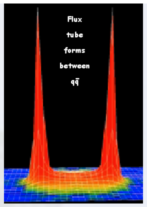
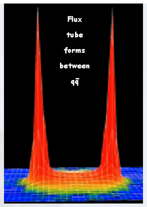


GlueX/Hall-D Physics

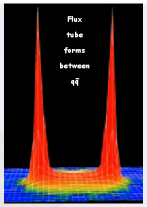
Curtis A. Meyer
Carnegie Mellon University

Jlab Users Meeting, June 2010



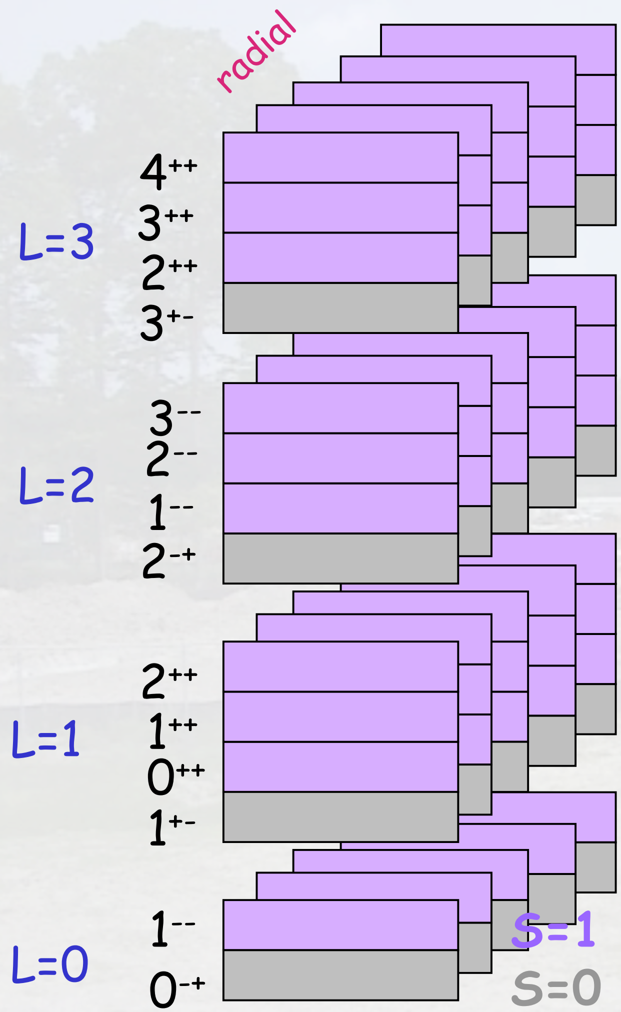
Outline

- Meson spectroscopy and hybrid mesons.
- New information from Lattice QCD.
- The experimental situation.
- Status of GlueX/Hall-D.
- Amplitude analysis.

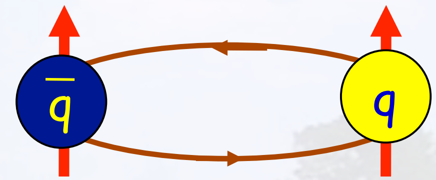


Spectroscopy and QCD

Mesons

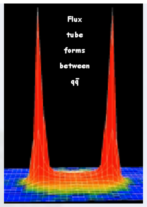


Quarkonium



Consider the three lightest quarks

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



Spectroscopy and QCD

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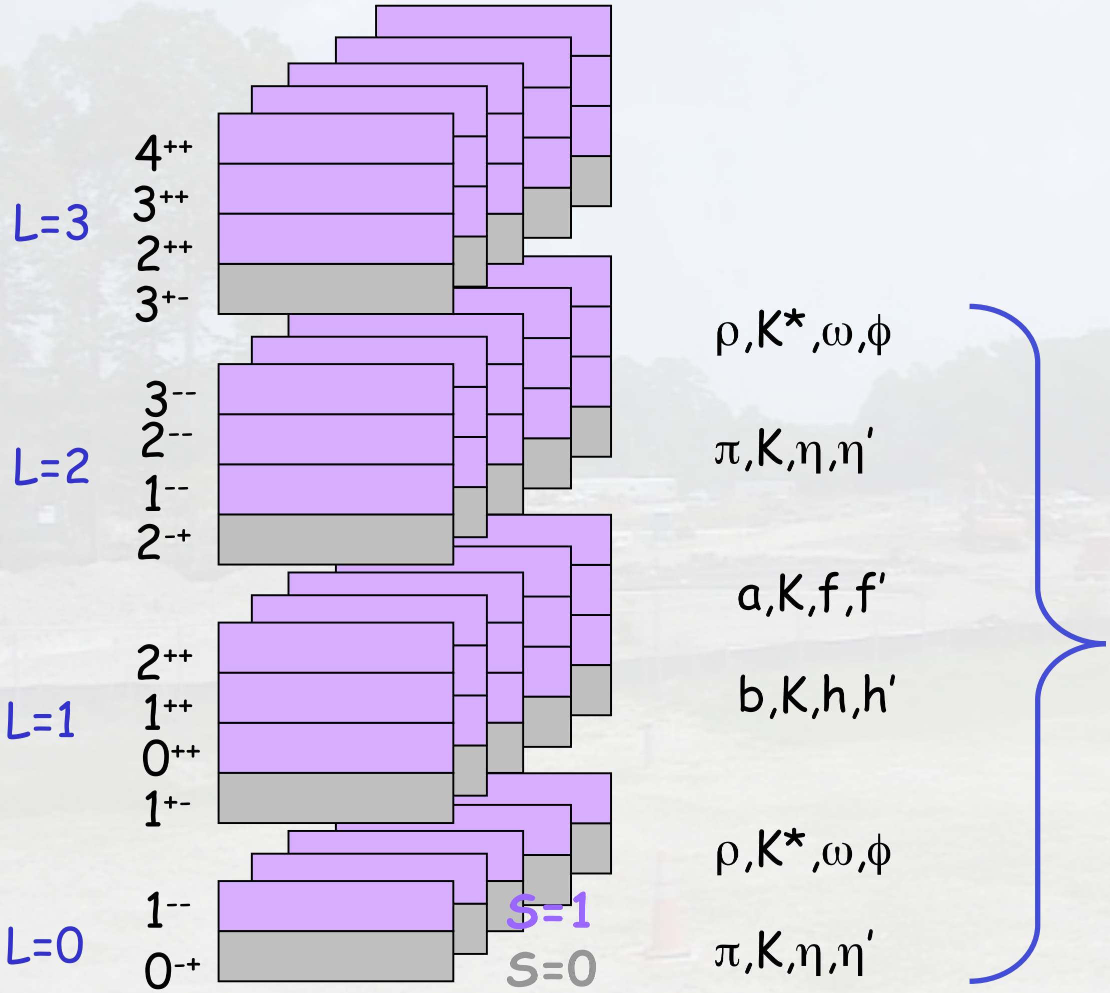

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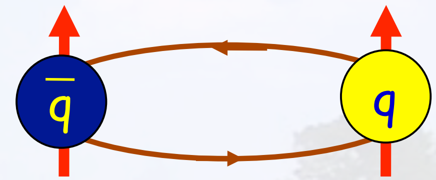
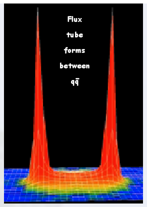


