Measuring the Radial Field of Muon g-2

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Abstract

In the measurement of the electric dipole moment (EDM), a leading systematic error is the presence of radial magnetic fields which tilts the precession plane and is indistinguishable from a true EDM. The average radial magnetic field can be determined by studying the muon beam distribution and its vertical components. To minimize this systematic uncertainty in EDM analysis, we re-designed a platform that will allow us to attach a Hall probe and directly measure the radial magnetic field as a function of azimuth.

Muon g-2

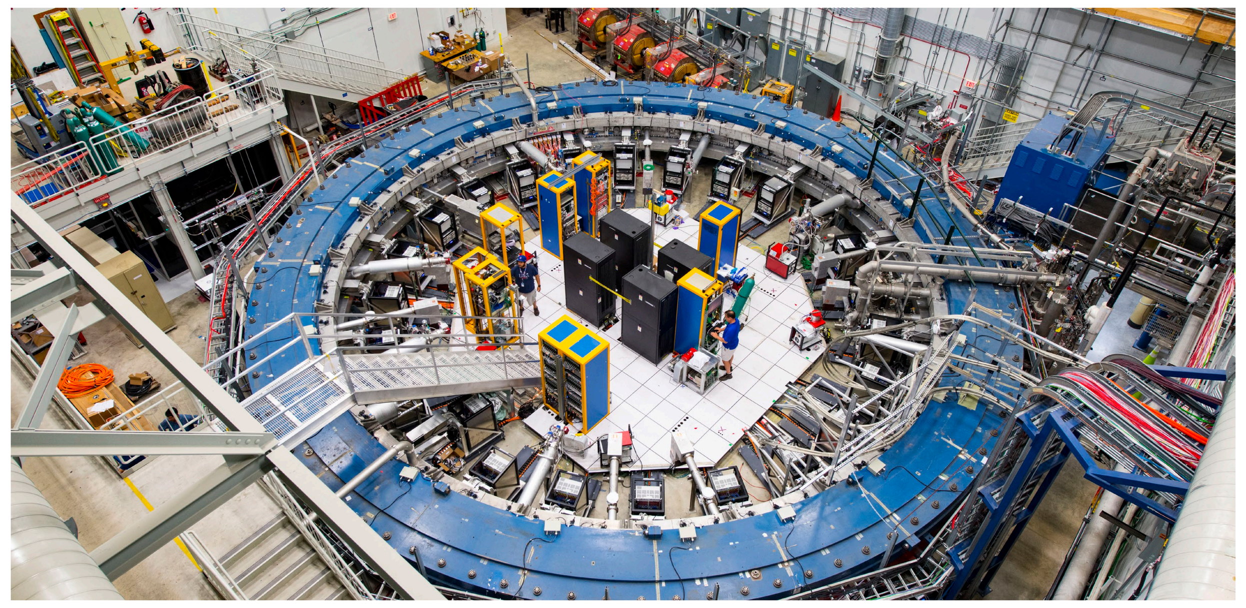


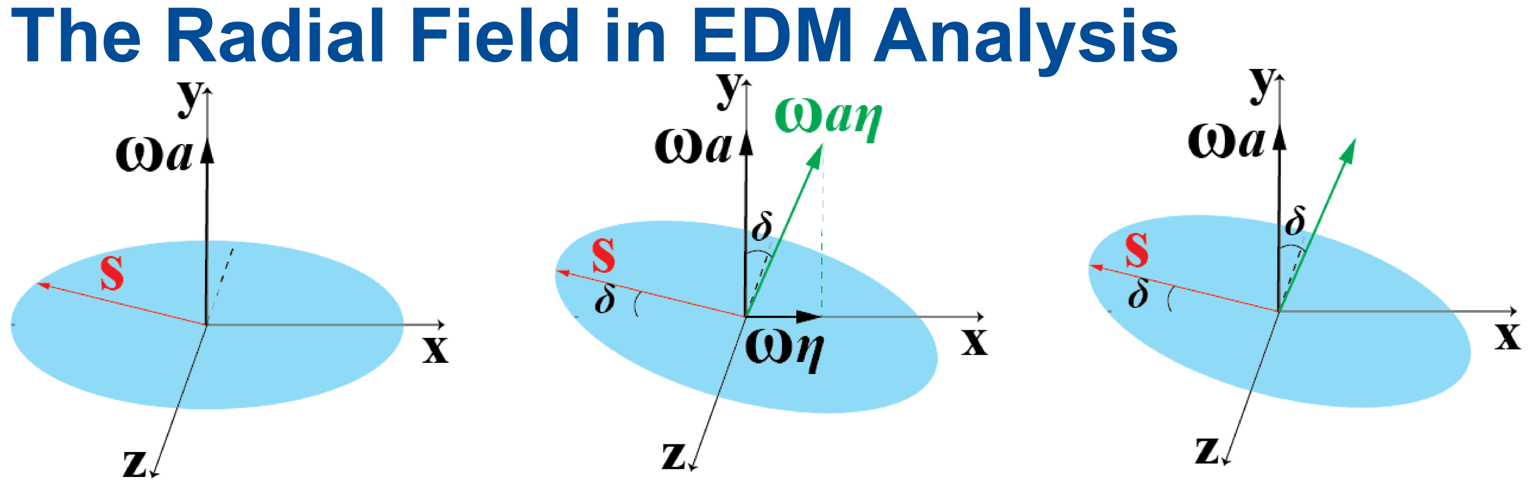
Figure 1: Muon g-2 at Fermilab. Photo: Reider Hahn, Fermilab (2017).

Muon g-2 aims to measure the anomalous magnetic moment of a muon: $a_\mu = (g_\mu - 2)/2$

Magnetic Dipole Moment: $\vec{\mu} = g\left(\frac{q}{2m_\mu}\right)\vec{s}$

To measure a_μ, we determine the muon precession frequency and the strength of the magnetic field in the muon storage region.

The Radial Field in EDM Analysis



(a) No EDM. (b) Non-zero EDM. (c) Radial Magnetic Field

Figure 2: The muon spin precession plane within the case of no EDM, non-zero EDM, and under an applied radial field.

The presence of a radial field causes the same effect on the muon spin precession plane as an electric dipole moment (EDM).

Beam Method

The radial field is proportionally related to the vertical position of the beam:

$$< y > \propto \frac{< B_r >}{V}, \quad < B_r > = < B_r^a > + < B_r^b >$$

By applying a range of radial fields and measuring the beam's vertical position over a fixed range of voltages, we can determine their linear relationship and calculate the background radial field, $< B_r^b >$.

