

Studying photon structure at an EIC

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A future Electron-Ion Collider (EIC) will deliver luminosities of $10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ for collisions of polarized electrons and protons and heavy ions over a wide range of center-of-mass energies (40 GeV to 145 GeV). One of its promising physics programs is to study the partonic structure of quasi-real photons. Measuring di-jets in photoproduction events, one can effectively access the underlying parton dynamics of the photons through the selection of the resolved photon processes. In this paper, we discuss the feasibility of tagging resolved photon processes and measuring the di-jet cross section as a function of jet transverse momentum in ranges of x_{γ}^{rec} at an EIC. These studies show that parton distributions in the photon can be extracted at an EIC.

*XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects
11-15 April, 2016
DESY Hamburg, Germany*

*Speaker.

1. Introduction

The studies of hadronic photon structure have a long history since Witten's theoretical work in 1977 [1]. On the experimental side, in the past decades we have seen large progress due to the data from HERA, where high energy electrons were collided with protons. The Parton Distribution Functions (PDFs) of the unpolarized photon can be extracted by tagging high transverse energy (E_t) jets [2, 3], high- p_T charged particles [4] or heavy quarks in photoproduction reactions at HERA, although these measurements have relatively large uncertainties. The future EIC, which will deliver luminosities of $10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ for polarized electron and proton collisions [5, 6], is an excellent tool to study the partonic photon structure with high precision. More importantly, one can access the unknown polarized photon PDFs.

In ep collisions, the interaction of electrons and protons at low virtuality is dominated by photoproduction processes with electrons scattering at small angles. Such reactions proceed via two classes of processes. The first one is a direct process (for example the photon-gluon fusion process in Fig. 1a), in which the photon couples directly to a parton from the proton with the entire energy of the photon going into the hard scattering. The second one is a resolved process (Fig. 1b), the photon manifests a hadronic structure because of quantum fluctuations, then partons from the photon and proton interact via the strong interaction. These resolved events allow for the study of the partonic structure of the photon.

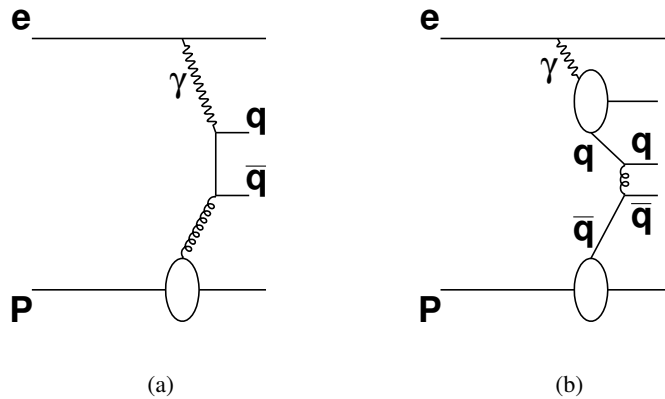


Figure 1: Examples of diagrams for direct (a) and resolved (b) processes in electron-proton scattering.

These proceedings are organized as follows: In Sec. 2, we present a method of reconstructing x_γ . The Monte Carlo simulations at a future EIC of the di-jet cross section is validated by the data collected with H1 detector at HERA in Sec. 3. Then we will briefly discuss the method of distinguishing resolved and direct processes, and the extraction of photon PDFs at EIC. Finally we close with a summary.

