PROCEEDINGS OF SCIENCE

The GPD program at COMPASS II

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The high energy polarised muon beam available at CERN with the option of using positive or negative muons with opposite polarisation gives COMPASS an excellent possibility to study generalised parton distributions via deeply virtual Compton scattering and hard exclusive meson production. In a first step an unpolarised proton target will be used to measure the x_{Bj}-dependence of the t-slope of the pure DVCS cross section to study the shrinkage of the nucleon with increasing x_{Bj}. Furthermore, the beam charge and spin difference and sum will be measured over a wide kinematical range to determine the Compton form factor related to real and imaginary parts of the GPD H. An exploratory measurement was performed in 2012 with the COMPASS spectrometer upgraded with a proton recoil detector surrounding a 2.5 m long liquid hydrogen target and an enlarged acceptance for photon detection. The perspectives for the planned measurements in 2016/17 will be shown. As a second step the use of a transversely polarised proton target to collect data to constrain the GPD E is investigated.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects,
28 April - 2 May 2014
Warsaw, Poland

[*]Speaker.
[†]Supported by the BMBF

PoS(DIS2014)242

1. Introduction

In the recent years the COMPASS collaboration has pursued a rich program in polarised deep inelastic scattering focussing on the contribution of quarks and gluons to the nucleon spin. In the next phase the total angular momenta carried by the constituents will be addressed, thus getting access to orbital angular momenta by exploiting Ji's sumrule [3]. In this sumrule the angular momenta are related to moments of generalised parton disitribution functions (GPD). 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 [1, 2]. Thus one obtains a "3-dimensional picture" of the nucleon which is often referred to as "nucleon tomography" [4].

At COMPASS GPDs are accessible via deeply virtual Compton scattering (see fig. 1 top left) and deeply virtual meson production [5]. For DVCS on an unpolarised target the GPD H yields the dominant contribution, while the GPD E is accessible with transverse target polarisation. All GPDs 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 struck parton. In DVCS and DVMP processes x is an internal variable, while the skewness ξ is related to the Bjorken variable $x_{Bj} = Q^2/2M\nu$ in the Bjorken limit: $\xi = x_{Bj}/(2 - x_{Bj})$.

The extraction of GPDs from such measurements 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}. The COMPASS measurements will provide a connection between these measurements by covering the kinematic regime of x around 0.1, where both, sea and valence quarks, are equally important.

2. Experimental requirements

A competing process is the Bethe-Heitler (BH) process (see fig. 1 top right) of elastic lepton-nucleon scattering with a hard Bremsstrahlung photon emitted by the incoming or outgoing lepton. It produces the same final state as DVCS so that both processes interfere at the level of amplitudes. In the COMPASS experiment, kinematic domains are accessible where either BH or DVCS dominate (fig. 1 bottom). At low x_{Bj} almost pure BH events are recorded which can be used as an excellent reference yield. The collection of almost pure DVCS events at higher x_{Bj} will allow a measurement of the t dependence of the cross section which is related to the tomographic image of the nucleon. In the intermediate domain the DVCS contribution will be enhanced by the BH process through their interference.

As DVCS is only a small contribution to the total cross section, a high luminosity measurement has to be performed, requiring a long target for the limited beam flux at a muon beam. Also exclusivity of the collected data has to be ensured by measuring the full final state, incoming and scattered lepton, high energy real photon and recoil proton with high acceptance and efficiency. To disentangle the two cross section contributions a precise measurement of angular distribution of exclusive photon production on the full ϕ range is mandatory.

