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

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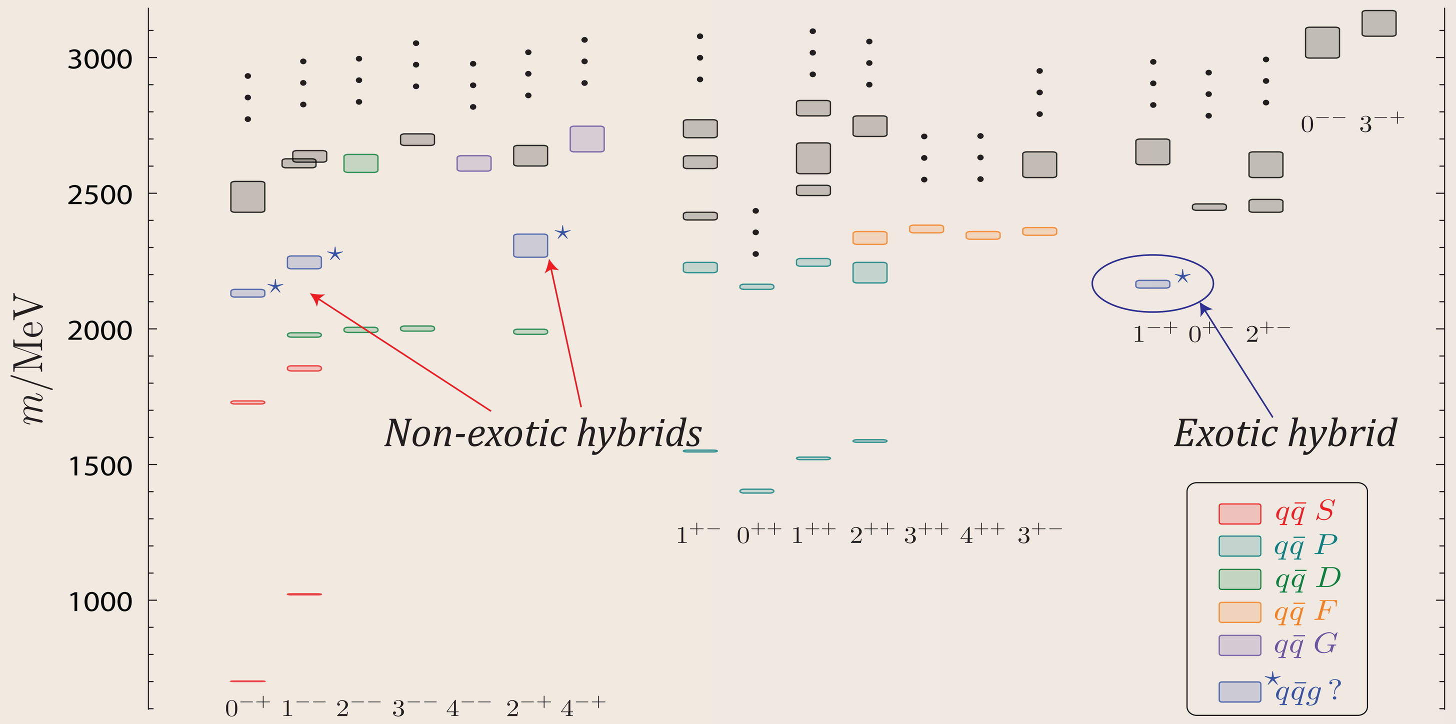
Hybrid Mesons

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.



