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A STUDY OF INELASTIC DIFFRACTION OF π^--MESON IN $\pi^+\pi^-\pi^-$-SYSTEM USING A "LIVE" TARGET OF SILICON

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During the diffraction dissociation of the meson on the nucleus as a whole, a boson 3π system is produced with a certain probability, while the nucleus remains in the ground state, i.e., one has a coherent process. To investigate the process one needs the experimental conditions which ensure mainly registration of the interactions in which the nucleus remains in the ground state. A usual system providing those conditions has anticoincidence counters around the target to exclude registration of events with nuclear excitation or nuclear break up. In this case the contribution of incoherent interactions is suppressed to a great extent and a more accurate statistical separation of the cross sections $d\sigma/dt'$ (t' is the 4-momentum transfer to the nucleus at the given produced mass of the 3π system) for coherent and incoherent processes by the form of the diffraction peak is possible.

For small 4-momentum transfers the incoherent-to-coherent event ratio is small (e.g., for the Si nucleus at $t' \simeq 0.002$ (GeV/c)^2 this ratio is $\sim$ 1:15), but it becomes much larger in the diffraction minimum region. To study the mechanism of the diffraction production of resonances, however, a separate analysis of coherent and incoherent events is necessary. This brings about a problem of their effective separation. The problem can be solved with the "live" target method /1/ which allows one to measure the energy of the recoil nucleus $T_A = \frac{t}{2m_A}$, where m_A is the atomic weight of the target nucleus, t is the 4-momentum transfer to the nucleus. Since for small t the kinetic energy of the nucleus is small (0.1÷1 MeV), there are no experimental methods of T_A measurements for a wide set of targets.

The experiment with a "live" Si target was carried out at the facility MIS JINR using the 40 GeV beam of the IHEP accelerator /2/. A target of 10 silicon detectors 20.5 mm in diameter, 200 μm in thickness was used in the experiment.

This paper deals with the partial wave analysis of coherent events selected according to the energy release in the detector-target.

Experimental data were obtained in the joint experiment carried out by the Institute of Physics (Milan) and JINR (Dubna) /2,3/, 220 000 events of the process $\pi^- + Si \to \pi^+ + \pi^- + \pi^- + Si$ were obtained using the detector-target. The same criteria were employed for selection of the events for analysis as in previous papers /2,3/, i.e., three-pion events were selected by the kinematics probability, the value of the missing longitudinal momentum, the vertex coordinate, etc. Besides, it was required that the event should satisfy the hypothesis on the interaction in one of 10 plates. 46 000 three-pion events were analysed.

The events were separated according to the types of interactions in the target and in matter in front of and behind the target by the procedure described in Ref. /4/.

We assume that the incoherent background consists mainly of interactions on quasi-free nucleons. Therefore in this approach the incoherent background was described by only two hypotheses: interactions either on the neutron or on the proton. Thus it was considered that an event belongs to one of the following groups:

"n" - interaction in the target on the neutron;
"p" - interaction in the target on the proton;
"Si" - interaction in the target on the Si nucleus (coherent interaction);
"21" - interaction in front of the target, three pions pass through the target;
"32" - interaction behind the target;
"33" - interaction in front of the target, two pions pass through the target.

All hypotheses were checked for each event. To construct likelihood functions $\mathcal{L}$ for the hypotheses, á priori probabilities $V_i (i = 1,\ldots,6)$ of those groups of processes were taken into account.

For example, the likelihood function for the interaction on the neutron in the k-th target detector has the form:

$$\mathcal{L}_K = V_1 \prod_{l=1}^{K-1} H_1^i \, H_2^K \prod_{j=K+1}^{10} H_3^j ,$$

where H_1, H_2, H_3 are the probabilities of the given energy release in the detector from one, two, three relativistic particles, respectively.

The á priori probabilities depend on the nuclear kinetic energy T_{kin}, therefore the whole range of momentum transfer variation was divided into 8 intervals(see the Table). The á priori probabilities were considered constant within each interval and were determined by the method of sequential approximations. All the á priori probabilities were taken equal to one in the zero approximation, and for the iterations to follow

$$V_i = \frac{0.1\, N_i}{N_{tot}}$$

for interactions in the target, and

$$V_i = \frac{N_i}{N_{tot}}$$

for interactions outside the target, where N_i is the number of events of the given group in the 4-momentum transfer interval under investigation and

$$N_{tot} = \sum_{i=1}^{6} N_i .$$

Solutions obtained for the á priori probabilities as functions of the iteration number for several 4-momentum transfer intervals are shown in Fig. 1. In the first interval the energy of the recoil nucleus is of the order of the detector resolution, therefore the á priori probabilities in that interval were determined by extrapolation from the intervals with larger 4-momentum transfer. The type of interaction was determined if the ratio of the maximum value of the likeli-

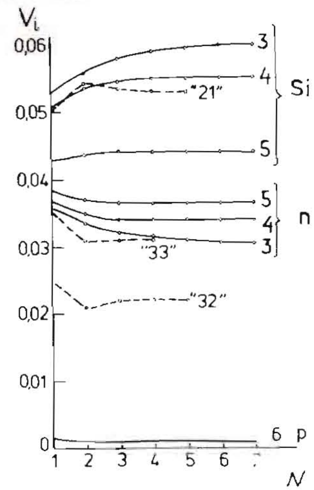


Fig. 1. Behaviour of á priori probabilities V_i as a function of the iteration number N. Numerals at the curves correspond to the numbers of t' intervals (see the Table).

