HADRON 2001 Summary: Experiment

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Abstract. Important contributions to Hadron'01 held at Protvino, Russia, August, 2001, are summarized.

INTRODUCTION:

A wealth of new and exciting data have been presented to the 9th International Conference on Hadron Spectroscopy. The new results were distributed over more than 140 contributions and it is of course impossible even to mention them all in this summary. The main focus of this review will be on results on light-quark spectroscopy with emphasis on the search for gluonic excitations. The excuse is that this field is the central issue of this conference series and a large amount of new results were presented. Ted Barnes in his summary [i1] has reviewed why it is important to search for mesons beyond the quark model, for hybrids and for glueballs.

Hybrids, mesons in which the gluon flux-tube carrying the forces between quark and antiquark is excited, may best be identified in searching for mesons with exotic quantum numbers, with quantum numbers which are not accessible to normal $q\bar{q}$ states. In particular the $J^{pc} = 1^{-+}$ wave has been studied intensively in a large number of final states. Since 1999, the last hadron conference, greatly improved statistics where accumulated in Brookhaven and in Protvino. The results of these analyses were presented during the conference and will be reviewed here. Hybrids are not limited to have exotic quantum numbers; they should also show up as additional states not finding their place in one of the meson nonets. This approach requires a careful discussion of light-meson spectroscopy, and of the decay pattern expected for $\bar{q}q$ states and for hybrids.

Glueballs are supposed to carry no constituent quarks; they manifest the new degrees brought into spectroscopy by color. In particular the lowest-mass glueball, according to lattice gauge calculations a scalar state at about 1700 MeV, is the object of an intense discussion since about two decades.

Before entering the field of meson spectroscopy, I would like at least to mention some of the highlights related to the Standard Model even though these results are slightly outside the main road of our field.

THE STANDARD MODEL

To the outstanding results presented at this conference belong of course the different measurements of CP-violation parameters. After a long controversy, the results on ε'/ε obtained at CERN and at FNAL now agree. The results now establish CP-violation in the weak decay amplitude at 10 standard deviations. The new world average is now [a1,a2]

$$Re(\varepsilon'/\varepsilon) = (17,2 \pm 1,8) \cdot 10^{-4}.$$

CP-violation is not only accessible for strange mesons but also in the heavy quark sector. New results were presented from BABAR and BELLE and they both have established that CP-violation can be measured in b-factories. When the results from various sources are combined, CP-violation in the $B^0\overline{B}^0$ system is now established at 3 standard deviations [a3]. Of course this is only a start and high precision data are expected in the years to come.

We all followed the difficult decision the CERN management had to take when first candidates for decays of the Higgs particle were reported. Events were found in which 4 B-quarks were identified indicating that the sequence [a4]

$$e^+e^- \rightarrow \text{Higgs}; \quad \text{Higgs} \rightarrow Z^0Z^0; \quad \text{with both } Z^0 \rightarrow \bar{b}b$$

was observed. The evidence was reported also here at this conference; it suggests that the Higgs might be just around the corner at a mass of slightly above 200 GeV/c^2. Sadly enough, LEP was closed and we have to wait for Fermilab to find out if the Higgs is really so close.

The standard model continues to resist all attends to find physics beyond its limits. Precise measurement of the weak boson masses [a5] and of the Cabbibbo-Kobayashi-Mascawa matrix elements were discussed [a6]. These measurements over-constrain the unitary triangle but show no evidence for any deviation. Also rare Kaon decays also challange the Standard Model at very large energies [a7,a8].

The decays of charmed [a9,a10] and beauty [a11] hadrons and of J/ψ and ψ' decays [a12,a13] provide valuable information: is the fragmentation of quarks independent on the production mechanism [a14]? What is the reason for the strange pattern of ψ_{2S} decays to vector and pseudoscalar mesons and can this anomaly be extended to other decay processes [a15]?

The new measurement of anomalous magnetic moment (g-2) of the muon challenges the standard model. In the new BNL-experiment, 400.000 muons were stored in a storage ring and observed to decay. The decay time distribution shows the known oscillatory behaviour due to the anomalous magnetic moment of the muon. 150 revolutions of the muon spin relative to its moment vector were observed leading to a very high precision in a_μ. The experimental result,

$$a_\mu(99) = (11659202 \pm 14 \pm 6) \cdot 10^{-10}$$

differs from the Standard Model prediction

$$a_\mu(SM) = (11659159.6 \pm 6.7) \cdot 10^{-10}$$

at the 2.5σ level [a15. Does this indicate physics beyond the Standard Model ?

A large contribution to the anomaly stems from hadronic loops in radiative corrections. The loops can be calculated by integration of the e^+e^- cross section for annihilation into hadrons (via formation of vector mesons). Very precise new data from Novosibirsk on vector mesons were reported at this conference on e^+e^- annihilation into pionic and kaonic final states, with an impressive reduction of the statistical and systematic errors [a16]. The sum of all channels measured contributes to the anomalous magnetic moment $702 \cdot 10^{-10}$. This value is now larger, the discrepancy reduces to 1.xxσ. Obviously, this is one of the places where the physics of the standard model and hadron physics meet, and for me the point where I can turn to a discussion of hadron spectroscopy.

As mentioned in the introduction, the most important topic in light-meson spectroscopy is to find out which consequences QCD has for the dynamics of quarks in an energy regime in which perturbative approximations fail. There is the exciting possibility that QCD leads to the existence of hybrids and of glueballs. The summary will concentrate on those contributions which contribute to a clarification of this question.

HYBRIDS

Is there a $\mathrm{J}^{\mathrm{PC}} = \mathbf{1}^{--}$ hybrid ?

In his speech opening Hadron 2001 A. Donnachie reviewed the status of vector-meson radial excitations [b1]. The status, as presented by the Particle Data Group, is not at all satisfactory. The

$$\rho(1450), \omega(1420), \Phi(1680), \mathrm{K}^*(1410)$$

are assigned to the $1^3\mathrm{S}_1$ nonet, the

$$\rho(1700), \omega(1650), \qquad\qquad , \mathrm{K}^*(1680)$$

to the $1^3\mathrm{D}_1$ nonet. It is clearly surprising that the $\mathrm{K}^*(1410)$ is lower in mass than the $\rho(1450)$ and $\omega(1420)$. Also the decay pattern of the $\rho(1450)$ is by no means consistent with expectations based on the $^3\mathrm{P}_0$ model. Table 1 shows theoretical expectations.

