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THE APPLICATION OF A PHENOMENOLOGICAL MODEL TO INELASTIC NUCLEUS-NUCLEUS INTERACTIONS FOR LABORATORY MOMENTA BELOW 5 GeV/c PER NUCLEON OF THE INCIDENT NUCLEUS

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1. INTRODUCTION

Intranuclear cascade calculations have long been used to sample hadron-nucleus interactions (1). The ideas of these models were also used in the construction of nucleus-nucleus interaction models. The aim of this work is to construct a simple model for the generation of inelastic nucleus-nucleus interactions. The model is based on the phenomenological hadron-nucleus and hadron-nucleon interaction models developed in a series of papers [2,3]. It is applicable to incident laboratory momenta from 0.5 GeV/c to 5-7 GeV/c per nucleon for reaction $A_1 + A_2 \to h_i + X$, where $A_{1,2}$ are colliding nuclei; h_i, emitted hadrons; and X, remaining nucleus fragments. The hadrons h_i may be attributed to pions, kaons or nucleons. Nucleon evaporation and low energy particles are taken into account only by calculating the sum of their energies (excitation energy). The model is described in Section 2 of this paper. A brief comparison with the data is given in Section 3. Section 4 contains a short summary of the main results.

2. DESCRIPTION OF THE MODEL

2.1. Basic Features

The two colliding nuclei are considered in their rest systems as spheres with uniform nucleon density distributions. The colliding matter is divided into different interaction regions:

a central interaction region and
a peripheral interaction region.

The boundary between the two regions is determined from a geometrical picture of the interaction [4].

While in the central region the fractions of both colliding nuclei interact with each other, the remaining fragments of the nuclei, which form the peripheral region, interact only with one nucleon of the other corresponding nucleus. In the central region the nucleons interact according to the row-on-row-picture [5] involving all nucleons from the interaction region of the nuclei. The Fermi momentum of the nucleons is taken into account. The interactions are point-like: energy, baryonic and electric charge and strangeness are conserved. Secondary interactions of the produced emitted particles and their absorption are not taken into account.

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2.2. Geometrical Picture of the Interaction

In order to model the nucleus-nucleus interactions, a simple geometrical/optical picture [5] is used. The interaction takes place in the two different regions.

For a given impact parameter b of the reaction (see Fig.1) one has the central region, consisting of two colliding nucleus fractions A_1'' and A_2'', and the noncentral (peripheral) region consisting of remaining fragments A_1' and A_2' of the nuclei A_1 and A_2, respectively. The fragments, which interact in the central region, are described by the collection of tubes which contain nucleons (nuclei tubes) (Fig.2). Within such a tube the nucleons are situated one behind the other moving with Fermi momenta relative to the original nucleus. The interaction takes place with front nucleons between two colliding tubes.

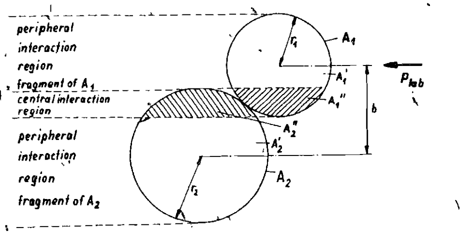


Fig.1. Geometrical representation of the interaction regions for two colliding nuclei in the pure optical model.

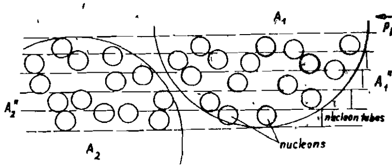


Fig.2. Geometrical representation of the nucleon tubes in the central region of the colliding nuclei.

In the peripheral region (see Fig.1) one nucleon from the nucleus $A_{1,2}$ (essentially from its central fraction) collides with the peripheral fragment $A_{2,1}$ of the other nucleus $A_{2,1}$ like in a nucleon-nucleus collision.

2.3. Determination of the Impact Parameter and Enlargement of the Central Interaction Region

The impact parameter b is determined by the Monte-Carlo method according to the normalized distributions

$$\frac{dn}{db} = \frac{2b}{(r_1 + r_2)^2}, \qquad \frac{dn}{d\theta} = \frac{1}{2\pi}$$

with $r_{1,2} \propto \sqrt[3]{A_{1,2}}$ — the radii of the nuclei $A_{1,2}$ and $\theta_{N_1N_2}$ — the azimuthal scattering angle of the nucleon N_1 on the nucleon N_2 inside the nucleus.

