Adaptive Alignment
&
Ground Motion

Kirti Ranjan, Nikolay Solyak, Valentine Ivanov
Fermilab

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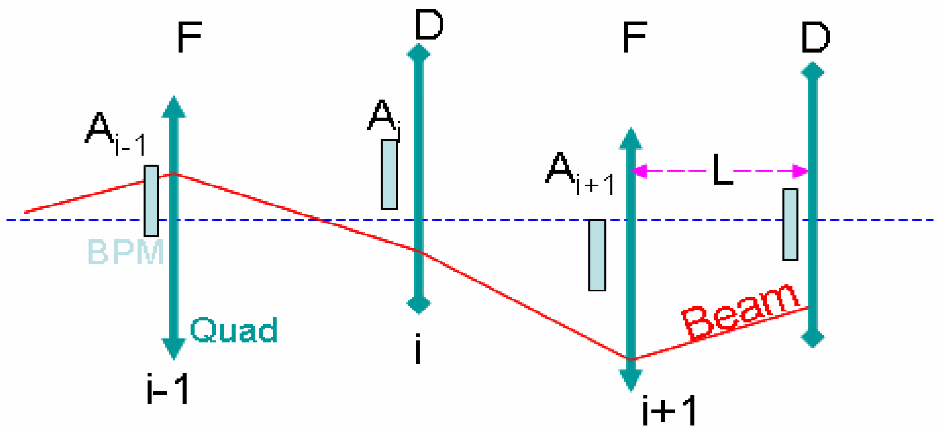
Overview

- ✓ Adaptive Alignment (AA)– Basic Principle
- ✓ AA
  - ➢ Single Quad Misalignment
  - ➢ Random Quad Misalignments
  - ➢ Sensitivity - BPM Offset, BPM resolution etc.
- ✓ Ground Motion in LIAR
  - ➢ AA in Perfect Lattice
  - ➢ AA in Dispersion Free Steered Lattice
  - ➢ Effect of BPM resolution on AA
- ✓ Lucretia – DFS Implementation
- ✓ Summary

Adaptive Alignment (AA)– Basic Principle



✓ Proposed by V.Balakin in 1991 for VLEPP project

✓ **"local" method**: *BPM readings (A_i)* of only 3 (or 5 or so on) neighboring quads are used to determine the necessary shifting of the central quad (Δy_i).

$$\Delta y_i = conv * [A_{i+1} + A_{i-1} - A_i * \{2 + K_i . L . (1 - \frac{\Delta E}{2E})\}]$$

conv : Speed of convergence of algorithm
A_i : BPM reading of the central quad and so on
K_i : Inverse of quad focusing length
L : Distance between successive quads (assuming same distance b/w quads)
ΔE : Energy gain between successive quads
E : Beam Energy at central quad

New position of quad & BPM:

$$y_i = y_i - \Delta y_i$$

✓ The procedure is iteratively repeated

Experimental Test

✓ Linac 96, V. Alexandrov, V. Balakin, A. Lunin at FFTB

✓ This algorithm smoothes the sharp thrusts very fastly, and more slowly - the fluent ones.

✓ Adaptive alignment is sensitive only to the real displacement of quads, but not to the beam oscillations.

Before AA (BPM rms: 53µm; Δy = -12.8µm)

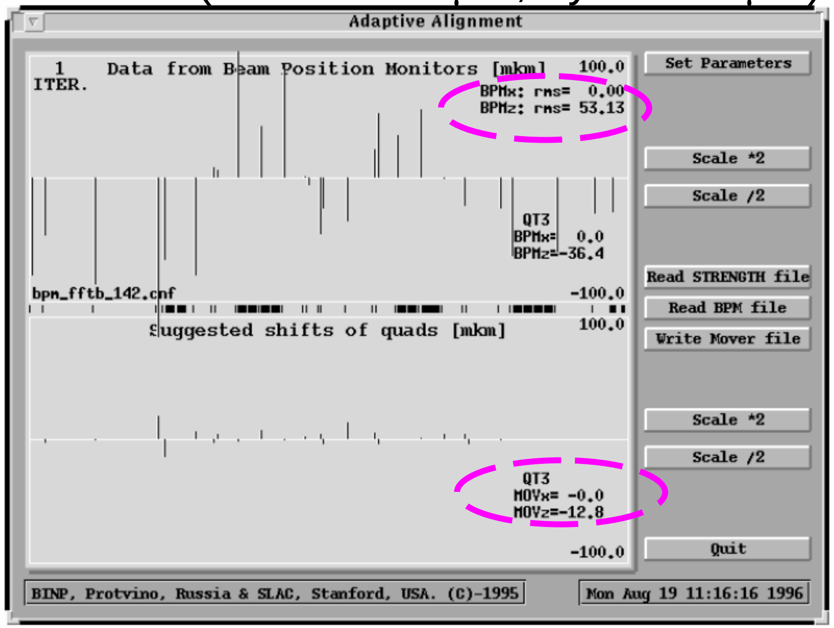


Fig. 1 Vertical component of the beam oscillations (upper part of the picture) and suggested shifts of quads (lower part of the picture) before the Adaptive Alignment.

7th AA iteration (BPM rms: 6µm; Δy = -1.4µm)

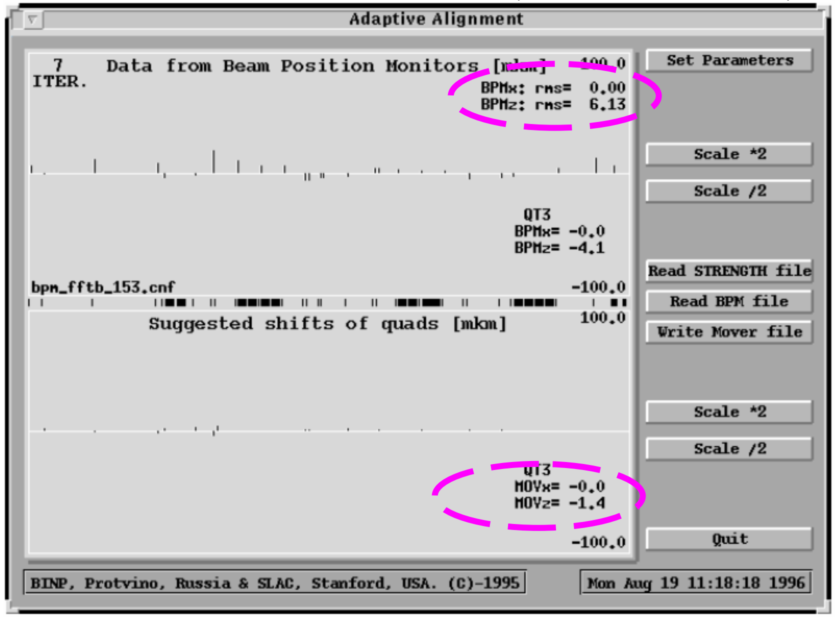


Fig. 2 Vertical component of the beam oscillations (upper part of the picture) and suggested shifts of quads (lower part of the picture) after 7 iterations of the Adaptive Alignment.

