

search & discovery

Dimuons at Fermilab suggest new form of hadronic matter

Neutrino experiments at Fermilab conducted over the past two years, in which pairs of muons are produced, appear to show the existence of a new form of hadronic matter. The discovery suggests that matter carrying a new quantum number has been observed. This quantum number is often generically referred to as "charm."

The experiments have been done by a collaboration between Harvard University, University of Pennsylvania, University of Wisconsin and Fermi National Accelerator Laboratory, consisting of Alberto Benvenuti, David Cline, William T. Ford, Richard Imlay, Ta-Yung Ling, Alfred K. Mann, Robert Orr, Donald Reeder, Carlo Rubbia, Ray Stefanski, Larry Sulak and Peter Wanderer. Their first results were reported in the summer of 1974 at the London Conference on High-Energy Physics.¹ Since then about 80 more events have been found so that the situation has become clearer.

Over the past couple of months the group has published three new papers^{2,3,4} reporting their results for neutrinos and antineutrinos and stating the case for their belief that they have found a new form of hadronic matter. The belief rests strongly on an analysis by Abraham Pais (Rockefeller University) and Sam Treiman (Princeton University), which puts stringent bounds on the properties of a heavy lepton; the experimental results lie outside these

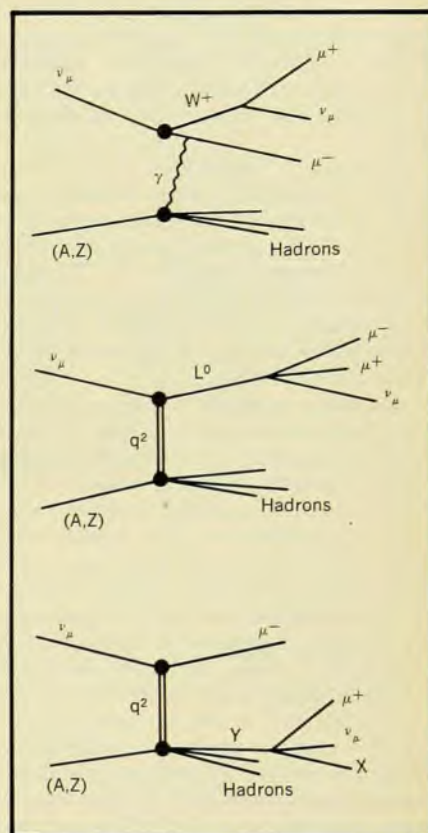
Pais-Treiman bounds.

Meanwhile a different neutrino experiment at Fermilab, done by Barry Barish, Frank Sciulli (Cal Tech) and their collaborators has also found two muons in the final state. The group reported their preliminary results at the Paris Conference held last March. In Paris Soviet experimenters from Serpukhov also reported two muons in the final state.

Recently at the Conference on Quarks and the New Particles held at the University of California, Irvine on 5 December, Juergen von Krogh (University of Wisconsin, Madison) reported that he and his collaborators, using the 15-foot bubble chamber at Fermilab, had observed four dilepton events, in which one of the leptons was a negative muon and the other a positron. (In all four events a K^0 was also seen.) Also at the Irvine conference, Charles Peyrou reported that experiments from Gargamelle at CERN had recently seen a second neutrino-induced event in which a negative muon and positron were produced.

The Fermilab experiment employs a beam of neutrinos striking a target. In most events a single muon is produced (although 30% of the events involve neutral currents; in this case no muon exists), but about 1% of the time a pair of muons comes off, usually one of each sign; such a pair is called a "dimuon." Over the past twenty years it has been

continued on page 19



Feynman diagrams for neutrino-induced production and subsequent decay of (top) charged intermediate vector boson, W^+ , (middle) neutral heavy lepton, L^0 , and (bottom) the proposed new type of hadron, Y .

Argonne and others propose intense pulsed neutron source

Development of an intense pulsed neutron source for solid-state physics research has been proposed by Argonne National Laboratory to the Energy Research and Development Administration. Meanwhile, scientists at Oak Ridge National Laboratory and Los Alamos Scientific Laboratory continue to examine their own facilities' advantages as source sites for neutron scattering studies.

