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Laura Bergamasco, Carlo Castagnoli

On the Primary Energy determination in nucleon-nucleus collisions

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Fisica. — *On the Primary Energy determination in nucleon-nucleus collisions.* Nota di LAURA BERGAMASCO e CARLO CASTAGNOLI, presentata (*) dal Socio G. WATAGHIN.

RIASSUNTO. — Si prendono in esame getti prodotti da protoni da 24 GeV e 28 GeV in emulsioni e camere a bolle per verificare gli abituali metodi per la determinazione dell'energia primaria. Si dà poi un termine correttivo da usare quando i getti abbiano parecchi rami neri N_h.

Esso viene applicato a getti dei raggi cosmici con energia di 1–10 TeV e se ne verifica la validità.

1. EXPERIMENTAL CHECK FOR THE γ_0 DETERMINATION.—In recent years much attention has been paid to the determination of the primary energy in cosmic ray jets. The purpose of our note is: 1) to check the validity of the main methods for the determination of the Lorentzian factor γ_0, 2) to estimate a corrective term for jets with many black or grey prongs N_h.

In our analysis we made use of data in emulsions and in bubble chamber at both accelerator and cosmic ray energies. The jets in emulsion have been divided into three groups A, B, C, corresponding to $N_h = 0 - 2$, $N_h = 3 - 6$ and $N_h \geq 7$ respectively.

We want to carry out a comparison between the $\langle \log \operatorname{cotg} \vartheta \rangle$ method [1], the median angle method and the one based on the constancy of the transverse moment. With this aim we took into consideration jets produced by the CERN proton-synchrotron working nominally at 24 GeV and 28 GeV. These jets have been observed both in hydrogen bubble chamber [2] and in emulsion [3, 4]. In this last case we considered only A–jets, to select a group of events which could be compared with the H–bubble chamber data.

We studied 181 jets in bubble chamber and 371 in emulsion. For each of them we computed the deviations from the effective value γ_0.

$$\Delta\gamma_c = \gamma_c - \gamma_0 = \exp\left\{\frac{1}{n_s}\sum_{i=1}^{n_s} \ln |\operatorname{cotg} \vartheta_i|\right\} - \gamma_0 .$$

$$\Delta\gamma_{1/2} = \gamma_{1/2} - \gamma_0 = \operatorname{cotg} \vartheta_{1/2} - \gamma_0$$

$$\Delta\gamma_1 = \gamma_1 - \gamma_0 = \sqrt{\frac{\operatorname{cosec} \vartheta_i}{2 \tan \frac{\vartheta_i}{2}}} - \gamma_0 .$$

Our results are shown in fig. 1 and 2 where the emulsion data are represented by dots and the bubble chamber data by crosses. These plots have a double aim: in fact while the $\Delta\gamma_c$ deviation, plotted as abscissa, is

(*) Nella seduta dell'11 marzo 1967.

