OpticsCorrection

RHIC Optics Status:

Optics Measurements and Corrections

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On behalf of RHIC Team

Outline

OpticsCorrection

- RHIC optics measurements status
- RHIC optics correction status
  - Free betatron oscillation based
  - Driven oscillation(AC dipole) based
- Summary

RHIC Optics Measurement Techniques

OpticsCorrection

technique	Full ring	Beta*	Online data analysis	Request on beam conditions
AC dipole based	**Yes**	**Yes**	**Yes**	**Minimize tune spread**
Modulating triplet quadrupole	No	Yes	Yes	Minimize coupling
Orbit Response Matrix	Yes	Yes	No	N/A
Tune-meter based	**Yes**	**Yes**	**Yes**	**Minimize tune spread**

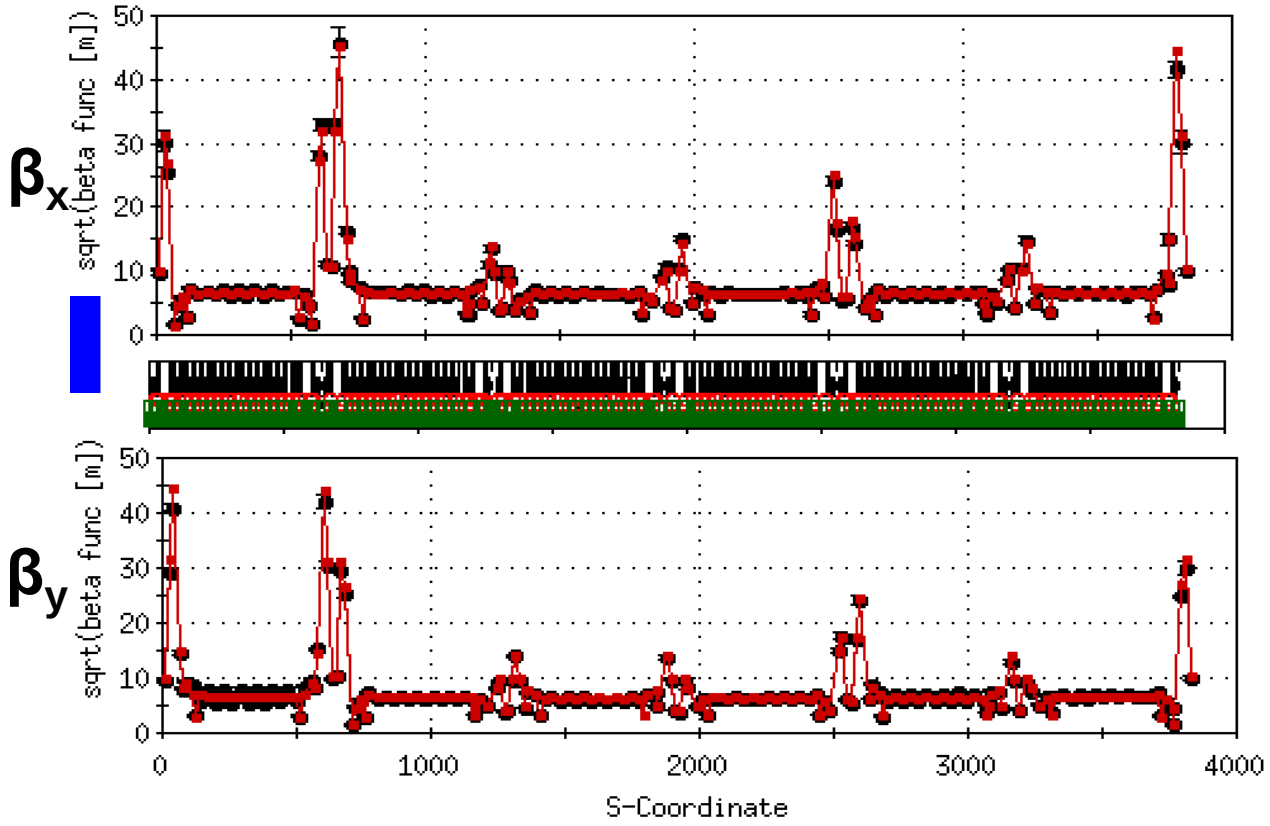
Status of RHIC AC Dipole Optics Measurement

OpticsCorrection

- Routine full ring beta/phase beat measurement using ac dipole for each operational lattice

Store Optics Measured by AC Dipoles: Blue

OpticsCorrection

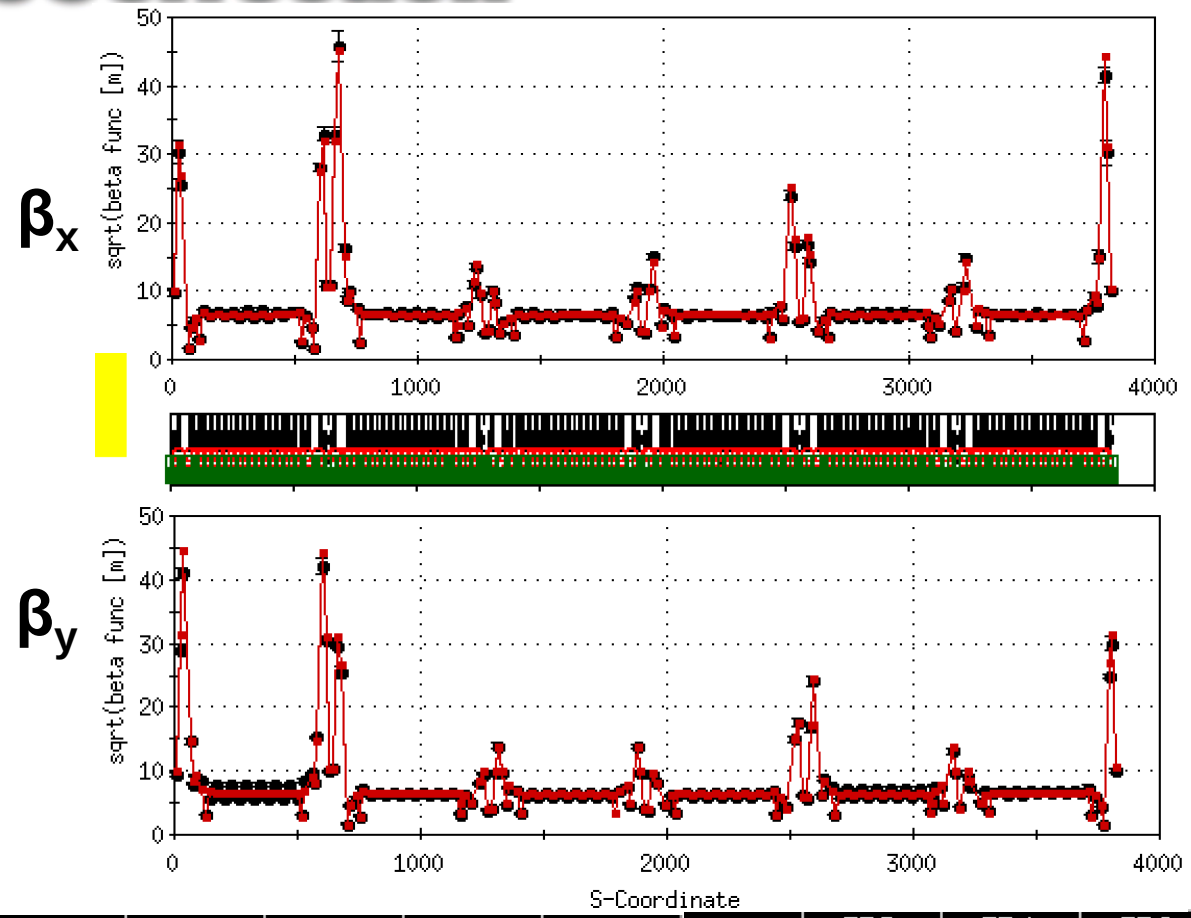


	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	2.23	6.05	0.68	0.58	6.82	6.01
H_bIP	2.26	6.06	0.68	0.59	6.95	6.04
H_s*	-0.26	-0.20	-0.02	0.08	-0.92	0.40

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	2.03	7.22	0.69	0.67	7.08	7.08
V_bIP	2.17	7.30	0.92	0.88	7.10	7.11
V_s*	0.53	0.78	0.39	0.37	-0.29	0.48

Store Optics Measured by AC Dipoles: Yellow

OpticsCorrection



	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	2.27	5.52	0.66	0.66	7.56	5.81
H_bIP	2.35	5.52	0.67	0.67	7.58	5.81
H_s*	0.42	0.12	-0.08	-0.09	-0.41	0.02

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	3.29	7.31	0.59	0.62	11.20	12.83
V_bIP	3.89	7.40	0.93	0.65	11.90	12.94
V_s*	-1.40	0.78	-0.45	0.13	2.80	1.18

