AGS Polarized Proton Operation in Run 2009

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Depolarizing Resonances in the AGS

Imperfection Resonances

ν_s =n (integer) $G\gamma$=5,6,...45 partial snake(s)

Vertical Intrinsic Resonances

$\nu_s = kP \pm \nu_y$

Strong ones: $G\gamma = 0+\nu_y, 12+\nu_y, 36\pm\nu_y$ strong partial snakes

Note: with two partial snakes in the AGS, P=1. There are a lot weak intrinsic resonances as the result.

Horizontal Intrinsic Resonances

1. non-vertical stable spin direction due to strong partial snake.

2. betatron motion coupled to the vertical betatron motion by coupling elements: solenoid, helical magnet.

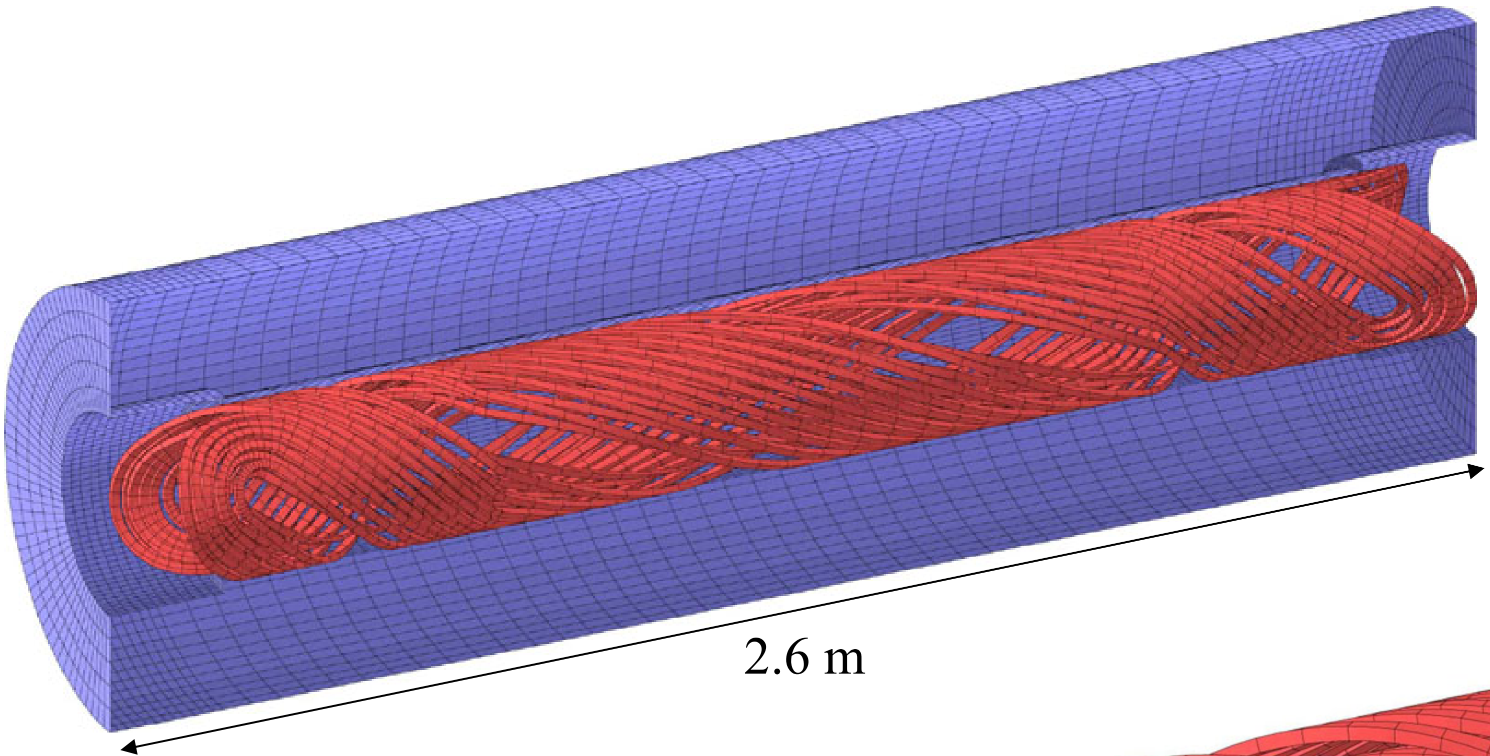
$\nu_s = k \pm \nu_x$ fast crossing speed, strong partial snakes

