Tracker EDM analysis note: A measurement of the longitudinal magnetic field in Run-1

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April 7, 2020

Abstract

This document briefly outlines the methodology of the longitudinal magnetic field, B_z, measurement using the tracker data in Run-1. The final results for the systematic uncertainty on ω_a due to B_z are presented, and are found to be: 0 ppm $< \frac{\Delta\omega_a}{\omega_a} <$ 4 ppm.

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1 Introduction

A presence of a longitudinal field, B_z, tilts the precession plane of the muon, as shown in Figure 1, and modifies [1] the observed precession frequency according to

$$\omega_a = a_\mu \frac{e}{m_\mu} B \rightarrow \frac{e}{m_\mu} \sqrt{(a_\mu B_y)^2 + \left(\frac{(1+a_\mu)B_z}{\gamma} \right)^2}. \tag{1}$$

It is therefore imperative to estimate this systematic effect on ω_a.

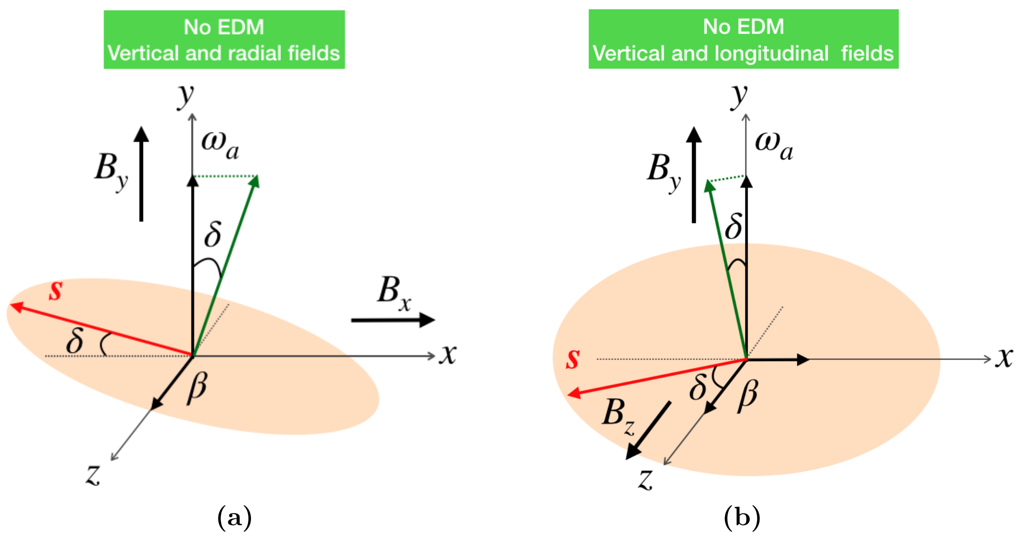


Figure 1: The tilt in the precession plane due to field components: a) radial (B_x) b) longitudinal (B_z). The momentum vector (β) is along the z-axis. The tilt due to the radial field - towards the centre of the ring - is analogous to an effect due to an EDM. The longitudinal field, however, would produce a tilt towards the direction of the stored beam, by an angle δ.

This tilt due to B_z can be used in the measurement of the average vertical angle of muon decay as a function of time: an up-down oscillation in-phase with ω_a would be indicative of a longitudinal field.

2 Methodology

In this study, the measurement of the vertical angle, θ_y, is coming from the tracking detector, where for each track a corresponding measurement of track time in a fill is available. This time is used to modulate data by the $g-2$ period, T_{g-2}, to remove any systematic effects that are not periodic with T_{g-2} (e.g. VBO). This is analogous to the method used in the BNL EDM analysis by M. Sossong [2]. The remaining analysis steps also follow the Sossong's methodology closely, and are presented in detail in DocDB:22201 [3]. These steps include fitting data for the number oscillation

