GLUEBALLS AND HYBRIDS IN THE 1-2 GeV REGION: AN EXPERIMENTAL OVERVIEW

A. Filippi*, I.N.F.N. Torino, Italy

Abstract

An overview of latest results on the search of glueballs, hybrids and exotic mesons in the 1-2 GeV mass region is presented.

INTRODUCTION

Several experimental observations have been collected in the last few years reporting evidences for the existence of a few exotic mesons, composed by gluons only (the glueballs) or by a mixture of gluons and quarks (known as hybrids). Their presence is required by QCD but their observation is rather elusive as in general it is very difficult to disentangle them from the huge hadronic background typical of this mass region, since they are likely to be large and/or often their quantum numbers are the same as for ordinary mesons.

The most interesting set of observations hinting at the possible existence of glueballs refers to the spectrum of the scalar mesons, which appears to be overpopulated if ordinary mesons only were present in the mass region below 2 GeV: too many scalars are observed for all of them to be compatible with a quarkuonia structure. At least one of them has the right features to be identified as glueball, namely, its flavor-blindness (*i.e.* the absence of a preference flavour pattern for its decay) and its scarce coupling to photons: the $f_0(1500)$. More details will be given in the first Section of this paper.

Some hints at the presence of glueballs with quantum numbers other than 0^{++} were suggested, but these objects are expected by theoretical calculations, lattice-QCD based, at higher masses. Some information about general glueballs and exotic mesons systematics is given elsewhere in these proceedings [1].

On the other hand, some observations have been recently made for objects whose quantum numbers, $J^{PC} = 1^{-+}$, are not compatible with a $\bar{q}q$ structure, and are therefore good candidates as hybrid mesons. Even if the conclusions of different experiments observing apparently the same signal disagree, there are now many indications for the existence of at least two candidates, dubbed as $\pi_1(1400)$ and $\pi_1(1600)$. An overview of the experimental state-of-art in the search of these objects will be given in the second section of this paper.

Finally, some information will be given for the existence of new exotic structures with vector quantum numbers that could explain the complexity of the observed meson spectrum and the peculiarity of some decay patterns of objects which probably cannot be trivially interpreted as radial excitations only.

* e-mail address:filippi@to.infn.it

GLUEBALL CANDIDATES IN THE 0^{++} SECTOR

As already mentioned in the Introduction, too many scalars have been observed so far to be accommodated without ambiguity in the 0^{++} ground nonet: at least two isovectors exist, the $a_0(980)$ and the $a_0(1450)$, instead of one only, and at least four (if not five) isoscalars, namely the $f_0(400-1200)$, also known as σ, the $f_0(980)$, the $f_0(1300)$, the $f_0(1500)$ and, probably, the $f_0(1700)$, instead of two.

A number of open problems, expecially concerning the isoscalars, still exist. For instance, no clear-cut evidences for the existence of σ are available, except for some observations in the D meson decay [2], whose interpretation is however still questionable in some respects; and the nature of both $a_0(980)$ and $f_0(980)$, that could be items of multi-quarks structures as well and $K\overline{K}$ molecular states, is still uncertain. In this scenario, it seems likely that at least one object composed by gluons only could enter the spectrum: it is important therefore to check whether its most important signatures are observed, as already mentioned the flavour blindness in its decay modes, and the absence of its coupling to real photons.

One of the objects observed so far which seems to be the best candidate as scalar glueball (which, according to lattice QCD calculations, would be the lightest specimen of the glueball spectrum) is the $f_0(1500)$, and in the following a short review about its features will be reported.

$\mathbf{f_0(1500)}$

First observations and further confirmations. The first observations for $f_0(1500)$ date back to 1983, when it was observed in deuterium bubble chamber in the $\bar{p}n \rightarrow 2\pi^-\pi^+$ reaction [3]. In contrast with $f_2'(1525)$, it was not observed to decay in $K\overline{K}$. For its spin parity the 0^{++} quantum numbers were cautiously suggested, but a few years later the ASTERIX Experiment, operating at LEAR and observing the same structure in the $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ [4], suggested it to be a tensor object. It is now known, thanks especially to the studies performed by OBELIX and CRYSTAL BARREL, which will be described later in this Section, that in this mass region two structures are present, a scalar one and a tensor one, reported in the PDG [5] as $f_2(1565)$. The latter is a good candidate as a quasi-nuclear $\overline{\mathcal{N}}\mathcal{N}$ bound state, and was likely observed by ASTERIX since they applied a technique to select annihilations from

P-wave initial states, from which the production of such a high spin object should be favoured.

