A.Zaitsev 20.02.02 Trieste

Diffractive production of exotic states

The expectations for hybrid mesons

VES facility

Exotic quantum numbers ($J^{PC} = 1^{-+}$)

$\pi^- N \to \eta \pi^- N$ VES , other results for $J^{PC} = 1^{-+}$, $M \approx 1.4$ GeV
$\pi^- N \to \eta' \pi^- N$
$\pi^- N \to b_1 \pi N$
$\pi^- N \to \rho^0 \pi^- N$
$\pi^- N \to \eta \pi^- \pi^- \pi^+ N$
Status of $J^{PC} = 1^{-+}$, $M \approx 1.6 - 1.8$ GeV

Features of π (1800)

$K^- N \to K^- \pi^- \pi^+ N$

Study of $\eta\pi^-$ production in Coulomb field

Extrapolation to COMPASS

Hybrid mesons

$q \quad \bar{q}$

$3c \otimes \bar{3}c = 1c \oplus 8c$

$\downarrow$

normal $\quad 8c \otimes 8c = 1c \oplus \ldots\ldots$

mesons $\quad q\bar{q} \quad g$ hybrids (three body system)

"Normal" mesons ($q\bar{q}$)

	S=1/2 1/2					
	↑ ↓	↑ ↑	↑ ↑			↑ ↓ ...
	L=0	L=0	L=1			L=1
J^{PC}	0^{-+}	1^{--}	0^{++}	1^{++}	2^{++}	1^{+-}
$n\,^{2S+1}L_J$	1^1S_0	1^3S_1	1^3P_0	1^3P_1	1^3P_2	1^1P_1 ...

$$P=(-1)^{L+1} \qquad C=(-1)^{L+S}$$

Exotic quantum numbers:

$$J^{PC}_{exotics} = 1^{-+} \quad 0^{+-} \quad 2^{+-} \quad 0^{--} \quad \ldots\ldots$$

Hybrid mesons can have exotic quantum numbers (Okun',Vainshtein 76)

Models, predictions

Potential models, Bag models, Flux tube model, QCD sum rules, Lattice QCD

$M(1^{-+}) \approx 1.6 - 2.0$ GeV $\qquad M(\hat{\rho}') = M(\hat{\rho}) + 0.2$ GeV

Predictions for decay widths are very model dependent:

**η` π , η π** $\quad A^2(\hat{\rho} \to \eta` \pi)/A^2(\hat{\rho} \to \eta\pi) = 1/tg\,\theta_{PS}$ {Close&Lipkin}

$\Gamma(\eta`\pi) \approx 3$ MeV {Narison,99} $\quad \Gamma(\eta`\pi) \approx 1$ GeV {Frere}

ρ π $\quad \Gamma(\hat{\rho}(1600) \to \rho\pi) = 2 \div 8$ MeV {Kokoski,Page}

$\Gamma(\hat{\rho}(1600) \to \rho\pi) = 10 \div 100$ MeV {Viron}

$\Gamma(\hat{\rho}(1600) \to \rho\pi) = 0.6$ GeV {Narison}

$b_1 \pi$ $\quad \Gamma(\hat{\rho}(1600) \to b_1\pi) = 50 \div 200$ MэB {Iddir,Page}

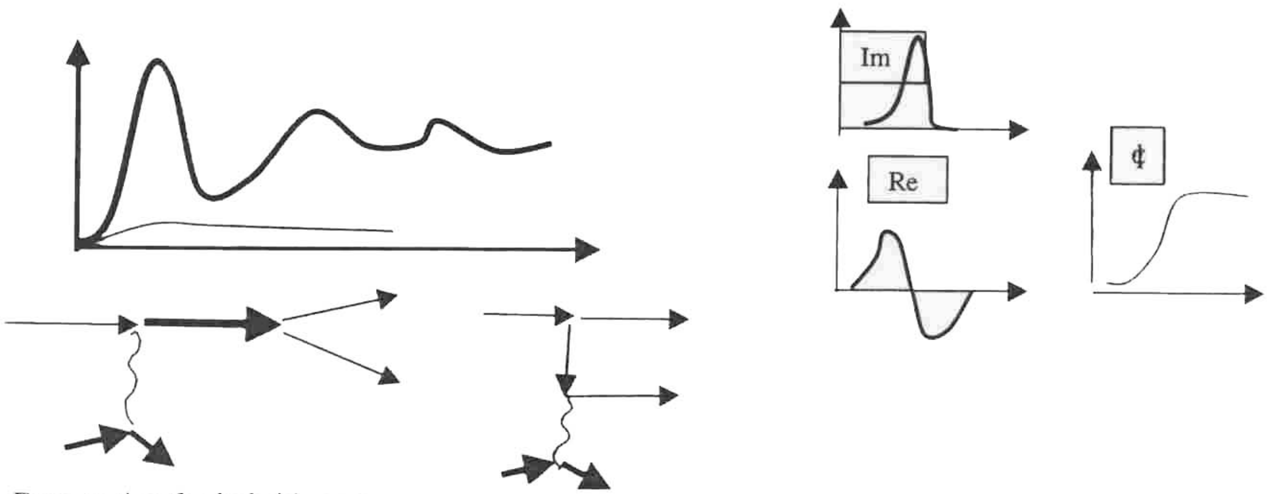
$f_1 \pi$ $\quad \Gamma(\hat{\rho}(1600) \to f_1\pi) = 10 \div 50$ MэB

Methods of hunting, problems

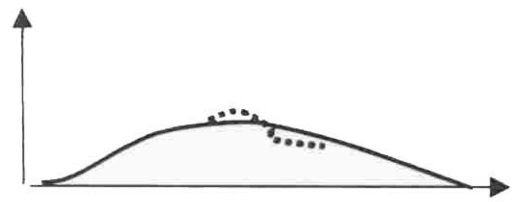
- search for "additional" states with normal quantum numbers
- search for "unusual" decays
  (suppression of decays to states with identical space wave function, decays to meson + glueball)
- search for mesons with exotic quantum numbers

Main problem – large nonresonance background.

Normal mesons:



Expectation for hybrid mesons:



- Nonresonance background in exotic channel is of the same scale as in normal one
- The production of hybrids is suppressed in comparison with normal mesons
- Mass of hybrid mesons is well above thresholds

Features of diffractive production

As pomeron is gluon enriched object the production of hybrid states in diffractive reactions could be enhanced.

