Analysis Plans for the GlueX Experiment

Curtis A. Meyer
Carnegie Mellon University
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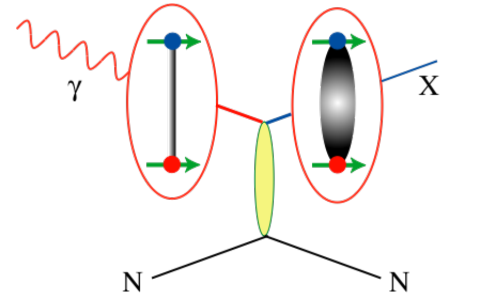
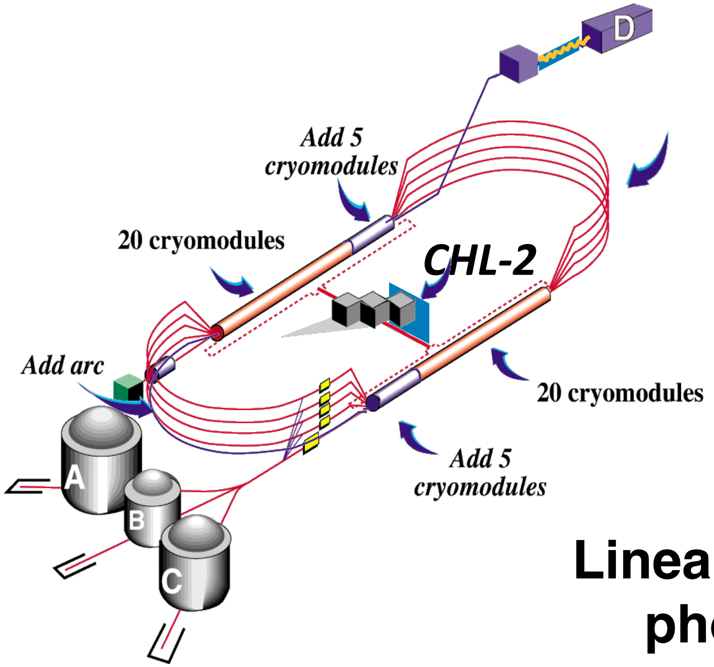
Outline

- The GlueX Experiment.
- Status and Timelines
- Exotic Hybrid Mesons.
- Reactions of Interest.
- Analyses.

