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INCLUSIVE AND SEMI–INCLUSIVE DOUBLE SPIN ASYMMETRIES AT COMPASS

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In 2002 the fixed target experiment COMPASS at CERN has taken data for the first time. Based on this data first results have been presented at this workshop. In this paper a measurement of the inclusive spin asymmetry A_1 is shown.

1 Introduction

COMPASS is a fixed target experiment at CERN which took data for the first time in 2002 [1]. The main goal of the initial period of this experiment are measurements of the polarized parton distributions in deep inelastic scattering of polarized muons off polarized nucleons. In this context the main focus lies on the determination of the gluon polarization ΔG but the constructed general purpose spectrometer is also suited to measure the transverse quark polarization δq as well as the longitudinal quark polarizations Δq which are the topic of this paper.

The first way to access the polarized quark distributions Δq is the inclusive measurement of the γ–nucleon cross section asymmetry A_1 (see equation 1). In the framework of the quark parton model (QPM) this quantity can be directly related to the polarized quark distributions via

$$A_1 = \frac{\sigma_{\gamma N}^{\uparrow\downarrow} - \sigma_{\gamma N}^{\uparrow\uparrow}}{\sigma_{\gamma N}^{\uparrow\downarrow} + \sigma_{\gamma N}^{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \left(\Delta q + \Delta \bar{q}\right)}{\sum_q e_q^2 \left(q + \bar{q}\right).} \tag{1}$$

In a μ–nucleon scattering experiment the measurable quantity is the μ–nucleon cross section asymmetry $A_{\mu N}$. This asymmetry can be determined from the observed interaction frequencies and some factors taking into account the non perfect polarization of target and beam (c.f. equation 2). Both asymmetries are related to each other by the so called depolarization factor D which describes the polarization transfer between muon and virtual photon.

$$A_{\mu N} = A_1 D = \frac{1}{P_t f P_b} \left(\frac{N_{\mu N}^{\uparrow\downarrow} - N_{\mu N}^{\uparrow\uparrow}}{N_{\mu N}^{\uparrow\downarrow} + N_{\mu N}^{\uparrow\uparrow}} \right) \tag{2}$$

In equation 1 quarks and anti-quarks appear on the same footing hence they can not be separated from each other. Furthermore the inclusive measurement provides only one equation for the three unknown quantities $\Delta u + \Delta \bar{u}$, $\Delta d + \Delta \bar{d}$

and $\Delta s + \Delta\bar{s}$, i.e. additional information is required to determine these quantities. This additional information is extracted under certain assumptions from hyperon decay data.

An independent determination of all Δq is possible in semi-inclusive DIS, where in addition to the scattered muon at least one hadron is detected. By requiring an additional hadron a new process is introduced: fragmentation. This process describes the transition between quarks and hadrons and is parametrized by the so called fragmentation functions D_q^h which determine how many hadrons of type h are generated by a quark q. Assuming that the fragmentation and the hard scattering process factorize the semi-inclusive asymmetries can be interpreted in the QPM:

$$A_1^h = \frac{1}{P_t f P_b D}\left(\frac{N_{\uparrow\downarrow}^h - N_{\uparrow\uparrow}^h}{N_{\uparrow\downarrow}^h + N_{\uparrow\uparrow}^h}\right) = \frac{\sum_q e_q^2\left(\Delta q\int D_q^h(z)dz + \Delta\bar{q}\int D_{\bar{q}}^h(z)dz\right)}{\sum_q e_q^2\left(q\int D_q^h(z)dz + \bar{q}\int D_{\bar{q}}^h(z)dz\right)}. \tag{3}$$

In general $D_q^h \neq D_{\bar{q}}^h$ thus quarks and anti-quarks are separable. In principle a full flavor separation is possible by measuring an appropriate set of hadron asymmetries.

In the following paper both techniques will be discussed for the data taken by the COMPASS collaboration in 2002.

2 The Experiment

The two major components of the COMPASS experiment (full description e.g. in [2]) which directly enter the inclusive and semi-inclusive analysis are the polarized beam and the polarized target:

2.1 The Polarized Muon Beam

COMPASS uses a muon beam with an energy of 160 GeV and an intensity of $2\cdot 10^8\ \mu$/spill (4.8 s each 16.8 s). The beam is naturally polarized as the muons mainly originate from the parity violating decay of pions produced by the 400 GeV SPS proton beam in a beryllium target.

