сообщения
объединенного
института
ядерных
исследований
дубна

E1-91-146

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HADRONS IN STATU NASCENDI

1991

1. INTRODUCTION

The question "How are hadrons produced in hadronic collisions?" should find its answer primarily in experiment. For that reason, the subject of this paper is an experimental study of the particle production process in hadronic collisions at high energies - above the threshold for the pion production.

A wealth of experimental data has been collected in the past on hadronic collisions, on the proton-proton collisions in particular. It is well known that most particles emerging from an inelastic proton-proton collision at energies high enough, above a few GeV, are relativistic and their Lorentz-factor $\gamma = E/mc^2 = (1 - v^2/c^2)^{-1/2}$ is large enough; for 1 GeV pions $\gamma \approx 7$, for 2.5 GeV pions $\gamma \approx 18$, for 3.5 GeV pions $\gamma \approx 26$, for 5 GeV pions $\gamma \approx 37$, for 10 GeV pions $\gamma \approx 70$, for 15 GeV pions $\gamma \approx 100$. As the collision reaction products are relativistic, their lifetimes τ_0 become Lorentz-dilated. The strong interaction range r_h of nucleons is approximately as large as the nucleon size or diameter $D_0 \approx 1.8$ fm. A characteristic interaction time for relativistic hadrons with nucleons is therefore of the order $\tau_{h^\circ} = 1.8 \cdot \text{fm/c} \approx 5 \cdot 10^{-24}$ sec. This interaction time gets Lorentz-dilated for the moving system of interacting hadrons, and so it is $\tau_h = \tau_{h^\circ} \cdot \gamma$. For an object with γ of about 100, emerging from a hadronic collision reaction, the undisturbed interaction-free existence lasts hardly longer than the collision reaction leading to the production of the object itself - it is of about 10^{-21} sec; the distance covered by the object is $z = c \cdot \tau_{h^\circ} \cdot \gamma$. In other words, a produced object - a resonance, for example, is like a short process of the final state interaction; such objects represent hadrons in statu nascendi, the short process is the hadron production process in hadronic collisions.

The quantitatively new and adequate experimental information which has to be used for elucidation of the production process must be obtained within the time intervals $10^{-24} \div 10^{-21}$ [sec] and within the spatial distances $10^{-13} \div 10^{-11}$[cm], therefore; information about the hadron production process obtained at larger time intervals and corresponding spatial distances only may yield false ideas of the collision reaction products. These space and time intervals we call "short" later. The standard methods provide information mainly within time intervals larger than about 10^{-21} [sec].

Within the short time intervals, the produced hadrons should be investigated experimentally by means of suitable detector. Any detector is something which causes the objects under study to interact and has a few parameters that can be varied in a controlled manner. Such detectors which have to be working during proper short time intervals of strong action and within corresponding short spatial distances, are provided by atomic nuclei/1/. Their sizes are of the order $r_A = 1.2\ A^{1/3}$ [fm]. Their variable parameters are the mass numbers A or the thicknesses $\lambda(b)$ in [nucleons/fm^2] of intranuclear matter layers at various hadron-nucleus collision impact parameters b - for nuclei massive enough.

Atomic nuclei massive enough, employed as fine detectors, can see all sorts of hadrons in statu nascendi - all resonances and may be bare or semidressed quarks.

In this paper, results of our experimental study of the space-time development of the particle production process are presented. In the studies of the process at short time intervals and space distances, our experimental data on pion-xenon nucleus collisions at 2÷9 GeV/c momentum/2-4/ and the wealth of experimental data on hadron-nucleus/5/ and hadron-nucleon/6/ collisions collected in the past by other physicists were used.

2. METHOD OF INVESTIGATION

The collision reaction products, appeared in its initial stage - within the short time intervals and space distances, should interact with surrounding medium and the interaction should produce observable effects, if one wants to "see" these products and study them experimentally. The only tool available now to realize such experiments is to apply single massive target nucleus as a fine detector/1-5/. The single nucleus has to be employed as the working medium in this detector. We call later such detector the "nuclear detector". The nuclear process - hadron passage through intranuclear matter/7/ may be applied as the physical basis of an operation principle of the detector.

The fime nuclear detector can provide conclusive information about hadrons in statu nascendi when works plunged into working medium of some total detector which allows one to obtain total information about the final state of the hadron-nucleus collision reactions.