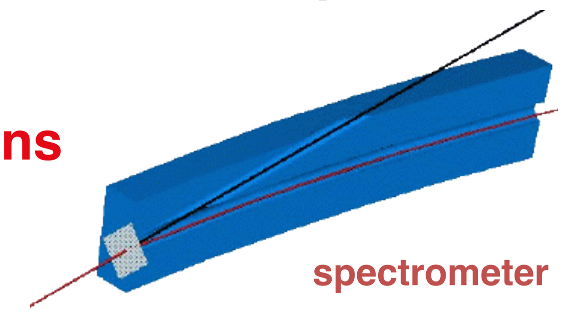
12-GeV CEBAF – Photoproduction





Linearly polarized photons out

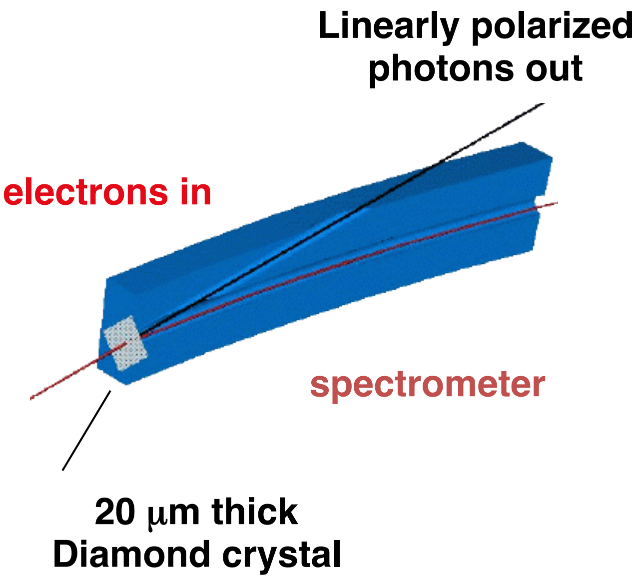
12GeV electrons

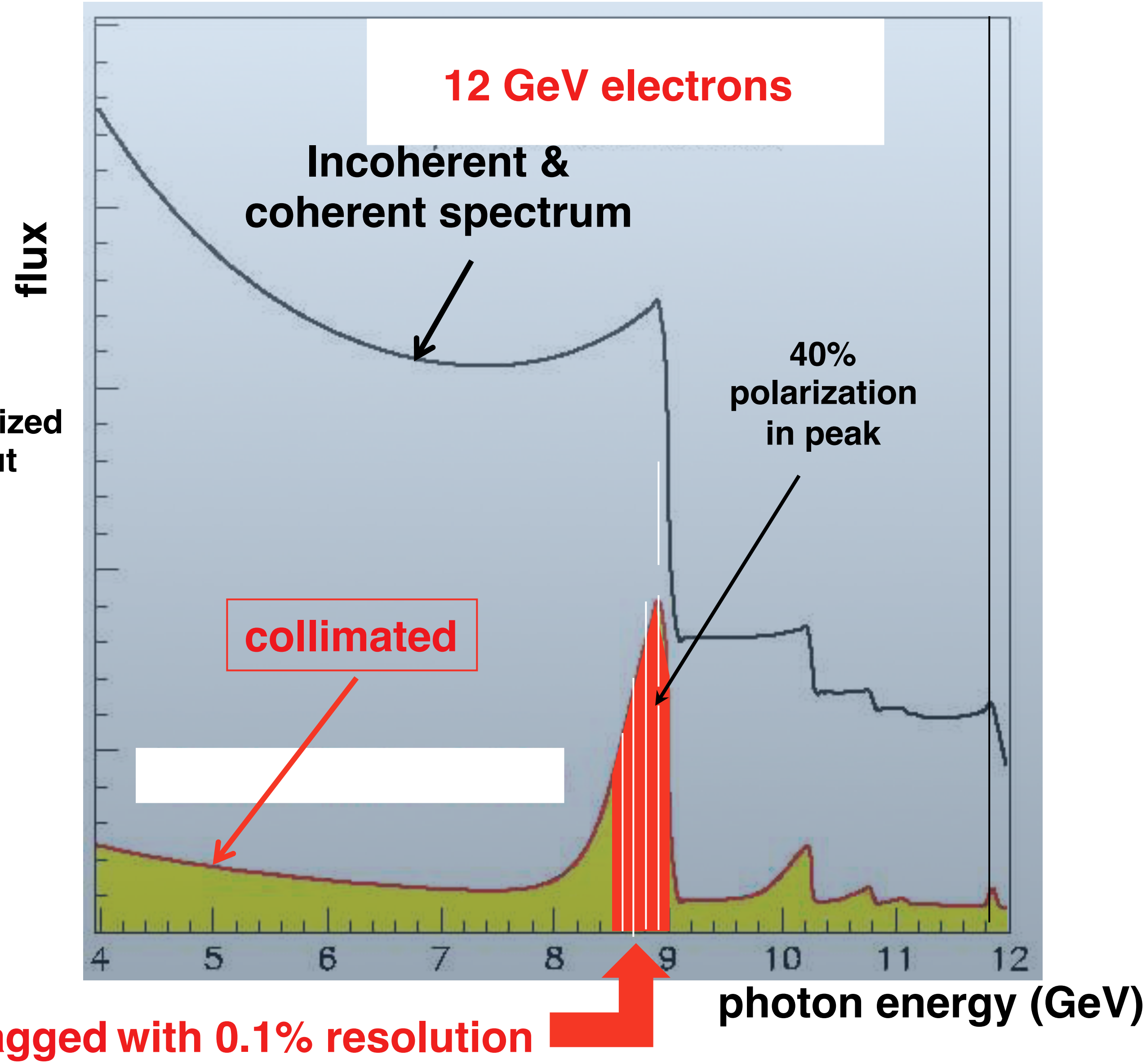


20 μm thick
Diamond crystal

Coherent Bremsstrahlung

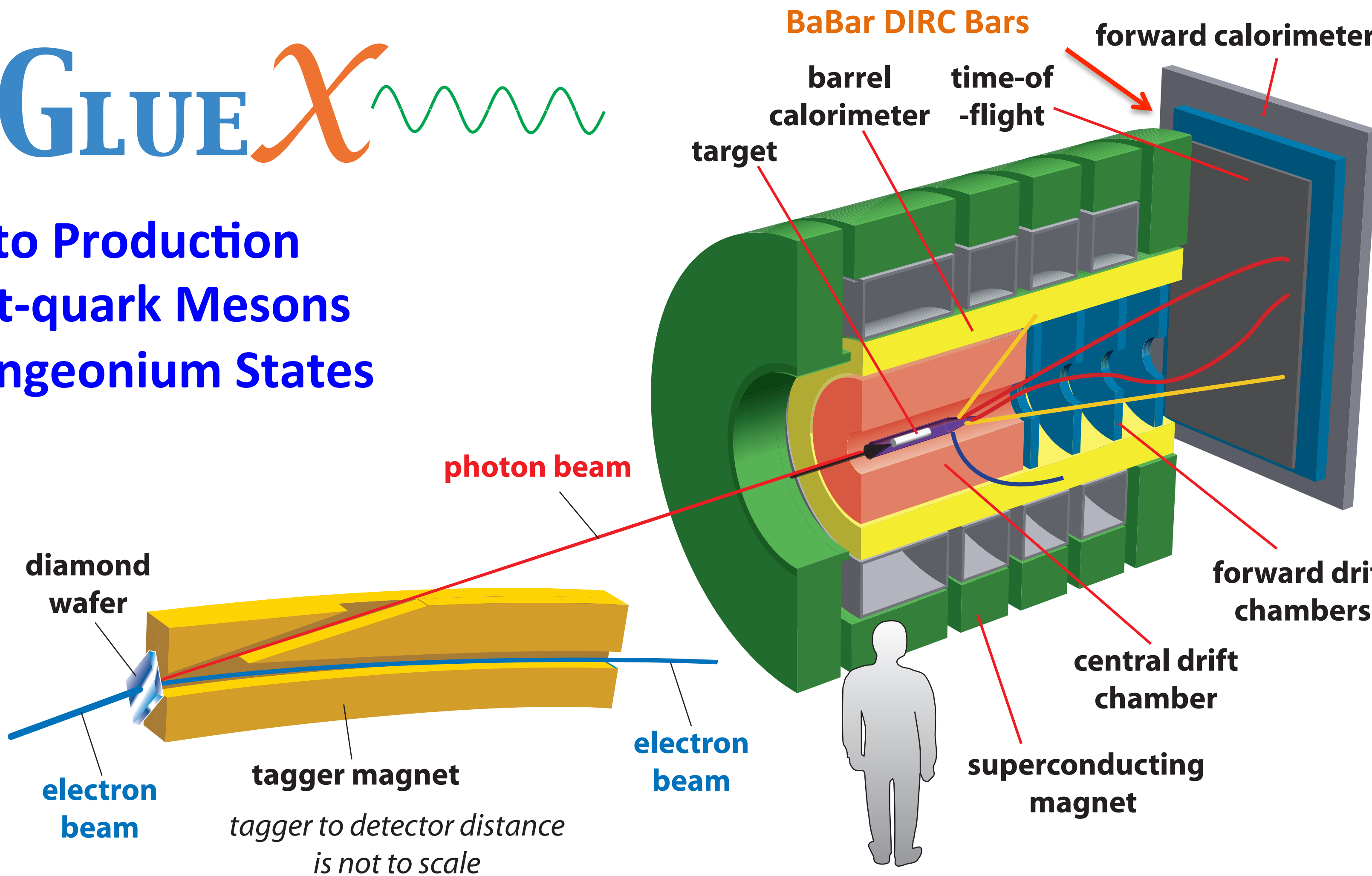
This technique provides requisite energy, flux and polarization





The GlueX Experiment at Jefferson Lab

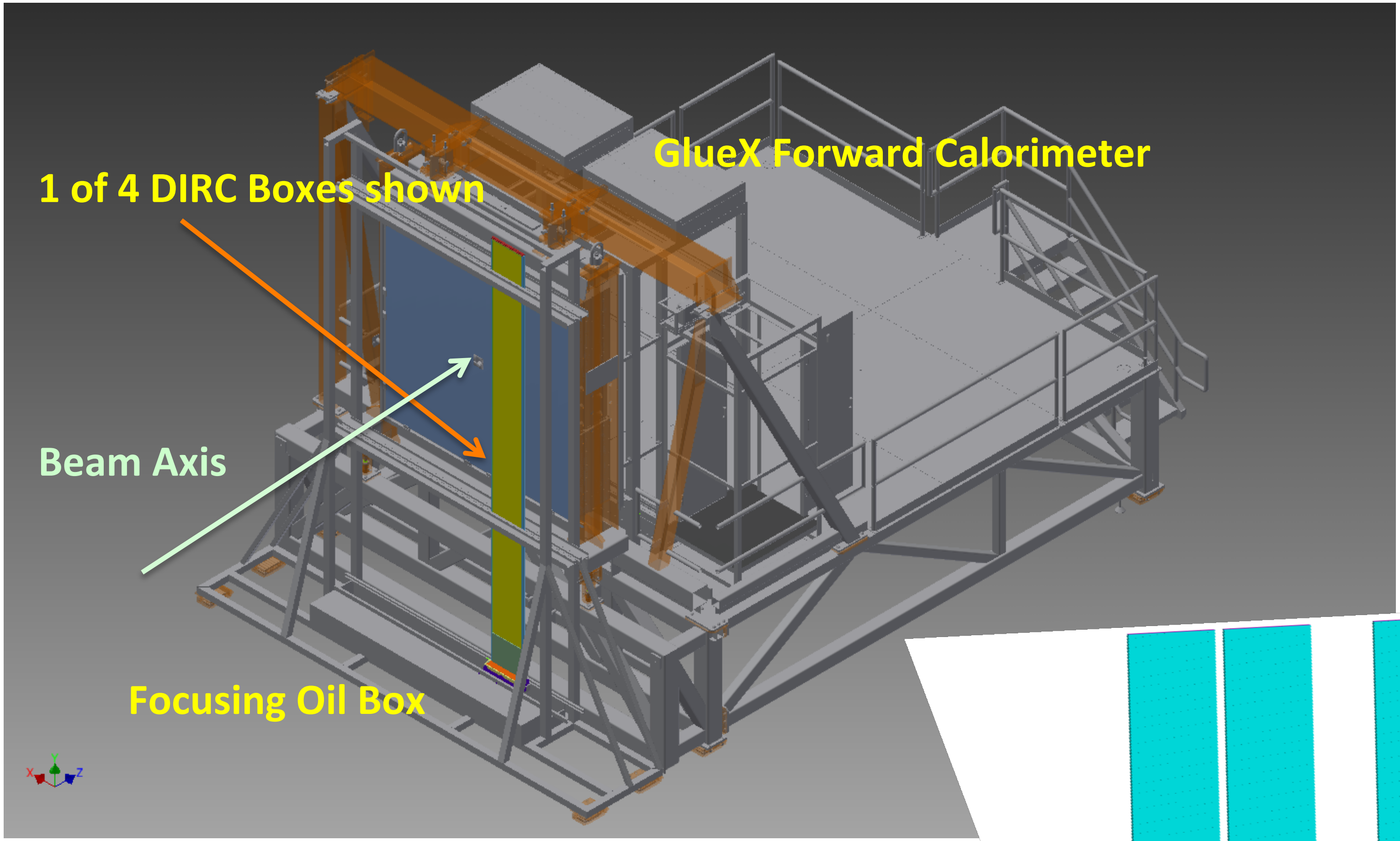
Photo Production
Light-quark Mesons
Strangeonium States

