Polarized Neutrons in RHIC

Ernest D. Courant
April 29, 1998

There does not appear to be any obvious way to accelerate neutrons, polarized or otherwise, to high energies by themselves. To investigate the behavior of polarized neutrons we therefore have to obtain them by accelerating them as components of heavier nuclei, and then sorting out the contribution of the neutrons in the analysis of the reactions produced by the heavy ion beams.

The best "neutron carriers" for this purpose are probably ^{3}He nuclei and deuterons. A polarized deuteron is primarily a combination of a proton and a neutron with their spins pointing in the same direction; in the ^{3}He nucleus the spins of the two protons are opposite and the net spin (and magnetic moment) is almost the same as that of a free neutron. In tritium (^{3}H), on the other hand, the net spin is essentially that of the proton, and the spins of the two neutrons cancel.

Let us see what the problems are in accelerating polarized ^{3}He or deuterons.

For ^3He:

Anomalous magnetic moment factor

$$G = \mu \frac{A}{2ZS} -$$

$$= -4.191$$

more than twice the magnitude for protons.

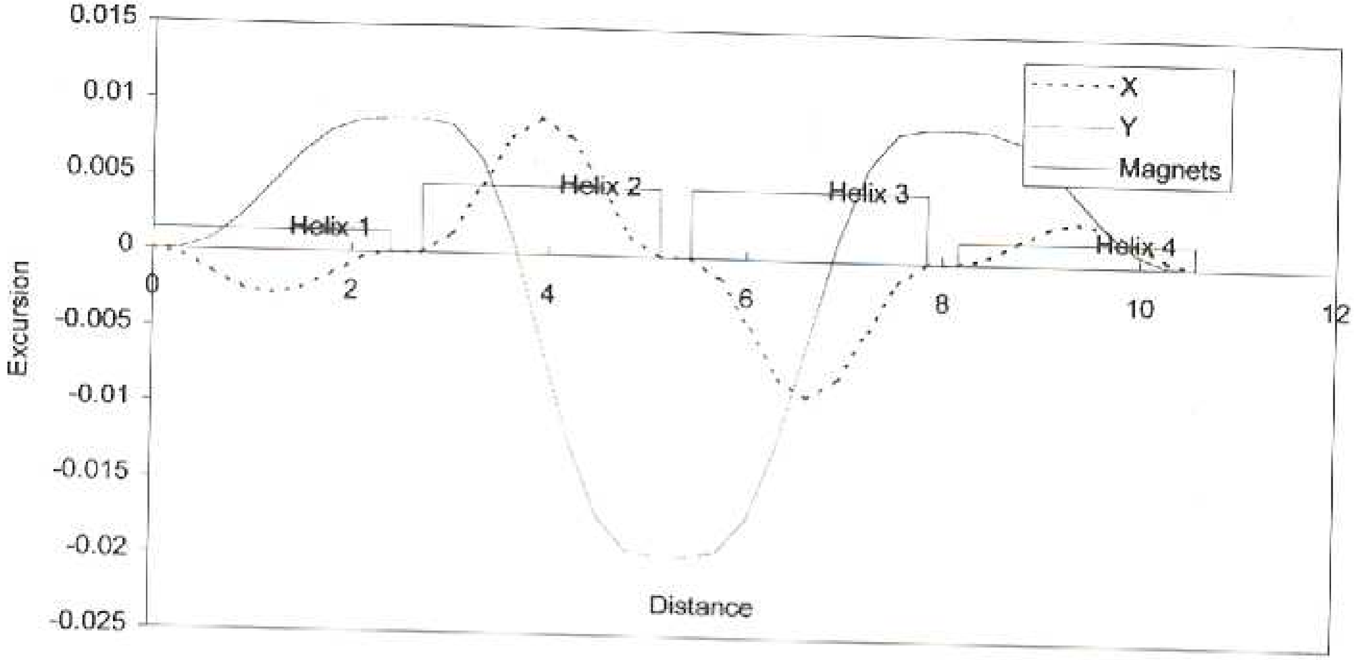
Siberian snakes need field strength scaled by factor *A/ZG*

$$=(3/2)(1.793/4.191) = 0.642$$

for ^3He as compared to protons:

Helical snakes need field of 2.6 T instead of 4.0.

