

GlueX: Photoproduction of Hybrid Mesons

Hybrid mesons – masses and decay modes

Expectations from LQCD and models

Photoproduction and GlueX

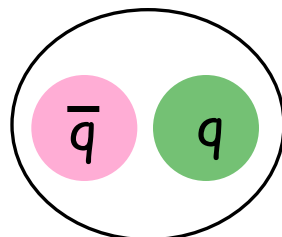
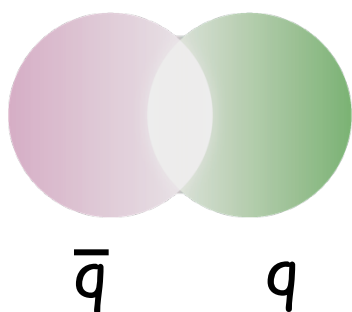
Elton S. Smith, Jefferson Lab

for the GlueX Collaboration

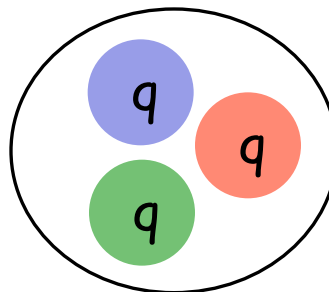
12th International Workshop on Meson Production,
Properties and Interaction

Quarks are confined inside colorless hadrons

Quarks combine to “neutralize” color force



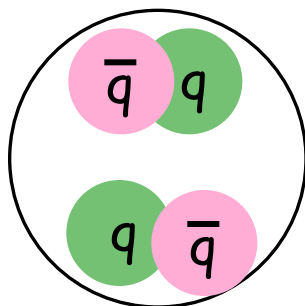
mesons



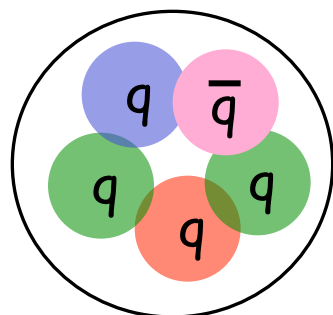
baryons



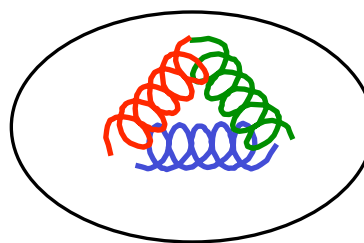
Allowed by QCD, but do they exist in nature?



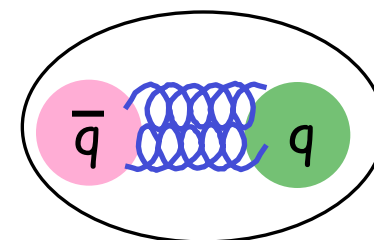
molecules



pentaquark



glueball meson

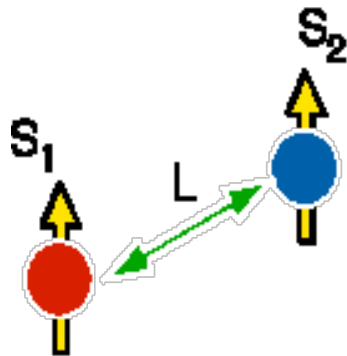


hybrid meson

Normal Mesons – $q\bar{q}$ color singlet bound states

Spin/angular momentum configurations & radial excitations generate the known spectrum of light quark mesons.

Starting with **u** - **d** - **s** we expect to find mesons grouped in **nonets** - each characterized by a given **J**, **P** and **C**.



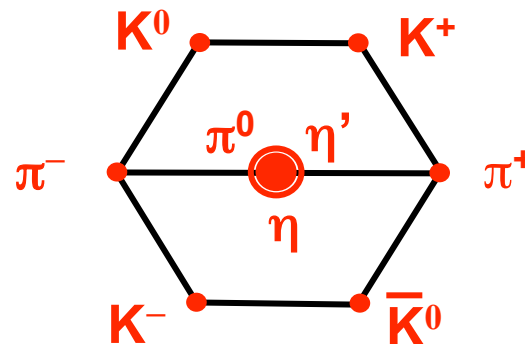
$$S = S_1 + S_2$$

$$J = L + S$$

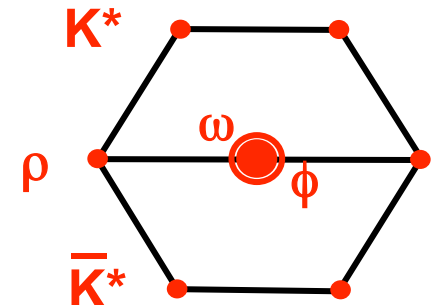
$$P = (-1)^{L+1}$$

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

Spin 0



Spin 1



$J^{PC} = 0^{-+} \quad 0^{++} \quad 1^{--} \quad 1^{+-} \quad 2^{++} \dots$

Allowed combinations

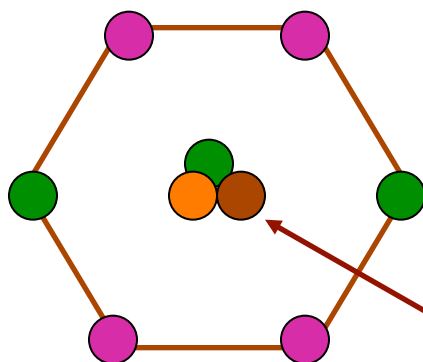
$J^{PC} = 0^{--} \quad 0^{+-} \quad 1^{-+} \quad 2^{+-} \dots$

Not-allowed: exotic

Families of Exotics

$$K_1 \quad I^G(J^{PC}) = \frac{1}{2} (1^-)$$

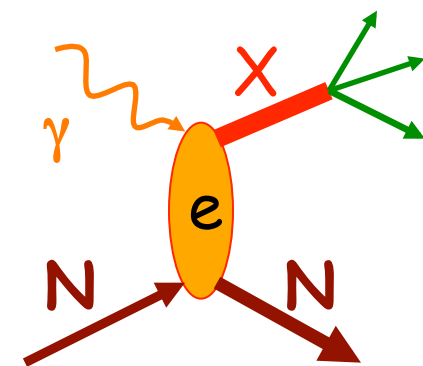
$$\pi_1 \quad I^G(J^{PC}) = 1^-(1^{++})$$



1^{--} nonet

$$\eta'_1 \quad I^G(J^{PC}) = 0^+(1^{--})$$

$$\eta_1 \quad I^G(J^{PC}) = 0^+(1^{--})$$



$$\gamma \Leftrightarrow \rho, \omega, \phi$$

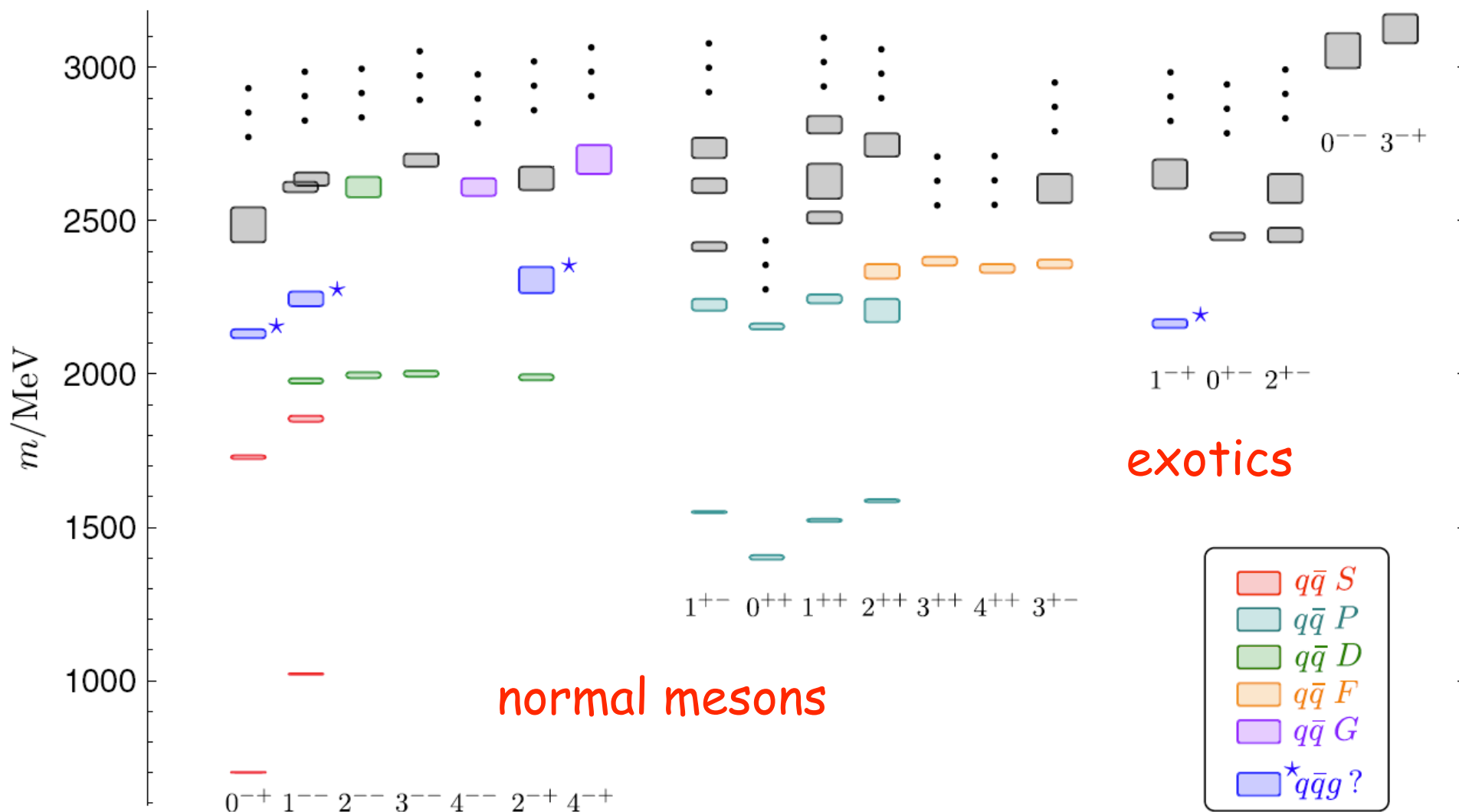
Couple to vector meson
+ exchanged particle