The e^+e^- annihilation cross-section into two $\pi^+\pi^-$ pairs has the same size as the one for $\pi^+\pi^-2\pi^0$; both cross sections reach a peak value of about 35 nb at 1500 MeV. The isobar h_1 contributes only to the latter and not to the former final state. The 4π final-state is therefore reached only via a_1 and not via h_1. This is a pattern expected for a hybrid !

The Crystal Barrel collaboration reported [b3] results from an analysis of variuous final states in $\bar{\mathrm{p}}\mathrm{n}$ annihilation at rest (in D_2). Imposing masses and widths for the two known $\rho(1450)$ and $\rho(1700)$, they find a pattern

	$\Gamma_{\pi\pi}$	$\Gamma_{\overline{\mathrm{K}}\mathrm{K}}$	Γ_{ω}	$\Gamma_{4\pi}$
Exp.	45 ± 13	23 ± 7	115 ± 89	121 ± 48
$2^3\mathrm{S}_1$	74	35	122	
Hybrid	0	0	0	140

TABLE 1. Decay widths in MeV calculated within the framework of the $^3P_0$ model [i1] for pure quarkonia states and for a hybrid state calculated within the framework of the flux-tube model [i1]. Decays marked with "–" are not part of the calculations (π^* is a shortcut for $\pi(1300)$).

decay mode	$\pi\pi$	$\omega\pi$	$a_2\pi$	$a_1\pi$	$h_1\pi$	$\rho\rho$	$\pi^*\pi$	$\rho\sigma$	$K\overline{K}$
Calculated partial widths in the $^3P_0$ model:									[i1]
$2^3S_1\,\rho(1465)$	74	122	0	3	1	0	–	–	35
$1^3D_1\,\rho(1700)$	48	35	2	134	124	0	14	–	36
$3^3S_1\,\rho(1900)$	1	5	46	26	32	70	16	–	1
Calculated partial widths in the flux-tube model:									[i1]
Hybrid-$\rho(\sim 1500)$	0	5–10	~ 0	140	0	0	0	–	–

The 4π partial decay-width is again too large (its decomposition into isobars does not agree with the results from e^+e^- annihilation, possibly due to the role of the spectator pion); the pattern of two-body decays supports however the $\bar{q}q$ interpretation of the $\rho(1450)$, and the large widths for decays into $\pi\pi$, $\pi\omega$ and $\overline{K}K$ are incompatible with the prediction - based on the flux tube model - for a hybrid state. On the other hand, the $\rho(1700)$ has a decay pattern suggesting that it is the 1^3D_1 state and not the 2^3S_1 ρ radial excitation. If the $\rho(1450)$ is a hybrid, where is the $\bar{q}q$ state ?

When the masses in the fit to the Crystal Barrel data are not fixed to PDG values, there is a surprise: the $\pi\omega$ phase rises very rapidly at rather low $\pi\omega$ masses: Thus the first resonance above the ω (782)π threshold could be at about 1200 MeV. So the question arises if there is a third nonet in this mass region.

The very precise Novosibirsk data are limited to energies below 1400 MeV but constrain of course also fits to the full energy range, covered by the DM2 results. The SND collaboration studied ω' radial excitations. M. Achasov [b3] reported an analysis of the $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\omega$ channels where three excitations were required to describe the data. The $\omega(1770)$ is very clear from the $\omega\pi^+\pi^-$ channel, the splitting of the $\omega(1420)$ of the PDG into a state at 1250 and 1400 MeV improves the fit but the evidence for the low-mass state is certainly not overwhelming.

Hence there is evidence that the $\rho(1450)$ and the $\omega(1420)$ might be split; the lower mass particles at around 1250 MeV being the 2^3S_1 radial excitation. The higher mass particle has - at least the $\rho(1450)$ - a decay pattern which follows the flux-tube prediction for a hybrid.

It should be mentioned here that there are new beautiful results on rare decay modes of vector mesons. The reader is referred to contributions [a16],[b1-b7].

Conclusions on 1^{--} hybrids:. At present, I would conclude that there are indications that non-$q\bar{q}$ mesons hide in the spectrum of vector mesons. Likely, we have however to wait for the energy upgrade of the Novosibirsk collider before we come to final conclusions and a clear view of vector mesons excitations.

$\mathbf{J^{pc} = 1^{-+}}$ exotics

Introduction. At Hadron 2001, the compatibility and consistency of the results from different channels and from the experiments at BNL and Protvino were discussed. Hence it seems adequate to point out some differences and similarities between the Brookhaven and the VES Experiment. A more detailed discussion can be found in [b8-b12].

The Brookhaven experiment uses a beam of 18 GeV/c while VES uses 28 and 37 GeV/c. Brookhaven uses a hydrogen target, VES uses a nuclear target. Also the analyses are different. Brookhaven fits directly amplitudes to the angular distributions while VES extracts the densitity matrix elements from the data. The amplitudes are then fitted to the density matrics elements. They have developed a new technique to emphasize the coherent amplitudes by extracting the largest density matrics elements. This new technique works very successfully and reduces the background. It should be mentioned that various sources of incoherent background exist. The nucleon may undergo a spin-flip. At VES, the nuclear target may become excited. Both are processes which are distinguishable and lead to a new incoherent set of amplitudes. Also the use of an incomplete set of amplitudes introduces some appearent incoherencies which need to be taken in account. The similarity of the amplitudes and phases from the two experiments proves that these differences in experimental technology have no significant impact on the physics results.

