COMPASS polarized target

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1 Introduction

COMPASS is one of the few experiments currently running at CERN. The experiment investigates the structure of nucleons by scattering a beam of muons off a fixed polarized target of nucleons. Since the energy of the beam is high 160 GeV, deep inelastic scattering takes place, and the muons have enough energy to break apart the nucleons. Nucleons consist of valence quarks which are kept together by gluons. The gluons can spontaneously break into quark-antiquark pair producing so called sea quarks. The deuterium target is solid granulated ^{6}LiD.
It is known that the quarks carry only a fraction 20-30% of the nucleon spin. The missing part could be explained by the gluon spin or the angular momentum of partons. One of the main goals of COMPASS is to measure the gluon polarization and its contribution to nucleon spin. The data taking started in 2002.

2 Theory and physics

The angular momentum sum rule tells us that if we sum over the momenta of all the partons in a nucleon, we must reconstruct the total momentum of such nucleon. Therefore, the nucleon spin can be decomposed in terms of contributions from quarks and gluons as follows:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta g + L_g \tag{1}$$

where $\Delta\Sigma$ is the spin of quarks, Δg is the spin of gluons, and L_q and L_g correspond to the orbital angular momentum of quarks and gluons respectively.
The COMPASS experiment explores the gluon polarization by the open charm leptoproduction (OCLP) via photon-gluon fusion process shown in Fig. 1. Muons in the longitudinally polarized beam are scattered off nucleons in the polarized target to an outgoing muon and a hadronic final state X. A virtual photon emitted from the muon beam interacts with a gluon in the nucleon of the target. A charm-anticharm pair is produced in the center of mass of the photon and gluon system.
The gluon contribution to nucleon spin can be obtained from comparison between the cross section of OCLP when the muon spin and the target spin are parallel, and that of the configuration in which the muon spin and the target spin are anti-parallel.

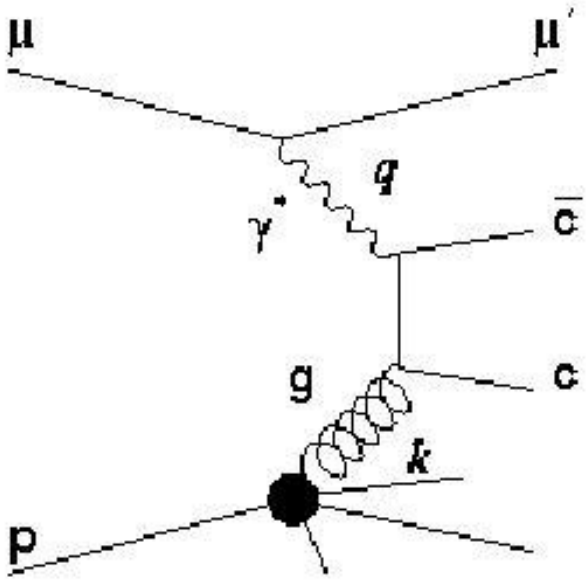

Figure 1: The process of open charm leptoproduction

3 COMPASS experimental set-up

COMPASS spectrometer

The spectrometer has several kinds of detectors for tracking, identification and energy measurement of the outcoming particles from the scattering events. The kinematics of muons, before and after the scattering must be determined, and the rest of the outgoing hadrons must be detected for better statistics and systematics. The spectrometer has two large magnets called SM1 and SM2.

COMPASS polarized target apparatus

The target has a dilution refrigerator providing low temperature and high cooling power at 50 - 300 mK, a superconducting solenoid producing a magnetic field of 2.5 T, two 10 W 70 GHz microwave generators for dynamic nuclear polarization (DNP), and the nuclear magnetic resonance (NMR) signal detection system for the polarization monitoring. The side view of this apparatus is shown in Fig. 2.

