International Linear Collider
at Stanford Linear Accelerator Center

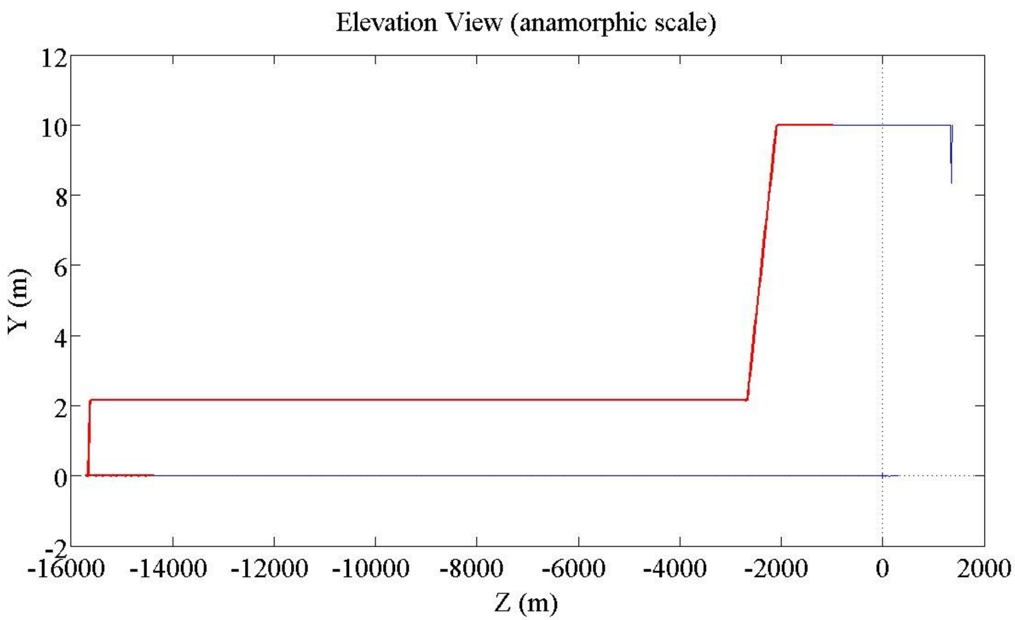
RTML tuning

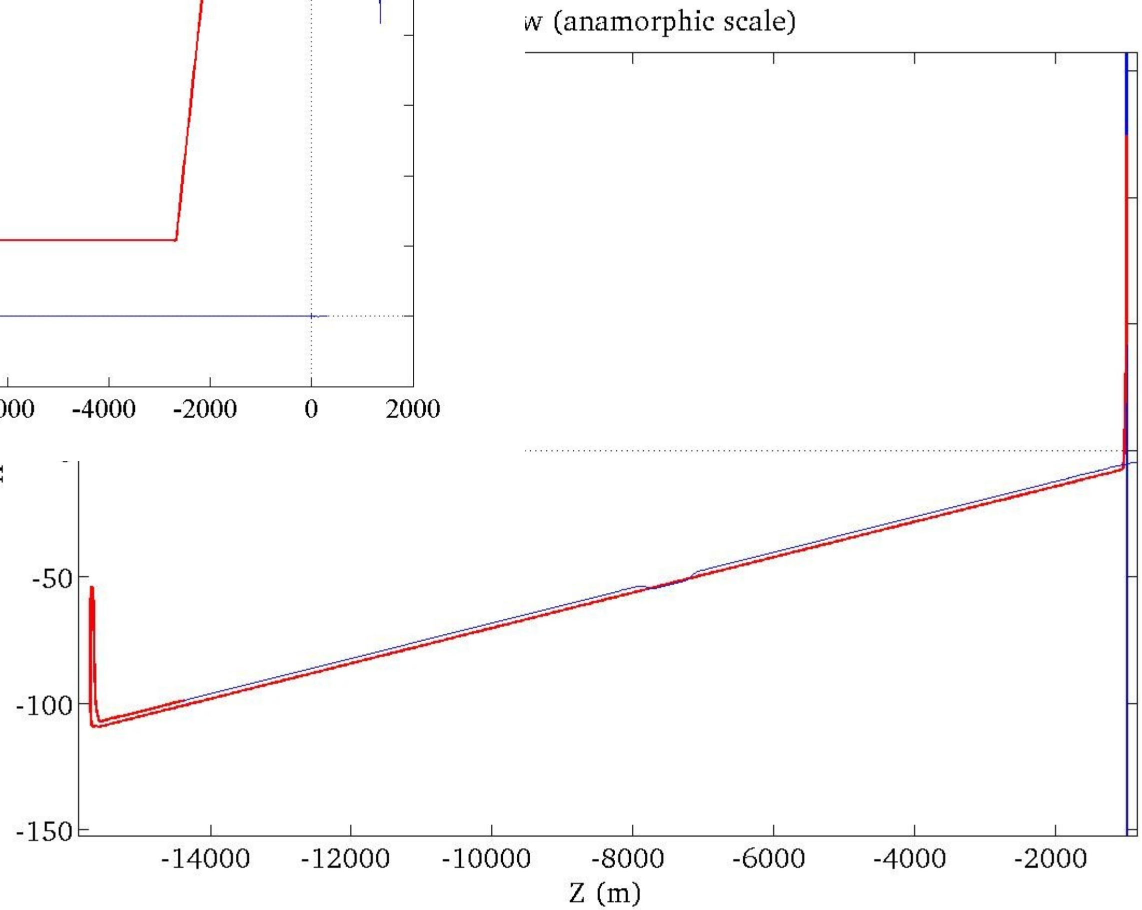
Work so far...

Steve Molloy – 13th November, 2007

With many thanks to Jeff Smith, PT,
Glen White, and Mark Woodley

Latest RTML layout





Slightly different from the decks I've studied so far.

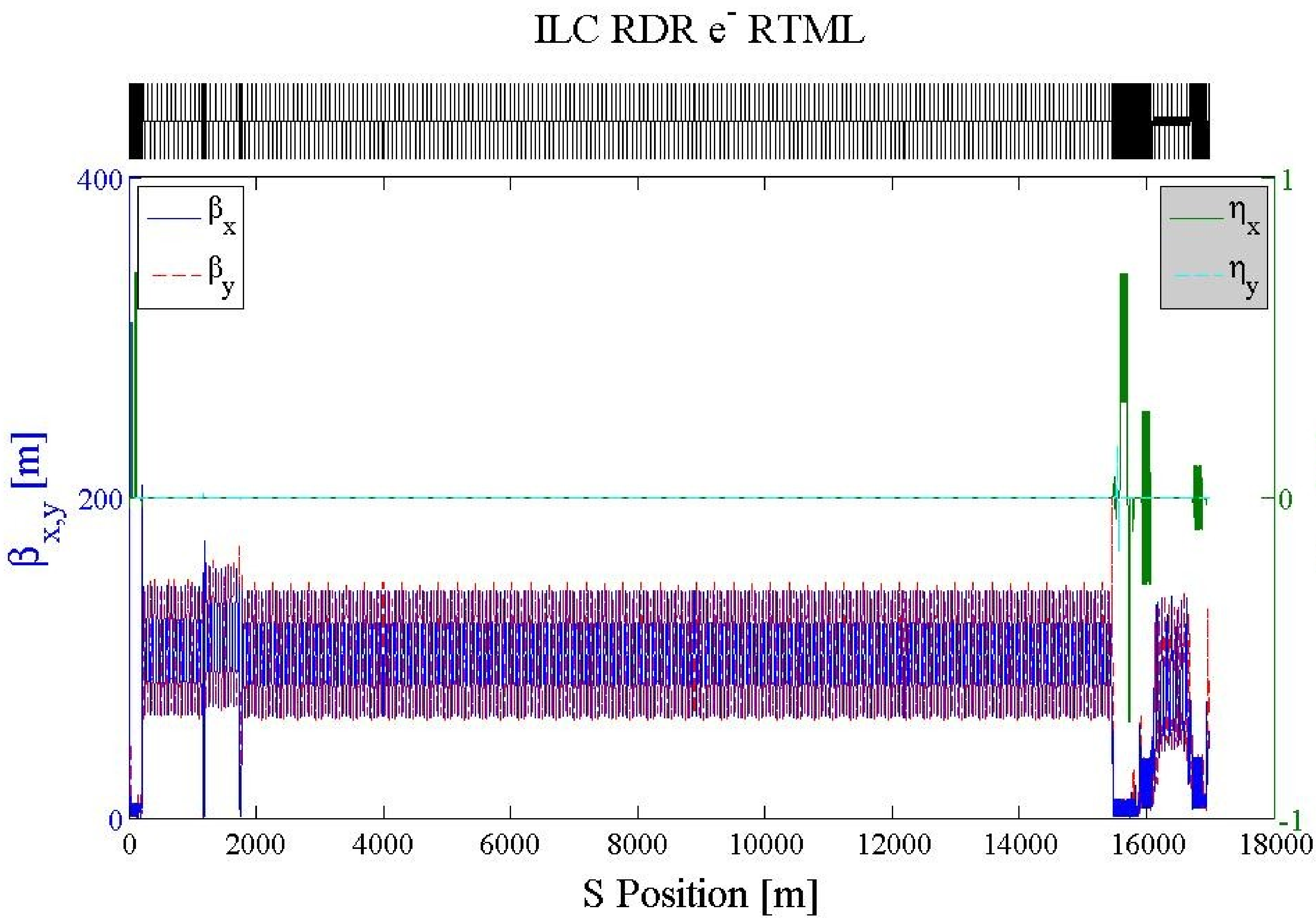
Plan of Attack (I)

