Beam Asymmetries from Light Scalar Meson Production on the Proton at GlueX

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Abstract. The GlueX facility, featuring a linearly polarised 9 GeV real photon beam delivered to a large-acceptance detector system, has recently completed its first phase of running, and analysis efforts of this dataset are well underway. It has been suggested that at GlueX energies, quark systems beyond the three quark and quark-antiquark systems of baryons and mesons, such as hybrid mesons, tetraquarks and glueballs, should exist, and studies of these systems could shed new light on how quarks combine under the strong force, particularly the role played by gluons.

Meticulous study of the spectrum of hadronic states is required to understand the strong force in the non-perturbative energy regime, and the light scalar meson sector is an area that remains poorly understood. GlueX data encompasses final states at energies where photoproduction of the $a_0(980)$ and $f_0(980)$ mesons can provide discriminatory evidence between various models, manifested in experimental observables such as the cross section and beam asymmetry, and performing detailed measurements of these quantities is considered a priority of the ongoing research program.

The work presented showcases efforts to measure the beam asymmetry of the reaction $\gamma p \rightarrow p\eta\pi$, whose mass spectrum encompasses several mesons, including the $a_0(980)$ light scalar, and the $a_2(1320)$ tensor. Future prospects for related analyses in the light scalar meson sector, informed by this measurement, will also be discussed.

1. Introduction
At present, the structure of light scalar mesons, states with spin zero and even parity, is poorly understood. These states have large widths, and significant overlap with background, as well as being in close proximity to $K\bar{K}$ and $\eta\eta$ thresholds, which has so far made determination of their properties difficult [1]. The latest generation of hadron physics experiments hopes to learn more about these states, by performing precision measurements of their properties, providing discriminatory power between models describing the light scalars and aiding our understanding of their production mechanisms and their natures in quark-gluon terms.

At sufficiently high beam energies, t-channel processes are dominant, and the t-dependence of observables can be studied free of lower energy backgrounds. Various models and approaches exist which can describe the photoproduction process and make predictions of experimentally observable quantities, and measurements of these quantities, such as cross sections and beam asymmetries, can provide constraints to these descriptions. For example, the magnitude and sign of the beam asymmetry can indicate the dominance of a particular exchange process.
Recent studies in lattice QCD, where an S-wave scattering amplitude is computed via a coupled-channel lattice calculation, suggests that something significant happens at $K\bar{K}$ threshold. Even allowing for the unphysical quark masses used in these calculations, it is still possible to interpret this as an $a_0(980)$-like resonance, coupled to $K\bar{K}$ and $\eta\pi$, and studies of $\eta\pi$ experimental data may allow further interpretation of this result [2].

Colleagues at the Joint Physics Analysis Centre (JPAC) describe photoproduction of the $\eta\pi$ system in terms of contributing waves from various mesons, with the possible influence of a $\pi_1(1600)$ exotic state expressible in terms of the beam asymmetry. When binned in small angles in the Gottfried-Jackson frame, approximating back-to-back $\eta\pi$ events in that frame, an exotic wave is shown to have a more pronounced effect on the measured beam asymmetry [3].

Phenomenological models describe the light scalars as anything from a simple $q\bar{q}$ pair to glueball and tetraquark states, with a model by Donnachie et. al. [4] using reggeised $\rho$ and $\omega$ exchanges, with a small contribution from $b_1(1235)$ exchange, to calculate photoproduction amplitudes for $a_0(980)$ and $f_0(980)$. This model has made cross section predictions for light scalar meson production, and was recently extended to include beam asymmetries.

This work focuses on the $\eta\pi$ system, where the $a_0(980)$ is the light scalar state of interest. The dependence of the beam asymmetry on the $\eta\pi$ mass is presented as a step towards providing insights to descriptions of the production of the light scalars.

2. Jefferson Lab and GlueX

The Thomas Jefferson National Accelerator Facility (JLab) is a US Department of Energy facility located in Newport News, Virginia. Its centrepiece machine is the Continuous Electron Beam Accelerator Facility (CEBAF), a superconducting RF accelerator, recently upgraded to deliver electron beams up to 12 GeV in energy simultaneously to up to four experimental halls. The four halls, named A, B, C, and D, are host to a varied range of experimental equipment, supporting a diverse physics program, with Hall D focused on experiments using a real photon beam produced from the primary CEBAF beam via the bremsstrahlung process.

