Search for Gluonic Hybrid Mesons via Photoproduction at Jefferson Lab

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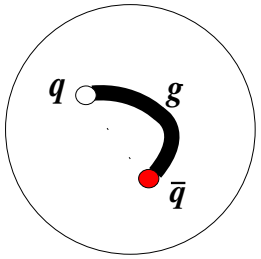
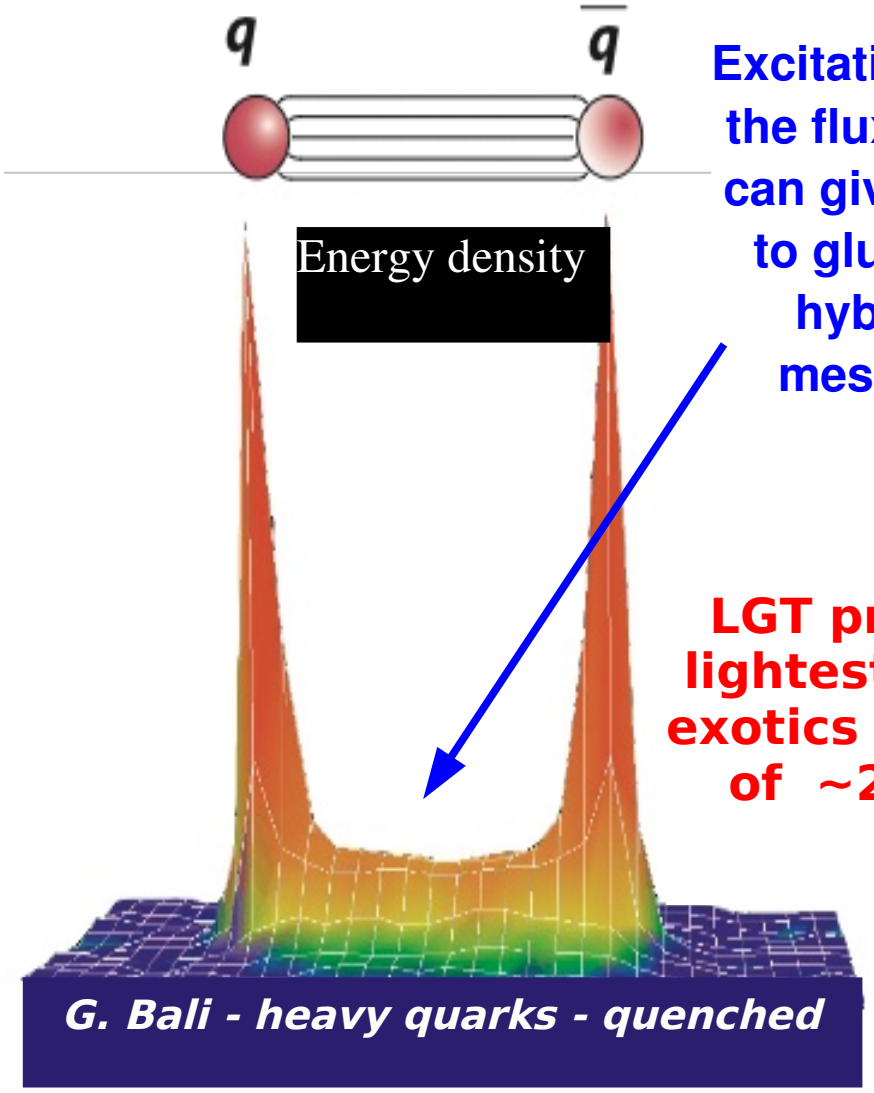
Overview

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

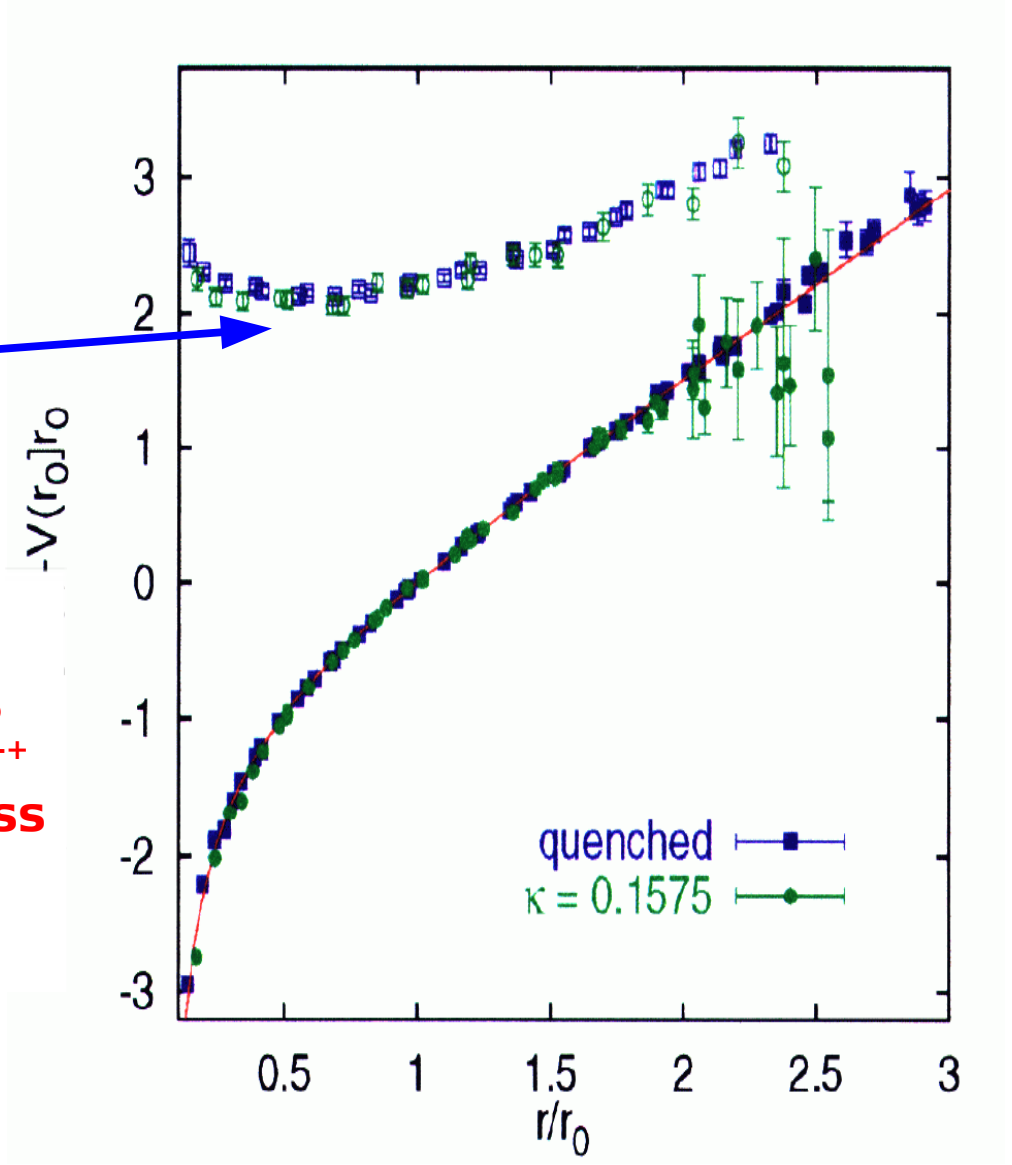


Gluonic Excitations

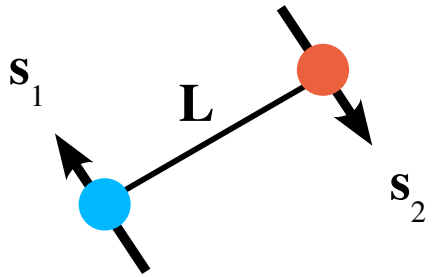


Excitations of the flux tube can give rise to gluonic hybrid mesons

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}

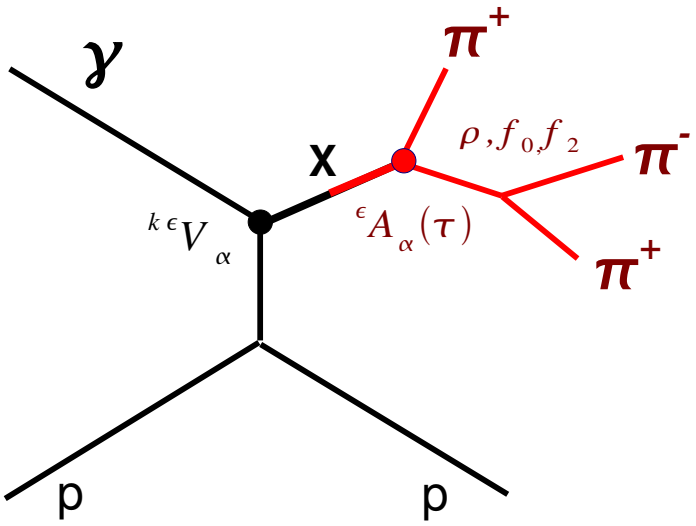
Allowed States:

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

Forbidden States(Exotics):

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

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

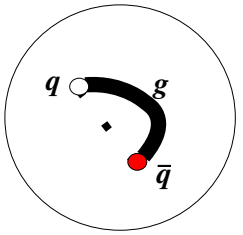
Clebsch-Gordan Coefficients

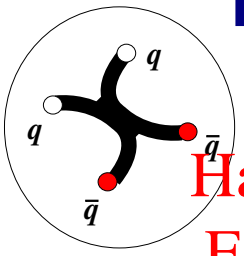
Mass Dependent Factor

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

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

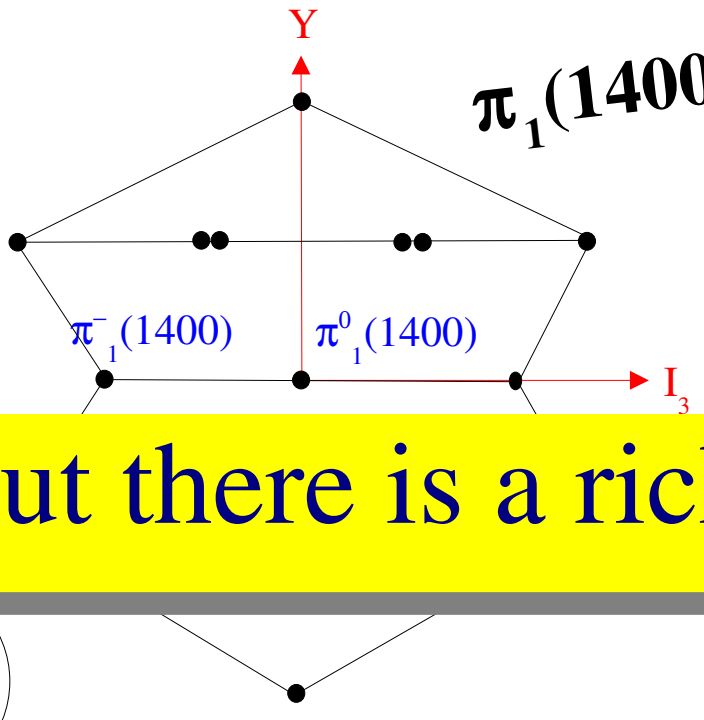
Several Exotic Candidates Exist

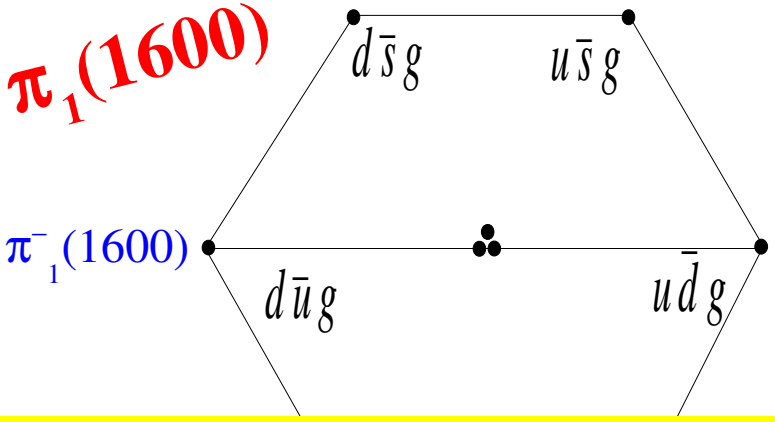




Have we observed an Exotic Multi-Quark?