On the other hand, GAMS made earlier observations of a state produced in $\pi^- p$ interactions, dubbed as $G(1590)$, decaying into $\eta\eta$ and $\eta\eta'$ [6], but not $\pi\pi$. It seems now rather likely that this signal scan be identified with the $f_0(1500)$.

The observations in $\pi\pi$ and $\eta\eta$ were confermed a few years later even at higher energies, by E760 (1992) [7] and E687 (1997) [8] at Fermilab, and by VES (1996) at IHEP Protvino [9]. E687 studied the features of the dipion system coming from the $D_S^\pm$ decay, obtaining some indication for the existence of an object at about 1475 MeV, 100 MeV wide, decaying into $\pi^+\pi^-$: its production in the D_S decay should also allow to conclude that it must have a non vanishing $\bar{s}s$ component in its wave function, and therefore its decay in $K\overline{K}$ should not be prevented. VES, on the other hand, could observe the production of $f_0(1500)$ (and its decay into $\eta\eta$ and $\eta\eta'$) in the decay of $\pi(1800)$, produced in $\pi^- p$ interactions at 28 GeV/c.

Observations in nucleon-antinucleon annihilations. The second generation experiments working at LEAR, in particular OBELIX and CRYSTAL BARREL, produced quite a wealth of results contributing to the identification of the $f_0(1500)$ as a glueball, thanks to its observation in several decay channels. The antinucleon-nucleon annihilation is one of the most suitable environments for the production of gluons and their possible aggregates; both the experiments studied not only the annihilation of antiprotons, in flight and at rest in hydrogen targets at different densities (controlling in this way the amount of S and P wave initial states), and in gaseous deuterium, but OBELIX could also exploit a new technique for the production of an antineutron beam that could allow to perform meson spectroscopy studies in annihilation channels complementary to the antiproton ones, with the particular feature of having the isospin quantum number fixed.

The most famous Dalitz plot obtained by CRYSTAL BARREL showing the $f_0(1500)$ (as a band close to the plot's corners) in its $\pi^0\pi^0$ decay is reported here in Fig. 1 [10]. A structure at a mass about 1500 MeV, 100 MeV wide, was also reported by CRYSTAL BARREL in its $\eta\eta$ decay (whose Dalitz plot is reported in Fig. 2 as a diagonal band) [11], in $K_L^0 K_L^0$ [12] and in four pions [13]. These observations vere recently confirmed in the study of annihilations in flight with antiprotons of momenta between 1350 and 1940 MeV/c.

The $\bar{n}p \to \pi^+\pi^+\pi^-$ Dalitz plot for events collected by OBELIX in flight, with antineutron momentum less than 405 MeV/c, is shown in Fig. 3 [14]. In this plot the signal due to $f_0(1500)$ is visible as little enhancementes close to the plots' corners. The analysis of this plot led to assert the presence of two states in this mass region, the $f_0(1500)$ and the $f_2(1565)$. As expected for a scalar state, the production on the former doesn't change with the antineutron momentum (*i.e.* with the energy available to the reaction), while it increases for the tensor one, in agreement with ex-

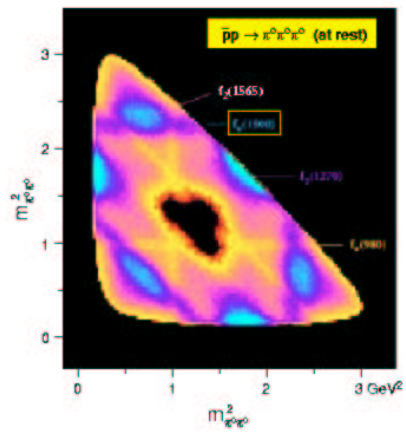

Figure 1: Dalitz plot for the $\bar{p}p \to 3\pi^0$ annihilation reaction at rest, CRYSTAL BARREL data. The $f_0(1500)$ is visible as a linear band crossing the plot close to its corners.