The experimental data on hadrons in statu nascendi presented in the next section are obtained by means of such very near to total detectors - by means of the 26 and 180 litre xenon bubble chambers/3/.

3. EXPERIMENTAL DATA FROM THE NUCLEAR DETECTOR

We may conclude, from experimental investigations of the particle production process/3,4/ by means of the fine $^{131}Xe_{54}$ nuclear detector, that:

I. In hadron-nucleus collisions particles are produced via some intermediate objects which decay after having left the parent nucleus; the objects we called/3/ generons.

II. Indications were obtained/3,4,7/ that particle production in elementary hadron-nucleon collisions, in nucleon-nucleon collisions in particular, goes through such objects as well; the objects decay into commonly observed resonances and particles after lifetime of $10^{-23}\div10^{-22}$ [sec]. In other words: in elementary hadronic collisions, hadrons are created through intermediate objects in quasiendoergic 2 → 2 type collision reactions; the observed "created" particles are decay products of the intermediate objects into resonances and particles.

III. The intermediate objects can produce new objects in collisions with downstream nucleons in intranuclear matter in ones turn, and this way an intranuclear cascade of the intermediate objects may develop inside parent nucleus; in most cases this cascade is collinear with the incident hadron course.

IV. It may be shown/6,7,9/ that the above-described mechanism of the particle production process allows one to derive formulas for frequency distributions of various quantities describing hadron-nucleus collisions in terms of frequency distributions of corresponding quantities in elementary hadron-nucleon collisions/8,9/.

4. PROPERTIES OF HADRONS IN STATU NASCENDI

The intermediate objects are in fact hadrons in statu nascendi. Characteristics of final decay products of the objects in dependence on the intranuclear matter layer thickness involved in interaction of the incident hadron with matter inside parent nuclei should contain the mostly adequate and promissing data on the hadrons in statu nascendi. As the measure of the intranuclear matter layer thickness the number n_N of the emitted nucleons may be employed/2,3,4,10/; the number n_p of the emitted protons can be used in first approximation as well. It was convenient to investigate characteristics of the produced neutral pions which are registered with nearly 100% efficiency within kinetic energy range $E_k \geqq 0$, in our experiments; energy and angular distributions of the pions may be determined simply with the accuracy high enough/11/.

Set forth below, the properties of the intermediate objects are presented, obtained in this work and in our former experimental investigations/3,4/.

4.1. General Properties of the Intermediate Objects

The intermediate objects, of some definite internal energy, decay into hadrons - they emit the "quanta" with substantial masses: mesons, resonances, etc. It could be reasonable to attribute appropriate mass to any of the objects, like it is commonly practiced in the case of the resonant states. It is reasonable to expect that the objects belong in general to a family of objects with a discrete internal energy spectrum, or a mass spectrum.

Depending on the electric charge of the colliding hadrons, intermediate objects may be electrically neutral, negative or positive. Similarly, they should be of definite baryonic charge.

A major property of the particle resonant states, found until now, is that all they are eigenstates of certain symmetry operators: spin, isospin, strangeness, parity, G-parity, etc. Per analogy, it is reasonable to think the intermediate objects are with such property as well.

After rough estimations of the lifetime of these objects we may accept the value larger than about 10^{-23} [sec]. It is reasonable to think the decays of such objects are caused by strong interactions.

4.2. Behaviour of the Intermediate Objects in Intranuclear Matter

The momentum and angular distributions of the pions emerged in final states of the pion-xenon nucleus collisions are presented in dependence on the thickness of the intranuclear matter layers involved in the collision reactions; the thickness may be expressed in nucleons per some area element $S \approx 10$ [fm^2]; instead of this unit protons per S were used, and then the number n_p of the protons emitted from the target nucleus is simply the measure of the intranuclear matter layer thickness λ in [protons/S] involved in a collision reaction/2,3/, $n_p = \lambda S$, figs.1-3.

The mostly evident property of the created pions is that the longitudinal and transversal components of their momenta decrease with n_p increase or, in other words, with increase of the intranuclear matter layer thickness involved in the collision.

