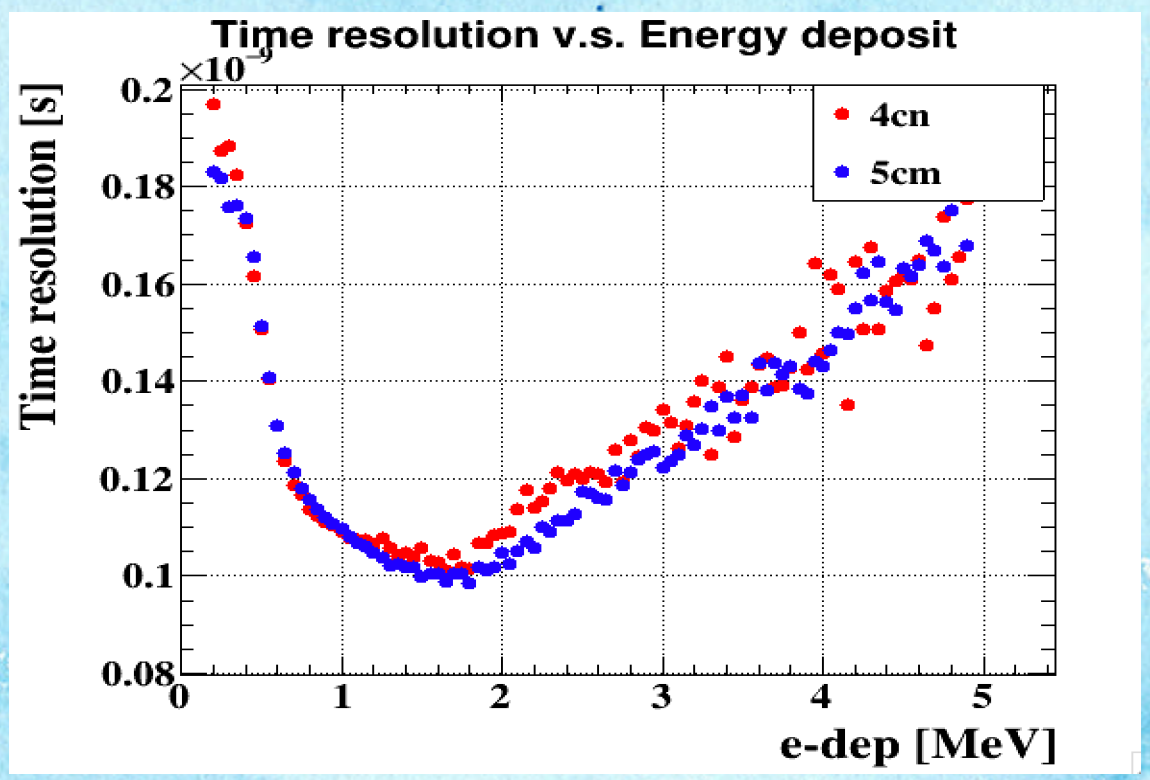






Energy deposit dependence

- There is also energy deposit dependence of timing resolution for single hit.



Formula

$$t_{\mathrm{single}} = \frac{\dfrac{t_{\mathrm{ch0}} - x_{hit}/v}{\sigma^2_{\mathrm{ch0}}} + \dfrac{t_{\mathrm{ch1}} + x_{hit}/v}{\sigma^2_{\mathrm{ch1}}}}{\dfrac{1}{\sigma^2_{\mathrm{ch0}}} + \dfrac{1}{\sigma^2_{\mathrm{ch1}}}}$$

Intra–pixel weighting at single counter for its 2 channels.

$$t_{\mathrm{multiple}} = \frac{\sum_{i_{\mathrm{hit}}} \dfrac{t^{i_{\mathrm{hit}}}_{\mathrm{single}} - (\mathrm{Time\ Of\ Flight})_{\,0\to i_{\mathrm{hit}}}}{\sigma^2_{i_{\mathrm{hit}}}}}{\sum_{i_{\mathrm{hit}}} \dfrac{1}{\sigma^2_{i_{\mathrm{hit}}}}}$$

Inter–pixel weighting for multiple hit in a track.