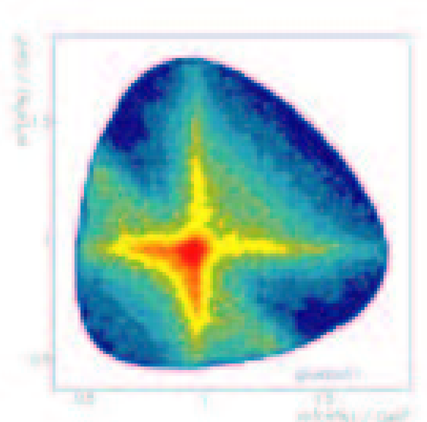

Figure 2: Dalitz plot for the $\bar{p}p \to \eta\eta\pi^0$ annihilation reaction at rest, CRYSTAL BARREL data. The $f_0(1500)$ is visible as a diagonal band passing through the plot center.

pectations as well. In antineutron data the $f_0(1500)$ had been observed even in its multipionic decay channel, in the $\bar{n}p \to 3\pi^+2\pi^-$ reaction [15].

Fig. 4 shows several Dalitz plots of data collected by OBELIX in $\bar{p}p$ annihilation into final states with three mesons, in three different density conditions of the target (from left to right: liquid H_2, NTP and low pressure H_2), which allow to select the amount of S- and P-wave from which the annihilation reaction may proceed [16]. In the first row the plots for the $\bar{p}p \to \pi^+\pi^-\pi^0$ are shown. The $f_0(1500)$ is visible again close to the plots' corners as bumps, which become more extended with the P-wave increase (from left to right), as a consequence of the enhanced production of $f_2(1565)$, produced in the same mass region.

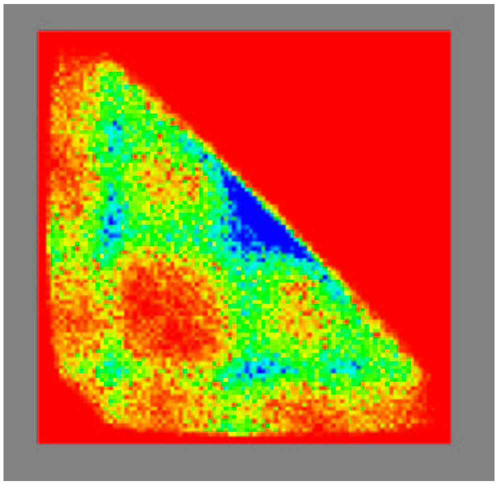

Figure 3: Dalitz plot for the $\bar{n}p \rightarrow 2\pi^+\pi^-$ annihilation reaction in flight, OBELIX data. The $f_0(1500)$ is visible as enhancements close to its corners.

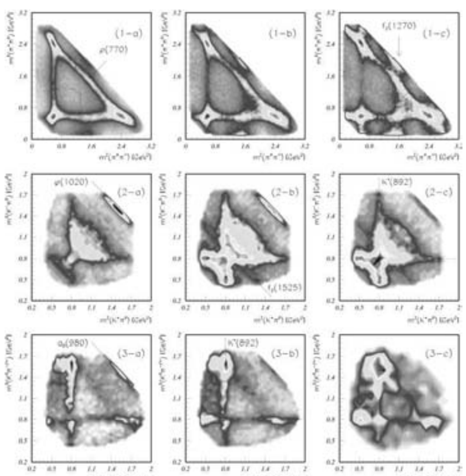

Figure 4: Dalitz plots for the $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ (first row), $\bar{p}p \rightarrow K^+K^-\pi^0$ (second row) and $\bar{p}p \rightarrow K^{\pm}K^0_S\pi^{\mp}$ (third row) annihilation reactions at rest, OBELIX data. The columns correspond to annihilations in liquid hydrogen (S-wave dominance), gaseous H_2 at normal pressure conditions and gaseous H_2 at low pressure (P-wave dominance). The $f_0(1500)$ is visible as enhancements close to the corners of the Dalitz plots in the first row.

Observations in channels with kaons. One of the cleanest indications for the existence of a kaonic decay channel for the $f_0(1500)$ is reported in Fig. 5, where the invariant mass of the K^+K^- system in the $\bar{n}p \rightarrow K^+K^-\pi^+$ reaction observed by OBELIX is shown. Beyond the ϕ line, one can observe a rather narrow prominence at about 1500 MeV. At about 1700, a second narrow peak can be seen, probably due to $f_J(1700)$.