Partial Snake Resonances

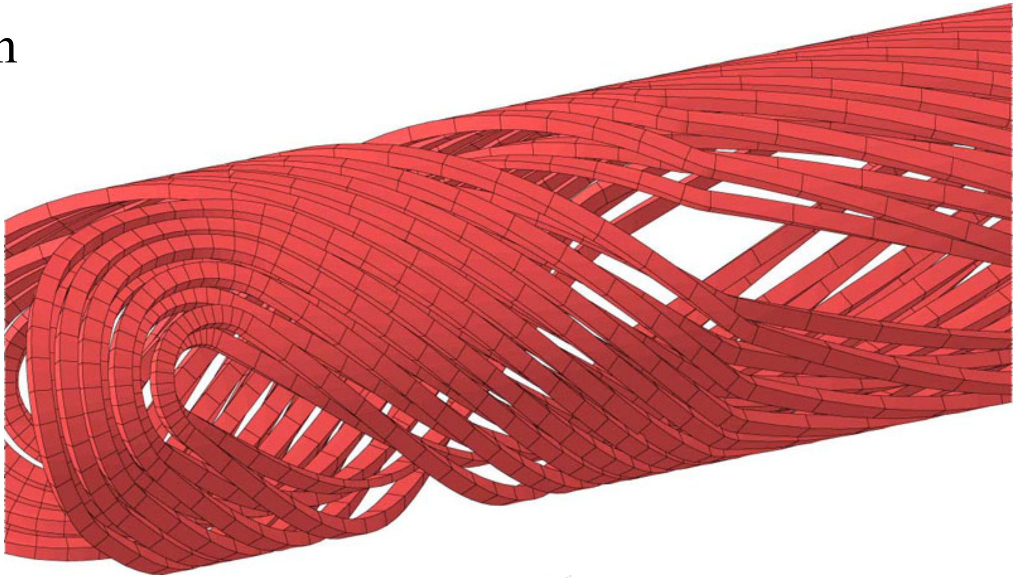
strength proportional to nearby intrinsic resonance strength.

