

Glueballs and hybrids in the 1-2 GeV region: an experimental overview

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Workshop on e^+e^- in the 1-2 GeV region
Alghero, 12.09.03

Outline of the talk

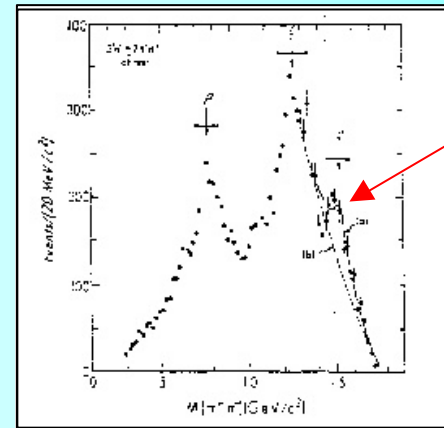
- Theoretical discussion of glueballs and hybrids properties: previous talk
- Experimental observations for the identification of the most important candidates for such structures
 - Glueballs: 0^{++} sector
 - $f_0(1500)$, $f_0(1300)$, $f_0(1710)$
 - Footprints can be seen "by eye" in Dalitz plots bands
 - Hybrids: 1^{-+}
 - $?_1(1400)$, $?_1(1600)$
 - Some hints about exotic structures in the vector sector

The problem of the scalar mesons sector

- The data collected so far show that there are far too many scalars in the ground 0^{++} nonet for all of them to be compatible with a quarkonia structure:
 - Two $a_0(980)$ and $a_0(1450)$ isovectors instead of one only;
 - At least four isoscalar instead of two:
 - $f_0(400-1200) ??$, $f_0(980)$, $f_0(1300)$, $f_0(1500)$ and (maybe) $f_0(1710)$
 - $K^*(1430)$ fills the $\frac{1}{2}$ state
- A number of open problems still exist:
 - What is ??
 - Clear signatures of its existence
 - $f_0(980)$ and $a_0(980)$ nature still uncertain
 - 4-quarks (? radiative decays favor this hypothesis) or $\bar{K}K$ molecular states
 - Probably (at least) one glueball enters the spectrum of the scalar mesons
 - Main signatures for a glueball:
 - Flavor blindness in its decay modes
 - Absence of coupling to real photons

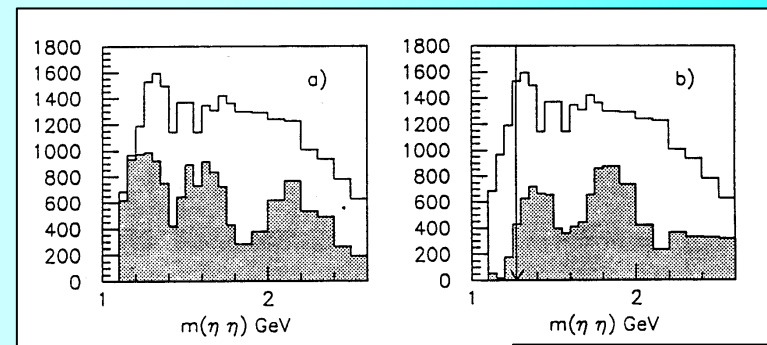
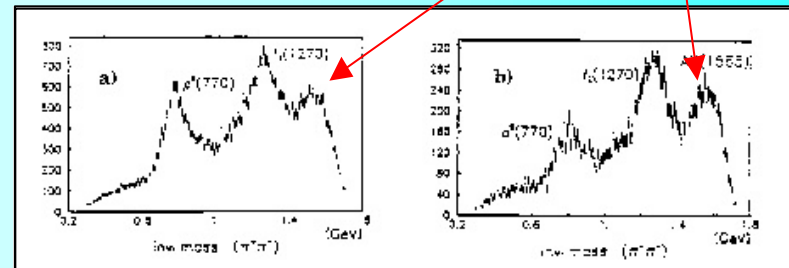
$f_0(1500)$: first observations

- 1st observation in $3\pi^0$, $2\pi^-\pi^+$ annihilation, bubble chamber data (1983, 1989)
 - Does not decay in $K\bar{K}$, in contrast to $f_2'(1525)$
 - Spin 0 hypothesis cautiously suggested
 - 2^{++} identified later
 - $f_2(1565)$: \underline{NN} quasi-bound state?
- GAMS (1983): scalar state decaying in $\pi\pi$ and $\pi\pi'$ at 1590 in $\pi^-\rho^+$ known as $G(1590)$
 - Not decaying to $\pi\pi$
 - Slightly higher mass and width (~ 250 MeV)



Deuterium Bubble chamber, 1983

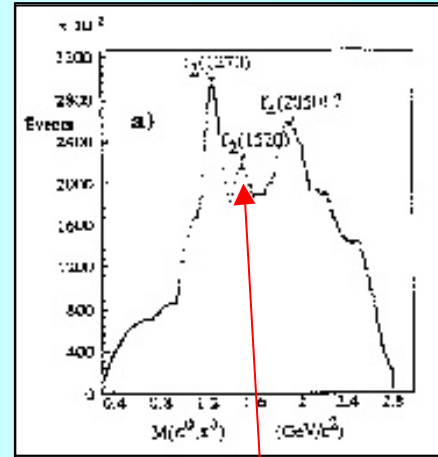
ASTERIX Experiment, 1989



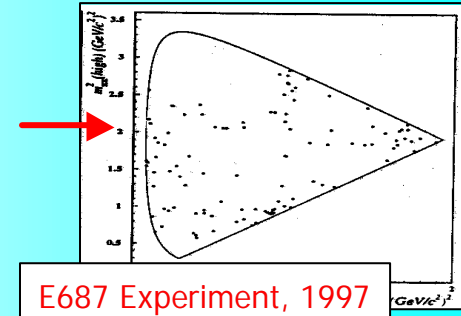
GAMS Experiment, 1983

$f_0(1500)$: further confirmations in ?? and ?? at higher energies

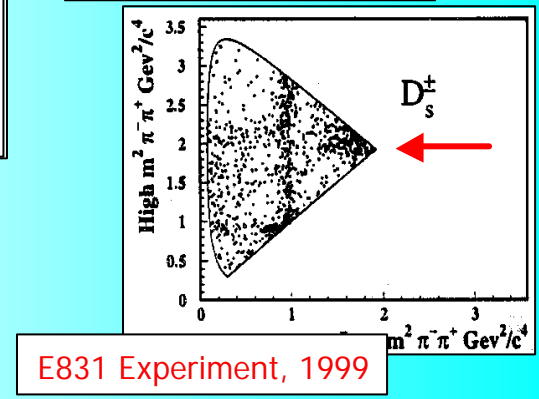
- E760, Fermilab (1992)
- E687, Fermilab (1997)
 - $D_s^+ \rightarrow \pi^+ \pi^+ \pi^-$
 - $\pi^+ \pi^-$ decay
 - $m = 1475, \pm 100$ MeV
 - $c \rightarrow s$ Cabibbo favoured:
 - $f_0(1500)$ must have a non vanishing ss component in its wave function and therefore decay also to KK



