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INVESTIGATIONS OF NEUTRAL PARTICLE PRODUCTION BY RELATIVISTIC NUCLEI ON THE LHE 90-CHANNEL γ-SPECTROMETER. RESULTS AND PERSPECTIVES

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Results of the experiments on neutral pion production at forward angles at 4.5 GeV/c per nucleon in nucleus-nucleus collisions are presented. The experiments were performed on the LHE 90-channel lead glass Čerenkov spectrometer FOTON. The ability of the setup for π^0 meson identification at high multiplicity of γ quanta and hadrons is shown. The list of the planned measurements on the spectrometer is given.

The investigation has been performed at the Laboratory of High Energies, JINR and was presented at the Workshop on the Perspectives of Relativity Nuclear Physics, May 31 — June 5 1994, Varna, Bulgaria.

Исследование образования нейтральных частиц в релятивистских ядро-ядерных взаимодействиях на 90-канальном γ-спектрометре ЛВЭ. Результаты и перспективы

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Представлены результаты экспериментов по исследованию образования нейтральных пионов в ядро-ядерных взаимодействиях при 4.5 ГэВ/с на нуклон. Эксперименты выполнены на 90-канальном черенковском спектрометре из свинцового стекла (установка ФОТОН). Показаны возможности установки по идентификации π^0-мезонов в условиях большой множественности γ-квантов и адронов и перечислены эксперименты, проведение которых планируется на спектрометре.

Работа выполнена в Лаборатории высоких энергий ОИЯИ и была представлена на Совещании по перспективам развития релятивистской ядерной физики, 31 мая — 5 июня 1994, Варна, Болгария.

The 90-channel lead glass spectrometer FOTON [1], developed at LHE, JINR in 1979, is successfully used up to now for physics information acquisition. Details of the construction and performance of the lead glass hodoscope are given in the table.

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Table. The basic parameters of the lead glass hodoscope

number of lead glasses	90 TF-1, total weight 4000 kg
module cross section	r = 9 cm insert circumference
module length	35 cm, 14 R.L.
spatial resolution	4 cm
angular resolution	0.7° at L = 340 cm
energy resolution	$(4.3/\sqrt{E})$ %, (E(GeV))
gain stability	(1÷2) %
dynamic range	50 MeV ÷ 6 GeV
minimum ionizing signal	384 MeV photon equivalent
total (rectangular) area	140× 215 cm^2

In 1987—1991 the setup was used to measure the cross sections of neutral pion production in proton-nucleus and nucleus-nucleus collisions at 4.5 GeV/c per nucleon.

The fragmentation of nuclei in high energy collisions into elementary particles with momenta far exceeding the average momentum per nucleon in the nucleus is one of the most interesting phenomena in high energy physics. This phenomenon, the so-called cumulative production of particles, was first observed by A.M.Baldin et al. [2]. Our motivation for these experiments was to obtain information about the production mechanism of neutral pions beyond the kinematic limit for free nucleon-nucleon and nucleon-nucleus collisions [3,4].

The pion production was investigated at $0° \le \theta_{\pi^0} \le 16°$, $E_{\pi^0} \ge 2$ GeV, where E_{π^0} and θ_{π^0} are the energy and angle of π^0 emission in the lab. system, respectively. We have also investigated the dependence of the cross sections on the number of nucleons in the target and in the projectile. The characteristic property of our experiment is the possibility of pion registration over a wide interval of transverse momentum during one experiment.

The experiment was performed at the LHE synchrophasotron using a single-arm lead glass Čerenkov spectrometer with scintillation counter hodoscopes. A schematic drawing of the experimental apparatus is given in fig.1. The setup includes: the beam monitor scintillator telescope (S_1÷S_2); the threshold Čerenkov counter ($\check{C}_1$); the halo scintillation counters (A); the target (M); the scintillation counter hodoscopes (SH); the lead glass calorimeter ($\check{C}_2$).