$\nu_s = kP \pm m\nu_y$, m>1 avoid the resonance tunes

AGS Super-conducting Helical Snake



15 cm warm bore
Helix with changing pitch



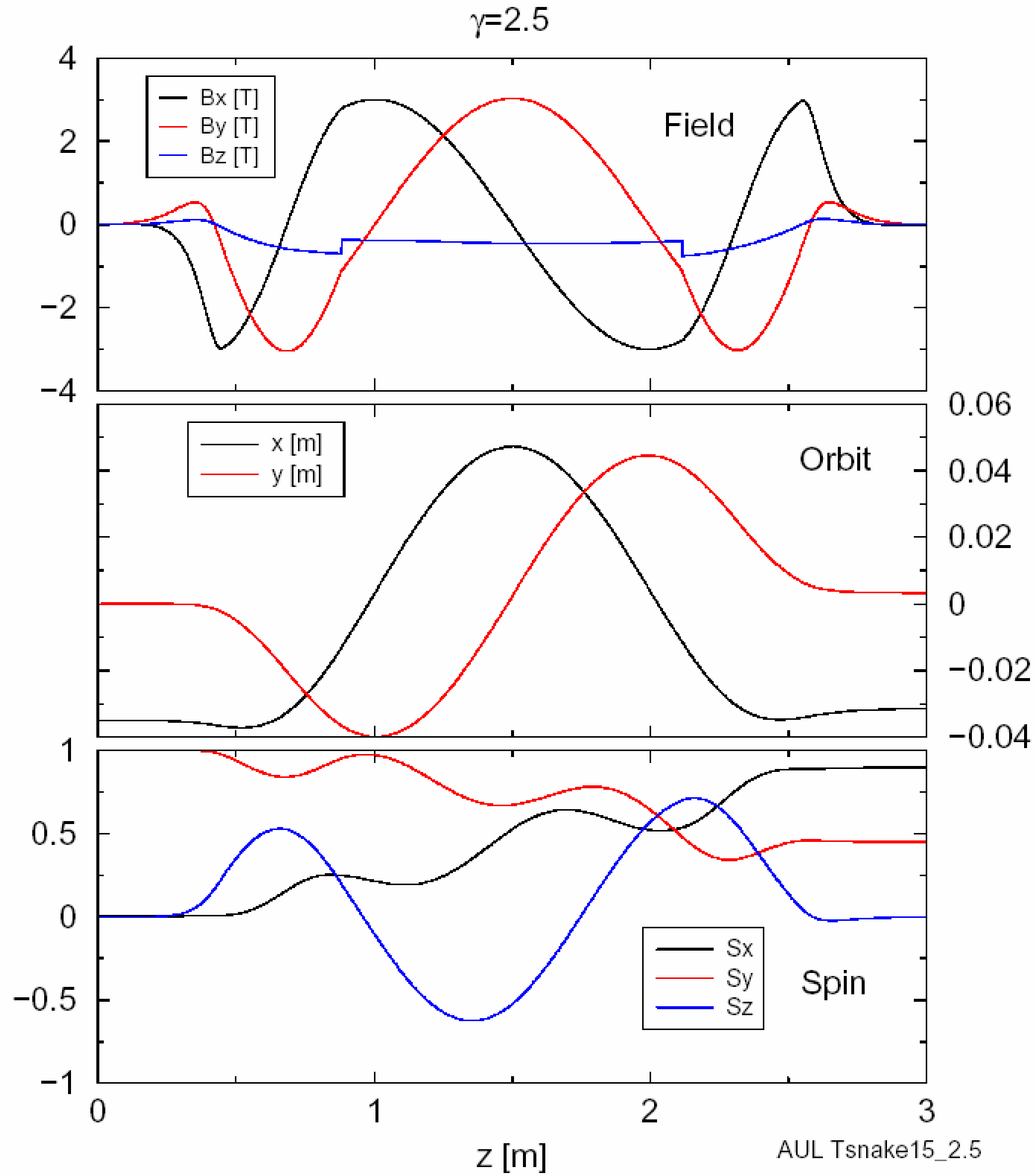
Design of ~ 25% Partial Snake

Changing pitch helix

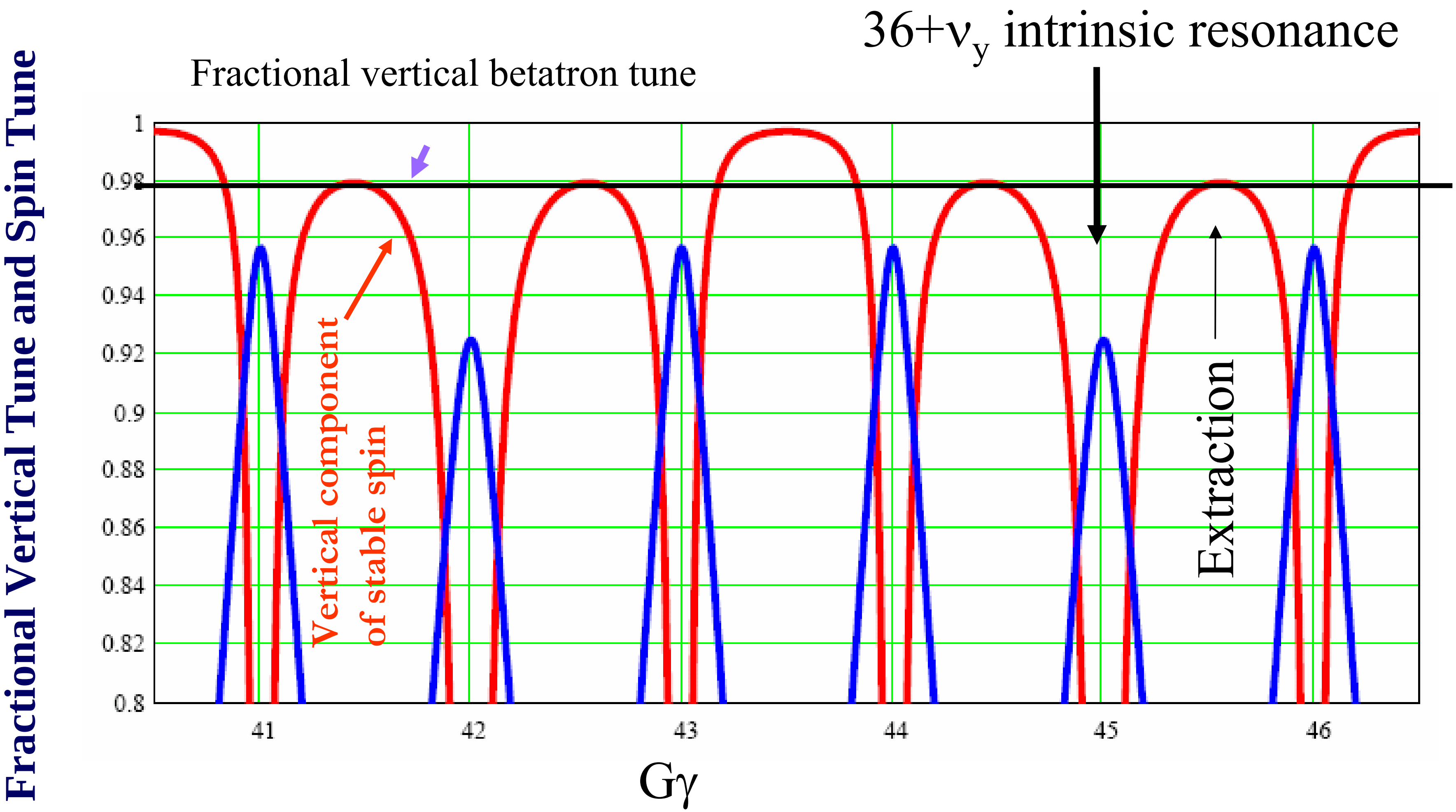
Horizontal orbit offset

