EXPERIMENTAL STUDIES OF GENERALISED PARTON DISTRIBUTIONS

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Generalised parton distributions (GPD) provide a new way to study the nucleon structure. Experimentally they can be accessed using hard exclusive processes such as deeply virtual Compton scattering and meson production. First insights to GPDs were already obtained from measurements at DESY, JLAB and CERN, while new ambitious studies are planned at the upgraded JLAB at 12 GeV and at CERN. Here, some emphasis will be put onto the planned COMPASS II programme.

1   Introduction

During the recent years the framework of generalised parton distributions (GPD) was developed [1] providing a comprehensive description of the partonic structure of the nucleon and containing a wealth of new information. It embodies both, form factors as observed e.g. in elastic electron scattering and parton distribution functions (PDF) as measured in deep inelastic lepton scattering. A GPD can be considered as a momentum-dissected form factor providing information on the transverse localisation of a parton as a function of the fraction it carries of the nucleon's longitudinal momentum. Thus one obtains a "3-dimensional picture" of the nucleon which is often referred to as "nucleon tomography" [2]. GPDs also allow access to such a fundamental property of the nucleon as the orbital angular momentum of quarks [3].

GPDs are experimentally accessible in exclusive reactions such as deeply virtual Compton scattering (DVCS) and hard exclusive meson production (HEMP), the first one being sensitive to the GPDs H and E, the second one to $\tilde{H}$ and $\tilde{E}$. They depend on the photon virtuality Q^2, the total four-momentum transfer squared t between the initial and final nucleon states and two additional variables x and ξ representing the average and half the difference between the initial and final longitudinal momentum fraction of the nucleon carried by the parton (see fig.1 left). In DVCS and HEMP processes x is an internal variable while the skewness ξ is related to the Bjorken variable $x_{Bj} = Q^2/2Mv$ in the Bjorken limit: $\xi = x_{Bj}/(2 - x_{Bj})$.

The cross section for exclusive photon production generally contains contributions from Bethe-Heitler (BH) as well as from DVCS processes. Making use of beam charge and helicity or target polarisation the real and imaginery part of the Compton form factor (CFF), Re $\mathcal{H}$ and Im $\mathcal{H}$ can be extracted from cross section differences and sums. The CFF is a sum over flavours f of convolutions of the respective GPDs with a perturbatively calculable kernel describing the hard γ^*q interaction. In leading order it can be related to the GPD H by

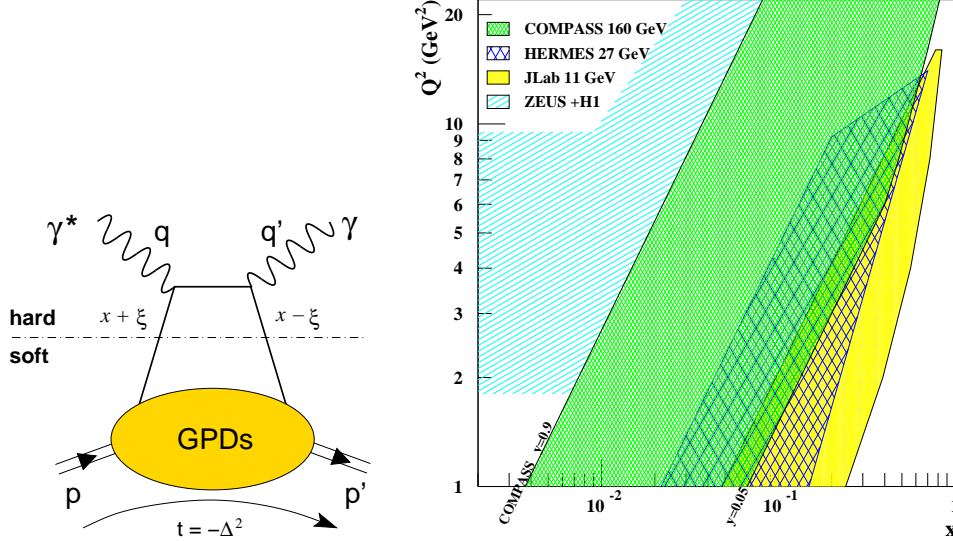$$\mathrm{Im}\,\mathcal{H}(\xi,t) \overset{\mathrm{LO}}{=} H(\xi,\xi,t)$$

Figure 1: Left: Handbag diagram for the DVCS process at leading twist, right: kinematic domains for measurements of hard exclusive processes (observe: $x=x_{Bj}$).

$$\mathrm{Re}\,\mathcal{H}(\xi,t) \overset{\mathrm{LO}}{=} \mathcal{P} \int_{-1}^{1} \mathrm{dx}\; H(x,\xi,t) \frac{1}{x-\xi}$$

where $\mathcal{P}$ is the Cauchy principal value.