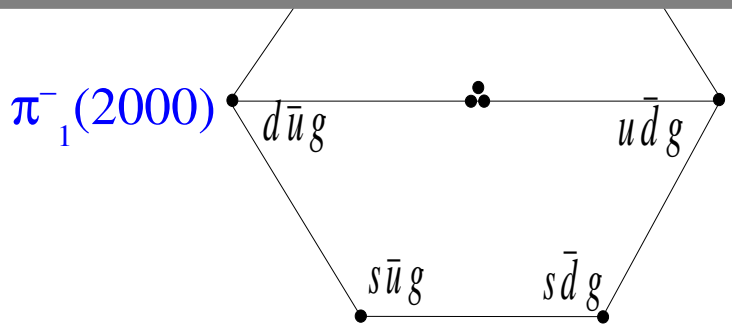
Have we observed a Gluonic Hybrid?





But there is a rich history of controversy

Multiplet 17



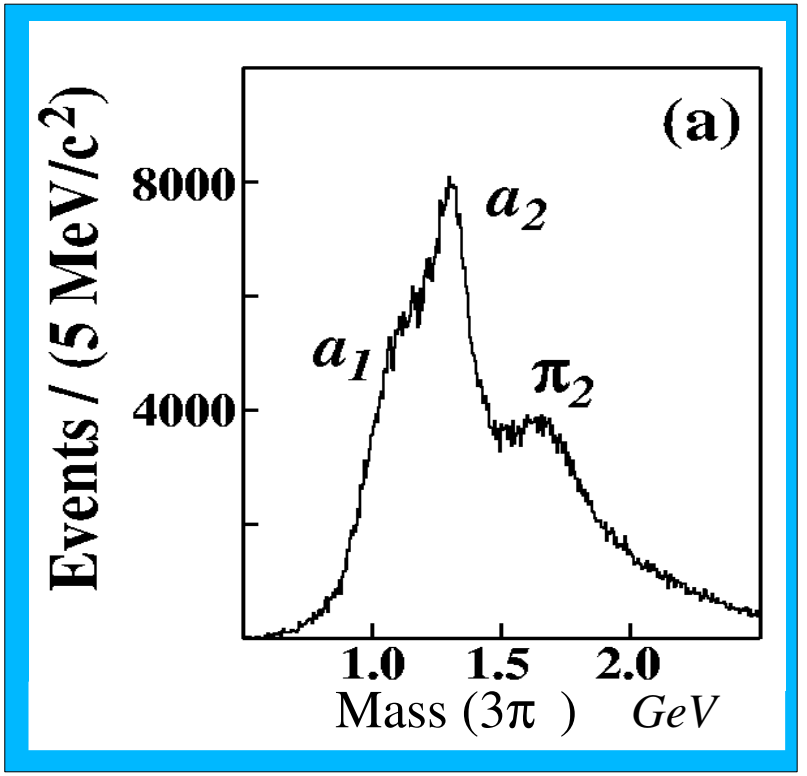
π1(1900)

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

$\pi_1(1600)$

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

- **BNL-E852**
  - Observe structure in the cross section & rapid phase motion
    - $\rho\pi$, $\eta'\pi$, $b_1\pi$, $f_1\pi$, $\omega\rho$
  - BNL-E852 Claims of Consistent Exotic Nature in all Decays
- **VES**
  - Observe structure in the cross section & rapid phase motion
    - $\rho\pi$, $\eta'\pi$, $b_1\pi$
  - VES Claims Exotic in $b_1\pi$



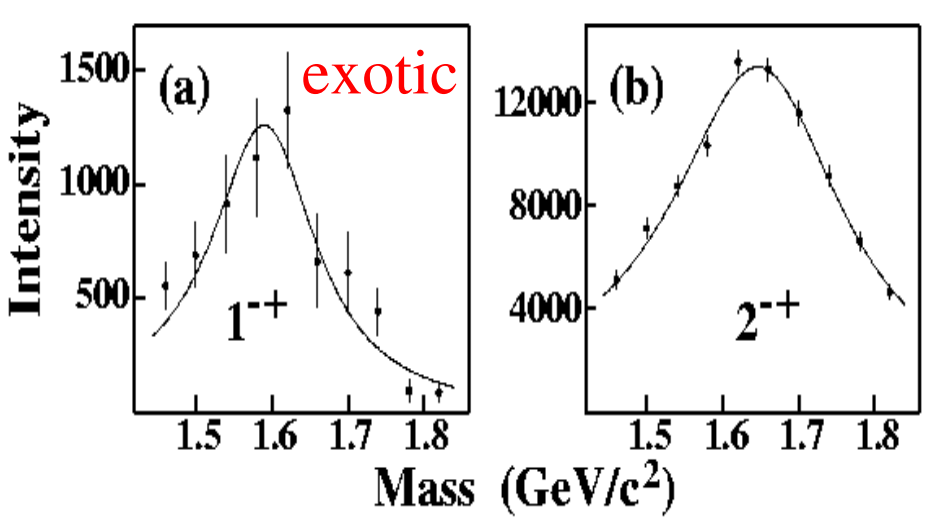
Both groups agree that a $\pi_1(1600)$ exists!

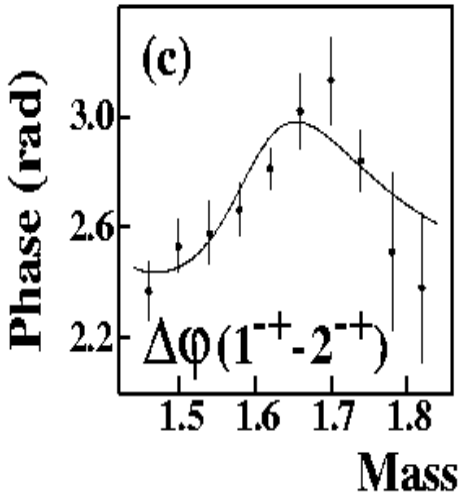
BNL-E852

PWA of $\pi^-\pi^-\pi^+$

Exotic $\pi_1 \rightarrow \pi^-\pi^-\pi^+$

250k events; 21-24 waves



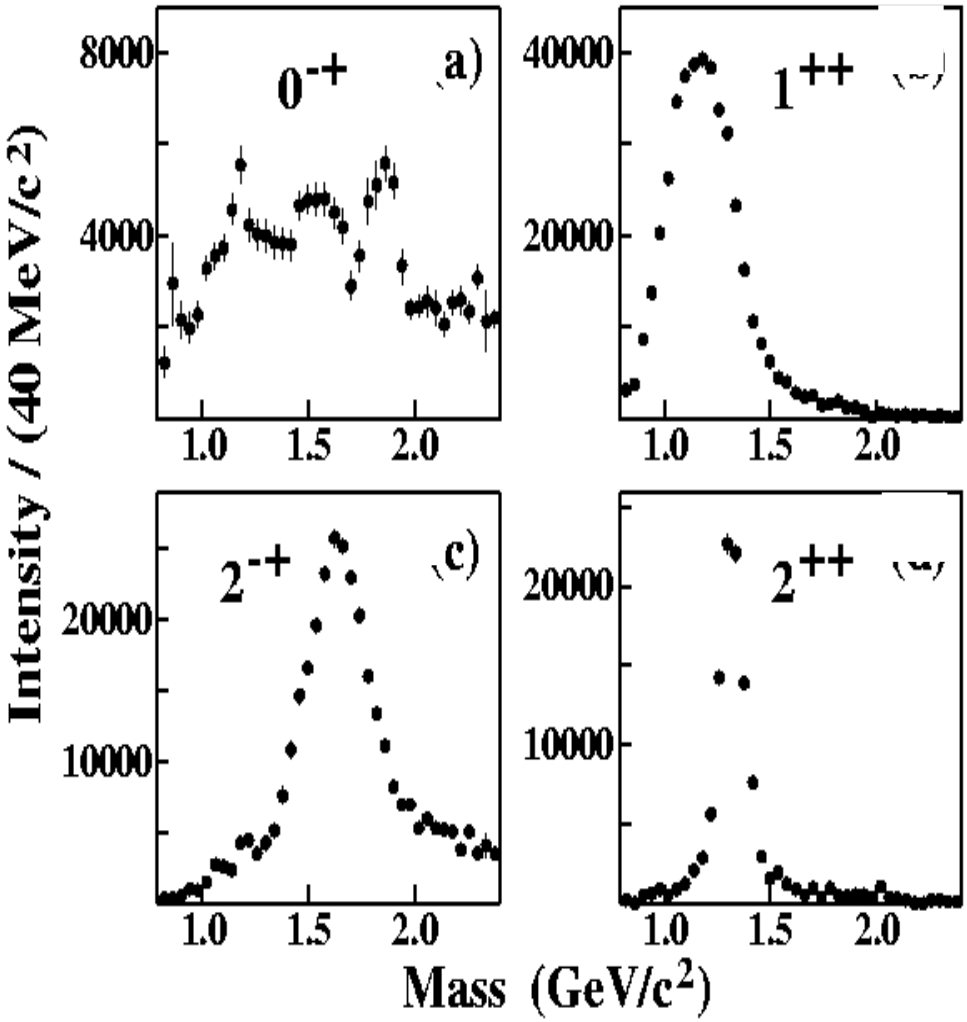


$J^{PC}=1^{-+}$

M=1593(±8)(+29-47)

Γ = **168**(±20)(+150–12)

250k events;
21-24 waves



Phys. Rev. D65 072001, (2002)