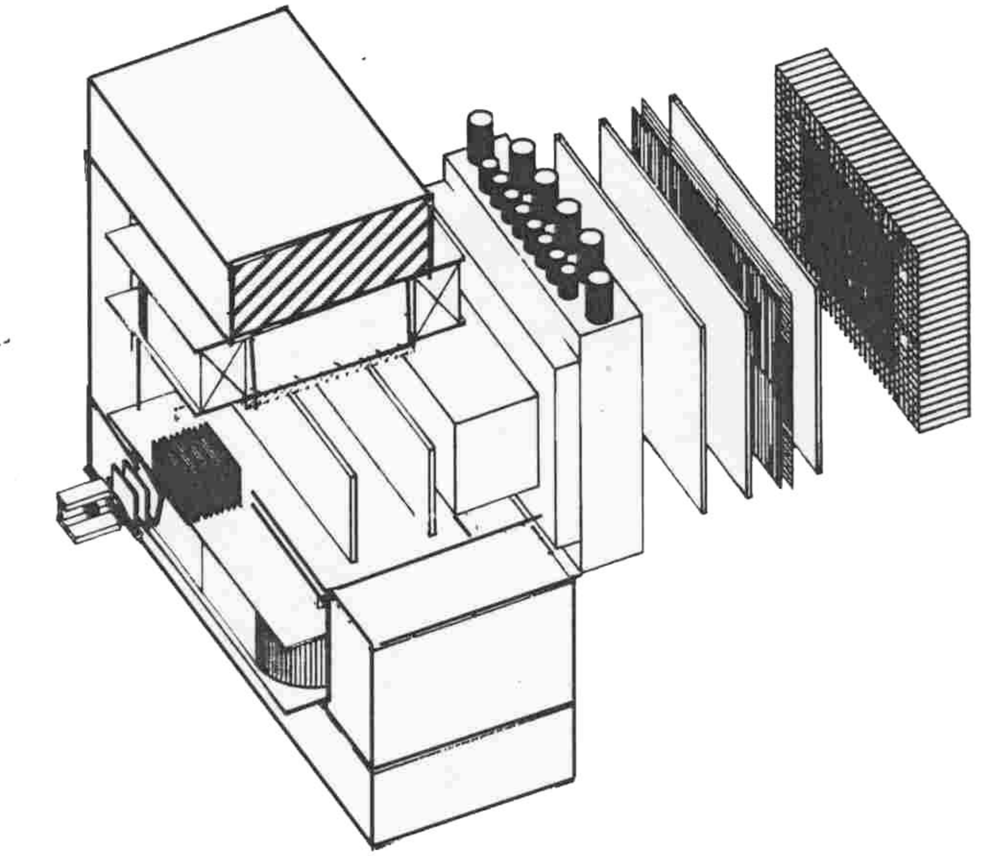
For $J^{PC} = 0^{-+} \quad 1^{++} \quad 2^{-+} \quad 3^{++} \ldots$

$\sigma \sim \text{const} \qquad d\sigma/dt \sim \exp(bt)$

For $J^{PC} = 1^{-+} \quad 2^{++} \quad 3^{-+} \quad 4^{++}$

$\sigma \sim p^{-(0.2\div0.4)} \qquad d\sigma/dt \sim t\exp(bt)$

VErtex Spectrometer (VES)



Main parameters

- Wide aperture magnet (W· H · L = 2 m · 1 m · 1.5 m   B= 1.3 T)
- Wire chambers (PC , DC) (8 000 channels)
- Lead glass multicell calorimeter (1600 channels)
- Multichannel threshold Cherenkov counter (28 channels)
- Scintillation counters and wide aperture hodoscope
- Fast DAQ (5 000 events/spill)
- High statictics of multiparticle events (10^9 events)

The goal – detailed study of meson resonances,
search for exotic resonances.

Main results

- **New** (or not well established) **states observation:**

	$= 0^{-+}$	$\pi(1800)$	$\rightarrow$	$\pi\pi\pi$, $\eta\eta\pi$, $KK\pi$...
	$= 1^{++}$	$a_1(1750)$	$\rightarrow$	$\pi\pi\pi$, f_1, π
J^{PC}	$= 2^{-+}$	$\pi_2(2000)$	$\rightarrow$	$\pi\pi\pi$
	$= 2^{++}$	AX(1560)	$\rightarrow$	$\eta\pi\pi$, $\omega\omega$
	$= 3^{++}$	$a_3(1900)$	$\rightarrow$	$\rho_3\pi$, f_2, π
	$= 4^{++}$	$f_4(1900)$	$\rightarrow$	$\omega\omega$
		$f_4(2400)$	$\rightarrow$	$\eta\pi\pi$

- **First observation of exotic wave $J^{PC}=1^{-+}$**
- **Indication on exotic resonance at M=1.6 GeV.**
- **New decays observation:**

a_2	$\rightarrow$	$\eta'\pi$
$f_1(1285)$	$\rightarrow$	$\rho\gamma$, $\varepsilon\eta$
$\pi_2(1670)$	$\rightarrow$	$\omega\rho$
$a_4(2000)$	$\rightarrow$	$\omega\rho$, $\rho\pi$, $f_2\pi$
$\rho_3(1690)$	$\rightarrow$	$a_2\pi$
$\pi(1800)$	$\rightarrow$	$\varepsilon\pi$, $f_0\pi$, $\eta\eta\pi$, $KK\pi$, $\omega\rho$

- **Study of $\eta\pi^-$ production in Coulomb field** (Primakoff reaction)

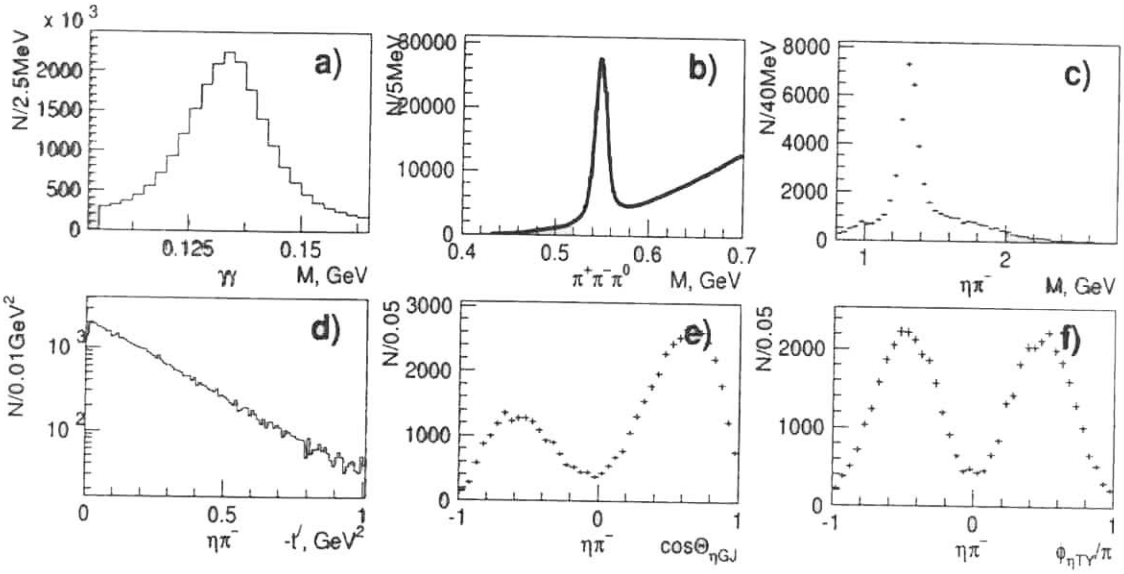
Plans

- **Continue data analysis**
- **Analysis of K^- N interactions**
- **Study of nuclear effects**

The reaction $\pi^- A \to \eta\, \pi^- A$

VES, 1993 , $P_\pi = 37$ GeV (first observation of exotic wave)