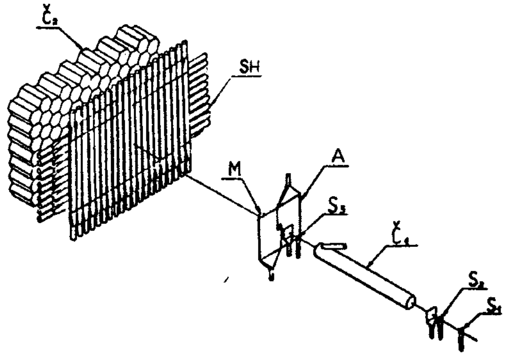

Fig.1. A schematic drawing of the setup

The possibility of π^0 identification of the setup is shown in fig.2.

The π^0 mesons are detected through their two-photon decay mode as a narrow peak in the invariant mass distribution. Photons are recognized as isolated and confined clusters (an area of adjacent modules with a signal above the threshold) in the electromagnetic calorimeter. The photon energy is calculated from the energy of the cluster by applying a position-dependent leakage correction. Assuming that the photon originates at the target, its direction is determined from the geometrical positions of the constituent crystals, weighted by the corresponding energy deposits.

Inclusive spectra of π^0 have been extracted from the raw data under the following selection criteria:

(1) $E_\gamma \geq 500$ MeV,

(2) $k_{\gamma\perp} \geq 120$ MeV,

(3) $P_\perp \geq 70$ MeV

for the reactions (p, d) + A, and

(1) $E_\gamma \geq 800$ MeV,

(2) $k_{\gamma\perp} \geq 180$ MeV,

(3) $P_\perp \geq 160$ MeV

for the reactions (α, C) + A. Here E_γ is the energy of γ-quanta (clusters), $k_{\gamma\perp}$ is the transverse momentum of γ -quanta and $P_\perp$ is the transverse momentum for $\gamma\gamma$ combinations.

In order to identify π^0 mesons, all photon pair combinations are used to calculate the invariant mass in each event. The dotted histograms in fig.2 represent the invariant mass distributions for $\gamma\gamma$ pair combinations selected accidentally from different events. These combinatorial distributions were used for background calculations.

There is an excess of $\gamma\gamma$ pairs at small decay angles for background events. The influence of these events on the invariant mass distributions is

