Muon Beam Storage Magnet B Field Shaping

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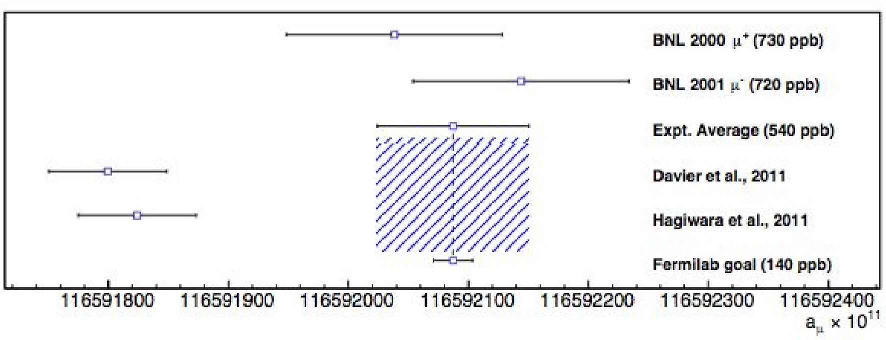
Abstract

The Muon G-2 Experiment at Fermi National Accelerator Laboratory is an attempt to measure an anomaly in the magnetic moment of the Muon to new levels of accuracy . It seeks to test the finer predictions of the Standard Model by measuring the contributions of QED, and hadronic and weak interactions to the anomaly. Current efforts revolve around shaping and mapping the magnetic field. This will decrease the deviation in measured positron energy, increasing the accuracy of the calculated anomaly well past that of the Brookhaven National Lab experiment (.7 ppm), to 140 ppb. This accuracy will allow for detailed calculations of effects on the muon not predicted by SM theories, providing insight into hitherto unknown physics.



Introduction

Background

The Muon is an point-like (elementary) spin ½ particle, identical to the electron (and tau), but with 207 times the electron mass. It has a rest frame lifetime of 2.2 microseconds. Discovered unexpectedly, it was thought to be an excited state of the electron for some time, until confirmed to be a unique particle. Like the electron, the muon is predicted the the Dirac equation to have a gyromagnetic factor (or "g") equal to 2. This is a coefficient in $W_p = g\ (e/2mc)\ B$, which predicts how fast a particle precesses (or rotates) in a magnetic (B) field. Many attempts to find the extent to which the muon g differs from the value of 2 were kickstarted by the success of the electron g-2 experiment, which found an answer closer to 2.002. (Ozben 2003) Since then theories have been developed and tested that fill out most of that discrepancy, but not all of it, as the BNL experiment demonstrated. Even after all known Standard Model effects are taken into account, as well as the systematic uncertainty, the result found at Brookhaven was 3 standard deviations from the best predictions. This clearly means that prior to its decay the muon interacts with forces or particles that exist outside of current theoretical frameworks. Quantifying exactly how large an effect this has should enable and inform the fleshing out of new theories.

Context

The goal of my group this summer was to finish lamination of the ring storage magnet poles around the time of the collaboration meeting, so the ring, with a now nearly perfect field, could be transferred to the beam group for testing and installation on the vacuum chambers. This comprised the ordering, cleaning, cataloguing, and sorting of about 9000 small iron foils. subsequently they were applied to 72 boards, and the magnet itself. This required consistent testing and calibration in the field, as well as constant analysis of the perturbations caused by the boards.

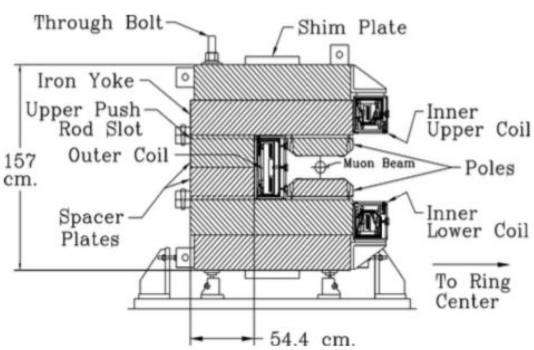
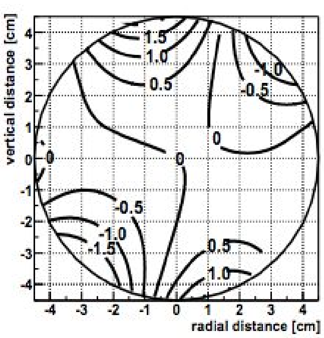


