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Hadron Polarimetry for the Electron-Ion Collider

Ana Sofia Nunes*, Elke Caroline Aschenauer, Oleg Eyser and William Schmidke

Brookhaven National Laboratory, Upton, USA

* anunes@bnl.gov

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Abstract

The Electron-Ion Collider (EIC) will be the first collider to use both polarized electron beams and polarized proton and light ion beams. It will therefore offer unique opportunities to study the structure of nucleons and to answer fundamental questions in QCD.

The uncertainties on the polarization measurement translate directly into the uncertainties of final physics observables. Hence, a precise measurement of the hadron beam polarization and a good control of systematic uncertainties are critical for the success of the spin program at the EIC.

Contrary to the case of electron beam polarimetry, which uses physical processes derived from first principles that allow a high precision extraction of the electron beam polarization, for hadron beams no such process is available. The currently best used methods rely on the process of elastic scattering in the Coulomb-Nuclear Interference (CNI) region, for which there are only effective models available.

The experience from RHIC, the only existing polarized proton collider, will be detailed and the challenges of the measurements at the EIC will be addressed. In particular, measurements of the present RHIC polarimeters and simulations of the future EIC polarimeters will be presented.

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1 From RHIC to the EIC

In 2020, it was announced that the Electron-Ion Collider (EIC) will be built at Brookhaven Lab. It will be the first collider of polarized electrons and of polarized protons or light ions, and the measurement of the polarization of the hadron beams will rely heavily on the experience gained at RHIC, the only collider of polarized protons in the world.

Hadron polarimetry is difficult because there is no known process that, from first principles, relates the beam polarization with direct measurements of physical quantities. Nevertheless it was possible at RHIC to implement a very successful hadron polarimetry program with very precise measurements, with systematic uncertainties of the order of 1.5%. Transverse beam polarization profile measurements and bunch by bunch polarization values are also provided.

At the EIC, there will be additional challenges. There will be an order of magnitude more beam bunches, with the bunches will closer in time, and the backgrounds produced by one bunch will overlap with the neighboring bunches. There will be different beam conditions that will imply higher temperatures at the carbon wires in one of the types of polarimeters, which will limit their lifetime. The systematic uncertainty goal is more ambitious than for RHIC, of the order of 1%, and bunch by bunch measurements will be mandatory. In addition, ^{3}He beam polarization will be measured for the first time.

2 Hadron polarimetry method

Hadron polarimetry relies on the process of elastic scattering in the Coulomb-Nuclear Interference (CNI) region, in which a particle from the beam interacts with a particle from a fixed target, a proton or a carbon nucleus at RHIC, that recoils left or right with different probabilities, giving rise to an asymmetry

$$\epsilon = \frac{N_R - N_L}{N_R + N_L} = A_N P \tag{1}$$

that is proportional to the polarization of the beam. The constant of proportionality is not known. When one can polarize the target and measure its polarization, we have access to an absolute measurement of the beam polarization, as with the HJet polarimeter at RHIC:

$$P_{\text{beam}} = \frac{\epsilon_{\text{beam}}}{A_N} = \frac{\epsilon_{\text{beam}}}{\epsilon_{\text{target}}} P_{\text{target}}. \tag{2}$$

At RHIC polarimetry measurement are done in a two-tier way, with the HJet polarimeter [1], using a jet of atomic polarized hydrogen to measure absolute values of polarization, and proton-carbon polarimeters, using very thin carbon ribbons, to measure relative values of polarization very fast and precisely. In both cases, silicon strip detectors are placed left and right of the beam axis to measure the time of flight and kinetic energy of the recoil particles, providing identification of the scattered particles.

3 Simulations

Monte Carlo simulations are being done for the current RHIC conditions, for conditions of possible future tests at RHIC and for the EIC conditions. The physics event generator Pythia6 was used, and the interaction of particles with matter was simulated using the program Hjet-Sim [2], based on Geant4. In Figures 1 and 2 one can see that the simulations of the current Hjet correctly describe the main features of the data. The plots show the simulation of one billion Phytia6 events of a proton beam impinging on a proton jet of $\sigma = 5$ mm and a beam bunch with 3.5 ns. The simulated data time of flight was corrected by -0.2 ns in order to better match the data. The subsample of events that resulted in particles emitted at polar angles w.r.t. the beam direction larger than 90° was artificially enhanced by a factor 200 to better match the data. This correction should be equivalent to using a diluted target of molecular hydrogen that is expected to extend longitudinally along the beam pipe in the vicinity of the atomic hydrogen target. It was found that the main source of background, of particles of low values of time of flight and deposited energy, are charged pions, as can be seen in Figure 2.

