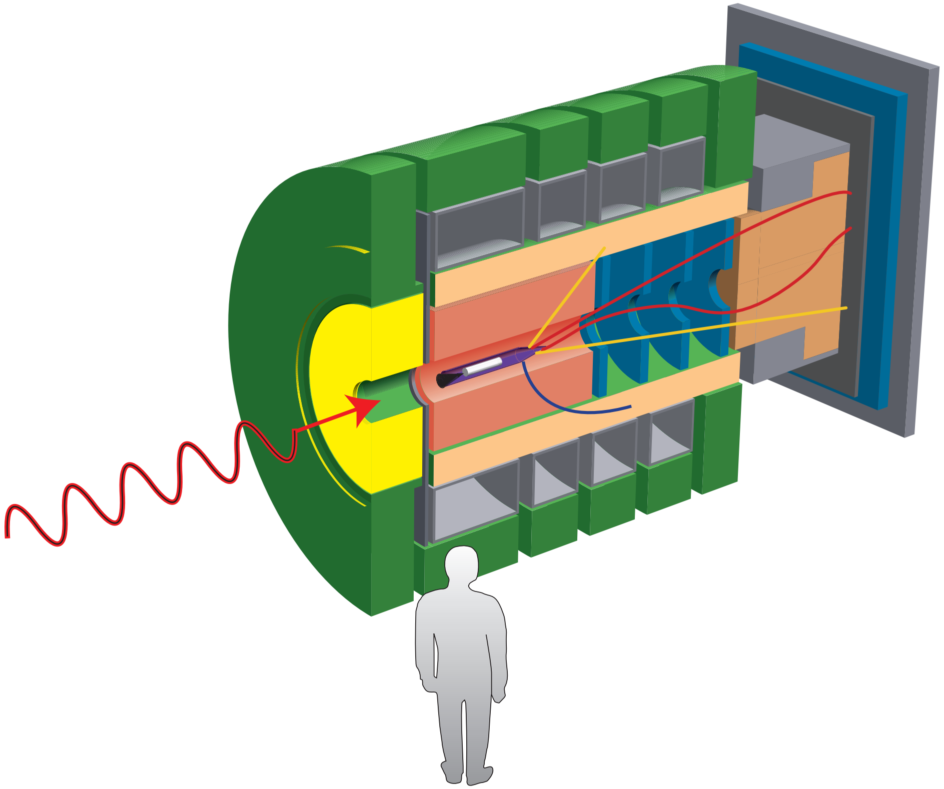
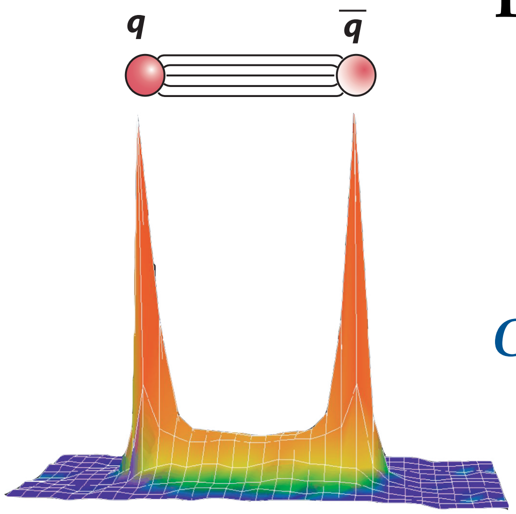




PAC30 Presentation

GlueX in Hall D

Overview, Goals, Status and Plans

Alex Dzierba

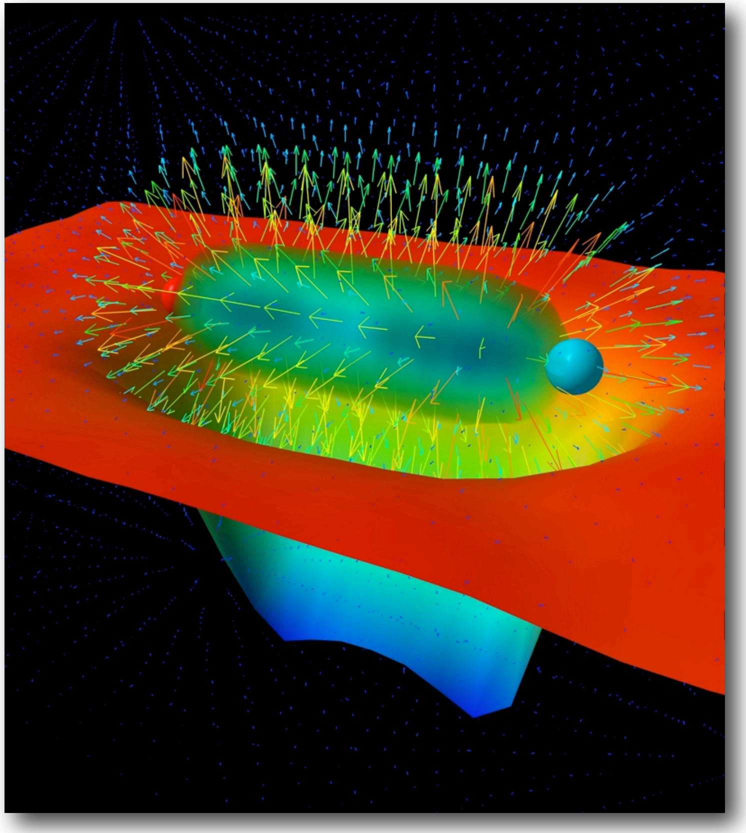
GlueX Presenters:

Elton Smith *(Interim Hall D Leader)*	*GlueX detector overview and R&D* *Beam tests*
Alex Dzierba *(Spokesperson)*	*This talk*
Jo Dudek *(GlueX Theory Leader)*	*Developments in LQCD* *Phenomenology of amplitude analysis*

Physics Goals of GlueX

The goal of the GlueX experiment is to map out the spectrum of exotic hybrid mesons in the light quark sector. The experimental information about this spectrum is essential in addressing one of the fundamental issues in physics:

> *A detailed understanding of the nature of the confinement of quarks and gluons in QCD.*



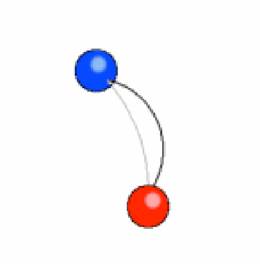
Thanks to Derek Leinweber

To meet this goal, GlueX will:

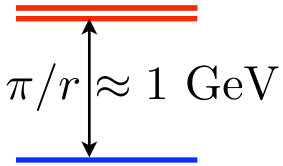
- **use linearly polarized 9 GeV photons produced via coherent bremsstrahlung from 12 GeV electrons;**
- **use a detector optimized to carry out an amplitude analysis of multi-particle exclusive reactions; and**
- **collect high-quality, high-statistics data needed to identify the quantum numbers, masses and decay modes of meson resonances.**

Flux Tube Model

- **The flux tube model provides us with a framework within which we can understand gluonic excitations and their properties.**

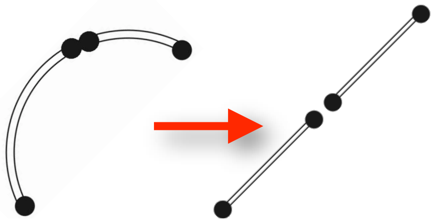


- **The quarks in a meson are sources of color electric flux and that flux is trapped in a flux tube connecting the quarks. The formation of the flux tube is related to the self-interaction of gluons via their color charge.**



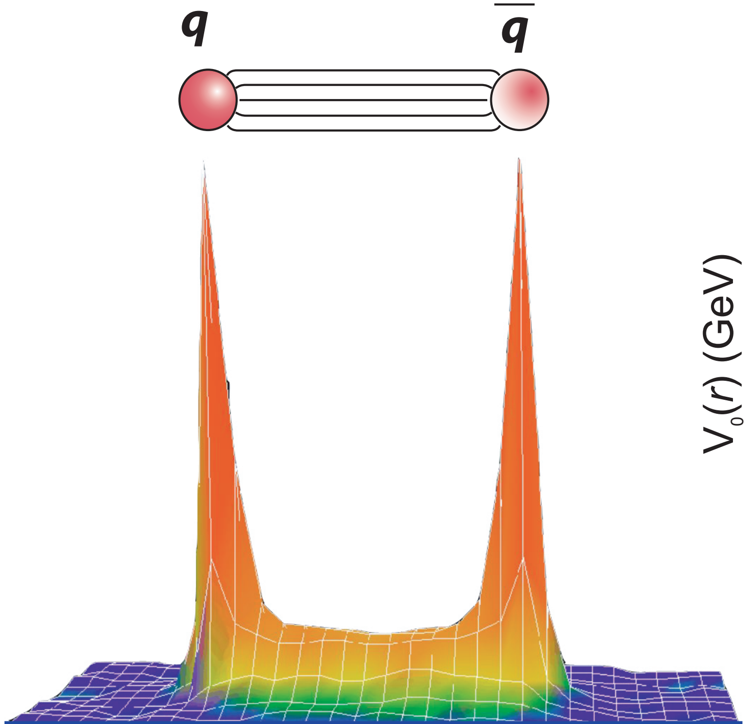
- **With the flux tube is in its ground state - conventional mesons occur. When the flux tube is excited, hybrid mesons result. The transverse vibrations, with static quarks, leads to a natural level spacing of 1 GeV above the ground state.**

- **The quantum numbers of the excited flux tube, when combined with those of the quarks can lead to exotic quantum numbers.**

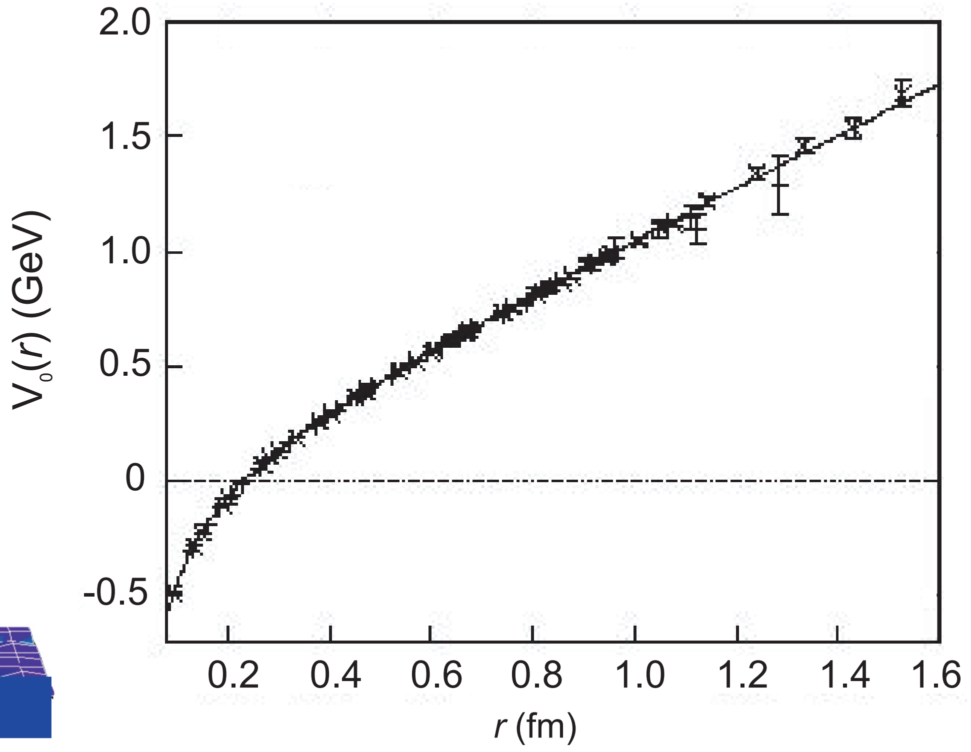


- **The 'S+P' selection rule for hybrid decays leads to complicated decay modes of hybrids - which could explain why they have not been seen earlier.**

