summer student report
Spread in measured polarization of the fixed target in the COMPASS experiment

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September 8, 2006

Contents

1 Introduction

The COMPASS experiment measures the spin dependent structure function of the nucleon by measuring the asymmetry in deep inelastic scattering of polarized muons of a fixed target with polarized nuclei. In the experiment, the polarization of the target needs to be as high as possible and homogeneous throughout the spatial extend of the target. The values of polarization measured in different years at different positions in the target show a spread which is not understood. In this project we attempt to understand the origin of this spread by plotting the data in terms of physical quantities as spin temperature, nuclear heat capacity and entropy, and by simulating the system of polarized nuclei with a simple model. [1]

2 Polarizing and measuring polarization

The experiment used a deuteron target with ^{6}LiD as target material, in the form of 2-4 mm diameter grains in two 60 cm long cylindrical target cells of

[1] For a previous study, see the summer student report by Drosoula Giantsoudi [1]

3 cm diameter. The target is polarized by the method of Dynamic Nuclear Polarization (DNP), and the polarization is measured using Nuclear Magnetic Resonance (NMR), with a total of 8 coils probing the target, 4 in each target cell. The system is described in [2], the polarization measurement in [3],[4].

The polarization P in thermal equilibrium is given by the Brillouin function $\mathcal{B}_J(x)$ [5]

$$P = \mathcal{B}_J(x) = \frac{2+J+1}{2J} coth\left(x\frac{2J+1}{2}\right) - \frac{1}{2J} coth\left(\frac{x}{2}\right) \quad (1)$$

where the spin number $J = 1$ for deuteron and ^{6}Li (and $J = 3/2$ for ^{7}Li), $x = \frac{hf_0}{k_B T_s}$, with k_B the Boltzmann constant and T_s the spin temperature. f_0 is the nuclear magnetic resonance frequency of the nucleus in the magnetic field. The nuclear heat capacity C_B is given by [5]

$$\frac{C_B}{R} = \left(\frac{x}{2}\right)^2 sinh\left(\frac{x}{2}\right) \quad - \quad \left(x\frac{2J+1}{2}\right)^2 sinh^{-2}\left(x\frac{2J+1}{2}\right) \quad (2)$$

where $R = 8.3144$ J K^{-1} mol^{-1} is the gas constant. The entropy S is given by [5]

$$\frac{S}{R} = \left(\frac{x}{2}\right)\left[coth\left(\frac{x}{2}\right) - (2J+1) coth\left(x\frac{2J+1}{2}\right)\right] + ln\left(\frac{sinh(x\frac{2J+1}{2})}{sinh(\frac{x}{2})}\right) \quad (3)$$

. For a discussion of spin temperatures and heat capacity in the polarized target of the COMPASS experiment, see [6] and [7]

3 Spread in measured polarization

In this section we look at the polarization for the 8 coils in use during all of the runs in 2001-2004. The polarization measured by the different coils during one year is shown in Fig. 1.

To characterize the average value of the polarization measured in a particular coil in a particular year, we need a measure for the polarization at the end of a polarization build up period. We take this to be the most probable value in the dataset of measured polarizations, and implement this in practice as the position of the center of the bin containing the maximum in the histogram of the dataset. In the experiment it is found that generally higher absolute values are obtained for positive polarizations. For this reason, positive and negative polarization are treated seperately. In Fig. 2(a), the histograms of measured polarization during one year for a particular coil are shown. From the polarization, the spin temperature can be calculated via Eq. 1, and the histograms of the obtained values for the spin temperature are shown in figure 2(b). From the spin temperature, the entropy and

