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ENERGY DETERMINATION OF HIGH ENERGY COSMIC RAYS PROTONS

M.M.Sherif
Physics department, Faculty of Science, Cairo University, 12613 Giza, Egypt

Abstract

Proton-emulsion interactions in the energy range between 6.2 and 800 GeV are analyzed. An empirical relation correlates the mean number of inelastic interactions between the incident proton and nucleons in the target nucleus and the multiplicity of nuclear fragments has been found. Another empirical relation to calculate the energy of the incident protons in high energy cosmic rays has been constructed by $<- \ln \tan \theta/2>$ and the multiplicity of nuclear fragments.

1. Introduction:

One interesting detector in high energy physics is the nucleus itself. It can act as a very sensitive detector for when the hadronization of excited nucleons takes place in space and time. In detection it is preferable to let the incident particle pass through a layer of nuclear matter as thick as possible. This can be done by either increasing the size of the target nucleus or by decreasing the impact parameter in a heavy nucleus. Shower particles (i.e. the number of singly charged particles with $\beta > 0.7$ and consistent mainly pions) n_s multiplicity's has frequently been used to investigate particle production mechanisms in hadron-nucleus reactions. Reference 1 describes a method of calculating the number of collisions $<\upsilon> = A.\sigma_{pn}^{in} / \sigma_{pA}^{in}$,between the incident proton and nucleons inside the target nucleus (where A ,$\sigma_{pn}^{in}$and σ_{pA}^{in} are the mass number of the target nucleus, inelastic p-N cross section and inelastic p-A cross sectionrespectively), or the effective nuclear size, from the knowledge of the number of slow particles (n_h) emitted in the reaction. This gives a possibility to divide the experimental emulsion data into bins with different $< \upsilon >$. There are two different ways to bin the data, either by using the multiplicity of grey particles n_g [1-2] (grey particles are mainly inelasticaly scattered protons with energies between 26 and 400 MeV), or by using the number of slow particles [1] n_h ($n_h = n_g + n_b$ where n_b the multiplicity of black particles are mainly singly and doubly charged particles with energies < 26 MeV (spectator particles)).

2. AN EMPIRICAL RELATION BETWEEN $<\nu>$ AND n_h :

In this work the experimental results of p-Em. interactions in energy range between 6.2 and 800 GeV [3-5]have been used to establish an empirical relationship between the number of collisions $<\upsilon>$,and the multiplicity of slow particles n_h (n_h could be a measure of the impact parameter of proton-nucleus collision (p-A)).The multiplicity of emitted slow particles depend very weekly on the incedent energy.I have deduced the following energy independent relations for $5 \leq n_h \leq 30$:

$$<\nu_{n_h}>_{pEm(200)} = (1.14 \pm 0.06)\sqrt{n_h} - (0.42 \pm 0.23) \qquad 1.a$$

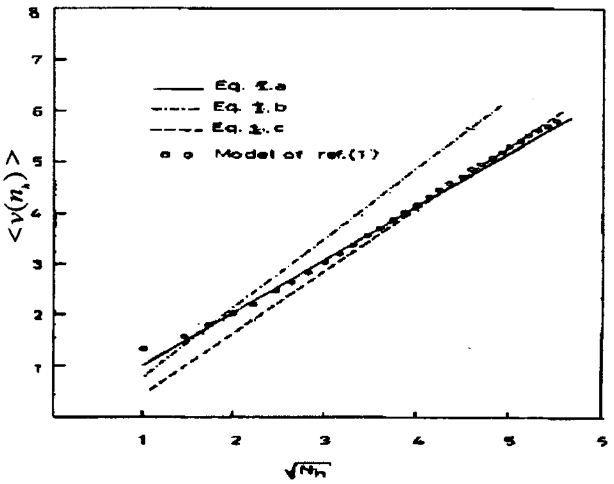

Fig. 1: The model in ref. (1) is shown together with the emperical relationships found in this work, (— Eq. 1.a), (-.-.- Eq. 1.b) and (oooo Eq . 1.c)

$$<v_{n_h}>_{pEm(400)} = (1.24 \pm 0.11)\sqrt{n_h} - (0.86 \pm 0.29) \qquad 1.b$$

$$<v_{n_h}>_{pEm(800)} = (1.37 \pm 0.18)\sqrt{n_h} - (0.57 \pm 0.31) \qquad 1.c$$

The first relation (1.a) is more accurate than (1.b) and (1.c), due to the high statistics of p-Em. and p-A collision at 200 GeV. Where these relationships are represented in figure (1).

