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OBSERVATIONS AND DETERMINATIONS OF THE HADRON MEAN FREE PATHS FOR PARTICLE-PRODUCING COLLISION REACTIONS IN INTRANUCLEAR MATTER

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Наблюдения и определение средних свободных пробегов адронов до генерирующих частицы реакций столкновения во внутриядерной материи

В адрон-ядерных столкновениях рождаются частицы — в основном π-мезоны — через промежуточные объекты G, распадающиеся на наблюдаемые «рожденные» адроны после выхода из материнского ядра. Наблюдаются и средние свободные пути во внутриядерной материи этих промежуточных объектов до столкновений, ведущих тоже к рождению адронов. Измерения позволяют определить их значения $\langle \lambda_G \rangle_{GN} = 5 \pm 1$ (протонов/S), где $S = \pi R_s^2 \approx 10{,}3$ фм^2, $R_S \approx D_0$; R_s — радиус действия ядерных сил, D_0 — диаметр нуклона. Значение $\langle \lambda_G \rangle_{GN}$ для рождения частиц промежуточным объектом G в столкновении с нуклоном N такое же, как для столкновений налетающего адрона с нуклоном во внутриядерной материи.

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Observations and Determinations of the Hadron Mean Free Paths for Particle-Producing Collision Reactions in Intranuclear Matter

In hadron-nucleus nuclear collisions, particles — mainly pions — are created through intermediate objects decaying into usually observed «created» hadrons after having left the parent nucleus. The mean free path of the intermediate objects for particle-producing collisions in intranuclear matter with downstream nucleons is observed as well; it is a measurable quantity. The measured quantity is $\langle \lambda_G \rangle_{GN} = 5 \pm 1$ (protons/S), where $S = \pi R_s^2 \approx 10.3$ fm^2, R_s is the strong interaction range as large approximately as the nucleon diameter $D_0 \approx R_S$ is. This value is practically as large as the mean free path for particle-producing collision reaction of pions in intranuclear matter.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 1996

1. INTRODUCTION

As it follows from our experimental investigations of the hadron-nucleus nuclear collision reactions mechanism [1—15], the particle (hadron) creation process goes on the background of the incident hadron passage through intranuclear matter. It is localized along the projectile course in intranuclear matter within the cylindrical region with the radius R_S as large as the strong interaction range, centered on the hadron course.

The particle (hadron) production in a hadron-nucleus collision starts in result of the particle-producing collision of the incident hadron with one of the downstream nucleons in intranuclear matter. The particle production is mediated by intermediate objects created first in a $2 \to 2$ type endoergic head-on reaction in the early stage of the collision. The intermediate objects, we called them «generons», use to move predominantly along the incident hadron course and behave themselves in intranuclear matter as usual hadrons do it [16].

The incident hadron mean free path in intranuclear matter is a measurable quantity, and it has been determined, for the particle-producing collisions, in fact [17,18].

But intermediate objects (generons) use to pass through layers of intranuclear matter within the target-nucleus, and are leaving it and decaying outside the parent nucleus into usually observed «produced» particles. In target nuclei massive enough, the intermediate objects may collide with a next of the downstream nucleons and create new intermediate objects or generons, the linear intranuclear cascade of the generons may develop along the incident hadron course in intranuclear matter, this way. Some mean free path $\langle \lambda_G \rangle_{GN}$ in intranuclear matter, for generon-nucleon particle creating collision should exist, and it may manifest itself in some of hadron-nucleus collisions outcomes — in some of its characteristics.

Hypothetically — in our works, the generons have been treated by us as some kind of usual hadrons.

The subject matter here is an observability and measurability of the generon mean free path in intranuclear matter. It is desirable the quantitative determination of this quantity, which is denoted here for the generon-nucleon collision in intranuclear matter as $\langle \lambda_{GN} \rangle$ and expressed in (protons/S), where $S \approx \pi R_h^2 \approx \pi D_0^2 \approx$ ≈ 10 fm^2; $R_h \approx D_0$ is the nucleon diameter.

Let start the description of our results with some heuristic considerations.

2. HEURISTIC CONSIDERATIONS

Suppose firstly that a hadron, a pion or a nucleon, for example, uses to collide with a massive target nucleus. This hadron starts to pass through the spherically shaped target nucleus. As the measure of the intranuclear matter layer thickness, involved in the collision, the thickness unit λ in nucleons/S or in protons/S will be used, where the area S (fm^2) is $S = \pi D_0^2 \approx 10$ (fm^2), D_0 is the nucleon diameter as large approximately as the strong interaction range R_h is, $R_h \approx D_0$. It is known from experiments [4,9], that the number n_p of the emitted fast ($\cong 20 - \cong 500$ MeV) protons which the incident hadron passage is accompanied by is equal to the number of the protons within the cylindrical volume $S\lambda$, where λ is in (protons/S).

