Neutrinos: Current Experiments at CERN

Geneva. Present attention to the European Organization for Nuclear Research (CERN) naturally centers on the cautious diplomacy leading towards CERN Mark II and the 300-Gev synchrotron (*Science*, 3 February). At Serpukhov, near Moscow, Soviet engineers are hurrying to complete their 70-Gev machine in time for the 50th anniversary of the Bolshevik revolution in November of this year. A large effort for improving the 28-Gev machine at CERN will culminate in the completion of intersecting storage rings for study of high-energy proton-proton collisions. Meanwhile research proceeds with both the existing proton synchrotron and also with the 600-Mev synchrocyclotron.

One of the noteworthy projects at CERN is the continuing study of the neutrino. CERN is at some disadvantage compared with Brookhaven in the number of high-energy protons produced by the big machines in a given interval. Brookhaven can make more neutrinos than CERN can. But the leader of the CERN nuclear physics apparatus division, C. A. Ramm, is confident that, by careful beam design and machine improvements, CERN can keep up with Brookhaven in neutrino experiments during the next 5 years. These years are likely to see neutrino physics becoming a matter of routine study with a thousandfold increase in the rate of occurrence of bubble-chamber events.

The new neutrino beam at CERN is itself a big advance and is expected to permit observation of several dozen events per day. The CERN neutrino count was already higher than that in other laboratories, and to increase it by a factor of ten seemed at first sight impossible. But it has been done by a combination of measures: (i) enlargement of the volume of the heavy-liquid bubble chamber (more than double) to 1180 liters, making it the biggest in the world; (ii) an improved magnetic horn and two new tubular magnetic reflectors for focusing the neutrino parents, pions and kaons, toward the bubble chamber; (iii) rebuilding the "stopper" of steel ingots that filters out unwanted particles. (This steel totals 6000 tons, and belongs to the Swiss government's strategic reserve.)

The stopper contains a mercury pipe which, when emptied, allows muons to pass through. This option permits checks to be made on the beam arrangement and also provides an opportunity for a pilot experiment on muon-proton interactions in the bubble chamber. In addition, the stopper is instrumented for measurement of the energy spectrum of muons within it, from which the energy spectrum of the emergent neutrinos can be deduced.

The bubble chamber enlargement gives a gain factor of 2.4 in the observable neutrino events; the other measures, a factor of 6. Further gains are expected from the increase in the proton synchrotron's pulse repetition rate next year, and from possible use of a heavier "stopper." In 1969, a very big heavy-liquid bubble chamber, "Gargamelle," with an effective volume seven times greater than that of the present bubble chamber is due for installa-

Table 1. Current experiments at CERN with the 28-Gev proton synchrotron. [Adapted from data in *CERN Courier* 7, 63–68 (1967)]

Study	Incident particles	Detector	Participating
Proton-proton scattering	Protons	Counters	CERN
Complex nuclei interactions	Protons	Emulsion	Valencia, Warsaw, CERN
Pion-proton scattering	Pions	Spark chambers	CERN
Scattering from polarized protons	Negative pions	Spark chambers	Saclay, CERN
Scattering from polarized protons	Negative kaons	Counters	FOM, Utrecht, CERN
Scattering from polarized protons	Various	Counters	Orsay, Pisa, CERN
Neutral meson resonances	Negative pions	Counters and spark chambers	Karlsruhe, CERN
Neutral meson decay	Negative pions	Spark chambers	Bologna, CERN
Neutral meson decay	Negative pions	Spark chambers	Zurich, CERN
Kaon and lambda/sigma production	Negative pions	Spark chambers	Orsay, Pisa
High-energy interactions	Negative pions	2 m*	Aachen, Berlin, Bonn, Cracow, Warsaw, CERN
Lambda particles	Negative pions	Emulsion	Ankara, Lausanne, Munich, Rome, CERN
Kaon decay	Neutral kaons	Spark chambers	CERN
Strange particles	Negative kaons	2 m	Paris, Orsay, Oxford
High-energy resonances	Negative kaons	2 m	Aachen, Berlin, London, Vienna, CERN
Lambda-sigma parity	Negative kaons	81 cm†	Heidelberg
Hyperon resonances	Negative kaons	81 cm	Heidelberg, Saclay, CERN
Hyperfragments	Negative kaons	Emulsion	Belgrade, Clermont-Ferrand, Delhi, Dublin, Brussels, East Berlin, London, Strasbourg, Warsaw, CERN
Strange particles	Antiprotons	2 m	Orsay, CERN
Lambda-antilambda pairs	Antiprotons	2 m	Paris
D^0 meson	Antiprotons	2 m	Paris, Liverpool, CERN
Proton-antiproton interactions	Antiprotons	2 m	Hamburg, Padua, Pisa
C^0, D^0, E^0 mesons	Antiprotons	81 cm	Liverpool, Paris, CERN
Discussed in text			
Neutrino-proton interactions	Neutrinos	Propane bubble chamber	CERN
Muon conservation	Neutrinos	Spark chambers	Fribourg, CERN
Muon gyromagnetic ratio	Stored muons	Counters	CERN
Nuclear chemistry	Protons	Mass spectrometer	Orsay

* 2-meter hydrogen bubble chamber. † 81-cm hydrogen bubble chamber.

tion by a group from Saclay, where it is being built. In the early 1970's, the beam intensity of the proton synchrotron is expected to be increased by a booster injector.

