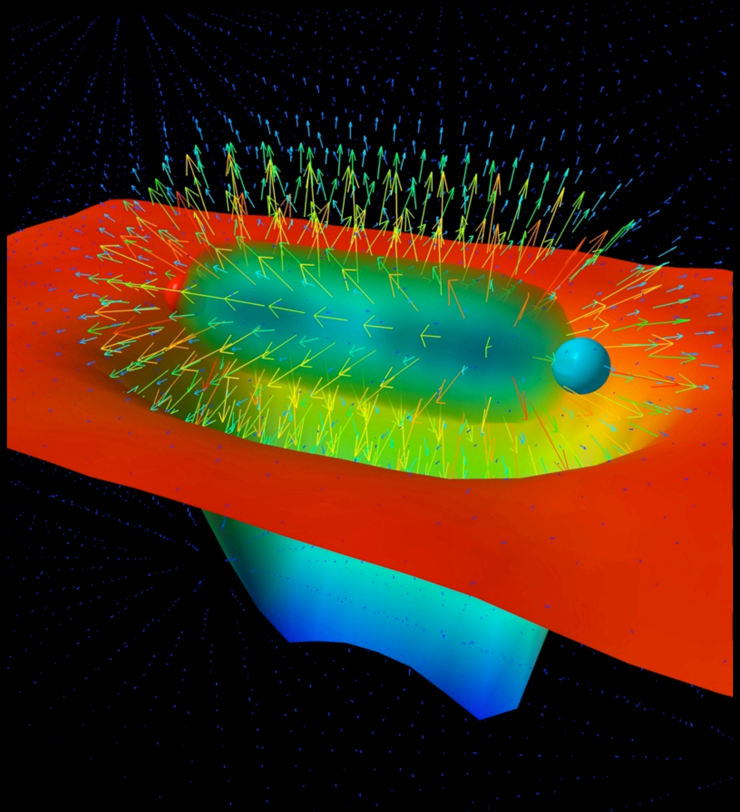
Rutgers

Joint Town Meeting on Quantum Chromodynamics

APS Division of Nuclear Physics:

2007 Long Range Plan



January 12-14 2007
Rutgers University

Experimental Meson Spectroscopy

Alex Dzierba
GlueX Collaboration Spokesperson
Indiana University and Jefferson Lab

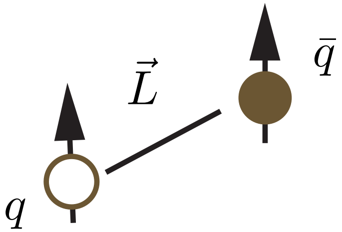
Experimental Mapping of the Hybrid Spectrum

- Ted Barnes and Jo Dudek have set the stage for why QCD mesons (glueballs and hybrids) outside of the conventional meson spectrum should exist and how information about their spectra is essential in understanding the confinement sector of QCD.

- Whether such mesons exist is an experimental question to be addressed by experiment. If these mesons exist, experiment will tell us about their masses and decay modes.

- What is the experimental status of these searches and what are the prospects for the future?

Conventional and Hybrid Mesons

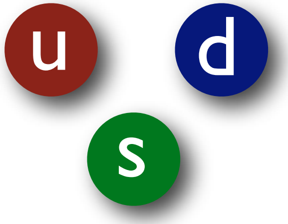


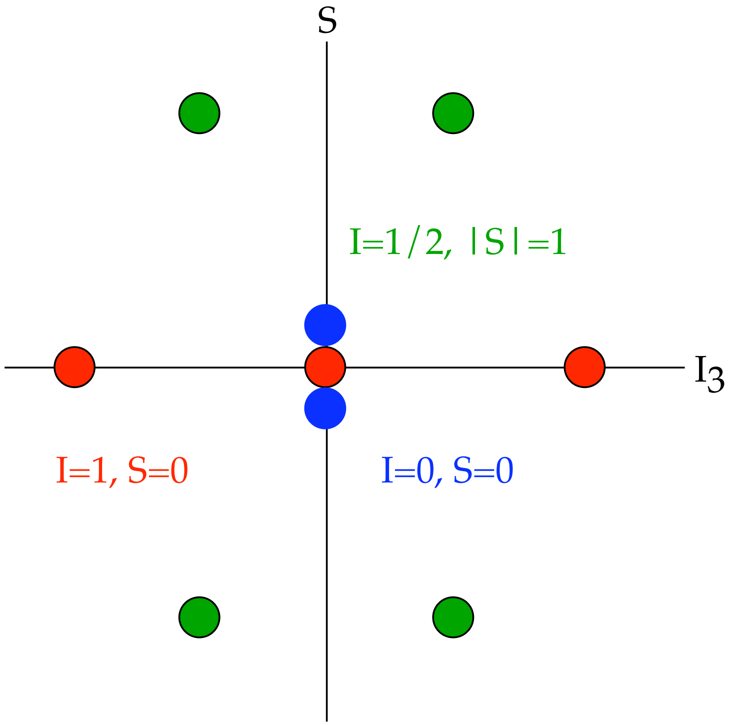
$$\vec{J} = \vec{L} + \vec{S}$$

$$P = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$

With three light quarks the conventional and hybrid mesons form flavor nonets - for each J^{PC}

