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Search for $f_1(1285) \to \pi^+\pi^-\pi^0$ decay with VES detector.

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Abstract

The isospin violating decay $f_1(1285) \to \pi^+\pi^-\pi^0$ has been studied at VES facility. This study is based at the statistics acquired in $\pi^- Be$ interactions at 27, 36.6 and 41 GeV/c in diffractive reaction $\pi^- N \to (f_1\pi^-)N$. The $f_1(1285) \to \pi^+\pi^-\pi^0$ decay is observed. The ratio of decay probabilities $BR(f_1(1285) \to \pi^+\pi^-\pi^0)$ to $BR(f_1(1285) \to \eta\pi^+\pi^-) \cdot BR(\eta \to \gamma\gamma)$ is $\sim$ 1.4%.

1 Introduction.

The decay $f_1(1285) \to \pi^+\pi^-\pi^0$ violates the isospin symmetry. It can proceed by means of $f_1(1285) \to a_1(1260)$ mixing and by a direct decay $f_1(1285) \to (\pi^+\pi^-\pi^0)$. The $f_1(1285) \to a_1(1260)$ mixing is driven mainly by the difference of light quark mass $\Delta m = m_d - m_u$ [1, 2]. Namely this Δm is responsible for known decays $\omega \to \pi^+\pi^-$, $\phi(1020) \to \pi^+\pi^-$, $\eta \to 3\pi$ and $\eta' \to 3\pi$. In

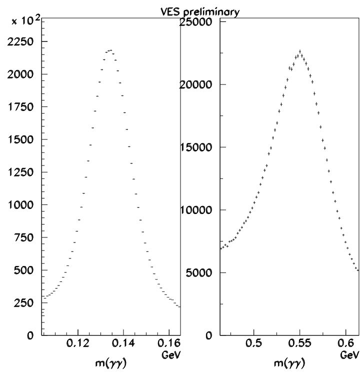

Figure 1: Effective mass of ($\gamma\gamma$ pairs a) reaction $\pi^- N \to \pi^+\pi^-\pi^-\pi^0 N$; b) reaction $\pi^- N \to \eta\pi^+\pi^-\pi^- N$;

the case of $f_1 \leftrightarrow a_1$ mixing it leads to a_1-like final states: $(\rho\pi), (f_0(600)\pi)$. Another effect can contribute to the decay $f_1(1285) \to \pi^+\pi^-\pi^0$, namely the $a_0(980) \leftrightarrow f_0(980)$ mixing predicted in 1979 [3]. Qualitatively speaking, loops with virtual K^+K^- and $K^0\bar{K}^0$ pairs cancel one another, but this cancellation is not perfect due to the difference in mass of charged and neutral kaons. The isospin symmetry violation reaches the maximum at the region between thresholds for pairs of charged and neutral kaons. The amplitude of the isospin violating transition depends on the couplings of scalar mesons with $K\bar{K}$ pairs, in other words, it can shed light on the structure of scalars. This phenomenon was discussed in details and several possibilities for its experimental observation were proposed, including a special polarization experiment [4], $f_1(1285)$ decays [5] and J/ψ decays [6]. Theoretial aspects of the expected $a_0(980) \leftrightarrow f_0(980)$ mixing are discussed in details in recent paper [7].

Diffractive reaction $\pi^- N \to (f_1\pi^-)N \to (\eta\pi^+\pi^-)\pi^- N$ represents a reach source of the $f_1(1285)$ mesons at low background. The branching ratio of $f_1 \to a_0\pi$ decay is large, $BR = 0.36 \pm 0.07$ [8]. The process chain

$$f_1(1285) \to a_0(980)\pi^0 \to f_0(980)\pi^0 \to (\pi^+\pi^-)\pi^0; \tag{1}$$

is well suitable for a search of expected isospin violation.

