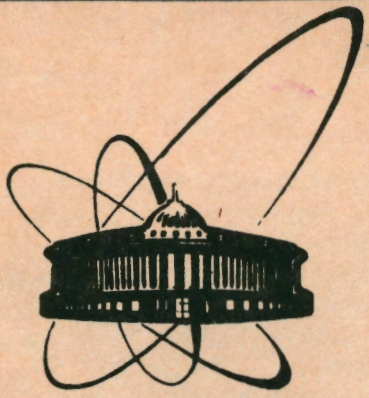

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INCLUSIVE NEUTRAL PION PRODUCTION AT FORWARD ANGLES AT 4.5 GeV/c PER NUCLEON IN NUCLEUS-NUCLEI REACTIONS

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We present measurements of fast forward π^0 production by relativistic alpha-particles on carbon and copper targets. 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 phenomena, the so-called cumulative production, was first observed by A.M.Baldin [1].

Our motivation in these experiments was to get more information about the production mechanism of neutral pions beyond the kinematic limit for free nucleon-nucleon and nucleon-nucleus collisions [2—5]. In this way we hoped to use neutral pions as a probe of short-distance effects in nuclei. It is also possible to find out to what extent such ideas as scaling and limiting fragmentation might be relevant for nuclear collisions at 4.5 GeV/c per nucleon.

The experiment was performed at the synchrophasotron of the Laboratory of High Energies (Dubna, Russia) using a single-arm lead glass Čerenkov spectrometer with scintillator counter hodoscopes. The primary beams were focussed producing on the target an elliptical beam spot with a horizontal axis of 3 cm and a vertical axis of 4 cm.

The used beam intensities varied from $5 \cdot 10^4$ per pulse up to $1.2 \cdot 10^5$. The pulse duration ranged from 0.40 to 0.55 s. The thickness of the targets used during data taking were 5.4 g/cm^2 for the Cu target and 12.6 g/cm^2 for the carbon one. To monitor the number of beam particles hitting the target, the monitor telescope composed of three scintillation counters was used. The electromagnetic lead glass calorimeter (FOTON-MASSER) was used to measure inclusive photon and π^0 energies. Details of the construction and performance of the lead glass hodoscope are given in Table 1.

The complete FOTON-MASSER setup has been tested and calibrated with an electron beam at the Dubna synchrophasotron [6]. the long-term gain stability of each of the lead glass modules was continuously monitored by 90 NaI (Tl) crystals using radioactive ^{241}Am α-sources. The center of the front surface of the lead glass hodoscope was spaced at 340 cm from the target and at an angle of 0° relative to the beam direction.

To detect charged particles, forty scintillation counter hodoscopes composed of $2 \times 10 \times 100$ cm^3 scintillators were used to determine the horizontal and vertical position of the particles. A schematic drawing of the experimental apparatus is presented in Fig.1.

Table 1. Basic Parameters of the Lead Glass Hodoscope

1.	Number of Lead Glasses	90 TF-1
2.	Module Cross Section	$R = 9$ cm Insert Circumference
3.	Module Length	35 cm; 14 R.L.
4.	Spatial Resolution	~ 4 cm
5.	Angular Resolution	~ 1°
6.	Energy Resolution	$(4.3/\sqrt{E})\%$; E (GeV)
7.	Gain Stability	$(1 \div 2)\%$
8.	Dynamic Range	50 MeV ÷ 6 GeV
9.	Minimum Ionizing Signal	400 MeV Photon Equivalent
10.	Total (Rectangular) Area	140×215 cm²
11.	Total Weight	4000 kg

The lead-glass modules were divided into 14 groups. Signals in each group linearly summed up were used in fast trigger after discrimination by amplitude.

The thresholds of the discriminators were at a level of 1.0 GeV. This energy level of triggering allowed the number of triggers from low energy events to be decreased. The mean velocity of triggering was about 15 events per pulse for an event length of 132 16-bit words. About $1.9 \cdot 10^9$ and $0.8 \cdot 10^9$ primary α-particles crossed the carbon and copper targets, respectively. A total of about $6 \cdot 10^5$ triggers was recorded during the experiment. Primary information was processed using a geometric reconstruction program. The inclusive spectra of π^0 were extracted from the raw data according to the following selection criteria:

1. $E_\gamma \geq 500$ MeV
2. $E_{\gamma T} \geq 180$ MeV
3. $N_\gamma \geq 2$
4. $p_T \geq 0.16$ GeV/c,

where E_γ is the energy of γ-quanta; $E_{\gamma T}$, the transverse momentum of γ-quanta; N_γ, the number of γ-quanta in the event; and p_T, the transverse momentum for $\gamma\gamma$ combinations.