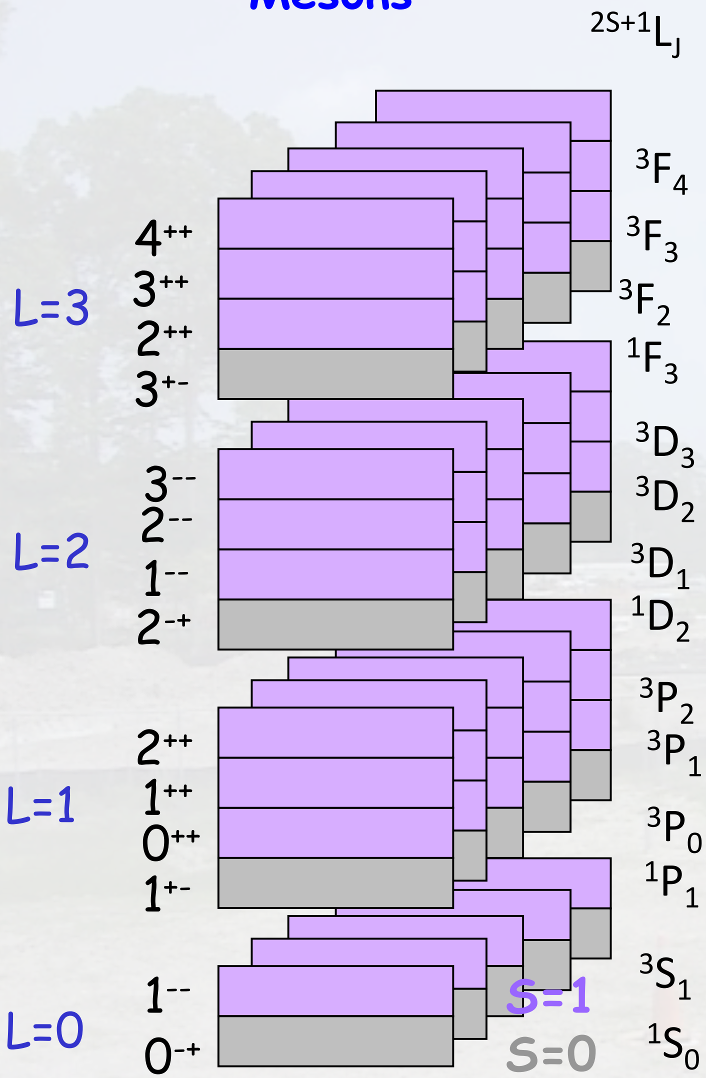
Mesons come in nonets of the same J^{PC} Quantum Numbers

SU(3) is broken
last two members mix



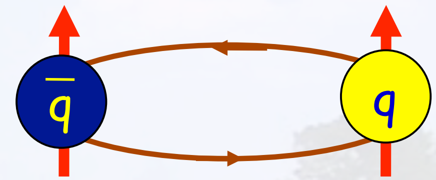
Spectroscopy and QCD

Mesons



Nothing to do with Glue!

Quarkonium

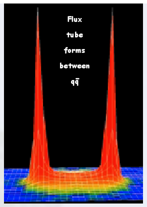


Allowed J^{PC} Quantum numbers:

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



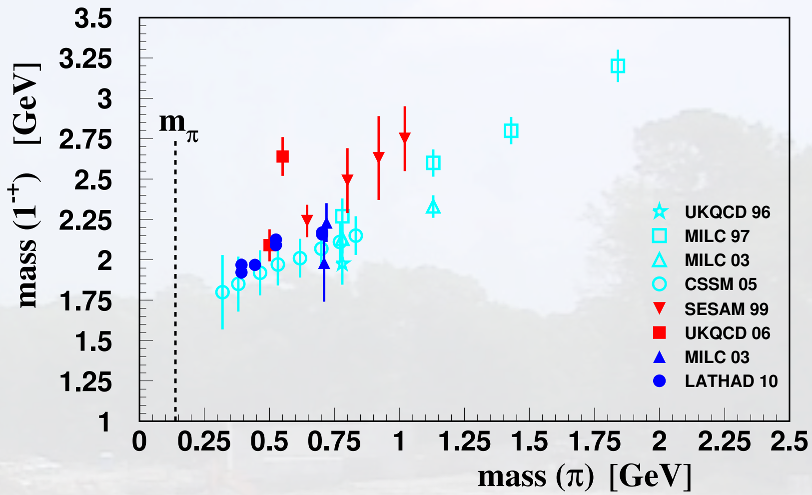
Hybrid Predictions

Flux-tube model: 8 degenerate nonets

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

S=0 S=1

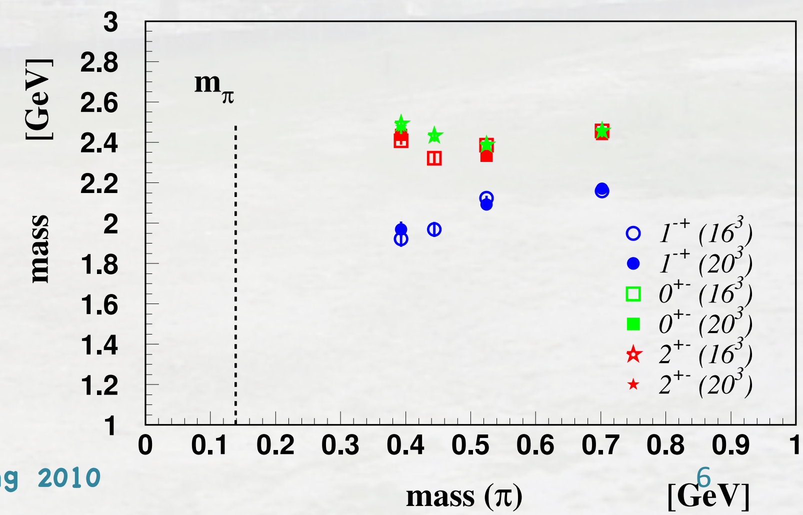
Lattice QCD Calculations



Lattice QCD Calculations

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

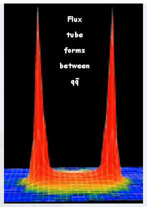
At the physical pion mass?



In the charmonium sector:

1^{-+}	4.39 ±0.08
0^{+-}	4.61 ±0.11

Many models predict exotic-QN hybrids.

