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Study of meson resonances in diffractive-like reactions

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for **VES collaboration**

$\pi^- N \rightarrow b_1 \pi N$

$\pi^- N \rightarrow \rho^0 \pi^- N$

$\pi^- N \rightarrow \eta' \pi^- N$

$\pi^- N \rightarrow \eta \pi^- N$

$\pi^- N \rightarrow \eta \pi^- \pi^- \pi^+ N$

$$\mathbf{J^{PC} = 1^{-+}}$$

The VES setup

@ $70\,GeV$ PS of IHEP

Secondary beam of few 10^6/spill π^-s
(+ few % of K^-s)

Typical $P_{beam} \approx 37\,GeV/c$

The setup includes:

- large aperture magnetic spectrometer
  $\approx 0.7\,GeV/c$ magnetic field kick
- lead glass electromagnetic calorimeter
  ~ 1500 cells
- multichannel threshold Čerenkov counter
  π/K separation for $4.2\,GeV/c < p < 20\,GeV/c$
- SCI trigger hodoscope
- VETO surrounding a nuclear target (^9Be)
- high speed data acquisition system
  up to $8\,K$ events, or $10\,MB$, per cycle (9 s).

Reactions to study:

$$\pi^- A \to A^* \, n(\pi^\pm) \, k(K^\pm) \, m(\gamma)$$

Among them

- diffractive - like
- charge exchange

Event selection criteria for a given reaction:

- the event contains a proper number of (identified) fast charged particles
- there is a required number of γs in the EM calorimeter
- the total energy of the registered particles is close to the beam energy ($34 < E_{tot} < 38\, GeV$ is a typical range)

Method to study a final state (mesonic) system:

Partial Wave Analysis

using angular and (when available) Dalitz-plot characteristics of events.

1^{-+} in the $\omega\pi^0\pi^-$ system

$$\pi^- A \rightarrow A\,\omega\,\pi^0\,\pi^-$$

with $\omega \rightarrow \pi^+\,\pi^-\,\pi^0$

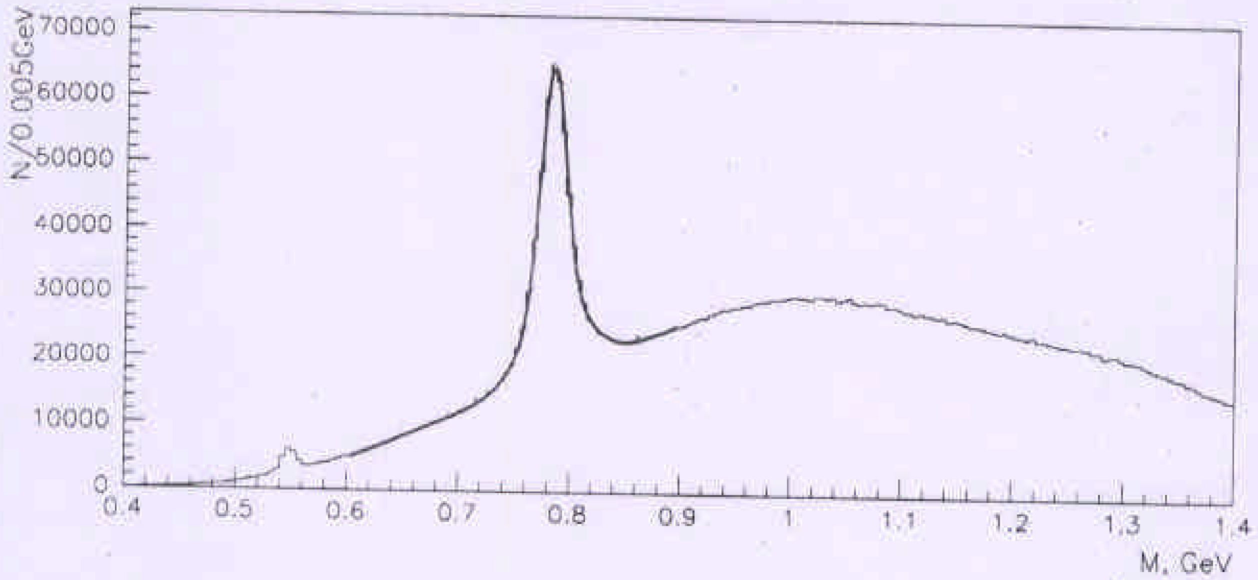
The PWA model

- Illinois PWA method $\rightarrow \Re\rho$, $\Im\rho$;
- isobar decay model;
- non-relativistic Zemach tensor formalism for the decay amplitude to LS state, where L - an orbital angular momentum, S - a total spin;
- relativistic Breit-Wigner isobar description.

Waves notation : $J^P M^\eta L[S](isobar)$

Isobars included in the fit:
in the $\pi^-\pi^0$ channel – ρ^-,
in the $\omega\pi$ channel – b_1, $\rho_1(1450)$, $\rho_3(1690)$.

