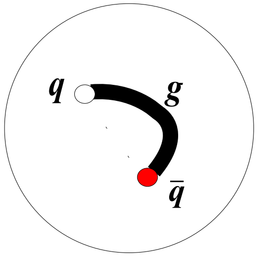
The GlueX Experiment
Search for Gluonic Hybrid Mesons via Photoproduction at Jefferson Lab

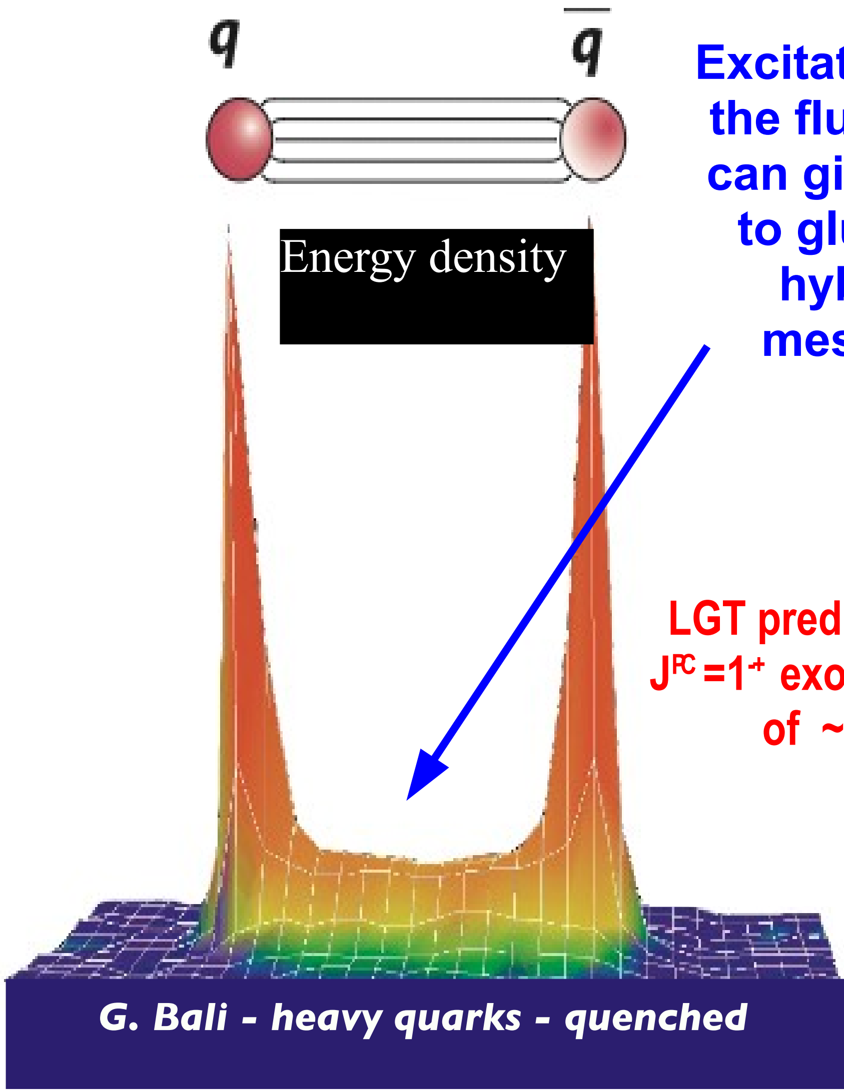
Paul Eugenio
Florida State University
Tallahassee, FL USA

Overview

- Motivation &Identification QCD Exotics
- Candidates for Exotic Mesons
- The GlueX Experiment
  - Hybrid Meson Search at Jefferson Lab
  - Additional Physics with GlueX

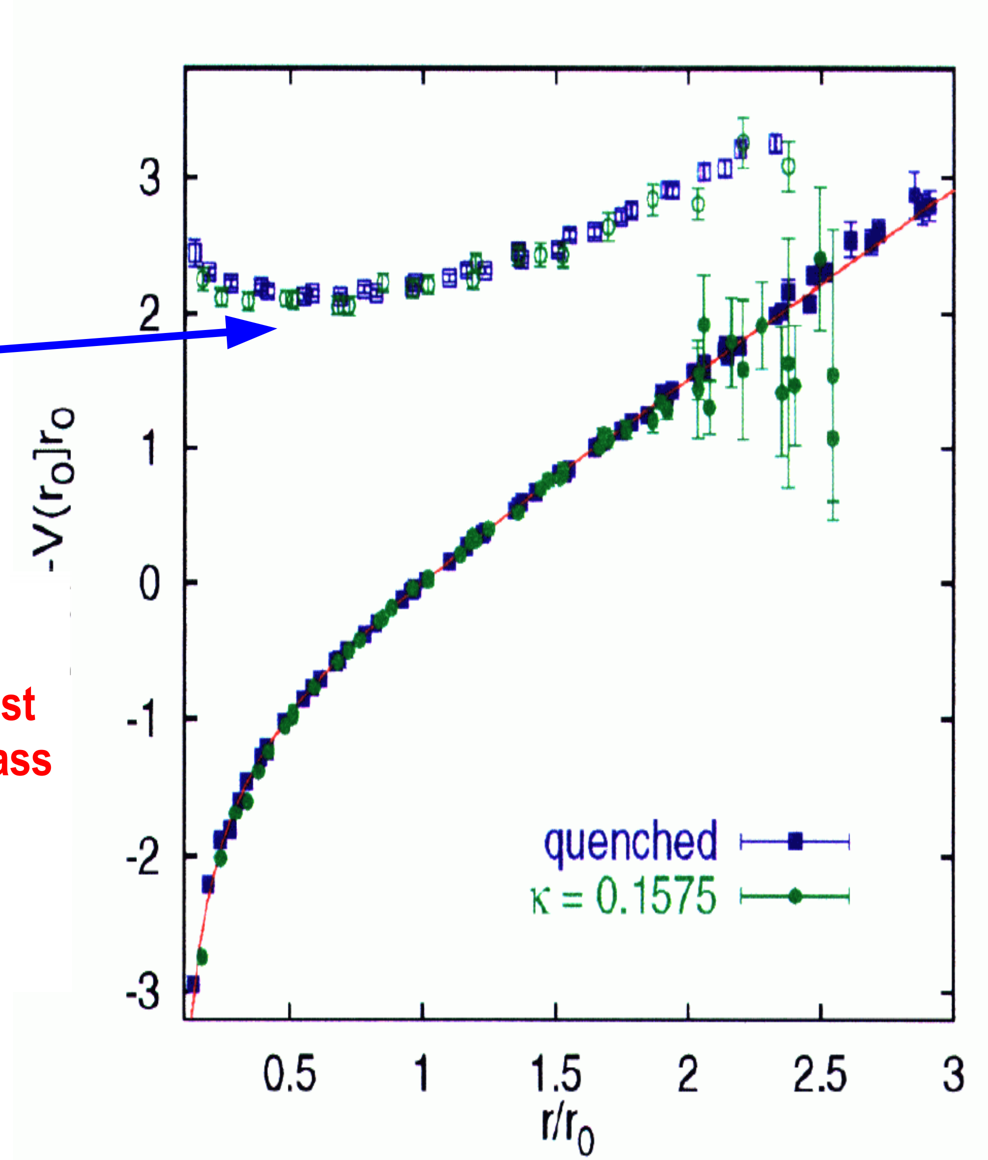


Gluonic Excitations

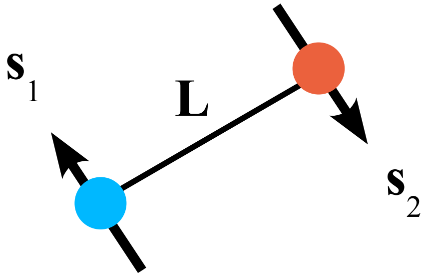


Excitations of the flux tube can give rise to gluonic hybrid mesons

LGT predicts lightest $J^{PC}=1^{-+}$ exotics w/ mass of ~2 GeV



Quark Model Meson Spectrum



$S = 0, 1$

$L = 0, 1, 2, 3, \cdots$

$\vec{J} = \vec{L} + \vec{S}$ $\quad P = (-1)^{L+1}$ $\quad C = (-1)^{L+S}$

Meson quantum numbers characterized by given J^{PC}

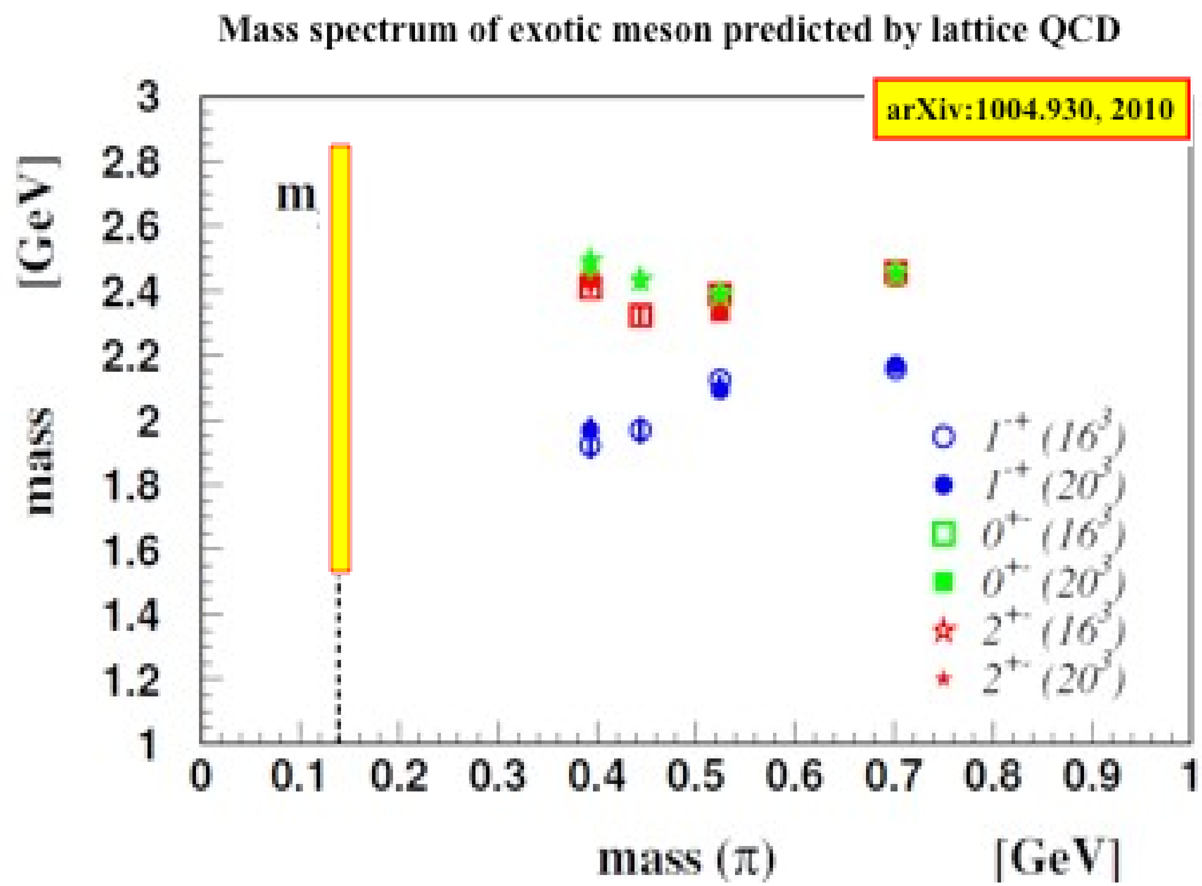
Allowed States:

