Deeply Virtual Compton Scattering at HERA and perspectives at CERN

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Standard parton distribution functions contain neither information on the correlations between partons nor on their transverse motion, then a vital knowledge about the three dimensional structure of the nucleon is lost. Hard exclusive processes, in particular DVCS, are essential reactions to go beyond this standard picture. In the following, we examine the most recent data from HERA (at low $x_{Bj} < 10^{-2}$) and their impact on GPD models. The most recent measurements of the Beam Charge Asymmetry by the H1 experiment is discussed. Perspectives are presented for further measurements of DVCS cross sections at CERN, within the COMPASS experiment.

1 Introduction

Measurements of the deep-inelastic scattering (DIS) of leptons and nucleons, $e+p \rightarrow e+X$, allow the extraction of Parton Distribution Functions (PDFs) which describe the longitudinal momentum carried by the quarks, anti-quarks and gluons that make up the fast-moving nucleons. These functions have been measured over a wide kinematic range in the Bjorken scaling variable x_{Bj} and the photon virtuality Q^2. While PDFs provide crucial input to perturbative Quantum Chromodynamic (QCD) calculations of processes involving hadrons, they do not provide a complete picture of the partonic structure of nucleons. In particular, PDFs contain neither information on the correlations between partons nor on their transverse motion, then a vital knowledge about the three dimensional structure of the nucleon is lost. Hard exclusive processes, in which the nucleon remains intact, have emerged in recent years as prime candidates to complement this essentially one dimentional picture.

The simplest exclusive process is the deeply virtual Compton scattering (DVCS) or exclusive production of real photon, $e+p \rightarrow e+\gamma+p$. This process is of particular interest as it has both a clear experimental signature and is calculable in perturbative QCD. The DVCS reaction can be regarded as the elastic scattering of the virtual photon off the proton via a colourless exchange, producing a real photon in the final state [2, 3]. In the Bjorken scaling regime, QCD calculations assume that the exchange involves two partons, having different longitudinal and transverse momenta, in a colourless configuration. These unequal momenta or skewing are a consequence of the mass difference between the incoming virtual photon and the outgoing real photon. This skewedness effect can be interpreted in the context of generalised parton distributions (GPDs) [4]. These functions carry information on both the longitudinal and the transverse distribution of partons. The DVCS cross section depends, therefore, on GPDs [4]. In the following, we examine the most recent data recorded from the DESY ep collider at HERA and their implication on models [2, 3].

2 Latest experimental measurements from HERA at low x_{Bj}

The first measurements of DVCS cross section have been realised at HERA within the H1 and ZEUS experiments [2, 3]. These results are given in the specific kinematic domain of

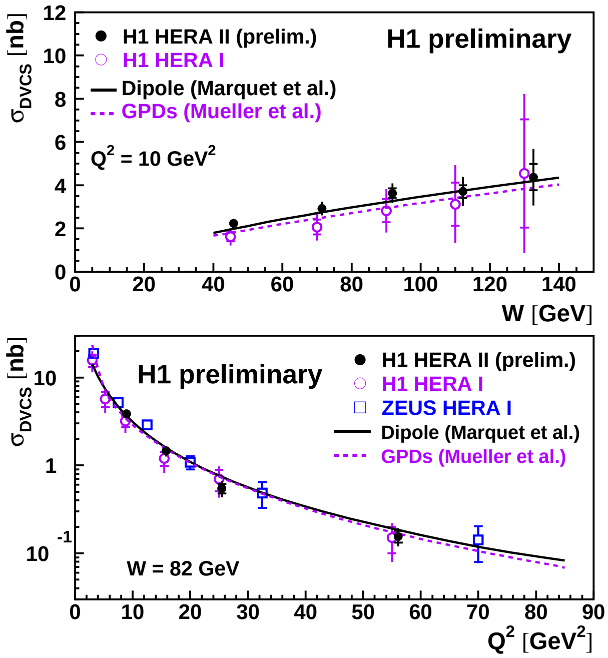

Figure 1: DVCS cross section for the full HERA data as a function of W and Q^2.