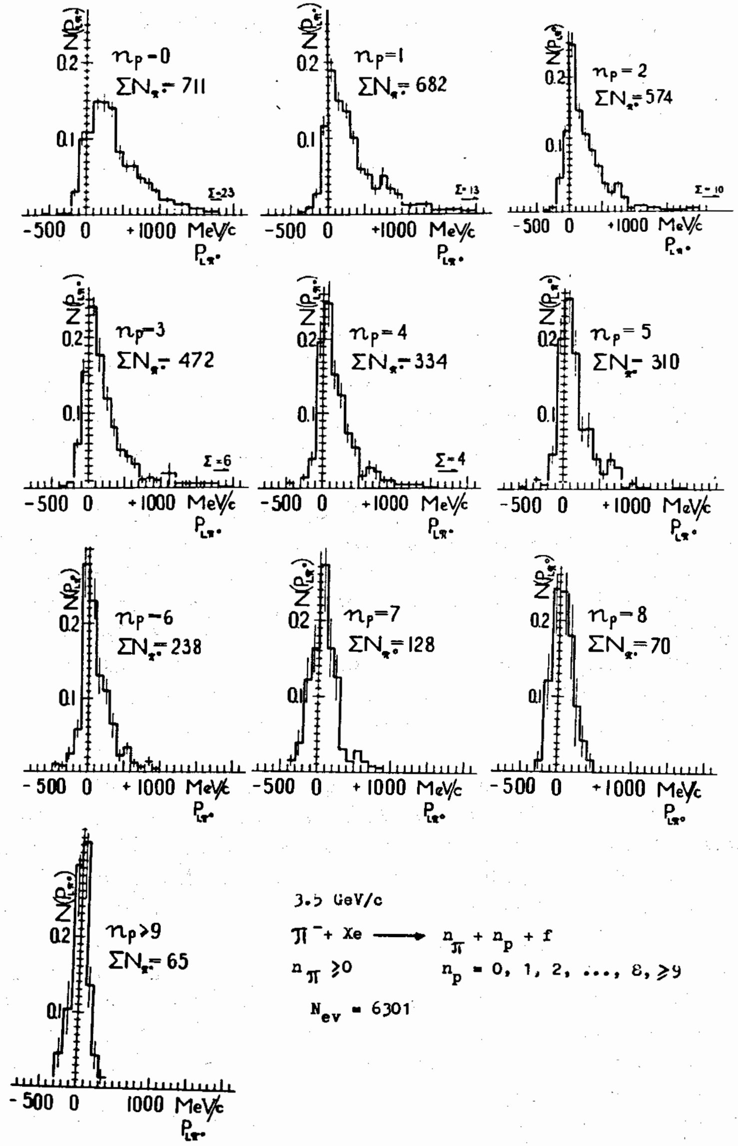
The longitudinal component values $P_{L\pi^0}$ of the produced Pi0 momentum are from about -600 [MeV/c] up to about +1800 [MeV/c]. For all the collision events the mean value $P_{L\pi^0} = 286 \pm 8$ [MeV/c] and it is definitely different from various classes of events, with various values of n_p; the mean value decreases from 456 [MeV/c] at $n_p = 0$ up to 90 [MeV/c] at $n_p = 8$, fig.1.

The transverse momentum $P_{T\pi^0}$ values are within 0 and 1300 MeV/c with the maximum at about 200-300 [MeV/c], fig.2; the mean value is $P_{T\pi^0} = 238 \pm 10$ [MeV/c]. The mean values in the classes of events with various n_p depend evidently on n_p, or on the thickness of the intranuclear matter layer - in other words. For the pion-xenon nucleus collisions at 3.5 [GeV/c] the mean values are from 270 ± 8 [MeV/c]at $n_p = 0$ up to 170 ± 9 [MeV/c] at $n_p = 8$.

The mean value of the emission angle of the produced pions is $\langle \cos\upsilon_\pi \rangle = 0.457 \pm 0.01$; about 20% of the pions are ejected into backward hemisphere. The mean value $\langle \cos\upsilon_\pi \rangle$ depends on the multiplicity n_p of the protons emitted from the target nuclei; at $n_p = 0$ $\langle \cos\upsilon_\pi \rangle = 0.64$, at $n_p = 8$ $\langle \cos\upsilon_\pi \rangle = 0.20$. The dependence of the $\cos\upsilon_\pi$ on n_p is shown in fig.3.

