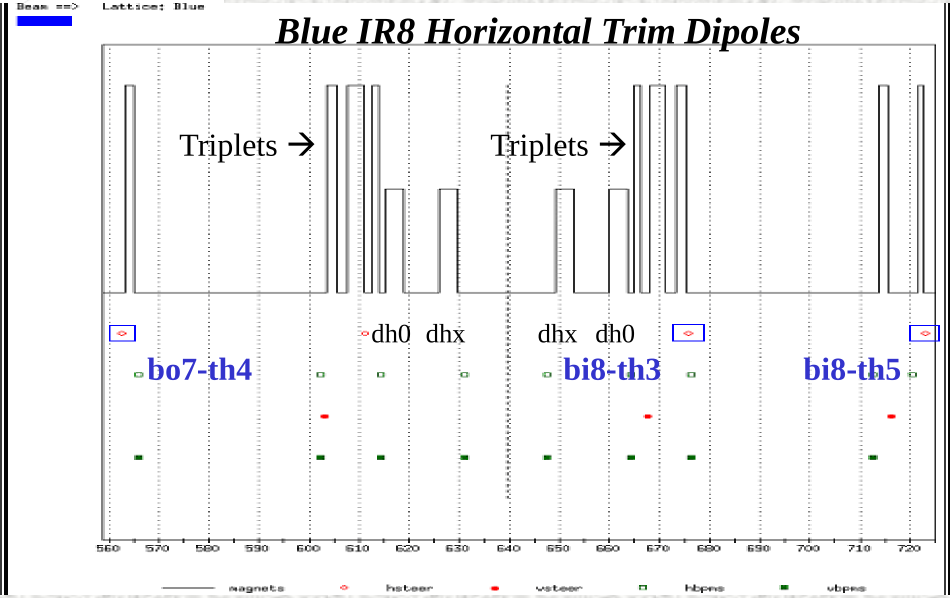
Run 8+9 Results and Future Plans for I.R. Non-linear Optics Corrections

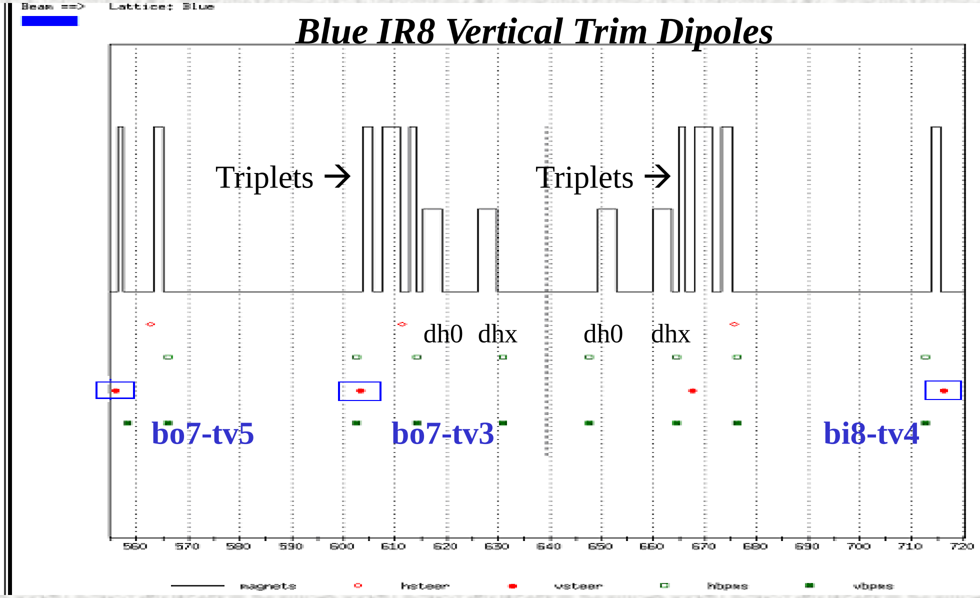
Chris Zimmer

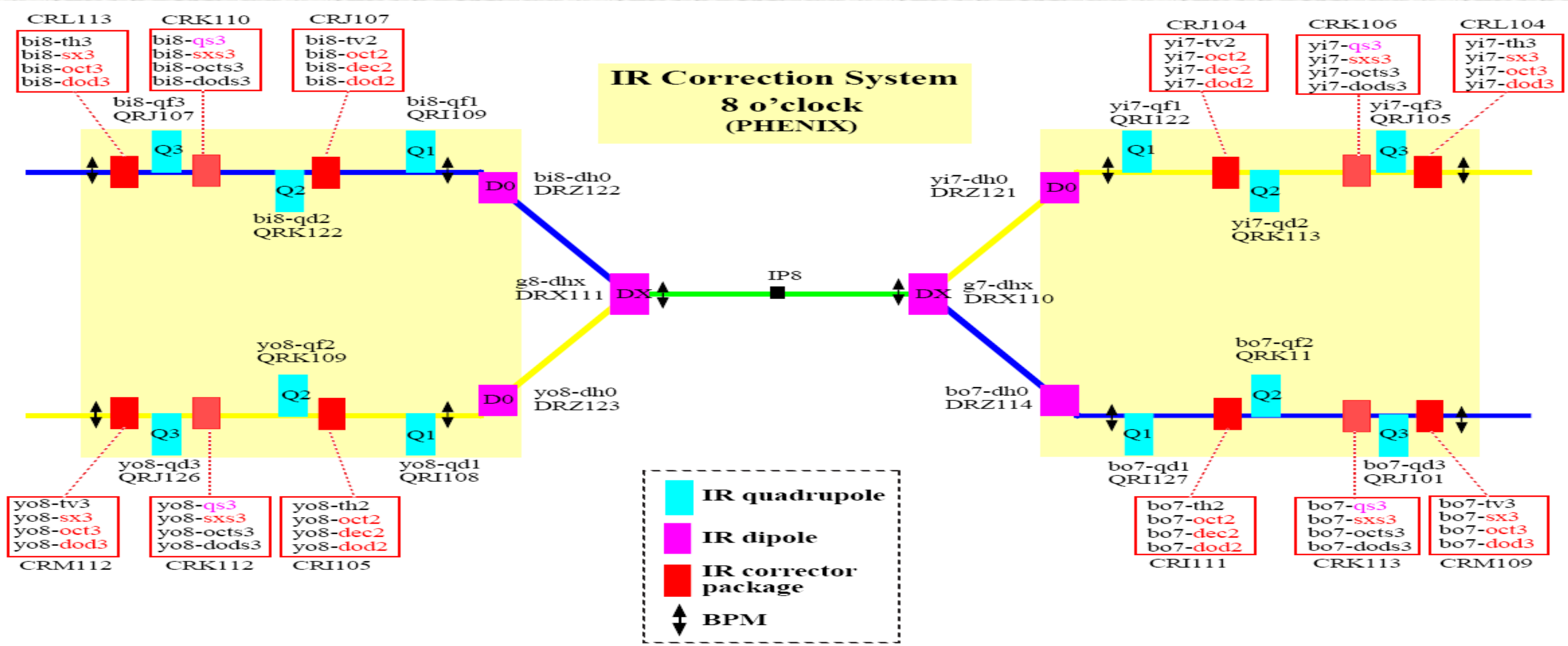
Introduction

- Normal sextupole and skew sextupole correction for the IR6 and IR8 triplets is adjusted during the set-up phase (octupole correction has been shown as effective but is not yet corrected for operationally)
- Dedicated 12x12 ramps
- Beam is anti-cogged to reduce beam-beam effects
- Orbit is corrected throughout the ring and centered through the triplets. The machine is de-coupled and the tunes are separated > 0.012 to further reduce coupling effects
- Apply a continuously-changing closed orbit three-bump to create an orbital excursion through the entire IR
- Orbital excursion through regions with non-linear fields (triplets) gives a measurable tune shift
- Horizontal bump used to produce tune-shift from normal sextupole fields, vertical bump used to produce tune-shift from skew sextupole fields in triplets
- One normal and one skew sextupole corrector for each triplet (two of each for a given IR/ring)
- Purposefully located at areas with relatively large β values
- Correctors at locations of higher β_x are more effective at nulling out horizontal tune shift, similarly correctors at locations of higher β_y more effective at nulling out vertical tune shift

