RESULTS CONCERNING STRONG INTERACTIONS*

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1. Introduction. Needless for me to mention that there are many important and interesting results on high energy strong interactions presented at this conference. The organizers of this conference were thoughtful in arranging two rapporteur talks on this topic to cover the whole range of papers. I would cover in my talk today some of the topics and Yash Pal would do the rest in his talk tomorrow. If some results are not mentioned by us, it should not be viewed as our judgement of their importance; lack of time restricts our coverage.

2. Accelerator Results. Cocconi's talk (1971) at the Hobart Conference on the CERN intersecting storage rings was a clear warning that the months, if not days, for doing high energy strong interaction physics using cosmic rays at energies less than 2000 GeV were numbered. Just to remind you, I present in Table 1 below the situation which is only

Table 1: Beam Intensities

Energy GeV	Cosmic Rays Aperture = 1 m^2. Ster.	Accelerators
≥ 300	Balloon altitudes: 1800 protons/hr Mountain altitudes: 13 protons/day	Nat. Accel. Lab (U.S.A.) 5 x 10^{11} protons/sec.
≥ 2000	Balloon altitudes: 72 protons/hr Mountain altitudes: 0.48 proton/day	CERN I.S.R. ≈10^5 interactions/sec.
≥ 3000	Balloon altitudes: 36 protons/hr Mountain altitudes: 0.24 protons/day	No competition at all (1973).

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too well known to the people working in this field. Vovyodic and Bellettini presented some of the results on strong interactions obtained at National Accelerator Laboratory (NAL) in the U.S.A. and at Intersecting Storage Rings (ISR) at CERN respectively. Their presentations are so highly condensed that it is impossible to summarize them any further. I will, therefore, present only two results from Bellettini's talk referring you for other results to current literature and to Proceedings of Conferences on High Energy Physics. The first concerns a test of Hypothesis of Limited Fragmentation (HLF) proposed by Benecke et. al. (1969). One defines a variable $\eta = \ell n \tan (\vartheta/2)$ where ϑ is the emission angle in the c.m.s. of a secondary with respect to the direction of incoming protons. The Pisa-Stonybrook collaboration experiment (Bellettini et. al. 1973), in which single particle distributions were measured in terms of the variable η, was done with (i) momenta of both the beams at 15.4 GeV/c and (ii) at 26.7 GeV/c and (iii) with momentum of beam 1 at 15.4 GeV/c and of beam 2 at 26.7 GeV/c. Results are given in Fig 1. In the fragmentation region of each beam ($\eta < -1.5$ for beam 1 and $\eta > 1.5$ for beam 2) one gets the same yield whether the momentum of the other beam is 15.4 or 26.7 GeV/c. This invariance can simply be transformed to the rest system of the particles in each beam and it then proves HLF. The second

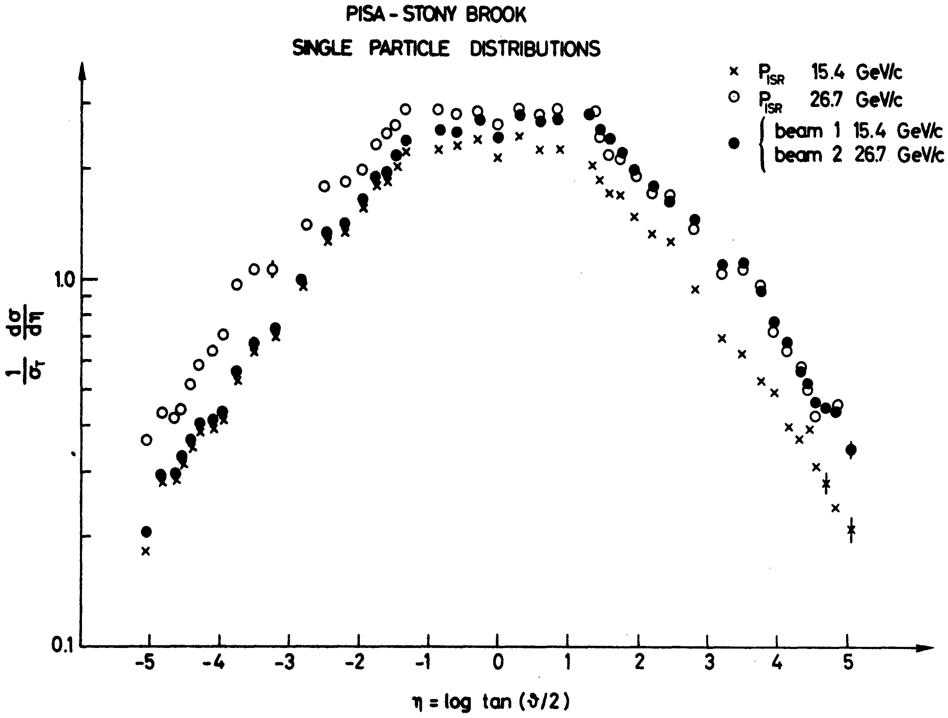

FIG. 1. See the text for legend

result concerns the two component (diffraction dissociation and pionization) model of inelastic collisions between two particles, say a and b. One marks by a short vertical bar on η axis, as shown schematically in Fig. 2, each outgoing charged particle from an inelastic collision. One could