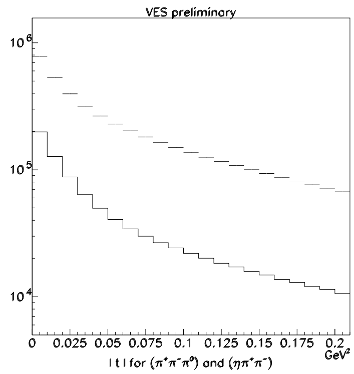

Figure 2: $|t'|$-distributions for reactions $\pi^- N \to \pi^+\pi^-\pi^-\pi^0 N$ (upper distribution) and $\pi^- N \to \eta\pi^+\pi^-\pi^- N$.

2 Experimental procedure.

This study is based on the statistics acquired by the VES experiment [9] in interactions of a π^- beam at the momentum of 27, 36.6 and GeV/c on a Be target, in reaction

$$\pi^- N \to \pi^+\pi^-\pi^-\pi^0 N. \quad (2)$$

VES is a wide-aperture magnetic spectrometer equipped with a lead-glass electromagnetic calorimeter and Cherenkov detectors for charged particle identification. Events from reaction

$$\pi^- N \to \pi^+\pi^-\pi^-\eta N \quad (3)$$

were selected also and used for normalization. The π^0 and η mesons were detected in the $\gamma\gamma$ mode. Selection criteria which have been applied for the selection of the $(\pi^+\pi^-\pi^-\eta)$ events are described in [10]. Similar selection procedure was used for the $(\pi^+\pi^-\pi^-\pi^0)$ events; here the effective mass of two photons was requested in the range $(0.105, 0.165)\, GeV/c^2$ (see Fig.1). A kinematical fit to the η or π^0 mass has been performed, respectively. The t-distributions for the reactions (2) and (3) are shown in Fig. 2. The low $|t|$ region is relatively higher for the reaction (3), which is a consequence of the diffractive production.

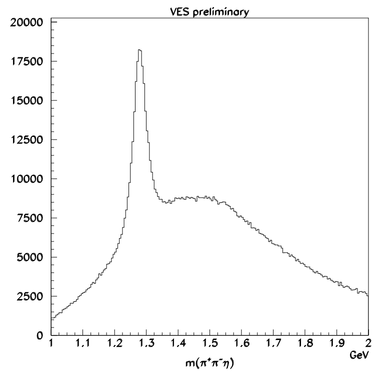

Figure 3: Effective mass of $(\eta\pi^+\pi^-)$ system produced in the reaction $\pi^- N \to (\eta\pi^+\pi^-\pi^-)N$ at low t', $|t'| < 0.04\ GeV^2$. There are two entries per event.

Fig.3 demonstrates the $f_1(1285)$ signal which is observed in the dominant decay channel, $f_1 \to \eta\pi^+\pi^- \to \gamma\gamma\pi^+\pi^-$ at low momentum transfer region, $|t'| < 0.04$. The estimated number of events in the f_1 peak is $N_\eta = 117600 \pm 1300$, assuming the Breit-Wigner shape of the signal. Concerning the f_1 production process, the results of the partial wave analysis of $\eta\pi^+\pi^-\pi^-$ system [11)] show that the $(f_1\pi^-)$ system is produced in diffractive reaction. The dominant wave is $J^{PC}M\eta = 1^{++}0+$, here M is the spin projection and the η denotes the exchange naturality. Then the intermediate system with spin-parity 1^+ decays into $f_1(1285)$ and extra π^-, this is a P-wave decay. Then the $f_1(1285)$ decays into $\eta\pi^+\pi^-$, this decay also includes a P-wave. The dominant angular term in the effective amplitude (which describes the chain of processes) is

$$A \sim sin(\theta_1) \cdot \sin(\theta_2) \cdot sin(\phi_0 - \phi_2) \quad (4)$$

here θ_1 is the Gottfried-Jackson angle of the extra π^-; θ_2 is polar angle of π^0 at the f_1 rest frame with Z-axis going along the direction of the extra π^- (so called "canonic system"); ϕ_0 and ϕ_2 are the azimuthal angles of the beam particle and the π^0 at the same system. The validity of this formula is demonstrated in Fig.4. Apart from the mass spectrum presented in Fig.3, similar distributions were accumulated in several intervals on the angular weight $W = |A|^2$. The ratio of two mass spectra, one of them for events at high W and another one

