Emittance Preservation via Steering In RTML

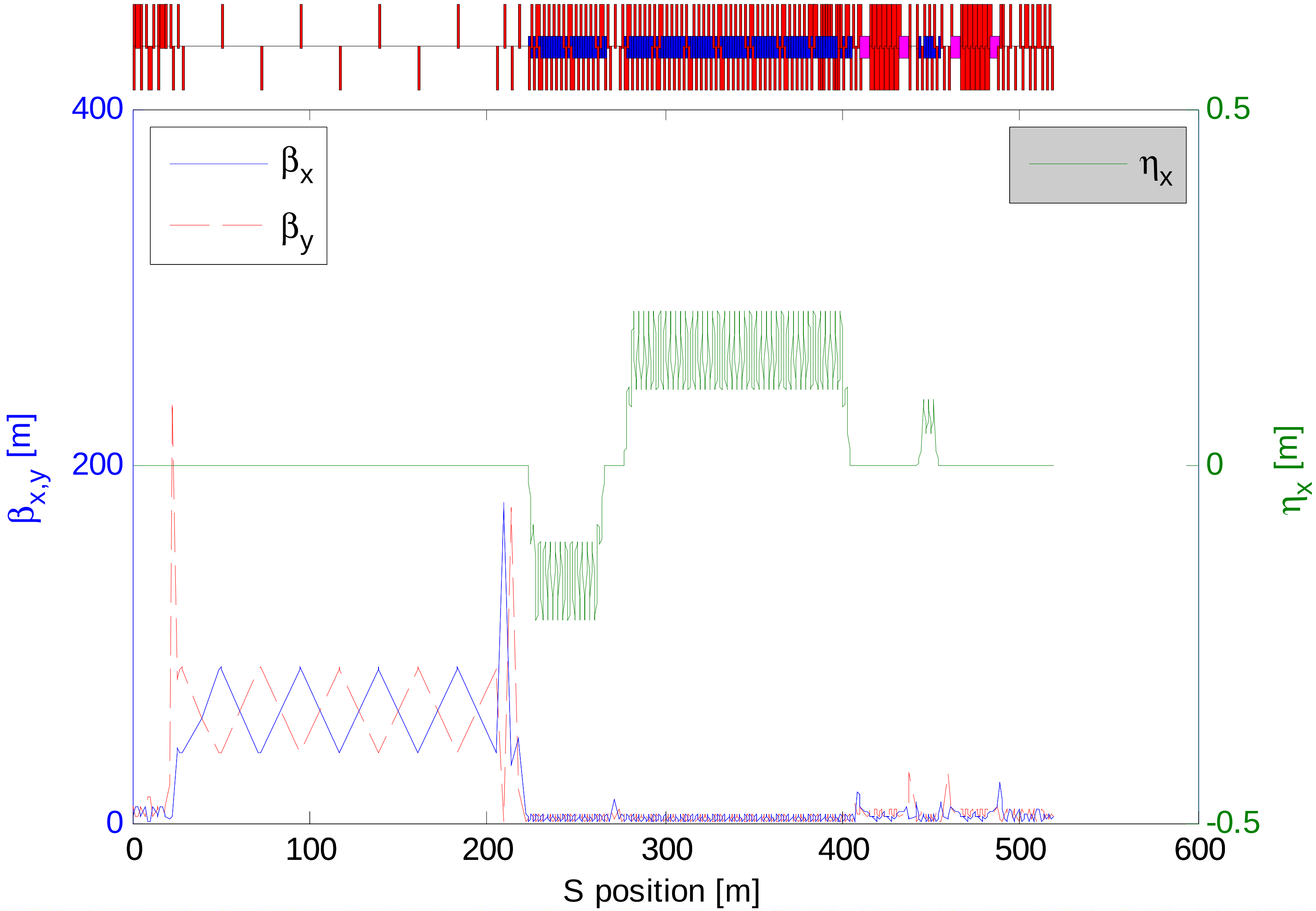
PT
SLAC

Introduction

- The portion of the RTML upstream of BC1 can have surprisingly large emittance growth
  - **Energy spread is small (0.15%), but…**
  - **Number of betatron oscillations is large (>20)**
  - **Strong focusing lattices**
    - Turnaround
    - SKEW and EMIT sections
  - **Strong bend and solenoid magnets**
- First line of emittance preservation is always finding a good orbit
- How do we do that?

