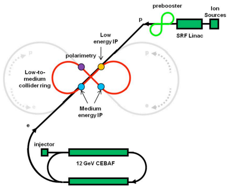
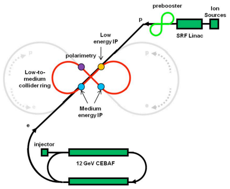


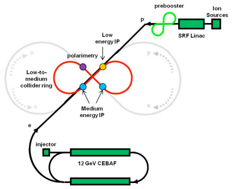
Meson spectroscopy with photo- and electro-production

Curtis A. Meyer
Carnegie Mellon University



Outline

- What are the current issues in spectroscopy?
- What is needed to do spectroscopy?
- What might be interesting in the future?



Observed Hadrons

Color singlet (white) objects observed in nature:

In nature, QCD appears to have two configurations.

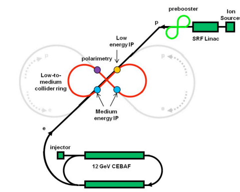
three quarks (qqq) Baryons

proton: uud neutron: udd

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

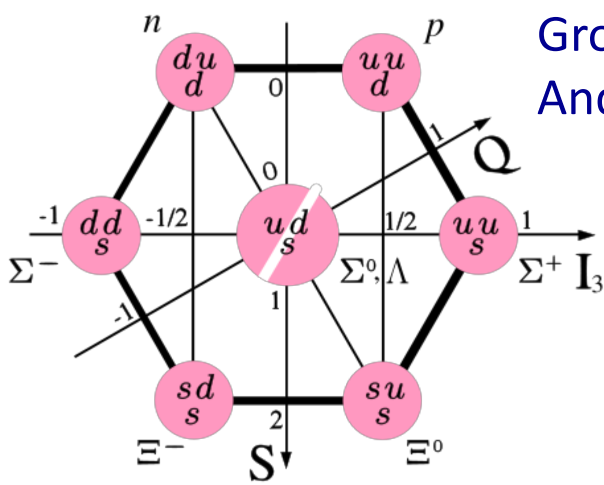
$$\pi^+(u\bar{d}) \quad \pi^0(u\bar{u} + d\bar{d})/\sqrt{2} \quad \pi^-(d\bar{u})$$

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.



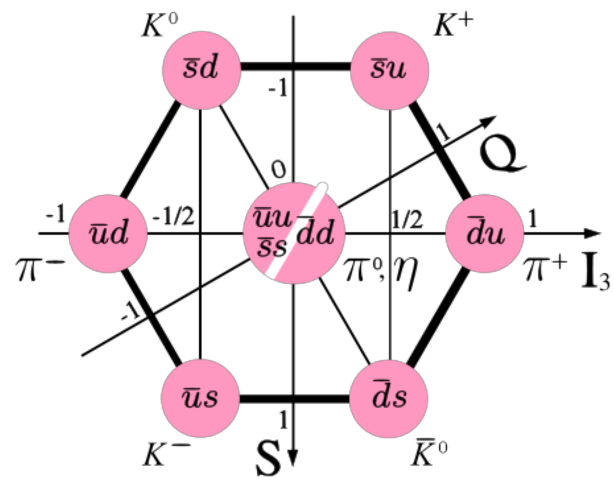
Observed Hadrons

Baryons



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

Mesons



Groups of
9 (nonet).

Other Configurations?