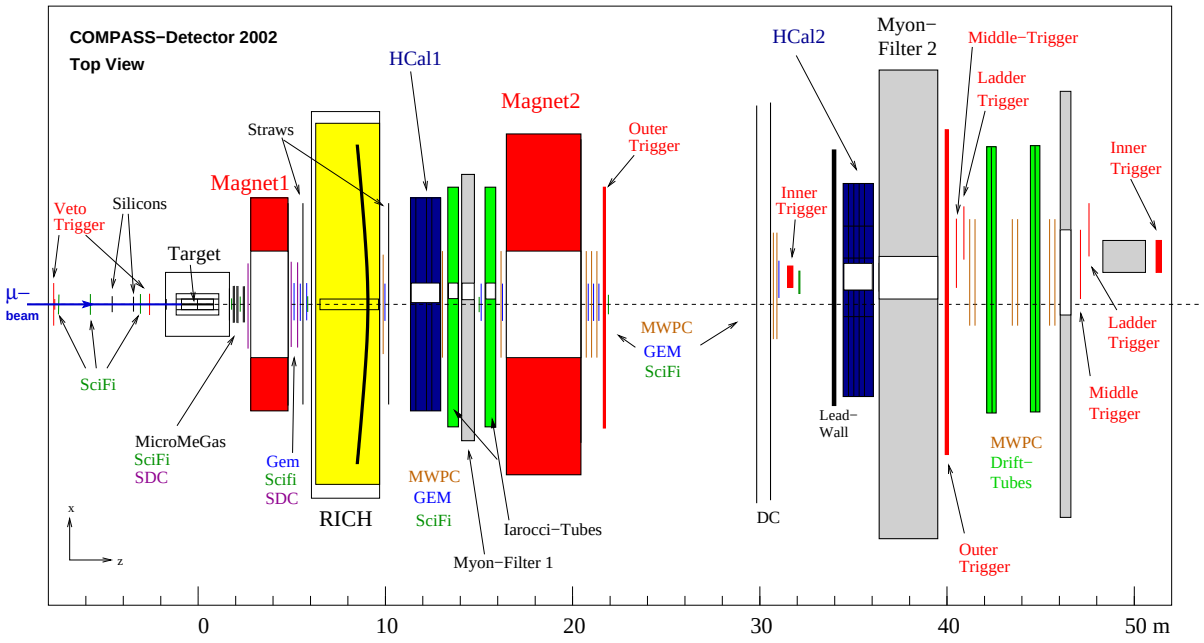

Figure 2: COMPASS general experimental set-up.

The target material is placed in two large 60 cm long and 3.0 cm diameter cells. The two microwave systems produce simultaneous dynamic nuclear polarization in the two target cells with opposite signs. The cells are polarized longitudinally with respect to the direction of the muon beam.

The field of the superconducting solenoid is rotated every 8 - 12 hours to allow spin reversal of the two target cells. Four NMR coils are placed inside each of the target cells to allow the measurement of the nuclear polarization. Deuteron NMR signals are recorded in 1 - 30 minutes intervals during the data taking.

4 COMPASS polarized target

Dynamic nuclear polarization (DNP)

At thermal equilibrium (TE) the nuclear polarization is small, about 0.05 % at 1.0 K and 2.5 T. High nuclear polarization in the target is obtained via dynamic nuclear polarization (DNP) process, in which microwaves are used to enhance the polarization above the TE value.

The material of the target, ^{6}LiD, is a crystal with face-centered cubic structure in which paramagnetic F-centers have been introduced - about $10^{-3} - 10^{-4}$ F-centers per nucleus.. Its structure can be seen in figure 3. An F-center consists of a vacancy in the anion sublattice of the crystal, in which a free electron is captured.

In the experimental conditions, the unpaired electrons have a polarization of about 96%, while that of the nuclei is below 1%. DNP transfers the high electron polarization to