2 Experimental results

The extraction of GPDs needs experimental data on hard exclusive processes in a broad kinematic range. Up to now information in the high energy regime at low x_{Bj} was provided by H1 and Zeus at DESY and by HERMES and JLAB experiments in the low energy regime at high x_{Bj}. Missing are high precision data in the kinematic regime where both sea and valence quarks are equally important (see fig. 1 right). Up to now the experiments concentrated on DCVS while only few HEMP measurements were performed [4].

At JLAB, experiments in Hall A used the high precision spectrometers to measure DVCS with very good statistics in limited kinematic range. Beam helicity dependent and independent cross sections, together with a check of factorisation, were measured at $\langle x_{Bj}\rangle = 0.36$ for few values of Q^2 using proton [5] and neutron [6] targets. Using the CLAS detector measurements of the beam spin asymmetries [7] were performed at different beam energies in a wide kinematic range of x_{Bj}, Q^2 and t. Recently also target spin asymmetries with a polarised NH_3 data were measured by E05-114.

The HERMES collaboration did extensive studies of azimuthal asymmetries using unpolarised and polarised proton [8] and deuteron [9] targets to disentangle the BH and the DVCS contributions. They also performed a study of the nuclear dependence [10]. Recently they published results with much improved statistics from the 2006/2007 data taking on using an unpolarised proton target [11]. Here also preliminary results were obtained using the newly installed proton recoil detector, which guarantees exclusivity [12].

At H1 [13] and ZEUS [14] the Q^2, W^2 and t dependence of the DVCS cross section was studied at very low x_{Bj}, where W^2 is the invariant mass of the hadronic final state. From the observed t dependence the transverse size of the proton was extracted (see fig. 2 right).

The JLAB and HERMES data were used in first global analyses where albeit under strong model assumptions a first estimate of the total angular momentum of u and d quarks was given

and the GPD H was extracted (see e.g. refs [15]).

3 Future measurements

In the near future, facilities at JLAB12 and COMPASS at CERN have an huge programme for hard exclusive measurements. In the long run the proposed electron ion collider would allow to study the 3-dimensional nucleon structure in an unprecedented kinematical reach.

3.1 Proposals for JLAB12

After the upgrade to 12 GeV a series of new DVCS experiments is proposed at JLAB12. E12-06-114 [18] in Hall A will continue the investigations started by E00-110 measuring DVCS on the proton at fixed x_{Bj} in an enlarged Q^2 range using several beam energies. The main emphasis lies on high precision cross section measurements of the t dependence and the extraction of Re$\mathcal{H}$, Im$\mathcal{H}$.

In Hall B new experiments with CLAS will profit from the large kinematic coverage at 11 GeV yielding an enlarged x_{Bj} range from 0.1 to 0.7. The second phase of E12-06-119 [19] will also include a polarised NH_3 target to measure BSA and TSA. For E12-11-003 [20] a new neutron recoil detector will designed for BSA measurements to allow a flavour separation of the GPD H.

3.2 COMPASS proposal

At CERN the COMPASS collaboration [21] is currently preparing an upgrade of their spectrometer [22] to allow high precision exclusive measurements. Using highly polarised 160 GeV μ^+ and μ^- beams scattering off a proton target cross section differences and sums as well as beam charge and spin asymmetries will be studied in a kinematic range between HERA and HERMES/JLAB kinematic ranges (see fig. 1 right), thus covering the region in x_{Bj} where both, valence and see quarks, contribute to the cross section. The BH and DVCS processes will be disentangled with the help of azimuthal distributions. They are dominated by BH at low x_{Bj}, thus supplying an excellent reference yield. At intermediate x_{Bj} the interference of BH and DVCS is studied, while the high x_{Bj} range is dominated by the DVCS cross process. In the first phase the 2.5 m long liquid hydrogen target is surrounded by a proton recoil detector to guarantee exclusivity of the measured events. Also the electromagnetic calorimetry will be upgraded to allow a large coverage in x_{Bj} and Q^2 for hard exclusive photon processes.

Extracting the beam spin and charge cross section difference the pure BH contribution cancels and the analysis of the ϕ dependence will provide a measurements of Re$\mathcal{H}$. The projected accuracy for the ϕ dependence of the beam charge and spin asymmetry is shown in Fig.2 left. It is compared to model calculations [23] and the result of a first analysis of the world data [17]. On the other hand in the beam charge and spin sum the BH contribution does not cancel and it has to be subtracted provided the contribution is not too large. Integrating over ϕ yields the t dependence of the cross section which is related to the transverse size of the nucleon at different values of x_{Bj}. In the simple ansatz $d\sigma(x_{Bj})/dt \sim exp(-B(x_{Bj})|t|)$ and $B(x_{Bj}) = B_0 + 2\alpha' \log(x_0/x_{Bj})$ the shrinkage parameter α' is used to describe the decrease of the nucleon size with increasing x_{Bj}. Figure 2 right shows the projected statistical accuracy compared to results from H1 [13] and ZEUS [14] at lower x_{Bj}. In parallel, HEMP of vector mesons will be studied which will give access to a flavour separation of GPD H. A first short data run will be performed already this year.