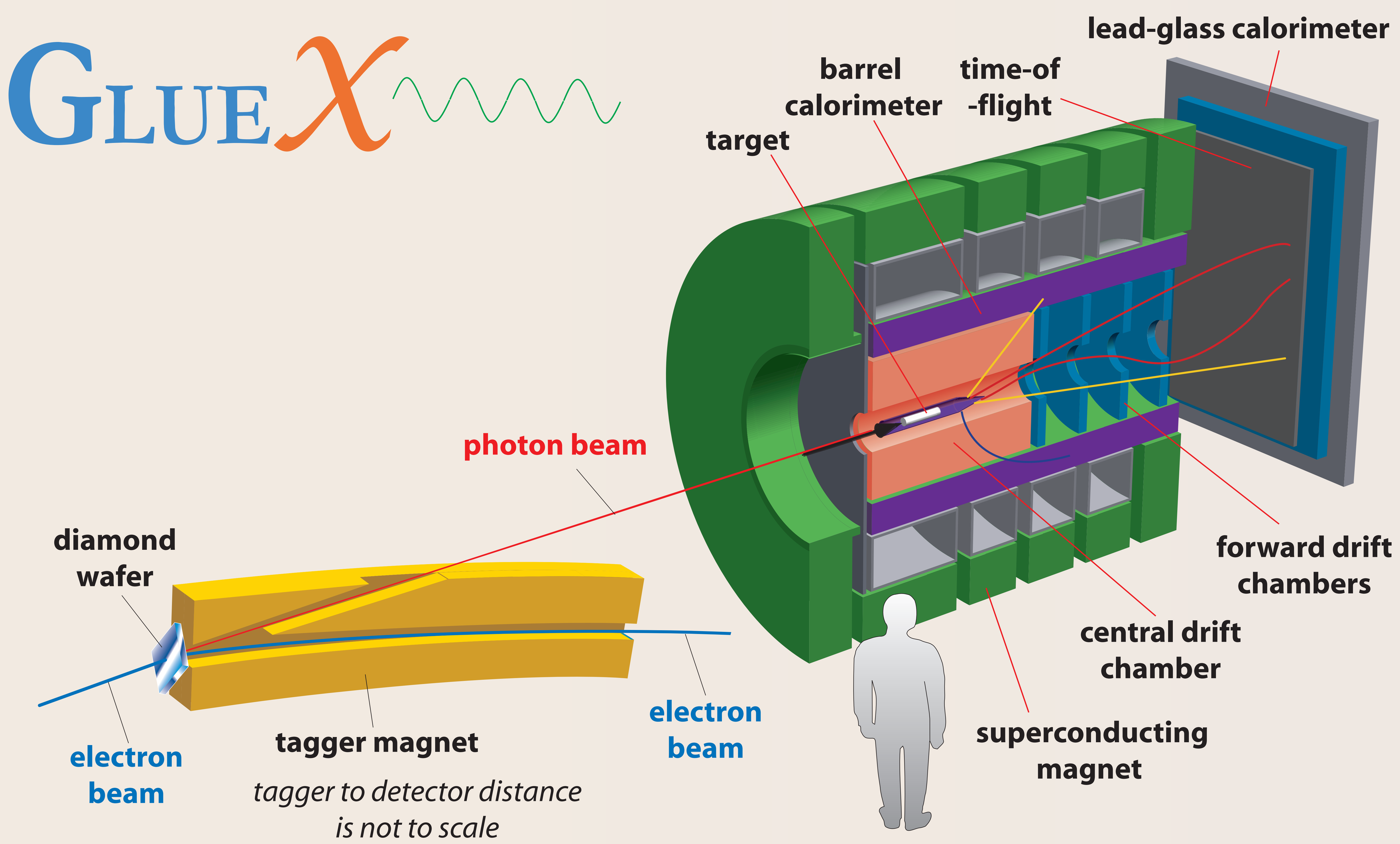
arXiv:1106.5515 and Phys. Rev. D 82, 034508 (2010)

The unquenched lattice QCD calculations above imply the existence of states that are not purely $q\bar{q}$. That is, in addition to quark degrees of freedom, a meson state may have some additional degrees of freedom in the gluonic field that 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 ($J^{PC} = 0^{--}, 0^{+-}, 1^{-+}$) which are not accessible by conventional $q\bar{q}$ states. The existence of these exotic hybrid mesons would give conclusive evidence of the role of gluons as constituent particles. The lightest exotic hybrid is expected to have a mass between 1 GeV and 2 GeV. The results plotted above are 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 decay with statistics after the first year of running that will exceed the current photoproduction data in hand by several orders of magnitude.

