Searching for Soft Glue: Hybrids and Glueballs*

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Abstract

The experimental and theoretical status of hybrids and glueballs is reviewed. Current ideas about the decays of hybrids and glueballs are also discussed.

1 Introduction

We present a brief summary of the status of QCD gluonic exotics – hybrids and glueballs. These states are exotic in the sense that they do not have $q\bar{q}$ or qqq valence quark content. In terms of a constituent picture of glue, exotics contain valence gluons. Alternatively, in the flux tube picture of glue, hybrids have their flux tubes in an excited state while glueballs are flux tubes with no associated valence quarks. Discovering, characterizing, and understanding exotics is clearly a vital step in understanding the behaviour of strongly coupled field theories at low energy. Thus exotics are important to learning about confinement and spontaneous symmetry breaking.

Before proceeding, it is worthwhile stressing something which is often glossed over. The notion of an exotic is not defined in QCD – it only

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exists with respect to the constituent quark model. Furthermore, quantum number-exotic hadrons also are defined with respect to the quark model (one should talk about "quark model exotics") – they have no absolute definition in QCD.

For the sake of brevity, in the following most of the information is presented in the form of tables with comments. References specific to the table appear in the same section for ease of use.

2 Hybrids (experiment)

2.1 $\pi(1800)$ and $\pi(1580)$

The $\pi(1800)$ is a longstanding hybrid candidate due to its peculiar decay properties. (Note that the situation has become more complicated with the report of a $\pi(1580)$ state by D.V. Amelin at Hadron '97). Theoretical expectations for decay widths are given below. The second column assumes that the $\pi(1800)$ is a 3S state (note that Godfrey and Isgur, Phys. Rev. **D32**, 189 (1985) predict a 3S π mass of 1880) and calculates its decays using the well-established $^3P_0$ model of hadronic couplings. The third and fourth columns assume that the $\pi(1800)$ is a hybrid state and calculates its decays using the IKP model (referenced below) or an alternative model. Both decay models assume that hybrids may be described with the flux tube model of Isgur and Paton, Phys. Rev. **D31**, 2910 (1985). Rows indicated by $\Rightarrow$ clearly distinguish the quarkonium and hybrid interpretations of the $\pi(1800)$. The fact that they do so for both hybrid decay models indicates the robustness of using the $\omega\rho$ and $\pi f_0(1300)$ decay channels as probes of the $\pi(1800)$ structure.

[1] T. Barnes, F. Close, P. Page, and E. Swanson, Phys. Rev. D55, 4157 (1997).
[2] N. Isgur, R. Kokoski, and J. Paton, Phys. Rev. Lett. 54, 869 (1985); F. Close and P. Page, Nucl. Phys. B443, 233 (1995).
[3] E. Swanson and A. Szczepaniak, Phys. Rev. D56, 5692 (1997).

A strong indication that the $\pi(1800)$ may indeed be a hybrid is shown in the following table. This table compares experimental and theoretical (using model [3] above) branching fractions. The agreement is remarkable.

[1] A. M. Zaitsev, Jad. Phyz. 59, 1674 (1996).
[2] P. Page, E. Swanson, and A. Szczepaniak, in preparation.

Γ (MeV)	$\pi_{3S}\|_{BCPS}$	$\pi_H\|_{CP}$	$\pi_H\|_{SS}$
$\pi\rho$	30	30	38
$\Rightarrow \omega\rho$	74	–	–
$\pi\rho(1465)$	56	30	4
$\Rightarrow \pi f_0(1300)$	6	170	73
πf_2	29	6	1
$K^*\bar{K}$	36	5	6
$K_0^*(1430)\bar{K}$			85

Mode	VES [1]	PSS [2]
$\pi\rho$	< 0.36	0.31
$\omega\rho$	0.4 ± 0.2	0
$\pi f_0(1300)$	0.9 ± 0.36	0.6
$K^*\bar{K}$	< 0.06	0.05
$K_0^*(1430)\bar{K}$	1.0 ± 0.3	< 0.7

2.2 $\rho(1465)$ and $\omega(1420)$

Although the $\rho(1465)$ and $\omega(1420)$ lie in the expected mass region for 2S vector quarkonia (Godfrey and Isgur predict masses of 1450 MeV and the 2S pion appears at 1300 as expected), their peculiar decay properties appear to require hybrid components to be explained. We simply refer to the following papers for further information:

[1] A. Donnachie and Yu. Kalashnikova, Z. Phys. **C59**, 621 (1993).

