

51st Session of CERN Council

The Council met on 19, 20 December under the Presidency of Professor W. Gentner

The Council Session opened, as usual, with progress reports from the Director Generals of Laboratory I and Laboratory II. Since we covered work on construction of the 400 GeV synchrotron, the SPS, at Laboratory II in the November and December issues, we will give here the report of Professor W. Jentschke concerning the physics which has come from the experimental programmes at the 28 GeV Proton Synchrotron and the Intersecting Storage Rings.

Progress in particle and nuclear physics is taking place on many different frontiers and most of them are represented within the broad range of the research programme at CERN. In 1973 CERN lead major advances in the knowledge of the behaviour of matter opening up new perspectives in our view of Nature.

The strong interaction and the nucleons

The nucleus of the atom contains protons and neutrons bound together by a force we call the strong interaction. Although an enormous amount of data exists, a real understanding of this force still eludes our grasp. In this field the ISR holds a unique and dominant position and recent experiments have given fresh insights into the character of the strong interaction at very high energies.

In the ISR range of energies the total proton-proton cross-section, which measures the probability that two protons will interact, increases with energy instead of remaining constant at the plateau value observed in experiments at the previous highest energies — up to 70 GeV at Serpukhov.

The ISR experiments carry the energy up to that equivalent to 2000 GeV for a proton incident on a stationary proton target. Although at these high energies the total number

of possible absorptive reactions for two colliding protons is very large, it appears that the two protons are still partially 'transparent' to each other — they do not behave like totally absorbing 'black discs'. The increase in cross-section occurs without much change in the average opacity and is mainly achieved by a small increase in the radius — the proton gets slightly fatter.

It is important to see how the cross-sections for other particles (pions, kaons and antiprotons) behave, in collisions with the proton. One of the first experiments carried out at Serpukhov by a joint CERN-Serpukhov team discovered a slow rise in the positive kaon-proton cross-section up to 70 GeV. Preliminary results from NAL also indicate that a rise has started for the positive pion-proton cross-section. NAL will also be able to study the antiproton-proton cross-section which is still falling at the highest energies investigated so far. The ISR would be able to add very high energy data on this cross-section if it proved feasible to store antiprotons in the machine. Further experiments at NAL and at the CERN SPS are needed to see how the picture develops, but the unexpected result is now established — very large steps in energy are required in order to measure change in the behaviour of the strong interaction; asymptopia lies even further away than the energy region — sixty times the nucleon mass — reached by the ISR.

It is a fundamental law of physics that to probe smaller distances we must go to higher energies. Here also the ISR has yielded results of great significance — the discovery of a process which must be related to very small scale structure of some kind. Collisions are observed in which particles carrying high momentum are emitted at large angles to the

direction of the incoming protons; although these 'high transverse momentum' events are very rare (less than 1 in 100 million collisions) they occur about ten thousand times more often than expected from a simple extrapolation of the low transverse momentum behaviour. It has also been shown that the higher the energy, the higher the probability that these events will occur.

High transverse momentum (over 4 GeV/c) implies a sensitivity to structure in the region of $5 \cdot 10^{-15}$ cm and observation of this new phenomenon is reminiscent of the large angle scattering of alpha particles which led Rutherford to the discovery of the nucleus. We may be seeing for the first time, through the strong interaction, an indication of granularity of the nucleon — perhaps a structure of point-like constituents which are also conjectured to account for similar behaviour in experiments in which nucleons are bombarded with high energy electrons (at the Stanford accelerator) or neutrinos (at CERN).

In terms of the simplest parton model the emission of particles with high transverse momentum can be imagined as the result of a rare collision between two partons, one from each proton. The picture predicts that, if a high transverse momentum particle is emitted, the number of particles created at the same time will be larger than usual. This is indeed found — the number of charged particles emerging in the same general direction as a pion of large transverse momentum is nearly twice the average number observed in the much more common events with small transverse momentum; in the opposite direction the number of particles (the multiplicity) rises to about four times the average value.