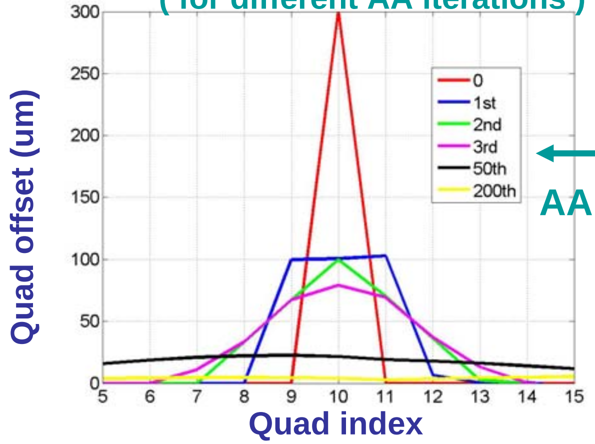
✓ After the procedure of AA the beam reduced its oscillations about 10 times. The suggested shifts are about zero. It means that the quads are in practically straight line.

Single Quad Misalignment (1/2)

- **ILC BCD Like Lattice (approx. 240 Quads/BPMs, distributed during ILC LET meeting)– Straight**

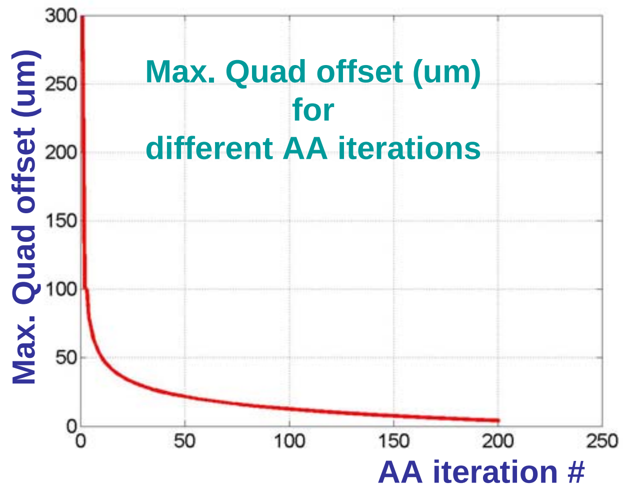
– Only one quad at 10th position is vertically misaligned by 300µm (BPMs are perfectly aligned with Quads, and have perfect resolution)

Quad y-position (um) vs. Quad index
(for different AA iterations)



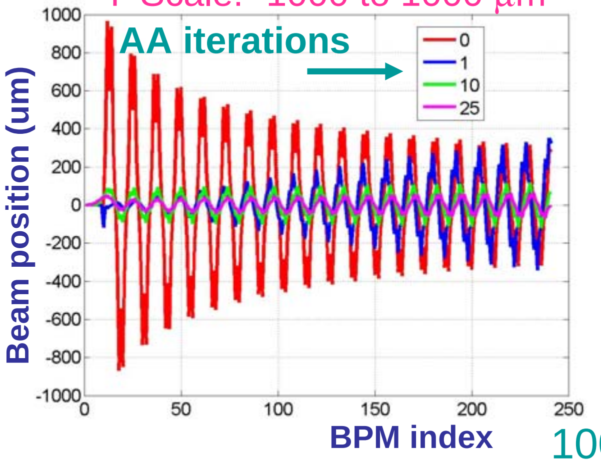
AA iterations

AA conv. = 0.33

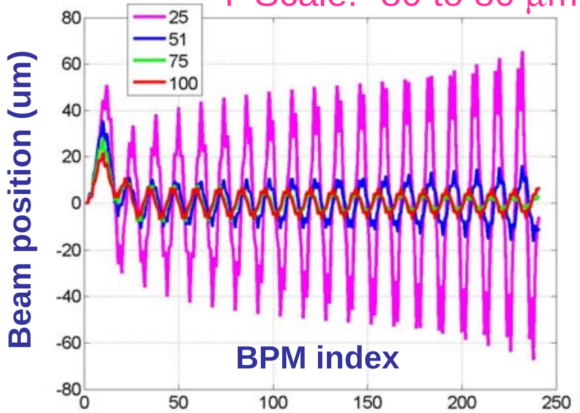


Beam y-position (µm) vs. BPM index (for different AA iterations)

