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2^- RESONANCES IN THE $\pi^+\pi^-\pi^-$ SYSTEMS

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Evidence for existence of the A3 meson was previously confused due to low statistics and bad resolution. In refs.[1-3] authors claim that there is an $f\pi$ enhancement in the $J^{P}LM\eta = 2^{-}SO^{+}$ partial wave at ~1650 MeV. Evidence that a resonance in phase increases with respect to other J^{P} waves was given in refs.[4-6]. High statistics experiment on the hydrogen target[7] provides the confirmation for A3 resonance.

In this paper we present new confirmations for unambiguous proof for an A3 resonance in several decay modes in partial wave $J^{PC} = 2^{-+}$.

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 and Pb). The experimental set-up is described elsewhere[8]. The acceptance of the apparatus decreases smoothly from ~100% at $M_{3\pi} = 0.8$ GeV/c^2 to ~85% at $M_{3\pi} = 2.0$ GeV/c^2. For the partial wave analysis a total sample of ~120000 $\pi^{+}\pi^{-}\pi^{-}$ events is used.

The results presented in this article 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 (e.g., $t'^{*} = 0.04$ (GeV/c)^2 for Be and $t'^{*} = 0.008$ (GeV/c)^2 for Pb). For this coherent region about 75% of the events are included in the analysis.

We have used for the partial-wave analysis the PWA program of the Illinois group[9] adjusted for the acceptance of our spectrometer. The analysis of the "coherent" events diffractively produced on nuclei at small t' due to the maximal interference between waves makes reliable the measurement of relative phases. The contribution of spin-flip amplitudes and amplitudes with eigenvalue of the reflection operator $\eta = -1$ are strongly suppressed. In that case the number of non-vanishing eigenvalue of the density matrix equals two and the number of parameters to be fitted is not so high. This is specially important for the high-mass region. The selection of waves necessary for the description of the data is in any case an iterative procedure. We have considered a wave as negligible when its intensity was smaller than 1% or equal to zero within errors. In the A3 region ($M_{3\pi} > 1.4$ GeV/c^2) the coherence factor between waves is of the order of 0.5-0.7 and we neglected even contribution a little stronger than 1% if it did not affect the relative phases of the main waves. The set of necessary waves in the region $M_{3\pi} > 1.4$ GeV/c^2 is: $0^{-}S$, $0^{-}P$, $1^{+}S$, $1^{+}P$,

$1^+D, 2^-S, 2^-P, 2^-D(\epsilon\pi)$. Besides that we study also the contribution $2^-D(f\pi)$, $2^+P1(f\pi)$, $2^-S1(f\pi)$, $3^+P(f\pi)$, $3^+D(\rho\pi)$, $3^+F(\epsilon\pi)$. The PWA was done for two ways to describe dipion 0^+. One is as a "ϵ" resonance (M_ϵ = 0.77 GeV, Γ_ϵ = 0.4 GeV) and another as elastic dipion phase shifts /10/. In the A3-region the results of analysis do not depend on the type of the parametrization of the dipion amplitude. The intensities and relative phase of waves varies inside the errors for different description of 0^+ dipion. The PWA was done for the "coherent" events of all targets together.

STATE $J^{PC} = 2^{-+}$

In the high-mass region, beyong the A1, A2 resonance the dominant effect is A3 production.

The intensities of $2^-S(f\pi)$, $2^-P(\rho\pi)$, $2^-D(\epsilon\pi)$ are shown in Fig.1 and a common broad enhancement centered at 1650 GeV/c^2 is seen. It is seen that $2^-S(f\pi)$ wave are most intensive. $2^-P(\rho\pi)$ wave has a big background contribution. The bumps observed in the $(\rho\pi)$ and $(\epsilon\pi)$ final states may be identified with the same phenomenon as the peak in $2^-S(f\pi)$. The interference between the 2^- waves is small.

The resonant nature of A3 is demonstrated by the relative phase motion of 2^-S, 2^-P, $2^-D(\epsilon\pi)$ waves with respect to contribution $1^+S(\rho\pi)$ shown in Fig.1. The relative phase motion for all three waves is ~110°. The phase of the $2^-S(f\pi)$ partial wave versus other 2^- waves is shown in Fig.2. There are only excursions of ~30° with respect to $2^-P(\rho\pi)$ and $2^-D(\epsilon\pi)$: a large phase variation is not expected with the A3 resonance coupling to all three channels.

