Low-Emittance Tuning at CesrTA

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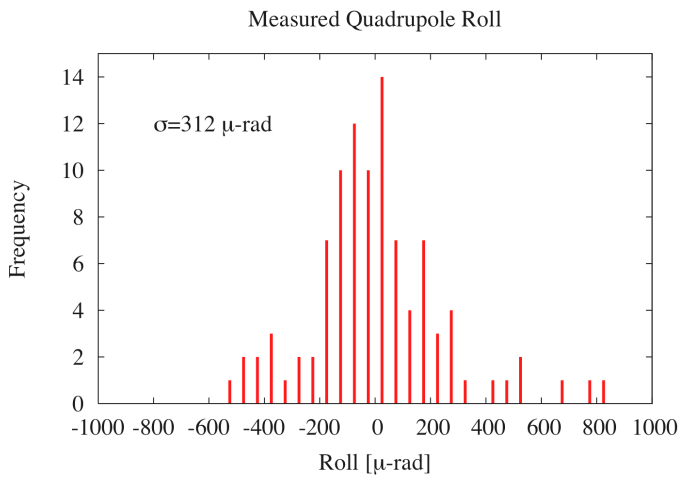
Outline

- Brief recap: results prior to November 2009
- November/December 2009 run
  - “AC eta” measurements
  - X-ray beam size monitor (xBSM)
  - Emittance tuning
  - Beam size vs. tunes
  - Gain mapping
- Plans for next run

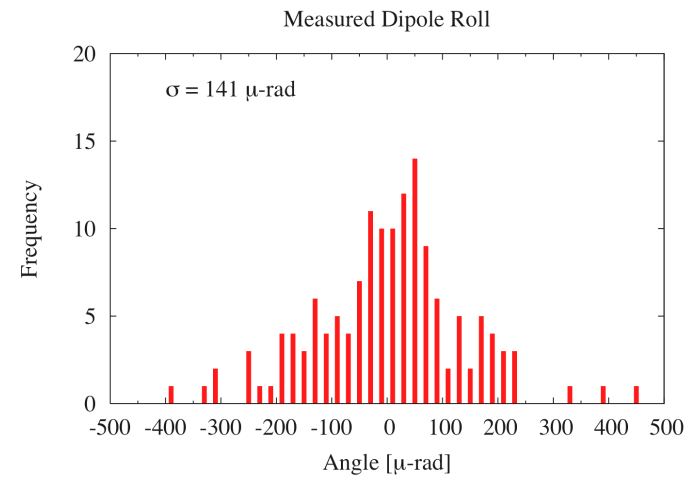
Status Prior to 11/2009

- Developed and implemented optics at a range of energies $1.8\text{GeV} < E_{beam} < 5.3\text{GeV}$
  - With and without damping wigglers
  - All optics corrected, ramped and recovered injection
  - Switching optics and energies is relatively fast
- Implemented multiple-stage optics correction (orbit+η, then η+coupling)
- Developed machinery for "AC dispersion" measurements
  - Longitudinal resonant excitation
  - Measure coupling to transverse modes
- xBSM is operating
  - After setup/calibration (~45 minutes), measurements performed "on demand", taking roughly one minute
- **Emittance achieved: ~40pm**

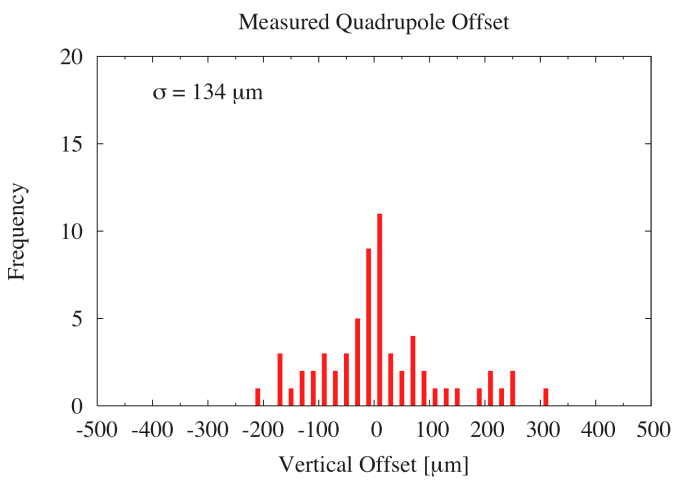
Magnet Alignment and Survey as of 12/02/2009



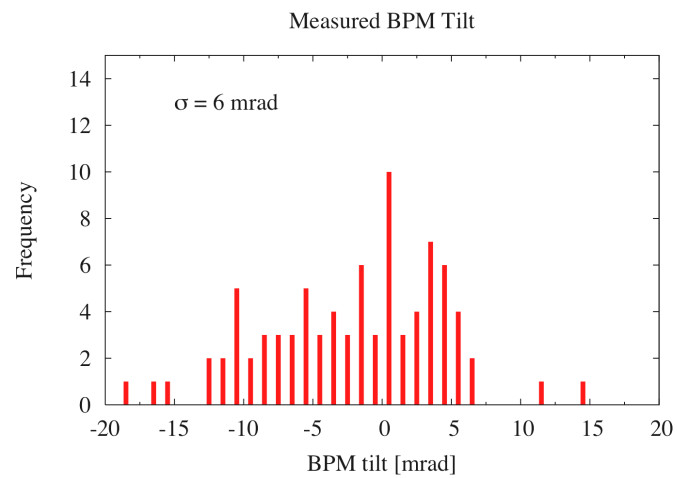
Quad roll σ ~ 300 μrad



Bend roll σ ~ 150 μrad



Quad offset σ ~ 134 μm

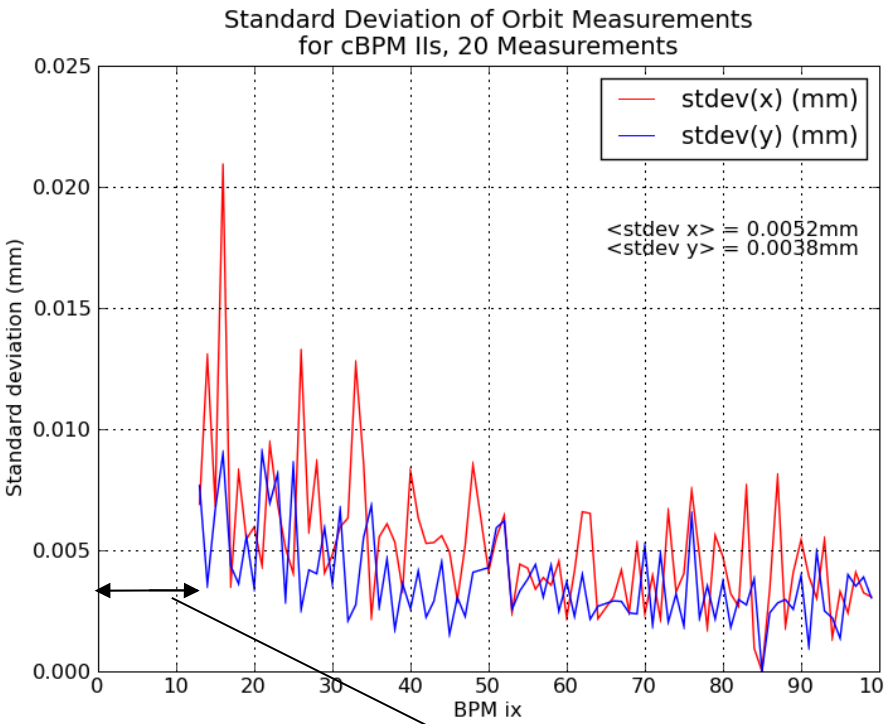


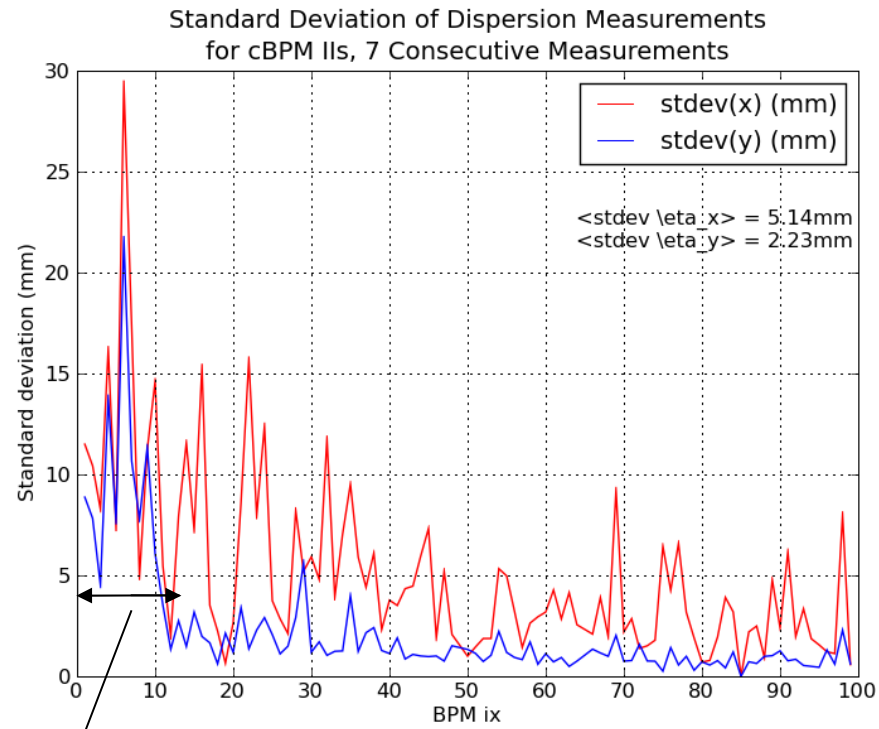
BPM tilt σ ~ 6 mrad

November/December 2009 Run

New Digital BPMs: Orbit, Dispersion Reproducibility

- Digital BPM system switchover 90% complete for December 2009 run
- Intrinsic orbit/dispersion resolution:





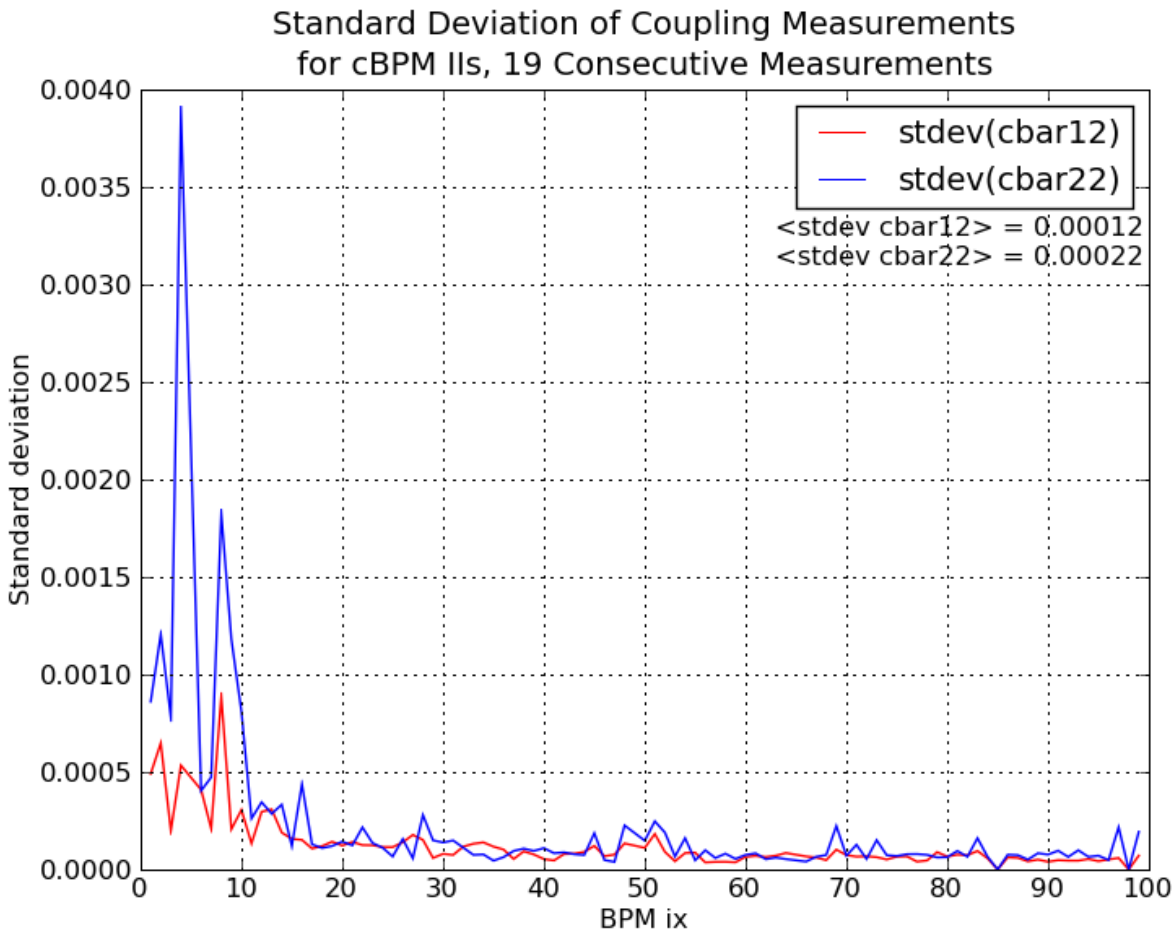
$\sigma x = 5.2\mu m$
$\sigma y = 3.8\mu m$

Old cBPM I (prototype digital) system, to be replaced

$\sigma(\eta x) = 5.2mm$
$\sigma(\eta y) = 2.2mm$

New Digital BPMs: Coupling Reproducibility

- Using resonant excitation method

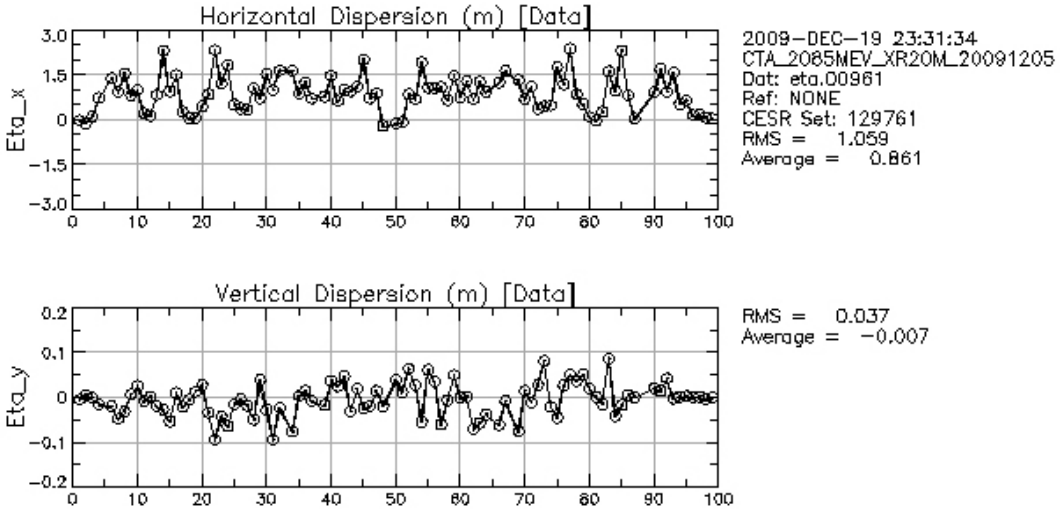


σ(cbar22) = 1.2e-4
σ(cbar22) = 2.2e-4

"AC Dispersion" Measurements

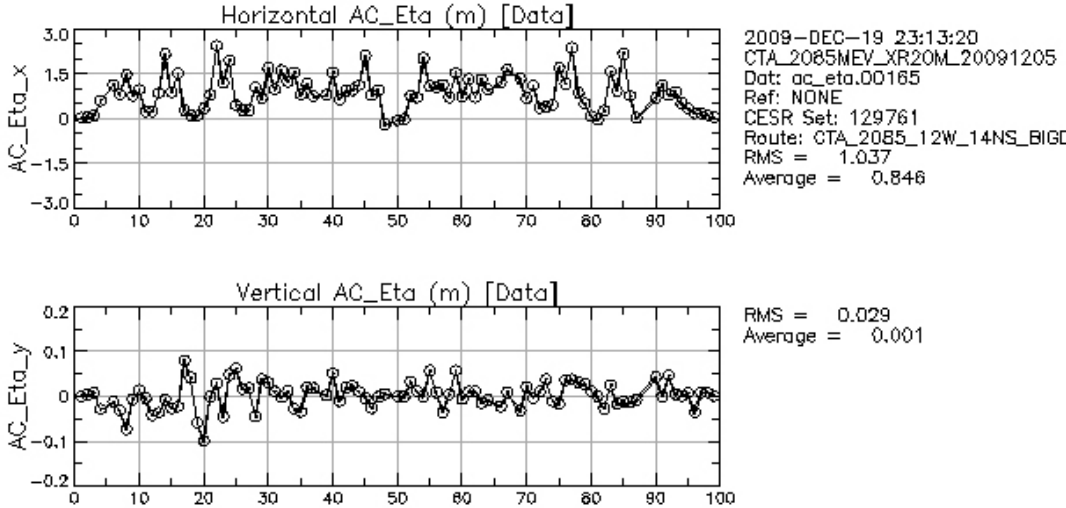
Traditional "DC" dispersion measurement

$\sigma(\eta_y) = 3.7$cm



"AC" dispersion measurement

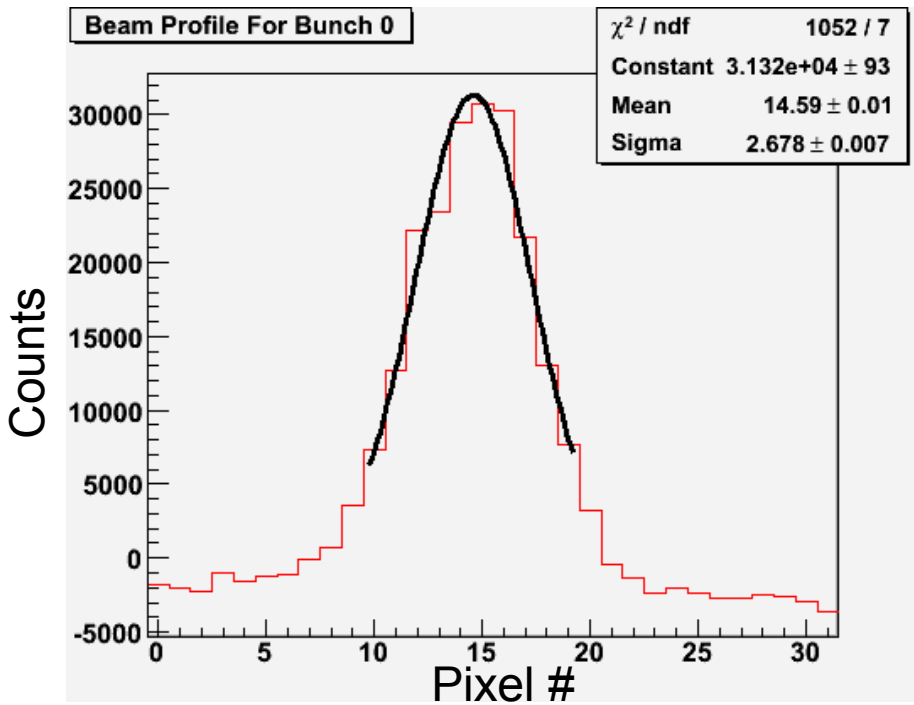
$\sigma(\eta_y) = 2.9$cm



xBSM: Overview

Overview

- Image synchrotron radiation with photodiodes
- Measure vertical beam size nondestructively
- Capable of measuring every bunch, every turn
  - Currently 14ns between bunches; soon 4ns