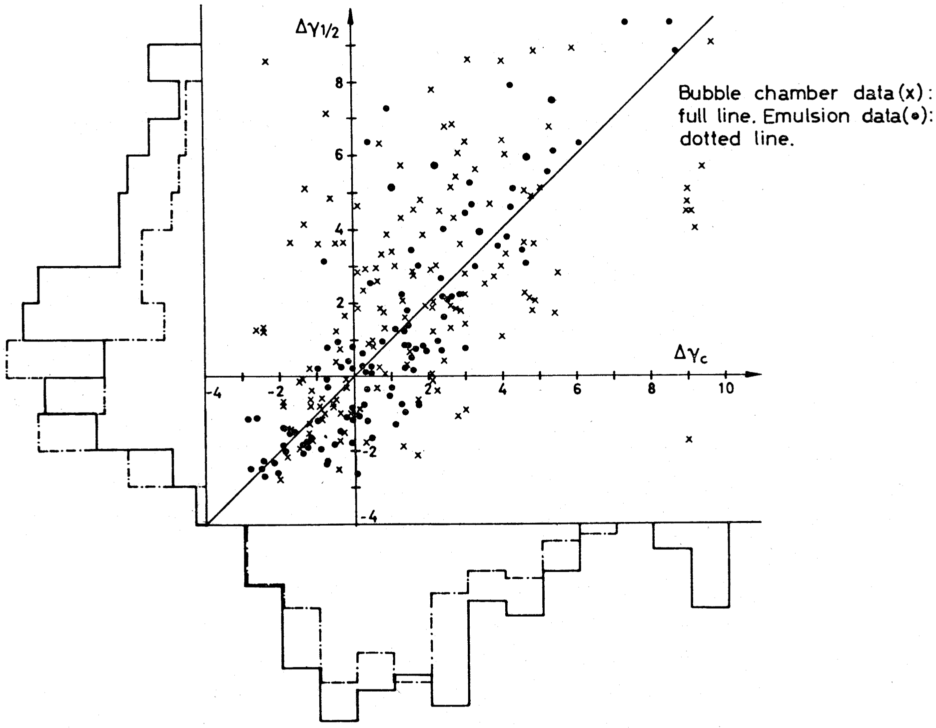

Fig. 1. – Comparison between the $\Delta\gamma_c$ and $\Delta\gamma_{1/2}$ values for the data in H–bubble chamber (full line and crosses) and in emulsion (dotted line and points).
The energy of the primary proton is 24 GeV for the bubble chamber data and 28 GeV for the emulsion data.

compared with $\Delta\gamma_{1/2}$ (fig. 1) and $\Delta\gamma_{\perp}$ (fig. 2), the hystograms give the dispersion of the experimental γ_0 values for each method. From the examination of the plots we conclude:

(1) the emulsion data on the A–jets are in good agreement with the H–bubble chamber data. This conclusion supports the interpretation of $N_h = 0 - 2$ jets as due to nucleon–nucleon collisions.

(2) The bubble chamber data agree with a previous analysis limited only to the emulsions [5], and show that:

(*a*) the γ_c and $\gamma_{1/2}$ values have similar dispersions but $\Delta\gamma_{1/2}$ appears slightly greater than $\Delta\gamma_c$.

(*b*) The dispersion for the $\gamma_{\perp}$ values is greater than for the γ_c ones, and also $\Delta\gamma_{\perp}$ is appreciably greater than $\Delta\gamma_c$.

(3) We therefore conclude that the primary energy of the jets due to nucleon–nucleon collisions is best determined by the $\langle \log \operatorname{cotg} \vartheta \rangle$ method, which gives the smallest deviation, makes the best use of all statistic information and permits the correction for the energy spectrum of the secondary particles.

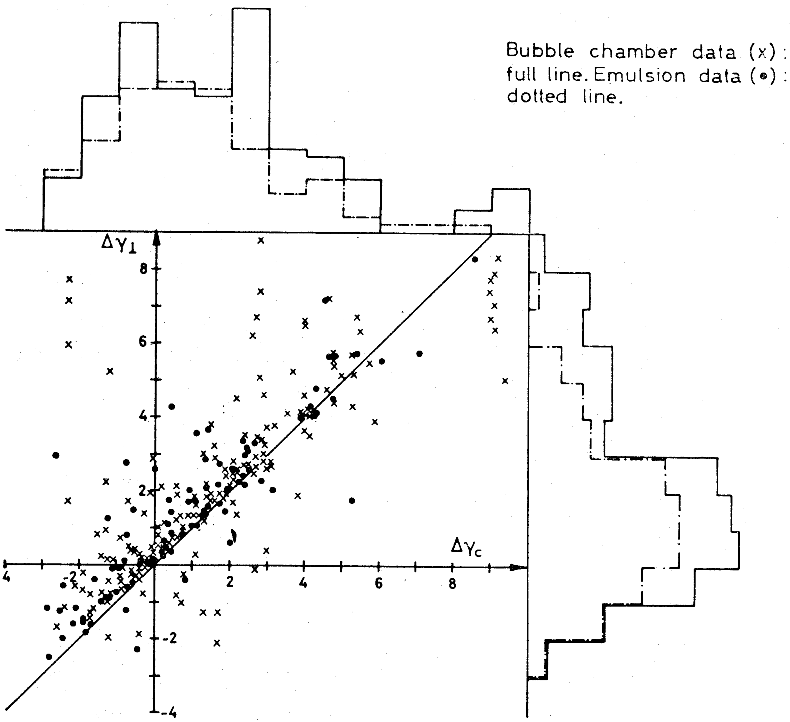

Fig. 2. – Comparison between the $\Delta\gamma_c$ and $\Delta\gamma_1$ values for the data in H–bubble chamber (full line and crosses) and in emulsion (dotted line and points).
The energy of the primary proton is 24 GeV for the bubble chamber data and 28 GeV for the emulsion data.