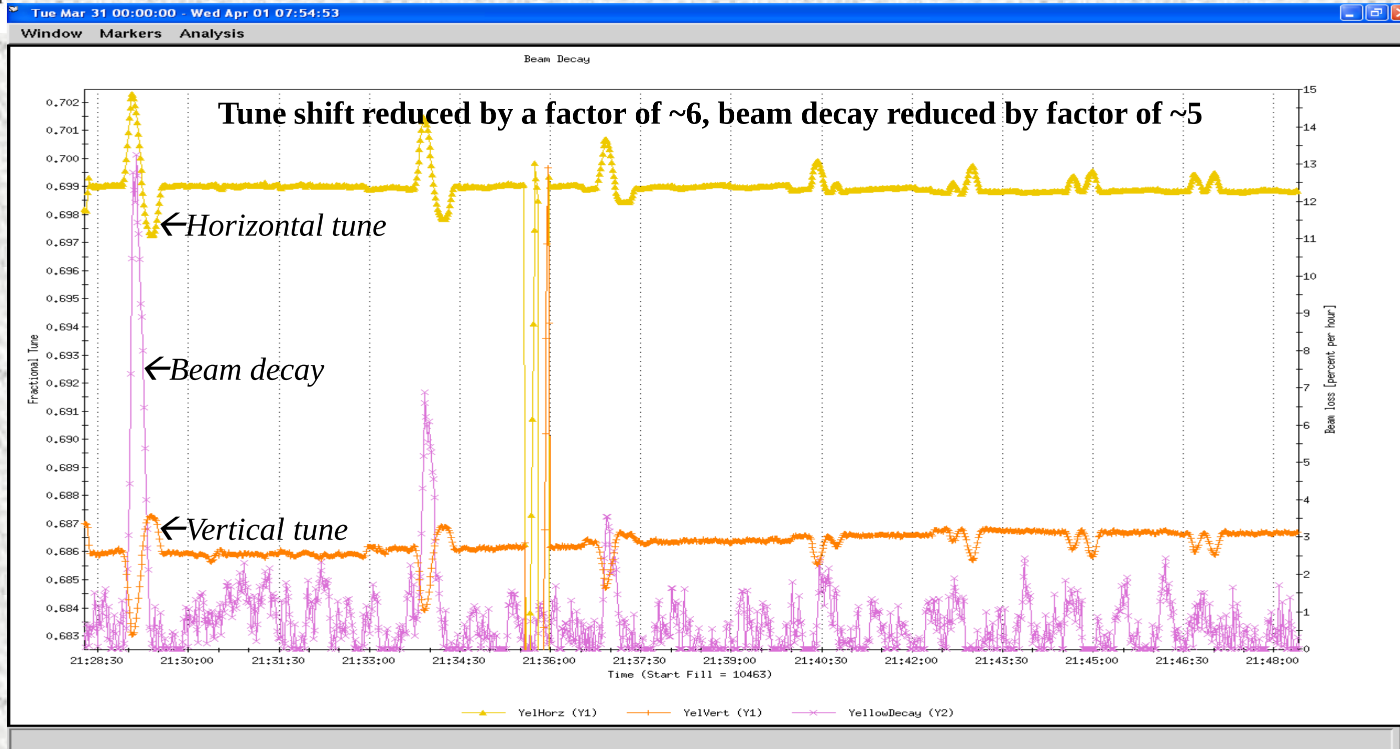
Magnet Locations

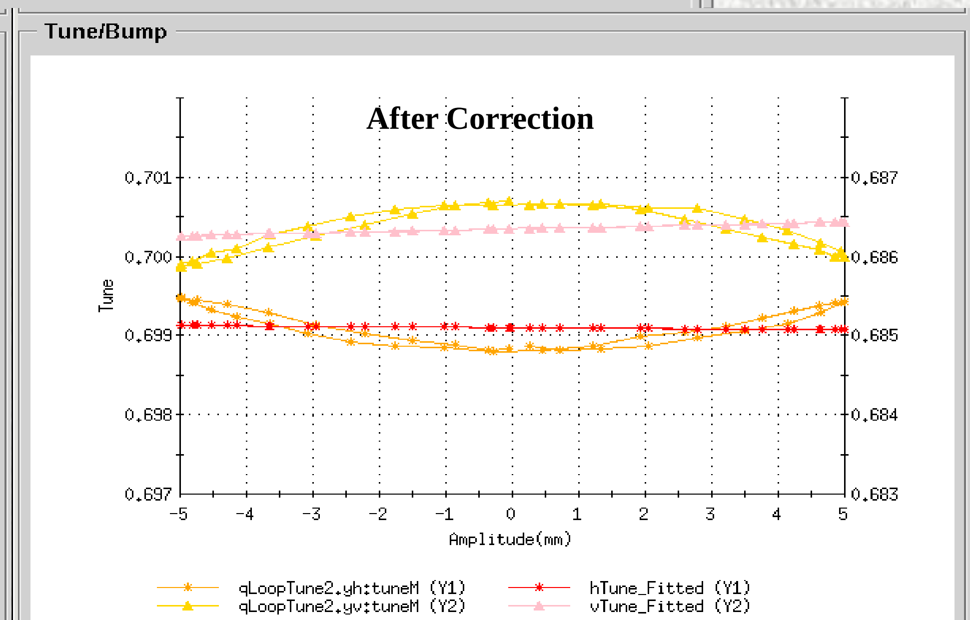




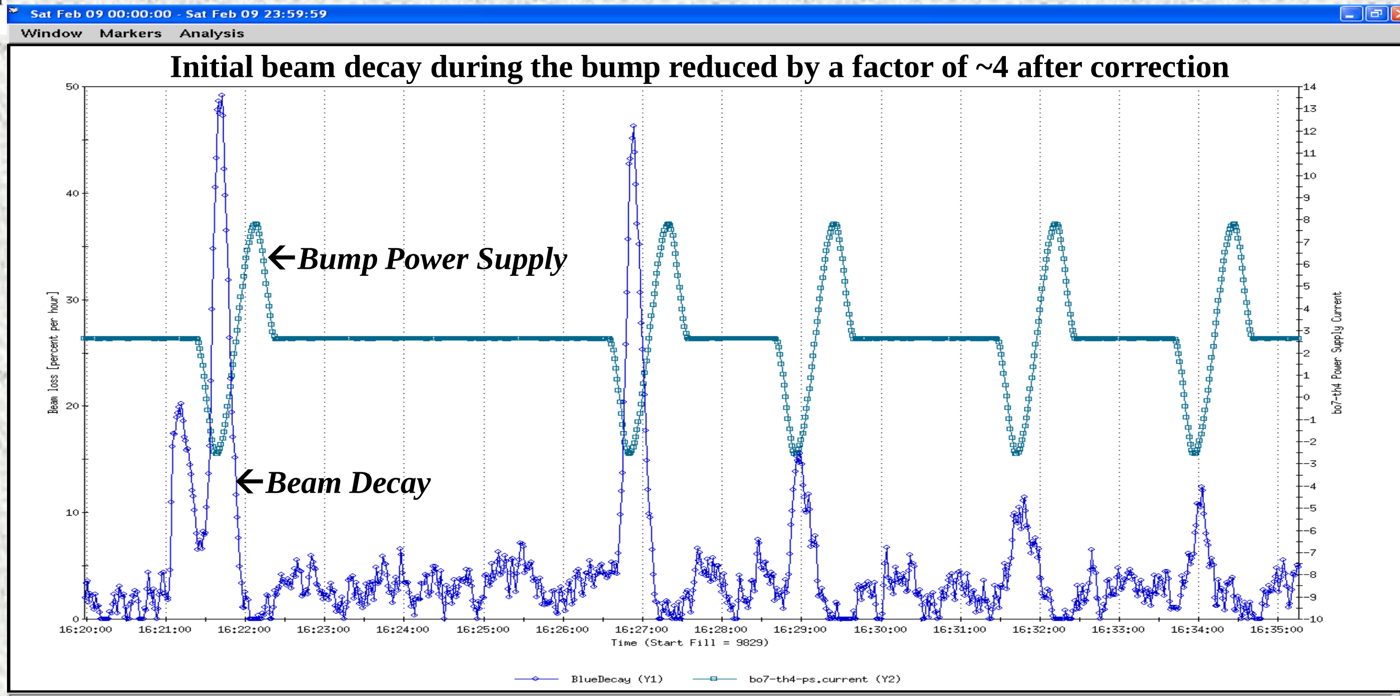


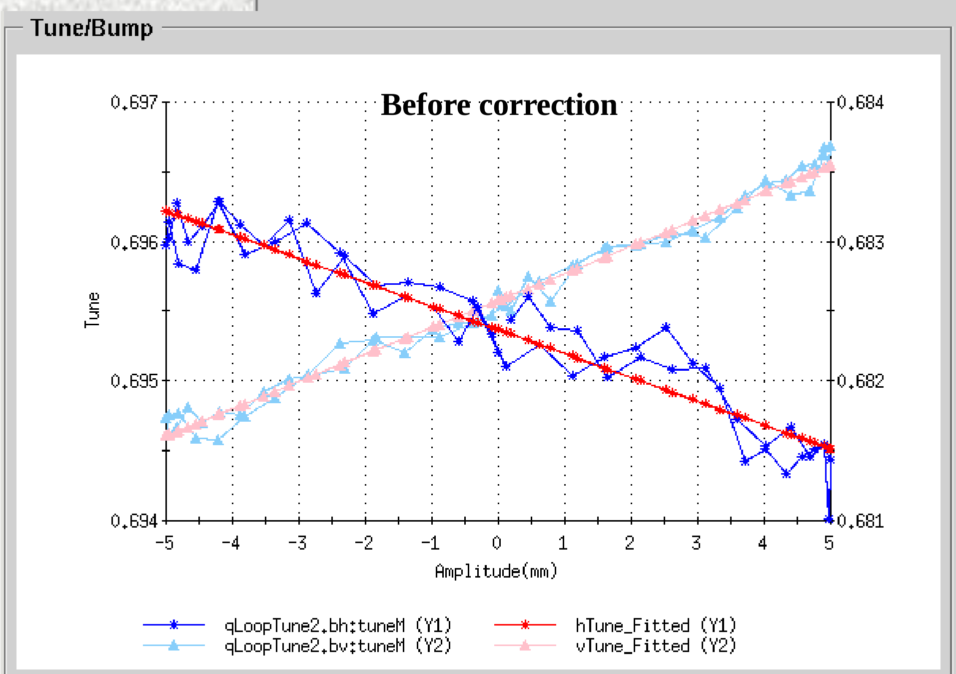
March 31st 2009 Normal Sextupole Correction Yellow IR8

