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Study of the decay $f_1(1285) \to \rho^0(770)\gamma$

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Abstract

Amelin D.V. et al. Study of the decay $f_1(1285) \to \rho^0(770)\gamma$. IHEP Preprint 94-91. - Protvino, 1994. - p.11,figs. 7, refs.: 14.

The decay $f_1(1285) \to \rho^0(770)\gamma$ was studied at the VES spectrometer of IHEP. A clear signal of $f_1(1285)$ is seen in the effective mass spectrum of the $\pi^+\pi^-\gamma$ system in the reaction $\pi^- N \to \pi^+\pi^-\pi^-\gamma N$ at the momentum $P_{\pi^-} = 37\ GeV/c$. The branching fraction of decay $f_1(1285) \to \rho^0(770)\gamma$ has been found to be

$$\mathrm{BR}(f_1(1285) \to \rho^0(770)\gamma) = (2.8 \pm 0.7(stat) \pm 0.6(syst)) \cdot 10^{-2}.$$

The ratio of the helicity amplitudes for ρ^0 meson in its rest frame was determined by the analysis of angular distributions :

$$\rho_{00}/\rho_{11} = 3.9 \pm 0.9(stat) \pm 1.0(syst).$$

Аннотация

Амелин Д.В. и др. Исследование распада $f_1(1285) \to \rho^0(770)\gamma$. Препринт ИФВЭ 94-91. - Протвино, 1994. 11с., 7 рис., библиогр.: 14.

На установке ВЕС ИФВЭ изучен распад $f_1(1285) \to \rho^0(770)\gamma$. Отчетливый сигнал от $f_1(1285)$ наблюдается в эффективном массовом спектре $\pi^+\pi^-\gamma$ системы в реакции $\pi^- N \to \pi^+\pi^-\pi^-\gamma N$ при импульсе $P_{\pi^-} = 37\ GeV/c$. Определена относительная вероятность распада $f_1(1285) \to \rho^0(770)\gamma$:

$$\mathrm{BR}(f_1(1285) \to \rho^0(770)\gamma) = (2.8 \pm 0.7(stat) \pm 0.6(syst)) \cdot 10^{-2}.$$

Путем анализа угловых распределений найдено отношение элементов матрицы плотности распада в системе центра масс ρ^0 мезона :

$$\rho_{00}/\rho_{11} = 3.9 \pm 0.9(stat) \pm 1.0(syst).$$

1. Introduction

Radiative decays of mesons are effective tools for the investigation of meson structure [1,2,3,4,5]. However, experimental information especially about E1 radiative transition is rather limited because of experimental difficulties for their investigation.

This paper is devoted to the experimental study of the decay

$$f_1(1285) \to \rho^0(770)\gamma. \tag{1}$$

It was previously detected in the process $J/\Psi \to \gamma(\gamma\rho)$ at MARK-III [6] and was studied by the collaboration WA-76 in the centrally produced exclusive final states at the CERN Ω-spectrometer at 300 GeV/c [7]. The branching fraction obtained for it in these experiments is higher than the upper limit from LEPTON-F experiment [8,9] and the predictions of the majority of the theoretical models [1,2,3,4].

2. Experimental procedure

The experiment was performed at the VErtex Spectrometer (VES) of IHEP in a pion beam with the momentum $P_{\pi^-} = 37\ GeV/c$ on a beryllium target. The VES is a large aperture magnet spectrometer with 29 planes of proportional and drift chambers, the 1600 channel lead glass electromagnetic calorimeter, the 200 channel scintillation hodoscope, the multichannel threshold Čherenkov counter for secondary particle identification. The magnet aperture is $2m \times 1m$. A detailed description of the spectrometer, trigger conditions, DAQ system and off-line analysis are published elsewhere [10,11].

The exclusive reaction

$$\pi^- N \to \pi^- f_1(1285) N \tag{2}$$

was used as a source of f_1 mesons. The decay mode of the $f_1(1285)$ meson

$$f_1(1285) \to \pi^+\pi^-\eta, \qquad \eta \to \gamma\gamma \tag{3}$$

was used as the reference one.

The effective mass spectrum of the $\pi^+\pi^-\eta$ system for the events of the reaction

$$\pi^- N \to \pi^+\pi^-\pi^-\eta N,$$

selected out of the same data set, is shown in Fig.1a. The peak is seen in the mass region of the f_1 meson. The partial-wave analysis of the $\pi^+\pi^-\pi^-\eta$ system [12] shows that this peak corresponds to decay (3).