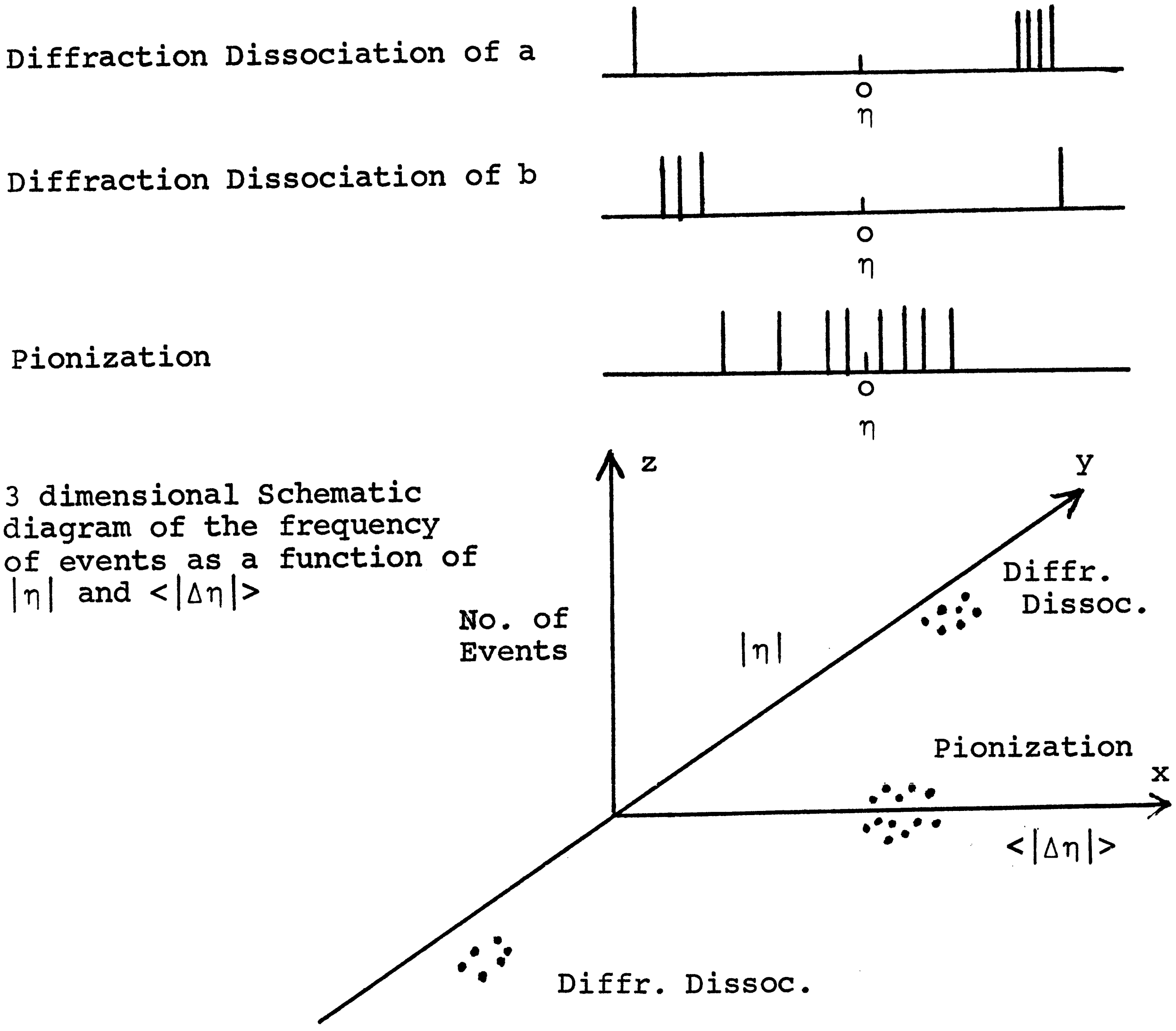

FIG. 2. See the text for legend

have either a diffration dissociation (upper two lines in Fig. 2) or pionization (third line in Fig. 2). Notice the short range correlations among the secondaries from diffraction dissociation, characterized by large $\langle \eta \rangle$ and small $\langle |\Delta\eta| \rangle$

and the absence of correlation among the pionization products characterized by small $\langle \eta \rangle$ and the large $\langle | \Delta\eta | \rangle$. Statistical fluctuations prevent unambiguous classification of each event. However, a large sample of inelastic events can be plotted in a 3 dimensional diagram (sketched in lower half of Fig. 2) to see if the two components separate out. Statistics is no problem at I.S.R. Bellettini showed several slides in which one could clearly see two large diffraction peaks and a low pionization peak at low multiplicities. As the multiplicity increases, the diffraction peak decreases. A preliminary value of the cross-section for either proton to diffraction dissociate is given as 6 mb. Gierula reminded that the two component model was demonstrated to hold good in their paper published two years ago (Gierula and Wolter 1971) and showed a slide (Fig. 3) to support his claim. It is based on an analysis of 1074 cosmic ray jets observed in nuclear emulsions. σ in Fig. 3 refers to the width of the distribution of secondaries from a jet in log tan θ plot and γ_c to the Lorentz Factor of the c.m.s. Notice the two peaks in jets with $n_s < 15$; the peak on the left represents diffraction dissociation and the one on the right, pionization.