$$\pi_1 \Leftrightarrow \rho\pi$$

$$\eta_1 \Leftrightarrow \rho b_1, \omega\phi$$

$$\eta'_1 \Leftrightarrow \phi\omega$$

Meson Spectroscopy from LQCD



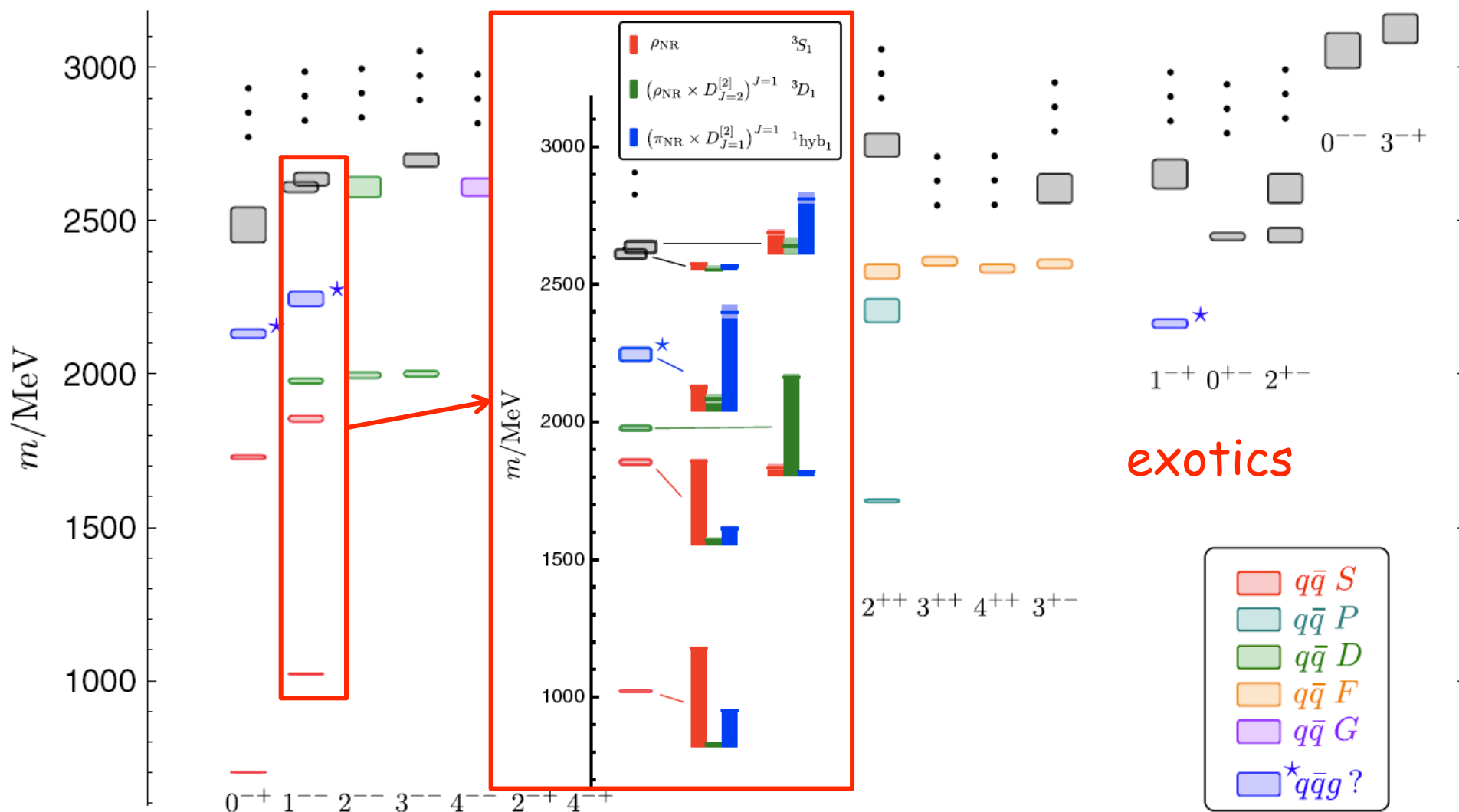
Isovector mesons, $m_\pi \sim 700 \text{ MeV}$

Dudek PRD 83 (2011) 111502

Friday Plenary 3

Dudek PRD 84 (2011) 074023

Meson Spectroscopy from LQCD



Isvector mesons, $m_\pi \sim 700$ MeV

Dudek PRD 83 (2011) 111502

Friday Plenary 3

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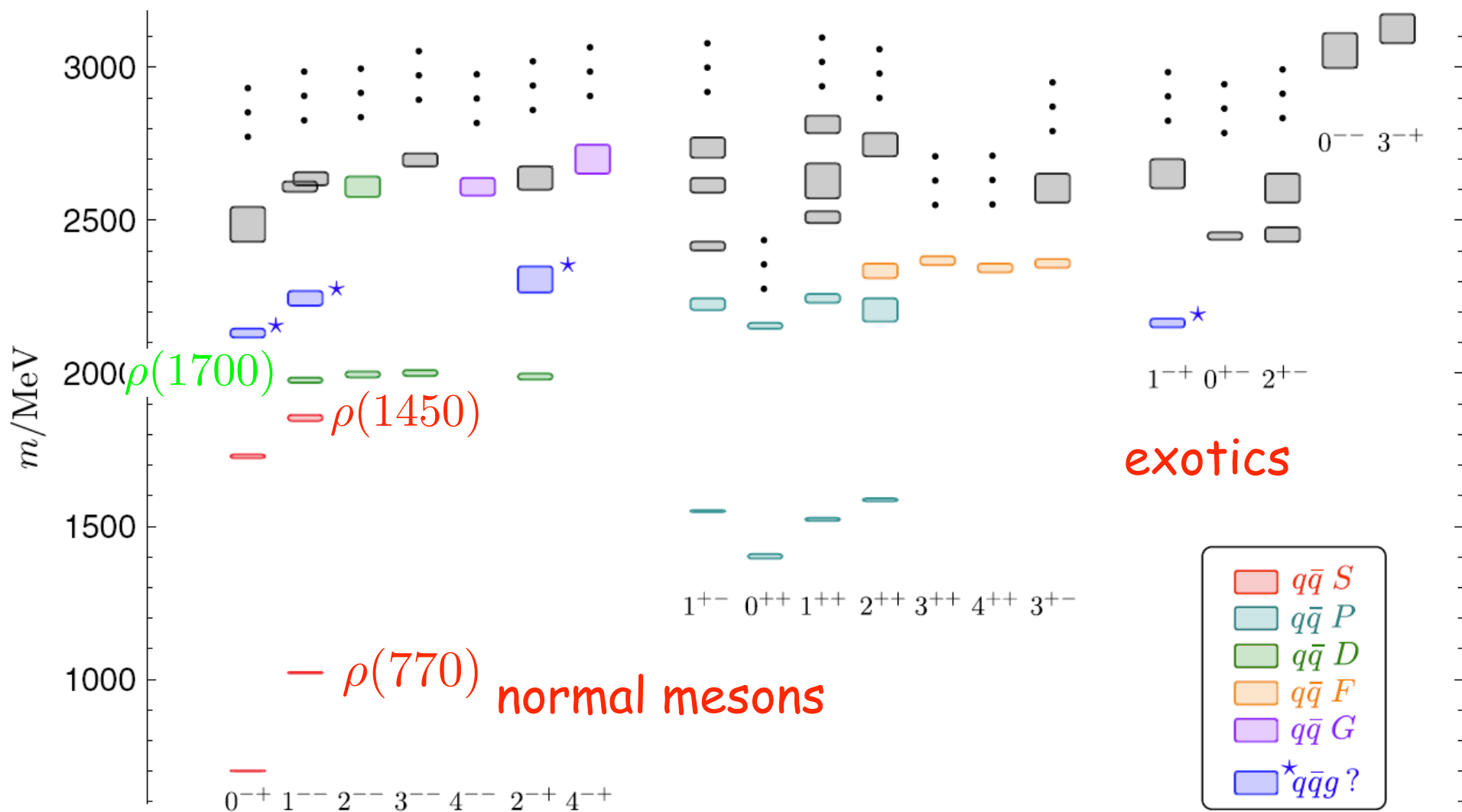
Jefferson Lab

