FEASIBILITY STUDY OF DEEPLY VIRTUAL COMPTON SCATTERING USING COMPASS AT CERN*

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(Received June 27, 2002)

Deeply virtual Compton scattering is a very suitable tool to learn about Generalized parton distributions. We propose to use the 190 GeV (or 100 GeV) muon beam at CERN to study Deeply Virtual Compton Scattering. The high energy of the lepton beam and the present luminosity allows to measure absolute cross section or beam charge asymmetry in a large range of Q^2 and $x_{\rm Bj}$ ($1 \leq Q^2 \leq 7$ GeV^2 and $0.03 \leq x_{\rm Bj} \leq 0.27$). We discuss the experimental implications for the existing COMPASS set-up.

PACS numbers: 13.60.–r

1. DVCS and Generalized Parton Distributions

Deeply Virtual Compton Scattering (DVCS) is a very suitable tool to learn about Generalized Parton Distributions (GPDs). These functions [1] seem very promising in the quest for understanding the structure of the nucleon. They provide a clear link between the elastic form factors and the parton distributions measured in Deep Inelastic Scattering (DIS). Moreover, GPDs complete the nucleon spin puzzle as they give a measurement of total angular momentum contribution of the quarks to the nucleon spin.

In terms of the quark and gluon nucleon wave functions, the usual parton distributions are the squared wave function components containing a parton with longitudinal momentum fraction x. This represents the probability for finding such a parton. In contrast, GPDs represent the interference of different components of the wave function, one where a parton has a longitudinal

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

momentum fraction $x+\xi$ and one where this fraction is $x-\xi$. The GPDs also depend on the momentum transfer t which has a transverse component at non zero scattering angle. For quarks, four different GPDs contribute to DVCS. They are $H^q(x,\xi,t)$, $E^q(x,\xi,t)$, $\tilde{H}^q(x,\xi,t)$, $\tilde{E}^q(x,\xi,t)$ where q is a quark flavor index. The H and $\tilde{H}$ are generalizations of the parton distributions $q(x)$ and $\Delta q(x)$ measured in DIS. The contribution of E^q and $\tilde{E}^q$ vanishes in the forward limit and these are really new functions.

A simple physical interpretation of GPDs has emerged [2] from the sum rule which relates the first moments of the GPDs to the form factors

$$\sum_q e_q \int\limits_{-1}^{+1} H^q(x,\xi,t)dx = F_1(t)\,.$$

The GPDs measure the contribution of the quarks with longitudinal momentum fraction x to the corresponding form factor. Given the fact that one can associate the Fourier transform of form factors with charge distributions in position space, one can expect that the GPDs contain information about the distribution of partons in tranverse position space. This has been demonstrated for $\xi = 0$. Qualitatively one expects that quarks with a large x come essentially from the small valence "core" of the nucleon, while the small x region should receive contributions from the much wider meson "cloud". Therefore, one expects a gradual increase of the t-dependence of $H(x,0,t)$ as one goes from larger to smaller values of x.

Deeply virtual Compton scattering is accessed by lepton scattering $lp \to l'p'\gamma'$. In this reaction, the final photon can be emitted either by the leptons (Bethe–Heitler process) or by the proton (genuine DVCS process). If the lepton energy is large enough, the DVCS contribution dominates over the BH contribution so that the cross section is essentially the square of the DVCS amplitude ($\xi \sim x_{\rm Bj}/2$ and t are fixed by the experiment)

$$T^{\rm DVCS} \sim \int\limits_{-1}^{+1} \frac{H(x,\xi,t)}{x-\xi+i\varepsilon}dx \ldots \sim \mathcal{P}\int\limits_{-1}^{+1} \frac{H(x,\xi,t)}{x-\xi}dx \ldots - i\pi H(\xi,\xi,t)\ldots\,.$$

At smaller lepton energy, the interference between BH and DVCS becomes large and offers a unique opportunity to study Compton scattering at the amplitude level. If a longitudinally polarized lepton beam is used, the helicity-dependent interference term is proportional to the imaginary part of the DVCS amplitude and this selects the GPDs at the specific values $x=\xi$. If a lepton beam with two possible charge states is used, the charge dependent interference term is then proportional to the real part of the DVCS amplitude which, for a given ξ, is sensitive to the complete dependence on x of the GPDs. The deconvolution (over x) of this formula to extract the GPDs is not yet clearly solved, but comparison to model predictions can easily be made.