- Use Lucretia as simulation package
- Apply standard set of errors.
- Develop static tuning techniques.
  - (No GM, beam jitter, etc.)
    - yet...
  - Aim for <4 nm vertical emittance growth.
    - DR exit through to linac entrance.
- Determine "best" tuning technique for each region
  - One-to-one? KM? DFS? Magic dispersion bumps?

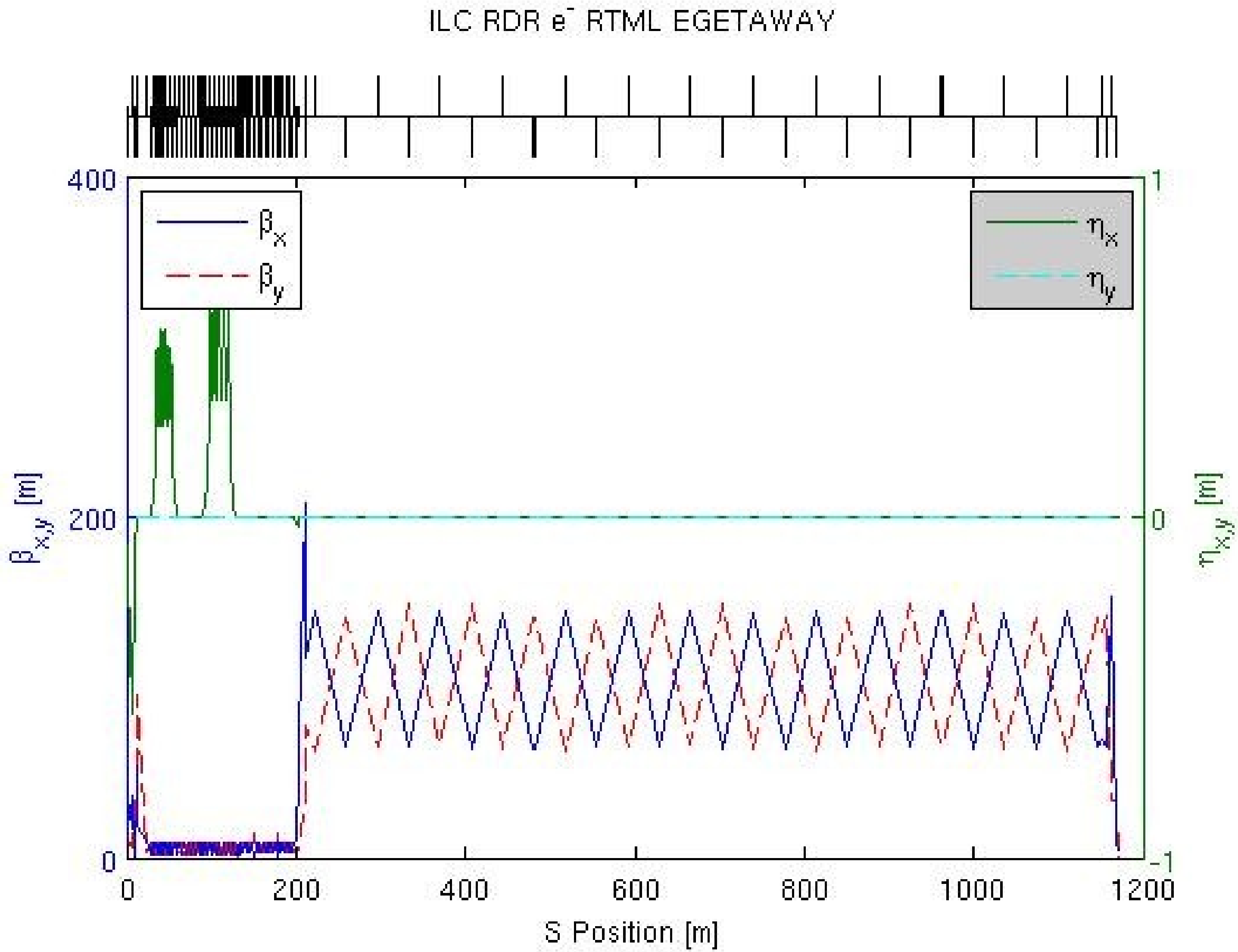
Plan of Attack (II)

- I'm very new to this!
  - Start with something “simple”
- Tune-up long transport line
  - No design coupling
  - No acceleration or compression
- Apply a couple of cheats
  - Perfect alignment between quad centres and BPMs
  - Turn off bend rolls
- Decided (*or PT told me*),
  - One-to-one first, then KM
  - DFS not appropriate (upstream of BC1).

