

Physics monitor

Configuration of a spectacular event seen by the UA2 experiment at the SPS proton-antiproton collider, where 127 GeV of transverse energy is released. The lengths of the lines are proportional to the particle energies. In these initial studies, a wedge has been removed from the UA2 central detector for installation of a single arm spectrometer (see June issue, page 177).

1 μ A has been accelerated. The accelerating field is so far the highest ever achieved in a multicell structure in a superconducting electron accelerator.

The 5 cell 25 cm long 3 GHz test cavity has been developed at Wuppertal and manufactured at Interatom, Bensberg, W. Germany. The cavity is of the spherical design, which is free of multipacting. Ten spherical half cells made from deep drawn niobium were electron beam welded. After appropriate surface treatment the 5 cell cavity was tested at Wuppertal and yielded at a temperature of 1.8 K an accelerating field of 5.8 MV per metre with a Q factor of 5×10^9 . The cavity was then transported to Darmstadt and mounted into a 5 m long cryostat. After cooling with liquid helium the cavity had exactly the same properties as during the test in Wuppertal.

After the successful first acceleration tests more tests are scheduled in which the beam optics of the linear accelerator will be improved, experience in cryogenics will be gained and various adjustments of r.f. parameters carried out. This will probably result in a higher energy gain. The accelerator eventually will be optimized for continuous operation for atomic physics experiments. In Wuppertal a 20 cell 1 m long structure is presently being assembled and tested. This will also be transported to Darmstadt and operated in conjunction with the present 5 cell structure in the linear accelerator.

The present prototype accelerator is an experimental stage for the planned 130 MeV superconducting electron accelerator for nuclear physics research. This accelerator has already been funded and its construction is under preparation.

CERN Jets set

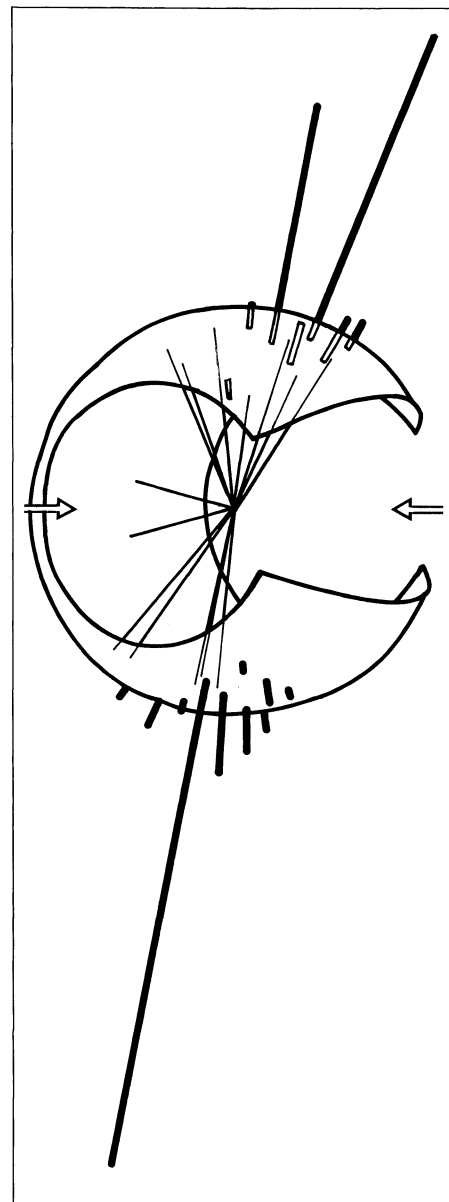
One of the interesting features of this year's physics conference in Paris (see page 311) was the resurgence of confidence in the evidence for the production of 'jets' — well defined clusters of hadrons — in the debris emerging from high energy hadron-hadron collisions.

In the rare but violent interactions when the small constituents (quarks and gluons) buried deep inside the hadrons collide with each other, they are wrenched from their hadronic bonding. Under normal conditions, these do not exist as free particles, and the liberated hadron constituents are understood to 'fragment' into sprays of hadronic matter more or less along the direction of motion of the 'liberated' constituents. Other secondary particles are created by the 'spectator' constituents which are left behind.

