Numerical detector analysis for the g-2 experiment

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Abstract

The G-2 experiment is attempting to determine the anomalous magnetic moment of the muon. In the first experiment at Brookhaven National Lab, E821, a 3.6 sigma difference was found from theory with a confidence level of 3 sigma. In the current experiment at Fermilab, E989, a 4-fold improvement in precision is being attempted to either support or refute BNL's results. Part of the the lack of precision in E821 was due to *coherent betatron oscillation (CBO)*, the betatron oscillations of the beam itself. To reduce uncertainties, it's important to better understand the effects of CBO. This project was aimed at studying the effects of the muon x-position, in the coordinate system where the muon is at the origin, on the detection rate of the particles and gammas formed from and after the muon decay.

Introduction

Charged particles in an electric and/or magnetic field are subject to the Lorentz force,

$$\frac{d\mathbf{p}}{dt} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

The magnetic field portion of this force can only cause a charged particle to accelerate radially. The constant magnetic field in the muon storage ring causes the relativistic muons to travel in a circle. When a muon decays into a positron and two neutrinos, the positron is more strongly radially accelerated by the Lorentz force due to its smaller momentum. As the positron 'falls' inward toward the center of the ring, it can come into contact with one of 16 calorimeters spaced equally around the ring, just inside and perpendicular to the muon beam.

Because the muon decays occur randomly, the ring cannot be constructed such that the positrons never pass through any part of the ring structure as they travel toward the calorimeters. Therefore, Bremsstrahlung (the possible ejection of photons as charged particles pass through matter) and pair-production (the possible creation of an electron-positron pair as a photon passes through matter) must be accounted for. Not all positrons hit a calorimeter, with fewer contacts the more matter the positron must pass through.

Method and Results

Python was used to track positrons as they 'fell' towards the center of the ring. A particle or gamma was 'killed' (removed from tracking) if it contacted the calorimeter, traveled inside the radius of the calorimeter, or traveled outside the outer electrode (the electrode on the right side of Figure 4).

Muon phase-space data was provided by David Ruben from Cornell. Based on the starting x-position of the muons, split into 1 cm starting regions, the following results were found (44732 particles were tracked).

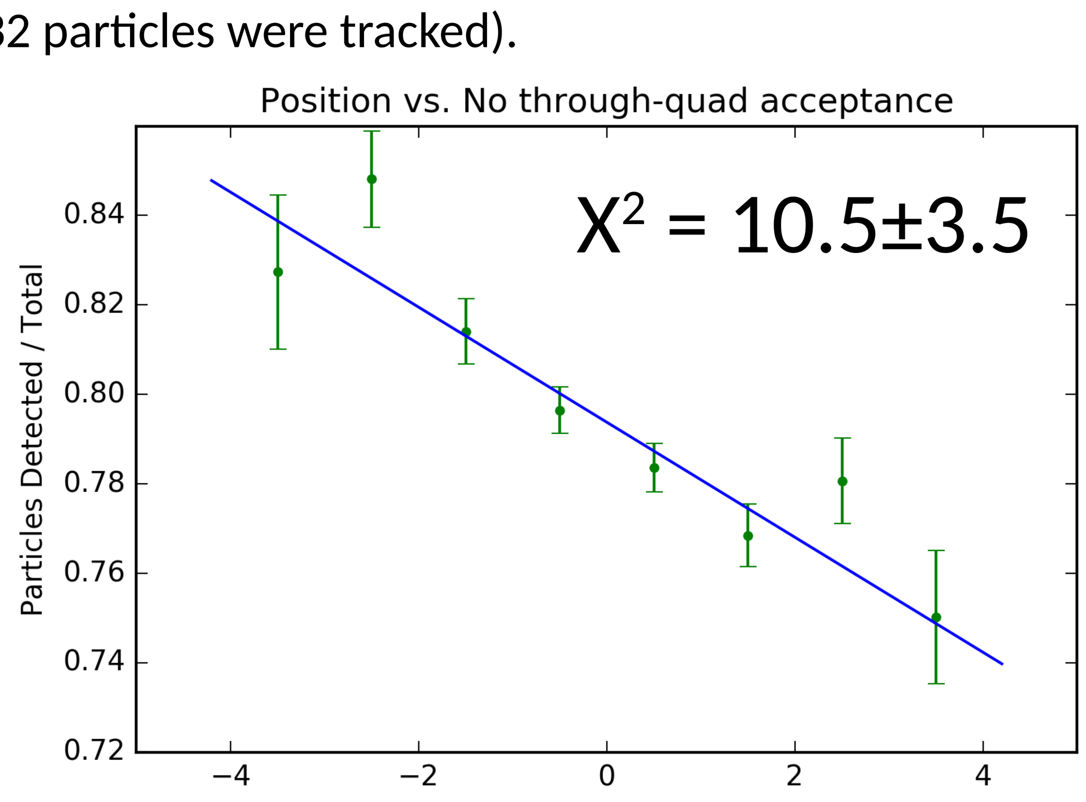

Figure 1 – Positrons detected as a function of muon starting position for particles that did not pass through any electrodes. The acceptance rate is consistent with linear.

