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STUDY OF THE PARTICLE PRODUCTION PROCESS USING NUCLEAR TARGETS.

III. Effects Testable in Hadron-Nucleon Experiments, Nature of Intermediate Objects, Conclusion

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1. INTRODUCTION

In the study of the particle production process [1,2], using nuclear targets as detectors [3], results have been obtained which prompted to conclude that the particle production in hadron-nucleon collisions is mediated by intermediate objects created first; we have called them generons [2]. The many-particle final states observed in hadron-nucleon collisions are the outcome of the decays of the generons into commonly known resonances and particles [2]. In other words, in the nucleon-nucleon collision, for example, each of the colliding nucleons turns during a collision or interaction time from its normal state into some state of "pregnancy" - each is turned into generon, continues to move in its new state along a new course during its lifetime [2] $\tau \geq 10^{-22}$s, decays in flight [2] into usually observed particles and resonances, and finally reaches its initial state - nucleon.

It is reasonable to think that two identical generons should be created in any collision of two identical nucleons, because of identical conditions for both the colliding particles.

Some properties of the generons have been presented [2]. In particular, it is peculiar to them, if of kinetic energy high enough, to create such objects in collisions with downstream nucleons, when passing through massive atomic nuclei; usually generons decay in flight after having left the most massive target-nuclei [2].

The existence of generons should obviously manifest itself in the collisions of hadrons with free nucleons as well. In investigating of such collisions additional new and independent information about the properties of generons shall be obtained. The data on the generons provided both by the hadron-nucleus and by hadron-nucleon collision experiments may shed light on the nature and on the production mechanism of these objects and, therefore, on the particle production process in particle-particle collisions at all.

The subject matter in this work, being the third part in the series [1,2], is just to look for additional evidences for the existence of generons, in analysing various data on particle-particle high energy inelastic collisions, mainly on the nucleon-nucleon collisions and to try to obtain this way some information about the nature and production mechanism of the generons.

In describing our searches we start with a short presentation of the data analysis procedure, thereupon we collect adequate essential experimental facts which an additional conclusion that generons exist may be based on, later we discuss the nature and production mechanism of the generons. At the end of this part, we consider shortly what follows from the existence of the generons for our knowledge of the nucleon structure.

2. DATA ANALYSIS PROCEDURE

We intend to consider now how it could be possible to "observe" generons in experiments in which high energy particle-particle collisions leading to the particle production are studied. In doing it, we hope to obtain a procedure in future experiments to follow in attempts to study the generon production mechanism.

The mediation of an object in the production of particles and resonances in high energy particle-particle collisions, in the proton-proton collisions for example, should manifest itself in many various characteristics of any particle-producing collision event. But only some of the observable characteristics may provide appropriate information. The problem arises, therefore: where the manifestation of the generon creation may be looked for?

In order to select proper characteristics, let us present, in fig.1, the scheme of the particle production process provided by our experiment [1,2]. The production mechanism has been studied, using nuclear targets as detectors [3] only in the hadron-nucleon collisions as yet.

One can see, from fig.1, that the particle-producing nucleon-nucleon collision process can be treated in its early stage - before the decay of the generons - as the two-particle final state scattering of the type $a_1 + a_2 \rightarrow a_3 + a_4$, or $2 \rightarrow 2$ scattering [4,5], where a_1 and a_2 are the colliding particles, and a_3 and a_4 denote the reaction product particles - the generons in the case under consideration.

Suppose at first that we are able to observe immediately the generons produced before their decays and let us discuss the relation between the variables expressing the state of motion of the colliding particles and the produced generons. After that we will discuss the connections between the variables describing the state of motion of the generons and the products of their decays - the finally observed particles and resonances; some of these connections should reflect obser-

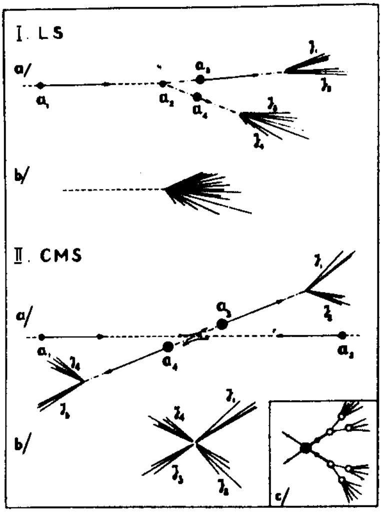

Fig.1. Scheme of the particle production process in the proton-proton collision, prompted by the experiment[1,2] in which target-nucleus is used as a detector[3]: I. In the laboratory system, LS; a) an event as it is developed in the time; b) an event as it is seen in a detector. II. In the centre-of-momentum system, CMS; a) an event as it is developed in the time; b) an event as it is seen in a detector; c) the simplified scheme of the process. a_1 and a_2 the colliding particles, a_3 and a_4 the reaction product particles, ● - proton, ⊙ - generon, - - - - trajectory of the proton, -·-·- - trajectory of the generon, ——- trajectories of the produced particles, arrows - impulses of the protons and generons, J_i ($i = 1,2,3,4$) - jets.

vable connections between the variables describing the colliding particles and the finally observed reaction product particles.

