Spectroscopy: Experimental Status and Prospects

Curtis A. Meyer
Carnegie Mellon University

Outline

- Baryons
- Mesons
- QCD Exotics
  - Glueballs
  - Hybrid Mesons
- Summary

The Baryon Spectrum

****, *** Known **,* Hints

In the quark model picture,
allow individual quarks to
be excited to higher levels:

baryon: q(1s)q(1s)q(1s)

1s -> 2s, 1s -> 2p

Nucleon

$L_{2I,2J}$ (Mass)	Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****

$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

****, *** Known **,* Hints

The Baryon Spectrum

In the quark model picture, allow individual quarks to be excited to higher levels:

baryon: q(1s)q(1s)q(1s)

1s -> 2s, 1s -> 2p

Nucleon $L_{2I,2J}$ (Mass)	Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****

Missing Baryons

$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

****, *** Known **,* Hints

The Baryon Spectrum

Treat a quark and a diquark as the fundamental particles. Allow excitations as before:

$L_{2I,2J}$ (Mass)	Nucleon Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****
$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

Looking in the wrong place

Nearly all the data used to identify baryons has come From π N scattering.

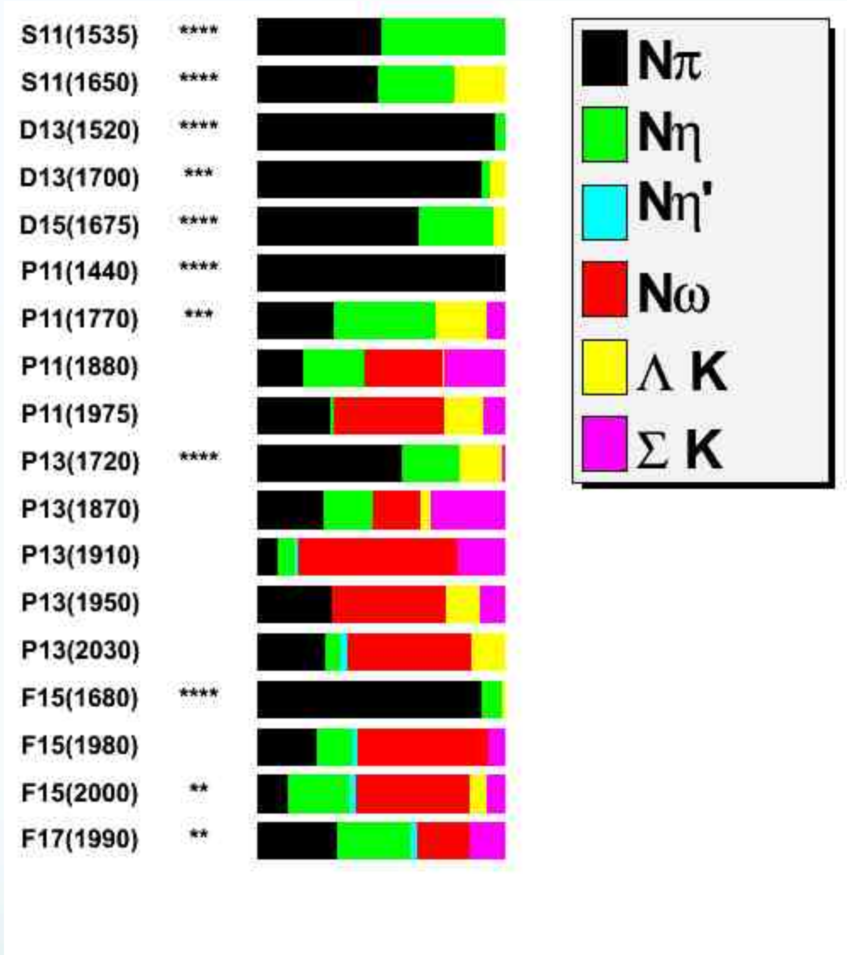
$\pi N \rightarrow \pi N$

What if the missing states do not couple to π N ?

Quark model predictions that many of the missing states have strong couplings to other final states:

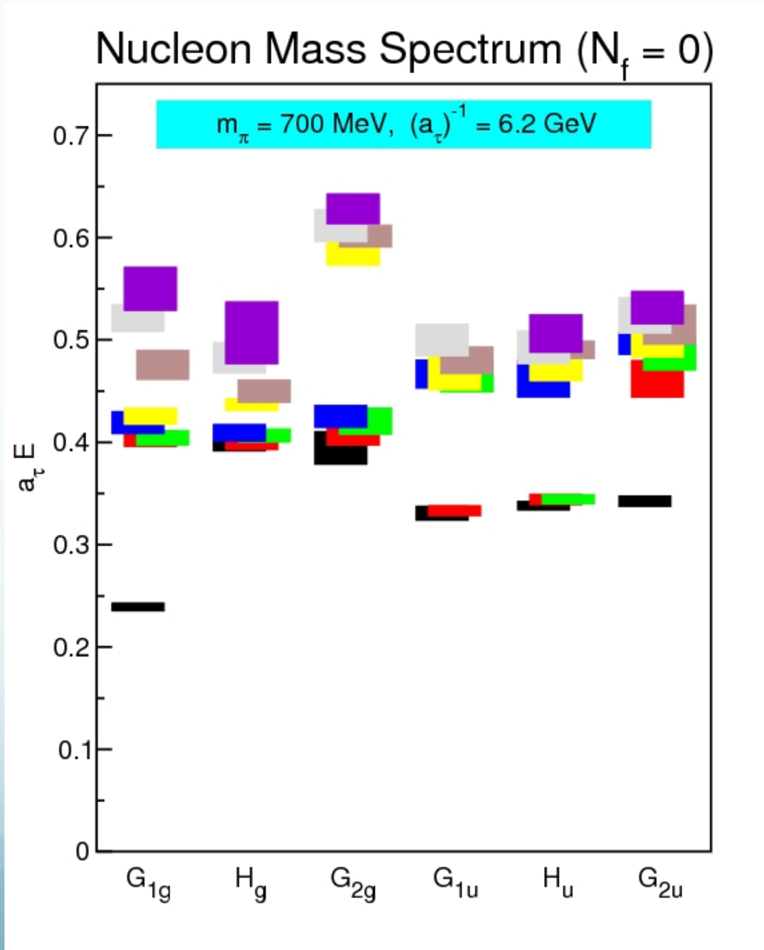
Nη Nω ...

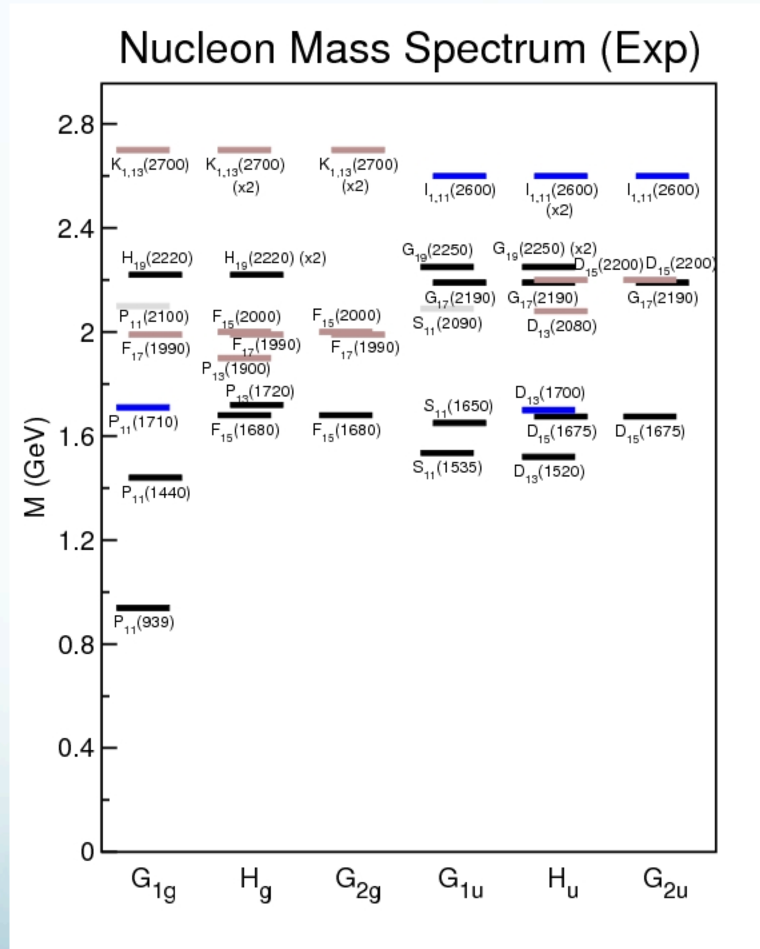
$(1/2)^-$
$(1/2)^-$
$(3/2)^-$
$(3/2)^-$
$(5/2)^-$
$(1/2)^+$
$(1/2)^+$
$(1/2)^+$
$(1/2)^+$
$(3/2)^+$
$(3/2)^+$
$(3/2)^+$
$(3/2)^+$
$(3/2)^+$
$(5/2)^+$
$(5/2)^+$
$(5/2)^+$
$(7/2)^+$



Lattice Calculations

First lattice calculation for baryons (2009). Many approximations, but shows what will be possible.





Observables in Photo-production

Photo-production of pseudo scalar mesons:

$$\gamma N \rightarrow M(0^{-+})\,N'$$

Photon beam			Target			Recoil			Target-Recoil								
						x’	y’	z’	x’	x’	x’	y’	y’	y’	z’	z’	z’
			x	y	z				x	y	z	x	y	z	x	y	z
Unpolarized		σ		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
Linearly	P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
Circular	P_γ		F		E	$C_{x'}$		$C_{z'}$	$O_{z'}$			G		H		$O_{x'}$	

There are 16 observables for these reactions.
Program in place with CLAS at Jefferson Lab to measure these for several systems.

Photo-production Data

γp	$\rightarrow$	$p\pi^0$	CLAS, CBELSA
γp	$\rightarrow$	$n\pi^+$	CLAS
γp	$\rightarrow$	$p\eta$	CLAS,CBELSA,LNS,GRAAL
γn	$\rightarrow$	$n\eta$	
γp	$\rightarrow$	$p\eta'$	CLAS
γp	$\rightarrow$	ΛK^+	CLAS
γp	$\rightarrow$	ΣK^+	CLAS

Extensive data sets have recently been published. A large effort is pushing polarization measurements

Analysis of the physical observables is being undertaken by several groups to achieve a consistent description of these data sets. EBAC, SAID, η-MAID, Bonn-Gatchina.

Analyses hint at missing baryons: $N(1720)P_{13}$ $N(2070)D_{15}$

Analysis

Bonn-Gatchina PWA coupling data from many channels together into a single analysis. Includes cross section, beam asymmetries, target asymmetries, recoil asymmetries, double-polarization observables and data to resolve isospin contributions. Data are not sufficient to converge to a unique solution.

