Quarks, QCD and Confinement: What we hope to learn at Jefferson Lab

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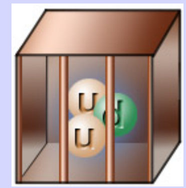
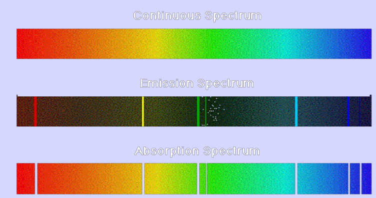
TexPoint fonts used in EMF

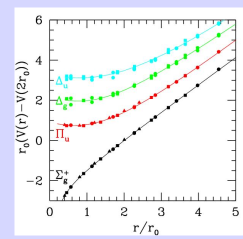
Quarks, QCD and Confinement: What we hope to learn at Jefferson Lab

- The strong force and QCD



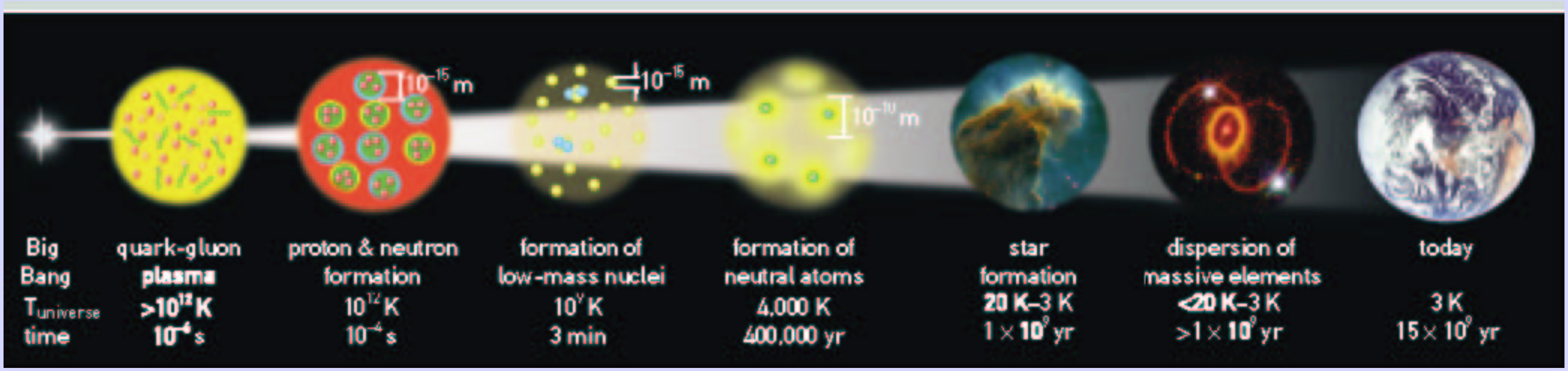


- Baryon Spectroscopy
- Color Confinement

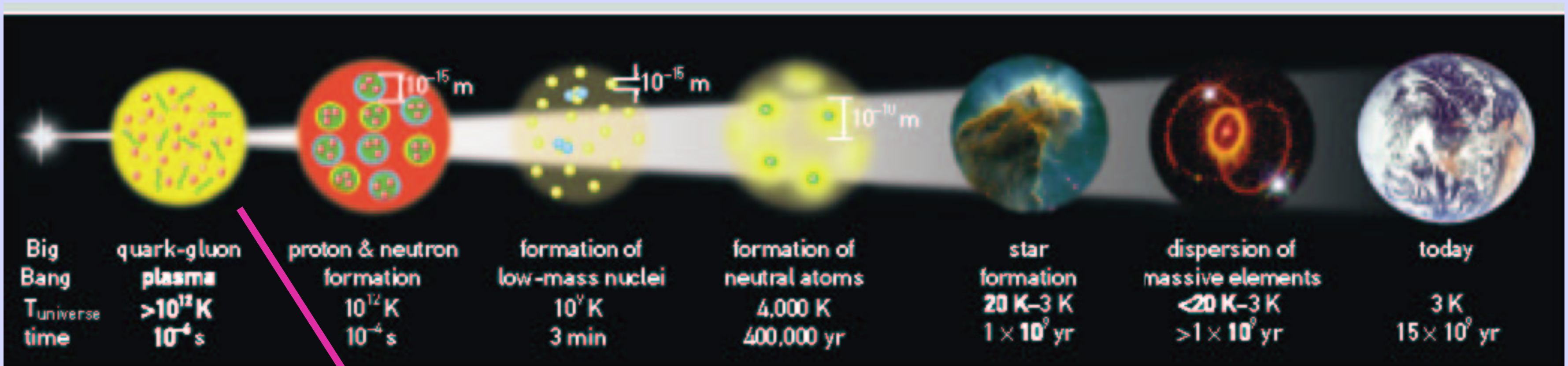


- Finding Gluonic Particles
- GlueX and the 12 GeV upgrade

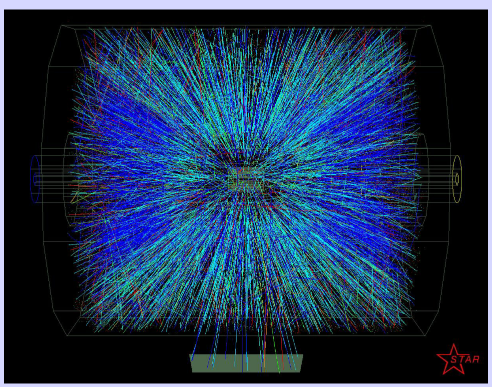
The First Seconds of The Universe



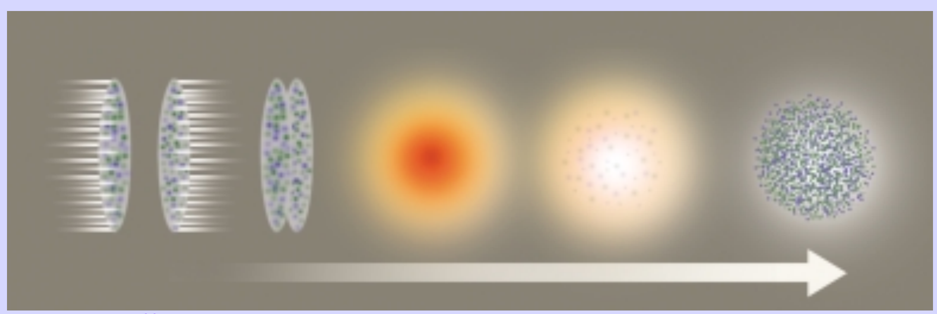
Quark Gluon Plasma



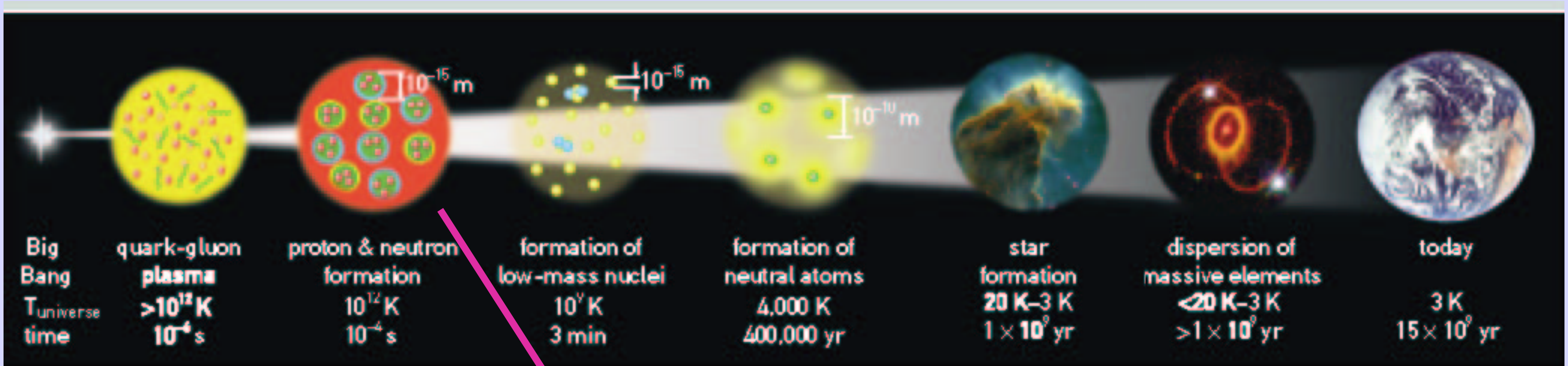
For a period from about 10^{-12} s to 10^{-6} s the universe contained a plasma of quarks, anti quarks and gluons.



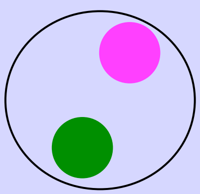
Relativistic Heavy Ion Collisions are trying to produce this state of matter in collisions



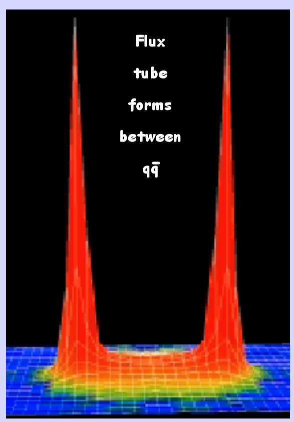
Confinement



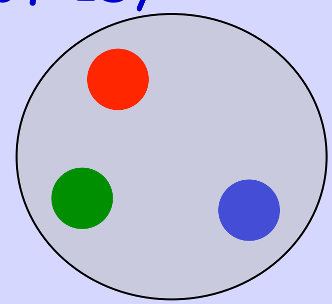
From about 10^{-6} s on, the quark and anti quarks became confined inside of Hadronic matter. At the age of 1s, only protons and neutrons remained.



Mesons

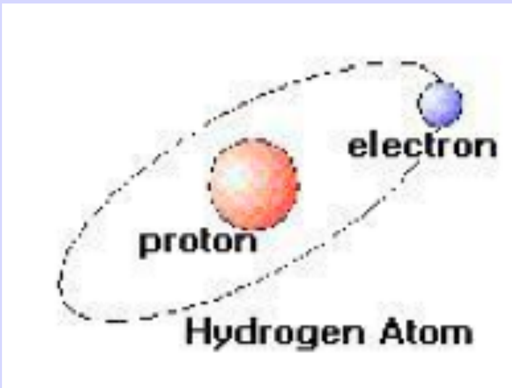


The gluons produce the 16ton force that binds the quarks.

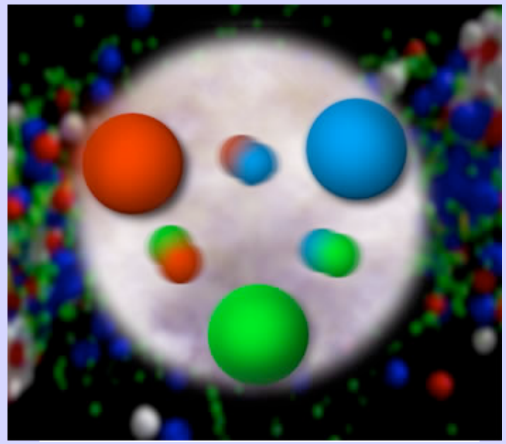


Baryons

Quantum Chromo Dynamics

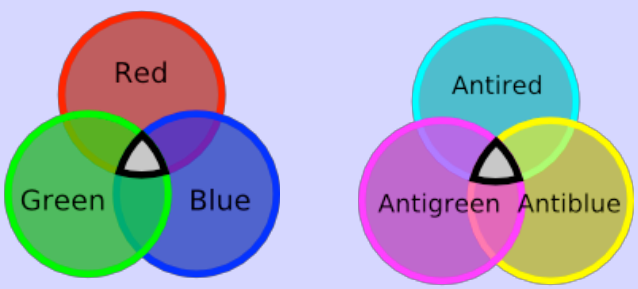


The rules that govern how the quarks froze out into hadrons are given by QCD.



Quarks have color charge: red, blue and green. Antiquarks have anticolors: cyan, yellow and magenta.

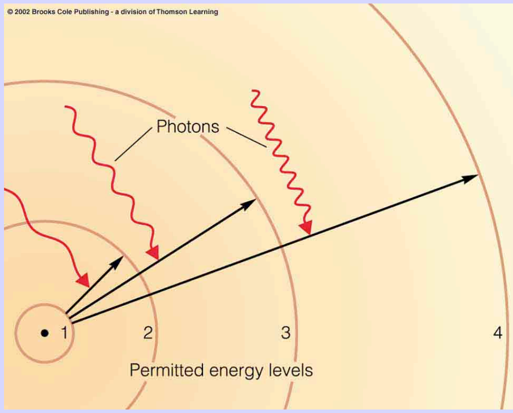
Atoms are electrically neutral: a charge and an anti-charge (+ -).



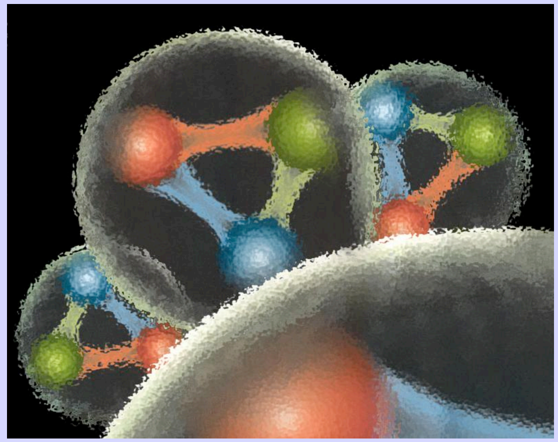
Hadrons are color neutral (white), red-cyan, blue-yellow, green-magenta or red-blue-green, cyan-yellow-magenta.

Quantum Chromo Dynamics

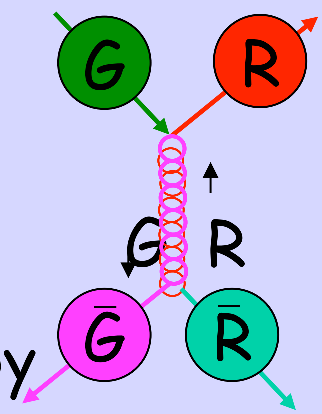
QCD describes the interactions of quarks and gluons.



Photons are the force carriers for the E-M force. Photons are electrically neutral.

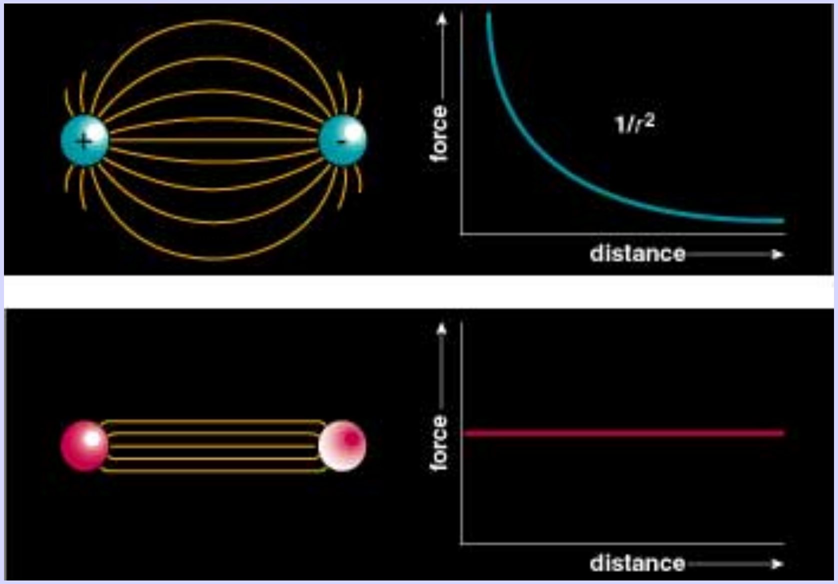


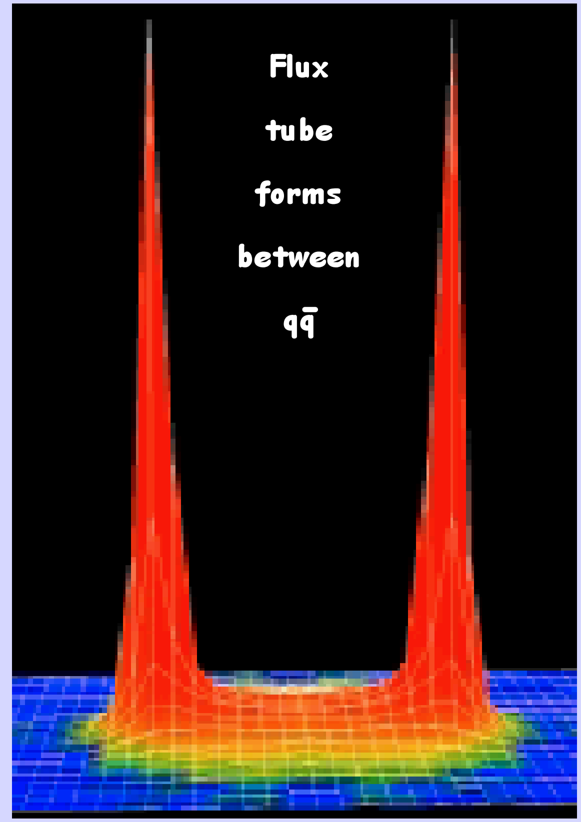
Gluons are the force carriers of QCD. Gluons carry a color and an anticolor Charge.