As is well known, the kinematics of the $2 \to 2$ scattering is completely determined by the two conservation relations between energies and momenta of the particles taking part in the reaction. It is widely discussed in any of existing monographs, for example in the written by A.M.Baldin, V.I.Goldanski and I.L.Rosenthal[4], E.Byckling and K.Kajantie[5], excellent review, containing kinematical relations just applicable in the case under discussion here, has been written by K.G.Dedrick[6]. It was not found necessary to rewrite many expressions that could be found in these works[4-6] and in works of many other authors referred to in them. We limit ourselves here to a qualitative description of the kinematical properties of the generons produced in the $2 \to 2$ type collisions.

As usually, we are interested in a laboratory frame, or system, of references, LS, and the centre-of-momentum system, CMS, in the latter the vector sum of momenta vanishes. The dynamical variables of a particle expressed in the CMS will be distinguished by attaching asterisks; they will be left without asterisks when the LS is being considered.

Following symbols will be used for variables expressing the state of motion of the i-th particle and for a description of the $2 \to 2$ collision ($i = 1,2$ are used for the colliding par-

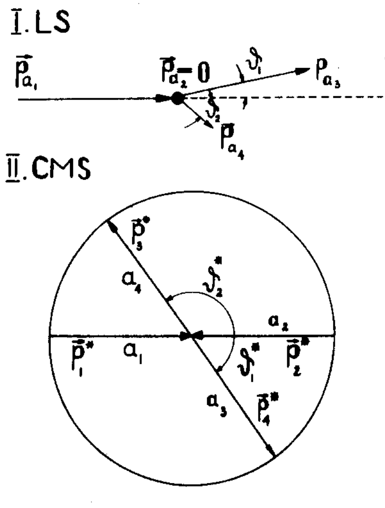

Fig.2. The scattering angles θ in the reaction $a_1 + a_2 \to a_3 + a_4$, where a_1 and a_2 the colliding particles, a_3 and a_4 the reaction product particles: I. In the LS, II. In the CMS; the CMS quantities are denoted by asterisks. The angles θ_1 and θ_2 are related in a complicated manner; the angles θ_1^* and θ_2^* are simply related. $\theta_1^* \equiv \theta_3^*$, $\theta_2^* \equiv \theta_4^*$. θ_3^* and θ_4^* are not denoted here.

ticles, $i = 3,4$ are for the two final state particles; in the LS $i = 1$ is used for the target particle) : $P_i = (E_i, \vec{p}_i c)$ – the four-momentum vector, E_i – the total energy of i -th particle, $\vec{p}_i$ – the space part of the P_i, c – the velocity of light, p_i – the magnitude of $\vec{p}_i$, $\sqrt{s} = \sqrt{(P_1 + P_2)^2} = \sqrt{(P_3 + P_4)^2}$ the total energy of the reaction, $t = (P_1 - P_3)^2 = (P_2 - P_4)^2 = M_1^2 + M_3^2 - 2E_1E_3 + p_1 p_3 c^2 \cos\theta_{13}$ the invariant momentum transfer squared, $M_i = m_i c^2$ the rest energy, m_i – the rest mass, $\lambda(s, M_1^2, M_2^2) = \{s - (M_1 + M_2)^2\}\{s - (M_1 - M_2)^2\}$ – kinematical function[6], $g_i = (\beta E_i^*)/(cp_i^*) = \beta/\beta_i^* = v/v_i^*$, v – the magnitude of the velocity of the moving frame of reference, v_i^* – the magnitude of the velocity of the i -th particle, E_{ik} – the kinetic energy of the i -th particle, $Q = (M_1 + M_2) - (M_3 + M_4)$ – the "Q-value", $E_{th} = -Q(M_1 + M_2 + M_3 + M_4)/2M_2$ – the bombarding particle energy threshold for the process as is seen on choosing the energy available in the center of mass $\sqrt{s}$ to be just equal to $(M_3 + M_4)$, $\gamma = 1/\sqrt{1 - \beta^2}$ is the Lorentz factor.

In the case of $2 \to 2$ reaction the phase space defined for the fixed $\sqrt{s}$ is two-dimensional and is parametrized, for example, by the scattering angle θ_3, fig.2, and one angular variable ϕ describing rotation around the projectile course. The latter is trivial leaving one essential final state variable in the present case. The total number of essential variables is two: one fixes the total energy; the other, the scattering angle. As energy-type variables E_i, P_i and $\sqrt{s}$ are usually used; as the frame-dependent angle-type variables the angle θ_3 between $\vec{p}_1$ and $\vec{p}_3$ either in the CMS or in the LS are used, fig.2. The invariant momentum transfer squared is the angle-type invariant variable.

