MOPAB014

First High Spin-Flip Efficiency for High Energy Polarized Protons

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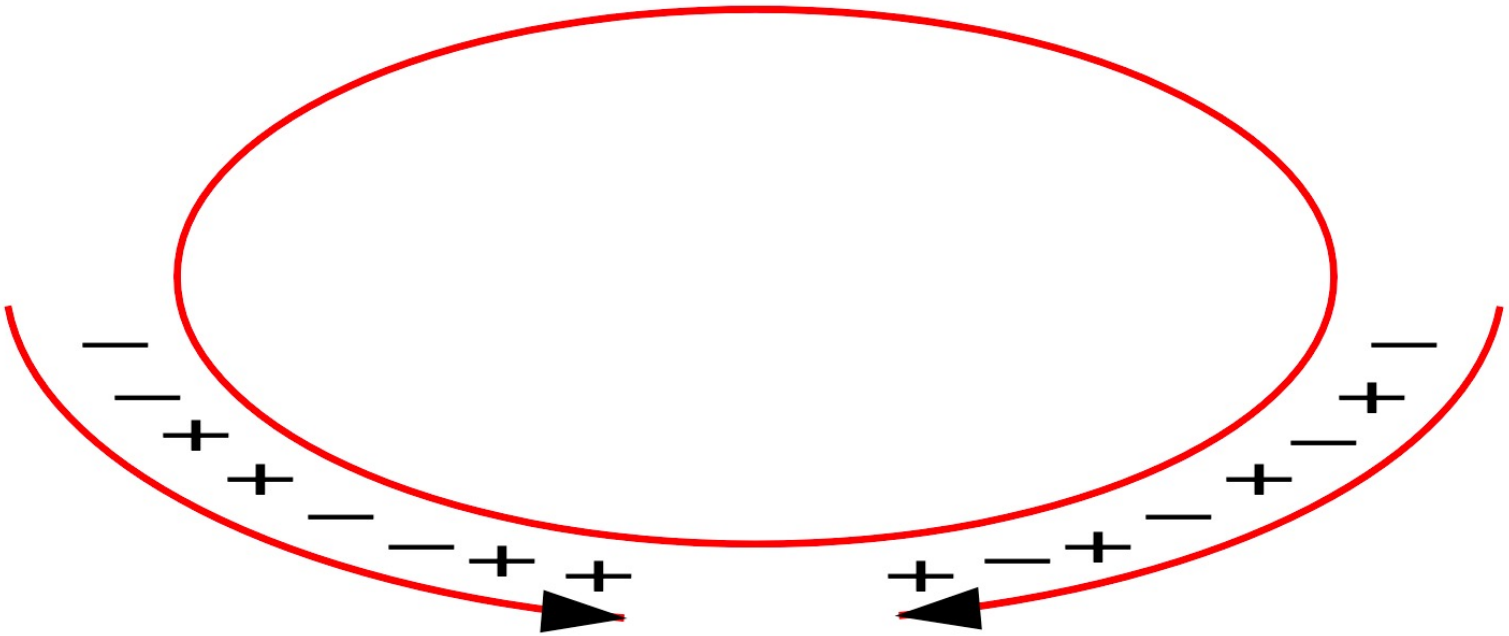
May 24, 2021
IPAC21

Why Spin Flipper Is Needed?



To reduce systematic error, collisions are arranged with various collision pattern (++, +-, -+,--). Because the same bunches collide for a given IP, periodically reversing the spin will reduce systematic errors for asymmetry measurements even further.