Result

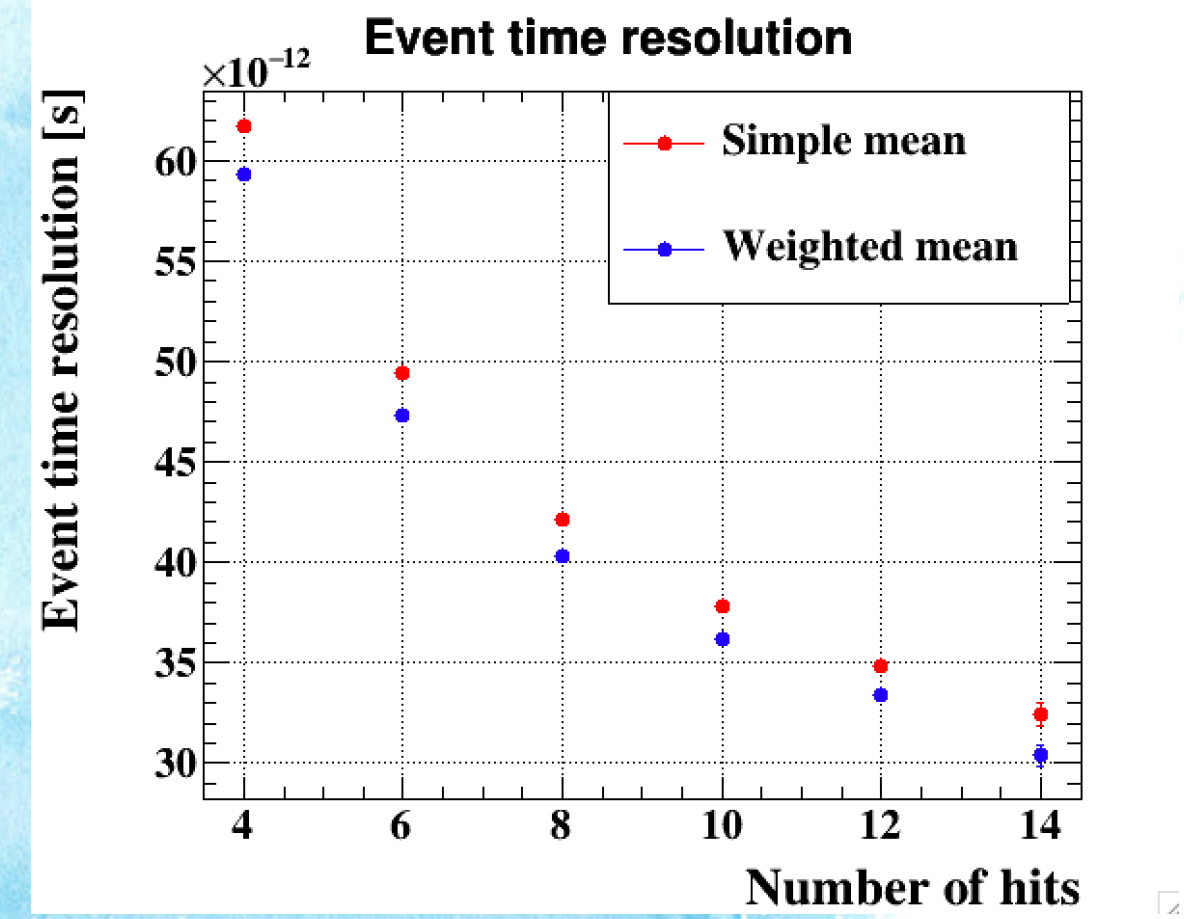
- Overall resolution :

Simple mean: 43.2 ps

↓

Weighted mean: 41.4 ps

~ 4.2% improve.



Summary & Prospect

- The pixelated Timing Counter (pTC) in the MEG II experiment aims to achieve the precise decay time of muons and efficient trigger information on the positron side.

- For more precise time reconstruction of pTC, weighting hit position and energy deposit dependence of time resolution had been suggested.

- The weighted mean method has been confirmed as effective.

- There are some challenges for implementation, such as creating a weight template with as small number of parameters as possible.