The ω parameters



$$N_\omega = (361 \pm 1) \cdot 10^3$$

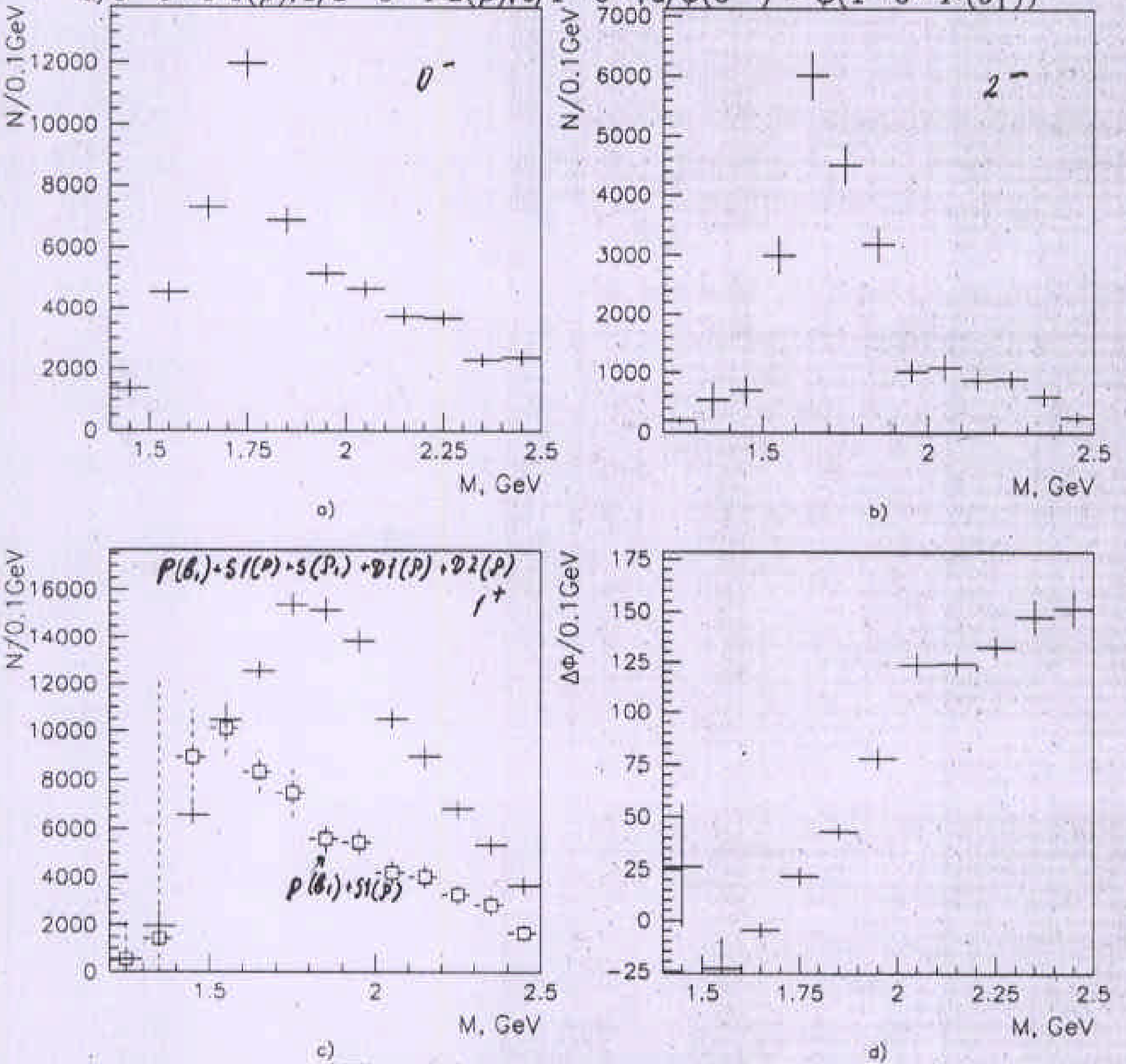
$$M_\omega = 783.37 \pm 0.06 \pm 1\,MeV$$

$$\Gamma_\omega = 26.2 \pm 0.2\,MeV$$

The background in the maximmum $\sim 30\%$.

The PWA results.

a) $0^-0^+P1(\rho)$, b) $2^-0^+P2(\rho)$, c) 1^+0^+, d) $\phi(0^-)-\phi(1^+0^+P(b_1))$



The $\pi(1800)$ parameters:

$$M = 1.737 \pm 0.005 \pm 0.015\,GeV,\ \Gamma = 0.259 \pm 0.019 \pm 0.06\,GeV.$$

The $\pi_2(1670)$ parameters:

$$M = 1.687 \pm 0.009 \pm 0.015\,GeV,\ \Gamma = 0.168 \pm 0.043 \pm 0.053\,GeV.$$

$$Br(\pi_2(1670)^- \to \omega\rho^-) = 0.027 \pm 0.004 \pm 0.01,$$

$$Br(\pi_2(1670) \to \rho_1\pi) < 0.0036,$$

$$Br(\pi_2(1670) \to b_1\pi) < 0.0019 \text{ at } 2\sigma.$$

PWA results: PAN 62 (1999) 445
Available as hep-ex/9810013

The $J^P M^\eta = 1^- 1^+$ with different $LS(isobar)$ were included in the wave set at large momentum transferred squared $(0.08 < -t' < 0.7\,GeV^2)$.
The most significant is