Polarization Passing through Resonance

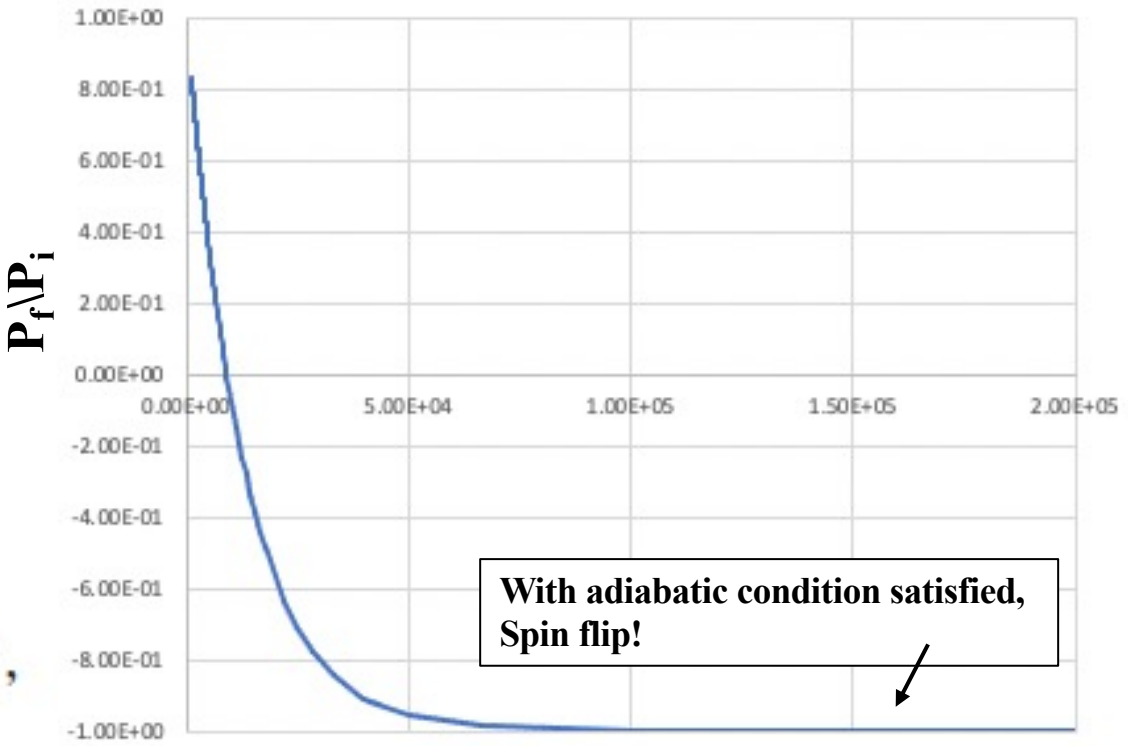
Resonance conditions depend on energy (γ) so during acceleration we pass through (cross) many resonances

What happens to the spin of a particle passing through a resonance of strength ε at a crossing rate α = (dGγ/dθ)

Initial spin->Final spin:

$$\frac{P_f}{P_i} = 2\exp^{-(\pi/2)(|\epsilon|^2/\alpha)} - 1,$$

P_f /P_i= final and initial polarization ratio
