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THE NUCLEAR MATTER MODIFICATION AT INTERMEDIATE ENERGIES. NONNUCLEON TARGETS AND SUPPRESSION OF THE RESONANCES PRODUCTION AT NUCLEUS

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1. Modification of the "target"

A few years ago the anomalous number of hadrons with high momentum was registered in hadron-nucleus collisions at LHE and ITEPH that contradicts the kinematics of the hadron-nucleon interactions. To explain the effect, A. M. Baldin[1] supposed that some nuclei interactions could be descend on a group of nucleons, but the nucleons do not lose their identity in the nuclear matter. Hence, the name "cumulative" appeared for the produced particles with "wrong" kinematics.

On the other hand, the well-known particles: mesons and resonances, realizing the interactions between nucleons, might attend virtually in the nuclei. And, finally, the particles deconfined in nuclei lead to [2] the presence of a small part of 'free' quarks and gluons in the nuclei. The same quarks, as well as mesons, and resonances may be examined as target objects inside the nucleus.

The energy E ($E \geq M_N$, where M_N is a nucleon mass) coming in the nuclei can strongly modify the nuclear matter in some part of the nucleus, or in the whole one, changing the particle parameters. But the search for free particles and resonances, with modified parameters, has not been successful so far.

So, the first hypothesis for testing was the following one: inside one nucleus there are a lot of known objects ready to serve as a target for incident particles. So, the experimental data [10] on CC, dC, CTa, p-C interactions at 4.2 GeV/c/nucleon were analyzed.

1-1. The method of testing

The way of target investigation was prompted by a very handy target-mass analysis, proposed 40 years ago by N. G. Birger and Yu. A. Smorodin [9]. Following [9] we write the target-mass M_t as:

$$M_t = \Sigma_i(E_i - p_{IIi}) - \varepsilon_0 \qquad (1)$$

Here, E_i, p_{IIi} are the energy and the longitudinal momentum of the particles, produced in the interaction ($i=3,..(n_s+2)$, -number of the charged particles), $\varepsilon_0 = E_1 - p_1$, where E_1, p_1 determine the initial energy and momentum.

In the case of the moving target, M_t distribution looks like a peak at:

$$M_{eff} + \langle T_{eff} - U_{eff} \rangle, \qquad (2)$$

Where T_{eff} . and U_{eff} are the kinetic and potential energies of the interacting objects. The width is determined by the target fermi-momenta inside the nucleus $p_{eff||}$, and $\langle p_{eff||} \rangle = 0$.

The invariant target mass square is

$$M_x^2 = (\Sigma P_i - P_1)^2 \qquad (3)$$

Here P_1 and P_i, the four-moment of the initial and produced particles were also used for the testing.

The method of missing mass was used for the separation of the events, which were suitable to the definite process kinematics.

The missing mass square was written as:

$$M_{mis}^2 = (\Sigma P_i - (P_1 + P_2))^2, \qquad (4)$$

$$\text{or:} \quad M_{mis}^2 = ((E_1 + M_{targ}) - \Sigma E_i)^2 - (\mathbf{p}_1 - \Sigma \mathbf{p}_i)^2 \qquad (5)$$

Where P_1,P_2 are the four-momentum of the initial particles, and P_i is the four-momentum of the produced particles; also E_1, $\mathbf{p}_1$- and E_i, $\mathbf{p}_i$ are the energies and moment of the initial and produced particles, respectively, M_{targ} is the mass of the object, which the interaction took place. The width of the maximum at $M_{mis}^2 = 0$ is determined by target fermi-momenta, by the measured errors and, of course by a natural width of resonance, if it occurs to be a target.