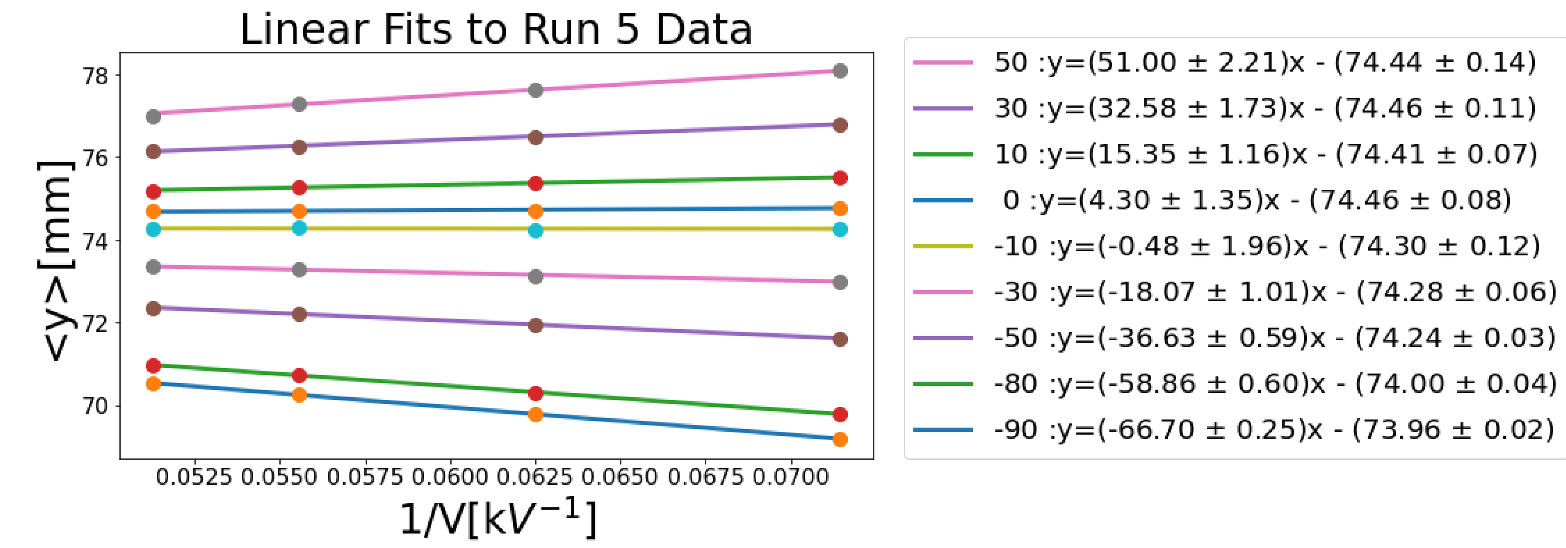


Figure 3: Linear fits of the vertical beam position for a range of fixed voltages at different applied radial fields. Data points were obtained by Dominika Vasilkova.

The vertical beam positions shown in Figure 5 are calculated by averaging the y-coordinates in the density plots of the decay positrons, as returned by each calorimeter.

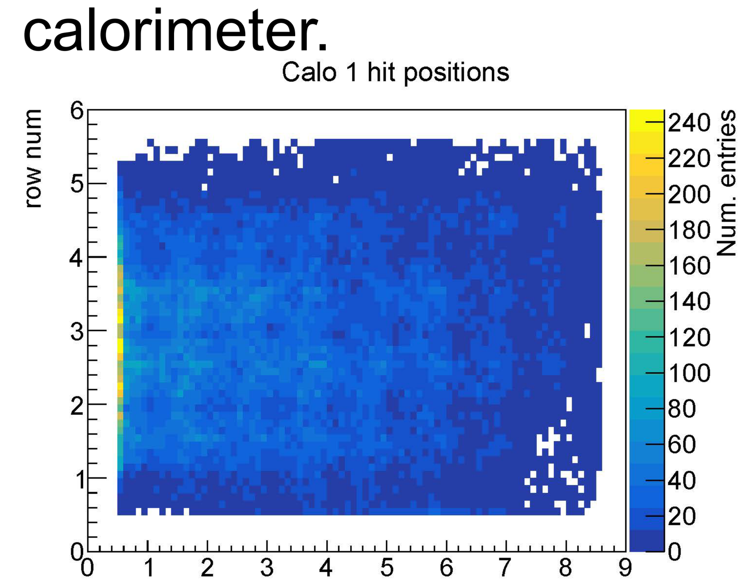


Figure 4: Azimuthal view of decay positron positions at calorimeter 1.

