Prospects For Measurements Of Generalized Parton Distributions At COMPASS

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Abstract. The concept of Generalized Parton Distributions extends classical parton distributions by giving a "3-dimensional" view of the nucleons, allowing to study correlations between the parton longitudinal momentum and its transverse position in the nucleon. Measurements of such generalized distributions can be done with the COMPASS experiment, in particular using Deeply Virtual Compton Scattering events. They require to modify the set-up of COMPASS by introducing a recoil proton detector, an additional electromagnetic calorimeter and a new liquid hydrogen target. These upgrades are presently under study, and the first data taking could take place in 2010.

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PHYSICS MOTIVATIONS

The parton distributions one can extract from inclusive deep inelastic scattering describe the longitudinal momentum of the partons inside the nucleon, but no transverse information is provided by such a description. The Generalized Parton Distributions [1] (GPD) can provide a more complete view of the nucleon structure, which extends the classical parton distributions. By using the optical theorem, one can show that the inclusive γ^*-nucleon DIS cross section is related to the imaginary part of the exclusive elastic γ^*-nucleon amplitude (see Figure 1a), where the transfer is zero. GPD can be extracted from such interactions by relaxing the zero transfer constraint and adding two additional parameters (see Figure 1b). Four Generalized Parton Distributions can be defined, two in non-polarized interactions E(x, ξ, t) and H(x, ξ, t), and two in polarized ones $\tilde{E}$ (x, ξ, t) and $\tilde{H}$ (x, ξ, t), where ξ, equal to $x_{Bj}/(2-x_{Bj})$, is the longitudinal momentum fraction transfer, x is the longitudinal momentum fraction average, and t the square of the momentum transfer to the target nucleon. The H and $\tilde{H}$ GPD are linked to classical parton distributions, as well as form factors.

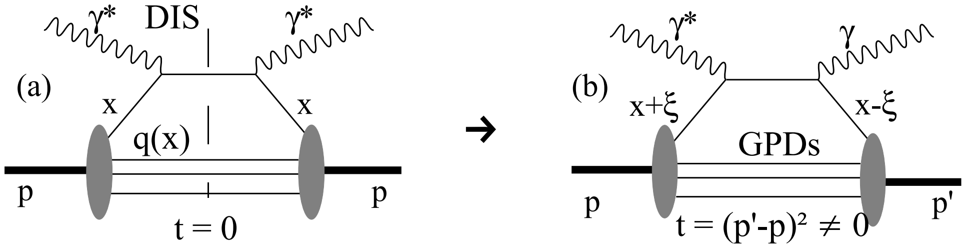

FIGURE 1. Parton distributions in symmetrized DIS, and GPD in DVCS

The t parameter is also the Fourier conjugate of the transverse distance from the parton to the nucleon center. The GPD can then provide a nucleon description which associates the longitudinal momentum and the transverse position of the partons. Several theories, like Chiral dynamics [2] or lattice computations [3, 4], predict that partons at high x_{Bj} like valence quarks, are concentrated in the center of the nucleon, giving a decrease of $<r_\perp^2>$ when x_{Bj} increases.

GPD MEASUREMENT AT COMPASS

COMPASS is a fixed-target experiment on the CERN SPS M2 polarized muon beam line, dedicated to nucleon structure and spectroscopy studies. GPD can be measured in this experiment by two methods, Deeply Virtual Compton Scattering (DVCS) and Hard Exclusive Meson Production (HEMP) (Fig. 2). DVCS is a direct and clean process, with two well separated hard and soft processes which can be factorized. HEMP is more complex as it introduces soft components on the hard part of the interaction, nevertheless flavor separation can be done by studying production of different sorts of mesons. Both processes will be studied at COMPASS, but only DVCS is presented here.

