PROCEEDINGS OF SCIENCE

New COMPASS results on the gluon polarisation using D^0 production asymmetries

Celso Franco* **on behalf of the COMPASS collaboration**
LIP-Lisboa
E-mail: celso@lip.pt

One of the main goals of the COMPASS experiment is the measurement of the gluon contribution to the nucleon spin. Among the processes studied by COMPASS, the Open-Charm D^0 meson production is the cleanest channel for the gluon polarisation estimation. The experimental spin asymmetry for these open-charm events was measured after an efficient removal of the combinatorial background using a method based on a Neural Network approach. The gluon polarisation was then estimated through the relation between this asymmetry and the analysing power (asymmetry at the partonic level) for the polarised "photon-gluon fusion" process, in a LO QCD approximation. A new D^0 decay mode was considered ($D^0 \rightarrow K\pi\pi\pi$), together with a first analysis of the COMPASS proton data (NH_3 target), producing a new result with an improved precision. This value includes all COMPASS data and it is shown here for the first time.

XVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, DIS 2010
April 19-23, 2010
Firenze, Italy

*Speaker.

1. Introduction

Over the last decade, the quark contribution to the nucleon spin was measured with a very good precision [1]:

$$\Delta\Sigma = 0.30 \pm 0.02 \pm 0.01 \; (\textit{world data at } Q^2 = 3(MeV/c)^2) \tag{1.1}$$

Taking into account the orbital momenta, **L**, of quarks and gluons, and the first moment of the gluon helicity, ΔG, the nucleon spin projection can be decomposed into the following sum:

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z \tag{1.2}$$

Since all the spin contributions must sum to 1/2, the big question is to find out why the quark helicity was found so small. It is well known from the past that the gluons were the solution to the missing momentum in the nucleon (they carry half of the proton momentum), so the first guess to solve this **spin puzzle** is to assume that a large fraction of the missing helicity comes from ΔG. This was a strong motivation for measuring $\Delta g(x)$ in dedicated experiments like COMPASS.

2. Event selection

In order to be sensitive to the gluon polarisation, one must tag a process involving a polarised lepton-gluon interaction. In COMPASS, one of the possibilities to do it is to reconstruct charmed mesons (Figure 1).

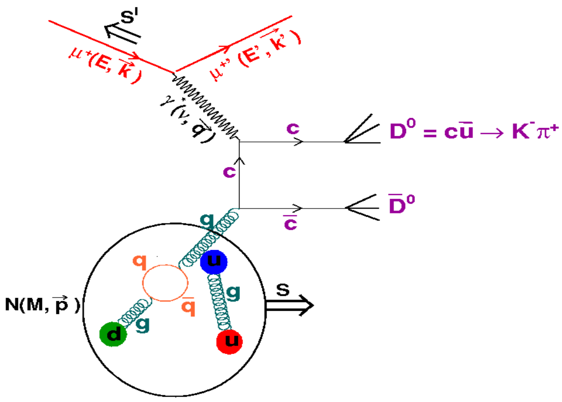

Figure 1: Open-Charm production from a polarised **P**hoton-**G**luon **F**usion process (LO PGF)

This method provides a clean PGF signature, in LO QCD approximation, because no significant intrinsic charm exists inside the nucleon (in the COMPASS kinematic domain). In this analysis D^0 mesons are used, with their production being limited to a small x_{Bj} range due to the absence of cross section for higher values ($x_{Bj} < 0.1$): the theoretical predictions for intrinsic charm shows that COMPASS is not sensitive to this kind of contamination, because it is dominant only at higher x_{Bj} values (see, for e.g, [2]). The COMPASS spectrometer [3] was designed to reconstruct the hadronized D^0 mesons (from c quarks), through the invariant mass calculation of their decay products ($K\pi$ pairs), and for that purpose the RICH detector plays an important role: requiring proper particle identification reduces the combinatorial background that masks the real PGF signal centered on the D^0 mass. Some kinematic cuts are also applied, in the fraction of the virtual photon energy carried by the D^0, $0.2 < z_{D^0} < 0.85$, and also in the angle of Kaon decay in the D^0 center-of-mass, $|cos(\theta^*)| < 0.65$. They are important to reduce the contamination produced by D^0 candidates coming from the struck quark fragmentation, because these events are collinear with the virtual photon direction or with a z_{D^0} close to zero. The combinatorial background can be further removed by studying the following channel: $D^* \to D^0\pi_{slow}$ with $D^0 \to K\pi$ (D^0 tagged with a D^*). By applying a cut on the reconstructed D^* and D^0 mass differences, one can check that there is not much room left for the slow pion momenta: $3.2\ MeV/c^2 < M^{rec}_{D^*} - M^{rec}_{D^0} - M_\pi < 8.9\ MeV/c^2$. Due to this cut the signal purity is greatly improved (even with looser kinematic cuts), and as a consequence three additional low purity channels can be studied (all tagged with a D^*): $D^0 \to K\pi\pi^0$, $D^0 \to K_{sub}\pi$, and $D^0 \to K\pi\pi\pi$. The first one appears as a sort of a 'bump' centered around $\approx -250MeV/c^2$, in the main tagged spectra, due to the fact that the extra π^0 is not directly reconstruced for this analysis. The second channel correspond to the candidates without RICH identification for the Kaons (sub-threshold candidates with p(K) < 9 GeV/c), and the last one is a new contribution introduced to improve the precision of the measurement. The final samples, per channel, can be seen in [3] for the full COMPASS deuteron (2002-2006) and proton data (2007).

