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First results on A_1^p and g_1^p at low x and low Q^2 from COMPASS

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The COMPASS experiment at CERN has collected a large sample of about 700 million events of quasi-real photoproduction in polarised $\mu^+ - p$ scattering using a beam momentum of 160 GeV/c in 2007 and 200 GeV/c in 2011. The events have a Bjorken scaling variable in the range $4 \times 10^{-5} < x < 4 \times 10^{-2}$ and a four-momentum transfer squared in the range $10^{-3} < Q^2 < 1$ (GeV/c)^2. They allow the most accurate determination to date of the longitudinal double spin asymmetry A_1^p and of the spin-dependent structure function g_1^p of the proton in the region of low x and low Q^2. These data complement our data for a polarised deuteron target in this kinematic domain. They have an order of magnitude better precision than the previous SMC results.

The preliminary results yield non-zero, positive asymmetries A_1^p and structure function g_1^p in the full studied ranges of the Bjorken variable x and of the virtual photon energy ν. It is the first time that spin effects are observed at such low x.

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1. Introduction

In the last decades, high energy experiments where leptons are scattered off nucleons have led to important discoveries in the physics of nucleons. The experiments without polarisation have reached great precision, but experiments where at least one of the interacting particles is polarised, which allow to probe the spin-dependent structure funcions of the nucleon, have yet to cover extensive regions of the phase space. In the DIS regime, the COMPASS experiment at CERN has contributed to this effort by measuring the longitudinal double spin asymmetries A_1^p and A_1^d and the spin-dependent structure functions g_1^p and g_1^d [1, 2].

The SMC experiment at CERN measured A_1^p and g_1^p down to values of the Bjorken variable of $x \sim 0.00011$ [3]. However, being a fixed target experiment, x is considerably correlated with Q^2, and while reaching such low values of x, low values of Q^2 were also reached. The same caveat applies to COMPASS, which can, nonetheless, reach even lower values of x, because of its particular trigger system [4] and of its much larger data set. On the other hand, theoretical models, still to be confronted with data, allow a smooth extrapolation to both the low Q^2 and the high Q^2 regions (using resummation, vector meson dominance) [5, 6, 7]. With the COMPASS data taken with a proton target, A_1^d and g_1^p can be measured at low x and low Q^2 with improved precision, complementing our measurement of A_1^d and g_1^d at low x and low Q^2 [8]. The non-singlet structure function $g_1^{\mathrm{NS}} = g_1^p - g_1^n$, which decouples from gluons, will also be extracted at a later stage. The results are presented as functions of x and ν, as suggested by [7].

2. The COMPASS experiment

The COMPASS experiment at CERN [9] is a fixed target experiment at the Super Proton Synchrotron. It uses naturally polarised muon beams, with a polarisation of about -80%, with momenta of 160 GeV/c in 2007 and of 200 GeV/c in 2011. It's target of ammonia, containing protons with a polarisation of about 85%, is 1.2 meters long and is composed of three independent cells. The experiment is also equiped with detectors for tracking, calorimetry and particle identification. In Fig. 1, the target cells' polarisation and the longitudinal spatial coordinate of the reconstructed interaction vertices are depicted.

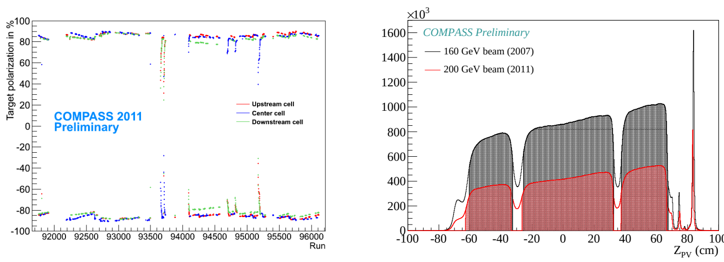

Figure 1: (Left) Target polarisation versus run numbers for the three different target cells. (Right) Interaction vertex longitudinal spatial coordinate, for the 2007 and 2011 final samples used for extraction of asymmetries. All event selection criteria were applied except the one on z_{PV} (unfilled histograms) and with all event selection criteria applied (filled histograms).