γp	$\rightarrow$	$N\pi$	$\Delta(1232)P_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	$N(1535)S_{11}$
γp	$\rightarrow$	$p\eta$	$N(1535)S_{11}$	$N(1720)P_{13}$	$N(2070)D_{15}$	$N(1650)S_{11}$
γp	$\rightarrow$	$p\pi^0\pi^0$	$\Delta(1700)D_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	
γp	$\rightarrow$	$p\pi^0\eta$	$\Delta(1940)D_{33}$	$\Delta(1920)P_{33}$	$N(2200)D_{13}$	$\Delta(1700)D_{33}$
γp	$\rightarrow$	ΛK^+	$S_{11}-wave$	$N(1720)P_{13}$	$N(1900)P_{13}$	$N(1840)P_{11}$
γp	$\rightarrow$	ΣK	$S_{11}-wave$	$N(1900)P_{13}$	$N(1840)P_{11}$	
$\pi^- p$	$\rightarrow$	$n\pi^0\pi^0$	$N(1440)P_{11}$	$N(1520)D_{13}$	$S_{11}-wave$	

Analysis New Baryons from this Analysis.

Bonn-Gatchina PWA coupling data from many channels together into a single analysis. Includes cross section, beam asymmetries, target asymmetries, recoil asymmetries, double-polarization observables and data to resolve isospin contributions. Data are not sufficient to converge to a unique solution.

γp	$\rightarrow$	$N\pi$	$\Delta(1232)P_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	$N(1535)S_{11}$
γp	$\rightarrow$	$p\eta$	$N(1535)S_{11}$	$N(1720)P_{13}$	$N(2070)D_{15}$	$N(1650)S_{11}$
γp	$\rightarrow$	$p\pi^0\pi^0$	$\Delta(1700)D_{33}$	$N(1520)D_{13}$	$N(1680)F_{15}$	
γp	$\rightarrow$	$p\pi^0\eta$	$\Delta(1940)D_{33}$	$\Delta(1920)P_{33}$	$N(2200)D_{13}$	$\Delta(1700)D_{33}$
γp	$\rightarrow$	ΛK^+	$S_{11}-wave$	$N(1720)P_{13}$	$N(1900)P_{13}$	$N(1840)P_{11}$
γp	$\rightarrow$	ΣK	$S_{11}-wave$	$N(1900)P_{13}$	$N(1840)P_{11}$	
$\pi^- p$	$\rightarrow$	$n\pi^0\pi^0$	$N(1440)P_{11}$	$N(1520)D_{13}$	$S_{11}-wave$	

CLAS PWA Results

$\gamma p \rightarrow \omega p$

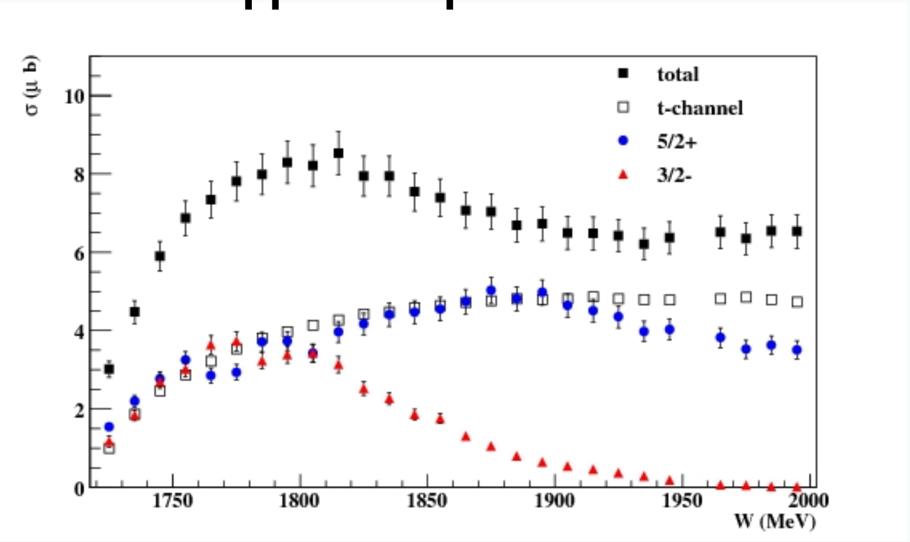
Fit showing three amplitudes.

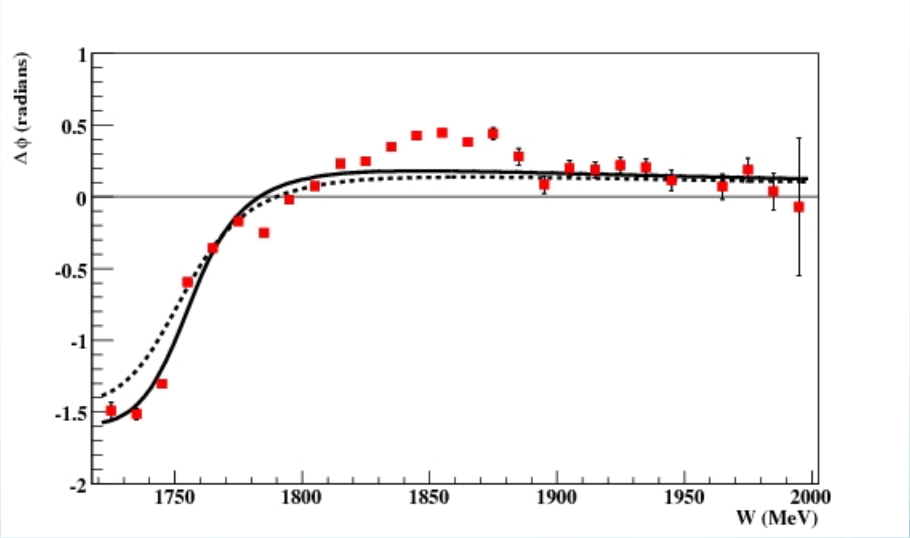
(3/2)$^-$ D_{13}
(5/2)$^+$ F_{15}
t-channel

Intensities

Phase Difference

Not Expected





Strong evidence for:

(3/2)$^-$ N(1700) ***
(5/2)$^+$ N(1680) ****
(7/2)$^-$ N(2190) ****

The strong signals are well known states!

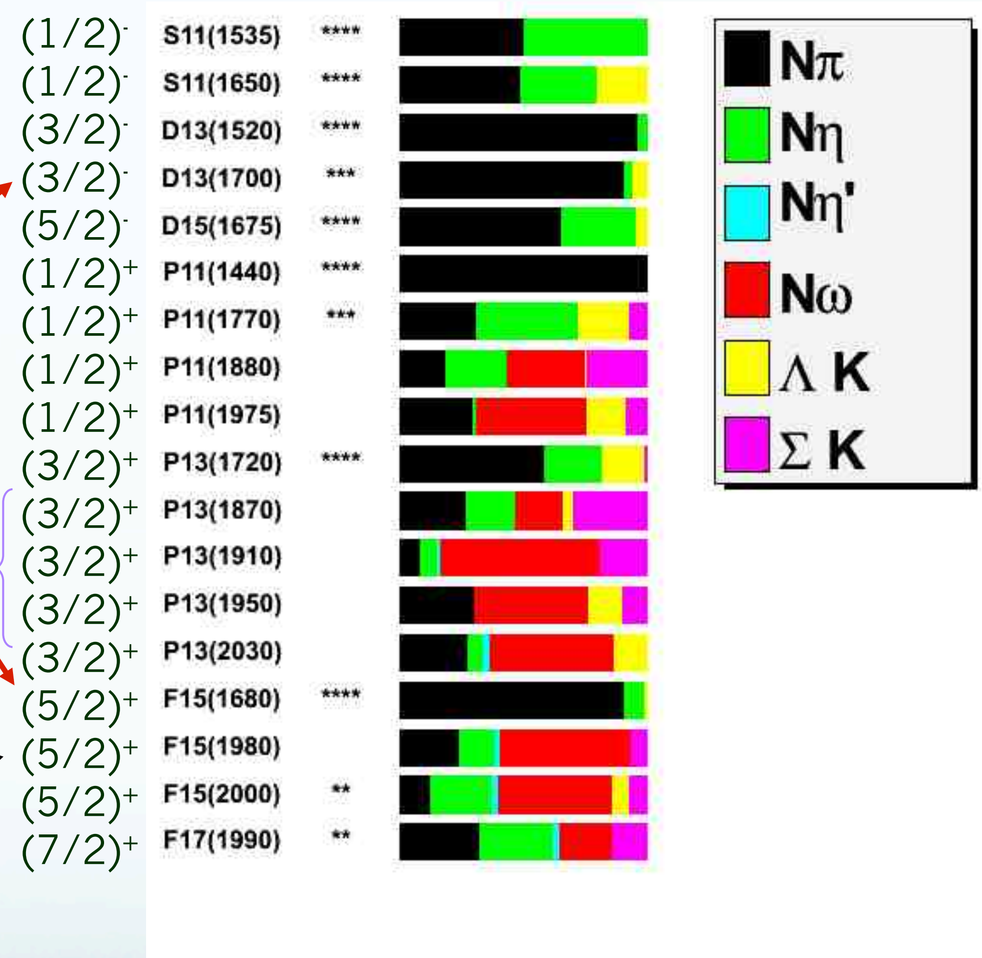
What is seen?

Strong evidence for:

(3/2)$^-$ N(1700) ***
(5/2)$^+$ N(1680) ****
(7/2)$^-$ N(2190) ****

Hints?

Good Evidence for:
(5/2)$^+$ N(2000)



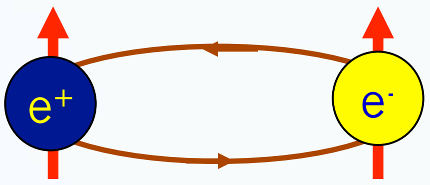
(7/2)$^-$ G_{17}(2190) ****

Baryon Summary

- A lot of work currently underway to add new data using polarized targets.
- Analysis efforts are taking advantage of large data sets.
- Starting to see results on missing baryons, but more work is still required.

