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Intelligent experiments through real-time AI: Fast Data Processing and Autonomous Detector Control for sPHENIX and future EIC detectors

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This new DOE FOA project, first funded by the DOE Office of Science Nuclear Physics AI-Machine Learning initiative in 2022, focuses on leveraging cutting-edge AI technology to address the data processing challenges posed by high-energy nuclear experiments, such as those at RHIC, LHC, and the future EIC. We first aim to develop a demonstrator to process high-rate data streams from sPHENIX experiment tracking detectors in real-time to identify rare heavy flavor events in p+p collisions. Our approach integrates real-time readouts and an intelligent control system, accelerating AI inference with FPGA hardware. This enables the efficient collection of rare heavy-flavor events in high-rate p+p collisions (~1MHz), optimizing the use of limited DAQ bandwidth (~15kHz). The project employs Graph Neural Network-trigger algorithms, trained with sPHENIX p+p collision simulation data, and leverages the hls4ml package for AI model conversion into Firmware. Real-time AI technologies are deployed on powerful FELIX-712 boards with Xilinx Kintex Ultrascale FPGA. Successful deployment of a demonstrator at sPHENIX promises immediate benefits, minimizing computation resources, and accelerating the end-to-end pipeline from experiments to physics discovery, in particular, heavy-flavor measurements in p+p and possibly p+Au collisions. The approach is transferable to other fields requiring high-throughput data streams and real-time detector control, including future EIC experiments. For the EIC, we are developing a DIS-electron tagger using AI-ML algorithms for real-time identification of DIS electrons and characterization of global kinematics. In this talk, we highlight the latest progress in AI-intelligent heavy-flavor triggering for sPHENIX and DIS electron tagger algorithm development for EIC, demonstrating the transformative potential of AI and FPGA technologies in high-energy nuclear and particle experiments' real-time data processing pipelines.

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