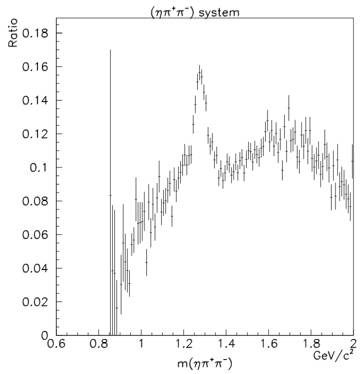

Figure 4: Ratio of two $m(\eta\pi^+\pi^-)$ spectra. The distribution for events at $W > 0.8$ is divided by the spectrum for events at $W < 0.2$ (see text).

at low W, is shown. One can see that the angular weight W strengthens the f_1 signal. This weight was used for the identification of the $f_1 \rightarrow \pi^+\pi^-\pi^0$ decay.

Now we consider the general characteristics of the reaction (2). Fig.5 demonstrates the mass spectra for the selected $(\pi^+\pi^-\pi^-\pi^0)$ sample. The $b_1(1235)$ signal and a wide peak centered near 1700 MeV are seen at the total mass spectrum (Fig.5a). For the $(\pi^+\pi^-\pi^0)$ system one can see a strong peak from the $\omega \rightarrow \pi^+\pi^-\pi^0$ decay and also the $\eta \rightarrow \pi^+\pi^-\pi^0$ peak in Fig.5b, as well as an accumulation of events at the mass close to 1300 MeV is seen which is close to the $f_1(1285)$ mass. Detailed analisis of this structure is given below. Concerning the $(\pi^+\pi^-)$ mass spectrum (Fig.5d),a sharp peak from $K^0 \rightarrow \pi^+\pi^-$ decay is seen as well as a sharp peak near 780 MeV, the later one is consistent with the ω mass and should be attributed to the suppressed $\omega \rightarrow \pi^+\pi^-$ decay. Wide background under the ω signal originates from the $\rho \rightarrow \pi^+\pi^-$ decay.

It worth mentioning that the $f_1 \rightarrow a_0\pi^0$ sample originates from the diffractive production. The subsequent processes, $a_0 \leftrightarrow f_0$ mixing and $f_0 \rightarrow \pi^+\pi^-$ decay, lead to four-pion final state. The background processes, $\pi^- N \rightarrow (\pi^+\pi^-\pi^-\pi^0)N$, i. e. production of four pions is not a diffractive process and it is suppressed. This suppression should facilitate the observation.

To improve the signal to background ratio, the following selection criteria have been applied: a) events at the low momentum transfer, $|t'| < 0.04$ were

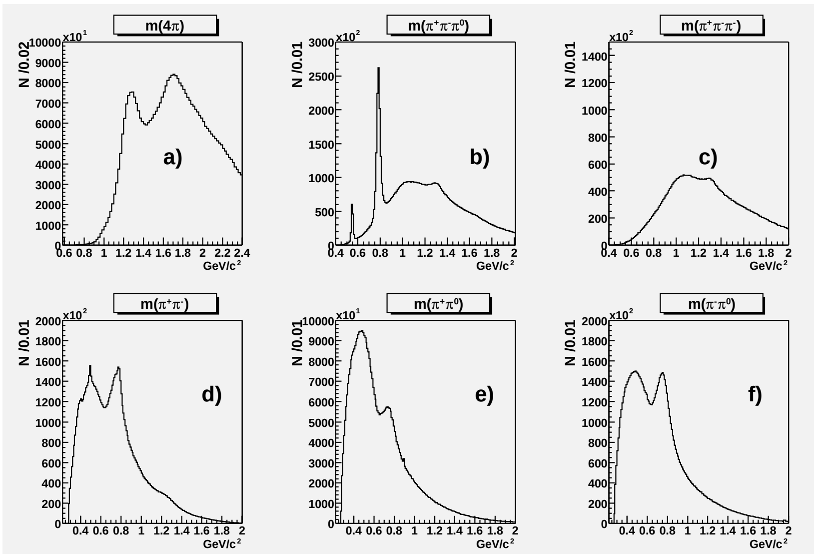

Figure 5: Effective masses for $(\pi^+\pi^-\pi^-\pi^0)$ system. a) total mass; b) $m(\pi^+\pi^-\pi^0)$; c) $m(\pi^+\pi^-\pi^-)$; d) $m(\pi^+\pi^-)$, a zoom of the mass region from 680 to 880 MeV is shown ; e) $m(\pi^+\pi^0)$; f) $m(\pi^-\pi^0)$.