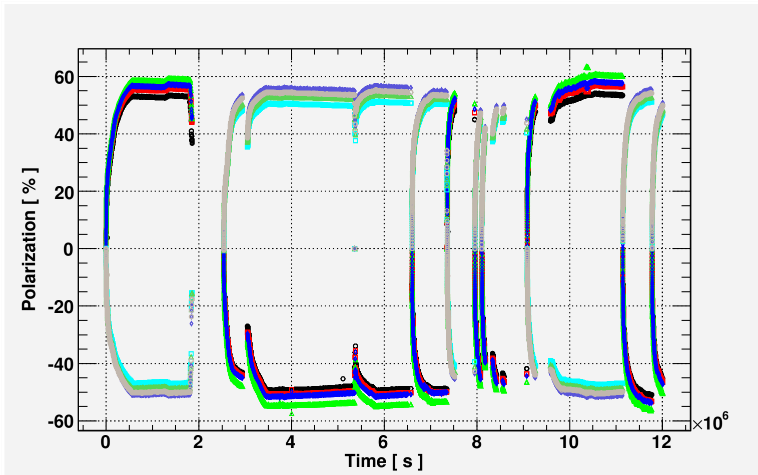


Figure 1: Polarization of all coils during one year

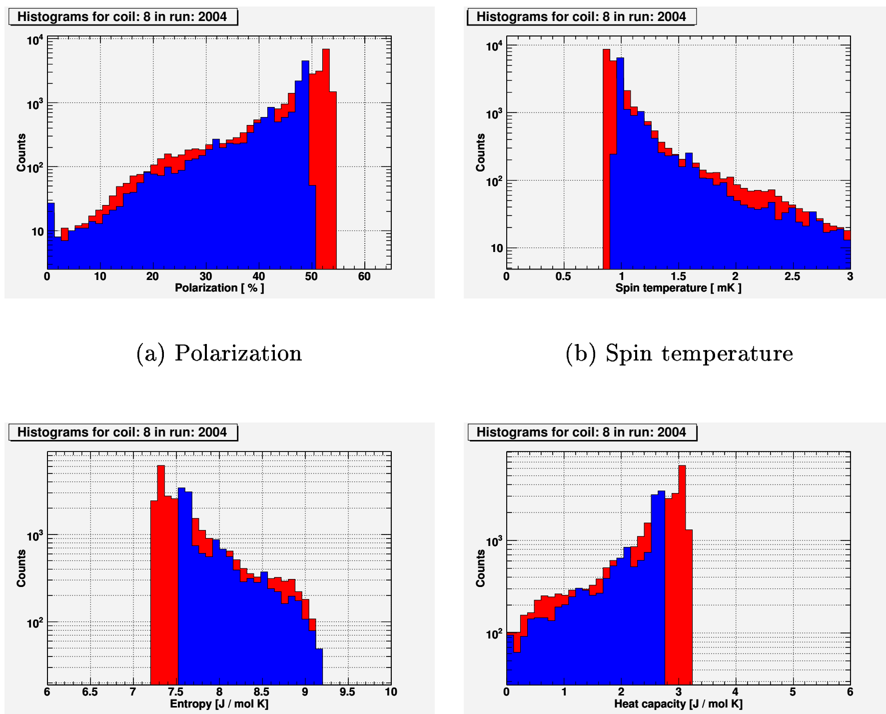
nuclear heat capacity are computed via Eq. 2 and Eq. 3, and displayed in the same way in Fig. 2(c) and Fig. 2(d). An overview of the programs used can be found in appendix A.

As an indication of the overall behavior of the system, we make a histogram of the averages obtained for each coil in each run (the maximum in the histrogram), as shown in Fig. 3(a) to 3(h). The histograms give an indication of the values for spin temperatures, entropies and heat capacities we are probing in the experimental system.

We can also plot the data points directly in terms of the entropy versus the spin temperature relation defined in Eq. 3, as shown in Fig. 4, where for each year the data points from all coils are shown. If higher polarizations are reached, it means that points on the curve with lower temperature and entropy are probed.

4 Simulation

An attempt was made to reproduce the experimental distribution for the spin temperatures using a simple model for the spin system in the target. We know that each coil is probing around 1000 crystals in the target. We assume that each crystal can be described by a single spin temperature, and the system of crystals probed by each coil by a distribution of spin temperatures, which we take to be a Gaussian with average T_a and standard deviation σ_g. To allow for changes of the averages spin temperature throughout the target and in the different years, we take T_a itself from a gaussian distribution, with standard deviation σ_l and the mean T_0 equal to the mean of the experimental distribution. In Fig. 5 the result of a Chi-Squared test (not normalized) between the experimental distribution and the simulated



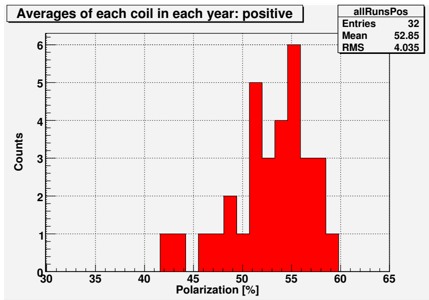
(a) Polarization

(b) Spin temperature

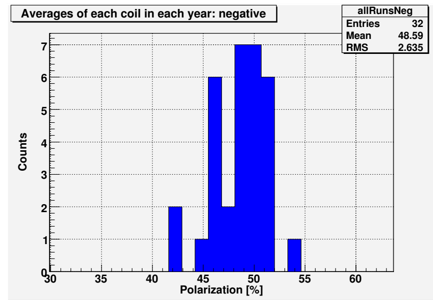
(c) Entropy

(d) Heat capacity

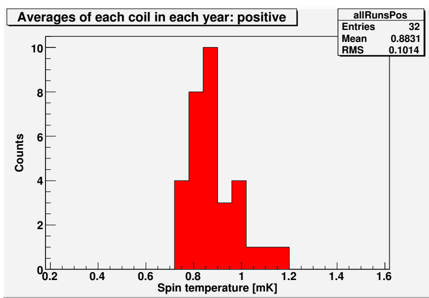
Figure 2: Histogram of measured polarization and derived quantities for a single coil during one year



