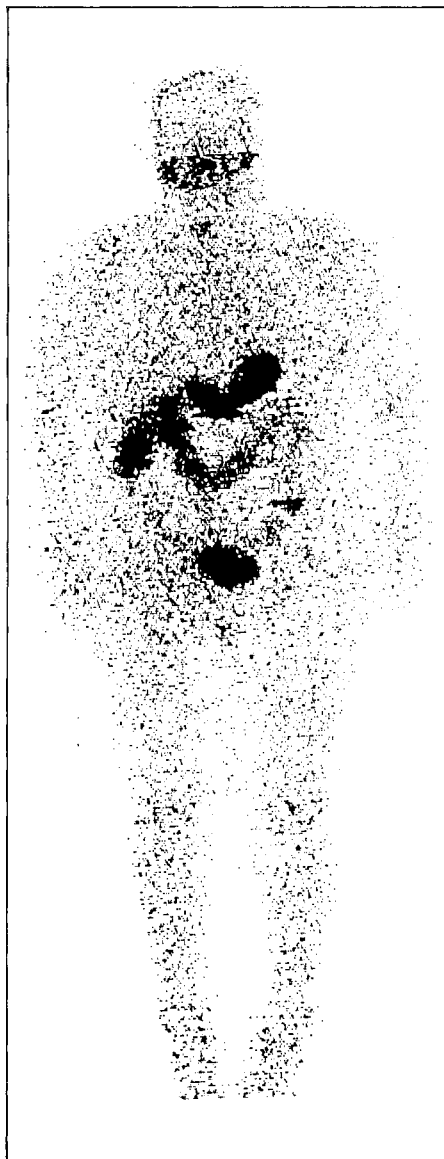


Looking for gluons



Whole body image of a patient with thyroid cancer taken using iodine-123 produced at the TRIUMF cyclotron.

500 MeV contains an irreducible 0.5 per cent of iodine-125 as an impurity. This contributes excessively to the patient radiation dose beyond 28 hours after production. As noted in the April issue of the *COURIER*, the ideal energy for producing pure iodine-123 is near 70 MeV, and TRIUMF has implemented a third extracted beam covering the 60 to 100 MeV range, with the production of iodine-123 (and other potential radiopharmaceuticals) as its main use. A 5 μ A extracted beam of good quality was obtained and a molten sodium iodide target is under development for early installation in this beam for iodine-123 production. Higher intensities are planned for a later stage, which will require several shielded target stations.

In addition to the above research programme, TRIUMF radiopharmaceuticals will be distributed commercially via an agreement negotiated with the Commercial Products Division of Atomic Energy of Canada Ltd. Financing from the British Columbia Development Corporation, through the University of British Columbia, is paying for the construction of high-level radioisotope laboratory facilities at TRIUMF for processing irradiated targets into radiopharmaceuticals. Also a commercial variable energy 42 MeV negative hydrogen ion cyclotron will be installed to provide additional production facilities for radioisotopes produced with proton energies between 11 and 42 MeV. Grants from the British Columbia Provincial Government have allowed the second cyclotron to be upgraded to become a potential neutron source for cancer therapy and the equipping of the radioisotope laboratories for the research programme.

by this gland is not observed; activity in the salivary glands, the gastrointestinal tract and the bladder is, however, present and diffuse uptake is visible in the lung. In addition, a small region of intense iodine uptake is seen in the vicinity of the left hip; this proved to be a metastasised thyroid tumour, exhibiting thyroid function in its new location.

The spallation reaction is also being exploited by this team for the research production of xenon-127, iron-52 and other materials, and by a second TRIUMF/University of British Columbia team for the production of short-lived positron emitters, carbon-11, nitrogen-13, oxygen-15 and fluorine-18. These are destined for application in positron emission tomography studies after incorporation into appropriate radiopharmaceuticals by chemical synthetic techniques.

