

# Final Report:

## Strange Mesons and Gluonic Excitations

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# 1 Introduction

During the course of this project the group consisted of a principal investigator, Professor Justin Stevens, one postdoctoral associate, four graduate students, and seven undergraduate students. The focus of our group is on the study of meson spectroscopy using the GlueX experiment in Hall D at Jefferson Lab (JLab). We collaborated with William & Mary (W&M) colleagues David Armstrong (NSF supported) and Kieth Griffioen and Todd Averett (DOE supported). The entire experimental nuclear physics group at W&M typically has 8-10 graduate students and 2-3 postdocs stationed at Jefferson Lab full-time. This strong presence, along with our close proximity to the lab, allows us to remain deeply involved in a broad program of research.

## 1.1 Group Overview and Personnel

The group's mission is to study the light-quark meson spectrum, utilizing the GlueX experiment at Jefferson Lab (JLab), with an emphasis on searches for exotic hybrid mesons, particularly those containing strange quarks. The PI trained both undergraduate and graduate students, as well as a postdoctoral associate, in experimental nuclear physics research. The personnel funded by this award were as follows:

**Faculty (Associate Professor):** Justin Stevens (PI)

**Postdoctoral Research Associate:** Wenliang Li

**Graduate Students:** Lydia Lorenti, Amy Schertz, Kevin Scheuer and Andrew Hurley

## 2 Research Highlights

There were many research highlights and technical achievements from this award, which are summarized here in three categories: DIRC, service to the GlueX collaboration and physics analysis. One of the primary objectives of this award was to construct, install and commission a new particle detector referred to as the DIRC, Detector of Internally Reflected Cherenkov light, in GlueX. This objective was achieved through the work of the PI as the Technical Coordinator for the DIRC, postdoctoral associate Wenliang Li and graduate student Andrew Hurley and many others in the GlueX collaboration, with the following highlights:

- **Construction of the DIRC detector:** The first “bar box” of fused silica radiators was successfully transported from SLAC to JLab in late 2017, with the remaining three bar boxes transported in 2018. The assembly and characterization of half of the Multi-Anode PMTs (MAPMTs) to be used for the DIRC readout was completed in 2018.
- **Initial Installation of the DIRC detector:** All “bar boxes” composed of fused silica radiators were successfully transported from SLAC to JLab and installed in Hall D in 2018. Half of the remaining optical components required to image the Cherenkov photons were successfully assembled and installed before a commissioning beamtime in February 2019.
- **Initial Commissioning of the DIRC detector:** Over ten days in February 2019 almost  $\approx 10^9$  events were collected with half of the DIRC readout to commission this new detector system. Nearly real-time analysis of this data showed good agreement with GEANT simulations.

- **Complete installation of the DIRC detector:** All of the components were successfully assembled and installed in Fall 2019 in preparation for commissioning and physics-quality data collection, referred to as GlueX Phase-II.
- **DIRC Commissioning and GlueX Phase-II:** Utilizing one week of commissioning beam-time in December 2019, almost  $10^9$  events were collected with the full DIRC readout, completing the commissioning of this new detector system. During January-March 2020 roughly  $200 \times 10^9$  events were collected as a part of GlueX Phase-II with a high-intensity photon beam and the complete DIRC detector.
- **Phase-II DIRC analysis:** Initial calibrations and reconstruction were performed in 2021, which demonstrated that the particle identification performance met the design specifications.

The PI served in several leadership roles for the GlueX collaboration during the course of this award with contributions to the technical achievements, physics analysis and collaboration management during this time:

- **GlueX Physics Analysis Coordinator:** The PI was elected to this position from 2017-2020 with the responsibility for overseeing physics analyses and coordinating the publication and presentation of physics results. During that time the GlueX Phase-I data was collected in 2017 and 2018 which resulted in many presentations of results at national and international conference as well as nine journal publications.
- **GlueX Deputy Spokesperson:** The PI was appointed to this position in 2020-2023 with the responsibility of co-organizing many collaboration activities with the Spokesperson, Matt Shepherd (Indiana University).
- **Determination of charged pion tracking efficiencies:** Graduate student Amy Schertz utilized exclusive  $\omega$  photoproduction events to determine the charged pion tracking efficiencies which demonstrated excellent agreement with GEANT simulations. This validation of the GlueX detector simulation was featured in the collaborations NIM article describing the beamline and detector performance.

