Orbit effects on polarization in RHIC

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RHIC Machine Advisory Committee
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Snake resonances and orbit related effects

- Depolarization is caused by high-order ("snake") resonances:

$$Q_y = \frac{2m+1}{2n} \pm \frac{\delta Q_{sp}}{n}$$

- Without orbit errors: only resonances with odd n (for instance, 7/10 resonance)

- The closed orbit errors affect:
  - The spin tune shift (δQ_s) and related split and shift of the snake resonance locations.
  - The snake resonance width.

    A) excitation of even-order (even n) snake resonances (for instance ¾ resonance)

    B) enhancement of odd-order snake resonances ($\sim\pi^2|\varepsilon_{imp}|^2$).

    Important only for very strong resonances ($|\varepsilon_{imp}| >> 0.1$)

The same effects as from the orbit errors can arise from snake imperfections.

Spin tune shift due to orbit errors

The following effects are important and have been considered:

- Difference of horizontal orbit angles in snake locations.
  This is present on ramp and may lead to large spin tune shifts.

- Difference of horizontal or vertical orbit angles in the rotator locations.
  The rotators are off on the ramp. Thus it is less important factor.

- Difference of dispersion angles in snake and rotator locations.
  Small spin tune shift, but the important contribution to the spin tune spread.

- Spin tune shift due to imperfection resonance strength.
  It was found to be the important contribution.

- Interplay of horizontal an vertical orbit bumps (in IR12 for H-jet) ($\sim xy^2$)
  Should be taken into account for large bumps (~ 10mm).

Control of spin tune shift due to the horizontal orbit angle in Snakes

The spin tune shift due to horizontal orbit angles in Snakes and rotators :

$$\delta Q_{sp} = \frac{1+G\gamma}{2\pi}(2\alpha_{sn} + \alpha_{rt_ip6} + \alpha_{rt_ip8})$$

$$\alpha_{sn} = x'_{co_sn9} - x'_{co_sn3}$$

$$\alpha_{rt_ip} = x'_{co_rt_left} - x'_{co_rt_right}$$

At 250 GeV:

	Orbit angle error, mrad	δQ_{sp}, 10^{-3}
Snakes	**0.1**	**15.4**
Rotator (in one IR)	**0.1**	**7.7**

On the acceleration ramp (the rotators are off) only α_{sn} contributes.

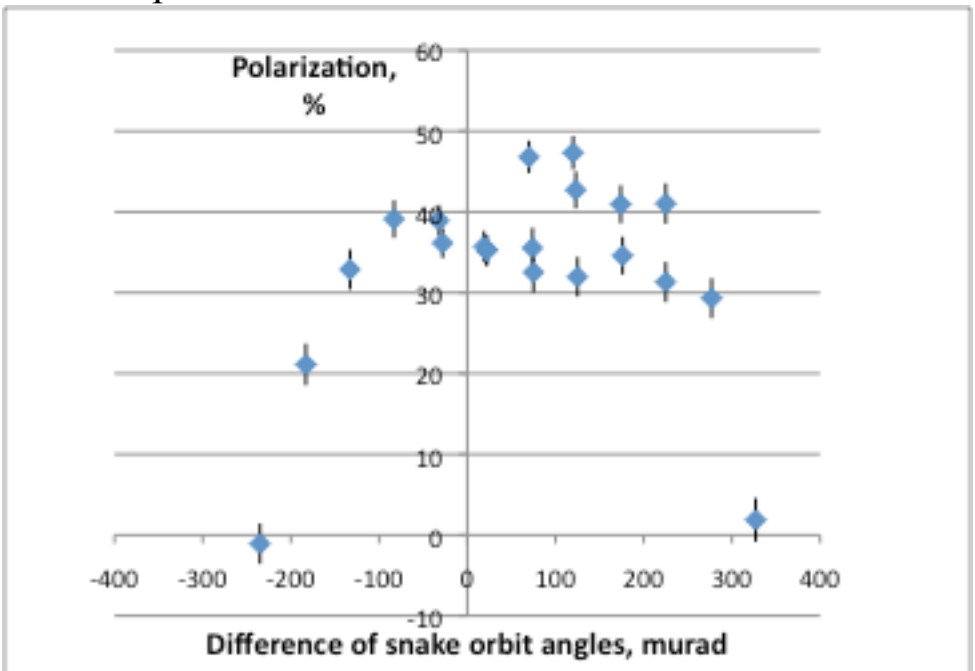
- Realignment of magnets around the snakes has been done before Run-9.
- The variation of snake angles on the (last half of) ramp was maintained within established tolerances during the Run-9:

7/10 resonance shift $< \pm 0.001$ => $\delta Q_{sp} < \pm 0.005$ => $\alpha_{sn} < \pm 30$ μrad

Spin tune versus snake orbit angle measurements

The depolarization caused by the difference of horizontal orbit angles at the Snakes was verified in dedicated experiment.