I would like to explain a basic problem in extracting resonant structures in an exotic partial wave using $\pi\eta$ scattering as an example. The scattering process may receive contributions from two different amplitudes, from formation of resonances in the s-channel or from t-channel exchange contributions. Resonance formation leads to a structure in the cross-section and to a rapid phase motion; the decays of a s-channel resonance should not depend on the production mechanism. Exchange processes in the t-channel are background amplitudes. They may be associated with slow phase motions and may also lead to some structure in the cross-section. In $\pi\eta$ scattering with orbital angular momentum 2, the scattering amplitude is dominated by the $a_2(1320)$ meson; the contribution of background amplitudes due to t-channel exchange processes is small. In the orbital angular momentum L=1 wave, resonance formation is certainly much weaker and hence the relative background amplitudes may be much larger. With this word of caution we discuss the experimental results on in the $J^{pc} = 1^{-+}$ partial wave.

The $\pi\eta$ system. Both experiments, at Brookhaven and at Protvino, find nearly identical amplitudes; the phases for the $J^{pc} = 1^{-+}$ wave show a rapid phase variation against the 2^{++}-wave. Amplitude and phase can be fitted using a Breit-Wigner ansatz and leads to a description of the data by one resonance at a mass of 1400 MeV or slightly below. This is the simplest explanation of the data and adopted by the BNL-group. The VES group is fully compatible with these findings. A Breit-Wigner fit describes the data very well and gives results fully compatible with the BNL result. Here one has to note that the VES group indeed found phase motion and the amplitude variation many years before this was reported from the Brookhaven experiment.

The VES group also investigated the necessity of a resonance in the partial wave. They tried hard to find background amplitudes in all participating waves which might conspire to mimic a resonance in the $J^{pc} = 1^{-+}$ wave. Indeed they succeed and this gives a warning that also other interpretations might be found which do not necessarily lead to the claim of resonances with exotic quantum numbers.

The question arises if the optimistic approach which assumes that an exotic resonance has been found is justified. May be the Crystal Barrel data may help here to resolve this question. In the reaction antiproton annihilation at rest on neutrons into $\pi^-\pi^0\eta$ the Crystal Barrel Collaboration observes a clear phase variation in the $\pi\eta$ L=1 partial wave. Hence the optimistic approach seems to be justified, and we may consider the resonant interpretation of the data as very likely.

The $\eta'\pi$ system:. Experimentally the situation is similar as in the $\pi\eta$ sector. Evidence for a non vanishing partial wave with a rapid phase motion was first reported by the VES collaboration but not interpreted as exotic resonance. Brookhaven observed this reaction and reported a new analysis with high statistics at this conference. The old data and new data show a very similar pattern and can be interpreted by a resonance with a mass at about 1600 MeV and a width of 340 MeV. The old VES data are experimentally very close to the Brookhaven result, however the new data with much higher sensitivity seem not to support a resonant structure. The Crystal Barrel collaboration reported supportive evidence for this exotic state from proton-antiproton annihilation into $\pi^+\pi^-\eta'$ [b13].

$\omega\rho$ and $b_1(1235)\pi$:. Both experiment agree that there is a resonant structure at 1600 MeV.

$\rho\pi$:. A sizeable background is present in the low mass range at VES and at BNL. In it particularly large at low masses and excludes the possibility to search for $\pi_1(1400) \rightarrow \rho\pi$ decays. The method of choosing the largest eigenvalue was used by the VES group. For large momentum transfer ($t' \geq 0.15$ GeV^2), a structure at 1600 MeV appears in the 1^{-+} wave but the group is not fully convinced that the peak requires a resonant interpretation. In a coupled channel analysis of $\eta'\pi$, $\rho\pi$ and $b_1(1235)\pi$, evidence for a $J^{pc} = 1^{-+}$ wave resonating at 1610 MeV was reported. In the BNL data - using the full t' range - a clear peak, also at 1600 MeV, in the exotic wave is observed. Its phase is measured against 6 other partial waves; all show a rapid phase advance by 180^0. Meyer-Wildhagen presented Crystal Barrel data on $\bar{p}n \rightarrow \pi^-3\pi^0$ [b14]. The exotic 1^{-+} wave is clearly identified; possibly both the $\pi_1(1400)$ and $\pi_1(1600)$ contribute.

Conclusions on 1^{-+} exotics:. In my view, there is good evidence that 2 1^{-+} exotic mesons have been discovered, the $\pi_1(1400)$ and $\pi_1(1600)$. Ted Barnes had reminded us that hybrids are expected - in the flux tube model - at masses at about 1.9 GeV and above. Low hybrid masses at 1.4 GeV are, however, certainly not fully excluded. So we ask: what is the nature of these two resonances? A striking feature is their decay pattern. The $\pi_1(1400)$ is seen only in the $\pi\eta$ decay mode; the $\pi_1(1600)$ is observed in several channels, including the $\pi\eta'$ decay mode, but not in $\pi\eta$. One may argue that the $\pi\eta'$ decay indicates a gluonic part in the $\pi_1(1600)$ wave function; this could be the reason why it decays into $\pi\eta'$ and not into $\pi\eta$. I do not share this view. In the limit of SU(3) flavour conservation and in the limit that the η is the octet particle, the decay a $J^{pc} = 1^{-+}$ into

$\eta\pi$ is forbidden. If the $\pi_1(1600)$ is an octet meson, it cannot decay into $\pi\eta$; it must decay into $\pi\eta'$. The suppression of the $\pi\eta$ decay mode is therefore not surprising. But why does then the $\pi_1(1400)$ decay into $\pi\eta$? It cannot belong to a meson octet; instead it has to be part of a decuplet. In turn, a decuplet cannot decay into $\pi\eta'$. The strange couplings of the $\pi_1(1400)$ and $\pi_1(1600)$ reflect therefore their different flavour content. The $\pi_1(1400)$ belonging to a decuplet of particles must be a 4-quark state and cannot be of hybrid nature. The $\pi_1(1600)$ however can be both, it could be a hybrid or a multi-quark state. Of course, the closeness in mass and the similarity of the production cross sections may be considered as a hint that both particles have a similar internal structure. One warning: the pattern $\pi_1(1400) \to \eta'\pi$, $\pi_1(1400) \to \rho\pi$ but not to $\pi_1(1400) \to \eta\pi$ which might be seen experimentally is incompatible with SU(3) for any multiplet.