3. *Quark Search*. Quark search continues in cosmic ray research. Since the Hobart Conference, no new group joined the hunt while some had actually given up. Referring you to the candid survey at Hobart by Lawrence W. Jones (1971) for the details of the various methods employed in this hunt, I will here just up-date the results as presented at this conference in Table 2 below which is self-explanatory. The only positive evidence at this conference is from the Tata Institute group (Tonwar et. al. 1973) who employed a multiplate cloud chamber to measure the energy of hadron and a set of scintillators to measure the delay of

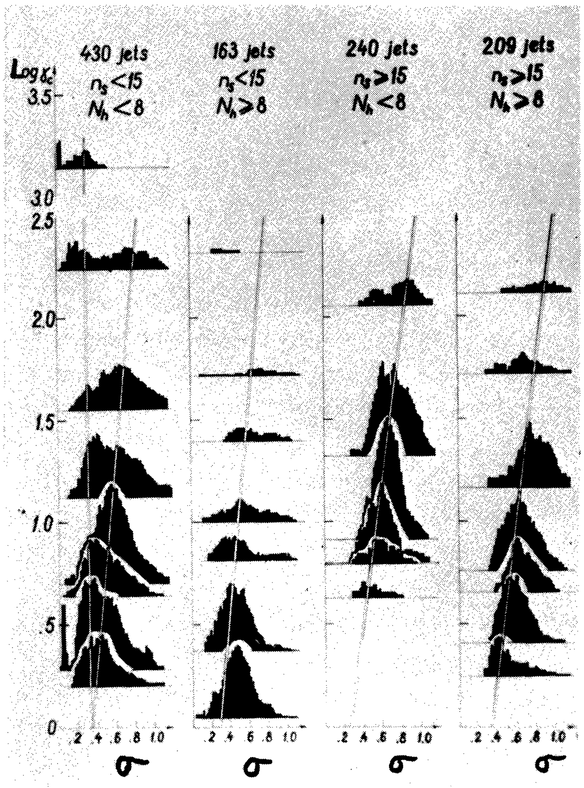

FIG. 3. See the text for legend.

Table 2: Quark Searches

Cosmic Ray Quark fluxes are given in units of 10^{-10} particles/cm^2 sec sr

	Charge	Hobart Conference*	This Conference
I. Negative Results			
A. Cosmic Rays			
(i) Hazen et al.	2e/3	<0.5	--
	e/3	--	<0.25
(ii) Clark et al.	2e/3	<0.3	<0.2
	e/3	<3.0	<0.8
(iii) Ashton et al.	e/3	<2.6	<0.55
B. Accelerators			
Leipuner et al.	e/3	--	$\sigma_{prod} \leq 10^{-35} cm^2$
	2e/3		for $m_Q \leq 11$ GeV/c^2
II. Positive Results			
(i) Sydney group	2e/3	2.4	Discontinued
(ii) Turin group	<2e/3	300	Paper withdrawn
(iii) Tata Inst. (OOTY) Tonwar et al.	Not measured	≈10	2 events

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[*] Some of the results, though not reported at the Hobart Conference, were known at that time; see Jones (1971) for references to pre-Hobart or Hobart Conference results. References to the results at this conference are given at the end of this paper.

its arrival with respect to that of the air shower front. The two events mentioned in the table have energies 36 and 28 GeV and are delayed by 41 and 25 ns respectively with respect to the air shower front. The authors have not analyzed the data fully yet and, therefore, the flux figures are not given at the conference. The observed delays are several tens of nanoseconds greater than what one expects for pions and nucleons and hence the events are potential candidates for heavy hadrons which could be quarks. To summarize, there are at this conference more definitive negative results and less emphatic and fewer positive results from quark search experiments than at the time of Hobart Conference.

4. (a) Inelastic interactions: General. The most probable angle of deflection in an elastic scattering is 2.3 milliradians at $E = 100$ GeV and it further decreases with increasing energy as $1/E$. Since cosmic radiation is not a well-defined beam, it is very difficult to measure such small deflections. It is not surprising therefore that there is no information on high energy elastic scattering reported at this conference. There are several papers reported on the inelastic collisions. As usual, the data are not presented in the form of differential distributions in 4-momentum transfer or Lorentz invariant inclusive differential cross-sections, two particle correlations, etc. as is the practice at the accelerators. Extremely low beam intensity precludes precision. Instead, one talked - as in the past - in terms of mean freepaths, inelasticities and average multiplicities, etc. Even on these topics there are no papers presented in a direct fashion. Often they entered the discussions in an indirect way, not only at the HE Sessions, but also at the MN and EAS Sessions. In particular, there was a very interesting HE Session chaired by Lawrence W. Jones and devoted to a presentation and discussion of new phenomena in Particle Physics at Ultra-High Energies. The time allotted for this session was insufficient and a special session was held in the night. High P_T , heavy and super-heavy quanta, scaling and the "zoo of new particles" were some of the topics discussed in the session. In spite of the best efforts of the chairman, there was no concensus on any of the topics and it was hoped that continued observations, increased statistics and more refined calculations would clear up the picture in the future. Usually conclusions were based on some vital assumptions. To illustrate, let me take an example. There have been claims made that the average multiplicity of secondary charged particles must increase faster than $\ell n s$ (or $\ell n E_{lab}$) to account for a variety of EAS phenomena. However, there are other attendant assumptions

regarding the composition of primaries, σ_{inel} and inelasticity parameters. There is also the problem of the target being a complex nucleus (nitrogen or oxygen) instead of being a proton. It is well known that cosmic ray propagation in the atmosphere is sensitive not to <u>all</u> the secondary particles but only to the more energetic among them. It is difficult to see how all these quantities bootstrap themselves into contradicting or confirming a simple law such as a $\ln s$ variation with energy of <u>all</u> the secondary particles produced in a p-p collision. It is highly desirable that experiments be undertaken at NAL to measure inclusive cross-sections in p-nitrogen and p-oxygen collisions. These results would help in interpreting cosmic ray data and in obtaining information on strong interactions at energies beyond those available at the present day accelerators. Adair has pointed out the difference that exists between Feynman scaling which is recent and Zatcepin and Pal-Peters scaling which is 15 years old. Feynman scaling refers to scaling for all the values of X (Feynman variable) from 0 to 1, whereas the other scaling refers essentially to values greater than 0.1 . Yash Pal will say more about this tomorrow. Having given a general view, I will now proceed with presenting you some of the interesting results reported at the conference.