The color carried by gluons gives rise to the interesting behaviors of QDC

Quantum Chromo Dynamics



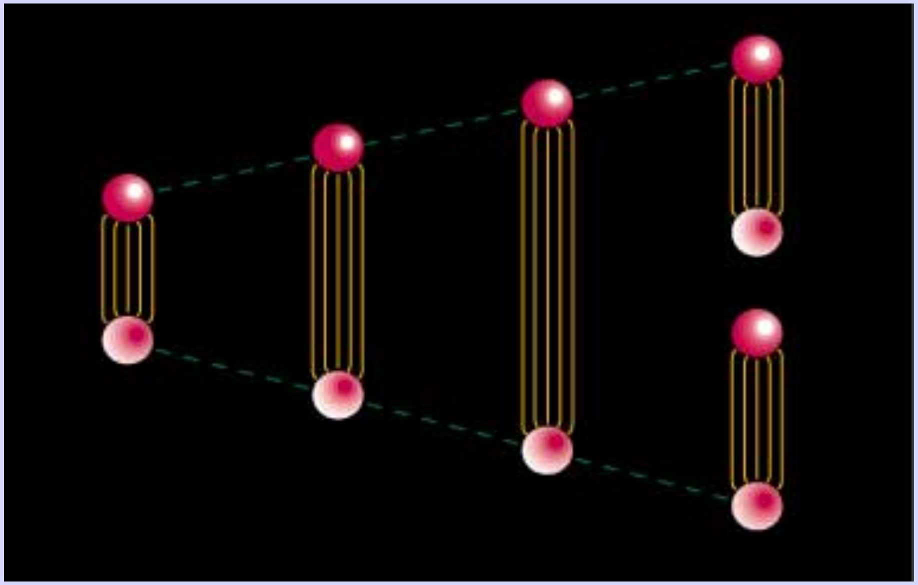


Color Field: Because of self interaction, confining flux tubes form between static color charges

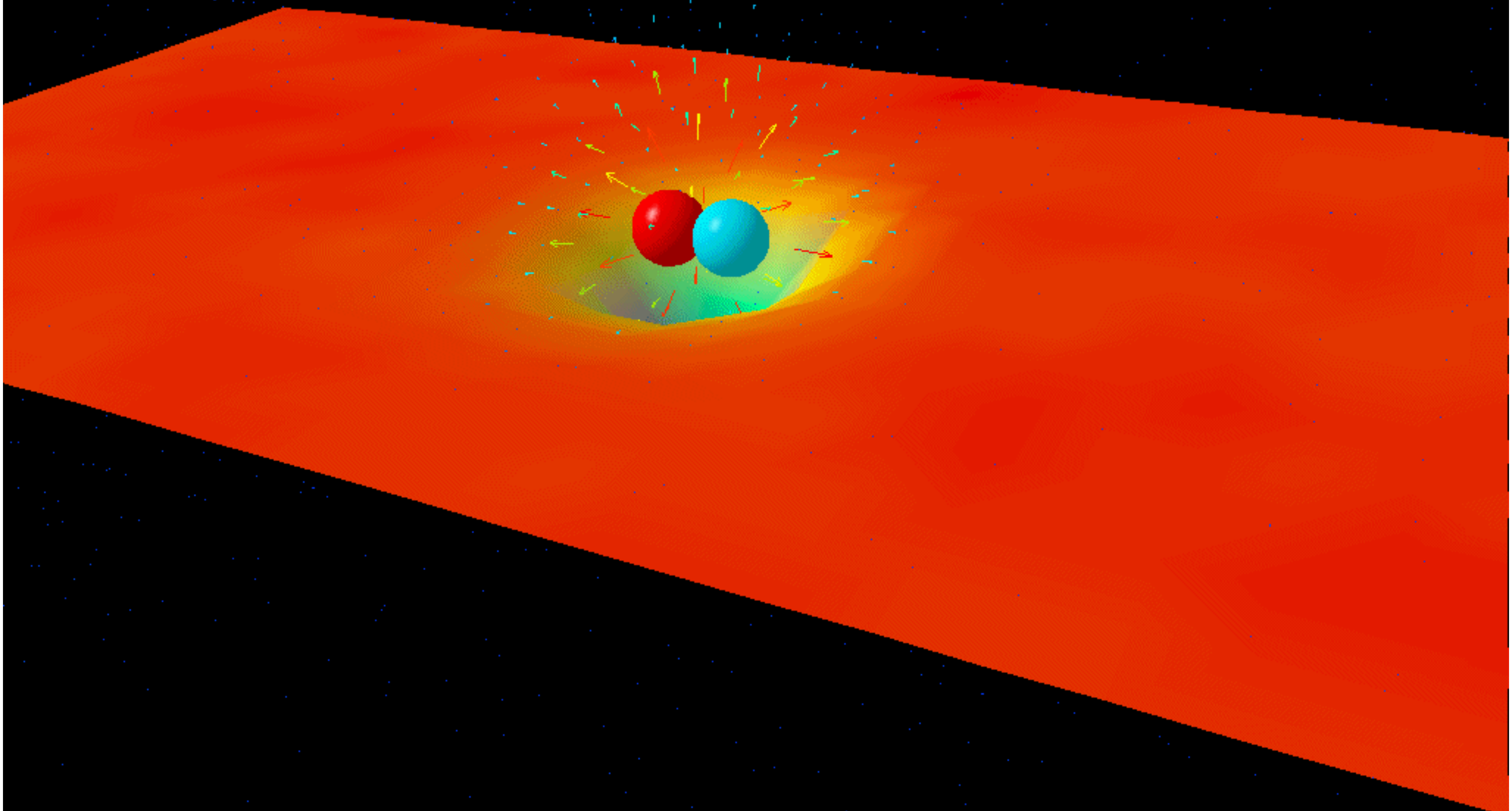
Confinement arises from flux tubes and their excitation leads to a new spectrum of mesons

Quark Confinement

- quarks can never be isolated
- linearly rising potential
  - separation of quark from antiquark takes an infinite amount of energy
  - gluon flux breaks, new quark-antiquark pair produced



Flux Tubes



Observed Hadrons

Color singlet (white) objects observed in nature:

In nature, QCD appears to have two configurations.

three quarks (qqq) Baryons

proton: uud neutron: udd

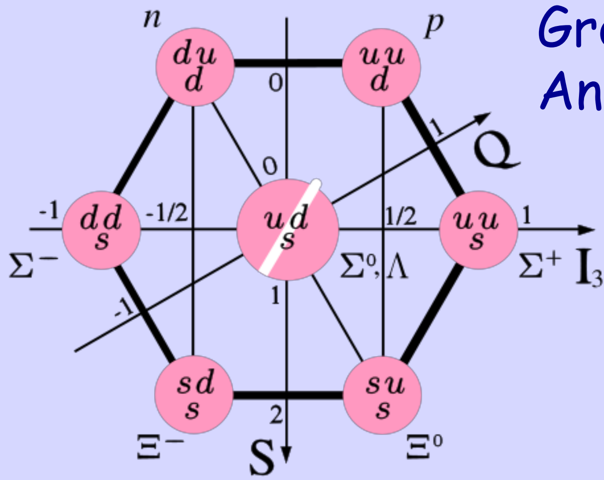
quark-antiquark ($q\bar{q}$) Mesons

$$\pi^+(u\bar{d}) \quad \pi^0(u\bar{u} + d\bar{d})/\sqrt{2} \quad \pi^-(d\bar{u})$$

There are a large number of excited states which are also considered particles. QCD should predict these spectra and we can compare them to experiment.

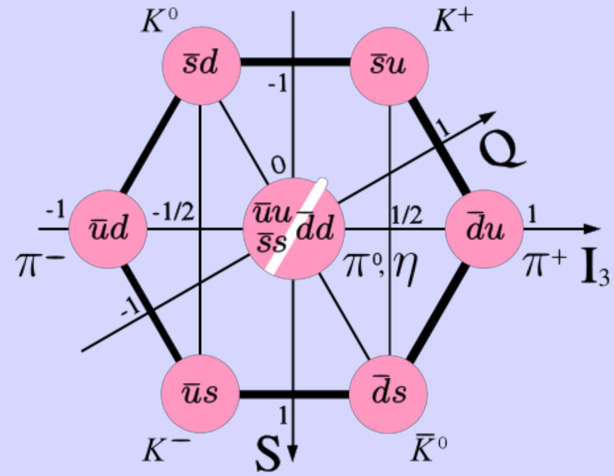
Observed Hadrons

Baryons



Groups of 8 (octet)
And 10 (decuplet).

Mesons



Groups of
9 (nonet).

Other Configurations?

$q\bar{q}q\bar{q}$ 4-quark

gg ggg glueballs

$qqq\bar{q}q$ pentaquarks

$q\bar{q}g$ hybrids

The Issues with Hadrons

The Baryons

What are the fundamental degrees of freedom inside of a proton and a neutron?

Quarks? Combinations of Quarks? Gluons?

The spectrum is very sparse.

The Mesons

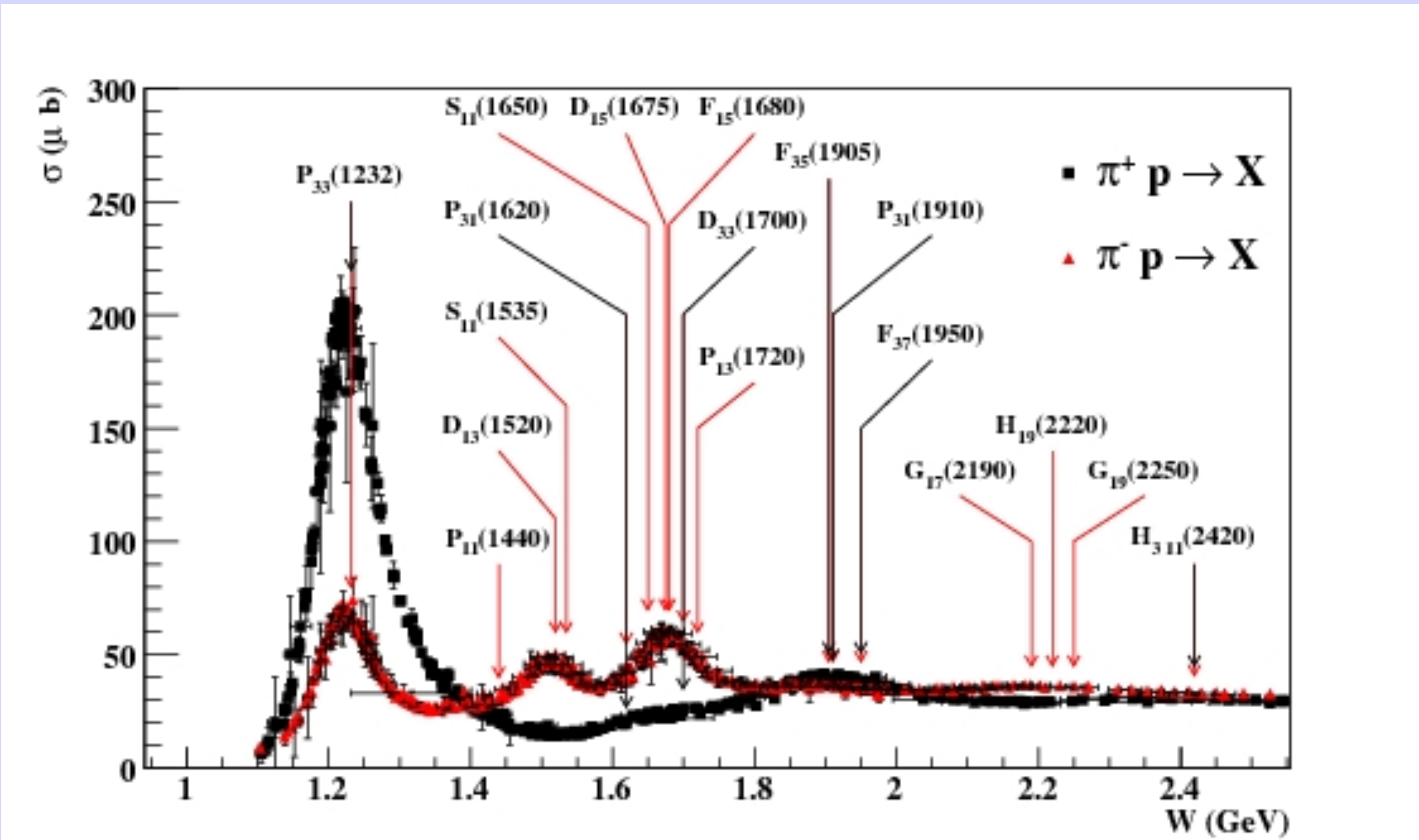
What is the role of glue in a quark-antiquark system and how is this related to the confinement of QCD?

What are the properties of predicted states beyond simple quark-antiquark? $q\bar{q}g$

Need to map out new states.

The Baryon Spectrum

Measured in the reaction $\pi N \longrightarrow \pi N$.
Work done in 60's to early 90's.



The Baryon Spectrum

**** , *** Known   ** , * Hints

In the quark model picture, allow individual quarks to be excited to higher levels:

baryon: q(1s)q(1s)q(1s)

1s -> 2s, 1s -> 2p

Nucleon

$L_{2I,2J}$ (Mass)	Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****

$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

The Baryon Spectrum

****, *** Known **, * Hints

In the quark model picture, allow individual quarks to be excited to higher levels:

baryon: q(1s)q(1s)q(1s)

1s -> 2s, 1s -> 2p

Nucleon

$L_{2I,2J}$ (Mass)	Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****

Missing Baryons

$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

The Baryon Spectrum

****, *** Known   **,* Hints

Treat a quarks and a diquark as the fundamental particles. Allow excitations as before:

Nucleon

$L_{2I,2J}$ (Mass)	Parity	Status
$P_{11}(938)$	+	****
$S_{11}(1535)$	-	****
$S_{11}(1650)$	-	****
$D_{13}(1520)$	-	****
$D_{13}(1700)$	-	***
$D_{15}(1675)$	-	****

$P_{11}(1440)$	+	****
$P_{11}(1710)$	+	***
$P_{11}(1880)$	+	
$P_{11}(1975)$	+	
$P_{13}(1720)$	+	****
$P_{13}(1870)$	+	*
$P_{13}(1910)$	+	
$P_{13}(1950)$	+	
$P_{13}(2030)$	+	
$F_{15}(1680)$	+	****
$F_{15}(2000)$	+	**
$F_{15}(1995)$	+	
$F_{17}(1990)$	+	**

Looking in the wrong place

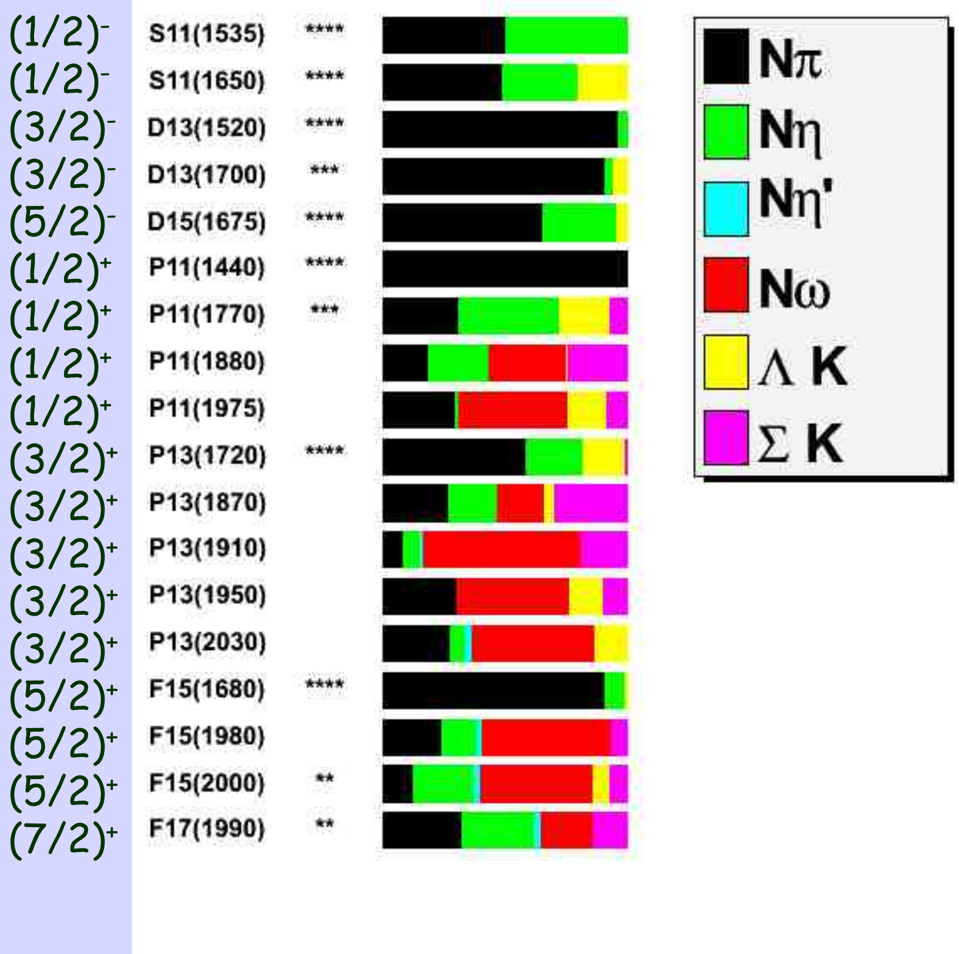
Nearly all the data used to identify baryons has come From πN scattering.

$$\pi N \rightarrow \pi N$$

What if the missing states do not couple to πN?