The observed decrease of produced pion momentum and emission angle cosine values with increase of the intranuclear matter layer thickness involved in the collision indicates that some kinetic energy loss of the intermediate objects occurs, in passing through intranuclear matter. Similar effects may appear if the incident hadron loses its kinetic energy in passing through target nucleus before to come in it into a collision reaction leading to production of the intermediate objects. Which of the two possibilities is realized in fact should be obtained from experiments.

In order to obtain an experimental answer to this question, one should prepare the produced pion multiplicity distributions for the classes of hadron-nucleus collisions with various multiplicities n_N of the emitted nucleons; the distributions may



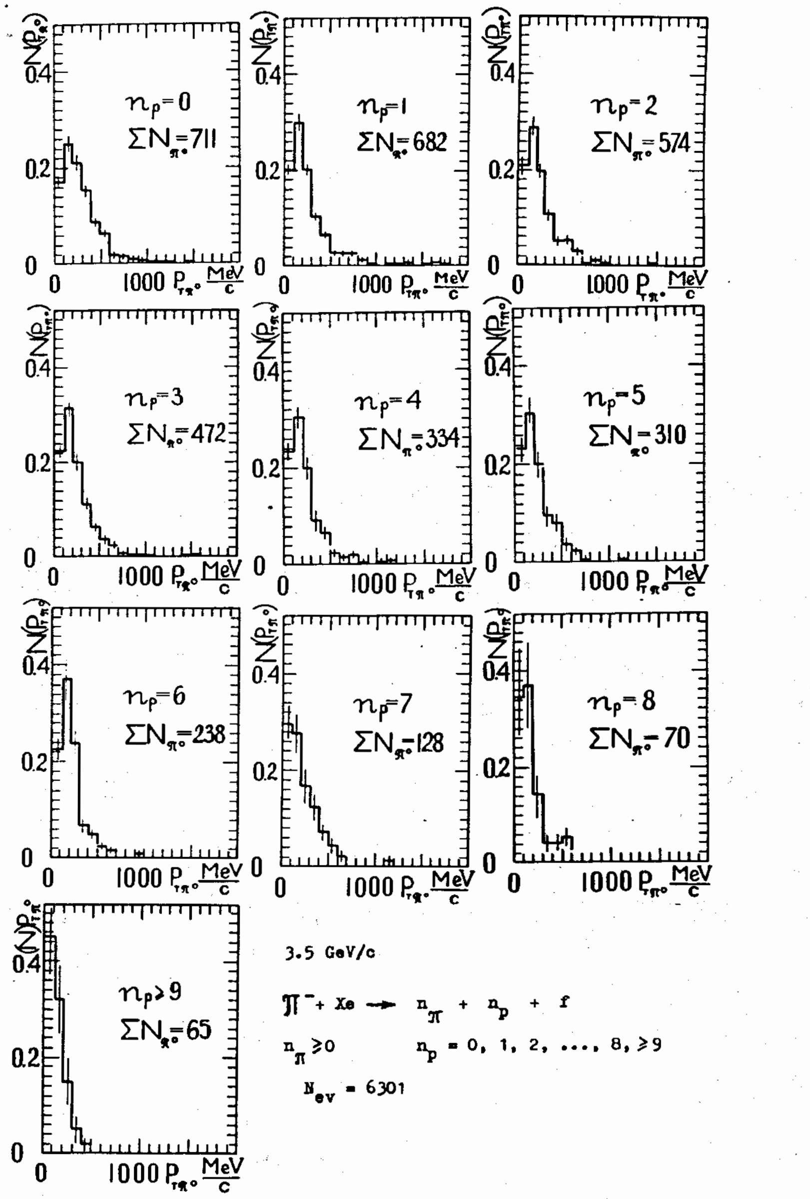
3.5 GeV/c

$\pi^- + Xe \longrightarrow n_\pi + n_p + f$

$n_\pi \geq 0$ $n_p = 0, 1, 2, \ldots, 8, \geq 9$

$N_{ev} = 6301$

Fig.1. Longitudinal momenta of neutral pions created in pion-xenon nucleus collisions at 3.5 GeV/c momentum in dependence on the multiplicity n_p of the emitted protons; the n_p are the measure of the intranuclear matter layer thickness involved in a collision. ΣN_{π^0} numbers of pions in the spectrum.



