Inelasticity for hadron-carbon nucleus collisions from emulsion chamber

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The inelasticity of hadron-carbon collisions for energies exceeding 100 TeV is estimated from the carbon-emulsion chamber data at Pamirs to be $\langle K_C \rangle = 0.65 \pm 0.08$. When combined with data on hadron-lead collisions taken at the same energy range it results in the $K \sim A^{0.086}$ mass number dependence of inelasticity. The evaluated partial inelasticity for secondary ($\nu > 1$) interactions, $K_{\nu>1} \simeq 0.2$, suggests that most of the energy is lost in the first interaction.

1. INTRODUCTION

The inelasticity of hadronic reactions, understood as the fraction of the incident beam energy spent on the production of secondaries, is (next to the inelastic cross section) the most significant variable for all cosmic ray experiments involved in cascade developments \cite{1,2}. Unfortunately, in the energy region exceeding a few hundreds of GeV there are no accelerator data on inelasticity on nuclear targets and only rough indications from cosmic ray experiments are available \cite{1,2}. Recently \cite{3} the inelasticity in hadron-lead collisions was estimated in the energy region exceeding 100 TeV. In this contribution we present similar analysis performed for $h - C$ interactions observed in carbon emulsion chamber (EC) exposed to cosmic rays at the Pamirs.

This EC consists of $\Gamma$-block of 6 cm Pb ($0.35 \lambda$, 10.5 c.u.) and two $H$-blocks of carbon layer of 60 cm thickness (66g/cm$^2$, 0.9$\lambda$, 2.5 c.u.) each followed by 5 cm of lead-emulsion sandwiches. In EC (which is a shallow calorimeter) only the energy transfered to the electromagnetic component is measured, i.e., $E_{\gamma h}^n = K_\gamma \cdot E_h$, and in the hadronic block a given nuclear-electromagnetic cascade (NEC) produces spots with optical density $D$ on X-ray film (cf., \cite{4} for details).

Such structure of the carbon EC allows for a relatively straightforward estimation of the total inelasticity for $h - C$ interactions \cite{5}. The proposed method is uses the repeated registration of the same cascade in the two subsequent hadronic blocks. If $N_1$ denote the number of cascades registered in the first hadronic block with visible energy $E_1 > (E_{\gamma h}^n)_1$ and $N_2$ the number of cascades repeated registered in second hadronic block with $E_2$ above the threshold $(E_{\gamma h}^n)_2$, then the ratios

$$\eta = \frac{N_2}{N_1} \quad \text{and} \quad \epsilon = \frac{E_2}{E_1} \quad (1)$$

are sensitive to total inelasticity $K$. The weak dependence of these quantities on the methodical errors and ease with which the experimental data may be obtained render this method very useful and promising for possible future applications.

2. INELASTICITY FOR CARBON TARGET

The experimental data collected from 110m$^2$ carbon EC contain $N_1 = 70$ hadrons with energies $E_1 > 30$ TeV and $N_2 = 24$ hadrons with energies $E_2 > 2$ TeV). They give the value of $\eta = 0.27 \pm 0.06$ (at energy threshold $E_2 > 4$ TeV, being free from the detection bias) and the energy ratio $\epsilon = 0.24 \pm 0.07$. These data have been

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then recalculated by using the simulated $D(E_h^2)$

The ratio $\eta$ of the number of hadrons repeatedly registered in two hadronic blocks and the number of all hadrons registered in the first hadronic block is presented in Fig.1 for different total inelasticities: $\langle K \rangle = 0.5, 0.65$ and $0.80$. Note that the ratio $\eta$ is more sensitive to the mean value of inelasticity $\langle K \rangle$ than the energy ratio $\epsilon$, shown in Fig.2. The comparison of experimental data with simulated dependences indicates that $\langle K_C \rangle = 0.65 \pm 0.08$ for hadron-carbon nucleus collisions at the hadron energies of above $\sim 100$ TeV is the most probably choice for the mean value of inelasticity for hadron-carbon collisions.

dependence [4]. The repeated registrations of hadron has been simulated by the Monte-Carlo event generator. Primary hadrons (assumed to consist of 75% nucleons and 25% pions) were sampled from the power spectrum representing distribution of the initial energy with a differential slope equal to $\gamma = 3$. The gamma quanta and electrons above 0.01 TeV, reaching the detection level within the radius of 5 mm, were recorded and the corresponding optical densities were calculated within the radii utilized in the experiment. Only cascades with the energies above $E_1 = 30$ TeV and $E_2 = 2$ TeV were selected.

