Recent results from VES detector

- *VES collaboration*
- **V.Dorofeev, R.Dzheliadin, A.Ekimov, Yu.Gavrilov, Yu.Gouz, A.Ivashin, V.Kabachenko, I.Kachaev, A.Karyukhin, Yu.Khokhlov, V.Konstantinov, M.Makouski, V.Matveev, A.Miagkov, V.Nikolaenko, A.Ostankov, B.Polyakov, D.Ryabchikov, N.Shalanda, M.Soldatov, A.A.Solodkov, A.V.Solodkov, O.Solovianov, A.Zaitsev**
- Presented by V.Nikolaenko

- *VES detector*
- *Observation o*f $f_1(1285) \rightarrow \pi^+\pi^-\pi^0$ decay
- Threshold peak in ($\omega\varphi$) system
- Upgrade of the detector

VES detector

-The VES detector is a wide aperture forward spectrometer, which is

Installed in unseparated beam of negative particles (mainly π^-)

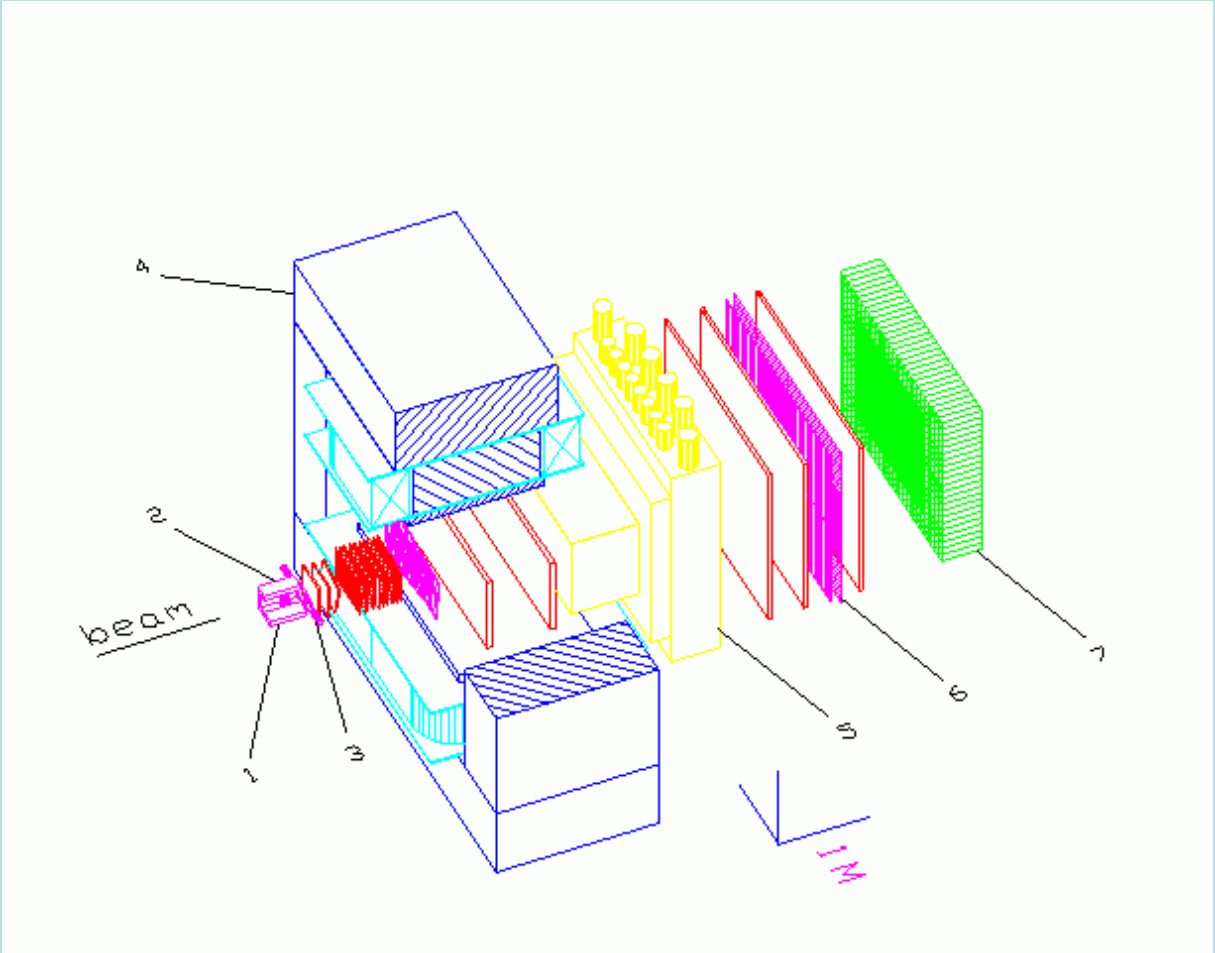
-Equipped with EM calorimeter

Cherenkov detectors for identification of beam and charged secondary particles

-Fast Data Acquisition system

-Forward multiplicity trigger

VES detector



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

- 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 →$a_0(980)\pi$ BR=(36±7)%
  f1(1285)→ $K\overline{K}\pi$ 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

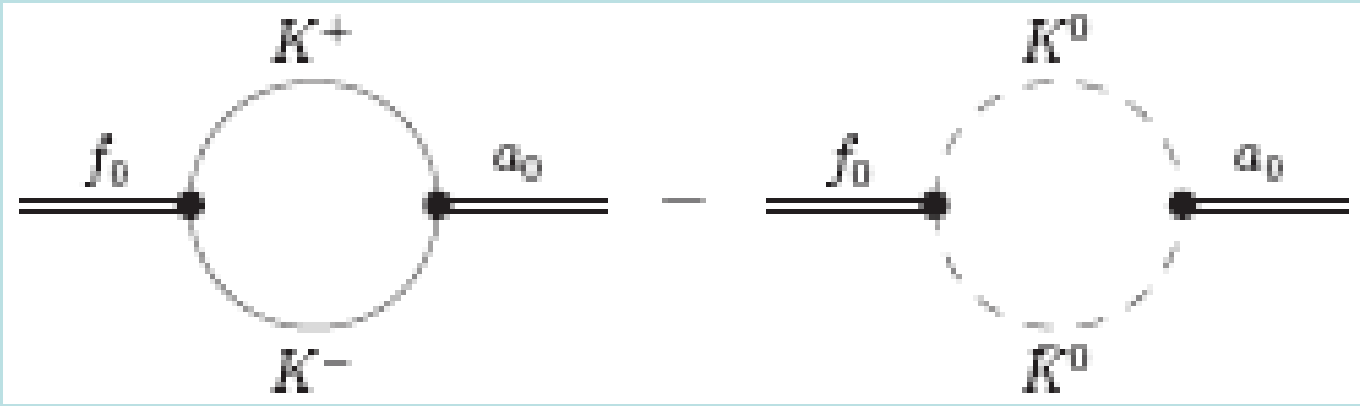
  - in EM processes

  - 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 loops 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