~ 4 cm max. excursion

Central solenoid for coupling correction



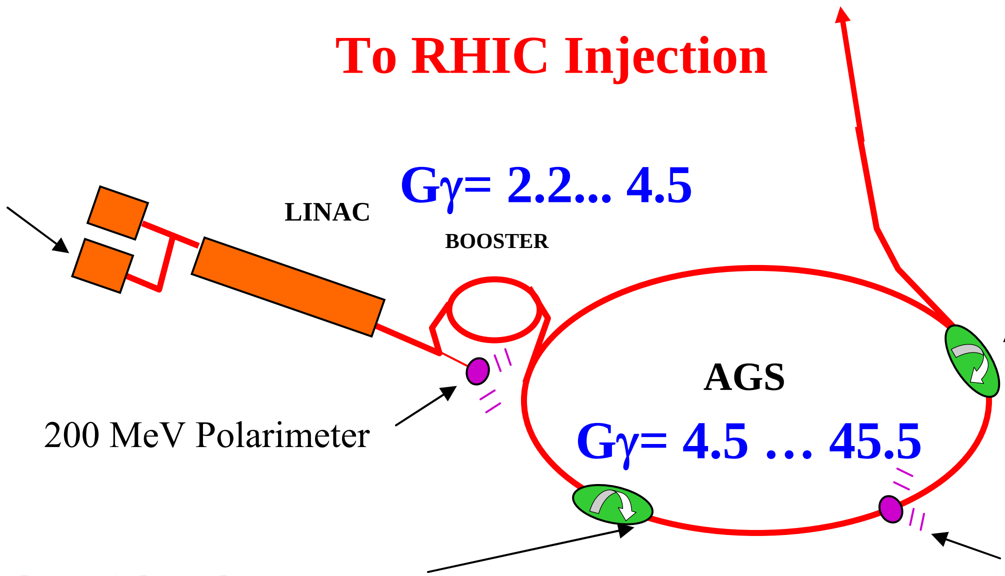
Spin tune with two partial snakes



Spin tune gap modulation of the period of 3 units of Gγ:

$$\cos\pi\nu_s = \cos G\gamma\pi \cos\frac{\theta_w}{2}\cos\frac{\theta_c}{2} - \cos