Spectroscopy
A probe of QED

Positronium



Spin: $S=S_1+S_2=(0,1)$

Orbital Angular Momentum: $L=0,1,2,\ldots$

Total Spin: $J=L+S$

$L=0, S=0 : J=0$ $L=0, S=1 : J=1$

$L=1 , S=0 : J=1$ $L=1, S=1 : J=0,1,2$

… …

Reflection in a mirror:
Parity: $P=-(-1)^{(L)}$

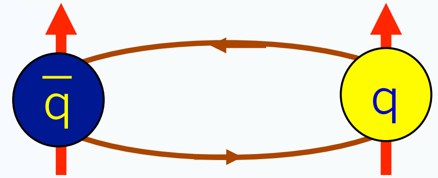
Particle<->Antiparticle:
Charge Conjugation: $C=(-1)^{(L+S)}$

Notation: $J^{(PC)}$ $0^{-+}, 1^{--}, 1^{+-}, 0^{++}, 1^{++}, 2^{++}$

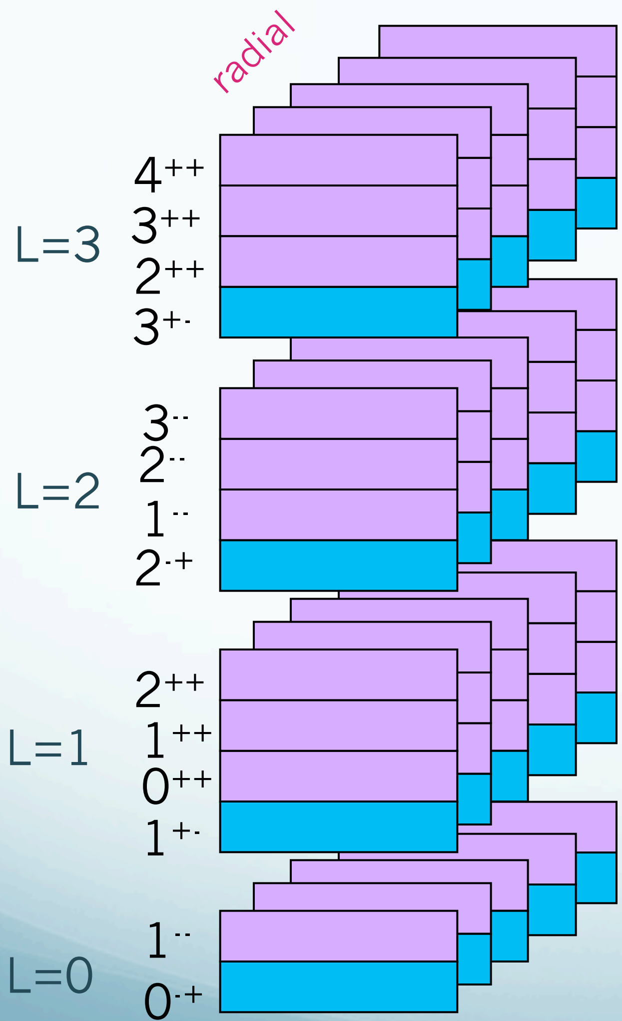
$^{(2S+1)}L_J$ $^1S_0, {}^3S_1, {}^1P_1, {}^3P_0, {}^3P_1, {}^3P_2,\ldots$

Spectroscopy and QCD

Quarkonium



Mesons



Consider the three lightest quarks

$$\left.\begin{array}{l} u, d, s \\ \bar{u}, \bar{d}, \bar{s} \end{array}\right\}$$ 9 Combinations

$$d\bar{s} \qquad u\bar{s}$$

$$d\bar{u} \qquad \frac{1}{\sqrt{2}}\left(u\bar{u} - d\bar{d}\right) \qquad u\bar{d}$$

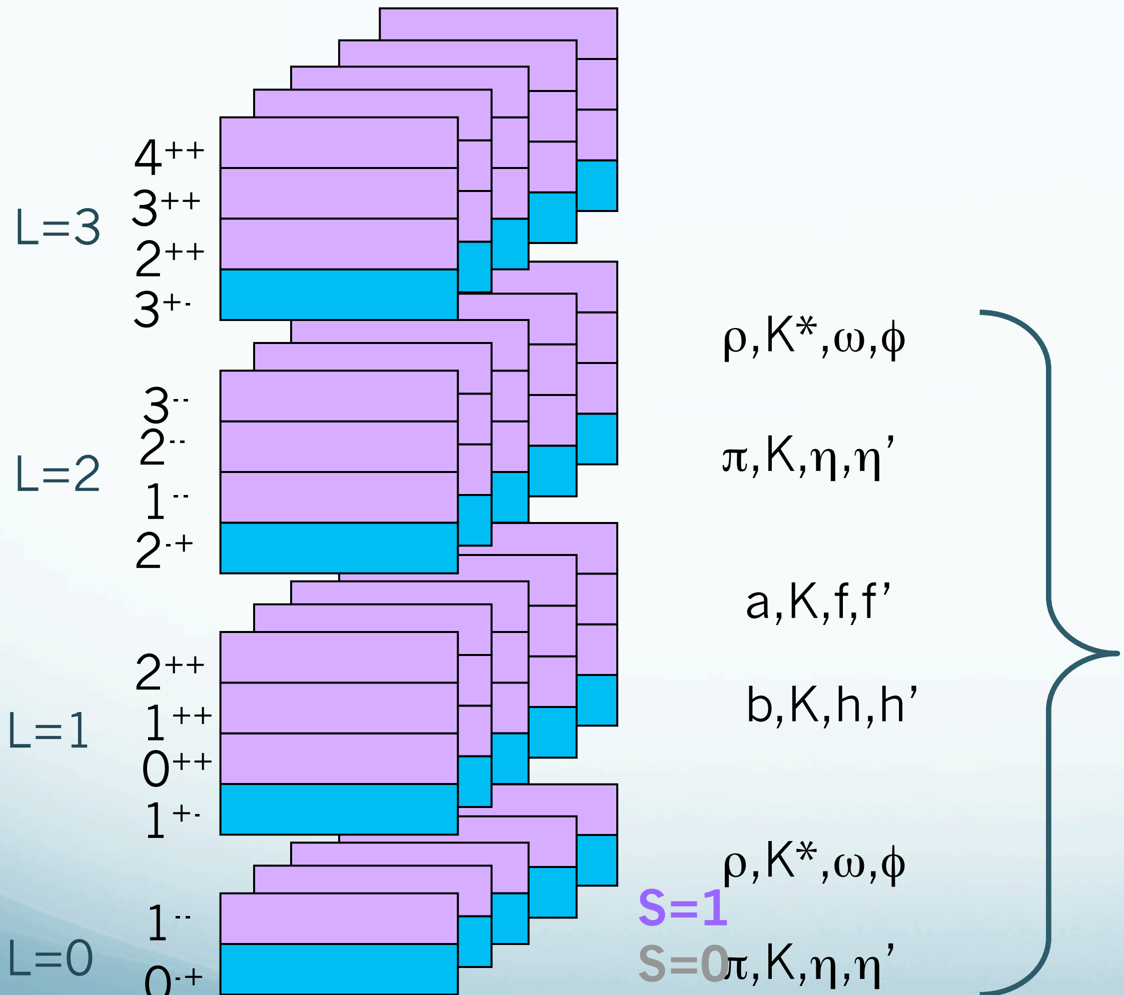
$$s\bar{d} \qquad s\bar{u}$$

S=1
S=0

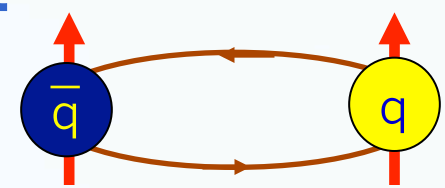
$$\frac{1}{\sqrt{3}}\left(u\bar{u} + d\bar{d} + s\bar{s}\right) \qquad \frac{1}{\sqrt{6}}\left(u\bar{u} + d\bar{d} - 2s\bar{s}\right)$$

Spectroscopy an QCD

Mesons



Quarkonium

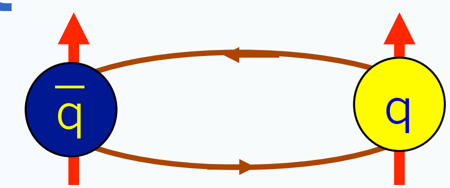


Mesons come in Nonets of the same J^{PC} Quantum Numbers

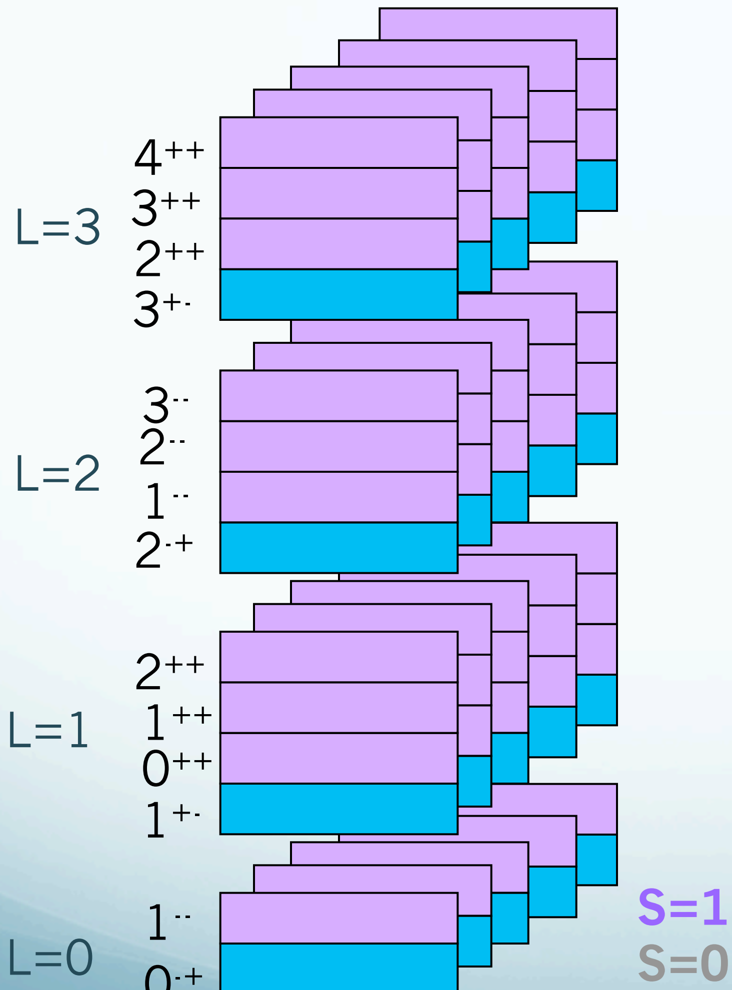
SU(3) is broken
Last two members mix

Spectroscopy an QCD

Quarkonium



Mesons



Allowed J^{PC} Quantum numbers:

0^{--}	0^{++}	0^{-+}	0^{+-}
1^{--}	1^{++}	1^{-+}	1^{+-}
2^{--}	2^{++}	2^{-+}	2^{+-}
3^{--}	3^{++}	3^{-+}	3^{+-}
4^{--}	4^{++}	4^{-+}	4^{+-}
5^{--}	5^{++}	5^{-+}	5^{+-}