The 2→ 2 scattering is kinematically extremely simple in the CMS, since energy- and angle-dependences are completely decoupled. The magnitudes of the space parts of the four momenta are:

$$p_1^* = p_2^* = \frac{\lambda^{1/2}(s, M_1^2, M_2^2)}{2\sqrt{s}},$$
$$p_3^* = p_4^* = \frac{\lambda^{1/2}(s, M_3^2, M_4^2)}{2\sqrt{s}}, \qquad (1)$$

while θ_3^* gives all other angles, fig.2.

The relations in the LS are more involved. Let us assume that $\sqrt{s}$ is fixed so that the initial state $P_1 + P_2$ is fixed, fig.2. Then, any of the four final state variables p_3, θ_3, p_4, θ_4 determines the remaining three. The most interesting relations, those relating p_3 and θ_3, p_4 and θ_4, θ_3 and θ_4, are discussed in any monograph/4,5/ and review/6/.

The kinematics of the final state particles is discussed usually in terms of the quantities g_i, where $i = 3,4$; the methods involved are discussed, for example, by K.G.Dedrick/6/ and by R.M.Sternheimer/7/.

In order to determine the general characteristics of the kinematics of a reaction which yields two particles in the final state, it is neseccary to make only a few brief computations and enter to the proper section of figs.6-9 in review of K.G.Dedrick/6/. Given M_1, M_2, M_3 and M_4, the sums (M_1+M_2) and (M_3+M_4) are first calculated and compared. In the case under discussion, when generons are created of the rest energies M_3 and M_4, we have always $M_3 + M_4 > M_1 + M_2$ and $M_3 > M_1$ and $M_4 > M_2$; it is endoergic reaction, when $Q < 0$. To this case correspond the characteristics of the Lorentz transformations presented in fig.8a in the work of K.G.Dedrick/6/. We present appropriate characteristics, per analogy, for the case considered here, in fig.3; one can see, fig.3a, that g_3 and g_4 both are larger than 1. To these values of g_i correspond the relation between θ_i and θ_i^*, fig.3b, and the relation between θ_3 and θ_4, fig.3c; the relation between θ_i and E_{ki} is shown in fig.3d. The graphical construction for adequate two-particle final state is shown in fig.3e.

It can be concluded, from the kinematics of the two-particle final state endoergic reaction, corresponding to the generon creation, fig.3, that: The emission angles θ_3 and θ_4 of the generons produced are limited in the LS, $\theta_3 < 90°$ and

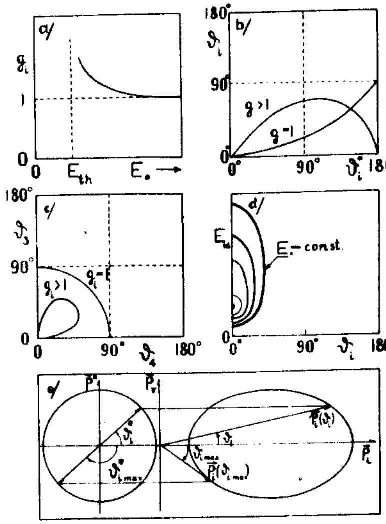

Fig.3. Properties of the kinematics of the two-particle final state for endoergic relation $Q=(M_1+M_2)-(M_3+M_4)<0$; $M_1+M_2<M_3+M_4$, when $M_1<M_3$ and $M_2<M_4$. All subscripts "i" arbitrarily refer to the $2\to 2$ reaction product particles, $i=3,4$, M_1, M_2, M_3, M_4 are respectively the rest energies of the bombarding particle, the target particle and the two reaction product particles; E_{ki} and θ_i are, respectively, the laboratory kinetic energy and laboratory reaction product particle emission angle, θ_i^* is the corresponding centre-of-momentum angle; $g_i \equiv \frac{\beta E_i^*}{P_i^* c} = \frac{\beta}{\beta_i^*} = \frac{v}{v_i^*}$ is the angle transformation parameter, where $\beta = v/c$ and $\beta_i^* = v_i^*/c$, v and v* are, respectively, the magnitude of the velocity of the i-th particle in the CMS, c is the light velocity, E_i^* and P_i^* are the total energy and the momentum of the i-th particle in the CMS. a) The dependence of the quantity g_i on the bombarding particle energy E_0; $E_{th}=[(M_3+M_4)^2-(M_1+M_2)^2]/(2M_2)$ is the bombarding particle energy threshold for the reaction. b) The relations between θ_i and θ_i^* for $g_i>1$ and $g_i=1$, $i=3,4$. c) Corresponding emission angles θ_3 and θ_4 of the two reaction product particles when both are produced in the same $2\to 2$ collision, if: $g_3>1$ and $g_4>1$; $g_3=1$ and $g_4=1$. d) The kinetic energy E_{ki} in dependence on θ_i when $g_i>1$, for both $i=3$ and $i=4$; larger values of E_0 are represented by heavier solid lines. e) Graphical construction for one case of the two-particle final state reaction, when $g_i>1$. P_L - longitudinal, P_T - transverse momentum.

