Partial Wave Analyses of the $\pi^+\pi^-\pi^-$ System at upgraded VES Setup

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Partial Wave Analysis of the $\pi^+\pi^-\pi^-$ system produced by 29 GeV/c π^- beam on berillium target is presented. About $30 \cdot 10^6$ events in the wide $|t'|$ range $0 \ldots 0.8$ GeV^2/c^2 are collected with upgraded VES setup. The size of the data sample is 2.5 times larger than that previously analyzed by VES. Data are analyzed using formalism of density matrix with unlimited rank. We discuss status of the $a_1(1420)$, $a_2(1700)$, $a_3(1875)$ states, structure of exotic $\rho(770)\pi$ P-wave with $J^{PC} = 1^{-+}$.

1 VES setup and events selection

We present preliminary results of mass independent PWA of the $\pi^+\pi^-\pi^-$ system on the data obtained after VES upgrade. We compare them with data obtained before upgrade and discuss structures which can be considered resonant. Currently we do not claim any numerical results.

VES setup is full featured magnetic spectrometer which operates on mostly π^- beam (2% of K^-) with energy 37 GeV/c before upgrade and 29 GeV/c after upgrade. It is equipped with electromagnetic calorimeter and multicellular Cherenkov counter for particle identification. Description of VES setup before upgrade can be found in [1] and after upgrade in [2]. For charged 3π system net result of the upgrade is severely large acceptance (see Fig. 1) due to taking out of trigger hodoscope and severely large statistics due to upgraded DAQ.

Diffractive production of charged 3π final state dominates at VES energies, so data selection is simple and background is negligible. We require beam particle identified as π^-, 3 tracks with charges $+--$ (identification as π mesons is done for old data only), total energy for charged tracks 27–31 (36–38) GeV, free (not associated with tracks) energy in the electromagnetic calorimeter less than 0.5 GeV and vertex of interaction inside the target. Analysis is done for $M(3\pi) = 0.6$–2.6 GeV/c^2 in 20 MeV/c^2 bins and four $|t'|$ intervals 0–0.03–0.15–0.30–0.80 GeV^2/c^2. We have about $30 \cdot 10^6$ 3π events after upgrade and about $12 \cdot 10^6$ 3π events before upgrade.

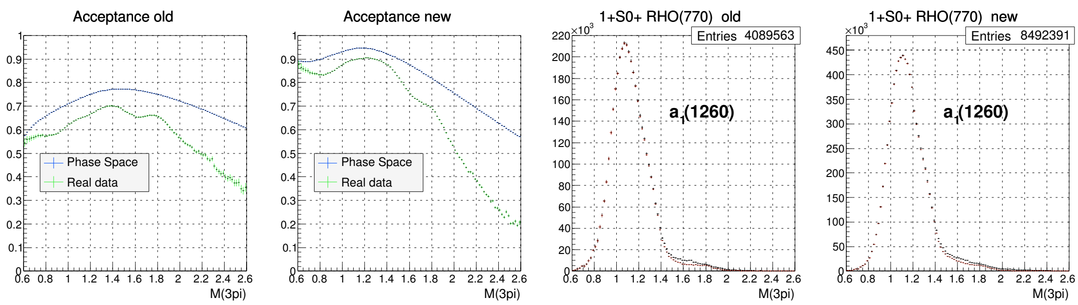

Figure 1: VES geometric acceptance before and after upgrade; largest wave $1^+S0^+\rho(770)$ for $|t'| < 0.03\,GeV^2/c^2$ in old and new data.

2 Method of the analysis

Our method of the analysis is based on Illinois PWA [3]. We are using extended likelihood event by event fit with positive definite density matrix as parameters. No restrictions are placed on the rank of the matrix. Amplitudes are constructed using isobar model, sequential decay of 3-particle system via $\pi\pi$ subsystem, with relativistic corrections according to [4]. Wave has quantum numbers $J^P LM^\eta$ R where J^P is spin-parity for 3π system, M^η is projection of spin and exchange naturality, R is the known resonance in $\pi\pi$ system and L is orbital momentum in Rπ decay. Isospin and G-parity $I^G = 1^-$ are the same for all 3π charged states. To describe broad part of $\pi\pi$ S-wave we use modified M solution from [5]. To make this amplitude broad we drop 4-th order terms and coupling to $K\bar{K}$. We name this pseudo state ε, it should describe among other things $f_0(1400)$ and possible $\sigma(600)$. Narrow $f_0(975)$ and $f_0(1500)$ are included separately. Purely geometric (not GEANT) model of the acceptance is used.