Figure 1 demonstrates the separation of one definite channel of interactions of initial particles with nucleons. All necessary weights are used here (see sect. 1-2) and the nucleon mass is taken as M_{targ} . The events having the M_{mis}^2 values

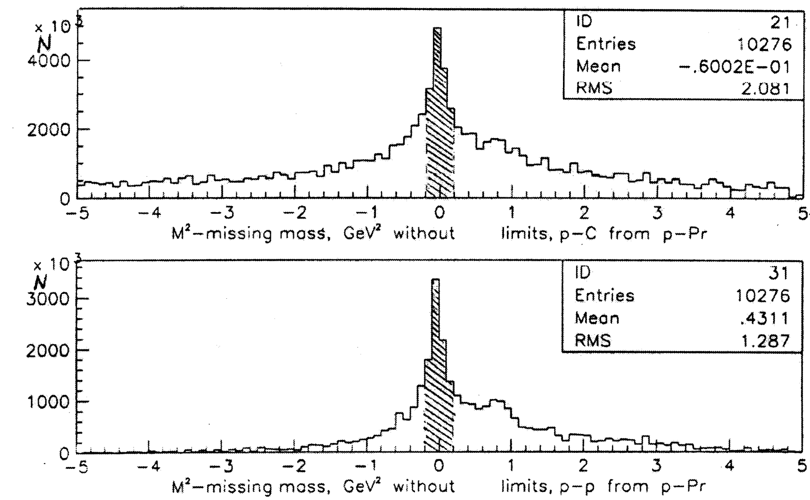

Fig. 1. Missing-mass spectrum M_{mis}^2 for p-C (Top), p-C and p-p-interactions (Bottom) with weights 'wt' and 'wp'. The mass of the target is: M_{targ}=M_N.

inside the narrow region near zero of the distribution correspond to the process, which is searched for.

1-2. Background reduction

i. Indeed, in the propane bubble chamber the distinction of protons from π^+ mesons was successful to momentum ~ 0. 7 GeV/c only. At the higher momenta the identification was made by the statistic weight, wp [11]. To reduce the neutron contribution, the events with only one well- identified proton were taken into account.

ii. Bad measured tracks, the lost particles, as well as the events containing unambiguously identified particles, were taken into account with the help of the corresponding weights [11].

iii. Obviously, the proposed consideration requires all particles to be registered thoroughly. To exclude the events, in which neutral particles were not registered, as well as to share out the effect, the test of transverse momentum compensation was applied. The request of the transverse momentum compensation means that a sum of transverse momenta components p_{xi} and p_{zi} does not exceed a small value, designated as the p_x and p_z limits simultaneously. Fig. 2. shows transverse momenta of all charged particles produced in CC interactions at 4.2 GeV/c [10]. The events from the narrow stripes determined by measurement errors, were taken for the further analysis.

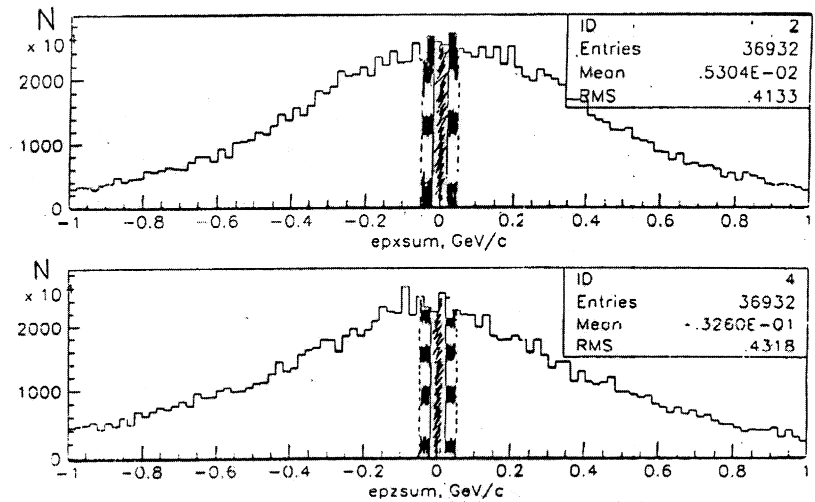

Fig.2. Summary transverse momentum components Σp_{xi} and Σp_{zi} for all measured CC-interactions. The request of the transverse momentum compensation means that the Σp_{xi} and Σp_{zi} do not exceed any small value simultaneously – only the events from the narrow stripes of Σp_{xi} and Σp_{zi} are taken for the analysis.