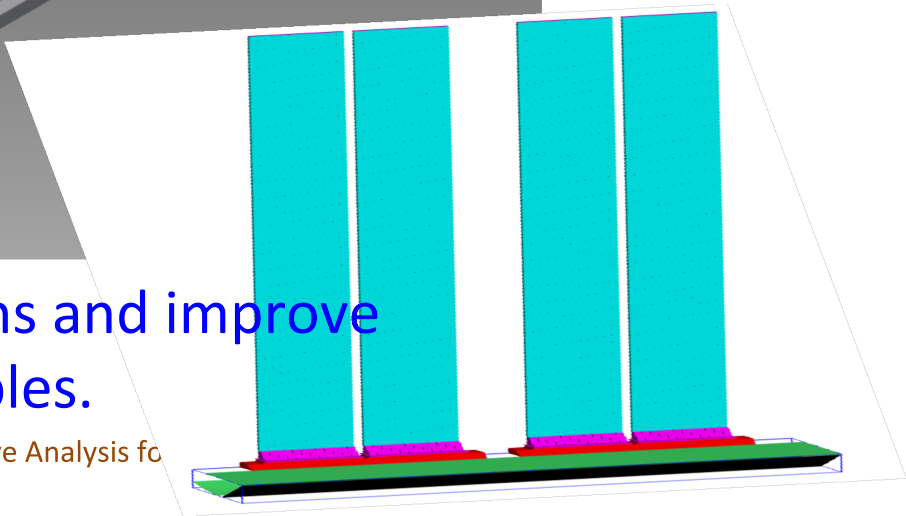


Physics in 2016

Upgraded Kaon Identification

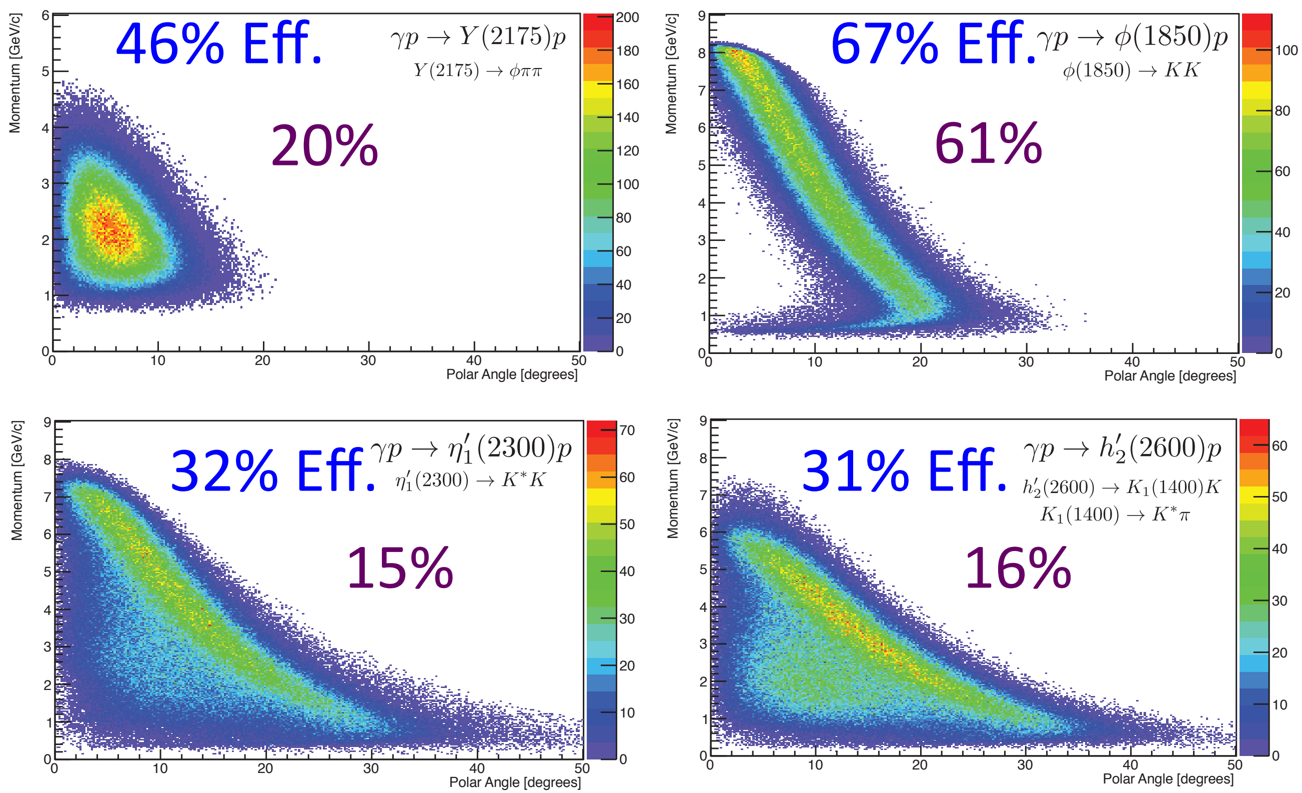
In June 2014, GlueX was given four of the twelve BaBar DIRC boxes.

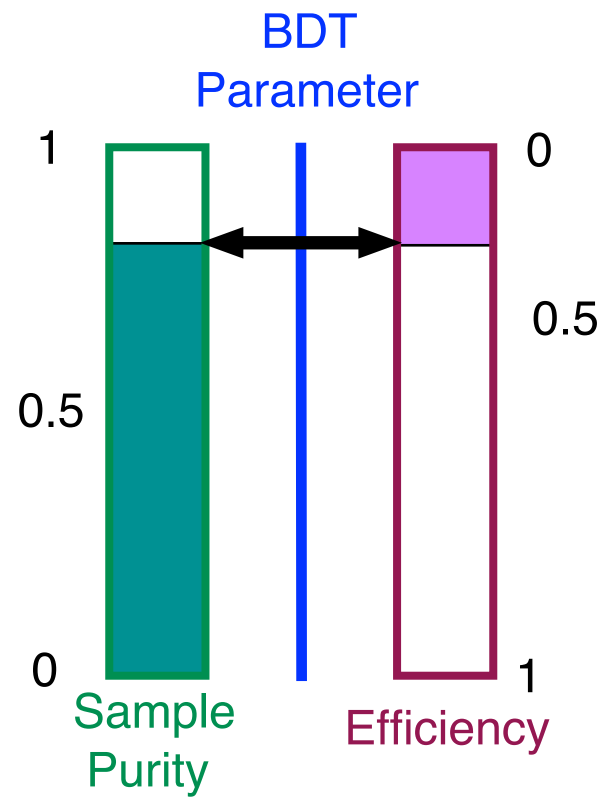




This will extends the range of reactions and improve the purity of the resulting event samples.