However, many puzzles still confront advocates of the parton picture. The most naive version is not correct

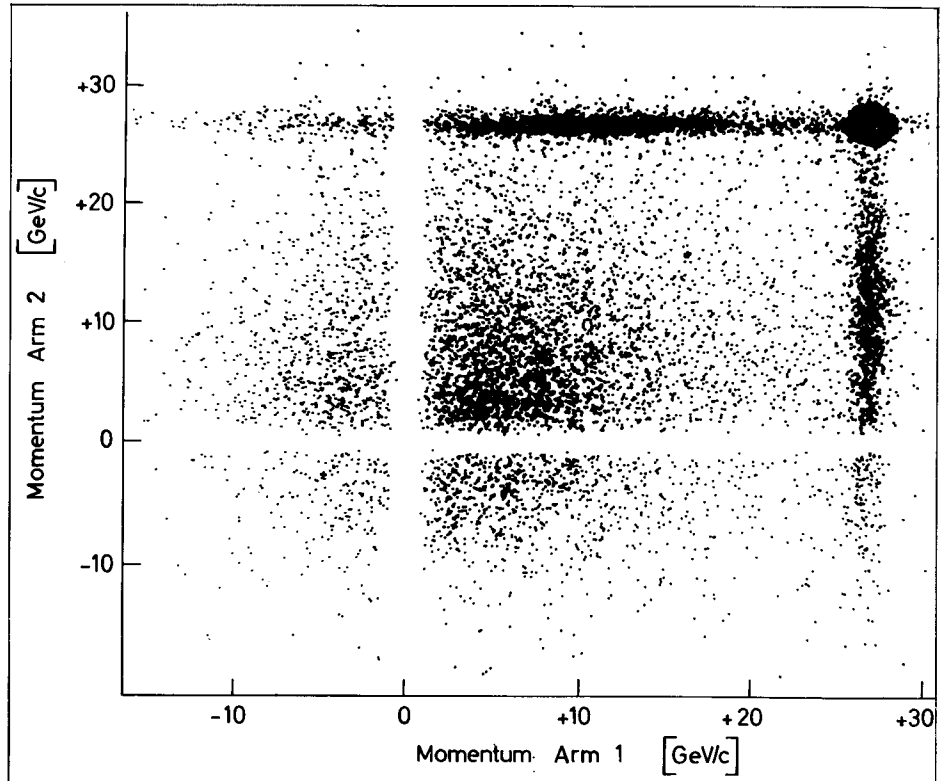
A 'scatter diagram' where points represent the measured momenta of particles emerging from proton-proton collisions in the ISR. 'Elastic' events where the protons brush against one another and emerge retaining their incoming momenta appear as the black blob in the top right-hand corner. The two well populated horizontal and vertical bands correspond to the situation where one proton or the other was not significantly disturbed.

and it is not yet clear whether it is useful to proceed on the basis of this attractively simple model or to follow other explanations derived from the familiar strong interaction mechanisms extended to an extreme short range form.

At the ISR, matter can be studied under conditions so extraordinary as to be met elsewhere only in the extreme astrophysical domain. One way of representing the situation is to use energy density, rather than energy, as a characteristic parameter. The interaction between two protons is confined to a region whose dimensions are of the order 10^{-13} cm (the range of the strong interaction); the total energy in a collision can be 60 GeV and so the energy density reached during the collision (for the brief interval of less than 10^{-23} seconds) is about 10^{40} GeV/cm³, or about 10^{17} gm/cm³. This is about a hundred times the density inside an atomic nucleus and is only otherwise attained within objects like neutron stars or 'black holes'. It is remarkable to contemplate that such situations can be created, if only very briefly, in the laboratory.

The most obvious result of this violent encounter between two energetic concentrations of matter is well known. Numerous particles (on average about eighteen) are created by the transformation of energy into mass during the collision.

