APEX Optics Correction Organization

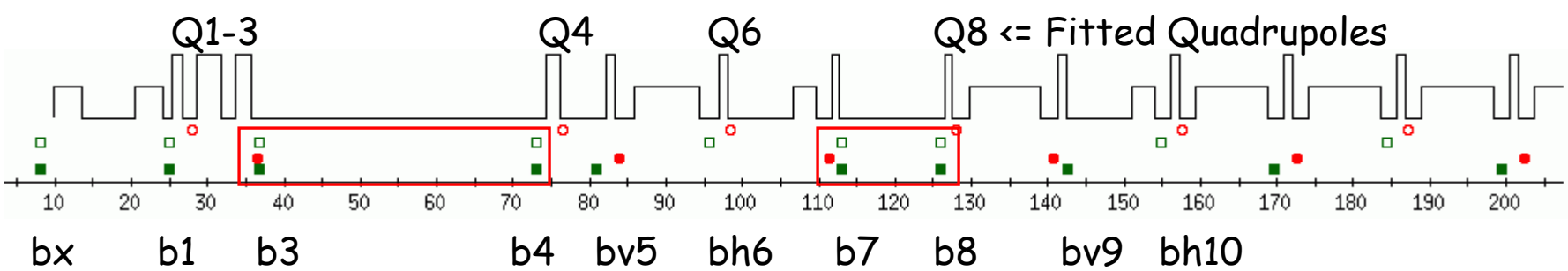
- Functional optics correction is becoming one of APEX high priorities
  - Lower beta* requires optics correction: β^*=>0.5m (or lower) in pipeline
  - Direct impacts on machine performance
    - lifetime, model understanding, orbit and nonlinear corrections...

- Multiple groups/approaches
  - Todd: ORM (multiple average orbit diffs from dipole corr changes; 1-2h)
    - Also provides BPM, corrector gain calibration, local coupling information
  - Mei/Gang: AC dipole TBT orbit, fit phase advances, SVD quadrupole fit
    - Requires careful ACD setup; safer with beam in only one ring; very fast
  - Rogelio/Rama: Kicked or AC dipole TBT orbit, fit phases, SVD quad fit
    - Different type of phase analysis performed for phase fitting
    - Also interested in chromatic beta-beat, local coupling/dispersion msmts

- Which approach is the best one to use?
  - ~~Mine~~
  - All of them have advantages and disadvantages