$\theta_4<90°$; the values of these angles are expressed by the relations:

$$\mathrm{tg}\,\theta_3 = \frac{\sin\theta_3^*}{\gamma(\cos\theta_3^*+g_3)}, \quad \mathrm{tg}\,\theta_4 = \frac{\sin\theta_4^*}{\gamma(\cos\theta_4^*+g_4)}, \qquad (2)$$

where $0°\le\theta_3^*\le 180°$ and $0°\le\theta_4^*\le 180°$; $\mathrm{tg}\,\theta_{i\,max}=\gamma^{-1}(g_i-1)^{-1/2}$, for $i=3,4$, what means that at $E_0\to\infty$, when $g_i\to 1$ and $\gamma^{-1}\to 0$, generons can be emitted at the angles $\theta_{i\,max}=90°$.

Definite double-valued angle relationship exists between θ_3 and θ_4; it is useful in coincidence experiments, when it is important to know θ_3 at a given value of the θ_4, or θ_4 at a given value of θ_3, fig.3c.

Definite double-valued relationship exists between E_{ki} and θ_i, $i=3,4$; it can be useful in coincidence experiments.

We have so far treated kinematical characteristics of the generon-producing $2 \to 2$ endoergic reaction. But, generons are indetectable directly, they decay in flight [2] into particles and resonances observed usually in experiments. The behaviour of the decay products depends on the kinetic energy E^*_{kG} of the generon produced and of the mode of the decay. This energy E^*_{kG} is in the CMS of the same order as that of the incident particle, if E^*_0 is high enough. In fact, it is known, from experiments, that at energies high enough - at more than some of tens GeV - only a very small portion ΔE^*_k of the kinetic energy E^*_k of the bombarding particle is transferred into the rest energy $M = \sum_i M_i = \Delta E^*_k$ of the produced particles and resonances, $i = 1,2,...$

It is not excluded that some number of generons decay into two decay-products: two particles, two resonances, or a particle and a resonance. The cases are kinematically determined completely; each of the two generons produced, of the rest energies M_{G1} and M_{G2}, decays in flight obeying the two-particle final state kinematics: $M_{G1} \to M'_{11} + M'_{12}$ and $M_{G2} \to M'_{21} + M'_{22}$, where M'_{i1} and M'_{i2} $(i = 1,2)$ are the rest energies of the i-th generon decay products; decays take place in the LS - the generons fly in the CMS, where the collision is considered to be taking place. The characteristics of the Lorentz transformation depend on the angle transformation parameter g_i which depends on the decaying particle kinetic energy E_{kG}, fig.4. When $E_{kG} > E_c$, where $E_c = \frac{1}{2}[(M_G - M'_2)^2 - M'^2_1]/M'_2$ and M'_1 and M'_2 are the rest energies of the generon decay products, $g_i > 1, (i=1,2)$. In this case, $g_i > 1$, the decay angle θ'_{12} - the angle between the decay product emission directions - is limited and always $\theta'_{12} < 90°$.

Now we can give the answer to the question formulated at the beginning of this section. 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. In general, special analysis of the existing experimental data on the particle-particle collisions, in particular on the nucleon-nucleon particle-producing collisions, should be performed and new special experiments must be done. Now some of the testable properties of the reactions, being the consequence of the existence of generons and of the particle production mechanism presented in section 1, may be confronted to the existing experimental data.

