Cornell Laboratory for
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CesrTA Low Emittance Tuning

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Abstract

Low emittance tuning and characterization of electron cloud phenomena are central to the CesrTA R&D program. A small vertical emittance is required in order to be sensitive to the emittance diluting effects of the electron cloud. We have developed techniques to systematically and efficiently eliminate optical and alignment errors that are the sources of vertical emittance. Beam based measurements are used to center the beam position monitors with respect to the adjacent quadrupoles, determine the relative gains of the BPM button electrodes, and measure the BPM tilts, thus allowing precision measurement of transverse coupling and vertical dispersion. Low emittance also requires that the tune plane be relatively clear of nonlinear coupling resonances associated with sextupoles. We report on tests of a sextupole distribution designed to minimize resonance driving terms. We also report on efforts to measure sextupole strengths. Our standard low emittance tuning procedure typically yields sub 20pm emittance in one or two iterations. With tuning, we achieve a vertical emittance of ε_V ~15 pm at 2.1 GeV.

Beam Based Quadrupole Center Measurement

Problem:

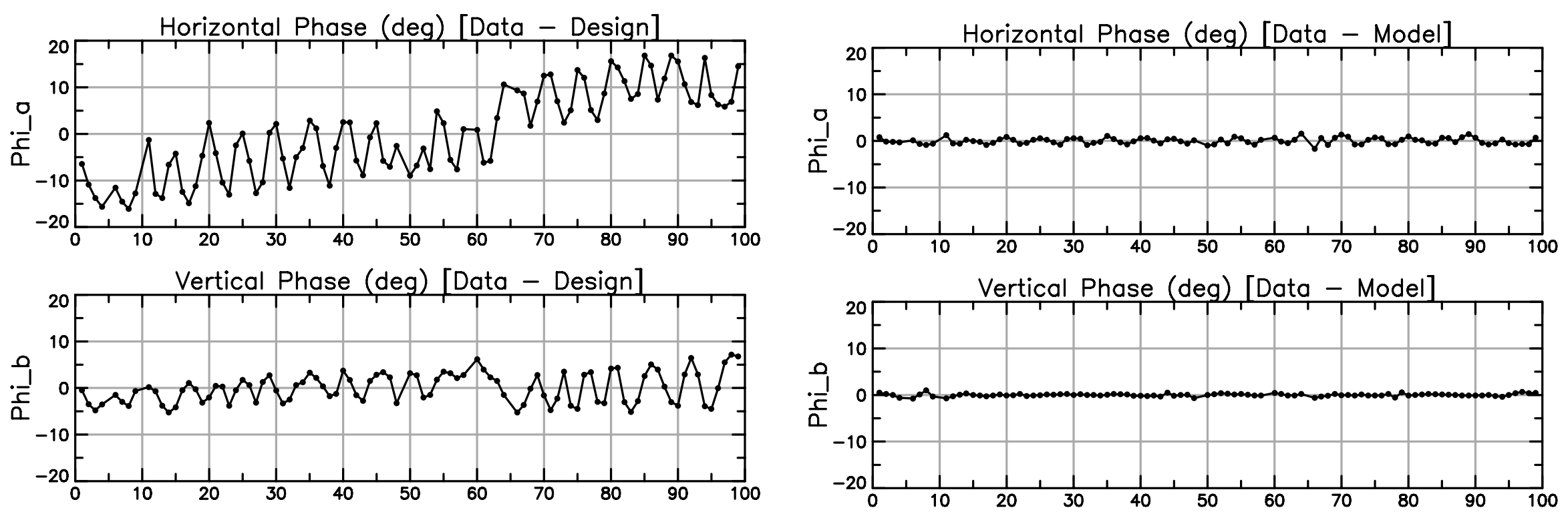
To measure the centers of the quadrupole magnets.

Solution:

