ACCELERATION OF POLARIZED BEAMS USING MULTIPLE STRONG PARTIAL SIBERIAN SNAKES

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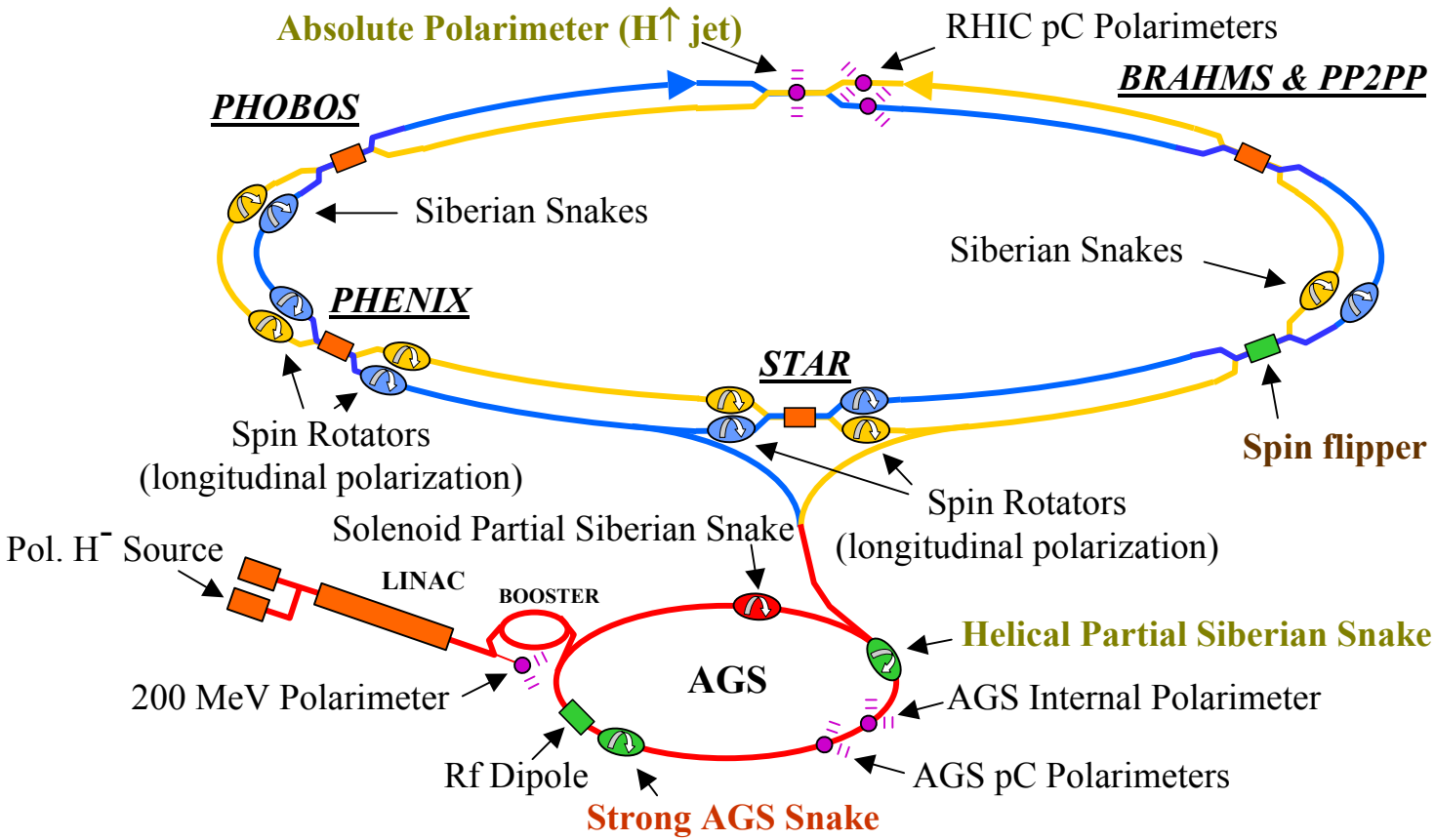
RHIC polarized proton accelerator complex



- Installed and commissioned during FY04 run
- Plan to be commissioned during FY05 run
- Plan to be installed and commissioned during FY05 run

Spin Dynamics in Rings

Precession Equation in Laboratory Frame:
(Thomas [1927], Bargmann, Michel, Telegdi [1959])

$$d\mathbf{S}/dt = -(e/\gamma m)\,[G\gamma \mathbf{B}_{\perp} + (1+G)\,\mathbf{B}_{o}\,] \times \mathbf{S}$$

Lorentz Force equation:

$$d\mathbf{v}/dt = -(e/\gamma m)\,[\;\;\mathbf{B}_{\perp}\;\;] \times \mathbf{v}$$

- For pure vertical field:
  Spin rotates $G\gamma$ times faster than motion, $\nu_{sp} = G\gamma$
- For spin manipulation:
  At low energy, use longitudinal fields
  At high energy, use transverse fields

Spin tune and Depolarizing Resonances

Spin tune: Number of 360 degree spin rotations per turn

Depolarizing resonance condition:

Number of spin rotations per turn = Number of spin kicks per turn

Imperfection resonance (magnet errors and misalignments):

$$\mathbf{G\gamma = \nu_{sp} = n}$$

Intrinsic resonance (Vertical focusing fields):

$$\mathbf{G\gamma = \nu_{sp} = Pn \pm \nu_y}$$

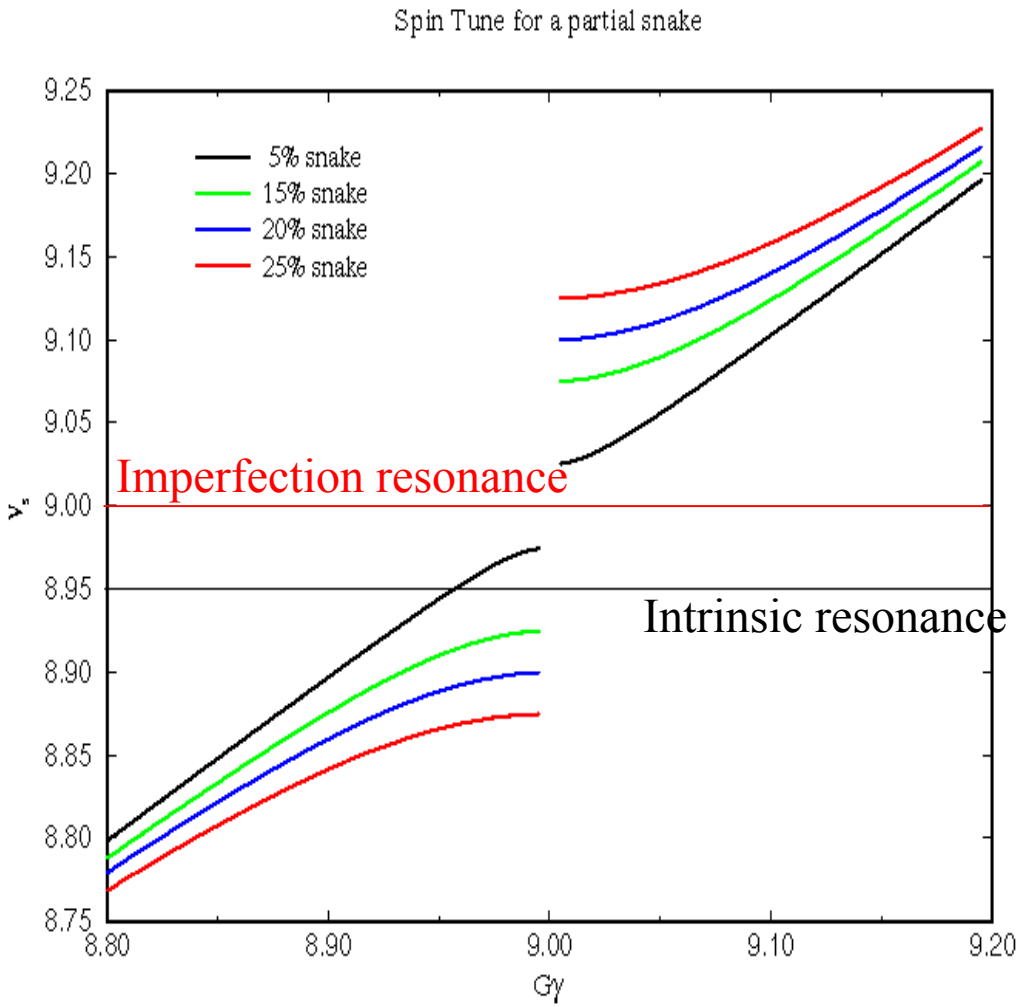
P: Superperiodicity [AGS: 12]
ν_y: Betatron tune [AGS: 8.75]

Strong Partial Siberian Snake for AGS

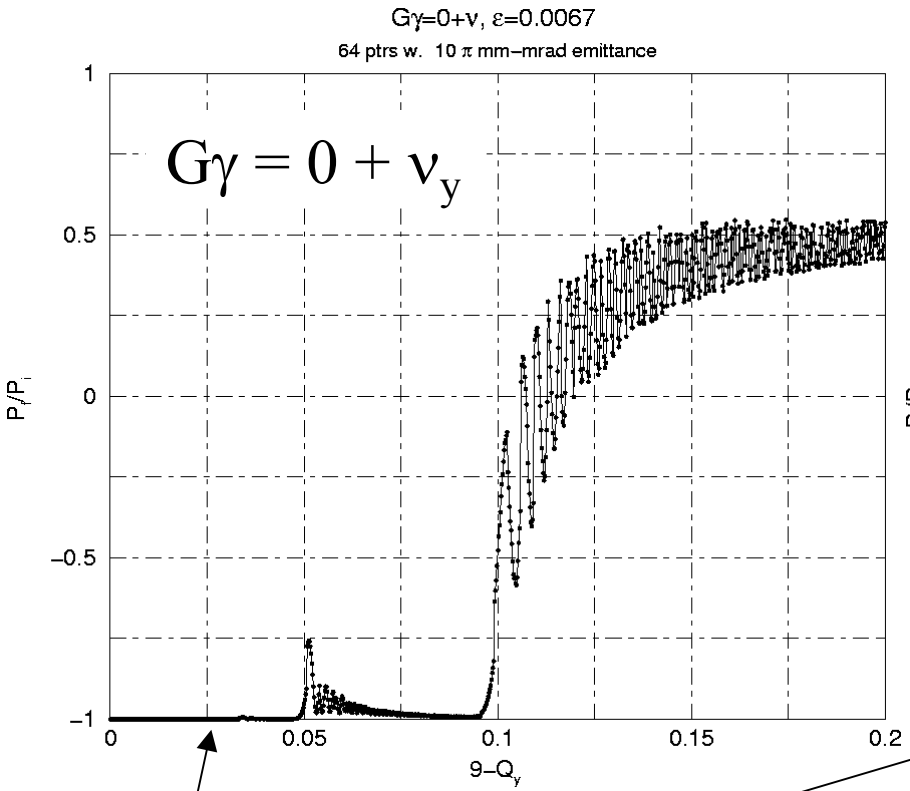
A strong partial Siberian snake generates large spin tune gap for Gγ = n. With strong enough snake, gap is large enough to cover both imperfection and intrinsic spin resonances.