G\gamma\frac{\pi}{3}\sin\frac{\theta_w}{2}\sin\frac{\theta_c}{2}$$

AGS as RHIC Polarized Proton Injector



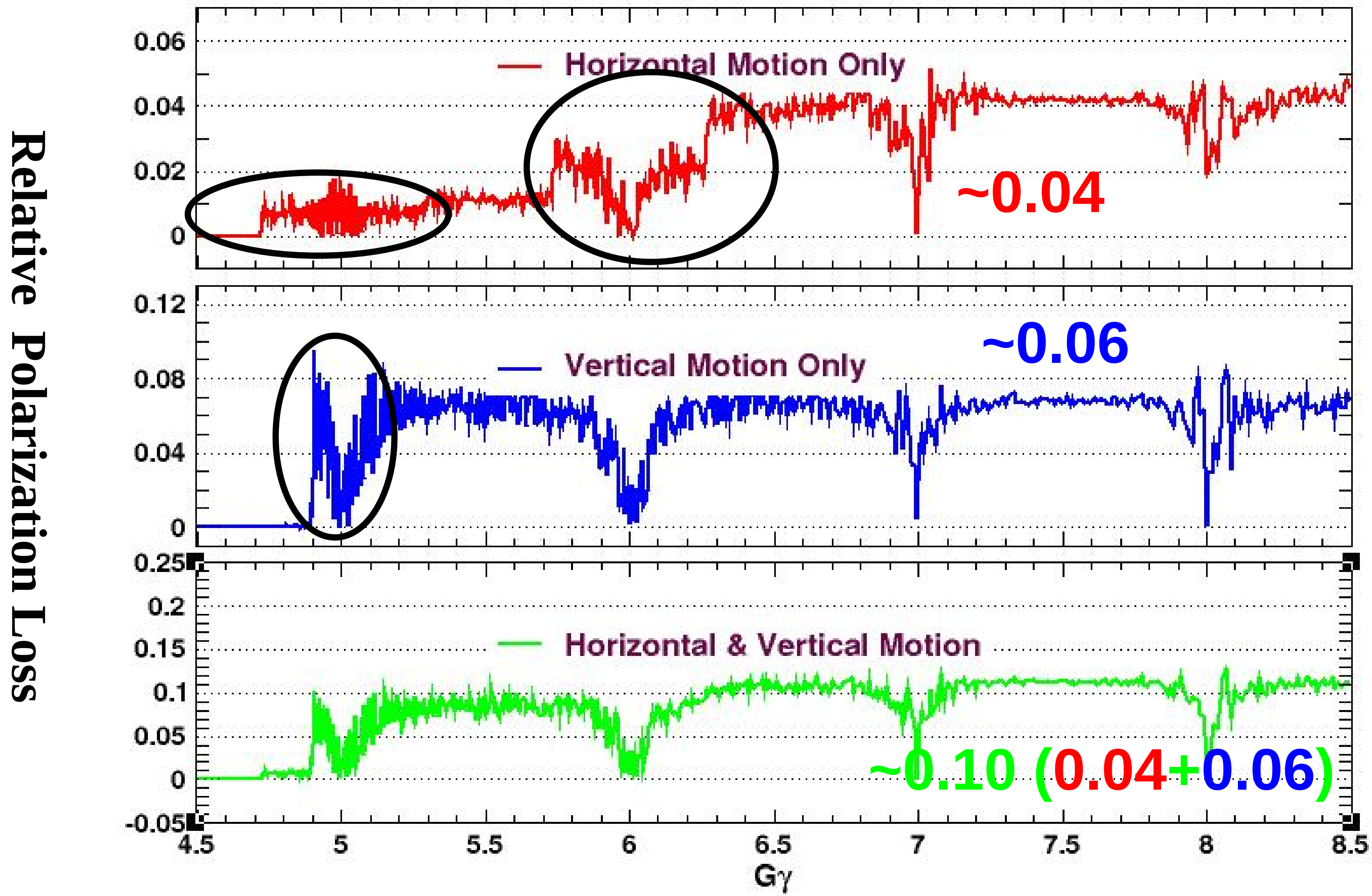
AGS ramp rate is 2.2T/s, or 450ms for 2.4GeV to 23.8GeV. Two partial snakes match spin better and maintain polarization up to 65% with 82% input polarization.

