THE COMPASS POLARIZED TARGET

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The COMPASS experiment runs the largest ever built polarized target system to study the spin structure of the nucleon by deep inelastic muon scattering process. This target, largely reusing the Spin Muon Collaboration target apparatus, consists of two cells opppositely polarized in a 2.5T field and filled up with granulated ^{6}LiD as a deuteron target. The excellent stability and polarization performances of the target system gave the opportunity of 2 world records of polarization in ^{6}LiD under these conditions between 2001 and 2004.

1. The goal and the challenge

The main goal of the COMPASS muon program is to determine the gluon contribution to the nucleon spin by measuring the double spin asymmetry accessible through the open charm leptoproduction and high-p$_T$ hadron pair events from the scattering of a 160 GeV polarized muon beam on a longitudinally and oppositely polarized deuteron double cell target.
The double spin asymmetry is experimentally given by

$$A^{exp} = \frac{N^{\rightleftarrows} - N^{\leftleftarrows}}{N^{\rightleftarrows} + N^{\leftleftarrows}} = P_B P_T f A^{\mu N \to q\bar{q}X} \; , \tag{1}$$

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$A^{\mu N \to q\bar{q}X}$ is the cross section asymmetry that would be directly measured for a pure target material, target and beam 100% polarized. N is the counting rate for parallel and antiparallel spin orientations between the beam and the target.P_B is the beam polarization, P_T the target polarization, the dilution factor f is the ratio of the polarizable nucleons to the total amount of nucleons. For a given beam polarization P_B the quantity $P_T \cdot f$ which depends on the target material must be maximized. The challenge for such a target is:

(1) to run the largest solid polarized target to get a high luminosity to obtain a higher statistic,
(2) to achieve the highest possible polarization requested in Eq. (1),
(3) to measure the polarization without disturbing the experiment,
(4) to reduce the multiple scattering for an efficient reconstruction of events by minimizing the non target material,
(5) to allow the frequent change of the sign of the polarization to fight against false asymmetries from acceptance changes.

2. The target system overview

The COMPASS muon program has restarted the SMC target system[1,2]. This is mainly composed of two target cells in line of 3cm in diameter and each 60cm long separated by a 10cm gap and cooled by a ^{3}He/^{4}He dilution refrigerator. The cells filled with ^{6}LiD are located in an homogeneous longitudinal 2.5 T magnetic field and irradiated by microwaves to buid up the polarization by dynamic nuclear polarization (DNP) process. A system of nuclear magnetic resonance (NMR) measures the degree of polarization.

2.1. *The dilution refrigerator*

A powerful dilution refrigerator is used to perform the cooling of the 350g of ^{6}LiD grains loaded in the 2 target cells[1]. Its large cooling power can absorb the amount of microwave power during the DNP process where more than 350mW are necessary at the beginning. From 200-350mK when polarizing, this dilution refrigerator can lower and maintain the target at about 50mK in the frozen spin mode to slow down the spin-lattice relaxation when the microwave are switched off.

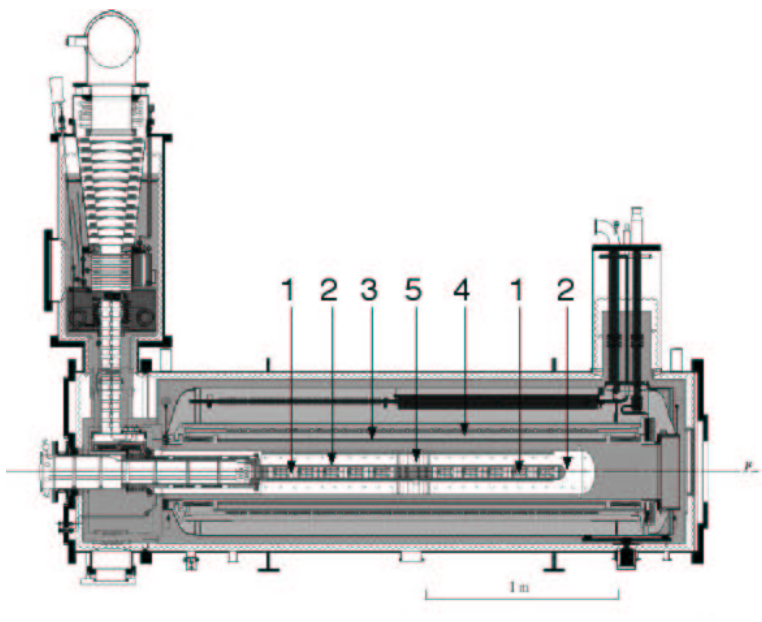

Figure 1. Side view layout of the target system. The muon beam enters the cryostat from the left. (1) target cells, (2) microwave cavity, (3) solenoid, (4) dipole, (5) microwave stopper

2.2. *The superconducting magnet system*

It consists of a main solenoid producing a 2.5T longitudinal field with respect to the beam axis and a dipole generating a perpendicular 0.5T field. A longitudinal field homogeneity $\Delta B/B$ as good as $3.5 \cdot 10^{-5}$ over the target volume is guaranted by 16 additional correction coils along the solenoid. The dipole is used to perform the magnetic field rotation procedure or to allow the transverse target polarization to investigate the transverse cross section asymmetry.

The procedure of magnetic field rotation is used to reverse the target spin orientation which is needed to fight against the false asymmetries coming from the difference of the spectrometer acceptance of the 2 target cells. This procedure helps also to reduce the systematic errors coming from the time dependant variation of the spectrometer efficiency and of the beam intensity.