α = crossing rate
|ε| = resonance strength



Unlike **betatron resonance: when adiabatic condition is satisfied, $\frac{|\epsilon|^2}{\alpha} \gg 1$, polarization amplitude can be preserved, by a full spin flip**

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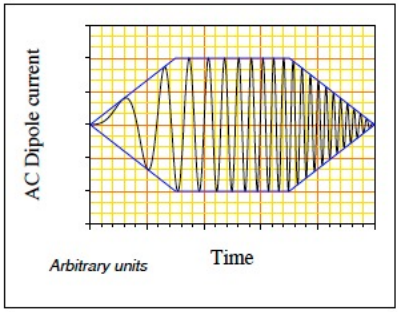
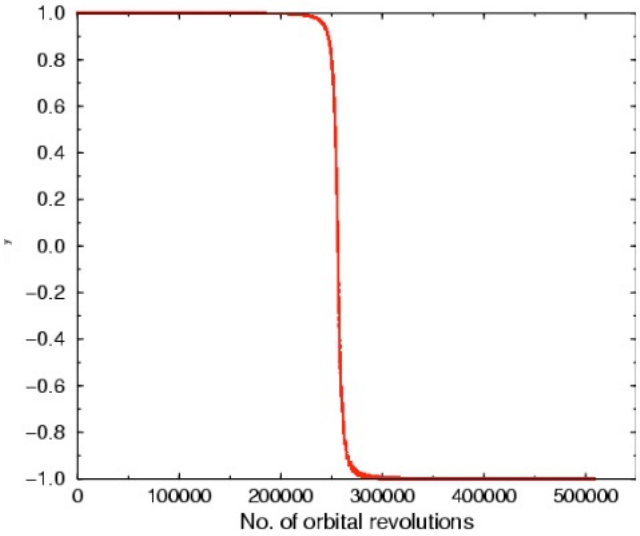
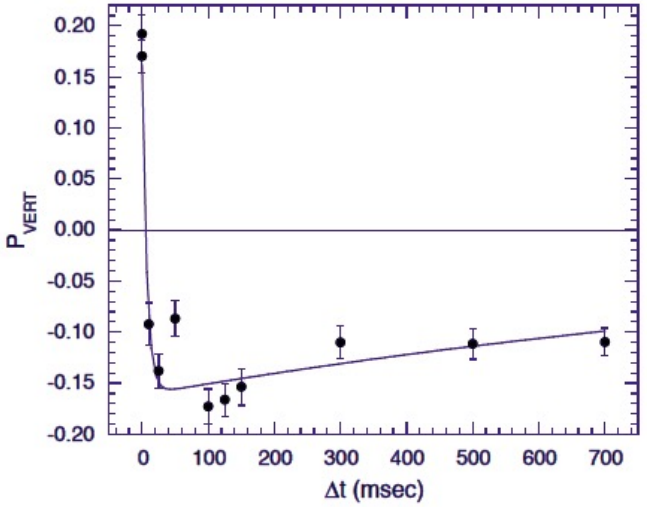
Spin Flipper

