Operational results with the pixelated Time Detector (pTC) of MEGII experiment during the first year of physics data taking

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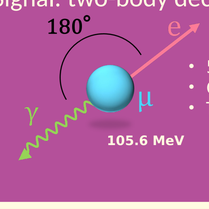
Abstract: The experiment MEG II is designed to improve by an order of magnitude the current sensitivity 4.2×10^{-13} reached by MEG on the search for $\mu^+\to e^+\gamma$ decay. A crucial part of MEG II is a pixelated Timing Counter (pTC) developed to measure the positron timing with high accuracy. The pTC is segmented into 512 scintillation counters. Since the positron time is measured independently by several counters (~9 on average), the timing resolution improves significantly compared to single counter resolution. We constructed and installed the pTC and performed commissioning runs at piE5 beam line at PSI starting from 2015. 2021 was the first year of physics data taking. Timing resolution was excellent at ~38 ps since the start, in the following years some problems emerged: SiPM detachment, noise, radiation damage. Those issues are discussed and the steps to solve or mitigate them are detailed. The possibility of an partial upgrade is presented.

Motivation

In MEG II experiment we search for the charged lepton flavor violation, $\mu^+ \to e^+\gamma$ decay, which would be evidence of BSM physics [1].

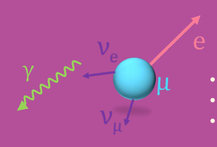
Precise measurement of emission angle, energy, and trelative iming of positron and γ are essential.

Signal: two-body decay



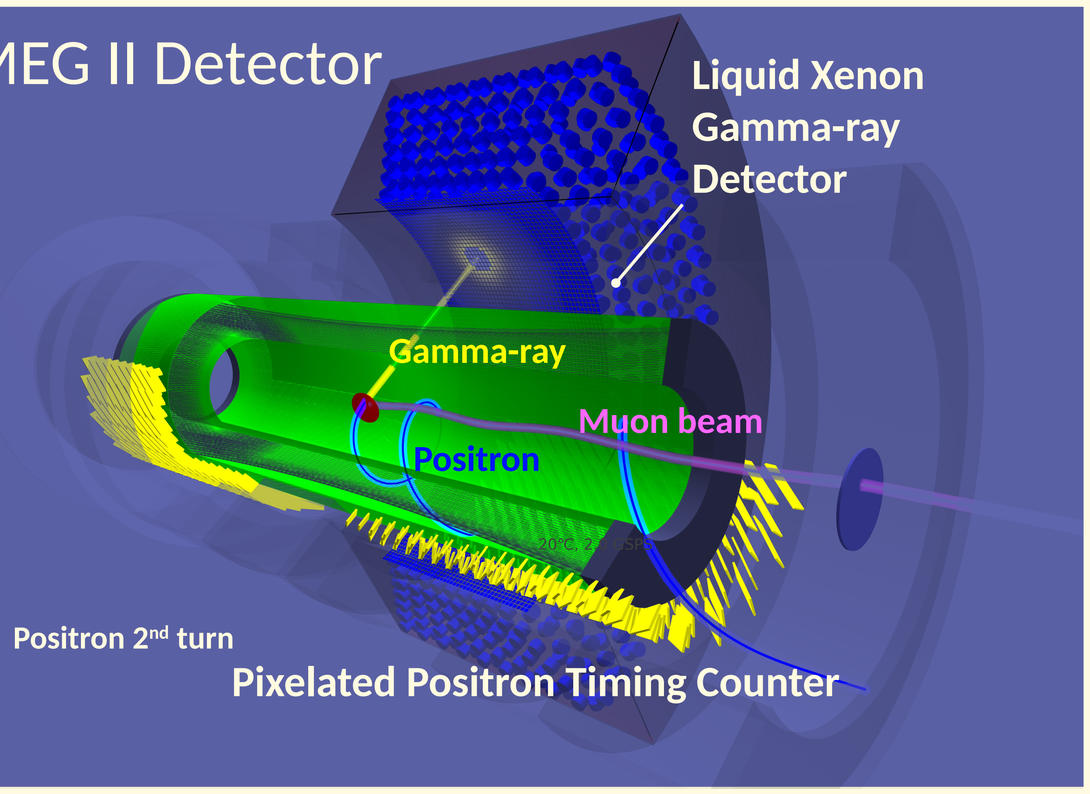
- 52.83 MeV
- Opening Angle 180°
- Time Coincident