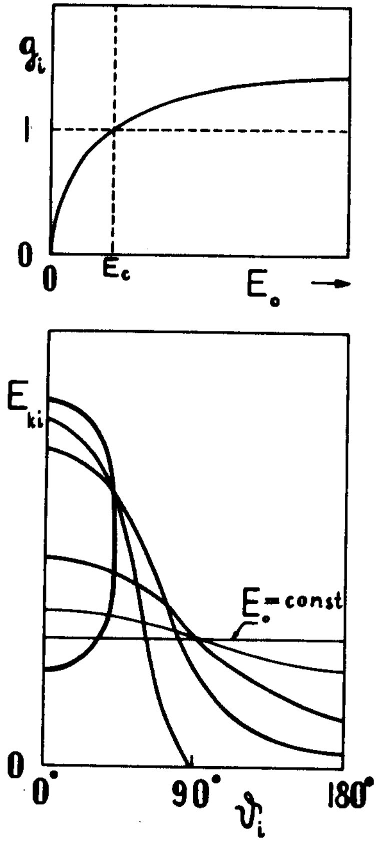

Fig.4. Properties of kinematics of the two-particle final state for decay-in-flight reactions. The subscript "i" arbitrarily refer to the observed reaction product particle. The quantity g_i is the angle transformation parameter. The quantity $E_c = [(M_1 - M_4)^2 - M_3^2]/(2M_4)$, where M_i for $i = 1,3,4$, are the rest energies of the decaying particle and of the decay product particles correspondingly. E_0 is the decaying particle energy, E_{ki} is the kinetic energy of i-th decay product particle. θ_i is the angle of emission of the i-th particle in the LS, $i = 3,4$.

3. QUALITATIVE PREDICTIONS FOR AN EXPERIMENTAL TESTING IN THE PROTON-PROTON COLLISIONS

This section is devoted to the description of expected pictures which may be observed in the particle-producing proton-proton collisions, if the generons mediate the particle production. The expectations are based on the results of considerations from foregoing section.

The picture is to be observed in an experiment depends on the frame of reference in which observations will be carried out. Two kinds of the frames will be used here: the CMS and the LS.

3.1. The Picture Expected in the CMS

In the CMS the picture expected is extremely expressive and clear in its simplicity. Suppose, we are able to detect all the particles emerged in the final state - electrically charged and neutrals. The existence of generons and, consequently, the particle production scheme prompted by our experiment [1,2], fig.1, led to the following general experimentally testable properties of the proton-proton collision events in which many particles are observed in the final state:

1) Groups of 2,3,4,..., n hadrons, ejected from the area within which the collision can be located, appear; usually such groups of hadrons are called "jets". More adequate tentative definition, used in Jacob's work [8], in generalizing from the basic properties of hadron production, will be applied in this paper: jet is defined as a set of hadrons with limited transverse momenta, typically $\langle p_T \rangle \approx 0.35$ GeV/c, with respect to the global momentum $\vec{p}_j$ of the set, and with longitudinal momenta $\vec{p}_L = x\vec{p}_j$ distributed in a scaling way[9], the x distribution being independent of $\vec{p}_j$. This definition is adequate just for the case under consideration. In fact, generons decay into resonances and particles, but resonances decay with observed Q values limiting the energy of the daughter particles in the resonance rest frames to values of the order of 0.35 GeV. The line on which $\vec{p}_j$ lies we will call the jet axis.

2) Collision events consisting of 2,3,4,... jets can be met, depending on the kinetic energy E_k of the colliding particles: a) At the projectile energy E_k of the value near the threshold E_{thG} for the generon production, the generons produced can decay into single particles or into resonances and particles and correlated groups of particles cannot be observed visually, without special analysis; the trajectories of the particles observed in the final state are isotropically distributed. b) At higher values of the kinetic energy E_k of the incident particles, but much smaller than the extremely high energies E_e, say $E_e \approx 2000$ GeV in the LS, at $E_{thG} \ll E_k \ll E_e$, jets start to be visible and simply detectable, because of the kinematical transformations which undergo the decay products of the generon decays - the resonances and particles. When all the particles finally produced are observed, the vectors $\vec{p}_{ji}$ characterizing the total momenta of an i-th jet can be combined in such two sums $\vec{p}_{jI}$ and $\vec{p}_{jII}$, where $\vec{p}_{jI} = \sum_{i} {}_{I} \vec{p}_{ji}$ and $\vec{p}_{jII} = \sum_{i} {}_{II} \vec{p}_{ji}$, that the vectors $\vec{p}_{jI}$, $\vec{p}_{jII}$, $\vec{p}_{a1}$ and $\vec{p}_{a2}$ are coplanar. c) At higher energies of the bombarding particles, when $E_k \to \infty$, only two-jet events are expected to occur; jets with the axes $\vec{p}_j$ at various angles to the bombarding particle course, $0 \le \theta^*_{p_j} \le 180°$ can be met; it is useful to emphasize that two-jet events with large total momenta p_j perpendicular to the colliding particle course

are expected. In all such two-jet events, at $E_k \to \infty$, the vectors $\vec{p}_{jI}$, $\vec{p}_{jII}$, $\vec{p}_{a1}$ and $\vec{p}_{a2}$ are coplanar.

3) Collision events with particles in the final state of the transverse momentum values $p_T \gg 0.35$ GeV/c will be observed; in some cases, the values can be of the order of the bombarding particle momentum $p^*_{a1} = p^*_{a2}$.

4) Resonances should be observed in jets, in predominant portion of events at energies high enough to produce the resonant states.

