Run-8 Polarized Protons

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The goal for Run-8 and beyond

- Achieved $\mathcal{L}_{\text{store, avg}} = 20 \cdot 10^{30}\,\text{cm}^{-2}\text{sec}^{-1}$ in Run-6

- $\mathcal{L}_{\text{store, avg}} = 40 \cdot 10^{30}\,\text{cm}^{-2}\text{sec}^{-1}$ in Run-8,
  $\mathcal{L}_{\text{store, avg}} = 60 \cdot 10^{30}\,\text{cm}^{-2}\text{sec}^{-1}$ in Run-9

- Maintain polarization transmission in RHIC (presently close to 100 percent up to 100 GeV)

How can we get there?

Luminosity formula:

$$\mathcal{L} = \frac{N^2 f_c}{4\pi\epsilon\beta^*}$$

Collision frequency f_c is already maximized (111 bunches). Remaining "free" parameters are bunch intensity N, emittance ϵ, and β^*.

What are the limitations on these?

Beam-beam formula:

$$\xi = \frac{r_0 N \beta^*}{4\pi\gamma\sigma^2}$$
$$= \frac{r_0 N}{4\pi\gamma\epsilon}$$

Beam-beam is independent of β^*.

$\Rightarrow$ squeeze β^* as much as possible.

Limitations on β^* :

- magnet strength and triplet aperture
- hourglass effect (need shorter bunches)

Main luminosity improvement has to come from higher intensity ($N = 2 \cdot 10^{11}$/bunch). Fortunately, AGS polarization seems largely intensity-independent.

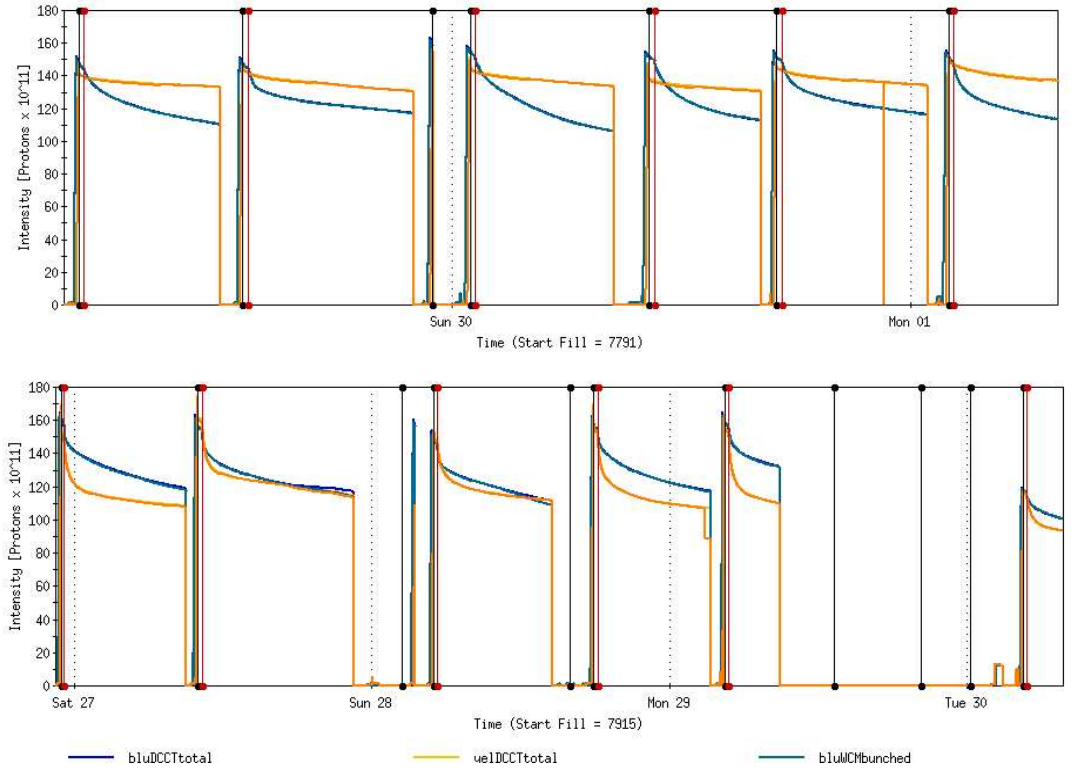
But: higher intensity (or smaller emittance) increases beam-beam tuneshift.

