CERN COURIER

NO. 6 VOL. 17 JUNE 1977

CERN COURIER, Journal of High Energy Physics, is published ten times yearly in English and French editions.

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Printed by: Cherix et Filanosa SA,
1260 Nyon, Switzerland
Merrill Printing Company
765 North York, Hinsdale,
Illinois 60521, USA

Published by:
European Organization for Nuclear Research
CERN, 1211 Geneva 23, Switzerland
Tel. (022) 834103, Telex 23698
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Cover photograph: On 2 June a ground breaking ceremony was held at the Stanford Linear Accelerator Center for the LBL/SLAC electron-positron storage ring, PEP. The construction workers in the foreground are, left to right, Andy Sessler (Director of LBL), Alan Cranston (Senior Senator, California), Robert Thorne (ERDA), Paul Gilbert (President of P.B.Q. and D.), Don Beattie (ERDA) and Pief Panofsky (Director of SLAC). On the podium in the background can be seen John Rees and Tom Elioff, the Director and Deputy Director of PEP. No doubt they will ensure that the project goes ahead with as much gusto as attended the digging of these first spadefuls of earth. (Photo Joe Faust)

Thinking ahead in Europe

At its 21st Plenary Meeting on 25 May, the European Committee for Future Accelerators (ECFA) passed a recommendation which essentially promotes a high energy electron-positron colliding beam machine as the prime candidate for further study as Europe's major high energy physics project for the 1980's. This recommendation (the full text of which is reproduced below) was submitted to the CERN Scientific Policy Committee at its meeting on 21 June. It seems an appropriate time to summarize some of the options which have been under consideration as future European research facilities for particle physics and to indicate why ECFA is promoting the electron-positron machine.

The term 'major project' is an important one because under this heading do not come such small/medium scale projects which may prove feasible as extensions of CERN's existing facilities. There are three contenders which can be so described — projects involving different use or revamping of the Intersecting Storage Rings, the project to collide protons and antiprotons in the SPS, the project to collide protons and electrons at the SPS.

Possible projects which extend the physics potential of existing CERN facilities

Contender number 1, involving an upgraded ISR, was a subject of a two week Workshop in October of 1976 (see November issue of CERN COURIER). The physics interest of higher energy proton-proton colliding beams would be to augment the knowledge gleaned mainly with the existing ISR. This includes the information on low and high transverse momentum phenomena and on lepton and photon physics.

There are several schemes to achieve the ISR upgrading. One scheme, known as SCISR (SuperConducting ISR), proposes changing the conventional magnet rings for superconducting rings. The existing ISR tunnel dimensions and the location of injection beam lines and experimental areas dictate a peak energy of around 100 GeV per beam (4.5 T field from the superconducting magnets would be equivalent to 108 GeV) with four intersection regions. Injection at 25 GeV from the PS and phase displacement acceleration could give 10 A per beam at top energy and a luminosity in the 10^{32} per cm^2 per s region.

SCISR looks the most attractive of the upgraded ISR schemes, at the moment, but there are other possibilities which aim to collide ISR protons with SPS protons. The SPS protons would have a peak energy of 270 GeV, since the power dissipation limits the storage ring type operation of the SPS magnets to this level, and could collide with ISR protons with energy of 60 GeV by stringing the two conventional magnet rings into one ring (a scheme known as MISR-Moved ISR). Collisions could take place at long straight section LSS5 of the SPS which has been kept free.

The second leg of the Workshop on the future of the ISR will be held later this year and preferences as to the future of the ISR (or, of course, as to the desirability of giving preference to other projects) are likely to emerge at that time.

Contender number two is the project to collide protons and antiprotons in the SPS. It has become thinkable following the work on the new techniques of electron cooling at Novosibirsk and of stochastic cooling at CERN which should make it possible to build up and hold intense beams of antiprotons. This will then give luminosities which are adequate to do good physics. The techniques were covered in some detail in the December 1976 and March 1977 issues of the COURIER.

The project has been pushed particularly by Carlo Rubbia and studies on the project are being carried out under Simon der Meer. The aim is to achieve a luminosity of 10^{30} per cm^2 per s in a low beta insertion in LSS5 (and possibly LSS4) of the SPS with a collision energy of 270 GeV per beam. It requires accumulating some 10^{12} antiprotons per day which could be done without interfering with the physics programmes which run at present (though of course when proton-antiproton experiments are in action the rest of the SPS programme would stop).

The great physics attraction is that it may be the quickest and most economical way of reaching the energy region where the intermediate vector bosons, W and Z with masses around 70 GeV, and possibly Higgs bosons, are predicted to exist. The quark and antiquark content of the proton and antiproton will almost certainly give a higher production rate for these particles than proton-proton collisions.

Unfortunately, the hadronic nature of the interactions are likely to involve a high background from which the particle signals will have to be extracted. The Z and the W should be observable and some of their properties could be decipherable. But to uncover detailed information will very probably require the advent of other machines.

The scheme so far developed to produce the antiproton beam involves ejection at 26 GeV/c from the PS, antiproton production on a target off the beam line which leads to the ISR, injection and storage of the antiprotons at 3.5 GeV/c in a 25 m radius shuttle ring where stochastic cooling is applied, deceleration to about 0.45 GeV/c and transfer to a cooling ring (of the same average radius) where electron cooling (more efficient at this low energy) is applied, transfer back to the shuttle ring when an intensity of 10^{12} is reached, acceleration to about 5 GeV/c or higher and, finally, anticlockwise injection into the SPS taking the route of the beam line which was used to convey protons from the PS to the West Hall and doubling back down the SPS ejection beam line to the West Hall.

Preliminary experiments on the two cooling techniques are being prepared under the acronym ICE (Initial Cooling Experiments). They will use the g-2 magnet ring rebuilt in the former Gargamelle building with the necessary insertions for the electron cooling and with the stochastic systems and lots of diagnostic equipment. It is hoped that experiments can start at the end of this year.

It is worth recalling that the Fermilab is pursuing a similar scheme and hopes to start cooling experiments at about the same time. Given the parameters of the two existing acceleration systems it looks as if CERN potentially has an edge on antiproton yield per unit of time.

The last of the three options is a scheme to add an electron ring at the SPS so as to achieve proton-electron collisions at high energies. This project has gathered the name CHEEP and has been promoted particularly by Bjorn Wiik. Kurt Hubner is heading a machine study. Electron-proton possibilities have also been considered at Berkeley/Stanford as a second phase of the PEP project, at Brookhaven as an option on Isabelle, at Fermilab where it was dropped to concentrate on the Doubler, and at CERN as an option on the LSR (see below). DESY have also planned a contribution to the necessary techniques by adding a Van de Graaff proton injector so that electron-proton beam-beam effects can be studied in DORIS. The CERN scheme achieves higher collision energy than other schemes under consideration at present.

The attraction of CHEEP is that it gives such high interaction energy and high luminosity for modest investment (cheap) and can study the lepton-parton interaction in a way which is not accessible at proton-proton or electron-positron rings. It can study the weak interaction at much higher energies than are presently available, covering the W and Z predicted mass range. It could add more on neutral currents and reveal new quarks and new leptons. It could give information to help select between gauge theory models of the strong interaction.

The design has the electron magnet ring suspended from the roof above the proton magnet ring in the SPS tunnel with the beams brought into collision in LSS5 (and possibly also in LSS4). An intricate geometry at the intersection point makes it possible to bring longitudinally polarized electrons into interaction, which has physics advantages.

Both the electron beam and the proton beam have sixty bunches. With 1.5×10^{13} electrons and 2×10^{13} protons, the luminosity could reach 0.5×10^{32} per cm^2 per s at 270 GeV proton energy and 25 GeV electron energy. With some limitations the proton energy can span from 145 GeV to 400 GeV (or higher) and the electron machine could give 30 GeV if more r.f. power is added.

For the injection system it has been proposed to use a 5 GeV fast cycling synchrotron. Components of the NINA electron synchrotron which closed down at Daresbury at the beginning of April might be made available for the injector. (The late NINA is surely the most popular of accelerators — it has been incorporated in half a dozen other accelerator schemes up to now !)

One final point on CHEEP. The electron ring would make a fine injector should high energy electron-positron rings ever come to the CERN site.

All these contenders for extensions of the research potential of the existing CERN machines remain under discussion. By the end of this year, the second leg of the ISR Workshop and a meeting on the electron-proton scheme (see page 200) will have taken place and experiments on the antiproton cooling scheme will be ready to begin. From this melting pot it is hoped that priorities will emerge so that the necessary resources can be allocated by CERN.

In these belt-tightening days, it is almost certain that such resources will have to be found within annual budget levels approximately the same as those under which CERN is now operating. To buy some new physics, it will probably be necessary to sacrifice something which is under way at present.

Possible major projects for Europe in the future

When thinking of the desirable facilities for high energy physics research in Europe a decade or more ahead, there are three main chapter headings — a proton synchrotron 'fixed target' machine in the thousands of GeV range (several TeV), a proton-proton colliding beam machine in the range of hundreds of GeV per beam, an electron-positron colliding beam machine in the range around 100 GeV per beam. All three possibilities have been thought about and the last two have been studied in some detail.

A factor, which is influencing the selection of projects, to a greater extent than it has done in the past, is the desirability of achieving a balanced array of research facilities world-wide. This is one consequence of the large investments, in money and manpower, which are now needed to construct a major facility and a consequence of the close international collaboration in the field. It was agreed at the Study Group on future accelerators, which met in Serpukhov in May 1976 with representatives from all the regions involved in high energy physics, that new regional facilities should be selected in close collaboration between the regions to ensure coverage of the broadest possible programme of research. The Study Group also recommended joint utilization of such facilities by scientists of different countries. (See June issue 1976 for more details.)

The physics potential of a multi-TeV proton synchrotron was studied in the course of 1975 and the deliberations of the Study Group were published as a CERN Yellow Report 76-12 edited by L. Camilleri. Such a project has not been pursued further. In the USA a 1 TeV machine is in prospect at the Fermilab (the Energy Doubler/Tevatron) and is currently in its research and development phase. In the Soviet Union a 2 to 5 TeV proton synchrotron (UNK) is under study — see September issue 1976.

Proton-proton storage rings, with a peak energy of 400 GeV fed by the CERN SPS, have received quite detailed study in a group led by Kjell Johnsen. Their physics potential was covered in the same report, 76-12, mentioned above. Such rings would cover the W and Z predicted mass region (though with the complications of hadron-hadron interactions), probably answer the questions on the rate of rise of the total cross-section, add more on scaling which is already in trouble at the ISR, perhaps see also the strange hadronic events recently detected in cosmic ray research, add more on the high transverse momentum / jet phenomena...

The machine design has two rings of superconducting magnets (4 T fields) installed in an oval tunnel (5.8 km circumference, 1.45 km and 2 km 'diameters'). Intensities are 7 A per beam and special attention has been given to the design of the intersection regions to cover the different classes of physics. A luminosity of 1.3×10^{33} per cm^2 per s would be possible with 12 m free for detector installation in two low beta regions and the four other general purpose regions with 130 m free would have 6×10^{31} or 10^{31} (high beta regions for small angle investigations).

An electron ring could be added to collide bunched electron beams at 20 or 25 GeV against coasting protons with a luminosity of 10^{32} in one or two intersection regions. Polarized electrons would be feasible with the ability to rotate the polarization into the longitudinal plane.

In the USA a proton-proton colliding beam project of 200 GeV, Isabelle, has been under preparation at Brookhaven for several years. There is now considerable optimism that this project will soon get the go-ahead (see page 200). The design team also considered a 400 GeV design with a 3.8 km circumference and 5 T magnets.

Electron-positron storage rings of higher energy than the PETRA (DESY) and PEP (Berkeley/Stanford) machines which are now under construction, were investigated by Burt Richter during a sabbatical year at CERN 1975-76. The physics interest was the subject of another Study Group, chaired by Pierre Darriulat, whose deliberations were published as a CERN Yellow Report 76-18. There was also an ECFA Study at DESY in February of this year and preliminary looks at a possible design of such a machine have been under way mainly at CERN under Eberhard Keil.

The machine would cover the predicted mass region of the W and Z particles (and perhaps the Higgs bosons) and would produce such particles in cleaner conditions than hadron collisions. (A high background problem may be encountered, however, due to the two-photon process.) It will probably be possible to determine many of the new particle properties. The machine will extend electron-positron cross-section measurements to higher energies with the implications of the possible existence of other heavier quarks. It covers the range where the weak and electromagnetic forces are predicted to become of comparable strength bringing a new regime of particle behaviour under investigation. It would probe down to dimensions of a hundredth of a fermi and other phenomena may well come to light when these smaller dimensions become accessible for the first time.

A first look at a design for an electron-positron ring of 100 GeV energy per beam has set a luminosity aim of 10^{32} per cm^2 per s. The other parameters are then largely fixed. For example, a ring of 50 km circumference would need over 100 MW of r.f. power requiring some 2.5 km of installed r.f. cavities. (If superconducting r.f. cavities operating in the relevant frequency range could be developed, the financial and physical relief to such a project could be considerable.)