The second row of Fig, 4 shows, on the other hand, the $\bar{p}p \rightarrow K^+K^-\pi^0$ Dalitz plots for OBELIX data, collected again on hydrogen targets of different density. The coupled channel analysis of all the plots reported in the picture suggests the presence of the $f_0(1500)$ signal with a non negligible branching ratio even in the $\overline{K}K$ final state. According to OBELIX, the ratio between the branching ratios for the decay of $f_0(1500)$ on $K\overline{K}$ and $\pi\pi$ is about 30% (more precisely, (0.24 ± 0.04) for annihilations from $^1S_0$ and (0.30 ± 0.04) for annihilations from $^3P_1$ wave [16]). This figure is confirmed by WA102, which observed, in pp central collisions at 450 GeV, the $f_0(1500)$ decaying into K^+K^- and $K^0_SK^0_S$, and quoted $R = B.R.(f_0(1500) \rightarrow K\overline{K})/B.R.(f_0(1500) \rightarrow \pi\pi) = (0.33 \pm 0.03 \pm 0.07)$ [17]. Though observed, this experiment confirms as dominant decay mode the pionic one.

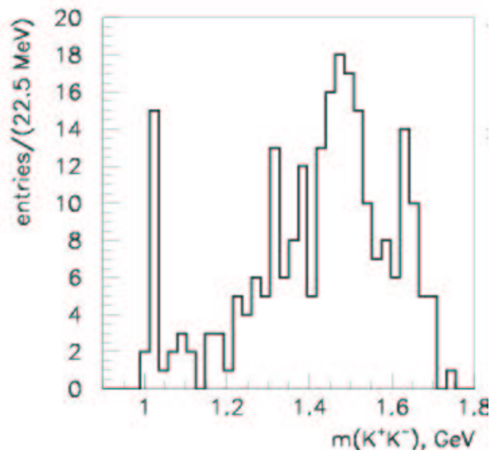

Figure 5: Invariant mass distribution of the K^+K^- system in the $\bar{n}p \rightarrow K^+K^-\pi^-$ reaction, OBELIX data. The central peak is a clean signature of $f_0(1500)$, seen in a kaonic decay channel.

A value for this ratio less than 0.3 would indicate, however, a negligible weight of a possible $\bar{s}s$ component on the $f_0(1500)$ wave function. For instance CRYSTAL BARREL disagrees with the reported extimations, quoting for the ratio the value (0.138 ± 0.038) [12]. In general, it seems likely that this value is a little too low (probably due to the procedure used for the extraction of the couplings from the data), and that either a not negligible $\bar{s}s$ component or a sizeable glue content (coupling to whichever quark flavour, feature known as "flavour blindness") is present in the $f_0(1500)$ wave function.

Absence in $\gamma\gamma$ interactions. The second distinctive feature for a real glueball is the absence of its coupling to photons, as gluons do not couple directly to them. Therefore, reactions as $e^+e^- \rightarrow \gamma\gamma$ can be considered as true anti-glueball filters; e^+e^- interactions are probably the worst environment to search for the production of glueballs.

Experiments performed at LEP have shown that indeed $f_0(1500)$ is missing, when studying production of final channels proceeding from two real photons.

For instance, L3 (1999) [18], in the analysis of the

$K_L^0 K_L^0$ final state below 2 GeV, reports the esixtence of three peaks, attributable to $f_2(1270)$, $a_2(1320)$ and $f_2'(1525)$, but no scalar object in the 1500 MeV mass region is required to get good fits of the experimental data. The experimental spectrum can be observed in Fig. 6.

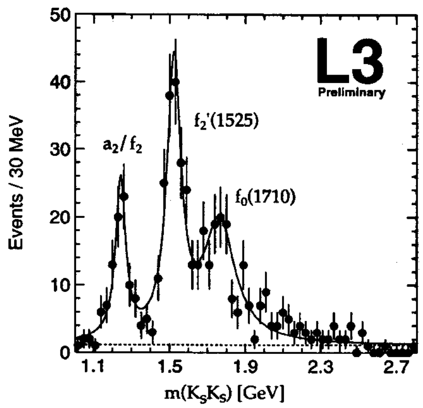

Figure 6: $K_S^0 K_S^0$ invariant mass spectrum, L3 data.

ALEPH (1999) [19] again reports the absence of $f_0(1500)$ in the $\gamma\gamma \to \pi^+\pi^-$ reaction: its measured width in the $\gamma\gamma$ channel is about 0.17 KeV. This figure should be compared to the coupling to $\gamma\gamma$ of a typical $\bar{q}q$ meson, like for instance $f_0(1370)$: $\Gamma_{\gamma\gamma} \simeq 4$ KeV.

