

ePHENIX for eRHIC

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Addition of a high intensity polarized electron beam facility which could realize Deep Inelastic Scattering (DIS) research with one of the RHIC beams is one of the future upgrades to the Relativistic Heavy Ion Collider (RHIC) presently under consideration. To take a full advantage of such machine evolution, after more than a decade of exciting physics results, both with heavy ion and polarized proton collisions, PHENIX Collaboration has launched a detector upgrade study consistent with the above collider upgrades, going in to the eRHIC era.

1 Introduction

One of the realization of the future Electron Ion Collider is eRHIC – by adding 5–30 GeV electron beam facility to the existing RHIC hadron beam facility, accelerating and colliding polarized protons and nuclei in wide range of masses [1]. In this presentation we consider possible Deep Inelastic Scattering (DIS) measurements with a future upgraded PHENIX detector (ePHENIX) at eRHIC.

Our goal is to fully utilize sPHENIX upgrade being proposed by PHENIX collaboration to further advance the study of cold and hot nuclear matter in nuclear collisions and nucleon spin structure in polarized proton collisions [2]. We discuss the requirements to ePHENIX detector imposed by DIS goals [3] to provide smooth evolution from sPHENIX to ePHENIX.

2 Physics goals and detector requirements

With ePHENIX we hope to perform a wide range of measurements summarized in [3] to greatly expand our knowledge in the following major themes:

- The spin and flavor structure of the proton
- Three dimensional structure of the nucleons in momentum and configuration space
- QCD matter in nuclei.

Another major topic of Electroweak physics and the search for physics beyond the Standard Model discussed in [3] requires higher energies and luminosities anticipated in the latter phase of eRHIC, and they are not discussed in this presentation.

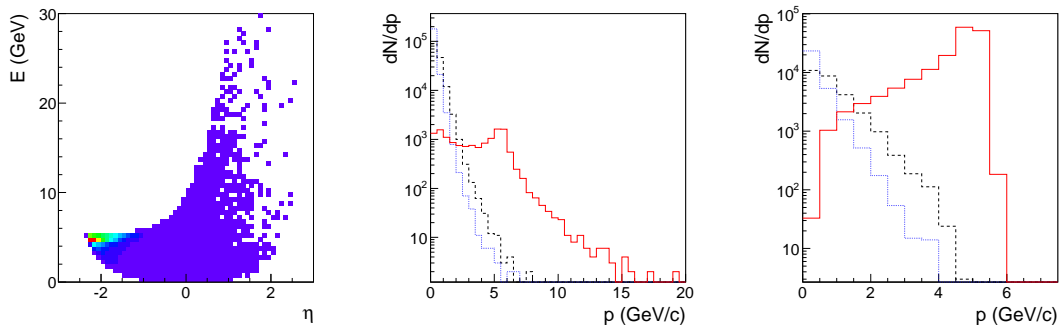


Figure 1: From PYTHIA for 5 GeV (electron) \times 100 GeV (proton) beam energy configuration: scattered electron energy vs pseudorapidity distribution (left); momentum spectra for scattered electron (red), charged pions (black dashed) and decay photons (blue dotted) detected in central rapidity, $|\eta| < 1$ (middle) and backward rapidities, $\eta < -1$ (right).

2.1 Inclusive DIS and scattered electron measurements

Inclusive DIS measurements implies reconstruction of only the scattered lepton in the final state of a reaction. Measurements of energy and angle of the scattered lepton provide the reconstruction of the kinematics of the inclusive DIS, which is described by two independent variables, the Bjorken scaling variable x and square of the four momentum transfer Q^2 .

Inclusive DIS provide “golden” measurements for the gluon polarization in the nucleon and its contribution to the nucleon spin via scaling violation of the structure function g_1 , as well as quark and gluon distribution in nuclei via structure functions F_2^A and F_L^A .

In collider geometry the DIS electrons are scattered mainly in backward (electron beam direction) and central rapidities, see Fig. 1 left. Central rapidity selects scattering with higher Q^2 and higher x (due to its correlation with Q^2). The energy of the scattered electron varies in the range from zero to electron beam energy and even to higher values for electrons detected in central and forward rapidities.