RTML Twiss Plots



RTML Twiss Plots



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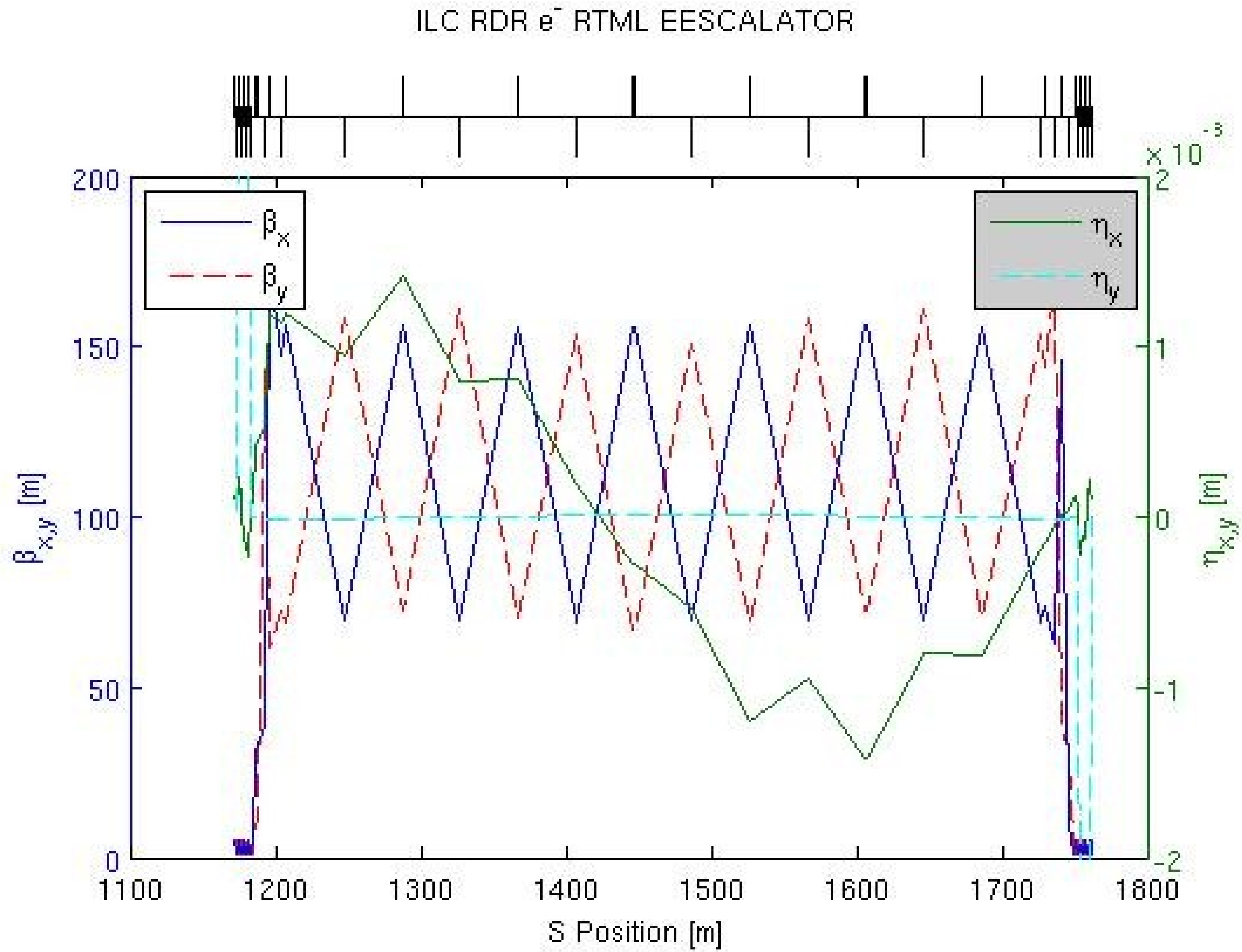
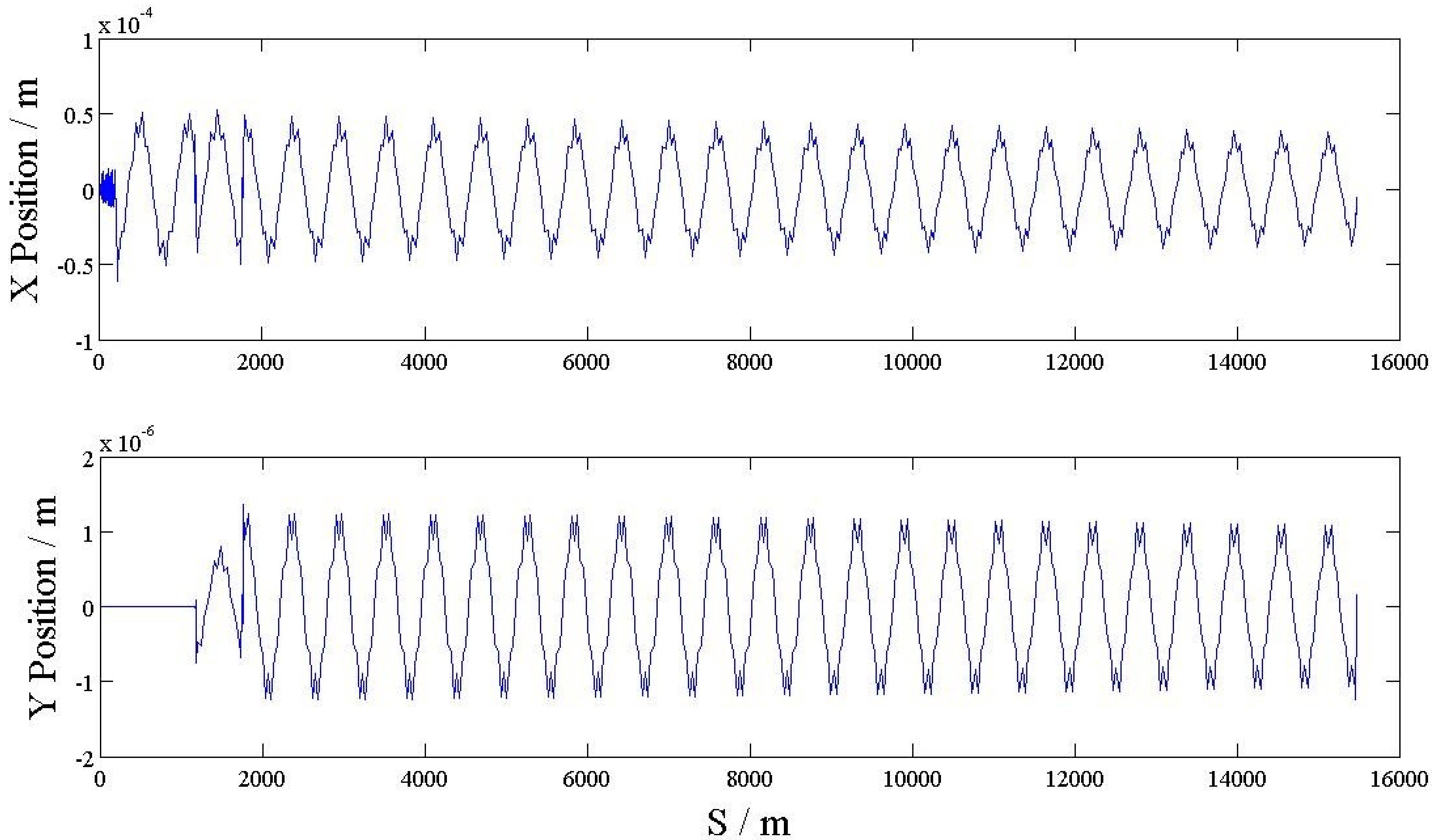
RTML Twiss Plots



Perfect Lattice – 2nd Order Dispersive Orbit



Zero momentum spread beam results in flat orbit.

Tuning Procedure

Misalign

One-to-one steering
(steer to put beam through centre of BPMs)

Kick minimisation (KM)
(Use correctors to cancel off-centre quad kicks)

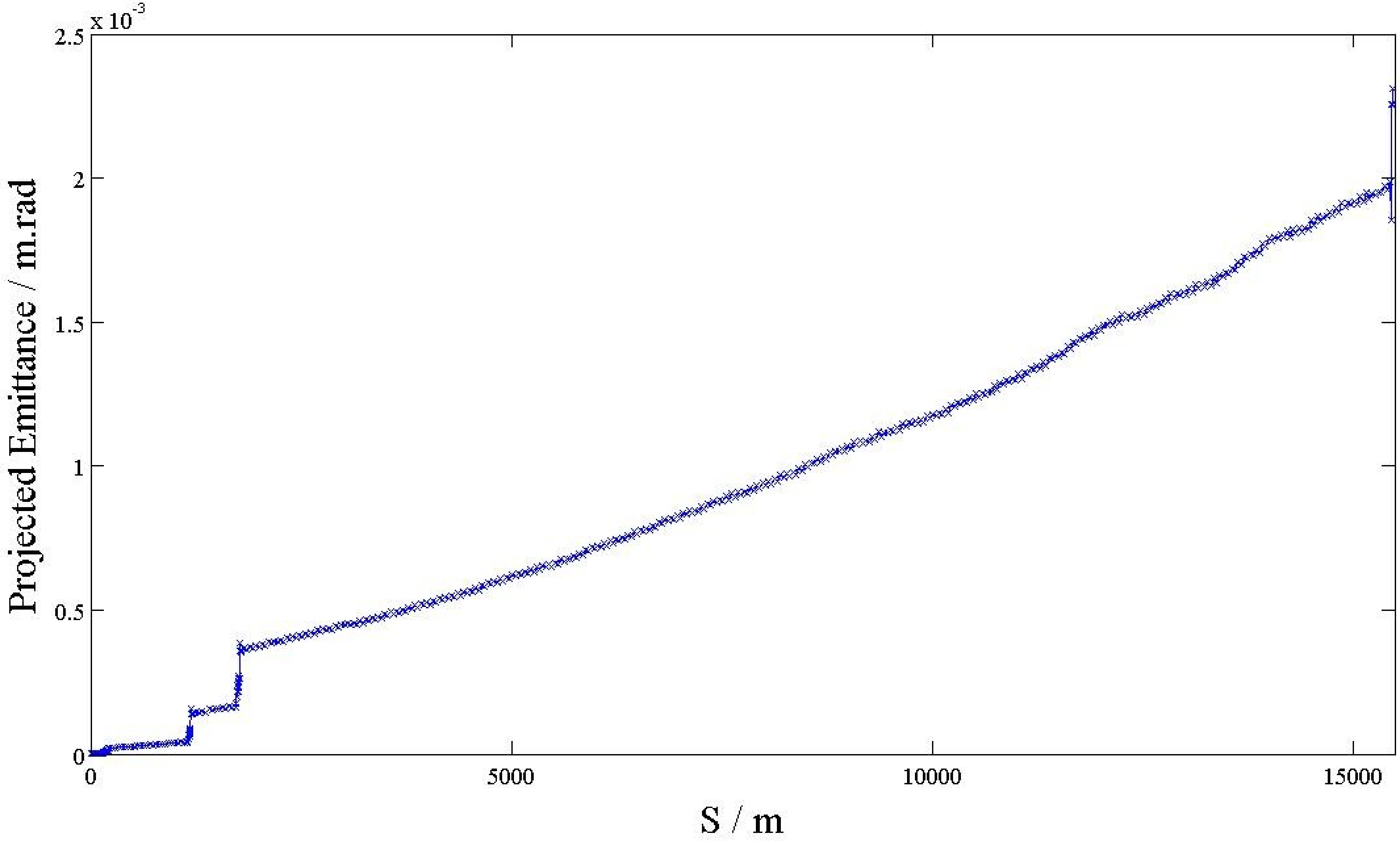
Errors

cav_misalign = 300e-6;
cav_pitch = 300e-6;
quad_misalign = 300e-6;
quad_rot = 300e-6;
bpm_misalign = 200e-6;
cryo_misalign = 200e-6;
cryo_pitch = 25e-6;
quad_strength = 2.5e-3;
bend_strength = 5e-3;
bend_rot = 0;

