PROSPECTS FOR GENERALIZED PARTON DISTRIBUTIONS STUDIES AT COMPASS

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The measurement of generalized parton distributions will allow to obtain a three-dimensional picture of the nucleon structure. They can be probed in hard exclusive meson scattering and deeply virtual Compton scattering (DVCS). This paper presents the required modifications of the COMPASS experiment for the DVCS measurement. In addition, simulations have been performed to show the ability to distinguish between different models. Hard exclusive meson scattering is studied in the current setup, while DVCS could be measured in the future in a modified setup.

1. Generalized Parton Distributions

What do we know about the structure of the nucleon and what could we learn? In deep inelastic scattering experiments the parton density distributions are determined in terms of the variable x, the momentum fraction of the nucleon carried by the parton. Thus one gets a kind of one dimensional picture of the nucleon. The generalized parton distributions (GPDs) allow to describe the density distributions depending on two variables, the parton momentum in longitudinal direction and additionally the parton position $r_{y,z}$ in the transverse direction. Thus one can get a three dimensional picture of the partonic nucleon structure. The GPDs can be probed in processes like hard exclusive scattering and deeply virtual Compton scattering (DVCS), see Fig. 1.

Several predictions give a hint on what we can learn from the three dimensional picture of the nucleon content. In lattice calculations in unquenched QCD it has been shown that the fast partons are close to the center of the nucleon forming a small valence quark core, while the slow partons are far from the nucleon center giving rise to the widely spread sea quarks and gluons.[1,2] In another model the gluon density at large distance is generated by the pion cloud.[3] Here one expects a significant increase of

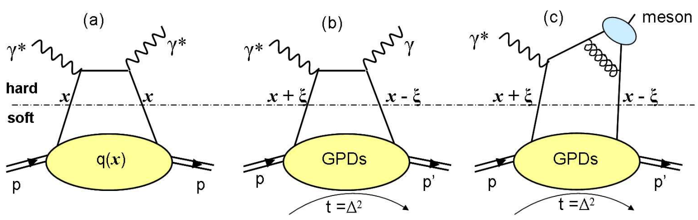

Figure 1. Handbag diagrams for the forward Compton amplitude (a) (the imaginary part gives the deep inelastic scattering cross section), deeply virtual Compton scattering (b) and hard exclusive meson scattering (c) at leading order.

the transverse size of the nucleon for $x_{Bj} < m_\pi/m_p = 0.14$. This is exactly the domain of COMPASS.

General parton distributions depend on three variables: the longitudinal quark momentum fraction x, the longitudinal momentum transfer 2ξ with $\xi = x_{Bj}/(2 - x_{Bj})$ and the momentum transfer squared to the target nucleon t. The latter is the Fourier conjugate of the transverse impact parameter r. Four generalized parton distributions are contributing to the simplest exclusive process, DVCS: Two helicity independent distributions $H(x, \xi, t)$ and $E(x, \xi, t)$ and two helicity dependent distributions $\tilde{H}(x, \xi, t)$ and $\tilde{E}(x, \xi, t)$. They are also accessible in hard exclusive meson production. In vector meson production H and E are probed, while in pseudoscalar meson production $\tilde{H}$ and $\tilde{E}$ are measured.

The dynamics of the partons in the nucleon models are described by parameterizations of the generalized parton distributions. In experiments the observables are typically integrals of the GPDs over x. The GPDs can then be obtained by fits of model parameters to the data.

The first moments of the generalized parton distributions yield the Dirac, Pauli, axial-vector and pseudo-scalar form factors.[4] In the limit of $t \to 0, \xi \to 0$ one gets the unpolarized and polarized spin density distributions of the quarks in the nucleon, $H(x, 0, 0) = q(x)$, and $\tilde{H}(x, 0, 0) = \Delta q(x)$, respectively. The generalized parton distributions can also be related to the nucleon spin contribution from the total angular momentum of the quarks, which is so far unknown:[4] $J_q = \frac{1}{2}\int_{-1}^{1} dx\, x(H(x, \xi, 0) + E(x, \xi, 0))$

The measurement of generalized parton distributions via DVCS requires large Q^2 and $t \ll Q^2$. In addition for the hard exclusive meson production the photon must be polarized longitudinally so that factorization can be applied. For both processes the quark and gluon contributions are involved.

