THE PROBLEM OF FIREBALLS AND I S R-RESULTS

By M. Mięsowicz

Institute of Nuclear Physics, Cracow*

(*Received June 4, 1973*)

The paper discusses the relevance of ISR results concerning particle production for the fireball model. It is argued that there is no contradiction between the ISR data and cosmic ray data concerning the rapidity distribution. The evidence of cluster production is discussed.

1. Introduction

One of the most important results concerning particle production obtained at the CERN Intersecting Storage Rings was that the logtan $\Theta^*/2$, or rapidity distribution, is flat near 90°. An opinion was expressed that these results are in disagreement with the cosmic ray data, where a dip near 90° in the logtan $\Theta^*/2$ distribution has been found. This was also considered as evidence against the two fireball model (see *e. g.* [1]).

The aim of the present note is to discuss this opinion and to summarize the cosmic ray data both at and above 10^{12} eV from the point of view of the existence of fireballs.

The dip in logtan $\Theta^*/2$ distribution was observed many years ago and in the original papers on fireballs was considered as the main argument of the model [2]. However, it was later observed that the double maximum structure of logtan Θ distribution cannot always be interpreted in terms of the fireball model (see *e. g.* [3], where one can find also references to older papers). Therefore we defined what we understand by fireballs and investigated the possibility of their observation [3]. We defined a fireball as a group (cluster) of particles with isotropic angular distribution in the rest system of the group and momentum distribution corresponding to phase space, such that $p_t \simeq 0.4$ GeV/c, *i. e.* the value observed experimentally. This definition corresponds to the main practical characteristics of the group of particles in logtan Θ-distribution, *i. e.*, to its constant width or dispersion $\sigma \simeq 0.4$. Using the actual terminology one can say that we understand by fireballs clusters with the above mentioned properties.

---

* Address: Instytut Fizyki Jądrowej, Kawiory 26a, 30-055 Kraków, Poland.

What we are now looking for in cosmic rays is the existence of this type of "isotropic" clusters. So we do not speak now about "two-fireball-model" but about "fireball model" independently of the number of fireballs.

2. The flat distribution of logtan $\Theta^*/2$ at ISR and its comparison with the cosmic ray data

Three groups working at ISR obtained for logtan $\Theta^*/2$ a roughly flat distribution near 90° [4]. The comparison of these ISR-data with cosmic rays had been done on the basis of emulsion work, namely on the diagram presented in Fig. 4 of an earlier paper of Bombay -CERN-Cracow collaboration [5]. Therefore we start from some methodical remarks concerning the emulsion technique in cosmic ray jet investigation.

It is well known that the photographic emulsion is a very complicated target. We can expect no more than 30% of interaction with a single nucleon (free or quasi-free). In particular we cannot consider a dip in logtan $\Theta^*/2$ distribution as a criterion for elementary N–N collision, because, as we well know (see *e. g.* [3]), we observe also a dip in collisions of nucleons with nuclei.

The diagram presented in Fig. 4 of Ref. [5] in the form of an ideogram, representing cosmic ray data at 1000 GeV, is based on the experimental material summarized in a paper of Gierula and Wolter [6], where one can find all the experimental details concerning the sample used in the above mentioned Ref. [5]. The material consists of 55 jets of known and nearly the same energy $\simeq 10^{12}$ eV, obtained by unbiased scanning, along nucleons from fragmentation of nuclei. In Ref. [6] we can find individual logtan $\Theta^*/2$ distributions of all the events. The authors have selected from these 55 jets, 21 events for which a dip was observed. The ideogram of Fig. 4 of the BCC-coll. (paper [4]), had been constructed using only these 21 selected events. In my opinion this procedure cannot be considered as the evidence of the "existence" of a dip in cosmic ray N–N collisions at $\simeq 10^{12}$ eV.

There are further points supporting this opinion. We have now a very rough possibility to check that a given sample is rich in elementary collisions. We know actually that the $\langle n_{ch} \rangle$-value for ISR-interactions at $\simeq$ 1000 GeV is $\simeq$ 11. But for the sample shown in the discussed ideogram from Ref. [4] $\langle n_{ch} \rangle \simeq 17$ which is in significant contradiction with the ISR-value, showing that the role of collisions with nuclei in the discussed cosmic ray sample must be considerable.