Large tuneshift parameters make working point search very delicate. Working points in the two rings need to be different to avoid coherent beam-beam effects.

FY06 pp-run was already largely beam-beam limited.

Run-6 intensities before and after working point swap

Working point constrained by 2/3 and 7/10



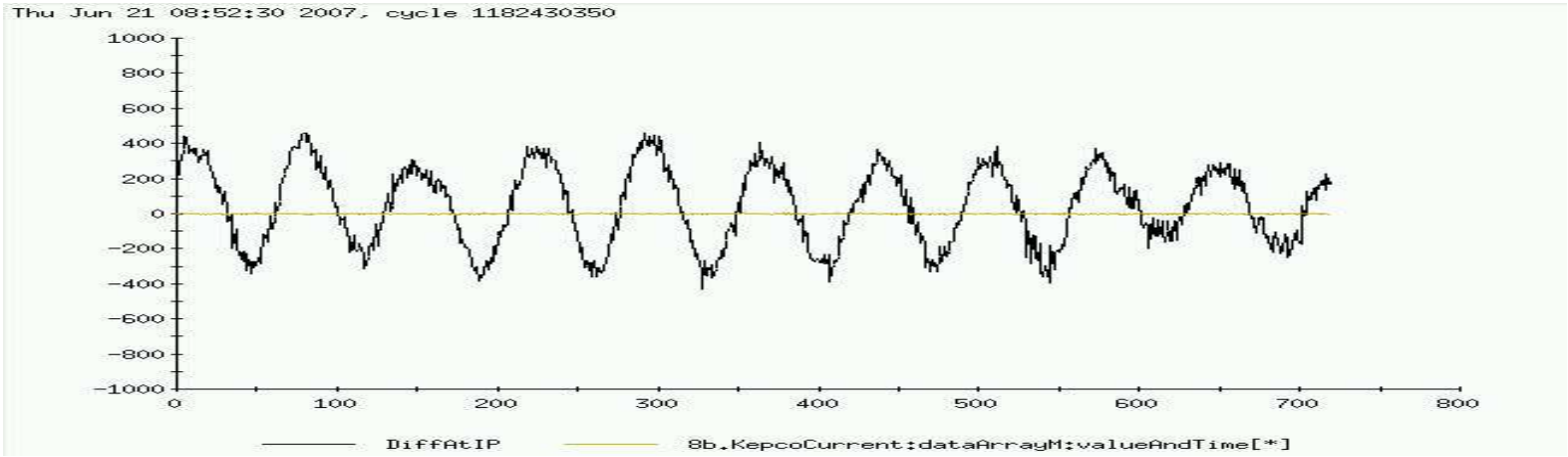
$Q_x = 2/3$ limits lifetime and luminosity performance

What can (and needs to) be done?

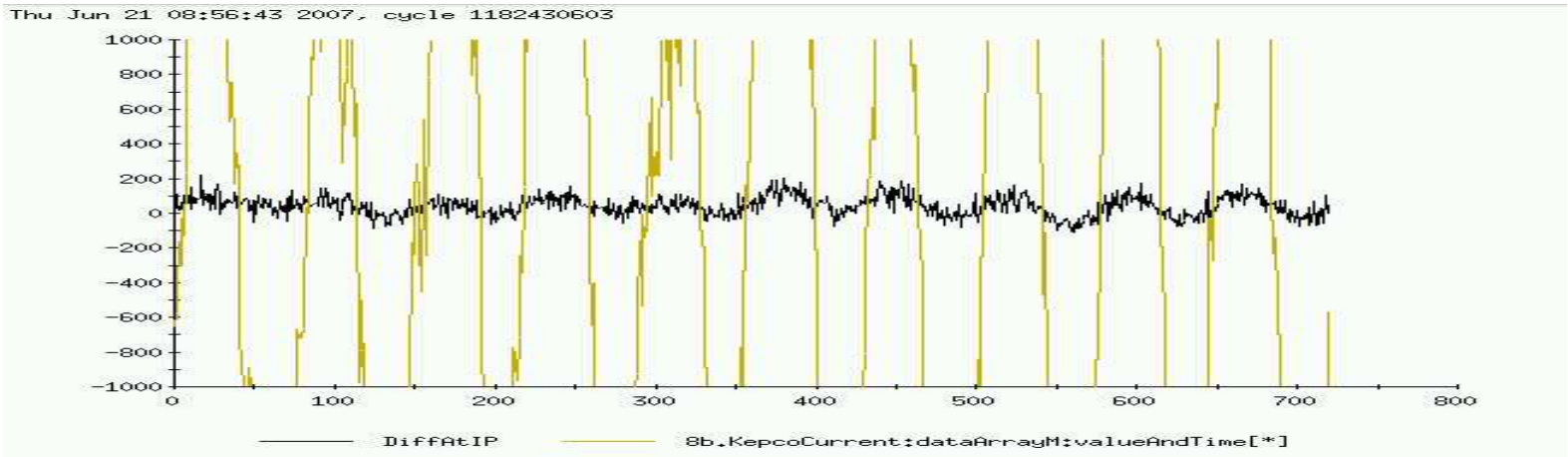
- Correct nonlinear chromaticity (smaller tune footprint)
- Eliminate 10 Hz beam-beam modulation
- β^* reduction to 90 cm
- Hourglass effect reduction (shorter bunches, 9 MHz cavity)
- New working point