Example of measurements done in Blue at 250 GeV



Making use of the depolarization by 0.75 (second order) spin resonance:

- vertical betatron tune is put sufficiently close to 0.75 (in this example, $Q_y = 0.73$)
-gradual change of the snake orbit angles causes the spin tune shift from ½ and therefore the shift of spin resonance from 0.75
-the depolarization is observed when the spin resonance shifted to the location of Q_y

Snake axis imperfections BPM offsets

$$\delta Q_{sp} = \frac{\delta\phi_{sn}}{\pi} + \frac{(1+G\gamma)}{\pi}\left(\alpha_{sn} - \alpha_0\right)$$

Making the measurements at different energies allows to identify $\delta\phi_{sn}$ and α_o and, thus interpolate the spin tune shift on the whole ramp.

Spin tune shift caused by imperfection resonances

$$|\Delta Q_s| \le \frac{1}{\pi}\arcsin\left[\sin^2\frac{\pi\varepsilon_{imp}}{2}\right]$$ where ε_{imp} is the resonance strength

The problem with reversed BPM offsets was found during the Run-10 (see later slides in this talk). Reversed offsets led to closed vertical orbit rms ~1 mm and the maximum imperfection resonance strength exceeding 0.1.

Corresponding spin tune shift along the acceleration ramp:

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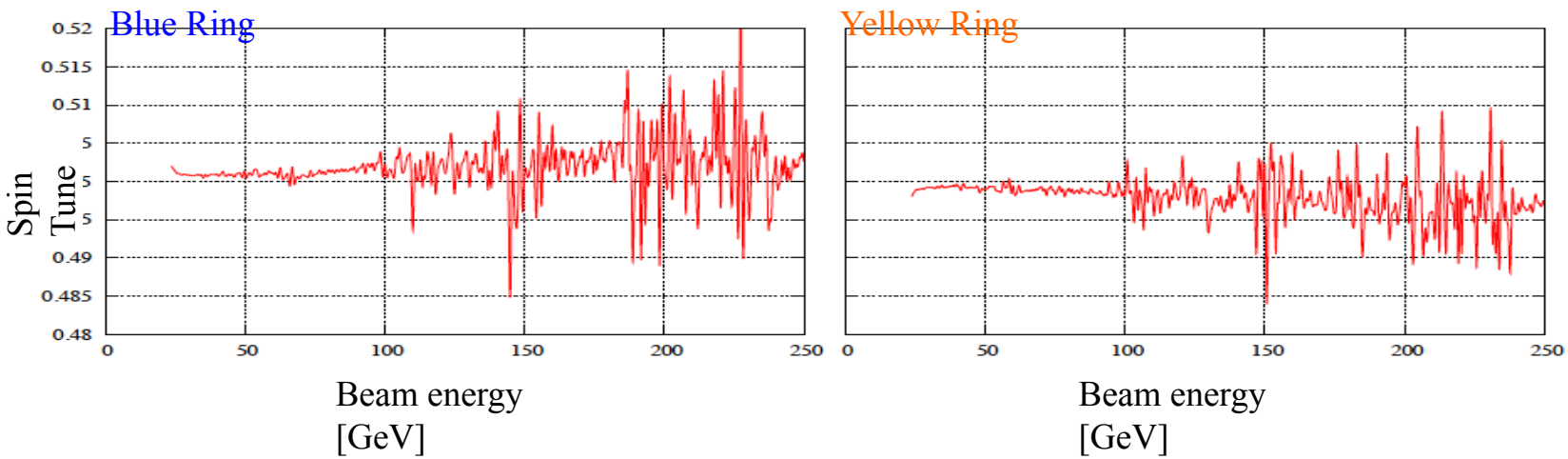


Above 100 GeV the spin tune shifts are considerable (>0.02 in Blue ring). Corresponding 7/10 resonance shift up to 0.004-0.005.

The effect of dispersion

The spin tune shift due to horizontal dispersion angles in the Snakes and rotators:

$$\delta Q_{sp} = \frac{1+G\gamma}{2\pi}\left(2\Delta D'_{sn} + \Delta D'_{rt_ip6} + \Delta D'_{rt_ip8}\right)\left(\frac{\Delta p}{p}\right)_{ave}$$

$$\Delta D'_{sn} = D'_{sn9} - D'_{sn3}$$

$$\Delta D'_{rt_ip} = D'_{co_rt_left} - D'_{co_rt_right}$$

On the ramp only the Snake locations contribute.

