The Search for QCD Exotics and

The Jefferson Lab Hall D Project

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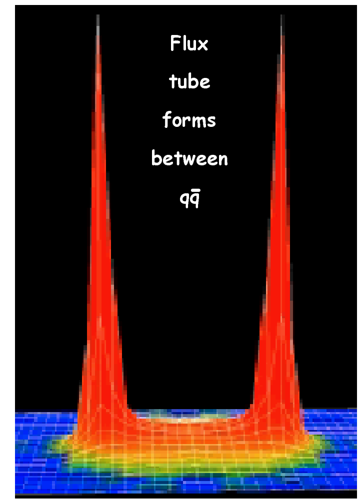
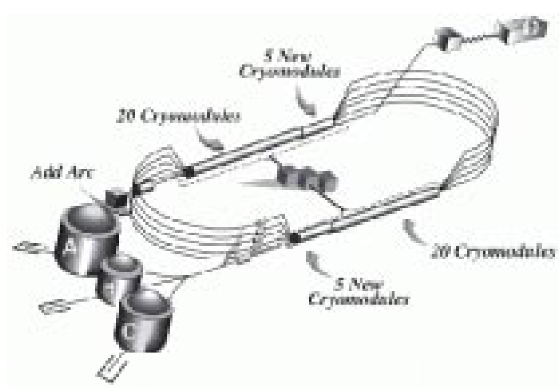
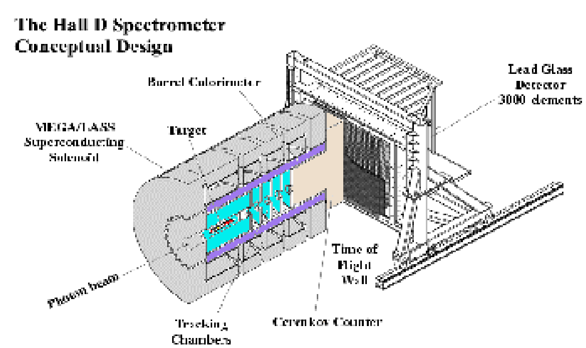


SLAC Seminar, 10 January, 2002





Outline

Meson spectroscopy and gluonic excitations

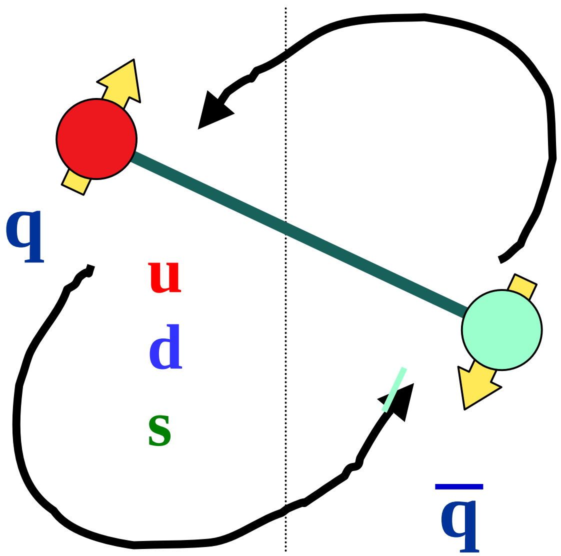
Experimental Evidence

The Hall D Project

History and Timelines

Summary

Light Quark Meson Spectroscopy

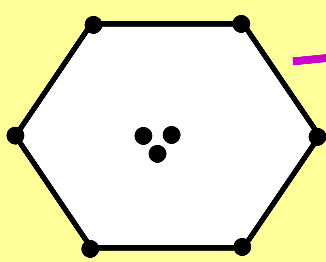


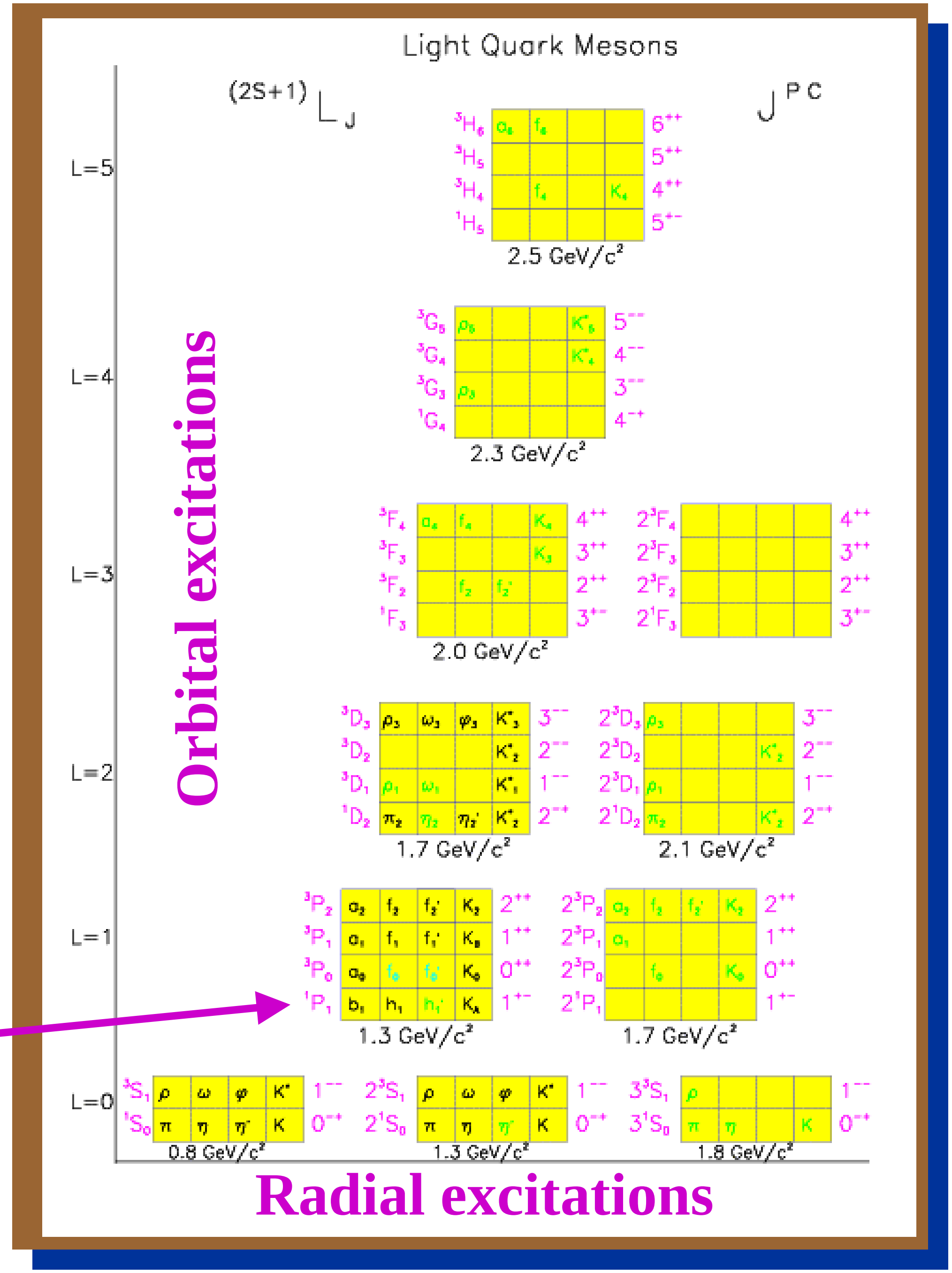
$J = L + S$

$P = -(-1)^L$

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

Nonets



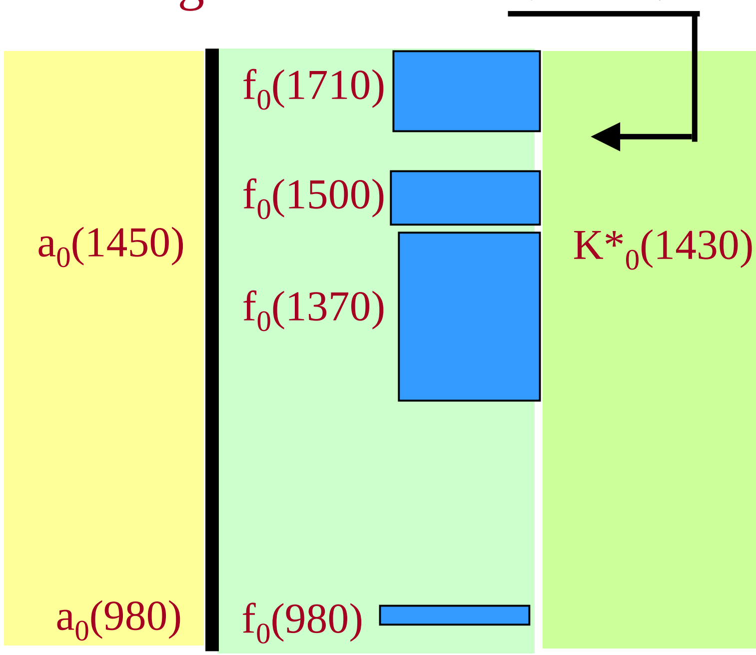


QCD is a theory of quarks and gluons

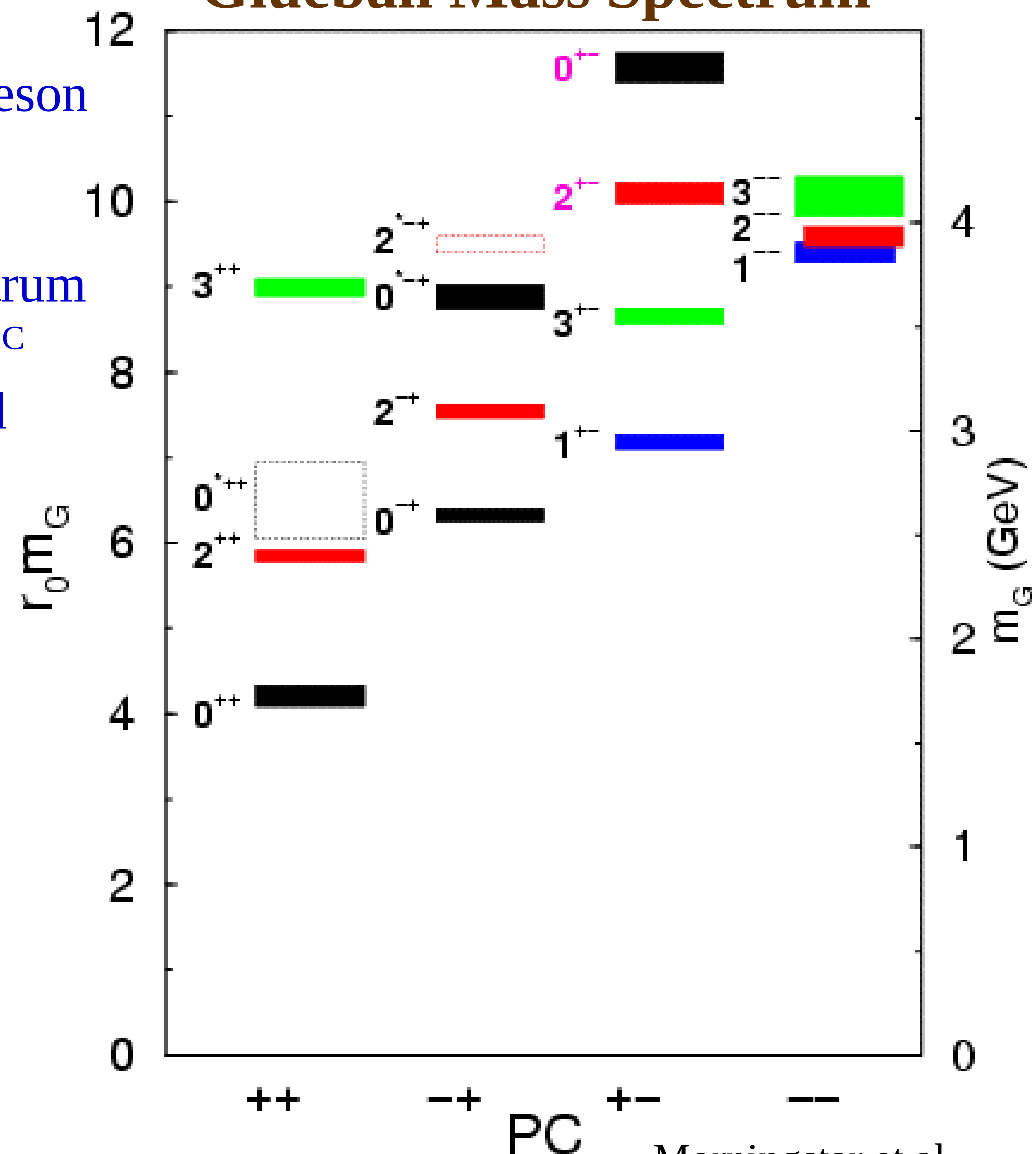
What role do gluons play in the meson spectrum?