On the background of the passage, the particle-producing collisions of the incident hadron with a downstream nucleons occur. Let us analyse the neutral pion production only. If the incident hadron comes into only one particle creating collision with a downstream nucleon during its passage through the target nucleus, almost identical pion multiplicity n_{π^0} distributions will appear at projectile energy high enough — as high as its energy loss does not disturb the pion multiplicity distribution. At such conditions, the distribution of the generated pion mean multiplicity $\langle n_{\pi^0}\rangle$ in dependence on the thickness of the intranuclear matter layer involved in a collision, or on the n_p (protons/S) will be regular, fig.1a; n_p is the multiplicity of the emitted fast protons in the collision event under analysis. It follows from the independence of the neutral pion multiplicity distribition at various proton multiplicities, fig.17 in our former publication [19].

In fact, when the incident hadron mean free path for particle-creating collision is smaller by much than the intranuclear matter layer involed into collision process (for example, this layer is about two times larger than the mean free path), a visible decrease of the $\langle n_{\pi^0}\rangle$ values will be observed with the increase of the intranuclear matter layer thickness n_p (protons/S) involed; it takes place at incident hadron energies high enough. At lower energies, when the energy loss manifests itself remarkably, the decrease of the $\langle n_{\pi^0}\rangle$ values occurs due to a degradation of neutral pion production ability with decreasing of the projectile energy, as well; but, without some irregularities — smoothly, with one maximum.

Nevertheless, hadrons in the nuclear collisions at high energies are created through intermediate objects which, in turn, may come into collisions with the downstream nucleons in the intranuclear matter, as well. The secondary collisions

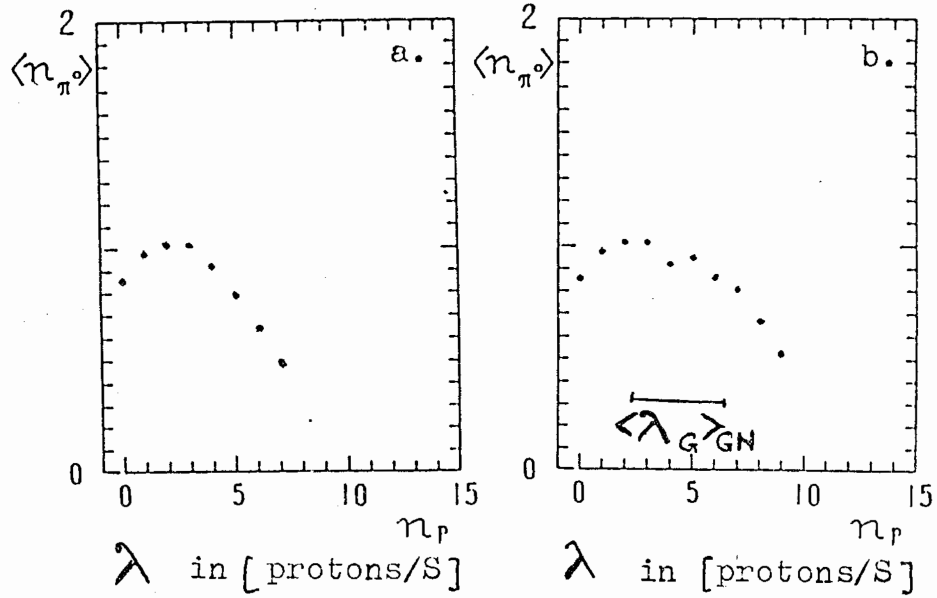

Fig.1. The picture illustrating the expected shapes of the $\langle n_{\pi^0}\rangle$–n_p distributions: a) when the particle-producing collisions of the intermediate objects («generons») do not occur with the downstream nucleons in intranuclear matter; b) when they are occurring in it. The relation $\langle n_{\pi^0}\rangle$–n_p, is equivalent to the relation $\langle n_{\pi^0}\rangle$–λS, for the length λ units in protons/S; the relation exists $n_p = \lambda S$, $S = \pi R_s^2 \approx \pi D_0^2 \approx 10.3$ fm^2

should manifest themselves in some hadron production characteristics; the mostly probably it may happen in the mean multiplicity of the produced hadrons $\langle n_h\rangle$ dependence on the miltiplicity n_p of the emitted fast protons (or on the intranuclear matter layer thickness n_p (protons/S)) in the collision event; it should manifest itself in the $\langle n_{\pi^0}\rangle$–n_p dependence, as well.