	Design ΔD', mrad	δQ_{sp}, 10^{-3}
Snakes	**53.6**	**4.2**
Rotator	**5.3**	**0.2**

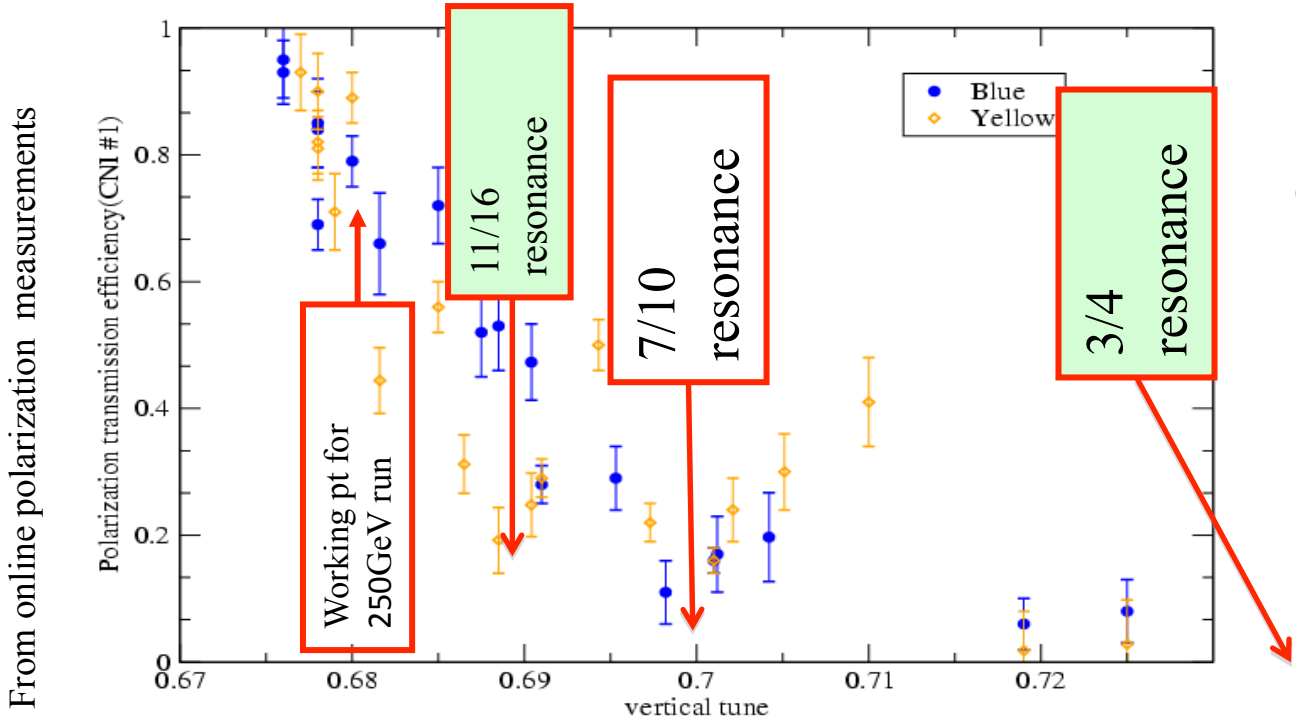
The table is for dp/p = $5 \cdot 10^{-4}$ which corresponds to the orbit radial shift ~0.8mm
The radial orbit excursion of the ramp is less than that

Chromatic tune spread on the ramp: $\Delta Q_{sp} = \frac{1+G\gamma}{\pi}\Delta D'_{sn}\left(\frac{\Delta p}{p}\right)_{rms}$ ~0.005 at 250 GeV

Recently lattice modifications to reduce the chromatic spin tune spread have been searched for.
But no good solution has been found yet.

Measured snake resonances and some conclusions

The orbit and snake errors lead to the even order resonances (light green)