Eight collision straight sections were included in the design. The injection field at 20 GeV is 109 G rising to 544 G at top energy. The magnet design uses conductor to determine the field shape and avoids iron close to the beam because of permeability effects. The vacuum system is also affected by the low fields — distributed sputter ion pumps would not be adequate at the injection field. The beam currents were set at 15 mA in 32 bunches per ring. Wiggler magnets would control the luminosity variations with energy. A version with, for example, a peak energy of 70 GeV could be built initially by leaving out some of the r.f. system (a 'missing cavity' machine) saving about 20 % on the initial construction costs.

The 100 GeV machine first came into discussion with the acronym LEP, for Large Electron Project, and has since been called LEAP, for Large Electron Accelerator Project including the 70 GeV initial phase. It would certainly be a great LEAP for the high energy physics community. No other

Around the Laboratories

region has such a project under study at present.

ECFA recommendation

After deliberating on these various possibilities the European high energy physics community, via its ECFA representatives, has emerged with this recommendation to the CERN Scientific Policy Committee, which we reproduce here in full:

'The physics motivations are very strong for a study of phenomena in electron-positron collisions in the range of 100 - 300 GeV centre of mass (c.m.) energies, where weak and electromagnetic interactions are expected to become of comparable strength. A 200 GeV c.m. energy e^+e^- ring might have a radius of 7 km, and possibilities for extension up to 300 GeV c.m. energy with future technical development. This project would be complementary to planned and present facilities elsewhere in the world.

Rough estimates indicate that an e^+e^- machine of 200 GeV c.m. energy is a project on a scale which could be realized as a European project in the 1980's, and would not necessarily require the interregional collaboration considered for the Very Big Accelerator (VBA) Project. However, the extension to the range above 200 GeV c.m. energy, which was considered as one of the main options for the VBA, may well require a more extended collaboration.

We recommend that:

(1) An e^+e^- storage ring of about 200 GeV c.m. energy, possibly with an initial phase of 140 GeV, be considered by the high energy physics community as the prime candidate for a major European project for the 1980's.

(2) As a first step a location near the Meyrin site should be investigated by CERN.

(3) The technical, scientific and financial aspect of such a European project be further studied to allow the high energy physics community, via CERN and ECFA, to submit a proposal for this project to the CERN Scientific Policy Committee.

(4) Technical research and development of importance for the project should be taken up or pursued at CERN and the Laboratories of the Member States, in particular on superconducting r.f. cavities, high power coupling devices, etc.

(5) Studies of the design of the machine and of its operation, on which preliminary results were reported at the ECFA study week at DESY, should be pursued with high priority.

(6) The interest in non-CERN Member States of joining such a project should be actively explored.'

The recommendation will probably have the effect of concentrating efforts for possible future projects in Europe on the electron-positron option rather than having them spread over the different alternatives. It has a long way to go before it reaches the stage of being a project that can be seriously discussed in terms of timescales and money.

It is a suitably sobering thought that the SPS which was inaugurated in May of this year was first recommended by ECFA in 1963.

DESY
Polarized beams for PETRA

The polarization of electron and positron beams in storage rings due to the emission of synchrotron radiation was predicted theoretically by A.A. Sokolov and I.M. Ternov in 1963 and confirmed early in the 1970s by experiments at Orsay on ACO and at Novosibirsk on VEPP-2. Also during the early days of SPEAR operation at Stanford (beam energies around 2 GeV) analysis of the physics data showed that the beams were polarized.

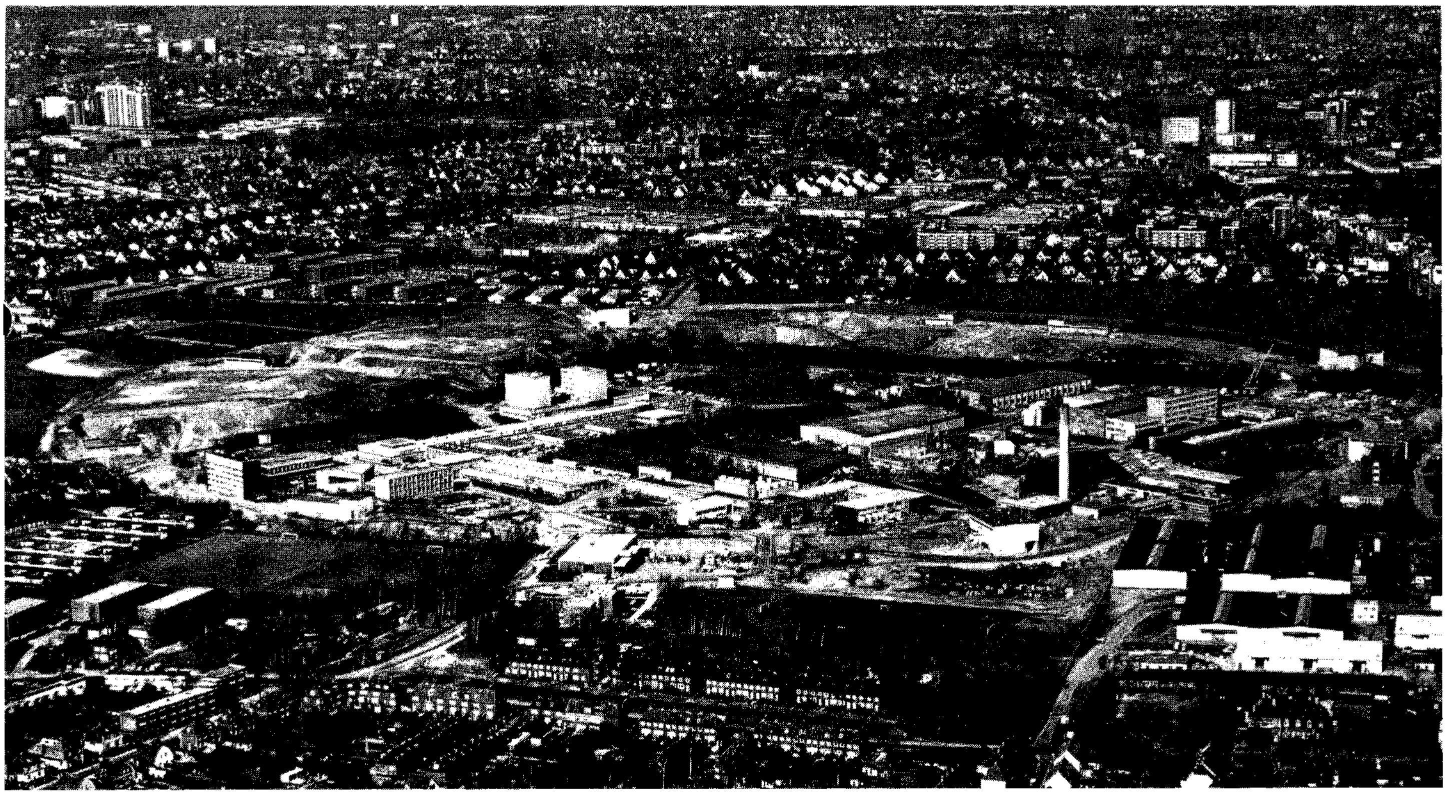
The usefulness of polarized beams for electron-positron physics increases at the higher energies and it was therefore a disappointment to find that the polarization in SPEAR disappeared after the machine was modified for higher energies.

There are several possible sources of depolarization associated with various types of spin resonances. These effects can be enhanced by the quantum nature of the synchrotron radiation, especially at the higher energies, and the observations in SPEAR were attributed to one of these effects associated with the vertical dimensions of the beam. Extrapolation of this explanation to PETRA and PEP energies in the 15 GeV range made it look unlikely that these machines would have polarized beams.

However, the explanation was not universally accepted and over the past six months there have been many animated discussions about the relative importance of the various depolarizing mechanisms. At DESY, where there is a strong interest in having polarized electron and positron beams, a critical evaluation of depolarization effects in PETRA has been carried out using the extensive theoretical work on stochastic depolarization that has

The DESY site now that the PETRA tunnel is completed.

(Photo DESY)



been published (mainly from the Soviet Union) over the past few years.

A recent concurrence at CERN of Ya. S. Derbenev from Novosibirsk, who has made major contributions to the subject, and J.D. Jackson from Berkeley, led to an improved understanding of these depolarizing phenomena. This has been applied to PETRA by Bryan Montague, visiting DESY from CERN for a few months, and indicates that there is good hope of obtaining polarized beams in PETRA.

The main reason for this renewed optimism is the now general agreement that the various contributions to the vertical beam size give rise to different strengths of depolarizing effect. The overall effect arising from the vertical betatron motion in PETRA can be made very much smaller than previously supposed, by careful choice of the Q values (betatron tunes) and by adjusting the operating energy to avoid the strong spin resonances.

There remain, however, potential depolarization mechanisms which must be kept carefully under control. At PETRA energies, the most critical appear to be the one due to vertical closed-orbit errors and the one arising from the stochastic nature of the colliding beam-beam forces. The beam-beam depolarization can be kept to a sufficiently low level by operating the machine somewhat below the traditional beam-beam limit at the expense of a slight reduction in luminosity. The closed orbit spin resonances are not so easily avoided and peak vertical closed orbit deviations in PETRA must be kept below 3 to 5 mm — a tight but feasible requirement.

Vertical closed orbit errors may limit the maximum energy for polarized electron and positron beams in any machine to not much more than 30 GeV, even with the most refined measurement and correction techniques. The implications of the ideas from Novosibirsk, see page 190, will need detailed study to learn if they are applicable in the tens of GeV range. In PETRA it may be necessary to apply special tricks above about 15 GeV to suppress certain harmonics and to have a rapid means of polarization measurement for checking their effectiveness. A laser back-scattering polarimeter is foreseen and the main requirements and performance estimates have been evaluated by R.H. Milburn from Tufts University during a short visit to DESY. A similar device is under construction for SPEAR.

Thus, with a little extra effort in the construction, instrumentation and operation, electron–positron storage rings should provide transversely polarized beams up to around 30 GeV. Various methods have been studied for rotating the polarization vector parallel to the beam direction. The PETRA design already takes into account the installation of such a facility by the choice of a beam height above the tunnel floor sufficient to accommodate the necessary vertical bending. The longitudinal polarization obtainable with such a scheme will provide a valuable addition to the physics potential of PETRA.

The usefulness of longitudinal polarization for physics is not confined to electron-positron rings. It is of even greater importance in the proposed CERN electron-proton colliding beam projects like CHEEP and the LSR electron-proton option, where the beam polarization provides an effective way of distinguishing between the effects of the weak and the electromagnetic interactions in the energy range where they become of comparable strength.

FERMILAB Doubler string tested

As we mentioned briefly in our May issue, there were successful tests in April on a string of four, twenty-two foot long, superconducting dipole magnets designed for the Energy Doubler at the Fermilab. This was the first large scale demonstration of magnet protection for a superconducting magnet string and is an important step on the way to construction of the Doubler. Physicists who participated in this work were Peter Limon, George Kalbfleisch, Rae Stiening and Paul Brinkza.

The string was powered to 4.3 kA, giving fields equivalent to an energy of 1050 GeV (1.05 TeV) in the Doubler, and the energy stored in the four dipoles reached approximately 2 MJ. Quenches, transitions of the magnet coils from the superconducting to the normal state, were induced at this current to investigate the characteristics of the safety system.

The tests have shown that — the existing pressure relief system is adequate to prevent damage to the cryostats during quenches; the stored energy of four dipoles can be dumped into an external resistor when a quench is initiated with safety leads provided at every quadrupole; the voltages induced during quenches (up to 1.8 kV to ground) can be held safely by the coil insulation system; a quench does not propagate from the point where it originates to adjacent magnets; and the magnets do not exhibit any 'amnesia'.

The static heat load of the magnet cryostats in the operating string has been measured to be 8 W per magnet. Newer cryostats have demonstrated static heat leaks of about 5 W per magnet. The temperature rise along the string is between 0.05 and 0.1 K. Vacuum observations in the cold bore have indicated that the helium leak is less than 10^{-11} torr l/s and that the hydrogen partial pressure at 4.5 K and 10^{-10} torr is so far undetectable.

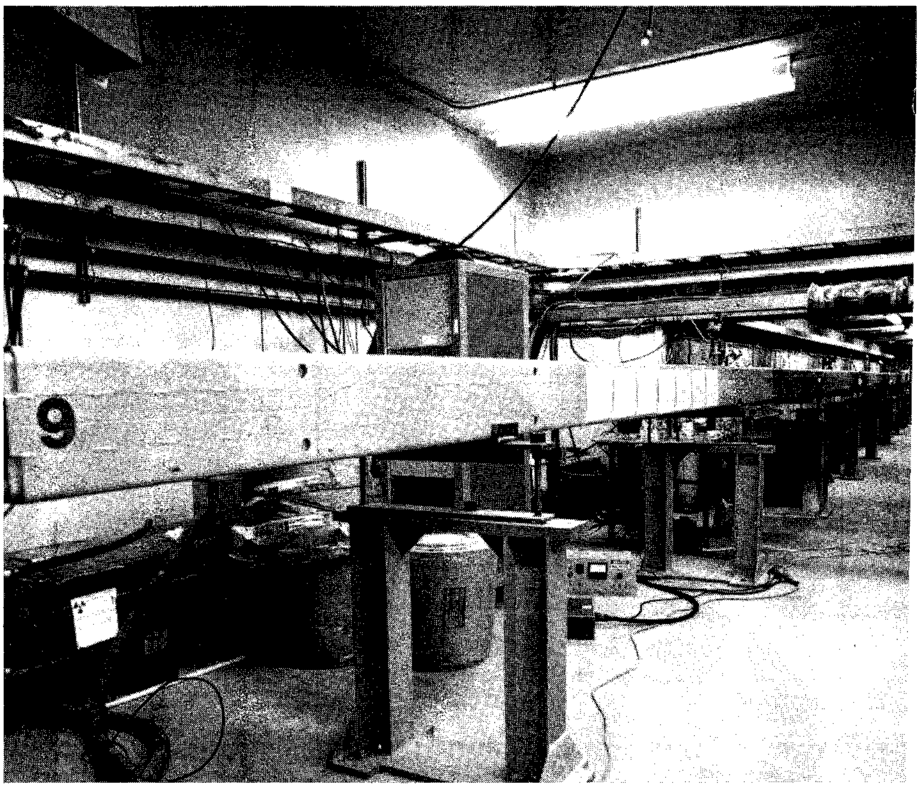
In June the string was replaced by four new magnets. Following tests with this assembly, four other magnets will be added and subsequently the string will be increased to sixteen, equivalent to half of an Energy Doubler cryogenic circuit.

