

to transitions between different triplet charmonium levels, in much the same way that sharp spectral lines show up when ordinary atoms are excited. In addition, a small but statistically significant peak was seen in the spectrum corresponding to a new charmonium state of mass 2983 MeV. Some months later, the Mark II group (Berkeley / SLAC), announced the first evidence for a specific eta-c decay mode, while another decay mode was found by the Crystal Ball shortly afterwards. This was already sufficient to make theoreticians feel better, but to pin down this new candidate charmonium state, its quantum numbers first had to be fixed.

The Crystal Ball is well suited to measure electromagnetically showering particles like electrons and photons. To handle charged hadrons required more work, and further evidence in favour of an eta-c assignment for the new state came from analysis of channels containing appropriate combinations of hadrons.

At present, the characteristics of the state are highly suggestive of the eta-c, but further work is needed.

Elsewhere in the photon spectrum from radiative charmonium decays, the Crystal Ball shows evidence for decays producing a meson of mass 1420 MeV. A small sample of specific decay modes for a meson of this mass was also reconstructed by both Mark II and the Crystal Ball. A spin one meson of this mass, the E, has been known for some time through the analysis of bubble chamber exposures to hadron beams.

In the Crystal Ball, the radiative transitions producing E-mesons appeared to be quite copious, and this led some people to speculate that the E, rather than being a conventional meson built up of a quark and an antiquark, could be an example of a 'glueball' — a new type of matter much talked about but never before seen.

Current thinking says that quarks interact through the 'colour' force

mediated by the exchange of so-called gluons, similar in some respects to the photon exchange responsible for the familiar electromagnetic force. As well as transiently flitting between quarks, these gluons should also be able to stick together to form 'gluonium' or 'glueballs'. Whether the E-meson signal seen in radiative charmonium decays is a glueball or not remains to be settled.

With Mark II having already moved to the bigger PEP ring, the Crystal Ball is presently the only detector operating at SPEAR. Even though its move to PEP has been approved, this will not take place for at least a year. An important task remaining at SPEAR is to continue to search for the F-meson, carrying both charm and strangeness. F candidates have now been reported from experiments at several Laboratories, but as yet none from SPEAR. Other objectives include more eta-c data and a scan of the SPEAR energy regions so far largely neglected.

Physics monitor

Ultrahigh energy cosmic rays

Cosmic ray experiments have traditionally provided physicists with glimpses of behaviour beyond the energy range attainable with artificial particle beams. However with the CERN antiproton project promising to provide collision energies equivalent to those of 155 000 GeV beams, and with the prospect of ISABELLE at Brookhaven going even higher, physicists hope that some of the exotic behaviour reported from cosmic ray studies will

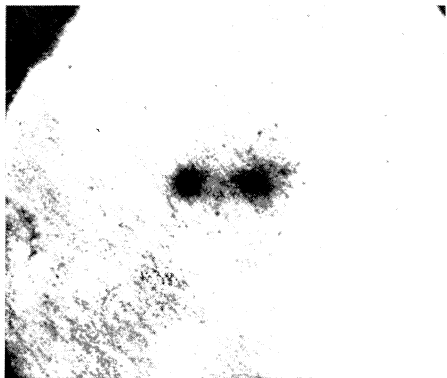
soon come within the reach of laboratory experiments.

Meanwhile the cosmic ray specialists continue their studies, and from 20–29 October, the city of Nakhodka in the Soviet Far East was host to a Soviet-Japanese symposium on processes at ultrahigh energies in cosmic rays, investigated using emulsion chambers exposed at altitude. There were participants from the Japanese/Brazilian collaboration at Mount Chacaltaya in the Andes, from the group carrying out experiments on Mount Fuji, Japan, and from the 'Pamir' Soviet-Polish collaboration.

Various characteristics of the fragmentation region of inelastic hadron-nucleus interactions were covered, and detailed comparison of the comparable data obtained by all three groups shows quite reasonable agreement in a number of respects.

