DVCS Measurements at COMPASS-II

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Abstract. A major part of the future COMPASS program [1] is dedicated to the study of Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) to investigate the nucleon structure through Generalized Parton Distributions (GPD). The high energy muon beam from CERN SPS allows to measure these processes in a wide and up to now uncovered range in Bjorken x and Q^2. In the following we will focus on the DVCS measurement from unpolarized protons.

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INTRODUCTION

The future COMPASS-II experiment is situated at the CERN SPS M2 beam line. It provides high energy muon beams of either charges. The muons are produced in pion and kaons decays. Hence, they are naturally longitudinally polarized and the helicity is charge dependent. As will be discussed later this is an important and unique feature of COMPASS-II to access GPDs via DVCS. The existing COMPASS detector [2] equipped with a 2.5 m long liquid hydrogen target will be used. In order to accomplish the detection of exclusive events a 4 m long recoil proton detector (CAMERA) will be installed around the target. A further large angle electromagnetic calorimeter (ECAL0) placed just downstream of the target will be added. It increases significantly the acceptance of the detection of DVCS. The comparison of the kinematic Q^2 and x_B region of COMPASS-II with other experiments is shown in Fig. 1. As can be seen COMPASS-II will cover the uncharted region between the collider experiments at HERA and the fixed target experiments as HERMES and the planned 12 GeV extension of JLAB.

DVCS MEASUREMENTS

The final state of DVCS is similar to the one of the Bethe-Heitler (BH) process, which is elastic lepton-nucleon scattering with a hard photon emitted by either the incoming or outgoing lepton. Hence, the two processes interfere at the level of amplitudes and the differential cross section for hard exclusive muoproduction of a single real photon off an unpolarized proton target is given by

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

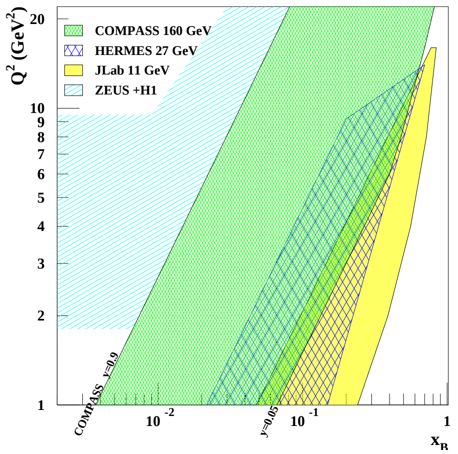

FIGURE 1. Kinematic domains for measurements of hard exclusive processes.

where P_μ and e_μ is the polarization and charge of the muon beam, respectively and I is the interference term between DVCS and BH. ϕ is the angle between the scattering plane and the photon production plane. Due to the high energy beam COMPASS-II reaches kinematic domains where either BH or DVCS dominates. This is illustrated in Fig. 2, showing a Monte Carlo simulation for $Q^2 > 1\,\mathrm{GeV}/c^2$. For $x_B < 0.01$ the BH process dominates, which provides an excellent reference yield to monitor the detector acceptance and the luminosity measurement. For $x_B > 0.03$ DVCS dominates. The distribution for DVCS is not flat in ϕ. This is given by acceptance effects as the simulation was performed without ECAL0. The size of the interference term increases with rising x_B and offers via its characteristic ϕ variation additional possibilities to access GPDs.

Building the Beam Charge (C) and Spin (S) Difference of the cross sections for Unpolarized (U) proton the BH contribution cancels out:

$$\mathscr{D}_{CS,U} \equiv \mathrm{d}\sigma^{+\leftarrow} - \mathrm{d}\sigma^{-\rightarrow} = 2\left(P_\mu \mathrm{d}\sigma^{DVCS}_{pol} + e_\mu \mathrm{Re}I\right) \propto \left(c_0^I + c_1^I \cos\phi\right). \tag{2}$$

In the last step the DVCS amplitude is expanded in $1/Q$ keeping only twist-2 terms [3]. The coefficients c_0^I and c_1^I are for COMPASS kinematics mainly related to the real part of the Compton Form Factor (CCF) $\mathscr{H}$ which is in leading order a weighted sum over flavors f of convolutions of the GPDs H^f with a kernel describing the hard interaction of virtual photon and quark. The projected statistical accuracy of the measurement of $\mathscr{D}_{CS,U}$ is shown in Fig. 3 on the left. It corresponds to a luminosity of $L = 1222\,\mathrm{pb}^{-1}$, which is equal to two years of data taking. Two of the curves are calculated using the VGG GPD model [4]. The other two curves are predictions based on first fits to world data [5, 6].