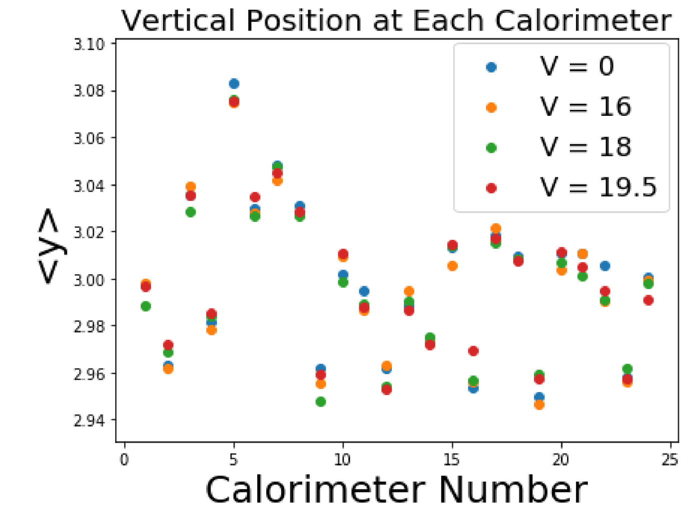


Figure 5: Averaged vertical position of the beam at each calorimeter.

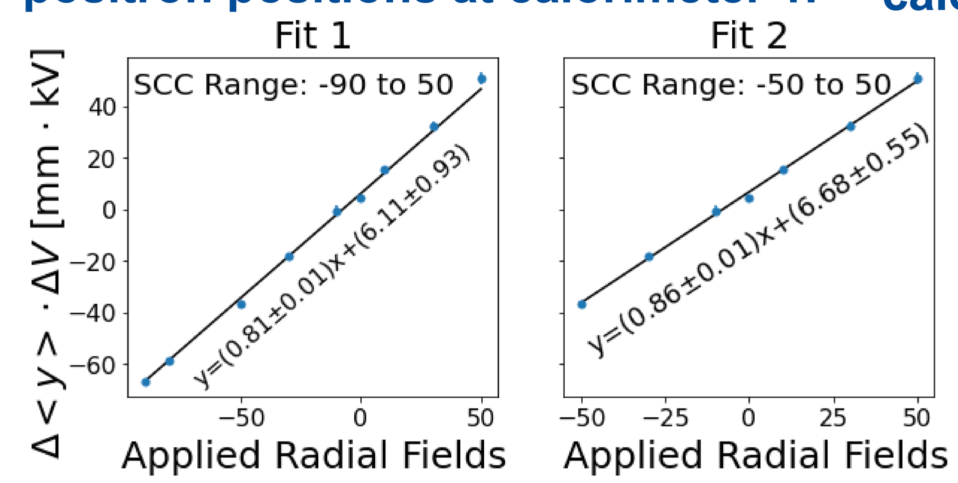


Figure 6: Gradient vs. applied radial field. Optimal applied radial field for zero gradient is 7.53 ± 1.15 ppm and 7.74 ± 0.65 ppm, for Fit 1 and Fit 2 respectively.

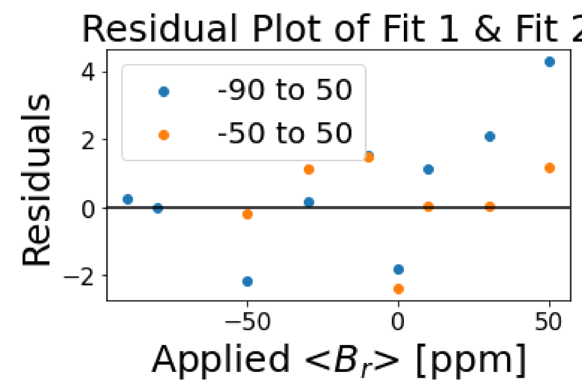


Figure 7: Residual plot for fits in Fig 6. Fit 1 shows that we are losing muons at scans < -50 ppm.

Directly Measuring the Radial Field

We can directly measure the radial magnetic field by using a Hall probe. The Hall probe will detect the magnitude of the magnetic field using the Hall effect, such that the output voltage of the Hall probe will be directly proportional to the strength of the magnetic field.