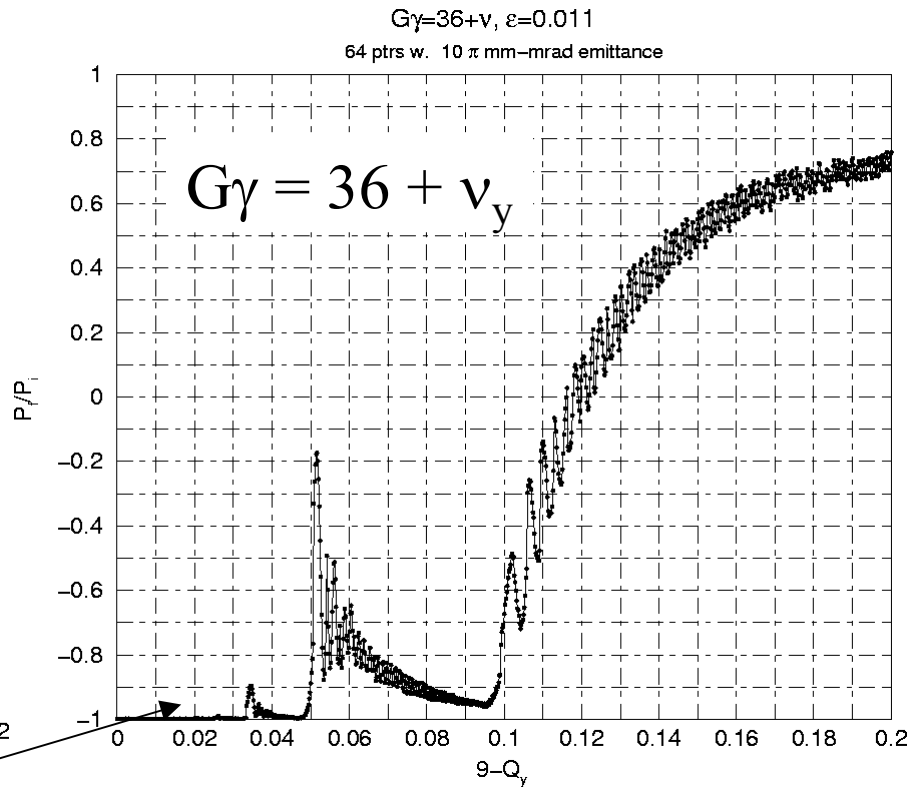
$$\nu_{sp} = \frac{1}{\pi}\cos^{-1}\left(\cos(\delta/2)\cos(\pi G\gamma)\right)$$

Note: With a strong snake, the stable spin detection will deviate from vertical direction (18 degree for 20% snake).