The model suggested by Stenlund and Otterlund [(1)], predicts almost linear relationship between $<v>$ and $\sqrt{n_h}$. In figure (4) the prediction from the model of ref. (1) is shown together with the empirical relationships found in this work (i.e. relations 1.a, 1.b and 1.c).

3. ASYMPTOTIC BEHAVIOR OF THE NORMALIZED SHOWER PARTICLE MULTIPLICITIES:

In p-A collisions the inclusive pseudorapidity (η) distribution ($\eta = -\ln(\tan \theta/2)$, where θ is the space angle of shower particles in the laboratory frame) of relativistic particles are scale invariant in both the projectile and target fragmentation region[(4,6)] ,whereas the height of the central region of pseudorapidity distribution increases with increasing primary energy. The average multiplicity of produced particles in p-A and p-N collisions can be evaluated in three different parts:

$$<n_s>(A,E) = <n_s>_T + <n_s>_C + <n_s>_P$$

Where $<n_s>_T$, $<n_s>_C$ and $<n_s>_P$ are the average values of shower multiplicities in target fragmentation, central fragmentation and projectile fragmentation regions in the rapidity space respectively. Due to the limiting behavior of fragmentation processes for proton energies until 800 GeV ,the values of $<n_s>_T$ and $<n_s>_P$ should be energy independent parts, but $<, n_s>_C$ is energy dependent part. Some authers [(5, 6)] they suggested to study the energy dependent part of multiplicities by estimating ratios like

$$R(E_1,E_2) = <n_s(E_1)> - <n_s(E_2)> / <n_{ch}(E_1)> - <n_{ch}(E_2)> .$$

where R is a quantity where the energy independent contributions from fragmentation regions have been subtracted. To study the normalized multiplicity ($R = <n_s>/<n_{ch}>$) in central region of rapidity for p-Em. collision. In this work the data are divided into different n_h bins as follows $5 \le n_h \le 10$, $11 \le n_h \le 22$, and $23 \le n_h \le 30$. While $<v>$ in each group is determined by relation 1.a. Figure (2) exhibits the dependence between $<n_s>_{pEm}$ and $<n_{ch}>_{pp}$ (the multiplicity in p-p collision at the corresponding energy) for different n_h bins. The fit to the straight lines are given in table (1).

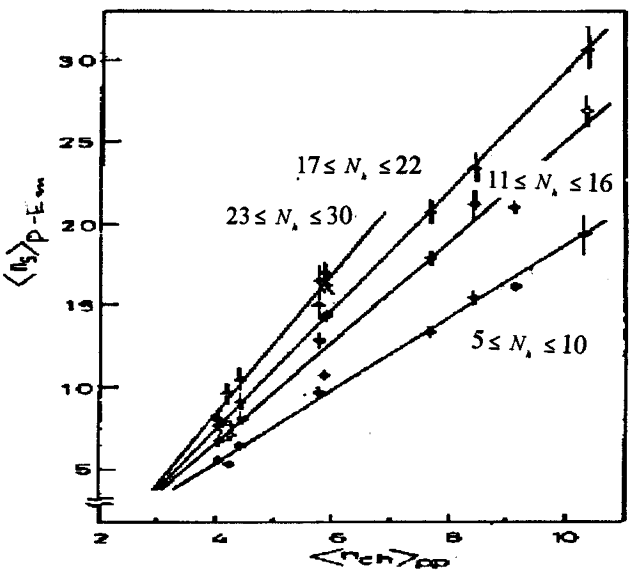

Fig. 2 The dependence between $<n_s>_{pEm}$ and $<n_{ch}>_{pp}$ for different nh bins. The straight lines are best fits to the experimental points.