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

Forbidden States(Exotics):

$J^{PC} = 0^{+-}, 0^{--}, 1^{-+}, 2^{+-}, 3^{-+}, 4^{+-}, \cdots$

Mass Predictions of Exotic Mesons



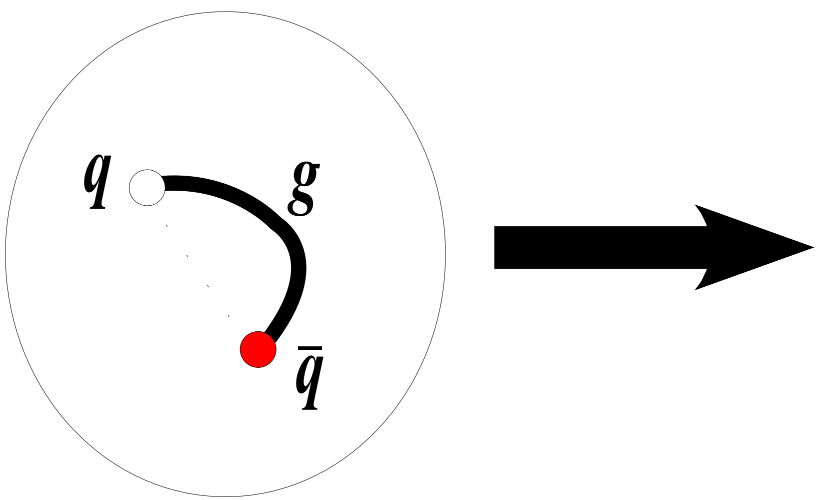
- The lightest hybrid meson nonet predicted by lattice QCD is $J^{PC} = 1^{-+}$
- Predicted hybrid meson mass region for experimental search: 1.5 GeV – 2.9 GeV

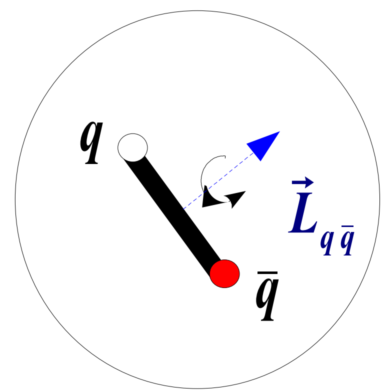
Flux-Tube Hybrid Decays

$$Hybrid \rightarrow q\,\bar{q}\,(L=1) + q\,\bar{q}\,(L=0)$$

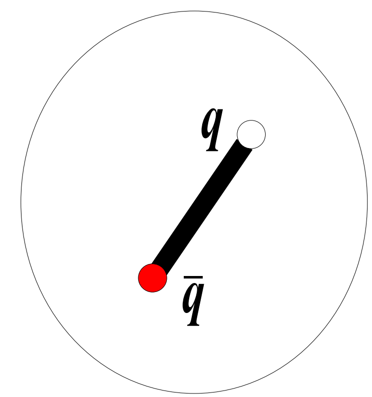
favored decay modes

- $b_1(1235)\pi$
- $f_1(1285)\pi$
- $a_2(1320)\pi$
- ...





+

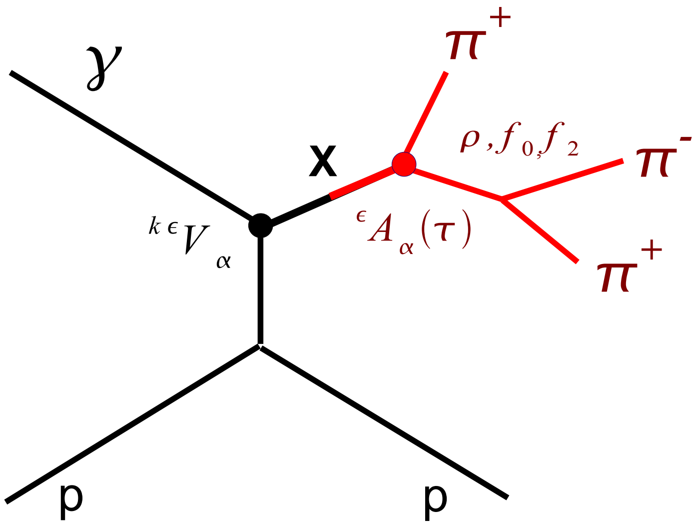


$$Hybrid \not\rightarrow q\,\bar{q}\,(L=0) + q\,\bar{q}\,(L=0)$$

forbidden/suppressed decay modes

ππ, ηπ, ρπ, ωπ, ...

Isgur & Paton, Phys Rev D31, 2910 (1985)



Partial Wave Analysis
unraveling the bumps

$$I(\tau)=\sum_{k\epsilon\epsilon'}\epsilon\epsilon'\rho_{\epsilon\epsilon'}(\tau)\sum_{\alpha\alpha'}{}^{k\epsilon'}V^*_{\alpha'}\,{}^{\epsilon'}A^*_{\alpha'}(\tau)\,{}^{k\epsilon}V_\alpha\,{}^{\epsilon}A_\alpha(\tau)$$

For unpolarized beam & target:

$$I(\tau)=\frac{1}{2}\sum_{k\epsilon}\left|\sum_{\alpha}{}^{k\epsilon}V_\alpha\,{}^{\epsilon}A_\alpha(\tau)\right|^2$$

unknown

Complex parameters varied in the PWA to fit the data

Helicity Decay Amplitudes

$$A_{\alpha,M}(\tau)=A_X^{\lambda_1\lambda_2;M}*A_{iso}^{\nu_1\nu_2;\lambda_1}\cdots$$

$$A_X^{\lambda_1\lambda_2;M}=D^J_{\lambda M}(\theta,\phi)\frac{\tilde{L}}{\tilde{J}}(L0;S\lambda|J\lambda)(S_1\lambda_1;S_2-\lambda_2|S\lambda)K$$

Wigner D-functions

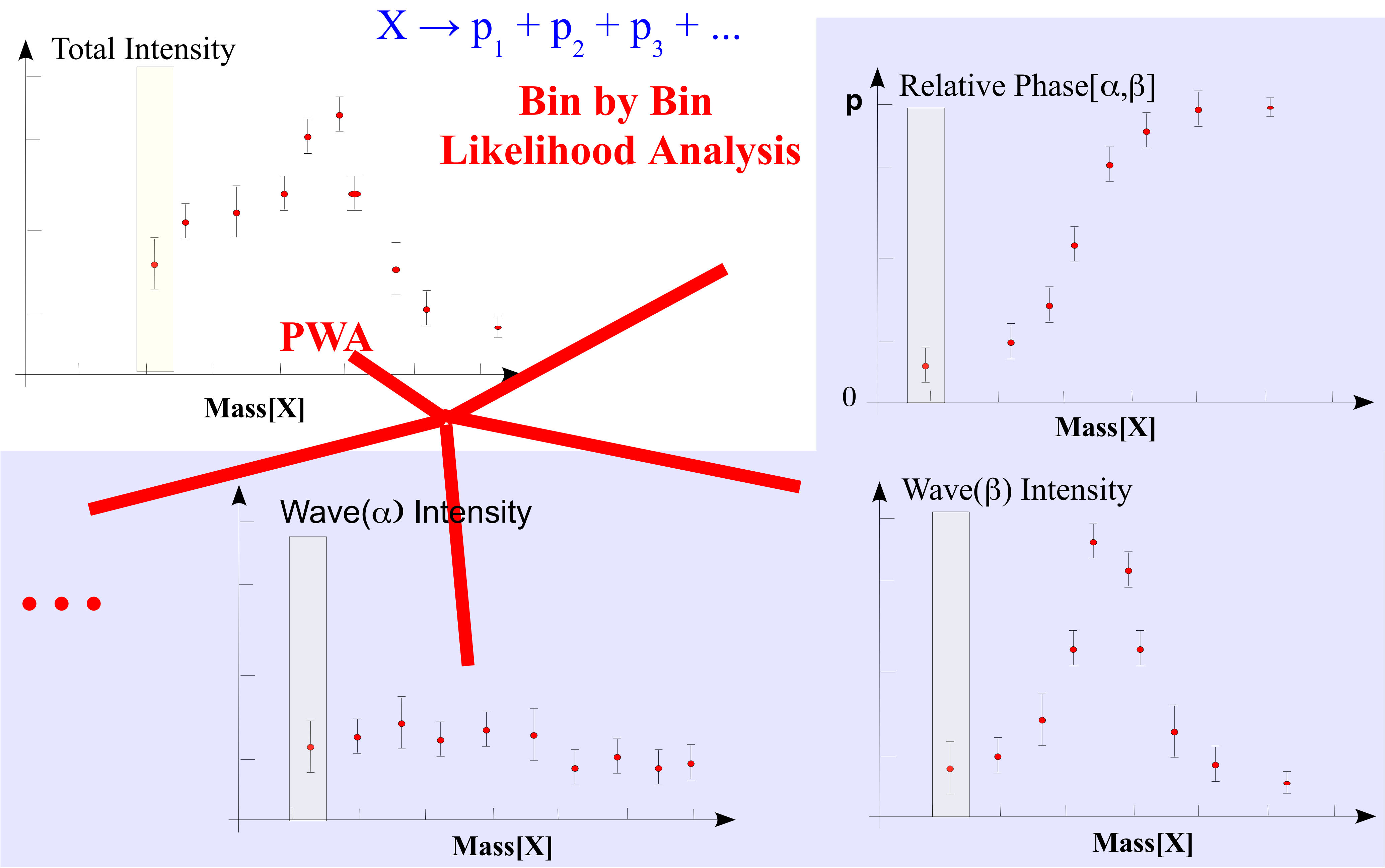
Clebsch-Gordan Coefficients

Mass Dependent Factor

$${}^{\epsilon}A_\alpha(\tau)=a[A_{\alpha,M}(\tau)\ \pm\ b\,A_{\alpha,-M}(\tau)]$$