2.1 Coherent part of density matrix

Coherent part of the density matrix ρ is the largest part of the matrix which has rank one and behaves like vector of amplitudes. Let us decompose ρ with dimension d into its eigenvalues and eigenvectors:

$$\rho = \sum_{k=1}^{d} e_k V_k V_k^+ \quad \text{where} \quad \begin{cases} e_k \text{ is k-}th\text{ eigenvalue} \\ V_k \text{ is k-}th\text{ eigenvector} \end{cases}$$

Let $e_1 \gg e_2 > \ldots > e_d > 0$. This condition is often met for 3π system. Leading term $\rho_L = e_1 V_1 V_1^+$ is coherent part of density matrix and $\rho_S = \rho - \rho_L$ is the rest, incoherent part. This decomposition is stable with respect to variations of ρ matrix elements. Experience shows that resonances tend to concentrate in ρ_L while ρ_S can contain non-leading exchanges, albeit it often contains garbage. Results for full ρ are drawn below as black points with errors, for ρ_L as red one.

3 Fit results

In Fig. 1 one can see wave $1^+S0^+\rho(770)$ for low $|t'|$ region in both old $37\,GeV/c$ and new $29\,GeV/c$ data. The wave contains huge contribution from $a_1(1260)$ and a shoulder at $M(3\pi) \approx$

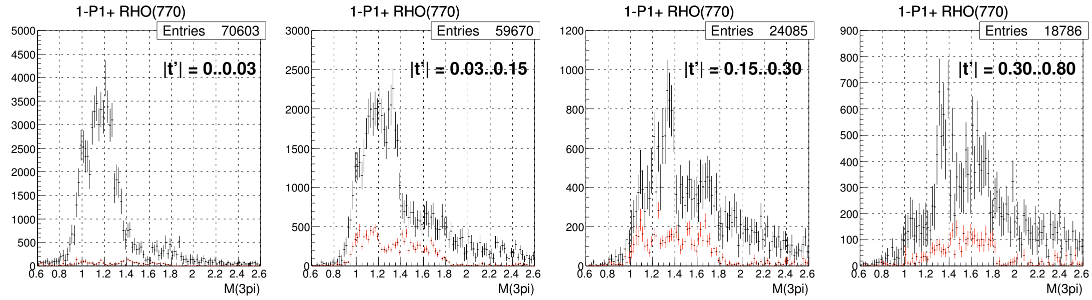

Figure 2: Exotic wave $1^-P1^+\rho(770)$ in all four $|t'|$ regions, old 37 GeV/c data.

$1.7\,GeV/c^2$ which can correspond to $a_1(1700)$. Two conclusions can be drawn here — first, the structure of the wave is approximately the same in both old and new data; next, data for the coherent part of the density matrix fill the whole wave. The same is true for all other largest waves, like $0^-S0^+\varepsilon$ and $2^-S0^+f_2(1270)$ (not shown here).

Probably the wave with exotic quantum numbers $J^{PC} = 1^{-+}$ has the most controversial status in the whole 3π PWA. Corresponding objects $\pi_1(1300)$ and $\pi_1(1600)$ are long discussed. The wave $1^-P1^+\rho(770)$ is shown in Fig. 2, 3 for all four $|t'|$ intervals both for old and new data. The wave is small — no more than 2–5% on the total number of events for old and new data in all $|t'|$ regions. This wave does not correspond to coherent part of density matrix — results for ρ_L are 2–10 times smaller than for the whole ρ. Prominent feature of the new data is that this wave is two times larger than in old data with respect to total number of events for $|t'| < 0.03\ GeV^2/c^2$ and is slightly more structured in other $|t'|$ regions. We think that our model of the setup is still too crude. Given this data existence of both π_1 objects looks questionable.

Now we will discuss some other possibly resonant waves. To save space only new 29 GeV/c data are shown. As it was shown in the presentation new data have better quality although old data mostly lead us to the same conclusions. In Fig. 4 (a) one can see wave $2^+D1^+\rho(770)$ for medium $|t'| = 0.03\ldots0.15\ GeV^2/c^2$ region with well known $a_2(1320)$. State $a_2(1700)$ is discussed in this wave. One can see that the state $a_2(1320)$ is in the coherent part of the density matrix ρ_L and there is nothing in this wave outside $a_2(1320)$ region, especially in its