Recent experiments at the ISR and at NAL suggest that the creation of new matter in high energy collisions is a two-stage process. In the first stage, matter appears to be produced in the form of heavy but very short-lived objects (often called fireballs or clusters). In the second stage, each of these splits up into several 'ordinary' particles. Only the latter particles are detected by the experimental equipment but, by the presence of certain



correlations between them, we may infer the existence of the heavier clusters from which they emerged.

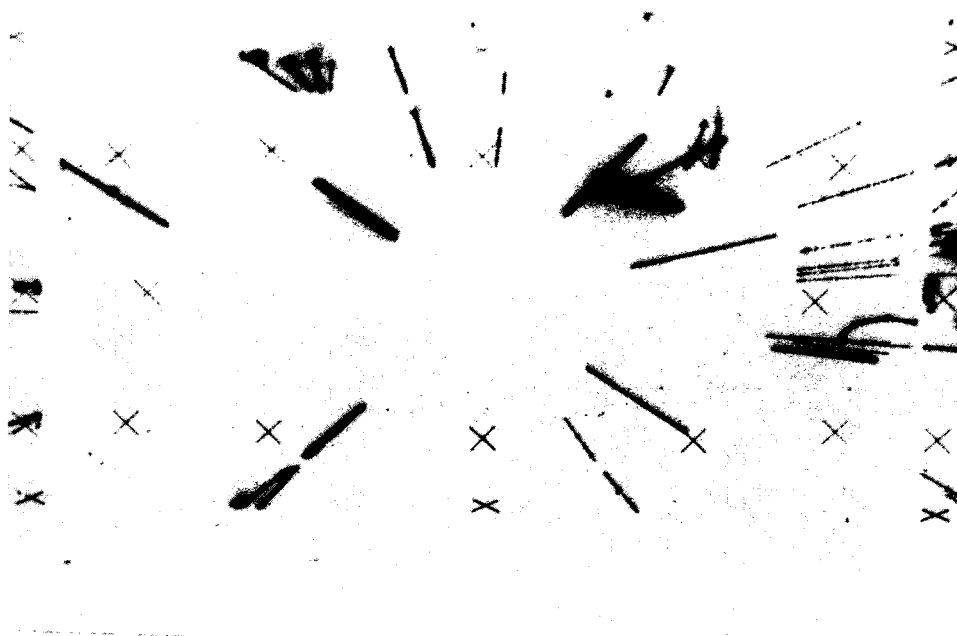
The ISR observations also suggest two dominant mechanisms of cluster formation. One is called fragmentation in which the particles emitted retain a strong memory of the parent nucleon motion; the other is called production from the central region in which, particles (mainly mesons) are emitted more or less equally in all directions. The relative importance of the fragmentation and central regions as sources of particles has been studied at the ISR in a variety of ways.

First, there is an important class of events, about 20% of the total, in which only one proton is significantly disturbed by the collision and the other continues with just a slight change in energy and direction. There is no contribution of particles emitted at large angles, from the central

region, and the only particles created appear as a low multiplicity narrow cone, or jet, of particles lying close to the trajectory of one of the protons. This is a special case of fragmentation of one proton. Similar processes (called proton diffraction dissociation) have been observed in experiments at the PS but the striking result seen at the ISR is that this mechanism can result in excitation of a proton to conditions of much higher mass than was expected. The production of states of up to ten times the nucleon mass has been demonstrated and the further investigation of these states is of great interest in our quest to understand nucleon structure.

The most common interactions are those in which both protons are excited and the central region also plays a role. A suitable choice of parameters allows a very clear demonstration of the contributions arising from these different sources of par-

A photograph taken in the streamer chamber surrounding intersection I-7 in the ISR. It records a proton-proton collision in which many particles are detected emerging from the interaction. A story on the streamer chamber will appear in the next issue.



ticles. The striking feature as we move to the class of events with high multiplicity is the growth of particle emission from the central region. Events of small total multiplicity are dominantly due to fragmentation while collisions in which the central region is dominant lead to higher multiplicities.