Global Particle Identification



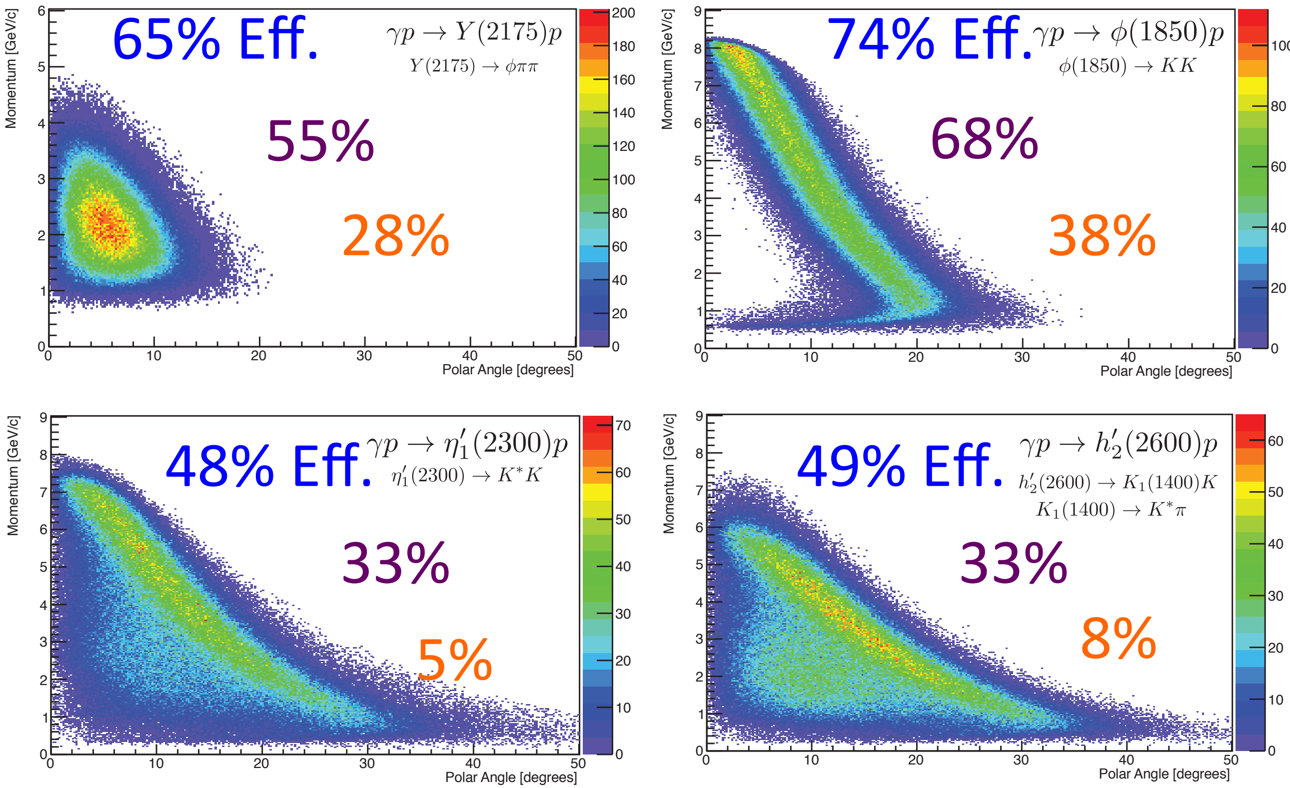


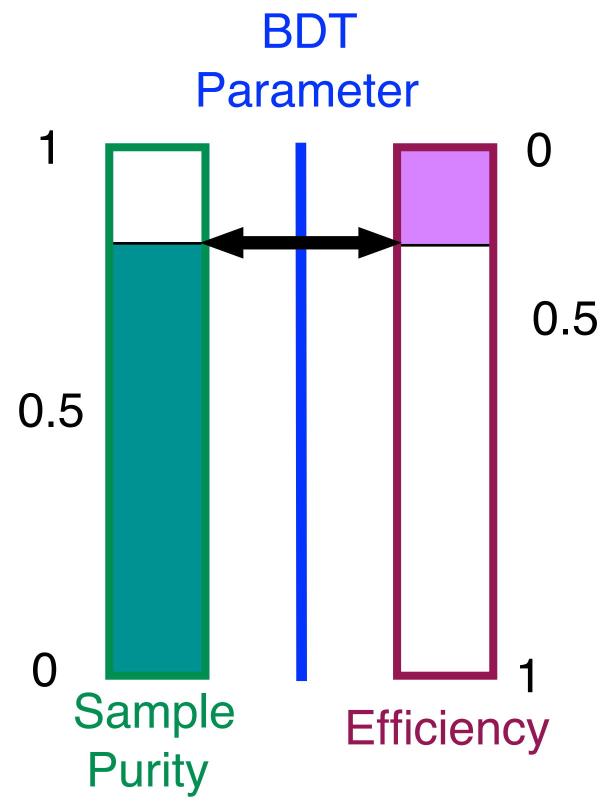
Request 90% purity in the event sample.

Request 95% purity in the event sample.

The baseline GlueX detector can provide pure kaonic event samples with good efficiency.

Global Particle Identification





Request 90% purity in the event sample.

Request 95% purity in the event sample.

Request 99% purity in the event sample.

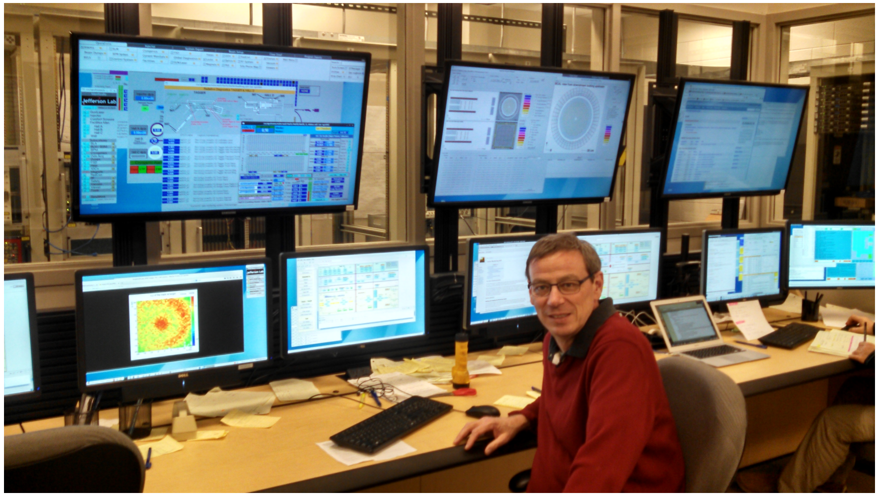
The baseline GlueX detector can provide pure kaonic event samples with good efficiency. The DIRC will significantly enhance this capability.

GlueX Running

- GlueX took commissioning data Oct. to Dec. 2014.
- There is an on-going commissioning run now.
    - Beam energy is below 6-GeV.
    - Some linear polarization.
    - Hydrogen target.
- Commissioning run in Fall 2015.
    - 12-GeV electron beam.
    - Linearly polarized photons.
    - Software trigger tests.
- Physics Commissioning in Spring 2016.
    - Low-intensity running.
    - Full baseline detector.
    - Software trigger tests.
- Physics running in Fall 2016/ Spring 2017.
    - Move to higher intensity.
    - Implement software trigger
- Upgraded kaon identification in Fall 2017/Spring 2018.
    - High intensity running with full detector capabilities.

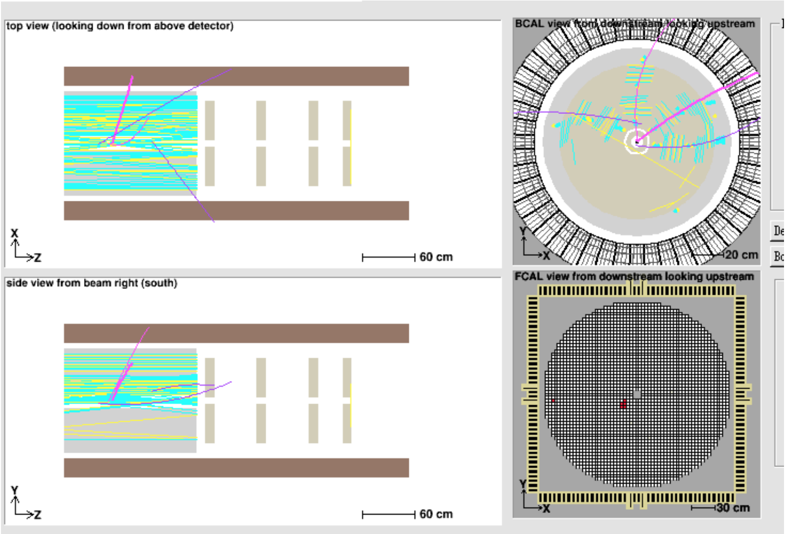
Fall 2014 GlueX Commissioning

- Ran from late October until just before Christmas.
- All systems worked and all detectors recorded data simultaneously.
- Multiple triggers tested.
- 120TB of data collected, all data have since been processed multiple times.
- Calibration and alignment is in an advanced state.
- Hoped to complete calibrations using Spring'15 commissioning data.