BNL-E852

PWA of $\pi^-\pi^-\pi^+$

Exotic $\pi_1 \rightarrow \pi^-\pi^-\pi^+$

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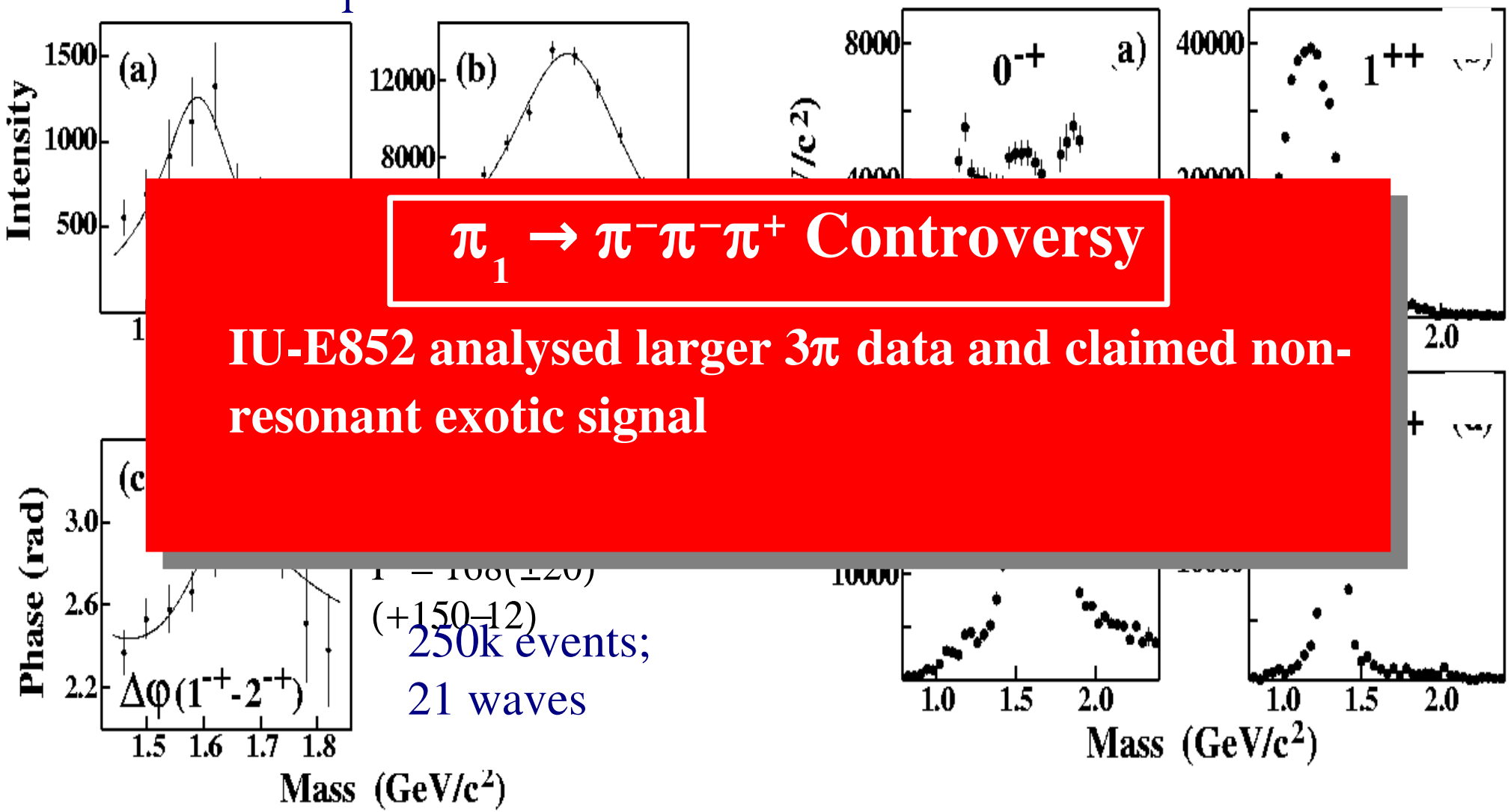


$\pi_1 \rightarrow \pi^-\pi^-\pi^+$ Controversy

IU-E852 analysed larger 3π data and claimed non-resonant exotic signal

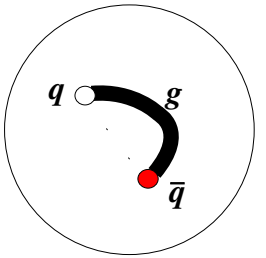
(+150–12)

250k events;
21 waves

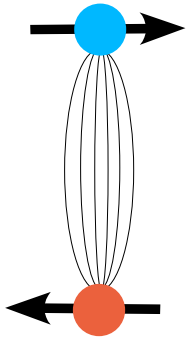
Phys. Rev. D65 072001, (2002)

Photoproduction of Gluonic Excitations

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

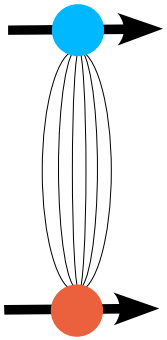


pseudoscalar probe



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

vector probe



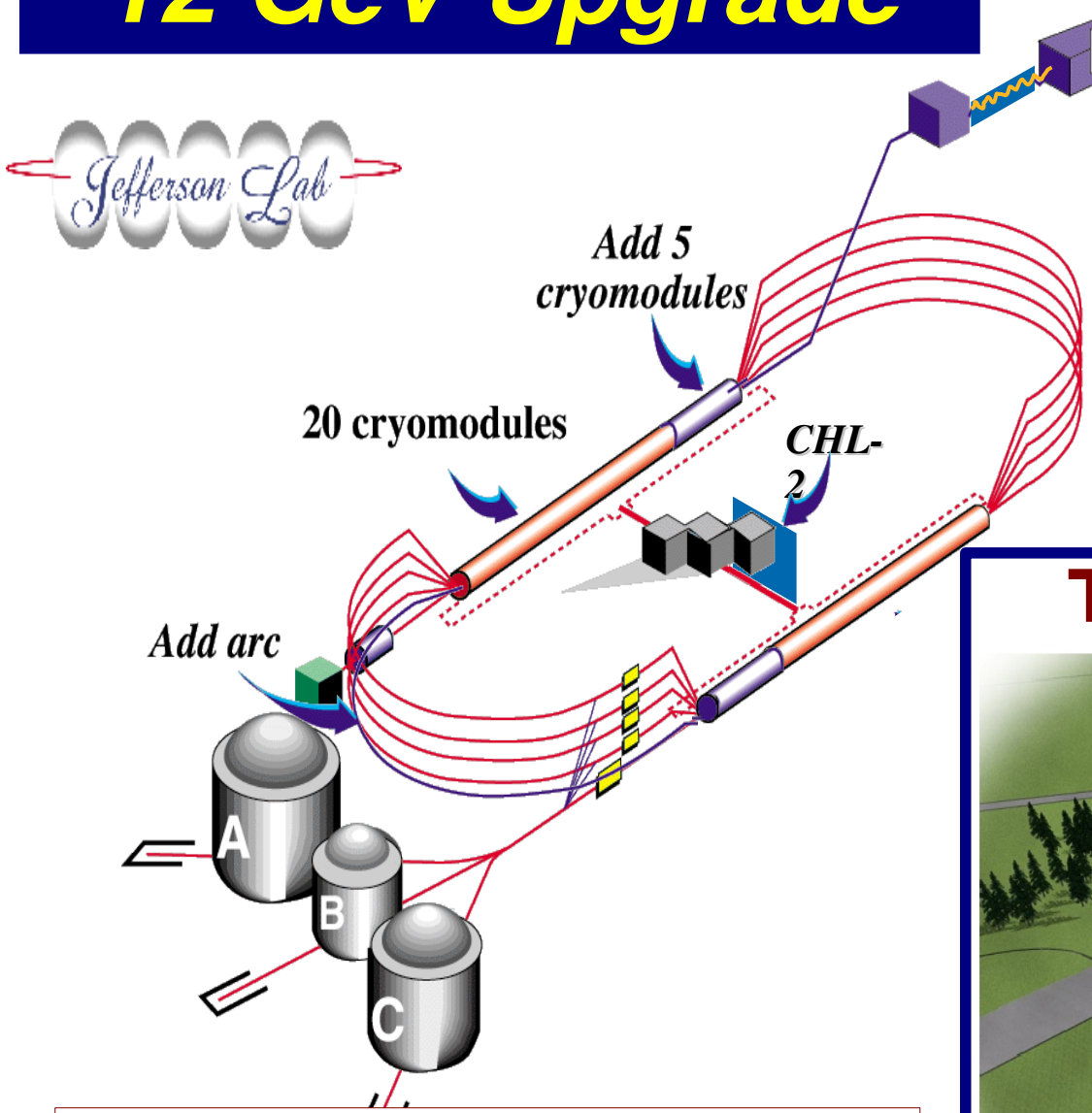
$$_{quarks}J^{PC} \otimes {}_{flux\ tubes}J^{PC} = 0^{-+},\ 1^{-+}\ 2^{-+},\ 0^{+-},\ 1^{+-},\ 2^{+-}$$

[1]Close *et al*. Phys. Rev. D52:1706 (1995)

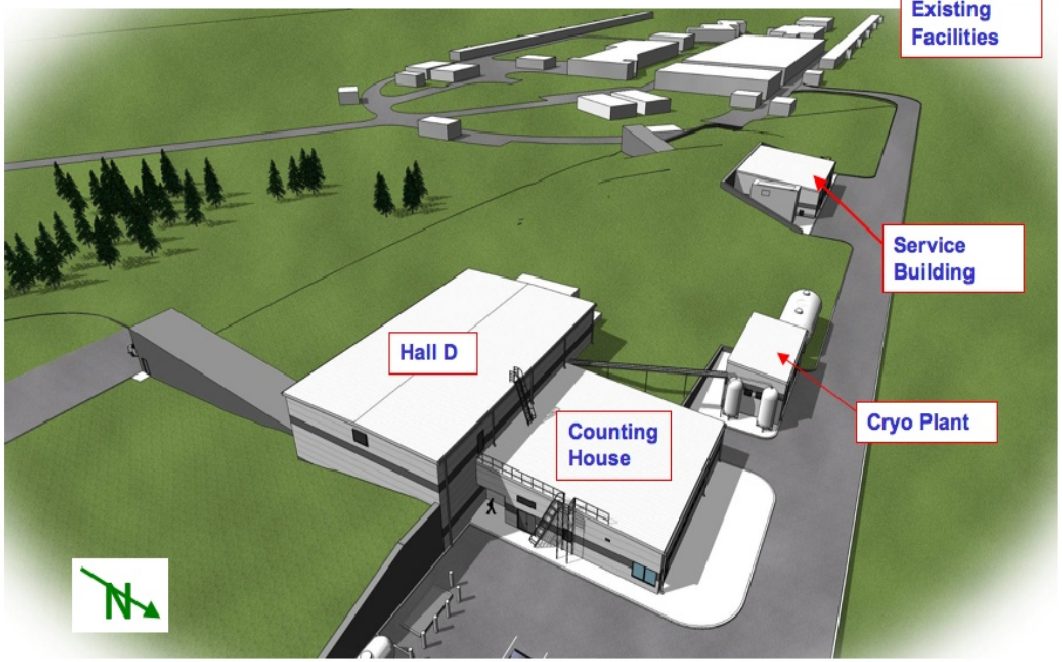
[2]Afanasev *et al*. Phys. Rev. D57:6771 (1998)