Much evidence has been accumulated for the production of hadron jets in electron-positron annihilations, and more recently in lepton-hadron scattering. However hadron-hadron scattering is much more complicated to study because of the relatively high level of accompanying 'soft' hadronic debris which could hide the quark or gluon jets.

Earlier experiments at the Intersecting Storage Rings (ISR) looked for those interactions in which the large transverse energy produced in the violent interactions between constituents is funnelled into a single particle. When triggering on these single particles, the experiments pick up an accompanying spray of hadrons with jet-like properties (see May issue, page 147).

However triggering on a single particle does not necessarily give a representative sample of the total behaviour, and could introduce un-



wanted biases of the event sample. These questions could be sidestepped if large calorimeters could be used to collect as much as possible of the produced hadron energy.

Initial such studies at the CERN SPS proton synchrotron found no evidence for jets (see May 1981 issue, page 155), and this has been underlined by subsequent studies at Fermilab. However these fixed target calorimeter experiments might not

have been able to see the wood for the trees. Under the prevailing conditions, the softer global behaviour of the big 'fluffy' hadrons still dominated the hard constituent interactions. To observe the violent inner collisions, different conditions are required.

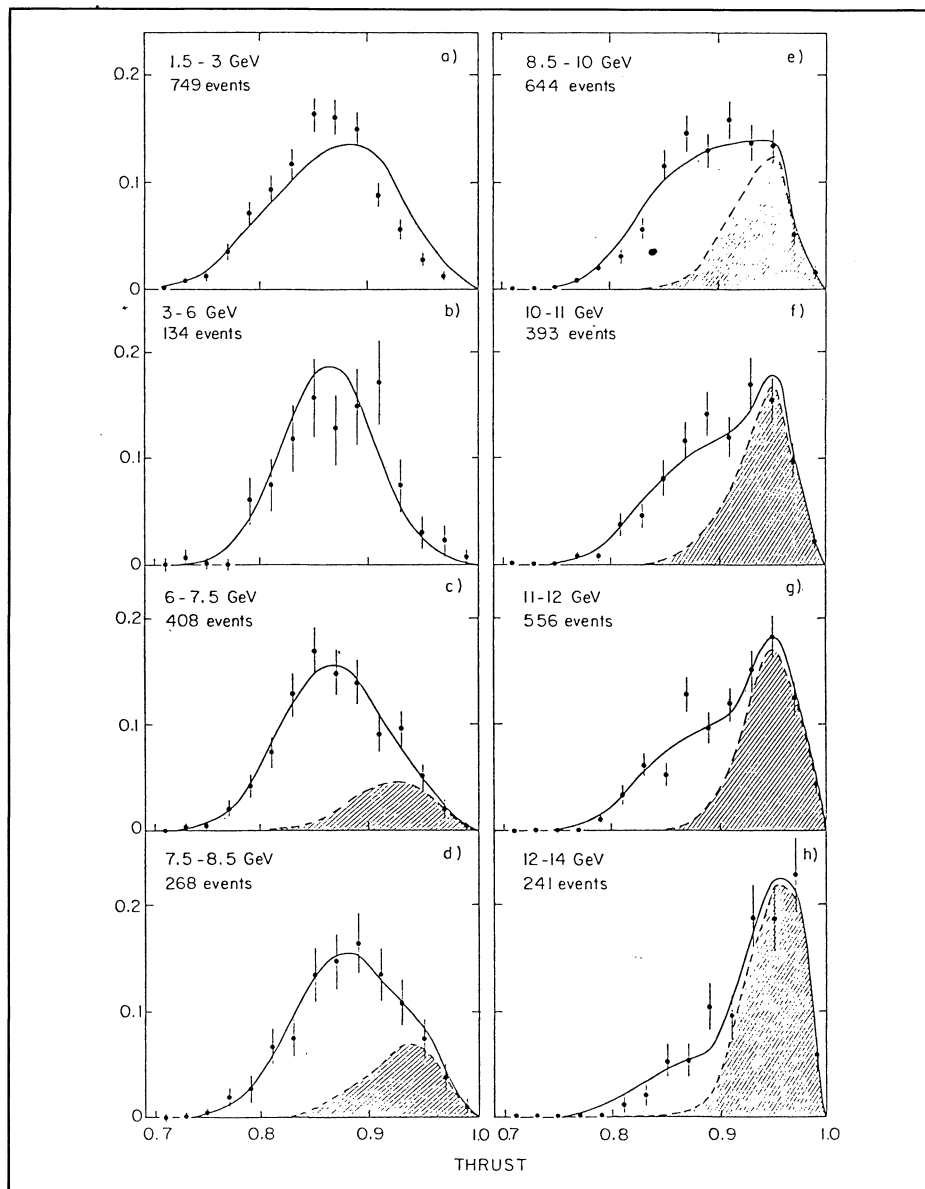
One key quantity is transverse energy/momentum. If the collision energies are high enough, the transverse energy produced in the head-on constituent collisions can be large enough for the produced particles to be easily distinguishable from those originating from softer collisions between complete hadrons. From the appearance of initial results from the UA1 and UA2 experiments at the SPS proton-antiproton collider at CERN, these conditions could already have been attained.