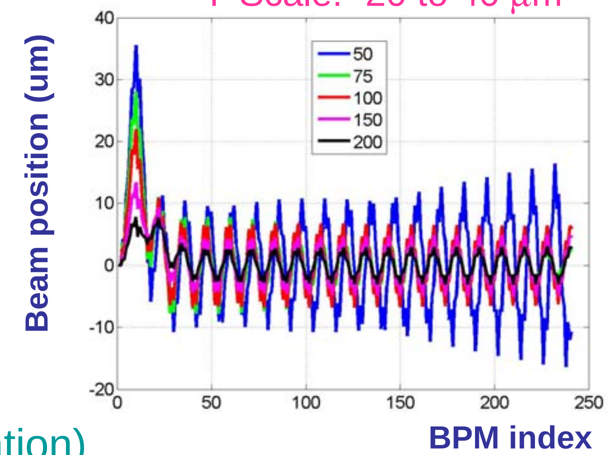
Y-Scale: -1000 to 1000 µm



Y-Scale: -80 to 80 µm

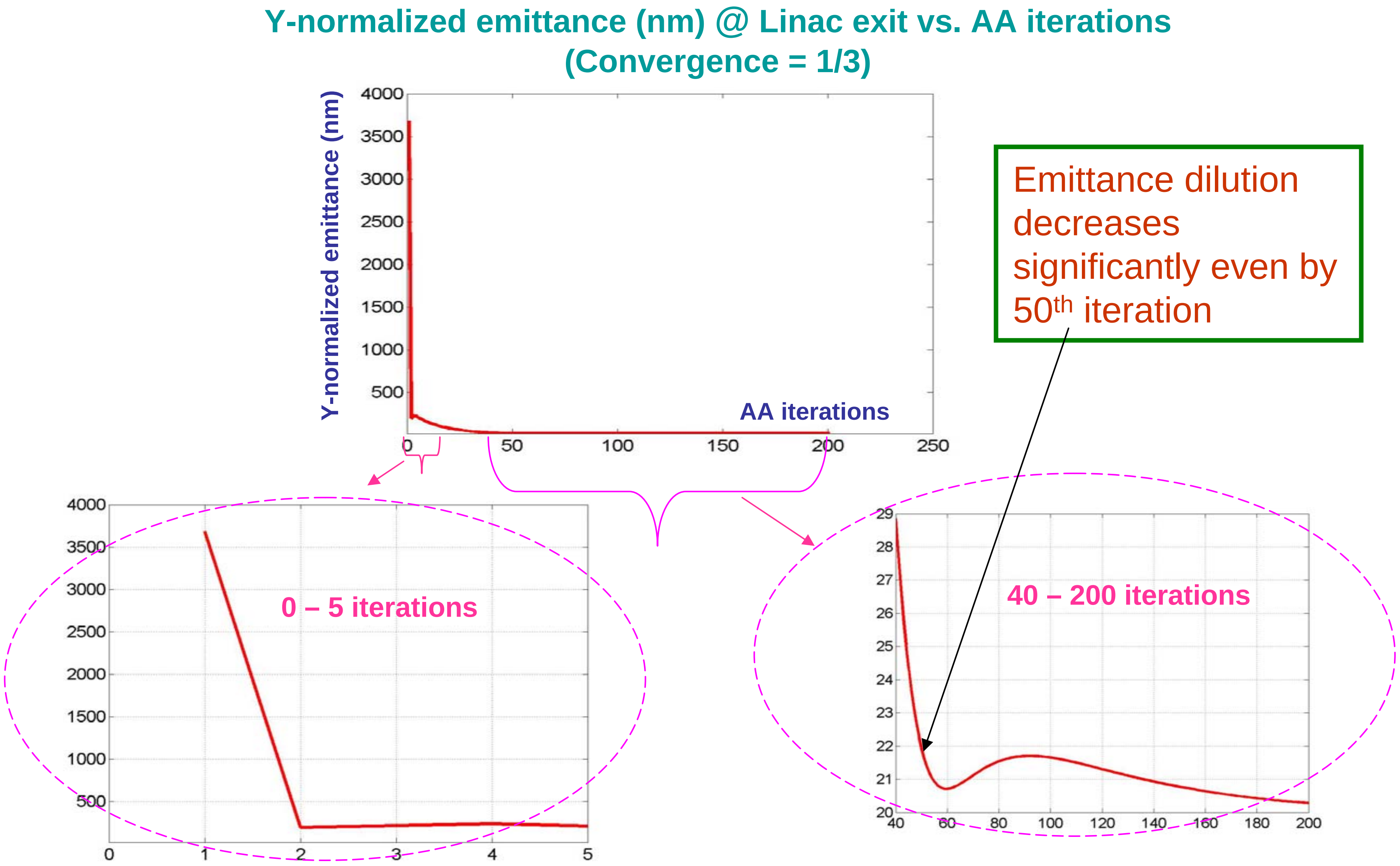


Y-Scale: -20 to 40 µm



1000µm (initial) → 10µm (200th iteration)

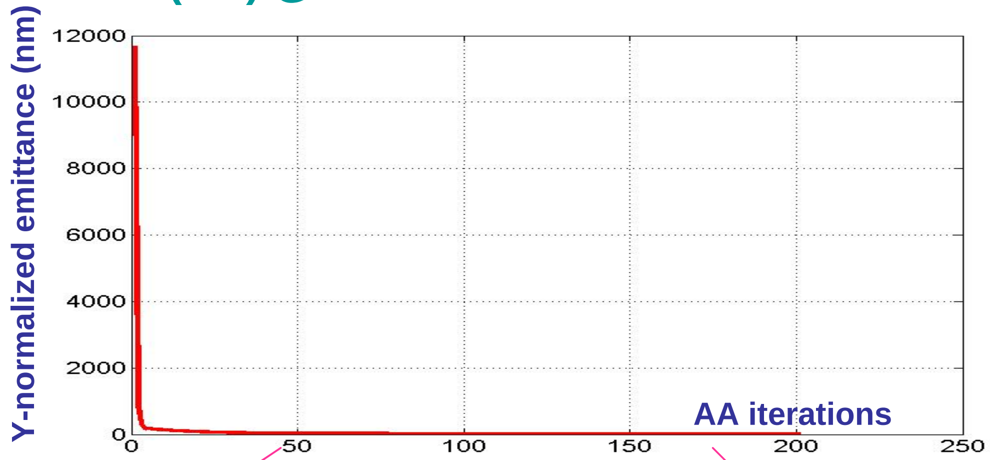
Single Quad Misalignment (2/2)



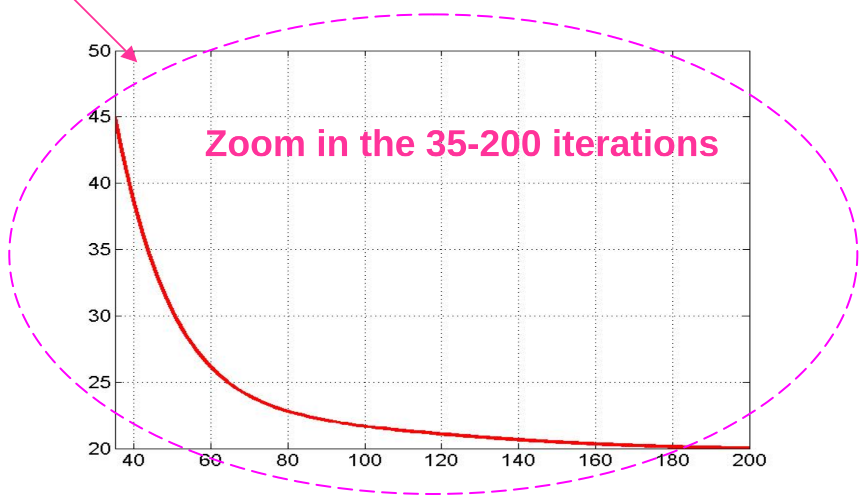
Random Quad Misalignments (1/3)

- 100 FODO cells, straight lattice
- Misalignments: Random Quad offset=100μm RMS; BPM aligned with Quads; No other errors

Y-emittance (nm) @ Linac exit vs. No. of AA Iterations (Conv. = 1/3)