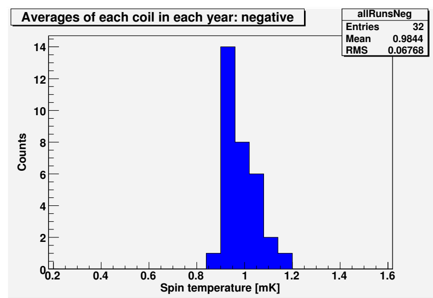
(a) Positive



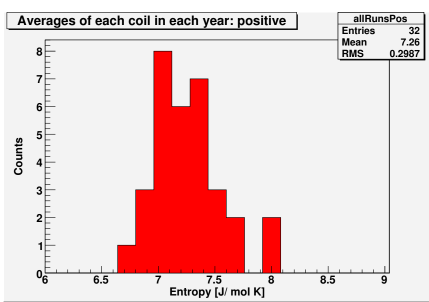
(b) Negative



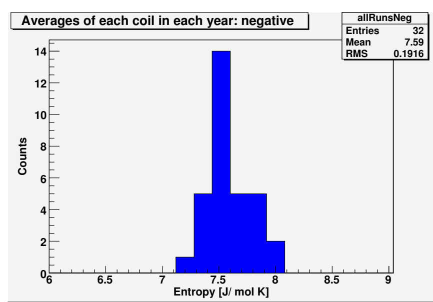
(c) Positive



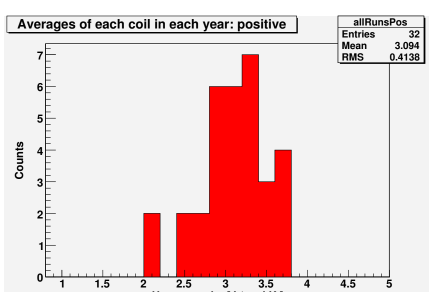
(d) Negative



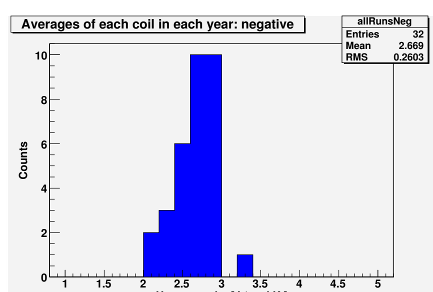
(e) Positive



(f) Negative

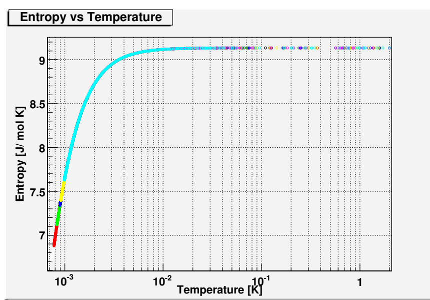


(g) Positive

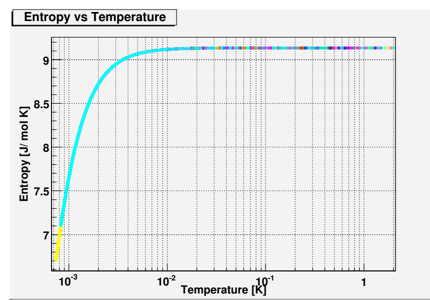


(h) Negative

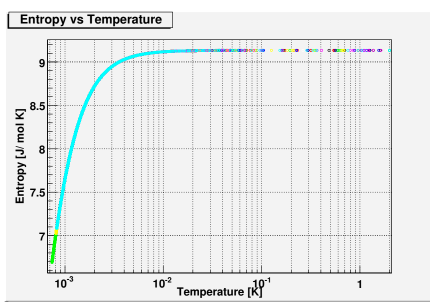
Figure 3: Histograms of average polarization and derived quantities in each coil in each year, separated in contributions from positive and negative polarizations



