The latest performance and refurbishment of the pixelated Timing Counter (pTC) in the MEG II physics data acquisition

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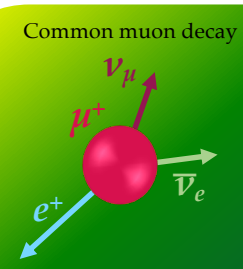
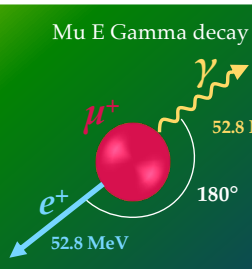
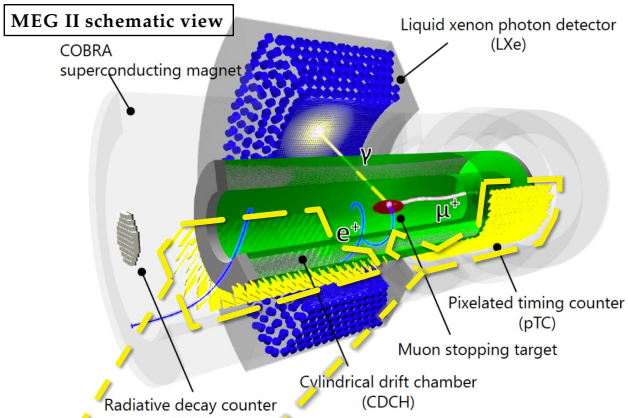
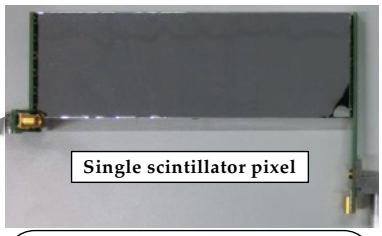
We have operated the MEG II pixelated timing counter maintaining its overall timing resolution at high level for precise timing measurement of positrons. Since its construction in 2017, the detector's pixels have shown degradation in their timing resolution with high-rate beam irradiation and components (plastic scintillators, silicon photo-multipliers (SiPMs)) aging over time. This work is dedicated to the refurbishing of the pixels using new 960 SiPMs. In 2024, we produced and mounted new 80 pixels onto the detector. The performance expectation based on laboratory testing and latest operational results are also shown.





- The most common muon decay mode: $\mu \to e\nu\nu$, so-called the Michel decay after Louis Michel, accounts for almost 100 % of muon decays.
- **The Mu E Gamma decay: $\mu \to e\gamma$**, is hypothetical and one of the simplest charged Lepton Flavor Violation processes which emits only a pair of positron and gamma ray at the same time and with the monochromatic energy.
- The MEG II experiment[1] has been running since 2021 to search for $\mu^+ \to e^+\gamma$ with the world's most intense DC anti-muon beam $> 10^7\ \mu^+/s$ at Paul Scherrer Institute (PSI), inheriting the MEG experiment which had set the current upper limit: $\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13}$.



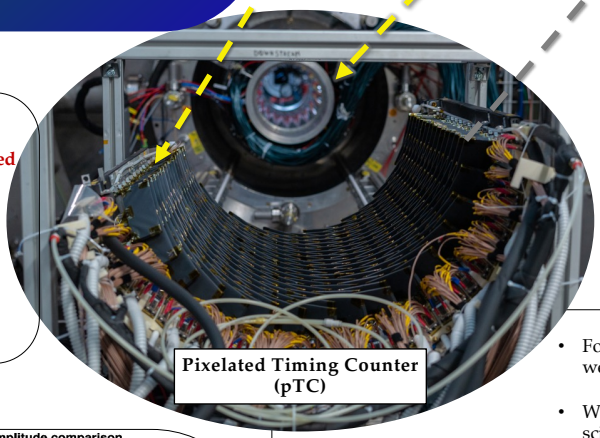


The individual pixel consists of a fast plastic scintillator tile BC-422 (12 cm width, 4 (or 5) cm height, 5 mm thickness) wrapped in a 32-μm thick ESR2 film and a Tedlar® black sheet.

