PROCEEDINGS OF SCIENCE

Diffractive production of $\pi^-\pi^-\pi^+$ and $\pi^-\pi^0\pi^0$ systems at VES.

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The VES experiment has collected high statistics of exclusive reactions with three pions in the final state: $\pi^-\pi^-\pi^+$ (about $43 \cdot 10^6$ events) and $\pi^-\pi^0\pi^0$ (about $20 \cdot 10^6$ events). The 3π systems are produced by impinging of 28.9 GeV π^- beam on the beryllium target. The dominant production mechanism is the Pomeron exchange between incoming beam pion and the target. At the very low momentum transfer squared t' the data clearly shows coherent diffractive production on the whole nucleus which is replaced by incoherent process on the individual nucleons at higher $0.05 < t' < 1\text{GeV}^2$. The mass-independent partial wave analysis is performed dividing data into the bins of $m(3\pi)$ and t'. The comparison of results with two models of PWA: using formalism of unlimited-rank density matrix and, using rank=1 is presented. The predicted isospin relations (assuming $I = 1$ of 3π systems) and observed ones for intensities in $\pi^-\pi^-\pi^+$ and $\pi^-\pi^0\pi^0$ are shown.

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1. The reaction. PWA framework. Isospin relations.

We present the preliminary analysis of two reactions: $\pi^- Be \to \pi^-\pi^-\pi^+ Be$ (about $43 \cdot 10^6$ events) and $\pi^- Be \to \pi^-\pi^0\pi^0 Be$ (about $20 \cdot 10^6$ events), with π^- beam of 28.9 GeV and beryllium target. The data were taken with upgraded VES detector, using secondary negatively charged beam from the U70 proton synchrotron in Protvino. The previous analysis of 3π states at upgraded VES can be found in [2],[3],[4],[5],[6].

The partial-wave analysis of the reaction $\pi^- N \to 3\pi N$ assumes that π^- beam particle is excited into 3π system by t-channel reggeon exchange so that nucleus or nucleon N stays intact and gets very small momentum transfer $t' = |t| - |t|_{min} \sim q_t^2$ (q_t is recoil 3-momenta perpendicular to the incoming beam direction). The 3π final states are described by $J^{PC}M^{\varepsilon}[isobar]\,L$ quantum numbers where J is total spin of 3π system, $M > 0$ is spin projection in the Gottfried-Jackson frame, $\varepsilon = \pm 1$ is reflectivity. The dipion intermediate state is called $[isobar]$ having definite spin S and isospin $I_{2\pi}$, L is relative orbital angular momentum between isobar and batchelor pion. The included isobars are $\rho(770)$, $\rho_3(1690)$ with isospin $I_{2\pi} = 1$ and $f_0(600)$, $f_0(980)$, $f_0(1500)$, $f_2(1270)$ with $I_{2\pi} = 0$. The complex functions describing process $J^{PC}M^{\varepsilon} \to ([isobar]\pi)_L$ are called the decay amplitudes $\psi_i^{\varepsilon}(\tau)$ and are the functions of 3-body phase space variables τ. The mass-independent PWA model has probability density $P(\tau) = \sum_{\varepsilon}\sum_{i,j}\rho_{ij}\psi_i^{\varepsilon}(\tau)\psi_j^{\varepsilon *}(\tau)$ where ρ_{ij} is spin-density matrix. It contains information on amplitudes intensities and their relative phases. Two different PWA frameworks were applied: using rank=1 of spin-density matrix and using unlimited-rank spin-density matrix. In the last case the eigenvector corresponding to the largest eigenvalue (LEV-eigenvector) can be extracted [1].