GlueX



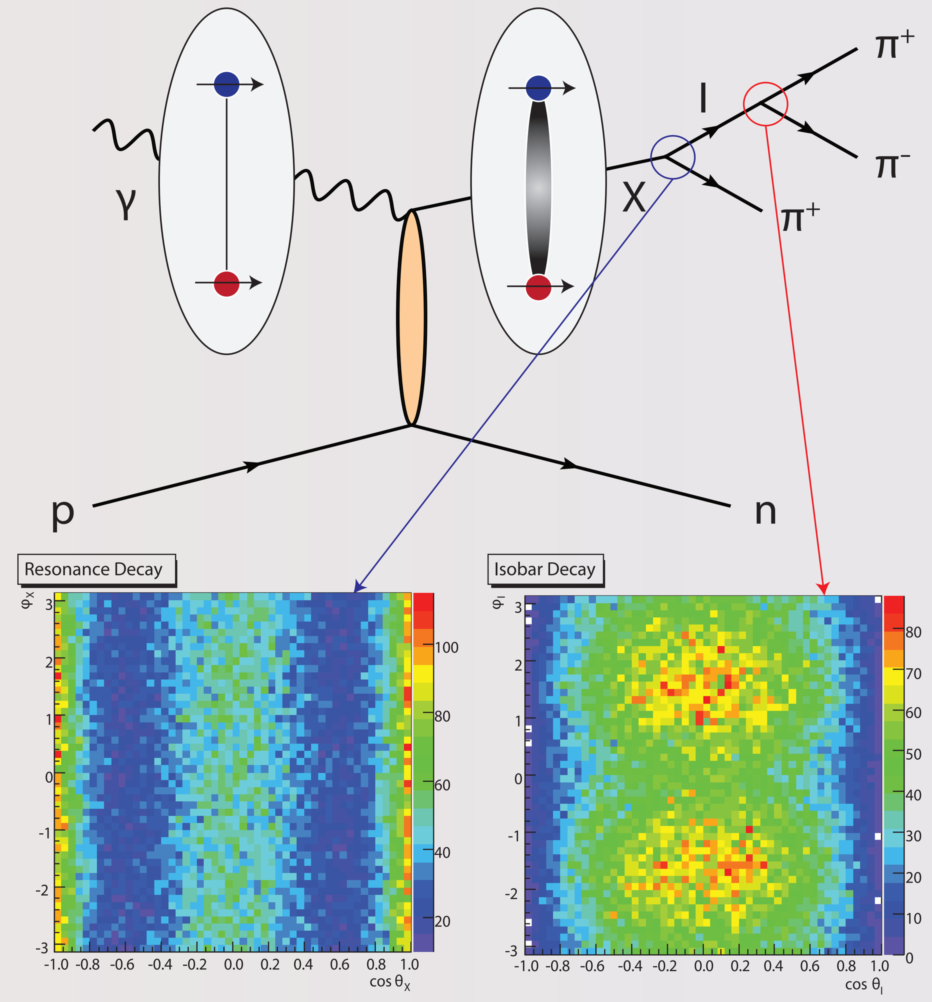
Amplitude Analysis

Amplitude analysis will be used at GlueX to extract masses, widths and quantum numbers of resonances, using information on the magnitude of momentum and the angular distributions of the final state particles. For resonances of interest at GlueX, it is insufficient to look for peaks in the invariant mass spectrum as they may be wide and overlapping.

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) 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

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

where $V_{\varepsilon,\beta}$ represents the amplitude to produce the state X and $A_{\varepsilon,\beta}(\boldsymbol{x})$ 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 $V_{\varepsilon,\beta}$ 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.



$a_2(1320) \longrightarrow \rho\pi \quad D-wave$

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 coherent sums over resonances. These two sums are then added incoherently.