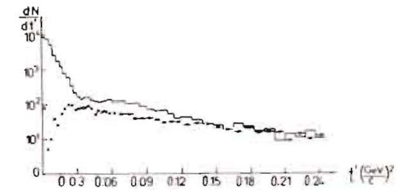


Fig. 2. Distribution of events over the 4-momentum transfer t'. The hystogram shows coherent events, crosses stand for incoherent events.

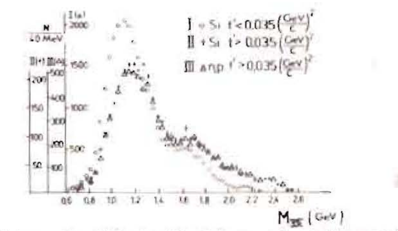


Fig. 3. Distribution of coherent (Si) and incoherent (n,p) events over the effective mass of the $\pi^+\pi^-\pi^-$ -meson system.

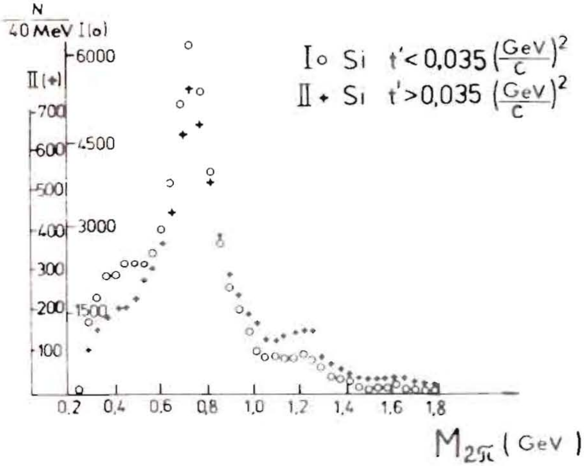


Fig. 4. Distribution of coherent events over the effective mass of $\pi^+\pi^-$-mesons in two t' intervals.

Table

No	T_{kin}(MeV)	$\overline{T}_{kin}$(MeV)	$\overline{t'}$(GeV/c)^2
1.	0 - 0.025	0.015	0.00052
2.	0.025-0.05	0.037	0.00162
3.	0.05-0.1	0.074	0.00354
4.	0.1-0.15	0.124	0.00625
5.	0.15-0.2	0.174	0.009
6.	0.2-0.3	0.245	0.0129
7.	0.3-0.4	0.346	0.0185
8.	0.4-0.5	0.444	0.0238

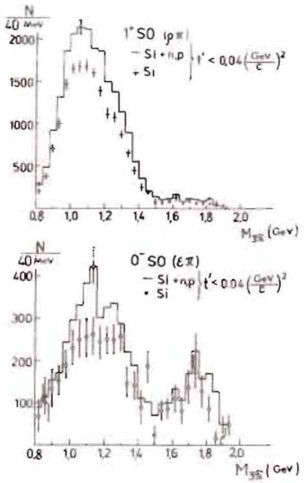


Fig. 5. Intensities of 1^+SO^+ and 0^-SO^+ waves for coherent (Si) and a sum of coherent and incoherent (Si + n,p) events.

hood function to the closest one for the tested hypotheses was over two.

Distributions of coherent and incoherent events over the 4-momentum transfer t' ($t' = t - t_{min}$ where t_{min} is the minimal momentum transfer for the given produced mass) are given in Fig. 2. The slope of diffraction peak in the t' distribution is 138±7 (GeV/c)$^{-2}$, and the slope of the incoherent cross section is ~ 8 (GeV/c)$^{-2}$. The ob-

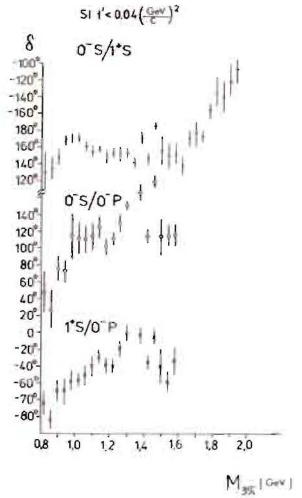
served drop of the distribution at small t' for incoherent events is in agreement with theory, i.e., the cross section for the incoherent interaction tends to zero at $t' \to 0$.

