Observation of $f_1(1285) \to \pi^+\pi^-\pi^0$ decay at VES detector

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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_0(980)π BR=(36±7)%
f1(1285)→ $K\bar{K}$π BR=(9.0±0.4)%
f1(1285) → ργ BR=(5.5±1.3)%

Isospin symmetry violation

- $f_1(1285)$ has $I^G J^{PC} = 0^+\ 1^{++}$
- The $f_1(1285)$ decay into three pions is prohibited by isospin symmetry
- But the isospin symmetry is violated

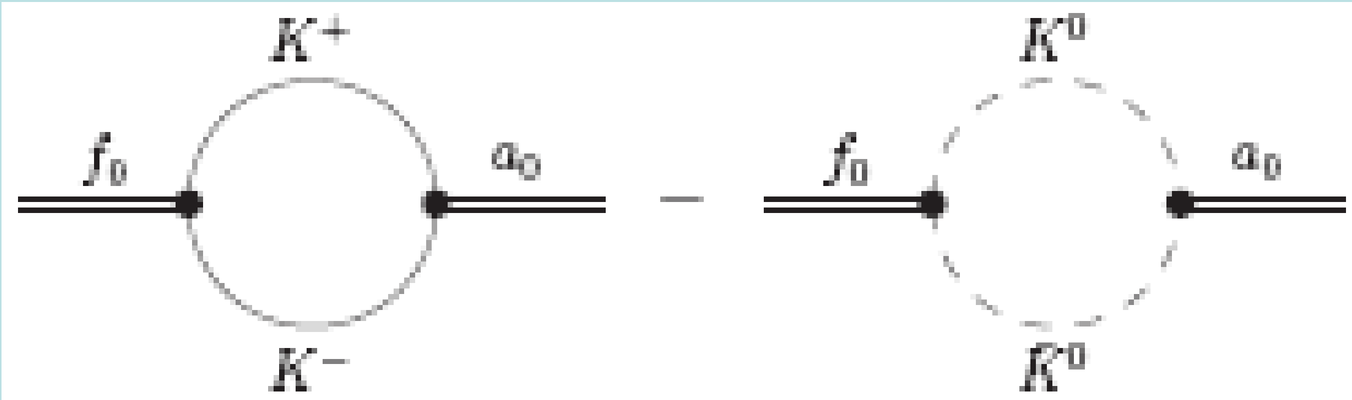
  - in EM processes

  - due to the quark mass difference $m_d > m_u$

    known isospin-violating decays:

$\omega \to \pi^+\pi^-$, $\varphi \to \pi^+\pi^-$, $\eta \to 3\pi$, $\psi(2s) \to J/\psi\pi^0$

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



- $f_0(980)$ has $I^G J^{PC}=0^+ 0^{++}$
- $a_0(980)$ has $I^G J^{PC}=1^- 0^{++}$
- Isospin symmetry violation makes possible $a_0(980)\leftrightarrow f_0(980)$ mixing
- A mechanism of $a_0(980)\leftrightarrow f_0(980)$ mixing via looks of virtual kaons was proposed

$a_0(980) \leftrightarrow f_0(980)$ mixing (2)

- **by N.Achasov, S.Devyanin, G.Shestakov Phys.Lett.B88 (1979) 367;**
- **diagrams with pairs of virtual ($K^0\overline{K}^0$) and (K^+K^-) cancel one another but this cancellation is not perfect because of the mass difference between charged and neutral kaons**
- **The effect has a maximum at the mass region between 987.3 MeV < m < 995.3 MeV i.e. (K^+K^-) above threshold but ($K^0\overline{K}^0$) below threshold**

This mechanism leads to a narrow peak on m(ππ).

$f_1(1285) \leftrightarrow a_1(1260)$ mixing

- Another possible mechanism which leads to $f_1(1285)$ decay into three pions is $f_1(1285) \leftrightarrow a_1(1260)$ mixing, see for example S.A.Coon, B.H.J.McKellar, V.G.J.Stoks, Phys.Lett.B385(1996)25;

  predicted mixing depends on the $a_1(1260)$ width which is not well known

Proposed experiments

- **Several methods for search of the $a_0(980)\leftrightarrow f_0(980)$ mixing were proposed:**

- **a) the $f_1(1285)\rightarrow a_0(980)\pi$ decay as a source of $a_0(980)$-mesons, and search for $f_0(980)\rightarrow\pi\pi$ decays;**
- **b) a special polarization experiment;**
- **c) the $J/\psi\rightarrow f_0(980)\gamma$ decay, and search for $a_0(980\rightarrow)\eta\pi$ decays;**
- **d) central production of $f_0(980)$ in pp-collisions and search for $a_0(980\rightarrow)\eta\pi$ decays;**

e) asymmetries in polarized-p+n $\rightarrow$ De π^0 η, and polarized-p+p $\rightarrow$ De π^+ η ;

References

- **N.N.Achasov, G.N.Shestakov, Phys.Rev.D70 (2004) 074015, hep-ph/0312214 ;**
- **N.N.Achasov, S.A.Devyanin, G.N.Shestakov,**

  Yad. Fiz. 33 (1981) 1337; Sov.J.Nucl. Phys. 33 (1981) 715;
- **Jia-Jun Wu, Qiang Zhao and B.S.Zou, hep-ph 0704.3652 ;**
- **C.Hanhart, B.Kubis, J.R.Pelaez, hep-ph 0707.0262**
- **A.**; **E. Kudryavtsev, V.E. Tarasov, Yad.Fiz.66 (2003) 1994-2000,2003; nucl-th/0304052**

Central production in pp-collisions

- Central production of the $\eta\pi^0$ system has been observed in WA102 experiment It can be interpreted as an experimental indication on possible $a_0(980)$-$f_0(980)$ transition. (F.Close, A.Kirk, Phys.Lett. B489 (2000) 24;). However, an exchange by secondary Regge trajectories can lead to the observed $\eta\pi^0$ production too.
- Therefore another interpretation is possible (see N.N.Achasov and A.V.Kisilev, Phys.Lett. B534 (2002) 83 ;)

Proposal of polarization experiment

- Needed transverse proton polarization;
- Reaction $\pi^{--}p \rightarrow (\eta\pi^0)n$;
- the existence of the $a_0(980) \leftrightarrow f_0(980)$ mixing can be unambigously established through the presence of a strong jump in the azimuthal (single-spin) asymmetry of the S-wave $\eta\pi^0$ production cross section near the KK thresholds