4. (b) Inelastic Interactions: Individual Results.

(1) Dobrotin presented an analysis of the events (Anzon et. al. 1973) observed in nuclear emulsions exposed to 200 GeV/c proton beam at NAL. Two important results emerged from this experiment. First, the coherent inelastic scattering cross-section in proton 'emulsion' nucleus collisions is of the order of 10 mb (approximately 1.5% of all the σ_{inel}) and this seems to be growing with energy (see Fig. 4). Secondly, there seem to be short range correlations among the secondaries emitted in inelastic interaction. If the secondaries are completely uncorrelated and emitted

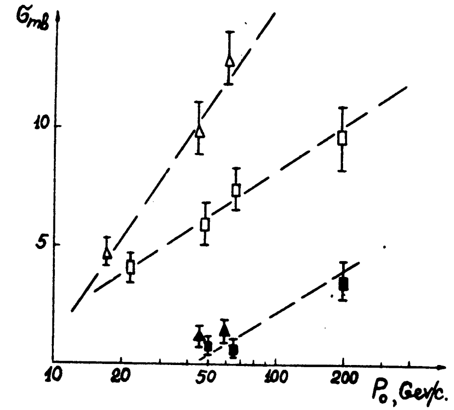

Fig.4. The dependence of the cross sections for coherent interactions with the production of three (□) and five (■) particles by protons and by pions (△, ▲) respectively.

FIG. 4. See the text for legend.

isotropically in the c.m.s., one would expect to see σ , the width of the distribution in ℓn tan θ plot to be 0.39. This expectation is not borne out by the experiment (see Fig. 5).

(2) Nikolsky's group submitted a paper (Nam et. al. 1973) in which they claimed to have shown on the basis of their calorimeter experiment that the fraction of energy, K_γ^n , that goes into γ - rays in nucleon-nucleus collisions decreases from 0.20 to 0.15 as the incident energy increases from 2 to 8 TeV. On the other hand, the authors claim, K_γ^H for <u>all</u> the hadrons remains constant at a value of 0.24 up to $E_0 \approx$ 10 TeV and then it increases by 20% at higher energies. This increase in K_γ^H is attributed to a progressively increasing pion/nucleon ratio at energies ≥ 10 TeV.

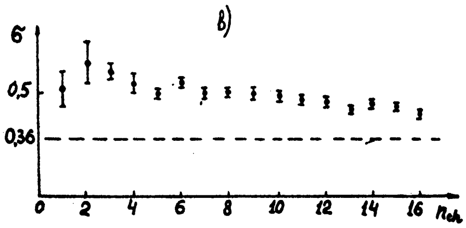

FIG. 5. σ , the width of ℓn tan θ plot is shown as a function of n_{ch}, the average number of charged secondaries.

(3) A Moscow State University group (Aganina et.al. 1973) has studied the shapes of ionization growth curves in their calorimeter and claimed to have found evidence for a new mechanism of high energy hadron interactions. The authors were not present here to explain the many clarifications one would have sought.

(4) The Echo Lake group (Viswanath et.al. 1973) have reexamined their data on the multiplicity in proton-proton interactions and traced the discrepancy in the average multiplicity values between their experiment and those at NAL to the inefficiency of their wide gap spark chambers for recording large multiplicities. The new corrected multiplicities, shown in Fig. 6, do not quite agree with

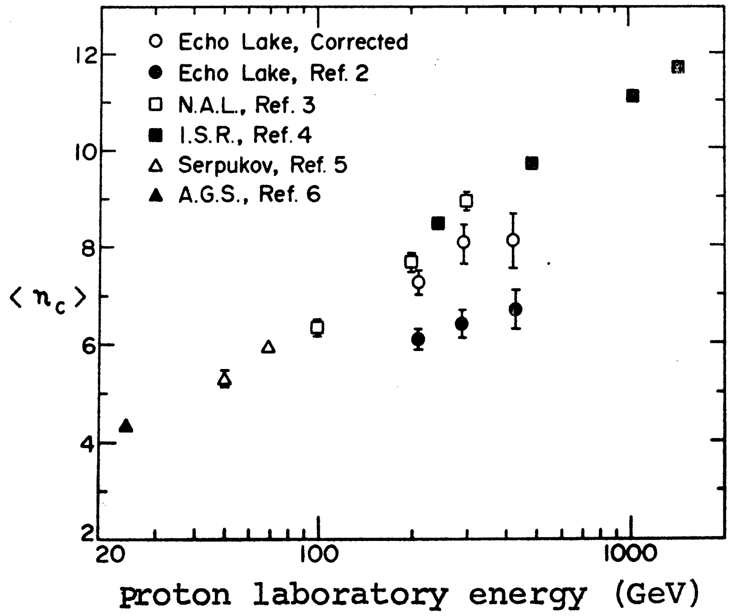

FIG. 6. See text for legend.

the machine results; this residual discrepancy is due to various biases in the experiment.

