

GPDs at an EIC

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The feasibility for a measurement of the exclusive production of a real photon, a process although known as Deeply Virtual Compton Scattering (DVCS) at an Electron Ion Collider (EIC) has been explored. DVCS is universally believed to be a golden measurement toward the determination of the Generalized Parton Distribution (GPDs) functions. The high luminosity of the machine, expected in the order of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ at the highest center-of-mass energy, together with the large resolution and rapidity acceptance of a newly designed dedicated detector, will open a opportunity for very high precision measurements of DVCS, and thus for the determination of GPDs, providing an important tool toward a 2+1 dimensional picture of the internal structure of the proton and nuclei.

1 GPDs and DVCS

In order to open a new window into a kinematic regime that allows the systematic study of quarks and gluons, the world's most versatile nuclear microscope, the Electron Ion Collider (EIC), has been proposed. With its wide range in energy, nuclear beams and high luminosity, the EIC will offer an unprecedented opportunity for discovery and precision measurements, allowing us to study the momentum and space-time distribution of gluons and sea quarks in nucleons and nuclei.

One of the main goals of an EIC will be a precise determination of the Generalized Parton Distribution functions (GPDs), which lead to a 2+1 dimensional imaging of the protons/nuclei in the impact parameter space. GPDs are functions describing the distribution of quarks and gluons in the nucleon with respect to both position and momentum. Moreover, GPDs allow us to study how the orbital motion of quarks in the nucleon contributes to the nucleon spin - a question of crucial importance for nucleon structure.

It is universally believed that the golden measurement toward the determination of the whole set of GPDs is Deeply Virtual Compton Scattering (DVCS), which is the exclusive production of a real photon. This process is sensitive to both quarks and gluons and, unlikely the exclusive production on Vector Mesons, it is not affected by the uncertainty on the VM wave-function. Furthermore it shows a very clean experimental signature consisting of two clusters in the calorimeter with a track matching one of the clusters and a leading proton eventually measured in the forward detectors (Roman Pot spectrometer).

The important observables sensitive to the GPDs are the differential cross section as a function of the four-momentum transfer at the proton vertex, $|t|$, and the charge- and spin-asymmetries. For the purpose of the cross section measurement it is important to remove from the signal the background coming from the Bethe-Heitler (BH) events. The latter is essentially a QED process, known to an uncertainty in the order of $\sim 3\%$ coming from the uncertainty

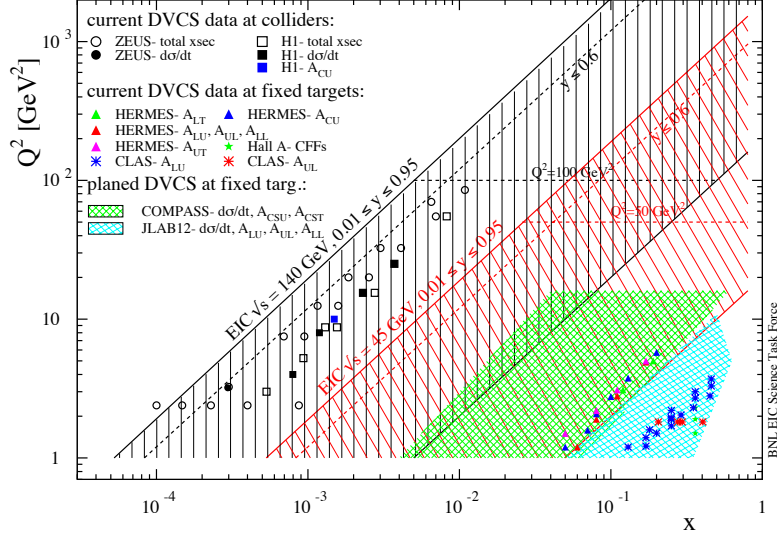


Figure 1: The EIC phase space for stage-1 (red) and stage-2 (black) compared with available data and expected future experiments.