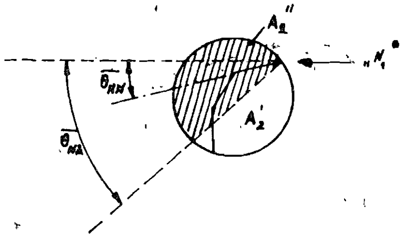


Fig.3. Geometrical representation of the increase of the central interaction region for the nucleus A_2.

Knowing the impact parameter, the numbers of nucleons inside the central and peripheral regions of the nuclei can be determined. The boundary between the two regions does not follow the pure optical considerations of Fig.1. For laboratory momenta of ~0,5 up to 5÷7 GeV/c per nucleon the scattering angle of the particles is not negligible. Therefore a more realistic picture is somewhat different from that shown in Fig.1. The central region grows with increasing the average scattering angle $\langle\theta_{NN}\rangle$ of the participating nucleons depending on collision energy. The corresponding values are known from hadron nucleon scattering data, see, e.g., [2] and references therein. A rough estimation of the average scattering angle $\langle\theta_{NA}\rangle$ for nucleon N_j of the nucleus A_j on the boundary between the peripheral and central regions depends on the average collision number $\langle n_{NA}\rangle$ of this nucleon inside the nucleus A_1 and on the average nucleon-nucleon scattering angle $\langle\theta_{NN}\rangle$ see Fig. 3.

$$\langle\theta_{N_jA_1}\rangle = \langle n_{N_jA_1}\rangle \cdot \langle\theta_{N_jN_1}\rangle \qquad \langle\theta_{N_jN_1}\rangle \leq \pi$$

$$= \pi \qquad \langle\theta_{N_jA_1}\rangle \geq \pi .$$

The increase of the central region is therefore dependent on the size of nucleus $\langle n_{N_jA_1}\rangle = z \cdot \sqrt[3]{A_1}$, z = const and on the laboratory momentum of the primary nucleons (p_{lab}) because of the single particle scattering mechanisms, which give

$$\langle\theta_{N_jN_1}\rangle \approx \frac{f}{\sqrt{15\pi}\; p_{lab}}, \qquad f = \text{const}.$$

and finally

$$\langle\theta_{N_jA_1}\rangle \approx \frac{F \sqrt[3]{A_1}}{\sqrt{15\pi}\; p_{lab}}, \qquad \text{with} \quad F = z \cdot f \approx 4,$$

see, e.g., Figs.2 and 4.

The increase of the central region acts as an effective lower collision parameter b' of the colliding nuclei. Regarding this

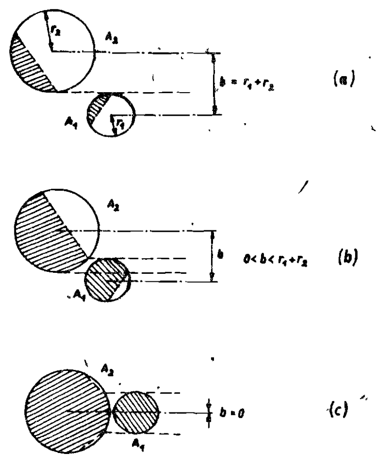


Fig.4. Representation of the interaction regions for two colliding nuclei at different impact parameters b *(a)* $b = r_1 + r_2$ *, (b)* $0 < b < r_1 + r_2$ *, (c)* $b = 0$*.*