Separation of definite reactions (CC and Cp from C-C_3H_8 or pC and pp interactions from p- C_3H_8) was made by the weights, calculated in [11] on the base of the known inelastic cross section mainly.

1-3. 'Targets' inside the target

The mass-targets M_t for different demands on transverse momentum balance are shown in Fig. 3. All criteria besides "missing mass" were used here.

As seen from the figure, the nucleon was used as a target approximately in 30% of the events, a lot of all events (~20 %) have the mass-target less than a proton mass. For those last events the separate groups may be identified with the ones where quarks or π mesons, pairs $\pi^+\pi^-$, rest from ω, η- mesons, or ρ mesons and $M_{N3/2,3/2}$, are used as a target. Further, the missing mass method was applied to " C-p", "p-C" and "p-p"-interactions in different assumptions about M_{targ} –value: M_{targ}= $M_{N3/2,3/2}$, M_N, M_ρ ,M_π and ~M_q

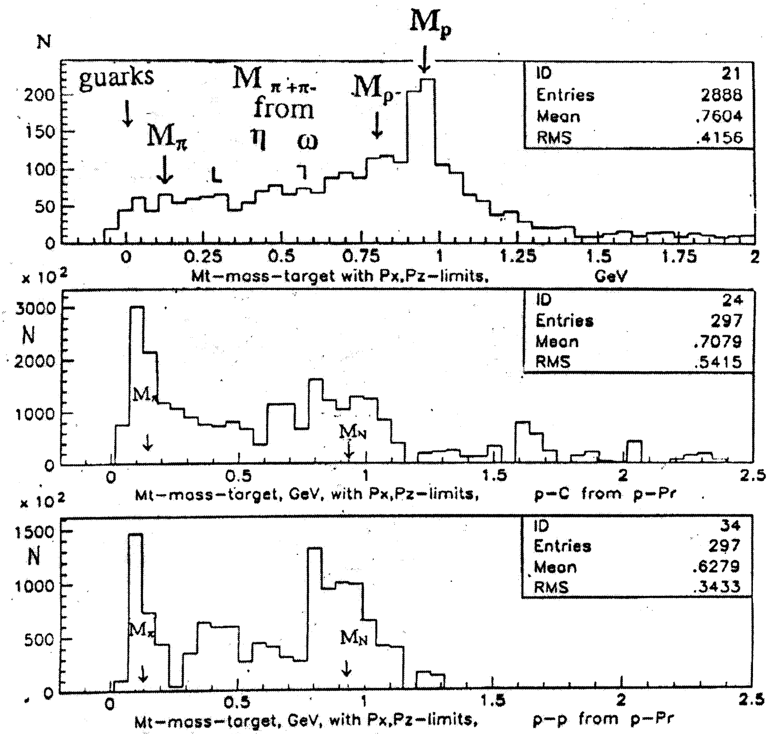

Fig. 3 . Mass-target (M_t) distributions with transverse momentum balance: $\Delta\Sigma p_t = \mathrm{sqrt}((\Sigma p_{xi})^2 + (\Sigma p_{yi})^2) = \pm$ 140 Mev/c.
(Top): C-C-interactions without weights, (Middle) pC-interactions from p-C_3H_8-interactions with the weights 'wt', 'wp' and 'we'; (Bottom) p-p-interactions from p-C_3H_8-interactions with the weights 'wt', 'wp' and 'we'.

The results are shown in Figures 4,A,B,C and 5. The groups of events where initial particles interacted with objects having the mass equal or less or greater than the nucleon mass, are separated clearly.