$\mathbf{f_0(1700)}$

The $f_0(1700)$ represents the second most likely candidate as glueball. Its spin assignment, whether it could be a tensor or a scalar object, has been debated for long. Rather recently, it seems that the scalar hypothesis is favoured, as suggested by MARKIII and WA102, which observed it in the $\pi\pi$ and K^+K^- systems, in the radiative J/ψ decay. A typical structure of $f_0(1700)$ observed in the K^+K^- decay channel by MARKIII [20] is shown in Fig. 7.

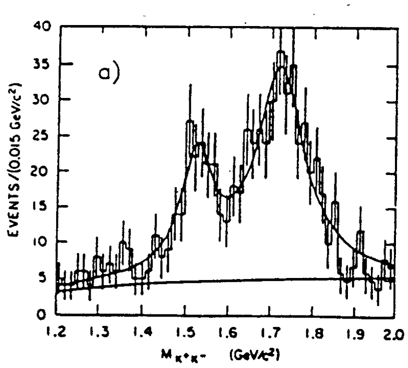

Figure 7: K^+K^- mass spectrum from $J/\psi \to \gamma K^+K^-$, MARKIII Experiment.

If its quantum numbers seem now rather settled, its inner structure is far from being understood. In the scalar sector the $\bar{s}s$ meson is nowadays still missing and, since it's expected beyond 1600 MeV, this meson seems to be the most natural candidate: its coupling to the $K\overline{K}$ channel is not negligible –but, on the other hand, not exclusive. However, it is not observed in a significant way in $\bar{p}p$ annihilation: this could be a possible consequence of its $\bar{s}s$ dominant content, which should prevent its coupling to nucleons due to OZI rule.

HYBRIDS CANDIDATES IN THE 1^{-+} SECTOR

Several experimental hints at the presence of two 1^{-+} exotic mesons have been found the π^-p interactions at intermediate energies studied at KEK, IHEP and BNL. In these reactions the responsible mechanism for the production of such mesons is a Reggeon exchange with the recoil nucleon, which leads to either isoscalar or isovector mesons, decaying mainly to light quarks [21].

Recently a confirmation for the existence of such structures came from $\bar{p}p$ annihilation, namely by CRYSTAL BARREL [22].

The 1^{-+} mesons are called "exotics" since these quantum numbers are not accessible to simple quarkonia states: their structure is likely to be a mixture of $\bar{q}q$ and gluons. Their presence is foreseen in the $(1.4 \div 2)$ GeV by several models, which however predict fairly different masses and decay branching ratios. For instance, the flux-tube model predicts a mass of about 1.9 GeV and dominant decays in $b_1(1535)\pi$ and $f_1(1265)\pi$; the di-quark cluster model, on the other hand, suggests a mass of about 1.5 GeV and $\rho\omega$ as dominant decay mode. Finally, QCD sum rule calculations expect a mass in the range $(1.4 \div 1.6)$ GeV, and $\rho\pi$ as dominant decay.

In the following the most important features of the two most reliable candidates as hybrids observed so far will be reported.

$\boldsymbol{\pi_1(1400)}$

The first observations for such a state were performed by GAMS (IHEP-CERN) in the $\pi^-p \to \pi^0\eta n$ at 100 GeV/c [23]: a forward-backward asymmetry of the angular distributions in the $\pi^0\eta$ system suggested a swing in the $a_2(1320)$ region, which could be explained by a strong interference between a spin two (D_0) and a spin one (P_0) waves.

Shortly afterwards the experiment E179 at KEK found new evidences in the reaction $\pi^-p \to \pi^-\eta p$ at 6.3 GeV/c [24]. A partial wave analysis showed again that D_+ and P_+ waves peak, with a resonant behaviour, in the $a_2(1320)$ region.

The most important evidences were reported by BNL-E852 in the systematic study of the reactions $\pi^-p \to \pi^-\eta p$ and $\pi^-p \to \pi^0\eta n$ at 18 GeV/c [25]. As shown in Fig. 8, the $\pi\eta$ spectrum shows a strong $a_2(1320)$ signal with a typical peripheral production; the relative phase motion of the P_+ wave with respect to $a_2(1320)$ requires the presence of a resonant state at about 1400 MeV.