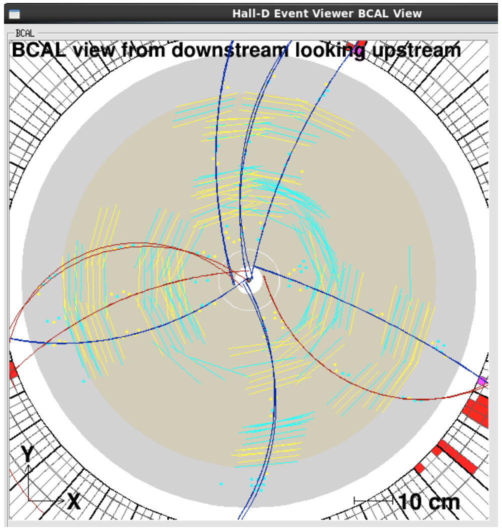


Fall 2014 GlueX Commissioning

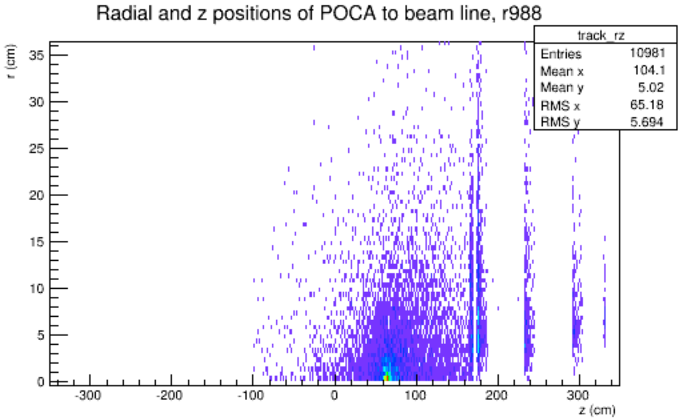
First beam, November 5, 2014



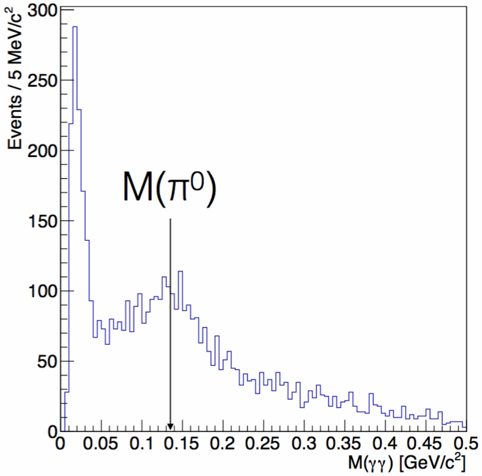
November 6, 2014



Targets installed on November 11, 2014

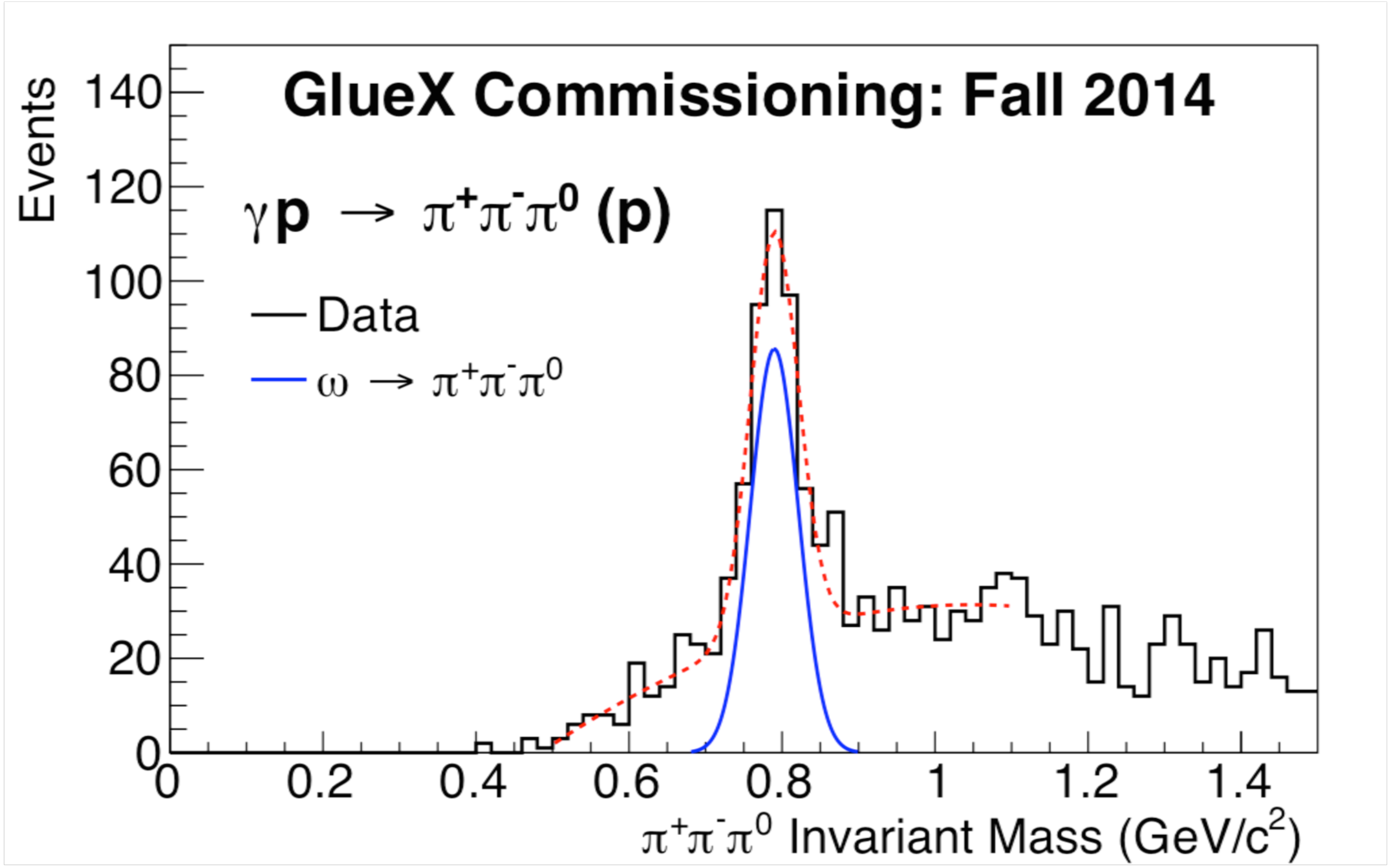


First π^0 in FCAL November 27, 2014



Fall 2014 GlueX Commissioning

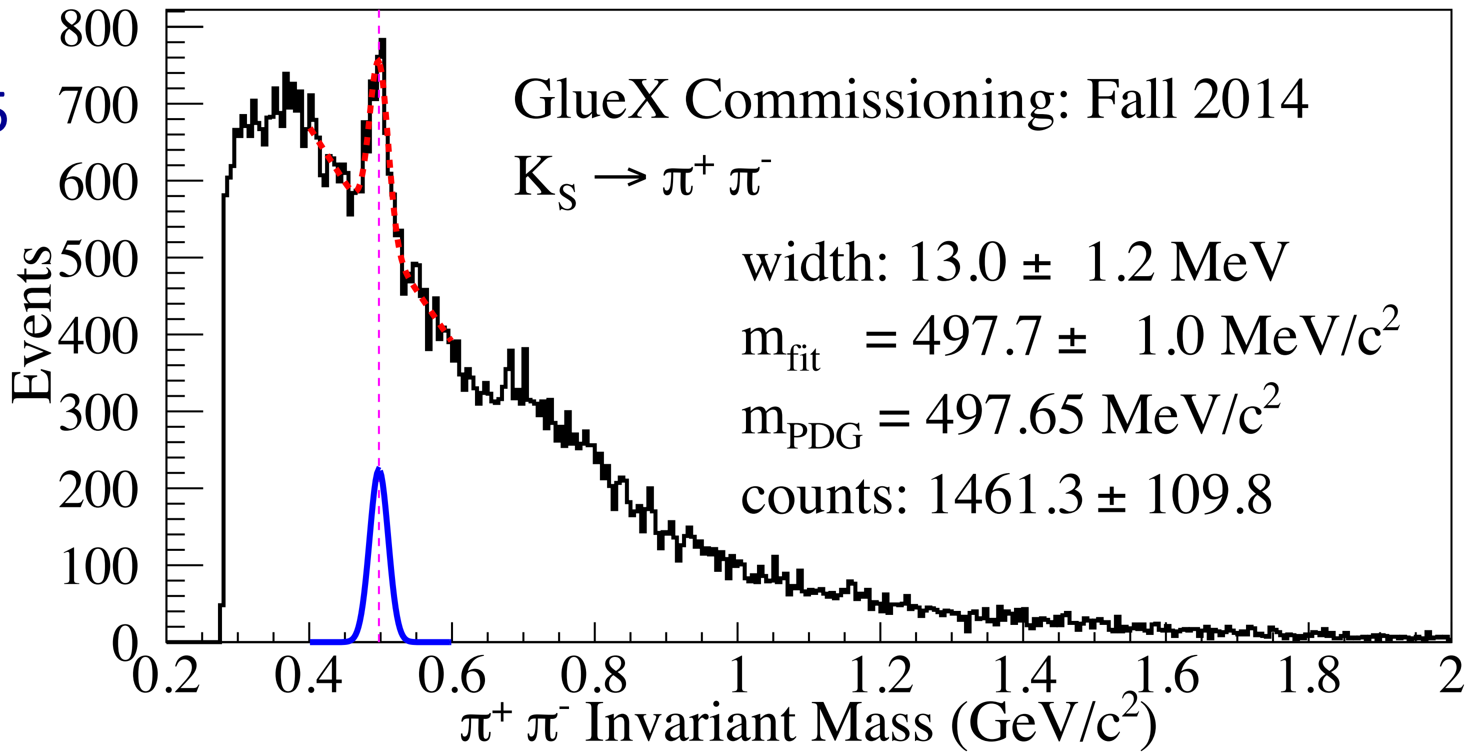
January 2015



Reconstruct the $\pi^0 \to \gamma\gamma$ decay and then combine with a positive and negative track. Clear signal for $\omega \to \pi^+\pi^-\pi^0$