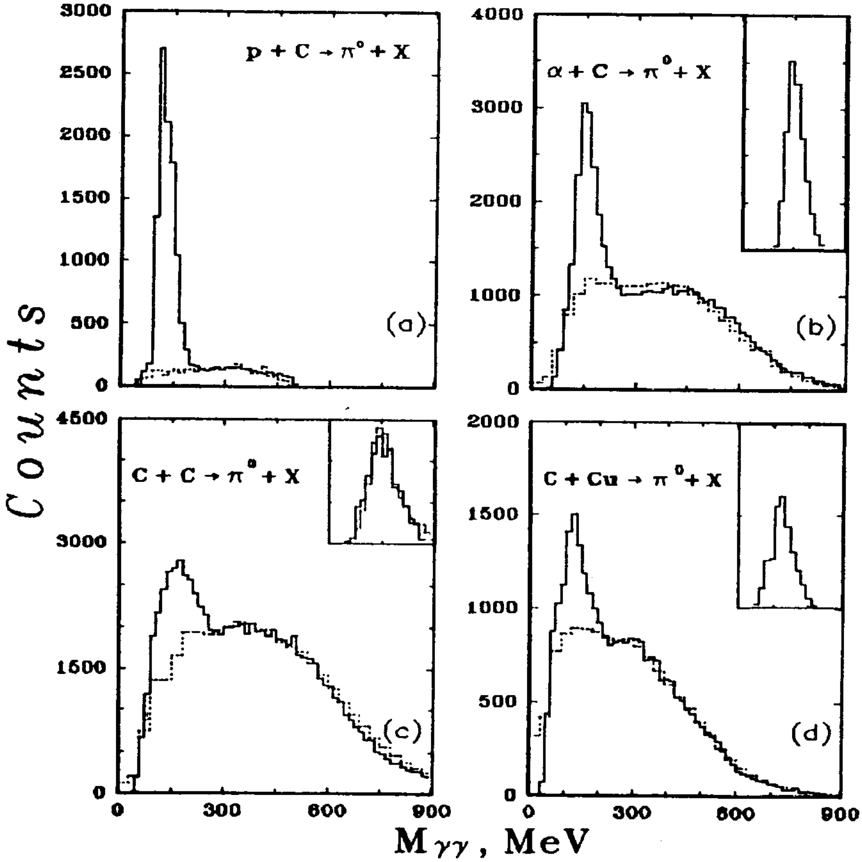

Fig.2. Invariant mass spectra of $\gamma\gamma$ pairs for p + C (a), α + C (b), C + C (c) and C + Cu (d) reactions at 4.5 GeV/c per nucleon. The dashed lines indicate the background. The insets show the π^0 peak after background subtraction. The dashed histogram in (c) is the spectrum of $\gamma\gamma$ pairs from π^0 decay generated by the Monte-Carlo method under real conditions of the experiment. The center of the front surface of the lead glass hodoscope is located at 340 cm (a+c) and 520 cm (d) from the target

essential for M < 100 MeV only. These masses were excluded from the data analysis.

The data analysis method has previously been described in detail in ref. [3].

Among main results of the experiment we would like to note the following:

1. We have measured forward π^0 production in the reactions:

$$A_B(p, d, \alpha, \mathrm{C}) + A_T(\mathrm{C}, \mathrm{Cu}) \rightarrow \pi^0 + x \quad (1)$$

at 4.5 GeV/c per nucleon. We have observed pions with energy 1.9 times as large as a maximum available in collisions between two free nucleons. The production of such pions must involve nuclear effects. The cumulative number variable X was used to find a simple universal parametrization of the data. The variable X derived from energy and momentum conservation laws for the reaction $XN_i + N_T \rightarrow (X + 1)N_f + \pi^0$ is equal to

$$X = \frac{M_N E_{\pi^0} - M_{\pi^0}^2/2}{E_N M_N - E_N E_{\pi^0} - M_N^2 + P_N P_{\pi^0} \cos\theta_{\pi^0}},$$

where M_N, M_{π^0}, P_N, P_{π^0}, E_N, E_{π^0} are the nucleon and π^0 mass, momentum and energy, respectively; θ_{π^0} is the angle of π^0 emission (lab system); $P_N = 4.5$ GeV/c. The variable X is similar to the Bjorken x and introduced to take into account the particle masses involved in the reaction. In the parton models the X dependence of the cross section over the considered range ($E_p \gtrsim 3.5$ GeV/nucleon and $X \gtrsim 1$) is interpreted as a longitudinal momentum distribution of partons in nuclei. Within this range the invariant cross section is written as [5]:

$$E\frac{d\sigma}{d\mathbf{P}} = \mathrm{Const}\cdot G_{A_p}(X, A_p),$$

where G_{A_p} is the quark-parton structure function of the fragmenting nucleus: the projectile nucleus in this case.

According to the above considerations, the cumulative effect is defined as inclusive reactions in the region $X \gtrsim 1$. The quark-parton structure function of nuclei in this region is the probability that a constituent quark carries the momentum of a nucleon group [6].

The parametrization of the structure function of nuclei by the expression $G(X) \sim \exp(-X/X_0)$ makes it possible to extract the parameter X_0 characterizing the first momentum of the structure function.

The growth of X_0 is observed with increasing the number of nucleons in the fragmenting nucleus: it is equal to 0.145 ± 0.002 for α particles and 0.176 ± 0.007 for the carbon nucleus (the data are given for $P_\perp \cong 0$; the quoted errors are statistical only).

A great difference between the parameters X_0 is observed at 2.9 [4] and 4.5 GeV/c per nucleon. A substantial difference for the carbon nucleus is observed when we compare our data at 4.6 GeV/nucleon with the corresponding ones for higher energies [7]. Thus the scaling begins at higher energies with increasing projectile mass.