[2] A. Donnachie, Yu. Kalashnikova, and A.B. Clegg, NCSU/JLab Workshop Proceedings (1997).

2.3 1^{-+} exotics

The subject of quantum number-exotic hybrids has recently been invigorated by claimed observations of several possible 1^{-+} states at Brookhaven. It is worthwhile, however, to note that there is a reasonably long history of observations, some of which are summarized in the table below.

[1] Z. Phys. **C34**, 157 (1987)

[2] Alde et al., Phys. Lett. **205B**, 397 (1988)

group	exotic mass	mode	ref.
CERN-Ω	1.9	$b_1\pi$	[1]
GAMS	1.4	$\pi\eta$	[2]
SLAC	1.8	$\pi\rho$, πf_2	[3]
VES	1.6	$\pi\eta$, $\pi\eta'$	[4]
KEK	1.4	$\pi\eta$	[5]
BNL	1.6-2.2	πf_1	[6]

[3] Condo et al., Phys. Rev. **D43**, 2787 (1991)
[4] Beladidze et al., Phys. Lett. **313B**, 276 (1993)
[5] Aoyagi et al., Phys. Lett. **314B**, 246 (1993)
[6] Lee et al., Phys. Lett. **323B**, 227 (1994)

The recent results of E852 at Brookhaven and the confirmation by the Crystal Barrel Collaboration are summarized below. It appears certain that something is happening at 1400 MeV but whether this is an exotic resonance is problematic (see the comments of A. Dzierba, NCSU/JLab Workshop Proceedings, Nov. 1997). It certainly is too light compared to theoretical prejudices and recent quenched lattice calculations. It also appears in the $\pi\rho$ channel which is not favoured by hybrid decay models. In these regards, the newer sightings at 1600 and 1800 MeV appear to be much more favourable.

expt	mass	Γ	ref
E852	$1370 \pm 16^{+50}_{-30}$	$385 \pm 40^{+60}_{-105}$	[1]
CBAR	$1400 \pm 20 \pm 20$	$310 \pm 50^{+50}_{-30}$	[2]
E852	$1593 \pm 8 \pm ?$	168 ± 20	[3]
E852	~ 1800	?	[4]

[1] D.R. Thompson *et al.* (E852) Phys. Rev. Lett. **79** 1630 (1997).
[2] A. Abele *et al.* (CBAR), to appear Phys. Lett. B.
[3] D.P. Weygand and A. Ostrovidov, Hadron '97.
[4] J. Cummings, NCSU/JLab Workshop Proceedings, (1997).

3 Hybrids (theory)

Theorists have been calculating hybrid masses for 21 years now. The most popular early methods were the MIT bag or bag-like models and QCD sum rules. More recently, flux tube models have been in favour. I stress that none of these models should be regarded as reliable – much more work comparing to experimental and lattice data is required before one may be confident in their predictions. We are fortunate that lattice gauge theory calculations are finally able to predict hybrid masses with some degree of certainty (although the calculations remain quenched, have difficulty reaching light quark masses, and typically have the wrong number of quark flavours).

Since there is not sufficient space to discuss these models, predictions for various 1^{-+} hybrids are presented below without comment.