New this year for AC dipole Optics Measurement

OpticsCorrection

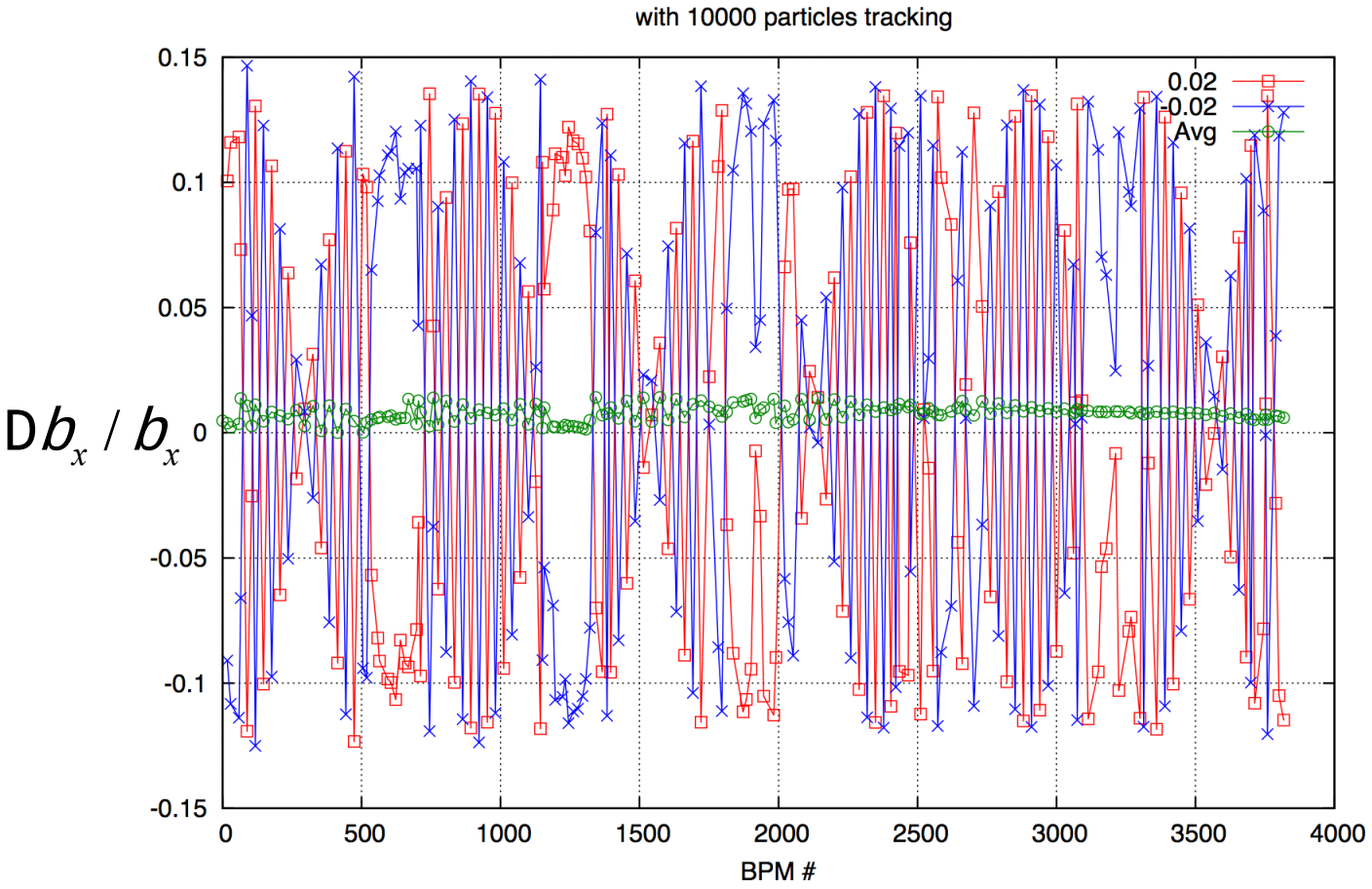
- Applied Independent Component Analysis algorithm[1] to analyze the turn-by-turn data. This was developed and implemented by X. Shen from Indiana University. The advantage of ICA is this algorithm has been proven to be much more robust and superior than traditional SVD
- ICA was first developed by telecommunication industry for signal processing. Its strength is to identify each individual source $s_i(t)$ out of $\vec{X}(t) = A\vec{s}(t) + \vec{N}(t)$ with **S**econd **O**rder **B**lind **I**dentification algorithm after first de-correlate and normalize data with PCA(similar to SVD). Here $\vec{N}(t)$ is the white noise.
- This was first successfully applied to Fermilab Booster optics measurement by X. Huang[2].

[1] J.-F. Cardoso, in Acoustics, Speech and Signal Process- ing, 1998. Proceedings of the 1998 IEEE International Conference on, Vol. 4 (IEEE, 1998) pp. 1941–1944.
[2] X. Huang, S. Lee, E. Prebys, and R. Tomlin, PRST-AB 8, 064001 (2005)

New this year for AC dipole Optics Measurement

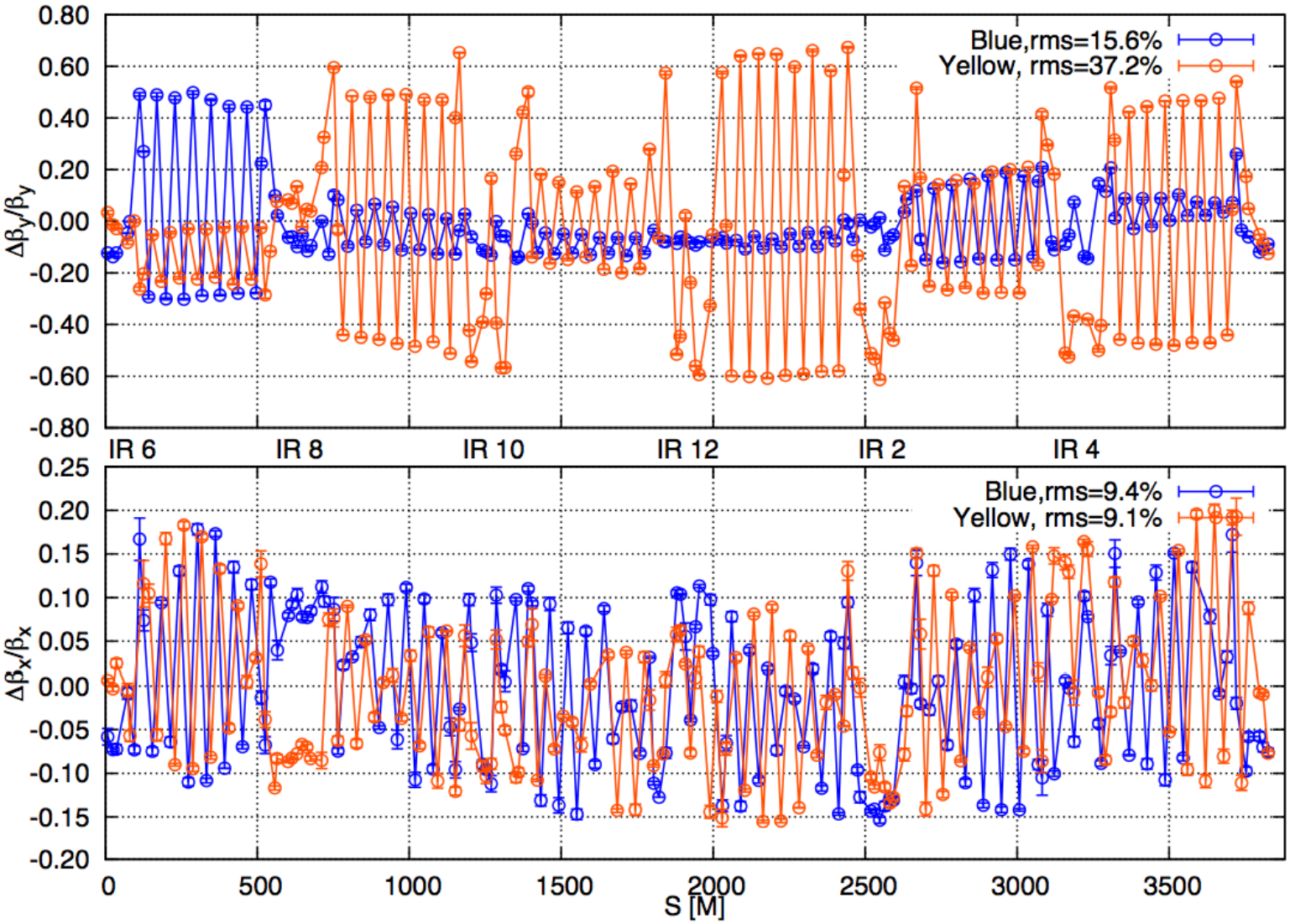
OpticsCorrection

- Implemented the technique to minimize the systematic errors on the optics extracted from driven oscillations



