CERN Muon Ring Finds g Agrees with Electrodynamics

To study the muon, catch one and watch its spin precess. Any difference between the precession rate you see and the one predicted by modern electrodynamics may be a clue to that puzzling enigma: What is the real difference between the muon and the electron? They appear to be alike except that the muon is 207 times as massive as the electron. But nature usually observes strict economy and does not display any particles that do not fit uniquely into the scheme of things.

The experiment in which Francis J. M. Farley and his CERN coworkers (John Bailey, Walter Bartl, Robin Brown, Hans Jostlein, Simon van der Meer, Emilio Picasso) watch muons (PHYSICS TODAY, December, page 61) still shows the same value of $(g - 2)/2$ that electrodynamics predicts: $0.001\,165 \pm 0.000\,003$. This is the last published result in their so-called "$g - 2$" experiment (*Nuovo Cimento* **44**, 281, 1966.) But now they have introduced refinements that will lead to a ten-fold improvement in their accuracy in the anomaly, $(g - 2)/2$, reaching, perhaps, one part in 3000. We discussed it with them on a recent visit to CERN.

Recent refinements needed to improve accuracy are as follows: More counters improve the statistics. The system now accepts five bunches from the synchrotron out of every 20 instead of the former two. Self-servo nuclear-resonance probes monitor the magnetic field. They find the resonance and lock on so that the output frequency is exactly proportional to the field. Determination of the muon orbit frequency in the early part of the pulse enables calculation of the mean radius of the orbit. The calculation is necessary for finding the mean field because the field has a gradient with respect to radius.

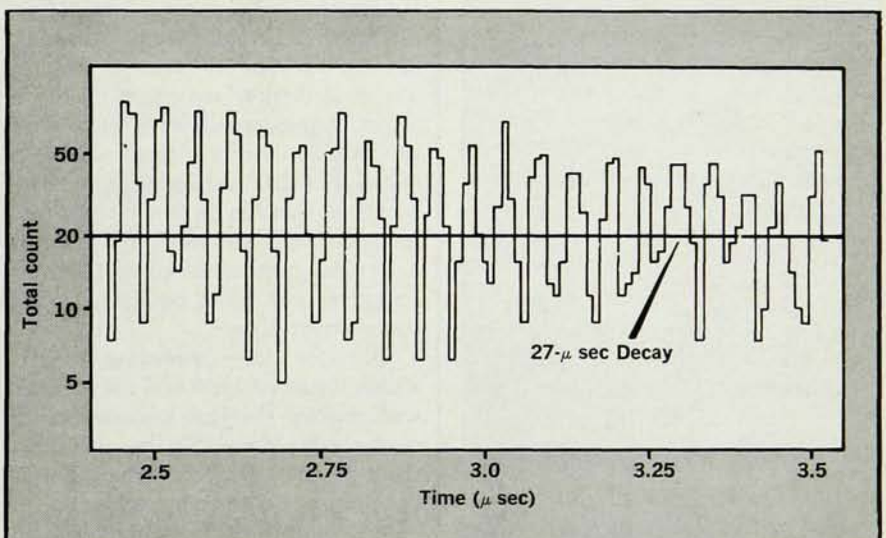
Catching and watching muons isn't easy. The Farley group accomplishes the task with a 5-meter-diameter storage ring that has a 17.1-kilogauss field. A burst of 10^{11} 10-GeV protons from the CERN proton synchrotron strikes a target from which come about a million 1.3-GeV negative pions. The pions get trapped in the ring and decay into muons with a 250-nanosecond dilated half-life. Thus about 20% of them decay into muons while the pion bunch makes its first circuit. The fastest of the newborn muons and most of the pions strike the target at the end of the first circuit and are lost. But about 100 muons are born with just the right momentum (about 1.28 GeV/c) to miss the target and stay trapped in the ring with an orbit slightly smaller than their parent pions had. Nonconservation of parity ensures that these muons born with a special momentum are also born with their spins lined up parallel to their velocities.

Pion decay occurs with a natural half-life of 25 nsec, but in this experiment relativistic time dilation stretches this half-life to about 250 nsec. Meanwhile muon decay, dilated, is occurring with a half-life of 27 microsec instead of the normal 2.2 microsec. Thus for purposes of the experiment the injected muons are an instantaneous pulse, 97% polarized with the spin parallel to the muon linear momentum.