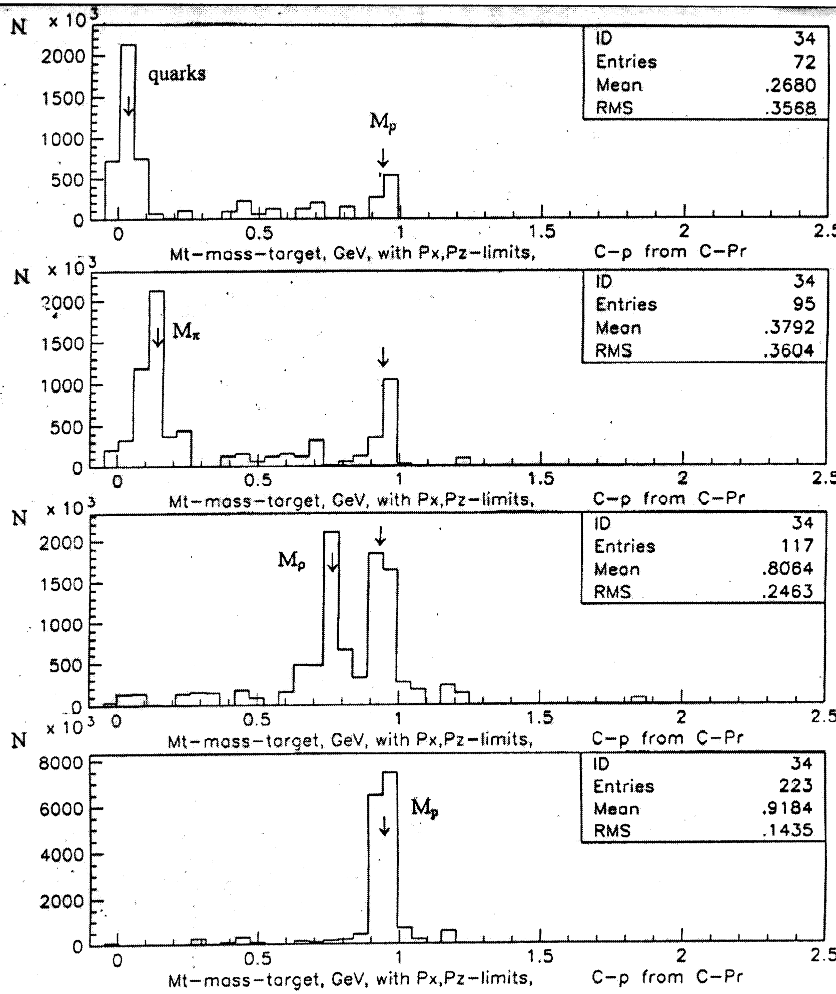

Fig. 4A. Mass-target M_t- distributions of the candidates for separate reactions of protons with (from top to bottom correspondingly) quarks, π-mesons, ρ mesons and nucleons. Cp -interactions.

M_x^2 distributions demonstrate the same effects, but they are not so descriptive as at the M_t spectra.

