RTML Tuning

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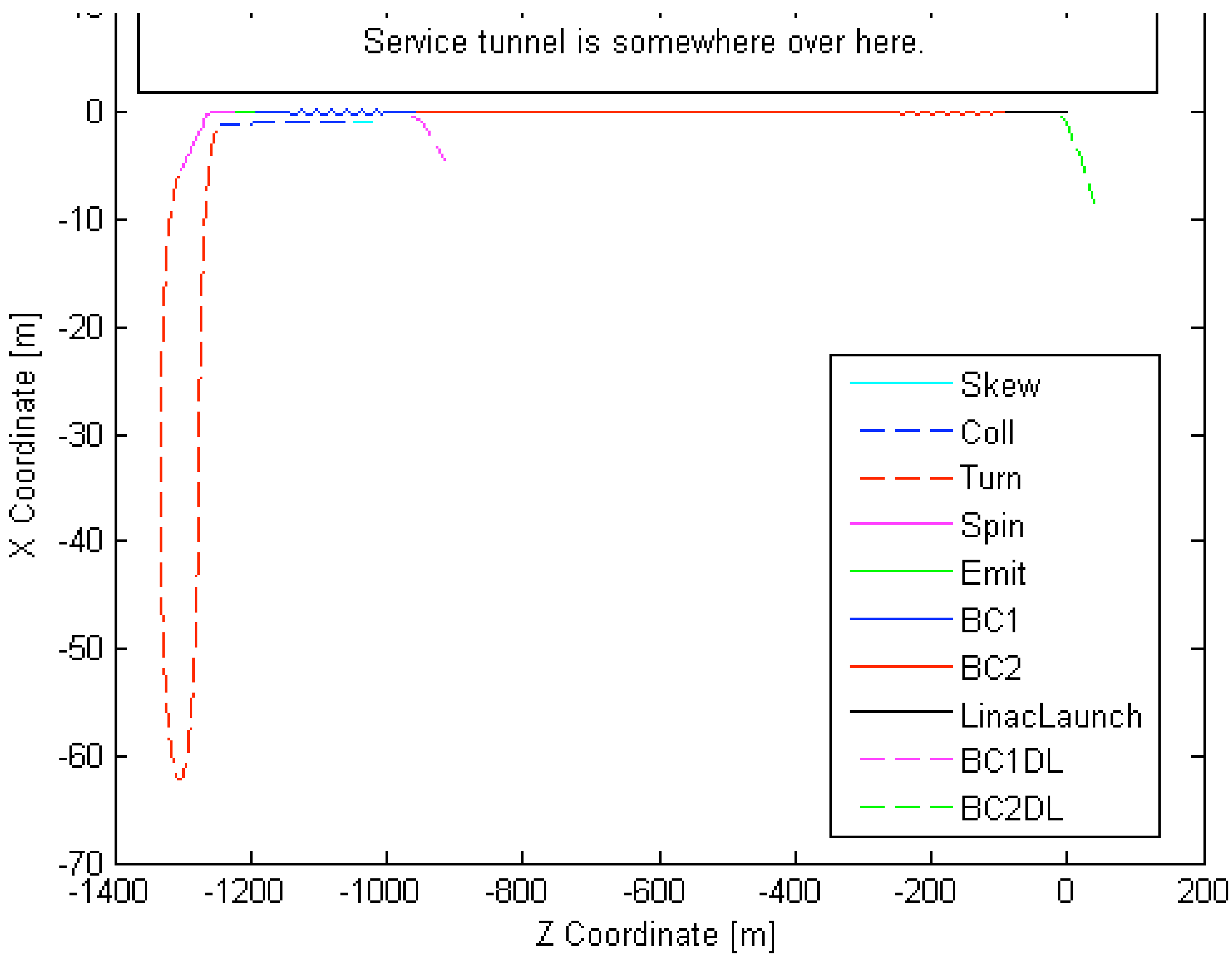
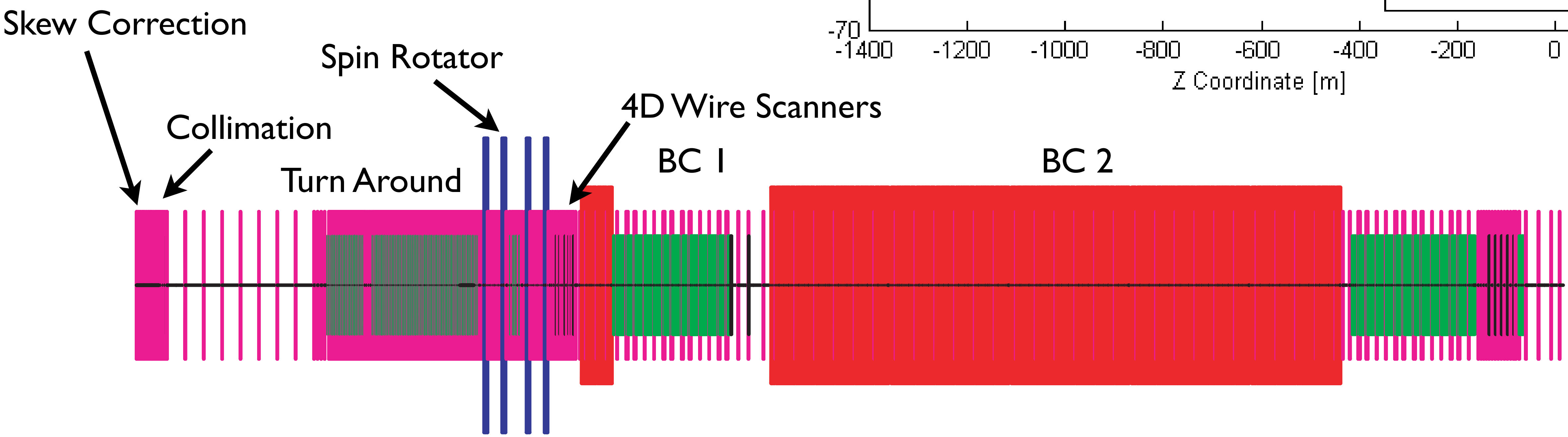
The lattice used

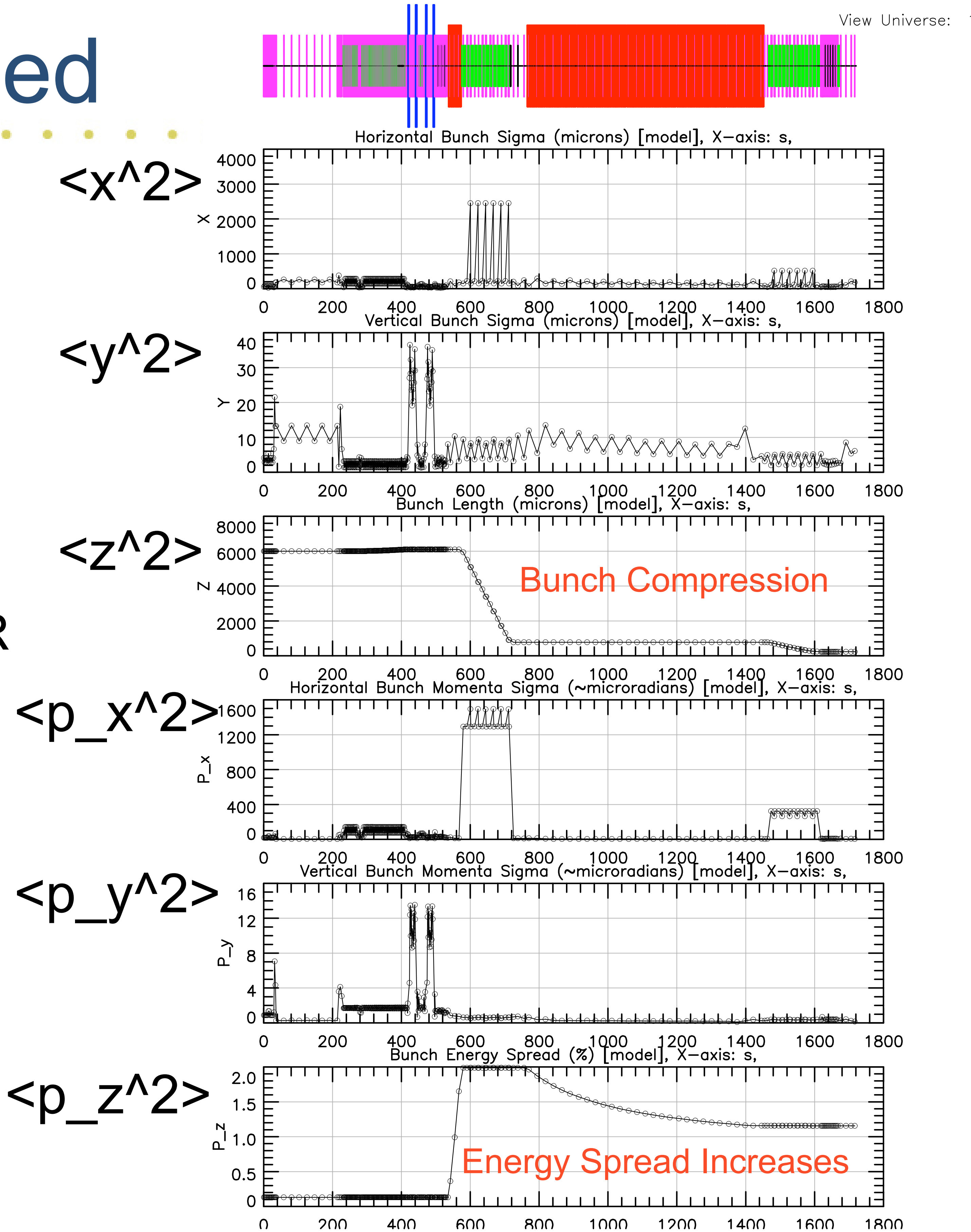
- Created in spring 2006
  - **Purple -- quadrupole**
  - **Green -- bend**
  - **Blue -- solenoid**
  - **Red -- RF Cavity**