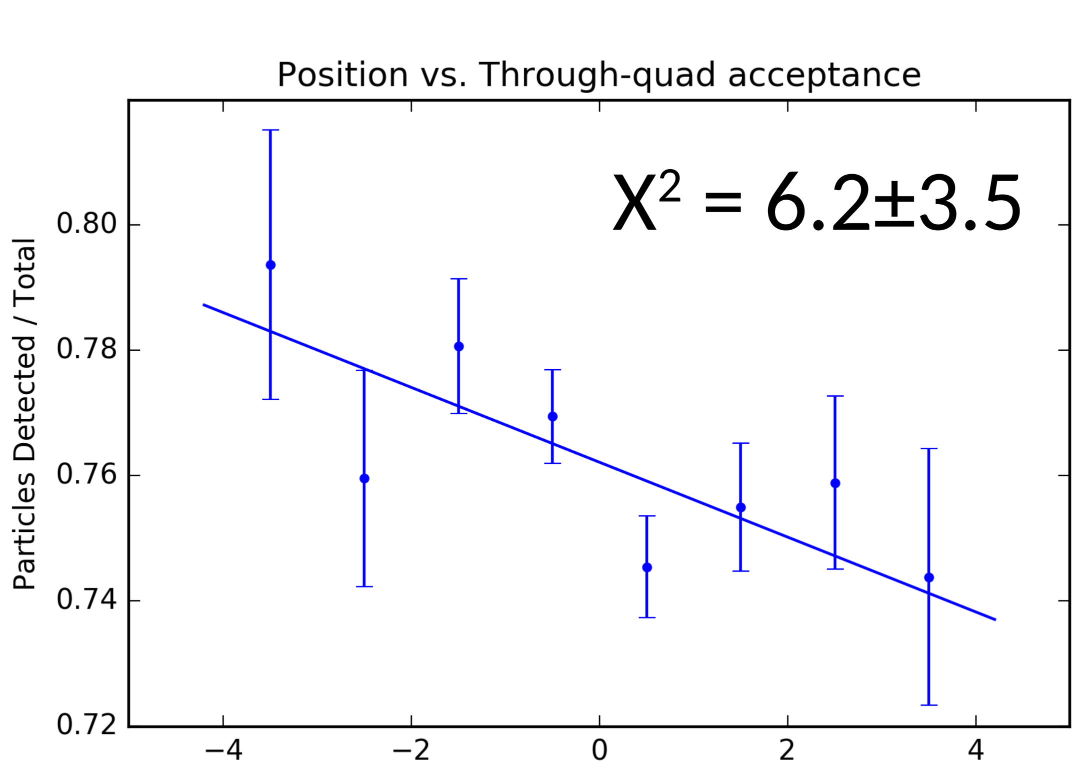

Figure 2 – Positrons detected as a function of muon starting position for particles that passed through an electrode. The acceptance rate is consistent with linear.

In order to improve the results, many more muon decays need to be tracked as only then will a quadratic dependence become noticeable

Next I looked at positron/gamma pairs. If a positron passed through matter and created a gamma, and if the gamma and positron both contacted the calorimeter, the distance between the positron and gamma was plotted as a function of the energy of the positron at contact. This provides insight into an event referred to as 'pile-up' where multiple particles and/or gammas can contact a calorimeter near each other and within a short period of time of each other and the computer will see it as a single high-energy particle. Or, if they contact the calorimeter at different locations, the computer will record two separate low-energy interactions, which will result in seeing two muon decay events when only one actually occurred. Figure 3 below gives the results.

