Optics Measurements in the Booster

Meghan McAteer
The University of Texas at Austin
11/9/11

We're measuring optics in the Booster using three methods:

- K modulation
- Orbit response
- Fourier decomposition of turn-by-turn data

Method I: Measuring beta via K modulation

The tune shift due to a quadrupole error is proportional to the beta function at the location of the error:

$$\Delta\nu = \frac{1}{4\pi}\beta\,\delta q$$

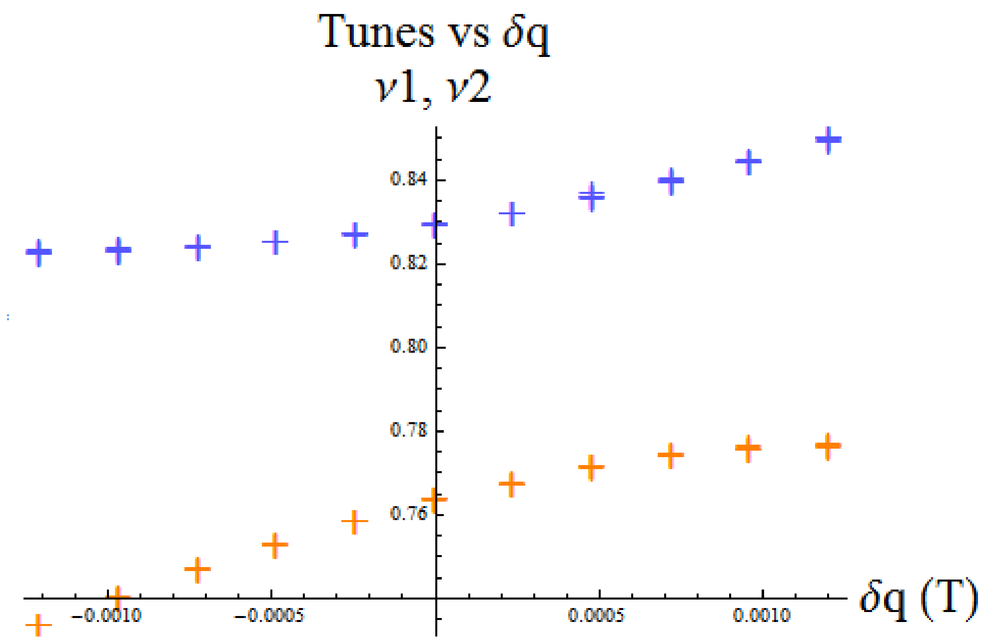
The Booster has significant transverse coupling, which changes the measured tunes:

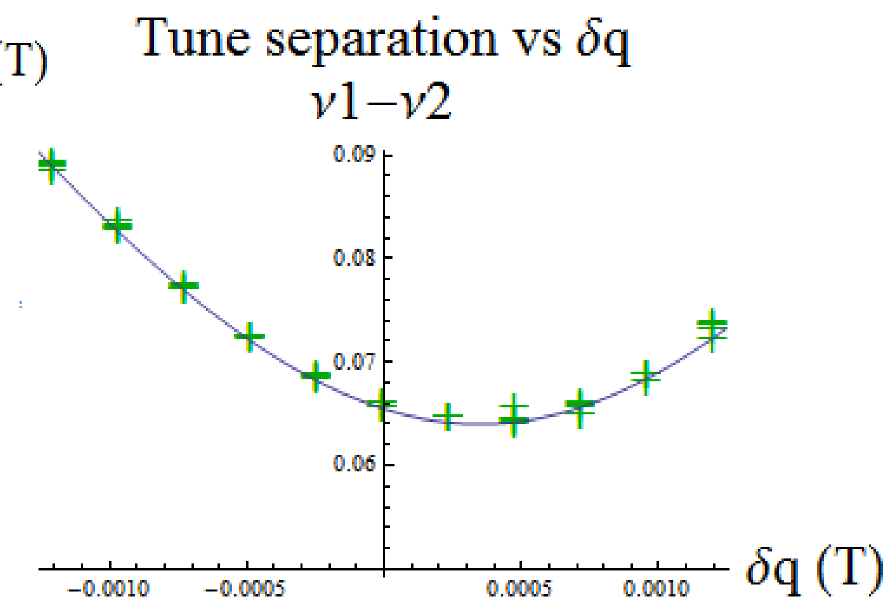
$$\nu 1 = \frac{1}{2}(\nu x + \nu y) + \sqrt{\kappa^2 - (\nu x - \nu y)^2}$$

$$\nu 2 = \frac{1}{2}(\nu x + \nu y) - \sqrt{\kappa^2 - (\nu x - \nu y)^2}$$

ν1, ν2 are measurable eigentunes
νx, νy are uncoupled tunes
κ is coupling parameter/minimum tune separation