Exotic Quantum Numbers
non quark-antiquark description

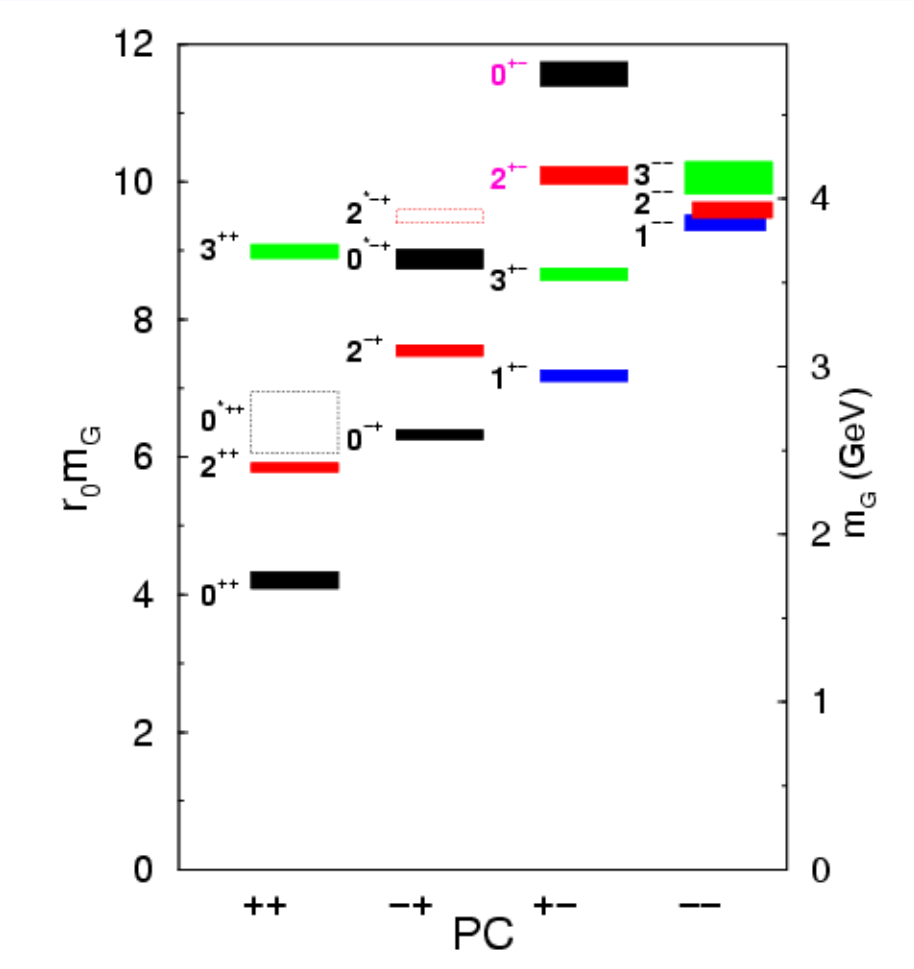
Lattice QCD Glueball Predictions

Gluons can bind to form glueballs
EM analogue: massive globs of pure light.

Lattice QCD predicts masses
The lightest glueballs have "normal" quantum numbers.

Glueballs will Q.M. mix
The observed states will be mixed with normal mesons.

Strong experimental evidence
For the lightest state.



Identification of Glueballs

Lightest Glueball predicted near two states of same Q.N..

“Over population” Predict 2, see 3 states

Glueballs should decay in a flavor-blind fashion.

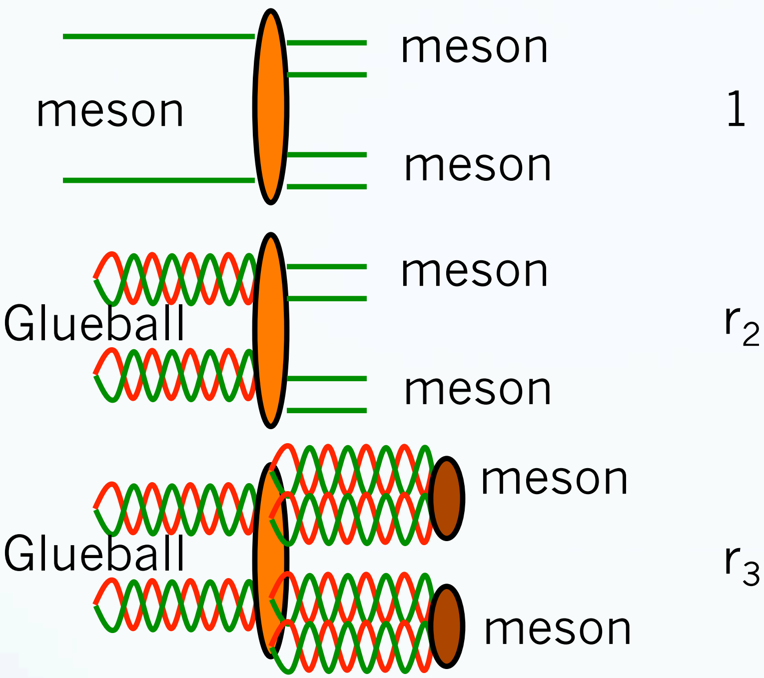
$$\pi\pi : K\bar{K} : \eta\eta : \eta'\eta' : \eta\eta' = 3 : 4 : 1 : 1 : 0$$

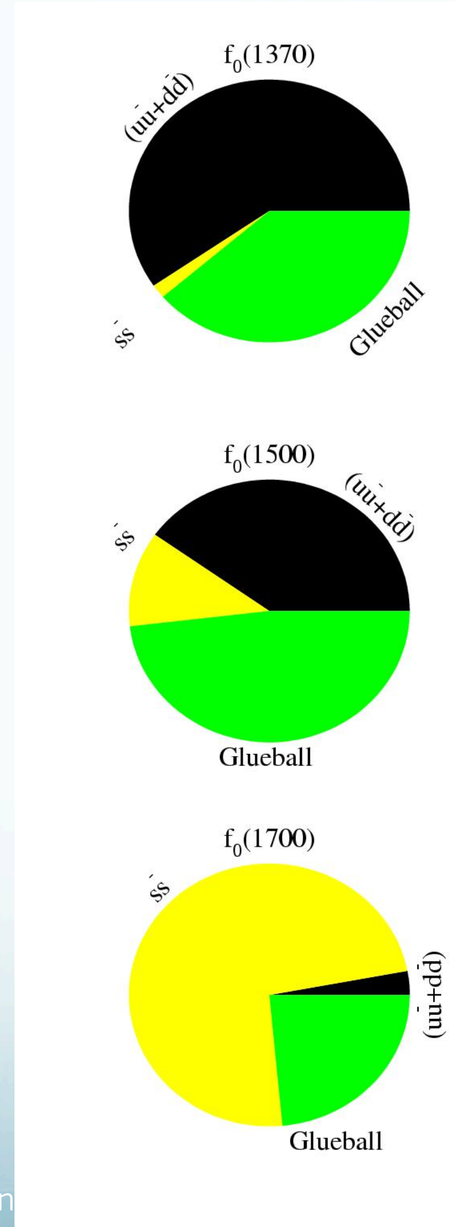
Production Mechanisms:

Certain are expected to by Glue-rich, others are Glue-poor. Where do you see them?

Proton-antiproton
Central Production
J/ψ decays

Glueball-Meson Mixing



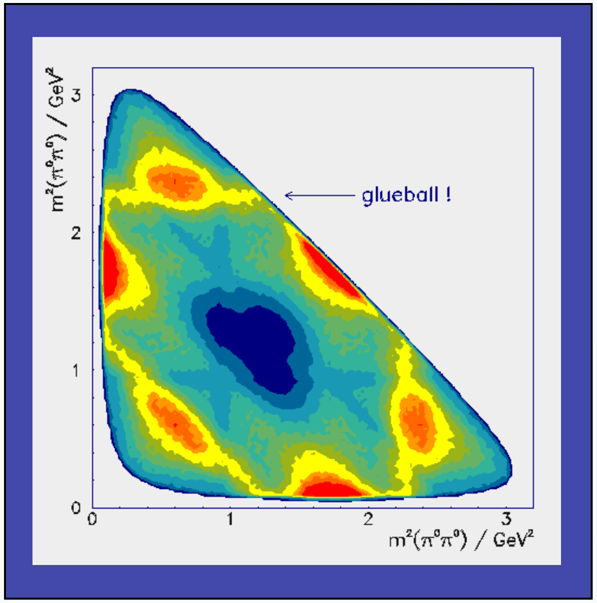


$G \rightarrow q\bar{q}$ flavor blind? r

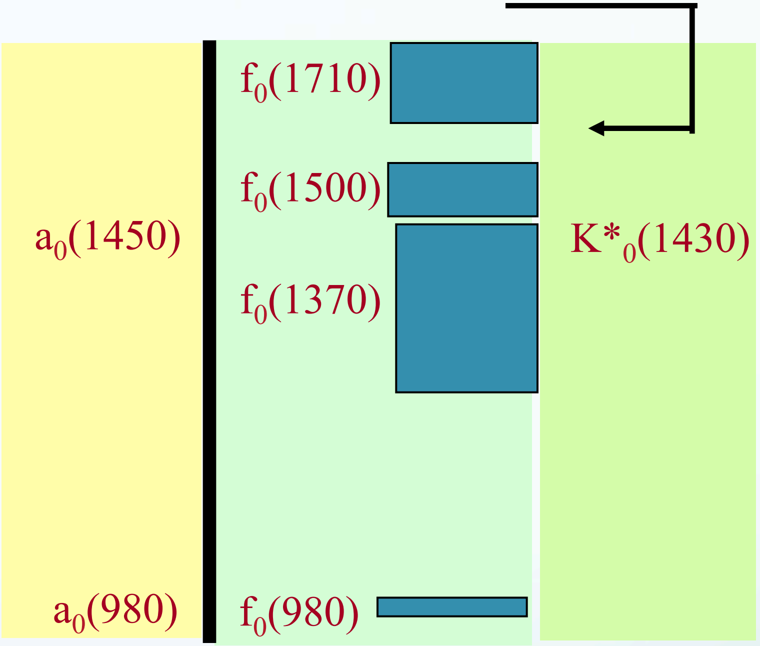
$$u\bar{u}\,,\, d\bar{d}\,,\, s\bar{s}$$

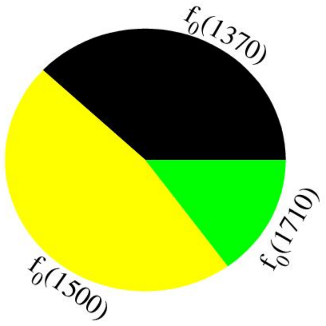
Solve for mixing scheme

Experimental Evidence



Scalar (0^{++}) Glueball and two nearby mesons are mixed.





Glueball spread over 3 mesons

Are there other glueballs?

Higher Mass Glueballs?

Part of the BES-III program will be to search for glueballs in radiative J/ψ decays.