The $\eta(1295)$, radial excitation or non-$q\bar{q}$ state ?

There is another state at comparatively low mass which cannot be a quark anti-quark state and must therefore have a more complicated structure. This is the $\eta(1295)$. The Particle Data Group in the year 2000 edition lists the following nonet of pseudoscalar radial excitations:

$\pi(1300)$	$\eta(1295)$	$\eta(1440)$	K(1460)

New data presented at this conference show that this assignment must be wrong. First I show that the $\eta(1440)$ cannot be the pseudoscalar $s\bar{s}$ state. The $\eta(1440)$ is produced in the pion exchange reaction

$$\pi^- p \to \; n\,\eta(1440)$$

as a strong signal. No signal is however observed in the reaction

$$K^- p \to \; \Lambda \;\; \eta(1440).$$

States with hidden strangeness are abundantly produced in Kaon induced reactions while in pion induced reactions no $s\bar{s}$ states can be produced. The experimental pattern proves therefore that the $\eta(1440)$ cannot be a dominant $s\bar{s}$ state. But then, why is the $\eta(1440)$ decay into $K\bar{K}$ so strong? This can be understood on the basis on the $^3P_0$ model for meson decays. Let us assume that the $\eta(1440)$ is the pseudoscalar radial excitation of the η. Under this assumption the transition amplitude of a radial excitation into $a_0(980)\pi$ vanishes at a mass of the radial excitation of about 1450 MeV. The decay of the $\eta(1440)$ into $a_0(980)\pi$ is then largely suppressed and shifted to low masses. The $K\bar{K}$ decay mode does not suffer from the zero in the transition amplitude and appears unshifted, and with not reduced strength. The $^3P_0$ model therefore predicts that the radial excitation of the η, if it has a mass in the 1400 to 1500 MeV range, should decay strongly into $K\bar{K}$ while the $a_0(980)\pi$ decay mode should be suppressed and shifted to low masses. With its large $n\bar{n}$ component, it should be produced abundantly in pion induced reactions. All the predictions have been observed experimentally.

Then, what is the $\eta(1295)$? The $\eta(1295)$ is seen in various pion reduced experiments, for instance recently by the Brookhaven group in the reaction proton into neutron plus

$\eta\pi\pi$ at 18 GeV as reported this conference [b11]. The pseudoscalar intensity is now even stronger than the $f_1(1285)$ intensity, the 1^{++} wave. The 0^{-+} contribution shows peaks at 1.295 and at 1.4 GeV. The 1^{++} wave peaks at 1285 MeV and also at 1.4 GeV but the wave is grately reduced compared to the pseudoscalar wave. Hence a pseudoscalar state at 1295 MeV is likely to exist even though we note that the properties of the $f_1(1285)$ and the $\eta(1295)$ depend very much on experiment and analysis; obviously there is some feedthrough between $f_1(1285)$ and $\eta(1295)$, Also the new BNL data require the properties of the $f_1(1285)$ to be changed.

In any case, the $\eta(1295)$ cannot be a normal $q\bar{q}$ state. The L3 collaboration reported production of pseudoscalar resonances in two photon collisions. At low (transverse) q^2, they observe in the $K\bar{K}\pi$ mass distribution a clear signal at 1450 MeV but no signal at 1295. At large q^2 ($\geq 1 GeV^2$), a second peak shows up at below 1300 MeV. Note that two real photons (or nearly real photons) do couple to pseudoscalar mesons but not to states with spin 1, due to the Yang-Landau theorem. The strong signal at low q^2 must therefore be due to $\gamma\gamma \rightarrow \eta(1440)$; the $\eta(1295)$ obviuosly decouples from 2 photons. The large 2γ coupling of the $\eta(1440)$ excludes any glueball interpretation of the $\eta/1440)$; the small 2γ coupling of the $\eta(1295)$ makes it very unlikely that it is a conventional $q\bar{q}$ state. At (transverse) q^2 larger than 1 GeV^2, a peak at ~ 1.3 GeV shows up. Virtual photon do have coupling to 1^{++} states; the signal has therefore to be assigned to the $f_1(1285)$ and cannot stem from the $\eta(1295)$.

The two-γ coupling of the $\eta(1440)$ and the decoupling of the $\eta(1295)$ supports the conclusion that the $\eta(1440)$ must be a radial excitation while the $\eta(1295)$ requires an exotic interpretation. We note in passing that the early experiments had observed no signal at 1440 MeV for two untagged (real) photons while a few events were seen when one photon was tagged. This result was interpreted as evidence for the glueball nature of the $\eta(1440)$ and as evidence that the $f_1(1420)$ really exists.

A similar argument has been put forward by the Crystal Barrel Collaboration [b15]. They observe in $p\bar{p}$ annihilation at rest a strong signal due to $\eta(1440)$ production while no signature is observed from $\eta(1295)$. The production rate of the $\eta(1440)$ (in $p\bar{p} \rightarrow \pi^+\pi^-(\pi^+\pi^-\eta)$ is of the same order of magnitude as that for production of the $\pi(1300)$. The rate for $\eta(1295)$ production is however lower by a factor 30 than this naive expectation. Again, the $\eta(1440)$ makes a much better compagnon of the $\pi(1300)$ than the spurious $\eta(1295)$.

Finally I would like to mention that the OBELIX collaboration reportet a scalar resonance at 1420 MeV, with isospin 2 [b16]. The identification of exotics in the baryon sector is even more difficult. There are states with possibly anomalously large couplings to final states with strangeness [b17]. Possibly, they are pentaquarks and contain hidden strangeness.

Conclusions on 0^{-+} hybrids or glueball:. I believe that there is only one $\eta(1440)$ in the 1400 to 1500 MeV mass range. Its splitting can be understood within the $^3P_0$ model. The $\eta(1440)$ and not the $\eta(1295)$ is the radial excitation of the η. It is the nature of the $\eta(1295)$ which is unclear.