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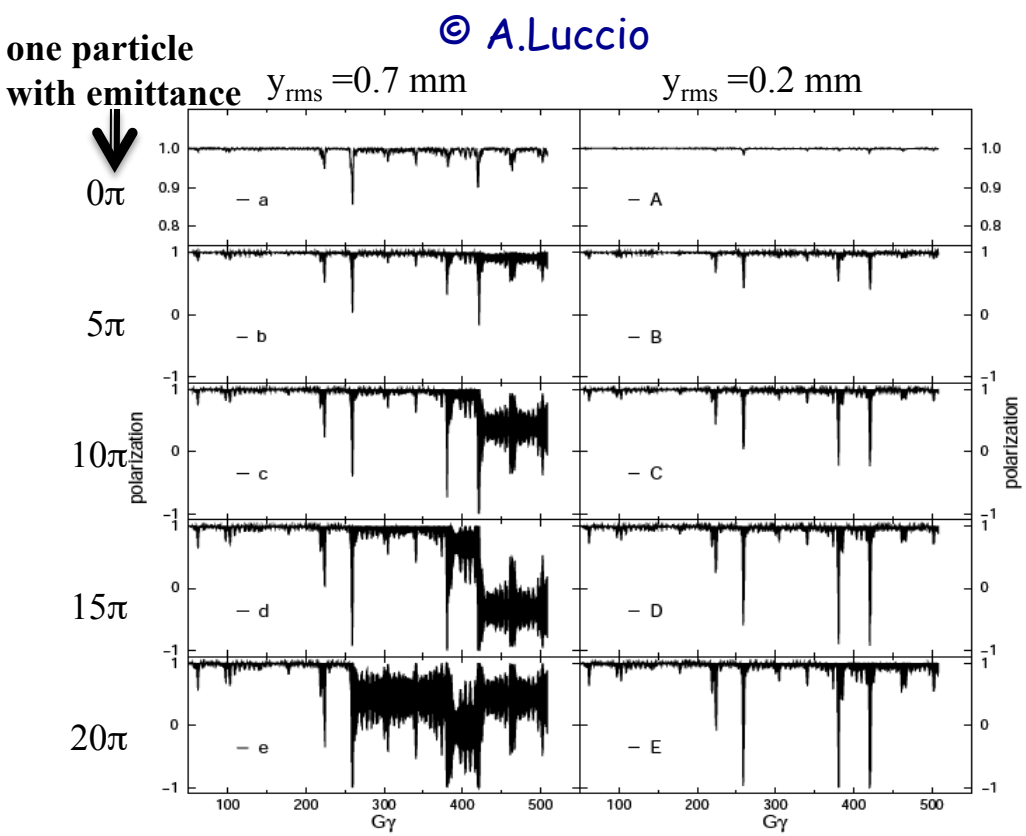
- Very strong depolarization from ¾ resonance indicates large imperfection error. Most probably originating in the vertical closed orbit errors.
- Could the imperfections be large enough to enhance also odd 7/10 resonance?

Polarization simulations with orbit errors



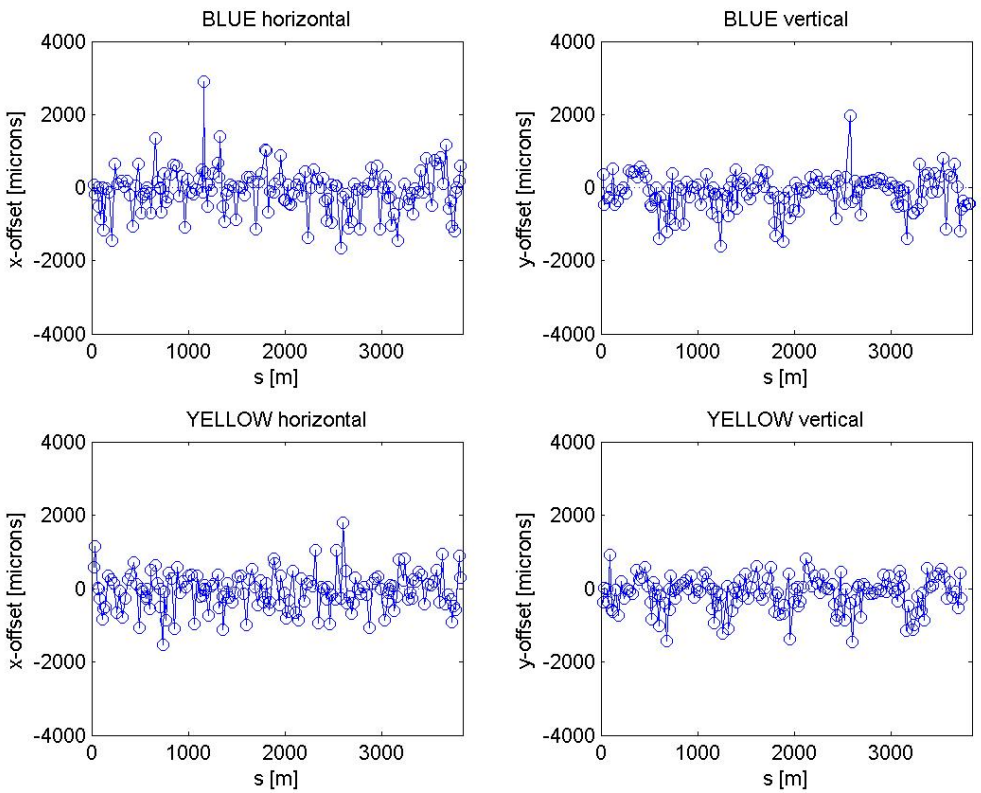
The simulations done on the design stage of RHIC establish the tolerance on vertical closed orbit rms at 0.3 mm.
$|\varepsilon_{imp}| < 0.07$

- The depolarization on the acceleration ramp from the high-order resonances can not be calculated analytically.
- The simulations are crucial for understanding observed depolarization and planning for improvements!
- The work is underway to prepare to and perform the simulations using UAL-SPINK and Zgoubi codes. The simulations will include the study of the orbit imperfections. *(M.Bai, A.Luccio, F.Meot, V.Ranjbar)*

Factors to achieve flat orbits

- In order to reach required tolerances on the closed orbit rms the following factors have to be considered and controlled:
  - BPM-to-quad misalignments
  - Relative quadrupole misalignments
  - Quality of the orbit correction
  - Closed orbit variation with the time