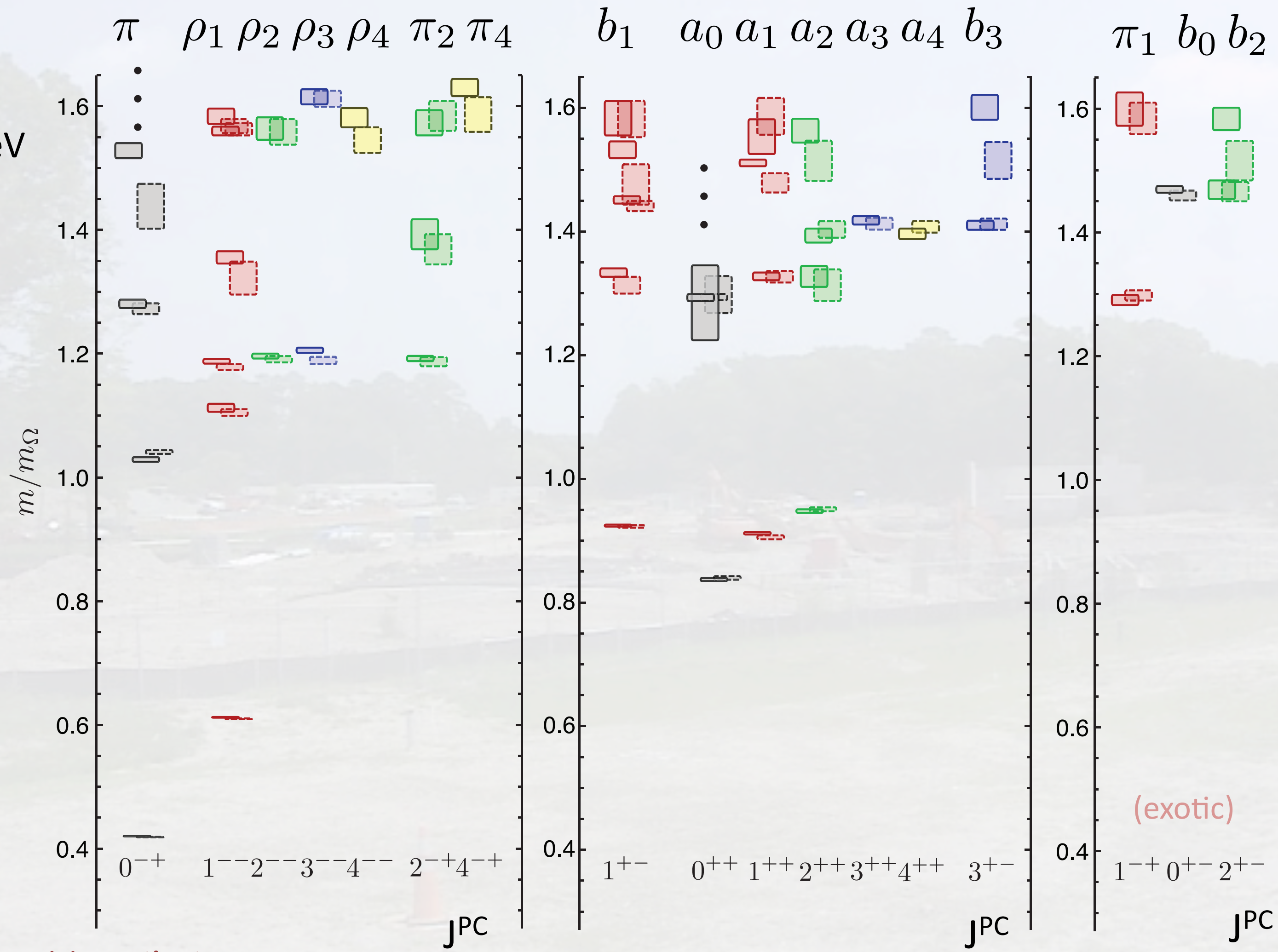


LQCD: The Spectrum of Mesons

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

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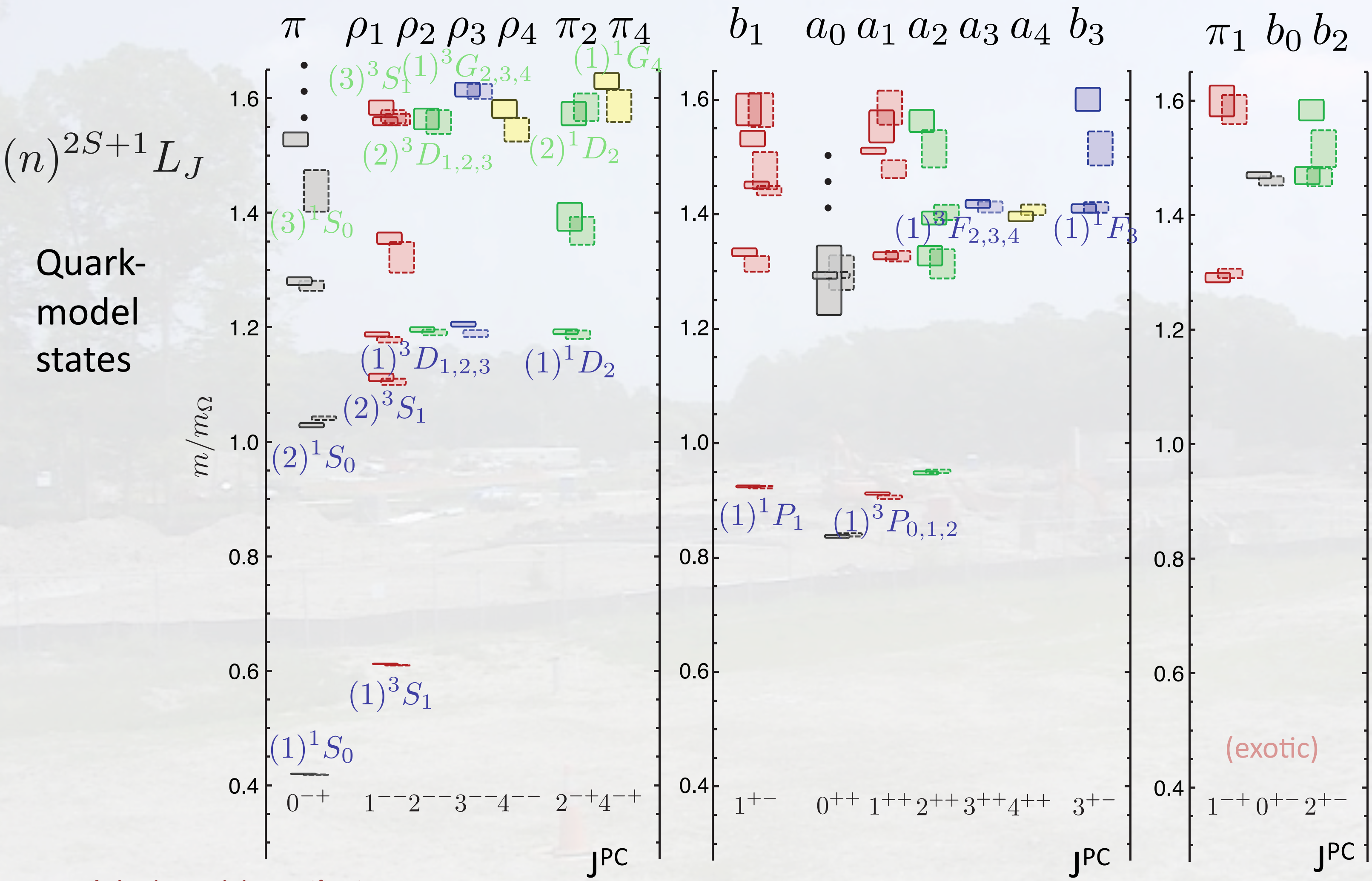

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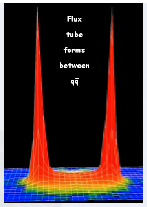