both experiments, at low x_{Bj} ($x_{Bj} < 0.01$) but they take advantage of the large range in Q^2, offered by the HERA kinematics, which covers more than 2 orders of magnitude, from 1 to 100 GeV^2. It makes possible to study the transition from the low Q^2 non-perturbative region (around 1 GeV^2) towards higher values of Q^2 where the higher twists effects are lowered (above 10 GeV^2). The last DVCS cross sections as a functon of Q^2 and $W \simeq \sqrt{Q^2/x}$ are presented on Fig. 1. A good agreement with GPDs [4] and dipole [5] models is observed. A very fundamental observation is the steep W dependence in $W^{0.7}$, visible on Fig. 1. This means that DVCS is a hard process. Thus, it is justified to compare DVCS measurements with perturbative QCD calculations, GPDs or dipole approaches, as displayed in Fig. 1.

A major experimental achievement of H1 and ZEUS [2, 3] has been the measurement of DVCS cross sections, differential in $t = (p' - p)^2$, the momentum transfer (squared) at the proton vertex. A good description of $d\sigma_{DVCS}/dt$ by a fit of the form $e^{-b|t|}$ is obtained [2, 3]. Hence, an extraction of the t-slope parameter b is accessible and it can be achieved experimentally for different values of Q^2 and W (see Fig. 2). Again, we observe the good agreement of measurements with GPDs and dipole models.

3 Nucleon Tomography and Perspectives at CERN

Measurements of the t-slope parameters b are key measurements for almost all exclusive processes, in particular DVCS. Indeed, a Fourier transform from momentum to impact parameter space readily shows that the t-slope b is related to the typical transverse distance between the colliding objects [4]. At high scale, the $q\bar{q}$ dipole is almost point-like, and the

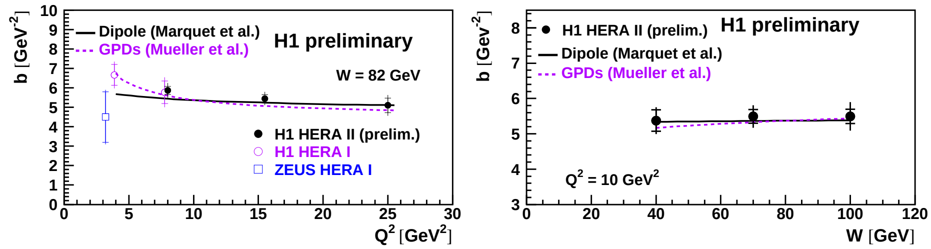

Figure 2: The logarithmic slope of the t dependence for DVCS exclusive production, b as a function of Q^2 and W, extracted from a fit $d\sigma/dt \propto \exp(-b|t|)$ where $t = (p - p')^2$.

t dependence of the cross section is given by the transverse extension of the gluons (or sea quarks) in the proton for a given x_{Bj} range. More precisely, from GPDs, we can compute a parton density which also depends on a spatial degree of freedom, the transverse size (or impact parameter), labeled $R_\perp$, in the proton. Both functions are related by a Fourier transform

$$PDF(x, R_\perp; Q^2) \;\; \equiv \;\; \int \frac{d^2\Delta_\perp}{(2\pi)^2}\, e^{i(\Delta_\perp R_\perp)}\, GPD(x, t = -\Delta_\perp^2; Q^2).$$

