The GlueX/Hall-D
Research Management Plan

GlueX-doc 1978
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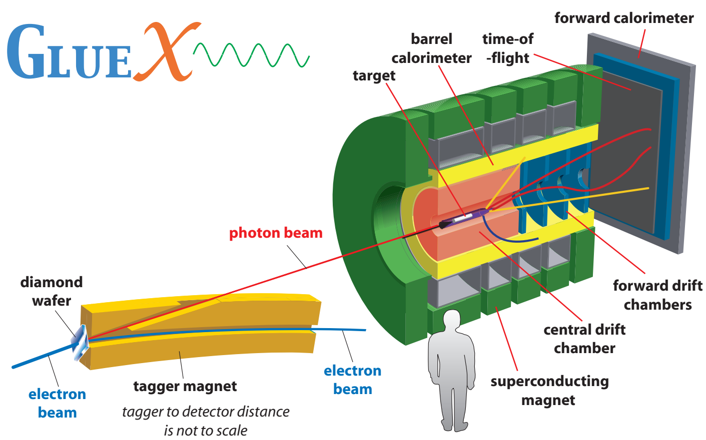

The GlueX Collaboration

Athens University, Arizona State University, Carlton University, Carnegie Mellon University, Catholic University, Christopher Newport University, University of Connecticut, Florida International University, Florida State University, University of Glasgow, Indiana University, Jefferson Lab, University of Massachusetts Amherst, Massachusetts Institute of Technology, MEPHI, University of North Carolina A&T, University of North Carolina Wilmington, Old Dominion University, Oxford University, University of Pittsburgh, University Técnica Federico Santa María and University of Regina.

1 Physics Motivation

A long-standing goal of hadron physics has been to understand how the quark and gluonic degrees of freedom that are present in the fundamental QCD Lagrangian manifest themselves in the spectrum of hadrons. Of particular interest is how the gluon-gluon interactions might give rise to physical states with gluonic excitations. One class of such states is the hybrid mesons, which can be naively thought of as quark anti-quark pairs coupled to a valence gluon ($q\bar{q}g$). Recent lattice QCD calculations [1] predict a rich spectrum of hybrid mesons as shown in Figure 1. A subset of these hybrids have an unmistakable experimental signature: angular momentum (J), parity (P), and charge conjugation (C) that cannot be created from just a quark-antiquark pair. Such states are called exotic hybrid mesons. The primary goal of the GlueX experiment in Hall D is to search for and study these mesons.

A detailed overview of the motivation for the GlueX experiment as well as the design of the detector and beam line can be found in the initial proposal to the Jefferson Lab Program Advisory Committee (PAC) 30 [2] and a subsequent PAC 36 update [3] as well as the upcoming PAC 39 [4]. The initial 120 days of beam time with the baseline detector configuration will allow GlueX an unprecedented opportunity to search for exotic hybrid mesons, the existing baseline design is inadequate for studying mesons or baryons with strange quarks. A second phase focuses on developing additional detector capability that will allow GlueX to identify kaons and operate at high intensity. This functionality is essential in order for the GlueX experiment to pursue its primary goal of solidifying our experimental understanding of hybrids by identifying *patterns* of hybrid mesons, both isoscalar and isovector, exotic and non-exotic, that are embedded in the spectrum of conventional mesons.

Lattice QCD calculations have for the first time shown a clear and detailed spectrum of exotic J^{PC} mesons. This spectrum, as shown in Fig. **??**, finds a lightest 1^{-+} lying a few hundred MeV below a 0^{+-} and two 2^{+-} states. Beyond this, through analysis of the matrix elements $\langle n|\mathcal{O}^\dagger|0\rangle$ for a range of different quark-gluon constructions, $\mathcal{O}$, we can infer [1] that although the bulk of the non-exotic J^{PC} spectrum has the expected systematics of a $q\bar{q}$ bound state system, some states are only interpolated strongly by operators featuring non-trivial gluonic constructions. One may interpret these states as non-exotic hybrid mesons, and, by combining them with the spectrum of exotics, it is then possible to isolate a lightest hybrid supermultiplet of $(0,1,2)^{-+}$ and 1^{--} states, roughly 1.3 GeV heavier than the ρ meson. The form of the operator that has strongest overlap onto these states has an S-wave $q\bar{q}$ pair in a color octet configuration and an exotic gluonic field in a color octet with $J_g^{P_gC_g} = 1^{+-}$, a *chromomagnetic* configuration. The heavier $(0,2)^{+-}$ states, along with some positive parity non-exotic states, appear to correspond to a P-wave coupling of the $q\bar{q}$ pair to the same chromomagnetic gluonic excitation.