VES experiment

- The VES detector is a wide aperture forward spectrometer, which is
- Installed in unseparated beam of negative particles (mainly π^-)
- Equipped with EM calorimeter
- Cherenkov detectors for identification of beam and charged secondary particles
- Fast Data Acquisition system
- Minimum bias trigger

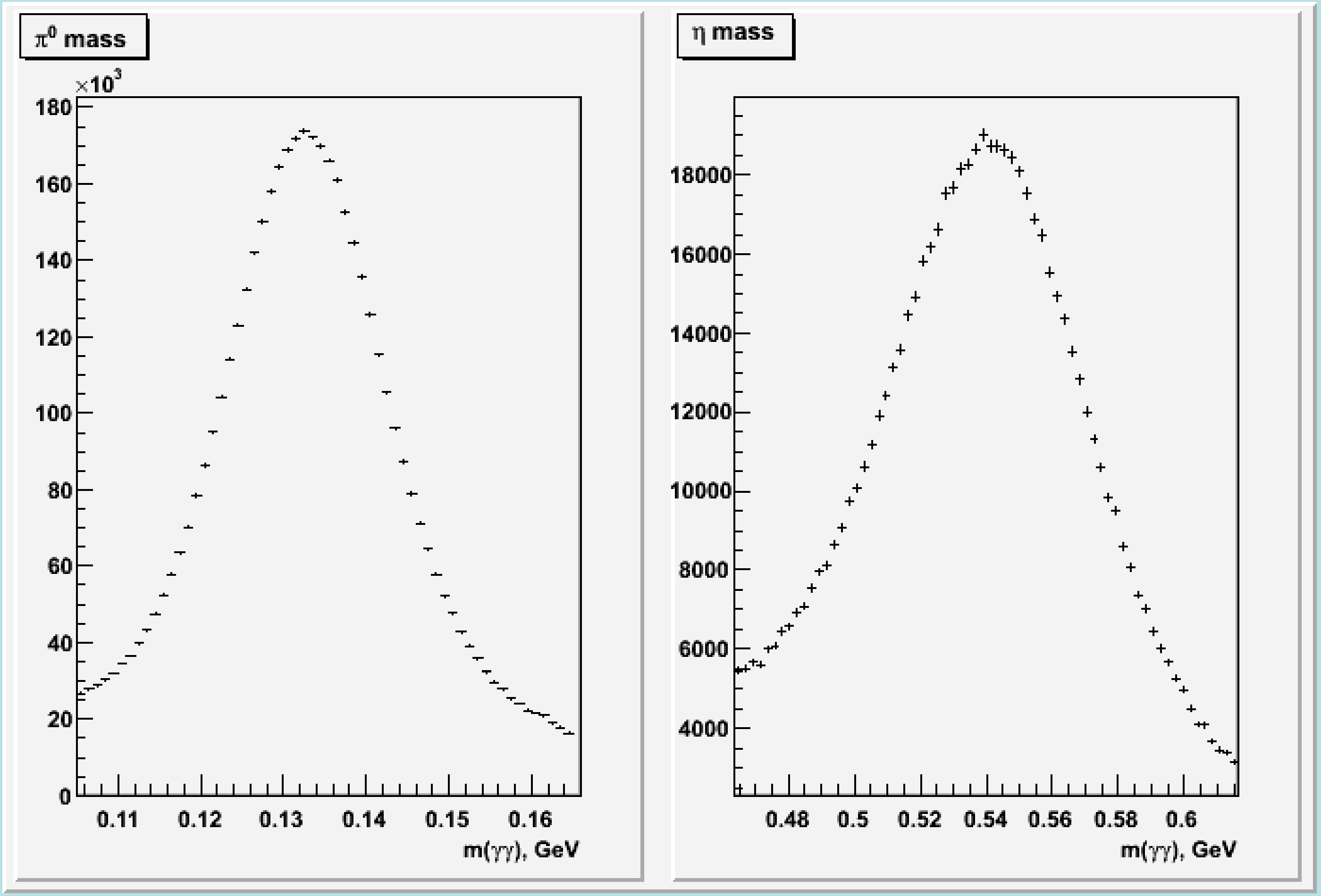
reaction $\pi^- N \rightarrow (f_1 \pi^-) N$

- **is suitable for search of $f_1 \rightarrow \pi^+\pi^-\pi^0$ decay:**
- **this is a diffractive reaction, the cross section is large and the l t l-distribution is narrow;**
- **background reaction π-N→(4π)N is not a diffractive process and it is relatively suppressed, particularly at low l t l;**
- **the dominant decay, $f_1 \rightarrow \eta\, \pi^+\pi^-$, and the rare decay $f_1 \rightarrow \pi^+\pi^-\pi^0$ 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 analyzed**
- **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 π^0 –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 (π+ π- π0 π-) events is ~$9.0 \cdot 10^6$.**
- **Events with l t'l < 0.04 GeV2 were kept for analysis**