2. DETERMINATION OF γ_0 FOR $N_h \geq 3$ JETS.—The determination of the primary energy with the kinematic methods does not consider possible secondary interactions at the inside of the nucleus, and this limits its validity to the A–jets.

In this section we evaluate a corrective term C to be used in the energy determination of jets B, C with $N_h \geq 3$.

To take account of secondary interactions inside the nucleus we shall suppose that n_i secondary particles are produced in the i–th collision inside the nucleus and introduce the assumptions $n_{i-1} > n_i$; $\gamma_{0,i-1} > \gamma_{0,i}$. The number of particles observed is then $N = \Sigma n_i$ which would lead to an experimental value for the Lorentz factor of the jet:

$$\ln \gamma_{\text{exp}} = \frac{1}{N} \sum_{i=1}^{N} \ln |\operatorname{cotg} \vartheta_i| \tag{1}$$

Actually we have for each interaction

$$\ln \gamma_{c,i} = \frac{1}{n_i} \sum_{j=1}^{n_i} \ln |\operatorname{cotg} \vartheta_j| \tag{2}$$

and combining equations (1) and (2) we obtain for the effective primary Lorentz factor:

$$\ln \gamma_{c,i} = \ln \gamma_{\exp} + C \tag{3}$$

$C = \sum_{i=1}^{\nu} C_i$ is the corrective term which accounts for ν internal interactions, that is

$$C_i = \frac{n_{i+1}}{N_{i+1}} \ln \frac{\gamma_{c,1}}{\gamma_{c,i+1}} \quad ; \quad N_{i+1} = \sum_{s=1}^{i+1} n_s . \tag{4}$$

For the computation of C we consider two different models.

If the particles produced in every interaction behave independently in the successive collisions, the total energy (in unity of $m_p c^2$) in the C.M.S. of the first collision, is $w'_1 = 2\gamma_{c,1}$.

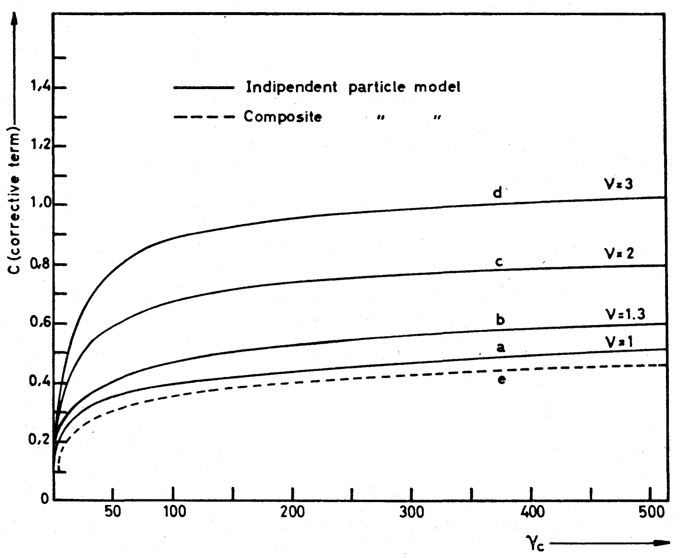

Fig. 3. – Corrective term C for collisions inside the nucleus plotted against γ_c for four values of the number ν of internal collisions.

We do not consider production of strange particles, and assume that both the incident and target nucleons remain at rest after the collision: then the mean energy of each meson in the C.M.S. and in the L.S. is respectively $\varepsilon'_1 = 2(\gamma_{c,1} - 1)/n_1$; $\varepsilon_1 \cong \varepsilon'_1 \cdot 2 \cdot \gamma_{c,1} = \varepsilon'_1 \cdot w'_1$.

The total energy and the Lorentz factor of the successive i–th interaction are

$$w_i = \varepsilon_{i-1} + 1 \quad ; \quad w'_i = \left\{ 2 w_i + \left(\frac{m_\pi}{m_p}\right)^2 - 1 \right\}^{1/2} \quad ; \quad \gamma_{c,i} = \frac{1}{2} w'_i . \tag{5}$$

From Fermi theory the number of particles produced in the i–th interaction is then [6]

$$n_i = A \frac{(w_i - 2)^{3/2}}{w_i}$$

where A = 1.3; this is in good agreement with the experimental results summarized by Malholtra et al. [7].

