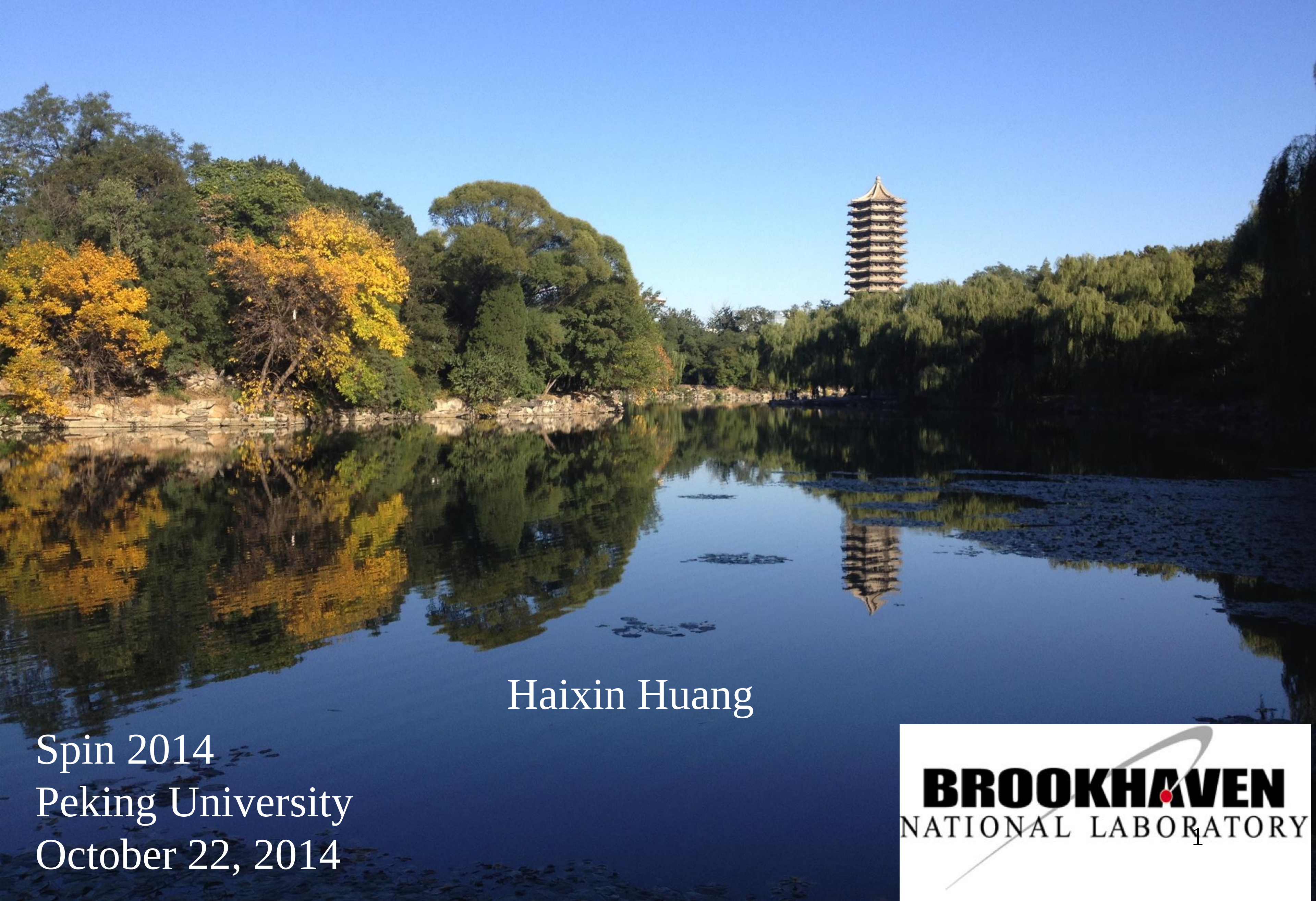
Multiple Tune Jumps to Overcome the Horizontal Depolarizing Resonances