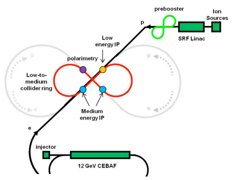
$q\bar{q}q\bar{q}$ 4-quark

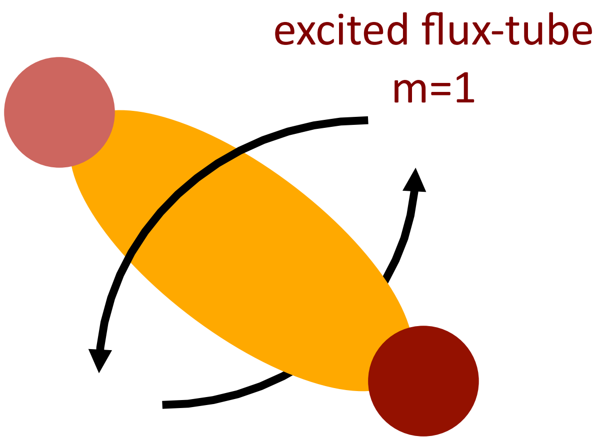
$qqq\bar{q}q$ pentaquarks

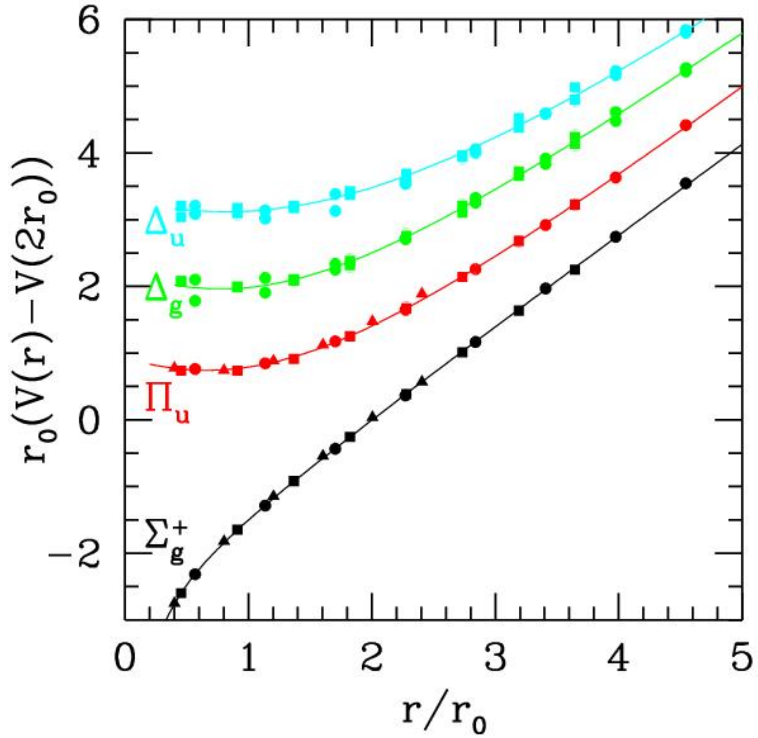
$gg \quad ggg$ glueballs

$q\bar{q}g$ hybrids

QCD Potential

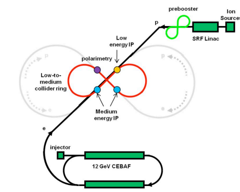






Gluonic Excitations provide an experimental measurement of the excited QCD potential.

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^{+-}

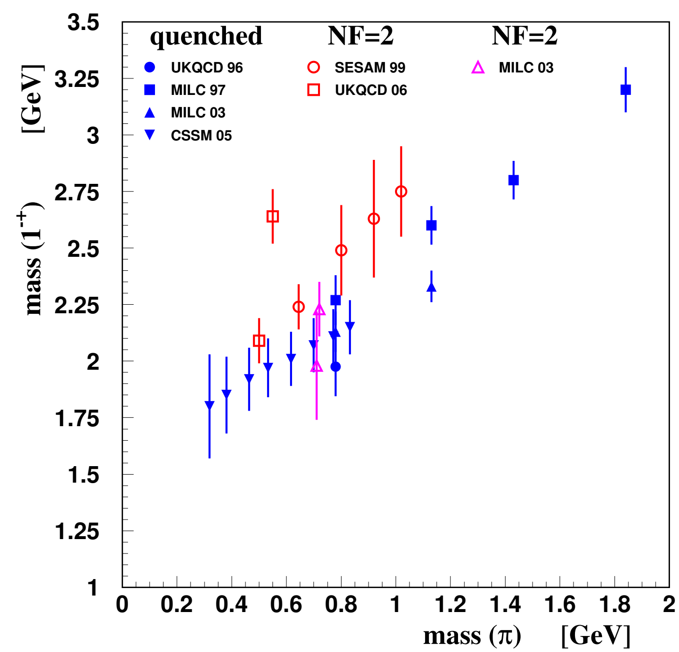
8 degenerate nonets

~1.9 GeV/c²

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

Mass Hierarchy

1^{-+}	1.9+/- 0.2 GeV/c²
2^{+-}	2.0+/- 1.1 GeV/c²
0^{+-}	2.3+/- 0.6 GeV/c²

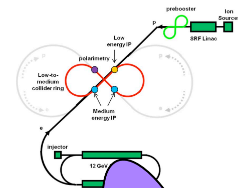


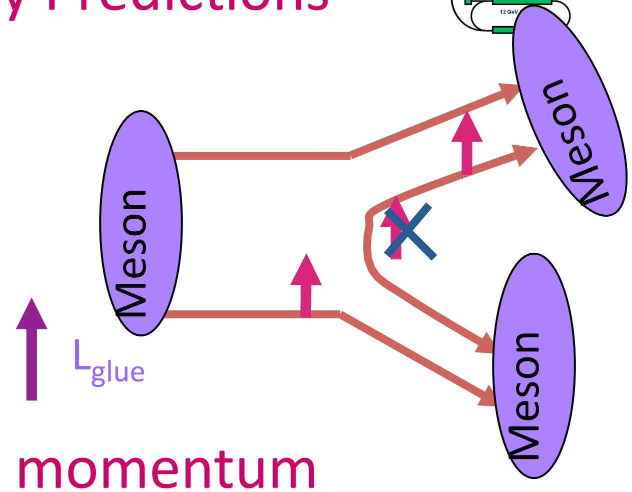
In the charmonium sector:

1^{-+}	4.39 ±0.08 GeV/c²
0^{+-}	4.61 ±0.11 GeV/c²

Looking for Hybrids

Decay Predictions





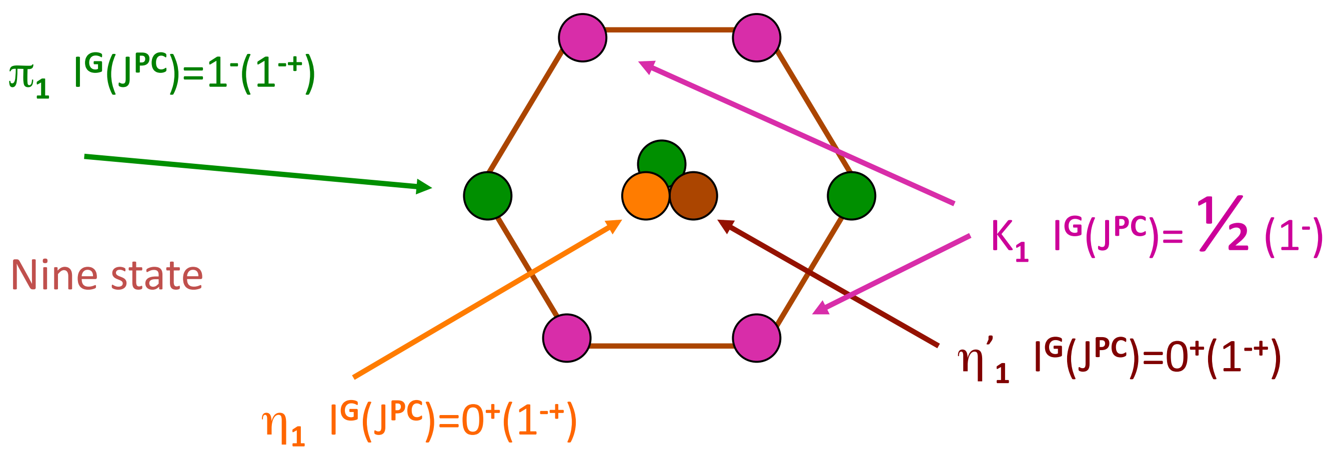
Angular momentum
in the gluon flux stays confined.

Analysis Method

Partial Wave Analysis

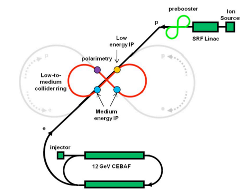
Fit n-dim. angular distributions

Fit models of production and decay of resonances.



This leads to complicated multi-particle final states.

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.

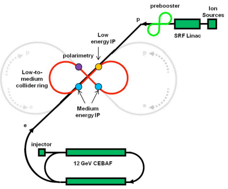
The Mesons

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

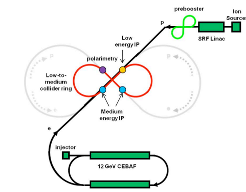
What are the properties of predicted states beyond simple quark-antiquark? $q\bar{q}g$

Need to map out new states.

Detector Specifications

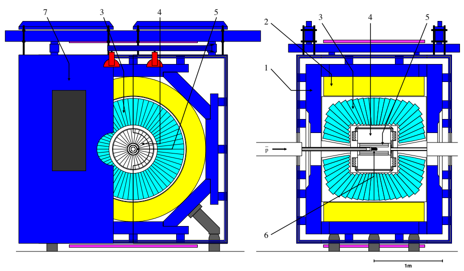


- Nearly full detector coverage for both charged particles and photons. We need to be able to reconstruct 8-10 particle final states with good efficiency.
- Good to excellent resolution depending on the physics (are states narrow such as charmonium?).
- Good particle identification.

