JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-6-4. Characteristics of High Energy Nuclear Interactions*

An Experimental Study with the Combined Techniques of Multiplate Cloud Chamber, Air Cerenkov Counter and Total Absorption Spectrometer

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An experiment is in progress at Ootacamund (2.2 km altitude corresponding to 800 gm/cm^2 pressure) to study the characteristics of high energy nuclear interactions induced by cosmic ray particles of energies ≥ 30 Bev. The plan of the experimental arrangement is shown in Fig. 1. A multiplate cloud chamber of dimensions $60\times60\times20$ cm^3 having two producing layers of graphite each 4 cm in thickness is placed above a total absorption spectrometer described in detail in another paper in this proceedings (III-4-20). The total absorption spectrometer gives a measure of the energy of an incident particle producing a nuclear interaction in the carbon inside the chamber. The chamber has five 1/4″ brass, one 3/4″ brass and two 1/2″ lead plates below the graphite blocks in that order to measure the energies of γ-rays produced by the decay of neutral pions originating in the nuclear interaction in the graphite blocks. A spacing of about 10 cm is given between the producer and the first brass plate, so that the secondaries from the interaction in graphite to diverge and enable the measurement of the angular distribution at the point of production.

The chamber is triggered whenever Geiger counter trays just above and below the chamber have a coincident discharge simultaneous with the occurrance of two or more particles in a liquid scintillator below the chamber attended by energy release of at least 10 Bev in the spectrometer. Two Geiger counter trays of area 1/2 m^2 each kept near the chamber, feed pulses in anticoincidence with the above trigger pulse to eliminate air showers. In addition, an air Cerenkov counter is placed above the chamber which enables us to distinguish whether an incident particle producing a nuclear interaction in the chamber is a proton or a pion, if the energy of the incident particle is known to be less than 40 Bev. This is known only in part of the cases since additional detectors like Geiger tray on top of the air Cerenkov counter were required to be set off before information from the air Cerenkov detector was considered. For obtaining reliable information from the air Cerenkov detector, it was demanded that only one charged particle was incident on

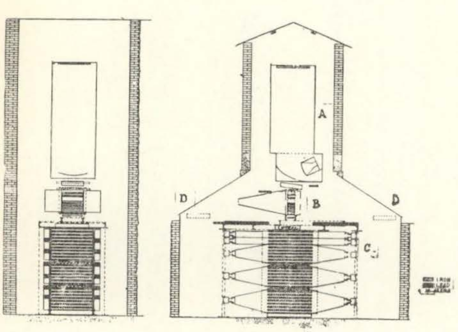

Fig. 1. Experimental arrangement at Ootacamund.

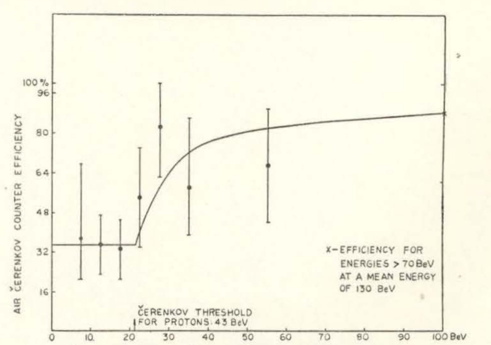

Fig. 2. Efficiency of Cerenkov counter for nuclear active particles as a function of energy observed in the total absorption spectrometer.

* This paper was read by M. G. K. Menon.

the effective area of the air Cerenkov counter. Results presented here are based on an analysis of 30 nuclear interactions observed in the graphite layers inside the cloud chamber. This represents only part of the data collected so far.