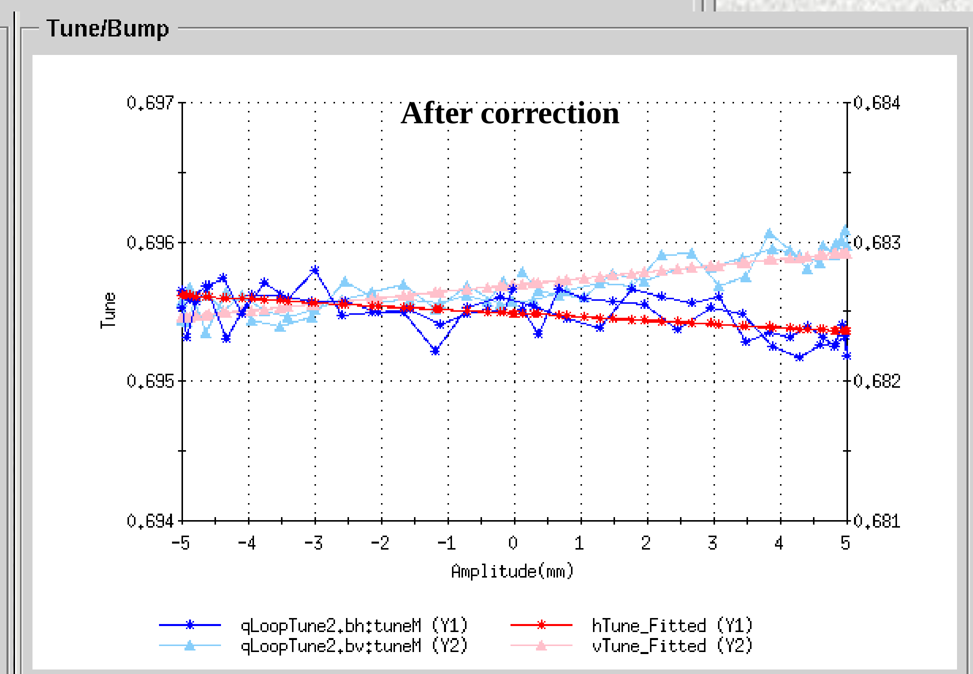




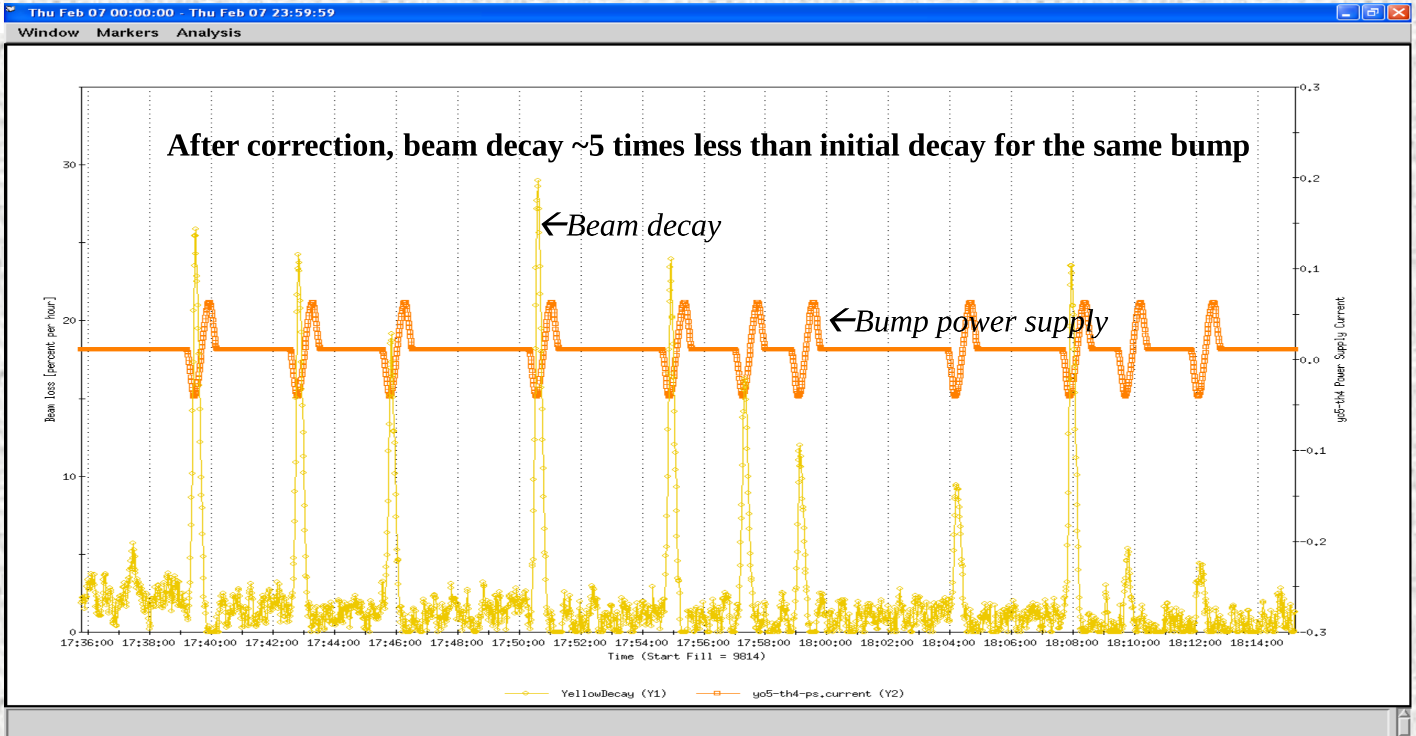
Feb. 9th 2008 Normal Sextupole Correction Blue IR8