The iodine-123 produced at

In his concluding talk at the Geneva high energy physics conference earlier this year, Abdus Salam predicted that the gluon is likely to be discovered sooner than the long-awaited intermediate particles of weak interactions. In the light of the new high energy results, from PETRA (see September issue, page 307), this prediction now looks a pretty safe bet.

The existence of gluon is far from being physics history, but evidence is steadily mounting. Even if high energy proton-antiproton collider projects live up to their promise and quickly reveal the intermediate weak particles, the gluon seems to be winning the race at the moment.

Spin one gluons are postulated to be the carriers of the 'colour' force acting between quarks, and are thus ultimately responsible for all strong interaction phenomena. Theorists are gradually piecing together a quantitative theory of quantum chromodynamics (QCD) to describe these forces at work deep inside hadrons.

Delicate effects (so-called 'scaling violations') seen in neutrino experiments had previously given useful encouragement to the QCD theorists. But the contributions from QCD mechanisms can be masked by other effects and so be difficult to measure.

However high energy annihilation of electrons and positrons at DESY, first at the souped-up DORIS ring and then at the new PETRA ring, have provided a new and effective way of testing QCD.

There are a number of big problems which beset QCD. Firstly, it is limited, like all relativistic field theories, to a perturbation-style approach where progressively smaller contributions are added together to converge (hopefully) on a final result. This convergence should improve at

higher energies.

In addition, no recipe has been found to explain the apparent confinement of quarks and gluons within hadrons — at least at the energies we know, quarks and gluons do not appear as free particles.

The perturbative QCD formalism therefore has to be embedded in an empirical 'hadronization' formula which describes how quarks and gluons produce jets of hadronic matter in high energy collisions.