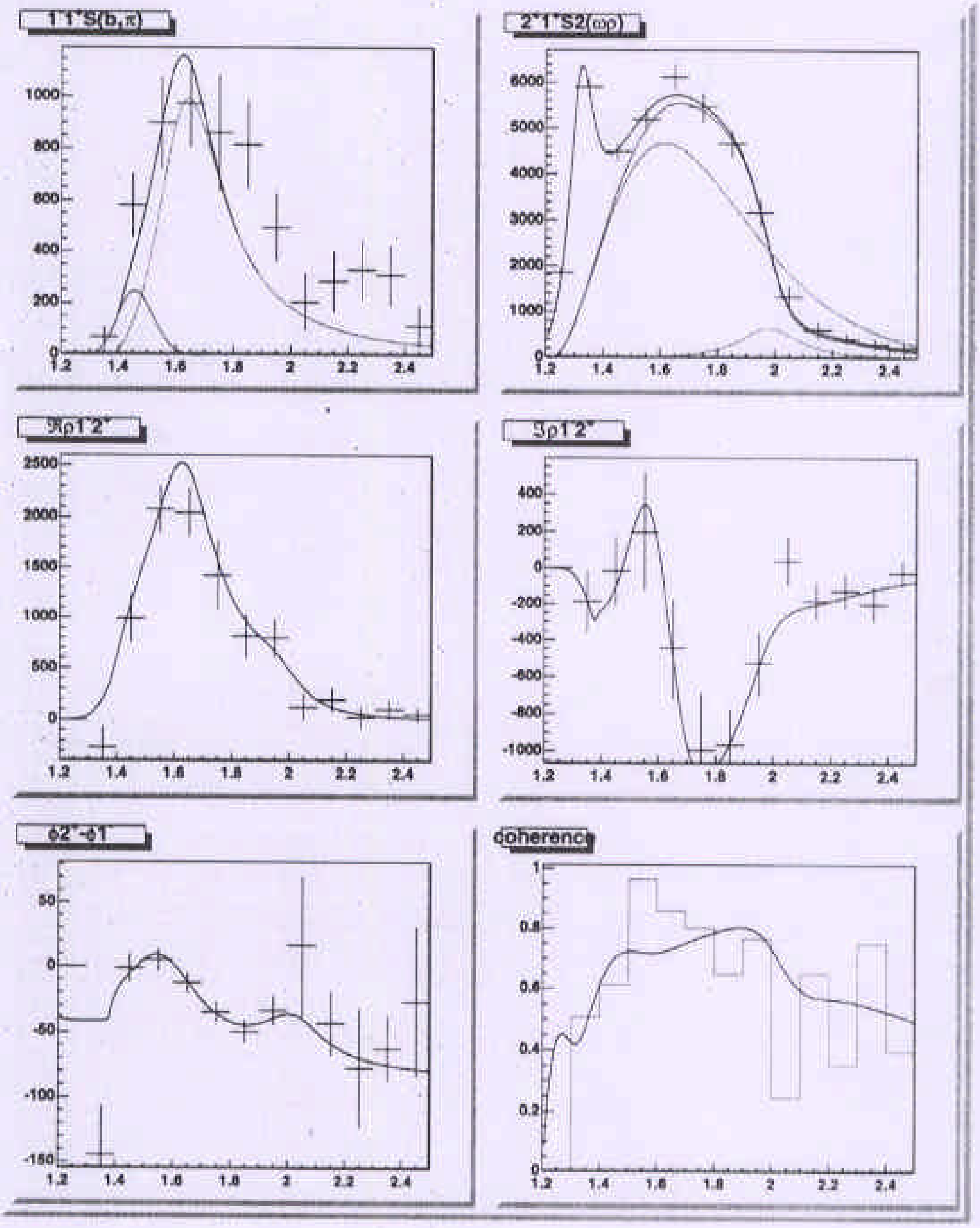
$$1^- 1^+ S(b_1)$$

with its maximum @ $1.6 \div 1.7\,GeV$

To describe its mass dependence a dominant $2^+ 1^+ S 2\rho$ wave with a clear $a_2(1320)$ signal is taken as reference.

Fit to the ρ-matrix elements with models with a (coherent) background and Breit-Wigner resonance(s) in either only one or both waves.
The fit favours a resonance behaviour of the $1^- 1^+ S(b_1)$ wave, although the fit parameters are not well constrained due to uncertainty in the reference wave model.

An example of the fit to the $1^{-}1^{+}S(b_1)$ and $2^{+}1^{+}S2(\rho)$ waves production.



1^{-+} in the $\pi^+\pi^-\pi^-$ system

PWA model

- Illinois PWA method $\rightarrow \Re\rho, \Im\rho$;
- isobar decay model;
- relativistic covariant helicity formalism for decay amplitudes;
- relativistic Breit-Wigner isobar description.

The previous observations of a signal @ $1.6\,GeV$:
VES(1992) Yu.Gouz, XXVI ICHEP, Dallas
$M \approx 1.6\,GeV$, $\Gamma \approx 0.2\,GeV$
E852(1997)
$M = 1593 \pm 8^{+20}_{-47}\,MeV$, $\Gamma = 168 \pm 20^{+150}_{-12}\,MeV$

The analyzed data

Events were sorted into two samples in t' and each into $0.02\,GeV$ bins in $M_{3\pi}$.
Within bin the angular distributions and the Dalitz-plot were fitted.

t' samples:

$$t' < 0.06\,GeV^2$$

$$0.06 < t' < 0.7\,GeV^2$$

The density matrix expansion in terms of the eigenvalues:

$$\rho^{ij} = \sum_{k=1}^{d} V_k^i * V_k^j * e_k = \rho_L^{ij} + \rho_S^{ij};$$

where:

$$\rho_L^{ij} = V_1^i * V_1^j * e_1$$

$$\rho_S^{ij} = \sum_{k=2}^{d} V_k^i * V_k^j * e_k$$

- The breakdown of the full rank ρ-matrix:
  – "coherent" term ρ_L is a matrix product of eigenstate of a leading eigenvalue;
  – "incoherent" term ρ_S accumulates all the rest.

The known resonances (a_1, a_2, $\pi_2(1670)$, $\pi(1800)$) are well described by ρ_L

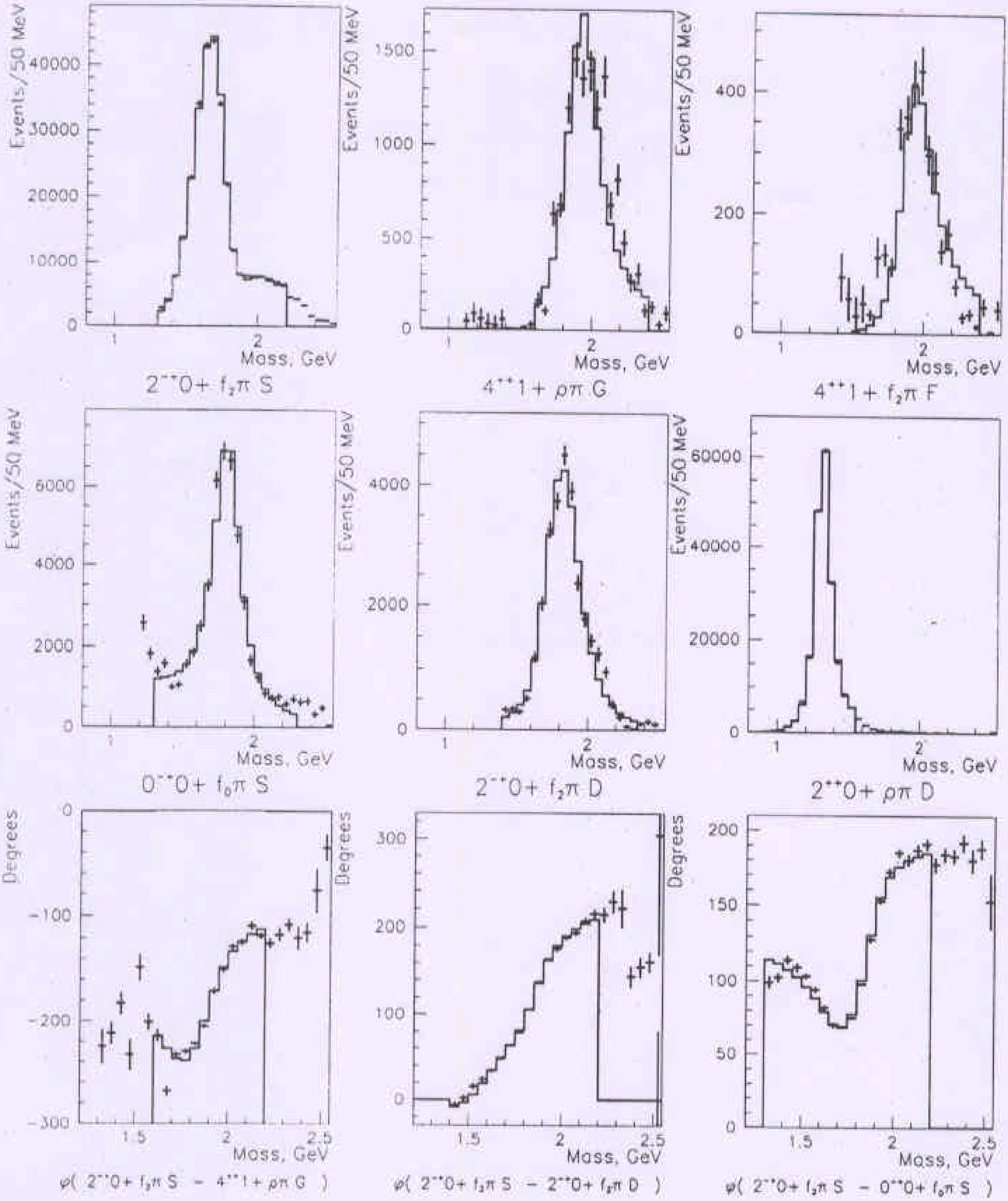
A wide ($\Gamma \approx 0.3\, GeV$) small signal is observed at $M \approx 1.6\, GeV$ for $0.06 < -t' < 0.7\, GeV^2$ in the coherent part ρ_L of the density matrix in the $1^-1^+P\rho$ wave.