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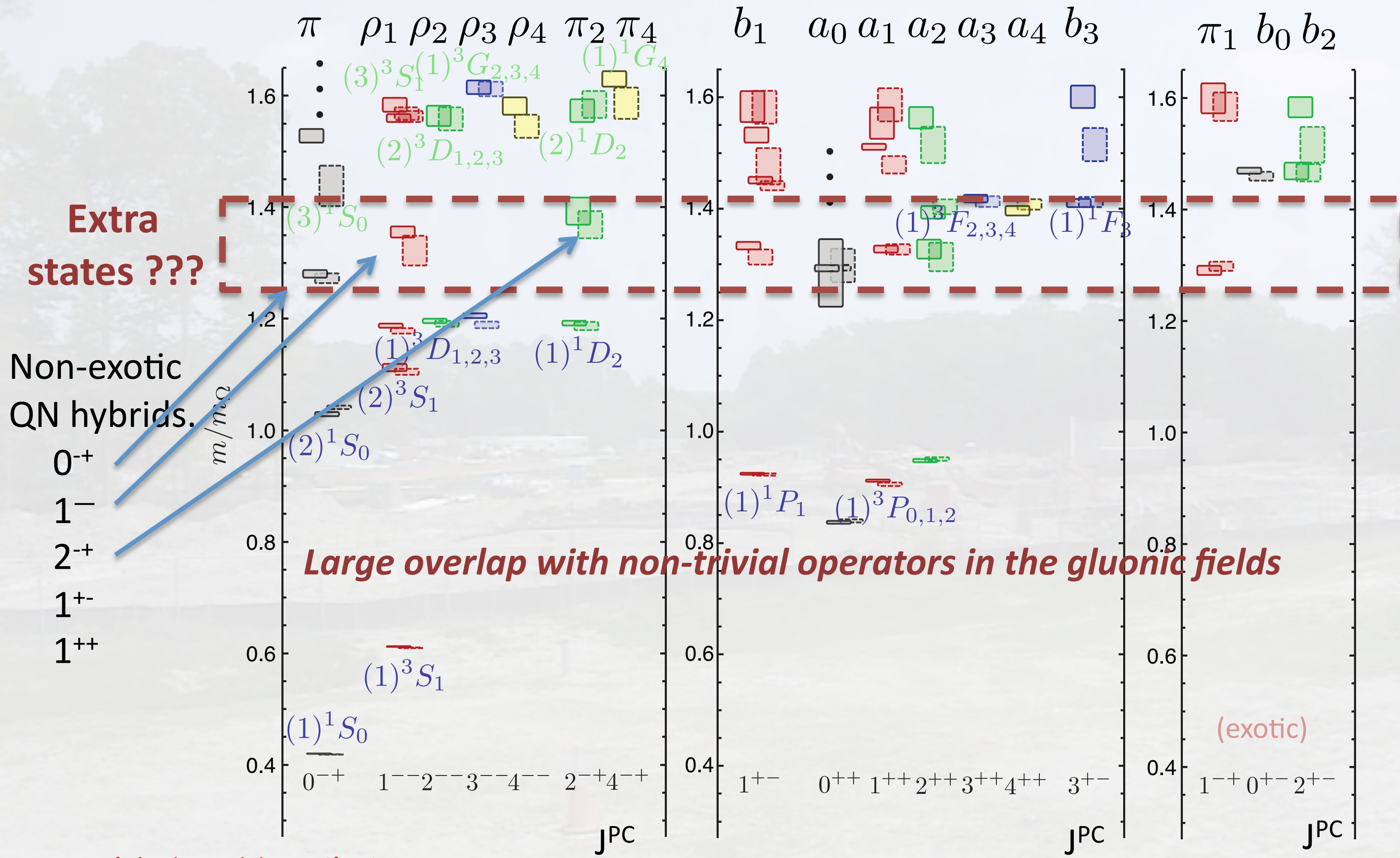

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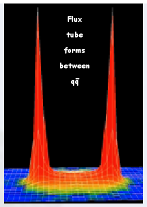
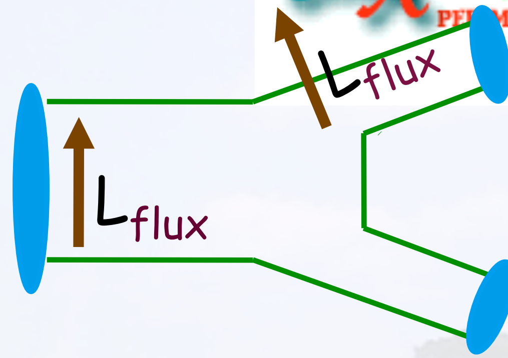


Hybrid Decays



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

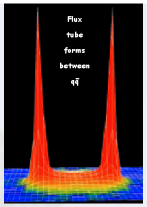
$\pi_1 \rightarrow \pi b_1 , \pi f_1 , \pi\rho , \eta a_1$
$\eta_1 \rightarrow \pi(1300)\pi , a_1\pi$

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

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

Mass and model dependent predictions

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



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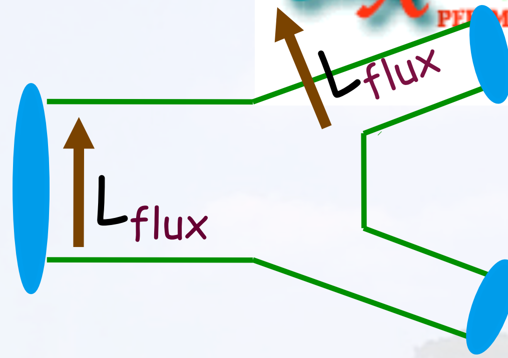

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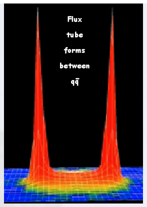
Mass and model dependent predictions

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

The good channels to look at with amplitude analysis.



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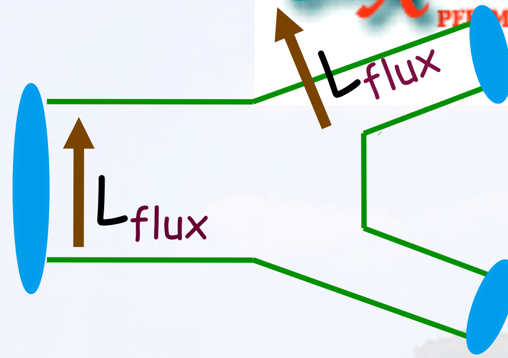

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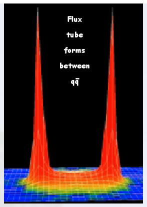
Mass and model dependent predictions

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

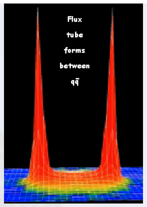
The good channels to look at with amplitude analysis.

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.



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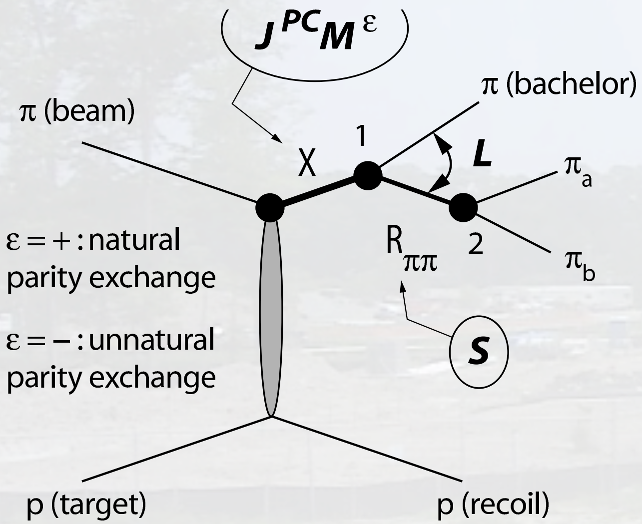