Flux Tube Notions Supported by LQCD

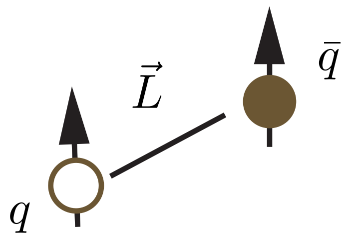


from Bali - quenched - heavy quarks



- **Flux tubes lead to a linear, confining potential.**
- *More on flux tubes and LQCD will come in the talk by Jo Dudek.*

Conventional and Hybrid Mesons



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

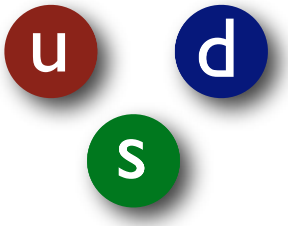
$$P = (-1)^{L+1}$$

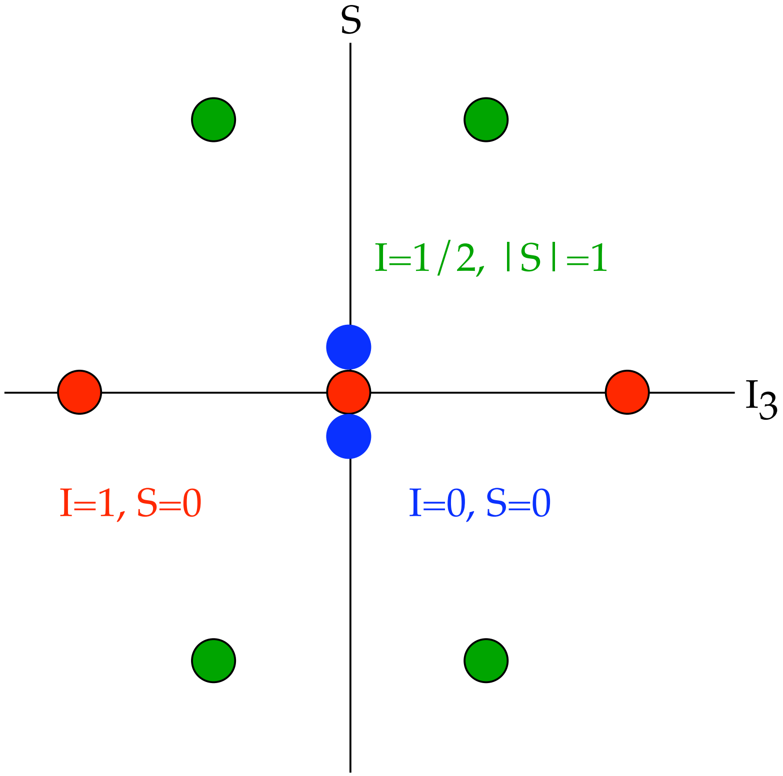
$$C = (-1)^{L+S}$$

these exotic combinations not allowed:

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

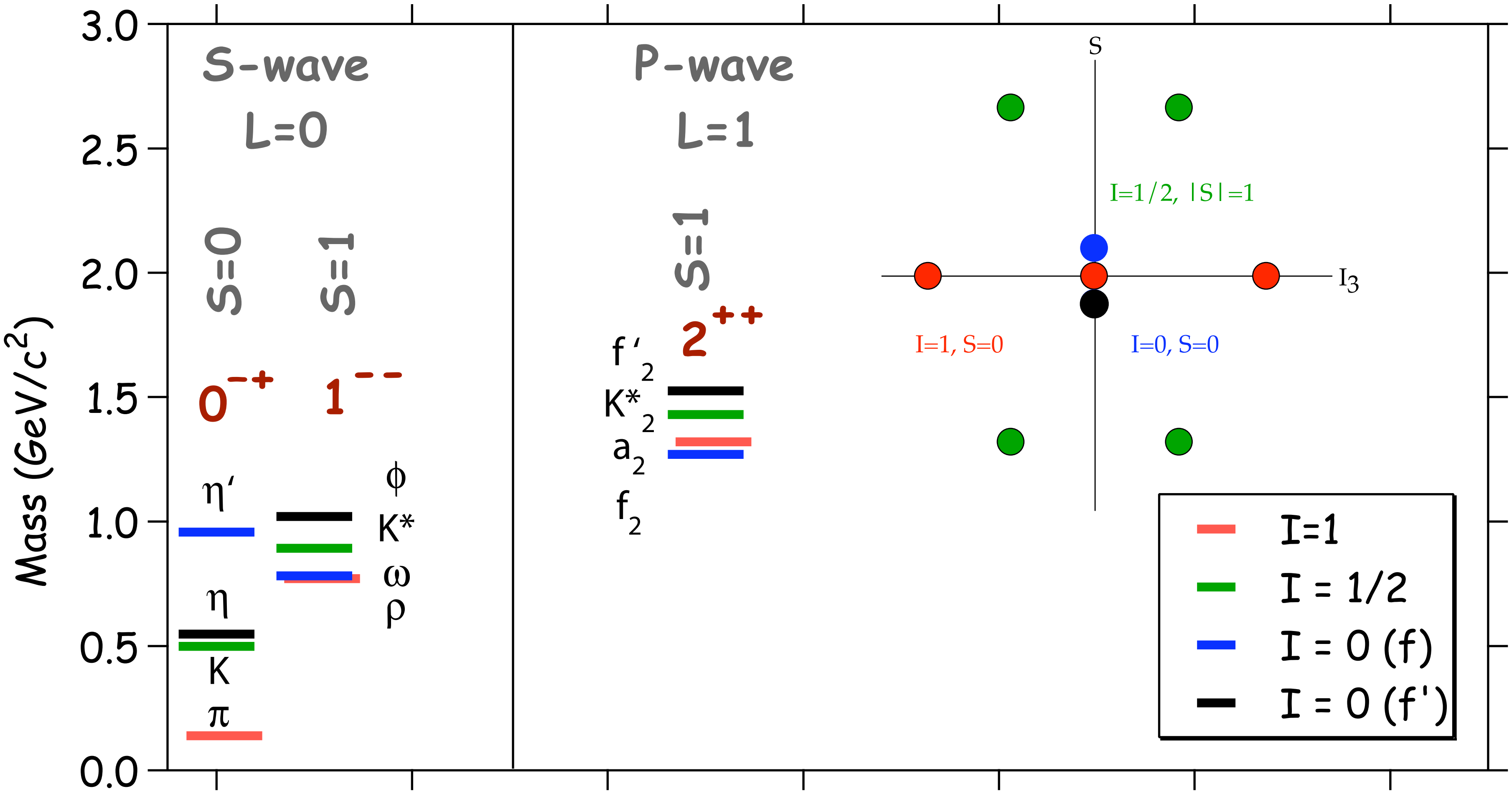
With three light quarks the *conventional* *and* *hybrid* *mesons form flavor nonets - for each* J^{PC}





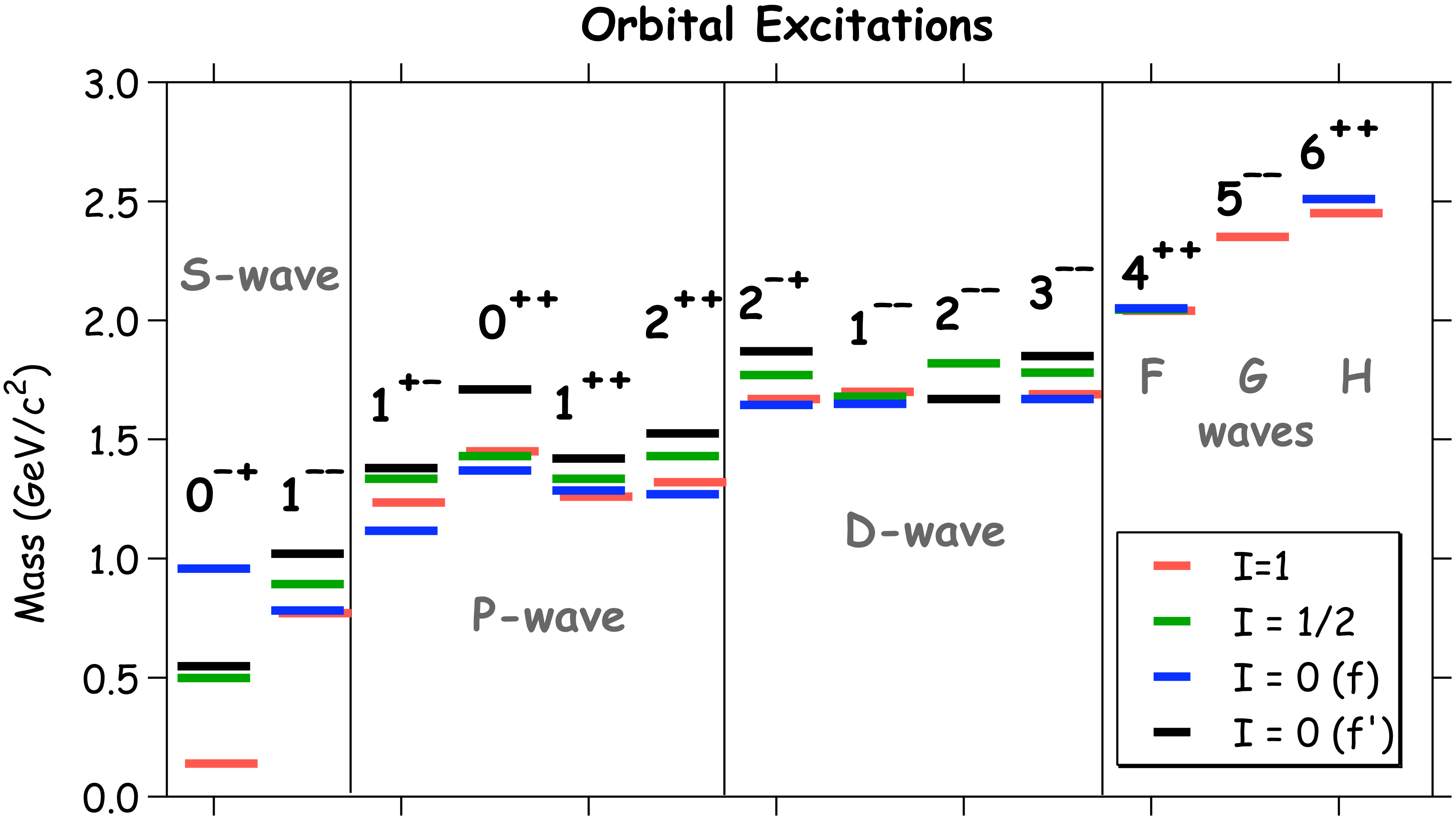
With the flux tube in its excited state the *hybrid* *mesons arise and the QN of the excited flux tube combine with those of quarks giving rise to hybrid mesons with conventional and exotic* J^{PC}