Research has continued on the performance characteristics of the cryogenic and magnet systems under Doubler operating conditions. These tests are also being used to develop hardware and software for monitoring Doubler operation using the present Fermilab accelerator control system.

At a Users Meeting in May, the Laboratory Director Bob Wilson, introduced the words 'Tevatron' to describe the conventional ring plus Doubler complex and also speculated as to the maximum energy proton machine which could be incorporated on the existing Laboratory site — a 2.5 TeV synchrotron dubbed the 'Celestron'.

Portent of things to come — the four magnet string for the Fermilab Energy Doubler that recently completed successful magnet protection tests. Other magnets will be added to make a string of eight dipoles, followed by installation of eight additional dipoles between the legs of the support stands for a sixteen magnet test.

(Photo Fermilab)



Meson Lab upgrade

The Meson Area at Fermilab was committed to construction while the Fermilab machine was still a 200 GeV project. Since then the Meson Laboratory staff has exercised its ingenuity and powers of persuasion to coax the switchyard line to 400 GeV and then the M1 and M2 charged beams along with the M3, M4 neutral beams to match the switchyard energy. Recently a major effort was launched to implement the design parameters of the M2 diffracted proton beam which called for targeting 10^{10} protons per pulse in the Detector Building.

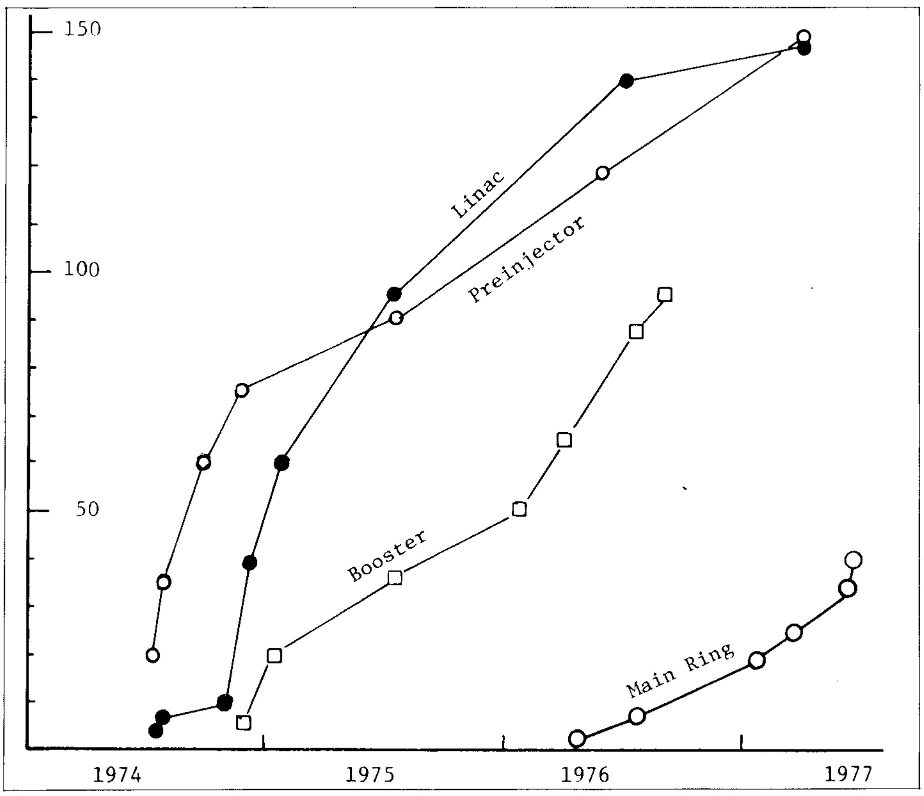
In April the design intensity was reached during the running of a dimuon experiment carried out by Northeastern University. Radiation measurements around the shield indicate the beam can be routinely targeted at intensities up to 10^{11} protons per pulse. Proposals being submitted for the June Program Advisory Committee meeting in Aspen are already reflecting the usefulness of this new facility for exploring the currently popular high transverse momentum regions.

Further down the line, the Meson Area target train is being revamped to provide greater flexibility in targeting. A new target holder with a greater choice of targets is being built. An ingenious system of magnets devised by John Elias and Alan Wehmann will be added to the train upstream of the target. It makes it possible to vary the angle with which the proton beam strikes the target, without changing the position of the beam on the target, by turning a single knob.

By steering the beam towards either the M1 or M6 beam line, experimenters in those beam lines may be able to obtain up to 10^9 pions per pulse. This will make a new range of physics accessible in these beams. Alternatively, the protons may be steered away from M1 or M6 to increase the number of 'minority' particles (kaons, antiprotons) in the beam. With these changes M2 will have gained several orders of magnitude in intensity, while M1 and M6 will have gained an order of magnitude and a new capability for minority particle physics.

In the future a Mark II target train will be constructed with compatibility for 1000 GeV targeting. This will include the option of targeting at 0° in either M1 or M6.

For the more distant future, the Meson Department has initiated development of a three-magnet superconducting beam line module. Using Energy Doubler dipoles and an existing Helium Liquefaction Facility, the equipment and techniques are being developed to install and operate such magnets on a routine basis in experimental area beam lines. Several such modules will eventually be installed in M6. This would raise the energy for M6 to about 600 GeV and result in a very large saving in power, since M6 is a particularly complex beam. Installation of the superconducting version of M6 is planned for early 1979.

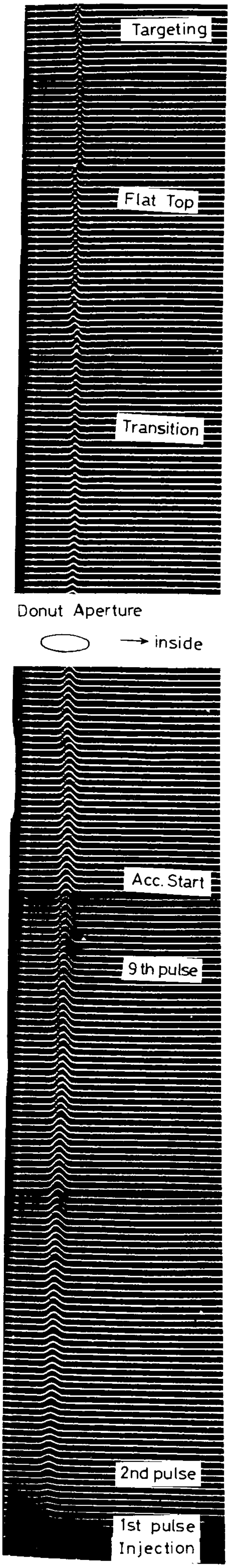


Graph of beam intensity in the four components of the KEK proton synchrotron during the past three years. The intensity is plotted as percentages of the design values. The main ring is designed to deliver 2 × 10^{12} protons per pulse.

KEK Synchrotron performance

In March 1976, the proton synchrotron at the KEK Laboratory in Japan achieved the energy of 10.4 GeV beam and since then effort has concentrated on improving control of the main ring power supply and the r.f. system.

When 10 GeV was reached for the first time, an analog control system was used to produce the pattern of the main ring magnetic field. It was far from adequate and lost the flat top at the end of the pulse because of too



Beam profile (radial direction) in the KEK synchrotron during the acceleration cycle. The signals are picked up every 5 ms. Injection, acceleration, flat top and the time for the fields to fall back to injection level each take 500 ms.

small a correction for magnet saturation at energies over 9 GeV. This analogue system was replaced by a digital control system, with a minicomputer, which worked successfully.

On 23 December 1976, KEK succeeded in accelerating protons up to 11.8 GeV. The maximum beam intensities achieved so far from the main ring are 2 x 10^{11} protons per pulse when a single pulse from the booster is injected and 8.2 x 10^{11} ppp when nine pulses are injected.

The construction of a new 500 MeV beam line started in August of last year to enable the booster beam to be used for research in various fields such as neutron diffraction experiments, pion and muon physics and cancer therapy. The booster is operated at a repetition rate of 20 Hz while the main ring, whose diameter is nine times that of the booster, is operated at a repetition rate of 0.5 Hz. The main ring can accept only nine pulses every two seconds out of forty booster pulses. Therefore about thirty pulses every two seconds (1.2 μA on average) are available for other research by ejection down the new beam line.

The machine was shut down from August to October of last year to allow the construction of this new beam line. It is now almost complete and a budget for neutron diffraction experiments has been approved.

FRASCATI
New vector meson

The three detection systems in operation on the electron-positron storage ring, Adone, at Frascati have seen a resonant structure at an energy of 1820 MeV with a width of about 40 MeV.

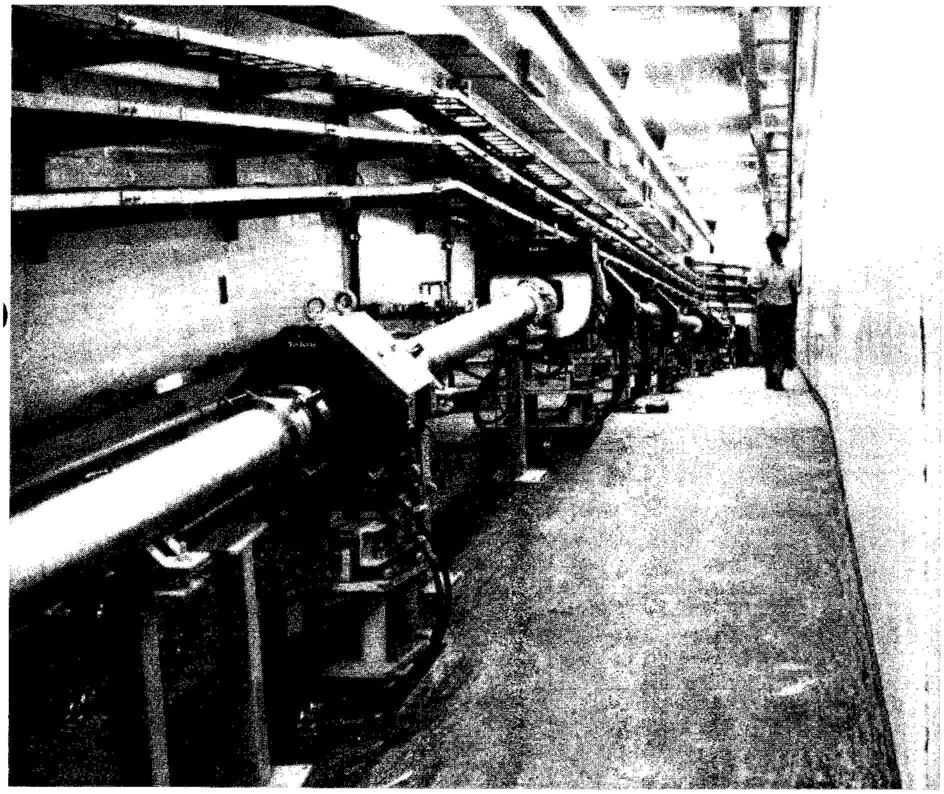
The detection systems are in many respects complementary and consist of a wide solid angle detector with high efficiency for gamma detection (called gamma-gamma 2), a solenoidal magnetic spectrometer with wide gap spark chambers and shower detectors (MEA) and a system of co-axial hodoscopes of scintillators covering a wide solid angle (baryon-antibaryon).

The new resonance has been detected during a survey of narrow structures in the electron-positron cross-section which has been under way at Adone since last year. The 1700 to 1950 MeV centre of mass region has been explored in the periods of September-October 1976 and February-March 1977. The three systems have collected a luminosity of 236 nb^{-1} in this region and detected a total of 1425 events with not less than three charged particles (and a gamma) in the final state.

The observed structure is a candidate for one of the vector meson recurrences which should be located in the energy interval explored at Adone. Further analysis on the data are being performed, in order to identify the nature of this new vector meson. The groups involved belong to the Laboratori Nazionali di Frascati and the INFN Sections at the Universities of Naples, Padua, Pisa and Rome and of the Istituto Superiore di Sanità.