The view from Argonne. The Argonne laboratory's proposed facility would be a much more ambitious version of the earlier projected ZGS Intense Neutron Generator, a \$16 million effort, which was to have employed the lab's new in-

jector for the Zero Gradient Synchrotron. The present \$58 million proposal specifies construction of the intense pulsed source in two stages: The first stage would be based upon the 500-MeV ZGS Booster II synchrotron, which will be capable of generating 5×10^{12} protons/pulse at 30 Hz and which is expected to operate in the autumn of 1976. In the second phase, an 800-MeV dedicated high-intensity synchrotron system would produce 5×10^{13} protons/pulse at 60 Hz. Two neutron-producing targets would be employed in separate facilities for slow-neutron scattering and for radiation-effects research.

Researchers chose the synchrotron as

their proton accelerator because it can provide the very short pulses needed for high-resolution slow-neutron spectroscopy. In the neutron scattering source, a hydrogenous moderator would serve to produce short pulses for scattering research. In the radiation damage source, a tungsten moderator surrounding the target would enhance the fast-neutron flux for radiation-effects experiments.

In the first state, the 4π -equivalent thermal neutron flux at the neutron-scattering facility would be 1.5×10^{15} neutrons/cm²-sec; in the second, the peak flux would reach 10^{16} neutrons/cm²-sec. In addition, the neutron spec-

tra from the moderators are expected to be rich in "epithermal" neutrons (more energetic than thermal ones). In the radiation-effects facility, time-average fast neutron ($E > 0.1$ MeV) fluxes of 1.5×10^{13} and 3×10^{14} neutrons/cm²-sec would be generated in the two stages. The accompanying flux of gamma rays would be very small, an advantage for many kinds of measurements.

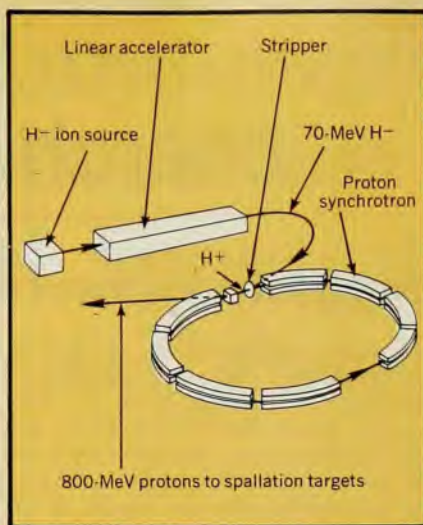
The Argonne lab has submitted a major construction proposal for the source, according to John Carpenter, project manager, for consideration by ERDA's Materials Research branch. The agency is examining the possibility of funding the proposal for fiscal year 1978.

Research in preparation for the first phase of the intense pulsed facility has gone on at the laboratory for two years by means of a prototype device based on the 200-MeV Booster I. Experimenters conducted neutron-diffraction and inelastic-scattering studies, reports David Price, director of Argonne's Solid State Science Division.

Oak Ridge considers. A group at the Oak Ridge laboratory has met to analyze the feasibility of modifying the Oak Ridge Electron Linear Accelerator to provide thermal neutrons for solid-state physics experiments. The facility was built originally for neutron cross-section studies of nuclei. Robert Peelle, co-director of the accelerator, urges that the changes necessary to make the device also a source for slow neutrons would be minor and—at \$9 million, including \$2 million for experimental facilities—comparatively inexpensive. However, no formal proposal has been made, though the idea has been extensively studied.

The Oak Ridge facility has a high pulse rate, 1000 pulses per second. If a narrow pulse width of less than 1 microsecond were assumed, and if the entire accelerator capability were utilized, a fast-neutron production rate of 10^{16} neutrons/sec could result, spread among the 1000 pulses. This is about five to ten times weaker than is provided for in Argonne's proposal for research with epithermal neutrons. Peelle suggests that the chief advantage of the contemplated modification is that, for a low capital investment, a facility three orders of magnitude higher in pulsed fast neutron production than any device currently devoted to scattering research would be obtained.