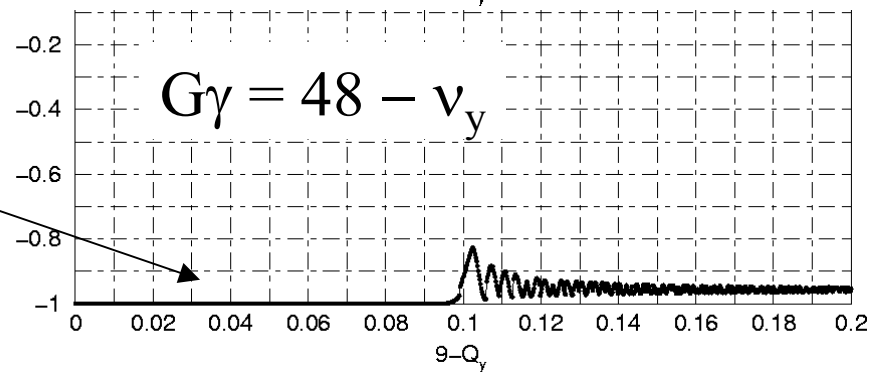


Modeling of AGS resonances with 20% Snake





No depolarization

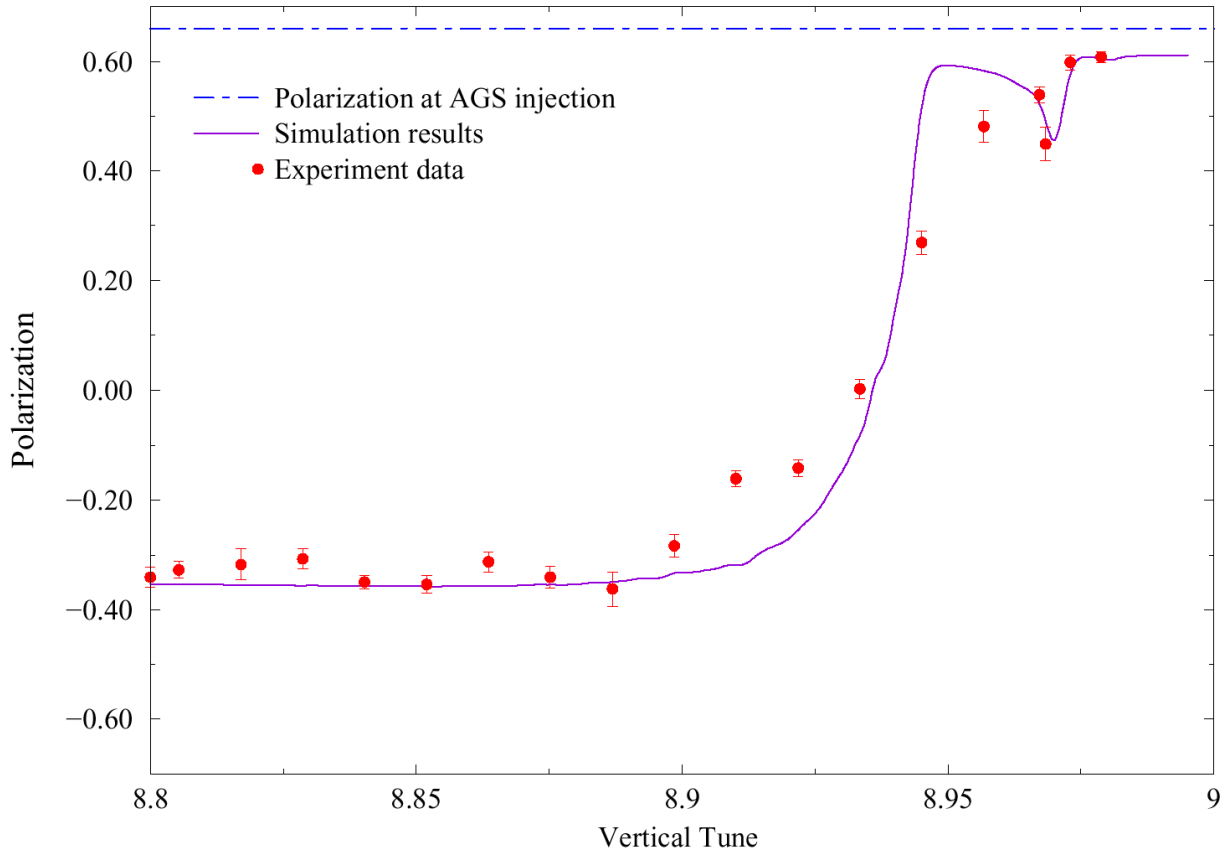


(Tracking by M. Bai)

Test results with 10% solenoid snake at 0 + ν

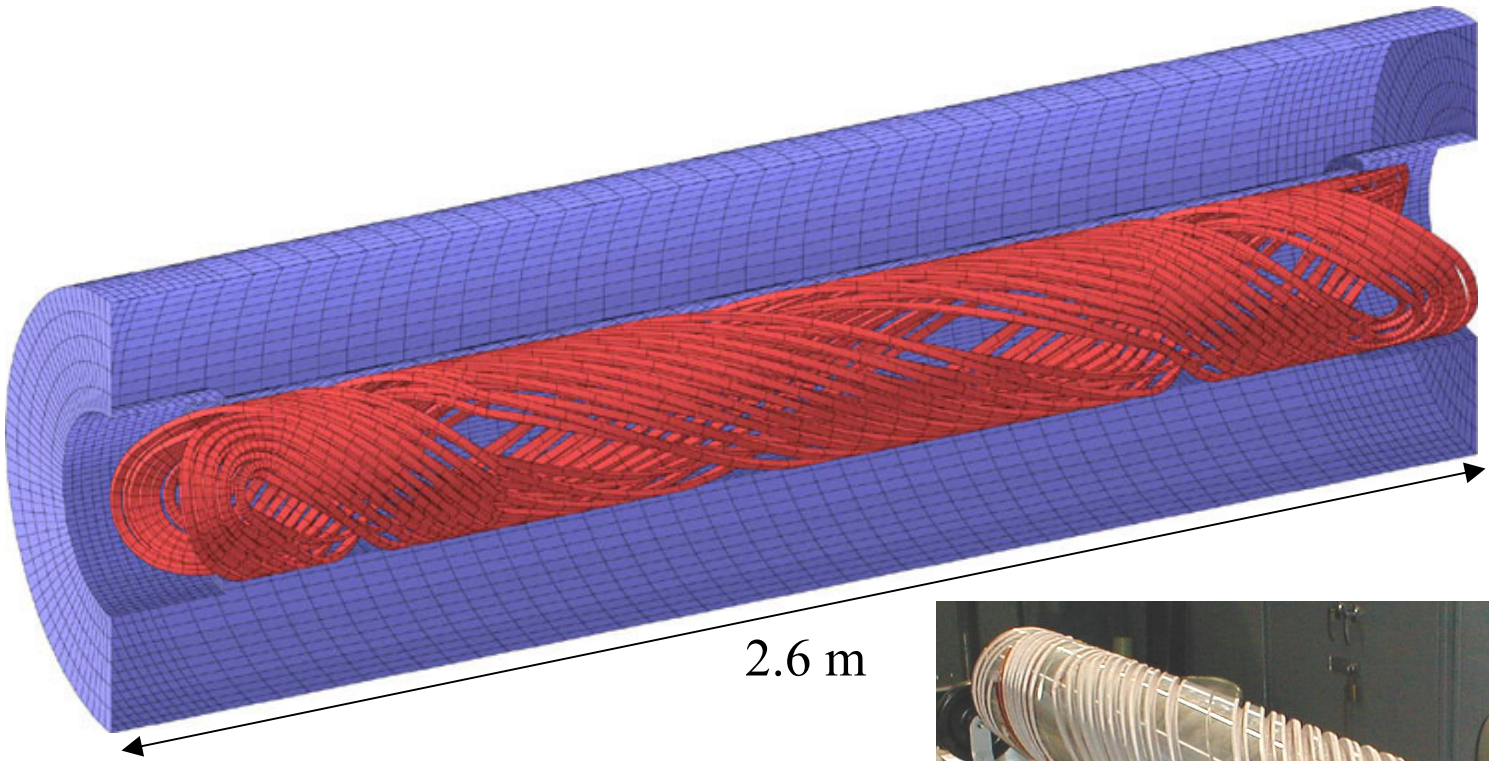
The difference between the red measurements and blue line is due to the coupling resonance and tilted stable spin direction.