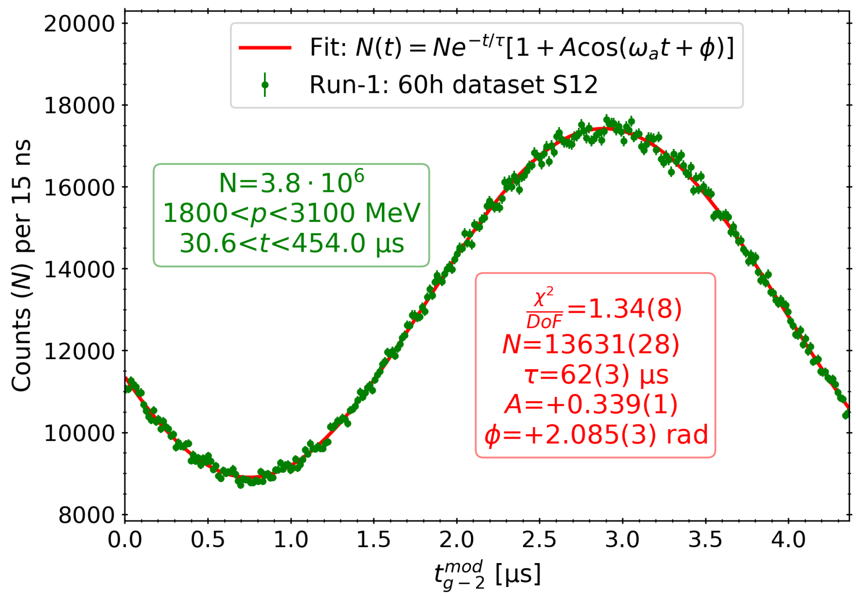
$$N(t) = Ne^{-t/\tau}[1 + A\cos(\omega_a t + \phi)], \tag{2}$$

using a constant value of 1.439 311 MHz for ω_a, as measured at the BNL $g-2$ [4]. This is shown in Figure 2a. The value of ϕ from Equation (2) is then used in the fit to the vertical angle oscillation

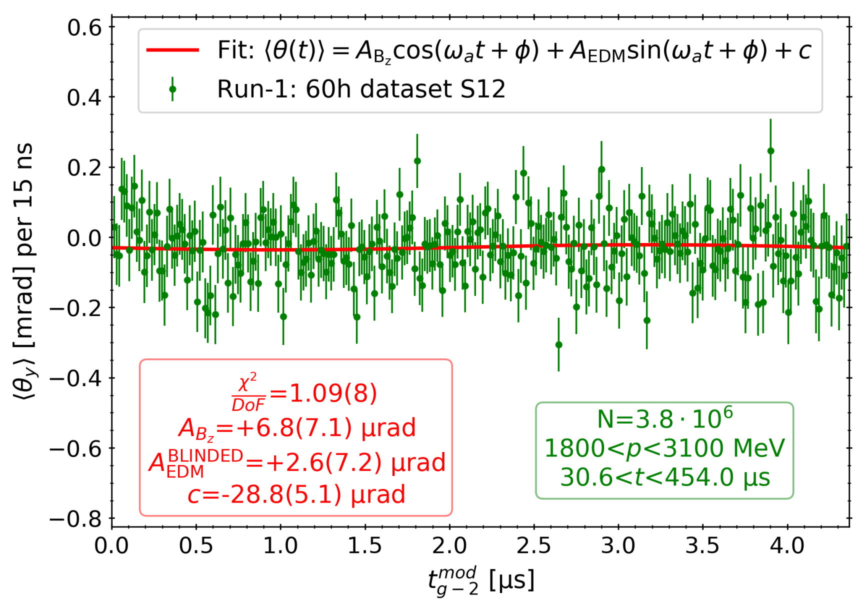
$$\theta(t) = A_{\mathrm{B_z}} \cos(\omega_a t + \phi) + A_{\mathrm{EDM}} \sin(\omega_a t + \phi) + c, \tag{3}$$

where $A_{\mathrm{B_z}}$ is the amplitude due to the longitudinal magnetic field, A_{EDM} is the EDM amplitude, c is the overall offset. This is shown in Figure 2b. A_{EDM} is blinded with data, as discussed in DocDB:22201 [3].

