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The PWA of $\pi^-\pi^0$ system in the presence of a significant irremovable background

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Abstract. 7×10^6 events of the reaction $\pi^- N \to \pi^-\pi^0 N'$ were collected at the VES experiment. Mass independent angular analysis is performed to study production mechanism of ρ-meson. t-channel ω-exchange and π-exchange are isolated. The analysis is done for 8 bins of a four momentum transfer squared to extract cross-section dependence of t'. Novel method of waves extraction is applied to deal with a significant irremovable background.

1 Introduction

The paper is devoted to analysis of reaction (1) for the dipion mass interval from the threshold to 1.2 GeV.

$$\pi^- N \to \pi^-\pi^0 N' \to \pi^- \gamma\gamma N' \tag{1}$$

Two aspects should be mentioned as motivation of the work. First of all, the dipion system was studied in the seventies of the previous century at low invariant mass interval [1–4] and never been studied for invariant mass of $\pi^-\pi^0$ more then 2 GeV. Since excitation states of mesons are far from being understood, high statistics data sample collected at VES experiment could shed some light there. The current work was planned to be the first step of such analysis. Secondary, the low mass interval of the dipion system is populated by ρ-meson decay events. The highest statistics of the ρ-meson enables a detailed study of its production mechanisms.

The VES experiment operates with 28 GeV pion beam, so t-channel reaction is dominant mechanism of a final state production ($\sqrt{s} \approx 7.3$ GeV for reaction on the proton). Because of angular momentum and G-parity conservation ρ-meson is mostly produced in π and ω exchanges. a_1, a_2 trajectories are suppressed by coupling constants. Unlike π-exchange, ω-exchange results in production of ρ-meson with a projection. Amplitude as a function of a polar angle of the final state particles at the resonance rest frame is symmetric for π-exchange, and antisymmetric for ω-exchange. It allows to separate their contributions. For details see [5, 6].

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The VES is a general purpose magnetic spectrometer with electromagnetic calorimetry. A beryllium blank is used as the target. The experiment is installed at a secondary beam line of the U-70 accelerator of IHEP. The access to the one-prong events became possible after recent upgrade [7]. Then new data were collected in two runs with the fully operational setup. The present analyses are based on data taken in the fall of year 2012.

2 Event selection

To select the exclusive reaction (1) a trigger requirements and the cuts which were applied list below.

- The trigger contained three main parts. First, the beam counters before target fed to a coincidence circuit to provide beam. Second, small beam counters after target fed to an anticoincidence circuit. Third, signal from a veto counter around target also fed to an anticoincidence circuit.
- Track for a beam particle, identified as pion.
- Exactly one track for outgoing particle are reconstructed in the magnetic spectrometer.
- An angle between beam and secondary track was restricted by minimal value 3 mrad to eliminate events without interaction or elastic scattering processes.
- Exactly two γ candidates are reconstructed in the EM-calorimeter. Showers with energy less then 0.5 GeV were not taken into account.
- A vertex is reconstructed within a volume of the target.
- An invariant mass of γ candidates was cut by interval $M_{\pi^0} \pm 15$ MeV.
- Finally events were selected with the total momentum of secondary particles being close to the nominal beam momentum. The permitted interval was from 25 GeV to 30 GeV.

Selected data sample contained $\sim 7 \times 10^6$ events.

2.1 The background

The main background to the reaction (1) comes from diffractive reaction with three pions in a final state

$$\pi^- N \to \pi^- \pi^0 \pi^0 N' \to \pi^- \, 4\gamma \, N'. \qquad (2)$$

Losing of two γ-quanta from one π^0 decay gives the same final state to (1). Such events can pass all cuts (see Sect. 2), if missing π^0 has low energy and γ-quanta hit neither the EM-calorimeter nor the veto detector around the target.

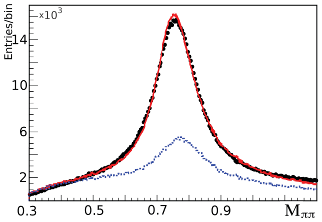

Figure 1. The fit of the invariant mass of $\pi^-\pi^0$ system by the sum of the modified Breit-Wigner function (see Eq. 3) and the background function from the simulation. The real data is plotted with black points, the fit curve is red, the background contribution evaluated by the fit is plotted with blue points.