Selecting a certain ratio between pion and muon energy determines the beam polarization. Although the relation between the two particle energies and the beam polarization can be easily calculated only a MC-simulation can take into account all relevant effects. Using this simulation and the measured beam momentum profile the average beam polarization can be calculated. Figure 1 shows the obtained polarization distribution for the 2002 μ–beam. The average polarization was 76 %.

2.2 The polarized Target

The COMPASS polarized target consists of two cylindrical cells with a radius of 1.5 cm and a length of 60 cm separated by 10 cm along the beam direction. They are labeled upstream and downstream target cell. The cells are filled with ^{6}LiD as deuteron target material and are placed inside a supra-conducting solenoid and a cryostat to allow the material to be polarized by the dynamic nuclear polarization technique. The target polarization regularly achieved in 2002 was above 50 %.

The main feature of the ^{6}LiD material is its high dilution factor f. In good approximation ^{6}LiD can be seen as $\alpha + 2\mathrm{D}$, which results in a naive expectation for the dilution factor of $f = 0.5$. Taking into account impurities of the material and incorporating the radiative corrections lead to a smaller and x_{bj}–dependent value for f. In figure 2 the dilution factor observed in 2002 is compared to the dilution factor of the deuteron target of SMC.

The two target cells are oppositely polarized to suppress false asymmetries originating from variations in the beam flux. In general there is a different acceptance for particles stemming from the different target cells. To cancel the false asymmetries originating from this effect it is necessary to reverse the polarization of both cells on a regular basis.

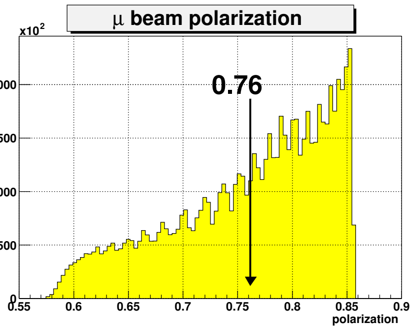

Figure 1. Distribution of the beam polarisation obtained from the measured momentum distribution and a beam–MC.

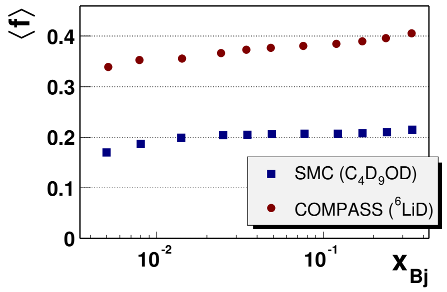

Figure 2. Dilution factor for ^{6}LiD (COMPASS) and deutorated Butanol (SMC) as target material.

The measured A_1 is then given by the average of the count rate asymmetries for the two different spin configurations

$$A = \frac{A_1 + A_1'}{2} = \frac{1}{2}\frac{1}{P_t f P_b D}\left(\frac{N_u - N_d}{N_u + N_d} - \frac{N_u' - N_d'}{N_u' + N_d'}\right). \tag{4}$$

where $N_{u(d)}$ and $N'_{u(d)}$ denote the number of scattering events observed in the upstream (downstream) target before and after polarization reversal, which was done every 8 hours.

3 The Inclusive Analysis

In the data selection two sets of cuts have been applied. The first set assures that the primary vertex lies unambiguously inside one target cell and that both target cells had been subject to the same incident muon flux (by asking that the incident muon would have passed both target cells if no reaction would have occurred).

The second set of cuts are purely kinematic:

- $Q^2 > 1\,\mathrm{GeV}^2$: Assures the possibility to interpret the measured asymmetry in the frame work of perturbative QCD.
- $0.1 < y < 0.9$: The higher cut on the relative energy loss y suppresses events where large radiative corrections have to be applied. The lower cut removes events where the polarization of the virtual photon is small.
- $140 < E_\mu < 180\,\mathrm{GeV}$: This cut accounts for the range of beam energies where the beam MC allows to determine the beam polarization.

After these cuts around 6.5 million DIS events could be used for the A_1 determination. Thanks to the high beam energy these events cover a kinematic range from $x_{Bj} = 0.4$ down to $x_{Bj} = 0.003$ with a strong emphasis on the low x_{Bj}–region which can presently only be reached by COMPASS.

