Asymmetries from Semi-inclusive Polarized Deep Inelastic Scattering

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Abstract

We present the analysis of semi-inclusive data from deep inelastic scattering of polarized muons off polarized protons and deuterons. The resulting charged hadron asymmetries are used to determine polarized valence and sea quark distributions and their moments. In addition, a new approach to derive inclusive asymmetries is discussed.

To investigate the spin structure of the nucleon SMC studies deep inelastic scattering of polarized muons off polarized protons and deuterons. The SMC-NA47 experiment used the M2 muon beam of the CERN SPS at incident energies of 100 and 190 GeV. Data with polarized proton and deuteron targets were taken between 1992 and 1996 using butanol or ammonia respectively deuterated butanol as target materials. The target polarisation was measured to a precision of 2–3% by 10 NMR coils embedded in the target material. The polarisation of the naturally polarized muon beam of about 80% was determined from the spin asymmetry in elastic muon electron scattering. Scattered muons and charged hadrons are detected in an open forward spectrometer and electron-hadron separation is achieved with the help of an iron scintillator calorimeter (for details, see [1]).

In the standard analysis the spin structure function g_1 is determined from the measured inclusive asymmetry using scattered muons only. The produced hadrons can be used in two ways: Firstly, by requiring any hadron in addition to the scattered muon a true deep inelastic scattering is signaled and thus a discrimination between these events and background events like radiative events or elastic electron muon scattering is achieved. Secondly, semi-inclusive asymmetries from positively and negatively charged hadrons can be used to determine the polarized valence and sea quark distributions as a function of the momentum fraction carried by the struck quark, x.

In the first approach a complementary method of determining inclusive asymmetries is being developed. In the standard analysis the measured photon nucleon asymmetry is related to the total cross section by $A^{\gamma\mathrm{N}}_{\mathrm{meas}} = \Delta\sigma_{\mathrm{tot}}/\sigma_{\mathrm{tot}}$ where

$$\sigma_{\mathrm{tot}} = \lambda\sigma_{1\gamma} + \sigma^{\mathrm{el}}_{\mathrm{tail}} + \sigma^{\mathrm{qel}}_{\mathrm{tail}} + \sigma^{\mathrm{inel}}_{\mathrm{tail}}$$

$$\Delta\sigma_{\mathrm{tot}} = \lambda\Delta\sigma_{1\gamma} + \Delta\sigma^{\mathrm{el}}_{\mathrm{tail}} + \Delta\sigma^{\mathrm{qel}}_{\mathrm{tail}} + \Delta\sigma^{\mathrm{inel}}_{\mathrm{tail}}$$

where σ_{tail} ($\Delta\sigma_{\mathrm{tail}}$) is the cross section from radiative tails (elastic, quasielastic and inelastic) and λ is a polarisation independent multiplicative factor for the one-photon cross section $\sigma_{1\gamma}$ ($\Delta\sigma_{1\gamma}$) accounting for vacuum polarisation and vertex corrections.

Thus, the one-photon asymmetry $A_1^{\gamma\mathrm{N}} = \Delta\sigma_{1\gamma}/\sigma_{1\gamma}$ is diluted by these additional processes and corrections have to be applied to determine $A_1^{\gamma\mathrm{N}}$ from

$$A_1^{\gamma\mathrm{N}} = \frac{\sigma_{\mathrm{tot}}}{\lambda\sigma_{1\gamma}} A_{\mathrm{meas}}^{\gamma\mathrm{N}} - \frac{1}{D} \cdot \frac{\Delta\sigma_{\mathrm{tail}}}{\lambda\sigma_{1\gamma}},$$

where D is the depolarisation factor for the virtual photon. An additional dilution is due to the presence of unpolarized nuclei in the target. If an efficient selection of true deep inelastic events is obtained then most of the contributions to σ_{tot} and $\Delta\sigma_{\mathrm{tot}}$ vanish and the dilution of $A_1^{\gamma\mathrm{N}}$ is much smaller, giving a more accurate measurement of $A_1^{\gamma\mathrm{N}}$ although the event sample is smaller.