(5) Lord's group (Martin et. al. 1973) showed that the slope of n_h vs n_s curve in hadron-"emulsion" collisions decreases with increasing primary energy

(6) Grieder (1973) drew the attention of all the Monte Carlo calculators to the need to consider the hadron collisions in air as hadron-nucleus collisions and not as hadron-nucleon collisions as has been done in most calculations.

(7) There are a number of measurements and calculations reported on the fluxes of various components in the atmosphere. I shall not quote any of these fluxes but just mention some of the papers. (i) Siohan et. al. (1973) reported hadron fluxes at sea level and at mountain altitude (ii) Hodson (Hazen et. al 1973 b) reported a few cases of high transverse momentum from their measurements on particle densities in subcores in air showers with the aid of a cloud chamber. However, the interpretation depended on the assumed height of the previous interaction and the results were preliminary (iii) Gaisser and Yodh (1973) presented their calculations on fluxes of unaccompanied hadrons in the atmosphere at high energies (iv) Wdowczyk (Kempa et al. 1973) presented a survey of some aspects of propagation of nuclear-active particles in the atmosphere. Assuming a constant value for the inelasticity parameter, the authors deduced that the rise in σ_{pp} seen at ISR (Amaldi et. al. 1973, Amendolia et. al. 1973) does not continue to rise beyond 2000 GeV or rises at the most to a value of 50 mb at 10^{14} eV. The rise, if it indeed exists, is consistent, according to the authors, with the lower bound given by the formula of Amaldi et.al. (v) Daniel and Stephens (1973) presented results from their theoretical studies on the propagation of secondary electron-photon component in the atmosphere. These calculations are useful in evaluating the background effects in some classes of experiments.

4. (c) Inelastic interactions: γ ray families. There are reports from emulsion chamber work from Chacaltaya (Lattes et. al. 1973), Mt. Fuji (Ohta et. al. 1973) and Pamirs (Anischenko et. al. 1973). All the emulsion chamber work essentially pertains to primary energies $\gtrsim$ 10 TeV; therefore, it constitutes in principle an extension of the accelerator work at I.S.R. energies. See the original papers referred to above for details of construction of the chambers and analysis of results. We

show few of the results presented by Lattes et. al. Integral distribution of the number of γ - rays per event in the carbon target is shown in Fig. 7 as a function of $E_\gamma/(\Sigma E_\gamma)$, a quantity that corresponds within a constant factor to the Feynman variable, X. Notice that the points fall on a universal curve independent of ΣE_γ in the range 7 TeV < (ΣE_γ) <40 TeV, thus confirming scaling. The same authors calculate the masses of fireballs from which the observed γ rays are assumed to have been emitted isotropically. The distribution of such masses is shown in Fig. 8. 62 events towards the left are attributed to H (heavy) quantum and 13 on the right to SH (super-heavy) quantum. The average "γ -ray masses" are given as 1.3 and 6 GeV respectively. The actual masses may be a factor of 2 greater. The same Chacaltaya group studied with another set of emulsion chambers γ-ray families from the atmosphere. Based on the lateral distribution of the γ-rays, the authors could separate out the families produced at heights less than a kilometer above the apparatus (these are called clean A jets) from the rest. The spectrum of ΣE_γ from the clean A jets has an exponent 1.8 whereas the local electro-proton component has a slope of 2.00. From this difference the authors conclude that the effective multiplicity varies with energy as $N_{eff} \sim (E_0/1\text{TeV})^{0.1}$.

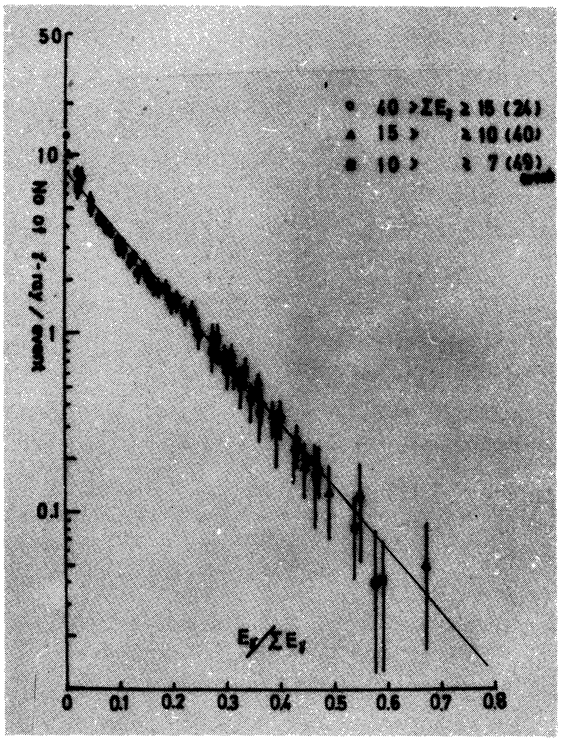

FIG. 7. See text for legend

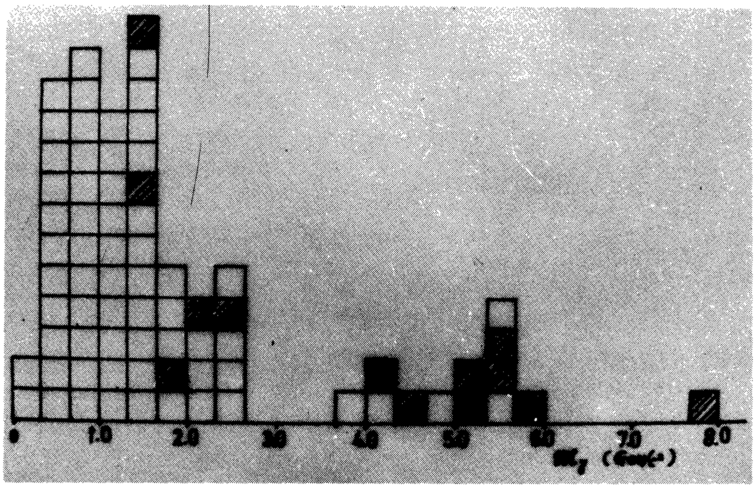

FIG. 8. Histogram of "γ-ray masses" of H and SH Quanta.