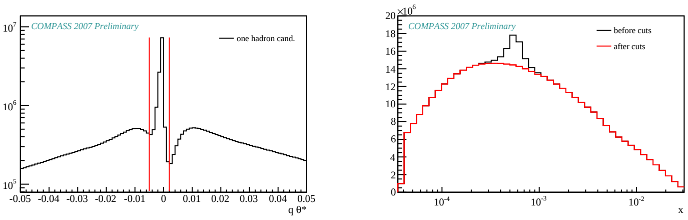

Figure 2: (Left) Distribution of the variable $q\theta^*$ (charge times angle of the track of the hadron candidate with respect to the virtual photon direction) for 2007 events with one hadron candidate in the interaction vertex. Events between the vertical lines were removed from further analysis. (Right) x distribution of events before and after the μe event rejection for the 2007 sample.

Care is taken to reduce possible sources of false asymmetries, due to effects related to acceptance variations, namely: (a) three target cells are used, with opposite longitudinal polarisations in consecutive cells; (b) the direction of the polarisation is reversed every twenty-four hours; (c) the data are grouped in bunches taken every fourty-eight hours, for the extraction of spin asymmetries, the results being subsequently combined; (d) the direction of the magnetic field of the solenoid that creates and maintains the polarisation with respect to the direction of the target cells polarisation is changed at least once per data-taking campaign.

3. Data samples

The data samples used for the extraction of A_1^p and g_1^p were collected in 2007, using a beam of 160 GeV/c, and in 2011, using a beam of 200 GeV/c. The main selection criteria of the events included the following: (a) there had to be, in addition to the scattered muon, at least one other track stemming out of the interaction point; (b) the event should not be one in which a muon from the beam had scattered elastically off an electron from the target material; (c) $Q^2 < 1$ (GeV/c)^2; (d) $x \geq 4 \times 10^{-5}$; (e) the fraction of the energy lost by the interacting muon should obbey $0.1 < y < 0.9$. The first condition was also used by the SMC, which verified that it doesn't introduce a bias to the inclusive asymetries at low x. After applying all the selection criteria, the final samples amounted to 676×10^6 events, of which 447×10^6 events were taken with a 160 GeV/c beam, and 229×10^6 events were taken with a 200 GeV/c beam. As compared to the SMC low x, low Q^2 proton data, with 4.5×10^6 events, the COMPASS data set has about 150 times more events than SMC. In Fig. 2, the effect of applying the condition (b) is illustrated.

The phase space coverage of the final samples used for the A_1^p and g_1^p extraction is shown in Fig. 3.

4. Method

The measured experimental asymmetry can be defined as $A_{\rm exp} = \frac{N^{\leftrightarrows} - N^{\rightrightarrows}}{N^{\leftrightarrows} + N^{\rightrightarrows}}$, where $N^{\leftrightarrows}$ ($N^{\rightrightarrows}$) is the number of events in which the polarisations of beam and target particles are antiparallel (parallel). For the COMPASS case, the (virtual photon-proton) double spin longitudinal asymmetry can be approximated by $A_1^p \simeq \frac{A_{\rm exp}}{D}$, where D is the depolarisation factor (the fraction of the polarisation of the beam that is transmitted to the virtual photon). In order to minimize the statistical errors on

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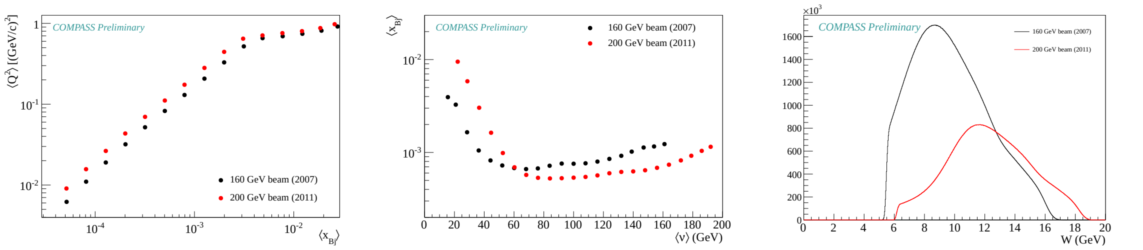