Nonets of Conventional Light Quark Mesons



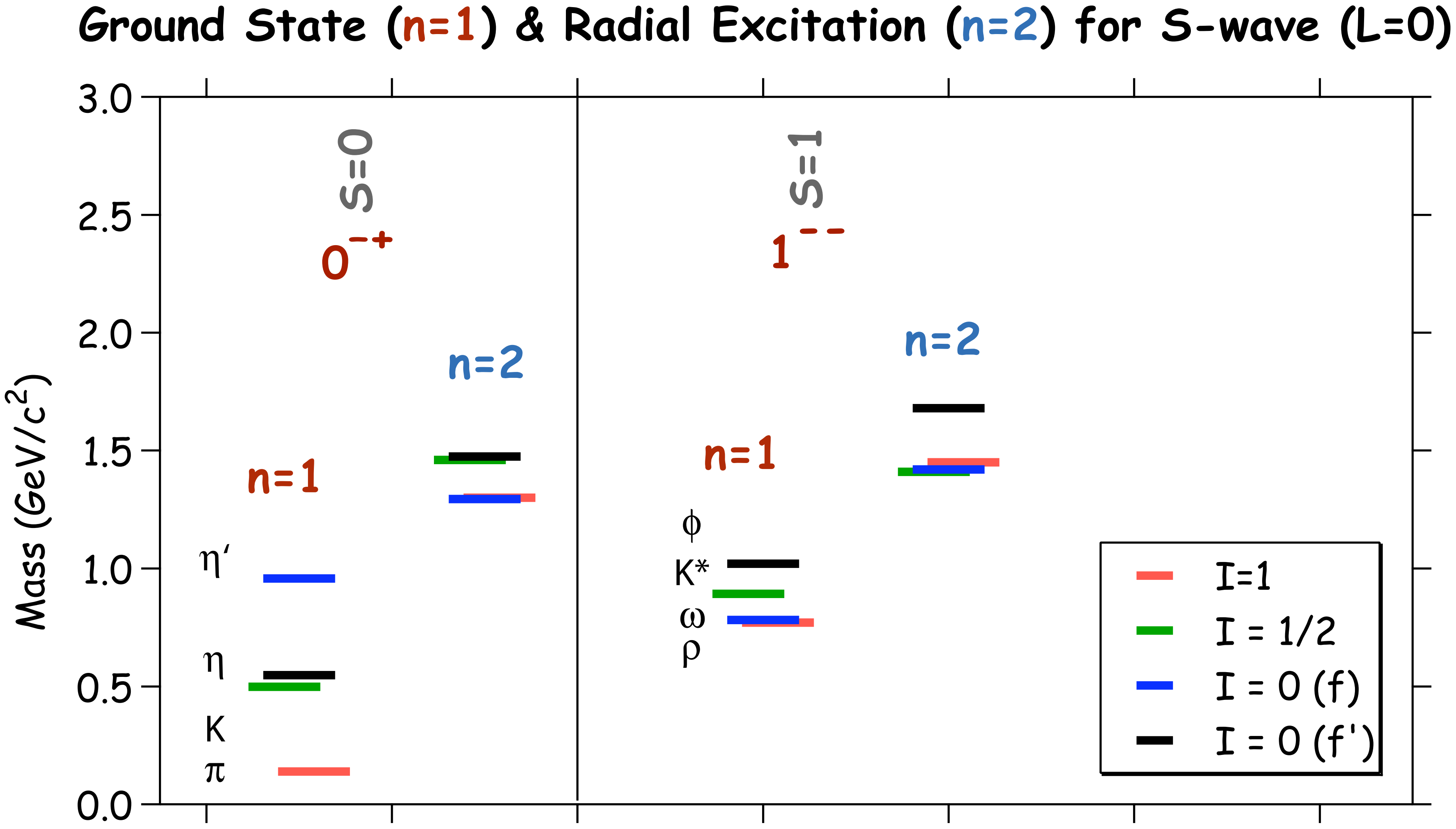
- using assignments from Quark Model Review - 2006 PDG WWW pages

Nonets of Conventional Light Quark Mesons



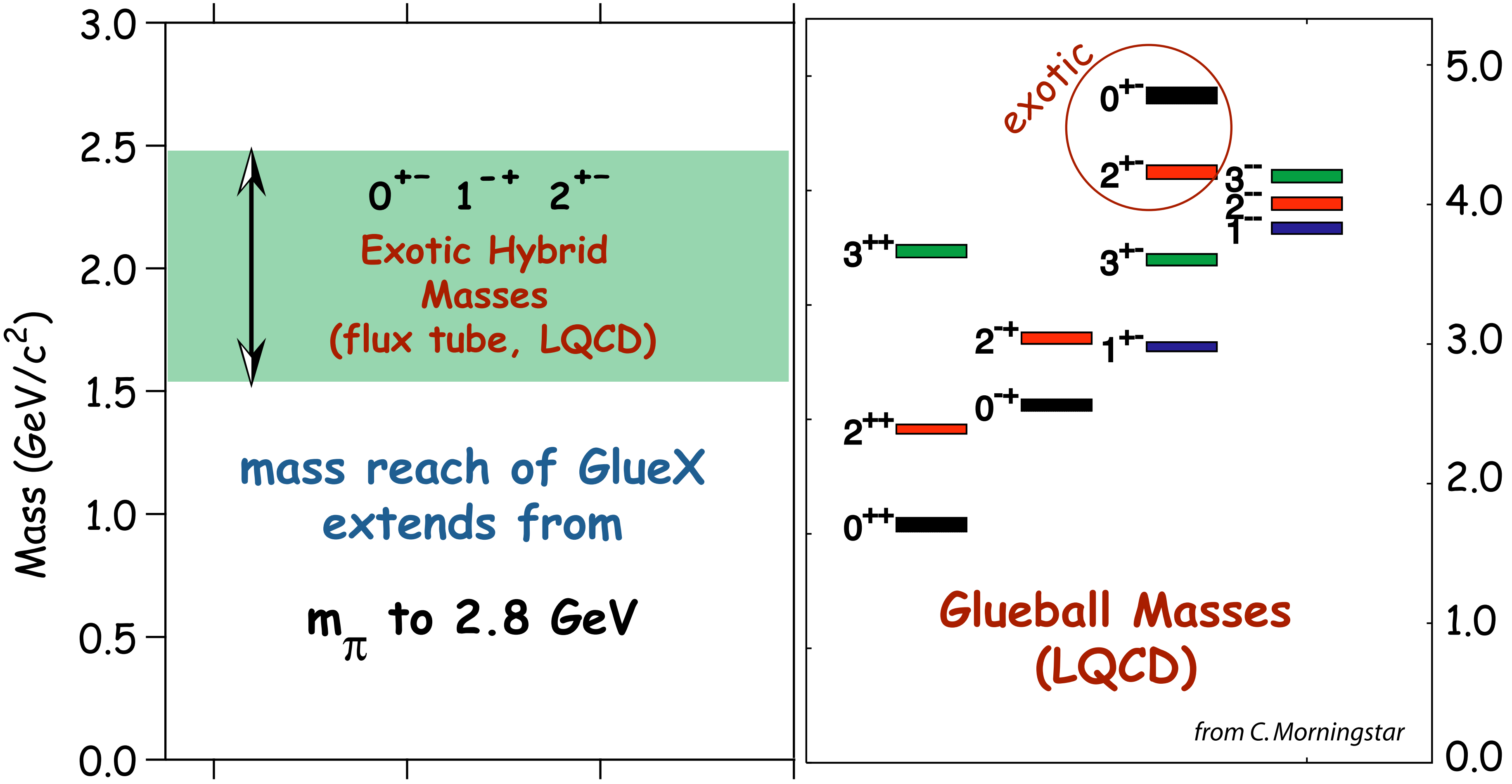
- using assignments from Quark Model Review - 2006 PDG WWW pages

Nonets of Conventional Light Quark Mesons



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

Hybrid and Glueball Masses



mass reach of GlueX extends from

m_π to 2.8 GeV

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
$\pi_1(1600) \rightarrow b_1\pi$ $\pi_1(1600) \rightarrow f_1\pi$	
$\pi_1(2000) \rightarrow b_1\pi$ $\pi_1(2000) \rightarrow f_1\pi$	

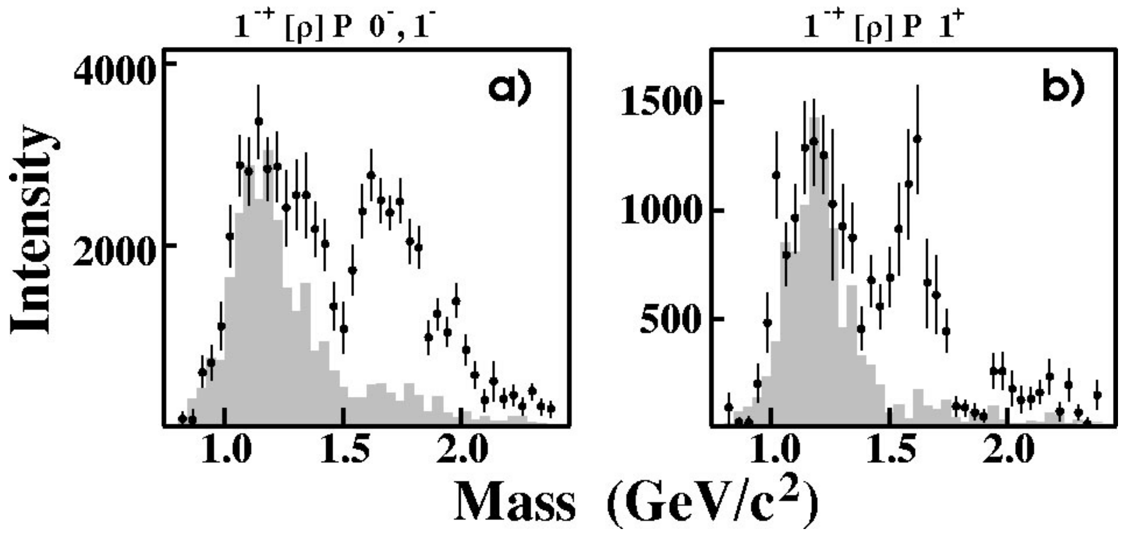
These states are not without controversy. Amplitude analysis issues include:

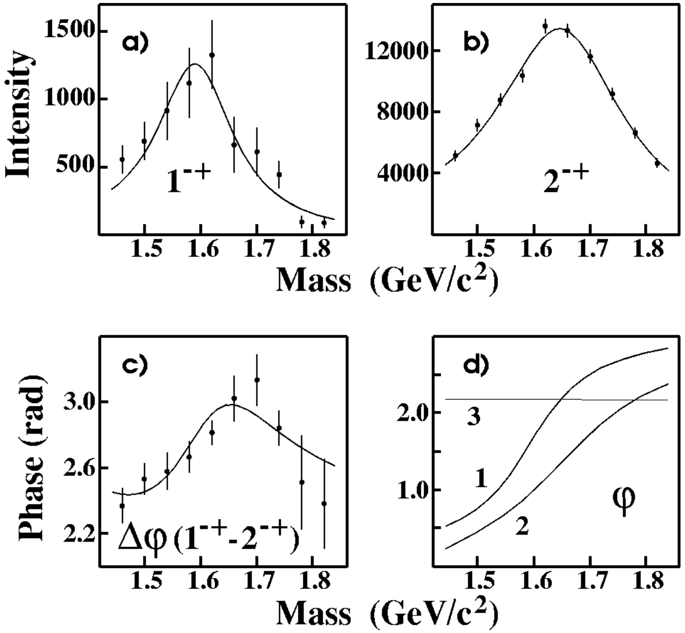
- possible leakage due to acceptance or insufficient wave sets
- interpretation of line shapes and phases

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

E852

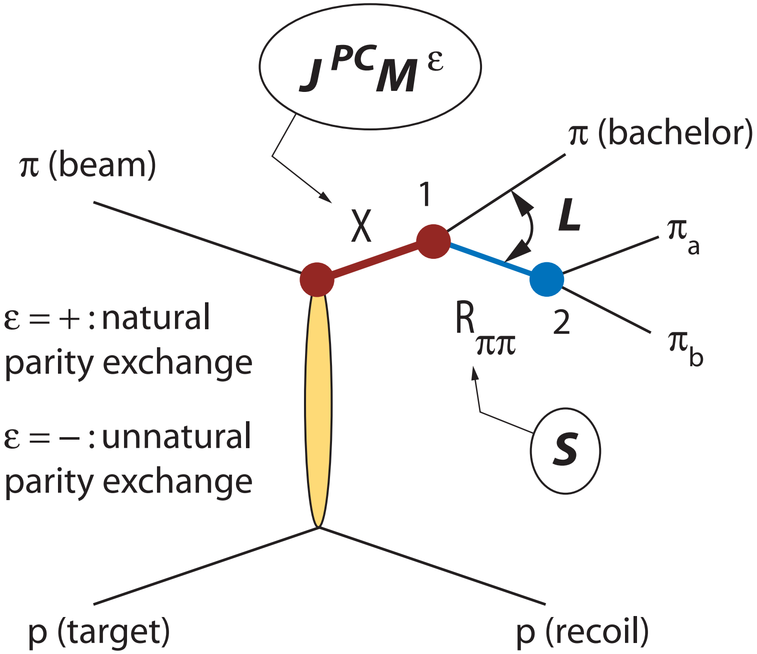
S. U. Chung et al, Phys. Rev. ***D65*** *(2002) 072001*





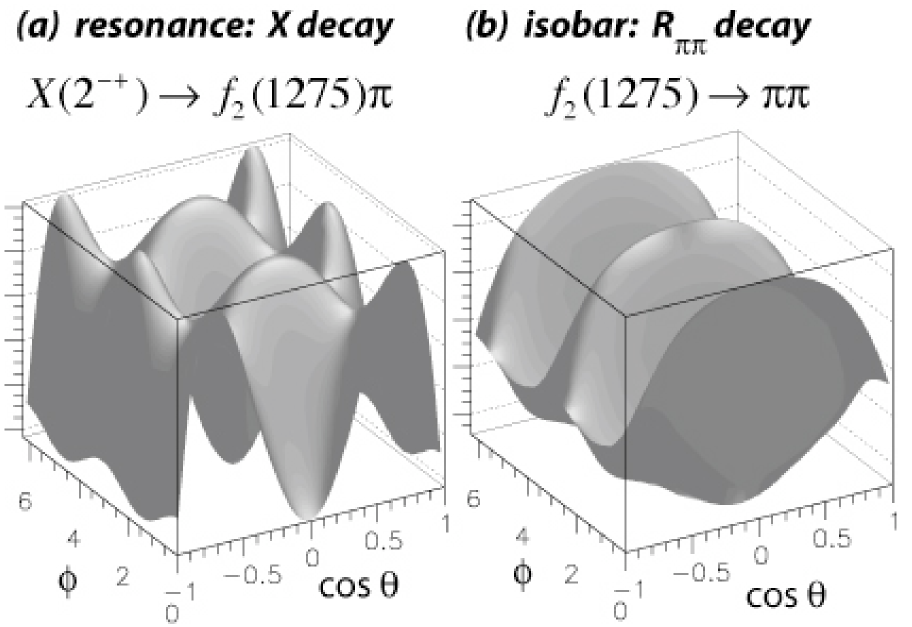
Based on 250K events of the reaction: $\pi^- p \to \pi^- \pi^- \pi^+ p$