Thus, the transverse extension $\langle r_T^2 \rangle$ of gluons (or sea quarks) in the proton can be written as

$$\langle r_T^2 \rangle \;\; \equiv \;\; \frac{\int d^2R_\perp\; PDF(x, R_\perp)\; R_\perp^2}{\int d^2R_\perp\; PDF(x, R_\perp)} \;\; = \;\; 4\, \frac{\partial}{\partial t} \left[\frac{GPD(x,t)}{GPD(x,0)} \right]_{t=0} = 2b$$

where b is the exponential t-slope. Measurements of b presented in Fig. 2 corresponds to $\sqrt{r_T^2} = 0.65 \pm 0.02$ fm at large scale Q^2 for $x_{Bj} < 10^{-2}$. This value is smaller that the size of a single proton, and, in contrast to hadron-hadron scattering, it does not expand as energy W increases. This result is consistent with perturbative QCD calculations in terms of a radiation cloud of gluons and quarks emitted around the incoming virtual photon. The fact the perturbative QCD calculations provide correct descriptions of b measurements (see previous section) is a proof that they deal correctly this this non-trivial aspect of the proton (spatial) structure. The correlation between the spatial transverse structure and the longitudinal momenta distributions of partons in the proton is one major challenge of the GPDs model.

Another natural experimental way to address this problem is proceeds from a determination of a cross section asymmetry with respect to the beam charge. It has been realised recently by the H1 experiment by measuring the ratio $(d\sigma^+ - d\sigma^-)/(d\sigma^+ + d\sigma^-)$ as a function of ϕ, where ϕ is the azimuthal angle between leptons and proton plane. The result is presented on Fig. 3 with a fit in $\cos\phi$. After applying a deconvolution method to account for the resolution on ϕ, the coefficient of the $\cos\phi$ dependence is found to be $p_1 = 0.16 \pm 0.03(stat.) \pm 0.05(sys.)$ (at low $x_{Bj} < 0.01$). This result represents obviously a major experimental progress. Using present HERA data at low x_{Bj}, as well as JLab and HERMES data at larger x_{Bj} ($x_{Bj} > 0.1$), a first global parametrisation of GPDs can be done [4]. This is an essential step forward in the field. However, some efforts have still to be made in the intermediate x_{Bj} domain.

Feasabilities for future Beam Charge Asymmetry (BCA) measurements at COMPASS have been studied extensively in the last decade [6]. COMPASS is a fixed target experiment which can use 100 GeV muon beams and hydrogen targets, and then access experimentaly the DVCS process $\mu p \rightarrow \mu\gamma p$. The BCA can be determined when using positive and negative muon beams. One major interest is the kinematic coverage from 2 GeV^2 till 6 GeV^2 in Q^2 and x_{Bj} ranging from 0.05 till 0.1. It means that it is possible to avoid the kinematic domain dominated by higher-twists and non-perturbative effects (for $Q^2 < 1$ GeV^2) and keeping a x_{Bj} range which is extending the HERA (H1/ZEUS) domain.

In Fig. 4, we compare QCD predictions of the GPDs model used in Ref. [2] to simulations of the BCA extraction at COMPASS using a muon beam of 100 GeV [7]. We present the data/theory comparisons for one value of Q^2 (4 GeV^2) and two values of x_{Bj} (0.05 and 0.1). Simulations have been done unsing the VGG model to derive BCA values [6]. As mentioned above, this is obviously an essential measurement, to be done in 2011/2012, in order to cover the full kinematic range. It would give some results in the intermediate x_{Bj} range between H1/ZEUS and JLab/HERMES experiments and would allow obviously a further step forward in GPDs models.