3. Method to extract the gluon polarisation

The number of D^0 events collected in a given time interval is given as a function of signal and background asymmetries [4]:

$$\frac{dn}{dmdX} = a\phi\eta(s+b)[1+P_tP_\mu f(\frac{s}{s+b}A_S + \frac{b}{s+b}A_B)] \tag{3.1}$$

With $m = M_{K\pi}$, X represents a set of kinematic variables $(Q^2, Z_{D^0}, ...)$ defining the event, a is the spectrometer acceptance, ϕ is the integrated muon beam flux, and η is the number of target nucleons. P_μ, P_t and f represent the experimental factors diluting these asymmetries: they are the beam polarisation, the target polarisation and the fraction of polarisable material inside the target. $s/(s+b)$ is the signal purity with signal events, s(m, X), coming from the invariant mass spectra peak. s(m, X) and b(m, X) represent the differential unpolarised cross section of signal and background events folded with the experimental resolution. In LO QCD, A_S can be defined as a convolution between the ratio of polarised/unpolarised cross sections (($\Delta\hat{\sigma}/\hat{\sigma}$) for the process $\mu g \to \mu' c\bar{c}$), and the ratio of polarised/unpolarised gluon structure functions ($\Delta g/g$):

$$A_S(X) = \frac{\int \Delta\hat{\sigma}\Delta g F dY}{\int \hat{\sigma} g F dY} = a_{LL}(X)\frac{\Delta g}{g}(X) \tag{3.2}$$

$$a_{LL}(X) = \frac{\int \hat{a}_{LL}\hat{\sigma} g F dY}{\int \hat{\sigma} g F dY} \quad with \quad \hat{a}_{LL} \equiv \frac{\Delta\hat{\sigma}_{\mu g}}{\hat{\sigma}_{\mu g}} = \left(\frac{\hat{\sigma}^{\leftrightarrows}_{\mu g} - \hat{\sigma}^{\leftleftarrows}_{\mu g}}{\hat{\sigma}^{\leftrightarrows}_{\mu g} + \hat{\sigma}^{\leftleftarrows}_{\mu g}}\right) \tag{3.3}$$

F describes the fragmentation of c quarks into D^0 mesons, and the integration is done over the partonic variables, Y, not accessible from the event kinematics, like for example the gluon momentum fraction x_g. Since the factors $s/(s+b)$ and a_{LL} (in Equation 3.1) have a large dispersion, a weighting method was used to minimize the statistical error [4]: $\omega_S = P_\mu \cdot f \cdot a_{LL} \cdot s/(s+b)$ and $\omega_B = P_\mu \cdot f \cdot D \cdot b/(s+b)$ were used as signal and background weights, where D represents the polarisation transfer from the muon to the virtual photon.

In COMPASS, the fixed target consists in 2 consecutive cells longitudinally polarised in opposite directions [3]. In order to minimize the impact of their different acceptances (3 cells were used for 2006 and 2007 data to reduce this systematic effect), the target spins were reversed every eight hours: as a result we end up with 4 spin configurations from 2 cells. Consequently, one can define 4 equations from Equation 3.1, for the number of events produced inside each cell configuration, and by weighting them with ω_S and then with ω_B we end up with 8 equations and 10 unknowns ($\langle \Delta g/g \rangle$, A_B, and the 8 acceptance factors $\alpha_C^t = \int a^t \cdot \phi^t \cdot \eta^t \cdot (s+b) \cdot \omega_C \cdot dX$; with $C = s$, b and t referring to a specific cell configuration). Since acceptance variations with time affect both cells in the same way, the number of unknowns is reduced to 8 (the ratio between both cells acceptances is the same before and after the field reversal), and the system can be solved simultaneously for $\langle \Delta g/g \rangle_x$ and A_B [4]. To solve the system however, one needs a_{LL} and $s/(s+b)$ for every event.