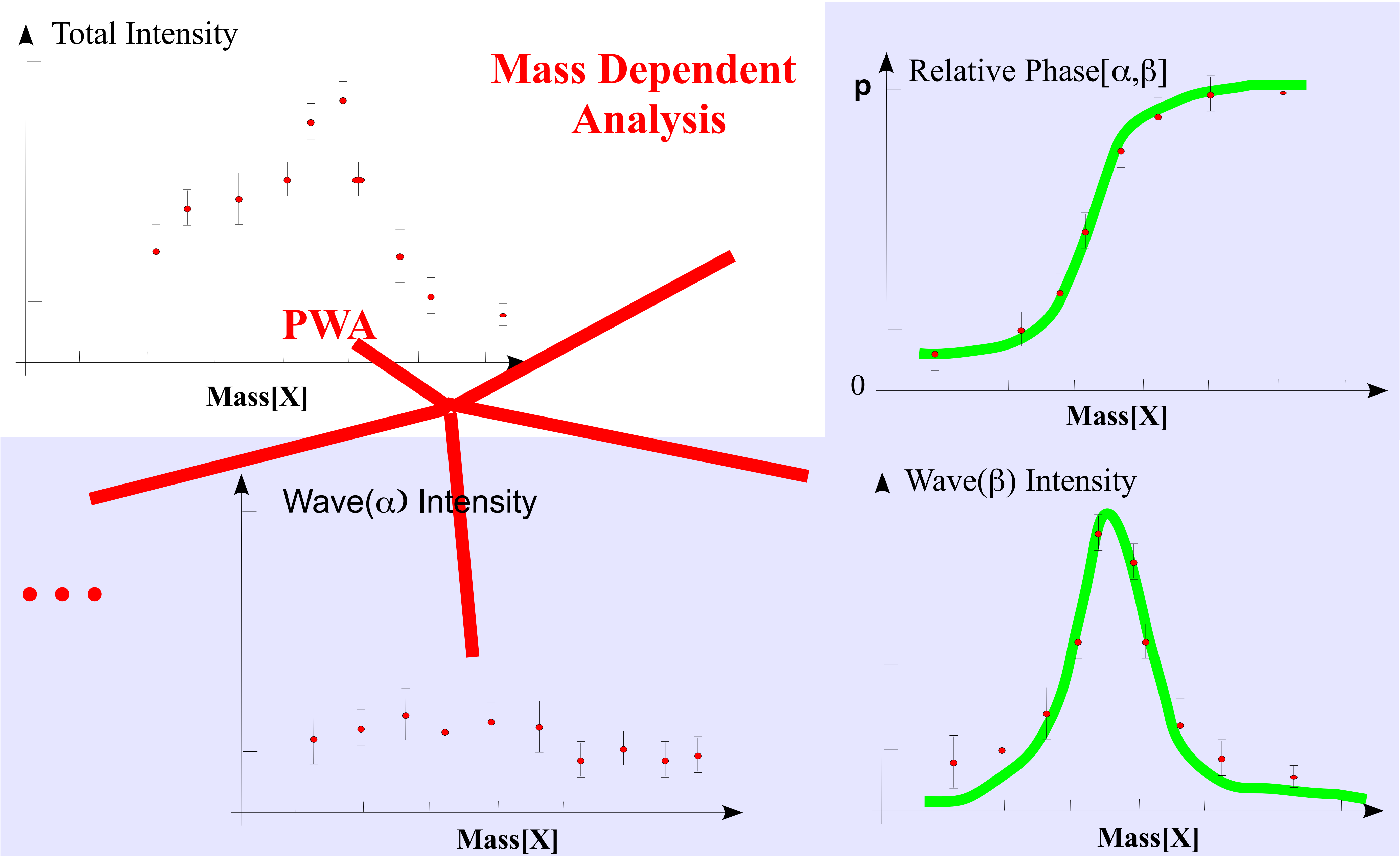
$$\tilde{J}=\sqrt{J(J+1)}$$

Partial Wave Analysis
Step 1: Decompose to Partial Waves

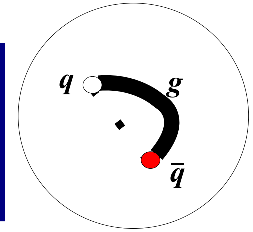


Partial Wave Analysis

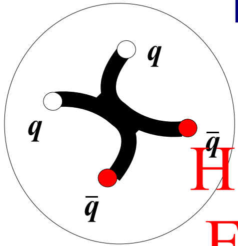
Step 2: Extract Resonance Parameters



Several Exotic Candidates Exist

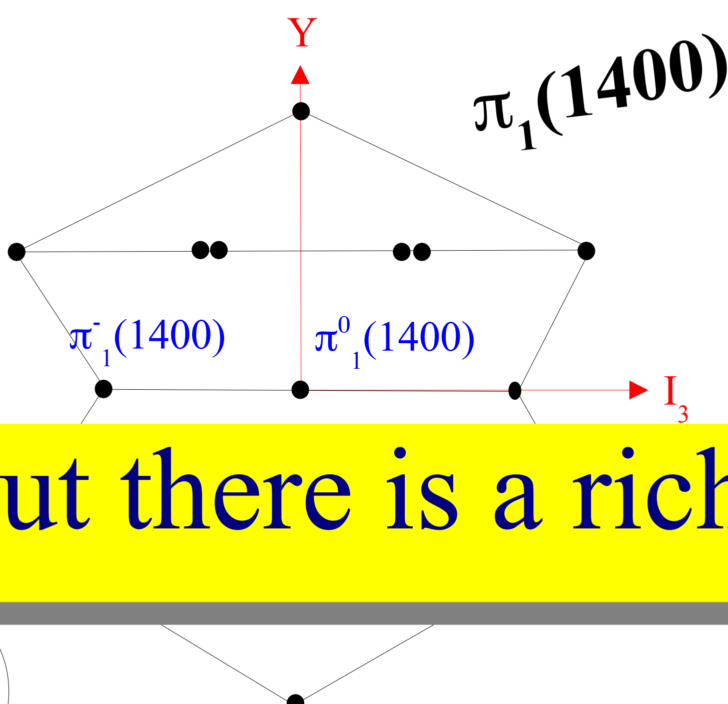


$J^{PC} = 1^{-+}$

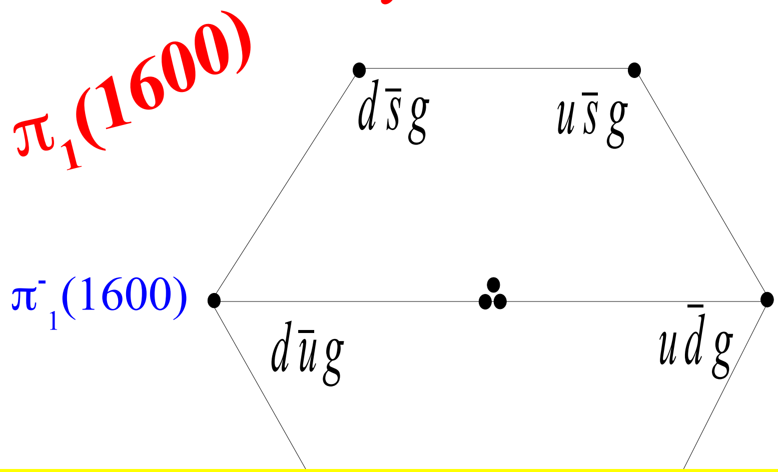


Have we observed an Exotic Multi-Quark?

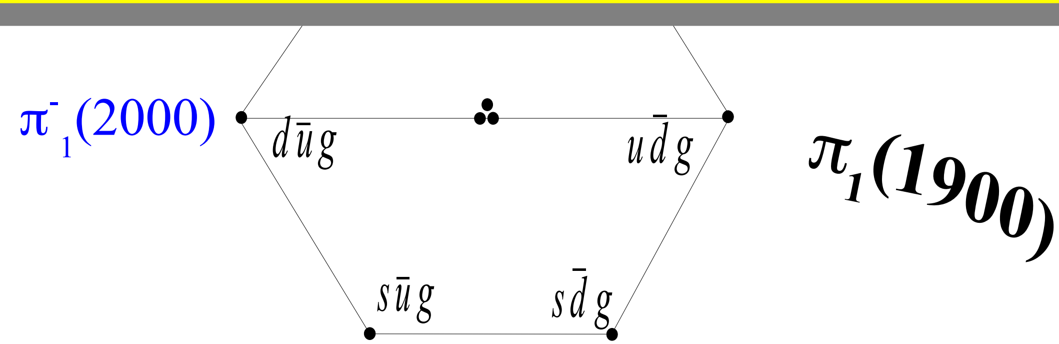
Have we observed a Gluonic Hybrid?



