The SMC Experiment

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Abstract The status of the forthcoming muon experiment at CERN for measuring the spin-dependent structure function of the neutron and of the proton is discussed. Expected accuracies for the evaluation of spin-related sum rules, in particular the Bjorken sum rule, are given.

The Spin Muon Collaboration (SMC) will study deep inelastic scattering events of polarized muons on polarized deuterons and on polarized protons [1]. The experiment uses the muon beam line M2 of the SPS, a large polarized target, and the muon spectrometer which was originally built by the EMC [2]. This spectrometer was substantically upgraded by the New Muon Collaboration (NMC) in the years 1986 to 1989 [3]. The proton data will considerably improve on the precision of the previous CERN [4] and SLAC [5] experiments.

The longitudinal spin asymmetry of the cross section is the principal quantity to be determined, $A = (d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}) / (d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow})$. The spin-dependent structure function, $g_1(x)$, can be computed from A with knowledge of the unpolarized structure function $F_2(x)$:

$$g_1(x) = \frac{A(x)}{D(x)} \frac{F_2(x)}{2x(1+R)}, \qquad (1)$$

where D is the depolarization factor for the virtual photon and $R = \sigma_L/\sigma_T$. Relation (1) holds for the deuteron (note that here $F_2^d = F_2^p + F_2^n$) as well as for the proton. For the neutron follows $g_1^n(x) = g_1^d(x) - g_1^p(x)$.

Primarily observed is the spin asymmetry of the event yield (N') for antiparallel and parallel spin configurations of muon beam and target under otherwise constant experimental conditions:

$$A_m = (N^{\uparrow\downarrow} - N^{\uparrow\uparrow}) / (N^{\uparrow\downarrow} + N^{\uparrow\uparrow}) = A \cdot P_\mu \cdot P_T \cdot f \cdot (1 + r_c)^{-1}, \qquad (2)$$

where $P_\mu (P_T)$ is the beam (target) polarization, f is the dilution factor for the target (ratio of number of polarizable protons (deuterons) to total number of protons (deuterons)), and r_c is a radiative correction factor. For the SMC experiment the product of $(P_T \cdot f)$ will be about 0.1, for deuterated as well as for hydrogeneous target material This value reduces the asymmetry A_m to about 10% of A. This puts stringent requirements on the apparatus in order to keep false asymmetries arising from instrumental effects well below the expected values of A_m.

There are two provisions built into the experiment to guard against such instrumental effects. Firstly, the target is a "twin" arrangement of two target sections which are oppositely polarized. These sections are simultaneously exposed to the beam and are separated in longitudinal direction by 30 cm. $N^{\uparrow\downarrow}$ and $N^{\uparrow\uparrow}$ are thereby measured simultaneously and variations of beam flux do not effect A_m. This important feature was already incorporated in the target used by the EMC [6]. Secondly, the polarization of both sections can be reversed in common by the method of (slow) adiabatic rotation. This allows to correct for acceptance and density differences of the two target sections and to eliminate effects of changing spectrometer acceptance on the measured A_m, provided the reversal sequence is fast compared to the time scale of instability of the apparatus.

The muon beam line will be reoptimized for operation in the momentum range 100-200 GeV/c to provide a reduced lateral beam size (about 4.5 cm dia.) and reduced beam halo intensity. The improvement on beam halo conditions is a prerequisite for efficient high intensity (up to $4.4 \cdot 10^7$ muons per 2.8 sec pulse) running. With the smaller beam size the target thickness can be increased while keeping the target volume constant. Thus more polarized material can be exposed to the beam for a given cooling power of the refrigerator. The muon beam is naturally longitudinally polarized, with a high polarization of $P_\mu \simeq 0.8$ for a fixed muon-to-pion energy ratio of 0.9. Positive muons will be used which have negative helicities.

The collaboration is building a polarimeter which is located downstream of the forward spectrometer, in the area of the former CERN NA4 experiment. Two methods will be used. With the decay method, ($\mu^+ \rightarrow e^+\nu\bar{\nu}$), a polarization measurement can be made to the required precision in several hours; the (μ^+e^-) scattering method will need about two days for a measurement, but it provides an important cross check on the calibration. Both methods will share parts of the set-up. A conceptual description has already been given before [7]. The advantage of using a muon beam for the spin structure measurements lies in the automatically high and presumably stable polarization. In addition a high energy muon beam is of considerable advantage for reaching the kinematic region of very small x values. The intensity of the beam, however, is small compared to intensities of electron beams.

The polarized target is of the solid-state type, employing the method of dynamic nuclear polarization. A new, powerful dilution refrigerator will be built and, likewise, a new superconducting solenoid with field values of 2.5 T and $\Delta B/B \simeq 10^{-5}$. Incorporated into the solenoid is a transverse dipole-field coil which will allow a maximum field strength of 0.5 T. This arrangement will be used for polarization reversals by field rotation: ramping the solenoid field down, reversing polarity, and ramping up again, while, in step, the dipole field is increased and then decreased. Starting with a field of 0.5 T in frozen-spin mode, the reversal time is estimated to be about 5 minutes. The dipole field is also of importance for enabling a transverse polarization of the target when it is in the frozen-spin mode. In this polarization configuration a measurement of the spin-dependent structure function $g_2(x)$ can be performed. To provide an accurate polarization measurement, ten NMR coils will be distributed in the target. Precise thermometry is also necessary. For the 1991 running period the "old" EMC target [6] will be used, having as major upgrade and improvement a dipol winding added to the outside of its microwave cavity. The 0.1 T dipol field will likewise allow frequent reversals and eliminate the dominant systematic error of the EMC asymmetry measurement [4].