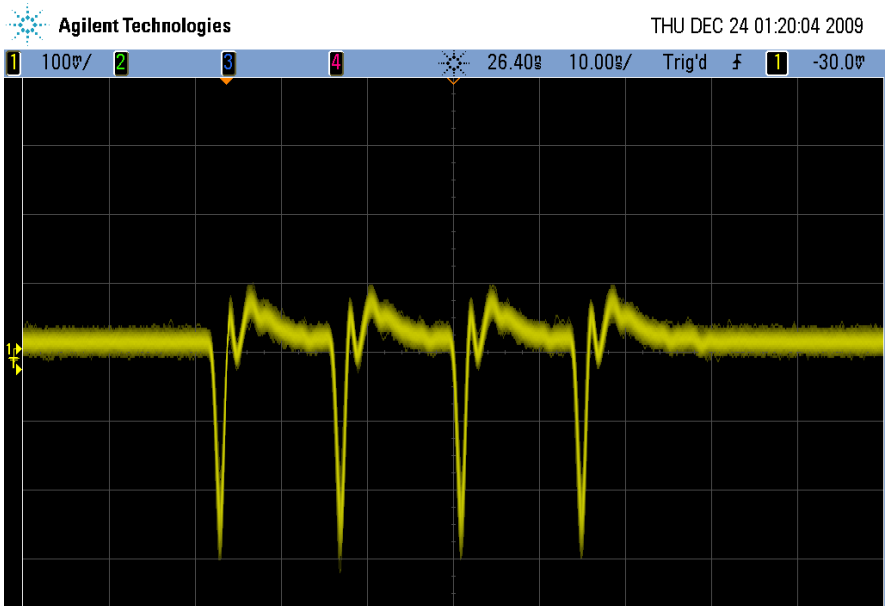


- Pinhole optics, "white" beam
- Averaged over 1000 turns
- Pixel width = 50μm
- Magnification = 2.4

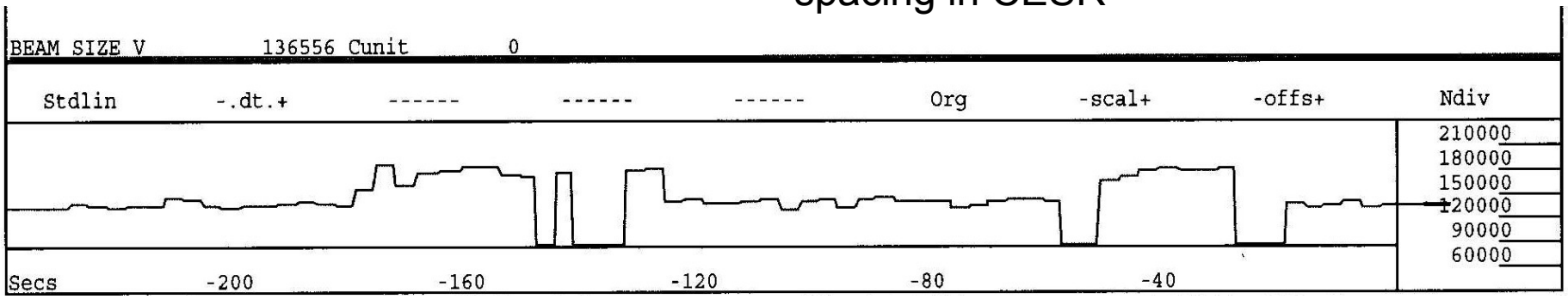
→ Measured beamsize = 56μm

xBSM: Updates

- Live beam size updates to control room
  - Updates every ~2s
- Electronics upgrade for 4ns bunch spacing progressing
  - Redesigned amplifier
  - New data acquisition unit



Output of new amplifier with 4ns bunch spacing in CESR



Beam size chart in CESR control room

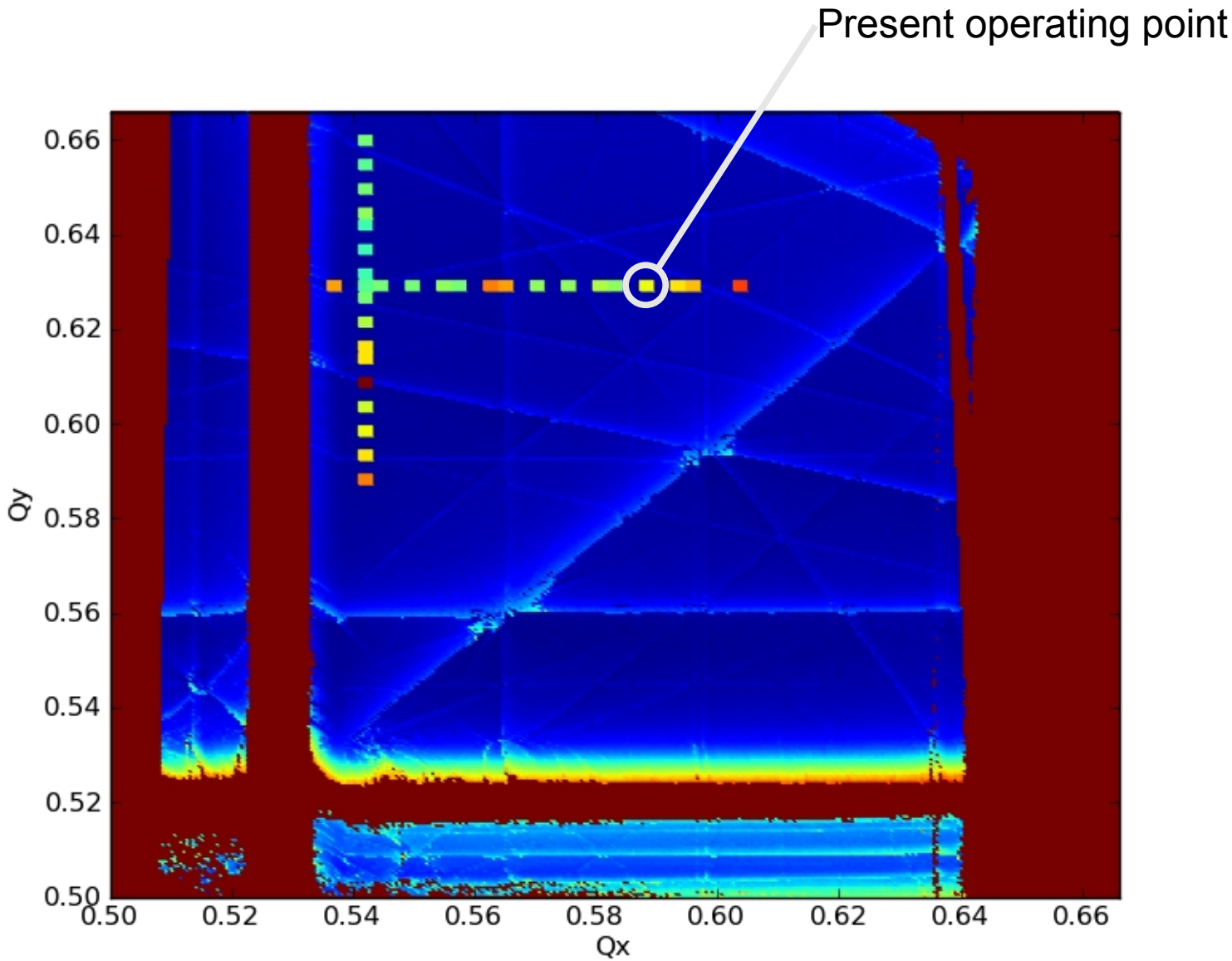
Low-Emittance Tuning

- New optics-- increased β_y at xBSM source from 5.8m to 17m
  - Yields better resolution
- Standard tuning technique:
  - Measure/correct:
    - Orbit
    - Phase/coupling
  - Measure η_y, remeasure orbit; correct together
  - Remeasure coupling, η_y; correct together