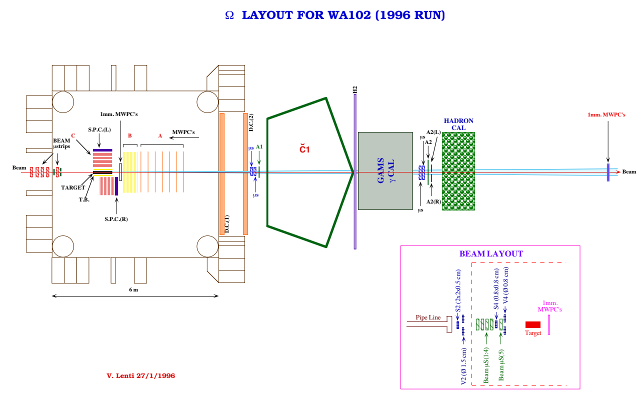


Spectroscopy Experiments

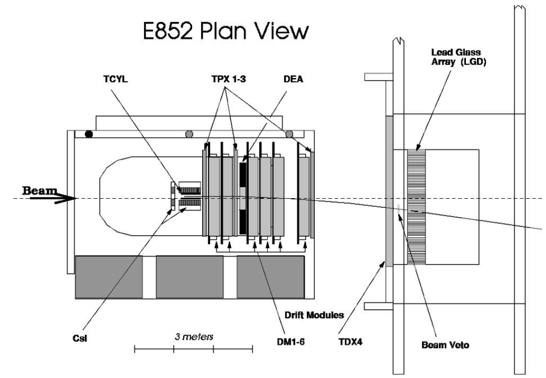
Crystal Barrel: LEAR/CERN



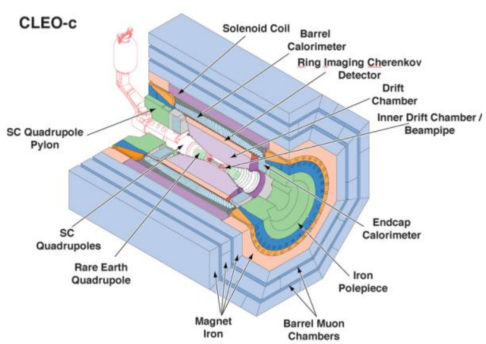
WA102: CERN



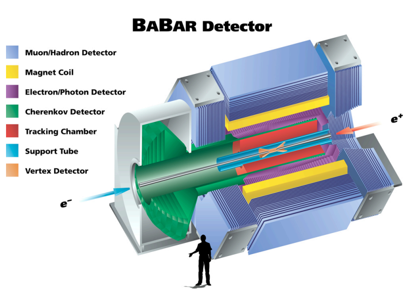
E852:BNL



CLEO-c:Cornell



BaBar: SLAC



Detector Features

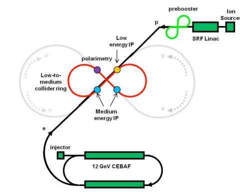
Good charged particle tracking.

Good photon detection.

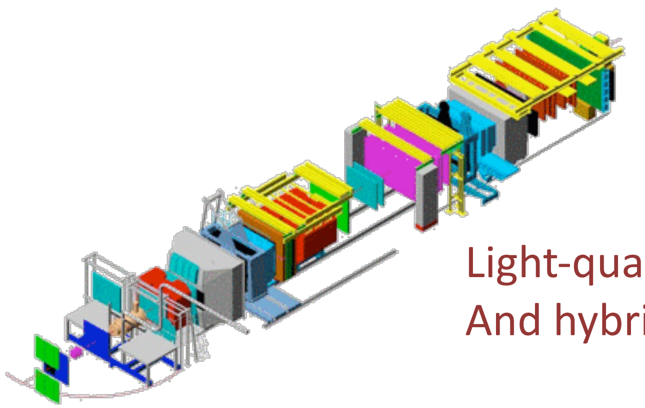
Good particle identification.

Very large and uniform acceptance

Spectroscopy Experiments



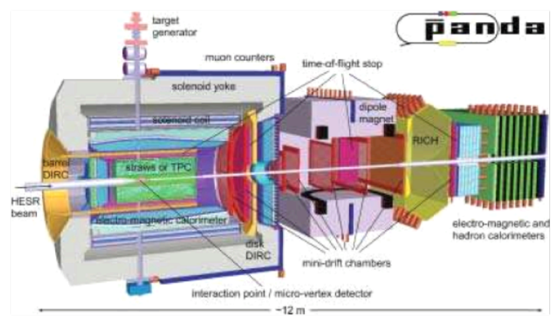
COMPASS: CERN (now)



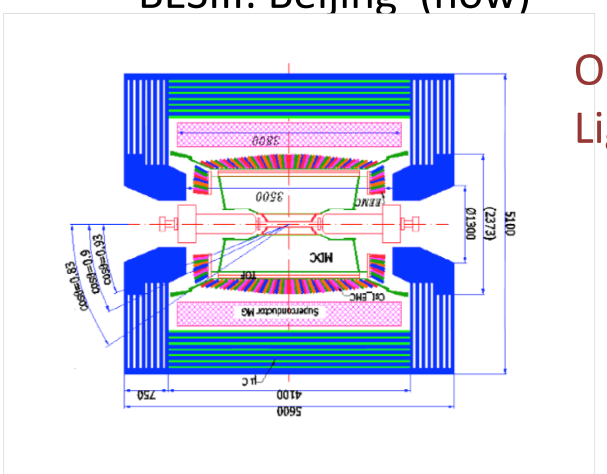
Light-quark systems, glueballs
And hybrid mesons

charmonium and charmonium
hybrids

PANDA: GSI (~2015)

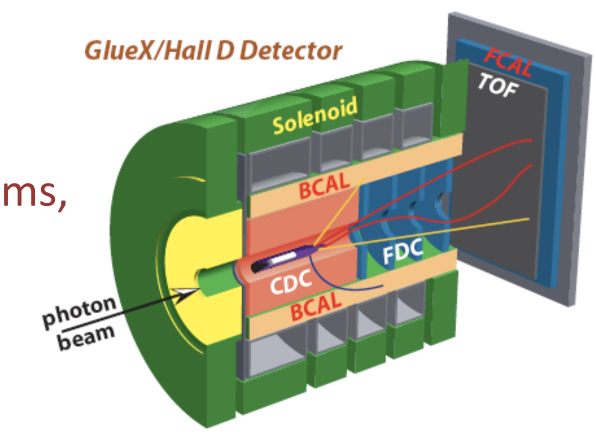


BESIII: Beijing (now)