2000 , $P_\pi = 28$ GeV



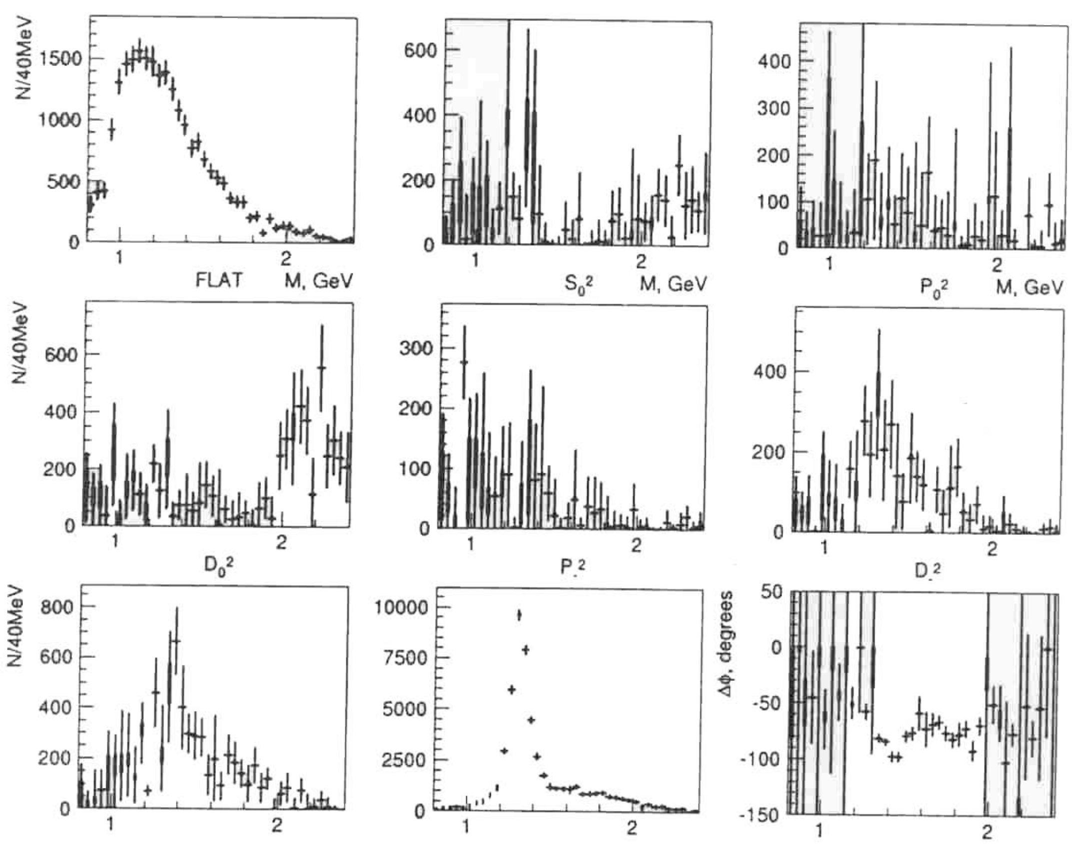
The amplitude depends on 5 variables: **s, t, $M_{\eta\pi}$, θ , φ**

Assuming full coherency at fixed **s, t, $M_{\eta\pi}$** the intensity could be written as:

$I(\Omega) = \left| \sum_{J,M} a^J_{M-} F^J_{M-} \right|^2 + \left| \sum_{J,M} a^J_{M+} F^J_{M+} \right|^2$

$F^J_{M\eta}(\Omega) = Y^J_M(\Omega) - \eta\, (-1)^M\, Y^J_{-M}(\Omega)$ (η – "naturality")

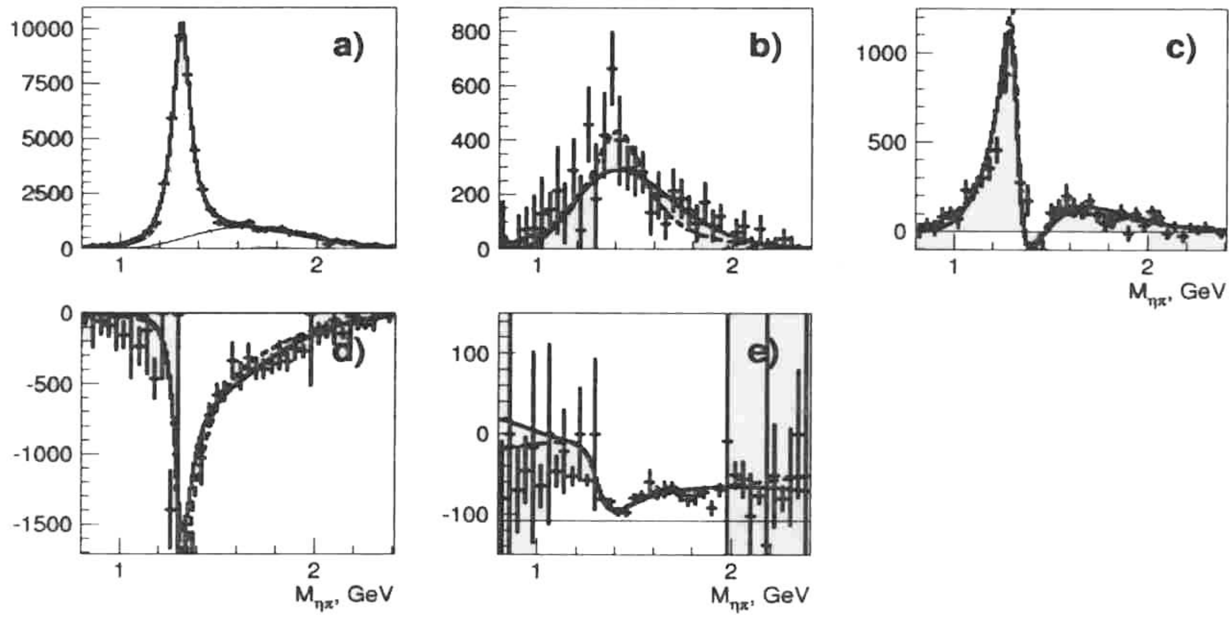
Seven waves: S0, P0, P-, D0, D- ; P+, D+



Mass-dependent analysis of D+ and P+ waves in $\eta\ \pi$

The wave **D+** is dominant :
The resonance $\mathbf{a_2}$ and broad signal at high mass

Broad signal in the wave **P+** is clearly seen
These results are confirmed by E852.



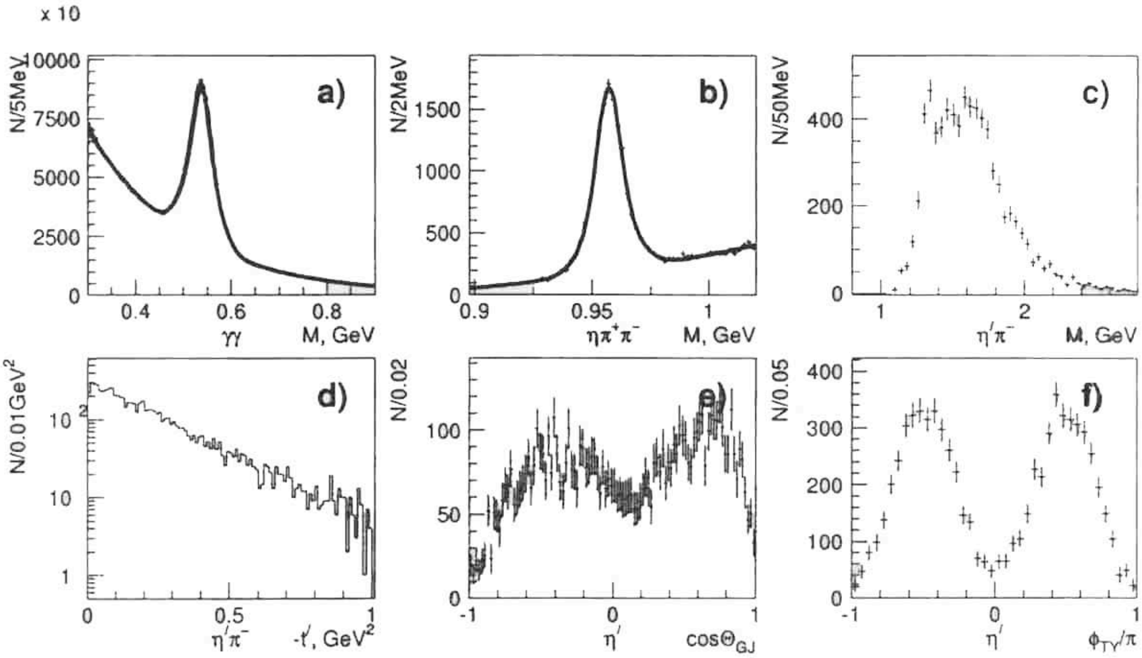
a) Intensity D+. b) Intensity P+.
Real c) and imaginary d) parts of interference term D+ P+.
c) Relative phase D+ / P+

The results are fitted equally well by broad resonance in **P+,** as well as by background with constant phase.