The result of PWA of the background reaction [8] was used to produce Monte Carlo data sample. Amount of generated events was 2×10^8 events. The simulation of detectors response was done by program based on Geant4. The cuts (see Sect. 2) were applied to select the the background data sample. All cuts were passed by $\approx 5\%$ of events. The dipion mass distribution for the background data sample and real data sample is shown in Fig. 1. The obtained distribution for the background looks very similar to the data, but in additional to ρ-meson signal, there is also non-resonance contribution. Shape of the distribution is used to evaluate background fraction.

We assume the invariant mass (one denotes m) of $\pi^-\pi^0$ from the ρ-meson decay distributed as Breit-Wigner function with dynamical width, appropriate for P-wave decay [9]. The Blatt-Weisskopf barrier factor is employed to suppress too fast increase of the function [10].

$$\frac{dN}{dm} = N_0 \times \frac{\Gamma(m)}{(m^2 - M^2)^2 + (M\Gamma(m))^2}, \quad \Gamma(m) = \Gamma_0 \frac{p(m)^3}{p(M)^3} \frac{M}{m} \frac{1 + R_\pi^2 p(M)^2}{1 + R_\pi^2 p(m)^2}, \tag{3}$$

where M, Γ_0 are mass and width of ρ-meson, R_π is the penetration factor. The normalization factor is denoted as N_0. $p(m)$ is a momentum of produced pions, $p(m)^2 \approx m^2/4 \times (1 - 4m_\pi^2/m^2)$. The fraction of the background is evaluated in each bin of the transverse momentum and varies from 40 % to 60 %.

3 Analysis of angular distributions

The classical partial wave analysis [5] cannot be used, because of the background. The large background fraction makes known methods [11] unstable. The alternative robust approach was needed. The analysis technique applied in the work was newly developed and allows to perform waves extraction in a presence of a significant background.

The analysis was performed independently at 20 bins (50 MeV width) for the invariant mass of $\pi^-\pi^0$ system and 8 bins of $t' = t - t_{min}(m_{\pi\pi})$ with approximately equal statistics. Here and below t is four momentum transfer squared.

3.1 Extraction of "moments"

The Gottfried-Jackson reference frame is considered to analyse angular distributions. The intensity I of the dipion system production at one bin of t' and $m_{\pi\pi}$ is the function of two angles (θ_{GJ}, ϕ_{TY}), so it can be expanded as a series of spherical harmonics ${}^{(-)}Y_{lm}$, defined in the paper [5]. We denote the coefficients of the expansion as H_{lm}, so called *moments*. The maximal value of l was 2 and $m = 0 \ldots l$. It is motivated by physical expectation of P-waves in the final state.

To evaluate H_{lm} the unbinned extended likelihood method [12] is used. Acceptance correction is performed simultaneously with the fit. The procedure is performed for each bin in the invariant mass of $\pi^-\pi^0$ system. The coefficients of the expansion for the real data and the background are shown in Fig. 2. Since intensity is linear combination of moments, the moment expansion of pure signal was calculated by subtraction of the real data moments and the background moments.

Next step which was done is evaluation of the ρ-meson production waves from obtained moments.

3.2 Fit by waves

We define the wave complex amplitudes S, P_-, P_+, P_0 as following:

$$I(\theta_{GJ}, \phi_{TY}) = \left|P_+ \, {}^{(+)}Y_{1,1}\right|^2 + \left|S \, {}^{(-)}Y_{0,0} + P_- \, {}^{(-)}Y_{1,1} + P_0 \, {}^{(-)}Y_{1,0}\right|^2. \tag{4}$$

We assume that the P_0 wave is appropriate to π-exchange and P_+ wave is ω-exchange.

