

DESY Theoryfest

The traditional annual Theory Workshop at the German DESY Laboratory in Hamburg concentrated this time on quantum chromodynamics (QCD) — the unchallenged but yet to be convincingly confirmed theory of quark and gluon forces in strong nuclear interactions.

In principle, QCD describes a broad range of phenomena, but it is a long way to get from the apparently simple basic equations of the theory to the observed experimental data. Tests of QCD are good only to within about 20 per cent, and in many cases a lot of work is required even to attain this goal.

However the workshop showed that theorists are far from discouraged by technical difficulties and try to make progress with refined perturbation methods and with numerical simulations.

A number of invited speakers discussed the production of 'jets' of hadrons in electron-positron and proton-antiproton annihilation. W. Scott of the UA1 experiment at the CERN proton-antiproton Collider summarized new data, reporting broad agreement with QCD. But there are large uncertainties, in particular when measuring the jet energy, making it difficult to give accurate production rates. The strength of the QCD coupling quoted by Scott was higher than that from previous electron-positron measurements at DESY's PETRA ring. It could be that higher orders of QCD perturbation theory are required or that the formation of hadrons from quarks and gluons ('fragmentation') does not follow the assumed pattern.

PETRA retires undefeated

On 3 November, the PETRA electron-positron storage ring at the DESY Laboratory in Hamburg ended its remarkable eight-year career as a machine for high energy physics experiments. By cunningly switching off ten days before the new TRISTAN ring at the Japanese KEK Laboratory collided 25 GeV beams (50 GeV total energy, see page 1), PETRA managed to retire with its record of 23.35 GeV colliding electron and positron beams still intact.

Built with a design goal of 19 GeV per beam, additional PETRA accelerating power was gradually wheeled in, eventually leading to the record figure early in 1984. As well as pushing up the energy of the collisions, PETRA supplied lots of them, with good luminosity being enjoyed by five experiments over the years — CELLO, MARK-J, JADE, PLUTO and TASSO, bringing together a total of about 400 physicists from 12 countries.

A milestone discovery in 1979 assured PETRA of a place in physics history. Clear two-jet structures, coming from quark pairs formed in the electron-positron annihilations, were seen almost as soon as PETRA was switched on. The sighting of a third jet showed that gluons were also being released. As well as providing the first direct evidence for the carriers of the inter-quark force, this new PETRA physics enabled the strength of the quark forces to be measured.

Although PETRA's energy was insufficient to isolate the W and Z boson carriers of the weak

nuclear force, delicate effects due to these particles were nevertheless observed. This boosted confidence in the underlying theory and helped pave the way for the discovery of the W and Z at CERN in 1983.

PETRA experiments also made pioneer contributions in the field of two-photon physics — the scattering of light by light.

Despite the big push for higher energy, the sixth ('top') quark was not reached, but this provided important new limits.

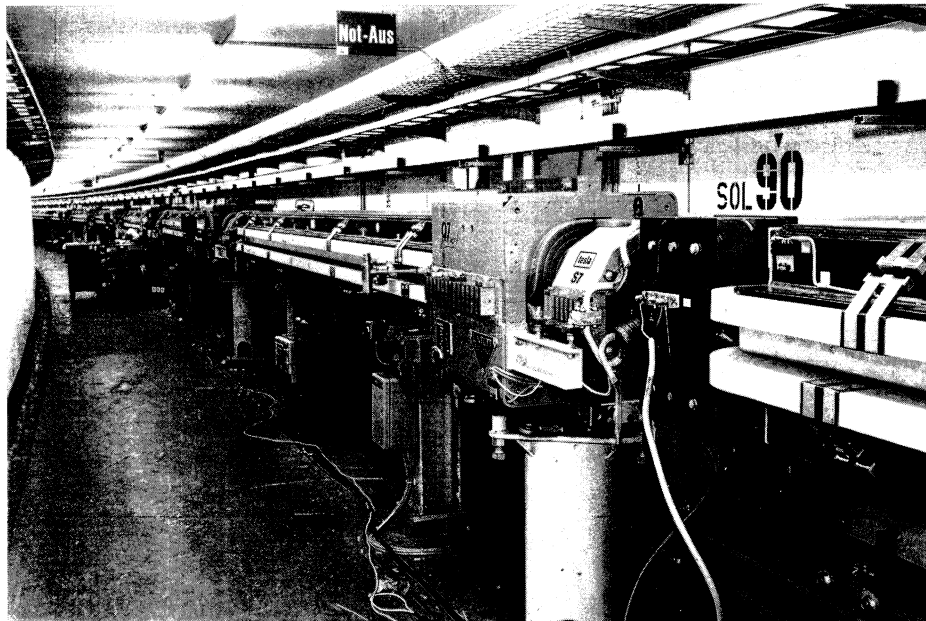
As well as physics successes, the groups working at PETRA also made notable contributions to instrumentation progress — the JADE jet chamber, precision vertex chambers, etc.

On the machine side, PETRA was to give the first example of the 'mini-beta' scheme in action. This technique had been proposed at DESY to squeeze the colliding beams even tighter together and improve the luminosity. Good polarization (spin alignment) levels were obtained thanks to careful machine tuning, while new materials, such as aluminium for vacuum chambers, were exploited. PETRA also served as a test-bed for prototype superconducting radiofrequency accelerating cavities, providing valuable experience in this new technology, now planned for several future machines.

Over the next twelve months, the PETRA ring will be modified for its new role as an electron, positron and proton injector for the HERA storage ring now being built at DESY.