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Peking University
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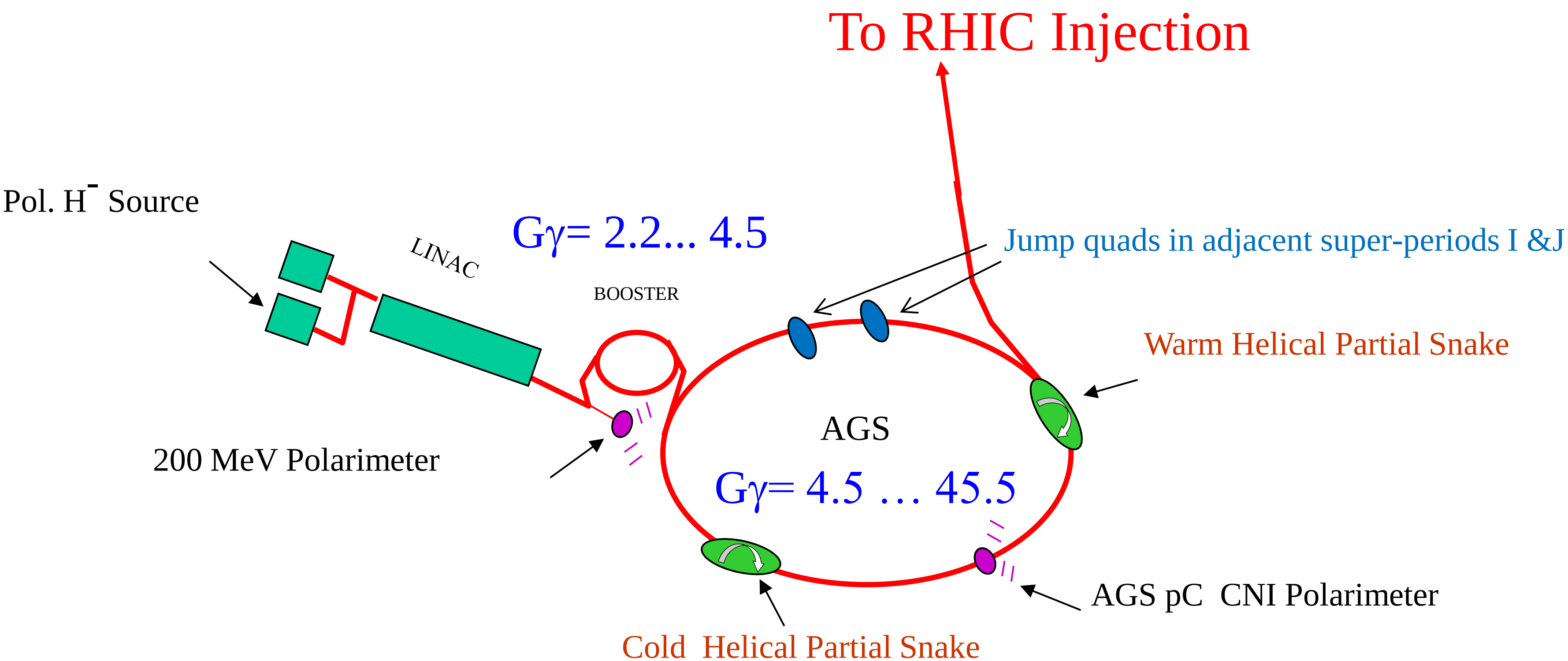
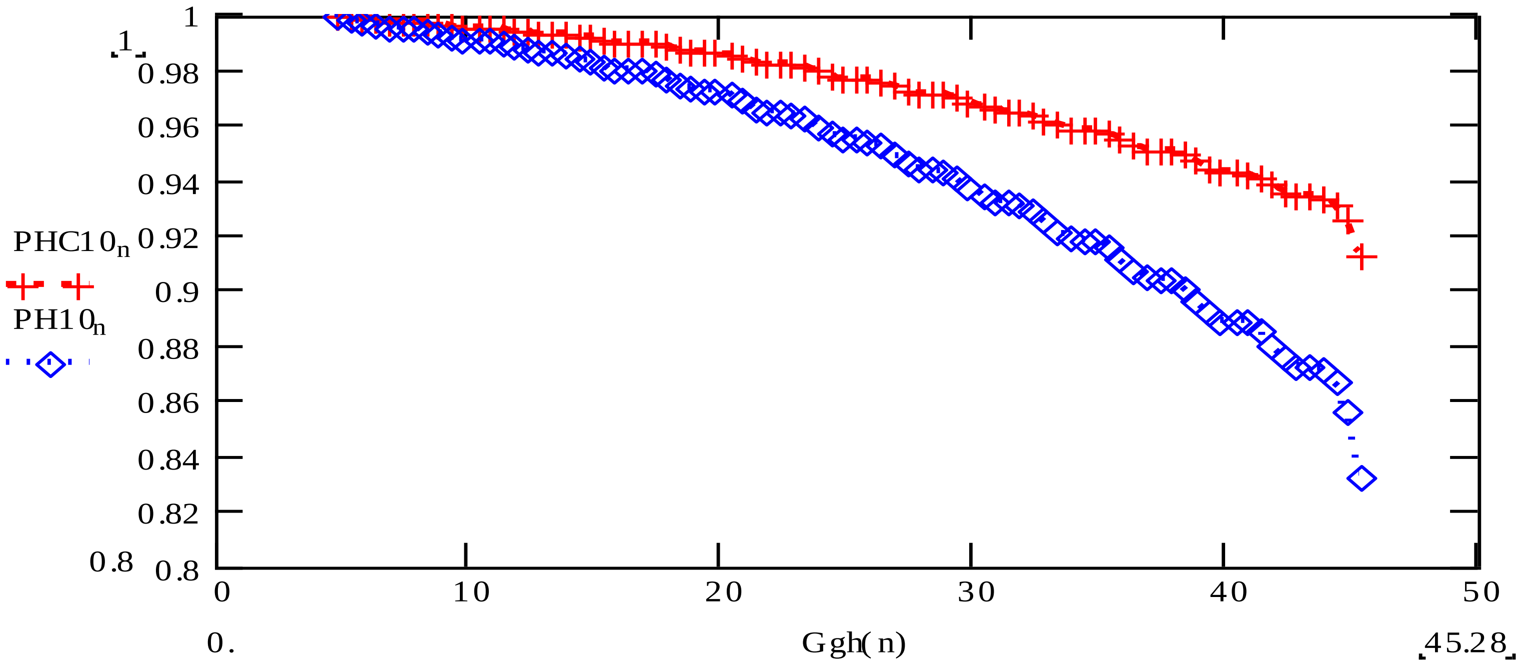
AGS as RHIC Polarized Proton Injector



AGS has been running as RHIC polarized proton injector with dual partial snakes and two horizontal tune jump quads. It has delivered ~70% polarization with ~2*10^{11}/bunch intensity with 80% as input polarization.

Simulation of Horizontal Intrinsic Resonances

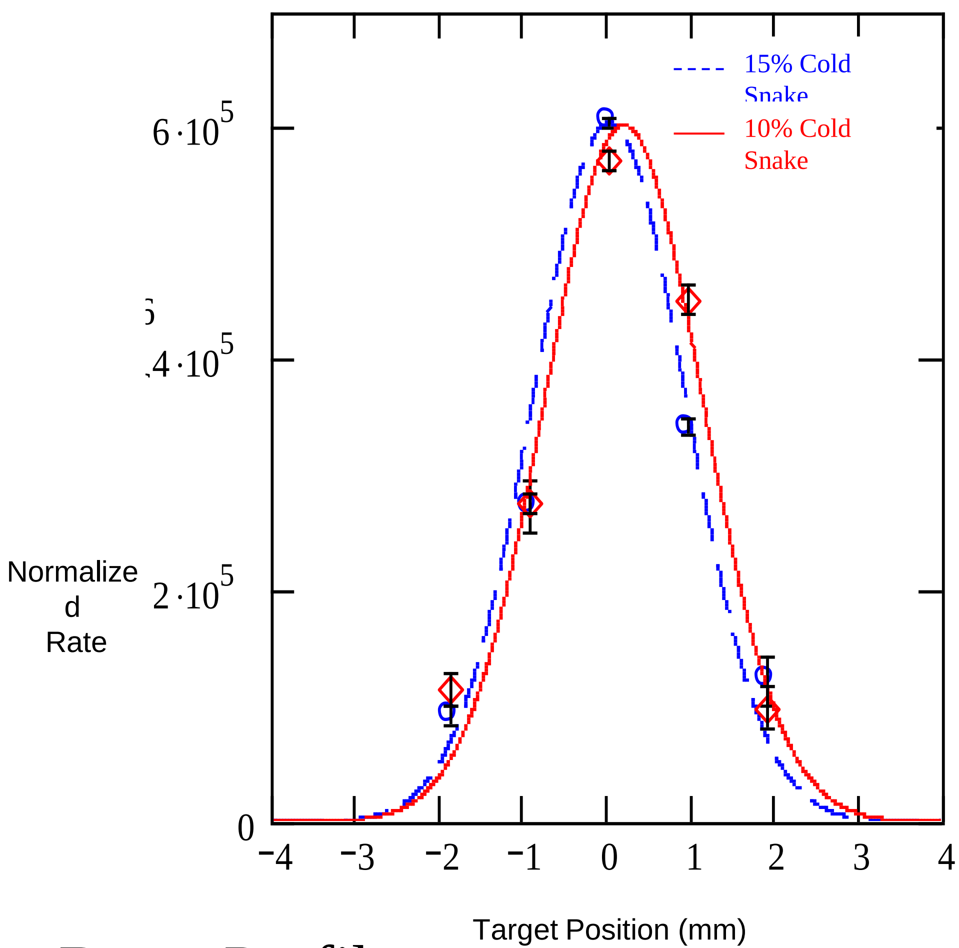
- Vertical intrinsic resonances and imperfection resonances have been avoided by introducing two partial snakes in the AGS. But the partial snake magnets also move the stable spin direction away from the vertical and consequently excite depolarizing resonances associated with horizontal tune, so-called horizontal intrinsic resonances. They are driven by vertical oscillating fields (horizontal focusing) with horizontal stable spin direction from partial snake
- For 10% and 5.9% partial snakes and 15 π horizontal emittance polarization transmission is predicted to be 91% in beam center (red), 83% for average (blue)



