RHIC Polarization at 250 GeV Beam Energy

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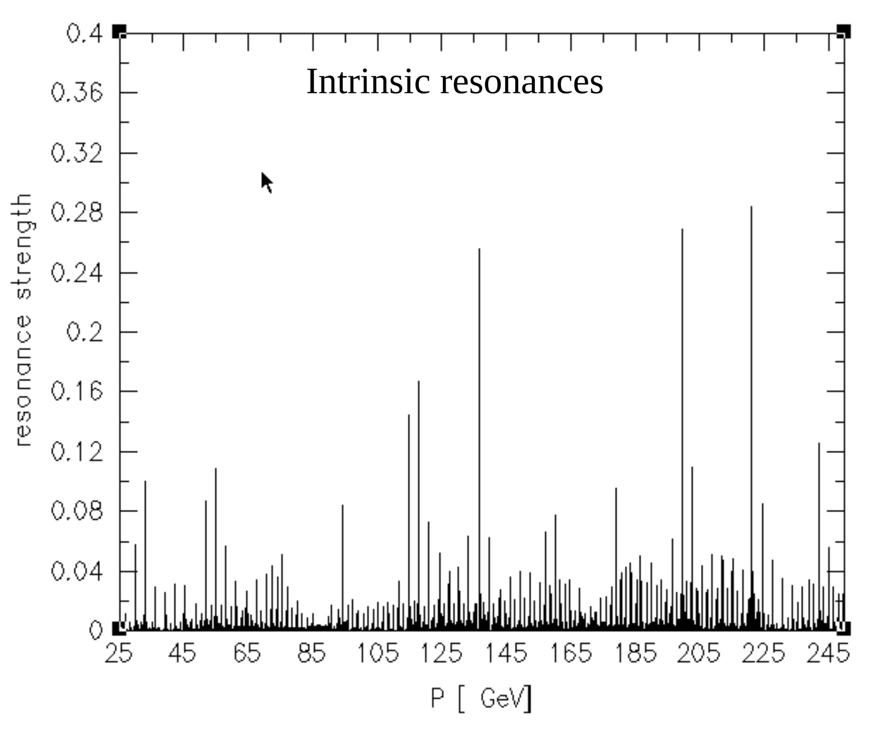
pp Run4 Experience

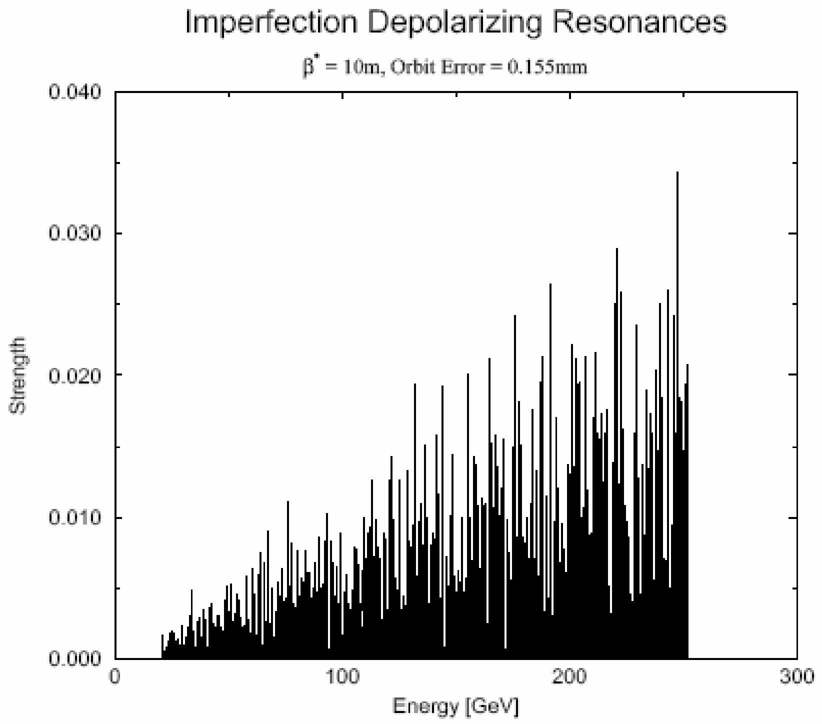
- Last polarized proton run demonstrated that polarized protons can be accelerated to 100 GeV energy with minimal polarization loss.
- Polarization transmission efficiency (store/injection):
  - Blue ring: ~90%
  - Yellow ring: ~80%