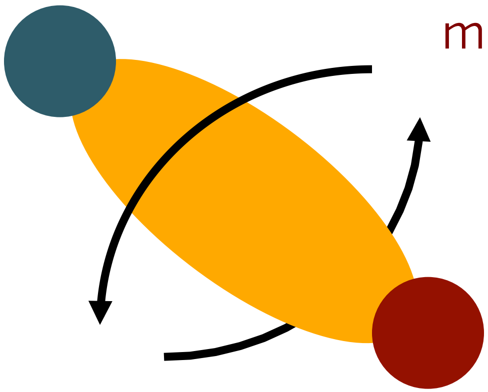
Lattice predicts that the 2^{++} and the 0^{-+} are the next two, with masses just above $2GeV/c^{2}$.

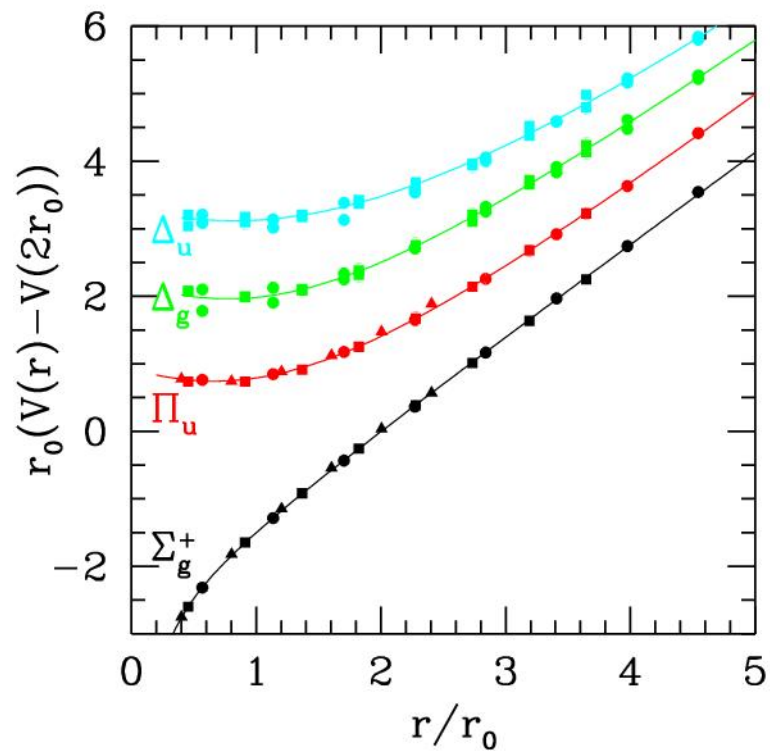
Radial Excitations of the 2^{++} ground state
L=3 2^{++} States + Radial excitations
f2(1950), f2(2010), f2(2300), f2(2340)…

2'nd Radial Excitations of the η and η', perhaps a bit cleaner environment! (I would Not count on it though....)

I expect this to be very challenging.

QCD Potential





Gluonic Excitations provide an experimental measurement of the excited QCD potential.

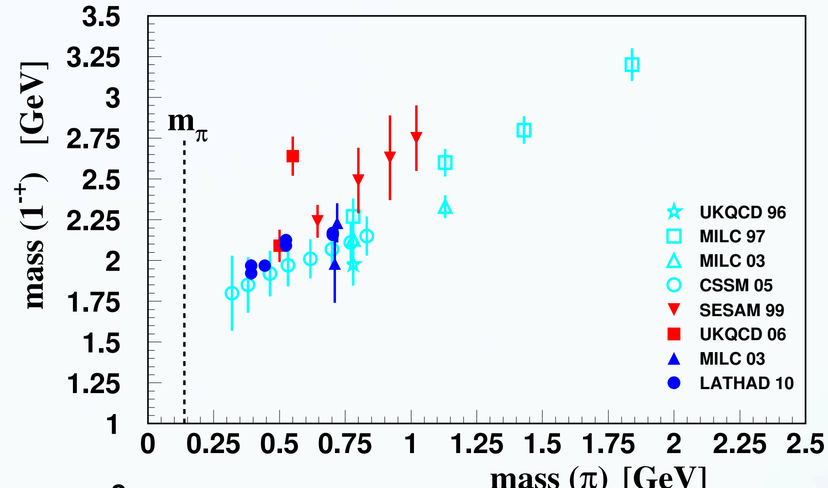
Observations of the nonets on the excited potentials are the best experimental signal of gluonic excitations.

Hybrid Predictions

Flux-tube model: 8 degenerate nonets

$1^{++}, 1^{--}$ $0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}$ ~1.9 GeV/c^2

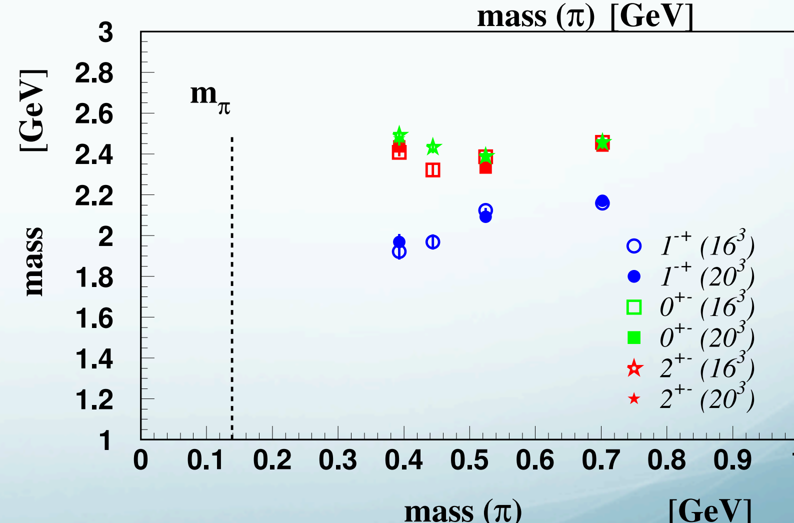
S=0 (over 1^{++}) S=1 (over the other seven)



Lattice QCD Calculations

1^{-+}	~1.9
2^{+-}	~2.2
0^{+-}	~2.2

At the physical pion mass?



In the charmonium sector:

1^{-+}	4.39 ±0.08
0^{+-}	4.61 ±0.11

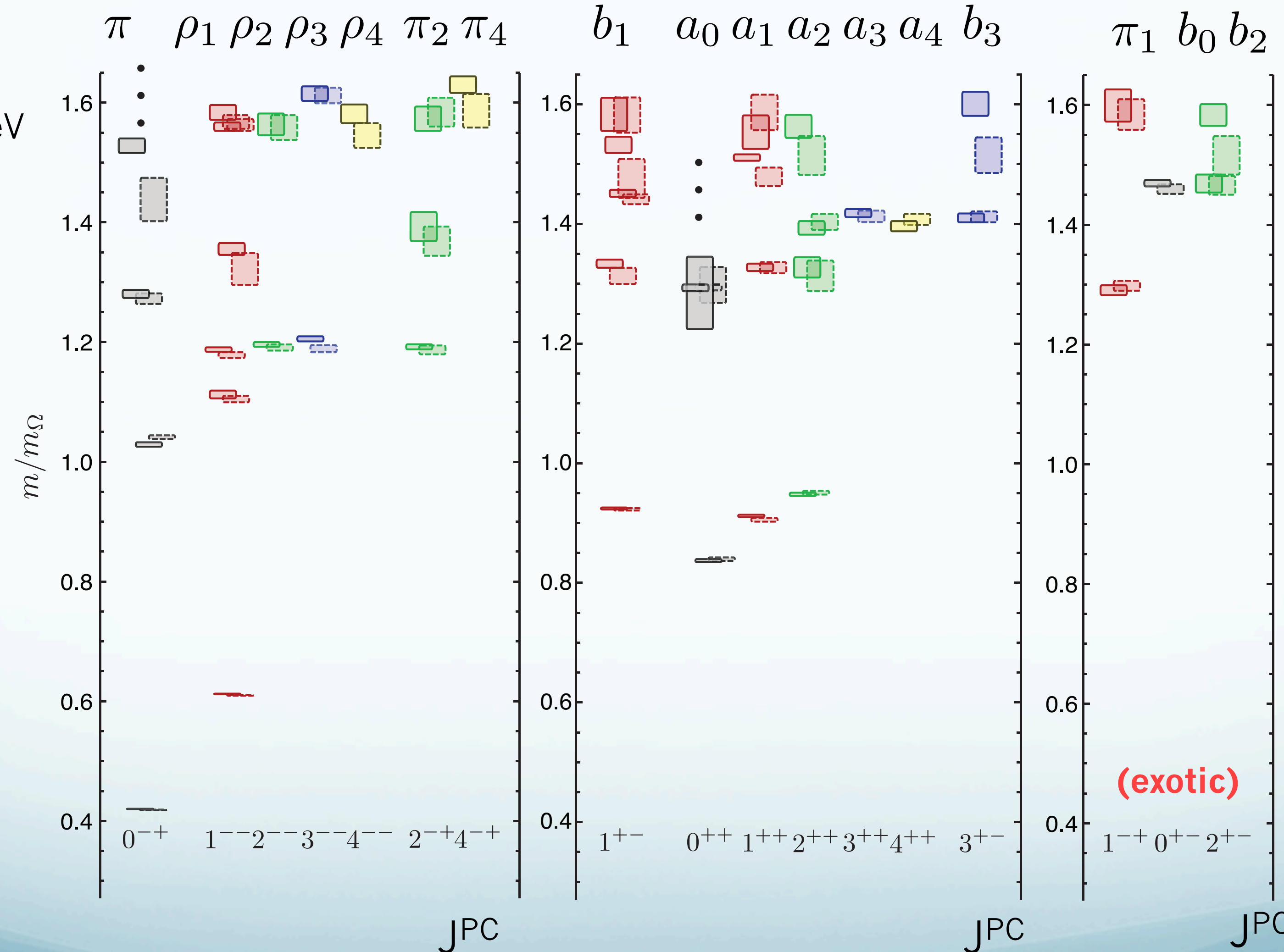
Many models predict exotic-QN hybrids.

LQCD: The Spectrum of Mesons

Dynamical calculation of the isospin-one light-quark mesons.