Some experiments have looked in more detail at production from the central region and have found evidence that events of high multiplicity correspond to the formation of several clusters which later break up.

This concept of a two step process — formation of a cluster and then, after a time of about 10^{-23} seconds, break-up into three or four particles observed in the detecting apparatus — may be given additional support by a very different sort of experiment. The production of three pions by a collision of an incident pion with a

large nucleus has been studied at the PS, and elsewhere, in both bubble chamber and electronic experiments. The results show the surprising result that, under certain conditions, the three pion system seems to propagate through the nucleus with less attenuation than would be expected for three separate pions. With the three pion system, the probability for interaction in the nucleus is no bigger than for a single pion. The attractively simple explanation which now seems possible is that the first step is the formation of a cluster; the cluster would be moving with almost the velocity of light and its apparent lifetime would thus be extended by a factor of about ten — which gives it a chance to escape from the nucleus before breaking up into the three pions eventually observed.

Although the detailed interpretation is probably not as simple as this, there seems no doubt that such

experiments in nuclei offer a possibility of studying the behaviour of very highly excited states of matter which exist for only very short times.

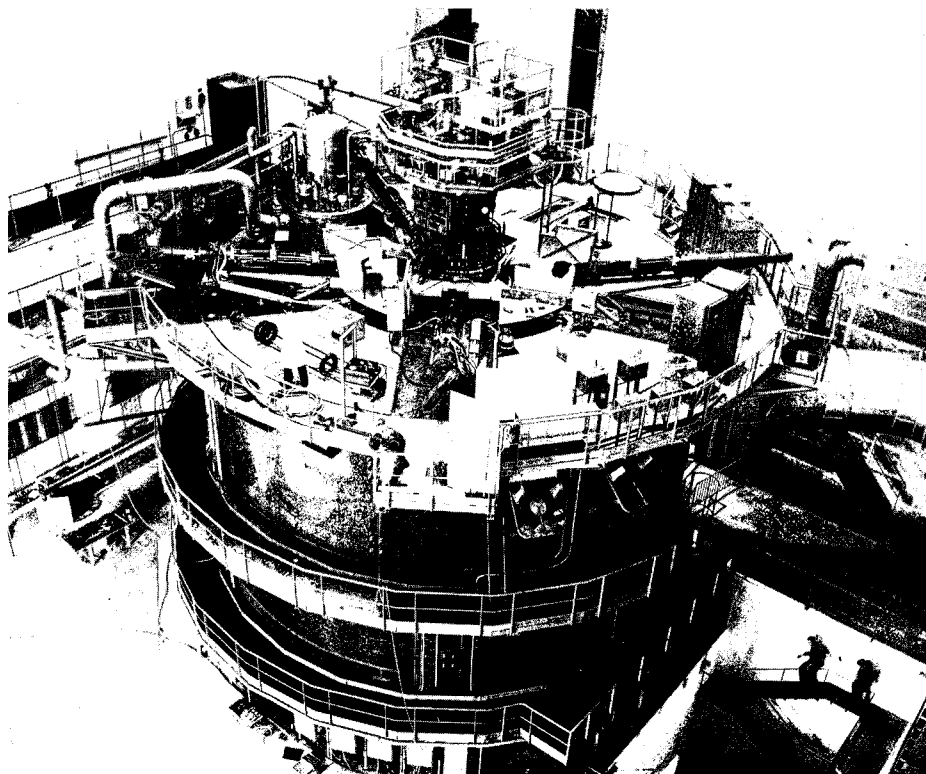
The weak interaction

It is rather easy to relate the strong and electromagnetic interactions to the appearance of the every-day world — the strong force keeps nucleons together in nuclei, the electromagnetic force keeps electrons around nuclei to form atoms and keeps atoms together to form molecules, and is thus responsible for the physical properties and appearance of matter in the large. The weak interaction plays a less obvious but equally fundamental role in determining the character of our world. It is one of the determining factors in the chemistry of nuclear reactions. For example, the sun releases its enormous store of nuclear energy slowly, with a lifetime of about ten thousand million years but if the weak interaction were not so weak, the sun could have burnt out long before life developed on the earth. The weak interaction is not without interest.