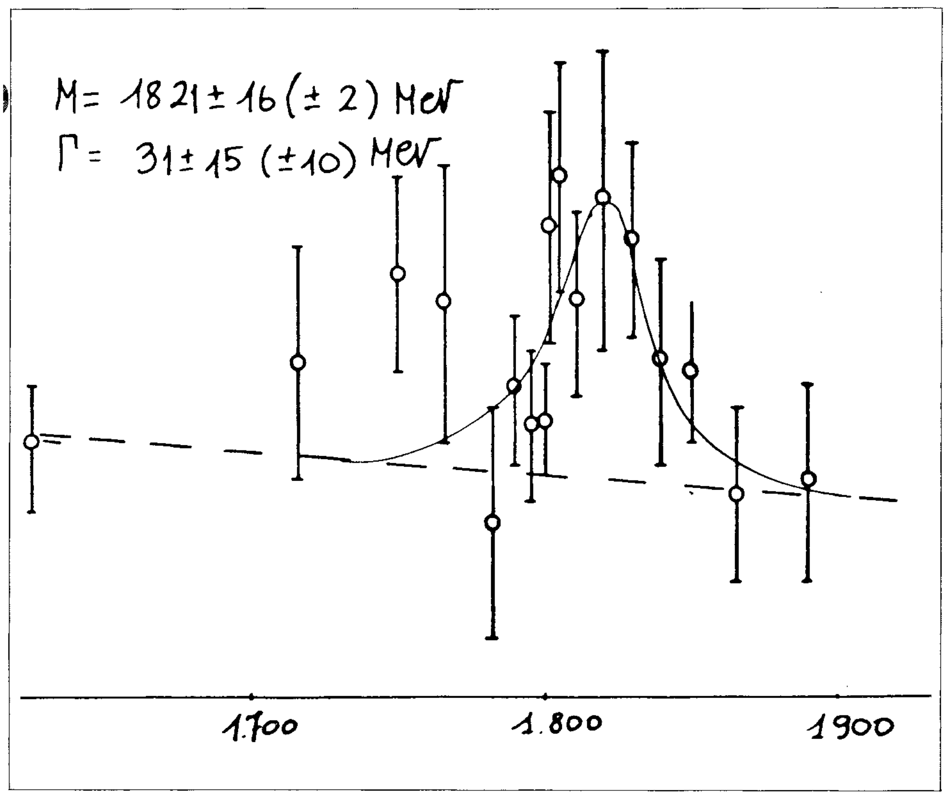
NOVOSIBIRSK
Polarization studies and experiments on VEPP-2M

Investigation of the polarization of electrons and positrons in storage rings began at Novosibirsk in 1965. The mechanism of radiative polarization, discovered earlier for homogeneous fields was studied theoretically in detail and it was shown that the interaction of the particle spin with radiation is not essentially affected



The new 500 MeV beam line at the KEK synchrotron looking upstream. The beam line will take protons from the booster, which are not needed for injection into the main ring, and will use them in neutron and meson physics and for cancer therapy.

(Photo KEK)



One of the signals gathered on the Adone electron-positron storage ring at Frascati indicating a new vector meson at 1820 MeV. The three detection systems at the storage ring have all seen similar signals.

when the fields are inhomogeneous, as they are in storage rings. However, a depolarizing effect appears due to the stochastic orbital motion of the particles caused by quantum fluctuations of the synchrotron radiation.

A second series of papers, from 1969, was devoted to the control of the polarization, especially with a view to obtaining longitudinal polarization of colliding beams. In 1970 a theory of spin motion was developed for fields which are arbitrarily changing their direction and value along the beam orbit. It was shown that, by switching special fields in the straight sections, it is possible to obtain the necessary polarization direction at the interaction point, in just as stable a way as transverse polarization in the usual storage ring vertical field. Specific examples to obtain longitudinally polarized beams have been considered, including colliding beams with either the same or opposite helicities.

The study of spin dynamics in complicated magnetic fields opens a new approach to the problem of polarization conservation during acceleration. This is especially topical for high energy polarized protons. It turned out that by switching sufficiently strong longitudinal fields or special transverse fields in the straight sections, the depolarization connected with crossing spin resonances can be completely eliminated.

The development of a spin diffusion theory in the resonance region, as well as investigation of polarization stability for colliding beams, could prove very important for subsequent applications.

Recently, the stability of radiative polarization at very high energies has been considered, taking account of specificity of particle motion in a storage ring and of radiative effects. As a result, it seems possible that experiments with polarized electron-positron colliding beams could be performed at energies up to hundreds of GeV with optimal luminosity.

Experiments which proved radiative polarization of beams started in Novosibirsk in 1970, first on VEPP-2 and later at VEPP-2M. The degree of polarization was measured by a new method suggested in the Institute consisting of detecting elastic scattering of the particles inside a bunch.

A jump in the counting rate is observed after rapid beam depolarization, using a noise-modulated high frequency longitudinal magnetic field resonant with a spin precession frequency. The limiting value of the polarization measured by this method was close to the theoretical value of 92 %. This indicates how small the depolarizing factors outside the spin resonances are. It was later shown that a number of resonances with betatron oscillations of first and second order could be crossed without destroying the polarization.

The proposal to use a longitudinal magnetic field for resonance stabilization has been studied on VEPP-2M near an integer resonance, when a frequency of anomalous spin precession equals a resolution frequency. Measurements showed that this method eliminates the depolarizing effect of a strong resonance even if it is crossed slowly.

By the technique of detecting elastically scattered electrons and positrons from inside bunches, it was shown that the polarization of colliding beams does not differ from that of a single beam in the usual range of currents. The achieved luminosity of polarized beams was 2×10^{29} per cm^2 per s. In 1975-76, two experiments with polarized electrons and positrons were performed to study anisotropy of muon and kaon production.

Observation of rapid resonance depolarization of the beam makes it possible to measure the spin precession frequency of a particle which, for a relativistic particle, is proportional to its energy. This fact may be used for precise absolute calibration of the average energy of the particles in a storage ring. At VEPP-2M such calibration was used for very accurate measurements on the phi mass, on the sum of the kaon masses and for a comparison of electron and positron anomalous magnetic moments as described below.

Physics results from VEPP-2M

Experiments on VEPP-2M started early in 1975. VEPP-2 is used as a booster to inject electrons and positrons at the energy required for the experiment. Additional filling takes place every 10 to 15 minutes providing continuous runs with an average luminosity close to the maximum. VEPP-2M has three low beta straight sections. Luminosities at different energies are — 0.02×10^{30} per cm^2 per s at 200 MeV per beam, 0.25×10^{30} at 380 MeV, 1.3×10^{30} at 500 MeV, 1.5×10^{30} at 620 MeV and 1×10^{30} at 670 MeV.

In autumn 1974 the first detection system — OLYA — was installed. It consists of four identical quadrants surrounding the interaction region and covering a solid angle of 0.64 of 4 π. Each quadrant has four 2-coordinate wire chambers with core memory and eight scintillation counters, four of which are used for triggering (the energy threshold for pions is 45 MeV), while the other four form a scintillation sandwich with lead, to distinguish between electrons and mesons. Time-of-flight between counters of opposite quadrants is used to suppress cosmic ray background.

The first experiment with OLYA was a search for narrow resonances. The energy interval from 760 to 1340 MeV was scanned in 0.5 to 1.0 MeV steps. The integrated luminosity per point was 200 to 300 per microbarn. No narrow resonances were found, in the two pion plus neutrals' system, larger than 100 eV.

From 900 to 1340 MeV events with two and four pions were studied. Maximum deviation of the experimental values of the pion form factor from the Gounaris-Sakurai curve was observed at 1200 MeV close to the predicted rho prime (1260 MeV) meson. However it is considered premature to interpret these results as observation of rho prime production. Analysis of the elastic channel of electron-positron annihilation must also take into account the inelastic channels whose contribution to the pion form factor may be of the order of the observed effect.

The OLYA detector was also used to measure the excitation curves of the phi meson in the two kaon and three pion channels with an integrated luminosity of 40 per nanobarn. After data processing, 2732 events of $K_S K_L$ and 949 of three pions have been selected. For precise determination of the phi mass an absolute calibration of beam energy was performed using resonance depolarization as mentioned above. The calibration accuracy was 10^{-4} and this set the phi mass at 1019.50 $\pm$ 0.13 MeV.

A shift of the resonance peak in the three pion channel allowed a determination of the relative phase of the omega-phi interference which is sensitive to a model of SU(3) violation. The data confirms the Orsay results giving evidence for opposite signs of the omega and phi corresponding to the mass mixing model.

Another experimental straight section of VEPP-2M was used to measure the average mass of the two charged kaons. It was performed at the phi meson energy. As the kaon kinetic energy constitutes only 1.5 % of the total energy, photo-emulsions can be used to provide high accuracy mass determination. The beam energy was calibrated to 2×10^{-5} and analysing about 300 events gave the following result: mass of the K^+ plus the mass of the K^- is twice 493.670 $\pm$ 0.029 MeV.

The observation of resonance depolarization, mentioned at the beginning of this article, has also allowed a precise comparison of the anomalous magnetic moments (AMM) of the electron and the positron in VEPP-2M.

In the absence of transverse electric fields in a storage ring, electrons and positrons have a common equilibrium orbit and strictly equal average energies. Electron and positron spins then move in the same average magnetic field and any difference in their AMM would result in a difference in the frequencies of their spin precession. Frequencies were measured at the moment of each beam depolarization by a jump in the counting rate of counters which detected elastic scattering inside each bunch.

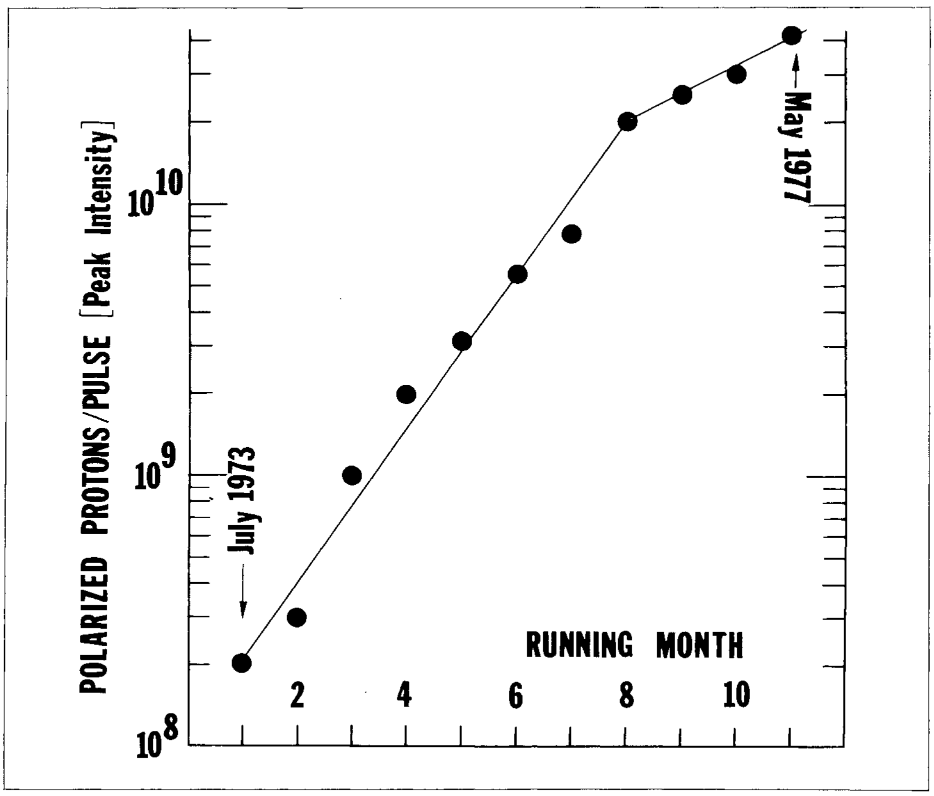
The accuracy to which a difference in frequencies of the electron and positron depolarization could be determined was limited by the reproducibility of the magnetic field as well as by the width of the frequency spectrum of the spin motion. Both beams were seen to be depolarized simultaneously and any possible difference in depolarization frequencies is less than 10^{-5} confirming the equality of AMM of electron and positron with the same accuracy. This result is two orders of magnitude better than previously achieved.

ARGONNE
Record beam polarization and intensity

Polarization of the 11.75 GeV/c proton beam in the Argonne Zero Gradient Synchrotron (ZGS) has now reached nearly 70 %, following careful, systematic studies during the April-May operating period. Only about 5 % depolarization now occurs during acceleration from injection all the way to the full ZGS energy. A record polarized beam intensity of 4.2×10^{10} protons per pulse was also achieved.

The VEPP-2M electron-positron storage ring at Novosibirsk which has been used for some novel work on beam polarization and for some refined physics experiments.

(Photo Novosibirsk)



The increase in the intensity of the beam in the Argonne Zero Gradient Synchrotron during the months for which the machine has been operated for polarized protons. The growth of intensity has been roughly exponential, although there seems to be a break in the curve.

A dimuon event recorded in the large detection system of the CERN / Dortmund / Heidelberg / Saclay collaboration set up in the neutrino beam from the SPS.
1. The event seen from the direction of the neutrino beam end-on to the detector. The drift chamber readings are picked out as crosses and show one muon, after passing through several chambers, exiting from the detector on the left, while the other curls round in the magnetic fields and passes all along the detector.
2. The same event as viewed from the side of the detector. The same information on the trajectories of the two muons can be seen.