Fixed to quad centre in these studies

Have since confirmed tuning works with bend rotation of 300e-6 rad

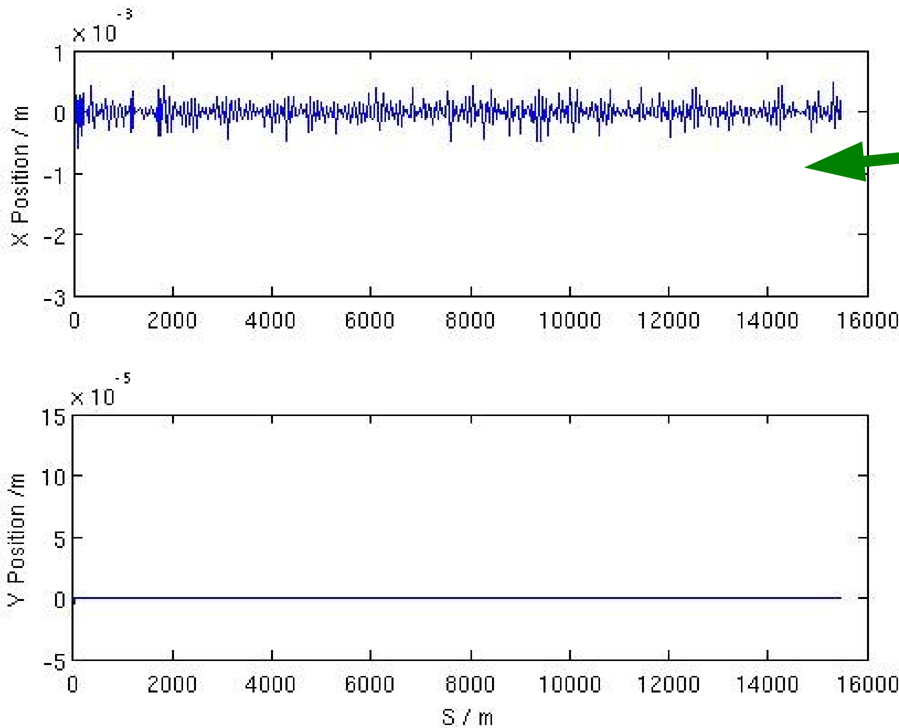
Projected Emittance (after errors)



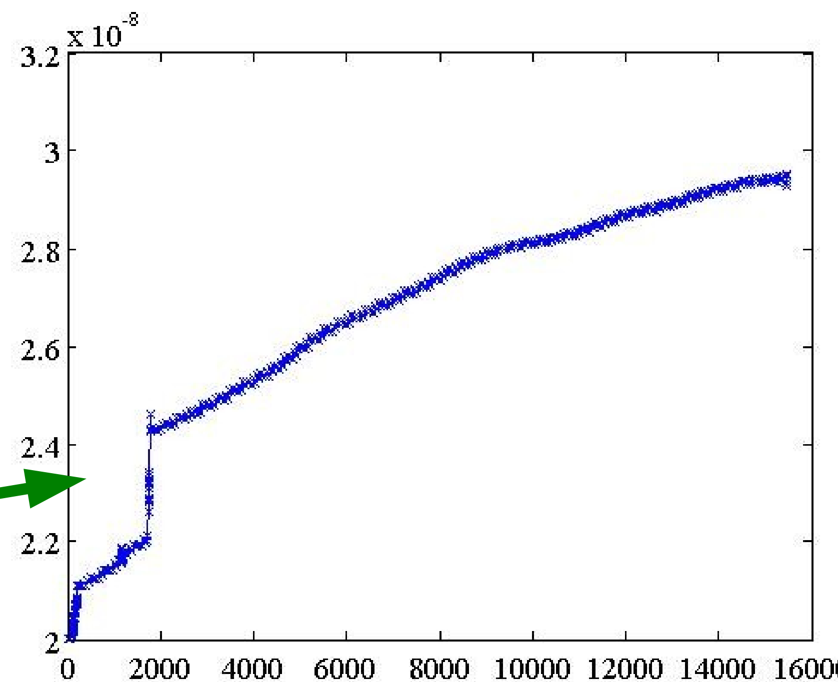
One-to-one steering on entire line

- Build giant response matrix for whole line
  - Response of all BPMs to all correctors
    - Both planes simultaneously
  - R12, R14, R32, R34
    - Measuring is easy, and reduces errors
- Record BPM readings
  - Static tuning so no averaging needed
- Invert matrix and multiply
  - Find corrector settings to zero BPMs
- Iterate
  - Five times in these studies
    - Overkill – three is enough

One-to-one results



Imperfect results in x due to “sparse” corrector arrangement



Normal-mode y emittance

Application of Kick Minimization to the RTML "Front End"

P. Tenenbaum

January 30, 2007

2.1 The Matrix Equation and its Solution

Let us define $\vec{B}_x$ as the vector of horizontal BPM readings, and $\vec{B}_y$ as the vector of vertical BPM readings. We can then define vectors of BPM readings which have been adjusted to take into account the strength of the nearby corrector magnets: $\vec{C}_x \equiv \vec{B}_x - \vec{\theta}_x/\vec{KL}$, $\vec{C}_y \equiv \vec{B}_y + \vec{\theta}_y/\vec{KL}$, where we take the usual convention that positive KL values are horizontally focusing and where the division is array division (ie, the resulting vector components are $\theta_i/(KL)_i$).

Now define the usual steering response matrices: matrix M_{xx} is the response of the horizontal BPMs to the horizontal correctors; M_{xy} is the response of the horizontal BPMs to the vertical correctors; and so on. Now let us define a set of steering matrices which are modified by the quad strengths: for example, N_{xx},

$$
\begin{aligned}
N_{xx,ij} &\equiv -\frac{1}{KL_i} + M_{xx,ij},\ i = j, \\
&\equiv M_{xx,ij},\ i \neq j.
\end{aligned}
\tag{2}
$$

The matrix N_{yy} is similarly defined except that the $1/KL$ term comes in with a positive sign and not a negative sign. The matrices N_{xy} and N_{yx} are identically equal to M_{xy} and N_{yx}, respectively.

