Proposal

E989 Muon $g-2$ reported in 2021 the world's most precise measurement of the anomalous magnetic moment of the muon, with an uncertainty of 0.46 ppm, or 0.35 ppm after combination with results of previous $g-2$ experiments [1]. In February 2023, the Muon $g-2$ collaboration reached its Technical Design Report (TDR) statistics goal of 21× the dataset taken in the E821 $g-2$ experiment at Brookhaven National Lab [2], and having reached this milestone we expect that the beginning of the 2023 Summer accelerator shutdown marks the end of the experiment's muon beam data collection. However, we plan to continue to operate the magnet and magnetic field measurement systems for a dedicated post-run study period, during which I will fill the role of Operations Manager. The TDR goal for the magnetic field measurement was an ultimate uncertainty of 70 ppb; with the analysis and hardware improvements already implemented and the effort of our post-run studies we believe that we will substantially beat this goal as well.

The experimental determination of the anomalous magnetic moment of the muon a_μ is accomplished in E989 by storing polarized 3.094 GeV/c muons in a 7.112 m-radius ring magnet and measuring the precession of their spins in the magnetic field as they orbit. a_μ is then constructed from the measurement of the anomalous precession frequency $\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c$, which is the difference between the total angular frequency of the spin precession and the cyclotron frequency of the stored muons, and the measurement of the magnetic field that muons experience in the ring. The expression for a_μ is

$$a_\mu = \frac{\omega_a}{\tilde{\omega}'_p(T_r)} \frac{\mu'_p}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2} \tag{1}$$

where the terms in the first ratio $\omega_a/\tilde{\omega}'_p(T_r)$ are our measured values of the anomalous precession frequency and the muon-weighted average magnetic field (expressed as the Larmor frequency of a proton shielded in a spherical water sample in that magnetic field at a reference temperature T_r, since we use Nuclear Magnetic Resonance (NMR) to measure the field). The other ratios are constants determined precisely by theory or other experiments [3]. Since ω_a and $\tilde{\omega}'_p(T_r)$ both appear directly in this expression, uncertainties on our measurements of the spin precession frequency and the magnetic field equally influence the final result.

In the months since reaching our "production" statistics goal, we have focused on systematic studies to better understand the corrections to and reduce uncertainties on the measurement of ω_a due to beam dynamics and detector effects. When the accelerators turn off this Summer, we will switch our focus to systematic studies relating to ω'_p. We expect to continue these magnetic field systematic studies at Fermilab until April 2024, followed by decommissioning and final absolute magnetic field calibration work at Argonne National Laboratory for a few months.

During the period of magnetic field studies we plan to more thoroughly investigate some of the known corrections and systematic uncertainties (such as the difference between the field that the muons experience and that which the field-mapping "trolley" measures due to presence or absence of materials in the muon storage volume in different configurations), carefully investigate transient field spatial dependencies (from the kickers and electrostatic quadrupoles), verify the sources of newly-discovered effects (such as the long-scale time dependence of discrepancies between trolley run field maps and fixed probe field tracking after a magnet ramp up, or the presence of an infinite series of magnetic "image charges" in the iron poles when the trolley is inserted), and perform the absolute field calibration to higher precision. Appendix A lists a number of the planned studies, with some motivation and detail for each.

During the magnet studies period, we plan to maintain roughly the same operations structure as we have used for beam data collection. The overall planning and organization will be the responsibility of the Operations Manager with the guidance of the overall field team's prioritization. There will be a set of run coordinators to directly oversee work in the experiment hall in MC-1, and field team experts proposing and carrying out studies will set up their experiments and provide instructions for shifters to monitor the data collection if needed. We will encourage participation from collaborators beyond the field team for run coordinator and shifter responsibilities.

The E989 final result is likely to remain the most precise measurement of the Muon's $g-2$ for at least a decade. It is key for us to make reasonable efforts now to reduce the final uncertainty and cross-check as many of our crucial measurements and methods as possible to improve our understanding of the systematics on this high-impact result.