The change of the $\langle n_{\pi^0}\rangle$–n_p dependence is expected to be as shown in fig.1; it may manifest itself in this dependence only, when the characteristics are totally determined, in a corresponding total experiment, at least for the emitted protons and for the generated neutral pions.

So, the hadron producing collisions of the intermediate objects with downstream nucleons in intranuclear matter may manifest themselves in $\langle n_{\pi^0}\rangle$–n_p distribution and may be observable. Consequently, the generon mean free path $\langle \lambda_G \rangle_{GN}$ in intranuclear matter may be determined — it is a measurable quantity. In the first approximation simply, the generon mean free path $\langle \lambda_G \rangle_{GN}$ for the generon G particle-producing collision with a downstream nucleon N is the distance as shown in fig.1b. More precise determination is desired, on the basis of the concrete experimental data.

3. EXPERIMENTAL RESULTS

According to the «Introduction» and the «Heuristic Considerations», experimental data collected for the topic in question should include information on the mostly frequent hadrons produced in hadron-nucleon collisions, and the material on the pion production was collected, therefore [20]. The experimental information is mainly from the 180 litre Xenon bubble chamber exposed to 3.5 GeV/c negative charged pion beam from the Moscow ITEPh accelerator.

The chamber worked practically as the 4π solid angle detector of the produced particles; the mostly effective and accurately are registered neutral pions in it with the efficiency practically near to 100% within their kinetic energy range $E_{\pi^0} \geq 0$ MeV.

The following experimental characteristics of the pion production process are presented below; characteristics of the pion production process are presented adequately to the problems in question, in figs.2–5.

Summing up shortly all what has been shown on the figures 2–5, it is possible to state that:

1. The neutral pion (π^0) multiplicity n_{π^0} distribution $N/\Sigma N$ in $\pi^- +$ + Xe collisions does not depend on the intranuclear matter layer thickness n_p (protons/S) involved in the collisions, fig.2; it seems to be a cor-

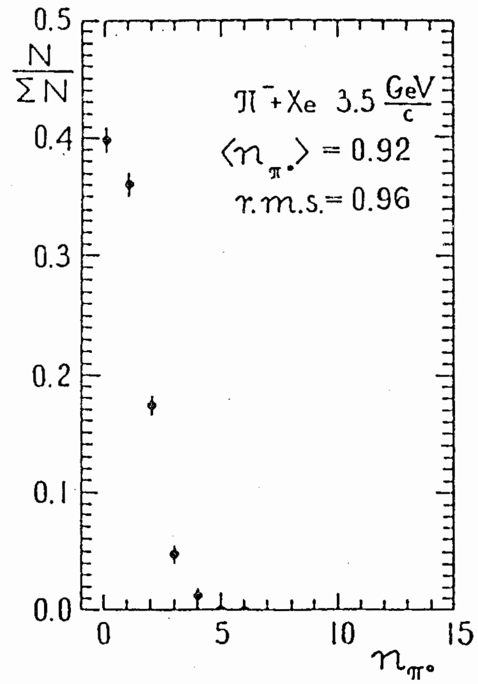

Fig.2. The neutral pion multiplicity n_{π^0} distribution $N/\Sigma N$ in $\pi^- +$ Xe collisions at 3.5 GeV/c [19,20]

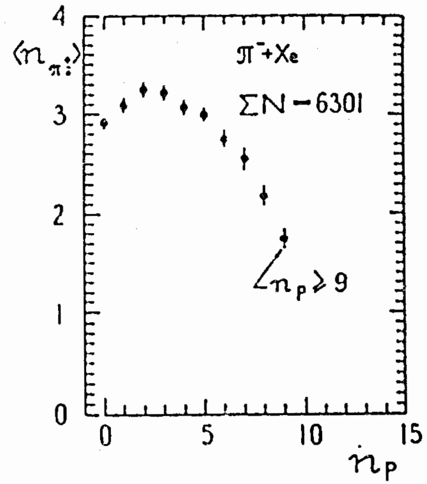

Fig.3. The dependence of the π^{+-0} mean multiplicity $\langle n_{\pi^{+-0}} \rangle$ on the emitted proton multiplicity n_p; within the length unit — in protons/S, with the $S \approx 10.3$ fm^2, the n_p multiplicity is the measure of the intranuclear matter layer thickness involved in the collision under study — because $n_p = \lambda S$, when λ is in protons/S [19,20]