Fig.2, t-distributions

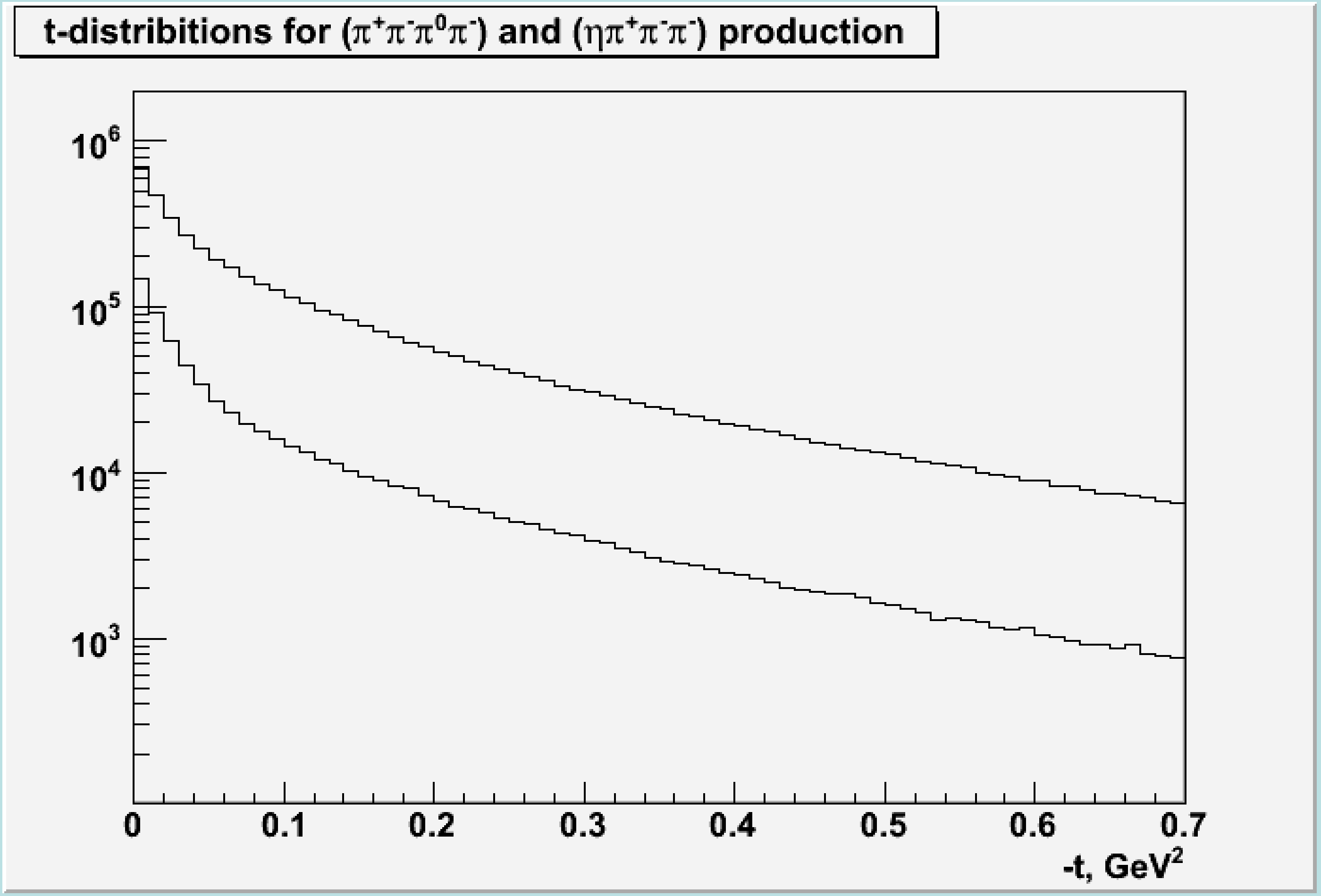
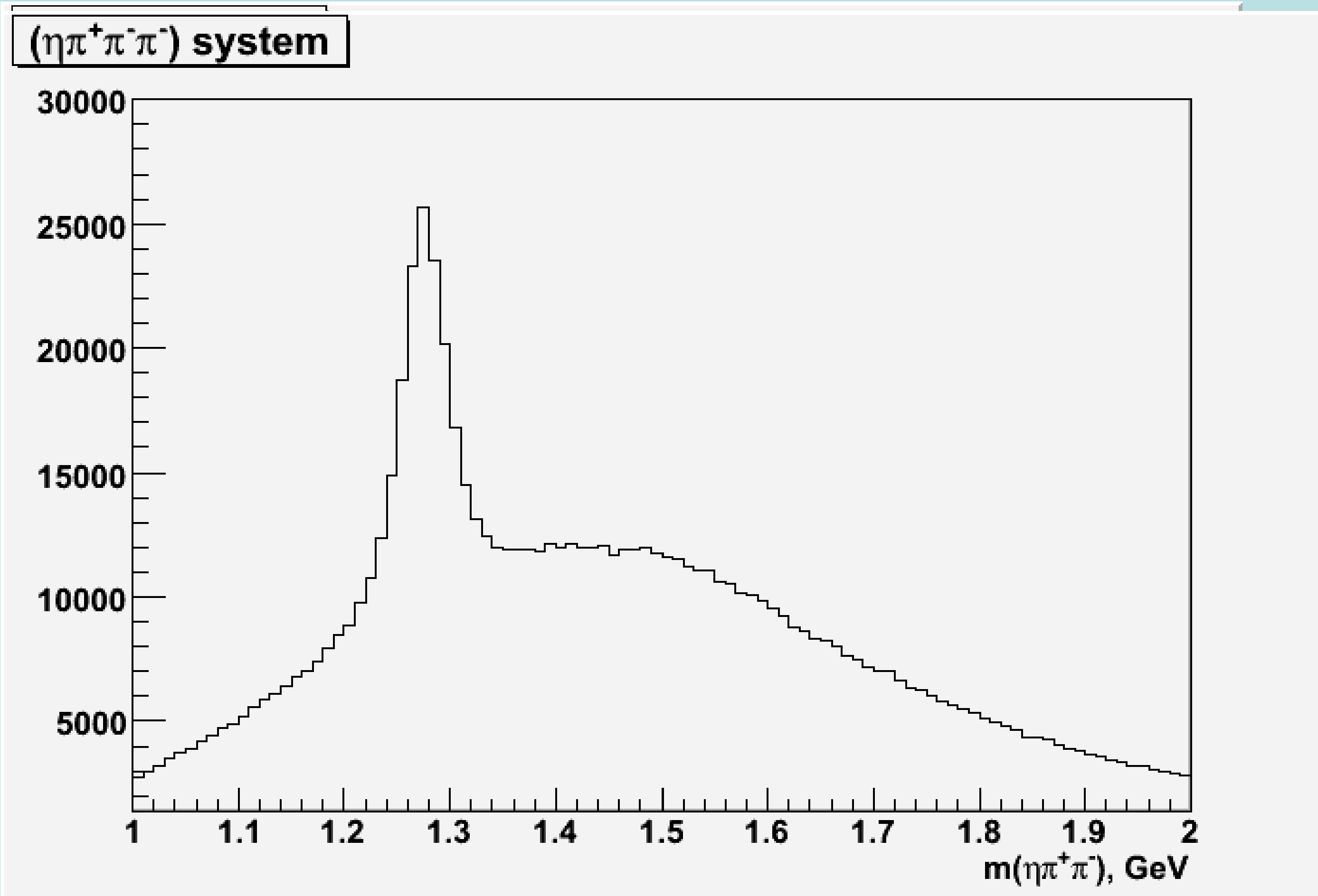