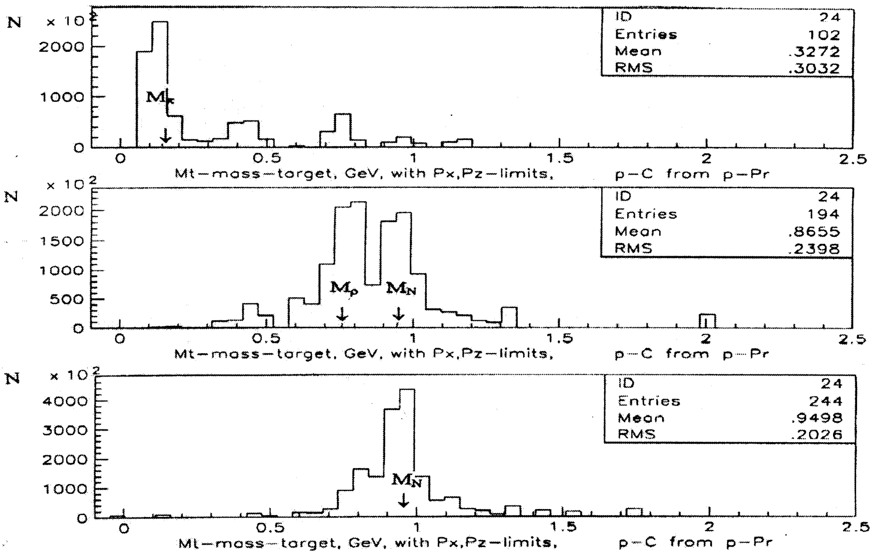

Fig. 4B. Mass-target M_t- distributions of the candidates for separate reactions of protons with (from top to bottom correspondingly), π-mesons, ρ mesons and nucleons for pC-interactions.

1. Suppressing of resonances production – does it exist?

While the high-energy collides try to probe the hot quark-gluon plasma at the low net baryon density, the matter possibly the quark-matter, may be produced at rather high baryon density and moderate temperature on the fixed target at the Nuclotron. Reproduction of hadron distributions on the base of central Si+A collisions' data at the AGS at freeze-out shows baryon densities exceeding the nuclear matter density by five times for typically a extended time of about 5 fm/c [3,4,5].

Intensive production or 'dressing' of resonances in such conditions increase the matter density even more. . Metag [6] on the base of calculations of S. A. Bass et.al.[7] and S. Teis et. al. [8] concluded that for 30 % of nucleon resonance population at 2AGeV, the mean distance between separate constituents became ~2fm, attaining the boundary in strong interactions. Thus the density of resonances is, thus, so high that they start to interact between each other, and then we can speak about these systems as of the resonance matter. It may be one from the causes of the fast resonances destruction.

Usually the increase of the charge particle multiplicity, particularly π mesons, happens due to the plenty of resonances. So, the observation [15] of abundance of a small π meson p_t momentum confirms this approval. Here the middle numbers of positive and negative mesons produced in carbon-carbon interactions are nearly two and seven times correspondingly greater than the ones, produced in proton –proton interactions.

The resonances are produced intensively in elementary particle interactions at 2-4 GeV, whereas in nuclear-nuclear interactions the resonances are hardly found at the same energies. What is the reason? We shall try to give the answer.