70% polarization was achieved at 6 GeV/c during 1974 but, during the first 11.75 GeV/c operation in February 1976, there was a 25% depolarization in going to the full ZGS energy. In the recent machine studies, the main cause of depolarization between 6 and 11.75 GeV/c was found to be imperfection depolarizing resonances, which are caused by horizontal fields due to misalignments or imperfections of the synchrotron magnets. While these resonances were known to be very serious in a strong focusing synchrotron, they were expected to be insignificant in the weak focusing ZGS. However, while each resonance typically causes only a 1% depolarization, twenty-two are passed in accelerating to 11.75 GeV/c giving a large depolarization.

These resonances can be corrected by applying a small pulsed horizontal field of a few Gauss which exactly cancels the effect of the imperfection fields. These fields are so small that only the beam polarization itself is sensitive enough to measure them. Moreover, since each resonance causes only a 1% polarization loss, which is difficult to measure precisely, it is hard to determine the exact correction field which removes all depolarization.

These corrections were finally made using a depolarization enhancement technique developed by an Argonne/CERN/Michigan accelerator research team while they were simulating strong focusing depolarization effects at the ZGS during the Summer of 1976. The depolarization is enhanced by slowing down the acceleration cycle near the resonance. Using this technique, 19 of the 22 imperfection resonances were carefully corrected permitting the polarization to reach 70%.

The remaining depolarization of about 5% may be due to the intrinsic depolarizing resonances. These very strong resonances, which can totally destroy the polarization, are passed by quickly shifting the ZGS tune using pulsed quadrupoles with a very fast rise time. It has been shown, both experimentally and theoretically, that decreasing this rise time reduces the remaining depolarization. However, these pulsed quadrupoles are now operating at their limit. Plans are under way to upgrade them, which may increase the polarization further to almost the 75% which is present at injection. This may also improve the polarization stability which sometimes becomes a little strained during Midwestern thunderstorms.

The polarized beam intensity increase was mostly due to improvements in the polarized ion source and the low energy beam transport line. The stability and reliability of the source has also improved and on many days the 24 hour average intensity was 3×10^{10} per pulse. The April-May run is the eleventh consecutive polarized beam operating period during which a new intensity record has been established.

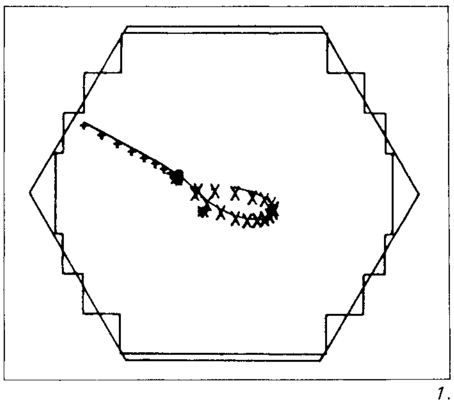
CERN
More on muons

In recent months we have carried two important muon stories — the discovery of trimuon events at Fermilab and the measurement of the muon magnetic moment at CERN to a new level of accuracy. We can add more to both stories.

World statistics on muon production in high energy neutrino-nucleon interactions received a tremendous boost when the CERN / Dortmund / Heidelberg / Saclay collaboration at the SPS, led by Jack Steinberger, announced its first batch of results.

In 55 000 examples of muon production using neutrinos, 256 events were seen with two muons of opposite sign, 43 with two muons of the same sign, and just 2 with three muons. The corresponding figures in 12 000 examples of muon production by antineutrinos were 40, 6 and 1 (although the group has reservations about this last observation and prefers to call it a 'half-event').

The dimuon statistics show a marked asymmetry — one muon normally being much more energetic than the other. Also, the higher the energy



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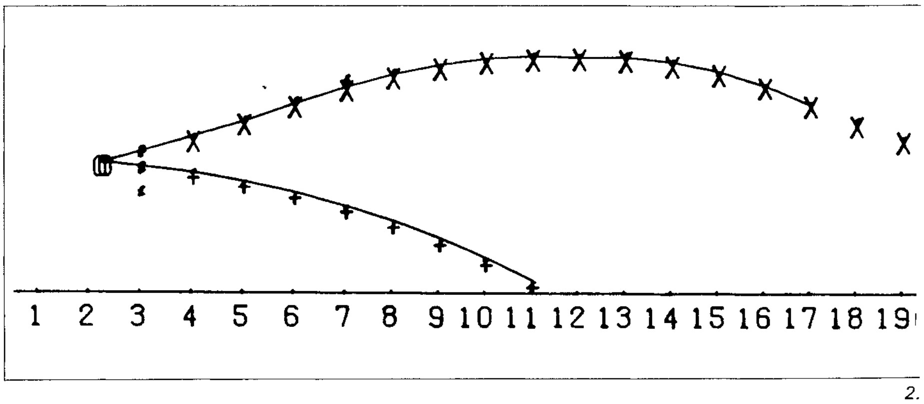

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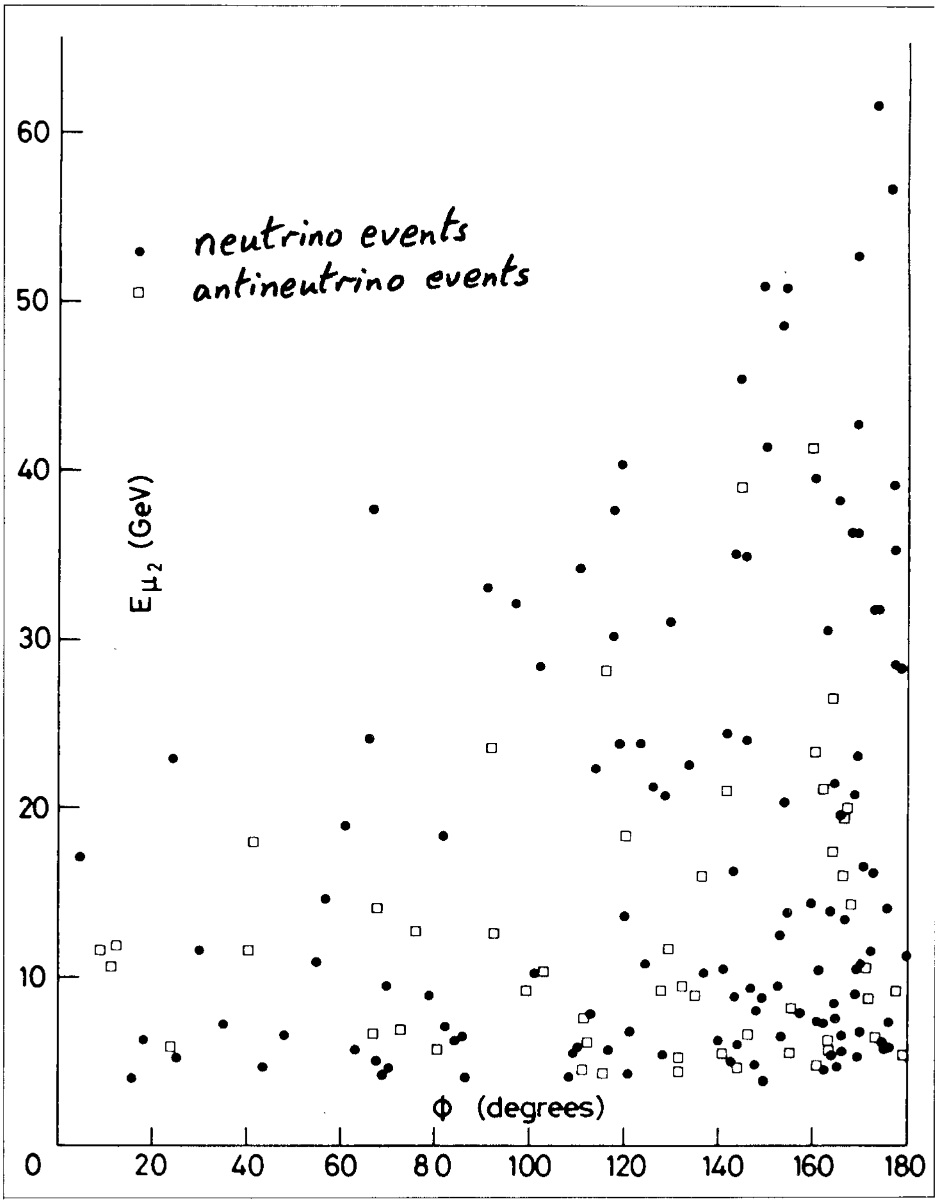
The wealth of data on dimuon events collected in the neutrino experiment, is evident in this graph. It plots the angle between the two muons, in the plane perpendicular to the incident neutrino or antineutrino, as a function of the energy of one of the muons. The higher the muon energy, the higher the angle is likely to be. This muon is correlated with the hadron shower coming from the interaction at 180° and seems to be clearly of hadronic origin (probably the decay of a charmed particle). The other muon is probably produced leptonically by a 'conventional' interaction.



of one muon, the greater the angle between it and the second. This, together with the limited amount of observed transverse momentum, points to an explanation where one muon is produced leptonically while the other is the result of the decay of a charmed hadron.

The results are in broad agreement with what would be expected on the basis of a charm quark / parton model. The charmed quark component of the produced hadron arises partially (totally in the antineutrino case) from the quark-antiquark 'sea' of the target nucleon and one interesting prediction to emerge from the experiment is that there must be about 30 times as many valence quarks as there are 'sea' quarks at any time.

Dimuon events of like sign are consistent with a background attributable to concurrent decays of pions and kaons, although a few of these events could be unaccounted for.

The two trimuon events seen in neutrino interactions have very different characteristics, while in the single event 'seen' with antineutrinos, one of the muons only had time to cross two drift chambers before escaping. In general, bona fide muons have to cross four drift chambers to qualify for inclusion in the statistics.

As well as measuring the anomalous magnetic moment of the muon very accurately (see May issue, page 148), experiments at the CERN muon storage ring have come up with the most precise determination so far of the lifetime of the negative muon and have confirmed that relativistic time dilation is exact.

Because of special relativity, a fast-moving muon appears to live much longer than a stationary one. In the CERN experiments, the speed of the muons is such that they live for more than 60 μs. Knowing the muon speed, the special relativity formula can be applied to give the corresponding lifetime at rest — a mere 2.1948 microseconds for the negative muon.

This agrees with previous measurements on static muons to within 0.2 %, and provides the most accurate test so far of the validity of the special relativity time dilation equation. It had been suggested by some people that special relativity might run into trouble at very small distances but the CERN experiments show that, if this is so, then these distances must be less than a hundredth of a fermi!

The lifetimes at rest of positive and negative muons are found to agree to within 0.2 %, effectively confirming that CPT is holding good for weak interactions.

Physics monitor

Jet set

Proton-proton scattering experiments at the CERN ISR and at Fermilab now show all the signs of highly inelastic collisions between small, hard objects hidden deep inside the protons. This is analogous to the classic experiment of Rutherford which showed for the first time that the nucleus is a small object hidden deep inside the atom.

If a target appears uniform to a beam of particles being thrown at it, the resulting scattering will look very much like a diffraction pattern with a central maximum and with an intensity dropping off sharply at wider and wider scattering angles. However if the target has some small impenetrable points buried in it, occasionally one of the particles from the beam will hit one of these points head-on and will bounce off at a very wide angle, possibly even backwards. Such wide angle scatterings are not to be expected from a 'grey' target of even density and are immediately indicative of some deep inner structure.

In the same way, if a proton presents a uniform target to an incoming beam, it should show a diffraction-like pattern of elastic scattering which would be a measure of the overall extent of the proton. This is indeed the dominant phenomenon at the ISR and in 1972 a diffractive minimum was observed for the first time in proton-proton scattering.

The existence of a substructure within the proton was first noticed on the electron linear accelerator at Stanford in high energy electron-proton experiments and was confirmed later at CERN in neutrino experiments using Gargamelle. These investigations gave the first information on the structure inside the proton, proposed by Feynman and others as being due to pointlike constituents called 'partons'.

The idea of parton constituents has more than a passing resemblance to the quark model and the neutrino measurements made using Gargamelle enabled these two pictures of proton structure to be reconciled. While the quark model gives the intrinsic properties of the proton constituents (spin, charge, etc.), the study of deep inelastic scattering gives the momentum distribution of the constituents — something which the quark model is unable to predict.

So, when probed in deep inelastic electron as at Stanford or in neutrino scattering experiments at proton Laboratories, the proton no longer behaves (under the influence of the electromagnetic force or of the weak force) as a solid particle with dimensions of the order of 1 fermi but as a collection of small, solid, quark-like objects.

But what happens in strong interactions ? In 1972, experiments at the ISR showed that they too can produce energetic particles at wide angles to the original beam, showing that the proton has a grainy inner structure for strong as well as electromagnetic and weak interactions. When these grains hit each other and interact as in the ISR, then the sparks really fly ! Actually the grains must sometimes hit each other at lower energies, but it is only at higher energies that the interaction really becomes noticeable.

The big question is whether these strong interaction effects are produced by the same quark / parton constituents as are responsible for the high momentum transfer phenomena seen in lepton-proton scattering ? This is proving difficult to answer, partly because of the difficulty of sorting the grain interactions from the rest of the hadronic debris.