3. Events selection. Kinematical cuts

The following criteria were used to select the events of the reaction $\pi^- N \to \pi^+\pi^-\pi^-\gamma N$:

1. The event has two negative and one positive tracks of charged hadrons.
2. The event has one γ with $E_\gamma > 3$ GeV. One additional γ-like shower is allowed with the energy not exceeding 0.5 GeV.
3. The total energy of the $\pi^+\pi^-\pi^-\gamma$ final state lies in the region of the "elastic peak": $34 < E_{tot} < 38$ GeV.
4. The effective mass of selected γ and any cluster in the γ-detector does not lie in the π^0 meson mass region.

The effective mass spectra of the $\pi^+\pi^-\gamma$ system and the $\pi^+\pi^-$ subsystem with the less energetic π^- of the two ones are shown in Fig.1b,c. The analysis of the combinatorial background coming from the fact that there are two π^- shows its smooth behavior at all interesting mass region. The clear signal from $\rho^0(770)$ can be seen on Fig.1c. There are four peaks in the spectrum shown in Fig.1b, which can be interpreted as follows :

- the low-mass peak results from the decay $\eta \to \pi^+\pi^-\gamma$;
- the peak in the mass region of 0.7-0.8 GeV and the left "arm" of the η-peak are due to the processes $\omega \to \pi^+\pi^-\pi^0$ ($\pi^0 \to \gamma\gamma$) and $\eta \to \pi^+\pi^-\pi^0$ with one photon lost;
- the peak at 0.96 GeV results from the radiative decay $\eta'(958) \to \pi^+\pi^-\gamma$;

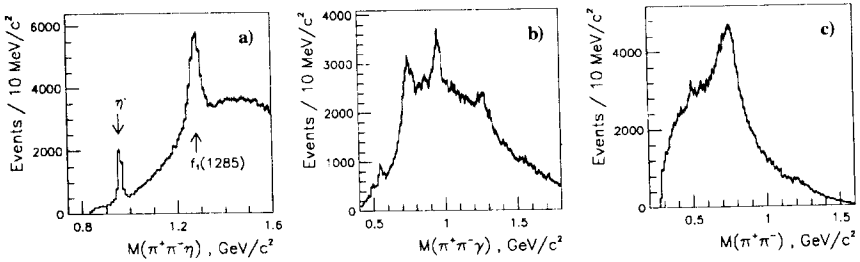

Figure 1. The effective mass spectra for the systems $\pi^+\pi^-\eta$ (a) for the events of the reaction $\pi^- N \to \pi^+\pi^-\pi^-\eta N$ and $\pi^+\pi^-\pi^-\gamma$ (b), $\pi^+\pi^-$ (c) for the events of the reaction $\pi^- N \to \pi^+\pi^-\pi^-\gamma N$.

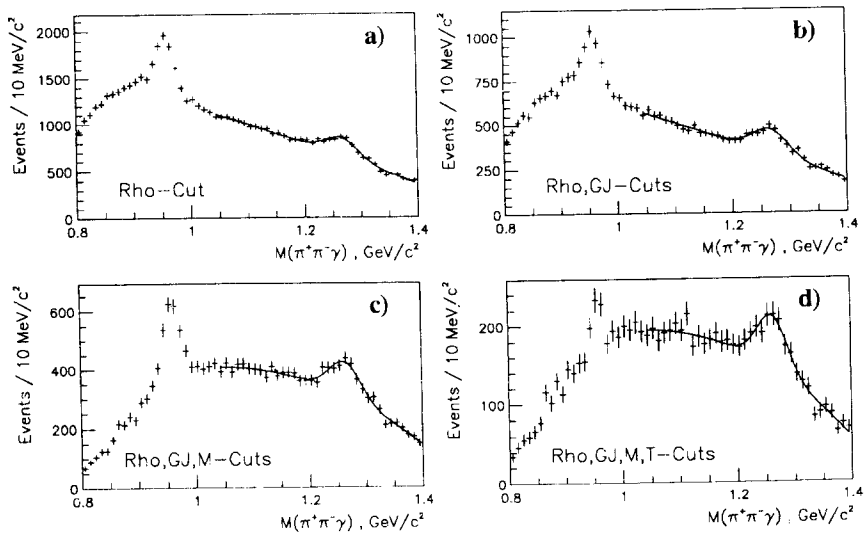

Figure 2. The influence of the cuts on the $\pi^+\pi^-\gamma$ mass spectrum.