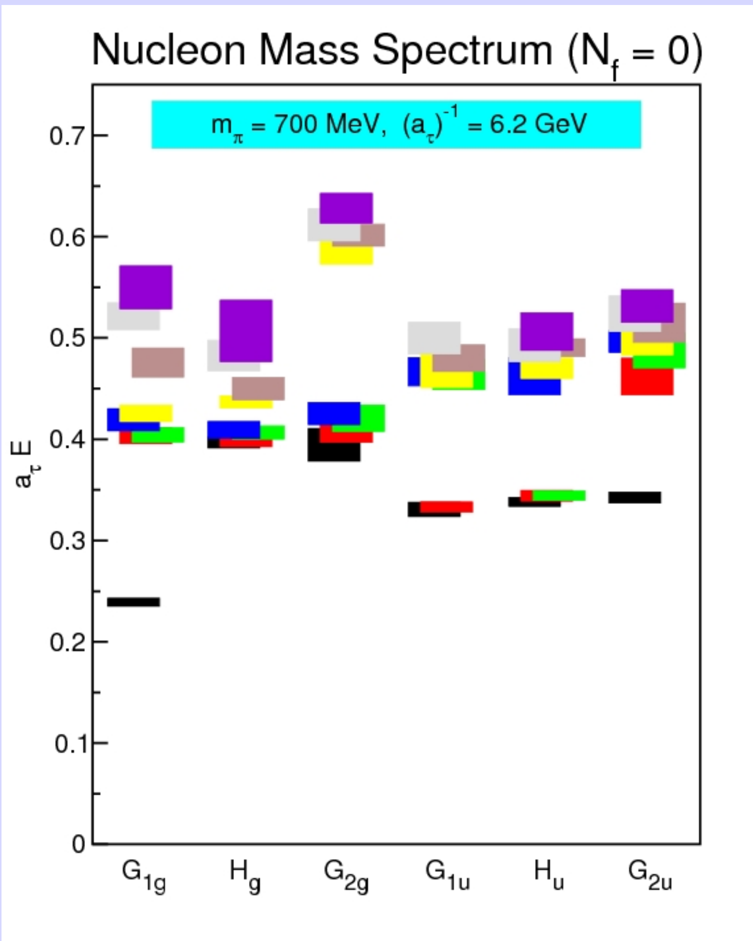
Quark model predictions that many of the missing states have strong couplings to other final states:

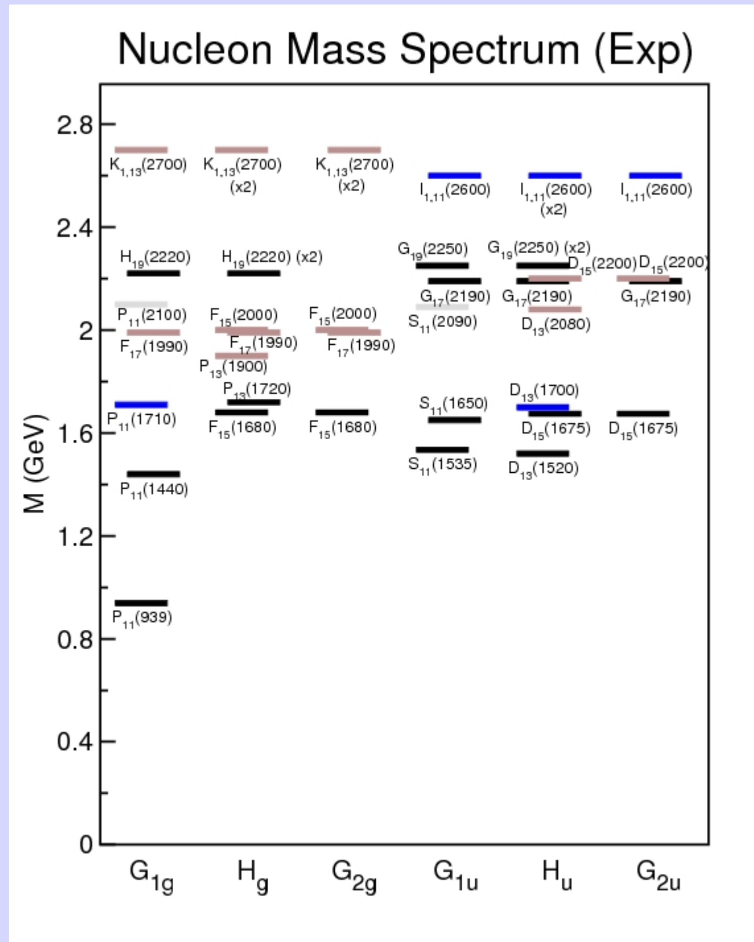
$$\eta N \quad \omega N \quad \ldots$$



Lattice Calculations

First lattice calculation for baryons . Many approximations, but shows what will be possible.



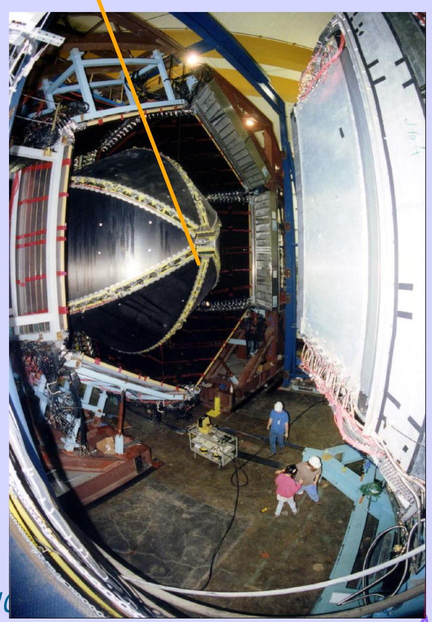


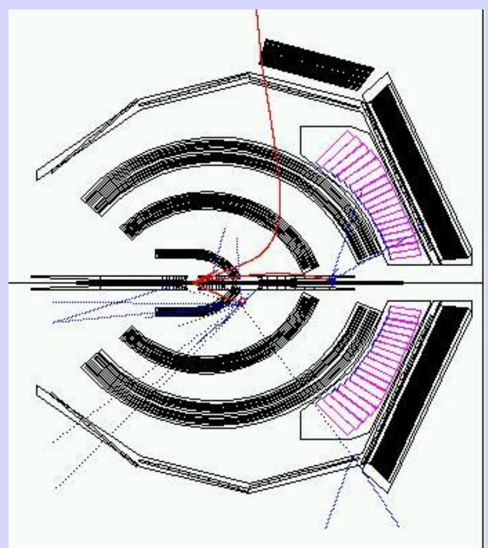
The CLAS Detector at JLab

Incident electron and tagged photon beams (both polarized and unpolarized) (<6GeV)

Targets (H, D, ^{3}He …) (both polarized and unpolarized)

Large acceptance detector with access to final states with several particles and PID





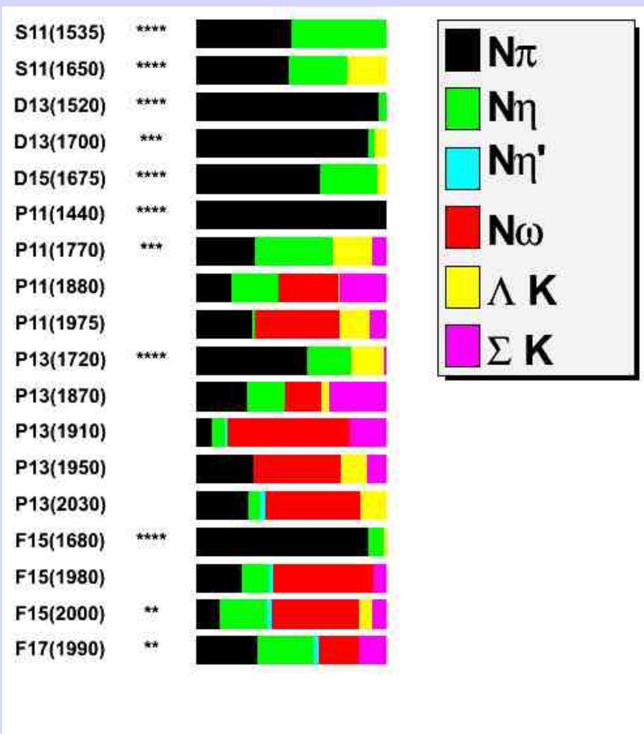
Large data sets both currently in hand as well as new ones expected in the next few years

Identify Baryons:
N*, **Δ**, **Λ**, **Σ**, **Ξ**

New Data Sets

None of these channels have been extensively studied, but are supposed to couple to some missing baryons.

Significant New Data



Using 11TB of CLAS data from a recent run period, simultaneously analyzing reactions:

$\gamma p \longrightarrow p\eta$	~700k events
$\gamma p \longrightarrow p\eta'$	~250k events
$\gamma p \longrightarrow p\omega$	~1300k events
$\gamma p \longrightarrow \Lambda K^+$	~1200k events
$\gamma p \longrightarrow \Sigma^0 K^+$	~1100k events

Enormous data sets require new tools to carry out the needed analysis.

Partial Wave Analysis

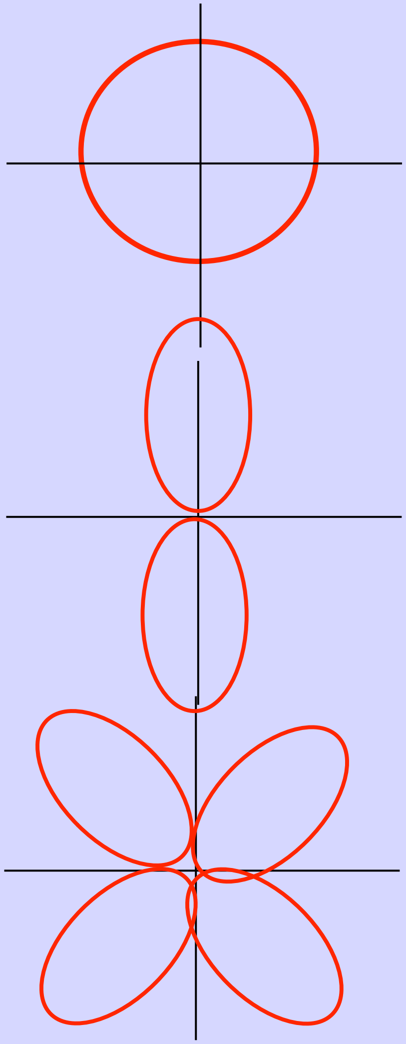
Angular distributions of reactions let you determine the spin and parity of intermediate resonances.

Classical Electrodynamics:

Monopole Radiation (L=0)

Dipole Radiation (L=1)

Quadrupole Radiation (L=2)



Partial Wave Analysis

For a given reaction energy, quantum mechanical amplitudes yields a probability distribution and predicts angular distributions.

Particles nominally occur as a resonance which has both an amplitude and phase as a function of the difference between its nominal mass and the reaction energy.

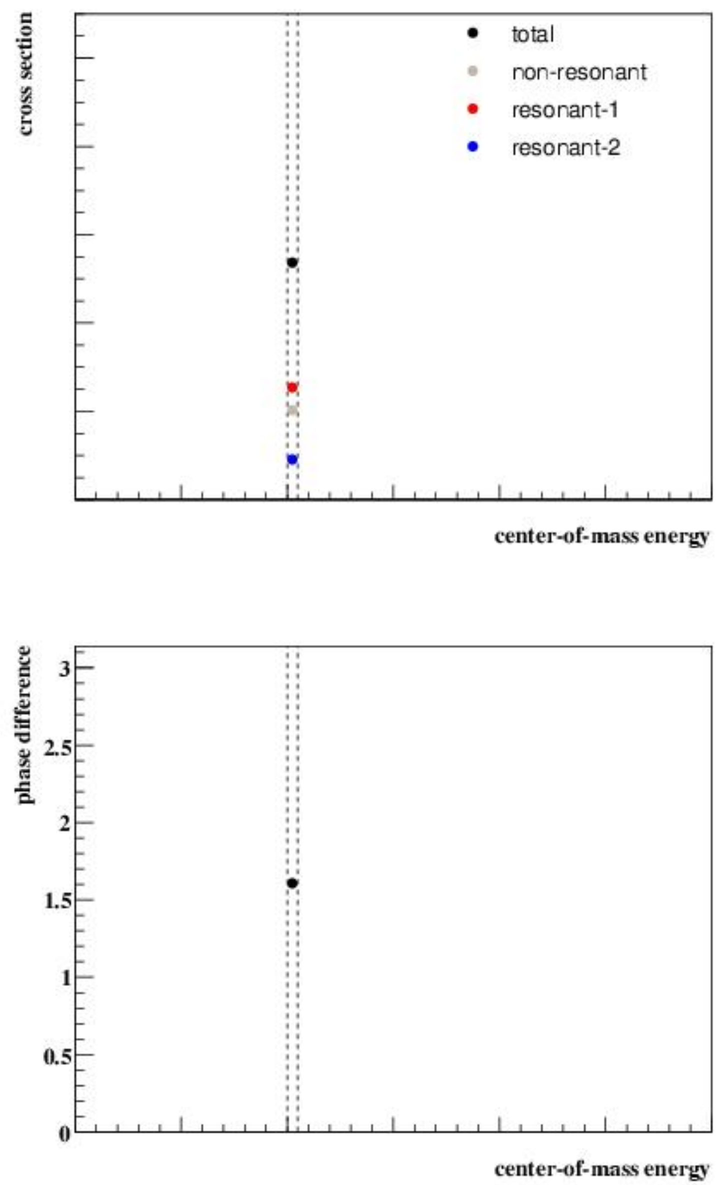
Fit the angular distribution as a sum of complex amplitudes which describe particular quantum numbers.

Partial Wave Analysis

A simple model with three complex amplitudes, 2 of which are particles with different QNs

Start with a single energy bin.

Fit to get the strengths and the phase difference between the two resonances.



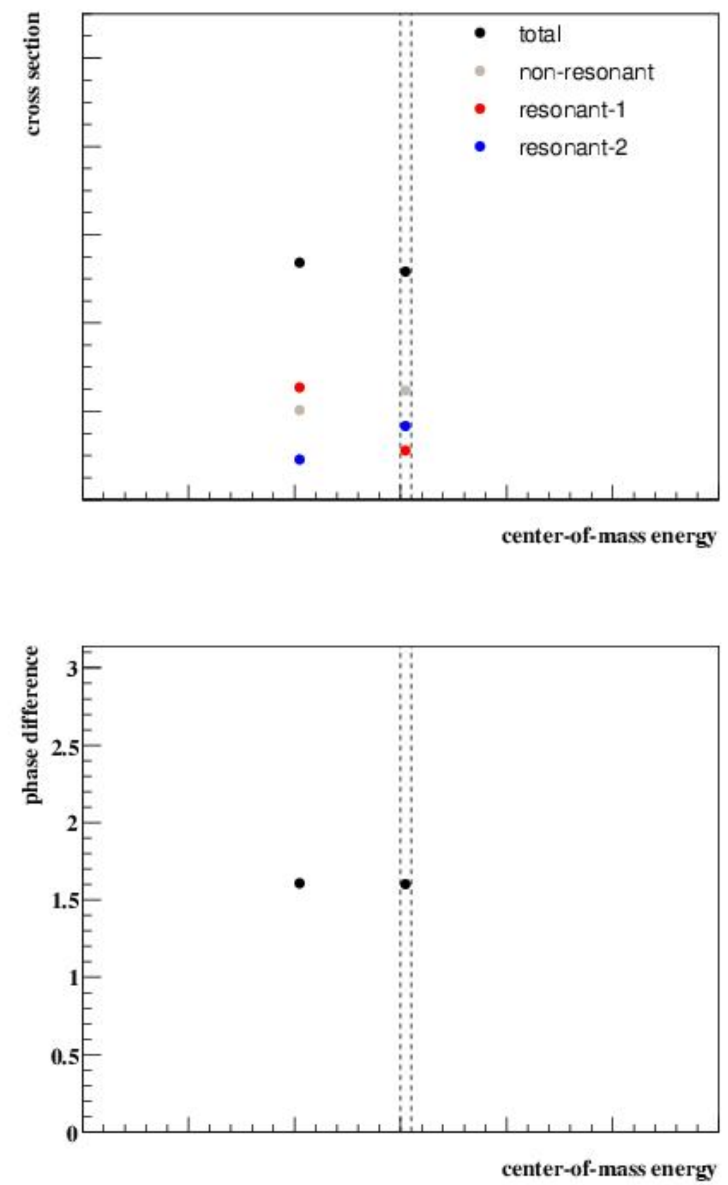
Partial Wave Analysis

A simple model with three complex amplitudes, 2 of which are particles with different QNs

Start with a single energy bin.

Fit to get the strengths and the phase difference between the two resonances.

Fit a 2nd bin.



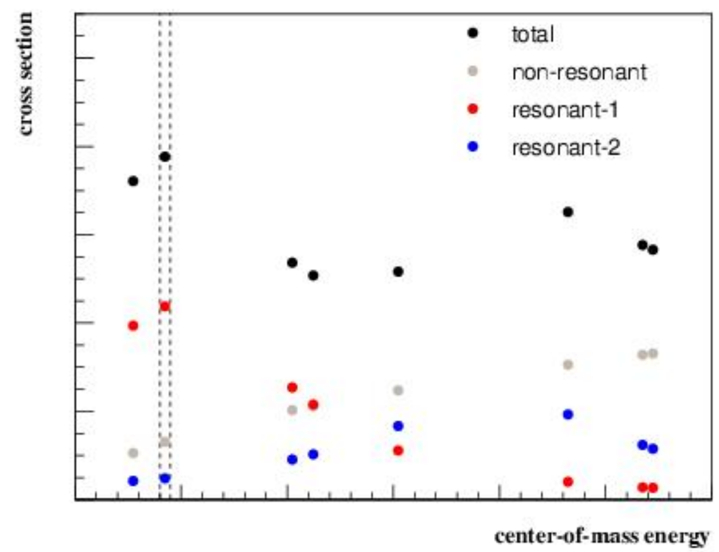
Partial Wave Analysis

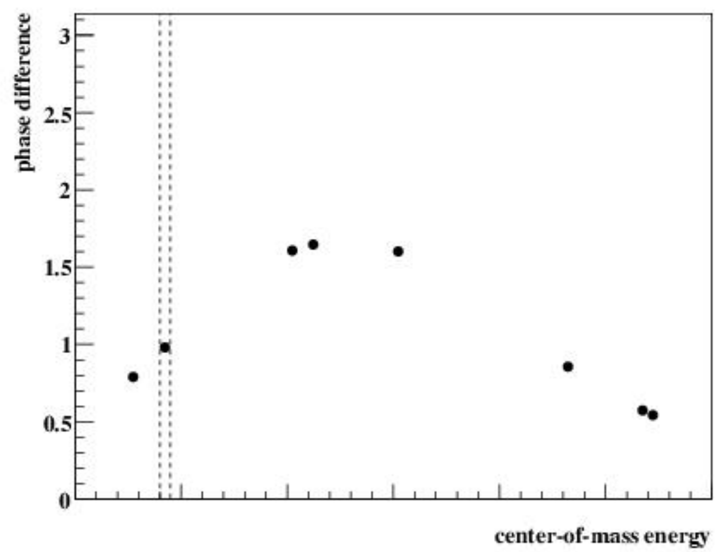
A simple model with three complex amplitudes, 2 of which are particles with different QNs

Start with a single energy bin.

Fit to get the strengths and the phase difference between the two resonances.