Elton S. Smith

MESON2012

May 31 – June 5, 2012

Meson Spectroscopy from LQCD



Isovector mesons, $m_\pi \sim 700 \text{ MeV}$

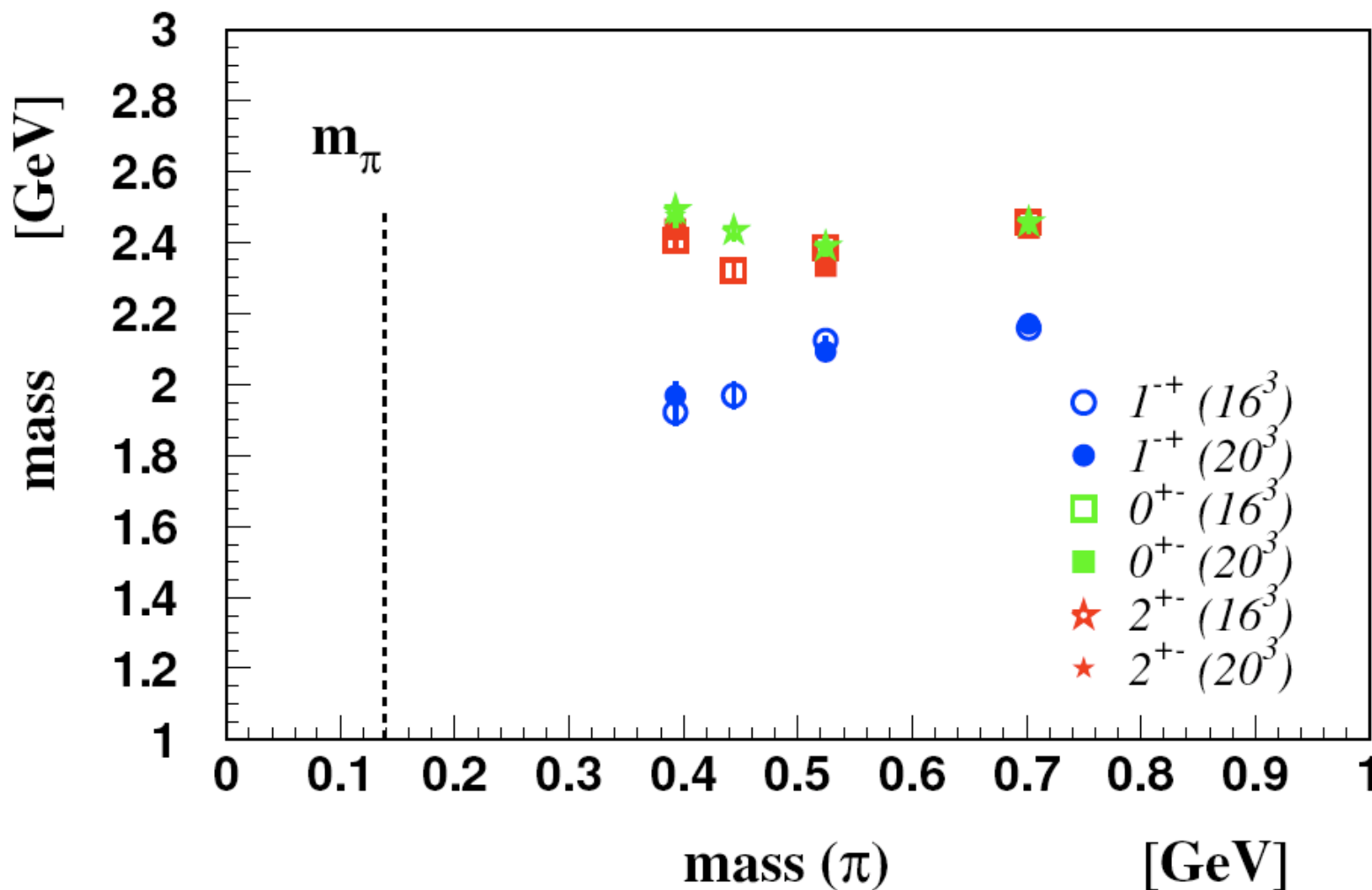
Dudek PRD 83 (2011) 111502

Friday Plenary 3

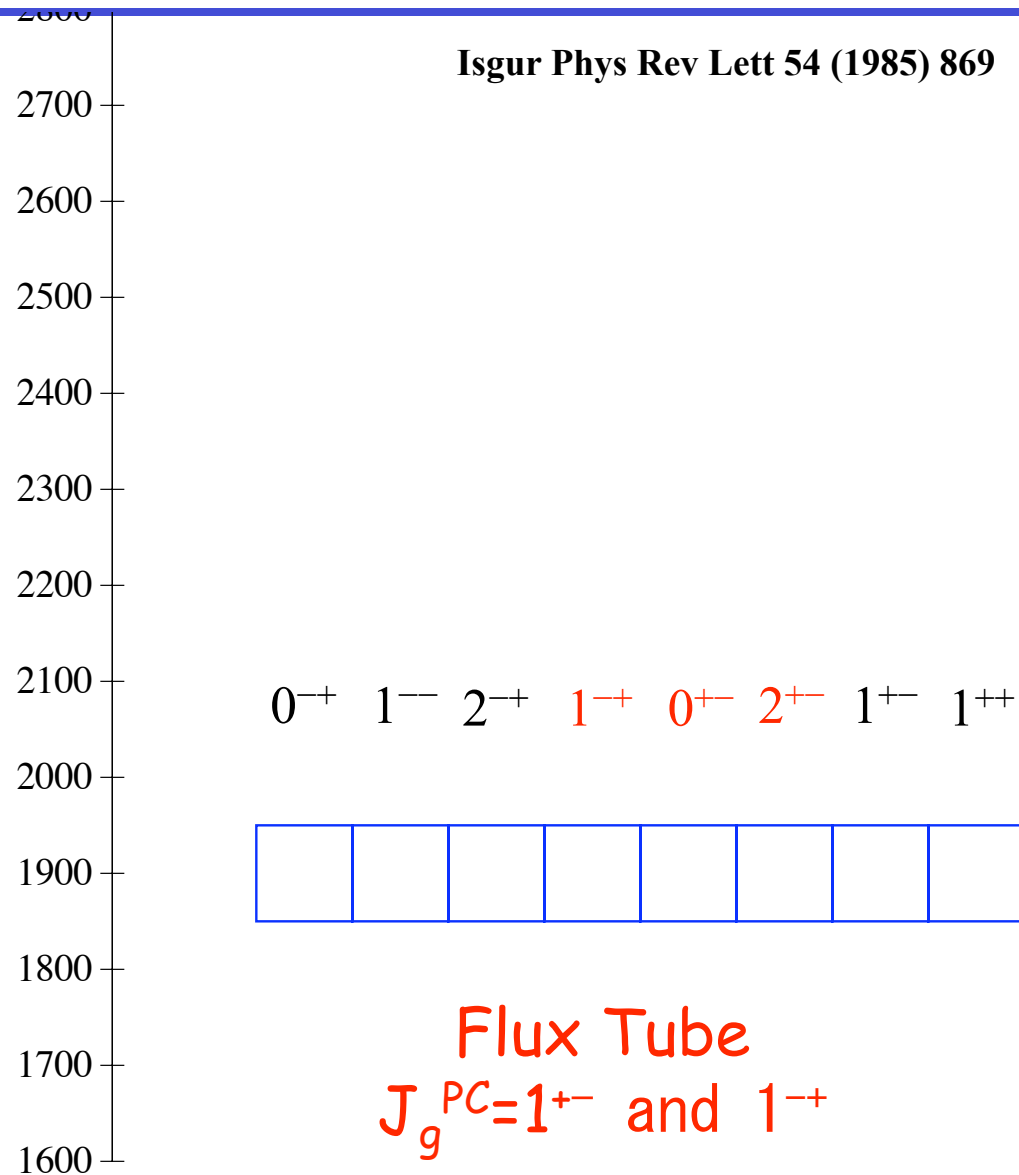
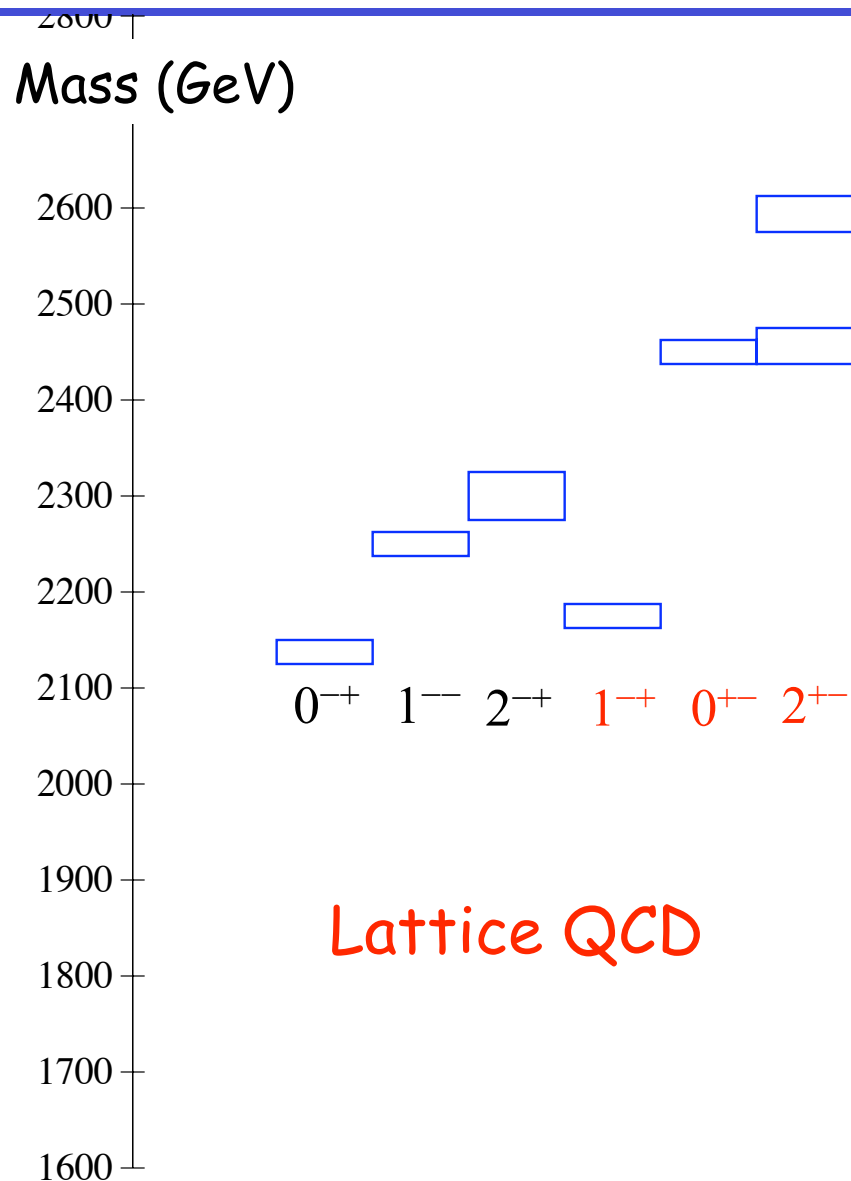
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Extrapolation to physical mass

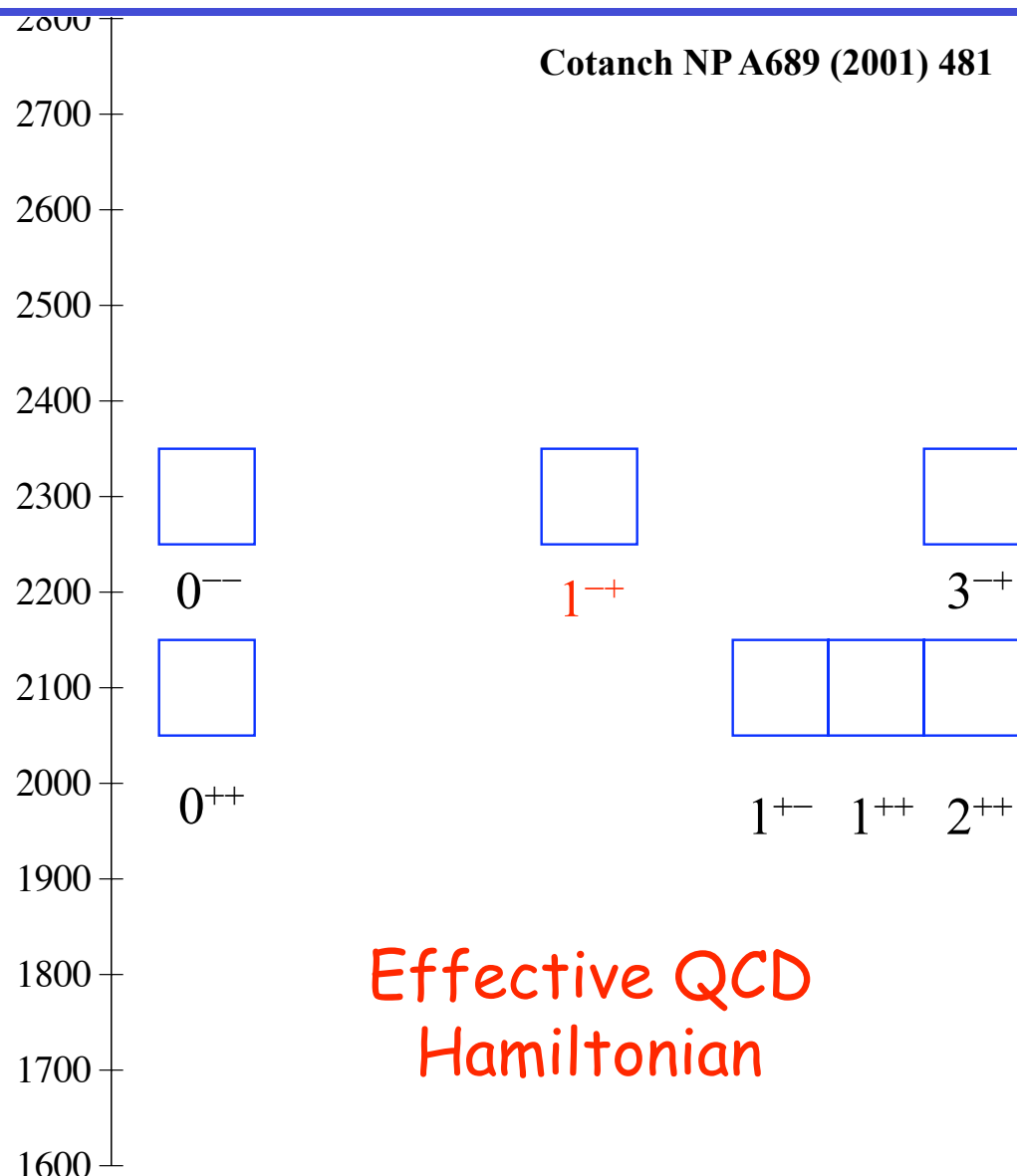
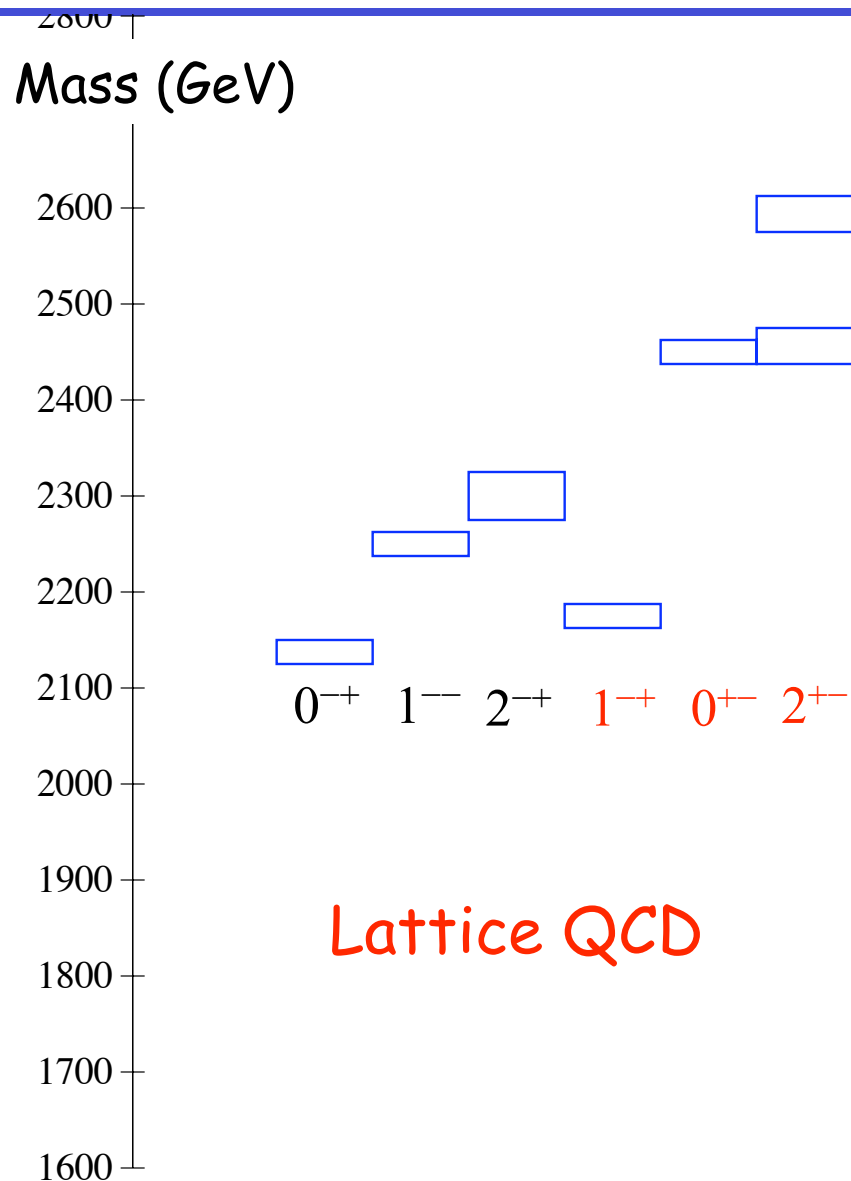
At $m_\pi = 400$ MeV, mass (1^-) ~ 1.9 GeV, mass (0^{+-}) ~ 2.5 GeV