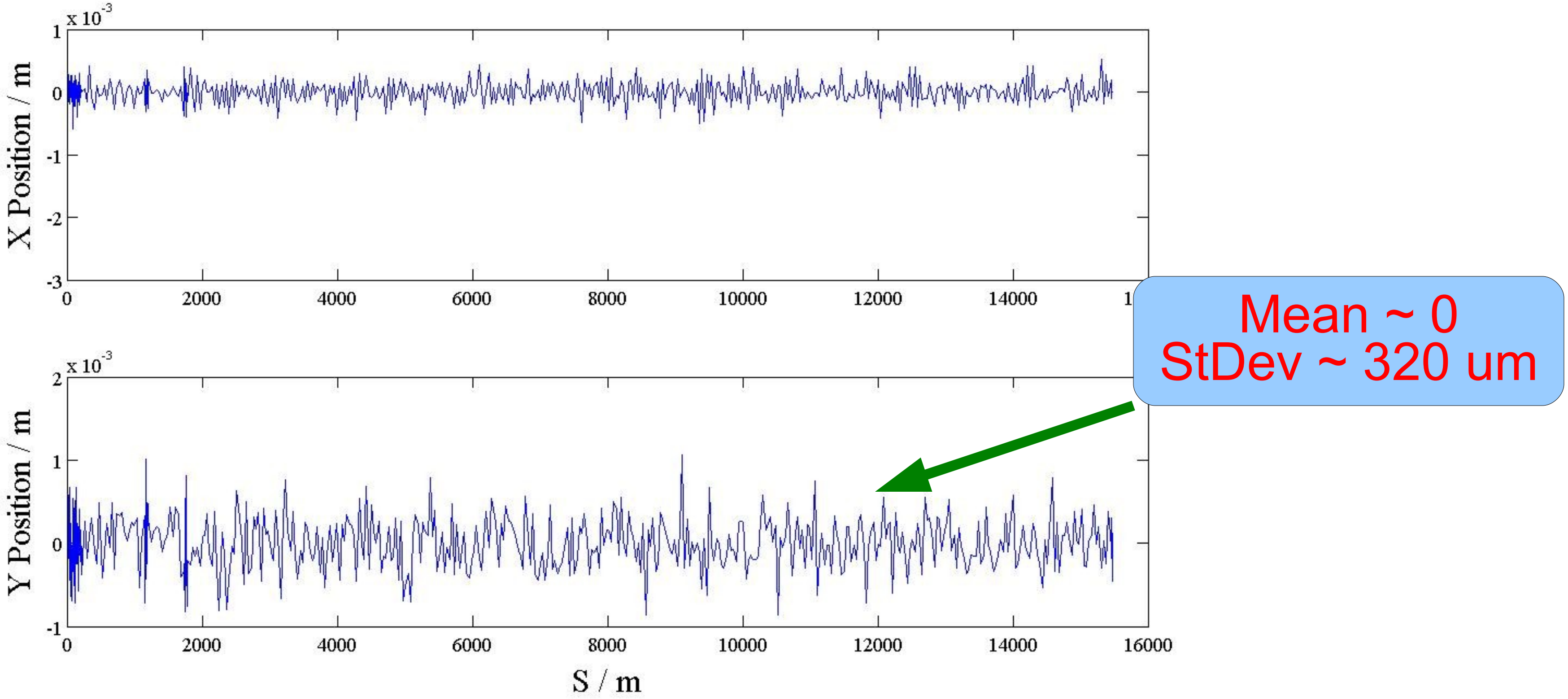
We can now put this together into a matrix equation as follows:

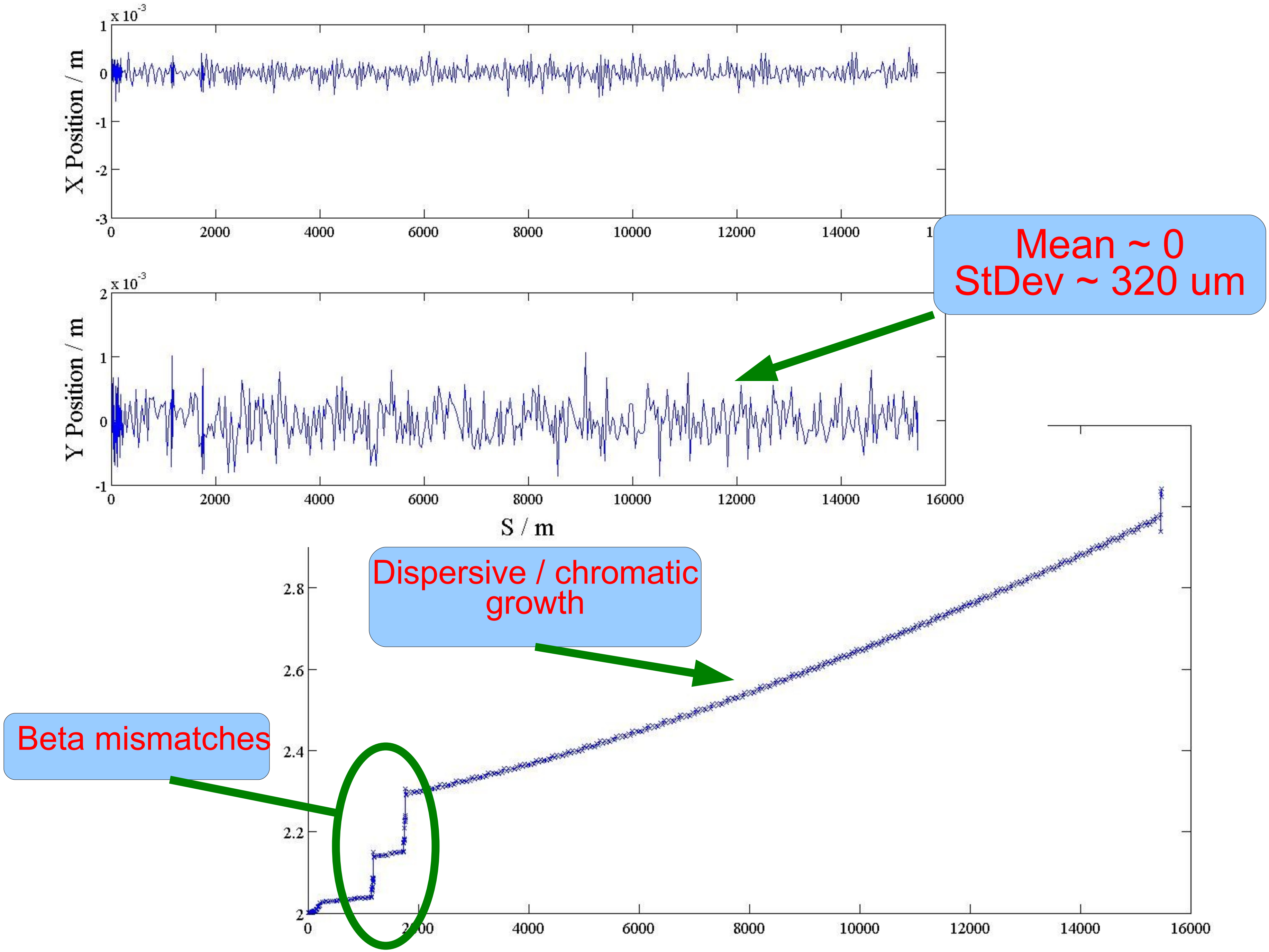
$$
\begin{bmatrix} \vec{B}_x \\ \vec{B}_y \\ \vec{C}_x \\ \vec{C}_y \end{bmatrix} = -\begin{bmatrix} M_{xx} & M_{xy} \\ M_{yx} & M_{yy} \\ N_{xx} & N_{xy} \\ N_{yx} & N_{yy} \end{bmatrix} \begin{bmatrix} \vec{\Delta\theta}_x \\ \vec{\Delta\theta}_y \end{bmatrix},
\tag{3}
$$

where $\vec{\Delta\theta}_{x,y}$ is the vector of corrector *changes* which are needed, relative to their current settings.