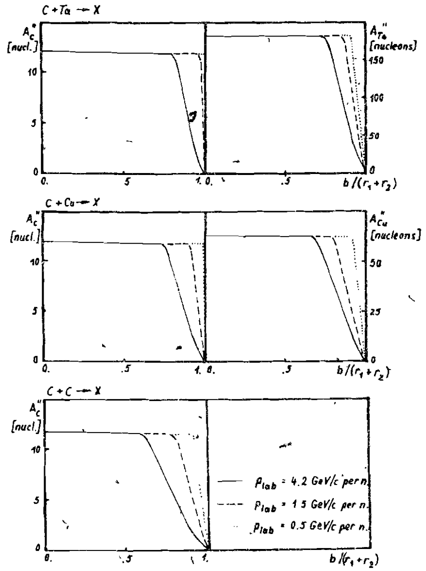


Fig.5. The average nucleon number of the central nucleus fraction as a function of impact parameter b *for several nuclei and laboratory momenta.*

average deflections, it becomes possible to calculate the number of nucleons of the colliding nuclei in the central region by geometrical calculation of the volumes of these nucleus fractions (sphere cut cones), see also Fig.5: $A''_{1,2} = A''_{1,2}(r_1, r_2, b, \langle\theta_{NA}\rangle)$. The increase of the central region and of the probability weight of effective lower collision parameters, respectively, corresponds to the derivation of thermodynamical model velocity distributions for the colliding nuclei.

The number of nucleons of the remaining peripheral nucleus fragments is $A'_{1,2} = A_{1,2} - A''_{1,2}$. The number of nucleons in a tube of the central nucleus fraction is Monte-Carlo distributed due to a truncated Gaussian around $A''_{1,2}$ as a rough approximation. The types of interacting nucleons are determined by the Monte-Carlo method due to the ratio of protons and neutrons in the nuclei A_1 and A_2.

2.4. Interaction Simulation

The nucleon-nucleon interaction inside the central region is described via the mechanism of Ref. /3/, while the interaction

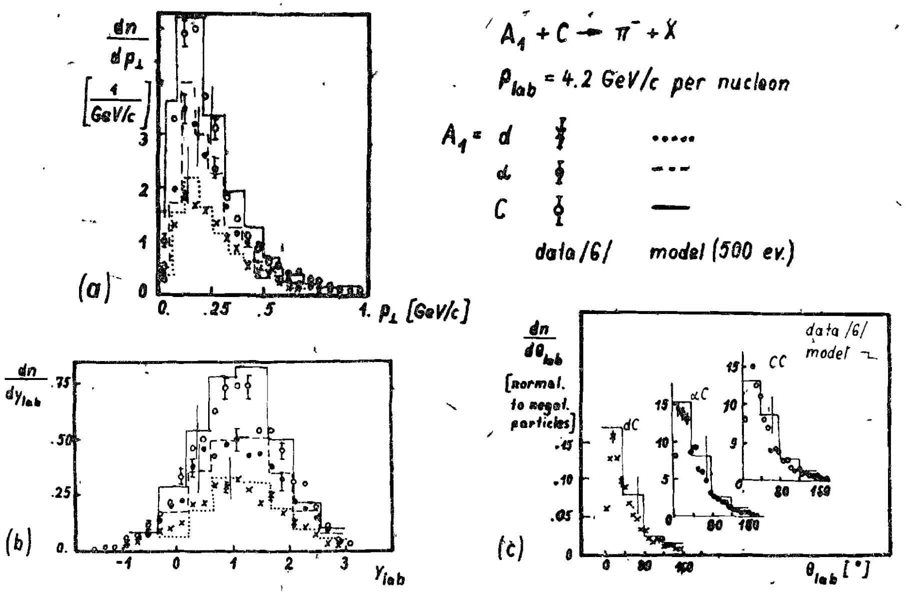
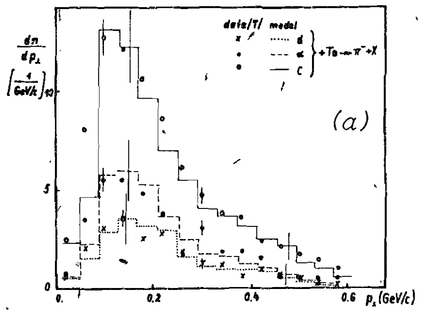


Fig.6. Comparison of the experimental and calculated differential distributions of π^-*-mesons in the reactions* $(d, \alpha, C) + C \to \pi^- + X$ *at* $p_{lab} = 4.2$ *GeV/c, (a) transverse momentum distributions, (b) rapidity distributions in the laboratory system, and (c) laboratory scattering angle* θ_{lab} *distributions.*