The discussed ideogram is also in disagreement with the fireball model in spite — or rather because of the very pronounced dip. If particles have a tendency to form fireballs, *i. e.* to cluster in the rapidity plots in individual events, the position of a cluster can vary from one event to another [7], and the overall distribution could be flat. Moreover, if we expect the presence of two fireballs — isotropic clusters — they have "no room" in the observed rapidity limits, shown in the discussed cosmic ray ideogram, to form two distinct well separated groups so near 90°.

What concerns the older emulsion data (*e. g.* published in [2]) we shall see from the next item that the real two fireball events *i. e.* characterized by two separated isotropic clusters are observed at higher energies *i. e.* $\geqslant 10^{13}$ eV.

3. *Existence of fireball-clusters at energies* $\geqslant 10^{13}$ eV

In jet material of Cracow Laboratory consisting of about 75 events with energies higher than $\simeq 10^{12}$ eV, with some limitation of evaporation and multiplicity ($N_h \leqslant 5$ and $n_s < 20$) Coghen [8] found 32 jets with well separated groups of tracks. The separa-

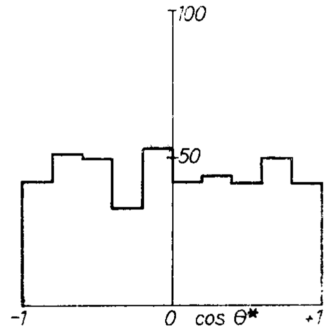

Fig. 1. The composite differential angular distribution in CMS of the cluster, for clusters of jets characterized by a distinct separation of the clusters [8]

tion criterion was that the gap between the largest angle of particle of the small angle group and the smallest angle of the large angle particle group, should be greater than 0.4 in the logtan Θ variable, to minimize the effect of spill-over of the particles from one to the

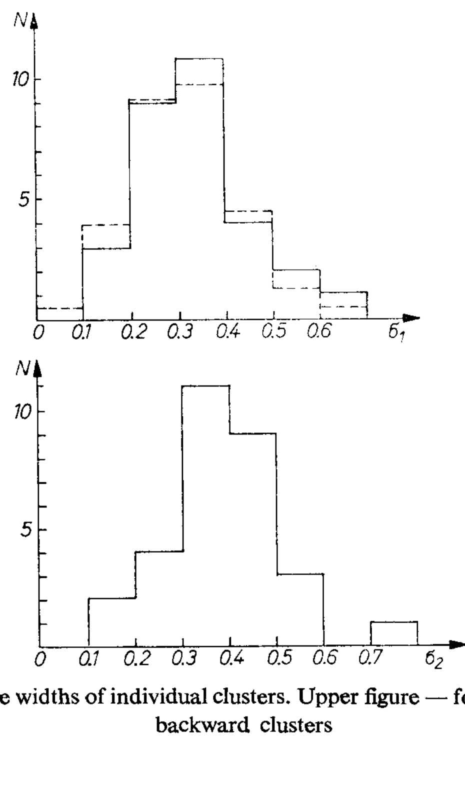

Fig. 2. The distribution of the widths of individual clusters. Upper figure — forward clusters, lower figure — backward clusters

other group. The analysis of the separated groups yielded that the angular distribution of particles in the rest frame of the group is isotropic (see Fig. 1). Moreover the individual σ-values of the separated groups from these 32 events are neatly distributed around

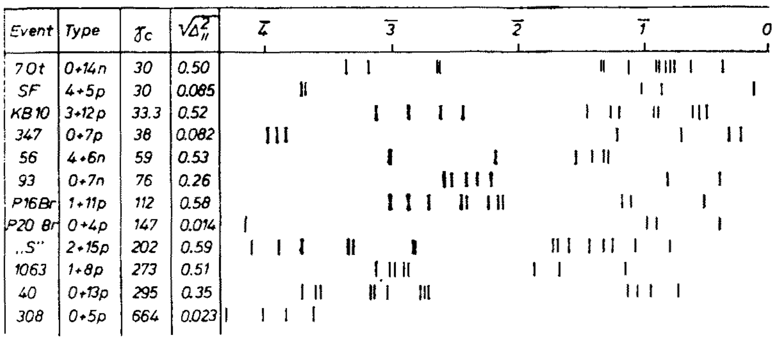

Fig. 3. The individual logtan Θ plots of 12 jets with small four momenta transfers between forward and backward particles

$\simeq$ 0.4 (see Fig. 2) — the width of the isotropic cluster in logtan Θ distribution corresponding in rapidity distribution to $\Delta y \simeq 1$. The mean energy of these two-fireballs events is however significantly higher than 10^{12} eV. It amounts to $\langle E_p \rangle \simeq 3 \cdot 10^{13}$ eV. For these events $\langle n_{ch} \rangle \simeq 13$, as we can expect for this energy for N–N collisions.