Continue fitting bins …





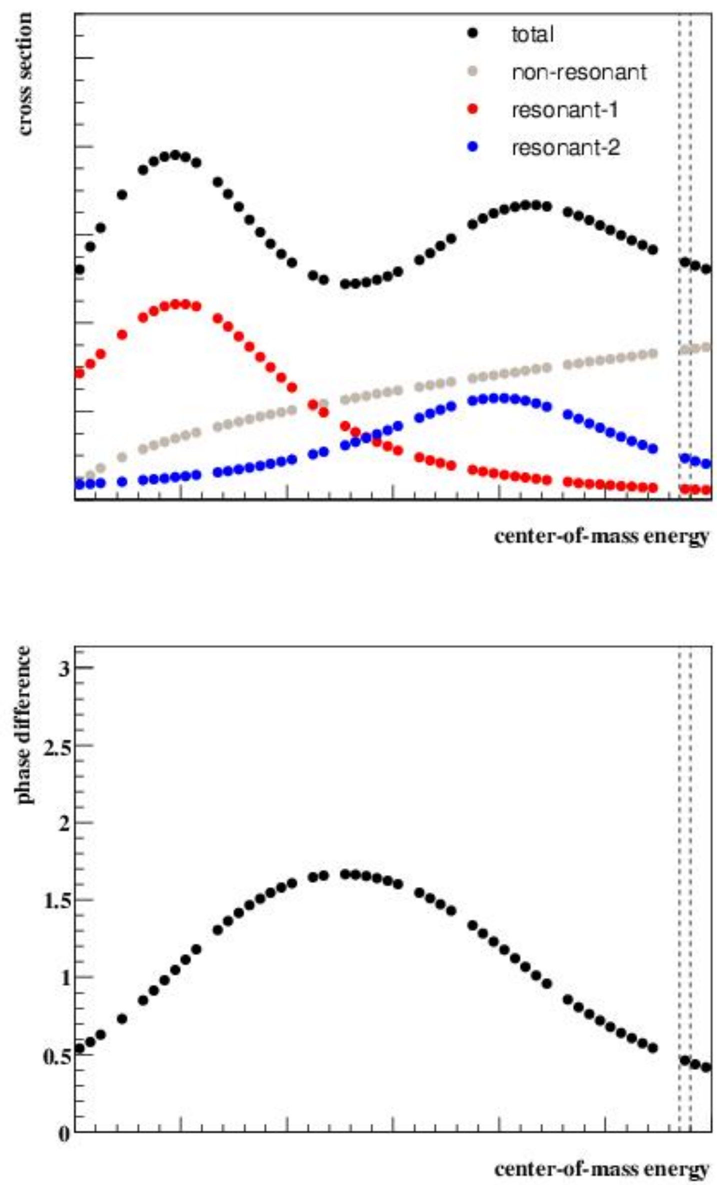
Partial Wave Analysis

A simple model with three complex amplitudes, 2 of which are particles with different QNs

Start with a single energy bin.

Fit to get the strengths and the phase difference between the two resonances.

… and continue …

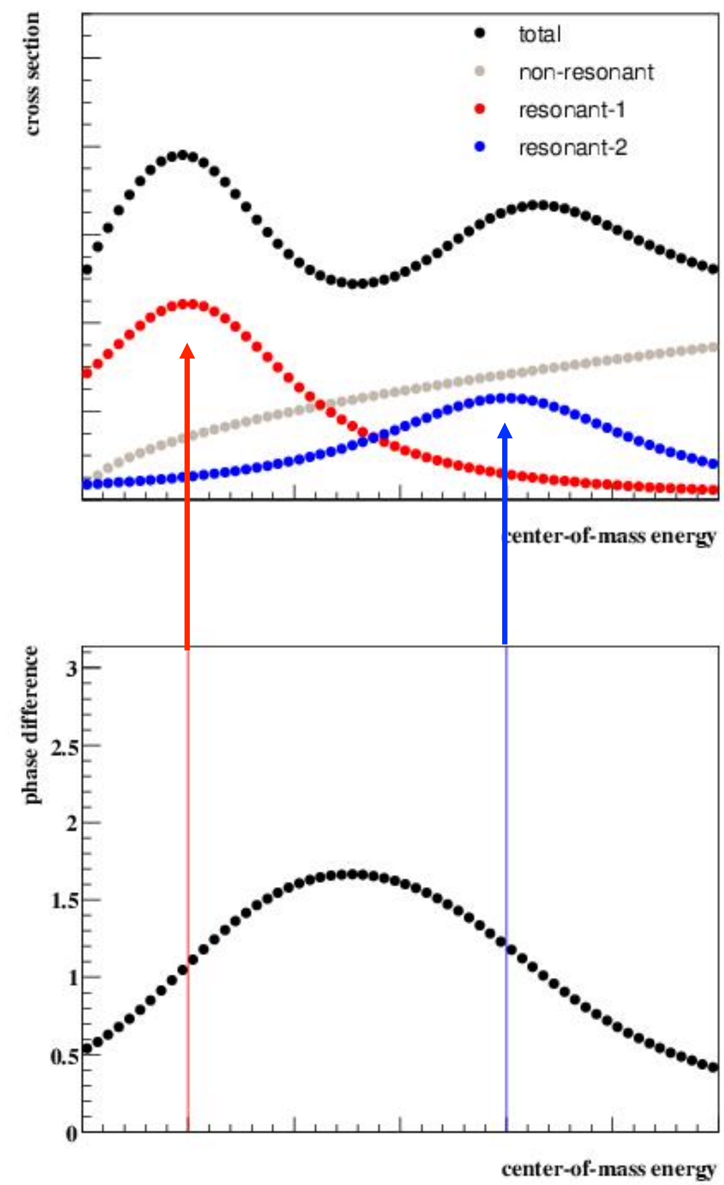


Partial Wave Analysis

A simple model with three complex amplitudes, 2 of which are particles with different QNs. The masses peak where the two lines are.

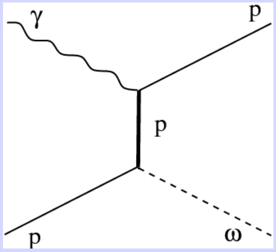
The need for intensity and the phase difference are indicative of two resonances.

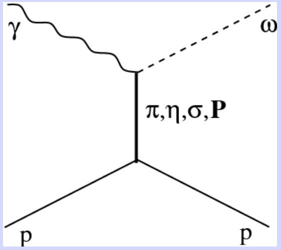
Can fit for masses and widths.

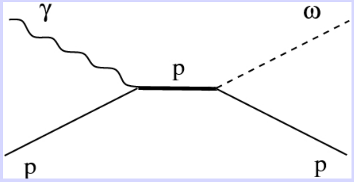


$\gamma p \rightarrow p\omega$

The $p\omega$ system has never been studied







Any analysis needs to incorporate many different processes. However, all the analyses of different channels need to be self consistent (E.g. coupling constants, production and decay …).

Tools developed at CMU over the last several years allow the easy input of any amplitude directly at the event level in the analysis

Theory ⇔ Experiment

Partial Wave Analysis

$$I = \sum | a_{lmn} A_{lmn} |^2$$

Complex amplitudes and complex fit parameters.

First time this type of PWA has been done for Baryons

About 13 million events in ~100 narrow energy bins

PWA Results

$\gamma p \longrightarrow p\omega$

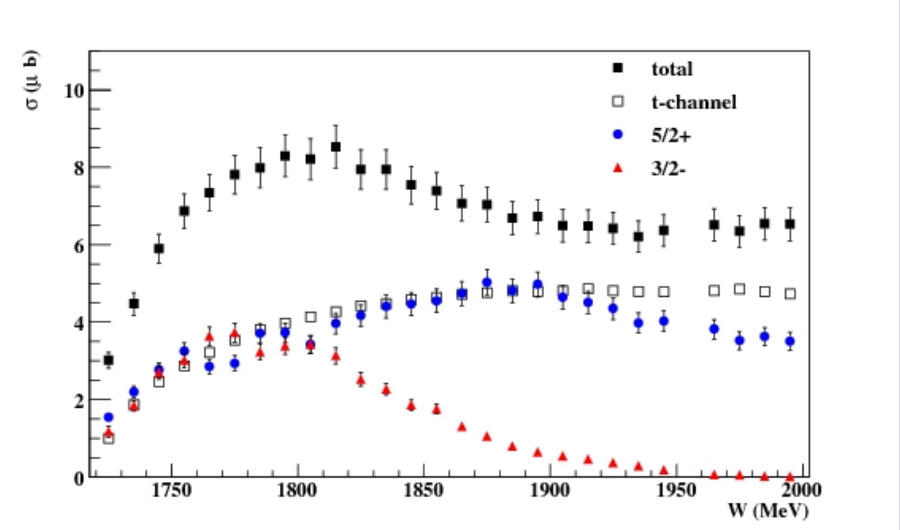
Fit showing three amplitudes.

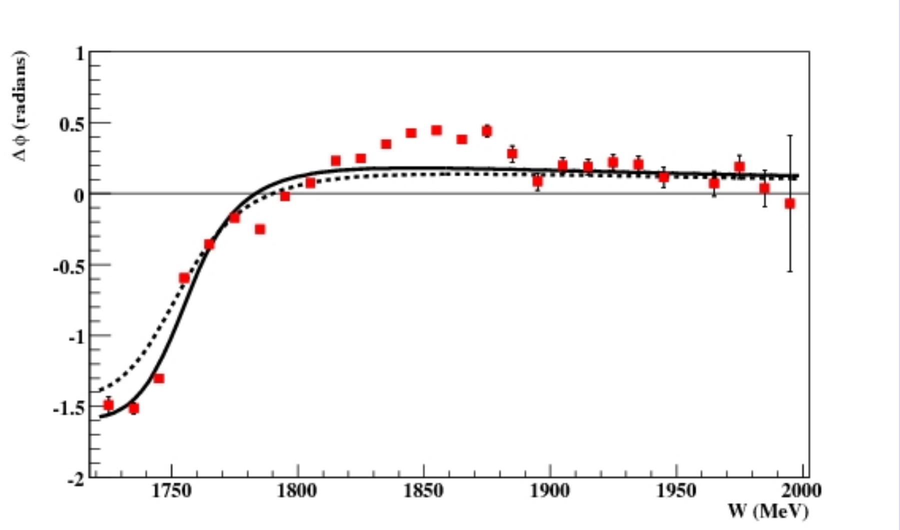
(3/2)⁻ D_{13}
(5/2)⁺ F_{15}
t-channel

Intensities

Phase Difference

Not Expected





Strong evidence for:

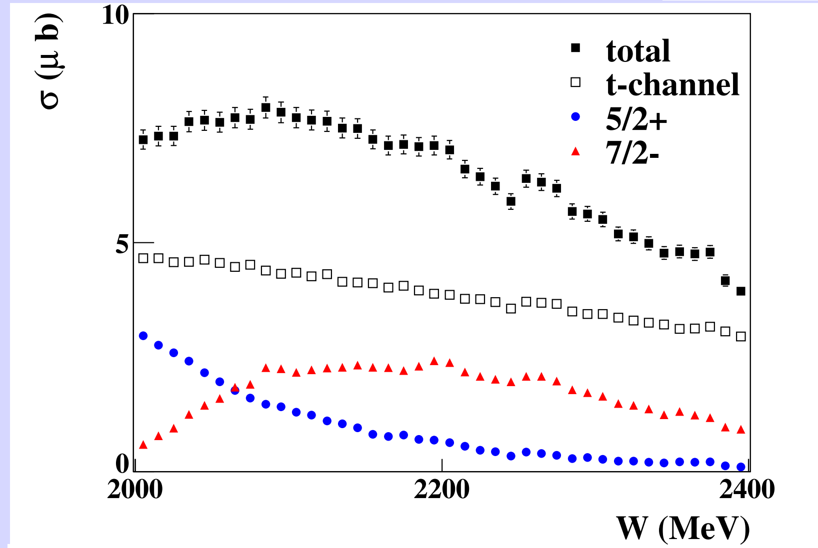
(3/2)⁻ N(1700) ***
(5/2)⁺ N(1680) ****

The strong signals are well known states!

PWA Results

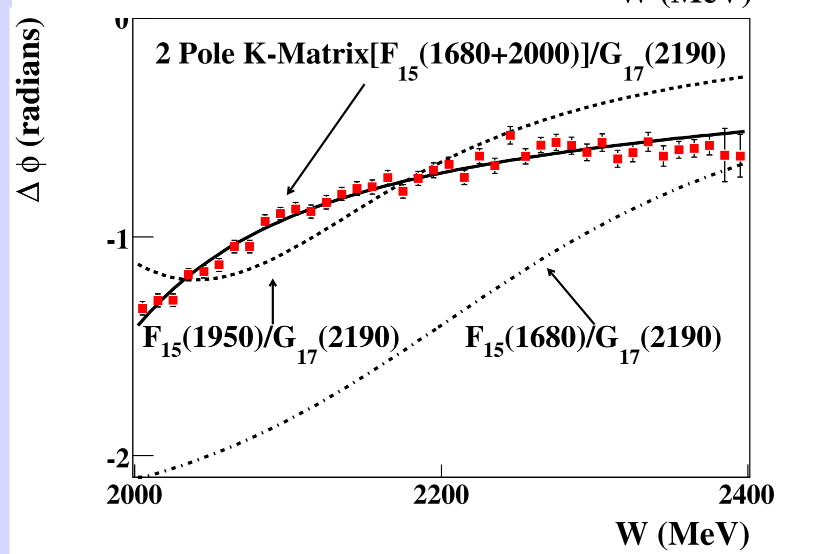
Fit showing three amplitudes.

$(5/2)^+$ F_{15}
$(7/2)^-$ G_{17}
t-channel



Strong evidence for:

$(5/2)^+$ N(1680) ***
$(5/2)^+$ N(1950) **
$(7/2)^-$ N(2190) ****



A Missing State!

What is seen?

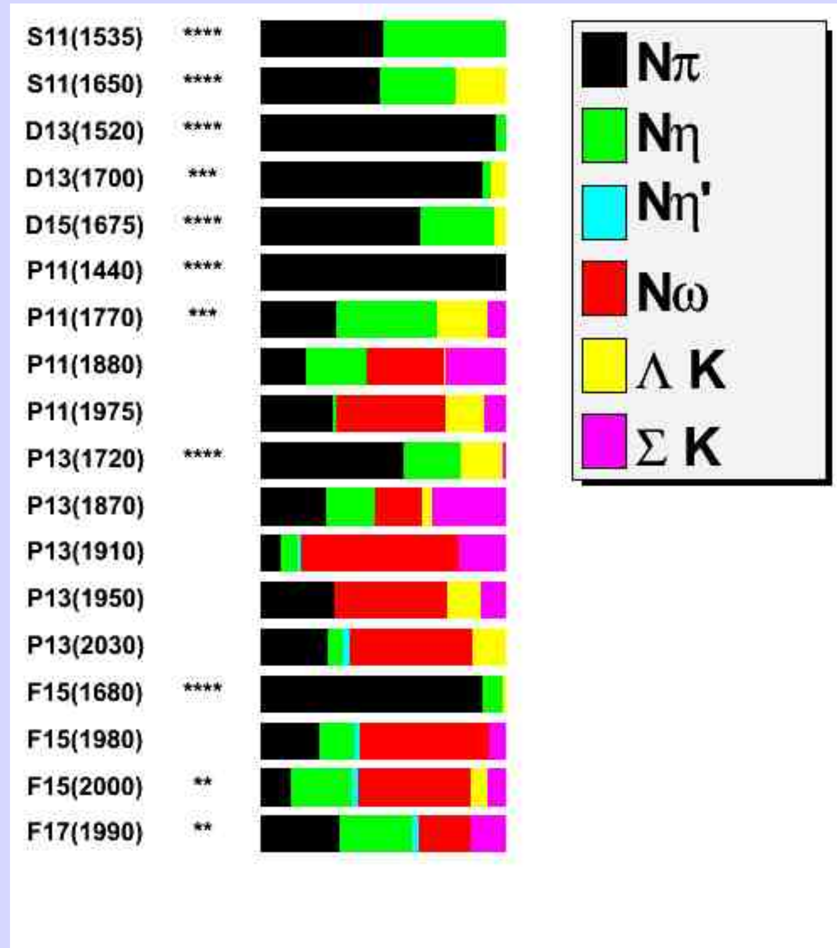
Strong evidence for:

(3/2)$^-$ N(1700) ***
(5/2)$^+$ N(1680) ****
(7/2)$^-$ N(2190) ****

Hints here

(5/2)$^+$ N(1950) **

(1/2)$^-$
(1/2)$^-$
(3/2)$^-$
(3/2)$^-$
(5/2)$^-$
(1/2)$^+$
(1/2)$^+$
(1/2)$^+$
(1/2)$^+$
(3/2)$^+$
(3/2)$^+$
(3/2)$^+$
(3/2)$^+$
(3/2)$^+$
(5/2)$^+$
(5/2)$^+$
(5/2)$^+$
(7/2)$^+$



(7/2)$^-$ G_{17}(2190) ****

Baryon Analysis

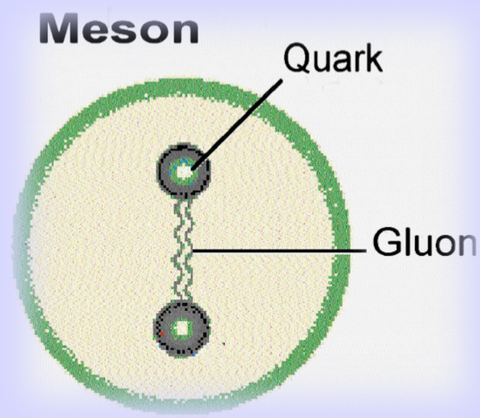
The data demand four baryon resonances:
$(3/2)^-$, $(5/2)^+$, $(5/2)^+$ and $(7/2)^-$.

There are hints of other missing baryons in the data, but the models for the non-resonant parts need to be improved (theoretical input).

High statistics data sets with sophisticated analysis tools allowed us to pull out signals.

There are limitations in the acceptance of CLAS that limit what can be done. For the $\gamma p \longrightarrow p\omega$, only about 7% of the events are fully reconstructed. No neutral particle detection.

Mesons: quark-antiquark systems



What is the role of glue in a quark-antiquark system and how is this related to the Confinement of QCD?

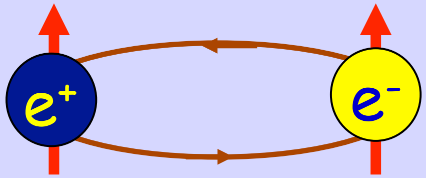
What are the properties of predicted States beyond simple quark-antiquark?

$$q\bar{q}g$$

Need to map out new states.

Spectroscopy
A probe of QED

Positronium



Spin: $S=S_1+S_2=(0,1)$

Orbital Angular Momentum: $L=0,1,2,\ldots$

Total Spin: $J=L+S$

$L=0,\ S=0 : J=0$ $\quad$ $L=0,\ S=1 : J=1$

$L=1,\ S=0 : J=1$ $\quad$ $L=1,\ S=1 : J=0,1,2$

... $\quad$ ...

