First spin flipping of a stored polarized deuteron beam

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A. Experimental setup

Frequent reversal of the polarization direction is desirable in experiments with polarized beams in order to minimize systematic errors. Stored, spin-½ particles have been successfully spin-flipped in the past [1,2]. With the recent interest in stored, polarized deuteron beams for nuclear physics experiments, e.g. at COSY, one also wishes to efficiently spin-flip deuteron beams. For a spin-1 particle beam from a polarized ion source, the component m_s of the spin along a quantization axis is either $m_s = +1$, 0 or –1. The beam is unpolarized if the particles are equally distributed among the magnetic substates, i.e. $N_{+1} = N_0 = N_{-1} = ⅓$. Analogous to the polarization of spin-½ particles, we call $P_z = N_{+1} - N_{-1}$ the vector polarization, while $P_{zz} = 1 - 3N_0$ is the tensor polarization of the ensemble.

The experiment was performed using a 270 MeV vector and tensor polarized deuteron beam stored in the Cooler. The beam had either positive vector and positive tensor polarization, negative vector and positive tensor polarization or pure tensor polarization of either sign. Data with unpolarized beam were also taken to study systematic errors.

The PINTEX detector [3] was used to measure the deuteron polarization. The target was a storage cell filled with hydrogen gas. Elastically scattered deuterons were detected in coincidence with the recoil protons. Known vector and tensor analyzing powers [4] were used to determine the deuteron beam polarization.

When polarized particles cross a depolarizing resonance adiabatically their polarization is flipped [5]. An RF solenoid [6] with a longitudinally oscillating magnetic field was used to generate a depolarizing resonance. The resonance occurs when $f_{sol} = f_c(k \pm \nu_s)$, where f_c is the circulation frequency, k is an integer and ν_s is the spin tune. In order to cross the resonance f_{sol} is ramped from one side of the resonance to the other.

B. Results

The magnetic moment of the deuteron is much smaller than that of the proton. Thus, using an RF solenoid which was originally built to spin-flip protons, the resonance is expected to be very narrow. The location and width of the resonance was measured by scanning the beam polarization as a function of solenoid frequency. The location of the resonance was at f_{sol} = 1402999 ± 17 Hz, and the width of the resonance was 75 ± 4 Hz for the vector and 101 ± 4 Hz for the tensor polarization.

The spin-flip efficiency depends on the rate at which the resonance is crossed. The transition through the resonance was accomplished by linearly ramping f_{sol} from 2 kHz below to 2 kHz above the resonance. The polarization after a single crossing was measured as a function of the ramp-time. Analogous to spin-½ particles, the vector polarization is expected to vanish if the ramp time is chosen such that the spin closed orbit ends up precessing in the ring plane. The polarization is expected to flip for long ramp-times. The behavior of the tensor polarization was predicted to be more complicated [7]. When the ramp time is chosen such that the spin closed orbit precesses in the ring plane, the tensor polarization is expected to change sign, but to retain only half its magnitude. For long ramp times the tensor polarization is expected to return to its original value. Fig. 1 shows the vector and tensor polarization as a function of ramp time Δt. The polarization behaves as expected. The curves in Fig. 1 are fits of the Froissart-Stora formula [5] and a modified Froissart-Stora formula [8] to the vector and tensor polarization respectively.

For practical applications a high spin-flip efficiency is desirable. The endpoints of the frequency range and the ramp rate were set to their previously determined optimum values. Then, the polarization was measured as a function on the number of frequency sweeps by ramping the solenoid frequency several times before the remaining polarization was measured. Fig. 2 shows the vector and tensor polarization as a function of the number of frequency sweeps. The curves are exponential fits yielding a vector spin-flip efficiency of 94.2±0.3% and an average tensor "spin-flip" efficiency for positive and negative tensor polarization of 81.2 ± 3.7 % at a ramp time of Δt = 1.5 s, i.e. where the tensor polarization retains its original sign. At a ramp time of Δt = 0.4 s, i.e. where the sign of the tensor polarization is actually inverted but is expected to only retain half its original value, the spin-flip efficiency is 49.6 ± 3.4 %.

A report of the results of this experiment has been accepted for publication [8].

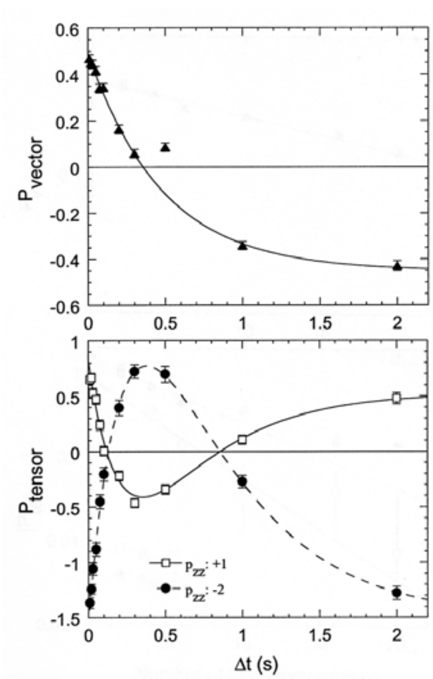

Fig. 1: Vector (P_z) and tensor (P_{zz}) polarization as a function of the solenoid ramp-time. The curves are explained in the text.

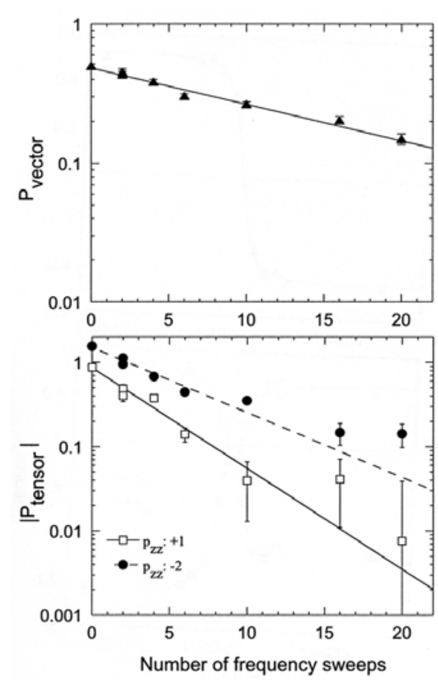

Fig. 2: Vector and tensor polarization as a function of the number of transitions through the resonance. The lines are exponential fits.

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