ORM APEX Data

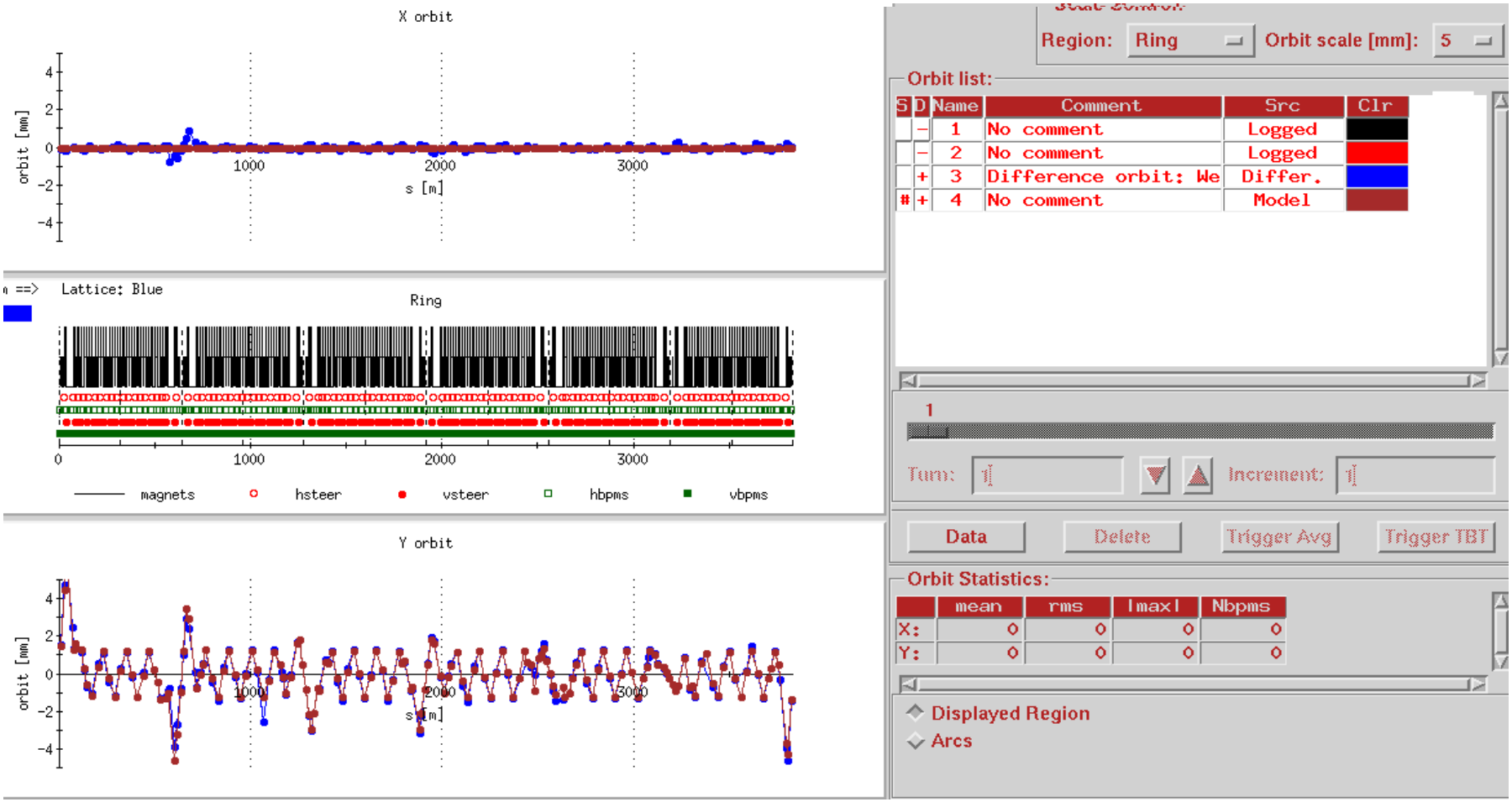
- Analysis performed with Johan Bengtsson, James Safranek, Greg Portmann
  - ORM analysis tends to diverge unless degeneracies are limited
    - This previously led to inapplicably large correction strengths
  - Originally lumped triplets together, fit Q4-9 separately
  - Best analysis so far fits lumped triplet, Q4,6,8, and quad rolls
    - This meets ORM preference for both planes of BPMs between quads used in fit
    - All fits reduced χ^2/dof from 700+ to 5 with a small number of iterations
    - These fits correct the observed 15-20% beta-beat
  - Problems
    - BPM average orbit data often dropped => Since fixed (see Michnoff talk)
    - TBT BPM data for AC dipole measurements also had timestamp problems



Straights for optics measurement

ORM APEX Data

- Best orbits selected and checked by hand for data analysis
  - A tedious process made necessary by BPM DAQ problems, since “solved”



ORM APEX Jan 8 2007 β*

Fill	Ring	File	Plane/IR	oddbeta	evenamp	evenbeta	beta* [m]
ORM dAu82	blue		h/8 dx	108.6		101.6	0.66
ORM dAu82	blue		h/6 dx	91.2		92.9	0.75
ORM dAu82	blue		v/8 dx	93.9		90.2	0.75
ORM dAu82	blue		v/6 dx	98.7		89.5	0.74
ORM dAu82	yellow		h/8 dx	144.2		65.1	0.66
ORM dAu82	yellow		h/6 dx	103.6		97.4	0.69
ORM dAu82	yellow		v/8 dx	49.8		89	1
ORM dAu82	yellow		v/6 dx	87		82.2	0.82
					ave bstar	6	0.75
						8	0.77

- Calculated β*s from fitted DX betas to account for waist
- Blue β*s are remarkably consistent with 0.75m
- Yellow horizontal seems to compensate yellow vertical β*s

ORM Summary

- Conclusions
  - ORM is still alive and kicking for RHIC
  - Analysis will vastly improve with improved BPM data integrity
  - ORM is leading to new tools to evaluate/fix BPM performance

- Recommendations
  - Iron correctors to eliminate phantoms, mask bad BPMs
  - Fix BPM data delivery integrity
    - Already much effort is going into improving BPM system
    - No reason that we should not see 100% data delivery
  - Improve ORM acquisition speed (currently 3-4 hours!)
    - A real barrier to routine measurement, APEX burden
    - Objective: 1.5 hours or less

- Combine with Gang/Mei/Rogelio/Rama, dispersion into optics plan

Gang/Mei AC Dipole Optics Correction

The intention of this work is to reduce the rms phase-beat from ~10% to ~5% or less. There are two steps:

- We firstly fit the turn by turn bpm data to obtain the phase advances between two adjacent well behaved bpms (There are 3 filters to exclude abnormal bpms.) using the following fitting formula.

$$x_i(s) = \frac{B_{acd}L}{4B\rho\sin\left(\pi\left(Q_{acd}-Q_x\right)\right)}\sqrt{\beta_{acd}\beta(s)}\cos(2\pi Q_{\mathrm{acd}}i-\Delta\psi(s)-\pi(Q_{\mathrm{acd}}-Q_x)+\chi_{\mathrm{acd}})$$
$$-\frac{B_{acd}L}{4B\rho\sin\left(\pi\left(Q_{acd}+Q_x\right)\right)}\sqrt{\beta_{acd}\beta(s)}\cos(2\pi Q_{\mathrm{acd}}i+\Delta\psi(s)-\pi(Q_{\mathrm{acd}}+Q_x)+\chi_{\mathrm{acd}})$$

The phase-beat is obtained by take the difference between the fitted phase advances and the phase advances from model.

- Then we use trim quadruples to reduce the phase beat. The strength of each trim quads can be solved from SVD of the phase response matrix and the phase-beat.

$$\left(\Delta kl\right)_i = \sum_{j=1}^{n_{bpm}} M_{i,j}^{-1}\Delta\psi_j^{(bpm)}$$

If the SVD of M is

$$M^{-1} = V\frac{1}{W}U^T$$

The Phase Response Matrix is calculated from

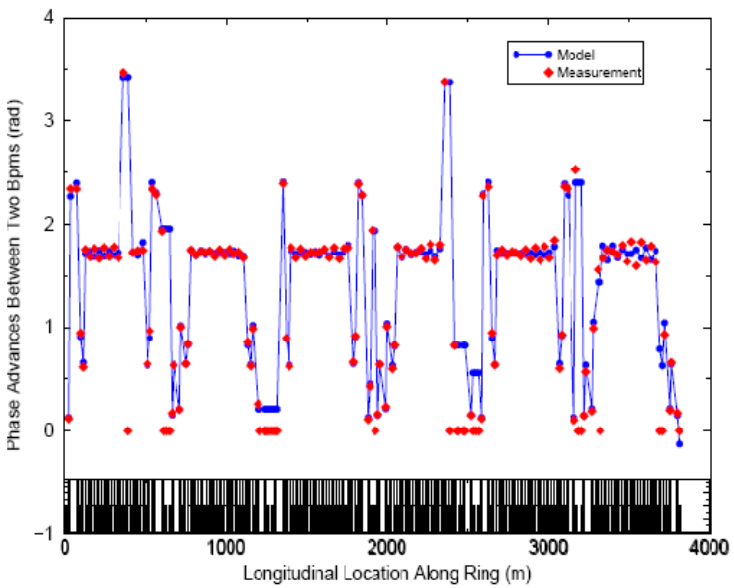
$$M_{i,j} = \frac{1}{4\sin(2\pi Q)}\beta_j^{(quad)}\{\sin\left(2\pi Q\right)+\sin\left(2\psi_j^{(quad)}-2\pi Q\right)$$
$$+sign\left(\psi_i^{(bpm)}-\psi_j^{(quad)}\right)\left[\sin\left(2\pi Q\right)+\sin(2\left|\psi_i^{(bpm)}-\psi_j^{(quad)}\right|-2\pi Q)\right]\}.$$

Gang/Mei: Preliminary ACD Offline Fitting Results

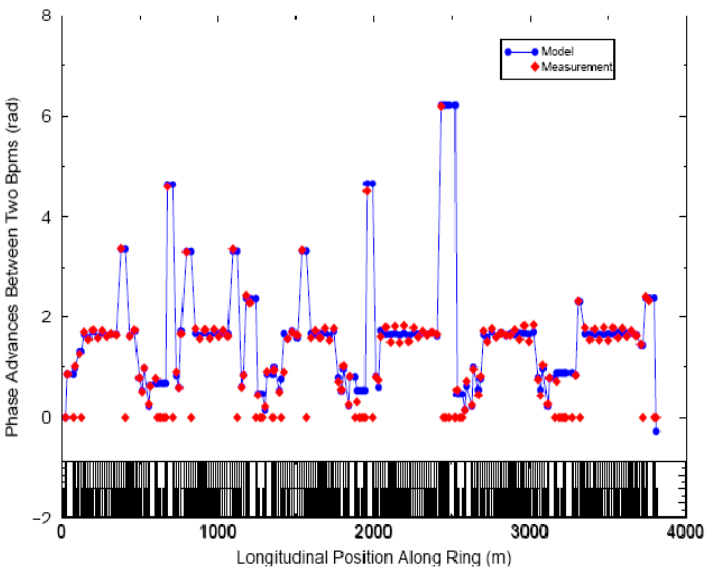
A few filters are applied to the bpm data to exclude poor behaved bpms from the analysis.

