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Review

The COMPASS future: COMPASS II

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ABSTRACT

Up to now the COMPASS experiment of Abbon et al. (2007) [8] contributed with the muon beam to precise measurements of the nucleon longitudinal momentum structure. A more complete nucleon description beyond collinear approximation includes the quark intrinsic momentum distributions which are described by the Transverse Momentum Dependent (TMD) Parton Distribution Functions (PDFs) and by Generalised Parton Distributions (GPDs). The next phase COMPASS Coll., (2010) [6] approved in December 2010 focuses on GPDs measurements through Deep Virtual Compton Scattering (DVCS) and Deep Virtual Meson Production (DVMP), in TMDs with Drell–Yan process and on Primakoff measurements. The latter shed light on the hadron structure through the hadron deformation in an external electromagnetic field described by the polarisabilities.

1. Introduction

COMPASS is a fixed target experiment at CERN using the unique CERN SPS M2 beamline that is able to deliver high energy hadrons and polarised muon beams within the energy range of 50–280 GeV. Its forward spectrometer extends along 50 m with two dipole magnets, more than 300 tracking planes and particle identification capabilities by a Ring Imaging CHerenkov (RICH) detector and two sets of electromagnetic and hadronic calorimeters. The target can be polarised longitudinally or transversely with respect to the beam direction, depending on the specific physics program.

Since 2002, COMPASS has been contributing to the description of the nucleon structure and the future physics program is going to improve this description through two complementary approaches. The extracted GPDs through the DVCS and DVMP measurements, provide a three dimensional description of the nucleon [1] (nucleon tomography) correlating fraction of longitudinal momentum of nucleon carried by the quarks with the spatial distribution in the transverse plane. On the other hand eight TMDs relating x_{Bj} to k_T are provided to get the complementary three dimensional description [2]. The DY measurements give access to the azimuthal asymmetries in the valence quark region where the theory predicts sizable asymmetry.

The COMPASS phase II also comprises an accurate and precise measurement of the pion polarisabilities through the Primakoff process and the first measurement of the kaon polarisability.

2. Deep virtual Compton scattering

GPDs are experimentally accessible in exclusive reactions such as DVCS and Deeply Virtual Meson Production (DVMP). In the COMPASS kinematic domain the GPD H yields the dominant contribution in measurements with an unpolarised target, while GPD H and E are accessible with a transversely polarised target. They depend on the photon virtuality Q^2, the total four-momentum transfer squared t between the initial and final nucleon states and two additional variables x and ξ representing

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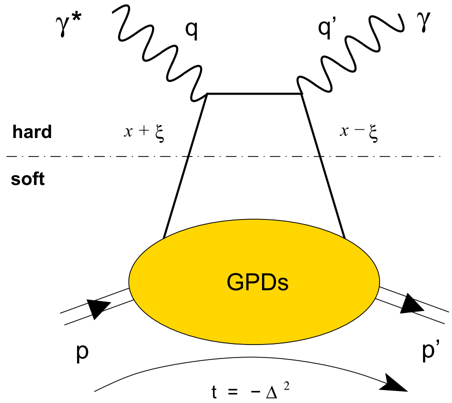

Fig. 1. Handbag diagram for the DVCS process at the leading twist.

the average and half the difference between the initial and final longitudinal momentum fraction of the nucleon carried by the parton (see Fig. 1). In DVCS and DVMP processes, x is an internal variable while the skewness ξ is related to the Bjorken variable $x_{Bj} = \frac{Q^2}{2M\nu}$ in the Bjorken limit: $\xi = \frac{x_{Bj}}{(2-x_{Bj})}$.

DVCS is considered as the cleanest of the experimentally accessible processes because the effects of the next-to-leading order and subleading twists are under theoretical control [3]. A competing process is the Bethe–Heitler (BH) process of elastic lepton–nucleon scattering with a hard Bremsstrahlung photon emitted by the incoming or outgoing lepton. It produces the same final state as DVCS so that both processes interfere at the level of amplitudes, $\mathscr{A}$:

$$d\sigma(\mu N \to \mu N\gamma) \propto |\mathscr{A}_{BH}|^2 + |\mathscr{A}_{DVCS}|^2 + \mathscr{A}_{BH}\mathscr{A}^*_{DVCS} + \mathscr{A}^*_{BH}\mathscr{A}_{DVCS}. \quad (1)$$

In the COMPASS experiment, kinematics domains are explorable where either BH or DVCS dominates. The collection of almost pure BH events at small x allows one to get an excellent reference yield and to control accurately the efficiency of the detection. On the contrary, the collection of almost pure DVCS at larger x will allow for the measurement of the x-dependence of the t-slope of the cross section which is related to the tomographic partonic image of the nucleon.

The dependence on ϕ, the azimuthal angle between the lepton scattering plane and the photon production plane, is a characteristic feature of the cross section. Integration over ϕ and/or analysis of the angular dependence in ϕ allows to isolate specific contributions that are sensitive to different combinations of quarks GPDs.

COMPASS is presently the only facility to provide polarised leptons with both charges: polarised μ^+ and μ^- beams. It should be noted that for muon beams the charge and polarisation are naturally reversed simultaneously. This feature allows with the same apparatus the measurement of the beam charge (C) and spin (S) sum $\mathscr{S}$ and difference $\mathscr{D}$:

$$\mathscr{S}_{CS,U} \equiv d\sigma^{+\downarrow} + d\sigma^{-\uparrow}, \qquad \mathscr{D}_{CS,U} \equiv d\sigma^{+\downarrow} - d\sigma^{-\uparrow}, \quad (2)$$

where the arrow indicates the beam polarisation and U the unpolarised target condition. From these measurements the real and imaginary part of Compton Form Factors (CFF) can be extracted. A CFF is a sum over flavours f of convolutions of respective GPDs with a perturbatively calculable kernel describing the hard γ^*q interaction. In the difference $\mathscr{D}_{CS,U}$ the pure BH cancels out and the analysis of the ϕ dependence will provide a measurement of the real part of the corresponding CFF. The projected accuracy for the ϕ dependence of the beam charge and the spin asymmetry is shown in Fig. 2.

In the $\mathscr{S}_{CS,U}$ the BH doesn't cancel out and it has to be subtracted. Integrating over ϕ yields the t-dependence of the cross section which is related to the transverse size of the nucleon at different values of x_{Bj}. In the simple ansatz

$$\frac{d\sigma(x_{Bj})}{dt} \sim \exp(-B(x_{Bj}))|t| \quad (3)$$

and

$$B(x_{Bj}) = B_0 + 2\alpha' \log\left(\frac{x_0}{x_{Bj}}\right) \quad (4)$$

the shrinkage parameter α' is used to describe the decrease of the nucleon size with the increasing x_{Bj}.

In 2008 and 2009 two test measurements were performed with a 40 cm long liquid hydrogen target using a recoil proton detector for the TOF, energy loss measurements and triggering purposes. These results have confirmed the feasibility of the future DVCS measurements. Fig. 3 represents the data collected during the 2009 beam test.

In order to perform the DVCS measurement new equipment and a spectrometer upgrade are foreseen. A 4 m long Recoil Proton Detector (RPD) housing the 2.5 m long hydrogen target will be built together with a new electromagnetic calorimeter, called ECAL0, positioned right behind the RPD to guarantee a larger photon angles coverage. These new detectors are the major projects. For a complete and comprehensive description and explanation of the spectrometer upgrade, we refer to Ref. [6].