# SIBERIAN SNAKE OVERCOMES "OVERLAPPING" DEPOLARIZING RESONANCES†

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Depolarizing resonances occur at certain energies in all circular proton accelerators, whenever the frequency of proton spin precession equals the frequency with which the protons encounter depolarizing magnetic fields. At these depolarizing resonances, the horizontal fields interact coherently with each spin and rapidly depolarize the beam.[1] The imperfection depolarizing resonances are due to imperfection horizontal fields or magnet misalignments. The intrinsic depolarizing resonances are due to the horizontal focusing fields. The successful acceleration of polarized proton beams at the ZGS, Saturne, the AGS,[2] and KEK required much hardware and difficult tuning to individually correct these resonances.

The Siberian snake technique[3] should correct all such depolarizing resonances without individually tuning through each resonance; a "full-strength" snake does this by rotating the spin of each proton by exactly 180° about a horizontal axis on each turn around the ring. The depolarizing fields should then cancel each other on two turns around the ring.

Our earlier experiments at the IUCF Cooler Ring demonstrated that a Siberian snake could easily overcome imperfection[4] and intrinsic[5] depolarizing resonances. We also found and overcame other types of depolarizing resonances such as the synchrotron depolarizing resonances,[5] and the RF-induced depolarizing resonances.[6] We also studied partial Siberian snakes, which rotate each proton's spin by less than 180°; these partial snakes should be able to overcome the relatively weak imperfection depolarizing resonances in accelerators of about 10 GeV, such as the Fermilab Booster.[7]

We recently produced and studied RF-induced depolarizing resonances by constructing and using an RF solenoid magnet.[6,8] As shown in Fig. 1, with no Siberian snake there was a strong depolarization dip as we swept the RF solenoid's frequency through the RF resonance. As shown by the circles the snake clearly overcame the RF depolarizing resonance and maintained full polarization throughout the entire frequency range.[9]

We also studied the effect of a weak partial Siberian snake on this RF resonance.[6] By varying the frequency of the RF solenoid, while measuring the vertical and radial polarization components at 120 MeV, we could determine the RF resonance frequency $f_r$ and study the synchrotron sidebands, as shown in Fig. 2 for different snake strengths. The central resonance frequency's dependence upon the snake strength agreed well with a simple theoretical calculation.

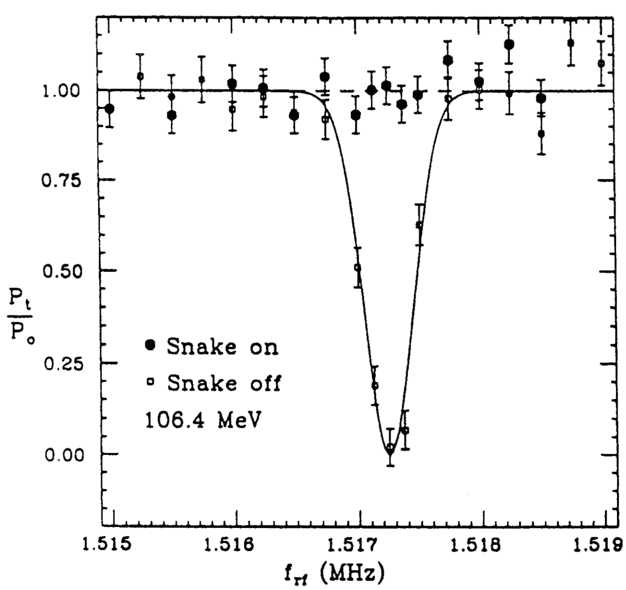


*Figure 1.* The ratio of the measured transverse polarization, $P_t = \sqrt{P_v^2 + P_r^2}$, to the injected polarization, $P_0$, is plotted against the frequency in the RF solenoid; the solenoid voltage was 12.5 kV. The imperfection $\int Bdl$ was set near zero. Data are shown with the Siberian snake both on (circles) and off (squares).[9]

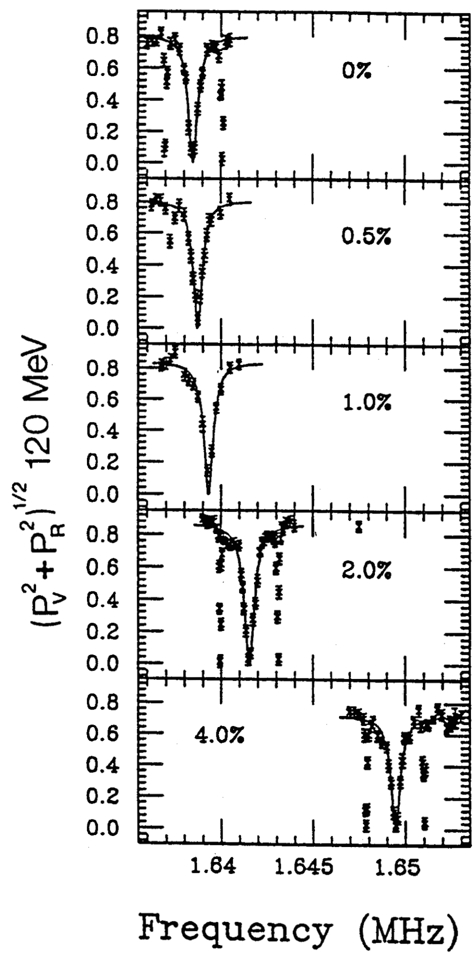


*Figure 2.* The measured total transverse polarization is plotted against the frequency of the RF solenoid magnet for each indicated partial snake strength at 120 MeV. The curves are fits to a resonance equation which determines the resonance frequency at each snake strength. The RF solenoid voltage was 22 kV.[6]