Spin precession. If g, the ratio between magnetic moment (in Bohr magnetons) and angular momentum (in units of $h/2\pi$) were exactly 2, the spin would precess just fast enough to stay lined up with the linear momentum as the particles run around the ring. But since g is not precisely 2, the spin precesses with respect to the momentum vector at a rate proportional to the anomaly, which has a magnitude of order $\alpha/2\pi$ where $\alpha = 1/137$ is the fine-structure constant. The effect is a purely quantum one due to the thin cloud of virtual photons surrounding the particle.

Now all you have to do is observe this precession rate, and Farley and his colleagues do so by counting the most energetic electrons produced by muon decay. Their counting method is a trick to make sure that the system is sensitive only to electrons emitted in the direction of the muon linear momentum. Lorentz transformation of electron energy ensures that in laboratory coördinates these decay electrons have high energies. Electrons emitted backward have low energies and are not detected.

The counting curve (figure) is basi-



COUNTING RATE FROM CERN MUON RING has modulation that corresponds to spin precession superimposed on relativistically dilated muon decay rate with 27-microsecond half-life. Experiment measures g – 2.

cally an exponential muon decay at dilated half-life of 27 microsec. Superimposed on it is the 3.7-microsec precession of the muon spin (which is not relativistically dilated).

Once more nonconservation of parity in beta decay ensures that when a muon decays to produce an electron, the electron comes off preferentially in the direction of muon spin. So when the spin is pointing forward, many forward decays occur and many energetic electrons are detected. When the spin points backward, the number of energetic electrons is small. Thus the electron counting rate is modulated at the frequency of spin precession.

Besides promising to increase by a factor of ten the accuracy with which $g-2$ for the muon is known, the experiment has some other accomplishments. It has provided the first clear demonstration of relativistic time dilation in an out-and-back system. And comparison with a $g - 2$ experiment performed by the same group in 1965 (*Nuovo Cimento* **37**, 1241, 1965) has already shown that negative and positive muons have the same g to an order of five parts in a million. Theoretically the two g's must be equal if any one of CPT, CP or C is a good symmetry. —RHE

Los Alamos Scyllac—A Better Theta Pinch

If Congress will approve, Los Alamos Scientific Laboratory is ready to build Scyllac, fifth in its series of Scyllas. The new device, according to its designers' hopes, would have a time-density product within a factor of 10–20 of the 6×10^{13} sec/cm^3 required for energy breakeven in a deuterium-tritium plasma. The time-density product is the product of plasma density (particles per cubic centimeter) and containment time.

Like the four preceding Scyllas, which began in 1958 and are credited with making the first laboratory thermonuclear plasma, Scyllac will be a theta pinch—a device in which current through a single-turn coil makes a plasma-compressing longitudinal field. Its 15-megajoule capacitor bank will drive a 15-meter linear device, which will subsequently be converted to a torus with a 5-meter major diameter.

Building the machine already has the unanimous recommendation of the ad hoc panel appointed to examine it by Amasa Bishop, director of the US Atomic Energy Commission controlled-thermonuclear-research program, and also of the AEC standing committee that examines all CTR projects. Now it needs about $8 million from Congress to start construction.

First step in the research program will be the 15-MJ bank and a building. Then will follow the linear device and after that the torus with a 5-meter major diameter. Besides its pinch field the torus (figure) will have auxiliary fields for equilibrium and stabilization.

Controlled-fusion physicists generally agree that the basic limitation in present large linear theta pinches is plasma loss from coil ends. This loss masks such phenomena as possible radial anomalous diffusion (microinstabilities) and gross (flute) instabilities that are too slow to be observed in present machines. Fred L. Ribe and Warren Quinn, who told PHYSICS TODAY about their plans for Scyllac, hope that both linear device and torus will have containment times long enough (for example, several hundred microsecs in the torus) to enable study of these phenomena. A theta pinch offers a unique opportunity to observe both kinds of instability, which have been extensively studied in low-beta, low-temperature plasmas, in the different, high-beta environment. The ratio β of particle pressure to confining-field pressure in the high-beta theta pinch is about one.

In a toroidal plasma one expects an outward plasma drift because confining field decreases with major radius. In a high-beta plasma, magnetic pressure is made uniform over the plasma surface with auxiliary fields that make the inner torus surface bumpy. Thus magnetic field lines have equal lengths inside and out. In Scyllac external stabilizing conductors, energized independently of the compression-heating field, will stabilize plasma drift. The figure shows these conductors in slots of the compression coil and their energizing capacitors connected from below. The large aspect ratio (slight curvature) of Scyllac makes drift time to the wall long enough to allow sepa-