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FINAL REPORT FOR AWARD
DE-SC0019999
DOE Office of Science, Office of Nuclear Physics
TITLE: Medium Energy Nuclear Physics: Exotic Physics & Advanced Tools at J.Lab and the EIC
PI: Prof. Mike Williams
Massachusetts Institute of Technology

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Summary of work done during grant period

This grant supported post-doc / research scientist Cristiano Fanelli (CF) and PhD student Yunjie Yang (YY), who obtained his PhD in spring 2021.

January 2019 – October 2019:

- Dirac Installation:
  - YY installed PMTs, dark sealed the optical box and bar boxes, verified cabling, and performed DAQ tests.
  - YY played a major role in data-quality monitoring and leading special run periods used to commission several DIRC components.
- Published a pheno/theory paper on axion-like particles (ALPs) in PRL which showed the potential of searches performed at JLab.
- Published collaboration with JPAC theorists on JLab-based pentaquark studies.

November 2019 – October 2020:

- Major progress was made on installation and calibration of the GlueX DIRC detector:
    - DIRC installed during the Fall 2019 run.
    - DIRC operational starting with the Spring 2020 run.
    - Verified that the number of Cherenkov photons per track in data is consistent with the expectations from the TDR.
    - Achieved a single-photon resolution of 8 mrad, better than the 10 mrad value in the TDR.
    - The K-pi separation, however, was found to be worse than expected due to worse performance of the GlueX tracking systems than expected.
    - After fixing issues found in the GlueX tracking, the K-pi separation was still worse than expected due to misalignment of the bars in the DIRC boxes.
- CF served as GlueX Run Coordinator.
- AI/ML work:
    - Published study on AI-optimized design for the EIC, specifically focusing on the dual-RICH detector
    - Published a study on using Deep Learning for RICH reconstruction
- YY served as GlueX shift leader.
- YY largely completed an ALP search using the full GlueX dataset, pushing this the entire way into an official internal analysis review.

November 2020 – October 2022

- YY defend his PhD.
- CF obtained a faculty position at William & Mary.
- CF developed clustering algorithm based on unsupervised hierarchical clustering implemented in JANA2 for the CLAS12 forward tagger calo and operating in streaming readout mode.
- CF played leading role in developing the ECCE proposal, which was successfully chosen as Detector 1 for EIC:
    - CF leader of AI-assisted design for ECCE
    - CF leader of tracking system development for ECCE
    - CF leader of developing the ECCE computing plan
- AI/ML work:
    - CF contributed to review article on ML in nuclear physics.
    - Published article on new AI method for anomaly detection.
    - Completed most of the work for a novel geometric-fitting approach that could be useful for jet physics at EIC.
- EIC Yellow Report contributions:
    - Development of the dual-RICH detector for PID
    - C Fanelli editor of the AI for EIC section

- Development of the EM calorimeter design
- Summarizing the streaming-readout activities at JLab

Publications from the final grant period

Journal articles (note that we omit GlueX papers where our group was not lead authors):

- D Aloni, C Fanelli, Y Soreq, M Williams, Photoproduction of axion-like particles, PRL 123 (2019).
- D Winney, C Fanelli, et al, Double polarization observables in pentaquark photoproduction, PRD 100 (2019).
- C Fanelli and J Pomponi, DeepRICH: Learning deeply Cherenkov detectors, ML Sci Tech 1 (2020).
- E Cisbani, A Del Dotto, C Fanelli, M Williams, et al, AI-optimized detector deisng for future EIC: the dual-radiator RICH case, JINST 15 P05009 (2020).
- A Boehnlein et al, Machine learning in nuclear physics, Rev Mod Phys 94 (2021) 031003.
- C Fanelli, J Giroux, Z Papandreou, Flux + mutability: A Conditional generative approach to one-class classification and anomaly detection, ML Sci Tech 3 (2022) 045012.
- GlueX collaboration (Y Yang and M Williams lead authors), Search for photoproduction of axion-like particles at GlueX, PRD 105 (2022) 052007.

Invited talks:

- C Fanelli, Physics opportunities with photon beams at JLab12, seminar at UC Riverside, May 7, 2019.
- C Fanelli, Machine learning in the online data acquisition, ML INFN PhD school, Genova, Italy, May 20, 2019.
- Y Yang, GlueX DIRC, JLab Users Group Meeting, JLab, June 25, 2019.
- C Fanelli, RICH detector development for hadron ID at EIC, iWoRiD 2019, Crete, Greece, July 7, 2019.
- C Fanelli, Machine learning for RICH counters, DIRC 2019, Geissen, Germany, September 11, 2019.
- C Fanelli, JLab pentaquark perspective, LHCb Implications Workshop, CERN, October 16, 2019.
- C Fanelli, The role of AI in exploring the nature of matter, colloquium at Virginia Tech, February 4, 2020.
- C Fanelli, AI opportunities at JLab and the EIC, colloquium at William & Mary, February 17, 2020.
- C Fanelli, AI optimized detector design, AI for Nuclear Physics Workshop, JLab, March 4, 2020.
- C Fanelli, AI-supported algorithms for streaming readout, Streaming Readout Workshop IV, JLab, May 13, 2020.

- C Fanelli, Subdector parameter optimization, Joint GlueX-EIC-PANDA ML Workshop, GSI, Germany, September 23, 2020.
- C Fanelli, Perspectives on hidden flavor multiquark states in photo(electro)production at JLab, seminar at Argonne National Lab, December 10, 2020.
- C Fanelli, Detector design optimization, Winter School on ML and Nuclear Physics, January 2021.
- C Fanelli, AI from JLab to EIC, JLab Users Organization, June 23, 2021.
- C Fanelli, AI for the optimization of the ECCE detector, NPPS meeting, Brookhaven National Lab, July 23, 2021.
- C Fanelli, AI/ML and detector co-design, EIC User Group Meeting, August 2, 2021.
- C Fanelli, AI/ML for imaging Cherenkov detectors -AND- AI/ML for detector design, AI4EIC Workshop, CFNS, September 7, 2021. (2 talks)
- C Fanelli, AI for the design and R&D phases of the ECCE detector, seminar at Oak Ridge National Lab, October 12, 2021.
- C Fanelli, AI for detector design in nuclear physics, IAEA Meeting, October 25, 2021.
- C Fanelli, Leverage data science in complex nuclear physics experiments: from JLab to EIC, colloquium at William & Mary, February 17, 2022.
- C Fanelli, AI/ML for the EIC, seminar at the Rome section of the INFN, May 6, 2022.
- C Fanelli, AI/ML codesign at the EIC, Canadian Assoc of Physicists meeting, Hamilton, Canada, June 6, 2022.
- C Fanelli, Leveraging on intelligent workflows to assist the design of the EIC first detector, Brookhaven National Lab AI/ML seminar, July 12, 2022.

Conference papers:

- C Fanelli, Machine learning for imaging Cherenkov detectors, JINST 15 C02021 (2020).
- A Ali et al, The GlueX DIRC program, JINST 15 C04054 (2020).
- L Barion et al, RICH detector development for hadron ID at EIC, JINST 15 C02040 (2020).
- F Ameli et al, Streaming readout of the CLAS12 forward tagger using TriDAS and JANA2, EPJ Web Conf 251 (2021).