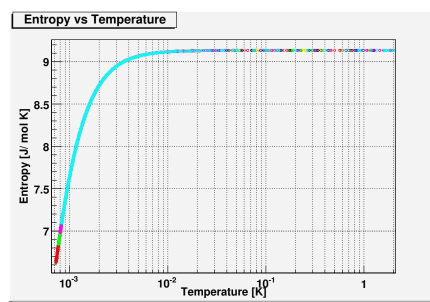
(a) run 2001



(b) run 2002



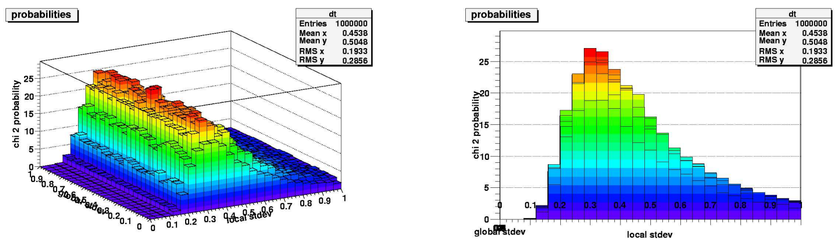
(c) run2003



(d) run 2004

Figure 4: Points of the entropy versus spin temperature relation as defined in Eq. 3, as probed in the experimental system. The different colors in the plot represent the different coils.

distribution is shown, for a range of values for σ_l and σ_g. It is seen that the result hardly depends on σ_g, and the probability for the two distributions to be the same is highest for $\sigma_l = 0.3$ mK. See appendix A for the program used in the simulation.



(a) 3-D view

(b) side view

Figure 5: Chi-Squared test (not normalized) of comparison between experimentally found distribution for spin temperatures and simulated distributions for a range of values for the parameters σ_l and σ_g (see text).

A simulated distribution of spin temperatures for a sample of 1000 crystals and the resulting 32 average spin temperatures are shown in Fig. 6. Is it seen that the simulated distribution does not reproduce the experimental distribution very well. Furthermore, the assumption of a gaussian distribution of spin temperatures in the sampled 1000 crystals (as the one in Fig 6(a)) might not be very realistic. Thus, the model probably needs to be adapted.

References

[1] D. Giantsoudi, summer student report (2004)

[2] F. Gautheron, Proceedings Spin 2004 (2004)

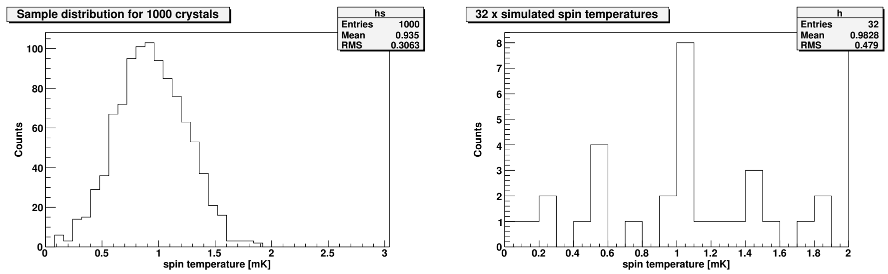
[3] K. Kondo et al., Nucl. Intr. and Meth. A 526 (2004)

[4] J. Koivuniemi, COMPASS Note 2005-19 (2005)

[5] F. Pobell, Matter and Methods at low temperatures, Springer-Verlag, Berlin (1996) 70-75

[6] J. Koivuniemi, COMPASS Note 2004-14 (2004)

[7] J. Koivuniemi, COMPASS Note 2004-19 (2004)



(a) Sample distribution of 1000 crystals

(b) simulated histogram of 32 average spin temperatures

Figure 6: Example of distribution obtained in the simulation using the values $\sigma_g = 0.5$ and $\sigma_l = 0.3$. The histogram of 32 average spin temperatures is obtained by generating 32 distributions as in Fig 6(a), and taking the mean for each distribution.

A Programs

Calculation of thermodynamical quantities from data

- Scripts (unnamed macros) to loop calculations of a quantity over a number of years

  scrCalcEntropy.C Calculate entropy from spin temperature

  scrCalcHeatcap.C Calculate heat capacity from spin temperature

  scrCalcPol.C Calculate polarization from polarization in different form of file

  scrCalcSpinT.C Calculate spin temperature from polarization

- Functions (named marcros) to calculate quantities

  calcPol.C Calculate polarization from polarization in different form of file

  calcSpinT.C Calculate spin temperature from polarization

  calcThermoVarbl.C Calculate value of thermodynamic quantity defined in terms of spin temperature

  computeSpinT.C Hart of the computing part of calculating spin temperature

  readPolRaw.C read polarization data in original format

  readRunData.C read data derived from polarization in format uesd in analysis (means: number of columns, specific meaningc of each column)

Making of histograms for a number of coils in a number of years

- Scripts (unnamed macros) to loop analysis over a number of years

  entropydirs.C make histograms of entropy

  heatcapdirs.C make histograms of heat capacity

  poldirs.C make histograms of polarization

  spinTdirs.C make histograms of spin temperature

Simulation average spin temperature

- **simspinTave.C** simulate a distribution and compare with experimental distribution