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Interaction region design and auxiliary detector systems for an EIC

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Abstract. There are a number of exciting physics opportunities at a future electron-ion collider facility. One possible design for such a facility is eRHIC, where the current RHIC facility located at Brookhaven National Lab would be transformed into an electron-ion collider. It is imperative for a seamless integration of auxiliary detector systems into the interaction region design to have a machine that meets the needs for the planned physics analyses, as well as take into account the space constraints due to the tunnel geometry and the necessary beam line elements. In this talk, we describe the current ideas for integrating a luminosity detector, electron polarimeter, roman pots, and a low Q^2-tagger into the interaction region for eRHIC.

1 Introduction

An extremely exciting physics program is being developed for a future electron-ion collider facility, which will definitively answer current open questions in the field (such as the proton spin puzzle and providing concrete evidence for gluon saturation) [1]. This ongoing effort involves both machine development of the collider facility and infrastructure, as well as the development and design of the detector apparatus on which the physics measurements will be performed. In addition to the main detector that is required to track and identify charged and neutral particles, auxiliary detector systems are also necessary to monitor beam condition as well as provide other supporting functionality to the experiment.

In this proceedings, we focus on the possible design and integration into the machine lattice of a luminosity monitoring system, an electron beam polarimeter, as well as forward and backward detectors designed to measure protons and electrons that scatter at small angle (less than 1°), which will miss the main detector acceptance. It is critical for the implementation of these subsystems to be studied in coincidence with the machine lattice development, as various constraints due to space, beam optics and backgrounds have to be considered and optimized together to get a functioning system.

In the following sections, we start by describing the software tools currently being used to perform the simulation studies. Then we will discuss the aforementioned subsystems, both their function and form. Finally we close with a summary.

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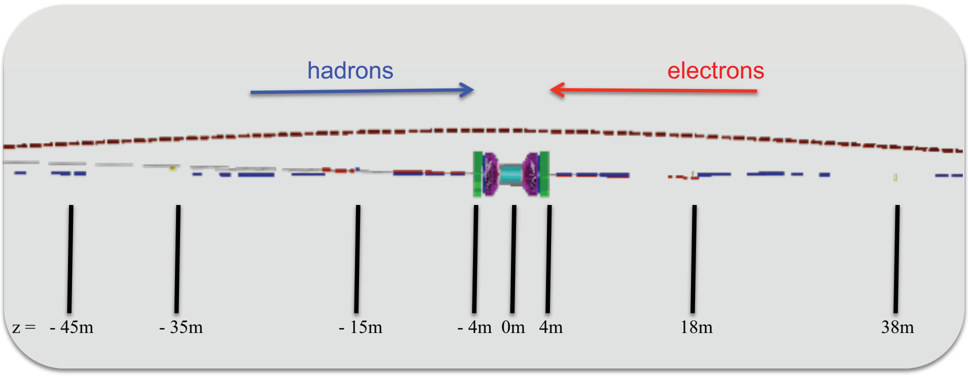

Figure 1. A picture of the interaction region from within the simulation framework.

2 Framework for detector simulations, EicRoot

A simulation framework has been developed at Brookhaven National Laboratory to aide in the design and optimization of detector components. The framework is called EicRoot [3]. EicRoot is an adaptation of the FairRoot software framework. The simulation package uses ROOT [4] for the detector and machine element geometry descriptions, GEANT3 or GEANT4 [5, 6] for the particle transport and interaction with materials, and also includes an event display module, code to digitize the registered GEANT signal and perform rudimentary reconstruction via cluster formation and tracking. The detector geometry is produced with scripts and the output is encoded in ROOT files so that components can easily be swapped in and out of the simulation setup, allowing for a quick turnaround in the simulation studies.