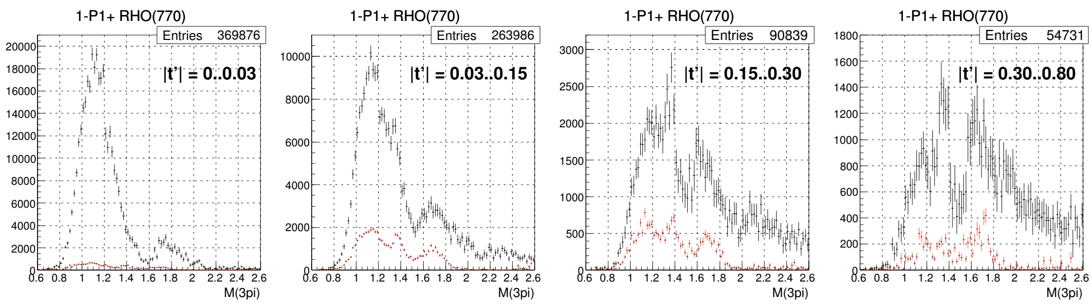

Figure 3: Exotic wave $1^-P1^+\rho(770)$ in all four $|t'|$ regions, new 29 GeV/c data.

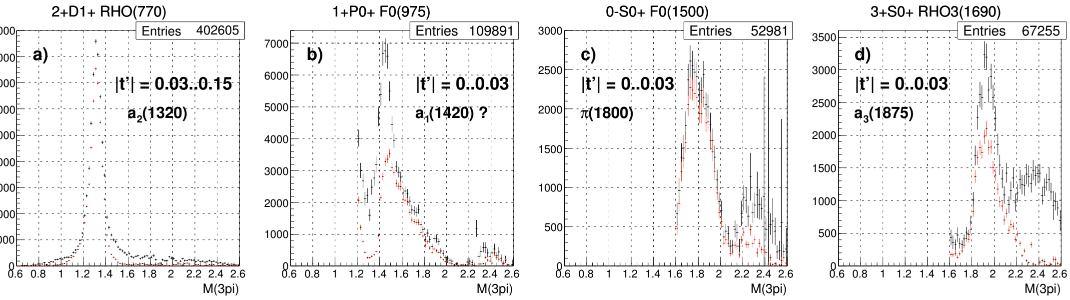

Figure 4: Waves $2^+D1^+\rho(770)$, $1^+P0^+f_0(975)$, $0^-S0^+f_0(1500)$, $3^+S0^+\rho_3(1690)$, new data.

coherent part. We can't see anything which can be interpreted as $a_2(1700)$.

Until the end of this section all waves are shown for $|t'| < 0.03\ GeV^2/c^2$. In Fig. 4 (b) the wave $1^+P0^+f_0(975)$ with discussed $a_1(1420)$ is shown. Good narrow resonant like structure can be seen at $M(3\pi) \approx 1.45\ GeV/c^2$. The same structure, albeit less prominent and never reported, can be seen in our old data. This structure has some peculiarities — its coherent and incoherent parts are approximately of the same magnitude; coherent part is severely wider than the peak itself. These features make difficult resonant interpretation of given structure.

In Fig. 4 (c) the wave $0^-S0^+f_0(1500)$ is shown. This is probably a decay mode $\pi(1800) \to f_0(1500)\pi$ which was studied before but is much more pronounced in new data. For this wave at $M(3\pi) \sim 1.8 GeV/c^2$ coherent part fills the whole wave which supports resonant interpretation of the peak. In Fig. 4 (d) one can see the wave $3^+S0^+\rho_3(1690)$. A peak at $M(3\pi) \sim 1.9\ GeV/c^2$ is clearly seen. The peak is even more pronounced in ρ_L. We think this is a decay mode $a_3(1875) \to \rho_3(1690)\pi$. The object $a_3(1875)$ is listed as "further states" in [6] and was last observed in [7]. Our analysis can be a ground to re-establish this state.

4 Conclusions

Mass-independent PWA is done for old 37 GeV and new 29 GeV $\pi^+\pi^-\pi^-$ data collected with VES setup. Preliminary results are shown. Large PWA waves look alike for 37 GeV and 29 GeV data. Some small waves are seen much better in new data. Decay modes $\pi(1800) \to f_0(1500)\pi$, $a_3(1875) \to \rho_3(1690)\pi$ are seen in 0^-S and 3^+S waves. State $a_2(1700)$ is not seen in $2^+D1^+\ \rho\pi$. Interpretation of $f_0(975)\pi$ in 1^+S wave at $M \sim 1.4\ GeV/c^2$ is controversial. The wave $1^-P1^+\rho(770)$ with $J^{PC} = 1^{-+}$ is small, no more than 2–4% from total number of events in all $|t'|$ regions both in old and new data. Its coherent part is 2–10 times smaller.

Acknowledgments

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