HYBRID CANDIDATES AT HIGH MASSES

In the flux tube model hybrids have masses at or above 1.9 GeV and do not need to have exotic partial waves. It is therefore important to identify high mass meson resonances and to establish the pattern of quarkonia states over the full mass range up to 2.2 GeV or even higher. A large number of resonances, partly new ones, partly known ones, were reported at Hadron 2001 [b8,b9,b18-b20].

Of particular interest are the $\pi(1800)$ and the $\pi_2(1900)$. The pseudoscalar isovector resonance at a mass of 1800 MeV had been discovered by VES and further studied at Brookhaven and at VES. The state is now seen in variuos decay channels; the observations can be grouped into channels where the $\pi(1800)$ has an apparently high mass of about 1870 MeV. These are $\eta\eta\pi$, with two identified isobars $f_0(1500)\pi$ and $a_0(980)\eta$, and $\eta\eta'\pi$. In contrast, the $\omega\rho$ amplitude shows a maximum at 1775 MeV. VES reports that the three-pion channel globally has a resonant π wave at 1775 MeV; BNL separates the 3π mode into one isobar, $\pi\pi_{\mathrm{s-wave}}$, at high mass and a low-mass state with $\rho\pi$ and $f_0(980)\pi$ isobars. Hence there is evidence that the $\pi(1800)$ is split into 2 states, a $\pi(1775)$ and a $\pi(1870)$.

Clearly, the quark model cannot accommodate two pionic excitations so close in mass. One of these needs to be of different nature, possibly a hybrid. This idea is suported by decay calculations which predict that a $q\bar{q}$ state and a hybrid should have different decay patterns [i1]. The expectations are listed in Table **??**.

TABLE 2. Partial width of a $\sim$ 1800 MeV $\bar{q}q$ and resonance and a hybrid with quantum numbers of a pion [i1].

Decay	$\rho\pi$	$\rho\omega$	$\rho(1465)\pi$	$f_0(1300)\pi$	$f_2\pi$	$\bar{K}K^*$	tot
3_0^S	31	73	53	7	28	36	228
hybrid	30	0	30	170	6	5	240

The high-mass component of the $\pi(1800)$ with its strong decay to scalar plus pseudoscalar can thus identified with a hybrid, the low-mass component with the second π radial excitation.

The π_2 wave also shows an interesting double structure. Fits to the 2^{-+} partial wave require not only the well known $\pi_2(1670)$ but also a second state at 1900 MeV. Both channels, $\rho\pi$ and $\omega\rho$, cannot be fitted with just one resonance; a high-mass shoulder is seen in addition to the well-established $\pi_2(1670)$. The $\omega\rho$ 2^{-+} partial wave - from which the evidence for the second state is derived - poses a problem: the $\pi_2(1670)$ is seen to decay into $\omega\rho$ via the intrinsic-spin 2 amplitude. This decay mode is incompatible with the $^3P_0$ predictions (using a $\vec{\sigma}\cdot\vec{p}$ operator). If the experimental result proves to be correct, the $^3P_0$ model is false and cannot be used to identify non-$q\bar{q}$ objects.

In any case, the occurence of two resonances in the same partial wave separated in mass only by 200 to 250 MeV is a challenge to the quark model and indicates the presence of dynamics beyond the $q\bar{q}$ system. This claim is supported by the possible observation of two η_2 states, one well known at a mass of 1645 MeV and second one at a mass of 1860 MeV. Likely the $\pi_2(1890)$ and $\eta_2(1860)$, if confirmed, belong to the same particle multiplet. The 2 η_2 states are certainly not a $n\bar{n}$ and a $s\bar{s}$ state since they both are produced with similar yield in $p\bar{p}$ annihilation.

Conclusions on high-mass hybrids:. There is good evidence that the $\pi(1800)$ is split into two components, a $\pi(1775)$ $\bar{q}q$ resonance and a $\pi(1870)$ hybrid. Also in the π_2 and η_2 partial waves two separate resonances were reported. The experimental evidence for two close-by states - where one is expected only in the quark model - is the primary reason for this evidence. In case of the $\pi(1800)$ there is addiditional support for this interpretation from the observed decay pattern. The decay of the supposedly $\bar{q}q$ $\pi_2(1670)$ into $\omega\rho$ with intrinsic spin 2 is however very intriguing: if confirmed it invalidates the $^3P_2$ model which is the basis for identification of resonances as quarkonia or hybrids.

SCALAR MESONS AND THE SEARCH FOR THE SCALAR GLUEBALL

The particle data group assigns the

$a_0(1450)$	$f_0(1370)$	$f_0(1750)$	$K_0(1460)$

to the lowest laying one triplet scalar meson nonet. The $a_0(980)$ and $f_0(980)$ are interpreted as molecules or four-quarks states. The $f_0(1500)$ is the tenth meson, not belonging to the scalar nonet. It is considered as scalar glueball of lowest mass. New data were presented as this conference which shake this interpretation.

The $f_0(980)$ and $a_0(980)$

There is a long standing debate on the nature of the $a_0(980)$ and $f_0(980)$ states. Both are close to the $\bar{K}K$ threshold and their mass is obviously strongly influenced by this. Their unexpected small width and their strong coupling to $\bar{K}K$ is the basis for their interpretation as $\bar{K}K$ molecules. Following Jaffe, there is a strong attraction between qq and $\overline{qq}$ in S-wave and spin singlet; a low-mass nonet can be constructed with $a_0(980)$ and $f_0(980)$ being the two $n\bar{n}s\bar{s}$ states. Again, the two states are not $\bar{q}q$ states, and can be disregarded when the lowest lying $\bar{q}q$ scalar nonet is constructed. There are, however, also arguments speaking in favor of the two states being normal $\bar{q}q$ mesons.

