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

VES collaboration

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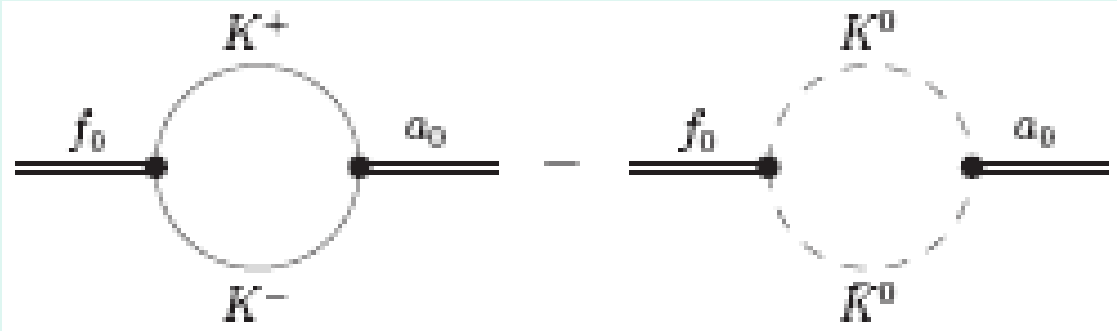
Introduction.

- f1(1285) mass: m=1281.8±0.6 MeV;
- width: W= 24.2±1.1 MeV;
- Known f1(1285) decays:
  f1(1285)→4π, BR=(33.1±2.1)%
  f1(1285) → ηππ, BR=(52 ±16)%
  including →a_0π BR=(36±7)%
  f1(1285)→ $K\overline{K}\pi$ BR=(9.0±0.4)%
  f1(1285) → ργ BR=(5.5±1.3)%

Theoretical predictions

- Decay $f_1 \rightarrow \pi^+\pi^-\pi^0$ violates the isospin symmetry
- This decay can proceed via $f_1 \leftrightarrow a_1$ mixing and due to the mixing $a_0(980) \leftrightarrow f_0(980)$ predicted by N.Achasov et.al., Phys.Lett. B88(1979) 367. The violation of isospin symmetry at this mass region should be particularly strong due to the mass difference between the pairs of charged and neutral kaons. It leads to significant enhancement at $m(\pi^+\pi^-) \approx 2m_K$.
- The f_1 decay is a reach source of $a_0(980)$

$a_0(980) \leftrightarrow f_0(980)$ mixing



Diagrams with pairs of charged and neutral kaons cancel one another, but this cancellation is not exact due to the kaon mass difference

