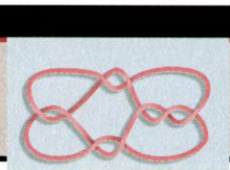
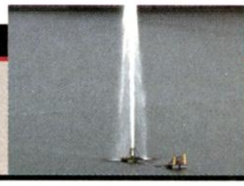
PAGE 965
Unraveling a knotty problem





965
Letting loose a killer

HIGH-ENERGY PHYSICS

Muon Experiment Challenges Reigning Model of Particles

The Standard Model of particle physics, for decades the seemingly unshakable ruler of the subatomic world, may have suffered a body blow this week. As *Science* went to press, physicists at Brookhaven National Laboratory in Upton, New York, were preparing to present results of a long-awaited experiment—results that contradict what the model predicts. The timing of the announcement prevented *Science* from contacting physicists not associated with the experiment. But barring a statistical fluke or undetected systematic error—both real possibilities—the Brookhaven observations appear to mark the best evidence yet that the Standard Model is just a province of a larger, shadowy realm: supersymmetry.

Particle men. Researchers working on Brookhaven's g–2 experiment pose atop the muon storage ring, a 14-meter-wide superconducting magnet. Early results seem to flout the Standard Model.

"It's a very high-precision measurement—the value is unequivocal. But the Standard Model itself is unequivocal," says Thomas Kirk, an associate lab director at Brookhaven. The measured and theoretical values disagree. "This implies that there must be physics beyond the Standard Model."

The Brookhaven experiment, known as g–2, measured the so-called "magnetic moment" of the muon, a heavier cousin of the electron. An object's magnetic moment describes how strongly it twists in a magnetic field. For classical objects, such as bar magnets, calculating the magnetic moment is easy. In the quantum realm, however, things get a good deal more complicated. Quantum objects such as electrons and muons exist amid clouds of evanescent particles that wink in and out of existence in fractions of a second. A muon might be surrounded by a zoo of photons, Z particles, and W particles, and it would interact with each member in the menagerie. Those interactions mess up the classical calculations of the muon's effective magnetic moment, throwing the value off by a tiny amount.

In the past, the Standard Model of particle physics has done a superb job of accounting for that anomaly. The model binds together all the fundamental particles—quarks, neutrinos, electrons, taus, muons, gluons, and so forth—with a mathematical framework that enables physicists to calculate statistically how particles will interact. Among many other triumphs, the model successfully predicts the anomaly in the electron's magnetic moment to within 1 part per billion—the limit of measurement error. "That's one of the major reasons why we believe the theory is really correct," says Gerry Bunce, project director for the experiment at Brookhaven. "It's a real underlying pillar of the Standard Model."

The muon's anomaly is less well known, as the particle is rarer. Theory predicts the value with an uncertainty of less than 1 part in a million, but experiments have not been precise enough to test the theory at that level—until now. For the past 3 years, physicists have been smashing beams of protons from Brookhaven's Alternating Gradient Synchrotron into targets, creating particles that eventually decay into muons. The muons, whose spins are all in the same direction, are fed into the field of a 14-meter-wide superconducting magnet. The field forces the particles to race in a circle and causes them to twist.

By analyzing the products of the muons' decay, the physicists can infer how much the muons twisted in the magnetic field, revealing their magnetic moment with an error of about 1.3 parts per million. The results show that the theoretical value and the experimental value disagree by about 4 parts per million. Statistically, the two values clash at the 2.6-sigma level of significance—a suggestive, but not definitive, result.

If the measurement holds up, the discovery will reveal a major flaw in the Standard Model. Physicists might respond by adopting an expanded model that includes new particles whose interactions affect the muon's magnetic moment. The best candidate thus far is supersymmetry, a theory that links the particles that make up matter (fermions) with those that carry forces (bosons) by providing every known particle with a still-undiscovered twin.

Most physicists would agree that a 2.6-sigma result is too weak to signal the beginning of the supersymmetric era. In high-energy physics, much firmer five- and six-sigma results fall through with alarming frequency (*Science*, 29 September 2000, p. 2260). But Lee Roberts, a Boston University physicist working on the experiment, says the Brookhaven result is less susceptible to statistical flukes than a standard particle hunt is because it comes from a more narrowly focused search. Furthermore, he notes, the Brookhaven team is still crunching numbers. Enough data remain on tape to reduce the error to half a part per million, Roberts says, and another year's run will bring the value down to one-third of a part per million. That would likely be enough to trumpet the failure of the Standard Model, if the discrepancy remains.

But Roberts acknowledges that this week's result stops far short of such a clarion call. "I would not claim discovery," he says. "But I would claim that it is very interesting and provocative." And it is indicative, one can predict to a high value of sigma, that more riveting announcements from Brookhaven are still to come.

–CHARLES SEIFE

CREDIT: BROOKHAVEN NATIONAL LABORATORY