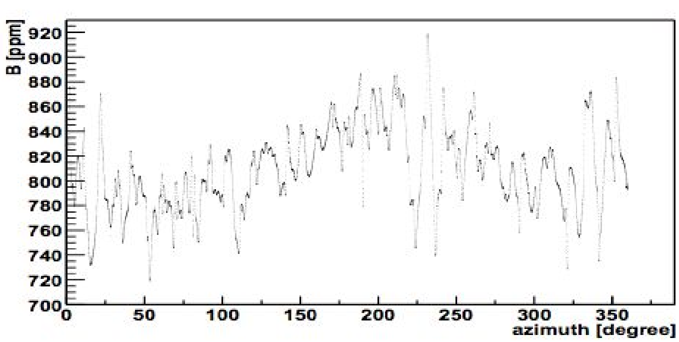
Fig. 2. A cross-section view of the magnet.



Multipoles (ppm)

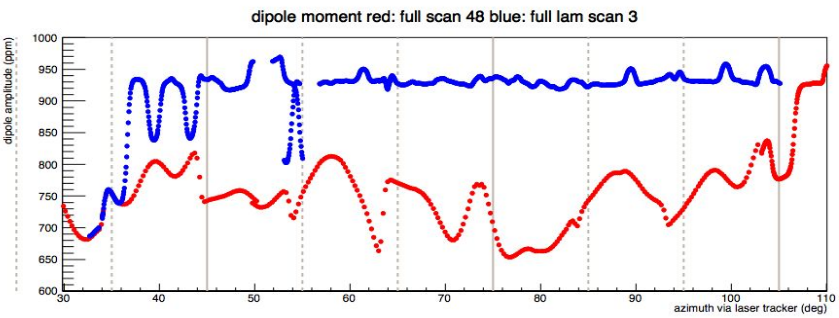
	normal	skew
Quad	0.24	0.29
Sext	-0.53	-1.06
Octu	-0.10	-0.15
Decu	0.82	0.54

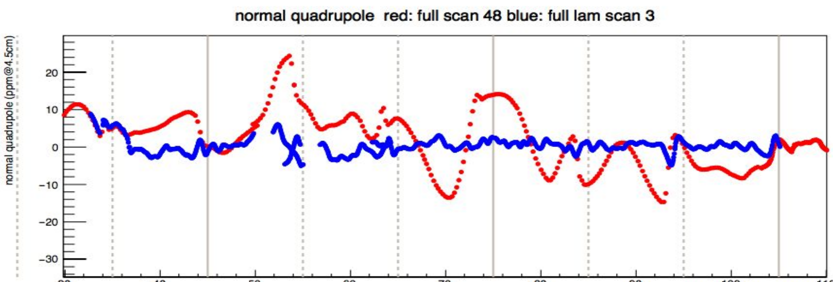
Fig. 13 : Contour plot of multipole expansion.



Methods

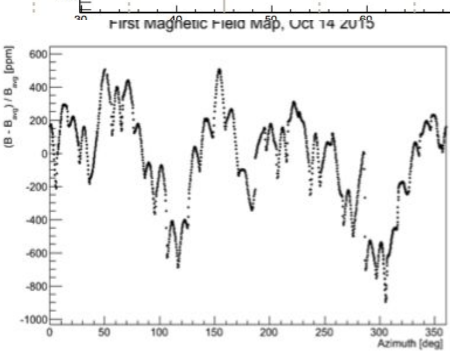
Tuning of the magnetic field occurs in several distinct ways. First is the adjustment of wedge shims, which raise and lower the pole pieces thousandths of an inch. This occurred prior to my arrival, though I confirmed that all adjustments were as expected at 400 points around the ring. Second is the addition of small strips of soft iron to sheets places inside the pole gap. This extremely low carbon, iron has a very low coercivity (a quality relating to a ferrous metal’s tendency to become magnetic).This allows it to quickly adopt the applied field and amplify it in accordance with its mass. By placing 8856 strips (plus gratings) over 72 poles (36 top and bottom) in 3 rows of 41 per pole, reduction of the field variation to less than 25 ppm azimuthally, and .5 ppm azimuthally averaged radially and vertically, is expected. The field is periodically measured using a non-magnetic cart containing 25 NMR probes, reading on average every .3 degrees. This data is analysed and used to inform corrections to the mass formulas, as well as what methods/orientations of placement and application of foils.

