Spin flipping of polarized deuterons in the IUCF Cooler Ring

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In CE-83 we recently studied spin flipping of the vector and tensor polarizations of a 270 MeV vertically polarized deuteron beam stored in the IUCF Cooler Ring, which was obtained using the new Cooler Injector Polarized IOn Source (CIPIOS) and the Cooler Injection Synchrotron (CIS).

We swept an rf-solenoid's frequency through an rf-induced spin resonance centered at f_r and observed the effects on the beam's vector and tensor polarizations. For this experiment, the degree of tensor alignment can be described by a quantity called the tensor polarization [1]

$$p_{zz} = 1 - 3(N_0 / N_T), \qquad (1)$$

where N_0 is the number of deuterons in the $m_z = 0$ state and N_T is the total number of deuterons.

We spin-flipped the deuterons by linearly ramping the rf-solenoid's frequency from $f_r - \Delta f$ to $f_r + \Delta f$, while measuring the polarizations after each frequency ramp. We optimized the rf-solenoid frequency's ramp time Δt, frequency range Δf, and voltage V to maximize the spin-flip efficiency for the vector polarization. For example, the measured vector polarization is plotted against the ramp time in Fig. 1. The average measured vector polarization was fit to a modified [2] Froissart-Stora formula

$$\frac{P_f}{P_i} = (1+\eta)\exp\left[\frac{-(\pi \varepsilon f_c)^2}{\Delta f / \Delta t}\right] - \eta, \qquad (2)$$

where P_f is the final polarization, P_i is the initial polarization, and η is the spin-flip efficiency. This fit, which ignores the apparently anomalous $\Delta t = 500$ ms point, gives a spin-flip efficiency of $91 \pm 5\%$. Fig. 1 also shows the interesting behavior in the tensor polarization data, which was fit to a modified Froissart-Stora formula extended to tensor polarization by using Eq. (1):

$$\frac{P_f}{P_i} = \frac{3}{2}\left\{(1+\eta)\exp\left[\frac{-(\pi \varepsilon f_c)^2}{\Delta f / \Delta t}\right] - \eta\right\}^2 - \frac{1}{2}. \qquad (3)$$

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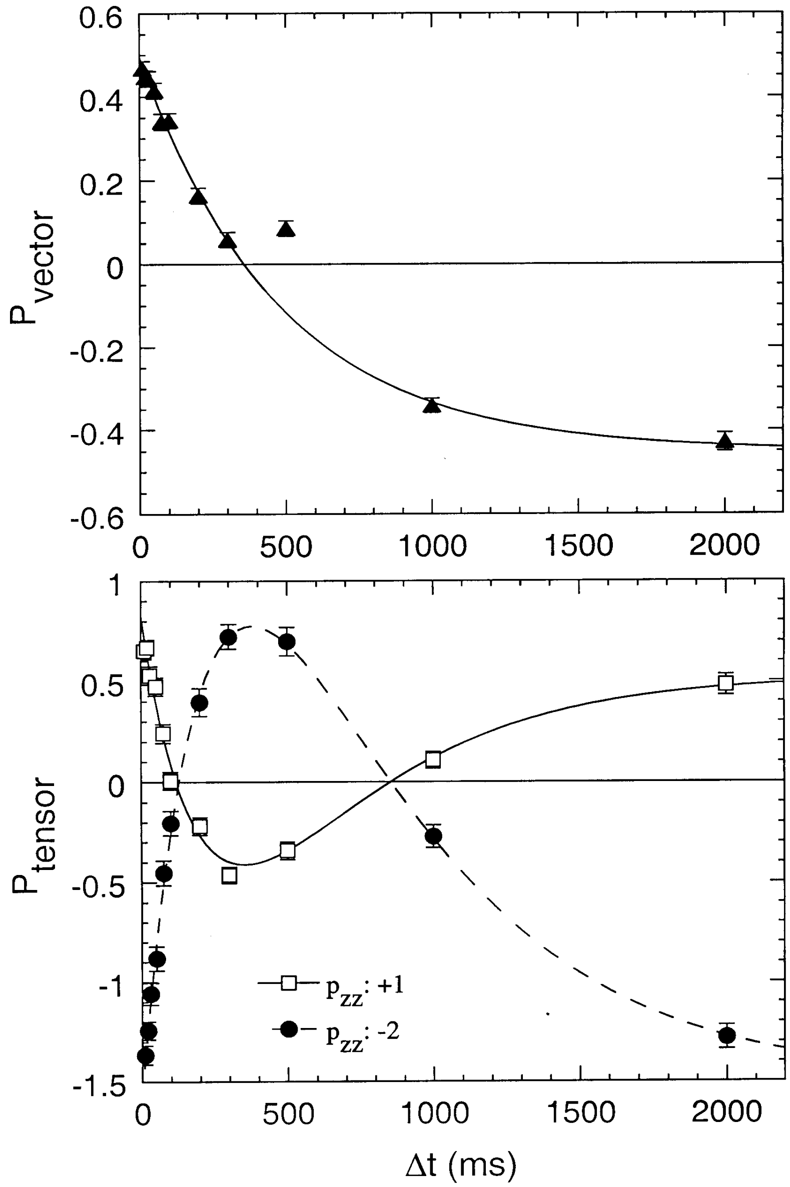