Diffractive production

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

VES: 37 GeV/c $\pi^- A \rightarrow A X^-$

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

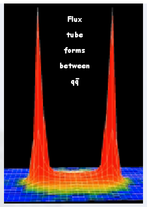
$$(\pi^\pm p \rightarrow p X^\pm, pp \rightarrow p_s X^0 p_f)$$

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	annihilation

$\pi_1(1600)$

Mode	Mass	Width	Production
3π	1598 ±8+29-47	168±20+150-12 $\bar{p}N$	$1^+,0^-,1-$
$\eta'\pi$	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^+
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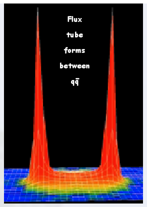

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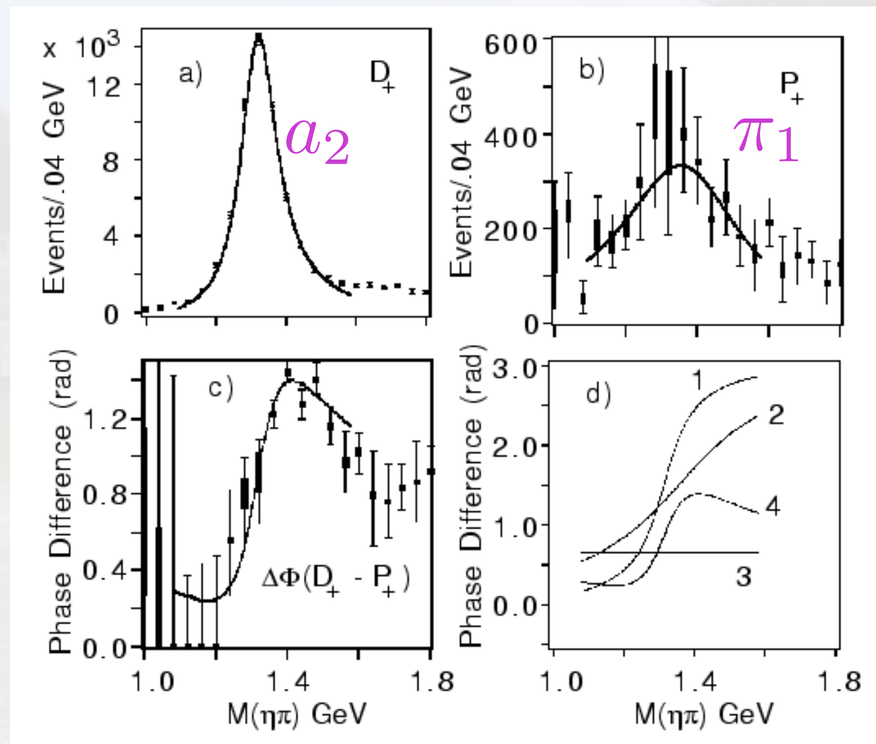
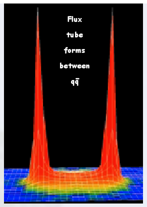
E852 + CBAR (1997)



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).



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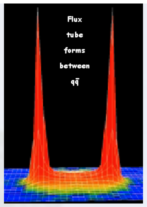

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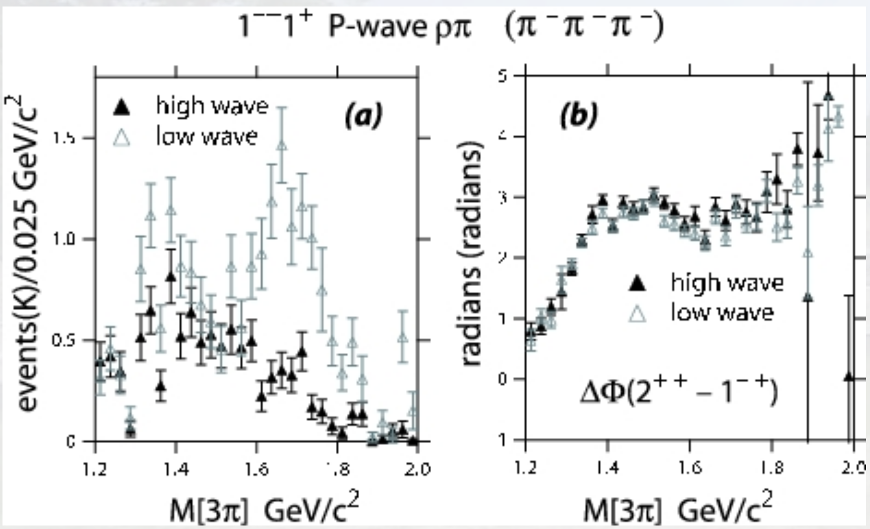
3π	1660 ±10+64-0	269±21+42-64	1^+ COMPASS

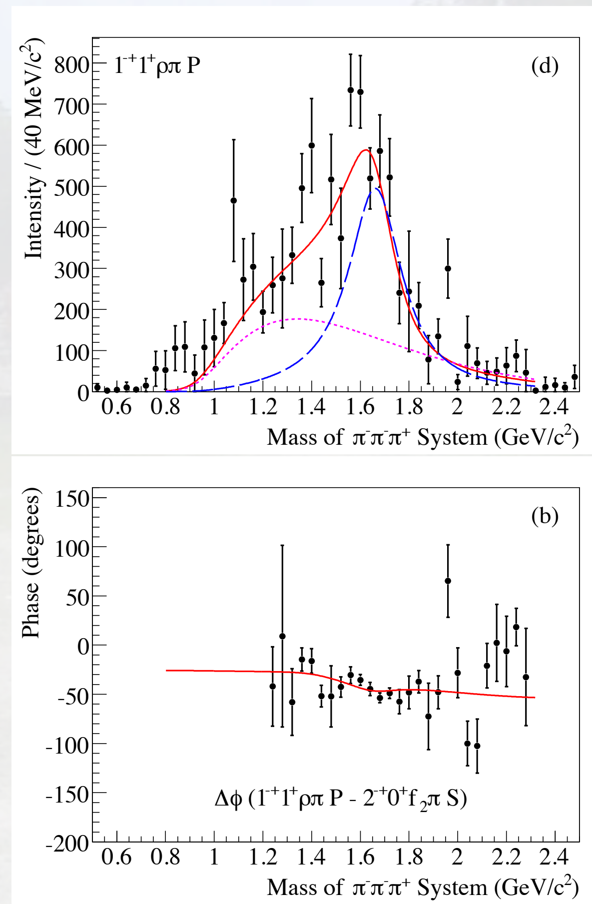
3π Decay mode sensitive to model



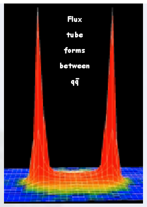
Confused production in E852??