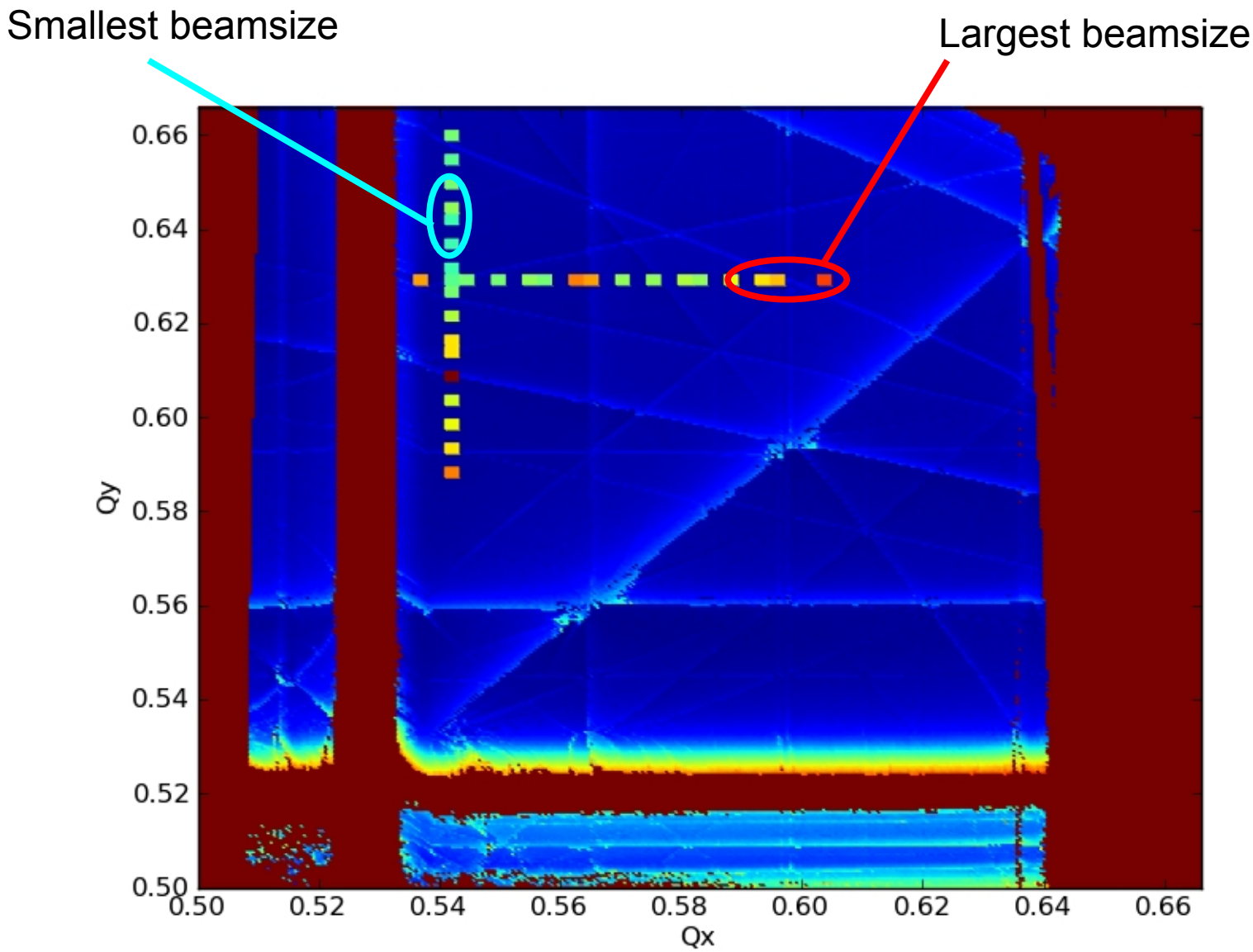
Low-Emittance Tuning: Continued

- With standard tuning technique, measure beamsize σ_y = 45μm
- Set bunch-by-bunch feedback gain to zero
  - **Big effect**-- reduces beamsize by a factor of 1.5 (45μm to 30μm)
    - Corresponds to ε_y = 49pm (with β_y = 17m at xBSM source)
    - Cross-check using original optics (β_y = 5.8m at xBSM source)
      - Measure σ_y ~ 16μm; corresponds to same ε_y
      - Implies we are not at the resolution limit of the detector in the new optics
- Turn off feedback amplifiers
  - Not as significant as zeroing feedback, but noticable (~2μm reduction)
- Tune scan
  - Real-time tune scan of beamsize is possible with xBSM
  - Minimum beamsize is not at our present working point!

Beam Size vs. Tunes

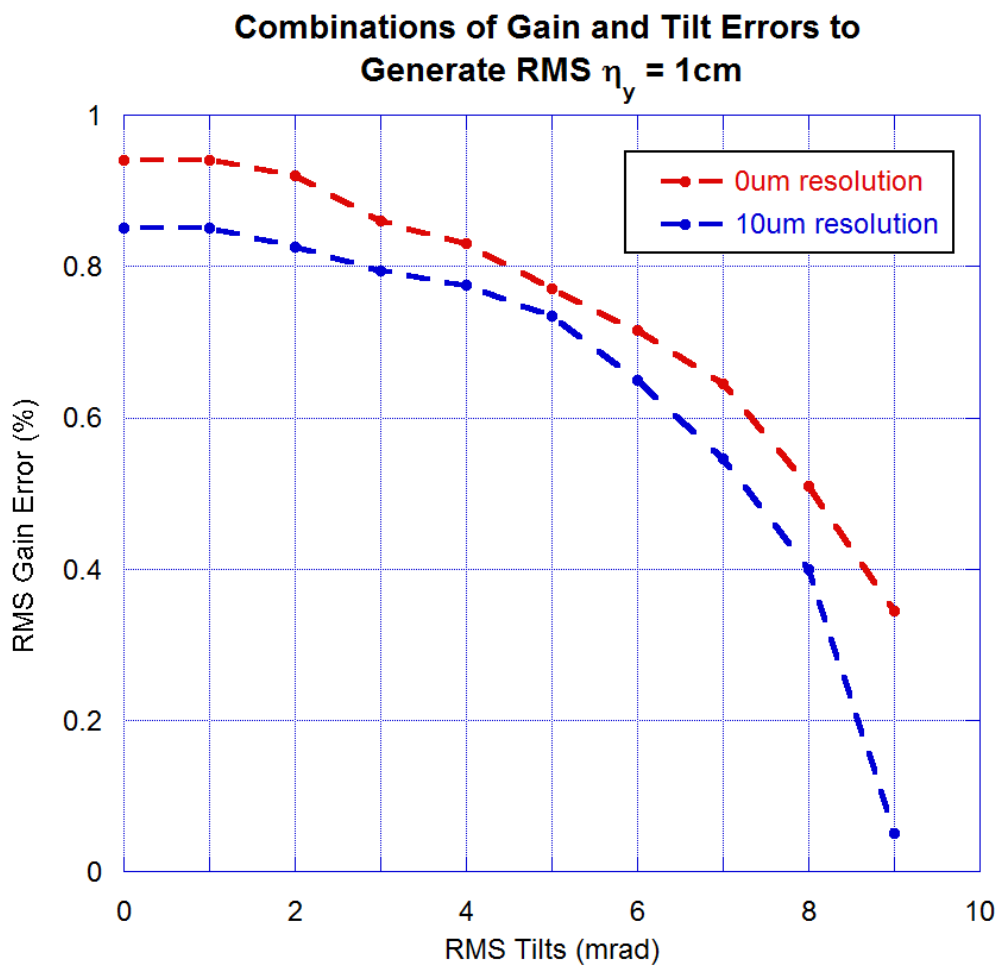


Beam Size vs. Tunes



BPM Calibration: BPM Errors and Vertical Dispersion

- 20pm vertical emittance target requires RMS η_y < 1cm
- To measure η_y to within RMS 1cm accuracy, we need to calibrate:
  - BPM gain errors to <1%
  - BPM tilts to < 10mrad
- Current plan for calibration:
  - Gain mapping for BPM button gains
  - Use in-phase elements of Cbar coupling matrix for BPM tilts



Gain Mapping: First Attempts

- Summary / Review:
  - Technique originally developed at KEK
  - The response of each button (b_i) to the passage of a bunch at (x,y) is modeled by solving the 2D Poisson equation
  - Measure a grid of orbits covering the cross-section of a BPM
  - Fit model b_i's to measured b_i's to determine button gains:

$$\chi^2 = \sum \left(b_{ij}^{(meas)} - b_{ij}^{(model)} \right)^2$$

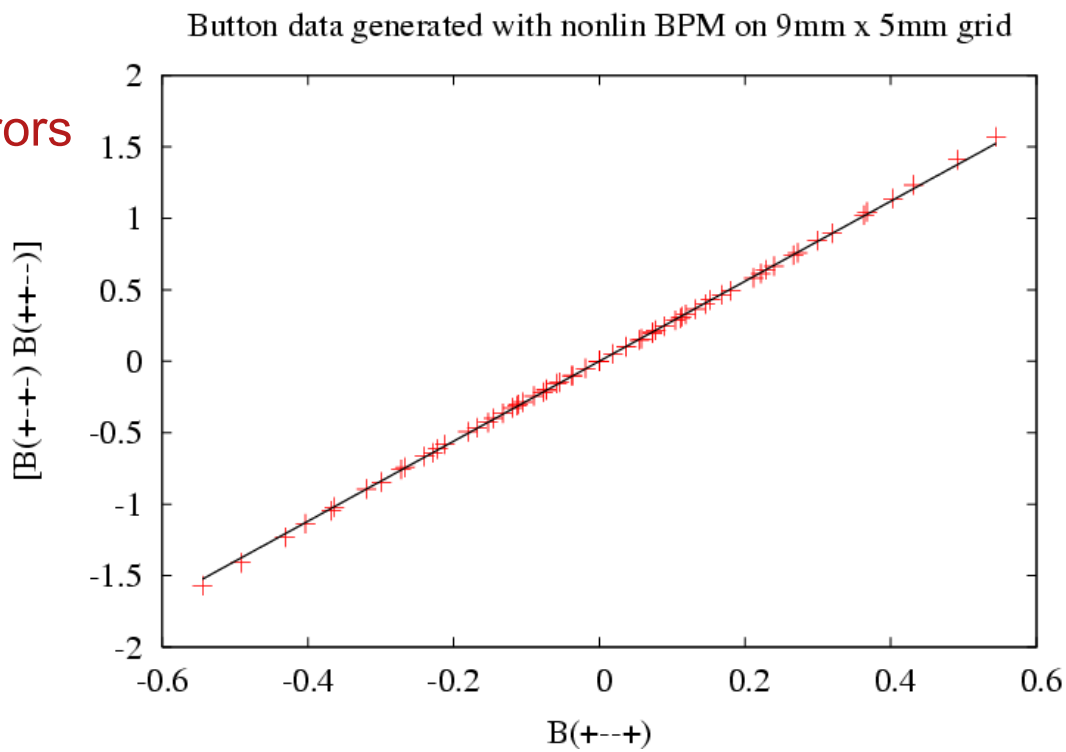
$$b_{ij} = g_i \cdot I_j \cdot F_i(x_j, y_j)$$