Additionally, the machine magnet geometry and fields can also be imported into the simulation, allowing for a full simulation of the IR with the detector and machine lattice integrated together. An example of the IR in the context of the simulation is shown in figure 1. The main detector is shown in the center. The red boxes along the beam lines represent the electron beam line magnets and the blue boxes along the beam lines represent the hadron beam line magnets. Locations of note are indicted by the distance markers. Various auxiliary detector systems have been integrated and will be discussed in the next sections.

3 The luminosity monitoring system

Essential to any measurement at an EIC is precise knowledge of the delivered luminosity of the beams, which can be monitored during running by measuring the elastic process $e + p \rightarrow e + p + \gamma$. This process can act as a useful diagnostic of the luminosity because it is a well-known calculable pure QED process [7]. Additionally, this process has a large cross-section and so statistics can be collected in a short time. Another desirable feature about this process is that the photons produced in the scattering are emitted in a very narrow cone in the direction of the electron beam, making measurement with a compact device possible.

The luminosity (L) can be measured if one measures the rate of photons hitting the detector (N_γ) while also knowing the true cross-section of the process (σ), and the acceptance correction factor for any photons that may not have been measured (A) via the relation $L = N_\gamma / A\sigma$.

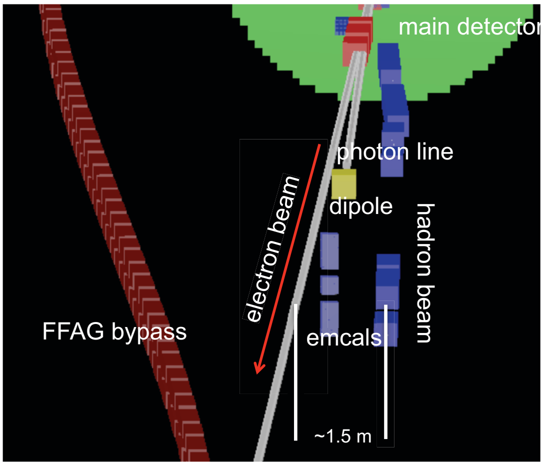

Figure 2. A display of the luminosity monitor in the simulation framework.

A dedicated luminosity monitoring system has been implemented and studied in simulation. It has been found that the current IR design of the machine leaves sufficient space for the setup and acceptance of the photons from the scattering process. A display of the setup in the simulation is shown in figure 2. Major components and landmarks are labeled in the figure.

The luminosity monitor is planned to be installed after the dipole bending magnet along the outgoing electron beam line where the beam is separated away from the bremsstrahlung photon from the process. The installation of two lumi systems is being considered. One system will feature an electromagnetic calorimeter in the plane of the beam (called the lzdc for the lumi-zero degree calorimeter from here on). This calorimeter will measure bremsstrahlung photons from the Bethe-Heitler process directly. The second system will feature a pair spectrometer, with a converter end-cap at the end of the photon transport line converting a fraction of the bremsstrahlung photons to e^+e^- pairs. These di-electrons will then pass through a dipole magnet (illustrated by the yellow box labeled "dipole" in the figure, located about 35m from the IP), in which the field is set to bend the electrons in the vertical direction and are measured by a set of calorimeters situated above and below the lzdc. The calorimeter systems are shown by the blue boxes labeled "emcals" in the figure and are currently placed about 45m from the IP. This setup has been utilized successfully in the ZEUS experiment [8].

This dual setup has the distinct advantage of allowing consistency checks within the luminosity measurement while also providing a well defined way to evaluate the systematic uncertainties. The contributions to the systematic uncertainties in each measurement will be substantially different. The main contributors to the systematic uncertainty utilizing either setup are the backgrounds in the detectors, the pileup of events from the high luminosity and the knowledge of the acceptance of the detector in the face of varying beam conditions. The backgrounds will be substantially different in the two setups, given the the lzdc resides in the plane of the primary synchrotron radiation fan of the bending electron beam, while the pair spectrometer calorimeters do not. Additionally, pile-up effects due to high rates will also be very different, since the converter in the pair spectrometer will reduce the overall rate in those calorimeters. The acceptance correction will also be very different in the two setups.