- Status filter : BPMs with bad status for any turn are excluded.
- Tune filter : As the drive tune should be sharply peaked at the drive tune, BPMs were excluded if their major FFT component is 0.5σ away from the average tune of all BPMs.
- χ^2 filter : BPMs with extremely large χ^2 (5 σ) are excluded.

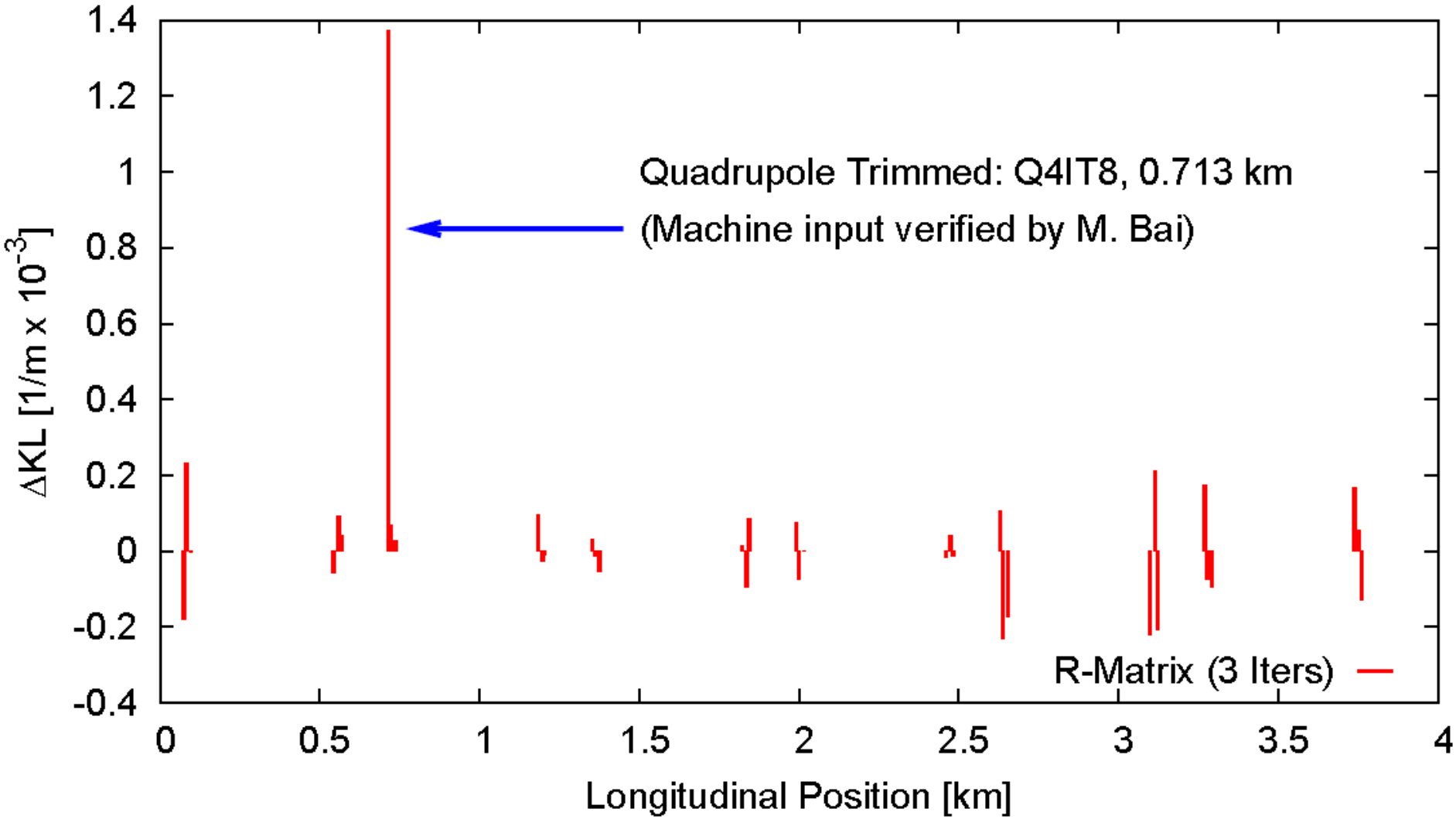
Vacd_inj_05 (rms phase-beat = 7%)



