Polarization Data Analysis of the COMPASS ^{6}LiD Target

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Abstract

The COMPASS experiment at CERN has been taking spin physics data in 2002 - 2004 with a double cell solid ^{6}LiD target with high +57 % and -53 % nuclear polarization. The measured asymmetries give access to longitudinal spin structure function, transverse Collins and Sivers asymmetries, and to gluon polarization. Stable and reproducible operation of the polarized target is essential in the typically 100 day long data taking periods. We discuss the present understanding of the polarization properties of our ^{6}LiD target measured with continuous wave nuclear magnetic resonance.

1. Target cells

COMPASS polarized deuteron target is described in Refs. [1, 2, 3]. The target cells are 60 cm long and have 3 cm diameter with 424 cm^3 cell volume.

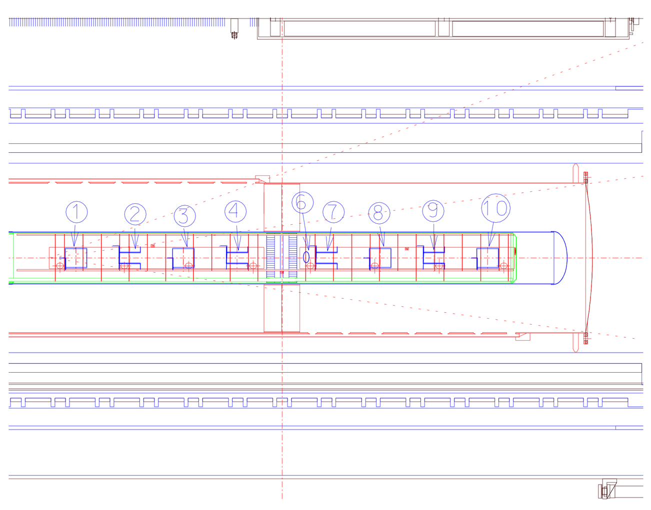

Figure 1: *The microwave cavity with target cells inside superconducting magnet. The cells are inside glass fiber mixing chamber with liquid ^{3}He/^{4}He mixture at 50 - 300 mK temperature. The NMR coils 1 - 4 are on the upstream target cell and 6 - 10 on the downstream cell. Two halves of the microwave cavity are separated with a microwave stopper [1]. Muon beam comes from left and produced particles in acceptance of 69 mrad come out from right.*

2. ^{6}LiD target material

Figure 2: *2 - 4 mm ^{6}LiD crystals floating on liquid nitrogen (or argon). The crystals have face-centered cubic structure and they were irradiated at Bonn with 20 MeV electron beam to create paramagnetic centers into the material [4].*

Table 1: *Summary of the elements inside the upstream (up) and downstream (down) target cells for 2003 in the COMPASS experiment [5].*

	mass [amu]	up [mol]	down [mol]
H	1.00794	0.11	0.11
D	2.0140	21.23	21.97
^{3}He	3.0169	0.7 ± 0.2	0.7 ± 0.2
^{4}He	4.0026	6.8 ∓ 0.3	6.6 ∓ 0.3
^{6}Li	6.0151	20.44	21.15
^{7}Li	7.0160	0.90	0.93

3. Packing factor

The amount of target material in the cells was determined after unloading by weighing [5]. With the measured cell volume this gave a packing factor of 0.49 - 0.54. Typical simulation of filling is shown in Fig. 3.

