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COHERENT PRODUCTION OF THE $(3\pi)^-$ SYSTEM ON NUCLEI
I. EVIDENCE FOR 0^-S RESONANCES

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ABSTRACT

Partial wave analysis has been performed on $\pi^-\pi^-\pi^+$ events coherently produced on nuclear targets in a π^- beam of 40 GeV/c at the Serpukhov accelerator (5th Joint CERN-IHEP experiment). Evidence has been found for a 0^-S resonance at 1.2 GeV with a width $\Gamma \simeq 0.330$ GeV. The data suggest also the presence of another 0^-S resonance of similar width near to 1.8 GeV. These observations can be interpreted as radial excitations of the π meson.

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The existence of $I^G J^P L = 1^- 0^- S$ states is expected in the frame of the quark model as radial excitations of the pion. Experimentally there are only indications that such states might exist in the 3π system[1,2]. In this paper we present a direct observation of $0^- S$ resonances in the data obtained in a coherent production experiment on nuclear targets.

The partial wave analysis (PWA) of the 3π system coherently produced on nuclei is less complicated than in the data obtained on protons owing to the following reasons:

i) The degree of coherence (angular interference between different pairs of waves) is maximal; therefore the measurement of relative phases is reliable.

ii) The data are in the region very near to $t' = |t - t_{min}| \simeq 0$; therefore spin amplitudes (including natural parity states) are negligible and sets of waves to be fitted are simpler.

iii) There are no complications with the N^* cuts.

The data have been obtained in the 40 GeV/c π^- beam of the Serpukhov accelerator using nine different nuclear targets (Be, C, Al, Si, Ti, Cu, Ag, Ta, Pb). The experimental set-up is described elsewhere[3]. We use for the PWA a total sample of $\sim$ 110,000 $\pi^-\pi^-\pi^+$ events. The acceptance of the apparatus decreases smoothly from $\sim$ 100% at $M_{3\pi} \simeq 0.9$ GeV to $\sim$ 80% at $M_{3\pi} \simeq 2.0$ GeV.

The results presented in this letter concern only "coherent" samples of events with $t' \leq t'^*$, where t'^* corresponds to the first diffractive minimum of the differential cross-sections for the different nuclear targets[3] [e.g. $t'^* \approx 0.04$ (GeV/c)^2 for Be and $t'^* \approx 0.008$ (GeV/c)^2 for Pb)]. These coherent samples contain $\sim$ ¾ of the events and have negligible background of incoherent interactions ($\sim$ 6% for Be and $\sim$ 1.5% for Pb).

We have used for the analysis the PWA program of the Illinois group[4]. The choice of waves to be fitted has been done in the same way as in Ref. 1. For the results presented in this letter we need a very simple set of the following amplitudes: 0^-S, 0^-P, 1^+S, 1^+P, and 2^-P everywhere; above $M_{3\pi} = 1.12$ GeV we have to add the 1^+D and 2^-S waves. The 0^-S and 1^+P waves decay into a problematic 0^+S dipion and a pion. We have parametrized this 0^+S dipion either as a "ε" resonance or using the elastic ($\pi^+\pi^-$) phase shifts[5]. In general these two parametrizations do not give identical results; however, for the data shown in this paper, there is no significant difference between them and we present therefore only results obtained with the "ε" parametrization, which gives systematically somewhat higher values of the likelihood function.

In Fig. 1 we show the mass distribution of the 0^-S amplitude which exhibits a peak in the A_1 region and an enhancement below $M_{3\pi} = 1.8$ GeV. A naïve fit, assuming a Breit-Wigner shape and an exponentially decreasing background, yields for the resonance in the A_1 region the position at $M_{3\pi} = 1.20 \pm 0.03$ GeV and the width $\Gamma = 0.33 \pm 0.04$ GeV.

The relative phase 0^-S-1^+S is fairly constant across the A_1 region as in all previous experiments[1,2] and is therefore not shown. On the other hand, the phase of 0^-S relative to 0^-P moves by at least 80°; we compare it in Fig. 2 with the corresponding phase motion observed in the data on nuclei at 15.1 GeV [1] and with the phase obtained by subtraction of the 1^+S-0^-S and 1^+S-0^-P phases measured on protons[2]. It should be noted that the reference wave 0^-P tends to increase above $M_{3\pi} \simeq 1.2$ GeV (e.g. relative to 2^-P, 1^+S, etc.) and therefore the "absolute" phase variation of the 0^-S wave is likely to be still larger than its relative phase shown in Fig. 2.