H. Huang, et al., *PRL*. **99**, 154801 (2007).

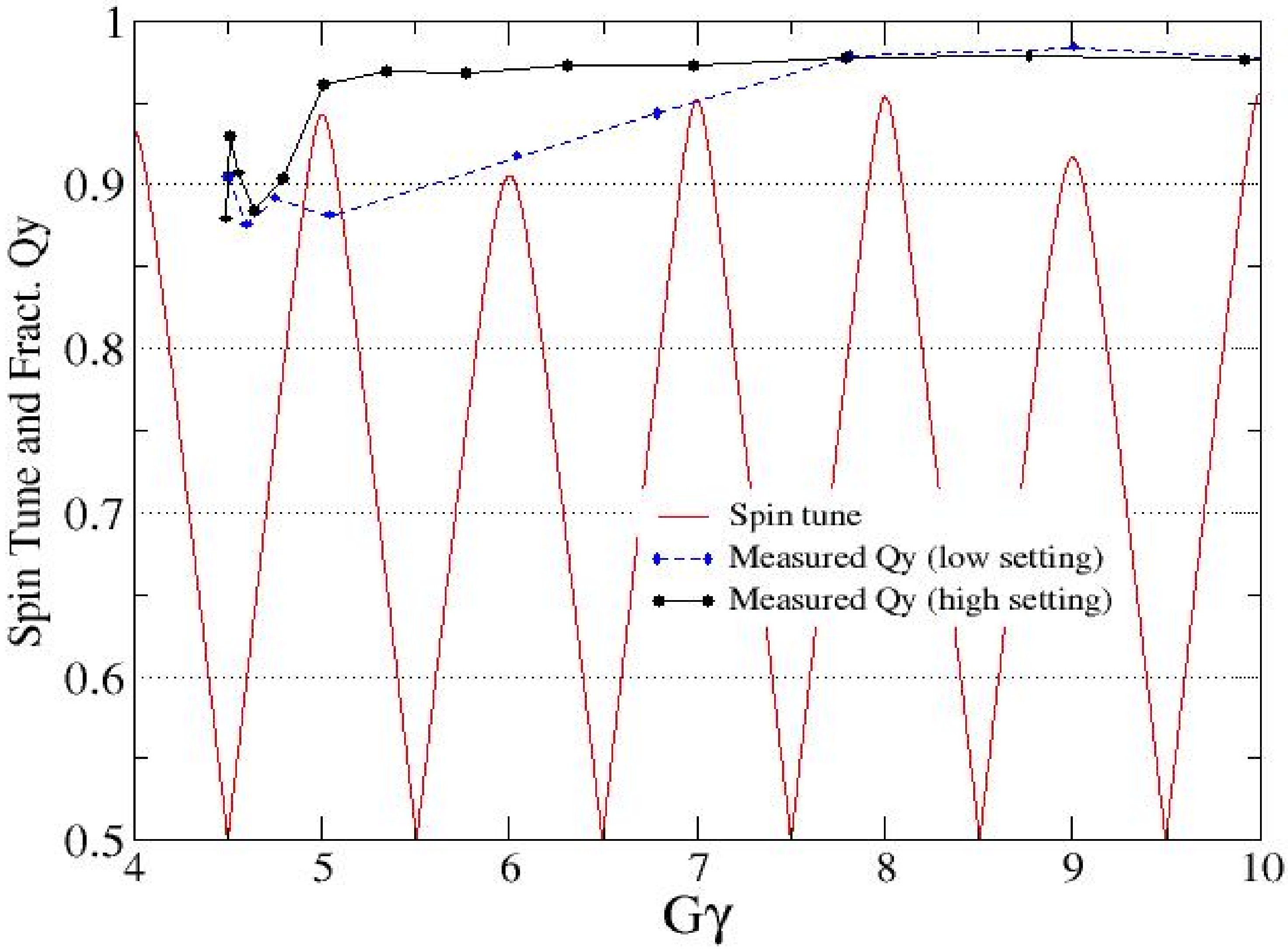
What Are the Sources of the Polarization Loss?