- First Results:
  - Fitted gains are only consistent to ~5% level between consecutive data sets
  - Simulations suggest we should be capable of fitting gains to within ~fraction of a percent
  - Still determining why these results aren't converging

New Gain Map Approach: Using TBT Data

- Advantages:
  - Uses Turn-By-Turn (TBT) data with fast acquisition time
    - We can incorporate gain corrections into standard LET procedure
  - Valid to second order
  - Independent of any BPM nonlinear response model *F(x.v)*

- Simulate an ideal BPM with no errors
- Plot $B_{+-+-}B_{++--}$ vs. B_{+--+}



New Gain Map Approach: Formalism

Signal at each button depends on bunch current (*k*) and position (*x,y*)

$$B_1 = kf(x,y)$$

$$B_1 \approx k\left(f(0,0) + \frac{\partial f}{\partial x}x + \frac{\partial f}{\partial y}y + \frac{1}{2}\frac{\partial^2 f}{\partial x^2}x^2 + \frac{1}{2}\frac{\partial^2 f}{\partial y^2}y^2 + \frac{\partial^2 f}{\partial x \partial y}xy + \ldots\right)$$

$$B_1 \approx k(c_0 + c_1 x + c_2 y + c_3 x^2 + c_4 y^2 + c_5 xy)$$

Signals on the four buttons are related by symmetry:

$$B_2 = kf(-x,y)$$
$$B_3 = kf(x,-y)$$
$$B_4 = kf(-x,y)$$

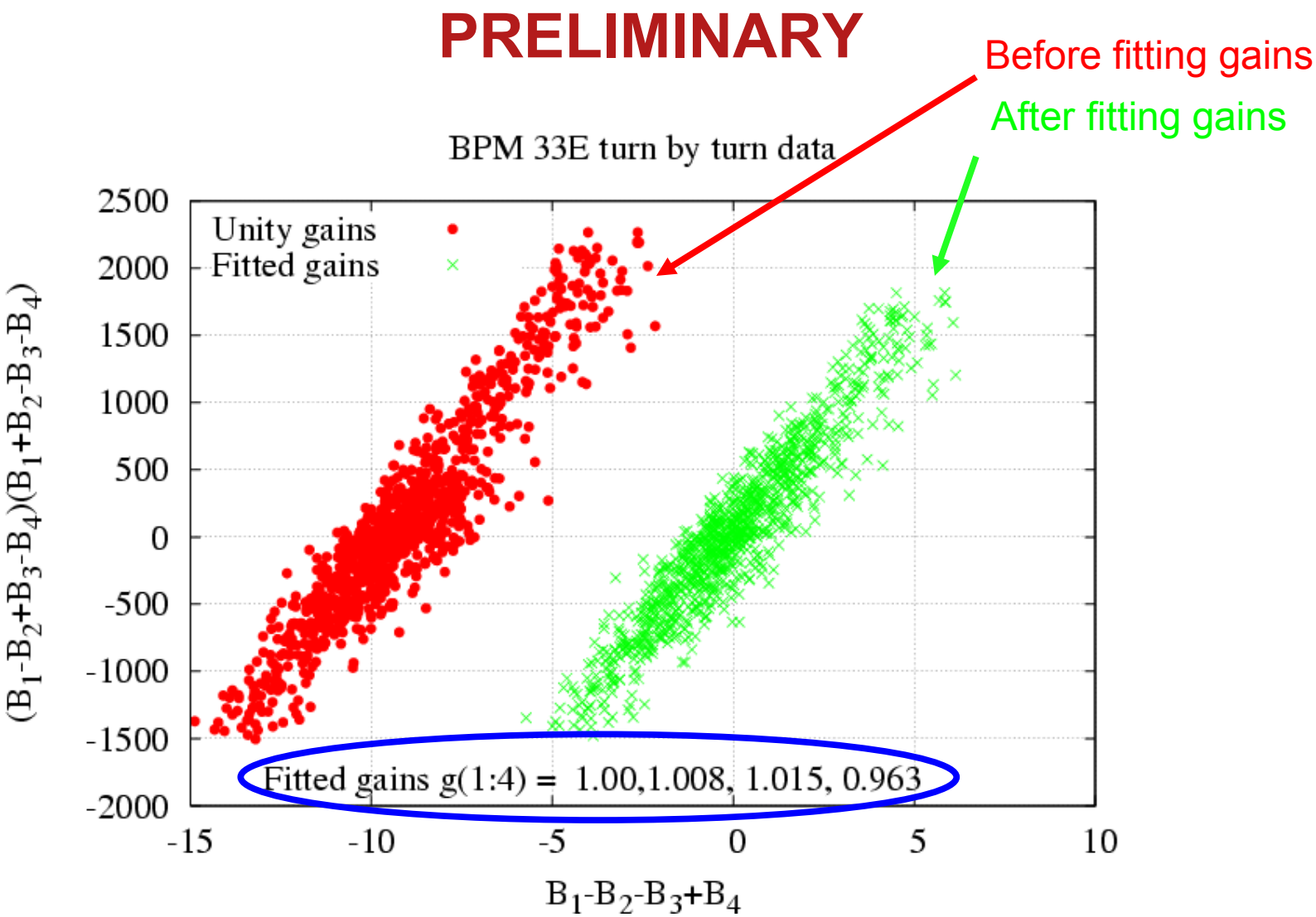
Combining sums and differences we find the following relationship, good to second order

$$B_1 - B_2 - B_3 + B_4 = \frac{1}{k}\left(\frac{c_5}{c_1 c_2}\right)(B_1 - B_2 + B_3 - B_4)(B_1 + B_2 - B_3 - B_4)$$

$$\boxed{B(+--+) = \frac{c}{k}B(+-+-)B(++--)}$$

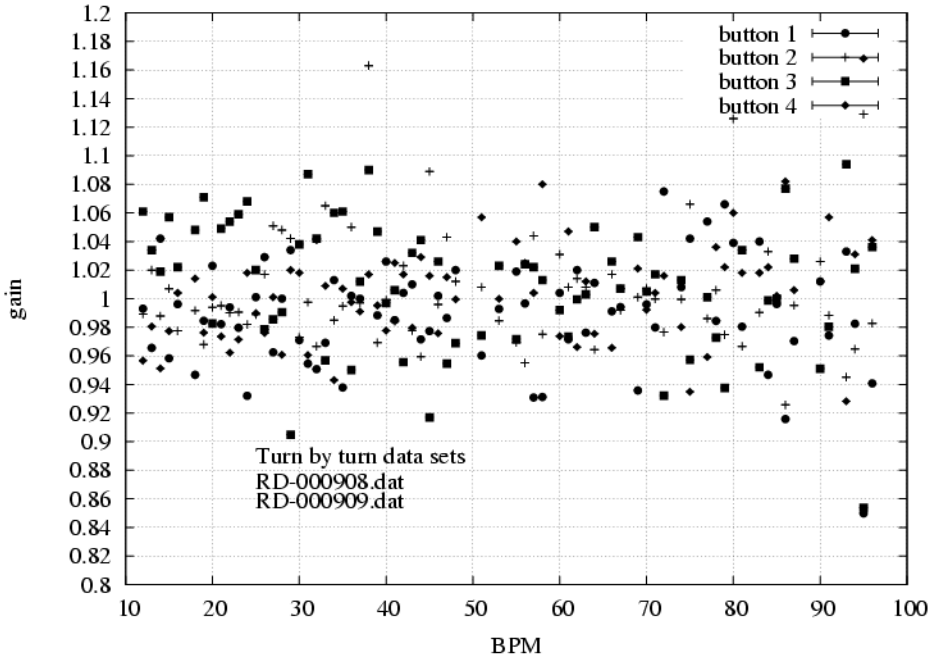
New Gain Map Approach: First Tests with Actual Data

PRELIMINARY

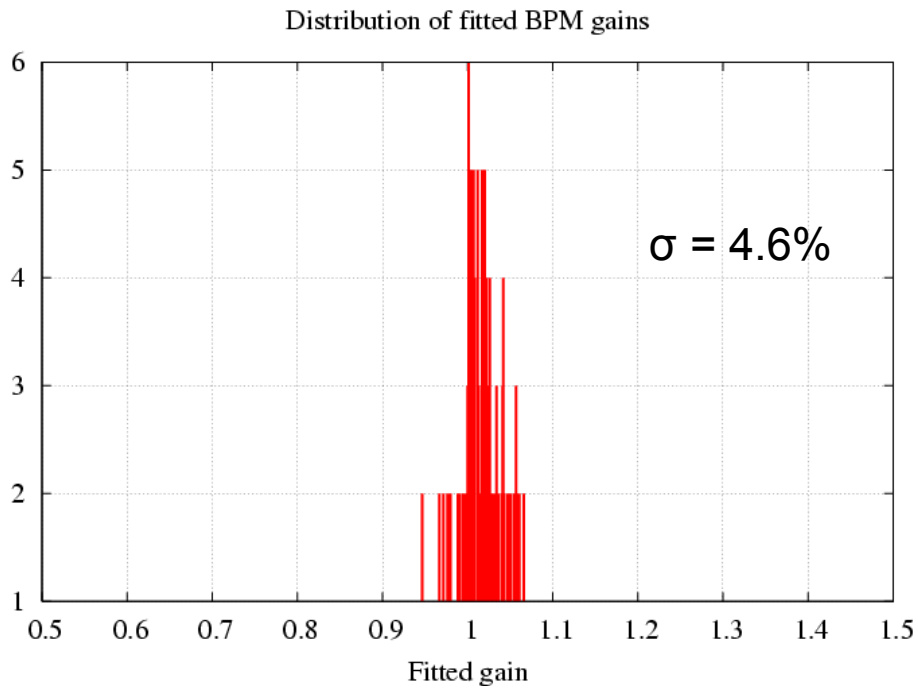


New Gain Map Approach: Summary of Fitted Gains

PRELIMINARY



Fitted gains for all 100 BPMs (single data set)