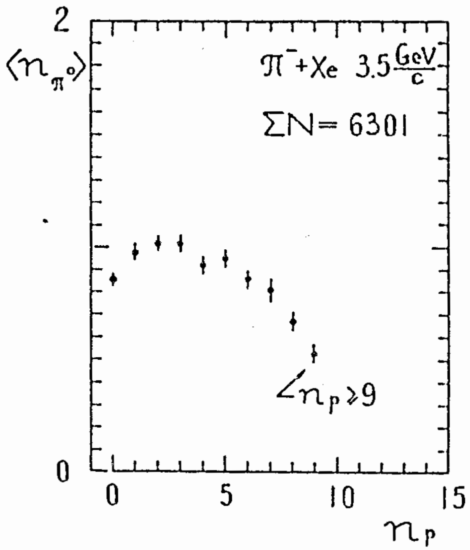

Fig.4. The dependence of the neutral pion mean multiplicity $\langle n_{\pi^0} \rangle$ on the multiplicity n_p of the emitted protons [19,20]

rect statement only for the n_p values range from $n_p = 0$ up to $n_p \leq 3$. At higher values of the n_p the mean values of neutral pion multiplicities $\langle n_{\pi^0} \rangle$ should be different and decreasing with n_p increase (it is mainly due to the incident pion energy degradation in its passage through thicker layers of intranuclear matter).

2. The irregularity in the $\langle n_{\pi^0} \rangle$ distributions in dependence on the intranuclear matter layer thickness n_p (protons/S) involved in the $\pi^- +$ Xe collisions manifests itself (figs.3,4,5) as it has been predicted in the heuristic considerations; this irregularity indicates on the intermediate object (or generon) action in layers of the intranuclear matter.

3. The interaction of the intermediate object (or generon) in intranuclear matter is observed; it comes into hadron-producing collision with downstream nucleons in intranuclear matter. The most clear it is seen in figs.4 and 5.

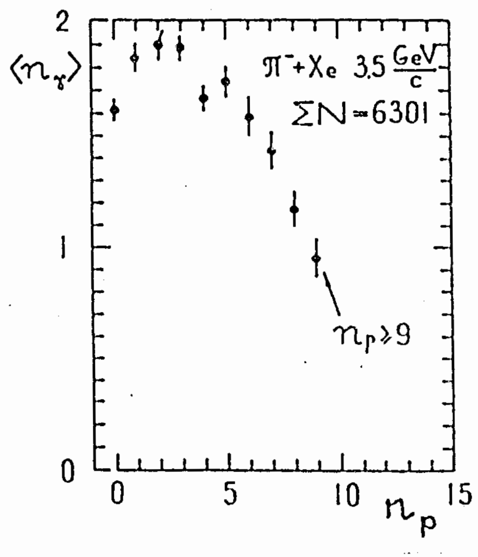

Fig.5. The dependence of the gamma quanta mean multiplicity $\langle n_\gamma \rangle$ on the multiplicity n_p of the emitted protons or on the thickness in protons/S of the intranuclear matter layer — according to the relation $n_p = \lambda S$. The gammas are from the neutral pions discussed here [19,20]

4. The mean free path of the generon G for the hadron-producing collision $\langle \lambda_G \rangle_{GN}$ with nucleons N in intranuclear matter is a measurable quantity; simple read-out from the pictures gives: $\langle \lambda_G \rangle_{GN} =$ $= 5 \pm 1$ [protons/S].

The comparison of this value $\langle \lambda_G \rangle_{GN}$ with the values of hadron producing interaction mean free paths of pionic projectiles with downstream nucleons in intranuclear matter, published in our former works [17,18], gives:

$$\langle \lambda_\pi \rangle_{\pi N} = 5.1 \pm 0.7 \ \text{(protons/S)},$$

$$\langle \lambda_\pi \rangle_{\pi N} = 5.9 \pm 0.7 \ \text{(protons/S)},$$

$$\langle \lambda_G \rangle_{GN} = 5 \pm 1 \ \text{(protons/S)}.$$

So, it can be stated: $\langle \lambda_G \rangle_{GN}$ is equal, within the error limits, to the $\langle \lambda_\pi \rangle_{\pi N}$ for the pion-nucleon collisions in intranuclear matter.

4. CONCLUSIONS AND REMARKS

The results obtained in this work allow one to conclude that:

1. The particle-producing interaction of the generons in intranuclear matter is observed.

2. The generon mean free path in intranuclear matter, for the hadron-producing collisions with downstream nucleons can be determined by measurement.

3. If generons might be treated as the quark bags [14], then it means that the quark bags mean free paths in intranuclear matter are measurable quantities, and we are measuring them.

The observed results, although correct, should be motivated once more by more wide numerical treatment in future works.

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