For $M_{3\pi}$ > 1.6 GeV/c^2 the noticeable contribution is made by the state $2^-D(f\pi)$. The intensity (Fig.3) of this wave rises rapidly to a peak ~1850 MeV/c^2, some 200 MeV above A3. The phase motion of this wave with respect to 1^+S has a rapid change of ~120°. Associated with the peak of $2^-D(f\pi)$ is a rapid drop on the relative phase $2^-S(f\pi)-2^-D(f\pi)$ (Fig.4). Since the 2^-S phase is roughly constant in this region, the conclusion must be that the phase of the $2^-D(f\pi)$ wave increases. This is evidence for the existence of a resonant state in $2^-D(f\pi)$ wave at the ~1.85 GeV/c^2.

However, the proximity of the A3 and the possibility of generations such an effect through interference with $2^-S(f\pi)$ wave must be taken with caution in accepting this simple interpretation.

In fact if the sign of an amplitude of one resonance with respect to another is opposite, the interference is constructive between the two resonances and destructive outside this range, giving a peak in the intensity and a rapid change of phase between the two.

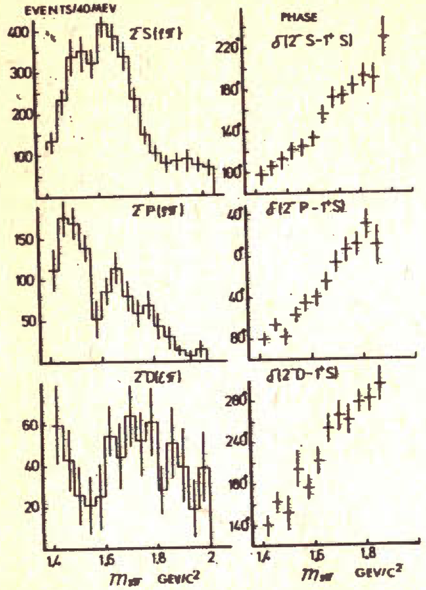

Fig.1. The intensities and the relative phases of 2^-S, 2^-P and 2^-D waves.

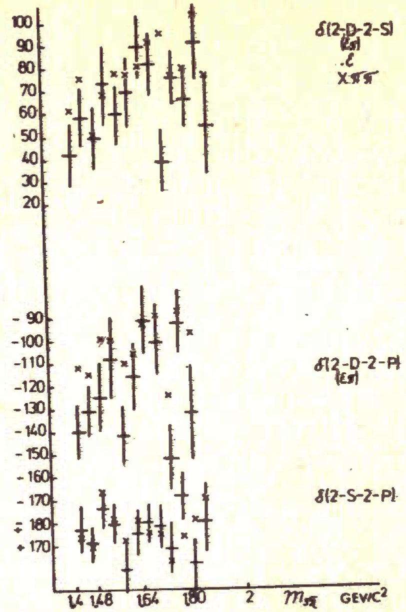

Fig.2. The phase of the $2^-S(f\pi)$ wave versus other 2^- waves.

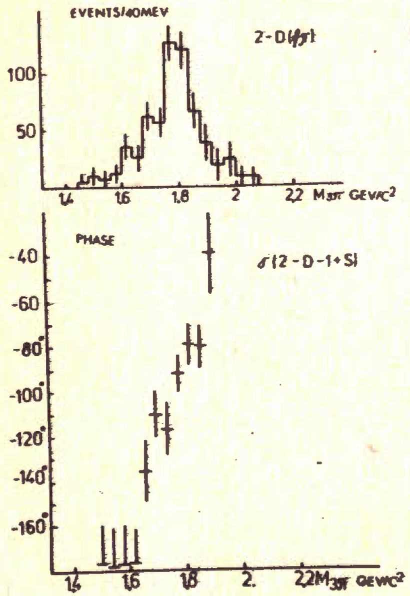

Fig.3. The intensity and the relative phase of $2^-D(f\pi)$ wave.

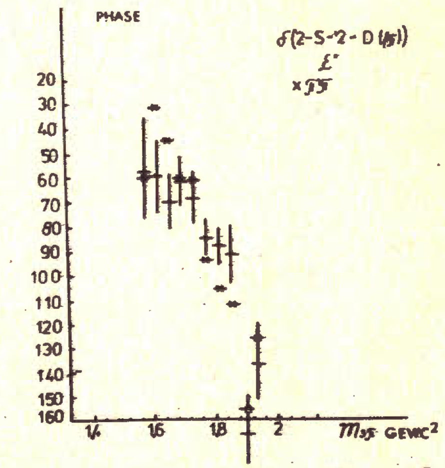

Fig.4. The relative phase of $2^-S(f\pi)$ and $2^-D(f\pi)$ waves.