RHIC Optics Measurement Using AC dipole

OpticsCorrection

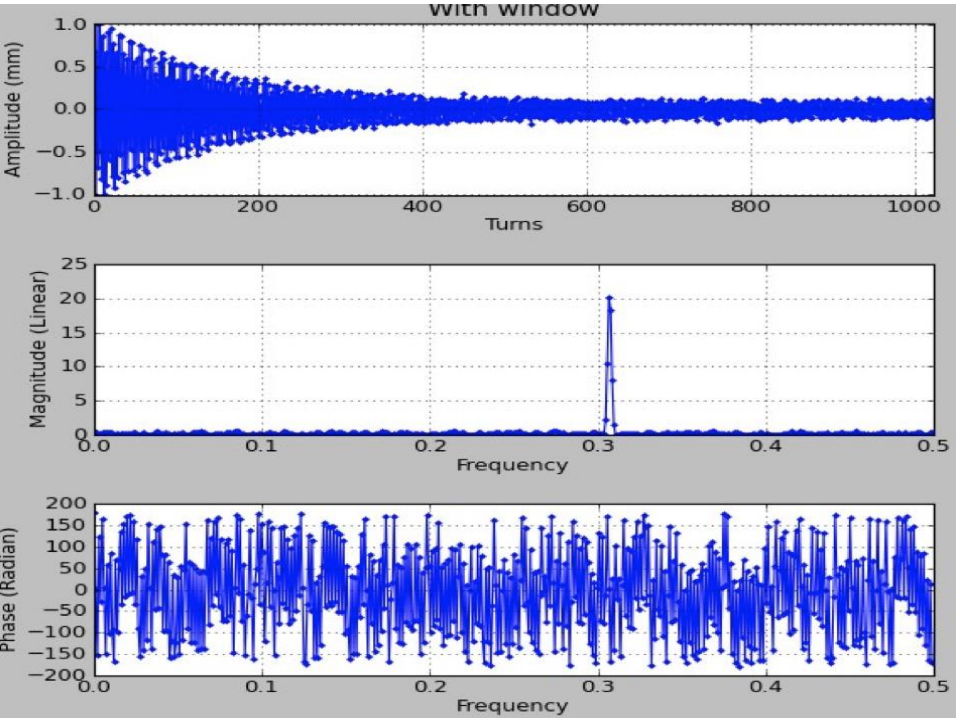


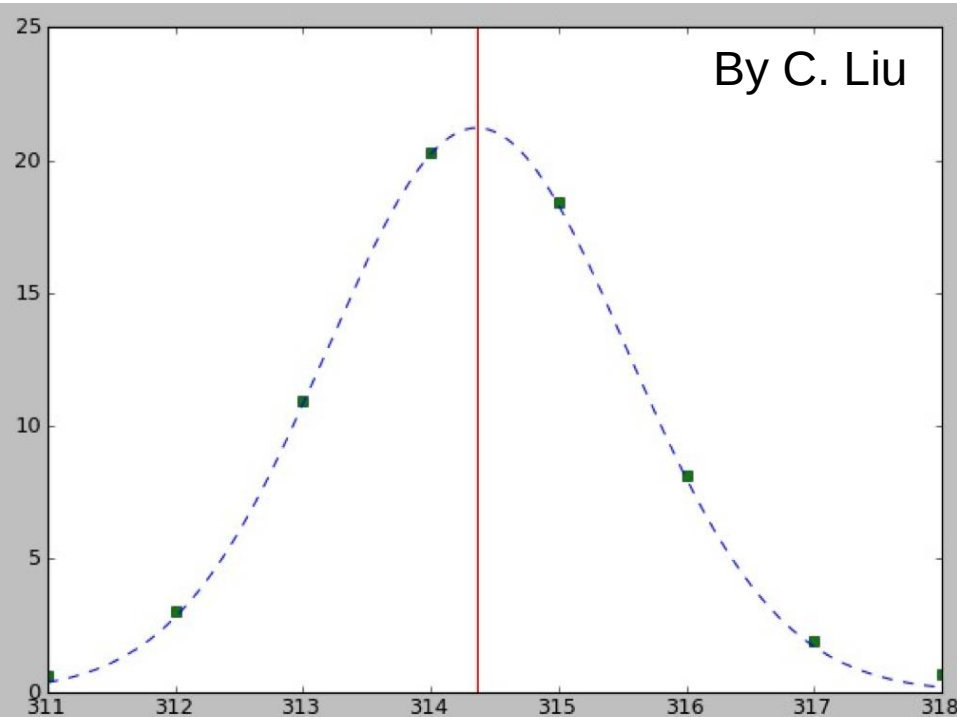
By X. Shen

Status of RHIC Optics Measurement Using Tune Kicker

OpticsCorrection

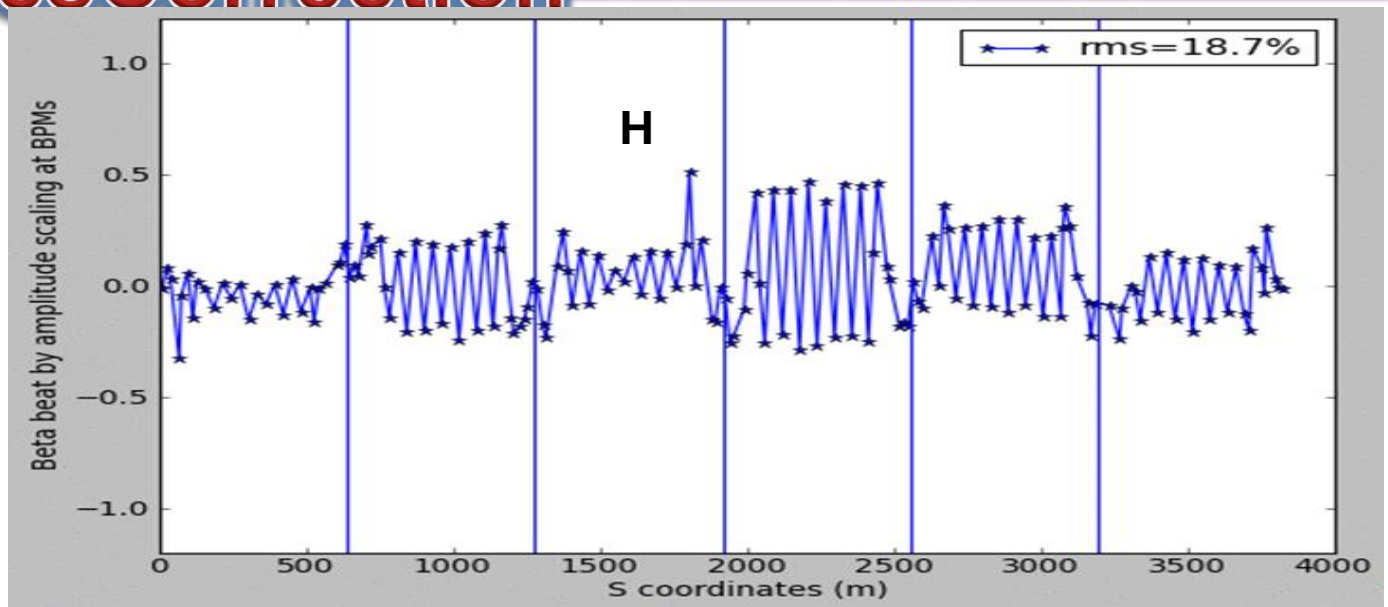
- Significant improvement of optics measurement using tune-meter kicker using Gasior/Godzalez technique [2](C. Liu)
  - frequency of a sinusoidal component can be determined with improved resolution by fitting an interpolating parabola through the three largest consecutive bins corresponding to the component
  - Apply CFT to get the amplitude and phase between bpms.

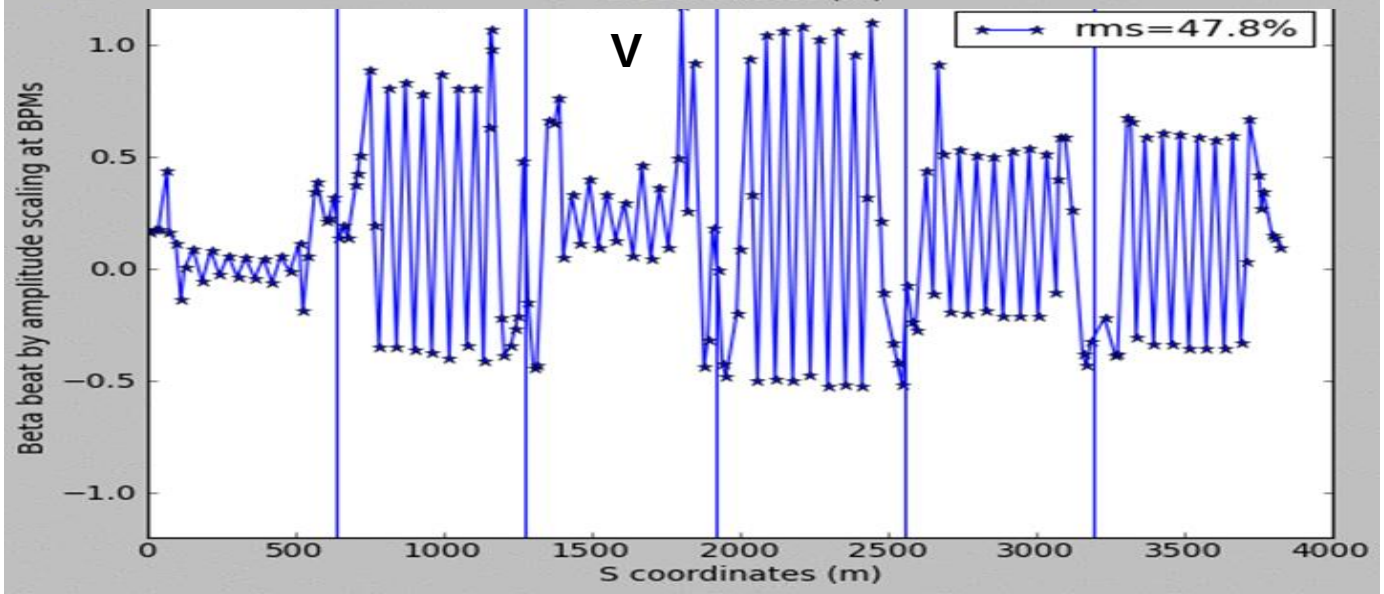




Optics Measurement at Store: Yellow

OpticsCorrection





By C. Liu

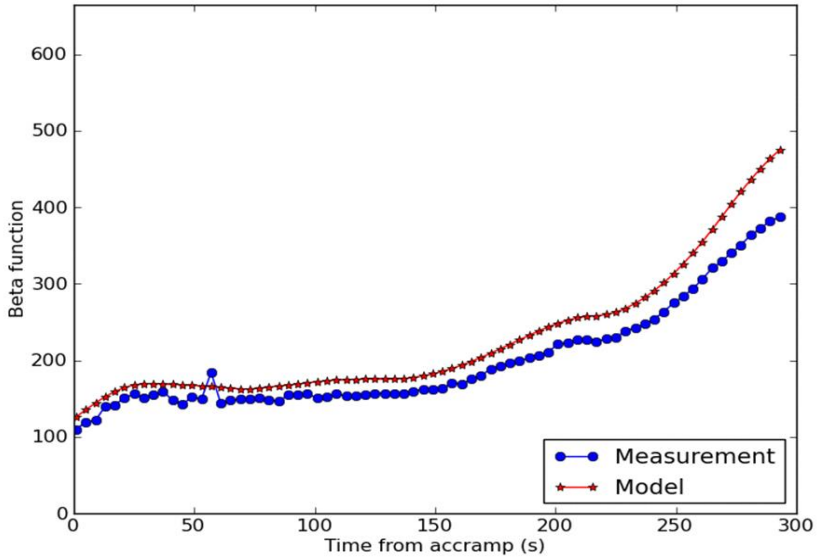
Status of RHIC Optics Measurement Using Tune Kicker