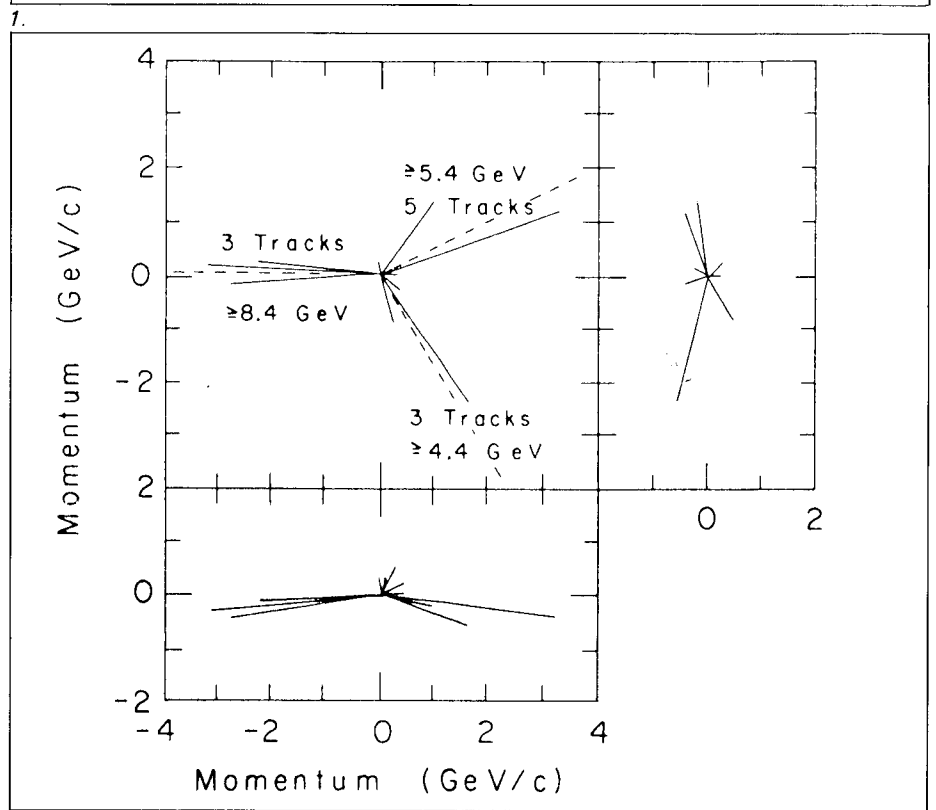
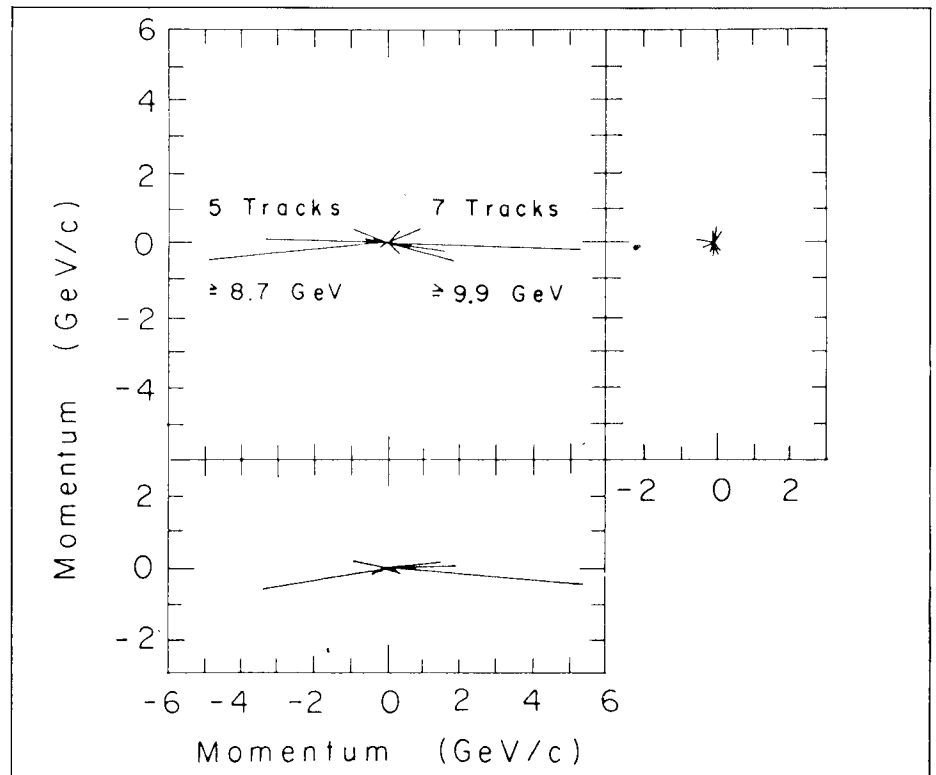
This limits the predictive power of the theory to situations where quark/gluon behaviour is not completely masked by hadronization. This is what makes the DESY electron-positron data on the formation and subsequent decay of heavy quark-antiquark bound states and on the emission of 'hard' (energetic) gluons so interesting.

The first evidence came from DORIS data on the decay of the Υ resonance. As a vector (spin one, negative parity) particle, this should decay into an odd number of vector gluons, analogous to the well-known decay of positronium (an electromagnetic bound state of an electron and a positron) into three photons.

