increase in beam current during injection as a function of time also enters the calculation. The measured polarization agrees within error bars with the expected polarization.

In summary, the spin flipper has been demonstrated to be a reliable device. If it is used to reverse the polarization of the stored beam, an increase in the average luminosity and the overall figure of merit is achieved, since it is no longer necessary to empty the ring prior to injection.

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TOWARDS LONGITUDINAL BEAM POLARIZATION IN THE COOLER

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Certain experiments with polarized beam on a polarized target require that both beam and target are polarized in the longitudinal direction. The Wisconsin/IUCF hydrogen atomic-beam target that is currently mounted in the A-region of the Cooler allows a free choice of the target polarization direction, but so far only vertically polarized beam has been available. The two experiments that require longitudinal beam polarization are the measurement of the spin-correlation parameter A_{zz} in pp elastic scattering (CE45) and the spin-dependent total cross section in pp → ppπ° (CE44).

It has been demonstrated that solenoid fields can be used to point the stable polarization vector at a given orbit location in any desired direction. Solenoids in straight sections with dispersion need to be accompanied by a series of quadrupole lenses to cancel the coupling of horizontal and vertical motion. For the six-sided Cooler it has been predicted that longitudinal polarization in the target section (A) at any energy can be obtained with two solenoids mounted in symmetric, but non-adjacent straight sections (C, T), both of which have low dispersion. This scheme makes use of three existing solenoids in the C-region (one of these solenoids is needed to confine the cooling electron beam, the others are normally used in a compensating mode, but can be operated with the same sign as the cooling solenoid, resulting in a longitudinal field integral of up to 1 T·m). One additional solenoid with up to 3.5 T·m in the T-section is then sufficient to allow longitudinal polarization in the A-region for proton beams of up to 500 MeV. Because of the limit on the solenoid field in the C-region, the polarization is not exactly longitudinal for energies above 200 MeV (but the longitudinal component is never less than 90% of the total polarization).

The current plan for development of longitudinal polarization in the Cooler calls for the installation of a 2 T·m solenoid in the T-region during the second half of 1995. In anticipation of this, it has been decided to start acquiring experience with non-vertical polarization using the existing C-region solenoids. This was done during a short run (CE45) on December 7, 1994.

Beam from the ANAC source was stack-injected into the Cooler. The injection energy was 197 MeV. The main solenoid (CSOL) and the two compensating solenoids (CSA, B) in the C-region were operated in different ways so as to give rise to an integrated longitudinal field of 0 (CSA, B opposite to CSOL), 0.40 T·m (CSA, B off), or 0.81 T·m (CSA, B and CSOL with same sign). In the course of the experiment, the beam energy was also ramped to 320 MeV.

Polarization measurements were carried out with a carbon skimmer and the CE35 detectors in the A-region. Polarization of alternating sign was injected in alternating cycles. The measured quantities were the magnitude of the polarization $P_{A,\perp}$ transverse to the beam direction and the tilt angle α of the polarization vector in the transverse plane with respect to the vertical.

During the course of the experiment, it was demonstrated that stack injection with a 0.81-T·m C-snake still works. Injection rates of up to 20 μA/min were observed. The snake strength could be varied relatively easily for the full range of 0 to 0.81 T·m. It was also demonstrated that the stored beam can be accelerated in the presence of the (non-ramping) snake.

The machine tune was measured at the injection energy for the 0.81-T·m snake while the strength of the vertical tune quad combo (QGVERT) was varied (the corresponding horizontal-tune quad combo was set to zero). This is shown in the lower half of Fig. 1. Horizontal and vertical bars indicate the fractional horizontal and vertical tune; crosses

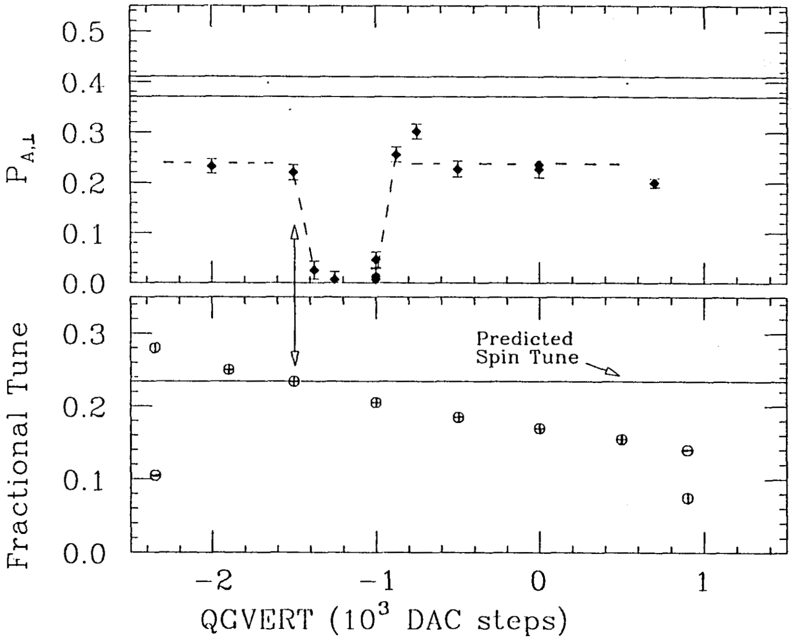

Figure 1. Upper panel: sideways polarization as a function of the vertical-tune quadrupole excitation (QGVERT). The two horizontal solid lines indicate the expected polarization as discussed in the text. The dashed line is to guide the eye. Lower panel: fractional tune versus QGVERT. Vertical and horizontal tunes are distinguished by vertical and horizontal symbols. The solid line shows the predicted spin tune: equal tune and spin tune are the conditions for a depolarizing resonance. This resonance is visible in the upper panel.

indicate measurements for which the two tune values were identical. The calculated spin tune is shown as a solid line. When the vertical tune coincides with the spin tune, a depolarizing resonance is expected. This resonance has been observed, as is shown in the upper part of Fig. 1. The condition "vertical tune = spin tune" points to one edge of the resonance rather than to the center (this finding is not yet understood).