Obligatory Optics Slide

Twiss functions Upstream Portion of RTML



Simple Steering Techniques

- 1:1 Steering
  - **Does what it says – zeroes each BPM's readings with a corrector**
  - **Need to steer x and y simultaneously**
    - Signficant design coupling in spin rotator area
  - **Original lattice design was poorly optimized for 1:1**
    - Arrangement was BPM, quad, corrector
    - Not good if quad is long
    - Replaced with quad, BPM, corrector – worked much better

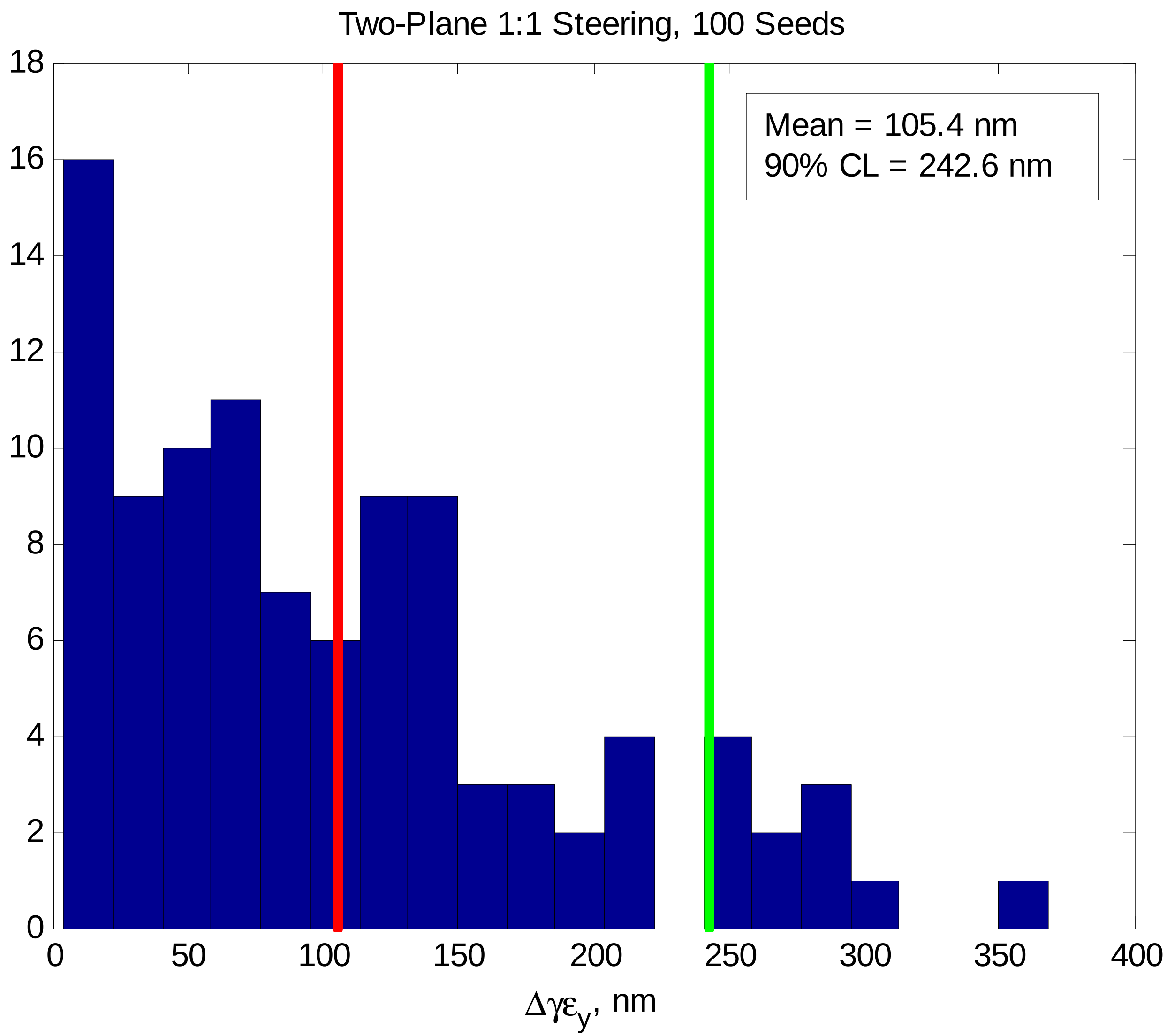
- Dispersion knobs
  - **Use pairs of skew quads in turnaround**
    - -I apart
    - Vertical dispersions add, coupling cancels out

