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STUDY OF $\pi\pi^0$ PRODUCTION BY PIONS IN THE NUCLEAR COULOMB FIELD AT THRESHOLD

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Among the experimental tests of colour degrees of freedom of quarks measurement of the π° lifetime is most accurate as far as the number of colours is concerned [1,2]. The measured π° lifetime agrees with the calculations made on the basis of the colour SU(3) theory and hypothesis on PCAC anomaly [3]. In the frame of this theory the processes $\pi^{\circ} \to \gamma\gamma$, $\gamma \to 3\pi$, $\gamma\gamma \to 3\pi$ and some others were shown [4] to be completely described in the l. energy limits by the simplest quark diagram as in fig.1a in a finite order of the renormalizable perturbation theory. However, since some authors [5] criticised the PCAC anomaly theor it is important to find other experimental opportunities to test both this theory and the colour SU(3) theory [1].

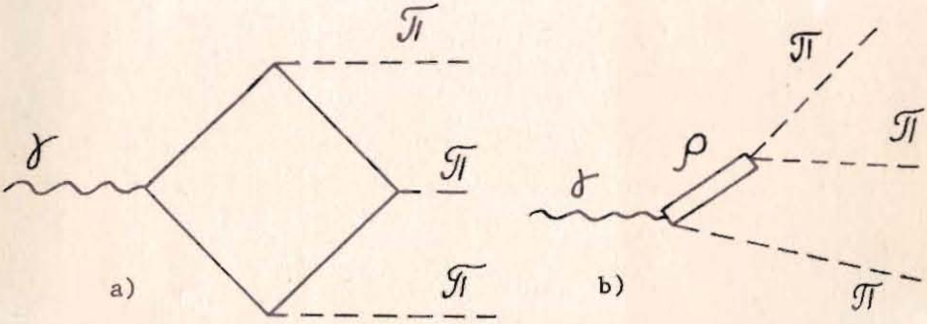

Fig.1. Diagrams describing the amplitude $F^{3\pi}$ of $\gamma \to 3\pi$: a) quark diagram completely determining $F^{3\pi}$ in the low energy limit; b) the diagram containing the ρ-meson in the intermediate state and contributing to $F^{3\pi}$ in the physical region.

For this purpose it was suggested in [1,7-9] to study $\gamma \to 3\pi$ via Coulomb $\pi\pi^{\circ}$ production on nuclei

$$\pi^{-} + (A, Z) \to \pi^{-} + \pi^{\circ} + (A, Z) \qquad (1)$$

near the threshold. The differential cross section of reaction (1) on nuclei with the charge Z is [7,8]

$$\frac{d\sigma}{dS\,dq^2\,d\cos\Theta} = \frac{Z^2\alpha(q^2-(S-m^2)/2E)^2(S-4m_\pi^2)^{3/2}}{1024\pi^2\ q^4\sqrt{S}}(F^{3\pi})^2\ \sin^2\Theta, \qquad (2)$$

where $F^{3\pi}$ is the amplitude of $\gamma\to 3\pi$, $S=(P_{\pi^-}+P_{\pi^0})^2$, Θ is the angle of the π^--scattering in c.m., E is the incident beam energy, q is the momentum transferred to a nucleus.

As was shown /6-8/ the low energy theorem follows from Alder's PCAC anomalies:

$$F^{3\pi}(0) = \frac{F^{\pi}(0)}{e f_\pi^2}, \qquad (3)$$

where f_π is the parameter of PCAC. Its value $f_\pi \simeq 93$ MeV can be obtained from experimental data on $\pi\to\mu\nu$, $e=(4\pi a)^{1/2}$. This theorem connects $F^{3\pi}$ and F^{π} which is the amplitude of $\pi^0\to 2\gamma$ in the limit of zero pion mass.