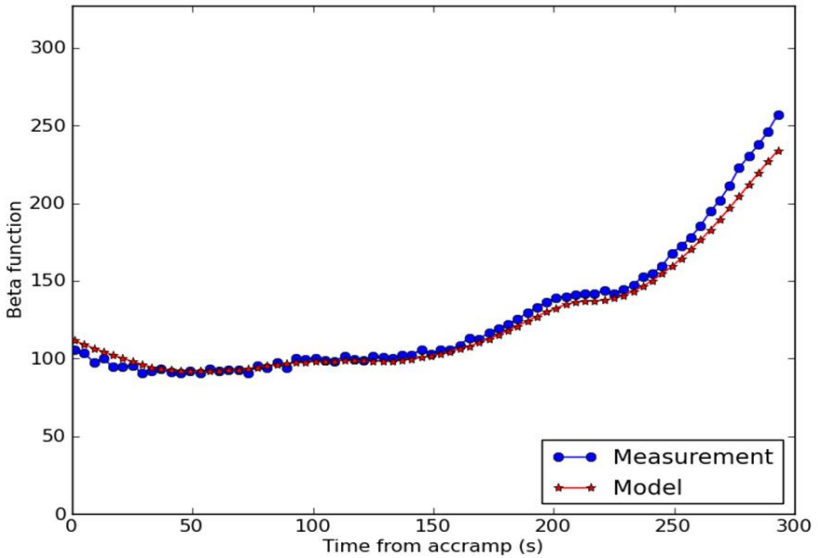
OpticsCorrection

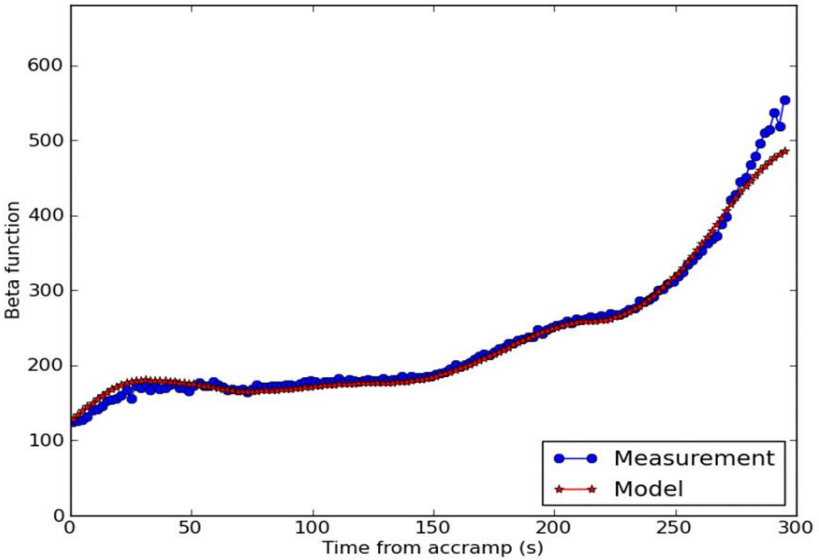
- Significant improvement of optics measurement with tune-meter kicker using Gasior/Godzalez technique[AB Note-2004-021. This was primarily implemented by C. Liu
  - frequency of a sinusoidal component can be determined with improved resolution by fitting an interpolating parabola through the three largest consecutive bins corresponding to the component
  - Apply Conitinous FFT to get the amplitude and phase between bpms
  - This improved the frequency resolution from kicked data from 1.9x10^-5 in 2009 to 1.3x10^-5 in 2012.
  - This allowed optics measurement along the energy ramp, which is implemented in 2013

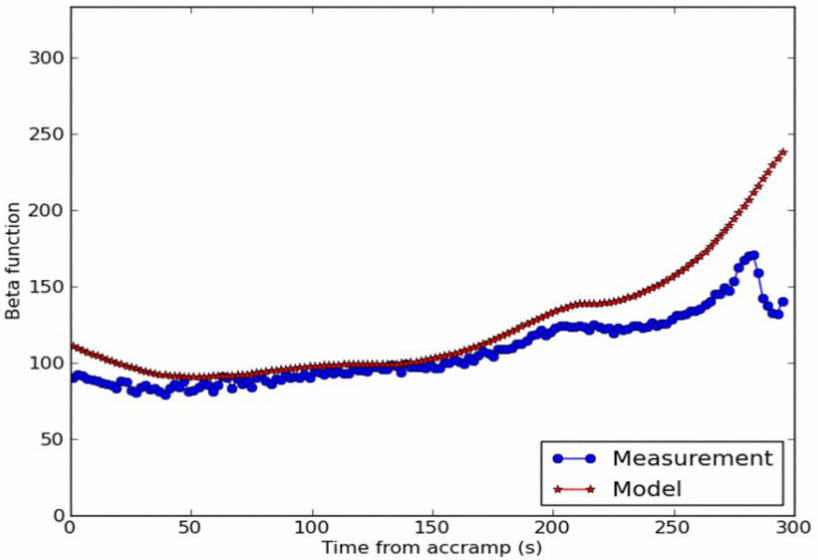
β-Function Measurement at IPM during the Energy Ramp

OpticsCorrection









By MInty

Status of RHIC Optics Correction

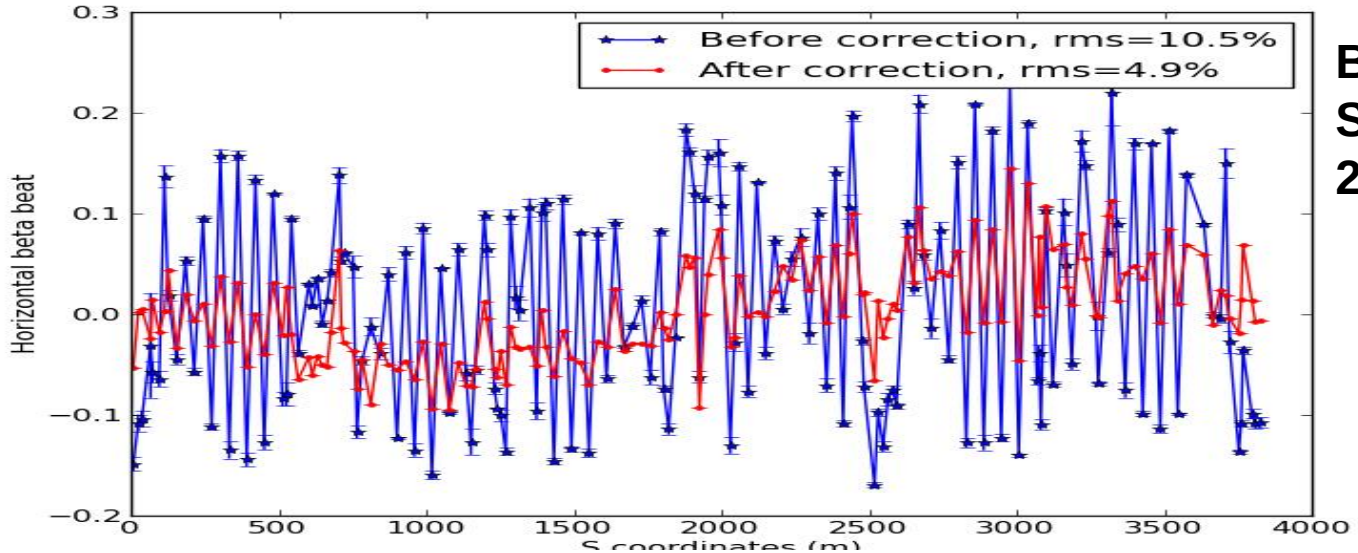
OpticsCorrection

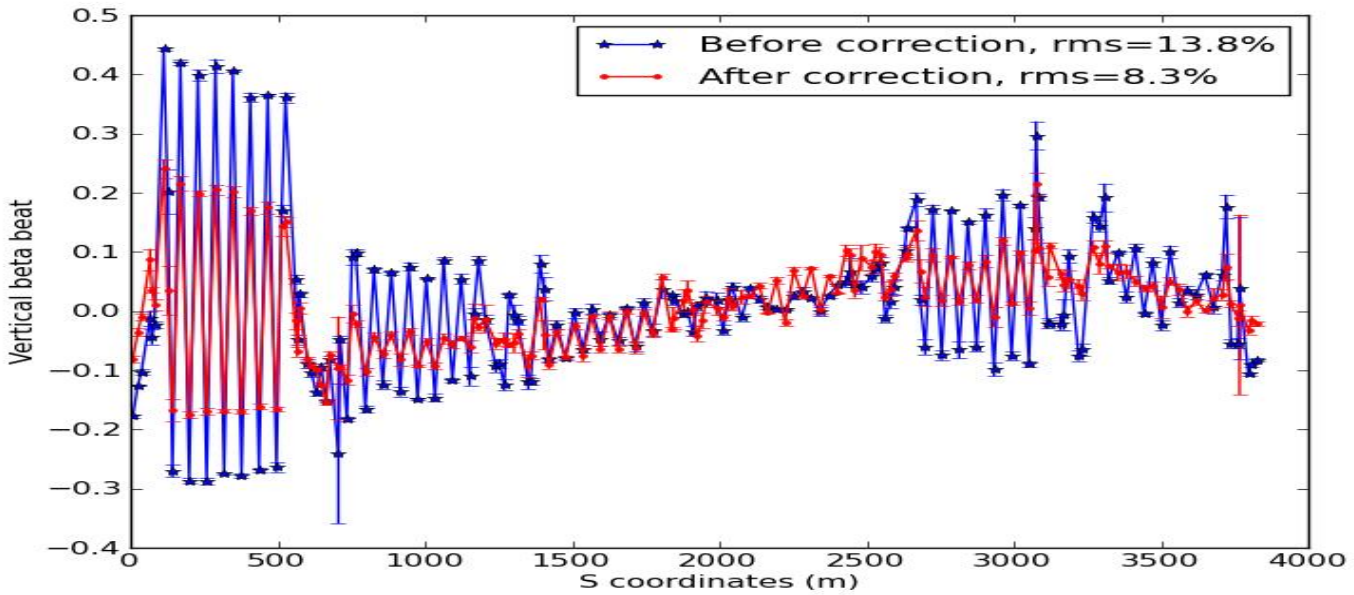
- Two independent methods were both implemented
  - SVD based correction based on beta-beat from free oscillation, implemented by C. Liu
    - Beta-beat response matrix based
    - Use all the independent quadrupoles in the IR
    - Applied with RHIC tune/coupling feedback