CERN has made many important contributions to the study of weak interactions and the results of an experiment in 1973 have captured the interest of the whole physics community. The experiment studies the weak interaction due to a beam of neutrinos passing through the large heavy liquid bubble chamber, Gargamelle, at the PS. The neutrino can only interact with matter through the weak interaction and, as an illustration of the meaning of weak, most of the pictures taken in the bubble chamber are blank even though a thousand million neutrinos are passing through ten tons of liquid freon each time a photograph is taken.

An event has been seen in Gargamelle which could be an example of elastic scattering of an antineutrino

One of the elements of the CERN improvement programme which came into action during 1973 — the 3.7 m European bubble chamber. The chamber is surrounded by a large cylindrical iron shield which retains the stray field of the superconducting magnet. The camera system looks in from the top.



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by an electron. This process is quite unlike the familiar form of the weak interaction, called a charged-current interaction, in which the neutrino would have changed into a muon (involving a change of electric charge between the neutrino which is always neutral and the muon which is always charged). This sort of interaction clearly forbids the elastic scattering process which can only take place if the so-called neutral-current interaction also exists. The event observed in Gargamelle was the first indication that this form of weak interaction might be present in Nature.

The question of the existence of neutral currents has assumed great importance because it is required by certain theoretical attempts to find a unified theory of the weak and electromagnetic interactions. The search for further examples of neutrino-electron scattering has very high priority and Gargamelle has embarked on another

1 million picture experiment, in which the PS Booster is being used for the first time to increase the neutrino yield.

Another type of event was observed in the Gargamelle neutrino experiment which is also evidence for the neutral current interaction. The normal charged current interaction between a muon-neutrino and a nucleon leads to the emission of a muon. The Gargamelle experiment has observed 165 events in which the muon is absent. A background of energetic neutrons could cause such events and neutrino interactions occurring in the magnet and other material surrounding the visible region of the bubble chamber provide a source for such neutrons but the number of muon-less events observed is about six times greater than the estimated neutron background. The muon-less events could be produced by neutrinos — a process which again requires a neutral current.

For many years the study of the nucleus has been concentrated at the 600 MeV synchro-cyclotron but in the last three years we have seen a rapid increase in the use of the PS for such experiments — out of the thirteen beam-lines at the PS, two are permanently in use for nuclear structure experiments.

In one experiment the PS is used as a source of high energy protons to bombard a uranium target and a most ingenious technique has allowed rare isotopes to be identified among the fragments even though their lifetimes are as short as about 1 ms. This experiment has observed and measured the masses of such extraordinarily neutron-rich nuclei as ^{11}Li (with four excess neutrons), ^{27}Na to ^{32}Na (with up to nine excess neutrons) and ^{48}K to ^{50}K (with up to eleven excess neutrons). The study of nuclei, with such extreme composition imposes severe tests on models of the nucleus.

The absorption of negative kaons by nuclei can also lead to the formation of an extraordinary sort of nucleus, called a hypernucleus in which, for a brief period of about 10^{-10} s, a lambda particle joins the protons and neutrons as a nuclear constituent. Experiments at CERN were the first to detect excited states of such nuclei by direct observation of the radiation emitted from them. There is now an active programme of such experiments which will be a fruitful source of information on the interaction between lambda particles and nucleons at low energy.

Professor Jentschke concluded by paying tribute to the quality of the accelerators and detection systems which have been built up at CERN. The strength of the experimental programme depends upon this quality.

During 1973, the 800 MeV Booster came into action at the proton synchrotron and high energy beam intensities of over 5×10^{12} can be achieved.