Collider kinematics allows us to clearly separate scattered electrons from other DIS fragments - hadrons and their decay products, which are detected preferably in forward region (hadron beam direction), leaving much softer spectra in central and backward rapidities, see Fig. 1. Reasonable tracking and electromagnetic calorimetry will provide enough rejection through E/p matching and shower profile analysis to allow us to reliably identify electrons down to momentum at least 1 GeV/c. Photon conversion in material on the way from beam line to tracker ($\sim 10\%$ of radiation length looks affordable) also is not expected to contribute sizable background except for very low momenta (< 1 GeV/c). Lower momentum electrons (< 1 GeV/c) only modestly extend the $Q^2 - x$ phase space of DIS kinematics. In addition, these events are more contaminated by radiative effects, so other approaches (e.g. Jacquet-Blondel method with hadronic final states) are supposed to be used for DIS kinematics reconstruction in these cases.

The energy and angular resolution requirements are presented on the example of F_L measurements in Fig. 2, for the 1% systematic uncertainty in each 0.1×0.1 bin in $\log_{10}(x) \times \log_{10}(Q^2)$ space, assuming that 1/5 of the systematics due to bin migration would contribute to the final systematic uncertainty. In the backward and central rapidity regions, covering the

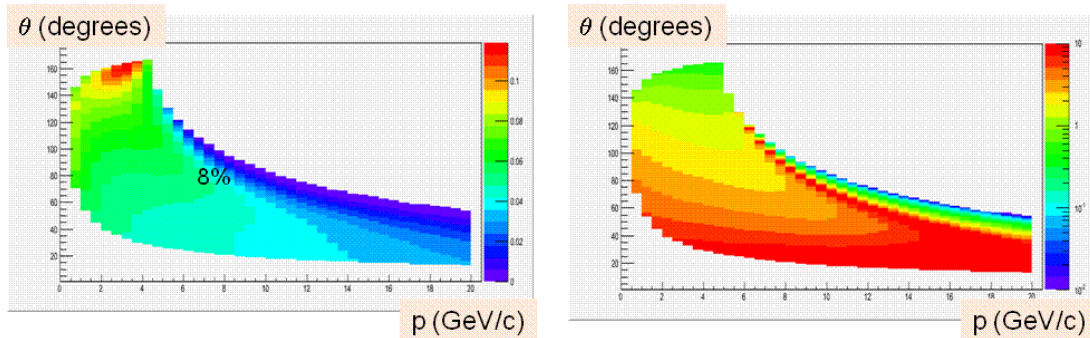


Figure 2: For 5 GeV (electron) \times 100 GeV (proton) beam energy configuration: momentum, $\delta p/p$ (left) and angular (right) resolution requirements (z-axis, color coded) for bins in scattered electron momentum and angle.

major of the DIS phase space (forward region corresponds to high x , while our main interest is in lower x) the detector resolution requirements are not strict and can be easily provided by tracking system with momentum resolution of $\delta p/p \sim 1\% \cdot p$. For higher electron beam energy the scattered electron energy is higher, and a combination of the tracking detectors with electromagnetic calorimetry with energy resolution of $\sigma_E/E \sim (10 - 15)\%/\sqrt{E}$ is expected to provide enough resolution for electron energy measurements.

2.2 Semi-inclusive DIS and hadron measurements

Hadron identification (pions vs kaons) is a requirement for flavor decomposition of quark and anti-quark polarization in the nucleon, as well as to study the transverse spin structure of the nucleon, in semi-inclusive DIS, when along with scattered lepton one measures one or more fragmented hadrons.

Charged hadrons are mainly scattered in central and forward (hadron beam direction) rapidities. A set of particular detectors is required for hadron identification in these regions. While in forward region we can consider various options, in central region we are limited by the space available inside the solenoid magnet [2], where only a compact detector in radial space can be affordable. Among other options, we consider DIRC with a very thin radiator (~ 5 cm), or proximity focused RICH, which can provide hadron identification up to momenta 4–5 GeV/c. It doesn't introduce any limitation on the accessible $Q^2 - x$ phase space in the central rapidity region, as can be seen from Fig. 3.