If instead the particles behave as a single compound particle, it follows from Fermi theory that

$$n_i = A\, k_i^{3/4}\, w_i^{1/2}$$

where $k = 1 - (i + 1)\ (1 + \varepsilon_i')/w_i$ is the ratio of the energy w_i to the energy available for meson production, and the values of w_i and ε_i' follow from relativistic considerations.

The results on the corrective term C for both models are shown in fig. 3 for different values of ν.

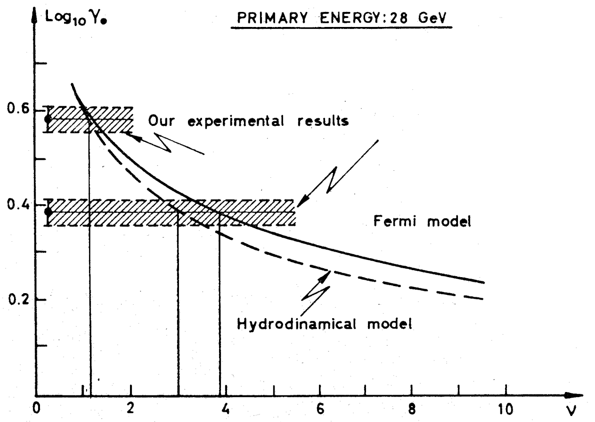

Fig. 4. – Corrective term C against the number of internal collisions for the given value 28 GeV of primary energy. The experimental results refer to jets B and C.

We used our emulsion data on the B and C jets for experimental information on ν. Taking into account the correction [3] brought by $\beta/\beta_i' \neq 1$, we obtain $\langle \log \gamma \rangle_B = 0.59 \pm 0.02$ and $\langle \log \gamma \rangle_C = 0.39 \pm 0.02$. In fig. 4 the corrective term C is plotted in function of the number ν of internal collisions for a value of $\gamma_0 = 3.92$ (full line). The same problem has been faced in the hydrodynamic theory of Landau; using Friedländer [8] formula with $\gamma_0 = 3.92$ we obtain the dotted curve of fig. 4 which shows the good agreement between the two models.

Corresponding to the experimental values $\langle \log \gamma \rangle_B$ and $\langle \log \gamma \rangle_C$ we find $\nu \sim 1.2$ and $\nu \sim 3$. In a previous work [3] from different considerations we obtained $\nu \sim 1.1$ and 2.7 respectively.

3. RESULTS AND DISCUSSION.—We assume the number ν of internal collisions not appreciably dependent on the energy, and consequently make use in every case of the information obtained at 28 GeV.

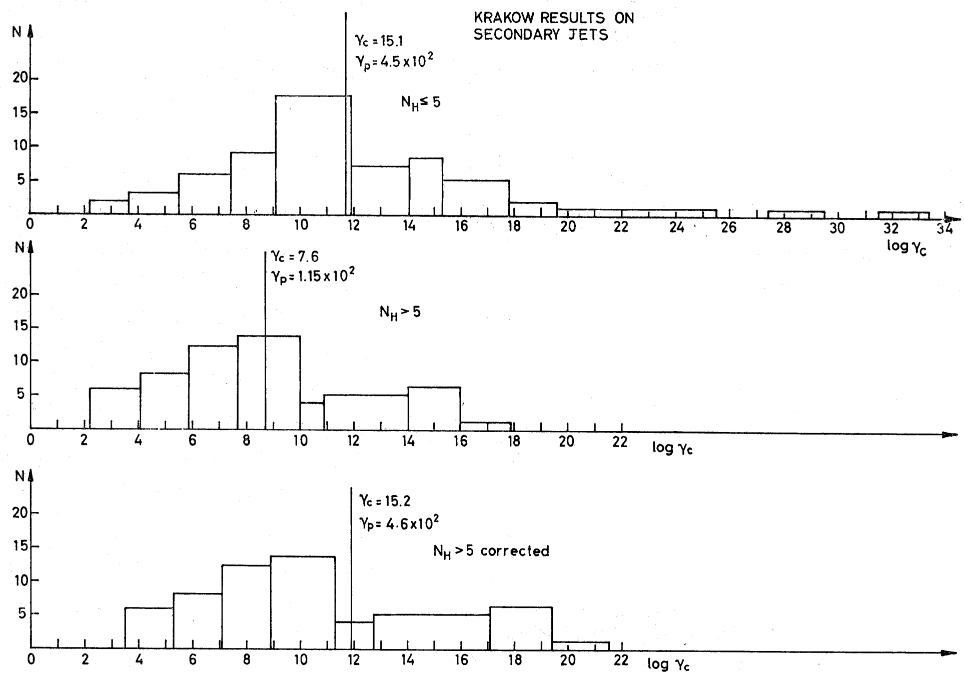

Fig. 5. – Results of the Krakow Emulsion Group on cosmic ray jets of primary energy ~ 10 TeV.