3.2. The Picture Expected in the LS

In the LS the picture is not so simple and expressive; its simple correspondence to the particle production mechanism is distorted due to the Lorentz transformation from the CMS to the LS. But, some of effects observed in the CMS are observable in the LS as well:

1) At the kinetic energies E_k of the bombarding particles of values near to the threshold for the ġeneron production the trajectories of particles appeared in the final state are not isotropically distributed; particles emitted into backward direction are met.

2) The portion of particles emitted into backward hemisphere decreases with the bombarding particle kinetic energy E_k increase; jet structures may be observed.

3) At the bombarding particle kinetic energy high enough, $E_k \gg E_{thG}$, not any event can be met with particles emitted into backward hemisphere; jet structures can be seen.

4) In both the cases, numbered above as 2 and 3, in some events - when all of the produced particles are observed, such two sums $\sum_{i} {}_{I} \vec{p}_{ji} = \vec{p}_{jI}$ and $\sum_{i} {}_{II} \vec{p}_{ji} = \vec{p}_{jII}$ can be completed that the vectors $\vec{p}_{jI}$, $\vec{p}_{jII}$, and $\vec{p}_{a1}$ are coplanar, where $\vec{p}_{a1}$ is the momentum of the bombarding particle. Two centers of the particle emission can be, therefore, distinguished this way.

5) At extremely high energies, when $E_k \to \infty$ 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.

6)' Particles appearing in the final state with the transverse momentum $p_T \gg 0.35$ GeV/c will be met at any energy $E_k \gg E_{thG}$.

Ending this section, it should be indicated that simple relations can be written for the total electric charge of the jets observed.

4. EXPERIMENTAL TESTING OF THE QUALITATIVE PREDICTIONS

Some only of a large variety of experimental works, in which particle production mechanism is studied, contain the data adequate for a direct comparison with some of the predictions presented in foregoing section.

Data from review papers, mainly of the written by M.Jacob[8], M.Miesowicz[10], R.Sosnowski[11], D.H.Perkins[12,13], J.Gierula[14] will be used here. Some of earlier original papers[15], which the reviews have been based on, and corresponding works recently made[16] will be taken into account here, as well.

The comparison presented here is fragmentary, qualitative, and very rough only. We limit ourselves to a presentation of adequate essential experimental facts; we do it dividing the total material into two parts: a) the data from the colliding beam experiments - the ISR data, b) the data from other experiments.

4.1. ISR Data

The information from ISR is mainly at $\sqrt{s}$ =53 GeV; first short information about the ISR operation at $\sqrt{s}$=540 GeV, and first photograph of an event has been published just recently[16].

The general property of the proton-proton collision events one can state, in analysing results from many experiments[8,11,15,16], is: When two protons collide head on, the emitted particles are almost always confined to two narrow cones centered on the axis defined by the two colliding beams. Occasionally, however, particles emerge from the point of impact roughly perpendicular to the beam axis; the particles are generally organized into well-collimated spurts of particles which have been named jets; four jet structures have been found.

The along-beams jets in the four-jet events are called usually the spectator jets, one of the jets detected at a large angle to the beam axis is called the trigger jet, the opposite-side jet is called the away jet.

As concerns the four-jet events, it has been found that[11]:

a) The spectator jets are present in the collisions with a large transverse momentum object produced; the spectator jets do not follow exactly the line of flight of incoming protons but deviate slightly in the away direction. b) Trigger jets and away jets do exist; the away jet transverse momentum does not balance that of the trigger jet. c) A rather high rate of the resonance production in jets is observed. d) The average transverse momentum of jet fragments with respect to the jet axis is $\langle p_T \rangle \approx 0.5$ GeV/c, this value does not depend on the momentum of the jet.

4.2. Other Experimental Data

The particle production mechanism in proton-proton collisions has been studied in various energy regions with the help of a variety of experimental techniques /10,12-14/.

More than twenty years ago, following facts were well known to physicists/10/: a) The independence of the average value of the transverse momentum p_T of secondary particles of the primary energy, $\langle p_T \rangle \approx 0.4$ GeV/c. b) In the CMS of the collision, the emission of secondary particles is anisotropic; particles are collimated in the direction of the motion of the colliding nucleons. c) At an energy of about 1 TeV, in the LS, produced particles often form two groups which can be seen in the angular distribution in the CMS of the colliding nucleons; the angular distribution can be represented by a superposition of two Gaussian distributions; the dispersions of these distributions correspond to isotropic emission from two centers moving in opposite directions along the axis of the collision in the CMS /10,17/.