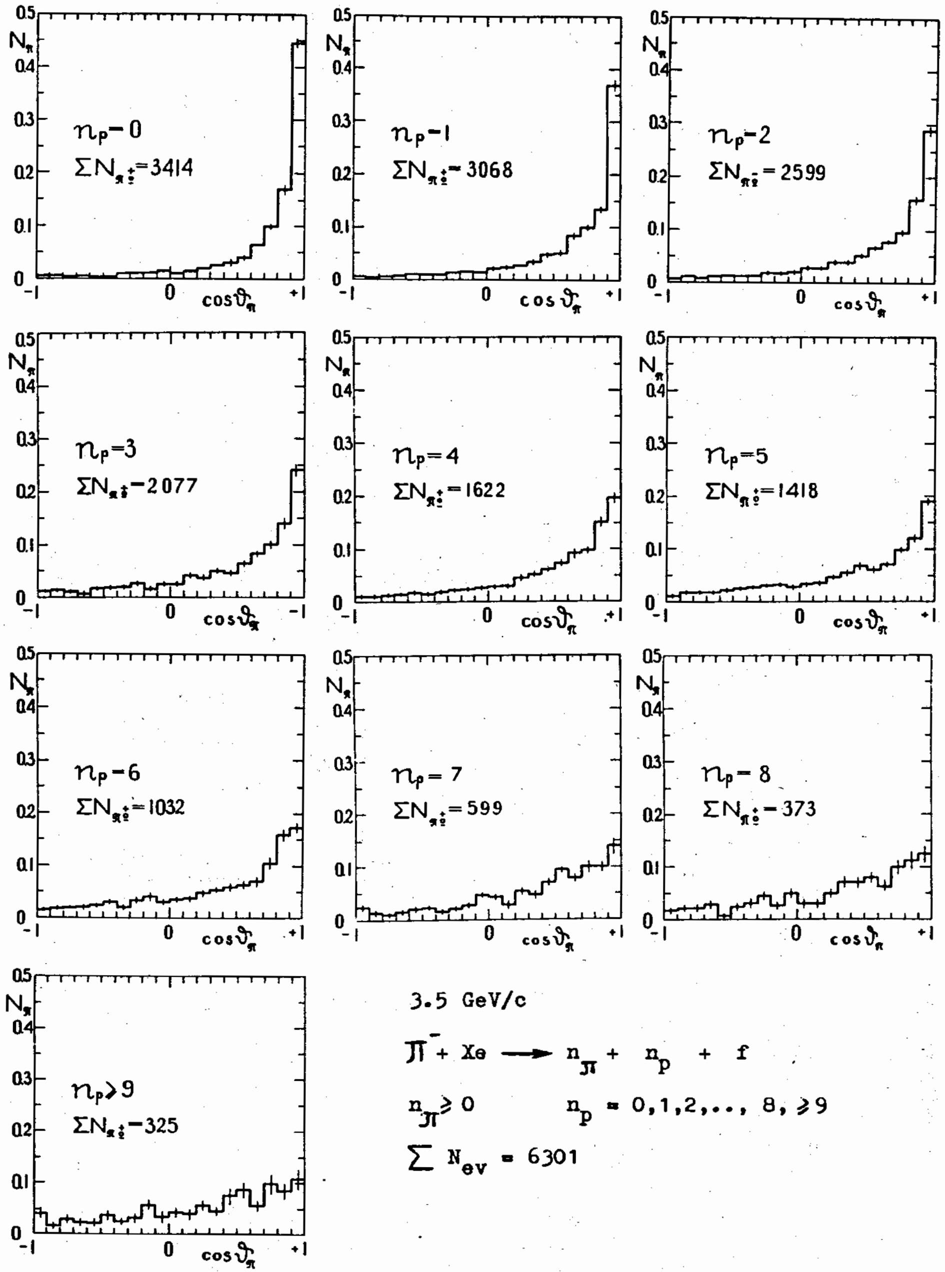
3.5 GeV/c

$\pi^- + Xe \longrightarrow n_\pi + n_p + f$

$n_\pi \geq 0$ $n_p = 0, 1, 2, \ldots, 8, \geq 9$

$N_{ev} = 6301$

Fig.2. Transverse momentum $P_{T\pi^0}$ spectrum $N(P_{T\pi^0})$ for neutral pions produced in pion-xenon nucleus collisions at 3.5 [GeV/c] in classes of events with n_p = 0.1,..., 8, ≥ 9 emitted protons. ΣN_{π^0} number of pions in a distribution.