Amplitude Analysis of the 3π System



$\varepsilon = +$: natural parity exchange

$\varepsilon = -$: unnatural parity exchange



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

---

decay

acceptance

production

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

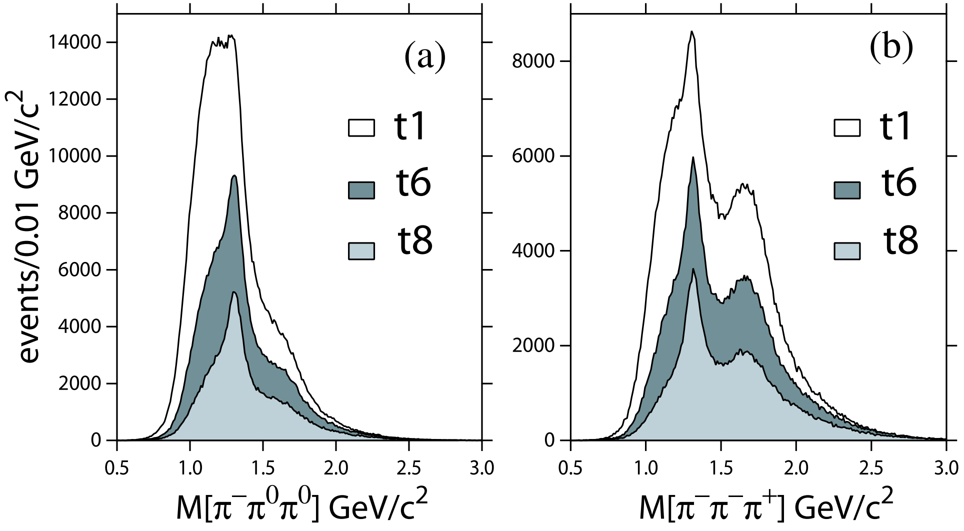
observed intensity

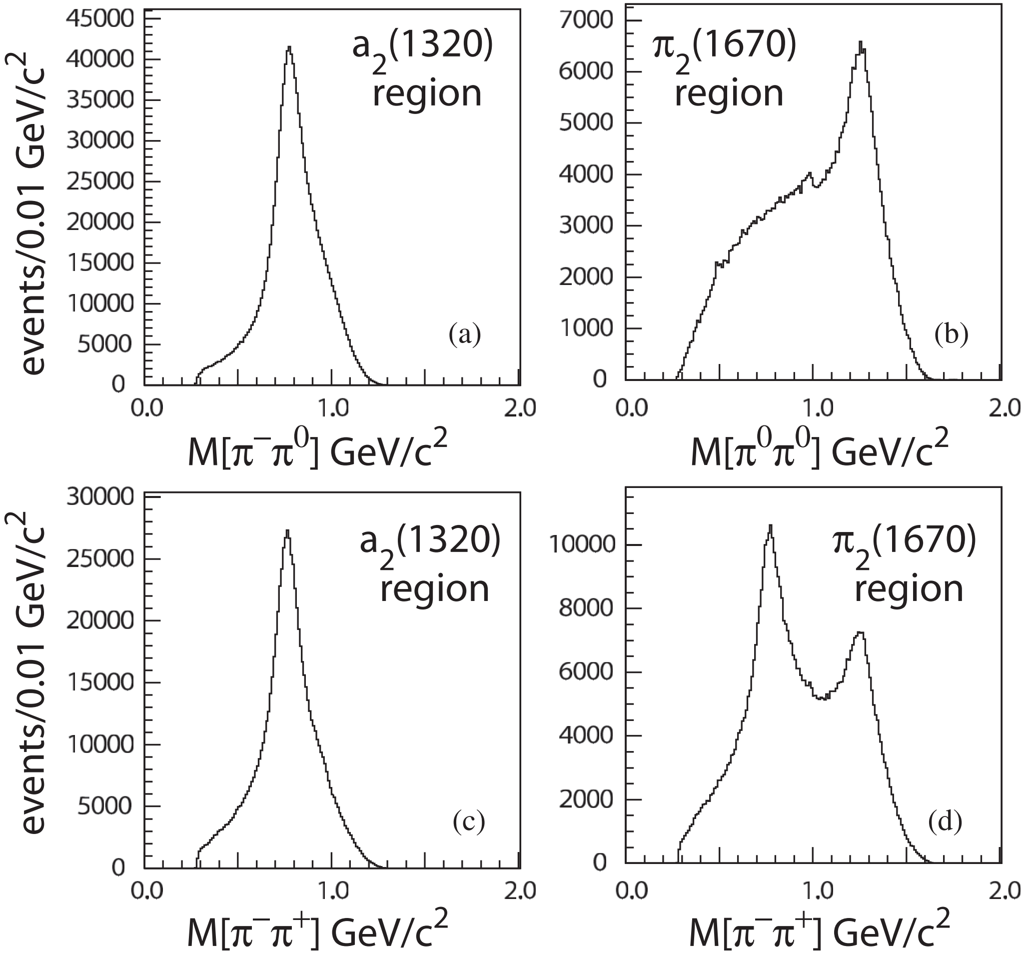
spin variables: J, M, S

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

Raw Data for the 3π System

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



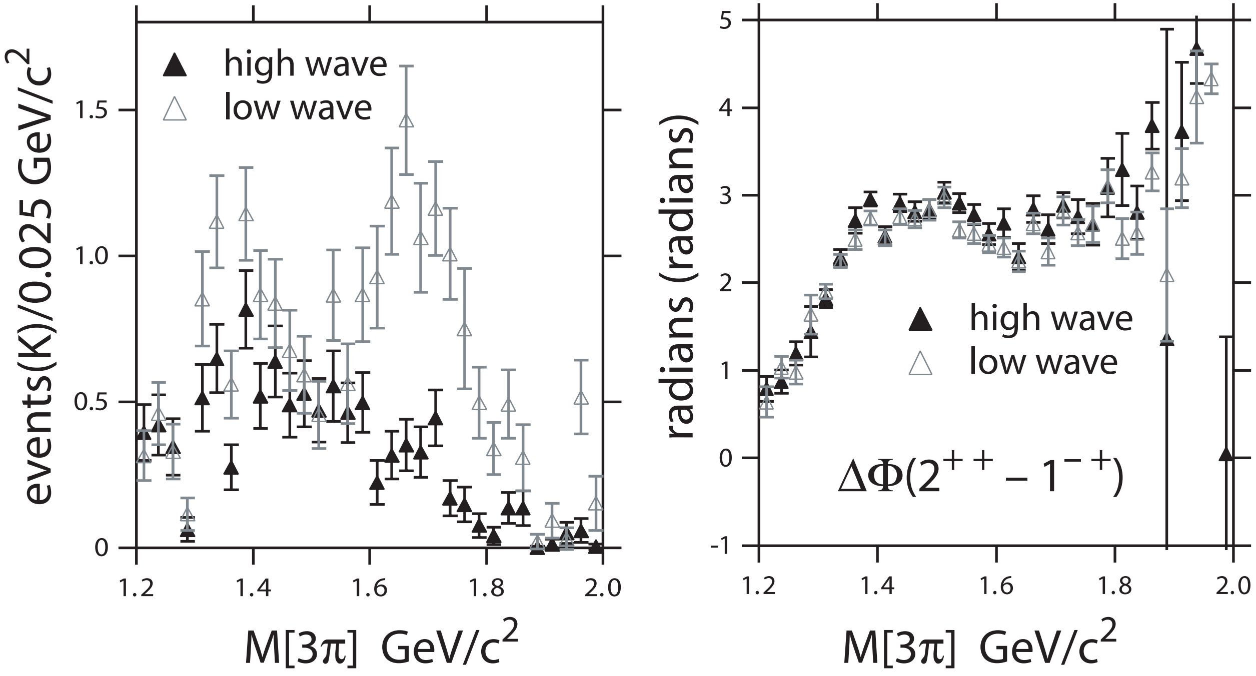


Revisiting $\pi_1(1600) \to \rho\pi$

A. R. Dzierba et al, 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.

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



$1^{-+}1^{+}$ P-wave $\rho\pi$

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

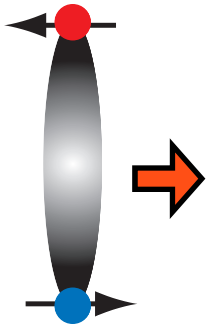
Low-wave set is the same as in the earlier E852 analysis while the high-wave set includes additional waves.

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?

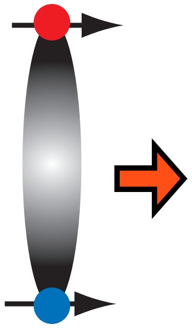
- *Evidence is tantalizing but not strong.*
- *Hermeticity and excellent resolution are needed to eliminate experimental biases.*
- *Assumptions in amplitude analyses must be well understood and controlled.*
- *Perhaps pions are not the optimal probe for producing exotic hybrids.*

Production of Exotic Hybrids with Photons



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

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



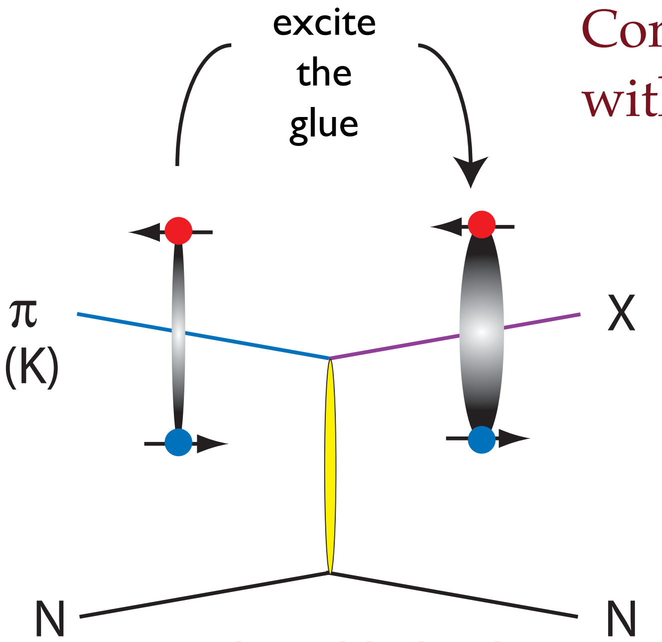
$J^{PC} = 0^{-+}, 1^{+-}, 2^{-+}$

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

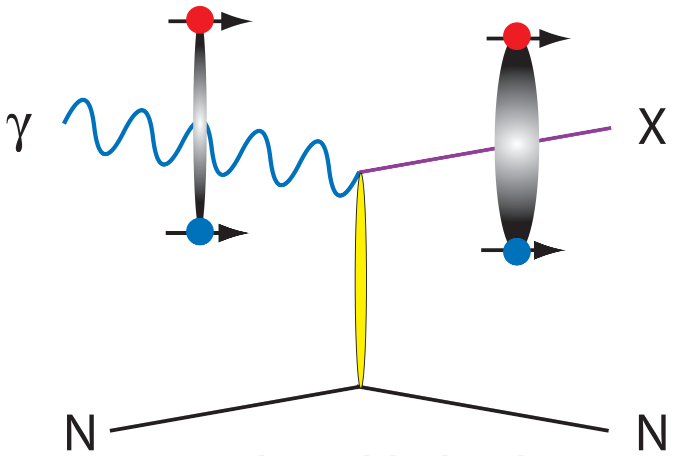
exotic

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

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



produced hybrids
are not expected to be exotic



produced hybrids
can be exotic

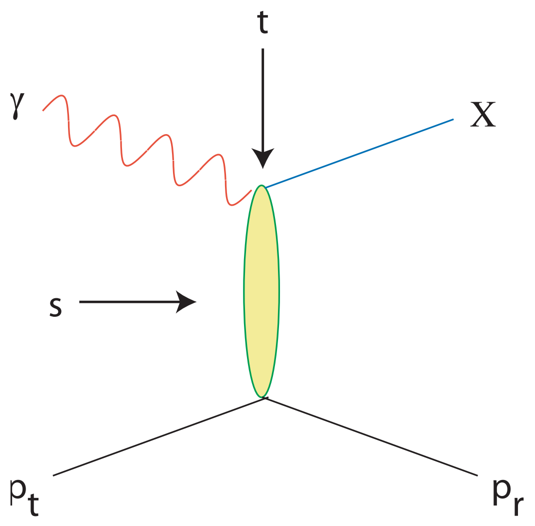
Requirements for Exotic Meson Discovery

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

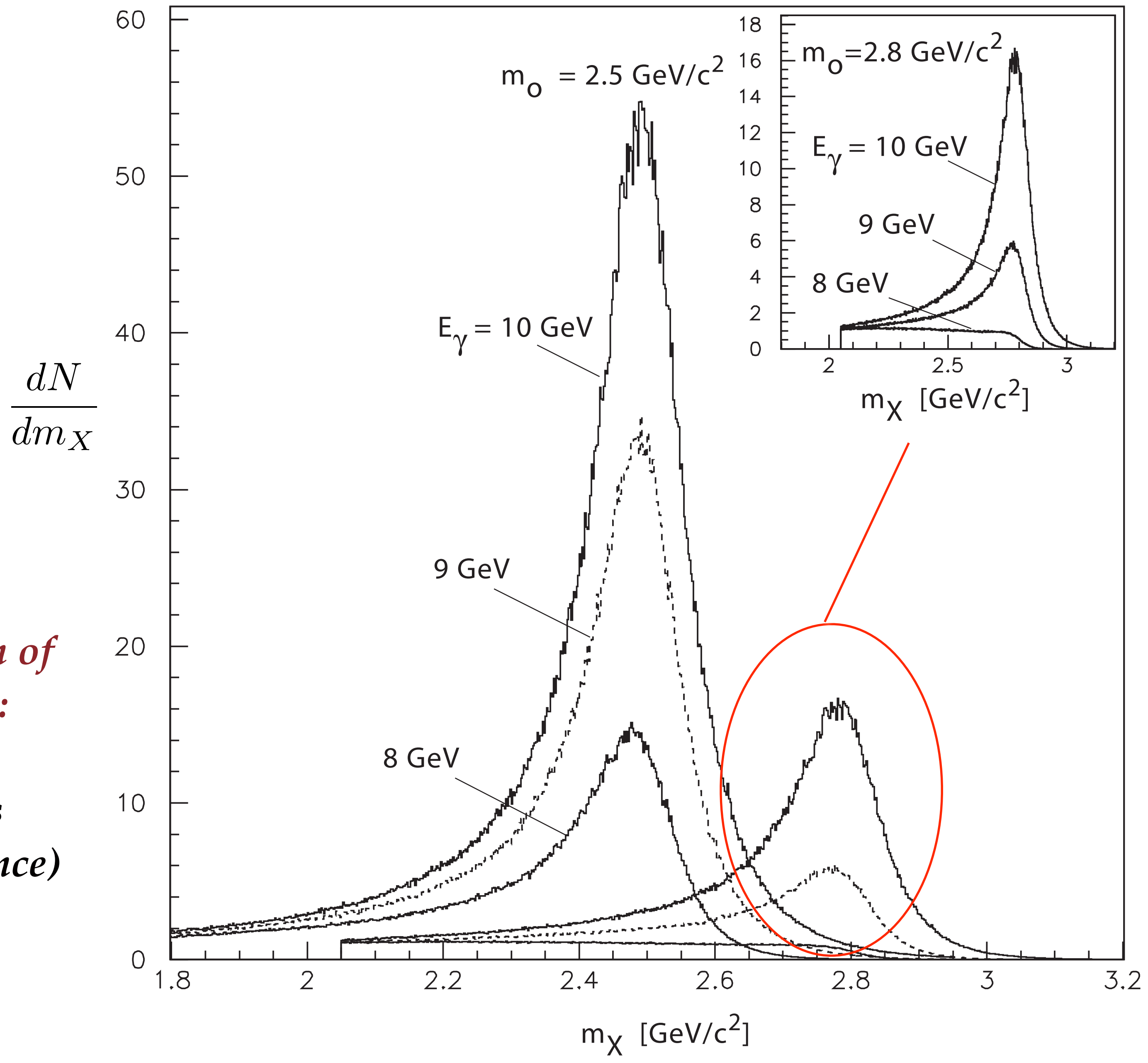
- **Linearly polarized photons of a degree and flux needed for the PWA.**
  - *Using coherent bremsstrahlung this implies 12 GeV electrons with the appropriate emittance, spot size and duty-factor.*