Parameter stability scans with fit start time, fit end time, momentum cuts, bin width, and a choice of T_{g-2} (i.e. ω_a) and ϕ are also presented in DocDB:22201 [3], and are found to be stable.



(a)

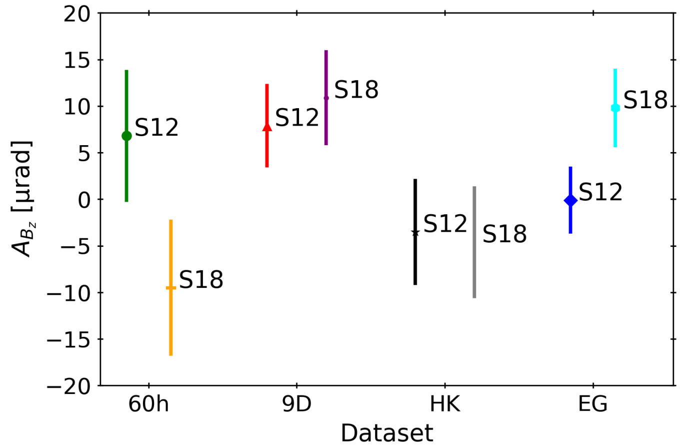


(b)

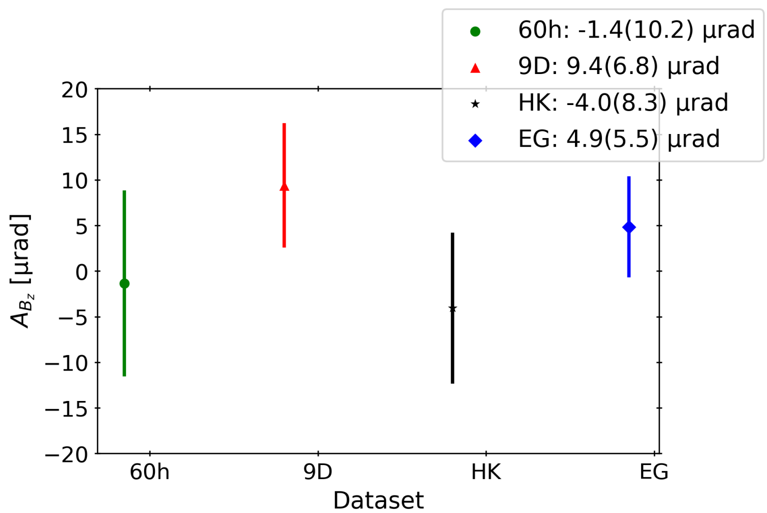
Figure 2: Fitting results in the 60h dataset for S12: a) number oscillation, and b) average vertical angle oscillation.

3 Results

The observed (i.e. fitted) amplitudes of the vertical angle oscillation due to B_z (i.e. $A_{\mathrm{B_z}}$) from all the four Run-1 datasets are presented in Figure 3.



(a)



(b)

Figure 3: Fitting results in all Run-1 datasets: a) S12 and S18 separately, and b) mean of the two stations. The individual fit results are summarised in DocDB:22201 [3].