10 Hz orbit error at IR8

Feedback OFF:

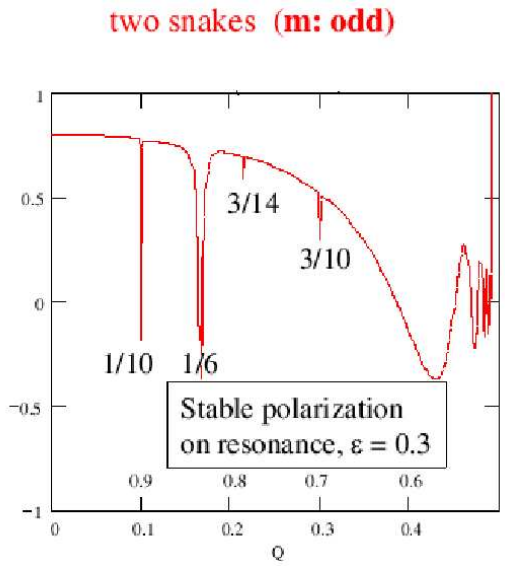


Feedback ON:



Choosing a new working point

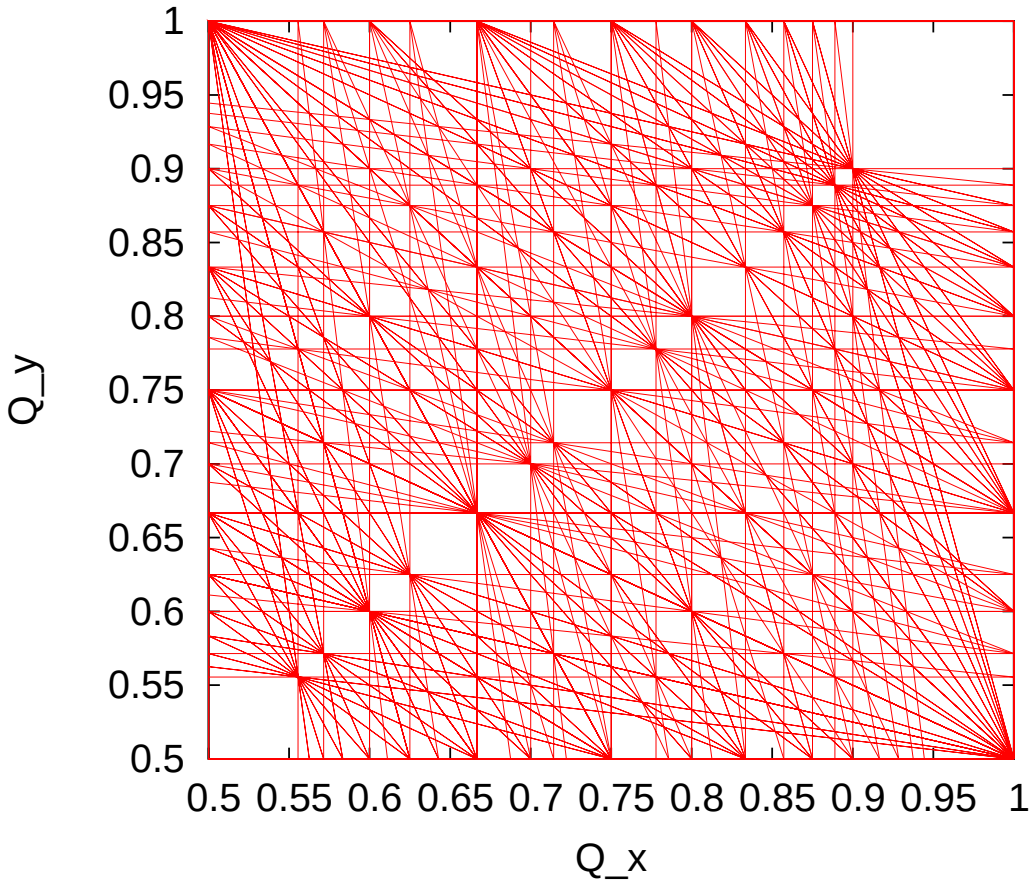
Snake resonances:



Resonance condition: $Q_y = \frac{k}{2 \cdot m}$

Near-integer tunes best for polarization

Nonlinear resonances, up to 10th order:



Near-integer working point provides largest tune space

Tracking studies

- Tracking studies were performed to compare dynamic aperture at current and proposed working points
- Latest IR magnet multipole data were included in the model
- Tune modulation added, based on experimental data
- Two interaction points, $N = 2{\cdot}10^{11}$, $\epsilon_n = 15\pi$ mm mrad (95 percent)

Dynamic apertures in σ at the Run-6 working point

29.695	< 4	5.7	6.8		
29.69	< 4	4.9			
29.685	< 4				7.1
29.68				7.5	7.7
29.675			7.1	6.5	6.6
	28.675	28.68	28.685	28.69	28.695

Above the diagonal, tune space is very limited, consistent with observations.

Dynamic apertures in σ for tunes below the integer

28.965	5.3	5.3	5.5	5.8	6.0		
28.96	5.6	5.8	6.1	6.3			
28.955	6.0	6.0	6.4				7.1
28.95	6.2	6.1				7.3	6.9
28.945	6.0				6.9	6.9	6.8
28.94				6.4	6.6	6.7	6.8
28.935			6.5	6.5	6.5	6.9	6.9
	27.935	27.94	27.945	27.95	27.955	27.96	27.965

Broad region of large dynamic aperture ($\approx 7\sigma$) below the diagonal.

Dynamic apertures in σ for tunes above the integer

29.085	5.5	6.3	6.2	5.6	5.8		
29.08	5.0	5.1	5.3	5.3			
29.075	5.8	5.8	5.5				5.2
29.07	5.9	5.8				5.5	5.3
29.065	6.2				5.8	5.5	5.6
29.06				5.9	6.0	5.7	5.5
29.055			6.2	6.1	6.2	5.6	5.5
	28.055	28.06	28.065	28.07	28.075	28.08	28.085

Not as good as below the integer.

Depolarizing resonances

$7th$ order depolarizing resonance $Q_y = \pm\frac{1}{2 \cdot 7}$ is a potential concern

Difficult to investigate in tracking studies, because required polarization lifetime is many hours

Therefore, resonance strength was artificially increased until depolarization occured

Application of the same model to $Q_y = 10/14$ showed that $Q_y = \pm 1/14$ has factor 10 longer polarization lifetime