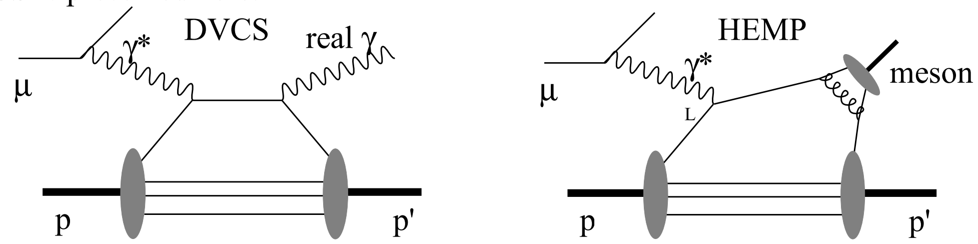

FIGURE 2. DVCS and HEMP processes

Bethe-Heitler processes (photon radiation by the muon) interfere with DVCS as they have the same final state. The relative amplitude of these two processes can be tuned by changing the beam energy [5]. With a 190 GeV muon beam, DVCS predominates, giving the possibility to measure the DVCS cross section. At 100 GeV, both processes have a similar amplitude, thus the interference term gives access to the DVCS amplitude as the Bethe-Heitler amplitude is already well known. The DVCS amplitude extraction is simplified by taking into account the dependence on the ϕ angle between the leptonic and hadronic planes of the interaction, and by comparing cross section measurements using muon beams with opposite charge and polarization. With a 100 GeV beam, the cross-section difference between both beams gives access to the integral of the GPD distributions (noted here *f*) over x, while the sum gives the GPD value at $x=\xi$.

$$\sigma(\mu^{+\rightarrow})-\sigma(\mu^{-\leftarrow})\sim\Re e\,A(\gamma^*_T)\sim P\int_{-1}^{1}dx\,\frac{f(x,\xi,t)}{x-\xi}$$

$$\sigma(\mu^{+\rightarrow})+\sigma(\mu^{-\leftarrow})\sim\Im m\,A(\gamma^*_T)\sim-i\pi\,f(x=\xi,\xi,t)$$

Requirements on the experimental set-up

A GPD measurement using the DVCS process would be possible in the COMPASS experiment at the expense of some modifications of the experimental set-up. COMPASS takes advantage of the longitudinally polarized muon beam with a tunable energy from 100 to 190 GeV, the beam particles can be polarized μ^+ in one direction and polarized μ^- in the other one. The beam current can reach 2.10^8 µ/spill at 100 GeV with a polarization around 80%. The integrated luminosity has already been measured by the NMC experiment [6], which took place on the same beam line, using hodoscopes counting rates and/or random beam samplings. The precision reached was around 1%, which is better than what is needed for the GPD measurement. The target which will be built for this experiment is a tube filled with liquid hydrogen, with a diameter of 3 cm and length of 2.5 m. The expected luminosity will be on the level of $1.3.10^{32}$ $cm^{-2}s^{-1}$.

Different modifications are needed for the detectors, to be able to detect the three final particles of the interaction. In particular it is important to detect the recoil proton to ensure the exclusivity of the reaction, as at beam energies over 100 GeV the standard missing mass method has a precision not better than $\Delta m_p^2 = 1$ GeV^2, which is higher than the required accuracy of 0.25 GeV^2 to exclude an additional pion. A recoil detector (Fig. 3) will be built to provide good hermiticity. It is composed of two barrels of 24 scintillators with a length of 4 m. Each will be read by photomultiplier tubes on both ends. A time resolution of 250 ps is needed to measure the time of flight of protons with an energy of 250 to 750 MeV with a good resolution on t transfer. Veto scintillators are also placed in front and back sides to complete the hermiticity of the set-up. Tests of a prototype are presently ongoing on the COMPASS beam line.