Fall 2014 GlueX Commissioning

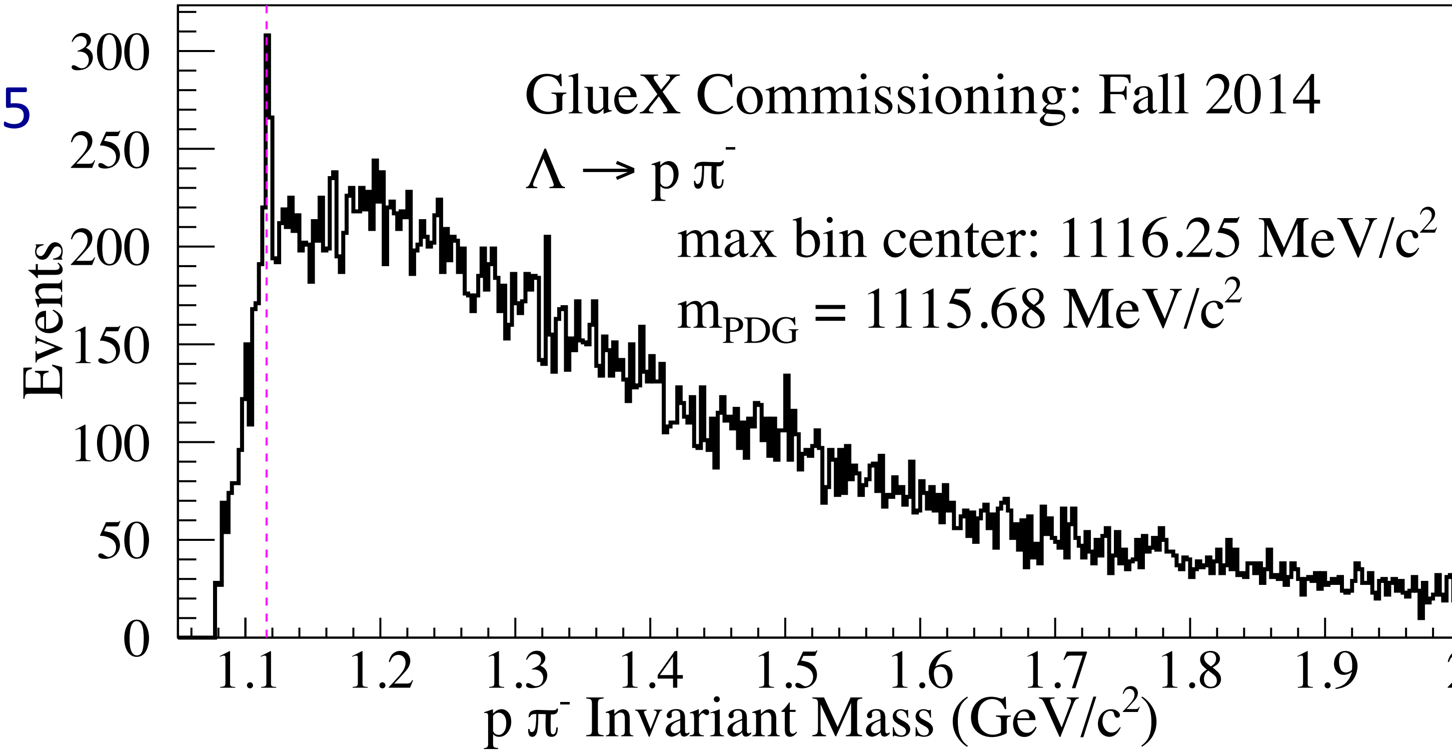
February 2015



Identify two charged particles from a secondary vertex. A clear signal for the $K_S \rightarrow \pi^+\pi^-$

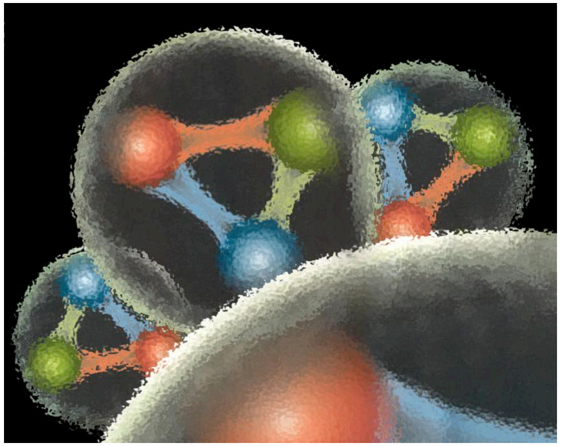
Fall 2014 GlueX Commissioning

February 2015



Identify two charged particles from a secondary vertex.
A clear signal for the $\Lambda \rightarrow p\pi^-$

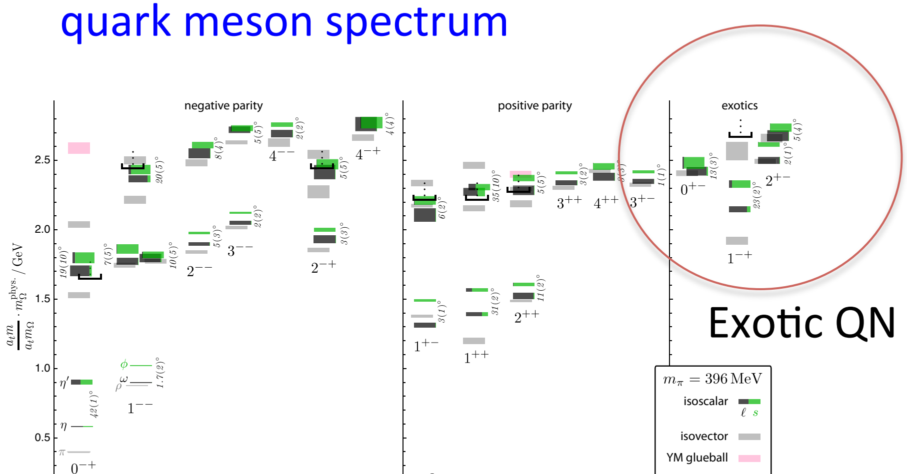
Quantum Chromo Dynamics



QCD describes the interactions of quarks and gluons and should predict the spectrum of bound-state baryons (qqq) and mesons ($q\bar{q}$).

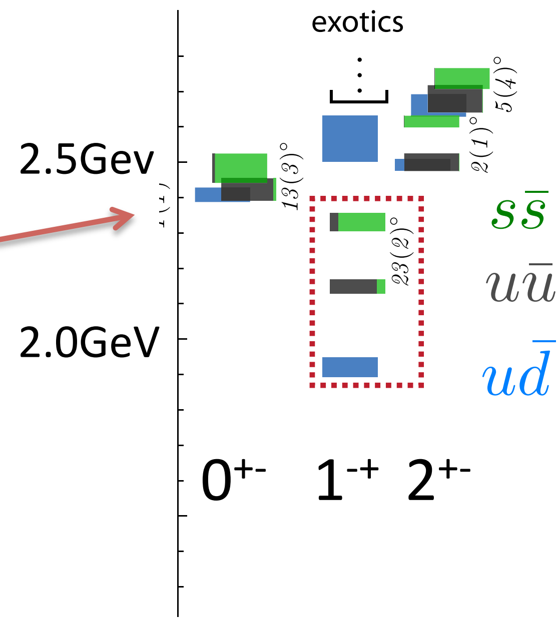
There should also be mesons in which the gluonic field contributes directly to the J^{PC} quantum numbers of the states --- hybrid mesons. Some are expected to have ``exotic'' quantum numbers.

