# Prospects for DVCS measurements using the COMPASS spectrometer at CERN

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**Abstract.** The study of exclusive reactions like Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) is one major part of the future COMPASS program to investigate nucleon structure through Generalized Parton Distributions (GPD). The high energy of the muon beam allows to measure the $x_{Bj}$-dependence of the $t$-slope of the DVCS cross section and to study nucleon tomography. The use of positive and negative polarized muon beams allows to determine the Beam Charge and Spin Difference of the DVCS cross sections to access the real part of the Compton form factor related to the dominant GPD H. As a second phase a transversely polarized proton target will be used to collect data to constrain the GPD E. In preparation of the future measurements two DVCS test runs were performed in 2008 and 2009.

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## INTRODUCTION

The COMPASS experiment is located at the unique CERN SPS M2 beam line that is able to deliver high-energy and highly-polarized $\mu^{\pm}$ particles. It consists of a high-resolution forward spectrometer and an unpolarized, longitudinally or transversely polarized target. By installing a recoil proton detector around a liquid hydrogen target to ensure exclusivity of the DVCS and DVMP events, COMPASS would become a facility measuring exclusive reactions within a kinematic domain ranging from $x_{Bj} \sim 0.01$ to about 0.1 using two existing ECAL1 and ECAL2 calorimeters. For higher values of $x_{Bj}$ a new large angle calorimeter ECAL0 will be added to extend $x_{Bj}$ up to $\sim 0.27$. COMPASS would thus explore the uncharted $x_{Bj}$ domain between the HERA collider experiments H1 and ZEUS and the fixed-target experiments as HERMES and the planned 12 GeV extension of the JLab (Fig.1).

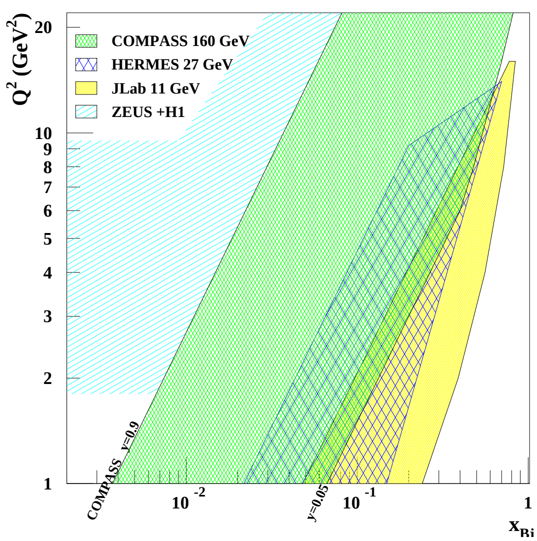


**FIGURE 1.** Kinematic domains for measurements of hard exclusive processes.

# DVCS MEASUREMENT WITH HIGH ENERGY POLARIZED $\mu^+$ AND $\mu^-$ BEAMS

A DVCS measurement with a 160 GeV muon beam was proposed for future COMPASS program [1]. In the first phase data will be collected with a liquid hydrogen target to constrain the GPD H. A second phase of data taking with a polarized target (to constrain the GPD E) will be presented in an addendum to the present proposal in the future. Data on DVMP will be recorded simultaneously to the DVCS measurement.

DVCS has the same final state as the competing Bethe–Heitler (BH) process, which is elastic lepton–nucleon scattering with a hard photon emitted by either the incoming or outgoing lepton. The differential cross section for hard exclusive muoproduction of real photons off an unpolished proton target can be written as[1]

$$\frac{\mathrm{d}^4\sigma(\mu p \to \mu p \gamma)}{\mathrm{d}x_{Bj}\mathrm{d}Q^2\mathrm{d}|t|\mathrm{d}\phi} = \mathrm{d}\sigma^{BH} + \left(\mathrm{d}\sigma^{DVCS}_{unpol} + P_\mu\, \mathrm{d}\sigma^{DVCS}_{pol}\right) + e_\mu \left(\mathrm{Re}\, I + P_\mu\, \mathrm{Im}\, I\right), \qquad (1)$$

where $P_\mu$ is the polarization and $e_\mu$ the charge in units of the elementary charge of the polarized muon beam. The interference term $I$ arises due to the interference of the DVCS and the BH processes. The dependence on $\phi$, the azimuthal angle between lepton scattering plane and photon production plane, is a characteristic feature of the cross section.