Joe has posted a great and comprehensive note [5], which deals with a conversion from an observed amplitude to an estimated value for B_z. The conversion steps are as follows. Asymmetry term, $A = 0.1$, is connecting the observed amplitude (A_{B_z}) with the actual precession plane tilt in the lab frame (δ')

$$A_{B_z} = 0.1\delta'. \tag{4}$$

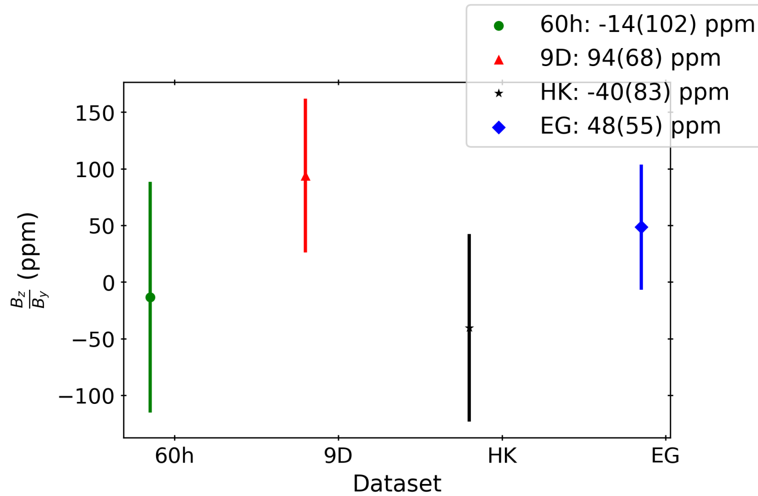
Asymmetry is accounting for the fact that not all positrons are emitted in the direction of polarisation vector [5]. Given that the muon motion is along z (c.f. Figure 1), there is no Lorentz boost in this direction. Therefore, the estimate of B_z is directly available from the measured angle in the lab frame, after the asymmetry term is taken into account. Hence,

$$\delta' = \tan(\frac{B_z}{B_y}) \approx \frac{B_z}{B_y} \tag{5}$$

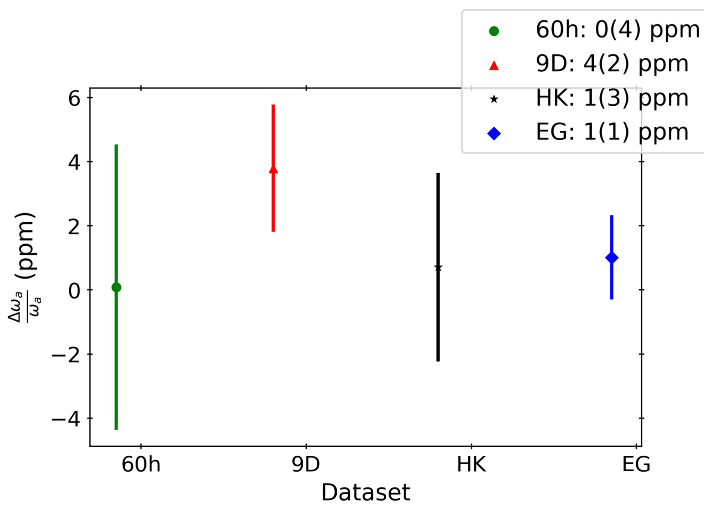
Finally, the corresponding systematic uncertainty on ω_a can be estimated using the formula in Bill's note [1]

$$\frac{\Delta\omega_a}{\omega_a} = \frac{1}{2}\left(\frac{(1+a_\mu)}{a_\mu\gamma}\frac{B_z}{B_y}\right)^2. \tag{6}$$

The final results of the application of Equations (5) and (6) to Run-1 vertical angle oscillation is given in Figure 4.



(a)



(b)

Figure 4: Run-1 systematic uncertainty results: a) B_z in ppm and b) ω_a in ppm.

Given the range of values in Figure 4b, the uncertainty spread on ω_a can be summarised as

$$0 \text{ ppm} < \frac{\Delta\omega_a}{\omega_a} < 4 \text{ ppm}. \tag{7}$$

References

[1] B. Morse, *Traceback and geometric phase systematic error,* $g-2$ DocDB:1839 (2014).

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Acknowledgements

I would like to express gratitude to Mark, Becky, Joe, James, Saskia, and Nick for their advice and guidance in this project. Also, I would like to thank the entire EDM group for their support and feedback.