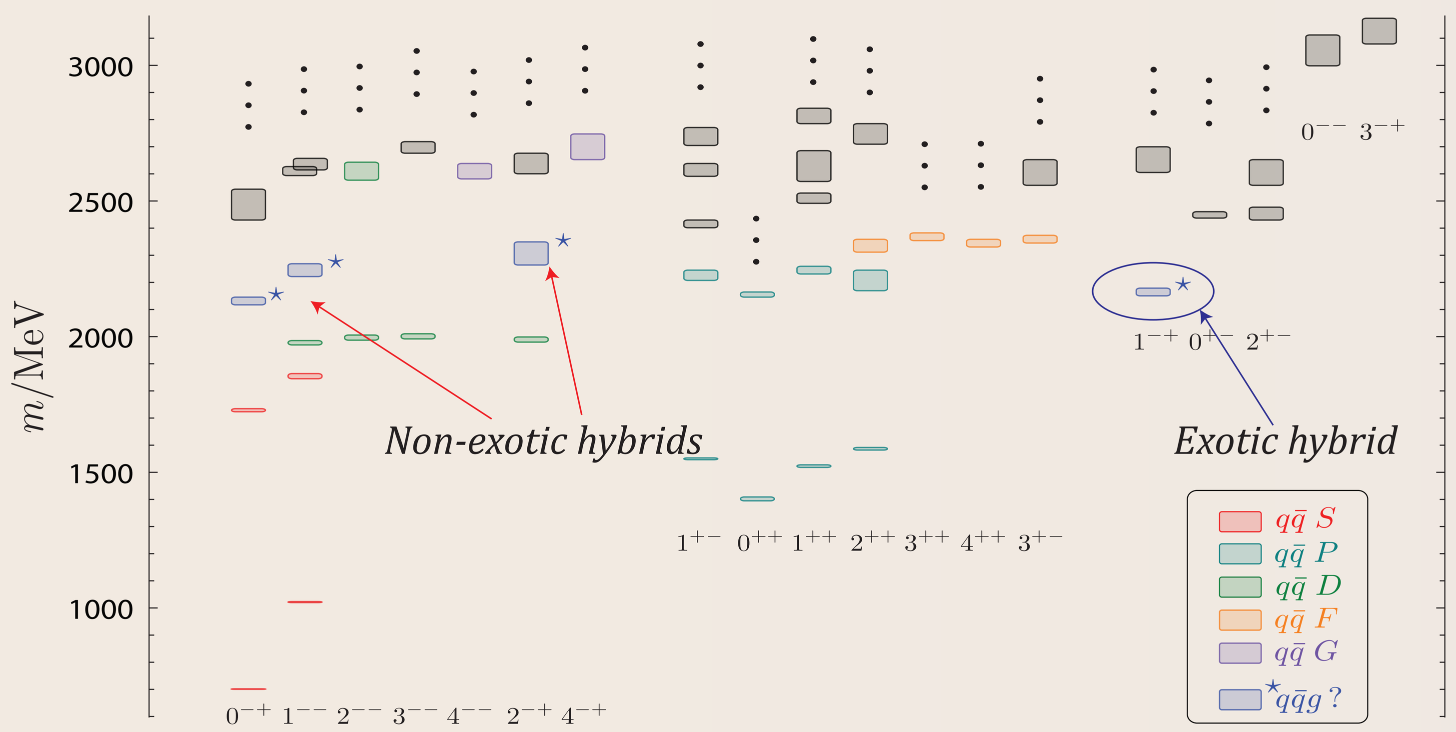
Simulated Amplitude Analysis of the $\pi^+ \pi^- \pi^+$ System with the GlueX Detector

Jake Bennett
Indiana University

Hybrid Mesons

In Quantum Chromodynamics (QCD), the color charge of quarks is mediated by massless, flavorless, vector bosons called gluons. Since gluons also carry color charge, gluon self-interactions create an anti-screening effect which dominates at low energies. This results in a stronger binding force, confining the quarks into color singlet hadrons.