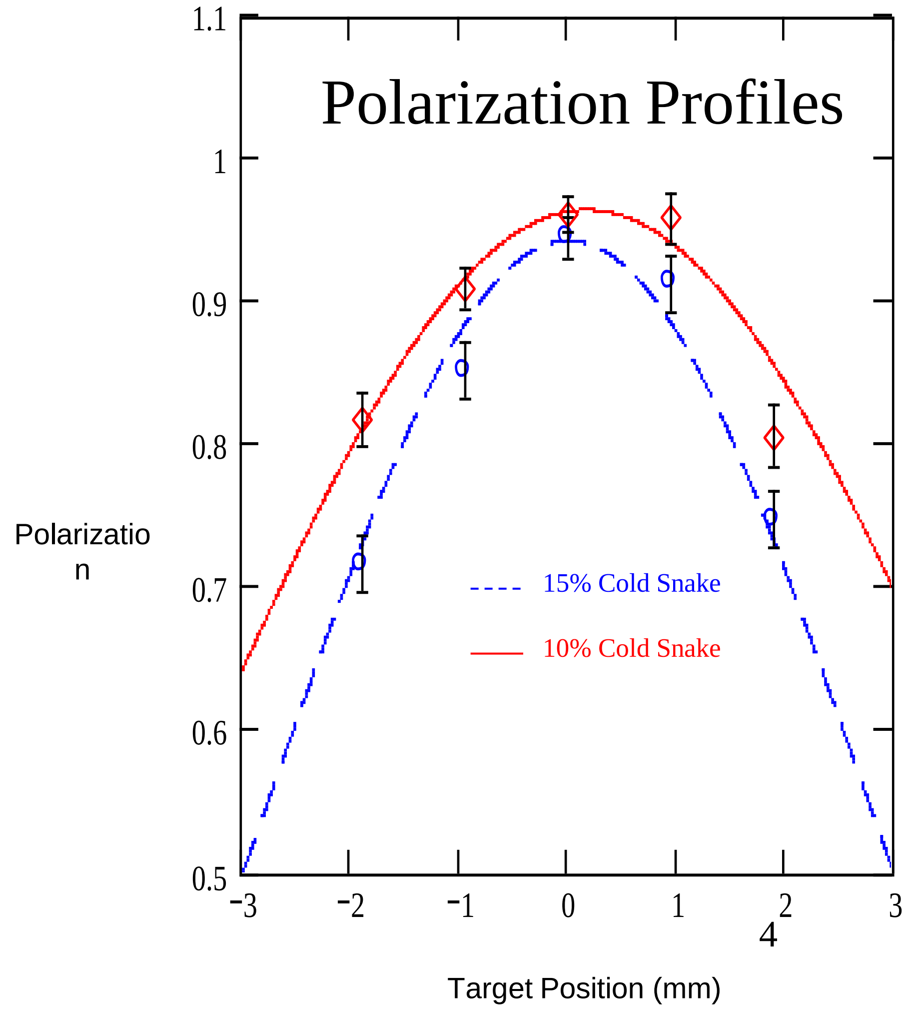
F. Lin, et al, *PR*. STAB 10, 044001(2007).