Multiplet 17

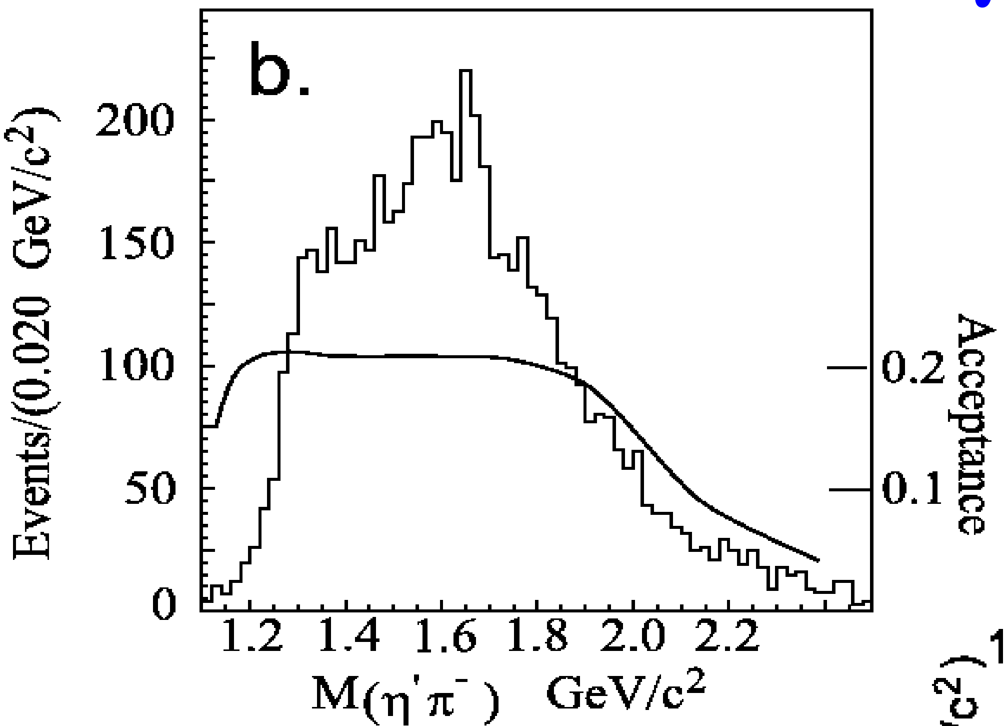


But there is a rich history of controversy



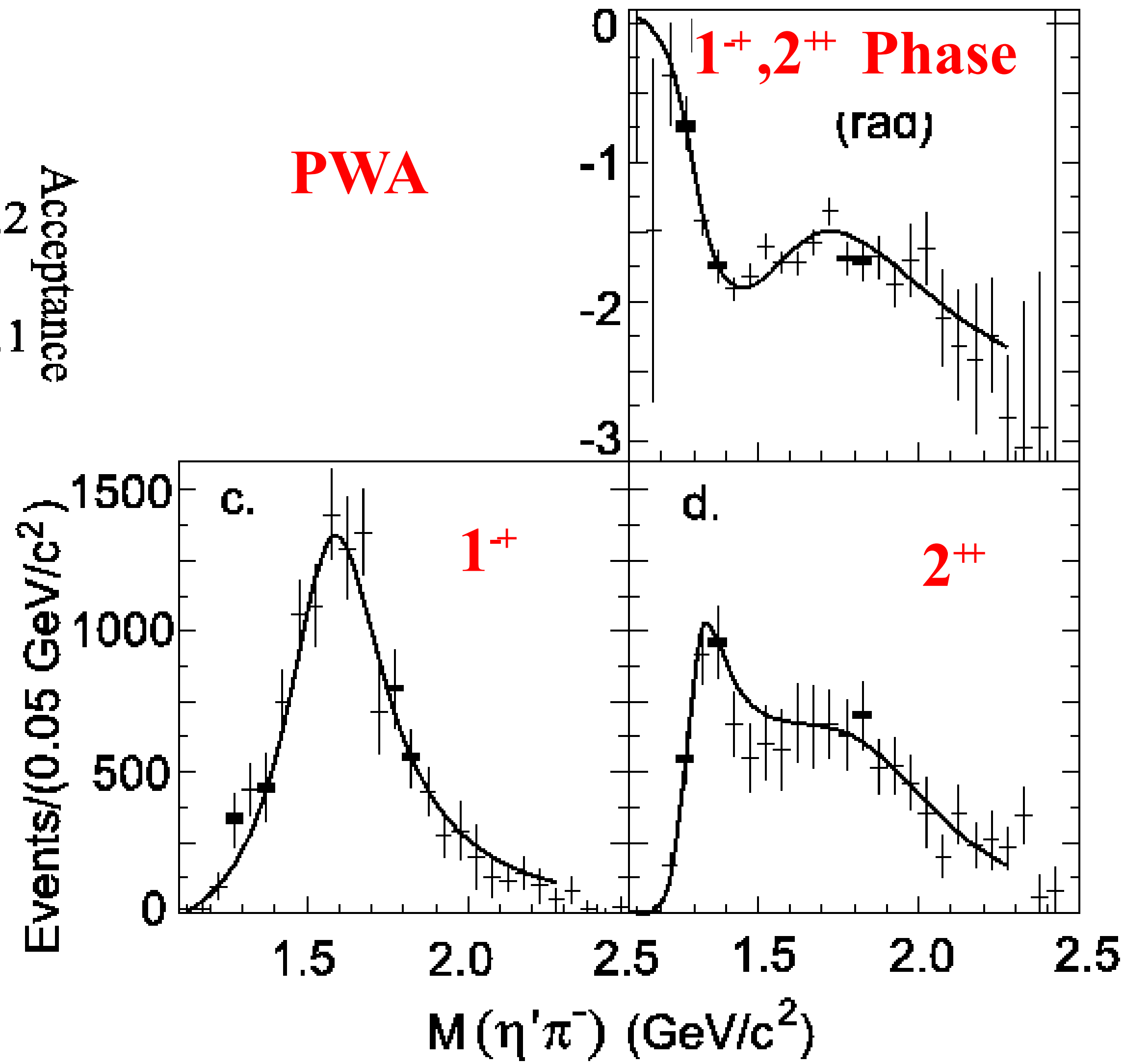
Observation of Exotic $\pi_1(1600)$

invariant mass



$\pi_1(1600) \rightarrow \eta'\pi$

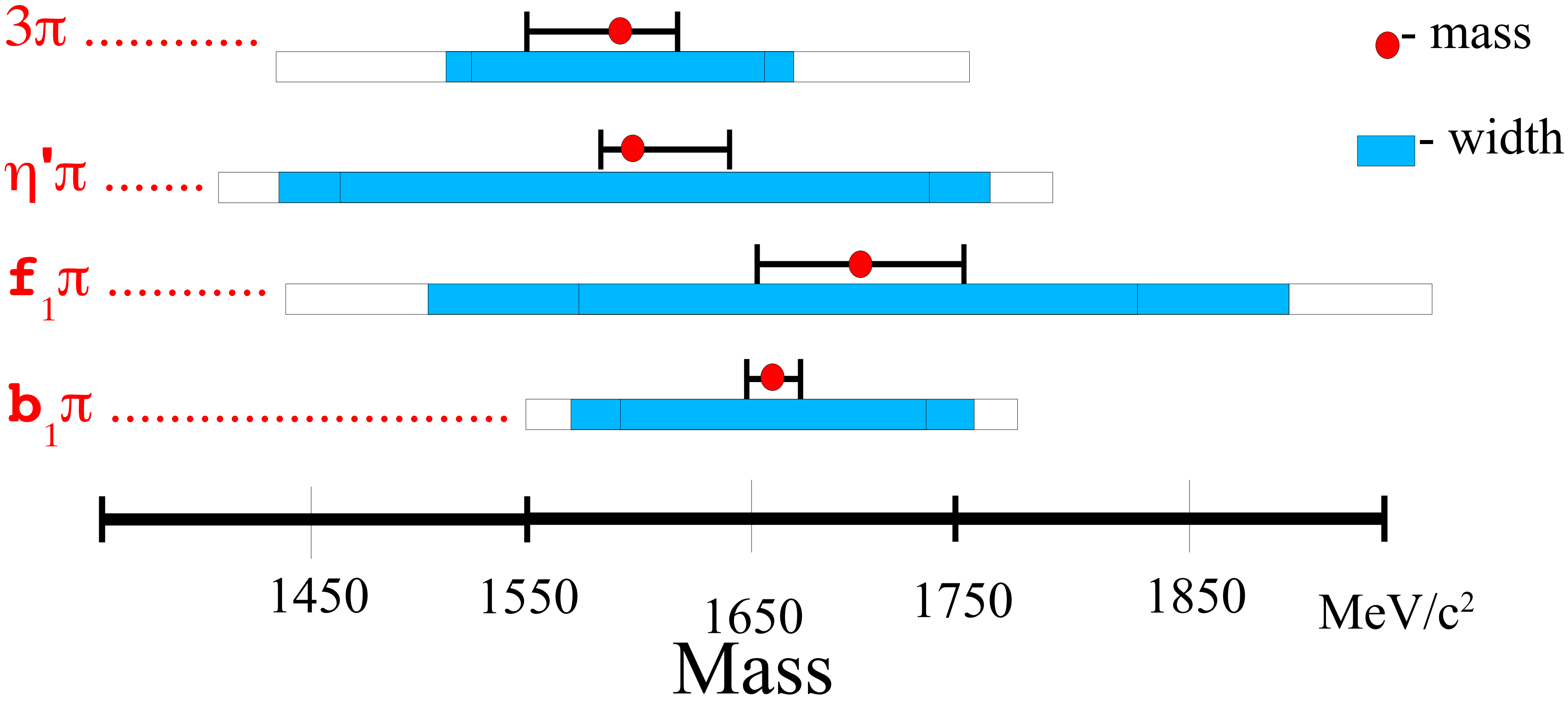
PWA



BNL-E852

$$\pi^- p \rightarrow p\, \eta'\, \pi^-$$

$\pi_1(1600)$ Consistency



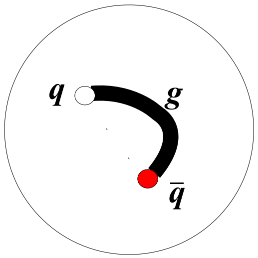
Not Outrageous, but not great agreement

$$\pi^- p \rightarrow p X^-$$

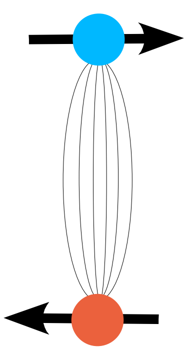
Results from all 4 channels suggest Pomeron production