E760 Experiment, 1992

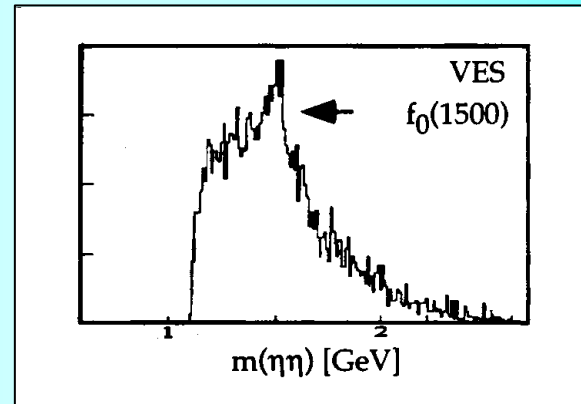


E687 Experiment, 1997



E831 Experiment, 1999

- VES (1996):
 - $\pi^+ p \rightarrow \pi^+ \pi^+ \pi^-$, $\pi^+ \pi^+ \pi^-$ '
 - @ 36 GeV/c
 - Production of $\rho(1800)$ decaying to $f_0(1500) \pi^-$, and $f_0(1500) \rightarrow \pi^+ \pi^-$, $\pi^+ \pi^+ \pi^-$

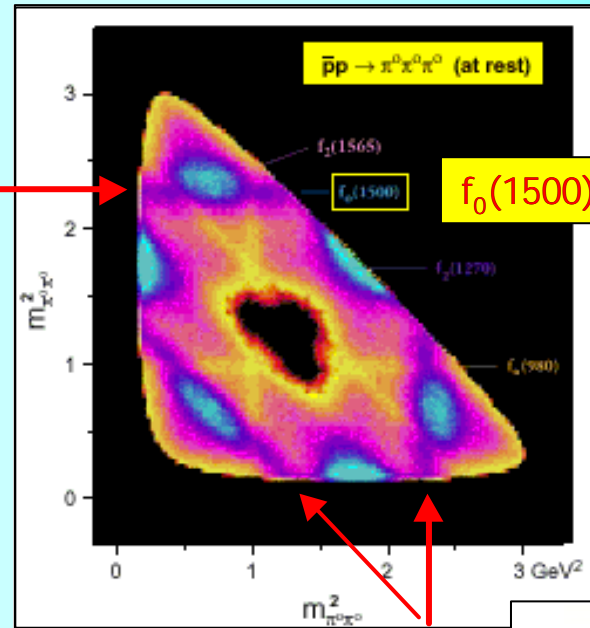


VES: $\pi^+ p \rightarrow \pi^+ \pi^+ \pi^-$

$f_0(1500)$: confirmations in ?? and ?? decay channels – CRYSTAL BARREL

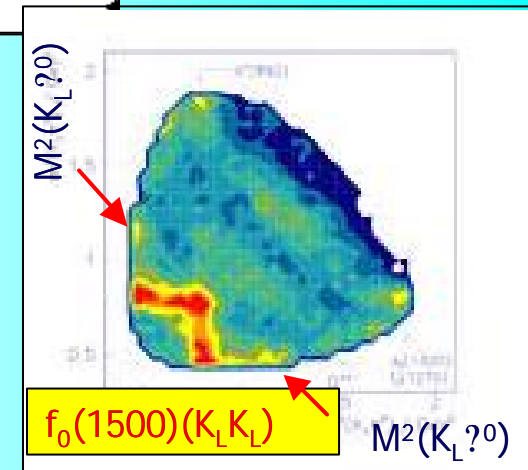
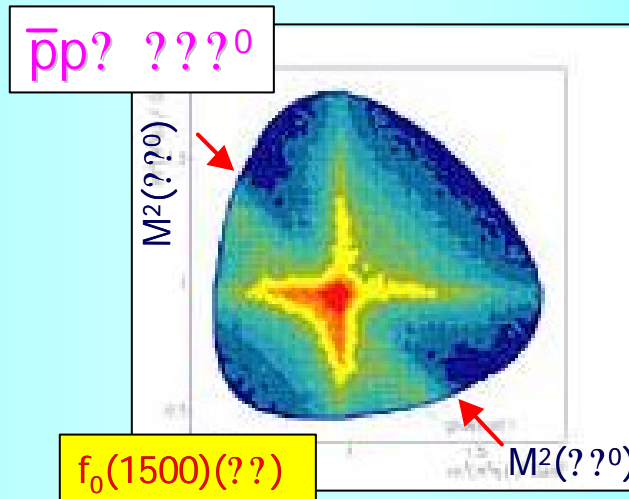
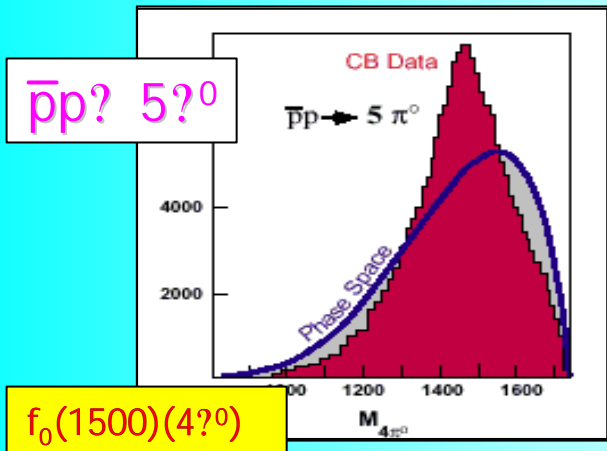
- **CRYSTAL BARREL:**

- $\bar{p}p$ annihilation at rest
 - ?? decay (1992)
 - $\pi^0\pi^0$ decay (1995)
 - 4π decay observed
 - $K_L K_L$ decay observed
- Confirmed by recent data in flight at different \bar{p} momenta between 1350 and 1940 MeV/c



