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THE MECHANISM OF PARTICLE PRODUCTION PROCESS IN HADRON-NUCLEON COLLISIONS

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1. INTRODUCTION

The only tool available now to investigate experimentally the mechanism of the hadron production process and to obtain its picture is to apply single massive nucleus as a fine detector [1—5]. Such detector allows one to observe the processes inside spatial regions of the diameters near to about 10^{-13} cm, occurring in time intervals of more than 10^{-24} seconds. The claim that atomic nuclei are potential tools for a study of the space-time development of strong interaction can be found in many papers, they are cited in my former paper [1], as well.

We call later such detector the «intranuclear detector»; something what is created in such nucleus may interact with surrounding intranuclear matter, some of the interaction products may be observable when the «intranuclear detector» is plunged into some track sensitive medium. For example, the intranuclear detector works well when ducked in bubble chamber working medium or in photonuclear emulsion.

The intranuclear detector is what causes the objects under study — the hadrons in statu nascendi — interact with the working medium — with the intranuclear matter, and has a few parameters that can be varied in a controlled manner:

1. Their size is

$$r_A \doteq 1.2A^{1/3}\ \text{fm}, \tag{1}$$

with variable mass number A.

2. Various layers of a definite thickness of the intranuclear matter are recognized by the numbers n_N of the nucleons emitted from nucleus when a hadron covered definite thickness λ nucleons/S,

$$n_N = \lambda S, \quad S = \pi R_s^2 \doteq \pi D_0^2 \doteq 10\ \text{fm}^2, \tag{2}$$

R_s — the strong interaction range, D_0 — the nucleon diameter which is as large as R_s, approximately; appropriate relation

$$n_p = \lambda S, \tag{3}$$

where n_p is the multiplicity of the emitted protons, accompanied the hadron passage through intranuclear matter, λ in protons/S, holds as well.

3. The mean free path of a hadron in the atomic nuclei, before to come into particle creation collision with one of the downstream nucleons is [6]:

$$\langle \lambda_a \rangle = k\frac{1}{\sigma_{\text{in}}}\ \text{nucleons/S}, \tag{4}$$

and the mean free path before any type of collision in the intranuclear matter λ_t is

$$\langle \lambda_t \rangle = \frac{1}{\sigma_t}\ \text{nucleons/S}; \tag{5}$$

$k = 3.0 \pm 0.15$, as determined experimentally for the pions projectiles; σ_{in} is the cross section for elementary hadron-nucleon inelastic collisions in S/nucleon units; λ_t is the hadron-nucleon total cross section in S/nucleon units.

The size (1) and the mean free paths (4) and (5) have to be compared with the duration of the interactions

$$\tau = \gamma\,\tau_0 \tag{6}$$

with the characteristic time τ_0 of the strong interaction which is about 1 fm/c and γ defined as

$$\gamma = \frac{E}{M} = \left(1 - \frac{v}{c}\right)^{-1/2}, \tag{7}$$

E and M are the energy and the mass of the hadron. The values of γ for pions at energies of about 6÷15 GeV are from about 40 to about 100. By increasing the incident hadron energy one has a control on γ. The time evolution can be almost arbitrarily slowed down in the laboratory by increasing γ, i.e. by increasing the velocity of the hadron.

Oftentimes, we have used to apply such xenon intranuclear detector during many years; the xenon intranuclear detector — the xenon nucleus — was plunged into liquid xenon in the xenon bubble chambers. A lot of experimental data have been collected from it, on hadron-nucleus and hadron-nucleon collisions, and the proton nucleon collisions in them.

The subject matter in this paper is to put on record the more important experimental data and information about the mechanism of the particle production process in elementary hadron-nucleon and, especially in the nucleon-nucleon collisions.

2. INVESTIGATION PROCEDURE

In studying the mechanism of the hadron-nucleon collisions, the space-time development of the collision process should be revealed experimentally using intranuclear detectors. The goal to the experiments in question are:

1. To vary the intranuclear matter layers thickness involved in collisions over a large range — from about 1 nucleon/S up to about 23 nucleons/S, depending on the intranuclear detector mass number A.
2. To vary the incoming hadron energy over a definite range.

The variations of the intranuclear matter layers thicknesses can be realized simply: by the variation of the mass number of the nuclei and using the dependence of the number n_N of the emitted fast nucleons, or fast protons only, on the thickness nucleons/S of the layers of intranuclear matter involved in an reaction.

The variation of the incoming energy is possible by the variation of the hadronic projectile initial energy.

The dependences of the reaction outcoming characteristics on the numbers n_N of the emitted fast nucleons, or of the emitted fast protons only n_p, and on the incident hadron momentum have been presented in our former works, therefore. The information contained in such characteristics motivates our manner of the data presentation used in many our works [7—9].