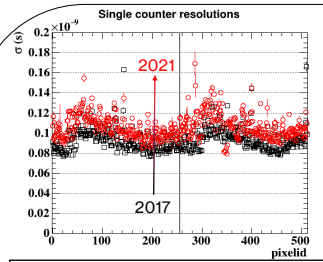
Readout by twin arrays of 6 series-connected SiPMs (3 × 3 mm², ASD-NUV3S-P).

pTC features

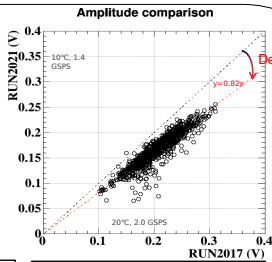
- Provides precise timing information of e^+.
- With a brand-new design from MEG as **pixelated with 512 fast plastic scintillator** tiles.
- Exploiting multiple-hits events, the overall uncertainty **improves with** $\sigma_{single}/\sqrt{N_{hit}}$.
- Readout by **twin arrays** of **6 series-connected SiPMs,** glued on opposite sides of each pixel.



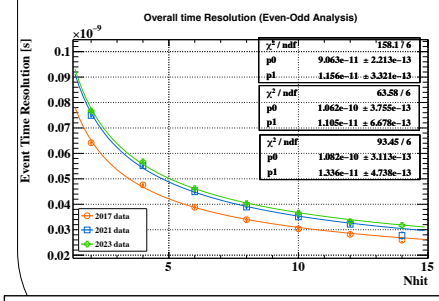
Pixel degradation



Resolution shift of each pixel



Light yield 2017 v.s 2021

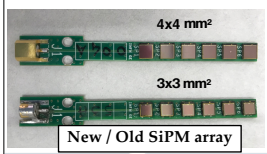


Number of hit v.s pTC overall time resolution
2017 (orange), 2021 (blue), 2023 (green)

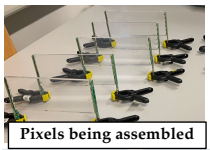
- ❑ The performances were evaluated by Michel e^+.
- ➢ **Deterioration in timing resolution (~ 19 %) and light yield (~ 18 %)** has been observed under the high-rate μ^+ beam.
- ➢ Dark current increment of the pixels with the radiation damage was also investigated[2].

Pixel refurbishment

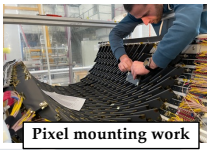
- For a still long-term operation towards 2026, we planned to renovate the pTC.
- We produced **new 94 pixels** with spare scintillators & **new 1128 SiPMs with a larger sensitive area 4 × 4 mm²** (ASD-NUV4S-P).



New / Old SiPM array



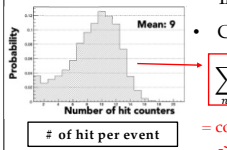
Pixels being assembled



Pixel mounting work

Soldering 6 SiPMs into series connection → SiPM array test of I-V & light yield → Pixel assembly → Pixel test of timing resolution → Pixel mounting on pTC

- In 2024 maintenance period, we **exchanged 80 pixels on pTC.**
- Contribution of individual pixel exchange was evaluated as:



# of hit per event

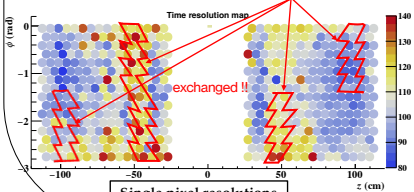
$$\sum_n f_n \sqrt{r_n^i\left(1-\frac{1-a_i^2}{n}\right)+\left(1-r_n^i\right)}\,\frac{\hat{\sigma}}{\sqrt{n}}$$

= contribution to overall resolution
-> **[0.03, 0.3] % per single counter**

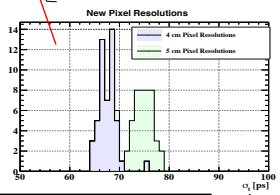
$a_i = \frac{\sigma_i}{\hat{\sigma}}$ (σ_i: time resolution of i-th pixel)

$r_n^i = \frac{\#\text{ of } n \text{ hits events for } i\text{-th pixel}}{\#\text{ of } n \text{ hits events}}$

$f_n = \frac{\#\text{ of } n \text{ hits events}}{\#\text{ of all the events}}$



Single pixel resolutions in 2023 operation



New pixel resolutions @ Labtest

References: [1] MEG II Collaboration. *Eur. Phys. J. C* 84, 190 (2024) [2] M. Usami et al., *Nucl. Instrum. Methods* A 936 (2019) 572–573