Dobrotin reported preliminary results from their emulsion chamber experiment (Anischenko et al. 1973) on Pamirs. The authors showed in the form of a table a wide variety of fluctuations from event to event in the numbers as well as in energies of γ ray and hadron secondaries.

4. (d) Inelastic interactions: Special isolated events.

(i) Fujimoto (Fujimoto et al. 1973) showed a special event "centauro" observed in their emulsion chamber No. 15 exposed at Mt. Chacaltaya. It is shown in Fig. 9. The primary energy is estimated to be 1.5×10^{15}eV. The remarkable thing about this event is that while there are 50 hadrons produced in the nuclear interaction in air (50 ± 15) m above the chamber, there is not even a single π° meson produced. This could be either a case of extreme fluctuation in the relative numbers of $\pi^{\pm}/\pi^{\circ}$ or a case of nucleon-antinucleon production completely dominating over pion production. (ii) Dobrotin and Tretyakova (1973) reported an old emulsion jet of the type 3 + 1 + 100p $(E_o \geq 5.10^{12}$ eV) which when analyzed in terms of t_{11} and Duller-Walker plot showed evidence for the emission of a superheavy fireball (m ≈ 60 GeV). If one plots F/(1-F) for all the secondaries taken together, one gets curve 1 in Fig. 10 which is not suggestive of any isotropic emission from any centre. On the other hand, if the secondaries are divided into two groups, one gets the curves 2 and 3 which represent the superheavy and heavy fireballs respectively, from the rest systems of which the secondaries are emitted isotropically. The Japanese physicists describe their events in terms of H and SH quanta, while the Russian physicists use the words heavy and

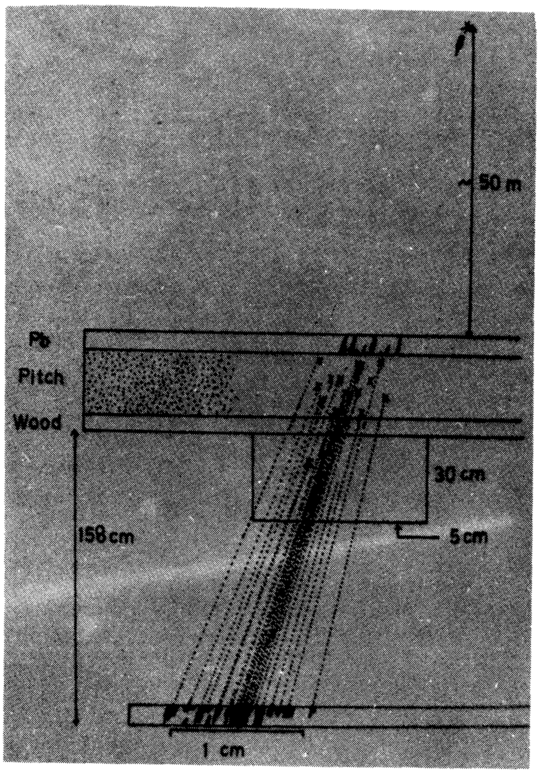

FIG. 9: Each X in the figure represents a point of collision of a hadron as reconstructed from the observed γ-rays; See the text for other details.

superheavy fireballs; clearly there is a need to adopt a common nomenclature. (iii) Niu (Kuramata et. al. 1973) reported further examples of jet events in nuclear emulsions wherein one or two charged secondaries showed sudden deflections with no apparent recoils or any other signs of interactions. These deflections are characteristic of charged particles decaying in flight and in many cases a π° meson (γ ray cascades) seems to align itself with the kink. When interpreted in terms of a new variety of unstable particles, they yield different masses and lifetimes - none of them agreeing with those of the particles in Rosenfeld Tables. More statistics are needed to confirm the evidence.

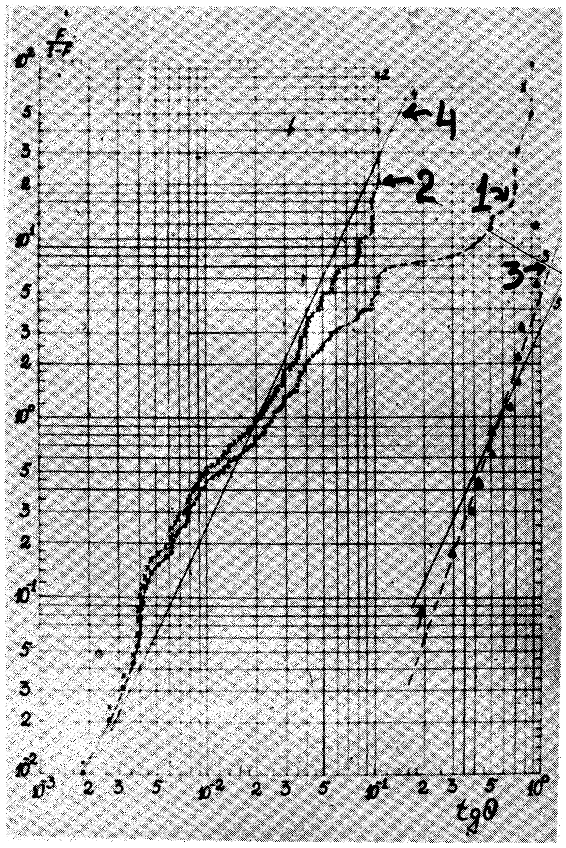

FIG. 10. See the text for legend.