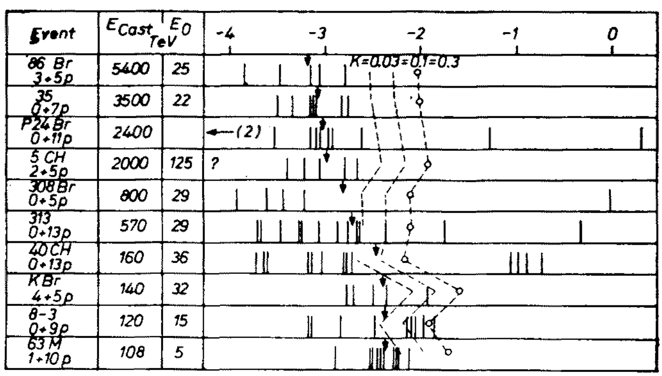

Fig. 4. Individual logtan Θ plots of "asymmetric", very strongly collimated events

11 examples of events with extremely separated groups of tracks are shown in Fig. 3 after Ref. [9]. They are events selected from the same sample described above by the criterion of small 4-momentum transfer between two groups obtained by simple division of the whole distribution by the mean value $\langle \text{logtan } \Theta \rangle$.

Very well separated clusters at very high energy have been observed in another form of selection of events in the so-called "asymmetric" jets [10]. They are events in which groups of particles are emitted very asymmetrically backwards or forwards in CMS. In cosmic ray jet work we observe only "forward events". They are observed in emulsions as groups of particles with extremely high collimation. The argument that these events are asymmetric is based on the fact that the primary energy estimates based on the assumption of symmetry are much too high ($\gtrsim 10^{14}$ eV) and would be inconsistent with primary spectrum and flux. Some of these events are shown in Fig. 4. The broken lines show the primary energy estimated under the assumption of several reasonable inelasticity coefficients and from the sum of energies of secondaries calculated from their Θ-angles and constant p_t-value 0.4 GeV/c. We see from Fig. 4 that the groups of particles here are extremely

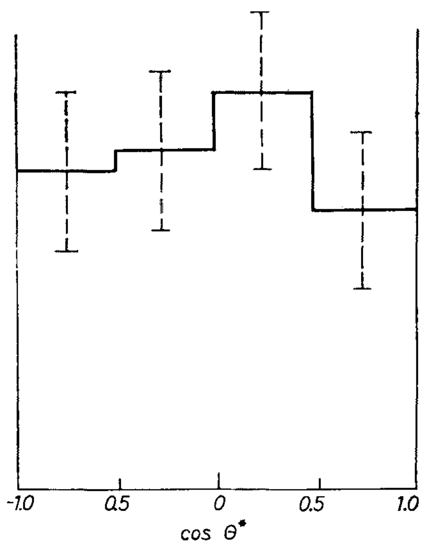

Fig. 5. The composite differential angular distribution in CMS for cluster presented in Fig. 4

well separated and some of events are even "single-cone" or "single-cluster"-events. These clusters are again well isotropic. Fig. 5 shows the overall angular distribution for these clusters in their rest frame. Although the statistics is very poor, the distribution may be again consistent with isotropy.

Asymmetric "single cone" jets of lower energies had been observed earlier by the Moscow Group [11] in a cloud chamber with ionization calorimeter.

4. *Results of Chacaltaya Laboratory for extremely high primary energies*

In the energy range 10–100 TeV investigations have been performed by the Japanese-Brazilian Group recording of γ-rays from π^0s produced by cosmic ray particles in Carbon target situated above very large emulsion chambers. Such a chamber consists of several emulsion sheets separated by lead layers. This apparatus is working at Mt. Chacaltaya in Bolivia, 5200 m above sea level [12]. The apparatus registers only γ-rays by means of cascades, but individual γ-rays are well separated. This high resolution is possible, because of large air gap between the producing layer and the chamber. The angular distributions and energies of γ-rays are measured through electromagnetic cascades developing in lead-emulsion chamber.