Dominant BG: accidental

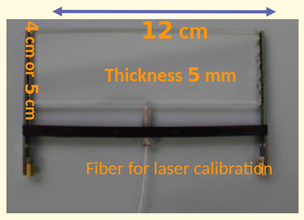


- <52.83 MeV
- Any angle
- Time Random

MEG II Detector



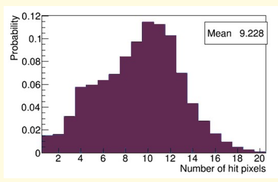
Pixelated Timing Counter (pTC)



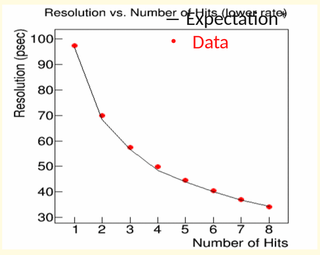
Fast Plastic Scintillator
BC422
Rise time 0.35 ns

6 SiPMs in series
AdvanSiD
3x3 mm²
50x50um² cells [2]

# of hits for signal e^+ (MC)



Resolution vs. Number of Hits (Data [3])



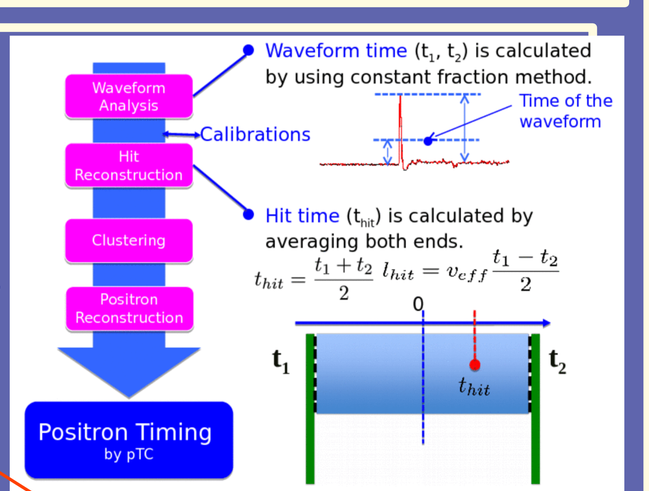
Physics Run 2021

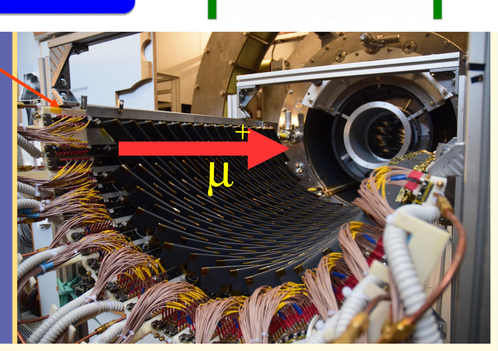
All counters (512) installed and tested in MEG II site, πE5 beam line at PSI.

- **Beam:** DC surface muon beam stopped at
- target (~5x10⁷ μ/s),.
- **All Detectors installed:** magnet, target, pTC,
- drift chambers, Lxe detcctor, RDC
- **Electronics:** Amplifier (x100), Shaper, Digitizer (WaveDAQ) at 1.4 GHz for pTC [4].

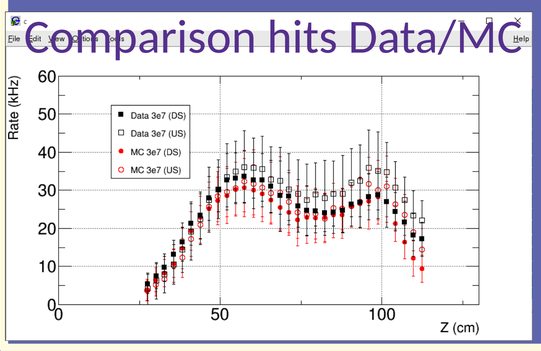
Trigger: $\mu^+\to e^+\gamma$ physics trigger,z