Evidence of Horizontal Resonances from Polarization Profile

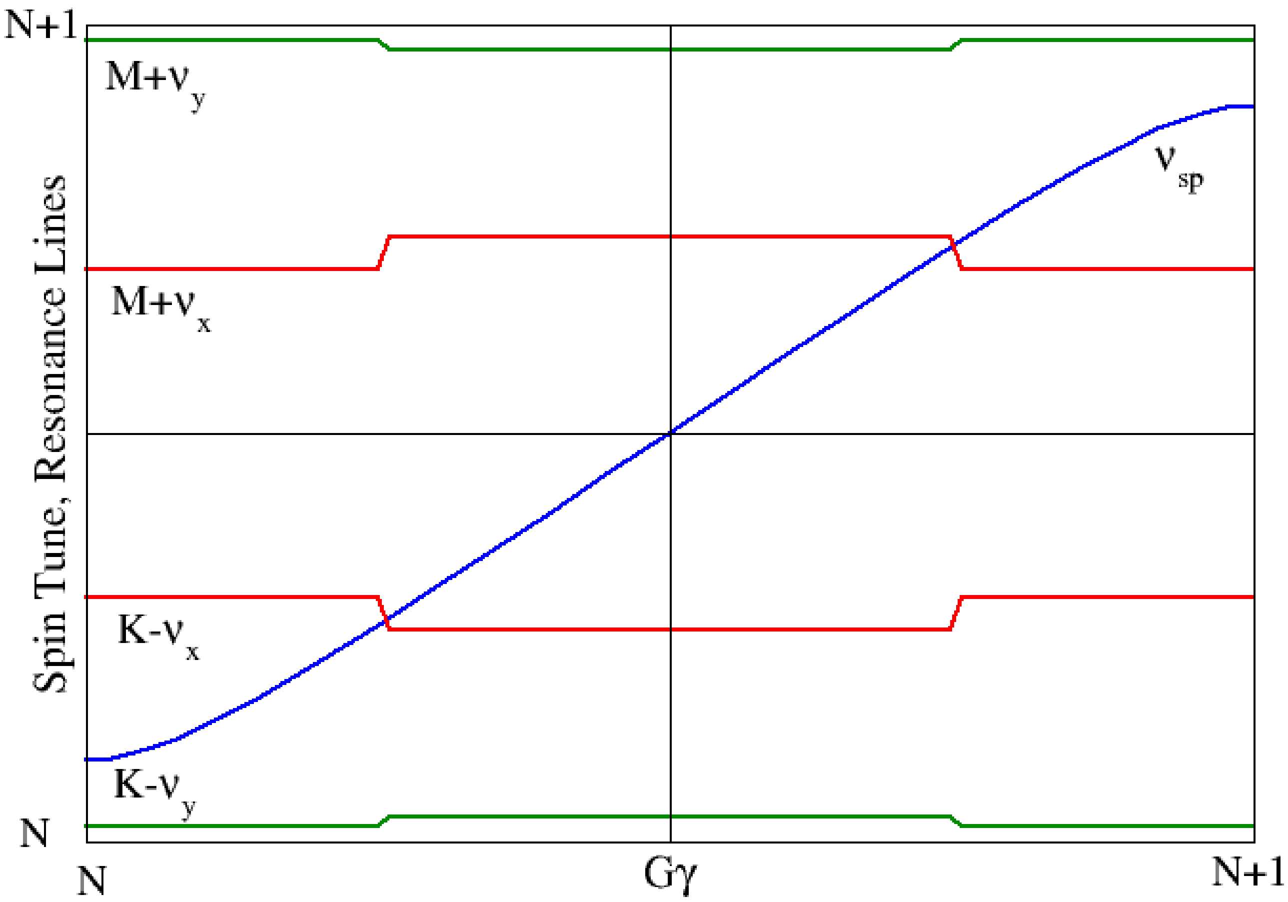
The horizontal resonance effect is measurable over the whole ramp.
The following snake setup gave the best polarization: 10% cold snake, 5.9% warm snake.



Beam Profiles



Horizontal Tune Jump



For an isolated resonance,

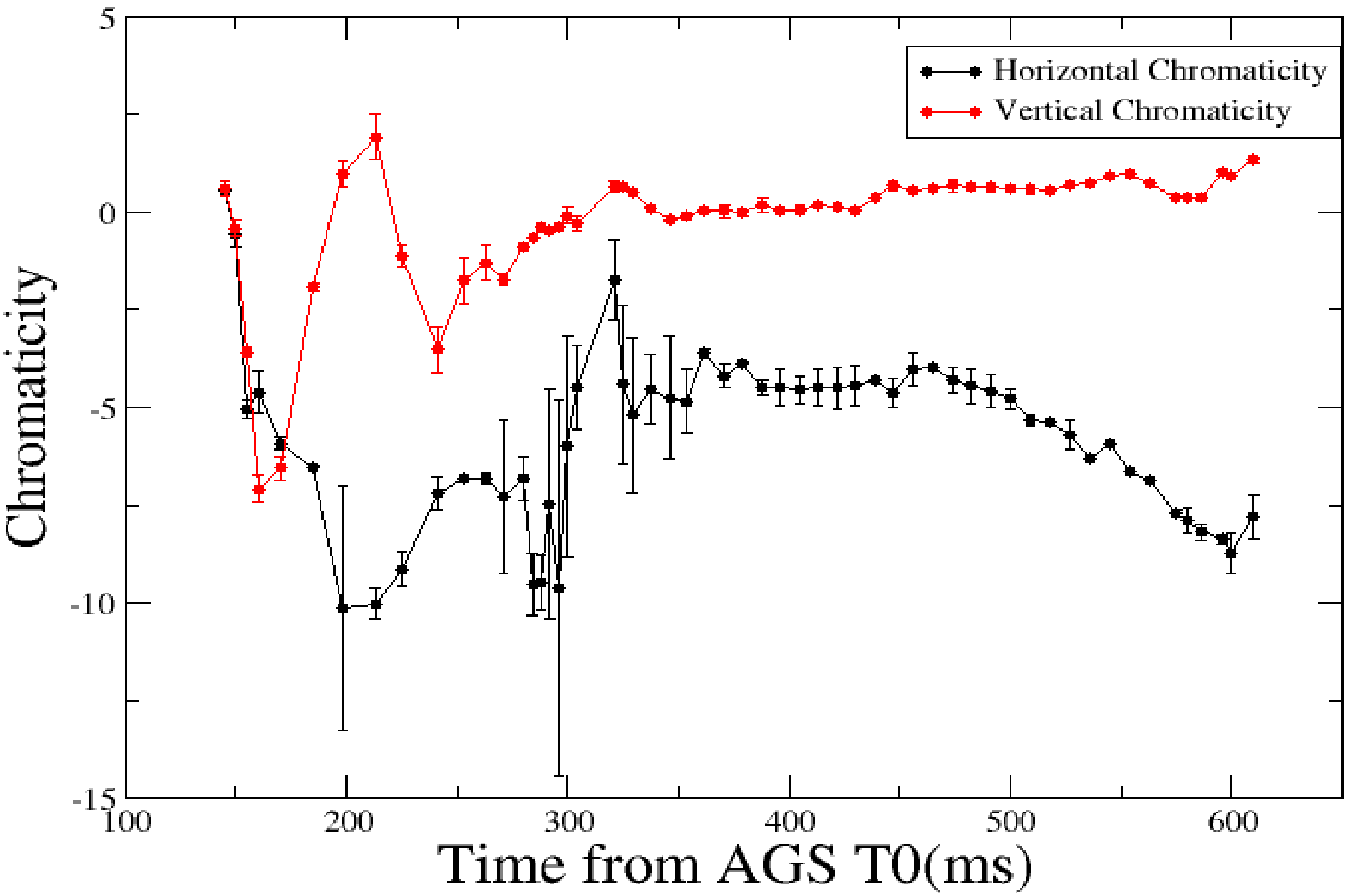
$$P_f = P_0\left(2e^{-\frac{\pi|\varepsilon|^2}{2\alpha}} - 1\right)$$