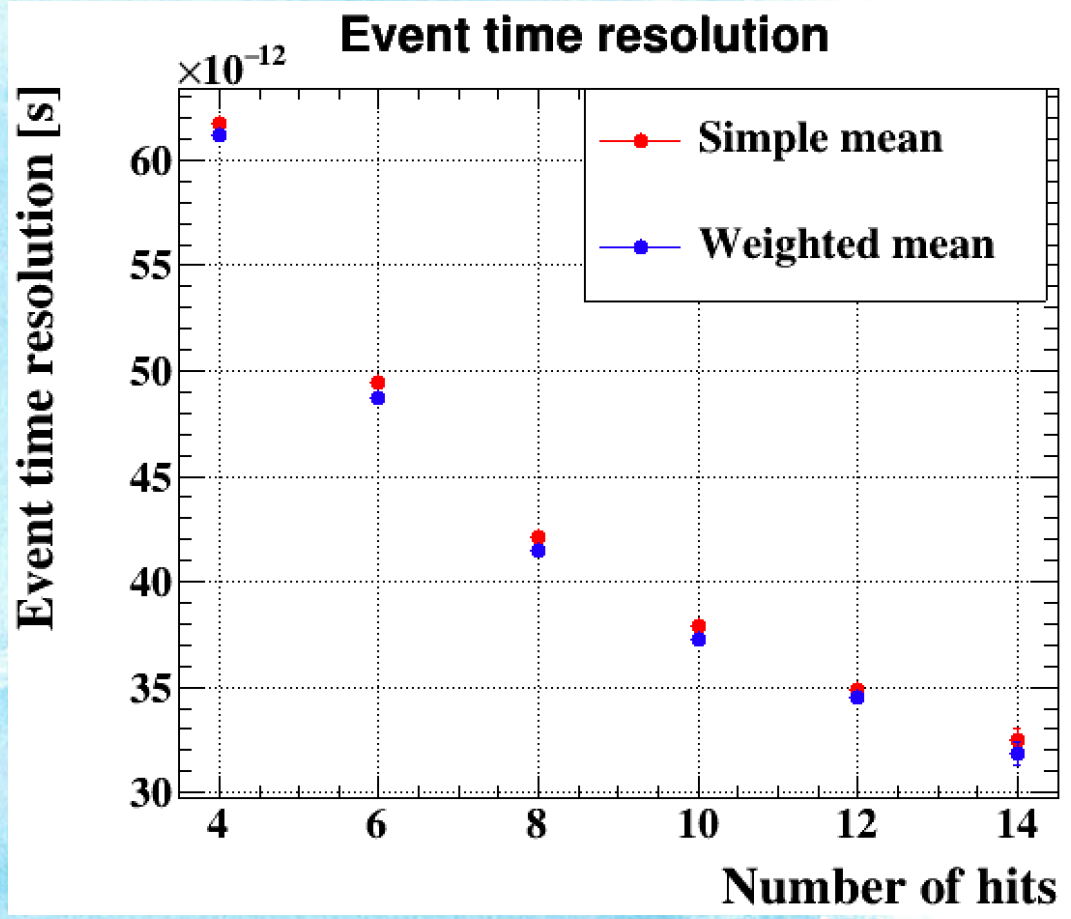
Back up

pTC operation in next 3 years engineering run

- The first chance for full channel operation.
- Operation and calibration methods have been basically developed.
- More refine is need for them.

Only hit position dependence weight

43.2 ps → 42.6 ps (~1.4% improve)



Previous Research for Run2017

Table 10.1: The effects of the new algorithms on the pTC resolution using the pER2017 data.

Algorithm	pTC resolution	Resolution improvement
Simple mean	~ 36.0 ps	
Energy deposit inter-pixel weight	~ 34.6 ps	~ 4.6 %
Hit position intra-pixel weight	~ 35.6 ps	~ 1.1 %
Hit position intra- and inter-pixel weight	~ 35.4 ps	~ 1.8 %

- K.Yanai, "Research on Long-term Operation and Analysis Method of Positron Timing Counter in MEG II Experiment". Master thesis. 2020.