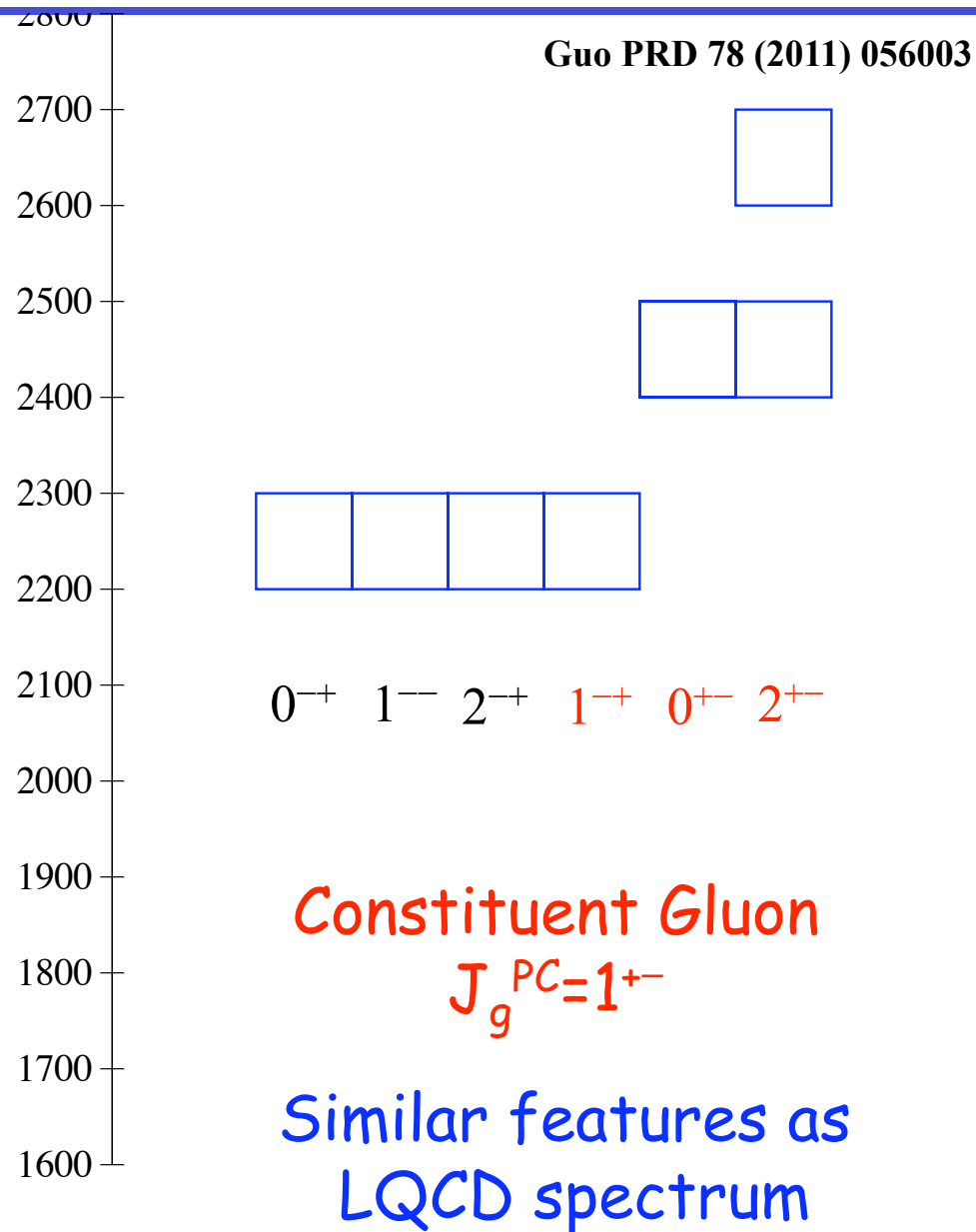
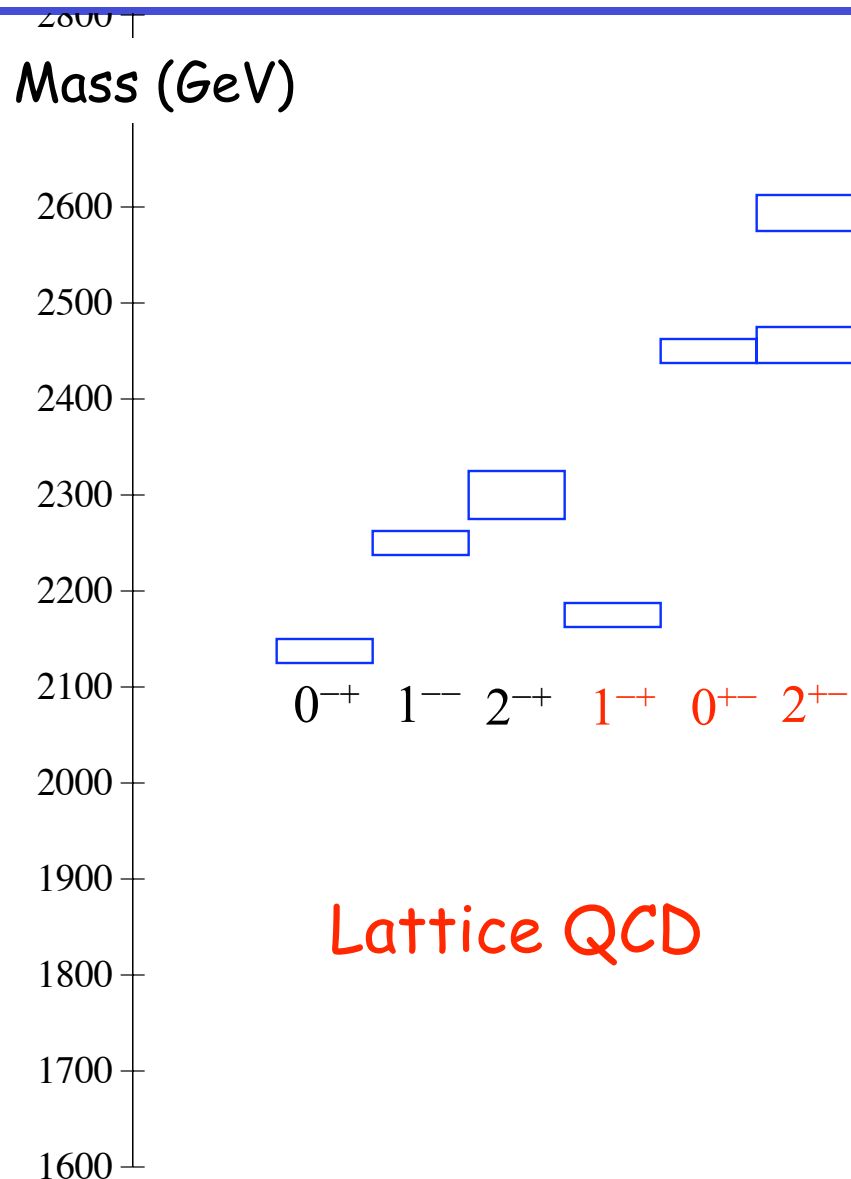
Models for hybrid mesons



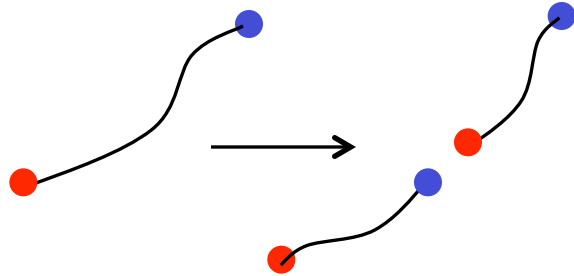
Models for hybrid mesons



Models for hybrid mesons



How do exotics decay?



Flux Tube Model

Possible daughters:

$L=1$: $\rho, \omega, \phi, \dots$

$L=0$: $\pi, \eta, \eta', \dots$

The angular momentum in the flux tube stays in one of the daughter mesons ($L=1$) and ($L=0$) meson, e.g:

flux tube $L=1$ quark $L=1$

Example: $\pi_1 \rightarrow \rho \pi$

$\quad \quad \quad \searrow \quad \swarrow$

$\quad \quad \quad \omega \pi \rightarrow (3\pi)\pi$

$\quad \quad \quad \text{or } \omega \pi \rightarrow (\pi\gamma)\pi$

simple decay modes such as $\eta\pi, \rho\pi, \dots$ are suppressed.

Partial width dependence on hybrid mass

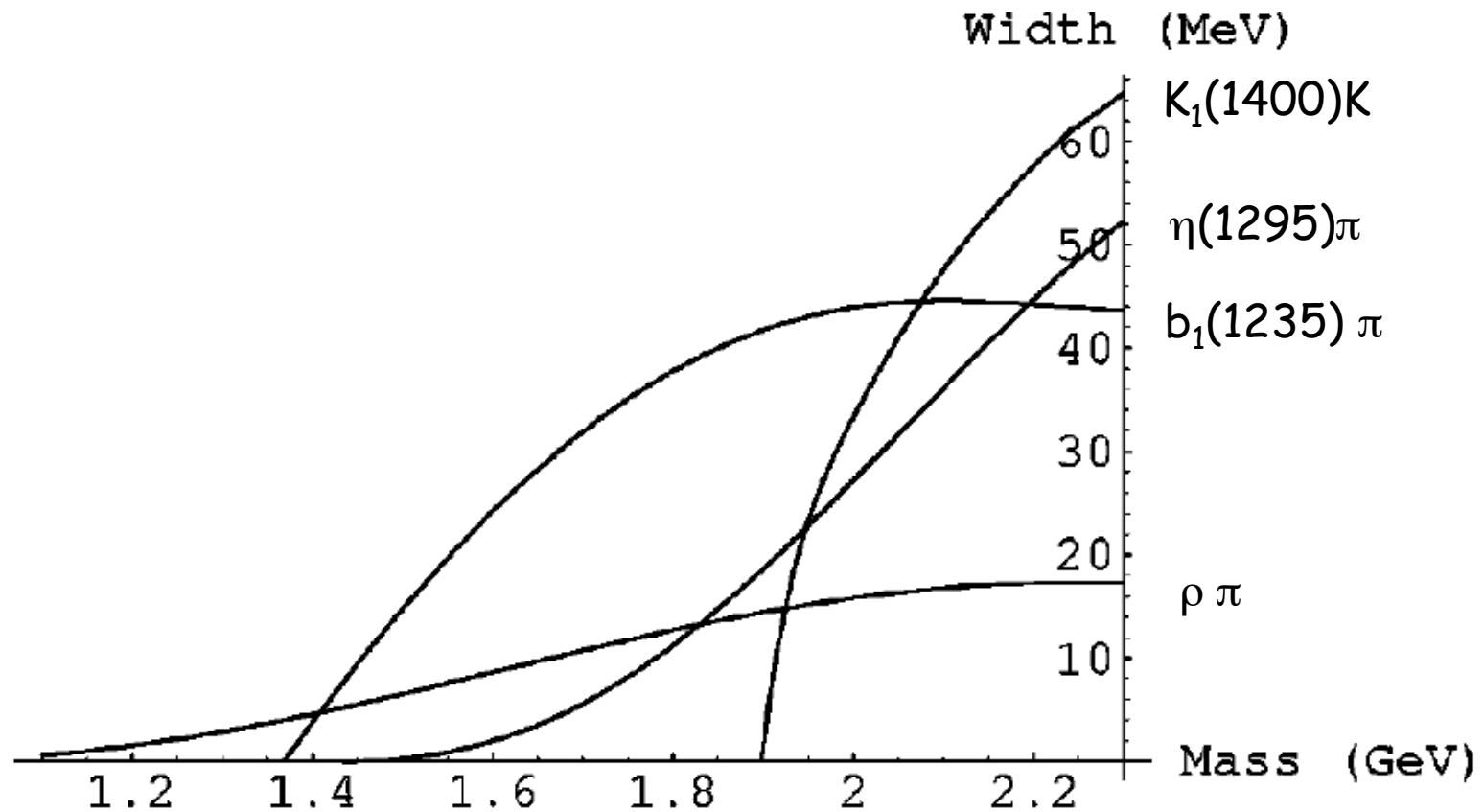


FIG. 1. Dominant partial widths of a 1^{-+} isovector hybrid at various hybrid masses. The partial widths to $K_1(1400)K$, $\eta(1295)\pi$, $b_1\pi$ and $\rho\pi$ correspond to the highest to the lowest intersections with the vertical axis.