Tolerances

Tolerance Type	RMS Value
Quad Misalignments (x,y)	150 um WRT survey line
BPM Offsets (x,y)	7 um WRT quad center
Quad Strength Errors	0.25%
Bend Strength Errors	0.5%
Quad Rotation	300 urad
Bend Rotation	300 urad

Note: We assume that BPMs are aligned to quads via quad shunting (BBA). Experience with FFTB and NLC prototypes suggests that 7 um is the accuracy limit for warm, solid-core iron-dominated magnets.

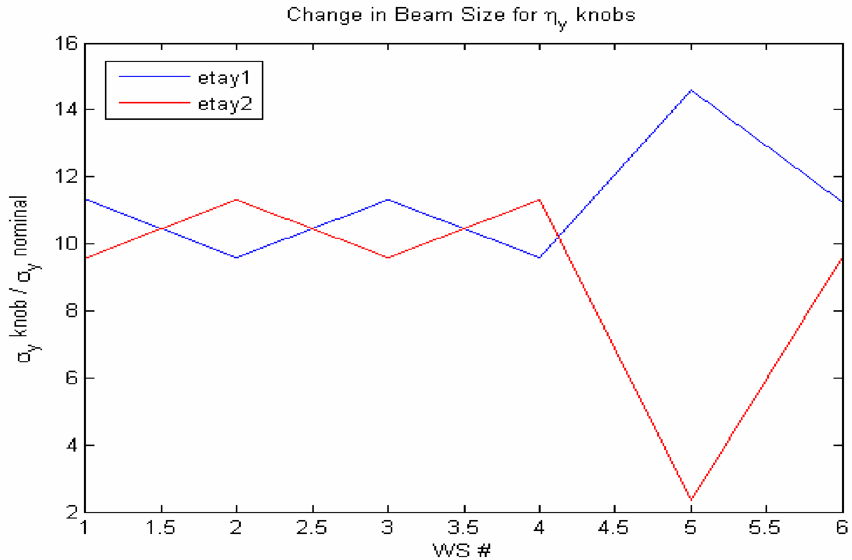
Results of 100 seeds of 1:1

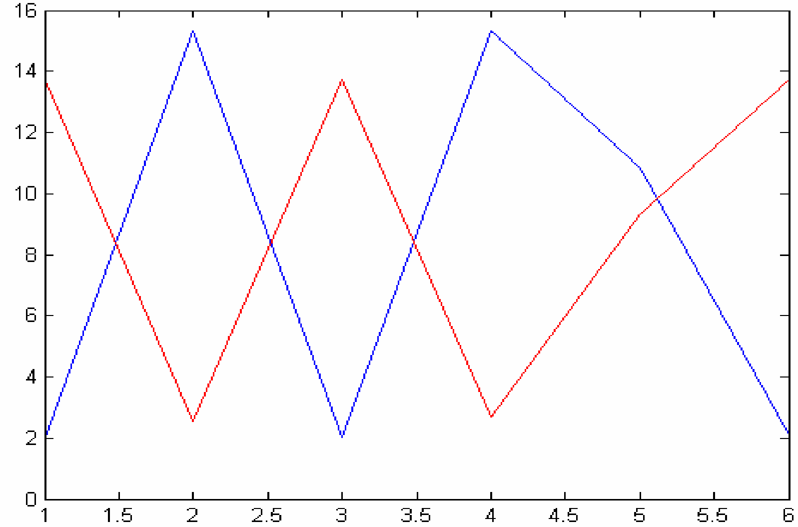


Room for improvement.