Coupling Measurement

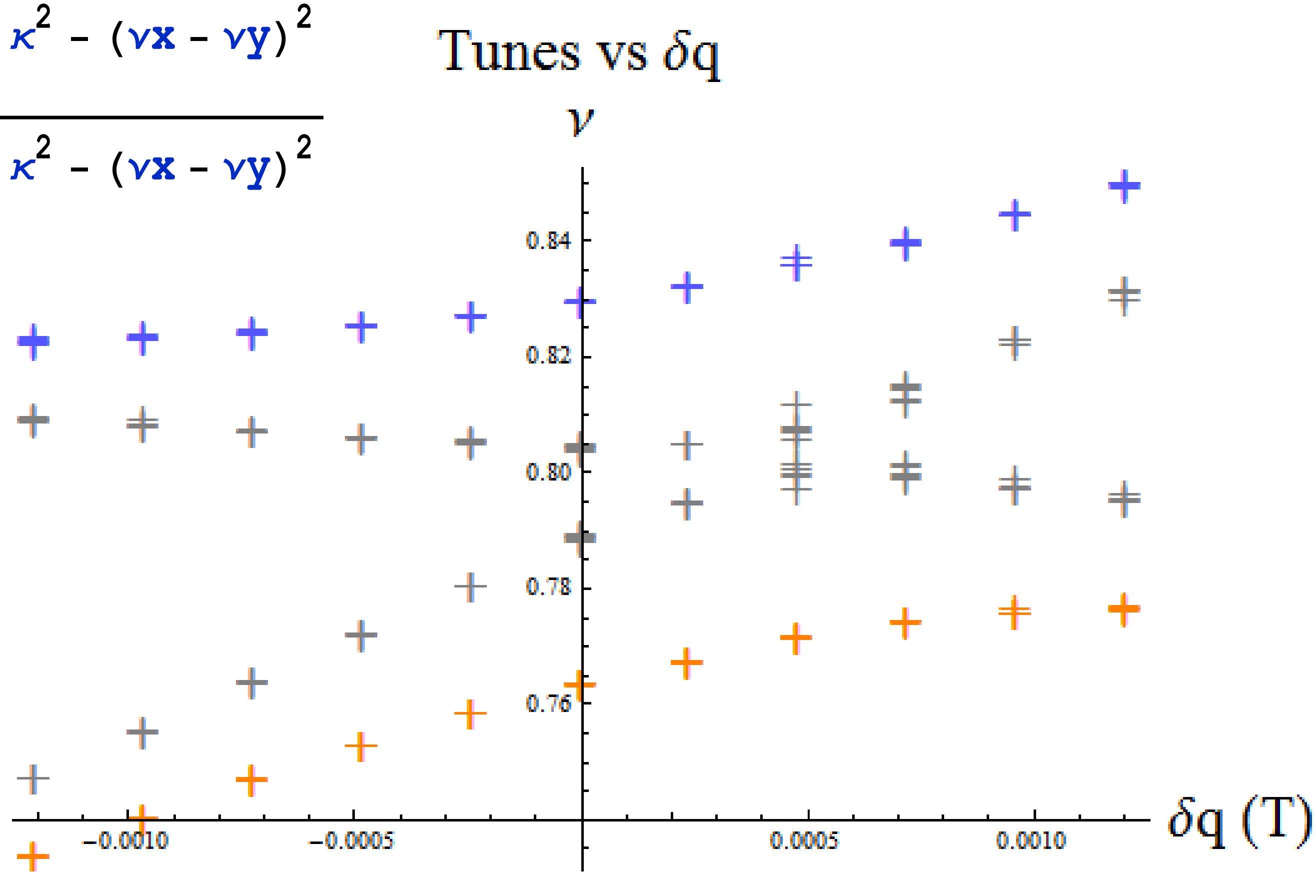




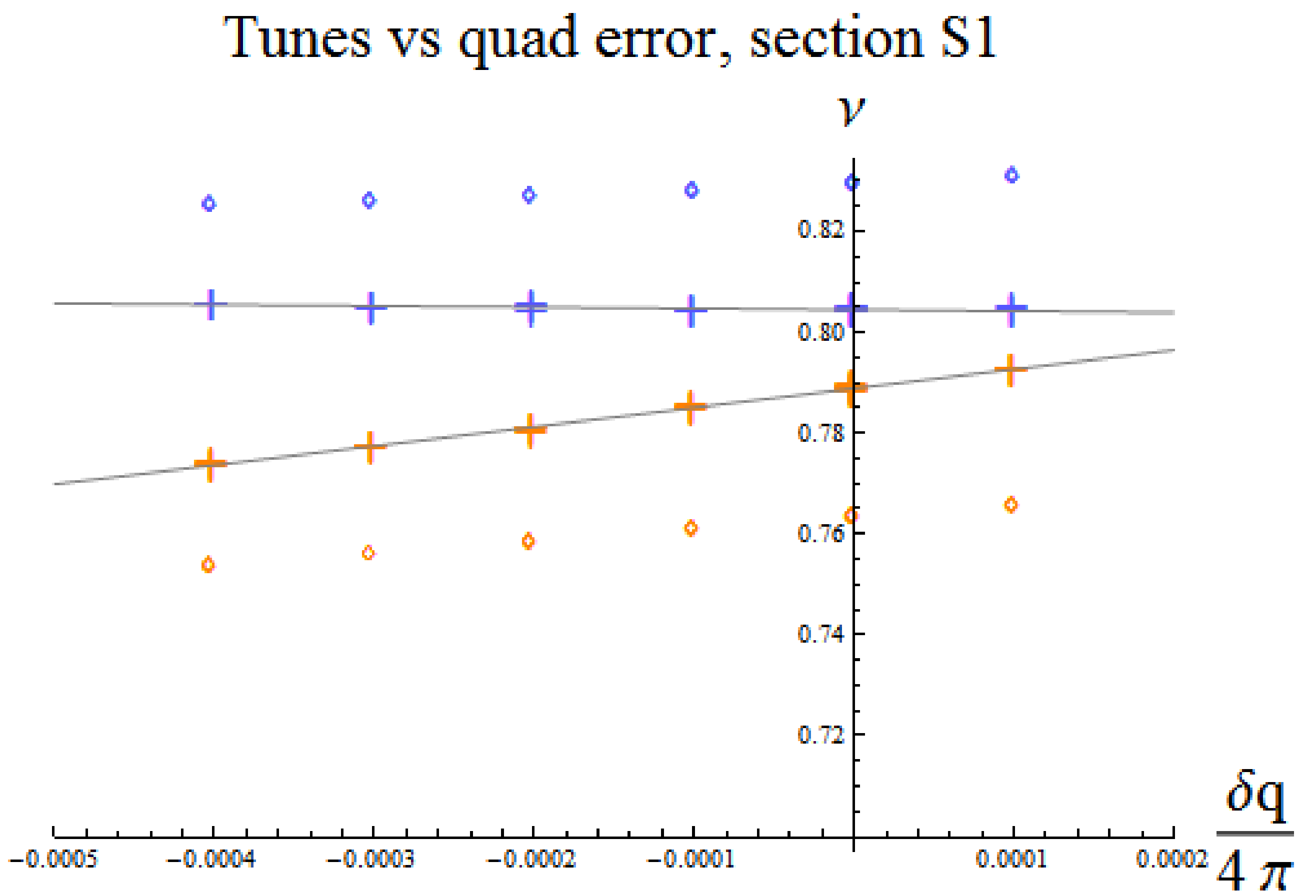
Calculation of uncoupled tunes

$$\nu 1 = \frac{1}{2}\ (\nu x + \nu y) + \sqrt{\kappa^2 - (\nu x - \nu y)^2}$$

$$\nu 2 = \frac{1}{2}\ (\nu x + \nu y) - \sqrt{\kappa^2 - (\nu x - \nu y)^2}$$

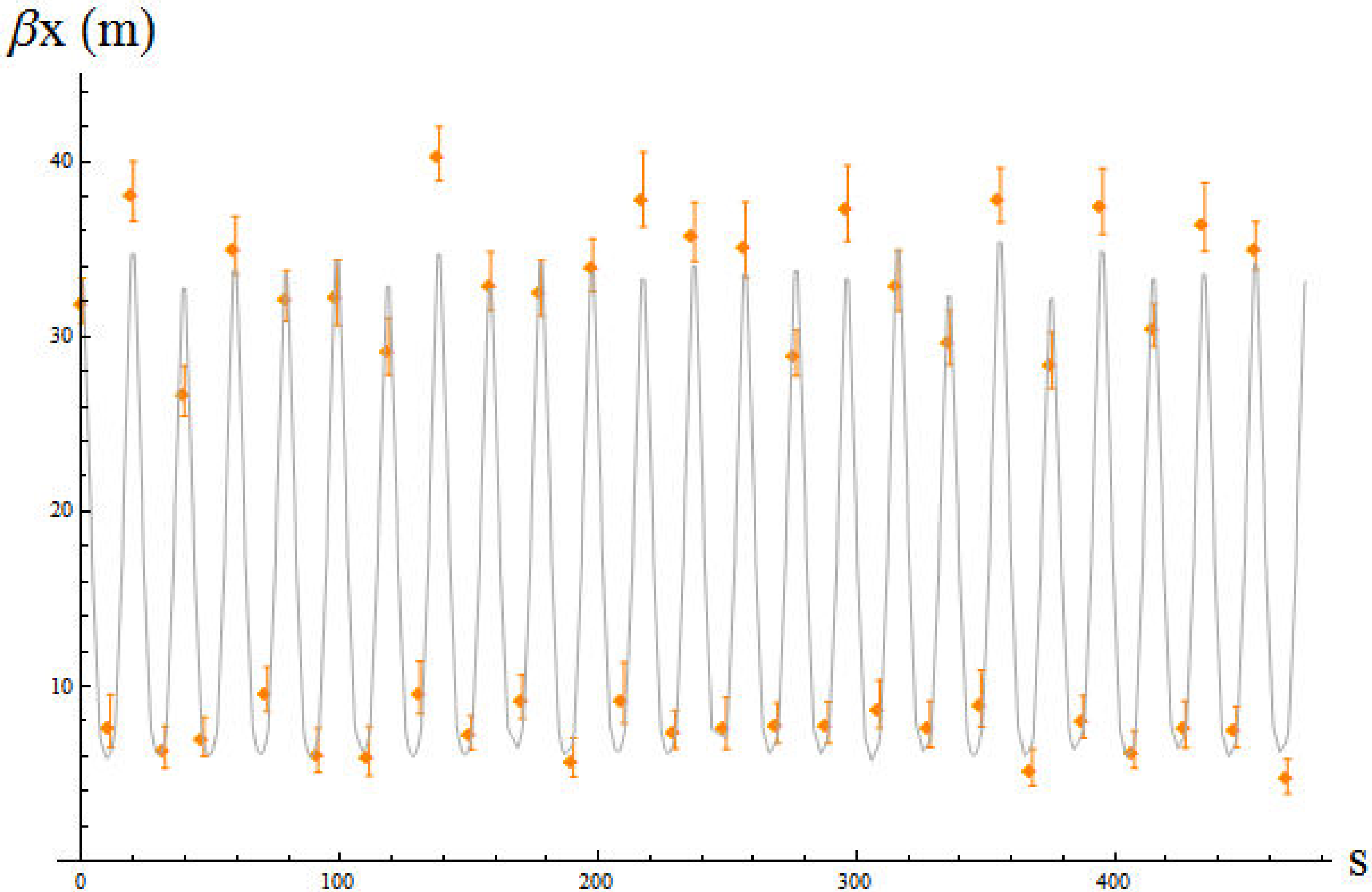


K modulation measurements

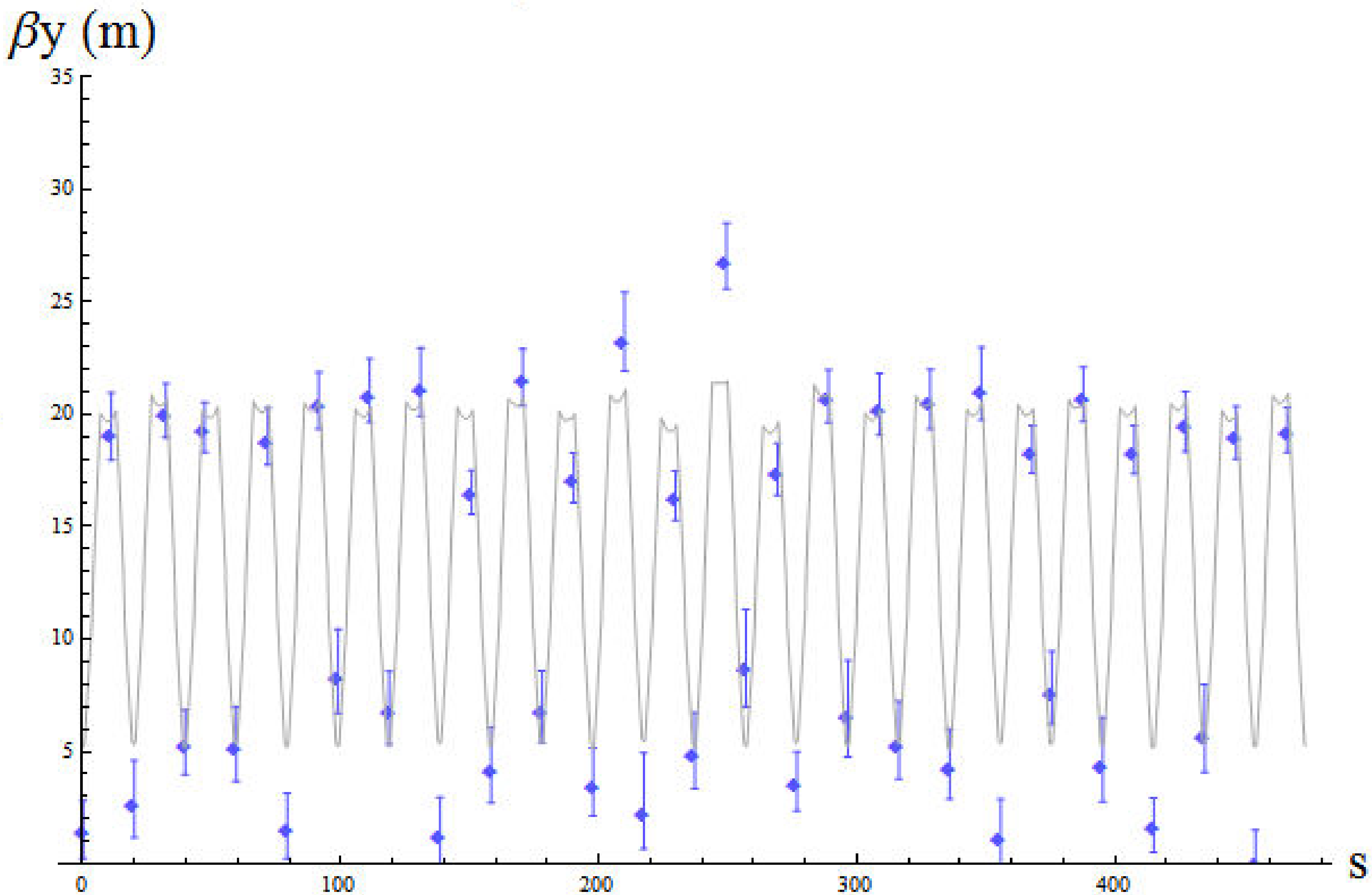


