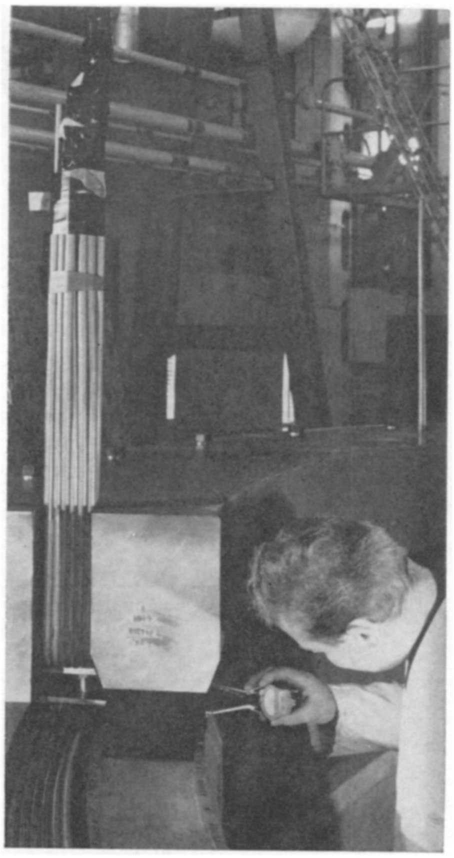
Right: checking the gap between magnet poles on the muon ring. Below: inspecting the electron counters inside the ring.



Seeking the why of the muon

Recent experiments still don't explain a particle that's been a puzzle for 30 years

by Dietrick E. Thomsen

"Consider the muon," Prof. I. I. Rabi once said. "Who ever ordered that?"

The muon, or mu meson to give its longer title, is only one of the things in particle physics that nobody ordered. But to many it is the most frustrating, since it has very little personality of its own.

In all the characteristics that distinguish particles from one another, the muon looks just like an electron, except in mass. The muon is about 200 times as heavy as the electron, and is often called the heavy electron.

Since it seems, apart from its mass, to be a duplication of effort, the question: Why the muon? has haunted quite a number of particle physicists.

The muon was so unexpected that for a long time after it was discovered it was mistaken for something else. When it was found in 1936, people thought it was the particle that Dr. Hideki Yukawa had predicted to be the carrier of the strong force that bound nuclei together.

But it turned out that the muon had nothing to do with carrying strong forces; the later-discovered pi meson is now accepted as the one that fits Yukawa's prediction.

The muon belongs to a group of particles that are mainly under the influence of the weak subatomic force, the one that governs beta radiation. This is a domain in which a number of strange things occur, including violations of basic symmetries of space and time (SN: 9/14, p. 265), and it is the center of great theoretical interest.

Physicists have sought a handle to the muon puzzle in attempts to find some additional characteristics in which it would differ from the electron and which might lead to a theoretical explanation of the mass difference and the muon's separate existence.

But despite an experiment recently done at the CERN laboratory in Geneva which probed the muon with greater intensity than ever before, the particle still shows no unambiguous difference from the electron.

The experiments were concerned with measuring the magnetic moment of the muon, its response to magnetic forces. They were designed to demonstrate some difference from the prediction of present theory, which does not explain why the muon and the electron should not be the same particle. On such a difference physicists might be able to build an explanation of the muon's existence.

The muon is an electrically charged body; it spins. This means that it sets up a small magnetic field as if it had a bar magnet along its spin axis. If a group of muons find themselves in an external magnetic field, the external field will try to line up the muon's fields with itself, just as the earth's field would line up so many compass

Photos: CERN

Farley: Test quantum electrodynamics.

needles. The numerical measure of the interaction between the two fields is the magnetic moment.

In the classical physics of macroscopic bodies, the magnetic moment depends on a body's mass and rate of spin. But in particle physics it was found experimentally that the classically derived value has to be multiplied by a so-called gyromagnetic ratio or g-factor.

The relativistic quantum theory worked out by Prof. P. A. M. Dirac predicted that the g-factor should be two for particles with half a unit of spin. The electron and muon are both in this category, and the prediction fits well enough with the accuracy of the experiments possible at the time.

In 1947, however, new measurements of certain atomic characteristics forced a change in the theory. Among other things, the new theory, quantum electrodynamics, predicts a slight increase over two in the g-factors: increases of 0.0011596 for the electron and 0.001165 for the muon.

It is to see whether these increases, the so-called anomalous magnetic moments of the particles, are exactly what theory predicts that the CERN experiments were set up. If a difference were found, it might force a change in theory that could give a plausible reason for the muon's existence.

On the other hand, however interesting such a difference might be to people who are curious about muon physics, it could prove a serious embarrassment to the theory of quantum electrodynamics. The theory has been precisely tested and confirmed with respect to the electron, and this has given physicists confidence in it. If the theory should fail with regard to the muon, it would be not only a surprise but a nasty dilemma for theorists.

The basis of the CERN experiment was that muons with the slightly increased magnetic moment will not behave as neatly in a magetic field as they would if their g-factor were exactly two. If the g-factor were two, the magnetic moments and therefore the spin axes of the muons would line up with the external field and stay that way. With the extra fraction added the moments precess around the direction of the external field the way the spin axis of a rotating top precesses around the vertical. And the speed of the precession will be proportional to the fraction by which the g-factor is greater than two.

To make the measurements, muons produced from energetic protons by a chain of interactions were collected and circulated in a muon storage ring having a magnetic field of 17 kilogauss. The precession was timed by recording electrons that are given off as the muons in the ring decay radioactively. The electrons come off in the direction that the muon axes happen to be pointing at the moment of any individual decay.

Repeated experiments of increasing accuracy have been giving measured values that appear slightly higher than the theoretical prediction. The latest result shows the anomalous part of the magnetic moment as being about four or five 10-thousandths of itself greater than theory predicts. For the entire magnetic moment this would result in an increase of two or three 10-millionths.

Whether or not these figures represent a significant deviation from theory depends on statistical arguments. At least one observer suggests that quantum electrodynamics may have difficulty adjusting to them. The authors of the latest experiment, Dr. F. J. M. Farley and his associates say only: "This result tests quantum electrodynamics to new levels of precision."

The next step is to carry the experiments to even higher precision to see whether some unambiguous departure from theory will show up. If theory has to be corrected at this very fine level, physicists feel it will probably be because here a purely electrodynamic theory no longer suffices.

The authors of the present experiment suggest that it may be the weak subatomic force, to which muons are known to be subject, whose effect is mixing in. Prof. Leon van Hove, who until recently headed CERN's theoretical physics department, goes even further and suggests that it may be the strong nuclear force that mixes in by way of some connection between itself and electromagnetic forces. Both of these would have to represent modification of existing electromagnetic theory, which deals only with electrical forces. ◇