The first two hystograms show their results for $N_h \leq 5$ and for $N_h > 5$. The third hystogram is obtained by applying our corrective term to the $N_h > 5$ jets.

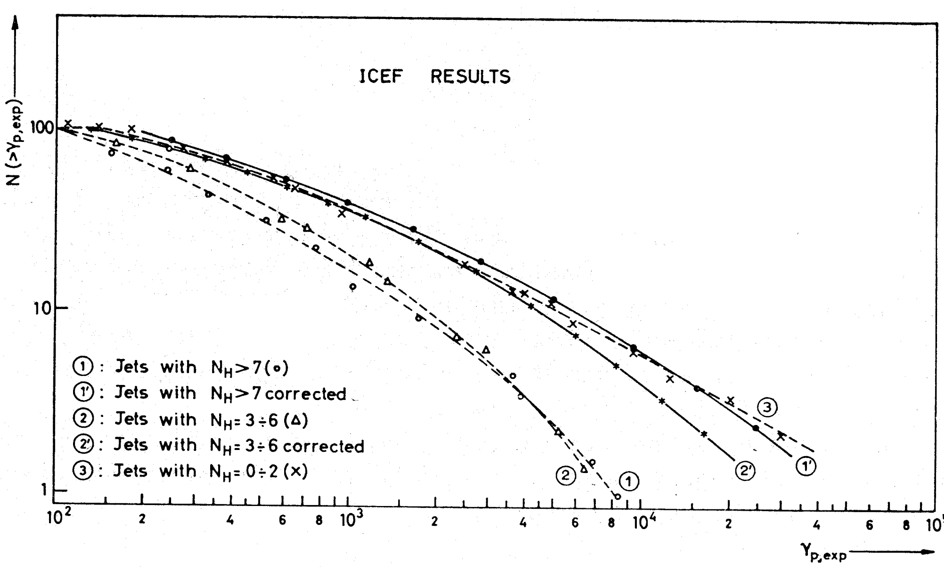

Fig. 6. – I.C.E.F. results on cosmic ray jets of primary energy > 1 TeV.

Curves 1, 2 and 3 give the γ_p distributions for the jets C, B, A as obtained with the $\langle \log \operatorname{cotg} \vartheta \rangle$ method. Curves 1′ and 2′ give the distributions corrected for internal collisions.

To verify our conclusions in the energy range of cosmic rays of primary energy > 1 TeV, we first examined some results [9] of the Krakow Emulsion Group on ~ 10 TeV cosmic ray jets ($\langle \log \gamma_c \rangle \sim 1.8$).

From fig. 5 (a, b) which shows their results on the secondary jets, and namely $\langle \log \gamma_c \rangle = 1.17$ for $N_h \leq 5$ and $\langle \log \gamma_c \rangle = 0.87$ for $N_h > 5$, we see that the $\langle \log \operatorname{cotg} \vartheta \rangle$ method underestimates the energy in this second type of jets. The introduction of our corrective term leads to the third hystogram, and we obtain $\langle \log \gamma_c \rangle = 1.19$, which is actually in good agreement with the one valid for $N_h \leq 5$.

We next used the I.C.E.F. data [10] on jets with primary energy > 1 TeV. Fig. 6 shows the normalized distribution curves of $\gamma_p = 2\gamma_c^2 - 1$ for the three groups of jets A B C (curves 3, 2, 1). Assuming that the efficiency bias does not play a big role, we should expect similar distribution curves for the three groups of events. They are instead different, and this is to be attributed to the internal collisions. We therefore apply our correction (assuming $\nu = 1.3$ for the B–events and $\nu = 3$ for C–events) and plot the corrected curves in the same fig. 6 (curves 2′ and 1′).

The agreement with the curve 3 for the A–jets shows the usefulness of our correction.

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