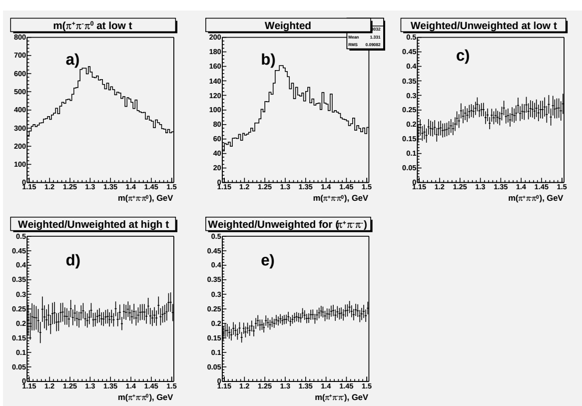

Figure 6: The three-pion mass spectra for $0.970 < m(\pi^+\pi^-) < 1.000$: a) $m(\pi^+\pi^-\pi^0)$ spectrum at low $|t'|$; b) like the previous one but weighted; c) ratio of two previous distributions, weighted/unweighted; d) ratio of weighted to unweighted mass spectra for $(\pi^+\pi^-\pi^0)$ system at high $|t'|$; e) ratio of weighted to unweighted mass spectra for $(\pi^+\pi^-\pi^-)$ system at low $|t'|$;

selected; b) events with a signal detected in the target guard system were rejected; c) events with $m(\pi^+\pi^-\pi^0) < 0.800\,GeV/c^2$ at any combination were rejected. First two cuts tend to select diffractive reaction, the third one rejects events with $\omega(780)$ or $\eta(550)$.

Apart from those general cuts, the event selection in different mass intervals for the $(\pi^+\pi^-\pi^0)$ and $(\pi^+\pi^-)$ were tested. The $m(\pi^+\pi^-\pi^0)$ distribution, which was obtained with requirements on the two-pion mass $0.970 < m(\pi^+\pi^-) < 1.000\,GeV$, is presented in Fig.6a. Clear peak is observed, and its mass is close to the $f_1(1285)$ mass. The effect, which arises from the application of the angular weight W to the same event sample, is demonstrated in Fig.6b and 6c. A peak at the same mass region is observed in the ratio of weighted distribution to the unweighted one. A similar procedure was applied for two another samples, namely to the event sample which was selected at large $|t|$ and to the $(\pi^+\pi^-\pi^-)$ system at low $|t|$. The ratios of the weighted to unweighted distributions are shown in Fig.6d and 6e, respectively. No signal is observed.

It is also possible to subdivide the event sample at low $|t|$ into bins on the three-pion mass and look for the mass spectrum of the two-pion system in individual bins. The mass bin width of $10 MeV$ was chosen and the $m(\pi^+\pi^-\pi^0)$ interval from 1200 to 1350 MeV was subdivided to 15 bins. The resulting spectrum for the mass bin $(1280, 1290)\,MeV$ is shown in Fig.7. The $\omega \to \pi^+\pi^-$ decay is seen, and another peak with mass close to $985\,MeV$. A fit by a sum of the Gaussian function for signal and a background term was performed in the mass interval from 880 to 1100 MeV. The product of three-particle phase space by a quadratic function with free coefficients was chosen as the background term. The fit at this bin yields the gaussian mean of $m = 983 \pm 3\,MeV$ and the gaussian $\sigma = 18 \pm 4\,MeV$. The fit $\chi^2/ND = 39.8/40$ and the statistical significance of the gaussial signal is $6.4\,\sigma$.