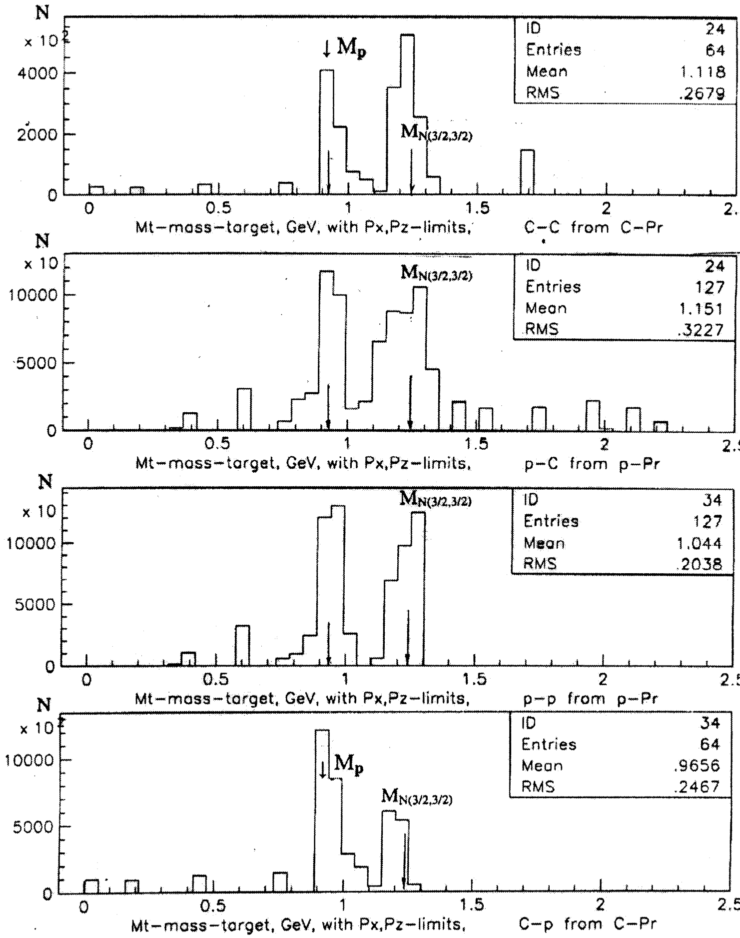

Fig. 5. Mass-target M_t- distributions of the candidates for separate reactions of protons with $\Delta(1232)P_{33}$ –isobars for CC, pC, pp and Cp-interactions (from top to bottom correspondingly).

2-1. Combinatorial background problem

The spectra of effective mass $\pi^+\pi^-$ mesons and $p\pi^+$ particles indicate the presence of the Δ^+ isobars and, maybe, ρ mesons in dC interactions. They disappear, however, in CC and CTa interactions with high charge particle multiplicity entirely (Fig.6). Here the observation of resonances are masked by combinatorial background. To reduce the number of "bad" (do not "contain" the resonances) combinations, the analysis of many - particles effective mass spectra was applied.

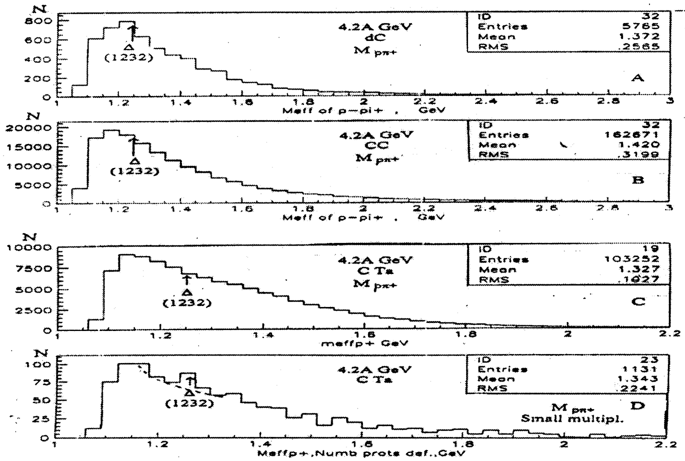

Fig. 6. Effective mass distributions for nuclear-nuclear interactions at 4.2 GeV: (A) the effective masses - $M_{p\pi+}$ for d-C interactions; (B) $M_{p\pi+}$ for C-C - interactions ; (C) $M_{p\pi+}$ for C-Ta interactions; (D) $M_{p\pi+}$ for C-Ta - events with multiplicities of charge particles $n_s < 6$.

It is known that the minimum value of n-particles ($n < N_{total}$) effective mass is equal to the sum of the particle masses:

$$MIN(M_{eff}^{n}) = \Sigma^{n} m_i$$

The differences between the minimum values of n-particles effective mass spectra with and without resonance producing are shown in Table. 1.

Tabl.1.

Group of charged particles		$\delta(MIN(M_{eff}^{n}))$
Without resonances	With resonances	GeV
$n\pi$	$(n-2)\pi + \rho$	~.500
$kp+(n-k)\pi$	$(k-1)p+(n-k-1)\pi + N_{3/2,3/2}$	~.310
$n e^{\pm}$	$(n-2) e^{\pm} + \rho$	~.750
$k p+(n-k)\pi$	$(k-1) p+(n-k-3)\pi + N_{3/2,3/2}+\rho$	~.640

So, all combinations of two particles effective masses coming from the δ-region: Min(M_{eff}^{n} without resonances)<MIN($M_{eff}^{n}$with resonances) of n-particles effective mass spectra may be rejected. This method may be named as "many particles mass restriction, Method-MPMR".