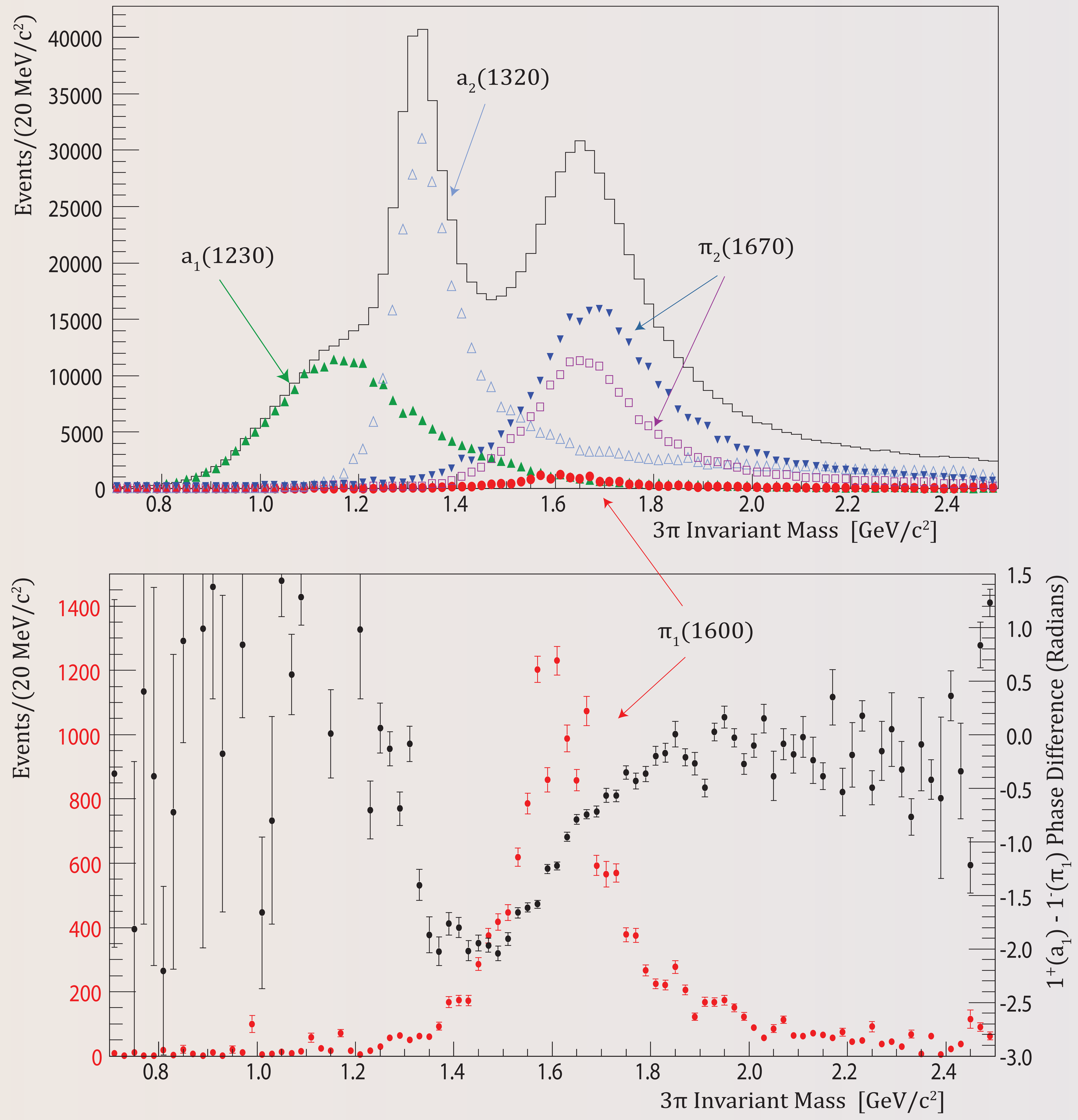
$$I = \sum_{p=\pm1} \frac{1+pf}{4} \left| \sum_{\beta=1}^{n} V_{\varepsilon_\gamma,\beta}\left(\langle X_i|R'\rangle + p e^{2i\alpha}\langle X_i|L'\rangle\right) \right|^2,$$

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

$$\begin{array}{ll} a_1(1230) \longrightarrow \rho\pi & S-wave \\ a_2(1320) \longrightarrow \rho\pi & D-wave \\ \pi_1(1600) \longrightarrow \rho\pi & P-wave \\ \pi_2(1670) \longrightarrow f_2\pi & S-wave \\ \pi_2(1670) \longrightarrow \rho\pi & P-wave \end{array}$$