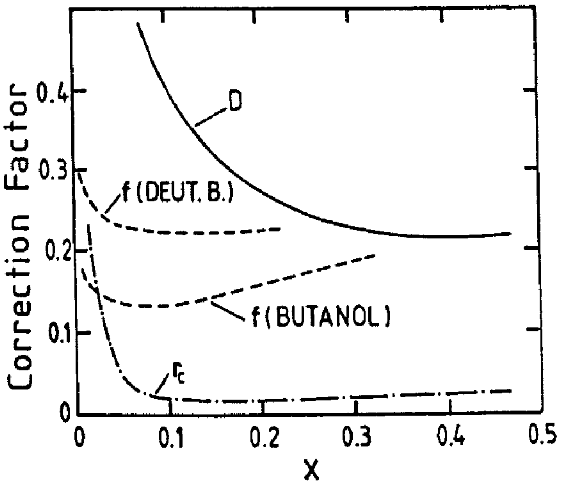

Fig. 1 The correction factors of equations (1) and (2) as a function of x.

The target material chosen consists of frozen beads of a mixture of 1-butanol, 5% water, and 3% EHBA-Cr(V) dopant. For the deuteron measurement all components will be taken in their per-deuterated form. The background from other materials will be small. The He^3/He^4 mixture between the beads does not contribute significantly to scattering because of its low density. The space between the two target section is filled with microwave absorbing sheets of low density. The advantage of the solid-state target lies in its very high nucleon density of $5 \cdot 10^{25}$ /cm^2. As mentioned, the "effective" polarization, $P_T \cdot f$ will only be 0.1, reducing any figure of merit (P^2L), calculated for a comparison, by almost two orders of magnitude. On the other hand, the factor f is well-known and stable, introducing no other adverse effects into the measurement (for deuterated material: $f \geq 0.23$, $P_T = 0.4$; for hydrogeneous material: $f \geq 0.13$; $P_T = 0.8$). Figure 1 shows the x dependence of the dilution factors.

The muon spectrometer, inherited from EMC and NMC, will again undergo additions and upgrades. The most important change is a replacement of the muon drift chambers W67 by a new arrangement of streamer tubes and drift tubes.

Data will be taken at energies of 100 and 200 GeV. It is planned to run 1/3 of the time on protons and 2/3 on deuterons. A total running time of 220 days is considered for the $g_1(x)$ measurement, taking into account an assumed efficiency of 0.35. With the small angle trigger ($\Theta_{min} = 0.3°$) the rate at 200 GeV can be kept reasonably high and small x-values can be reached. With $Q^2_{min} = 1\ GeV^2$ and $y_{max} = 0.85$, (the cut being dictated by the uncertainty of radiative corrections) the minimum x will be $x_{min} = 0.003$. The vertex resolution (in longitudinal direction) is still adequate at these small angles. Radiative corrections to the asymmetry will be about three times larger for polarized electron experiments, under comparable conditions.

The quality of the asymmetry data will be such that the statistical error for the measurement of the proton is expected to be 1/2 of that of the EMC result [4]. The new neutron asymmetry data will have a statistical error about twice the size of that of the proton data. Figure 2 shows the x dependence of the statistical error. Systematic errors will be considerably reduced compared to the previous EMC experiment. The influence of acceptance changes will be diminished to an insignificant level by a stable apparatus and frequent polarization reversals; the value of the structure function $F_2(x)$ is much better known with new insight from NMC and BCDMS data; the error from

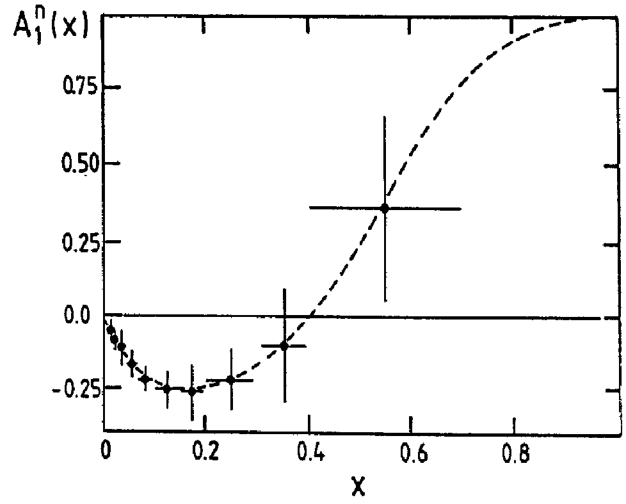

Fig. 2 Projected A_1^n(x) data points for SMC CERN NA47 experiment and prediction of a phenomenological theory [8] (dashed curve).

the lack of knowledge on $A_2(x)$ will be reduced by measuring it in the low x region; this will also give information on R and reduce the error connected with it.

For the statistical and systematic errors of the integrals of the spin-dependent structure functions the following absolute values can be anticipated: Bjorken sum rule with an error of 0.015 stat./0.018 syst.; Ellis-Jaffe sum rule, proton, with an error of 0.006 stat./0.010 syst.; Ellis-Jaffe sum rule, neutron, with an error of 0.011 stat./ 0.010 syst.; integral over g_1^d with an error of 0.009 stat./0.007 syst. It should be noted that the experiment can thus determine the predicted value of the Bjorken sum rule with an error of 10 %. Also noteworthy are the small errors in the integral of g_1^d. The fraction of the proton spin carried by quarks can be extracted relative directly from this integral, only data from hyperon decays have to be used in addition.

In its 1991 run the SMC collaboration will need time for testing the apparatus and tuning the equipment. Using a polarized proton target for data taking, it is estimated that about one-half of the wanted statistics could be accumulated in that year.

References

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