Fig. 1. The vector and two tensor deuteron polarizations measured at 270 MeV are plotted against the rf solenoid ramp time Δt. The open squares and black circles on the bottom graph denote the $p_{zz}:+1$ and $p_{zz}:-2$ tensor polarization states respectively. The rf solenoid's frequency range Δf was ± 2 kHz, and its $\int B \cdot dl$ was 0.7 T·mm rms. The curve in the top plot is a fit to the data using Eq. (2). The solid and dashed lines in the bottom plot are fits to the data using Eq. (3)

After setting Δt, Δf and V to maximize the spin-flip efficiency η for the vector polarization, we determined η more precisely by measuring the vector polarization while varying the number of frequency sweeps *n.* This measured vector polarization after n frequency sweeps is plotted against n in the top plot of Fig. 2. We fit this data using

$$P_n = P_i \cdot \eta^n , \tag{4}$$

where P_n is the measured radial beam polarization after n spin flips. The best fit gave a spin-flip efficiency of $94.2 \pm 0.3\%$. This high spin-flip efficiency was probably due to the rf-solenoid's rather slow turn-on, which apparently reduced losses in both the beam current and polarization. The tensor polarization data is plotted versus the number of frequency sweeps in the bottom portion of Fig. 2 and was fit to Eq. (4). The averaged depolarization per frequency sweep for the two tensor polarizations was about 82 ± 3%.

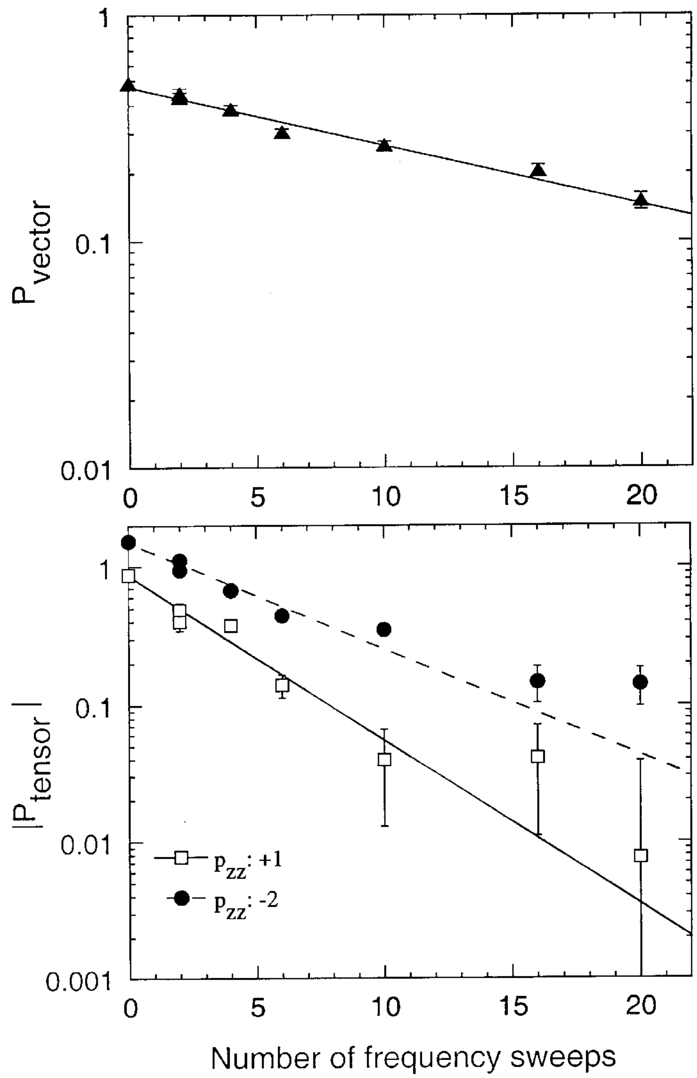

Fig. 2. The vector and two tensor deuteron polarizations at 270 MeV are plotted against the number of frequency sweeps. The open squares and black circles on the bottom graph are respectively the magnitudes of the $p_{zz}:+1$ and $p_{zz}:-2$ state tensor polarizations. The frequency ramp time Δt of the rf solenoid was 1500 ms; its frequency range Δf was ± 0.75 kHz, and its voltage was 4.5 kV peak-to-peak corresponding to an $\int B \cdot dl$ of 0.7 T·mm rms. The solid and dashed curves are fits to the data using Eq. (4)

In summary, using a stored 270 MeV polarized deuteron beam in the IUCF Cooler Ring, by adiabatically turning on an rf solenoid and optimizing its spin-resonance crossing parameters, for the first time one could spin-flip a deuteron's vector and tensor polarizations with a spin-flip efficiency of $94.2 \pm 0.3\%$ and 82 ± 3%, respectively. We also investigated the behavior of both vector and tensor polarizations of the deuteron beam for complete and partial crossings of the rf-induced depolarizing resonance. Using this resonance, we also studied the lifetimes of the vector to tensor polarizations near the resonance and found the vector to tensor lifetime ratio to be 1.9 ± 0.2.

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References:

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