Tunes are measured as changes are made to the current in a quadrupole; tune shift is proportional to beta function at the location of the quadrupole.

Horizontal Beta, K modulation measurements



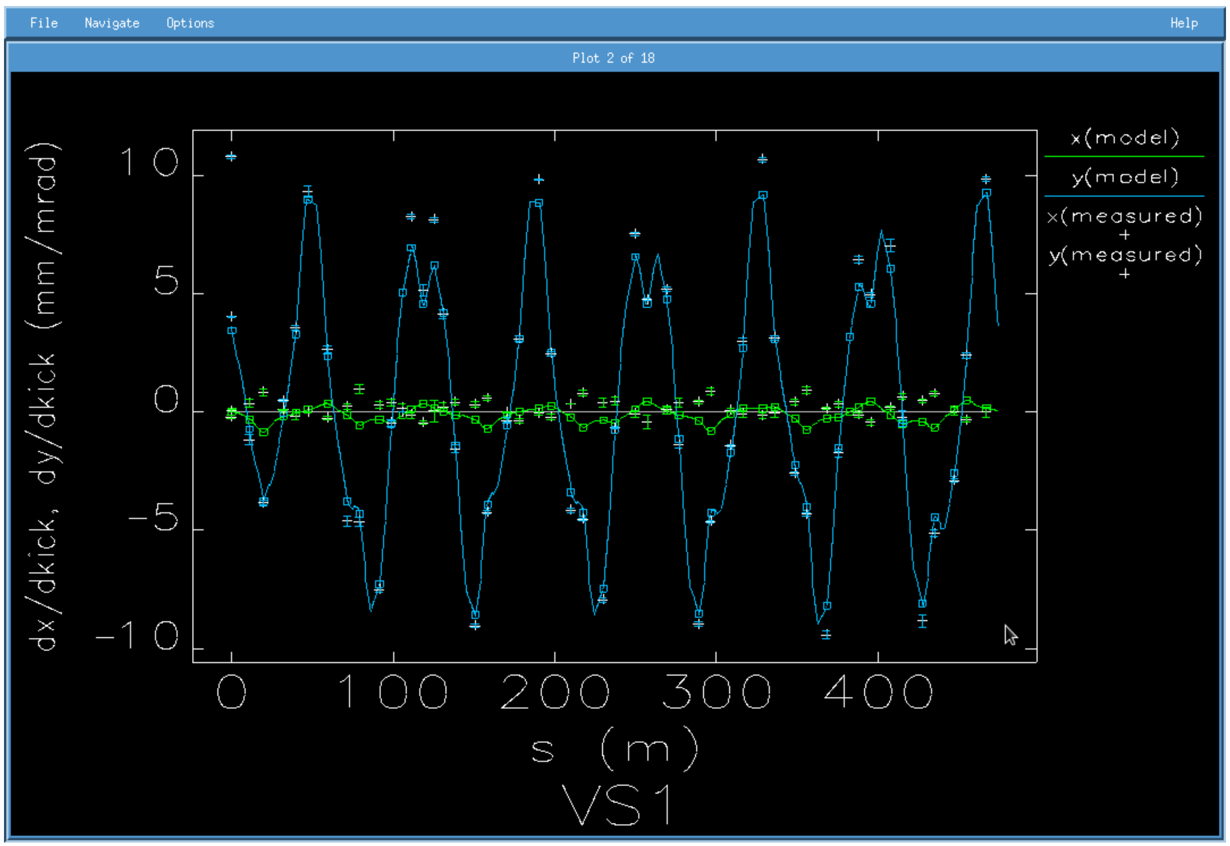
Vertical Beta, K modulation measurements



Method II: Measuring beta functions from orbit response

A steering error causes a change in the orbit proportional to the beta function at the location of the error:

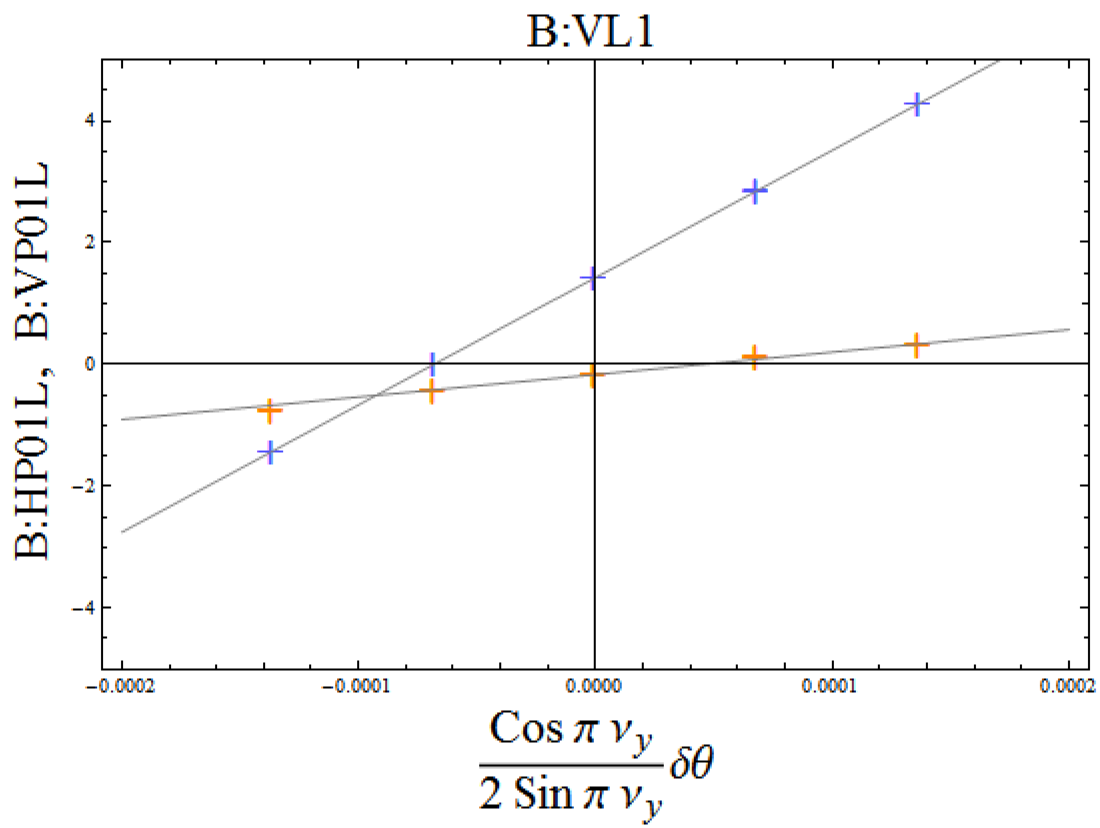
$$\Delta y(s) = \delta\theta \frac{\sqrt{\beta(s)\,\beta(s')}}{2\,\mathrm{Sin}[\pi\nu]}\,\mathrm{Cos}[\mathrm{Abs}[\psi(s)-\psi(s')]-\pi\nu]$$



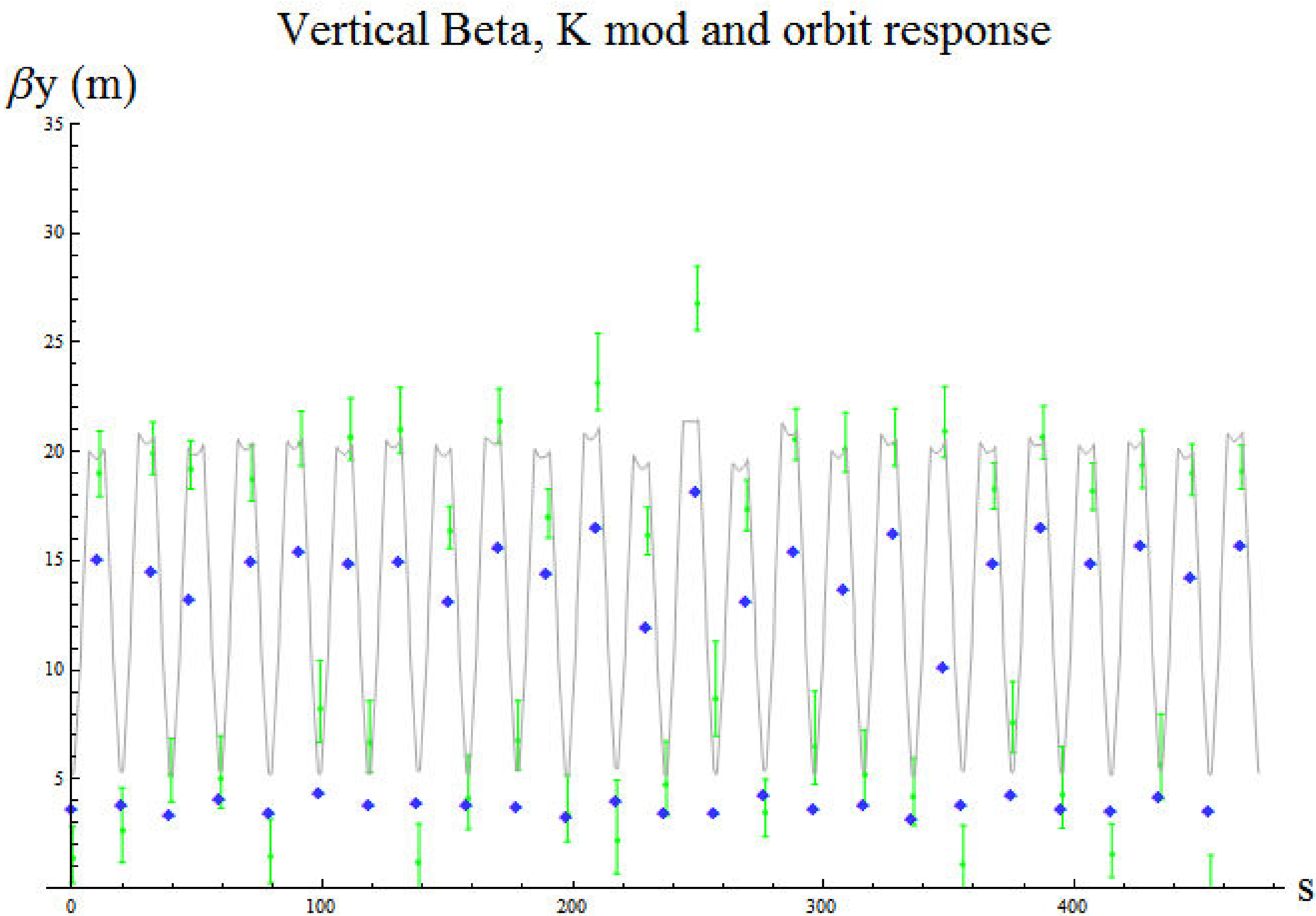
Orbit response measurements

If the position is measured in the same s location as the dipole error:

$$\Delta y(s) = \delta\theta \frac{\mathrm{Cos}[\pi\nu]}{2\,\mathrm{Sin}[\pi\nu]} \beta(s)$$