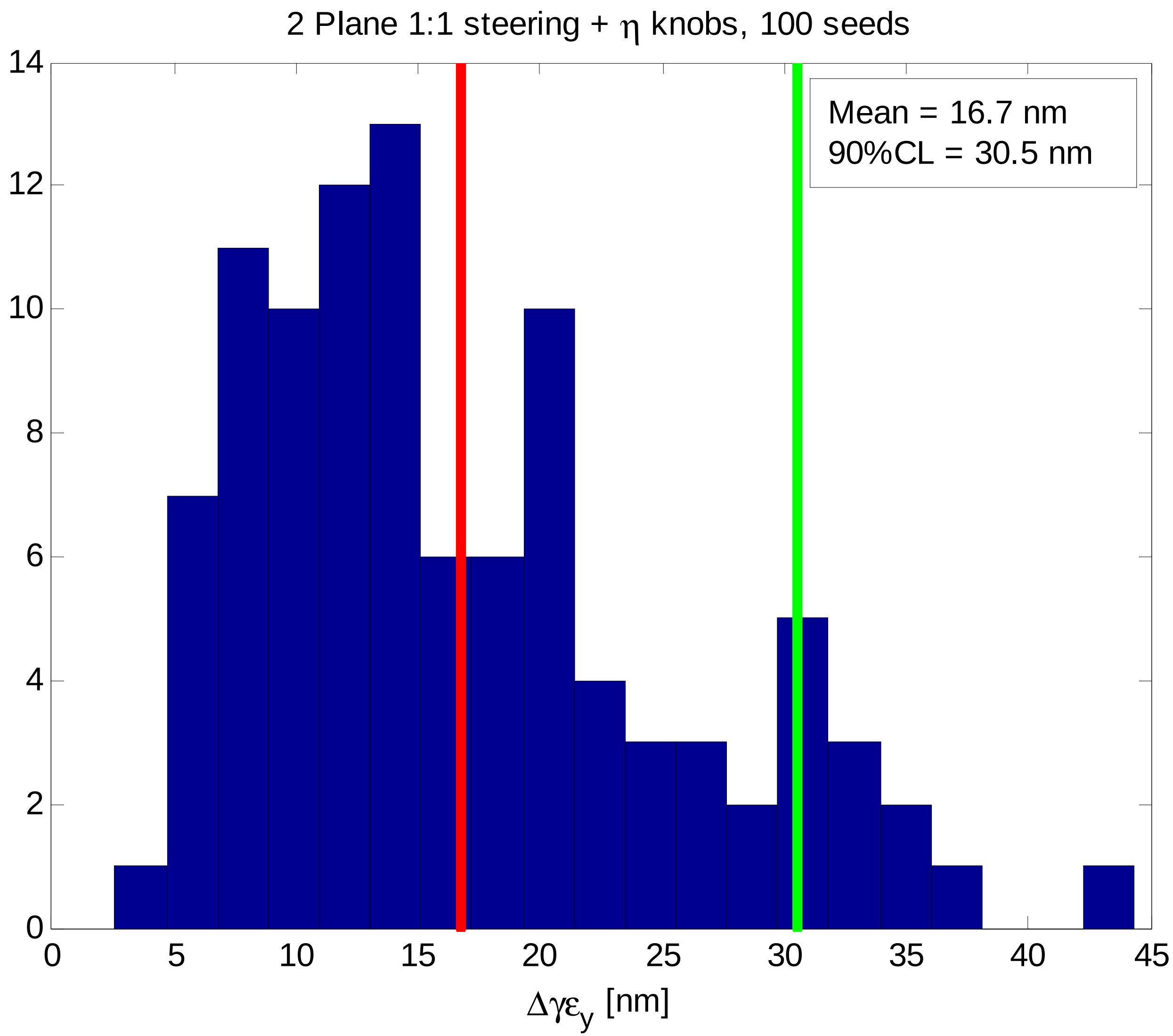
Dispersion Knobs

- Initial dispersion knobs were not effective
  - **2 skew quads per knob arranged in –I pair**
  - **2 knobs 90 degrees apart in betatron phase**
  - **Emittance after knobbing > before!**
- Found that the knobs were ~45° out of phase with wire scanners
- New knobs which use 4 skew quads designed
  - **One knob has maximum response on one wire, zero on wire 90° away**
  - **Second knob orthogonal to first**
- New knobs behaved much better





Add Dispersion Knobs to 1:1



Better, but far from acceptable.