In the SMC spectrometer mainly forward produced charged hadrons with momenta $p_{\mathrm{h}} > 5$ GeV are detected, that is hadrons with $z = E_h/\nu \approx 0.05$ with ν the energy transfer. Events with a high mass W of the final state contain in general several hadrons with high momenta. High W events are typically found at small x, so that a good acceptance is obtained for $x < 0.1$, whereas in the high x region many hadrons are not detected due to the low momenta at low W. Monte Carlo studies show that more than 80% of the deep inelastic events with $x < 0.1$ are found by requiring at least one additional hadron to the scattered muon.

For part of these hadrons that pass through the calorimeter also the ratio $e = E_{\mathrm{em}}/E_{\mathrm{tot}}$ between the energy deposited in the electromagnetic part to the total deposited energy in the calorimeter is measured. Particles with $e > 0.8$ are labelled electrons, with $e < 0.8$ hadrons. To suppress electrons from γ conversions of radiative photons electrons with $z > 0.2$ and $\alpha < 0.004$ for events with $y = \nu/E_\mu > 0.6$ were removed. Here, α is the angle between the electron and the photon reconstructed from the muon kinematics. The same cuts are applied to particles that could not be identified by the calorimeter due to the limited acceptance close to the muon beam or due to multiple tracks pointing to the same module.

The results for A_1^{p} using the 1996 data taken with an ammonia target are shown in fig.1 for $x > 0.0008$ and $Q^2 > 0.2$ GeV^2 and are compared to the results from the standard analysis [2]. Good agreement between the two results is obtained with the statistical error bars lower by a factor 0.6 to 0.9 for $x < 0.01$ for the hadron method (for details, see [3]). It was checked with Monte Carlo simulations that a possible bias for the asymmetries from the hadron method due to the selections applied is much smaller than the statistical error and will be included in the systematic error.

In the second approach polarized quark distributions are determined from semi-inclusive asymmetries using the different weighting of quarks and antiquarks due to favoured and unfavoured fragmentation functions $D_{\mathrm{q}(\bar{\mathrm{q}})}^{\mathrm{h}}$ [4]. In the quark parton model these hadron asymmetries are given by

$$A^{\mathrm{h}}(x,z) = \frac{\sum_{\mathrm{q}} e_{\mathrm{q}}^2 (\Delta q(x) \cdot D_{\mathrm{q}}^{\mathrm{h}}(z) + \Delta\bar{q}(x) \cdot D_{\bar{\mathrm{q}}}^{\mathrm{h}}(z))}{\sum_{\mathrm{q}} e_{\mathrm{q}}^2 (q(x) \cdot D_{\mathrm{q}}^{\mathrm{h}}(z) + \bar{q}(x) \cdot D_{\bar{\mathrm{q}}}^{\mathrm{h}}(z))}$$

with the unpolarized and polarized quark distributions, $q(x)$ and $\Delta q(x)$. Using parametrisations for the unpolarized distributions (GRV94 LO) [5] and the fragmentation