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

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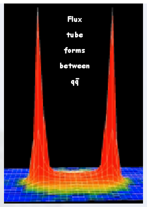

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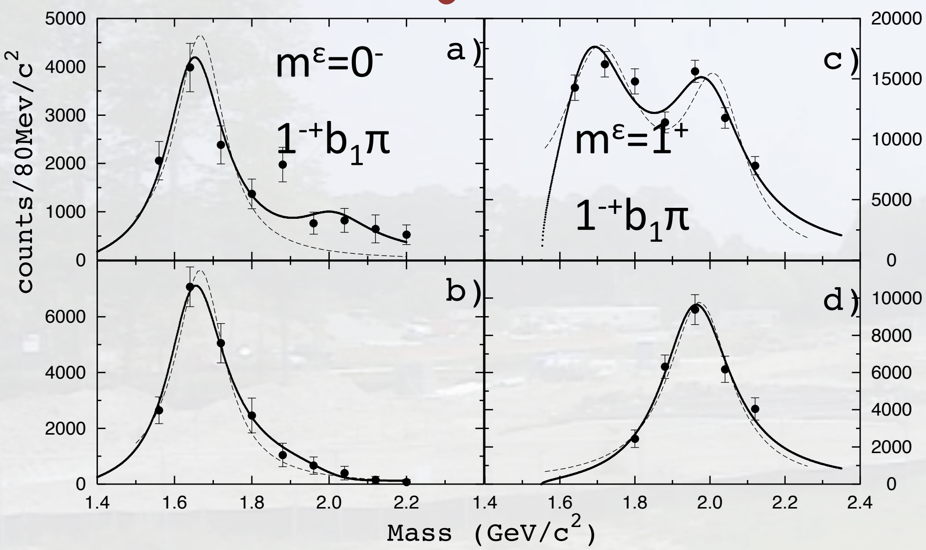
Need two $J^{PC}=1^{-+}$ states



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

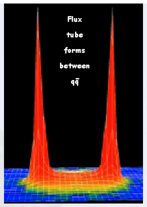
$M = 2014 \pm 20 \pm 16$ MeV/c^2

$\Gamma = 230 \pm 32 \pm 73$ MeV/c^2

Seen primarily in natural parity exchange.

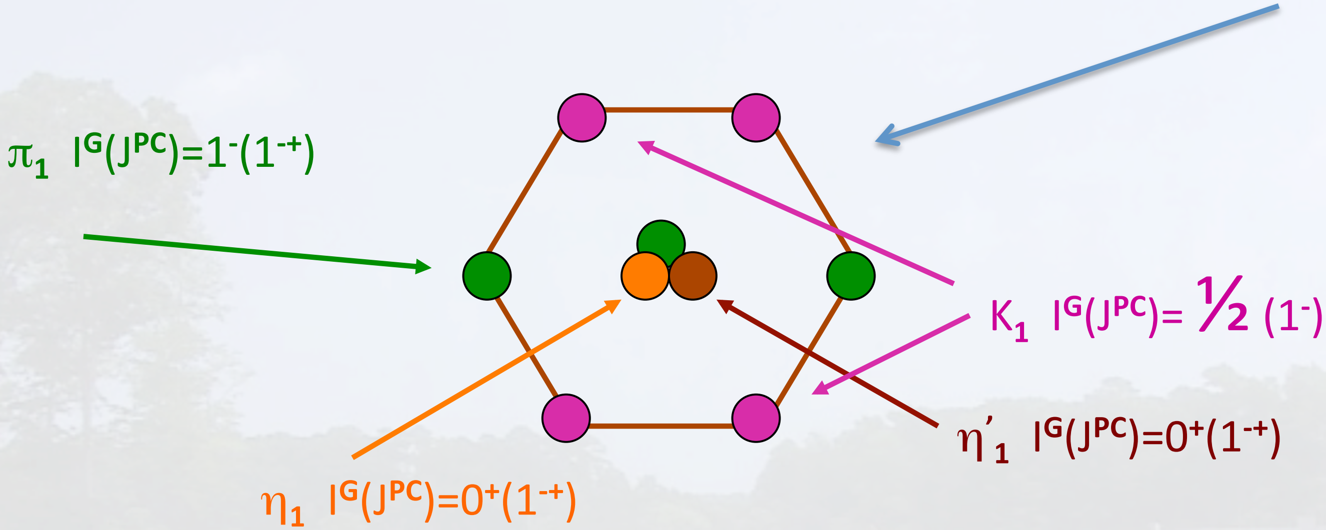
The natural dominates

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^{+-}



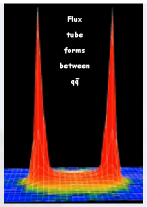
● $\pi_1(2015)$

● $\pi_1(1600)$

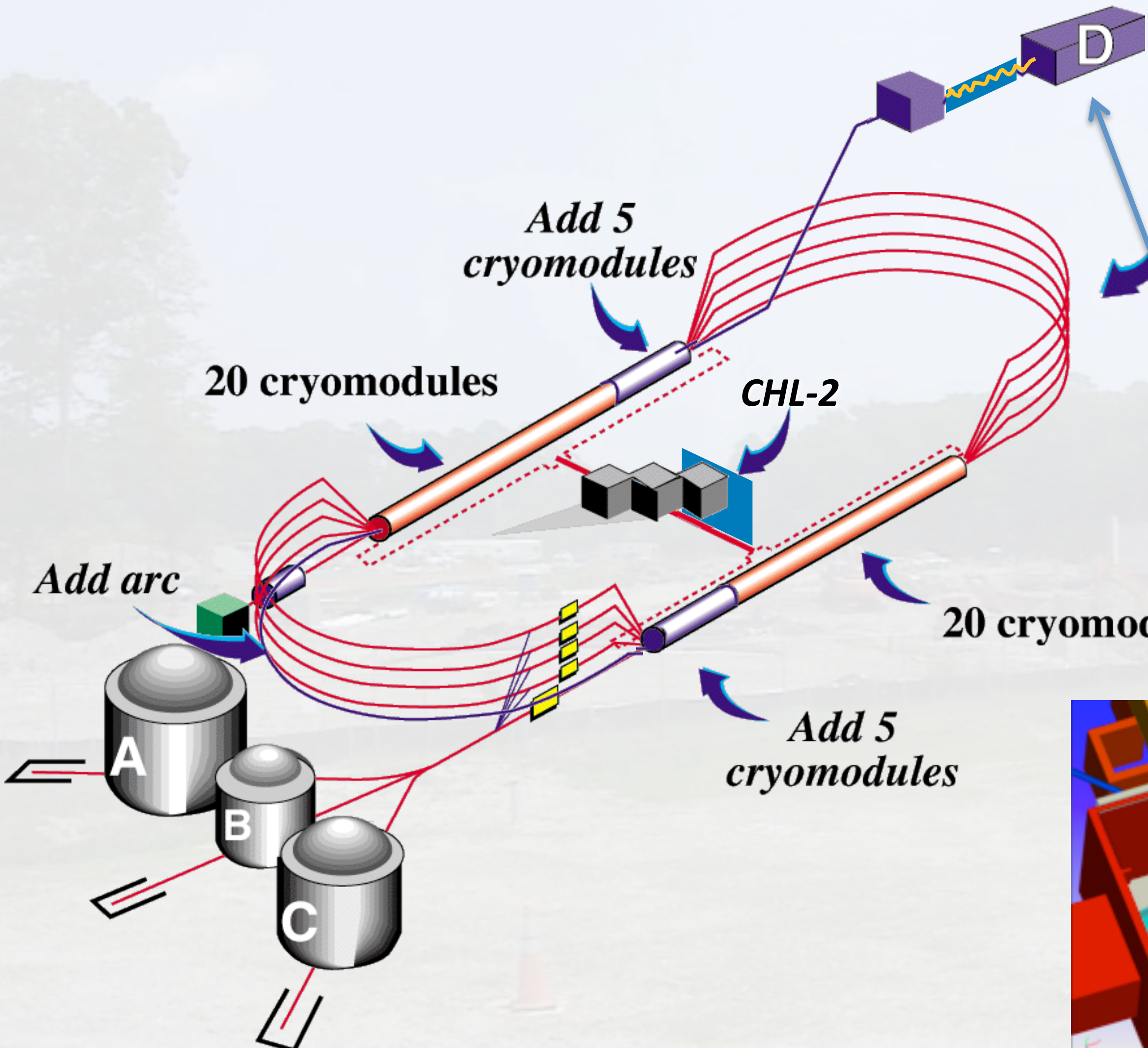
Lattice showed two states here.