2. We present the target and projectile dependences of the invariant cross section in the form

$$Ed\sigma/d\mathrm{p} \sim A_B^m, \text{ where } A_B = \alpha, \mathrm{C}; \quad (2)$$

$$Ed\sigma/d\mathrm{p} \sim A_T^n, \text{ where } A_T = \mathrm{C}, \mathrm{Cu}. \quad (3)$$

2.1. A strong dependence on the projectile mass is observed: the exponent m (eq. (2)) rises from a value of 1.2 ± 0.1 for lower momentum pions ($X\sim1$) to 2.1 ± 0.2 for pions produced beyond the nucleon-nucleon kinematic limit ($X = 1.9$); $m = 1.6\pm0.1$ for $P_\perp = 500$ MeV/c and $m = 2.3\pm0.2$ for $P_\perp = 900$ MeV/c. Such a behaviour of $m(X, P_\perp)$ indicates probably a strong redistribution of nucleon momenta in the nucleus.

2.2. The exponent n (eq. (3)) weekly depends on X and $P_\perp$ and equals 0.37 ± 0.02.

The parton models [5,8] predict that n is independent of X and $P_\perp$ at large X and small $P_\perp$. According to these models, an incident hadron fragments when one of its constituent quarks collides in the target. The spectator quarks that escape collision and thus retain their original fraction X of the projectile c.m. momentum can fragment or recombine with a slow quark ($X \approx 0$) and form large X-low $P_\perp$ fragments. The value of n has been estimated quantitatively assuming that recombination does not depend on X [8]. The following expression has been suggested:

$$(A_2/A_1)^{n(X,P_\perp)} = (\sigma_{NA_2} - \sigma_{qA_2}) / (\sigma_{NA_1} - \sigma_{qA_1}),$$

where σ_{jT} is the total nuclear absorption cross section for particle j-nucleon (N) or quark (q) that recombines into the final π^0 meson. From this we obtain ≈ 0.40 for n (with an uncertainty of ±0.06 for different nuclear density functions [9]).

To check these predictions, we have parametrized the target dependences of our data in the form $n = n_0 + kX$. The fitted value of k is equal to

$$k = -0.06\pm0.08.$$

The mean value of n equals 0.37±0.02. Thus the parton recombination model reproduces well both the mean value of n and the behaviour of the $n(X)$ dependence in the region $X > 0.6$. With increasing X, the observed decrease of $n(X)$ does not exceed a statistical uncertainty.

2.3. We have obtained an indication that the $n(X_F)$ dependence is different for $X_F \lesssim 0.8$ and $X_F \gtrsim 0.8$ for reactions (1) with the proton projectile [10], where X_F is the Feynman variable in $p + p$ system.

3. We have found the factorized representation of the $p + C \to \pi^0 + x$ reaction invariant cross section versus the variables X_F and $P_\perp^2$ for $X_F \geq 0.66$:

$$Ed\sigma/d\mathrm{p} = \sigma_0 \cdot (1 - X_F)^N \cdot \exp(-BP_\perp^2), \tag{4}$$

where $\sigma_0 = (158\pm10)$ mb·GeV^{-2}·c^3; $N = 2.30\pm0.05$; $B = (10\pm1)$ GeV^{-2}·c^2.

In future we are planning the following:

— To continue the experimental data analysis in the frame of different theoretical models of cumulative meson production;

— To determine the double differential cross section for the $d + C \to \pi^0 + x$ reaction and to search for the factorized representation of the invariant cross section. The accumulated statistics of π^0 mesons after background subtraction is about $3.7 \cdot 10^4$ events.

— To investigate heavier neutral particle (η, ω,...) production in relativistic nucleus-nucleus collisions using the γ-spectrometer;

— To search for a possible π-condensation in central nucleus-nucleus collisions when the critical densities of nuclear matter can be formed with pion vacuum violations.

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