PROCEEDINGS OF SCIENCE

The Evolution Of PHENIX Into An Electron Ion Collider (EIC) Experiment

PoS(DIS2015)223

Nils FEEGE[*] **for the PHENIX Collaboration**

Stony Brook University

E-mail: nils.feege@stonybrook.edu

The Electron Ion Collider (EIC, arXiv:1212.1701.v3) will allow for precision measurements of the partonic and spin structure of nucleons and the partonic structure of nuclear matter using e+p and e+A collisions, respectively. One of the realizations of the EIC, the eRHIC at BNL, plans to utilize the existing RHIC storage rings (polarized proton and other ion beams) and a high-intensity polarized electron facility to be built in the RHIC tunnel. Before the transition to eRHIC, RHIC itself still holds a huge potential for study leading to new insights into hadronic spin structure and cold nuclear matter with p+p and p+A collisions. An experiment based on the BaBar solenoid with barrel calorimeters and tracking detectors (sPHENIX, arXiv:1207.6378v2) and additional instrumentation in the proton-going direction (fsPHENIX) would realize this potential. By design, this detector is planned to smoothly evolve into a full-fledged EIC experiment at eRHIC with additional calorimeters, tracking, and particle identification systems (arXiv:1402.1209). We give an overview of the experiment in its RHIC and eRHIC stages, the respective physics goals, and detector simulations.

XXIII International Workshop on Deep-Inelastic Scattering
27 April - May 1 2015
Dallas, Texas

---

[*] Speaker.

1. Introduction

The Electron Ion Collider (EIC) will allow for precision measurements of the partonic and spin structure of nucleons and the partonic structure of nuclear matter using e+p and e+A collisions, respectively [1]. These measurements will help us understand how QCD actually gives rise to the formation of protons, neutrons, and nuclei. The EIC will answer three key questions: How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? Where does the saturation of gluon densities set in? How does the nuclear environment affect the distribution of quarks and gluons and their propagation?

One of the proposed realizations of the EIC, the eRHIC at Brookhaven National Laboratory (BNL), plans to utilize the existing RHIC storage rings (polarized proton and other ion beams) and a high-intensity polarized electron facility to be built in the RHIC tunnel [2]. The alternative realization, the medium-energy EIC (MEIC) at Jefferson Lab, would add an ion beam to the existing electron beam facility at that laboratory.

This paper describes the design of a detector that could evolve from the next planned RHIC experiment at BNL (Section 2) and could use the full potential of either EIC realization (Section 3). In addition to the stages of this experiment naturally building on top of each other, each stage would contribute their unique piece to solving the overall puzzle of nuclear physics.

2. A Large-Acceptance Jet and Upsilon Detector for RHIC at BNL

The next major nuclear physics experiment at BNL will be a large-acceptance jet and upsilon detector built around the BaBar solenoid (preliminary name ’sPHENIX’ [3]). This experiment will take the place of the existing PHENIX experiment at RHIC. It will use p+p and heavy ion collisions to measure additional properties of the Quark Gluon Plasma and study effects of hot and cold nuclear matter. An optional second stage of this detector would add forward instrumentation and allow for determining transverse spin distributions at an unprecedented level with p+p and p+A collisions at RHIC.

BNL has acquired the superconducting solenoid that was previously used in the BaBar experiment at SLAC. This magnet (inner radius 140 cm, outer radius 173 cm, length 385 cm) will be the basis of the large-acceptance jet and upsilon detector for RHIC and provides a very homogeneous field (inhomogeneity $< 3\%$ in the central region) of up to 1.5 T. Figure 1 (top) shows the coil and cryostat of the magnet and a current design of the return yoke that would allow all three stages of the experiment at RHIC and eRHIC (or MEIC) to be realized without modifications to the yoke. The first stage of the RHIC experiment foresees the installation of two layers silicon pixel vertex detector in the barrel and either five additional layers of silicon-strip detectors or a TPC as barrel tracking system. The barrel will also have a tungsten-scintillating fiber electromagnetic calorimeter (18 X_0 or 1 λ_{int} depth, 12 % / $\sqrt{E}$ energy resolution, $\eta \times \phi \sim 0.024 \times 0.024$ segmentation) and a hadron calorimeter (5 λ_{int} depth, 100 % / $\sqrt{E}$ energy resolution, $\eta \times \phi \sim 0.1 \times 0.1$ segmentation). The latter has two sections: A copper-scintillator tile calorimeter inside the solenoid and the flux return yoke instrumented as a steel-scintillator hadron calorimeter. Nonmagnetic stainless steel or brass are alternative absorber options for the inner hadron calorimeter.