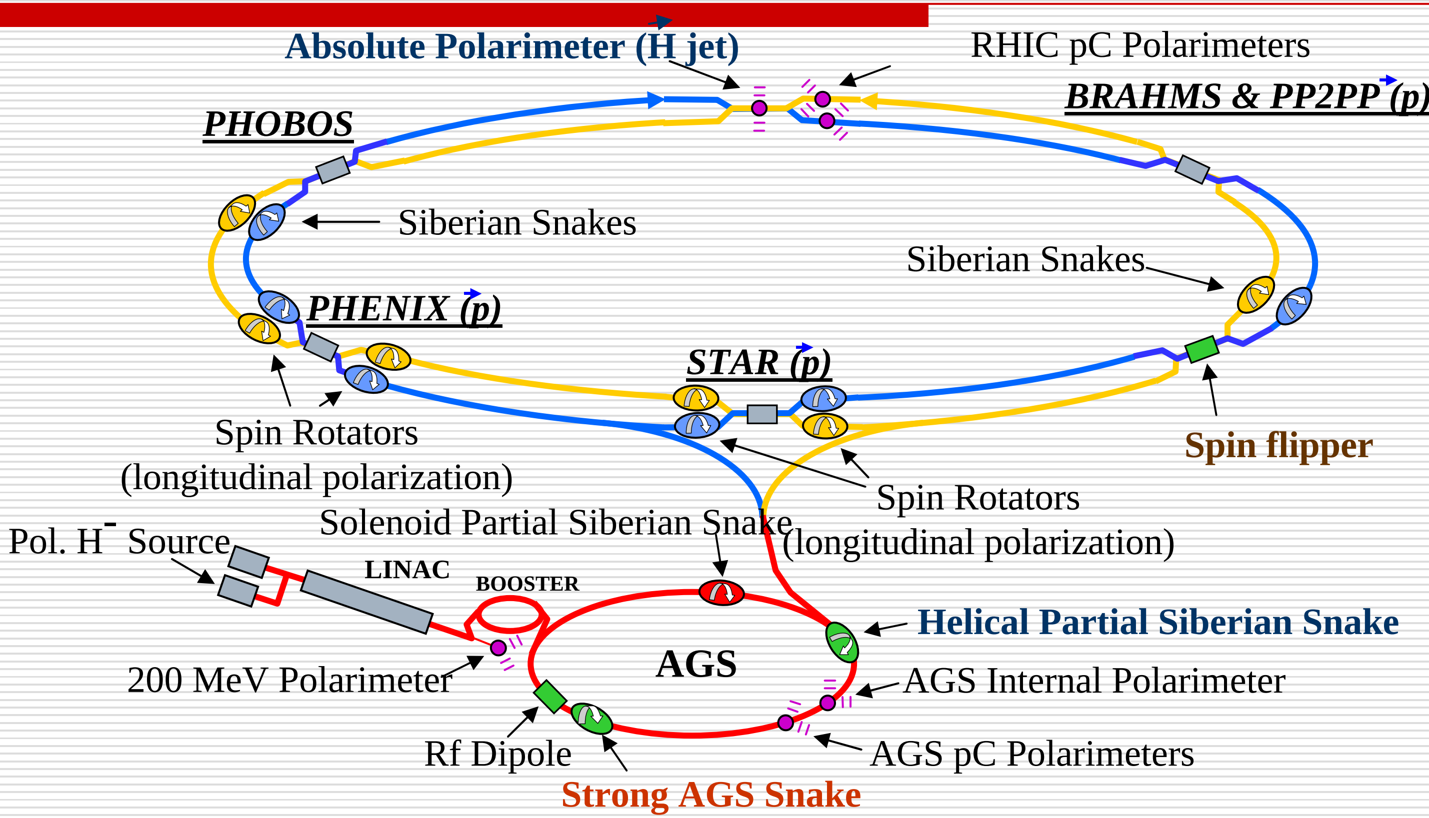
- Important observations were obtained on:
  - Depolarizing effect of high-order spin resonances (“snake” resonances) and
  - Polarization dependences on transverse amplitude.

Spin resonances

Achieving more than 70% polarization at 250 GeV presents big challenge since considerable growth of spin resonance strength with energy.





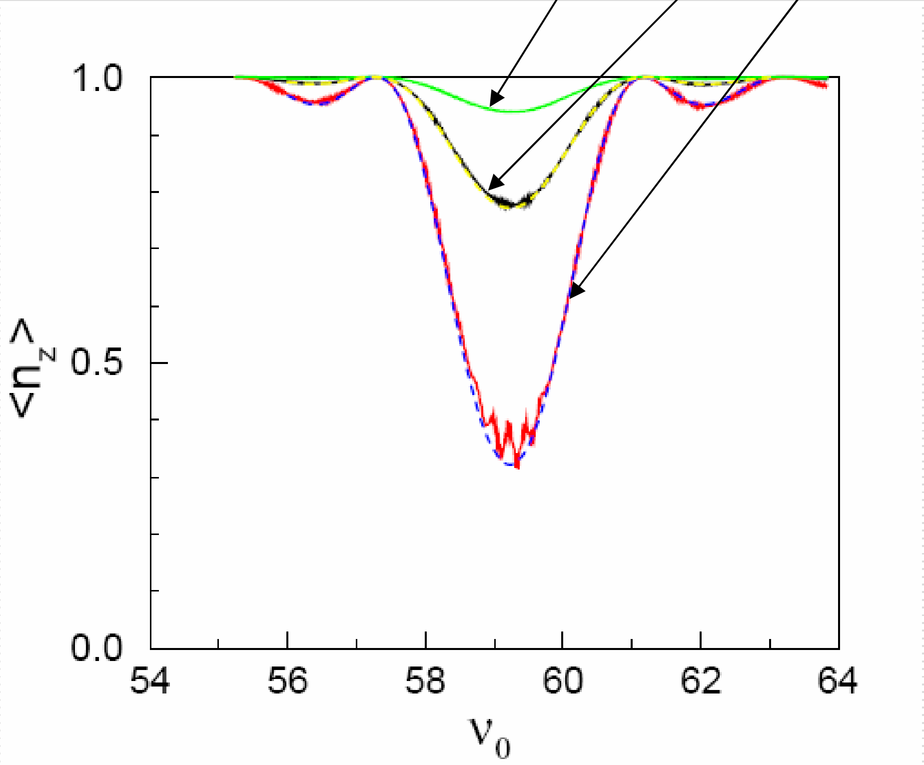


2 Siberian Snakes with 90° angle between snake axes: $\nu_s = ½$

Avoiding spin resonance conditions: $\nu_s = k + \nu_y$; $\nu_s = k$

Beam polarization near strong resonance

Resonance strength $|w_n|$= 0.12; 0.25; 0.5



Two snakes in the ring

Max angle deviation from vertical direction (resonance depth) :