And resonance crossing rate is given by:

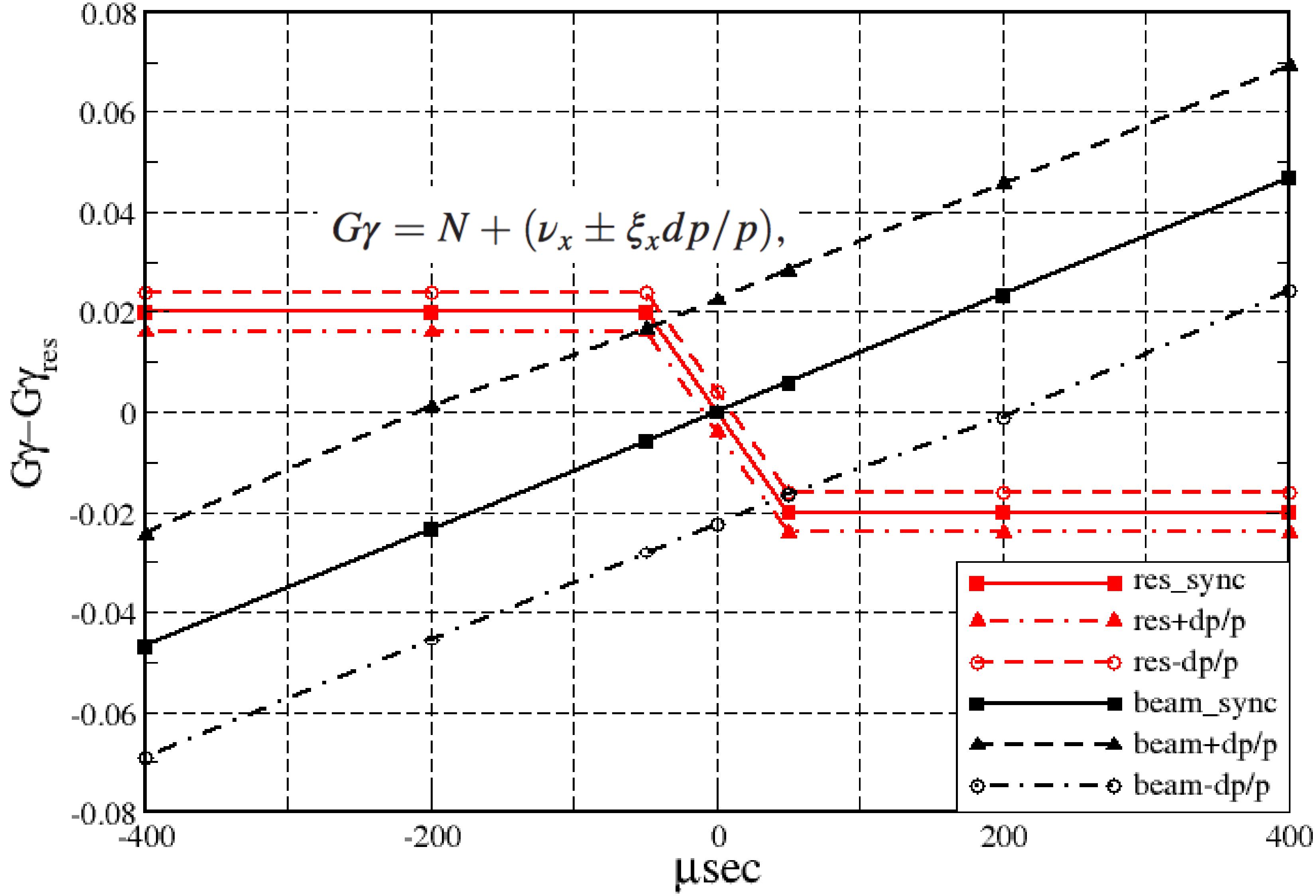
$$\alpha = \frac{dG\gamma}{d\theta} + - \frac{d\nu}{d\theta}$$

Change of ν_x is 0.04 in 100 µs. This increases the crossing speed in about 4 times. Maintain the adiabaticity is the key to minimize any emittance growth even for the benign tune jump.