- The spin flip can be achieved by an artificial resonance generated by an dipole running with certain rf frequency. It is done as following: ramping the frequency of the spin flipper tune ν_{osc} across the spin tune ν_{spin} adiabatically and the spin can be flipped following the Froissart-Stora formula:

$$\frac{P_f}{P_i} = 2\exp^{-\frac{\pi}{2}\frac{|\epsilon|^2}{\alpha}} - 1, \qquad \alpha = \frac{\Delta\nu_{osc}}{2\pi N}$$







V.A. Anferov, *et al.*, PR-AB Vol. 3, 041001(2000). Spin flip results at 202.7MeV with single AC dipole.

Spin Flipper Challenges at RHIC

- The simple device can't be applied to high energy colliders such as RHIC where spin tune is ½.
- First, a single AC dipole generate two resonances located at $\nu_s = \nu_{osc}$ and $\nu_s = 1 - \nu_{osc}$, the so-called mirror resonance. When ν_s is adiabatically sweeping across ν_s=1/2, the polarized beam simultaneously crosses the spin resonance $\nu_s = \nu_{osc}$ from one side and the spin resonance $\nu_s = 1 - \nu_{osc}$ from the opposite side. The contributions from both can cancel each other or interfere. No full spin flip can be achieved.
- Second, the orbit distortion due to the spin flipper has to be zeroed outside the spin flipper.
- Third, there is a spin tune spread related to the slope of dispersion function in the snake. Spin tune of a ring with two snakes is given by

$$\nu_s = \frac{1}{2} + \frac{(1+G\gamma)(\theta_1 - \theta_2)}{2\pi}$$

There is a spin tune spread related to the synchrotron motion and the resulting momentum spread:

$$\Delta\nu_s = \frac{(1+G\gamma)}{\pi}(D_1' - D_2')\frac{\Delta p}{p}$$

M. Bai and T. Roser, PR-AB 11, 091001(2008).
S.R. Mane, PR-AB 12, 099001(2009).

Eliminating the Mirror Resonance

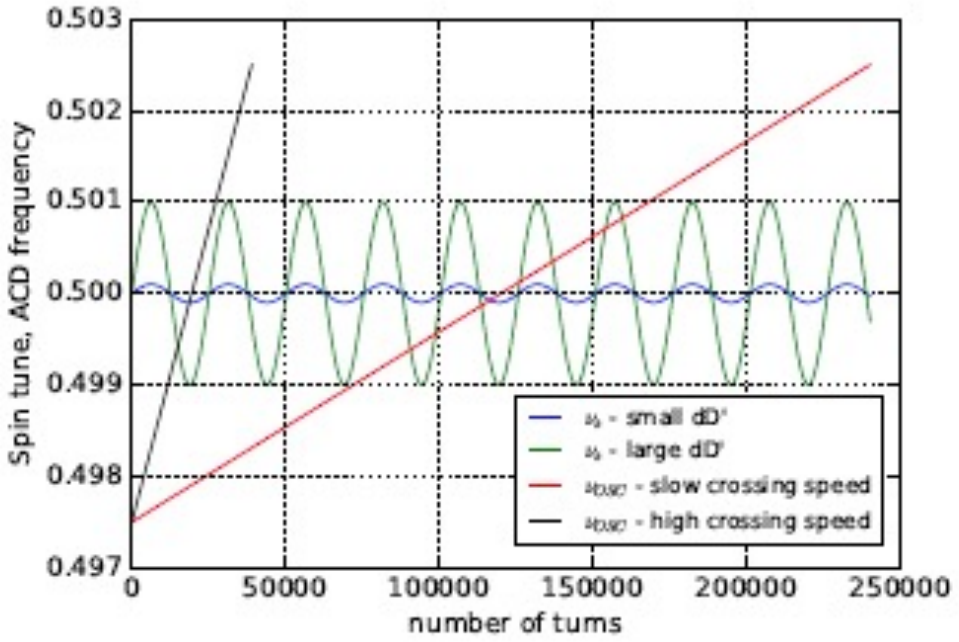
- Use 2 closed bumps to avoid spin rotations in quadrupoles and multipoles.
- Phase difference between the bumps must be equal to the spin rotation of one DC dipole.
- Phase difference accuracy better than ½ degree.
- Careful closure of the bumps.