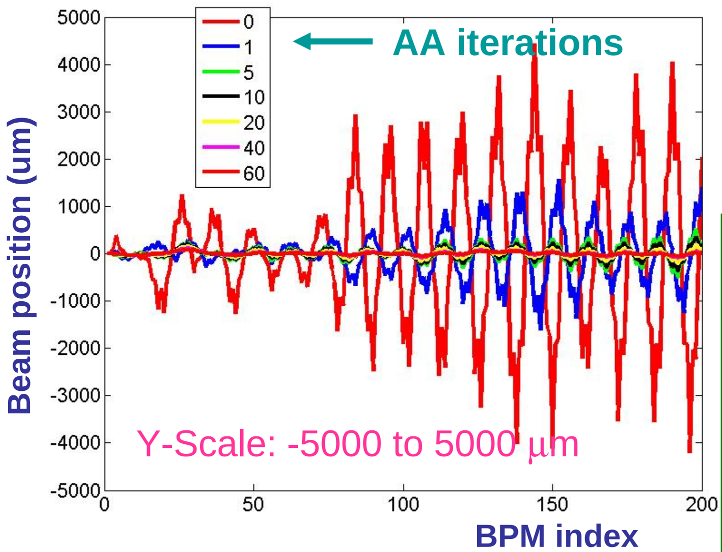


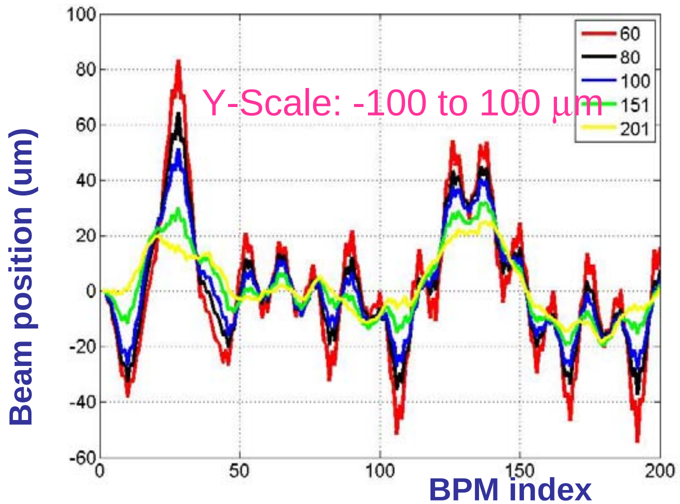
Emittance dilution decreases significantly for random quad misalignments after AA



Random Quad Misalignments (2/3)

Absolute Beam y-position (um) vs. BPM index after different AA iteration steps

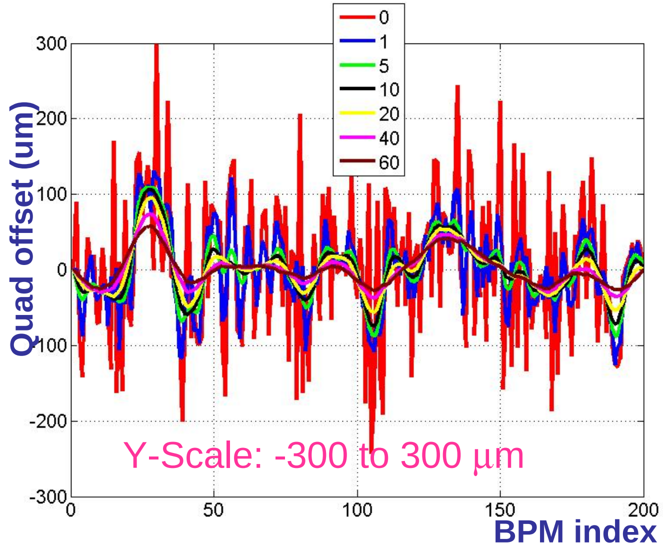


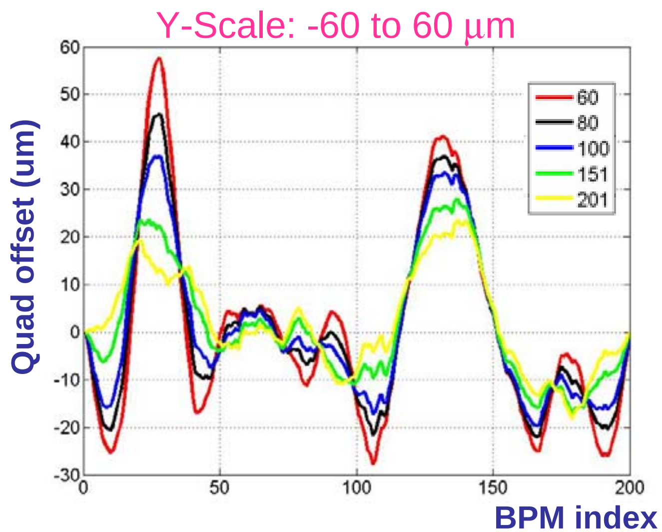


1. Beam oscillations go down from 4000um to 30um

2. Quad misalignments go down from 300um to 25um

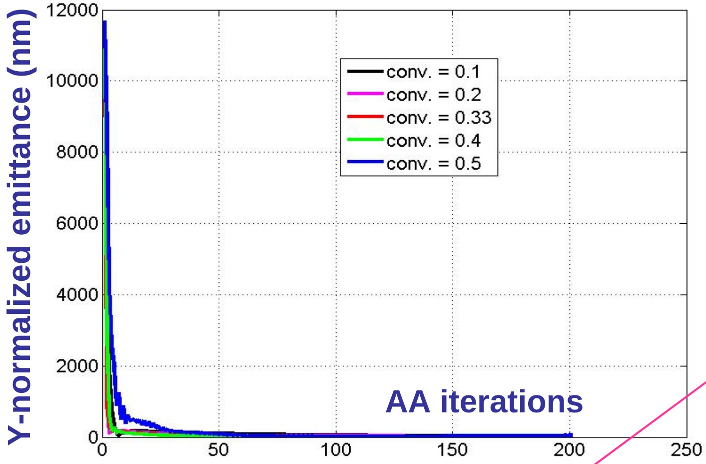
BPM or Quad y-position (um) vs. BPM index after different iteration steps