Good agreement with model.

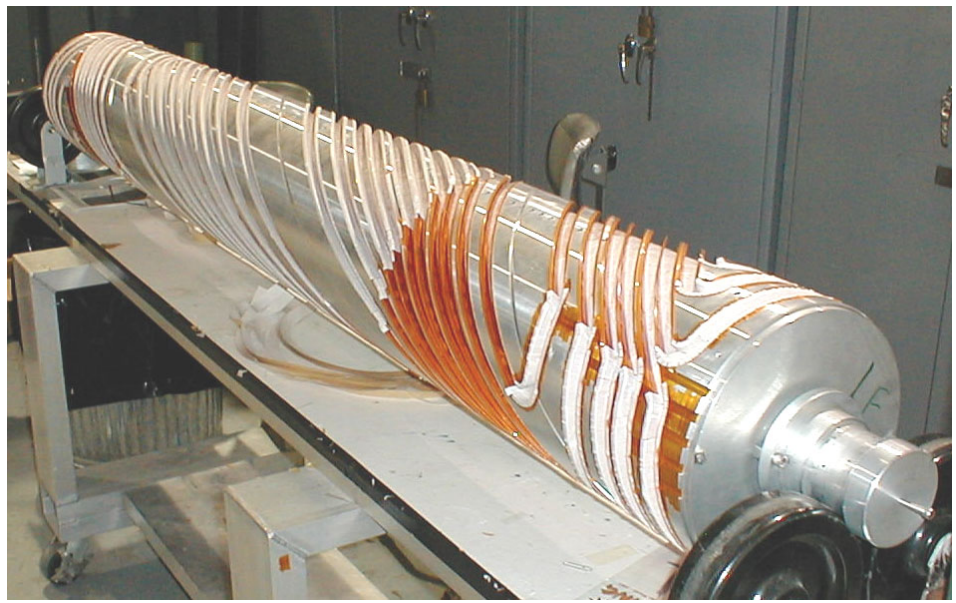


H. Huang et al., "Overcoming an intrinsic depolarizing resonance with a partial Siberian snake", Phys.Rev. ST Accel. Beams 7, 071001 (2004)