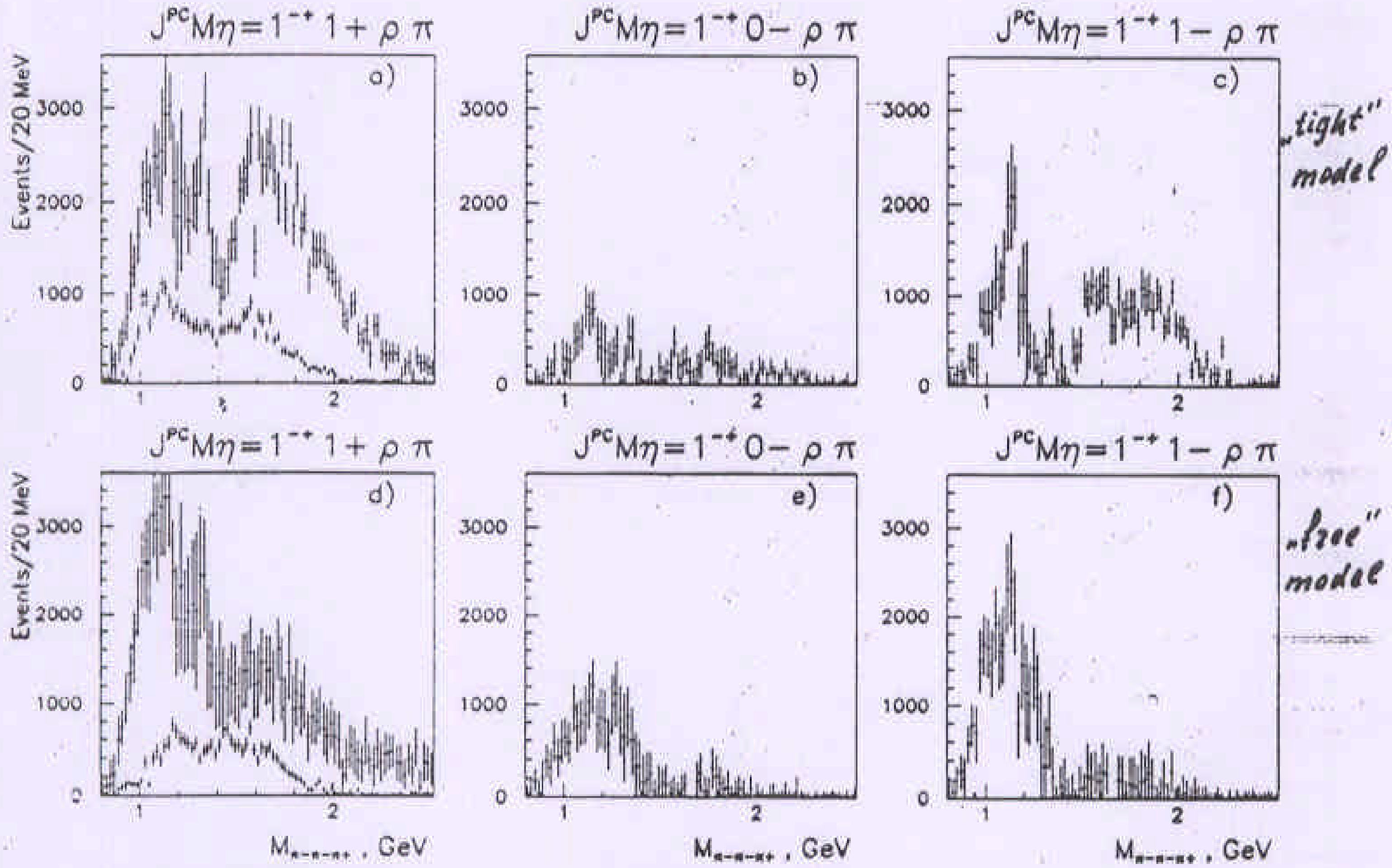
The signals of well established resonances
(**a_2(1320), π_2(1670), π(1800), a_4(2050)**)
are clearly seen.

In addition there are signals of not well established resonances (**a_1(1700), π_2(2100), a_3(1850)**).

The dominant waves and interference terms were fitted by the model with smooth background and one or two BW resonance in each wave. This model gives good description of observed structures.

The global fit of well established resonances was used to fix the absolute phases of these waves and to estimate the phase of exotic wave $\mathbf{J^{PC} = 1^{-+}}$.


Events/50 MeV
Mass, GeV
2⁻⁺0+ $f_2\pi$ S
4⁺⁺1+ $\rho\pi$ G
4⁺⁺1+ $f_2\pi$ F
0⁻⁺0+ $f_0\pi$ S
2⁻⁺0+ $f_2\pi$ D
2⁺⁺0+ $\rho\pi$ D
Degrees
φ(2⁻⁺0+ $f_2\pi$ S - 4⁺⁺1+ $\rho\pi$ G)
φ(2⁻⁺0+ $f_2\pi$ S - 2⁻⁺0+ $f_2\pi$ D)
φ(2⁻⁺0+ $f_2\pi$ S - 0⁻⁺0+ $f_0\pi$ S)



Within our PWA scheme ("free model") we do not observe neither narrow J^{PC} $M\eta=1^{-+}1+$ resonance at M~ 1.6 GeV with positive naturality exchange nor big signals in negative naturality exchange (contrary to BNL results).