- the peak in the 1.27 GeV mass region is interpreted as mainly the signal from decay (1) with some background from the decay

$$a_2^0 \to \pi^+\pi^-\pi^0,\ \pi^0 \to \gamma\ \gamma_{lost} \tag{4}$$

peaking at the same region.

To enhance the f_1 meson contribution into the $\pi^+\pi^-\gamma$ effective mass spectrum we applied the following kinematical cuts to the selected events based on the results of the PWA analysis of the $f_1(1285)\pi^-$ ($f_1 \to \pi^+\pi^-\eta$) system:

- cosine of the Gottfried-Jackson angle of the system $\pi^+\pi^-\pi^-\gamma$ lies in the region $-0.8 < \cos\theta_{GJ} < 0.4$ ("GJ-Cut"). The Gottfried-Jackson angle distribution of f_1 meson shows its "central" production.
- the total effective mass of the final state particles lies in the region $1.4 < M_{\pi^+\pi^-\pi^-\gamma} < 2.4$ GeV ("M-Cut"). The production of $f_1\pi^-$ system is most intensive for this total mass region.
- the transfer momentum squared $-t' < 0.05$ GeV^2 ("T-Cut"), because of the diffractive production of the $f_1\pi^-$ system.
- the effective mass of the $\pi^+\pi^-$ pair belongs to the ρ meson region $0.6 < M_{\pi^+\pi^-} < 0.9$ GeV ("Rho-Cut").

Fig.2 demonstrates the efficiency of these cuts.

The applying of the cuts listed above to the data gives the increase of the signal/background ratio in the $\pi^+\pi^-\gamma$ mass spectrum and reduces the width of the peak due to suppression of the background from decay (4). The Monte-Carlo simulation of this background gives a broad bump in $\pi^+\pi^-\gamma$ mass spectrum at 1.27 GeV. This background corresponds to about 40 % of the whole peak in $\pi^+\pi^-\gamma$ spectrum without cuts and is decreased strongly after "T","M","GJ" and "Rho" cuts. The remaining "flat" part of the background is mainly from the other processes with π^0(one γ lost) in the final state.

The signal at 1.27 GeV has a mass close to that of $f_1(1285)$ and the angular distributions for the events from this peak are similar to those for $f_1(1285)$ decaying into $\eta\pi^+\pi^-$ (see Fig.3). Note that for $\pi^+\pi^-\pi^-\gamma$ events "M","T" and "Rho" cuts were applied and side band background subtraction was performed.

The fit of the signal by Gaussian gives $\Gamma = 66 \pm 6$ MeV after all the cuts which is in the agreement with the Monte-Carlo simulation. The value $M = 1270 \pm 10$ MeV is obtained from the fit; the systematic error dominates here which is caused by the absolute energy calibration of the electromagnetic calorimeter and parameterization of the background. Fig.4 shows the $M_{\pi^+\pi^-}$ vs $M_{\pi^+\pi^-\gamma}$ scatter plot ("M" and "GJ" cuts are applied). The clear concentration

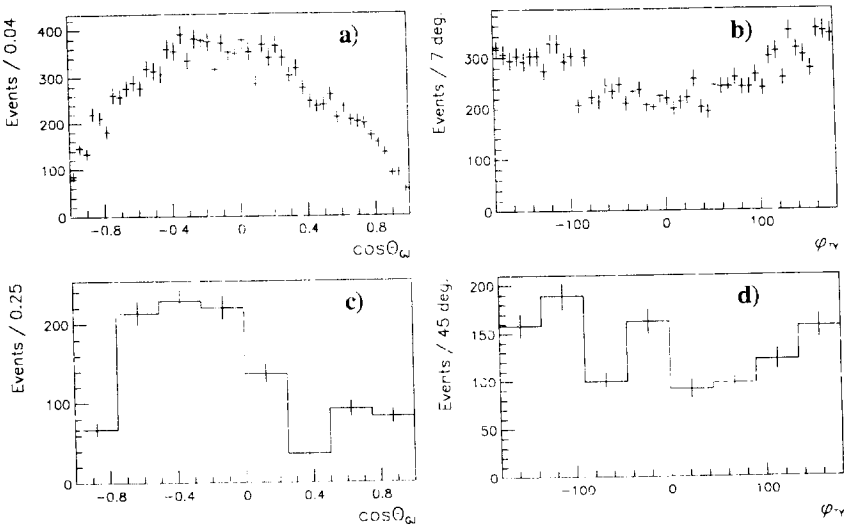

Figure 3 Angular distributions in the Gottfried-Jackson frame for the reaction (2) with subsequent decay $f_1(1285) \to \pi^+\pi^-\eta$ (a,b); the same for the $\pi^+\pi^-\pi^-\gamma$ events with the effective mass of $\pi^+\pi^-\gamma$ lying in the $f_1(1285)$ mass region (c,d).