Our experimental data on the position of 2^-D state and relative phase motion are similar to that seen in ref. [7]. Their two resonance fits reproduce all features of the 2^- amplitude. The peak of activity in the $2^-D(f\pi)$ amplitude ~ 1.85 GeV/c^2 is the result of such interference between one resonance with mass ~ 2.15 GeV/c^2 and another with mass ~ 1.65 GeV/c^2 - fourth decay mode of A3. In the quark model a second resonance 2.15 GeV/c^2 $2^-D(f\pi)$ is the radial-excited state of A3-meson.

To determine resonance parameters of A3 state we applyed Pade-approximation method [11] using all available information about intensities and relative phases. Our first step was to analyse each wave 2^-S, 2^-P, $2^-D(\epsilon\pi)$ together with 0^-S, 1^+S in the mass range (1.4-2.22) GeV/c^2 with the aim to describe their intensities and phases. The second step was to combine fit of 2^-S, 2^-P, $2^-D(\epsilon\pi)$ waves. Stable poles in low half complex energetic plane are found and resonance parameters are as follows:

$M_{2^-S} = (1624 \pm 21)$ MeV, $\Gamma_{2^-S} = (304 \pm 22)$ MeV,
$M_{2^-P} = (1622 \pm 35)$ MeV, $\Gamma_{2^-P} = (404 \pm 108)$ MeV,
$M_{2^-D} = (1693 \pm 28)$ MeV, $\Gamma_{2^-D} = (330 \pm 90)$ MeV.

The production cross section for 2^- state can be estimated from the data and equals (37 ± 5) μb/nucleon, and partial decay modes are 60%, 30% and 10% for 2^-S, 2^-P, $2^-D(\epsilon\pi)$ respectively.

STATE $J^PLM = 1^+D0^+$

The $1^+S(\rho\pi)$ intensity tails off beyond 1.4 GeV/c^2 with no indication of a secondary peak. The $1^+D0^+(\rho\pi)$ wave is small (3% of 1^+S intensity) up to 1.4 GeV/c^2 but rises to a sharp peak at ~ 1.7 GeV/c^2. The intensity and phase measured with respect to $1^+S0^+(\rho\pi)$ are shown in Fig.5. The relative phase $(1^+D - 1^+S)$ passes upwards through 90° between $(1.4 \div 1.9)$GeV/c^2. The relative phase $(1^+D - 0^-S)$ changes to 50° and afterwards became flat because two waves 1^+D and 0^-S are resonated in the same region. The peak in intensity and variation of phase has indication of resonance behaviour of 1^+D wave. Their intensity in mass range (1.5-1.9) GeV/c^2 reached 11%. Using Pade-method we found resonance parameters to be as follows:

$M_{1^+D} = (1.07 \pm 0.07)$ GeV/c^2, $\Gamma_{1^+D} = (0.3 \pm 0.1)$ GeV.

The results are in good agreement with ref. [6]. In the framework of the quark model this state is radial excitation of A1-meson.

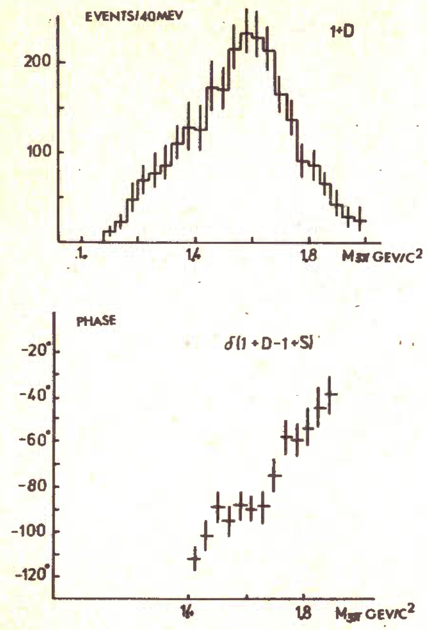

Fig.5. The intensity and the relative phase of 1^+D wave.

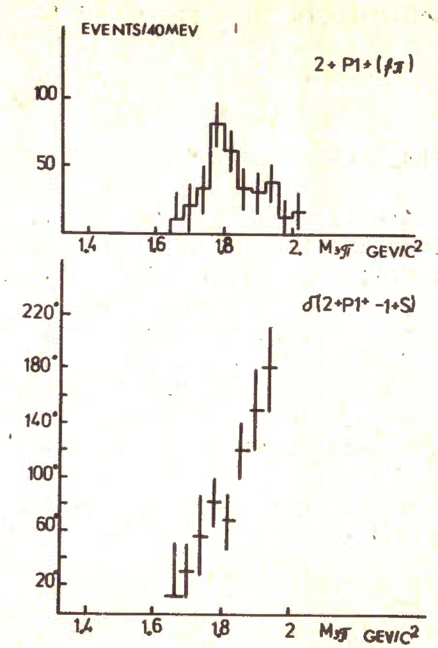

Fig.6. The intensity and the relative phase of $2^+P1^+(f\pi)$.