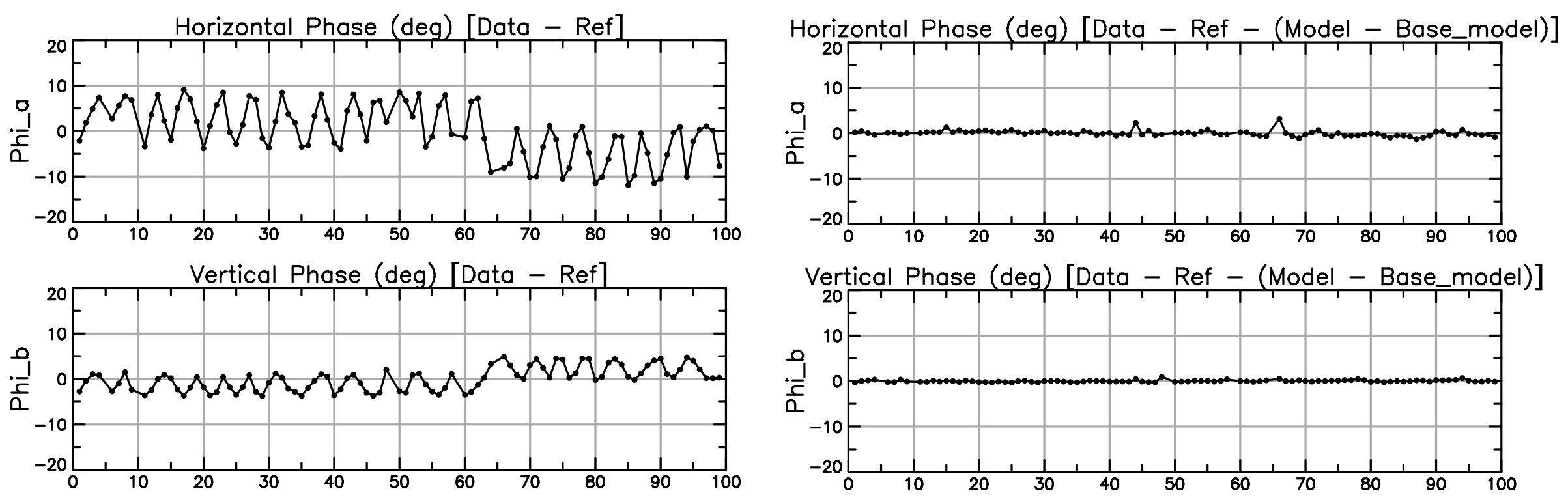
With the present CesrTA BPM system, simultaneous orbit, and betatron phase measurements can be taken. This ability makes practical a method whereby the orbit and phase data taken at two quadrupole settings is combined to accurately compute the quadrupole center. This reduces the number of orbit/phase difference measurements that need to be taken and hence reduces the measurement time.

Analysis:

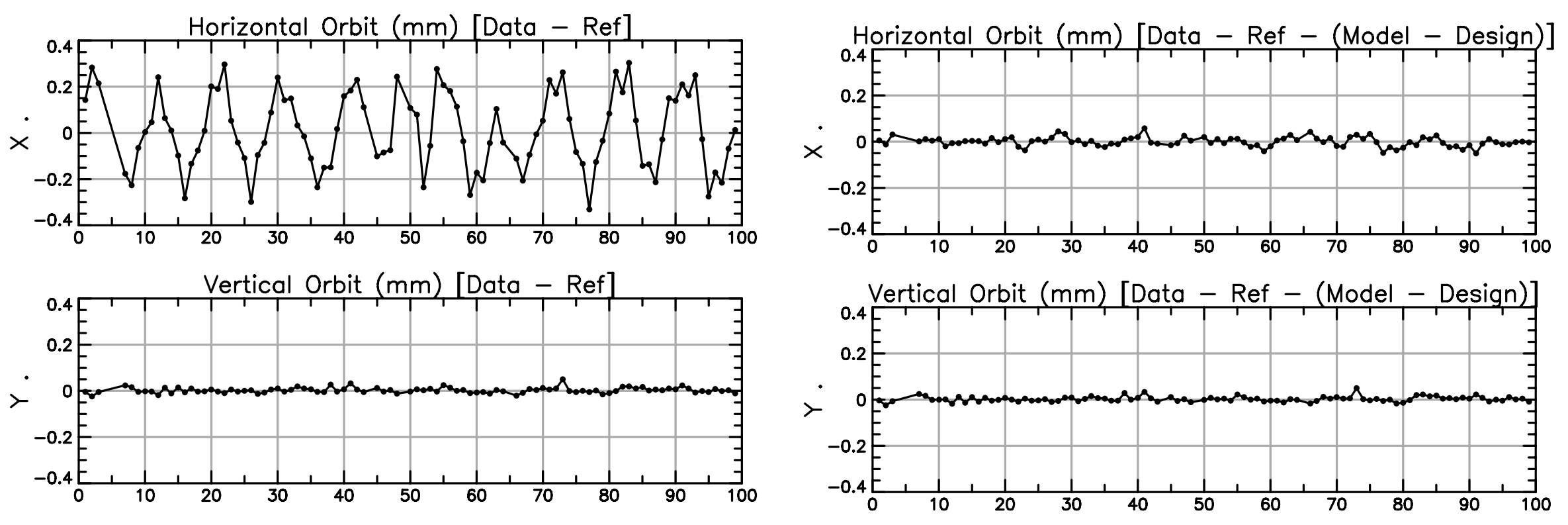
1st Step: Using a software model of the lattice, the model k of all the quadrupoles in the model are varied to match the calculated betatron phase to the phase measured at one setting of k of the "target" quadrupole being calibrated. This is called the "base" fit.



2nd Step: Starting with the base model, the k of the target quadrupole in the model is varied so that the model phase most nearly matches the measured phase from the second (non-base) measurement.



3rd Step: Starting from the model fit to the second data set, horizontal and vertical kickers that are superimposed on top of the target quadrupole in the model are used to fit the model orbit difference to the measured orbit difference.