There is the believe that radiative decays of the Φ meson into $a_0(980)$ and $f_0(980)$ should clarify the internal structure of these two important mesons. Results from Novosibirsk [c1] and preliminary data from CLOE [c2] were reported at this conference on the branching ratios for these two reactions. The two results agree approximately but not fully within the quoted errors. However, the CLOE result is still preliminary and the small discrepancies do not lead to different conclusions. N. Achasov [c3] argued in his contribution that the rates are only consistent with an $\bar{K}K$ molecule interpretation. A. Anisovich [c4] presented a calculation based on the hypothesis that the two scalar mesons are $\bar{q}q$ states, and obtained full agreement with data. The wave function at the origin is not calculated but has the same size as other $\bar{q}q$ mesons.

V. Uvarov [c5] compared the yields of various mesons in the decay of Z^0 bosons. The fraction of mesons produced in the fragmentation depends on their mass and on the intrinsic number of strange mesons. So the production rates for mesons like ω, ρ, $f_0(980)$ and $a_0(980)$, and $f_2(1270)$ lie on one line which is linear on a logarithmic scale. The K and K^* lie on a separate line due to having one strange quark, the Φ and the $f_2(1525)$ lie on a third line as function of their mass. Hence the first evidence favours a $\bar{q}q$ interpretation of the $f_0(980)$ and $a_0(980)$. However, V. Anisovich [c6] and Sarantsev [c7] assign a bare mass of 720 MeV to the $f_0(980)$. This mass would then fall on the line with two intrinsic unit of strangeness and hence the production rate could be compatible with a $\bar{K}K$ structure. The phase space is of course given by the physical mass; no argument is given why the pole in the K-matrix should be responsible. Also, the argument does not apply to $a_0(980)$ production.

In a very detailed way analysis the Delphi Collaboration has demonstrated that the production from Z^0 decay does not differ in any respect from the production of well known $\bar{q}q$ states and that an interpretation as four-quark state or molecule seems not plausible. Hence the question if the $f_0(980)$ and $a_0(980)$ are $\bar{q}q$ states, $\bar{K}K$ molecules or four-quark states seems still, from an experimental point of view, still unresolved.

Conclusions on $a_0(980)$ and $f_0(980)$:. Generally speaking, we should expect that these mesons have a complex Fock expansion and that a $\bar{q}q$ component, a molecular component and a four-quark component can coexist with open and presently unknown fractional contributions. Personally, I believe that the $\bar{q}q$ component is the largest one. The best possibility to find out the size of the various component might be to search for $a_0(980)$ to ργ radiative decays. In any case, if these mesons do have a $\bar{q}q$ component, this component then reflects the genuine $\bar{q}q$ state which is attracted by the $\bar{K}K$ threshold and thus acquires a large $\bar{K}K$ component. This view would be inconsistent with leaving these two mesons out of the discussion of ordinary $\bar{q}q$ states.

Scalar mesons with isospin zero

Beautiful results were presented from BABAR [c8,c9] and BELLE [c10] and from Fermilab [c11] on the decay of B mesons into different final states. These data may have a large impact on low-mass light mesons which are abundantly reduced in decays. Particularly interesting are decays of D_s mesons to three pions since in this decay there is primary formation of an $s\bar{s}$ state which then decays into non-strange particles. This transition remembers pseudoscalar mesons which also link $n\bar{n}$ components and $s\bar{s}$ components. But also decays of D_s into $K_s^0K_s^0\pi$ and D decays into 3 pions, into one Kaon and to two pions, two Kaons and one pion, and into 3 Kaons show very interesting structures. The statistics in these channels is limited at the moment but very high statistics data can be expected in the near future. Also, the analysis methods will partly need to become more sophisticated before final conclusions can be drawn.

BES reported a considerable increase in statistics in J/ψ radiative decays [c12] in a large variety of final states. Particularly interesting is the decay into $\bar{K}K$, the reaction in which the old θ(1690) was discovered. The new data show that the $f_J(1710)$ as it is called now, clearly has J=0. A small tensor distribution is possible but not really required. This resonance is discussed as possible scalar glueball.

In this context, its two photon width is very important. The BELLE Collaboration investigated photon-photon fusion to $\overline{K}K$ [c13]. They clearly see the $f_2(1525)$ and have further peaks at 1.75 GeV, 2 GeV and 3 GeV. The resonances at 1750 and 2000 MeV favour spin 2. In J/ψ decays, the dominant part had scalar quantum numbers. This part has little coupling to two photons; hence it is not $\bar{q}q$. The small tensor part in J/ψ decays is, in comparison, enhanced in two-photon fusion. That part is $\bar{q}q$.

Unfortunately, the situation is not so clear. The BELLE Collaboration also has data on photon-photon fusion into $K_s^0K_s^0$ [c14]. In this reaction they find the $f_2(1525)$, as before, and a resonance at 1750 MeV. This time the amplitude analysis favours spin zero. Clearly the K^+K^- and $K_s^0K_s^0$ must have identical partial wave contributions from scalar or tensor mesons and the situation is certainly not well understood.

Unfortunately the WA102 collaboration is not represented at this conference. But in this context, I have to mention their results on central production of four pions. The scalar part of four pion central production shows a strong peak due to the $f_0(1370)$, dip at 1500 MeV which is assigned to the $f_0(1500)$ and a wide bump at a mass of about 1800 MeV. The latter is decomposed into the $f_0(1750)$ and a further scalar meson at about 2 GeV. This distribution is seen in the $\pi^+\pi^-2\pi^0$ and in the $2\pi^+2\pi^-$ final states; the $4\pi^0$ final state has contributions only from the $f_0(1500)$.

The picture resembles very much to the one in the two-pion sector. The $f_0(980)$ is seen as a dip in a wide distribution [c15], called $f_0(1000)$ by Morgan and Pennington, and *reddragon* by Minkowski and Ochs [c16]. The wide distribution is of unknown nature; it may be a very wide glueball [c16] or generated by t-channel exchange. The strange behaviour of the 4π system can be understood assuming that it also generated by ρ exchange in the t channel. In Pomeron-Pomeron scattering, ρ exchange may lead to $\rho\rho$ but never to $4\pi^0$.