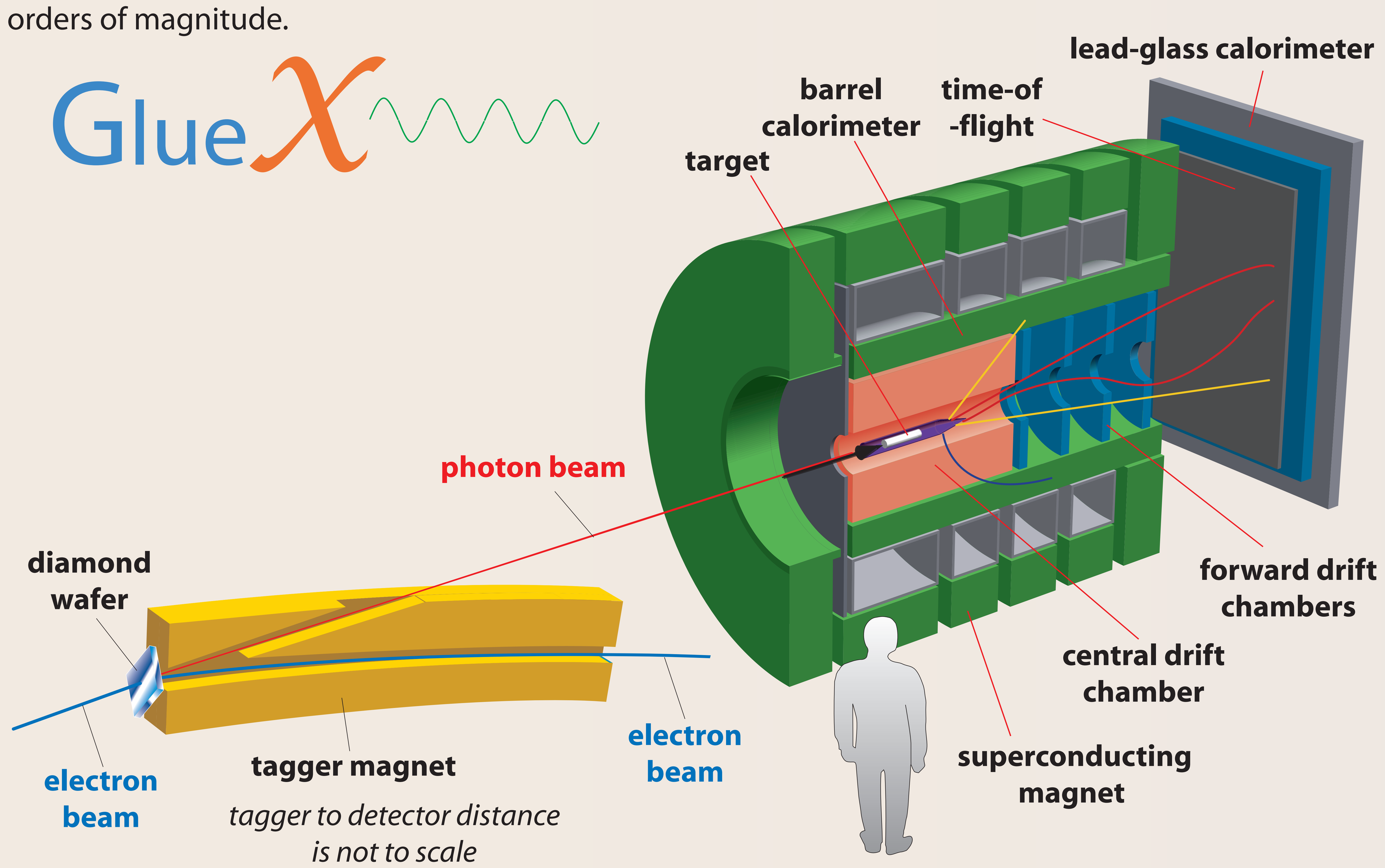


arXiv:1106.5515 and Phys.Rev.D82:034508,2010

The unquenched lattice QCD calculations above implies the existence of states that are not purely qqbar. That is, in addition to quark degrees of freedom, a meson state may have some additional degrees of freedom in the gluonic field which binds the quarks. Excitations of the gluonic field may produce hybrid mesons consisting of a quark-antiquark pair and a gluon. These states may have quantum numbers (J^{PC}) which are not accessible by conventional qqbar states (0^{--},0^{+-},1^{-+}). Such exotic hybrid mesons explicitly manifest gluonic degrees of freedom. The lightest exotic hybrid is expected to have a mass between 1 GeV and 2 GeV. The above plot shows the unquenched lattice calculations for light quarks at the strange quark mass.