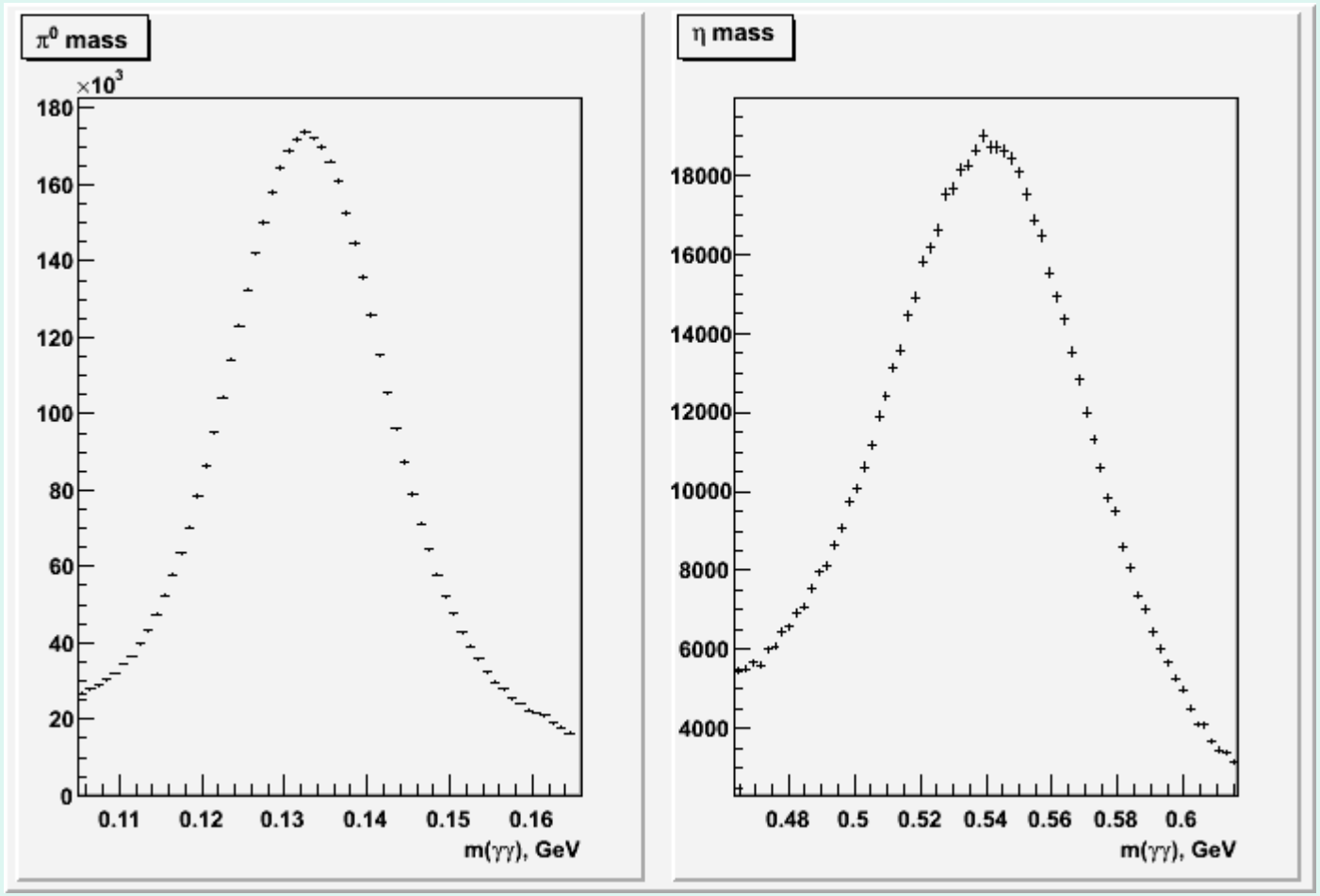
reaction $\pi^- N \to (f_1 \pi^-) N$

- is suitable for search of $f_1 \to \pi^+ \pi^- \pi^0$ decay:
  - this is a diffractive reaction, the cross section is large and the l t l-distribution is narrow;
  - background reaction $\pi^- N \to (4\pi) N$ is not a diffractive process and it is relatively suppressed, particularly at low l t l;
  - the dominant decay, $f_1 \to \eta \pi^+ \pi^-$, and the rare decay $f_1 \to \pi^+ \pi^- \pi^0$ are similar from the experimental point of view

Experiment and event selection

- **Statistics acquired in π^-Be interactions at 27, 36.6 and 41 GeV/c is analysed**
- **requested primary vertex, two neg. and one pos. outgoing track, two showers in ECAL, which are not associated with charged tracks and have E>250 MeV**
- **Events with identified e^{+-} or K^{+-} were rejected**
- **A requirement on the sum of energies of outgoing particles was imposed, which selected events in diffractive peak**

Fig.1, π^0 and η signals



selection requirements (cont.)

- **EM-showers with effective mass from 105 to 165 MeV were taken as π0 –candidates; the m-range for η-candidates was (435,620) MeV;**
- **Accepted (γγ)-candidates were subjected to a kinematical 1C-fit to a pion or η mass; fitted parameters were used at further steps . Number of selected ($\pi^+ \pi^- \pi^0 \pi^-$) events is $9.0 \cdot 10^6$.**
- **Events with l t'l < 0.04 GeV^2 were kept for analysis**