3 identical quarks, pion mass~700MeV

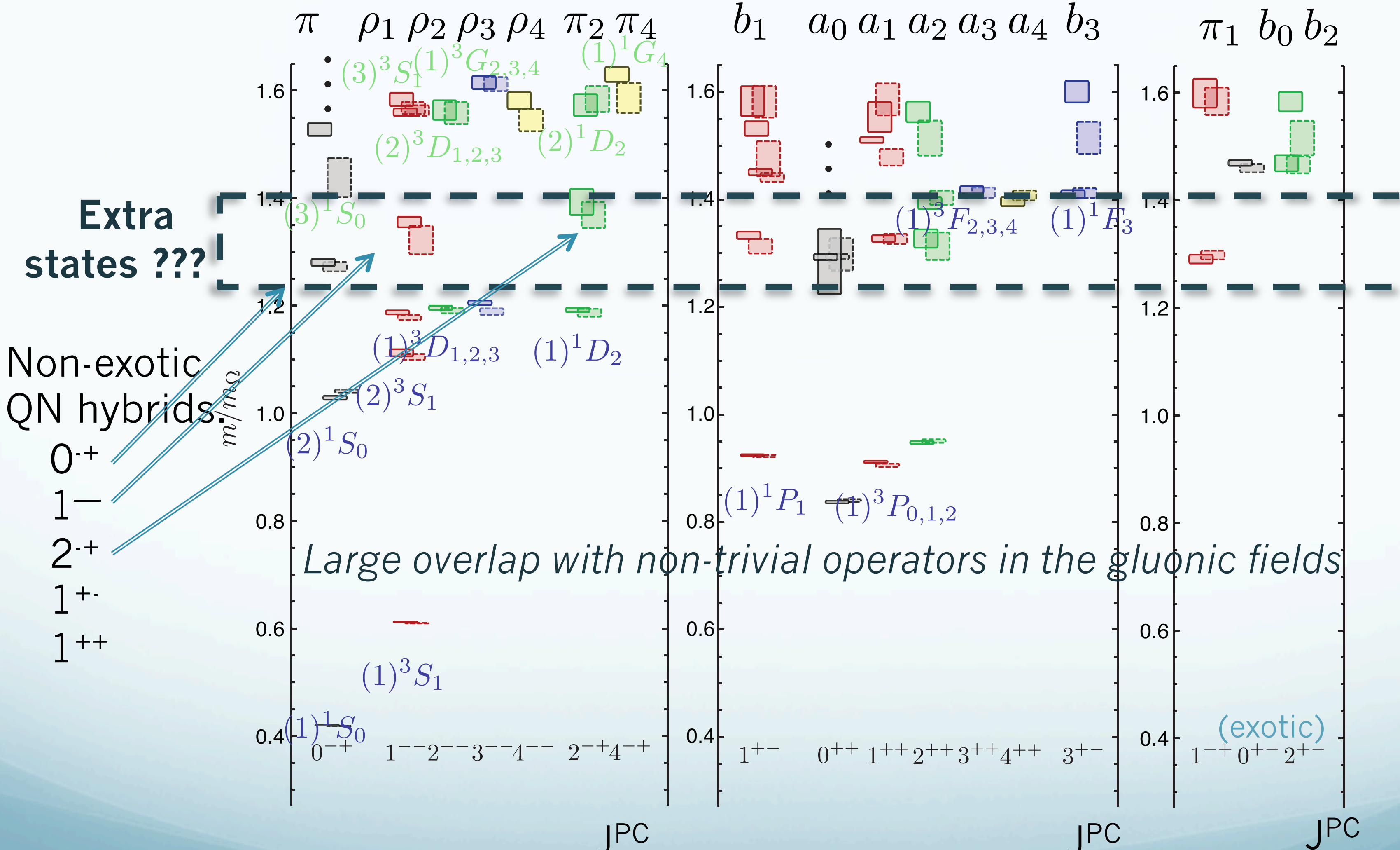
Two lattice volumes.



J.J. Dudek (et al.) arXiv:1004.4930

LQCD: The Spectrum of Mesons

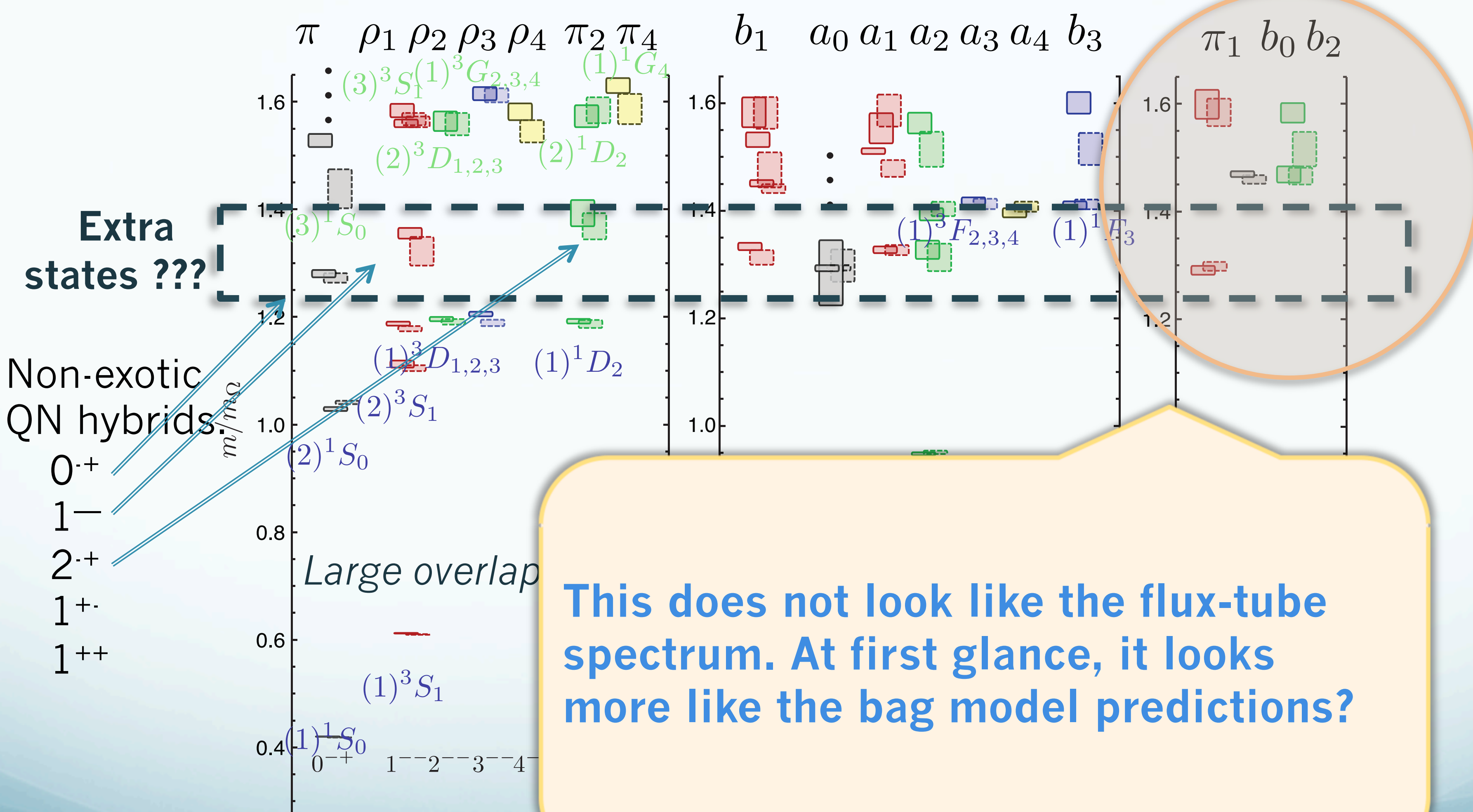
Dynamical calculation of the isospin-one light-quark mesons.



J.J. Dudek (et al.) arXiv:1004.4930

LQCD: The Spectrum of Mesons

Dynamical calculation of the isospin-one light-quark mesons.



This does not look like the flux-tube spectrum. At first glance, it looks more like the bag model predictions?

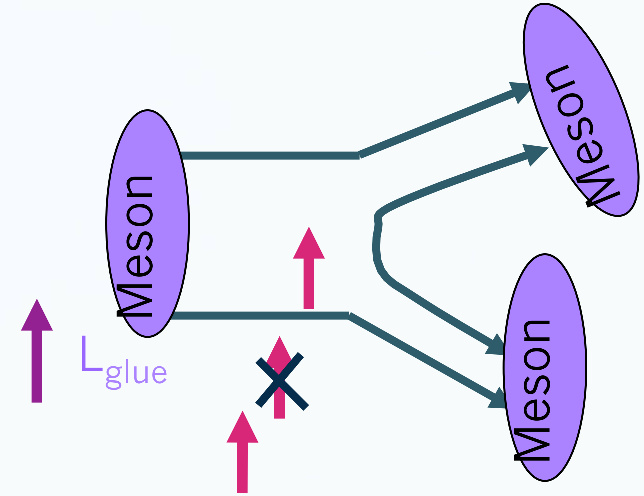
J.J. Dudek (et al.) arXiv:1004.4930

Looking for Hybrids

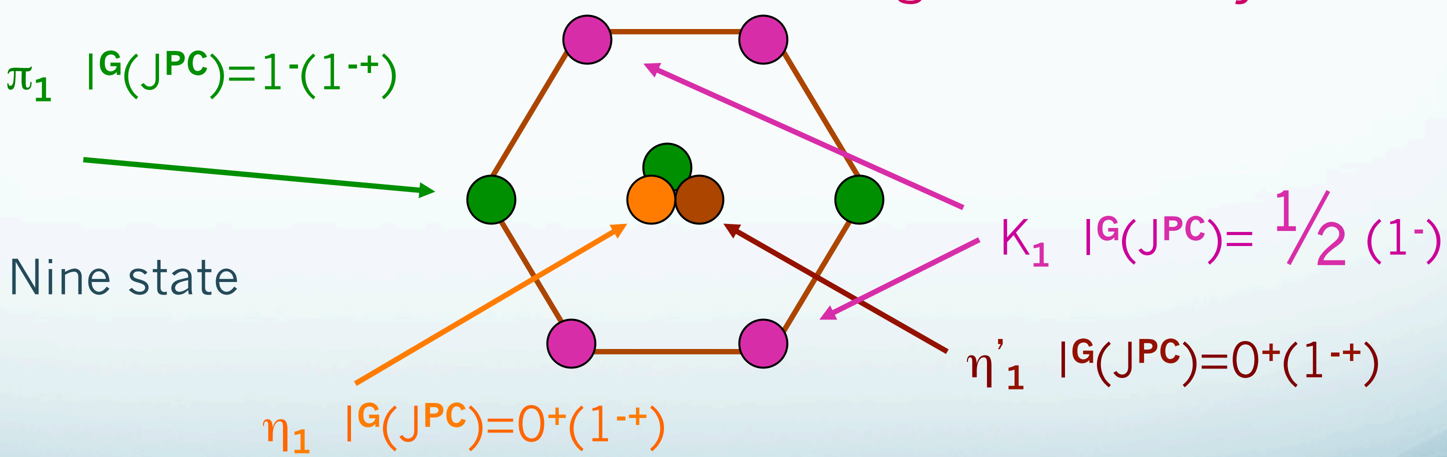
Decay Predictions

Analysis Method
Partial Wave Analysis

Fit n-D angular distributions
Fit Models of production and decay of resonances.