- Imperfection and vertical intrinsic resonances have been taken care of by the dual partial snakes (except a few vertical ones near injection as vertical tune is outside the spin tune gap).
- The sources of remaining polarization losses:
  - due to horizontal intrinsic resonances along the ramp.
  - the snake resonances associated with strong vertical intrinsic resonances, mostly at the strongest resonance $36+\nu_y$.
  - With the insertion of partial snakes, the super-periodicity P is one. The slow ramp rate and large lattice distortion near injection result polarization loss due to both horizontal and vertical intrinsic resonances.

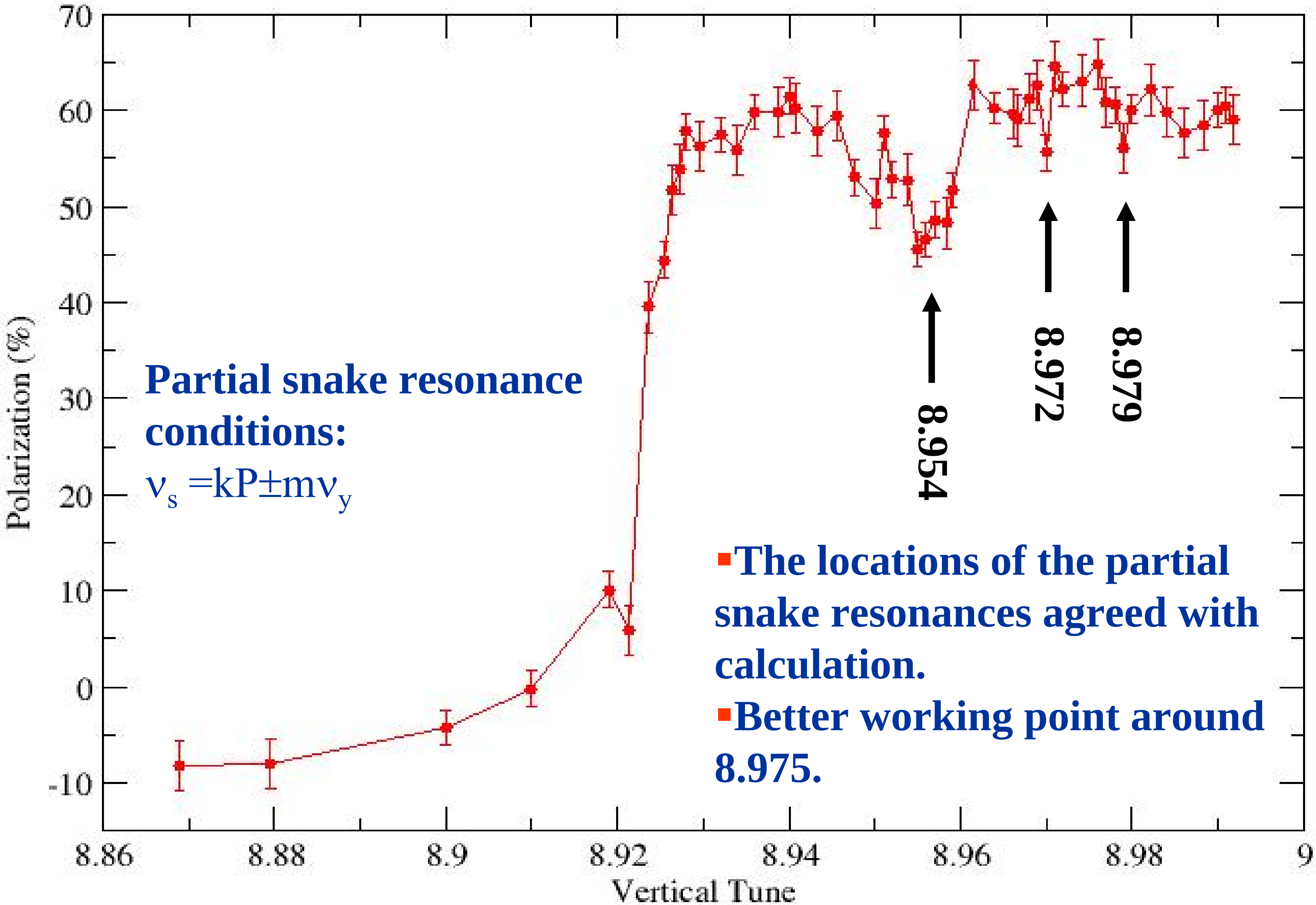
Polarization Loss Near Injection



Higher Q_y Near Injection: within Spin Tune Gap



Detailed Vertical Tune Scan at 36-

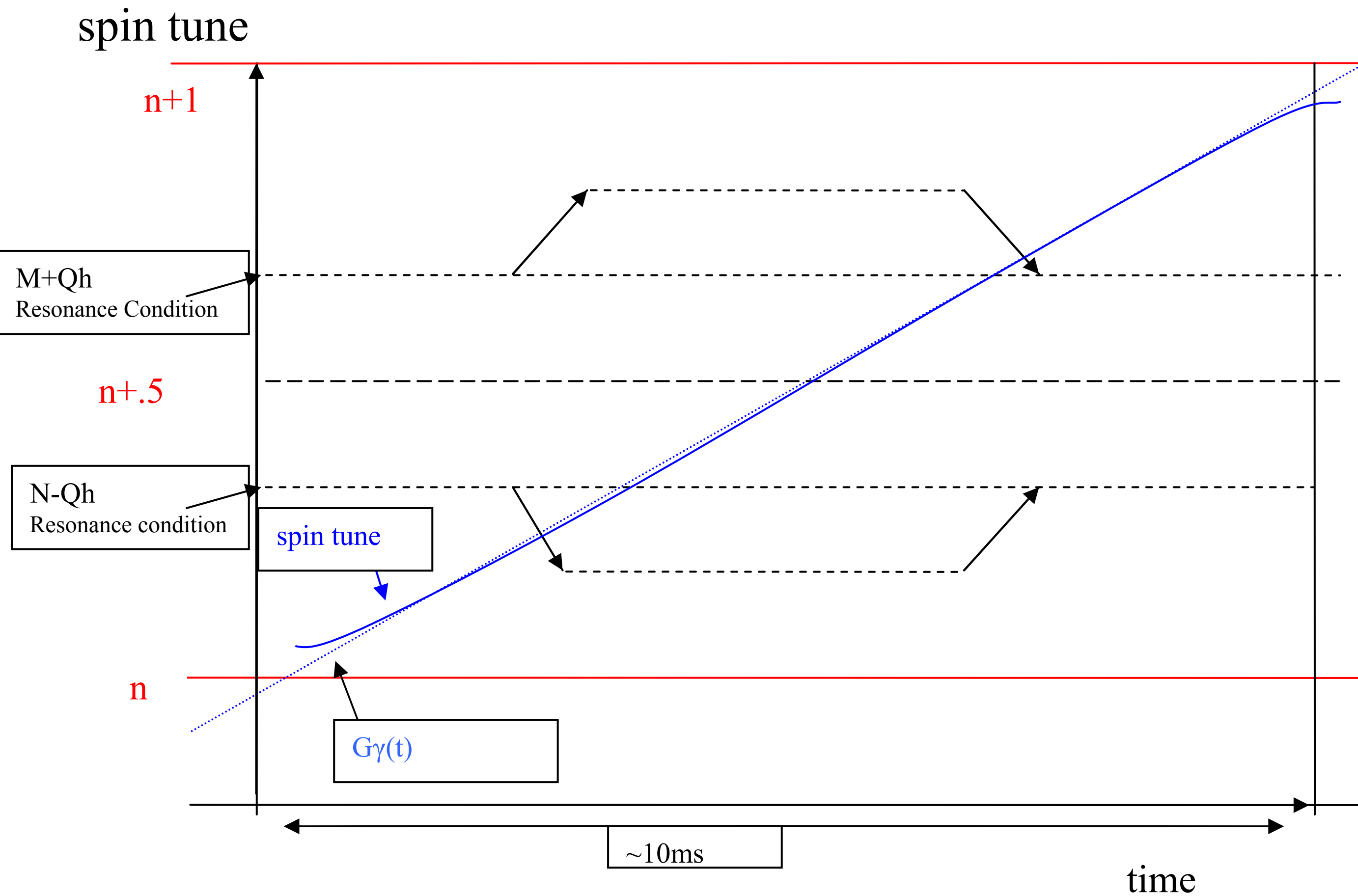


Partial snake resonance conditions:

$\nu_s = kP \pm m\nu_y$

- **The locations of the partial snake resonances agreed with calculation.**
- **Better working point around 8.975.**

