FEASIBILITY STUDIES FOR GPD'S MEASUREMENT AT COMPASS

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Abstract

Deeply Virtual Compton Scattering is a clean way to access the Generalized Parton Distributions of the proton. This paper deals with a possibility to perform such an experiment with the COMPASS apparatus which allows to access a large range in x_{Bj} (0.03 to 0.25) and Q^2 (1.5 to 7.5 GeV^2). A possible design for a recoil detector which is necessary to complement the COMPASS setup, is presented.

Preliminary results on exclusive ρ^o production from the COMPASS 2002 run are given. They look promising for future studies of deep ρ^o production.

Deeply Virtual Compton Scattering (DVCS) has been recognized few years ago as a very promising tool to probe the nucleon structure. A lot of theoretical work was done to determine properties and interpretations of Generalized Parton Distribution (GPDs) [1]. They provide a unified description of the nucleon, by interpolating between the parton distributions and the hadronic form factors. Experimentally the GPDs can be accessed through exclusive measurements such as DVCS and Hard Exclusive Meson Production. We propose to study these reactions with the high energy muon beam available at CERN which provides a large Q^2 and x_{Bj} range.

1. DVCS process

At leading order, the DVCS ($\gamma^* + \mathrm{p} \rightarrow \gamma + \mathrm{p}$) process reduces to the "handbag" diagram (figure 1). This process can be factorized [2] in two parts: a "hard" part calculable in perturbative QCD and a "soft" part for the proton described in terms of GPDs. This factorization is valid in the Deep Inelastic Scattering (DIS) regime and at small transfer t. GPDs depend on t, ξ and x, longitudinal momentum fractions of the quark ($\xi \sim x_B/2$). GPDs could also be extracted from Hard Exclusive Meson Production where a meson like π, ρ^o... is emitted.

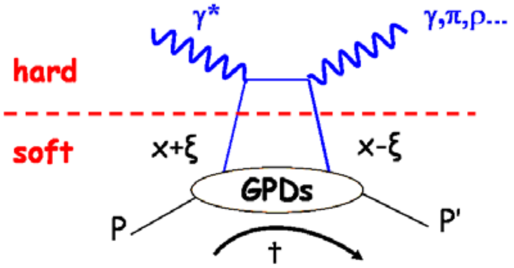

Figure 1. The DVCS "handbag" diagram describing the DVCS process at leading order.

2. DVCS experiment

COMPASS setup [3] is well suited to investigate DVCS [4] mainly due to its high muon beam energy which allows to access large Q^2 values (1.5 to 7.5 GeV^2) for x_{Bj} ranging from 0.03 to 0.25 (figure 2). The DVCS interferes with the Bethe-Heitler (BH) process. At COMPASS two scenarii could be considered : either DVCS cross section measurement at high energy (∼190 GeV) where the DVCS cross section dominates over the BH cross section or beam charge asymmetry measurement at lower energy where the amplitudes of both processes are similar.

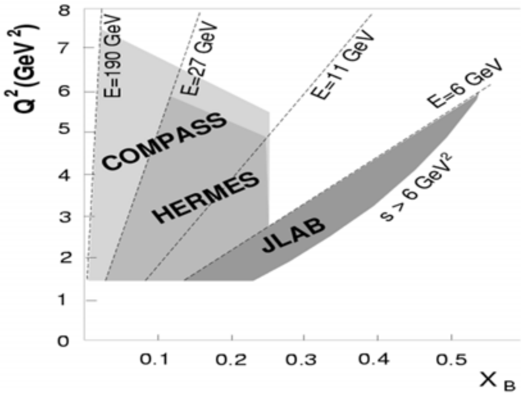

Figure 2. (x_{Bj}, Q^2) domains for the COMPASS, HERMES and JLab for DVCS studies.

3. Experimental issues

A possible experiment would use a 100-190 GeV muon beams which would scatter off a 2.5 m long liquid hydrogen target. A luminosity of 1.3 10^{32} $s^{-1}.cm^{-2}$ could be achieved under such conditions. The μ scattered in the very forward direction ($\leq 1^o$) would be measured in the present high resolution COMPASS spectrometer. The γ is emitted at larger angle, but below 10^o. It would be detected using the electromagnetic calorimeters, extended up to 24^o in order to improve the separation between γ and π^o production. The recoil proton has small momentum (<750 MeV/c) and scatters at large angle ($0^o < \theta_p < 90^o$). Therefore it could not be detected in the present COMPASS apparatus. Furthermore, the missing mass energy technique using the energy balance of the scattered μ and the photon is not accurate enough at high beam energy. Thus, a recoil detector has to be designed to insure the exclusivity of the DVCS process.