Reflection in a mirror:
Parity: $P=-(-1)^{(L)}$

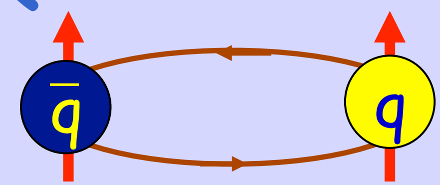
Particle<->Antiparticle:
Charge Conjugation: $C=(-1)^{(L+S)}$

Notation: $J^{(PC)}$ $\quad$ $0^{-+},\ 1^{--},\ 1^{+-},\ 0^{++},\ 1^{++},\ 2^{++}$

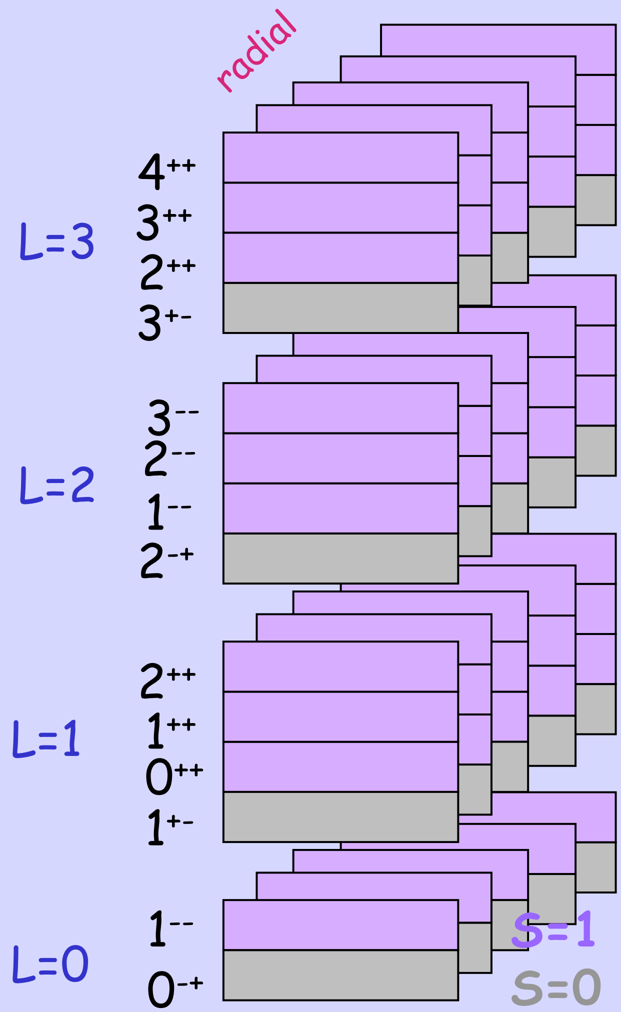
$^{(2S+1)}L_J$ $\quad$ $^1S_0,\ ^3S_1,\ ^1P_1,\ ^3P_0,\ ^3P_1,\ ^3P_2,\ldots$

Spectroscopy and QCD

Quarkonium



Mesons



Consider the three lightest quarks

$$\left.\begin{matrix} u, d, s \\ \bar{u}, \bar{d}, \bar{s} \end{matrix}\right\} \text{ 9 Combinations}$$

$$d\bar{s} \qquad u\bar{s}$$

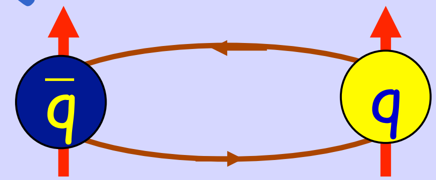
$$d\bar{u} \qquad \frac{1}{\sqrt{2}}\left(u\bar{u} - d\bar{d}\right) \qquad u\bar{d}$$

$$s\bar{d} \qquad s\bar{u}$$

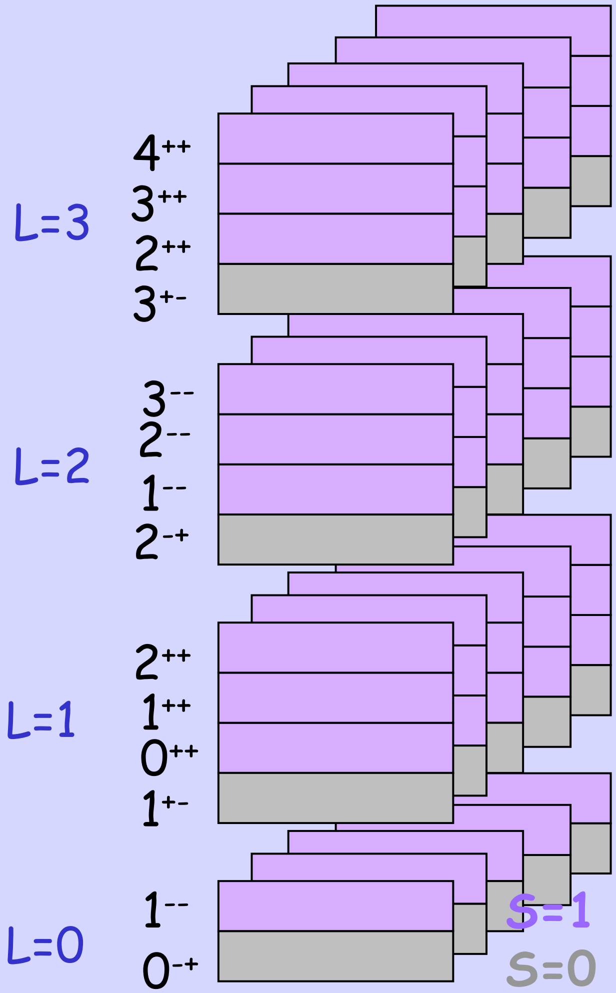
$$\frac{1}{\sqrt{3}}\left(u\bar{u} + d\bar{d} + s\bar{s}\right) \qquad \frac{1}{\sqrt{6}}\left(u\bar{u} + d\bar{d} - 2s\bar{s}\right)$$

Spectroscopy an QCD

Quarkonium



Mesons



Nothing to do with Glue!

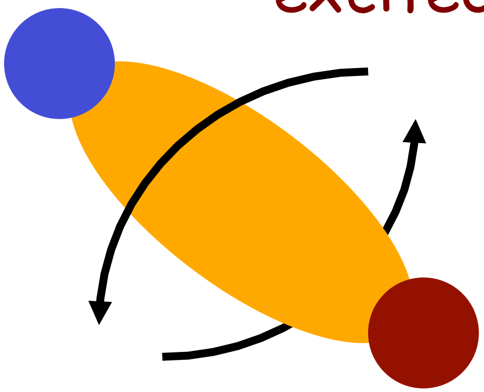
Allowed J^{PC} Quantum numbers:

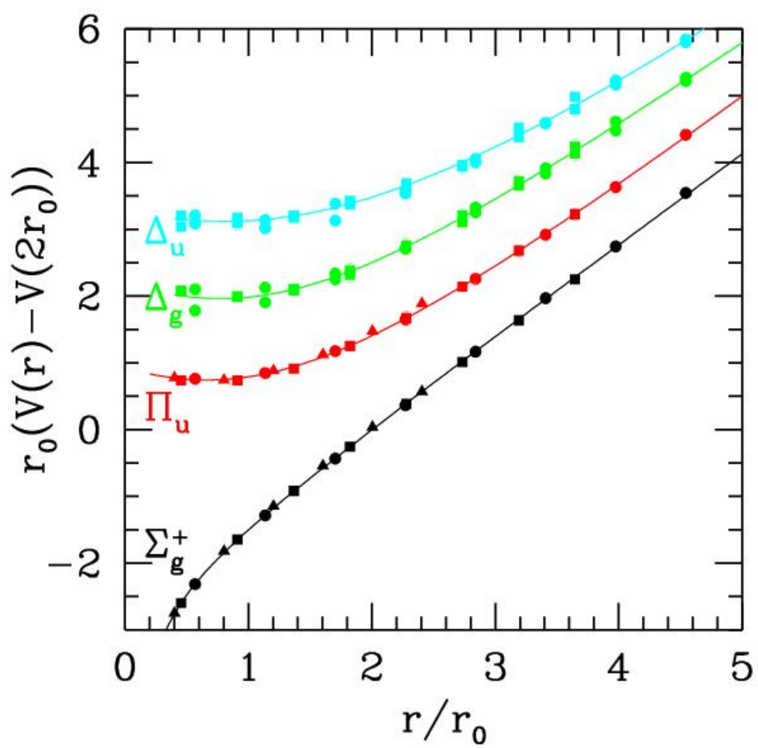
0^{--}	0^{++}	0^{-+}	0^{+-}
1^{--}	1^{++}	1^{-+}	1^{+-}
2^{--}	2^{++}	2^{-+}	2^{+-}
3^{--}	3^{++}	3^{-+}	3^{+-}
4^{--}	4^{++}	4^{-+}	4^{+-}
5^{--}	5^{++}	5^{-+}	5^{+-}

Exotic Quantum Numbers

non quark-antiquark description

QCD Potential





Gluonic Excitations provide an experimental measurement of the excited QCD potential.

Observations of the nonets on the excited potentials are the best experimental signal of gluonic excitations.

Hybrid Meson Predictions

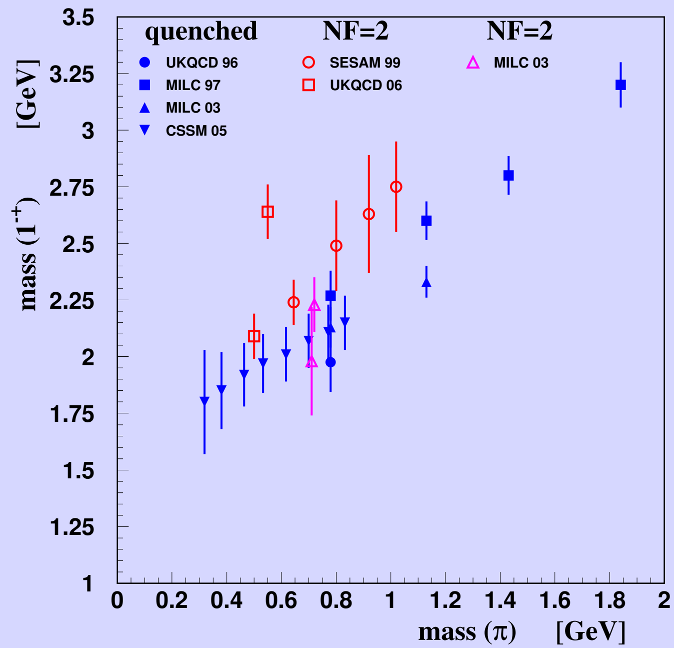
Flux-tube model, start with a $q\bar{q}$ system and add one unit of angular momentum in the flux tube.

S($q\bar{q}$)	J^{PC} of hybrid
0	1^{++} 1^{--}
1	0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}

8 degenerate nonets

~1.9 GeV/c^2

Lattice QCD: 1^{-+} nonet is lightest.



Mass Hierarchy

1^{-+}	1.9+/- 0.2 GeV/c^2
2^{+-}	2.0+/- 1.1 GeV/c^2
0^{+-}	2.3+/- 0.6 GeV/c^2

In the charmonium sector:

1^{-+}	4.39 ±0.08 GeV/c^2
0^{+-}	4.61 ±0.11 GeV/c^2

Looking for Hybrids

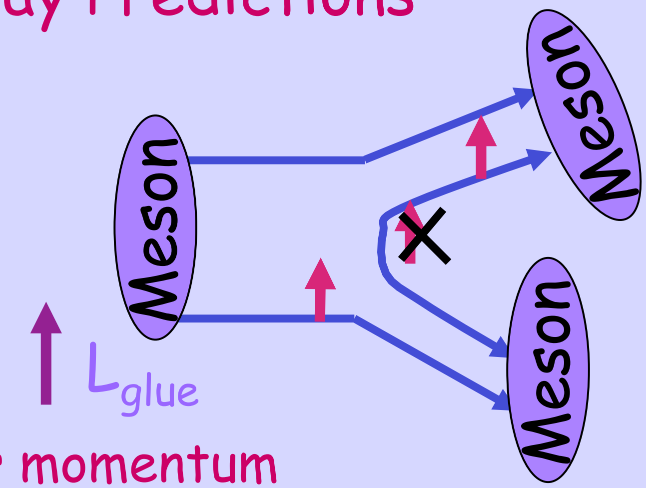
Analysis Method

Partial Wave Analysis

Fit n-dim. angular distributions

Fit models of production and decay of resonances.

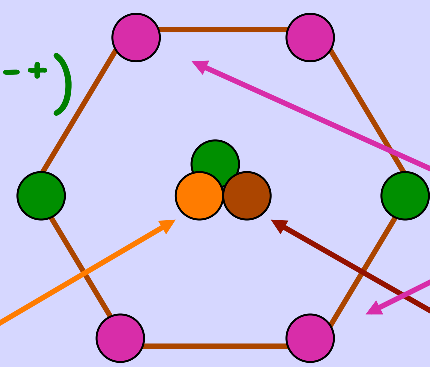
Decay Predictions



Angular momentum in the gluon flux stays confined.

π_1 $I^G(J^{PC})=1^-(1^{-+})$

Nine state



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

η'_1 $I^G(J^{PC})=0^+(1^{-+})$

η_1 $I^G(J^{PC})=0^+(1^{-+})$

This leads to complicated multi-particle final states.

Experimental Evidence for Hybrids

The most extensive data sets to date are from the **BNL E852 experiment**. There is also data from the **VES experiment** at Protvino and some results from the **Crystal Barrel experiment** at LEAR. There is a null result from **CLAS (Jefferson Lab)**. We have also just started to see results from the **COMPASS** experiment at CERN.

E852 Experiment

$\pi^- p$

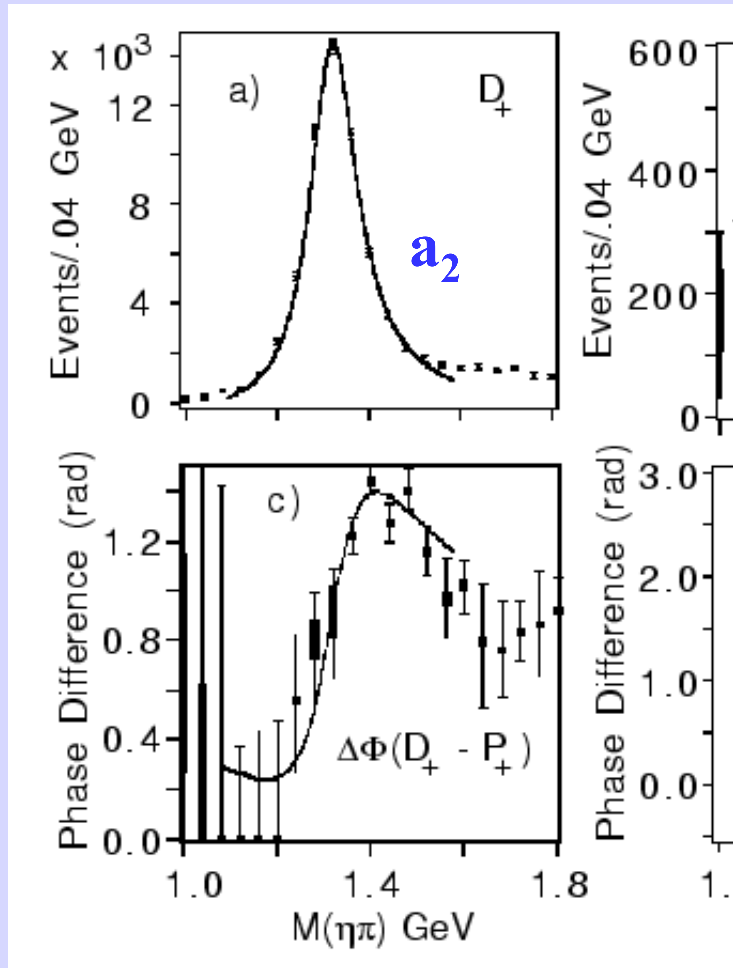
(1

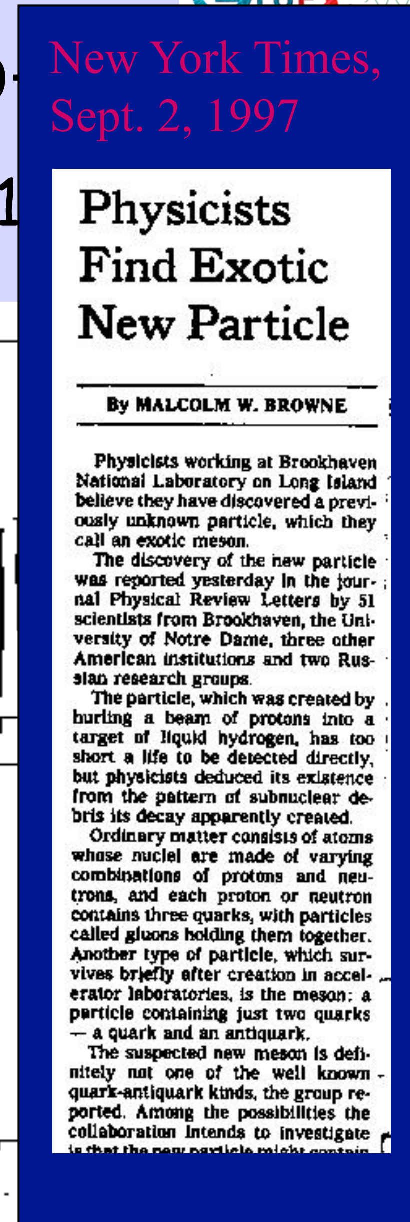
$\pi_1(1400)$ Mass = $1370 \pm 16^{+50}_{-30}$ MeV/c^2
Width= $385 \pm 40^{+65}_{-105}$ MeV/c^2

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.)

Seen by Crystal Barrel in $\eta\pi^-$ and $\eta\pi^0$




New York Times, Sept. 2, 1997

Physicists Find Exotic New Particle

By MALCOLM W. BROWNE

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The discovery of the new particle was reported yesterday in the journal Physical Review Letters by 51 scientists from Brookhaven, the University of Notre Dame, three other American institutions and two Russian research groups.

The particle, which was created by hurling a beam of protons into a target of liquid hydrogen, has too short a life to be detected directly, but physicists deduced its existence from the pattern of subnuclear debris its decay apparently created.