on the proton form factor, with the same final state topology of DVCS and can be subtracted from the signal by the means of MC technique. Thus, especially for an EIC where systematics will dominate the measurements, it is important to minimize the BH contribution, particularly at low energy configurations where BH tends to dominate over the DVCS. Presently available DVCS measurements provide some limited information on GPDs and more precise data, in a wider phase space and including transversely polarized target spin asymmetry, are required to pin them down. For more informations read D. Mueller contribution in this book of proceedings. New fixed target measurements are planned at COMPASS II using a polarized muon beam, extending HERMES kinematics to lower x_{Bj} , and at JLAB@12 GeV, see Fig. 1. EIC will cover a much larger phase-space and help quantify QCD phenomena at small x_{Bj} [1]. An access to GPDs requires a large data set with small errors. In the following we would like to illustrate the potential of an EIC machine for DVCS studies.

2 MC simulation

The Monte Carlo generator used for the present study is MILOU [2], which simulates both the DVCS and the BH processes together with their interference term. The simulated Q^2 and x_{Bj} range corresponds to the phase space achievable with an EIC. The electron and proton beam-energy configuration considered for the present study are: 5x100 GeV (stage-1) and 20x250 GeV (stage-2), as in Fig. 1.

The BH contamination has been investigated for each Q^2 , x_{Bj} , $|t|$ bin as a function of y . After all BH suppression criteria have been applied it was found that for stage-2 the BH

contamination grows from negligible (at low- y) to about 70% at $y \sim 0.6$. For stage-1, the BH contribution grows faster and can be dominant at large- y depending on the x_{Bj} -bin, nevertheless most of the statistics at this low center-of-mass energy is contained in the safe region: $y < 0.3$. It is then crucial to have a detector which makes the experimentalists fully capable to apply all the selection criteria required for a BH suppression (tracker: excellent angular resolution, em Cal: fine granularity and goes resolution at lower energies).

The data coming from MC simulation have been used as mock data to measure the $|t|$ -differential cross section and the charge- and spin-asymmetries. Results are based on the EIC version in consideration at BNL and known as eRHIC. Simulated data samples correspond to a luminosity of 100 fb^{-1} for stage-2 and 10 fb^{-1} for stage-1 configurations, both corresponding to approximately 1 year of data taking assuming a 50% operational efficiency. The variables have been smeared according to the expected resolution. A logarithmic fine binning of x_{Bj} and Q^2 has been applied, whereas in the case of the cross section measurement, $|t|$ has been binned three times larger than the expected resolution from the Roman Pot spectrometer, which can measure proton momentum in the range $0.03 < |t| < 0.88 \text{ GeV}^2$. For large values of $|t| > 1.0 \text{ GeV}^2$ the proton can be measured in the main detector.