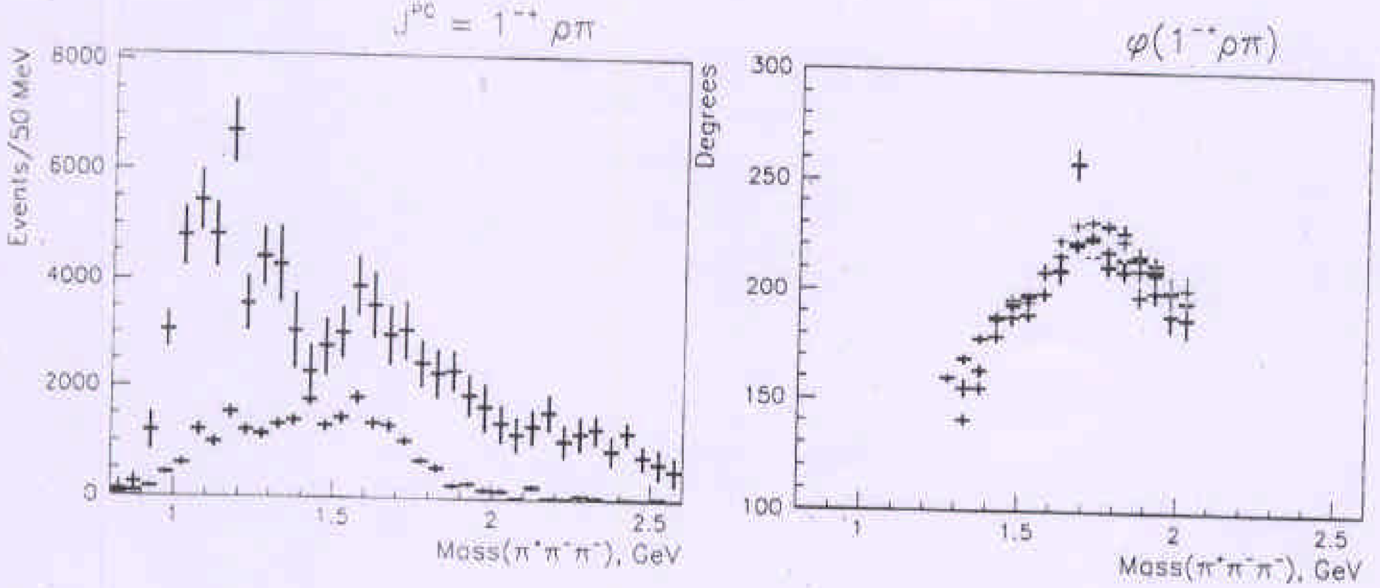
Instead the signal in the wave $J^{PC}=1^{-+}$ is broad.

Narrow signal at M~ 1.6 GeV in the wave J^{PC} $M\eta=1^{-+}1+$ and 1^{-+} signal in negative naturality exchange could be obtained in "tight model" with imposed coherency of dominant waves.

We attribute that rather large structure to the previous PWA model imperfection, namely to its "tightness".

In favour of this : in the "old" scheme the intensities of the 1^{-+} are comparable for "unnatural" and "natural" exchange sectors, which looks unlikely for a real signal contrary to an analyses artifact.

In the new model the "unnatural" exchange production is strongly ($\sim$ factor of 10) suppressed, similarly to the $\eta'\pi$ system.



The "coherent fraction" of the wave J^{PC} $M\eta=1^{-+}1+$ is very stable at the variation of PWA model .

To get the reference phase we used the results of mass-dependent fit of the most intensive waves by known BW resonances and phase space-like backgrounds.

The shape of the 1^{-+} signal and its phase rising at $M \approx 1.6$ GeV do not exclude the presence of the resonance in this region.

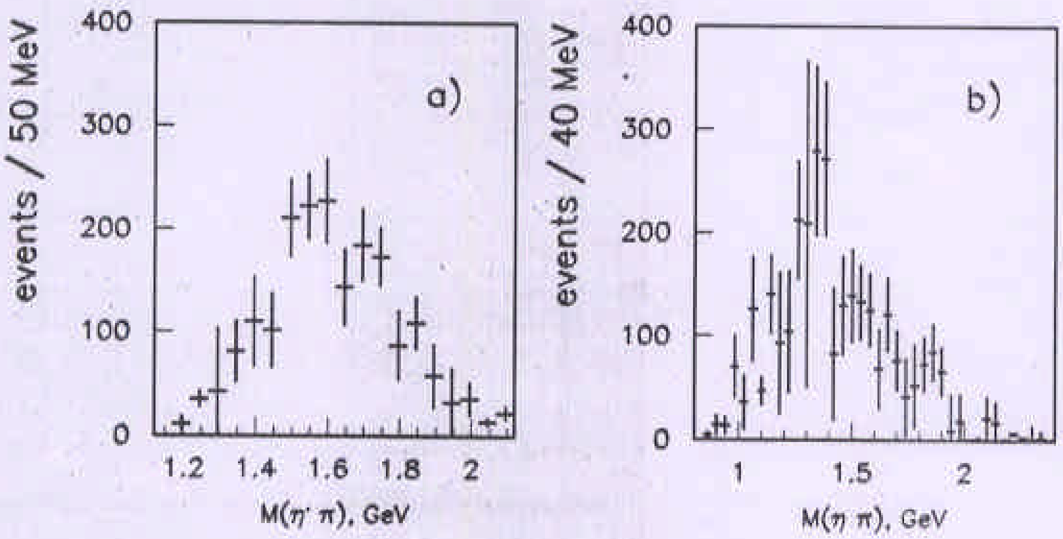
Due to its smallness and broadness this signal taken alone can not be interpreted without ambiguity.
At the same time clear bumps are seen at $M \approx 1.6$ GeV in $\eta'\ \pi$ and $b_1\ \pi$ channels. These observations taken alltogether point to the possible existence of exotic resonance at $M \approx 1.6$ GeV.

