Monte Carlo Studies of Fringe Field Estimates at Muon g-2

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ABSTRACT

The E-989 Muon g-2 experiment at Fermi National Accelerator Laboratory (Batavia, IL) is seeking to make the world's best measurement of the muon's anomalous magnetic moment. It hopes to achieve a precision of 140 parts per billion in order to resolve whether the greater-than-3 standard deviation discrepancy between the 2006 Brookhaven National Lab E-821 measurement and the Standard Model prediction is a harbinger of new physics or not.

My research will help understand the dynamics of the stored anti-muon beam using the electromagnetic calorimeters, such understanding being a key part of performing the measurement of the anomalous magnetic moment.

The experiment will be taking data for the first few weeks of my research, so I will also gain experience in the data collection process.

BIOGRAPHICAL SKETCH

My name is Grace Song and I am a junior majoring in physics and math. I was born in Pullman, Washington, but I grew up in Savannah, Georgia. My interest in physics started at a young age, when I first saw the rings of Saturn through a telescope at my elementary school's astronomy night, and the first research lab I joined at Cornell was the Niemack Group, where I helped test lenses that would be used in telescopes studying the cosmic microwave background. After my research internship at Kansas State University in the summer of 2018 where I studied neutrinos at Fermilab's MicroBooNE experiment, I decided to join a high energy group here at Cornell under Professor Anders Ryd to work on particle reconstruction in the Compact Muon Solenoid at CERN.

Outside of research, I have been a member of Cornell Mars Rover, and I am currently the Women in Physics and Diversity chair for the Society of Physics Students. In my spare time, I love rock climbing, dancing, cooking, and playing video games with my roommates.

STATEMENT OF PURPOSE

This summer I will be working on Muon g-2 under Professor Lawrence Gibbons at Fermi National Laboratory.

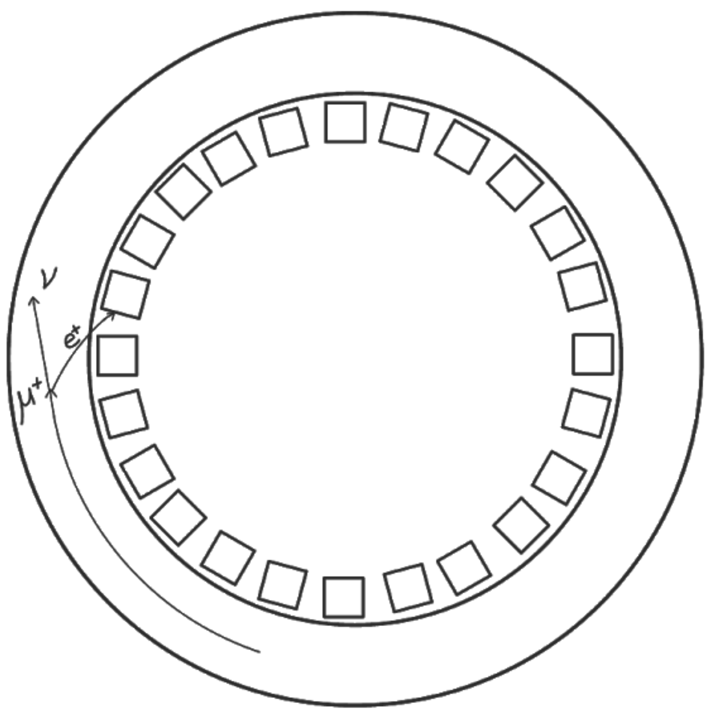
Muon g-2 is a high energy physics experiment that intends to make the most precise measurement of the anomalous magnetic moment of the muon. The anomalous magnetic moment is defined as

$$a = \frac{g-2}{2}$$

where the g-factor is a constant that describes how a particle's angular momentum is related to its interaction with a magnetic field. The muon anomaly has been theoretically calculated and experimentally measured to great precision, so any difference between theory and experiment suggest new physics beyond the Standard Model such as supersymmetry, new dimensions, or dark matter.

Brookhaven National Laboratory (BNL E-821 experiment) previously measured the muon anomaly to a precision of 540 parts per billion and discovered a greater-than-3 standard deviation discrepancy from the theoretical prediction, which does not meet the 5 standard deviation threshold to rule out a statistical fluctuation and claim a discovery. This motivated a new and improved Muon g-2 experiment (Fermilab E-989) that aims for a 140 parts per billion precision which is a factor 4 improvement over the BNL E-821 results.

The E-989 experiment, like its predecessor E-821, is a storage ring experiment. The Fermilab accelerator complexes produce a beam of positively charged pions that will decay into anti-muons. The anti-muons are injected into a big Penning trap that takes the form of a storage ring. In the storage ring magnetic field, the anti-muon spins precess and the anti-muons move about a circular orbit whose radius of curvature is dependent on the momentum of the anti-muon and the strength of the magnetic field. Eventually the anti-muons decay into neutrinos, which are neutrally charged, nearly massless fundamental particles which are not detected, and positrons, the antiparticle of the electron.



The positrons will have a shorter radius of curvature in the magnetic field than the anti-muon since they have a lower momentum, so they will curl towards the center of the ring and be detected by one of 24 electromagnetic calorimeters placed along the interior of the ring. When a positron hits a calorimeter, it is moving faster than the speed of light inside the material of the calorimeter and emits Cherenkov radiation. The energy of the positron is then calculated from the emitted light, alongside the position and time of the collision. This information can then be used to measure the spin precession frequency of the anti-muon and hence g-2 once it is convolved with a measurement of the magnetic field.

High precision measurements require systematic error to be accounted for and constrained. If we were to know perfectly the magnetic field the positrons traveled through to reach the calorimeter, we could accurately reconstruct where the muon decayed using the measured position and momentum of the positron when it hit the calorimeter and project the path of the positron backward to its origin. However, while we measure the field inside the ring to high precision to ensure the muons remain inside the ring, we do not know well the fringe fields between the ring and the calorimeters.

My project this summer will involve gauging our confidence in our estimates for the magnetic fringe field. We currently measure the beam's shape and distribution with external detectors, so being able to reconstruct the beam from the same calorimeter information used to measure the anomaly would reduce sources of systematic error. I will accomplish this through Monte Carlo studies comparing experimental data on the position of positron hits on the calorimeters with those simulated from a model of the anti-muon beam. Assuming the beam model is accurate, similarity between simulated and experimental results implies that our models of the fringe field are similar to the actual field in the experiment.