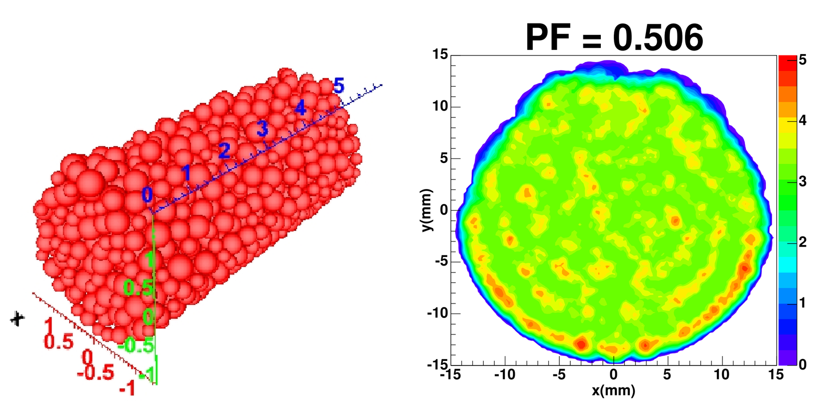

Figure 3: *Simulated target material packing with 0.50 packing factor. The 6 cm long and 3 cm diameter cylinder is filled with 2 - 4 mm diameter spheres.*

4. Nuclear magnetic resonance

The filling factor η_f tells how strongly the target material inside the coil changes the inductance of the coil [6]

$$L = L_0(1 + \eta_f \chi(\omega)). \quad (1)$$

Here $\chi(\omega) = \chi'(\omega) - j\chi''(\omega)$ is the dynamic susceptibility. Only the field transverse to the static field couples to the spins. The filling factor can be estimated to be [3]

$$\eta_f(\vec{r}) = \frac{B_t^2(\vec{r})dv}{2 \cdot \int_V B_{rf}^2 dv} \quad (2)$$

with B_t is the transverse part of radio frequency field and B_{rf} the total RF field. The integration is done inside the target cell volume. Since the excitation from the coil is linear instead of circular, there is a $\frac{1}{2}$ in the filling factor.

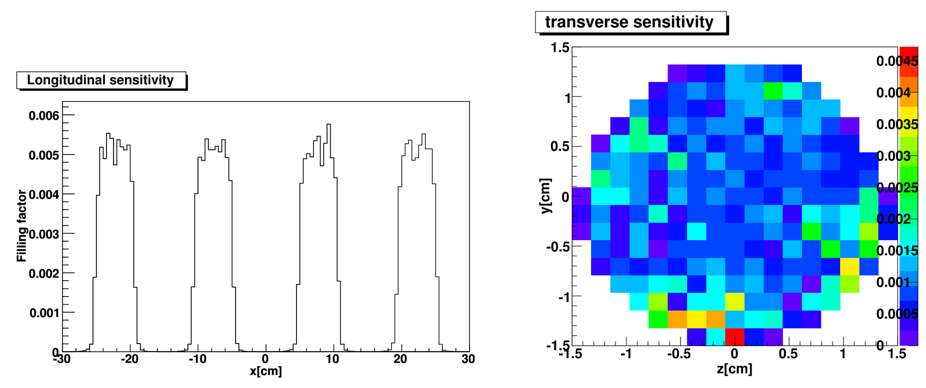

Figure 4: *Left: NMR signal intensity along the beam axis for 2003 and 2004 upstream deuteron coils. The bin width is 0.5 cm. Summing the bins for each coil gives total filling factor of 0.05 - 0.06. Right: Transverse sensitivity from the 95 % signal volume for all upstream coils in 2003 and 2004. The bin size is about 0.18 cm $\times$ 0.18 cm. The sensitivity close to the coil on the surface of the target cell is some what better.*

5. Nuclear magnetic lineshape

The Hamiltonian for the spin system contains Zeeman, dipole, quadrupole and hyperfine terms

$$H = H_z + H_{dip} + H_{quad} + H_{hf}. \quad (3)$$

The interaction terms determine the line-shape. The dipole interaction has the simple form [7]

$$D_{zz,jk} = \frac{\mu_0 \hbar \gamma_j \gamma_k}{4\pi r_{j,k}^3}(1 - 3\cos^2\theta_{j,k}), \quad (4)$$

where $r_{j,k}$ is the distance between the two nuclei and $\theta_{j,k}$ the angle between the external magnetic field and the position vector between the nuclei. γ_j and γ_k are the gyromagnetic ratios of the two nuclei. The distance between neighboring spins is half of the lattice constant or 2 Å.