The orbit difference dx is

$$dx(s) = (\tilde{x} - x_0(\bar{s}))\, dk\, L \frac{\sqrt{\beta(s)\beta(\bar{s})}}{2\sin\pi\nu}\cos(|\phi(s)-\phi(\bar{s})|-\pi\nu)$$

So the quadrupole center is computed via

$$\tilde{x} = \frac{dk}{L\, dk} + x_0(\bar{s})$$

Conclusion:

The ability to simultaneously measure the orbit, along with the betatron phase, provides a fast and accurate method for measuring quadrupole centers and avoids problems with hysteresis and quadrupole calibration inaccuracies. Currently, a single orbit/phase difference takes about a 30 seconds to measure and analyze.

Beam Based Measurement of BPM Electrode Gains and Tilts

Problem

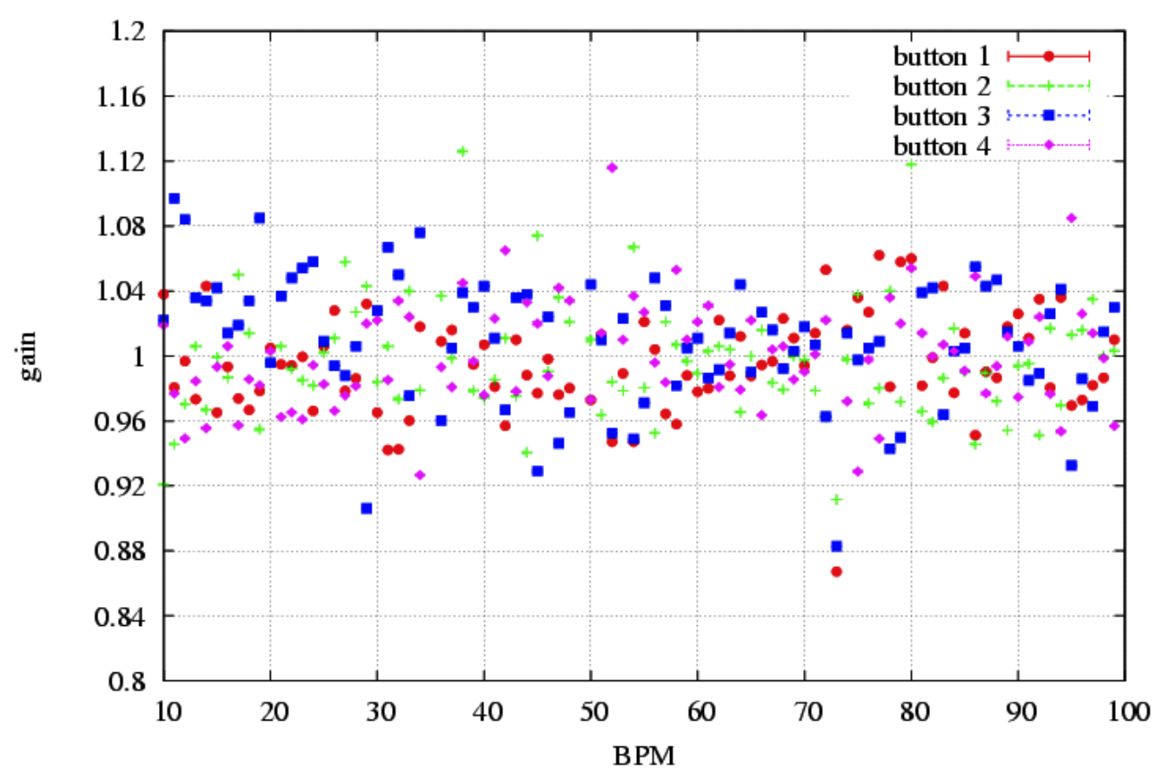
Variation of electrode gains in a BPM along with any tilts of the BPM as a whole makes for a systematic error in the position, dispersion and dispersion measurements.