Since the signal of 0^-P becomes negligible above $M_{3\pi} \sim 1.6$ GeV we have chosen the 1^+S as reference wave in the region of the second 0^-S enhancement. As is seen in Fig. 3 the 0^-S wave exhibits also in this region a rather fast phase variation. The evidence for this second resonance is of course less convincing owing to smaller statistics and greater complexity of the analysis.

In conclusion, we believe we have found for the first time evidence for a $I^G(J^P)L = 1^-(0^-)S$ resonance at $M_{3\pi} = 1.2 \pm 0.03$ GeV with $\Gamma = 0.33 \pm 0.04$ GeV. It is in remarkable agreement with a recent calculation based on quantum chromodynamics[6], which predicts for the first radial excitation of the pion (π') the mass of 1.194 GeV. Our data suggest also another resonance with the same quantum numbers as the pion somewhat below $M_{3\pi} \simeq 1.8$ GeV.

REFERENCES

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2) C. Daum et al., Diffractive production of 3π states at 63 and 94 GeV, preprint CERN-EP/80-219 (1980).

3) G. Bellini et al., The (3π)-nucleon collision in coherent production on nuclei at 40 GeV/c, preprint CERN-EP/81-40 (1981), submitted to Nuclear Physics.

4) G. Ascoli et al., Phys. Lett. 25 (1970) 962.

5) B. Hyams et al., Nucl. Phys. B64 (1973) 134.

6) For example: D.P. Stanley and D. Robson, Phys. Rev. 21 (1980) 3180.

Figure captions

Fig. 1 : Effective mass distribution of the 0^-S partial wave for the coherent samples ($t' < t'^*$). The data on the different nuclear targets are all grouped together.

Fig. 2 : Relative phase 0^-S-0^-P for the 3π mass range: 0.9-1.4 GeV. The data concern the present experiment at 40 GeV/c, the previous one at 15.1 GeV/c (Ref. 1) and a recent experiment on a hydrogen target (Ref. 2).

Fig. 3 : Relative phase 0^-S-1^+S for the 3π mass range: 1.55-1.95 GeV.