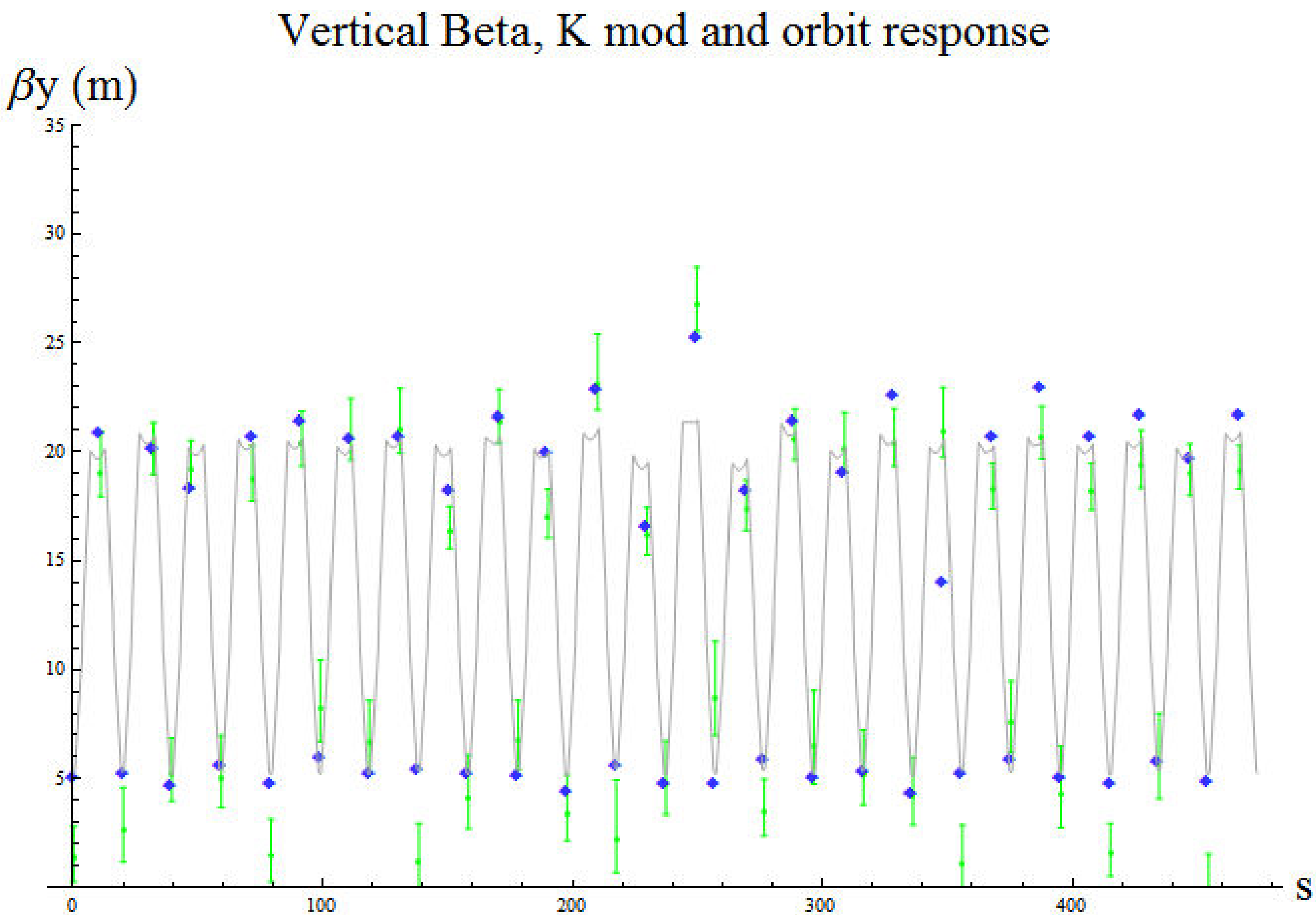


Comparison of ORM and K modulation measurements



There appears to be a scaling error in the ORM measurements; either bpms or dipoles are calibrated incorrectly.

Measurements agree when ORM data is rescaled by ~25%



Horizontal beta function measurements from orbit response

Horizontal measurements using this method are also affected by dispersion, since the rf feedback system changes the beam momentum to keep the position constant at the location of the RPOS pickup (in L20).

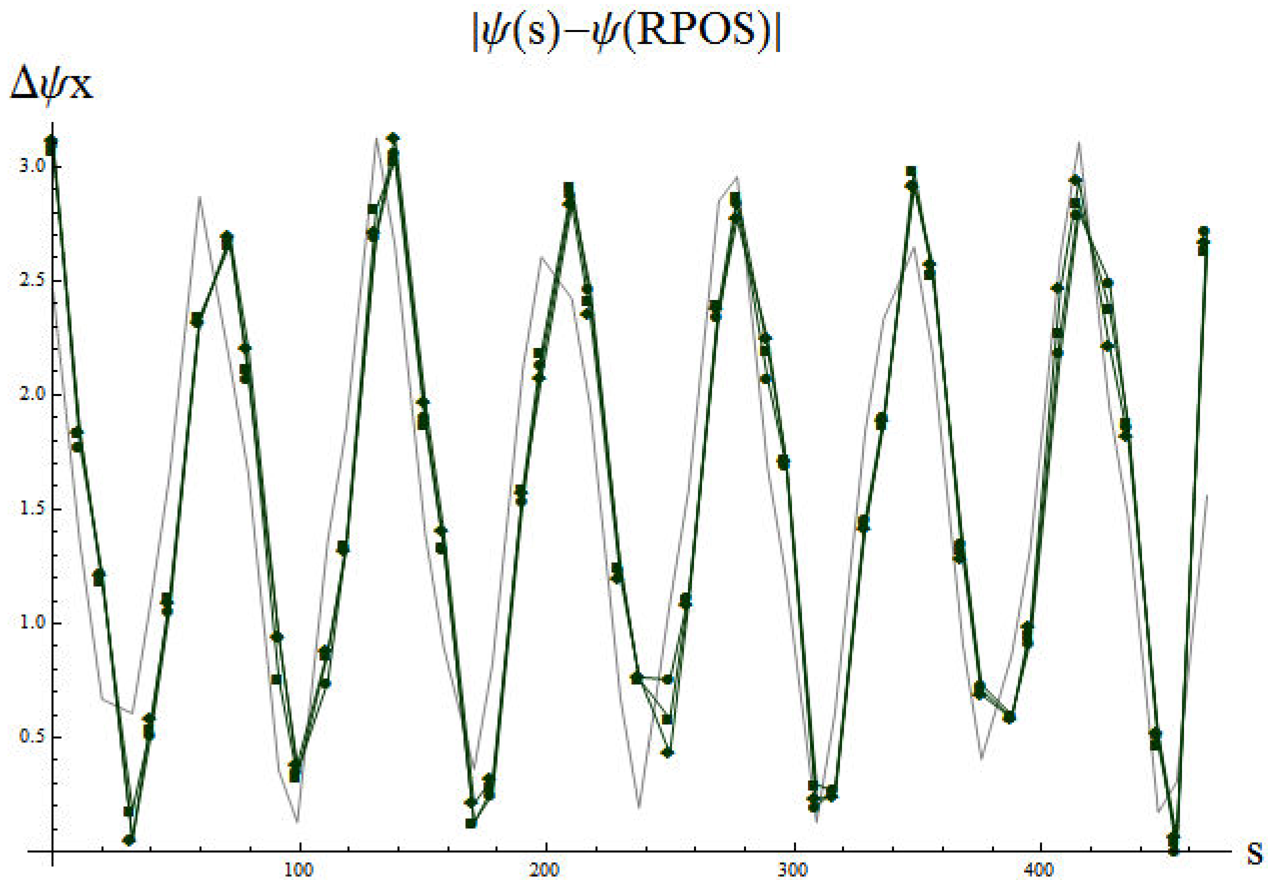
$$\Delta x[s] = \Delta x[CO] - \Delta x[RPOS] * Disp[s]$$

$$\Delta x[s] = \delta\theta \left(\frac{\mathrm{Cos}[\pi\nu]}{2\,\mathrm{Sin}[\pi\nu]}\,\beta[s] - \frac{\sqrt{\beta[s]\,\beta[RPOS]}}{2\,\mathrm{Sin}[\pi\nu]}\,\mathrm{Cos}[\mathrm{Abs}[\psi[s] - \psi[RPOS]] - \pi\nu] \right)$$

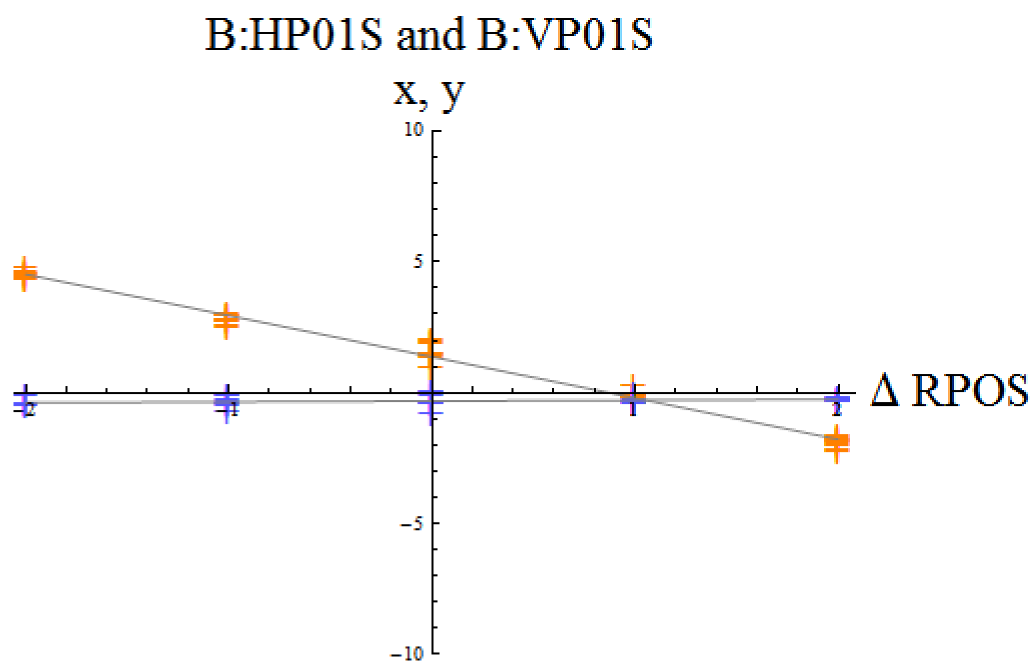
We need to measure betatron phase and dispersion in order to calculate the horizontal beta functions.