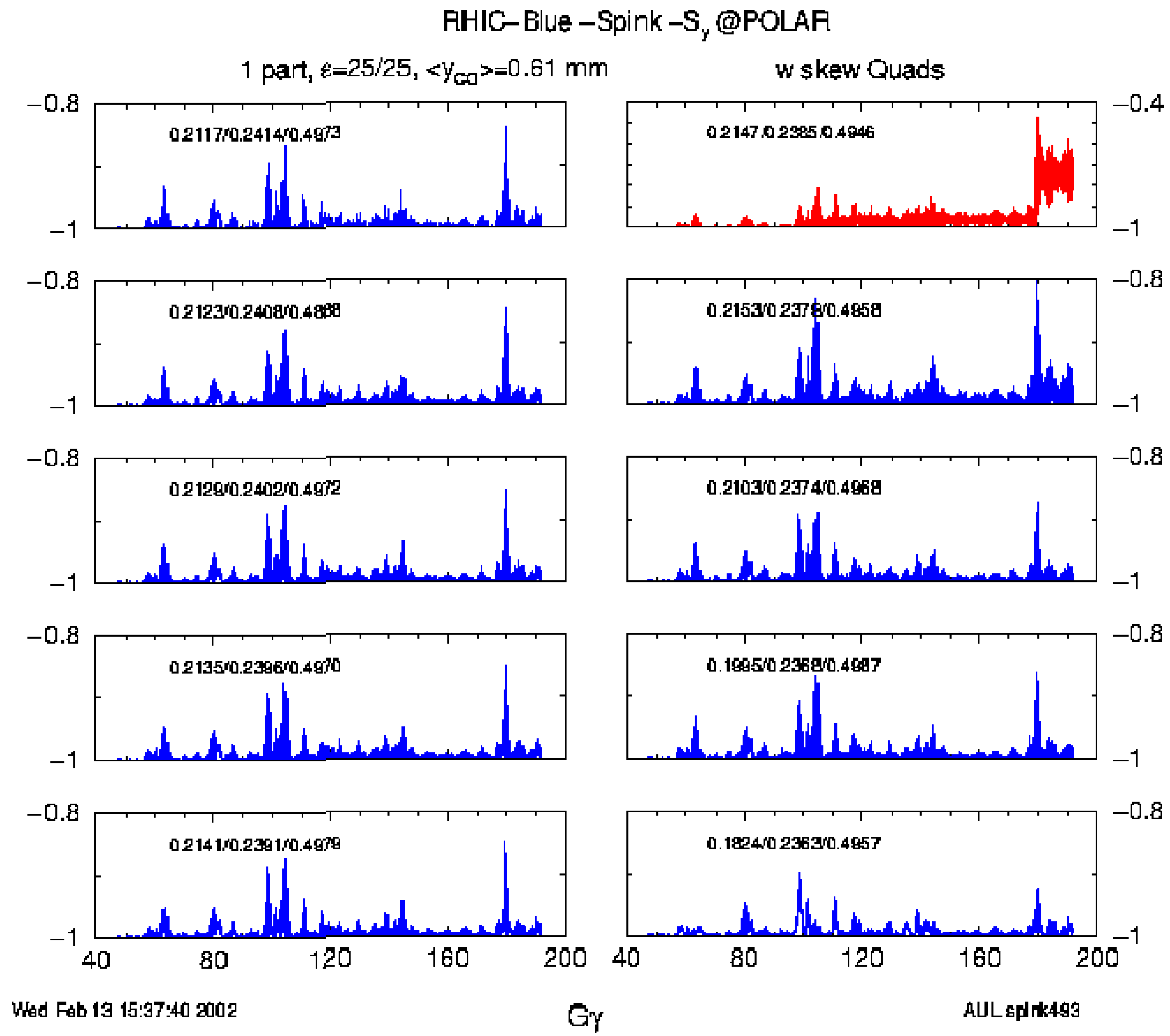
$$|\rho_{\max}| = \frac{\pi |w_n|}{\left|\sin\left(\nu_n - \frac{1}{2}\right)\pi\right|}$$

where w_n is resonance strength

and ν_n is resonance tune

Resonance crossing at acceleration is adiabatic with no polarization loss.

Depolarization by high-order spin resonance



A.Luccio
SPINK code simulations.

Resonance $\{\nu_x\} = 3/14$ caused by coupling.

High-order spin resonances (“snake” resonances)

First discovered and studied
by S.Y.Lee and S.Tepikian

$$\nu_\beta = \frac{2k+1}{2m} + \frac{\delta\nu_s}{m}, \quad |m|>1$$

leads to resonance splitting

ν_β *is* ν_y *or* ν_x

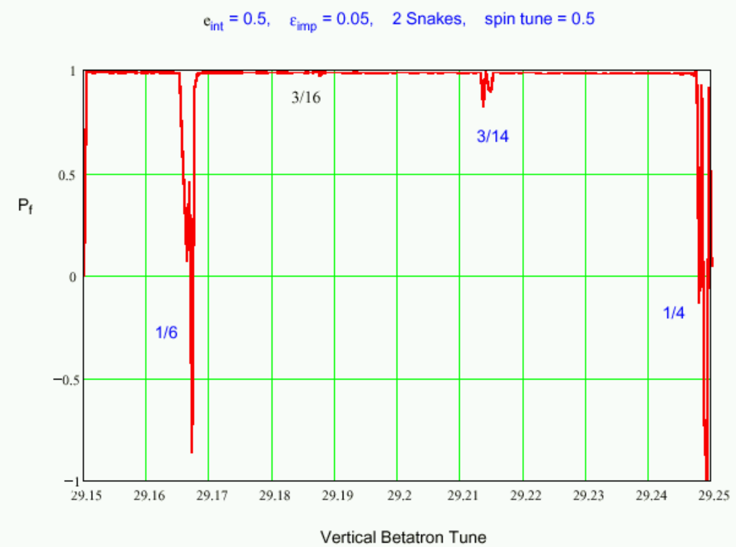


Figure 5.3: Vertical component of the polarization after acceleration through a strong intrinsic resonance and a moderate imperfection resonance shown as a function of the vertical betatron tune.

- Generated due to intrinsic nonlinearity of spin motion equations.
  (Contribution from magnet nonlinearities is negligible).

- Two types:
  - *m* odd.
    Caused by an intrinsic resonance alone.
  - *m* even
    Caused by an interference between imperfection and intrinsic resonances.

Resonances of interest.