a- The recoil detector

A recoil detector based on a time of flight measurement between two barrels of scintillating slats read at both ends is shown in figure 3. The inner barrel (∼2.5 m long) surrounding the target should be made of slats as thin as possible (∼ 4 mm) to allow low momentum proton detection. Thicker (∼ 5 cm) and longer (∼ 4 m) slats should be used for the outer barrel. A timing resolution of 200 ps is required for a time of flight measurement. External layers of scintillator interleaved with lead should be added to detect especially neutral particles to give an estimate of physical background. To insure the exclusivity of the reaction veto scintillators (V_i) and additional electromagnetic calorimeter (ECAL) set upstream of the dipole (SM1) should be added. The combination of measurements of the time of flight and of the energy loss in the various sensitive detectors would provide discrimination of DVCS in this detector.

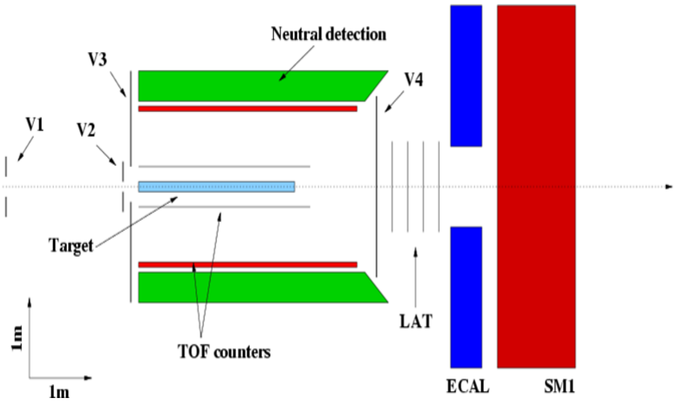

Figure 3. Proposition for a detector complementing the COMPASS setup. Recoil detector with two barrels of scintillating slats (TOF), an extended calorimetry from 10^o to 24^o, veto scintillators (Vi) have been added.

b- Feasibility studies

During COMPASS data taking in 2001, we have tested the ability to detect and to discriminate protons in realistic conditions. For that, a 10 cm CH_2 target (equivalent to 2.5 m liquid hydrogen) was used at the nominal beam intensity of COMPASS. Two short scintillators read at both ends, set parallel to the beam, at 25 cm for the thin one (4 mm) and at 80 cm for the thick one (5 cm), were used to detect charged particles. Figure 4 shows the energy loss in the thicker scintillator versus the velocity deduced from the measurement of the time of flight. For $0.2 \leq \beta \leq 0.62$ we are clearly able to discriminate protons from pions and deuterons. To go further, a prototype with real dimension (five times longer !) and an azimuthal coverage of 20^o is in preparation and should be installed downstream of COMPASS after 2005.

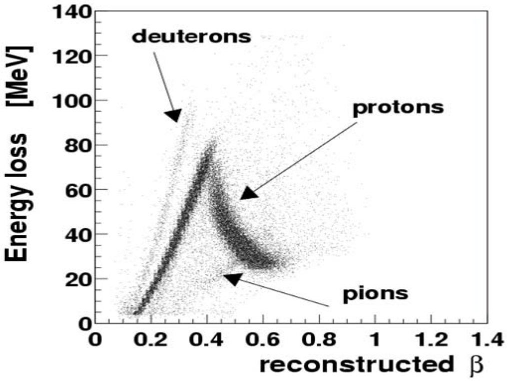

Figure 4. Energy loss in the thick scintillator with nominal beam intensity corresponding to a 10^{32} $s^{-1}.cm^{-2}$ luminosity as a function of β.

c- Background evaluation

In the DVCS process there are three particles in the final state: the scattered μ, the γ and the recoil proton. We have estimated the rate of hard processes which could mimic the DVCS using Pythia 6.1 [5]. This was done for the foreseen recoil detector with its acceptance and thresholds as well as acceptance of the existing COMPASS detectors for the muon and for the photon. Same cuts as for DVCS events were applied : one charged particle in the recoil detector, only one photon in the calorimeter, one scattered muon and no other charged particle in sensitive detectors. Under these conditions, it appears that DVCS dominates hard processes over the whole Q^2 range (figure 5).