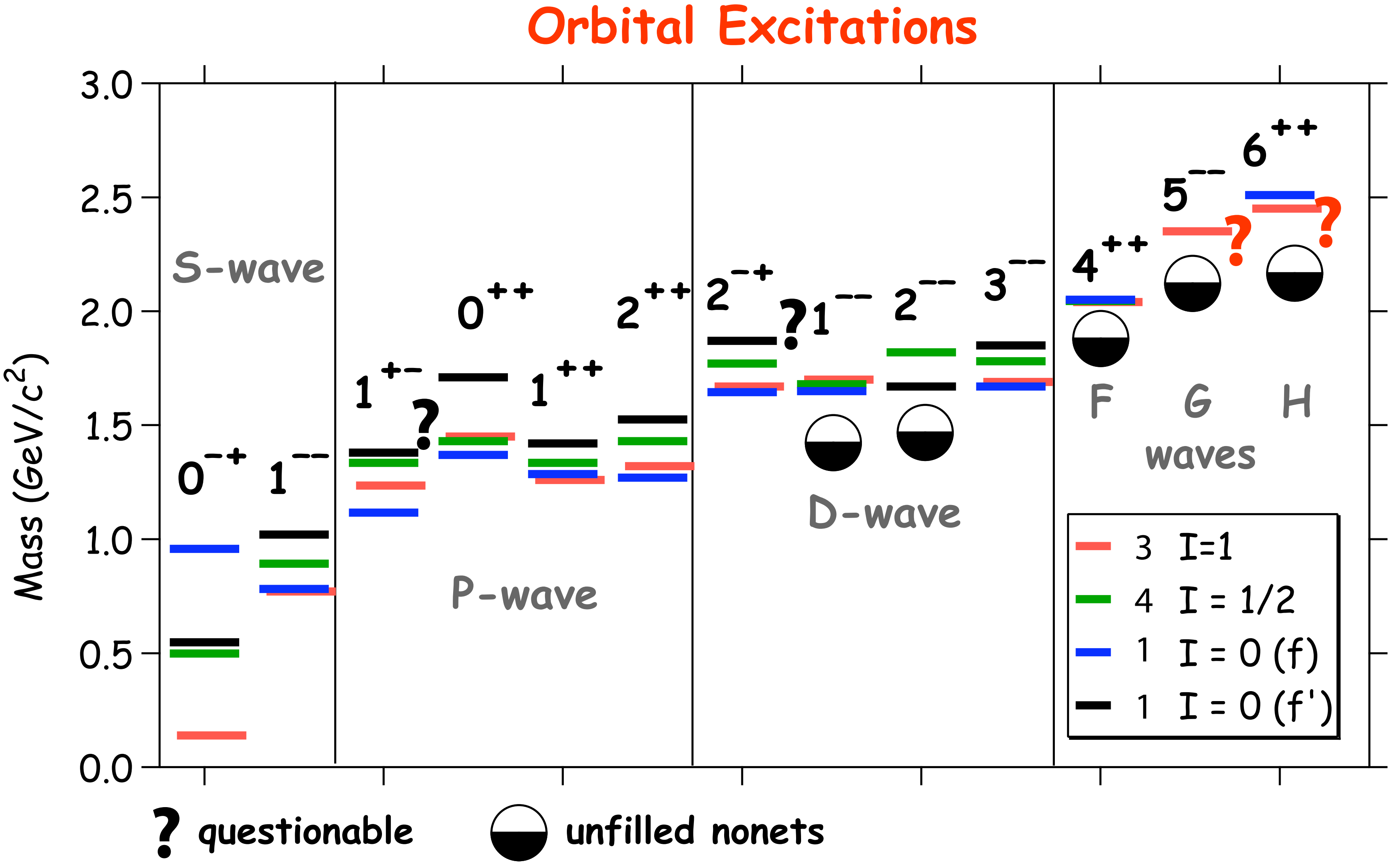




these exotic combinations not allowed:

$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$$

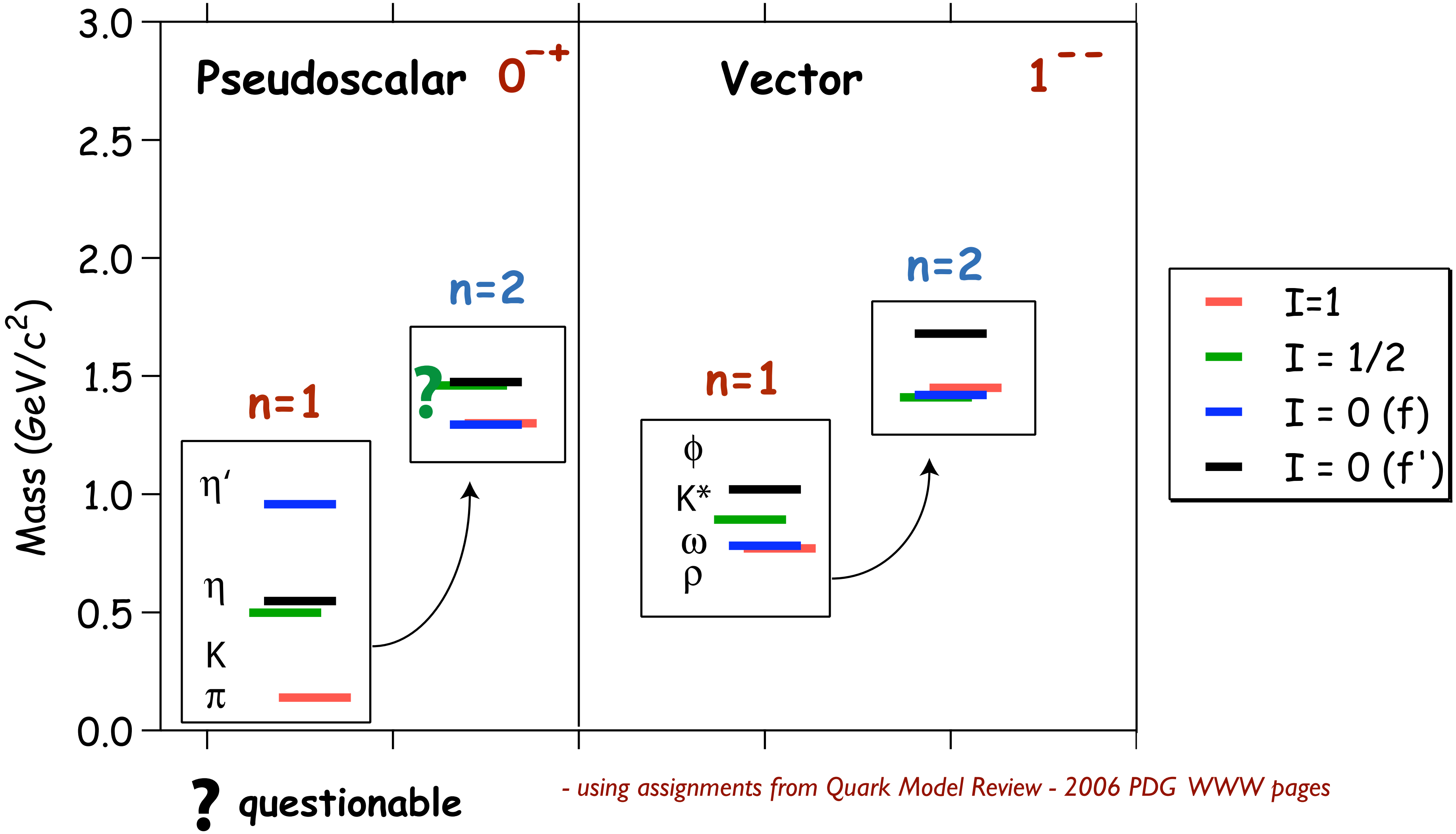
Nonets of Conventional Light Quark Mesons



- using assignments from Quark Model Review - 2006 PDG WWW pages

Nonets of Conventional Light Quark Mesons

Radial Excitations



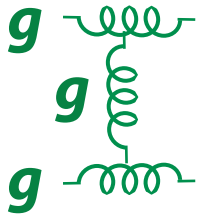
- using assignments from Quark Model Review - 2006 PDG WWW pages

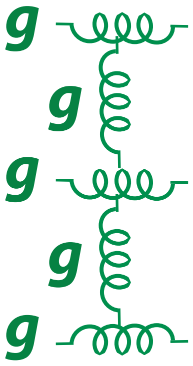
Non-$q\bar{q}$ Mesons

Do they exist?

Experiment has to answer this

Glueballs

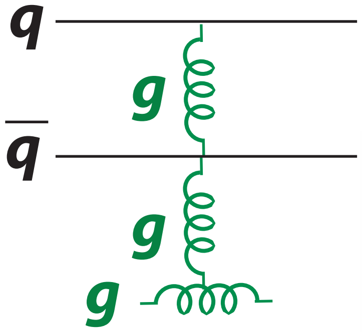


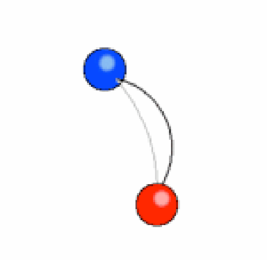


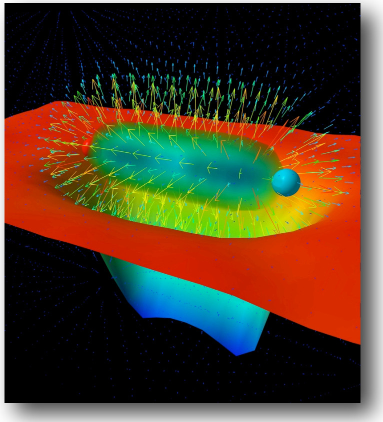
Their signature?