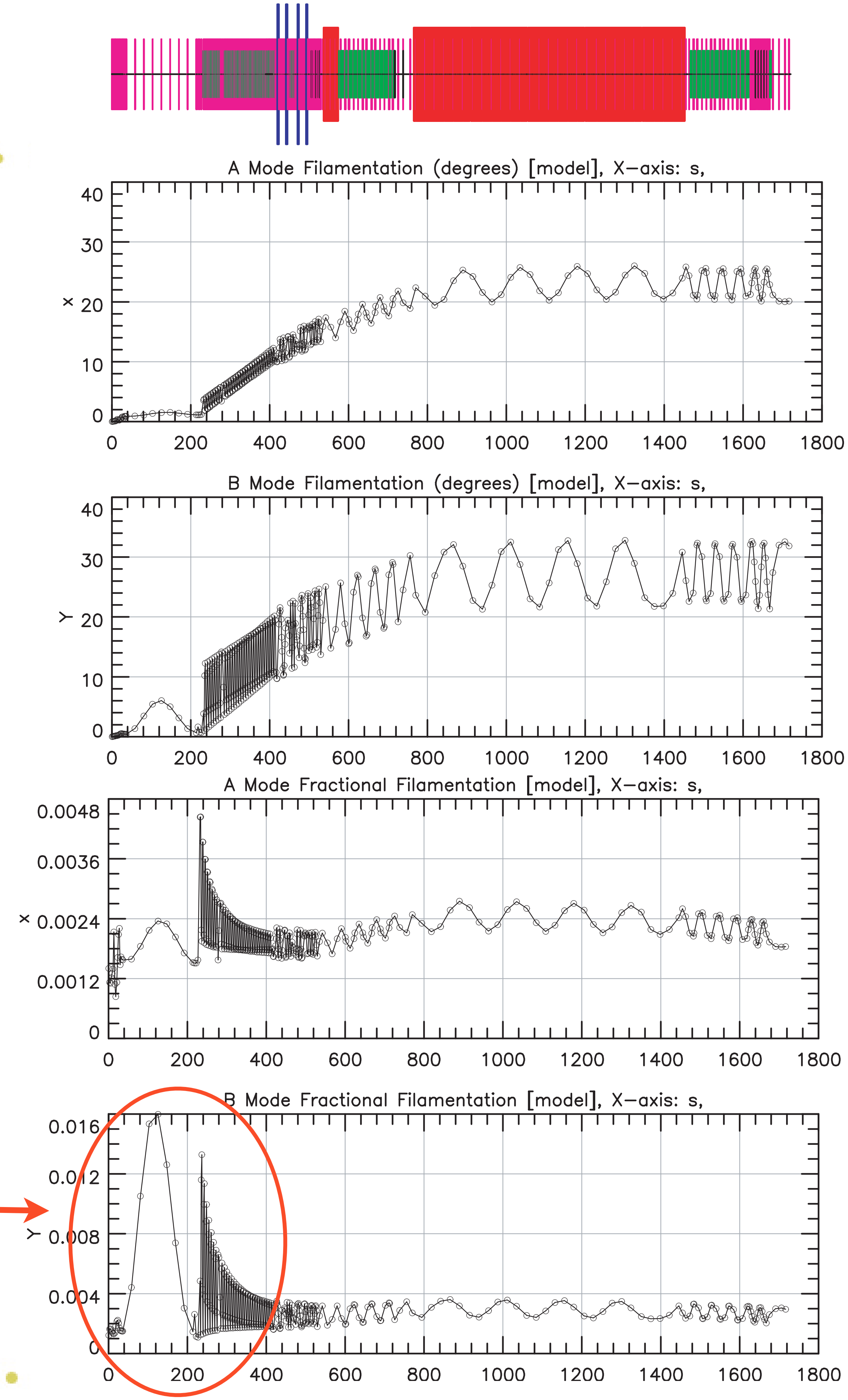
The lattice used

- RTML lattice
  - **Not the current lattice!**
    - turnaround FODO cells have changed to reduce phase advance
    - New skew quad correction before 4D mesurement
    - 5 Gev LET transport from DR
  - **New lattice being finished this week.**



The lattice used

- Filamentation is defined here as the phase advance error for a 1 sigma off-energy particle.
- The filamentation rate is the filamentation per unit phase advance (says where filamentation is increasing the fastest)
- Chromaticity and Filamentation is a slight problem in this lattice
  - **Will be fixed in new lattice**



Filamentation rate should be fixed

Alignment tolerances used

- Just looking at RTML up to bunch compressor.
  - This is all warm (except for solenoids)
- Misalignments used (based on FFTB tolerances):
  - **Quads:**
    - 150 μm RMS offsets in x and y
    - 0.25% strength errors
    - 300 μrad rotation errors
  - **Bends:**
    - 0.5% strength errors
    - 300 μrad rotation errors
  - **Solenoids**
    - 1% strength error
  - **BPMs:**
    - 0 um resolution (for starters)
    - 7 μm RMS offsets x and y to nearest quad
    - No rotations or scale errors
  - **Laser Wire Scanners:**
    - 0% error on measurement on each wire
    - 0 degree angle error on skewed wire