pTC



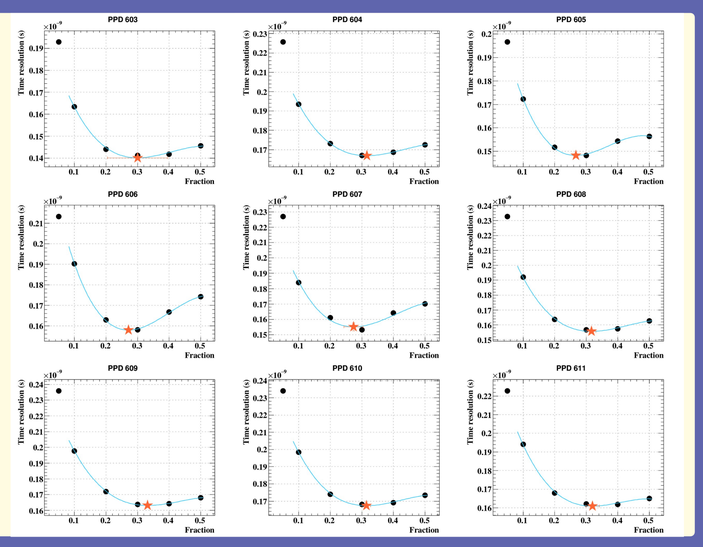


Comparison hits Data/MC



Constant Fraction Discriminator

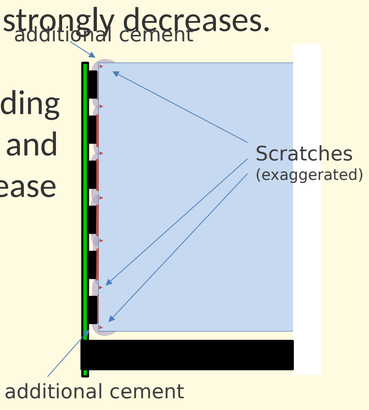
Scan CFD fraction and search for the minimal fraction optimizing time resolution.

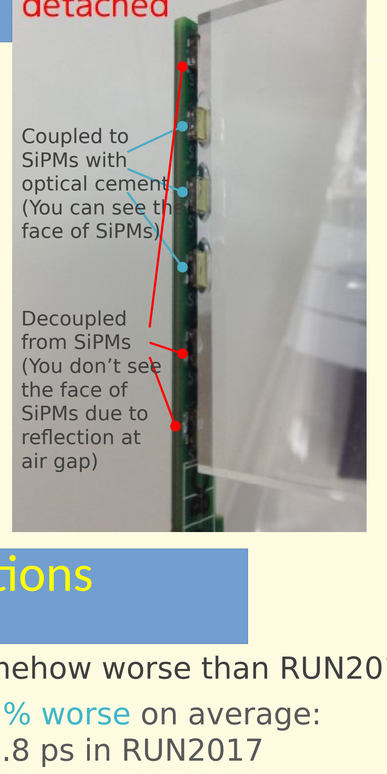


SiPM detachment

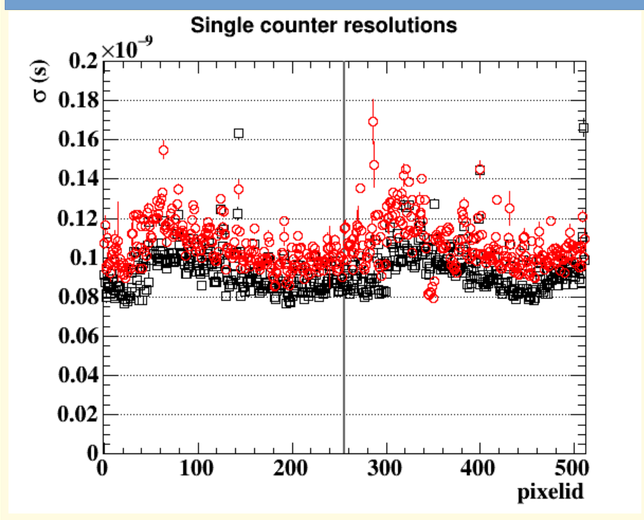
Over time some SiPMs loose proper optical contact with the scintillator (detachment).
For those SiPM the signal strongly decreases.