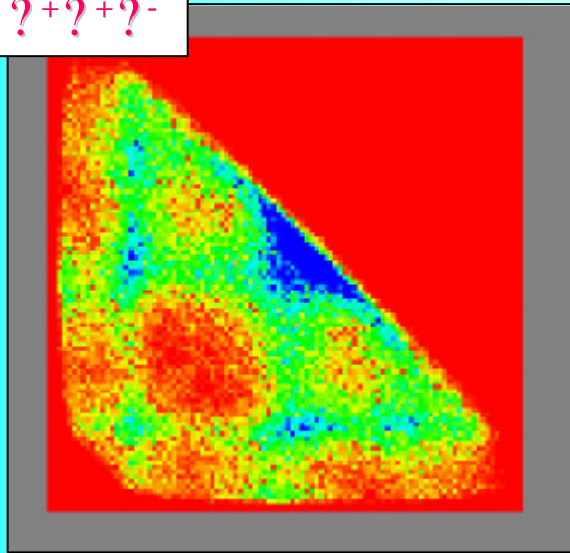
$\bar{p}p? \pi^0\pi^0\pi^0$

$\bar{p}p? K_L K_L \pi^0$

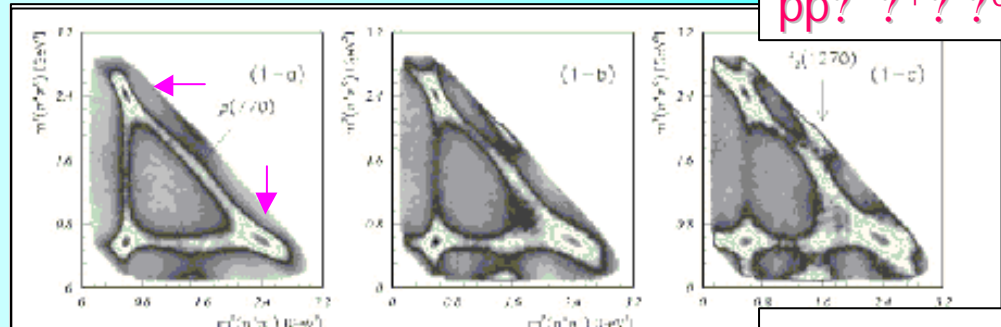


$f_0(1500)$: confirmations in $\pi\pi$ and $K\bar{K}$ decay channels - OBELIX

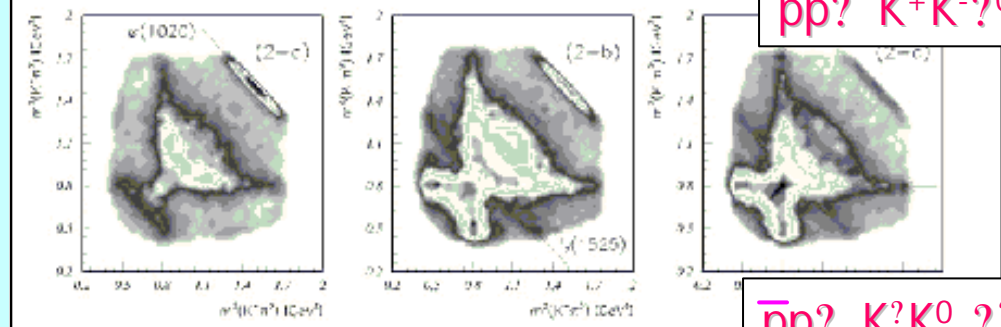
$\bar{n}p \rightarrow \pi^+\pi^-\pi^0$



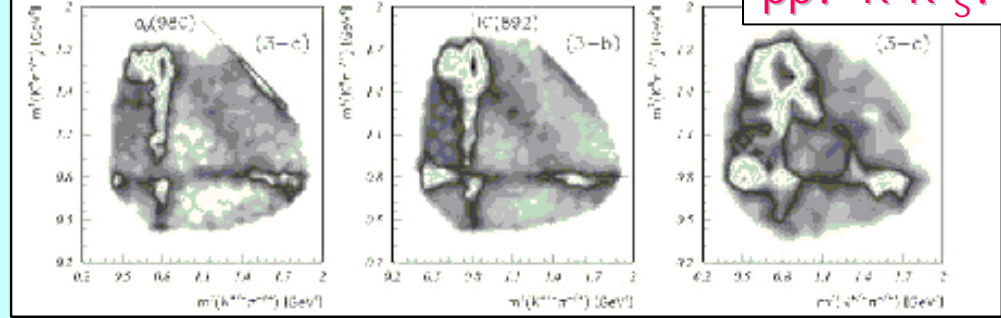
$\bar{p}p \rightarrow \pi^+\pi^-\pi^0$



$\bar{p}p \rightarrow K^+K^-\pi^0$



$\bar{p}p \rightarrow K^*K^0\pi^0$



OBELIX:

- $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ annihilation at rest at different target densities
- $\bar{n}p \rightarrow \pi^+\pi^-\pi^0$ annihilation in flight with $p_n < 400$ MeV/c
- $\bar{n}p \rightarrow 3\pi^+2\pi^-$ annihilation in flight

Liquid H₂

NP gas H₂

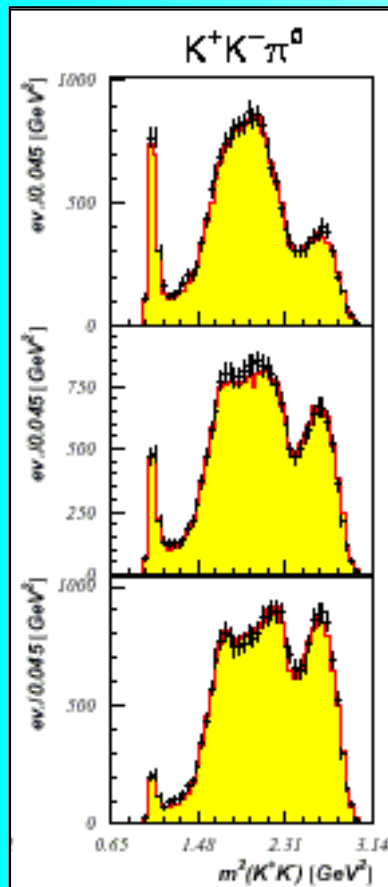
Low pressure H₂

? P wave content rise ?