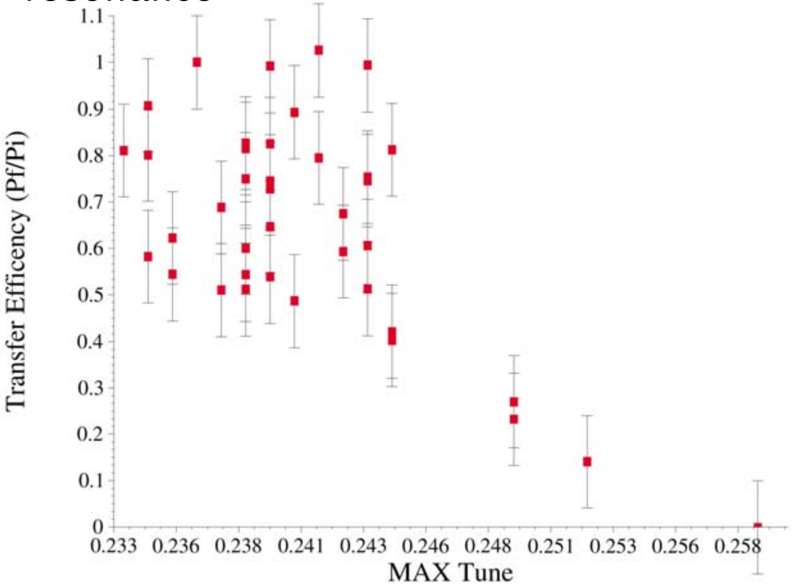
Before Run4: [0.2,0.25] bet.tune working area -> $\{\nu_\beta\}$ = *1/4 ; 3/14*

Run 4: [0.68,0.75] bet.tune working area -> $\{\nu_\beta\}$ = *3/4 ; 7/10*

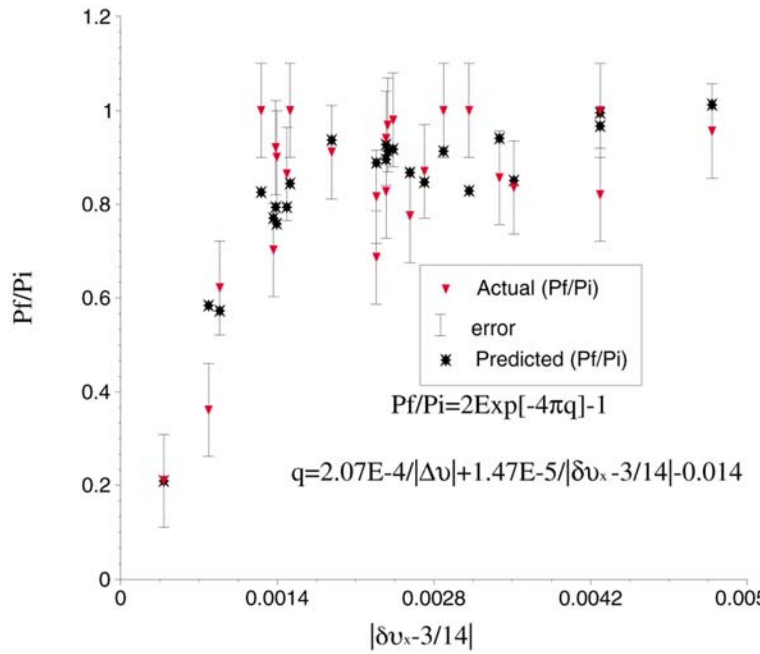
Experimental observation of high-order snake resonances

Analysis of polarization transfer efficiency based on correlation with tune, coupling and orbit data on the ramp and, particularly, in locations of strongest spin resonances. (V.H.Ranjbar et al., Phys.Rev.Let., v.91,n.3, 2003)
Betatron tunes were in 0.2-0.25 box.