On examination of individual events, one sees the two-maxima effect in a large portion of the angular distributions/18/. It was shown that, if the cases in which the cones of particles are well separated are analysed, the particles belonging to these cones could be considered as being emitted isotropically in their own rest system/10/. On the other hand, events of relatively weak anisotropy are observed fairly often, which none-the-less exhibit an absence of tracks around 90° in the CMS; the dispersions of each maximum taken separately are lower than for the isotropic distribution. As one of factors which could influence the isotropy T.Coghen adduces the possibility of non-collinear ejection of the centres of particle emission/19/. This possibility was investigated by Z.Czachowska et al./20/ in studying the azimuthal angular distributions, from the point of view of non-collinear emission of the centres of emission of the jet particles/10/. A deviation from isotropic distribution of azimuthal angles was found in a group of events in the energy region of several hundreds GeV, but no deviation was found for events at higher energies.

4.3. Comparison of the Experimental Facts with the Qualitative Predictions

It should be stated that none of properties of the proton-proton collisions, reviewed in foregoing section, contradict the picture of the particle production process prompted by our experiment[1,2]. The well and long since, starting from the observations of S.J.Lindenbaum and R.M.Sternheimer[21], known the two-centre particle emission mechanism can be treated just as an experimental support for our picture. The existence of the jet structures and possible emission of jets non-collinearly with the collision axis supports this picture as well.

Four-jet events exist; they should exist in fact at some incident hadron energies. The lack of the balance of the trigger- and away-jet momenta, and a slight deviation of a spectator jet from the line of flight of incoming protons may be regarded as additional supports. Probably, the balance should take place between total momenta of pairs of jets: the total momentum of one of the spectator jets and the trigger jet, and the total momentum of one of the spectator jet and the away jet.

The observation of the four-jet events at $\sqrt{s} = 53$ GeV and the observations of the two- or one-jet events only at higher energies, of about 100 TeV in the LS, can be interpreted as an indication that the jet structure may depend in fact on the energy of the colliding protons.

5. THE NATURE OF THE INTERMEDIATE OBJECTS

In this section we consider briefly the nature of the generons. We look first for similar objects in works of many authors where the particle production process has been analysed.

Many of physicists working on the problem of particle production were content to consider that the phenomenon observed at higher energies, at about 1 TeV, could be described by statistical hydrodynamical theories[22-26]. A common feature of these theories is that two high energy nucleons form after collision a single volume of highly concentrated energy which emits mesons. Such picture does not correspond to that obtained in our experiment[1,2]; a single volume formed from two interacting nucleons cannot behave itself as a generon does it in traversing nuclear matter. Moreover, more and more facts, presented in section 4, have been established which are inconsistent with the above-mentioned theories[10].

In 1958 the phenomenological "two-centre" model[10,17,27,28], which now is called[27] the "fireball" model, was proposed on a purely experimental basis for the description of these facts.

In this model: "After the collision of two nucleons of very high energy in the CMS the nucleons carry away a large fraction of the primary energy and are not deflected strongly from their primary directions. Two fireballs are produced which move behind the nucleons with lower velocities and also approximately along the collision axis..... Then the short-living fireballs decay isotropically in their own rest frames emitting mesons with an average energy of about 0.5 GeV"/10/. It is not found necessary to ascribe such nature to the generons; we do not have an experimental arguments to think that generons are consisting of the groups of mesons separated from nucleons. Moreover, generons behave themselves in a different way, in passing through nuclear matter - they can produce new generons in collisions with the downstream nucleons/2/.

The appearance of many particles in result of the nucleon-nucleon collisions has been discussed, in a different and original way, by V.F.Weisskopf and expressed clearly in his reviews/29-31/. The particles produced by the great accelerators can be regarded as a spectrum of excited states that decay to a few ground states. As concerns the particle-nucleon collision: "When a nucleon is hit by a particle of very high energy, it seems to behave somewhat as an atom or a nucleus does at considerably lower energy. The nucleon can be excited to a number of higher quantum states. After being excited it sometimes falls back to its original state with the emission of light quanta or lepton pairs, but in most cases, when the excitation is high enough, the emission consists of energy quanta of an unusual type: the mesons.... High energy physicists often refer to these excited states as "new elementary particles". I have felt for some time that it is more logical to consider them as higher quantum states of the nucleon, since they are very short-lived and revert to an ordinary proton or neutron"/30/.

Generons produced in nucleon-nucleon collisions can be regarded as such excited nucleons. In this particular case the term "baryon" introduced for the nucleon excited state by V.F.Weisskopf/30/ corresponds to our term "generon". But, we shall use later the most wide term "generon" because we hope our picture of the particle production process will be applicable for the collisions of any other particles, not only of nucleons.

In such a meaning, generons are excited states of the matter which exists usually in a kind of a few ground states; such excited states can behave themselves in many cases, in passing through nuclear matter, as the ground states do it.