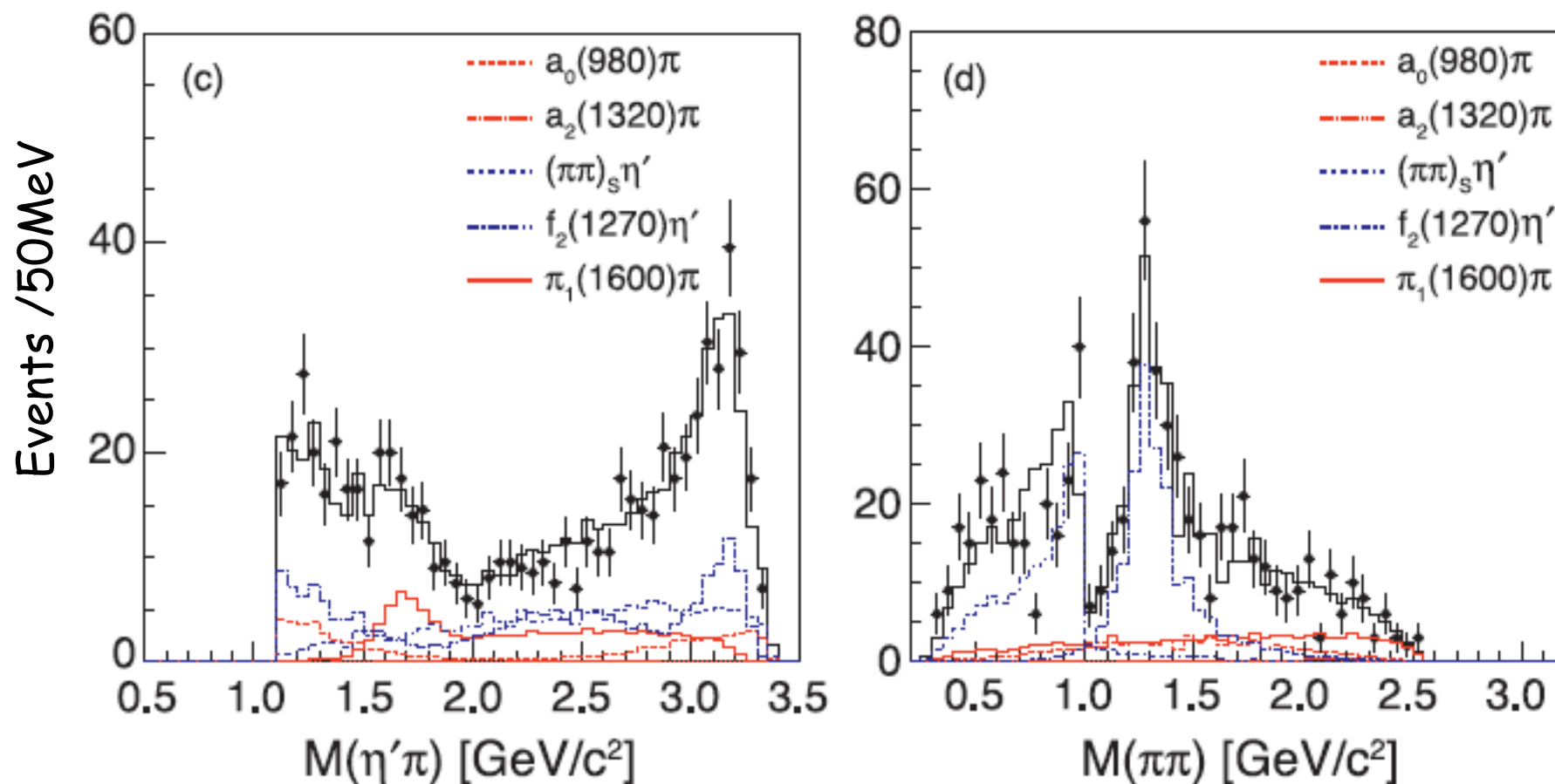
Page PRD 59, 034016-9

Experimental status of exotic $1^{-+} \pi(1600)$

VES	$\pi^{-} A$	$\rightarrow$	$\pi^{-} b_1 A$ $\pi^{-} f_1 A$ $\pi^{-} \eta' A$	For review see Meyer PRC 82 (2010) 025208 [Saturday Plenary 4]
E852	$\pi^{-} p$	$\rightarrow$	$\rho \pi^{-} p$ $b_1 \pi^{-} p$ $f_1 \pi^{-} p$ $\eta' \pi^{-} p$	
Crystal Barrel	$\bar{p} n$	$\rightarrow$	$b_1 \pi^{-}$	
E852-IU	$\pi^{-} p$	$\nrightarrow$	$\rho \pi^{-} p$ $\rho^{-} \pi^0 n$	
CLAS	γp	$\nrightarrow$	$\rho \pi^{+} n$	Only photoproduction search
COMPASS	$\pi^{-} A$	$\rightarrow$	$\rho \pi^{-} A$	
CLEO-c	$\psi(2S)$	$\rightarrow$	$\gamma \chi_{c1}, \quad \chi_{c1} \rightarrow \eta' \pi^{+} \pi^{-}$	

CLEO-c exotic π_1

$$\psi(2S) \rightarrow \gamma \chi_{c1}, \quad \chi_{c1} \rightarrow \eta' \pi^+ \pi^-$$



Exotic $1^{-+} \pi_1 \rightarrow \eta' \pi$ Mass = 1670 ± 36 MeV, $\Gamma = 240 \pm 78$ MeV
4 sigma significance

Adams PRD 84 (2011) 112009

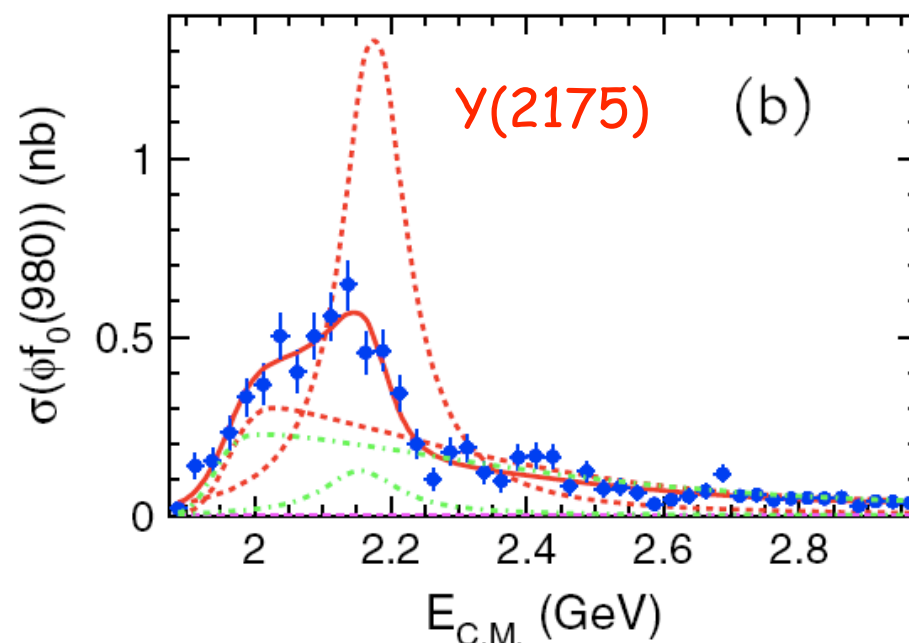
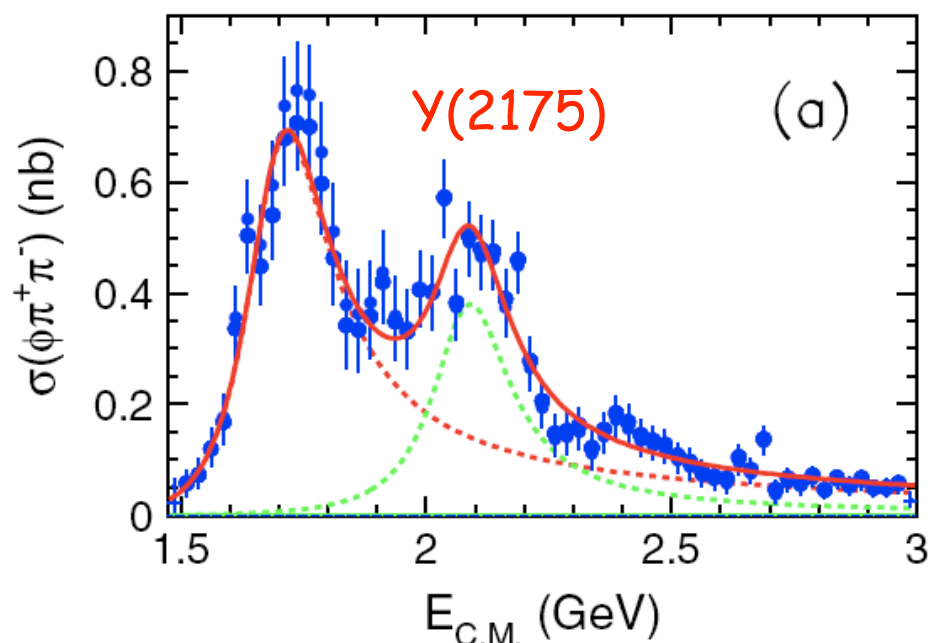
Other suspected hybrid signals

New state $\Upsilon(4260) 1^{--}$ state found by Babar/CLEO
Does not fit into the quark model spectrum
Properties consistent with hybrid charmonium state.

[Friday C2] Zhu Int J Mod Phys E 17 (2008) 283

A second new state $\Upsilon(2175)$ is proposed as its
light quark analog $s\bar{s}g$

[Friday C1]
Belle PRD 80 (2009) 031101



Photoproduction

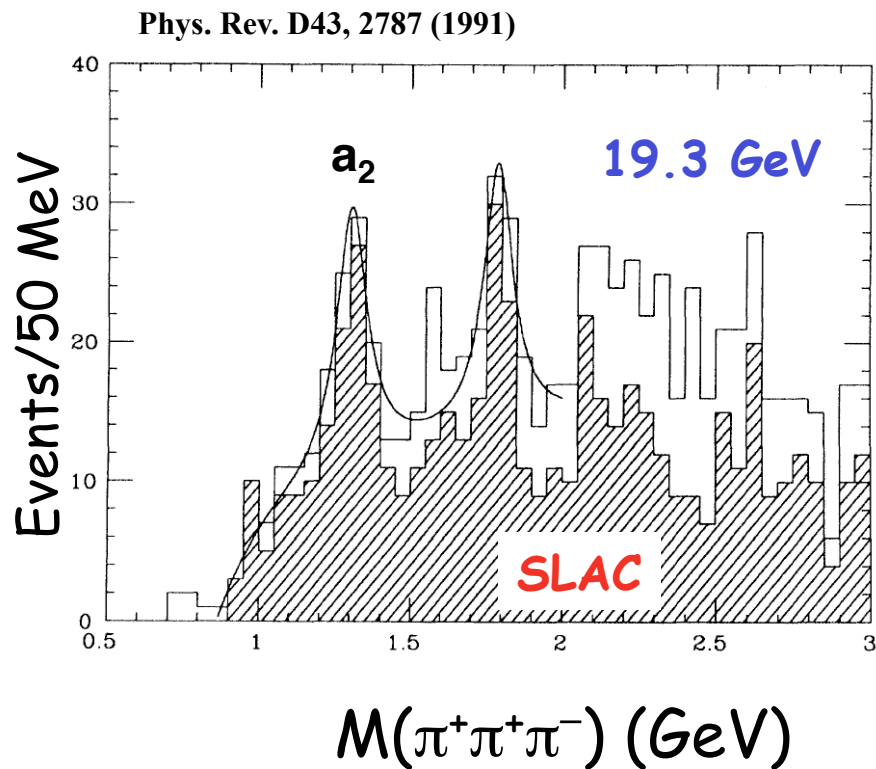
Decomposition of total cross section $E_\gamma = 9.3 \text{ GeV}$