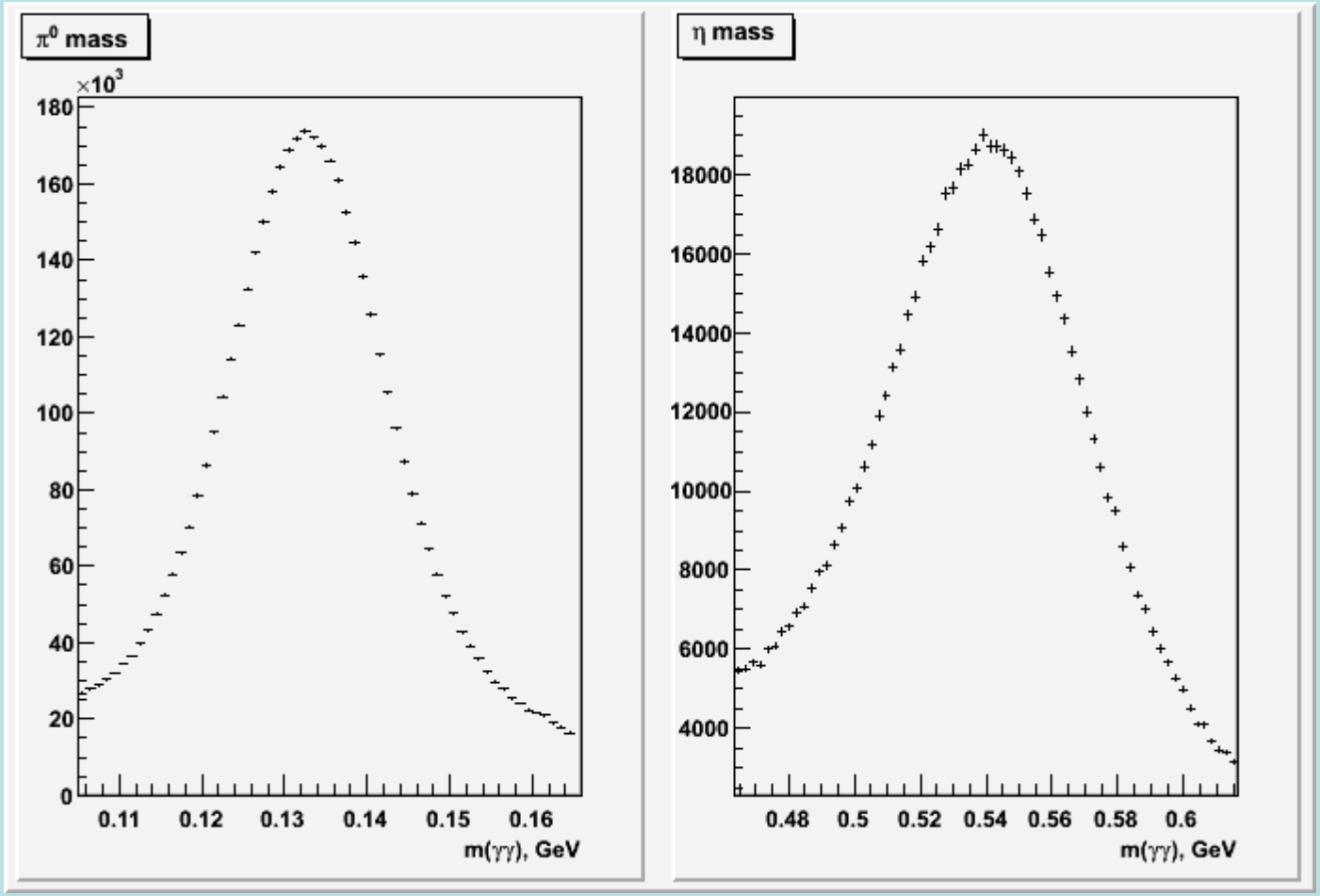
reaction $\pi^- N \rightarrow (f_1 \pi^-) N$

- **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$\rightarrow$(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

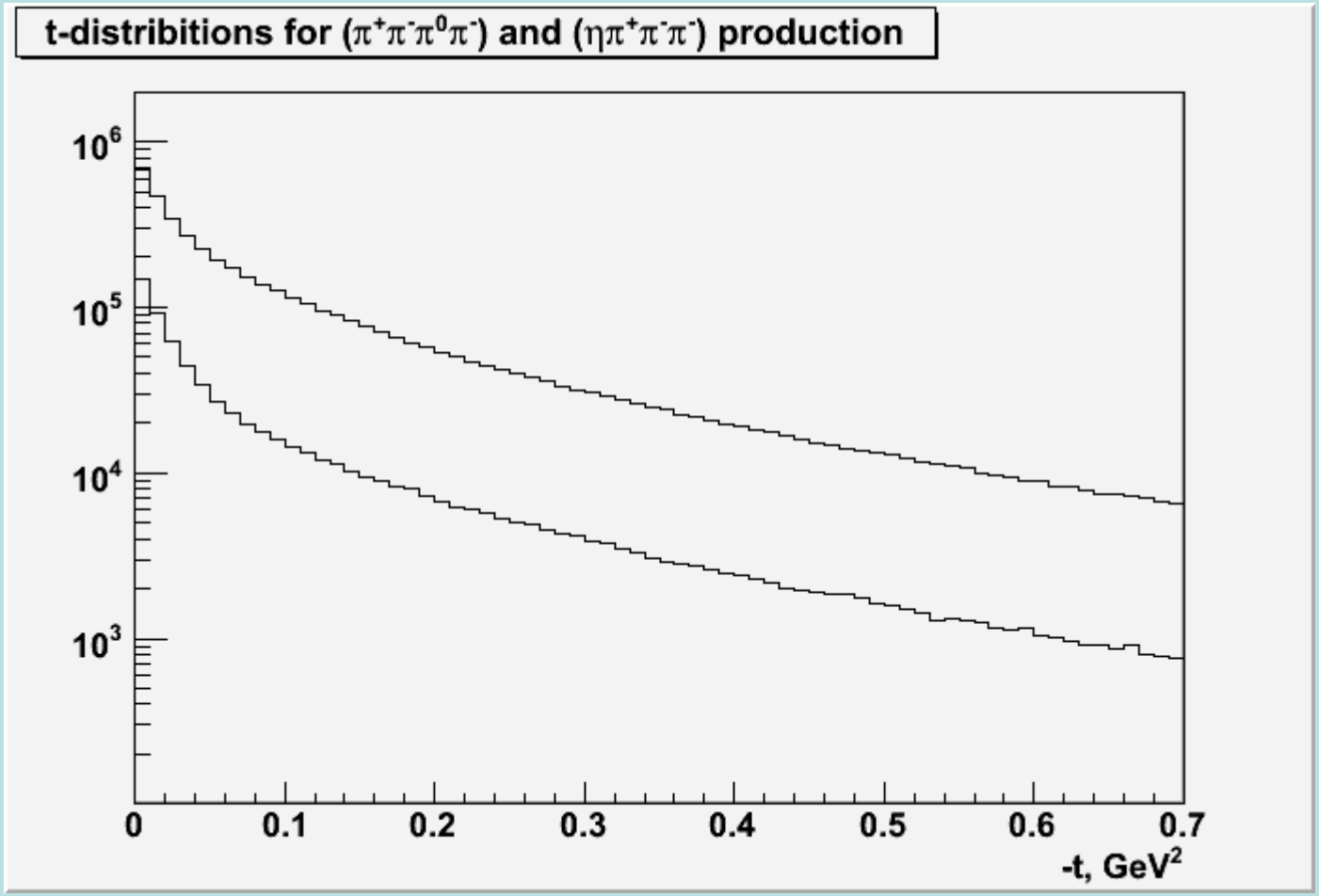
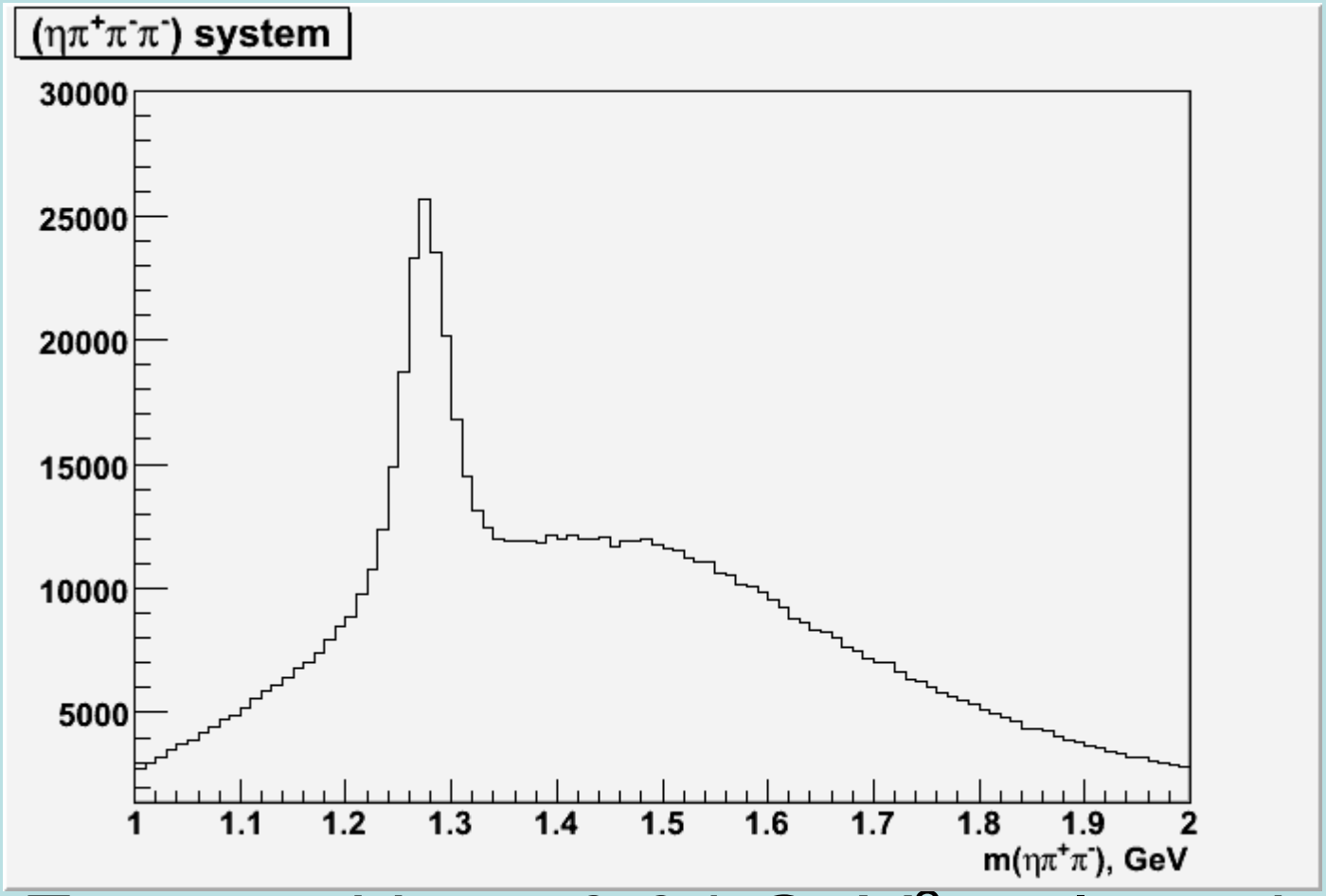