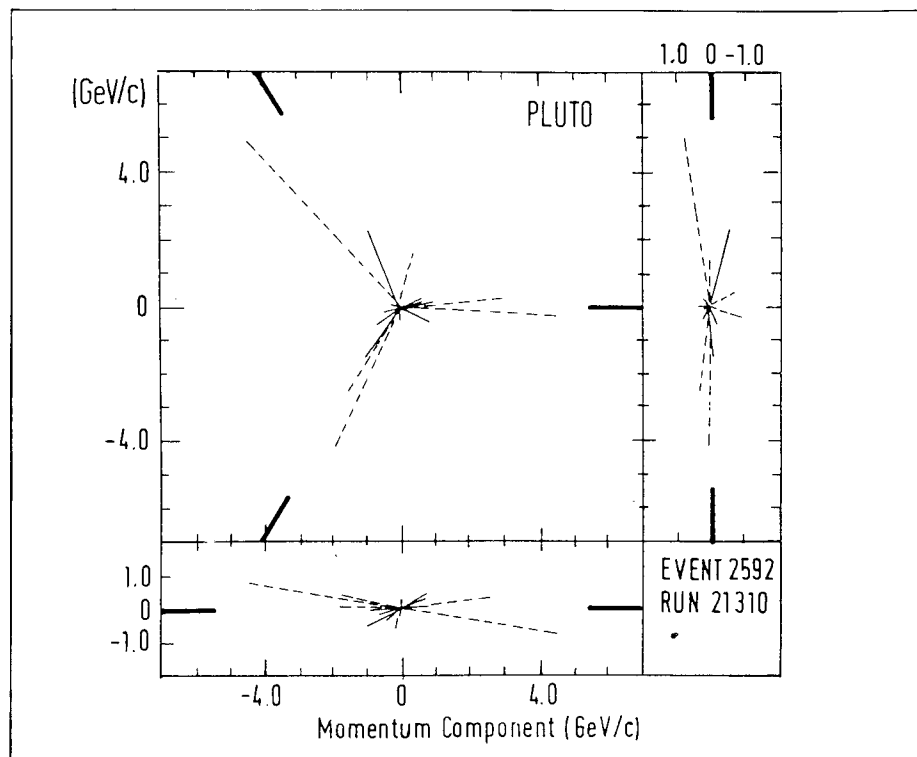
Hopefully these gluons would produce three clearly-defined jets of hadrons, but in the Υ mass range, this behaviour might not show up as clearly as might be hoped. It is difficult at these energies to differentiate between true jets and the amorphous behaviour given by a statistical decay model.

To distinguish clearly between three-jet events and the two jets coming from quark-antiquark pairs, the experimentalists need some means to measure the 'jettiness' of their data. This jet analysis should also be amenable to QCD calculations.

Momentum distributions in three projections for 1.— a two-jet event and 2.— a three-jet event, as measured by the TASSO detector in high energy electron-positron collisions at PETRA.



Momenta of the particles produced at 31.6 GeV total energy in the PLUTO detector at PETRA. Solid and dotted lines correspond to charged and neutral particles, respectively, and the thick bars show the directions of the jet axes.