Solution

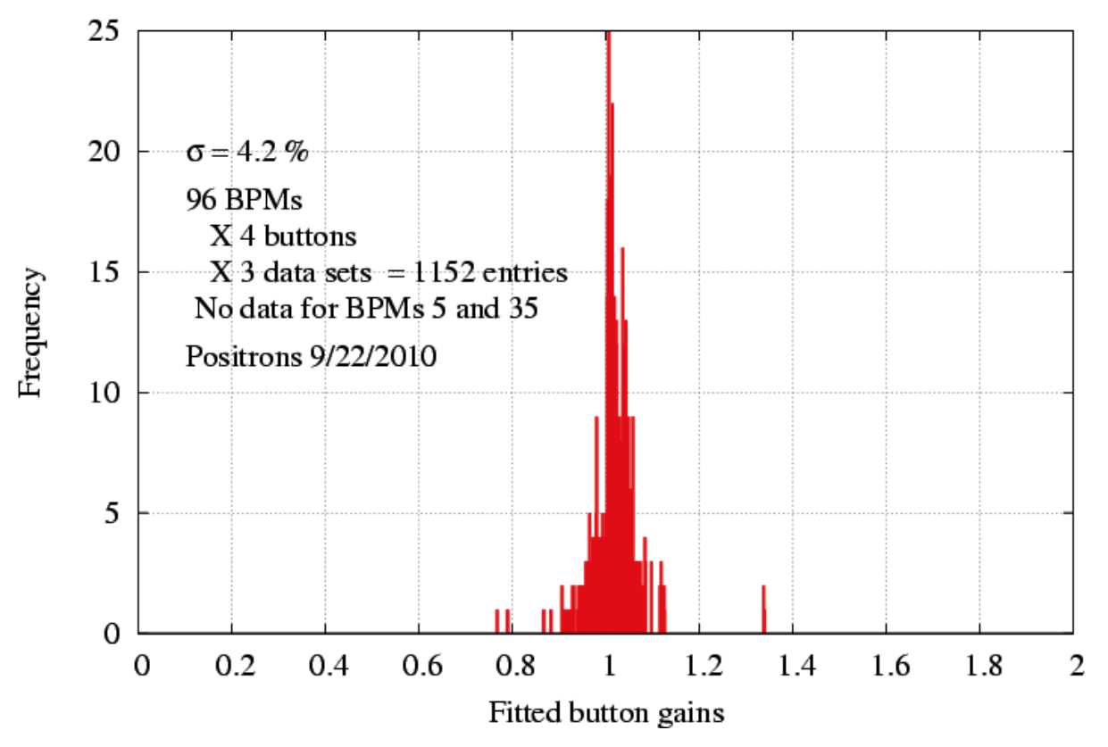
Measure the electrode gains by resonantly shaking the beam and taking turn-by-turn measurements. A fit to the gain corrected coupling measurements gives the tilts of the BPMs.

Analysis

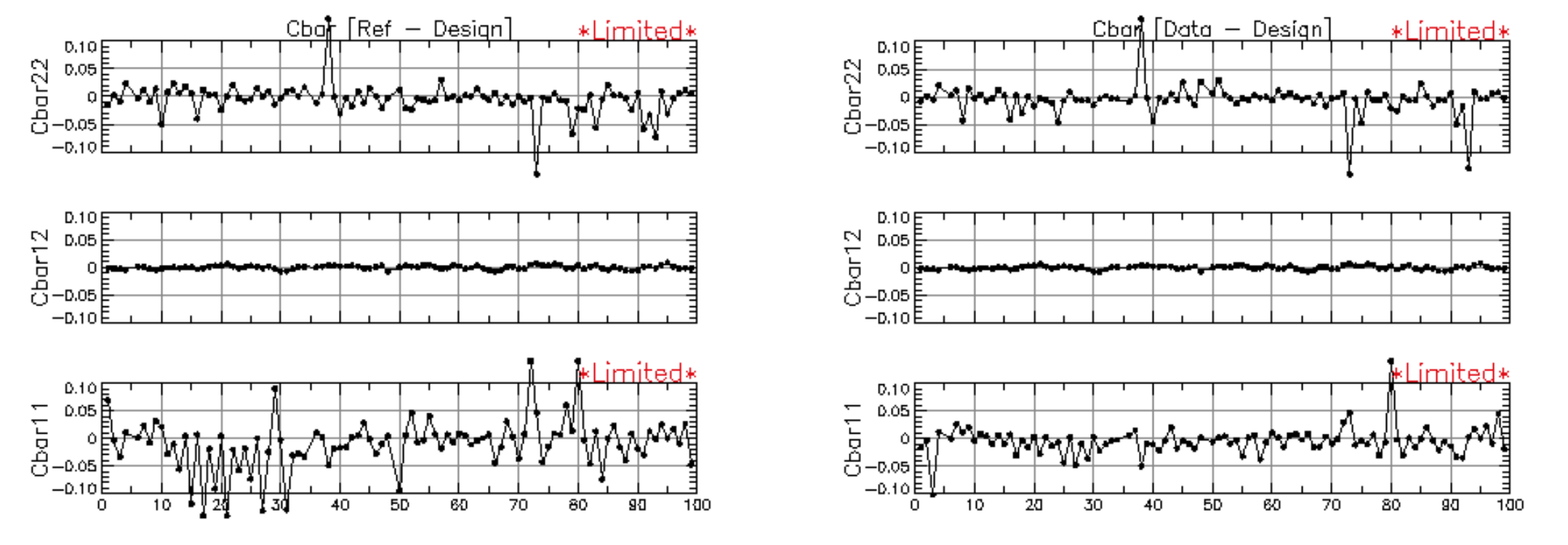
Fitted BPM button gains based on turn by turn data for a positron beam. The horizontal and vertical normal modes are resonantly excited and we collect button data at each BPM for 1024 turns. Three independent fits to three distinct sets of turn by turn data are combined in the figure. The error bar represents the spread in the fitted gains for the different data sets.



The histogram of the fitted gains for positrons shows the rms of the distribution is 4.2%, which is consistent with the specifications of the readout electronics.