Kick Minimization Steering (KM)

- If the BPM center is close to the quad center, *and*
- The beam has a good (ie, non-kicked) orbit, *then*
- There should be a correlation between the BPM reading at a quad and its corrector

- Can use this desired final correlation as an additional constraint on the steering solution

http://lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/lcsimu-20050310.pdf

Defining the Matrix Equation

Define:

$\vec{B}_{x,y} \equiv$ The vector of BPM readings

$\vec{\theta}_{x,y} \equiv$ The vector of corrector settings (in radians)

$\vec{K} \equiv$ The vector of quad integrated strengths (m^{-1})

$\vec{C}_{x,y} \equiv \vec{B}_{x,y} \mp \frac{\vec{\theta}_{x,y}}{\vec{K}}$ The vector of BPM readings compensated for corrector strengths (upper sign for x)

$M_{xx} \equiv$ 1:1 Steering matrix between x BPMs and x correctors

$M_{xy} \equiv$ 1:1 Steering matrix between x BPMs and y correctors (also M_{yx} and M_{yy} defined similarly)

$$N_{xx} \equiv -\frac{1}{K} + M_{xx}$$

$$N_{yy} \equiv \frac{1}{K} + M_{yy}$$

Additional matrices for KM steering, with integrated quad strengths subtracted/added to the diagonal

Defining the Matrix Equation (2)

Need to solve

Changes in corrector settings

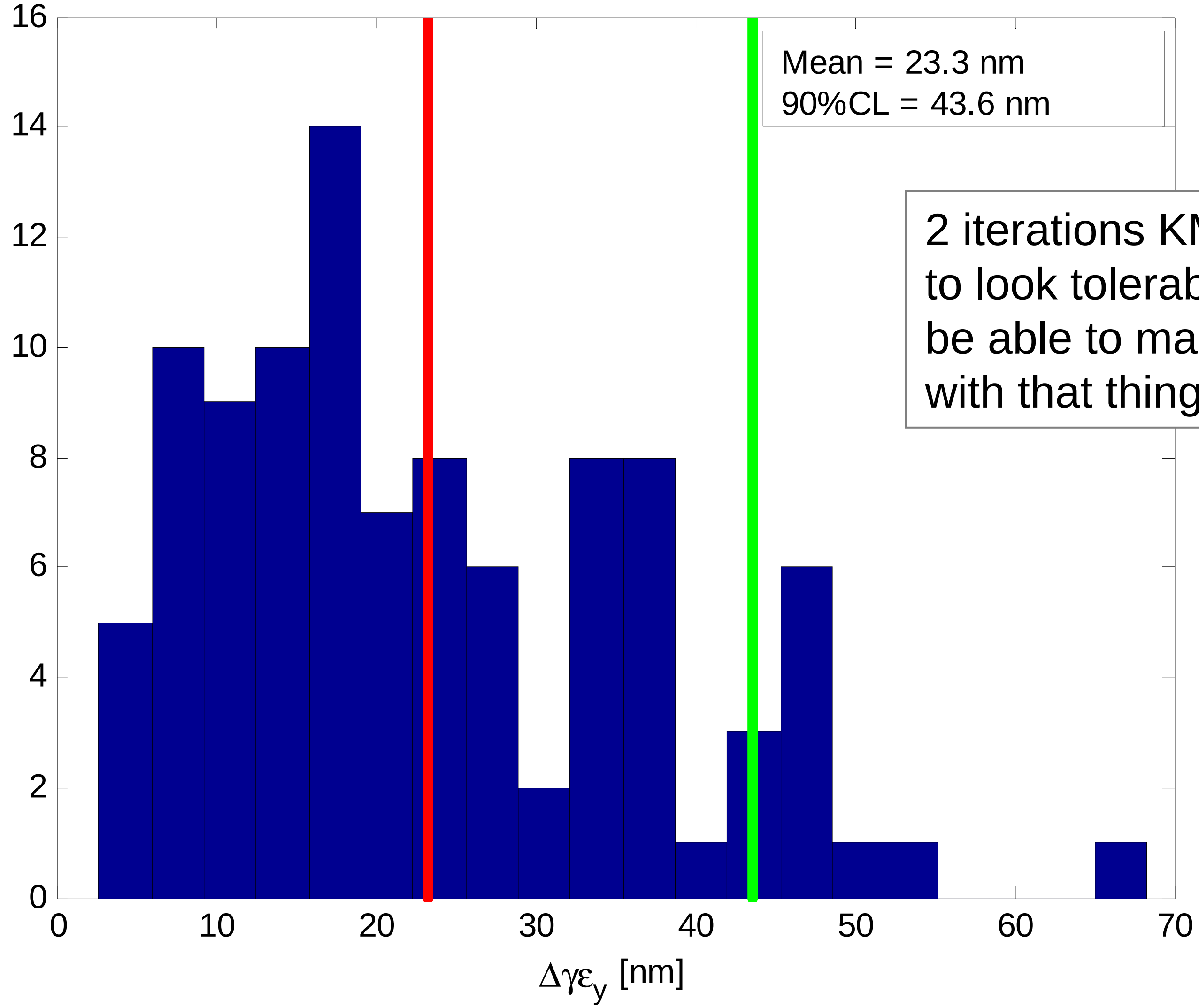
$$\begin{bmatrix} \vec{B}_x \\ \vec{B}_y \\ \vec{C}_x \\ \vec{C}_y \end{bmatrix} = -\begin{bmatrix} M_{xx} & M_{xy} \\ M_{yx} & M_{yy} \\ N_{xx} & M_{xy} \\ M_{yx} & N_{yy} \end{bmatrix} \begin{bmatrix} \Delta\vec{\theta}_x \\ \Delta\vec{\theta}_y \end{bmatrix}$$