Deep virtual Compton scattering interferes with the Bethe Heitler process. At COMPASS the muon beam can be varied: At 190 GeV the dominating DVCS cross section can be measured. At 100 GeV the interference term between the DVCS and Bethe Heitler process gives access to the DVCS amplitude. An additional advantage at COMPASS is that one can have positive and negative charged muons with opposite polarizations. The beam charge cross section sum allows to measure the imaginary part of the DVCS amplitude. The beam charge cross section difference gives rise to the measurement of the real part of the DVCS amplitude.

2. Experimental Setup

At COMPASS both a beam of positive and negative muons can be provided at a rate of at least $2 \cdot 10^8$ μ^+ and $2 \cdot 10^8$ μ^- with a polarization of -0.8 and $+0.8$, respectively. For the DVCS measurements a 2.5 m long liquid hydrogen target surrounded by a recoil detector to ensure exclusiveness has to be designed and built. The recoil detector has to detect protons in the 250–750 MeV/c momentum range. To identify these by time of flight a resolution of 200 ps is obtained by fast multi-hit ADCs located at both sides of 2 concentric barrels of 24 scintillators. A 30 degree, 4 m long prototype was built in a collaboration between Bonn, Mainz, Saclay and Warsaw and funded by the EU 6th framework program.

The scattered muon as well as the photon will be detected by the standard COMPASS setup with all of its trackers and the two electromagnetic calorimeters. Possibly the calorimeters will be topped up by an additional large angle (12-30 degrees coverage) electromagnetic calorimeter to determine more accurately the π^0 background.

3. Prospects

Simulations have been performed with two models[5,6] where different assumptions on the distributions of the partons are taken. COMPASS can access a kinematical range from $0.03 - 0.27$ in 3 x_{Bj} bins and 6 bins in Q^2 from 1.5 to 7.5 $(\mathrm{GeV}/c)^2$. With an assumed luminosity of $1.3 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and a running time of 150 days at an efficiency of 25 % a clear distinction between the two models will be possible (Fig. 2). COMPASS will be especially sensitive to different spatial distributions at different x_{Bj}.

In addition to DVCS it will be possible to measure cross sections of hard exclusive meson productions for vector mesons (ρ, ω, ϕ) and pseudoscalars (π, η). The largest cross section is that of the ρ, which is presently under study at COMPASS.[7]

The road map towards the investigation of generalized parton distributions at COMPASS is as follows:

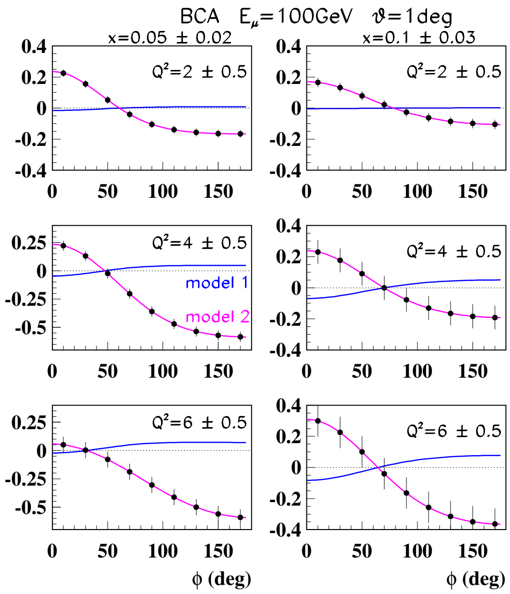

Figure 2. Azimuthal distributions of the beam charge asymmetries at E_μ=100 GeV for three regions in x and two in Q^2.

In 2005 an expression of interest has been submitted to the SPSC.[8] In 2006 a full scale recoil detector prototype will be tested in the COMPASS beam. A proposal will be written and in 2007–2009 the construction of the recoil detector, the liquid hydrogen target and the large angle electromagnetic calorimeter will take place to be ready for the study of GPDs after finishing the present COMPASS program in 2010. In parallel we are performing a complete analysis of ρ production and channels like ϕ and 2π with the present data taken with the longitudinally polarized target. The GPD ratio E/H is investigated with the transversely polarized target.

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