[3]Szczepaniak *et al*. Phys. Lett. B516:72 (2001)

Jefferson Lab 12 GeV Upgrade



The Hall D Complex

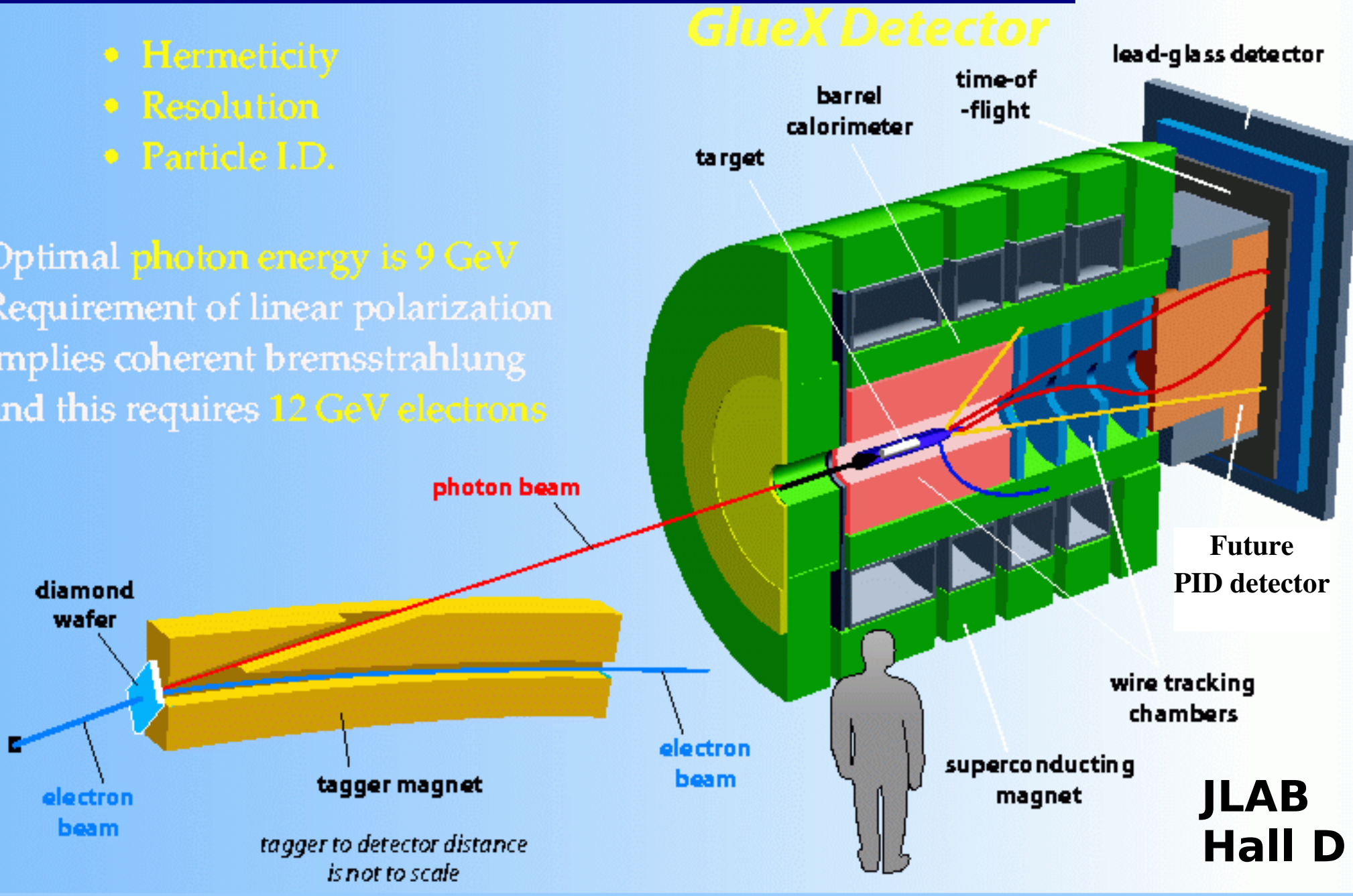


US Dept of Energy
Critical Decision 0 - 3 approved.
Start of construction soon

Optimized for doing amplitude analysis

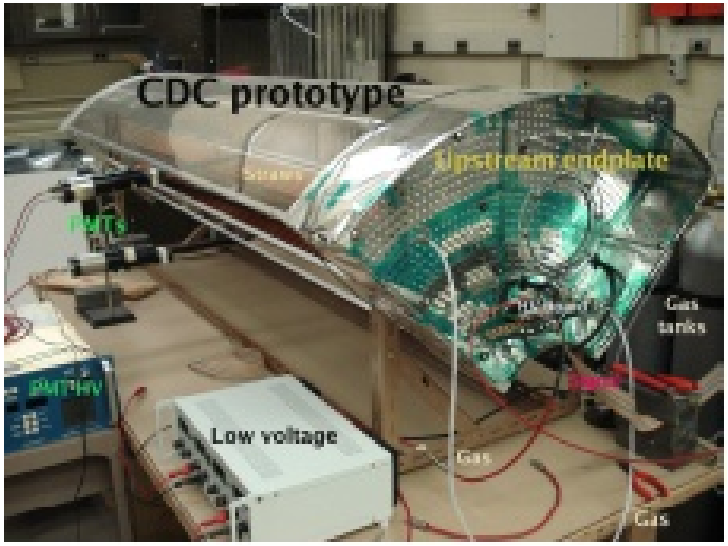
- Hermeticity
- Resolution
- Particle I.D.

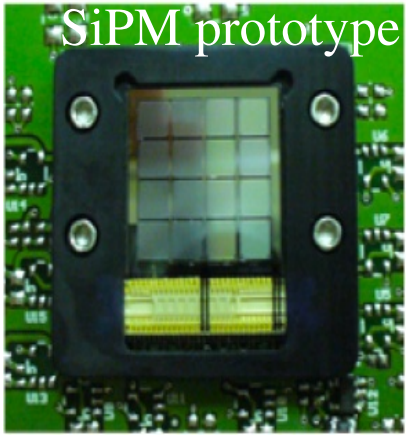
Optimal photon energy is 9 GeV
Requirement of linear polarization implies coherent bremsstrahlung and this requires 12 GeV electrons

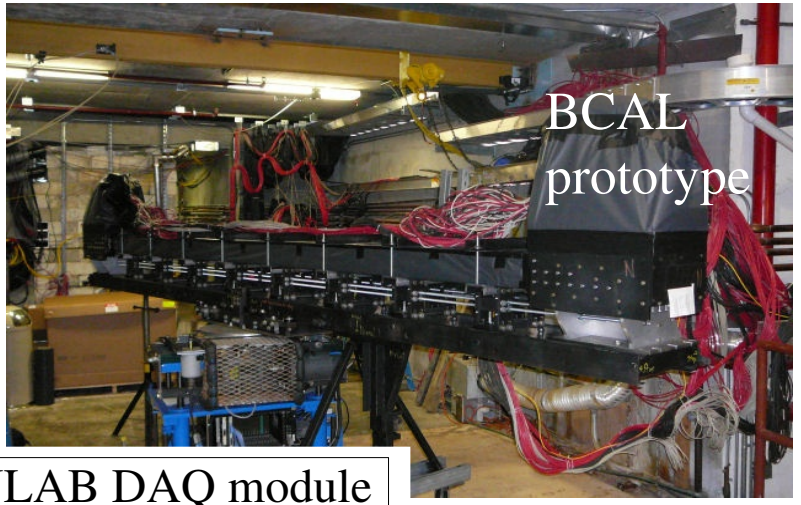


Collaboration has been carrying out R&D for the last 7 years

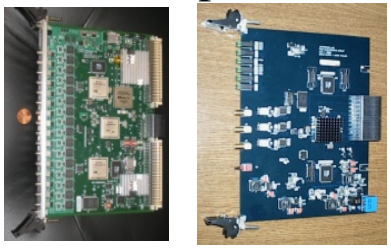
GlueX R&D

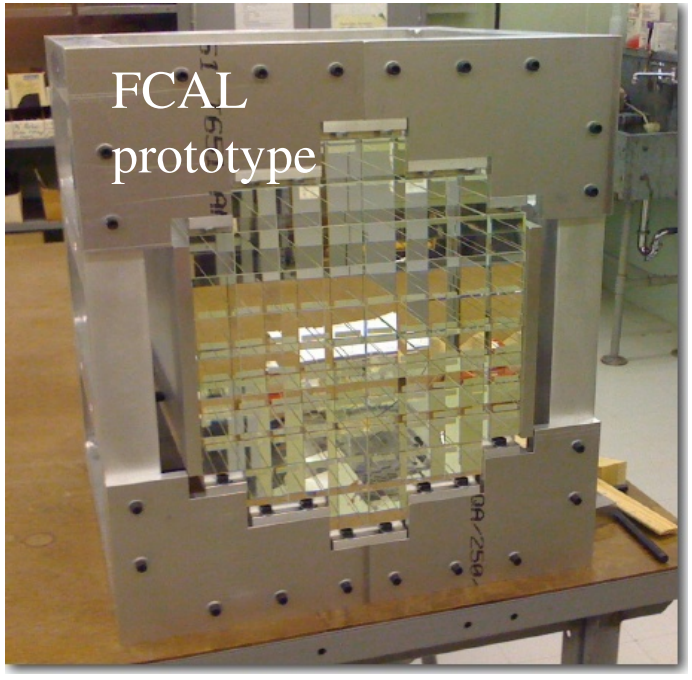


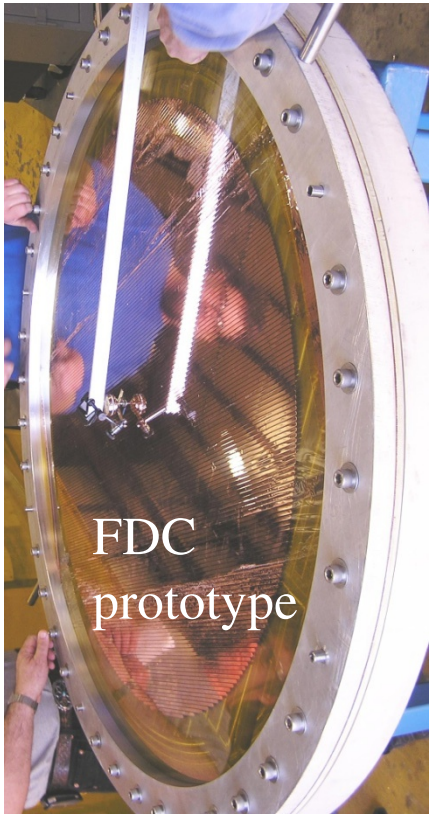


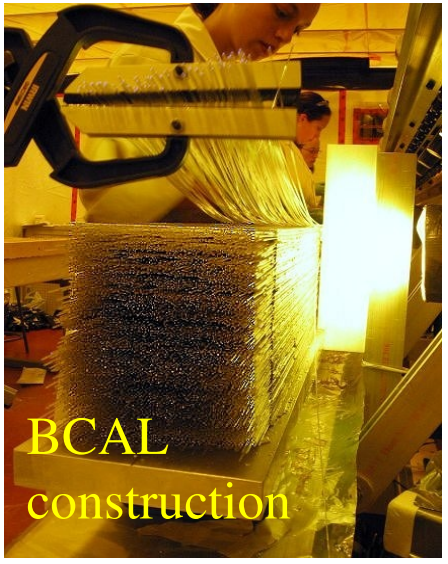


JLAB DAQ module development

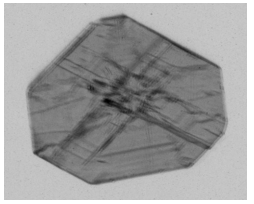








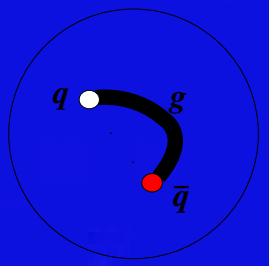
synthetic diamond R&D



Status of GlueX

- (DOE) CD-3 granted in September
- HALL-D civil construction start beginning 2009
- Detector procurement/construction starts now
- Beam on target: 2014