A similar calculation for isoscalar states uses both $u\bar{u}+d\bar{d}$ and $s\bar{s}$ constructions and is able to extract both the spectrum of states and also their hidden flavor mixing. (See Fig. **??**.) The basic experimental pattern of significant mixing in 0^{-+} and 1^{++} channels and small mixing elsewhere is reproduced, and, for the first time, we are able to say something about the degree of mixing for exotic-J^{PC} states. In order to probe this mixing experimentally, it is essential to be able to reconstruct decays to both strange and non-strange final state hadrons. The GlueX is ideally positioned to conduct a search for these predicted light-quark exotics and ultimately

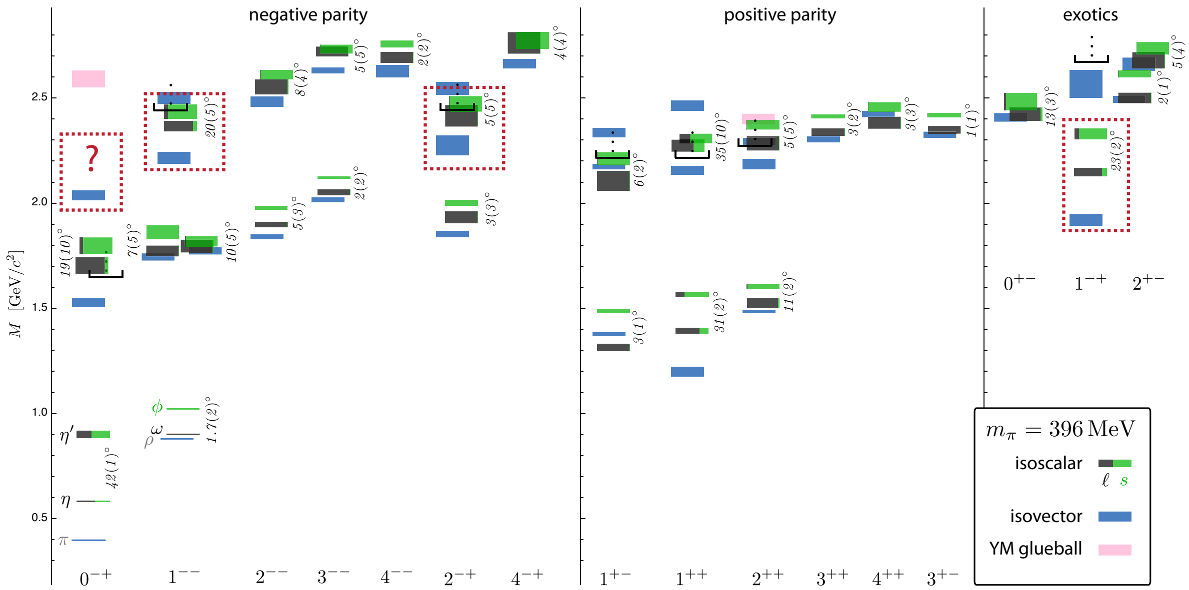

Figure 1: A compilation of recent lattice QCD computations for both the isoscalar and isovector light mesons from Ref. [1], including $\ell\bar{\ell}$ $\left(|\ell\bar{\ell}\rangle \equiv (|u\bar{u}\rangle + |d\bar{d}\rangle)/\sqrt{2}\right)$ and $s\bar{s}$ mixing angles (indicated in degrees). The dynamical computation is carried out with two flavors of quarks, light (ℓ) and strange (s). The s quark mass parameter is tuned to match physical $s\bar{s}$ masses, while the light quark mass parameters are heavier, giving a pion mass of 396 MeV. The black brackets with upward ellipses represent regions of the spectrum where present techniques make it difficult to extract additional states. The dotted boxes indicate states that are interpreted as the lightest hybrid multiplet – the extraction of clear 0^{-+} states in this region is difficult in practice.

provide experimental data on both the spectrum and mixing in light-quark hybrid mesons.