Lattice QCD calculation of the light-quark meson spectrum



Exotic QN

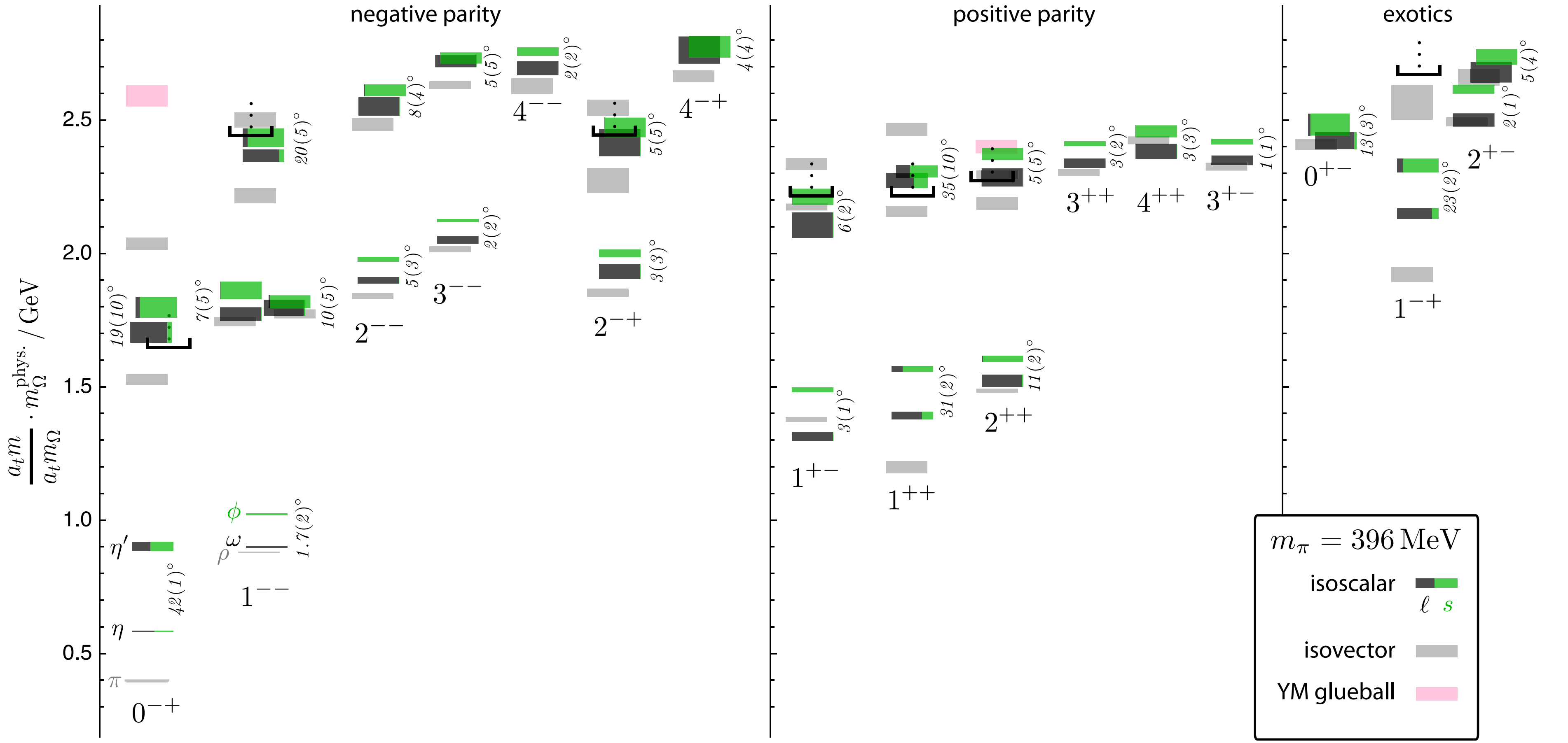
Normal QN



Several nonets predicted

Lattice QCD

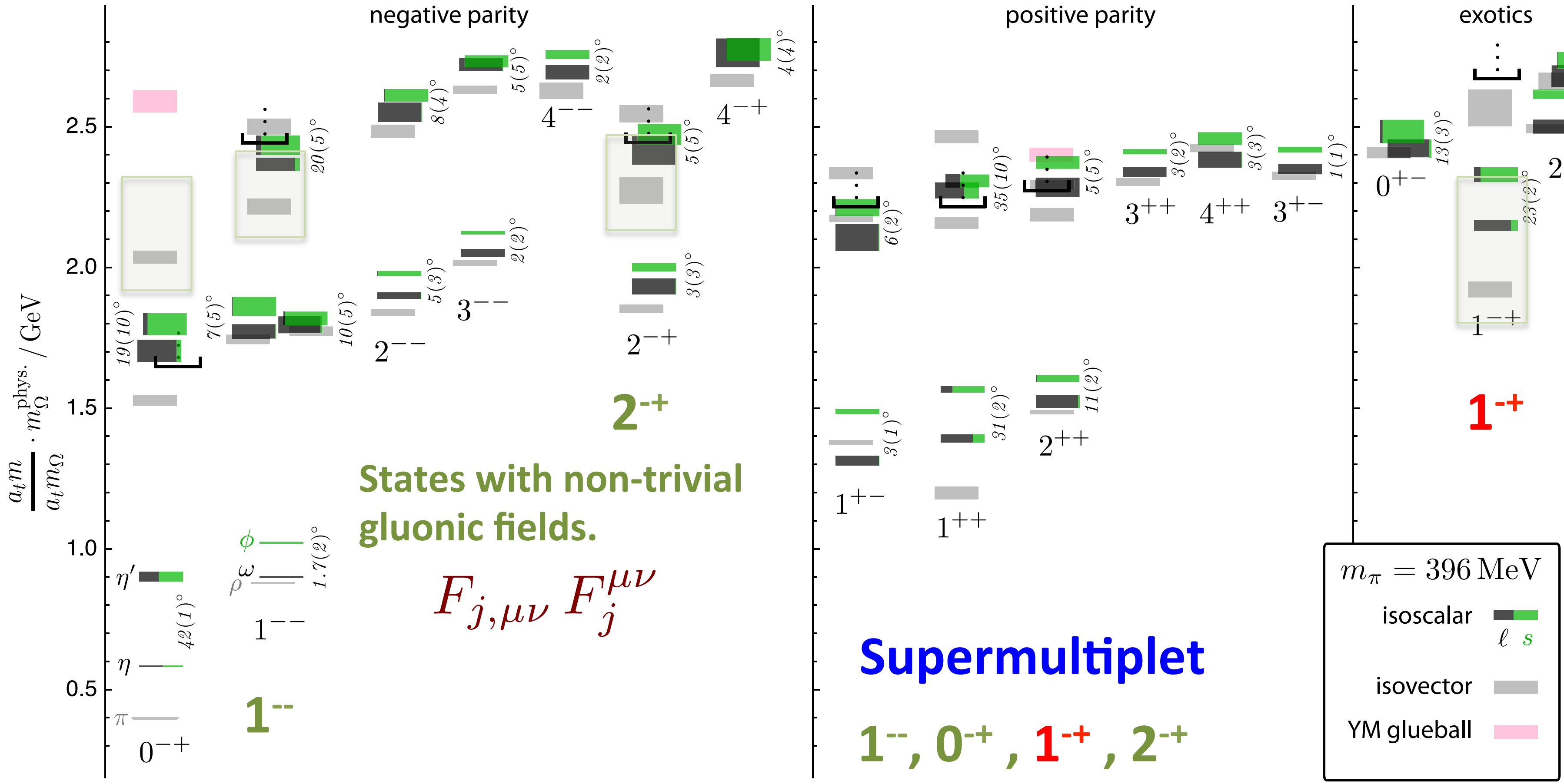
Light-quark Mesons (u,d,s)



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

Lattice QCD

Light-quark Mesons (u,d,s)



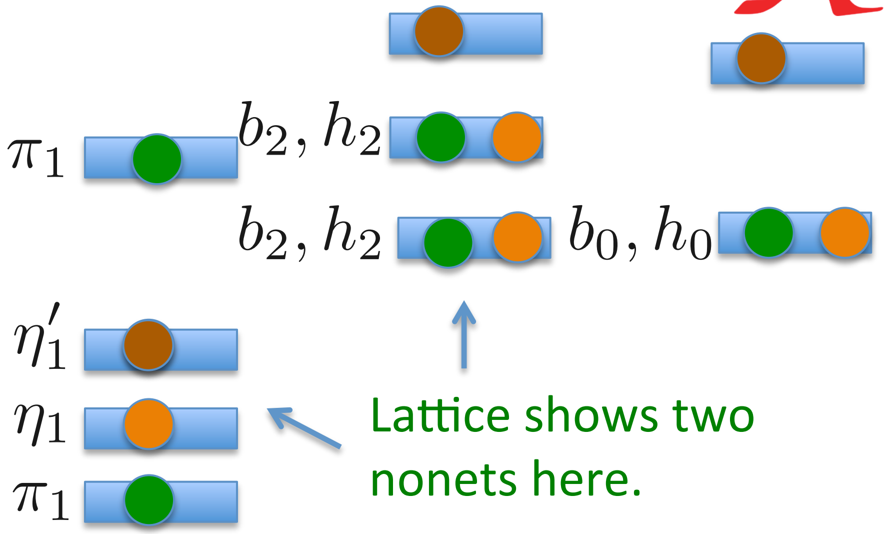
0^{-+}

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

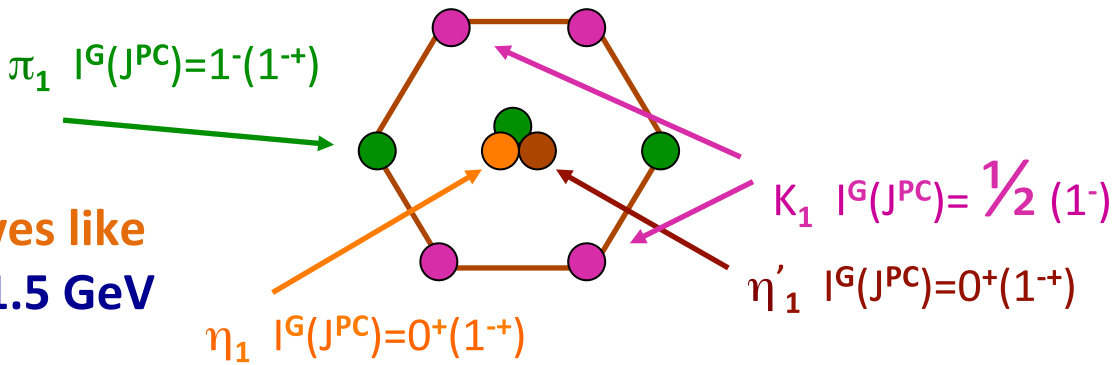
QCD Exotics

Lattice QCD suggests 5 nonets of mesons with exotic quantum number:

1 nonet of 0^{+-} exotic mesons
2 nonets of 1^{-+} exotic mesons
2 nonets of 2^{+-} exotic mesons



Experimental evidence exists for π_1 states.