Chromaticity on the Ramp

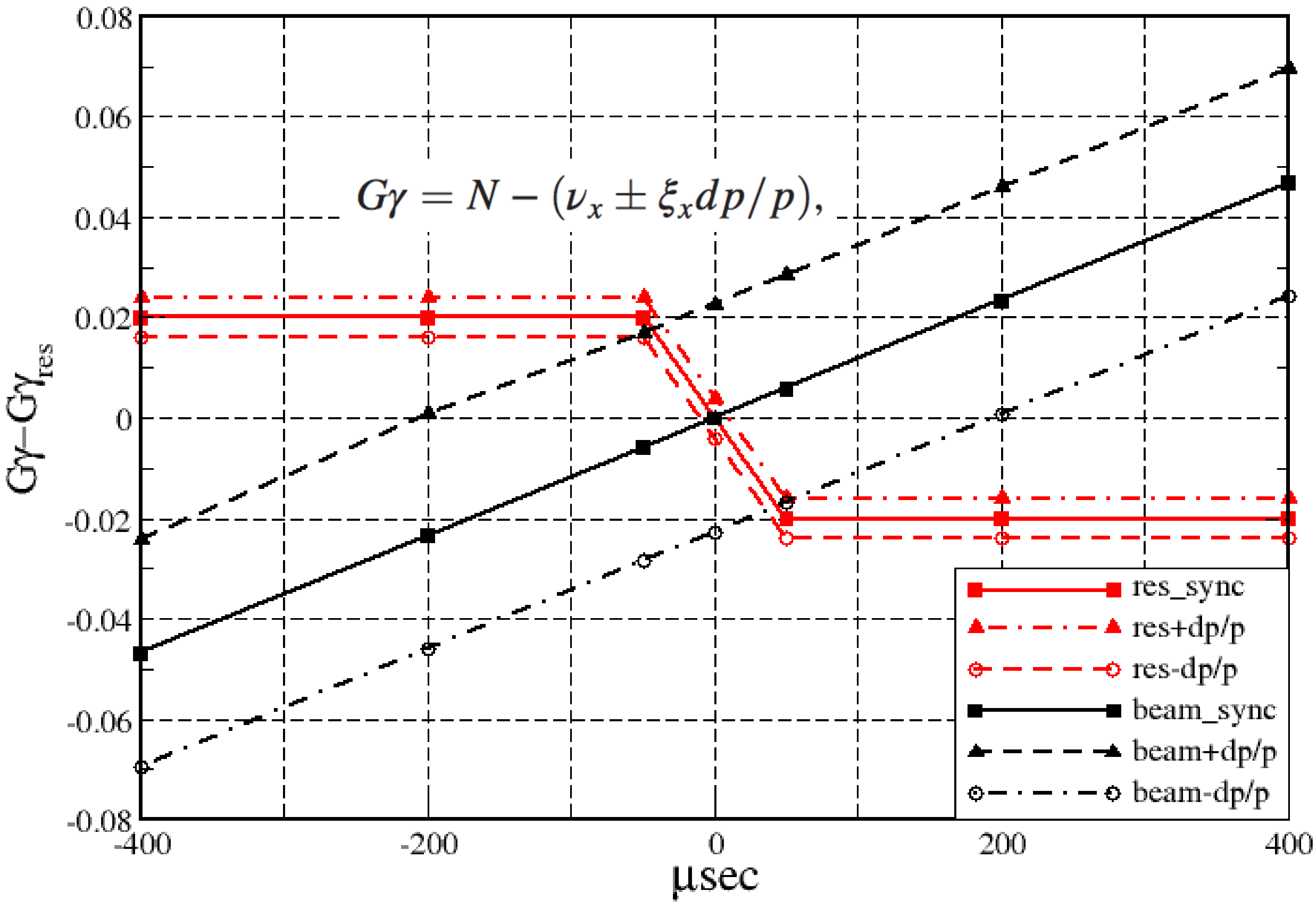


Resonance Crossing ($G\gamma=36+\nu_x=44.7$)

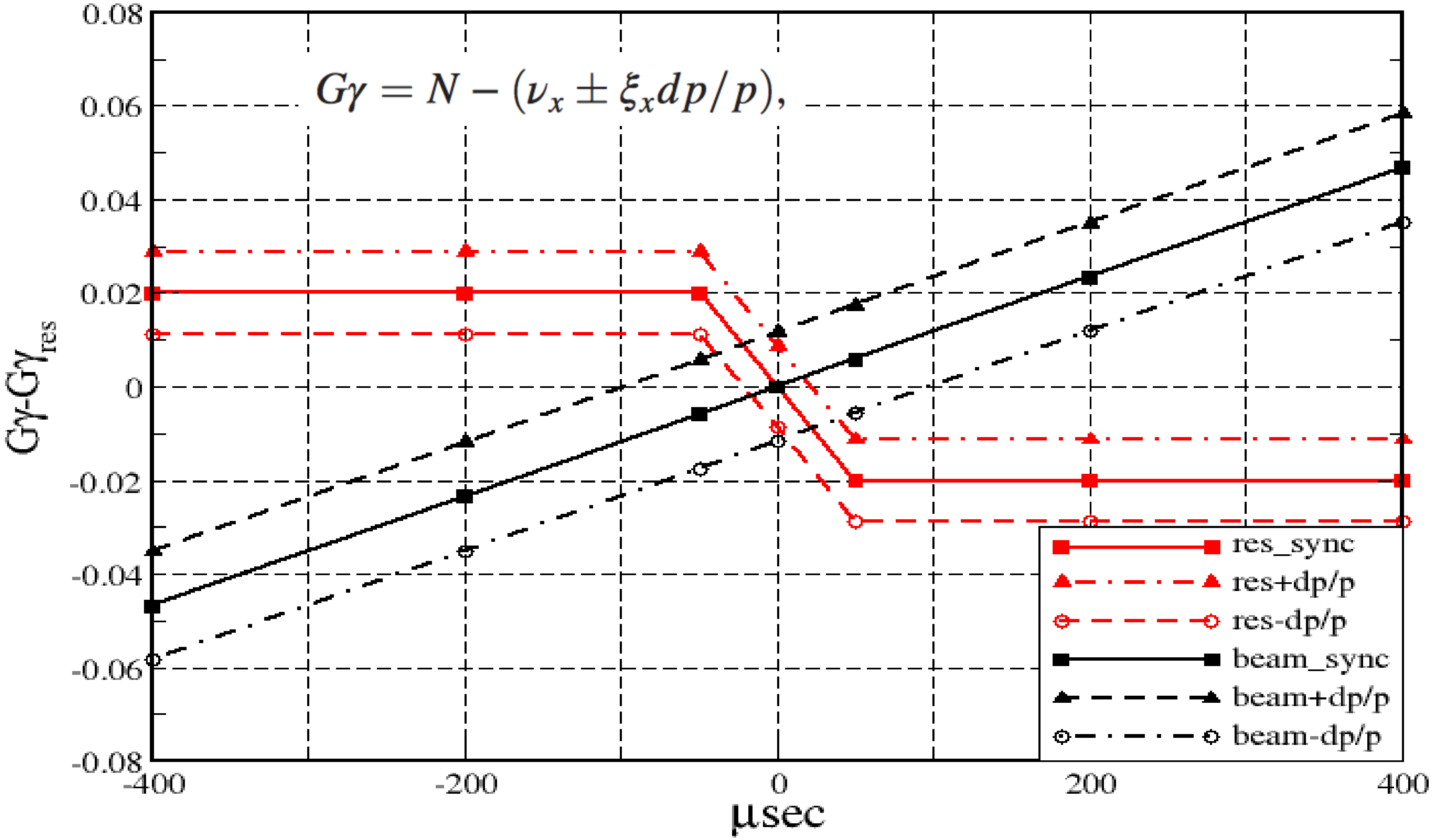


To benefit from the tune jump, the beam particles have to cross the resonance line during the jump. For the given beam parameters (tune jump amplitude, chromaticity, beam momentum spread), about 76% beam will benefit from the tune jumps above $G\gamma_{...}=19$.