States below 4 GeV have non-exotic Q.N. - mixing with conventional mesons complicates their identification

Hybrids





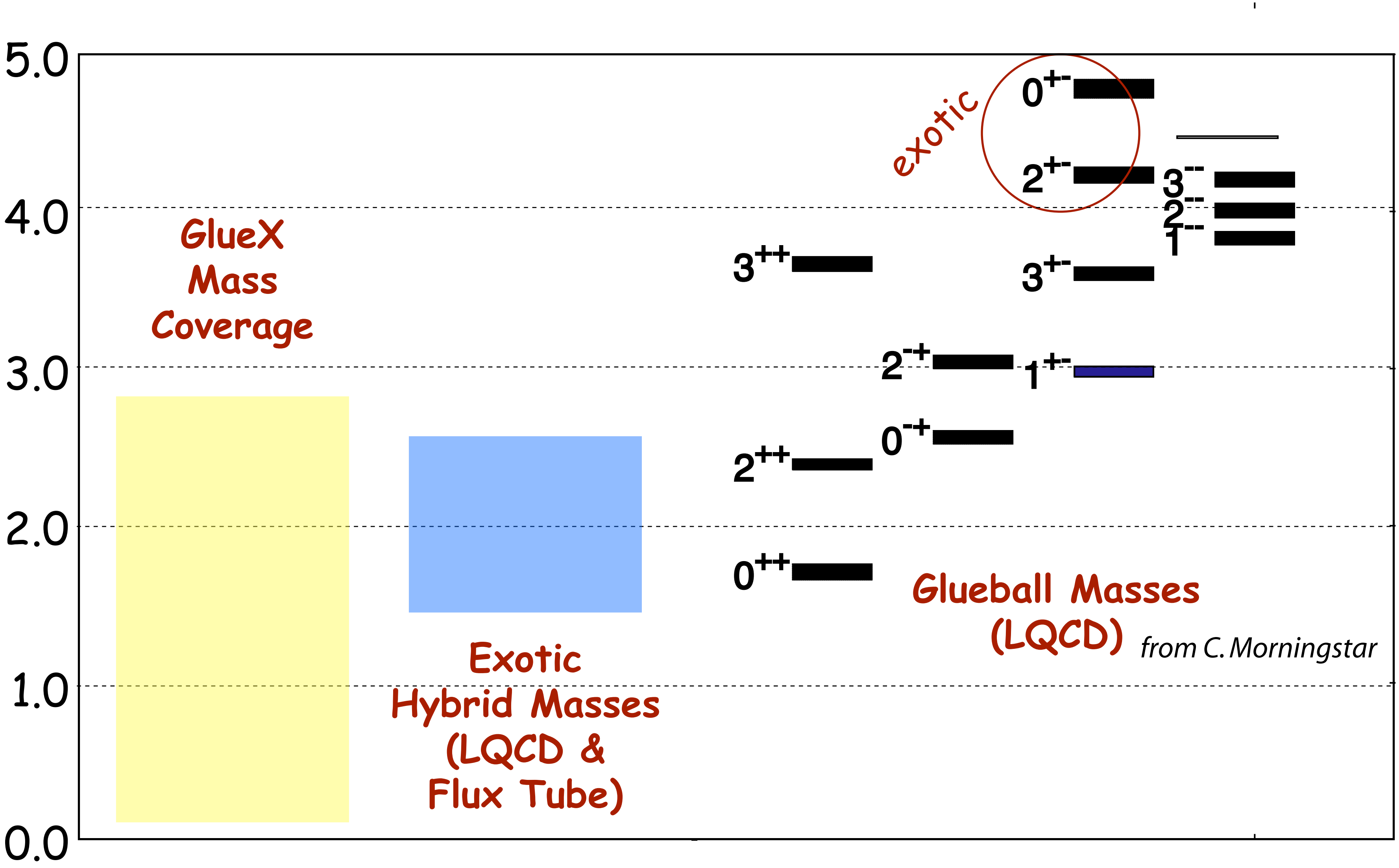


Their signature?

Within flux-tube model and LQCD the Q.N. of the excited glue couple with those of the quarks to lead to exotic quantum numbes

a 'smoking gun signature'

Exotic Hybrid and Glueball Masses



Evidence for Exotic Hybrids

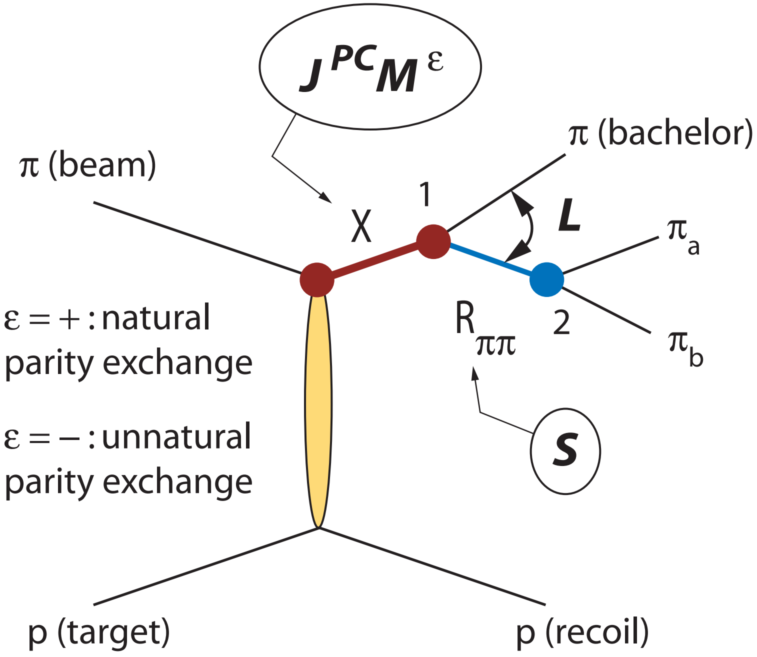
$$J^{PC} = 1^{-+}$$

State	*Processes*
$\pi_1(1400) \rightarrow \eta\pi$	$\pi^- N$ Interactions $\bar{p}N$ Annihilations
$\pi_1(1600) \rightarrow \eta'\pi$	
$\pi_1(1600) \rightarrow \rho\pi$	$\pi^- N$ Interactions
$\pi_1(1600) \rightarrow b_1\pi$ $\pi_1(1600) \rightarrow f_1\pi$	
$\pi_1(2000) \rightarrow b_1\pi$ $\pi_1(2000) \rightarrow f_1\pi$	

These states are not without controversy. Amplitude analysis issues include:

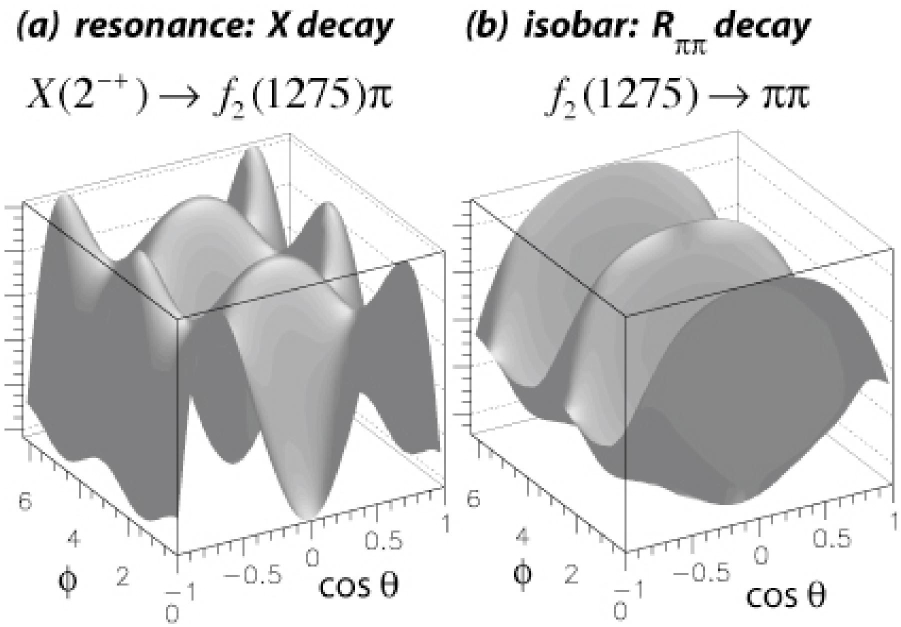
- possible leakage due to acceptance or insufficient wave sets
- interpretation of line shapes and phases

Example: Amplitude Analysis of the 3π System



ε = + : natural parity exchange

ε = – : unnatural parity exchange



(a) resonance: X decay

$X(2^{-+}) \to f_2(1275)\pi$

(b) isobar: $R_{\pi\pi}$ decay

$f_2(1275) \to \pi\pi$

The analysis is based on the ***isobar model*** *that assumes an intermediate 2π resonance*

---

decay

acceptance *production*

$$I(m_{3\pi}, t, \tau) = \eta(\tau) \sum_{\varepsilon} \left| \sum_{b} a_b^{\varepsilon}(m_{3\pi}, t) A_b^{\varepsilon}(\tau) \right|^2$$

spin variables: J, M, S

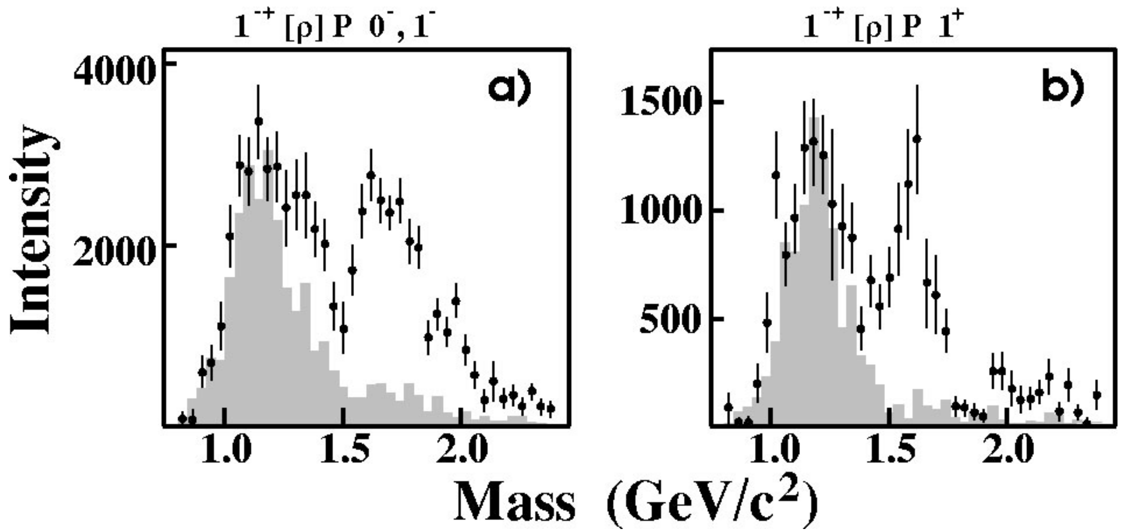
observed intensity

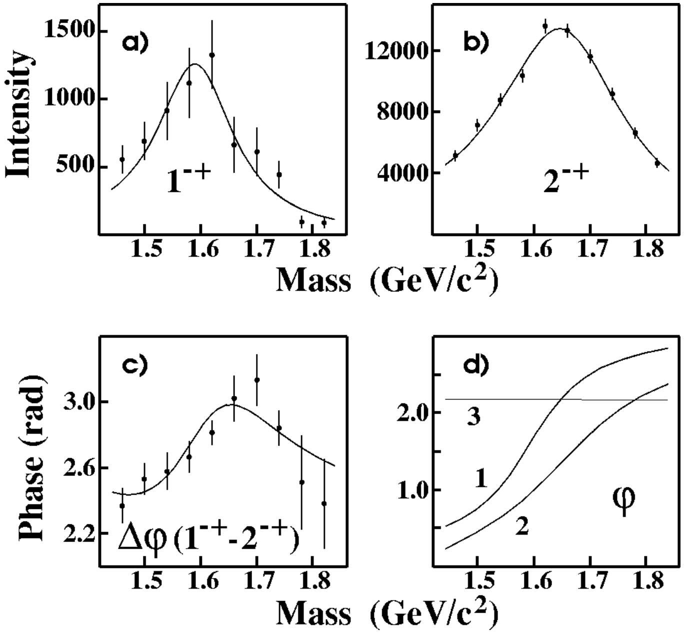
kinematic variables $\tau = \{\theta_{GJ}, \phi_{GJ}, \theta_H, \phi_H, m_{\pi\pi}\}$