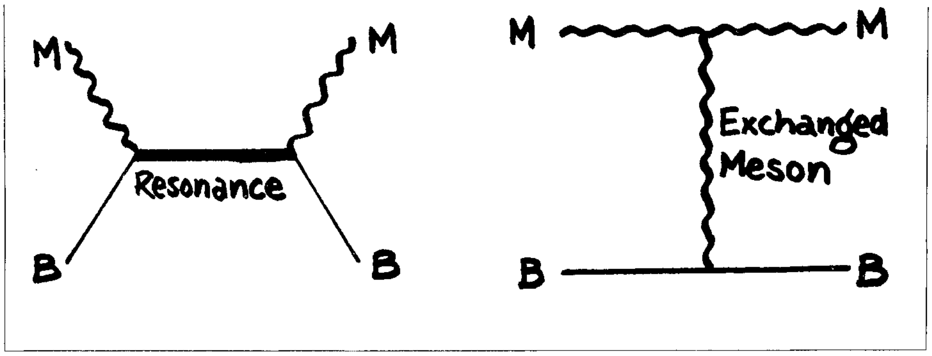
If nothing else were happening, the results of a deep scattering between two inner proton constituents should result in two coplanar 'jets' of secondary particles shot out at large angles to the incident beam direction and fairly well collimated along their directions of motion. These 'jets' need not necessarily be opposite each other. If they are the result of incoherent scattering of proton constituents, they will be opposite only in the centre-of-mass frame of the constituents, which is not necessarily the same as the proton-proton centre-of-mass system.

In practice the situation is blurred by the more usual types of strong interactions and early experiments at the ISR such as those of the Pisa / Stony Brook and Aachen / CERN / Heidelberg / Munich collaborations found it difficult to distinguish between wide angle scattering and everything else which was going on. Then experiments using double arm spectrometers, such as those of the CERN / Columbia / Rockefeller / Saclay collaboration, discovered that the observation of one secondary particle with large transverse angular momentum made it much more likely that other large transverse angular momentum particles would be picked up, both in the direction of the trigger particle and in the opposite direction.

Pioneer work by these collaborations together with observations by the CERN / Columbia / Rockefeller /Saclay/ Strasbourg and British / Scandinavian groups paved the way for the first reports of evidence for definite jet structure by a CERN group using the Split Field Magnet at the ISR. Supporting evidence is now coming from the CERN / Collège de France / Heidelberg / Karlsruhe and British / French / Scandinavian collaborations.

The components of the jets are confined not so much in angle but more in momentum. The observed particle momenta perpendicular to the jet axis is limited but is fairly independent of the jet momenta. This means that particles with only a small component of momentum along the jet axis can still move off at a large angle to the axis. To take this into account, and to get over the difficulty of the jets not necessarily being back-to-back, experiments have to try to measure momenta over as

1. The theoretical picture of meson-baryon scattering as it was seen in the mid '60s. Both diagrams had to be included in any calculation, although the resonance was supposed to be a good low energy approximation and the exchange was good for high energy reactions.



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wide a solid angle as possible. This has only lately been achievable at the ISR with the help of special instrumentation like the Split Field Magnet.

This technique together with the use of high momentum triggers has now enabled ISR teams to isolate the wide angle scattering products. Further progress will be made by using higher momentum particles as triggers, eliminating as much as possible of the unwanted hadronic background, and by determining as much as possible about as many secondary particles as possible.

It is too early to say whether these constituents which cause the jets are definitely the same quark / partons seen in lepton-nucleon scattering and which also characterise hadron formation in high energy electron-positron collisions. The form of the interaction between the constituents is also not known, although theorists make sure that there is no shortage of candidate mechanisms, many of which account for different aspects of the observed behaviour. The rich structure seen in ISR experiments has still to be fully explored.

Complementary experiments at Fermilab capitalise on the different experimental techniques available there and shed additional light on the problem. In particular, the intense incident beams enable higher momentum transfers to be monitored. The results show a strong excess of positively-charged secondary particles, which is just what would be expected from the quark constituents of the proton (two positively charged quarks and only one negatively charged).

Fermilab experiments also use pion beams to study large momentum transfers, and it is found that pions are more adept than protons at producing wide angle scattering. This could be because the pions, with only two quark components instead of three, are able to produce constituent-constituent interactions where a larger fraction of the momentum is available.

A particle with high transverse momentum can be produced in a number of ways. Either it is one of several coming from a jet with very high transverse momentum indeed, or it can be the lead particle in a jet where most of the transverse momentum has been given to one particle.

If, as at the ISR, the wide angle scatterings are monitored by looking for outgoing single particle triggers with large transverse momentum, then the second mechanism is detected in preference to the first. This means that much valuable information is being lost and is known in the trade as 'trigger bias'. To overcome this problem, experiments at Fermilab have collected all the energy coming off in a definite solid angle and have been able to trigger on a whole jet, as opposed to a single particle. This has boosted the observed transverse momentum yield by a factor of about 100.

Rutherford's epic experiments with alpha particles which gave us the first indication of the nuclear atom marked only the beginning of a long road of investigation into nuclear structure. If the inner structure of the proton proves as difficult to unravel, many models will come and go and many more experiments will have to be done before we begin to understand what is going on.

Just a few years ago, physicists thought that very high energies could bring simplicity to strong interactions. This could still be possible, but it looks as though it is the logarithm of the energy, and not the energy itself, which needs to be large ! However, if the detection techniques can be made sophisticated enough, then looking at large momentum transfers might be the place where hadron physics starts to become simple, with the exchange of gluons between quarks providing the basic interaction. We have travelled very deep into the proton since Rutherford showed us the way.

Baryonium explained ?

The appearance at CERN of two narrow proton-antiproton resonances is giving additional inspiration to theoreticians who have long been worrying about their picture of baryon-antibaryon interactions.

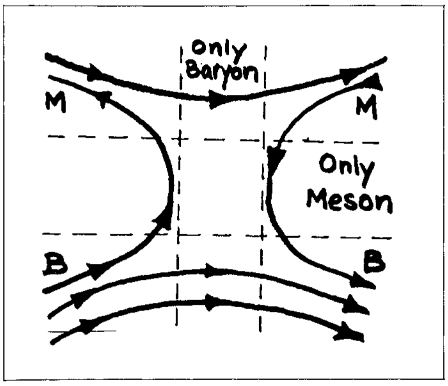
Ten years ago, people used to think of meson-nucleon interactions as either the result of an intermediate nucleon resonance decaying back into a nucleon and a meson, or as the result of the exchange of some meson between the two particles.

Then D. Horn, C. Schmid, G. Veneziano and others showed that these two mechanisms are really different disguises of the same basic interaction. This 'dual' picture of the meson-nucleon interaction can be represented by 'duality diagrams' where some of the participating quarks go straight through while others are exchanged. This way baryon resonances and exchanged mesons occur simultaneously.

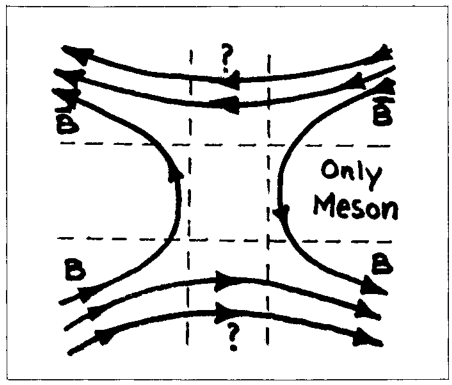
Although fine for the meson-meson and meson-nucleon interactions, this attractive picture breaks down for the baryon-antibaryon case. Duality diagrams here have to include intermediate states or exchanged mesons containing two quarks and two antiquarks. Until recently, these 'exotic' quark configurations did not correspond to anything that had been discovered. Application of duality ideas to baryon-antibaryon interactions was, therefore, frequently referred to by ominous names like the 'Rosner Paradox' or the 'Duality Catastrophe'.

Since then, theoreticians have been hoping that the experiments would come up with something, and have in the meantime been polishing up their models of baryon-antibaryon interactions.

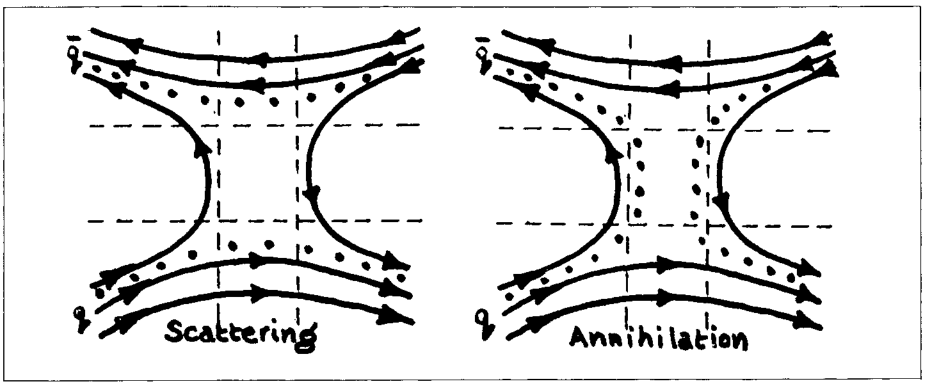
When the duality model was first proposed, people were not too concerned about quark 'colours' (of which



2. Duality diagram for meson-baryon scattering when the quark composition is invoked. An exchanged meson and an intermediate baryon resonance occur simultaneously.



3. Duality diagram for baryon-antibaryon scattering. Although an exchanged meson occurs as for the meson-baryon case, the other intermediate state (seemingly a four quark system which is indicated by a question mark) is worrying.



4. Extended duality diagram for baryon-antibaryon interactions, showing the direction of colour flow (dotted lines). The first case (scattering) has exotic single particle intermediate states, while the second (annihilation) has multimeson intermediate states.

we believe there are three varieties) and concentrated only on their flavours (of which we know four varieties — up, down, strange and charmed). As a result, their duality diagrams did not show whether the two particles simply scattered off each other or whether they annihilated into mesons.

When colour is brought into the picture, the difference between the two cases soon becomes clear. The duality diagram has to be extended by giving each baryon a colour-type degree of freedom. This brings a very different meaning into the diagrams in spite of the identical flavour structure. The first one (scattering) has exotic single particle intermediate states, while the second (annihilation) has just multimeson intermediate states.

However the original problem still remains: where are all the 'exotic' mesons? Peaks, which might be the answer, are seen in proton-antiproton experiments but these phenomena are usually very broad, typically extending over some 200 MeV. The first really narrow resonance in the proton-antiproton system was investigated in a bubble chamber experiment by the CERN / Liverpool / Mons / Padua / Rome / Trieste collaboration. There had been signs of it at Brookhaven even before this. It has a mass of 1936 MeV and a width of just 9 MeV.

Now a CERN / Collège de France / Ecole Polytechnique / Orsay collaboration working with the Omega spectrometer has made a thorough investigation of the interaction of a negative pion with a proton which gives a fast proton, p_F, shooting forwards. Identifying this fast particle on-line provides a very selective trigger for the spectrometer.

Among many other channels, the collaboration has studied the reaction $\pi^- p \rightarrow p_F \pi^- p\bar{p}$. In the final state proton-antiproton system, two narrow resonances have been found, both with widths of the order of 20 MeV and appearing at both 9 and 12 GeV/c pion beam momentum. Moreover the resonances, occurring at 2020±3 MeV and 2204±5 MeV, are seen mainly in association with Δ° (1232) and N° (1520) production in the $p_F\pi$ system, with the Δ° and N° coming off forwards and the proton-antiproton resonances coming out backwards.

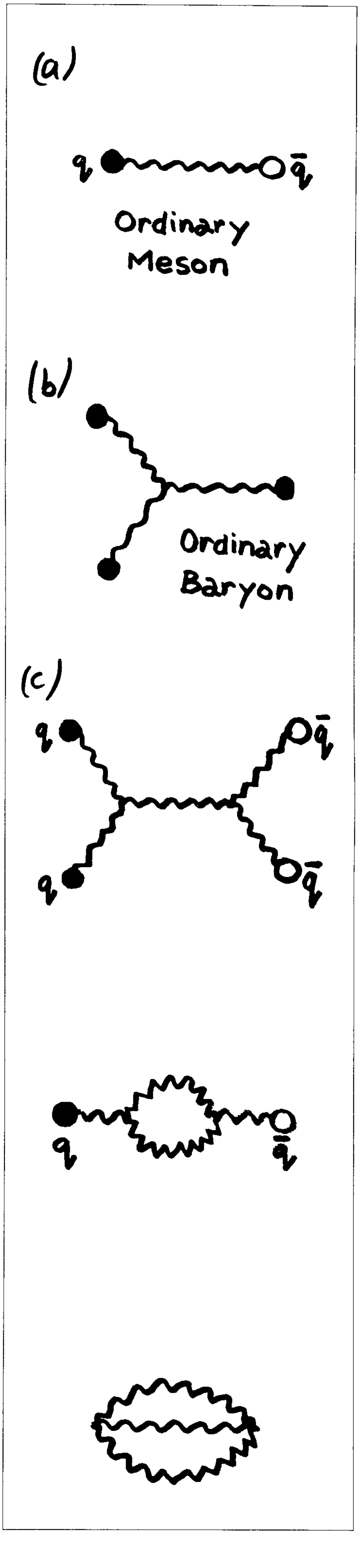
The theorists are predicting the existence of many such states with narrow widths, high spin values (higher than S=3) and a tendency to decay into a baryon-antibaryon pair plus mesons. In analogy with the electron-positron system called positronium and with the now familiar charmonium picture of the J/psi family, these new states are called baryonium.