2 GlueX Collaboration Management

The management structure for the GlueX collaboration in Hall-D is detailed in the collaboration's "Management Plan" [5]. The collaboration is led by an elected spokesperson who serves a four-year term and a six-person collaboration board whose members serve for two-year terms. On the Jefferson Lab side is the Hall-D group leader who is responsible for both the JLab staff and the operation of the Hall. In addition to these positions, the spokesperson nominates a deputy spokesperson to serve with him. This nomination must be approved by the members of the collaboration board.

The spokesperson, deputy spokesperson and the Hall-D leader form the "executive group" that is responsible for the operation of the experiment and the hall as well as being the official outside representation for the experiment and the primary contact for new collaborators. The

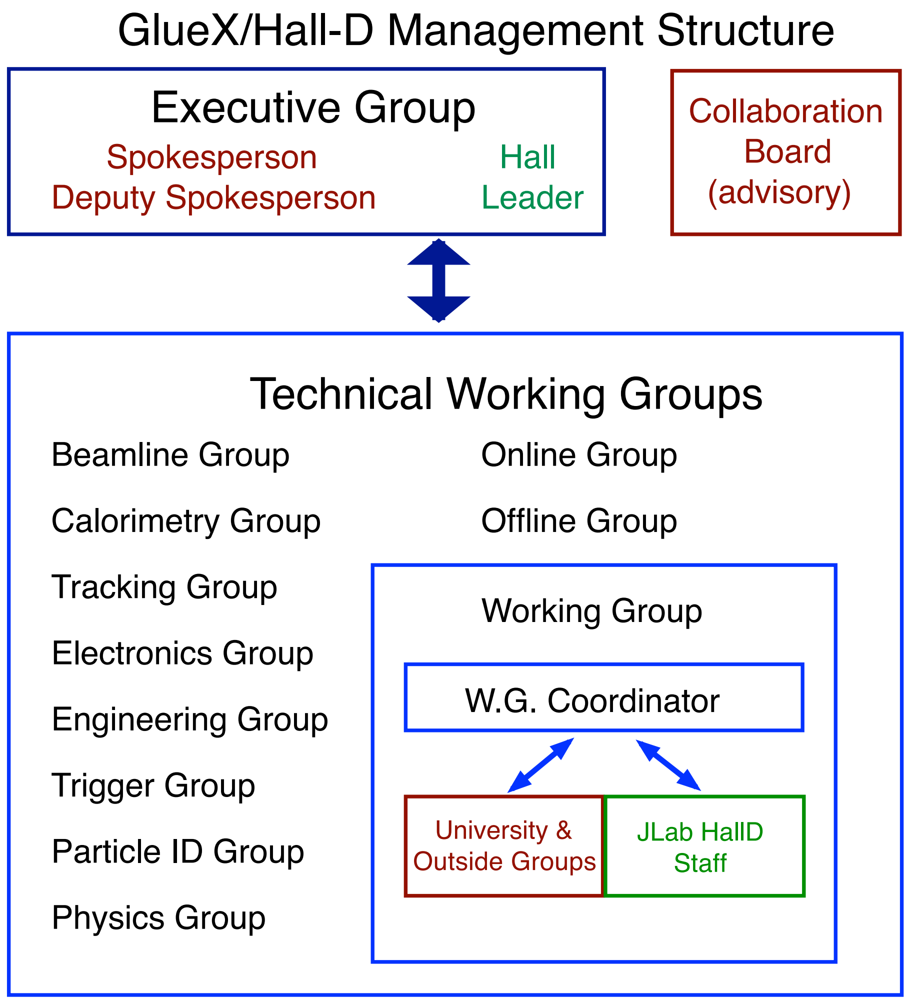

Figure 2: The GlueX/Hall-D management structure.