The problem with Spin Chromaticity

- The spin tune is $\nu = \frac{1}{2} + \gamma G(\theta_1 - \theta_2)$
- θ_1 and θ_2 are the total horizontal deflections angles in the two half rings between the snakes
- For an off-momentum particle the spin tune change is

$$\Delta\nu = \frac{\gamma G}{\pi}\left[(D_2' - D_1')\frac{\Delta p}{p} + higher \quad order\right]$$

- The lattice needs to have small $\Delta D'$ between the two snakes.



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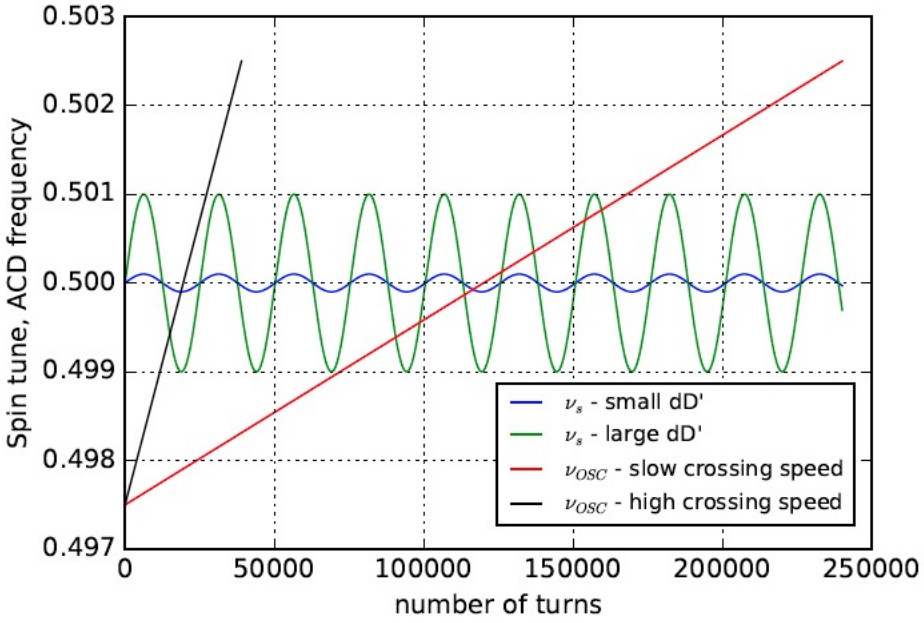
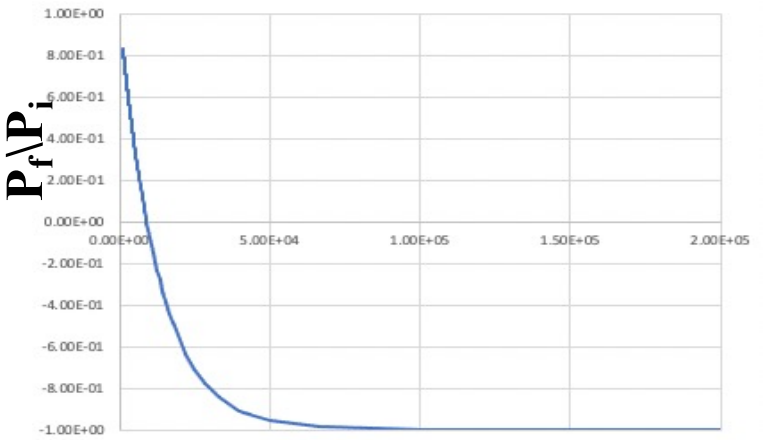
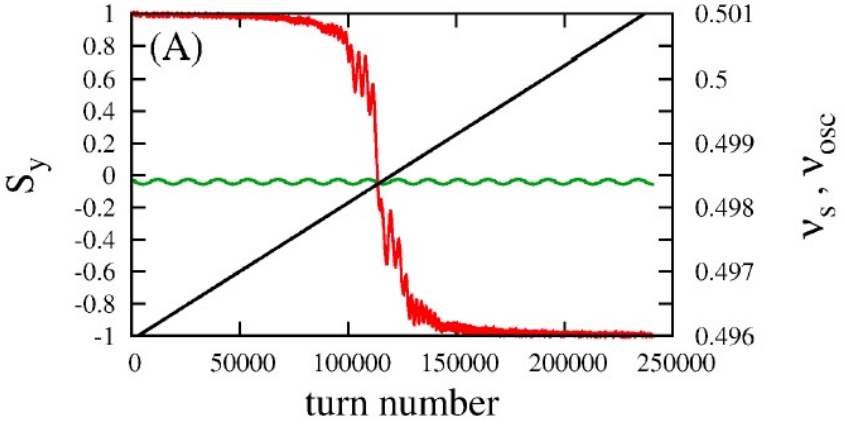
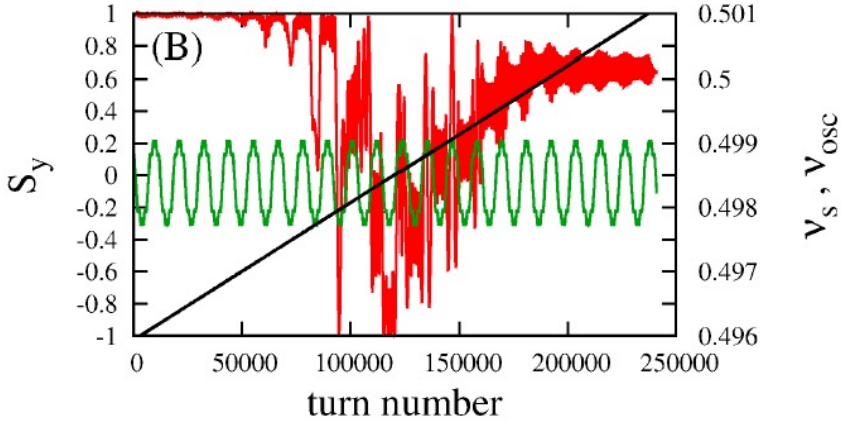
Fast or Slow Sweeping Speed?