Lattice calculations predict a spectrum of glueballs. The lightest 3 have J^{PC} Quantum numbers of 0^{++} , 2^{++} and 0^{-+}.

The lightest is about 1.6 GeV/c^2

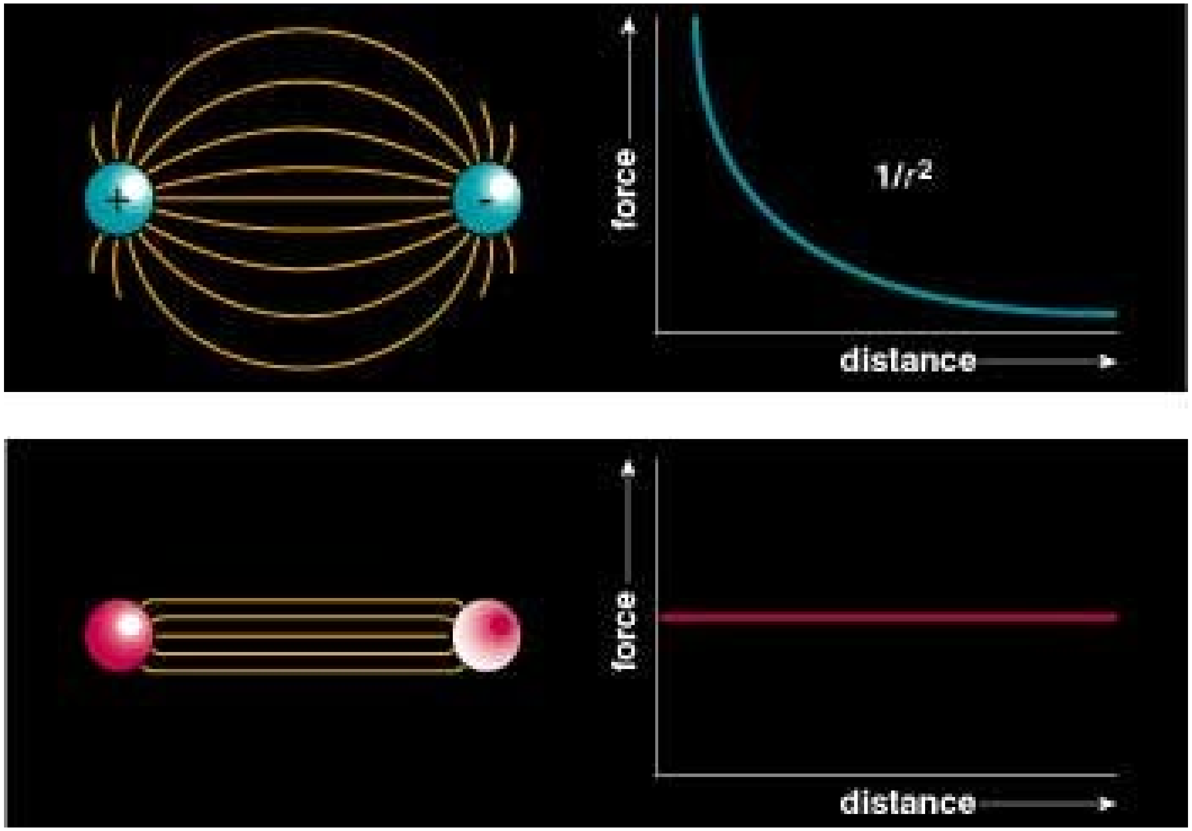


Glueball Mass Spectrum



Morningstar et al.

Flux Tubes and Confinement



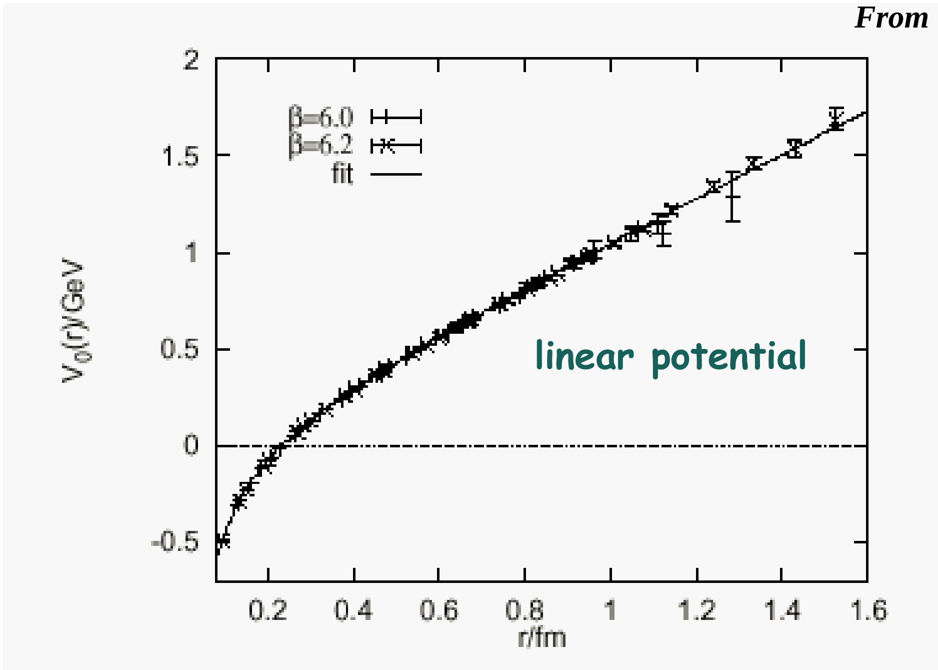
Color Field: Because of self interaction, confining flux tubes form between static color charges

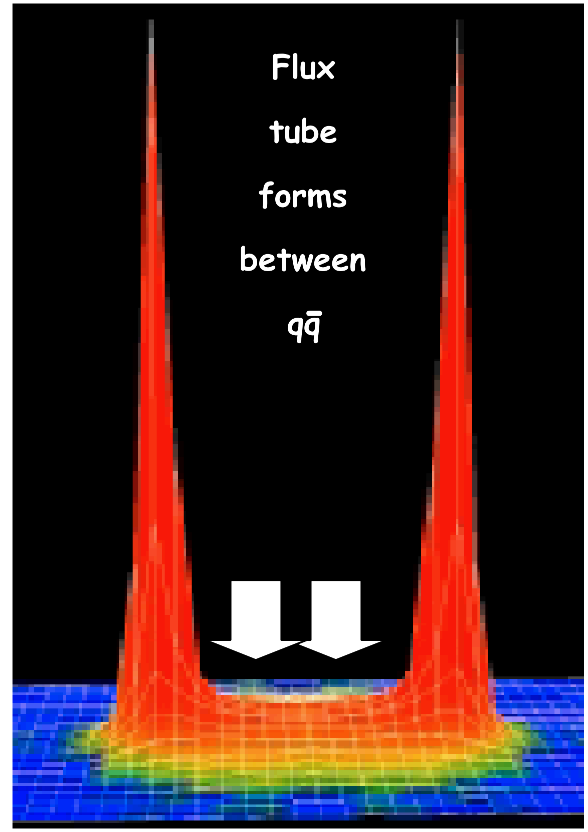
Notion of flux tubes comes about from model-independent general considerations. Idea originated with Nambu in the '70s

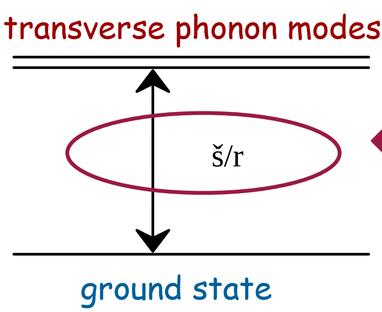
Lattice QCD

Flux tubes realized

From G. Bali







Hybrid mesons

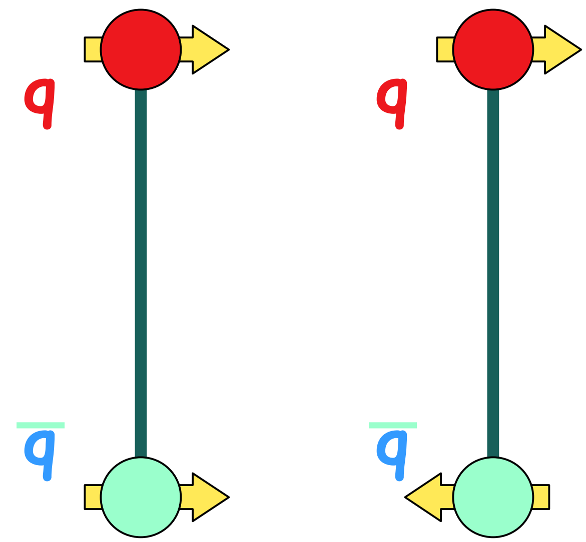
1 GeV mass difference

Normal mesons

Confinement arises from flux tubes and their excitation leads to a new spectrum of mesons

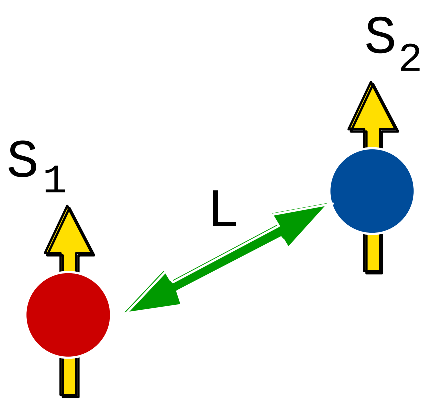
Normal Mesons

Normal mesons occur when the flux tube is in its ground state



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

Nonets characterized by given J^{PC}



$$S = S_1 + S_2$$

$$J = L + S$$

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

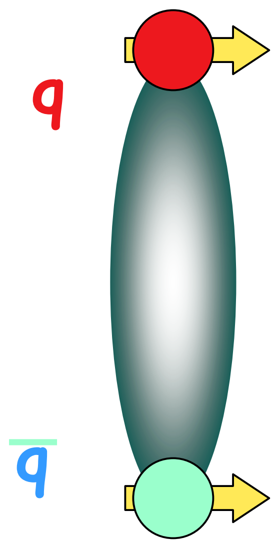
$$C = (-1)^{L+S}$$

Not allowed: exotic combinations:

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

Excited Flux Tubes

How do we look for gluonic degrees of freedom in spectroscopy?