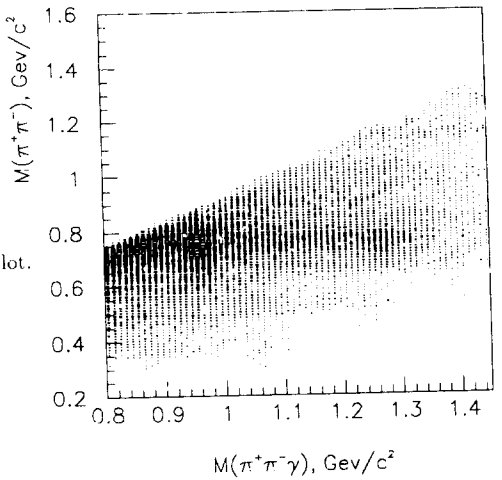

Figure 4. $M_{\pi^+\pi^-}$ vs. $M_{\pi^+\pi^-\gamma}$ scatter plot.

of events near the mass of $\rho^0(770)$ is seen for $M_{\pi^+\pi^-\gamma}$ above 0.96 and 1.27 GeV. It indicates that $f_1(1285)$ decays mostly into $\rho^0(770)\gamma$.

4. Analysis of angular distributions

The angular distributions for decay (1) are defined by the ρ_{00}/ρ_{11} ratio of density matrix elements for ρ^0 meson in its helicity frame. In particular the θ_{int} angular distribution, where θ_{int} is the angle between the π^+ and the γ in the ρ^0 rest frame, is

$$dN/\theta_{int} \propto \rho_{11} \cdot sin^2\theta_{int} + \rho_{00} \cdot cos^2\theta_{int}.$$

The experimental angular distributions are distorted by the background events as well as by the acceptance. To define the contribution from background decay (4) a partial-wave analysis of the reaction $\pi^- N \to \pi^- a_2^0 N$ was performed and its results were used for calculation of the angular distributions in the process

$$\begin{array}{l} \pi^- N \to a_2^0 \pi^- N \\ \qquad \hookrightarrow \pi^0\pi^+\pi^- \\ \qquad\quad \hookrightarrow \gamma\ \gamma_{lost}. \end{array} \tag{5}$$

The experimental angular distributions of the diffractive production of the $f_1\pi^-$ system and subsequent decay of $f_1(1285)$ were fitted out using maximum likelihood method. The fitting function was taken in the form:

$$f(\Omega) = X_{f_1} \cdot f_{f_1}(\rho_{00}/\rho_{11}, \Omega) + X_{bkg} \cdot f_{bkg}(\Omega).$$

Here f_{f_1} describes $f_1\pi^-$ production with sequential decays using the known f_1 density matrix and f_{bkg} describes angular distribution for background events (5); both functions are acceptance corrected after all kinematical cuts described above have been applied. Ω is a set of angles which fixes the event configuration. The "flat" background which has no bumps near 1.27 GeV was removed by the side band background subtraction in minimizing function. Three parameters of the fitting procedure are as follows: X_{f_1} - the amount of f_1, X_{bkg} - the amount of a_2^0 background events and ρ_{00}/ρ_{11} - the ratio of density matrix elements for ρ^0 meson in its helicity frame.

As a result of this fit a good description for all angular distributions was obtained. For example, Fig.5a shows the fitting result of θ_{int} distribution for experimental events at f_1 mass region after "flat" background subtraction. Contributions to the fit result from background decay of a_2^0 that has a specific shape and from the decay of f_1 are shown separately on Fig.5b. For the experimental