$\{\nu_y\} = 1/4$ resonance



$\{\nu_x\} = 3/14$ coupled resonance

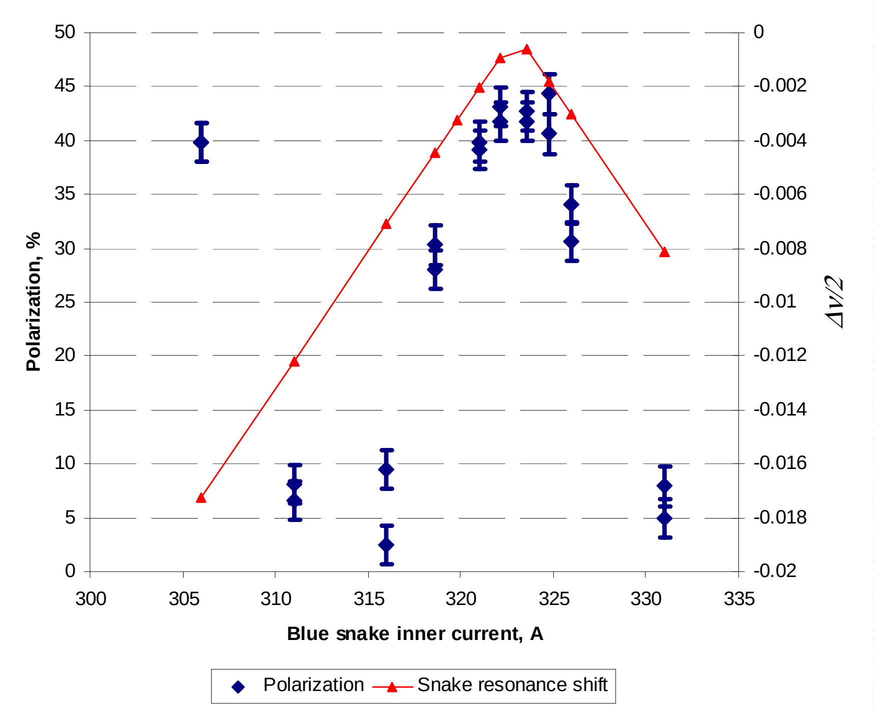


3/4 resonance observation from snake current scan

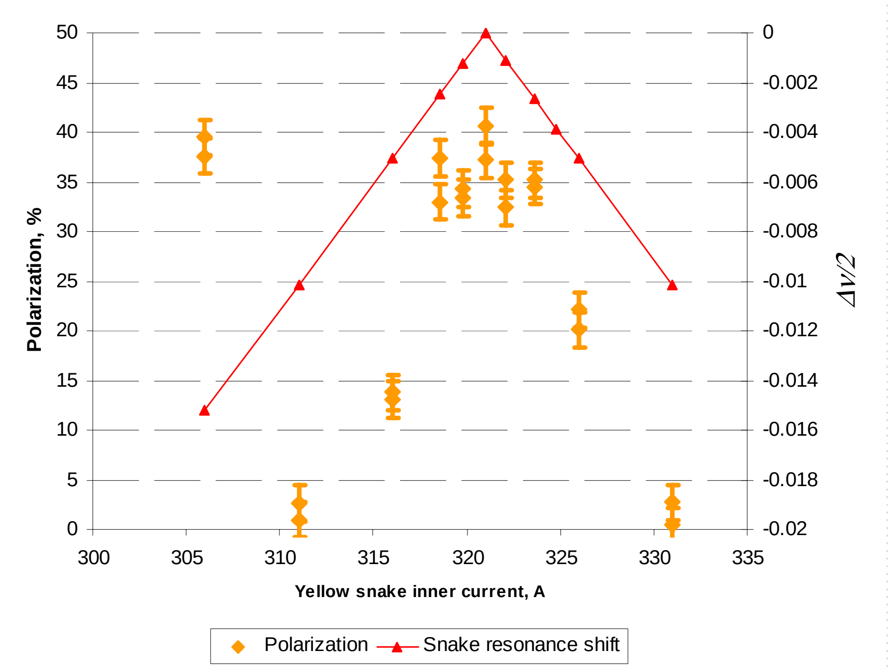
Done at the injection energy. Changing inner snake current effectively shifts the spin tune (and the position of the snake resonance).

$\{\nu_y\} = 0.74$

323 A optimum



321 A optimum



Factors affecting depolarization by high-order resonances

- Choice of the working point.
- Imperfection sources: snake field imperfections, vertical orbit deviation from horizontal plane.
- Betatron tune spread
- Spin tune spread
- Betatron coupling

Working point

- Working point:
  - Should stay far away from high-order spin resonances

    It should account also for possible shift of the resonance position because of orbit or snake imperfections
  - In the same time should be acceptable for beam dynamics (beam lifetime)
  - Enough tune space to accommodate betatron and spin tune spreads

- Two working point areas have been tried so far at RHIC

  [0.2,0.25] and [0.68,0.75]. The latter provided better polarization preservation with the tune jump applied before beta-squeze part of the ramp (M.Bai's talk).

More experimental and simulation studies are planned to learn about optimal working tunes for the polarization.

Orbit imperfectons

- Orbit imperfection sources:
  - BPM-to-Quad misalignment
  - Quad-to-Quad misalignments.
  - Limited accuracy of the orbit correction.

  Tolerance for the orbit imperfections defined from simulation results at the RHIC design stage was put at 300 microns.

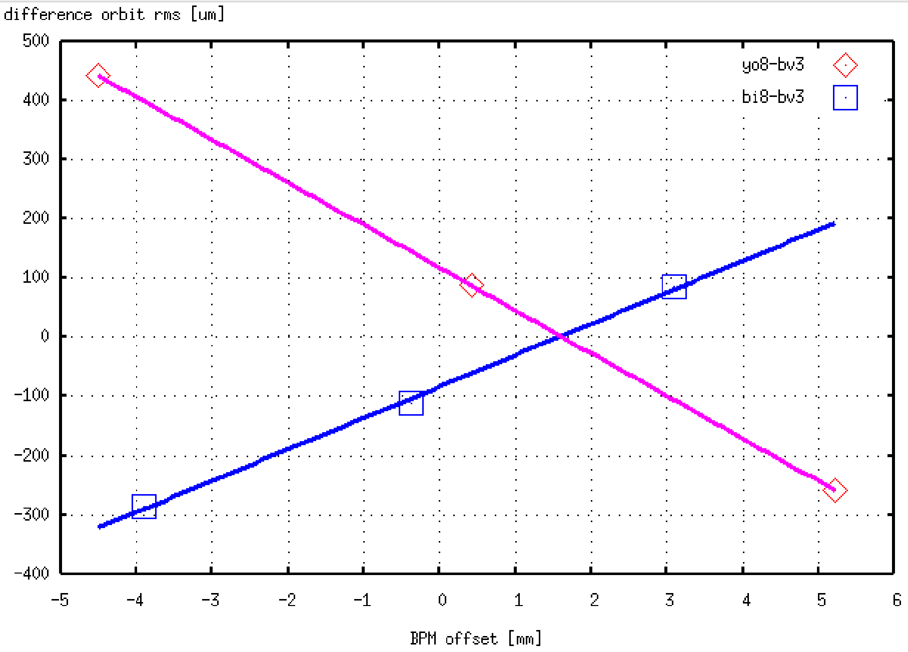
  Better choice of the working point may relax the tolerances.

- BPM-to-Quad misalignment
  - Measured rms ~150 microns
  - Measured misalignment data are taken into account when calculating the orbit position.
  - But several examples of large BPM-to-Quad offsets were observed last run. BPM electronics modification should help to eliminate this.
  - Beam-based misalignment measurement techniques are under development.

Beam-based misalignment measurements

Techniques under consideration:

1. Minimizing closed orbit distortion due to quadrupole gradient variation.
2. Minimizing betatron tune shift due to sextupole strength variation.