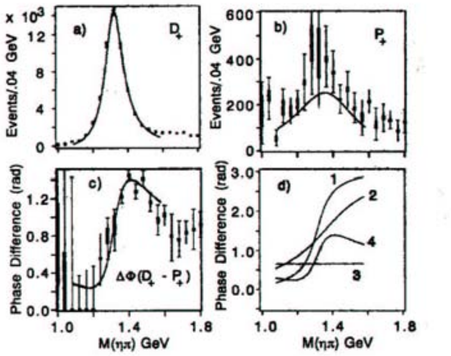

Figure 8: Results of the partial wave amplitude analysis by BNL-E852 experiment on $\pi^- p \rightarrow \pi^- \eta p$ data. Pictures a) and b) show respectively the fitted intensity distributions for the D_+ and the P_+ partial waves (the latter showing the signal due to $\pi_1(1400)$), picture c) their phase difference, and picture d) the phase of each partial wave amplitude inserted in the analysis (the curve labelled by 4 is the overall phase difference).

The same object has been studied by VES in the reactions $\pi^- N \rightarrow \pi^- \eta N,\ \pi^- \eta' N$ at 37 GeV/c [26]: the $\pi_1(1400)$ signal is present in the $\eta\pi$ channel but it is small and with large errors. Even if the phase motion is similar to that observed in BNL data, VES doesn't claim any meaningful 1^{-+} state to have been observed in the $(1.3 \div 1.4)$ GeV mass region.

The study of the annihilation reactions at rest $\bar{p}n \rightarrow \pi^- \pi^0 \eta$ and $\bar{p}p \rightarrow \pi^0 \pi^0 \eta$ [22] has been performed at LEAR by CRYSTAL BARREL, which found some evidence for the presence of an exotic at about 1400 MeV. The Dalitz plot for the first reaction is shown in Fig. 9, where the $\pi_1(1400)$ is claimed to be seen close to the crossing of the two $a_2(1320)$ bands. The decays of σ and ρ into $\pi\pi$, and of $a_2(1320)$ into $\eta\pi$ are not enough to describe correctly the data: the presence of an additional $\pi_1(1400)$ meson decaying into $\eta\pi$ is required by the fit. Both the channels need the introduction of a $\pi_1(1400)$ with a mass from 1360 to 1400 MeV, and a width from 220 to 310 MeV.

$\pi_1(1600)$

The heaviest 1^{-+} state has been observed by BNL-E852 in 3π $(\rho\pi)$ [27] and $\eta'\pi$ [28]. The study of the 3π system was performed on the $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ data, collected at 18 GeV/c, in the $0.05 < |t| < 1$ (GeV/c)^2 momentum transfer window. As shown in Fig. 10, a state at about 1600 MeV with a phase motion peculiar of a resonance with respect to all other partial waves was found. The decay width in $\rho\pi$ is about 170 MeV.

Its decay in $\eta'\pi$ was studied, on the contrary, in the $\pi^- p \rightarrow \eta' \pi^- p$ data, always at 18 GeV/c, with $0.06 < |t| < 2.5$ (GeV/c)^2 momentum transfer. The partial wave analysis showed that the most dominant contributions are from P_+ and D_+ (the latter strongly interfering with $a_2(1320)$). The phase motion of the 1^{-+} state peaking at about 1600 MeV is compatible with the existence of a resonance. Its width is quoted to about 340 MeV.

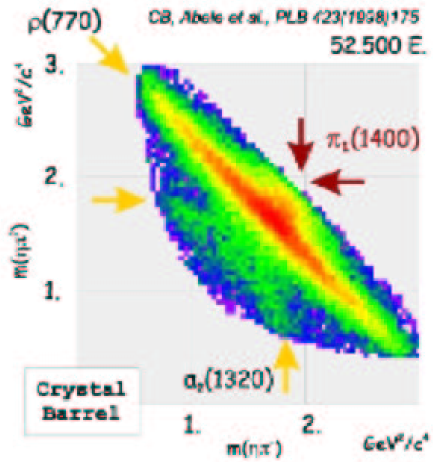

Figure 9: Dalitz plot of the $\bar{p}n \rightarrow \eta\pi^0\pi^-$ reaction, CRYSTAL BARREL data. The contribution of $\pi_1(1400)$ is seen as an enhancement close to the crossing of the $a_2(1320)$ bands.