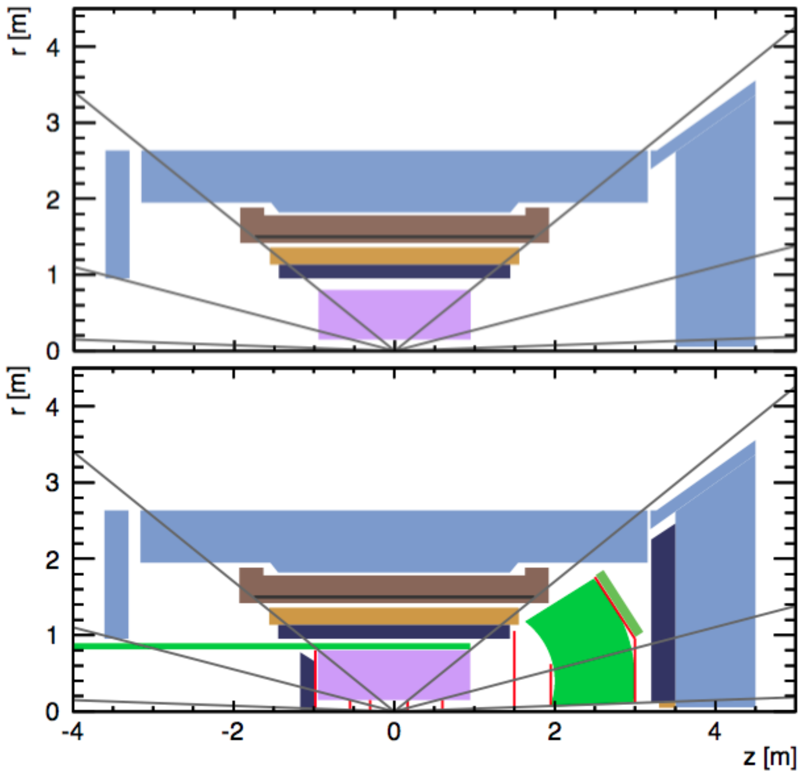

Figure 1: Detector evolution: a) The planned experiment at RHIC with BaBar magnet coil and cryostat (dark brown), flux return yoke (light blue), tracking system (violet), electromagnetic calorimeter (dark blue), and hadron calorimeter inside the magnet (light brown). b) Design of an EIC experiment at eRHIC or MEIC adding GEM trackers (red lines) and electromagnetic calorimeters (dark blue) in both positive and negative z direction, as well as a DIRC in the barrel (green) and a gas and aerogel RICH in the positive z direction (green). The grey lines indicate pseudorapidities $|\eta| = 1$, $|\eta| = 2$, and $|\eta| = 4$.

If a second stage is realized, it would add a forward silicon vertex detector (re-stacking and using the current PHENIX FVTX detector) and additional GEM tracking stations (position resolution $r\,d\phi \sim 50-100\ \mu$m and $dr \sim 1-10$ cm) in the positive z direction. Like the barrel yoke, the flux return yoke in this direction would be instrumented as a scintillator-steel hadron calorimeter. The muon ID system currently used in the PHENIX experiment could be added behind the forward hadron calorimeter to identify muons.