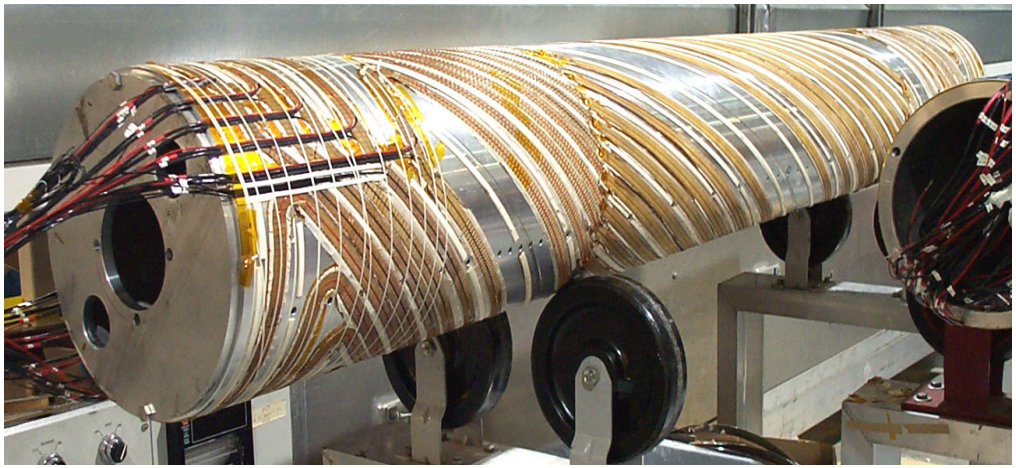
30 % AGS super-conducting helical snake



15 cm warm bore helix with changing pitch
Minimizes orbit excursions

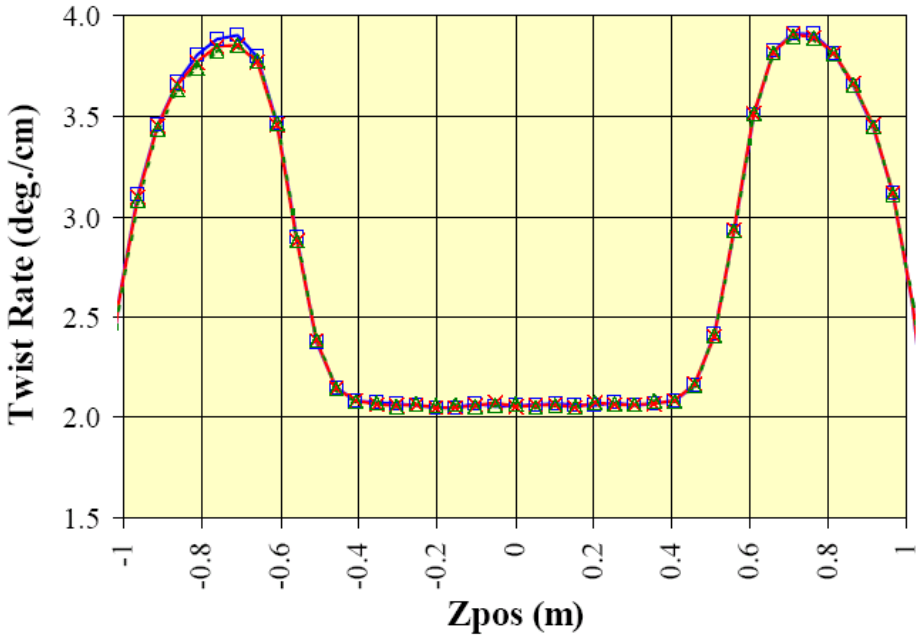


30 % AGS super-conducting helical snake



Completed helical dipole coil

Correction solenoid and dipoles



Measured twist angle
2 deg/cm in the middle
~ 4 deg/cm at ends

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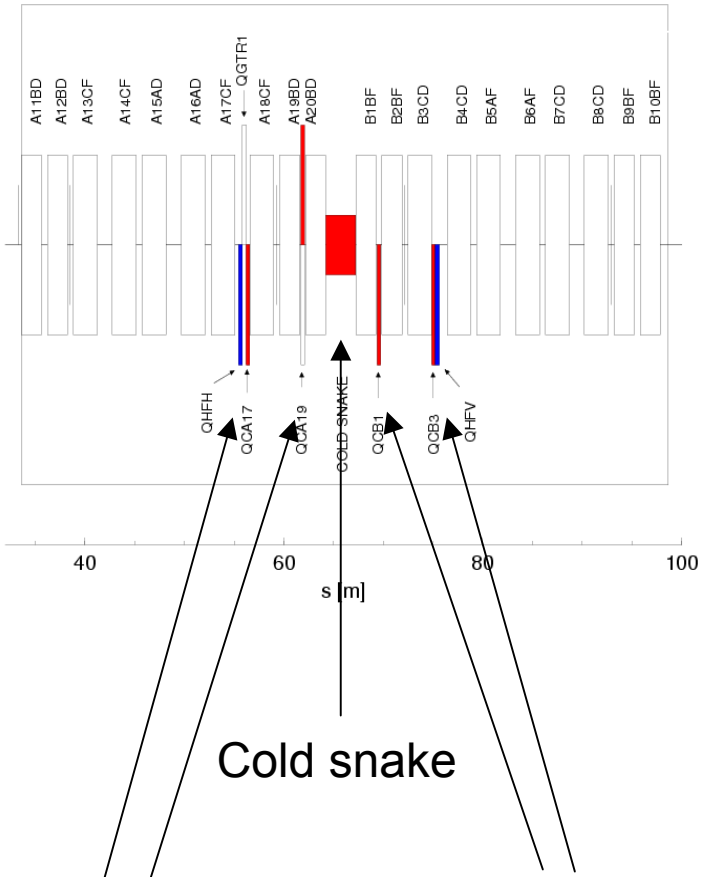
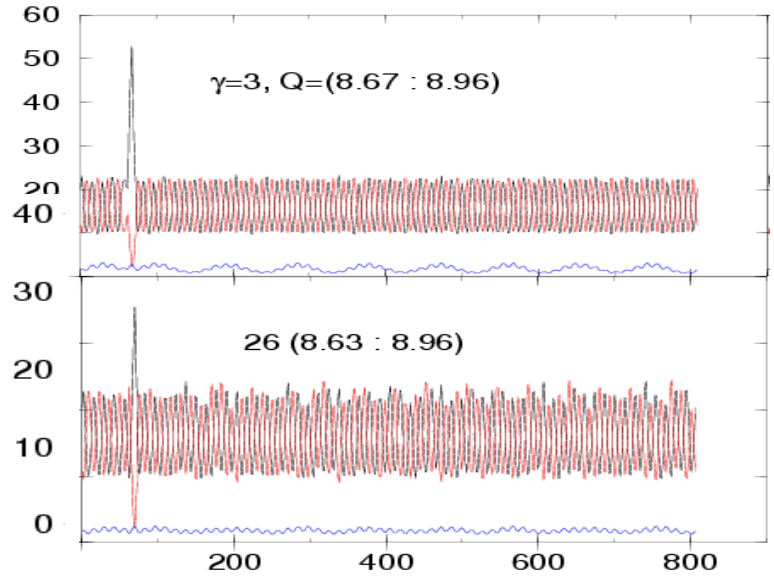
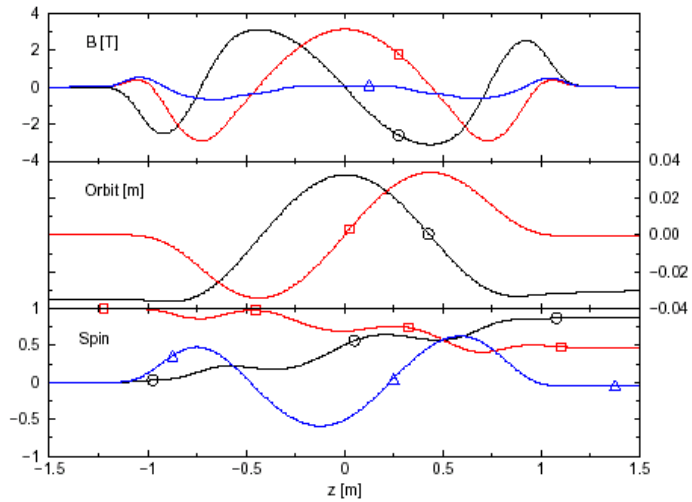
AGS strong snake – orbit and optics matching



