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The mott based double turn method for the MEG II spectrometer characterisation

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ABSTRACT

The MEG experiment has set the latest limit of 4.2×10^{-13} at 90 % Confidence Level (C.L.) to the branching ratio of the charged Lepton Flavour Violating (cLFV) decay $\mu^+ \to e^+\gamma$. The MEG II experiment will be more sensitive by an order of magnitude. High resolutions in terms of the kinematic variables used to identify a $\mu^+ \to e^+\gamma$ event are mandatory among other aspects to achieve this sensitivity. Thus careful calibration and monitoring of the experimental apparatus are required.

One of the dedicated calibration methods involves the Mott scattering process of a mono-energetic positron beam on the MEG II target. As a result positrons with energies around the MEG II signal energy get scattered into the drift chamber. The calibration and extraction of resolution can then be done by the double turn method presented in this article.

Contents

1. Introduction

The MEG II experiment is planned to look for the charged lepton flavour violating decay $\mu^+ \to e^+\gamma$ with a branching ratio sensitivity of 6×10^{-14} [1]. Today's upper limit was set by the predecessor experiment MEG to 4.2×10^{-13} at 90 % C.L.[2].

The experiment uses a liquid Xenon calorimeter for the photon detection and a cylindric drift chamber (CDCH) in combination with a dedicated timing counter to detect the positrons. A detailed description of the experimental setup can be found in [1]. More information about the CDCH are found in [1,3].

The expected signal (Fig. 1a) is characterised by a photon and a positron of 52.8 MeV energy each in back to back geometry and in coincidence. A limitation in the sensitivity to this decay channel comes from the tremendous amount of background. It consists of radiative muon decay (RMD, $\mu^+ \to e^+\nu_e\nu_\mu\gamma$) events where the two neutrinos carry hardly any energy (Fig. 1b) and of positrons emitted at the kinematic endpoint of the Michel decay coinciding with a photon from a different source like another RMD or annihilation in flight of a positron (Fig. 1c).

2. The Mott calibration

For the signal sensitivity and background rejection good calibrations and characterisations of the entire experimental apparatus are needed. One of the available calibration methods is based on a monochromatic positron beam at the expected signal energy. Due to Mott scattering on the stopping target, a fraction of the positrons gets scattered into the MEG II spectrometer.

By comparing Mott Monte Carlo truth and reconstructed values, one obtains a resolution of 82.4(7) keV in positron energy, 4.71(4) mrad

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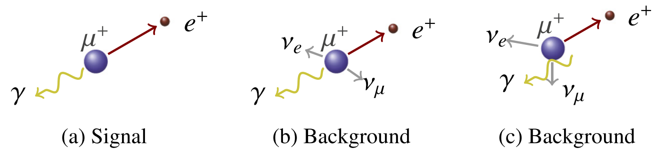

Fig. 1. Different event types.

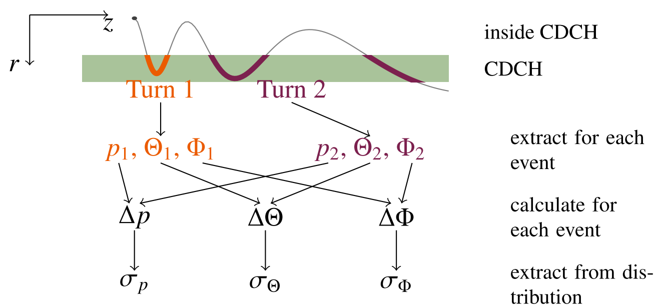

Fig. 2. Basic principle of the double turn algorithm.

in polar angle (w.r.t. beam axis) and 4.05(4) mrad in azimuth angle. Software used is described in [4–6].

3. The double turn algorithm

To perform a similar calibration on the real detector, one picks positron tracks with at least two turns. The two parts are analysed separately and the positron momentum p_i, polar angle Θ_i and azimuth angle Φ_i are extracted for each part as shown in Fig. 2.

As both parts originate from the same positron, they have the same underlying kinematic variables. Thus the statistic deviations have their origin in the limited resolution in given positron variables. As a result the width of the distribution of the differences Δp, $\Delta\Theta$ and $\Delta\Phi$ contains the information about the intrinsic resolution of the detector.