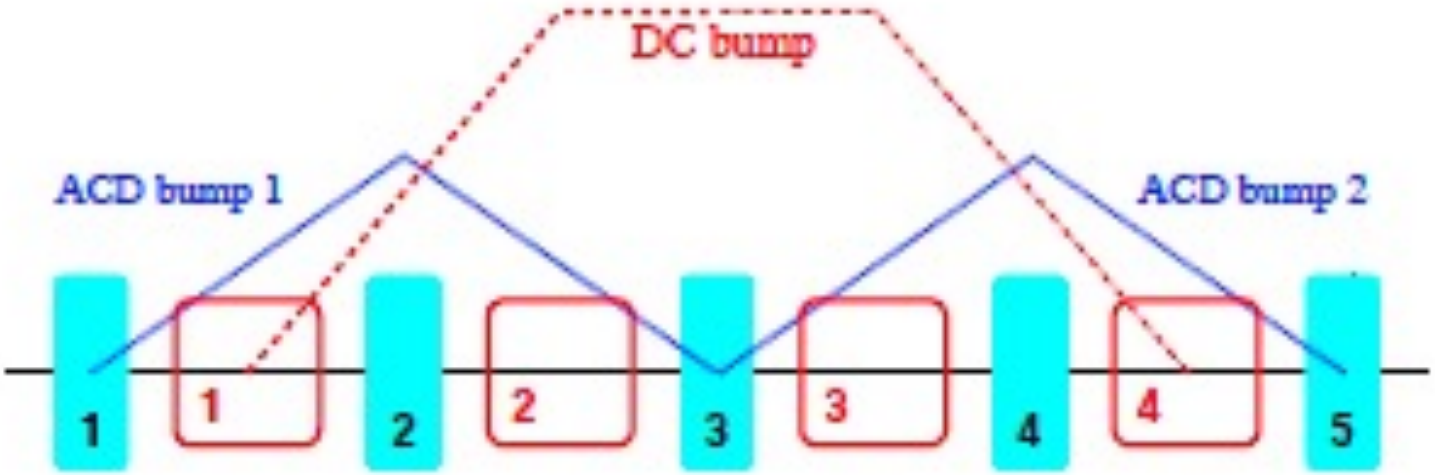






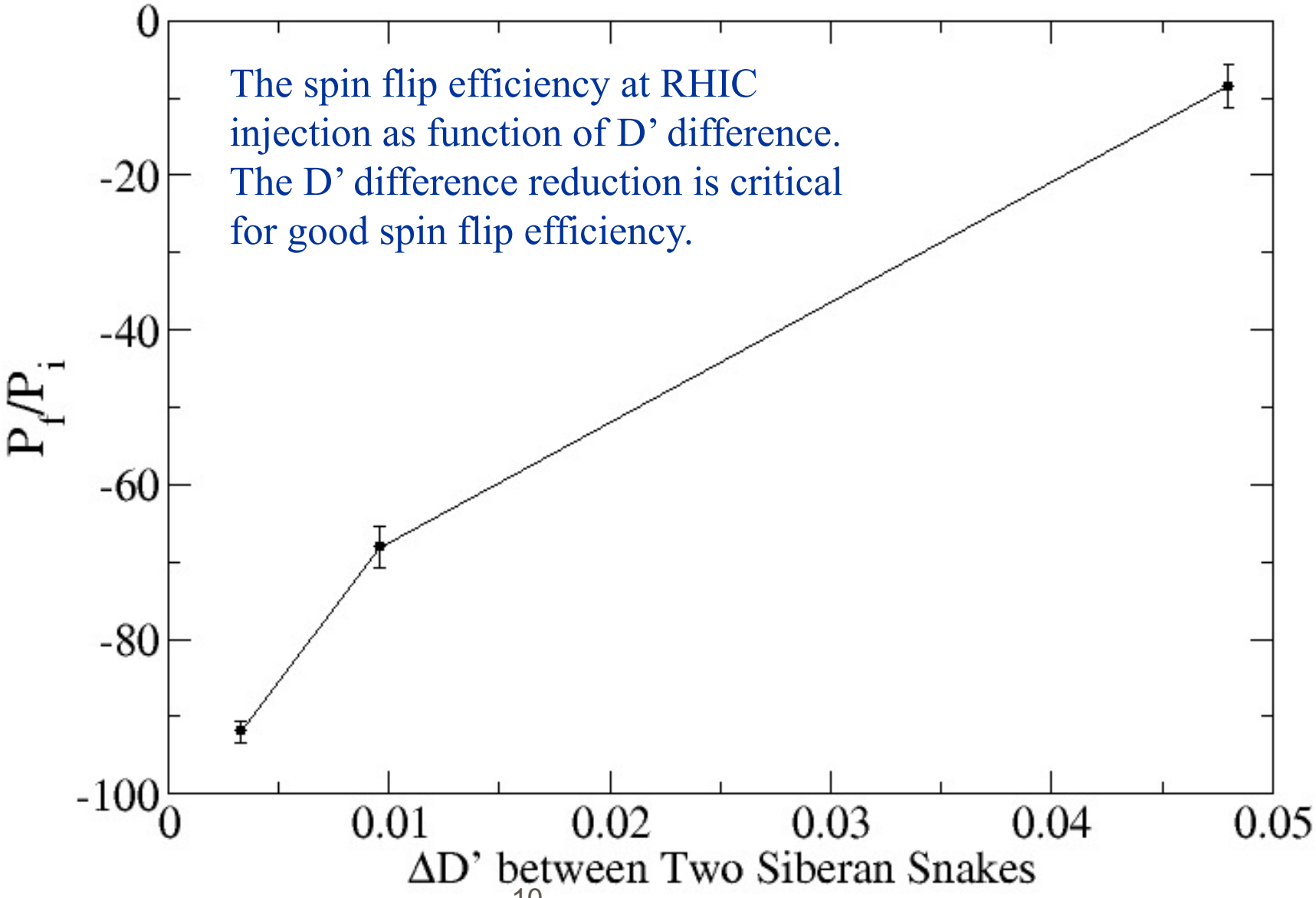
The choice is a compromise: as slow as possible but avoid multiple crossing.