Resonance Crossing ($G\gamma=54-\nu_x=45.3$)

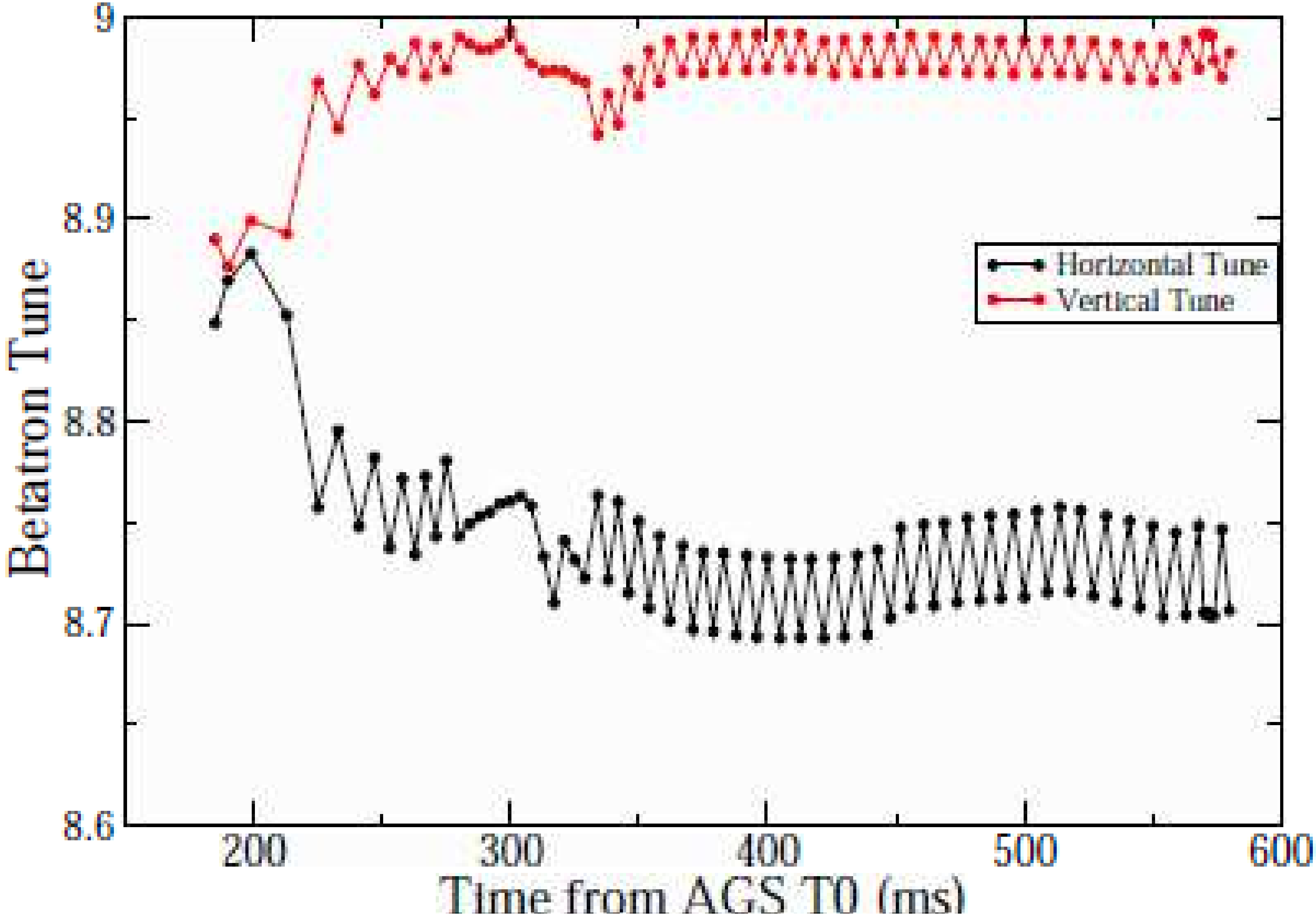


Resonance Crossing ($G\gamma=17-\nu_x=9.3$)



The black dashed lines includes 76% of the total beam. More beam benefit from the jump than higher energy cases.

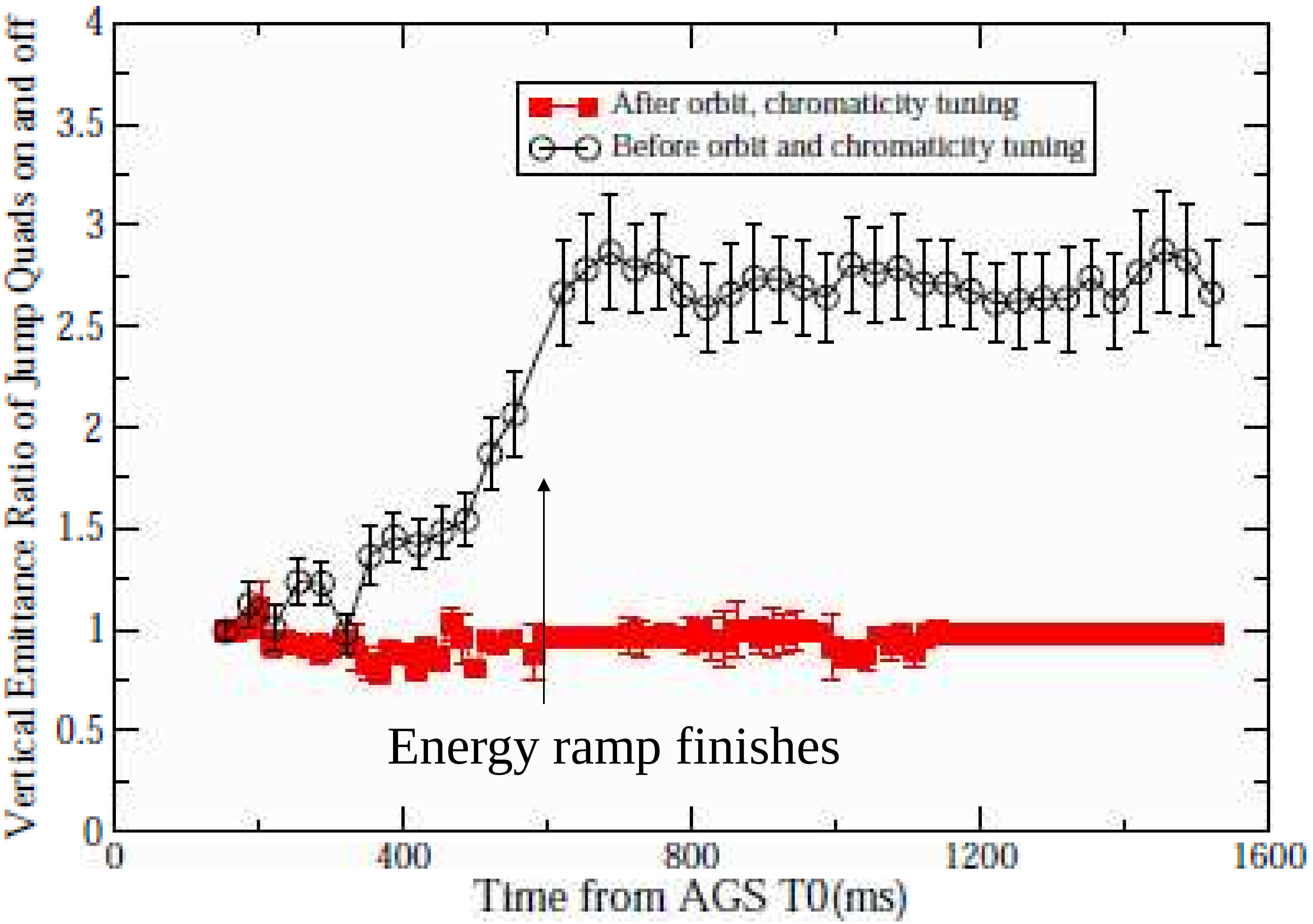
Measured Betatron Tune along Ramp with JQ on