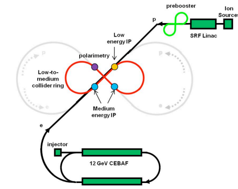
Open charm, glueballs,
Light-quark systems

GLUEX: JLAB-12GeV (~2014)



Light-quark systems,
Hybrids mesons,
baryons

Partial Wave Analysis



It is very helpful to know something about the production process:

Proton-anti-proton at rest: Initial atomic states are limited, know initial J^{PC}
e^+e^-: Initial state is known
Radiative decays: Initial state is known
Other decays: Initial state is known

Peripheral Production: Momentum transfer t
Peripheral Production: Energy dependence s

Take advantage of polarization: Beam, target, final states.

It is important to map out phase motion:

Need to observe production as a function of *mass*, and need to see the Production of more than one thing.

Production

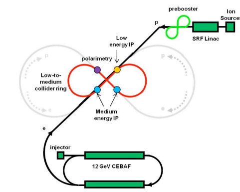
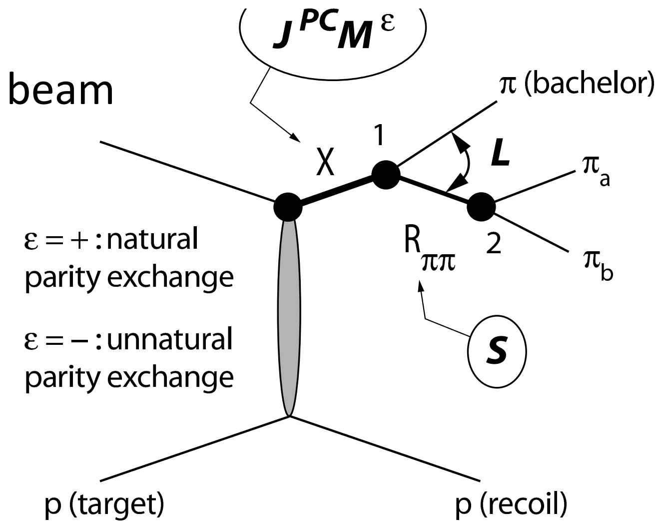
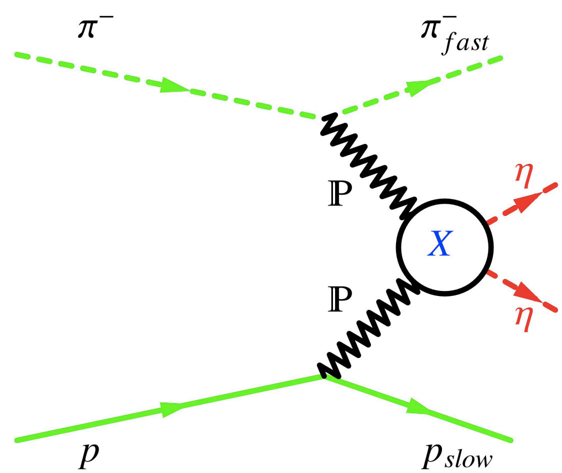


Photo- and Hadro-peripheral Production



Central Production



Very high energy for double pomeron

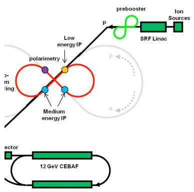
Need sufficient energy to produce "X".
Want small |t| to have larger cross section.
Isolate this process from others.