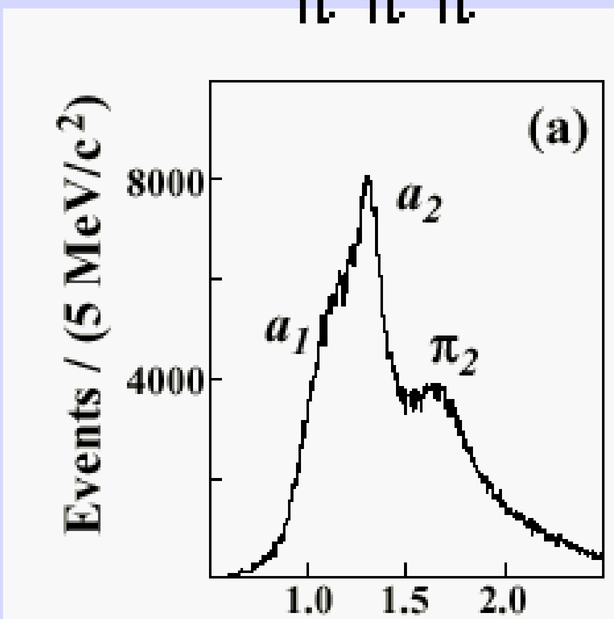
Ordinary matter consists of atoms whose nuclei are made of varying combinations of protons and neutrons, and each proton or neutron contains three quarks, with particles called gluons holding them together. Another type of particle, which survives briefly after creation in accelerator laboratories, is the meson: a particle containing just two quarks — a quark and an antiquark.

The suspected new meson is definitely not one of the well known quark-antiquark kinds, the group reported. Among the possibilities the collaboration intends to investigate is that the new particle might contain

E852 Results $\pi^- p \to p\pi^+\pi^-\pi^-$

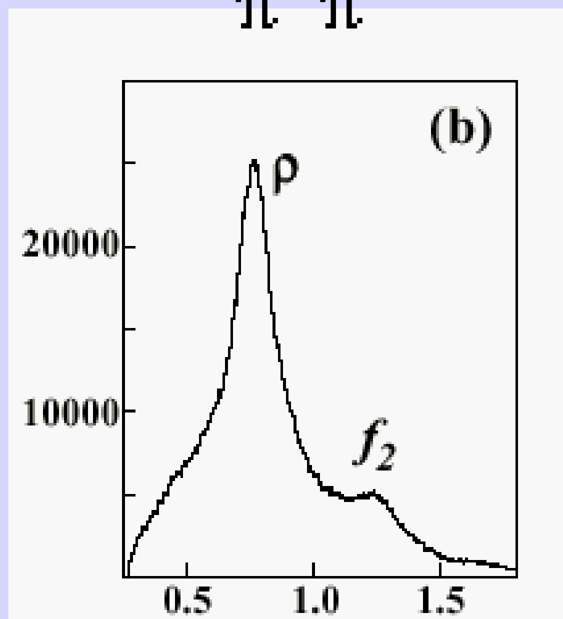
At 18 GeV/c

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



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

$\pi^+\pi^-$



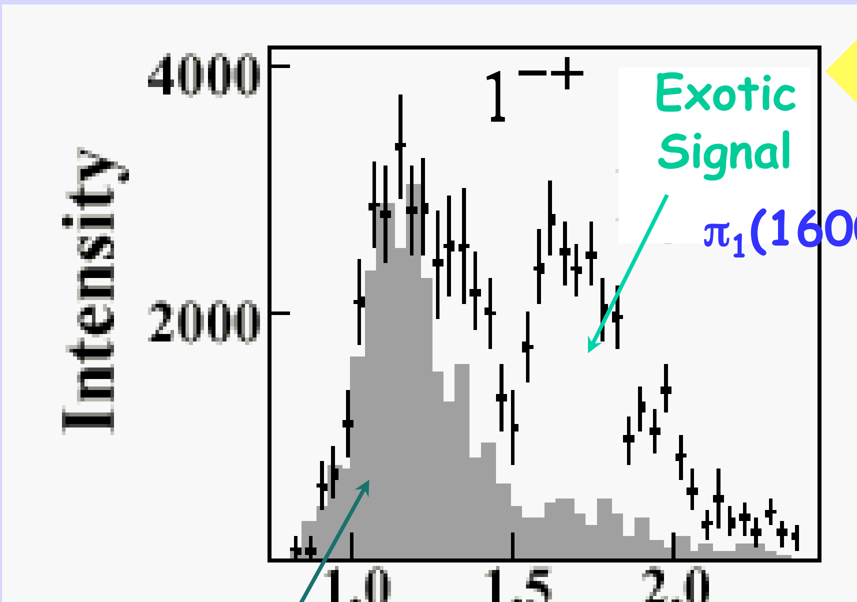
$M(\pi^+\pi^-)$ $[GeV/c^2]$

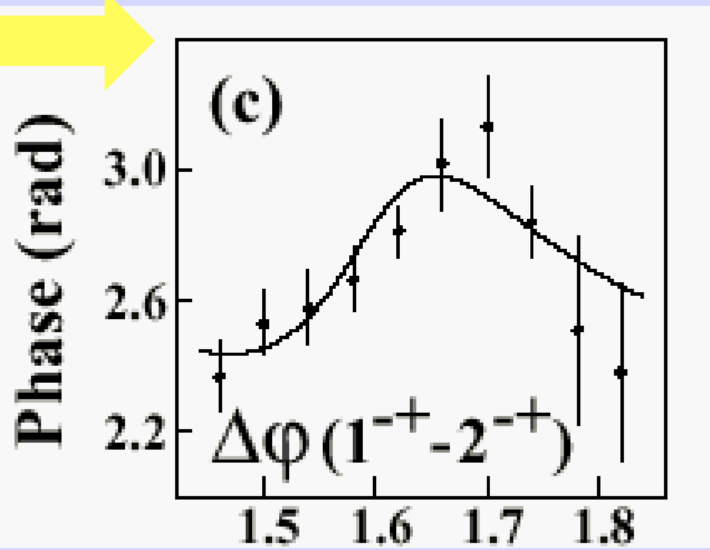
to partial wave analysis

suggests $\pi^- p \to \rho^0\pi^- p$
$\to \pi^+\pi^-\pi^- p$

An Exotic Signal

Correlation of Phase & Intensity





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

Leakage From Non-exotic Wave

due to imperfectly understood acceptance

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

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

In Other Channels

E852 Results

1^{-+} in $f_1\pi$ and $b_1\pi$

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

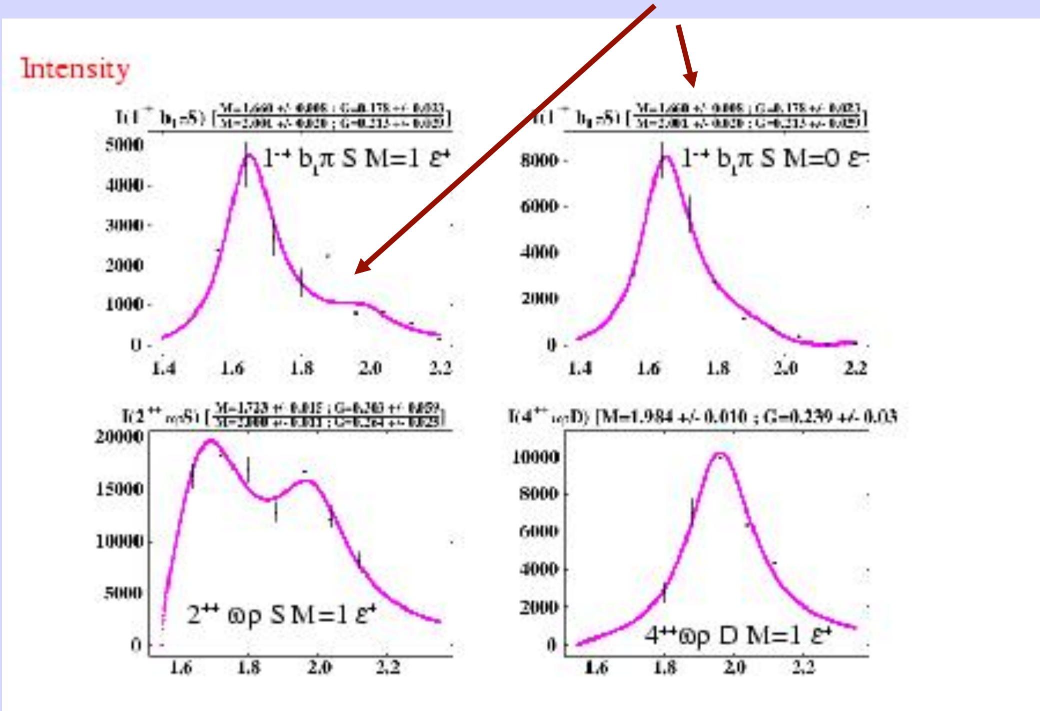
$\pi_1(1600) \rightarrow f_1\pi$

Mass=1.709±0.024 GeV

Width=0.403±0.08 GeV

In both $b_1\pi$ and $f_1\pi$, observe
Excess intensity at about
2GeV/c².
Mass ~ 2.00 GeV,
Width ~ 0.2 to 0.3 GeV

$\pi^- p \rightarrow \omega\pi^0\pi^- p$ $\pi_1(1600) \rightarrow b_1\pi$

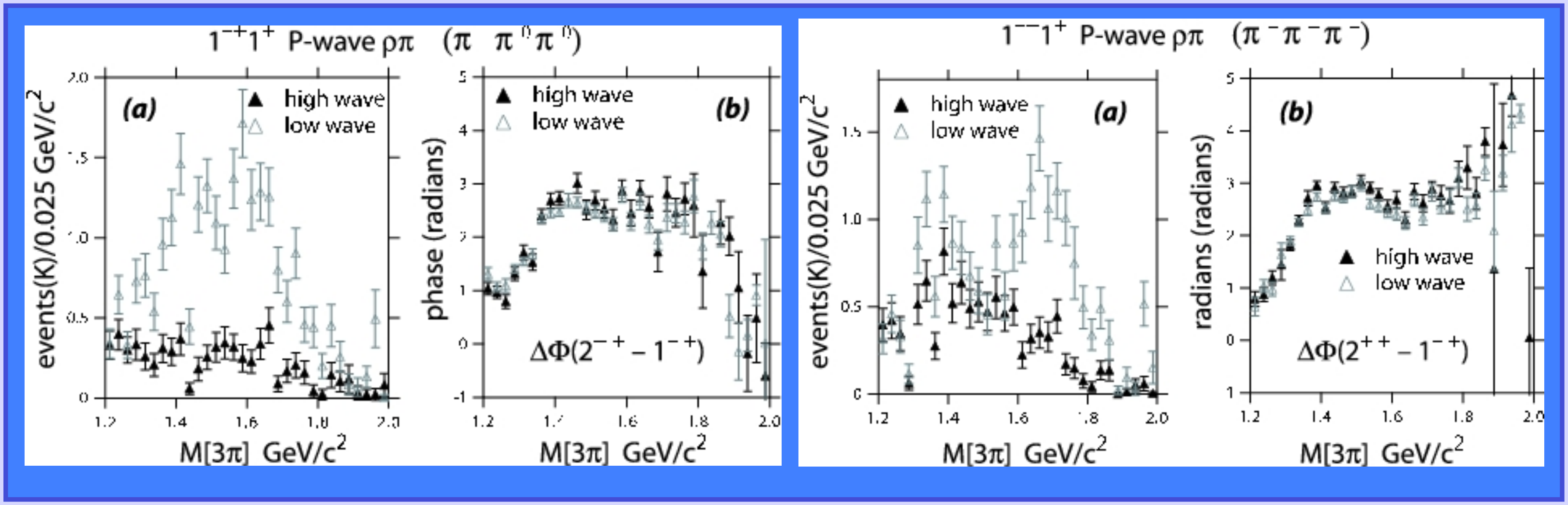


Mass = 1.687±0.011 GeV

Width = 0.206±0.03 GeV

New Analysis

Dzierba et. al. PRD 73 (2006)



Add $\pi_2(1670) \rightarrow \rho\pi$ (L=3)
Add $\pi_2(1670) \rightarrow \rho_3\pi$
Add $\pi_2(1670) \rightarrow (\pi\pi)_S\pi$
Add a_3 decays
Add $a_4(2040)$

10 times statistics in each of two channels.

Get a better description of the data via moments comparison

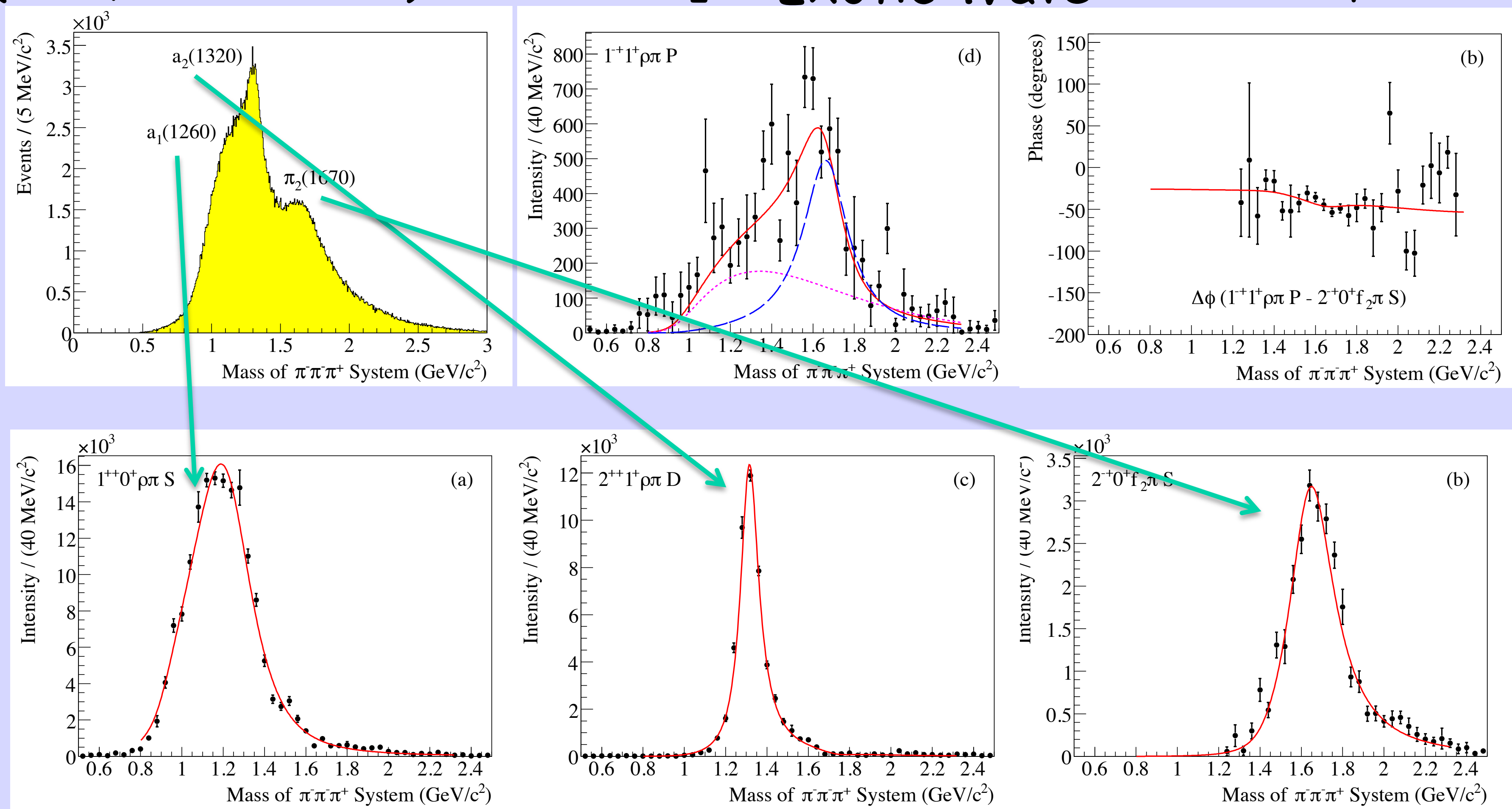
No Evidence for the $\pi_1(1670)$

COMPASS Experiment

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

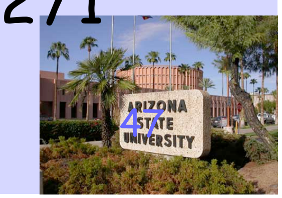
(420,000 Events)

1 ⁻⁺ Exotic Wave (180 GeV pions)



$\pi_1(1600)$ m=1660 Γ=269 $\pi_2(1670)$ m=1658 Γ=271

42 Partial waves included, exotic is dominantly 1⁺ production.



Summary of the $\pi_1(1400)$

Mode	Mass	Width	Production	
$\eta\pi^-$	1370±15+50-30	385±40+65-105	1^+	
$\eta\pi^0$	1257±20±25	354±64±60	1^+	(controversial)
$\eta\pi$	1400	310	seen in proton-antiproton annihilation	

Summary of the $\pi_1(1600)$

Mode	Mass	Width	Production	
3π	1598 ±8+29-47	168±20+150-12	$1^+,0^-,1-$	(controversial)
$\eta'\pi$	1597±10+45-10	340±40±50	1^+	
$b_1\pi$	1664±8±10	185±25±38	$0^-,1^+$	3π not seen in
$f_1\pi$	1709±24±41	403±80±115	1^+	Photoproduction
3π	1660 ±10+64-0	269±21+42-64	1^+	COMPASS

Summary of the $\pi_1(2000)$

Mode	Mass	Width	Production
$b_1\pi$	2014±20±16	230±32±73	1^+
$f_1\pi$	2001±30±92	332±52±49	1^+

Experimental Evidence

Hybrid Nonets

Establish other Nonets:

0^{+-} 1^{-+} 2^{+-}

Levels

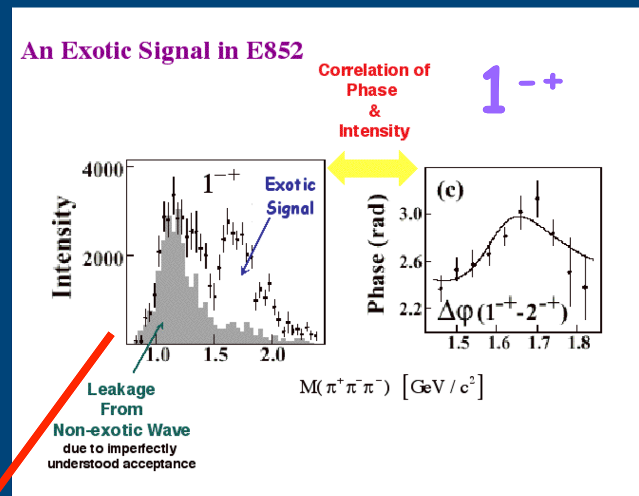
Built on normal mesons

$d\bar{s}$ $u\bar{s}$

$d\bar{u}$ $\frac{1}{\sqrt{2}}\left(u\bar{u} - d\bar{d}\right)$ $u\bar{d}$

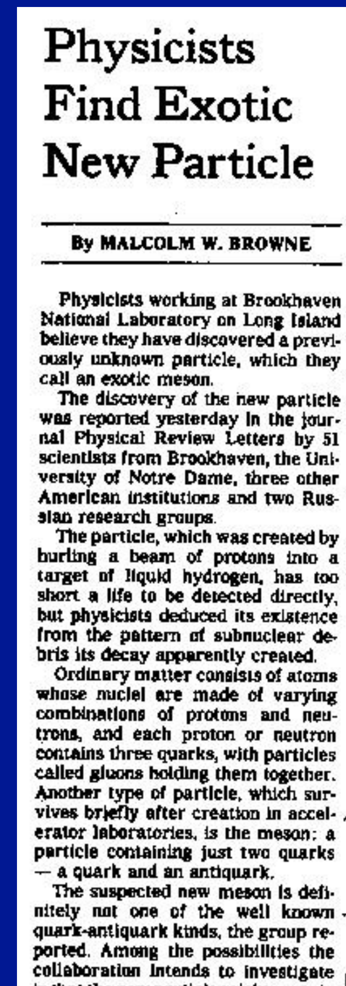
$s\bar{d}$ $s\bar{u}$

$\frac{1}{\sqrt{3}}\left(u\bar{u} + d\bar{d} + s\bar{s}\right)$ $\frac{1}{\sqrt{6}}\left(u\bar{u} + d\bar{d} - 2s\bar{s}\right)$



Identify other states in nonet to establish hybrid

New York Times, Sept. 2, 1997



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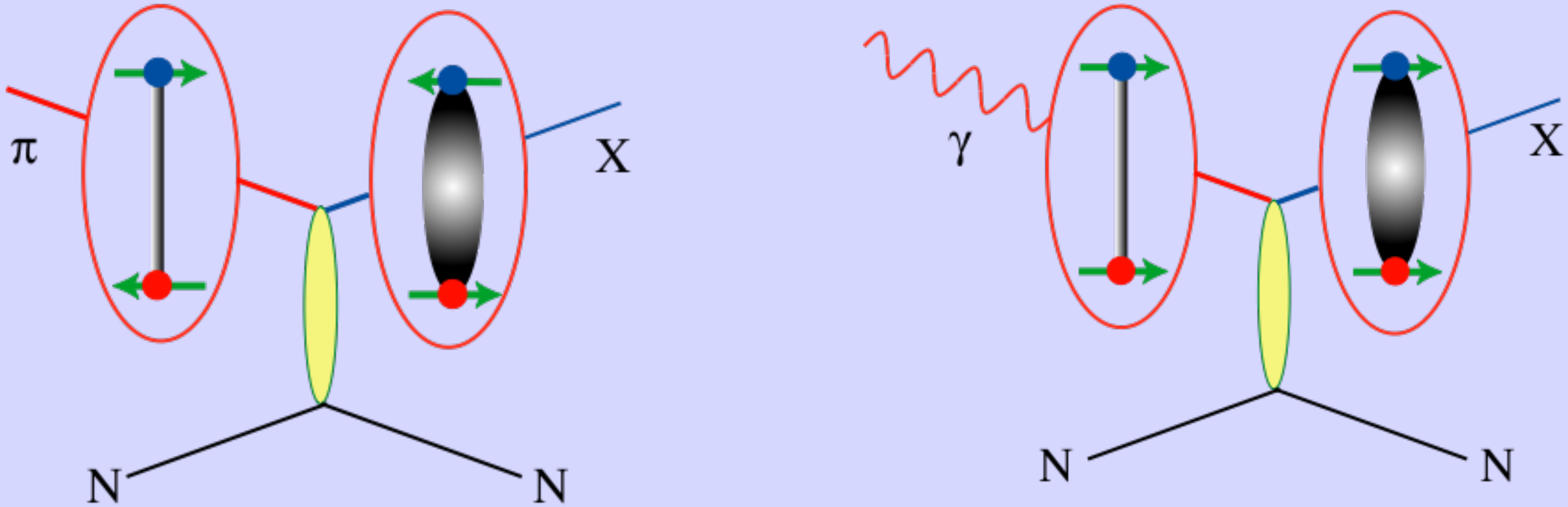
How to Produce Hybrids

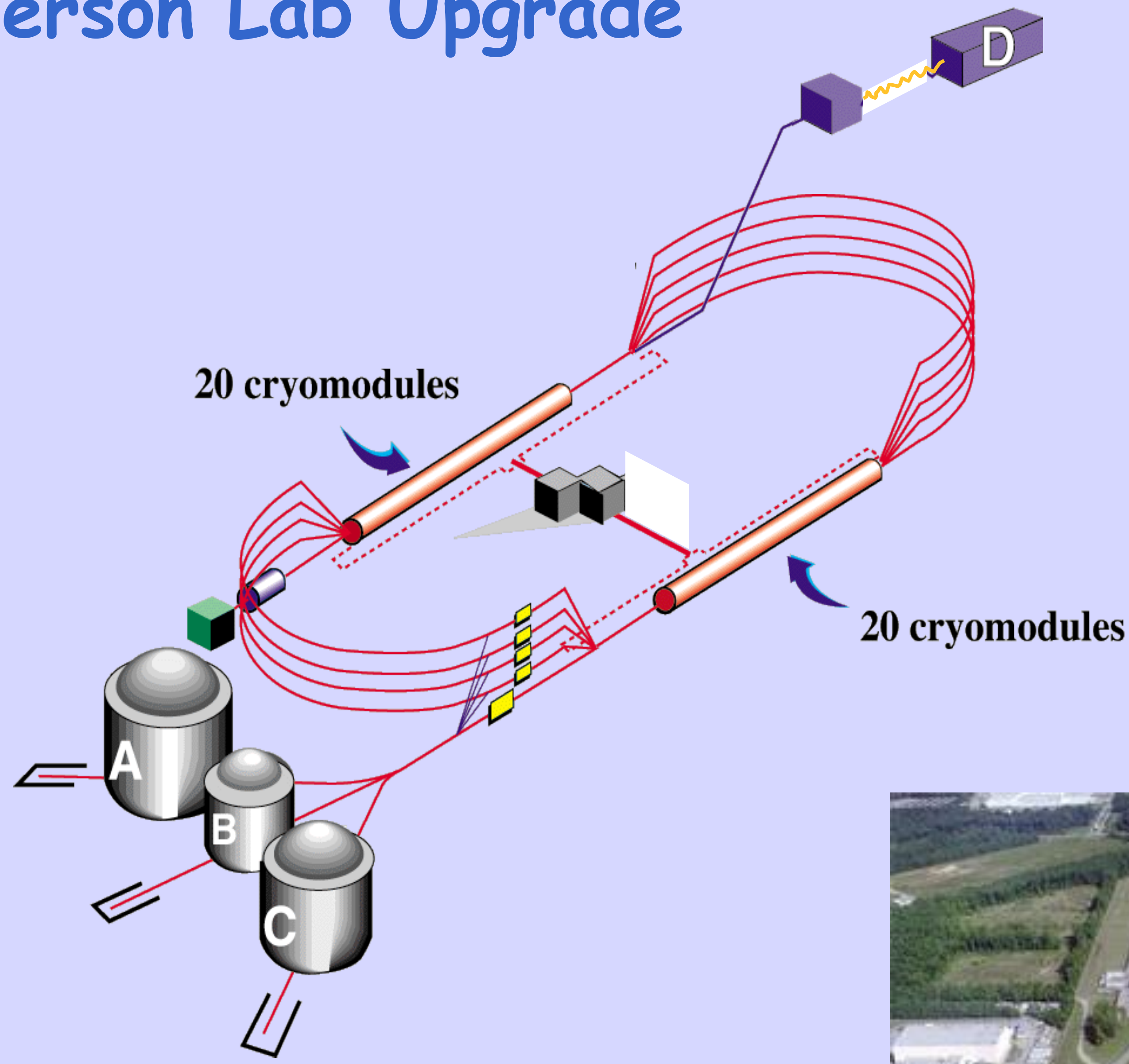


Beams of photons may be a more natural way to create hybrid mesons.

Simple QN counting leads to the exotic mesons

There is almost no data for photon beams at 9GeV energies. GlueX will increase data by 3-4 orders of magnitude.

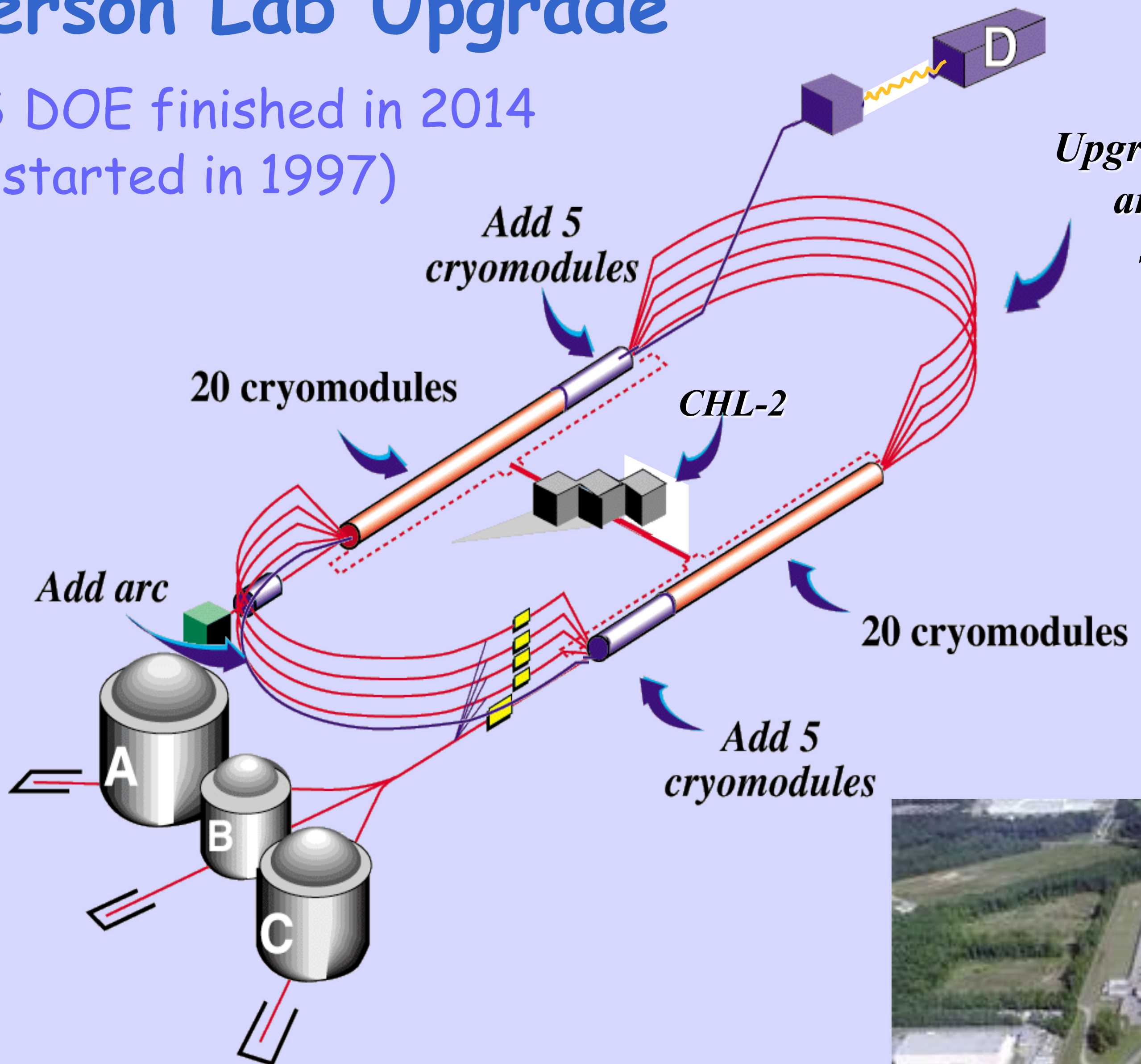
Jefferson Lab Upgrade



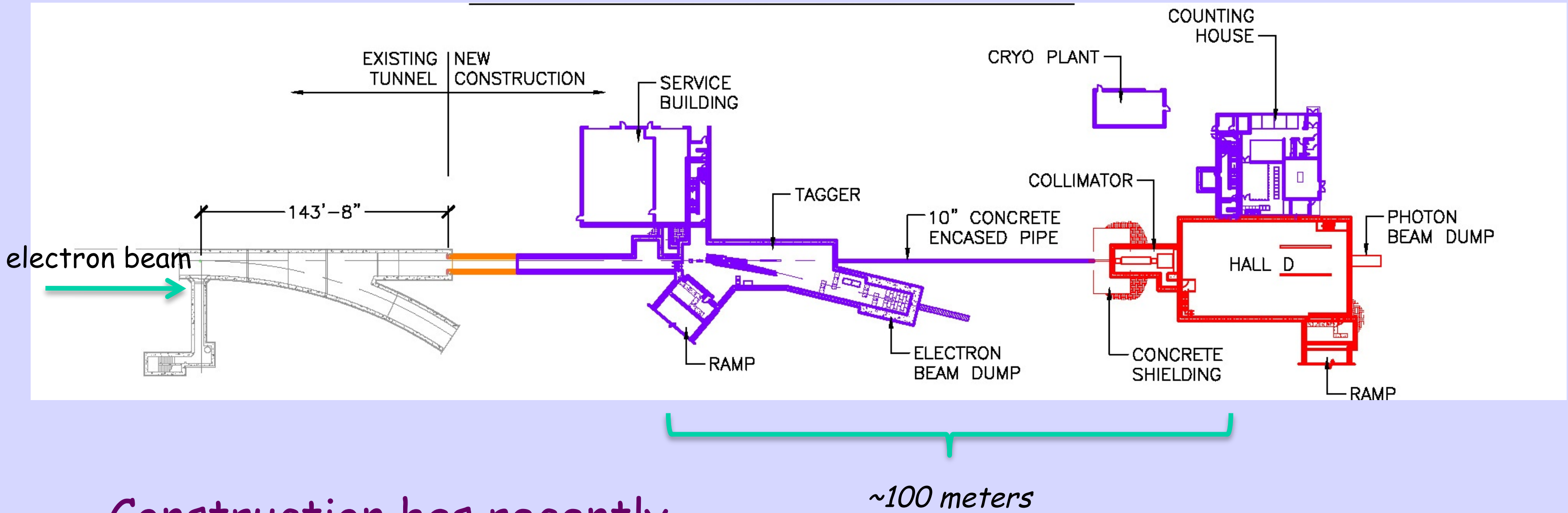
Jefferson Lab Upgrade

320M$ DOE finished in 2014

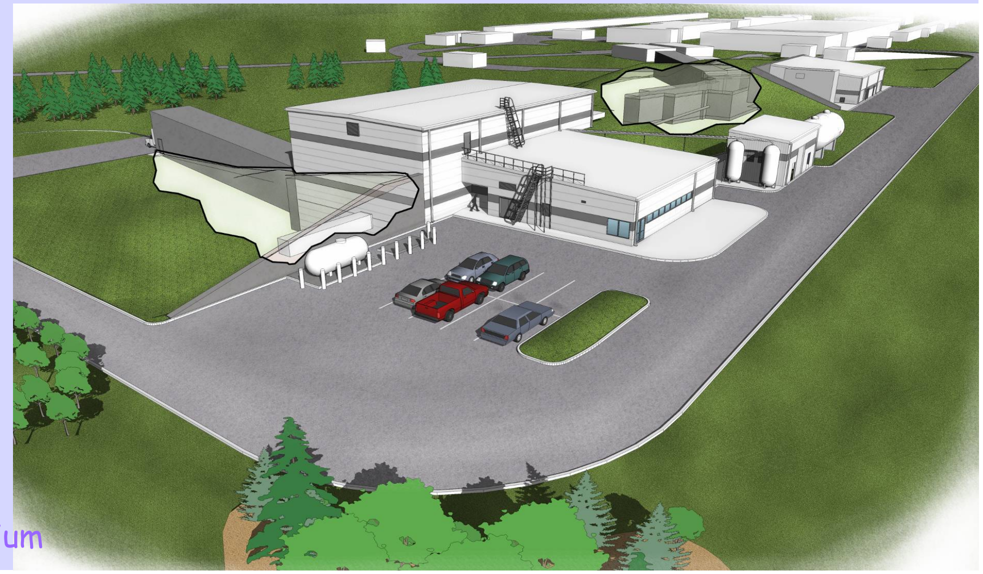
(I started in 1997)



Hall-D Complex at Jefferson Lab

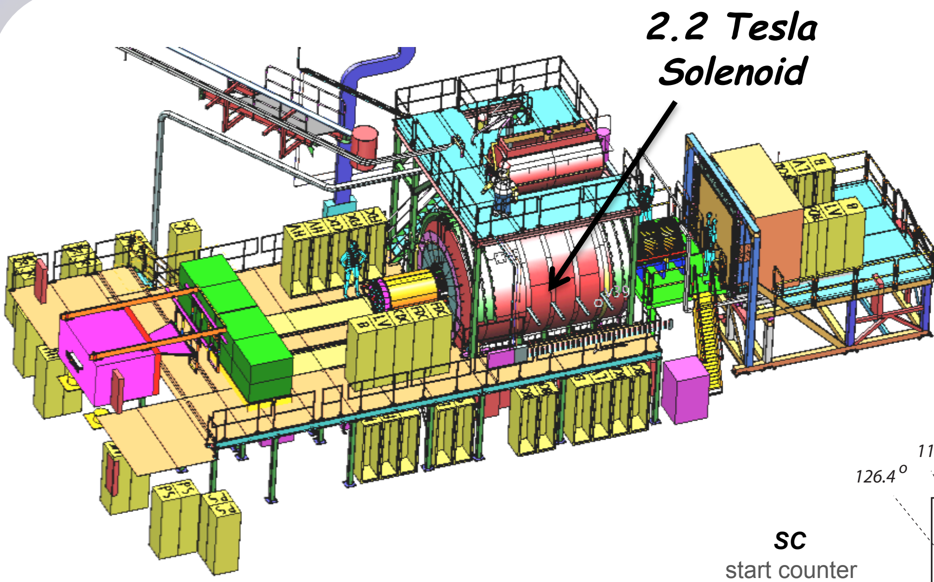


Construction has recently begun and will be completed Fall 2011. (Buildings only, detectors will follow)