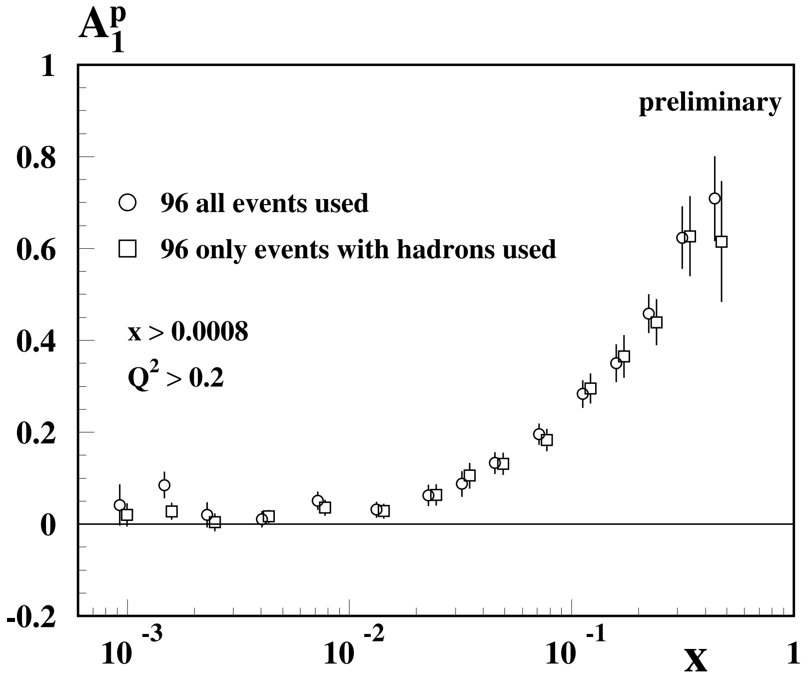

Figure 1: Preliminary results for $A_1^{\mathrm{p}}(x)$ obtained with the hadron method (open squares) compared to the ones from the standard analysis (open circles). The error bars are statistical errors.

functions from [6] the polarized quark distributions can be extracted from a combined analysis of the inclusive [2],[7] and the semi-inclusive asymmetries [8].

From all SMC measurements the asymmetries for positively and negatively charged hadrons were determined using tracks originating from the interaction point of the scattered muon eliminating tracks that were labelled as electrons. To allow the interpretation in the quark parton model a cut of $Q^2 > 1$ GeV^2 and $z > 0.2$ was applied. The resulting asymmetries are shown in fig.2 in the x range from 0.003 to 0.7. The average Q^2 is 10 GeV^2 and the total event sample includes $5 \cdot 10^6$ positive and $3.8 \cdot 10^6$ negative hadrons.

To extract the valence quark distributions $\Delta u_{\mathrm{V}}(x)$ and $\Delta d_{\mathrm{V}}(x)$ and the sea quark distribution $\Delta\bar{q}(x)$ additional assumptions are needed. Firstly, $\Delta\bar{u}(x) = \Delta\bar{d}(x) = \Delta\bar{q}(x)$ is used due to the limited statistics of the data set. Secondly, to constrain the polarized strange quark distribution $\Delta\bar{s}(x) = \Delta s(x) \sim s(x)$ is assumed with the integral $\int(s(x)+\bar{s}(x))\mathrm{d}x = -0.1$ in the range $0.003 < x < 1$ fixed to the value from the inclusive analysis [1]. The effect of this assumption on $\Delta u_{\mathrm{V}}(x)$, $\Delta d_{\mathrm{V}}(x)$ and $\Delta\bar{q}(x)$ is negligible due to the low sensitivity of the measured asymmetries to the strange distribution as 80% of the hadrons are pions. Also, possible Q^2 dependences of the asymmetries are neglected by using $A(x, Q^2_{\mathrm{meas}}) = A(x, 10\,\mathrm{GeV}^2)$.

The preliminary results for the polarized quark distributions $x\Delta q(x)$ are shown in fig.3 compared to $\pm xq(x)$ [5]. The valence quark distributions are positive for $\Delta u_{\mathrm{V}}(x)$ and negative for $\Delta d_{\mathrm{V}}(x)$ with a polarization of about 50% (–50%), respectively. The