The GlueX Experiment

The GlueX Experiment will be a part of the 12 GeV upgrade at the Thomas Jefferson National Accelerator Facility (JLAB) in Newport News, Virginia. The goal of GlueX is to provide critical data needed to address the existence of hybrid mesons. Photoproduction is expected to be particularly effective in producing exotic hybrids, but there are few data on the photoproduction of light mesons. GlueX will use the coherent bremsstrahlung technique to produce a linearly polarized photon beam. A solenoid-based hermetic detector will be used to collect data on meson production and decays with statistics after the first year of running that will exceed the current photoproduction data in hand by several orders of magnitude.



Amplitude Analysis

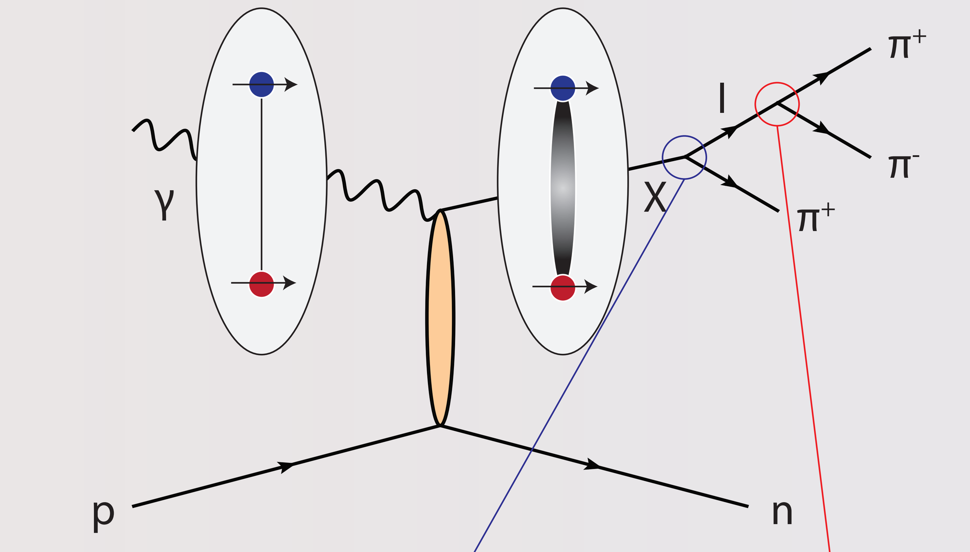
Amplitude analysis is the analysis technique used at GlueX for extracting masses, widths and quantum numbers of resonances. To achieve this, it is not sufficient to know the magnitude of the momentum of the particles. Information about the angular distributions is also necessary.