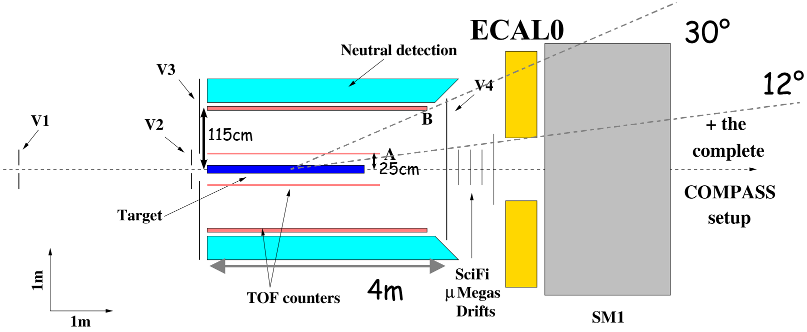

FIGURE 3. New recoil proton detectors around the liquid hydrogen target with additional veto scintillators, and new electromagnetic calorimeter ECAL0 in front of the first spectrometer dipole

The scattered muon and the photon will be detected by the present COMPASS spectrometers. However the COMPASS electromagnetic calorimeters used to detect the photon cover only an angular range of 0.4 to 12°. An additional calorimeter named ECAL0 is then foreseen to extend this coverage to 24° to better reject background by $\pi^0 \rightarrow 2\gamma$; it could be placed in front of the first spectrometer dipole magnet. The present electromagnetic calorimeters are built from lead glass blocks with an energy resolution of 5.5%/√E, and a position resolution of 6mm/√E.

PROSPECTS FOR THE RESULTS

DVCS measurements at COMPASS will cover a quite large kinematical domain in x_{Bj} from 0.03 to 0.27 and Q^2 from 1.5 to 7.5 GeV^2, split in 3 bins in x_{Bj} and 6 bins in Q^2. The Q^2 range could be extended up to 11 GeV^2 if the beam intensity is doubled. The projected results of the beam charge asymmetry between μ^+ and μ^- beams, with 150 days of data taking at 100 GeV with 25% efficiency, are shown in Fig. 4 for two of the 18 bins. They are compared with two models predictions produced by

Vanderhaegen, Guichon and Guidal. The model 1 [7] assumes the H generalized distribution to be equal to the product q(x) F(t), without correlation between the parton longitudinal momentum and its transverse position. The model 2, using inputs provided by [8], introduces such correlation with partons at high x concentrated in the center of the nucleon. One can see that one year data taking are clearly enough to be sensitive to different spatial distributions at different x_{Bj}. Comparisons with more sophisticated models are presently under study.

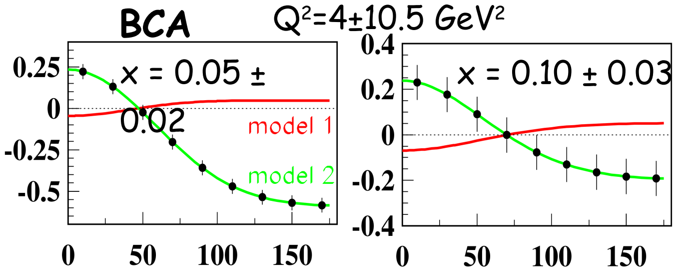

FIGURE 4. Expected beam charge asymmetry for two x, Q2 bins and comparisons with the two models (see text and [7, 8])

CONCLUSION AND ROAD MAP

The COMPASS experiment can provide key measurements for the study of generalized parton distributions, in particular using DVCS events. Compared to other experiments, it will allow GPD measurements in the low x_{Bj} region which is not covered elsewhere. These measurements can be done with only a few modifications of the COMPASS detectors and within a few years of data taking.

An expression of interest [9] has been presented to the CERN SPSC in 2005. A proposal is presently being prepared, it will be submitted in 2007. A prototype of the recoil detector is tested in 2006. It would be built, as well as the ECAL0 calorimeter and the liquid hydrogen target, in the next three years for a first data taking which could begin in 2010. In parallel, analysis are done on the present COMPASS data to study exclusive meson production events.

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