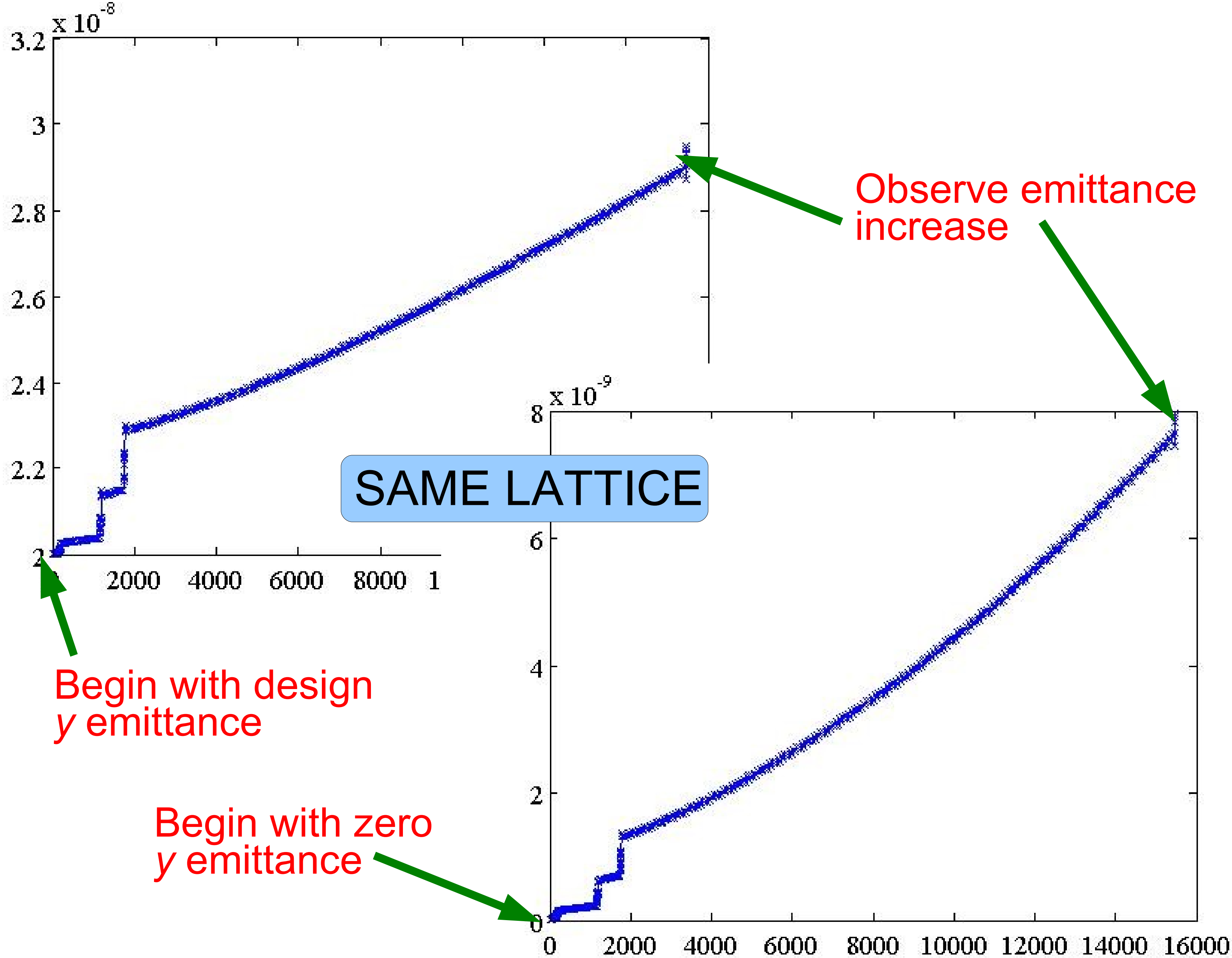
Application of KM

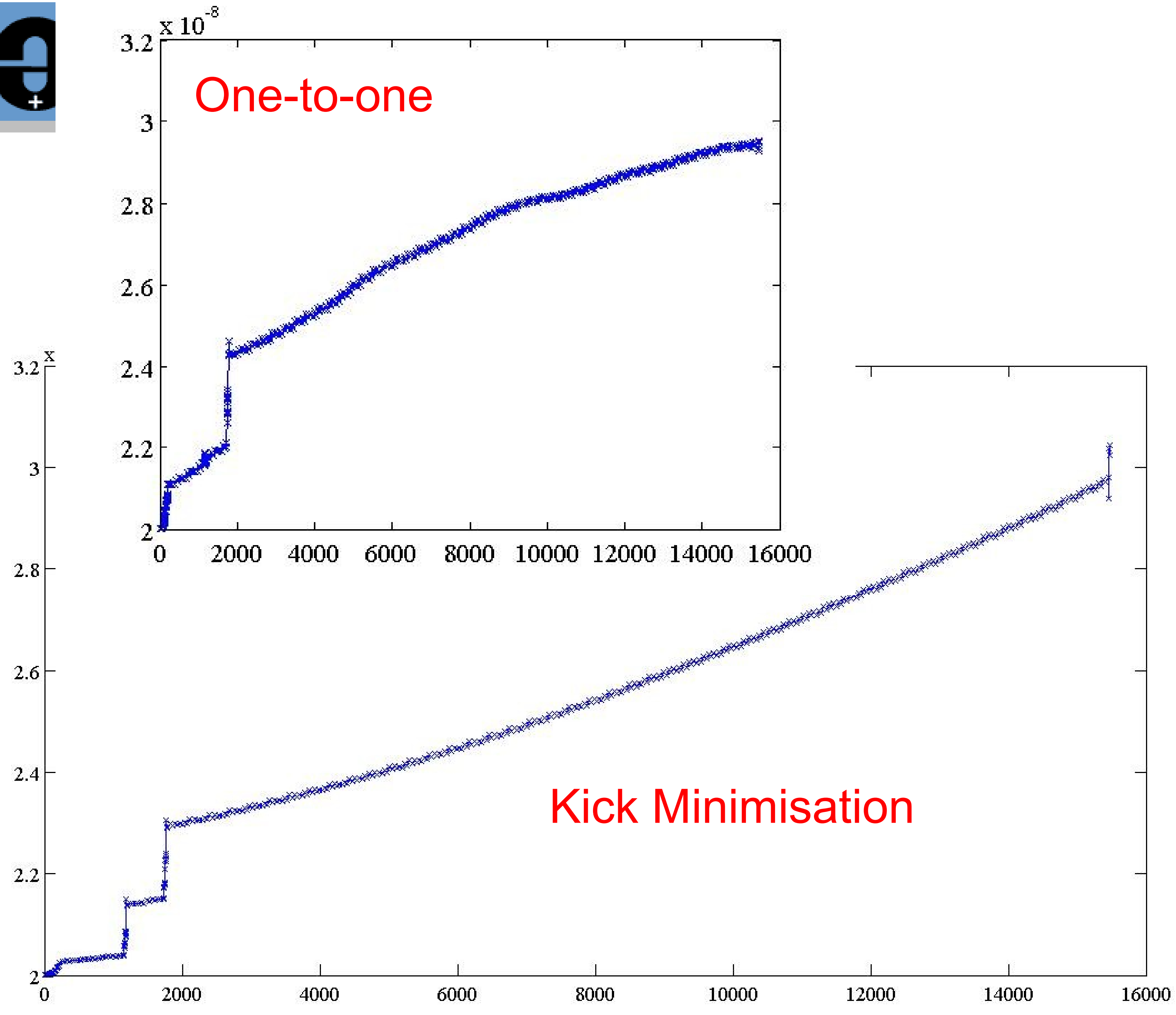
- Value of weighting,
  - "B" = square of RMS quad misalignment (300 um)
  - "C" = square of RMS quad-bpm difference (7 um)
- Applied only in y
  - Problems in x due to "sparse" corrector layout
    - More on that later...
- Applied to entire line in one go
  - Not practical in real life, but that's why we simulate!
- Iterate three times
  - Errors result in imperfect R matrices
  - Iterate to converge on solution


x 10-3
X Position / m
1
0
-1
-2
-3
0
2000
4000
6000
8000
10000
12000
14000
x 10-3
Y Position / m
2
1
0
-1
16000
S / m
Mean ~ 0
StDev ~ 320 um



X Position / m
x 10^-3
Y Position / m
x 10^-3
S / m
Mean ~ 0
StDev ~ 320 um
Dispersive / chromatic growth
Beta mismatches


x 10^-8
3.2
3
2.8
2.6
2.4
2.2
2000
4000
6000
8000
Observe emittance increase
SAME LATTICE
x 10^-9
8
6
4
2
0
0
2000
4000
6000
8000
10000
12000
14000
16000
Begin with design y emittance
Begin with zero y emittance



One-to-one
x 10^-8
3.2
3
2.8
2.6
2.4
2.2
2
0 2000 4000 6000 8000 10000 12000 14000 16000
Kick Minimisation
x
3.2
3
2.8
2.6
2.4
2.2
2
0 2000 4000 6000 8000 10000 12000 14000 16000

Some "issues"

- KM breaks in the presence of kick sources not included in response matrix
  - Kubo discovered this with tilted cavities in the linac
  - Bends are problematic in RTML
- Sparse xcors make KM unstable
  - Similar to previous problem
  - No XCORS at QDs
    - Kick direction is systematic
    - "Correct" solution is not stable
- Tuning lattice in segments does not yet work
  - Incoming position/angle not accounted for?
    - This is only a theory...