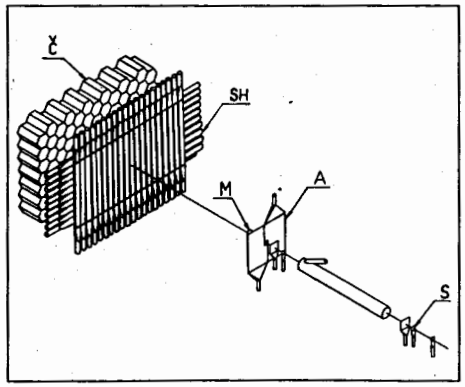

Fig.1. A schematic drawing of the experimental apparatus

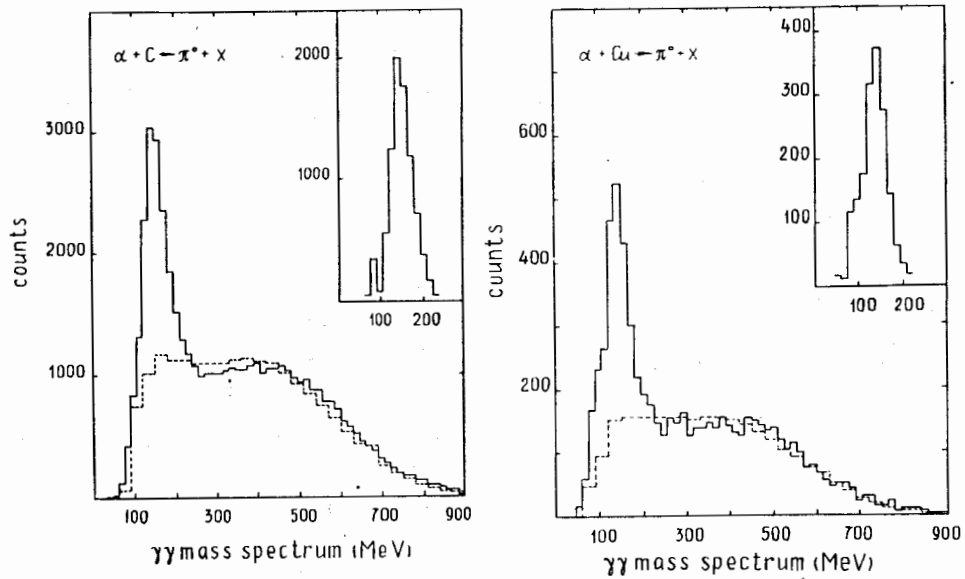

Fig.2. Invariant mass spectra of $\gamma\gamma$ pairs for α + C and α + Cu reactions at 4.5 GeV/c·nucleon. The insets show the π^0 peak after background subtraction

The combinatorial invariant mass ($M_{\gamma\gamma}$) distributions of $\gamma\gamma$ combinations selected according to criteria 1—4 are shown in Fig.2. The dotted histograms in Fig.2 present 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

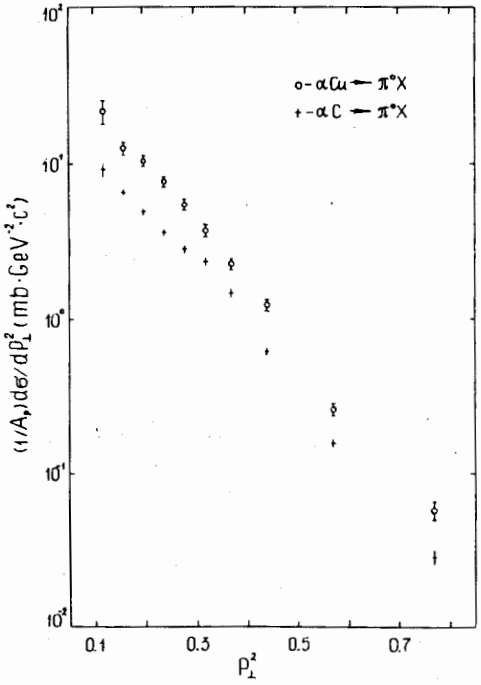

Fig.3. Inclusive p_T^2 distributions of neutral pions for $E_{\pi^0} \geq 2$ GeV and $\theta_{\pi^0} \leq 16°$. The errors in the figure reflect only statistical uncertainty