In the isobar model, relations are expected for amplitudes between $\pi^-\pi^-\pi^+$ and $\pi^-\pi^0\pi^0$. In case of $I_{2\pi} = 1$ isobars the resulting 3π isospin value can be $I_{3\pi} = 1$ and $I_{3\pi} = 2$. Assuming $I_{3\pi} = 1$ (which is true if Pomeron exchange dominates) isospin couplings connect $\rho^0\pi^-$ and $\rho^-\pi^0$ states to have same intensities (taking into account same structure of Bose-symmetrization). In case of $I_{2\pi} = 0$ isobars, $\pi^-\pi^0\pi^0$ and $\pi^-\pi^-\pi^+$ have $I_{3\pi} = 1$ and are connected just by isospin relation between $f \to \pi^0\pi^0$ and $f \to \pi^+\pi^-$ which gives 0.5:1 for their relative intensities in case of pure two-body decay. However, full 3-body amplitudes with $f\pi$ intermediate channel have different structure after Bose-symmetrization. Interference of two $f\pi^-$ terms on $\pi^-\pi^-\pi^+$ Dalitz-plot (which is absent in case of $\pi^-\pi^0\pi^0$) can break "naive" 0.5:1 ratio. The exact ratios can be calculated directly from the phase-space integrals of squared decay amplitudes, used in PWA.

2. Results for different $J^{PC}M^{\varepsilon}$

The high statistics of both reactions allows to perform PWA dividing the data into 20 MeV $m(3\pi)$-bins and separately in six t'-bins 0-0.015-0.033-0.060-0.060-0.090-0.200-1 GeV.

The $2^{++}1^+\rho(770)\pi\ D$ wave is strongly dominated by the $a_2(1320)$ meson signal. Its intensities as functions of $m(3\pi)$ are shown on fig. 1 separately in six t$'$ bins for $\pi^-\pi^-\pi^+$ system. The unlimited-rank density-matrix intensity (red) matches with intensity based on the largest eigenvalue (green) and with rank=1 model intensity (blue). However, at lowest t' bins where a_2-signal is relatively small, the unlimited-rank density matrix intensity without extracting LEV shows a leakage - which motivates us to exract largest eigenvalue from density matrix. On the other hand, dominance of $a_2(1320)$ signal in the LEV-eigenvector at very different values of t' demonstrates

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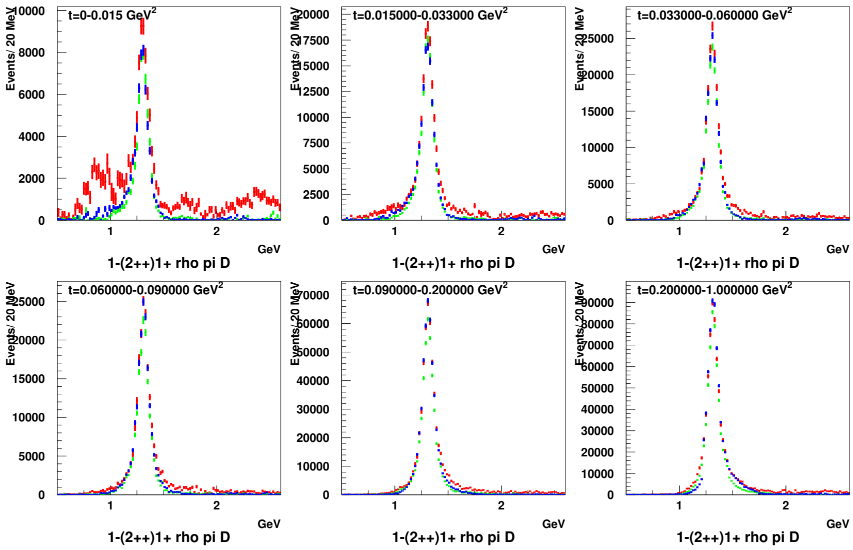

Figure 1: Intensities of $2^{++}1^{+}\rho\pi D$ in 6 t′-bins. Red color shows unlimited-rank density matrix model, green - the largest eigenvalue and blue shows rank=1 model.

high coherence between dominant amplitudes both for coherent diffraction on nuclei and also for incoherent processes on single nucleons.

The PWA intensities of 2^{++} for $\pi^-\pi^-\pi^+$ (in red here and later) and $\pi^-\pi^0\pi^0$ (in blue) , their ratios (in green) and calculated ratios from PWA normalization integrals (in purple) are shown in fig. 2, for the r=1 method and for the LEV-eigenvector. No additional scaling factor between two systems is applied. The plots show rather good agreement between calculated and measured ratious in the $a_2(1320)$ peak region.