Table (1) : The fitting parameters of $<n_s> = k <n_{ch}> + l$, for each different n_h bins :

n_h	k	l	$<n_h>$weighted in the bin
5 - 10	2.25	-3.70	7.1
11- 16	3.12	-5.92	13.3
17- 22	3.74	-7.68	19.4
23-30	4.38	-9.38	25.5

In figure (3) the slopes i.e. the R_0 from table (1) are plotted versus the $<v>$ values of each bin (where the value $<v>$ estimated by relation (1.a) . An apparent linear relation is observed giving :

$$R_0 = d <n_s>_{pEm} / d <n_s>_{pp} = (0.78 \pm 0.02)<v> + (0.25 \pm 0.05)$$

This is in good agreement with the values obtained in ref. (7), $R_0 \approx 0.90 <v> + 0.12$ where the emulsion data is analyzed, using grey tracks only.

4. ENERGY ESTIMATION FOR PARTICLE - NUCLEUS COLLISIONS:

In high energy cosmic ray experiments it is convenient to define a pseudo rapidity variable $\eta = -\ln(\theta/2) = \ln(2P_L/P_T)$, where θ, P_L, P_T are respectively the angle, the parallel and the perpendicular components of momentum of produced particles with respect to the incident particle momentum. In refs. (8,9) the collective tube model (CTM) has been used to estimate a relation between the incident particle's energy and $<\eta>$,

$$E \approx 0.62 \sum_i (\sin\theta_i)^{-1} \quad (\text{GeV}) \qquad 2$$

In refs. (8 and 9) they have also been determine the incident energy by assuming, that the produced particles are emitted with $<p_T> = 0.35$ GeV/c. This means that the total momentum carried away by the charged secondaries can be written as $P_{tot} = <p_T> \sum_i (\sin\theta_i/2)^{-1}$, where θ_i are the emission angles. Taking into consideration that on the average the neutral secondaries are about 1/2 of the charged particles they get,

$$E \approx 0.53 \sum_i (\sin\theta_i)^{-1} \quad (\text{GeV}) \qquad 3.$$

In this work, by using the experimental data of ref. (2) a plot between $<\eta>_{nh}$ and $\sqrt{n}_h$ for 67, 200, 300, and 400 GeV p-Em. collisions has been presented in figure (3). Indeed we can see that the points within the statistical errors can be fitted by parallel lines (a $\sqrt{n}_h + b$) with approximately fixed slope ($\approx$ 1/2 ln(E) + 0.78). Consequently the energy of p-Em. collision can be estimated by :

$$\ln(E) \approx 2 <\eta>_{nh} + 0.46 \sqrt{n}_h - 1.56 \qquad 4.$$

By using the data of ref. (6), the incident proton energies are estimated for a sample of 400 GeV p-Em. collisions by using the relation 4. Figure (5) present the distributions of incident proton energy obtained by relations 2 and 3, by using the same experimental data of ref. (6). It is clear that the distributions obtained by relations 2 and 3 are not centered around 400 GeV, while the distribution obtained from relation 4 (this work) is relatively centered around the correct energy.