Reversed BPM offsets



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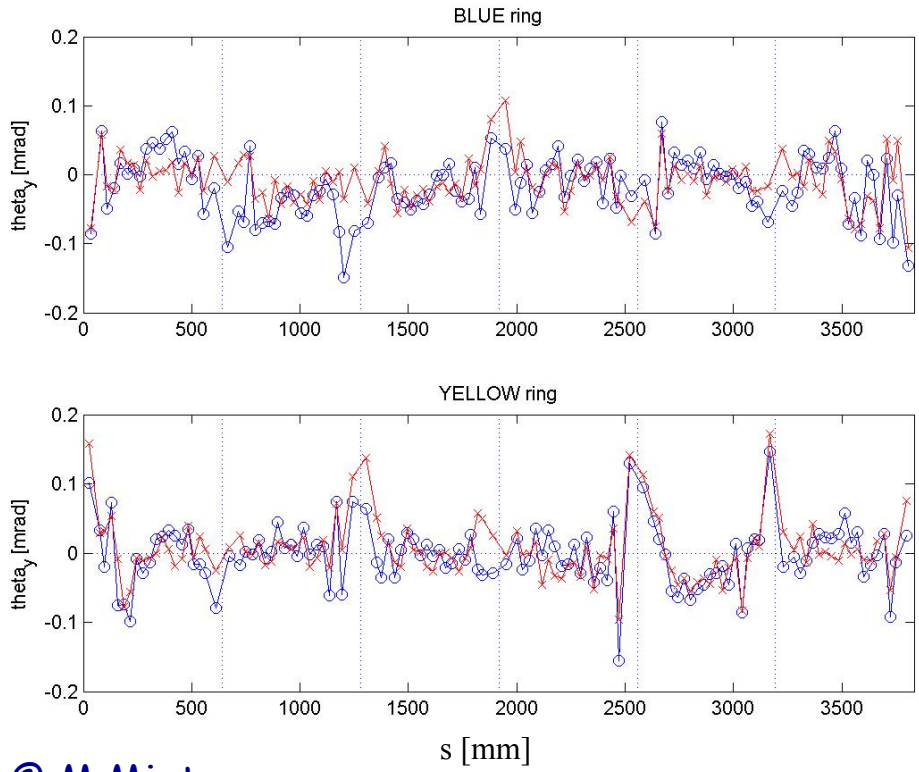
- On the RHIC construction stage the BPMs were surveyed and their offsets relative to neighbouring quad center were identified.
  During run 10, it was found that many of the RHIC BPM offsets were taken into the account with wrong signs. These include all vertical and half of the horizontal BPMs.
- The rms values of these offsets are at the range 0.45-0.6mm in both horizontal and vertical.
- Could that be a reason for the reduced polarization transmission efficiency in 250GeV run?
  - The effect on snake angles is small.
  - The effect on spin tune from imperfection resonance might create problems above 100 GeV (W.MacKay)
  - Corresponding imperfection resonance strength reaches 0.16 (in Blue), which is twice more than the tolerance value.