The reaction $\pi^- A \rightarrow \eta' \pi^- A$

VES, 1993 , $P_\pi = 37$ GeV

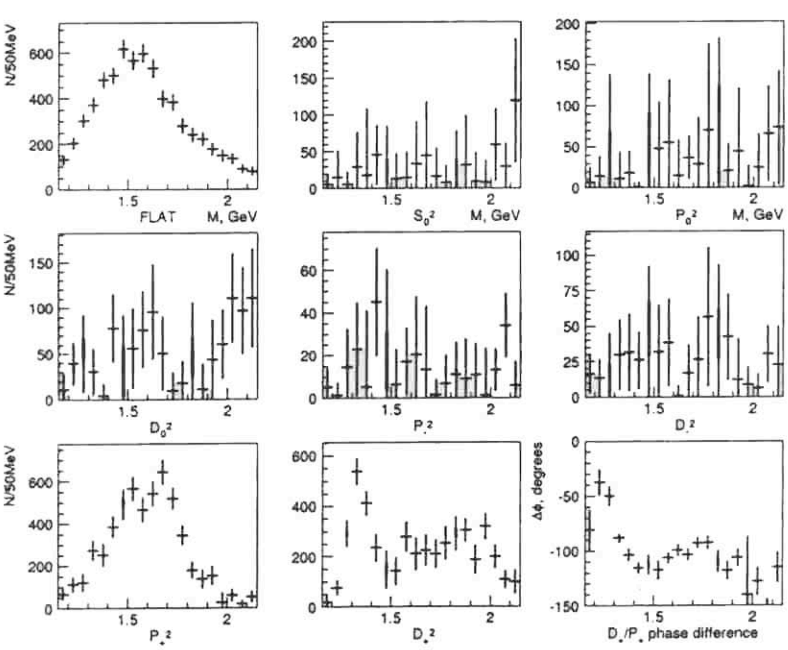
2000 , $P_\pi = 28$ GeV

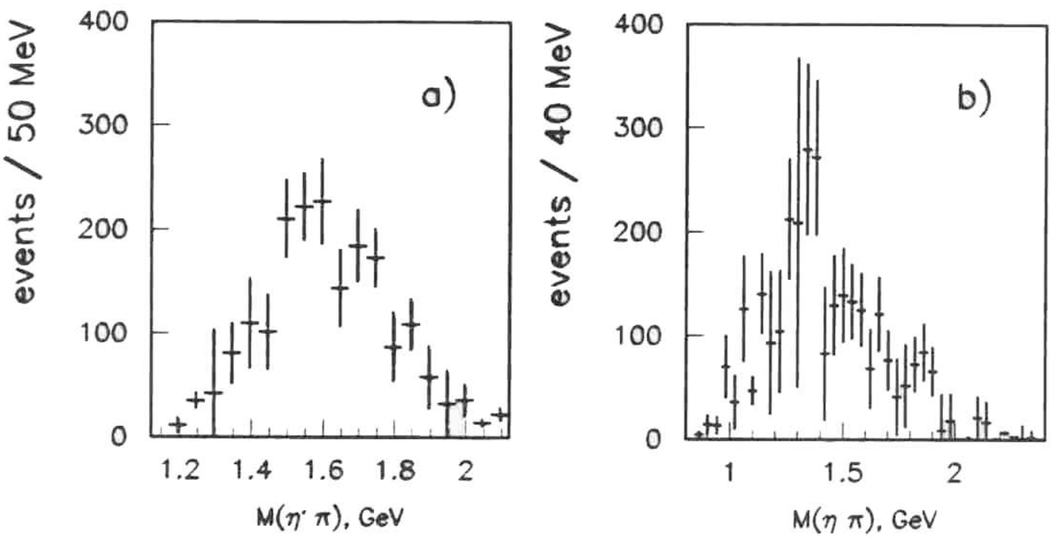


Two signals are clearly seen:

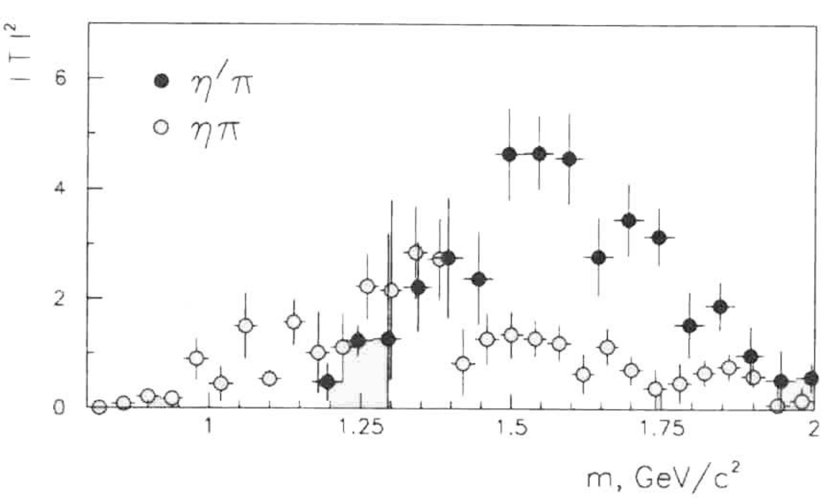
- the decay $a_2 \rightarrow \eta' \pi^-$ (VES, 1992)
- large signal in exotic wave **P+** c at $M(\eta' \pi^-) \approx 1.6$ GeV.

This result was confirmed by E852 recently.





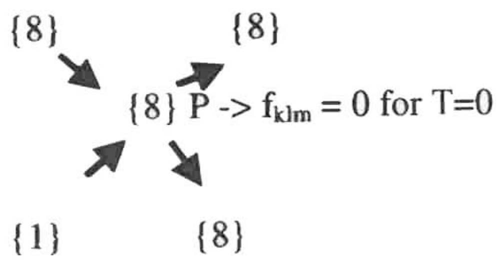
1^-1^+ wave intensity in the $\eta'\pi^-$(a) and $\eta\pi^-$ (b) systems



The matrix elements squared of the 1^-1^+ wave in the $\eta'\pi^-$ and $\eta\pi^-$ systems

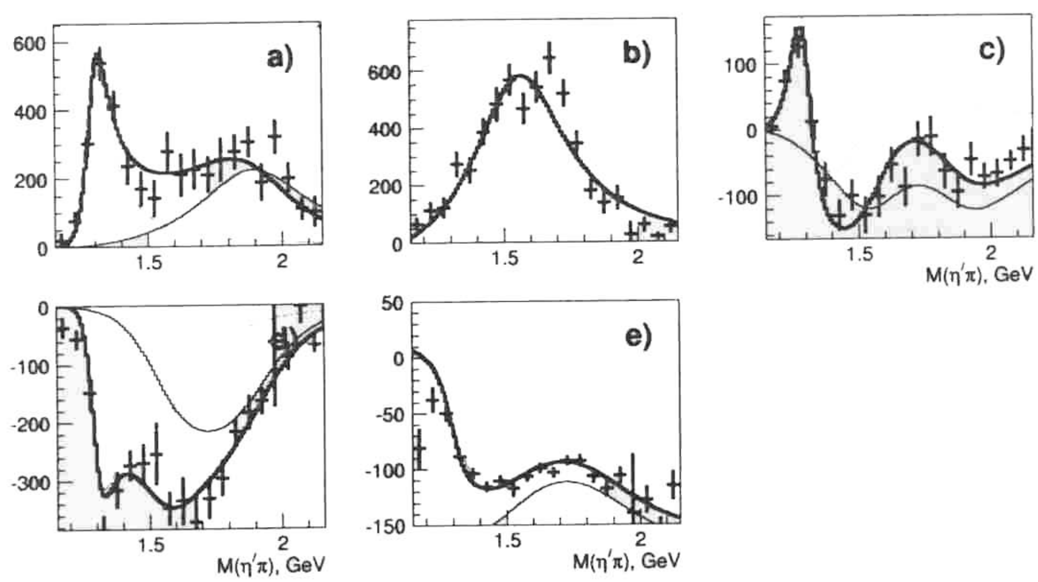
The inensity of the wave **P+** in the channel $\eta' \pi^-$ is much higher than that in the channel $\eta \pi^-$ in agreement with the expectations for hybrid mesons.