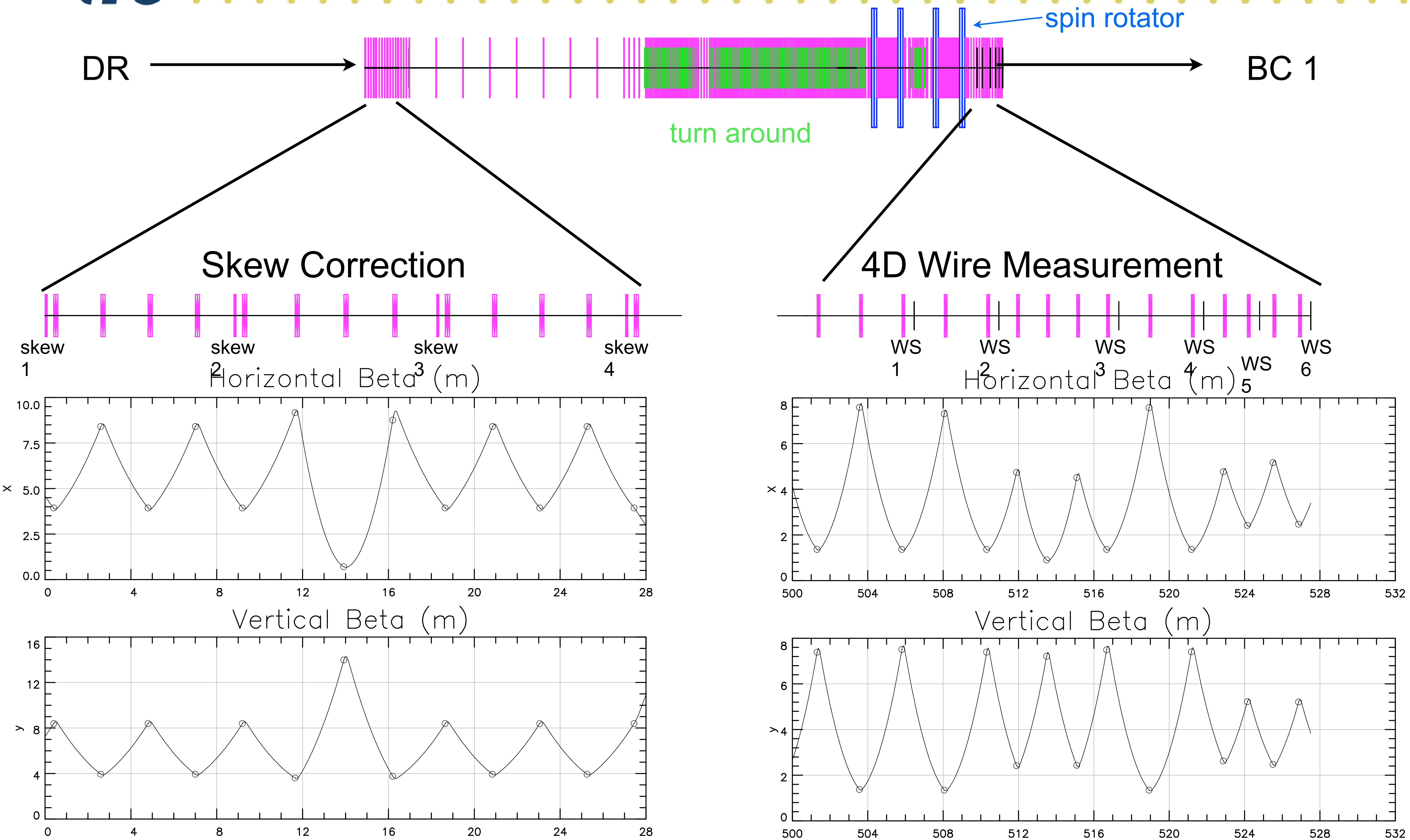
Dispersion Bumps

- In original RTML (before Valencia) the dispersion bumps consisted of pairs of quadrupoles separated by a -1 transport in the turnaround.
  - **Horizontal bumps were pairs of quads to adjust dispersion (but orbit change is zero outside bump).**
  - **Vertical bumps were pairs of skew quads to couple the horizontal dispersion in the turnaround into the vertical (again, orbit change is zero outside bump).**
- With the new layout there is a vertical dogleg (with vertical dispersion) to bring the beam down from the ceiling to the level of the turnaround (and main linac).
  - **So now, the vertical dispersion bumps are located in this dogleg and are pairs of normal quads -1 apart, working similar to the horizontal bumps above.**

Dispersion correction

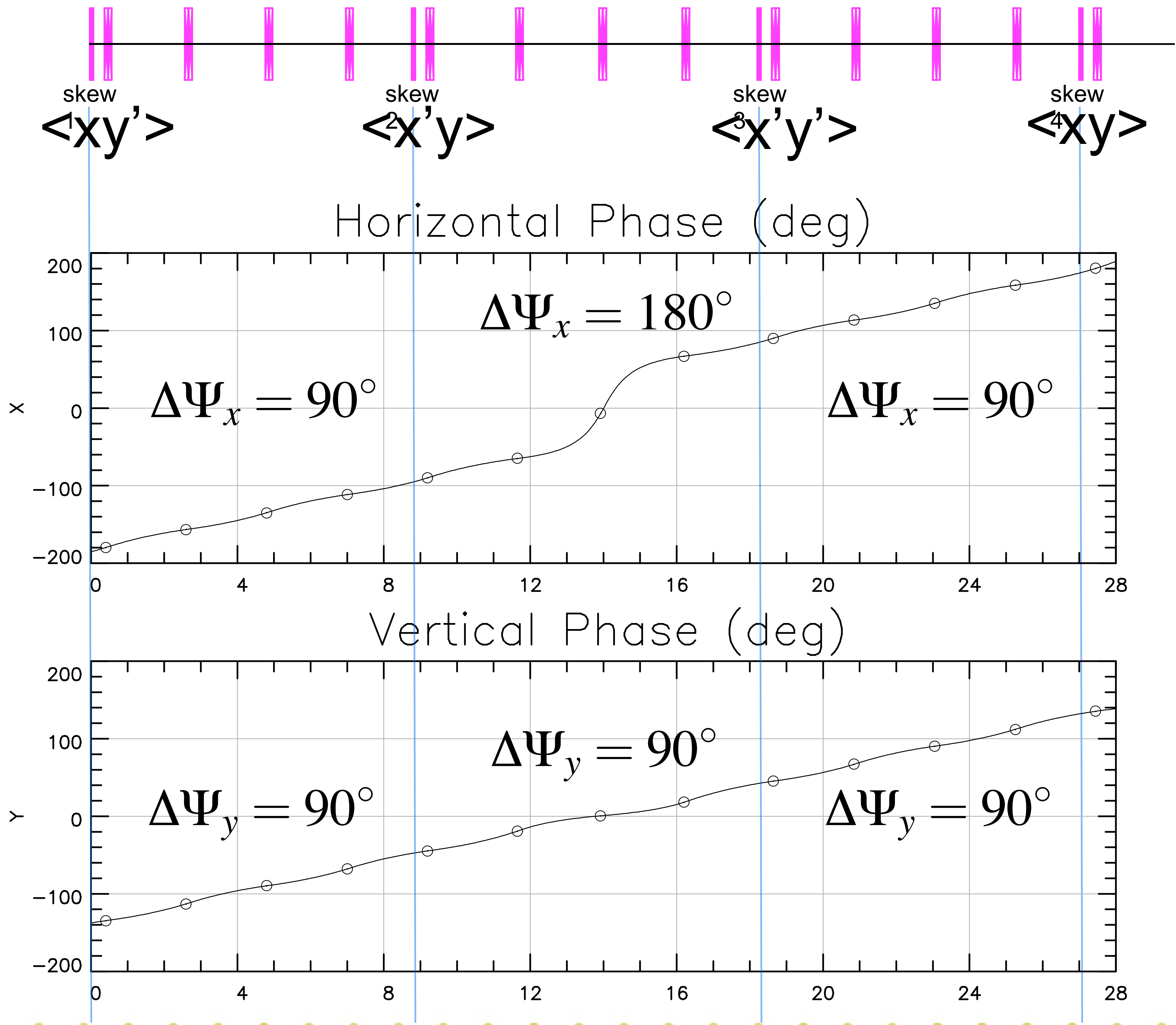
- Studies by PT and Kubo-san have shown that a combination of Kick Minimization and Dispersion Bumps can zero emittance growth due to dispersion.
  - **Kubo-san's talk will discuss this**
- Kick Mimimization in ILCv doesn't work as well for me (I think I know why) so I have been using Ballistic Alignment and Dispersion bumps combinations which works slightly worse