So for $F^{3\pi}(0)$ we have /6/:

$$F^{3\pi}(0) = -\frac{e}{4\pi^2 f^3}(Q_u^2-Q_d^2)N_c, \qquad (4)$$

where N_c is a number of quark colours, $Q_{u,d}$ is a charge of quarks. Expression (2) contains $F^{3\pi}$ in the physical region and the contribution of the diagram with ρ-meson (Fig.1b) should be taken into account /7,8/. The transition from $F^{3\pi}(0)$ to $F^{3\pi}(S_{12},S_{13},S_{23})$ can be done using the extrapolation formula /7,8/:

$$F^{3\pi}(S_{12},S_{13},S_{23}) = F^{3\pi}(0)[1+|C_\rho|e^{i\phi}(\frac{S_{12}}{m_\rho^2-S_{12}}+\frac{S_{13}}{m_\rho^2-S_{13}}+\frac{S_{23}}{m_\rho^2-S_{23}})], \qquad (5)$$

where $S_{ij}=(P_i+P_j)^2$, P_i is 4-momentum of the π-meson in $\gamma\to 3\pi$,

$C_\rho = \frac{2\cdot f_{\rho\pi\pi}f_{\rho\pi\gamma}}{m_\rho^2F^{3\pi}(0)}$, m_ρ is the mass of ρ-meson, $|f_{\rho\pi\pi}|\simeq 5.56$, $|f_{\rho\pi\gamma}|\simeq 0.217$ GeV^{-1} are the constants of the corresponding ρ-meson decay modes. But only absolute values of these constants are known and that is why indefinite phase ϕ enters into (5). Hence Coulomb production should be studied at the threshold, i.e., where S_{ij} are small and the contribution of the pure quark diagram dominates.

The experiment on $\pi^-\pi^0$ production in the nuclear Coulomb field was carried out at the IHEP accelerator with the SIGMA spectrometer at the same time as the Compton effect on the pion /10,11/ was studied. Figure 2 presents the layout of the experimental setup. The primary 40 GeV/c beam particle was identified by the differential and threshold gas Cherenkov counters and their trajectories were measured by scintillation

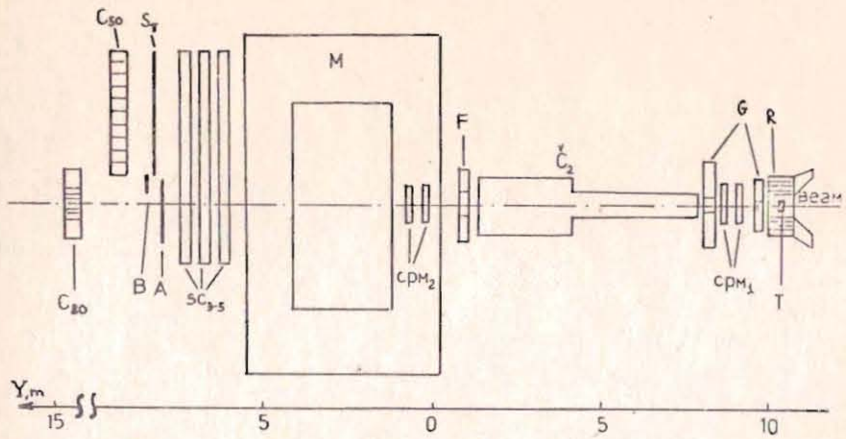

Fig.2. The experimental set-up layout.

hodoscopes and proportional chambers with an accuracy of σ_x = 0.6 mm and σ_Θ = 0.12 mrad C, Al and Fe targets of ~0.25 radiation length were used. Secondary π-mesons were detected by the magnetic spectrometer consisting of the magnet M, the proportional chambers $CPM_{1,2}$, the magnetostrictive spark chamber system SC, and scintillation hodoscope S_π. The energy and position of the photons from π^0-decay were measured with the help of the gamma-detector $\check{C}_{80}$ consisting of 80 lead glass Cherenkov counters. It comprised 64 counters 38x38x420 mm^3 in size and 16 outside counters 100x100x420 mm^3 in size.

The trigger selected events with π-meson and photons in the final state, which satisfied the following conditions:

- there is a track of a beam particles;
- there is one charged particle behind the magnet;
- there is no signal from the guard system around the target and from the threshold Cherenkov counter $\check{C}_2$ with the threshhold 18 GeV/c for π-meson;
- the energy deposited in 64 counters of the γ-detector exceeds 5 GeV.