$f_0(1500)$: observations in kaonic channels

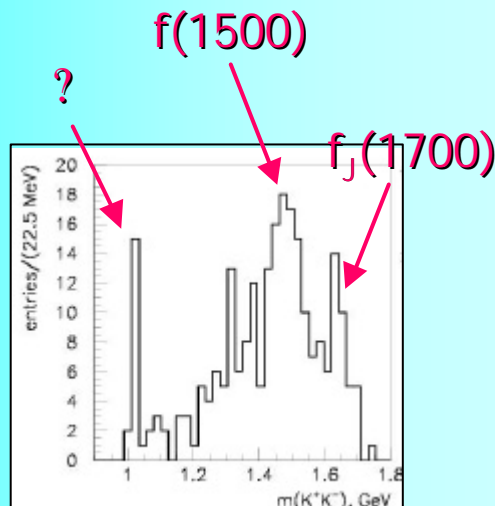
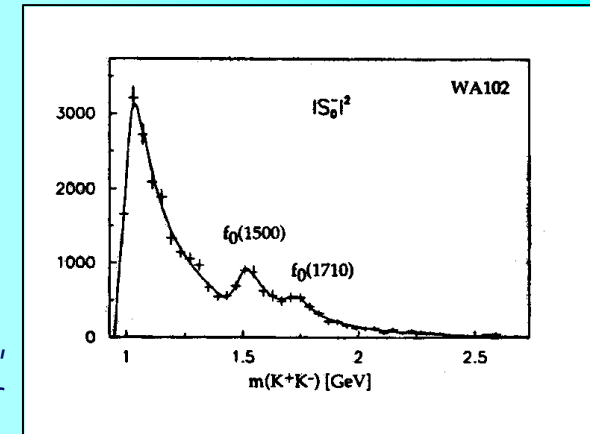
- **OBELIX, CERN:**

- $\bar{p}p \rightarrow K^+K^- \pi^0$
- $\bar{n}p \rightarrow K^+K^- \pi^+$



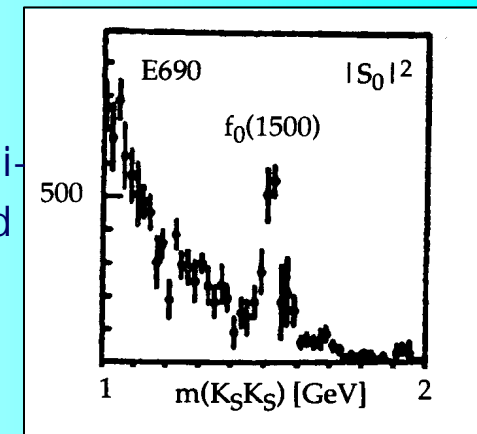
- **WA102, CERN:**

- pp central production at 450 GeV
 - K^+K^- decay
 - $K_S K_S$ decay
 - $\eta^+ \eta^-$ & $\eta^0 \eta^0$ decays confirmed, and this mode is favored over $\bar{K}K$
 - $f_0(1500)$ does not seem to have a large $\bar{s}s$ component



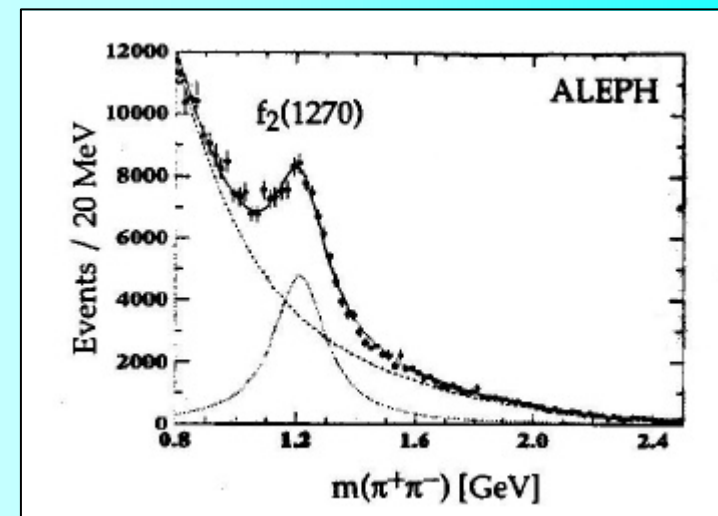
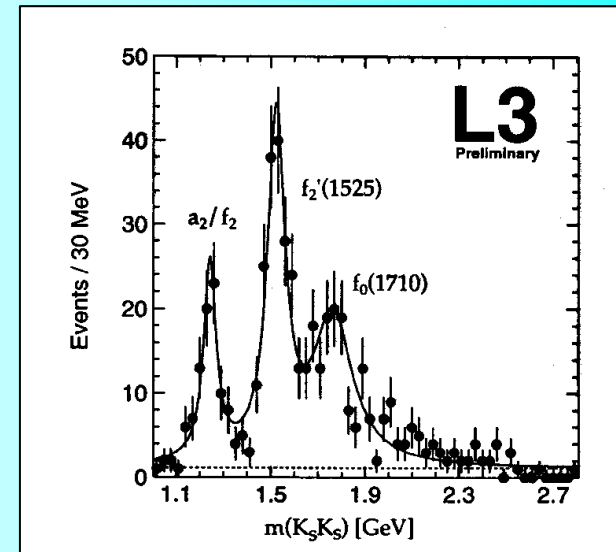
- **E690, Fermilab:** pp central production at 800 GeV:

- $pp \rightarrow K_S K_S pp$
 - Twofold ambiguity between 0^{++} and 2^{++} above 1550 MeV



$f_0(1500)$ in ?? interactions?

- ?? interactions are anti-gluon filters since gluons do not couple directly to ?
 - glueball production should be suppressed in these reactions
- LEP: L3 (1999)
 - 3 peaks on $K_L K_L$ observed below 2 GeV
 - $f_2(1270) + a_2(1320) + f_2'(1525)$
 - $f_0(1500)$ is missing
- LEP: ALEPH (1999)
 - In ??? $\pi^+\pi^-$ no $f_0(1500)$ is observed
 - $\Gamma_{??} \approx 0.17$ KeV
 - To be compared with a typical width of a $\bar{n}n$ scalar meson like $f_0(1370)$: 4 KeV



$f_0(1500)$: is it really flavor blind?