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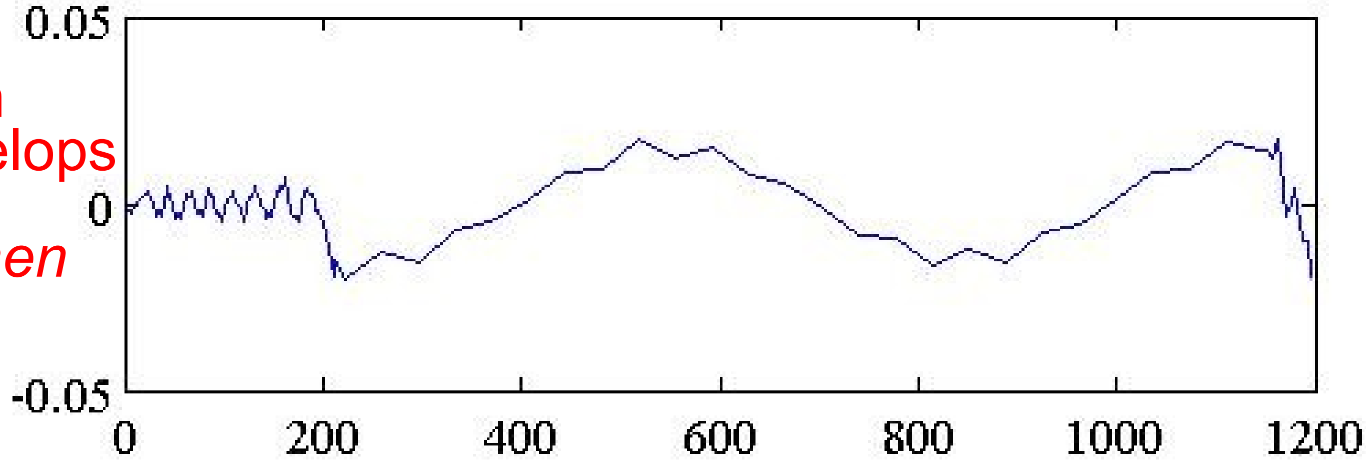
Simultaneous KM in x & y

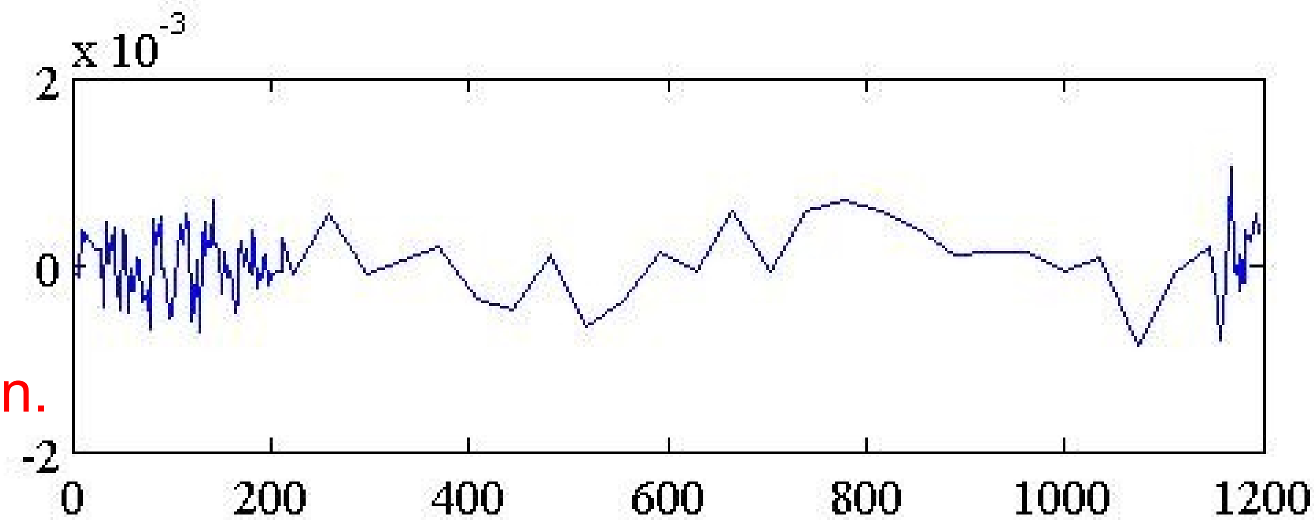
Large betatron oscillation develops

Not present when xcors added at every quad.



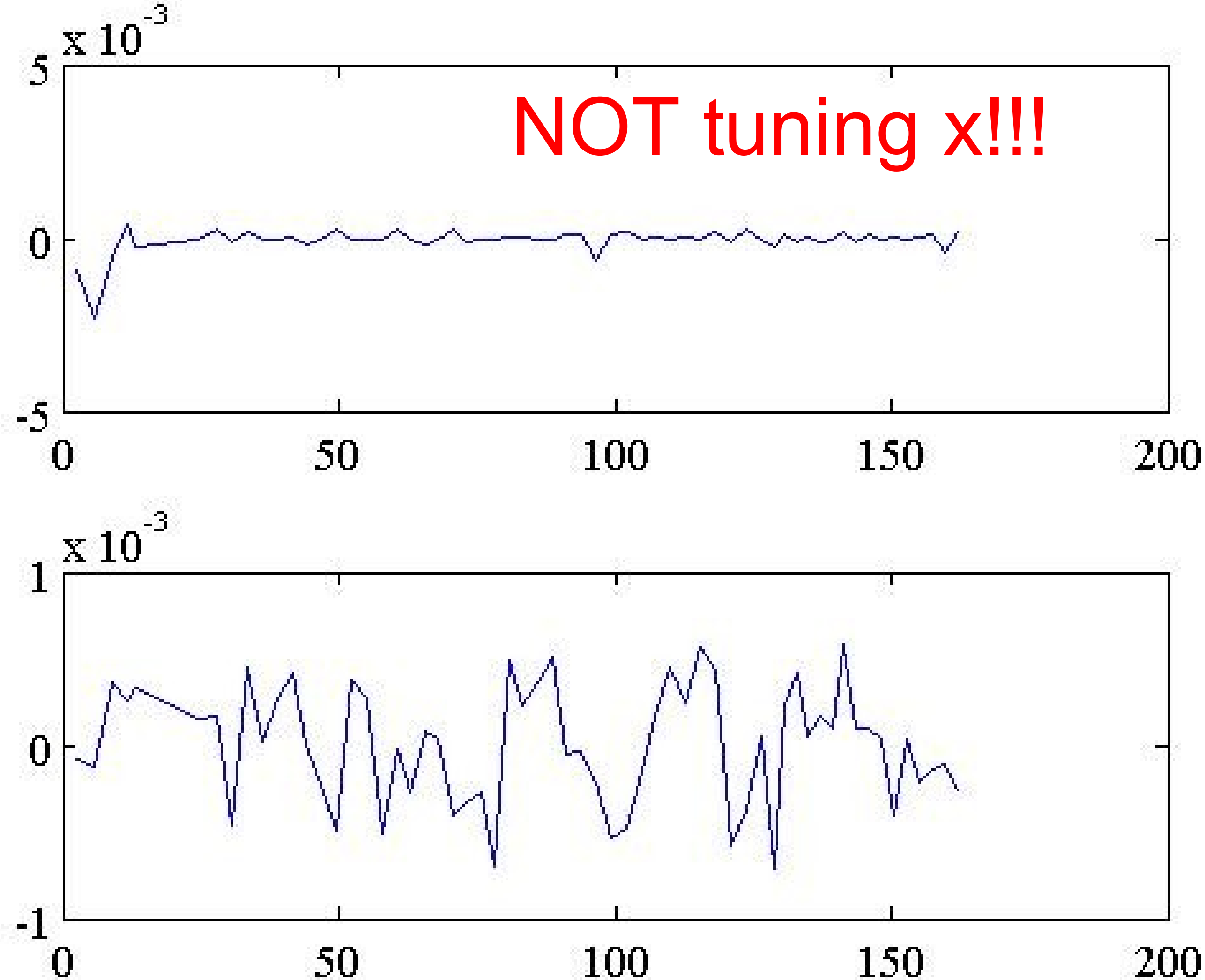
y plane works fine.

Deteriorates with iterating due to growing x oscillation.