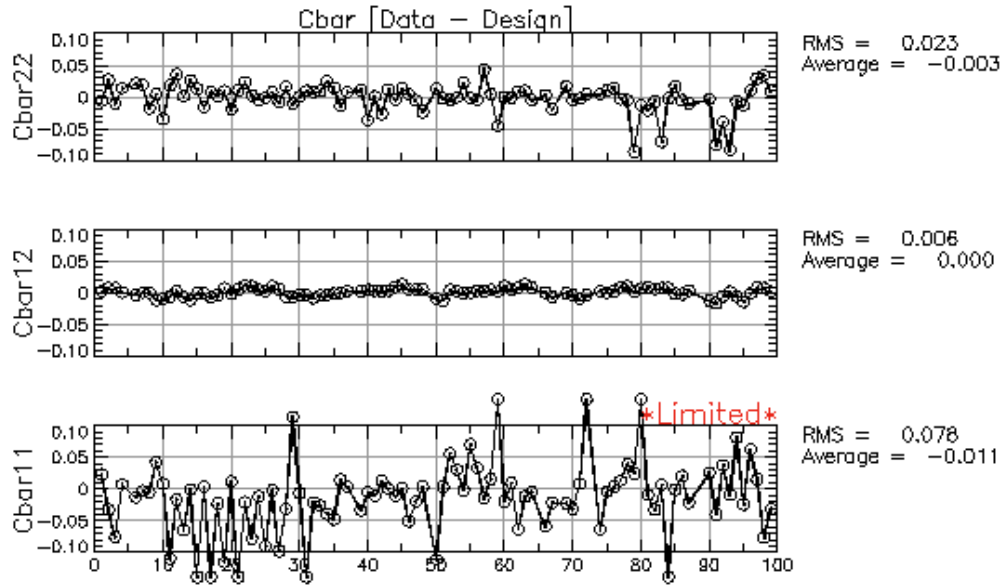


Distribution of fitted gains across all BPMs

*4 BPMs above cutoff on these plots

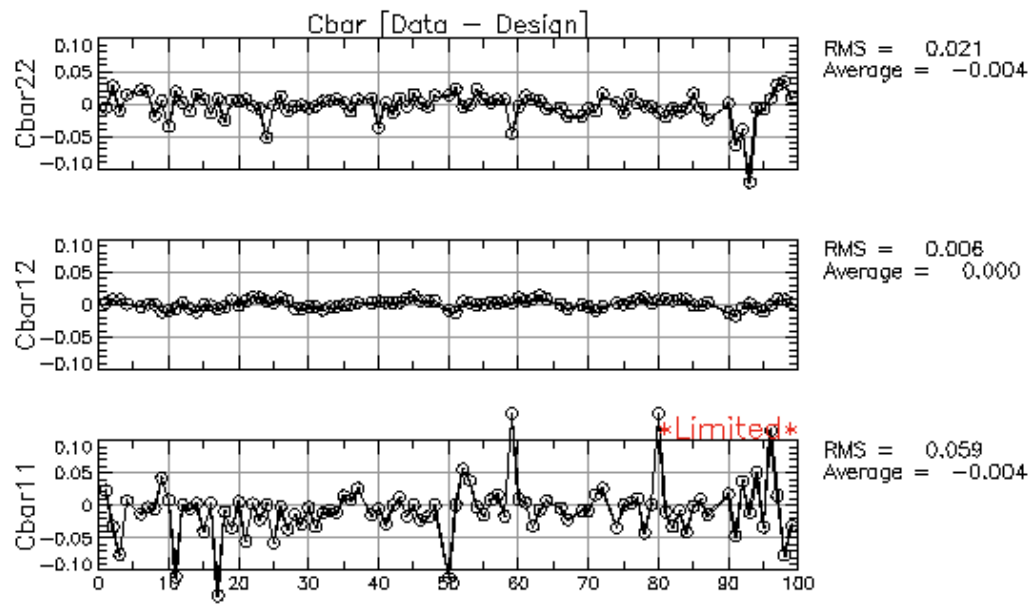
Apply Gains to Coupling Data

Coupling without gain correction



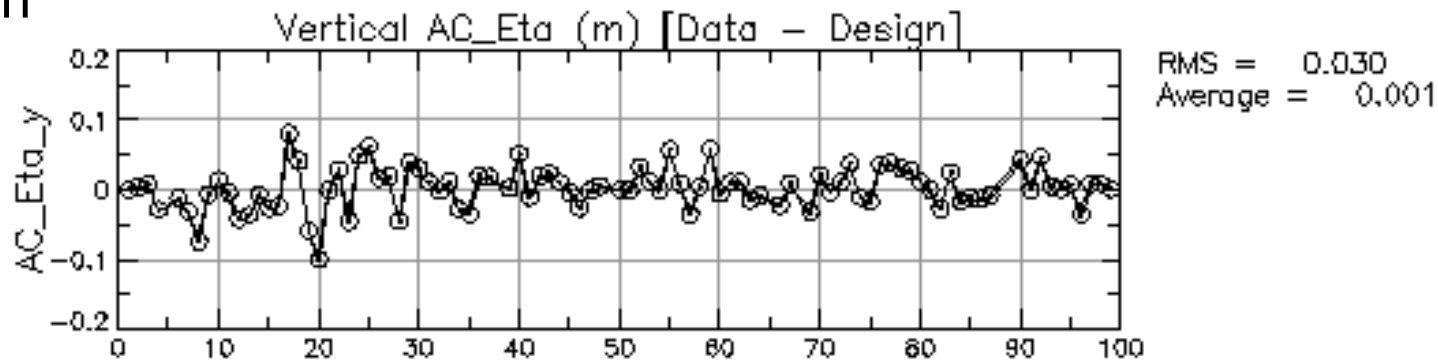
VERY PRELIMINARY

Coupling with gain correction



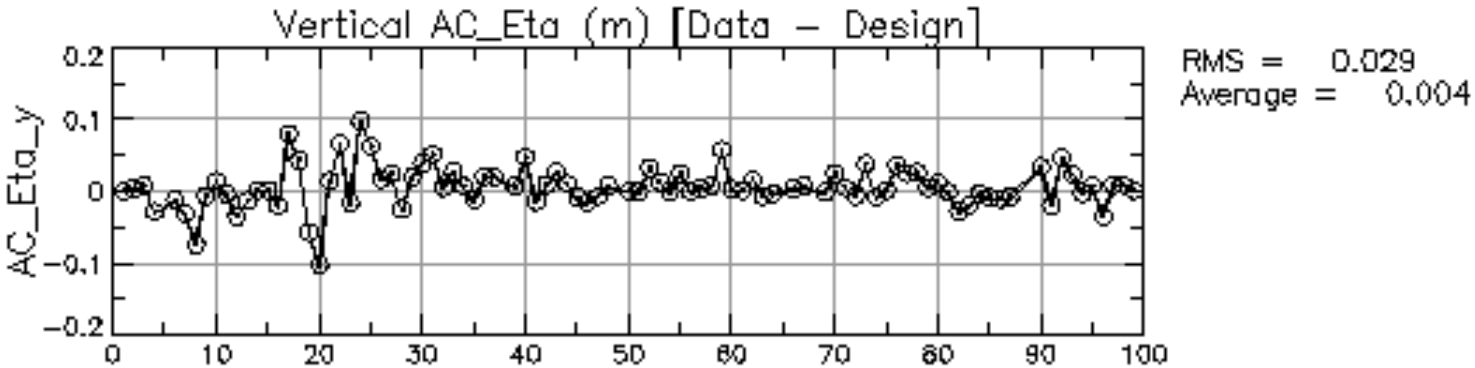
Apply Gains to η Data

Dispersion without gain correction



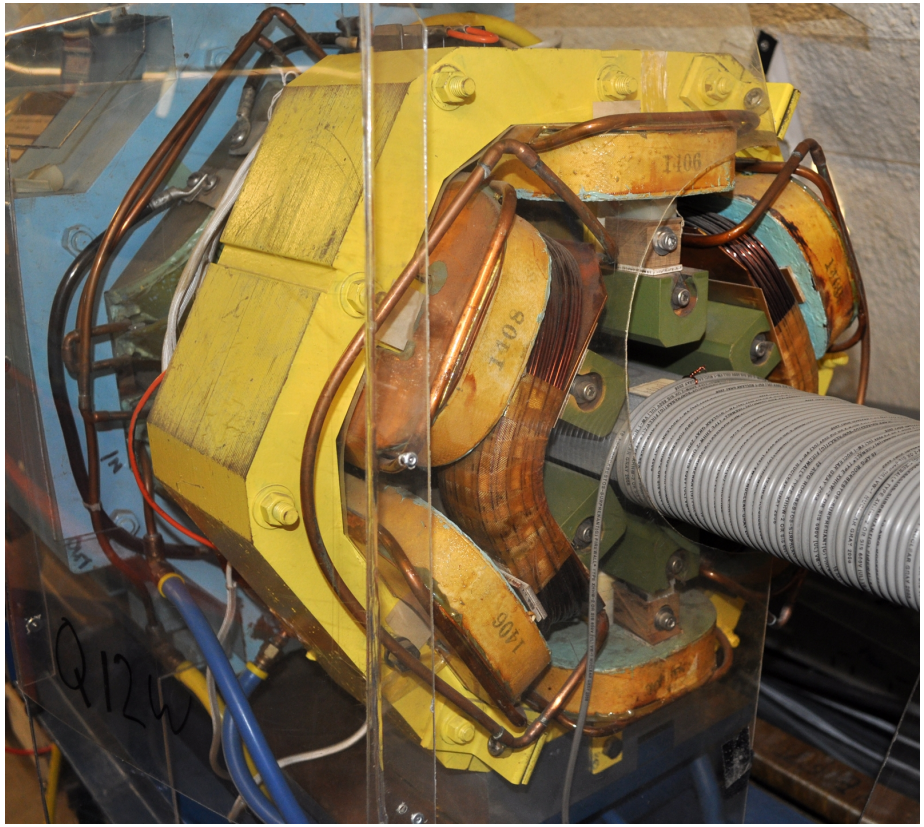
Dispersion with gain correction

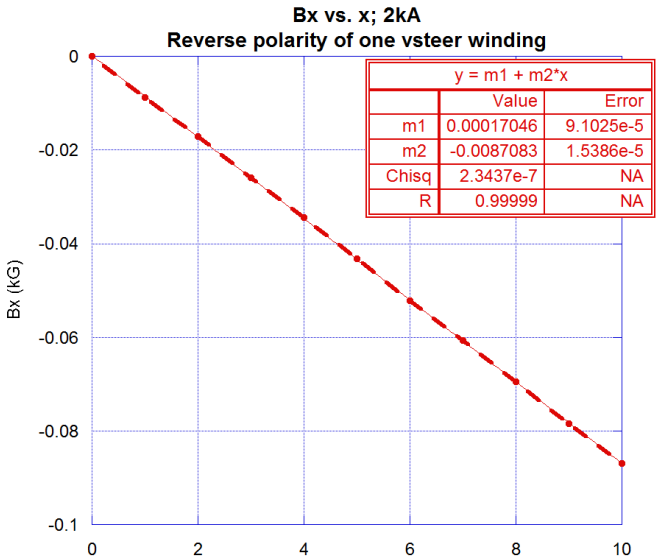
VERY PRELIMINARY

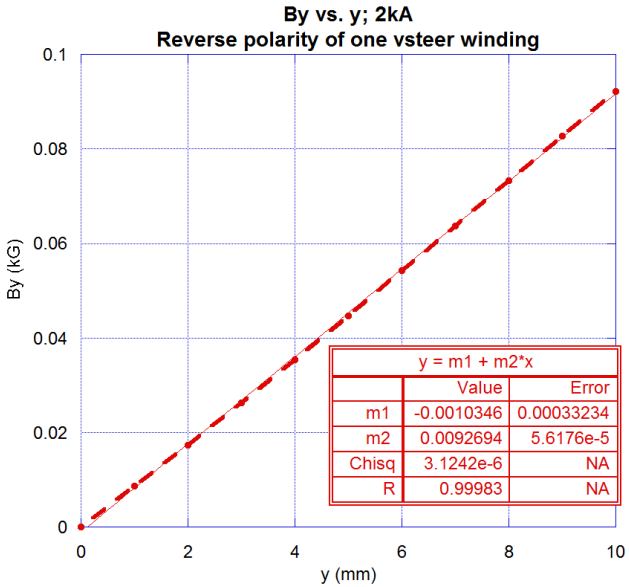


Sextupole Steering Trims as Skew Quads

- Skew quads near arc wigglers would allow for coupling bumps in the arcs and further local coupling correction
  - Sextupoles have vertical steering trims
  - Reverse polarity of one winding