Fig.2, t-distributions

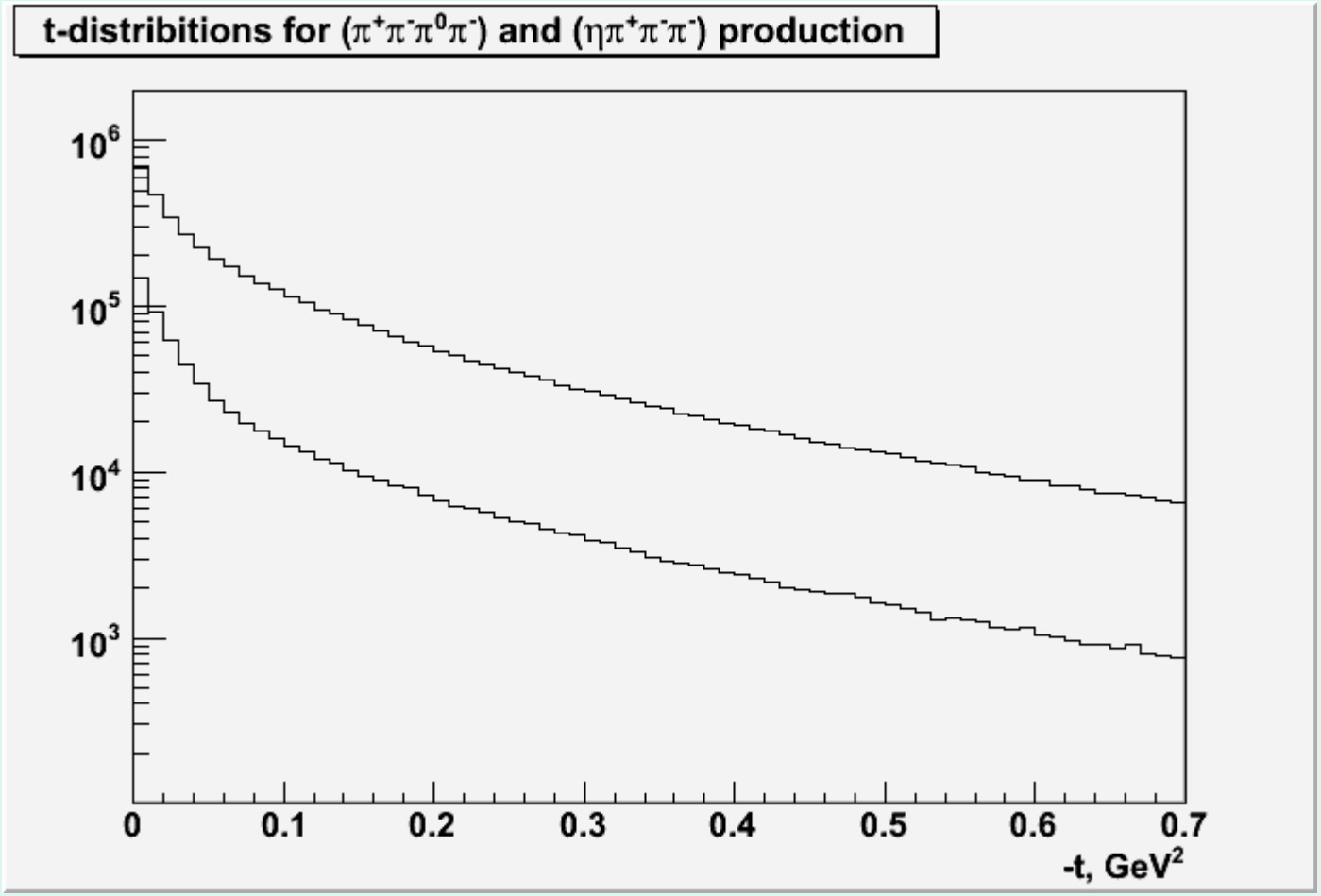
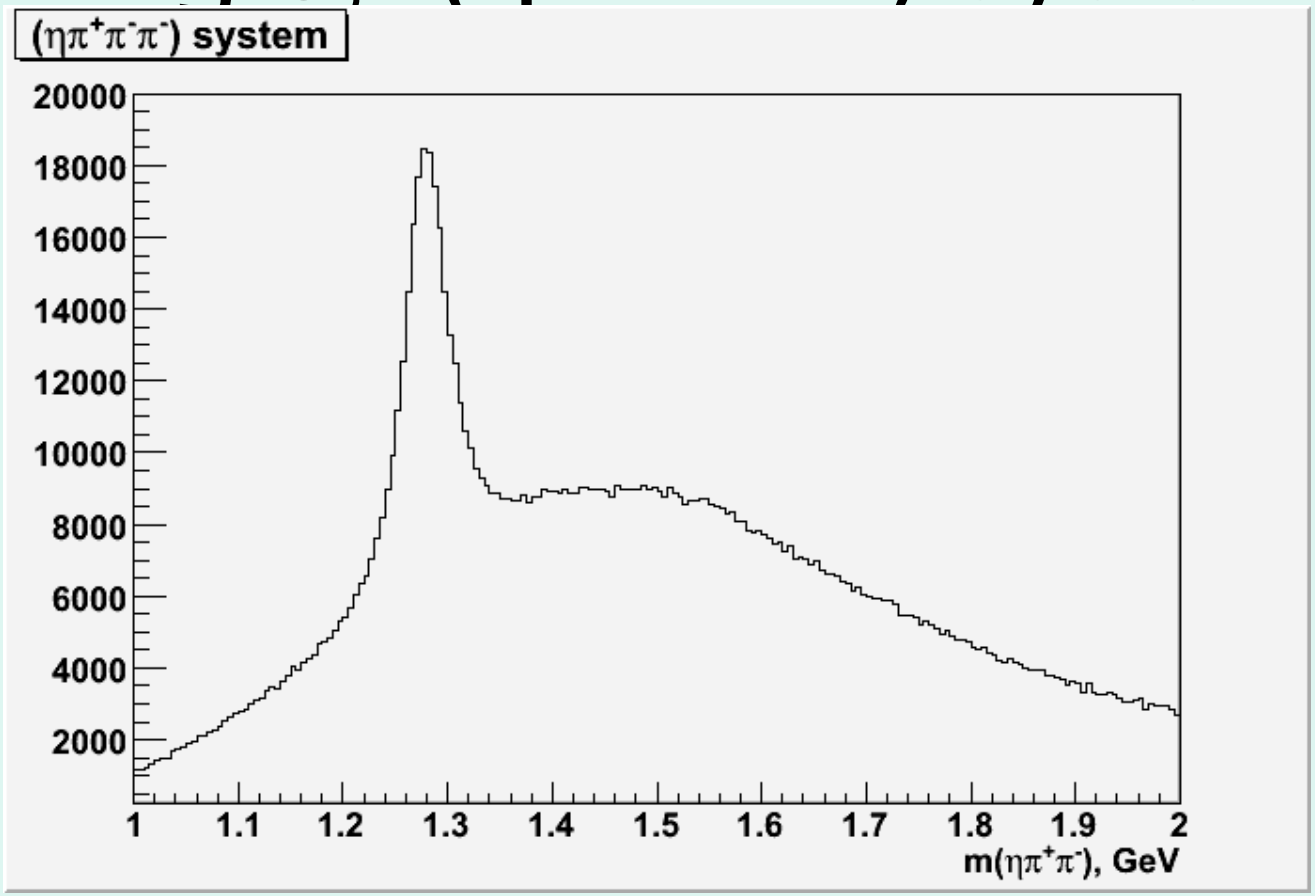


Fig.3. $(\eta\pi^+\pi^-\pi^-)$ system



- Events with $-t<0.04$ GeV^2 selected, the number of f_1 events is 69500±500

$(\eta\pi^+\pi^-)$ system

- The following observations were made:
- the $(f_1\pi^-)$ system is produced in spin-parity state J^P $m\eta = 1^+$ 0+;
- the decay of this system into f_1 ($J^P = 1^+$) and π proceeds in P-wave;
- the decay $f_1 \rightarrow \eta\pi\pi$ again involves a P-wave ;
- we derived an angular part of the amplitude which describe the sequence of production and decay processes:

angular amplitude

$$A = C \sin\theta_1 \sin\theta_2 \sin(\phi_0 - \phi_2)$$

here

θ_1 is the Gottfried-Jackson angle of the extra π^-;