2. Method of reconstructing x_γ

Predictions for the di-jet cross section are usually obtained in leading order quantum chromodynamics (LO QCD) by convoluting the parton densities in the photon and those in the proton with

the short-distance partonic cross section. As the parton densities in the proton are well known, a measurement of the di-jet cross section can be used to extract information on the parton densities of the photon [7, 8]. In order to extract the photon structure information through di-jet production, first we need to select resolved processes. The best variable to separate the two types of processes is x_γ , which represents the momentum fraction of the parton in the photon. Since in the direct processes the photon interacts with a parton from the proton as a structureless particle, x_γ of direct processes is equal to 1 at LO. Whereas in the resolved processes, the photon behaves like a source of partons, with only a fraction of its momentum participating in the hard scattering, therefore, the corresponding x_γ should be smaller than 1. The variable x_γ can be reconstructed knowing the momentum and angles of di-jet as,

$$x_\gamma^{rec} = \frac{1}{2E_e y} (p_{T,1} e^{-\eta_1} + p_{T,2} e^{-\eta_2}), \quad (2.1)$$

where E_e is the electron energy and y is the energy fraction taken by the photon from the electron ($y = \frac{E_\gamma}{E_e}$). Eq. (2.1) is valid in the lab frame.

3. Verification of Simulation with HERA data

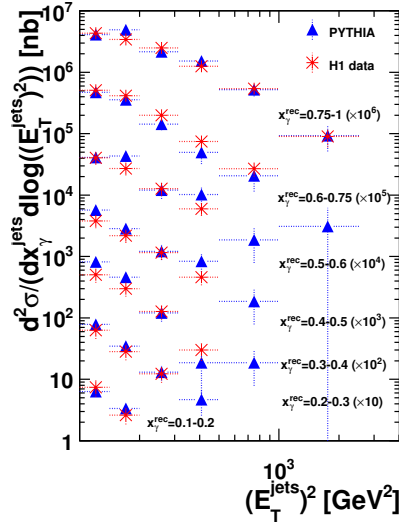


Figure 2: Comparison of the di-jet cross section from PYTHIA simulation with the selected HERA data. We used the same kinematic cuts as the data in the simulation.

The di-jet cross section measured by H1 at HERA [7] is shown in Fig. 2 as a function of the squared jet transverse energy E_T^{jets} in ranges of reconstructed x_γ . Here we use E_T^{jets} to represent the average transverse energy of trigger jet and associated jet, E_T^{jets} is required to be above $E_T^{jets} = 10$ GeV. The ratio of the difference and the sum of the transverse energies of the jets is required to be in the range of $\frac{|E_T^{jet1} - E_T^{jet2}|}{(E_T^{jet1} + E_T^{jet2})} < 0.25$. The fractional photon energy is between $0.2 < y < 0.83$. The average of pseudo-rapidity of the two jets is restricted between $0 < \frac{\eta^{jet1} + \eta^{jet2}}{2} < 2$, and the

difference of the jet pseudo-rapidities is required to be within $|\Delta\eta^{jets}| < 1$. The simulation results are obtained with 27 GeV electrons colliding on protons of 820 GeV, and the comparison shows the simulation reproduces the measured data reasonably well.

4. Photon structure at EIC

In this study, jets are reconstructed with the anti- k_T algorithm [9], which is parametrised by the power of the energy scale in the distance measure. All the stable and visible particles produced in the collision with $p_T > 250$ MeV/ c and $-4.5 < \eta < 4.5$ in the laboratory system are taken as input. The resolution parameter, R , is set to 1. This simulation for EIC is obtained colliding 20 GeV electrons with 250 GeV protons. Jets with the highest p_T are called the trigger jet, then we selected the jet with second highest p_T to be the associate jet. Events are selected with the requirement that the trigger jet has $p_T^{jet} > 5$ GeV and the associated jet has $p_T^{jet} > 4.5$ GeV. The PYTHIA 6.4 event generator [10] for electron-proton interactions is used. The photoproduction events are selected by requiring the four-momentum of the photon of $Q^2 < 1$ GeV². The inelasticity cut is $0.01 < y < 0.95$. The event kinematic variables Q^2 and y are obtained directly from PYTHIA simulations without applying the event kinematics reconstruction method.