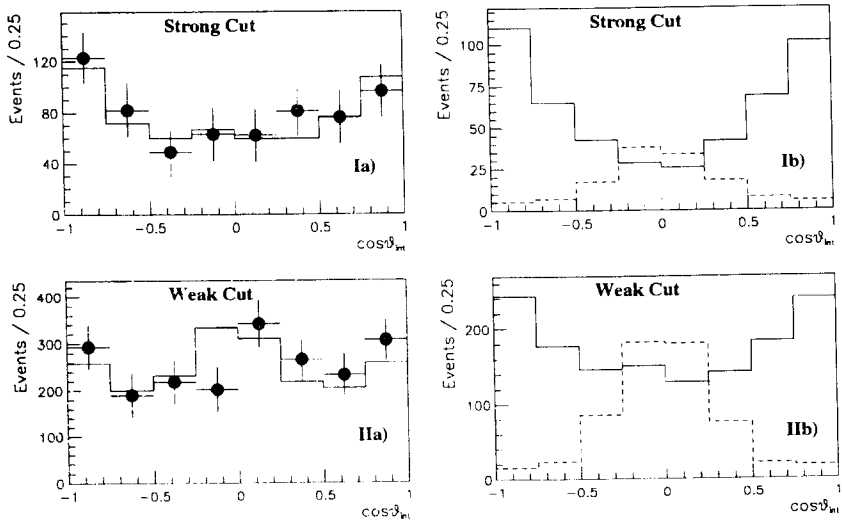

Figure 5. I,II(a) : The result of the fit of angular distributions for the events with the effective mass of $\pi^+\pi^-\gamma$ system lying in the $f_1(1285)$ mass region for the "strong" and "weak" kinematical cuts. I,II(b) : Contribution to resulting fitting function from f_1 decay events (solid line) and a_2^0 background events (dotted line).

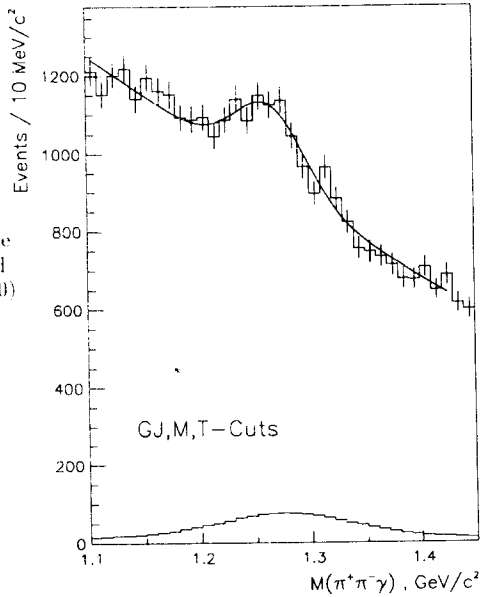

Figure 6. The final experimental $\pi^+\pi^-\gamma$ spectrum with the superimposed subtracted estimation of the $a_2(1320)$ background.

distribution a peak at $\cos\theta_{int}$=0 from a_2^0 background events is clearly seen for "weak" kinematical cut. After applying all cuts listed above ("strong" cut) this peak is reduced significantly.

The θ_{int} distribution for f_1 decay events reveals the clear $cos^2\theta_{int}$ behaviour that indicates the ρ_{00} dominance. The ratio of ρ-matrix elements of ρ^0 meson was found to be

$$\rho_{00}/\rho_{11} = 3.9 \pm 0.9(stat) \pm 1.0(syst).$$

Visible suppression of the ρ_{11} corresponds to what would be expected for an axial-vector particle decaying into ρ and γ in the framework of the vector dominance model taking into account the Landau-Yang theorem.

5. The branching fraction of $f_1(1285) \to \rho^0(770)\gamma$

To determine the branching fraction for the decay (1) we have used the experimentally measured ratio

$$R_{f_1} = Br(f_1 \to \rho\gamma)/Br(f_1 \to \pi^+\pi^-\eta).$$

To reduce possible systematic errors in R_{f_1} we have corrected it using table value [13] for the ratio

$$R_{\eta'} = Br(\eta' \to \rho\gamma)/Br(\eta' \to \pi^+\pi^-\eta)$$

for the processes with similar topologies and our result for $R_{\eta'}$ obtained from the same data set (Fig.1a).

The numbers of $f_1(1285)$ in both decay modes were obtained with "T","M" and "GJ" cuts optimized to get statistical significance and good signal to background ratio. The "Rho"-cut on $\pi^+\pi^-$mass was not used, because the shape of the ρ meson in the decay of f_1 is model-dependent, and this cut would cause systematic errors.