3. Evolving The Detector Into An EIC Experiment

One of the main processes of interest at an EIC is Deep Inelastic Scattering (DIS) with a scattered electron, a hadronic jet formed by the struck parton, and nuclear debris in the final state. Inclusive polarized DIS allows to access the longitudinal quark and gluon polarizations inside a nucleon. Semi-Inclusive DIS probes quark flavor-separated helicity and transverse-momentum dependent parton distributions and is used to study color propagation and hadronization in nuclear matter. Deeply Virtual Compton Scattering (DVCS), an example of exclusive DIS, allows to image the spatial distribution of gluons inside nucleons and nuclei. The detector described in the previous

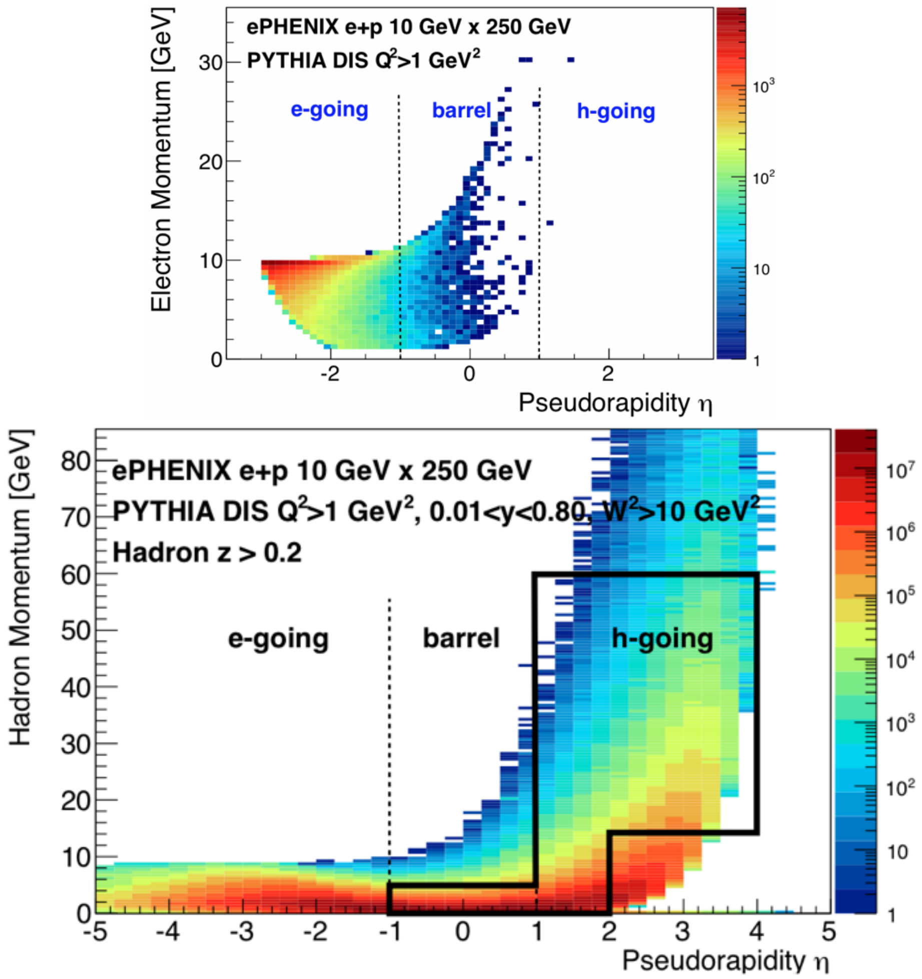

Figure 2: Top: Final state electron momentum as a function of pseudofrapitity η for PYTHIA generated DIS events. Bottom: Final state hadron momentum as a function of η for SIDIS events. The area surrounded by the black lines indicates the kaon ID coverage for barrel DIRC, forward gas RICH and aerogel RICH. [4]

section is an excellent basis for an experiment to measure these and other processes. It can be easily extended to be capable of doing all the day-one physics measurements and use the full potential of an EIC (see Fig. 1 bottom) [4].