Four-helix snake for He3. Energy per u 15.9 GeV Helix fields 0.81 and 2.62 Tesla; axis 135.0 degrees from transverse



The resonances in the AGS are likewise stronger and more closely spaced than with protons. But there should be no great difficulty in overcoming them with the partial snake for imperfections and the rf dipole for intrinsic resonances (as described by T. Roser and M. Bai). - The rotators that bring the spin into the longitudinal direction also have to be reduced by the same 64% factor as the snakes, and should function as in the proton case.

Other light nuclei that could, if desired, be handled the same way include tritium and/or ^{19}F.

Deuterons:

Here the magnetic anomaly is very small: G = -.143.

Result: Only ~ 18 imperfection resonances, 12 intrinsic.

But still strong enough to cause trouble.

Siberian snakes impossible (field required would be 25 times that for protons).

Intrinsic resonances can, however, be handled by the rf dipole method just as is done in the AGS; inducing coherent oscillations of amplitude 1 mm or so should be sufficient to make each intrinsic resonance strong enough for spin flip (the one at γ = 120.15 is anyway strong enough without help).

As for the imperfection resonances:

Use solenoids. Just as in the AGS, a solenoid of given strength *BL* rotates the spin by an angle

$$\vartheta = (1+G)BL/(B\rho)$$

producing integral resonances of strength $\varepsilon = \vartheta / 2\pi$ at all integral values of $G\gamma$. If the value of ε is large enough such that Froissart-Stora factor

$$F = 2\exp[-(\pi\varepsilon)^2 / \Delta] - 1$$

is practically equal to -1 we get complete spin flip (Δ = increment of $G\gamma$ per turn).

For deuterons $G = -.143$. With T (ramp time from $\gamma = 15$ to 135) = 1 minute, we have $\Delta = |G|(\gamma_f - \gamma_i)C/cT$ with $C = 3834$ m the circumference of RHIC, giving $\Delta = 3.66\times10^{-6}$. Thus to get $F <$ -0.99 (99% spin flip) we need $\varepsilon > (\Delta \ln 200)^{1/2}/\pi = 1.4\times10^{-3}$; using (5) and (6) we find that at top energy ($B\rho$ = 840 T-m) we need a solenoid of strength of 8.7 Tesla-meters, i.e. just twice the "partial snake" solenoid in use at the AGS. Such a solenoid, which could be warm or cold, would easily fit in one of the long Q3-Q4 gaps in an insertion. This solenoid will give complete spin flip at each of the 19 integer resonances in the acceleration range, provided only that the imperfection resonances we would have without the partial snake are weaker than 1.4×10^{-3}. Calculations using the SYNCH and DEPOL computer programs show that, with one particular random-number generator seed, and with rms alignment errors of ¼ mm in the quads in the arc, the resulting closed orbit has an rms excursion of 2.5 mm, and the strongest depolarization resonance (at $\gamma = 119$) has strength 0.003, but the resonances below $\gamma = 100$ are weaker than 0.001. Thus our 8 T-m solenoid should be able to cope with all integer resonances below about 200 GeV. If the MICADO orbit correction scheme is used, the calculations show that the rms orbit excursion is reduced to 0.6 mm and the strongest integer resonance is well below the strength of .001; thus the partial-snake solenoid should work just fine.

With the partial-snake solenoid scheme. the spin is very nearly vertical in the whole machine when the energy is reasonably far (more than several times ε) from the resonance. But just exactly at the resonance energy the closed-orbit spin vector will precess in the horizontal plane, and just 180° from the snake it will be longitudinal. Therefore experiments with longitudinal spin will be possible at this discrete set of energies, $-G\gamma$= 1,2,3,...,19 (energy at multiples of about 13.6 GeV). For helicity experiments at STAR (6 o'clock) the solenoid should be in the

12 o'clock insertion; for experiments at PHENIX (8 o'clock) it should be at 2 o'clock.