At lower collision energies, such as those of the ISR, higher overall transverse energies were initially difficult to measure. Other criteria had to be sought to filter out those events produced by hard scattering, such as the single transverse momentum triggers collected at the Split Field Magnet.

However new detectors and triggering methods at the ISR have enabled experimenters to look beyond the soft hadron behaviour to see the effects of the inner collisions.

The Axial Field Spectrometer at the ISR (Brookhaven / CERN / Copenhagen / Lund / Pennsylvania / Rutherford / Tel Aviv) now has evidence for the onset of jet production in 63 GeV proton-proton collisions. This evidence comes from events triggered by large deposition of energy in a wall of uranium/scintillator hadron calorimeter, with no requirement on the spatial distribution of particles within this wall. An oppositely mounted wall (see May issue, page 145) was used to record the recoiling particles. The amount of

Distributions of 'Thrust' ('jettiness') into one quadrant of the Axial Field Spectrometer at the CERN Intersecting Storage Rings. The shaded area shows the expected distribution for single jets of produced particles. This behaviour appears to separate out clearly as the transverse energy is increased.

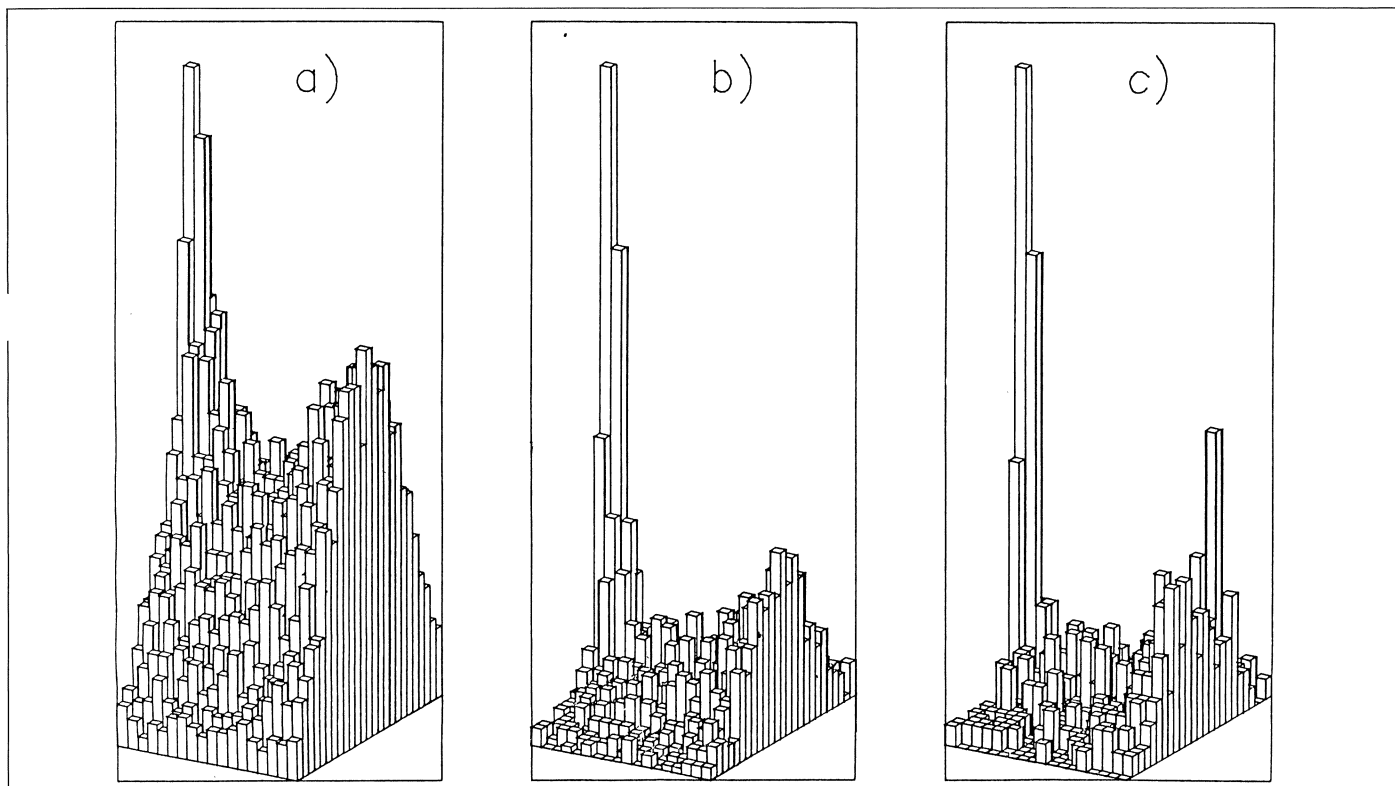


clustering in the hadronic showers was quantified by calculating the so-called 'thrust' of the events.

The observed thrust distributions show a uniform spread of energy flow for lower values of the transverse energy trigger, but as this trigger energy is increased, the shape of the energy flow starts to change. At about 10 GeV transverse energy in the trigger wall, the observed thrust distribution starts to show clear

signs of well-collimated hadron clusters. This collimation improves as the trigger transverse energy is increased up to about 14 GeV, when most of the energy deposited in the wall is found to be contained in a relatively small solid angle. The same behaviour is seen in the signals in the floor calorimeter, which picks up the recoiling hadrons, and is similar to that seen in the particles recoiling from single high transverse momen-