Data Supporting $\pi_1(1600) \to \rho\pi$

E852

Phys. Rev. ***D65*** *(2002) 072001*

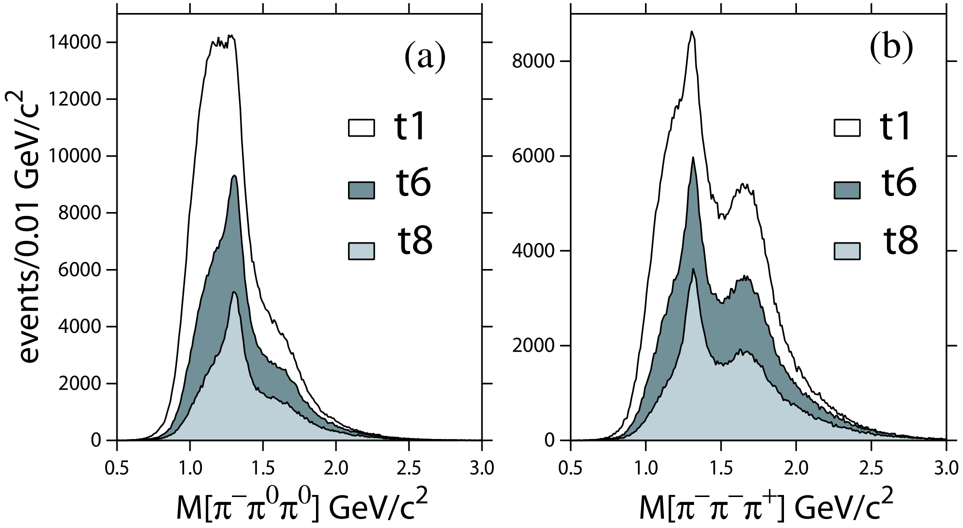


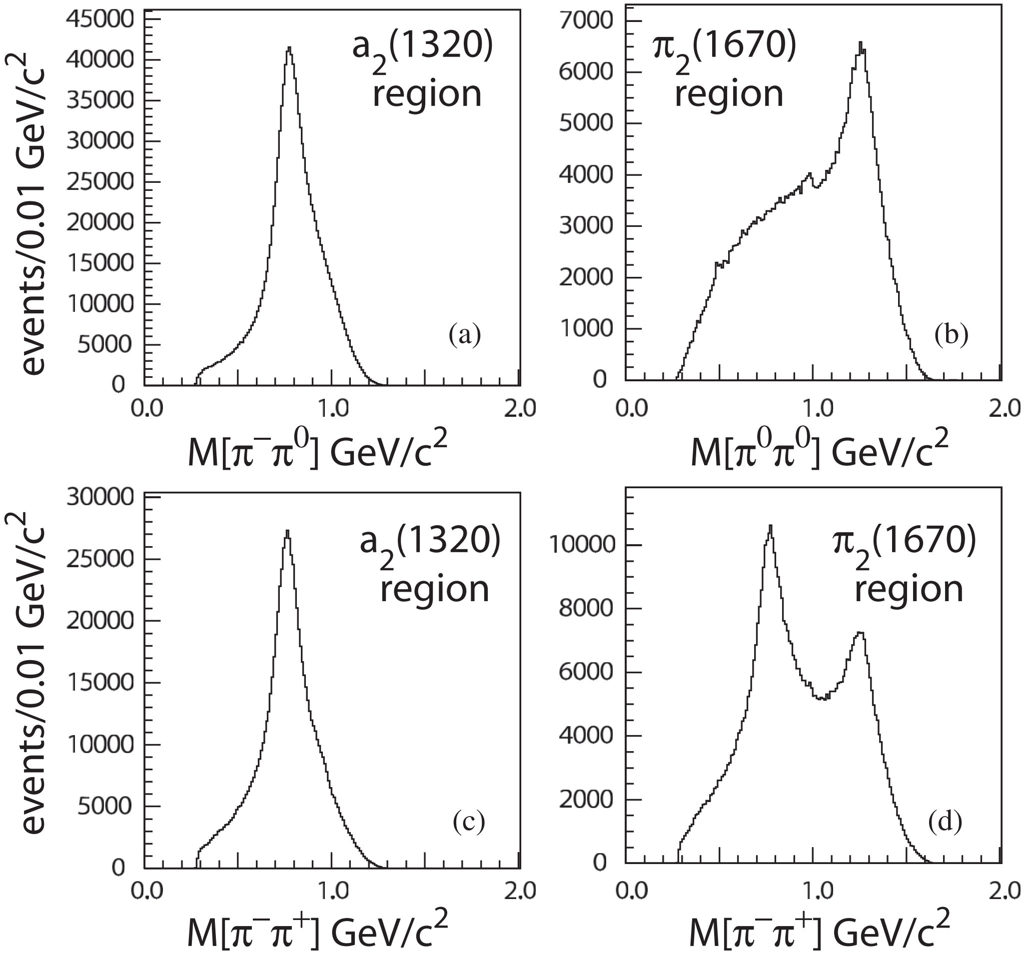


Based on 250K events of the reaction: $\pi^- p \to \pi^- \pi^- \pi^+ p$

Raw Data for the 3π System

$$\pi^- p \longrightarrow \begin{array}{ll} \pi^-\pi^-\pi^+ p & \text{(1) 2.6 M events} \\ \pi^-\pi^0\pi^0 p & \text{(2) 3.0 M events} \end{array}$$



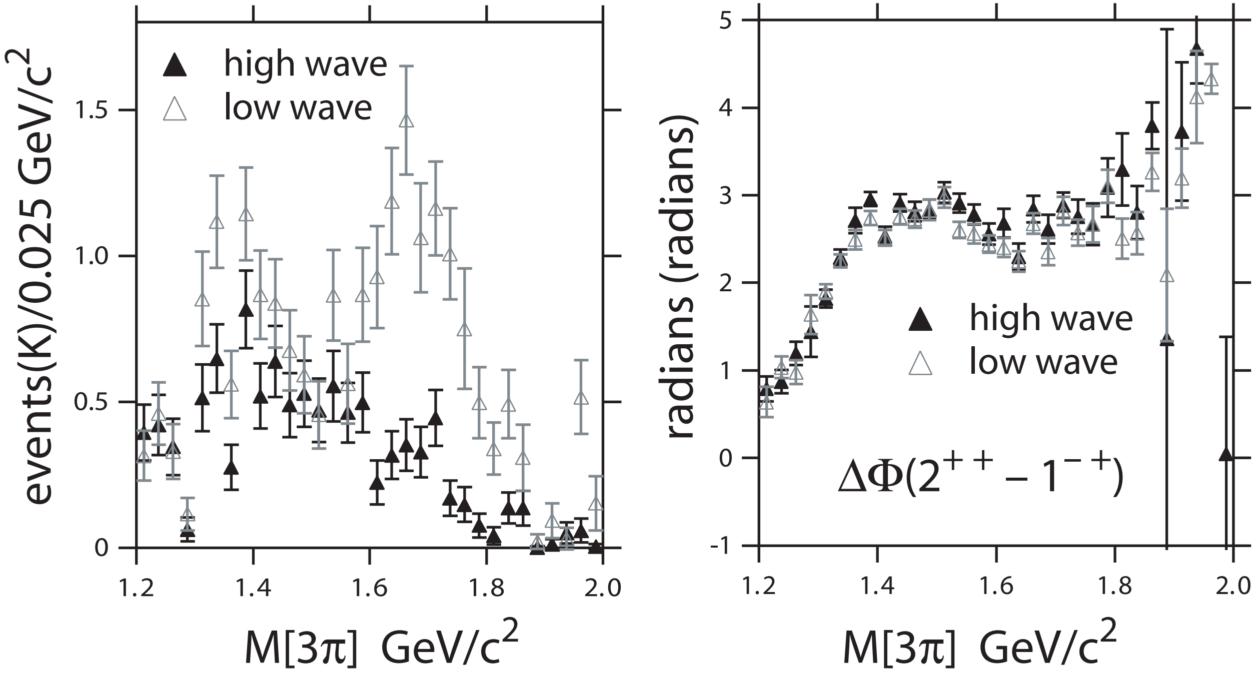


Revisiting $\pi_1(1600) \rightarrow \rho\pi$

Phys. Rev. ***D73*** *(2006) 072001*

A new analysis of E852 data based on larger statistics and two different 3π modes comes to another conclusion. This new analysis is similar to the previous analysis but included additional waves.

$$\pi^- p \rightarrow \begin{array}{ll} \pi^-\pi^-\pi^+ p & \text{(1) 2.6 M events} \\ \pi^-\pi^0\pi^0 p & \text{(2) 3.0 M events} \end{array}$$



$1^{-+}1^{+}$ P-wave ρπ

$(\pi^-\pi^-\pi^+)$

Low-wave set is the same as in the earlier E852 analysis while the high-wave set includes additional waves.