day-to-day operation of the experiment is handled by the "technical working groups" which are set up by the spokesperson and whose coordinators are selected by mutual agreement of the working group members and the executive group. The working groups meet via video conference every two weeks, and all working groups report at a collaboration-wide video conference held every two weeks. In addition, the collaboration holds three large meetings per year, usually at Jefferson Lab, as well as additional smaller meeting and workshops as needed. Generally, there is at least one member of the executive group present in each working group meeting and the collaboration is well represented at the larger meetings. This management structure is sketched in Figure 2.

As the experiment evolves from construction into commissioning, and ultimately data analysis, the mixture of working groups will need to change. The spokesperson can create and eliminate these groups as needed, and members of the collaboration are free to participate in any group they choose.

The collaboration board's primary responsibility is policy and by-laws within. This includes publications, talks, elections as well as heading off potential issues in the collaboration. They also vet new collaborators before the new groups go up for a full collaboration vote. Within the collaboration board, the group elects a chair who serves a one-rear term. The chair of the board is in close communication with the executive group.

3 The GlueX Detector

A schematic view of the GlueX detector is shown in Fig. 3. As of the spring of 2012, all major components of the detector are under construction at Jefferson Lab or various collaborating institutions. Beam for the experiment is derived from coherent bremsstrahlung radiation from a thin diamond wafer and delivered to a liquid hydrogen target. The solenoidal detector has both central and forward tracking chambers as well as central and forward calorimeters. Timing and triggering are aided by a forward time of flight wall and a thin scintillator start counter that encloses the target. The civil construction of Hall D is complete and the collaboration has had beneficial occupancy of both Hall-D and the tagger hall since early in 2012. The assembly of the detector within the hall is currently underway. In Table 1 we summarize all of the GlueX collaborating institutions and their primary responsibilities. The collaboration has grown significantly in the past four years; newer members who have joined since 2008 are noted in the table.

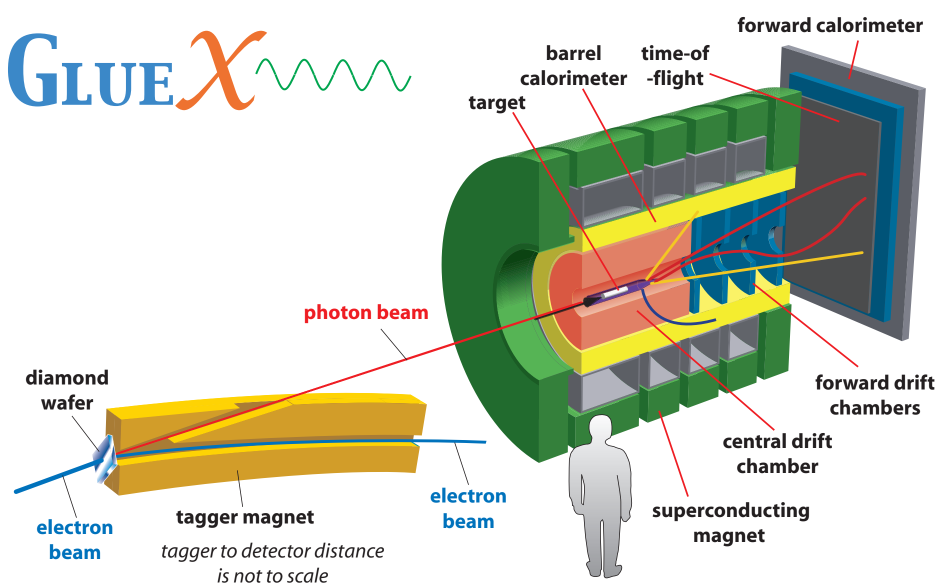

Figure 3: A schematic of the GlueX detector and beam in Hall-D.