Skew Correction and Wire Scanners



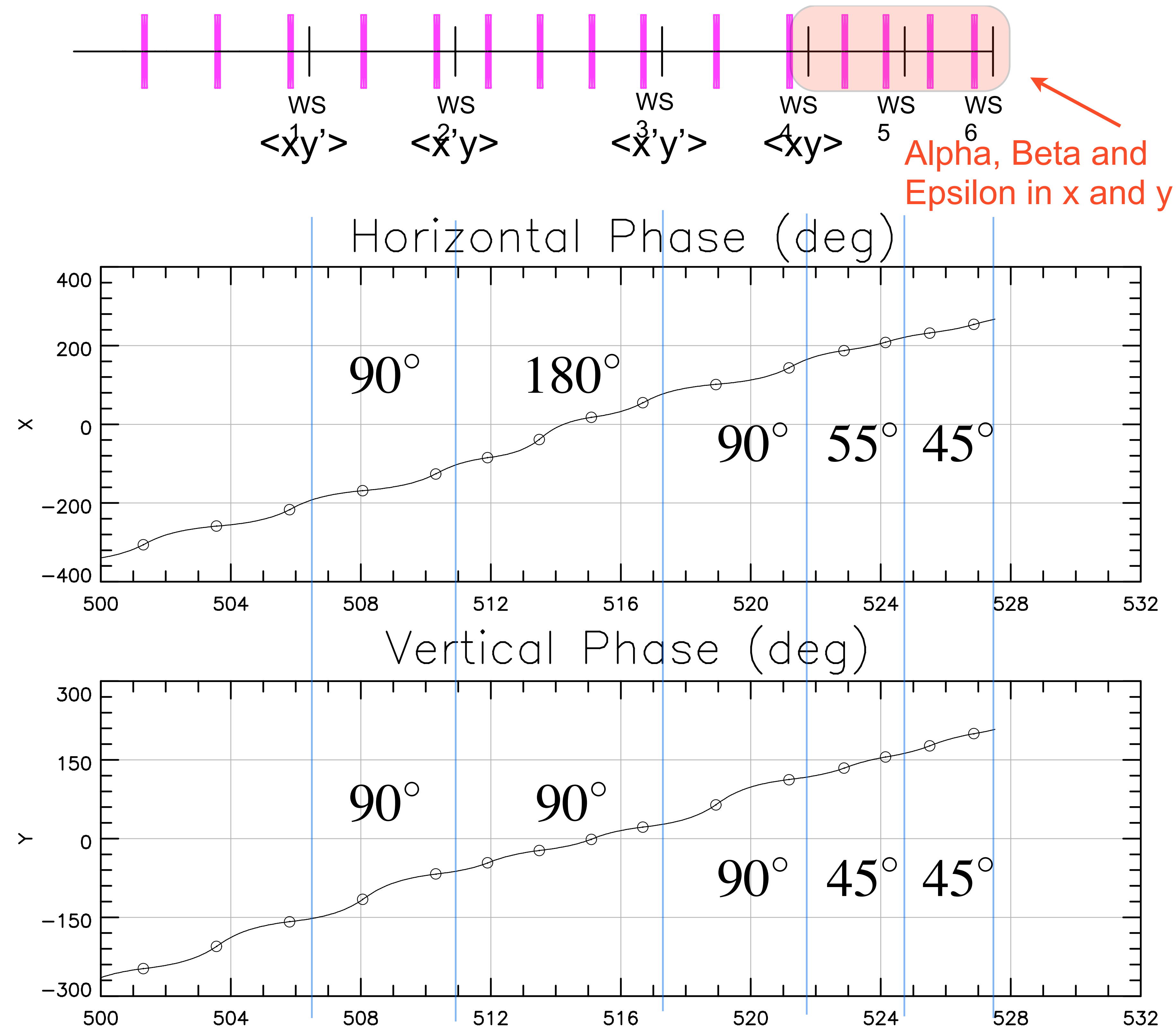
Skew Correction

- Four Skew quadrupoles phased properly can eliminate all four coupling components: <xy>, <x’y>, <xy’> and <x’y’>



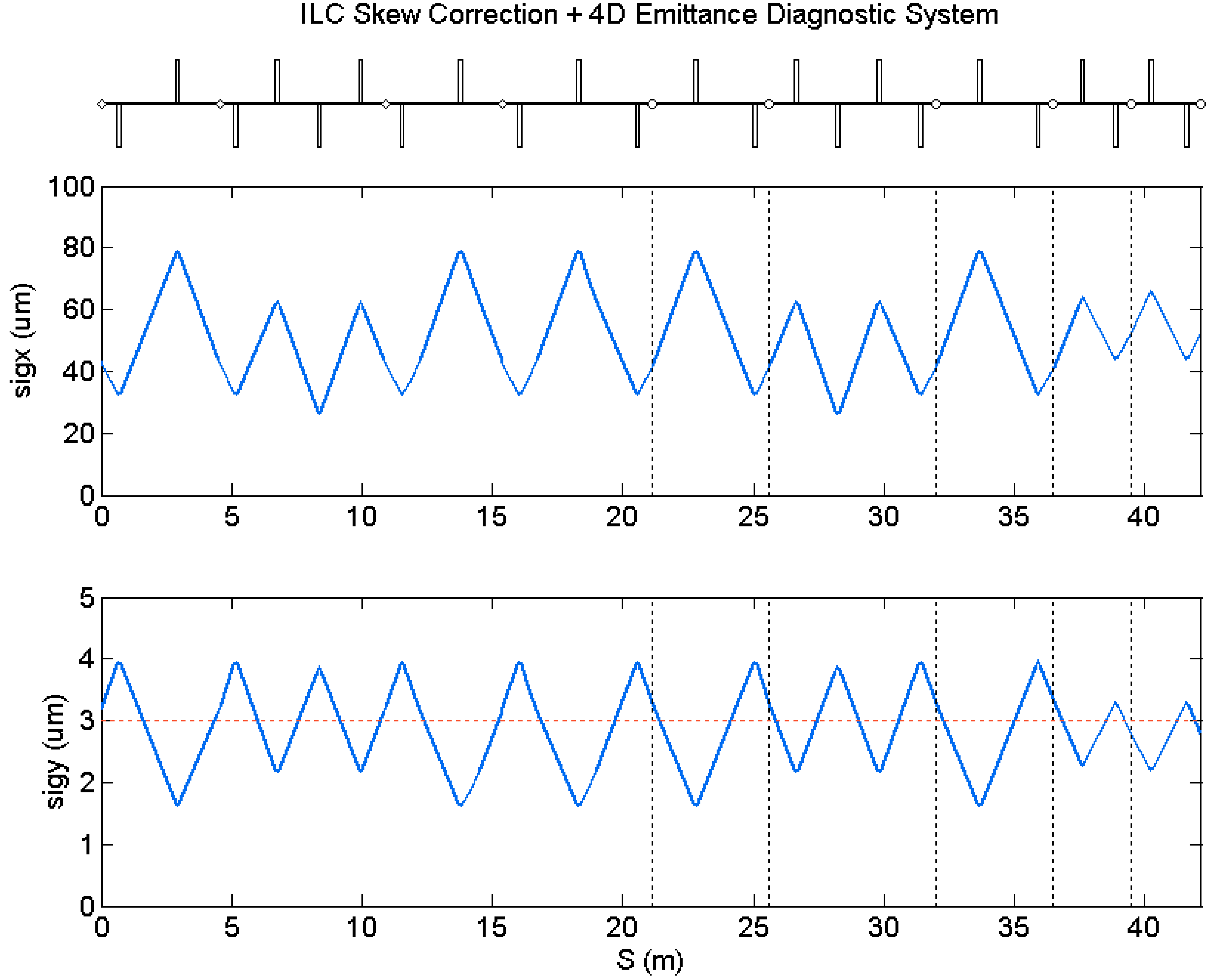
4D Emittance Measurement

- 6 Wire scanners properly phased can measure all four coupling parameters plus the three beam parameters for x and y (alpha, beta and epsilon)



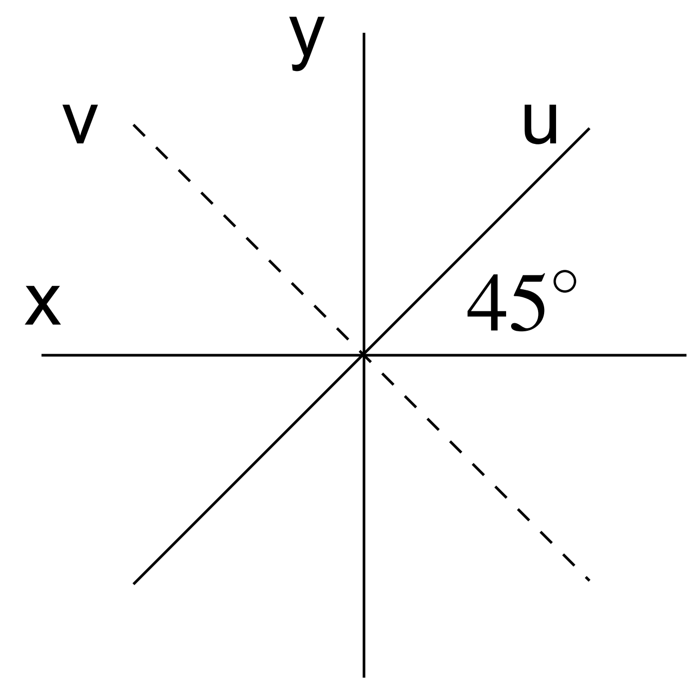
Wire Scanner minimum Beam Size

- Minimum vertical beam size at wire scanners is 3 microns.