And Los Alamos. The Los Alamos workers have recognized the potential for employing its nearly completed Weapons Neutron Research Facility as an instrument with which to conduct solid-state physics. The \$5.5-million device, scheduled for initial operation in late 1976, is to be a pulsed source that will utilize 800-MeV protons from the Clinton P. Anderson Meson Physics



Proposed Argonne intense neutron source is to use H⁻ ion stripping to obtain protons.

Facility (commonly called "LAMPF") to produce neutrons by spallation for time-of-flight spectroscopy. As presently planned, the proton beam intensity at the target will be up to 10^{12} protons/pulse at a repetition rate of 120 Hz, which provides a time-average current of 1.2×10^{14} protons/second. This

figure is comparable with the proton output of Booster II in the Argonne proposal, and the protons would be at a higher energy. For an equivalent target-moderator configuration, the Los Alamos facility would provide an approximate 60% increase over Argonne's thermal-neutron flux.

The lab has placed a \$10 million proposal before ERDA's Division of Military Applications for FY 1977 funding of a proton storage ring to enhance the facility's pulsed-neutron capability. The ring would be for weapons research, according to Physics Division leader Henry Motz and facility program manager Roger Perkins.

Overseas, the Soviet Union has progressed in the last 15 years through a succession of pulsed fast reactors, called "IBR's," at Dubna. The IBR-II, a 2-MW device that could generate a very high fast-neutron production rate, is expected to begin operation within a year. Pulsed facilities with a fast-neutron production rate of 10^{13} neutrons/sec exist at Tohoku in Japan and at Harwell in the United Kingdom. Scattering researchers anticipate a tenfold increase in this rate at Harwell upon completion of a new linear accelerator. —FCB

Promising new results from Alcator

New results from the MIT tokamak caused quite a stir when they were reported at the APS plasma-physics division meeting in St. Petersburg, Florida in mid-November. The experiment, known as "Alcator," achieved a value for the Lawson number, $N\tau$ (where N is the peak particle density and τ is confinement time) greater than 10^{13} sec/cm³. This value for $N\tau$ is five times greater than has been achieved in any other confinement experiment. It is generally believed that an $N\tau$ of about 10^{14} sec/cm³ and an ion temperature of about 6 keV must be achieved to reach breakeven conditions for a fusion plasma.

The Alcator plasma is unusually free from impurities. Furthermore, as the density has been raised, the scaling for which τ is proportional to N has continued to hold.

Alcator is located at the MIT Francis Bitter National Magnet Laboratory, and its development has been led by Bruno Coppi, Bruce Montgomery, Ronald Parker and Robert Taylor. In addition to other experimenters at MIT, the group has included people from the laboratories at Juthaas, Holland, Frascati, Italy, Fontenay-aux-Roses, France, and Kurchatov Institute, USSR.

Alcator, unlike most toroidal confinement devices, is capable of sustaining high plasma current densities without inducing macroscopic plasma instabili-

ties, thanks to its reduced dimensions and higher magnetic field that distinguish it from other tokamaks. In addition this device has produced a much wider range of plasma densities. In earlier experiments (PHYSICS TODAY, June 1975, page 18) the device was operated at 65 kG. The new results have been obtained at 75 kG, and the machine is expected to be able to reach 100 kG.

In the new experiments, the MIT team found that they could achieve high plasma densities by keeping constant the ratio of the poloidal field to the toroidal field (the ratio is about $1/25$) as they raised each field value. And the temperature increased essentially proportionally to the poloidal field.

For a current of 100 kA at 75 kG, the temperature at the center of the plasma column was about 1 keV. Density was about 6.5×10^{14} particles/cm³ and confinement times were greater than 20 millise. Thus $N\tau$ was greater than 10^{13} sec/cm³.

The observation of scaling behavior has pleased the MIT experimenters. They find that as N is increased, τ increases roughly proportionately, so that $N\tau$ increases roughly as N^2 . This behavior persists over the whole range of densities studied, which can be varied by a factor of 200. Coppi told us that the MIT group has no sure explanation of why τ is roughly proportional to N ,