Fig.3, $(\eta\pi^+\pi^-\pi^-)$ system



- Events with $-t<0.04$ GeV^2 selected, the number of f_1 events is 59300±600 (assuming gaussian shape of f_1).

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

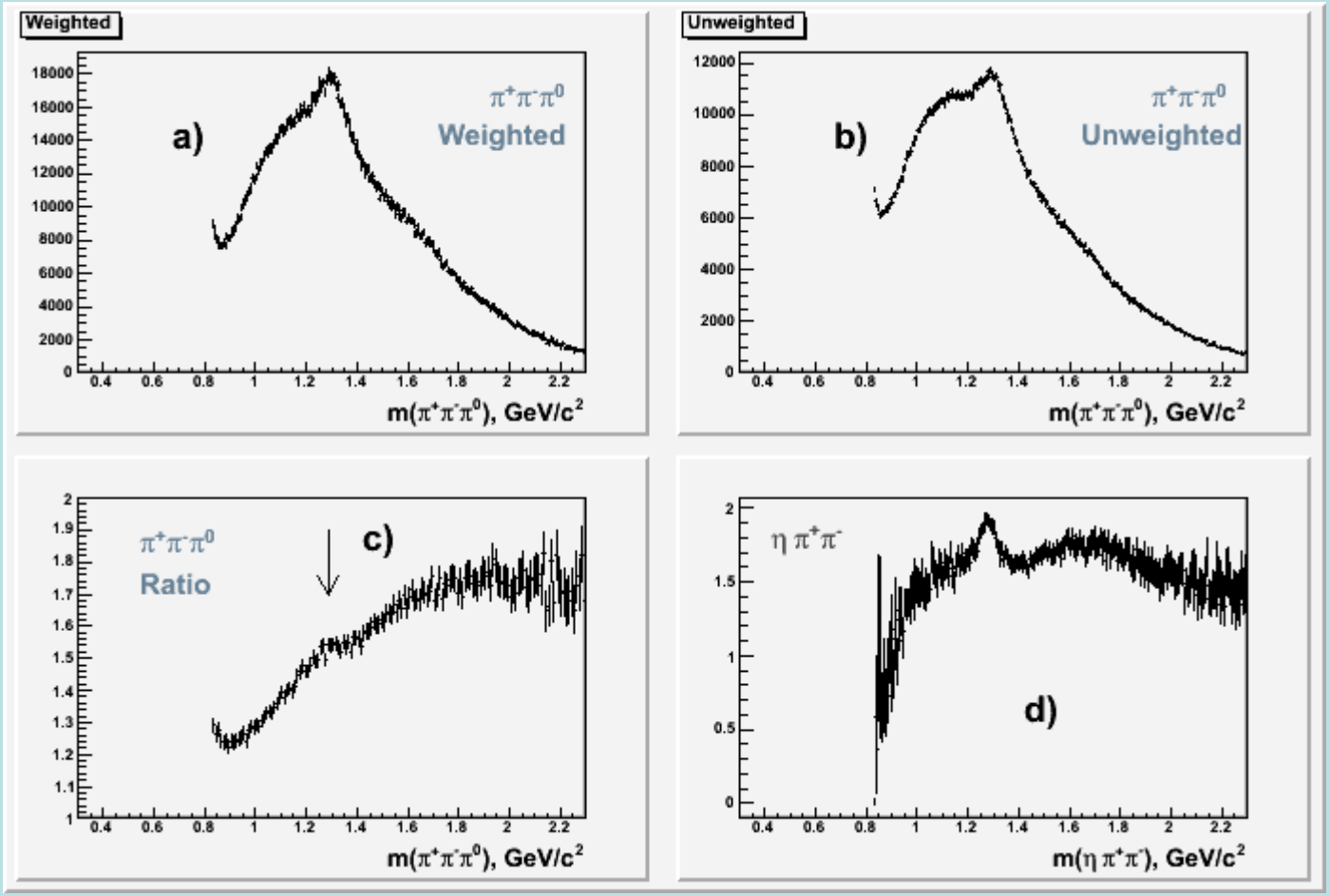
φ_0 and φ_2 are angles of the beam particle and the π^0 momentum projections to the plane which is orthogonal to the momentum of extra pion.

Validity of the corresponding weight,

$$W = |A|^2$$

is demonstrated at Fig.4d.