Coupling Parameter Calculation

- Three wires in wire scanner that measure the beam size along three axis: x, y and u
- These three beam measurements can be used to calculate the x-y coupling parameter <xy>
- The angled wire measures the beam size along a skewed axis so a rotational transformation relates the skewed wire measurement to the other wire measurements



$$\sigma_{uv} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \cdot \sigma_{xy} \cdot \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

$$\sigma_{uv}^{11} = \sigma_{xy}^{11}\cos^2\theta + \sigma_{xy}^{22}\sin^2\theta + 2\sigma_{xy}^{12}\sin\theta\cos\theta$$

$$< xy > = \frac{\sigma_{uv}^{11} - \sigma_{xy}^{11}\cos^2\theta - \sigma_{xy}^{22}\sin^2\theta}{2\sin\theta\cos\theta}$$

Beam Parameter Calculation

- <xx> and <yy> are measured at the last three wire scanners each about 45 degrees apart
- The relation between the <xx> measured at each wire is described by the transfer matrix, R, between the wire scanners:

$$\sigma_2^{11} = \sigma_1^{11} R_{11}^2 + 2\sigma_1^{12} R_{11} R_{12} + \sigma_1^{22} R_{12}^2$$

- If <xx> is measured at three wires and the wires are approximately 45 degrees apart then the full sigma matrix can be found at one of the wires:

$$\begin{pmatrix} \sigma_1^{11} \\ \sigma_2^{11} \\ \sigma_3^{11} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ (R_{11}^{12})^2 & 2R_{11}^{12} R_{12}^{12} & (R_{12}^{12})^2 \\ (R_{11}^{13})^2 & 2R_{11}^{13} R_{12}^{13} & (R_{12}^{13})^2 \end{pmatrix} \cdot \begin{pmatrix} \sigma_1^{11} \\ \sigma_1^{12} \\ \sigma_1^{22} \end{pmatrix}$$

- From the sigma matrix alpha, beta and epsilon can be found.

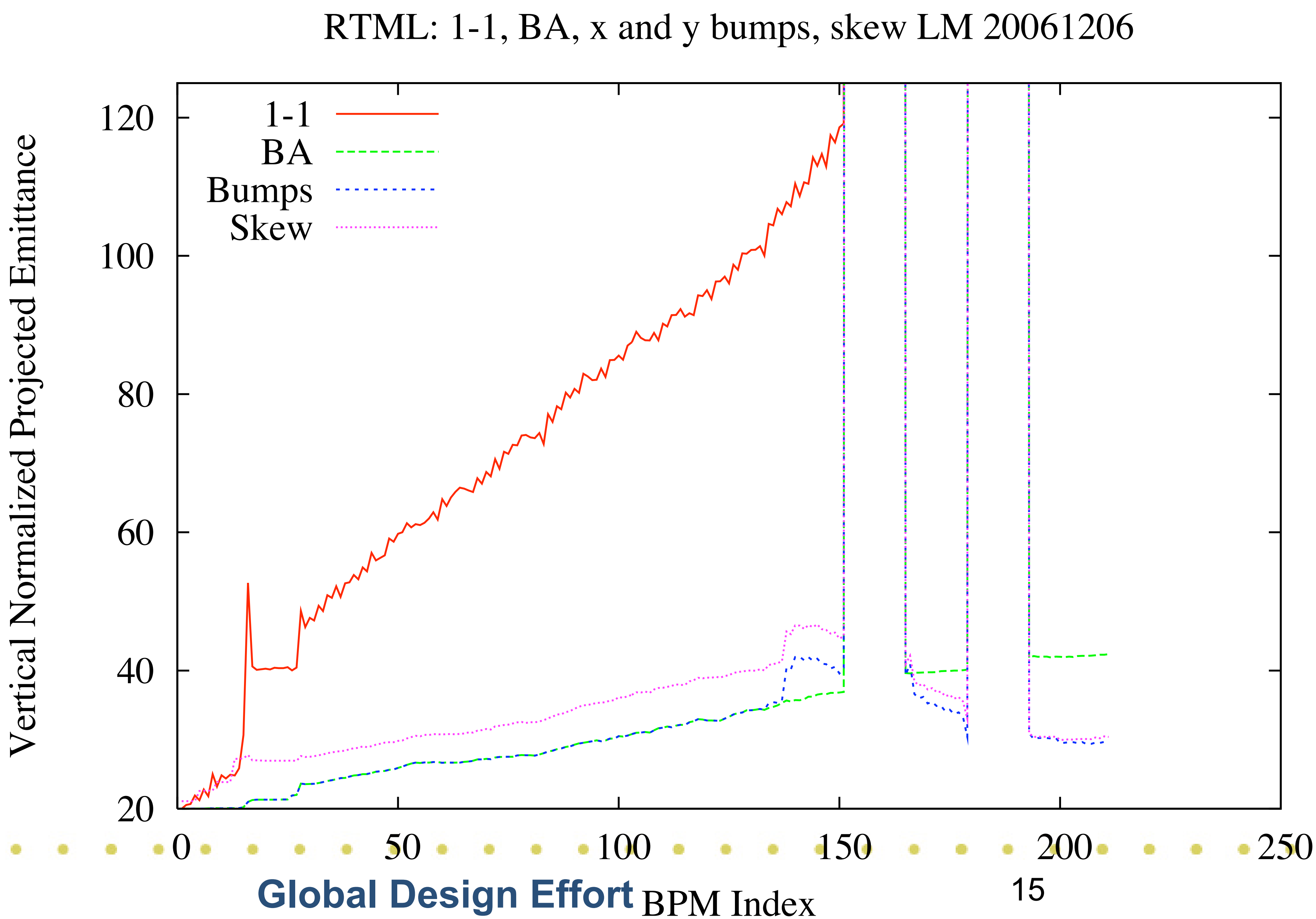
$$\sigma^{11} = \varepsilon\beta; \quad \sigma^{12} = -\varepsilon\alpha; \quad \sigma^{22} = \varepsilon \frac{1+\alpha^2}{\beta}$$

Coupling Correction Technique

- Found that the system is rather non-linear
  - 4 independent knobs that adjusts the 4 coupling measurements separately was not found to work well. Couldn't find orthogonal knobs.
  - Likewise, simple scans doesn't work well for me, system is too non-linear
  - Using a non-linear optimizer (Levenberg-Marquardt)
    - 4 data points (<xy>, <xy'>, <x'y>, <x'y'>)
    - 4 Variables (the 4 skew quads)
    - Find response matrix then iterate Levenberg Marquardt 10 times, then repeat twice more
  - I'm not performing an emittance calculation