This fact can not be used as strong argument in favor of hybrid interpretation of observed feature. The suppression of $\pi \eta_8$ in P- wave followes from $SU(3)_f$ symmetry:



Mass dependent analysis of D+ and P+ waves in the channel $\eta' \pi^-$

a) Intensity D+. b) Intensity P+.
Real c) and imaginary d) parts of interference term D+ P+.
c) Relative phase D+ / P+



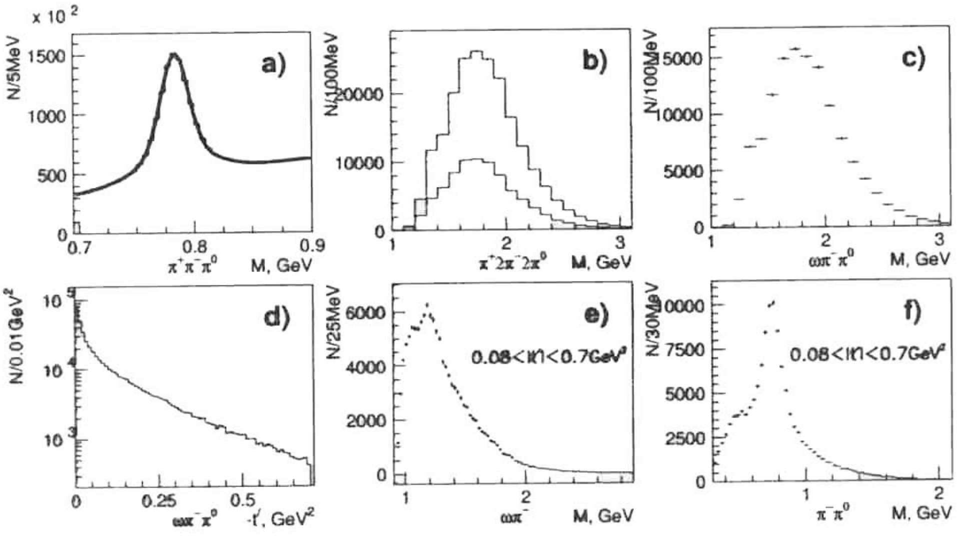
The results are fitted equally well/bad by broad resonance in **P+**, as well as by background with constant phase.

More complicated model is needed to describe the structure at M≈ 1.6-1.8 GeV

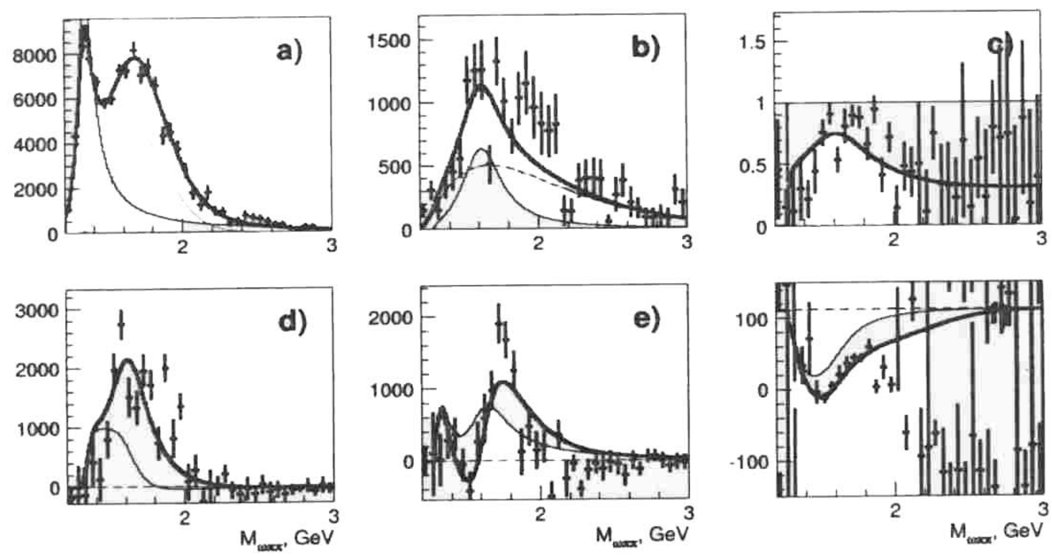
The reaction $\pi^- A \to b_1 \pi A$

VES, 1997 , $P_\pi = 37$ GeV
2000 г, $P_\pi = 28$ GeV

The reaction under study is $\pi^- A \to \pi^+ \pi^- \pi^- \pi^0 \pi^0 A$
The resonance b1(1235) was selected in the chanel $\omega(\pi^+ \pi^- \pi^0)\ \pi$
$I^G(J^{PC})=1^+(1^{+-})$