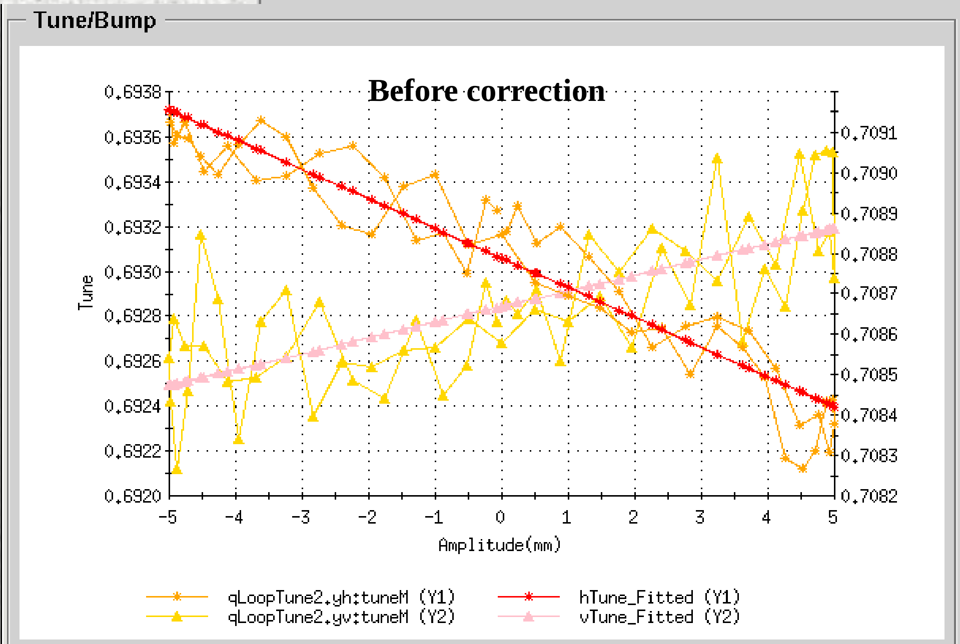


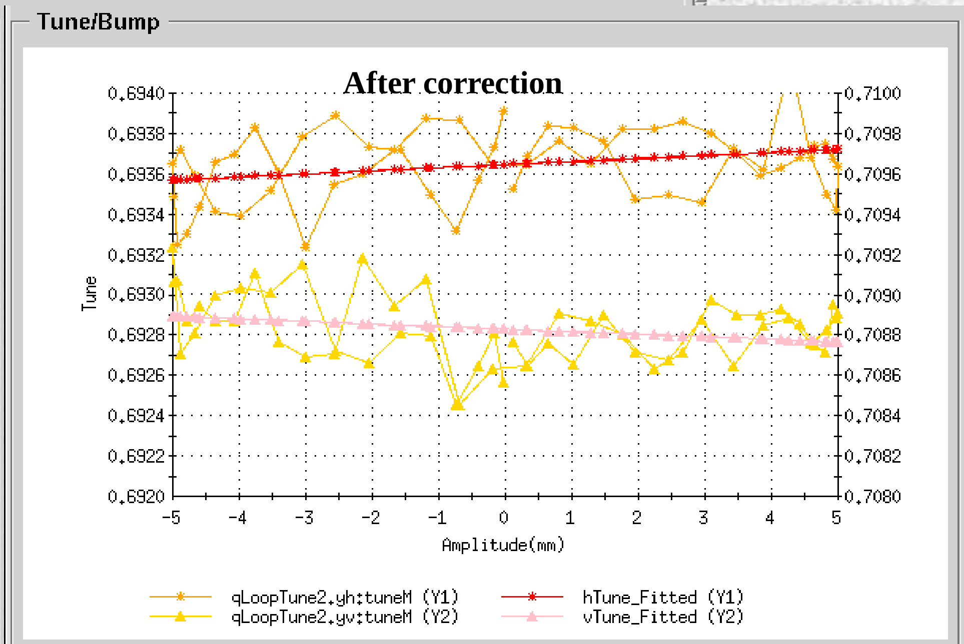




Feb. 7th 2008 Normal Sextupole Correction Yellow IR6

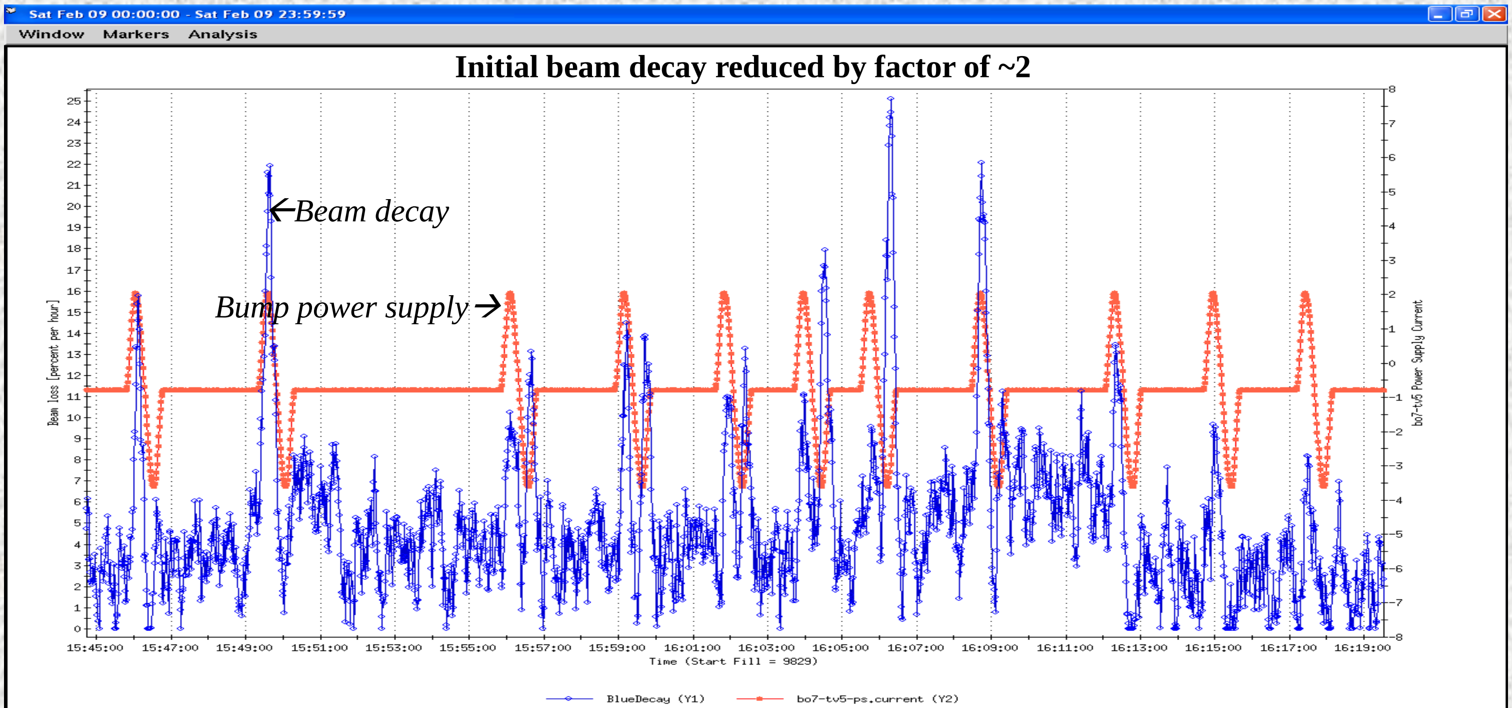