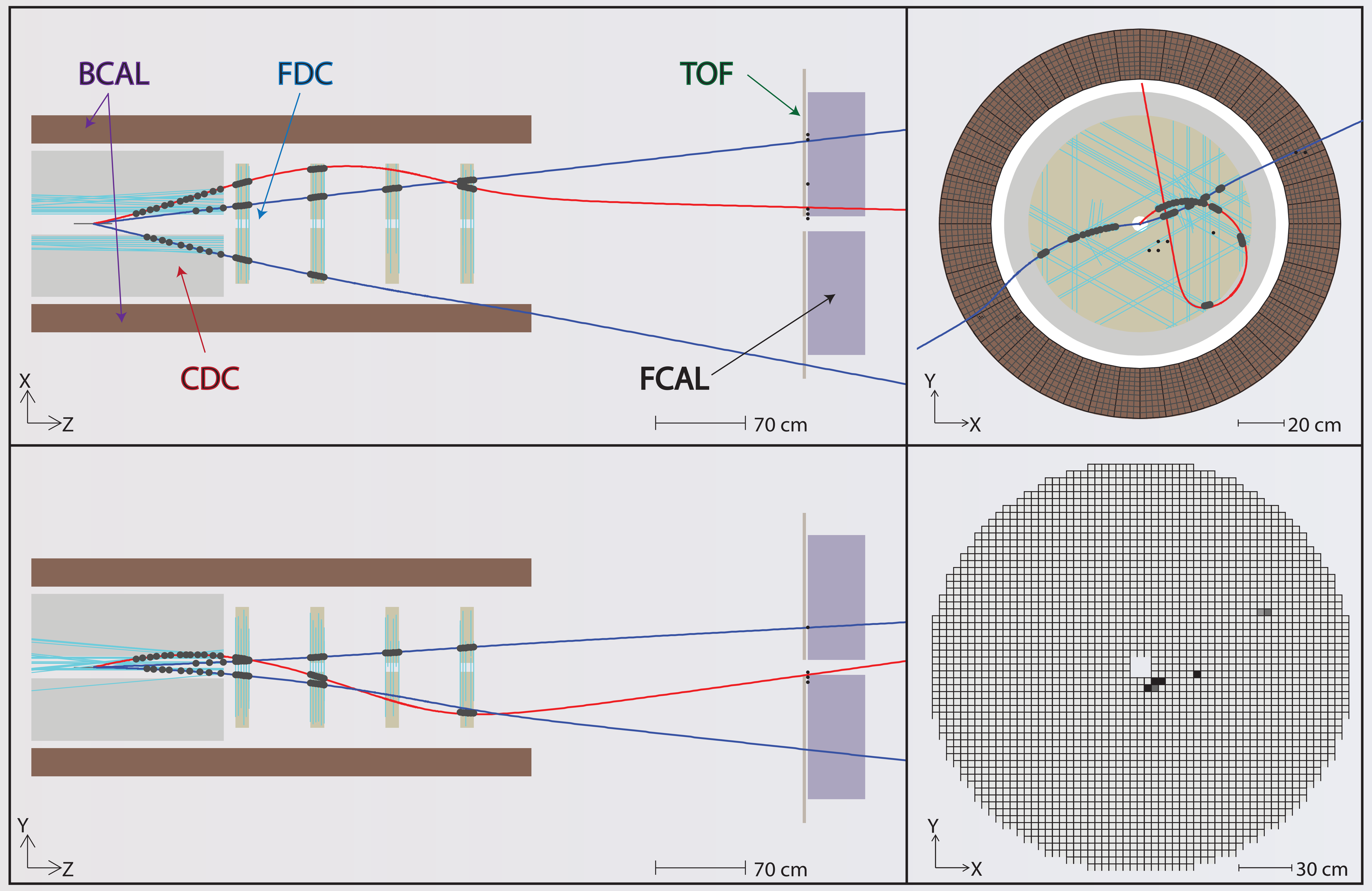
where the resonance decays to the given isobar and spectator in the given angular orbital momentum state. The exotic $\pi_1(1600)$ amplitude is generated at about 5% of the intensity of the a_2.

Simulated GlueX Data (3.5 Hours of Beam Time)



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 is 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 intensity of each amplitude is plotted to the left. It is apparent that even with an intensity corresponding to 1.6% of the data, the exotic signal can be detected.