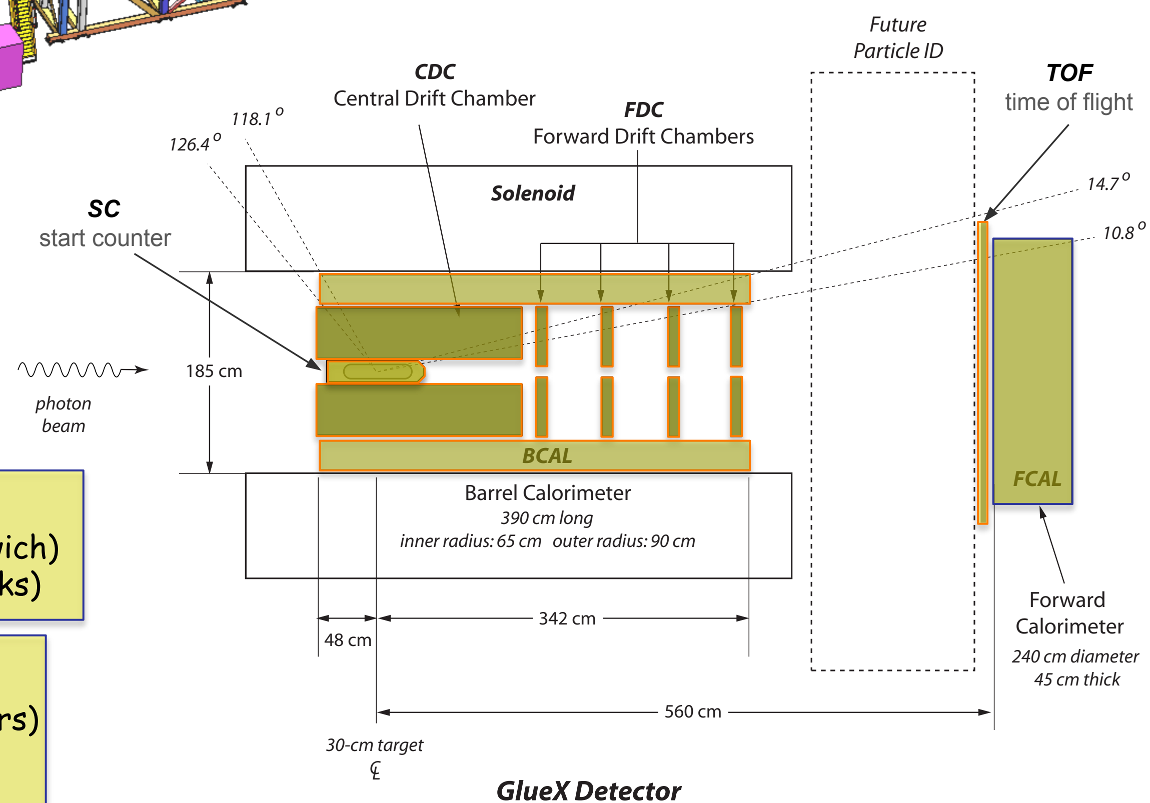


Hall D: February 2010

The GlueX Detector



- 2.2T superconducting solenoidal magnet
- Fixed target (LH_2)
- 10^8 tagged γ/s (8.4-9.0GeV)
- hermetic



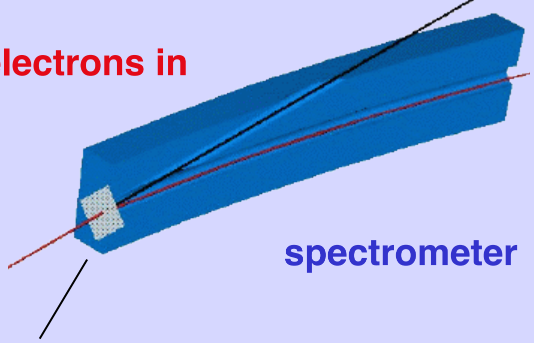
Charged particle tracking
- Central drift chamber (straw tube)
- Forward drift chamber (cathode strip)

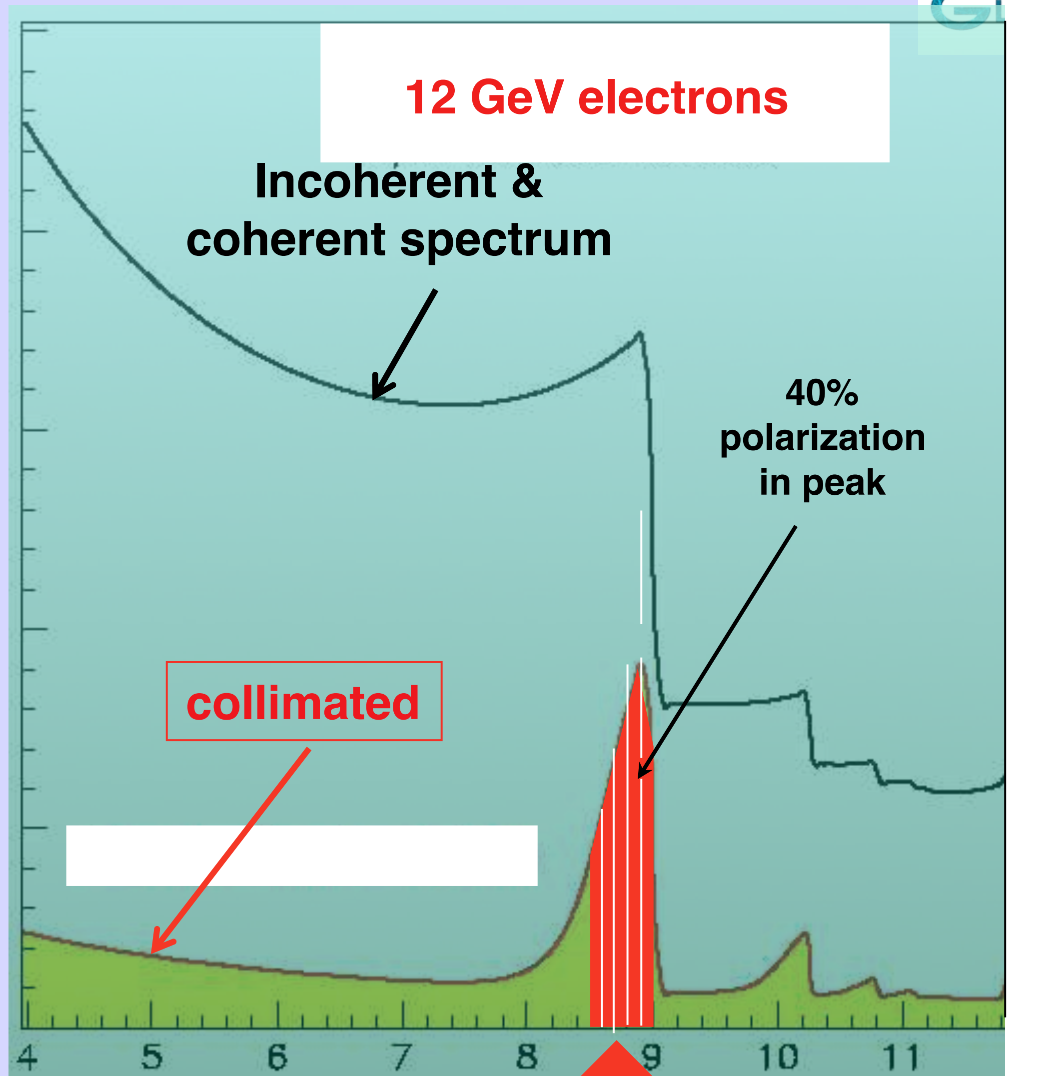
Calorimetry
- Barrel Calorimeter (lead, fiber sandwich)
- Forward Calorimeter (lead-glass blocks)

PID
- Time of Flight wall (scintillators)
- Start counter
- Barrel Calorimeter

Coherent Bremsstrahlung

This technique provides requisite energy, flux and polarization

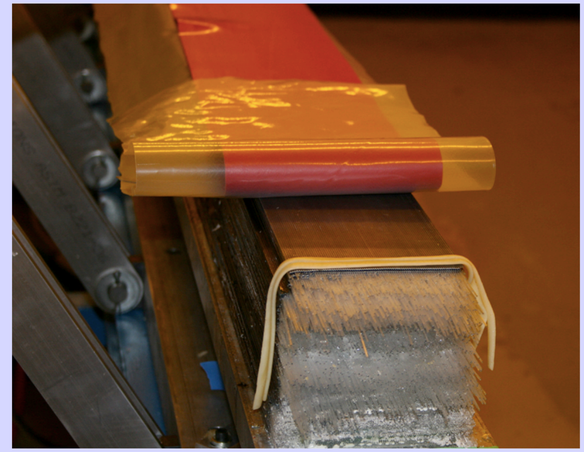


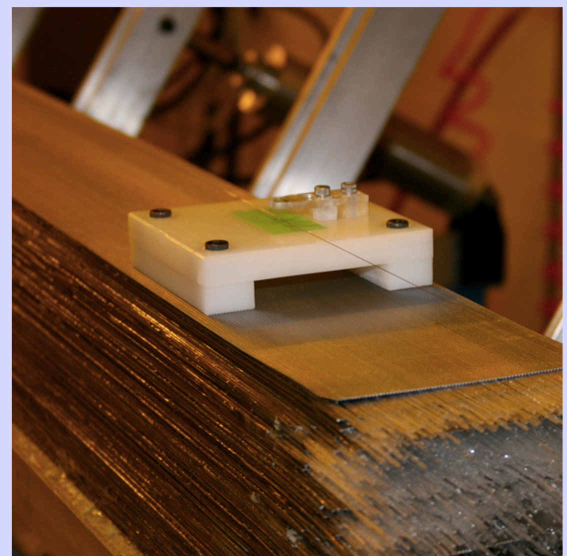


Detector Construction

48-module BCAL at University of Regina

- Completing modules 3 and 4.
- First shipments to JLab in April



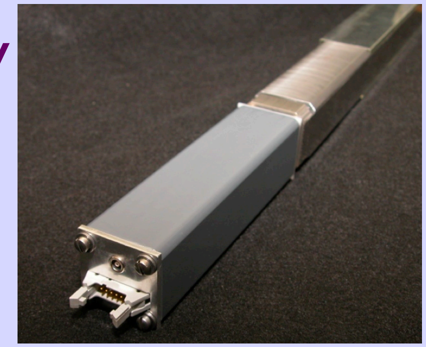


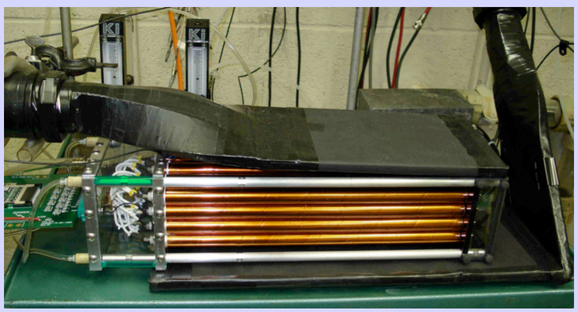
Detector Construction

Lead-glass Forward Calorimeter at Indiana University

Contract for construction in place soon.

Work starting spring 2010





Central Drift Chamber at Carnegie Mellon

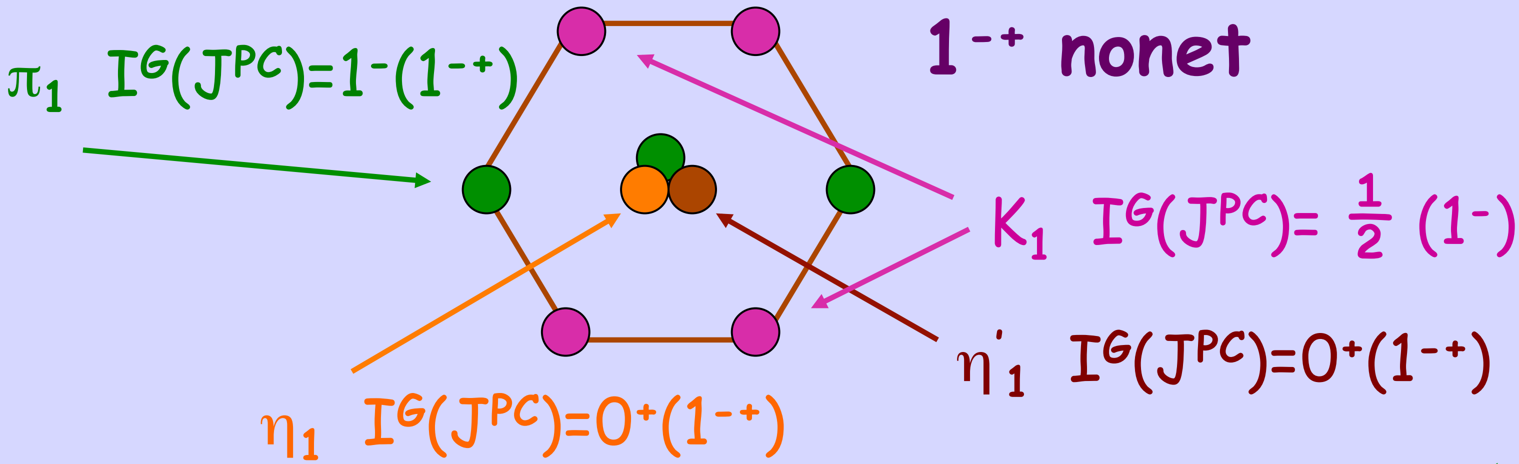
Contract for construction in place soon.

Work starting spring 2010

More contracts starting in 2011 and 2010

Exotics In Photoproduction

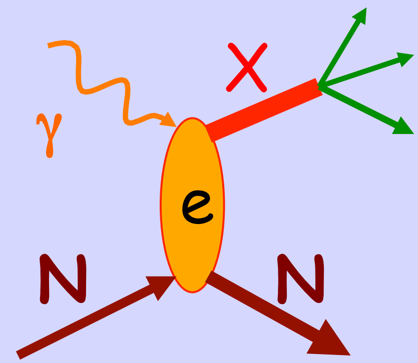
1^{-+} nonet



Need to establish nonet nature
of exotics: π η η'

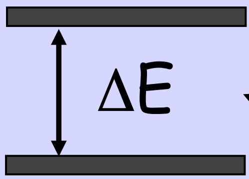
Need to establish more than one
nonet: 0^{+-} 1^{-+} 2^{+-}

Need very good partial wave analysis.

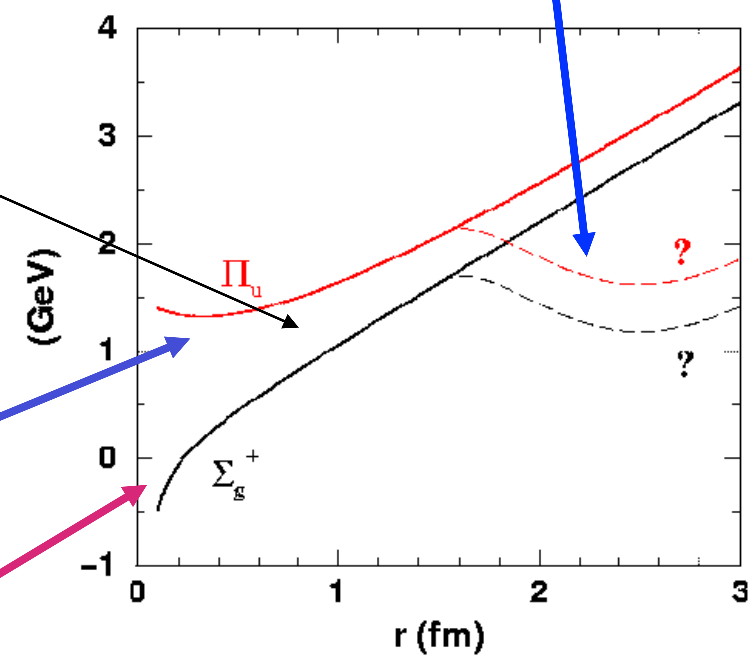


$\gamma \Leftrightarrow \rho,\omega,\phi$

Gluonic Hadrons and Confinement



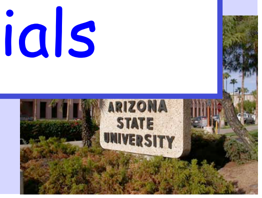
What are the light quark
Potentials doing?



Potentials corresponding
To excited states of glue.

Non-gluonic mesons –
ground state glue.

Lattice QCD potentials



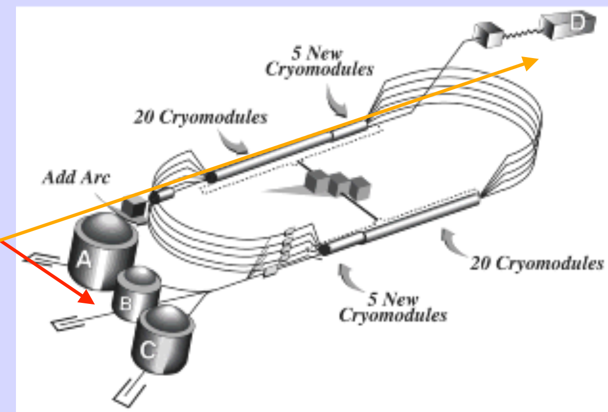
Conclusions

The quest to understand confinement and the strong force is about to make great leaps forward.

Advances in theory and computing will soon allow us to solve QCD and understand the baryon spectrum and the role of glue.

New results on baryons and theoretical work on models is near to giving us new insight on the observed baryons.

The definitive experiments to confirm or refute our expectations on the role of glue are being built.



The synchronized advances in both areas will allow us to finally understand QCD and confinement.

The GlueX Detector in Hall-D

- The 12 GeV upgrade of Jefferson Lab is currently under construction
- Construction of Hall-D broke ground in April 2009
- Construction of the GlueX detector has started

Hall-D Groundbreaking

Current plans call for the first beam in Hall-D/GlueX in late 2014