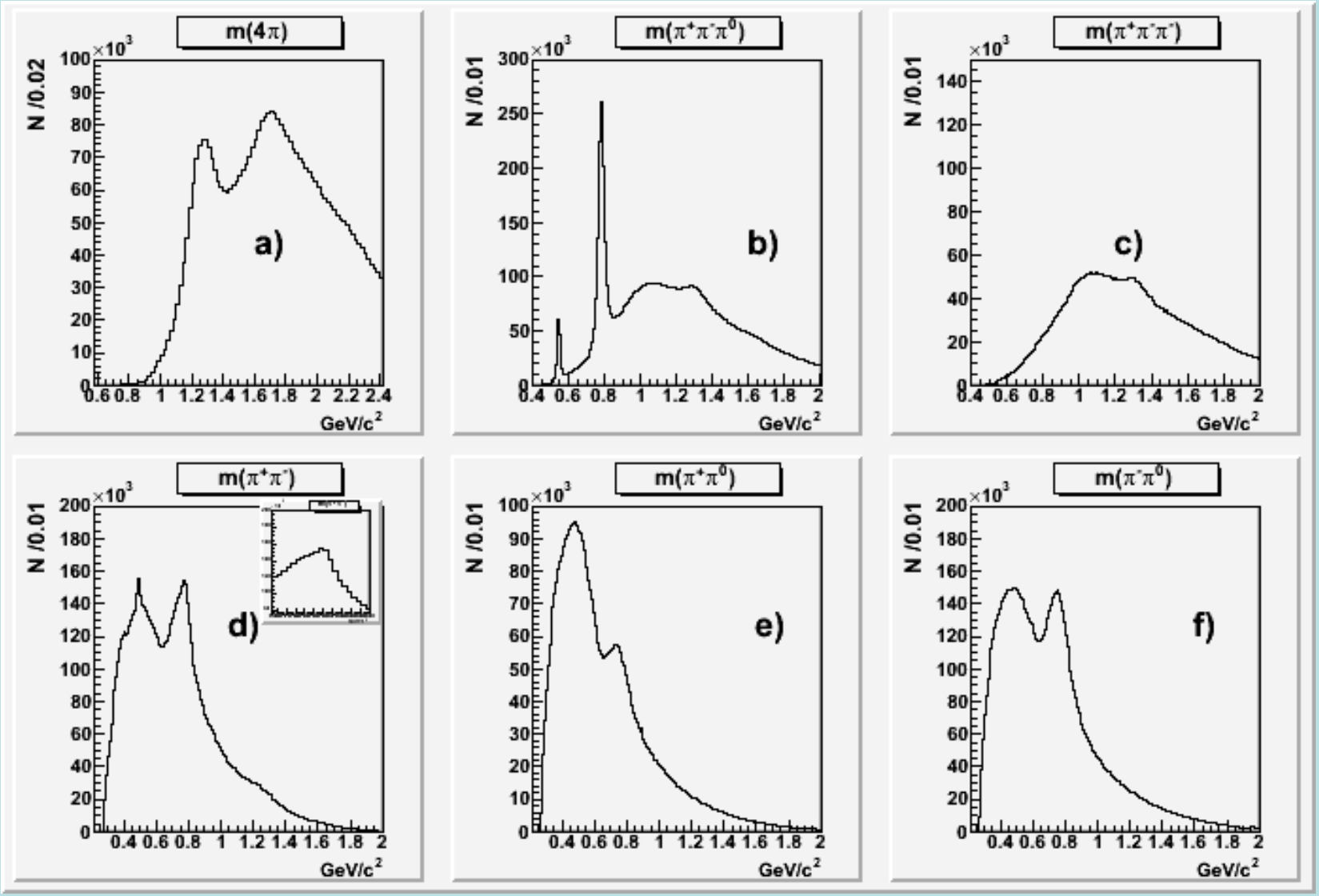
Fig.4, Angular weight



a-c) $m(\pi^+\pi^-\pi^0)$ distributions;

d) $m(\eta\pi^+\pi^-)$ distribution

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



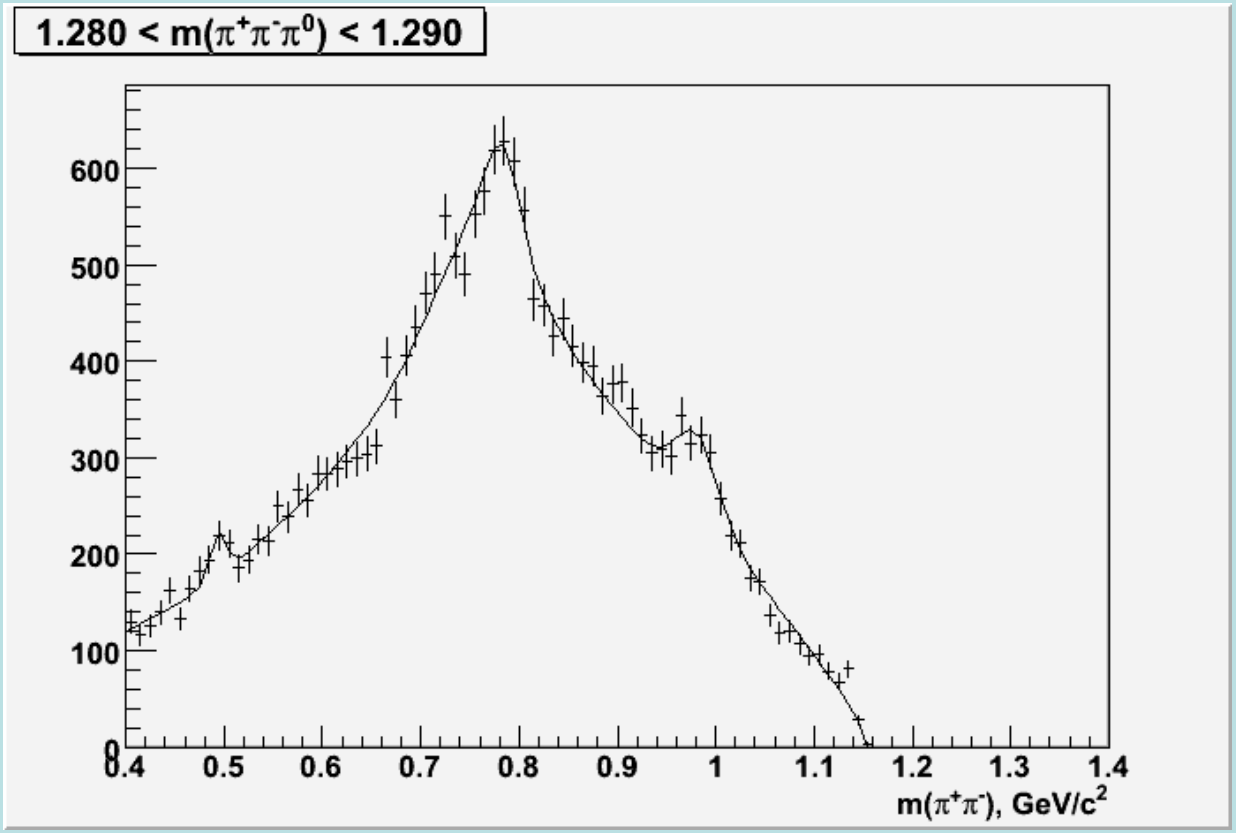
$(\pi^+ \pi^- \pi^0 \pi^-)$ system

- **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. 4 a-c)**

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 (NO angular weights used).
- 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.6). The fit with a gaussian signal and BG (phase space multiplied to a cubic function with arbitrary coefficients) plus gaussion signals for K^0 and ω plus BW for ρ - is shown.

