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A dedicated calibration tool for the MEG I and MEG II positron spectrometer

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Introduction - The MEG Experiment

- The **MEG experiment** [1][2] searches for the charged lepton flavor violating decay $\mu^+ \to e^+\gamma$.
- The Standard Model (SM) predicts a branching ratio $BR(\mu \to e\gamma) \approx 10^{-54}$.
- Many SM extensions foresee $BR(\mu \to e\gamma) \approx O(10^{-14})$ - $O(10^{-12})$. The observation of this decay would be a clear sign of new physics.
- MEG's 2009-2011 data: $BR(\mu \to e\gamma) \leqslant 5.7 \cdot 10^{-13}$ @ 90 % CL [1].
- MEG I data-taking finished in 2013, an upgraded version of the experiment (MEG II) [3] will start in 2016.
- **Simple 2-body decay kinematics**
  Muon decay at rest:
  - Back-to-back topology
  - Time coincidence
  - Energy $E_{e^+} = E_\gamma = \frac{E_\mu}{2} = 52.8$ MeV

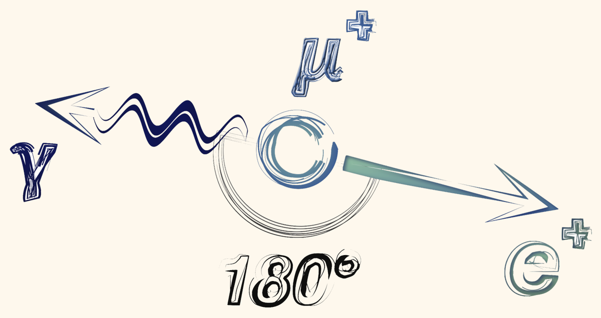

Figure 1: $\mu \to e\gamma$ event signature

The Positron Spectrometer

- Three components [2]: **Drift chamber system** + **COBRA** magnetic field for momentum measurement and determination of the e^+-vertex on the target, scintillation **timing counter** for e^+ time measurement and triggering (see Fig. 2).
- **CO**nstant **B**ending **RA**dius Magnet: Features a gradient magnetic field.
  - Particles exiting with $\sim 90°$ are swept away quickly from the sensitive detector volume;
  - Particles with equal *total* momentum follow trajectories with equal bending radius.
- Spectrometer calibration methods:
  - e^+ from Michel decay $\mu^+ \to e^+\nu_e\overline{\nu}_\mu$ (continuous energy spectrum for the e^+);
  - Cosmic Rays (straight μ tracks);
  - **New:** e^+ beam undergoing Mott scattering.