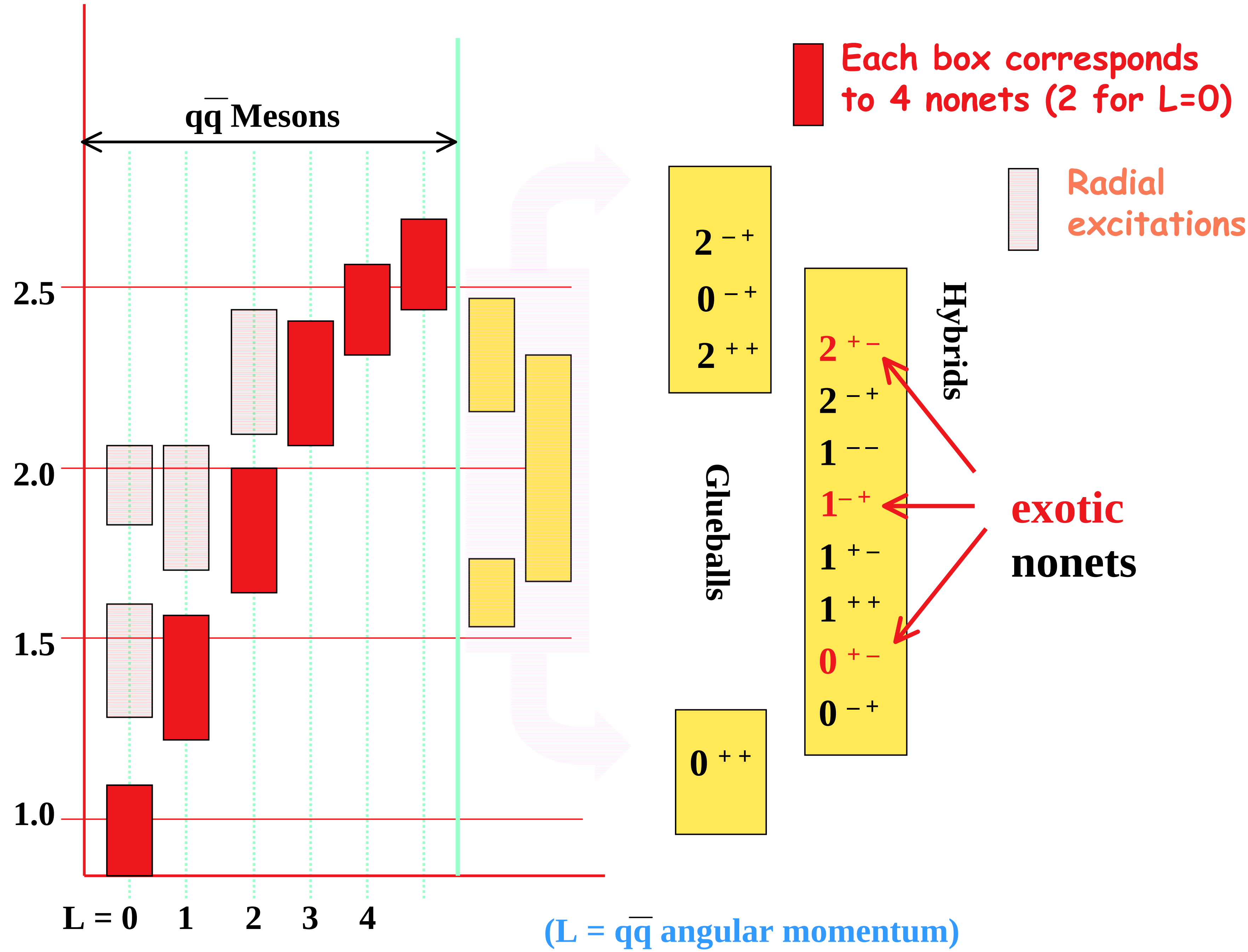
First excited state of flux tube has J=1 and when combined with S=1 for quarks generate:

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

exotic (0^{+-}, 1^{-+}, 2^{+-})

Exotic mesons are not generated when S=0

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



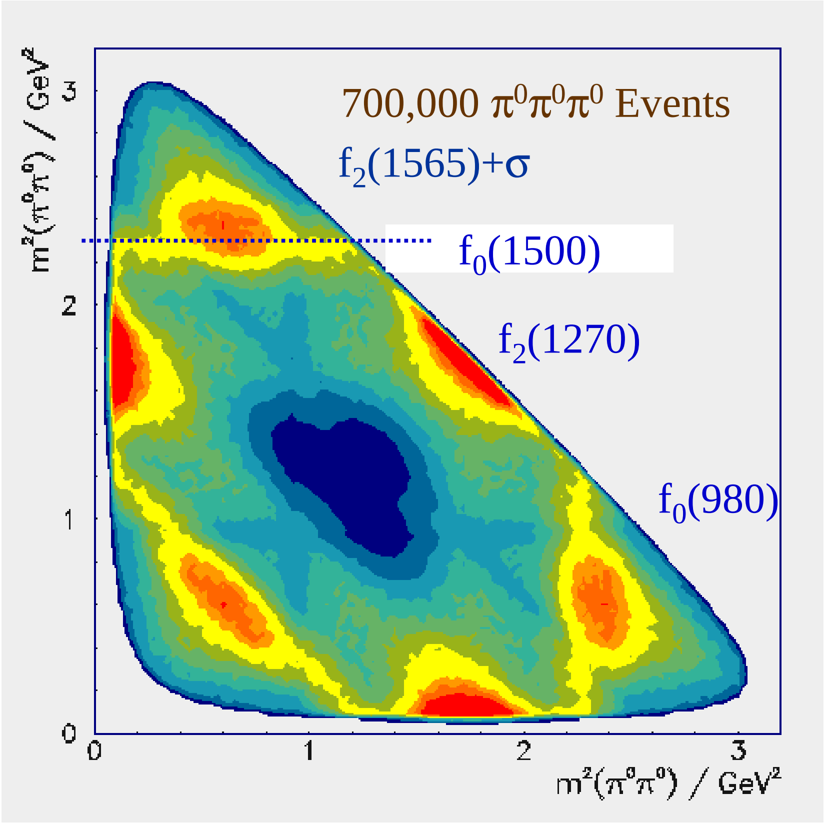
$q\bar{q}$ Mesons
Each box corresponds to 4 nonets (2 for L=0)
Radial excitations
2.5
2.0
1.5
1.0
L = 0 1 2 3 4
2^{-+}
0^{-+}
2^{++}
Glueballs
0^{++}
Hybrids
2^{+-}
2^{-+}
1^{--}
1^{-+}
1^{+-}
1^{++}
0^{+-}
0^{-+}
exotic nonets
(L = $q\bar{q}$ angular momentum)

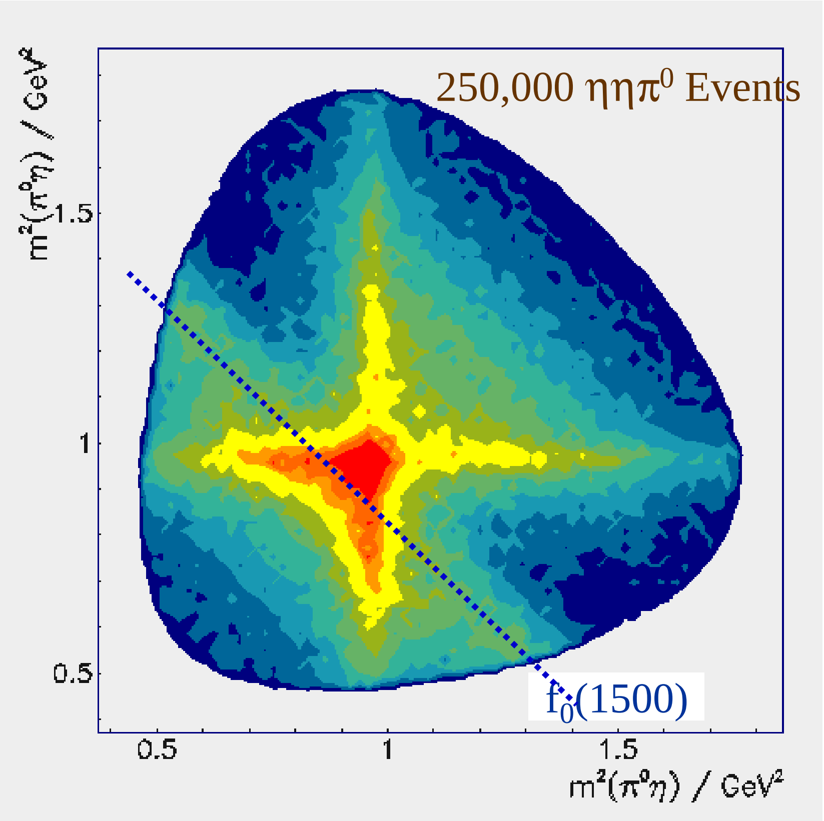
Crystal Barrel Results: antiproton-proton annihilation at rest

Discovery of the $f_0(1500)$
Discovery of the $a_0(1450)$

$f_0(1500) \Rightarrow \pi\pi, \eta\eta, \eta\eta', KK, 4\pi$

$f_0(1370) \Rightarrow 4\pi$





The Scalar Mesons

Overpopulation
Strange Decay Patterns
Seen in glue-rich reactions
Not in glue-poor

J/Ψ Decays?

$f_0(1370)$ seen
$f_0(1500)$????
$f_0(1710)$ seen

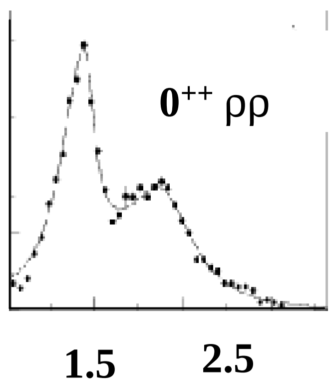
Awaiting CLEO-c

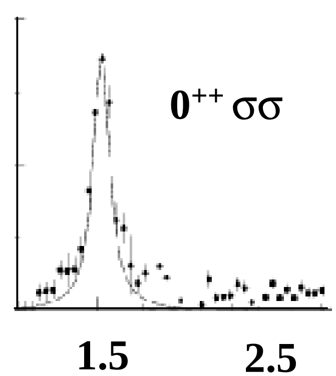
Glueball and Mesons are mixed, but what is the mixing scheme?

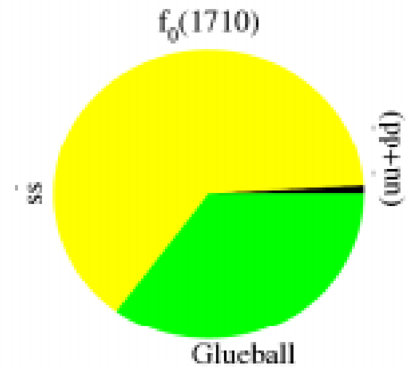
What about 2^{++} and 0^{-+} ?