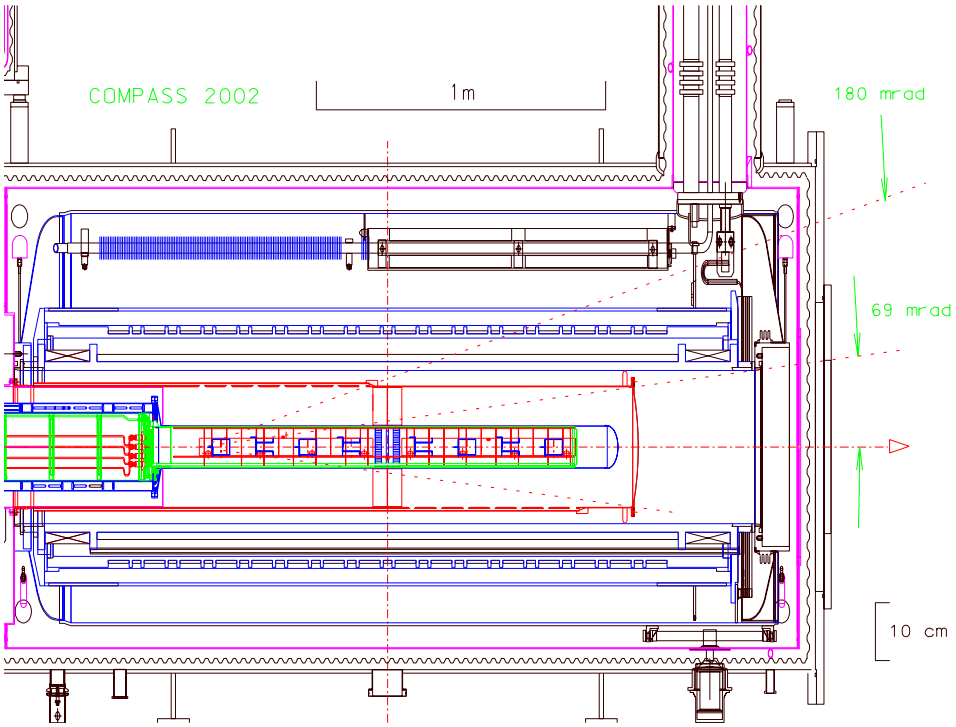

Figure 3: Side view of the COMPASS polarized target cells with NMR coils. The muon beam traverses from left to right.

nuclear spins. Polarization build up in time can be seen in figure 4.

The choice of the target material

^{6}LiD material is chosen for its large fraction of polarizable nucleons and for the high effective nuclear polarization that the molecule can reach (50% for both ^{6}Li and D at 2.5T magnetic field). This means that the beam time needed to achieve a certain statistical accuracy in the asymmetry measurement is minimized as the accuracy is proportional to the square of spin polarization. The ^{6}LiD target high polarization and the simple shape of the NMR deuteron spectrum allow an easy and accurate measurement of the polarization value.

5 NMR Measurements

The target polarization is measured with nuclear magnetic resonance (NMR). The determination of the polarization of the target must be done precisely because it affects the evaluation of the gluon contribution to nucleon spin.
The resonant peak for deuteron at 2.5T magnetic field takes place at the frequency of 16.35MHz. If the magnetic field is shifted from the nominal value, the NMR signal does not appear on the curve and we get only the background. By subtracting the background

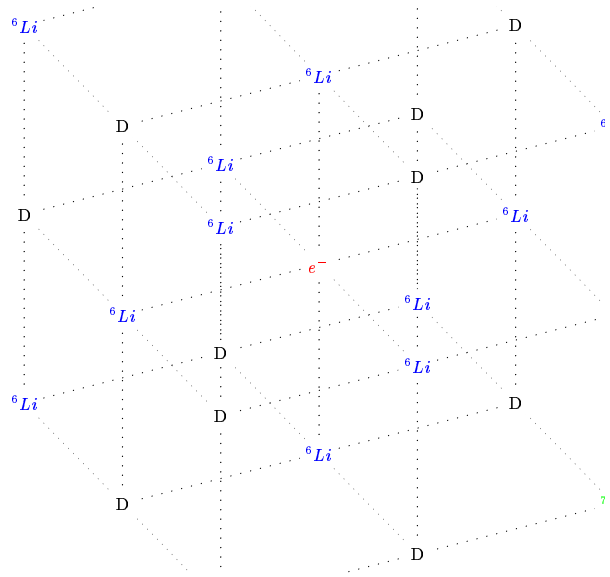

Figure 4: Target material ^{6}LiD crystal structure.

signal from the raw NMR data one can obtain the NMR signal. There is a small residual baseline left, however. The residual baseline can be subtracted from signal by fitting a straight line to off-resonance region. This curve can be integrated to obtain the area of the TE signal at known temperature. The target polarization at thermal equilibrium is proportional to the area of the NMR signal. The calibration is done at two or three different temperatures, e.g. 0.96K and 1.44K.