Photoproduction of Gluonic Excitations

- **It has been pointed out[1,2,3] that in the case of photoproduction exotic hybrids should be produced copiously.**

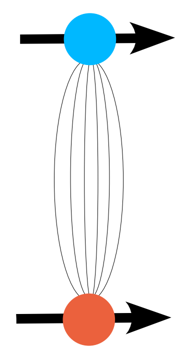


pseudoscalar probe



$${}_{quarks}J^{PC} \otimes {}_{flux\ tubes}J^{PC} = 1^{--},\ 1^{++}$$

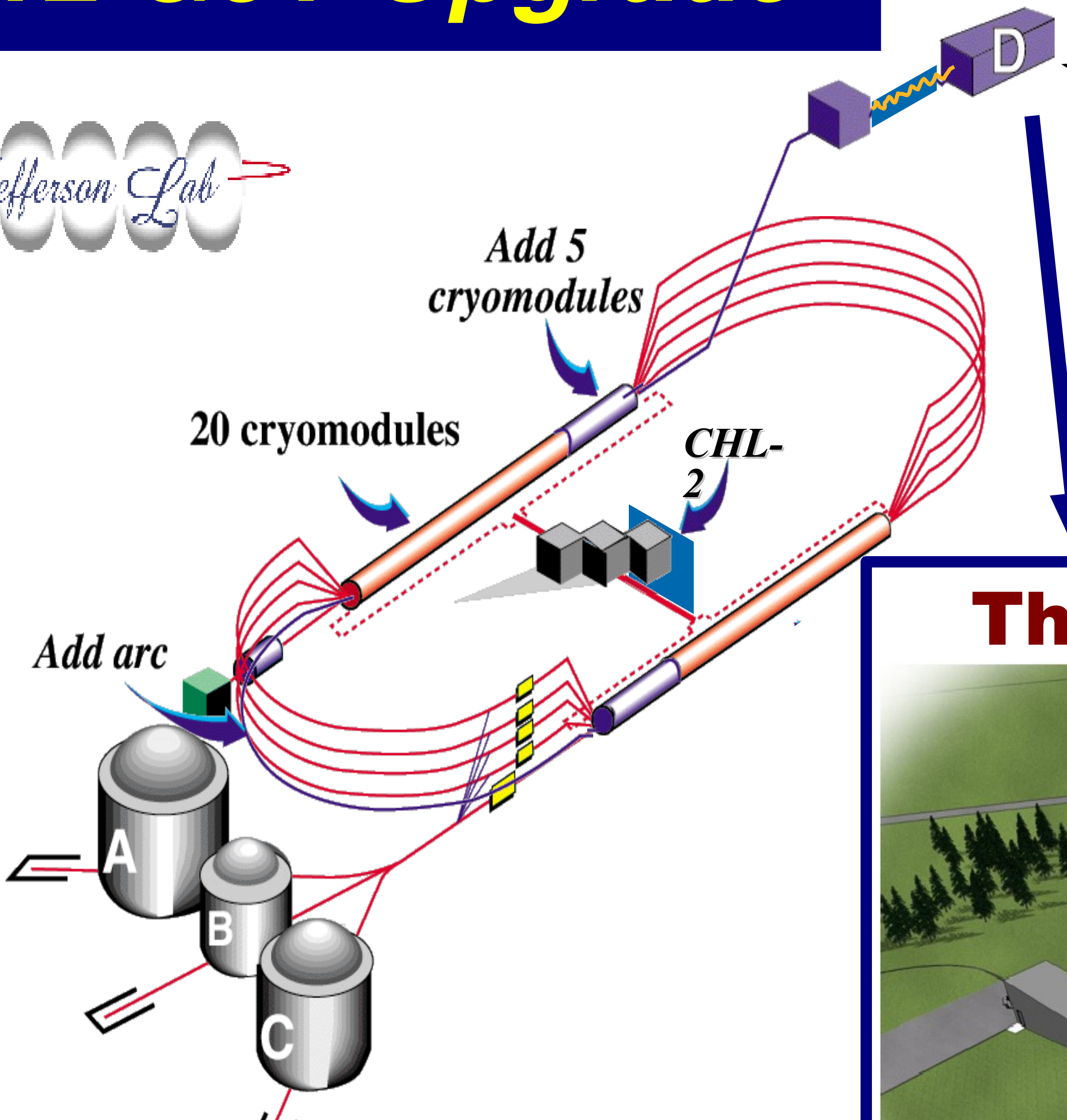
vector probe



$${}_{quarks}J^{PC} \otimes {}_{flux\ tubes}J^{PC} = 0^{-+},\ \boxed{1^{-+}}\ 2^{-+},\ \boxed{0^{+-},}\ 1^{+-},\ \boxed{2^{+-}}$$

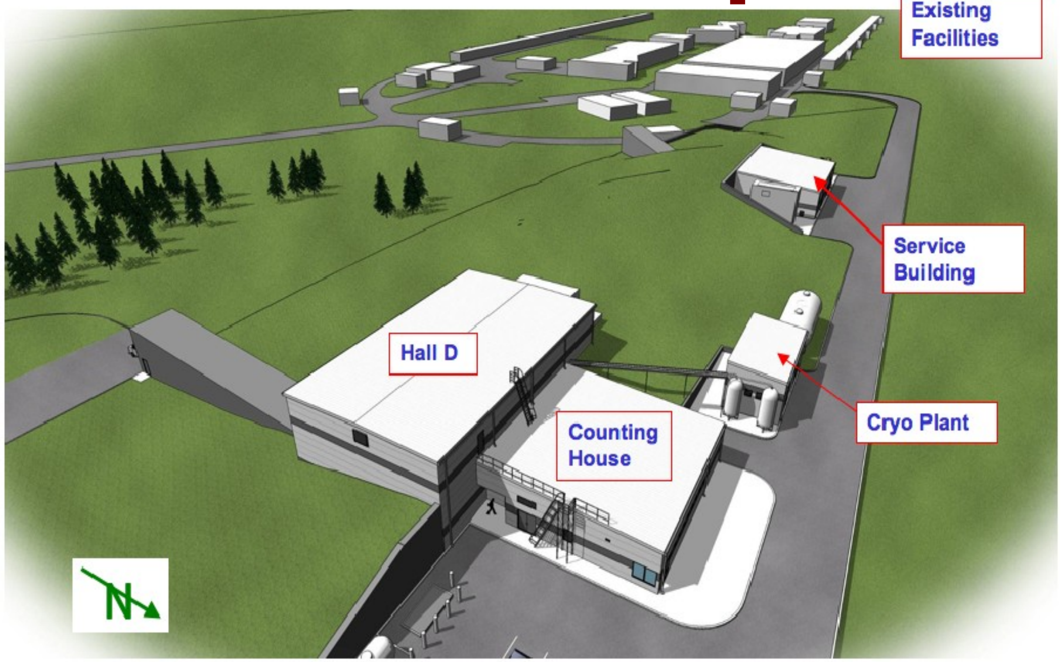
[1]Close *et al*. Phys. Rev. D52:1706 (1995)
[2]Afanasev *et al*. Phys. Rev. D57:6771 (1998)
[3]Szczepaniak *et al*. Phys. Lett. B516:72 (2001)

Jefferson Lab 12 GeV Upgrade



APRIL 2014 Beam Commissioning

The Hall D Complex



GlueX Detector

GlueX Experiment

Goal: map the spectrum of exotic hybrid mesons

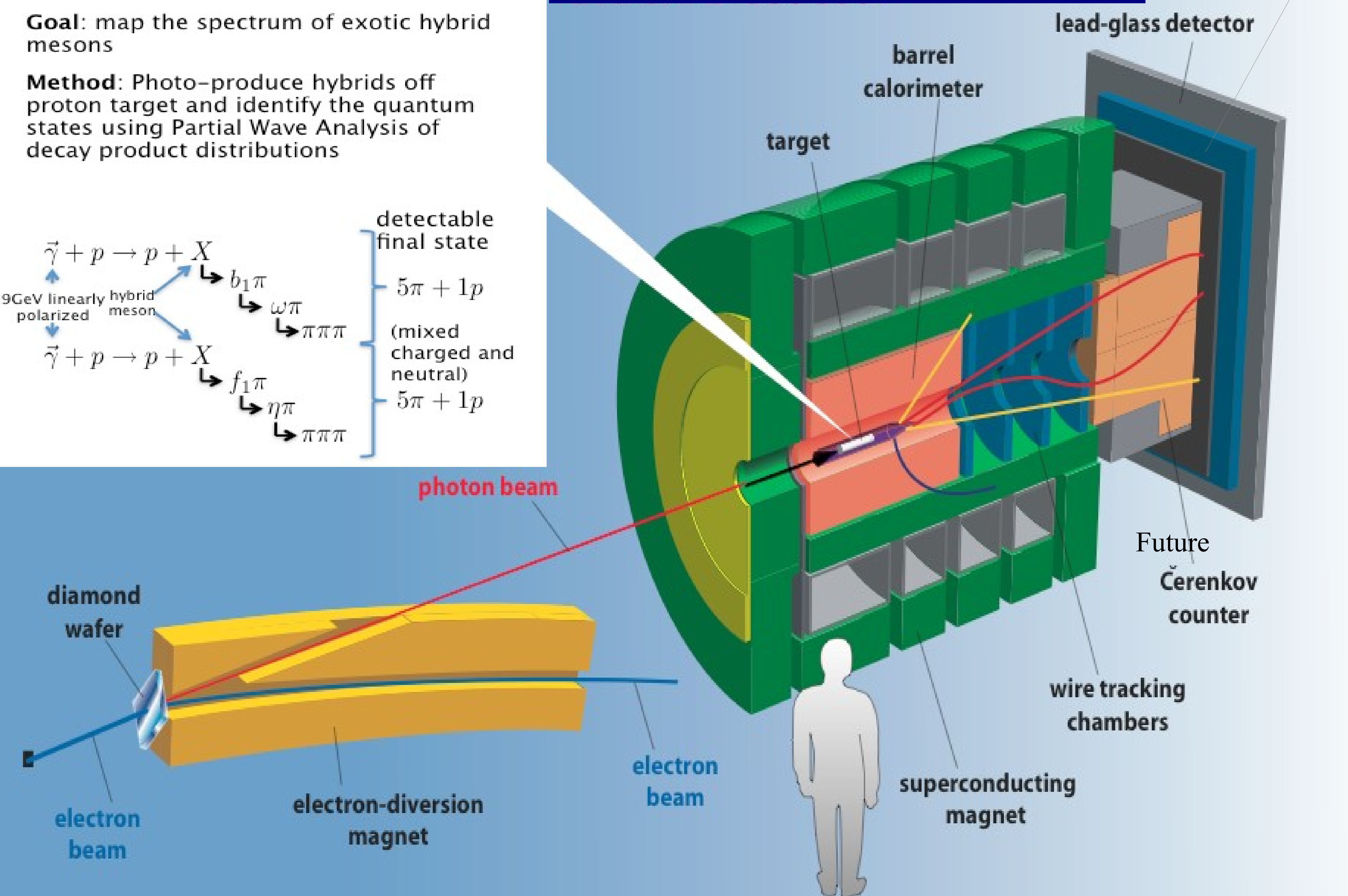
Method: Photo-produce hybrids off proton target and identify the quantum states using Partial Wave Analysis of decay product distributions