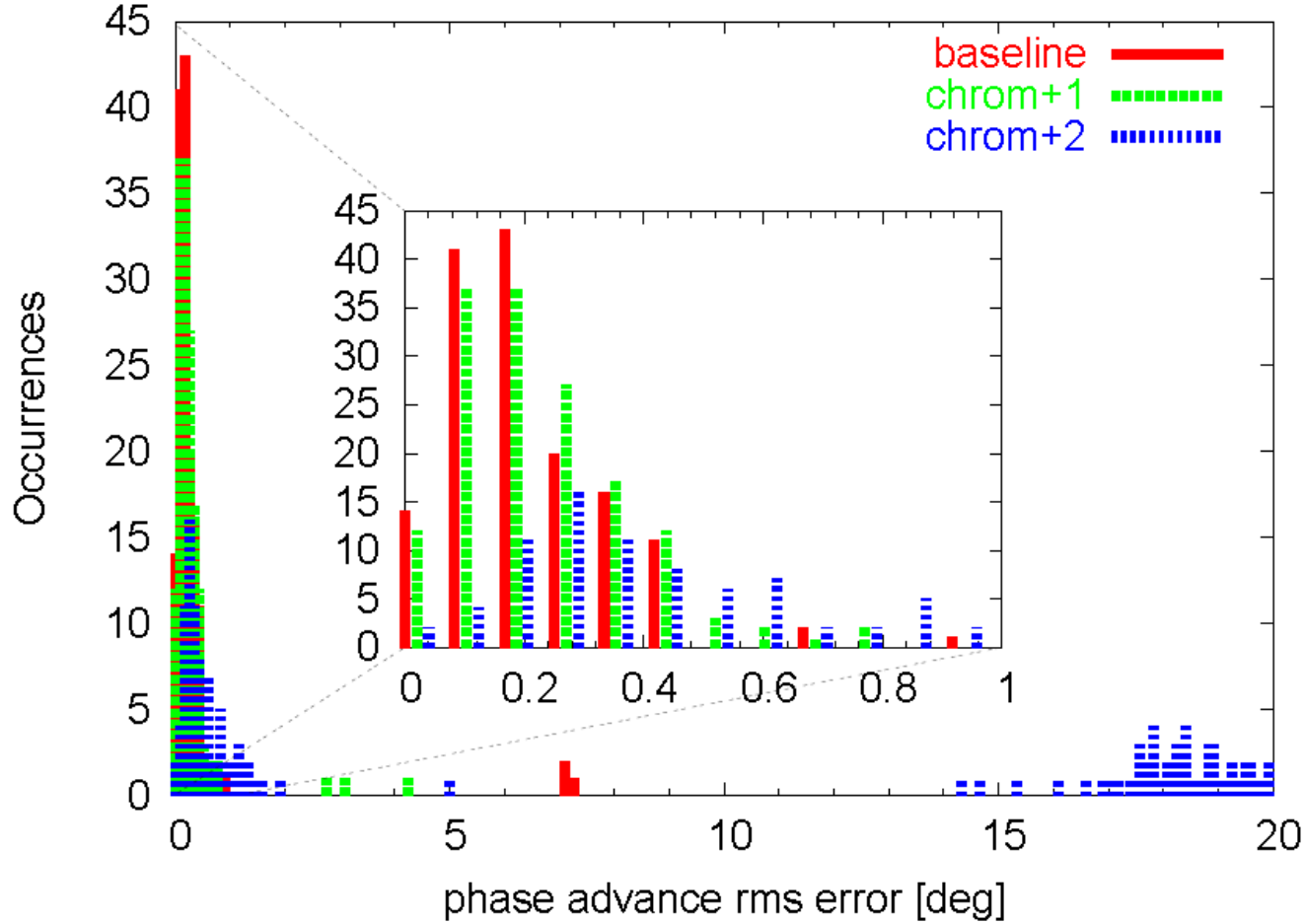
Hacd_inj_02 (rms phase-beat = 10%)



Exp II: AC Dipole (Reconstructed ΔKL)



Ph. Err (σ_ϕ), Chromaticity Scan



- $\sigma_\phi \sim 0.25°$ for low chromaticity (baseline)
- $\sigma_\phi \gg 1.0°$ with larger chromaticity, correction difficult (PAC07)