Finally, the group contributed to many physics analysis results, including the PhD thesis of two graduate students:

- **Amy Schertz, PhD 2022,** “Partial Wave Analysis of the  $\omega\pi^-$  Final State Photoproduced at GlueX”: In collaboration with our theory colleagues, we developed a complete set of amplitudes to describe the polarized photoproduction of a vector-pseudoscalar system, required for the amplitude analysis of the  $\omega\pi$  system. Amy’s thesis describes the partial wave analysis that demonstrate these amplitudes describe the GlueX-I data for the production of the charged  $b_1$  mesons and provide improved measurements on the ratio of  $D/S$ -wave amplitudes.
- **Andrew Hurley, PhD 2022,** “Partial Wave Analysis of Strange Mesons Decaying to  $K^+\pi^-\pi^+$  in the Reaction  $\gamma p \rightarrow K^+\pi^-\pi^+\Lambda(1520)$  and the Commissioning of the GlueX DIRC Detector”: Andrew utilized the same vector-pseudoscalar amplitudes described from Amy’s thesis to determine the dominant amplitudes in the reaction  $\gamma p \rightarrow K^+\pi^+\pi^-\Lambda(1520)$ .

## 3 Research Metrics

### 3.1 Invited Talks Given since September 2017

- **J. Stevens**, “Early results from GlueX”, American Physical Society Meeting (Virtual), April 2021
- **J. Stevens**, “Strange hadron spectroscopy with a secondary  $K_L$  beam in Hall D”, 9th Workshop of the APS Topical Group on Hadronic Physics (Virtual), April 2021
- **J. Stevens**, “Photoproduction at the EIC”, Workshop on forward physics and QCD with LHC, EIC, and cosmic rays (Virtual), January 2021.
- **J. Stevens**, “The GlueX DIRC Program”, DIRC 2019 Workshop on Fast Cherenkov Detectors (Geissen, Germany), September 2019
- **W. Li**, “GlueX DIRC at JLab”, International Conference on Instrumentation for Colliding Beam Physics (Novosibirsk, Russia), February 2020 (Remote presentation)
- **J. Stevens**, “Exotic meson spectroscopy”, International Nuclear Physics Conference (Glasgow, UK), July 2019
- **J. Stevens**, “Physics with the GlueX DIRC”, Conference on Meson-Nucleon Physics and the Structure of the Nucleon (Pittsburgh, PA), June 2019
- **J. Stevens**, “GlueX Path to Physics”, Joint GlueX-PANDA Workshop (Ashburn, VA), May 2019
- **J. Stevens**, “Meson spectroscopy: the GlueX perspective”, Bounds States in QCD III (St. Goar, Germany), April 2019
- **J. Stevens**, “Recent results from GlueX”, Canadian Association of Physicists Congress (Halifax, Nova Scotia), June 2018
- **W. Li**, “Backward meson production”, Next-generation GPD studies with exclusive meson production at EIC (Stony Brook, NY), June 2018
- **J. Stevens**, “Recent results from GlueX”, Conference on the Interactions of Particle and Nuclear Physics 2018 (Palm Springs, CA), May 2018
- **J. Stevens**, “Recent results from GlueX”, Light Cone (Jefferson Lab), May 2018
- **J. Stevens**, “Recent results from GlueX”, International Workshop on Hadron Structure and Spectroscopy (Bonn, Germany), March 2018
- **J. Stevens**, “The GlueX experiment”, PANDA Collaboration Meeting (Darmstadt, Germany), March 2018
- **J. Stevens**, “The GlueX meson program”, Pion Kaon Interactions Workshop (Jefferson Lab), February 2018
- **J. Stevens**, “Spectroscopy at Jefferson Lab”, Electromagnetic Interactions with Nucleons and Nuclei (Paphos, Cyprus), November 2017

- **J. Stevens**, “Experimental hadron spectroscopy”, Invited lecture at EINN: Frontiers and Careers (Paphos, Cyprus), November 2017
- **J. Stevens**, “GlueX results and overview of pentaquark searches”, Hadronic physics with lepton and hadron beams (Jefferson Lab), September 2017

