Features of pC Interactions at a Momentum of 4.2 GeV/c versus the Degree of Centrality of a Collision between a Proton and a Carbon Nucleus: Kinematical Features of Secondaries

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Received October 18, 2002; in final form, March 3, 2003

Abstract—The mean values of the momenta and emission angles of charged pions and protons in the laboratory frame are presented both for the total ensemble of interactions between 4.2-GeV/c protons and a carbon nucleus and for six groups of events characterized by different degrees of collision centrality. The distributions with respect to the total and the transverse momentum are presented for the particles being studied, along with the longitudinal-rapidity distributions. Our experimental data are compared with the predictions of the cascade—evaporation model and of two versions of the refined FRITIOF model. It is shown that, as the degree of collision centrality becomes higher, the mean momenta and rapidities of secondaries decrease, the transverse momenta remain virtually unchanged, and the mean angles of particle emission increase. This is consistent with the pattern of particle cascading in nuclei. However, the mean transverse momentum \( \langle p_t \rangle \) of participant protons that was obtained on the basis of the cascade—evaporation model decreases with increasing degree of collision centrality, in contrast to what is observed in our experiment. A satisfactory description of experimental data is obtained on the basis of the refined FRITIOF model taking into account \( \Delta^+ \) and \( \Delta^0 \) isobars. The stopping power of carbon nuclei for 4.2-GeV/c protons is also determined. © 2004 MAIK “Nauka/Interperiodica”.

INTRODUCTION

The interactions of protons with a carbon nucleus (pC interactions) at a momentum of 4.2 GeV/c under the conditions of 4\pi geometry were explored in a number of studies [1–9]. A detailed analysis of the multiplicities of charged secondaries from collisions between protons and carbon nuclei at various values of the impact parameter was given in [9]. The present study is a continuation of that which was reported there. Here, we present the kinematical features of secondaries, including the momentum, angular, and rapidity distributions of charged pions and protons for six groups of pC interactions from peripheral to central ones. In just the same way as in [9], the experimental results are compared with the predictions of the cascade—evaporation model [10] and two versions of the modified FRITIOF model. The stopping power of a carbon nucleus for 4.2-GeV/c protons is considered individually. Investigation of these features is of importance for reconstructing the space-time pattern of pC interactions at various values of the impact parameter—in particular, for clarifying the role of particle rescatterings in a carbon nucleus and for obtaining deeper insight into the mechanism of hadron—nucleus interactions.

It is well known that the spectrum of fast leading protons in pA interactions can be described quite successfully on the basis of the Glauber approach—that is, within the pattern of successive collisions between an incident particle and the nucleons of the target nucleus [11, 12]. In the central rapidity region and in the region of target-nucleus fragmentation, where, at energies of a few GeV, the contribution of target-nucleus nucleons is large, one can expect a violation of this pattern. Therefore, it is interesting to investigate the features of leading and nonleading hadrons.

It is assumed that the intranuclear-cascade model [13] describes particle yields from hadron—nucleus interactions well at the energy value being considered. It was shown in [9] that this model reproduces the multiplicity distributions of particles produced in pC interactions. At the same time, the model considerably overestimates the multiplicity of negatively charged pions in multinucleon collisions. It can be

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expected that the drawbacks of the cascade model will manifest themselves most clearly in the momentum distributions of negatively charged pions, especially in multiple collisions.

In the Glauber approach, as well as in the cascade model, it is assumed that hadron-nucleus and nucleus-nucleus interactions can be represented as a set of elementary-particle interactions.

As to the FRITIOF model [14, 15], it assumes a two-body kinematics of inelastic nucleon-nucleon interactions; that is, \( a + b \rightarrow a' + b' \), where \( a' \) and \( b' \) are excited states of primary nucleons. The excited states are characterized by a mass. The projectile mass increases as the result of successive collisions in the target nucleus, and this leads to an increase in the multiplicity of particles produced in its decay. In the present version of the FRITIOF model, it is assumed that excited nucleons of a target nucleus leave the nucleus without undergoing additional collisions and decay beyond it. In order to simulate cascade processes in a target nucleus within the modified FRITIOF model, use is made of the Reggeon cascade model [16]. A more detailed description of the model can be found in [17, 18].

The possibility of describing, on the basis of the FRITIOF model and the intranuclear-cascade model, the multiplicities of particles produced in \( pC \) interactions at \( p_p = 4.2 \) GeV/c was investigated in [9]. It was shown there that the cascade-evaporation model [10] overestimates the multiplicity of negatively charged pions in multinucleon interactions, but that the FRITIOF model underestimates the multiplicity of product pions. Since it was noticed in the experiment that the multiplicity of positively charged pions is proportional to the multiplicity of participant protons, there arose the idea to take into account, within the FRITIOF model, \( p \rightarrow n + \pi^+ \) and \( n \rightarrow p + \pi^- \) transitions caused by the existence of virtual \( \Delta^+ \) and \( \Delta^0 \) isobars in nuclei or their appearance in the Reggeon cascade. This made it possible to obtain a satisfactory description of the multiplicities of product particles versus the degree of centrality of collisions between protons and carbon nuclei.

Below, we present the kinematical features of particles in events differing by the degree of collision centrality. These data make it possible to reveal those phase-space regions where attempts at describing experimental results on the basis of the existing models run into the most serious difficulties. First of all, an analysis of peripheral interactions enables us to test the correctness of simulating elementary interactions. In multinucleon interactions, one can expect manifestations of collective effects. If they exist (for example, a fireball involving all colliding nucleons arises in central collisions), the kinematical features of particles must be weakly dependent on the degree of collision centrality. It will be shown below whether this is indeed so.

The ensuing exposition is organized as follows.

In Section 1, we give a brief description of special features of the experimental data used here. Further, we present the kinematical features of charged pions in Section 2 and the properties of participant protons in Section 3.

In Section 4, we determine the stopping power of carbon nuclei. In the physics of fast-particle propagation through matter, the stopping power is defined as the mean kinetic energy lost by a particle per unit path. It is assumed that these losses are low and that the particle moves nearly along a straight line. In the physics of nuclear collisions, energy losses are high, and it is difficult to discriminate between the projectile that survived and particles knocked out of the target. Therefore, the change in the rapidities of interacting nucleons is more often considered in high-energy physics [19, 20]. A systematics of the stopping power of nuclei that was found in this way is given in [21]. For a determination close to the classical one, use is usually made of model calculations. We rely on the FRITIOF model version that takes into account delta isobars. As was shown in [9], the momentum region \( p > 1.4 \) GeV/c is dominated by surviving protons, the momenta of nucleons knocked out of the target nucleus being less than 1.4 GeV/c. In Section 4, the features of leading \( (p > 1.4 \) GeV/c) and nonleading \( (p \leq 1.4 \) GeV/c) protons are considered separately; also, data on the distribution of energy between different types of secondaries are given there.

In the Conclusions, we summarize the main results of our study.

1. EXPERIMENTAL DATA

The experimental data used here were obtained on the basis of processing stereophotographs from the 2-m propane bubble chamber constructed at the High Energy Laboratory of the Joint Institute for Nuclear Research (JINR, Dubna), placed in a magnetic field of strength 1.5 T, and irradiated with a beam of protons accelerated to a momentum of 4.2 GeV/c at the JINR synchrophasotron.

Methodological issues associated with selecting events of inelastic \( pC \) interactions from the entire ensemble of proton interactions with propane (\( \text{C}_3\text{H}_8 \)) by introducing corrections for the number of secondaries and their angular and momentum features, as well as weights taking into account positively charged particles of momenta in excess of 0.5 GeV/c, were