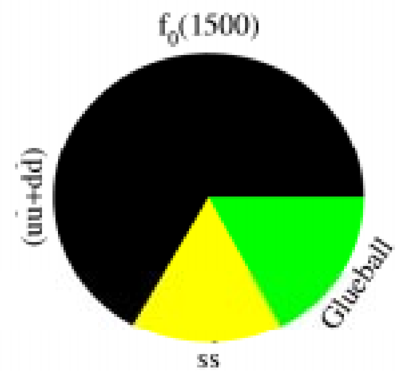
Central Production WA102

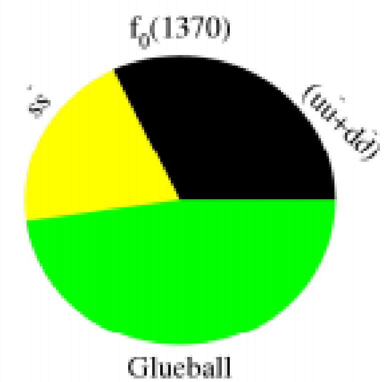
Observes
$f_0(1370)$
$f_0(1500)$
$f_0(1710)$











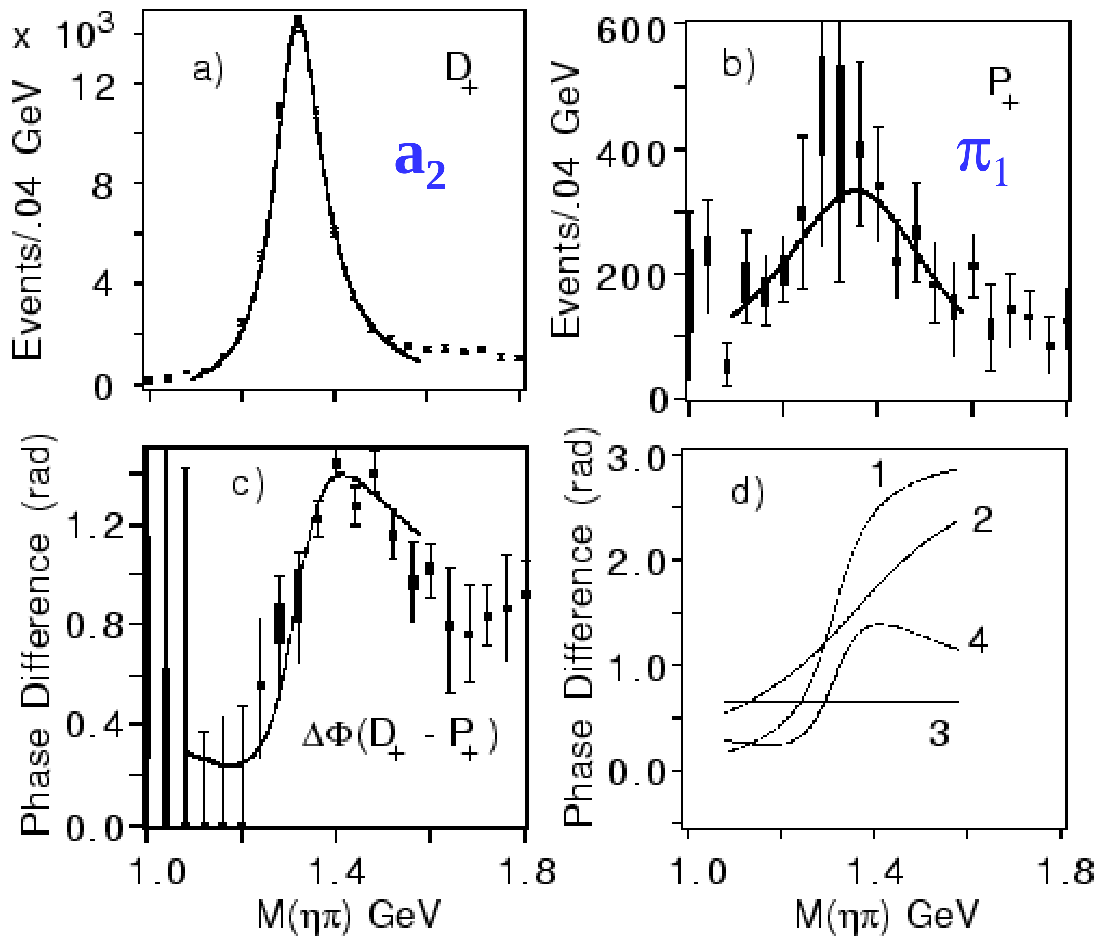
E852 Results

$\pi^- p \to \eta\pi^- p$ (18 GeV)

$\pi_1(1400)$ Mass = $1370 \pm 16^{+50}_{-30}$ MeV/c^2
Width = $385 \pm 40^{+65}_{-105}$ MeV/c^2

The $a_2(1320)$ is the dominant signal. There is a small (few %) exotic wave.

Interference effects show a resonant structure in 1^{-+}. (Assumption of flat background phase as shown as 3.)



Crystal Barrel Results: antiproton-neutron annihilation

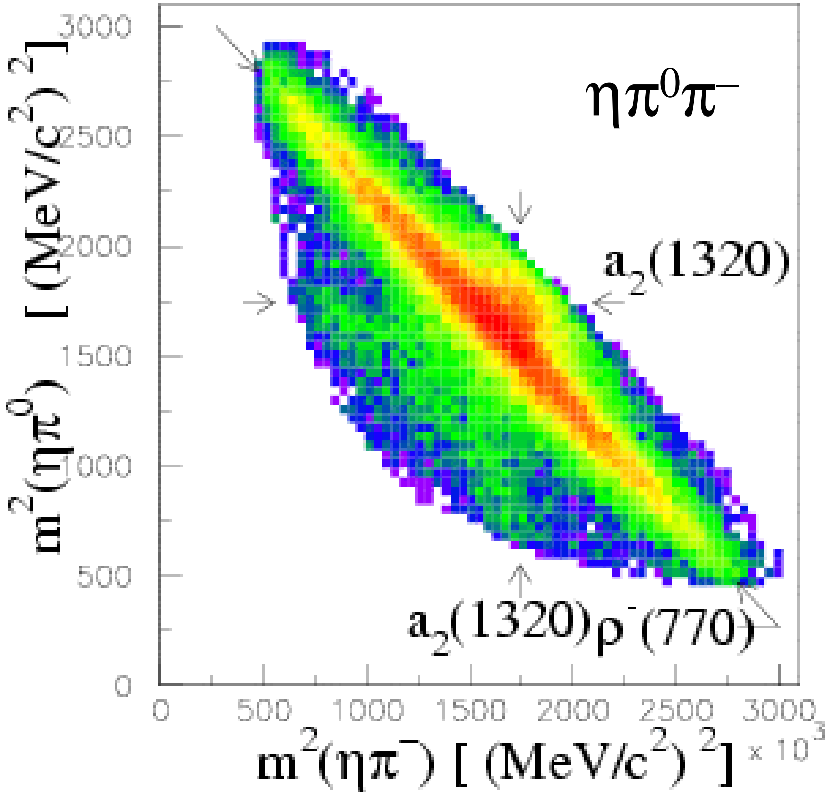
$\pi_1(1400)$ Mass = 1400 +- 20 +- 20 MeV/c^2

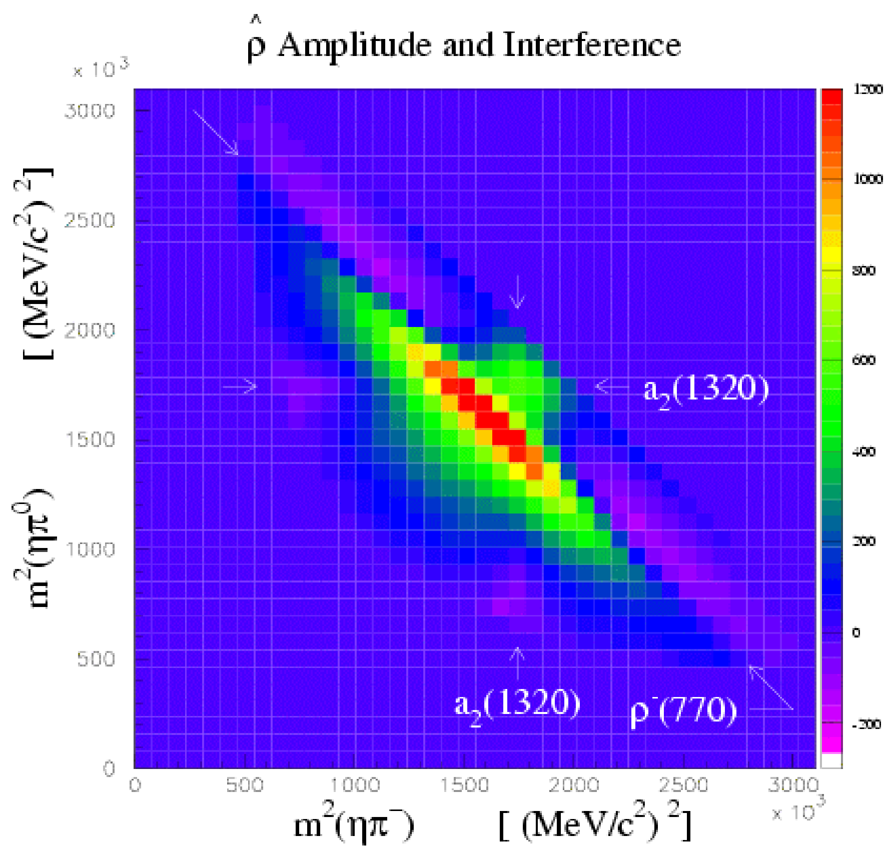
Width= 310+-50$^{+50}_{-30}$ MeV/c^2

Same strength as the a_2.

Produced from states with **one unit** of angular momentum.