Dipole Correctors before/after BPM Offset Fixes



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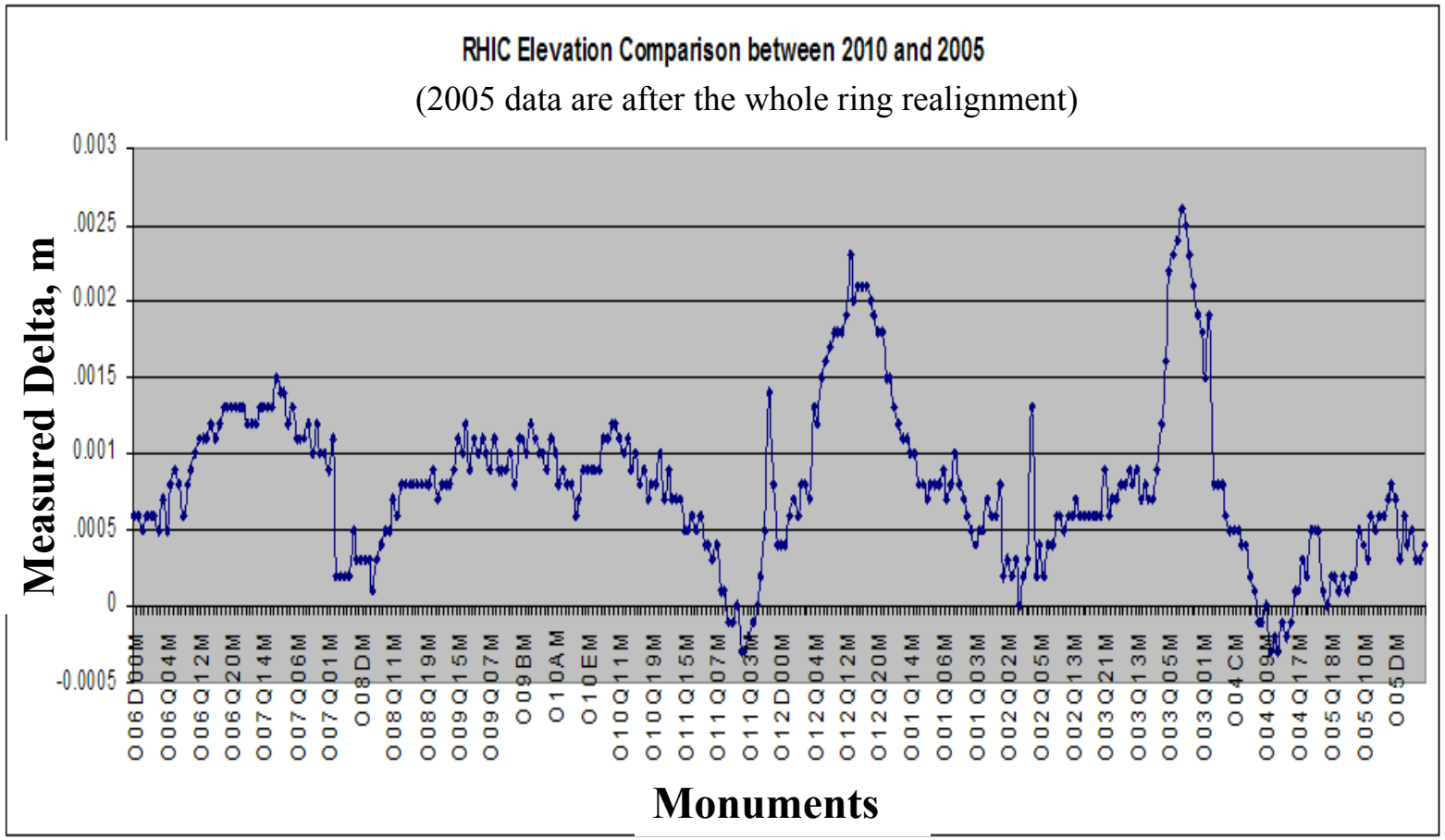
Shown are the dipole corrector strength (taken at the injection energy)
blue circles – reversed BPM offsets
red crosses – correct BPM offsets

Comparison of the dipole corrector values before and after BPM offset fixes shows that the change is not as dramatic as hoped:

	Blue ring	Yellow ring
rms strength before fix , mrad	0.046	0.044
rms strength after fix , mrad	0.035	0.043