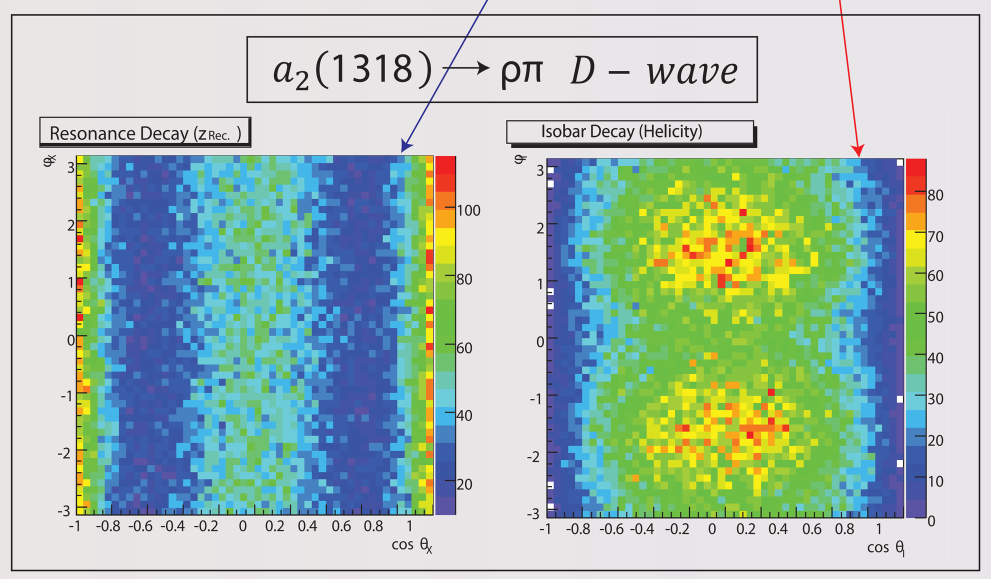
In the isobar model for peripheral photoproduction of $\pi^+\pi^-\pi^+$, a resonance (X) recoils off a nucleon. The resonance then decays to an isobar (I) resonance and a spectator pion. Finally, the isobar decays into a $\pi^+\pi^-$ pair.

The density of events in phase space is given by the intensity function

$$I(x) = \sum_{\epsilon_\gamma = x,y} \left| \sum_{\beta=1}^{N_{amps;\epsilon_\gamma}} V_{\epsilon_\gamma,\beta} A_{\epsilon_\gamma,\beta}(x) \right|^2$$

where $V_{\epsilon,\beta}$ represents the amplitude to produce the state X and $A_{\epsilon,\beta}(x)$ the amplitude for the state X to decay to the final state of interest. The polarization of the photon beam is represented by ϵ_γ. The intensity is used to construct the probability of finding an event in the detector as a function of position in phase space. The production amplitudes, $V_{\epsilon,\beta}$ can be replaced by a free parameter which will be optimized in a maximum likelihood fit. The angular distribution information of these decays are contained in the decay amplitude.





For a photon beam with fractional polarization f, we can write the intensity function for the production of n different resonances X_i as two incoherent sums over distinguishable linear polarization states.