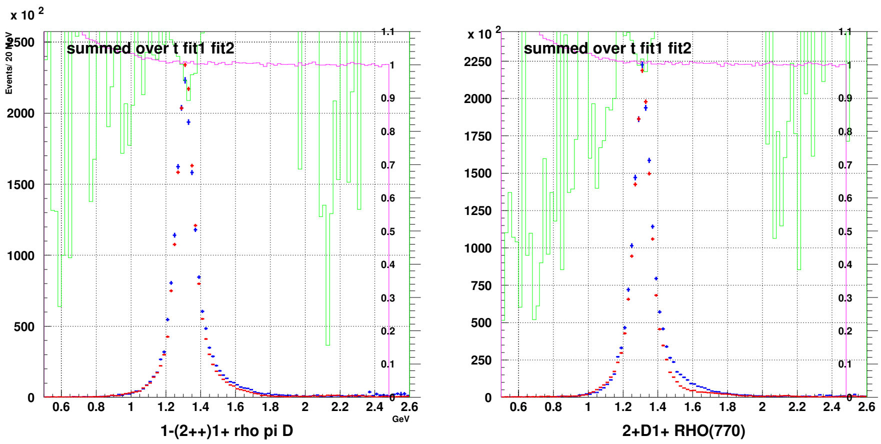

Figure 2: Intensities summed over t′ of $2^{++}1^{+}\rho\pi\ D$ for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector (right). No any scaling factor between different methods is applied here and further.

Figure 3 shows intensities of $1^{++}0^{+}\rho\pi\ S$, which dominates in 3π states. The peak in $\pi^-\pi^0\pi^0$ is significantly lower, similarly in two fit models. In contrast to 2^{++}, the $1^{++}\rho\pi\ S$ is not dominated by a single resonance. Visible violation of isospin relation could have several reasons. Reason

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could be inadequite parameterization of badly known $f_0(600)$ isobar which contributes 10-20% to 1^{++} states. Also the admixture of $K^+K^-\pi^-$ which amounts $\sim$ 10% of $\pi^-\pi^-\pi^+$ sample can influence the experimental ratio.

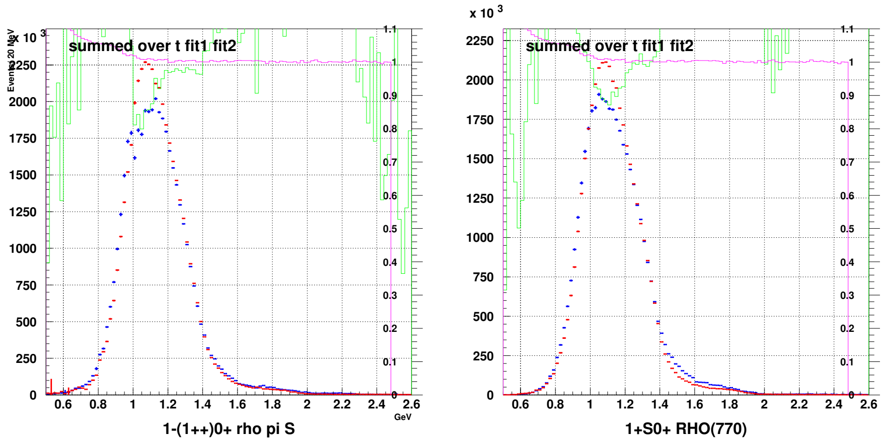

Figure 3: Intensities summed over t′ of $1^{++}0^{+}\rho\pi$ S for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector (right)

The small signal in $1^{++}0^{+}f_0(980)\pi$ P, see fig. 4 forms rather narrow peak at about 1.45 GeV, and was claimed as $a_1(1420)$ meson [7]. Here, the method of unlimited-rank density matrix demonstrates significantly lower intensity than rank=1 method in both 3π-systems.The observed isospin ratio is also somewhat smaller for $\pi^-\pi^0\pi^0$ than predicted value. To clarify the reason of those deviations, further studies are needed. Particularly, better knowledge of $f_0(600)$ and $f_0(980)$ amplitudes is needed, which are known to heavily interfere in $a_1(1420)$ region.