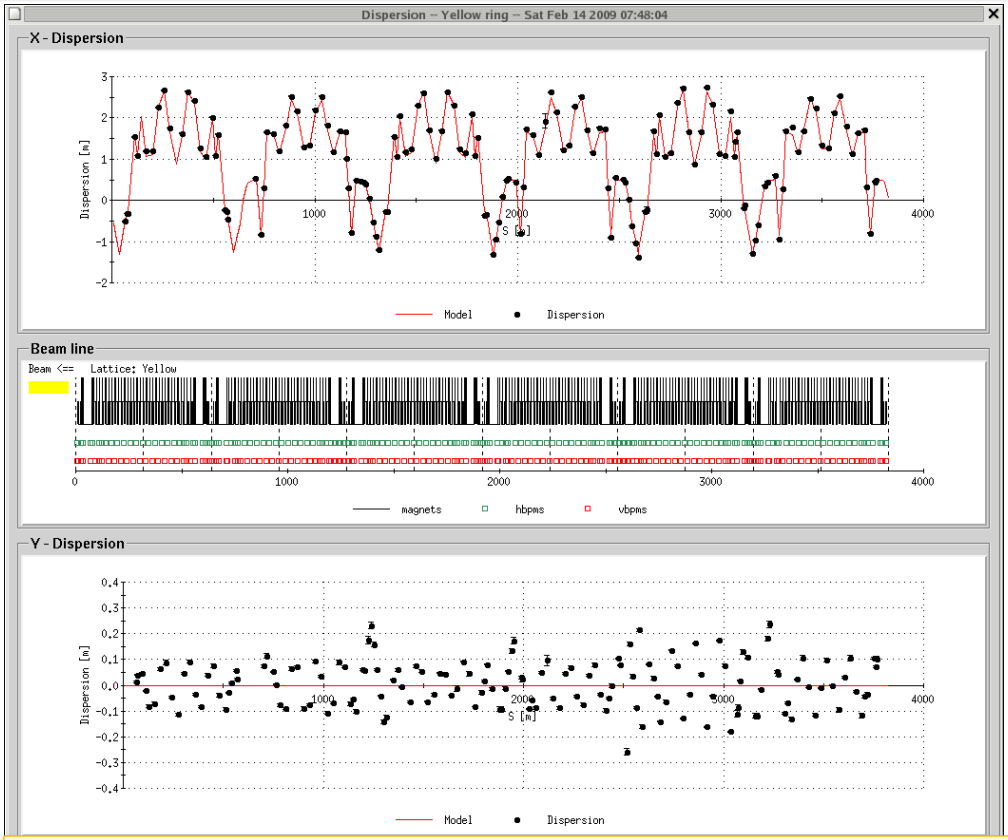
Measured vertical misalignments



F. Karl

The realignment of the whole ring is underway

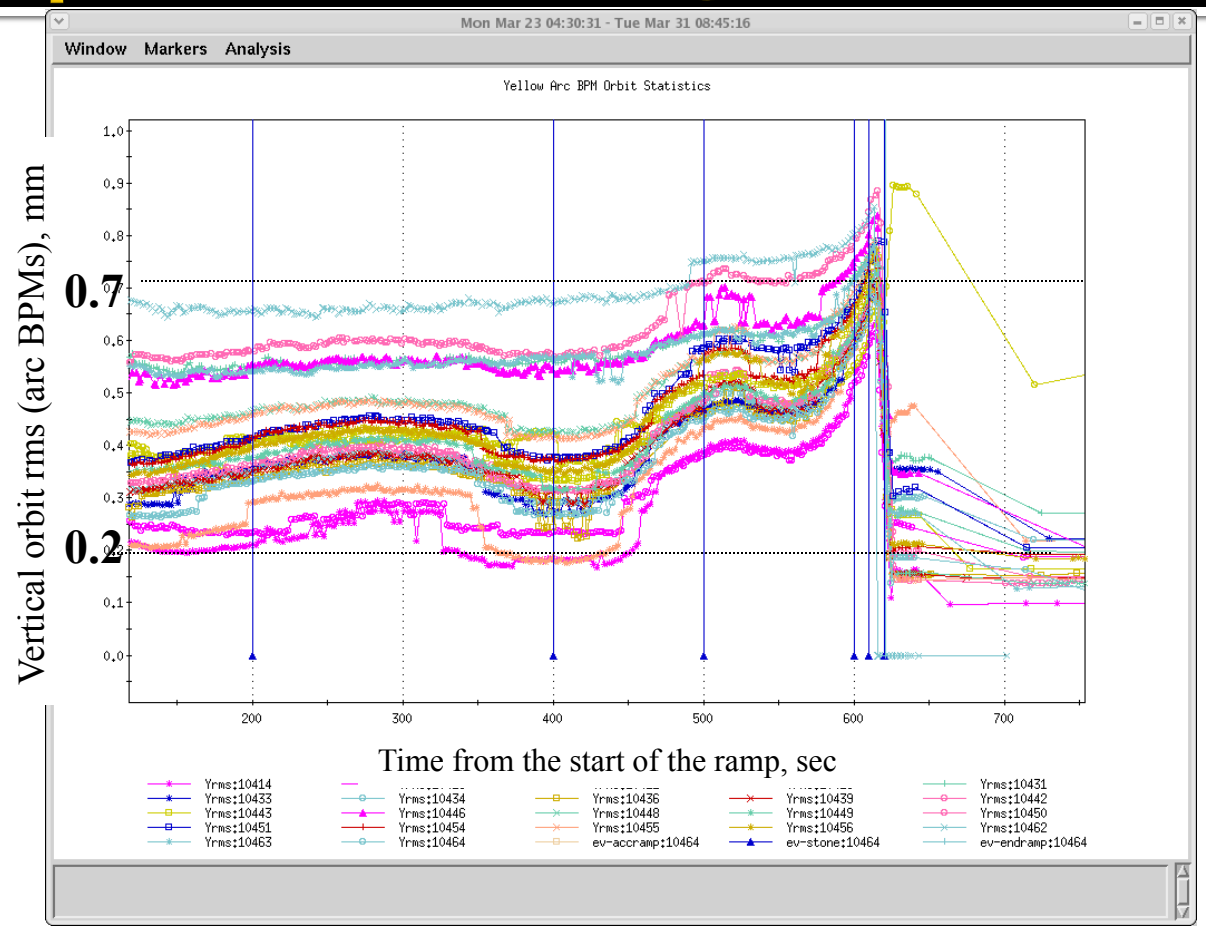
Vertical dispersion



Example of the dispersion measurement in Run-9 at the injection

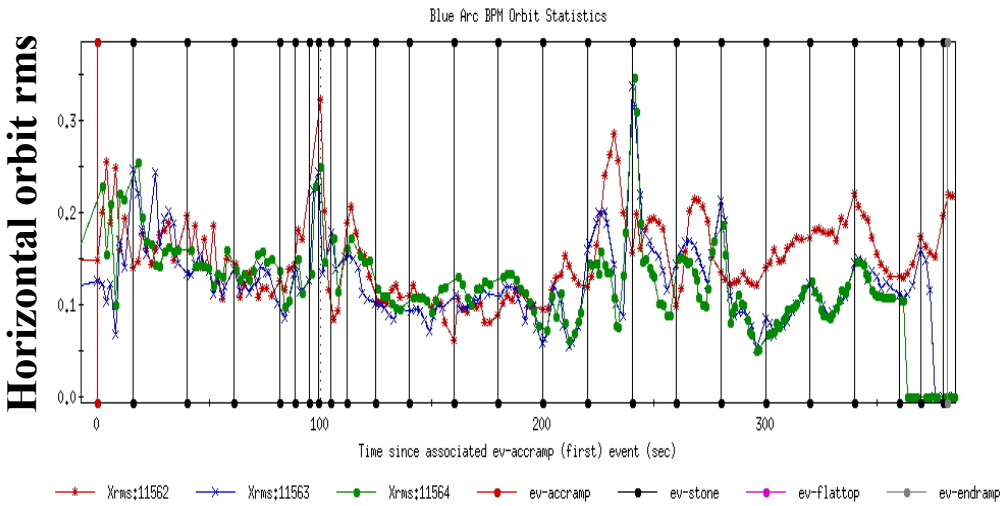
- Noticeable vertical dispersion was observed in previous runs.
- If the betatron coupling sources (quad rolls) would be well known the vertical dispersion could serve as the indicator of ring non-flatness.
- Algorithms to identify the local coupling errors and to correct the vertical dispersion are under consideration.

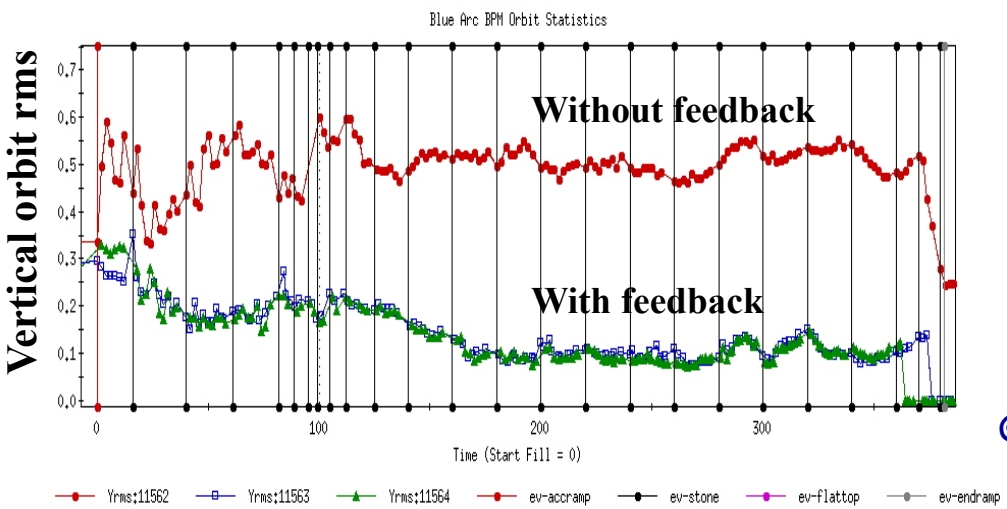
Slow orbit variation
Example from Run-9



Yellow vertical rms orbit taken during a week of the RHIC operation.
The data are from rotator ramp. No orbit corrections done during that time.

Slow orbit feedback





- Slow orbit feedback has been developed and successfully demonstrated in Run-10
- The feedback was used mainly for the ramp development.
- Ideally, should be kept on every ramp to ensure the vertical orbit rms (as measured by BPMs) below 0.3mm

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Summary