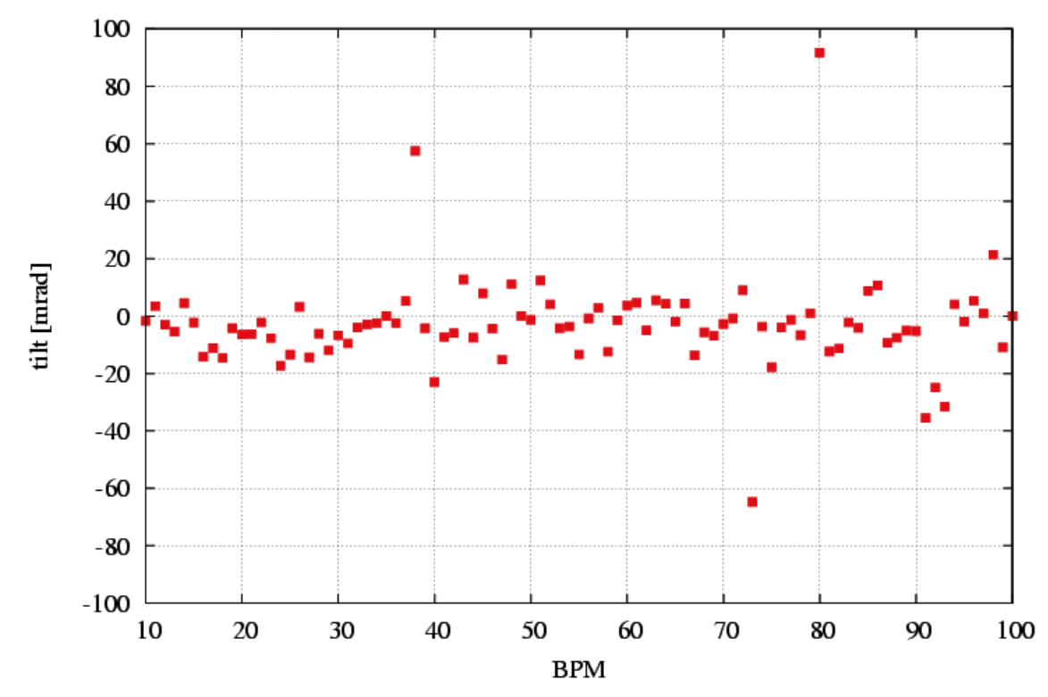
To determine transverse coupling the beam is resonantly excited in both transverse normal modes. Measurement of the relative amplitude and phase of horizontal and vertical motion at each BPM and at each of the two normal mode frequencies, is used to compute the elements of the coupling (C) matrix. The cbar12 component (middle plot) is largely independent of button gain and BPM tilt errors.



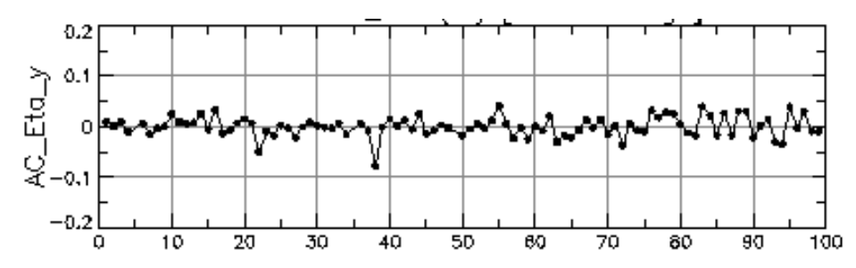
Coupling data with no BPM button gain corrections. Coupling data with BPM button gain corrections.

Note the sensitivity of the cbar11 and cbar22 components of the coupling matrix to BPM gain errors. We ascribe the residual, after gain correction to BPM tilts.

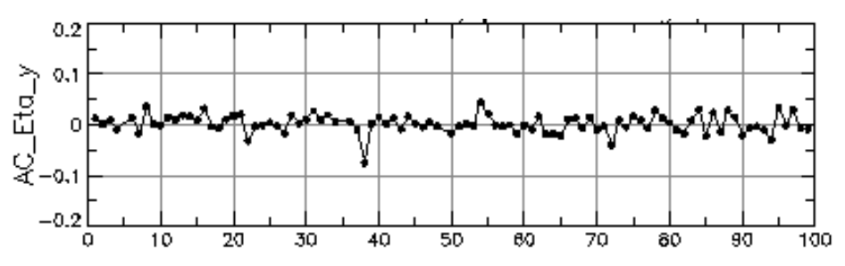
Fitting to the gain corrected coupling data yields a measure of the tilt of the BPM. The rms of the tilts for all the BPMs is 10mrad."