Fig. 1 shows the charge asymmetry which can be measured at COMPASS and the large sensitivity to two different models [3]. The first one relies on the simplest parametrization (factorization) of the t-dependence of the GPDs. The second one is based on the geometric description, with a gradual increase of the t-dependence of $H(x,0,t)$ as one goes from larger to smaller values of x (no factorization) for a given ξ, is sensitive to the complete dependence on.

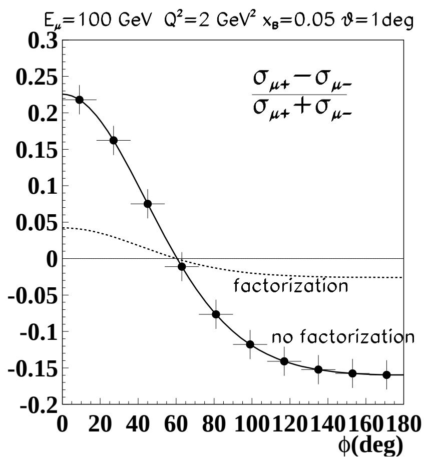

Fig. 1. Beam charge asymmetry measured at COMPASS for $E_\mu = 100$ GeV, $x_{\mathrm{Bj}} = 0.05 \pm 0.02$, $Q^2 = 2 \pm 0.5$ GeV^2, and $|t| \leq 0.3$ GeV^2 in 3 months of data taking for each μ^+ and μ^- beam of $2.10^8 \mu$ per spill and 100% efficiency.

The DVCS experiments are difficult to perform as they require high energy, high luminosity, and good resolution. They have been undertaken with the HERA collider to study mainly gluon contribution at very small x_{Bj} ($\leq 10^{-2}$) or with fixed target to investigate larger x_{Bj}. It is the case at JLab (at 6 GeV, with the hope for an upgrade at 11 GeV), at HERMES (at 27 GeV). An experimental program using COMPASS at CERN (at 100 or 190 GeV) will enlarge the kinematical domain (see Fig. 2 for comparison) and this program is now under evaluation. The high energy of the muon beam and the present luminosity allows to measure absolute cross section or beam charge asymmetry in a large range of Q^2 and x_{Bj} ($1 \leq Q^2 \leq$ 7GeV^2 and $0.03 \leq x_{\mathrm{Bj}} \leq 0.27$).

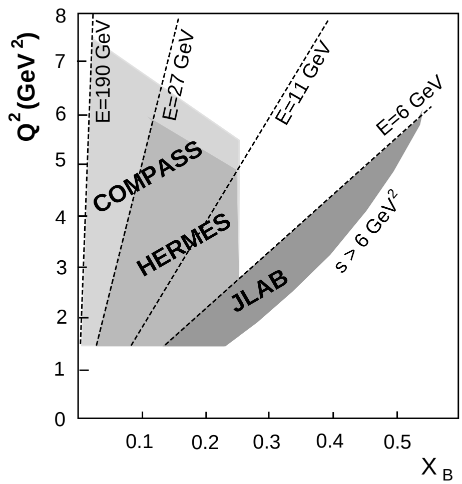

Fig. 2. Kinematical coverage for various planned or proposed experiments. The limit $s \geq 6$ GeV^2 assures to be above the resonance domain, and $Q^2 > 1.5\,\mathrm{GeV}^2$ allows to reach the deep inelastic regime.

2. Possible realization for a DVCS experiment at COMPASS

It is important to use the highest luminosity reachable at COMPASS, $\mathcal{L} = 1.5 \times 10^{32}$ cm^{-2}s^{-1} given by $2{\times}10^8$ muons per spill and a 2.5 meter long liquid hydrogen target. This luminosity allows one to expect the statistical accuracy presented in Fig. 1 for the beam charge asymmetry measurement.

This section presents the experimental procedure to select the exclusive DVCS channel and the different pieces of detection that are required. They are mostly part of the existing COMPASS set-up: muon detection which insures a good resolution in x_{Bj} and Q^2, photon detection with a reassembly of the present electromagnetic calorimeters ECAL1 and ECAL2. In fact to match as well as possible the kinematical phase space of the outgoing photon, defined by 2 domains:

domain I: 1 deg. $\leq \theta_\gamma \leq$ 8 deg. and $P_\gamma \leq$ 64 GeV/c

domain II: 8 deg. $\leq \theta_\gamma \leq$ 20 deg. and $P_\gamma \leq$ 16 GeV/c

and to insure a good separation of two photons of π^0 decay which is a large contribution of background, it is possible to use ECAL2 at 3m and ECAL1 at 13 m downstream from the target (see Fig. 3).