3.5 GeV/c

$\pi^- + Xe \longrightarrow n_\pi + n_p + f$

$n_\pi \geq 0$ $\quad$ $n_p = 0,1,2,\dots, 8, \geq 9$

$\sum N_{ev} = 6301$

Fig.3. The dependence of the $\cos\upsilon_\pi$ distributions $N(\cos\upsilon_\pi)$ on the numbers n_p of protons emitted in pion-xenon nucleus collisions at 3.5 GeV/c momentum. ΣN_π - numbers of pions in distributions.

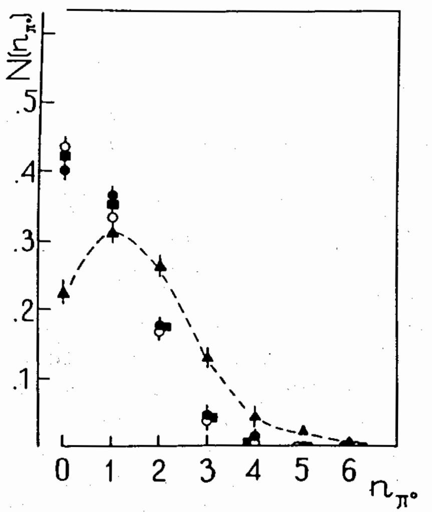


Fig.4. Neutral pion multiplicity n_{π^0} distribution $N(n_{\pi^0})$ in the classes of pion-xenon nucleus collisions with various multiplicities n_p of the protons emitted from the target nucleus. Experimental data: ● - when $n_p \geq 0$, ○ - when $n_p = 0$, ■ - when $n_p = 6$; ▲ - predictions from the intranuclear cascade model /11/.

be prepared in dependence on the multiplicity n_p of the emitted protons only - in a first approximation. In order to obtain the most clear experimental picture of the intermediate object energy loss, the hadron-nucleus reactions should be analysed at appropriate energy values, at about 3÷5 [GeV/c] momentum for the hadron-xenon nucleus collisions; at such energies the differences in the characteristics may be revealed.

In fig.4, the neutral pion multiplicity n_{π^0} distributions $N(n_{\pi^0})$ are shown for the classes of pion-xenon nucleus collision events with various multiplicities of the emitted protons n_p. From the distributions one can conclude: The $N(n_{\pi^0})$ distributions are the same for reactions with various $n_p \geq 0$, for $n_p = 0$, for $n_p = 6$. It means that the distributions are independent of the intranuclear matter layer involved in the collisions - we do not observe signals that the incident hadrons lose their energies in intranuclear matter before to come into particle-producing collision, what is observed is that the intremediate objects lose their energies in passing through layers of intranuclear matter. But, it may be the case due to the energy region at which the reactions under study happen; at higher energies, both the possibilities could be realized.

5. CONCLUSIONS AND REMARKS

In realizing this work, we have learned how it is possible in practice to investigate hadrons in statu nascendi. Maybe, quarks should be studied experimentally in such a manner. The way for experimental investigations of the particle production process within short space distances and time intervals is opened.

A question appears: How are the intermediate objects related to free quarks or system of quarks, maybe quarks reveal themselves in such a manner?

In the study of the particle production process, using nuclear targets as detectors[3,6,11-13], results have been obtained which prompted to conclude that the particle production in hadron-nucleon collisions is mediated by intermediate objects created first. The existence of such objects should manifest itself in the elementary hadron-nucleon collisions as well. A search for appropriate effects testable experimentally has been performed in analysing experimental data on the hadron-nucleon and on nucleon-nucleon collisions, in particular, at various energies[3,6,11-13]. As a result, it can be concluded that[12,13]: a) Many such effects are known from numerous experiments in which nucleon-nucleon collisions have been studied; b) None of properties of the proton-proton collisions contradict the picture of the particle production process prompted by experiments with nuclear targets; c) The particle-producing nucleon-nucleon collisions may be treated as 2 → 2 endoergic reactions, in their early stage.

