COMPASS - a facility to study QCD

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An overview on the new COMPASS II experimental programme is presented. The main topics include a study of Primakoff reactions, generalised parton distributions via deeply virtual Compton scattering and transverse momentum dependent distributions in Drell-Yan processes in the pion scattering off polarised protons. Moreover, the studies of semi-inclusive deep inelastic scattering on unpolarised target will be continued.

1 Introduction

The COMPASS experiment [1] uses the unique CERN SPS M2 beamline that is able to deliver high-energy hadron and polarised muon beams. The COMPASS apparatus [2] consists of a high-resolution two stage forward spectrometer and a versatile target section allowing to use polarised and unpolarised targets for the various physics programmes. Up to now measurements were performed to study the longitudinal and transverse spin structure of the nucleon in polarised muon-nucleon scattering as well as meson spectroscopy and Primakoff reactions using negatively and positively charged hadron beams.

Recently, the COMPASS II proposal [3] was submitted to improve the knowledge of the momentum structure of the nucleon towards a three dimensional picture. For this a series of new measurements is planned. A study of generalised parton distributions (GPD) will be done in exclusive reactions like deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP) [4, 5]. In parallel the study of flavour separation and hadron fragmentation in semi-inclusive deep inelastic scattering (SIDIS) will be continued. Drell-Yan processes will be used for a complementary study of transverse momentum dependent distributions (TMD) using a transversely polarised target [6]. At very low momentum transfers Primakoff reactions can be used to extract pion and kaon polarisabilities. The COMPASS II proposal was approved on December 2010 for an initial data taking of three years.

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2 Primakoff reactions

Chiral perturbation theory allows to predict the low energy behaviour of Compton scattering off pions and kaons [7]. The deviation from the response of a pointlike particle is parametrised in first order by the polarisabilities α and β in terms of $\alpha - \beta$ and $\alpha + \beta$. Although a number of measurements, mainly for $\alpha_\pi - \beta_\pi$, were performed no firm conclusion could be drawn on the comparison to the chiral prediction for $\alpha_\pi - \beta_\pi = 5.70 \pm 1.0 \cdot 10^{-4}$ fm^3 [8],

One of the unique features at COMPASS is the availability of pion and muons beams, where pointlike muons can be used for comparison and systematic studies. Switching between muon and pion beams is possible within few hours. Exploratory measurements were performed in 2004 and 2009 to establish the feasibility and to study the achievable systematic uncertainties in such measurements. With a total measurement time of about 120 d (90 d for π and 30 d for μ, planned in 2012) a statistical precision of $\alpha_\pi - \beta_\pi$ of $0.7 \cdot 10^{-4}$ fm^3 is expected. In addition, $\alpha_\pi + \beta_\pi$ as well as higher order terms will be accessible. The small kaon component in the negatively charged hadron beam will allow a first measurement of the kaon polarisability. Reactions with one or two neutral pions instead of a photon in the final state will allow to investigate the chiral anomaly and get further insight into chiral dynamics. [8].

3 GPD measurements

Generalised parton distributions provide a unified description of form factors and parton distributions and allow transverse imaging of the nucleon [9]. Two of them, GPD H and E, can be studied in DVCS using unpolarised and transversely polarised targets while all four GPDs, H, E, $\tilde{H}$ and $\tilde{E}$ can be accessed in DVMP. GPD H and E allow also to study the total angular momentum carried by quarks inside the nucleon [10].

The measurements will exploit the availability of 160 GeV $\mu^\pm$ beams with opposite polarisation scattering off a liquid hydrogen target in the initial phase. For a later stage also a transversely polarised NH_3 target is under consideration. The experiment will cover a unique kinematic range at intermediate values of the Bjorken scaling variable x_{Bj} $(0.01 < x_{\mathrm{Bj}} < 0.1)$, a region not yet covered by any other experiment. In this kinematic range the Bethe-Heitler process is a competing process. Being well known it can serve as a reference process. GPDs will be studied measuring the so called "beam charge and spin" difference and sum which allow to extract the real and imaginary part of GPD H from the obtained Compton amplitudes. The t dependence of the DVCS cross section can be parametrised as $\frac{\mathrm{d}\sigma}{\mathrm{d}t} \sim \exp(-B(x_{\mathrm{Bj}})|t|)$. Figure 1 (left) shows the projected statistical accuracy using two years of data taking for a measurement of the x_{Bj} dependence of the t slope parameter B of the DVCS cross section for two values of the slope parameter α'

with $B(x_{Bj}) = B_0 + 2\alpha' \log(x_0/x_{Bj})$. At small x_{Bi}, B can be related to the transverse size of the nucleon $< r_\perp^2(x_{Bj}) > \approx 2B(x_{Bj})$.

