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A-DEPENDENCE OF INCLUSIVE $\pi^{\pm}$-MESON PHOTOPRODUCTION

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А-ЗАВИСИМОСТЬ ФОТОРОЖДЕНИЯ ИНКЛЮЗИВНЫХ $\pi^{\pm}$-МЕЗОНОВ

Приводятся и обсуждаются экспериментальные данные по A-зависимости фотопионов в широком интервале энергии и углов вторичных $\pi^{\pm}$-мезонов. Показано, что если инвариантное сечение $f = \frac{E}{P^2}\frac{d^2\sigma}{dPd\Omega}$ представить в виде $f \simeq BA^{n}$, то в энергетической зависимости показателя n наблюдаются те же особенности, которые были наблюдены в аналогичных адронных процессах. Расширение углового интервала до 20 – 160° в л.с. предоставило возможность более детально изучить природу этих особенностей. Делаются попытки объяснения наблюденных особенностей в функции $n = n(T_{\pi})$ путем учета дополнительных (к прямому процессу фоторождения на ядерных нуклонах) источников образования инклюзивных π-мезонов.

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The experimental data on A-dependence of photopions in wide energy and angular intervals of secondary $\pi^{\pm}$-mesons are discussed. It is shown that if the invariant cross section $f = \frac{E}{p^2} \frac{d^2\sigma}{dp\,d\Omega}$ is represented in the form of $f \simeq BA^{n}$, then in the energy dependence of exponent n one can observe the same singularities as in the analogous hadron processes. The expansion of the angular interval up to 20 - 160^{0} in lab made it possible to study in detail the nature of these singularities. The attempts are made to explain the observed singularities in the function $n = n(T_{\pi})$ by taking into account additional (to the direct process of photoproduction on nuclear nucleons) sources of the inclusive π-meson production.

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1. Introduction

Owing to new phenomena revealed in the relativistic nuclear physics, in particular, to the cumulative effect [1, 2] and nuclear scaling [3, 4], much attention is given to production of particles on nuclei in the region forbidden for the two-particle kinematics (i.e. in the cumulative region). The dependence of cross section on the atomic number of the target nuclei (A-dependence) is one of the most important characteristics of these processes. The recent data on the production of backward π -mesons by hadrons (by protons [5], and by π -mesons [6]) have shown singularities in the A-dependence the exausting explanation of which is not so far found. So new data are needed, in particular for the other primary particles and under various kinematical conditions.

In the case of nuclear photoproduction the cumulative proton yield is studied comparatively well [7, 8], whereas experimental results on such mesons photoproduction are almost absent. In the present work we have presented the experimental data on A-dependence of $\pi^{\pm}$-mesons (both cumulative and noncumulative) produced by bremsstrahlung γ -quanta with the maximum energy 4.5 GeV at production angle 20 - 160^{0} and momenta 0.15 ÷ 1.3 GeV/c.

2. Experimental Setup

The experimental results are obtained with Γ-3 beam of the Yerevan electron synchrotron using a "Deuteron" setup described in detail in [9, 10]. $\pi^{\pm}$-mesons were identified with two detectors. The first one was a range detector [9] allowing to identify $\pi^{\pm}$-mesons (without charge sign division) with the kinetic energy $T_{\pi} = 45 \div 160$ MeV at production angle of $20 - 160^{o}$. The absolute energy spreads and solid angle were $\Delta T = 12 \div 8$ MeV and $\Delta\Omega = 10$ msterad, respectively. As the second detector we have taken a magnetic spectrometer with the time-of-flight measurement technique, which enabled to identify [10] $\pi^{\pm}$-mesons with the kinetic energy $0.18 \div 1.2$ GeV at $20 - 120^{o}$. The relative momentum resolution and the solid angle of the spectrometer were $\Delta P/P = \pm 6.5$ % (at $P_{\pi} \gtrsim 1.0$ GeV/c) and $\Delta\Omega = 1.25$ mster, respectively. The time-of-flight was measured in the interval $\tau = 15-50$ nsec (on the basis of 4.5 m) with the relative errors $\Delta\tau/\tau \lesssim \pm 5$ % ($\Delta\tau = \pm$ 0.8 nsec).