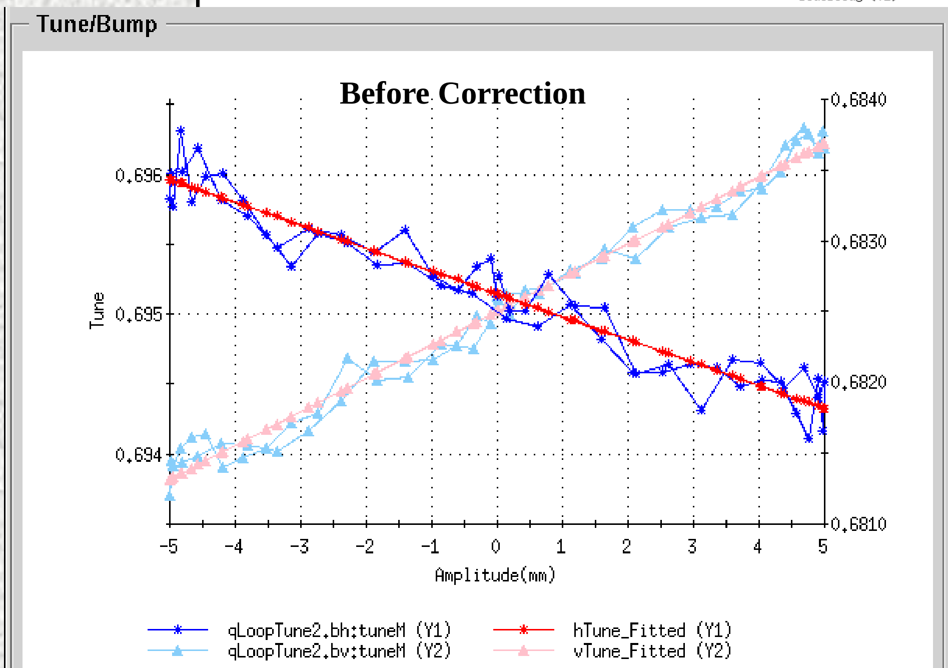


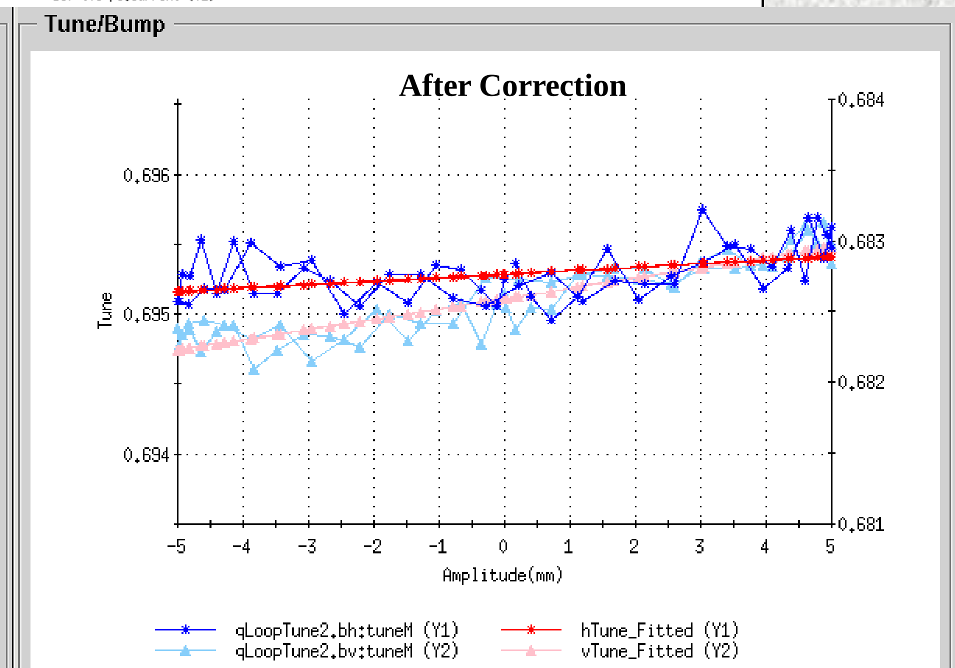


BROOKHAVEN NATIONAL LABORATORY

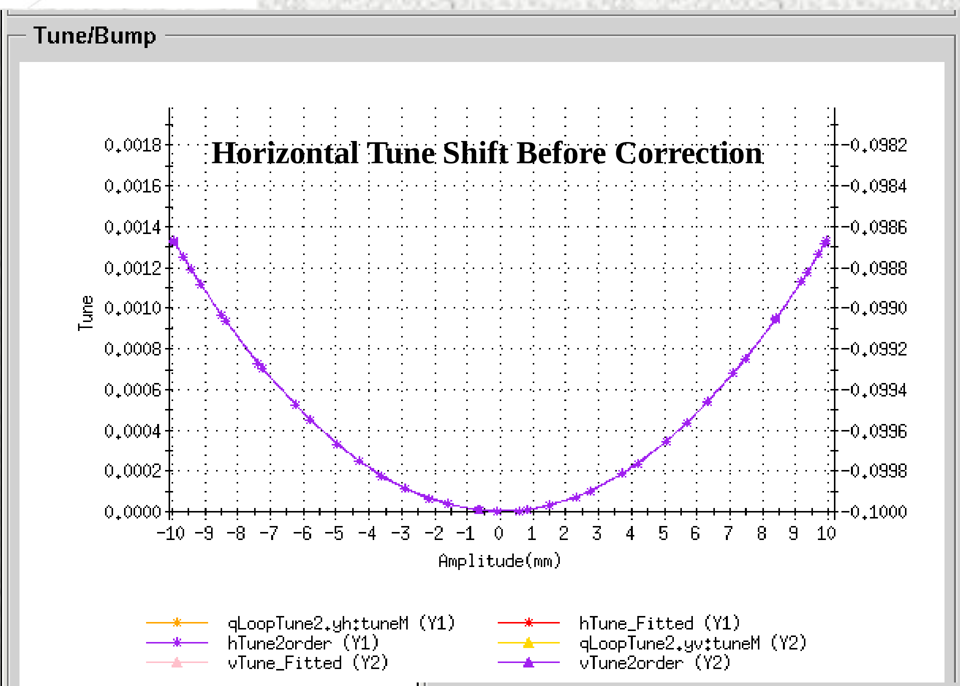
Feb. 9th 2008 Skew Sextupole Correction Blue IR8