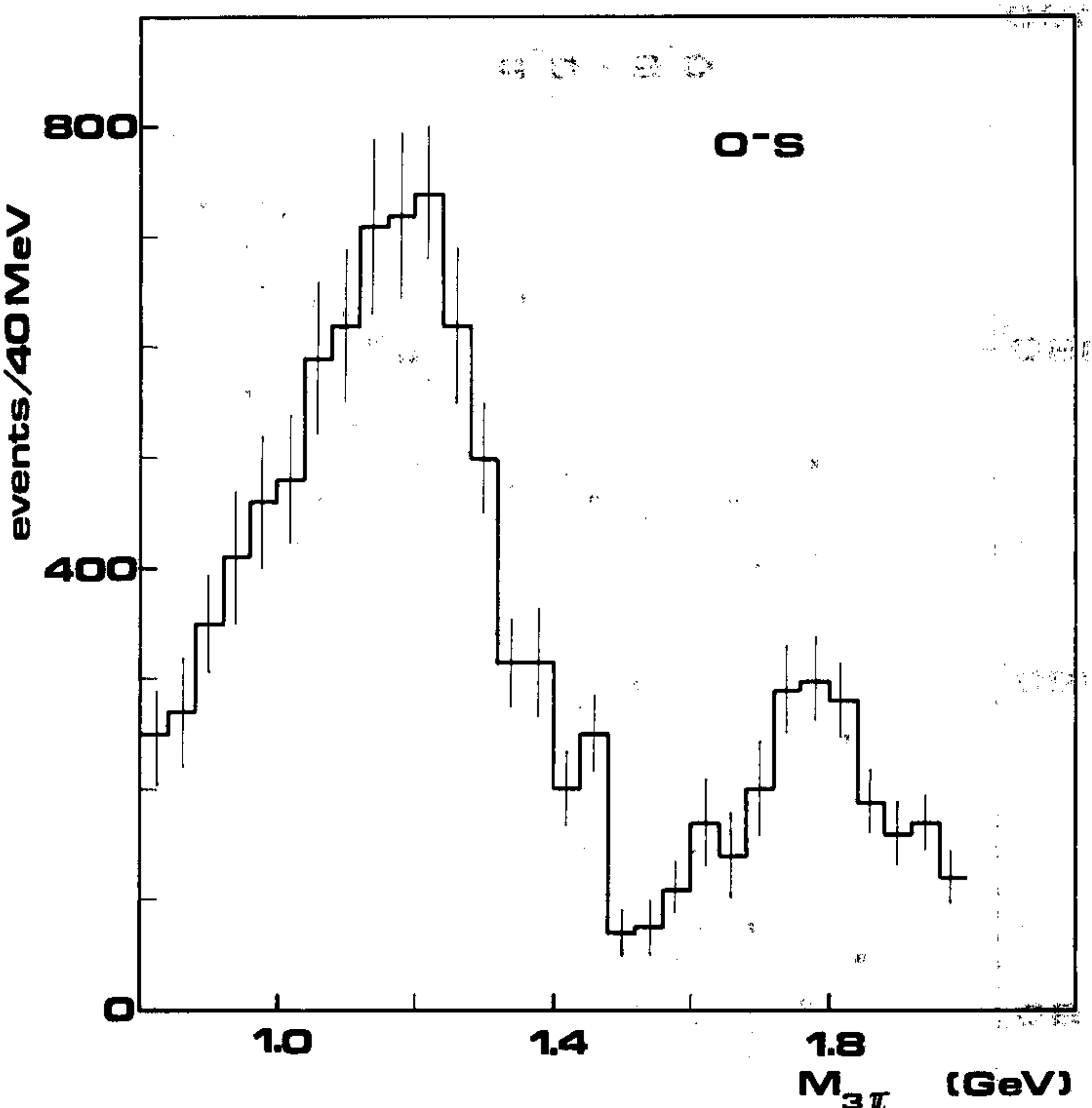
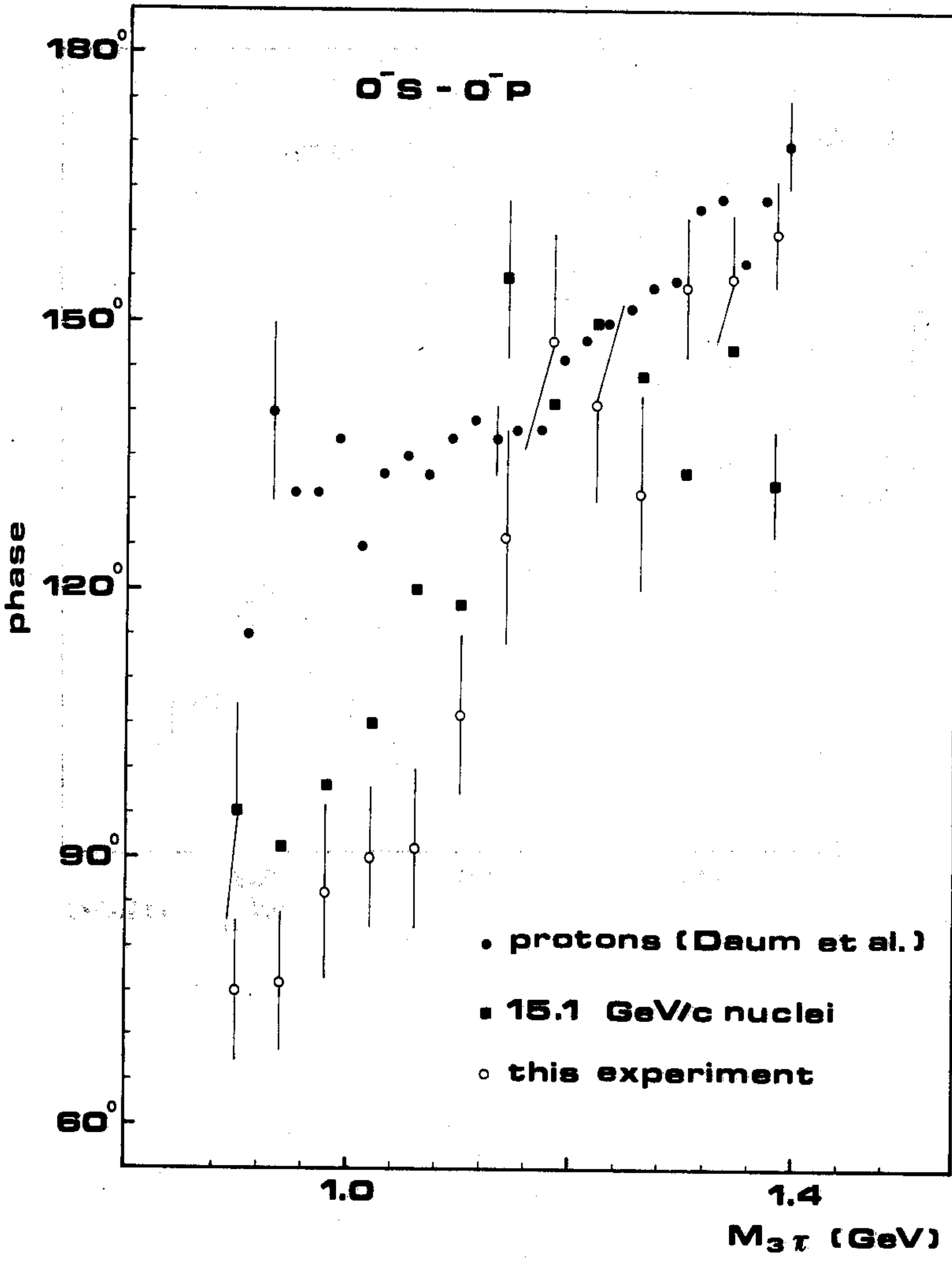