Topology	$\sigma \text{ } (\mu\text{b})$	% of σ with neutrals
1-prong	8.5 ± 1.1	100
3-prong	64.1 ± 1.5	76 ± 3
5-prong	34.2 ± 0.9	86 ± 4
7-prong	6.8 ± 0.3	86 ± 6
9-prong	0.61 ± 0.08	87 ± 21
With visible strange decay	9.8 ± 0.4	-
Total	124.0 ± 2.5	82 ± 4

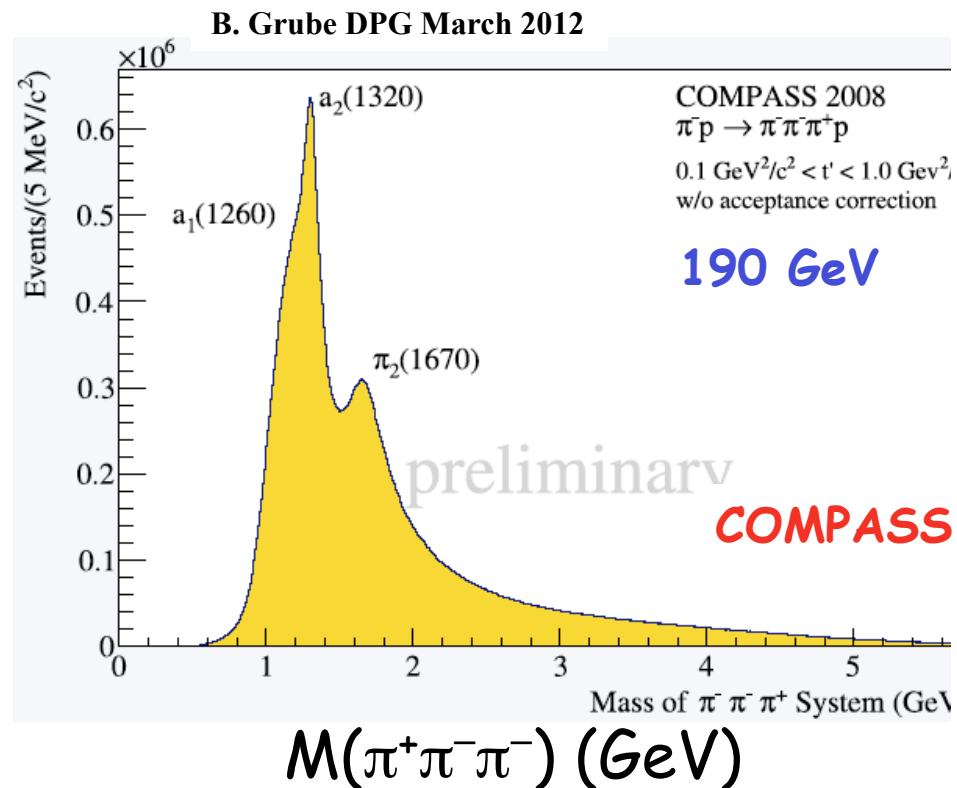
Approximately the 70% of total cross section in the energy region $E_\gamma \sim 7\text{-}12 \text{ GeV}$ has multiple neutrals and is completely unexplored

γ and π beams

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



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



Note: much more photon data from Jlab at lower energy

Photoproduction and linear polarization

■ Production

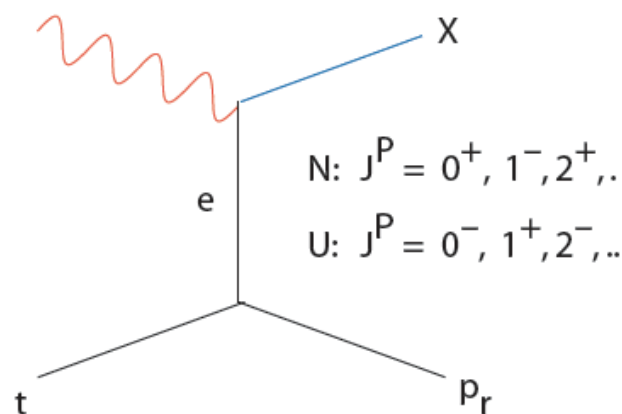
- The expectation from the flux tube model is that hybrids will be produced at a rate comparable to normal mesons.
- This expectation is corroborated by recent lattice calculations that show that the strength of charmonium hybrid radiative decays are similar to normal mesons

$$\Gamma(\eta_{c1} \rightarrow J/\psi\gamma) \sim 100\text{keV}$$

Dudek PRD 79 (2009) 094504

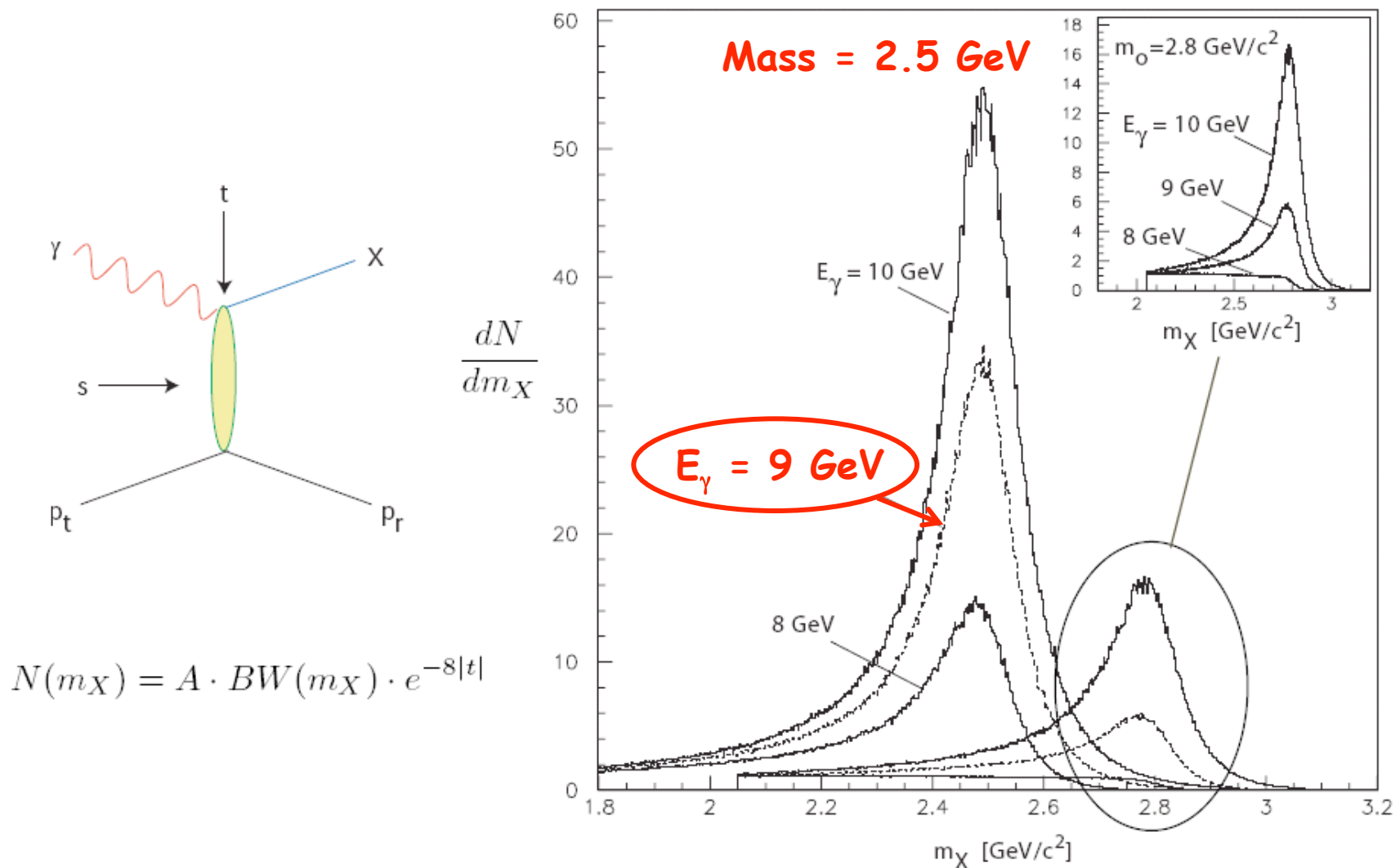
■ Polarization

- For a given produced resonance, linear polarization enables one to distinguish between naturalities of exchanged particles.
- If the production mechanism is known, linear polarization enables one to filter resonances of different naturalities.



Filter on naturality

Minimum photon energy for search

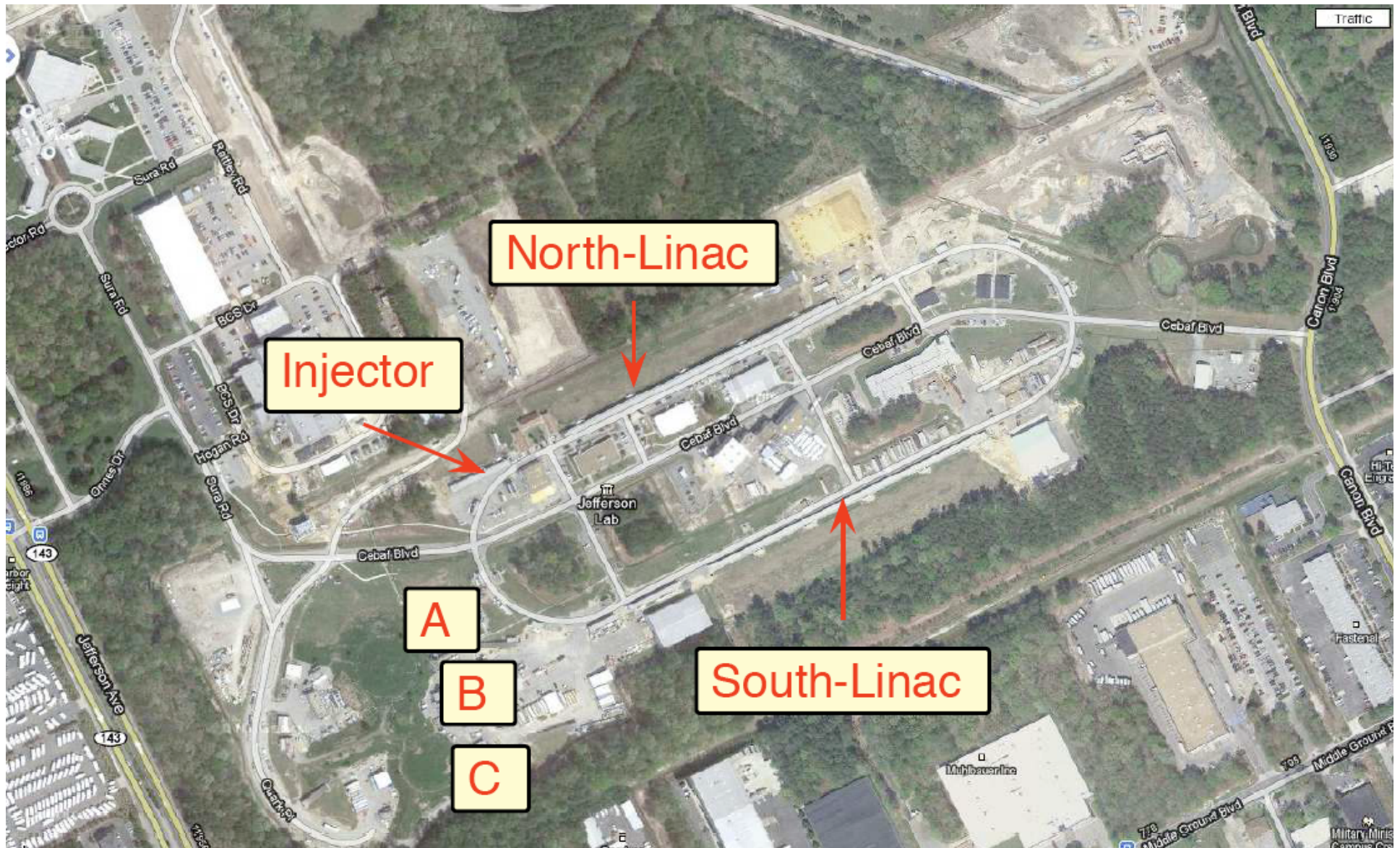


Resonant shapes generated with the same widths and production cross sections. Yield and line shape determined by production kinematics.