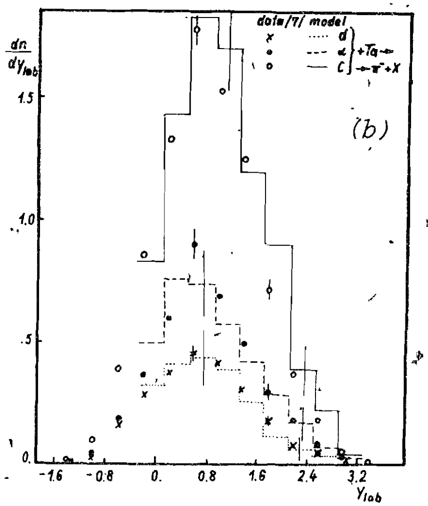


Fig.7. Comparison of the experimental and calculated differential distributions of π^-*-mesons in the reactions* $(d, \alpha, C) + Ta \to \pi^- + X$ *at* $p_{lab} = 4.2$ *GeV/c, (a) transverse momentum distributions and (b) rapidity distributions in the laboratory system.*

in the peripheral region is described by the phenomenological model of Ref.[2]. The Fermi-momentum of nucleons inside the nucleus is taken into account. The Fermi-momentum of nucleons inside the central region is also regarded. Pion absorption, multiple scattering and secondary interactions of hadrons, going out of any nucleon-nucleon or nucleon-nucleus fragment collision, are neglected. The energy of evaporated nucleons and low energy particles is summed up as an excitation energy, see also [3]. These processes are not simulated in the model.

The particle variables are Lorentz-transformed into the laboratory system. The simulated events conserve energy, baryonic and electric charge and strangeness.

3. COMPARISON WITH THE DATA

The single differential cross section data are compared with sampled particle distributions in Figs. 6-8. Figures 6 and 7 contain angular, transverse momentum and rapidity distribution of produced negative pions for the reactions $(d,\alpha,C)+(C,Ta)\to\pi^- + X$ at laboratory momenta of 4.2 GeV/c per nucleon, and Figure 8 presents the angular distributions of protons for the reactions $Fe+(Al,Cu,W)\to p+X$ at laboratory momenta of 1.88 GeV/c per nucleon. All calculated distributions agree well with the data over the whole considered kinematic regions within experimental and statistical errors. The energy dependence of the distributions as well as the dependence on the nucleon numbers of the projectile and target nuclei are described by the model. For low transverse momenta of the pions (below ≈150 MeV/c) the calculations show some systematic deviations from the experimental data, particular for reactions on heavy nuclei. The origin lies in the neglect of secondary particle interactions; the model takes all particles coming from hadron-nucleon or hadron-nucleus fragment reactions into the final state of the event sampled. But just these secondary hadron-nucleon interactions inside the colliding matter play an increasing role at low hadron energies. This deviation is unimportant as compared to the whole spectrum of the hadron momenta.

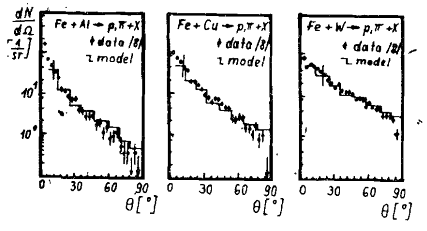


Fig. 8. Comparison of the experimental and calculated single differential distributions of fast particles from high multiplicity events at 1.88 GeV/nucleon in the reactions of Fe *with* Al, Cu *and* W *as a function of scattering angle* θ_{lab} *in the laboratory system.*

Figure 9 demonstrates a correct dependence of the model results on the nucleon number of the projectile nucleus as compared to the experimental data.