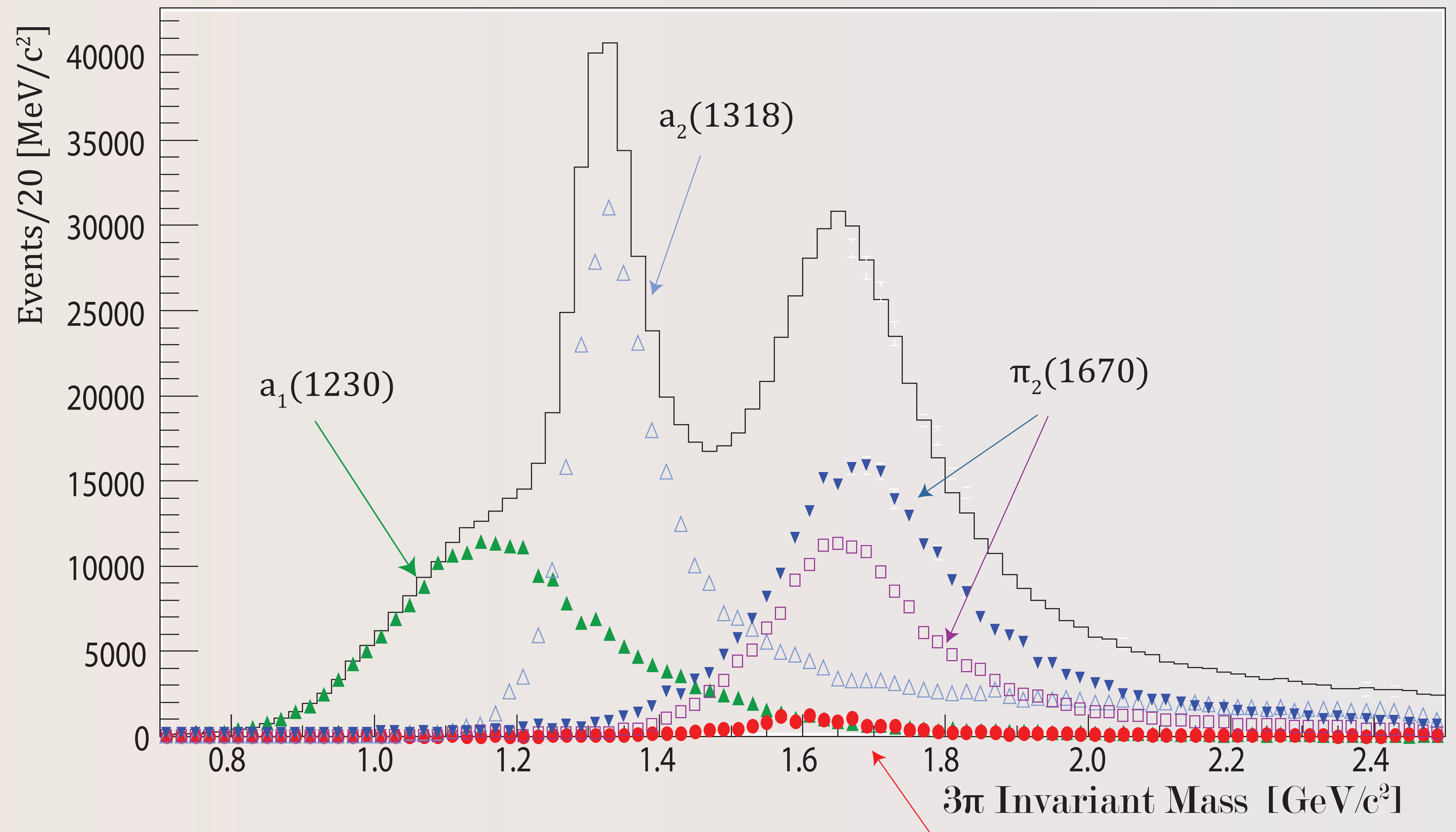
$$I(x) = \sum_{p=\pm1} \frac{1+pf}{4} \left| \sum_{\beta=1}^{n} V_{\epsilon_\gamma,\beta} \left(\langle X_i | R' \rangle + p e^{2i\alpha} \langle X_i | L' \rangle \right) \right|^2$$