4. Partonic asymmetry and signal purity

The analyzing power for the Open-Charm production, a_{LL}, is dependent on the full knowledge of the partonic kinematics. As a consequence, this asymmetry is not experimentally accessible because only one D^0 meson is reconstructed per event: the information associated with the second charm quark is lost. Nevertheless, a_{LL} can be obtained in LO with the help of a Monte Carlo generator for heavy flavours (AROMA). After a full Monte Carlo chain, where the generated events are constrained to the COMPASS acceptance, all D^0 mesons (for each of the 5 channels) are reconstructed in the simulated spectrometer. The polarised and unpolarised partonic cross sections are calculated with this information, and then the kinematic dependences of a_{LL} are parameterised ([3], [4]) with the help of a Neural Network [5]. Finally, the Monte Carlo parameterisation is used to obtain a_{LL} for each real data event.

The Neural Network is also used to parameterise $s/(s+b)$, but this time only on real data. The goal is to obtain D^0 probabilities for every event, and in [3] one can see the outcome of this parameterisation: inside bins of $s/(s+b)$ the spectrum is behaving like a signal probability (increasing its purity towards unity). As a consequence, the precision of the gluon polarisation measurement is improved due to a good separation of the physical events from the combinatorial background. To accomplish this, two real data samples are used as inputs to the Neural Network: the signal model, *gcc*, and the *wcc* sample as a background model. The first one refers to the real D^0 spectra, containing the signal plus background, and it is called the **g**ood **c**harge **c**ombination of the D^0 decay particles. The *wcc* sample is selected in a similar way, by applying the same kinematic cuts, with the exception of a **w**rong sign applied to the pion charge (avoiding a D^0 reconstruction). Then, the Neural Network performs a multidimensional comparison between the relevant kinematic variables, from both samples, and if the background model is good enough the Network is able to distinguish the signal events out from the combinatorial background (inside the *gcc* sample). One example of a good learning variable can be seen in [3], the Kaon angular distribution in the D^0 rest frame, where both input samples are compared (for this variable) using events under the signal or in the peak sidebands: the Neural Network uses the different shapes under the peak to recognize the *gcc* background events contaminating the signal (on the sidebands plot, one can check the good quality of the background model). Finally, $s/(s+b)$ is obtained from a simple function applied to the Neural Network response, and then the mass dependence is included (as a correction) from a fit to the spectra inside probability bins. By respecting the correct D^0 kinematic dependencies, this parameterisation allows us to use the signal purity inside the event weight in an unbiased way.

5. Results

The gluon polarisation was extracted from the measured asymmetry on D^0 production, using the method described above, with the following result (A_B was found to be consistent with zero):

$$\left\langle \frac{\Delta g}{g} \right\rangle = -0.08 \pm 0.21 \pm 0.11(syst.) \quad @\ \mu^2 \approx 13\ (GeV/c)^2,\ \langle x_g \rangle \approx 0.11 \quad (preliminary) \tag{5.1}$$

Conservatively, the systematic error of [4] was indicated (still under study). In Figure 2, one can check the good agreement between this point and the high-pt results: small values of $\langle \Delta g/g \rangle$ are favored, clearly indicating that the nucleon **spin puzzle** remains to be solved.

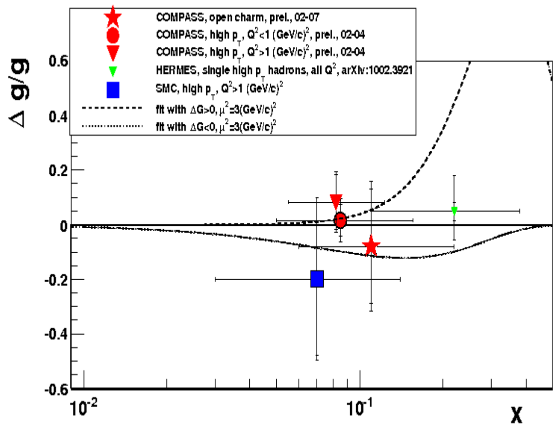

Figure 2: Comparison of $\langle \Delta g/g \rangle)$ measurements obtained from Open-Charm and high-pt analysis. The curves display two parameterisations from the COMPASS QCD analysis at NLO (next to leading order) [1].

References

[1] COMPASS, V. Yu. Alexakhin et al., Phys. Lett. B **647** (2007) 8

[2] S.J. Brodsky, et al., Phys. Lett. B **93** (1980) 451

[3] Slides:
`http://indico.cern.ch/materialDisplay.py?contribId=203&sessionId=9&materialId=slides&confId=86184`

[4] COMPASS, V. Alekseev, et al., Phys. Lett. B **676** (2009) 31

[5] R. Sulej et al. Measur.Sci.Tech.18: 2486-2490, 2007