Meanwhile, what physics is being done with the new neutrino beam? In an earlier CERN experiment, the data mostly concerned elastic neutrino-neutron interactions in the bubble chamber in the nuclei of the constituents of a freon (CF_3Br), producing observable protons and muons. Now data on inelastic neutrino-proton interactions is being sought. Neutrino-proton interactions produce pions as well as muons, but in heavy nuclei, such as those of freon, the pions tend to be absorbed: hence the switch to propane (C_3H_8) as the liquid in the bubble chamber. Propane contains a greater number of protons per unit volume than liquid hydrogen does, and therefore several neutrino-proton events are observable each day; the presence of carbon nuclei gives five times as many events, but most of the secondary particles from these interactions can be sorted out by the use of a 27-kilogauss magnetic field within the chamber. Beyond the bubble chamber, an array of spark chambers will be used to observe neutrino-produced muons deflected by the magnetic field in the bubble chamber, and thus to verify (to an accuracy of one event in a thousand) the muon-conservation law that the neutrino always yields a negative muon while the antineutrino yields a positive muon.

More generally, the new experiments will represent a big advance over the rather crude neutrino experiments of the past. "The aim," as L. van Hove, chief theoretician at CERN, puts it, "is to study absolutely precise, clean reactions." Deeper questions are now being asked: for example, do neutrons "look" the same to neutrinos as they do to other particles, such as electrons?

Another important study at CERN promises the most precise determination of one of the very few properties of the muon that distinguishes it from the electron: the gyromagnetic ratio relating its spin and magnetic moment, which differs from that of the electron by half a percent. With the use of a muon storage ring 5 meters in diameter, the gyromagnetic ratio of negative muons has been determined to be better than one part in a thousand, and the value agrees with the predictions from quantum electrodynamics. Reversal of the polarity of the storage ring, and improved instrumentation, should now give an even more precise value for the gyromagnetic ratio of the positive muon.

Despite the growing interest in neutrinos and other leptons (weakly interacting particles), the work at CERN continues to be dominated by investigation of the strong nuclear force—in particular by the classification of hadrons (strongly interacting particles) according to unitary symmetry. Several experiments are in progress to aid understanding of particle collisions in terms of the new classifications through systematic comparisons of interactions between protons and a wide range of incident particles. Table 1 shows current work with the proton synchrotron at CERN and serves, incidentally, to illustrate the international character of the undertaking.

At the end of June a key piece of equipment for a new and unique CERN facility arrived at Geneva from the University of Aarhus, Denmark. It is the isotope separator for the Isolde project, which is linked to CERN's 600-Mev synchrocyclotron and will open up new opportunities to nuclear physicists. The creation, separation, and study of very short-lived nuclides has generally depended on what nuclear chemists call the RAFAP technique (Run as Fast as Possible) for transporting irradiated material to the laboratory. The trend now is toward on-line analysis, and, in the CERN project, it has reached a high pitch, with successive chemical and electromagnetic separators producing isotopically pure ion beams that are fed to an array of detectors by ion optics or moving-tape collectors. Nuclides with half-lives from 10 seconds down to 0.1 second will become susceptible to study.

Fewer than half of the "credible" nuclides, those believed to be stable against nucleon emission, have so far been identified. Further exploration of the very short-lived neutron-rich and neutron-depleted nuclei on either side of the ribbon of known stable and radioactive nuclides will be of interest to theorists as knowledge of binding energies and deformed nuclei becomes available. The high-energy processes of fission and spallation that give rise to the short-lived nuclei must also occur in stars and are therefore relevant to theories of the astrophysical formation of the elements.

The first experiments with the new facility will be concerned with the production of short-lived isotopes of xenon, krypton, mercury, and alkali metals. The development and use of special techniques appropriate to various target elements will occupy experimenters for years to come. The target element for production of mercury isotopes, for example, will be lead which will have to be kept near its melting point to allow the mercury atoms to diffuse rapidly out of the target. Beside CERN's own nuclear chemists, participants in the project come from Aarhus, Copenhagen, Gothenburg, Heidelberg, Orsay, Oslo, and Stockholm. A group from Orsay, using the proton synchrotron but without the chemical separator, has already carried out a similar experiment at CERN. The group has discovered new, short-lived rubidium and cesium isotopes.

The atmosphere of CERN today is one of hard work and high confidence. The imminent completion of the 70-Gev accelerator at Serpukhov does not seem to dismay anyone, and van Hove guesses that CERN still has about as good a chance as any laboratory of discovering the long-sought quarks, the hypothetical particles of which the other particles are composed.

—Nigel Calder

APPOINTMENTS

Robert E. Stowell, scientific director of the Armed Forces Institute of Pathology, to chairman of the department of pathology and assistant dean of the School of Medicine, University of California, Davis. . . . **Norman J. Boyan**, associate professor of education, Stanford University, to director of the Division of Educational Laboratories, Bureau of Research, U.S. Office of Education. . . . **Shannon McCune**, educational consultant to a United Nations mission in Indonesia, to director of the American Geographical Society. . . . **Roy O. Greep**, dean of the Harvard School of Dental Medicine, to John Rock Professor of Population Studies, Public Health Department, Harvard, and to director of the Laboratory of Human Reproduction and Reproductive Biology, Harvard Medical School. . . . **Charles H. Boettner**, chief of surgery, Public Health Service Hospital, Chicago, to associate director of the Bureau of Health Manpower, U.S. Public Health Service.