Pseudorapidity Distributions from Pion–Emulsion Interactions in the Energy Range 60 GeV to 300 GeV

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Abstract. The analysis of experimental data for pion–nucleus interactions in the energy range 60 GeV–300 GeV is presented. The pseudorapidity distributions of shower particles are analyzed in terms of pion energy and the average number of intra-nuclear collisions of the projectile. The particle densities in the projectile fragmentation region are compared to predictions of the additive quark model. The relation between the average number of wounded quarks in the projectile and the number of fast protons emitted from the struck nucleus is derived and used to extract from the experimental n–emulsion data the fragmentation functions for both wounded and spectator quarks. These functions are then used to describe the results of independent n–proton and n–deuteron experiments.

1. Introduction

In spite of the fact that in recent years many papers dealing with hadron–nucleus interactions have been published [1], we still have only partial answers to the questions related to the particle production mechanism. The proper understanding of hadron–nucleus collisions may have important implications for planning and performing new accelerator experiments with heavy ion beams. Heavy ion collisions have become, recently, the subject of intense experimental and theoretical investigation, following the suggestion [2] that, as a result of the high energy density achieved in the collision, new physical phenomena, such as the formation of a quark gluon plasma, may occur.

From the experiments with hadron beams we have learned that the multiplicity of produced particles does not depend strongly on the atomic mass of the target nucleus and that the increase of the multiplicity compared to hadron–nucleon collisions, is confined, mainly, to the target fragmentation region. These facts have been explained by models [3,4] in which the particle production in hadron–nucleus collisions is described by multiple collisions of the projectile (or its constituents) with nucleons within the target nucleus.

In this paper we present the analysis of experimental data for pion–nucleus interactions in the energy range 60 GeV–300 GeV. The paper is organized as follows. In Sect. 2 the pseudorapidity distributions of shower particles are analyzed in terms of pion energy and the average number of intranuclear collisions of the projectile. In Sect. 3 the particle densities in the projectile fragmentation region are compared to predictions of the additive quark model. The relation between the average number of wounded quarks in the projectile and the number of fast protons emitted from the struck nucleus is derived and used to extract from the experimental n–emulsion data the fragmentation functions for both wounded and spectator quarks. These functions are then used to describe the results of independent n–proton and n–deuteron experiments. Section 4 contains discussion and conclusions.

2. Pseudorapidity Distributions of Shower Particles

2.1 Experimental Material

The data analyzed in this paper consist of 788, 973 and 2115 inelastic interactions of negative pions in nuclear emulsion at the energies of 60 GeV, 200 GeV and 300 GeV respectively. At each energy the same experimental procedure was applied to obtain the characteristics of the analyzed events. The details are given in [5]. In each event the emission angles $\Theta$ of relativistic $(\beta > 0.7)$ shower particles $n_\pi$ were measured and the number of heavy ionizing $(\beta \leq 0.7)$ disintegration products of the struck target nucleus were carefully counted. The latter were divided into two categories: gray track producing particles $N_g$ which velocities fall into the intervals $0.25 < \beta < 0.7$ (it corresponds to proton energies $30 \text{ MeV} < E < 400 \text{ MeV}$) and particles producing black tracks $N_b$ with velocities $\beta \leq 0.25$. The gray tracks can be recoil protons as well as protons originating from low energy nucleonic cascade initiated by recoil protons. The black tracks are evaporation products of the remaining excited target nucleus.
2.2 The Dependence on Primary Energy

In Fig. 1 the normalized inclusive angular distributions of shower particles \( n_s \) produced in \( \pi^- \)-emulsion interactions at different energies are presented using pseudorapidity variable \( \eta = -\ln \tan (\Theta_{25}/2) \). For pions this variable is a good approximation \( (m^2 \ll p^2) \) to the longitudinal rapidity. Note that in the target fragmentation region \( (\eta \leq 1.0) \) the distribution of shower particles does not depend on the energy of primary pion. In the central region, a plateau becomes more visible with increasing primary energy and for 300 GeV interactions the plateau extends for about two units of pseudorapidity. The projectile fragmentation region has been examined in the antilaboratory frame using the variable \( \eta' = \eta - \eta_{\text{max}} \) where \( \eta_{\text{max}} \) is the rapidity of the projectile. It is seen from Fig. 2 that the pseudorapidity distributions for different energies exhibit the scaling behaviour for \( \eta' \approx -4.0 \).

2.3 The Dependence on Effective Target Thickness

It was argued in several papers [6–8] that the number \( N_g \) of gray particles emitted from struck nucleus is related to the number \( v \) of projectile collisions with nucleons inside the target nucleus. The number \( v \) gives the thickness of the target as seen by the impinging hadron in units of the mean free path of the projectile in nuclear matter. Different models [8,9] have been developed to construct the distribution function \( P(v, N_g) \), which gives the probability that \( v \) intranuclear projectile collisions yield \( N_g \) gray particles. In the model proposed by Anderson et al. [8], it is assumed that each collision inside the nucleus gives an independent contribution to the final \( N_g \) distribution and that the distribution in a single collision is of the geometrical type. Under above assumptions the \( N_g \) distribution for \( v \) collisions was derived:

\[
P^v(N_g) = \binom{N_g + v - 1}{N_g} (1 - X)^v X^{N_g}
\]

where \( X = (\bar{N}_{\text{tot}}/\bar{v})/(1 + \bar{N}_{\text{tot}}/\bar{v}) \). The probability of finding an event with \( v \) collisions and \( N_g \) gray particles is:

\[
P^A(v, N_g) = P(v) P^v(N_g)
\]

where \( P(v) \) is the probability distribution of \( v \). Finally, the mean number of collisions in an event with a given number \( N_g \) equals

\[
\bar{v}(N_g) = \frac{\sum_v v P^A(v, N_g)}{\sum_v P^A(v, N_g)}.
\]

The \( \bar{v} \) vs \( N_g \) dependence for \( \pi^- \)-emulsion interactions is depicted in Fig. 3. It can be seen from this figure that the range of \( \bar{v} \) studied by measuring the gray tracks is much wider than that achieved by changing targets from hydrogen to uranium as indicated on the abscissa. This gives us the possibility to analyze various characteristics of hadron–nucleus collisions over a wide range of \( \bar{v} \).

The procedure described above allows us to select the interactions with different mean number \( \bar{v} \) of projectile collisions by dividing our sample of \( \pi^- \)-emulsion interactions into subsamples according to the number \( N_g \) of gray particles. The examples of pseudo-