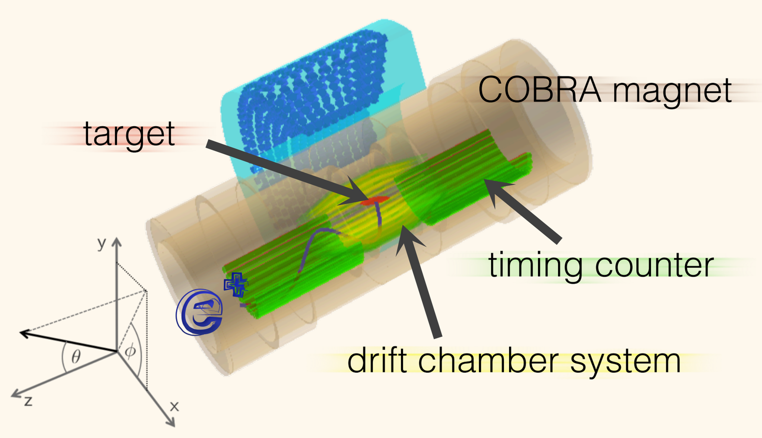

Figure 2: e^+ spectrometer

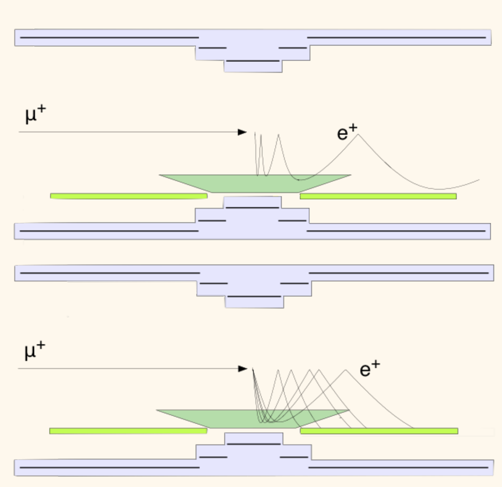

Figure 3: Gradient magnetic field

The Mott Scattering Calibration Method

- **The basic idea**
  - Instead of using the usual μ^+ beam, utilize an e^+ beam and tune it to momenta around $p = 52$ MeV/c ($\approx$ signal e^+ momentum).
  - Typical momentum byte $\frac{\Delta p}{p} \approx 300 - 500$ keV/c.
  - e^+ hit MEG target (ca. 200 µm of polyethylene) and undergo Mott scattering.
  - The well-known Mott scattering cross section has a strong dependence on the scattering angle θ (see Fig. 4).
- **The Mott energy line**
  - Outgoing momentum of the e^+ is $\approx$ equal to initial momentum $\Rightarrow$ energy spectrum is a "monochromatic line" (see Fig. 5).
  - Not a perfectly monochromatic line because
    1. of finite detector resolutions and the fact that the outgoing momentum varies slightly as a function of θ ("limitations" intrinsic to the method) $\to \sigma_{Mott}$;
    2. the beam has a certain momentum spread $\to \sigma_{beam}$.

    The total width σ_{tot} of the Mott energy line is given by:

$$\sigma_{tot}^2 = \sigma_{Mott}^2 + \sigma_{beam}^2 \approx (350 \text{ MeV/c})^2 + (500 \text{ MeV/c})^2 = 610 \text{ MeV/c}.$$

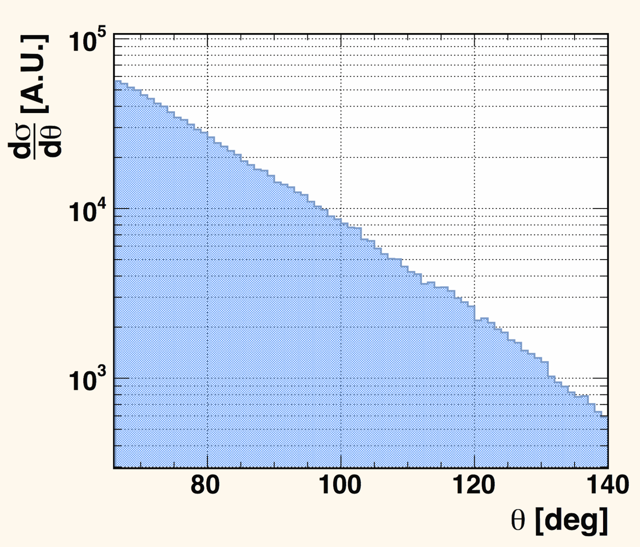

Figure 4: Simulated Mott cross section as a function of the scattering angle θ

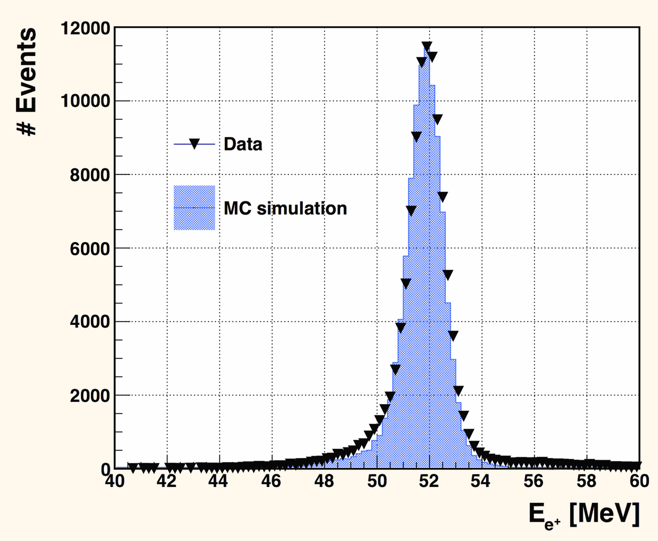

Figure 5: The Mott energy line (error bars not visible)

Spectrometer Resolutions

- Determine **spectrometer resolutions** in ...
  - ... momentum p;
  - ... angular variables θ and ϕ;
  - ... vertex position (x, y) on the target.
- Is there a way to get rid of the contribution from the beam spread and the scattering? Yes! Consider tracks which feature two turns in the DC system ("**double turn track**").
- Extraction of resolutions:
  - Each of the two turns is treated as an independent track and propagated towards the target (see Fig. 7).
  - Compute the difference of the first and the second turn for the observable of interest (e.g. $\Delta p = p_{\text{turn 2}} - p_{\text{turn 1}}$) for all double turn tracks.
  - Extract from the resulting double Gaussian distributions the core and the tail resolution.