Mass dependent analysis of D+ and P+ waves in the channel $b_1 \pi$

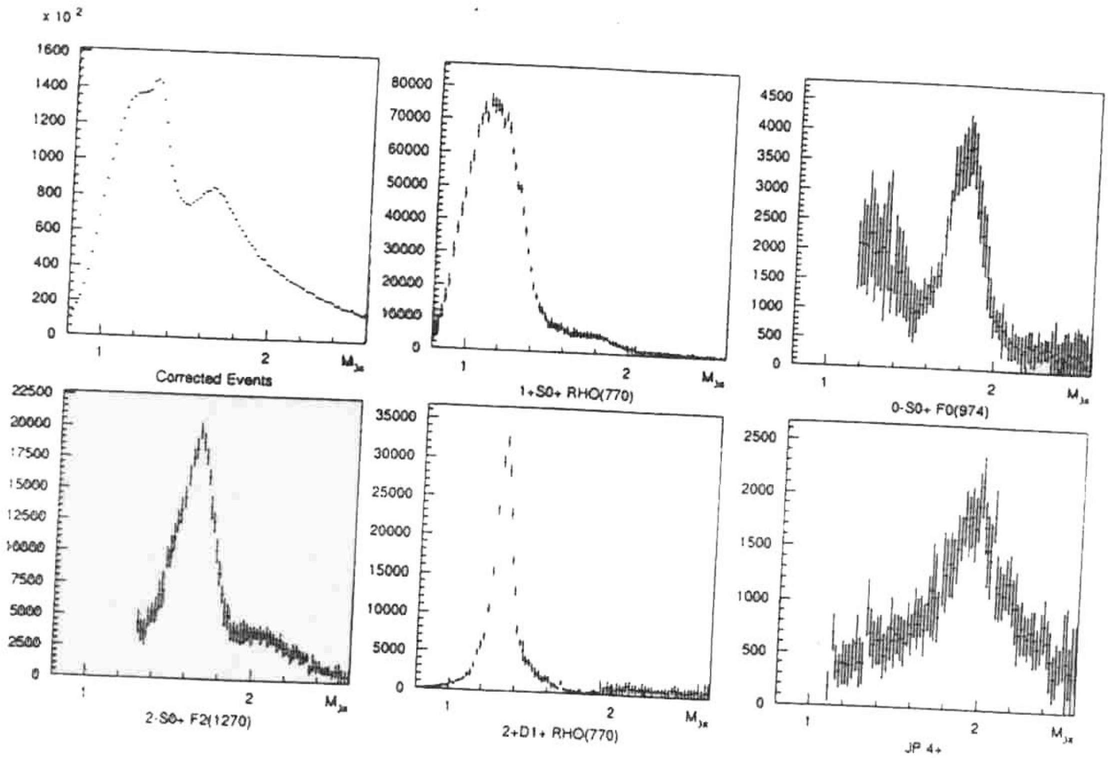


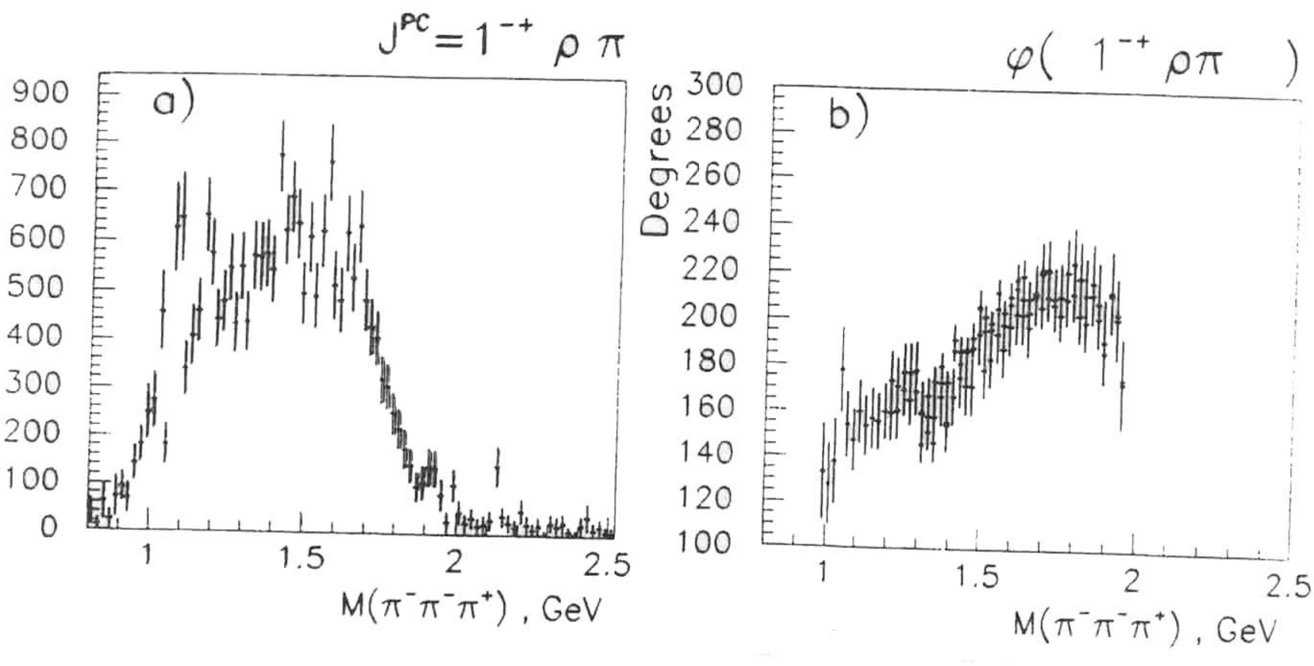
a)Intensity D+. b) Intensity P+. c) Coherency D+ P+. Real d) and Imaginary e) parts of interferece term D+ P+. f) Relative phase D+ / P+

These results point to possible existence of the resonance $I^G(J^{PC})=1^-(1^{-+})$ at M≈1.6÷1.8 ГэВ

The reaction $\pi^- A \rightarrow \pi^+ \pi^- \pi^- A$

VES, 1995, $P_\pi = 37$ GeV
2000, $P_\pi = 28$ GeV





Broad exotic wave $\mathbf{I^G(J^{PC})=1^-(1^{-+})}$ is clearly seen in the channel $\boldsymbol{\rho\pi}$ with very low intensity (~2% of the wave a_2).
There is no evidence of narrow resonance (contrary to E852).

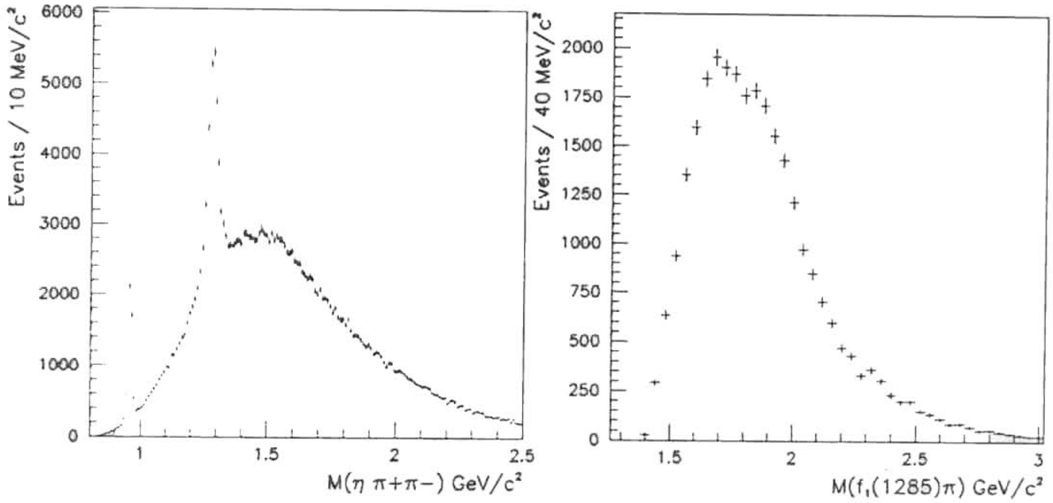
The reaction $\pi^- A \rightarrow f_1 \pi^- A$

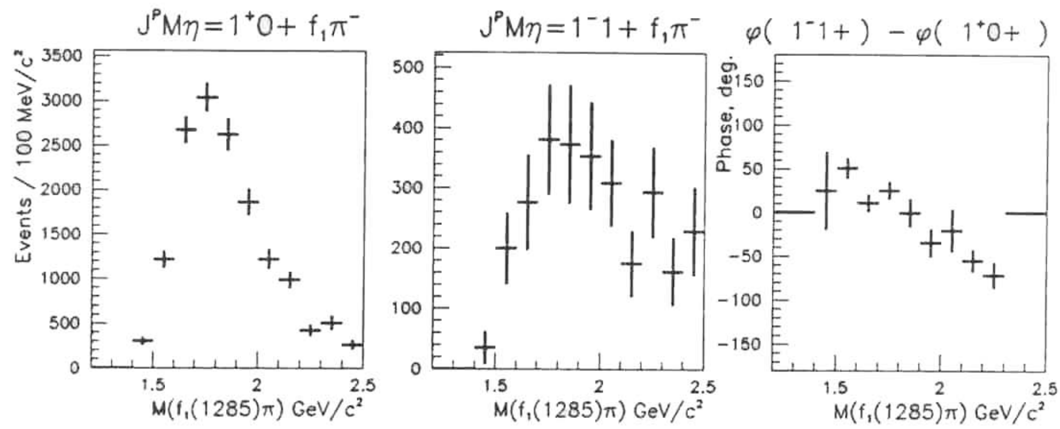
VES, 1995г, $P_\pi = 37$ ГэВ

The reaction under study is $\pi^- A \rightarrow \pi^+ \pi^- \pi^- \eta A$

The resonance f1(1285) was selected in the channel $\eta \pi^+ \pi^-$

$I^G(J^{PC})=0^+(1^{++})$





The most intensive wave $J^P M\eta=1^+0+$ has maximum at $M \approx 1.7$ GeV

No indication to resonances in exotic wave $J^P M\eta=1^-1+$.