Without π_1 χ^2/ndf = 3, with = 1.29



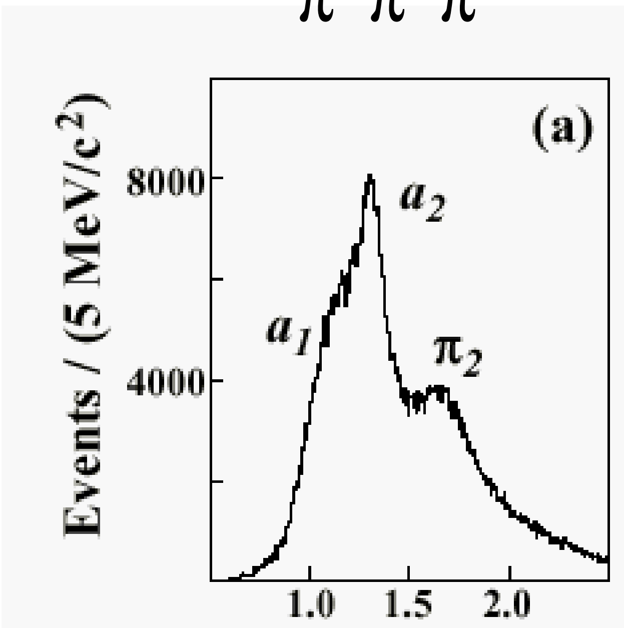


E852 Results

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

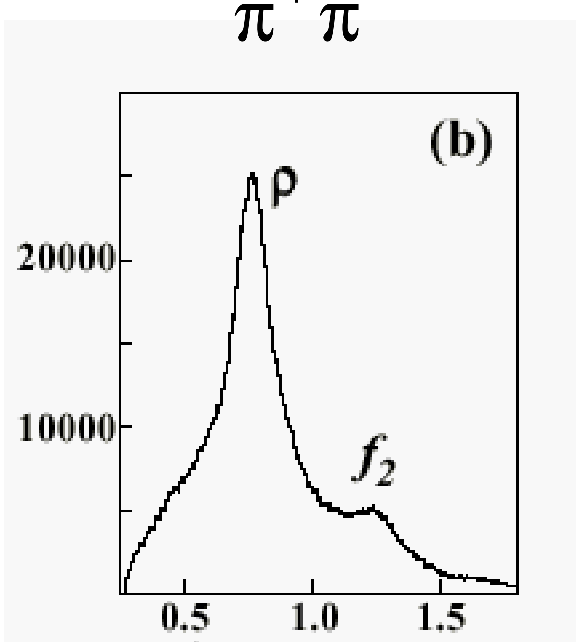
At 18 GeV/c

$\pi^+\pi^-\pi^-$



$M(\pi^+\pi^-\pi^-)$ $\left[\mathrm{GeV}/c^2\right]$

$\pi^+\pi^-$



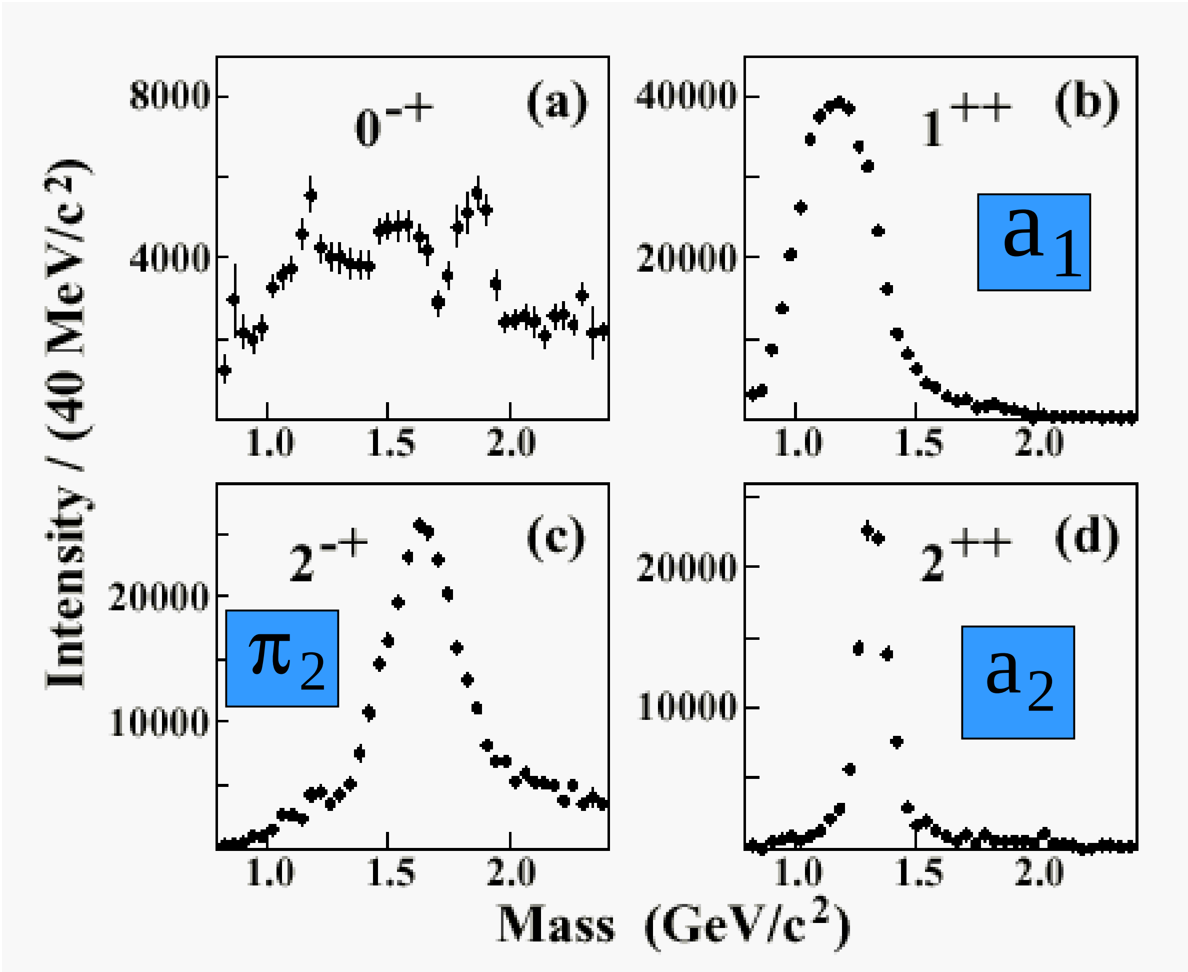
$M(\pi^+\pi^-)$ $\left[\mathrm{GeV}/c^2\right]$

to partial wave analysis

suggests $\pi^- p \rightarrow \rho^0 \pi^- p$

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

Results of Partial Wave Analysis

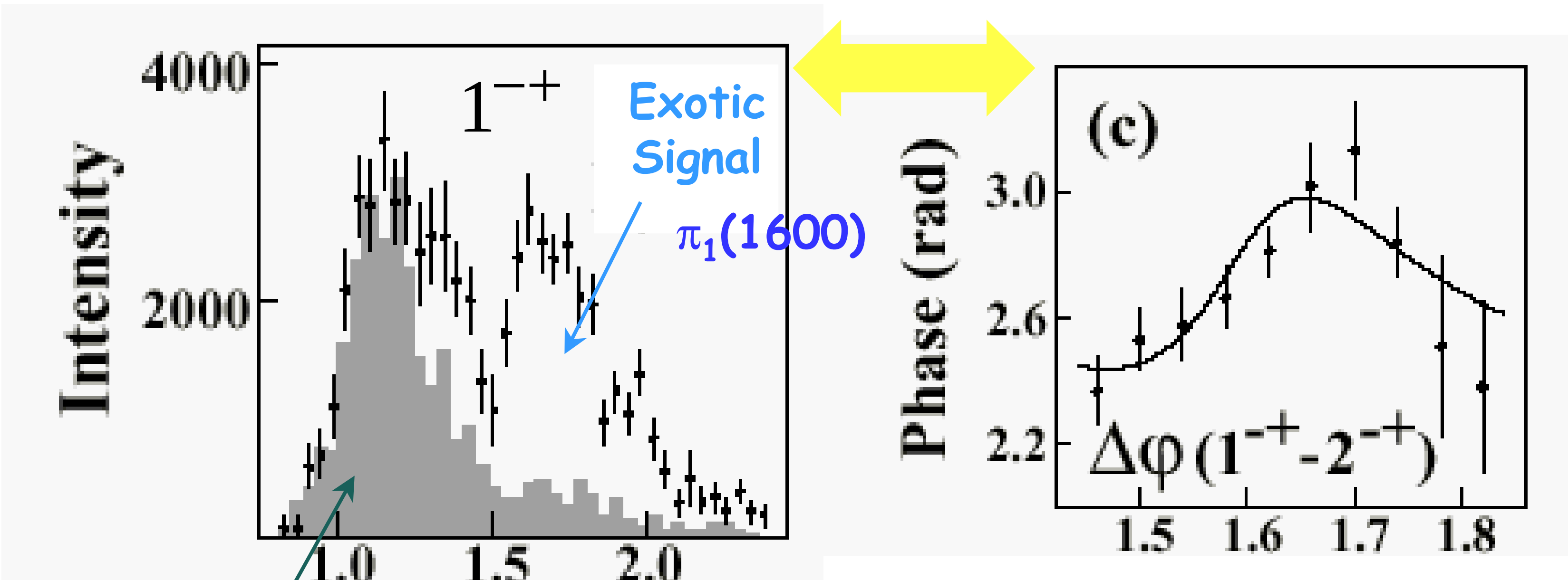


Benchmark Resonances
$a_1(1270)$
$a_2(1320)$
$\pi_2(1670)$

Benchmarks are needed to show resonant behavior.

An Exotic Signal in E852

Correlation of
Phase
&
Intensity



Leakage
From
Non-exotic Wave
due to imperfectly
understood acceptance

$M(\pi^+\pi^-\pi^-)\ \ [GeV/c^2]$

$3\pi\ \ m=1593{+-}8^{+28}_{-47}\quad \Gamma=168{+-}20^{+150}_{-12}$

$\pi\eta'\ \ m=1597{+-}10^{+45}_{-10}\quad \Gamma=340{+-}40{+-}50$

Current Evidence

Have gluonic excitations been observed ?

Glueballs

Overpopulation of the scalar nonet and LGT predictions suggest that the glueball and the scalar mesons are mixed