2-2. Resonances production in nuclear-nuclear interactions at 4.2AGeV.

The results of method-MPMR application to pp(quazi) and to CC-interactions at 4.2AGeV are shown on Fig. 7 and Fig. 8 correspondingly.

These results are preliminary ones because only one part of the total statistics is used. Also, the restriction of minimal effective masses was put on three particles effective mass only (n=3). So, as seen from Fig. 7 and Fig. 8, in comparison with Fig. 6, the resonances $\Delta(1232)P_{33}$ and $N(1440)P_{11}$-isobars and ρ-mesons are displayed clearly.

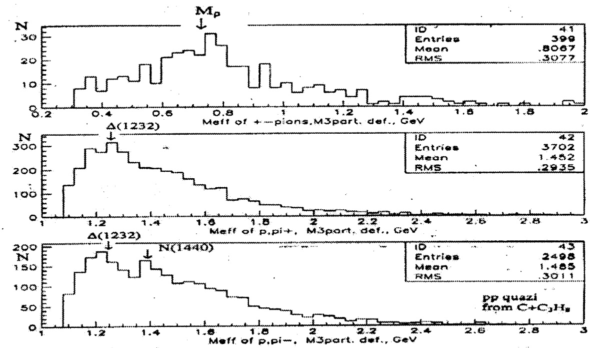

Fig 7. Effective mass distributions for pp-quasi - interactions shared out from $C+C_3H_8$ interactions. Method MPMR for background restriction at n=3 was applied here: (Top) - the effective mass distributions of $\pi^+\pi^-$ - pions - $M_{\pi+\pi-}$; (Middle): $M_{p\pi+}$; (Bottom): - $M_{p\pi-}$.

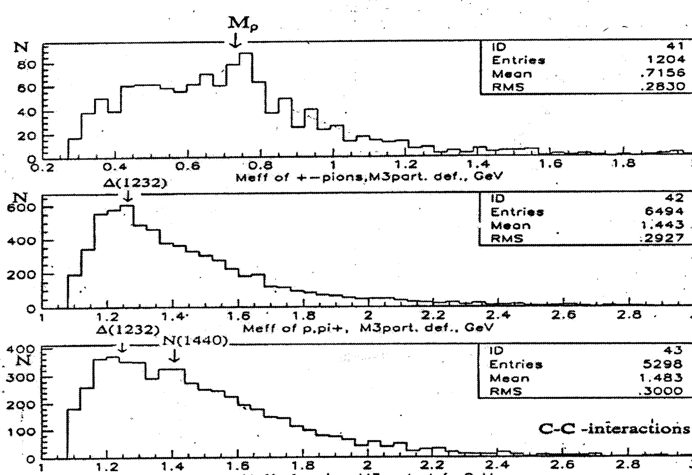

Fig. 8. Effective mass distributions for CC- interactions at 4.2 A GeV/N. See description of Fig.7 for details.

The impression is (the exact estimations are not carried out else), that the resonances are produced in both types of interactions with the similar intensity. The restriction of four-particle effective masses (n=4) indicate (Fig. 9) that the production of two resonances: $\Delta(1232)P_{33}$ –isobars and ρ-mesons simultaneously in the same CC-interaction give the noticeable contribution.