Fig.3, $(\eta\pi^+\pi^-\pi^-)$ system



- Events with $-t<0.04$ GeV^2 selected, the number of f_1 events is 117600±1300

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

$$A = \frac{3}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin(\phi_0 - \phi_2)$$

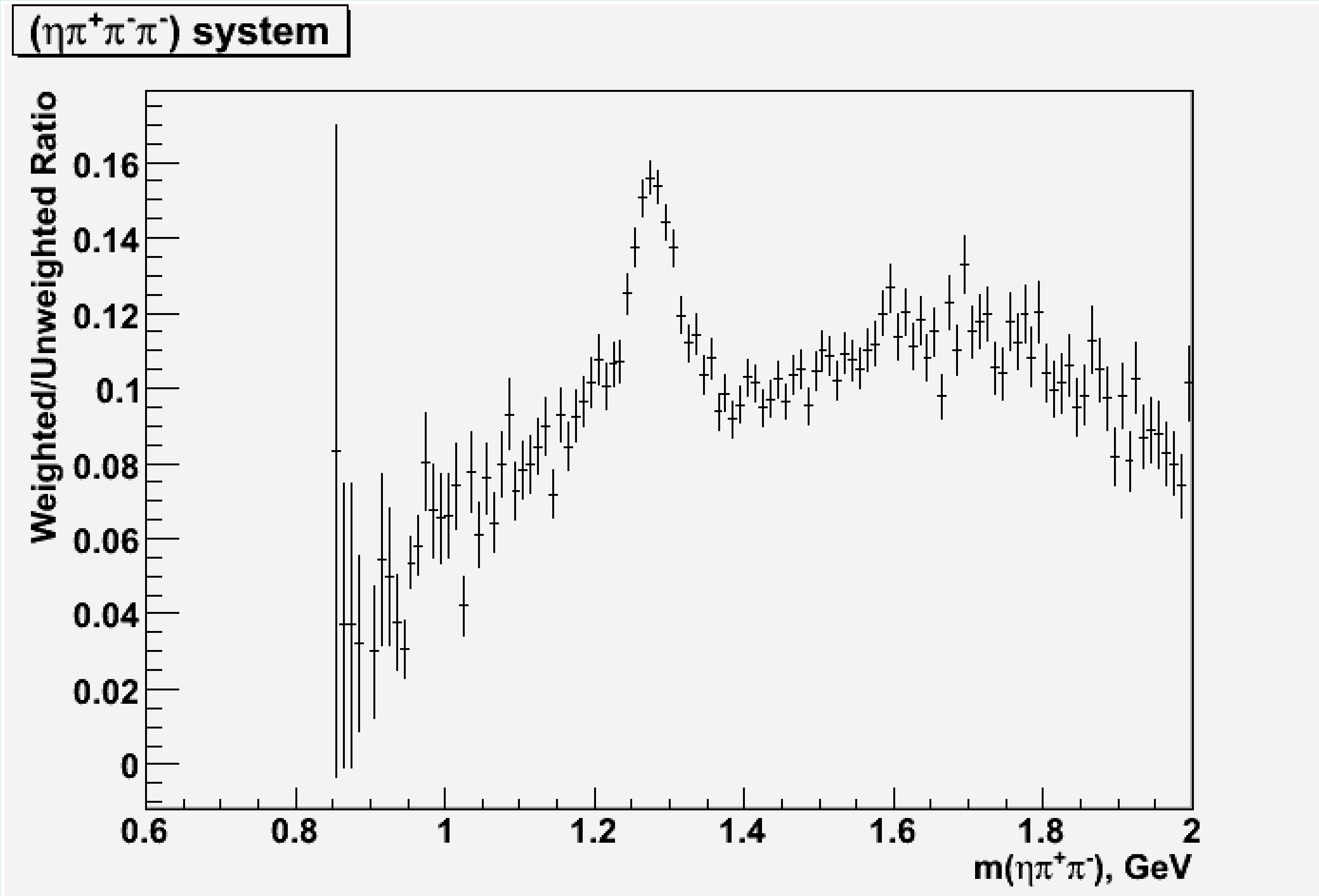
here

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 angles of the beam particle and the π^0 momentum projections to the plane which is orthogonal to the momentum of extra pion.
Validity of the corresponding weight,

$$W = |A|^2$$

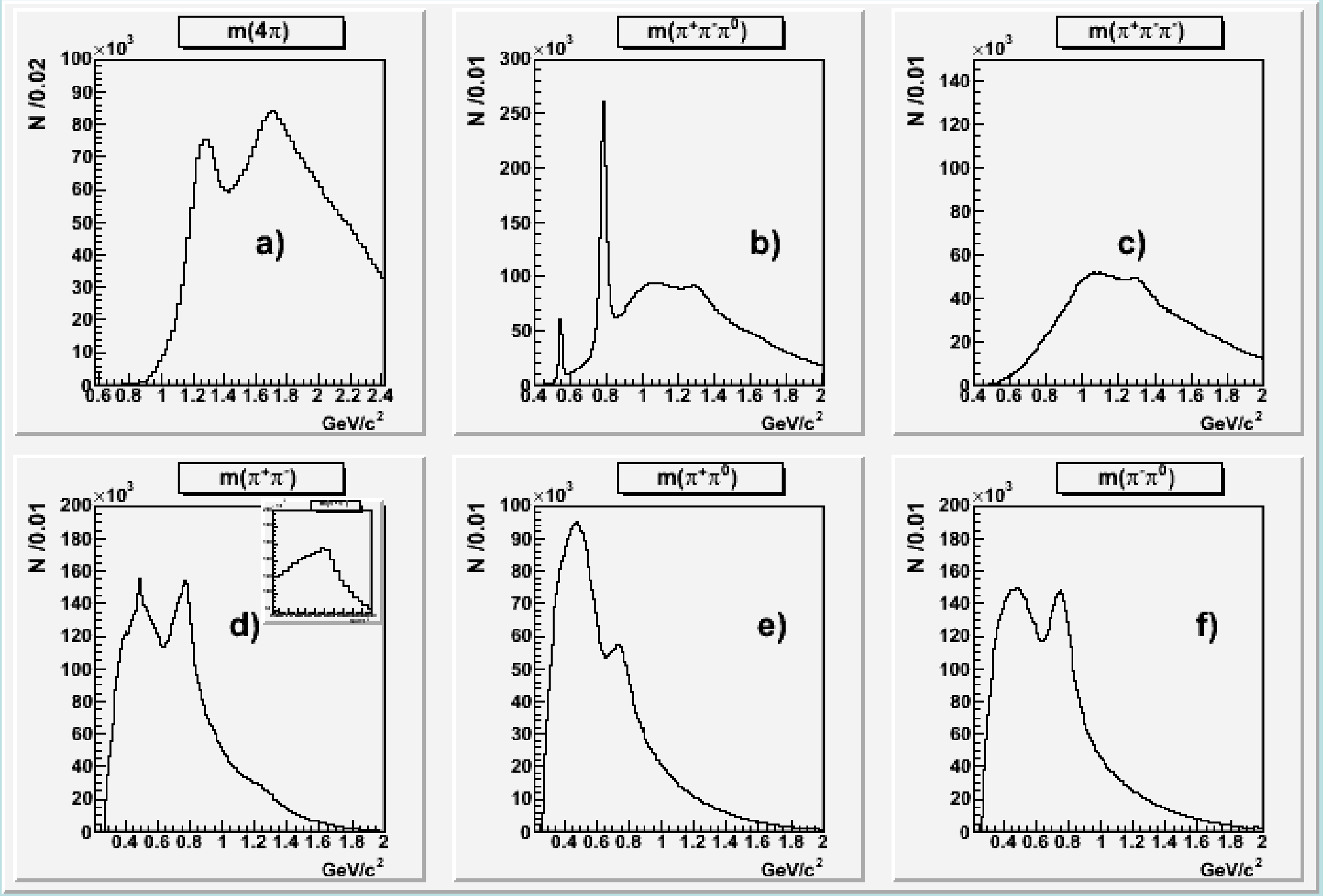
is demonstrated at Fig.4.