π , η , η' , K → π_1 , η_1 , η'_1, K_1	1^{-+}	
b_0, h_0, h_0', K_0	0^{+-}	
b_2, h_2, h_2', K_2	2^{+-}	

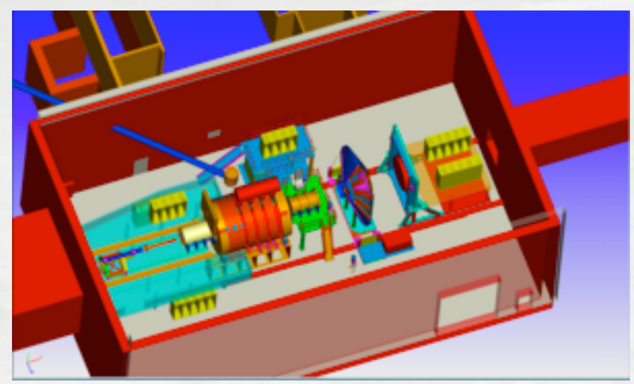
What are the mixing angles between the isoscalar states?

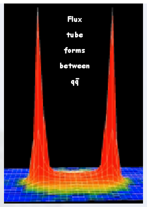


The GlueX Detector in Hall-D



Upgrade magnets and power supplies





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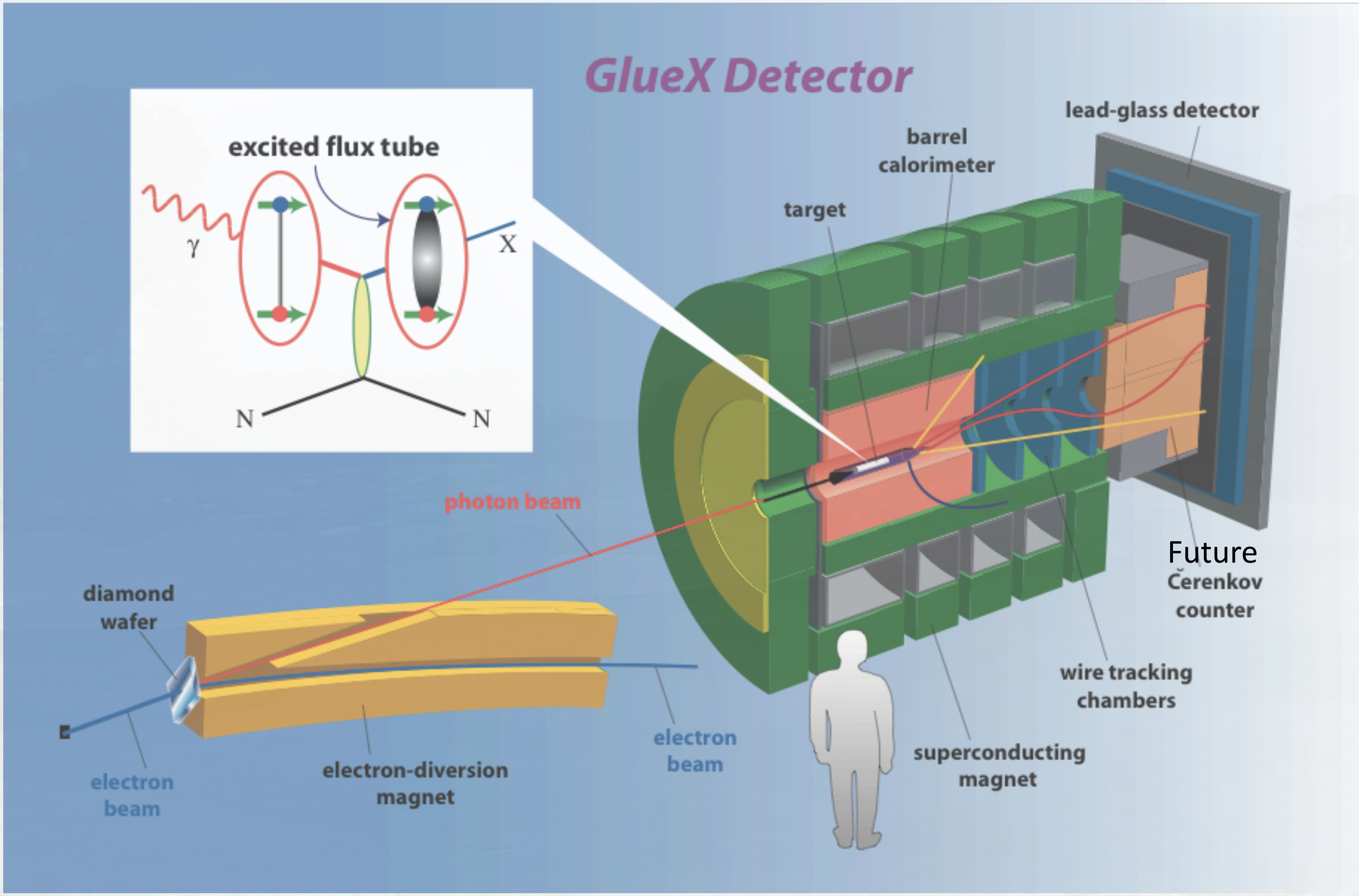
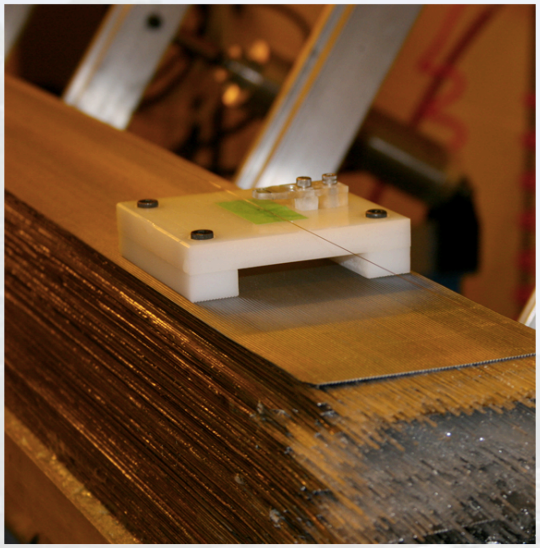