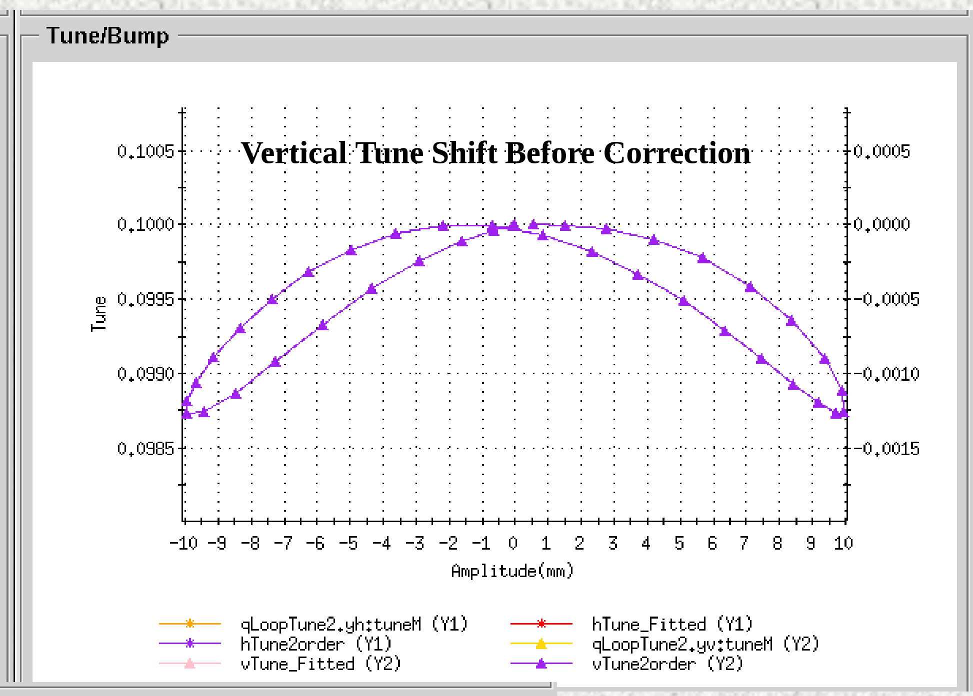


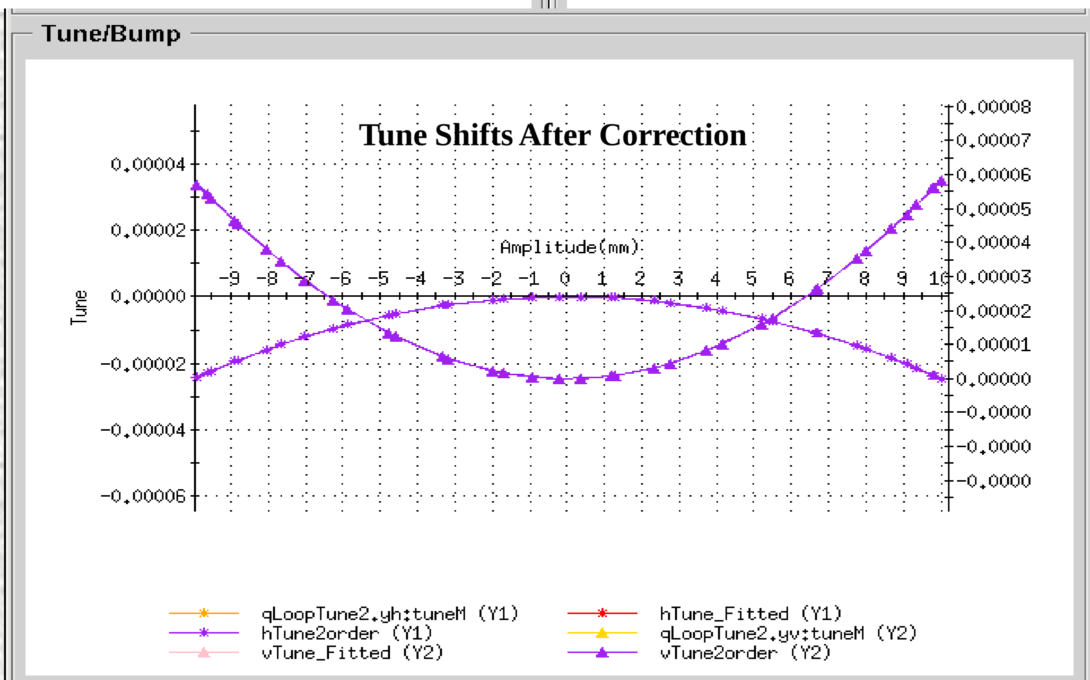




Normal Octupole Correction (July 6th 2009 Yellow IR8)