Fig. 3 shows the measured asymmetry versus x_{Bj}. The shown error bars represent only the statistical error. It can be seen on this plot that in the important range of $x_{Bj} < 0.02$ the statistical accuracy of the preliminary COMPASS result is comparable to the accuracy of the final SMC result [3]. At high x_{Bj} the statistical error increases due to the decreasing polarization of the virtual photon and due to a limited trigger acceptance at high Q^2.

With an enlarged trigger acceptance in 2003 and additional data from 2003 and 2004 data taking an increase in statistics of a factor of four is expected.

There are two complementary strategies to determine the systematic error introduced by false asymmetries:

- MC-studies are planned to calculate with high precision the false asymmetry induced by known sources like instabilities in the detector efficiencies.
- Alternatively real data can be used to search for false asymmetries caused by any source. By choosing combinations of event rates N in equation 4 without any physical asymmetry (so called fake configuration) a resulting asymmetry is entirely due to false asymmetries. The accuracy of this method is limited by statistics to the same precision as the determination of A_1 itself.

Fig. 4 shows the asymmetry observed with the fake configuration versus x_{Bj}. The plotted asymmetry values are compatible with the '$A_1^{false} = 0$' hypothesis with 70 % probability, i.e. within the statistical accuracy there is no sign for a false asymmetry.

4 The Semi–Inclusive Analysis

As explained in the introduction the measurement of semi–inclusive asymmetries allow to disentangle the contributions of the various quark flavors. At COMPASS we intend to measure six different asymmetries namely $\vec{A}_1^d = \left(A_1, A_1^{h^+}, A_1^{h^-}, A_1^{K^+}, A_1^{K^-}, A_1^{K_s^0}\right)$. Where the upper index denotes which hadron type has to be detected in addition to the scattered muon. The necessary fragmentation functions have either been measured [4] or must be determined from MC.

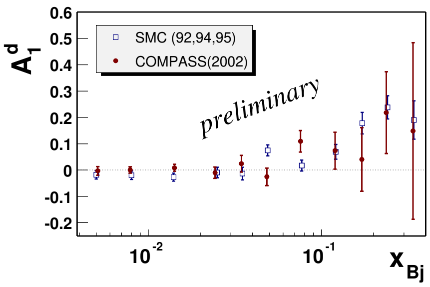

Figure 3. Measured asymmetry A_1^d for COMPASS 2002 data compared with the published SMC result basing on three years of data taking

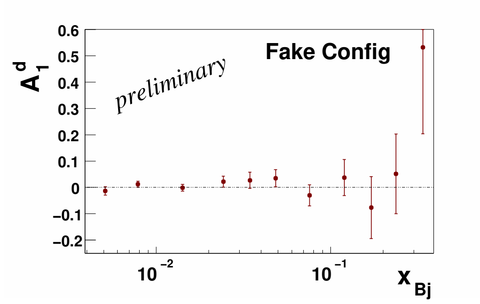

Figure 4. Measurement of the false asymmetry. Within the statistical accuracy of this method no false asymmetry has been found.

For the also needed unpolarized parton distributions many sources can be found in the literature.

As a consequence of the deuteron being an iso–scalar particle a full flavour decomposition is impossible with data from deuteron targets alone. Nevertheless from deuteron data alone it is still possible to determine the three quantities: $\Delta u + \Delta d, \Delta\bar{u} + \Delta\bar{d}, \Delta s = \Delta\bar{s}$, i.e. the determination of the interesting strange quark polarization is possible even without the missing proton data from COMPASS. As in the inclusive case the COMPASS measurement will extend the range in x_{bj} where Δs is known by one order of magnitude as compared to the published Hermes result [5] with a comparable precision, hence reducing the uncertainty of the first moment of Δs.

5 Summary

A first determination of the inclusive spin asymmetry A_1 have been shown. The obtained result is compatible with the final result of SMC. In the low x–range the precision of the COMPASS measurement is comparable with the accuracy obtained by SMC. With the additional data collected in 2003 and projected for 2004 the statistical errors will shrink by a factor of two. A study of the systematical errors is underway. The semi–inclusive analysis which is technically more demanding is ongoing.

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