COMPASS offers the advantage to provide various kinematic domains where either BH or DVCS dominate. As the Bethe-Heitler amplitude is well known the almost pure BH events at small $x_{Bj}$ can be used as an excellent reference yield. In contrast the collection of almost pure DVCS events at larger $x_{Bj}$ will allow the measurement of the $x_{Bj}$-dependence of the $t$-slope of the cross section which is related to the tomographic partonic image of the nucleon. In the intermediate domain, the DVCS contribution will be boosted by the BH process through the interference term. COMPASS is presently the only facility to provide polarized leptons with either charge: polarized $\mu^+$ and $\mu^-$ beams. It should be noted that with muon beams one naturally reverses both charge and helicity at once. This feature allows with the same apparatus the measurements of Beam Charge ($C$) and Spin ($S$) Difference for Unpolarized ($U$) protons: $\mathscr{D}_{CS,U} \equiv d\sigma^{\overset{+}{\leftarrow}} - d\sigma^{\overset{-}{\rightarrow}}$ in which the BH contribution *cancels out* and Beam Charge and Spin Sum of cross sections: $\mathscr{S}_{CS,U} \equiv d\sigma^{\overset{+}{\leftarrow}} + d\sigma^{\overset{-}{\rightarrow}}$ in which the BH contribution *does not cancel out*.

From these measurements the real and imaginary part of Compton form factors (CFF) can be extracted. A CFF is a sum over flavors $f$ 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 analysis of the $\phi$ dependence will provide a measurements of the real part of the corresponding CFF. Fig.2(left) shows the projected statistical accuracy in a particular $(x_{Bj}, Q^2)$ bin, for a measurement of the $\phi$-dependence of the $\mathscr{D}_{CS,U}$. Two of the curves are calculated using the “VGG" GPD model [3]. The additional curve is the

[1] For simplicity $\mathrm{d}\sigma$ is used in the following instead of $\frac{\mathrm{d}^4\sigma(\mu p \to \mu p \gamma)}{\mathrm{d}x_{Bj}\mathrm{d}Q^2\mathrm{d}|t|\mathrm{d}\phi}$.