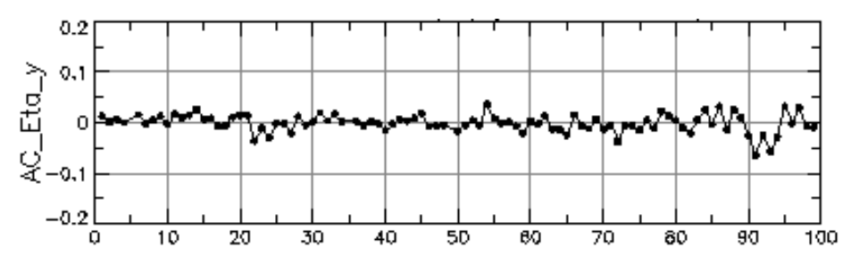
The measured vertical dispersion with no gain or tilt correction. The residual is 20mm.



With gain correction the residual is reduced to 18mm.



With gain and tilt corrections the residual is only 17mm.



Conclusion

We use turn by turn button data to calibrate relative button gains and then gain corrected coupling data to determine BPM tilts. With low emittance tuning we typically are able to reduce the residual vertical dispersion to less than 15mm.

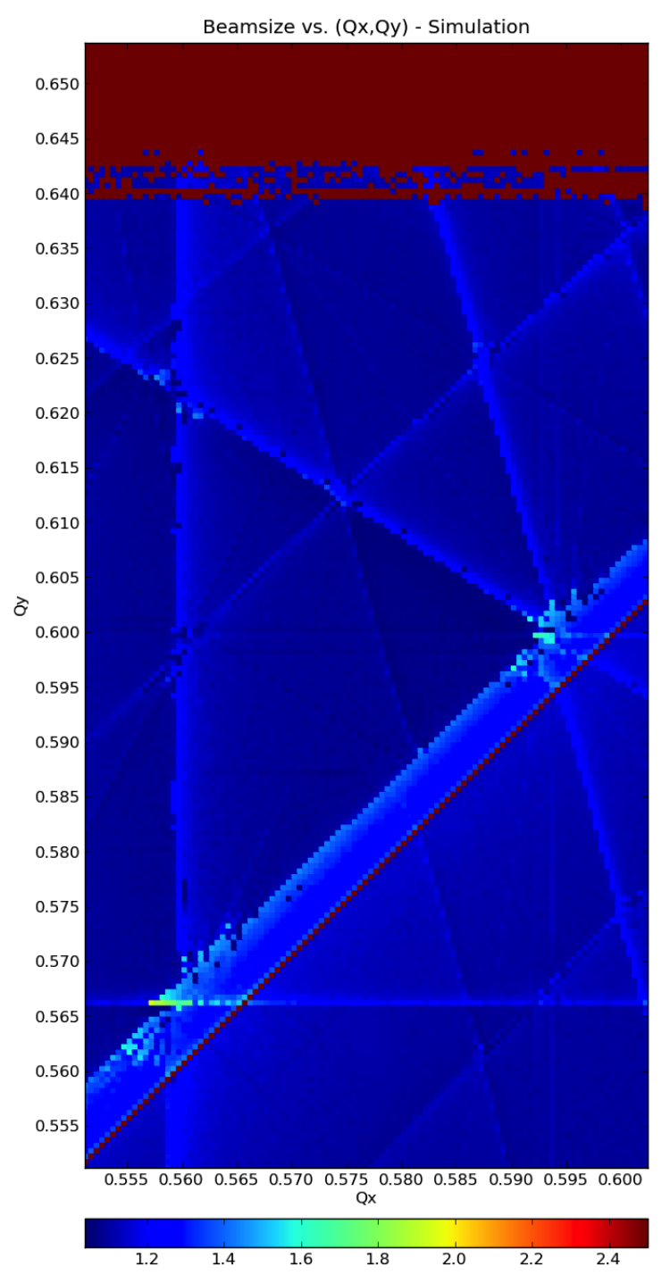
Tune Scans with the x-ray Beam Size Monitor

Our X-ray Beam Size Monitor (xBSM) is capable of measuring bunch-by-bunch, turn-by-turn beam sizes for a 14ns bunch spacing. To reduce the effects of turn by turn jitter, the profile is fitted on each turn to a Gaussian and the standard deviations are averaged over 100 turns.