Fig. 6, Fit of $m(\pi^+\pi^-)$ spectrum

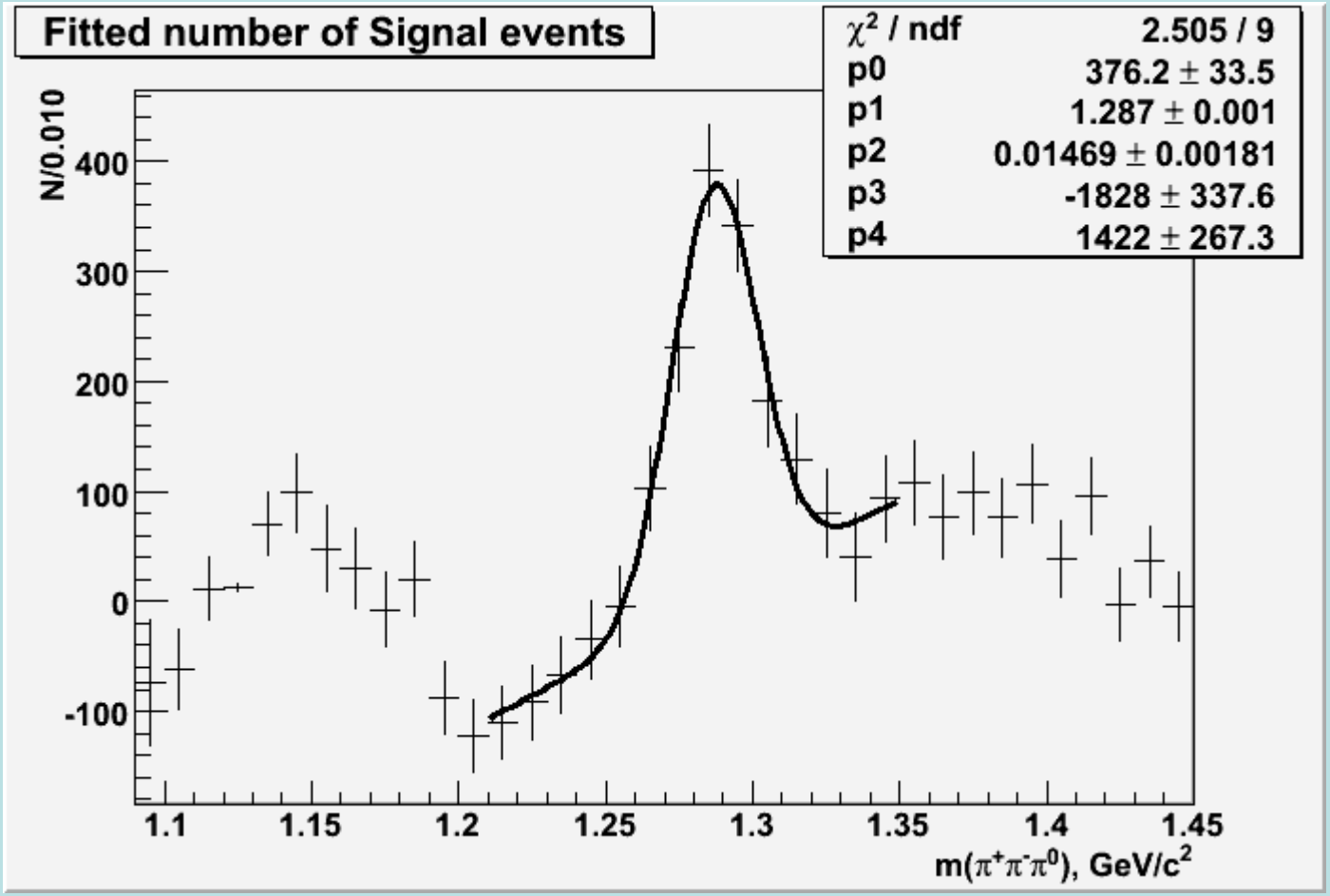


Selected events at $1.280<m(\pi^+\pi^-\pi^0)<1.290$ GeV. Masses and widthes of K^0, ω, ρ are fixed (widthes at values estimated from experimental resolution).

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.7. A peak is observed at this summary plot, with mass 1287±2 MeV and Gaussian width of 14.7±2.5 MeV
- The sum of observed signals N=1400±300 events.
- A similar procedure with binning on the m($\pi^+ \pi^- \pi^-$) was performed, no signal at the f_1 region was found.

Fig.7.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 intensity of the ρ^{+-} signal as a function of 3-pion mass.
- No enhancement of the ρ^{+-} signal at the $f_1(1285)$ mass is observed

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

- A fit of the observed ρ^{+-} yields (assuming the gaussian f_1 signal with fixed mass and width) and a background
- BG = P2 + BW(a_2)
- gives the number of $f_1 \rightarrow \rho^{+-}\pi^{-+}$ events, N = --95 ± 444
- This number can be transformed to the upper limit :
- BR($f_1(1285) \rightarrow \rho^{+--}\pi^{-+}$) < **0.10** % at **95%** conf. level

Limit on f1↔a1 mixing

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

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

Upper limit $BR(f_1(1285) \to \rho^{+--}\pi^{-+}) < 0.1\ \%$

leads to:

$\Pi_{f1a1} < 0.0027\ GeV^2$ for $\Gamma_{a1} = 200$ MeV

$\Pi_{f1a1} < 0.0047\ GeV^2$ 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 $\omega \to \pi^+\pi^-$, $\varphi \to \pi^+\pi^-$, $\eta \to 3\pi$ (Coon, Scadron, 1994)

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

Results for $f_1(1285) \rightarrow \pi^+\pi^-\pi^0$

- **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

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

$$= (2.4 \pm 0.5 \pm 0.4)\%;$$

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.

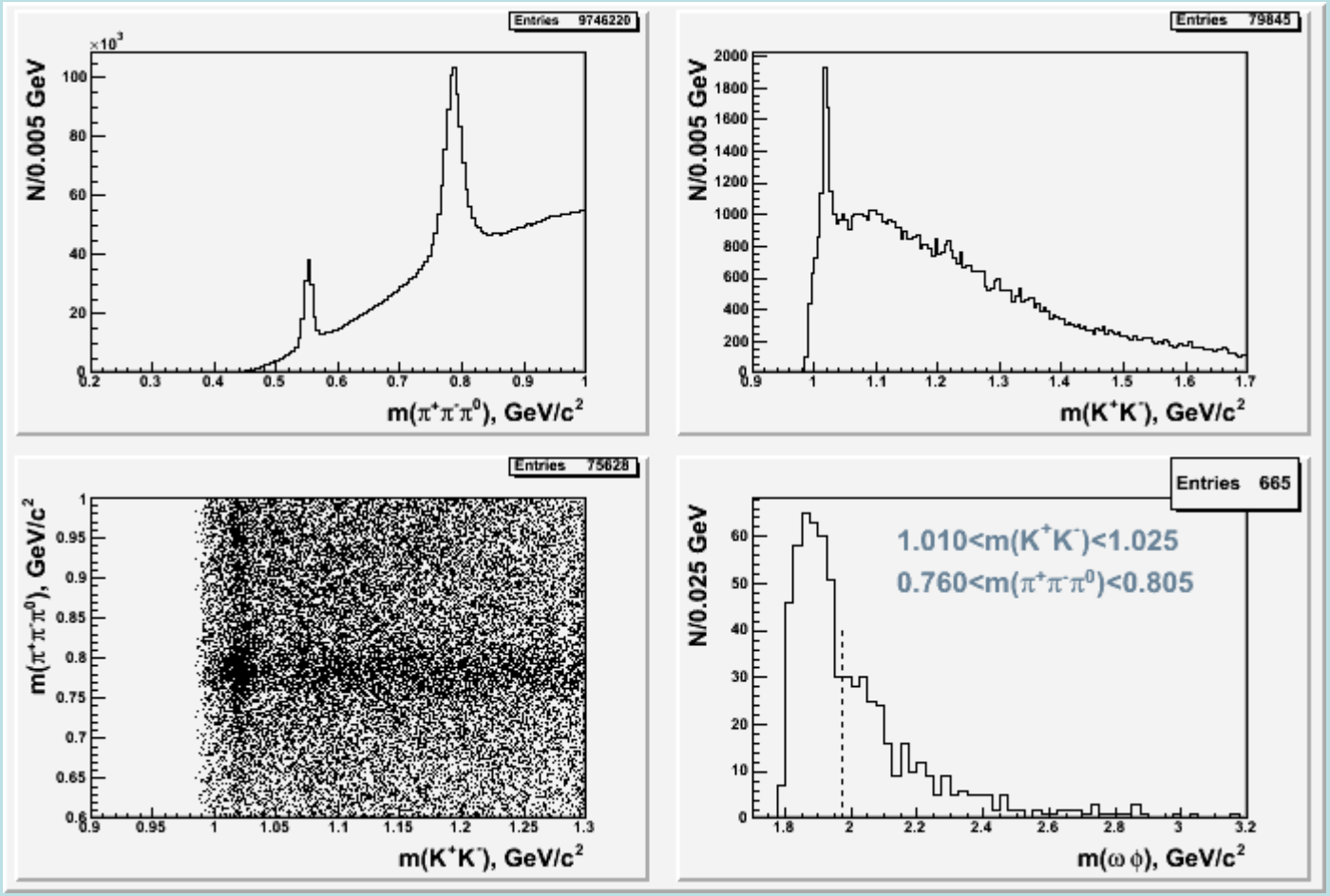
estimations

- For neutral $a_0(980)$
  $BR(a_0^0\ (980) \rightarrow \pi^+\ \pi^-) = (3.3 \pm 1.4)\ \%$
- $BR(f_1(1285) \rightarrow \rho^{+--}\ \pi^{-+}) < 0.10\ \%$ at 95% conf. level