Reproducibility

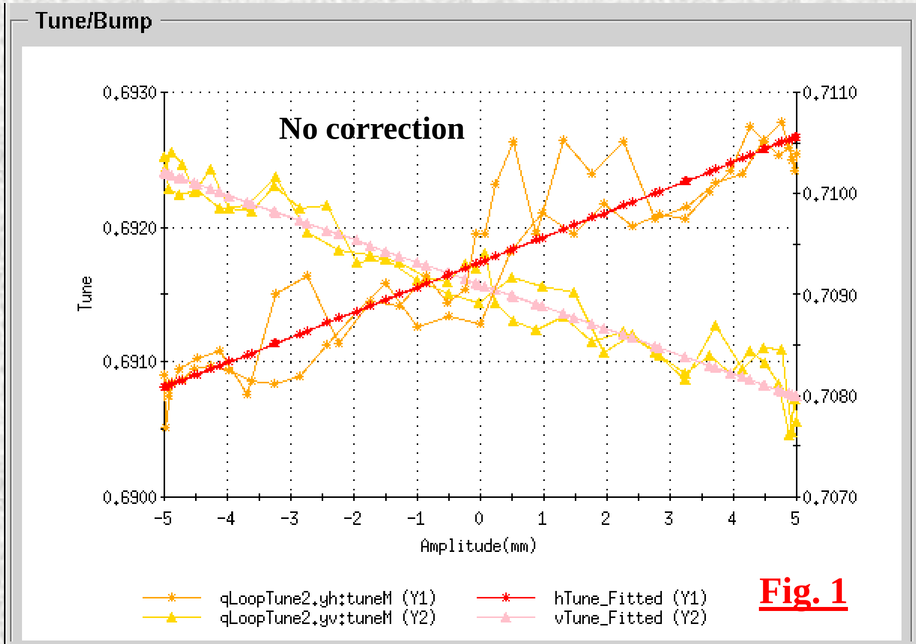


Fig. 1

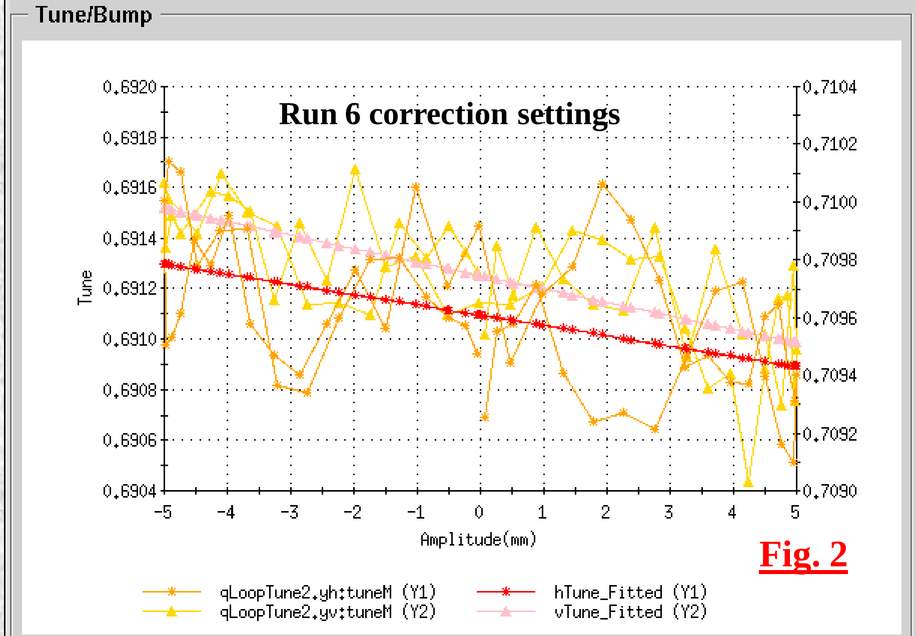
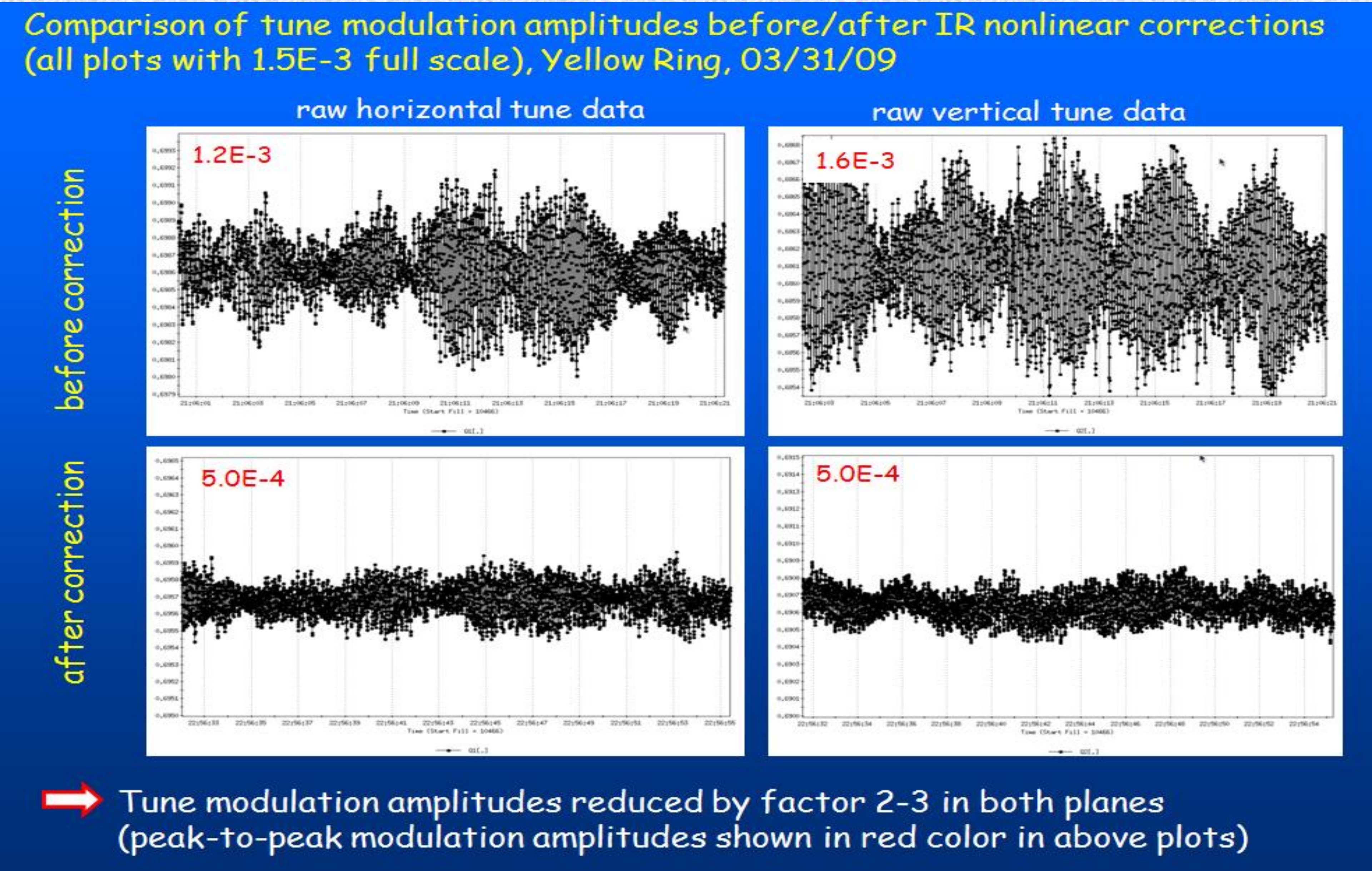


Fig. 2

- (Fig. 1)Run 8 p-p with no correction
- (Fig. 2)Run 8 p-p with run 6 skew sextupole corrector settings in place
- Corrections are reproducible