GlueX strategy for hybrid meson search

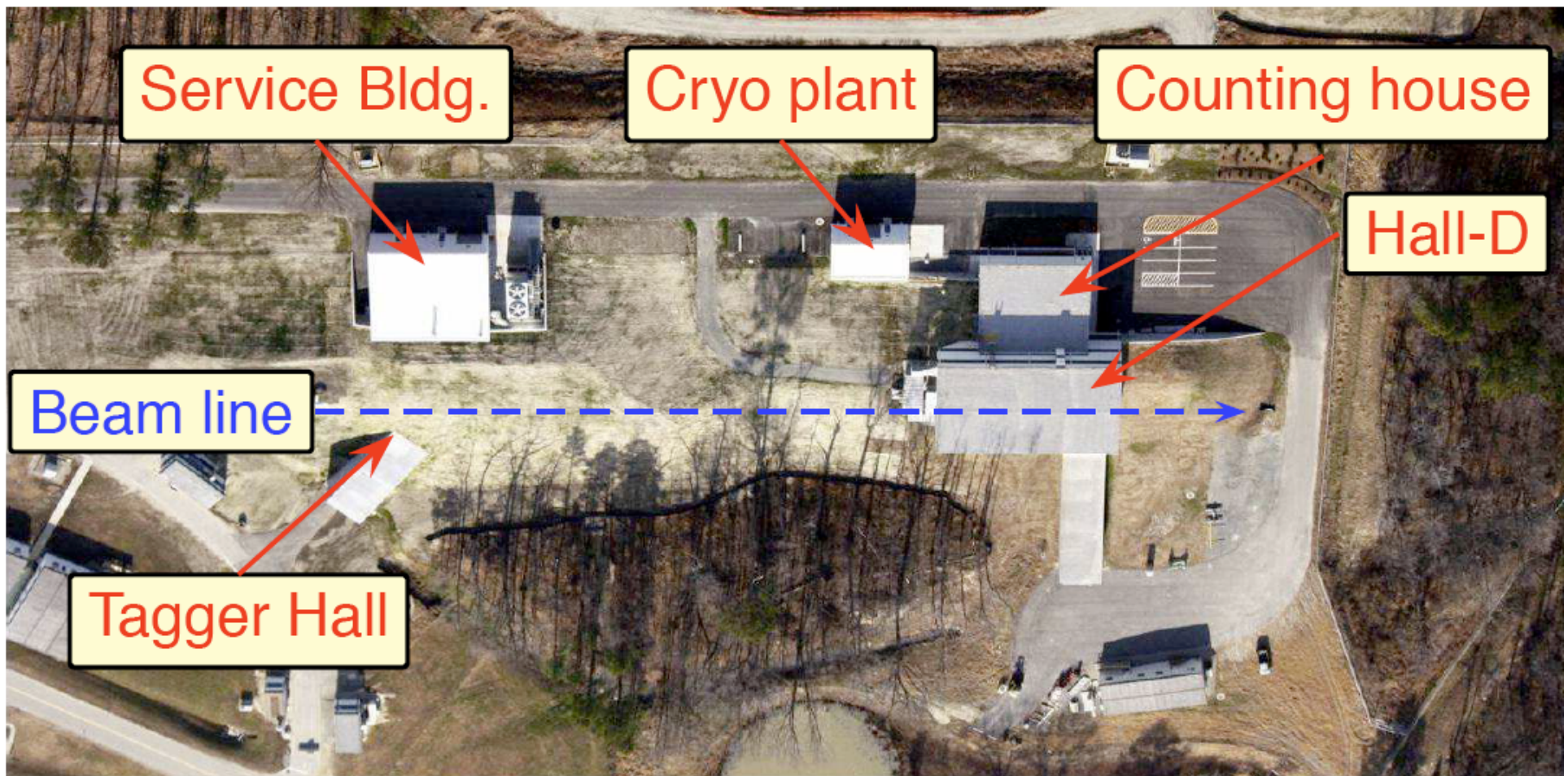
- Use 8 – 9 GeV polarized photons (12 GeV electron beam)
 - Expect production of hybrids to be comparable to normal mesons
 - Dearth of experimental data
- Use hermetic detector with large acceptance
 - Decay modes expected to have multiple particles
 - hermetic coverage for charged and neutral particles
 - high data acquisition rate to enable amplitude analysis
- Perform amplitude analysis
 - identify quantum numbers as a function of mass
 - check consistency of results in different decay modes

Areal view of accelerator



Hall D civil construction complete

Summer 2011



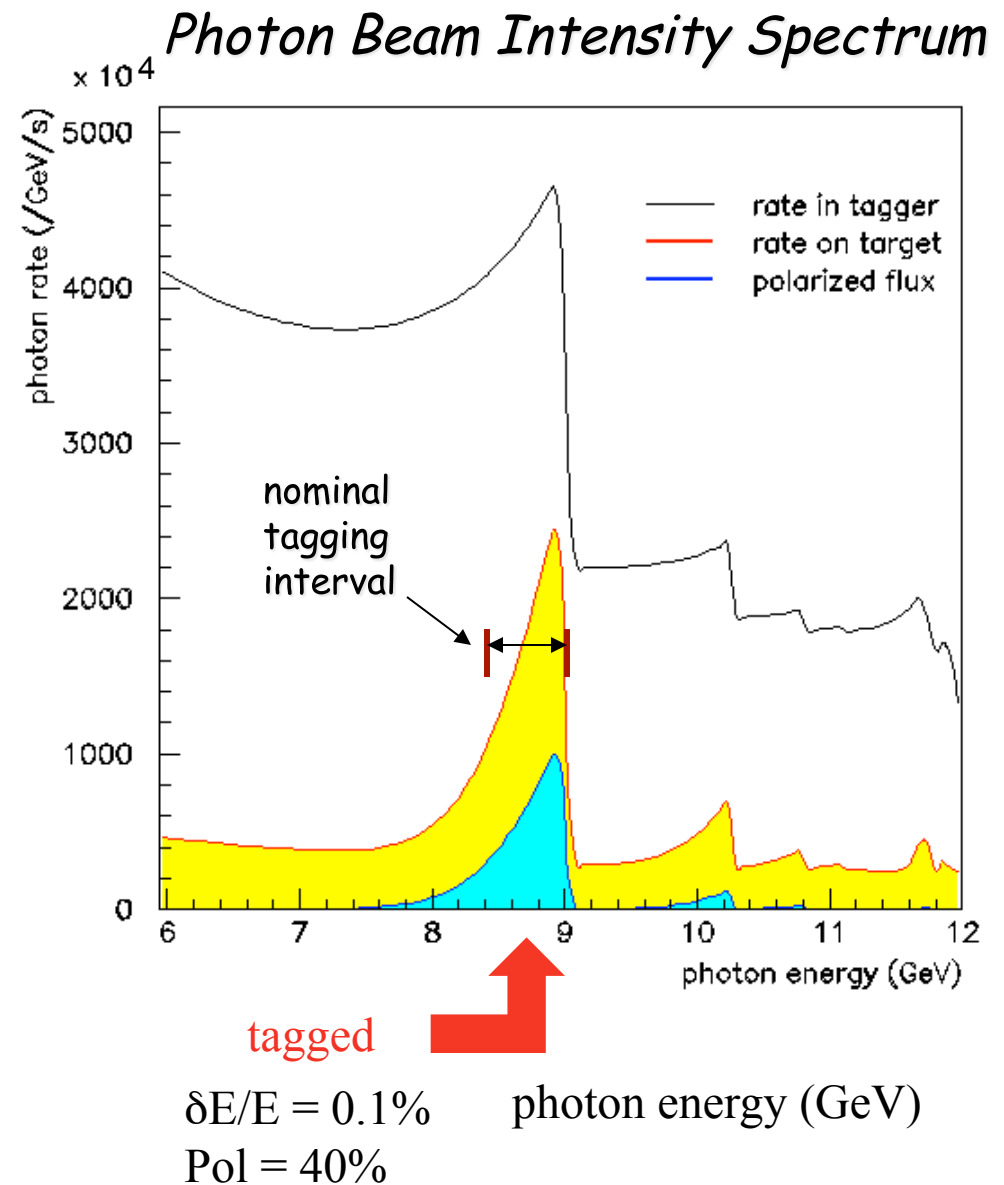
Linearly Polarized Photon Beam

Rates are based on

- 12 GeV electron beam
- 20 μm diamond crystal
- 300 nA electron beam
- Rad-collimator: 76 m
- Collimator diameter: 3.5mm

Leads to $10^7 \gamma/\text{s}$ on target

Design is expandable to $10^8 \gamma/\text{s}$

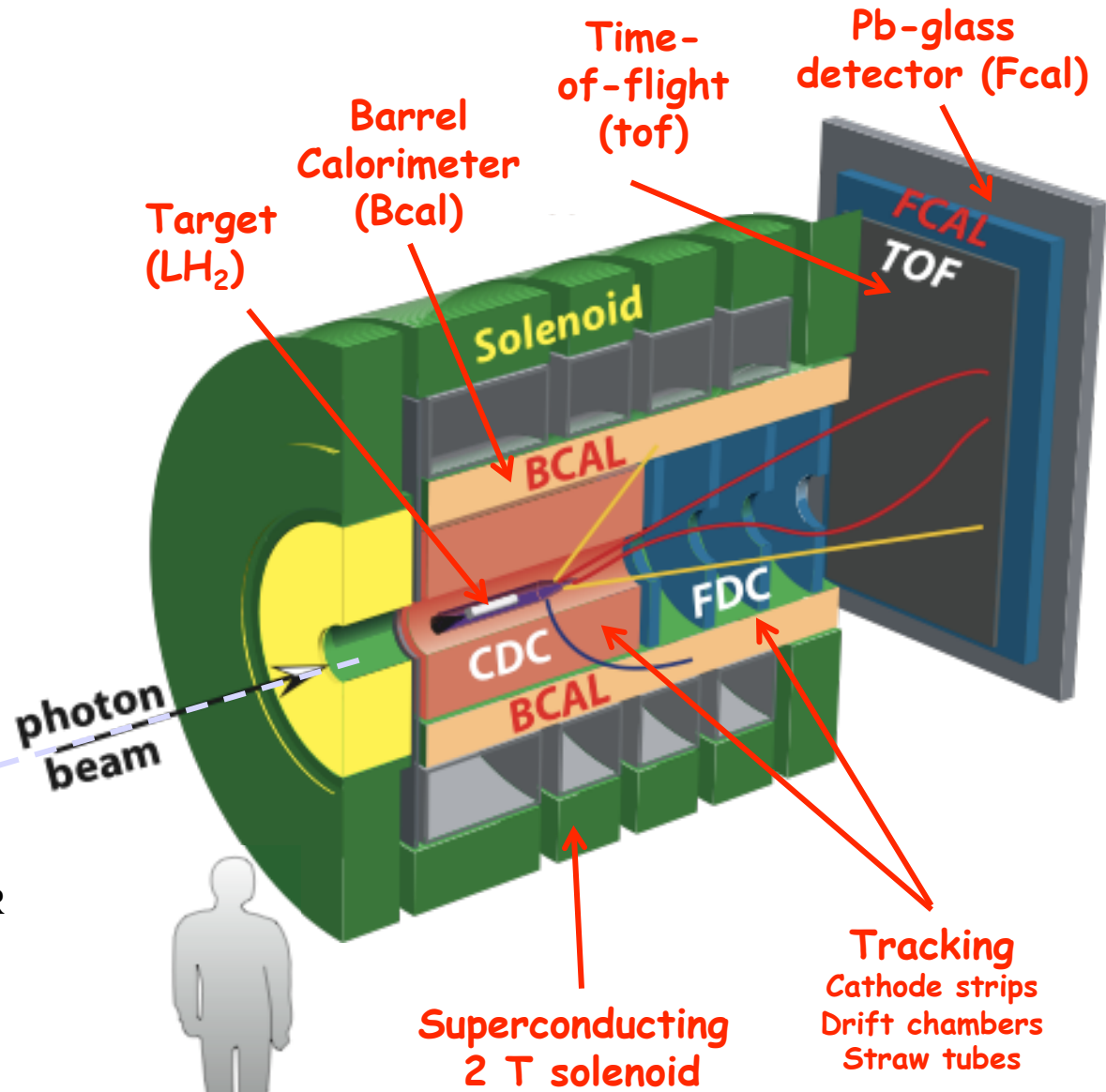


Hall D – GlueX detector

Hermetic detection
of charged and
neutral particles in
solenoid magnet

Initial Flux $10^7 \gamma/s$
18,000 FADCs
4,000 pipeline TDCs
20 KHz L1 trigger
300 MB/s to tape