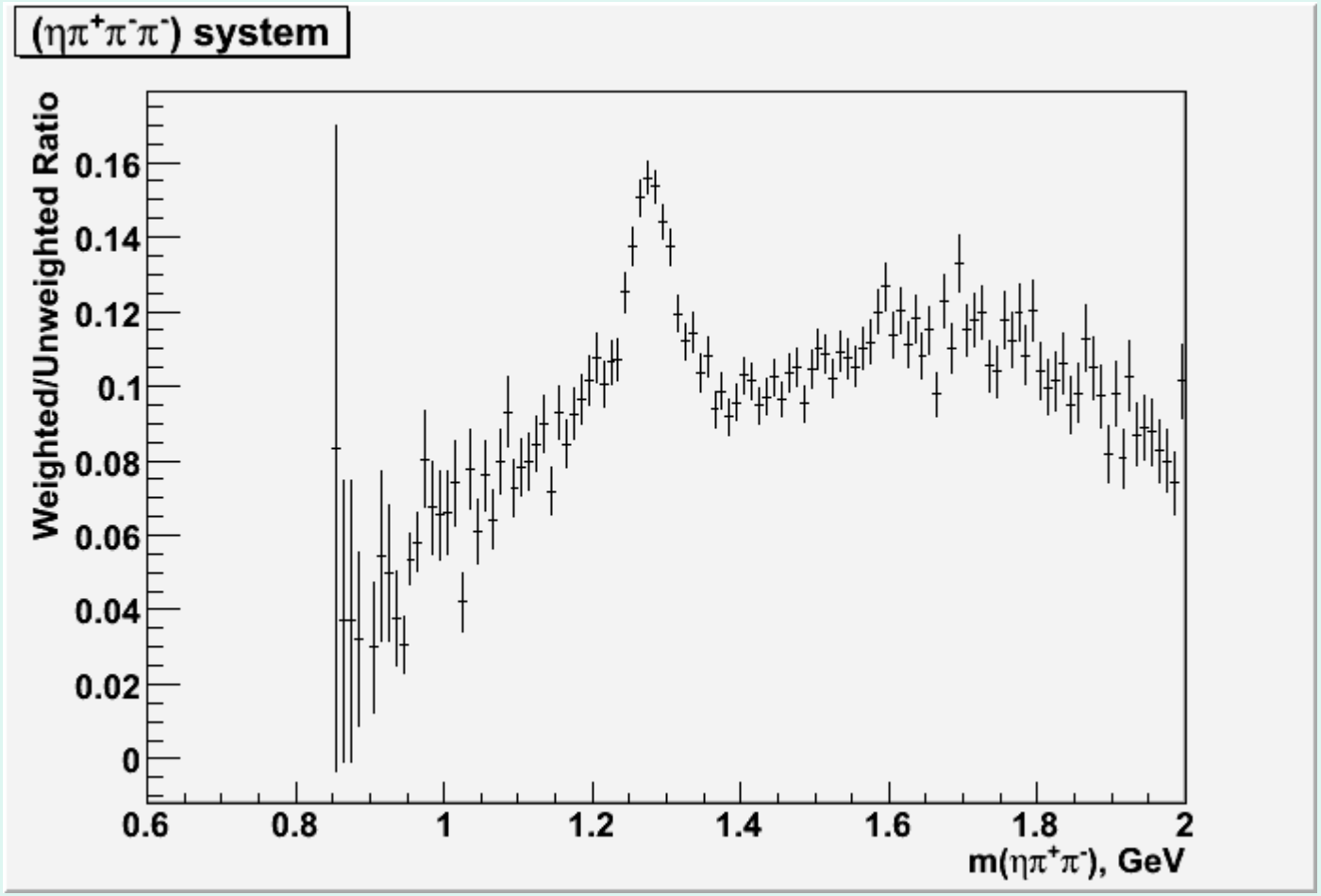
θ_2 is the polar angle of π^0 at the f_1 rest frame with Z-axis going along the direction of extra π^- ;

φ_0 and φ_2 are azimuthal angles of the beam particle and the π^0 at the same system, respectively.The validity of the corresponding weight,