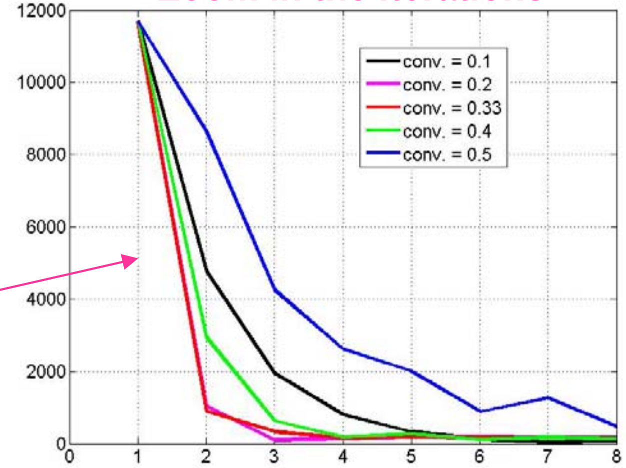


CONVERGENCE

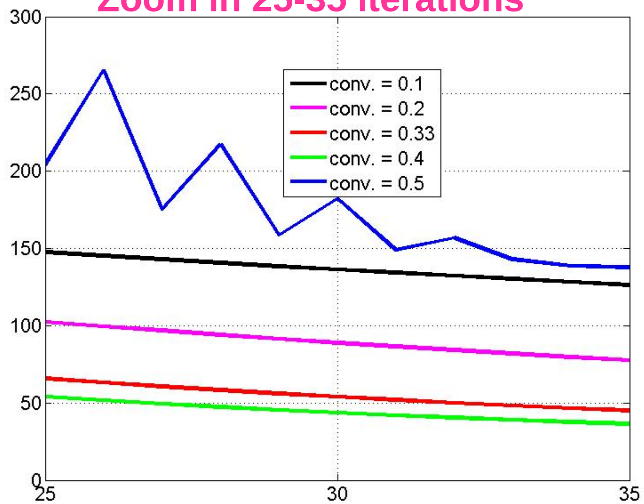
Y-emittance (nm) @ Linac exit vs. No. of AA Iterations for different conv. values



Zoom in the iterations

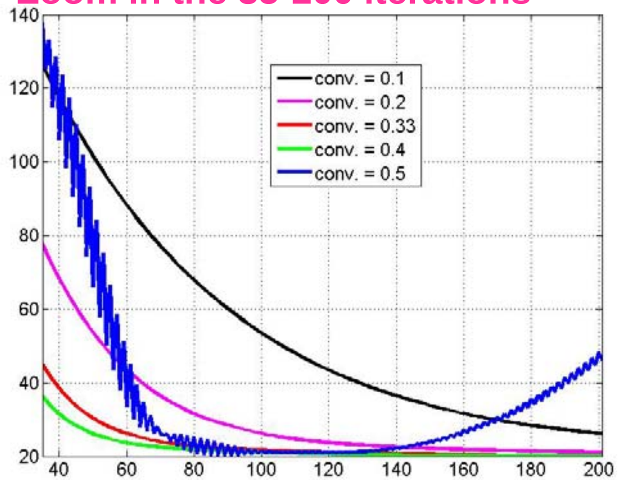


Zoom in 25-35 iterations



- Smaller conv. speed value takes more iterations to converge
- Solution doesn't converge for conv.>=0.5

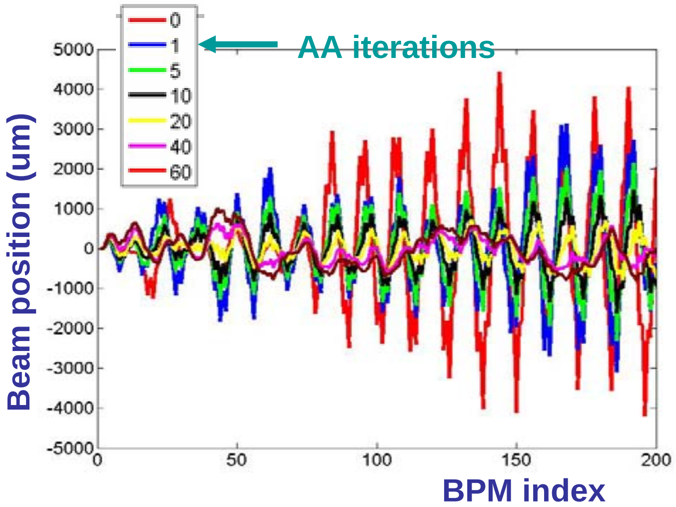
Zoom in the 35-200 iterations

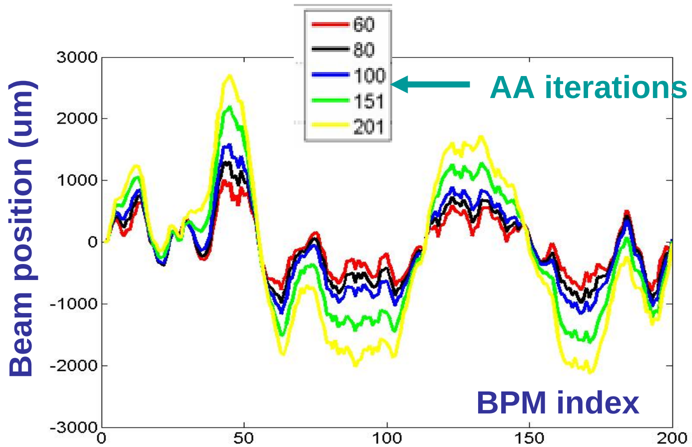


Random BPM Misalignments w.r.t. Quad (1/2)

- 100 FODO cells, straight lattice
- Misalignments: Random Quad offset = 100 μm RMS ; BPM offsets w.r.t. Quad = 100 μm RMS

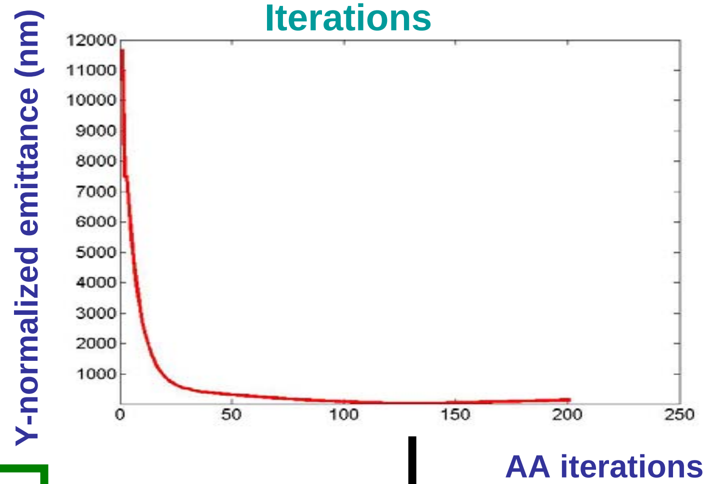
Absolute Beam position (um) vs. BPM index for different AA iteration steps