The polarization reversal by magnetic field is very useful because it takes only 33 minutes and can be operated every 8 hours through an automatic procedure. That avoids to have to repolarize by DNP because the polarization build up time is considerably longer in the case of ^{6}LiD (see Sec. 2.4). The procedure also guarantees that the field is never below 0.5T to preserve the degree of polarization.

2.3. *The target material*

The most important criteria to select suitable target material are the degree of polarization and the dilution factor. Because the quantity $N^{\rightleftarrows} + N^{\leftleftarrows}$ in Eq. (1) is proportional to the measuring time, the beam time t to reach a certain statistical accuracy ΔA shows the dependency

$$t^{-1} \propto \rho (fP)^2 \tag{2}$$

where ρ stands for the density of the material. From Eq. (2) it is clear that as higher the product $f \cdot P$ as shorter is the requested beam time for a given statistical accuracy. To characterize the material we define the figure of Merit (FoM) which is given by

$$FoM = \rho k (fP)^2 \tag{3}$$

including the packing factor k corresponding to the ratio of the volume occupied by the material to the volume of the target cell.

The Table 1 shows the values needed to determine the FoM of ^{6}LiD used in COMPASS and also of the materials from the previous experiment SMC. ^{6}LiD and D-Butanol have an equivalent degree of deuteron polarization which is much lower than for the proton target NH_3 but the FoM is better for ^{6}LiD due to a much higher dilution factor. Here we do not discuss the residual space between the pieces of material occupied by the ^{3}He/^{4}He mixture which slightly reduces the dilution factor[3,4].

Table 1. Comparison of the quantities of Eq. 3 and figure of merit for different target materials.

	SMC	SMC	COMPASS
Material	NH_3	D-butanol	^{6}LiD
Density	0.85	1.10	0.84
Polarization	H :∼0.90	D :∼0.50	D :∼0.50
Packing factor k	0.60	0.60	0.55
Dilution factor f	0.176	0.238	∼0.50
FoM	10.3	6.7	16.0

2.4. *The microwave system*

Two independent EIO[a] tubes are used to polarize the two target cells in opposite spin directions. Both cells are located in the microwave cavity but isolated one from the other by a microwave stopper (see Fig. 1). For ^{6}LiD at 2.5T, the frequencies used for positive (negative) polarization are [70.180 - 70.238]GHz ([70.285 - 70.245]GHz). The frequencies and powers are continuously adjusted depending on the degree of polarization reached. In addtion, a frequency modulation of about 5MHz at a rate of 500Hz is used during the process to optimize the speed and the degree of the polarization[5]. From Fig. 2 it can be seen that $|P|$=40% after 1 day of DNP. This can be

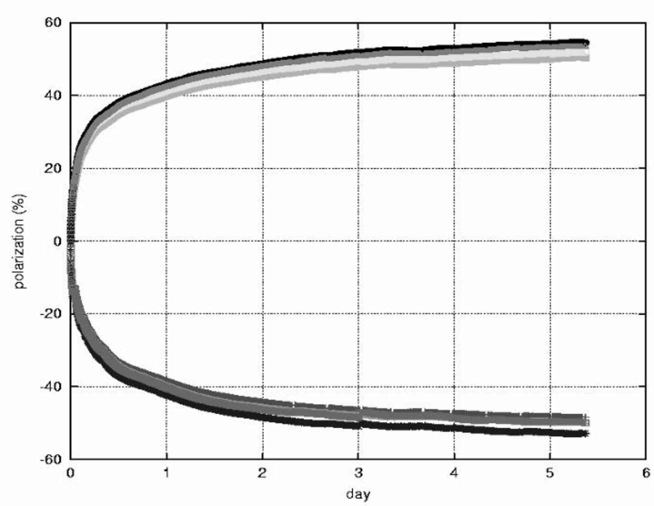

Figure 2. Typical polarization build up curve of ^{6}LiD at 2.5 T. The 4 curves for positive/negative polarization are the response from the 4 NMR coils used for each cell.

compared to the 5-6 hours needed to get the same degree of polarization with D-butanol. After more than 5 days of DNP the average polarizations are about +55%/-51% but with a strong asymptotic behaviour making it meaningless to continue polarization build up thereafter.

[a]Extended Interaction Oscillator

2.5. *The NMR system*

The polarization is determined from 8 NMR coils distributed along the target cells and tuned to the deuteron Larmor frequency at 2.5 T. They are driven simultaneously by a radiofrequency synthetizer with a frequency sweep of ±50kHz around the deuteron Larmor frequency (16.38MHz)[6]. The spectra obtained from this scan are the direct result from the change of the coils impedance through inductance change induced by the evolution of magnetic susceptibility $\chi(\omega)$ of the material which is proportional to the polarization[7]. A Q-meter determines the resulting variation of voltage. The background signal is acquired by driving the magnetic field out of resonance. Subtracting it from the raw signal give access to the "real" line shape which is integrated over a suitable frequency range to extract the polarization value.

3. Results and perspectives

The large COMPASS polarized target is running since 2001 in a very reliable way. A first world record of ^{6}LiD polarization with +56.8% and -52.7% was reached in 2002. In 2004 a second world record occured with +57.1% and -53.0% still at 2.5T. In order to increase the acceptance for hadrons from 70 mrad to 180 mrad a new solenoid with a larger diameter is under construction and will be combined with a dedicated microwave cavity. A promissing trytil-doped D-butanol material with a substantial improvement of the maximum polarization in under investigation at Bochum university[8,9]. A deuteron polarization higher than 80% seems to be accessible with this material which would increase the FoM up to 21 - 22. That features would improve the statistical accuracy of the double spin asymmetry by 30% for a given beam time.

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