The experimental setup was described in detail in refs. /10,11/.

In the off-line analysis the following criteria were used for selection of the events of reaction (1):

- only one negative particle with the momentum $P<18$ GeV/c was detected by the magnitude spectrometer;
- the tracks of incident and scattering pions were matched in the target;
- the pion scattering angle is $\Theta_{lab}>3.5$ mrad;
- 2 photons with the energy over 1 GeV were detected in the spectrometer $\check{C}_{80}$.

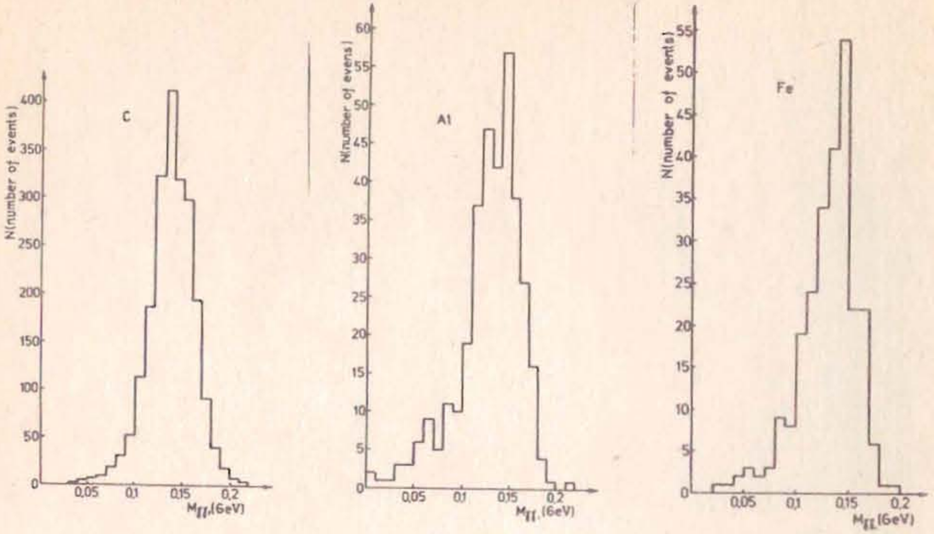

Fig.3. Distribution of events over effective mass of photons.

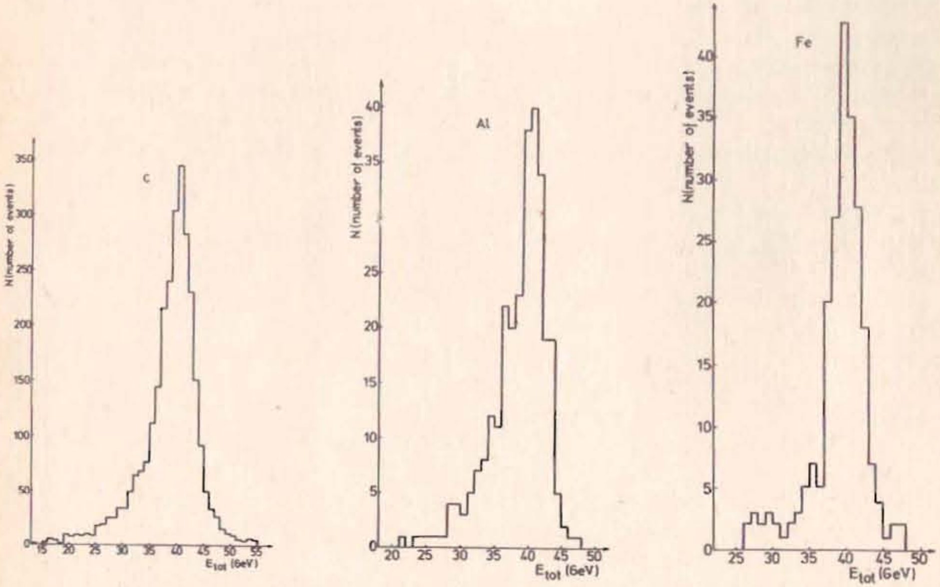

Fig.4. Distribution of events with the π°-meson in the final state over the total energy $E_{tot} = E_{\pi^-} + E_{\pi^\circ}$.