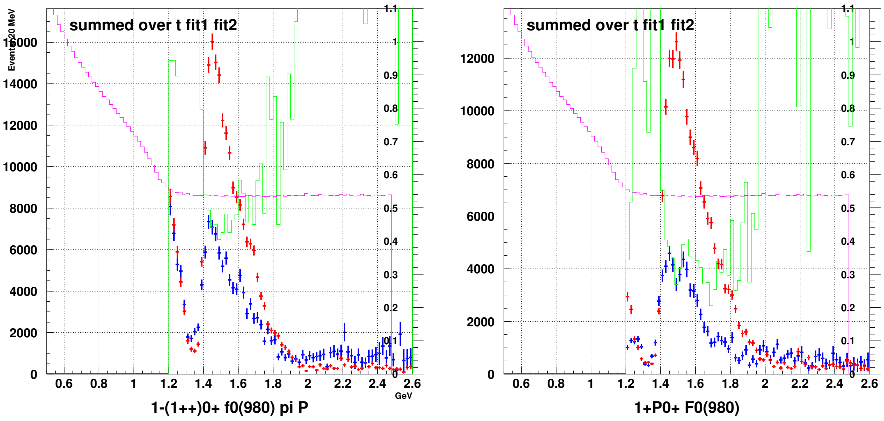

Figure 4: Intensities summed over t′ of $1^{++}0^{+}f_0(980)\pi$ P for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector (right)

Another partial wave with $f_0(980)$ isobar is $0^{-+}0^{+}f_0(980)\pi$ S, see fig. 5. It shows clear signal of $\pi(1800)$, having low-mass background shoulder. This is an example when two PWA models give very similar results - concerning heights of the peaks, and also isospin relations at the resonant peak.

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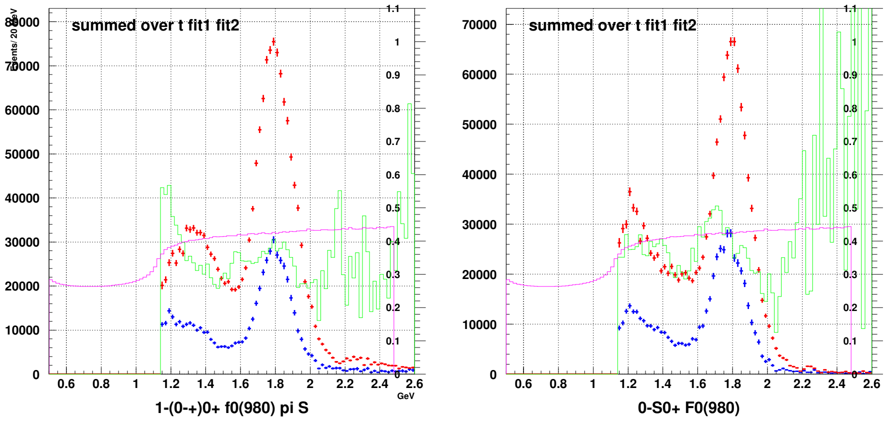

Figure 5: Intensities summed over t′ of $0^{-+}0^{+}f_0(980)\pi\ S$ for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector (right)

Finally, two higher spin partial waves: $3^{++}0^{+}\rho_3(1690)\pi\ S$ (see fig. 6) and $4^{++}1^{+}\rho(770)\pi\ G$ (see fig. 7) are compared. For the first time isospin relation is studied for amplitude containing $\rho_3(1690)$ as an isobar. Two PWA models give very similar peak height in $\pi^-\pi^-\pi^+$. The corresponding peak in $\pi^-\pi^0\pi^0$ is excessive, but it clearly sits on low-mass background, better seen in fig. 6 right plot. $4^{++}1^{+}$ looks very clean and demonstrates reasonable isospin symmetry at the peak, however its amount is significantly lower for unlimited rank method.