Figure 1. Dependence of $\eta = N_2/N_1$ on the energy threshold $E_{th}^2$ in the second hadronic block for: $\langle K \rangle = 0.65$ (solid line), $\langle K \rangle = 0.50$ (dotted line) and for $\langle K \rangle = 0.80$ (black dots), compared with the experimental data.

Figure 2. Dependence of $\epsilon = E_2/E_1$ on the thickness $H/\lambda$ of carbon target (the plotted curves correspond to different $\langle K \rangle$ as in Fig. 1).

This result can be now compared with $\langle K_{Pb} \rangle = 0.83 \pm 0.17$ obtained in similar analysis of successive hadron interactions registered in the thick-lead-emulsion chamber at Pamirs [3]. Both results lead to the $K \simeq A^{0.086}$ mass number dependence of inelasticity. If we extrapolate this $A$ dependence to $A = 1$ we obtain hadron-proton
in this energy range being equal to $K_{h-p} = 0.53$ (notice that the same value can be obtained from Eq. (3) below where $K_1 = K_{h-p}$). Assuming further that $N_\pi/N_h \sim 0.25$ and that $K_{\pi-p} = 1.5K_{p-p}$, we obtain that in the energy range exceeding 100 TeV inelasticity in proton-proton collisions is equal to $K_{p-p} = 0.46$ (which agrees with our earlier predictions [1,6]).

3. PARTIAL INELASTICITY $K_\nu$

Following Ref. [2] we shall now estimate the so called partial inelasticity $K_\nu$. In the framework of Glauber multiple scattering formalism [7] it is defined by

$$\langle 1 - K \rangle = \sum_{\nu=1} P_\nu \langle 1 - K_\nu \rangle^\nu$$

(2)

where $P_\nu$ is the probability for encountering exactly $\nu$ wounded nucleons in a target of mass $A$ and $\langle 1 - K_\nu \rangle$ is the mean elasticity of the leading hadron in collisions with exactly $\nu$ wounded nucleons. Assuming that $K_{\nu>1} = K_2$ the total elasticity can be written as

$$\langle 1 - K \rangle = (1 - K_1) \sum_{\nu=1} \langle 1 - K_2 \rangle^{\nu-1} P_\nu.$$  

(3)

The ratio $\kappa$ of elasticities (given by eq.(3)) in collisions on Pb and C targets depends only on $K_2$ once the $P_\nu$ is known. Assuming Poisson distribution for the number of wounded nucleons, $\nu$, the value of $K_2$ for the expected mean number of wounded nucleons $\langle \nu \rangle = \frac{A_{h-p}}{2\beta A} \sim A^{1/3}$ and for the experimentally evaluated value of $\kappa = 0.5$ is equal to $K_2 \approx 0.2$. (Notice tacit assumption made here that the ultimate identity of the final state nucleon is determined only once during the interaction with the nucleus - in [2] it means that $\beta = 1$ for the parameter specifying the fraction of isospin preserving reactions).

4. CONCLUDING REMARKS

For hadron-carbon nucleus collisions in energy region exceeding 100 TeV the inelasticity is estimated to be equal to $\langle K_C \rangle = (6.5 \pm 0.8)$. Our estimation of $K_2 = 0.2$ at energies above 100 TeV is consistent with low energy data (cf. Ref. [3]). Note that inequality $K_{\nu>1} < K_1$ is characteristic to all string-type interaction models (cf. Quark-Gluon String model [3] or Dual Parton Model [4]) whereas the SIBYLL model [5,6] predict much smaller value of $K_2$ in the examined energy region. It is important to notice that the new results for inelasticity on lead target, $\langle K_{h-p} \rangle \approx 0.6 \pm 0.05$ reported at this conference [1] when compared with our $\langle K_{h-C} \rangle$ result in $K_2 \approx 0$ and $\langle K_{h-p} \rangle = \langle K_{h-C} \rangle$ which exceeds noticeably the value $\langle K_{pp} \rangle \approx 0.41$ as evaluated from the collider data [1].

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