Evidence for the clustering of high transverse momentum secondary particles as measured by the UA1 experiment at the SPS proton-antiproton collider. Left, the distribution of all secondaries accompanying a 4 GeV/c trigger particle. Centre, distribution of those secondaries above 1 GeV/c and right, above 2 GeV/c, for the same trigger.



tum particle triggers.

The same onset of jet behaviour is seen by measuring the distribution of produced charged particles in the experiment's central cylindrical drift chamber. As transverse energy is increased, the energy flow on the trigger side and the opposite side is seen to become narrower.

The calorimeter is being enlarged. Further studies should enable well-defined jet cross-section measurements and more detailed comparisons of these jets with those seen in electron-positron annihilation.

Elsewhere at the ISR, the CERN / Columbia / Oxford / Rockefeller group has adopted a different approach. High transverse momentum neutral pions are frequently found as part of a spray of accompanying particles. While this itself is an initial jet-like signature, the analysis goes further. It is found that these neutral pions carry 70 per cent or more of

the total jet momentum, and are closely aligned with the jet axis. The analysis then concentrated on roughly back-to-back pairs of neutral pions, detected in oppositely mounted arrays of lead-glass Cherenkov counters.

The behaviour of these oppositely produced neutral pions can be used, to a good approximation, as a mirror of the behaviour of the inner colliding quarks. The observed behaviour of the pions, for instance their production rates and angular distributions, can be compared with the predictions of the theory (quantum chromodynamics) of quark and gluon interactions. The results are encouraging and hint that this type of approach could be usefully extended.

Although the initial collision rates are low, it is at the SPS proton-antiproton collider where the collision energies attain the levels where the produce of hard constituent scatter-

ing could be seen.