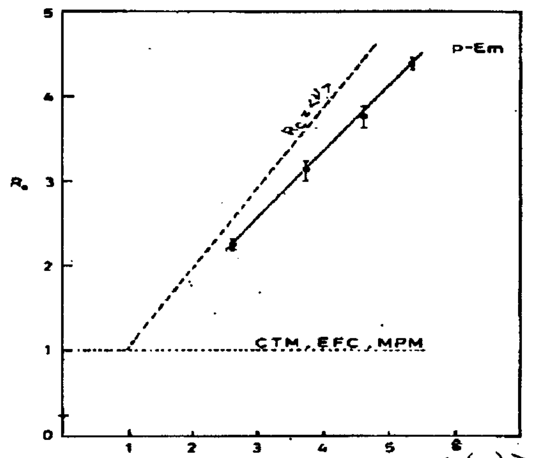

Fig 3 Ro valuesfrom table (1) versus $<\nu>$ values for each nh-bins (— R=$<\nu>$). (R $\to$ 1)

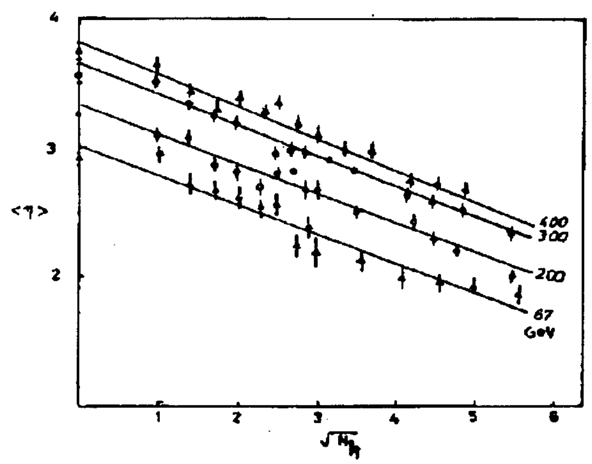

Fig. 4 The Average "pseudorapidity" $<\eta>$, as a function of $\sqrt{n_h}$ at different energies. The straight line are the best fits to the experimental points.

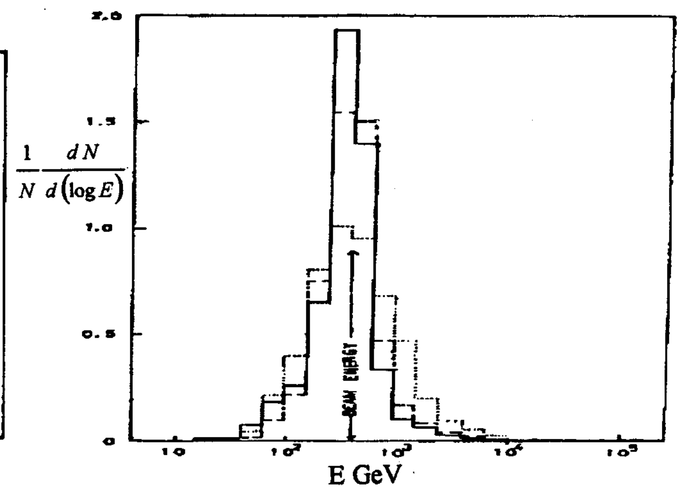

Fig 5: The incident proton energies estimated from a sample of 400 Ge V p-Em collisions of ref. (7). (Solid histogram eq. (4) (this work)), (dashed histogram eq. 2), and dotted histogram eq. 3).

5. CONCLUSION:

In this work an empirical relation is given between the multiplicity of nuclear fragments n_h and the number of average number of collision $<\nu>$,

$$<\nu(n_h)> = (1.14\pm0.06)\sqrt{n}_h - (0.42\pm0.23) \qquad 5\leq n_h \leq 30 .$$

The n_h can be used as a measure of the impact parameter in hadron--nucleus collisions.

From the correlations between multiplicities of shower particles n_s and nuclear fragments we obtain the value $R_0 = 0.78<\nu> + 0.25$ for the asymptotic value of the normalized multiplicity $R = <n_s>_{pEm}/<n_s>_{pp}$ i.e. the ratio of particle densities in the central region of rapidity.

A new relation has been deduced to determine the energy of the incident protons in high energy cosmic ray collision, by using the average value of pseudorapidity corresponding to definite values of nuclear fragments,

$$\ln(E) \approx 2<\eta>_{nh} + 046\sqrt{n}_h - 1.56$$

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7. REFERENCES.

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