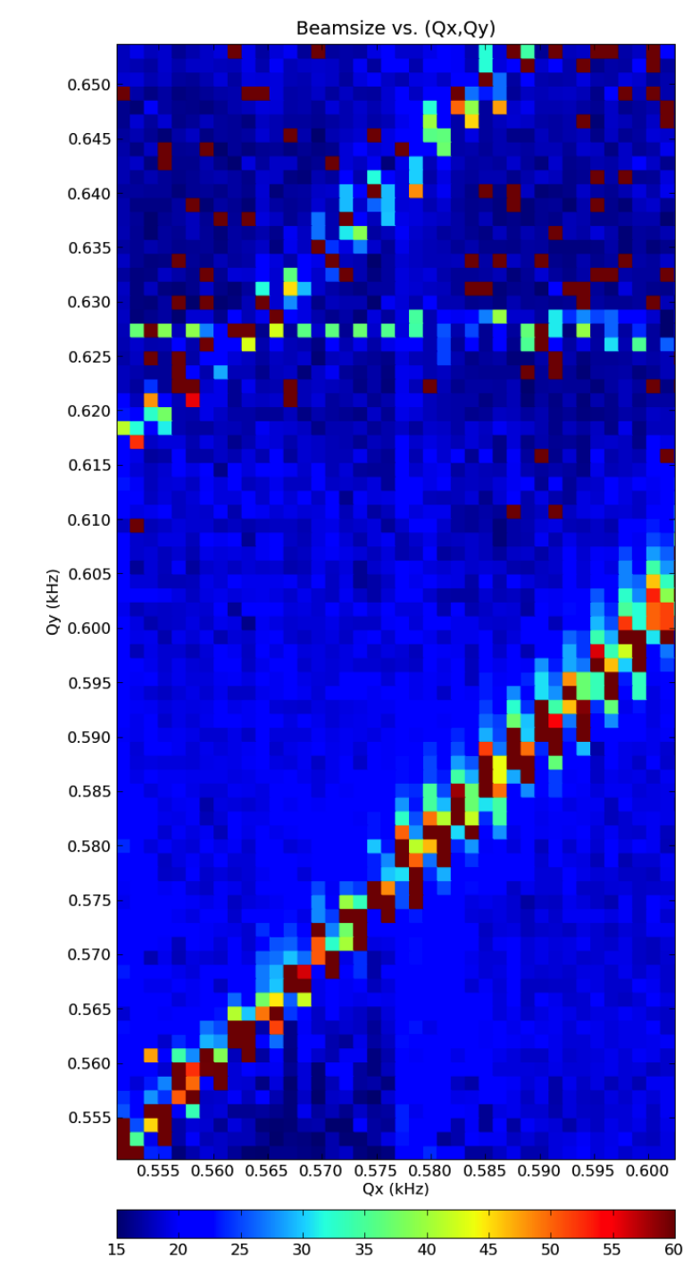
The fast response (~3 seconds) of our xBSM allows us to measure the effects of changing the optics in real-time. We have developed an automated method for scanning the tune plane and measuring the beam size at each point. We use a simple pinhole optics for the xBSM. The pinhole diameter of 16mm determines the minimum measurable beam size.

A tune scan was performed on a lattice with sextupole distribution optimized according to the standard prescription to reduce resonance-driving terms and increase dynamic aperture. For the simulated tune scan, errors of RMS 220 micro-radian tilts and 125 micron vertical offset were included on all quadrupoles. Quad K1 errors comparable to a corrected machine do not affect the simulation significantly.