Complication is mixing with conventional qq States

Need to observe additional glueball states

Hybrids

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

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

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

by BNL E852, CBAR and VES

Not without controversy

Not in expected decay modes

Collaboration

A. Dzierba (Spokesperson) - IU
C. Meyer (Deputy Spokesperson) - CMU
E. Smith (JLab Hall D Group Leader)

Collaboration Board

L. Dennis (FSU)
J. Kellie (Glasgow)
G. Lolos (Regina) (chair)
R. Jones (U Conn)
A. Klein (ODU)
A. Szczepaniak (IU)

US Experimental Groups

Carnegie Mellon University

Catholic University of America

Christopher Newport University

University of Connecticut

Florida International University

Florida State University

Indiana University

Jefferson Lab

Los Alamos National Lab

Norfolk State University

Old Dominion University

Ohio University

University of Pittsburgh

Renssalaer Polytechnic Institute

Other Experimental Groups

University of Glasgow

Institute for HEP - Protvino

Moscow State University

Budker Institute - Novosibirsk

University of Regina

90 collaborators
25 institutions

Theory Group

CSSM & University of Adelaide

Carleton University

Carnegie Mellon University

Insitute of Nuclear Physics - Cracow

Hampton University

Indiana University

Los Alamos

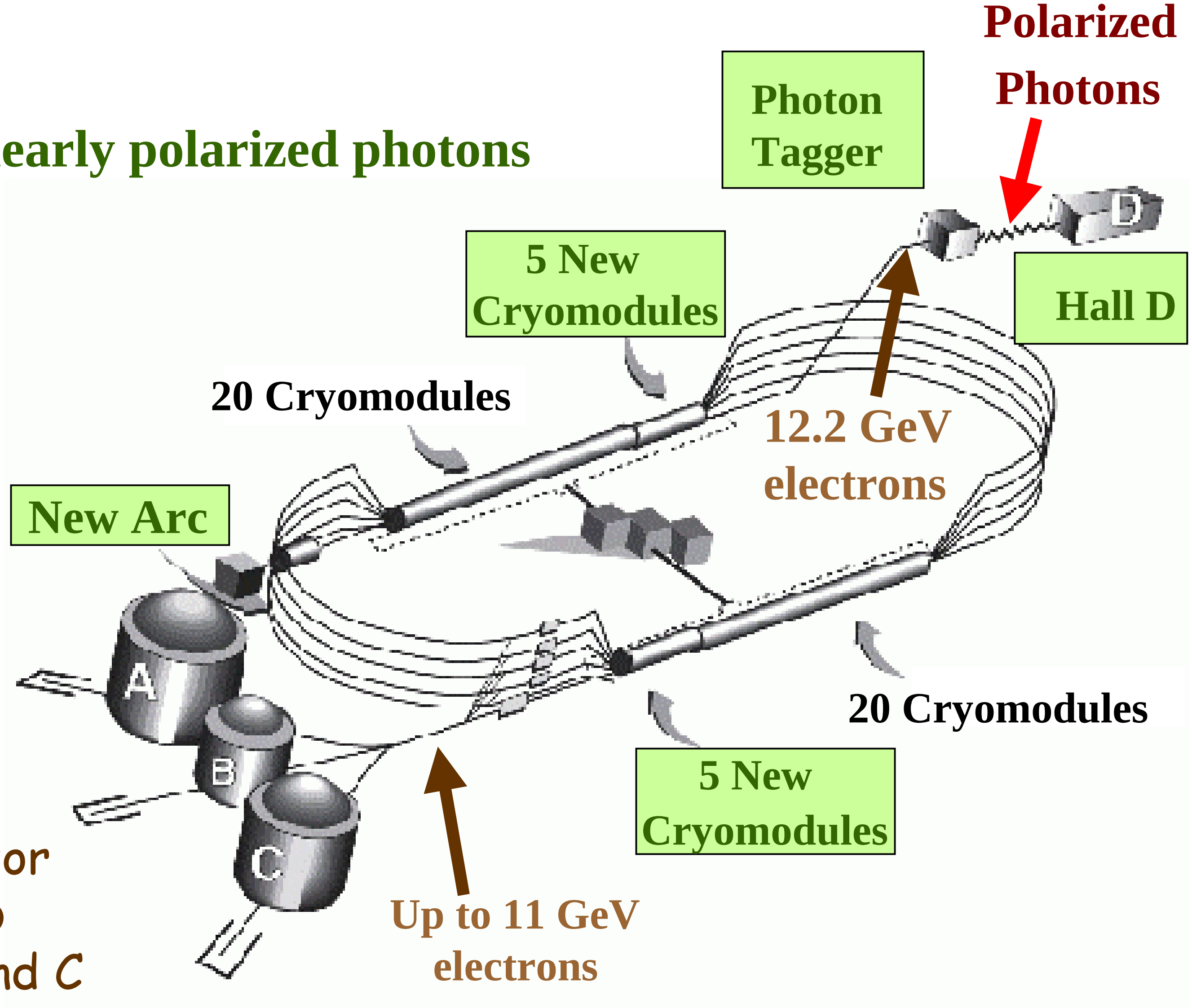
North Carolina Central University

University of Pittsburgh

University of Tennessee/Oak Ridge

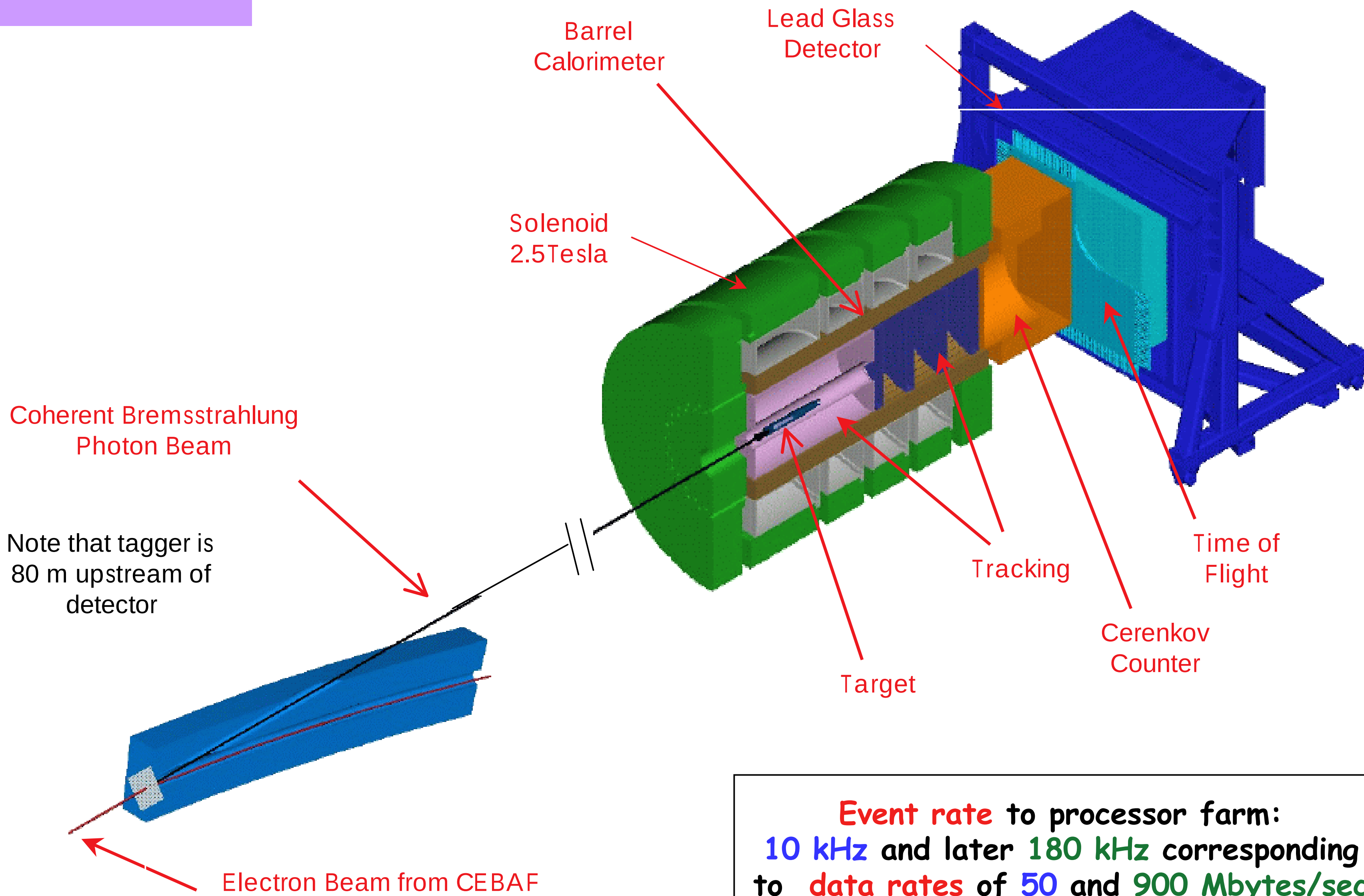
The Jlab 12 GeV Upgrade

Intense tagged, linearly polarized photons



$70 Million Accelerator
$35 Million for Hall D
$45 Million for A,B and C

Detector

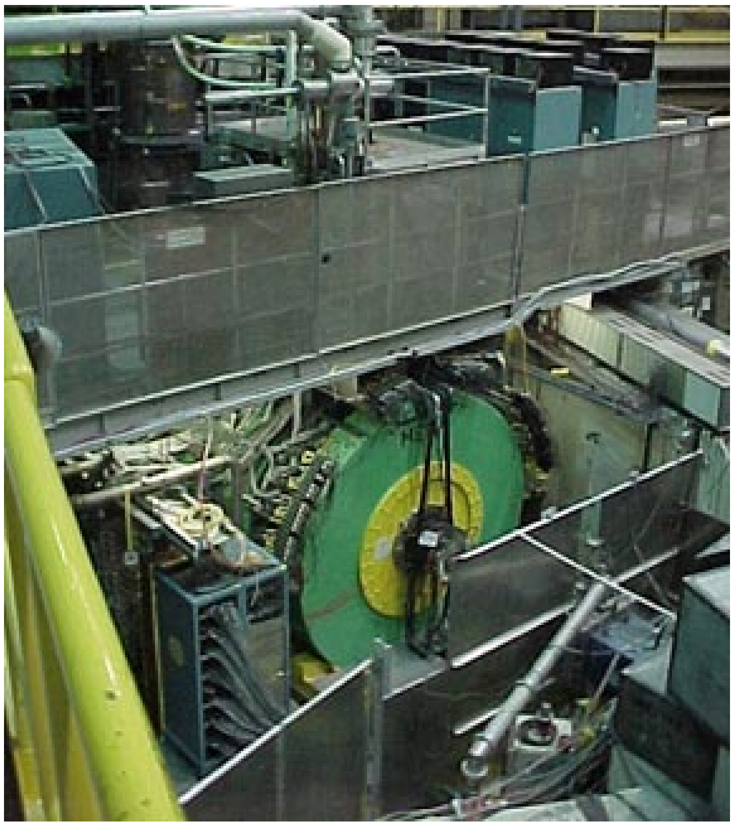


Event rate to processor farm:
10 kHz and later 180 kHz corresponding
to **data rates** of 50 and 900 Mbytes/sec
respectively