Figure 3: (Left) Average values of Q^2 versus average values of x of the bins used in the $A_1^p(x)$ and $g_1^p(x)$ extractions, for the 2007 and 2011 data samples. (Middle) Average values of x versus average values of ν of the bins used in the $A_1^p(\nu)$ and $g_1^p(\nu)$ extractions, for the 2007 and 2011 data samples. (Right) Distribution of W, the mass of the system recoiling against the scattered muon, for the 2007 and 2011 data samples.

the results, each event is given a weight of $\omega = fDP_b$, where f is the dilution factor (the fraction of particles in the target material that is polarisable), D is the depolarisation factor and P_b is the polarisation of the beam particle. The asymmetries are corrected for radiative effects, both unpolarised, using TERAD [10], and polarised, using POLRAD [11], and for the fact that the nuclei of ^{14}N in the target material are polarisable. The polarised radiative corrections amount to, at most, 25% of the statistical errors and the correction for the presence of ^{14}N amounts to, at most, 1% of the statistical error. Thorough checks were made to the data, in order to detect possible sources of false asymmetries. Based on these studies, the systematic errors are estimated to be smaller than the statistical errors.

The spin-dependent structure function g_1^p is, for the COMPASS kinematics, approximately given by $g_1^p \simeq F_1^p A_1^p = \frac{F_2^p}{2x(1+R)} A_1^p$, where F_1^p and F_2^p are the spin independent structure functions of the proton, and R is the ratio of the cross-sections of absorption by the nucleon of a photon with longitudinal and transverse polarisations, $R = \sigma_L/\sigma_T$. Unfortunately, there are no direct measurements of F_2^p nor of R at the lowest values of x and Q^2 which COMPASS can access. The values of $F_2^p(\langle x\rangle, \langle Q^2\rangle)$ were taken therefore from the SMC fit to data or from a model (for low x and Q^2) [12], whereas the values for R were taken from an extension to low Q^2 of a SLAC parameterisation, as described in [8].

5. Results

The results on A_1^p are show in the first row of Fig. 4. The two samples obtained with different beam energies yield results that are compatible within errors. Furthermore, the extracted asymmetries are significantly positive. Comparing $A_1^p(x)$ with results of other experiments shows that the COMPASS results significantly improve the precision of the measurement. Furthermore, those values are compatible with the model of [5] for the values of its parameter $C \in [0, +4]$, *i.e.* they favour a vector meson dominance contribution to g_1 of the same sign as the partonic contribution.

In the bottom row of Fig. 4, the results on g_1^p are presented. No significant dependence with the virtual photon energy is observed, in contrast with the prediction of a significant dependence of the singlet structure function g_1^S with ν predicted by the model of [7].

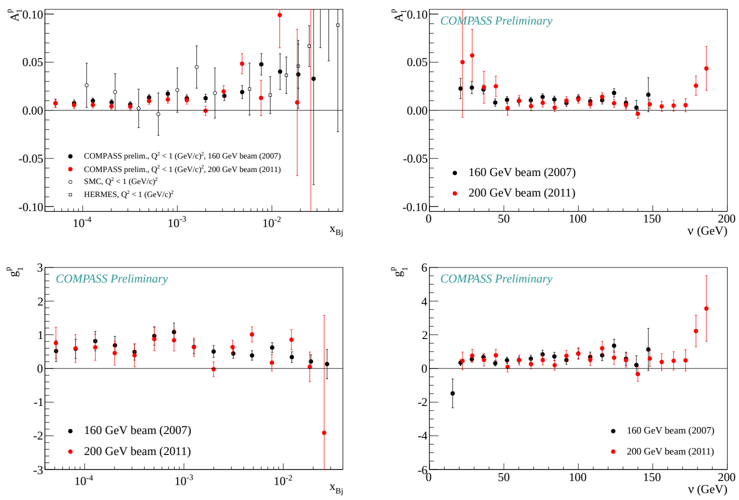

Figure 4: Longitudinal double spin asymmetries A_1^p as a function of x (top left) and of ν (top right), obtained from 2007 and 2011 data, after corrections due to the polarised radiative asymmetry and the presence of ^{14}N in the ammonia target. In the top left plot, the asymmetries from the SMC[3, 13] and from HERMES for $Q^2 < 1$ (GeV/c)^2 are also shown. Spin dependent structure function g_1^p as a function of x (bottom left) and of ν (bottom right), obtained from 2007 and 2011 data.

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