STATE $J^PLM = 2^+P1^+$

Intensity of $2^+P1(f\pi)$ wave in the region of high mass shows a peak centered in the range (1.75-1.85) GeV/c^2. This is minor wave, its intensity is small. Phase variation with respect to $1^+S(\rho\pi)$ is shown in Fig.6. This result is an indication of a resonance in $2^+P1(f\pi)$ at 1.8 GeV/c^2 similar to a A2-meson in the low mass region.

CONCLUSION

The results of this experiment demonstrate conclusively the existence of the A3(2^-) meson, diffractively produced. The A3 meson has a mass of ~ 1.65 GeV and a width of 300 MeV,coupling to the channels $2^-S(f\pi)$, $2^-P(\rho\pi)$, $2^-D(\epsilon\pi)$ and $2^-D(f\pi)$. The A3 meson is degenerate with the g-meson and is to be assigned to the singlet D-wave quark-antiquark configuration. No isoscalar candidates for this nonet are known. The masses found for A3 suggest that the effects of spin-spin and spin-orbit coupling in D-wave $q\bar{q}$-system are small. There are indications from this experiment for new states $1^+D(\rho\pi) \sim 1.7$, $2^+ \sim 1.8$, $2^+ \sim 2.15$ GeV/c^2 which in the quark model correspond to radial excitation of A1, A2 and A3-mesons.

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Беллини Д. и др. E1-84-280

2^- резонансы в $\pi^+\pi^-\pi^-$ системе

Осуществлен парциально-волновой анализ ~120000 $\pi^+\pi^-\pi^-$-событий, когерентно рожденных в пучке π^--мезонов на ядерных мишенях при энергии 40 ГэВ. Эксперимент выполнен с помощью магнитного спектрометра ОИЯИ. На основании поведения интенсивностей и большого изменения относительных фаз доказаны резонансные свойства A_3-мезона в состоянии $J^{PC} = 2^{-+}$ в каналах распада $f\pi$, $\rho\pi$ и $\epsilon\pi$. Положение и ширины резонансных состояний найдены с помощью метода Паде-аппроксимации, использующего всю имеющуюся информацию об интенсивностях и фазах волн. С помощью этого метода установлены стабильные полюса в амплитудах в нижней части комплексной энергетической плоскости, ответственные за положение резонансов. Параметры A_3-мезона установлены следующие:

M_{2^-S} = /1624±21/ МэВ/c^2 Γ_{2^-S} = /304±22/ МэВ
M_{2^-P} = /1622±35/ МэВ/c^2 Γ_{2^-P} = /404±108/ МэВ
M_{2^-D} = /1693±28/ МэВ/c^2 Γ_{2^-D} = /330±90/ МэВ.

Сечение рождения получено равным /37±5/ мкбн/нуклон. Получены указания на существование также новых резонансных состояний в волнах 1^+, 2^- и 2^+.

Препринт Объединенного института ядерных исследований. Дубна 1984

Bellini G. et al. E1-84-280

2^- Resonances in the $\pi^+\pi^-\pi^-$ Systems

A partial-wave analysis has been performed for ~120 000 $\pi^+\pi^-\pi^-$ events coherently produced on nuclear targets in a π^--beam of 40 GeV. Partial wave intensities and a large phase variation prove the resonant nature of the A_3-meson in the $J^{PC} = 2^{-+}$ partial wave. The resonance behaviour of the 2^- partial wave has been determined in the $f\pi$, $\rho\pi$, $\epsilon\pi$ decay mode. The position and width of the resonant states have been found with Pade-approximation method, using all available information about intensities and phases of partial waves. The position of the stable pole in the amplitude in the lower half of the complex energetic plane has been found, which is responsible for the resonance position. The resonance parameters are as follows:

M_{2^-S} = (1624 ± 21) MeV/c^2 Γ_{2^-S} = (304 ±22) MeV
M_{2^-P} = (1622 ± 35) MeV/c^2 Γ_{2^-P} = (404 ±108) MeV
M_{2^-D} = (1693 ± 28) MeV/c^2 Γ_{2^-D} = (330 ±90) MeV.

The production cross-section is equal to (37 ± 5) μb/nucleon. Evidence has been found for further enhancements in the 1^+, 2^-, 2^+ waves. Their positions and widths are as follows: M_{1^+D} = (1670 ± 90) MeV, Γ_{1^+D} = (300 ± 100) MeV; $M_{2^-D(f\pi)}$ = 1850 MeV, Γ_{2^-D} = 300 MeV; M_{2^+P} = 1750 MeV.

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