TAGGER SPECTROMETER
(UPSTREAM)

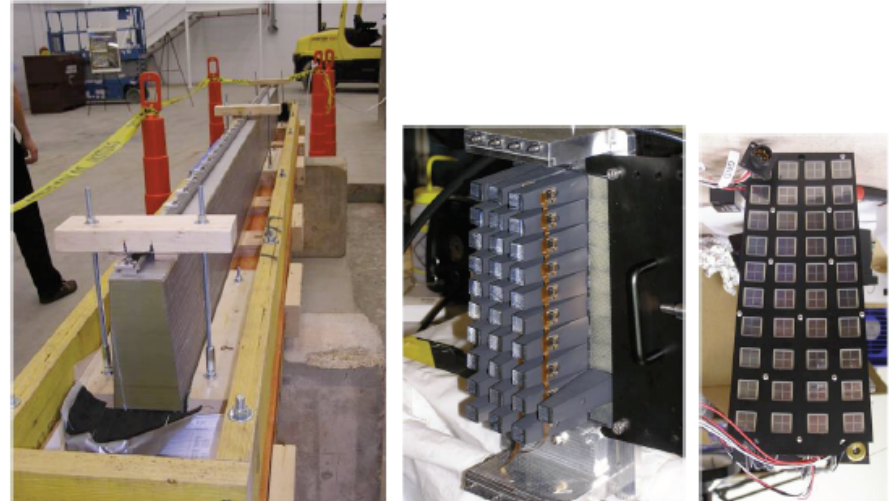


Detector status

Solenoidal Magnet: tested at 1500 A



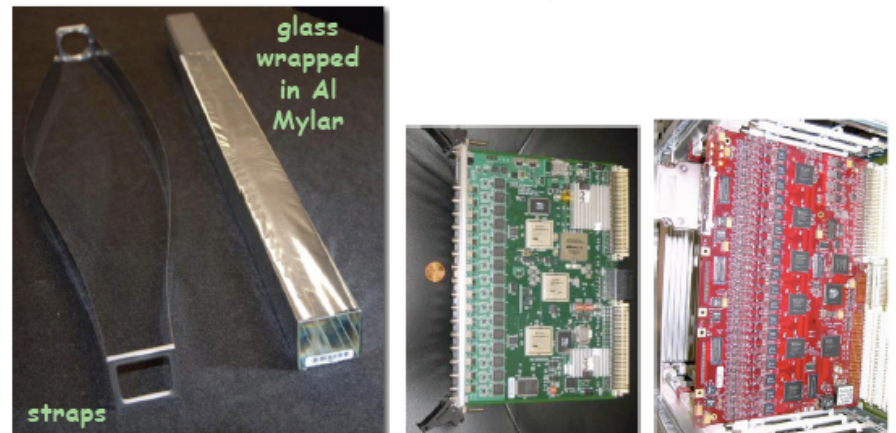
BCAL: All 48 modules built



CDC: all 3500 wires strung



FCAL: all 2800 lead glass and PMTs



FDC: 60% done

Electronics: 70% ordered

Sample amplitude analysis with GlueX

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

generated waves

$$a_1(1260) \rightarrow \rho\pi \quad (\text{S} - \text{wave})$$

$$a_2(1320) \rightarrow \rho\pi \quad (\text{D} - \text{wave})$$

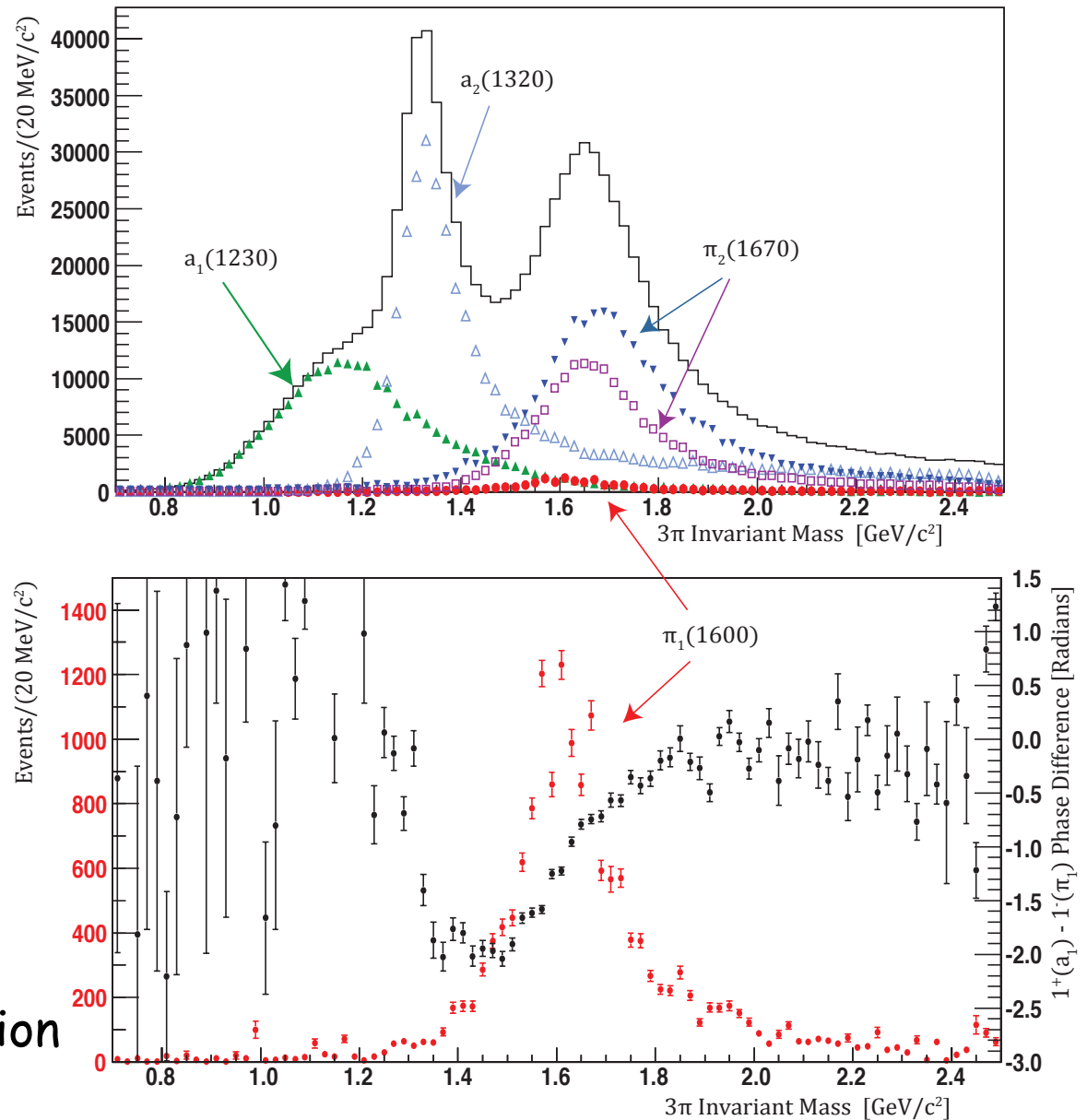
$$\pi_1(1600) \rightarrow \rho\pi \quad (\text{P} - \text{wave})$$

$$\pi_2(1670) \rightarrow f_2\pi \quad (\text{S} - \text{wave})$$

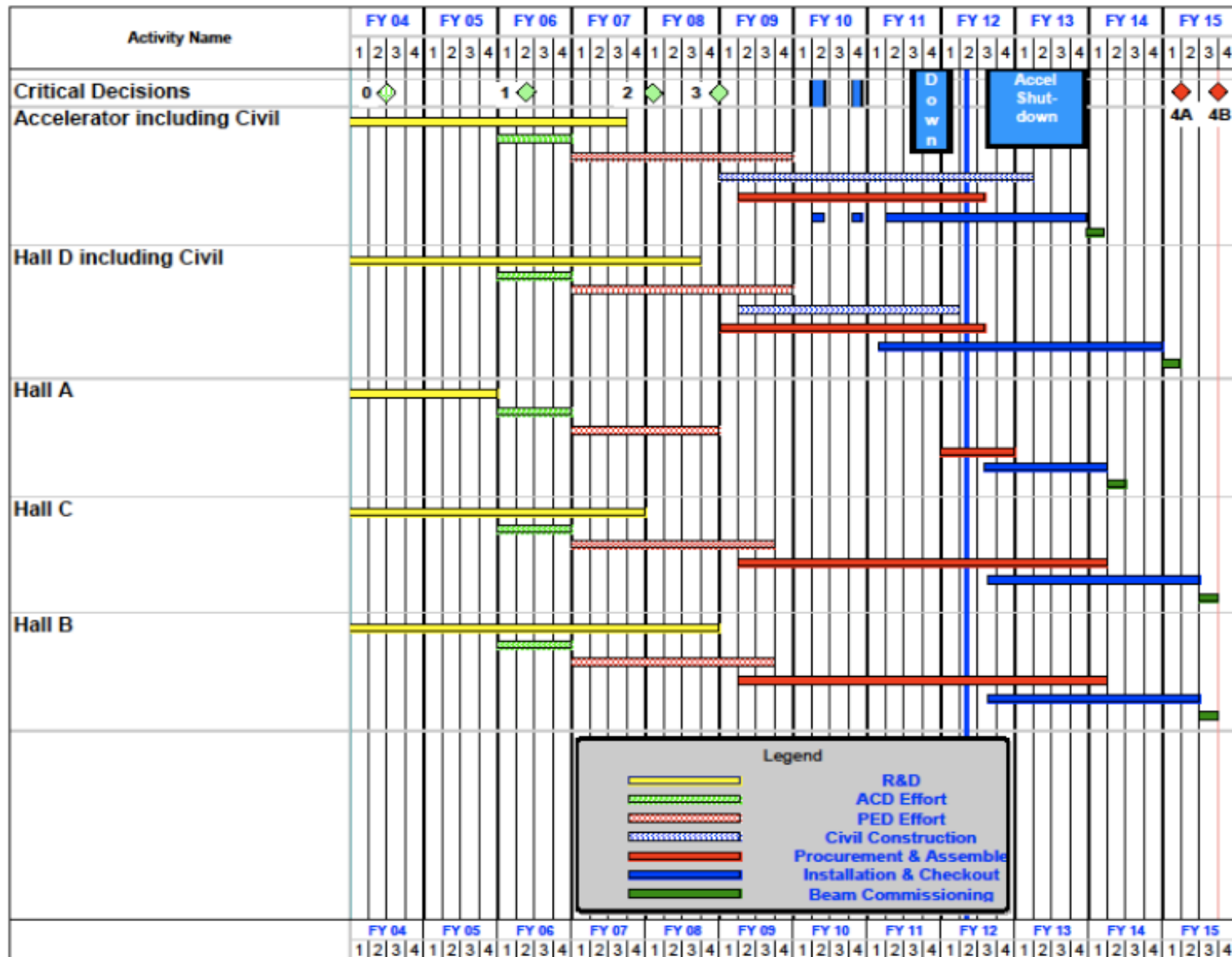
$$\pi_2(1670) \rightarrow \rho\pi \quad (\text{P} - \text{wave})$$

1^- exotic wave
generated with 1.6%
relative strength

Corresponds to 3.5 hours
GlueX data, full detector
simulation and reconstruction



12 GeV Project Schedule



- Hall A commissioning start Jan 2014
- Hall D commissioning start October 2014
- Halls B and C commissioning start April 2015

Summary

- QCD on the Lattice

- Lattice calculations have made great strides in calculating the spectrum of normal and hybrid mesons.
- Hybrid masses are expected in the range of 1.8 to 2.7 GeV
- The spectrum is consistent with the constituent gluon model ($J_g=1^{+-}$)

- Model expectations

- In photoproduction, gluonic excitations will be produced with roughly the same cross sections as normal mesons.
- Gluonic excitations are expected to decay preferentially to multi-particle final states

- The GlueX experiment will study the spectrum of mesons with a polarized photon beam up to $M \sim 2.8$ GeV with sensitivities of a few percent of the total cross section.