For inclusive DIS, only measurements of the energy and the angle of the scattered electron are required to reconstruct the kinematics of the interaction. Most final state electrons from e+p collisions at 10GeVx250GeV end up in the electron-going and barrel direction (see Fig. 2). In this region, electrons need to be identified and separated from hadrons and photons. A calorimeter with good energy- and position resolution combined with a tracking system covering these areas can accomplish this. An EIC detector would choose a TPC over a full silicon tracking system because of its lower material budget and the goal to measure electron energies down to 1 GeV. The barrel calorimeter described in Sec. 2 provides adequate performance. In the electron going direction, the current detector design foresees additional GEM tracking stations (position resolution $r\,d\phi \sim 50-100\,\mu$m) and a lead-tungstate crystal calorimeter with $2\times2\,\mathrm{cm}^2$ crystals and an energy resolution of 1.5 % / $\sqrt{E}$.

In order to analyze semi-inclusive DIS, the leading hadron in the final state jet needs to be identified and measured in addition to the scattered electron. Fig. 2 illustrates the angles and momenta for final state hadrons in e+p collisions at 10GeVx250GeV. The detector needs tracking and calorimeter coverage suitable to measure hadrons in these areas, as well as particle identification systems that allow separating pions, kaons, and protons. The tracking and calorimeter coverage from the detector in Sec. 2 is sufficient for the barrel region. In the hadron going direction, the EIC detector design adds an electromagnetic calorimeter and additional GEM tracking stations. Three RICH detectors would provide adequate PID coverage: A DIRC (re-using the BaBar DIRC) in the barrel, and a gas RICH and aerogel RICH detector in the hadron-going direction.

DVCS processes are characterized by the creation of a real photon in the electron-proton interaction, where the proton remains intact. All three final state particles need to be measured. The pseudorapidity distribution for DVCS photons extends from the electron-going direction over the barrel to the hadron-going direction. Therefore, the detector needs electromagnetic calorimeter coverage in all these regions. In addition, electrons and photons need to be separated from each other, which motivates the choice for small crystals in the electron-going crystal calorimeter. Roman Pots further down and close to the beam pipe allow the identification of the intact proton after the collision.

As an example of the physics scope of the EIC and the detector described in this paper, Fig. 3 (top) illustrates the large ranges in x (proton momentum fraction of the struck parton) and Q^2 (virtual photon 4-momentum squared) for polarized DIS measurements covered by this experiment and how it expands existing data sets. The long lever arm in Q^2 in particular allows for a precise measurement of the evolution of the longitudinal spin-dependent nucleon structure function and therefore the longitudinal gluon spin distribution. Figure 3 (bottom) shows the projected reduction of uncertainty of the latter that the EIC and this experiment can achieve.

4. Conclusion

Despite all we have learned already about QCD, the interaction of quarks and gluons, and the structure of matter, many key questions remain unanswered and nuclear physics will remain an active field. Exciting results have recently emerged from the heavy ion program of the LHC at CERN with lead-lead collisions at very high energies [5]. The COMPASS experiment at CERN uses high-intensity muon and hadron beams for the investigation of the nucleon spin structure and the spectroscopy of hadrons [6]. Upcoming nuclear spin experiments at Jefferson Lab will complement this by revealing new aspects of nucleon structure by using polarized electron beams to image spatial distributions of quarks inside nucleons, for example [7]. Both RHIC and the EIC will play a key roles in exploring further missing links. RHIC will soon enter uncharted territory with a large-acceptance jet and upsilon detector to measure more properties of the Quark Gluon Plasma, study effects of hot and cold nuclear matter, and, if the forward upgrade is realized, potentially reveal the origin of transverse spin phenomena. At the same time, this detector is designed to be a suitable basis for an EIC detector, and adding crucial subsystems would turn it into an experiment that could use the full potential of an EIC (either eRHIC or MEIC) to measure spin and 3D structure of nucleons, effects of cold nuclear matter, and discover the Color Glass Condensate.