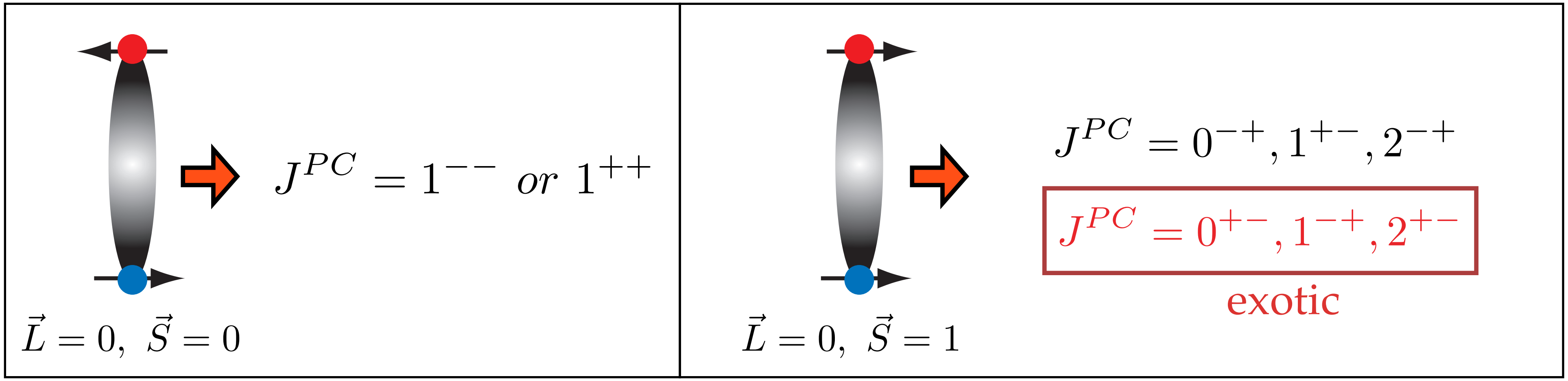
Conclusion: *Structure in the exotic wave disappears when one includes additional waves corresponding to decays of the* $\pi_2(1670)$

What to Conclude from Existing Evidence?

- Evidence is tantalizing but not strong.
- Hermeticity and excellent resolution are needed to eliminate experimental biases.
- Assumptions in amplitude analyses must be well understood and controlled.
- Perhaps pions are not the optimal probe for producing exotic hybrids.

Production of Exotic Hybrids with Photons

Combine excited glue QN ($J^{PC} = 1^{+-}\ or\ 1^{-+}$)
with those of the quarks:



$J^{PC} = 1^{--}\ or\ 1^{++}$

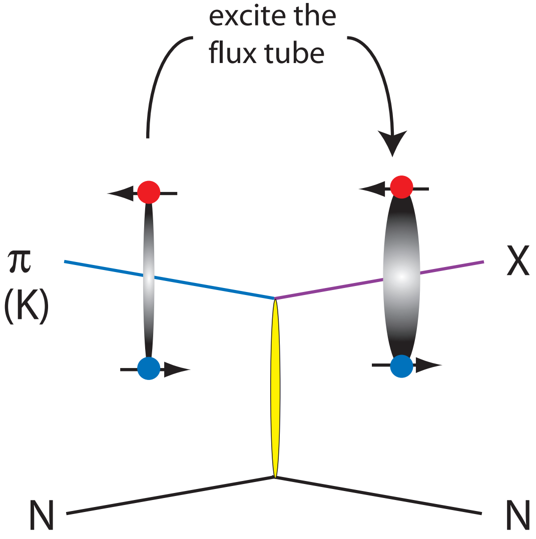
$\vec{L} = 0,\ \vec{S} = 0$

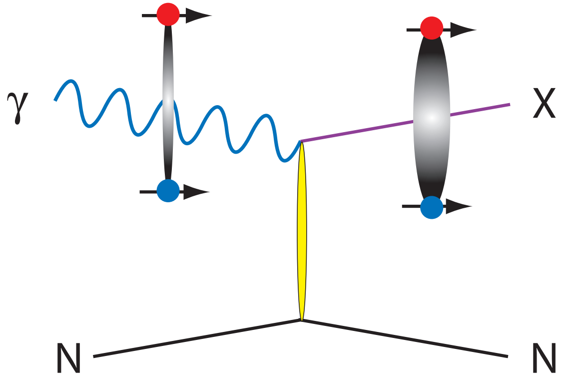
$J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}$

$\boxed{J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}}$

exotic

$\vec{L} = 0,\ \vec{S} = 1$





Requirements for Exotic Meson Discovery

- **Photon beam with sufficient energy for the mass reach.**
  - *9 GeV photons ideal.*

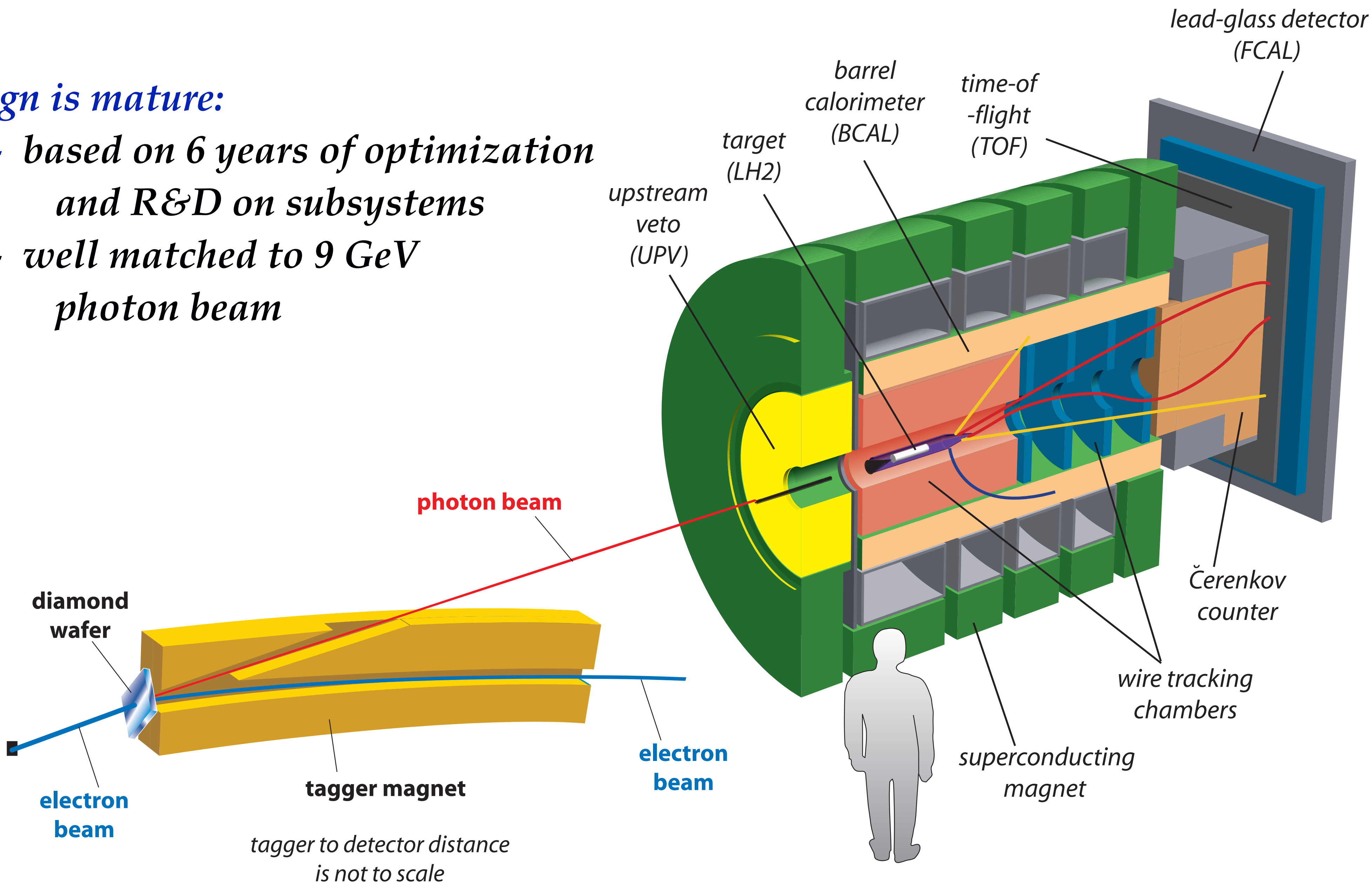
- **Linearly polarized photons of a degree and flux needed for the PWA.**
  - *Using coherent bremsstrahlung this implies 12 GeV electrons with the appropriate emittance, spot size and duty-factor.*