Betatron phase advance

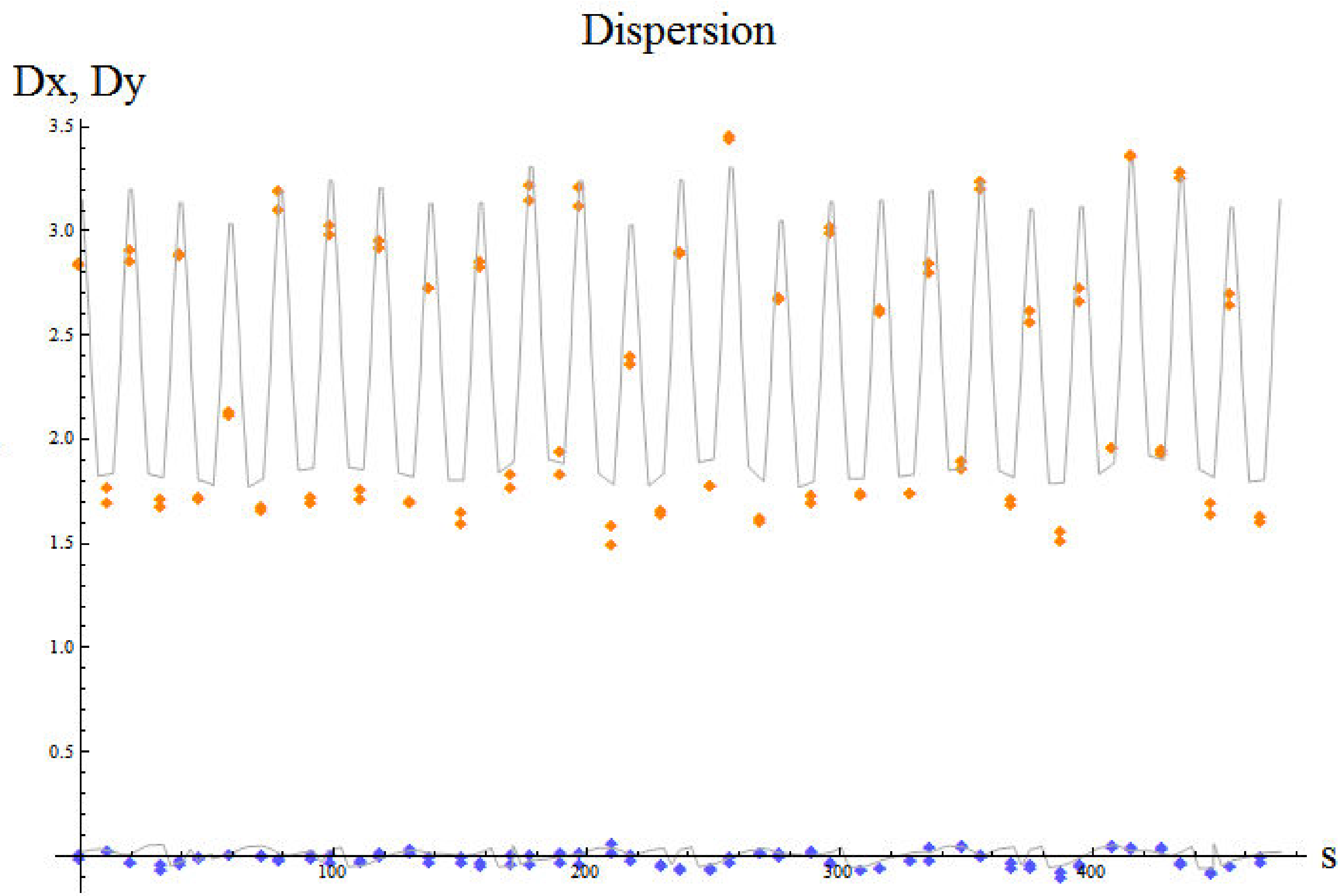
The betatron phase advance was measured using the SUSSIX Fourier transform algorithm. The phase measured from turn-by-turn data showed good agreement among three data sets, as well as good agreement with the MAD model.



Dispersion measurements

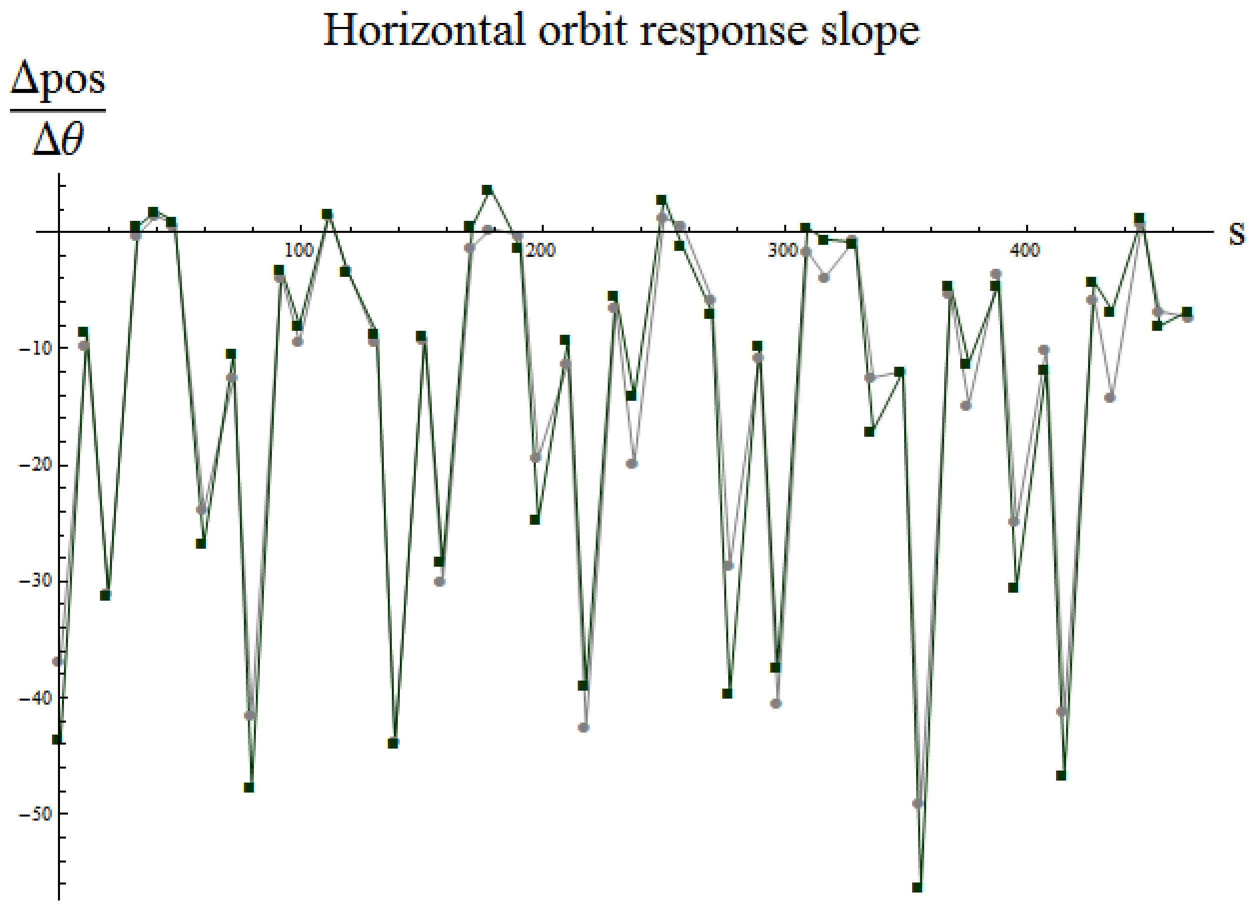


Dispersion was measured by changing RPOS and measuring the change in position at each location.