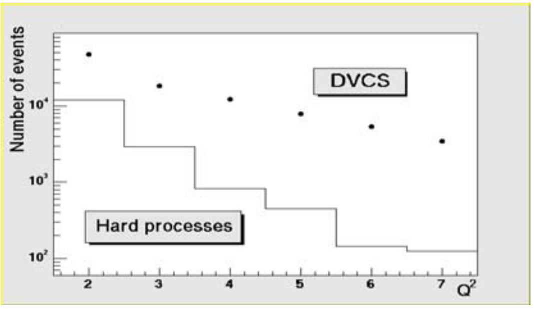

Figure 5. Background estimation coming from hard processes using Pythia 6.1 compared to DVCS.

4. Beam charge asymmetry predictions at COMPASS

With a 100 GeV muon beam, the interference between DVCS and BH becomes large and offers a unique opportunity to study Compton scattering amplitude. The difference of cross sections $\sigma(\mu^{+\downarrow}) - \sigma(\mu^{-\uparrow})$ allows one to select the real part of the DVCS amplitude [4]. At 100 GeV, we should get μ^+ and μ^- beams of comparable beam intensity but opposite polarization [6]. The Beam Charge Asymmetry (BCA) predictions are shown in figure 6 for various (x_{Bj}, Q^2) domains versus the azimuthal angle ϕ between leptonic and hadronic planes. Statistical error bars are evaluated for 6 months of data taking with a 25% global efficiency. The data should al-

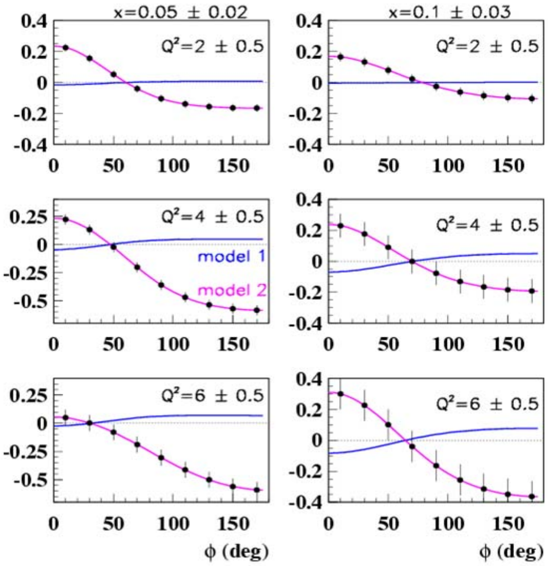

Figure 6. Beam Charge Asymmetry for 6 months data taking with 25% efficiency. Models are described in the text.

low for a discrimination among various extreme models. Model 1 [7] uses a simple ansatz to parameterize GPDs based only on nucleon form factors, parton distributions and fulfills the GPD sum rules. Model 2 [8] integrates these ingredients and in addition includes the fact that valence and sea quarks are not distributed randomly in the proton. In this case, proton is pictured as a compact core of valence quarks surrounded by sea quarks and gluons. Thus, a BCA measurement at COMPASS should answer how relevant is this picture.

5. Exclusive ρ^o production with COMPASS

As it was mentioned, GPDs can be studied from hard exclusive meson production, e.g. $\mu^+ p \to \mu^+ \rho^o p$ where ρ^o decays mainly in a $\pi^+\pi^-$ pair. A preliminary analysis of 1/6 of 2002 data was done. Events with only two opposite charged hadrons and one scattered muon in the final state were selected. An additional cut on the missing mass is added to enhance the exclusivity of this reaction. 1.3 millions of events have passed successfully these criteria, ranging from quasi-real to DIS regime. No acceptance and smearing corrections were applied in the following data distributions.

a- Mass distribution

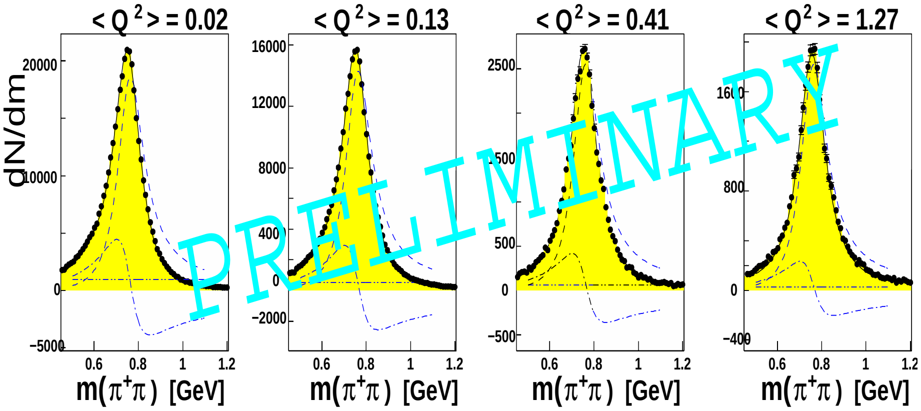

Figure 7. ρ^o mass distribution for four Q^2 bins.