$$W = |A|^2$$

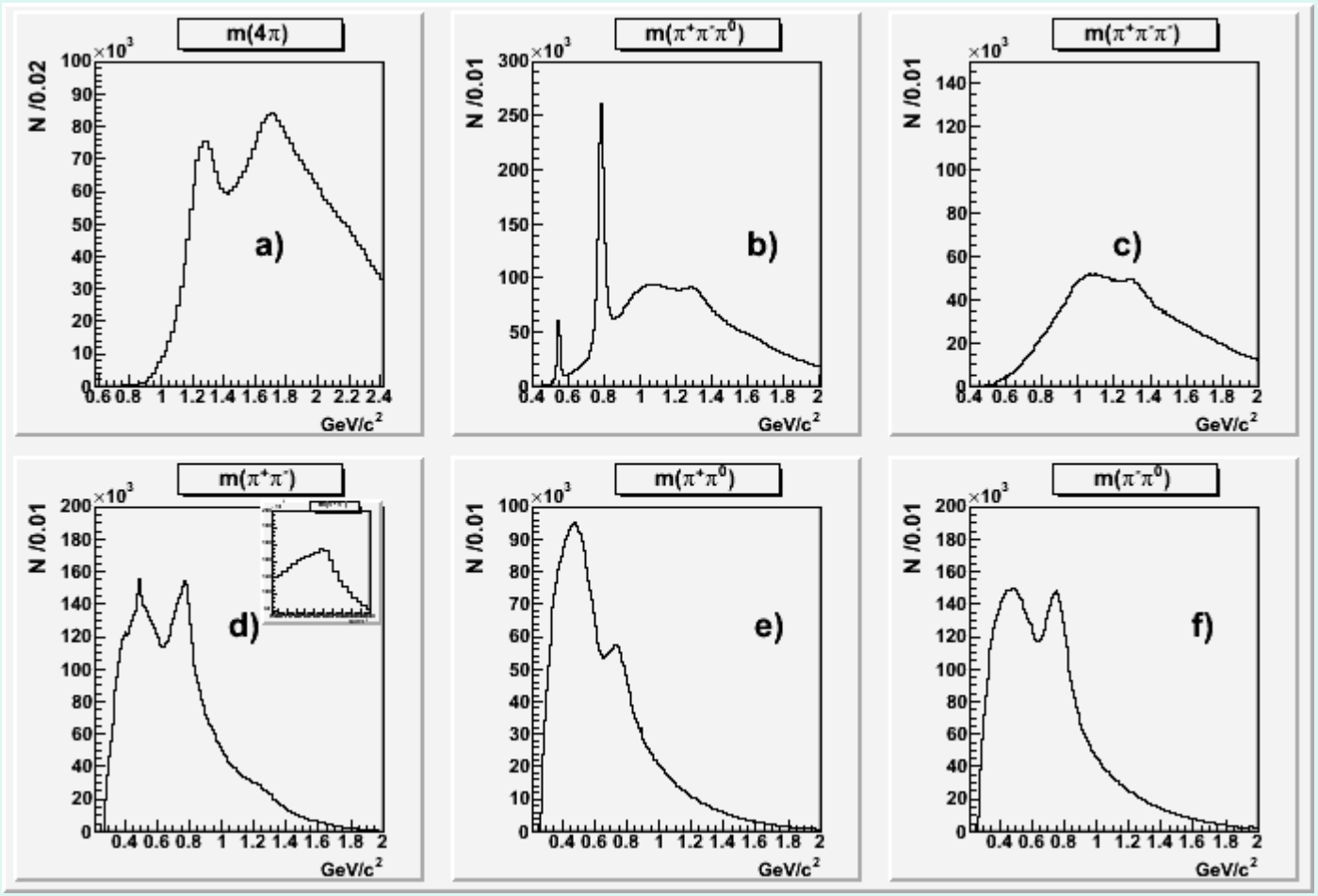
is demonstrated at Fig.4.

Fig.4, $(\eta\pi^+\pi^-\pi^-)$ system



$m(\eta\pi^+\ \pi^-\ )$ distribution for events at $W>0.8$ is divided by a similar spectrum at $W<0.2$