3.1 Predicted 1^{-+} Hybrid Masses

Model	$u\bar{u}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$
MIT Bag [1]	1.3-1.8		~ 3.9	10.5
HHKR bag [2]			3.9	10.49(20)
QCD Sum Rules [3]	2.1-2.5		4.1-5.3	10.6-11.2
Flux Tube [4]	1.8-2.0		4.2-4.5	10.8-11.1
BCS [5]	1.8-1.9	2.1-2.2	4.1-4.2	
UKQCD [6]		2.00(20)		
MILC [7]	1.97(9)(30)	2.17(8)(20)	4.39(8)(20)	
adiabatic [8]			4.2	10.8
adiabatic [9]				10.8
NRQCD [10]				11.10(16)

[1] T. Barnes, CalTech PhD thesis, 1977; T. Barnes, F.E. Close, and F. de Viron, Nucl. Phys. **B224**, 241 (1983); M. Chanowitz and S.R. Sharpe, Nucl. Phys. **B222**, 211 (1983); M. Flensburg, C. Peterson, and L. Sköld, Z. Phys. **C22**, 293 (1984).
[2] P. Hasenfratz, R. Horgan, J. Kuti, and J.M. Richard, Phys. Lett. **95B**, 229 (1981).

[3] J. Goevarts, F. de Viron, D. Gusbin, and J. Weyers, Nucl. Phys. **B248**, 1 (1984); Phys. Lett. **128B**, 262 (1983); (E) Phys. Lett. **136B**, 445 (1983); J. Latorre, S. Narison, P. Pascual, and R. Tarrach, Phys. Lett. **147B**, 169 (1984).
[4] N. Isgur and J. Paton, Phys. Rev. **D31**, 2910 (1985); J. Merlin and J. Paton, J. Phys. **G11**, 439 (1985); Phys. Rev. **D35**, 1668 (1987).
[5] T. Barnes, F. Close, and E. Swanson, Phys. Rev. **D52**, 5242 (1995).
[6] P. Lacock *et al.* (UKQCD Collaboration), Phys. Lett. **B401**, 308 (1997); hep-lat/9708013.
[7] C. Bernard *et al.* (MILC Collaboration), hep-lat/9707008.
[8] S. Perantonis and C. Michael, Nucl. Phys. **B347**, 854 (1990).
[9] K. Juge, J. Kuti, and C. Morningstar, hep-lat/9709131.
[10] T. Manke *et al.* (UKQCD Collaboration), hep-lat/9709001.

For the sake of completeness, I also present other recent lattice hybrid mass calculations below. The citations refer to those in the previous table. Of particular note is the recent paper of Juge, Morningstar, and Kuti, hep-lat/9709131. These authors have performed a detailed calculation of the adiabatic potential surfaces of a heavy hybrid. These results will be vital in testing the viability of models of hybrids and have already ruled several of them out (Swanson and Szczepaniak, hep-ph/9804219v2).

J^{PC}	quark content	mass (GeV)	ref
0^{+-}	$c\bar{c}$	4.61(11)	[7]
0^{+-}	$s\bar{s}$	2.26(20)	[6]
2^{+-}	$s\bar{s}$	2.37(20)	[6]
1^{--}	$b\bar{b}$	11.08(1)	[10]
0^{++}	$b\bar{b}$	11.23(6)	[10]
1^{++}	$b\bar{b}$	11.13(5)	[10]
2^{++}	$b\bar{b}$	11.11(5)	[10]

3.2 Hybrid Decays

Understanding how hybrids couple to hadronic states is crucial if we are to detect and identify exotic states. Theoretical models of hybrid decay contain two ingredients (1) a model of the hybrid (2) a model of the decay vertex. The earliest models assumed constituent glue hybrids ($q\bar{q}g$) and allowed them to decay via the naive application of perturbation theory [1,2].

The most widely quoted model is that of Isgur, Kokoski, and Paton [3,4]. The authors assume the validity of the flux model description of hybrids and associate decay with quark pair production via the $^3P_0$ mechanism followed by the requisite flux tube reformation into ground state flux tubes.