The events with π°-meson in the final state were selected in analysis of the spectrum of effective mass of photons (Fig.3). The events from interval $0.09 < M_{\gamma\gamma} < 0.17$ were selected. For

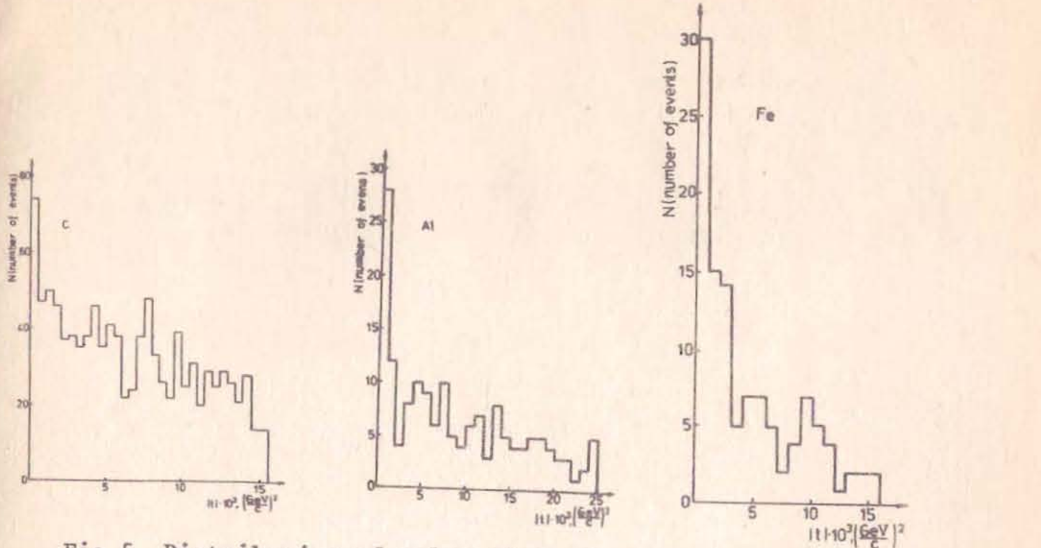

Fig.5. Distribution of selected events over t squared 4-momentum transferred to nucleus.

these events a clear peak was observed at 40 GeV in the total energy distributions ($E_{tot} = E_{\pi^-} + E_{\pi^\circ}$) (Fig.4). For further analysis we selected events belonging to this peak ($35 < E_{tot} < 45$ GeV). In the distribution of these events over t-squared 4-momentum transferred to a nucleus, the peak at small t (with the width corresponding to the experimental resolution $\sigma_q \simeq 25$ MeV), characteristic of the interactions with the nuclear Coulomb field was observed (Fig.5). The analysis of the distribution of selected events over S-invariant mass of the $\pi^-\pi^\circ$ system showed that almost all detected events belonged to the region $S < 10 m_\pi^2$. It agrees with the set-up acceptance calculated by the Monte-Carlo method.

The full cross section of reaction (1) in the nuclear Coulomb field at C, Al and Fe was determined at $t < 2\cdot10^{-3}$ $(GeV/c)^2$, $S < 10 m_\pi^2$. The linear extrapolation of the number of events from the region of $4\cdot10^{-3} < t < 9\cdot10^{-3}$ $(GeV/c)^2$ was used for estimation of the strong interaction background in the region of small t. The error in subtraction of this background was taken 30% of its value. The contribution from this error determined the value of the systematic error of the cross section for reaction (1). The analysis of data of a special run without a target showed that under our selection criteria the background from interaction outside the target and from decay of K-mesons in the beam is negligible.