This is in accordance with the observation of the Crystal Barrel Collaboration observing a strong signal from $f_0(1370)$ in its $4\pi^0$ decay, both in the reaction $\bar{p}p\to 5\pi^0$ and $\bar{p}n\to \pi^-4\pi^0$. This is a clear conflict between WA102 and Crystal Barrel data and may indicate that the $f_0(1370)$ decay modes are not independent of its production mechanism. This unusual behaviour suggests that the (1370) is not a s-channel resoance but rather generated by t-channel exchange processes, in particular by ρ exchange. Hence theoreticians should be cautious when using the $f_0(1370)$ in mixing scenarios in which $\bar{q}q$ states are mixed with the lowest scalar glueball.

Finally I should mention that the t-channel poles which we observe do not necessarily need to be the genuine $\bar{q}q$ resonances as calculated for instance in quark models. The bare states couple to their final states and this may result in grossly shifted resonance positions. Anisovich an collaborators assign the K matrics pole to the bare poles, to the true $\bar{q}q$ states. This pattern of states is very different from the pattern of T-matrix pole positions which are listed by the PDG. Of course, this is a highly theoretical issue but we should have in mind that a straight forward interpretation of meson resonances may lead to wrong conclusions. This warning is particularly true in case of scalar mesons. The shifts are much smaller in cases where the orbital angular momentum barrier is active.

Conclusions on scalar mesons and the scalar glueball:. I do not share the optimistic view that the scalar glueball has unrevealed its existence and has been identified by mixing between adjacent $\bar{q}q$ states. Such scenarios have several rather weak points.

The $f_0(980)$ belong, in my view, to the scalar $\bar{q}q$ states. (Admittly, it may have a large $K\overline{K}$ component). The $f_0(1370)$ is likely generated by t-channel exchanges and is rather a $\rho\rho$ molecule and not a genuine $\bar{q}q$ state. Its decay properties seem to depend on the production mechanism. In the solution offered by Anisovich et collaborators, $f_0(980)$ is described by two K-matrix poles far apart from the T-matrix pole position. At large momentum transfer to the $\pi\pi$ system, the $f_0(980)$ is seen as clear peak above little background, and it seems unnatural that two K-matrix poles conspire to produce a peak above a small residual background. Thus I believe that the scalar nonet is given by the nine states

$a_0(980)$	$f_0(980)$	$f_0(1500)$	$K_0(1460)$

The $a_0(1450)$, $f_0(1750)$, $f_0(1750)$ and $K_0(1950)$ could form the nonet of scalar radial excitaions. The broad scalar background has certainly contributions from t-channel exchange processes; it may comprise contributions from the scalar glueball. But this is speculative, mass and width can certainly not be given.

The tensor glueball

Finally I would like to recall searches for the tenser glueball. There is one famous candidate the so called $\zeta(2220)$. It is observed to decay into $\pi\pi$, $\eta\eta$, and proton antiproton, but in all channels with low statistical significance. In particular it is unclear if the width is really so small as claimed. The decay of the $\zeta(2220)$ to $\pi\pi$ and to proton antiproton allows to calculate the production cross section with which one should see the state in proton antiproton annihilation in flight. The Crystal Barrel Collaboration has searched for the resonance in a fine scan of antiproton proton annihilation into various final states and no signal was found at the expected height. So there is at least an inconsistency in the decay pattern. Certainly, the statistical significance of this state is not large enough to claim that an anomalous state was discovered which could be identified with the tensor glueball. Another longstanding claim for the tensor glueball was made at Brookhaven from the reaction π^- + proton $\rightarrow$ neutron + $\Phi\Phi$. New data on $\Phi\Phi$ from the ??? experiment were shown at this conference. The signal is clearly seen, the mass distribution shows a threshold enhancement which can be fitted using one resonance only. A slightly improved description can be found using two tensor resonances; three are certainly not required. From the quark model, we expect two $s\bar{s}$ tensor states in this mass region. So the claim for a tensor glueball which mixes with the two quarkonia states is no longer justified.

BARYON SPECTROSCOPY

Baryons are hadrons! For a long time, light baryon spectroscopy played pratically no role in the hadron conference series. Now I am very pleased to see that there are several talks related to baryon spectroscopy. The reason for this is of course the chance that the field may get a boost because of the new facilities at Jefferson lab, Spring8, Grenoble, MAMI, and ELSA. Surprisingly, the clearest resonant structures came from BES. The preliminary partial wave analysis of the reaction $J/\psi \to p\pi^-\bar{n}$ suggests that the $N^*_{1/2^-}(1535)$, $N^*_{3/2^-}(1520)$, $N^*_{5/2^+}(1675)$, and $N^*_{5/2^+}(1680)$ are observed. The phase space ends at slightly above 2 GeV, but the power of the method is established. Study of ψ' decays will open the phase space up to the interesting region up to 2.7 GeV.

Photo- and electroproduction

At Jefferson lab, electroproduction of $K^+\Lambda$ was studied with very high precision, and over a wide energy range. Total and diferential cross section and the polarisation transferred to the Λ were measured over a wide range of momentum tranfers. The precision of the data is certainly a challange to any theoretical model aiming at describing the $s\bar{s}$ production mechanism.

From MAMI and ELSA, a test of the Gerasimov-Drell-Hearn sum rule was reported. The summation over all energies over the total photoabsorption cross section $\sigma_{3/2} - \sigma_{1/2}$ for polarised photons and polarised protons is related to the anomalous part of the proton magnetic moment. The high-precision data from MAMI covering the range up to 860 MeV are now augmented by data from ELSA up to 2.4 GeV. The integrated cross section difference starts to level off approaching the GDH sum rule value. If the high-energy part as expected from dispersion relation is added the sum is slightly overshot.

The GRAAL collaboration reported measurements of the η photoproduction. Precise data are available from MAMI [**?**] but only up to 800 MeV. The new GRAAL data extend the range to 1.1 GeV, and (not yet analysed) data at higher energies are on tape. The Crystal Ball was used at BNL to study pion and Kaon induced η production at threshold. In both cases the cross section rises steeply; in pion scattering due to the onset of the $NS_{11}(1535)$; in Kaon scattering the $\Lambda S_{01}(1670)$ is observed. These two resonances have large couplings to the η plus ground state; they share this property with the $\Sigma S_{11}(1750)$. These are the only known resonances with large couplings to the η. Crede (for the CB-ELSA collaboration) reported first results on photoproduction of $\pi^0\eta$ where they may see a $\Delta\eta$ threshold enhancement. Data on $2\pi^0$ production also show intersting structures over a wide mass range: baryon spectroscopy has entered a new phase and we may expect a substantial increase in our knowledge.