3. Experimental results

We have investigated the reaction

$$\gamma + A \rightarrow \pi + X , \qquad (1)$$

where X is the residual system. As solid targets the nuclei ^{12}C, ^{27}Al, ^{63}Cu, ^{118}Sn and ^{208}Pb were used whose characteristics are given in Table 1.

The yield of reaction (1) was measured simultaneously for $\pi^{\pm}$-mesons and protons in the case of the range detector and for π^{+}-mesons and protons in the case of the magnetic spectrometer. In the latter case transition to the measurement of the yield of π^{-}-mesons is done by changing the magnetic field polarity. According to the measured yields the invariant cross sections were composed

$$f = \frac{E}{P^2}\frac{d^2\sigma}{dP d\Omega} = \frac{E}{P^2}\cdot C\,\frac{N}{\Delta\Omega(\Delta P/P)\;P\,N_{nuc}N_\gamma} \tag{2}$$

where N - is the measured yield, E , P and $\Delta P/P$ are respectively total energy, momentum and momentum resolution of measurements, $\Delta\Omega$ - is the solid angle, N_{nuc} and N_γ are respectively the number of nuclei on the beam way in the target and the number of equivalent γ -quanta defined by measuring the beam power with a Gaussian-type quantameter. The coefficient C in (2) takes into account corrections due to nuclear absorption and multiple scattering in the target and detector matter, pairproduction in the target, decay in flight and the particle detection efficiency. The obtained values of the invariant cross section at fixed energy and angle were presented as a function of atomic number A of the target nuclei. Fig.1 gives some data as an example. Only statistical errors are shown. The absolute errors, which are mainly due to the uncertainties in definition of the coefficient C and measurement of N_γ , do not exceed, by estimates, 20 % and are inessential for the present work.

The solid lines in fig.1 are drawn by the least squares method according to the representation

$$f = BA^n . \tag{3}$$

In the present work we have analyzed [5, 6] the behaviour of the exponent n as a function of energy and detection angle of inclusive $\pi^\pm$ -mesons.

4. Discussion of Experimental Results

Considering in detail the behaviour of exponent n in π production on nuclei at 180° by 8.6 GeV protons the authors of Ref.[5] observed complex dependence of n on kinetic energy of secondary particles. It turned out that with increasing the energy (beginning from ~100 MeV) n (>1) first decreases, passes through a minimum (at $T_\pi \simeq 150$ MeV), and then increases and at high energies (already in cumulative region) becomes again $n \geqslant 1$. A minimum value of n (150) $\simeq$ 0.8. Such a strange behaviour of n was confirmed in the experiment [6] with primary π^- -mesons with momentum 4.4 GeV/c, not for the fixed angle $\vartheta_\pi = 180^o$, but for the interval $110^o \leq \vartheta_\pi \leq 150^o$. Thus it was shown the presence of complex dependence of exponent n in A^n -dependence of cross section on the energy of backward inclusive π -mesons in the hadron-caused processes. If this phenomenon is universal, then it must take place also in analogous reactions with primary electromagnetic (and weak) particles.

In fig.2 there is shown the dependence of n for reaction (1) (dashed points) on kinetic energy of secondary π -mesons (without charge sign division) at $\vartheta_\pi = 120^o - 160^o$. By blank points the results of Ref. [5] are shown, too. As one can see, in photoproduction processes a minimum in the values at $T_\pi \approx 150$ MeV is observed, although the general character of interaction of γ -quanta as well as of hadrons with nuclei in the investigated region of initial energies is different [11] (if $\sigma_t^{\gamma A} \sim A$, then $\sigma_t^{hA} \sim A^{2/3}$).

The authors of Refs [5] and [6] made no effort as to explain the causes of the above mentioned behaviour of exponent n .