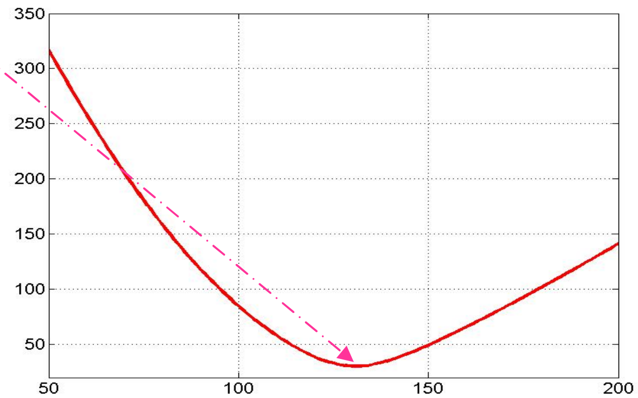


AA getting confused because of large BPM offsets

Y-emittance (nm) @ Linac exit vs. No. of AA Iterations

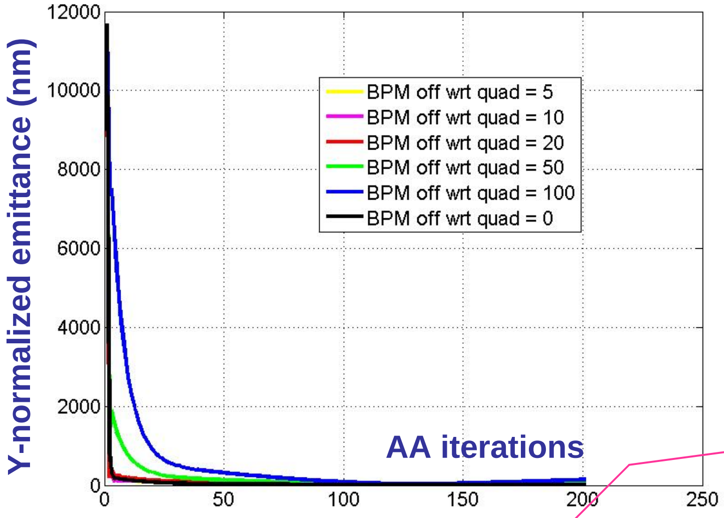


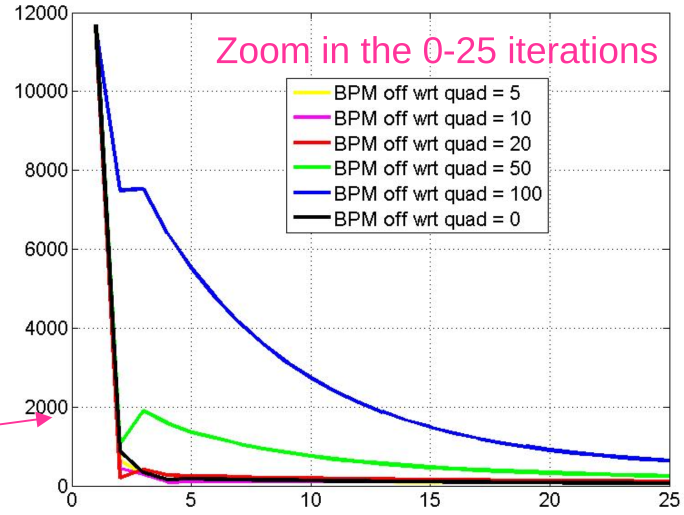
Zoom in the 50-200 iterations



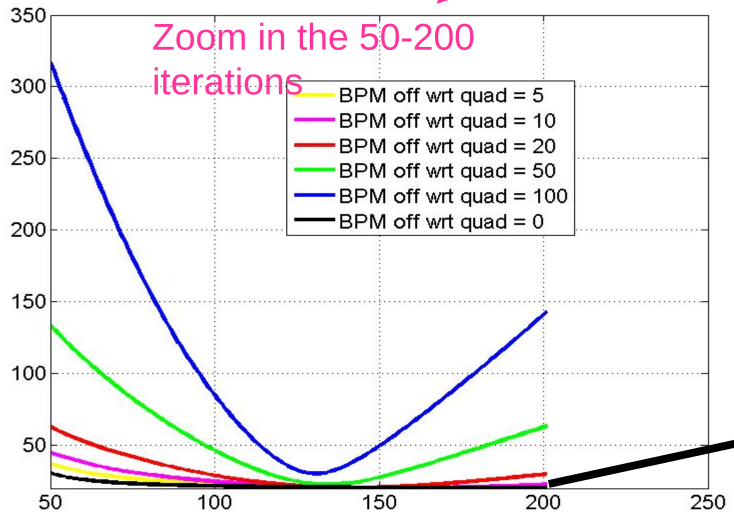
Random BPM Misalignments w.r.t. Quad (2/2)

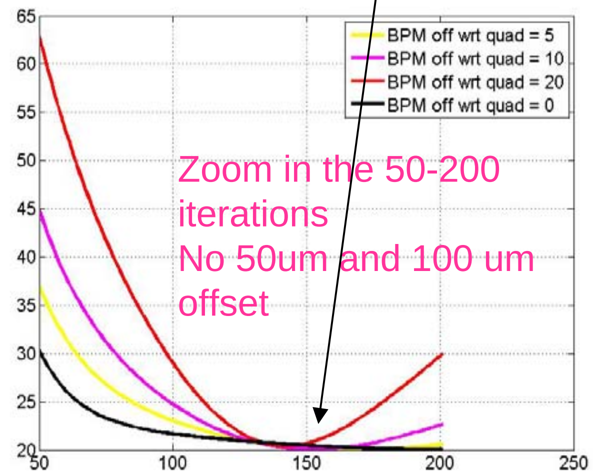
Y-emittance (nm) @ Linac exit vs. No. of AA Iterations for different BPM offsets wrt Quads