Corretion for the energy measurements by the total absorption spectrometer was determined by studying the variation of efficiency of the air Cerenkov counter with the energy of the nuclear active particles, (which were identified by their interactions in the cloud chamber and whose energies were determined by the total absorption spectrometer). This variation is shown in Fig. 2. A break in the efficiency at 21 Bev is identified as the Cerenkov threshold energy of 43 Bev for protons. The fall in efficiency below this threshould shows that $40\pm9\%$ of the charged nuclear active particles are pions near an energy of 30 Bev. The above effiiciency plot indicates that at a proton energy of 43 Bev, about 22 Bev is dissipated in energy losses in the spectrometer (heavy fragments) which is not sampled by the liquid scintillators. The observed energy loss distribution in the spectrometer for nuclear active particles of these energies, shows that very little energy escapes from the spectrometer (750 gm/cm^2 of Fe in total). As a first approximation, the spectrometer energies were shifted by 20 Bev as a systematic correction for invisible losses

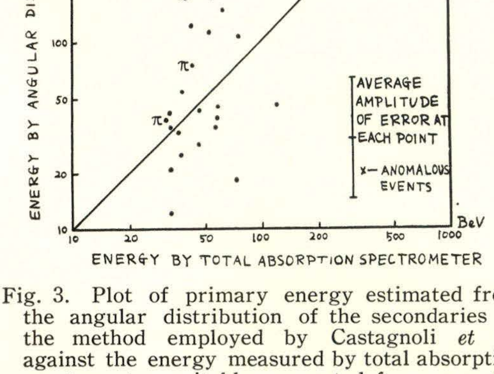

Fig. 3. Plot of primary energy estimated from the angular distribution of the secondaries by the method employed by Castagnoli *et al.* against the energy measured by total absorption spectrometer suitably corrected for unsampled energy losses.

at the energies involved here. The actual energy measured from the spectrometer is accurate to within 10% but the correction for invisible energy lossses are uncertain and could be an underestimate at energies >40 Bev.

Fig. 3 shows a plot of energies of 27 nuclear active particles observed to produce nuclear interactions ($n_s\geq3$) in the graphite blocks inside the chamber. The sum of the energy observed in the spectrometer and the visible energy in the cloud chamber is plotted on the abscissa and the energy deduced from the angular distribution of the secondaries of the interaction by the well known formula:

$$\log\gamma_c=\frac{1}{n_s}\Sigma\log\cot\theta_i$$

on the ordinate. The amplitude of error at each point for the angular distribution method was taken to be given by

$$\Delta\log\gamma_c=\frac{0.36}{\sqrt{n_s}}$$

which is indicated in the figure for $n_s=5$. Except for the three cases indicated by crosses, the energy estimates by the two methods may be considered to be in agreement. The points marked by crosses show considerable deviation (more than two standard deviations). It is interesting to note that two of these anomalous cases are likely to be pions as deduced from the response of the air Cerenkov counter. It is also interesting to note that in general pion interactions seem to have energy estimated by the angular distribution method higher than that given by the spectromenter. It is conceivable that such an overestimate of the primary energies in the case of pion interactions could be due to the target mass participating in such collisions being smaller than that of a nucleon, probably of the order of pion mass itself. As regards the "normal" events the nature of whose primaries are not indentified, considering the fact that about 40% of them would be due to pions as estimated earlier, we can say that in a majority of nucleon-nucleon collisions at energies ~50 Bev, there are no sharp asymmetries of angular distribution of secondaries in their center of mass. (Figs. 4, 5 and 6 are examples of some of the events obtained.)

The average fast charged secondary multiplicity (n_s) for the cases of identified pion interactions is 4 ± 1. This value applies to the energy region 30–40 Bev. For the cases of other charged primary interactions in the energy region 30–60 Bev, the mean charged multiplicfty is 5.7 ± 0.6 after correcting for forward protons. γ-ray energies have been estimated from the track lengths and shower development in the plates. For eighteen events in the primary energy range 30–60 BeV, the fractional energy radiated as pions is $3\Sigma E_{\pi 0}/E_0=13$–17%. The upper limit in the above value results from indistinguishability of γ-rays from secondary interactions in a few cases and also from estimates of energies of γ-ray showers which are only partially absorbed in the plates in certain cases. A correction has to be applied for loss of γ-ray at large angles to the direction of incident primaries. A rough upper estimate of this can had, if we assume that π°-mesons emitted in the backward direction in the centre of mass system of the collision would give rise to γ-rays which would be lost for observation in the chamber. This leads to an increase of K_π deduced above by 30% if we assume that π°-mesons are emitted isotropically with a mean energy independent of the primary energy. The statistical error of the estimate of K_π is about 25%.