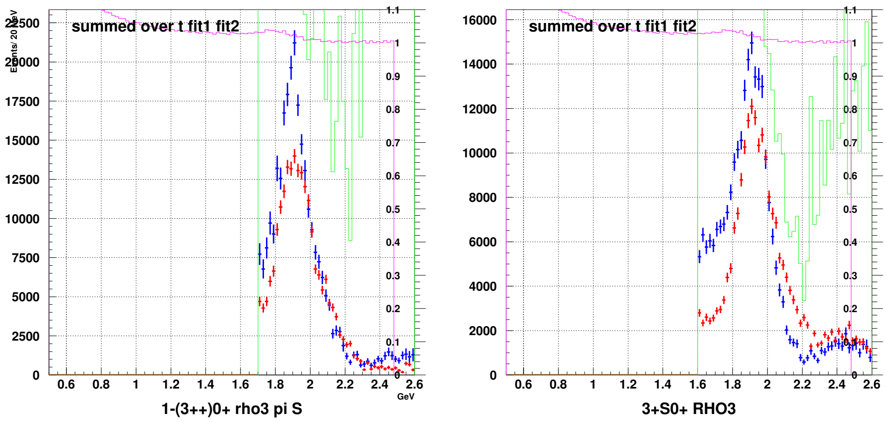

Figure 6: Intensities summed over t′ of $3^{++}0^{+}\rho_3(1690)\pi\ S$ for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector(right)

3. Conclusions and outlook

We present for the first time the comparison of PWA of two reactions $\pi^-Be \to \pi^-\pi^-\pi^+Be$ and $\pi^-Be \to \pi^-\pi^0\pi^0Be$ using two different PWA frameworks rank=1 model for the spin-density matrix and unlimited-rank density matrix (with further extracting LEV-eigenvector). The isospin relations between amplitudes of two reactions are presented as ratious of intensities and compared with calculated values within isobar model. The results using rank=1 method are mostly compatible with unlimited-rank method and extracting of largest-eigenvalue amplitudes, however the reduction of intensities at the peaks of resonances is observed when using the second method. The intensities

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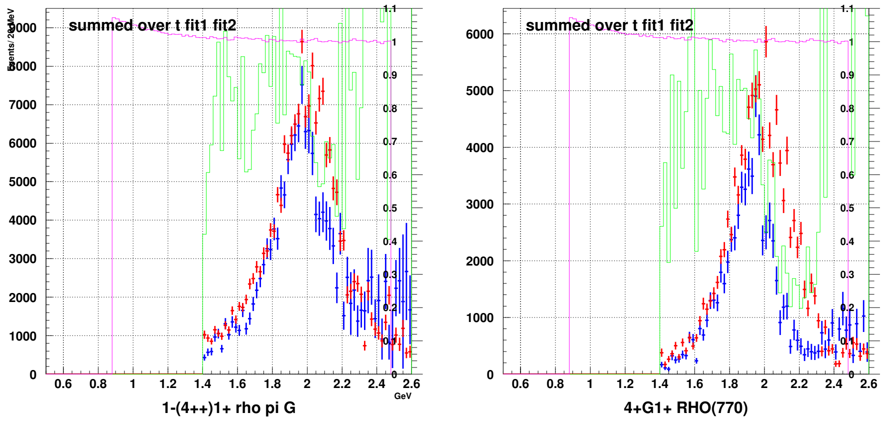

Figure 7: Intensities summed over t′ of $4^{++}1^{+}\rho(770)\pi\ G$ for $\pi^-\pi^-\pi^+$ (red) and $\pi^-\pi^0\pi^0$ (blue), using rank=1 (left) and LEV-eigenvector (right)

obtained from the unlimited-rank density matrix (without extraction of LEV-eigenvector) contain leakages - especially in case when a given intensity is relatively small. Results in different J^{PC}-sectors are compared in detail: $J^{PC} = 0^{-+}, 1^{++}, 2^{++}, 3^{++}$ and 4^{++} Small but interesting signals are presented such as $1^{++}0^{+}f_0(980)\pi$ and $3^{++}0^{+}\rho_3(1690)\pi$. They demonstrate similar results using two PWA methods and reasonable isospin relations.

Acknowledgments

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