In multi-TeV accelerators there would be thousands of depolarizing resonances. Some of these depolarizing resonances would be so strong that they would be wider than their separation and would overlap each other.[7,10,11] We have recently started to study such overlapping resonances by using our RF solenoid to induce an RF resonance and then force it to overlap the $G\gamma=2$ imperfection resonance.[9] The quantity G=1.792847 is the proton's anomalous magnetic moment and $\gamma$ is the relativistic kinetic factor $E/m_p$. We studied this overlap at 106.4 MeV which is near the $G\gamma=2$ resonance. We varied the imperfection resonance strength $\int Bdl$ for several different RF solenoid frequencies to study the effects of overlapping resonances. As shown in Fig. 3, the dips in these data suggest some destructive interference due to the overlap of the imperfection resonance and the RF resonance.

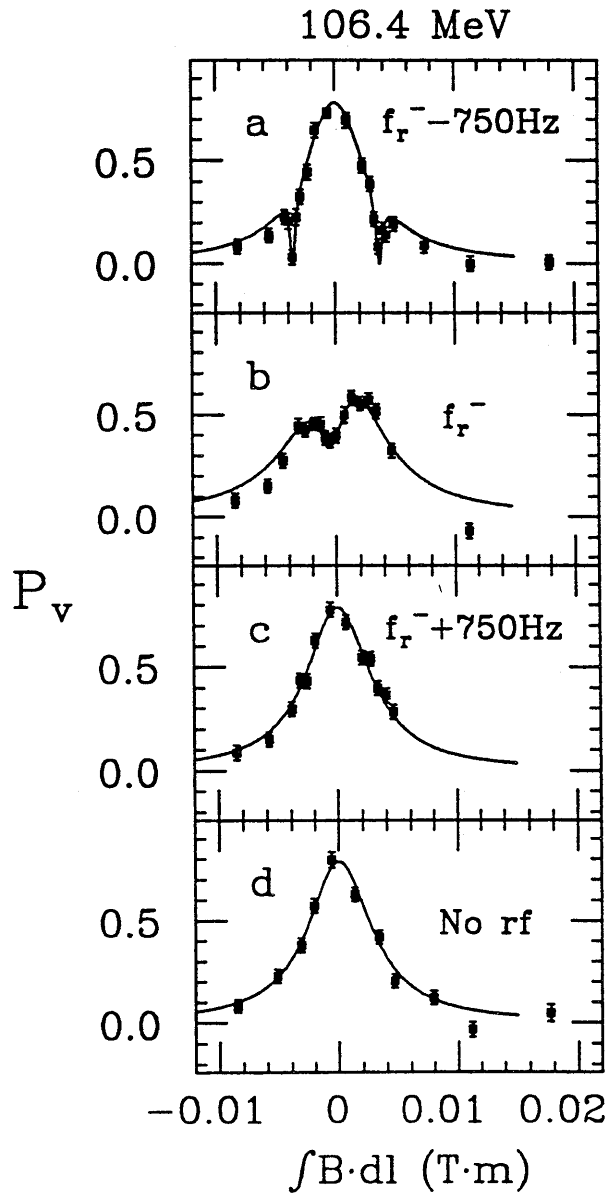


*Figure 3.* The vertical polarization, $P_v$, at 106.4 MeV is plotted against the imperfection $\int$ Bdl for different solenoid frequencies. The frequency, $f_r^-$, was chosen to be near the center of an RF resonance dip; the RF voltage was 6.25 kV. The curves are fits with certain equations for the peaks and dips.[9]

When we turned on the Siberian snake, the full polarization was maintained over the whole region of the overlap and beyond as shown in Fig. 4. Thus, a Siberian snake appears capable of overcoming all depolarization due to these overlapping depolarizing resonances.

Thus, a full Siberian snake can overcome all depolarizing resonances so far encountered. This result along with earlier results[4–6] indicate that Siberian snakes should allow the acceleration of polarized proton beams in TeV facilities.[7,10] We are now constructing a rampable warm partial snake to study the adiabatic turn-on of a Siberian snake.

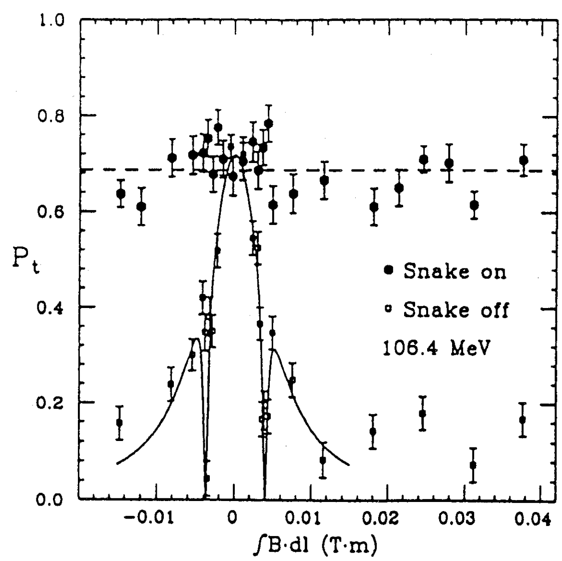


*Figure 4.* The total transverse polarization, $P_t$, is plotted against the imperfection $\int$ Bdl for an RF solenoid frequency of 1516.75 kHz = $f_r^-$ − 750 Hz with the full Siberian snake both on (circles) and off (squares); RF voltage was 6.25 kV. The solid line is a fit similar to Fig. 3(a); the dashed line is a fit to a constant for the snake-on data.[9]

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