The mass distributions of the $\pi^+\pi^-$ pairs for these events is shown on figure 7 for various Q^2 bins. If one uses the Söding parametrization [9] which takes into account the interference between resonant ρ^o production (dashed curve) and "Drell-type" background processes (dash-dotted curve), a rather good fit (full curve) with the data is achieved. Moreover, non exclusive two pion production is found to be negligible.

b- Angular distribution

The study of angular distributions in ρ^o production and decay provides information on the ρ^o polarization. In the γ^*p rest frame, three angles are traditionally defined to describe the ρ^o production : Φ the angle between leptonic and hadronic plane, ϕ the angle between leptonic and ρ^o decay plane and θ the decay angle between the ρ^o and the π^+ in the ρ^o rest frame. Integrating over Φ and ϕ, the angular distribution reduces to $W(cos\theta) = 3/4[(1 - r^{04}_{00}) + (3r^{04}_{00} - 1)cos^2\theta]$ where r^{04}_{00} is a matrix element which represents the fraction of longitudinal ρ^o. Furthermore, if we assume the s-Channel Helicity Conservation (SCHC), the angular dependence on Φ and ϕ reduces to a $\Psi = \phi - \Phi$ dependence. Integrating over θ, we obtain $W(\Psi) = 1/2\pi[1 + 2\epsilon r^{-1}_{1-1} cos2\Psi]$. Moreover natural parity exchange in the t channel gives $r^1_{1-1} = 1/2(1 - r^{04}_{00})$. On figure 8 are plotted $cos\theta$ and Ψ distributions for 4 different Q^2 bins. The curves, obtained from previous relations, fit rather well the data.

One may remark the evolution of the $cos\theta$ distribution from a $sin^2\theta$ to a $cos^2\theta$ shape and the attenuation of the Ψ oscillations when Q^2 increases. This is consistent with increasing fraction of the longitudinally polarized ρ^0 when larger Q^2 are selected. This is an encouraging sign for future deep ρ^0 study because it is mandatory to select a longitudinal ρ^0 to fulfill the factorization between soft and hard part of the "handbag" diagram if we want to investigate GPDs.

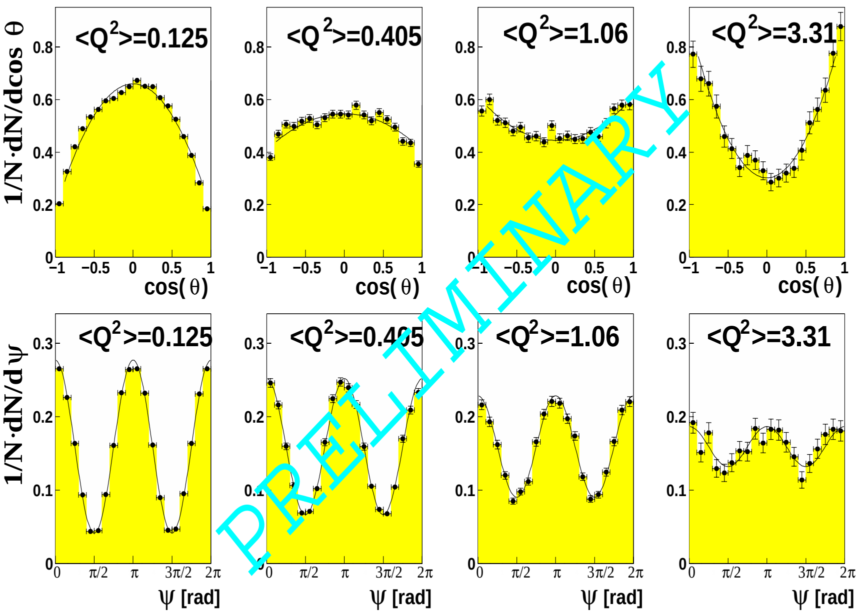

Figure 8. ρ^0 angular distributions for four Q^2 bins.

6. Conclusion

DVCS is an exciting physics case where theoretical and experimental communities are very active. With its large domain in (x_{Bj}, Q^2) COMPASS offers an exceptional opportunity to investigate this topic. Measurements of DVCS will be considered in a proposal including a recoil detector integrated to the present COMPASS setup to insure the exclusivity of the reaction. European funding has been provided to build a prototype detector to demonstrate the feasibility of such an experiment.

The preliminary analysis of the ρ^0 production using COMPASS is promising. The data should allow to investigate hard exclusive ρ^0 production and to have a first look at GPDs.

References

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