The separated groups of π^0-mesons with isotropic angular distributions and momentum spectrum in rough agreement with the phase space in the rest system of the group have been observed. In these experiments only γ-rays with energies higher than $\simeq$ 250 GeV have been recorded without bias. But according to the authors, this limit of the bias is low enough to see a significant gap between the groups of the most collimated particles and the residual distribution in the rapidity variable. The mean multiplicity of γ-rays at primary energies 10^{13}–10^{14} eV was about 8, in the isotropic cluster, which would correspond to the mean charged multiplicity in one cluster also about $\langle n_{ch} \rangle \simeq 8$.

5. *Correlations in inclusive spectra as a way of observing clusters*

What we discussed up to now concerned the possibilities of selecting clusters by looking for separated groups of tracks with a given Δy, which of course must be much smaller than the interval of possible y values. But it seems that if there are indeed clusters, we should expect positive short-range correlations between the rapidities of two particles. Furthermore if the fireballs decay isotropically, then rather small correlation length, of the order of one unit is expected. This result follows easily if one remembers that in the rapidity scale the width of the single isotropic cluster is approximately given by $0.4 \log_e 10 \simeq 1$.

Such positive correlations between particles have been observed at ISR energies by CERN-Pisa-Stony Brook collaboration [13]. Recently CERN-Hamburg-Vienna collaboration reported about results of an analysis of a reaction at three ISR energies $p+p \to \gamma+ch+$anything, in which correlations between two particles $\gamma+ch$ has been studied [14]. Positive short range correlations were found with a correlation length 1.17 ± 0.05, see a discussion in [15].

Thus it seems that the existing data on correlations in inclusive spectra are also consistent with the fireball model.

6. *Conclusions*

1. There is no contradiction between the ISR data and cosmic ray data concerning the rapidity distributions. There is no reliable evidence of the existence of a dip in this distribution for cosmic ray elementary interactions at energies of about 1000 GeV. The ISR data are inconclusive, as far as the existence or not existence of isotropic clusters is concerned.

2. There is some evidence in cosmic ray jets at energies higher than $\simeq 10^{13}$ eV, for the existence of clusters of constant rapidity width, fulfilling the definition of fireballs.

3. It seems possible that particle short range correlations observed in ISR experiments can be understood in terms of isotropically decaying clusters.

REFERENCES

[1] D. R. O. Morrison, *Review Paper at the High Energy Conference*, Oxford 1972.

[2] P. Ciok, T. Coghen, J. Gierula, R. Hołyński, A. Jurak, M. Mięsowicz, T. Saniewska, O. Stanisz, J. Pernegr, *Nuovo Cimento*, **8**, 166 (1958); G. Cocconi, *Phys. Rev.*, **111**, 1699 (1958); K. Niu, *Nuovo Cimento*, **10**, 994 (1958).

[3] M. Mięsowicz, *Progress in Elementary Particle and Cosmic Ray Physics*, **10**, 103 (1971).
[4] Aachen-CERN-Genova-Harvard-Torino coll., G. Barbiellini *et al.*, *Phys. Letters*, **39B**, 294 (1972); M. Breidenbach *et al.*, *Phys. Letters*, **39B**, 654 (1972); Bombay-CERN-Cracow coll., J. Babecki *et al.*, *Phys. Letters*, **40B**, 507 (1972).
[5] Bombay-CERN-Cracow coll., *Phys. Letters*, **36B**, 611 (1971).
[6] J. Gierula, W. Wolter, *Acta Phys. Polon.*, **B2**, 95 (1971).
[7] A. Krzywicki, B. Petersson, *Preprint* Calt 68–351.
[8] T. Coghen, *Thesis*, Kraków 1967.
[9] J. Babecki, T. Coghen, M. Mięsowicz, K. Niu, *Acta Phys. Polon.*, **26**, 71 (1964).
[10] J. Gierula, M. Mięsowicz, *Nuovo Cimento*, **27**, 149 (1963).
[11] N. A. Dobrotin *et al.*, *Proc. Intern. Conf. Cosmic Rays*, Kyoto-III, 375 (1962).
[12] Japanese and Brazilian Group, *Intern. Conf. Cosmic Rays*, Budapest 1969.
[13] G. Belletini, private communication, March 1973.
[14] CERN-Hamburg-Vienna coll., CERN *preprint* 1973.
[15] A. Białas, K. Fiałkowski, K. Zalewski, *Phys. Letters*, **45B**, 337 (1973).