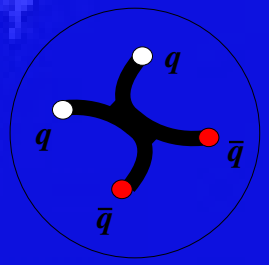
Summary & Outlook



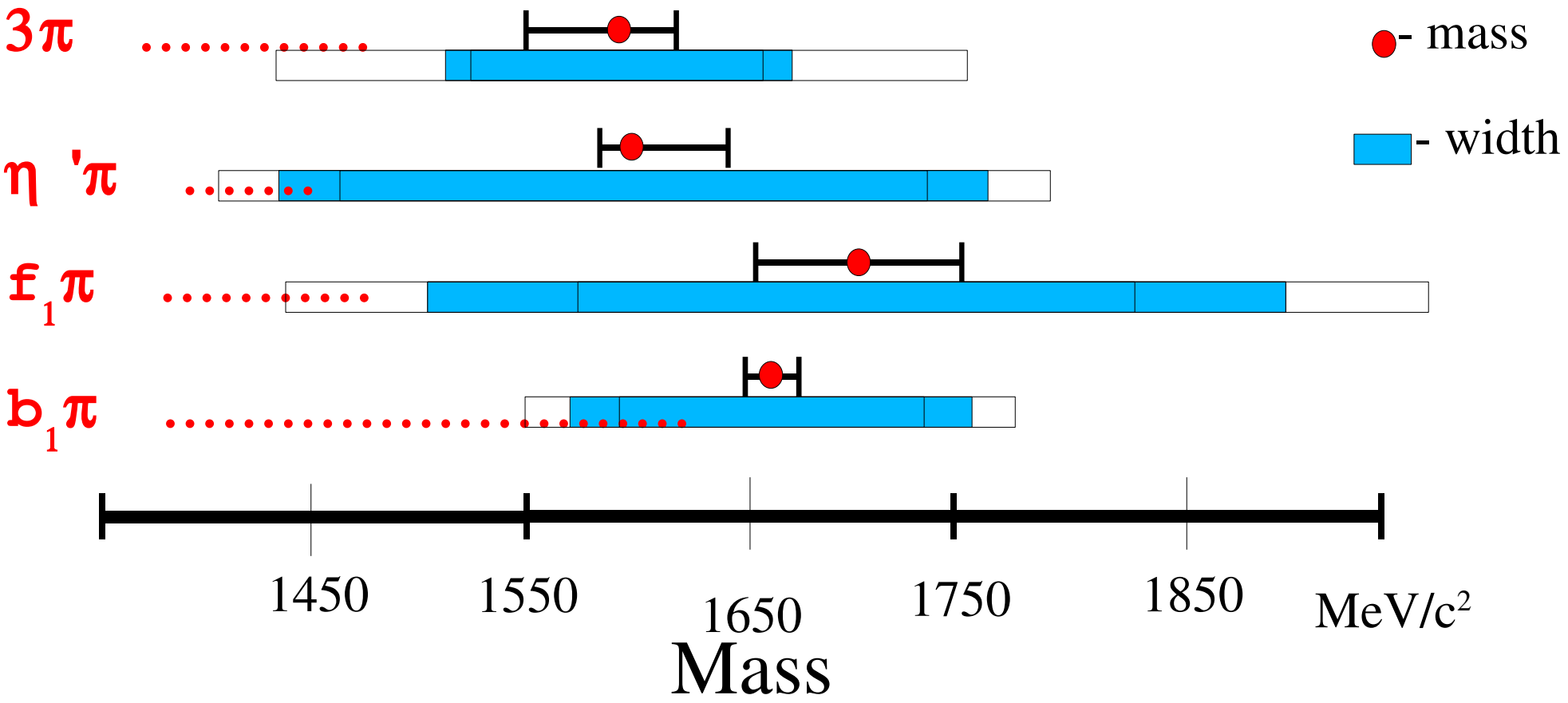
- The Quark Model of hadrons works surprisingly well, yet QCD allows for a much richer spectrum of hadronic matter