The Effect of AA divergence is less pronounced for smaller BPM offsets wrt Quads

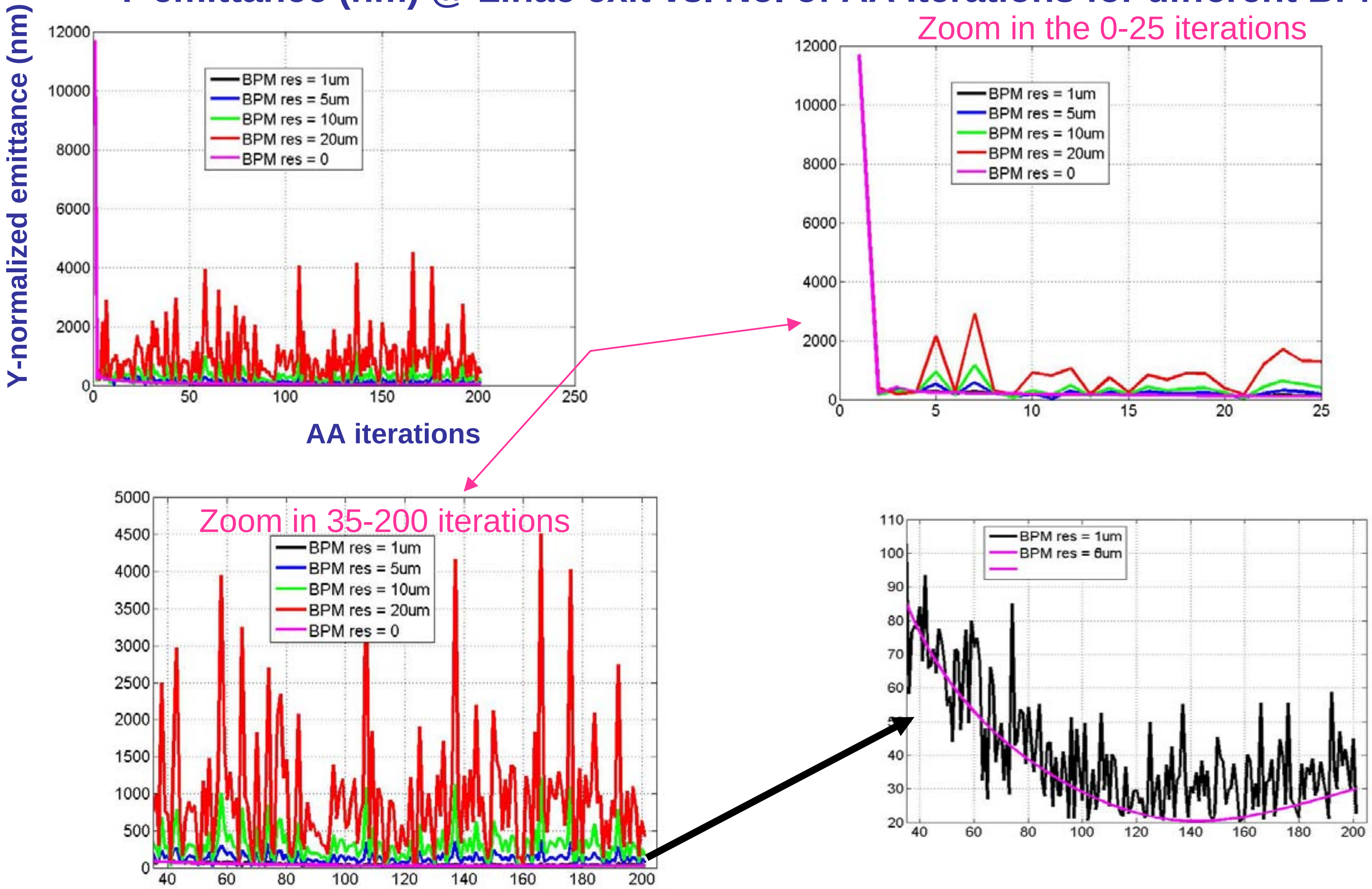




BPM Resolution

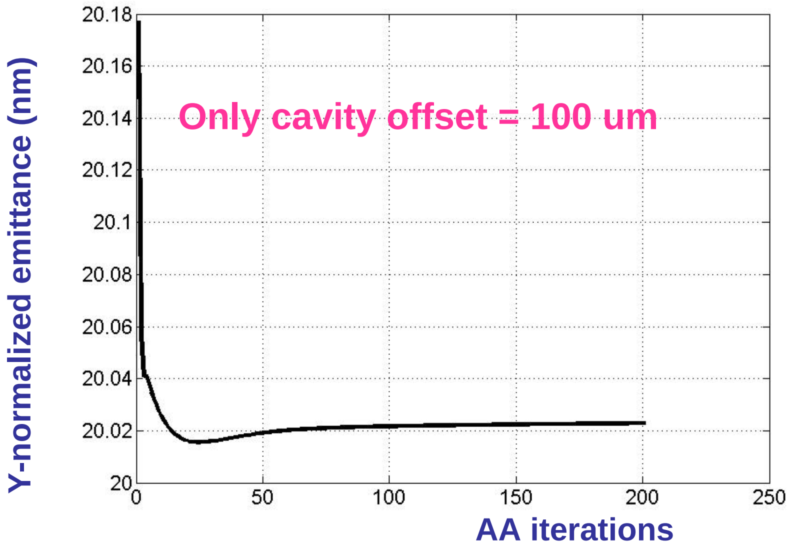
- 100 FODO cells, straight lattice; Misalignments: Random Quad offset = 100 μm RMS ; BPM offsets w.r.t. Quad = 20 μm RMS; BPM resolution is varied

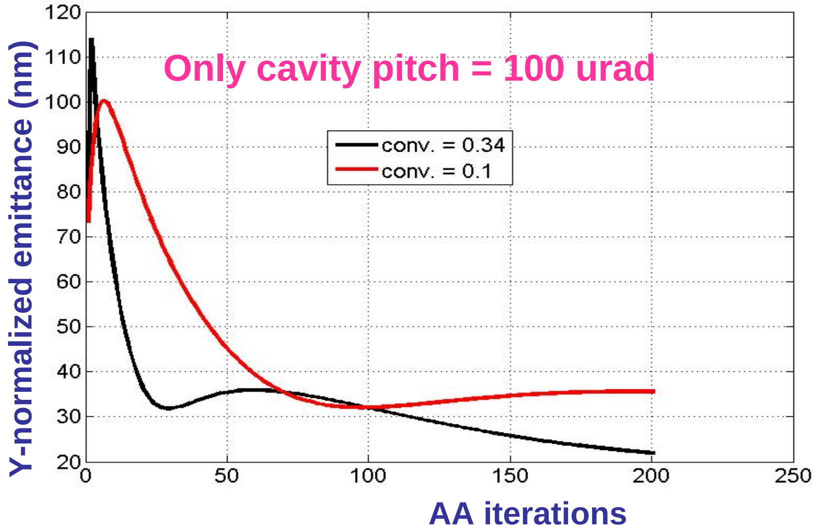
Y-emittance (nm) @ Linac exit vs. No. of AA Iterations for different BPM resolution



Other Effects

Y-emittance (nm) @ Linac exit vs. No. of Iterations





Cavity offsets are OK; but large values of **Cavity pitch** and **BPM offsets wrt Quad** confuses AA. Also sensitive to **BPM resolution.**

Ground Motion (GM) in LIAR

Recent developments of LIAR Simulation Code, PT, Hendrickson, Seryi, Stupakov, SLAC, EPAC 2002

- ✓ Modeled with a 2-D Power Spectrum P(w,k)

$$P(\omega,k) = \frac{A_d}{\omega^2 k^2}\left(1-\cos(kB_d/A_d/\omega^2)\right) + \sum_i D_i \cdot U_i.$$

$$U_i = \frac{2}{\sqrt{(\omega/v_i)^2 - k^2}}, \quad |k| \le \omega/v_i,$$
$$= 0, \quad |k| > \omega/v_i,$$
$$D_i = \frac{a_i}{1+[d_i(\omega-\omega_i)/\omega_i]^4}.$$