Free Oscillation Based Optics Correction Result

C. Liu, M. Minty, A. Marusic

OpticsCorrection





Blue Ring at Store energy of 255GeV

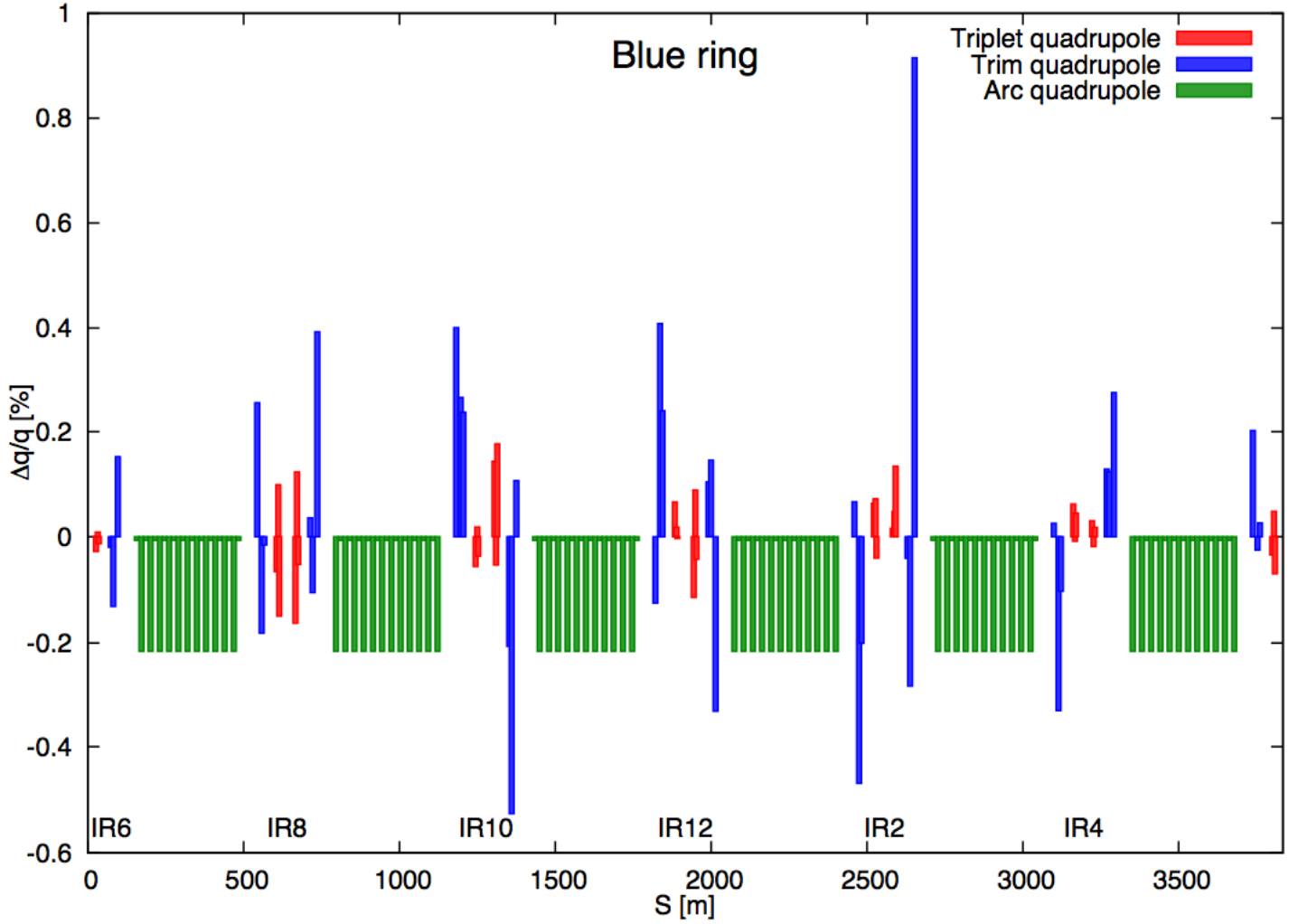
Status of RHIC Optics Correction

OpticsCorrection

- Two independent methods were both implemented
  - Optimum global optics correction(OGOC) based on beta-beat measured by AC dipoles: implemented by X. Shen
    - Beta-beat and betatron tune response matrix based
    - Use all the independent quadrupoles in the IR including triplets as well as all arc quadrupoles.
    - Minimize beta-beat without changing tune

Calculated Correction Strength for Measured Beta-beat in Blue Ring

OpticsCorrection

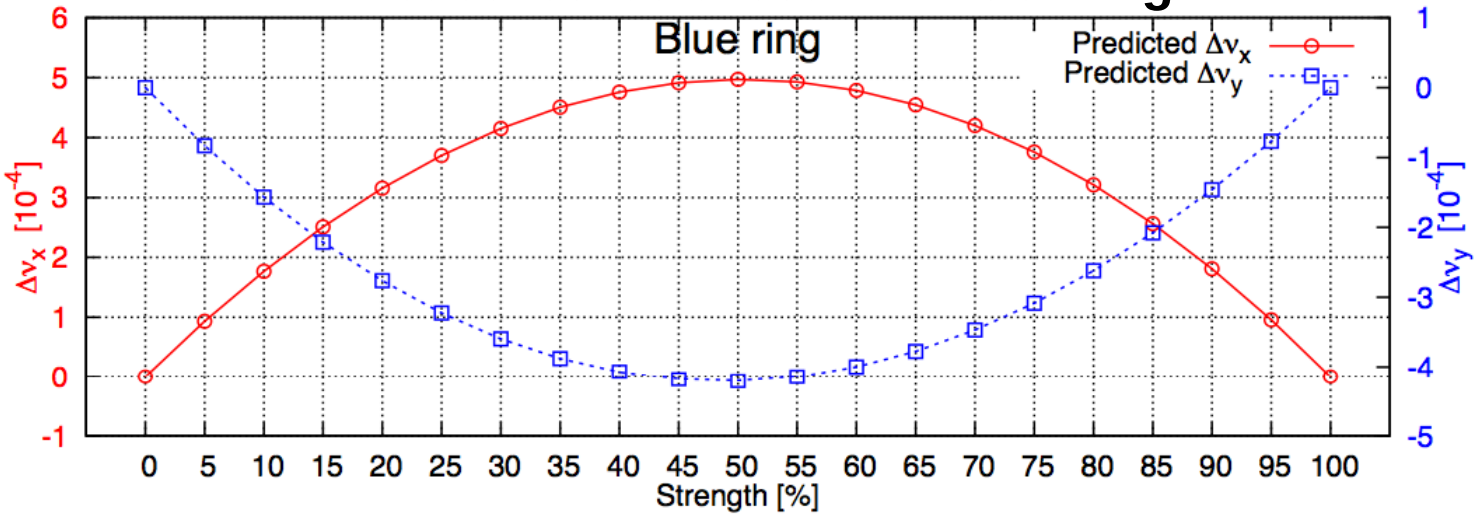


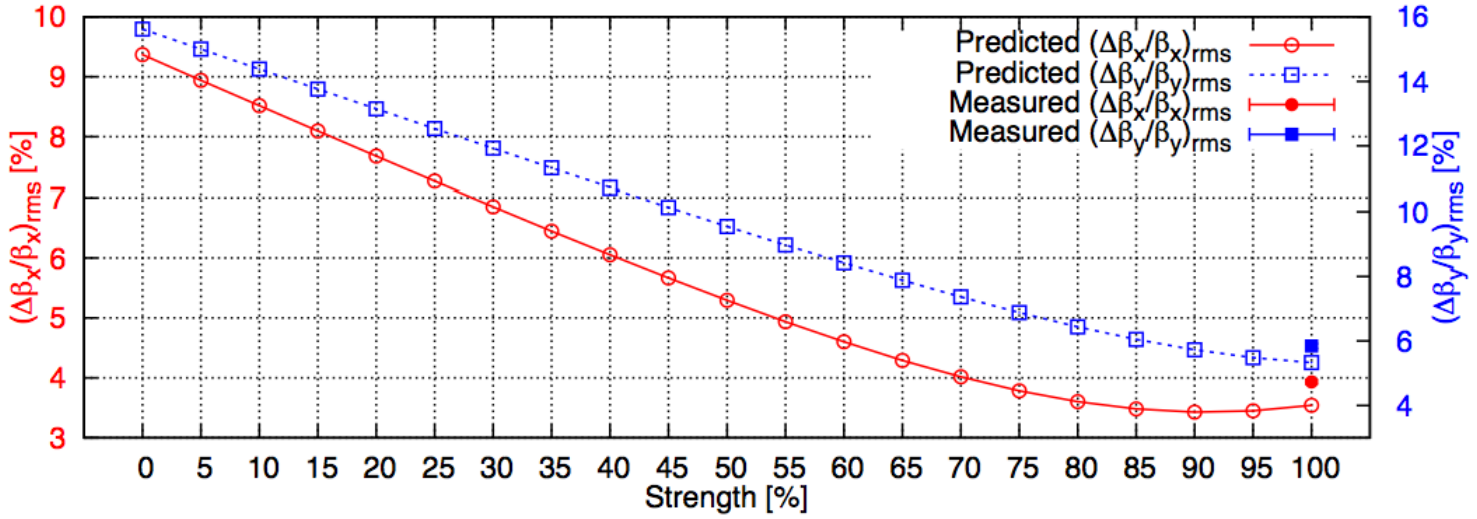
By X. Shen

Prediction of OGOC Knob in BLUE

OpticsCorrection

Calculated tune-change/residual beta-beat for correcting Measured beta-beat in Blue Ring