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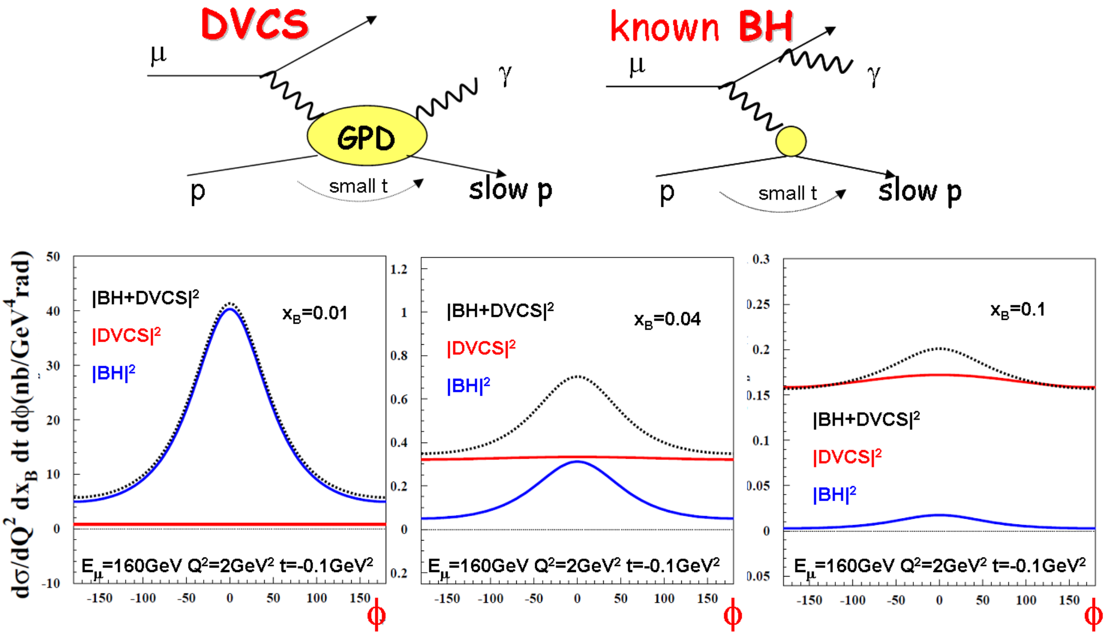

Figure 1: DVCS (top left) and BH process (top right), ϕ dependence of the contribution to the cross section at COMPASS kinematics for three different x bins and $Q^2 > 1$ (GeV/c)^2 (bottom).

3. Experimental set-up in 2012

The COMPASS experiment [6] at the M2 beam line of the CERN SPS consists of a two stage spectrometer, each stage equipped with tracking detectors, electromagnetic and hadron calorimeters and PID detectors. For a short DVCS measurement in 2012, the setup was upgraded with a new target region consisting of a 2.5 m long liquid hydrogen target and a 4 m long recoil proton detector, and electromagnetic calorimetry (see fig. 2). Here, the hermeticity of the existing calorimeters covering angles up to about 10 degrees was improved (see fig. 2 for details) and a prototype of an additional calorimeter covering large photon angles up 14.6 degrees was added. This additional calorimeter will especially improve the measurements in the large x region where DVCS dominates. The full calorimeter will be available for the next muon data taking.

The recoil proton detector CAMERA consists of two barrels of 24 scintillator slabs (A and B in fig. 2). This detector serves the double purpose to reconstruct and identify recoil protons via time-of-flight (ToF) and energy loss measurements. The M2 beam line allows for a fast changeover between muon and hadrons beam. Therefore, CAMERA is calibrated using elastic pion-proton scattering before the DVCS measurements with the muon beam. Figure 3 shows the energy loss spectra obtained quasi-online from ring B versus β from the ToF measurement for exclusive events for pion and muon beam data. Part of the protons are stopped in, part traverse the outer ring, yielding a unique calibration by the kink in the measured energy loss distribution. Observe that only protons are detected in the exclusive events without a visible contamination from e.g. pions.

