Exploring QCD with COMPASS-II

Catarina Quintans, on behalf of the COMPASS Collaboration

LIP-Lisbon, Portugal

Abstract. The future COMPASS-II experimental program is presented. Following a decade of successful studies of the nucleon structure and spectroscopy, the COMPASS Collaboration is now proposing an extensive program to further explore these experimental fields. The DVCS process in an unpolarized target will allow to access the GPD H in a phase-space not yet covered by any experiment. In parallel with the DVCS unpolarized measurement, and in the sequence of previous COMPASS analyses, the semi-inclusive deep inelastic scattering of muons off an unpolarized target will be studied, in order to improve the present knowledge of the strange quark PDF and to access the kaon fragmentation functions. A new measurement of TMD PDFs will be done, complementary to those already performed in COMPASS with SIDIS, using the polarized Drell-Yan process. The predicted Sivers and Boer-Mulders TMDs sign change when measured in SIDIS or in Drell-Yan will be checked. Another study proposed is the measurement of the polarizabilities of pions and kaons using the Primakoff reaction.

Keywords: Spin structure of the nucleon. Generalized parton distributions. Transverse Momentum Dependent PDFs. Pion and kaon polarizabilities.
PACS: 13.88.+e, 24.85.+p

COMPASS is a fixed target experiment taking data at CERN since 2002, with the main goals of studying the spin structure of the nucleon, and doing hadron spectroscopy. Extensive QCD studies were possible thanks to a multipurpose spectrometer and a versatile beam line. Important results concerning the gluon polarization, and the flavor-separated quarks contribution to the nucleon spin have been obtained. The new COMPASS physics program [1] is already approved and will start in 2012. This program will extend our knowledge of the nucleon structure functions in several ways. Transverse imaging of the nucleon will be done studying exclusive processes like the Deeply Virtual Compton Scattering (DVCS). The Transverse Momentum Dependent (TMD) parton distribution functions (PDFs) accessed using the polarized Drell-Yan process will provide information on the transverse dynamics of the nucleon. And in the low energy QCD regime, COMPASS will measure the pion and kaon polarizabilities, and in this way test the Chiral Perturbation theory.

COMPASS is located in the M2 beam line of the SPS/CERN, which provides either muon or hadron beams, in a momentum range of 50 to 280 GeV/c. Its forward spectrometer extends along 50 meters, with 2 dipole magnets, more than 300 tracking planes, and particle identification capabilities by means of a Ring Imaging Cherenkov detector and two sets of electromagnetic and hadronic calorimeters [2]. The target can be either unpolarized or polarized (longitudinally or transversely) to the beam direction. For the new physics program, the target region will have to be adapted to each specific measurement.

The study of exclusive processes induced by a polarized muon beam in an unpolarized liquid hydrogen target is one of the main physics topics covered by COMPASS-II. The DVCS process $\mu p \to \mu p \gamma$, as well as the Deeply Virtual Meson Production (DVMP)

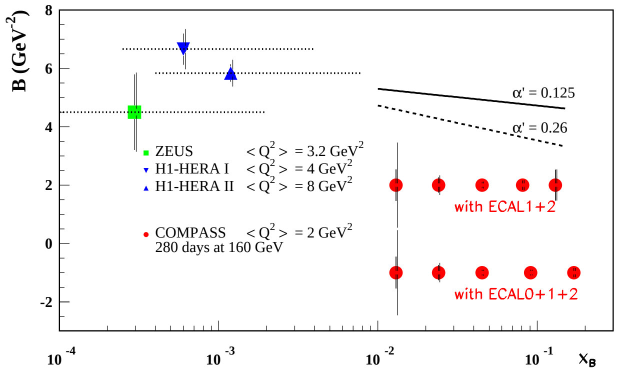

FIGURE 1. Statistical precision on the B impact parameter as a function of x_{Bj}. Published results from ZEUS and H1 are also shown.