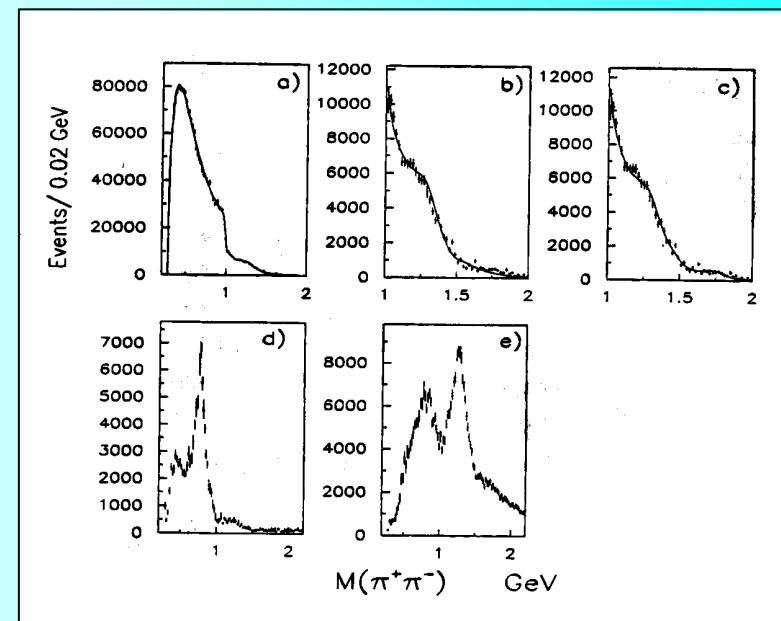
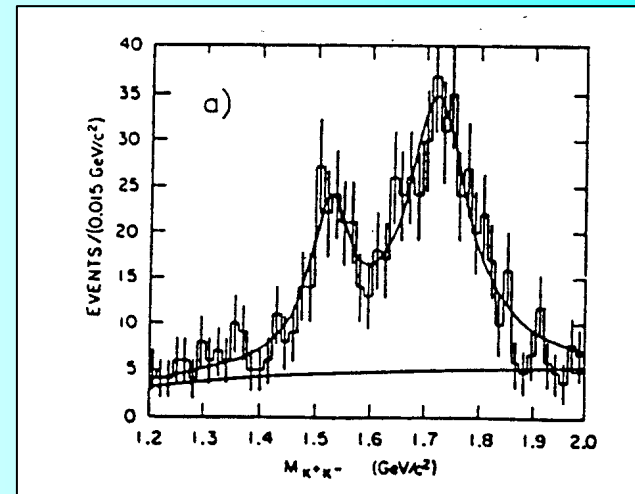
- Its absence in ?? collisions suggests a large gluonic component in the wave function
- Important to check its branching ratios for the decay into mesons with different flavor content

$$R \approx \frac{B.R.(f_0(1500) \rightarrow K\bar{K})}{B.R.(f_0(1500) \rightarrow ??)}$$

- **OBELIX:**
 - 0.24 ± 0.04 1S_0
 - 0.30 ± 0.04 3P_1
- **WA102:** $(0.33 \pm 0.03 \pm 0.07)$
- **CRYSTAL BARREL:** (0.138 ± 0.038)
 - A value of the ratio less than 0.3 indicates that a possible $\bar{s}s$ component is not dominant

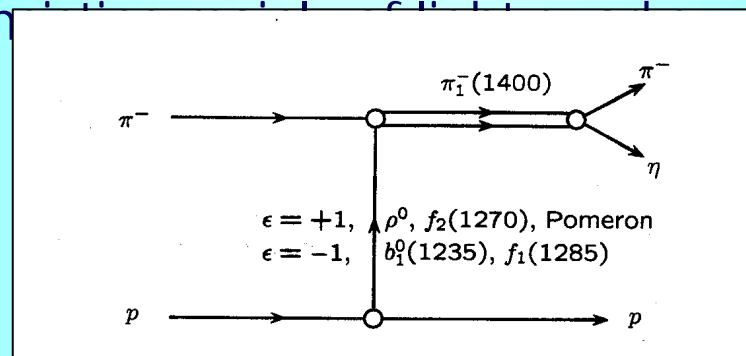
A second glueball candidate? $f_0(1710)$

- Long debate about its spin: is it 0^{++} or 2^{++} ?
 - MARK III & WA102 (observations in $\pi\pi$, and K^+K^-) confirm that it is a scalar structure
- Structure?
 - $\bar{s}s$ meson in the scalar nonet still missing
 - Expected beyond 1600 MeV
 - Should have favoured decays into mesonic channels
 - Not observed in $\bar{p}p$ annihilations: in agreement with $\bar{s}s$ structure due to OZI?
 - Not observed by CRYSTAL BARREL



Exotic mesons produced in π^-p interactions

- Several experimental hints at the presence of **two** exotic 1^- mesons have been found in π^-p interactions at intermediate energies studied at KEK, IHEP/Protvino and BNL
 - The produced mesons are mediated by Reggeon exchanges with recoil nucleons, so they can be either isoscalar or isovector, compared with the following



- Confirmation of the observations in pp annihilation reactions

The 1^{-+} exotic: general features

- $J^{PC} = 1^{-+}$ are exotic quantum numbers not accessible to simple quarkonia states
- Several models predict the presence of a $(n\bar{n}+g)$ meson in the (1.4?2) GeV range
 - Predicted masses and decay branching ratios are fairly model dependent
 - **Flux tube model:**
 - Mass around 1.9 GeV
 - Dominant decays: $b_1(1235)?$, $f_1(1285)?$
 - **Di-quark cluster model:**
 - Mass around 1.4 GeV
 - Dominant decay: ??
 - **QCD sum rule calculations:**
 - Mass in the (1.4?1.6) GeV range
 - Dominant decay: ??