The authors of Ref. [12] gave qualitative considerations in order to interpret the presence of a minimum in distribution $n = n(T_\pi)$ in the data of Ref. [5]. The essence of these considerations is as follows. The produced secondary π -mesons when passing through a nucleus scatter on nuclear nucleons. The cross section of this interaction has two resonances. A first one is due to the absorption of π -mesons by nucleon pairs and take place at 120-130 MeV [13]. A second one is generally known: at $\sim$ 190 MeV the total cross section of (πN)-interaction has a maximum [14]. The total effect of these two processes is responsible for the maximum of the total cross section of π-mesons scattering inside the nucleus at about 150 MeV. The increase of the cross section results in the increase of losses of particles from the given angular and energy interval. As far as the scattered particles, as a rule, lose their energy, the "transfer" of the particles from the resonance energy region to the low-energy region occurs. Such a "transfer" is stronger, the heavier is the nucleus. As a result, in the resonance region exponent n has a minimum value, while in the region of lower energies may grow notably and become more than unity. As to the high-energy region, proceeding from the fact that here $n \approx 1$, the authors [12] conclude on the decrease of the effective absorption of $\pi^{\pm}$-mesons, in other words, on the decrease of πN-cross section inside the nucleus. Since the $\pi^{\pm}$-meson energy is still small for the account of increase of longitudinal distances in πN-interactions, this conclusion seems not quite grounded.

It is doubtless that the absorption process of the secondary particles affects the A-dependence character. However, it seems that this process can scarcely account for the experimentally observed character of $n = n(T_{\pi})$ dependence. This is seen particularly well on the photoproduction example.

Haven't there been secondary interactions of π-mesons and other particles with the residual nucleus, the cross section $\sigma_t(\gamma A \to \pi)$ would have been proportional to A^1, since photons interact with all individual nucleons of the nucleus. The scattering of pions on nuclear nucleons must have brought to the decrease of exponent n in A^n-dependence. Hence for the total cross section of $\pi^{\pm}$-meson photoproduction $\sigma_t(\gamma A \to \pi)$ n must have been less than unity. Actually in Ref. [15] we have measured A-dependence of total (integrated over angle and energy) cross section of charged π -mesons by photons with energy E_{γ}^{max} = 4.5 GeV and shown that exponent in this case was no more than 0.84 ± 0.023. Obviously $\bar{n}$ =0.84 is the mean characteristic of the $\pi^{\pm}$-meson photoproduction on nuclei and does not exclude the presence of local singularities in $n(T_{\pi})$ dependence. Here we only wish to emphasize that the "introduction" of the secondary interaction results in the decrease of this mean characteristic from $\bar{n}$ = 1 down to $\bar{n}$ = 0.84. Therefore, if for some value of energy, owing to the resonance increase of the interaction cross section, the absorption of $\pi^{\pm}$-mesons increases, this must result in decrease of the exponent as compared to the mean value $\bar{n}$ =0.84 , which fact is observed neither in hadron nor in photon experiments. The latters proved that $n_{min} = \bar{n}$ (see fig.2).

Thus, the nature of rise of a minimum in $n = n(T_{\pi})$ is connected not with additional losses of $\pi^{\pm}$-mesons at $T_{\pi} \simeq$ 150 MeV, but on the contrary, is apparently the consequence of the presence of additional sources of $\pi^{\pm}$ -meson production in the region $T_{\pi} \lesssim$ 150 MeV which enhance A-dependence at notably high energies.

In order to confirm this hypothesis let us consider the dependences $n = n(T_{\pi})$ for different angles of $\pi^{\pm}$ -mesons. These data on photoproduction are given in fig.3, where it is seen that, first, with decreasing the angle the minimum on the energy scale T_{π} is shifted to the region of high energies and then disappears, and, second the increase of n in the region T_{π} < 150 MeV enhances in the case of small angles.