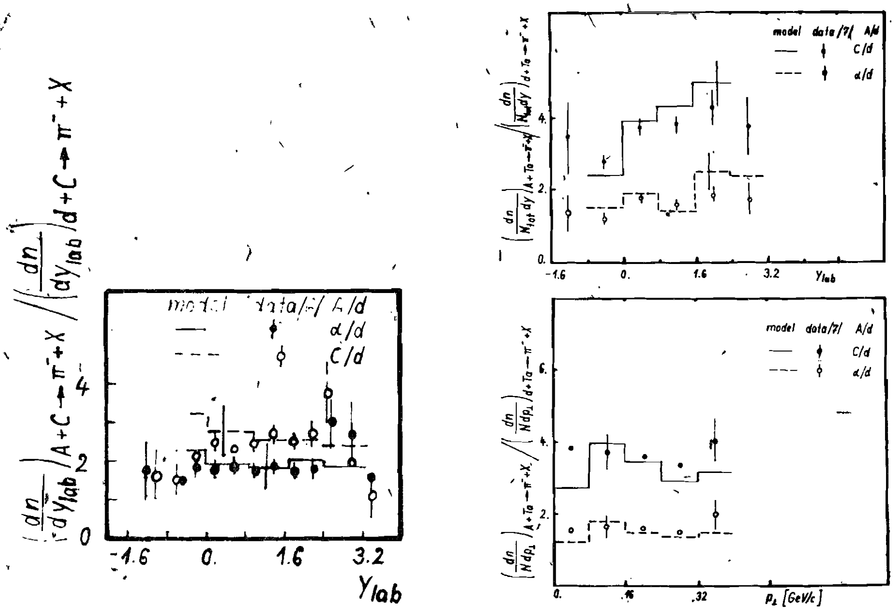


Fig. 9. Comparison of the experimental and calculated ratios of the differential distributions from Figs. 6 and 7. The ratios of the produced π^-*-mesons in the reactions are (a)* $C+Ta$ *to* $d+Ta$, $\alpha+Ta$ *to* $d+Ta$, *(b)* $C+C$ *to* $d+C$, $\alpha+C$ *to* $d+C$.

4. SUMMARY

The above model for inelastic nucleus-nucleus interactions is based on simple geometrical considerations to divide the collision matter into central and peripheral regions. Nucleon-nucleon and hadron-nucleus interaction models are used to describe interactions in these regions. The Fermi-momentum of nucleons is taken into account. The absorption of hadrons, secondary hadron-nucleon interactions and nucleon evaporation processes are neglected. Energy, baryon number, electric charge and strangeness are conserved. The model is applicable to a laboratory momentum region from ≈0.5 up to 5 ÷ 7 GeV/c per nucleon of the projectile nucleus. All nuclei are suitable for projectiles and targets. The model is able to describe the distributions of hadrons versus scattering angle and momentum of the observed particles and versus the nucleon numbers of the colliding nuclei. Deviations from the experimental data occur for low momenta of the observed pions because of the neglect of secondary hadron-nucleon interactions.

The model provides a Monte-Carlo computer program, which can be used to sample exclusive events. It is suitable for the simulation of detectors and for tests of event analysis methods.

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Применение феноменологической модели для неупругих взаимодействий ядер с ядрами при импульсе ниже 5 ГэВ/с на нуклон налетающего ядра

Описана феноменологическая модель для неупругих взаимодействий ядер с ядрами при импульсах ниже 5 ГэВ/с на нуклон. Взаимодействие частиц внутри взаимодействующих ядер описывается с использованием феноменологических моделей взаимодействия адрон-ядро и адрон-нуклон. Розыгрыш по Монте-Карло дает кинематические переменные для изучаемого набора событий. Сравнение моделированных инклюзивных распределений для различных частиц и ядро-ядерных взаимодействий находится в хорошем согласии с экспериментальными данными.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Grishin V.G., Hänsgen K., Kladnitskaya E.N. E1-85-73

The Application of a Phenomenological Model to Inelastic Nucleus-Nucleus Interactions for Laboratory Momenta below 5 GeV/c per Nucleon of the Incident Nucleus

A phenomenological model for inelastic nucleus-nucleus interactions is described and compared with some data. The model is based on a geometrical picture of the interaction. Particle interactions inside the colliding nuclei are described by phenomenological models of hadron-nucleus and hadron-nucleon interactions. The secondary particles can be attributed to pions, nucleons or kaons, for which the Monte-Carlo model provides the kinematic variables in the events sampled. The simulated events conserve energy, baryonic and electric charge and strangeness. The comparison of the inclusive differential particle distributions of the sampled events with the data shows a good agreement.

The investigation has been performed at the Laboratory of High Energies, JINR.

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