Cold snake

4 quadrupoles for optics matching





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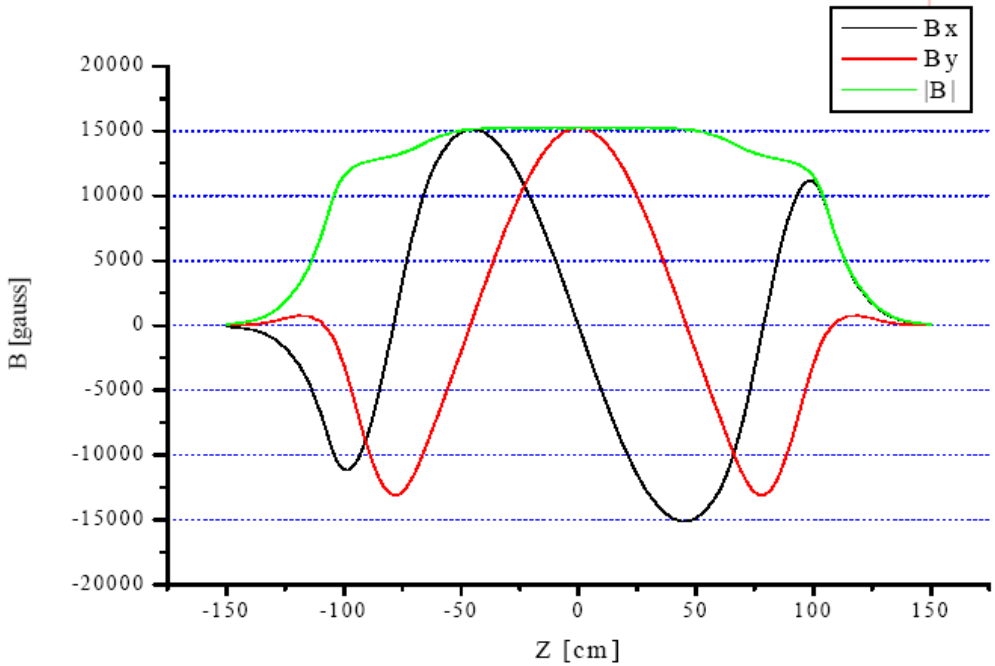
Warm helical partial Siberian snake



- Replaced solenoidal partial snake
- Same design as cold snake (dual pitch)
- 1.5 Tesla field
- ~ 6 % partial snake (w/o generating coupling)
- Funded by RIKEN, built by Takano Ind.

Multiple partial Siberian snakes

Single partial snake rotating by angle δ :

$$\nu_{sp} = \frac{1}{\pi}\cos^{-1}\left(\cos\left(\delta/2\right)\cos\left(\pi G\gamma\right)\right)$$

Two partial snakes rotating by angle δ_1 and δ_2 and separated by 1/m of ring:

$$\nu_{sp} = \frac{1}{\pi}\cos^{-1}\left(\cos\left(\frac{\delta_1}{2}\right)\cos\left(\frac{\delta_2}{2}\right)\cos\left(\pi G\gamma\right) - \sin\left(\frac{\delta_1}{2}\right)\sin\left(\frac{\delta_2}{2}\right)\cos\left(\frac{\pi(m-2)}{m}G\gamma\right)\right)$$

- Max. effective snake strength at $G\gamma = mn$: $\delta_1 + \delta_2$ (n: integer)
- Min. effective snake strength at $G\gamma = mn + m/2$: $\delta_1 - \delta_2$
- For max. strength at intrinsic resonances m needs to be a common factor of both vertical tune and super-periodicity ($G\gamma = Pn \pm \nu_y$)
- To avoid minimum strength at imperfection resonances m needs to be an odd integer.