The data for $\vartheta_{\pi} = 30^{0}$ show that for the region T_{π} > 200 MeV the exponent n remains constant and is equal to 0.8 ÷ 0.85 , i.e. close to $\bar{n}$ =0.84 for A-dependence of total cross section of $\pi^{\pm}$-meson photoproduction. And this is quite natural: at small angles and high energies of

π -mesons the process of direct photoproduction on nuclear nucleons is dominating. The secondary rescatterings in the nucleus reduce n from 1 down to 0.8 - 0.85. With increasing the angle the increase of n is observed, since a new mechanism - the cumulative production of $\pi^{\pm}$-mesons which enhances A-dependence, begins contributing. As to the kinetic energy region $T_{\pi} < 150$ MeV, here the enhance of growing n for small angles is apparently due to the cascade π -meson production. The probability of the latters in the region of small angles is higher since the high-energy secondary particles are produced mainly forward, and the higher is the energy of these particles the higher is the probability of produced by them low-energy cascade π -mesons. Certainly, the high-energy secondary particles are also at large angles, however, their amount is extremely small (with increasing the production angle the spectra of both π -mesons and protons become notably steeper). As a result of that, the enhance of A-depenedence for large angles and low energies of secondary $\pi^{\pm}$ -mesons is relatively weak. As to the increase of n which is due to the mechanism of resonance absorption [12] of $\pi^{\pm}$ -mesons, it must take place both for large and small production angles, since there is no chosen direction in the nucleus for secondary particles. In other words, the character of $n = n(T_{\pi})$ dependence in this case must be similar for all the angles, which fact contradicts the experiment.

In fig.4 are given the angular dependences of exponent n for various energies. It is seen that actually for $T_{\pi} < 150$ MeV n decreases as the angle grows, in the region $T_{\pi} \simeq 150 - 300$ MeV n =const =0.8-0.85 and at large energies n grows with ϑ_{π} and becomes more than unity. The latter circumstance, as it was mentioned above, is apparently connected with the cumulative effect, the physical essence of which cannot be at present considered clear.

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Table 1

	C	Al	Cu	Sn	Pb
Atomic number	12	27	63	118	208
Charge	6	13	29	50	82
Width in rad units	0.036	0.059	0.13	0.16	0.25
Number of nuclei in cm², 10^{22}	7.35	3.41	1.51	0.72	0.485