### 3.2 Contributed Talks Given since September 2017

- **A. Hurley**, “Analysis of the Photoproduction reaction  $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p'$  at GlueX”, American Physical Society Meeting (Virtual), April 2021
- **W. Li** “Backward Meson Electroproduction Opportunities at EIC”, Backward-Angle (u-channel) Physics Workshop (Virtual), September 2020
- **A. Schertz**, “Amplitude Analysis of the  $\omega\pi$  System at GlueX”, American Physical Society Meeting (Virtual), April 2021
- **J. Stevens**, “Backward-angle meson photoproduction with the GlueX experiment”, Backward-Angle (u-channel) Physics Workshop (Virtual), September 2020
- **A. Hurley**, “The GlueX DIRC upgrade and its utilization in the upcoming high intensity experiments”, Division of Nuclear Physics of the APS (Arlington, VA), October 2019
- **A. Schertz**, “Studies of the  $\omega\pi\pi$  Final State at GlueX”, Division of Nuclear Physics of the APS (Arlington, VA), October 2019

### 3.3 Publications since September 2017

- S. Adhikari *et al.* (GlueX Collaboration) “Measurement of spin-density matrix elements in  $\rho(770)$  production with a linearly polarized photon beam at  $E_\gamma=8.2\text{--}8.8$  GeV,” Phys. Rev. C108, 055204 (2023)
- S. Adhikari *et al.* (GlueX Collaboration) “Measurement of the  $J/\psi$  photoproduction cross section over the full near-threshold kinematic region,” Phys. Rev. C108, 025201 (2023)
- S. Adhikari *et al.* (GlueX Collaboration) “Search for photoproduction of axionlike particles at GlueX,” Phys. Rev. D105, 052007 (2022)
- S. Adhikari *et al.* (GlueX Collaboration) “Measurement of spin density matrix elements in  $\Lambda(1520)$  photoproduction at 8.2–8.8 GeV,” Phys. Rev. C105, 035201 (2022)
- S. Adhikari, *et al.* (GlueX Collaboration) “Measurement of beam asymmetry for  $\pi^- \Delta^{++}$  photoproduction on the proton at  $E_\gamma = 8.5$  GeV” Phys. Rev. C103, 022201 (2021)
- S. Adhikari, *et al.* (GlueX Collaboration) “The GlueX Beamline and Detector,” NIM A 987 (2021) 164807
- A. Ali, *et al.* “Installation and Commissioning of the GlueX DIRC,” JINST 15 (2020) 09, C09010
- A. Ali, *et al.* “The GlueX DIRC Program,” JINST 15 (2020) 04, C04054, arXiv:2002.07990 [physics.ins-det].

- S. Adhikari *et al.* (GlueX Collaboration) “Measurement of the Photon Beam Asymmetry in  $\vec{\gamma}p \rightarrow K^+\Sigma^0$  at  $E_\gamma = 8.5$  GeV,” Phys. Rev. C101, 065206 (2020)
- A. Ali *et al.* (GlueX Collaboration) “First measurement of near-threshold  $J/\psi$  exclusive photoproduction off the proton,” Phys. Rev. Lett. 123 (2019) 7, 072001
- T. D. Beattie *et al.* “Construction and Performance of the Barrel Electromagnetic Calorimeter for the GlueX Experiment”, Nucl. Instrum. Meth. A896, 24 (2018)
- M. Sher and J. Stevens “Detecting a heavy neutrino electric dipole moment at the LHC”, Phys. Lett. B777, 246 (2018)
- S. Adhikari, J. Stevens (co-spokesperson) *et al.* (GlueX Collaboration) “Strange Hadron Spectroscopy with a Secondary  $K_L$  Beam at GlueX”, JLab PAC45 Proposal (resubmitted to PAC46), arXiv:1707.05284 [hep-ex].

## 4 Student Tracking Information

Student	Date Entered Graduate School	Joined Group	Degree Program	Degree Awarded or Expected	Advisor
Amy Schertz	Aug. 2015	June 2017	Ph.D.	April 2022	Stevens
Andrew Hurley	Aug. 2016	June 2017	Ph.D.	October 2022	Stevens
Lydia Lorenti	Aug. 2019	June 2020	Ph.D.	Expected May 2027 (Medical Leave)	Stevens
Kevin Scheuer	Aug. 2020	June 2021	Ph.D.	Expected May 2026	Stevens