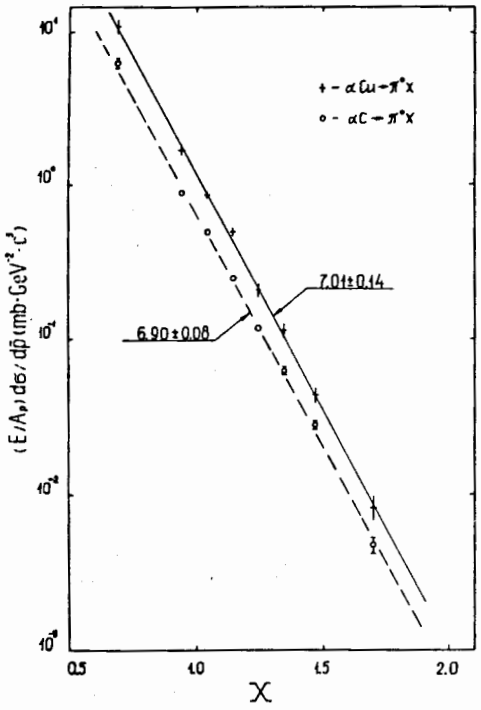

Fig.4. Invariant inclusive cross sections of neutral pions at $p_T \approx 0$ for 4.5 GeV/c·n alpha projectile on carbon and copper targets versus cumulative number X. Figures appointed on the curves are meanings of parameter X_0^{-1}

distributions is essential only for M < 100 MeV. These masses were excluded in the data analysis.

Figure 3 shows the inclusive p_T^2 spectra of neutral pions on carbon and copper targets for $E_{\pi^0} \geq 2$ GeV and $\theta_{\pi^0} \leq 16°$, where E_{π^0} and θ_{π^0} are the energy and angle of π^0 emission in the laboratory system, respectively. The data are described by exponential parametrization $d\sigma/dp_T^2 \sim \exp(-Ap_T^2)$. We get the following values for slope parameters A:

In the reaction $\alpha\, C \to \pi^0 x$

$$A = (6.5 \pm 0.4)\ (\text{GeV/c})^{-2} \text{ for } 0.16 \leq p_T^2 \leq 0.32 \text{ and}$$
$$A = (10.5 \pm 0.3)\ (\text{GeV/c}^{-2}) \text{ for } 0.32 \leq p_T^2 \leq 0.77.$$

In the reaction $\alpha\, Cu \to \pi^0 x$:

$$A = (7.7 \pm 0.7)\ (\text{GeV/c})^{-2} \text{ for } 0.16 \leq p_T^2 \leq 0.32 \text{ and}$$
$$A = (10.0 \pm 0.4)\ (\text{GeV/c})^{-2} \text{ for } 0.32 \leq p_T^2 \leq 0.77.$$

In Fig.4 we present the invariant inclusive cross sections of neutral pions at $p_T \approx 0$ for the 4.5 GeV/c·nucleon alpha projectile on carbon and Cu targets versus cumulative number X. The inclusive cross sections in Fig.4 were multiplied by $\left(0.1 + 0.9e^{-2.7\cdot\langle p_T^2\rangle}\right)^{-1}$, where $\langle p_T^2\rangle$ is the mean value of p_T^2 for a given interval of X (see Table 2).

Table 2

ΔX	0.6—0.9	0.9—1.0	1.0—1.1	1.1—1.2	1.2—1.3	1.3—1.4	1.4—1.6	1.6—2.0
$\langle p_T^2\rangle$ $(\text{GeV/c})^2$	0.12	0.16	0.20	0.23	0.25	0.27	0.29	0.32

The cumulative number X is equal to:

$$X = \frac{2\cdot M_N \cdot E_{\pi^0} - M_{\pi^0}^2}{2\left(E_N \cdot M_N - E_N \cdot E_{\pi^0} - M_N^2 + p_N \cdot p_{\pi^0} \cdot \cos\theta_{\pi^0}\right)}.$$

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}, the angle of π^0 emission (lab).

The data in Fig.4 are well described by exponential parametrization $Ed\sigma/d\vec{p} \sim \exp(-X/X_0)$, where the parameter X_0 characterizes the quark-parton structure function of the nucleus. We present the target dependence of the form $Ed^3\sigma/d^3p \sim A_T^n$, where A_T is the nucleon number of the target. The results are shown in Figs.5 and 6 where we have plotted «n» against p_T^2 and cumulative number X, respectively, for pions produced by 4.5 GeV/c·nucleon alpha projectiles. We see that $n \approx 0.37$ indicating that collisions leading to the production

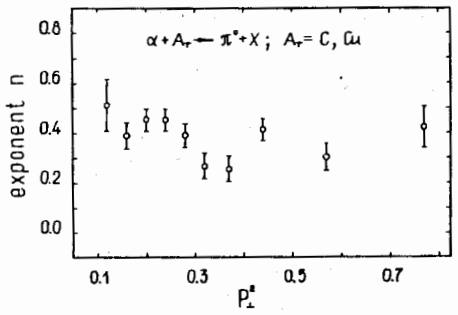

Fig.5. Target mass dependence for π^0 production. The data were fitted to the form $Ed^3\sigma/d^3p \sim A_T^n$ for carbon and copper targets. Exponent «n» is plotted versus p_T^2 for 4.5 GeV/c per nucleon alpha projectiles