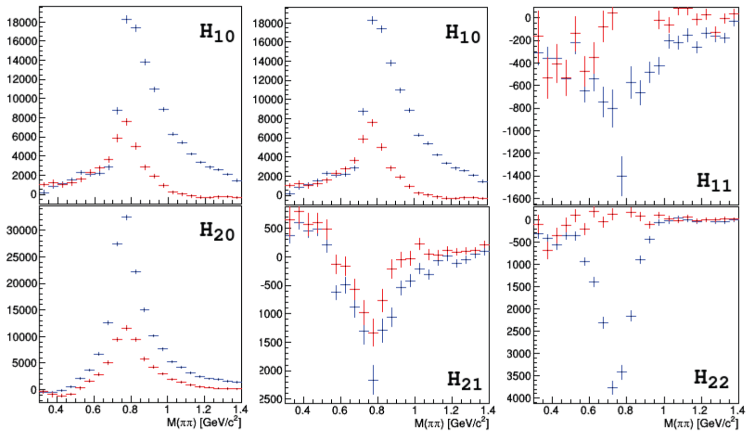

Figure 2. The moments H_{lm} for the real data (blue) and the background (red). The normalization of background is given by the fit of the invariant mass distribution (see Sect. 2.1). $0.0005\,\text{GeV}^2/\text{c}^2 < t' < 0.008\,\text{GeV}^2/\text{c}^2$.

If waves are known, the moments can be uniquely calculated. To extract the waves χ^2 fit of the moments were done. The functional was taken as follows

$$\chi^2(w) = \sum_{i,j} (H_s - H(w))_i\, E_{ij}\, (H_s - H(w))_j, \tag{5}$$

where w is the set of amplitudes sought for (S, P_-, P_+, P_0), $(H_s)_i$ is the calculated set of moments (H_{lm}), E_{ij} is the covariance matrix, $i, j = 1..6$, as we consider 6 moments (see Fig. 2). In general, each set of the moments corresponds to two sets of the waves [5]. Based on our physical assumption the solution with smaller S-wave is chosen as physical one. The obtained solutions for the waves in all mass bins are shown in Fig. 3. The intensities for P_+ and P_0 waves were fitted by function (3) and integrated over mass. N, M, R_π were parameters of the fit.

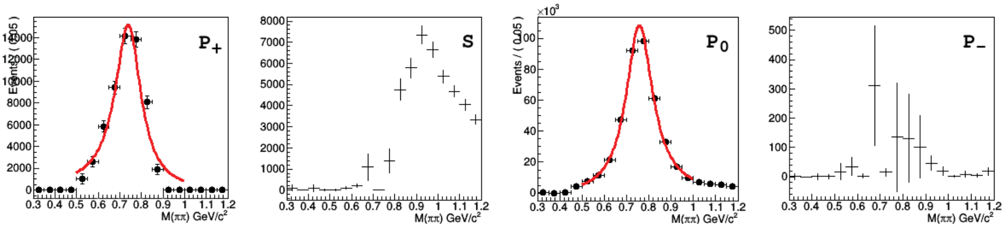

Figure 3. The intensities of the waves, calculated for all invariant mass bins. The four momentum transfer squared is in the interval $0.0005\,\text{GeV}^2/\text{c}^2 < t' < 0.008\,\text{GeV}^2/\text{c}^2$.

The same procedure was performed for the 8 bins in t', the integrals of P_0 and P_+ waves intensities divided by bin size are plotted in Fig. 4.

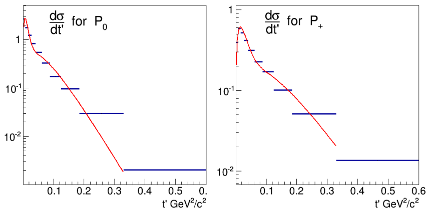

Figure 4. The t' dependence of the P_0 wave is plotted in the left side and that of the P_+ wave in the right side. The histograms are fitted by function $f(t') \sim f t' e^{-\alpha_1 t'} + (1-f) t' e^{-\alpha_2 t'}$, where $\alpha_{1,2}$, f are free parameters.

4 Results and discussion

Fig. 3 shows the result of the background subtraction. It can be seen that the P_- wave is small. The intensity of S-wave is also small compare to P_0 and P_-. Nevertheless systematic studies are required.

The ω-exchange for ρ-meson production was early observed at low energy of the incoming beam (5 GeV) [2–4]. It was shown that the contribution of ω-exchange is not negligible. From our preliminary study we conclude that the ω-exchange contribution can be extracted as a function of t'. It is significant and comparable to π-exchange for medium and high t' ($t' > 0.03\,\mathrm{GeV}^2/\mathrm{c}^2$).

Acknowledgements

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