- **Detector optimized for PWA and detecting a variety of decay modes.**
  - *The GlueX detector design optimizes:*
    - *(1) hermeticity*
    - *(2) energy and momentum resolution*
    - *(3) particle identification*
    - *(4) data rate*

GlueX Detector

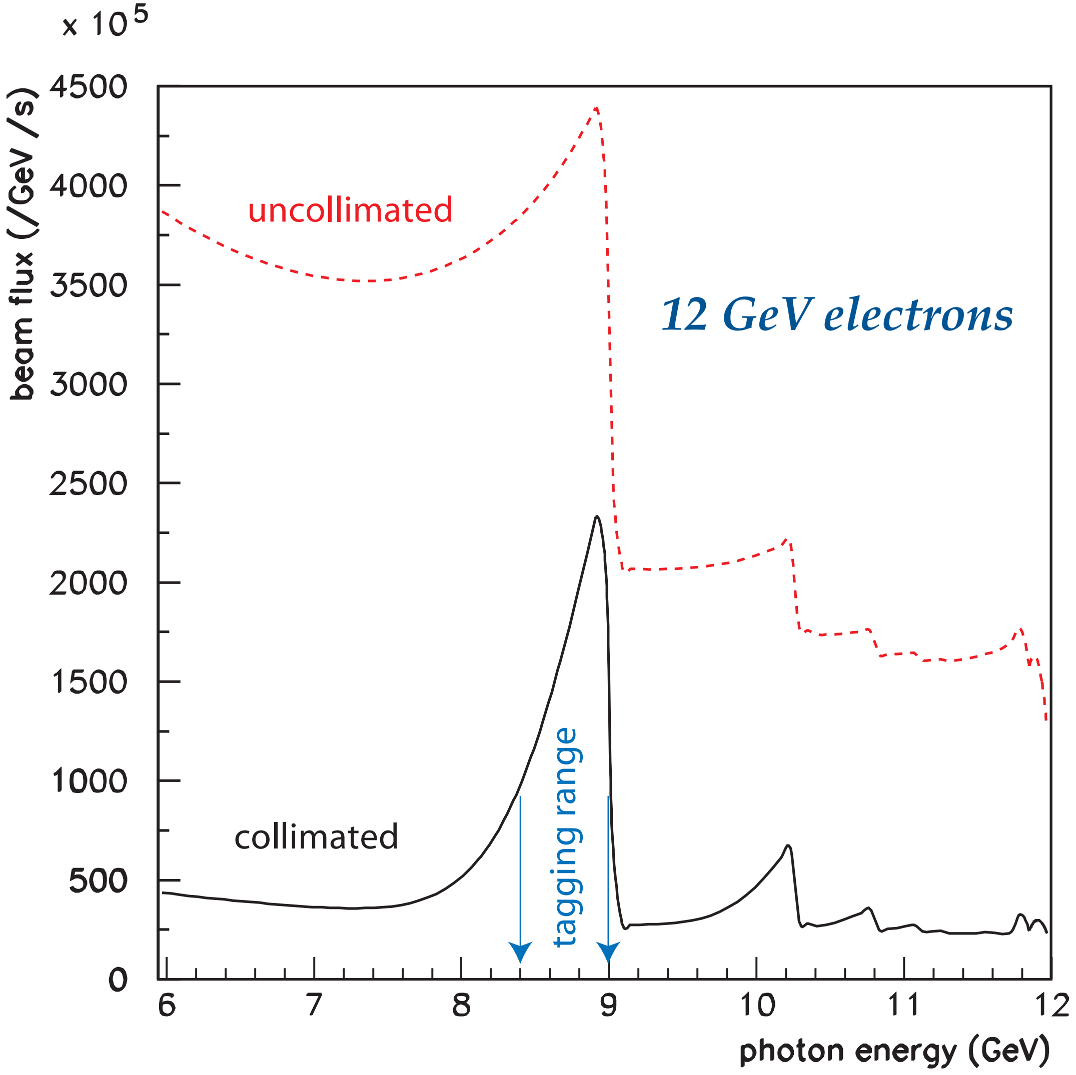
Design is mature:

- *based on 6 years of optimization and R&D on subsystems*
- *well matched to 9 GeV photon beam*

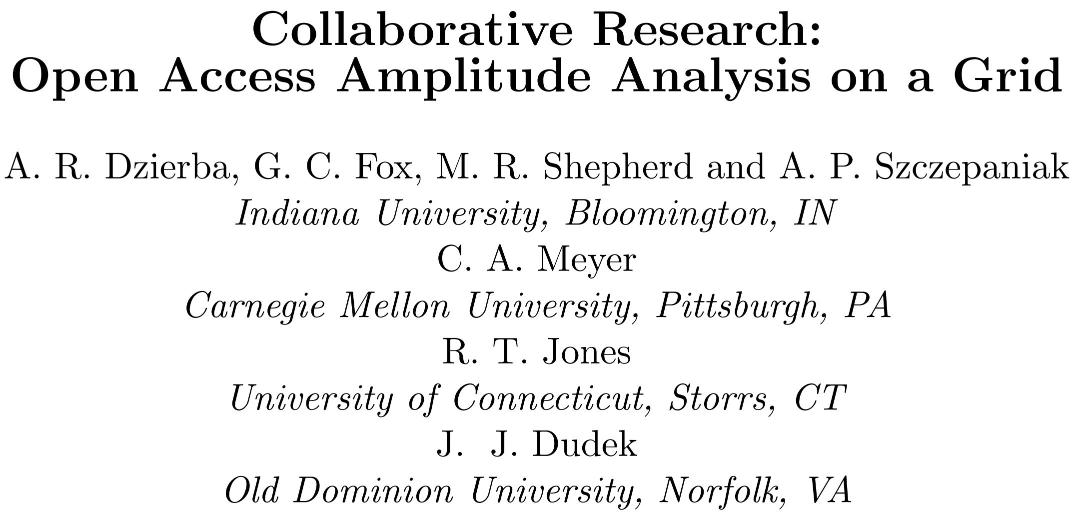


Coherent Bremsstrahlung

provides linear polarization and with collimation reduces backgrounds from low-energy incoherent photons