They are also predicting that the quantum numbers of baryonium states can be exotic, and could show up in further experiments using deuterium targets. In a picture where mesons and baryons are made up of quarks tied up with strings, baryonium can be made up of higher order diagrams with three strings joining together.

Do quark stars exist?

These days theorists are giving a lot of attention to the problem of the non-appearance of isolated quarks. Even though the quark picture explains many different aspects of particle behaviour, nobody has convincing evidence for a free quark and much theoretical work, involving such exotic things as bags, strings, solitons, etc... has attempted to explain why (see for example the December issue 1975).

One answer might be that quarks, at least under normal laboratory conditions, can't exist in a free state and have to be permanently confined inside nuclear matter. Perhaps the attractive force between the quarks grows dramatically as the quarks move



5. Quark/string structures for meson (a), baryons (b) and 'Baryonium' (c) where baryon and antibaryon are in combination.

away from one another. However at very high densities with quarks packed closely together, such mechanisms, which confine quarks and make sure that nobody sees them, might no longer dominate and matter could behave like a gas of free quarks. The transition point at which quarks are freed must occur at densities higher than those normally encountered with baryon states under laboratory conditions.

Neutron stars or stable cold stars could provide densities high enough for free quarks to exist, but initial calculations using the 'quark bag' picture showed that neither of these alternatives were probable. New calculations by George Chapline and Michael Nauenberg using notions of quantum chromodynamics and general relativity suggest that a new regime of cold stars — possibly formed as a result of the collapse of neutron stars — could exist and consist mainly of free quarks.

The model, in principle, allows free quarks to exist both in neutron stars and in other bodies where matter has been compressed to higher densities than exist in neutron stars, so that there would be a smooth transition of quark matter from neutron stars to higher density stars.

Chapline and Nauenberg point out that the parameters required to enable free quarks to exist inside neutron stars do not look physical, and propose instead that free quarks can exist in a new type of cold star, where matter has been compressed even more than in neutron stars. And if such quark stars do exist, how on earth (literally) will we observe them?

Still on quarks, here is an entertaining thought from Jogesh Pati and Abdus Salam. They suggest that one of the first people to hit on a possible solution to the problem of the non-appearance of quarks was Archimedes. Their model of partial quark confinement is therefore dubbed 'The Archimedes Effect' in honour of the Ancient Greek who loved to ponder on matters of the moment while supported in part by the mass of water he displaced.

Just as Archimedes was lighter and freer inside his bath than outside it, so Pati and Salam surmise that quarks and gluons, massive and elusive to find as isolated particles, are relatively light and free inside hadrons. This hypothesis of partial confinement, which is also part of the SLAC bag theory of quark containment, is nothing new in physics. Apart from Archimedes, other examples of bodies behaving effectively as free particles but with effective masses different to their physical masses occur in the theory of metals and in models of nuclear shells.

Pati and Salam admit, however, that the mathematical treatment of partial confinement for quarks promises to be more difficult than that for Archimedes himself.

People and things

Project authorizations

The Aladdin project, for a 750 MeV electron storage ring devoted to synchrotron radiation research, promoted by the Physical Sciences Laboratory at the University of Wisconsin, received final approval from the National Science Board on 20 May. Wisconsin has been a pioneer of this research with nine years of operation of a 240 MeV ring, Tantalus 1. The new ring will considerably extend the research potential.

The process of obtaining authorization for Isabelle, the 200 GeV proton-proton storage rings proposed by the Brookhaven National Laboratory, has begun in the United States Congress. Though money for the project did not appear in the initial budget, the House Science and Technology Committee on 11 May introduced legislation for a partial authorization of $ 10.5 million for Fiscal Year 1978 (beginning on 1 October 1977) to be included in the ERDA budget. Several further steps are needed prior to the passage of the necessary bill by the House and Senate but the process of obtaining approval has begun.

ECFA ep Study Week

A Study Week, covering both the accelerator technology and the physics potential of large electron-proton colliding rings, is being organized by the European Committee for Future Accelerators with the support of the Rutherford Laboratory. It will be held from 10-15 October at a residential College located near Rutherford and the format of the meeting will be similar to that on electron-positron colliding rings organized by ECFA at DESY, which proved very successful. There will be a mix of general talks and detailed work on various topics by smaller working groups. A total of seventy can be accommodated at the College and physicists interested in participating should contact John Thresher at the Rutherford Laboratory (Chilton, Didcot, Oxfordshire OX11 0QX) not later than 1 August.

Photographing the heart

Techniques used in the data collection system for the CERN Omega spectrometer have been applied in an instrument to study the behaviour of the heart. The instrument was developed by the Rutherford Laboratory and the Oxford Department of Engineering Science and has been described in the 'Journal of Physiology'. It involves a high definition TV camera and associated fast electronics. The behaviour of isolated heart muscle specimens under various conditions, such as response to cardiac drugs, can be measured more accurately than before by monitoring displacement of two small (20 μm) pins inserted in a uniform undamaged part of the muscle.

A 'radiation camera' to take three dimensional pictures of the heart is under development at the Lawrence Berkeley Laboratory under Steve Derenzo with Haim Zakland as engineer and Tom Budinger as research physician. It has a detection system consisting of a ring of 280 crystals, which surround the patient, able to record positron emissions from the rubidium-82 isotope (specially developed at LBL by Yokio Yano for heart imaging). 9000 measurements from a 30 cm diameter area can be taken and, via computer processing, a sequence of slices through the heart region can be monitored (tomoscanner technique — see March issue page 65) to build up three dimensional images. Labelling amino acids may also make the brain accessible to the same technique. The camera is expected to be operational by October when all the components of the system will be assembled together.

EPICS joins HRS

A second large, high precision magnetic spectrometer has been installed at the 800 MeV proton linear accelerator, LAMPF, at Los Alamos. The installation of the first one, the High Resolution Spectrometer (HRS), was reported in the May issue 1976. The new one, known as EPICS for Energetic Pion Channel and Spectrometers, will be used in experiments on pion scattering on nuclei and is designed to give very accurate measurements (energies to better than 50 keV and angles to better than 10 mrad) on the pions in the energy range from 100 to 500 MeV. It has a total weight of about 300 tons including two 90 ton dipoles. Tests of the system are now under way and experiments are due to start in the Autumn.

On people

On 4 May, V.F. Weisskopf from MIT, Director General of CERN from 1961 to 1965 and one of its main sources of inspiration, received the Ludwig Boltzmann Prize (the first to be awarded) which was instituted in 1976 on the occasion of the 15th anniversary of the Ludwig Boltzmann Society. This highest science award of the Austrian State is intended to honour contributions to Austrian research and research policy. In presenting the prize, Hertha Firnberg, Austria's Minister of Science and Research, praised Vicky Weisskopf ('this eminent Austrian and citizen of the world') as a scientist helping to solve the human and social problems of our time.

1. Vicky Weisskopf
2. Leon Van Hove
3. Georges Charpak
4. Betsy Ancker-Johnson

Degrees of Doctor Honoris Causa have been conferred on two CERN scientists in recent weeks. On 27 May, Leon Van Hove, theoretician of high repute and now Research Director General of CERN, received the degree at the University of Helsinki. On 3 June, Georges Charpak, renown for his development of new particle detection techniques, received the degree at the University of Geneva.

T. Nishikawa has succeeded S. Suwa as Director of the KEK Laboratory in Japan. Dr. Suwa led the Laboratory for the past six years (the maximum allowed — the office can be held for three years, renewable once) and now moves to head the Physics Department. Dr. Nishikawa's place as head of the Accelerator Department is taken by T. Kamei (previously leader of the Control Group). K. Kikuchi, who was in charge of administration in the Accelerator Department becomes Director of the Scientific and Technical Services Department. A reorganization in April has created a new Department grouping technicians and some engineers under the leadership of K. Kikuchi. A Programme Coordinator's Office was started at the same time under A. Kusumegi.

On 1 July Robert Sachs, Director of Argonne National Laboratory, takes over as Chairman of the Physics Section of the National Academy of Sciences for a three year term of office. The Academy advises the USA Government on science and technology.

Betsy Ancker-Johnson has been appointed Associate Laboratory Director for Physical Research at Argonne. Doctor Ancker-Johnson has had a distinguished career in industry, education and government service and moved to Argonne in May from the position of Assistant Secretary for Science and Technology in the Department of Commerce.

The 1977 Oppenheimer Memorial Prize, awarded by the Center of Theoretical Studies at the University of Miami, has gone to Feza Gursey and Sheldon Glashow for their contributions to elementary particle physics theory.

Boyce McDaniel, Director of the Laboratory of Nuclear Studies at Cornell which carries out research with the 10 GeV electron synchrotron of the Wilson Synchrotron Laboratory, has been appointed Floyd R. Newman Professor of Nuclear Studies at Cornell.

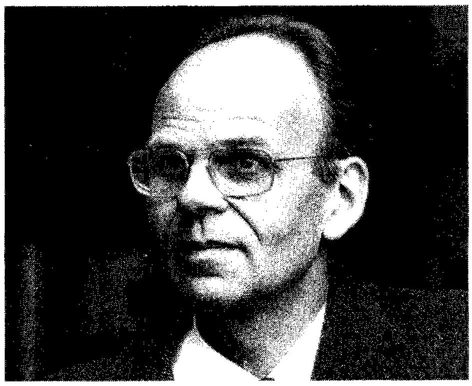
Aerogel at DESY

TASSO, one of the new detectors being built for the PETRA electron-positron storage ring at DESY, will be equipped with two hadron arms each containing a three-layer Cherenkov detector. The innermost layer (to separate protons, pions and kaons of momenta above 1.5 GeV/c) will consist of aerogel with a refractive index of 1.02 or less. About 2 m^3 of aerogel is needed and a special laboratory has been built to produce it. Detailed studies of production methods are under way; many samples of various sizes and refractive indices have been made. Their light transmission was tested with a laser beam and with Cherenkov radiation from an electron beam. Several pieces, 5 cm diameter and 3 to 6 cm long, have extremely low indices between 1.007 and 1.008. Transparency and homogeneity are very good.

MHD magnet at Argonne

With the experience of two large superconducting magnets for bubble chambers (the Argonne 12 foot and Fermilab 15 foot) behind them, an Argonne team has successfully tested the world's first large superconducting


1.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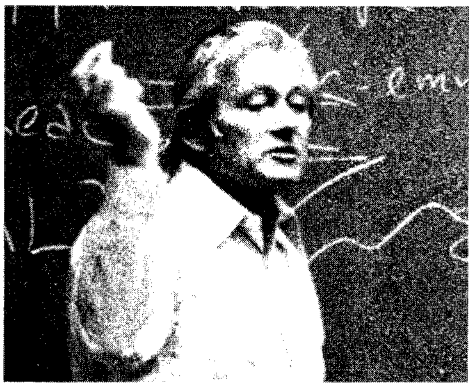
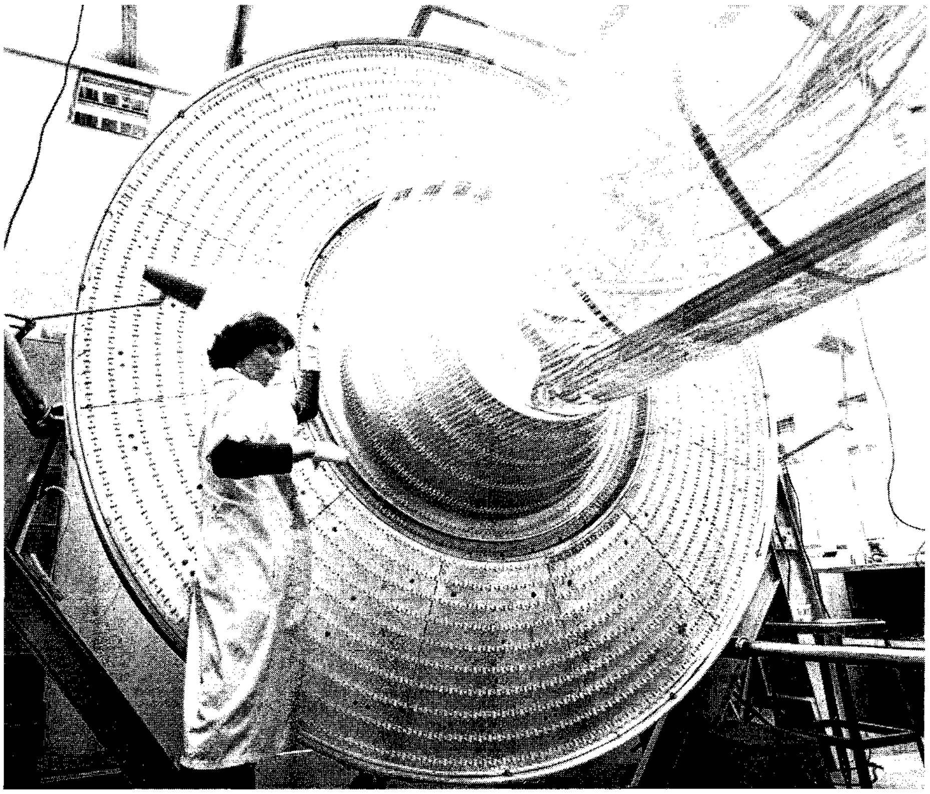

3.