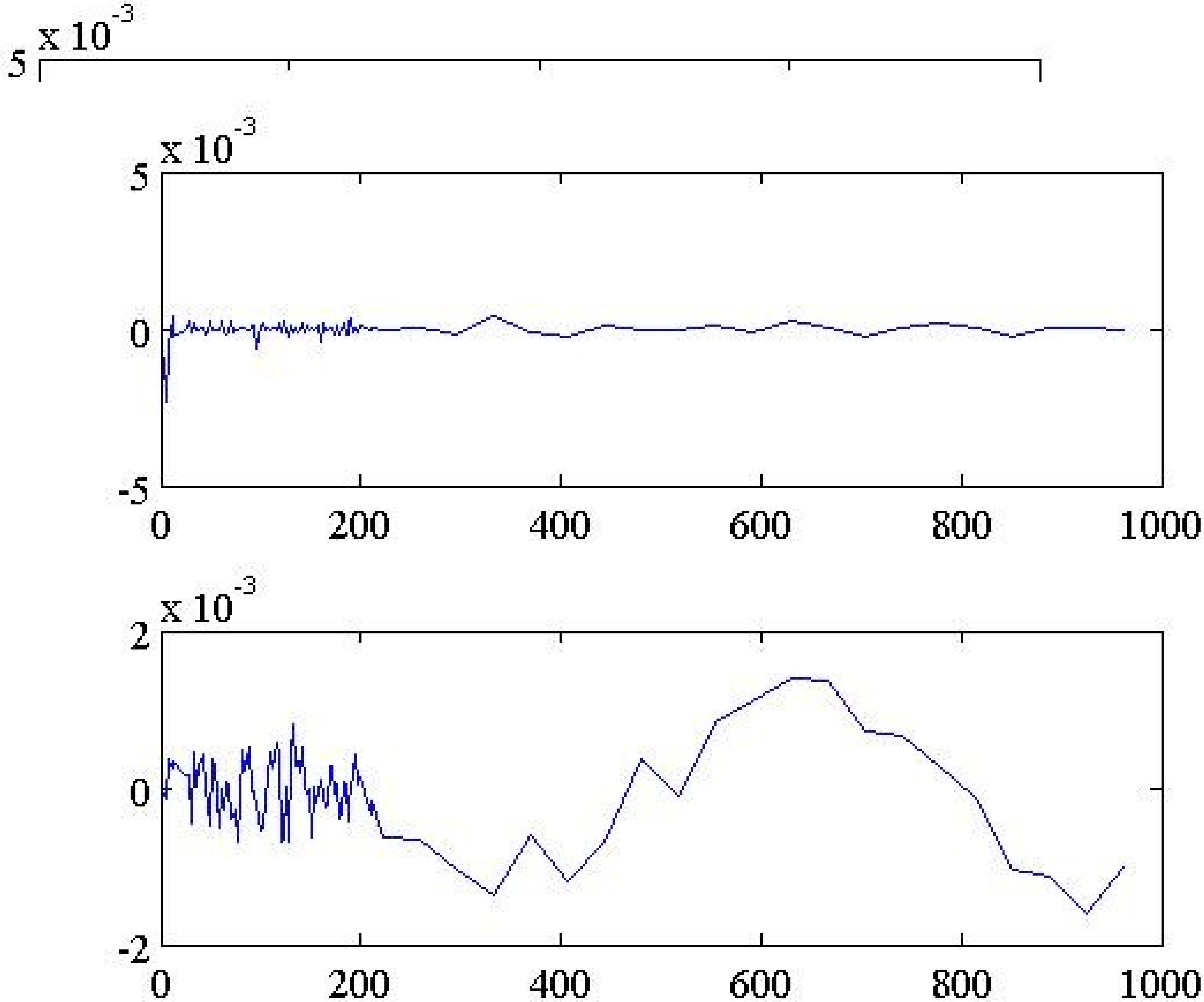


Tune machine in segments

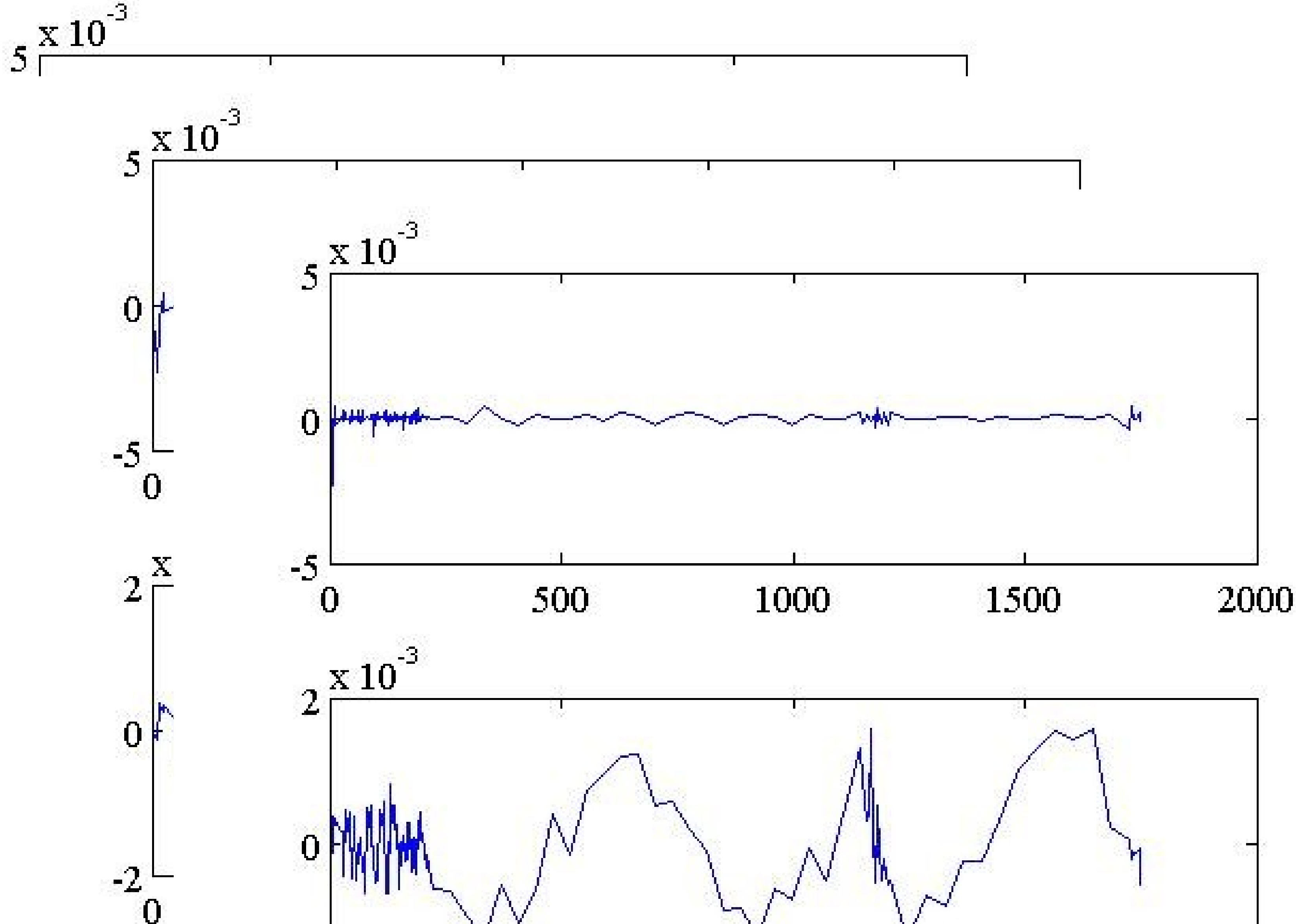
- Tuning ~16 km in one go is not practical (!)
- Instead,
  - Tune region containing *n* BPMs
    - e.g. *n = 40*
  - Move on to next *n* BPM region, overlapping with previous by *n/2*
- Doesn't work (see next slides)
  - Region #1 is fine
  - KM misbehaves in subsequent regions
    - Smoking gun is that these begin with non-zero position and angle
    - Haven't proved this yet...



Works fine on this segment...



Obvious betatron oscillation develops in segment 2...



x 10^-3
5
x 10^-3
5
0
-5
0
x 10^-3
5
0
-5
0
500
1000
1500
2000
x
2
0
-2
0
x 10^-3
2
0
-2
0
500
1000
1500
2000

Summary

- Developed one-to-one and KM tuning algorithms in Lucretia
- Have tuned up to end of the return line.
  - ~10 nm emittance growth
    - Many problems may be fixed by beta matching
    - Also coupling-correction & dispersion knobs.
  - Expecting BC1&2 to be troublesome...
- Encountered problems with KM
  - Tuning one region at a time does not (yet) work
  - Tuning in x-plane (with no QD correctors) is unstable
    - One-to-one may suffice for x-plane
- Now to move onto spin rotator and BC1&2