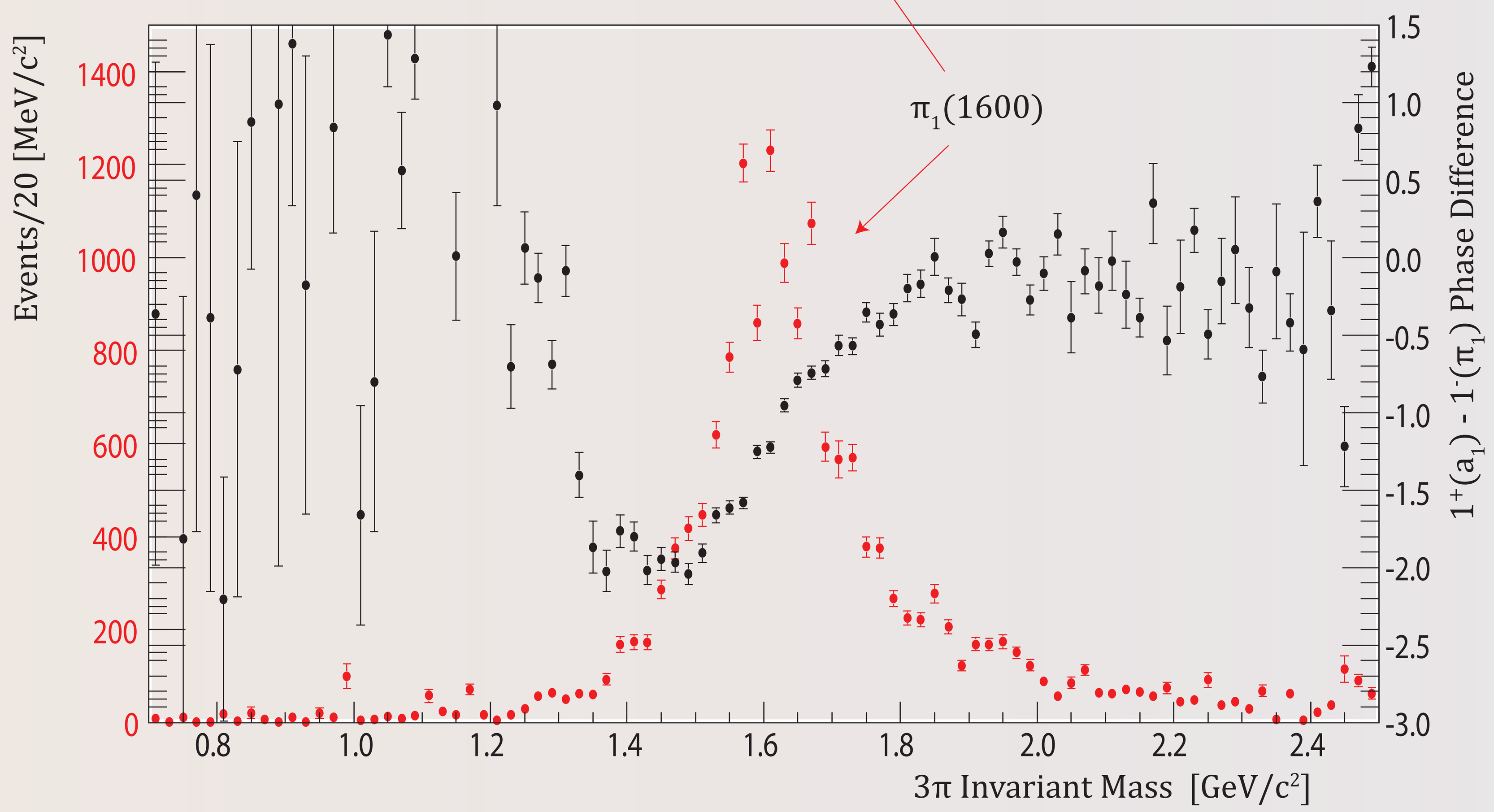
where $|R'\rangle = |\lambda_\gamma = 1\rangle$ and $|L'\rangle = |\lambda_\gamma = -1\rangle$ are photon helicity basis states and α is the angle between the production plane and the plane of polarization of the photon beam. In the incoherent sum, $p=+1$ represents $\epsilon_\gamma = x$ and $p=-1$ represents $\epsilon_\gamma = y$. For this analysis, the coherent sum over β includes the following amplitudes,

$$a_1(1230) \rightarrow \rho\pi \qquad S-wave$$
$$a_2(1318) \rightarrow \rho\pi \qquad D-wave$$
$$\pi_1(1600) \rightarrow \rho\pi \qquad P-wave$$
$$\pi_2(1670) \rightarrow f_2\pi \qquad S-wave$$
$$\pi_2(1670) \rightarrow \rho\pi \qquad P-wave$$

where the resonance decays to the given isobar and spectator in the given angular orbital momentum state. The exotic $\pi_1(1600)$ wave is generated at about 5% of the intensity of the a_2.