Fig. 1



$0^-S - 0^-P$
180°
150°
120°
90°
60°
phase
1.0
1.4
$M_{3\pi}$ (GeV)
• protons (Daum et al.)
■ 15.1 GeV/c nuclei
○ this experiment

Fig. 2

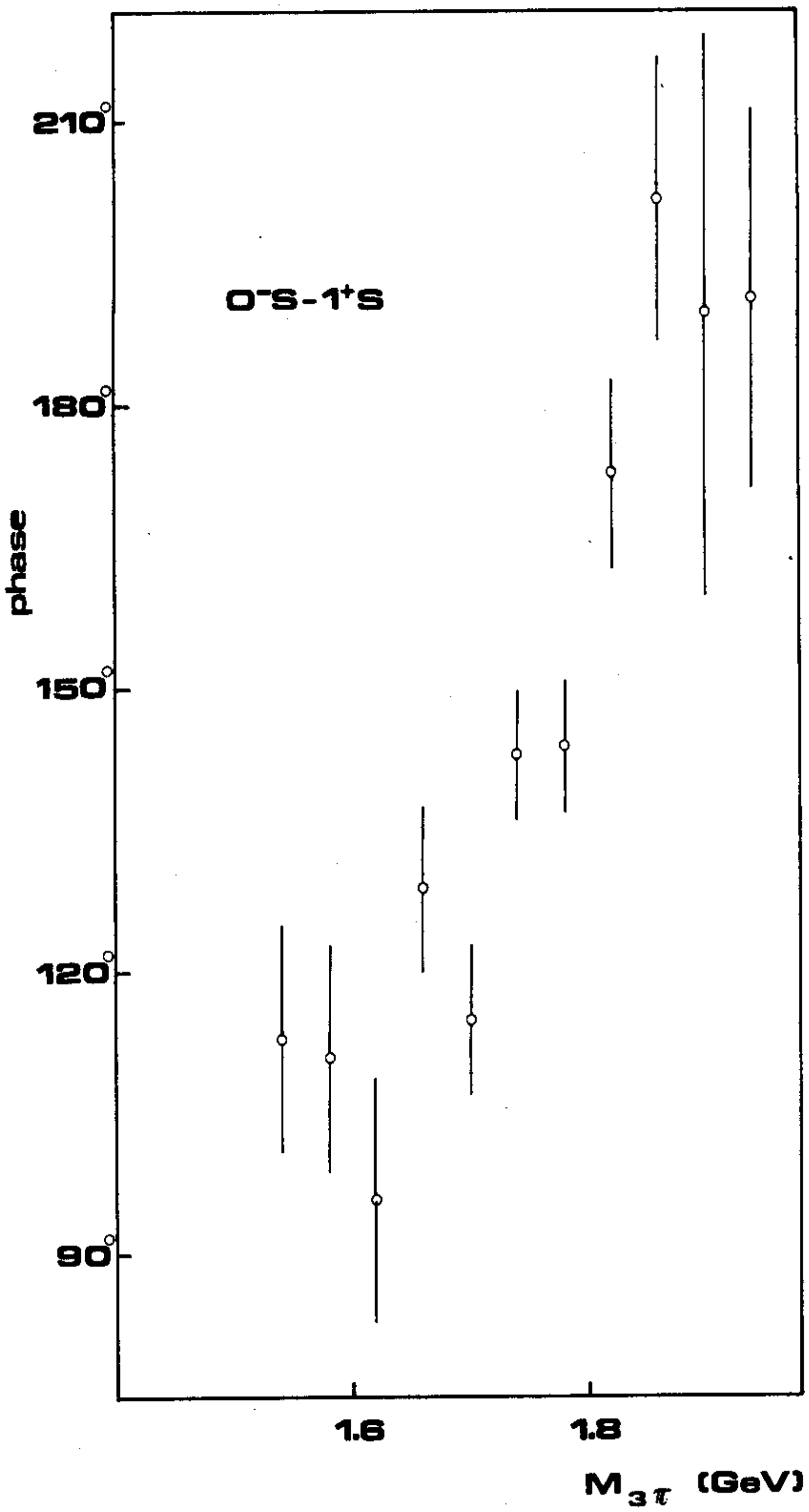


Fig. 3