4.

Construction of the Mark II detector at SLAC to be used initially on the SPEAR electron-positron storage ring and then on its more energetic successor, PEP. The photo was taken during the stringing of the sense wires, about 40 μm in diameter, between the field shaping wires of a drift chamber.

(Photo Joe Faust)



magnet for use in a magnetohydrodynamic (MHD) generator. Such generators, which use a stream of high velocity hot conductive gas rather than the armature of a conventional generator, may improve the efficiency of conversion into electrical power by as much as 20 %. The Argonne magnet weighs 45 tons and is about 4 m long and 2 m in diameter. It reached its design field of 5 T in May.

HEP information

The Milan journal 'Le Scienze', the Italian edition of 'Scientific American', has just published a volume entitled 'Il Mondo Subnucleare — La Fisica delle Particelle' (The Subnuclear World — Particle Physics). Its twenty papers, introduced by P. Caldirola and E. Fiorini, cover two decades of research and discovery, from the collapse of parity conservation to the finding of the J/psis. A paper by V.F. Weisskopf (Le Scienze, 1968) on the three spectroscopies lays the foundation of this survey together with three classic contributions to 'Scientific American' (1959-1965) from G. Chew, M. Gell-Mann, A.H. Rosenfeld, S.B. Treiman and E.P. Wigner. The other papers have appeared in 'Le Scienze' between 1970 and 1977. The volume represents the most up-to-date collection of articles in the field published in Italian. (Le Scienze, S.p.A., Milan, 231 pages, A4, 5600 lires.)

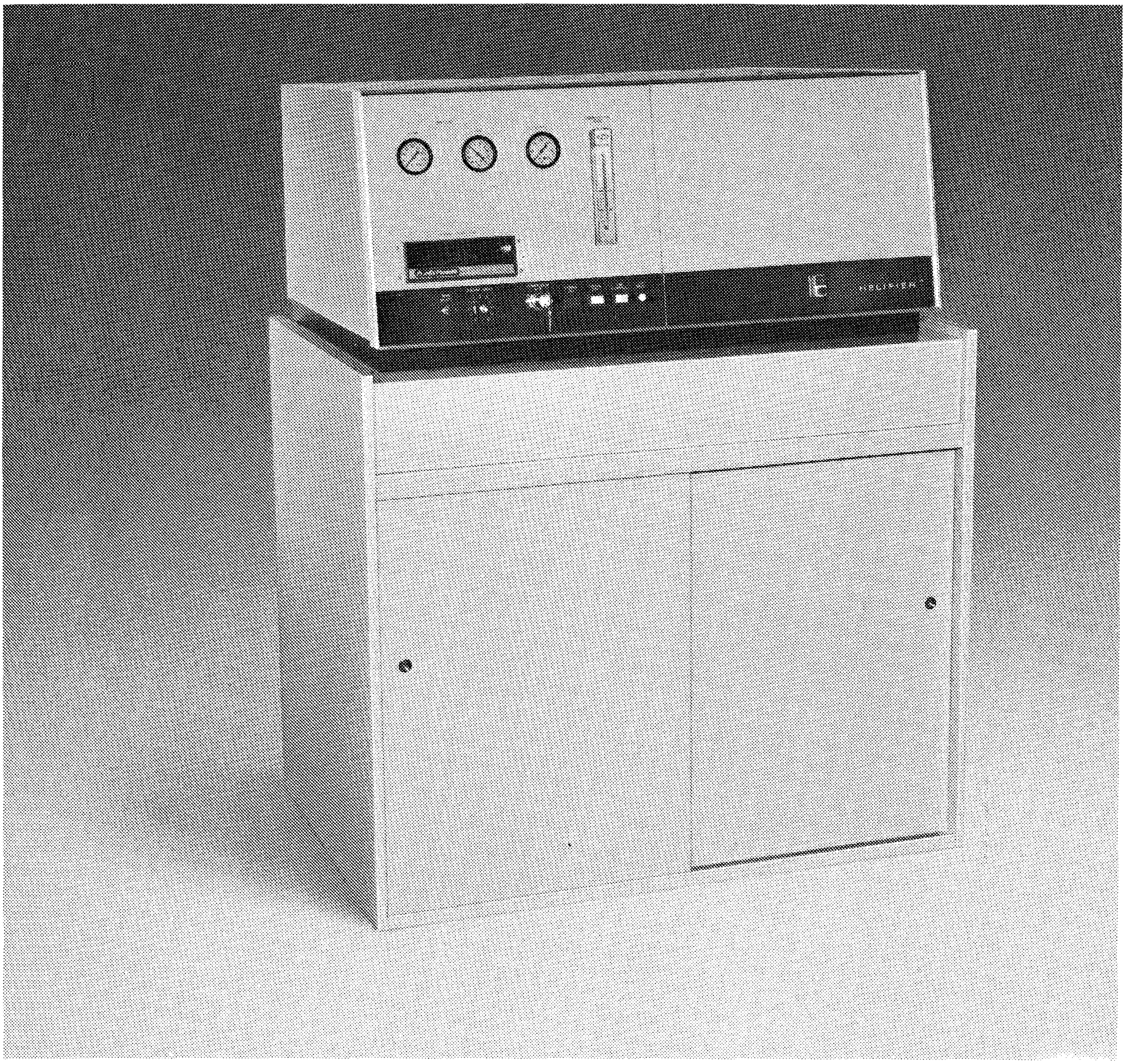
The French Institut National de Physique Nucléaire et de Physique des Particules (IN2P3) has published a 'Textbook on Elementary Particle Physics' — the first of a series which under preparation. It is entitled 'Weak Interactions' and is edited by M.K. Gaillard and M. Nikolic. It evolved from lectures given at the International School of Elementary Particle Physics (Basko Polje). Copies are available from Service des Relations Extérieures, IN2P3, 11 rue Pierre et Marie Curie, 75231 Parix Cedex 05. 374 pages. 40 FF to individuals, 60 FF to libraries plus 10 FF postage.

All fives at the Booster

The CERN PS Booster has reached the 5th Anniversary of first acceleration to 800 MeV design energy on 16 June 1972. This has provoked reflections on the theme of five. There are five bunches per Booster ring; the machine is nursed by five sections (magnets, power supplies, r.f. and kickers, electronics, controls); it has achieved several five-fold increases between the first and fifth years of operation (in operating hours, in PS intensity, in vertical and horizontal phase space density) and a five-fold decrease in unscheduled downtime. Moving to five squared — this is the Booster radius in metres and is the number of children born to Booster staff since the start of construction (a somewhat mysterious relationship). Moving to root five — this is the planned increase in repetition rate and other Booster parameters which will keep people busy in the immediate future.

Polarized ions from LAMPF

A polarized ion beam has been accelerated to 800 MeV for the first time in the linear accelerator, LAMPF, at Los Alamos. Polarized negative hydrogen ions are drawn from a Lamb-shift type of source (built by E.P. Chamberlin). The peak current achieved in the first tests was 0.2 nA with a polarization of 76 %. The source will ultimately yield 0.5 μA of polarized ions.



Interfacing with fast Nims

The expanding range now includes linear and logic fan outs, logic fan-in/outs and coincidence modules designed to meet a wide variety of nuclear physics experimental requirements.
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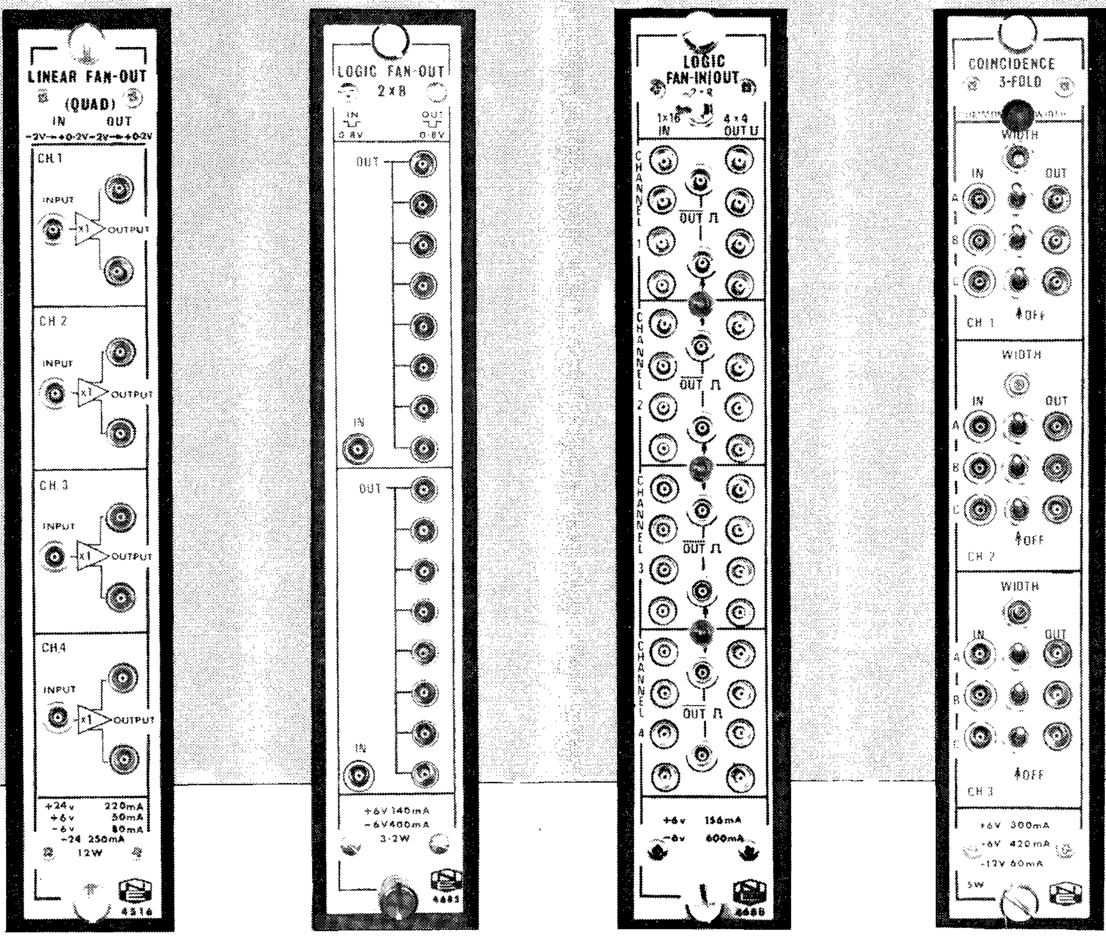

NE 4516 Linear Fan-out
4 channels each with a fan-out of 2.
INPUTS dc coupled, +0.2V to -2V range into 50 ohms, ±200V protected.
OUTPUTS Two per channel, non-inverting, ‹3ns rise and fall times, +0.2V to -2V range into 50 ohms.
GAIN X1 – 5%, nonlinearity ‹2%
DELAY 2.4ns
OVERLOAD RECOVERY 3ns for X10 overload
POWER +24V, 220mA; +6V, 50mA; -6V, 80mA; -24V, 250mA;12W

NE 4685 Fast Logic Fan-out
2 channels each with a fan-out of 8.
INPUTS dc coupled, fast NIM logic level into 50 ohms, duration› 2ns, ±100V protected.
OUTPUTS 8 fast NIM logic levels per channel, non-inverted, ‹1.4ns rise time, ‹1.9ns fall time, duration as per input.
PROPAGATION DELAY 3.3ns; Differential delay, ‹±0.1ns.
MAXIMUM COUNTRATE 200MHz
POWER +6V, 140mA; -6V, 410mA; 3.3W

NE 4688 Logic Fan-in/out
4 sections selectable by front panel control to give quad 4-fold fan-in/fan-out, or dual 8-fold fan-in/fan-out, or single 16-fold fan-in/fan-out with LED indication of mode.
INPUTS 4 per section, dc coupled, fast NIM logic level into 50 ohms, protected to ±100V.
OUTPUTS Fast NIM logic level, 4 per section non-inverting plus 2 per section complementary, 2.5ns rise and fall times, duration as per input.
PROPAGATION DELAY 8.5ns; Differential Delay, ±0.25 ns
MAXIMUM COUNTRATE 100MHz
POWER +6V, 150mA; -6V, 420mA; -12V, 90mA; 4.5W

NE 4691 Coincidence 3 Fold
3 channels each with up to 3 coincidence inputs.
INPUTS 3 per channel, dc coupled, can be individually disabled by front panel control. Fast NIM logic levels, duration greater than 1.8ns, protected to ±100V.
OUTPUTS 3 fast NIM logic levels, negative ‹2.5ns rise and fall times, duration adjustable from 5 to 50ns per channel or common.
COINCIDENCE RESOLVING TIME Greater than 1ns overlap, set by input duration.
PULSE PAIR RESOLUTION ‹9ns
POWER +6V, 350mA; -6V, 430mA; -12V, 56mA; 5.3W

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