Solenoid & Lead Glass Array

Recycling of existing equipment

LASS/MEGA Solenoid



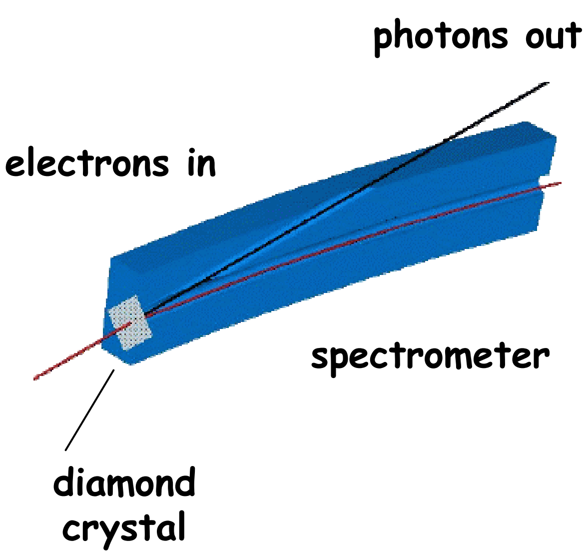
Being Moved to JLab

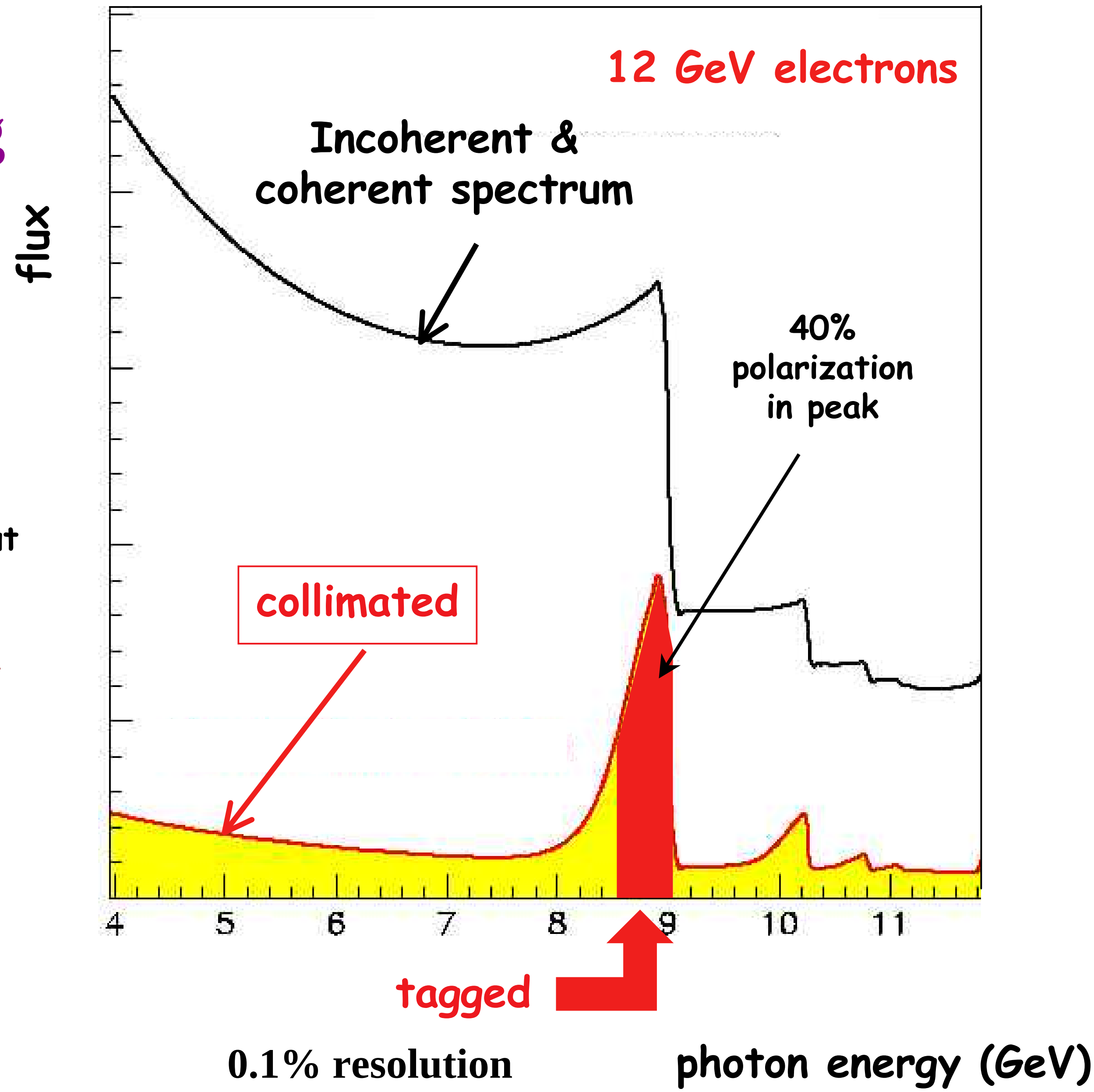
BNL E852 Pb-Glass Array

Now at JLab

Coherent Bremsstrahlung

This technique provides requisite energy, flux and polarization



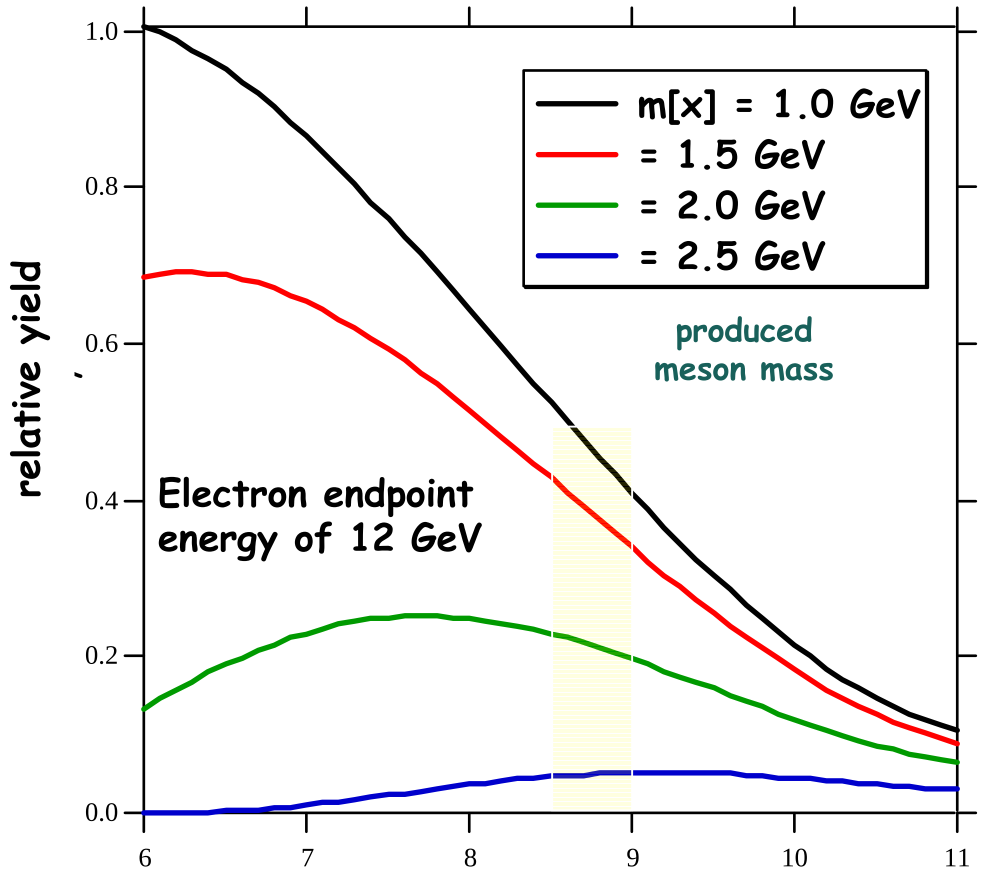


Optimal Photon Energy

Figure of merit based on:

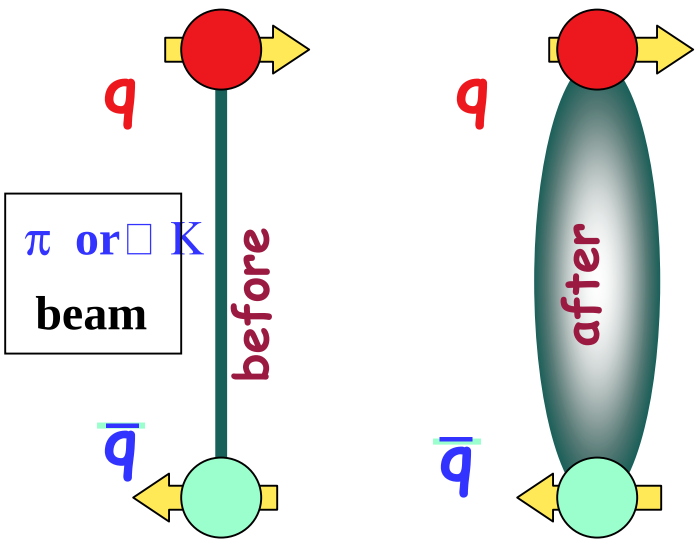
1. Beam flux and polarization
2. Production yields
3. Separation of meson/baryon production

Optimum photon energy is about 9 GeV



Staying below 10 GeV allows us to use an all-solenoidal detector.

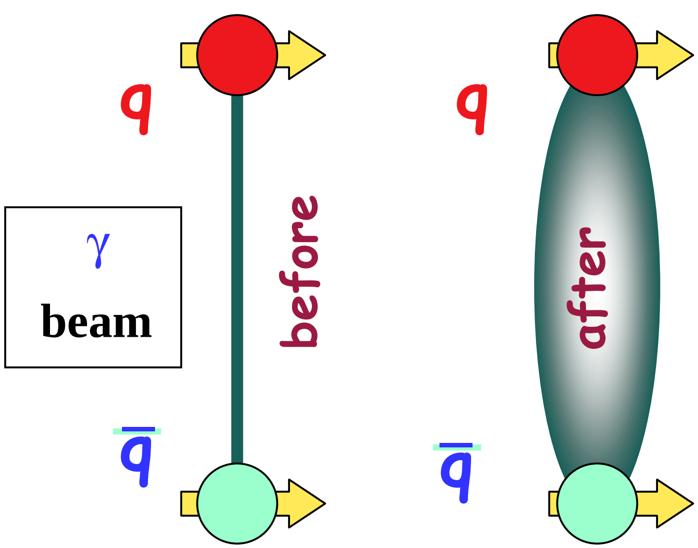
Why Photoproduction ?



Quark spins anti-aligned

A pion or kaon beam,
when scattering occurs,
can have its flux tube excited

Much data in hand but little
evidence for gluonic excitations
(and not expected)

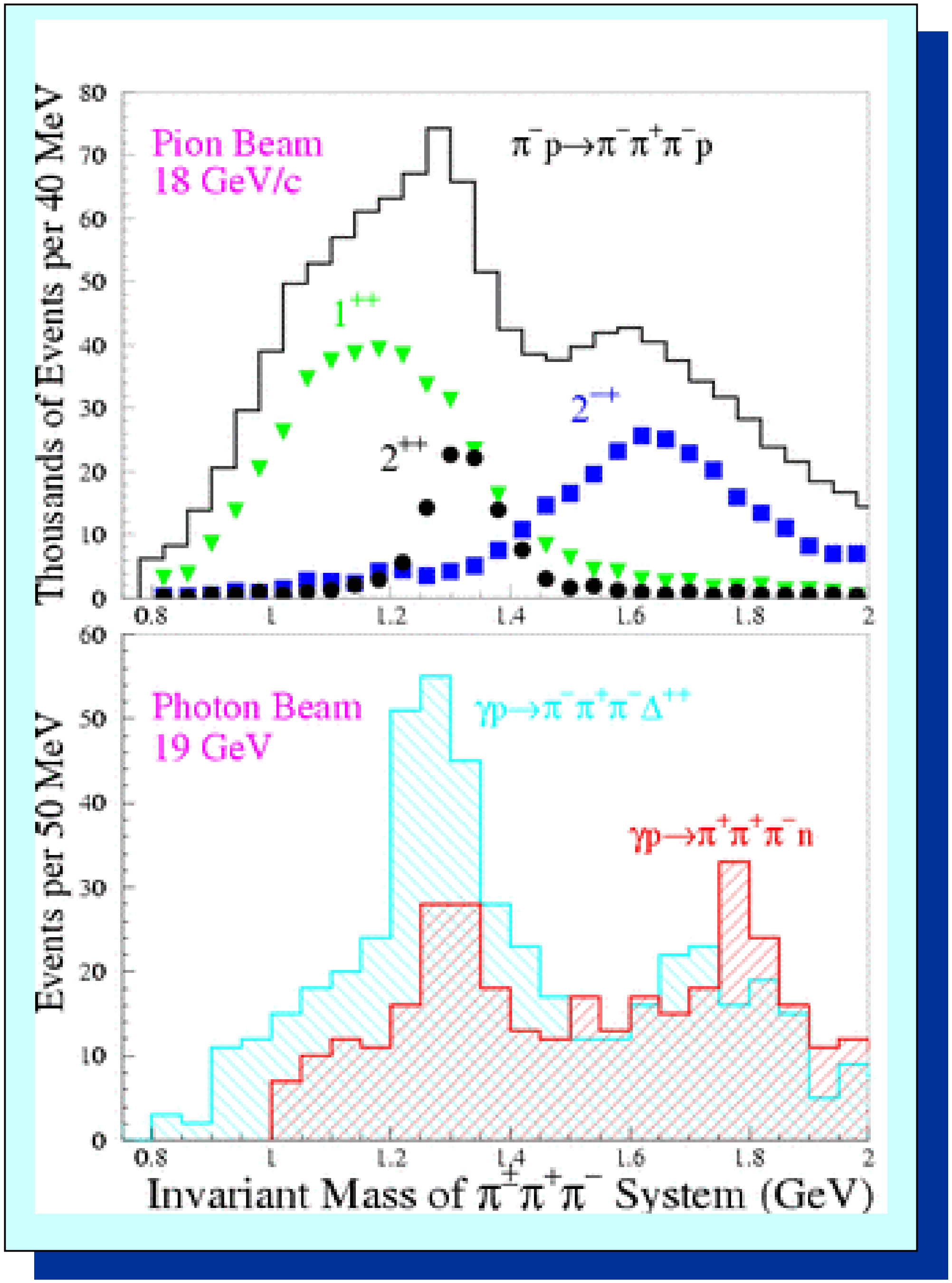


Quark spins aligned

Almost no data in hand
in the mass region
where we expect to find exotic hybrids
when flux tube is excited

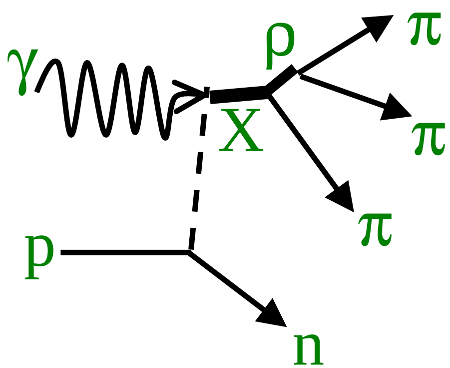
Very little photoproduction data exist. What little there is hint at a different resonance structure than what is seen in pion production.