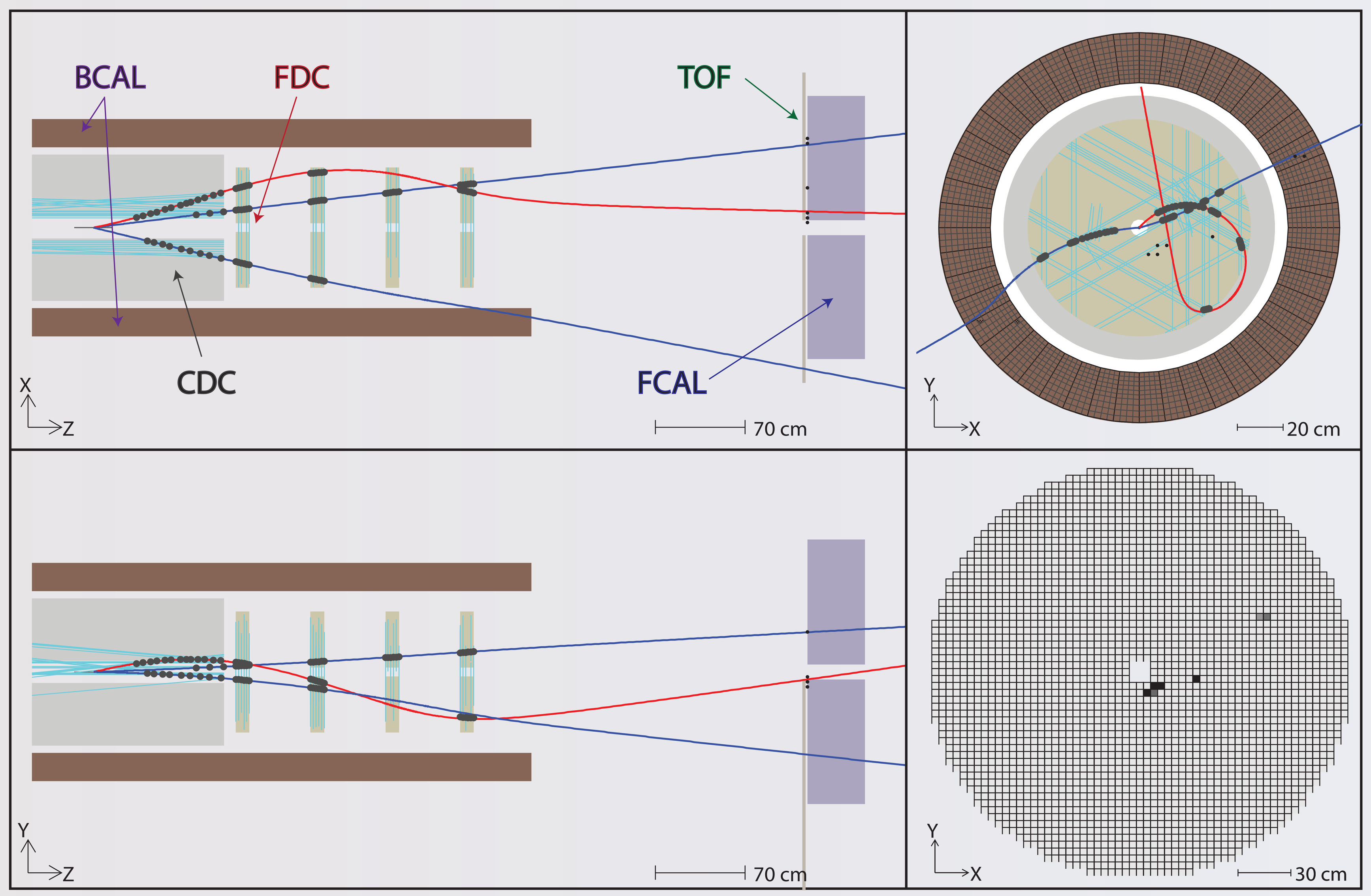
3.5 Hours of Simulated GlueX Data





GlueX Detector Simulation

Inside the clear bore of the magnet of the GlueX detector, a 30 cm-long liquid hydrogen target is surrounded by scintillation counters (START), a cylindrical drift chamber array (CDC) and an electromagnetic lead/scintillating fiber calorimeter with a barrel geometry (BCAL). Downstream of the target are an array of planar drift chambers (FDC). Outside and downstream of the clear bore of the magnet are a wall of scintillation counters (TOF) to measure time-of-flight and an electromagnetic calorimeter (FCAL) consisting of a stack of lead-glass blocks.



A Monte Carlo simulation that included the details of the detector response and reconstruction algorithms was used to generate a mock data set for analysis. Next, an amplitude analysis was performed in each bin of $\pi^+\pi^-\pi^+$ invariant mass. The results for the production amplitudes are plotted at left. From this fit it is apparent that an exotic signal ***can be detected*** if it exists on the order of 5% of the a_2.