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

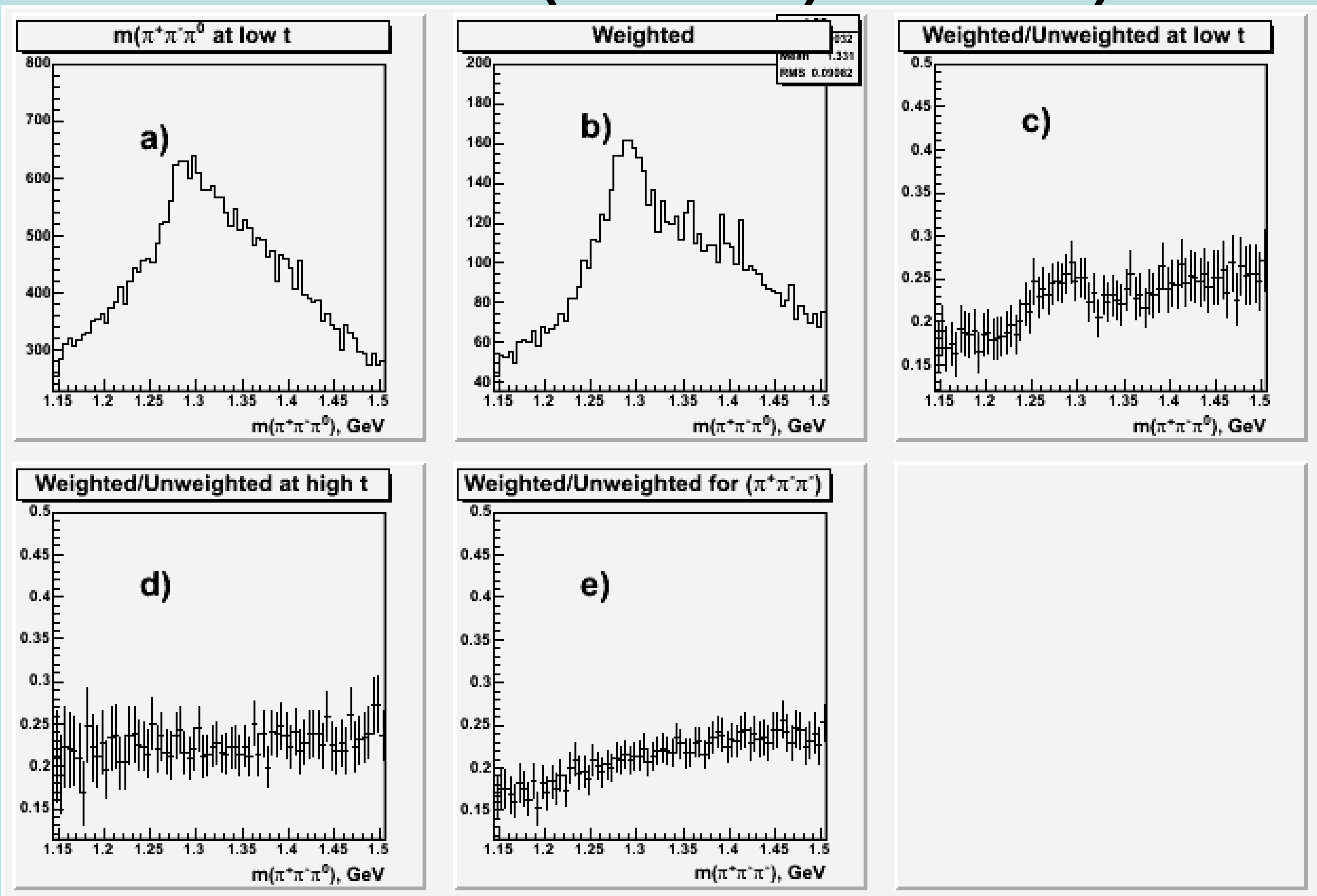
Fig.5, ($\pi^0\pi^+\pi^-\pi^-$) system



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

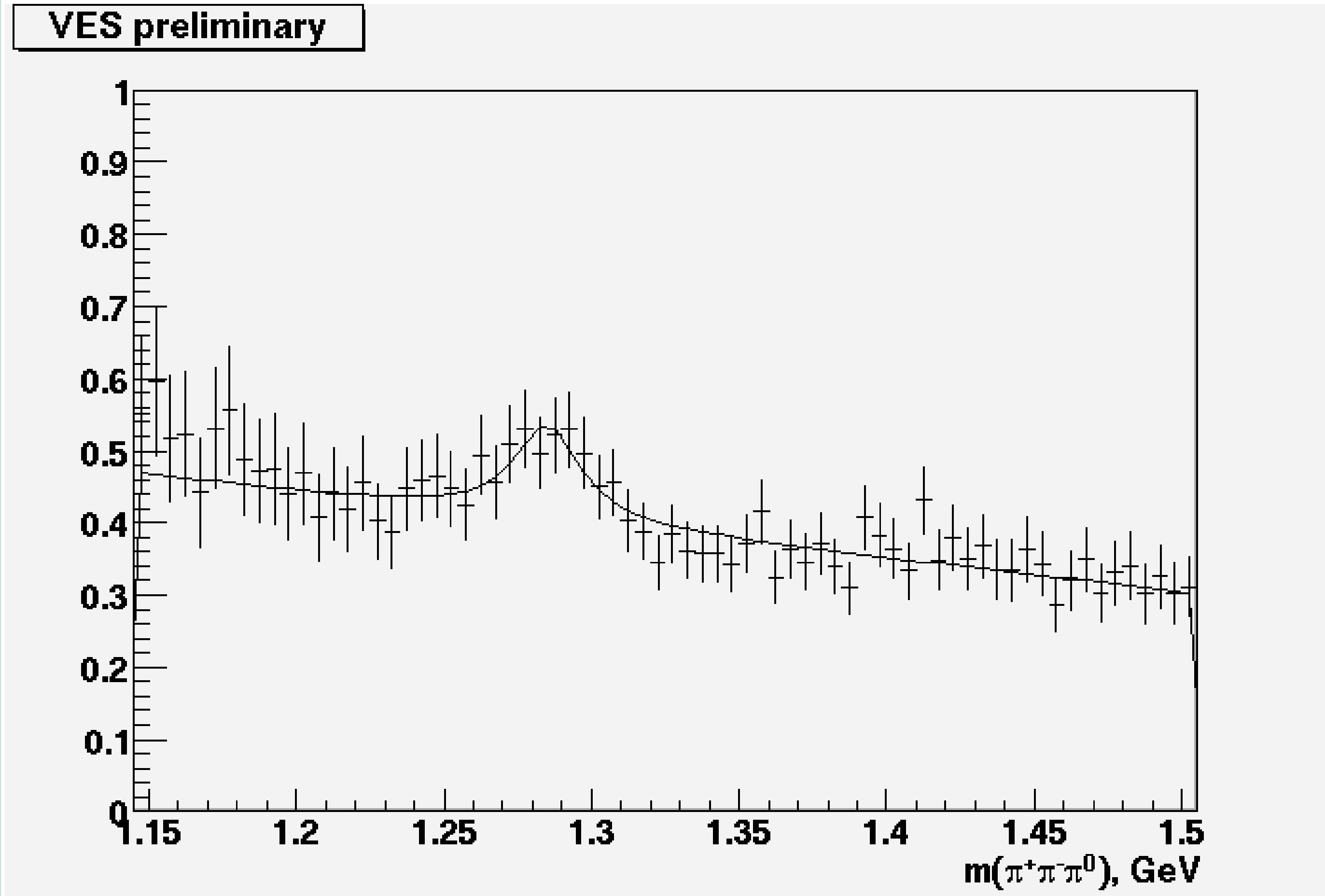
- **The total mass and the mass spectra of 2- and 3-body combinations are shown at Fig.5 .**
- **There are two entries per event at Fig. 5b, 5d, 5f**
- **It worse mentioning that the decay $\omega \rightarrow \pi^+ \pi^-$ is seen at Fig.5d (see zoom at the corner).**
- **A structure seen at Fig.5b near 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 .**