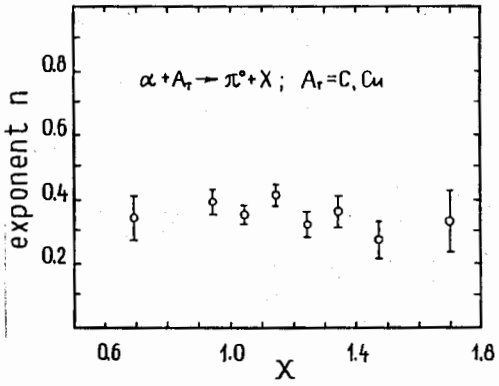

Fig.6. Target mass dependence for π^0 production. The data were fitted to the form $Ed^3\sigma/d^3p \sim A_T^n$ for carbon and copper targets. Exponent «n» is plotted versus X cumulative number for 4.5 GeV/c·nucleon alpha projectiles

of neutral pions have a A_T-dependence expected for processes which are peripheral with respect to the target nucleus. There is no discrepancy between the A_T-dependence of our data and the quark fragmentation model [7] which predicts $n \approx 0.4$ independent of pion momentum for large X. We have parametrized the target dependences of our data for carbon and copper targets for p_T^2 and cumulative number X in the form $n = k \cdot X(p_T^2) + n_0$. The fitted values of k and n_0 are presented in Table 3.

Table 3

	$n = f(X)$ $0.69 \le X \le 1.70$	$n = f(p_T^2)$ $0.16 \le p_T^2 \le 0.77$	$n = f(p_T^2)$ $0.28 \le p_T^2 \le 0.77$
k	-0.06 ± 0.08	-0.16 ± 0.11	0.09 ± 0.16
n_o	0.43 ± 0.09	0.43 ± 0.04	0.30 ± 0.07

CONCLUSION

We have performed the experiment to measure forward π^0 production in α C $\to \pi^0 x$ and α Cu $\to \pi^0 x$ collisions at 4.5 GeV/c · nucleon. We have observed pions having twice the maximum energy available in collisions between two free nucleons. The productions of such pions must involve nuclear effects. The X cumulative number variable was used to find a simple universal parametrization of the data. The dependence of the cross sections on the mass of the target is approximately $A_T^{0.37}$. The target mass dependence suggests that fast pions detected in this experiment are produced peripherally with respect to the target. The target mass dependence for large pion momenta is reproduced by the quark-parton model of the nucleus.

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REFERENCES

1. Baldin A.M. et al. — Sov. Journ. Nucl. Phys., 1974, 18, p.41; 1975, 20, p.629.
2. Abraamyan Kh. et al. — JINR, P1-88-334, Dubna, 1988.

3. Abraamyan Kh. et al. — JINR, P1-89-240, Dubna, 1989.
4. Abraamyan Kh. et al. — JINR Rapid Commun. No. 7[46]-90, Dubna, 1990.
5. Moeller E. et al. — Phys. Rev. C, 1983, v.28, No.3, p.1246.
6. Abraamyan Kh., Khachaturian M., Khudaverdyan A. — PTE, 1988, 6, p.24.
7. Berlad G., Dar A. — Phys. Lett., 1981, 102B, p.385.

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Абраамян Х.У. и др. E1-92-307

Инклюзивное образование нейтральных пионов
под передними углами в ядро-ядерных взаимодействиях
при импульсе 4,5 ГэВ/с на нуклон

С помощью калориметра из свинцового стекла измерены распределения поперечных импульсов и кумулятивных чисел нейтральных пионов в реакциях $\alpha + C \to \pi^0 + x$ и $\alpha + Cu \to \pi^0 + x$ при импульсе 4,5 ГэВ/с на нуклон. Измерена зависимость сечения образования пионов от массы ядра-мишени.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1992

Abraamyan K. et al. E1-92-307

Inclusive Neutral Pion Production
at Forward Angles at 4.5 GeV/c per Nucleon
in Nucleus-Nuclei Reactions

Transverse momentum p_T, cumulative number X distributions of inclusive neutral pions are measured with a lead glass calorimeter in 4.5 GeV/c per nucleon $\alpha + C \to \pi^0 + x$ and $\alpha + Cu \to \pi^0 + x$ reactions. The target-mass dependence for π^0 production is presented.

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

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