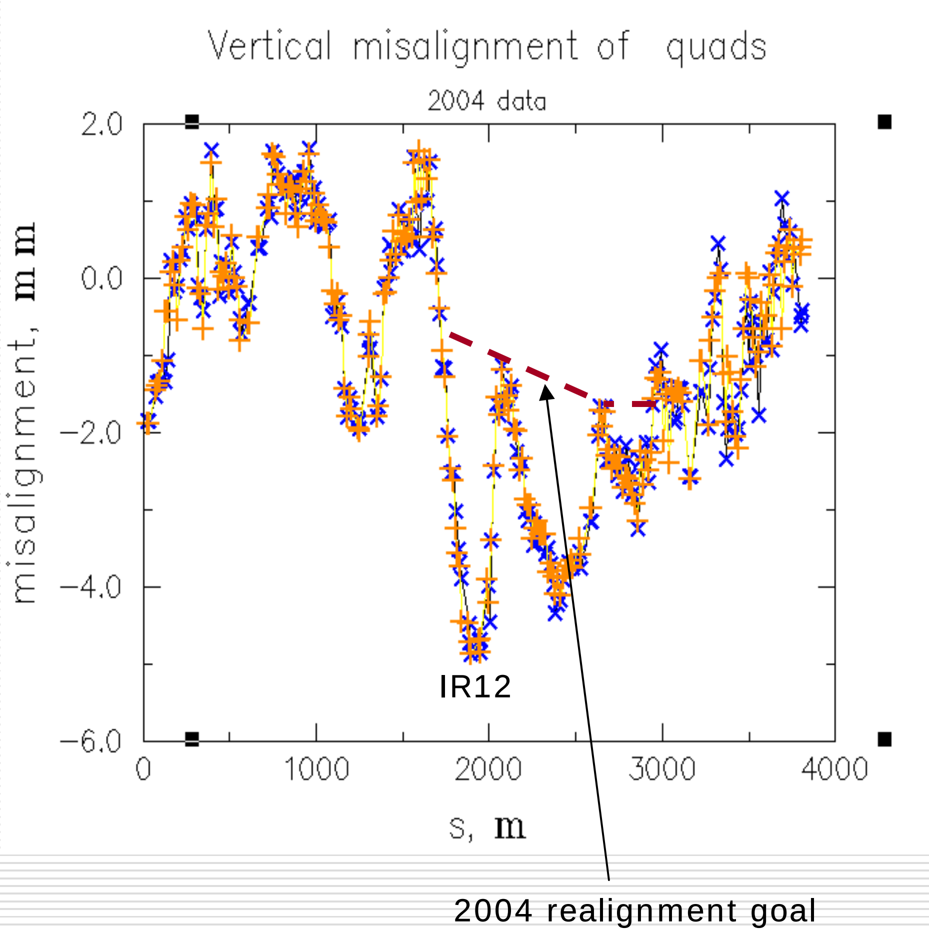
Quadrupole gradient variation technique has been used last run for measuring IR BPM offsets (V.Ptitsyn, T.Satogata, R.Thomas)

Plot shows closed orbit distortion rms at different orbit positions at an IR quadrupole (as measured by BPM) created by the IR quad gradient change.

Measured zero orbit rms corresponds to the quad center.

Difficulties come from magnet power supply scheme at RHIC -> no individual magnet current control for arc quadrupoles and sextupoles

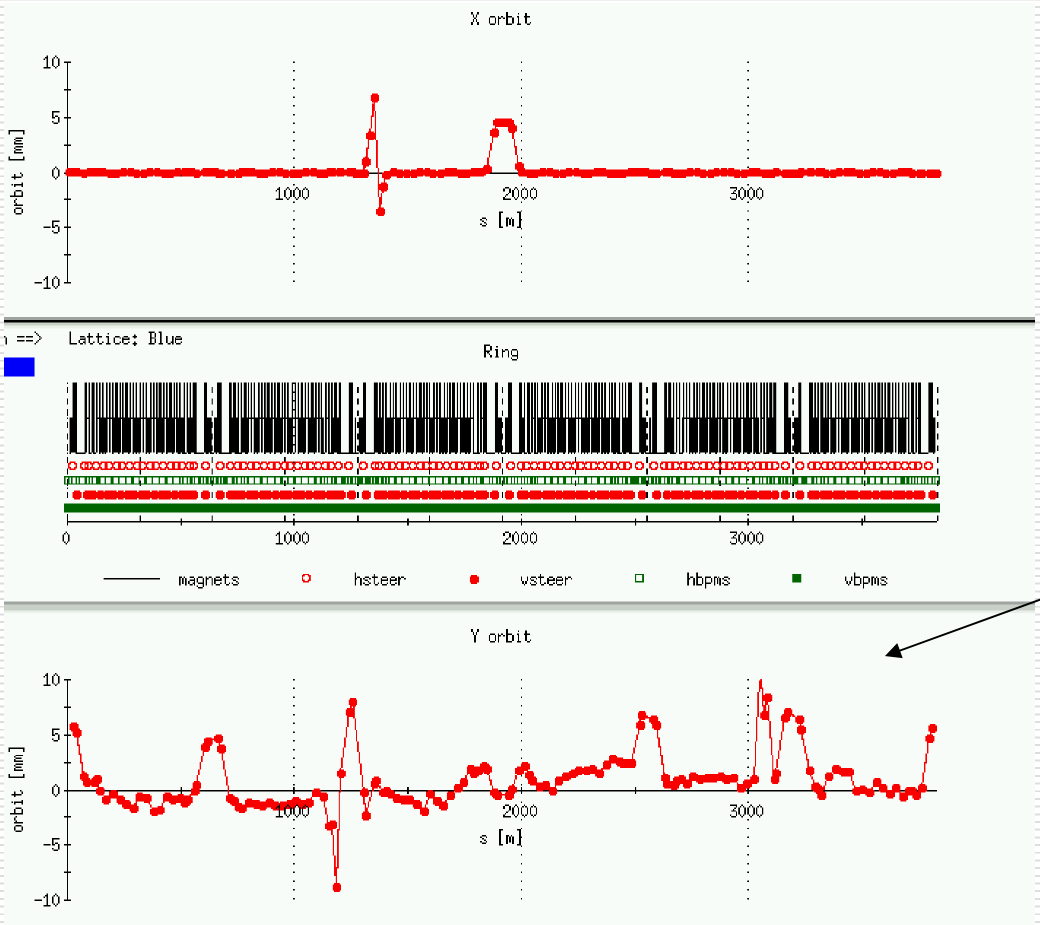
Quad-to-Quad misalignments



- Misalignment oscillations at the level of few mm.
- Misalignment dips are at the interaction regions.
- Some sections of the ring as well as several individual quadrupoles have been realigned in 2002 and 2004.
- Development of beam-based alignment techniques is under development:
  - Minimizing vertical dispersion (based on DFS approach, R.Assmann, LEP,SLAC)
  - Analysis of dipole corrector strengths