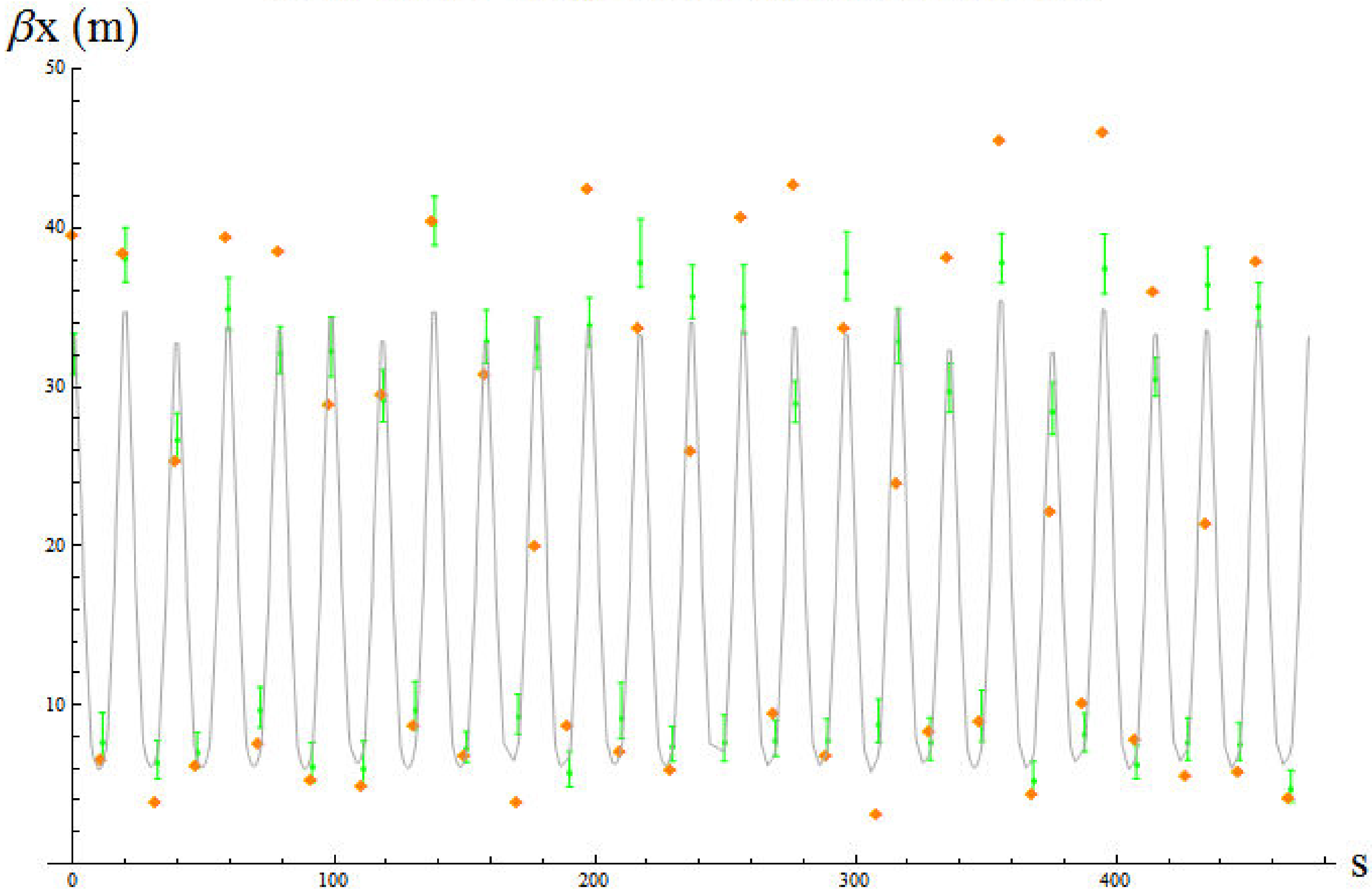
We measured only dispersion relative to dispersion at the location of RPOS; results are scaled by the MAD value for dispersion at RPOS.

Horizontal orbit response measurements



$$\Delta x[s] = \delta\theta \left(\frac{\text{Cos}[\pi\nu]}{2\,\text{Sin}[\pi\nu]}\, \beta[s] - \frac{\sqrt{\beta[s]\,\beta[\text{RPOS}]}}{2\,\text{Sin}[\pi\nu]}\, \text{Cos}[\text{Abs}[\psi[s] - \psi[\text{RPOS}]] - \pi\nu] \right)$$

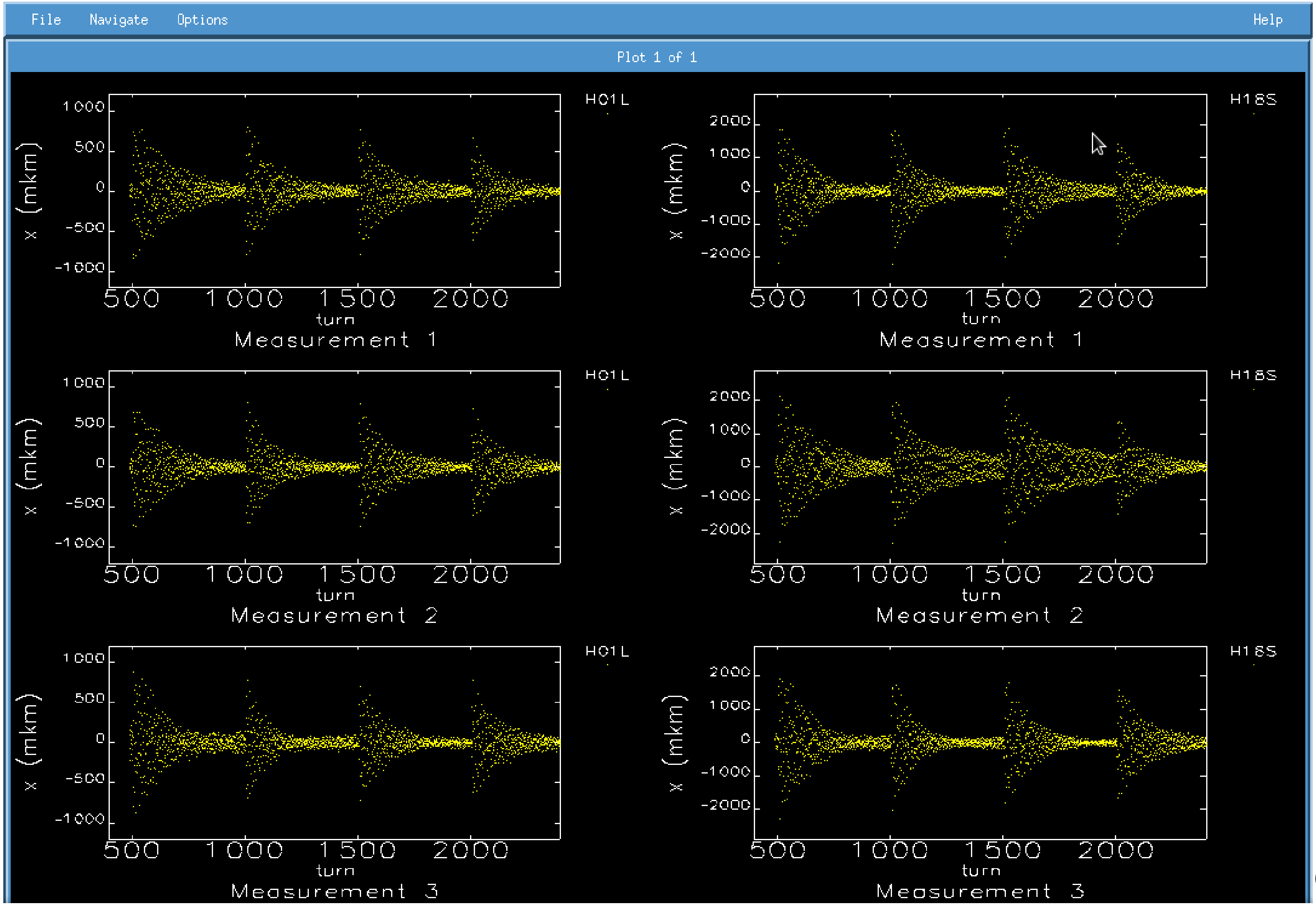
Horizontal Beta, K mod and orbit response