$q\bar{q}$ - exotic $J^{PC} = 1^{-+}$ wave in $\eta'\pi^-$, $\pi^+\pi^-\pi^-$ and $\omega\pi^0\pi^-$ systems

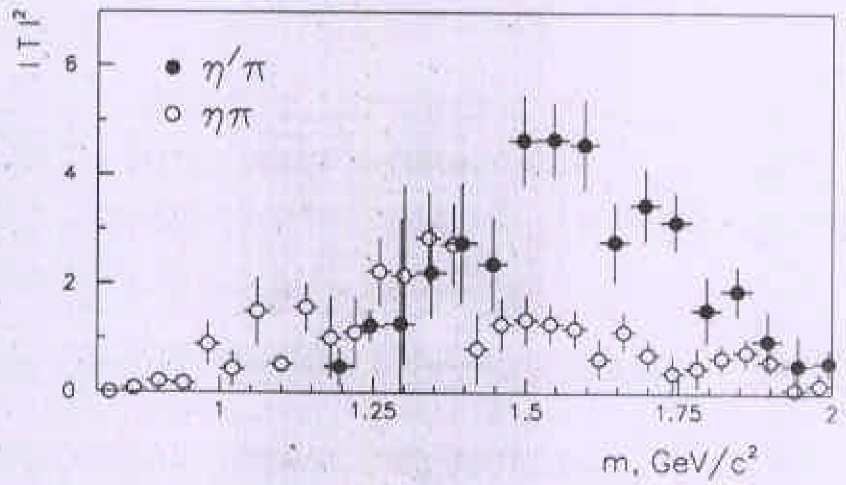
$\eta'\pi^-$ system PWA features

Phys.Let. **B313** (1993), 276

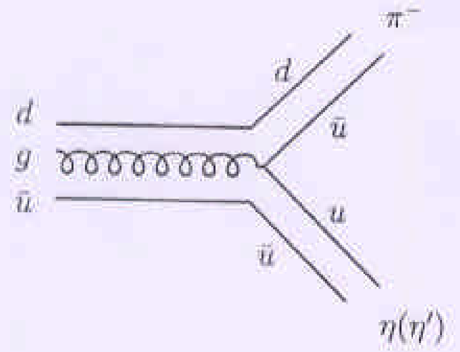
- discrete ambiguities in two spinless particles PWA
- P-wave state of the system has these exotic $J^{PC} = 1^{-+}$ numbers
- a dominance of the $J^P M^\eta = 1^- 1^+$ wave at $\sim 1.6\,GeV$
- remarkable excess of the P-wave over that in $\eta\pi^-$ system



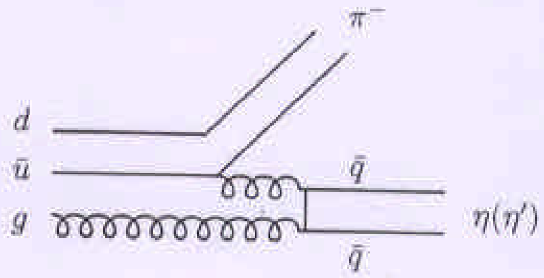
1^-1^+ wave intensity in the $\eta'\pi^-$(a) and $\eta\pi^-$ (b) systems



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



a)



b)

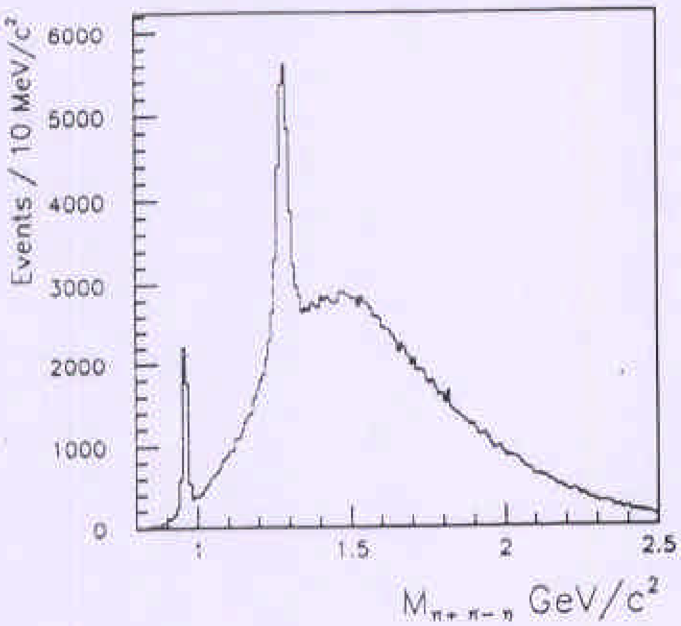
Diagrams of charged $q\bar{q}g$ - system transition to $\pi^-\eta(\eta')$

- The a) diagram is forbidden for $L = 1$ $\pi^-\eta(\eta')$
- The b) diagram is allowed for both but strengthen for $\pi^-\eta'$ w.r.t. $\pi^-\eta$

The conclusion was:
A system with valence gluon ($q\bar{q}g$) plays a large rôle in the formation of $\eta'\pi^-$ at $1.6\,GeV$

$$\pi^- A \rightarrow \pi^+ \pi^- \pi^- \eta A$$

$$N = 8.4 * 10^4$$



$f_1(1285)_{\eta\pi^+\pi^-}$ π^-

$a_0(980)_{\eta\pi}$ $\rho(770)$

$a_2(1320)_{\eta\pi}$ $\rho(770)$

$a_2(1320)_{\pi^+\pi^-\pi^-}$ η

$a_1(1260)_{\pi+\pi^-\pi^-}$ η

$a_0(980)_{\eta\pi}$ $f_2(1270)$

The states with $J^P M\eta = 1^+0+,\ 2^-0+,\ 3^+0+$ **are dominant.**

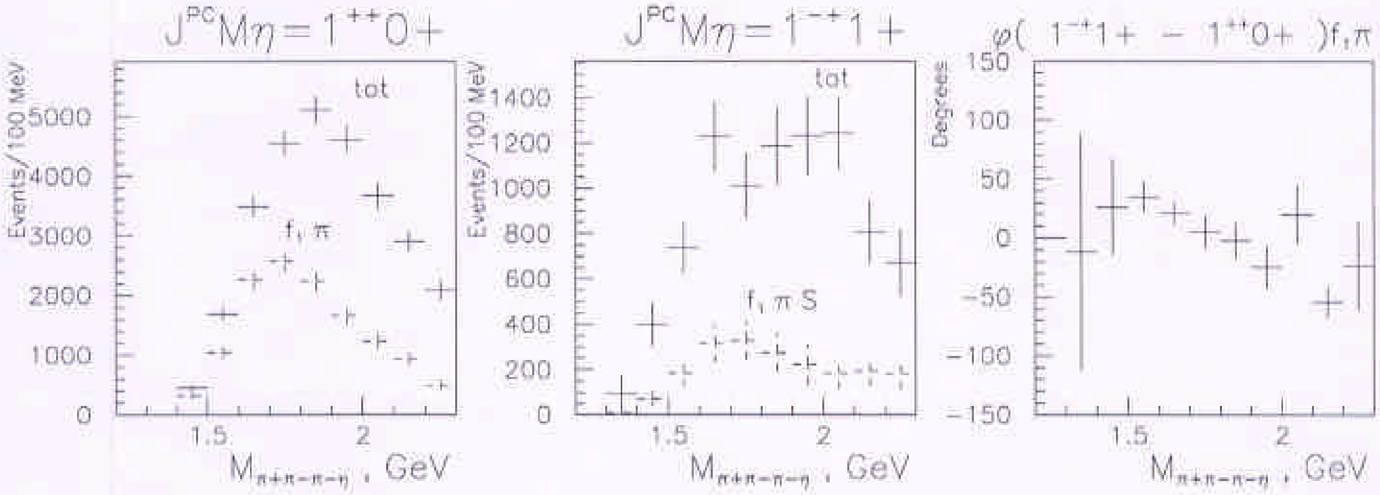
Other states $J^P M\eta = 1^-1^+,\ 2^+1+,\ 3^-1+$ **are less significant.**