This measurement was also repeated with a weaker snake (0.40 T·m). We found that the resonance width increases with decreasing snake strength. We also found that the observed tunes for the two different snake strengths are very similar, indicating that the focussing of the C-solenoids does not have a large effect on the tune.

The tilt angle α was measured as a function of the strength of the vertical-tune quad combo (QGVERT) at the injection energy (197 MeV) and for a single QGVERT at the top of the ramp (320 MeV) for both the 0.40-T·m and the 0.81-T·m snake. Shown in Fig. 2 is the result for the 0.81-T·m snake at 197 MeV. The tilt angle, as one would predict it from the known strength of the solenoids and the beam energy, is given as a solid line; the dashed lines indicate a change in beam energy by ± 3 MeV. The measurement is in agreement with the prediction.

The polarization $P_{A,\perp}$ can be predicted as follows. Assuming that the incoming polarization is vertical, only a fraction $\cos\phi$ is projected onto the spin closed orbit $\vec{n}$, where ϕ is the polar angle of $\vec{n}_I$ at the injection point (and anywhere else!), at the injection energy. Seen as $P_{A,\perp}$ in the A-region is only the fraction that is not longitudinal, namely $({\vec{n}_{A,x}}^2 + {\vec{n}_{A,y}}^2)^{1/2}$. The incident polarization was determined as $P_{inc} = 0.68 \pm 0.04$ from combining

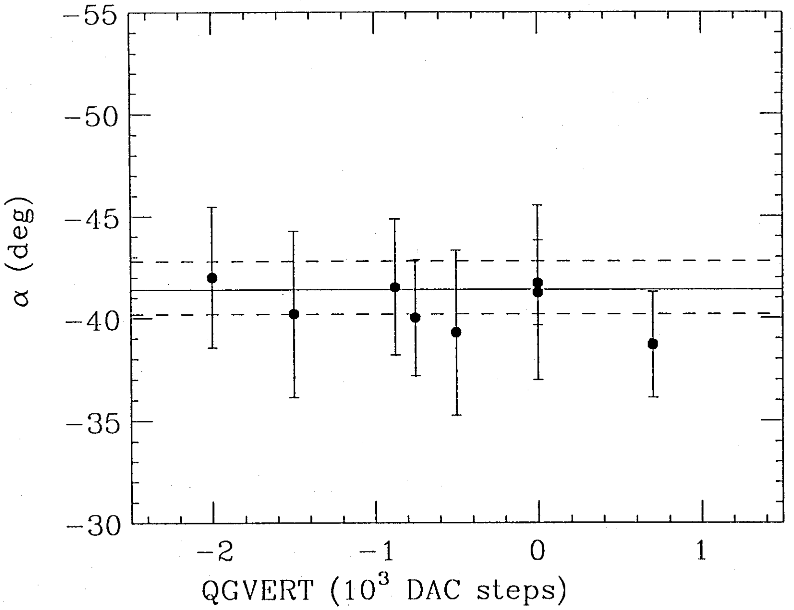

Figure 2. Angle between the sideways component of the stable spin direction and the vertical direction as a function of the vertical-tune quadrupole excitation. Also shown is the same angle predicted from the known field strengths (solid line) and its error (dashed lines).

a measurement with the BL2 polarimeter with a polarization measurement in the ring using the CE35 apparatus but *without* snake in the C-region (solenoids compensated).

The predicted value of the polarization at 197 MeV *with* a 0.81-T·m snake is indicated by two solid lines in the upper part of Fig. 1. The separation of the lines represents the uncertainty of the prediction. It is clear that the measurement is lower than the expectation by about 20%. This low polarization measurement could be explained if the incident polarization would not have been vertical but tilted away from the vertical direction by about 10°. Such a tilt angle is conceivable and has been observed in the past, but there is no independent evidence that this was the case during this run. A definite study of this has to wait for a run where the beam line precession solenoids are operational and allow a change of the polarization direction at the injection point of the Cooler.

When the beam energy increases, the spin tune increases, too. Thus, the depolarizing resonance (Fig. 1) moves to the left, towards smaller QGVERT values, during the acceleration. Thus, when a QGVERT value to the left of the resonance is chosen before the energy ramp is started the resonance will be crossed during the ramp, while for an initial value of QGVERT to the right of the resonance no crossing occurs. The following study was done with the 0.40-T·m C-snake with beam ramped from 197 MeV to 320 MeV. For the horizontal and vertical components of the polarization in the A-region, we have observed the following without or with resonance crossing :

QGVERT= +0.8	$P_x = -\ 0.07 \pm 0.03$	$P_y = +\ 0.49 \pm 0.03$
QGVERT=−1.0	$P_x = +\ 0.01 \pm 0.03$	$P_y = -\ 0.44 \pm 0.03$

We have thus shown that the crossing of the resonance does not destroy the polarization, but reverses its direction with an efficiency of (90±9)%. This is an interesting accelerator physics topic to study further.