5. <u>Techniques.</u> In the sessions devoted to techniques, there were many papers reported on the transition radiation detectors (T.R.D.). Transition radiation, first proposed by Ginzburg and Frank, is produced when a relativistic charged particle traverses the interface between two media of different dielectric constants. For ultra-relativistic particles, much of the energy is radiated in the X-ray region and the total intensity is proportional to $\gamma(= E/mc^2)$, the Lorentz factor. Herein lies the attraction of this device; for it is extremely difficult to measure γ by any other technique. The radiation emitted by a single foil is so weak that one is forced to employ several foils separated from each other, to detect the radiation. Garibian contributed extensively to a theoretical understanding of the situation. Early experimental work on the T.R.was done

by Alikhanian and his colleagues and by Luke Yuan and his colleagues (see the following 4 papers for references to earlier work and details of construction of T.R.D.). At this conference, groups from the University of Chicago (Cherry et. al. 1973), Lebedev Institute (Slavatinsky et. al. 1973) Maryland-Hawaii-Oxford (MHO) collaboration (Ellsworth et. al. 1973) and Osaka City University (Higashi et. al. 1973) reported their experimental results. Two techniques are employed to detect the rather weak X-radiation in the presence of the parent charged particle. One deflects the incident charged particle away by a suitable magnetic field and records the X-radiation alone. This technique is possible only when one is dealing with well-defined beams such as those at the accelerators but not with cosmic rays. The second method is to record repeatedly the ionization caused by both the incident particle and the T.R.X-rays and show that the average ionization is more than what one expects due to the ionization loss alone of the charged particle. It is this latter method (called sandwich array method) that is suitable for cosmic ray work. We show in Fig. 11 the evidence for and some features of T.R. emission reported by the M.H.O. collaboration (Ellsworth e.al. 1973). Notice that the peak occurs at the same X-ray energy as one varies γ (i.e. the electron energy) and the tail of the distribution extends to higher and higher X-ray energies as γ increases. The Maryland group (MacFall et. al 1973) plans to use a sandwich array of T.R.D. in conjunction with an ionization calorimeter at their mountain laboratory to distinguish p, $\pi^{\pm}$ and $K^{\pm}$ from one another at energies > 300 GeV. and measure their fluxes. Ionization calorimeter measures the total energy while the T.R.D.s measure γ ; a combination of the two determines the mass. The <u>expected</u> mass separation is shown in Fig. 12 which is based on a Monte Carlo calculation. Likewise, the University of Chicago group (Cherry et. al. 1973) has calculated and shown that it is possible to separate pions and electrons if

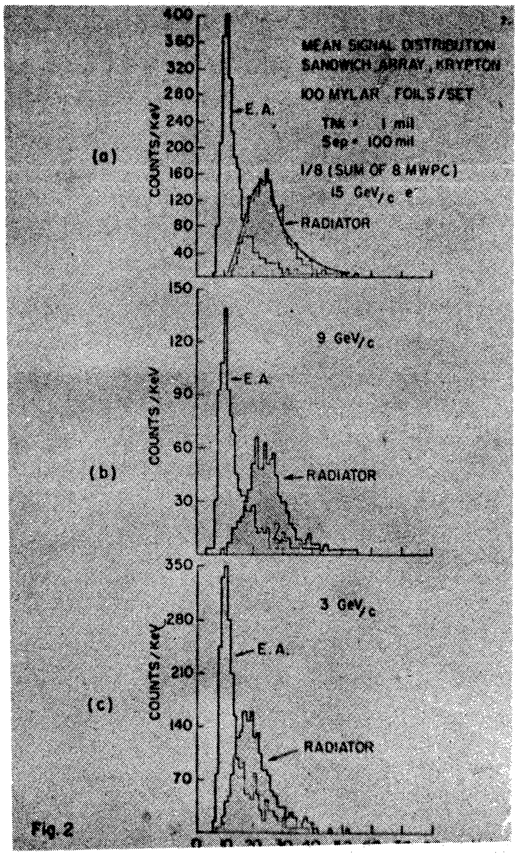

FIG. 11. See the text for legend.

one uses a number of T.R.D. (see Fig. 13). The authors mentioned a possible application of their detector to measure the cosmic ray primary electron spectrum in the presence of a much larger number of protons. I feel that the T.R.D. is readily useable to distinguish two species of particles in situations when the two species occur with comparable intensities. On the other hand, if one is dealing with a situation where one species overwhelms the other in intensity one has to be extremely careful about the precise shapes of the long tails of pulse height distributions. This is, of course, not to say that it is impossible but just to caution. In any case, at this conference, the point is made. Several recipes were tried and found to be good. We expect, therefore, at the next conference to hear some physics from the experiments but not, we hope, their potentialities once again.

