Calibration tools of the MEG-II CDCH

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Introduction

- the MEG-II experiment [1] searches for the previously unobserved charged lepton flavour violating decay $\mu^+ \to e^+\gamma$
- the Standard Model with massive neutrinos allows for BR$(\mu^+ \to e^+\gamma) \approx 10^{-55}$. SM extensions predict BR$(\mu^+ \to e^+\gamma)$ attainable experimentally
- MEG-II, located at PSI (Switzerland) is an upgrade of the MEG experiment which set the lowest sensitivity on this decay with a 90% C.L. BR upper limit of 5×10^{-14} in 2016 [2]. MEG-II aims at 1 order of magnitude improvement
- **A two-body decay of the muon at rest:** $E_{e^+} = E_\gamma = E_{\mu^+}/2 = 52.8$ MeV, $\Delta t_{e\gamma} = 0$ s and $\theta_{e\gamma} = 180$ degrees

Figure 1: The $\mu^+ \to e^+\gamma$ decay

The Positron Spectrometer

- Three main elements: the COnstant Bending RAdius (COBRA) magnet and the Cylindrical Drift CHamber (CDCH) for reconstructing the positron momentum and its vertex on the target and the Timing Counter (TC) for positron timing and triggering.
- COBRA's non-uniform magnetic field is tuned in order to have a track bending radius dependent only on the momentum. The CDCH is a unique volume with 9 concentric layers of 192 drift cells defined by ~12k wires.

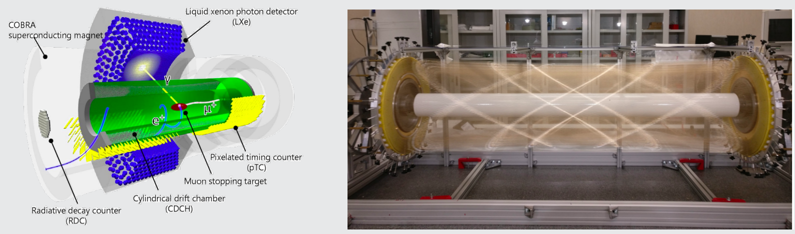

Figure 2: (Left) Design of the experiment. (Right) The Cylindrical Drift Chamber.

Calibration tools

- CDCH performances can be estimated:
  - through a fit of the Michel decay $(\mu^+ \to e^+\nu_e\overline{\nu_\mu})$ spectrum edge; the edge of the spectrum at 52.8 MeV is fitted considering the theoretical Michel spectrum, an error function for the CDCH acceptance and a Gaussian resolution:

$$\boxed{(\textbf{THEORETICAL MICHEL} \times \textbf{ACCEPTANCE}) \circledast \textbf{RESOLUTION}}$$

  - through Mott-scattered positrons: an e^+ beam is tuned to $\mathbf{p} = 52$ MeV and is sent towards the MEG-II target where it undergoes the well-known Mott scattering process
  - cosmic rays: straight μ tracks
  - straight and curved e^+ and e^- tracks from External Pair Conversion (EPC) (see next sections)

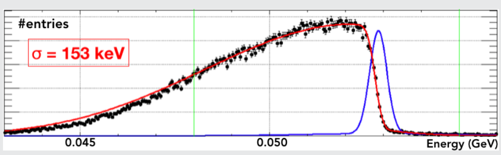

Figure 3: Example of Michel edge fit. Fit function is shown in red and Gaussian resolution with fitted parameters in blue. 2021 data with a muon beam rate of $3 \times 10^7 \mu^+$/s: resolution $= 153 \pm 5$ keV. Calibration optimization still in progress.

Straight tracks from EPC

- a novel idea to evaluate the basic parameters of the CDCH (active cells, working channels, gain alignment) is to make use of the 17.6 MeV Lithium γ line.
- usually a calibration tool for the γ calorimeter, this line is obtained sending protons from a Cockcroft–Walton beam line on a lithium target (440 keV resonance)
- with COBRA magnetic field off and through External Pair Conversion, it leads to ~ 9 MeV e^+ and e^- straight tracks into the CDCH

Curved tracks from EPC

- these EPC pairs can also be used with COBRA magnetic field on (and tuned for 9 MeV particles) to extract the resolutions of the detector: this method is able to saturate the DAQ (up to 100 Hz) and doesn't require the use of the main muon beam

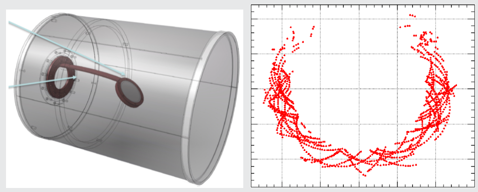

Figure 4: (Left) Setup for EPC production: Li target held by heat-dissipating copper arm and surrounded by 400 μm carbon fiber. (Right) Curved tracks in CDCH.

- the CDCH is expected to show similar performances at both low and high momenta: both simulations show ~25 hits/track
- for further comparison, monochromatic lines were simulated through Monte-Carlo at 9.2 MeV (EPC geometry) and 52.8 MeV (MEG geometry): the reconstructed energy spectrum is fitted by a Gaussian to extract the resolution

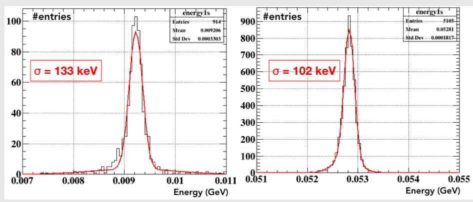

Figure 5: Reconstructed energy spectrum fit for 9.2 MeV (left: EPC geometry - resolution: (133 ± 8) keV) and 52.8 MeV (right: MEG geometry - resolution: (102 ± 3) keV) lines

- a significant resolution difference is observed, in part due to the different geometries: it needs to be investigated further to fully make use of the EPC calibration presented above

Conclusion

The MEG-II CDCH is a state-of-the-art detector designed to achieve a momentum resolution of $\mathcal{O}(100$ keV). Complementary and redundant methods are needed to make sure the detector performances are maintained in time. A novel method based on e^+ and e^- tracks from External Pair Conversion (EPC) is under development. The resonance of a Li target leads to 9 MeV straight/curved (COBRA off/on) e^+ and e^- tracks which can be used to extract both detector basic parameters and particles' kinematic resolutions. This method doesn't require the use of the main muon beam and is capable of saturating the DAQ.

References

[1] A. M. Baldini et al. The design of the MEG II experiment. *The European Physical Journal C*, 78(5), may 2018.

[2] The MEG Collaboration. Search for the lepton flavour violating decay $\mu^+ \to e^+\gamma$ with the full dataset of the meg experiment, 2016.