We reconstruct x_γ with di-jet events. The strong correlation between the reconstructed x_γ and the input x_γ from PYTHIA is shown in Fig. 3(a), and it indicates the di-jet observable is ideal for this measurement. The x_γ^{rec} distribution is shown in Fig. 3(b). The resolved (direct) process dominates at low (high) x_γ^{rec} regime, which provides a good way of separating the two types of processes. For example, by selecting events with $x_\gamma^{rec} < 0.6$ or > 0.6 , one can divide the di-jet events into subsamples in which the resolved and direct processes dominate.

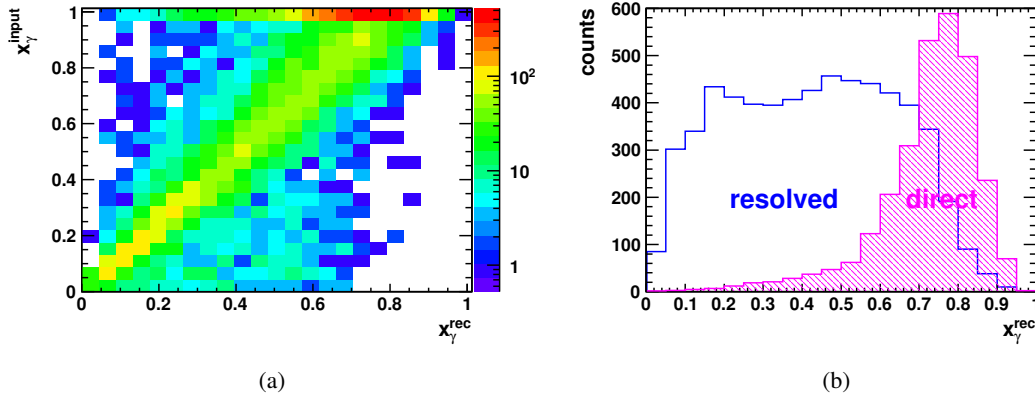


Figure 3: (a) Correlation between x_γ^{input} and x_γ^{rec} , (b) x_γ^{rec} distributions in resolved (blank) and direct (shaded) processes.

The double differential di-jet cross section in photoproduction can be measured with high accuracy in a wide kinematics range of fractional energy x_γ^{rec} at EIC, see in Fig. 4. In a global fit photon PDFs can be extracted from the cross section.

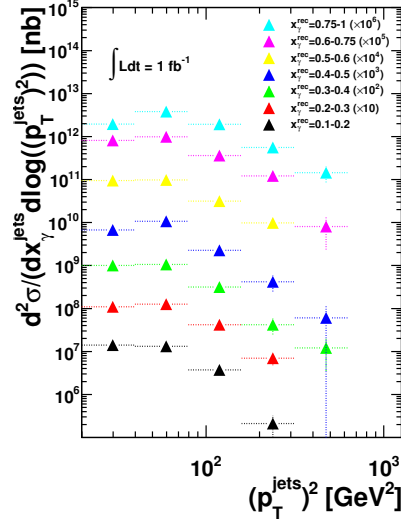


Figure 4: Di-jet cross section depends on transverse momentum of the jets p_T^{jets} and the reconstructed x_γ for an integrated luminosity of 1 fb^{-1} .

5. Summary and outlook

In resolved processes, the photon has a hadronic structure. At an EIC, di-jet produced in direct and resolved process can be well separated by reconstructing x_γ . The reconstructed x_γ^{rec} has a strong correlation with the input x_γ . One can effectively extract the underlying photon PDFs by measuring di-jet cross section in photoproduction events. If we use polarized beams, polarized photon PDFs can be extracted, which is a critical input for ILC $\gamma\gamma$ option.

6. Acknowledgements

We are very grateful to the EIC group at BNL whose ongoing efforts made this analysis possible. We acknowledge BNL EIC task force for effective discussions. This work is also supported by the program of Introducing Talents of Discipline to Universities (B08033), the NSFC (11475068) and the National Basic Research Program of China(2013CB837803).

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