(ωφ) system

- Used data acquired at 27 and 36.6 GeV/c
- Selected events with 2 positive, 2 negative tracks and two showers in ECAL forming a π^0 , in “elastic peak”.
- Requested K^+ and K^- identified in Cherenkov detector - seen φ
- Two remaining charged tracks taken with pion mass and π^0 - seen ω
- Seen accumulation of events at intersection of φ and ω bands

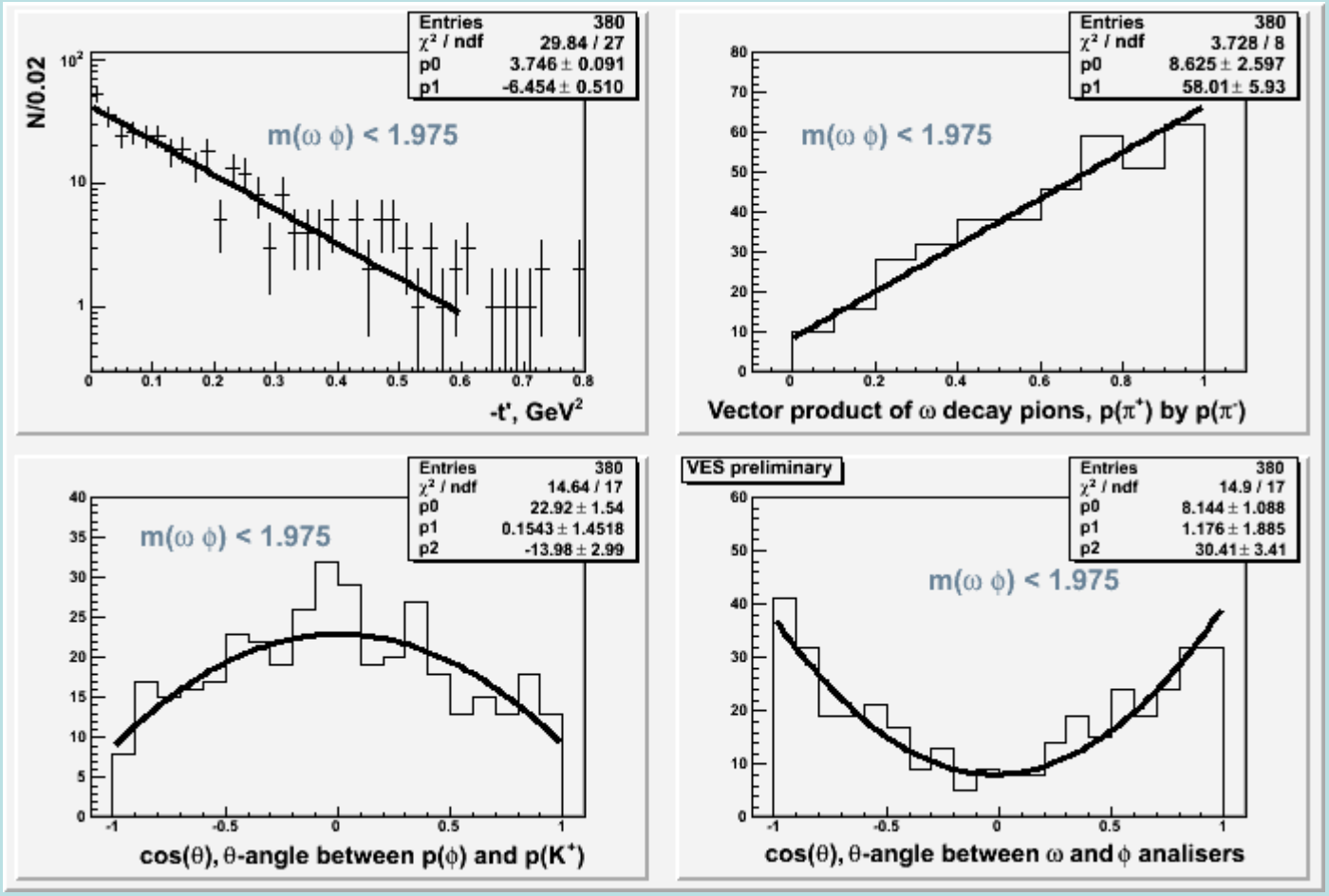
(ωφ) system


Entries 9746220
N/0.005 GeV
m(π⁺π⁻π⁰), GeV/c²
Entries 79845
N/0.005 GeV
m(K⁺K⁻), GeV/c²
Entries 75628
m(π⁺π⁻π⁰), GeV/c²
m(K⁺K⁻), GeV/c²
Entries 665
1.010<m(K⁺K⁻)<1.025
0.760<m(π⁺π⁻π⁰)<0.805
N/0.025 GeV
m(ω φ), GeV/c²