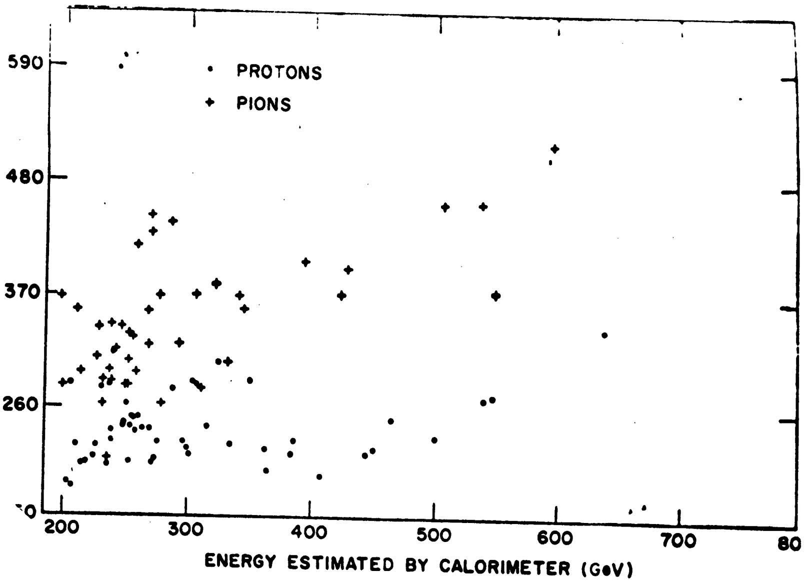

FIG. 12. See the text for legend.

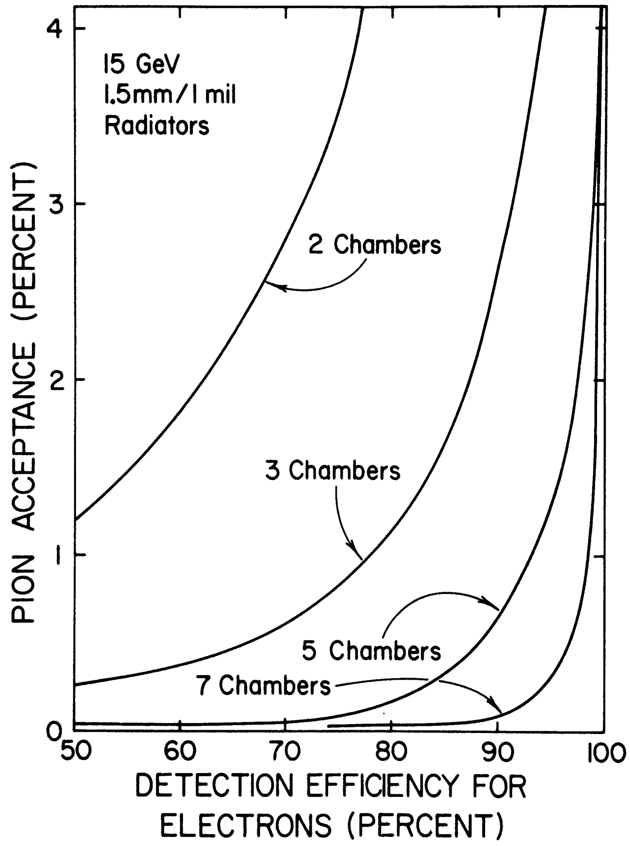

FIG. 13. See the text for legend.

Let me just mention some of the other contributions at the Techniques sessions. Baruch et. al. (1973) have shown that the e.m. cascade transition effect does not preclude the use of ionization calorimeters of mixed materials. Stottlemeyer et al. (1973) have shown that the magnet cloud chamber, which they originally intended to use to measure momenta ≈ 200 GeV/c .

cannot be used to measure momenta ≥ 23 GeV/c. Ted Bowen and his collaborators (Bowen et. al. 1973) described their elegantly instrumented cosmic ray mass spectrometer consisting of scintillators, wire spark chambers and a super-conducting magnet. It has an aperture of 90 cm^2 ster. Used as a momentum spectrometer, it has a m.d.m. of 625 GeV/c and used as a mass spectrometer, it has a mass resolution $\Delta M_o/M_o \approx 0.55$ at $P_{max} = 3.6\ M_o/c$.

6. Conclusion. Several cosmic ray physicists expressed sentiments during the conference - both in written and verbal modes - that many of the new parameters now being used by the accelerator physicists for analyzing the inelastic events were originally used in cosmic ray discussions more than a decade ago. To illustrate:

Cosmic Rays	Accelerators
$\eta = - \ln \tan (\theta/2)$	Rapidity $y = 1/2 \ln \frac{E + P_L}{E - P_L}$
$E_\gamma/(\Sigma E_\gamma)$	X, Feynman variable
isobar model	Diffr. Dissoc., Nova Model
Zatcepin, Pal-Peters scaling	Feynman scaling

Claims apart, the right thing to do is for the cosmic ray physicists to realize that they can establish only the trends leaving the details to accelerator physicists when the relevant cosmic ray energies are overtaken by the accelerators and for the accelerator physicists to acknowledge and refer to the trends gleaned from the cosmic ray data such as the sizeable nucleon-antinucleon production (Tonwar et. al. 1971) at high energies and rising cross-sections (Grigorev et. al. 1965, Yodh et. al. 1972), prior to their establishment at the accelerator energies.

In my talk I have presented some of the highlights of the conference on strong interactions at high energies. I have not attempted to predict the future course of high energy strong interaction studies using cosmic rays for the reason that predictions in the past have gone wrong. Yash Pal may deal with this aspect in his talk tomorrow.

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