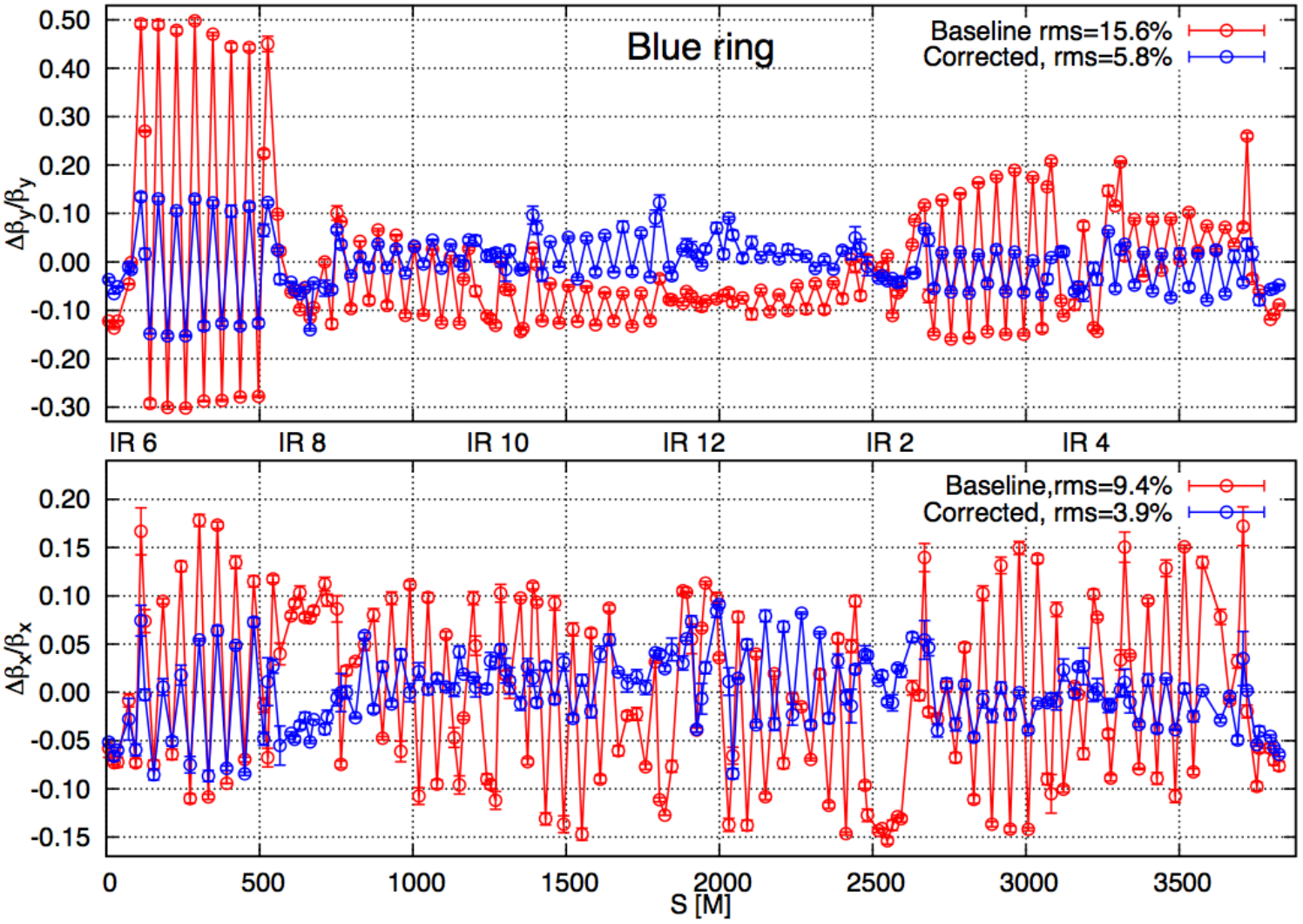




By X. Shen

Calculated Correction Strength for Measured Beta-beat in Blue Ring

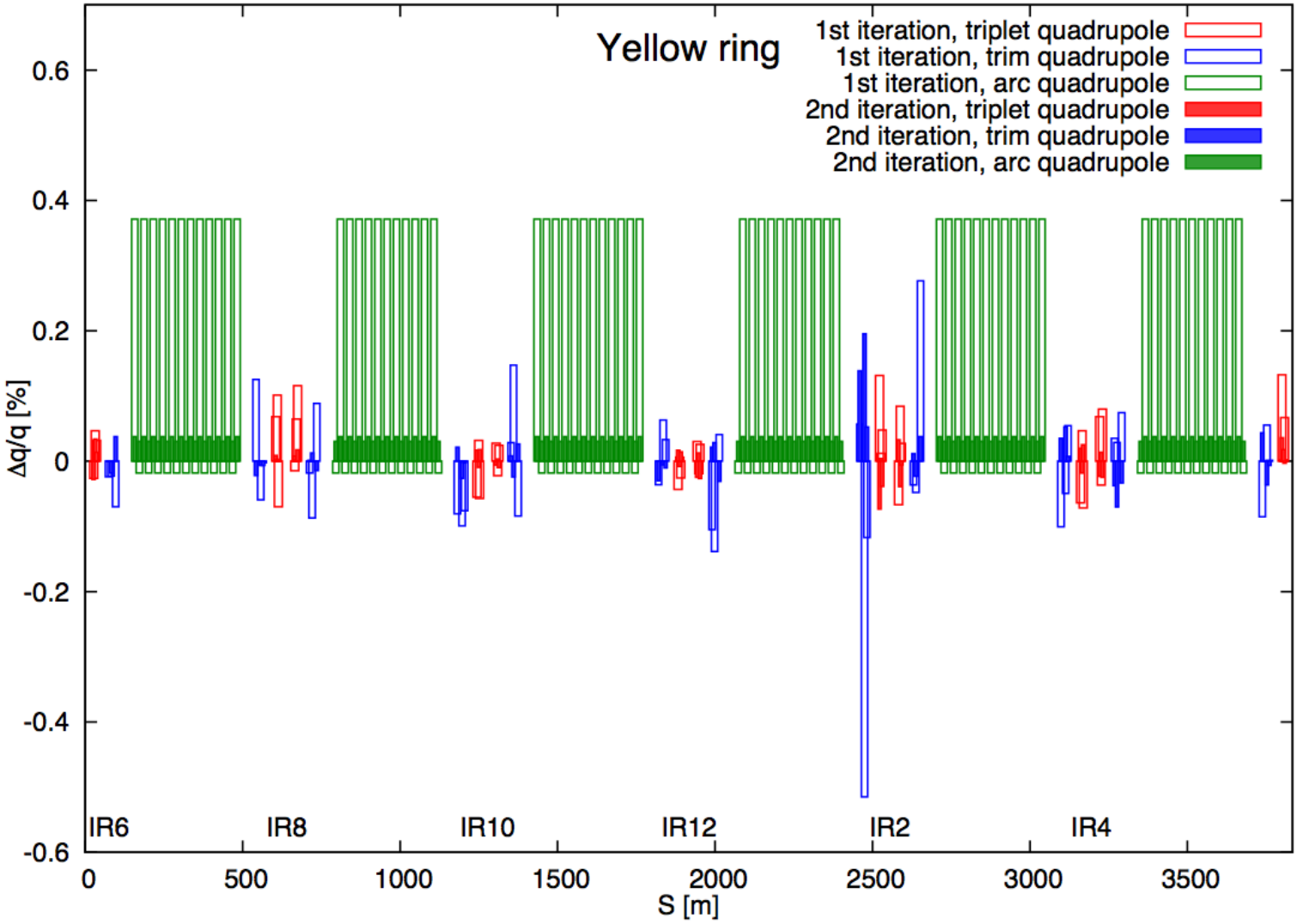
OpticsCorrection



By X. Shen

Calculated Correction Strength for Measured Beta-beat in Yellow Ring

OpticsCorrection

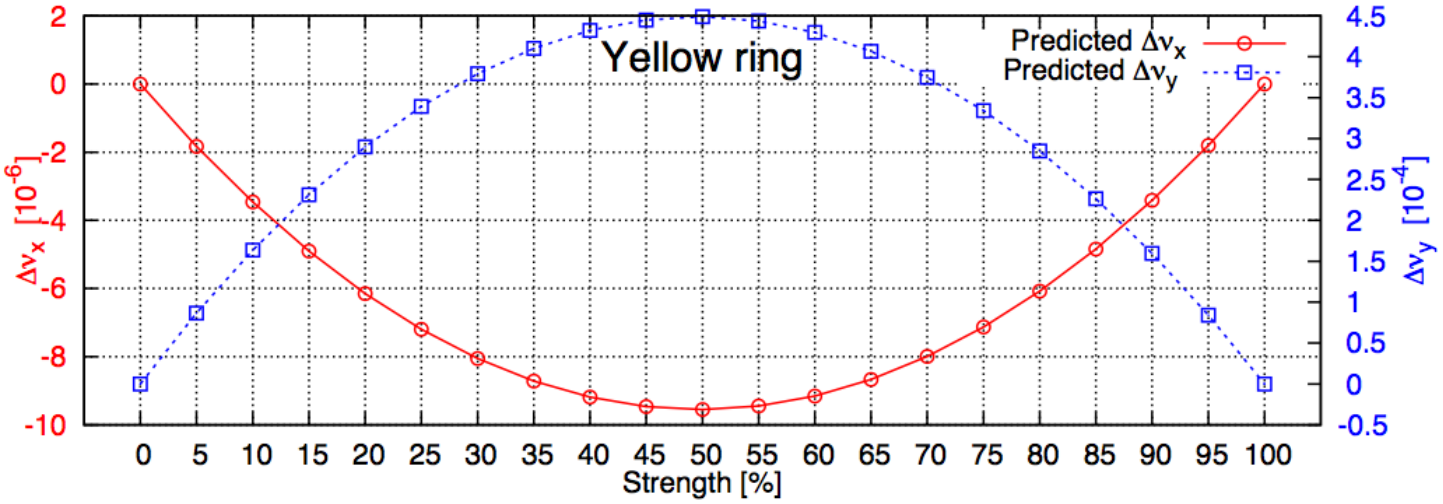


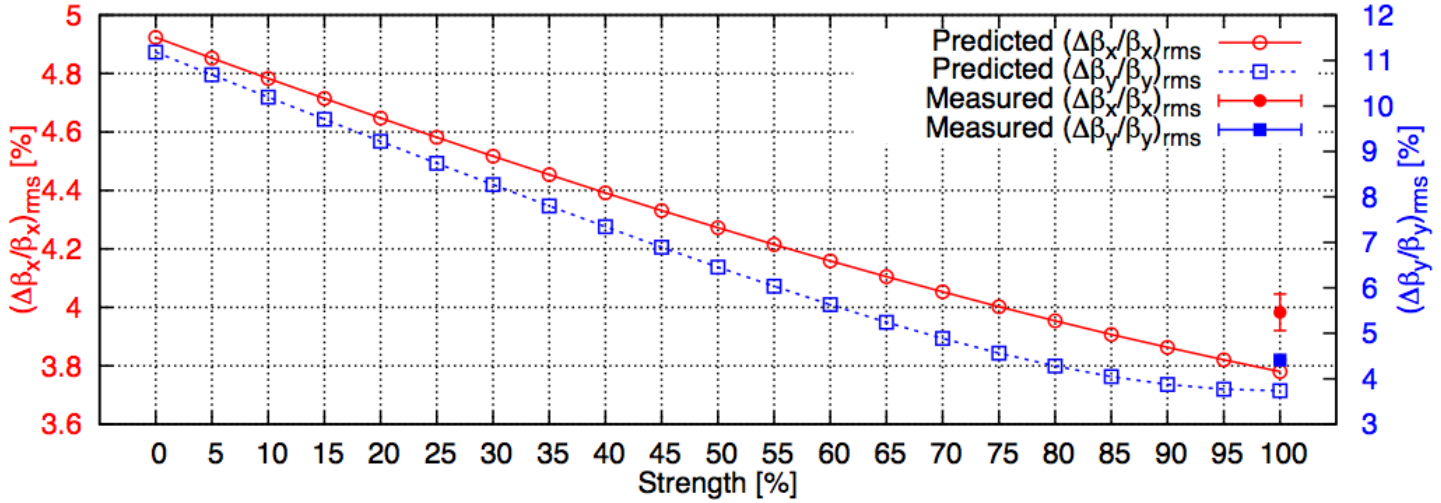
By X. Shen

Prediction of OGOC Knob in YELLOW

OpticsCorrection

Calculated tune-change/residual beta-beat for correcting Measured beta-beat in Yellow Ring