- 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
  -



$\pi_1(1600)$ Consistency



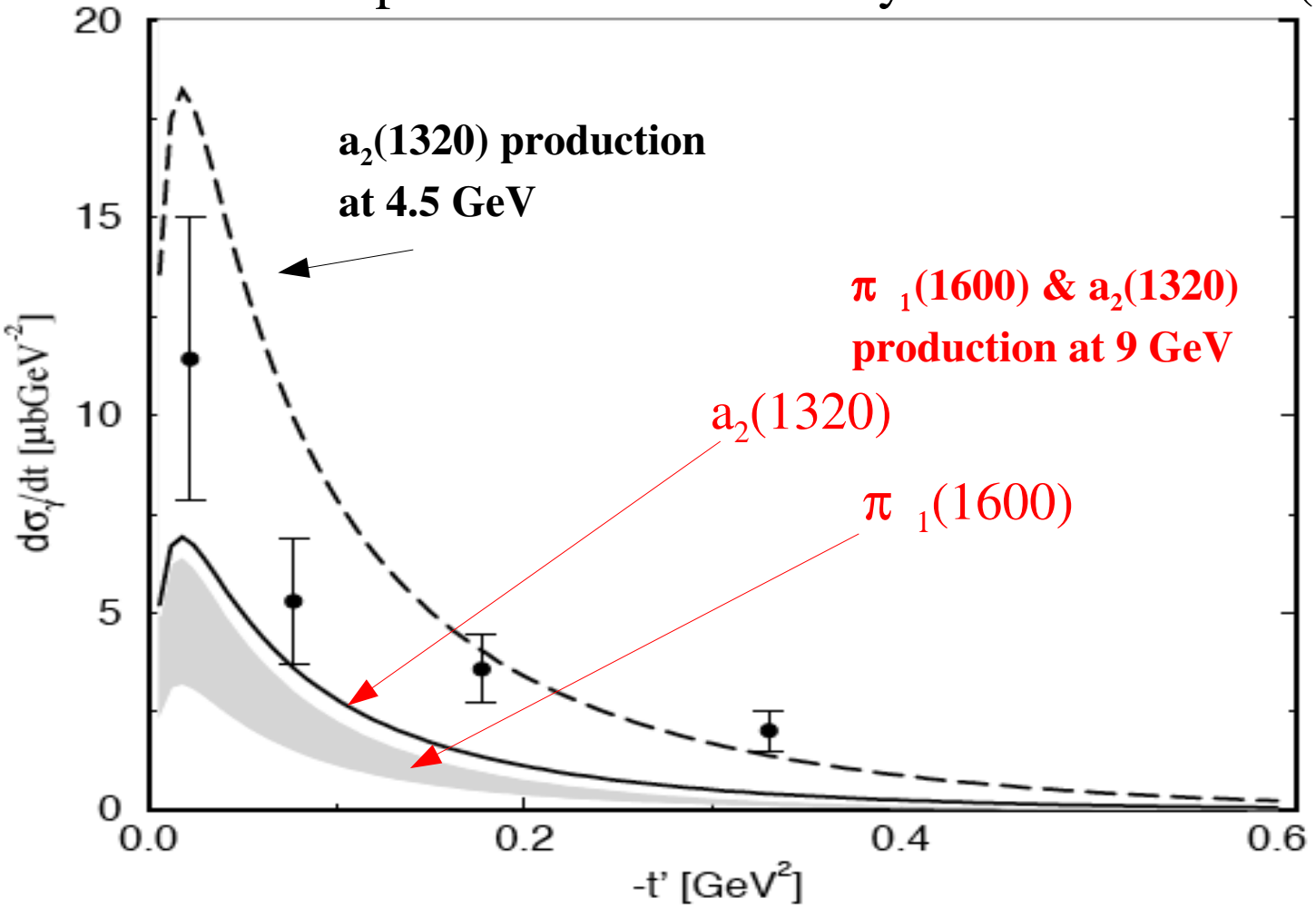
Not Outrageous, but not great agreement

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

Results from all 4 channels suggest Pomeron production

Role of Photoproduction in Exotic Meson Searches

A. Szczepaniak & M. Swat Phys. Lett. B516 72 (2001)



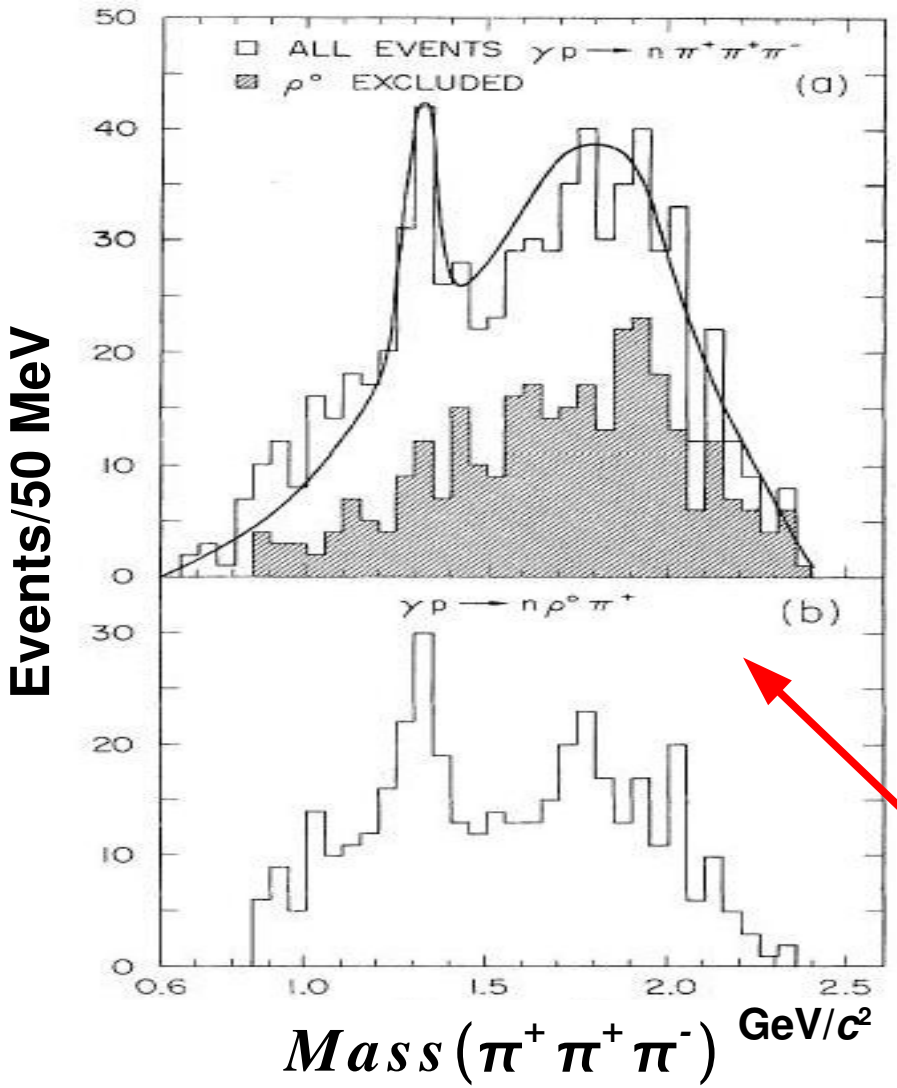
the ratio of exotic to nonexotic meson-production cross sections is expected to be by a factor of 5 to 10 larger, in photoproduction then in hadroproduction

Existing Meson Photoproduction Data

$\gamma p \to \pi^- \pi^+ \pi^+ n$

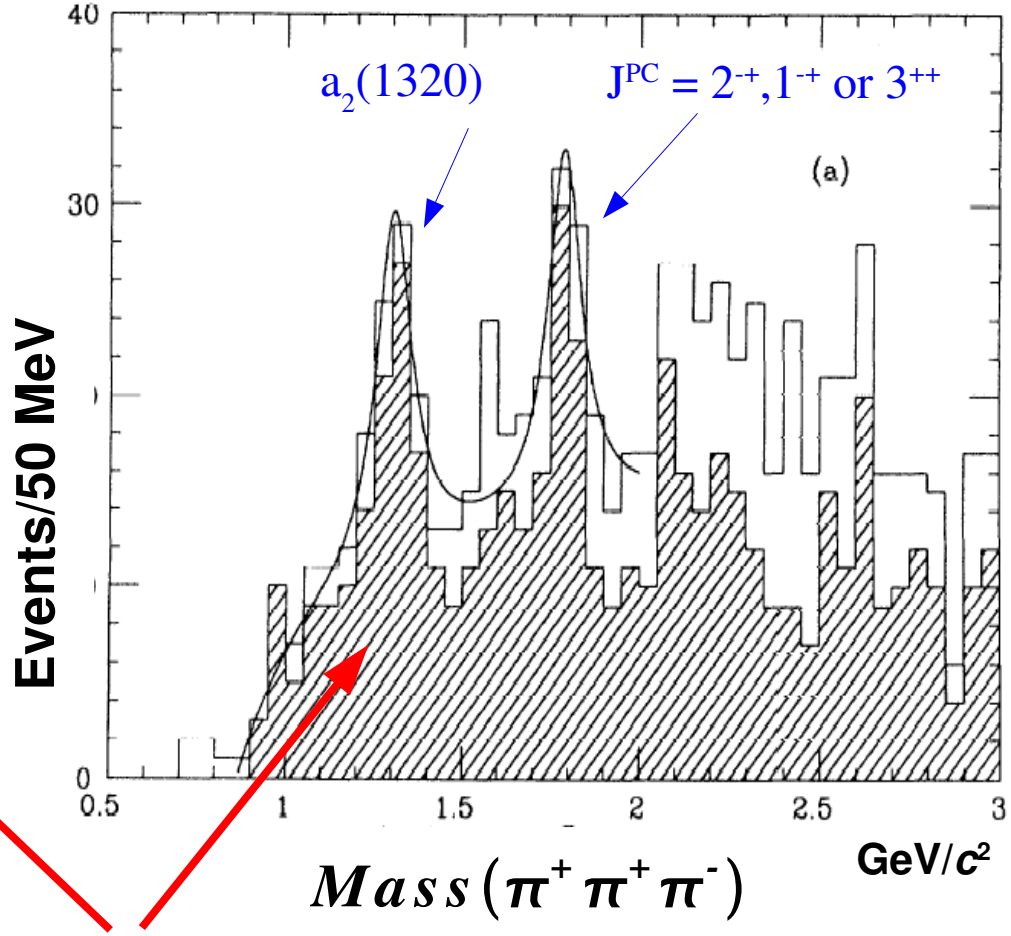
$E_\gamma = ۵.۴ \;\&\; ۴.۳ GeV$

Ballam et al., PRL **23**, 1322 (1969)



$E_\gamma \approx 19 GeV$

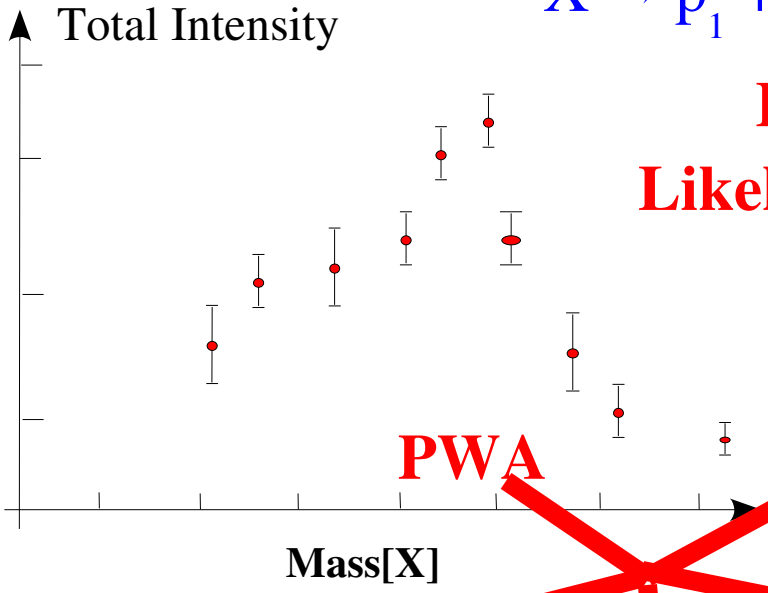
Condo et al., PRD 43 #9, 2787 (1991)



~600 events

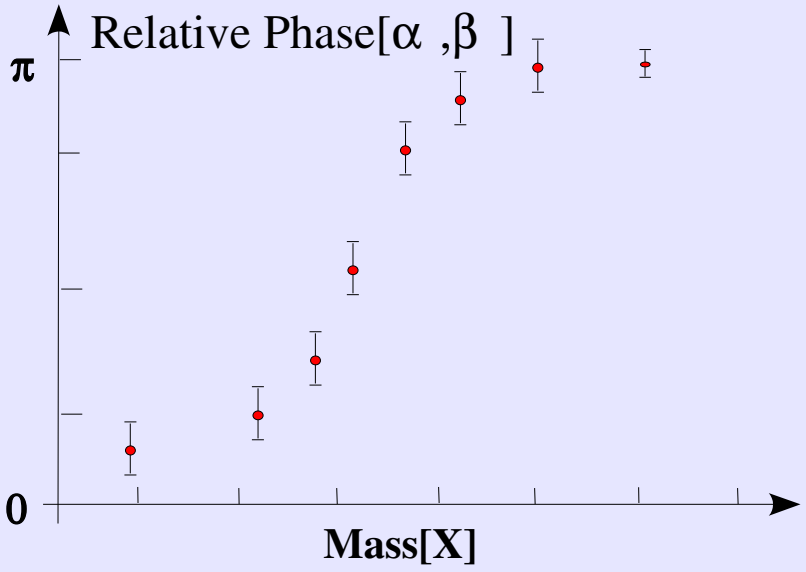
Partial Wave Analysis
Step 1: Decompose to Partial Waves

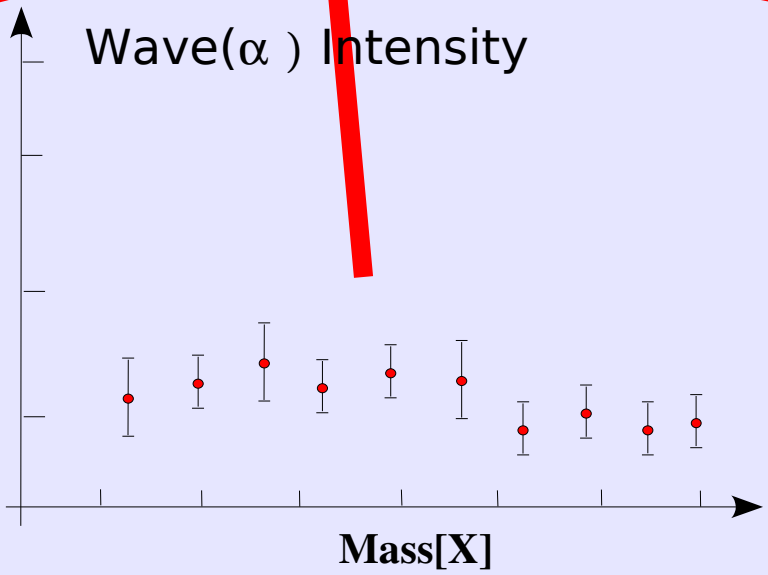
$X \rightarrow p_1 + p_2 + p_3 + \ldots$