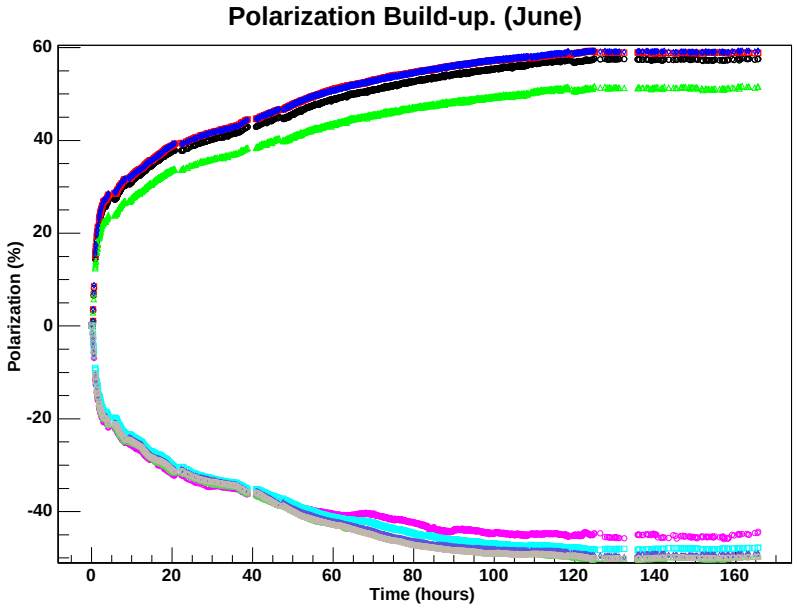

Figure 5: Polarization build-up in time. May 2003.

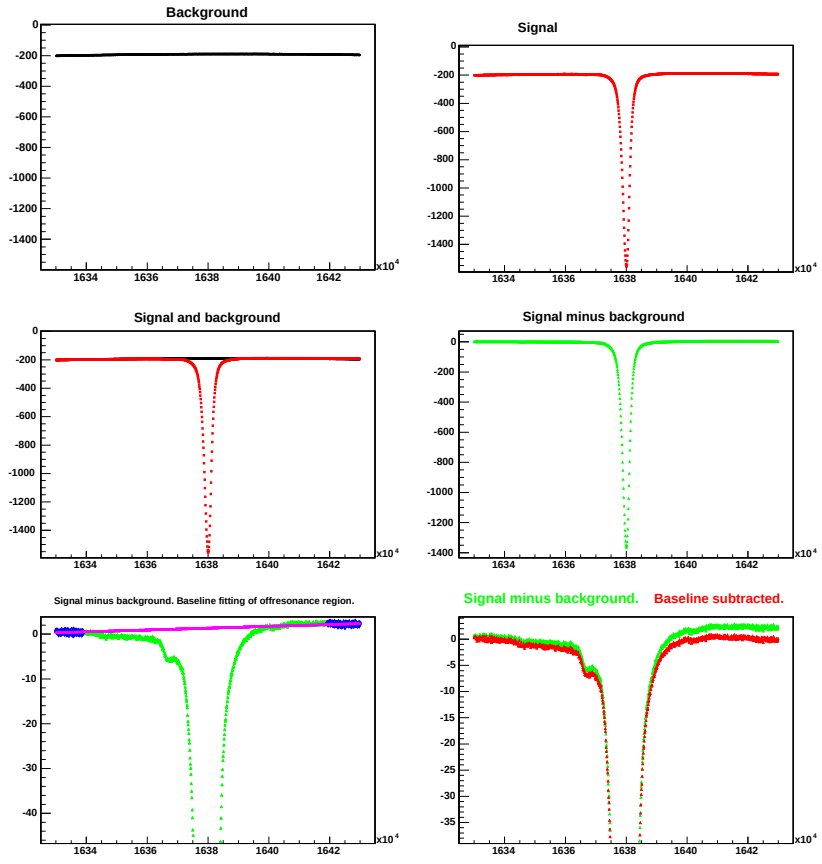

Figure 6: Analysis of NMR signals. From top to bottom and left to right: background; signal; signal and background together; signal after background has been subtracted; baseline fitting of off-resonance region; comparison between signal, and signal after baseline has been subtracted.