processes $\mu p \to \mu p V$ (with V being the vector-mesons ρ, ω or ϕ) can be used to make transverse imaging, i.e. a sort of tomography, of the nucleon. These processes give us access to the Generalized parton distributions (GPDs). Namely, the COMPASS measurement will provide information about the GPD H in the intermediate x range ($0.01 < x < 0.1$), a region not yet covered by any existing experiment. In this x region the DVCS process competes with the Bethe-Heitler process. The latter is know, thus ideal to use as a reference. The so-called "beam charge and spin asymmetry" obtained in the interference of DVCS and Bethe-Heitler processes has amplitudes which are proportional to the GPD H. If using a transversely polarized target, in a similar way one can access the GPD E, a measurement planned to be done at a later stage. The DVMP measurement, on the other hand, can give access to all 4 GPDs, H, E, $\tilde{H}$ and $\tilde{E}$ and with flavor separation, and will be done in parallel with DVCS. These studies require a set-up including a recoil proton detector to guarantee the exclusivity of the processes, as well as large acceptance electromagnetic calorimetry to identify the emitted photon. The feasibility of the experiment was shown in a beam test performed in 2009.

The DVCS cross-section as a function of t, the momentum transfer between initial and final hadron states, behaves as a decreasing exponential with slope parameter B. This "impact parameter" B can be related to the transverse radius of the nucleon: $B \approx \langle r_\perp^2 \rangle / 2$. Fig.1 shows the expected statistical precision in B as a function of x_{Bj} assuming 280 days of data-taking (two times five months), together with the existing measurements from ZEUS and H1. Two scenarios are shown, one considering the presently existing calorimeters, and another where a larger coverage calorimeter ECAL0 is added. As can be seen, the COMPASS measurement can improve very significantly the present knowledge of the nucleon transverse dimensions.

In parallel with the previously exposed measurement, COMPASS-II will further study Semi-Inclusive Deep Inelastic Scattering (SIDIS). In polarized muon induced DIS processes the identified scattered muon gives us information about the parton distribution functions inside the nucleon. The additional information provided by a final state hadron allows us to access the flavor separated PDFs. These are relatively well constrained in the case of light quarks, but for the strange quark the uncertainties are still considerably large. COMPASS can give valuable input to help constraining the unpolarized

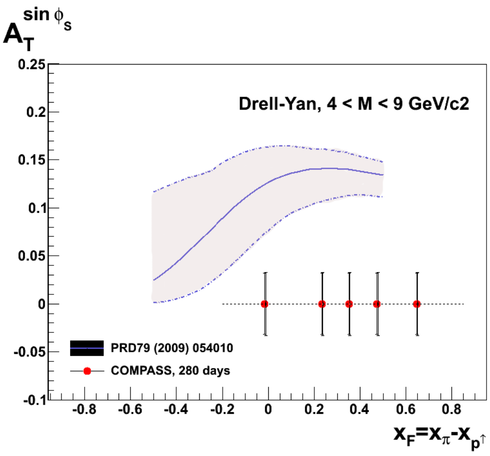

FIGURE 2. Statistical accuracy of the Sivers asymmetry in 2 years of data-taking, compared with the theory prediction from [3], for the Drell-Yan COMPASS case in the dimuons high mass region.

strange quark distribution function $s(x)$ in the region of large x ($x_{Bj} > 0.006$). The final state hadrons from the unpolarized SIDIS processes are identified by the RICH and the calorimeters. From this study we will access the Fragmentation Functions (FF) in general, and the kaon FF in particular. All this information put together with previous COMPASS results will be used in a leading order analysis with significantly increased statistics on proton target. The amount of data that can be collected is so large that the scanning of the PDFs and FFs as a function of x and z will be possible, and consequently also a future NLO global analysis. A significant improvement of the statistical accuracy of $(s + \bar{s})$ PDF is expected, even with only one week of data-taking.