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

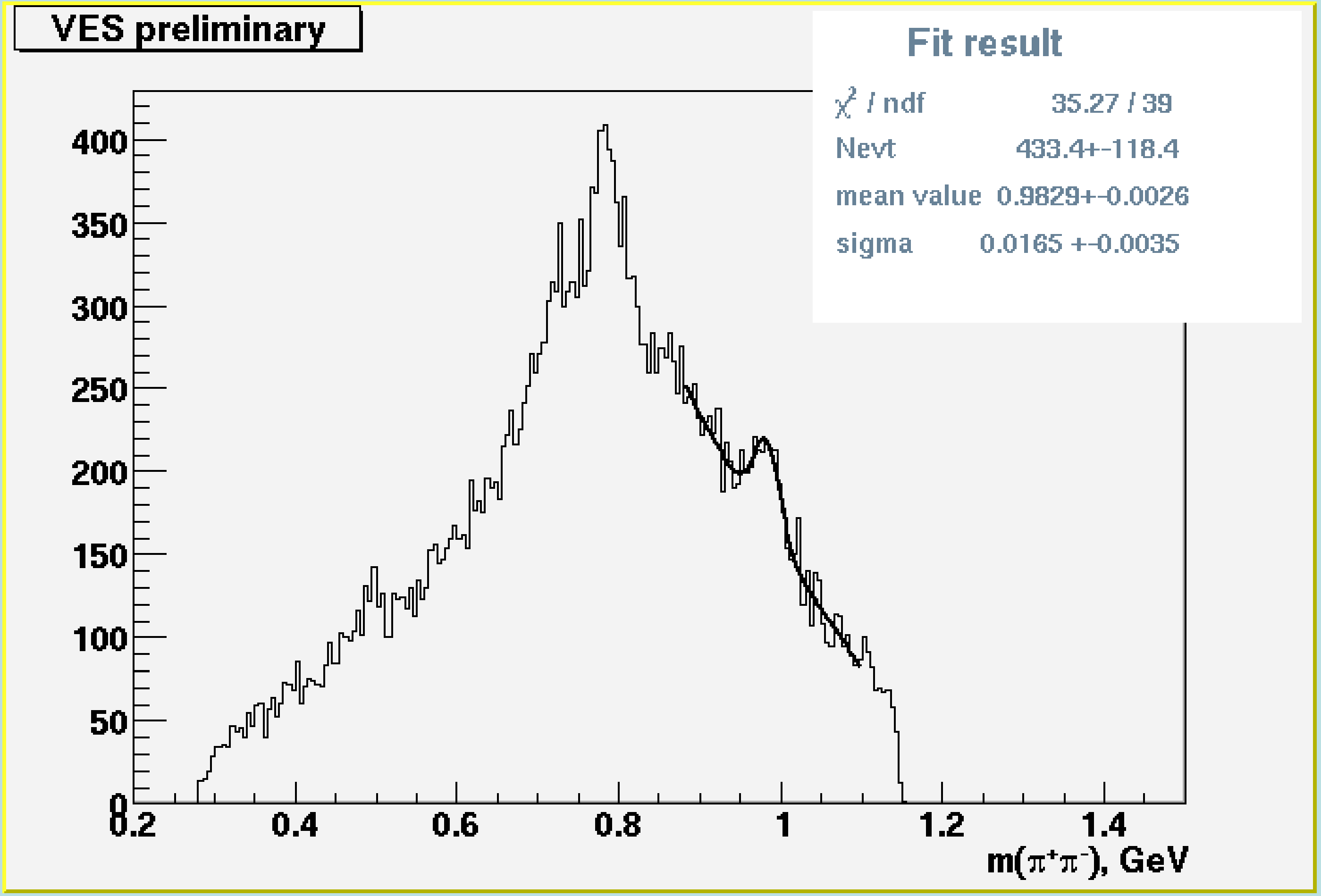


- **$m(\pi^+\pi^-\pi^0)$ spectrum at low I t I is divided by a spectra sum:**
- **sum = $m(\pi^+\pi^-\pi^0)$ at high I t I plus $m(\pi^+\pi^-\pi^-)$ at low I t I; fit by BW + linear Background yields m=1285±5 MeV and Width 28±10 MeV; the signal significance is 4 σ**