- **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*

Line Shape & Yield



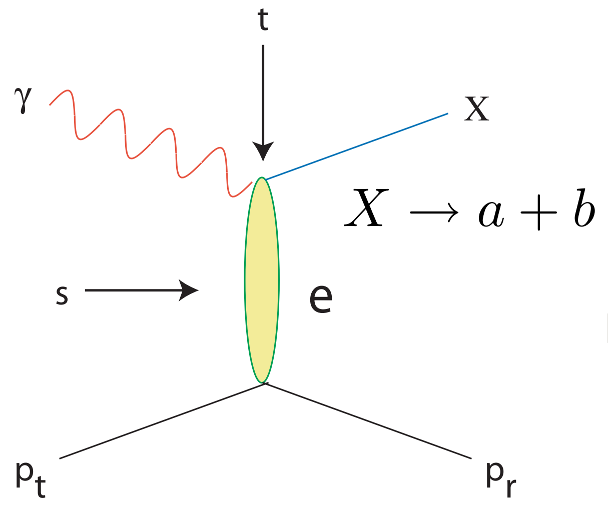
$$N(m_X) = A \cdot BW(m_X) \cdot e^{-8|t|}$$



Variation of t_{min} as a function of meson mass and photon energy:

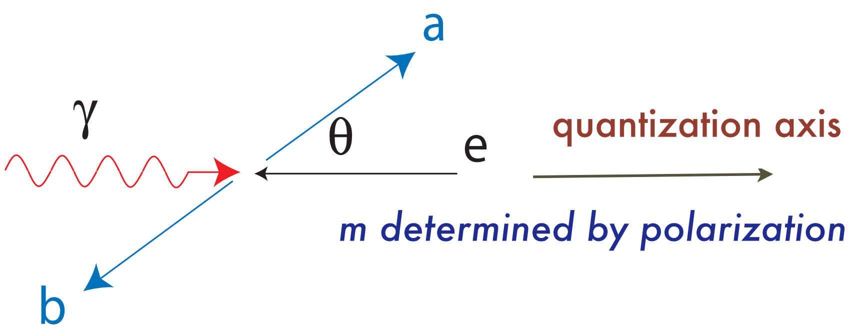
- *affects production rate*
- *line shape (if t_{min} varies rapidly across width of resonance)*

Linear Polarization



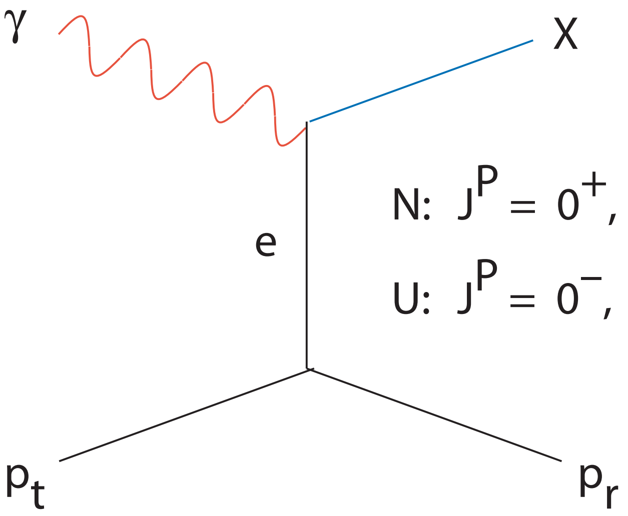
$X \rightarrow a + b$

$$Y_\ell^{\pm 1}(\theta, \phi) \propto P_\ell(\cos\theta) e^{\pm i\phi}$$



m determined by polarization of photon

Only linearly polarized photons provide azimuthal angle dependence.



N: $J^P = 0^+, 1^-, 2^+, \ldots$

U: $J^P = 0^-, 1^+, 2^-, \ldots$

Exotic Production:

Takes place via unnatural (U) parity exchange

Diffractive Production:

Through natural parity (N) exchange

Only linearly polarized photons can distinguish between U and N.

Coherent Bremsstrahlung

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

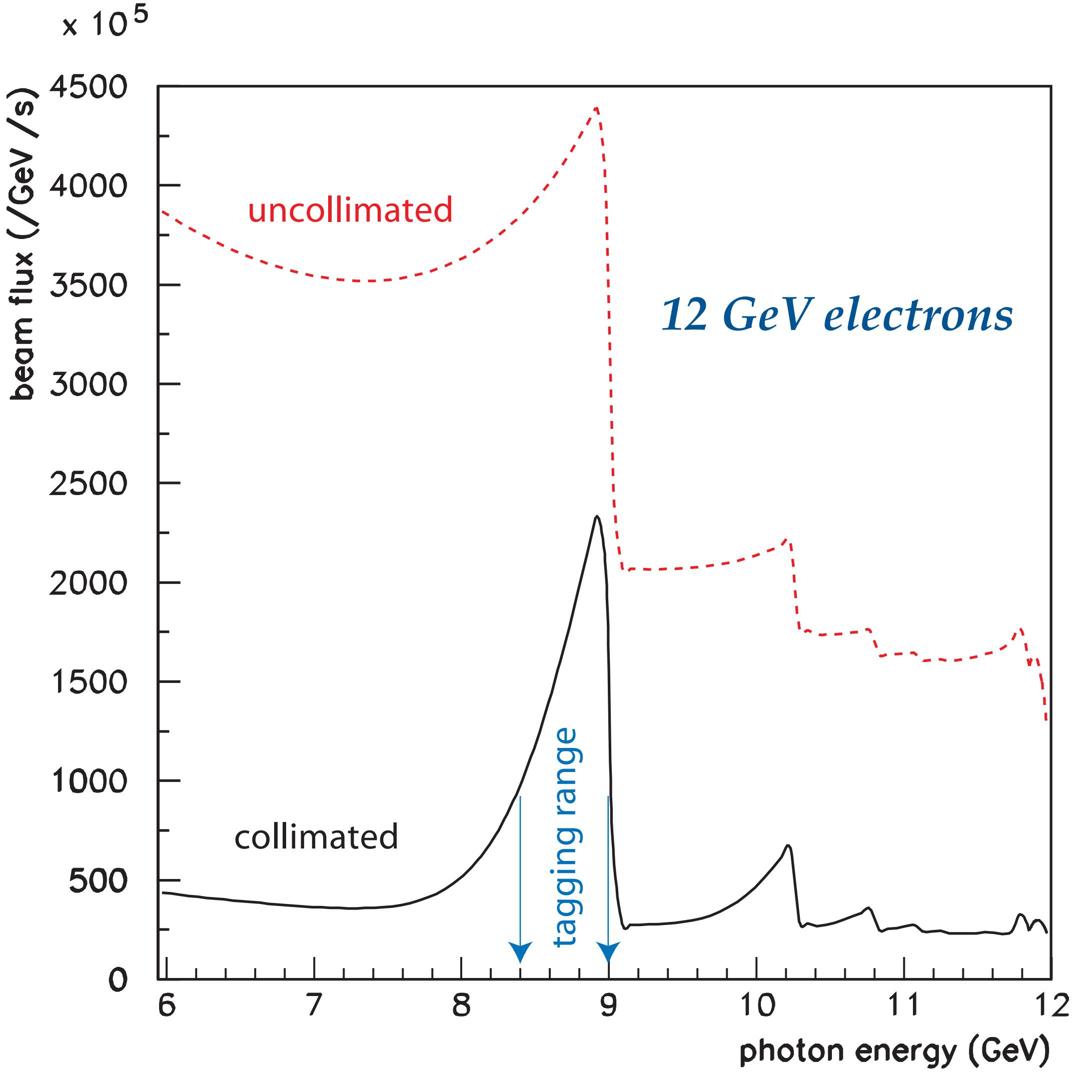
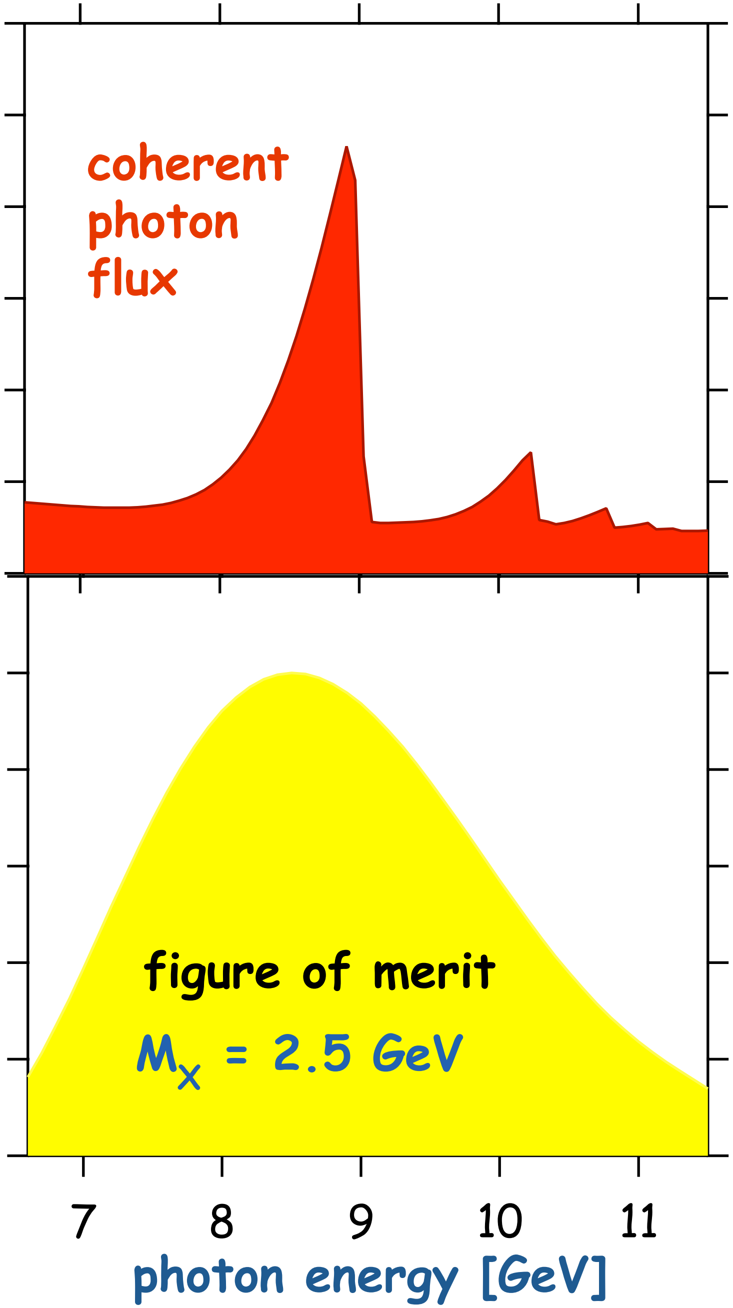
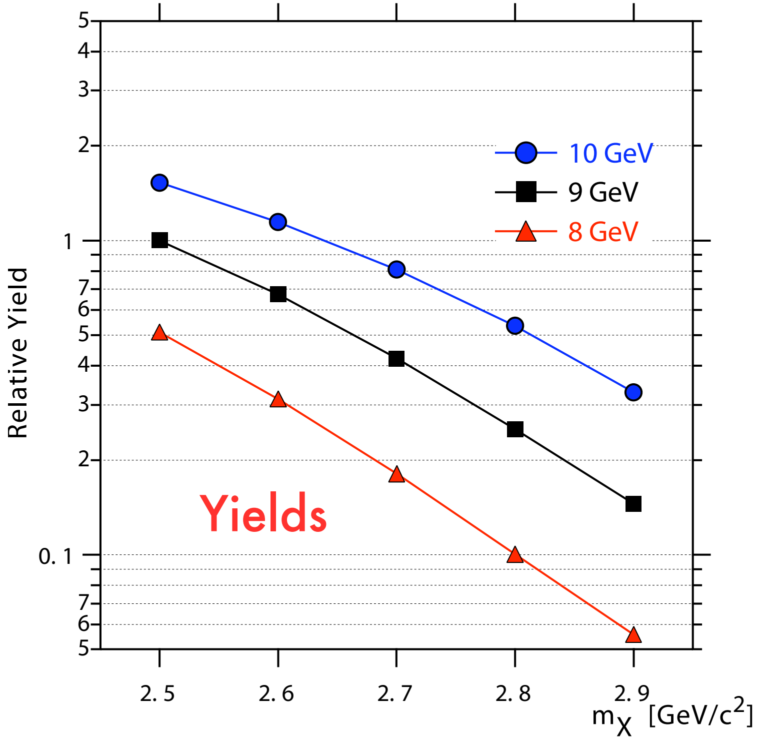
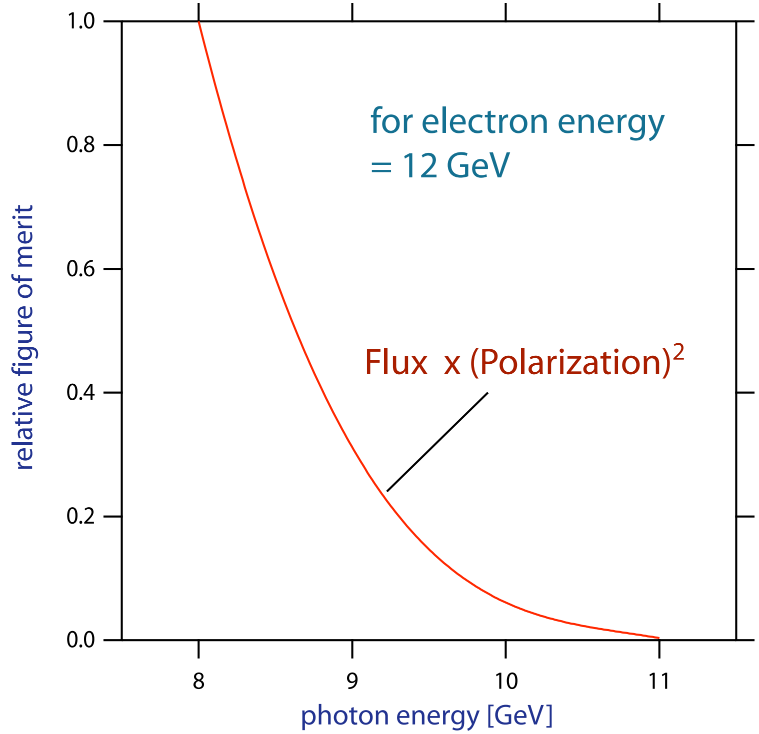