Ideal orbit for polarized protons

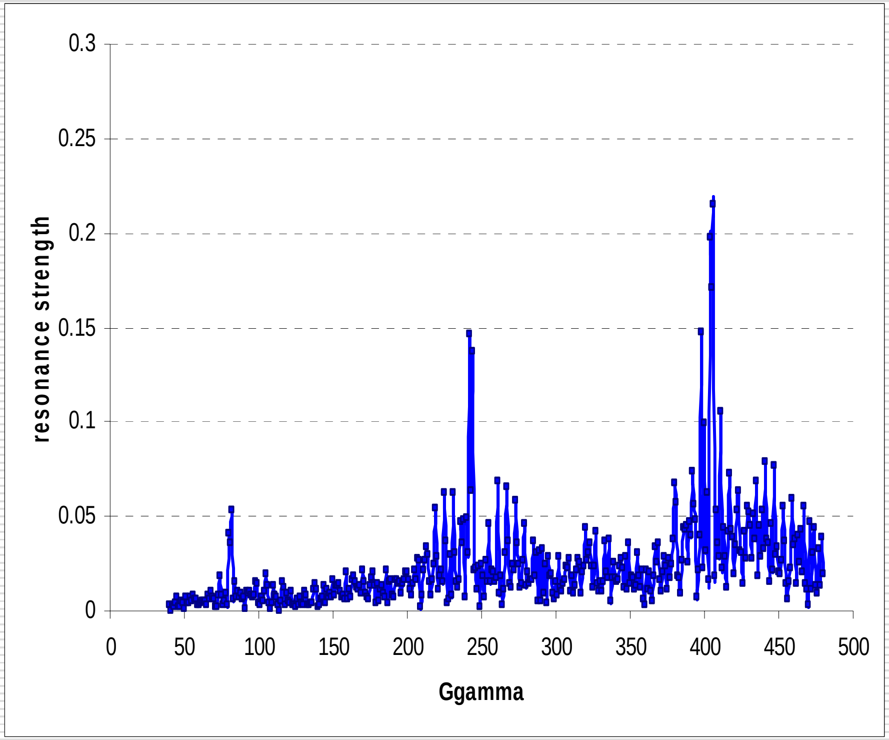
BPM data for ideal orbit at the injection



Based on the misalignment data the ideal “plane” vertical orbit was constructed and tested in previous runs.
The ideal orbit inlcudes also special orbit bumps (at IRs and snakes).

This orbit is used as a goal orbit for orbit correction.

Resonance strength for the ideal orbit



Vertical orbit corrrected to the plane in vertically focusing quads.
No correctors in defocusing quads, so there are orbit excursions there.

Resonance strength tolerance is at 0.05 level at high energy end.