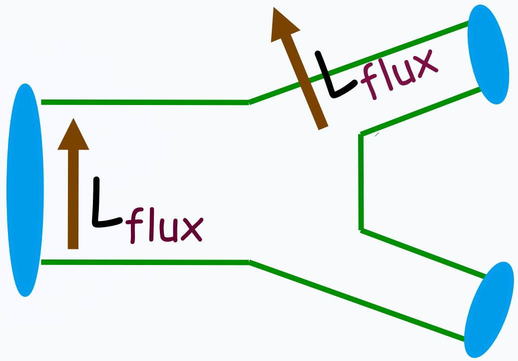
Angular momentum in the gluon flux stays confined.



This leads to complicated multi-particle final states.

Hybrid Decays

The angular momentum in the flux tube stays in one of the daughter mesons (an (L=1) and (L=0) meson).



Exotic Quantum Number Hybrids

$\pi_1 \rightarrow \pi b_1$, πf_1 , $\pi\rho$, ηa_1
$\eta_1 \rightarrow \pi(1300)\pi$, $a_1\pi$

$b_2 \rightarrow a_1\pi$, $h_1\pi$, $\omega\pi$, $a_2\pi$
$h_2 \rightarrow b_1\pi$, $\rho\pi$, $\omega\eta$

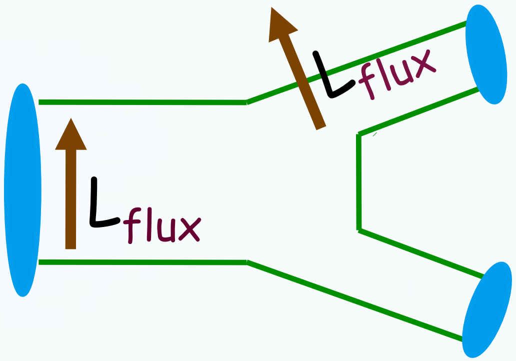
$b_0 \rightarrow \pi(1300)\pi$, $h_1\pi$
$h_0 \rightarrow b_1\pi$, $h_1\eta$

Mass and model dependent predictions

Populate final states with $\pi^{\pm}$,π^0,$K^{\pm}$,K^0, η , (photons)

Hybrid Decays

The angular momentum in the flux tube stays in one of the daughter mesons (an (L=1) and (L=0) meson).



Exotic Quantum Number Hybrids

$\pi_1 \rightarrow \pi b_1$, πf_1 , $\pi\rho$, ηa_1
$\eta_1 \rightarrow \pi(1300)\pi$, $a_1\pi$

$b_2 \rightarrow a_1\pi$, $h_1\pi$, $\omega\pi$, $a_2\pi$
$h_2 \rightarrow b_1\pi$, $\rho\pi$, $\omega\eta$

$b_0 \rightarrow \pi(1300)\pi$, $h_1\pi$
$h_0 \rightarrow b_1\pi$, $h_1\eta$

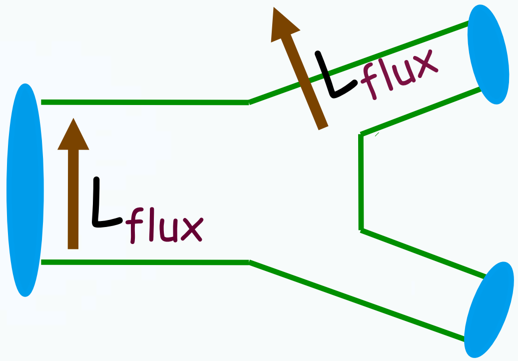
Mass and model dependent predictions

Populate final states with $\pi^{\pm}, \pi^0, K^{\pm}, K^0, \eta$, (photons)

The good channels to look at with amplitude analysis.

Hybrid Decays

The angular momentum in the flux tube stays in one of the daughter mesons (an (L=1) and (L=0) meson).



Exotic Quantum Number Hybrids

$\pi_1 \to \pi b_1$, πf_1 , $\pi\rho$, ηa_1
$\eta_1 \to \pi(1300)\pi$, $a_1\pi$

$b_2 \to a_1\pi$, $h_1\pi$, $\omega\pi$, $a_2\pi$
$h_2 \to b_1\pi$, $\rho\pi$, $\omega\eta$

$b_0 \to \pi(1300)\pi$, $h_1\pi$
$h_0 \to b_1\pi$, $h_1\eta$

Mass and model dependent predictions

Populate final states with $\pi^{\pm}, \pi^0, K^{\pm}, K^0, \eta$, (photons)

The good channels to look at with amplitude analysis.

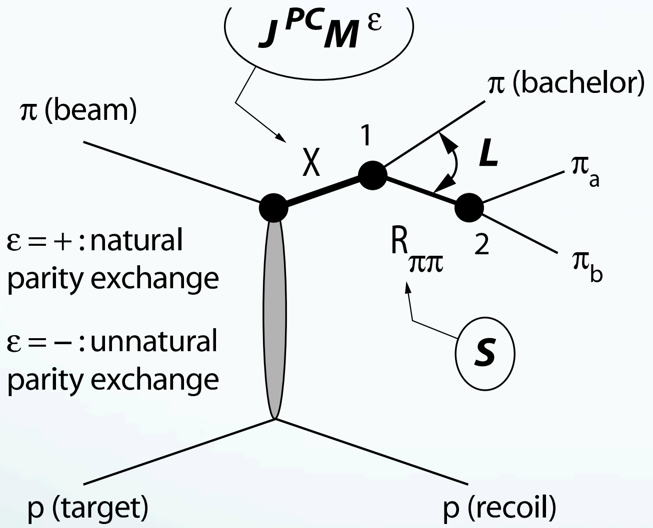
Other interesting channels for amplitude analysis.

Experimental Evidence for Hybrids

The most extensive data sets to date are from the **BNL E852 experiment**. There is also data from the **VES experiment** at Protvino and some results from the **Crystal Barrel experiment** at LEAR. Finally, there is a **CLAS (Jefferson Lab)** result. We have also just started to see results from the **COMPASS** experiment at CERN.

Experimental Evidence for Hybrids

The most extensive data sets to date are from the **BNL E852 experiment**. There is also data from the **VES experiment** at Protvino and some results from the **Crystal Barrel experiment** at LEAR. Finally, there is a **CLAS (Jefferson Lab)** result. We have Also just started to see results from the **COMPASS** experiment at CERN.



Diffractive production

E852: 18 GeV/c $\pi^- p \to (p,n) X^{(-,0)}$

VE 37 GeV/c $\pi^- A \to A X^-$

COMPASS:160 GeV/c $\pi^- Pb \to Pb X^-$

$$(\pi^{\pm} p \to p X^{\pm}, pp \to p_s X^0 p_f)$$

M: spin projection
ε : reflectivity

Natural-parity-exchange: $J^P=0^+,1^-,2^+, \ldots$
Unnatural-parity-exchange: $J^P=0^-,1^+,2^-, \ldots$

Experimental Evidence for Hybrids

$\pi_1(1400)$

Mode	Mass	Width	Production
$\eta\pi^-$	1370±15+50-30	385±40+65-105	1^+
$\eta\pi^0$	1257±20±25	354±64±60	1^+
$\eta\pi$	1400	310	seen in $\bar{p}N$ annihilation

$\pi_1(1600)$

Mode	Mass	Width	Production
3π	1598 ±8+29-47	168±20+150-12	$1^+,0^-,1^-$
$\eta'\pi$	1597±10+45-10	340±40±50	1^+
$b_1\pi$	1664±8±10	185±25±38	$0^-,1^+$
$f_1\pi$	1709±24±41	403±80±115	1^+
3π	1660 ±10+64-0	269±21+42-64	1^+

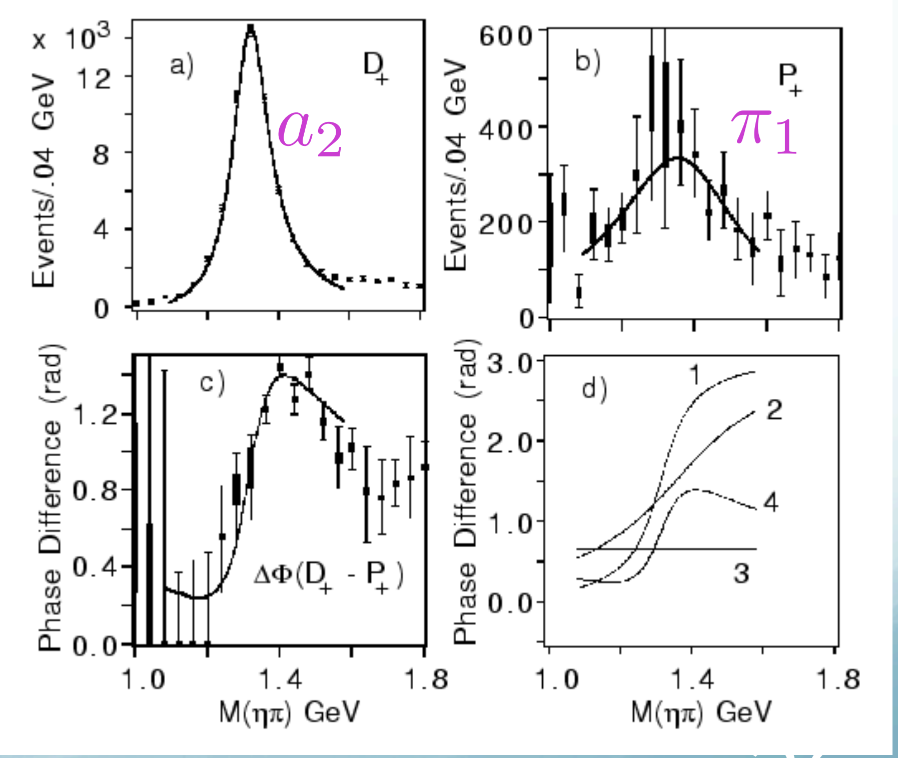
$\pi_1(2015)$

Mode	Mass	Width	Production
$b_1\pi$	2014±20±16	230±32±73	1^+
$f_1\pi$	2001±30±92	332±52±49	1^+

Experimental Evidence for Hybrids

	Mode	Mass	Width	Production
$\pi_1(1400)$	$\eta\pi^-$	1370±15+50-30	385±40+65-105	1^+
	$\eta\pi^0$	1257±20±25	354±64±60	1^+
	$\eta\pi$	1400	310 seen in $\bar{p}N$	annihilation

E852 + CBAR (1997)



While everyone seems to agree that there is intensity in the P^+ exotic wave, there are a number of alternative (non-resonant) explanations for this state.