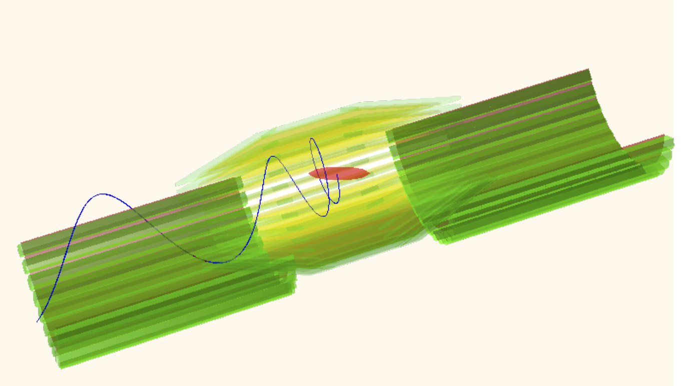

Figure 6: A double turn track

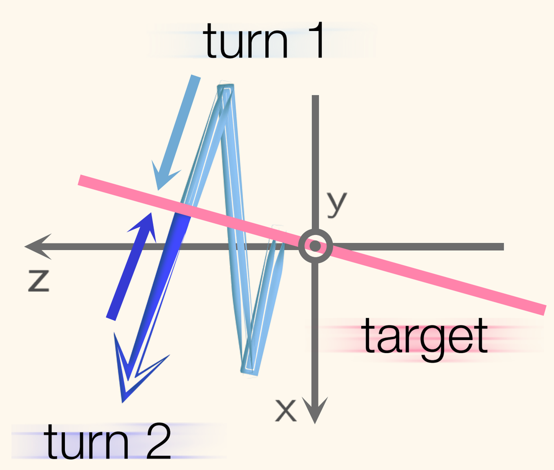

Figure 7: The double turn method

Drift Chamber Alignment

- **Check of DC alignment:** Mott scattering cross section has no ϕ-dependence $\Rightarrow$ reconstructed central momentum $\hat{p}$ ("position of the Mott line peak") as a function of ϕ should give a flat distribution when DCs are well-aligned. Non-aligned DCs give a distorted distribution of $\hat{p}$ vs. ϕ and consequently result in a broader Mott energy line.

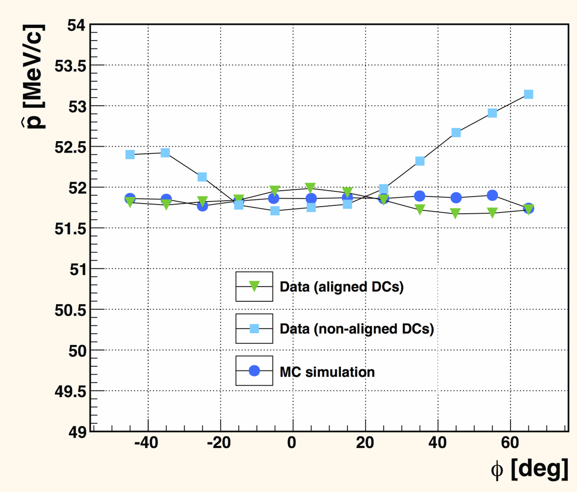

Figure 8: Reconstructed central momentum $\hat{p}$ vs. ϕ (error bars not visible)

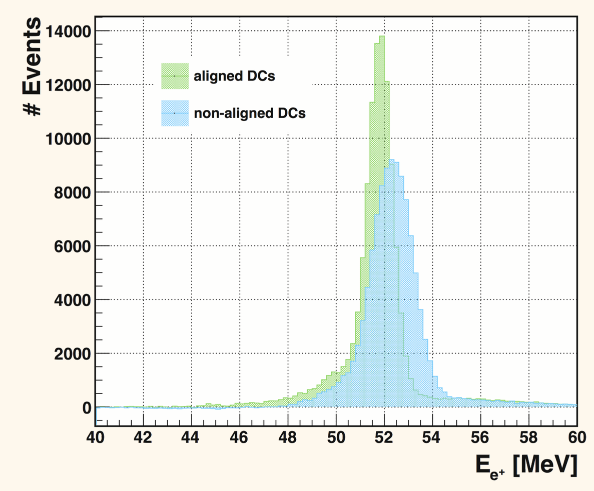

Figure 9: Mott energy line (integrated over all ϕ) for aligned and non-aligned DCs

- **Performance of the DC alignment** by means of an iterative procedure which tries to minimize the hit-track-residuals.

Conclusion

The MEG spectrometer calibration method involving a Mott scattered positron beam tuned to the approximate $\mu^+ \to e^+\gamma$ signal positron energy of 52 MeV/c has proven to be a powerful tool to...

- ... extract the resolutions of the positron spectrometer;
- ... check the alignment of the spectrometer's drift chamber system;
- ... perform the alignment of the spectrometer's drift chamber system;
- ... do a lot more of things that didn't fit onto this poster.

In particular, the resulting resolutions and the alignment are consistent with what has been obtained by other calibrations methods, endorsing the latter ones.

References

[1] J. Adam et al., *New Constraint on the Existence of the $\mu^+ \to e^+\gamma$ Decay*, Phys. Rev. Lett. **110** (2013), no. 20, 201801.

[2] J. Adam et al., *The MEG detector for $\mu^+ \to e^+\gamma$ decay search*, Eur.Phys.J. **C73** (2013), no. 4, 2365.

[3] A.M. Baldini et al., *MEG Upgrade Proposal*, (2013).

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