At these high energies for muons and photons, the complete final state needs to be detected because missing mass techniques are not efficient due to the experimental resolutions. Thus our studies have focused on the possibility to design and successfully operate a dedicated recoil detector.

This detector must identify protons in the range 250–750 MeV/c and 30–70 deg. Fig. 3 shows such a detector. Here, the identification of the proton is performed through the correlation of its time of flight (between the inner (A) and outer (B) layers of scintillator) with respect to its energy loss in the outer layer of scintillator which is 5 cm thick.

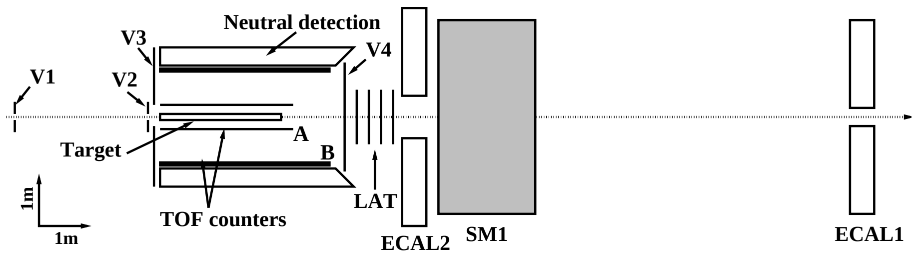

Fig. 3. Global set-up with the recoil detector upstream from SM1 and the new position of the electromagnetic calorimeter, ECAL2 at 3m and ECAL1 at 13m downstream from the target in order to provide a good detection of photons in a large forward acceptance. The complete COMPASS equipments are not clearly indicated, but should be present.

The detector must also be sensitive to competing reactions in which neutral particles such as photons and neutrons are produced. Thus we plan to detect neutral particle in another scintillator layer placed after a converter surrounding the time of flight detector.

The role of the veto V4 is to insure the exclusivity by a good rejection of additional charged particles in the forward direction.

3. Tests at CERN

We have tested the concept of this detector using the already existing muon beam (with intensity of 2×10^8 muons per spill) and a simplified set-up (one sector of scintillators with reduced length). The muon beam was scattered off a 10 cm long polyethylene target, mostly equivalent in radiation length to the forseen long liquid hydrogen target. We used two scintillators read-out at both sides, a 4mm thick close to the target (A), a 5 cm thick 80 cm away from the target (B). The rates observed in the scintillator close to the target is of the order of 1 MHz (mainly due to δ-rays). It demonstrates that the background environment is acceptable for the time of flight system.

The result of the time of flight operation (see Fig. 4) shows a clear proton signal even though most of the hits are coming from pions and electrons. The position resolution obtained on (A) and (B) and the time of flight resolution are better than 2 cm and 300 ps, respectively. This is the goal for the DVCS experiment. An efficiency study of such a recoil detector is being performed.

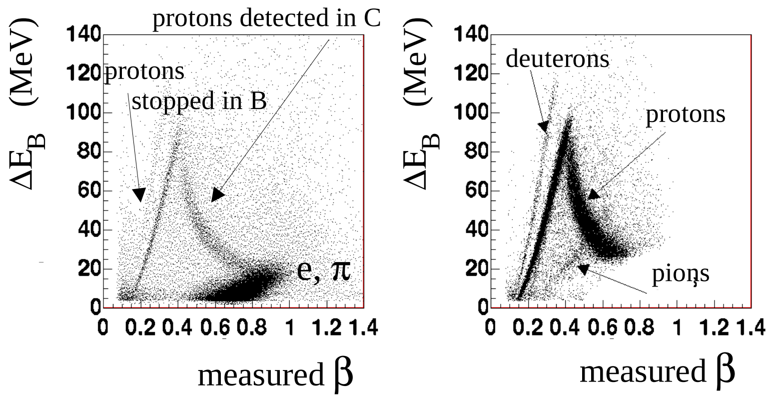

Fig. 4. Energy loss in the (B) scintillator as a function of the measured β for raw data (left) and corrected data with energy loss cuts in the (A) scintillator (right).

4. Conclusion

This is a first attempt to define the outline of a DVCS experiment at COMPASS which takes advantage of the high energy of the muon beam and the large domain in Q^2 and $x_{\rm Bj}$. This study will certainly be improved by the expertise of the COMPASS collaboration. Complementary studies on deep meson production have to proceed in order to determine the optimized COMPASS set-up and to enlarge the scope of the experiment with respect to the physics of the GPDs.

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