A Summary of Hybrid Masses and Decay

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Abstract

This document is a summary of the lattice calculations of the masses of hybrid mesosn. While many calculations have been performed, they are all still limited by systematic uncertainties that could move the mass of the lightest nonet (the 1^{-+}) by ± 0.2 GeV/c^2. The mass splittings between the lightest state, and the next two exotic nonets also have a large deal of uncertaintly, but nominally the 2^{+-} is on the order of 02. GeV/c^2 heavier than the 1^{-+}, while the 0^{+-} nonet is predicted to be around 0.5 GeV/c^2 heavier.

1 Hybrid Masses

Lattice QCD calcuations provide our most accurate estimate to the masses of hybrid mesons. While these calculations have progressively gotten better, they are still limited by a number of systematic effects. The most significant of these is that all caluclations to date have been performed in the *quenched approximation*. In addition to this, the calculations are made with varying quark masses, and then extrapolated to the light-quark limit. In fact, all efforts to date calculate what it effictively the $s\bar{s}$ member of the nonet, and then some approximation is made to move estimate the $u\bar{u}/d\bar{d}$ mass. The bottom line is that no one would be surprised if the true hybrid masses differed by $0.2\,GeV/c^2$ from the best predictions.

1.1 The 1^{-+} Mass

One of the earliest predictions for hybrids comes from the flux-tube model in which all eight hybrid nonets are degenrate with a mass of about $1.9\,GeV/c^2$. Lattice QCD calculations howvever consistently show that the exotic 1^{-+} nonet is the lightest. Table 1 lists predictions made over the last several years. These results fall in the range of 1.8 to $2.1\,GeV/c^2$, with an average about in the middle of these numbers. When it is available in the publication, we report the mass of the $s\bar{s}$ state in addition to the light-quark state.

Author			1^{-+} Mass (GeV/c^2)	
Collab.	Year	Ref.	$u\bar{u}/d\bar{d}$	$s\bar{s}$
UKQCD	(1997)	[1]	1.87 ± 0.20	2.0 ± 0.2
MILC	(1997)	[2]	$1.97 \pm 0.09 \pm 0.30$	$2.170 \pm 0.080 \pm 0.30$
MILC	(1999)	[3]	$2.11 \pm 0.10 \pm (sys)$	
SESAM	(1998)	[4]	1.9 ± 0.20	
Mei& Luo	(2003)	[5]	$2.013 \pm 0.026 \pm 0.071$	
Bernard *et al.*	(2004)	[6]	1.792 ± 0.139	2.100 ± 0.120

Table 1: Recent results for the light-quark 1^{-+} hybrid meson masses. For the charmonium spectrum, the difference is taken from the $1S$ state. The table is based on a similar table in [7].

1.2 Mass Splittings of Exotic Nonets

There are fewer predictions for the masses of the other exotic-quantum number states. Bernard [2] cacluate the splitting between the 0^{+-} and the 1^{-+} state to be about 0.2 GeV/c^2 with large errors. They later calculate this with a clover action [3] and find a splitting of 0.270 ± 0.2. The SESAM collaboration [4] has one such calculation, the results of which are shown in Table 2.

Multiplet	J^{PC}	Mass
π_1	1^{-+}	$1.9 \pm 0.2\,GeV/c^2$
b_2	2^{+-}	$2.0 \pm 0.11\,GeV/c^2$
b_0	0^{+-}	$2.3 \pm 0.6\,GeV/c^2$

Table 2: Estimates of the masses of exotic quantum number hybrids.

2 Hybrid Decays

In the sense that hybrid mesons are just excitations of the gluon field, they should be produced in all reactions which populate the excited $q\bar{q}$ spectrum. However, it is believed that the spin of the initial particle will likely be transfered directly into the spin of the $q\bar{q}$ system in the hybrid. This means that beams of π's and K's are likely to produce hybrids built on spin zero objects, 1^{--} and 1^{++}. Similarly, beams of spin one particles are more likely to produce hydrids built on spin-alligned quarks, 0^{+-}, 0^{-+}, 1^{+-}, 1^{-+}, 2^{+-} and 2^{-+}. Hybrids should in principal be produced as strongly as other states.

Predictions for the widths of hybrids are currently based on model calculations with the most recent work [8] given in Table 3 for states with exotic quantum numbers, and in Table 4 for hybrids with normal $q\bar{q}$ quantum numbers. As can be seen, a number of these states are expected to be broad. In particular, most of the 0^{+-} exotic nonet are quite borad. However, states in both the 2^{+-} and the 1^{-+} nonets have much narrower expected widths. The normal quantum numbers states will be more difficult to disentangle as they are likely to mix with nearby normal $q\bar{q}$ statess. Finally, the expected decay modes of these states involve daughters that in turn decay. This makes the overall reconstruction more complcated then simple peseudoscalar mesons.

However, these decays can be used as a guideline when looking for these states. Almost all models of hybrid mesons predict that the ground state ones will not decay to identical pairs of mesons, and that the decays to an $(L = 0)(L = 1)$ pair is the favored decay mode. Essentially, the one unit of angular momentum in the flux–tube has to go into internal orbital angular momentum of a $q\bar{q}$ pair. In addition, the nonet with non $q\bar{q}$ quantum numbers provide a striking signal for these objects. It is also true that lattice calculations predict that the 1^{-+} nonet, (exotic) is the lightest (see table 1). Above this, the exotic 0^{+-} and the 2^{+-} are the next lightest. It is also important to keep in mind that the splittings between nonets is due to the gluonic degrees of freedom, so a measurement of this quantity can provide insight into the confining potential of QCD.