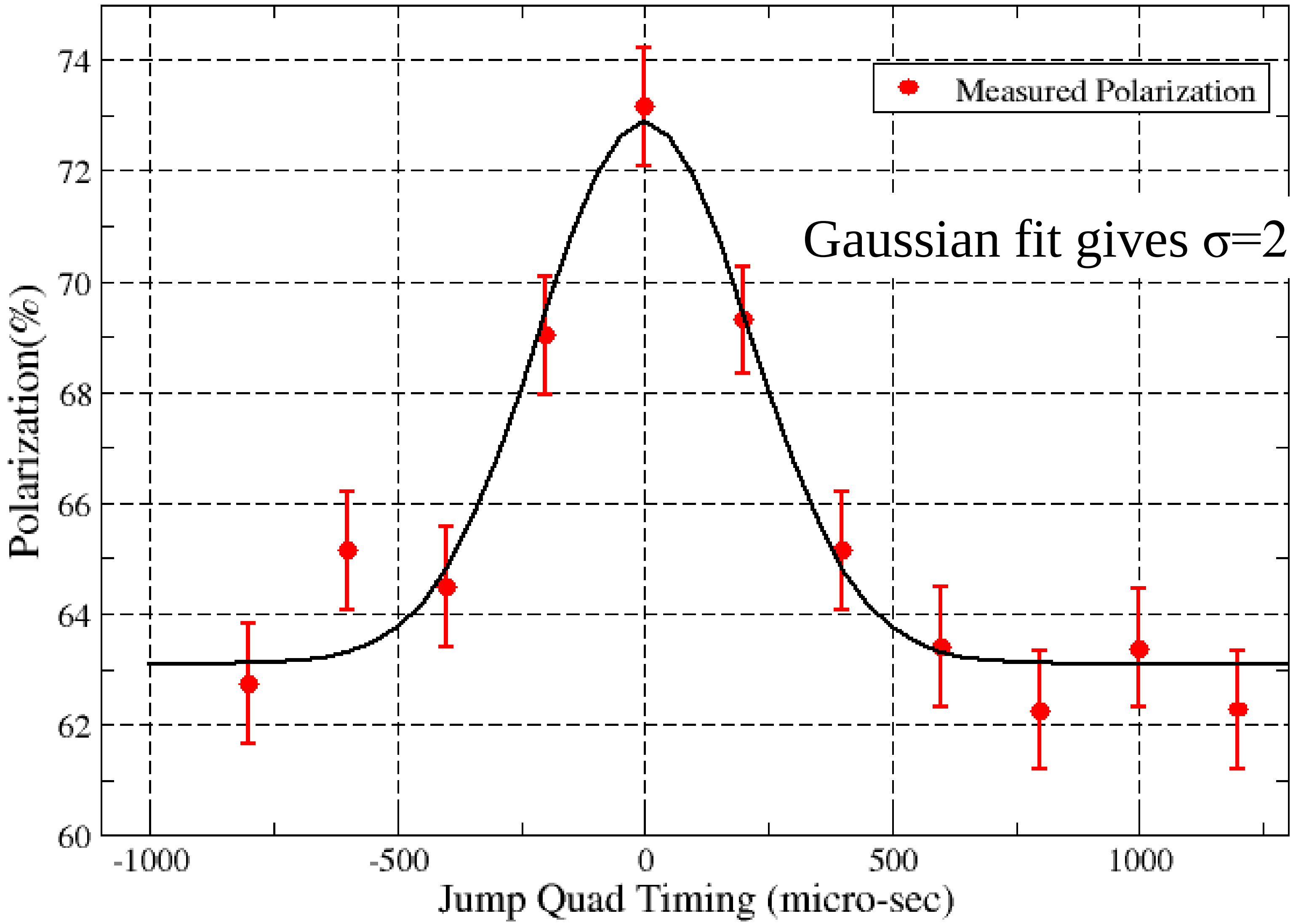
Three Issues with Tune Jump Quads On

- First one is the vertical emittance growth when both jump quads on. The vertical beta functions at the locations of both quads have to be equal to avoid emittance growth. A horizontal 6^{th} harmonic was introduced during the run to minimize the beta beating.
- Over time, the orbit could drift away from the quad center. An orbit feed forward system based on 9^{th} harmonics were used.
- The energy of beam has to be known along the ramp accurately so that the jump quad timing can be driven correctly(82 jumps). We are talking about ~100μs accuracy for 82 times.

Vertical Emittances with Jump Quads on



Overall Jump Quad Timing Scan



Gaussian fit gives σ=214μs

H. Huang, et al, *PR*. STAB 17, 081001(2014).

Summary

- The introduction of partial snakes generates horizontal intrinsic resonances. They are generally weak but could cause accumulated polarization loss if left uncorrected.
- A modest horizontal tune jump system has been used to overcome these weak but numerous resonances while maintaining the transverse emittances. A relative gain of 10-15% polarization has been achieved with the tune jump system.
- The keys for the system are the accurate control of the jump quad timing and the elimination of any emittance growth.
- This scheme paves the way to use partial snakes to preserve polarization in the medium energy synchrotrons without the concern of losing polarization due to additional horizontal intrinsic resonances.