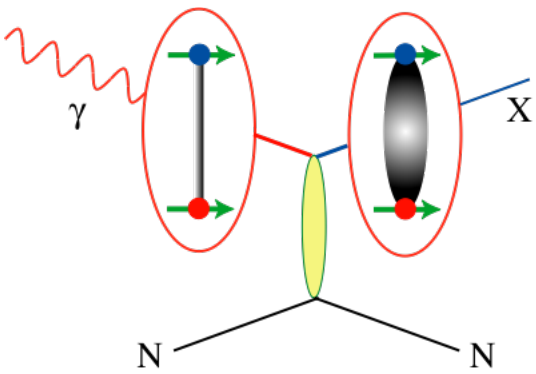
``Constituent gluon'' behaves like $J^{PC} = 1^{+-}$ with a mass of 1-1.5 GeV

The lightest hybrid nonets:

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

Possible Decay Modes

$\pi_1 \rightarrow \pi\rho, \pi b_1, \pi f_1, \pi\eta', \eta a_1$
$\eta_1 \rightarrow \eta f_2, a_2\pi, \eta f_1, \eta\eta', \pi(1300)\pi, a_1\pi,$
$\eta_1' \rightarrow K^*K, K_1(1270)K, K_1(1270)K, \eta\eta'$



$b_2 \rightarrow \omega\pi, a_2\pi, \rho\eta, f_1\rho, a_1\pi, h_1\pi, b_1\eta$
$h_2 \rightarrow \rho\pi, b_1\pi, \omega\eta, f_1\omega$
$h'_2 \rightarrow K_1(1270)K, K_1(1270)K, K_2^*K, \phi\eta, f_1\phi$

$b_0 \rightarrow \pi(1300)\pi, h_1\pi, f_1\rho, b_1\eta$
$h_0 \rightarrow b_1\pi, h_1\eta$
$h'_0 \rightarrow K_1(1270)K, K(1460)K, h_1\eta$

Early Reach **With Statistics** **Hard**

Hybrid kaons do not have exotic QN's

Models suggest narrower states are in the spin-1 and spin-2 nonets, while the spin-0 nonets are broad.

Key First Measurements

Demonstrate that we understand the detector and the reconstruction software.

$$\gamma p \to (\eta, \omega, \eta')p$$

Measure cross sections and polarization observables.

$$\frac{d\sigma}{d\Omega} \quad \Sigma \quad \rho_{ij}^{0,1,2}$$

Meson ``two body" final states.

$$\gamma p \to (\pi, \eta, \omega, \eta')\pi p$$

The $\eta\pi$ and $\eta'\pi$ reactions are of high interest.

GlueX Physics Analysis

GlueX is ready to do physics and several analyses are being worked out using the full suite of GlueX/Hall-D software and data from large-scale data challenges.

Physics reactions of interest:

Understand the detector

$$\gamma p \to \pi^0 p$$
$$\gamma p \to \eta p$$
$$\gamma p \to \rho p$$
$$\gamma p \to \omega p$$
$$\gamma p \to \eta' p$$
$$\gamma p \to \phi p$$

Initial exotic hybrid searches

$$\gamma p \to \eta\pi(n,p)$$
$$\gamma p \to \eta'\pi(n,p)$$
$$\gamma p \to \rho\pi(n,p)$$
$$\gamma p \to \omega\pi(n,p)$$
$$\gamma p \to \omega\pi\pi(n,p)$$
$$\gamma p \to \eta\pi\pi(n,p)$$

Strange Baryons

$$\gamma p \to K^+\Lambda$$
$$\gamma p \to K\Sigma$$
$$\gamma p \to KK\Xi$$

Interesting for Exotic Searches

$\gamma p \to \pi\pi\pi p, \pi\pi\pi n$

$X \to \rho\pi, f_2\pi, \pi\pi\pi \ldots$

Lots of challenges in this reaction.
No signal in CLAS at 5GeV for recoil neutron.

$\gamma p \to \eta\pi\pi p, \eta\pi\pi n$

$X \to \rho\eta, f_2\eta, a_2\pi, \eta\pi\pi \ldots$

Couples to a number of exotic hybrids through several decay paths. In principle, these can couple to **π_1, η_1, b_2, h_2**

These channels should provide a framework to test new amplitudes developed for these.

Amplitude Analysis

Describe the process of producing a particular final state as a set of possible amplitudes : $\mathcal{A}_j(\gamma p \to p\pi^+\pi^-\pi^0)$

E.g. $\mathcal{A}_1(\gamma p \to pX_i \to p\rho^+\pi^- \to p\pi^+\pi^-\pi^0)$

Build a total amplitude by coherently summing all the individual amplitudes. This total amplitude yields a probability that the given sum describes a particular event ``k''.

$\mathcal{N}$ is a normalization factor and
a_j are complex coefficients.

$$P(e_k) = \frac{1}{\mathcal{N}} |\sum_j a_j \mathcal{A}_j(e_k)|^2$$

Form the likelihood $\ln \mathcal{L} = \sum_k \ln P(e_k)$ and then minimize the natural log of it with respect to the a_j. This is a CPU-intensive problem that appears to scale well on graphical processor units (**GPUs**). To do this requires the four-vectors of all events plus a comparable Monte Carlo data sample to do the normalization.

Amplitude Analysis

- We generally try to find the smallest set of a_j to describe the data.
- This is done summing over all of the experimental and simulated data.
- We look at the amplitudes described by each of the partial waves and look for intensity and phase motion between them.

Observables

- What if we take a very large number of A_js, but do not attribute meaning to the individual ones. Instead, we try to extract the complex amplitude.

$$A_{tot} = \sum_j a_j A_j$$

- It is easier to compare a model to an observable than to the original data.
- With a good model, one can then fit the data directly.

Example of ω Photo Production

Total amplitude is an excellent description of all the data in all of its dimensions:

$$\mathcal{M}_{m_i,m_\gamma,m_f,m_\omega}(\vec{x},\vec{\alpha}) \approx \sum_{j=\frac{1}{2}}^{\frac{21}{2}} \sum_{P=\pm} \mathcal{A}^{J^P}_{m_i,m_\gamma,m_f,m_\omega}(\vec{x},\vec{\alpha})$$

However, the fit coefficients α_i may have no physics meaning, they are just fitting parameters.

Because the amplitude does describe the data, it can be used to project observables.

The method handles both circularly and linearly polarized photons on an event-by-event basis.

Example of ω Photo Production

- The method also does detector acceptance automatically. Use the fit parameters to determine the intensity of a given event.

$$I_i = \sum_{m_i, m_\gamma, m_f} \left| \sum_{m_\omega} \mathcal{M}_{m_i, m_\gamma, m_f, m_\omega}(\vec{x}, \vec{\alpha}) \right|^2$$

- The acceptance for a set of events near some event, $\vec{x}$ is

$$Acc(\vec{x}) = \frac{\sum_{i=1}^{N_{acc}} I_i}{\sum_{j=1}^{N_{th}} I_j}$$

Sum over accepted MC events

Sum over generated MC events

Amplitudes Lead to Observables

- What are the observables that can be measured in a reaction?
- A_{tot} has indices associated with initial and final spin states.
  – Cross sections. $$\frac{d\sigma}{d\Omega} \propto A_{tot} A^*_{tot}$$
  – Spin Observables. Sum over A's with flipped spin indices.
  – Moments ….

What are the Observables?

- Can we define observables that can be extracted independent of a partial-wave interpretation of a particular reaction?
- With such observables, many (complicated) models of the data can be tested.
- A smaller subsets of vetted models can then be used to directly confront the data.

Summary

- GlueX had a very successful commissioning run and is looking forward to its first physics data soon.
- Analysis and Amplitude Analysis issues will quickly move into the forefront of our experimental efforts.
- The techniques discussed here, and being developed now will be crucial to our ultimate success.
- Are there other observables beyond amplitude analyses results?