Spin Flipper Layout



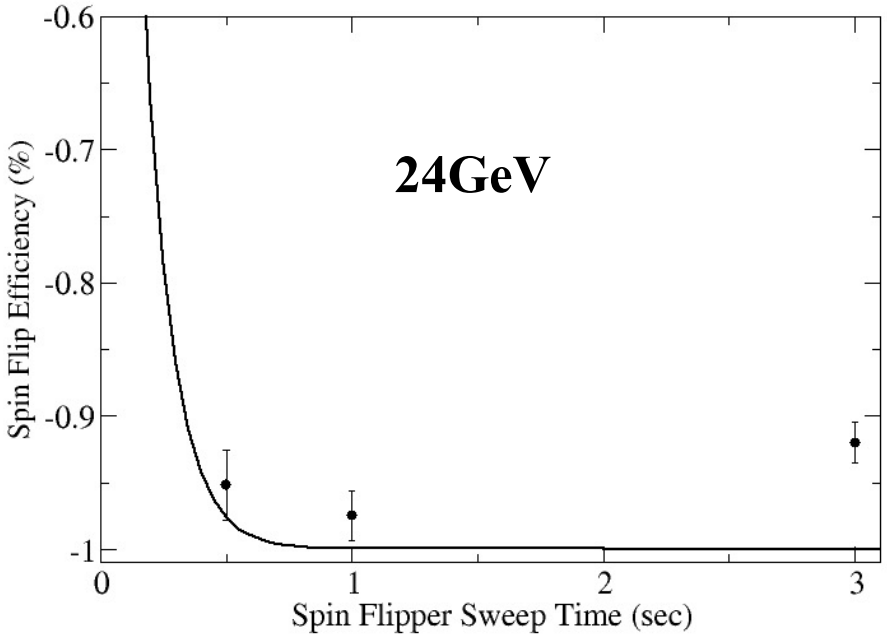
The spin flipper system consists of four DC dipole magnets and five AC dipole magnets. The aim of this configuration is to produce a rotating field which eliminates the mirror resonance. Multiple AC dipoles are needed to localize the driven coherent betatron oscillation inside the spin flipper.

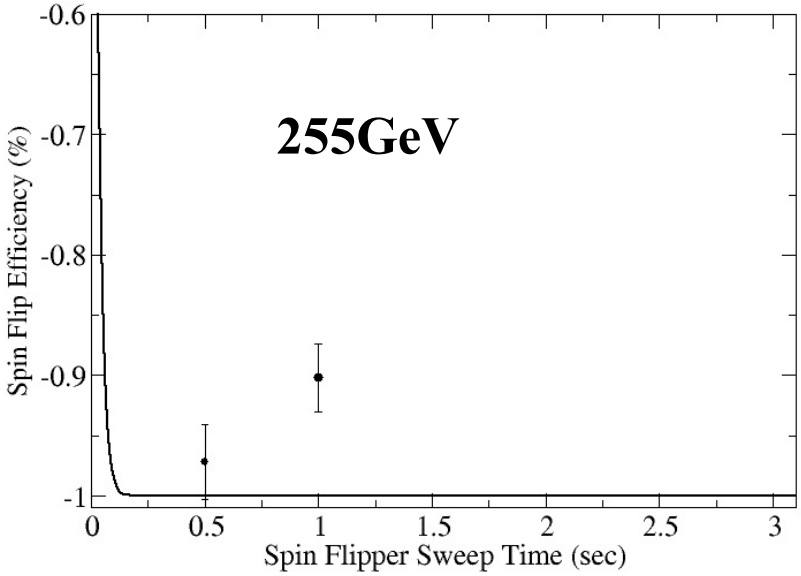
Spin Flip Efficiency vs. ΔD'



Spin Flip Efficiency vs. Sweep Time

At longer sweep time, the multiple crossing is the reason for less spin flip efficiency.





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Summary

- It has been shown that the 9-magnet spin flipper eliminated the "mirror" resonance.
- With the lattice for which the dispersion slope difference at the two Siberian Snakes is greatly suppressed, a spin flip efficiency of over 97% has been achieved for polarized proton beam at 24GeV and 255GeV.
- The dispersion slope difference at the location of the two Siberian Snakes as 0.003 at 24 GeV and 0.0001 at 255GeV.