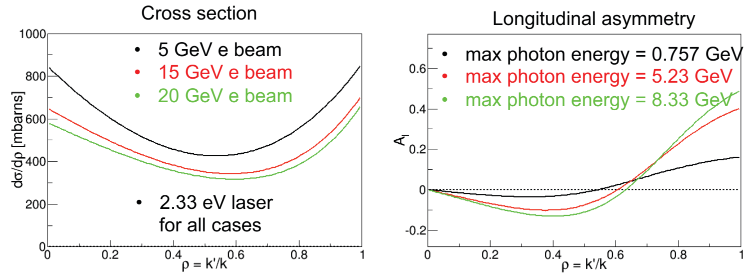

Figure 3. Left: The differential cross section for Compton scattering of electrons off of circularly polarized photons with different electron energies. Right: The longitudinal asymmetry, A_l for different electron energies. Both quantities are plotted as a function of ρ, or the scattered photon energy relative to the maximum allowed photon energy from kinematics (Compton edge).

4 Electron polarimetry

Precise knowledge of the polarization fraction of the electron beam is essential to the physics program at an EIC. The same level of precision for the luminosity measurement is needed for the polarization of the electron beam, better than 1%. This is especially important since the polarization of the beam will enter the calculation for the luminosity (as the Compton cross-section is dependent on polarization). The electrons are to be longitudinally polarized at the IP. It is necessary not only to determine the longitudinal polarization fraction of the beam, but also to determine the transverse polarization component to ensure that the spin is fully rotated to longitudinal. The Compton backscattering process will be used to measure the polarization of the electron beam.

The key to measuring the polarization of the beam is to measure an asymmetry between collisions with two different helicity states. The Compton events are produced by impinging a laser beam onto the electron beam at some location, and measuring the scattered electron or photon in the process. The polarization state of the laser will be flipped from +1 or -1, giving rise to two electron/photon helicity states in which the asymmetry can be measured. The Compton cross section, as well as the asymmetry expected, can be calculated exactly in QED. In the case of the longitudinal polarization component, the important parameters are related by the following expression: $A_{exp} = P_e P_\gamma A_L$. In the equation, A_{exp} is the experimentally measured asymmetry, P_e is the polarization of the electron beam, P_γ is the polarization of the laser beam, and A_L is the theoretical asymmetry calculated from QED.

The polarimeter will be placed on the incoming electron beam far from the IP. The system needs to be placed before the IP, but after the spin rotators. A natural location for the polarimeter is found where the orbit shift occurs to bring the electron beam into the IP. The magnets used for this purpose can also be used to separate scattered photons and electrons from the main electron beam. There is space both for detectors for the scattered photon, as well as for the scattered electron. We are currently investigating both options.

A possible photon detector would be a simple segmented calorimeter. Longitudinally polarized electron beams colliding with circularly polarized laser results in an energy asymmetry, while a transversely polarized electron beam results in an energy dependent position asymmetry due to the spin component of the electron breaking azimuthal symmetry. A well calibrated, segmented calorimeter would be able to make both measurements. Simulations on this topic are ongoing.

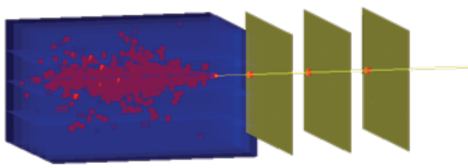

Figure 4. The current design of the low Q^2-tagger.

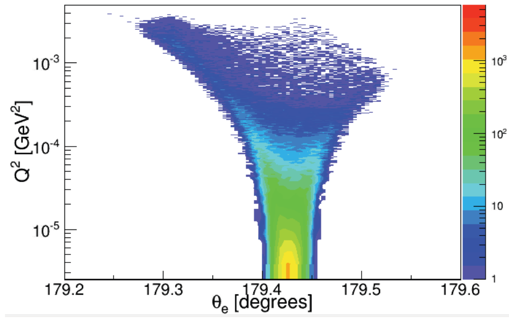

Figure 5. The range of acceptance in Q^2 and scattering angle, θ, of electrons from PYTHIA events.