2.3 Exclusive DIS and DVCS

Exclusivity implies the reconstruction of the complete final state, which includes reconstruction of the scattered proton with small four momentum transfer $-t$ at about $1 (\text{GeV}/c)^2$ or lower. Among exclusive processes, Deeply Virtual Compton scattering (DVCS) is of particular interest because it provides theoretically the cleanest access to Generalized Parton Distributions (GPDs), describing the correlation between parton momentum and (transverse) position within the nucleon. One of the important aspects of GPDs is that they are connected to the total quark and gluon angular momentum.

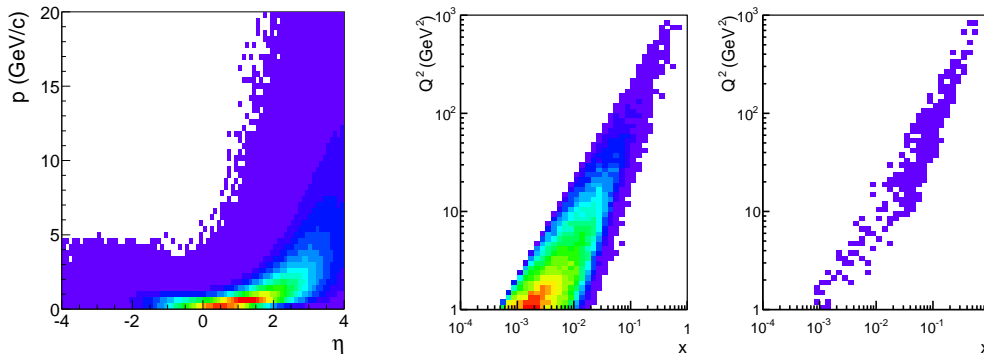


Figure 3: From PYTHIA for 5 GeV (electron) \times 100 GeV (proton) beam energy configuration: charged pion momentum vs pseudorapidity distribution (left); Q^2 vs x coverage in DIS events with charged pions detected in central rapidity ($|\eta| < 1$) with $p < 4$ GeV/c (middle) and $p > 4$ GeV/c (right).

The produced DVCS photon momentum versus pseudorapidity distribution is shown in Fig. 4. For 5 GeV electron beam, near half of photons are detected in central rapidity. For higher electron beam energy more photons scatter in backward direction, still leaving about a third of photons scattered in central region with electron beam energy 20 GeV. The photon momentum in central rapidity varies in the range ~ 1 –4 GeV/c near independently on beam energy in the range considered for eRHIC. Photons in backward rapidity are more correlated with electron beam and have energy varied roughly from 1 GeV/c to electron beam energy.

3 Summary

The reasonably minimal detector configuration considered for ePHENIX should provide scattered electron and photon measurements in the central and backward (electron beam direction) rapidities, hadron identification and momentum measurements in central and forward (hadron beam direction) rapidities, and scattered proton measurements in very forward direction (within beam pipe) in exclusive reactions. Adding new detector systems should provide a smooth evolution from sPHENIX (as a pp and Heavy Ion detector) to ePHENIX (as a DIS detector).

References

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- [2] K. Boyle, this proceedings.
- [3] BNL/INT/JLab report, arXiv:1108.1713.
- [4] E. Perez, L. Schoeffel and L. Favarat, arXiv:hep-ph/0411389.

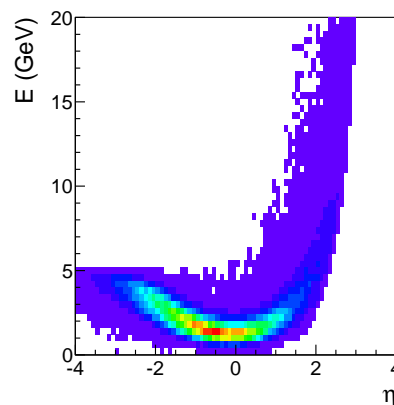


Figure 4: MILOU DVCS generator ([4]) for 5 GeV (electron) \times 250 GeV (proton) beam energy configuration: DVCS photon energy vs pseudorapidity distribution.