Fig. 3 shows distributions of coherent events over the effective mass of three pions $M_{3\pi}$ for $t' < 0.035$ (GeV/c)^2, $t' > 0.035$ (GeV/c)^2 and the distribution of incoherent events for $t' > 0.035$ (GeV/c)^2. In the spectra of effective masses of two pions (Fig. 4) the ρ-meson contribution dominates in coherent events both at large and small t'.

The mass spectrum of the three-pion system is known to have a complicated structure /5-7/. To determine the contribution of states with different spin and parity, we made a partial wave analysis employing the programme of the Illinois University used in our earlier papers /2,3/. The coherent events were analysed in each 40-MeV interval of the 3π effective mass spectrum for $t' < 0.04$ (GeV/c)^2 with the same set of waves as in Refs. /2,3/. Dipion 0^+ was described by the elastic phase of the $\pi^+\pi^-$ scattering, and dipions 1^- and 2^+ - by ρ and f mesons respectively.

In Fig. 5 one can see intensities of the waves 1^+SO^+ and 0^-SO^+ for the Si target with and without separation of coherent events. Distributions of the basic wave 1^+SO^+ intensity are practically identical for both types of interactions. As to the wave 0^-SO^+, it has a wider peak in the region of small masses and a narrower peak at large masses for coherent events if compared with the case without separation. The sensitivity of the wave 0^-S to the selection of events indicated at somewhat different forms of 0^-S distribution in diffraction on the nucleon and on the nucleus. Fig. 6 shows the behaviour of phases of the waves 0^-S and 1^+S with respect to each other and to the wave 0^-PO^+ for coherent events. The intensity of the wave 0^-PO^+ for $M_{3\pi} > 1.6$ GeV is small, therefore the data on phases in this region are not given.

The behaviour of the 1^+S ($\rho\pi$) wave intensity and variation of its phase with respect to the 0^-P wave in the 0.8-1.4 (GeV/c)^2 mass region are a direct indication of the resonance properties of the 1^+S wave (A_1 meson). A significant variation of the relative phase $0^-S/0^-P$ in the (0.8-1.4) GeV/c^2 mass region, constancy of the phase of this wave with respect to the resonance wave 1^+S in the same mass region as well as the shape of the mass spectrum indicate at the resonance in the 0^-S wave in the system $(\pi^+\pi^-)_S + \pi^-$ with quantum numbers of the pion (π' resonance /2,3/). In the (1.4-2) GeV/c^2 mass region there is a second peak, as is seen from the mass spectrum of the 0^-S wave (Fig. 5). Variation of the relative phase $0^-S/1^+S$ in this mass region is ~ 120°. This resonance (π'' resonance) is pro-



bably narrower as compared with the results of the analysis without separation of coherent events /2,3/.

Thus the results of the wave analysis of the separated coherent events confirm our result /3/ concerning the observation of radial excited states of the π- meson (π' and π'' resonances).

Distributions of other waves are given only for separated coherent events without comparison with incoherent ones, because the intensities of the waves

Fig. 6. Behaviour of relative phases of 0^-S, 1^+S, 0^+P waves for coherent events at $t' < 0.04\ (GeV/c)^2$.

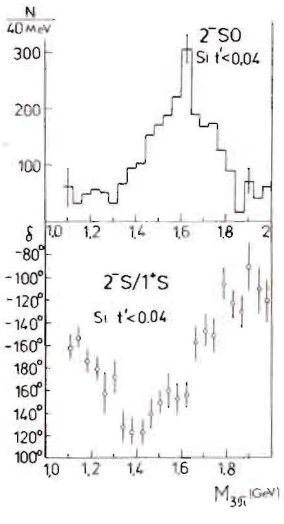


Fig. 7. Intensity of 2^-SO^+ wave and relative phase of 2^-S and 1^+S waves.

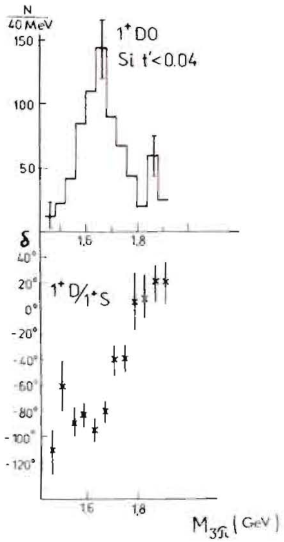


Fig. 8. Intensity of 1^+DO^+ wave and relative phase of 1^+D and 1^+S waves.