Beam Line and Tagger

The Hall-D beam line is designed to deliver high-energy photons into the Hal and starts in the separate tagger hall located upstream of Hall-D. A 12 GeV electron beam is incident on a thin diamond radiator. The Connecticut group has an active program in collaboration with industry to both measure the quality and properties of the diamond targets as well as thin thicker diamonds down to the $20\,\mu m$ needed for GlueX. These diamonds to be held in a goniometer with the Glasgow group taking the lead on the specifications and design of this element. The electrons undergo coherent bremsstrahlung in the thin diamond radiator, emitting linearly polarized photons. The selected coherent peak is from about 8 to 9 GeV in energy.

The scattered electrons are bent in a conventional magnet where JLab has the responsibility for design, procurement and installation. The scattered electrons are then detected in a pair of scintillator-based hodoscopes. A course-binned system designed and built by Catholic University will detect electrons over the entire energy range, while a fine energy-binned "microscope" designed and built by Connecticut will measure the electrons corresponding to the coherent peak.

The photons travel down an 80 m long beam pipe from the tagger hall into the alcove of Hall-D. There, they are incident on a active collimator designed by Connecticut and built at Florida State that provides feed back on beam location to the accelerator. The beam then passes through a narrow collimator and through a magnet to remove produced charged particles. It then passes through a pair-spectrometer magnet and detector system which is the responsibility of NC Wilmington. Integrated into this will be a polarimeter system which will actively measure the linear polarization of the beam. This system is the responsibility of the Arizona and Glasgow groups.

Solenoidal Magnet and Target

The photon beam then travels into the 2.2 T superconducting solenoid. The refurbishment and testing of this venerable magnet is taken care of by JLab, while much of the early work was subcontracted to Indiana. The four coils were successfully tested at or near full current and the magnet was then assembled in Hall-D. Work is currently underway to install cryogenic infrastructure with a full magnet test planned during the next 9 months.

The beam then interacts in a 40 cm long liquid hydrogen target about 65 cm into the bore of the magnet. The target is a joint effort by JLab and University of Massachusetts. Immediately surrounding the target is a scintillator based start counter being built by Florida International. This will provide sufficient information to identify the accelerator beam bucket that produced the photon.

Charged Particle Tracking

After a beam photon has interacted in the target, the resulting particles travel outward through the GlueX detector. Charged particles are tracked using two drift chamber systems. Roughly centered about the target at the upstream end of the solenoid is a straw-tube drift chamber, the CDC. It consists of 28 layers of straws in both axial and stereo orientation. The CDC is built by the Carnegie Mellon Group and will be delivered to JLab for installation in April of

2013. Downstream of the CDC are four drift-chamber packages known as the FDC. These drift chambers contain both wire and cathode readout to provide near 3D spatial points along the track. The system is being built by JLab and will be installed in the magnet just before the CDC goes in. The combined system of chambers is able to reconstruct charged particles from about 1° away from the beam line to about 130° in the backward hemisphere. Because of the fixed target arrangement, this maps into nearly 4π coverage for charged particles.

Institution	Responsibilities
Arizona State U.*	beam-line polarimetry, beam-line support
Athens	BCAL and FCAL calibration
Carnegie Mellon U.	CDC, offline software, management
Catholic U. of America	tagger system
Christopher Newport U.	trigger system
U. of Connecticut	tagger microscope, diamond targets, offline software
Florida International U.	start counter
Florida State U.	TOF system, offline software
U. of Glasgow*	goniometer, beam-line support
Indiana U.	FCAL, offline software, management
Jefferson Lab	FDC, data acquisition, electronics, infrastructure, management
U. of Massachusetts, Amherst *	target, electronics testing
Massachusetts Institute of Technology*	forward PID, offline software
MEPHI*	offline and online software
U. of North Carolina A&T State*	beam-line support
U. of North Carolina, Wilmington*	pair spectrometer
U. Técnica Federico Santa María	BCAL readout
U. of Regina	BCAL, SiPM testing

Table 1: A summary of GlueX institutions and their responsibilities. The star ($\star$) indicates that the group has joined GlueX after 2008.