Performance is very poor

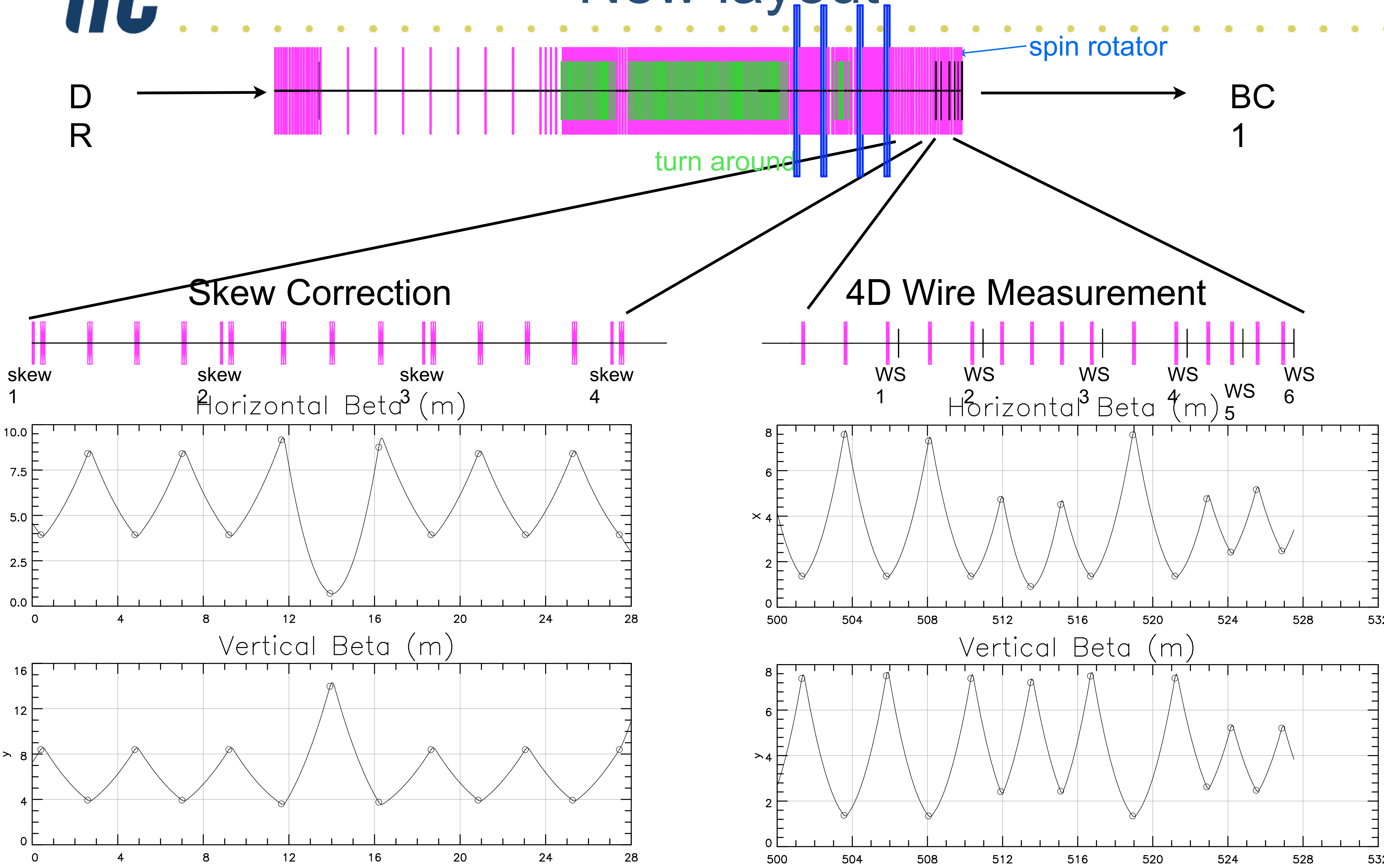
- The problem is the coupling correction interferes with the dispersion bumps



The problem with the skew correction

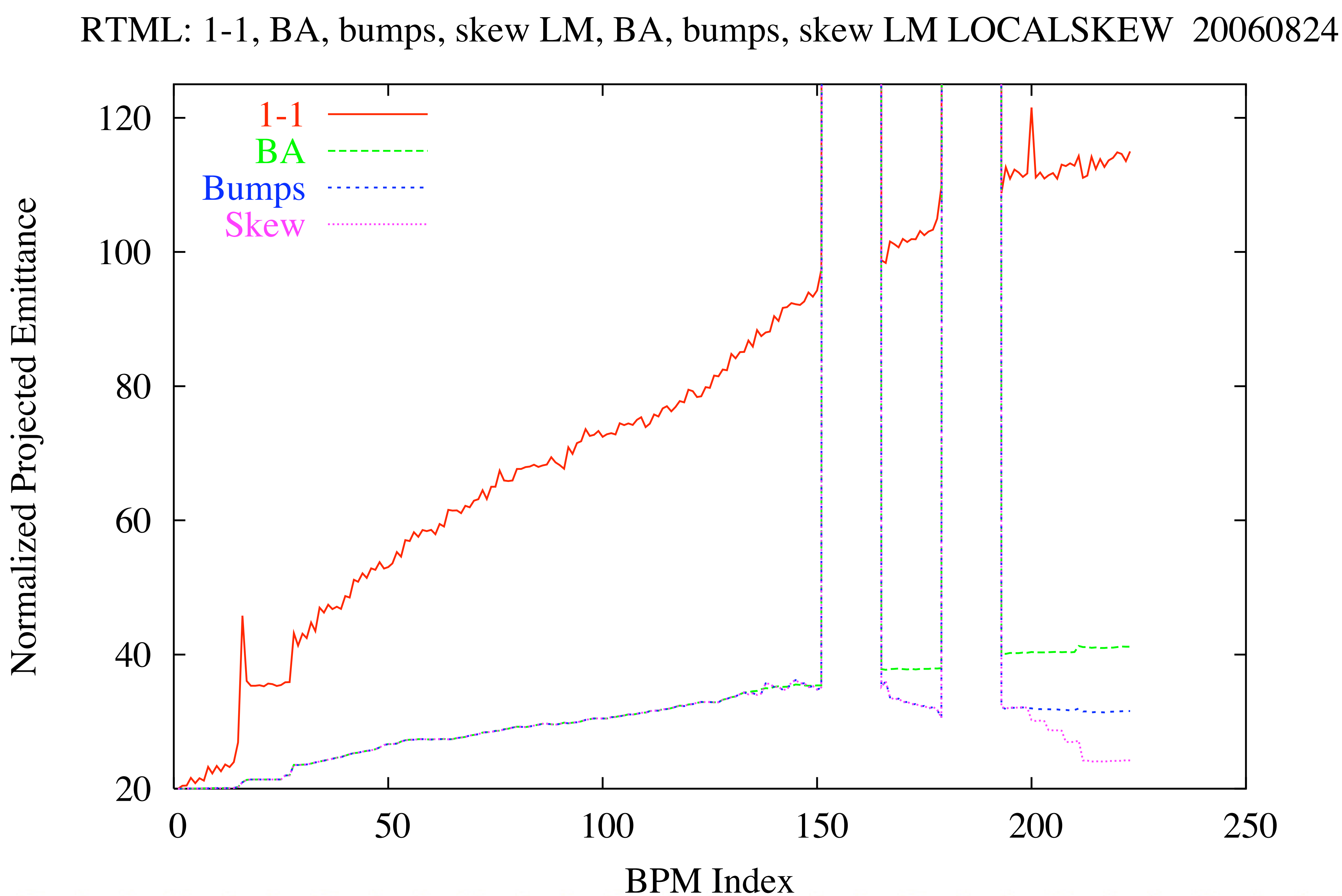
- The skew correction as it stands is a global correction
- Adjusting the skew quads will introduce orbit deflections and dispersion through the RTML
  - **This screws up the dispersion bumps because they too are global corrections**
  - **Also, the skew correction will introduce large chromatic emittance growth which cannot be easily removed**
  - **Basically, in certain seeds, the dispersion bumps and skew correction work against each other.**
  - **Keep in mind that sometimes the skew correction works OK and most times doesn't degrade emittance by much. However, sometimes it really degrades emittance.**

New layout


D
R
spin rotator
BC
1
turn around
Skew Correction
4D Wire Measurement
skew 1
skew 2
skew 3
skew 4
WS 1
WS 2
WS 3
WS 4
WS 5
WS 6
Horizontal Beta (m)
Vertical Beta (m)
Horizontal Beta (m)
Vertical Beta (m)

Performance much be better

- The skew correction is now a local correction.
- Also found that simple scans works very well in this case.