At leading twist the cross section of the Beam Charge (C) and Spin (S) Sum for Unpolarized (U) proton can be written as:

$$\mathscr{S}_{CS,U} \equiv \mathrm{d}\sigma^{+\leftarrow} + \mathrm{d}\sigma^{-\rightarrow} = 2\left(\mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS}_{unpol} + e_\mu P_\mu \mathrm{Im}I\right) \propto 2\mathrm{d}\sigma^{BH} + c_0^{DVCS} + s_1^I \sin\phi. \tag{3}$$

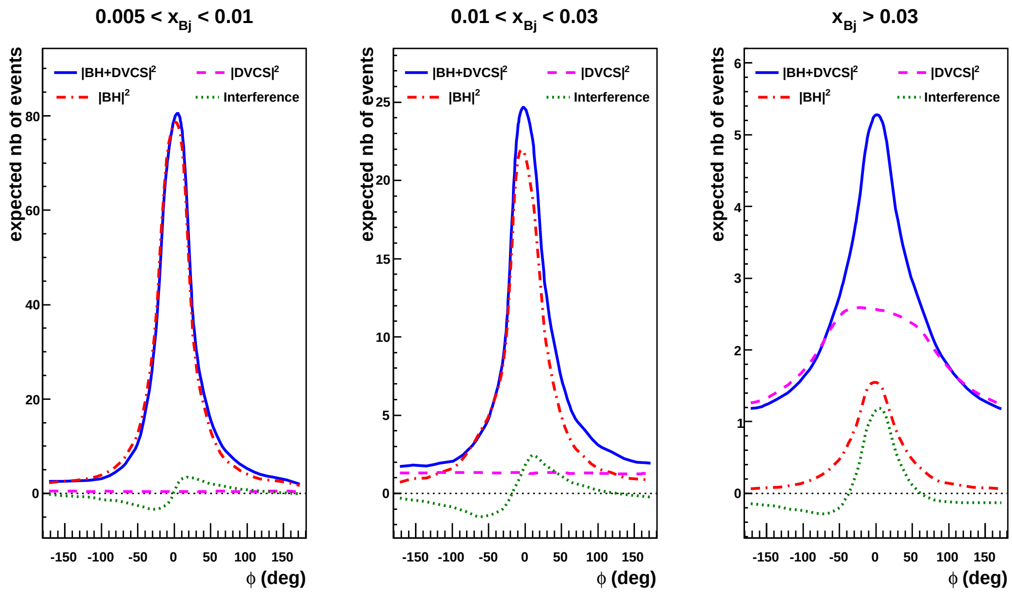

FIGURE 2. Monte Carlo simulation of exclusive muoproduction of single hadrons at COMPASS-II without ECAL0. Shown are the ϕ distributions of reconstructed events in three bins of x_B for $Q^2 > 1\,\mathrm{GeV}/c^2$.

The analysis of the $\sin\phi$ modulation gives access to s_1^I. Its dominant contribution is related to the imaginary part of the CCF $\mathscr{H}$, which is proportional to the GPD H. As well, we will study the ϕ integrated cross section $\mathscr{S}_{CS,U}$. Subtracting the BH contribution the quantity c_0^{DVCS} can be isolated and its characteristic t-slope as a function of x_B can be determined using the ansatz $\mathrm{d}\sigma/\mathrm{d}t \propto \exp(-B(x_B)\cdot|t|)$, with $B(x_B) = B_0 + 2\alpha' \log(x_0/x)$. At small x_B the overall transverse size of the nucleon is $\langle r_\perp^2(x_B)\rangle \approx 2 \cdot B(x_B)$. The projected statistical accuracy for this measurement is shown in Fig.3 on the right. Two values $\alpha' = 0.125$ and $\alpha' = 0.26$ were used in the simulation. The larger value correspond to the minimal slope, which can be measured with $2.5\,\sigma$ having only the existing calorimeters ECAL1 and ECAL2. The smaller one can be achieved using an additional large angle Calorimeter (ECAL0).