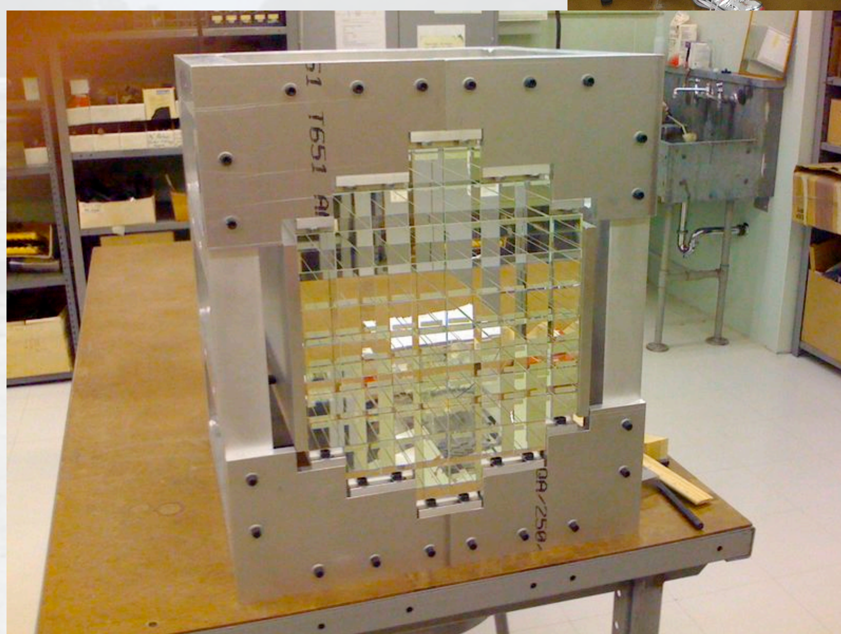
Detector Construction Underway

BCAL at Univ. Regina

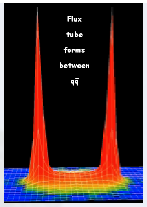


CDC at CMU

FCAL at IU



First 4 of 48 modules have been delivered to Jlab.



Amplitude Analysis

In order to find the exotic QN exotics, it is necessary to carry out an amplitude analysis:

$$\gamma p \rightarrow Xp \rightarrow a_2(1320)\pi p$$

Analyze a particular final state

$$\gamma p \rightarrow \pi_2 p \rightarrow a_2(1320)\pi p$$
$$\gamma p \rightarrow b_1 p \rightarrow a_2(1320)\pi p$$
$$\gamma p \rightarrow b_3 p \rightarrow a_2(1320)\pi p$$

Consider normal meson channels:
$J^{PC} = 2^{-+}, 1^{+-}, 3^{+-}, \ldots$

$$\gamma p \rightarrow b_2 p \rightarrow a_2(1320)\pi p$$

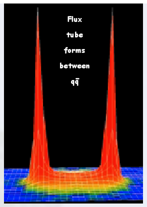
Consider exotic meson channels:
$J^{PC} = 2^{+-}$

$$a_2^+ \pi^- p$$
$$a_2^- \pi^+ p$$
$$a_2^+ \pi^0 n$$
$$a_2^0 \pi^+ n$$

Different isospin channels

$$a_2 \rightarrow \rho\pi, \eta\pi$$

Different decay modes



Amplitude Analysis

Write down quantum mechanical amplitudes for each process: $A_\alpha(\vec{p^\mu})$

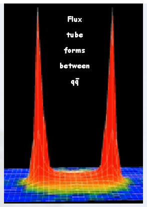
Create a total amplitude which yields an intensity: $I = \sum_\beta |\sum_\alpha [A_{\alpha,\beta}(\vec{p^\mu})]|^2$

(Fitting angular distributions in some high-dimensional space)

$$Probability = \Pi_{events}(I/Normalization)$$

Maximize the probability (likelihood).

$$-\ln L = -(\sum_{events} \ln I) + \ln(Normaliztion)$$

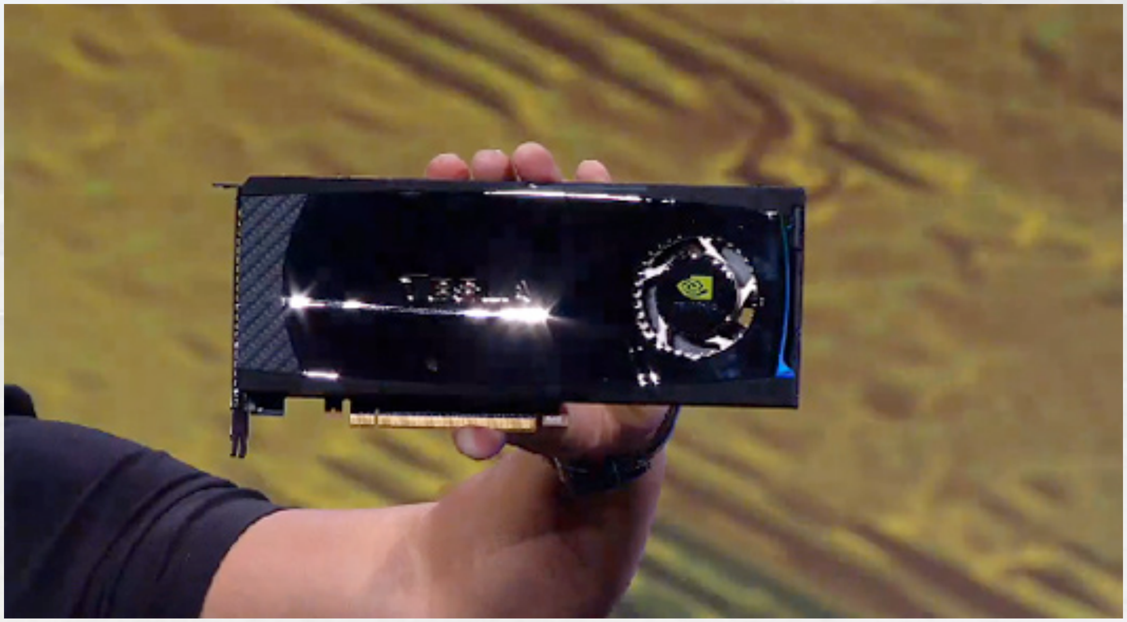


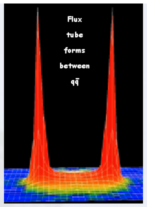
Amplitude Analysis

If one can compute the normalization once, then relatively quick, but this limits the form of the amplitude and may bias your answer. If you wanted to allow the mass and width of a resonance to be fit, you have to recompute the normalization each step.

GPUs

The problem appears well suited to run on graphical processor (GPU). The next generation will have up to 512 cpu cores per GPU and four can be installed per box. We are currently studying how well the problem scales, but our first studies have been very promising. These work because there are a lot of repeated parallel calculations.



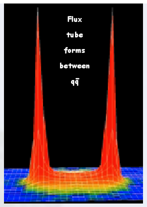


Amplitude Analysis

- We have also developed tools to facilitate the writing of amplitudes (qft++). This has been used to analyze the photoproduction of Baryons using CLAS data.

- GlueX is a member of the OpenScienceGrid (OSG) and we are currently able to generate and process Monte Carlo data on the grid. We believe that this will be a major part of our data model.

- We are working on pushing our A.A. onto the grid, but the recent results with GPUs may change our paradigm.

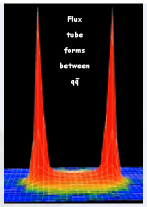


Amplitude Analysis

- We are currently carrying out A.A. on several promising channels using simulated data and the full GlueX Monte Carlo and reconstruction code base.

- We are working with phenomenologists to develop better formulations for our amplitudes that satisfy known physical constraints. These are more computationally challenging, but the GPUs may solve this problem.

- Members are performing PWA on CLEO-c, BES-III, E852 and CLAS data.



Summary

- The search for exotic hybrids still remains limited by statistics, and information only exists for isospin-one 1^{-+} states.
- Exciting recent lattice results reaffirm the case for these states and provide theoretical methods to measure the gluonic content of states.
- The GlueX/Hall-D complex is under construction with detector elements delivered to Jlab and we are on-track to first beam in 2014.
- Work continues on Amplitude Analysis with a lot of interesting progress. By 2014 we should have a very robust set of tools.