Unlikely to be a hybrid based on its mass. Also , the only observed decay should not couple to a member of an SU (3) octet. It could couple to an SU(3) decuplet state (e.g. 4-quark).

Experimental Evidence for Hybrids

$\pi_1(1600)$

Mode	Mass	Width	Production
3π	1598 ±8+29-47	168±20+150-12	$1^+, 0^-, 1^-$
$\eta'\pi$	1597±10+45-10	340±40±50	1^+
$b_1\pi$	1664±8±10	185±25±38	$0^-, 1^+$
$f_1\pi$	1709±24±41	403±80±115	1^+
3π	1660 ±10+64-0	269±21+42-64	1^+

$\pi_1(1600)$

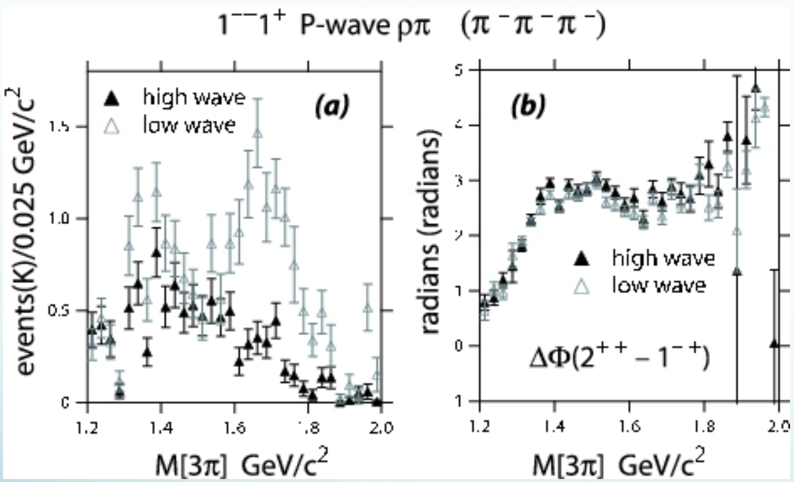
Mode	Mass	Width	Production
3π	1598 ±8+29-47	168±20+150-12	$1^+, 0^-, 1^-$
$\eta'\pi$	1597±10+45-10	340±40±50	1^+
$b_1\pi$	1664±8±10	185±25±38	$0^-, 1^+$
$f_1\pi$	1709±24±41	403±80±115	1^+
3π	1660 ±10+64-0	269±21+42-64	1^+

Experimental Evidence for Hybrids

$\pi_1(1600)$

Mode	Mass	Width	Production
3π	1598 ±8+29-47	168±20+150-12	$1^+,0^-,1^-$ E852
$\eta'\pi$	1597±10+45-10	340±40±50	1^+ E852,VES
$b_1\pi$	1664±8±10	185±25±38	$0^-,1^+$ E852,VES,CBAR
$f_1\pi$	1709±24±41	403±80±115	1^+ E852,VES
3π	1660 ±10+64-0	269±21+42-64	1^+ COMPASS

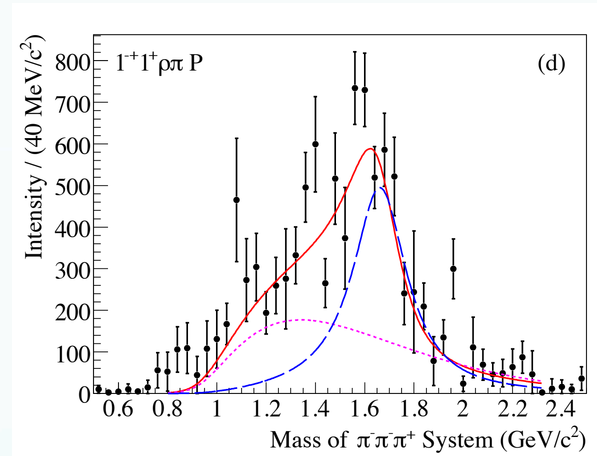
3π Decay mode sensitive to model

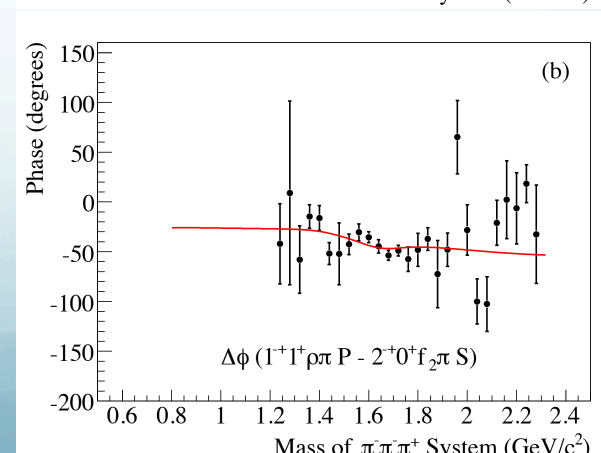


Confused production in E852??

But not in COMPASS

Exactly the same mass and width as the $\pi_2(1670)$





This is consistent with a hybrid meson

Experimental Evidence for Hybrids

$\pi_1(2015)$

Mode	Mass	Width	Production
$b_1\pi$	2014±20±16	230±32±73	1^+
$f_1\pi$	2001±30±92	332±52±49	1^+

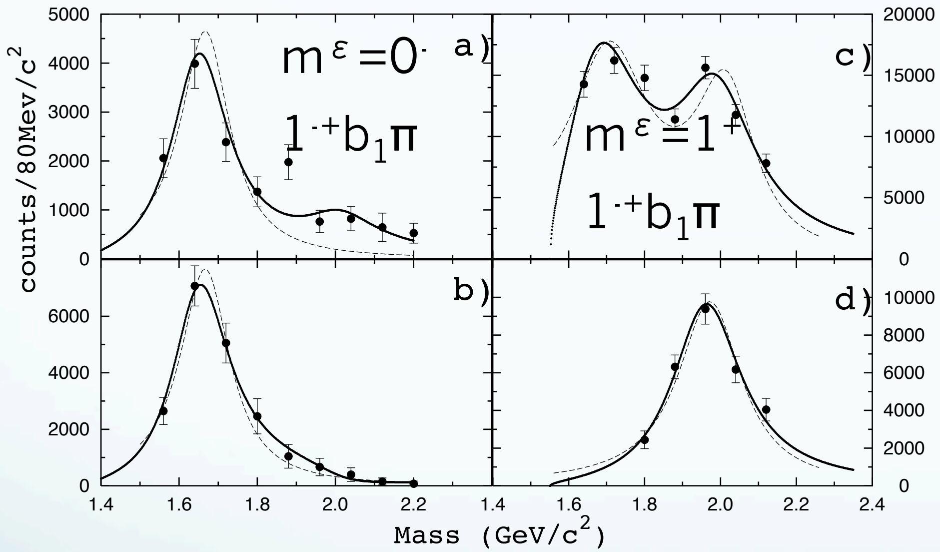
$\pi_1(2015)$

Mode	Mass	Width	Production
$b_1\pi$	2014±20±16	230±32±73	1^+
$f_1\pi$	2001±30±92	332±52±49	1^+

Experimental Evidence for Hybrids

$\pi_1(2015)$	Mode	Mass	Width	Production	
	$b_1\pi$	2014±20±16	230±32±73	1^+	E852
	$f_1\pi$	2001±30±92	332±52±49	1^+	E852

Need two $J^{PC}=1^{-+}$ states



$\pi_1(2000)\rightarrow b_1\pi$

$M = 2014\pm20\pm16$ MeV/c²

$\Gamma = 230\pm32\pm73$ MeV/c²

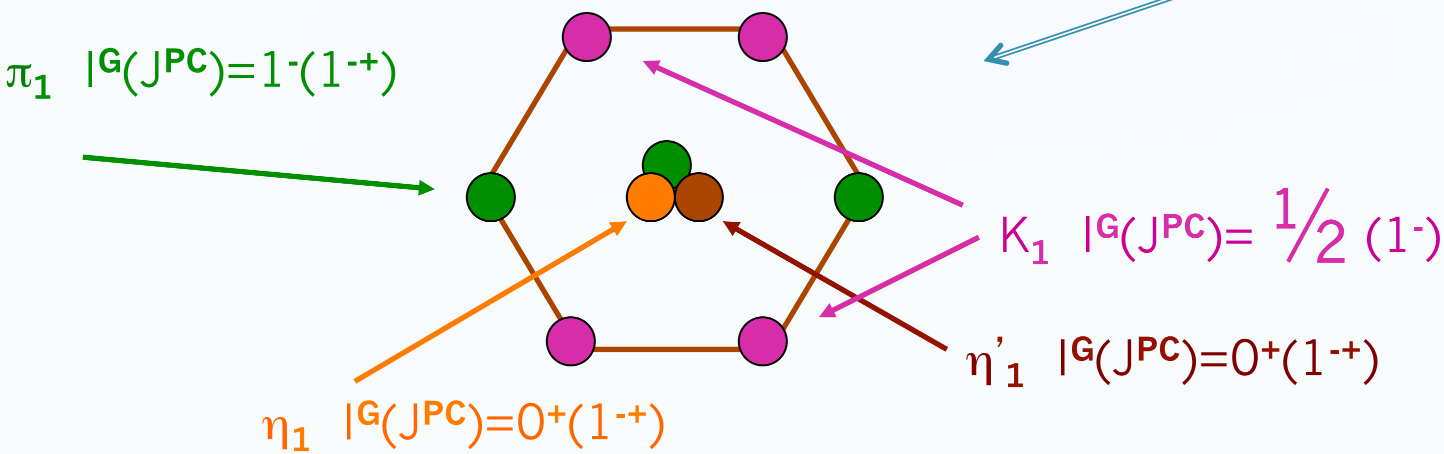
Seen primarily in natural parity exchange.

The natural dominates

Seen in one experiment with low statistics It needs confirmation. If this exists, it is also a good candidate for an exotic hybrid meson.

QCD Exotics

We expect 3 nonets of exotic-quantum-number mesons: 0^{+-}, 1^{-+}, 2^{+-}



- $\pi_1(2015)$
- $\pi_1(1600)$

Lattice shows two states here.

$\pi, \eta, \eta', K \rightarrow \pi_1, \eta_1, \eta'_1, K_1$ 1^{-+}

b_0, h_0, h_0', K_0 0^{+-}

b_2, h_2, h_2', K_2 2^{+-}

What are the mixing angles between the isoscalar states?

Future Prospects:

- COMPASS at CERN collected a large data set in 2009. Analysis is underway.
- BES III in China has been running for over a year. Analysis on χ decays are looking for light-quark exotics.
- GlueX at Jefferson Lab will use photo-production to look for exotic mesons at Jefferson Lab. First physics in 2015.
- PANDA at GSI will use antiprotons to search for charmed hybrid states.
- CLAS12 at Jefferson Lab will look at low-multiplicity final states in very-low Q**2 reactions.