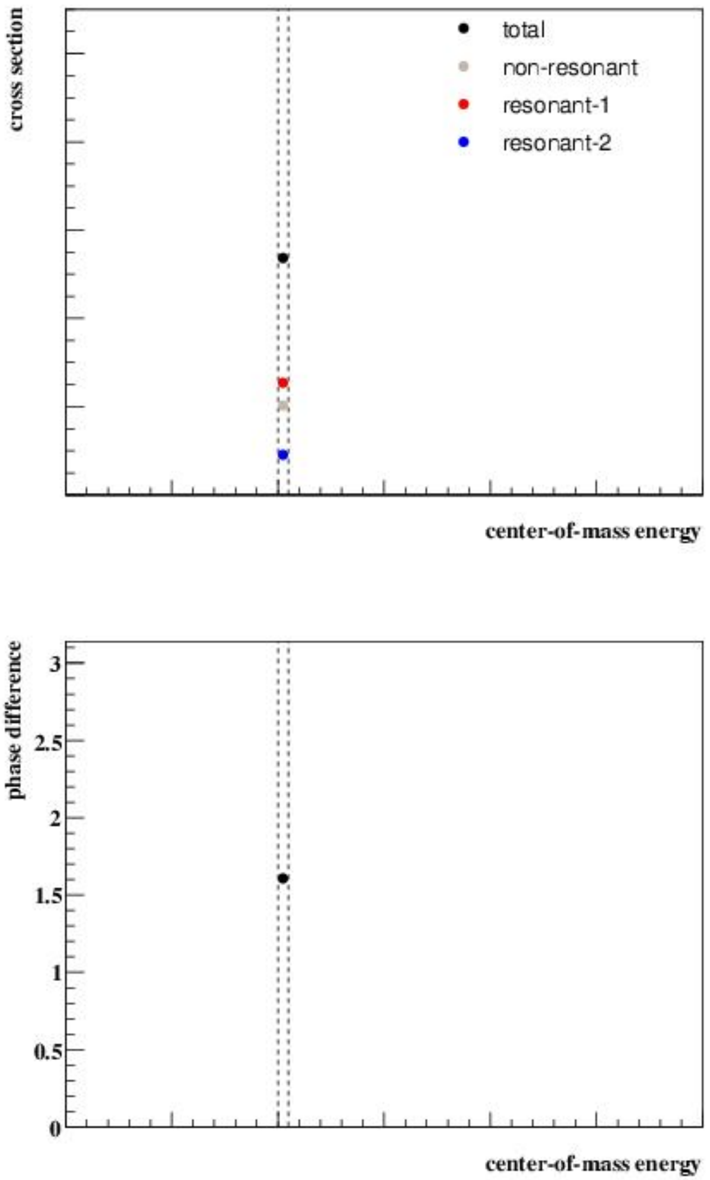
Partial Wave Analysis

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.





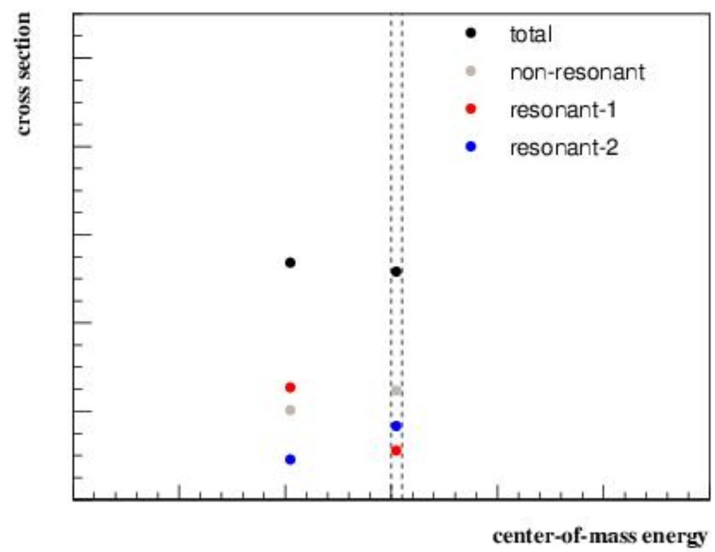
Partial Wave Analysis

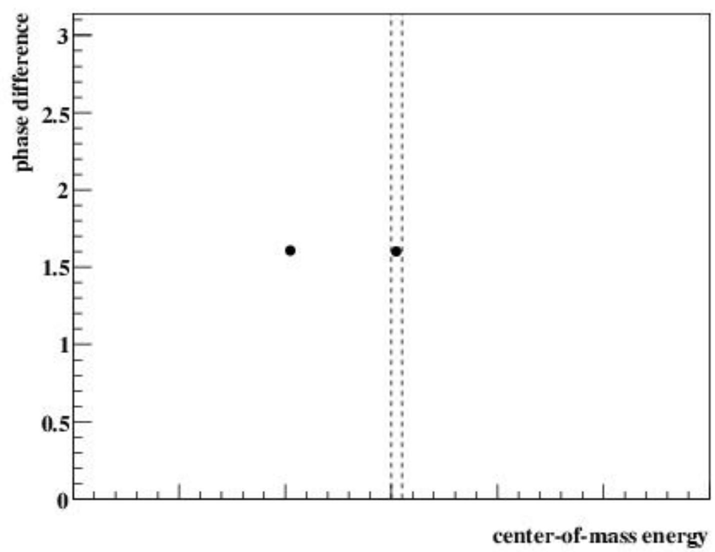
A simple model with three complex amplitudes, 2 of which are particles with different QNs

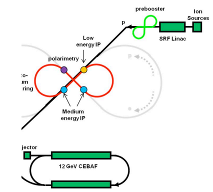
Start with a single energy bin.

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

Fit a 2nd bin.