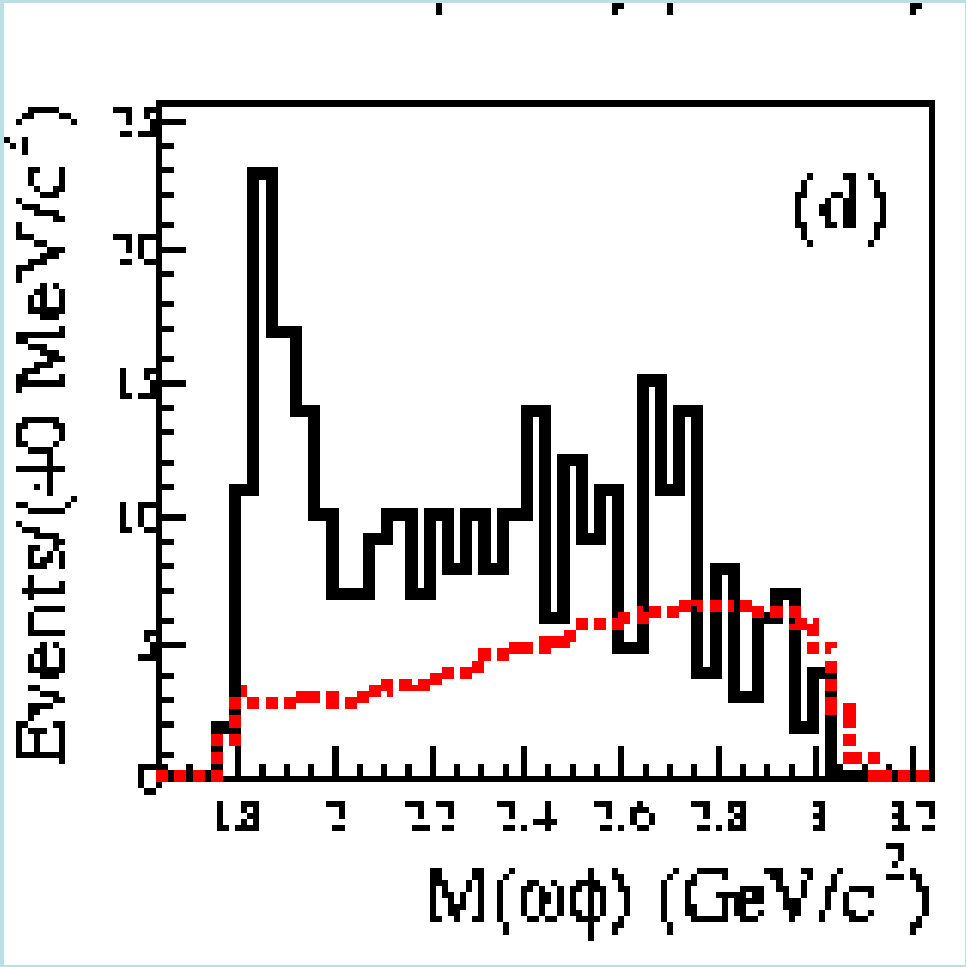
(ωφ) system

- Taken events at the intersection of ω and φ bands
- Clear bump near threshold is observed
- t- slope is consistent with pion exchange
- Angular distributions: the ω- and φ- analyzers are shown
- COS of the Angle between two analyzers is shown, it is consistent with $\cos^2$ (expected for the scalar decaying into two vectors in S-wave) plus background
- We have 380 (ωφ) events – and 99 φφ ev.

(ωφ) system


Entries 380
χ² / ndf 29.84 / 27
p0 3.746 ± 0.091
p1 -6.454 ± 0.510
m(ω φ) < 1.975
N/0.02
-t', GeV²
Entries 380
χ² / ndf 3.728 / 8
p0 8.625 ± 2.597
p1 58.01 ± 5.93
m(ω φ) < 1.975
Vector product of ω decay pions, p(π⁺) by p(π⁻)
Entries 380
χ² / ndf 14.64 / 17
p0 22.92 ± 1.54
p1 0.1543 ± 1.4518
p2 -13.98 ± 2.99
m(ω φ) < 1.975
cos(θ), θ-angle between p(φ) and p(K⁺)
VES preliminary
Entries 380
χ² / ndf 14.9 / 17
p0 8.144 ± 1.088
p1 1.176 ± 1.885
p2 30.41 ± 3.41
m(ω φ) < 1.975
cos(θ), θ-angle between ω and φ analisers

Observed in J/ψ→(γ ω φ)



By BES Collaboration. (Ablikim et al.), Phys. Rev.Lett.96:162002,2006, hep-ex/ 0602031

(ωφ) system

- With higher statistics and in another production process we confirm the resonance-like bump with probably scalar quantum numbers

VES detector upgrade

- Main direction of the ongoing upgrade: to increase resolution and identification capability of the spectrometer and to improve the performance during the data taking. Will gain in "exclusivity", kinematics accuracy, backgrounds suppression, and also gain in statistics (dead time decrease from 100 mksec to 15-20 mksec).

VES detector upgrade

- Major steps:
- improvement of multichannel Cherenkov counter for pion-kaon discrimination: new mirrors with better focusing, more stable amplifiers for PMTs. Commissioned.
- construction of beam spectrometer with momentum resolution of 0.8% at 30 GeV/c. Commissioned, still room to improve.

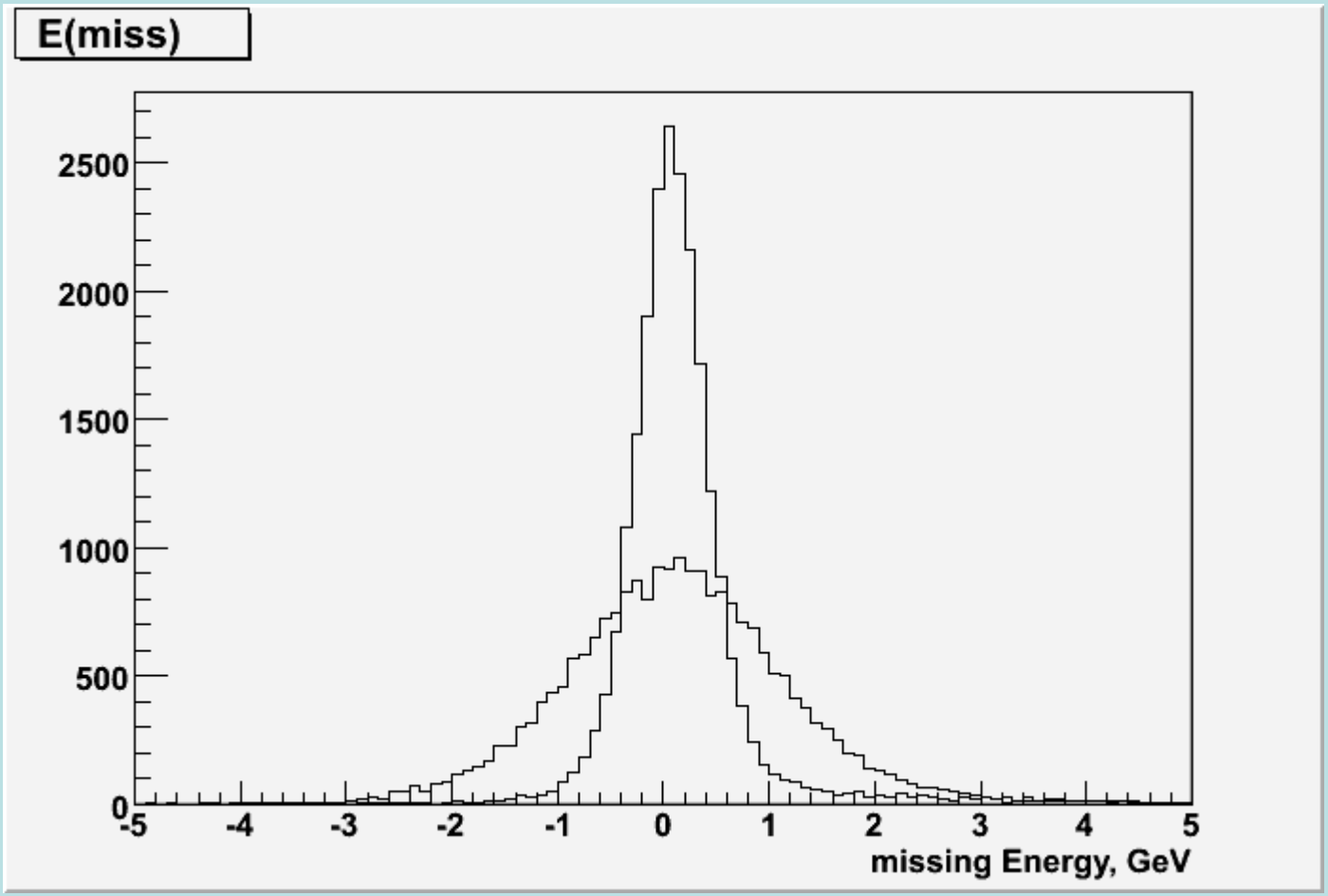
VES detector upgrade

- modernization of electromagnetic calorimeter: fine layers "shashlyk" against lead glass for better (almost factor 2) energy resolution. In progress, yy.2008-2009.
- replacement of large (~2.5 by 2 m) drift chambers in self-quenching regime of gas amplification with new ones in proportional mode. Straws in consideration.

VES detector upgrade

- All these is supplemented with ReadOut electronics, DAQ, Slow Control and software improvements.