TEST MEASUREMENTS IN 2008 AND 2009

In 2008 and 2009 test measurements were performed using the COMPASS detector in the configuration for hadron spectroscopy. A 40 cm long liquid hydrogen target surrounded by a 1 m long recoil proton detector was used. The short run in 2008 proved the capability of the detection and reconstruction of exclusive single photon events. The measured ϕ dependence was found to be compatible with the dominant BH process. In 2009 approximately 10 times more statistics was collected allowing to observe the ϕ distributions in three bins in x_B (see Fig. 4). The solid lines represent the expected BH event yield while the histogram shows the measured single photon yields including misidentified π^0 events. As can be seen from these plots the COMPASS experiment provides an ideal tool to access this physics objectives.

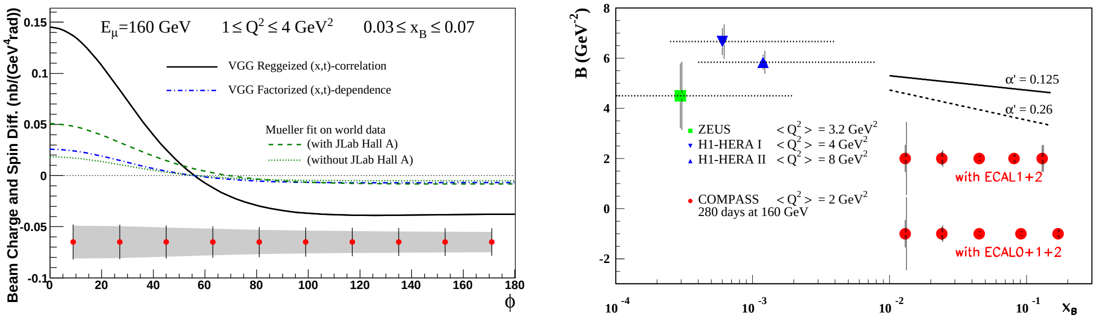

FIGURE 3. Left: Expected statistical (error bars) and systematic (gray band) accuracy for the measurement of the ϕ-dependence of $\mathscr{D}_{CS,U}$ for $1 \leq Q^2 \leq 4\,\mathrm{GeV}/c^2$ and $0.03 \leq x_B \leq 0.07$. Right: Projections for the t-slope parameter $B(x_B)$ measurement. The left error bars are indicating the statistical errors and the right the total, including systematics. In addition selective HERA results at similar $\langle Q^2 \rangle$ are shown [7, 8, 9]

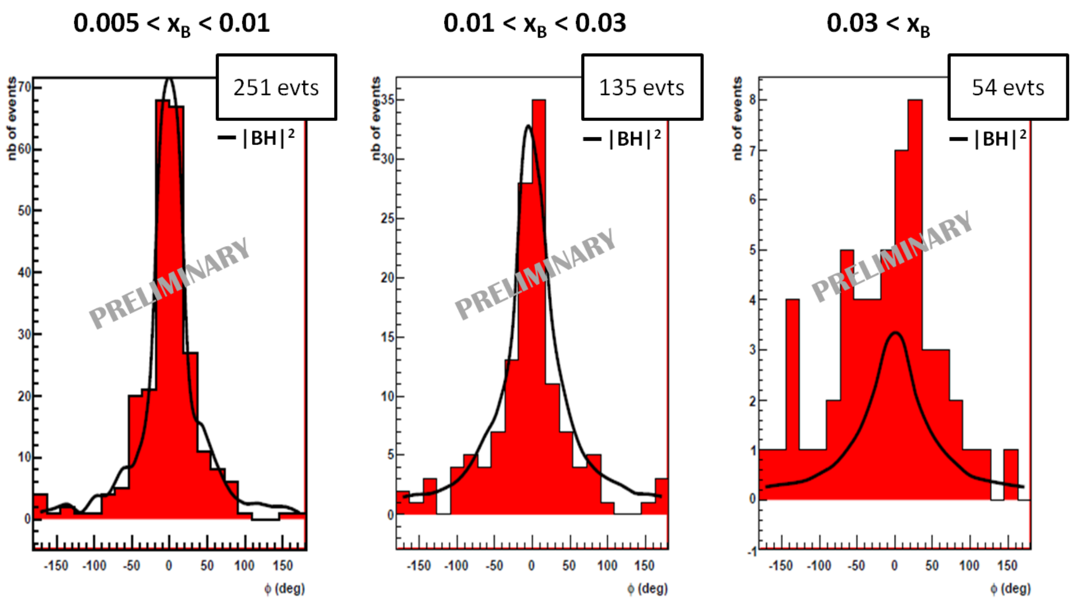

FIGURE 4. ϕ distributions measured in the 2009 DVCS test run at COMPASS. The solid lines represent the expected BH event yield.

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