An alternative hybrid decay model has recently appeared [5] which is also based on the flux tube picture of hybrids but which assumes a different decay vertex from that of [3]. The essential difference between the two models is that the quark pair is produced with $^3P_0$ quantum numbers in [3] and with $^3S_1$ quantum numbers in [5]. The models have been compared extensively in [6].

In spite of the widely varying assumptions in these decay models, they all share the following features: hybrids do not decay to identical S-wave mesons and hadrons with quark spin zero do not decay to hadrons which also have zero quark spin. These two rules, coupled with the expected hybrid masses, are frequently enough to determine many properties of hybrids, and may thus be expected to be universal in some sense [7]. While both of these rules are predicated on nonrelativistic quantities, it is very likely that they will be useful guides to hybrid decay.

[1] M. Tanimoto, Phys. Lett. **116B**, 198 (1982).

[2] A. Le Yaouanc, L. Oliver, O. Pene, J.-C. Raynal, and S. Ono, Z. Phys. C **28**, 309 (1985); F. Iddir, A. Le Yaouanc, L. Oliver, O. Pene, and J.-C. Raynal, Phys. Lett. **207B**, 325 (1988).

[3] N. Isgur, R. Kokoski, and J. Paton, Phys. Rev. Lett **54**, 869 (1985).

[4] F.E. Close and P. Page, Nucl. Phys. **B443**, 233 (1995).

[5] E. Swanson and A. Szczepaniak, Phys. Rev. **D56**, 5692 (1997).

[6] P. Page, E. Swanson, and A. Szczepaniak, to appear.

[7] P. Page, Phys. Lett. **B402**, 183 (1997).

4 Glueballs (experiment)

4.1 $f_0(1500)$

The $f_0(1500)$ is a justifiably famous exotic candidate. The isoscalar scalar meson spectrum is very much overpopulated, with far too many states below

2 GeV. Since the lattice 0^{++} glueball is predicted to be at approximately 1600 MeV, the $f_0(1500)$ (along with the $f_J(1720)$) is a likely glueball candidate. We are fortunate that its mass and decay modes are well known. Indeed, the major obstacle appears to be one of interpretation. This is made especially difficult by the strong $gg \leftrightarrow q\bar{q} \leftrightarrow q\bar{q}q\bar{q}$ mixing expected in the scalar sector. This is discussed further in section 5.2.

Rather than review the evidence for the glueball nature of the f_0 (for which the reader is referred to [1]) we present some recent speculation on this state. Significant f_0 has been observed in $J/\psi \to 2\pi^+2\pi^-$ [2]. However there is no evidence for f_0 in $J/\psi \to \pi^+\pi^-$, $K\bar{K}$ [3]. This may be problematical in view of a recent observation of an S-wave enhancement at 1500 seen in $K^-p \to \Lambda K_s K_s$ because it is not seen in $2\pi^+2\pi^-$ [3]. If the enhancement *is* the $f_0(1500)$ these observations are at odds with those mentioned above. Clearly further experimental effort is in order here.

[1] C. Amsler and F. Close, Phys. Lett. **B353**, 385 (1995); Phys. Rev. **D53**, 295 (1996); T. Barnes, Phys. Lett. **B165**, 434 (1985).

[2] D. Bugg et al., Phys. Lett. **B353**, 378 (1995)

[3] B. Dunwoodie, SLAC-Pub-7163 (1997); private comm.

4.2 $\xi(2230)$

The $\xi(2230)$ is a tantalizing tensor glueball candidate [1,2] (although its quantum numbers are not known for certain!) for several reasons. Among these are its decays to $\pi\pi$, $K\bar{K}$, $p\bar{p}$, and $\Lambda\bar{\Lambda}$, which appear to be in agreement with the flavour blindness hypothesis (see below for a discussion of this point). Furthermore, the total width, $\Gamma = 20^{+25}_{-10} \pm 10$, is anomalously small compared to $q\bar{q}$ states at >2000 MeV, again indicating the peculiar nature of this resonance. In particular we note that $\Gamma(f_4(s\bar{s})) > 130$ MeV and $\Gamma(f_2(s\bar{s})) > 400$ MeV. Finally, its mass is very close to lattice expectations (see below).