Figure of Merit







Need for 12 GeV Electrons

9 GeV photons ideal for the meson mass reach and is well-matched to solenoidal detector.

Keep the photon energy fixed at 9 GeV and vary the energy of the electron beam to understand the figure of merit.

Conclusion:

12 GeV electrons essential

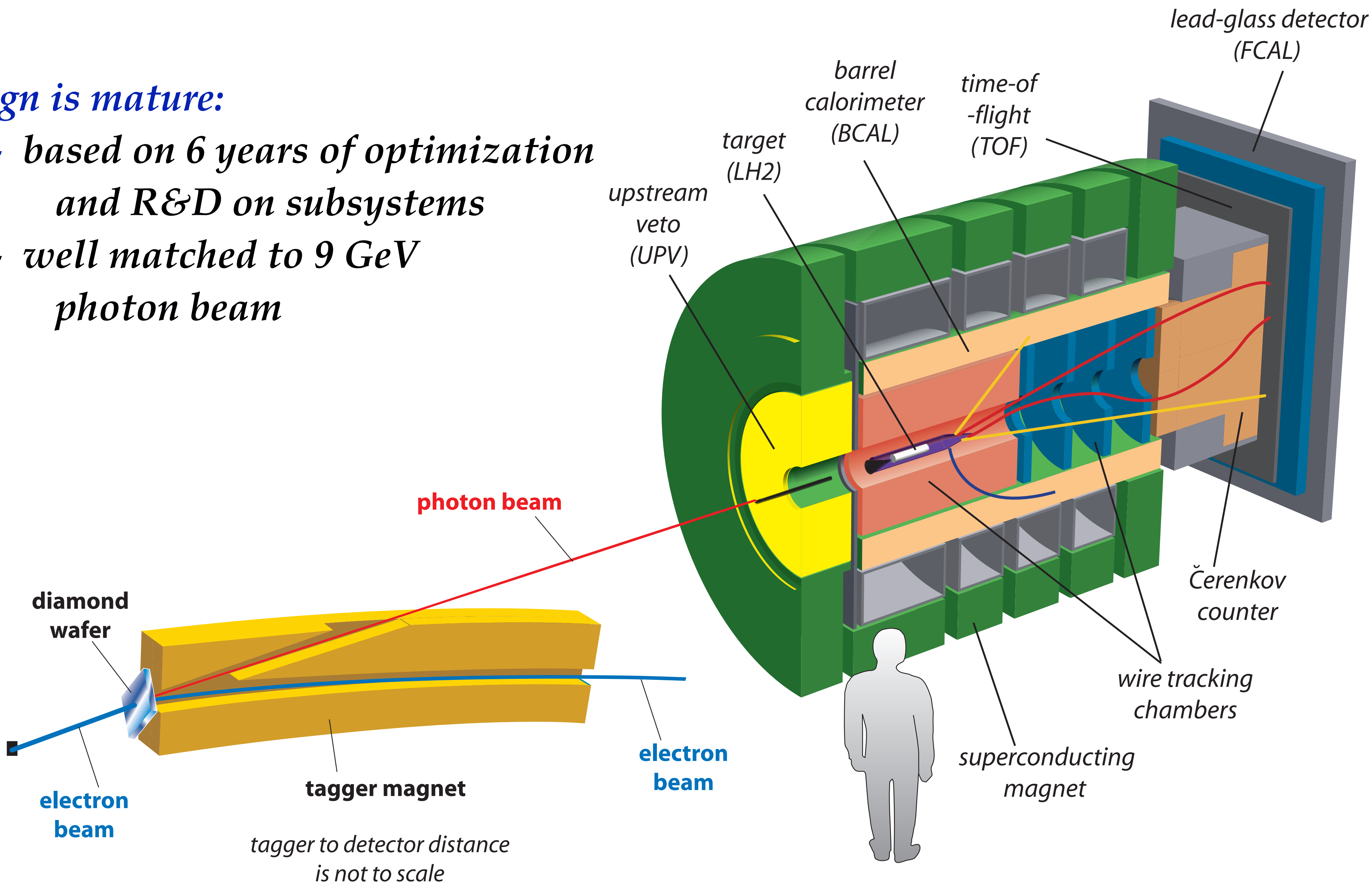
electron energy:	10 GeV	11 GeV	12 GeV
Photon flux in peak (million per sec)	32	67	100
Average degree of polarization	0.08	0.24	0.37
Figure of merit relative to 12 GeV	0.015	0.263	1.0

total hadronic rate fixed at 370 kHz

GlueX Detector

Design is mature:

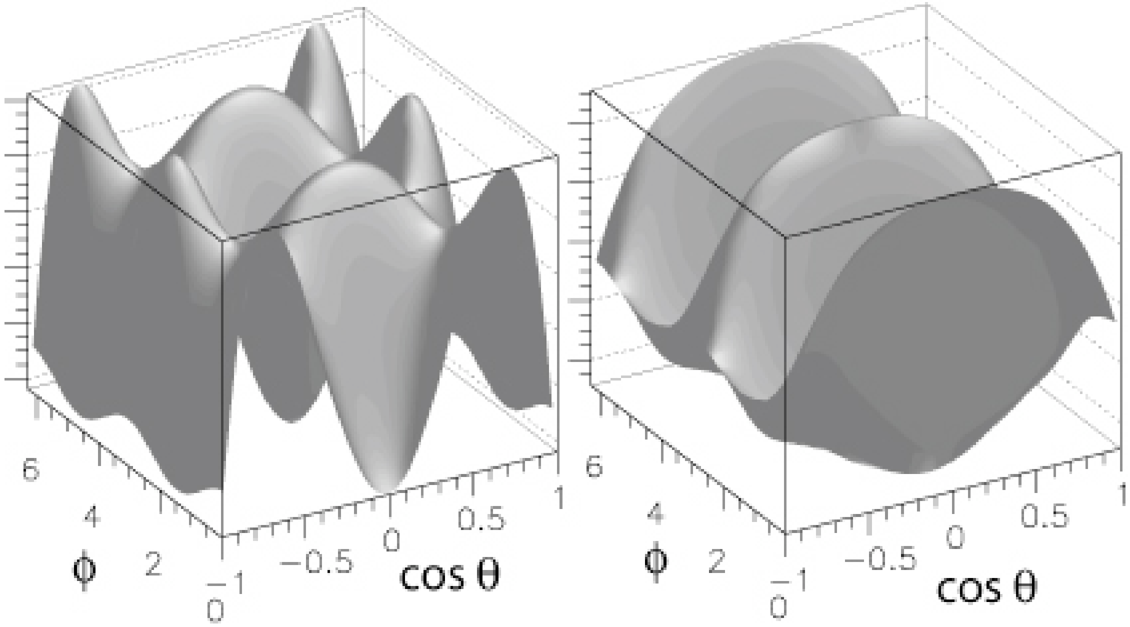
- *based on 6 years of optimization and R&D on subsystems*
- *well matched to 9 GeV photon beam*