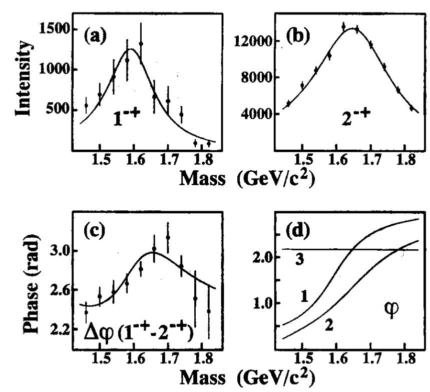

Figure 10: BNL-E852 data: Partial wave intensities for a) 1^{-+} and b) 2^{-+} waves; c) shows the phase difference between the two waves, d) reports the phases for each partial waves. Both the amplitudes are resonant: the D-wave corresponds to $f_2(1270)$, the P-wave to the exotic at about 1600 MeV.

VES confirms these observations in the study of the reaction $\pi^- N \rightarrow \pi^- \eta' N$ at 37 GeV/c [29]. The signal was observed in several decay channels, as emerges from a coupled channel analysis: $\rho\pi$, $\eta'\pi$ and $b_1(1235)\pi$. The mass is reported as 1610 MeV, the width as 290 MeV.

EXOTIC STRUCTURES IN THE 1^{--} SECTOR

Some hints for the presence of an exotic structure even in the vector mesons sector can be inferred by the study of the radial excitations of known mesons, which exhibit some anomalies, incompatible with the expectations of well extablished quark models, like the $^3P_0$ one.

The most of the experimental observations in this sector comes from the experiments CMD, Novosibirsk and CLEO, Cornell, which studied, among many subjects, the formation of resonances in the reaction $e^+e^- \rightarrow 4\pi$ [30]. It is now well known, for instance, that a huge object labelled as $\rho'(1600)$ is probably to be understood as a superimposition of two distinct resonances, a $\rho(1450)$ and, at higher mass, a $\rho(1700)$ [31]. For this isovector mesons, tentatively interpreted as radial excitations of $\rho(770)$, isoscalar counterparts were found and labelled as $\omega(1420)$, $\omega(1650)$ and $\phi(1680)$.

The decay pattern of all these objects, however, poses some inconsistencies that can be solved only in the hypothesis that at least one of the ρ states has a non $\bar{q}q$ structure. The $^3P_0$ model expects for instance, for the decay of the first ω orbital excitation 1^3D_1 into $a_1\pi$ and $h_1\pi$, a width of about 105 MeV for each channel, which is compatible with the experimental observations. On the other hand, very small widths are expected for the decay in the two mentioned channels of the first ρ radial excitation 2^3S_1, just $(1 \div 3)$ MeV.

The decays of the two excitations contribute to the four pion final states via the two mentioned channels, leading to $2\pi^+2\pi^-$ and $\pi^+\pi^-2\pi^0$ for $a_1\pi$, and to $\pi^+\pi^-2\pi^0$ only for $h_1\pi$. If the decay widths expected by $^3P_0$ model were effective, one would expect $\sigma(e^+e^- \rightarrow \pi^+\pi^-2\pi^0) > \sigma(e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-)$, that however is contrary to the experimental observation, for which below 1.6 GeV the two cross sections are essentially the same.

The observed production rates of the four pions final states could be easily explained if one of the observed ρ's had a $q\bar{q}g$ structure, which implied a dominant hadronic decay in $a_1\pi$, suppressing the $h_1\pi$ channel.

CONCLUSIONS

A new e^+e^- machine operating in the $(1 \div 2)$ GeV range probably won't add anything new about the production of glueballs, as their intrinsic structure prevents them to be coupled to two photons. The only way to get some insight about some of their features would be to exploit the decay of the J/ψ meson, for which however a τ-charm factory would be necessary, beyond the energy scale foreseen for DAΦNE2. Even concerning the search of a 1^{-+} exotic, it seems that the DAΦNE2 energy window will probably not be enough to study systematically its existence and decay features.

On the other hand, it appears quite more likely that a decisive boost in the understanding of the vector sector systematics will be achieved if a e^+e^- machine with high luminosity will be available in the next future, to improve the still unclear experimental scenario as observed by the experiments at Novosibirsk and Cornell.