3. EXPERIMENTAL DATA

The data presented here, in this section, come from two sources of the information about the mechanism of the particle production process in hadron-nucleon collisions: One of the sources is a series of our experimental data from the xenon target nucleus, i.e. from the xenon intranuclear detector. The second of the sources is the series of the data from experiments with various nuclear targets at various incident hadron energies.

3.1. The Main Data from the Xenon Intranuclear Detector

The general information based on the data from the xenon intranuclear detector is [1,2,4,5]:

The particle production in hadron-nucleon collisions is mediated by intermediate objects created first. The usually observed in the lab system many-particle final states are the outcome of the decays in flight of these objects into commonly known resonances and particles. A particle-producing nucleon-nucleon collision may be treated therefore in its early stage as two-particle final state 2 → 2 endoergic reaction: $P_1 + P_2 \rightarrow G_1 + G_2$, where P_1 and P_2 are the colliding particles with energies at rest $M_1 = m_1c^2$ and $M_2 = m_2c^2$, G_1 and G_2 are the collision reaction products — the intermediate objects or generons — with the rest energies $M_{G_1} = m_{G_1}c^2$ and $M_{G_2} = m_{G_2}c^2$, which obey the relations $M_1 + M_2 < M_{G_1} + M_{G_2}$, $M_1 < M_{G_1}$, $M_2 < M_{G_2}$. The reaction products G_1 and G_2 are the intermediate states which continue to move along the incident hadron course and decay into the finally observed «created» particles after the lifetime of about 10^{-22} s.

The appearance of the well-collimated spurts of particles, or jets, in the final state, the baryon number conservation, and the large transverse momenta values of secondary hadrons are, therefore, a simple and indispensable consequence of such mechanism of the particle production, of the particle creation through the intermediate objects, which in the light of their creation mechanism should be treated as the excited states of the colliding particles. We called these states «generons» [10]. The generons behave themselves in passing through intranuclear matter as usual hadrons do it [11,12].

3.2. The Main Data from Experiments with Various Nuclear Targets at Various Incident Hadron Energies

In result of investigations of the particle production process in hadron-nucleon collisions [2,5,10—13], using intranuclear detectors [1], it has been obtained that:

The particle production process in nucleon-nucleon collisions goes through intermediate objects created first in a 2 → 2 endoergic collision reaction, $N_1 + N_2 \rightarrow G_1 + G_2$, decaying into finally observed particles and resonances. In the nucleon-nucleon collisions two such identical objects should be created because of identical conditions for both the nucleons. The average lifetime of the objects is [2] $\tau_G \gtrsim 10^{-22}$ s.

This particle production mechanism in hadron-nucleon collisions has been tested experimentally [10,14] in hadron-nucleus reactions at about 9 and 37.5 GeV/c momentum. Comparisons of predictions of the model [15], based on above presented mechanism of the particle generation in hadron-nucleon collisions, with the experimental data show the quantitative agreement [14].

3.3. Experimental Results of General Validity

Let us sum up the main results concerning the mechanism of the particle production process in nucleon-nucleon collisions; it concerns the mechanism of the hadron-nucleon collision process as well:

1. Particles are produced via intermediate objects created first in the 2 → 2 endoergic collision reactions [4,11].

2. The intermediate objects, called generons, decay into finally observed particles and resonances after this lifetime $\tau_G \lesssim 10^{-22}$ [10].

3. The jet structure [17], the large transverse momenta values, and the baryon number conservation are the indispensable results of the particle creation through intermediate objects [10,11].

4. In passing through intranuclear matter, generons lose their kinetic energy; the energy loss of the generons is similar to the energy loss of usual hadrons [12]. .

5. Generons may be treated as some sort of new hadrons through which all of the usual hadrons are generated; the generons seem to be in fact the hadrons in some excited states.

6. Generons represent the initial stage of the hadron production process.

4. THE MECHANISM OF THE HADRON-NUCLEON COLLISION PROCESS LEADING TO PARTICLE PRODUCTION

Let us state that a collision of two strongly interacting particles occurs when the distance d between their centers is smaller than the strong interaction range R_s which is as large as the diameter of the nucleon. The impact parameter d in the collisions should be

$$0 \lesssim d \lesssim R_s . \tag{8}$$

The particle production in a collision does not occur in any of the collisions, it takes place only at impact parameters near to 0, at $d \approx 0$ — at the central or head on collisions only, as it has been stated experimentally [2]. We call such colllisions the particle-producing collisions later. In such collisions the intermediate objects — generons — are formed first. The kinematics of the generon-producing collisions has been discussed in detail in our former works [2,11], especially in part III of the series [2] and in the analysis of the kinematics of jets [11].

4.1. The Qualitative Picture

So, in the particle-producing collisions of two high energy hadrons — of two nucleons, for example — two intermediate objects are created — two generons. Whether the generons occur and exist in some bound state or separately, the answer should be found in experiments; especially, appropriate experimental data should be the subject of special analysis in order to obtain information about the creation and behaviour of intermediate objects in the particle producing electron-nucleon, neutrino-nucleon, pion-pion, and similar collision reactions. For the nucleon-nucleon particle-producing collisions such analysis has been performed [2,11] — the generons seem to keep their individuality.