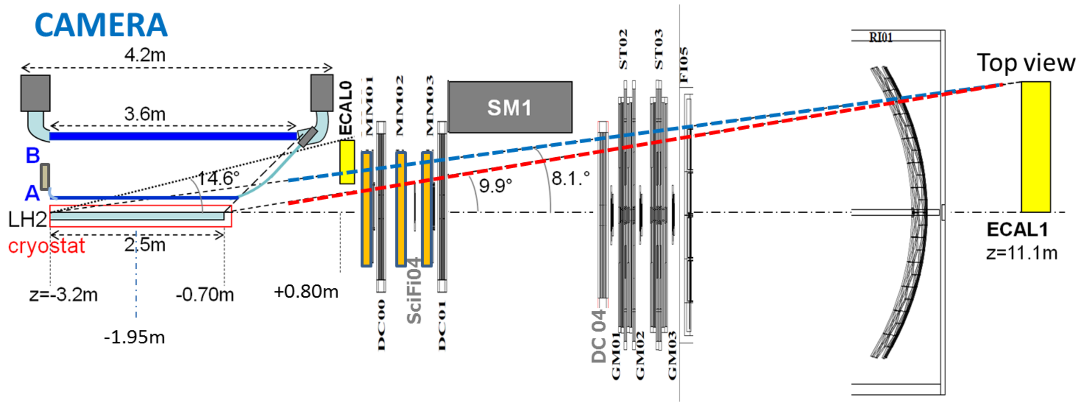

Figure 2: Target region and first spectrometer for the 2012 DVCS measurement

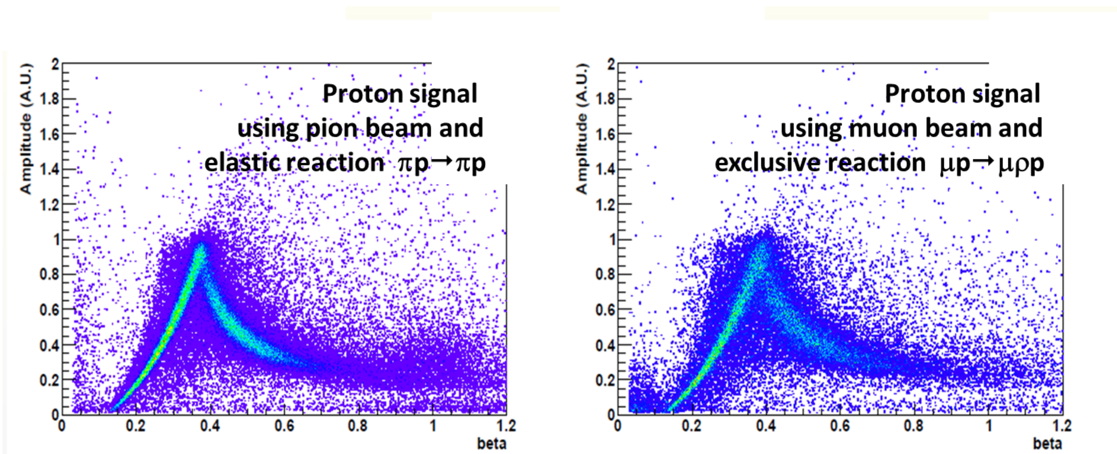

Figure 3: Energy loss from ring B versus β from ToF for elastic pion nucleon scattering and muoproduction of exclusive photons.

4. Projected results

The differential cross section for muon production of real photons on an unpolarised proton target is given by

$$\frac{d^4\sigma(\mu p \to \mu p \gamma)}{dx_{Bj} dQ^2 d|t| d\phi} = d\sigma^{BH} + [d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol}] + e_\mu [ReI + P_\mu ImI] \tag{4.1}$$

where I is the interference term mentioned above, P_μ the beam polarisation and e_μ the beam charge in units of the elementary charge. The distribution of the azimuthal angle ϕ between the lepton scattering and the photon production plane is very sensitive to the different contributions.

All COMPASS DVCS measurements will exploit the availability of positive and negative muon beams with opposite polarisation. This allows to measure with the same apparatus the beam charge(C) and spin(S) sum $\mathscr{S}$ and difference $\mathscr{D}$: $\mathscr{S}_{CS,U} \equiv d\sigma^{+\downarrow} + d\sigma^{-\uparrow}$ and $\mathscr{D}_{CS,U} \equiv d\sigma^{+\downarrow} - d\sigma^{-\uparrow}$ where the arrow indicates the beam polarisation. From these measurements the real and imaginary part of Compton form factors (CFF) can be extracted allowing a detailed study of the GPD H. A CFF is a sum over flavours f of convolutions of the respective GPDs with a perturbatively calculable kernel describing the hard $\gamma^* q$ interaction.

In the difference $\mathscr{D}_{CS,U}$ the pure BH contribution cancels and the analysis of the ϕ dependence will provide a measurements of the real part of the corresponding CFF (see [5]). On the other hand in $\mathscr{S}_{CS,U}$ the BH contribution does not cancel and it has to be subtracted, using the pure BH contribution at low x as a reference yield. 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 related to the decrease of the nucleon size with increasing x_{Bj} as illustrated in fig. 4 right. Figure 4 left shows the projected statistical accuracy compared to results from H1 [7] and ZEUS [8] at lower x_{Bj} for a two years data taking in 2016/17. The 2012 measurement focusses on the exploratory measurement of the DVCS cross section. The expected result for the slope parameter is added to fig. 4 left.