PETRA at the DESY Laboratory in Hamburg, retired undefeated champion of the electron-positron ring.

(Photo DESY)



New calculations in quark dynamics have already begun (reported by R. K. Ellis of Fermilab). Results for jets are not yet available but a study of single hadron production shows large effects, particularly in the angular dependence.

A fundamental problem in all this work is the appearance of terms which increase rapidly with energy and must therefore be summed. D. Soper of Oregon explained how to deal with such soft gluons.

When using only a few orders of QCD perturbation, it is important to choose the coupling constant correctly to minimize contributions from higher orders. M. Fontannaz of Orsay gave a phenomenological justification for this optimization in the case of photoproduced hadrons.

During the fragmentation of high energy quarks into observable particles, cascades of gluons are radiated away. B. Webber of Cambridge showed that the coherence of this radiation has important implications.

A traditional test-bed for QCD is the quark structure (structure functions) of nucleons measured with penetrating lepton beams. C. Geweniger of Heidelberg concluded that the detailed kinematic dependence from QCD is applicable over a narrower range of exchanged momentum than had been thought (Q^2 above about 10 GeV^2).

For electron-positron physics in the u psilon region, D. Wegener of Dortmund had many results to report, including improved limits on certain τ lepton decays which, if seen, would upset conventional dogma.

The u psilon particles are understood as bound states of beauty quarks and antiquarks. Full QCD treatment is difficult and physicists habitually resort to non-relativistic potential models, covered by J. Kühn of MPI Munich. This approach describes the u psilon's quite well, but there are still a few missing states. The emerging form of this potential is also suggested by numerical studies of lattice gauge theories (described by C. Michael

of Liverpool), but the correlation of the two approaches is not straightforward.

No convincing evidence was presented for glueballs (particles composed of gluons rather than quarks) although there are candidates such as the $\eta(1440)$.

M. Pennington of Durham covered a careful analysis of pion and kaon pair production in proton-proton collisions (see page 17) which suggests several resonances, of which at least one could be a glueball.

QCD sum rules are one method for avoiding perturbation theory difficulties, and were described by L. J. Reinders of Bonn. However the most promising attempts to solve QCD at laboratory energies are coming from numerical calculations based on a theoretical lattice. While new predictions are beginning to emerge, the method is still in its infancy (A. Kronfeld of DESY — 'Solving QCD on a computer'). This is because realistic numerical QCD simulations using today's algorithms need 10^{20} arithmetical operations, not easily digestible by today's computers.

But the algorithms are being improved and computing time can be saved by improving the simulation procedures and overcoming the effects of the lattice, holding out new hope. More powerful computers would be an asset, and A. Terrano of Columbia related how some theoreticians have turned their attention to the design of special computers with highly parallel architectures.

Several completed or nearly completed machines attain speeds of between 0.1 and 10 Giga-operations per second, and are significantly cheaper than commercial machines with comparable performance. However the potential user

Roberto Peccei (left) and Martin Lüscher at the traditional Theory Workshop organized by the DESY Laboratory in Hamburg.

(Photo DESY)



has to confront reduced flexibility and difficult software.

Even if a full QCD simulation on a lattice is still a dream, some interesting physics follows from bold approximations. G. Martinelli of CERN told of promising results for the weak decays of kaons into pions.

A crucial question underlying the whole lattice approach is whether the continuum limit of the (artificial) lattice really exists, and whether a perturbation approach is correct. Hints can come from numerical calculations, but a full analytic proof would be more acceptable. G. Mack of Hamburg spoke on the continuum limit of lattice field theories and showed how the 'phase space cell expansion' (essentially a variant of the Wilson-Kadanoff

block spin transformation) gives reason to be optimistic.

There is growing interest in the link between QCD and nuclear physics as pictures of the strong nuclear force under different conditions. F. Lenz of SIN covered a simple non-relativistic model for the interaction between many quarks and antiquarks, opening up, for example, the role of quark exchange in pion scattering and the states of the helium-4 nucleus.

The long-awaited quark-gluon plasma, where the quarks and gluons break loose from their conventional nucleon confinement, may be transiently produced in the collision of high energy ions, as indicated by H. Satz of Bielefeld. With no detailed understanding of the underlying scattering process,

thermodynamic approaches can pay dividends.

At low temperatures, H. Leutwyler of Bern showed how the situation is well understood in terms of a pion gas whose properties can be calculated elegantly and accurately. At higher temperatures lattice techniques have to be brought in, and the phase transition to a quark-gluon plasma comes at an energy density of some 2.5 GeV/fm^3 . With $20\text{--}50 \text{ GeV/fm}^3$ expected from heavy ion collisions, the creation of the plasma looks on the cards. How could it be recognized? One possibility would be a dilepton spectrum without or with a reduced J/ψ signal, as plasma quarks are not expected to form bound meson states.

The members of the DESY Theory Workshop Organizing Committee were R. Baier, H. Fritzsch, M. Lüscher, R. D. Peccei and K. Schilling.

From M. Lüscher

BROOKHAVEN More from spin

For more than a decade it has been known that hyperons produced by protons are polarized to an unexpected degree. Most models try to relate these observations to polarization effects at the underlying quark level: polarization of the quark-antiquark pairs produced when colour-flux strings break, and/or the Thomas precession effect have been suggested as mechanisms responsible for the polarization. This type of model has had several successes and a few failures (see September 1986 issue, page 15).