A deeper insight into the nature of generons may be achieved in studying the inner structure of their ground states -

of the nucleons in particular. The experimental information about a complex internal structure of nucleons, consisting of pointlike entities - partons [32] or quarks [33,34], obtained in the SLAC experiments reviewed by H.W.Kendall and W.K.H.Panofsky [35] should be analysed from this point of view.

6. CONCLUSION AND REMARKS

In result of our investigations of the particle production mechanism, using nuclear targets as detectors and analysing the properties of the nucleon-nucleon collision process, it can be stated that the existence of the objects - generons - mediating the particle production should be postulated. We are inclined to think these objects, with the properties described in parts I and II of this work, exist in fact in the nature and, therefore, the particle-producing hadron-nucleon collisions may be treated in their early stage as $2 \to 2$ endoergic reactions.

The discovery of the generons can be regarded as an experimental support for the V.F.Weisskopf concept of the nature of the baryons [30].

In the light of the result obtained, new scheme of the large transverse momentum processes in nucleon-nucleon collisions, fig.1 - right corner low, should be used in attempts to apply the four-jet events for nucleon structure studies [8]; this scheme is testable experimentally.

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REFERENCES

1. Strugalski Z. JINR, E1-81-576, Dubna, 1981.
2. Strugalski Z. JINR, E1-81-577, Dubna, 1981.
3. Strugalski Z. JINR, E1-80-548, Dubna, 1980.
4. Baldin A.M., Goldanski V.I., Rosenthal I.L. Kinematics of Nuclear Reactions, Pergamon Press, Oxford, 1961.
5. Byckling E., Kajantie K. Particle Kinematics. John Wiley & Sons, London, 1973.
6. Dedrick K.G. Rev.Mod.Phys., 1962, 34, p.429.
7. Sternheimer R.M. Phys.Rev., 1954, 93, p.642.
8. Jacob M. Phys.Scripta, 1979, 19, p.69; Sci.American, 1980, 242, p.46, No.3.
9. Feynman R.P. Phys.Rev.Lett., 1969, 23, p.1415.
10. Miesowicz M. Progr. in Elem.Part. and Cosmic Ray Phys., 1965, 10, p.101.
11. Sosnowski R. Proc. 19th Int.Conf.High Energy Phys., Tokyo, 1978, p.693.
12. Perkins D.H. Progr.in Elem. Part. and Cosmic Ray Phys., 1960, 6, p.259.

13. Perkins D.H. Proc. Int. Conf. on Theor. Aspects of Very High Energy Phenomena, 1961, CERN, 61-22, p.90.
14. Gierula J, Fortschr.d. Phys., 1963, 11, p.109.
15. Jets in High Energy Collisions. Phys.Scr., 1979, vol.19, No.2.
16. The Staff of the CERN Proton-Antiproton Project. First Proton-Antiproton Collisions in the CERN SPS Collider. Phys.Lett., 1981, 107B, p.306.
17. Ciok P. et al. Nuovo Cim., 1958, 8, p.166; 1958, 10, p.741.
18. Rybicki K. Nuovo Cim., 1967, 49, p.233.
19. Coghen T. Inst.Nucl.Res., Rpt. 552/VI, Warsaw, 1964.
20. Czachowska Z., Jurak A., Linscheid A. Inst.Nucl.Res., Rpt. 788/VI, Warsaw, 1967.
21. Lindenbaum S.J., Sternheimer R.M. Phys.Rev., 1957, 105, p.1874; 1957, 106, p.11/7.
22. Wataghin A. Phys.Rev., 1948, 74, p.975.
23. Heisenberg W. Kosmische Strahlung. Springer Verlag, 1953, p.48.
24. Fermi E. Phys.Rev., 1951, 81, p.683; 1953, 92, p.452; 1954, 93, p.1434.
25. Landau L.D. Izv.AN SSSR, 1953, 17, p.51.
26. Koba Z. Fortschr.d.Phys., 1959, 7, p.1.
27. Cocconi G. Phys.Rev., 1958, 111, p.1699.
28. Niu K. Nuovo Cim., 1958, 10, p.994.
29. Weisskopf V.F. Science, 1965, vol.149, No.3689, p.1181.
30. Weisskopf V.F. Sci.Am., 1968, vol.218, No.5, p.15.
31. Weisskopf V.F. Physics in the Twentieth Century, The MIT Press, Cambridge, 1972.
32. Feynman R.P. In: High Energy Collisions, Third Int.Conf., State University of New York, Stony Brook, 1969 (eds. C.N.Yang, J.A.Cole, M.Good, R.Hwa, J.Lee-Franzini). Gordon and Breach, New York, 1969.
33. Bjorken J.D., Paschos E.A. Phys.Rev., 1969, 185, p.1975.
34. Kuti J., Weisskopf V.F. Phys.Rev., 1971, D4, p.3418.
35. Kendall H.W., Panofsky W.K.H. Sci.Am., 1974, 224, June, p.60.

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