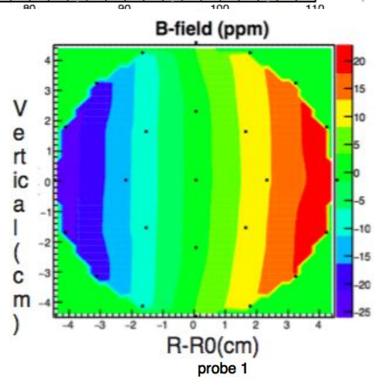


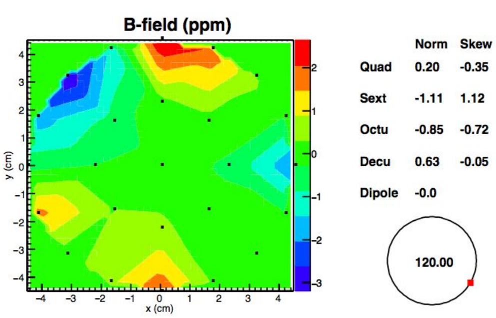


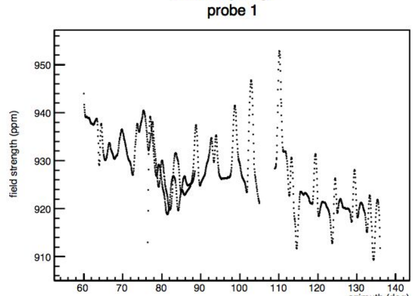
Data

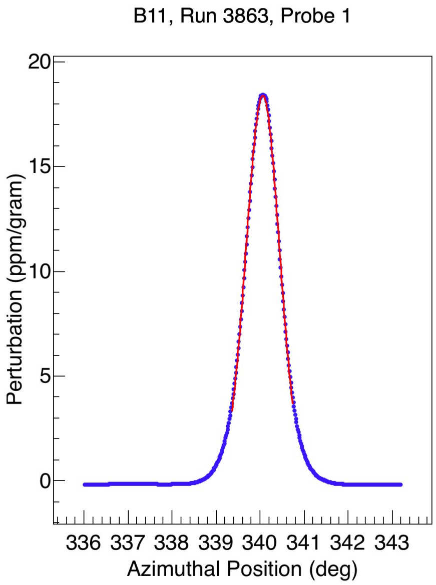
The field has, as a result of our laminations, improved considerably thus far, and should continue to well below our stated tolerances. The BNL experiment ended with a systematic uncertainty of 540 ppb, a variation of ~200 ppm azimuthally, and less than 1 ppm azimuthally averaged. The goal of “shimming” is to reduce those variations to 25 ppm azimuthally, .5 ppm azimuthally, and help limit systematic uncertainty to 140 ppb. Currently field is at 40 ppm for the worst laminations, and well within 25 for the majority. Azimuthally averaged, especially for higher order perturbations, the field is still outside of .5 ppm for the worse foils. Seen here without gratings are some of the before and after variations in multipole effects, as well as early and more recent field graphs.











Analysis

While laminating, we switched from foils hand-cut in the lab to foils mass cut by the University of Washington with a laser cutter. During this process the iron was heated enough to alter its magnetic characteristics, thereby increasing the perturbation it caused. For 1mm wide foils this was 36%. Once foils were 3.5mm, the effect was reduced to less than 1%. This increase was accounted for in the programs that calculated the foil distributions, and the effect has not increased overall field variation. Similarly, for the gratings that cover the stationery NMR (Nuclear Magnetic Resonance) probes, several problems were encountered. Radially placed foils produced too large of a gradient near their edges, rendering data from the probes unuseable. Once we switched to azimuthally laid down foils, this effect was neutralized, but the total perturbation produced by our calculated gratings was 12% too large. We reduced the mass accordingly, and the gratings currently appear to be performing as expected.

Acknowledgements

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