    - Very linear response for < 10mm orbit
    - Skew quad k~0.002/m² @ 14A





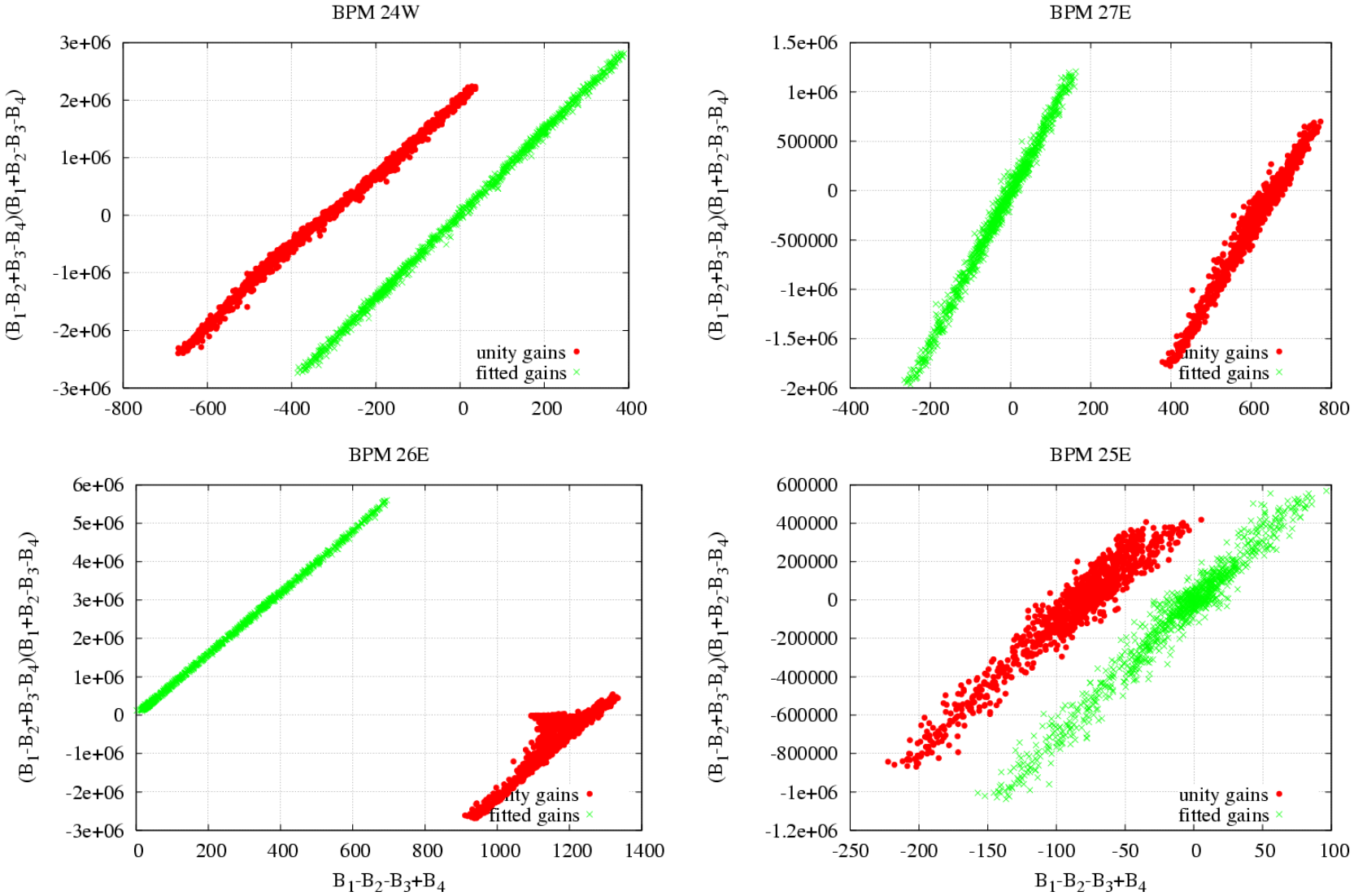


Summary

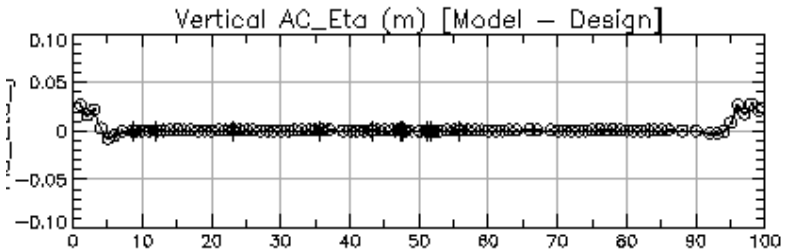
- **Achieved σ_y = 23μm <--> ε_y = 31pm**
- New gain map technique being developed. Next steps:
  - Implement corrections
  - Accurate determination of BPM tilts using in-phase coupling data
- Explore new working point:
  - Beam size vs. tune scan over a 2D grid
  - Beam size vs. RF voltage
  - Measurements are possible because of real-time xBSM readout
- New, more thoughtful sextupole distribution may help reduce some key resonances
- Vertical steering trims on sextupoles powered as skew quads?
  - Closed-η_y bumps in arc wigglers and further coupling correction
- Intensive magnet survey/alignment already underway in preparation for next run