The amount of the background from $a_2^0\pi^-$ was determined by fitting angular distributions using the same procedure as described above and the Monte-Carlo $\pi^+\pi^-\gamma$ spectrum for this background was subtracted from experimental distribution for $\pi^+\pi^-\gamma$ mass. Fig.6 shows this background spectrum superimposed on the experimental $\pi^+\pi^-\gamma$ mass distribution which was used to define the numbers of $f_1(1285)$. Finally taking into account acceptances calculated for the four decays the branching fraction under question was found to be

$$Br(f_1(1285) \to \rho^0(770)\gamma) = (2.8 \pm 0.7(stat) \pm 0.6(syst)) \cdot 10^{-2}.$$

6. The decay $f_1(1285) \to \phi(1020)\gamma$ and the axial nonet mixing angle

The decay

$$f_1(1285) \to \phi(1020)\gamma, \quad \phi(1020) \to K^+K^- \tag{6}$$

was also searched for at the VES spectrometer using the same data set. We used the same exclusive reaction (2) as the source of f_1 mesons, selection criteria identical to those described above and the same kinematical cuts to enhance the f_1 meson contribution. The information from multichannel threshold Čherenkov counter was used for secondary particle identification.

Fig.7a shows effective mass spectrum of the $K^+K^-\pi^0$ system for the events of the reaction $\pi^-N \to K^+K^-\pi^-\pi^0N$. The clear signal from $f_1(1285)$ meson is seen, this f_1 decay mode has been used for normalization.

The K^+K^- mass spectrum for the $K^+K^-\pi^-\gamma$ final state is presented in Fig.7b and shows a distinct peak, corresponding to $\phi(1020)$ meson. The final $K^+K^-\gamma$ mass spectrum for the events selected from ϕ-peak mass region with the background from the adjacent to ϕ mass intervals subtraction is shown in Fig.7c. No signal from decay (6) is seen. Taking into account acceptances and known branching fraction [13] for the decay $f_1(1285) \to K^+K^-\pi^0$ we found

$$Br(f_1(1285) \to \phi(1020)\gamma) < 0.9 \cdot 10^{-3} \text{ at CL=95\%}.$$

This limit doesn't contradict within the error bars the branching fraction from LEPTON-F [14] where decay (6) was observed.

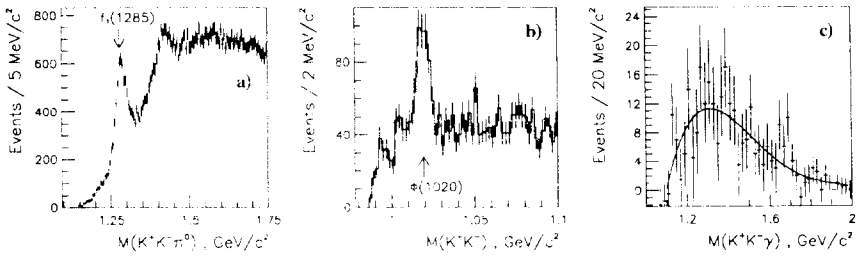

Figure 7. The effective mass spectra for the systems $K^+K^-\pi^0$ (a) for the events of the reaction $\pi^-N \to K^+K^-\pi^-\pi^0N$ and K^+K^- (b), $K^+K^-\gamma$ (c) for the events of the reaction $\pi^-N \to K^+K^-\pi^-\gamma N$.

In the framework of a simple quark model one may show:

$$\frac{Br(f_1 \to \phi\gamma)}{Br(f_1 \to \rho\gamma)} \approx \frac{4}{9} \cdot \left(\frac{P_{f_1 \to \phi\gamma}}{P_{f_1 \to \rho\gamma}}\right)^3 \cdot tg^2\alpha,$$

where $P_{f_1 \to \rho\gamma}$ and $P_{f_1 \to \phi\gamma}$ are photon momenta for the corresponding decays in the f_1 rest frame. Then, using the values presented in this work, we found the upper limit on the axial nonet mixing angle $\alpha = |\theta_{ideal} - \theta_{axial}|$:

$$\alpha < 32^\circ \text{ at CL=95\%}.$$

7. Conclusion

The decay $f_1(1285) \to \rho^0(770)\gamma$ was studied in the reaction $\pi^- N \to \pi^- f_1(1285)N$. Its branching fraction was measured to be $(2.8 \pm 0.7(stat) \pm 0.6(syst)) \cdot 10^{-2}$. This value is in agreement with the estimation for the E1 transitions in the framework of the quark model [2].

The ratio of ρ-matrix elements for ρ^0 meson in its helicity system was determined by the analysis of angular distributions : $\rho_{00}/\rho_{11} = 3.9 \pm 0.9(stat) \pm 1.0(syst)$.

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