Analysis problems and a common data base

Dytman demonstrated how refined the analyses have to become to get the best precision out of the data. Combined analyses of several reactions in multi-channel fits are required to identify the exact pole positions. Here I guess we - the meson spectroscopy community - have to learn a lesson: groups working at J-Lab (and elsewhere) have formed BRAG, a baryon resonance analysis group. Data are made publicly available; data are published with fits and reference to an analysis paper describing in details the analysis methods. The Carnegie Mellon University plans to set up a large data-base center for multiparticle production experiments (like we had at Durham for data on cross sections). I firmly believe that this is the way we have to go, and we all should contribute to support such a center.

FUTURE FACILITIES

e^+e^- colliders

We have seen the substantial increase in significance which was obtained by an increase of the statistics in J/ψ decays from a few million events to now 24 10^6 events. Bejing plans an further improvement of the luminosity []; in parallel, Cornell has decided to go down in energy and up in luminosity []. In a couple of years we will have 10^9 J/ψ and ψ′ decays. These data will have a decisive impact on light-meson spectroscopy. In particular we can hope that the question if glueballs exist can finally be answered. Does the low-mass scalar glueball manifest itself by mixing with $^3P_0$ $\bar{q}q$ mesons [**?**], has it to be identified with the *reddragon* of Minkowski and Ochs [**?**], or is the life time of glueballs so short that they do not manifest themselves in meson spectroscopy [**?**] ?

We also will see high-statistics data from KLOE and from Novosibirsk. KLOE will provide not only data on ε'/ε from Φ decays $\bar{K}K$. In parallel we will get precise information on radiative decays of Φ mesons into light mesons. The energy upgrade in Novosibirsk will provides for precision studies of light vector mesons.

At the high-energy end, we have seen the significant impact B factories will have on the spectroscopy of light mesons [,]. We can anticipate that also D^* resonances will play a major role as bridge from light to heavy mesons.

Photo- and electroproduction

The Jefferson laboratory proposes an energy upgrade to 12 GeV. One of the fascinating options will be to use coherent bremsstrahlung to produce a linearly polarised photon beam of 8 GeV, collimated to accept only the narrow (0.5 GeV) energy window in which the polarisation is high. The hope is that the polarised photon beam has a particularly large coupling to mesonic systems with intrinsic quark spin 1, and that the string providing the binding between quark and antiquark can and will be excited.

MAMI in Mainz will receive an upgrade to 1.4 GeV. This will allow precision experiments at different thresholds; the limits of chiral symmetry will be tested at larger energies, e.g. at the strangeness production thresholds. The lower baryon resonances will be mapped precisely, and transition form factors to these states can be determined. Several other facilities extend the energy range all over the baryon resonance region, Spring8, GRAAL, ELSA and, of course, J-lab with its present facility.

The GSI Project

The Gesellschaft für Schwerionenforschung plans a complex facility, with a wide range of experimental possibilities. The core of the facilility is a high-intensity 60 GeV proton synchroton with fast cycling superconducting magnets. The complex allows studies of rare isotopes, plasma physics and hadronic matter at highest baryon densities. Of particular importance for us is the option to produce intense beams of antiprotons. A high-energy /15 GeV) storage ring for antiprotons will support a rich program. There is the chance that hybrids with hidden charm can be formed; some of these hybrids may be below the preferred decay mode, one S-wave and one P-wave D-meson, and could thus be narrow. The potential of such an instrument was demonstrated at Fermilab but certainly not exploited in full.

Intense Kaon beam are not yet part of the GSI proposal but I am shure, the pressure on GSI to install such a beam line will increase once the proton synchroton is operational. Kaon induced reactions are mandatory for a proper understanding of low-energy phenomena; the beams can make a significant contribution to meson and baryon physics, to nuclear physics and - through Kaon decays - possible also to physics beyond the atndarad model.

The future

There are several first-class facilities allowing to study strong interaction in the confinement region. Some of them have just started operation, others are being constructed, other are in the planning stage. Even if not all of the new ones will be funded, there is ample room for imaginative new experiments. The future of the field does not depend on others, it depends on us: we have to ask the right questions, we have to find the right answers, and we have to communicate our enthusisme for the field to others: to our students, to our colleagues and to the general public.

CONCLUDING REMARKS

I would like to conclude in expressing my satisfaction that the study of baryons became again a lifely subject in hadron spectroscopy. In light-meson spectroscopy we became used to think in a rather well-defined frame: mesons are described as excitations of constituent quarks, the intrinsic forces are given by a kind of effective gluon exchange. And gluons play an important dynamical role, in creating hybrids and glueballs. The widespread conviction that this picture is correct is however much more driven by theoretical visions than by experimental facts. I believe that baryon spectroscopy can provide very important check of this understanding of low-energy strong interaction. First, baryons are three-quark systems. There is more freedom in the system and the the internal interactions are unrevealed in a more direct way. And, secondly, the community has developed a different language to describe strong interactions. When strong interactions is discussed, the concept of gluon exchange is replaced by quark- and gluon-condensates.

And instead of quenched lattice QCD, superconductivity provides a frame of visualising strong QCD. It is my hope that the study of mesons *and* baryons and joint efforts of both communities will lead to better understanding of strong interactions in the low-energy range. And this is of course our *mission*, certainly not stamp collection but also not just to identify hadronic systems beyond the quark model.

Last not least, it is my priviledge as concluding speaker to thank the organisers for the work they did in order to host this exciting conference. We all will memorize the friendly atmosphere, the concerts, the excursion and the forest around the place and, above all, the frendship and hospitality we received at HADRON2001 in Protvino.

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