While these points make the $\xi(2230)$ a promising exotic candidate, several issues have been raised about this state. For example, the ξ decays to $p\bar{p}$ and thus one would expect to see it in $p\bar{p}$ annihilation at LEAR, however this is not the case [3]. Finally, the relatively low statistics and highly structured spectrum in the 2200 region may be producing a tendency to fit bumps. Indeed it has been suggested that the data is consistent with a relatively broad resonance with $\Gamma \sim 200$ [3], thereby explaining the nonobservation in $p\bar{p}$.

[1] J. Bai et al., Phys. Rev. Lett. **76**, 3502 (1996).
[2] X. Shen , Hadron '97.
[3] E. Klempt, Hadron '97 Summary Talk.

4.3 $f_2(1980)$

Crystal Barrel has recently reported the observation of a 2^+ state in $p\bar{p} \to \eta\eta\pi$ with a mass of 1980 ± 50 and a width of $\Gamma = 500 \pm 100$ [1]. Because of the strong production of the f_2 in P-wave and its proximity to the lattice predictions, the authors speculate that this state may be the tensor glueball.

The authors also report the confirmation of the $f_0(2100)$ in $\eta\eta$ and speculate that it may be a radial excitation of the scalar glueball.

[1] A. Abele et al. (CBAR) draft; D. Bugg, priv. comm.

5 Glueballs (theory)

5.1 Selected Glueball Mass Predictions

Glueball masses were the first observables calculated on the lattice and remain a staple of pure gauge lattice work to this day. The story here is one of gradual progress; with decreasing lattice spacing and increasing lattice volume leading to more reliable mass estimates. The biggest source of concern is the use of the quenched calculation, which is expected to be especially problematical in the scalar sector.

Model calculations of glueball masses should perhaps be described as speculative. Simply put, our understanding of the dynamics and characteristics of soft glue is too rudimentary to perform any sort of reliable calculations. Thus, in the table below, one sees reasonable agreement amongst lattice mass calculations and what must be described as poor theoretical predictions (the only exception being possibly [13]).

[1] C.J. Morningstar and M. Peardon, hep-lat/9704011.
[2] G.S. Bali *et al.* (UKQCD) Phys. Lett. **309B** 378 (1993).
[3] J. Sexton, A. Vaccarino, and D. Weingarten, Phys. Rev. Lett. **75**, 4563 (1995).

Model	0^{++}	$(0^{++})'$	0^{-+}	2^{++}	2^{-+}
lattice (aniso) [1]	1.63(6)(8)			2.40(1)(12)	
lattice (UKQCD) [2]	1.55(5)			2.27(10)	
lattice (GF11) [3]	1.74(7)			2.36(13)	
lattice [4]	1.57(9)	2.87(34)	2.16(27)	2.22(12)	3.06(26)
lattice (SESAM) [5]	1.66(5)			2.32(25)	
QCDSR (SVZ) [6]	∼1.2		2-2.5	∼1.2	
QCDSR [7]	1.5(2)		2.05(20)	2.0(1)	
bag (MIT) [8]	∼1		∼1.2	∼1	∼1.2
bag [9]	∼1		∼1.5	∼1.5	∼2.1
flux tube [10]	1.52	2.75	2.79	2.84	2.84
const glue [11]	∼1.5	∼2.1	∼1.5	∼1.8	∼2.1
const glue [12]*	1.5		1.76	2.08	
const glue [13]	1.60	2.64	2.03	2.05	2.82