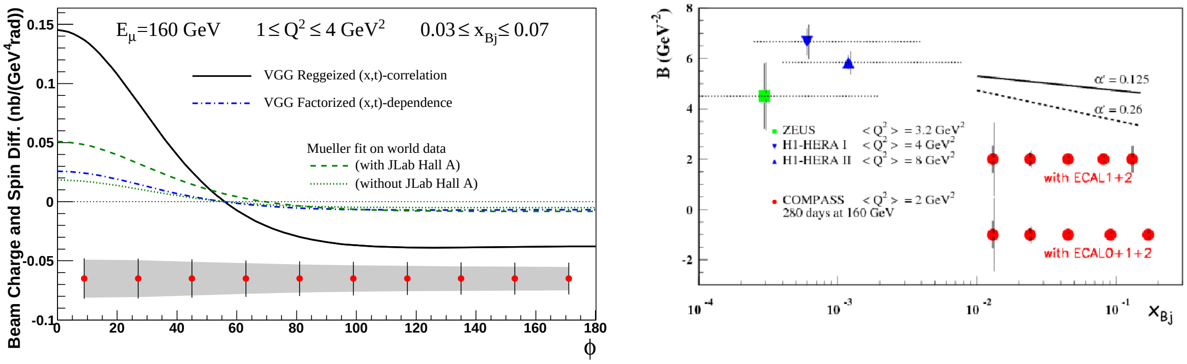


**FIGURE 2.** **Left:** Projected statistical (error bars) and systematic (grey band) accuracy for a measurement of the $\phi$ dependence of the $\mathscr{D}_{CS,U}$ at COMPASS for 2 years of data taking (equivalent to an integrated luminosity of 1222 $pb^{-1}$) and an overall *global efficiency* $\varepsilon_{global} = 0.1$. **Right:** Projections for measuring the $x_{Bj}$ dependence of the $t$-slope parameter $B(x_{Bj})$ of the DVCS cross section. For comparison some HERA results are shown [5, 6]. The left vertical bar on each data point indicates the statistical error only while the right one includes also the systematic uncertainty, using only ECAL1 and ECAL2 (first row) and also ECAL0 (second row).

result of a fitting procedure [4] including next-to-next-to leading order (NNLO) corrections which was developed and successfully applied to describe DVCS observables from very small values of $x_{Bj}$ for the HERA collider to large $x_{Bj}$ for HERMES and JLab. Fig.2(right) shows the projected statistical accuracy for a measurement at COMPASS of the $x_{Bj}$-dependence of the $t$-slope parameter $B(x_{Bj})$ of the DVCS cross section. In the simple ansatz $\frac{d\sigma}{dt} \propto \exp(-B(x_{Bj})\,|t|)$ and $B(x_{Bj}) = B_0 + 2\,\alpha' \log(\frac{x_0}{x})$. At small $x_{Bj}$, where amplitudes are predominantly imaginary, the overall transverse size of the nucleon $\langle r_\perp^2(x_{Bj})\rangle \approx 2 \cdot B(x_{Bj})$. Data on $B$ exist only for the HERA collider $x_{Bj}$-range from $10^{-4}$ to 0.01 [5, 6]. In the valence region, where no experimental determinations of $B$ exist, some information comes from fits adjusted to form factor data which give $\alpha' \simeq 1$ GeV$^2$ [7, 8]. For the simulation two values $\alpha' = 0.125$ and $\alpha' = 0.26$ are shown which correspond to the half and the total of the value for Pomeron exchange in soft scattering processes. The larger value can be determined with an accuracy better than 2.5 sigma by using the two existing calorimeters ECAL1 and ECAL2 while the smallest value requires a new ECAL0 to get a better precision at large $x_{Bj}$.

## FIRST OBSERVATION OF BH AND DVCS EVENTS IN THE 2008 AND 2009 TESTS

In both years test runs were performed using the set-up for data taking with hadron beams. For the hadron spectroscopy measurements with a 40 cm long liquid hydrogen target a short Recoil Proton Detector (RPD) used for Time-of-Flight (TOF), energy loss measurements and triggering purposes was constructed. Apart from the shorter target and the corresponding RPD lengths, this set-up has the same features as the one planned for the proposed GPD program.