They can be recovered adding additional optical cement and scratching the surface to ease the grip of the glue





Comparison of pixel timing resolutions



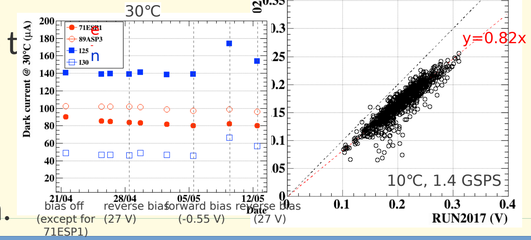
Somehow worse than RUN2017

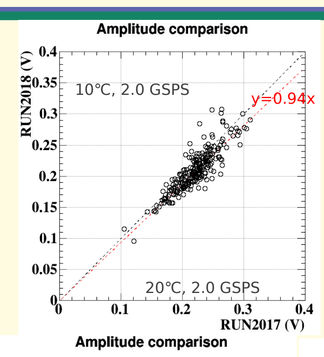
- 11% worse on average:
  93.8 ps in RUN2017
  104.5 ps in RUN2021
- Noise reduction by exchanging digitizer boards gave improvement
- Some worsening by different sampling frequency (2.0 vs. 1.4 GSPS).
- Bad resolution outliers due to SiPM detachments.

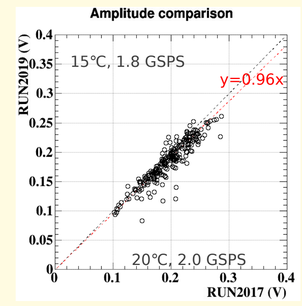
Resolution degradation

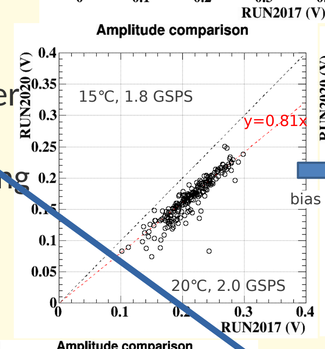
The signal amplitudes (MPV of Landau for Michel events) have degraded over the years for all channels.
Time resolution of the single channel is inversely proportional to the signal amplitude.
Different causes are possible and under investigation: SiPM radiation damage, scintillator aging, shift in SiPM operating voltage.

Irradiated SiPMs with electrons and neutrons showed dark current increase. They have been to annealed at 30° for 2 weeks.
Some recovery (up t 11%) for electron irradiation, no improvements for neutron irradiation.

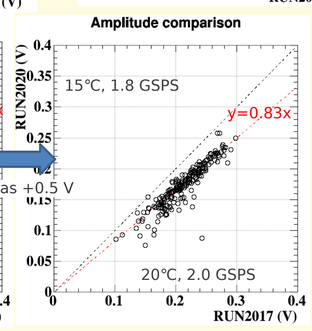


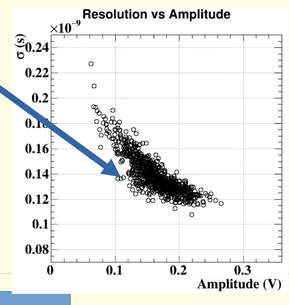






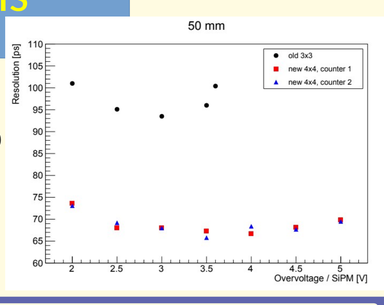
bias +0.5 V





Upgrade with improved time resolutions

Rather than producing spare counters to replace those broken or with degraded time resolution we plan to equip ~100 available scintillator plates with 4x4 mm² SiPM.
In preliminary tests time resolution improves from ~90 ps to ~60 ps consistent with expectations from area ratio.



Summary

- The full MEGII was installed and tested in PiE5 at PSI.
- MC/Data comparison hit rate for all counters.
- Optimization of CFD fraction
- Time resolution somehow degraded by noise, detachment and radiation damage
- Time resolution improved by a factor of 2 with respect to MEG.

References
[1] M. Cannoni et al., Phys. Rev. D 88, 075005 (2013).
[2] P. W. Cattaneo et al., IEEE Trans. Nucl. Sci. 61 (5) 2657-2666. arXiv:1402.1404 (2014) .
[3] M. Nishimura et al, PoS PhotoDet2015 011 (2016) .
[4] S. Ritt et al., NIM-A, 623, pp. 486 – 488, Nov. (2010).

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