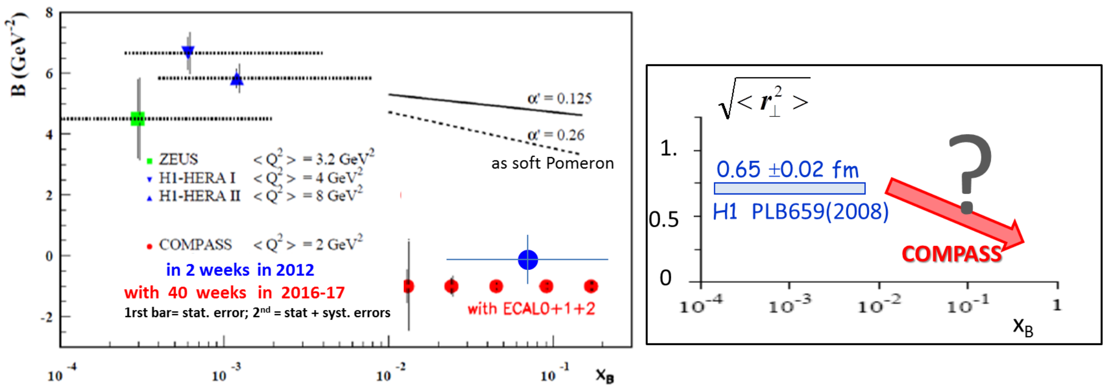

Figure 4: Projections for the measurement of the x_{Bj} dependence of the t-slope parameter $B(x_{Bj})$ of the DVCS cross section for a two years data taking compared to the 2012 run (left), sketch of the corresponding x_{Bj} dependence of the mean proton radius (right).

To obtain insight into the GPD E and to study the role of orbital angular momentum of quarks, transverse target spin asymmetries for DVCS are important observables. They will be accessed in the second part of the program using a transversely polarised ammonia target similar to the one presently used by COMPASS. In this case the recoil detector will have to be integrated into the cryostat of the superconducting solenoid. As an alternative solution the use of an externally polarised target with only a small holding field is studied. In this approach a more conventional recoil detector can be used. The expected statistical accuracy for both solutions for the measurement of the transverse asymmetry $A_{\mathrm{CS,T}}^{D\sin(\phi-\phi_s)\cos\phi}$ is illustrated in fig. 5 for two years of data taking.

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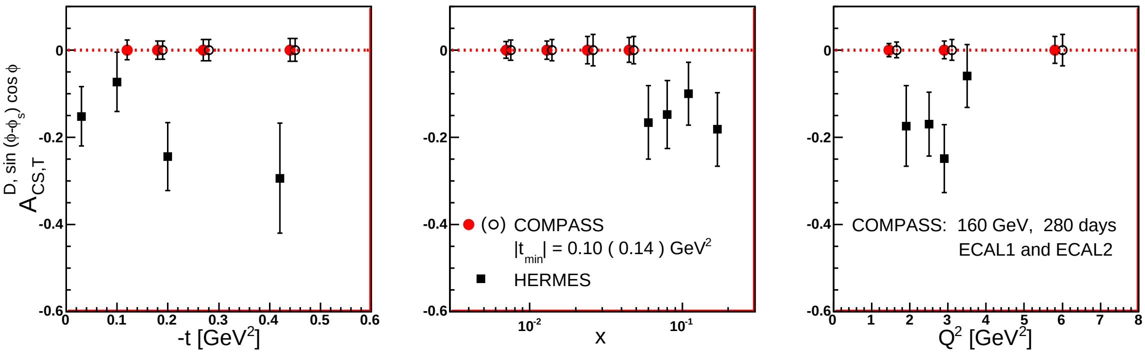

Figure 5: Expected statistical accuracy of the transverse asymmetry as a function of t, x_{Bj} and Q^2 for a two years measurements with two different target configurations mentioned in the text compared to the published HERMES results [9].

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