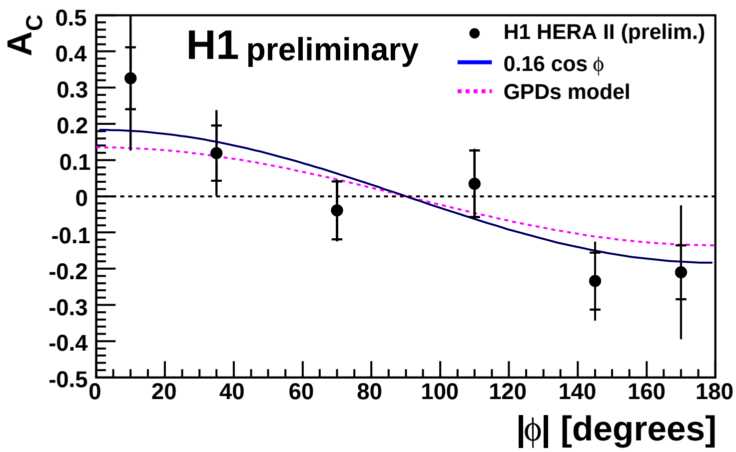

Figure 3: Beam charge asymmetry as a function of ϕ measured by H1. Statistical and systematical uncertainties are shown. Data are corrected from the migrations of events in ϕ. A comparison with the GPDs model described in Ref. [4] is presented. It fits very nicely with the best fit to the data, in $p_1 \cos\phi$ ($p_1 = 0.16$).

4 Summary and outlook

DVCS measurements in the HERA kinematics at low x_{Bj} ($x_{Bj} < 0.01$) are well described by recent GPDs models, which also describe correctly measurements at larger values of x_{Bj} in the JLab kinematics. DVCS measurements in the HERA kinematics are also nicely described within a dipole approach, which encodes the non-forward kinematics for DVCS

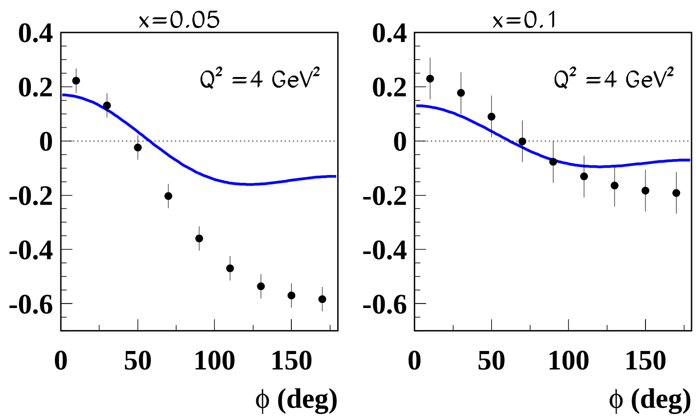

Figure 4: Simulation of the azimuthal angular distribution of the beam charge asymmetry measurable at COMPASS at $E_\mu = 100$ GeV. We present the projected values and error bars in the range $|t| < 0.6$ GeV^2 for 2 values of x_{Bj} (0.05 and 0.1) at $Q^2 = 4$ GeV^2 ([6]). The prediction of the GPD model with a non-factorised t dependence is shown (full line). The case of a factorised t dependence would lead to a prediction of the BCA compatible with zero and is not displayed.

only through the different weights coming from the photon wavefunctions. Recently, H1 and ZEUS experiments have also shown that proton tomography at low x_{Bj} enters into the experimental domain of high energy physics, with a first experimental evidence that gluons are located at the periphery of the proton. A new frontier in understanding this structure would be possible at CERN within the COMPASS experimental setup. Major advances have already been done on the design of the project and simulation outputs.

References

[1] Slides: `http://indico.cern.ch/materialDisplay.py?contribId=115&sessionId=4&materialId=slides&confId=53294`

[2] F. D. Aaron *et al.* [H1 Collaboration], Phys. Lett. B **659** (2008) 796; A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C **44**, 1 (2005); C. Adloff *et al.* [H1 Collaboration], Phys. Lett. B **517** (2001) 47.

[3] S. Chekanov *et al.* [ZEUS Collaboration], JHEP **0905** (2009) 108; S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. B **573**, 46 (2003).

[4] D. Mueller et al., these proceedings.

[5] C. Marquet, R. B. Peschanski and G. Soyez, Phys. Rev. D **76** (2007) 034011.

[6] E. Burtin et al., these proceedings.

[7] L. Schoeffel, Phys. Lett. B **658** (2007) 33.