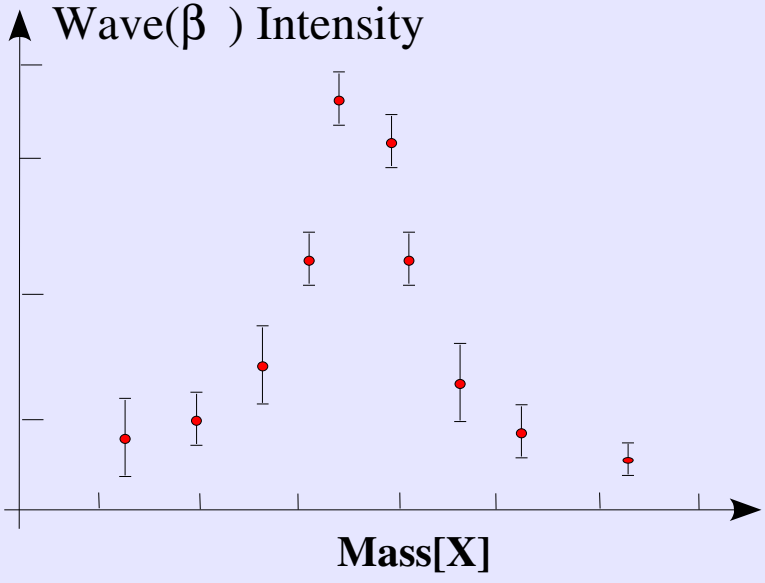


Bin by Bin
Likelihood Analysis

PWA

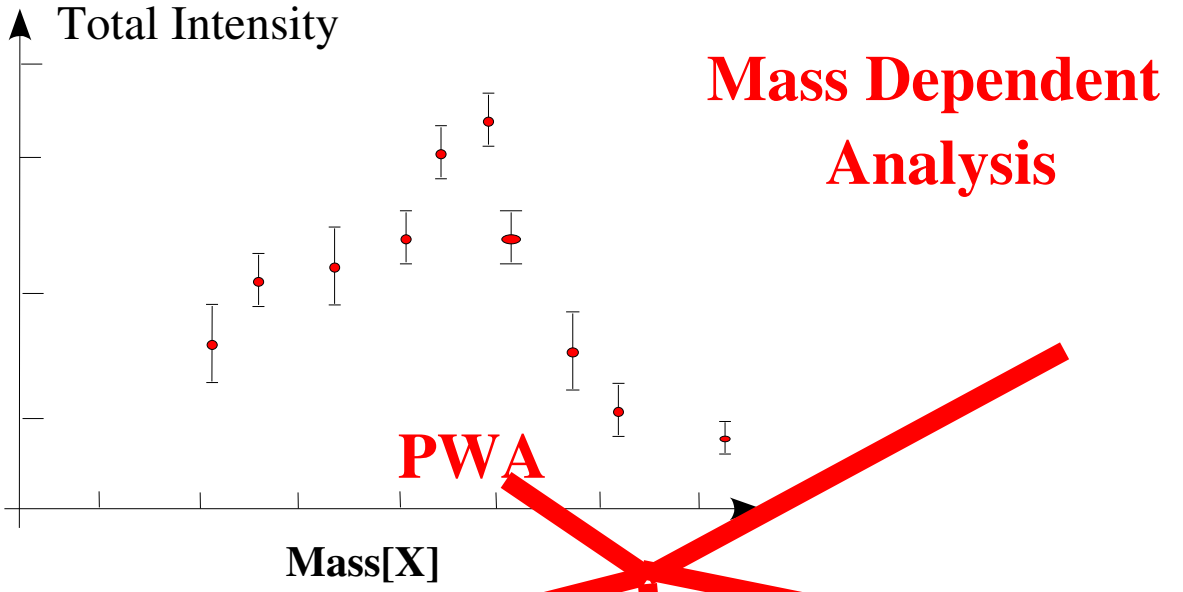






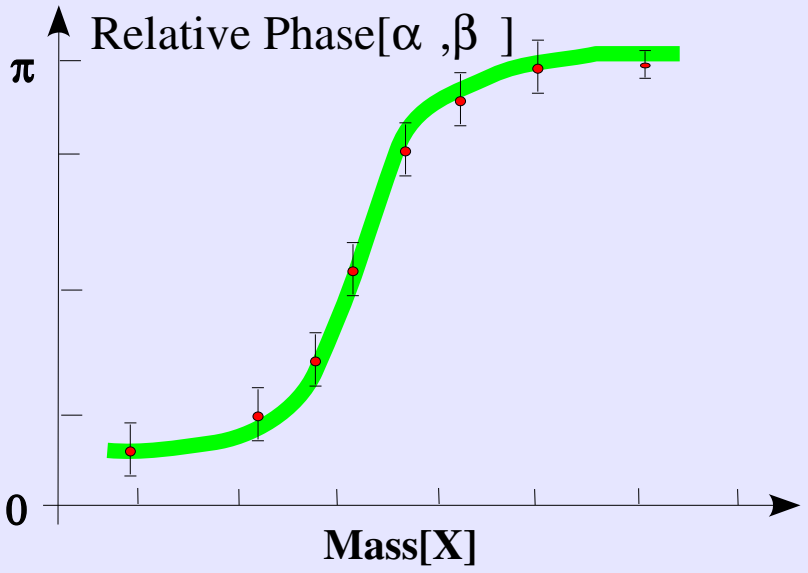
Partial Wave Analysis

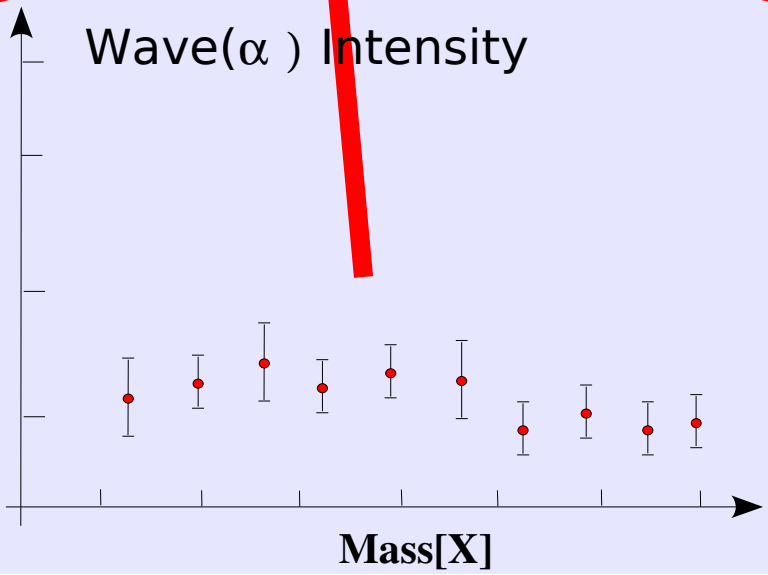
Step 2: Extract Resonance Parameters

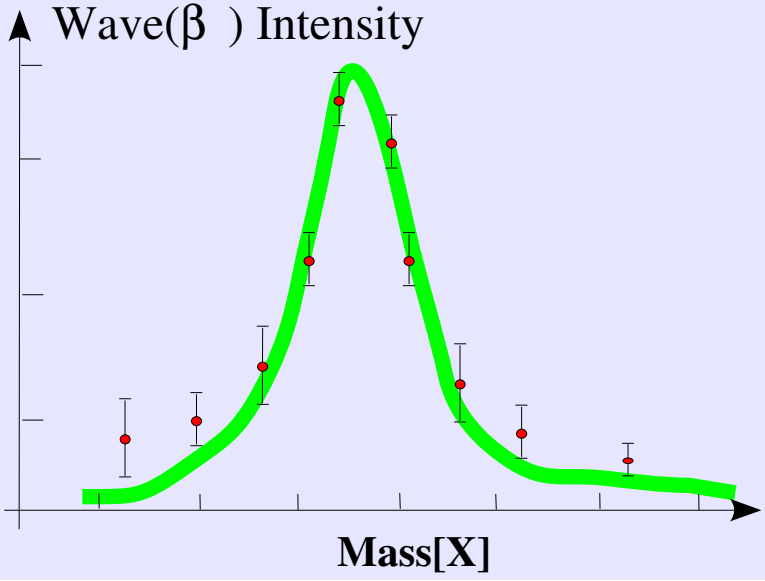


Mass Dependent Analysis

PWA



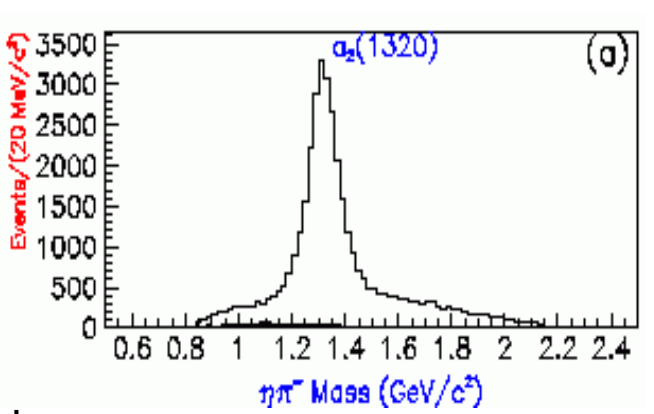


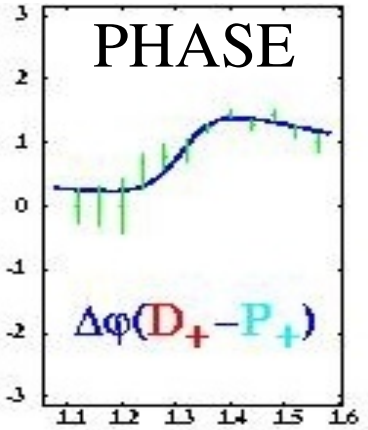


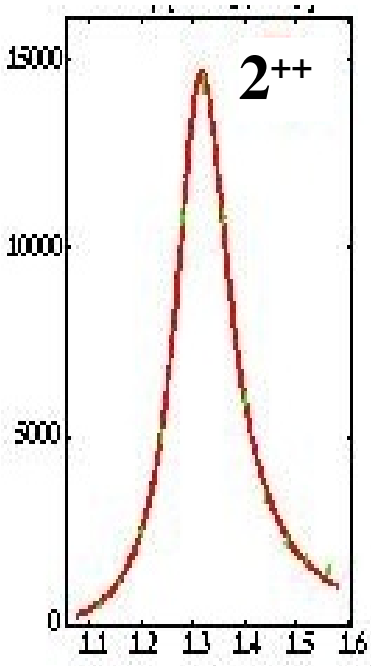
$J^{PC} = 1^{-+}$ Exotic Candidate

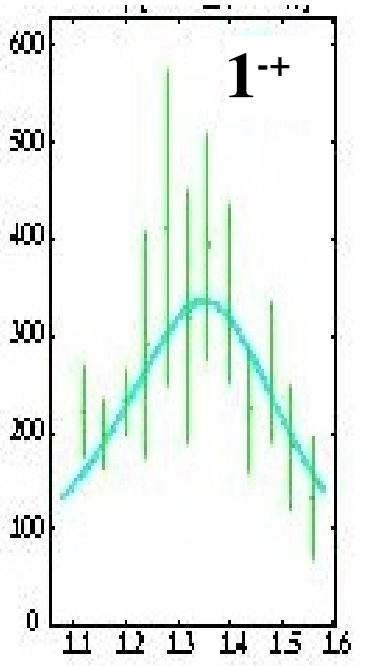
$\pi_1(1400) \rightarrow \eta\pi$

- **BNL-E852 & Crystal Barrel**
  - Observe structure in the cross section & rapid phase motion
  - Simple Breit-Wigner ansatz describes data
  - Both Claims of Exotic Nature
- **VES & IU-E852$_{\eta\pi 0}$**
  - Observe structure in the cross section & rapid phase motion
    - VES reported results earlier but no claims of exotic
    - IU-E852 $\eta\pi^0$ result differs slightly in the phase
  - Results compatible with BNL findings
  - VES Did not Claim Exotic
  - IU-E852 claims rescattering effect