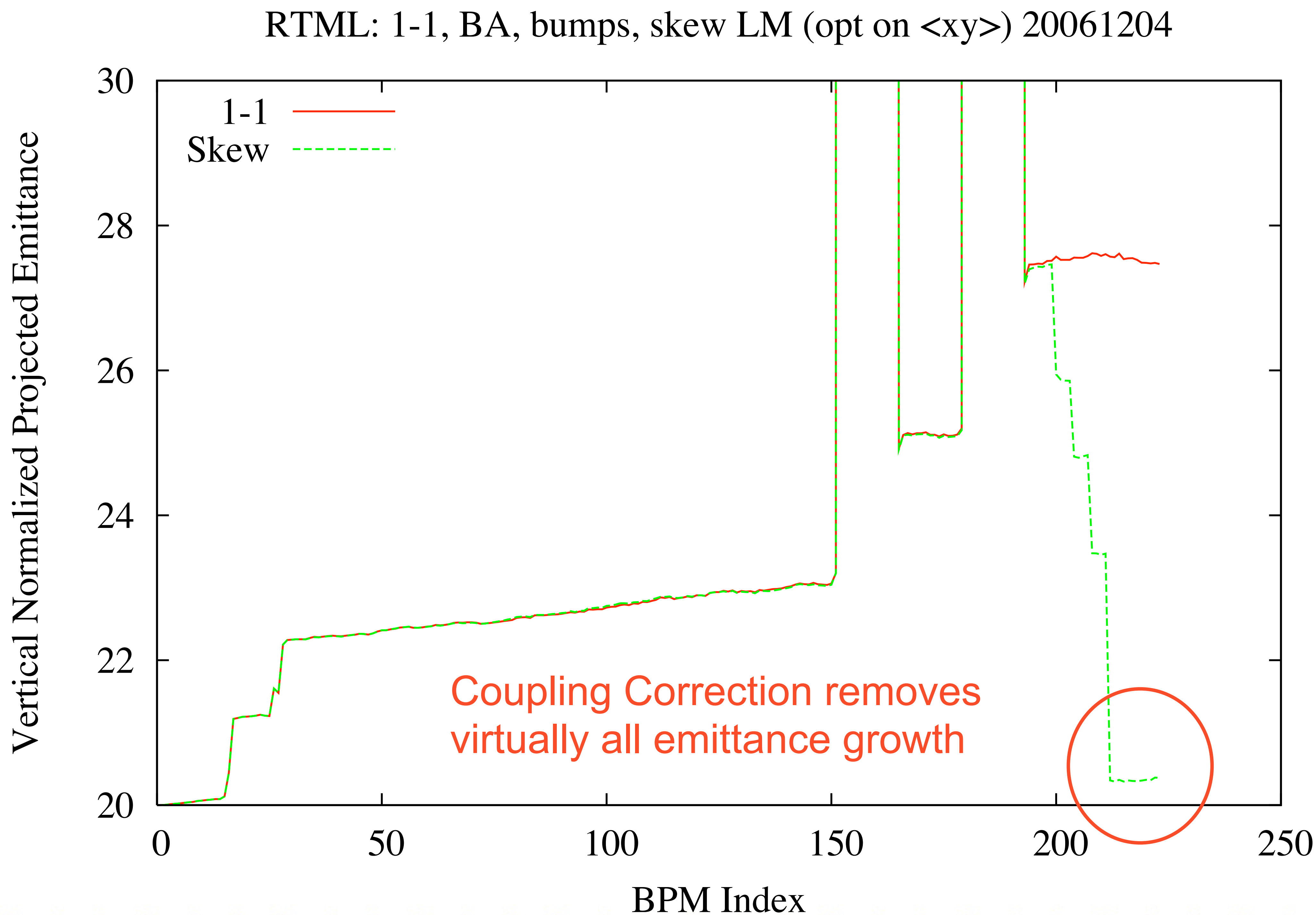


Tuning off of <yy>

- The current design has fewer wire scanners and cannot measure all four coupling parameters. The thought being we can tune coupling off of the <yy> measurements (and the emittance calculation).
- Will this work? I tried this earlier and it didn't work well. But my algorithm has changed since then, so maybe it'll work now.
- For this test I first zeroed the energy spread to eliminate all sources of emittance other than coupling. Then I ran my coupling correction (using levenberg-Marquardt) after inserting all errors.

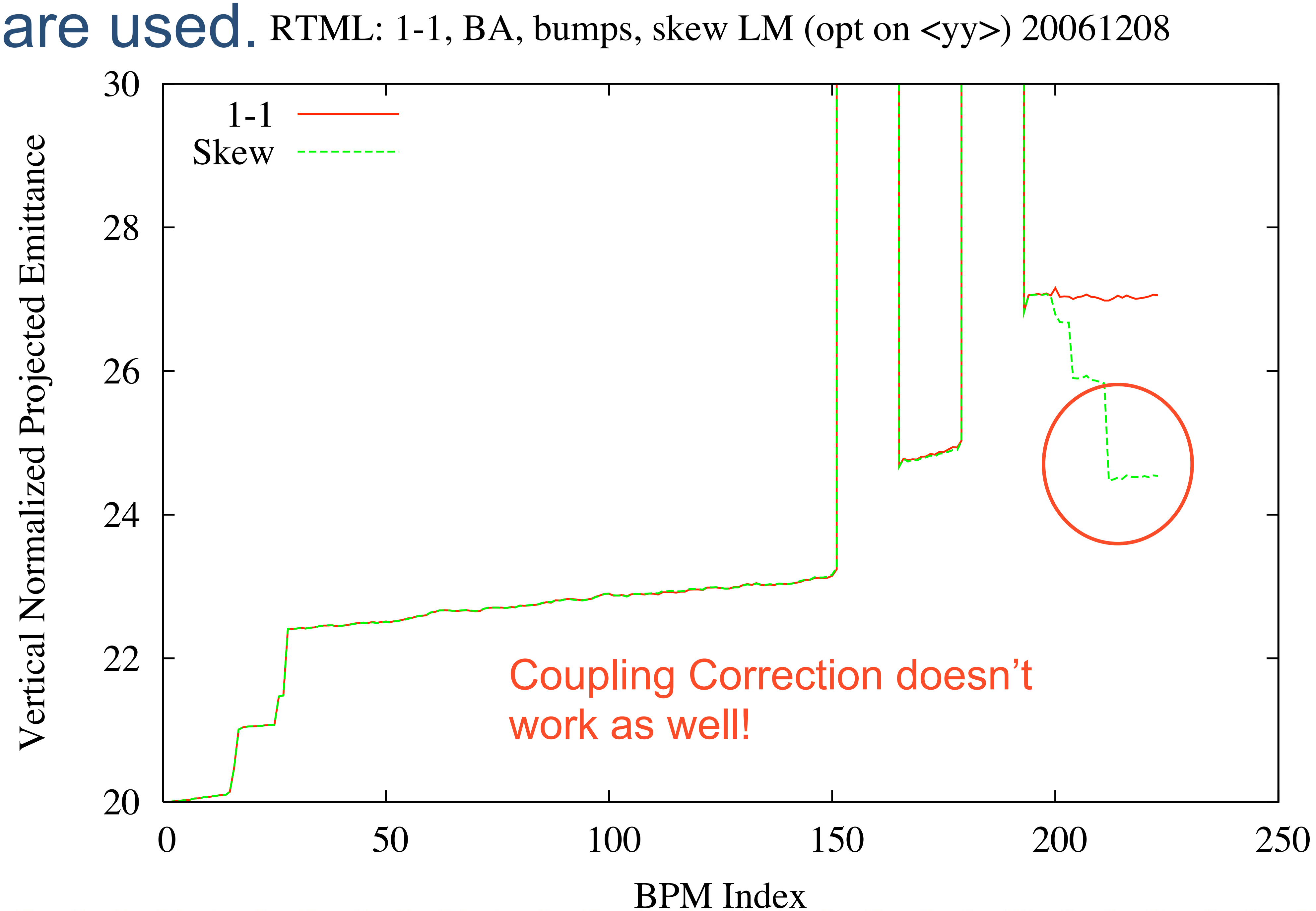
First the control

- This is optimizing off the normalized coupling terms like I always do: <xy>/sqrt(<xx><yy>)