The lightest 1^{-+} state: $\rho_1(1400)$

First observations

- First observation by **GAMS (IHEP-CERN)** in the reaction $\pi^- p \rightarrow \pi^0 n$ @ 100 GeV/c
 - Forward-backward asymmetry of angular distributions in the $\pi^0 n$ system suggest a swing in the $a_2(1320)$ region
 - Strong interference between even/odd waves
 - PW analysis: D_0 and P_0 waves are resonant close to $a_2(1320)$
 - Dominant decay channel for both $a_2(1320)$ and $\rho_1(1400)$ is $b_1(1235)\pi$, due production via unnatural parity exchange
- Second observation by **E179 at KEK** in the reaction $\pi^- p \rightarrow \pi^+ p$ @ 6.3 GeV/c
 - Observed in the $\pi^+ p$ system
 - PW analysis: D_+ and P_+ waves peak in the $a_2(1320)$ region:
 - f_2 and ρ exchange play a dominant role
 - Both the waves have a resonant behavior

The lightest 1^{-+} state: $\rho_1(1400)$ the observations by BNL-E852

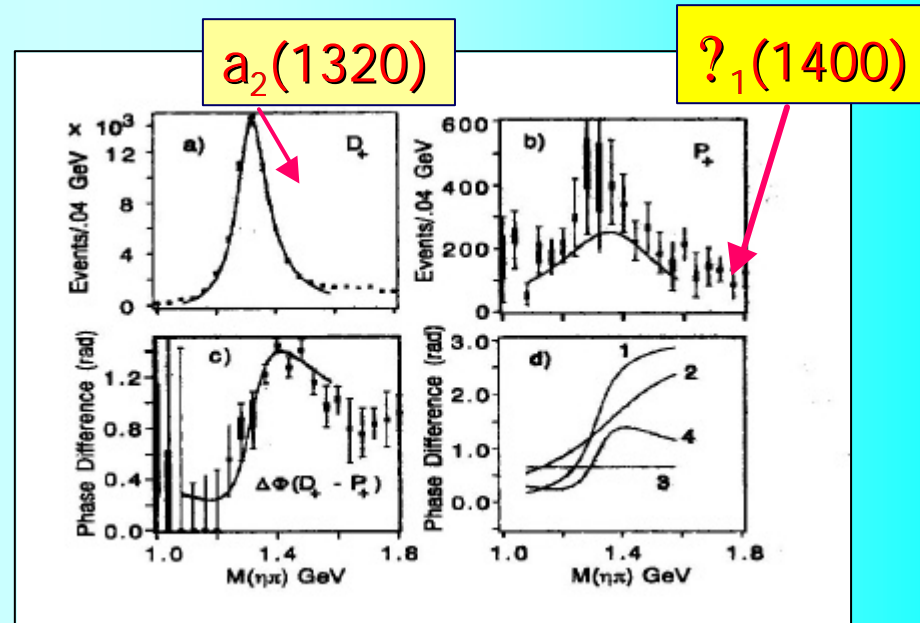
- Systematic study of the reactions

$\rho^0 p \rightarrow \rho^+ p$ and

$\rho^0 p \rightarrow \rho^0 n$ @ 18 GeV/c

- The ρ^0 spectrum shows a strong $a_2(1320)$ signal with a typical peripheral production

- The relative phase motion of P_+ wave with respect to $a_2(1320)$ requires the presence of a resonant P wave $\rho_1(1400)$ state



$$M = (1359^{+16+10}_{-14-24}) \text{ MeV},$$

$$\Gamma = (314^{+31+9}_{-29-66}) \text{ MeV}$$

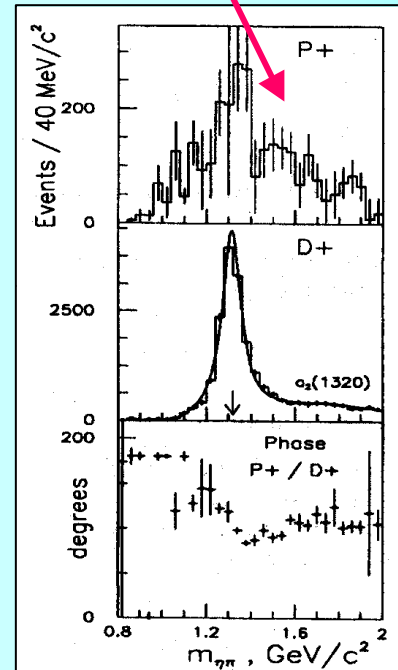
The lightest 1^-+ state: $\omega_1(1400)$ the observations by VES

- Systematic study of the reactions

$\omega^-N?$ $\omega^-\omega N$, $\omega^-\omega'N$

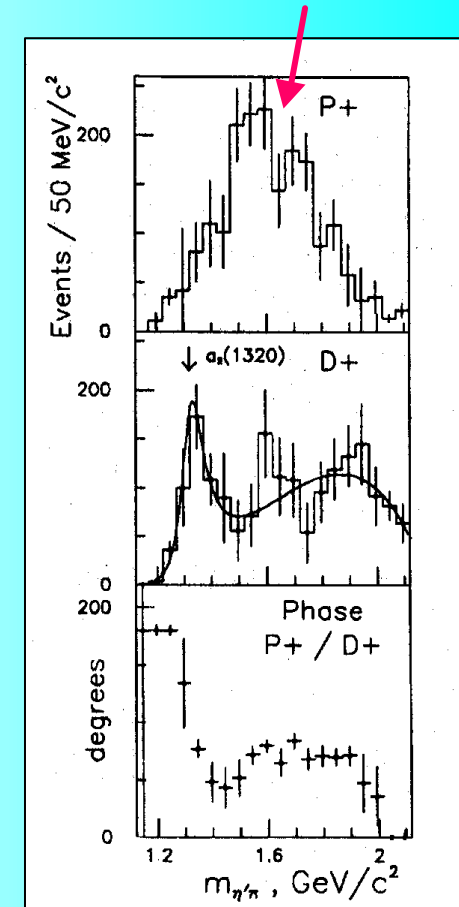
@ 37 GeV/c

- The $\omega_1(1400)$ signal is present in the $\omega\omega$ channel but it is small and with large errors
- The phase motion is similar to that of BNL data
- They don't claim for any significant 1^-+ state to have been observed in the 1.3-1.4 GeV region



??

Broad bump peaking at about 1.6 GeV



ω'?