The Hall D photon beam facility produces real, linearly polarised photon beams in the tagger hall, a separate building to Hall D. The primary electron beam from CEBAF impinges on a radiator and produces photons via the bremsstrahlung process. The energy-degraded electrons are swept out of the beamline by the tagger magnet, and the photon beam continues to the experimental hall. The beam is collimated then enters the main experimental hall, passing through devices designed to monitor the flux and polarisation of the beam, before interacting with the target at the centre of the GlueX spectrometer.

When a diamond radiator is used, the resulting photon beam is linearly polarised in one of two orientations, referred to as PARA or PERP, parallel or perpendicular to the floor of the experimental hall. This 90 degree rotation of the polarisation planes is utilized in the computation of the beam asymmetry, which will be discussed later in these proceedings.

The GlueX detector in Hall D is a hermetic, solenoid based detector, comprising central and forward tracking systems, barrel and forward calorimeter devices, start counter, and time-of-flight scintillator paddles. This provides good charged and neutral particle identification, with uniform acceptance over $4\pi$ solid angle. A schematic of the GlueX detector and photon tagging facility is shown in figure 1. Experimental operations with GlueX commenced in 2016, and its first phase of running concluded in the autumn of 2018.

3. Analysis

This work focuses on studying beam asymmetries of the $\eta\pi$ channel, where $\eta$ and $\pi$ each decay to a pair of photons. A kinematic fit is used to identify particles and filter data, with cuts applied on vertex position, energy loss in the drift chamber for proton tracks, and photon beam energy. Candidate $\eta\pi$ events are subjected to further processing to select event samples corresponding
to meson photoproduction processes. Specifically, cuts are applied on $p\pi^0$ and $p\eta$ invariant mass to reduce the level of baryon production events in the final event sample. Figure 2 shows the $\eta\pi$ invariant mass after this initial event selection.

3.1. Beam Asymmetries

The beam asymmetry, $\Sigma$, can be expressed in terms of the reduced cross section

$$\sigma = \sigma_0[1 - P_{\gamma}\Sigma\cos(2(\phi - \phi_\gamma))]$$ (1)

To measure it, we can take the difference over the sum of events with PARA and PERP beam polarisation

$$A(\phi) = \frac{N(PARA) - N(PERP)}{N(PARA) + N(PERP)} \approx P_{lin}\Sigma\cos(2\phi)$$ (2)

By doing this using the proton azimuthal angle distributions for PARA and PERP data in a number of $\eta\pi$ invariant mass bins, we can fit a function of the form of equation 2 to these asymmetry distributions. The beam asymmetry (more accurately, the beam asymmetry, modulated by the degree of photon polarisation) is then extracted from the magnitude of the $\cos(2\phi)$ term.

4. Results

Figure 4 shows preliminary results for the beam asymmetry versus $\eta\pi$ invariant mass for the entire range of Gottfried-Jackson angles. The vertical error bars represent statistical uncertainties only. No obvious exotic signature is discernible, and due to limited statistics, the asymmetry is not shown for ranges of small Gottfried-Jackson angles, where comparisons to the JPAC model could determine the signature of an exotic state [3].

Figure 1. The GlueX detector and photon tagger.
Figure 2. Invariant Mass of $\eta\pi$ after initial event selection, including cuts to veto baryon events and subtraction of tagger accidentals.

Figure 3. (left) Example asymmetry fit for the $\eta\pi$ mass bin spanning the $a_0(980)$ meson. The magnitude of the $\cos(2\phi)$ term of the fit corresponds to the beam asymmetry, modulated by the magnitude of photon beam polarisation. (right) Schematic showing the reaction plane and the intersection of the photon polarisation plane.

5. Conclusion
We present preliminary measurements of the beam asymmetry for the four photon final state of the $\eta\pi$ system. No obvious exotic signal is seen, however follow up measurements binned in Gottfried-Jackson angle, using experimental moments to overcome the limited statistics available at smaller angles, may provide additional insights. This measurement is also a first step toward several follow up measurements that GlueX will make in this system that may provide further insights into understanding the nature and production mechanisms of light scalar mesons in this reaction topology. These will include the $a_0(980)$ beam asymmetry and cross section, and full partial wave analysis of the $\eta\pi$ system.
Figure 4. Beam asymmetry, $\Sigma$, versus $\eta\pi$ invariant mass. Errors are statistical only.

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