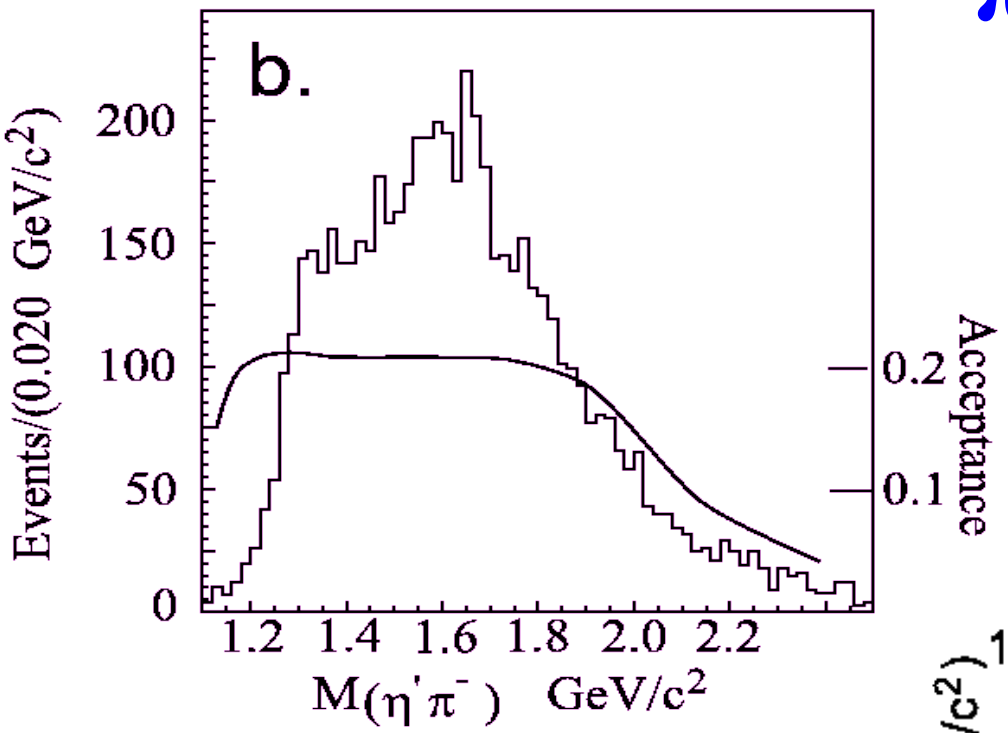




Mass($\eta\ \pi$)

All groups agree on findings but disagree on interpretation

Observation of Exotic $\pi_1(1600)$

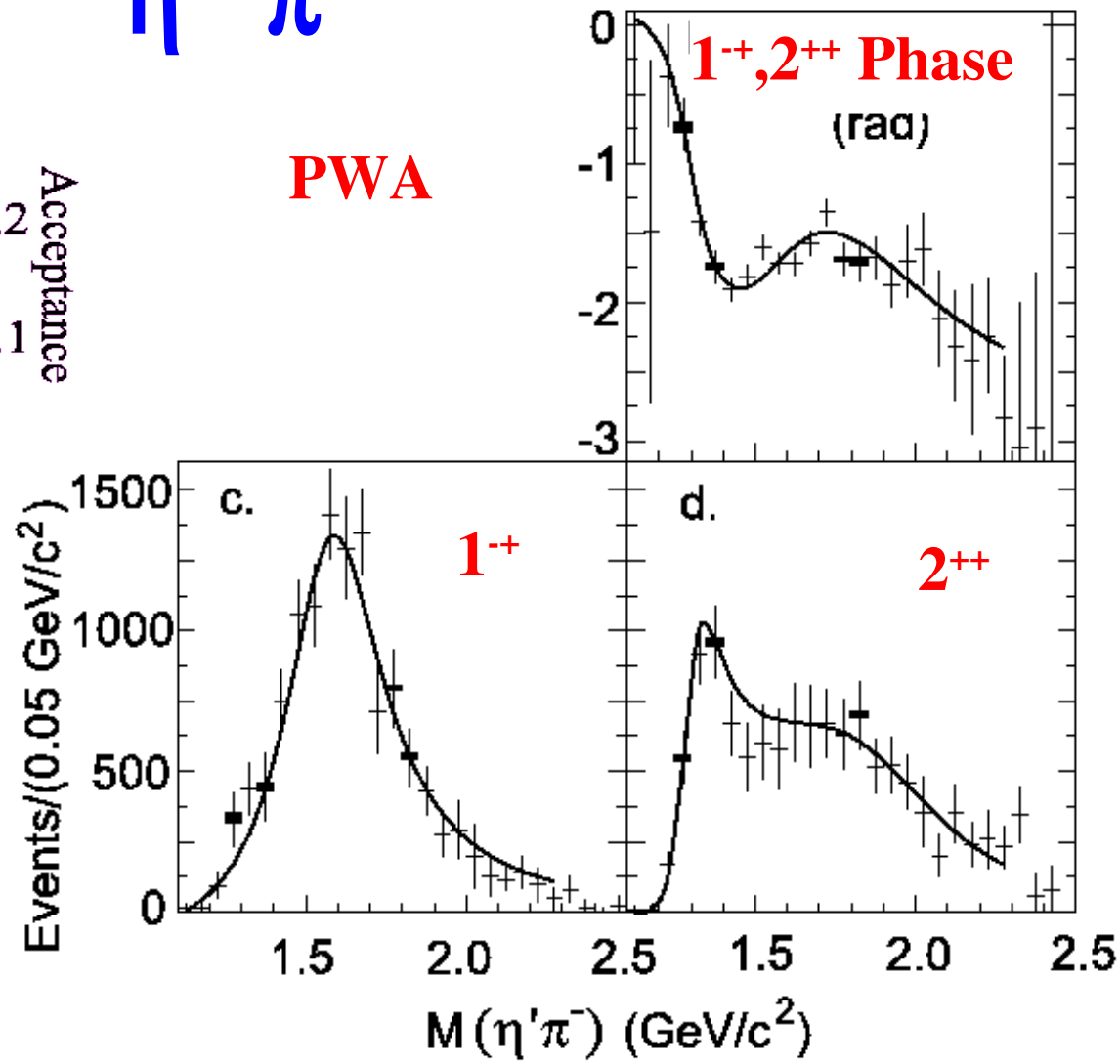


BNL-E852

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

$\pi_1(1600) \to$

$\eta\ \pi$ ***Mountain in the Molehill***

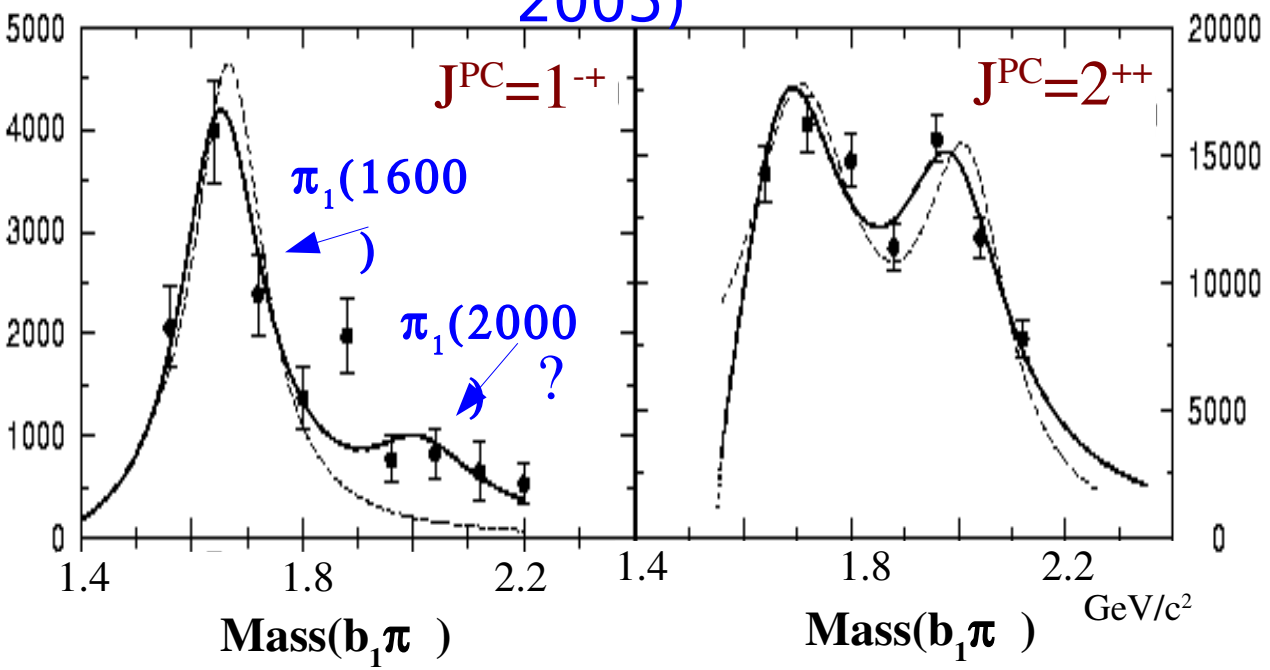


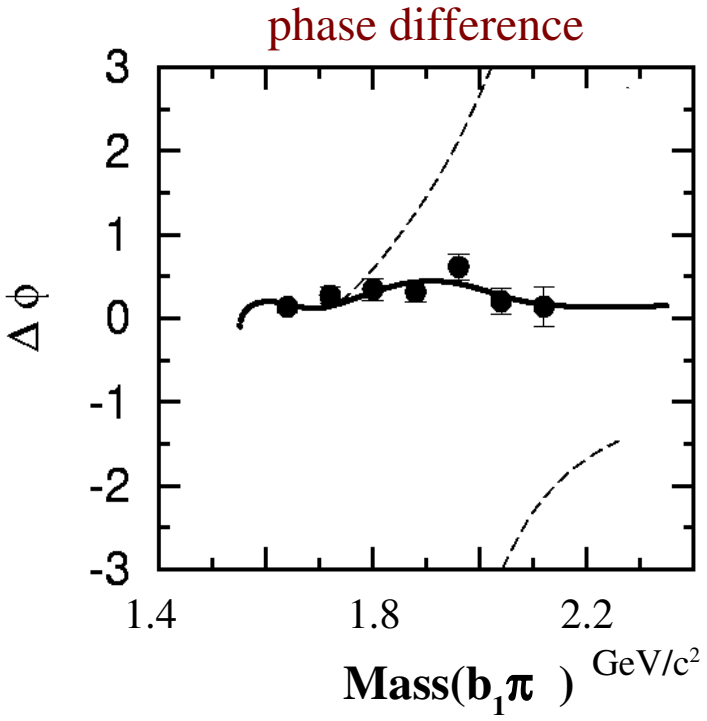
Yet Another $J^{PC} = 1^{-+}$ Exotic Candidate

BNL-E852 $\pi_1(1600)$ & $\pi_1(2000)$

Observe structure in the cross section & rapid phase motion

- $f_1(1285)\,\pi$ (Phys. Lett. B595 109 2004)
- $b_1(1235)\,\pi$ (Phys. Rev. Lett. 94 032002 2005)





BNL-E852 Claims of Consistent Exotic Nature in both Decays