In the second phase measurements with a transversely polarised NH_3 target and an adapted recoil detector will allow to extract the GPD E, thus giving access to the total angular momentum of the different quark flavours.
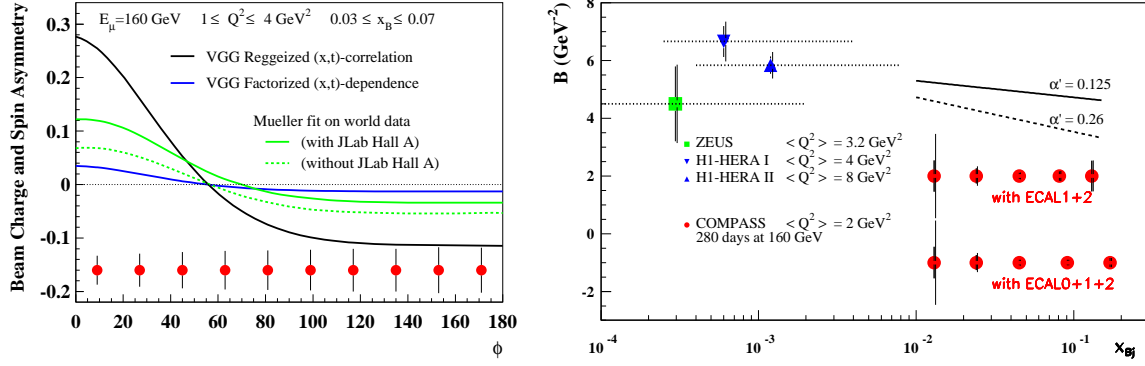
Figure 2: Left: Projected statistical accuracy for a measurement of the ϕ dependence of the beam charge and spin asymmetry, for the curves see text. Right: Projections for measuring the x_{Bj} dependence of the t-slope parameter $B(x_{Bj})$ of the DVCS cross section compared to previous measurements.

Acknowledgments

References

1. D. Mueller *et al*, Fortsch. Phys. 42 (1994) 101.
2. M. Burkardt, *Phys. Rev.* D **62**, 071503 (2000), erratum*Phys. Rev.* D **66**, 119903 (2002).
3. X. Ji, PRL **78**, 610 (1997); PRD **55**, 7114 (1997).
4. see e.g. CLAS, S.A. Morrow *et al*, *Eur. Phys. Journal* A **39**, 5 (2009);
   HERMES, A. Airapetian *et al*, *Phys. Lett.* B **679**, 100 (2009);
   COMPASS, C. Adolph *et al*, *Nucl. Phys.* B **865**, 1 (2012).
5. Hall A, C. Munoz Camacho *et al*, *Phys. Rev. Lett.* **97**, 262002 (2006).
6. Hall A, M. Mazouz *et al*, *Phys. Rev. Lett.* **99**, 242501 (2007).
7. CLAS, F.X. Girod *et al*, *Phys. Rev. Lett.* **100**, 162002 (2008);
   G. Gavalian *et al*, *Phys. Rev.* C **80**, 035206 (2009).
8. HERMES, A. Airapetian *et al*, *JHEP* **0911**, 083 (2009); *JHEP* **1006**, 019 (2010); *Phys. Lett.* B **704**, 15 (2011).
9. HERMES, A. Airapetian *et al*, *Nucl. Phys.* B **829**, 1 (2010); *Nucl. Phys.* B **842**, 265 (2011).
10. HERMES, A. Airapetian *et al*, *Phys. Rev.* C **81**, 035202 (2010).
11. HERMES, A. Airapetian *et al*, *JHEP* **1207**, 032 (2012).
12. HERMES, A. Airapetian *et al*, arXiV:1206.5683
13. H1, F.D. Aaron *et al*, *Phys. Lett.* B **681**, 391 (2009).
14. ZEUS, S. Chekanov *et al*, *JHEP* **0905**, 108 (2009).
15. H. Moutarde, *Phys. Rev.* D **79**, 094021 (2009);
16. M. Guidal, *Phys. Rev.* D **293**, 17 (2010);
17. K. Kumericki, D. Mueller, *Nucl. Phys.* B **841**, 1 (2010).
18. http://www.jlab.org/exp-prog/proposals/06/PR12-06-114.pdf.
19. http://www.jlab.org/exp-prog/proposals/06/PR12-06-119.pdf.
20. http://www.jlab.org/exp-prog/PACpage/PAC37/proposals/NEW%20Proposals/PR-11-003.pdf.
21. COMPASS, SPSC-2010-014/P-340.
22. COMPASS, P. Abbon *et al*, NIMA **577**, 455 (2007).
23. M. Vanderhaeghen *et al*, PRD **60**, 094017 (1999).