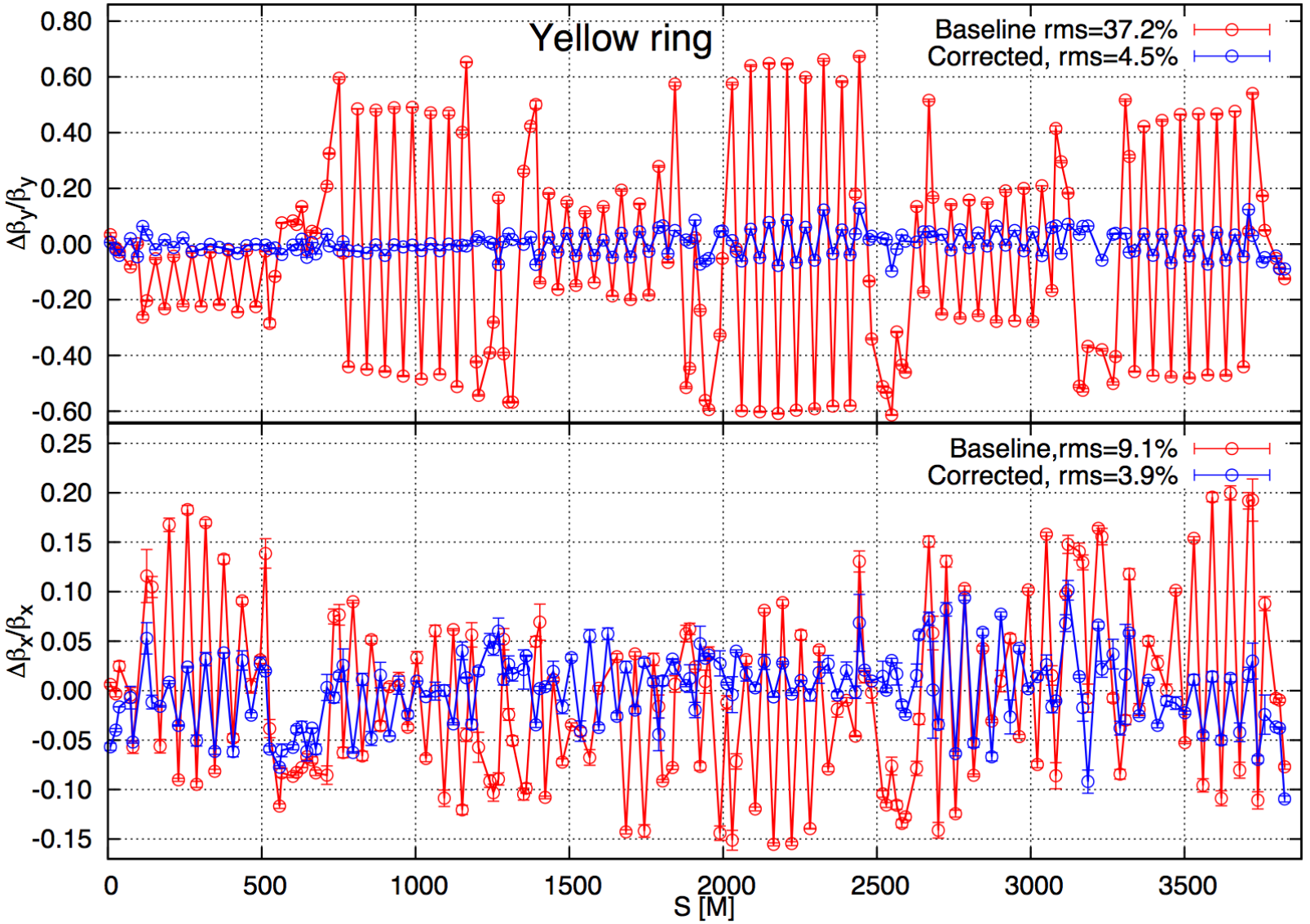




By X. Shen

AC dipole Based Optics Correction Result

OpticsCorrection



By X. Shen

Status of RHIC Optics Correction

OpticsCorrection

- Two independent methods were both implemented
  - Optimum global correction based on beta-beat measured with AC dipoles: implemented by X. Shen
    - Beta-beat and betatron tune response matrix based
    - Use all the independent quadrupoles in the IR as well as all arc quadrupoles
    - To minimize beta-beat without tune change
  - With the success of optimum global optics correction , we all tested the technique of using arc sextupoles to further reduce the arc beta-beat, proposed by R. Tomas(CERN) and S. White.

Proof-of-Principle Arc Beta-Beat Correction using Arc Sextupoles with Orbit Bumps

OpticsCorrection

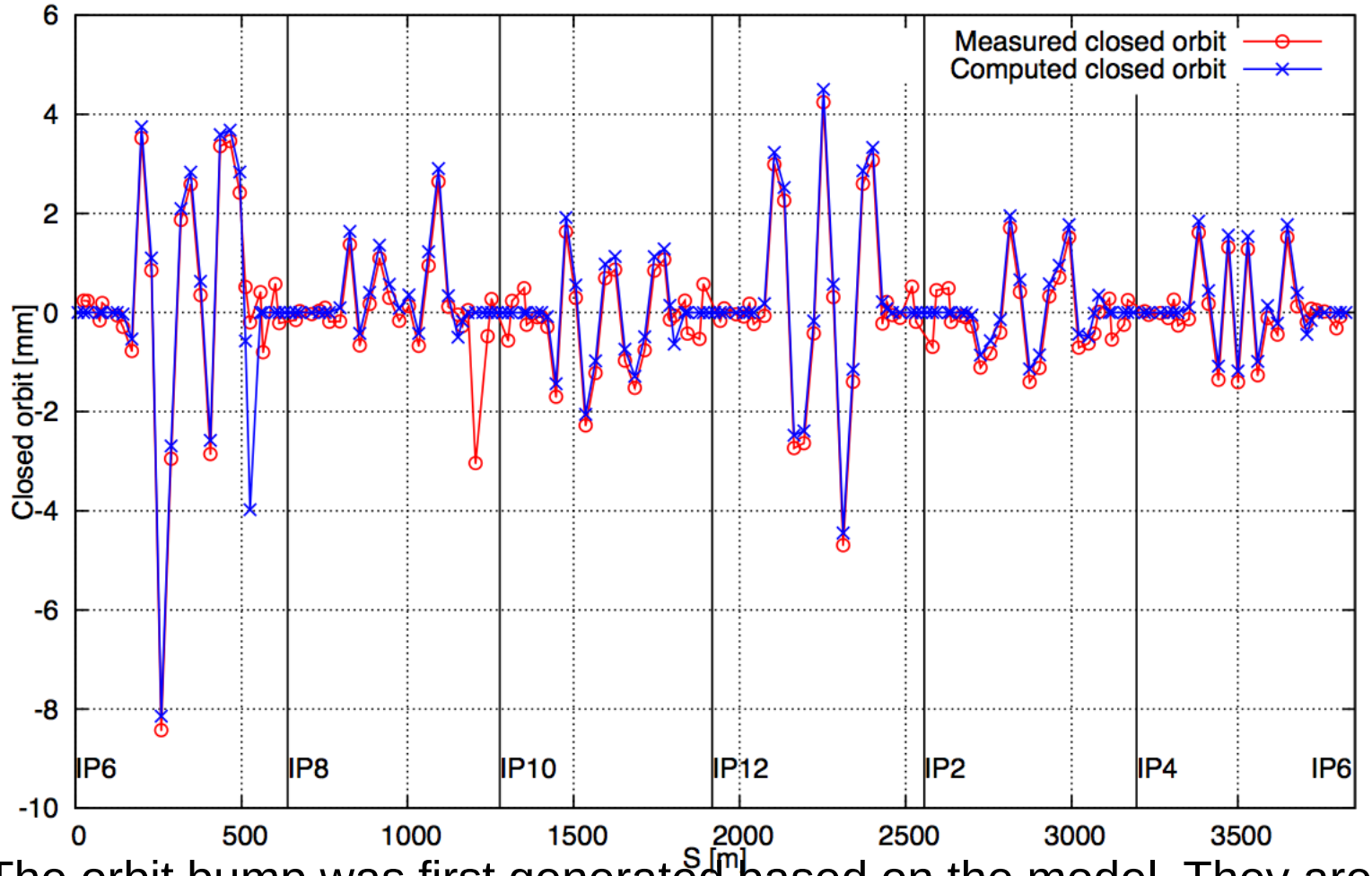
- RHIC quadrupoles in the arc don't have their own individual power supplies. Not possible to have independent knobs in these areas

- Proposed by R. Tomas and S. White to construct independent beta-beat knobs using arc sextupoles with their localized orbit bumps

- If demonstrated, this allows one to have much better control of the phase advance in the arcs for applications which desire specific requirements on optics

Orbit Bumps at Arc Sextupoles

OpticsCorrection

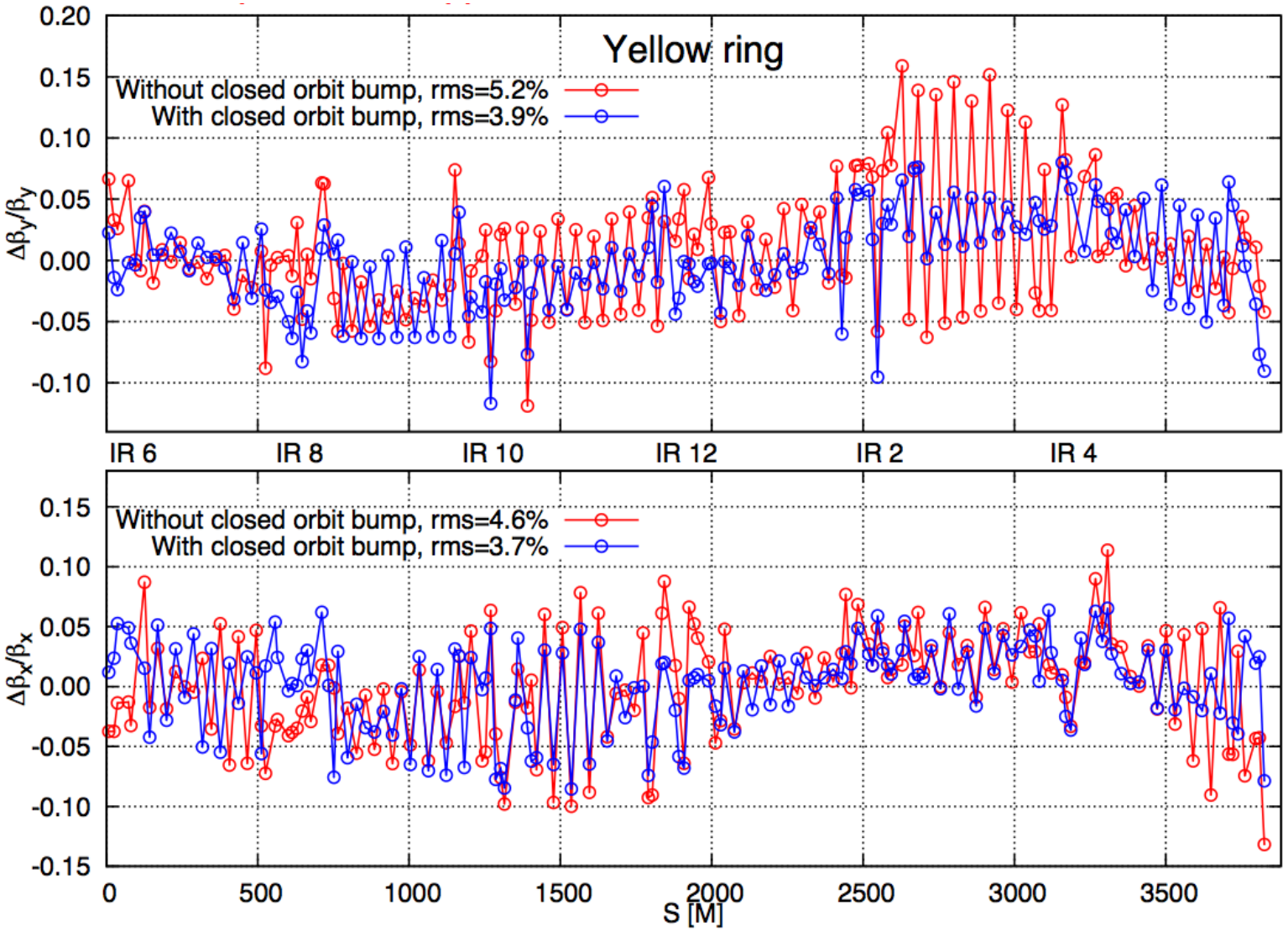


The orbit bump was first generated based on the model. They are implemented with the orbit feedback[X. Shen and A. Marusic].