Generons decay then into resonances and particles after the lifetime [1,2,11] $\tau_G \lesssim 10^{-22}$ s. In the nucleon-nucleon collisions, two such generons are created — because of identical conditions for both the colliding nucleons.

4.2. Some Quantitative Relations

The existence of the generons should manifest itself in the definite kinematical relations for the secondary particles and for the groups of secondary particles observed finally in the particle-particle collision experiments. Special kinematical analyses of the experimental data, in particular on the nucleon-nucleon collisions leading to the particle production were performed [2,11]. The testable properties of the reactions, being the consequence of the generon existence and of the particle production mechanism presented above were obtained in our works [2,11,15], for experimental testing.

4.3. Crucial Observable Effects

Let some of the general effects be named here:

1. The appearance of the well-collimated spurts of particles, or jets, in the final state of the particle-producing collision reactions; predictions were given for this effect at various energies [11].

2. The produced particle multiplication R inside the nucleus, given usually as

$$R = \frac{\langle n \rangle_{hA}}{\langle n \rangle_{hp}} , \tag{9}$$

predicted on the basis of the mechanism of particle production through intermediate objects [2] describes appropriate experimental data quantitatively, with any free parameters[2]; $\langle n \rangle_{hA}$ is the average multiplicity or number of particles produced in the collision of a hadron h with a nucleus A, and $\langle n \rangle_{hp}$ is the average multiplicity of particles produced in hadron-proton collision at the same energy.

3. The intensity distributions of charged particles produced in hadron-nucleus collisions at above a few GeV momentum are reproduced quantitatively by the free-parameterless model [14,15], in terms of the data on the intensity distributions of charged particles produced in hadron-nucleon collisions [16] and on the target nucleus size and matter density distribution in it. The model is based on the particle production mechanism through intermediate objects.

4. At extremely high energies, when $E_h \to \infty$ one or two jet events will be observed; in the two-jet events the axes of jets are coplanar with the bombarding particle momentum vector.

5. Two-centra particle emission events at energies high enough should be observed.

5. EXPERIMENTAL TESTING OF THE MECHANISM OF THE PARTICLE PRODUCTION PROCESS PROMPTED EXPERIMENTALLY

In hadron-nucleon, in nucleon-nucleon collisions especially, particles are produced through intermediate objects formed first and decaying into observed «produced» particles and resonances after the lifetime $\tau_G \gtrsim 10^{-22}$ s; this particle-producing collision mechanism of two nucleons was prompted in experiments performed by means of the intranuclear detector — in studying the hadron-nucleus collision processes.

It would be desirable, therefore, to test this mechanism in the elementary hadron-nucleon and, first of all, in elementary nucleon-nucleon collisions. The experimental testing has been performed in our work, using large variety of appropriate experimental works; data from review papers, mainly written by M.Jacob [17], M.Miesowicz [18], R.Sosnowski [19], D.H.Perkins [20,21], J.Gierula [22] and others [23] were used.

It should be stated that none of the properties of the proton-proton collisions, reviewed in the papers contradict the picture of the particle production process prompted by our experiments and presented here [2,11,14].

6. CONCLUSIONS AND REMARKS

Now, when the investigations of the mechanism of the hadronic particle-producing collision processes, and of the nucleon-nucleon collision process first of all, were performed, and conclusive results were obtained, I am in the position to state: Particles are produced in hadronic collisions, and in nucleon-nucleon collisions in particular, through intermediate objects called generons — formed first in 2 → 2 type endoergic reactions and decaying into finally observed particles and resonances after the lifetime $\tau_G \lesssim 10^{-22}$ s.

This experimental fact should be taken into account in considerations about many topics of today particle and high energy nuclear physics, such as: Particle systematics, the large values of the transverse momenta of the produced particles, quark-gluon plasma searching and identification in nuclear collisions, physical meaning of the outcomes observed from collision reactions at various energies — from above pion production threshold up to the extremely high — in collider experiments and in cosmic ray experiments, physical foundation of the energy amplifiers for cleaner and inexhaustible nuclear energy production driven by a particle beam accelerator [27].

The mechanism of the particle production process revealed by means of the intranuclear detector throws new light on the physical outcomes observed in hadronic and nuclear collision experiments.

Really, many believe that the hadron constituents which often are identified with quarks or partons do not appear as such but materialize as hadronic jets [17,23], but the hadronic jet structure is naturally simple and indispensable consequence of the particle production mechanism prompted experimentally — by intranuclear detectors.

In my opinion, what is observed in the outcomes from hadronic and nuclear collisions are the decays of the quark or parton bags in highly excited states. It has been stated, some time ago [24], that in our experiments we observe the behaviour of the bags of quark or partons in their passage through intranuclear matter [12,24], the results presented in this paper support this statement.

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