Preliminary TBT Gain Map Results

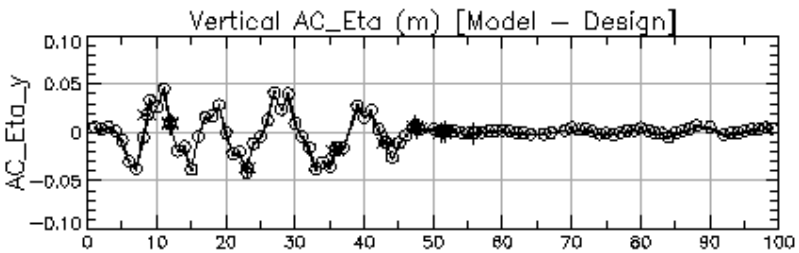
- Results of preliminary BPM data:



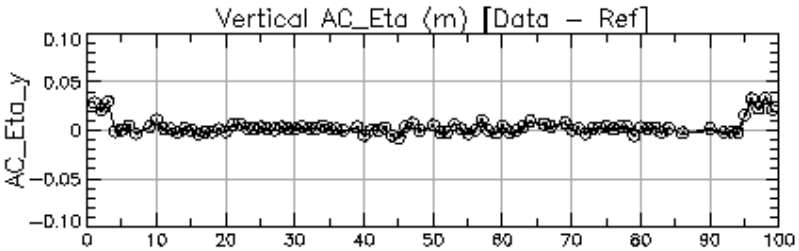
AC dispersion



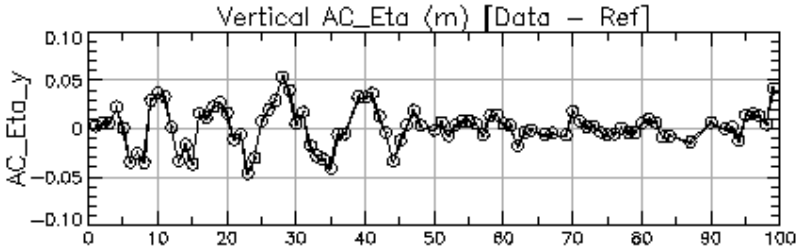
Modeled dispersion bump in L0 wiggler straight



Modeled dispersion bump in arc

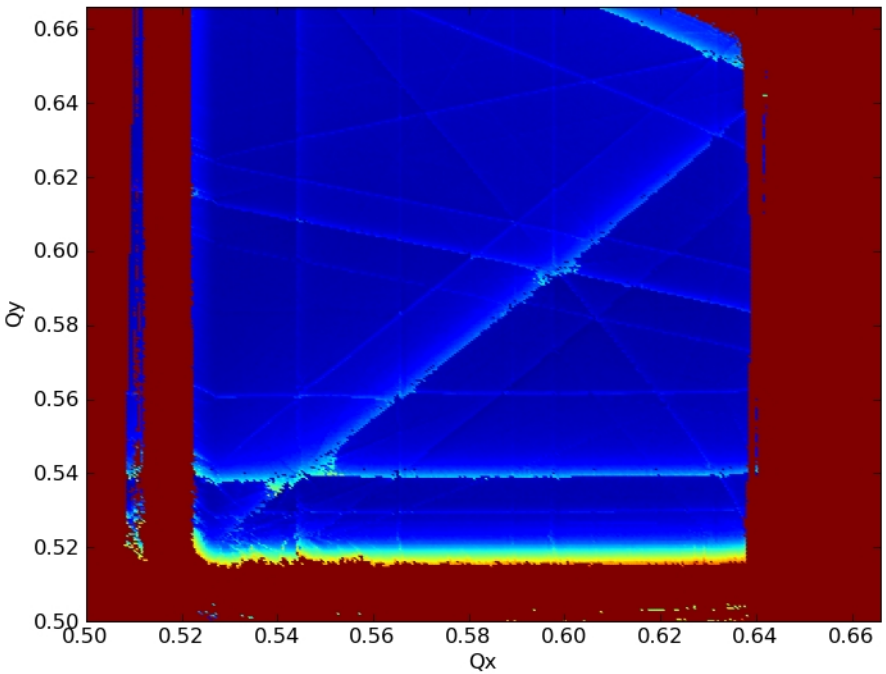


Measured effect of L0 η bump

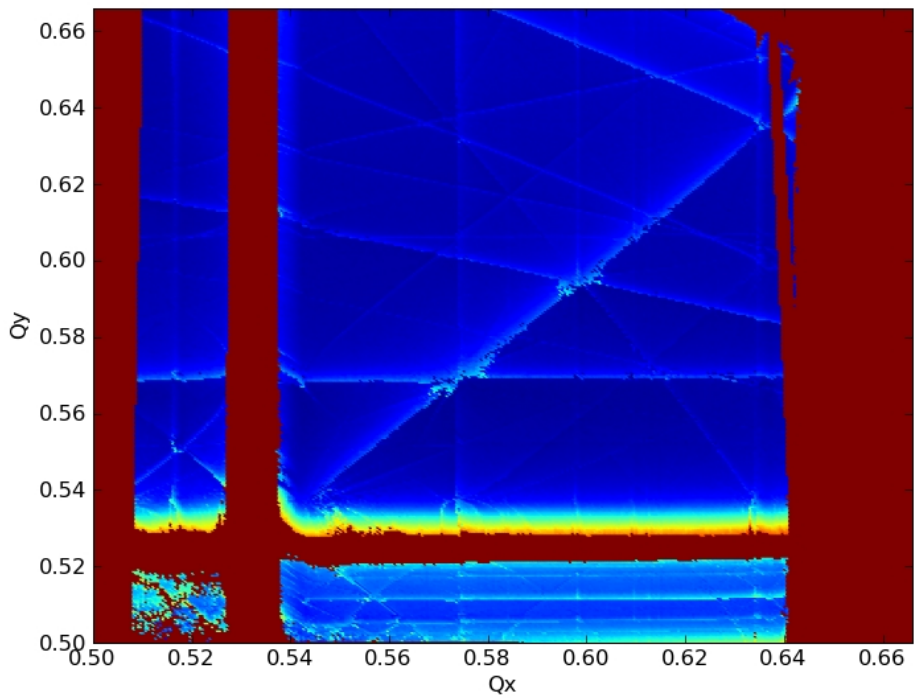


Measured effect of arc η bump

3MV, 8MV RF



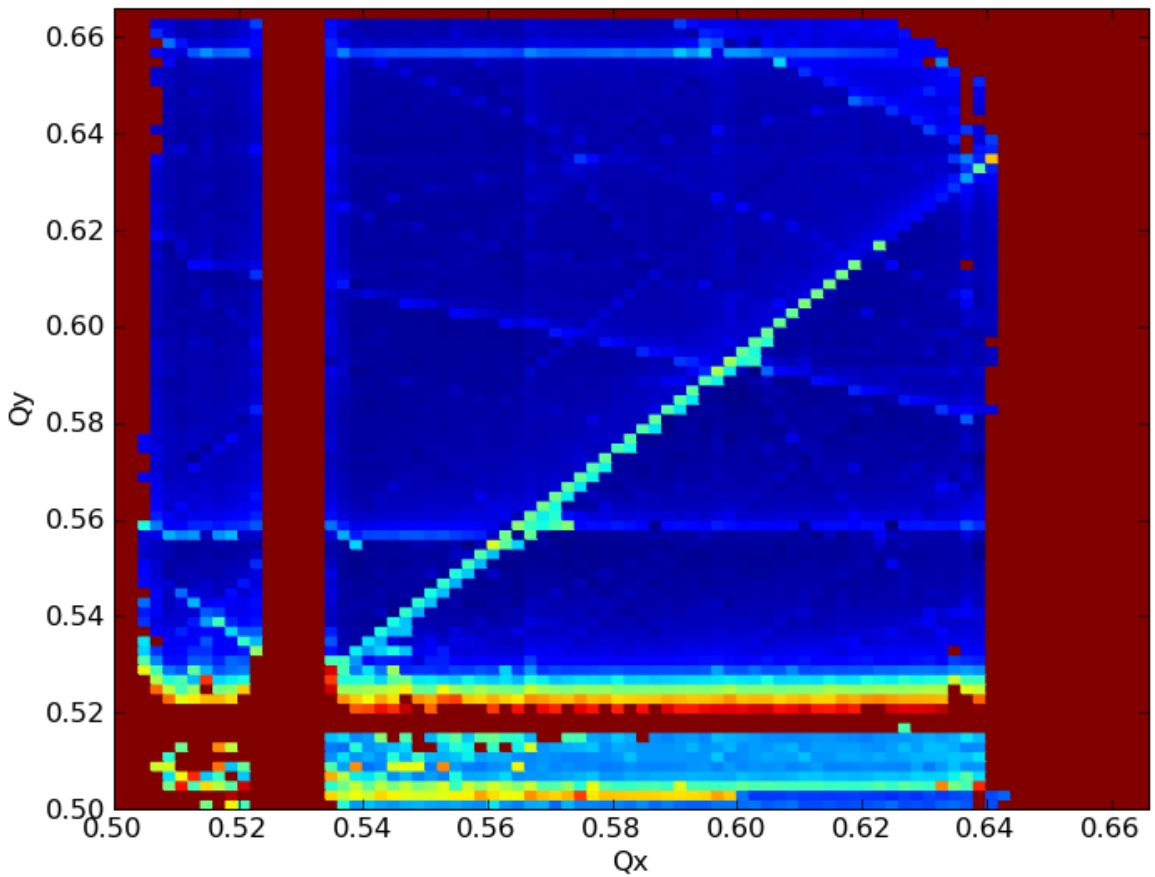
3MV RF



8MV RF

Realistic Dipole, Quad Errors

Quad y-offset: 134 micron
Quad tilt: 300 micro-radians
Bend rolls: 150 micro-radians
Sextupole y-offset: 300 micron



1% Sextupole K2 Errors

[K2] errors = 0.012 = 1%