Conclusions on exotic wave $I^G(J^{PC})=1^-(1^{-+})$

Exotic wave $I^G(J^{PC})=1^-(1^{-+})$ is clearly seen in a number of reactions:

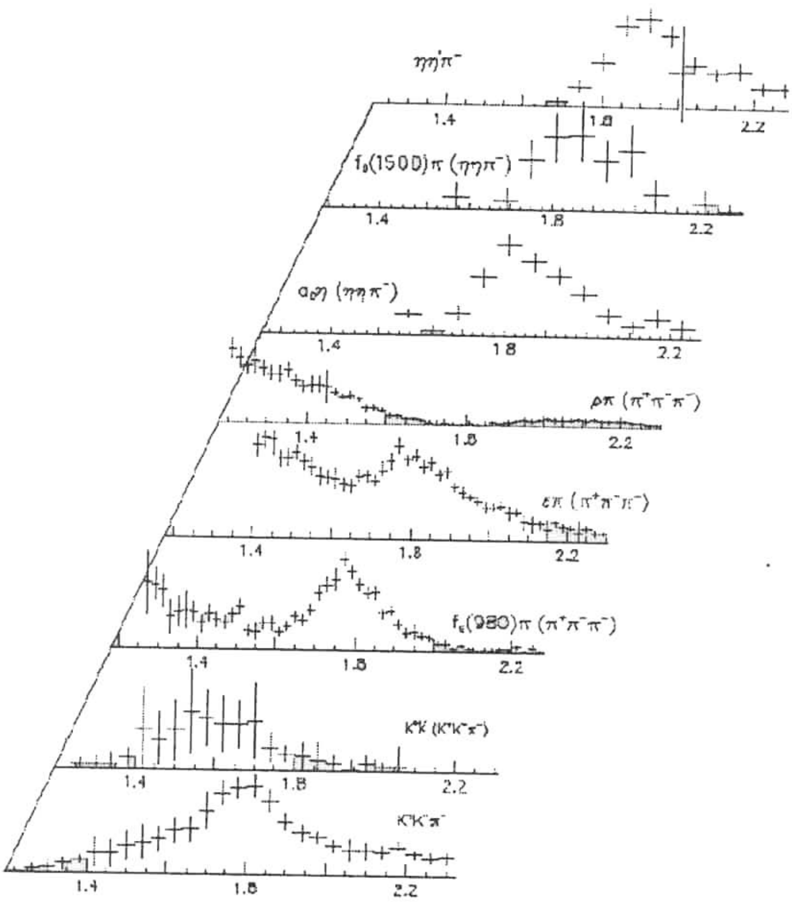
$\pi^- A \rightarrow \eta \pi^- A$
$\pi^- A \rightarrow \eta' \pi^- A$
$\pi^- A \rightarrow b_1 \pi A$
$\pi^- A \rightarrow \rho^0 \pi^- A$
$\pi^- A \rightarrow \eta \pi^- \pi^- \pi^+ A$

There are indications on the existence of exotic resonance in the channel $b_1 \pi$ (and probably in $\eta' \pi^-$) at $M \approx 1.6 \div 1.8$ GeV

The resonance π (1800) $(I^G(J^{PC})=1^-(0^{-+}))$

First observation: Dubna-Milan (at Protvino) in 1981 .

This resonance was studied at VES in different channels



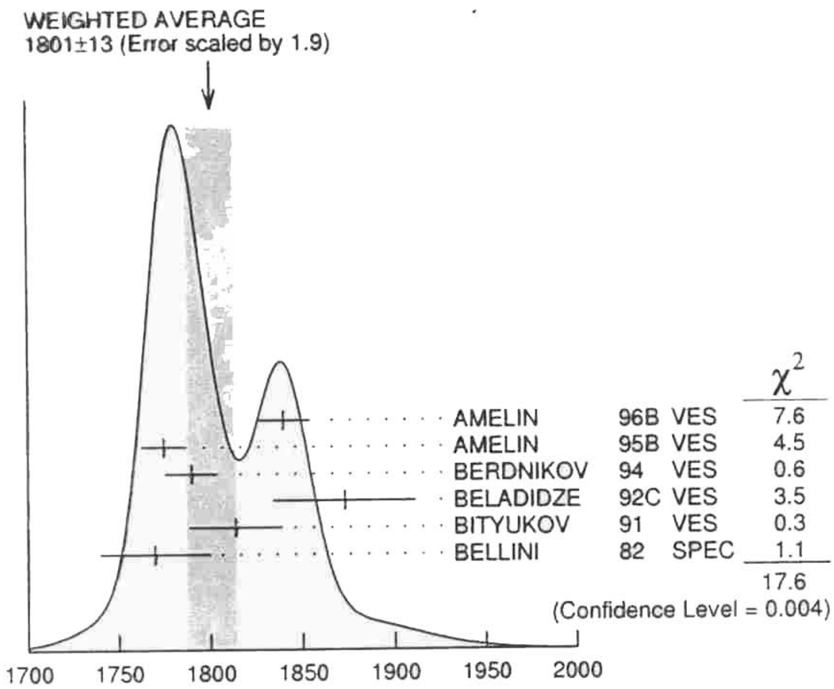
Main features:

- abnormally high branching to $f_0(980)\ \pi$
- suppression of decays to V P
- decay to $f_0(1500)\ \pi$

Last two features are specific for hybrid states.

π (1800) – hybrid or 3^1S_0 ? $K^*\ \bar{K}^*$ molecule ?

One resonance or more?



Conclusions on π (1800)

The resonance π (1800) have some features of hybrid mesons.

There are indications that at M≈1.8 GeV two objects with $I^G(J^{PC})=1^-(0^{-+})$ are seen.

π (1800) and physics of D – mesons

The mass of π (1800) is close to the mass of D – mesons, therefore this resonance can have influence on the decays of D – mesons and on the transitions D <-> $\overline{D}$:

- enhancement of CP violation in D – mesons decays
- enhancement of the thransitions D <-> $\overline{D}$