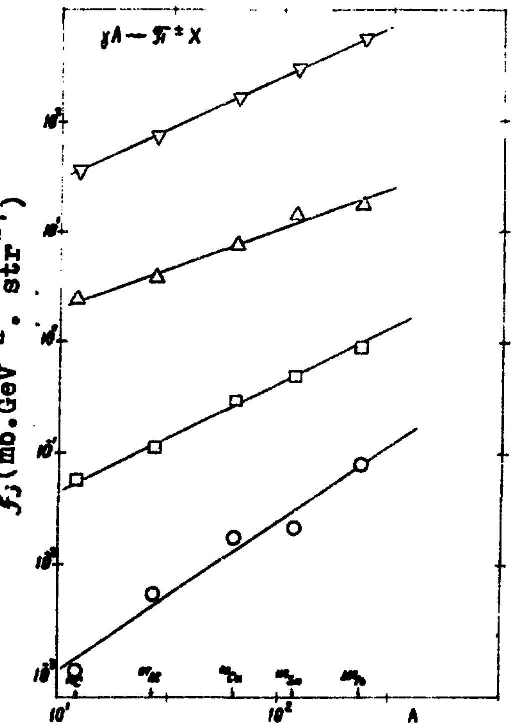
γA → π± X
f_i (mb.GeV⁻². str⁻¹)
A

Fig.1

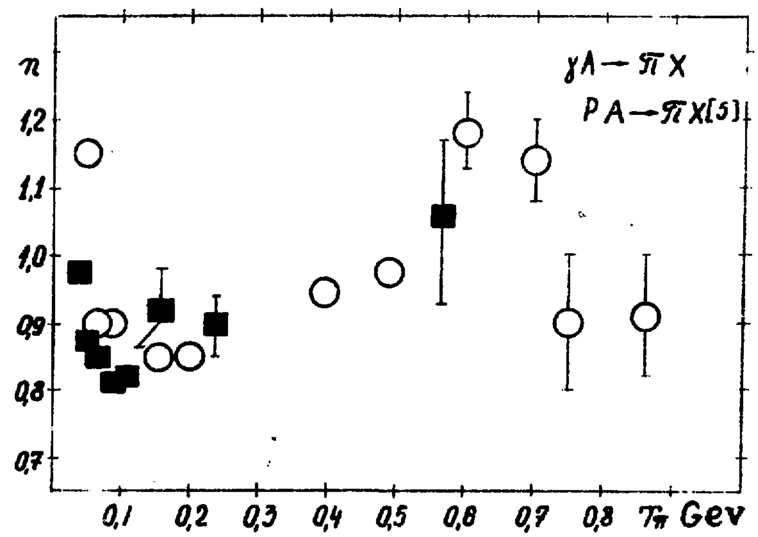
n
γA → π X
PA → π X[5]
1,2
1,1
1,0
0,9
0,8
0,7
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
Tπ Gev

Fig.2

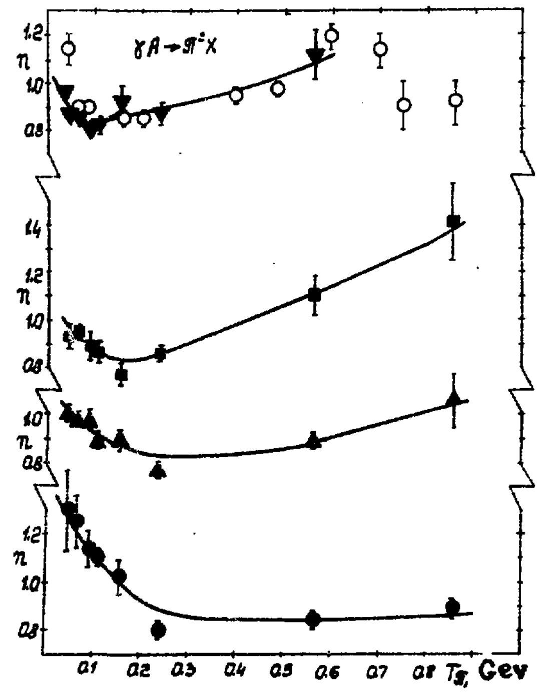
γA → π°X
n
1.2
1.0
0.8
1.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Tπ, Gev

Fig.3

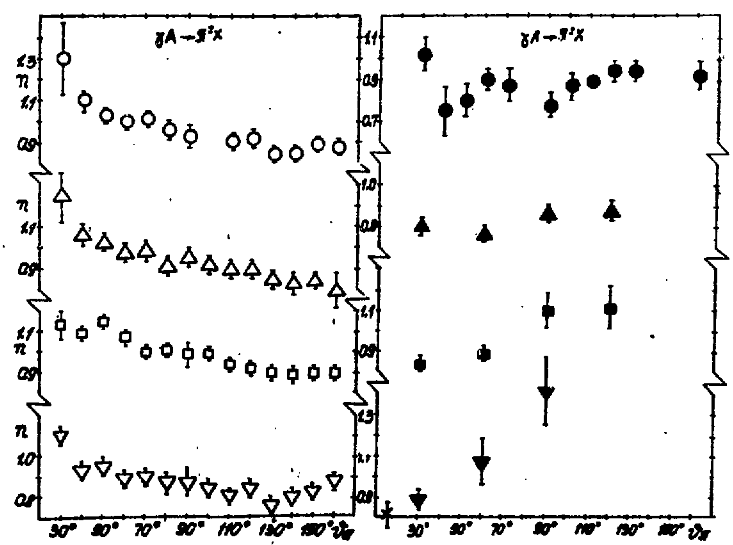
γA → π°X
n
30°
50°
70°
90°
110°
130°
150°
ϑπ

Fig.4

CAPTIONS

Fig.1 Dependence of invariant cross section f of reaction $\gamma A \to \pi^{\pm} X$ at E_{γ}^{max} =4.5 GeV and production angle $\vartheta_{\pi}=90^{o}$ on mass number of target nuclei A. ○ - kinetic energy of $\pi^{\pm}$-mesons, T_{π} =851 MeV, □ -356 MeV, △ -283 MeV, ▽ - 67 MeV.