[4] M. Teper, OUTP-95-06P.
[5] G. Bali *et al.* (SESAM), hep-lat/9710012.
[6] M. Shifman, A.I. Vainshtein, and V. Zakharov, Nucl. Phys. **B147**, 385, 448 (1979).
[7] S. Narison, hep-ph/96012457.
[8] R. Jaffe and K. Johnson, Phys. Lett. **60B**, 201 (1976).
[9] T. Barnes, F.E. Close, and S. Monaghan, Nucl. Phys. **B198**, 380 (1982); M. Chanowitz and S. Sharpe, Phys. Lett. **132B**, 380 (1982); C. Carlson, T. Hansson, and C. Peterson, Phys. Rev. **D27**, 2167 (1983).
[10] N. Isgur and J. Paton, Phys. Rev. **D31**, 2910 (1985)
[11] T. Barnes, Z. Phys. **C10**, 275 (1981).
[12] J. Cornwall and A. Soni, Phys. Lett. **120B**, 431 (1983). * I have taken m_g = 650 MeV to fit the 0^{++}.
[13] A. Szczepaniak, E. Swanson, C. Ji, and S. Cotanch, Phys. Rev. Lett **76**, 2011 (1996).

5.2 Glueball Decays

The topic of glueball decays has a longstanding lore associated with it, some of which is not necessarily correct. For example, it has been stated that glueballs are narrow. I believe that this notion originates with Ref. [1], where the suggestion was based on the expected small size of the strong coupling constant. It is difficult to justify this belief today.

It has also been stated that glueballs decay like hybrids [2]. Thus for example, the famous selection rules mentioned in section 3.2 will apply to glueballs. The idea here is that it is not reasonable to expect naive perturbation theory to be applicable to strong QCD, at the every least one must employ bound state perturbation theory. In the latter case, glueballs are expected to couple to meson-meson states via intermediate hybrids, justifying the statement made above. This is reasonable, but it should be remembered that infinitely many intermediate states are summed over and this may have the effect of modifying the effective decay operator, obviating the hybrid selection rules.

Perhaps the most persistent dogma is the notion that glueball decays are flavour blind. This belief stems from the flavour symmetric coupling of gluons to quarks in perturbative QCD. However, as stressed above, naive perturbation theory is irrelevant here. Indeed, Amsler and Close [3] have pointed out that a possible decay mechanism for glueballs is conversion into a $q\bar{q}$ state followed by hadronic decay to the final meson-meson state. The flavour structure of the intermediate spectrum has the effect of breaking flavour symmetry. Using this idea, Amsler and Close have identified the $f_0(1500)$ with the glueball and the $f_J(1710)$ with the $s\bar{s}$ state. However, Weingarten [4] has made a similar analysis and finds the opposite conclusion: the $f_0(1500)$ is predominantly $s\bar{s}$ while the $f_0(1710)$ is predominantly gg. This conclusion is supported by a recent lattice calculation [5]. The authors of [5] calculated the scalar quarkonium and glueball masses in the quenched approximation. They also evaluated the matrix element which mixes these states. Unfortunately, the calculation appears to suffer from some inconsistencies. For example, the authors calculate the bare $s\bar{s}$ mass to be 1322(42) MeV but choose to fit this mass in their calculation. The result is 1510 MeV, not in very good agreement with the rest of their work. The fit was probably necessitated by their choice for the bare $n\bar{n}$ mass of 1470 MeV (motivated by the spectrum) – clearly a bare $s\bar{s}$ mass of 1322 is inconsistent with this. Finally, the authors choose to ignore the $f_0(980)$, however; the light f_0 exists and is known to couple strongly to $K\bar{K}$. There is no reason to expect this not to be true of, say, the $f_0(1710)$ (which is near $K^*\bar{K}^*$ threshold). Thus mixing to the meson-meson continuum should not be ignored in these calculations.