- The closed orbit can cause depolarization either by shifting snake resonance locations or by introducing new snake resonances or by enhancing strength of existing snake resonances.

- Difference of snake orbit angles has been controlled to minimize the spin tune shift on the acceleration ramp in Run-9.

- The improvements for next run include:
  - Fixed BPM offsets
  - Vertical realignment of the whole ring.
  - Slow orbit feedback application on all ramps.

- The simulations are important to explain and analyze the observed depolarization effects and the corresponding work is underway .

Summary of most important effects

		Effect	Tolerance	Comment
Difference of X orbit angles at Snakes	ramp and store	spin tune shift	± 30 μrad	
Difference of dispersion angles at Snakes	ramp and store	spin tune shift	radial shift < 1mm	
		spin tune spread		~0.005
Closed orbit rms, mm	ramp and store	spin tune shift even-order resonances, enhancement of odd-order resonances	< 0.3 mm $\varepsilon_{imp} < 0.07$	should be verified by simulations
Difference of X orbit angles at rotators	store	spin tune shift	± 60 μrad	
Difference of Y orbit angles at rotators	store	spin tune shift	± 60 μrad	3 mm IR separation bump: δQ_{sp} up to 0.013

Tolerances on angles at Snake and rotators are shown for $\delta Q_{sp} < 0.005$ at 250 GeV