1. The cross-section of the hadron inelastic interaction with an air nucleus still increases at least up to energies of 10^{15} eV at nearly the same rate as at accelerator energies.
2. At ultrahigh energies there is considerable deviation of scaling not only in pionization but also in the

A 'binocular' event seen by the 'Pamir' collaboration looking at the effects of ultrahigh energy cosmic rays passing through a 5 cm lead plate. The spot on the left contains more than sixty quanta while that on the right is due to a single quantum with an estimated energy of over 500 TeV.



fragmentation region. Here it is assumed that the composition of the primary cosmic radiation does not change at ultrahigh energies.

3. The energy dissipation of the incident hadron in the strong interaction collision increases considerably. Apparently the number of secondary particles in the fragmentation region at ultrahigh energies is growing with the energy of the primary cosmic ray, E , as fast as $E^{1/4}$, and maybe even faster at energies above 10^{16} eV. The inelasticity increases correspondingly and the role of leading particles in the development of nuclear cascades is considerably diminished. The energy spectrum of secondary particles becomes softer.

4. Among the different so-called 'families' of ultrahigh energy events, there is a significant number of secondary particles with large (over 5 GeV) transverse momenta. Sometimes these events are also anisotropic in the plane perpendicular to the primary direction. There are events of a pronounced jet structure with a comparatively large number (more than five) of jet particles and comparable energies of the separate jets (for two-, three- and many-jet events). The percentage of unusual events grows with increasing energy of the primary particle. The study of this type of event makes for useful comparisons with the predictions of

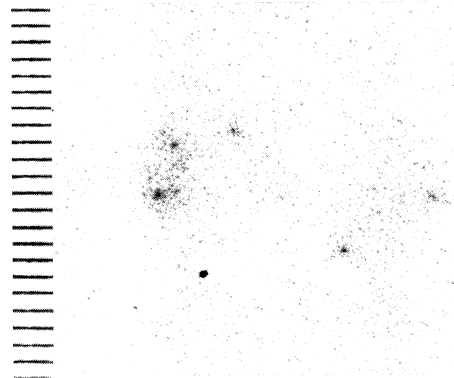
quantum chromodynamics.

5. At ultrahigh energies, some peculiar processes exist which produce exotic events, particularly of the so-called 'Centauro' type, where most, if not all, of the energy goes into producing long-lived secondary hadrons with few neutral pions. The Japanese-Brazilian collaboration has found about half a dozen reliable examples of Centauros, while the Pamir group has also seen a few events of this type, but less clean. Simulations based on standard physics models indicate that these events cannot be due to fluctuations. A few examples of other exotic events have also been seen which likewise await an explanation. The study of these phenomena is of great interest and could lead to the need for new types of quark or new baryon states.

Results using present cosmic ray techniques show that the behaviour seen at ultrahigh energies is not a simple extrapolation of the detailed and reliable results obtained at accelerators. This provides clear motivation for higher energy projects and suggests possible directions for future studies.

At the same time, cosmic ray specialists are anxious to extend their present experiments with emulsion chambers and accumulate more data in the interesting ultrahigh energy region. For this, good collaboration between different experimental groups will be important, and the Symposium was a move in this direction.

(We are grateful to S.A. Slavatinsky of the P.N. Lebedev Institute, Moscow, for transmitting news of this Symposium.)



Dark spots recorded in X-ray film from the 'Centauro-1' cosmic ray event seen by a Japanese-Brazilian collaboration. The top picture is taken in the upper chamber, under 7.8 cm of lead. The lower picture is from the lower chamber, under 3 cm of lead and a carbon hadron converter. (The unit on the attached scale is 1 mm.) The big surprise is the asymmetry between the patterns recorded in the top and bottom chambers — hence the name Centauro. This is interpreted as an absence of neutral particles (producing electromagnetic showers) in the initial interaction.