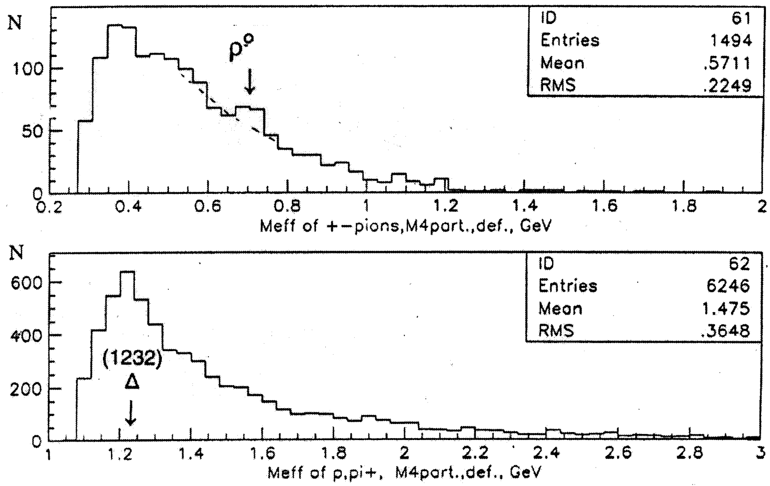

Fig. 9. Two particle effective mass distributions (top) $M_{\pi+\pi-}$ and (bottom) $M_{p\pi+}$, obtained by method MPMR at n=4 for CC-interactions.

Conclusion

In consequence of some expounded speculations we can conclude that the hypothesis about the presence in the nucleus of the objects other than nucleons, which can serve as the target, has some confirmation. At 4.2 GeV/c/nucleon the results for CC- interactions do not contradict the following evidence: initial nuclear collisions between particles, having a mass less or greater than the nucleon one, may happen in a large part (R>20%) of all events. Many known resonances or particles and, possibly quarks, can be used as the target. Separate groups of such events are clearly seen.

The production of the so-called cumulative particles [1] can be explained by the interaction of the incident particle with heavy resonances. Heavy resonances have the great binding energy, and it may change its mass in rather wide boundaries.

The testing of the second hypothesis: resonance production suppressing in nuclear-nuclear interaction, has not obtained full confirmation.

But, the $\Delta(1232)P_{33}$ and $N(1440)P_{11}$-isobars and ρ-mesons are produced in the C-C- and C-Ta- interaction with the same intensity as in nucleon-nucleon interactions. Hence it follows that some suppression exists, particularly for more 'central' events (with high $N_{part.}$).

The nature of this suppression is not clear so far. It is known that the secondary interactions may suppress resonances not more than by
20-30%. It is necessary to perform a more detailed study of this problem. Probably, the resonance matter model with anomalous high cross-sections of the interaction between constituents in superdense matter will help to perform it. However, obviously the development of such researches requires enlarging statistics.

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Модификация ядерной материи при промежуточных энергиях. Ненуклонные мишени и подавление резонансной продукции в ядрах

Рассматривается гипотеза о взаимодействии адронов с веществом ядер, где, как предполагается, наряду с нуклонами ядра в качестве мишени для налетающего адрона могут служить известные частицы, резонансы и, возможно, кварки. Проверка гипотезы была проведена на основе экспериментальных данных CC-, dC-, CTa-, pC-взаимодействий при 4,2 ГэВ/с/нуклон. Кроме того, анализ рождения $\Delta(1232)P_{33}$-, $N(1440)P_{11}$-изобар и ρ-мезонов в этих же взаимодействиях обнаруживает некоторое подавление их образования в рассматриваемых ядрах по сравнению с взаимодействиями на нуклонах, что, возможно, связано с образованием в ядре плотной «резонансной» материи.

Работа выполнена в Лаборатории высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2002

Penev Vl., Shklovskaia A. E1-2002-172

The Nuclear Matter Modification at Intermediate Energies. Nonnucleon Targets and Suppression of the Resonances Production at Nucleus

A new hypothesis of hadron interactions with the nuclear matter is discussed. It is supposed that the well-known particles and resonances as well as nucleons may serve as a target in the nucleus. The experimental data on CC, dC, CTa, pC interactions at 4.2 GeV/c/nucleon is used for testing the hypothesis. A certain suppression of the $\Delta(1232)P_{33}$, $N(1440)P_{11}$ isobars and ρ-mesons production is observed in these interactions, compared to nucleon-nucleon interactions. It may be caused by formation of the so-called dense «resonance matter» in the nucleus. Special experiments with multiple rising statistics are required to examine the hypothesis.

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

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