The wave $I^G J^P = 1^-1^-$ **(exotic quantum numbers) is clearly seen in** $f_1(1285)\pi^-$ **channel.**

Exotic wave $J^{PC}M\eta = 1^{-+}1+$ in $\eta\,\pi^+\pi^-\pi^-$ channel

The sum of all waves with $J^{PC}M\eta = 1^{-+}1+$ is very broad without clear signal at M≈ 1.6 GeV.

The channel $f_1\,\pi$ (S-wave) is the most intensive one among exotic waves $J^{PC}M\eta = 1^{-+}1+$. The intensity of this wave does not demonstrate clear resonance signals. The phase difference $\varphi\ (1^{-+}1+\ -\ 1^{++}0+)\ f_1\,\pi$ is flat .



Th description of $f_1\,\pi$ signal by resonance+background is very ambiguous and we do not include this channel to global fit of exotic waves $J^{PC}M\eta = 1^{-+}1+$.

The results on the wave $J^{PC} = 1^{-+}$ in $\mathbf{b_1 \pi}$, $\mathbf{\eta` \pi}$ and $\boldsymbol{\rho \pi}$ channels point to the existence of resonance at $M \approx 1.6$ GeV.

Combined fit of all three channels gives following parameters:

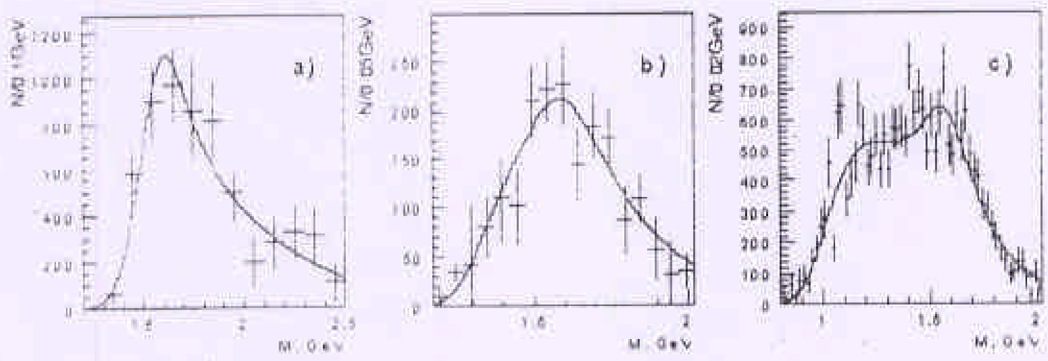
M = 1.56 +- 0.06 GeV

Γ = 0.34 +- 0.05 GeV

The relative branching ratios are:

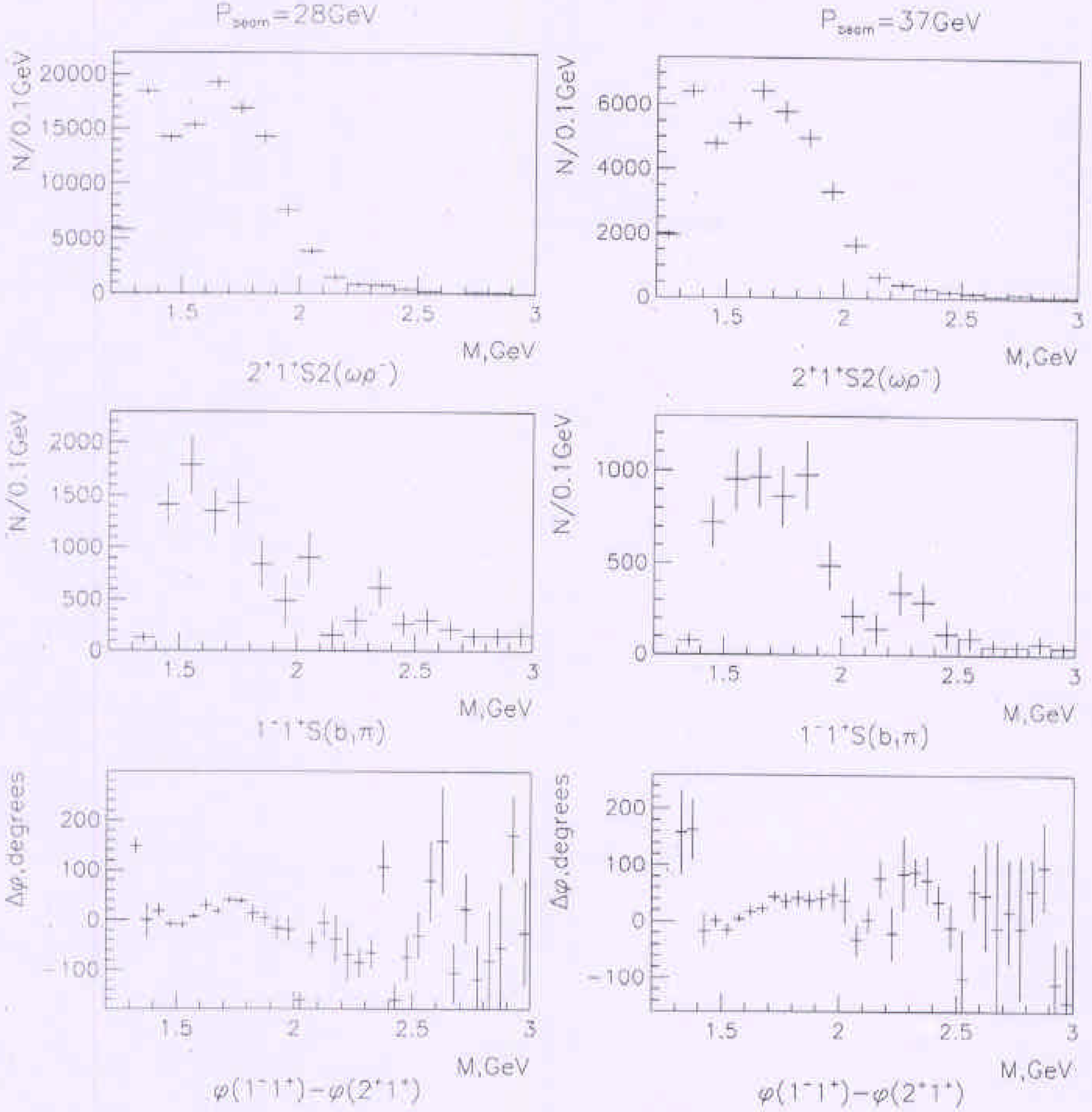
Γ(η` π) : Γ(b₁ π) : Γ (ρ π) = 1 : 1.0 +-0.3 : 1.5 +- 0.5