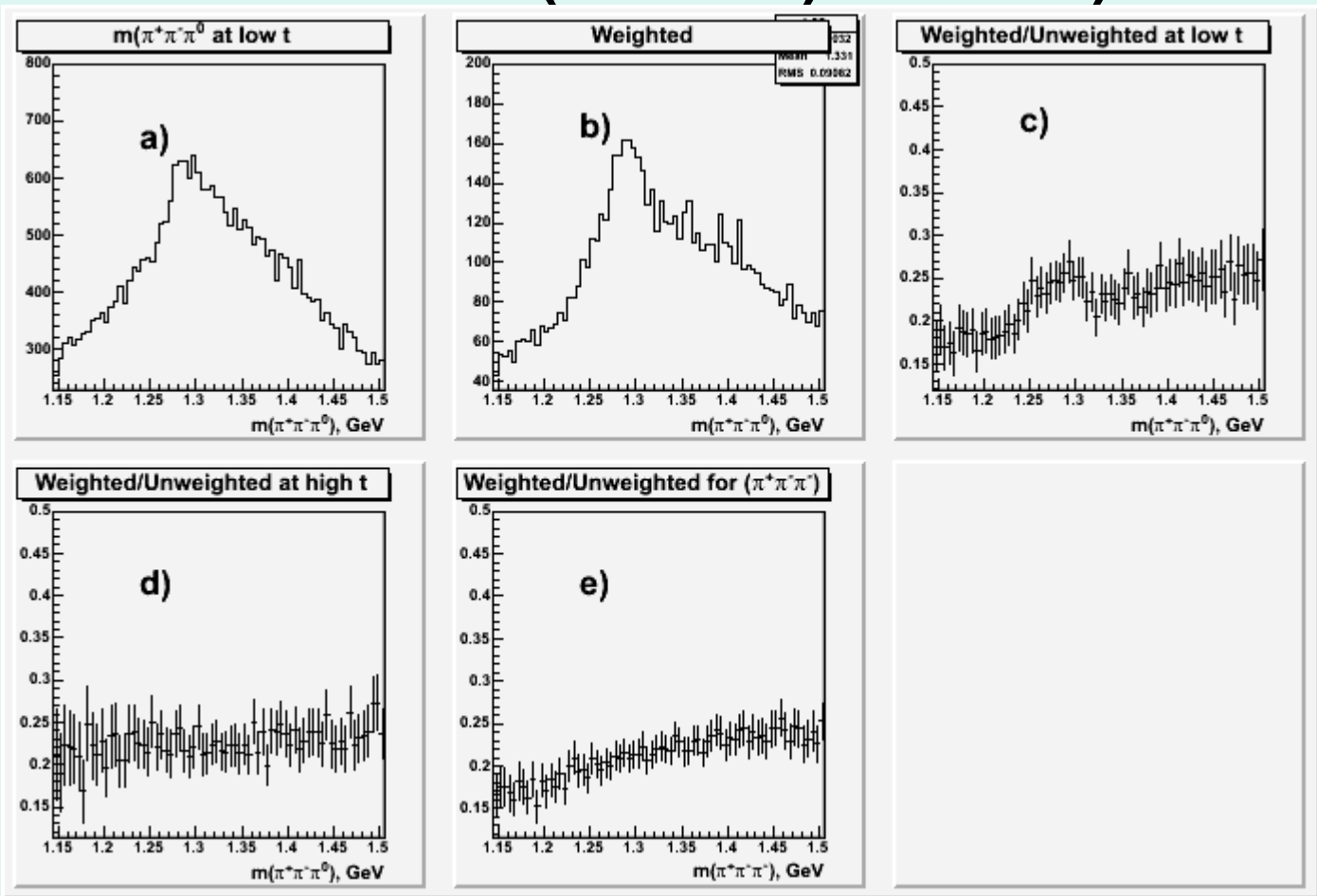
Fig.5, ($\pi^0\pi^+\pi^-\pi^-$) system



$(\pi^+ \pi^- \pi^0 \pi^-)$ system

- **The total mass and the mass spectra of 2- and 3-body combinations are shown at Fig.5 .**
- **There are two entries per event at Fig. 5b, 5d, 5f**
- **It worse mentioning that the decay $\omega \rightarrow \pi^+ \pi^-$ is seen at Fig.5d (see zoom at the corner).**
- **A structure seen at Fig.5b near m=1300 MeV was subjected to detailed analysis.**
- **New cut: events with $m(\pi^+ \pi^- \pi^0) < 800$ Mev were discarded.**
- **Angular weight W obtained in the analysis of the $(\eta\pi^+ \pi^-)$ system was applied**

Fig.6, Selected events at $0.97<m(\pi^+ \pi^-)<1.00$)



- **a) $m(\pi^+\pi^-\pi^0)$ at low I t I; b) the same but weighted; c) ratio of Weighted to Unweighted spectra; d) similar ratio for $m(\pi^+\pi^-\pi^0)$ at high I t I; e) similar ratio for $m(\pi^+\pi^-\pi^-)$ at low I t I .**

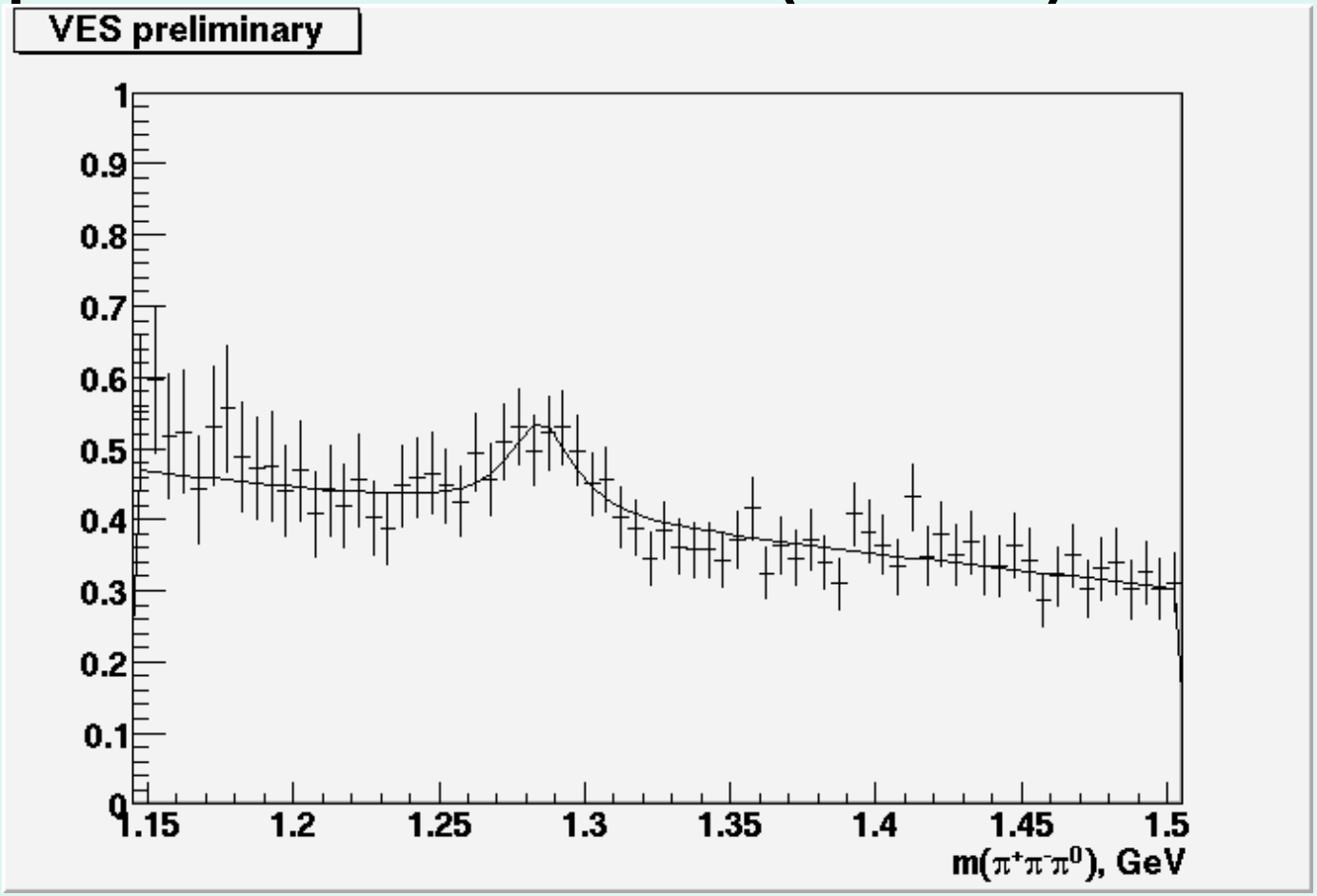
Next steps

- Results from two different methods are shown:
- 1) events with m($\pi^+ \pi^-$) in interval 0.97<m<1.00 GeV were selected, and the 3-body mass spectra, m($\pi^+ \pi^- \pi^0$) and m($\pi^+ \pi^- \pi^-$) were produced, at low | t | and at high | t |, weighted with angular weight and unweighted. Some distributions are shown at Fig.6 and 7.