Finally, we display the results of several calculations of glueball decay properties in the following table. The first row is the ratio of decay amplitudes as calculated in the naive perturbative approach (here $\rho = \langle G|\mathcal{O}|s\bar{s}\rangle / \langle G|\mathcal{O}|u\bar{u}\rangle$). Flavour symmetry is recovered at $\rho = 1$. The next three columns represent glueball widths normalized to the $\eta\eta$ width under differing assumptions. The second row contains the traditional flavour blind decay ratios often quoted in the literature. The fifth row is a calculation of f_0' decay widths in a nonet mixing model [6]. The sixth row is a $^3P_0$ model calculation of the widths of a hypothetical $s\bar{s}$ at 1500 MeV and the last row is a summary of the experimental situation taken from [6].

	$\pi\pi$	$K\bar{K}$	$\eta\eta$	$\eta'\eta$	$\eta'\eta'$	$\sigma\sigma$
$\mathcal{A}$	1	ρ	$\frac{1+\rho^2}{2}$	$\frac{1-\rho^2}{2}$	$\frac{1+\rho^2}{2}$	large
$\Gamma(\rho = 1, PS = 1)$	3	4	1	0	1	
$\Gamma(\rho = 1, M_G = 1.5\,\mathrm{GeV})$	4.3	4.4	1	–	–	–
$\Gamma(\rho = \frac{m_u}{m_s}, M_G = 1.5\,\mathrm{GeV})$	9.4	3.4	1	–	–	–
$\Gamma(f_0'; \mathrm{mixed})$	4.4	10	1	2	–	–
$\Gamma(f_0'(s\bar{s}); {}^3P_0\mathrm{model})$	–	3.0	1	1.5	–	–
$\Gamma(f_0(1500); \mathrm{expt})$	4.39(16)	1.1(4)	1	1.42(96)	–	14.9(32)

[1] H. Fritzsch and P. Minkowski, N. Cimento **30A** 393 (1975).
[2] N. Isgur and J. Paton, Phys. Rev. **D31**, 291 (1985).
[3] C. Amsler and F. Close, Phys. Lett. **353B**, 385 (1995).
[4] D. Weingarten, Nucl. Phys. **B53** (proc Suppl.), 232 (1997).
[5] W. Lee and D. Weingarten, hep-lat/9805029.
[6] C. Meyer, hep-ex/9707008.

6 Conclusions

The theme of the last five years of research in exotics has been one of steady progress in the experimental and lattice fronts. Lattice calculations of the exotic spectrum are now at the point of a few percent accuracy (within the quenched approximation) for heavy quarks and are beginning to produce reliable results for light quarks. We eagerly await similar quality unquenched data. The recent experimental results at Brookhaven and

CERN have rekindled interest in the field. Hopefully JLab and the AGS will be able to carry this programme further.

It is apparent that the scalar meson sector needs to be clarified. This is true experimentally, with regards to the decay and production modes of the $f_0(1500)$ and the quantum numbers and decay modes of the $f_J(1710)$. It is also true for lattice work, which needs to be unquenched, most importantly in the scalar sector. The phenomenology of hadron mixing in the scalar sector needs to converge in technique and conclusions. Lastly, we need a reliable theoretical guide to hadronic couplings to assist experimental, phenomenological, and lattice efforts.

It is almost certain that something is happening at 1400 MeV in the 1^{-+} channel. Whether this is a resonance or not remains an open issue – in large part because of theoretical expectations which are not in accord with the light mass and decay mode of this state. Alternatively, the states claimed at 1600 and 1800 are very exciting and we look forward to learning more about these. Furthermore, the $\pi(1800)$ remains an intriguing hybrid candidate. Since a 3S quarkonium state is expected in this mass region, it is desirable to obtain a much clearer experimental picture of the pseudoscalar sector at 1.8 GeV. Finally, the $\xi(2230)$ needs to be studied more if we are to accept it as a tensor glueball.

The rapid advances in lattice calculations and experimental work have made it clear that a new generation of models of strong QCD is needed. These must be capable of describing hadronic couplings, pions, and gluonic and nonvalence degrees of freedom with some reliability.

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