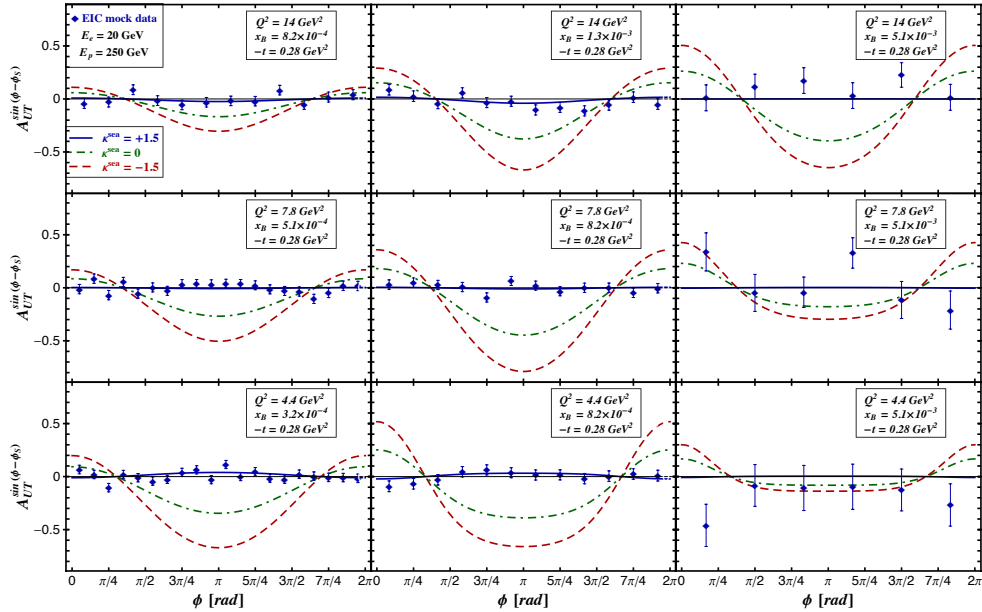


Figure 2: Transverse target-spin asymmetry uncertainties for EIC stage-2 mock data (diamonds) compared to theory model with large positive (solid), vanishing (dot – dashed), and large negative (dashed) E^{sea} contributions.

The simulation proves that an EIC can perform accurate measurements of cross sections and asymmetries in a very fine binning and with a statistical acceptance often as low as a few percent. For more details and figures see the D. Mueller's and M. Diehl' contributions. This implies that the measurement is actually limited by systematics. For the purposes of the present study, a systematic uncertainty of 5% has been assumed, based on the experience achieved at HERA and the expected acceptance and technology improvements of a EIC new detector. The

overall systematic uncertainty due to the uncertainty on the measurement of luminosity was not considered here, since it simply affects the normalization of the cross section measurement. As an example of the precision achievable at an EIC, Fig. 2 shows the expected uncertainty for the transverse target-spin asymmetry (A_{UT}) as a function of the azimuthal angle ϕ between the production and the scattering planes for a particular $x_{Bj}, Q^2, |t|$ bin, compared to theoretical expectations.

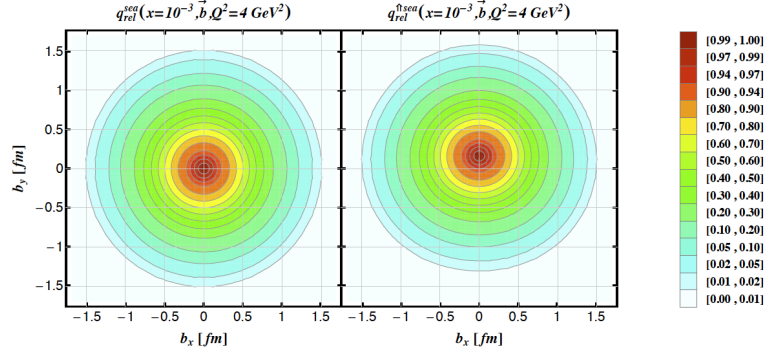


Figure 3: Tomographical picture of the sea-quarks distribution in the impact parameter space for an unpolarized (*left*) and a polarized (*right*) proton beam.

Mock data have been then used, together with the data presently available, to constrain the GPDs. It was found that an EIC would have a great impact on the knowledge of GPDs, especially of GPD E , which at the moment remains unconstrained. For more details and discussion see D. Mueller’s contribution. Fig. 3 shows an example of a tomographic picture of the sea-quarks distribution in the nucleon in the impact parameter space, as resulting from EIC mock data analysis, for a particular x_{Bj}, Q^2 bin, for the case of an unpolarized and a polarized target-beam.

3 Conclusions

To conclude, an EIC will be a unique facility to study DVCS with high precision and accuracy. The very high luminosity of the machine together with the precision of $|t|$ measurement from a dedicated spectrometer and the tracker acceptance at large rapidities opens the possibility of a

fine binning in Q^2 and x_{Bj} and $|t|$ with a very low uncertainty. This will give a precious contribution to the GPDs extraction and will help to discriminate among different theoretical models.

References

- [1] D. Boer et al., “Gluons and the quark sea at high energies: Distributions, polarization, tomography”, 2011, [arXiv:1108.1713](#).
- [2] E. Perez, L. Schoeffel, and L. Favart, (2004), [hep-ph/0411389](#).