MC study for ($\eta\pi^-\pi^+\pi^-$) system

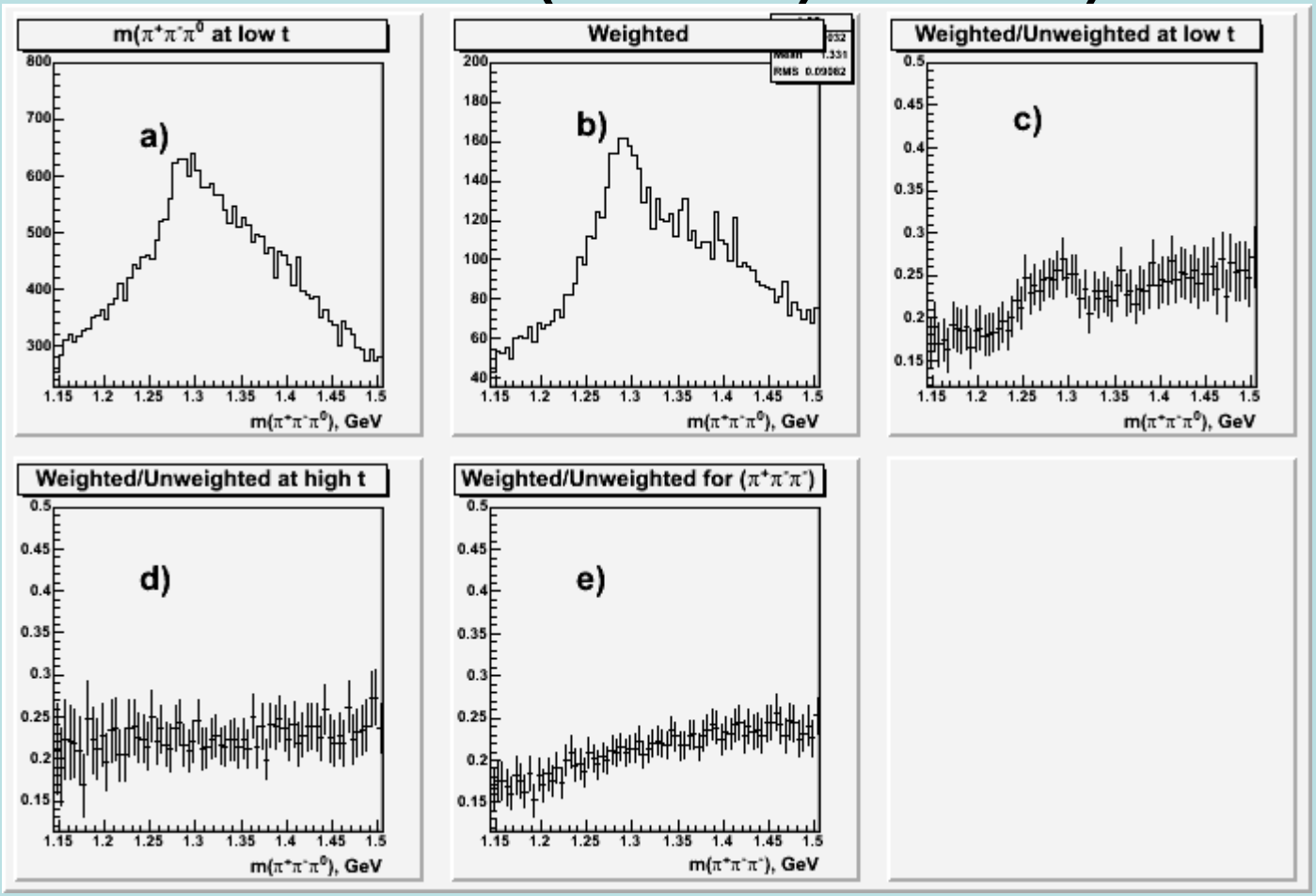


Expected improvement in missing energy resolution from new beam spectrometer and new ECAL

Conclusions

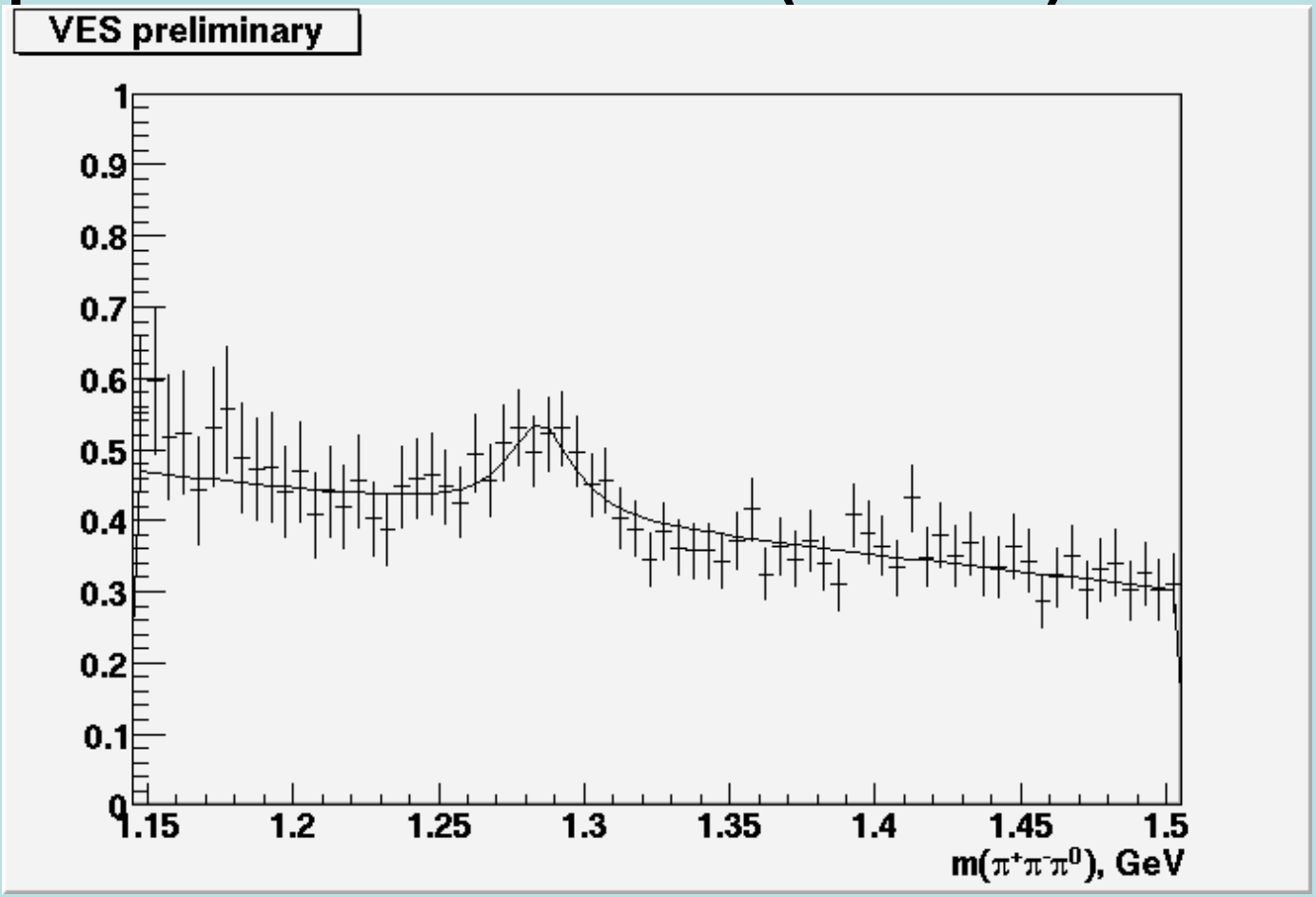
- $f_1 \rightarrow \pi^+\pi^-\pi^0$ decay is observed, which violates the isospin symmetry, and the observed pattern of this violation agrees with mechanism which has been proposed by N.Achasov et.al. in 1979. An upper limit for $f_1 \leftrightarrow a_1$ mixing is obtained.
- A peak in m(ωφ) near threshold is observed, $J^P = 0^+$. Similar object has been observed in $J/\psi \rightarrow (\gamma\ \omega\ \varphi)$ decay at BEC.

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**