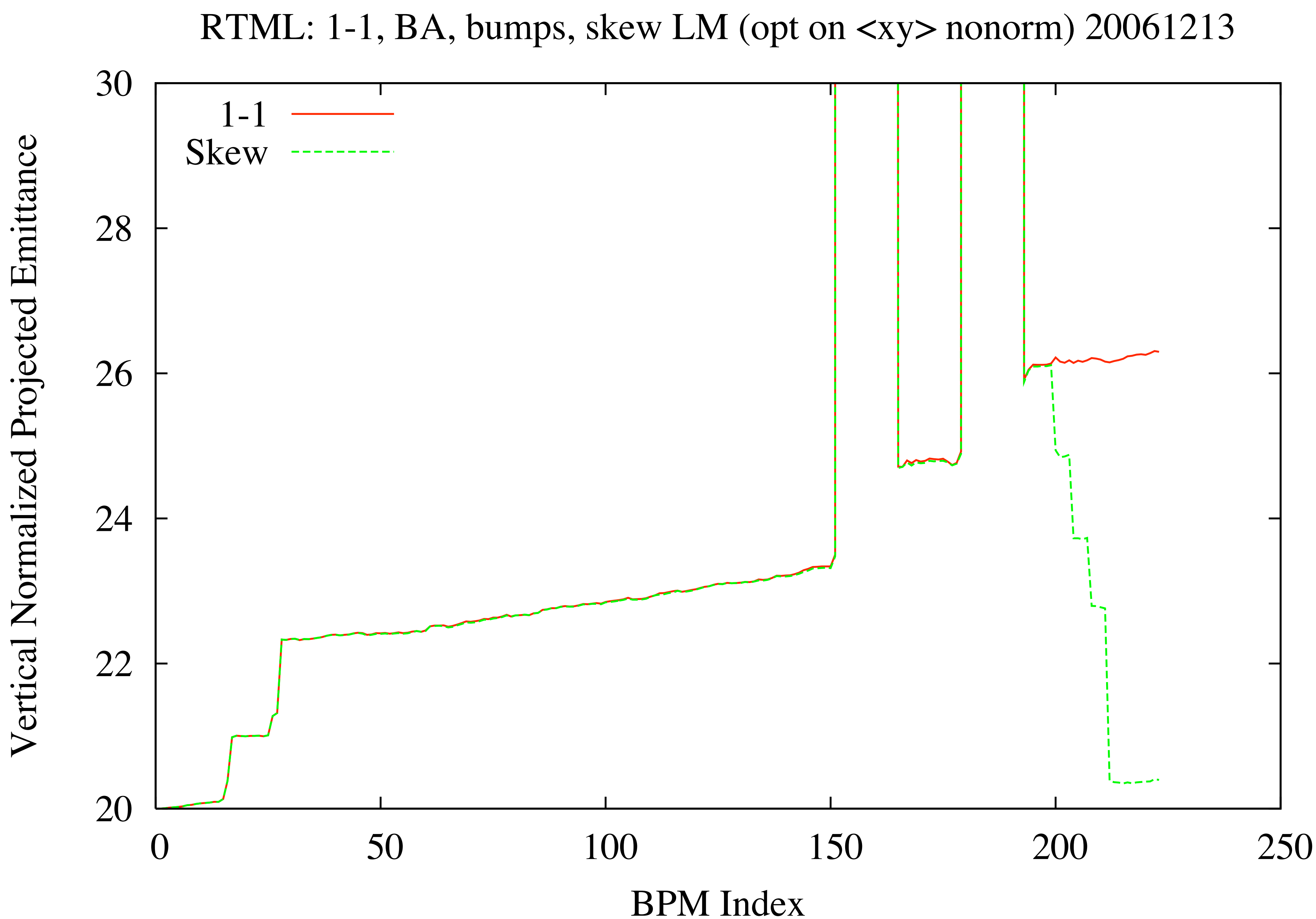
Now try <yy>

- Exact same test except optimizing off of <yy>. To keep everything else constant, the same four wire scanners are used.



Is it the normalization?

- I normally use <xy>/sqrt(<xx><yy>) which normalizes the coupling measurement and removes the sensitivity to changes in emittance. What if I use <xy>?
- If I optimize off of <xy> it still works marvelously

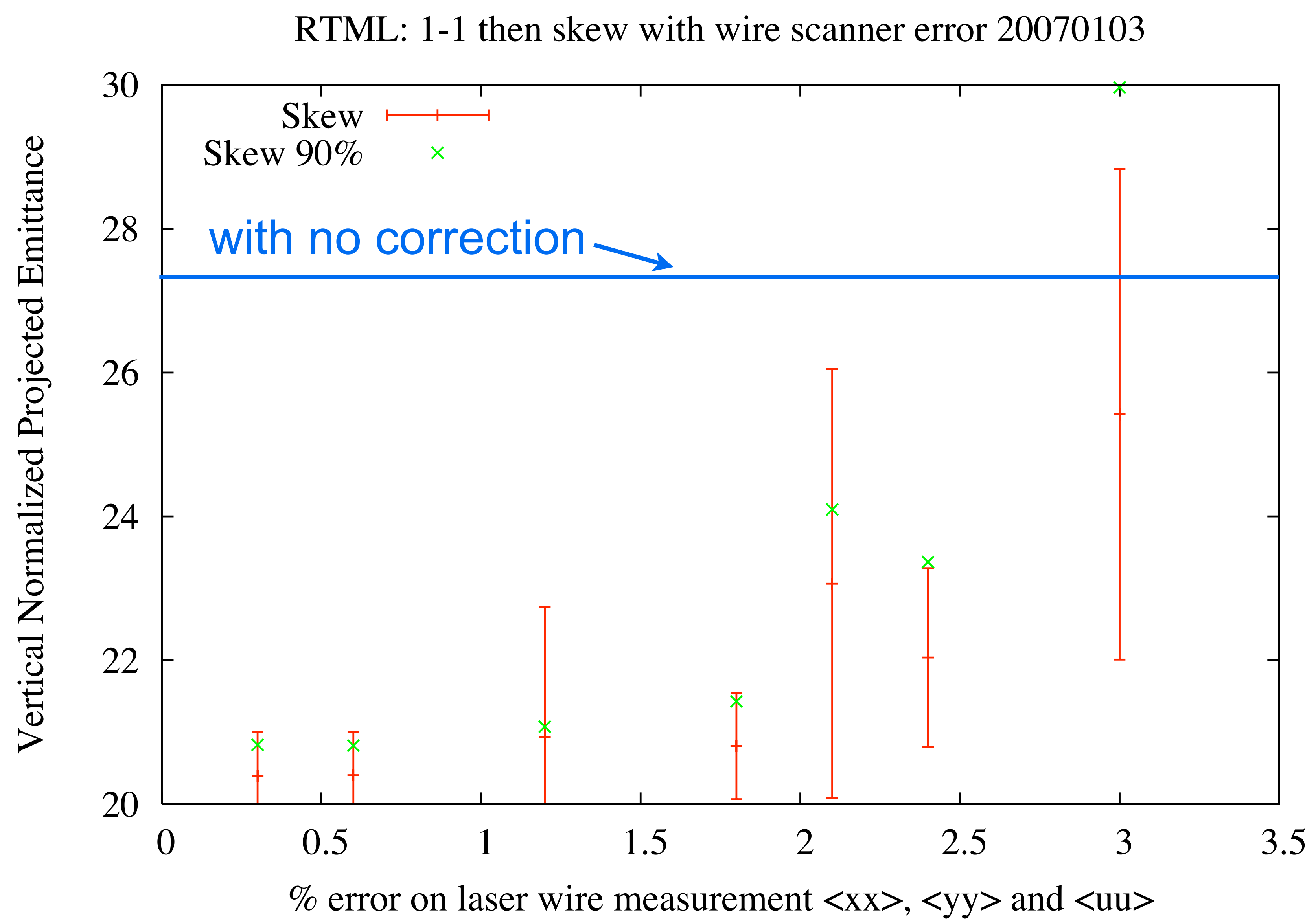


<xy> is better

- Using the <xy> measurement appears to work better
- This is in the absence of measurement errors and other sources of emittance.
- If those were added in, I would guess the situation would only be worse.
- In principle optimizing off of <yy> should work. It just appears to be more difficult.
  - **I suspect it's due to two causes:**
    - More complex function space.
    - Not optimizing to zero measurement
      - <xy> goes to 0.0 but <yy> goes to nominal value
- Keep in mind that optimizing on <yy> should work, it just appears to be more difficult

Including wire scanner errors

- Included error on wire scanner <xx>, <yy>, <uu>
- Error on <xy> will about 1.73 times this error.
- About 2% error before appreciable degradation in performance.
  - This is tight!
- This data while using optimizer
  - might work better using scans since there is a fitting of a curve to the data (smoothing out the noise).
  - Just thought of this so haven't tested it yet!



Including wire scanner errors

- When using skew scans the results appear to be different when using wire scanner errors.
- Preliminary results shows that a larger measurement error may be used.
  - **Just requires more iterations to converge than no errors.**

Conclusions

- Global skew correction can be tricky and doesn't work well in the presence of other global emittance corrections
  - Simple skew scans doesn't work in this case
  - Need to use non-linear optimizer
- Simple skew scans will work for a local skew correction
- Optimizing off of <xy> works much better than <yy>
  - The other wire stations can be added in without changing the optics of current RTML design
- Tolerances on wire scanner measurement errors appears to be tight
  - Even tighter if performing emittance measurement (per Woodely & Emma)