Correction Benefits

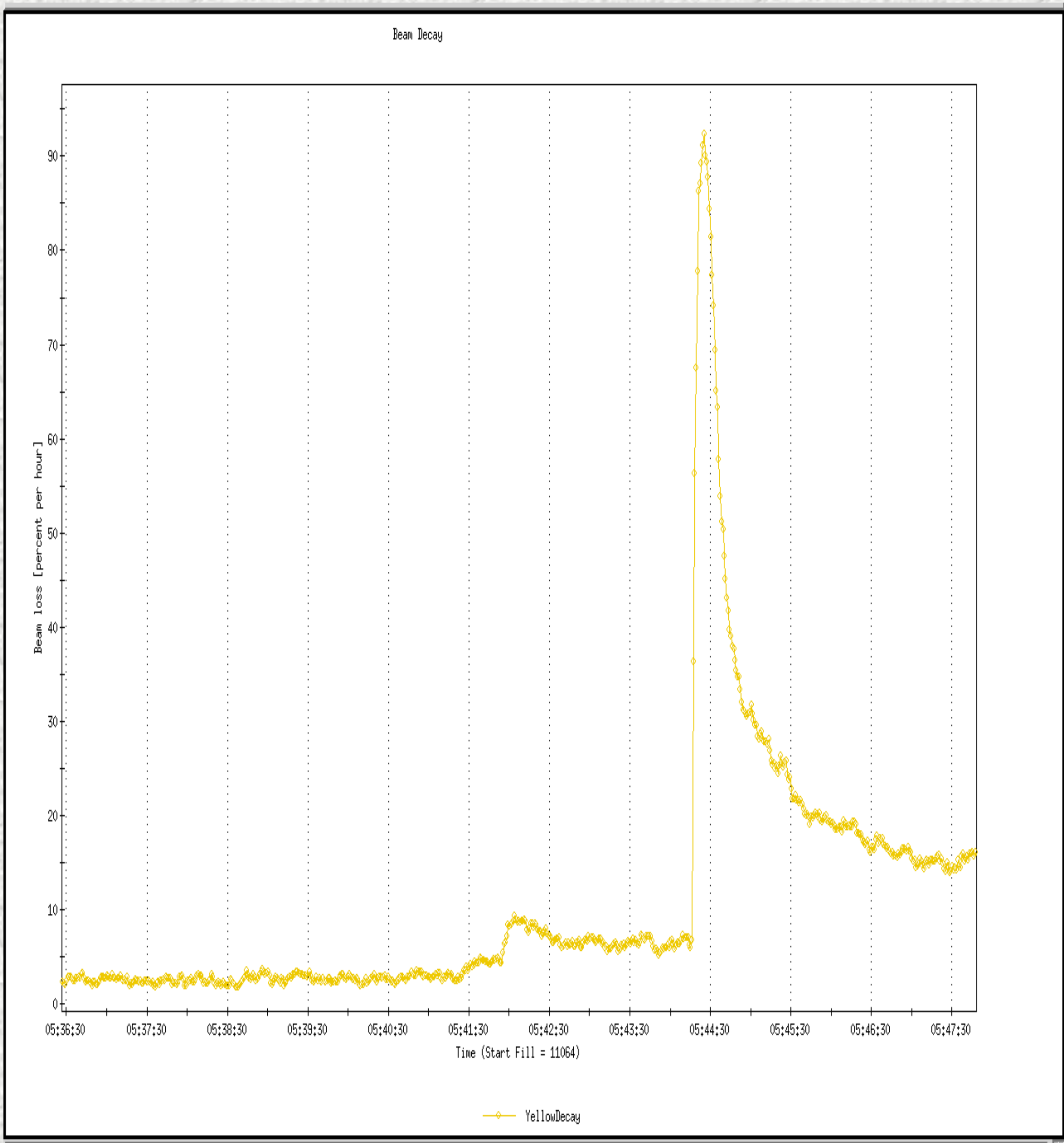
"The tune modulation (10 Hz due to triplet vibration via feeddown effect; that is, tune modulation due to off-axis beam in sextupoles driven by off-axis beam in triplet quadrupoles) was observed to reduce by a factor of 2-3 after non-linear corrections in the Yellow Ring" (courtesy M. Minty).



BROOKHAVEN NATIONAL LABORATORY

Correction Benefits

- Without correction in place, beam decay is higher as opposed to when correction is in place
- This figure shows the effect of simply removing the normal and skew sextupole correction settings in Yellow IR8
- The dynamic aperture of the machine is increased
- After removing this correction a 10mm bump was applied and beam was aborted
- After refilling RHIC and replacing the correction settings, a 10mm bump could successfully be made



Future Plans and Ongoing Work

- Work is underway to automate the process of non-linear optics correction, specifically for the sextupole, skew sextupole and octupole cases
- A sextupole algorithm has already been written and is up for testing during run 10. Automated skew sextupole and octupole correction is also expected to be ready at the beginning of run 10 and will undergo testing as well
- These algorithms will replicate the process currently undertaken by the system expert; specifically:
  1) Apply a closed bump and look at the ensuing tune shift
  2) Adjust corrector magnets in an attempt to null out the tune shift, then apply another bump
  3) Determine whether the tune shift is now better or worse and adjust accordingly
  4) Repeat these steps in a recursive manner (using the tune shift as a figure of merit) until no further improvement can be made
- For testing purposes the algorithms will initially be designed to run independently from each other in order to see how each works by itself
- After confidence has been gained the algorithms will be combined into a single self-sufficient process that corrects several types of multipole effects *simultaneously*
- For the time being there will still be a necessity for the user to prepare the machine for corrections (orbit, coupling, anti-cogging etc.) but in theory some of this ‘prep work’ could also be automated

Conclusion

- Over the past several years it has been demonstrated that we have an effective method for non-linear optics correction that is consistent and reproducible
- This correction has for the most part NOT been used to its full potential. Ideally it should always be followed by judicious beam manipulation at each I.R. to take full advantage of the benefits provided by an increased dynamic aperture (time constraints and experimental programs make this difficult)
- Although correction has mainly been an expert activity that necessitates manual adjustments, we are in the process of transitioning to an automated scheme which will be the focus of our activities during run 10
- For more information see:

http://www.cadops.bnl.gov/AGS/Operations/OpsWiki/index.php/IRBump

or alternatively search for 'IRBump' in the operations wiki

Theory

- The magnetic errors in an accelerator magnet can be described in terms of the multipole errors $\mathbf{a_n}$ and $\mathbf{b_n}$ defined as:

$$B_y + iB_x = B_N \sum_{n=0}^{\infty} (b_n + ia_n) \left(\frac{x+iy}{R_r} \right)^n$$

- Here $\mathbf{B_N}$ represents the main field of some magnet measured at a reference radius $\mathbf{R_r}$. For a quadrupole, for example, $\mathbf{B_n/R_r}$ is the gradient. $\mathbf{b_n}$ and $\mathbf{a_n}$ are respectively the **normal** and **skew** harmonics of magnet errors
- An excursion of the local orbit through a region having non-linear fields generates feed-down effects to lower order field harmonics
- The most useful observable effects come from the feed-down to the zero and first order harmonics (i.e. dipole and quadropole resonances), which affect the beam closed orbit and betatron tunes respectively
- It is possible in theory to infer local non-linear effects both from the measure of residual RMS orbit and of tune shifts generated by a local orbit bump in the IR. Given existing limitations on the resolution of the orbit measurement and on the allowable bump amplitude at the triplets, **in practice we have used so far almost exclusively the measurement of tune shift as a function of bump amplitude for non-linear correction**
- The measured tune shifts arise from either the feed-down to the normal gradient or from the repelling effect of linear coupling
- The tune shift (**ΔQ**) and the linear coupling term (**Δc**) for different bump planes (H and V) and for different multipole errors […]nds for ei[…]

$$\Delta Q(H,norm) = g(b_n, x_{co}) \; ; \qquad \Delta Q(V,norm,odd) = -1^{(n-1)/2} g(b_n, y_{co})$$

$$\Delta Q(V,skew,even) = -1^{n/2} g(a_n, y_{co}) \; ; \qquad \Delta c(H,skew) = h(a_n, x_{co})$$

$$\Delta c(V,norm,even) = -1^{(n-1)/2} h(b_n, y_{co}) \; ; \qquad \Delta c(V,skew,odd) = -1^{(n+1)/2} h(a_n, y_{co})$$

Where the functions g and h are defined as:

$$g(c_n, z_{co}) = \frac{n}{4\pi} \frac{1}{B\rho} \int \beta_z B_N c_n \frac{z_{co}^{n-1}}{R^n} ds$$

$$h(c_n, z_{co}) = \frac{n}{2\pi} \frac{1}{B\rho} \int \sqrt{\beta_x \beta_y} B_N c_n \frac{z_{co}^{n-1}}{R^n} e^{i(\mu_x - \mu_y)} ds$$

- Whether the feed-down from a […] oupling depends on things such as the plane of the bump, on whethe[…] ulti-pole order n as summarized in this table:

Bump	b_2	a_2	b_3	a_3	b_4	a_4	b_5
H	ΔQ	Δc	ΔQ	Δc	ΔQ	Δc	ΔQ
V	Δc	ΔQ	ΔQ	Δc	Δc	ΔQ	ΔQ

- This table implies that for reasonable measurement of a tune shift due to I.R. magnetic field errors, the following bump types should be used to identify the relevant multipole: **horizontal for Sextupole**(b_2), **vertical for Skew Sextupole** (a_2), **horizontal and vertical for octupole** (b_3) etc. A **diagonal bump for skew octupole** is necessary; the mathematics are beyond the scope of this presentation