Next steps (cont.)

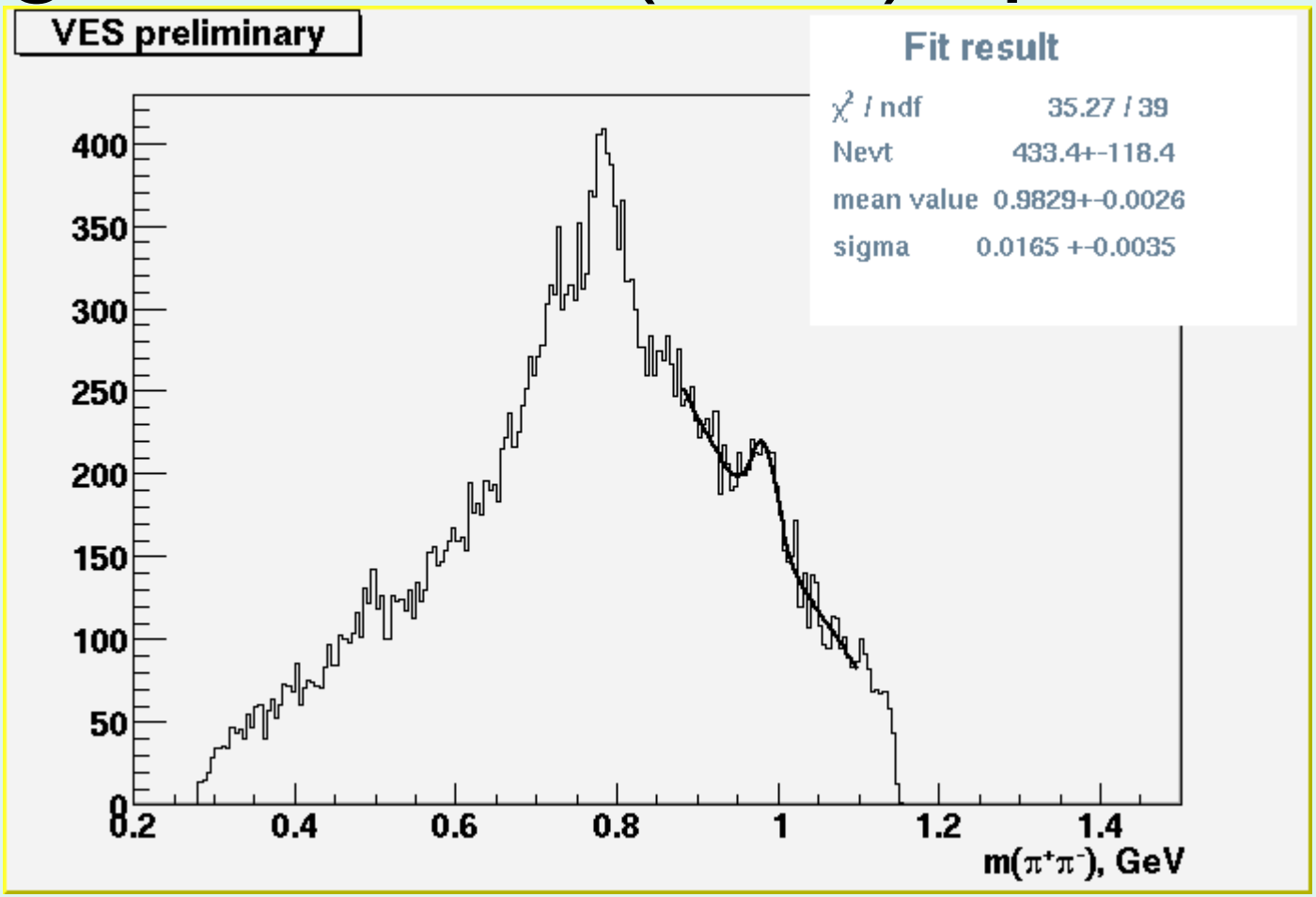
- 2) events with 3-body mass, $m(\pi^+ \pi^- \pi^0)$ in the interval from 1.20 to 1.35 GeV were taken. This interval was subdivided into 15 bins, the bin width is 10 MeV. The $m(\pi^+ \pi^-)$ spectra in individual bins were inspected. A bump at the mass close to 985 MeV is observed at the bin from 1280 to 1290 (Fig.8). The fit with a gaussian signal and BG (phase space multiplied to a quadratic function with arbitrary coefficients) is shown.

Fig. 7, Ratio of weighted mass spectra at $0.97<m(\pi^+ \pi^-)<1.00$)



- **$m(\pi^+\pi^-\pi^0)$ spectrum at low I t I is divided by a spectra sum:**
- **sum = $m(\pi^+\pi^-\pi^0)$ at high I t I plus $m(\pi^+\pi^-\pi^-)$ at low I t I; fit by BW + linear Background yields m=1285±5 MeV and Width 28±10 MeV; the signal significance is 4 σ**