Next steps (cont.)

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

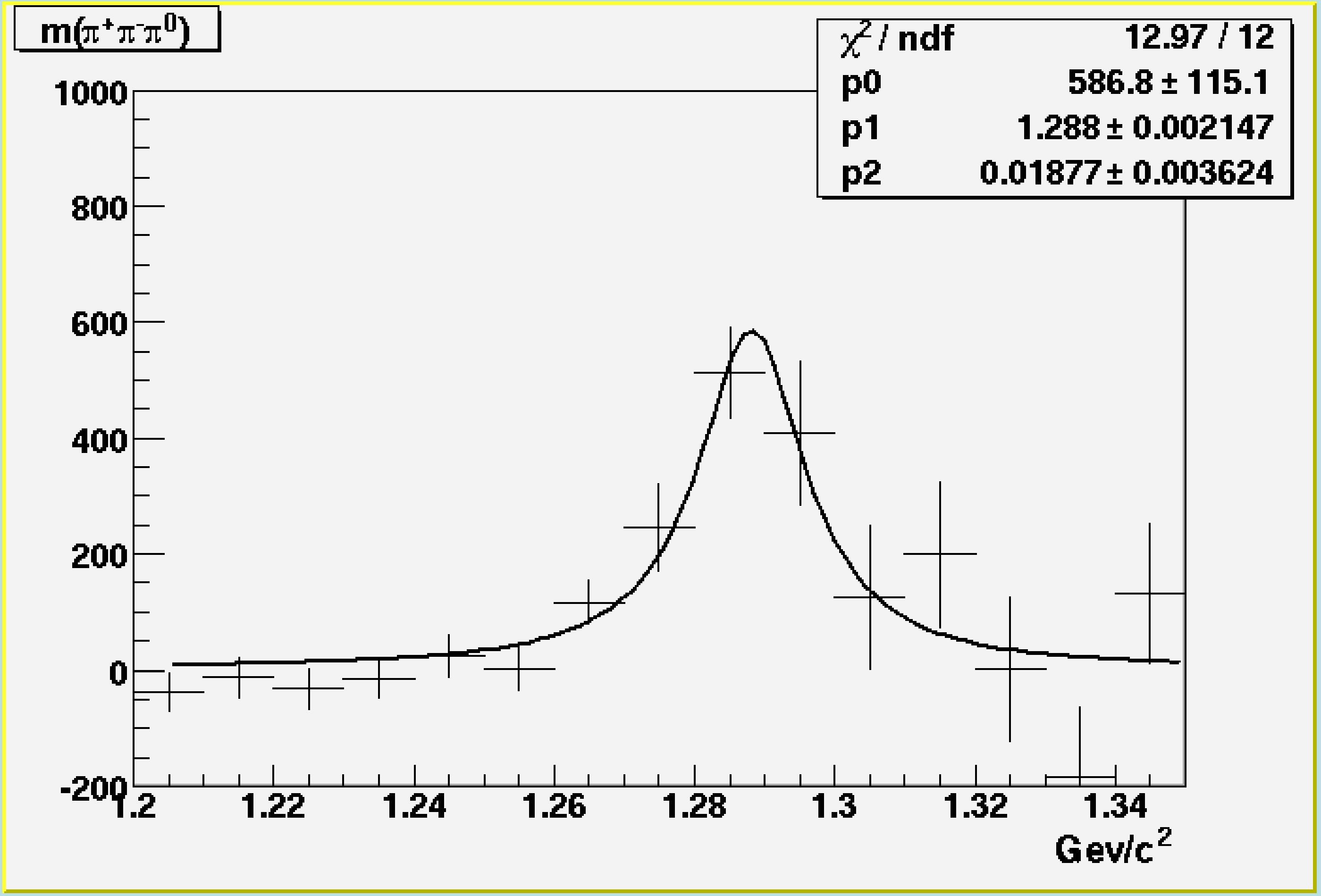


selected events at 1.280<m($\pi^+\pi^-\pi^0$)<1.290 GeV

Last steps

- The gaussian width of the fitted signal was determined at mass bin from 1280 to 1290 MeV, and then it was fixed. **St**atistical 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 data