$\vec{\gamma} + p \rightarrow p + X$
↳ $b_1\pi$
↳ $\omega\pi$
↳ $\pi\pi\pi$

$\vec{\gamma} + p \rightarrow p + X$
↳ $f_1\pi$
↳ $\eta\pi$
↳ $\pi\pi\pi$

9GeV linearly polarized — hybrid meson

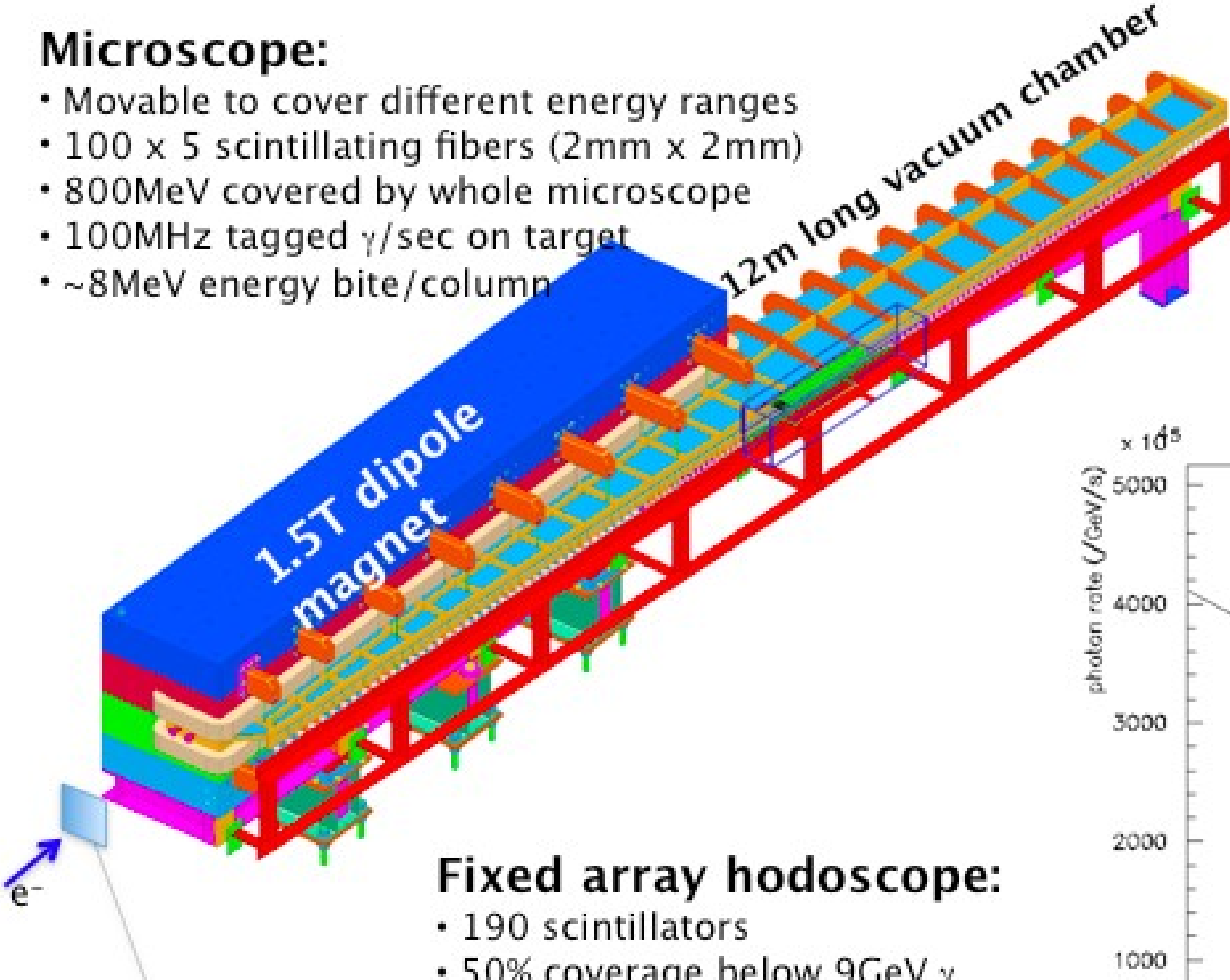
detectable final state: $5\pi + 1p$ (mixed charged and neutral) $5\pi + 1p$



DETECTOR DESIGNED FOR PWA

Linearly Polarized Photon Beam

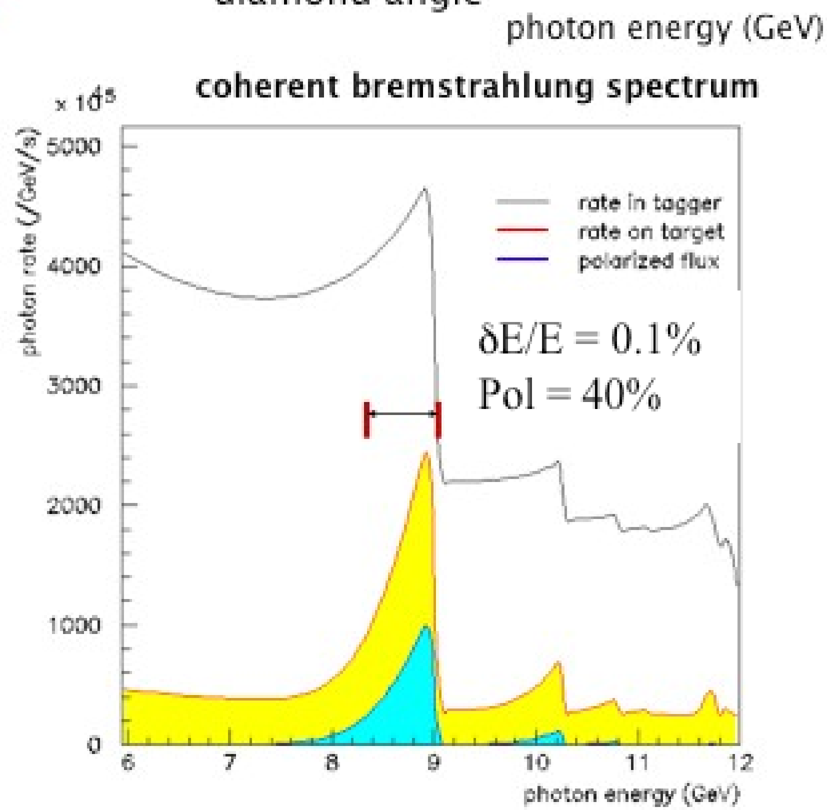
Microscope:
- Movable to cover different energy ranges
- 100 x 5 scintillating fibers (2mm x 2mm)
- 800MeV covered by whole microscope
- 100MHz tagged γ/sec on target
- ~8MeV energy bite/column



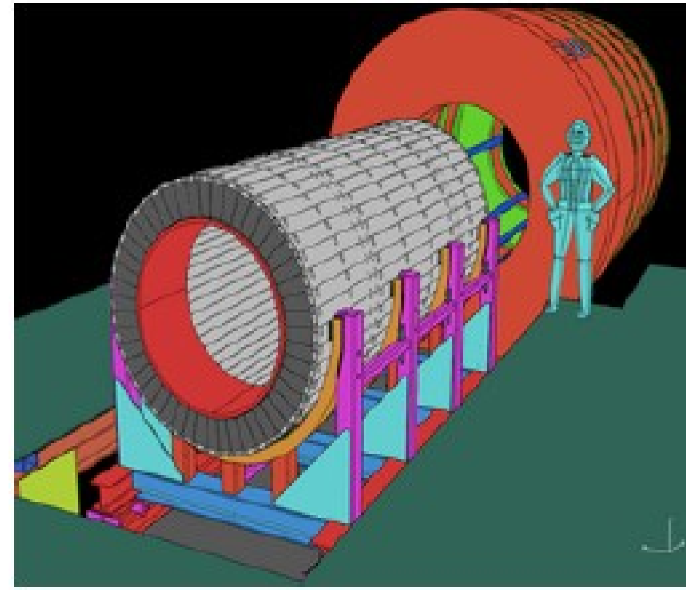
20μm diamond radiator

Fixed array hodoscope:
- 190 scintillators
- 50% coverage below 9GeV γ
- 100% coverage above 9GeV γ
- Tags 3.0-11.7 GeV γ
- ~30MeV energy bite/counter
- 3.5 - 17 MHz/counter

Photon Polarization:
- 20 μm diamond radiator
- Coherent peak is linearly polarized
- ~40% polarization with peak @ 9GeV
- Peak location tunable with diamond angle