The lightest 1^{-+} state: $\rho_1(1400)$ the observations by CRYSTAL BARREL

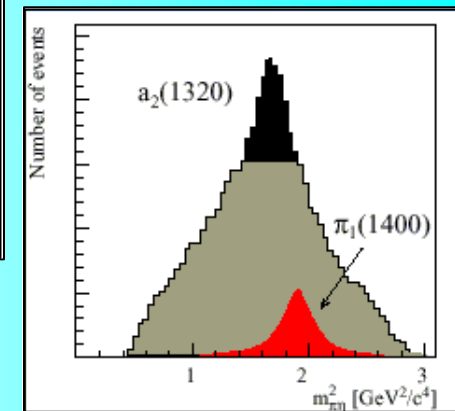
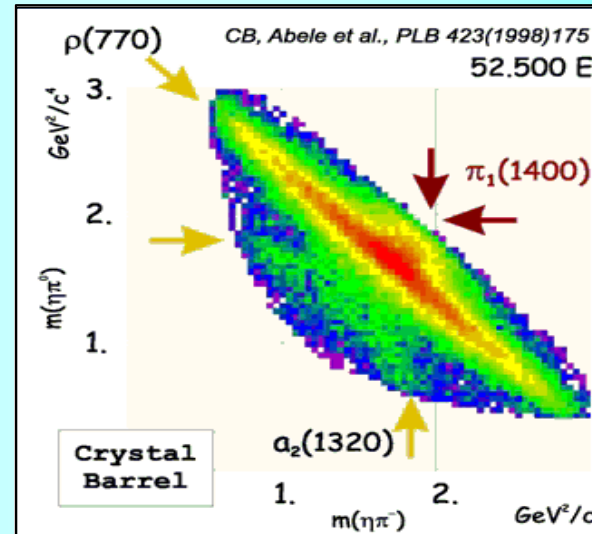
- Study of the annihilation reactions at rest

$\bar{p}n?$ $\rho-\rho^0?$ and

$\bar{p}p?$ $\rho^0\rho^0?$

- The decays of ρ and ρ^0 into $\rho\rho$ and of $a_2(1320)$ into $\rho\rho$ are not enough to describe correctly the data

- The presence of a $\rho_1(1400)$ meson, decaying into $\rho\rho$, is needed



$$M = (1400 \pm 20 \pm 20) \text{ MeV},$$

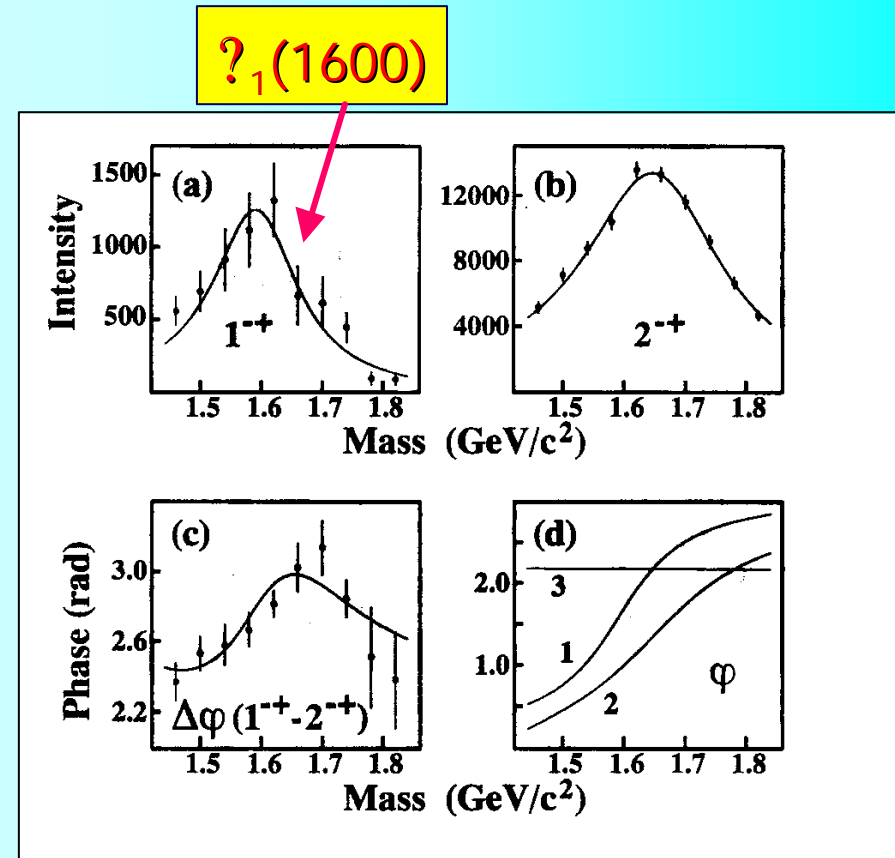
$$\Gamma = (310 \pm 50^{+50}_{-30}) \text{ MeV}$$

$$M = (1360 \pm 25) \text{ MeV},$$

$$\Gamma = (220 \pm 90) \text{ MeV}$$

The heaviest 1^{-+} state: $\omega_1(1600)$ the observation by BNL-E852 in 3ω

- State reported in $\omega\omega$ and $\omega\omega$ channels
- Study of the 3ω system by E852 in the reaction $\omega^- p \rightarrow \omega^+ \omega^- \omega^- p$ @ 18 GeV/c with $0.05 < -t < 1$ (GeV/c)² momentum transfer
- Found a 1^{-+} state at 1600 with the phase motion peculiar of a resonance with respect of all other partial waves



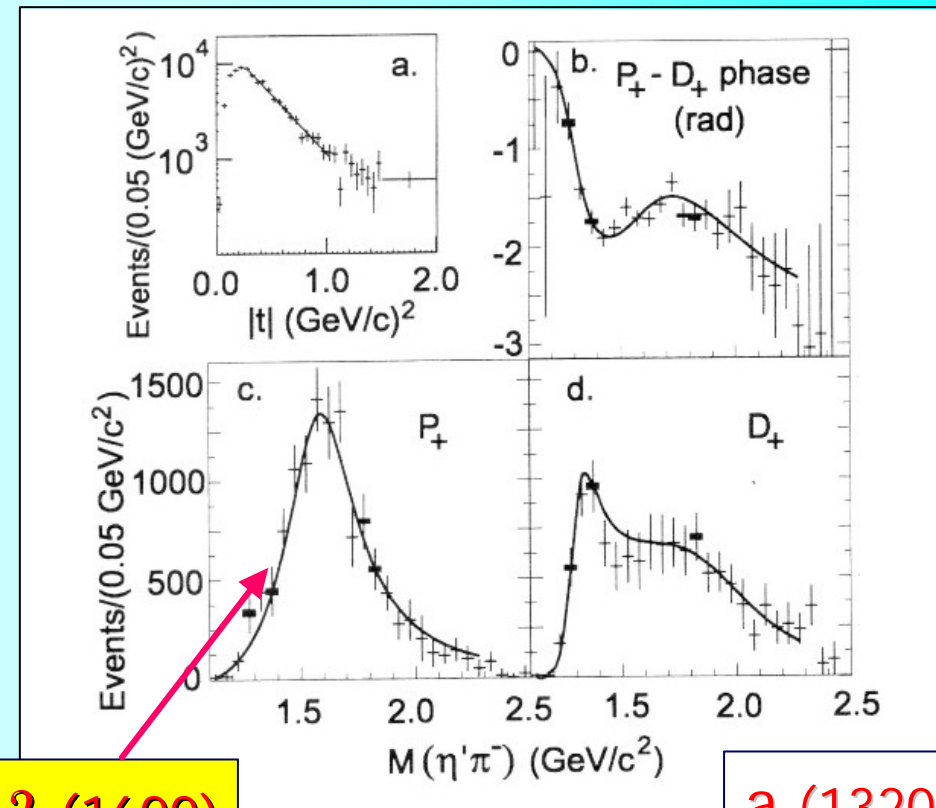
$$M_{\omega_1} = (1593^{+20}_{-47}) \text{ MeV},$$

$$\Gamma_{\omega_1} = (168^{+20}_{-12}) \text{ MeV}$$

The heaviest 1^{-+} state: $\eta_1(1600)$ the observation by BNL-E852 in $\eta'\eta$