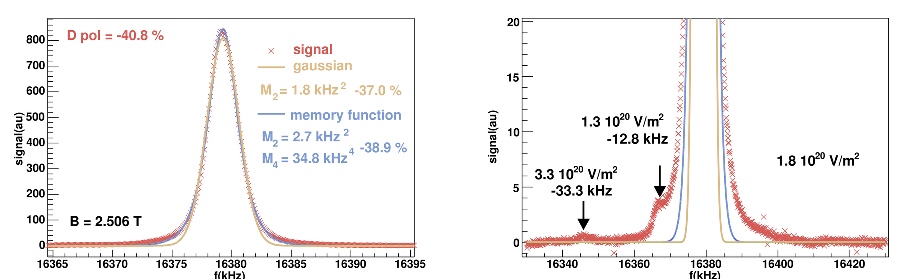

Figure 5: *Left: Deuteron NMR signal measured with outside coil #9 with -40.8 % polarization is fit to the Memory function (blue line) [8]. For comparison also a fit to simple Gaussian is shown (brown line). The fit gives a 2nd moment of 2.7 kHz^2 and a 4th moment of 35 kHz^4. From the fitted area polarization of -38.9 % can be calculated while the area of Gaussian fit gives -37.0 %. The Gaussian fit gives an underestimated 2nd moment of 1.8 kHz^2. Right: Small satellite is observed in the NMR-line - probably due to broken crystal symmetry close to paramagnetic centers.*

6. Thermal equilibrium calibration

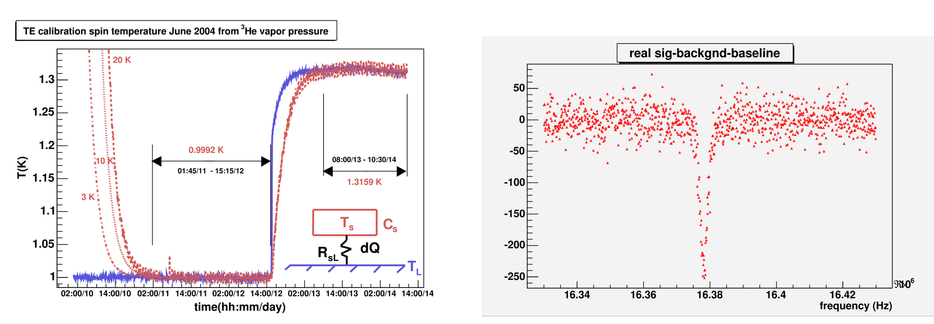

Figure 6: *Left: Thermal equilibrium spin temperature during polarization calibration. The spin system (red) reaches thermal equilibrium with helium (blue) in about 15 hours. Primary thermometer based on ^{3}He vapor pressure given by the International Temperature Scale ITS-90 is used. Right: Typical NMR signal during calibration.*