Prepare for GlueX Challenge - Use Existing Data



Collaborative Research:
Open Access Amplitude Analysis on a Grid

A. R. Dzierba, G. C. Fox, M. R. Shepherd and A. P. Szczepaniak
Indiana University, Bloomington, IN
C. A. Meyer
Carnegie Mellon University, Pittsburgh, PA
R. T. Jones
University of Connecticut, Storrs, CT
J. J. Dudek
Old Dominion University, Norfolk, VA

submitted - September 2006

Data from existing experiments E852 at BNL and CLAS at JLab will be used in developing the Amplitude Analysis Toolkit

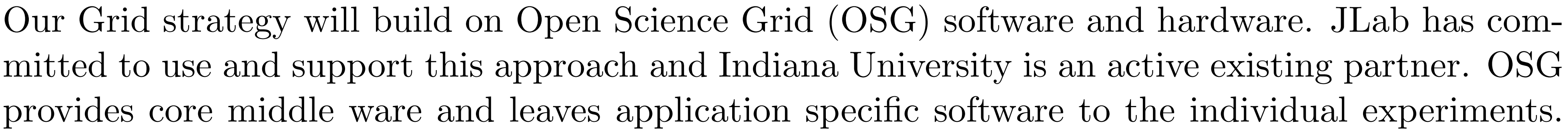
Sample sizes:

- ***E852 - tens of GB (10 TB raw)***
- ***CLAS - factor 10 larger***

Start using OSG in Summer 2007 for a 3-year period.

The proposal requests funding for four postdoctoral fellows to work on: (1) phenomenology; (2) GRID; and (3) tools for fitting.

Grid Implementation



Our Grid strategy will build on Open Science Grid (OSG) software and hardware. JLab has committed to use and support this approach and Indiana University is an active existing partner. OSG provides core middle ware and leaves application specific software to the individual experiments.

The Fitting Challenge

$$I(m_{3\pi},t,\tau)=\eta(\tau)\sum_{\varepsilon}\left|\sum_{b}\boxed{a_b^{\varepsilon}(m_{3\pi},t)}A_b^{\varepsilon}(\tau)\right|^2$$

the fit parameters

Do unbinned maximum likelihood fit for n events:

Calculation of L can be done over parallel machines

$$L=\frac{e^{-\mu}\mu^n}{n!}\prod_{i=1}^{n}\frac{I(\tau_i)}{\boxed{\int\eta(\tau)I(\tau)d\tau}}$$

normalization determined using N Monte Carlo events

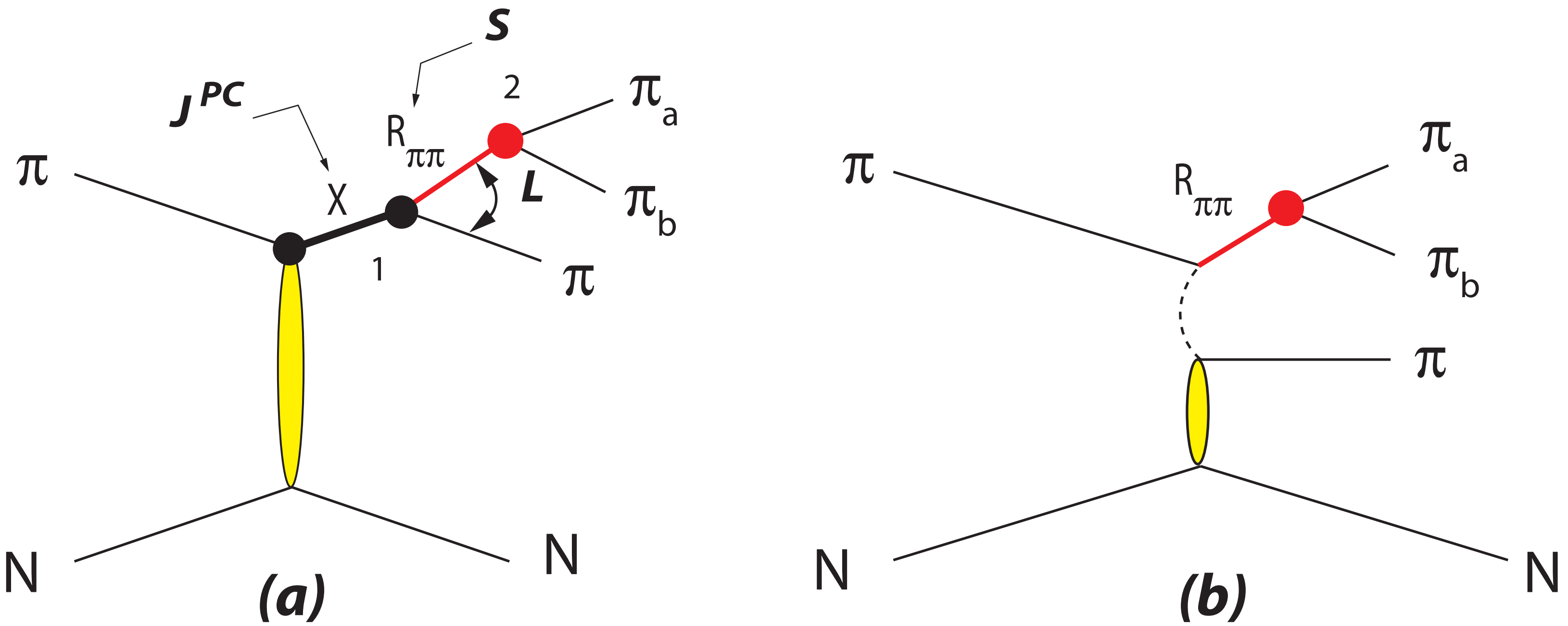
Minimize – ln(L)

$$-\ln L\propto-\sum_{i=1}^{n}\ln\left(\sum_{bb'}a_b a_{b'}^{*}\underline{A_b A_{b'}^{*}}\right)+\sum_{bb'}a_b a_{b'}^{*}\underline{\left(\frac{1}{N}\sum_{i=1}^{N}A_b A_{b'}^{*}\right)}$$

for a given fit these are fixed: so compute & cache - a simplification arising from the isobar model assumption and its inherent factorization.

Example: Going Beyond the Isobar Model

This involved exploring physics that break factorization:



Isobar Model: ***Data from Brookhaven E852 have been analyzed using this model.***

Other Mechanisms: ***The so-called 'Deck Model' is one of several that will be studied.***

Conclusions

- The upgraded CEBAF and GlueX detector place us in a unique position to discover and map the exotic spectrum.

- The detector design is mature and optimized for this search.

- Expertise exists within the collaboration to carry out the analysis and work is in progress to develop the necessary analysis tools and underlying phenomenology.

- If exotic mesons exist - we will find them. And if they don't exist - we won't "find" them.