REFERENCES

[1] F. Llanes Estrada, *these proceedings*

[2] E791 Collaboration, E.M. Aitala *et al.*, Phys. Rev. Lett. **86** (2001), 765
E791 Collaboration, E.M. Aitala *et al.*, Phys. Rev. Lett. **86** (2001), 770

[3] T. E. Kalogeropoulos *et al.*, Phys. Rev. **D24** (1981), 1759

[4] ASTERIX Collaboration, B. May *et al.*, Phys. Lett. **B225** (1989), 450

[5] Particle Data Group, Review of Particle Properties, K. Hagiwara *et al.*, Phys. Rev. **D66** (2002), 0100001

[6] V. Alde *et al.*, Nucl. Phys. **B269** (1986), 485

[7] T. Armstrong *et al.*, Nucl. Phys. **A558** (1993), 53c

[8] E687 Collaboration, P.L. Frabetti *et al.*, Phys. Lett. **B407** (1997), 79

[9] D.V. Amelin *et al.*, Phys. Atomic Nucl. **59** (1996), 976

[10] CRYSTAL BARREL Collaboration, C. Amsler *et al.*, Phys.Lett. **B342** (1995), 433

[11] CRYSTAL BARREL Collaboration, C. Amsler *et al.*, Phys. Lett. **353** (1995), 571

[12] CRYSTAL BARREL Collaboration, A. Abele *et al.*, Phys. Lett. **B385** (1996), 425

[13] CRYSTAL BARREL Collaboration, A. Abele *et al.*, Eur. J. **C19** (2001), 667

[14] OBELIX Collaboration, A. Bertin *et al.*, Phys. Rev. **D57** (1998), 55

[15] OBELIX Collaboration, A. Filippi, in *Proceedings of the Ninth International Conference on Hadron Spectroscopy*, Protvino, Russia, 2001; ed.s D. Amelin, A.M. Zaitsev; American Institute of Physics, 2002, p. 582

[16] OBELIX Collaboration, M. Bargiotti *et al.*, Eur, Phys. J. **C26** (2003), 371

[17] A. Kirk, in *Proceedings of the Workshop on Hadron Spectroscopy*, Frascati Physics Series XV (1998), p. 29

[18] S. Braccini, in *Proceedings of the Workshop on Hadron Spectroscopy*, Frascati Physics Series XV (1998), p. 53

[19] A. Wright, in *Proc. Int. Eur. Phys. Conf.*, Jerusalem, 1999; Ed.s D. Lellouch *et al.*; p. 343

[20] L.P. Chen *et al.*, Nucl. Phys. **B** (Proc. Suppl.) **21** (1991), 80

[21] S.U. Chung, in *Proceedings of the XXIX International Workshop on Gross Properties of Nuclei and Nuclear Excitations*, Hirschegg, Austria, 2001; ed.s H. Feldmeyer *et al.*; p. 118

[22] CRYSTAL BARREL Collaboration, A. Abele *et al.*, Phys. Lett. **B423** (1998), 175
CRYSTAL BARREL Collaboration, A. Abele *et al.*, Phys. Lett. **B446** (1999), 349

[23] D. Alde *et al.*, Phys. Lett. **B205** (1988), 397

[24] H. Aoyagi *et al.*, Phys. Lett. **B314** (1993), 246

[25] D. R. Thompson *et al.*, Phys. Rev. Lett. **79** (1997), 1630

[26] G.M. Beladidze *et al.*, Phys. Lett. **B313** (1993), 276

[27] S.U. Chung *et al.*, Phys. Rev. **D60** (1999), 092001

[28] E852 Collaboration, A.V. Popov, in *Proceedings of the Ninth International Conference on Hadron Spectroscopy*, Protvino, Russia, 2001; ed.s D. Amelin, A.M. Zaitsev; American Institute of Physics, 2002, p. 135

[29] VES Collaboration, V. Dorofeev, in *Proceedings of the Ninth International Conference on Hadron Spectroscopy*, Protvino, Russia, 2001; ed.s D. Amelin, A.M. Zaitsev; American Institute of Physics, 2002, p. 143

[30] V.N. Ivanchenko, in *Proceedings of the Workshop on Hadron Spectroscopy*, Frascati Physics Series XV (1998), p. 667
V.N. Ivanchenko, in *Proceedings of the 2001 "e^+e^- physics at Intermediate Energies" Workshop*, Stanford Linear Accelerator Center, Stanford, California, April 30 - May 2, 2001; p. 74

[31] A. Donnachie, in *Proceedings of the 2001 "e^+e^- physics at Intermediate Energies" Workshop*, Stanford Linear Accelerator Center, Stanford, California, April 30 - May 2, 2001; p. 90