7. Target polarization

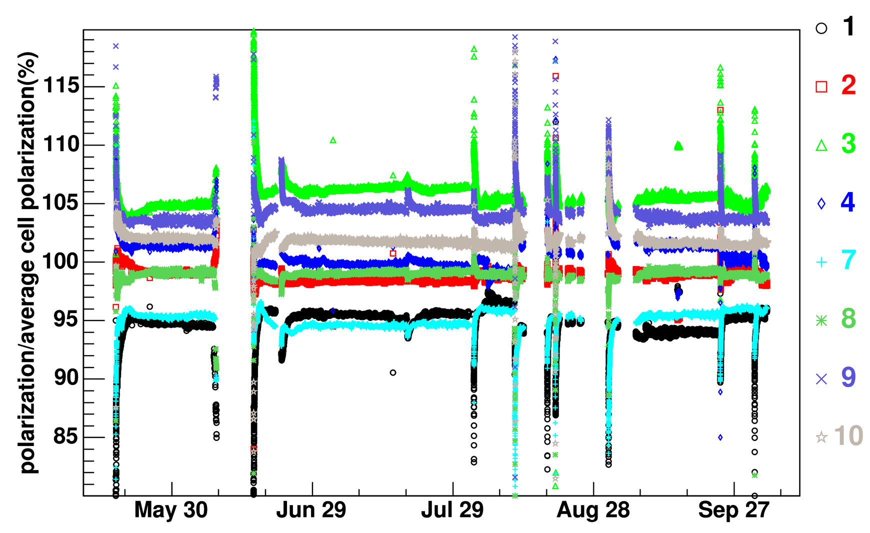

Figure 7: *The polarization measured by different coils is compared to the average cell polarization for 2004. The average positive polarization was +57 % and negative -48 %, but also symmetric cell polarization +53 % and -53 % was reached. After the start of each polarization build up stable distribution is reached fast with $\pm$6 % from the cell average. The distribution is quite stable for the whole run 2004. It is not very sensitive to the changes in microwave field or in ^{3}He flow in the dilution cryostat.*

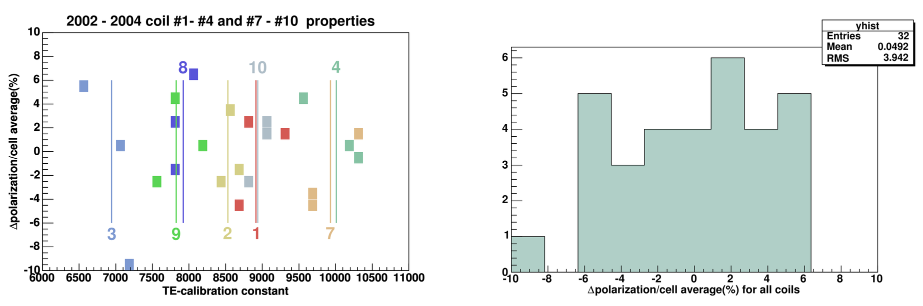

Figure 8: *Left: Thermal equilibrium calibration constants vs. relative polarization of coils for 2002 - 2004. No correlation between coil position and polarization is seen. There is symmetry in the calibration constants with respect to the microwave stopper in center. Right: Histogram of relative coil polarizations 2001 - 2004. The deviation in the measured polarization seems to be less than relative 6 %.*

8. Frozen spin mode

The polarization is lost about 0.05 %/day in frozen spin mode in 2.5 T field below 90 mK and 0.7 %/day in 0.42 T during transverse data taking, see Fig. 9.

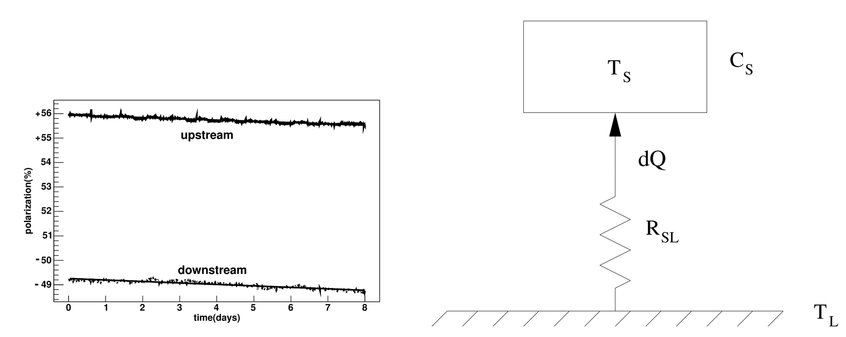

Figure 9: *Polarization relaxation in frozen spin mode can be understood as heat flow to the nuclear spin system. At high polarization of 50 % the spin system with heat capacity C_s about 3 J/mol·K has spin temperature T_s around $\pm$1 mK.*

References

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