Two partial Siberian snakes in the AGS

Vertical tune ~ 9, super-periodicity = 12 $\rightarrow$ m = 3

Two partial snakes rotating by angle δ_1 and δ_2 and separated by 1/3 of ring:

$$\nu_{sp} = \frac{1}{\pi}\cos^{-1}\left(\cos\left(\frac{\delta_1}{2}\right)\cos\left(\frac{\delta_2}{2}\right)\cos(\pi G\gamma) - \sin\left(\frac{\delta_1}{2}\right)\sin\left(\frac{\delta_2}{2}\right)\cos\left(\frac{\pi}{3}G\gamma\right)\right)$$

Max. effective snake strength at Gγ = 3n (energy of AGS intrinsic resonances):

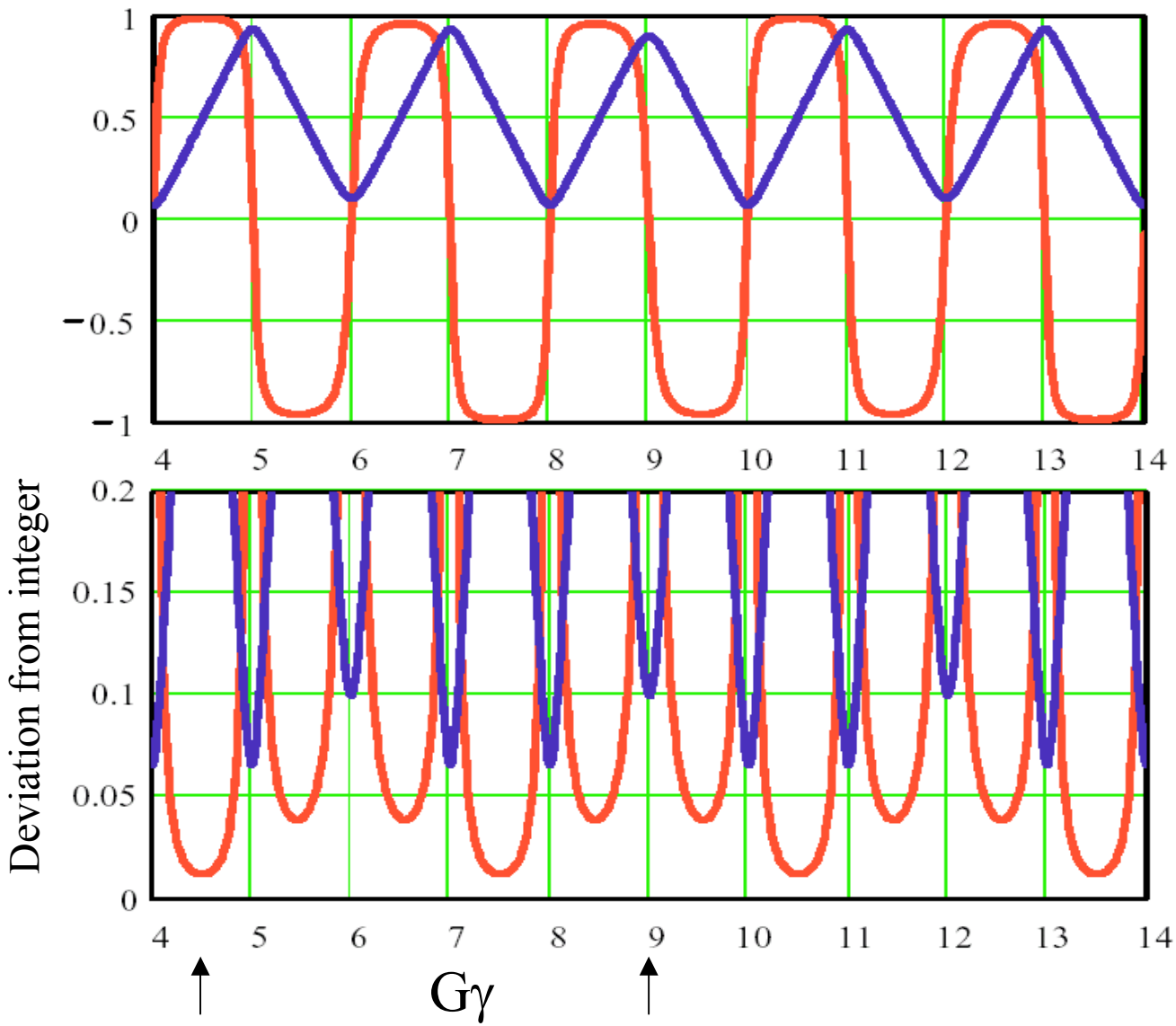
$$\delta_{tot} = \delta_1 + \delta_2$$

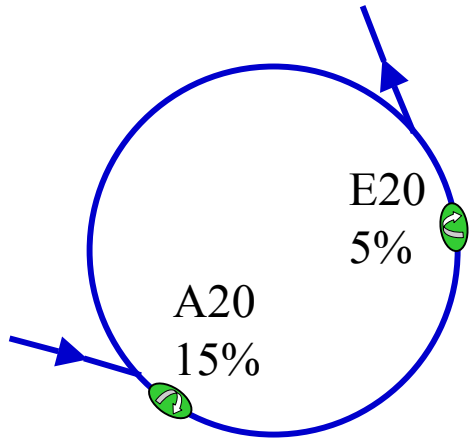
Min. effective snake strength at Gγ = 3n + 1.5 (energy of AGS injection/extraction):

$$\delta_{tot} = \delta_1 - \delta_2$$

At this energy the stable spin direction is close to vertical, which simplifies spin matching. Two equal partial snakes give perfect spin matching.

Two partial snakes in the AGS





Vertical component of stable spin

Fractional part of spin tune

Conclusions

- Strong partial Siberian snakes can overcome intrinsic depolarizing resonances. Operation is analogous to full snake situation.
- If vertical tune and super-periodicity have common factor that is odd multiple partial snakes can be used to give larger effective strength
- With proper choice of injection and extraction energy multiple partial snakes can solve the spin matching problem