Calorimetry

In addition to charged particles, the GlueX detector has a pair of calorimeter systems to reconstruct photons. Inside the solenoid, surrounding the tracking detectors is a lead-scintillating fiber based calorimeter system. The 48 four-meter long elements of this barrel calorimeter system (BCAL) were built in Regina and all of them have been transported to Jefferson lab. Light guides being built by the Santa María group will be installed at JLab, and the then the SiPM readout system will be installed. Testing of the Hamamatsu SiPMs is being carried out primarily at Santa María and Jefferson Lab with some tests being performed in Regina.

Down stream of the solenoid is the 2600 block lead-glass calorimeter being built by Indiana. The blocks and phototubes originally came from a BNL experiment, while the support structure and Cockcroft-Walton bases have been designed by Indiana. The blocks for the forward calorimeter (FCAL) have been refurbished and wrapped by Indiana and are currently in storage at Jefferson Lab. For both calorimeters, a calibration system is being built by collaborators in Athens.

Particle Identification

In the baseline design of GlueX, particle identification in the down stream direction is provided by a scintillator-based time-of-flight wall. This is being built by Florida State and will provide K-π separation up to about 1.8 GeV/c. As the TOF sits directly infront of the FCAL, it can also be used to help veto charged particles in the calorimeter.

The original GlueX design contained a threshold Ĉerenkov system between the exit of the solenoid and the TOF system. It was descoped for budgetary reasons in 2008, but with the addition of MIT to the collaboration, efforts are ramping up to develop a system to fill the hole in particle identification. During a workshop in May of 2012, several possible designs were presented and the collaboration has developed an evaluation plan to quickly come to a decision on the right design for GlueX.

Trigger and Electronics

Most of the hardware trigger system and the electronics for the experiment were designed by JLab with support on the trigger from the Christoper Newport group. This work includes most of the specialized boards to connect the VXS crates into the trigger system as well as the F1 TDC and 250 MHz flash ADCs for use with the calorimeters. The 125 MHz flash ADC system for the drift chambers was designed and prototyped and Indiana with the final details before production carried out by JLab. For the drift chambers, the preamplifiers and high-voltage boards were done by Jefferson Lab with participation by both U.Penn and CMU. For the BCAL, the readout board with cooling was also done by Jefferson Lab.

As these electronic modules, as well as the SiPMs arrive, they need to undergo testing. This work for the SiPMs is done by both Santa Marìa and Jefferson Lab. Other electronics will be tested at both UMass and JLab, while work on the hardware trigger algorithms is currently being done by JLab.

In addition to the hardware (level-one) trigger, the original GlueX design had a software-based level-three trigger. While this will be needed to go to the full design luminosity, it was descoped in 2008. The collaboration has started to look a bringing this back into the GlueX detector. It is hoped that with early tests at low rates, the full system can be made to quickly pay for itself in terms of saving in event storage.

Online Data Acquisition Systems

The online and data acquisition for GlueX is being handled by the JLab group. Much of the actual system is developed by the JLab DAQ group as part of the CODA system. In addition, the JLab computer center is responsible for the transfer of data from the experimental hall to disk, and then ultimately to tape.

Offline Event Analysis

The offline event reconstruction will take the data written to disk and tape, and then reconstruct this into events that will be suitable for physics analysis. In addition to the reconstruction, the experiment also has a detailed GEANT simulation of the detector including the beam line with generators to not only produce physics, but also the full hadronic and electromagnetic backgrounds expected in the detector.

The reconstruction framework, JANA, was developed at Jefferson Lab as well as the core algorithms to reconstruct charged tracks. Calorimetry code was initially provided by Regina and Indiana. With the base reconstruction written, much work is now focused on identifying and fixing problem areas in the software. There is active participation by Carnegie Mellon, Connecticut, Florida State, Indiana and Jefferson Lab on this effort and significant improvements have been achieved over the last year.

The GEANT simulation is primarily managed by the Connecticut group with work done by JLab and Indiana. The current simulation is based on GEANT3. It is expected that this will be migrated to GEANT4 when manpower can be identified. We also note that much of the current GEANT simulations run on the Open Science Grid where GlueX is a virtual organization that has contributed resources. This effort is the work of Connecticut. In addition to event reconstruction, GlueX physics also requires an amplitude analysis. Significant effort in this has been provided by Indiana, Carnegie Mellon and Connecticut.