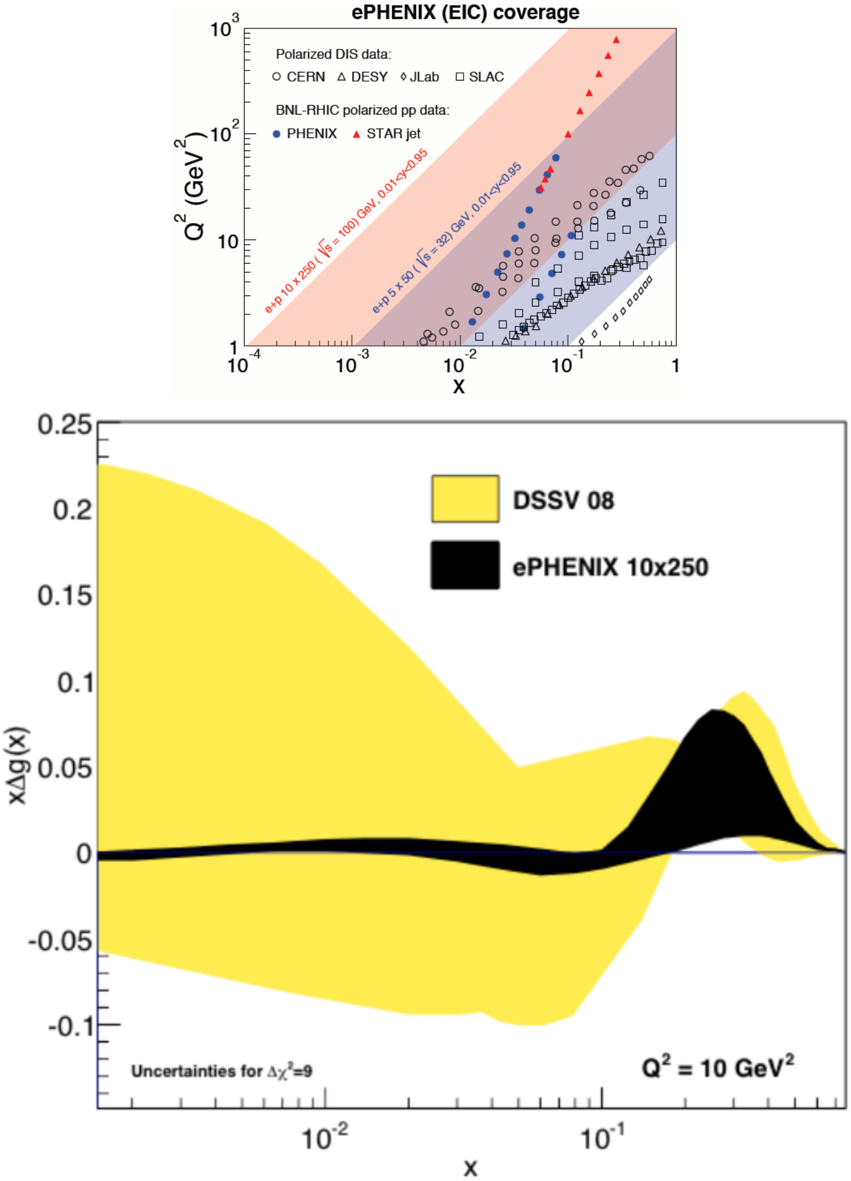

Figure 3: Top: ePHENIX x-Q2 coverage for polarized DIS measurements. Bottom: The projected reduction in the uncertainty on the gluon longitudinal spin distribution based on simulated Pythia events corresponding to an integrated luminosity of 10 fb^{-1} at a 10 GeV $\times$ 250 GeV beam energy configuration. A 1% systematic uncertainty in beam and target polarization is applied. [4]

References

[1] A. Accardi et al., "Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all", arXiv:1212.1701.v3, 2012

[2] E.C. Aschenauer et al., "eRHIC Design Study: An Electron-Ion Collider at BNL", arXiv:1409.1633, 2014

[3] A. Adare et al., "An Upgrade Proposal from the PHENIX Collaboration", arXiv:1207.6378v2, 2015

[4] A. Adare et al., "Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid", arXiv:1402.1209, 2014

[5] P. Steinberg, "First results from the LHC heavy ion program", New J of Phys 14 (2012) 035006, 2012

[6] P. Abbon et al., "The COMPASS experiment at CERN", NIMA 577 (2007) 455?518, 2007

[7] J. Dudek et al., "Physics Opportunities with the 12 GeV Upgrade at Jefferson Lab", Eur.Phys.J. A48 (2012) 187, 2012