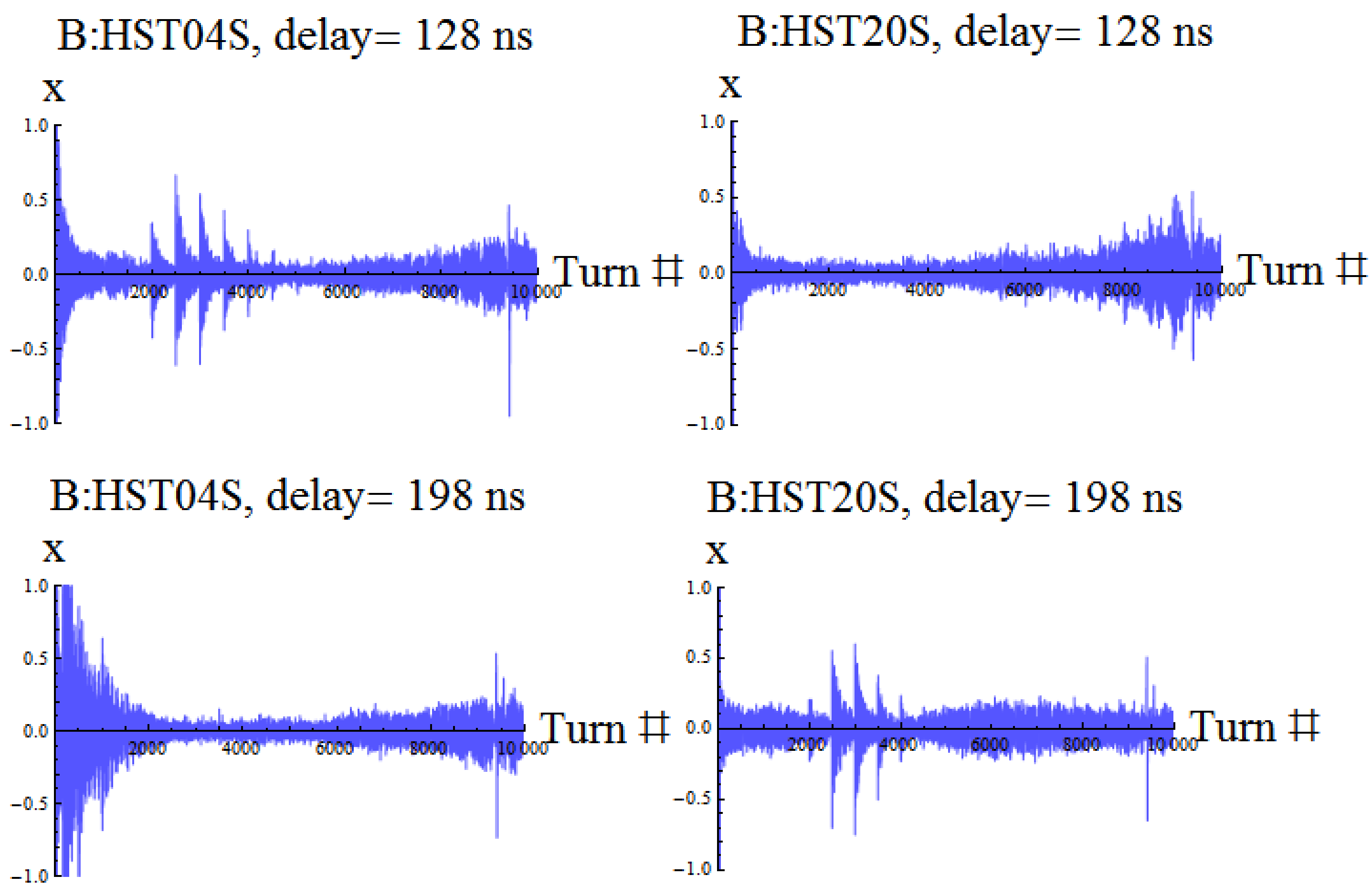
Method III: optics from turn-by-turn data

- problems with tbt data:
  - Turn-by-turn measurements of oscillating beam motion are not reproducible; the decoherence envelope varies by data set, especially at certain bpms
  - different bpms are measuring different bunches, as shown by the fact that pings can be recorded by some bpms and not by others

Decoherence time at a given bpm varies among different data sets

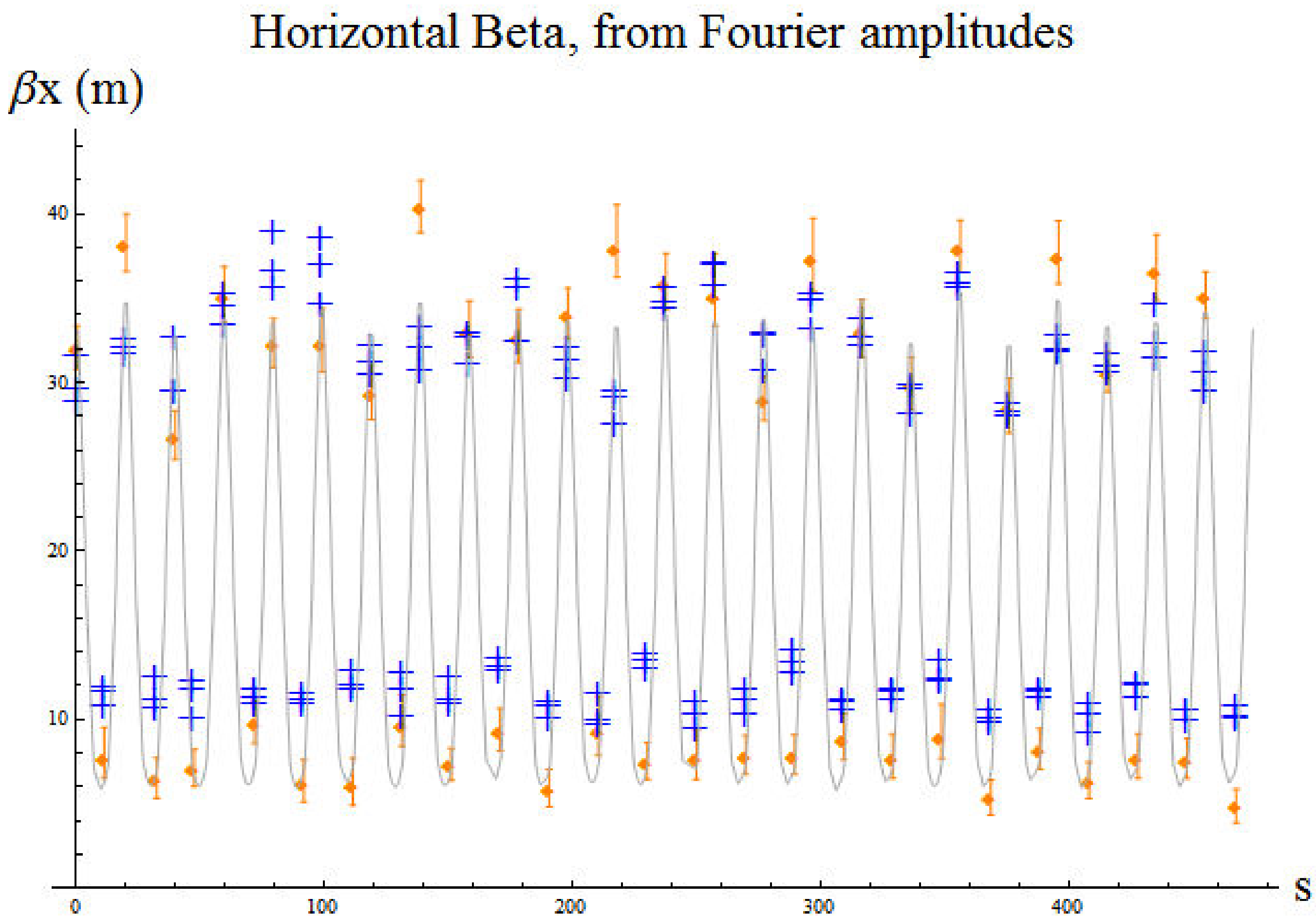


BPM Timing errors



When only five bunches are pinged, the oscillations are visible at different times in the acceleration cycle at different bpms; 80 bunches must be pinged in order for the oscillations to be visible at all bpms throughout the acceleration cycle.

Betatron amplitudes from turn-by-turn data, using SUSSIX



Conclusions

- K modulation and orbit response both give good results, and we should be able to build a very accurate model of Booster optics
- issues with bpms need to be resolved before tbt data will work well for optics measurements