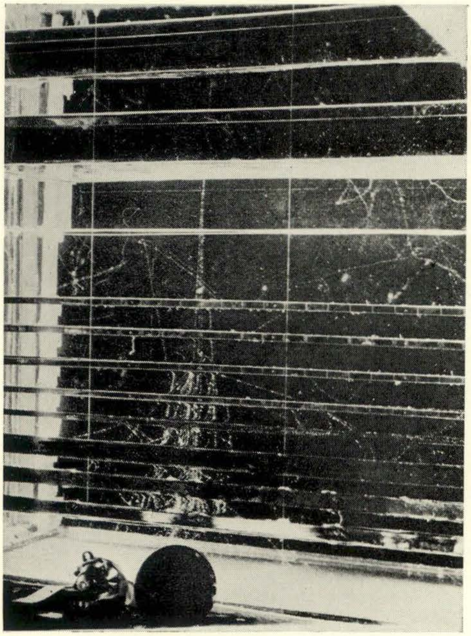

Fig. 4. An example of an interaction induced most probably by a pion which gives rise to an anomalous case plotted in Fig. 3. An energy estimate of 800 $^{+1200}_{-\ 500}$ Bev is given by the angular distribution method, which the spectrometer gives an energy less than 40 Bev.

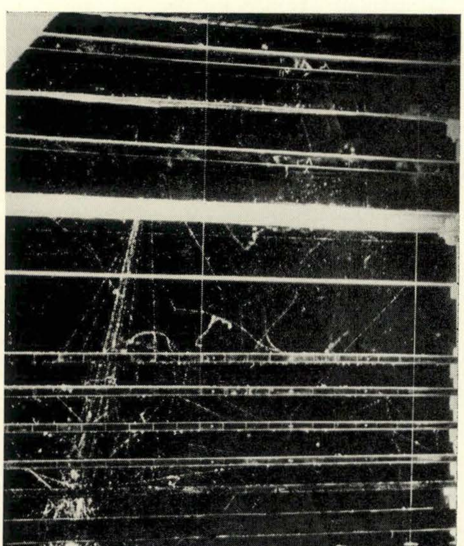

Fig. 5. A case of agreement between the two methods. Estimate by angular distribution method gives 316 $^{+234}_{-134}$ Bev and that by total absorption spectrometer is 258 Bev.

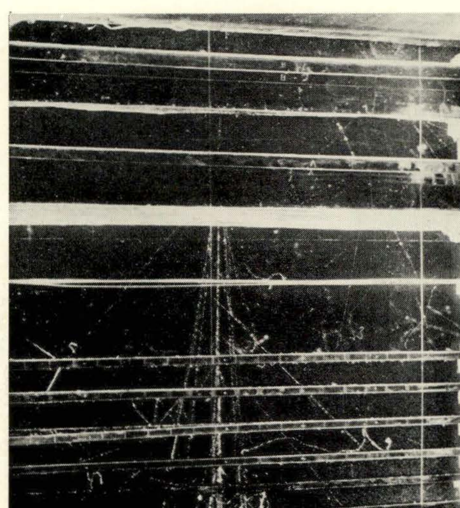

Fig. 6. A case where total absorption energy is in excess of the energy from angular distribution but the deviation is less than two standard deviations. The former gives 124 Bev and the latter 50 $^{+44}_{-23}$ Bev.