Fig. 8, Fit of $m(\pi^+\pi^-)$ spectrum

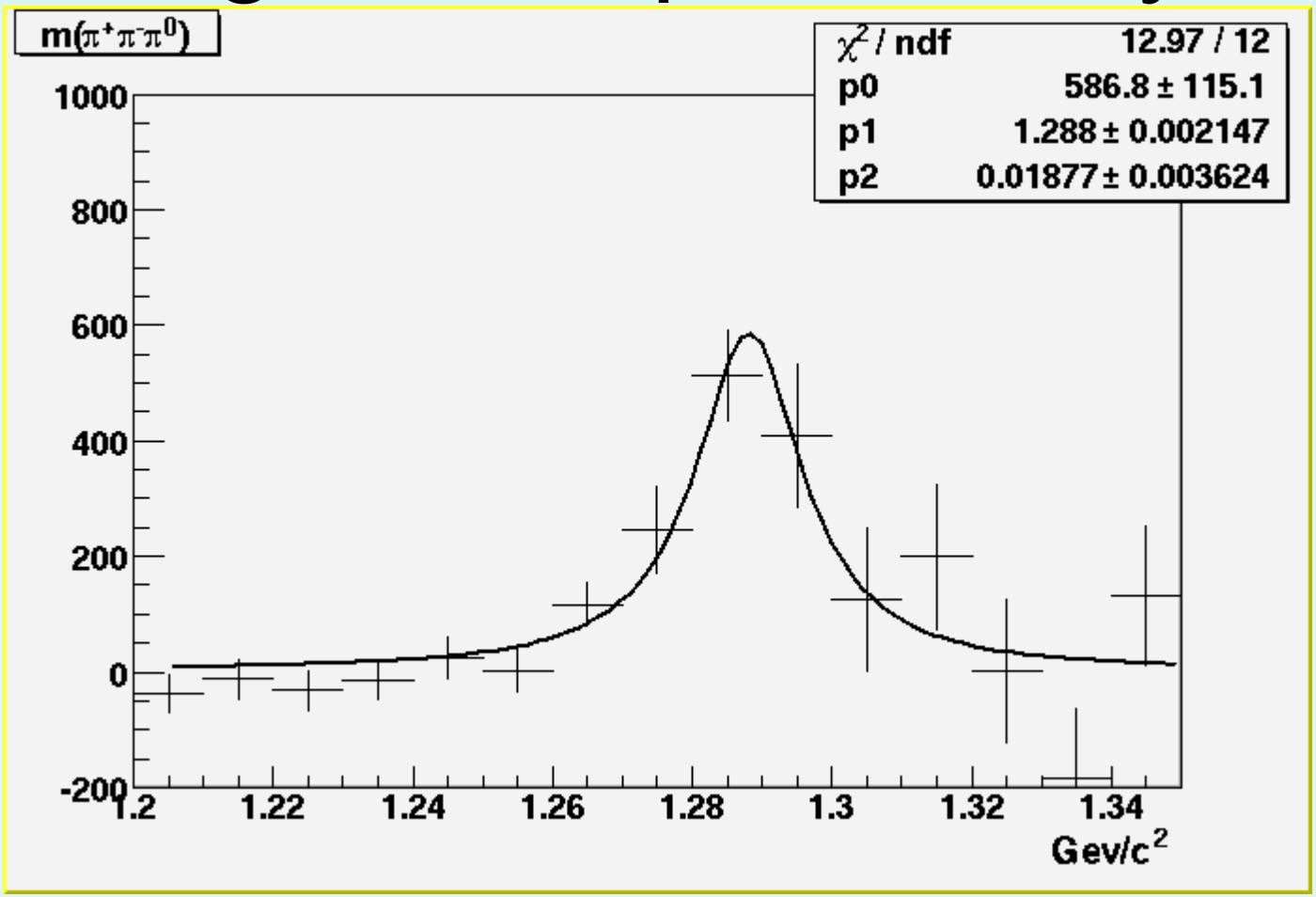


selected events at $1.280<m(\pi^+\pi^-\pi^0)<1.290$ GeV

Last steps

- The gaussian width of the fitted signal was determined at mass bin from 1280 to 1290 MeV, and then it was fixed. Statistical significance of the signal in this bin increased to 6.0 σ. Then fits at other bins were made, with fixed gaussian width.
- Results are shown at Fig.9. A peak is observed at this summary plot, with mass 1288±2 MeV and Breit-Wigner width of 19±4 MeV
- The sum of observed signals N=1491±334 events.
- A similar procedure with binning on the $m(\pi^+ \pi^- \pi^-)$ was performed, no signal at the f_1 region was found.

Fig.9.VES preliminary



Fitted number events in the peak at $m(\pi^+\pi^-)$ spectrum near 985 MeV as a function of $m(\pi^+\pi^-\pi^0)$

Conclusions

- **All elements of the observed pattern fit well in the hypothesis that the decay $f_1(1285) \rightarrow \pi^+\pi^-\pi^0$ is observed and that the mechanism of the isospin symmetry breaking, which has been predicted by Achasov and collaborators in 1979, works in this decay.**
- **From the observed number of events in $(\eta\pi^+\pi^-)$ and $(\pi^+\pi^-\pi^0)$ channels we determine the relative branching ratios.**

Our estimations are obtained actually in restricted interval of $m(\pi^+\pi^-)$, between 960 and 1010 MeV/c^2 :

Branching ratios

$$\frac{BR(f_1(1285) \to \pi^+\pi^-\pi^0(0.96 < m(\pi^+\pi^-) < 1.01))}{BR(f_1(1285) \to \eta\pi^+\pi^-) \cdot BR(\eta \to \gamma\gamma)} =$$

$$= (2.1 \pm 0.5)\%;$$

or

$$BR(f_1(1285) \to \pi^+\pi^-\pi^0(0.96 < m(\pi^+\pi^-) < 1.01)) =$$

$$= (0.29 \pm 0.11)\%$$

This value agrees with predictions of Achasov et al.