Similar fitting procedure was applied to all mass bins mentioned above with parameters as determined from the central bin. The result for the number of signal events in all mass bins is presented in Fig.8. The total number of events from decay $f_1 \to \pi^+\pi^-\pi^0$ in all bins is 1572 ± 227. This number of events, taken together with the number of events in $f_1 \to \eta\pi^+\pi^-$ channel, gives the relative branching ratio. The ratio of the detection efficiencies, $R = \varepsilon(\pi^+\pi^-\pi^0)/\varepsilon(\eta\pi^+\pi^-)$ was estimated from a Monte-Carlo simulation and taken

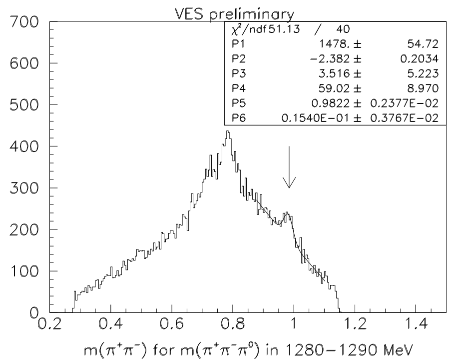

Figure 7: $m(\pi^+\pi^-)$, selected combinations with $m(\pi^+\pi^-\pi^0)$ in the mass interval (1.280,1.290) GeV/c^2,

into account, $R = 0.95 \pm 0.05$.

The measured dependence of the observed signal on the $m(\pi^+\pi^-\pi^0)$ can be fitted by a Breight-Wigner function, and the result of this fit is shown in Fig.8. The fitted peak has $m = 1288.3 \pm 2.6 MeV$ and the width $\Gamma = 21 \pm 4 MeV$, which are in good agreement with the table values.

We tested a presence of a similar signal in charge mode by means of a similar procedure, i.e. by subdivision of the event sample into bins on the $m(\pi^+\pi^-\pi^-)$ and looking for the $m(\pi^+\pi^-)$ spectrum in individual bins. No signal is observed in the vicinity of the $f_1(1285)$.

3 Discussion and conclusions

One can see that the signal at $m(\pi^+\pi^-) \sim 985\, MeV/c^2$ is associated with the peak at $m(\pi^+\pi^-\pi^0) = m(f_1(1285))$ having $J^{PC} = 1^{++}$.

All elements of the obseved pattern fit well with predictions based on the mechanism suggested by Achasov and collaborators in 1979 [3].

The relative branching ratio is determined from the observed number of events in the $\eta\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$ channels. The experimental efficiencies for both reactions are very similar. We estimate

$$\frac{BR(f_1 \to \pi^+\pi^-\pi^0(0.96 < m(\pi^+\pi^-) < 1.01))}{BR(f_1 \to \eta\pi^+\pi^-)\cdot BR(\eta \to \gamma\gamma)} = (1.41 \pm 0.21 \pm 0.42)\%;$$

here statistical and systematic errors are indicated. This relative branching

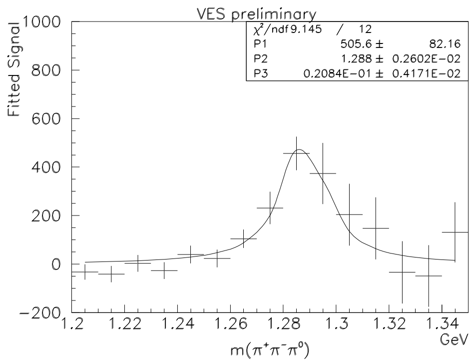

Figure 8: $m(\pi^+\pi^-\pi^0)$; fitted number of signal events as a function of $m(\pi^+\pi^-\pi^0)$;

ratio is consistent with estimation made by Achasov et al. [5].

With PDG values for $BR(f_1 \to \eta\pi\pi) = 0.52 \pm 0.16$ and $BR(\eta \to \gamma\gamma) = 0.3939 \pm 0.0024$ [8, 12] it leads to
$BR(f_1 \to \pi^+\pi^-\pi^0(0.96 < m(\pi^+\pi^-) < 1.01)) = (0.19 \pm 0.09)\%$.

4 Acknowledgements

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