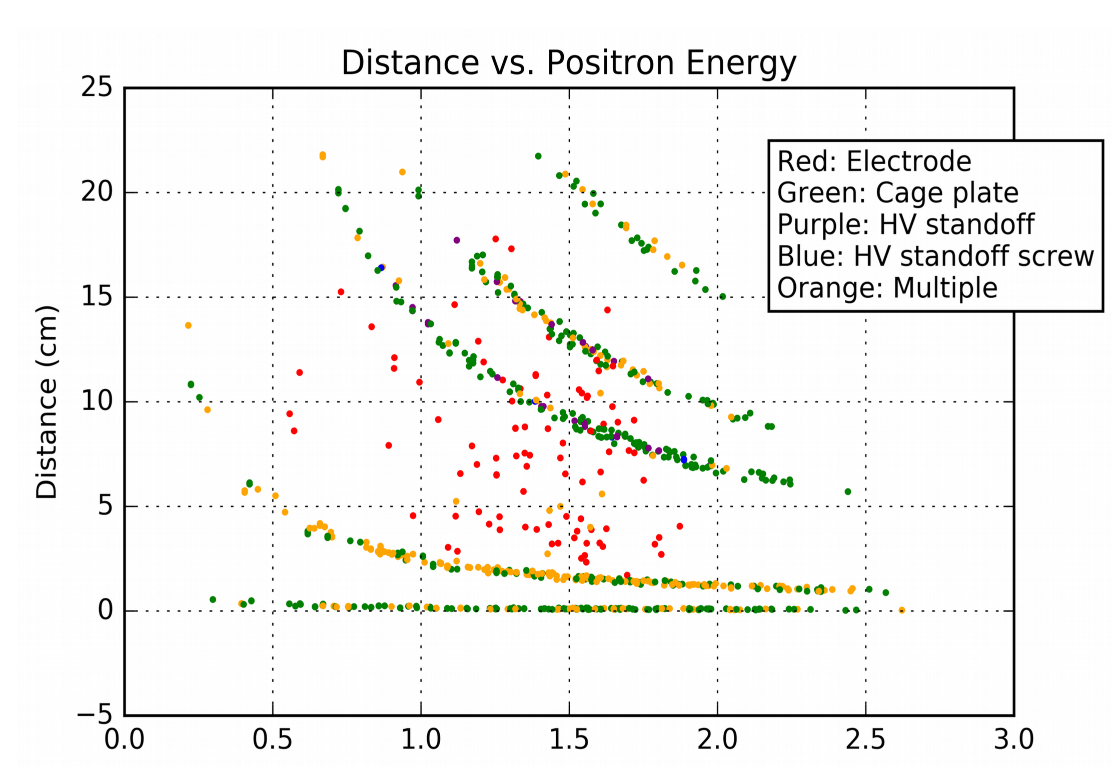

Figure 3 – Distance between a positron/gamma pair as a function of the positron energy at the time of contact with the calorimeter. Except for orange, the colors represent the *only* element that the positron passed through.

From figure 3, we can see that the majority of the positron/gamma pairs come from contact with the cage plate (see figure 4). In fact, in the majority of the pairs where the positron passed through multiple elements (the orange points), the positron also passed through a cage plate. The table below provides some basic results from the project.

Particles tracked	44732
Calorimeter contacts by positrons	34328 (~77%)
Gammas created	9510
Calorimeter contacts by gammas	998 (~10%)

Conclusion

Two important results were presented here. First, that the possible pile-up of positrons/gamma pairs occur primarily due to the location of the cage plates. Second, it was found that for both the particles that passed through matter before contacting the calorimeter and those that did not, the acceptance rate is consistent with linear. Therefore, the assumption of linearity is currently valid, however, more data is needed to verify this.

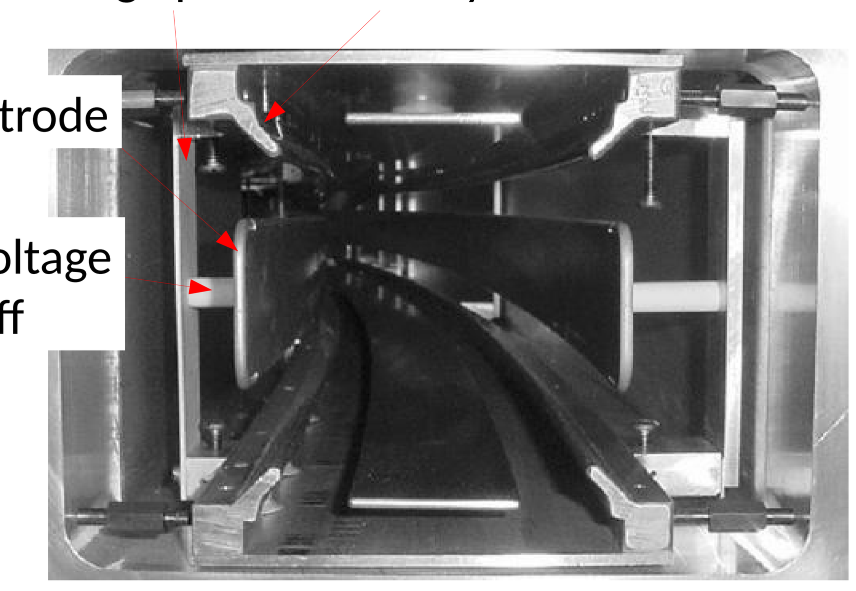

Figure 4 – Photo of the inside of the muon ring. To the left is towards the inside of the ring and the calorimeters.

Photo from Semertzidis, Yannis K. et al. "The Brookhaven Muon (g-2) Storage Ring High Voltage Quadrupoles." Nuclear Instruments and Methods in Physics Research Section A: 503.3 (2003): 458-84.

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