Acceptance

Excellent and well understood acceptance is essential for the amplitude analysis to succeed

Structure associated with a particular partial wave:



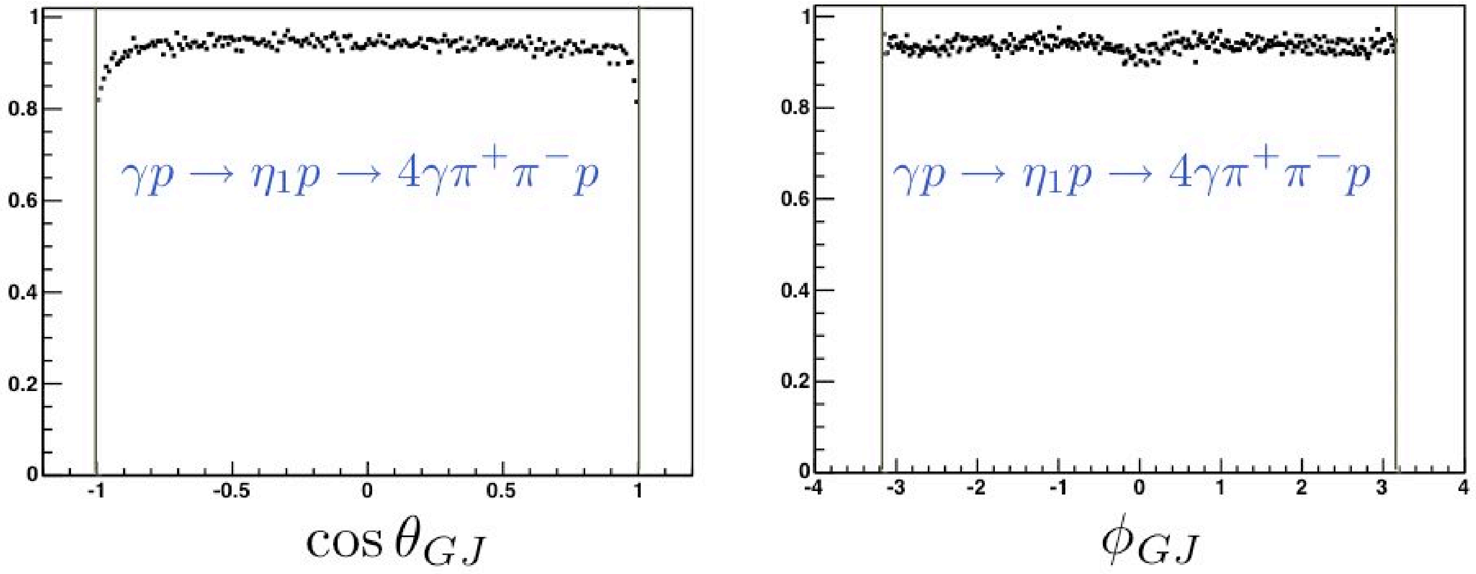
(a) resonance: X decay

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

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

$f_2(1275) \rightarrow \pi\pi$

Acceptance for a particular reaction:



Run Plan for the First Two Years of Beam Time

- **Detector Commissioning (first six months)**
  - *preceded by several months of pre-beam commissioning*
- **Physics Commissioning (next six months)**
  - *duplicate existing measurements of*
    - *density matrices of vector mesons*
    - *properties of the well established $a_2(1320)$*
- **Exotic Hybrid Search (second year)**
  - *concentrate on favored channels*

Rate Estimates

Assume: $10^7 \ \gamma/s$ beam flux & 30-cm LH_2 target

Leads to: $\sigma = 1 \ \mu b \Rightarrow 12.6 \ Hz$

Yield per month assuming 30% efficiency: 10M events

Vector Mesons: ***Measure spin-density matrices***

Meson	ρ	ω	ϕ
$\sigma(\mu b)$	20	2	0.4
Modes	$\pi^+\pi^-$	$\pi^+\pi^-\pi^0$ $\pi^0\gamma$	K^+K^- K_LK_S $\pi^+\pi^-\pi^0$ $\eta\gamma$

Modes of the $a_2(1320)$

- **A well-established meson**
- **Cross section:** $\gamma p \to a_2^+ n \quad \approx 1\ \mu b$
- **Modes:**

Mode	$(\rho\pi)^+$	$\eta\pi^+$	K^+K_S	$\pi^+\eta'$
B. R. (%)	70	15	5	0.5

- **Final States:**

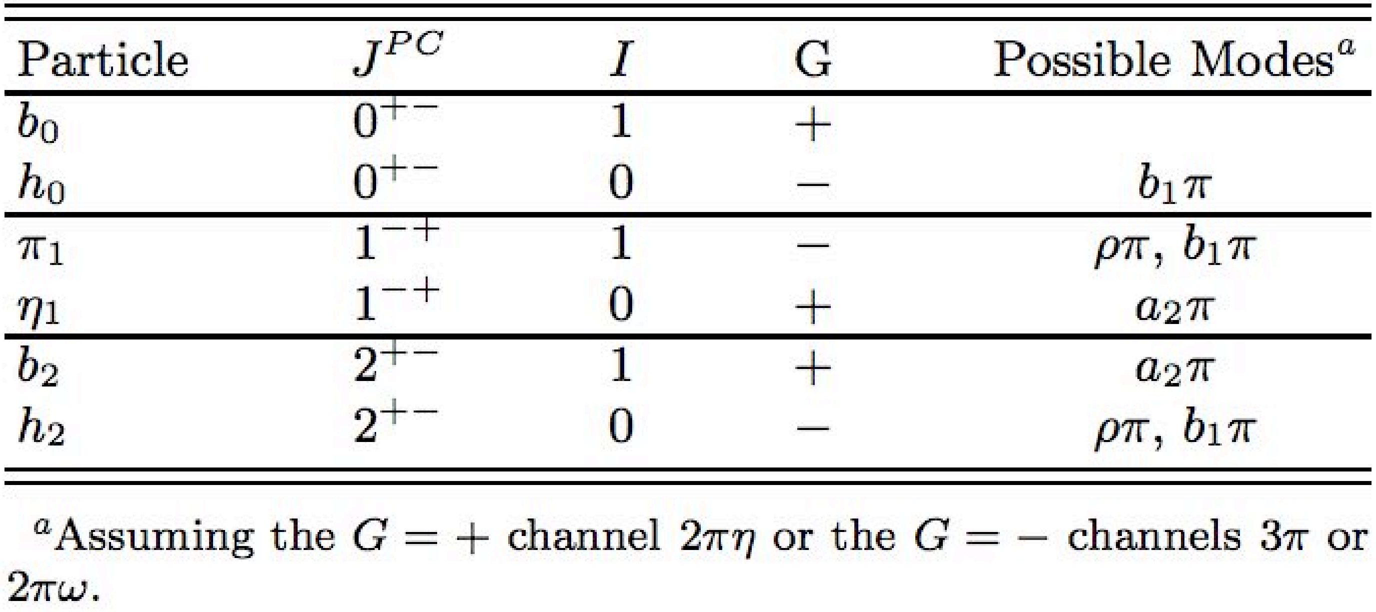
$$(\rho\pi)^+ \to \pi^+\pi^+\pi^-;\ \pi^+\pi^0\pi^0$$

$$\eta \to 2\gamma; \pi^+\pi^-\pi^0;\ 3\pi^0$$

$$K_S \to \pi^+\pi^-;\ \pi^0\pi^0$$

$$\eta' \to \eta\pi^+\pi^-;\ \eta\pi^0\pi^0;\ \rho\gamma$$

Initial Exotic Hybrid Search Modes



Particle	J^{PC}	I	G	Possible Modes^a
b_0	0^{+-}	1	$+$	
h_0	0^{+-}	0	$-$	$b_1\pi$
π_1	1^{-+}	1	$-$	$\rho\pi,\ b_1\pi$
η_1	1^{-+}	0	$+$	$a_2\pi$
b_2	2^{+-}	1	$+$	$a_2\pi$
h_2	2^{+-}	0	$-$	$\rho\pi,\ b_1\pi$

^{a}Assuming the $G=+$ channel $2\pi\eta$ or the $G=-$ channels 3π or $2\pi\omega$.

$\rho \rightarrow 2\pi$

$a_2 \rightarrow \eta\pi$

$b_1 \rightarrow \omega\pi$

So the final states of interest include:

$(3\pi)^0 p$ $\quad (3\pi)^+ n \longleftarrow \sigma \approx 10\ \mu b$

$(\eta 2\pi)^0 p$ $\quad (\eta 2\pi)^+ n \longleftarrow$

$\sigma \approx 0.2\ \mu b$

$(\omega 2\pi)^0 p$ $\quad (\omega 2\pi)^+ n \longleftarrow$

Beam Requirements

During initial running, the requirements placed on the beam into Hall D will steadily increase until we reach those necessary for physics running.

	Engineering Running	Initial Physics	Hybrid Searches
Min. Energy	10 GeV	11 GeV	12 GeV
Min. Current	$1\,nA$	$1\,nA$	$1\,nA$
Avg. Current	$1 - 300\,nA$	$\sim 300\,aA$	$0.3 - 3\,\mu A$
Max. Emitance	$50\,\text{mm}\cdot\mu r$	$20\,\text{mm}\cdot\mu r$	$10\,\text{mm}\cdot\mu r$
Max. Energy Spread	$< 0.5\%$	$< 0.5\%$	$< 0.5\%$
Max. Halo Fraction	$< 10^{-4}$	$< 10^{-5}$	$< 10^{-5}$
Max. e^- Polarization	*unspecified*	*unspecified*	$< 1\%$

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.*