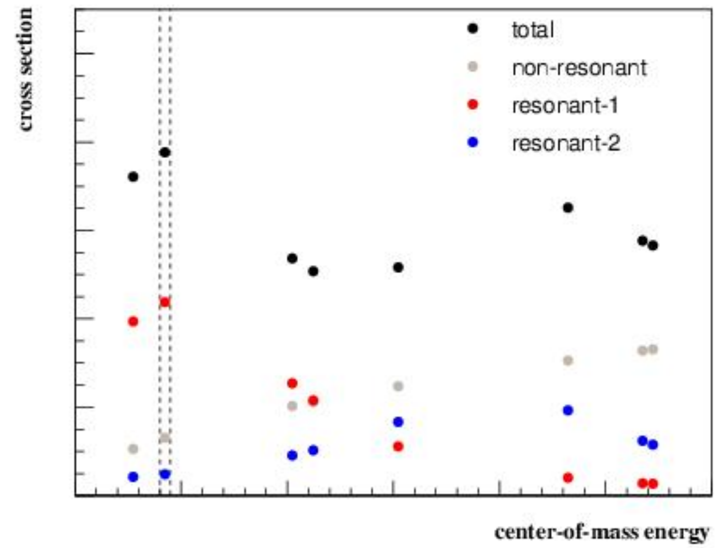
Partial Wave Analysis

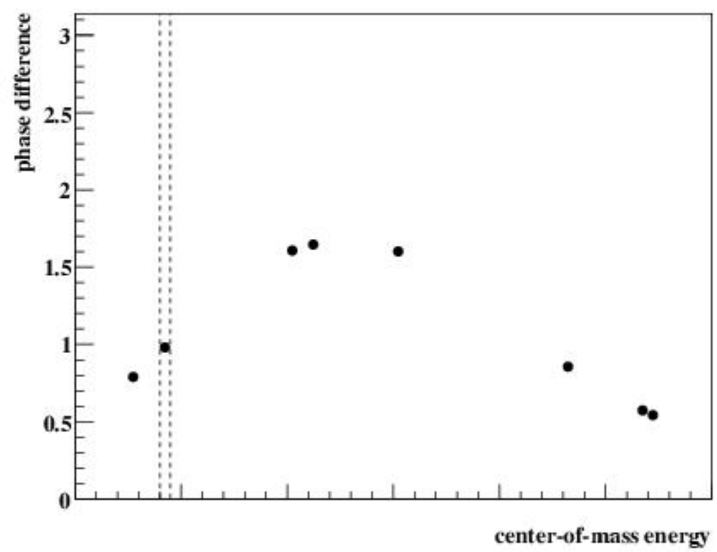
A simple model with three complex amplitudes, 2 of which are particles with different QNs

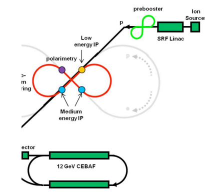
Start with a single energy bin.

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

Continue fitting bins …







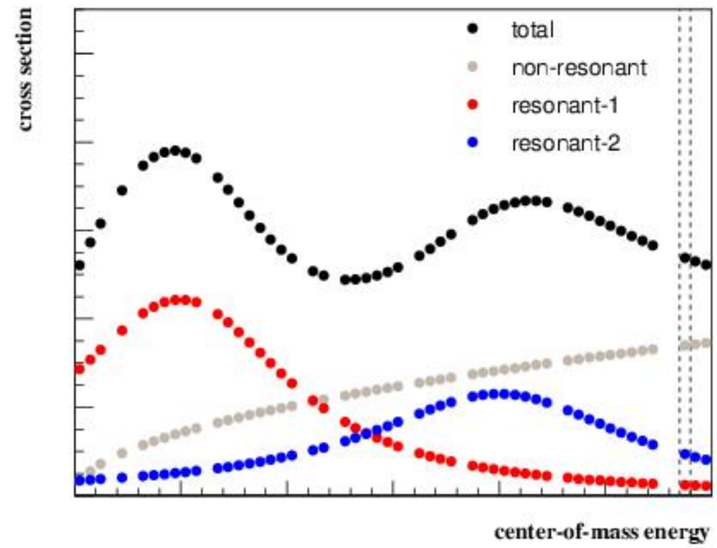
Partial Wave Analysis

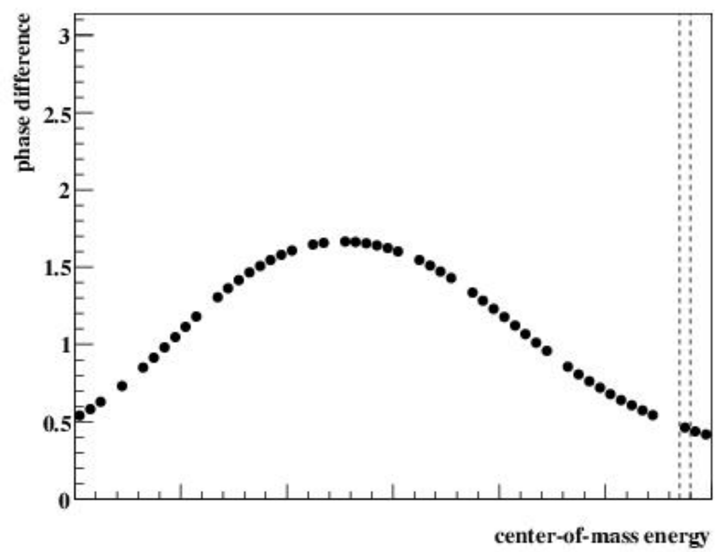
A simple model with three complex amplitudes, 2 of which are particles with different QNs

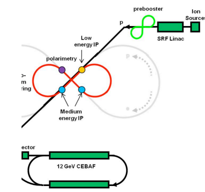
Start with a single energy bin.