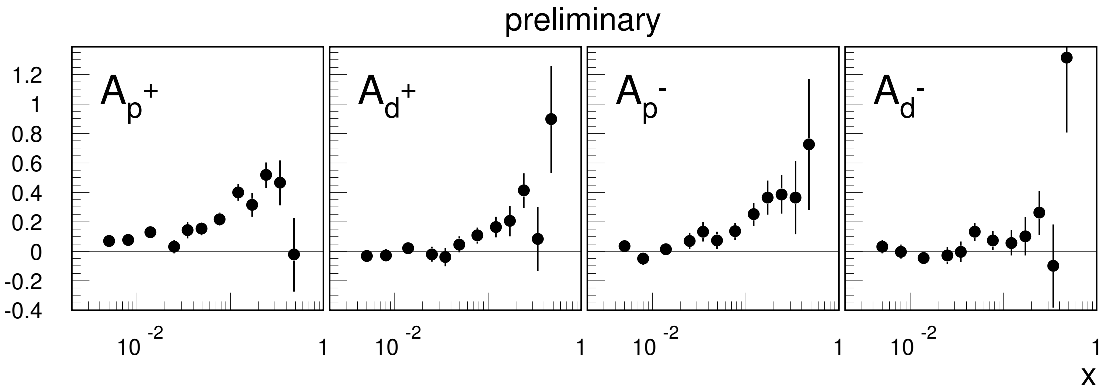

Figure 2: Preliminary results for the semi-inclusive photon asymmetries for positively and negatively charged hadrons from proton and deuteron targets as a function of x with statistical error bars.

non-strange sea quark distribution is consistent with zero over the measured range.

To determine the moments of the polarized quark distributions extrapolations to $x = 1$ and $x = 0$ are needed. They are estimated from fits to the data and from parametrisations determined in leading order QCD analyses of all existing inclusive results [9]. The extrapolation to $x = 1$ leads to a negligible contribution, where as the low x extrapolation results in contributions of about 0.05 with a similar error for the valence quark moments. We obtained for the integrals $\int_0^1 \Delta q \mathrm{d}x = \Delta q$

$$\begin{aligned} \Delta u_{\mathrm{V}} &= 0.92 \pm 0.11(\mathrm{stat.}) \pm 0.07(\mathrm{syst.}), \\ \Delta d_{\mathrm{V}} &= -0.53 \pm 0.15(\mathrm{stat.}) \pm 0.07(\mathrm{syst.}), \\ \Delta \bar{q} &= -0.02 \pm 0.05(\mathrm{stat.}) \pm 0.02(\mathrm{syst.}). \end{aligned}$$

These results for the valence quark moments are in good agreement with results obtained from the axial matrix elements of weak baryon decays F and D (for the values, see [1]) assuming a SU(3) flavour symmetric sea.

References

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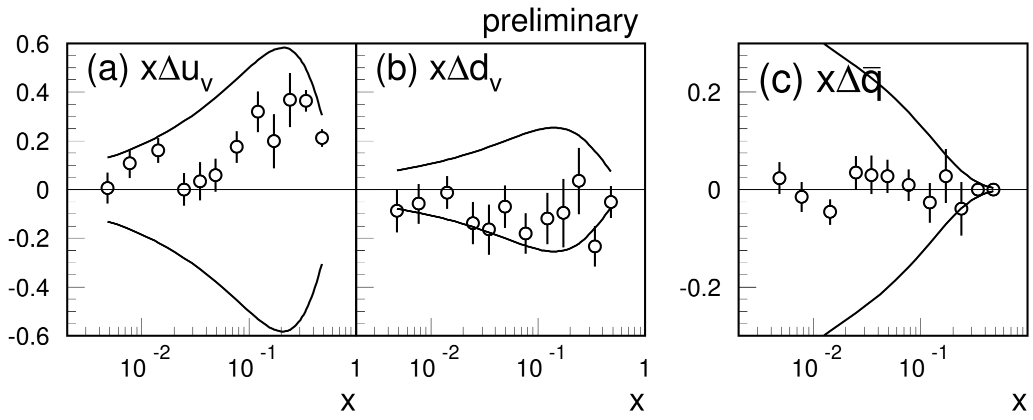

Figure 3: Preliminary results for the polarized quark distributions (a) $x\Delta u_{\mathrm{V}}$, (b) $x\Delta d_{\mathrm{V}}$ and (c) $x\Delta\bar{q}$ as a function of x at $Q^2 = 10$ GeV^2 with statistical error bars. For the curves, see text.

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