

A Precision Measurement of the Anomalous Magnetic Moment of the Muon

David Kawall, University of Massachusetts Amherst

Objective and Motivation: Experiment E989 is a new Intensity Frontier experiment, whose purpose is a precision test of the Standard Model and search for new physics at Fermilab, through a four-fold improved measurement of the anomalous magnetic moment of the muon to an accuracy of 140 parts-per-billion.

Most fundamental particles, such as protons, neutrons, and electrons, have a magnetic moment and behave like a compass needle in a magnetic field. The strengths of the magnetic moments of electrons and muons (which are like heavy electrons) can be predicted to very high precision using techniques of theoretical physics. Interestingly, part of the strength of a particle's magnetic moment is determined by the existence of "virtual" particles that appear and disappear out of vacuum, "dressing" the bare particle and changing its properties. This anomalous part of the magnetic moment, called $g-2$, is of great interest since it is affected to some extent by *all* the particles that exist in nature - the ones we know about, called the Standard Model particles, and the ones we don't.

There is great interest in a measurement published 2006 of the anomalous magnetic moment of the muon from Brookhaven National Laboratory. The result differed from predictions based on the Standard Model particles by more than 3 standard deviations, hinting perhaps at the existence of new particles. New physics is expected since the Standard Model is incomplete; it cannot accommodate the complete dominance of matter over anti-matter in the universe, or explain the nature of dark matter, dark energy, neutrino masses, or the tremendous range in the relative strengths of the fundamental forces. The improved precision of the Fermilab measurement is important to detect or reject the existence of the new physics hinted at by Brookhaven.

Experimental Method: The experimental procedure, in a nutshell, is to collide an intense pulsed beam of high energy protons with a target. Particles called pions emerge that are captured in a beam-line. The pions decay to muons, which are guided into a large circular magnet called a storage ring, which is the centerpiece of the experiment. The muons circle inside the storage ring and eventually decay to positrons (the anti-matter partner of the electron) that are detected. The detection rate oscillates in time at a rate proportional to $g-2$ and to the storage ring magnetic field strength. By measuring two things, the oscillation rate and the field strength with very high precision, the anomalous magnetic moment can be determined.

Fellowship Activities: The Intensity Frontier Fellowship will support work on the precision magnetic field measurement, where an accuracy of 70 parts-per-billion is required. The magnetic field is measured using Nuclear Magnetic Resonance (NMR), an unsurpassed technique for high precision work, which also forms the basis of MRI (magnetic resonance imaging). We will develop high precision NMR equipment and techniques to measure the $g-2$ magnet field strength. The Fellowship will also support work on preparing the storage ring magnet, feedback systems to stabilize the storage ring magnetic field, and the analysis of magnetic field data.