In order to be able to use the software, information on detector calibrations and run-time conditions need to be stored in a database. The database software was developed by members of the Moscow (MEPHI) group while visiting Jefferson Lab.

Engineering and Infrastructure

Nearly all of the engineering and infrastructure effort in building the hall and detectors has been carried out by the JLab group. This work include not only final drawings of most to the detector, but also working out the specifications to allow us to put things out to bid, and then test them when they come in.

Calibration and Commissioning

To first order, the calibration of the various detector elements will be led by the group that built the device. Since all of these will also require offline reconstruction, they will also involve the JLab group in their role in both the offline software and the calibration data base. Calibrations have already been carried out on prototypes of the CDC, FDC, FCAL and BCAL, and a simulated calibration of the actual FCAL has been performed using π^0s reconstructed in the FCAL. This calibration work is currently ongoing as part of the appropriate working groups. The commissioning of the detector will involve all members of the collaboration, with plans now being formulated.

4 Research Program

As noted in Section 1, the primary goal of the search for and identification of exotic-quantum-number mesons. These particles are found using an amplitude analysis on exclusive final states, where the clearest signature is the interference between these new states with other known and unknown normal mesons. The nature of these searches requires running with an open-trigger, making the large data set available for many different physics analyses. Lattice QCD predicts several nonets of exotic-quantum-number mesons in the mass reach of GlueX. These include $J^{PC} = 1^{-+}$, 0^{+-} and 2^{+-}, with the lightest spin-one nonet being part of an approximately mass-degenerate family of four nonets, three of which have non-exotic quantum numbers (1^{--}, 0^{+-} and 2^{+-}).

The initial phase of GlueX physics running as detailed in reference [2, 3] will focus of states made mostly from the light u and d quarks, with emphasis on photo-production channels with relatively large cross sections. Examples of these reactions are listed here, where measured cross sections suggest that we should have enough events in the first two years of running of low intensity photon beams to carry out amplitude analyses.

$$
\begin{aligned}
\gamma p &\rightarrow (p,n)3\pi \\
\gamma p &\rightarrow (pn)\eta\pi \\
\gamma p &\rightarrow (pn)\eta'\pi \\
\gamma p &\rightarrow (p,n)b_1(1235)\pi \\
\gamma p &\rightarrow (p,n)a_2(1320)\pi \\
\gamma p &\rightarrow (p,n)f_1(1285)\pi
\end{aligned}
$$

The final state containing $b_1(1235)\pi$ is particularly interesting as models suggest that exotic-quantum-number mesons from all nonets could couple to this final state.

In this physics working group, full amplitude analyses on simulated data have been performed on the $\eta\pi$ and 3π final states. There has also been a lot of work to look at the more complicated $b_1\pi$ and $f_1\pi$ final states. The $b_1\pi$ will be seen as

$$
\begin{aligned}
\gamma p &\rightarrow p\pi^+\pi^+\pi^-\pi^-\pi^0 \\
\gamma p &\rightarrow n\pi^+\pi^+\pi^-\pi^0\pi^0 \, ,
\end{aligned}
$$

while the $f_1\pi$ will be seen as

$$
\begin{aligned}
\gamma p &\rightarrow p\eta\pi^0\pi^0\pi^0 \\
\gamma p &\rightarrow p\eta\pi^+\pi^-\pi^0 \\
\gamma p &\rightarrow n\eta\pi^+\pi^0\pi^0 \\
\gamma p &\rightarrow n\eta\pi^+\pi^+\pi^- \, .
\end{aligned}
$$

These reactions have sufficient particles in the final states that they full test the track and photon reconstruction of the detector.

Initial analyses will focus on individual channels, but ultimately the different channels will need to be combined into a more global analysis that will allow us to both verify states in multiple decay modes, but also measure the relative decay rates of the u and d-quark hybrid mesons.

References

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