Horizontal Tune Jump



For an isolated resonance,

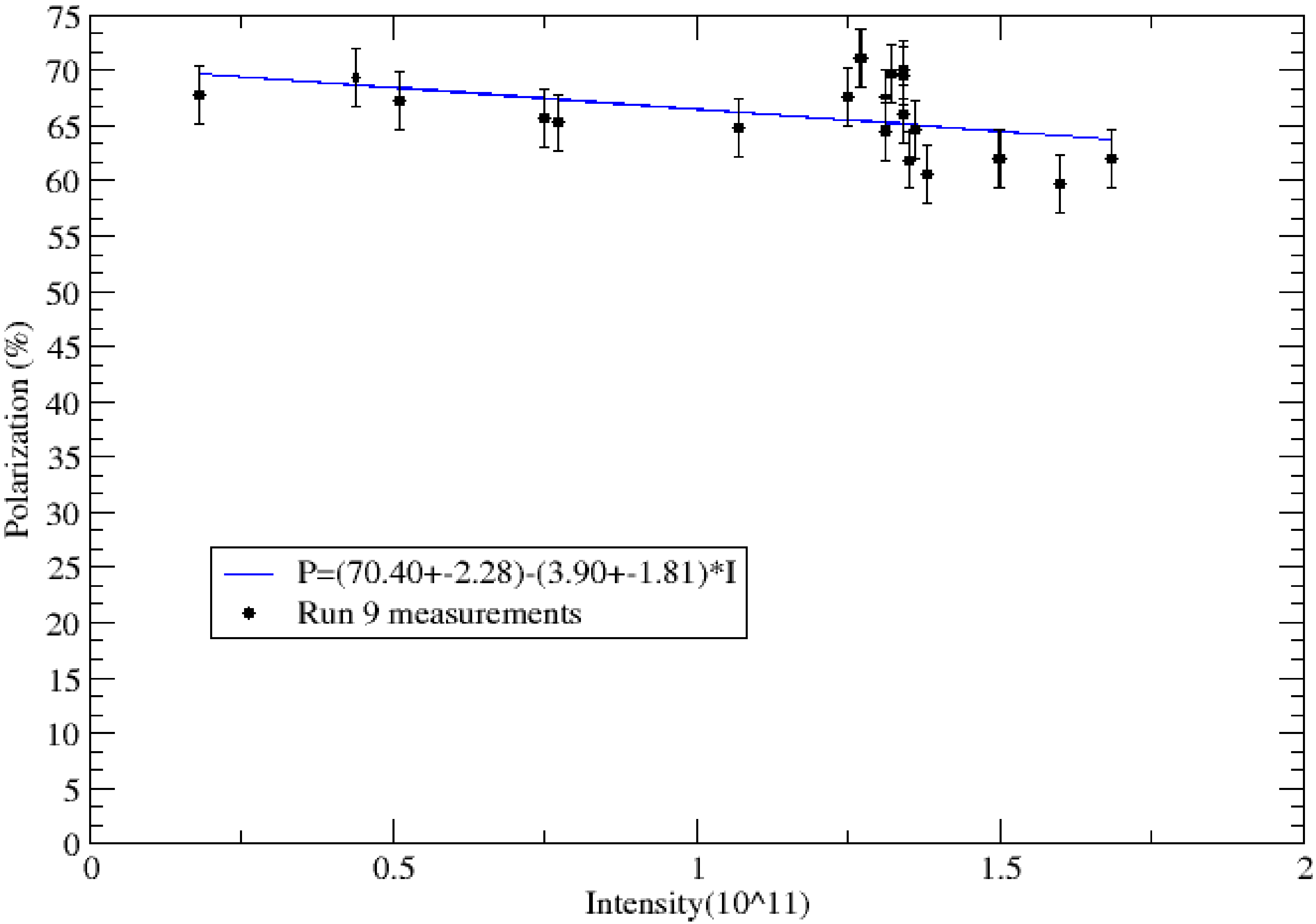
$$P_f = P_0\left(2e^{-\frac{\pi|\varepsilon|^2}{2\alpha}} - 1\right)$$

And resonance crossing rate is given by:

$$\alpha = \frac{dG\gamma}{d\theta} + - \frac{d\nu}{d\theta}$$

Change of ν_x is 0.04 in 100 μs. This increases the crossing speed in about 4 times. The two quads are ready for installation and beam test will follow. Maintain the adiabaticity is the key to minimize any emittance growth even for the benign tune jump.

Polarization vs. Intensity



Summary

- Imperfection and vertical intrinsic resonances have been overcome by the dual partial snakes, including the ones near injection after raising the vertical tune into the spin tune gap.
- The vertical tune path has been carefully mapped out in the vicinities of strong intrinsic resonances to optimize polarization level (36-ν as an example). Work continues for other intrinsic resonances.
- The new horizontal tune jump system will be tested to overcome the horizontal intrinsic resonances.