A New Platform Location

In order to best measure the magnetic field that the muons experience, the Hall probe will be installed inside the vacuum chamber. This is a new location compared to measurements done in 2016 (Osofsky, 2019). This new location is at ~180° in the storage ring and will take place of the trolley garage. Therefore, the dimensions of the trolley garage serve as parameters for the new platform design.

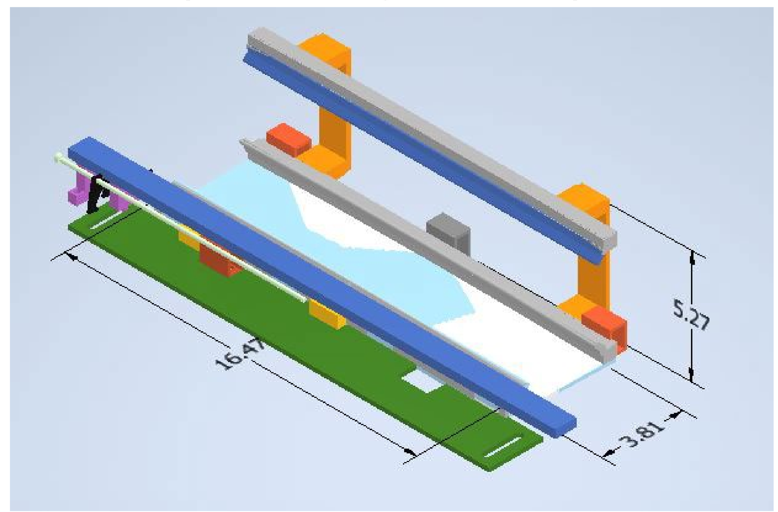
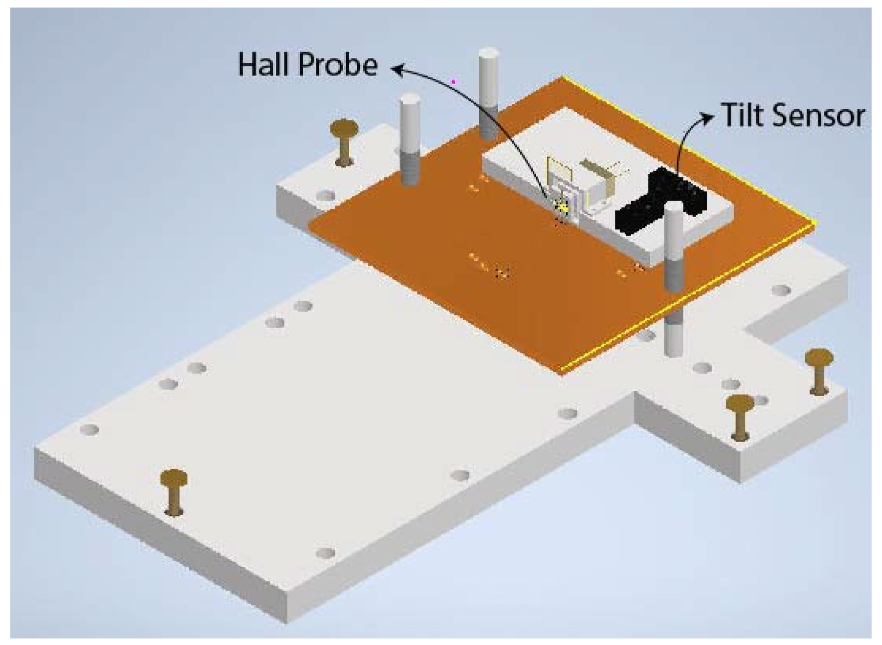


Figure 8: 3D model of the garage.

Platform Design



This model was designed such that the height, radial, and azimuthal position of the Hall probe can be easily adjusted.

Figure 9: Current platform design created with Inventor (CAD).

Next Steps

1) Build the platform!
2) Obtain data.
3) Apply data to EDM analysis.

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