Another major topic that will be covered by COMPASS-II is the TMD PDFs accessed from the polarized Drell-Yan process. The TMDs provide us with a dynamic picture of the nucleon, by taking into account the intrinsic transverse momentum k_T of its constituents. Until now COMPASS has studied TMDs from SIDIS processes. The predicted sign change of the "naive time reversal" odd TMDs when accessed from SIDIS or from Drell-Yan can be tested in COMPASS with basically the same spectrometer, providing an answer to this crucial test of non-perturbative QCD. In COMPASS four azimuthal asymmetries can be studied, which are proportional to convolutions of PDFs of the pion and the proton: Boer-Mulders, Sivers, pretzelosity and transversity. The measurement will probe the valence quarks region $x_p > 0.1$, where the theory predicts sizable asymmetries.

The Drell-Yan measurement will be done with a π^- beam at 190 GeV/c and a two-cells NH_3 transversely polarized target. A long hadron absorber placed downstream of the target will reduce the background of produced hadrons (pions and kaons which may decay to muons), and contain along the beam axis a tungsten plug to stop the non-interacted beam. A dimuon trigger based on large acceptance hodoscopes will select the interesting events. The like-sign muon pairs sample will be used to estimate the combinatorial background, which is expected to be negligible in the high mass region

($4 \leq M_{\mu\mu} < 9$ GeV/c^2) where we propose to do the main measurement. Because the Drell-Yan cross-section is very small in this mass region, it is also interesting to study the dimuon masses $2 \leq M_{\mu\mu} < 2.5$ GeV/c^2 where the cross-section is 5 times larger, but at the price of having a non-negligible background. The DY-J/ψ duality is another interesting topic, motivated by the possible analogy between Drell-Yan and the J/ψ production via $q\overline{q}$ annihilation, which is believed to start dominating in our energies. The J/ψ production mechanisms can also be studied by varying the π beam energy.

Beam tests already performed have shown the feasibility of the measurement and validated the Monte-Carlo simulations. In 280 days of data-taking, one expects to collect 230 000 high mass Drell-Yan events. In Fig.2 the statistical accuracy of the Sivers asymmetry is shown together with a theory prediction available for the high mass Drell-Yan case at COMPASS, from [3]. COMPASS has the potential to become the first experiment to access the TMDs of the nucleon in a polarized Drell-Yan experiment.

Finally, the COMPASS measurement of pion and kaon polarizabilities will provide a test of chiral perturbation theory, the theory predicting the strong interaction dynamics of Goldstone bosons. The deviation from the point-like behavior of the pion is revealed by its response in the presence of an electromagnetic field. This effect, called the pion polarizability, is given in leading order by a sum of three terms which depend on αs and $beta$s, the dipole and quadrupole electric and magnetic responses. Up to now, only one of these terms was experimentally measured, $\alpha_\pi - \beta_\pi$.

COMPASS will measure the polarizabilities using the Primakoff reaction, $\pi A \rightarrow \pi A \gamma$. Embedded in this reaction is the inverse Compton process $\gamma\pi \rightarrow \gamma\pi$ with the γ being deviated at an angle θ. By measuring the modulations in θ one accesses each of the polarizability terms. In a year of data-taking, COMPASS can measure all three terms, and in the case of $\alpha_\pi - \beta_\pi$ improve the present accuracy by an order of magnitude. An important aspect of the proposed measurement is that $1/3$ of the time will be devoted to the measurement with muon beam, a situation where one expects zero polarizability, thus providing us a good measure of systematic effects. The kaon polarizabilities can also be measured in COMPASS for the very first time, thanks to the beam particle identification provided by the CEDAR detectors in the COMPASS beam line.

The COMPASS new physics proposal was already approved by CERN. The experiment will start taking data in 2012, hopefully to provide us with many answers to important and long standing QCD questions.

ACKNOWLEDGMENTS

The author would like to thank the financial support of Fundação Luso-Americana para o Desenvolvimento (FLAD) to attend this conference. This work was partially funded by the portuguese Fundação para a Ciência e Tecnologia.

REFERENCES

1. COMPASS Coll., *COMPASS-II proposal*, CERN-SPSC-2010-014, SPSC-P-340, 17 May 2010.
2. COMPASS, P. Abbon *et al*, *Nucl. Instrum. Meth. A* **5**77 (2007) 455.
3. M. Anselmino *et al*, *Phys. ReV. D* **7**9 (2009) 054010.