are much lower and the difference does not exceed the errors. Fig. 7 illustrates the distribution of the 2^-SO^+ wave intensity and phase with respect to the 1^+SO^+ wave. A resonance behaviour of the 1^+SO^+ wave phase can be seen in the A_1-meson region (1.25 GeV); it is replaced by the resonance behaviour of the 2^-SO^+ wave phase in the A_3-meson region (1.65 GeV). The distribution in Fig. 8 shows the first radial excitation of the A_1-meson A_1' (1.7 GeV) in the 1^+DO^+ wave /8/. Fig. 9. shows intensity distributions of ρ waves (0^-PO^+, 1^+PO^+, 2^-PO^+). A common peculiarity of those distributions is interesting: the intensity decreases at 1.25 GeV for 0^-P, at 1.3 GeV for 1^+P, at 1.7 GeV for 2^-P, which is due to probably a destructive interference of resonances with the coherent background. The behaviour of the S wave phases also indicates at a strong interference of the background with resonances: the phase variation is less than 180^0 for all resonances.

It should be noted in conclusion that the use of silicon detectors as a "live" target and the developed technique of data processing allowed us to separate events of the meson diffraction on Si

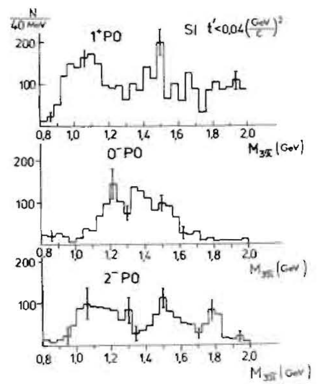


Fig. 9. Intensities of 1^+PO^+, 0^-PO^+, 2^-PO^+ waves in coherent events at $t' < 0.04\ (GeV/c)^2$.

nuclei with a significant suppression of the incoherent background. The "live" target method is especially important for investigations of coherent processes in the region of the 2nd diffraction maximum. Dependences of intensities and behaviour of relative phases obtained in this paper for the separated coherent events show clearer the resonance properties of the states 0^-S (π' and π''), $1^+S(A_1)$, $1^+D(A_1')$ which we found earlier without separation of events. For instance, a larger change in the phase behaviour in S waves and a narrower peak in the intensity of the resonance π'' (1.77) are observed. Besides, the t' distribution has a larger slope for diffraction cone $138\pm7\ (GeV/c)^{-2}$, as compared with the value $105\pm5\ (GeV/c)^2$ obtained by the statistical separation of the coherent cross section.

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References

1. P.F.Manfredi, Particles and Nuclei, V15, Part 5, 983, Dubna, 1984.
2. G.Bellini et al. Nucl.Phys., B199, 1 (1982).
3. G.Bellini et al. Phys.Rev.Lett., 48, 1697 (1982).
4. G.Bellini et al. Commun.JINR 13-83-139, Dubna, 1983.
5. Y.Pernegr et al. Nucl.Phys., B134, 436 (1978).
6. M.Bonesini et al. Phys.Lett., 103B, 75 (1981).
7. C.Daum et al. Nucl.Phys., B182, 269 (1981).
8. G.Bellini et al. Yad.Fiz., v. 41 (1985) pp. 12-23.

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Веньи Г. и др. E1-85-498

Исследование когерентной неупругой дифракции π^--мезона с импульсом 40 ГэВ/с на ядре кремния с использованием мишени-детектора

При изучении процесса дифракционной диссоциации π^--мезонов в 3π-систему при импульсе пучка 40 ГэВ/с на установке МИС ОИЯИ проведено разделение реакций когерентного и некогерентного типа на основе измерения энерговыделения в кремниевой многослойной мишени-детекторе. Для выделенных когерентных событий проведен парциально-волновой анализ. Зависимость интенсивностей и относительных фаз парциальных волн от массы 3π-системы подтверждают полученные нами ранее данные о наблюдении резонансных состояний в волнах $0^-S(\pi', \pi'')$, $1^+S(A_1)$, $2^-S(A_3)$ и $1^+D(A_1')$. Данные, полученные в настоящей работе, свидетельствуют о том, что дифференциальное сечение некогерентного рождения 3π-системы стремится к 0 при $t' \to 0$.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ

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A Study of Inelastic Diffraction of π^--Meson in $\pi^+\pi^-\pi^-$-System Using a "Live" Target of Silicon

When studying the process of diffraction dissociation of π^--mesons into a 3π-system at beam momentum 40 GeV/c at the facility MIS JINR, we have separated coherent and incoherent reactions by measuring the energy release of recoil in the multilayer Si detector target. A partial wave analysis was performed for the separated coherent events. Dependence of intensities and relative phases of partial waves on the mass of the 3π-system confirms our earlier data on observation of resonance states in the waves 0^-S (π' and π''), $1^+S(A_1)$, $2^-S(A_3)$ and $1^+D(A_1')$. The data obtained in this paper show that the differential cross section for the incoherent production of the 3π-system approaches zero at $t' \to 0$.

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

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