From this picture of the particle production process, it follows that[12]:

1. The jet structure of the outcome in nucleon-nucleon collisions is a simple and indispensable consequence of the particle production mechanism revealed in our experiments in which nuclear targets were used as detectors.
2. The picture of the jet structure of the collision outcome observed in the CMS of the colliding nucleons depends on the energy of the nucleons; the simply visible many-jet events should appear within a definite energy interval only; outside this interval the many-jet structure may be detected only by means of some special analysis.
3. The scheme of the particle production in nucleon-nucleon collision reactions revealed in the experiments differs from the currently being in use hard-constituent-scattering scheme. But, using relations (1)÷(3´), given in our former work[12], it is possible to distinguish experimentally which of the two schemes corresponds to reality.

In my opinion, all particle-producing collision schemes being currently in use when collisions of any sort of particles are considered[14-16] should be tested experimentally in a similar way, as it is possible to do it in the case of the nucleon-nucleon collisions.

We may conclude, from the facts presented above, that what we observe in this work, and in the works cited in it, that the jets of hadrons are produced through intermediate objects[12]. In this work, we observe that intermediate objects lose their kinetic energies in passing through intranuclear matter. The intermediate objects convert into jets[2,12,13] after about 10^{-23} sec. But, now many belive[14-16] that quarks do not appear as such but they materialize as observed well-collimated spurts of particles, which have been named jets.

And so, the intermediate objects may be regarded to be partons or quarks, systems of quarks or partons. We may state, therefore, that in experiments discussed here we observe them by means of the massive atomic nucleus employed as detector, we observe their behaviour in passing through intranuclear matter.

REFERENCES

1. Strugalski Z. - The Target Nucleus as an Indicator of Various Properties of the Hadron-Nucleus and Hadron-Nucleon Collision Processes. JINR Comm., E1-80-548, Dubna, 1980.
2. Strugalski Z. - JINR Comm., E1-81-576, Dubna, 1981.
3. Strugalski Z. - JINR Comm., E1-81-577, Dubna, 1981.
4. Strugalski Z. - JINR Comm., E1-85-231, Dubna, 1981.
5. Faessler M.A. - Annals of Physics, 1981, 137, p.44.
6. Mulas E., Strugalska-Gola E., Strugalski Z. - JINR Comm., E1-90-460, Dubna, 1990.
7. Strugalski Z. - Hadron Passage Through Nuclei. Proc. XX Intern. Cosmic Ray Conf., Moscow, USSR, August 2-15, 1987, Vol.5, p.46.
8. Strugalski Z. - JINR Comm., E1-82-401, Dubna, 1982.
9. Strugalski Z. et al. - JINR Comm., E1-85-230, Dubna, 1985.
10. Strugalski Z., Mousa M., Zawislawski Z. - JINR Comm., E1-90-17, Dubna, 1990.
11. Strugalski Z. et al. - JINR Comm., E1-90-459, Dubna, 1990.
12. Strugalski Z. - Jets in High Energy Nucleon-Nucleon Collisions, JINR Comm., E1-82-347, Dubna,1982.
13. Strugalski Z. - JINR Comm., E1-82-287, Dubna, 1982.
14. Jacob M. - Physica Scripta, 1979, 19, p.69.
15. Jets in High Energy Collisions, Physica Scripta, 1979, 19, p.85.
16. Field R.D. - Physica Scripta, 1979, 19, p.131.

Received by Publishing Department
on April 3, 1991.

Стругальски З. E1-91-146

Адроны в состоянии рождения

Ядра используются в качестве подходящих детекторов для исследования пространственного и временного развития процессов столкновения адронов. Такие детекторы являются чувствительными на все адроны, резонансы и, возможно, на кварки и системы кварков - словом, на адроны в состоянии рождения. Они высоко эффективны из-за большой плотности внутриядерной материи. Кратко, предварительные результаты следующие: адроны рождаются в адрон-нуклонных столкновениях через промежуточные объекты. В экспериментах, обсуждаемых в этой статье, мы наблюдаем адроны в состоянии рождения и их поведение при прохождении через внутриядерную материю.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1991

Strugalski Z. E1-91-146

Hadrons in Statu Nascendi

Nuclei were empoyed as suitable detectors to study space- and time-intervals of strong action.Such detectors can see all sorts of hadrons, resonances, and maybe even bare or semibare quarks - in other words,hadrons in statu nascendi.They are efficient owing to high density of intranuclear matter.In short,preliminary results are:The hadron production in hadronic collisions goes by means of some intermediate objects. In experiments discussed in this paper, we observe hadrons in statu nascendi and their behaviour in passing through intranuclear matter using massive nuclei as detectors.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1991