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

… and continue …





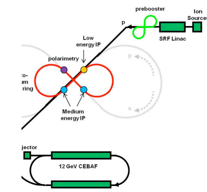


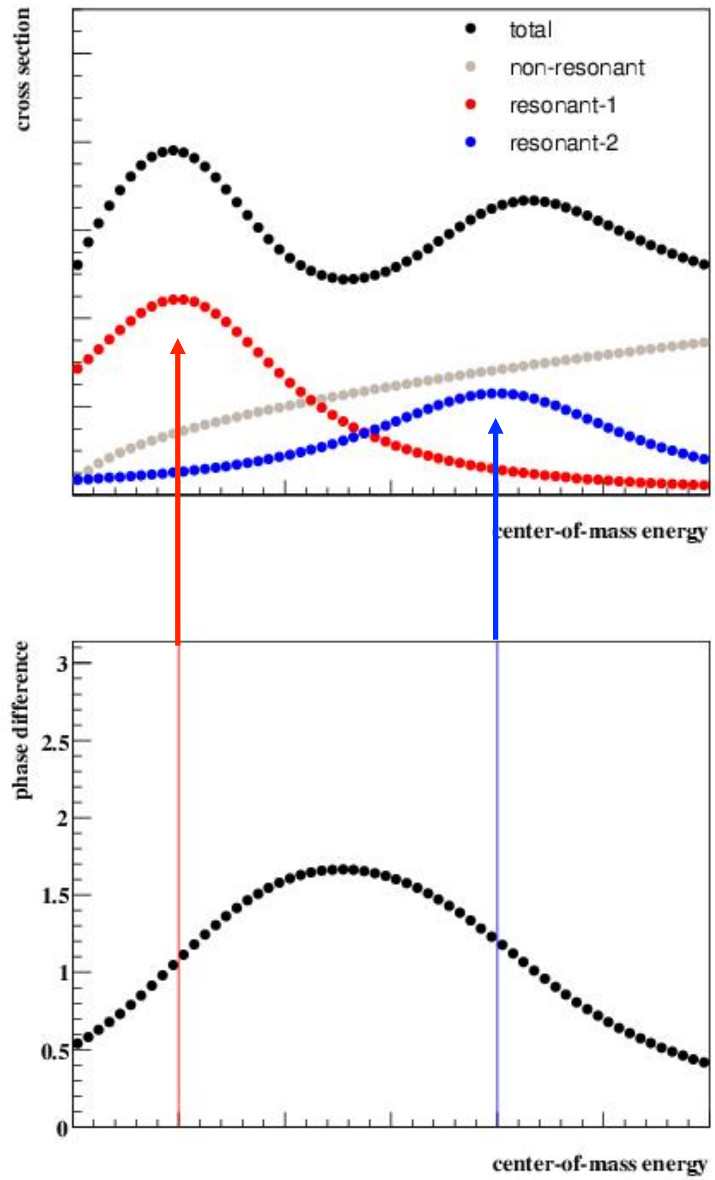
Partial Wave Analysis

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

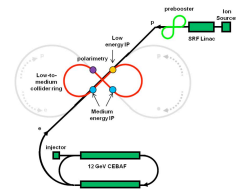
The need for intensity and the phase difference are indicative of two resonances.

Can fit for masses and widths.





Electroproduction



There is a lot of data on the electroproduction of ``simple" systems:

$$ep \to e'(\omega, \rho, \phi)p$$

$$ep \to e'(\pi, \eta, \eta')p$$

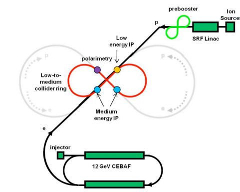
$$ep \to e'\Delta$$

$$ep \to e'S_{11}(1535)$$

$$ep \to e'K(\Lambda, \Sigma)$$

What is the Q^2 dependence?
Can we measure form factors?

Electroproduction



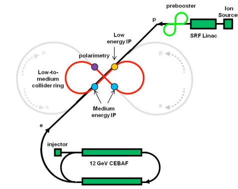
Presumably anything that can be photoproduced can also be electroproduced.

$$eN \to e' X N'$$

Hybrid mesons – need to determine which have the largest cross sections. They are broad states with 4-6 particles in the final state, so a PWA is also required.

Are form factors different from conventional states?

Electroproduction

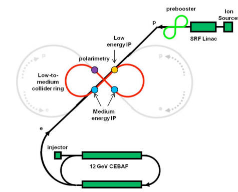


Presumably anything that can be photoproduced can also be electroproduced.

$$eN \to e' f_0(1500) N'$$

Glueballs – not expected to be a good production mechanism, but they are mixed with normal mesons. Can we say anything?

Are form factors different from conventional states?



Summary

- There is a robust spectroscopy program from now through the end of the current decade: COMPASS, BESIII, GlueX and PANDA (designed for spectroscopy).
- What we learn from photoproduction exotic and other mesons may lead to an interesting electroproduction program.
- To exploit such a program, it is important to design detectors with spectroscopy in mind from the beginning.