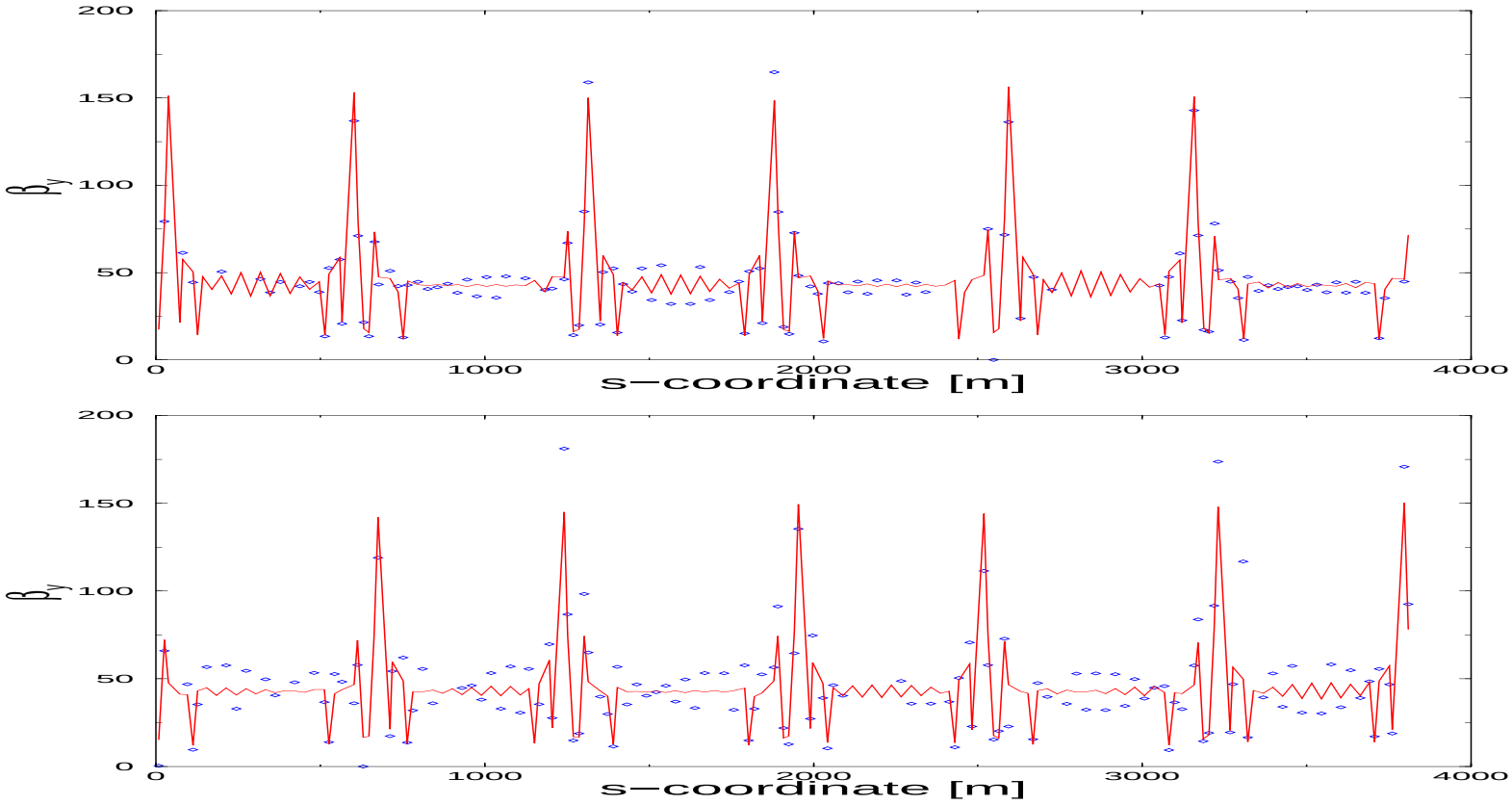
Measurements show polarization lifetime of several hours at $Q_y = 10/14$

$\rightarrow$ $Q_y = \pm 1/14$ expected to have sufficient polarization lifetime

Experimental studies

- Near-integer working point was studied during FY07 Au-Au run (injection only)
- β-beat is a major concern due to $1/\sin(2\pi Q)$ dependence
- Tunes set to $(28.08, 29.05)$ in Blue, $(27.93, 28.94)$ in Yellow
- Optics measurements with AC dipole

Vertical β-functions in Blue and Yellow



Harmonic β-beat correction under development

Necessary tools

- Tune feedback, with full replay capability
- Local and global (harmonic) β-beat correction
- 10 Hz IR orbit feedback to counteract larger oscillations at near-integer tunes
- Instrumentation/controls applications need to be modified to allow different working points in the two rings (example: ARTUS)

Summary

- At the current working point, RHIC polarized proton luminosity is limited by $Q_x = 2/3$ resonance
- Nonlinear chromaticity correction reduces footprint; tune space can then be used for beam-beam
- A near-integer working point overcomes this limitation

- Tracking studies indicate significant increase in dynamic aperture for tunes around $(27.96, 28.95)$

- Beam experiments with Au show significant β-beat at these tunes; harmonic correction being developed

- Proposed working points for Run-8:
  Yellow at $(28.695, 29.685)$, Blue at $(27.96, 28.95)$

- Tune feedback is mandatory