In one year of initial running, expect 100 times pion statistics

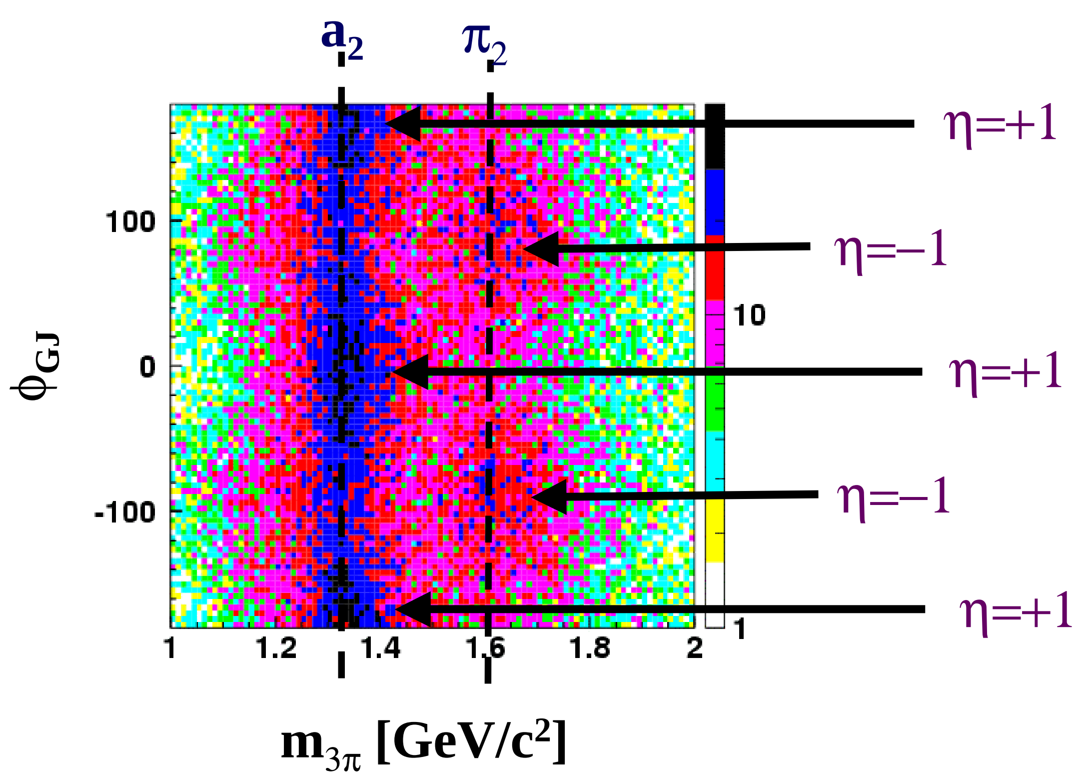


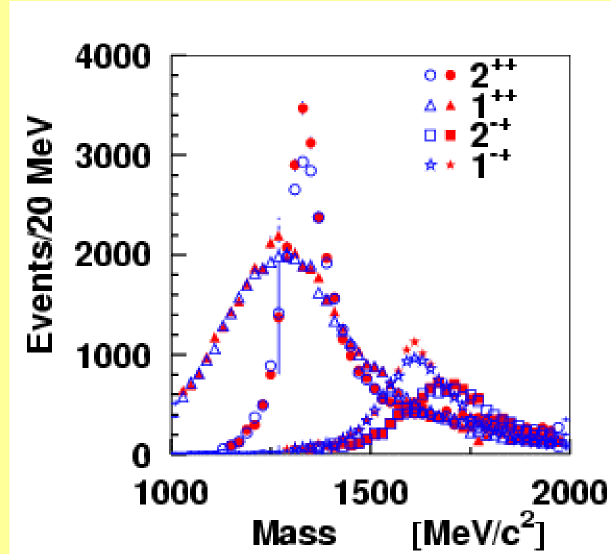
Detector designed to do Partial Wave Analysis

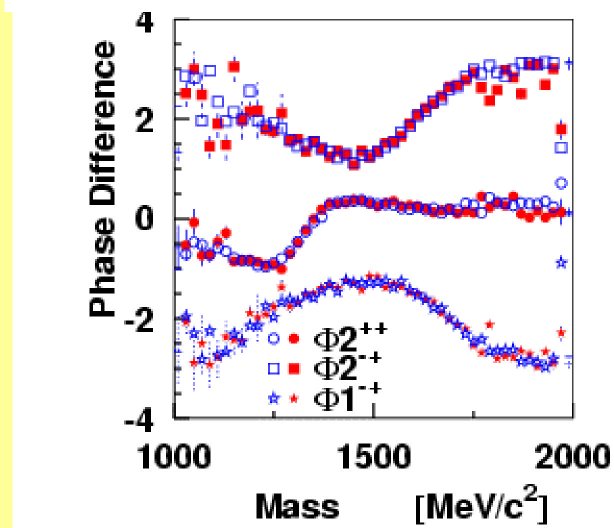
Double blind studies of 3π final states



Polarization







Detection of Exotic Mesons

Hybrids predicted to decay to S+P mesons
$S=\pi,\rho$ nonets $P=b_j,a_j$ nonets

Predicted		Observed?
π_1	$f_1\pi$, $b_1\pi$ (high multiplicity)	$\rho\pi$, $\eta\pi$, $\eta'\pi$
η_1	$a_1\pi$, $a_2\pi$	

γ**p -> [**$\pi\pi\pi\pi$ **,** $\eta\pi\pi\pi$**,** $\omega\pi\pi$] N

Hybrid Decays

Hall D will be sensitive to a wide variety of decay modes - the measurements of which will be compared against theory predictions.

Gluonic excitations transfer angular momentum in their decays to the internal angular momentum of quark pairs not to the relative angular momentum of daughter meson pairs - this needs testing.

For example, for hybrids: $X \rightarrow \pi + b_1$ favored

Measure many decay modes! $X \rightarrow \pi + \eta$ not-favored

To certify PWA - consistency checks will be made among different final states for the same decay mode, for example:

$$b_1 \rightarrow \omega\pi \begin{cases} \omega \rightarrow \pi^0\gamma \rightarrow 3\gamma \\ \omega \rightarrow \pi^0\pi^+\pi^- \rightarrow 2\gamma\pi^+\pi^- \end{cases}$$

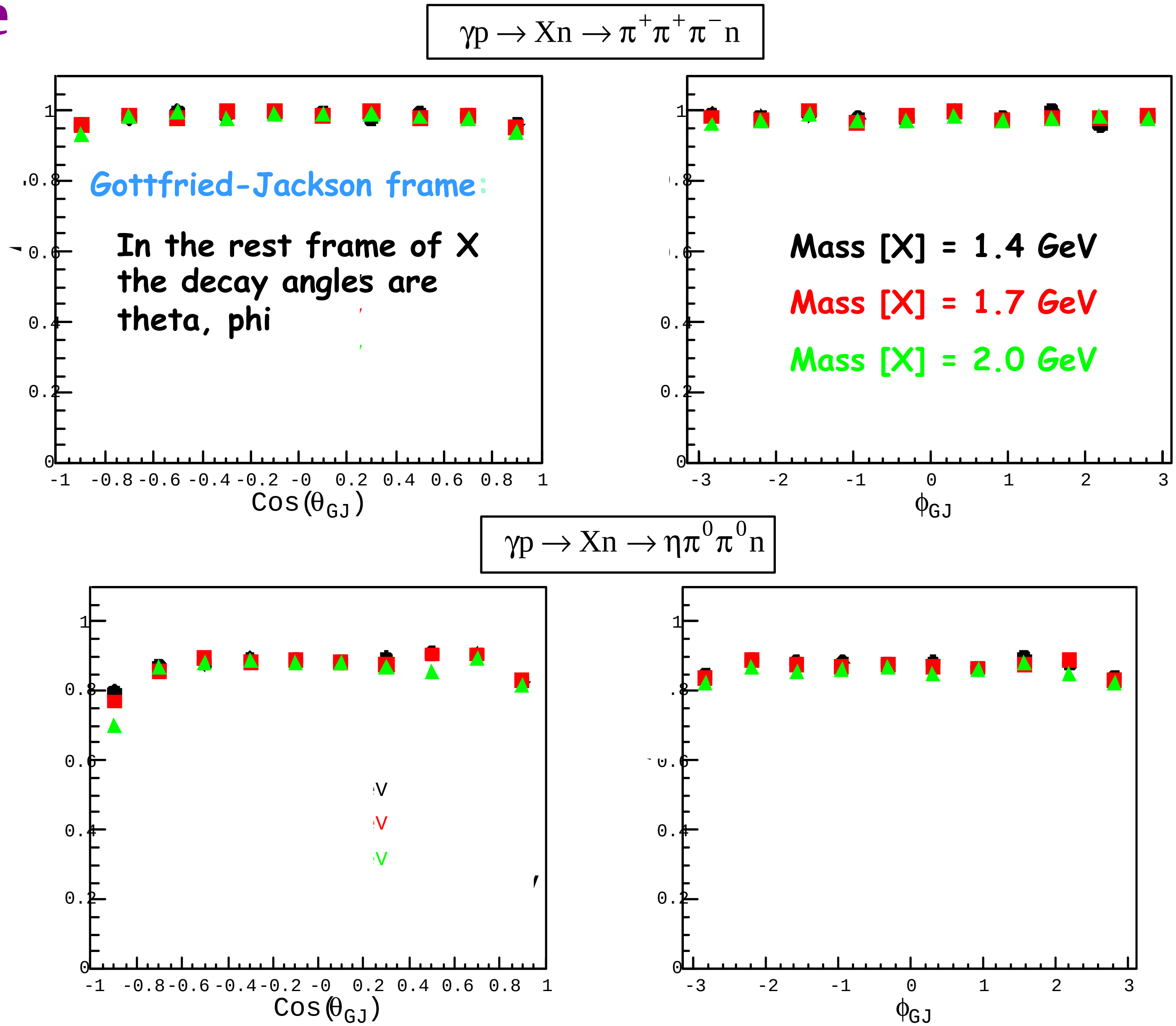
Should give same results

Acceptance

Acceptance in

Decay Angles

assuming 9 GeV
photon beam



Acceptance is high and uniform

Complete Study of neutral and charged final states

Hybrids are expected to decay into complicated final states.
Exotic QN's are smoking guns, but there are non exotic QN's as well.
Need to know decay patterns to understand mixing.

Initial running will be at $5*10^7$ γ/s, will eventually reach 10^8

One year of initial running will yield 100 times pion statistics in the 3π channel. Many weaker channels will have sufficient statistics for full PWA. (Will probe fraction of nb cross sections)

PWA is sensitive to channels at about 0.5% of major component and to widths of several hundred MeV.

If Exotics are there, they will be seen. If they are not there, then we will need to reexamine our understanding of QCD.
The first hints of exotic states already disagree with what we think we understand about them.

PROJECT STATUS

January	**1999**	**Letter of Intent to Jlab PAC**
December	**1999**	**Cassell Committee Review of Project**
August	**2000**	**Key Part of the JLAB 12 GeV Upgrade**
December	**2000**	**Presentation at NSAC Town Meeting**
April	**2001**	**Reccomendation in NSAC LRP**
August	**2001**	**DOE Review of JLAB, push for CD0**
January	**2002**	**NSAC LRP Released**
Winter	**2002**	**CD0 Status at DOE**
....		
	2007	Start Data Taking (hopefully).

Summary

QCD predicts a spectrum of states directly associated with the gluonic degree of freedom and confinement. Exotic Quntum numbers are a definitive signature

Experiments have started to observe states with exotic quantum numbers, but the observations are few, and not in agreement with theoretical expectations.

Photoproduction is expected (vector meson beams) are expected be a very good, yet unexplored way to produce these states.

Hall D will be able to map out a detailed picture of these states and their decays with statistics 100 times better than current pion experiements. Such information will yield important data on the dynamics of glue and its role in QCD.