Simulation



Measured

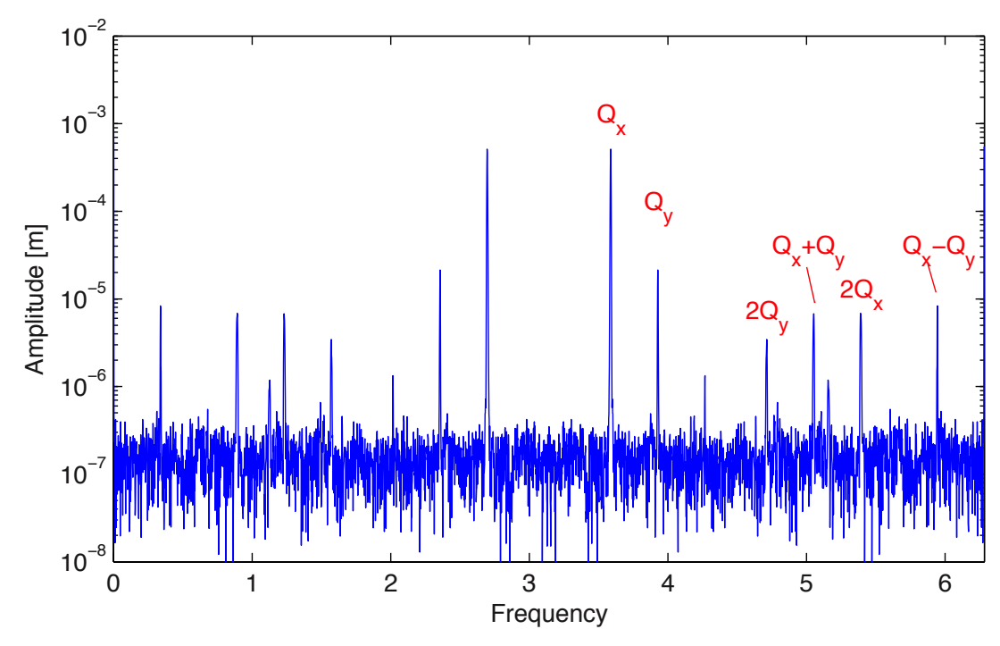


Conclusion

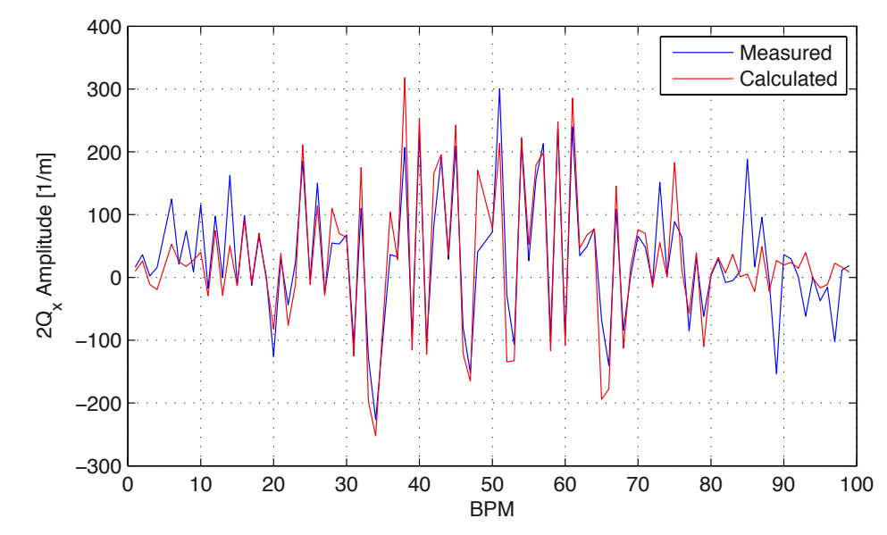
A tune scan in the vicinity of our standard working point has enabled us to locally optimize the working point which produces smaller beam size measurements. Resonance structures are mostly in agreement between measurement and simulation.

Studying Sextupole Resonances Using Turn-By-Turn Data

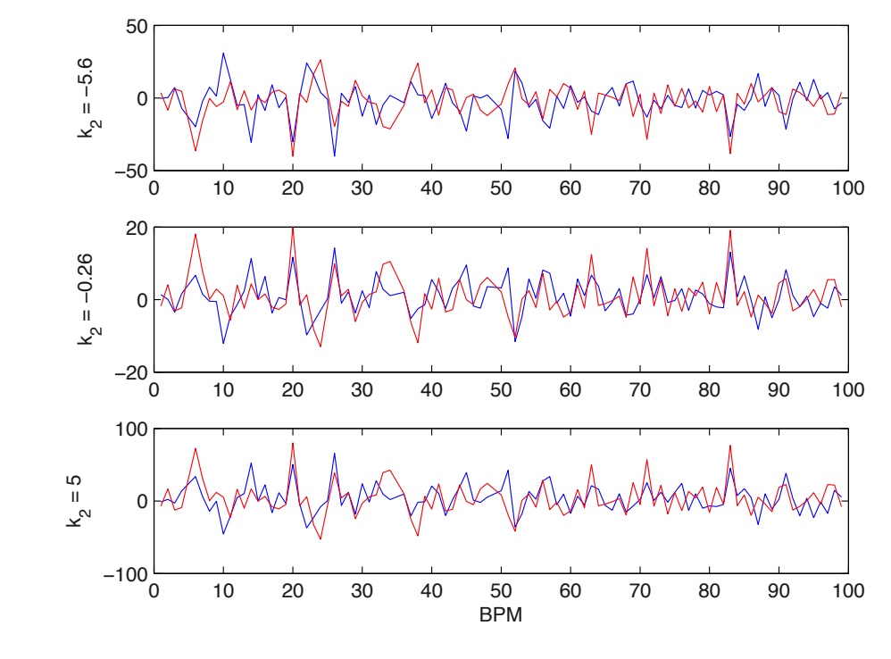
To first order, the transverse motion of a freely oscillating beam is characterized by the tunes, Qx and Qy, and the linear Twiss parameters. Non-linear components such as sextupole magnets introduce higher order resonances at frequencies n*Qx+m*Qy. We can use our beam position monitors (BPMs) to extract data on the transverse behavior of the beam. An example reading from one BPM is given below: The logarithmic plot of the Fourier spectrum over 4096 turns clearly shows how the dominate Qx resonance, but second order harmonics give a significant contribution.



The non-linear effects of the sextupoles can be modeled using normal form analysis. Shown below is one example, the in-phase component of the 2Qx resonance. The blue line denotes the actual component as measured by the BPMs while the red line shows the analytic calculation.



Our goal in analyzing these resonances is better understanding and control of the beam. If our analytic model can tell us the expected result of changing sextupole beam strengths, we can numerically optimize these strengths to improve the beam quality. Shown below is the predicted and measured effect of changes in the field strength of a single sextupole. Our plots show the change in the in-phase 2Qx component as we vary the field strength, showing again BPM measurements in blue and analytic calculation in red.



Conclusion: Our initial studies of the sextupole resonances show results in line with the prediction of our model. Work is ongoing on turning these results into a practical method and incorporating them into our procedures for optimizing the beam.

LEPP, the Cornell University Laboratory for Elementary-Particle Physics, has joined with CHESS to become the Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE). LEPP's primary source of support is the National Science Foundation. Visit us on the web at: www.lepp.cornell.edu