Abnormally high branching to **η` π** as well as diffractive-like energy dependence indicate that this resonance is hybrid meson.



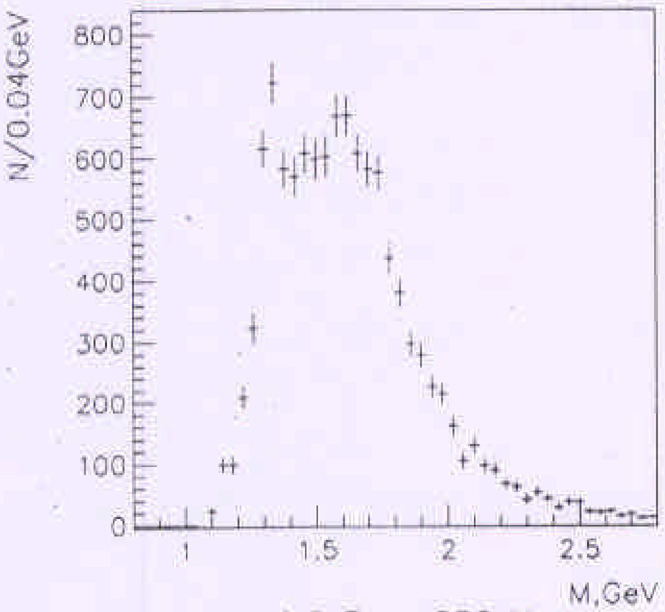
$b_1 \pi$ $\eta` \pi$ $\rho \pi$

Comparison of 2^{++} and 1^{-+} waves in $\omega\pi^-\pi^0$ channel at p_{beam}= 28 GeV and p_{beam}=37 GeV

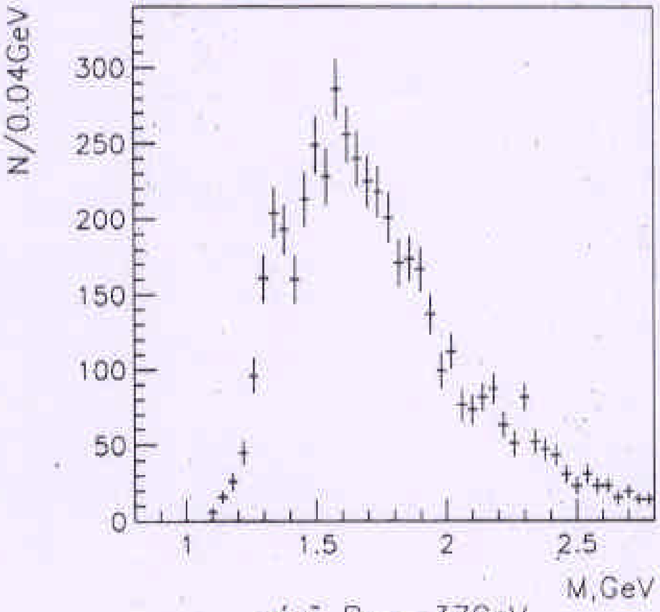


The waves 2^{++} and 1^{-+} as well as relative phase of these waves are very similar at p_{beam}=28 GeV and p_{beam}=37 GeV. The relative intensity of 1^{-+} wave to 2^{++} wave is much higher at p_{beam}=37 GeV than at p_{beam}=28 GeV.

Comparison of 2^{++} and 1^{-+} waves in $\eta' \pi^-$ channel at p_{beam}= 28 GeV and p_{beam}=37 GeV



$\eta'\pi^-$, P_{beam}=28GeV



$\eta'\pi^-$, P_{beam}=37GeV

The same growing of 1-+ wave with energy is seen in $\eta' \pi^-$ channel. This observation confirms that in **$b_1 \pi$** and $\eta' \pi^-$ channels we see one and the same signal.

From p_{beam}=28 GeV to p_{beam}=37 GeV the ratio

$R=\sigma(\pi^- N \to \hat{\rho}^- (1600)\, N) / \sigma(\pi^- N \to a_2^- N)$

grows by factor R_{37}/R_{28} = 1.5 +- 0.2

Taking beam momentum dependence of **a_2** production as $\sigma(\pi^- p \to a_2^- p) \sim p_{beam}^{-0.61 \pm 0.05}$ (Bromberg et al., 83) we can estimate momentum dependence of $\hat{\rho}^-$ (1600) production:

$\sigma(\pi^- N \to \hat{\rho}^- (1600)\, N) \sim p_{beam}^{0.7 \pm 0.3}$

This very unusual momentum dependence points to pomeron exchange dominance.

Conclusion

The exotic $J^{PC}=1^{-+}$ wave with $M^{\eta} = 1^{+}$ is studied in $b_1 \pi$, $\rho^0 \pi^-$, $\eta' \pi^-$, $\eta\ \pi^-$ and $\eta\ \pi^- \pi^- \pi^+$ systems.

A structure @ 1.6 GeV is observed in first three channels ($b_1 \pi$, $\rho^0 \pi^-$, $\eta' \pi^-$):

M = 1.56 +- 0.06 GeV

Γ = 0.34 +- 0.05 GeV

$\Gamma(\eta' \pi) : \Gamma(b_1 \pi) : \Gamma(\rho \pi) = 1 : 1.0 \pm 0.3 : 1.5 \pm 0.5$

This signal could be regarded as strong candidate to a hybrid bound state .