of the universally held belief in conservation of lepton number. They do not see a third muon (trimuons); so they believe that the third lepton in the final state is a neutrino. Thus they observe the following reaction:

$$\nu_\mu + (A,Z) \rightarrow \nu_\mu + \mu^- + \mu^+ + \text{hadrons}$$

In a process initiated by a muon neutrino, one automatically expects a negative muon in the final state. But where do the positive muon and the second muon neutrino come from? They could be coming from the decay in flight of a pion or kaon. To check for this possibility the group used targets with two different hadron absorption lengths—solid iron and a liquid scintillator. The probability of a pion or kaon decaying in flight is roughly four times less in the iron than in the liquid scintillator. So you would expect, if pions or kaons are being produced, that the number of dimuon events in the liquid scintillator would be four times larger than in the iron for equal masses of target. Instead, the number of events is equal.

A second possible source of the second muon and second neutrino is from a direct process. The calculated cross section for this four-fermion process is 1000 times smaller than the rate the experimenters observe.

**All other possibilities** are of considerable interest. It could be a charged intermediate vector boson, W; it could be a neutral heavy lepton, $L^0$; it could be a new type of hadronic matter, which the experimenters call a Y particle.

Mann told us there are several reasons for ruling out the charged W and the $L^0$. From their data on single-muon production, the experimenters find that the mass of the charged W would probably be greater than 25 GeV—a value too high to account for the dimuon events. If a low-mass charged W were being formed in the single-muon events, the mean four-momentum transfer would severely depart from linear dependence. Instead it is linear with energy up to 200 GeV.

Pais and Treiman, in their analysis,[5] assume that a heavy lepton is formed and then show that the data do not agree with this assumption. To describe in dynamic detail the process of a heavy lepton producing muon pairs is extremely complicated because one must assume details of the production mechanism (or mechanisms), the decay mechanism, the polarization and the mass. Instead, Pais and Treiman found an argument that depends on practically no theoretical assumptions.

They assume that the heavy lepton or leptons have spin ½ and that the decay coupling of the heavy lepton to the positive muon, negative muon and neutrino is local; that is, the coupling is vector, axial vector, scalar, pseudoscalar or tensor.

Pais and Treiman were able to find a simple upper and lower bound on the size of the ratio $R$ of the average energy of the negative muon to the average energy of the positive muon. They found that

$$[9 - 4(2)^{1/2}]/7 \le R \le [9 + 4(2)^{1/2}]/7$$

That is, the ratio has to lie between 0.48 and 2.1. To their delight this bound was useful. The experimentally observed value is 3.7 ± 0.65. Thus the experimental value lies outside the region allowable for a heavy lepton.

(A less general argument concerning the same ratio was made for the charged W several years ago by Robert Brown, now at Case Western Reserve University, and John Smith of the State University of New York at Stony Brook. They found that the ratio would be about 0.4.)

**New hadronic matter.** With all other possibilities eliminated, the group concludes that they have found a new form of hadronic matter. Indeed in 1973 George Snow (University of Maryland) pointed out[6] that one of the most characteristic signals for the existence of charmed particles would be the discovery of neutrino-induced dilepton events.

Mann explains that the new matter must necessarily carry a new quantum number because the Y particles decay weakly to a second muon and a neutrino. If there were no new quantum number, the massive Y particles would decay strongly or electromagnetically. Because the new quantum number must be conserved, the decay of the Y particle by strong or electromagnetic processes is forbidden.

The experimenters do not know how many of the new particles exist, but at least some of them have masses in the range 2–4 GeV. Their lifetimes are less than $10^{-10}$ sec. At least some of them are charged.

In addition Mann expects Y particles to exhibit a weak decay into hadrons exclusively, as well as the observed semileptonic or leptonic decay modes. (Such a hadronic decay was reported last March in Paris by Robert Palmer and his collaborators at Brookhaven.) Furthermore, in neutrino and antineutrino inelastic reactions, single Y particles seem to be produced about as abundantly as single strange particles.

The Harvard-Penn-Wisconsin-Fermilab group has also found seven dimuon events produced[4] in antineutrino-induced interactions. Further analysis shows that the rate for dimuon events produced by neutrinos and by antineutrinos could be roughly comparable. If this is indeed the case, then, Pais and Treiman[7] note, important new constraints arise on the question, much discussed recently, how many kinds of generic charm exist. The simplest possibility, according to them, is that there is only one kind of charm—the type introduced by J. D. Bjorken (SLAC) and Sheldon Glashow (Harvard) in 1964. That is, instead of three quarks, one would need one more, the charmed quark. If there is only one kind of charm and if the new experiments are correct, then it follows that the charm-producing antineutrino reaction is associated with the so-called "sea" of quark–antiquark pairs in the nucleon. That result would put very severe constraints, they say, on attempts to build a model that involves right-handed doublets of quarks. —GBL


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## Indiana cyclotron begins scattering experiments

Scientists at the Indiana University Cyclotron Facility have extracted a proton beam from the cyclotron and are beginning high-resolution scattering experiments. The $11-million variable-energy device represents a joint effort on the part of the university and the National Science Foundation.

Protons were first accelerated to an energy of 130 MeV at the laboratory in August, with energies of up to 200 MeV anticipated. The beam was subsequently delivered to a target at the spectrograph station, and early inelastic scattering spectra were obtained with 0.07% overall energy resolution. Thus the device, the largest isochronous cyclotron in the US, is nearly ready for full operation.

About 60% of the initial capital funds for the regional facility were provided by NSF and the rest by Indiana University. The design of the cyclotron was conceived and directed by Martin Rickey, and it has been brought into operation under the direction of Robert Pollock; both are members of the university's physics department. □