In a weighted least-squares sense. Weights:

$$\chi^2 = \frac{\sum\left(B_{x,i}^{meas} - B_{x,i}^{model}\right)^2}{(150\mu m)^2} + \frac{\sum\left(B_{y,i}^{meas} - B_{y,i}^{model}\right)^2}{(150\mu m)^2} + \frac{\sum\left(C_{x,i}^{meas} - C_{x,i}^{model}\right)^2}{(7\mu m)^2} + \frac{\sum\left(C_{y,i}^{meas} - C_{y,i}^{model}\right)^2}{(7\mu m)^2}$$

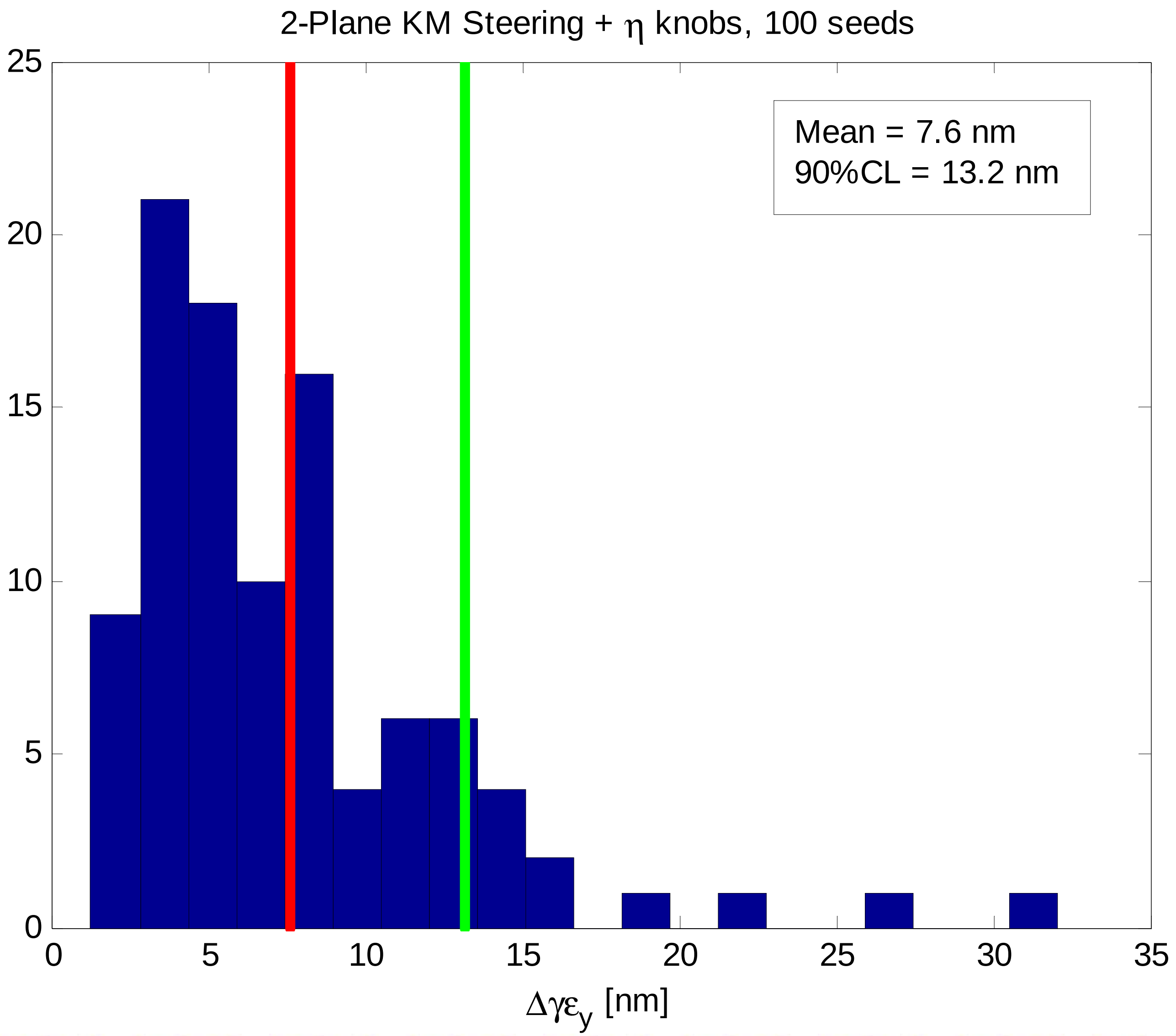
Results of KM Steering

2-Plane KM Steering, 100 seeds



2 iterations KM steering – starting to look tolerable ("hey, we might be able to make some luminosity with that thing!")

Add Dispersion Knobs to KM



Remaining Emittance Growth

- To understand the remaining growth, took the 100 seeds of KM + knobs, and tracked with
  - **Zero energy spread beam**
    - Remaining growth all from xy coupling
  - **Zero x emittance beam**
    - Remaining growth from dispersion and chromaticity
      - Normal-mode emittance shows blowup from chromaticity and high-order dispersion
      - Projected emittance includes chromaticity, high order dispersion, plus linear dispersion
- Looked at several sets of errors
- Allows us to deduce the sources of errors

Sources of Emittance growth

Note: All values are mean over 100 seeds

Errors	Emittance Growth	Growth from Chromaticity	Growth from Dispersion	Growth from Coupling
Transverse misalignments	0.37 nm	0.37 nm	0.00 nm	0.00 nm
Above plus quad strength	3.20 nm	0.82 nm	0.01 nm	2.39 nm
Above plus bend strength	3.25 nm	0.82 nm	0.06 nm	2.39 nm
Above plus quad rolls	7.60 nm	1.49 nm	0.00 nm	6.08 nm
Above plus bend rolls	7.61 nm	1.49 nm	0.02 nm	6.08 nm

Conclusions and Like That

- KM Steering appears to be much more effective than 1:1 steering in the RTML Upstream area
  - **Deserves publication in a journal!**
- KM + Knobs appears to be able to completely eliminate linear dispersion from RTML upstream area
- Need to integrate this study with coupling correction
- Need to improve matching system designs to eliminate chromatic growth
- It would be great if somebody else would try to reproduce this result!

Acknowledgements

Thanks to K. Kubo and J. Smith!

Questions / Comments

"Keep your eyes on the road,
Your hands upon the wheel…"

-The Doors