References

[1] P. Lacock *et al.*, Phys. Lett. B**401**, 309, (1997), `hep-lat/9611011`.

[2] C. Bernard *et al.*, Phys. Rev. D**56**, 7039, (1997).

Particle	$\mathbf{J^{PC}}$	Total Width MeV [8]	[9]	Large Decays
π_1	1^{-+}	$81-168$	117	$b_1\pi$, $\rho\pi$, $\eta(1295)\pi$
η_1	1^{-+}	$59-158$	107	$a_1\pi$, $\pi(1300)\pi$
η_1'	1^{-+}	$95-216$	172	$K_1(1400)K$, $K_1(1270)K$, K^*K
b_0	0^{+-}	$247-429$	665	$\pi(1300)\pi$, $h_1\pi$
h_0	0^{+-}	$59-262$	94	$b_1\pi$
h_0'	0^{+-}	$259-490$	426	$K(1460)K$, $K_1(1270)K$
b_2	2^{+-}	$5-11$	248	$a_2\pi$, $a_1\pi$, $h_1\pi$
h_2	2^{+-}	$4-12$	166	$b_1\pi$, $\rho\pi$
h_2'	2^{+-}	$5-18$	79	$K_1(1400)K$, $K_1(1270)K$, $K_2^*(1430)K$

Table 3: Exotic quantum number hybrid width and decay predictions.

Particle	$\mathbf{J^{PC}}$	Total Width MeV [8]	[9]	Large Decays
ρ	1^{--}	$70-121$	112	$a_1\pi$,$\omega\pi$, $\rho\pi$
ω	1^{--}	$61-134$	60	$\rho\pi$, $\omega\eta$, $\rho(1450)\pi$
ϕ	1^{--}	$95-155$	120	$K_1(1400)K$, K^*K, $\phi\eta$
a_1	1^{++}	$108-204$	269	$\rho(1450)\pi$, $\rho\pi$, K^*K
h_1	1^{++}	$43-130$	436	K^*K, $a_1\pi$
h_1'	1^{++}	$119-164$	219	$K^*(1410)K$,K^*K
π	0^{-+}	$102-224$	132	$\rho\pi$,$f_0(1370)\pi$
η	0^{-+}	$81-210$	196	$a_0(1450)\pi$, K^*K
η'	0^{-+}	$215-390$	335	K_0^*K,$f_0(1370)\eta$, K^*K
b_1	1^{+-}	$177-338$	384	$\omega(1420)\pi$,K^*K
h_1	1^{+-}	$305-529$	632	$\rho(1450)\pi$, $\rho\pi$, K^*K
h_1'	1^{+-}	$301-373$	443	$K^*(1410)K$, $\phi\eta$, K^*K
π_2	2^{-+}	$27-63$	59	$\rho\pi$,$f_2\pi$
η_2	2^{-+}	$27-58$	69	$a_2\pi$
η_2'	2^{-+}	$38-91$	69	K_2^*K, K^*K

Table 4: Non-exotic quantum number hybrid width and decay predictions.

[3] C. Bernard *et al.*, **Exotic meson spectroscopy from the clover action at** $\beta = 5.85$ **and** 6.15, Nucl. Phys. B(Proc. Suppl.) **73**, 264, (1999), `hep-lay/9809087`.

[4] P. Lacock, K. Schilling (SESAM Collaboration), **Hybrid and Orbitally Excited Mesons in Full QCD**, Nucl. Phys. Proc. Suppl. 73, 261, (1999), `hep-lat/9809022`.

[5] Zhong-Hao Mei and Xiang-Qian Luo, **Exotoc mesons from quantum chromodynamics with improved gluon and quark actions on the anisotropic lattice**, Nucl. Phys. Proc. Suppl. **119**, 263, (2003), (`hep-lat/0206012`).

[6] C. Bernard, T. Burch, C. DeTar, Steven Gottlieb, E.B. Gregory, U.M. Heller, J. Osborn, R. Sugar and D. Toussaint, Phys. Rev. D**68**, 074505, (2003).

[7] C. Morningstar, **The study of exotic hadrons in lattice QCD**.

[8] P. R. Page, E. S. Swanson and A. P. Szczepaniak, **Hybrid Meson Decay Penomenology**, Phys. Rev. D**59**, 034016 (1999).

[9] N. Isgur, R. Kokoski and J. Paton, **Gluonic Excitations of Mesons: Why they are missing and where to find them**, Phys Rev Lett. **54**, 869, (1985).

[10] H.P. Shanahan, *et al.* (UKQCD Collaboration), **The effect of tree-level and mean-field improvement on the light-hadron spectrum in quenched QCD**, Phys. Rev. D**55**, 1548, (1997), `hep-lat/9608063`.

[11] P. Lacock, C. Michael, P. Boyle, P. Rowland (UKQCD Collaboration), **Orbitally excited and hybrid mesons from the lattice**, Phys. Rev. D**54**, 6997, (1996), `hep-lat/9605025`. K

[12] P. Lacock, C. Michael, P. Boyle and P. Rowland (UKQCD Collaboration), **Hybrid and Orbitally Excited Mesons in Quenched QCD**, Nucl. Phys. Proc. Suppl. **63**, 203, (1998), `hep-lat//9708013`.

[13] K. J. Juge, J. Kuti and C. Morningstar, Phys. Rev. Lett. **82**, 4400, (1999).

[14] T. Manke *et al.*, Phys. Rev. Lett. **82**, 4396, (1999).