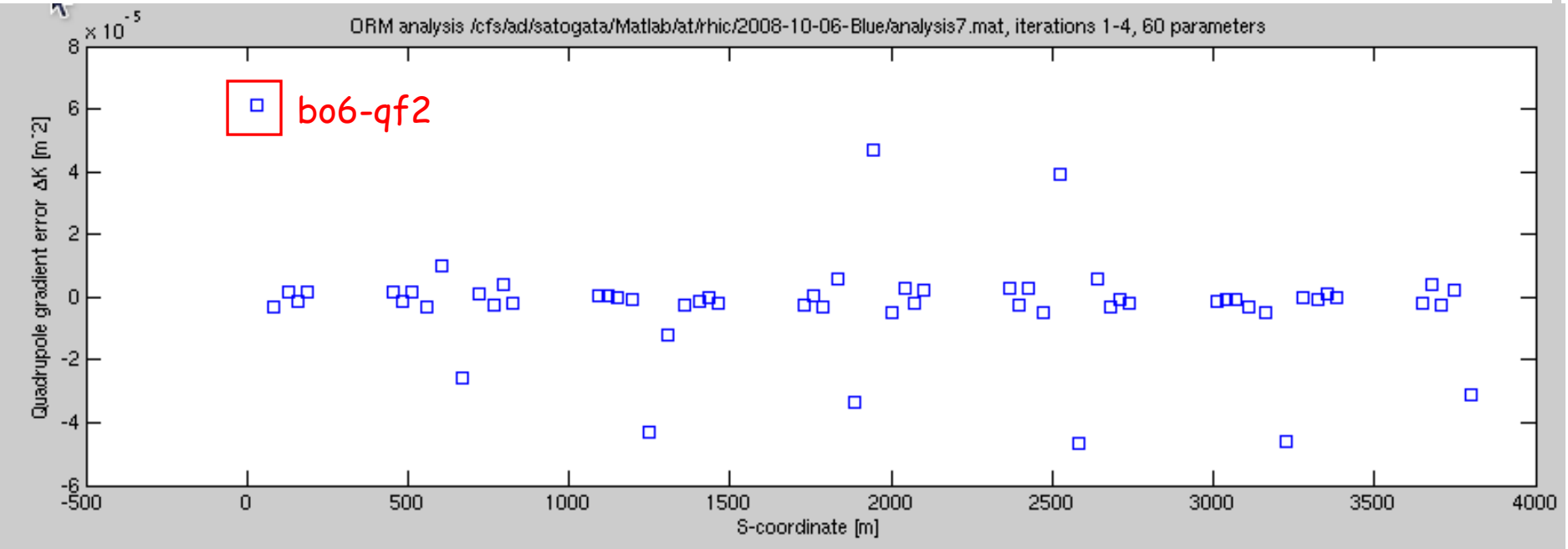
Optics Correction Recommendations

- We have a wealth of options for RHIC optics corrections
  - All have shown progress but none has closed correction loop yet
  - All methods work very well with simulated (complete) data
  - BPM data integrity is a common Achilles' heel for all methods
    - Improvements in BPM calibration, data delivery will eliminate this deficiency for the upcoming run

- Which methods to use?
  - BPMs/correctors are calibrated with ORM convergence
    - Should demonstrate this at least once, early in run
  - Optics measurements are much fastest with AC dipole methods
    - Should develop this for "routine" optics correction
  - With careful chromaticity settings, measured phase errors are very small
    - Much less than 1 degree!

- Further recommendations
  - Good AC dipole optics measurements will lead to other studies
    - Chromatic beta-beating
    - Local impedance measurements

Quadrupole Strengths and Correction Ranges



10^{-3} errors are at the level of $\Delta K = 2 - 9 \times 10^{-5}$ m^{-2}; for triplets, this is about $\Delta K = 5 \times 10^{-5}$ m^{-2} in all lattices. The typical quad current is dominated by the main quadrupole current of about 4600 A in top-energy store conditions. Shunt supplies can change this current by perhaps 100 A, or about 2%; a more typical change is on the order of 10 A, or about 0.2%. 10^{-3} relative strength errors should therefore be correctable with existing power supplies, assuming they are not near limits. (For example, a 6.6×10^{-5} m^{-2} change in a QF2 is about 5.4 A.)

- From reference AP note in progress
  - 10^{-3} relative strength errors are correctable