The value of the cross section for reaction (1) in the nuclear Coulomb field at C, Al and Fe was obtained by normalizing

Table

Experimental values σ/Z^2 obtained on different target for $t < 2\cdot10^{-3}$ $(GeV/c)^2$, $S < 10 m_\pi^2$ and theoretical σ/Z^2 for $N_c = 3$ and $\phi = 0$

	Experimental σ/Z^2 (This paper), nb	Theory [7,8], nb
C	$1.2\pm0.3_{stat}\pm0.8_{syst}$	
Al	$1.48\pm0.40_{stat}\pm0.29_{syst}$	1.1
Fe	$1.62\pm0.33_{stat}\pm0.15_{syst}$	

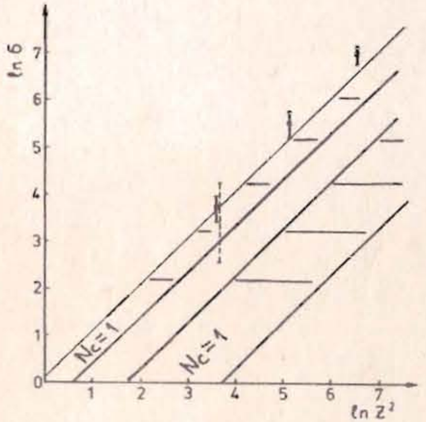

Fig.6. Experimental cross section of reaction (1) over Z^2 and regions of theoretical values of σ for $N_c = 3$ and $N_c = 1$ for all possible phases ϕ.

our data to the total number of another process - Compton-effect on pion detected at the same time [10,11]. The measured cross section of the latter process is in good agreement with the one calculated in electrodynamics. So such normalization allows one to reduce significantly errors in monitoring and defining the detection efficiency.

Acceptance of the experimental set-up was Monte-Carlo calculated using cross section (2), and in region $t < 2\cdot10^{-3}$ $(GeV/c)^2$, $S < 10 m_\pi^2$ its average value was $\epsilon_a = 0.14$. The efficiency of event selection in the off-line analysis programme under all cuts was $\epsilon_c = 0.8$. The errors of ϵ_a and ϵ_c were included in the systematic error of the cross section.

The obtained values of cross section for Coulomb $\pi^-\pi^0$ production on C, Al and Fe in the region $t < 2\cdot10^{-3}$ $(GeV/c)^2$, $S < 10 m_\pi^2$ are shown in Fig.6. In the Table there are values of σ/Z^2 for the investigated nuclei. One can see that dependence of the cross section of Z^2 is in satisfactory agreement with

the linear one. It confirmes Coulomb character of the detected process (1). Figure 6 presents also theoretical values of the cross section for reaction (1) calculated by (2)-(5) for the number of quark colours $N_c = 3$ and $N_c = 1$ and for all possible phases.

The obtained result agrees with the theoretical value of the cross section for $N_c = 3$ and it confirms theorem (3) with the accuracy of approximation (5), which is in favour of PCAC anomaly.

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Антипов Ю.М. и др. E1-84-514

Исследование процесса образования пионных пар пионами в кулоновском поле ядер в околопороговой области

Впервые экспериментально исследован процесс околопорогового образования пионных пар пионами в кулоновском поле ядер. Определено сечение реакции $\pi^- + (A,Z) \to \pi^- + \pi^0 + (A,Z)$ на ядрах C, Al, Fe при 40 ГэВ в области малых переданных ядру 4-импульсов $t < 2\cdot 10^{-3}$ ГэВ/с^2 и инвариантных масс $\pi^-\pi^0$-системы $S < 10\, m_\pi^2$. Полученный результат согласуется с предсказаниями гипотезы Адлера об аномальных условиях частичного сохранения аксиального тока и цветной SU(3) -теории.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1984

Antipov Yu.M. et al. E1-84-514

Study of $\pi\pi^0$ Production by Pions in the Nuclear Coulomb Field at Threshold

The $\pi\pi^0$ production in nuclear Coulomb field at threshold has been studied for the first time experimentally. The cross section of the reaction $\pi^- + (A,Z) \to \pi^- + \pi^0 + (A,Z)$ at 40 GeV on C, Al, Fe nuclei has been determined for small 4-momentum transfers $t < 2\cdot 10^{-3}$ (GeV/c)^2 and invariant mass of $\pi^-\pi^0$ $S < 10\, m_\pi^2$. The obtained result is in agreement with Adler's PCAC anomaly and colour SU(3) theory.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1984