- Study of the $\eta'\eta$ system by E852 in the reaction $\eta'p \rightarrow \eta'\eta p$ @ 18 GeV/c with $0.06 < |t| < 2.5$ (GeV/c)² momentum transfer

- PW analysis: the most dominant waves are P_+ and D_+
 - Found a 1^{-+} state at 1600 with the phase motion peculiar of a resonance
 - Two D waves in interference (one of them is the $a_2(1320)$)



$\eta_1(1600)$

$a_2(1320)$

$$M_{\eta'\eta} = (1597^{+45}_{-10}) \text{ MeV},$$

$$\Gamma_{\eta'\eta} = (340^{+40}_{-50}) \text{ MeV}$$

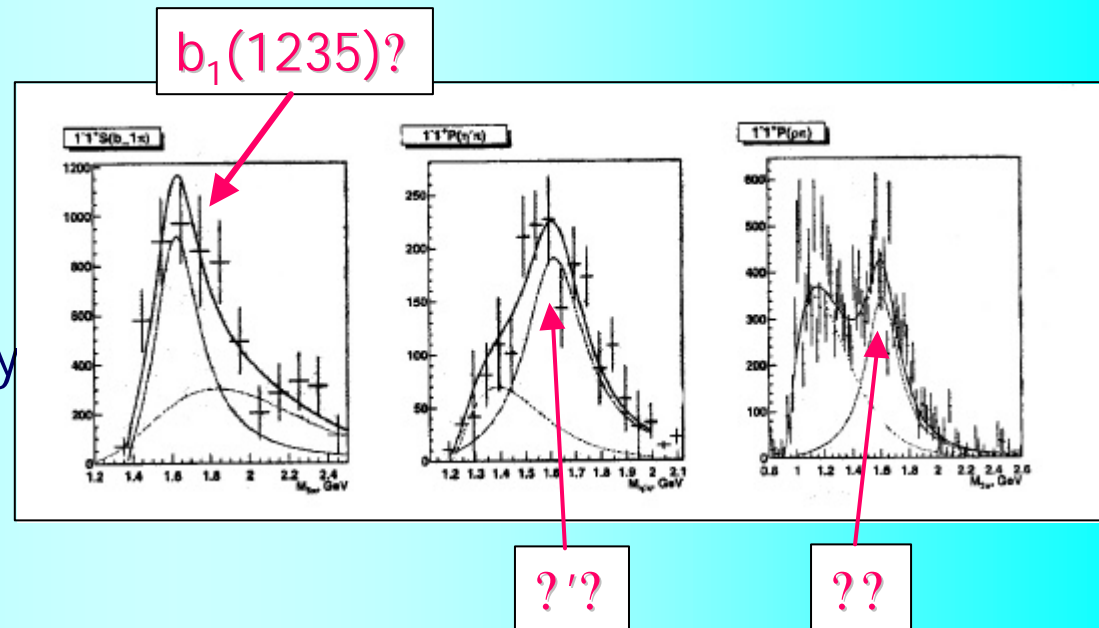
The heaviest 1^- state: $\eta_1(1600)$

the observations by VES in $\eta\eta'$ and other channels

- Study of the reaction
 $\eta\text{-}N \rightarrow \eta'\text{-}N$
 @ 37 GeV/c

- A coupled channel analysis shows the presence of $\eta_1(1600)$ in the decay channels:

- $\eta\eta'$
- $\eta\eta$
- $b_1(1235)\eta$



$$M_{\eta\eta'} = (1610 \pm 20) \text{ MeV},$$

$$\Gamma_{\eta\eta'} = (290 \pm 30) \text{ MeV}$$

Hybrids in the vector sector

- Existence confirmed for $\omega'(1600)$ – which can be a composite object, formed by $\omega(1450)$ & $\omega(1700)$
 - Observed at CMD Novosibirsk and CLEO in $e^+e^- \rightarrow 4\pi$
 - They have isoscalar counterparts in $\omega(1420)$, $\omega(1650)$ and $\omega(1680)$
 - Are all of them radial excitations?
 - If so, their width is incompatible with expectations from 3P_0 model
 - $\omega(1420)$: $\omega(2^3S_1)$ & $a_1(1260)$, $h_1(1159)$ Γ 1-3 MeV: too small
 - $\omega(1650)$: $\omega(1^3D_1)$ & $a_1(1640)$, $h_1(1590)$ Γ 105 MeV: consistent with 3P_0
 - $a_1(1640)$ $\rightarrow \pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-2\pi^0$ while $h_1(1590)$ $\rightarrow \pi^+\pi^-2\pi^0$ only:
 - one would expect $\Gamma(e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0) > \Gamma(e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-)$ which is **contrary** to experimental observation:
below 1.6 GeV: $2\Gamma(e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0) \gg \Gamma(e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-)$
 - SIGNATURE OF NEW PHYSICS? $q\bar{q}g$ state?
 - In this mass range the dominant hadronic decay channel of the vector hybrid ω_H is expected to be $a_1\pi$

Conclusions

- **Scalar glueball:**
 - the $f_0(1500)$ is a good candidate as a glueball due to its many decay channels, observed by several experiments in different reactions
- **1^{-+} hybrid:**
 - the presence of at least one hybrid meson decaying into ?? at 1.6 GeV seems confirmed, as it had been observed in different reactions – several confirmations also for the state observed at 1.4 GeV
- **1^{--} hybrid:**
 - Hints at the possible identification of $\omega'(1600)$ with a vector hybrid, due its preferred decay channel into a_1 ?