A similar technique has already been in use during the MEG experiment [5,7]. The method was adjusted to the MEG II geometry and was applied to various sets of MC simulations.

4. Results of the double turn method

In a first set of studies, the double turn algorithm has been applied to different kind of events. The Δp results are shown in Fig. 3a. Mott events (orange) exhibit a very similar distribution compared to signal events (green). Distributions based on Michel events (violet) are broader. By selecting only Michel events reconstructed close to the kinematic endpoint above 50 MeV, the distribution of the differences approaches the obtained distributions for Mott and signal events. This, however, happens at the cost of a significantly lowered event rate.

In Fig. 3b the obtained Δp distributions for different initial momentum beam spread are shown. The results are the same up to statistical fluctuations. This underlines the advantage of the double turn method: As it is comparing estimated values of the same event, uncertainties due to the beam quality and details of the scattering process cancel each other out. What remains is the information about the intrinsic detector resolution.

Comparing the standard deviation from the double turn algorithm with the results obtained from comparing the MC truth values, a factor of 1.5 to 1.6 can be observed. This deviation is expected as the double turn method is based on the difference of two estimates based on fitting the two parts of a track. The MC truth values are based on the true value at the beginning of the simulation and just one estimate based on a whole track that usually consists of one or one and a half turns. For the angular variables very similar results are obtained.

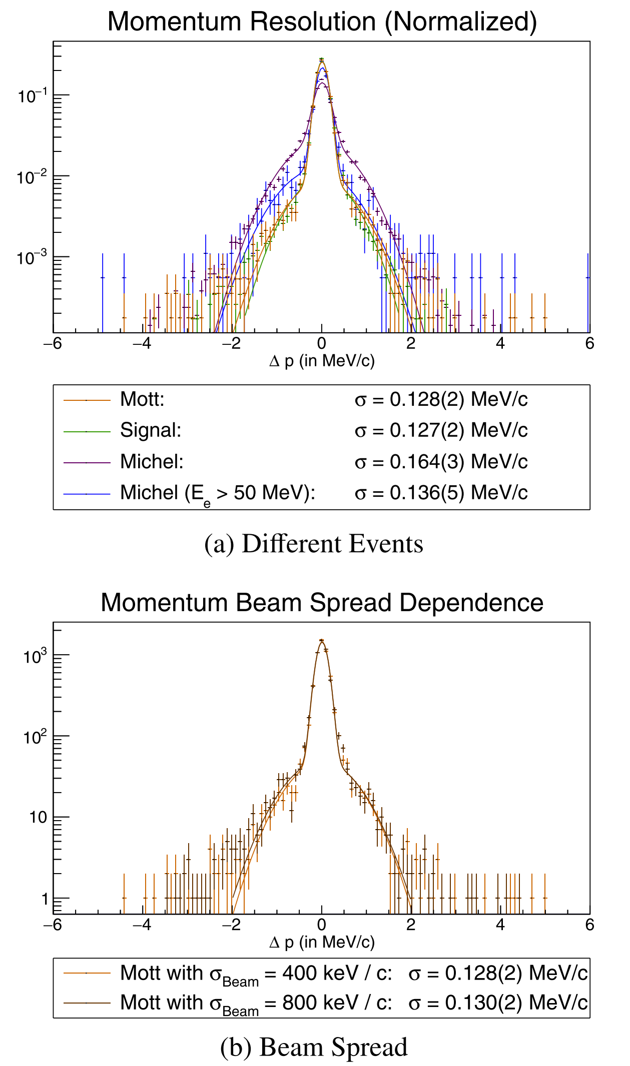

Fig. 3. Δp distributions obtained with the double turn algorithm. Standard deviations refer to the central peak. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5. Conclusion

MC simulations show that the double turn method is able to extract the intrinsic CDCH resolutions in terms of the positron variables momentum, polar angle and azimuth for MEG II. The use of Mott scattered positrons around the signal energy provides results closest to the expected behaviour of signal events.

The double turn method relies only on reconstructed values accessible during the experiment. The deviations observed between the resolutions obtained from MC truth values and the estimated standard deviations are as expected and can be explained by the differences in the two methods.

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