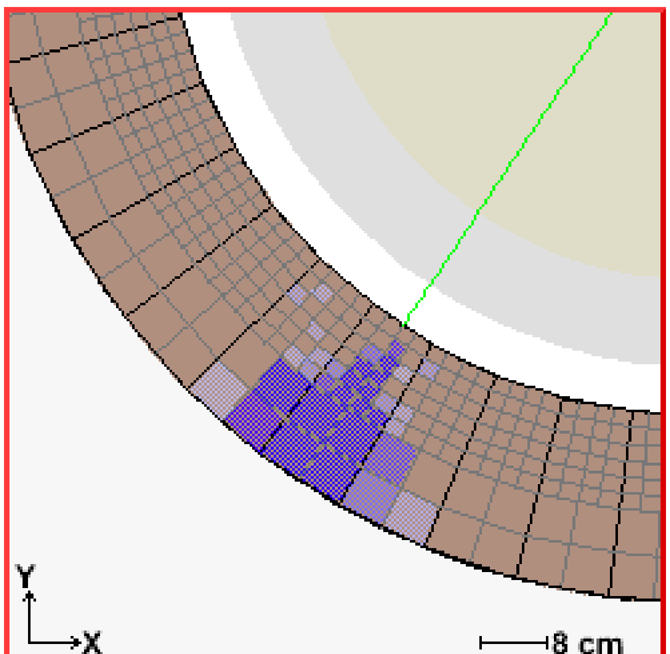


Barrel Calorimeter

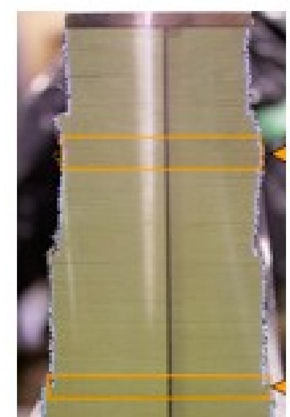


191 layer Pb-scintillating fiber sandwich (15.5X_0)
12.5% sampling fraction
1152 + 192 = 1344 readout sections/end
$\sigma_E/E = (5.54/\sqrt{E} \quad 1.6)$ %
$\sigma_z = 5mm/\sqrt{E}$
$\sigma_t = 74ps/\sqrt{E} \quad 33ps$
angular coverage $11^\circ < \theta < 120^\circ$

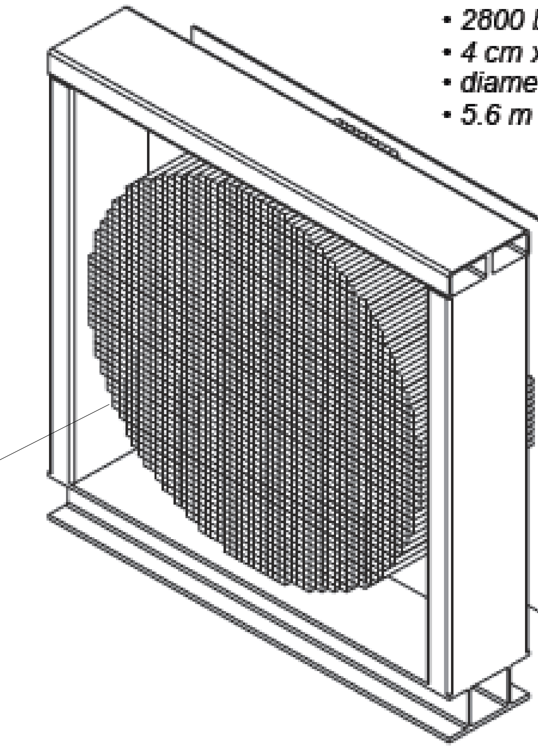
BCAL has 2-ended readout allowing one to reconstruct in 3-D



BCAL module being constructed



Forward Calorimeter



- *2800 blocks*
- *4 cm x 4 cm x 45 cm*
- *diameter: 240 cm*
- *5.6 m from target*

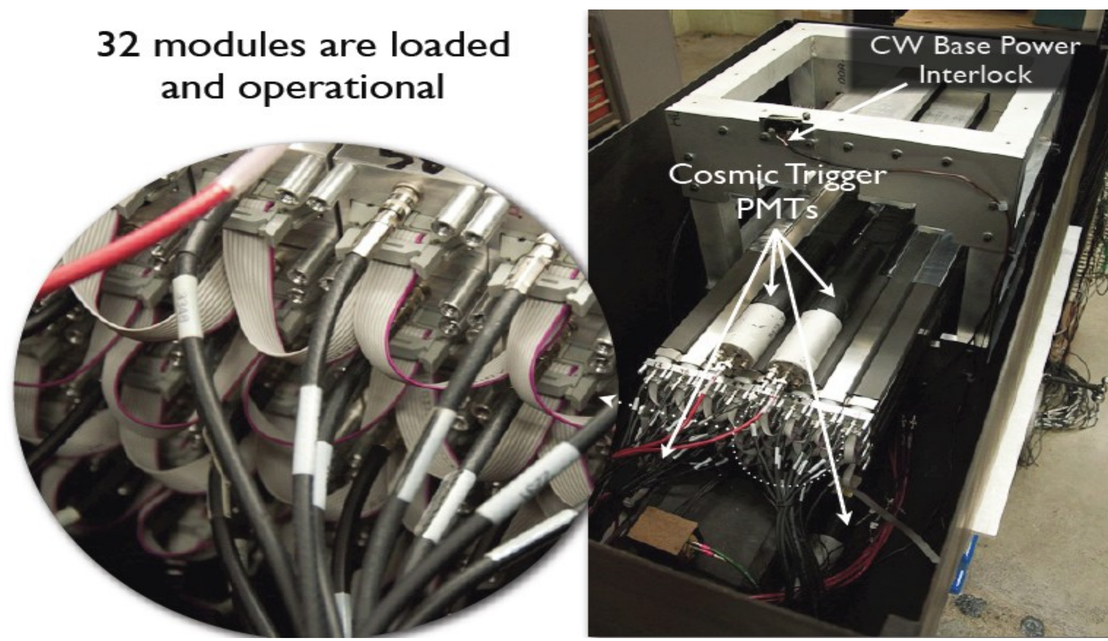
Lead Glass Calorimeter:

- 2800 F8-00 and F108 (center) Pb-glass blocks
- 4cm x 4cm x 45cm
- $\sigma_E/E = (5.7/\sqrt{E} \qquad 2.0)\ \%$
- $\sigma_{xy} = 6.4\text{mm}/\sqrt{E}$
- angular coverage $2^\circ < \theta < 11^\circ$

An FCAL module

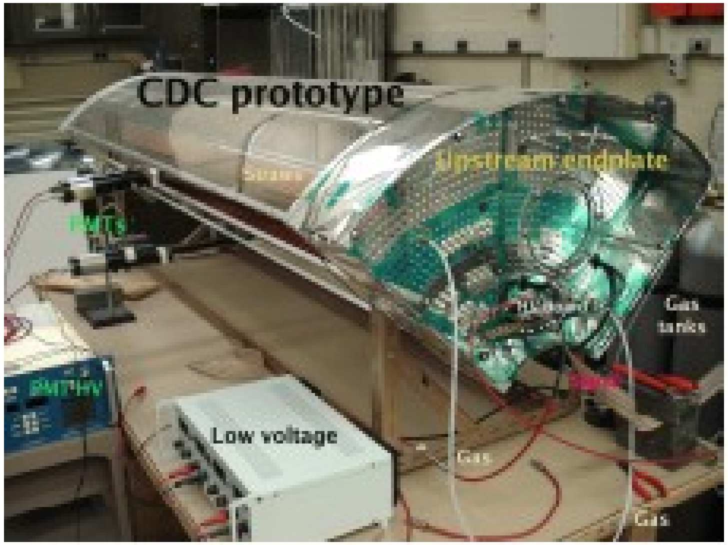
prototype array

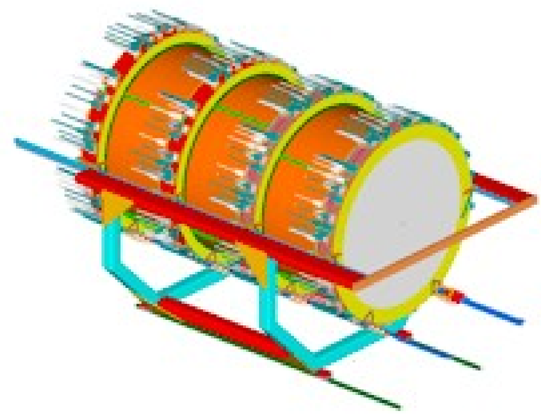
32 modules are loaded
and operational



Charged Particle Tracking

central & forward drift chambers





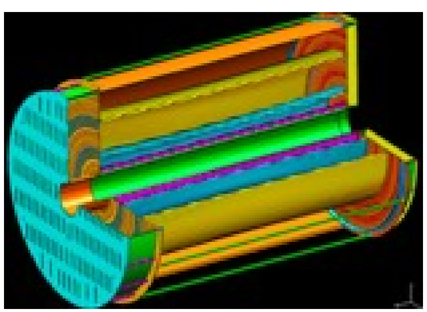
Forward Drift Chamber:

- 4 packages, 6 planes/package, 96 wires/plane (2304 sense wires)
- cathode strip readout (48 planes x 216 strips/plane = 10,368 strips)
- σ_r = ~200μm perpendicular to wire (drift time)
- σ_s = ~200μm along wire (cathode strips)
- angular coverage $1^\circ<\theta<30^\circ$

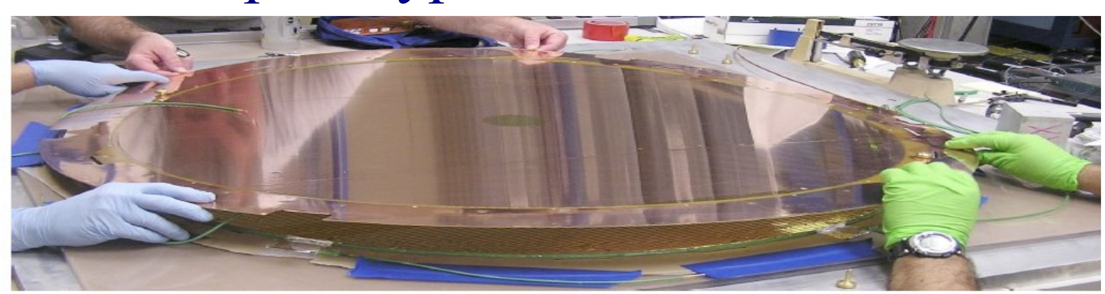
Central Drift Chamber:

- 3522 straw tubes (1.6cm diameter)
- 12 axial layers, 16 stereo layers (6°)
- dE/dx for $p < 450$ MeV/c
- σ_r = 150μm
- angular coverage $6^\circ<\theta<155^\circ$

σ_p/p : 1.5 – 3.0%



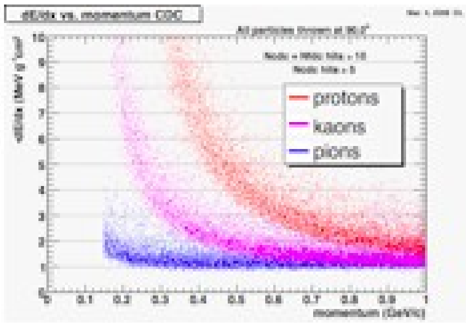
prototype FDC chamber



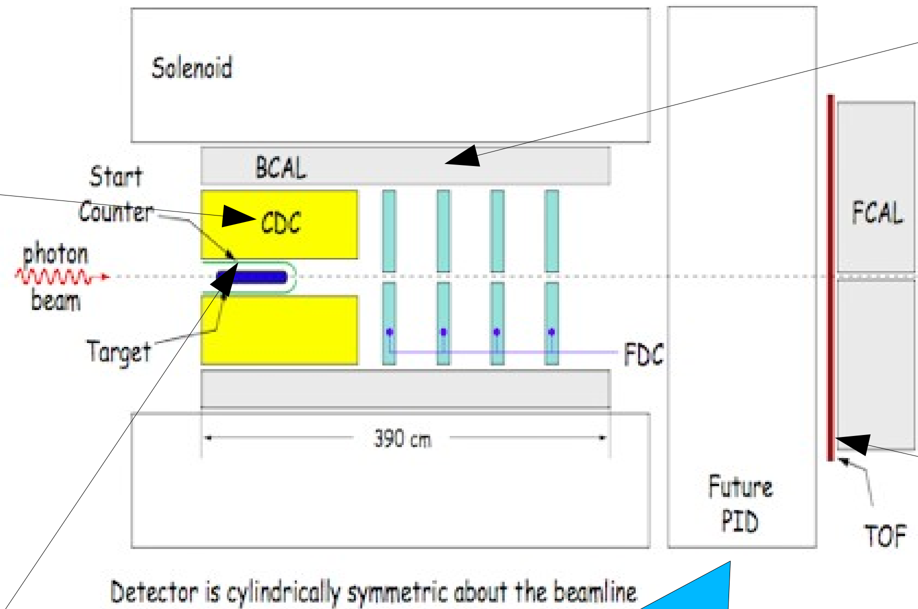
Particle Identification

Time-of-flight & dE/dx

CDC dE/dx



- πp separation <450MeV/c
- πK separation <275MeV/c

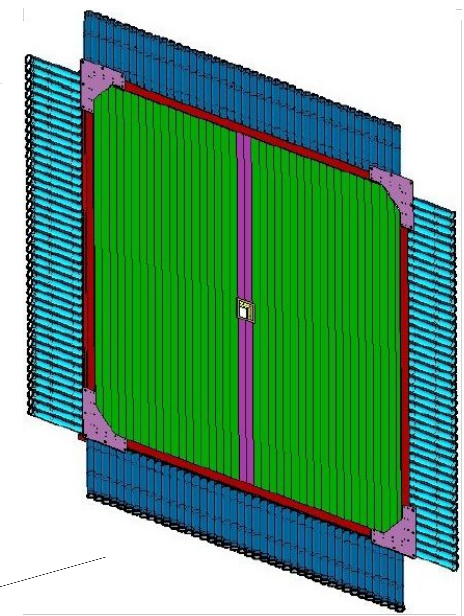


BCAL$_{TOF}$

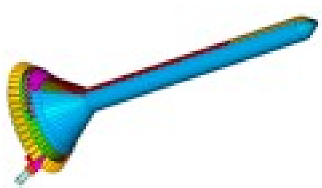
- σ_t = 74ps/$\sqrt{E}$ + 33ps
- πp separation <450MeV/c
- πK separation <275MeV/c

Opportunity for new collaborators

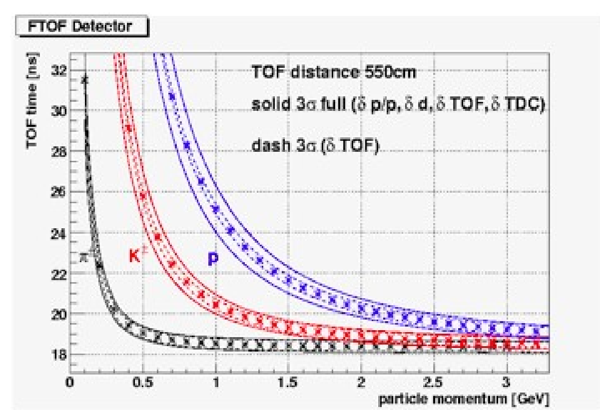
Time-of-Flight



Start Counter



- 40 scintillators
- 300 ps (w/tracking)
- Used for start-up



- 168 modules
- σ_{TOF} < 80/$\sqrt{2}$ ps
- πK separation < 2GeV/c

GlueX Acceptance

GlueX vs BNL-E852
Acceptance
$\pi^0\eta$ final state

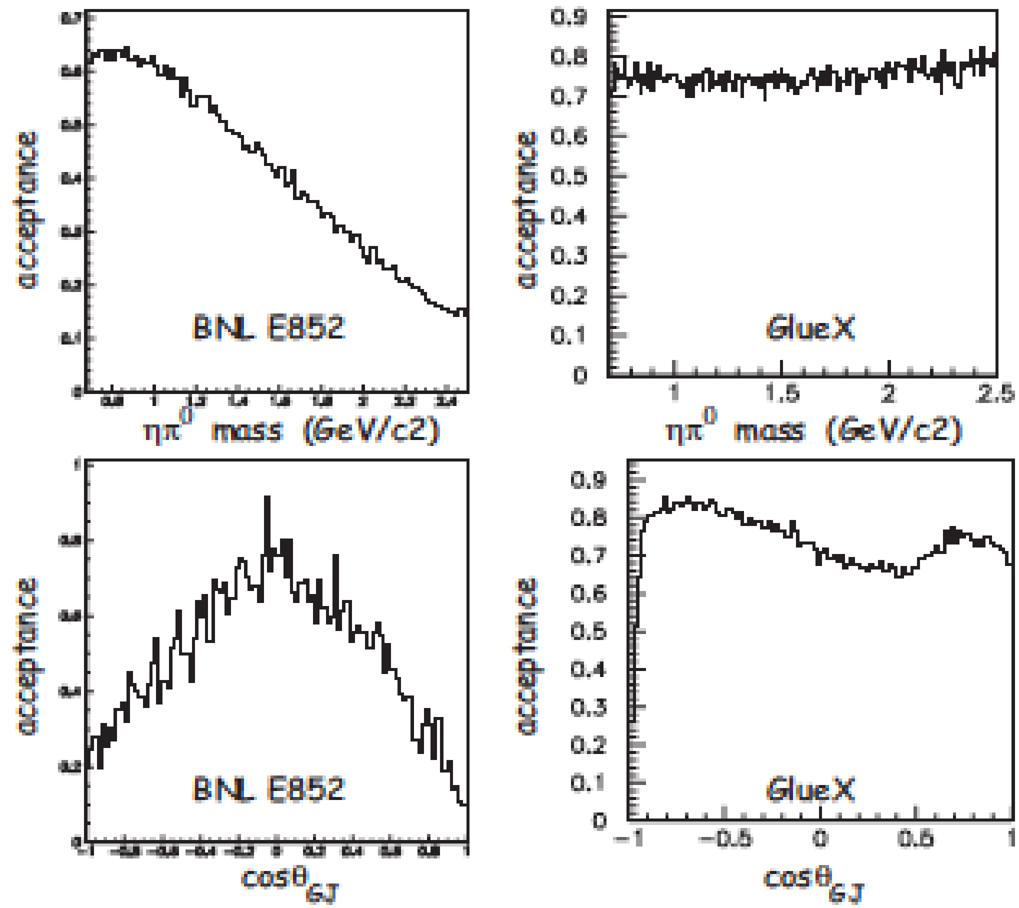
GlueX

High, and reasonably uniform
Acceptance up to 2.5 GeV/c2.

Sensitive to charged particles
And photons.

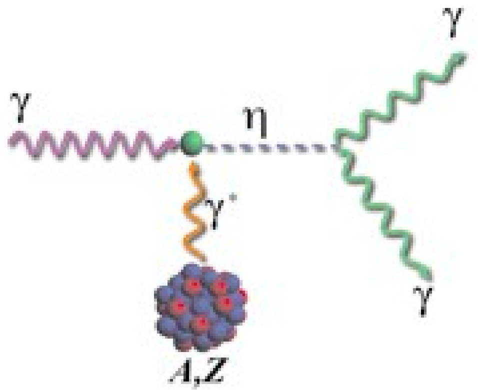
Some particle ID in the initial
phases, plans to upgrade this.

Able to fully reconstruct the 4-12
Particle final states.

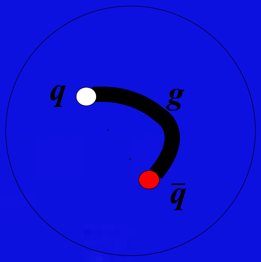


Additional Physics with GlueX

- Cascade Spectroscopy
- Search for Missing Strangeonia
- PrimEx at 12 GeV
    - Measurement of $\Gamma(\eta \rightarrow \gamma\gamma)$ via Primakoff Effect



Summary & Outlook



- The Quark Model of hadrons works surprisingly well, yet QCD allows for a much richer spectrum of hadronic matter

- The excitation of the gluonic fields leads to an entirely new spectrum of mesons
  - Several promising exotic candidates exist
  - Exotic hybrids should be copiously produced via photoproduction
    - ➔ Virtually unexplored production

- The JLAB GlueX program plans to firmly identify and map out the exotic spectrum
  - Beam on Target in April 2014!
  - New Collaborators Welcome