Fig.2 Dependence of exponent n on kinetic energy of $\pi^{\pm}$ -mesons. Experimental points: ● -reaction $\gamma A \to \pi^{\pm} X$ at production angle $\vartheta_{\pi}=120^{o} - 160^{o}$, ○ - reaction $pA \to \pi^{+} X$ at $\vartheta_{\pi} = 180^{o}$ [5].

Fig.3 Dependence of exponent n on kinetic energy of $\pi^{\pm}$ -mesons at various production angles of $\pi^{\pm}$ -mesons in reaction $\gamma A \to \pi^{\pm} X$. Experimental points: ● - production angle $\vartheta_{\pi}=30^{o}$, ▲ - 60^{o}, ■ -90^{o}, ▼ - $120^{o}-160^{o}$, ○ - reaction $pA \to \pi^{\pm} X$, $\vartheta_{\pi} = 180^{o}$ [5].

Fig.4 Dependence of exponent n on production angle of $\pi^{\pm}$ -mesons at various kinetic energies of $\pi^{\pm}$ -mesons in reaction $\gamma A \to \pi^{\pm} X$. Experimental points: ○ - kinetic energy T_{π} =48 MeV, △ - 67 MeV, □ - 91 MeV, ▽ - 108 MeV, ● - 155 MeV, ▲ - 238 MeV, ■ - 356 MeV, ▼ - 851 MeV, × - 900 MeV [16].

R E F E R E N C E S

1. A.M.Baldin et al. Preprint JINR, P9-5442 (1970).
2. A.M.Baldin et al. Yad.Fiz., V.18, 79 (1973).
3. Yu.D.Bayukov et al. Yad Fiz., V.18, 1246 (1973).
4. G.A.Leksin. Proceedings of Intern. Symp. on High Energy Physics, Tbilisi 1976, V.1, A6-3 (1977).
5. A.M.Baldin, V.S.Stavinsky. Proceedings of Intern. Symp. on Problems of High Energy Physics, Dubna 1978, p.261.
   A.M.Baldin et al., Preprint JINR, 1-12396 (1979).
6. Yu.D.Bayukov et al., Preprint ITEP - 30 (1979).
7. M.D.Amarian et al. Sci. Report EPI -173 (19) - 76,
   K.V.Alanakian et al. Sci. Report EPI -174 (20) -76.
8. K.V.Alanakian et al. Yad.Fiz. V.26, 5 (1977);
   K.V.Alanakian et al. Sci. Report EPI -384 (44) - 79.
9. K.V.Alanakian et al. Sci.Report EPI -155 (76).
10. K.V.Alanakian et al., Sci.Report EPI - 408 (15) - 80.
11. M.I.Strikman, L.L.Frankfurt, Yad.Fiz., V.29, p.490 (1979).
12. M.I.Strikman, L.L.Frankfurt. Proceedings of XIV Winter School LINR, 1979.
13. D.Ashery, Proc. of 8-th Intern. Conf. on High Energy Phys. and Nucl. Str., Vancoover, 1979, Amsterdam, N-Y, Oxf., 1980, p.385.
14. V.S.Barashenkov, Sechenie vzaimodejstviya elektromagnitnikh chastits. "Nauka", Moscow 1966.
15. K.V.Alanakian et al., Sci.Report EPI - 153 (75).
16. L.O.Abrahamian et al. Sci.Report EPI - 150 (75).

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