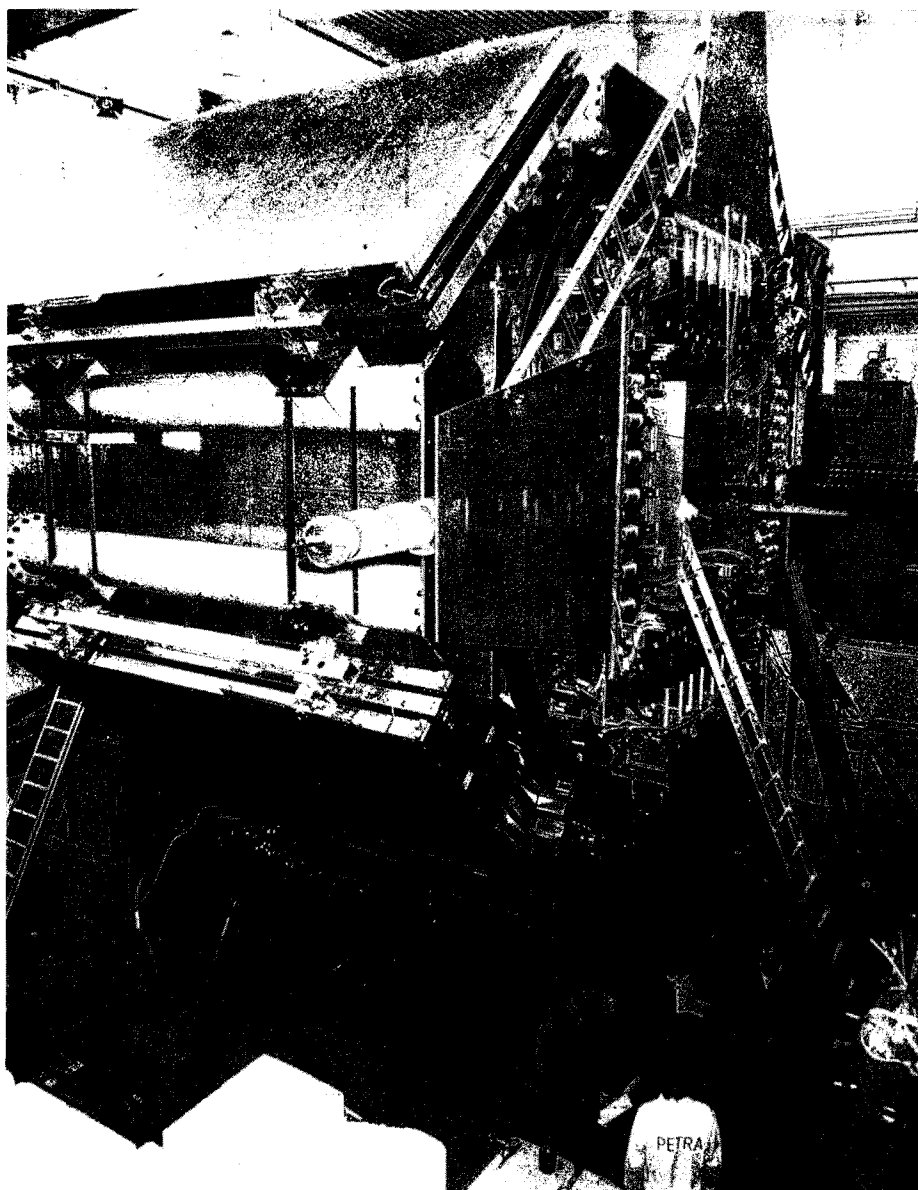
One such parameter which has emerged takes the name of 'thrust'. A decay producing two back-to-back particles would have a thrust value of exactly one, and the deviation from this value indicates the likelihood of additional energetic particles.

Analysis of upsilon decays revealed more events with low thrust than would be expected from the production of quark-antiquark pairs, and found decay products grouped in a plane. This gave the first hint that a new kind of behaviour was being seen, and the hunt for the gluon began in earnest.

The next step came with the availability of higher electron-positron annihilation energies in PETRA to search for signs of three distinct jets produced by a quark, an antiquark and a hard gluon. The annihilation energies at DORIS are too low for the perturbative QCD mechanisms to pierce through the accompanying hadronization and produce observable effects.

Following preliminary evidence from the TASSO collaboration, all the PETRA groups now have some evidence which suggests that hard gluon emission (called 'Gluestrahlung' by some) is being seen. While the data up to collision energies of 17 GeV can be explained by quark-antiquark production, energies round the 30 GeV mark show clear signs of three-body behaviour.

The next step is to measure the spin of the additional particle which is emitted along with the quark and the antiquark. Indications from upsi-



The Mark-J detector at PETRA. As well as finding evidence for three-jet events, the Aachen / DESY / MIT / NIKHEF (Amsterdam) / Peking collaboration has also made important studies of the production of electron, muon and tau particle-antiparticle pairs.

(Photo DESY)

Exploiting muon spin rotation

ion decays and from lepton scattering experiments suggest spin one, but a final conclusion cannot yet be made. Confirmation should come from analysis of the jet angular distributions.

While it is important to confirm the existence of the gluon and to pin down its quantum numbers, another vital test is to search for evidence of a single gluon decaying into a gluon pair. This three-gluon coupling has no analogue in more familiar field theories, such as quantum electrodynamics, but is a necessary consequence of QCD.

This three-gluon coupling, which would be seen as a softening and broadening of gluon jets at high energy compared to the showers coming from quarks, provides a vital test of QCD.