5 Low Q^2-tagger

It is planned to install a dedicated low Q^2-tagger to measure electrons that scatter at small angle from low Q^2 events. These electrons will miss the main detector, and so installing an auxiliary device is essential for low Q^2 physics. The current concept of the low Q^2-tagger is shown in figure 4. It consists of three tracking layers followed by an electromagnetic calorimeter. Initial simulation studies show that this type of device can help to reconstruct the scattering angle of the electron and hence measure the Q^2 of the event. The detector is placed near the outgoing electron beam roughly 15m from the IP after the first set of bending dipole magnets where the scattered electrons will separate from the main beam. Figure 5 shows the Q^2 acceptance to electrons from PYTHIA [9] events. The coverage goes to a low Q^2 of about 10^{-5}.

6 Forward proton tagger

Another essential detector for the planned physics program at an EIC is a forward proton tagger. Like the electrons that scatter at small angle, there will be protons that scatter at small angle and will escape the main detector. Exclusive measurements need to capture these protons and so forward tracking systems are needed. In order to maximize acceptance of these protons, it is necessary to place the tracking sensors as close the the proton beam as possible. One possible implementation of the tagger currently being considered is roman pots. With this type of setup, the tracking sensors would be installed inside bellows with a movable arm so that the sensors can be retracted during fill time and moved into position during running. Multiple stations located at various distances from the IP would be needed in order to gain as much acceptance as possible (since protons that scatter and lose less energy will take a greater distance to be separated from the main beam). Figure 6 shows the acceptance of scattered protons from deeply virtual compton scattering (DVCS) events generated from the MILOU generator [10] for 20x250GeV e+p collisions. The top row shows the hit distribution in the x-y plane on the surface of the sensor. The top left is for low |t| events, while the top right is for low |t| events (where |t| is the momentum transfer at the proton vertex and goes as p_T^2). The bottom plot shows the acceptance (number hitting sensor/number generated) as a function of |t|. The acceptance is good at moderate |t|, but suffers at high |t|. It has been found that protons with high |t| are lost in the yoke of the first superconducting magnet. Thus we are also investigating placing some type of forward sensor very close to the main detector.

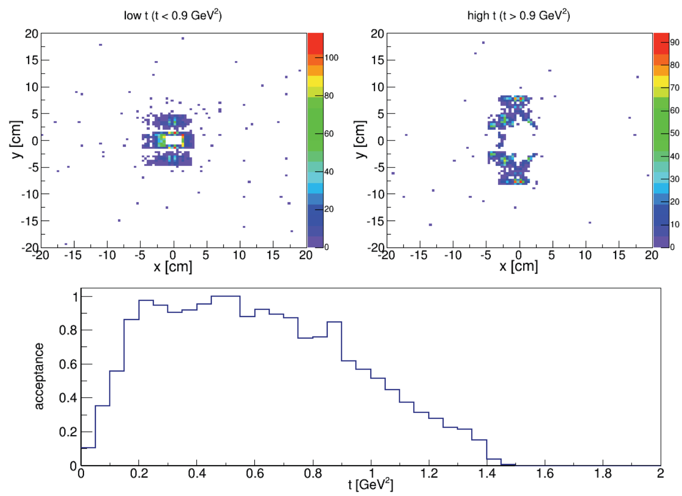

Figure 6. The acceptance of a roman pot station in |t| installed at 18m from the IP.

7 Summary

The status of the interaction region design and integration of auxiliary detector subsystems at eRHIC has been discussed in this proceedings. The detectors focus on far forward and backward detectors and consist of a luminosity monitoring system, electron polarimeter system, low Q^2-tagger for electron detection and a forward proton tagger. The basic location integrated into the IR has been determined and overall the current IR design is very compatible with the needs arising from the physics requirements on the program. Simulation studies in this regards are ongoing.

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