Strong resonances at (2k+1)*81

3*27

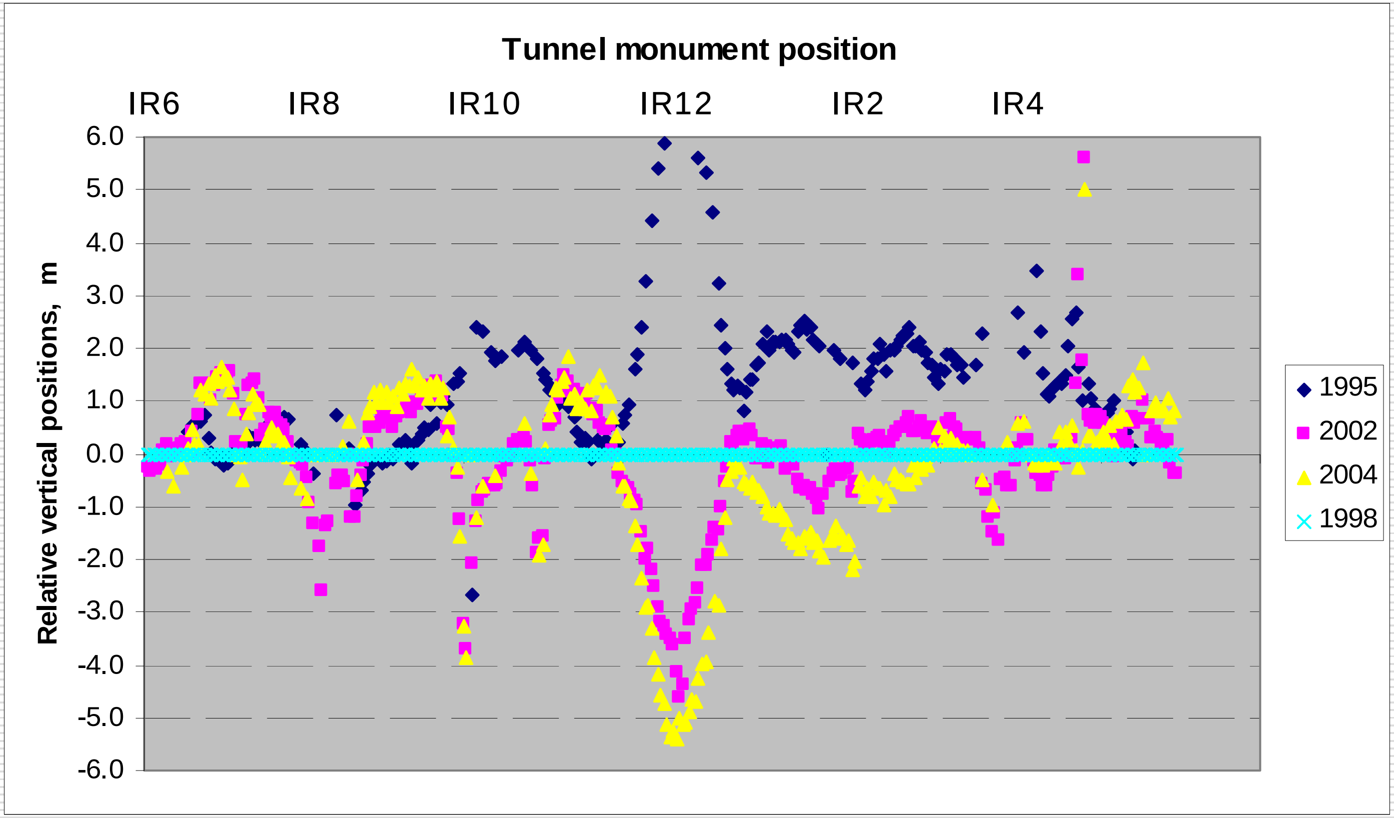
superperiodicity

cells per superperiod

For accelerating polarized proton to 250 GeV the ring realignment may be required with accuracy below 300 microns.

History of the ground motion at RHIC

Based on 4 alignment measurements:1995,1998,2002,2004.
Monuments are in RHIC tunnel floor near every magnet.
The data shown are RELATIVE with respect to the 1998 data.
IR regions have been sinking. IR12 total vertical shift is about -11mm for 9 years.



Snake Imperfections

- Two snakes setup:
  - Spin rotation by snake: $\mu = 180^o + \delta\mu$
  - Snake angle difference: $2\phi = 90^o + 2\delta\phi$
  - Corresponding spin tune shift and vector n errors:

$$\delta\nu_s \approx -\frac{2\delta\phi}{\pi} + \frac{(\delta\mu)^2}{4\pi}\cos G\gamma\pi \qquad |n_\perp| = |\delta\mu|\left[1+\cos\left(G\gamma\pi+2\phi\right)\right]$$

- Snake tolerances:

  For $\delta\nu_s < 0.01$ and $|w_n| < 0.05$: $\delta\mu < 5^o$, $\delta\phi < 1^o$

Snake currents are adjusted at the injection to satisfy required tolerances.

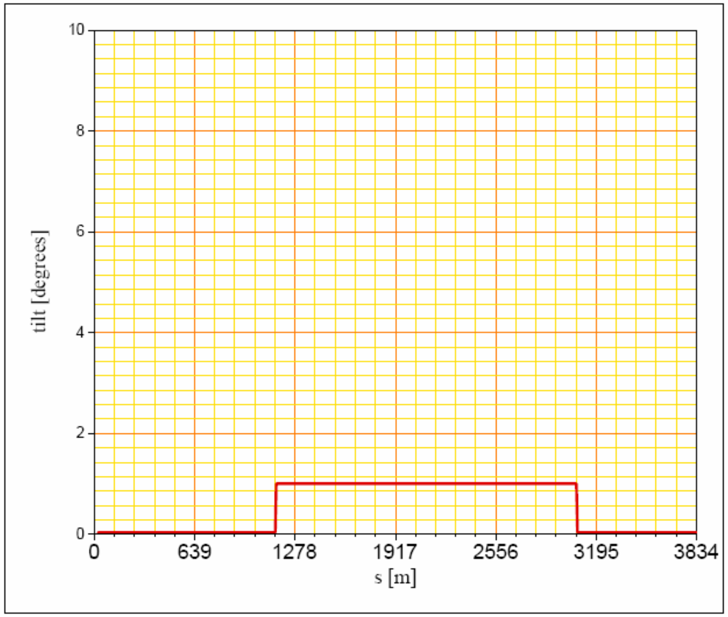
Snake and Orbit Imperfections Combined

Rotation angle and snake axis errors of *1°*.

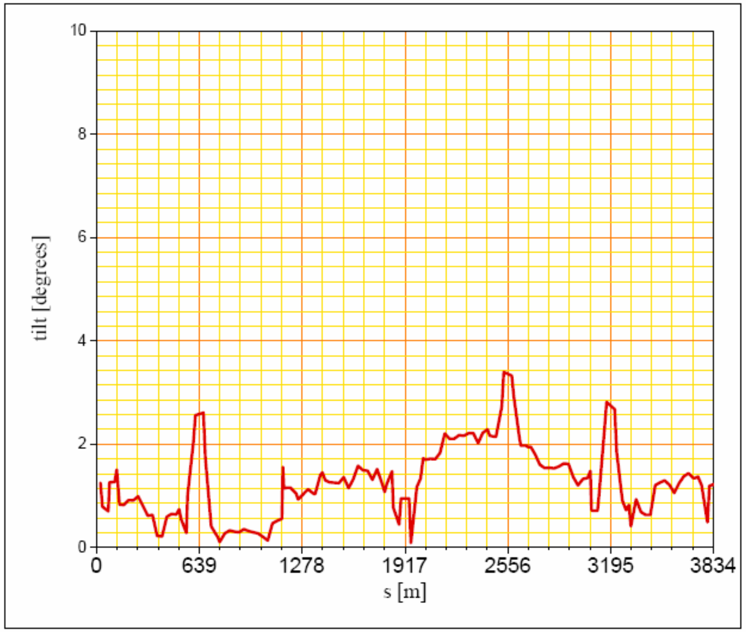
Vertical orbit is corrected to the center of the quads.

W.W.MacKay

Snake error only



Combined effect from snake and vertical orbit



Conditions for successful polarization preservation to 250 GeV

- Careful choice of the working point to satisfy both beam lifetime and polarization preservation. (Detuning from high-order resonances.)

- Precise setup of the snake currents ($\delta\phi < 1^o$).

- Vertical orbit rms below 300 microns relative to the horizontal plane. (Though better working point choice might relax the orbit tolerance)
  - Magnet realignment.
  - Improved quality of the orbit correction.
  - Development of beam-based measurement techniques to measure bpm-to-quad and quad-to-quad misalignments

- Improved control of tune, coupling and chromaticity on the ramp.