All this will be helped by the availability of full energy (2×19 GeV) in PETRA next year, and the hunt for the gluon will soon be given another boost when experiments begin at the new PEP electron-positron ring at Stanford.

Last year, some twenty per cent of the available beam time at the CERN 600 MeV synchro-cyclotron (SC) was taken up by studies using the technique of muon spin rotation (μ SR).

The idea of muon spin rotation dates back some twenty years to the pioneer experiments on parity violation in weak decays, but it has only come into its own as an experimental technique in the 1970s.

Polarized positive muons are brought to a stop in a target and precess in the local magnetic fields. (Negative muons are quickly captured by nuclei and are much less useful.) Because of parity violation, positrons from the decay of these positive muons are preferentially emitted in the direction of the muon spin.

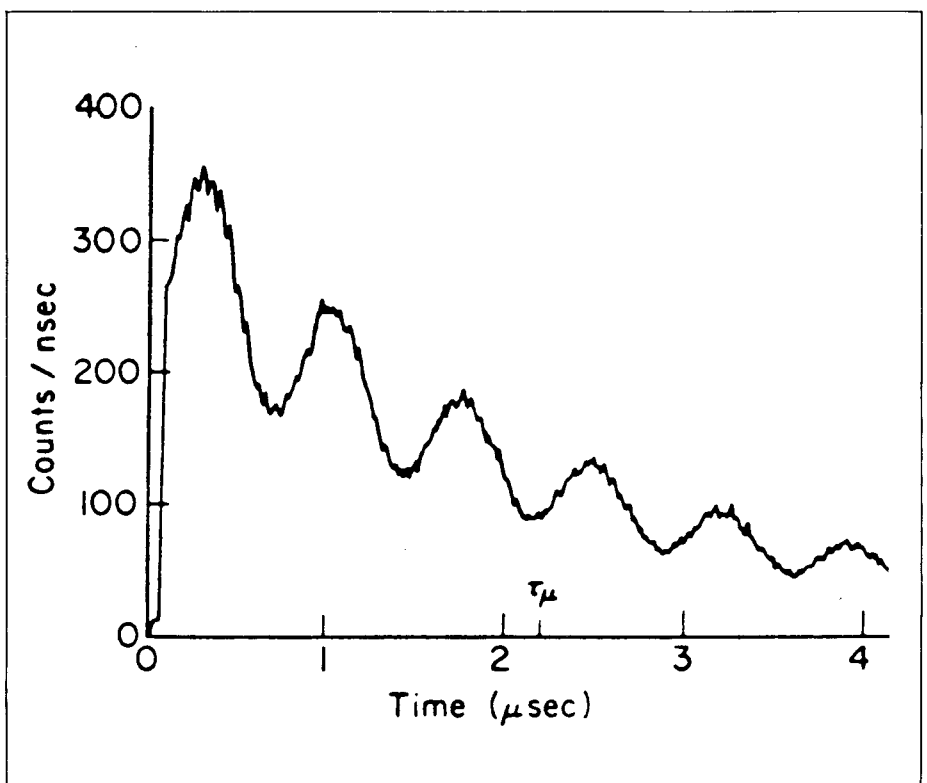
This behaviour can be monitored by positron detectors which record the rate of muon decay and show the

characteristic precession of the muons. In this way the stopped muons can be used to probe the inner structure of a wide range of materials.

Early experiments had shown that at sufficiently low temperatures, muons come to rest in metals and that the muon precession rates in ferromagnets can be used to measure internal magnetic fields at the muon sites. Early μ SR applications at CERN were aimed at ferromagnetic materials.

However it was soon discovered that, first, much more had to be learnt about the way muons interact in metals, and in particular, what types of sites in the crystals the muon energies prefer.

The importance of the electric field which the charged muons exert on the surrounding nuclei was first realized at CERN. Once this was understood, stopping sites could be confi-



Typical muon spin rotation signal showing the characteristic pattern due to the precession of the stopped muons in a sample. This technique is finding increasing application in physics, chemistry and biology.