The highly segmented calorimeters of the UA2 experiment cover a large solid angle and are able to intercept a large proportion of all the particles produced in these 540 GeV energy collisions. Events were selected according to the total amount of transverse energy deposited in the calorimeter. For low total transverse energies, the event rate falls off with increasing transverse energy, as seen in lower energy experiments with fixed targets. However at the high total transverse energies captured by UA2, the event rate no longer falls off so rapidly. This is the first clue that some new behaviour is being seen.

Analysis of the clustering of this total transverse energy in the separate calorimeter compartments shows that as the total transverse energy increases, the events contain fewer clusters of particles, but each

cluster contains higher transverse energies — the spread of the particles becomes less homogeneous and more jet-like. In particular, all events with total transverse energy greater than 60 GeV have two-thirds of their transverse energy contained in just two clusters of produced particles. 59 events are found containing at least one cluster carrying more than 20 GeV transverse energy.

For events containing two high transverse energy clusters, these clusters like to be back-to-back when viewed along the beam axis. However these events are only a small fraction of the total high transverse momentum sample.

The calculated rate of production of jets is in broad agreement with theoretical expectations. In the kinematical region covered by this experiment, most of the jets in fact result from the scattering of the gluons accompanying the quarks.

The UA1 detector had an initial sample of 48 000 events with a magnetic field of 0.56 T in the central detector, and another 39 000 events at 0.28 T. In this way the validity of the procedures used in data analysis could be checked. An initial clue that something special is being seen comes from the original observation that already at transverse momenta of 10 GeV, the secondary particle yield is a thousand times up on what is seen at the ISR. As well as the hadrons produced by 'fragmentation' of the colliding constituents, there appear to be indications that gluon radiation too plays a role in the particle production process.

In the angular distributions of particles produced relative to a single high transverse momentum trigger, a clear signal is seen as the particles cluster around the trigger. The effect becomes more marked if lower momenta particles are excluded. A similar phenomenon is also seen in

the recoil direction. This provides initial qualitative evidence for constituent scattering. Further investigations will be possible when larger data samples are available.

Taken together, this provides impressive evidence that experiments are now able to isolate and study the interactions of the tiny constituents hidden deep in the interior of protons.

ARGONNE

Future proton decay experiments

Earlier this year over 70 physicists, with a common interest in searching for new phenomena in low background, deep underground experiments, gathered at Argonne for the 1982 Summer Workshop on Proton Decay Experiments. The Workshop focussed on plans for the next generation of proton decay experiments in the United States, and the US experiments, proposals, and detector development programs were, of course, well represented. In addition, active participation by proton decay experimenters from Europe, by physicists doing other types of underground experiments, and by the theoretical physics community, provided breadth and perspective to the discussions.

The Workshop was organized at the suggestion of the US Department of Energy Technical Assessment Panel (TAP) on Proton Decay, which met early this year to review recent developments and to consider proposals for three new US experiments. The TAP's main recommendation was that new experiments be delayed pending initial results from the large water Cherenkov detectors, which were in the final stages of construction. The TAP also felt that future planning of the US program

would be helped considerably by further in-depth discussions, in the open format of a Workshop, of the optimum design, deployment, and timing of the next generation of proton decay experiments.

The week-long Workshop agenda was divided about equally between talks by the participants and the activities of five Working Groups which were charged with addressing specific questions raised by the TAP. These included defining a set of goals for the next generation of experiments, taking into consideration the expected performance of experiments already in operation or construction, and recommending a timetable for the start of the next round of experiments. A closely-related question dealt with the detection techniques to be used in new experiments and involved a critical comparison of the different types of detectors which have been proposed: the water Cherenkovs, the fine-grained iron-plate calorimeters, and the totally-active liquid-scintillator calorimeters. Here, the main conclusion reached was that the next generation should emphasize the detection of decay modes to which the present experiments will be relatively insensitive. Decays involving a single neutrino, and particularly the neutrino plus kaon mode recently predicted by supersymmetric models, will be difficult for any presently approved detector to distinguish from background.

In order to accomplish this, any new experiment should have fine-grained tracking and be able to tell the direction of motion of a particle along its trajectory (by timing and/or ionization measurements); also, good energy resolution and charge determination for muons and hadrons are required. Since the sensitivity of present experiments to some decay modes will be limited by