By X. Shen

Proof-of-Principle Arc Beta-Beat Correction using Arc Sextupoles with Orbit Bumps

OpticsCorrection



By X. Shen

Summary

OpticsCorrection

- A lot optics activities happened during RHIC RUN 13. Great!!!
  - The implementation of Gasior/Godzalez technique by Liu greatly improved the capability of using free oscillation data to measure optics including fantastic optics measurement during energy ramp. This also led the great success of SVD based global optics correction
  - The AC dipole based optics measurement was greatly improved with both the **ICA** algorithm(Shen) as well as the technique to minimize the driven oscillation systematics.

Summary

OpticsCorrection

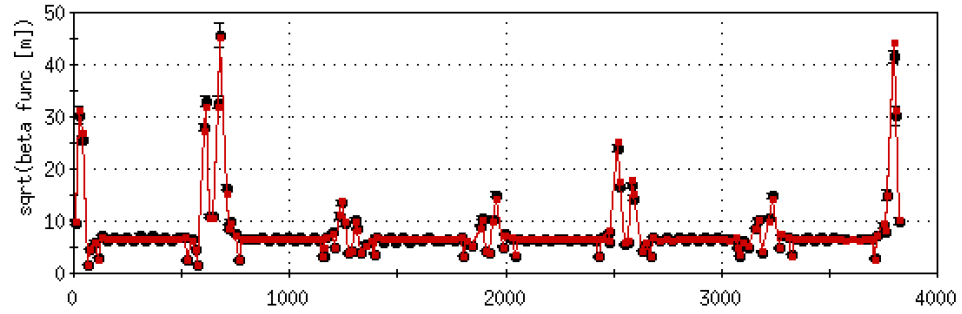
- A lot optics activities happened during RHIC RUN 13. Great!!!
  - An optimum global optics correction algorithm was also successfully developed and implemented, on the basis of which, the proof-of-principle of using arc sextupoles to further reduce the arc beta-beat was successfully demonstrated in the Yellow Ring at store energy of 255GeV

- Plan for next run
  - Absorb the successes from RUN 13 and Improve the online optics application(Guillaume) for optics measurement as well as optics correction

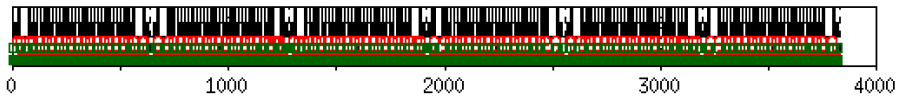
High Level Application (Guillaume)

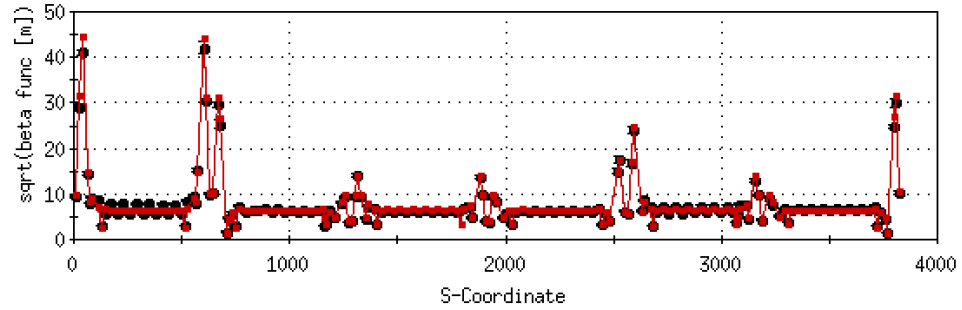
OpticsCorrection

Betatron/Phase Advance | Betatron (w/o model) | Beta Beat | Chi-Square



Beam ==> Lattice: Blue





Setup/Betatron Tunes

	/\Qd	Amp	Up	Flat	Down	Tune	Qd
H:	0.3050	0.0195	1.0000	1.0000	1.0000	0.6950	1.0000
V:	0.3150	0.0000	1.0000	1.0000	1.0000	0.6850	1.0000

PS State

Horizontal	Off	On
Vertical	Off	On

Options

Trigger AC Dipole

Accumulate Avg

Horizontal Beta* at IPs

	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	2.23	6.05	0.68	0.58	6.82	6.01
H_bIP	2.26	6.06	0.68	0.59	6.95	6.04
H_s*	-0.26	-0.20	-0.02	0.08	-0.92	0.40
H_muIP	104.471	165.801	200.851	125.026	115.685	166.700

Vertical Beta* at IPs

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	2.05	7.31	0.70	0.67	7.17	7.17
V_bIP	2.19	7.40	0.92	0.88	7.19	7.20
V_s*	0.53	0.78	0.39	0.37	-0.30	0.47
V_muIP	208.1	192.5	190.5	110.8	220.7	225.4

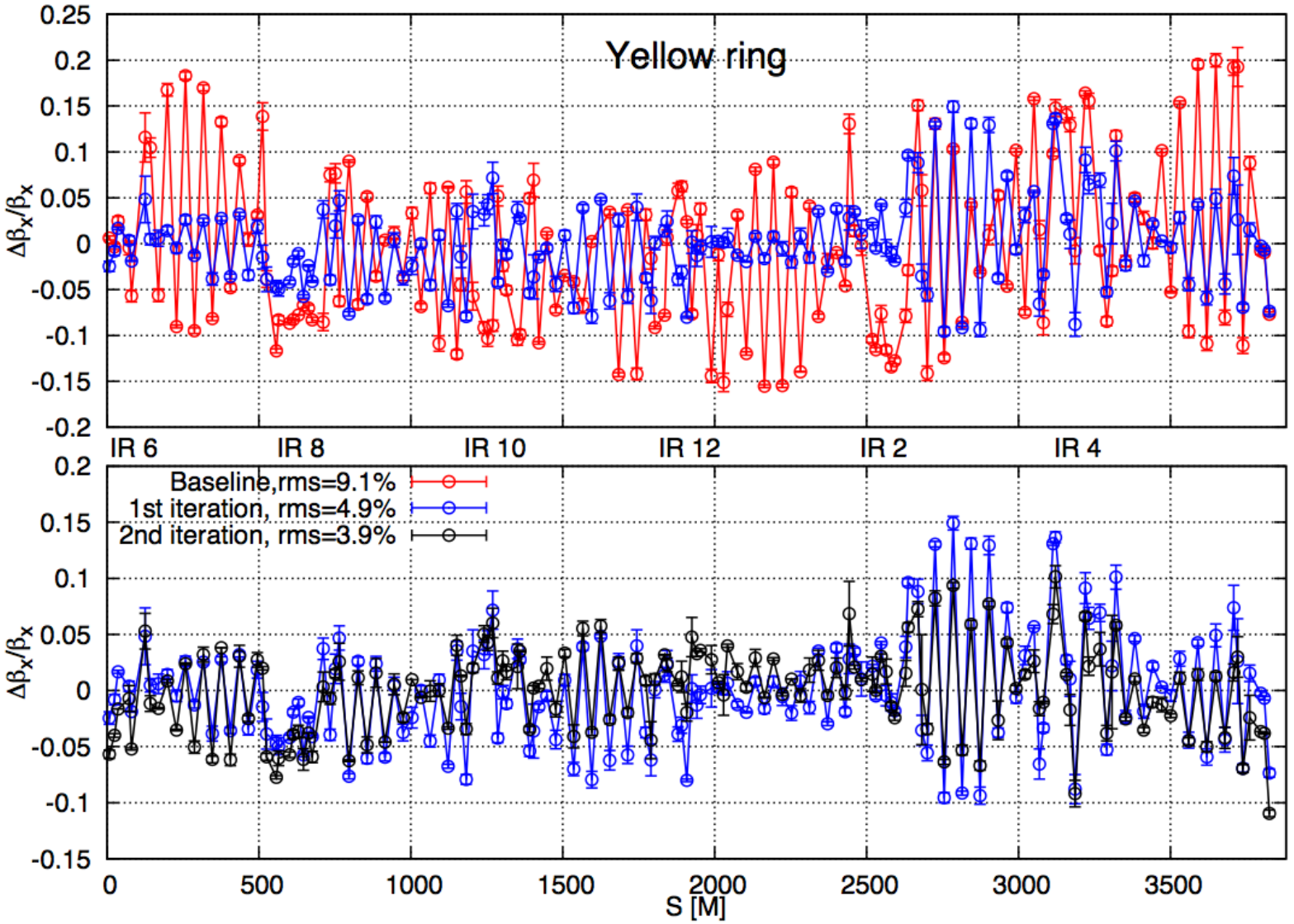
Summary

OpticsCorrection

- Plan for future
  - Absorb the successes from RUN 13 and Improve the online optics application(Guillaume) for optics measurement as well as optics correction
  - New algorithm for AC dipole based optics measurement/correction to eliminate the driven oscillation systematic. And new technique to make ac dipole driven oscillation more robust and adiabatic to avoid beam loss and emittance growth in the presence of non-zero tune spread.

AC dipole Based Optics Correction Result (H)

OpticsCorrection



AC dipole Based Optics Correction Result (V)

OpticsCorrection