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Muon g-2 experiment result represents world's most precise measurement yet of the anomalous magnetic moment of the muon

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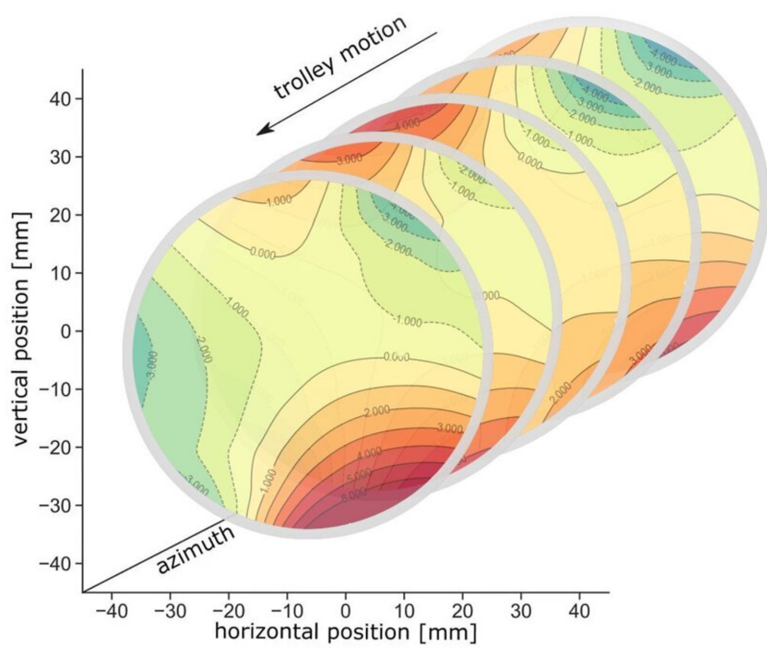

Typical magnetic field variations as mapped by the trolley at different positions in the Muon g-2 experiment's storage ring. Credit: Argonne National Laboratory.

The Muon g-2 collaboration has announced their much-anticipated updated measurement. The new result aligns with the collaboration's first result, announced in 2021—and it's twice as precise. In fact, it's the most precise measurement ever made using a particle accelerator.

The collaboration consists of 181 scientists from seven countries and 33 institutions, including the U.S. Department of Energy's (DOE) Argonne National Laboratory. The experiment takes place at DOE's Fermi National Accelerator Laboratory and aims to measure a magnetic property of the muon, a fundamental particle whose behavior might indicate the existence of new particles or forces.

Other Argonne scientists on the Muon g-2 experiment are postdoctoral researchers Yongyi Wu and Sam Grant, who will be maximizing precision in the determination of the magnetic field for the remaining datasets. The collaboration describes the result in a paper that they have submitted to *Physical Review Letters*.

Muons have a quantum mechanical property called spin, which causes them to act like a tiny magnet. When placed in a magnetic field, the muon's internal magnet precesses, much like the wobble of a spinning top. The speed of this wobble is determined by a quantity known as the magnetic moment, which scientists represent with the letter 'g'.

In the early 2000s, an experiment at DOE's Brookhaven National Laboratory measured the muon's magnetic moment and found a discrepancy between the experimental result and what was predicted by the Standard Model, scientists' current understanding of the particles and forces in the universe. The Fermilab Muon g-2 experiment is a recreation of Brookhaven's, built to challenge or affirm the discrepancy with quadrupled precision.

"With this second result, we have improved the precision by slightly more than a factor of two over both the Brookhaven experiment and our first result," said Argonne physicist Peter Winter, co-spokesperson for the Muon g-2 collaboration. "We are well on our way to improving the ultimate precision by a factor of four by the end of our analysis."

During the experiment, a beam of muons travels hundreds to thousands of times around a large, hollow ring under the influence of a strong magnetic field. As the muons circle the ring at near the speed of light, the magnetic field causes their spins to precess, and a flurry of so-called virtual particles influences that precession. The scientists determine 'g' by detecting the spin precessions of the muons and measuring the magnetic field strength in the ring extremely precisely.

At the simplest level, theory predicts 'g' to be two. But subtle influences from virtual particles popping in and out of existence can affect the muon's spin precession, causing its true 'g' to be slightly greater than two. The collaboration is measuring this difference, hence the name Muon g-2 (pronounced Muon g minus two).

"Every particle in existence plays a role in how a muon behaves in a magnetic field," said Argonne assistant physicist Yuri Oksuzian, a production manager for the Muon g-2 collaboration. "Instead of trying to observe these virtual particles directly, we are measuring their effects on the muon's behavior."

The new experimental result for g-2 is 0.00233184110. The measurement bolsters the result announced in 2021 with an unprecedented precision of 0.20 parts per million overall. It incorporates data taken during the first three out of six years of the experiment.

Two types of uncertainty affect the overall precision of the measurement. The statistical uncertainty depends on the amount of data analyzed; the more data, the more certain scientists are of their result. The statistical uncertainty was +/- 0.00000000043. With less than half of the total data analyzed, the team is already halfway to meeting their ultimate statistical uncertainty goal.

"We collected an enormous data set—more than 21 times the size of Brookhaven's data set," said Oksuzian, who leads the effort to process and prepare the large volume of data for analysis. The collaboration aims to incorporate all six years of data within the next few years.

The other factor, systematic uncertainty, is based on experimental imperfections, which the Muon g-2 scientists have been working diligently to minimize over the last several years. This uncertainty was +/- 0.00000000019.

"We do every little thing we can to squeeze the most out of these measurements," said Argonne assistant physicist Simon Corrodi, who led the analysis as field analysis coordinator and operations manager for Muon g-2. "Now, we have reached a total systematic uncertainty of 70 parts per billion, far surpassing our ultimate goal of less than 100 parts per billion." Corrodi will now serve as analysis co-coordinator for the remaining large datasets.

One of Argonne scientists' major contributions has been the precision measurement of the magnetic field strength around the ring. Although the muons travel through an impressively constant magnetic field, ambient temperature changes and effects from the experiment's hardware cause slight variations in the field. To measure these variations, the scientists mounted hundreds of probes to the walls of the ring. They also sent a trolley full of probes around the ring every few days.

To ensure the probes yield accurate readings, the scientists calibrate them using a solenoid magnet test facility at Argonne. The facility enabled the scientists to achieve field measurements down to just a few parts per billion—like measuring the volume of water in a swimming pool down to the drop.

During the next few years, a collaboration of theoretical and experimental physicists known as the Muon g-2 Theory Initiative will be hard at work to resolve tension between two ways of calculating the Standard Model prediction of g-2. In 2020, the initiative announced the best Standard Model prediction for g-2 available at that time. But a new calculation based on a different theoretical approach—lattice gauge theory—disagrees with the 2020 calculation.

"Our precise measurement is now even more important as we try to understand the theory discrepancy," said Corrodi. "It's a beautiful example of the dialog between theory and experiment."

Provided by Argonne National Laboratory

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