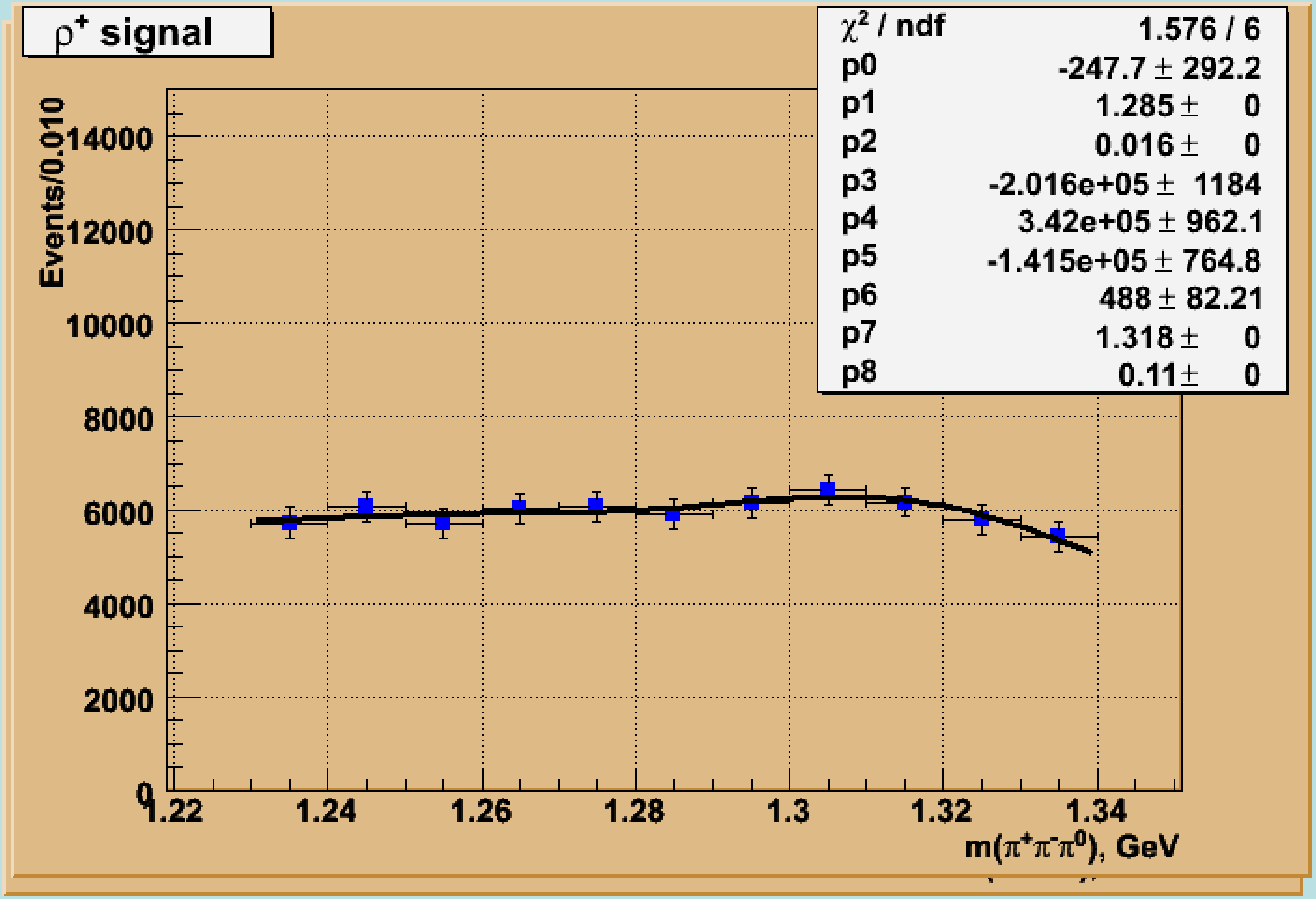


Fitted number events in the peak at $m(\pi^+\pi^-)$ spectrum near 985 MeV as a function of $m(\pi^+\pi^- \pi^0)$

Search for $f_1(1285)$-$a_1(1260)$ mixing

- This mixing should lead to $(\rho^{+-}\pi^{-+}) \rightarrow \pi^+\pi^-\pi^0$ final states
- A fit of the $m(\pi^+\pi^0)$ spectra in several intervals of $m(\pi^+\pi^-\pi^0)$ gives the variation of the ρ^+ signal
- No enhancement of the ρ^+ signal at the $f_1(1285)$ mass is observed

fitted ρ^+ signal vs $m(\pi^+\pi^-\pi^0)$



Limit on the $f_1(1285)$-$a_1(1260)$ transition

- A fit of the observed ρ^+ yield assuming the gaussian f_1 signal (with fixed mass and width) and a background
- BG = P2 + BW(a_2)
- gives the number of $f_1 \to \rho^+ \pi^-$ events, N = --993 ± 1172
- This number can be transformed to the upper limit :
- BR(f_1(1285)$\to \rho^{+-} \pi^{-+}$) < 0.4 % at 90% conf. level

Limit on $f_1 \leftrightarrow a_1$ mixing

- $BR(f1 \rightarrow \rho\pi) = \Gamma_{a1\rightarrow\rho\pi} / \Gamma_{f1} \cdot (\Pi_{f1a1} / (m^2_{a1} - m^2_{f1} - i(m_{f1}\Gamma_{f1} - m_{a1}\Gamma_{a1}))^2$

$$\approx \Pi^2_{f1a1} / (m^2_{f1}\Gamma_{f1}\Gamma_{a1})$$

Upper limit $BR(f_1(1285) \rightarrow \rho^{+-}\pi^{-+}) < 0.4$ %
leads to:

$\Pi_{f1a1} < 0.0056\ GeV^2$ for $\Gamma_{a1} = 200$ MeV
$\Pi_{f1a1} < 0.0097\ GeV^2$ for $\Gamma_{a1} = 600$ MeV

It can be compared with prediction based on the assumption of universality of charge symmetry breaking in different channels like $\omega \rightarrow \pi^+\pi^-$, $\varphi \rightarrow \pi^+\pi^-$, $\eta \rightarrow 3\pi$ (Coon, Scadron, 1994)

$\Pi_{f1a1} = 0.005\ GeV^2$

Conclusions

- **All elements of the observed pattern fit well in the hypothesis that the decay $f_1(1285) \to \pi^+\pi^-\pi^0$ 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

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

$$= (1.41 \pm 0.21 \pm 0.42)\%;$$

or

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

$$= (0.19 \pm 0.09)\%$$

This value agrees with predictions of Achasov et al.

estimations

- For neutral $a_0(980)$
  $BR(a_0^0\ (980) \rightarrow \pi^+\ \pi^-) = 1.52 \pm 0.72\ \%$
- $BR(f_1(1285) \rightarrow \rho^{+-}\ \pi^{-+}) < 0.4\ \%$ at 90% conf. level