Study of $\eta\pi^-$ production by pions in the Coulomb field

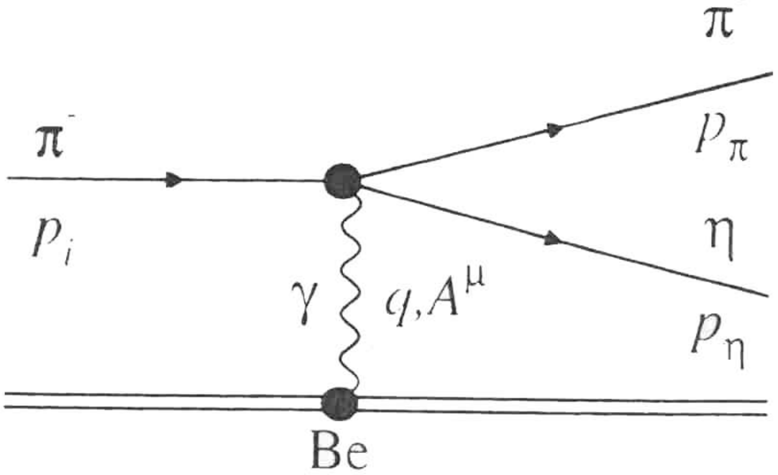
VES, 1997

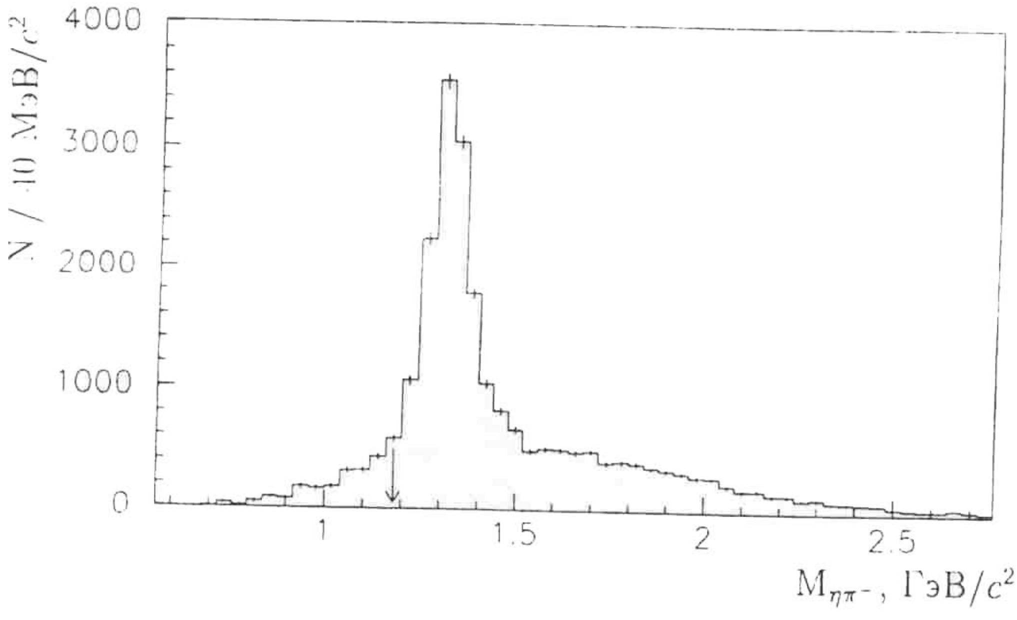
$\pi^- Be \rightarrow \eta\pi^- Be$ $P_\pi = 37$ GeV/c

The subject of the study is the process $\pi^-\gamma \rightarrow \eta\pi^-$
Its amplitude at low $M_{\eta\pi}$ can be expressed as

$$M_{\eta\pi\pi\gamma} = -i\varepsilon_{\mu\nu\rho\sigma}A^\mu p_i^\nu p_\pi^\rho p_\eta^\sigma F_{\eta\pi\pi\gamma}(s,t,u)$$

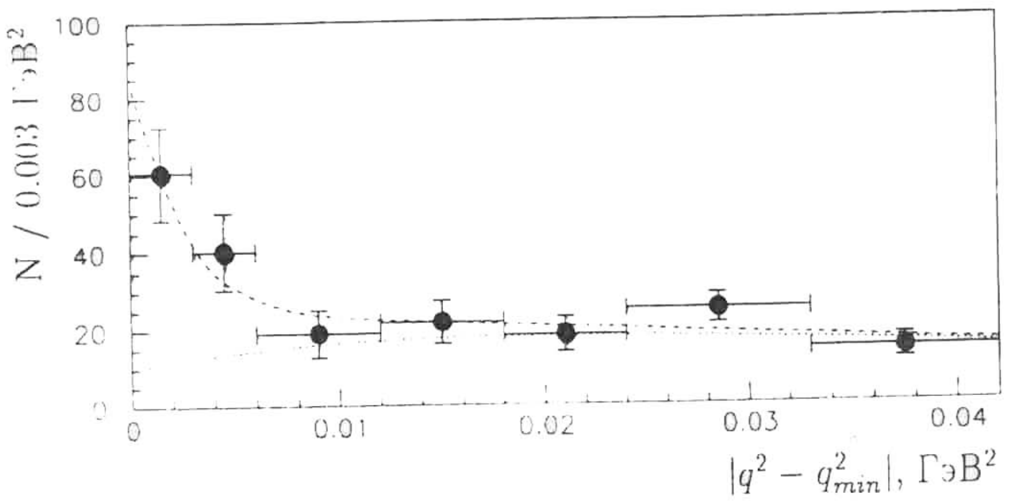
$$F_{\eta\pi\pi\gamma}(0,0,0) = e/(4\pi f_\pi^3)(f_\pi/f_8 \cos\theta_p/\sqrt{3} - f_\pi/f_0 \sqrt{2/3}\sin\theta_p)$$

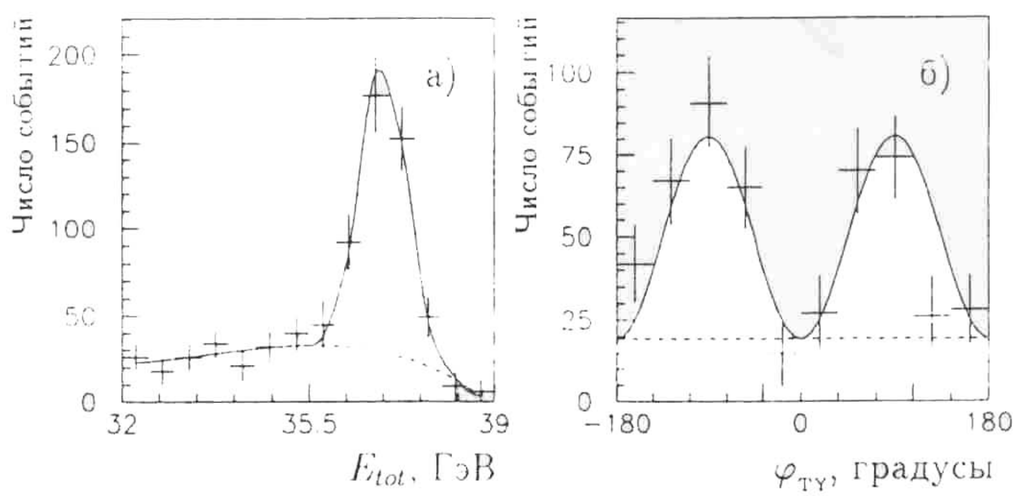




Background subtraction (t-dependence !)

Absolute normalization
(Milan – Dubna results on $\pi^- Be \rightarrow \pi^+ \pi^- \pi^- Be$)





σ_{coul} (m <1.18 GeV) = 145 +- 34 nb

Using this crossection and the width of the decay $\eta \rightarrow \pi\pi\gamma$
we calculated $F_{\eta\pi\pi\gamma}(0,0,0)$ and the effective mass of vector meson m_ρ
within the framework of model for formafactors (B.Holstein)

$$F_{\eta\pi\pi\gamma}(0,0,0) = 6.9 \pm 0.7\ \text{GeV}^{-3}$$

$$m_\rho = 900 \pm 120\ \text{MeV}/c^2$$

Extrapolation to COMPASS

$\sigma \sim$ const

better pomeron dominance
better separation of diffraction from barion excitation
higher crossections for Primakoff reactions

better effective threshold for γ and probably for charged hadrons
($E_{th}/E_{beam\ VES} \approx 0.5$GeV/40 GeV $\rightarrow$ $E_{th}/E_{beam\ COMPASS} \approx 1$GeV/200 GeV)
better precision in E_γ $\quad \sigma(E)/E \sim 1/\sqrt{E}$

better statistics ($DAQ_{VES} = 50\ \mu s \rightarrow DAQ_{COMPASS}$ few μs)

⇩

~~two~~ weeks run at COMPASS
pions
$P \approx 150$ GeV
intensity $\sim 10^7$ /s
target: (LiH ?) $\rightarrow$Be C $\rightarrow$Cu
0.1 int.l. 0.05 int.l.
trigger: diffraction $\rightarrow$ $4 \cdot 10^4$ ev/s $\rightarrow$ **10^{10} events/run**

⇩

revision of light meson spectroscopy
(including radiative and other rare decays)

search for and study of hybrid mesons

$\sim$ 10 Primakoff reactions