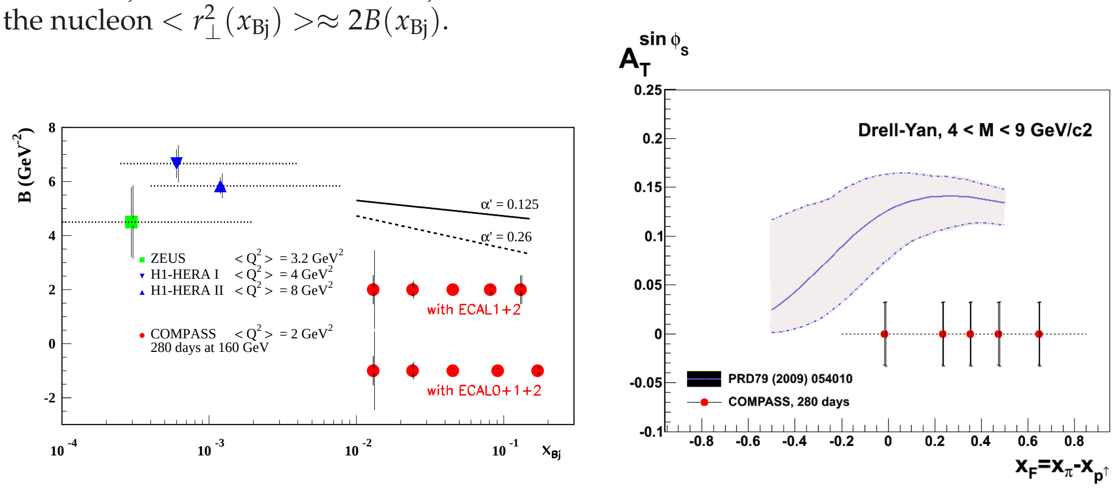

Figure 1: Projections for the statistical accuracy of (left) the slope parameter $B(x_{Bj})$ of the DVCS cross section for $1 < Q^2/(\mathrm{GeV}/c)^2 < 8$; also shown are published data with a similar Q^2, (right) the Sivers asymmetry for two years of data taking compared to the prediction of [11] for the high mass region.

For these measurements the COMPASS spectrometer has to be upgraded with a 2.5 m long liquid hydrogen target, a 4 m long recoil proton detector and hermetic coverage with electromagnetic calorimetry. The feasibility of the measurement was studied in several test measurements, the latest in 2009 which showed a clear DVCS signal at high x_{Bj}. A first data taking with the full set-up is planned for the end of 2012.

In parallel to the DVCS and DVMP measurements the study of SIDIS will be continued. The main aim is to improve the knowledge on fragmentation functions, especially for strange quarks, and to constrain the strange quark distribution. Due to the large amount of data, detailed studies of the dependence on several kinematic variables like x_{Bj}, z, Q^2 and p_T for hadron multiplicities will be possible, which will also provide high precision inputs to NLO pQCD analyses. Moreover, the study of TMDs in unpolarised SIDIS off protons will complement the previous measurements with the COMPASS polarised ^{6}LiD target.

4 Drell-Yan measurements

Complementary aspects of the nucleon can be studied with TMDs. They provide a dynamic picture using the intrinsic transverse momentum of partons inside the nucleon. Previously COMPASS had access to e.g. the Sivers TMD and the Boer-Mulders TMD in SIDIS off transversely polarised targets. In these measurements TMDs are convoluted with fragmentation functions. An alternative approach is offered by Drell-Yan processes. Here a convolution of two TMDs from the projectile and the target is studied. Such data will allow a test of the factorisation ansatz: the sign of the Sivers and Boer-Mulders functions are expected to be opposite in DY and SIDIS.

The measurements will be done using a 190 GeV pion beam impinging of the transversely polarised COMPASS NH_3 target. In the final state a pair of oppositely charged muons will be selected using a new dimuon trigger system. To reduce the high hadron background an absorber will be placed downstream of the target which also contains a tungsten plug to absorb the non-interacting beam. The dominant process is the annihilation of a valence anti-quark from the pion with an valence quark from the proton. The combinatorial background can be estimated using like-sign muon pairs. Muon pairs in the mass range of $(4 \leq M_{\mu\mu}/(\mathrm{MeV}/c^2) \leq 9)$ will be used to extract the signal as the estimated background is very small in this region. In two years of data taking 230000 high mass DY events are expected. In Fig. 1 (right) the achievable statistical accuracy for the Sivers asymmetry is compared to a recent theoretical prediction [11].

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