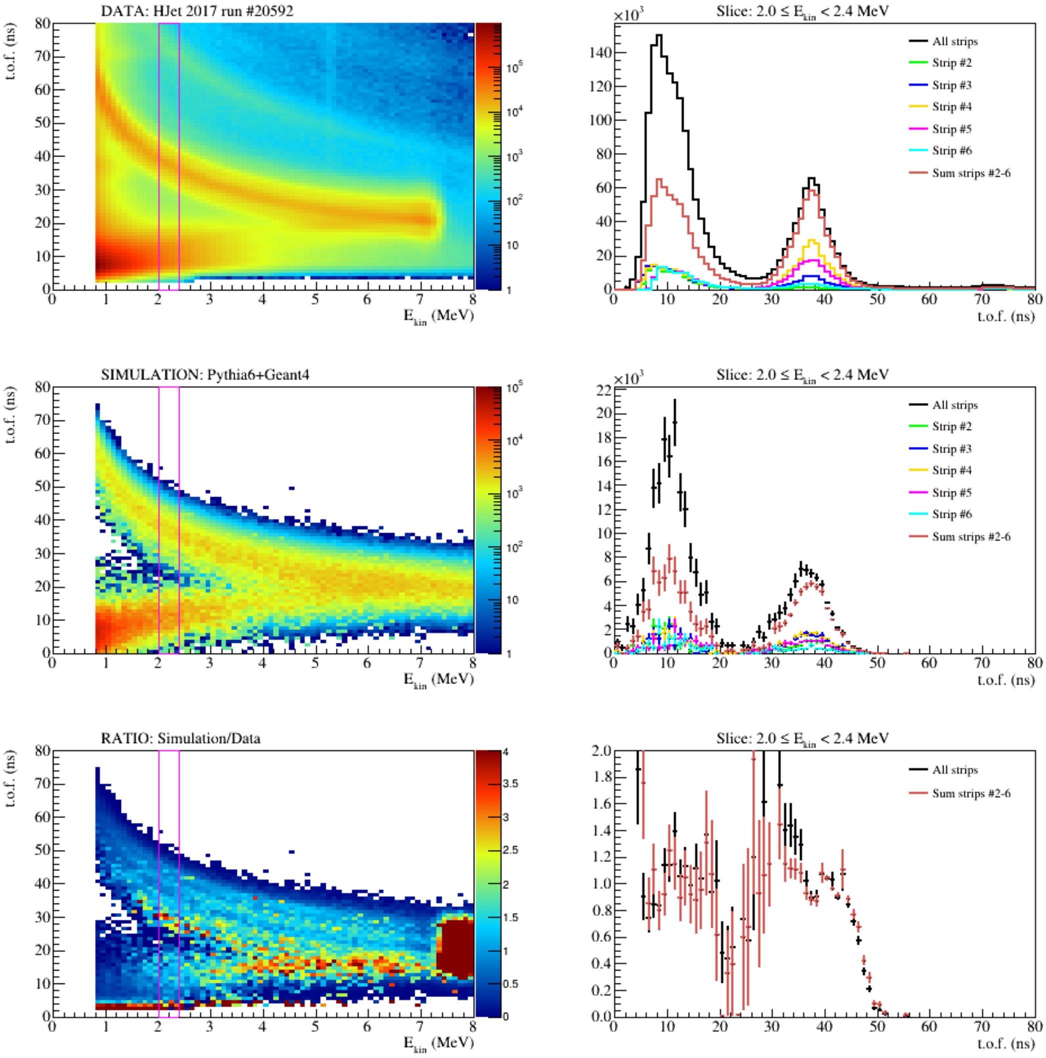

Figure 1: Data, simulation and their ratio for (left) the time of flight vs deposited energy of particles reaching the silicon detectors of the Hjet polarimeter and (right) the distribution of the time of flight of hits on the relevant silicon strips in the detectors, for a selected deposited energy range (from 2 to 2.4 MeV). In the first row, data from one run of 2017 is shown; in the second row, the results from simulations; in the third row, the ratio between data and simulation.

4 Conclusion

The EIC will be the first collider using polarized electrons and polarized light ion beams (protons and ^{3}He). The experience gained at RHIC can be used for the program of hadron beam polarimetry, which is extremely important for precise physics measurements relying on the beam polarization. Overall, the EIC faces additional challenges with respect to RHIC: a more stringent requirement of 1% for the systematic uncertainty of the polarization measurements, which should, aditionally, be done bunch-by-bunch; also, the measurement of ^{3}He beam polarizations was never done in a collider. Moreover, there will be a higher beam bunch frequency, leading to an increased sensitivity to the background to the elastic events, which should be eliminated, *e.g.* by use of a second layer of silicon detectors. Also, tagging breakup fragments of ^{3}He nuclei is required for ^{3}He beam absolute polarimetry. The expected increase of the heat-

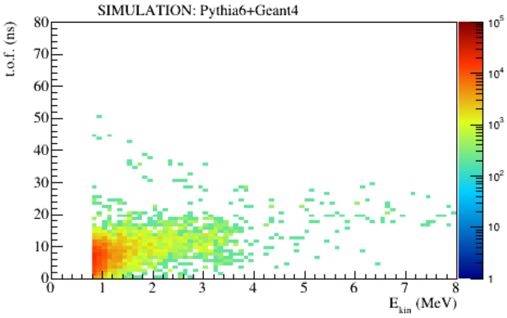

Figure 2: Results of the simulation for the time of flight vs deposited energy of charged pions reaching the silicon detectors of the Hjet polarimeter.

ing of the carbon wires of the proton-carbon polarimeters has led to a search for alternative materials for the targets of these fast and precise RHIC polarimeters.

Detailed simulations using Pythia6 and Geant4 have sucessfully described the conditions at the current HJet polarimeter at RHIC, and in particular identifying charged pions as a source of the particles reaching the silicon detectors with low time of flight and small values of deposited energy in the silicon detectors.

There are tests that can be done in the next few years, during RHIC operations, namely with ^{3}He beams, both polarized and unpolarized. These will be done using zero degree calorimeters previously used at RHIC (ZDCs), at a distance of about 18 m from the HJet, in order to detect protons and neutrons and, in this way, tag events where a helium nucleus broke up.

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