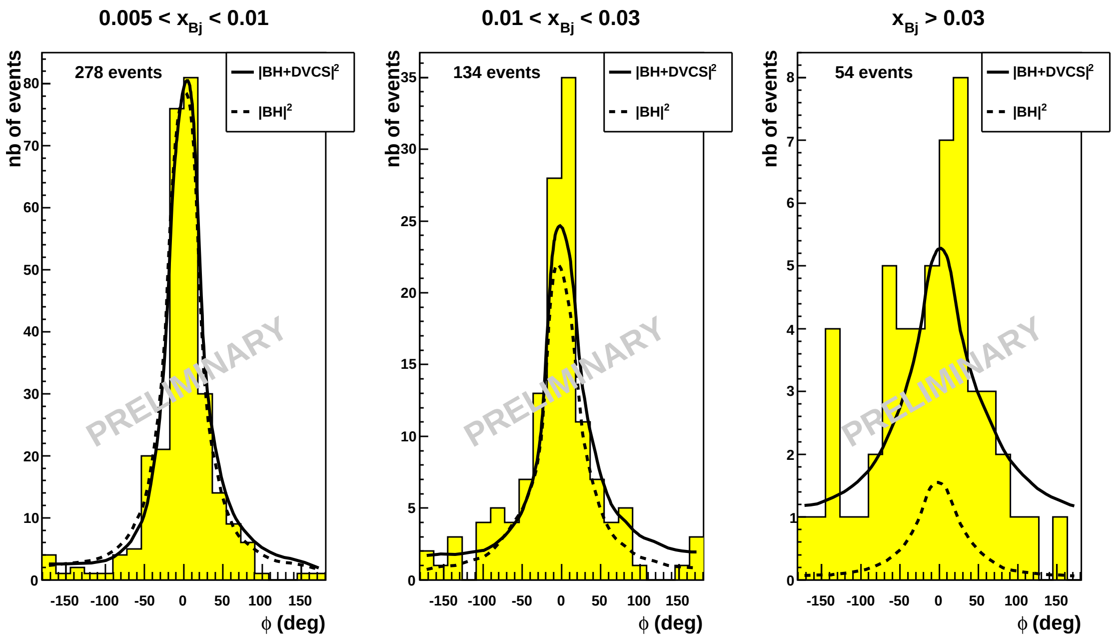


**FIGURE 3.** Distributions of the azimuthal angle $\phi$ for measured exclusive single-photon events ($Q^2 > 1\ (GeV/c)^2$) and comparison of these distributions with MC in the three $x_{Bj}$ intervals.

The 2008 DVCS test run allowed to detect the first exclusive single-photon events. The observed $\phi$ dependence of these events was compatible with the dominant BH process. A detection efficiency of $0.32 \pm 0.13$ for $\mu p \to \mu' p \gamma$ reaction was derived for $Q^2 > 1\ (GeV/c)^2$ region. The global overall efficiency, including also SPS beam and spectrometer availabilities, trigger and DAQ efficiencies, was found to be close to the value of 10% assumed firstly for Letter of Intent and later for the proposal.

The 2009 DVCS test run provided a first direct measurement of the relative contributions of the BH and DVCS (see Fig.3). At low $x_{Bj}$ ($0.005 < x_{Bj} < 0.01$) BH is dominant, while at $x_{Bj} > 0.03$ DVCS component is more important than BH one. As can be noted the $\phi$ dependence of the DVCS cross section predicted by the MC simulation is not flat. This effect will be corrected by new large angle calorimeter ECAL0 described in the COMPASS II proposal [1].

## REFERENCES


1. COMPASS-II proposal, SPSC-P-340.
2. A.V.Belitsky, D.Müller and A.Kirchner, Nucl. Phys. B **629** (2002) 323.
3. M.Vanderhaeghen, P.A.M.Guichon and M.Guidal, Phys. Rev. Lett. **80** (1998) 5064; Phys. Rev. D **60** (1999) 094017; K.Goeke, M.Polyakov and M.Vanderhaeghen, Prog. Part. Nucl. Phys. **47** (2001) 401.
4. K. Kumericki,D. Mueller and K. Passek-Kumericki, Nucl. Phys. **B 794** (2008) 244, K. Kumericki and D. Mueller, arXiv 0904.0458[hep-ph]
5. H1, A. Aktas *et al.*, Eur. Phys. J.C **44** (2005) 1, F.D. Aaron *et al.*, Phys. Lett. B **659** (2008) 796.
6. ZEUS, S. Chekanov *et al.*, DESY-08-178, arXiv:hep-exp:0812.2517v3.
7. M. Diehl *et al.*, Eur. Phys. J. C **39** (2005) 1.
8. M. Guidal *et al.*, Phys. Rev. D **72** (2005) 054013.