Diffusive "ATL" ground motion　　　Isotropic plane wave motion

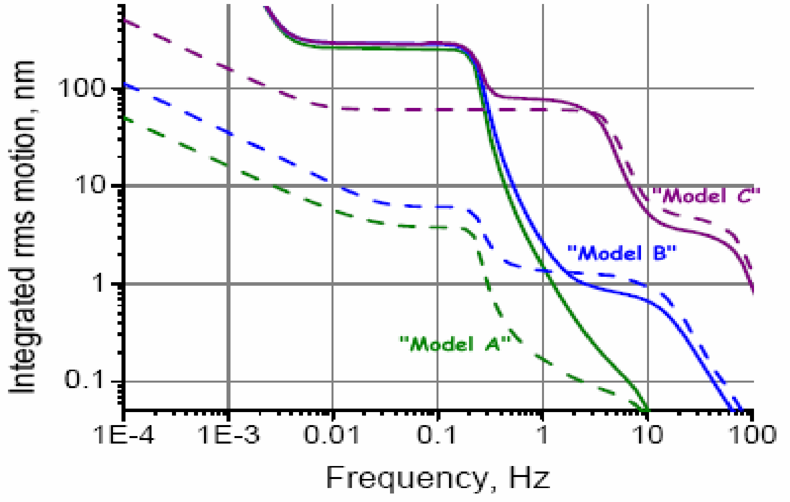


Figure 1: The integrated absolute ground motion spectra (solid lines) and the integrated relative motion of 2 objects separated by 50 m (dashed lines)

Eq. 1 describes wavelike ground motion where the power spectrum falls off with the inverse fourth power of frequency from each of a series of peaks; the parameters a_i, ω_i, d_i, v_i correspond to the amplitude, frequency, and width of the peak and the frequency-velocity relation of the waves, respectively. The parameter A_d is the amplitude of the diffusive ground motion, which falls as the inverse square of frequency. Note that, since the diffusive motion falls more slowly than wavelike motion, this model would tend to predict that the relative motion of two separated objects will, for some frequencies, exceed their absolute motion. In order to prevent this, an ATL correction term, B_d, is added.

- ✓ Different GM Models in LIAR

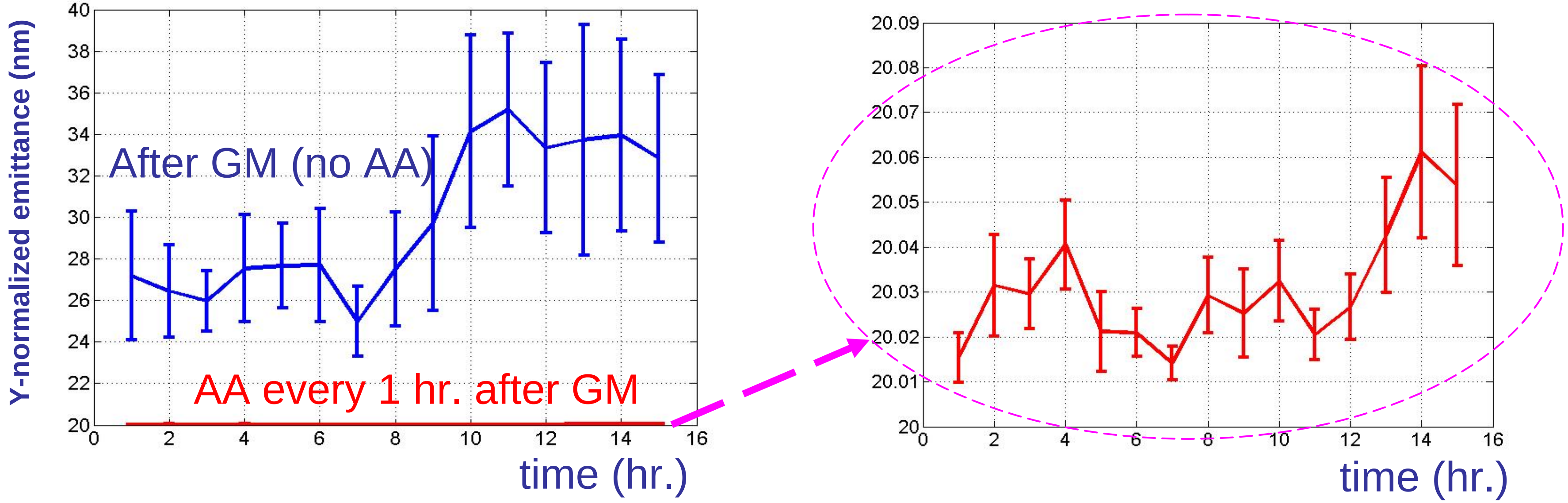
GM – Effect on Perfect Lattice

- Perfectly straight lattice – ILC BCD Like Straight Lattice (240 Quads)
- 10 different GM seeds (GM – Model 'C') A [m**2/m/s] : 1.00000E-17

In each seed

- GM of 15 hrs. in step of 1 hr.
- When AA incorporated: AA of 100 iterations after every one hr. (perfect BPMs, conv = 0.2, no GM during AA iterations)

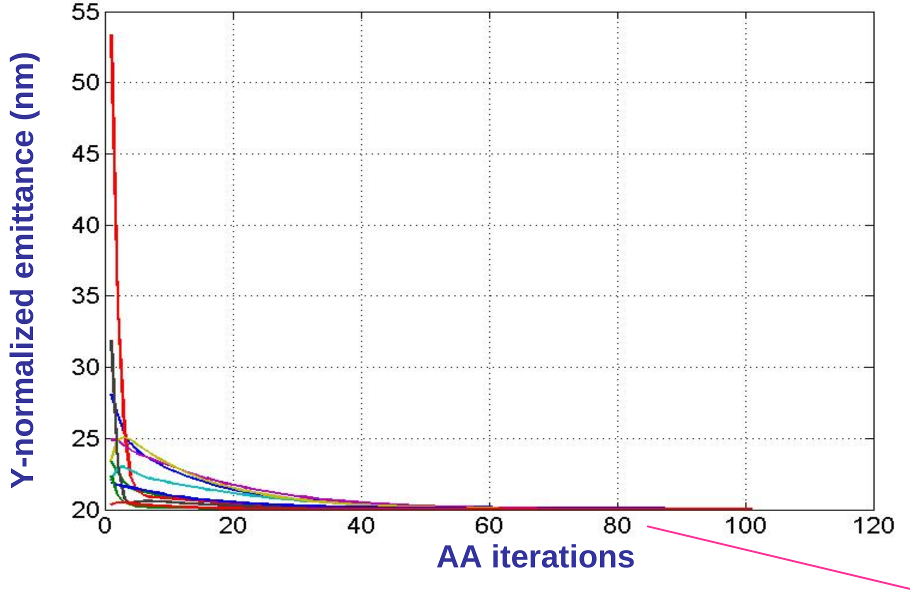
Y-emittance (nm) @ Linac exit vs. time (hrs.)
Mean of 10 random GM seeds

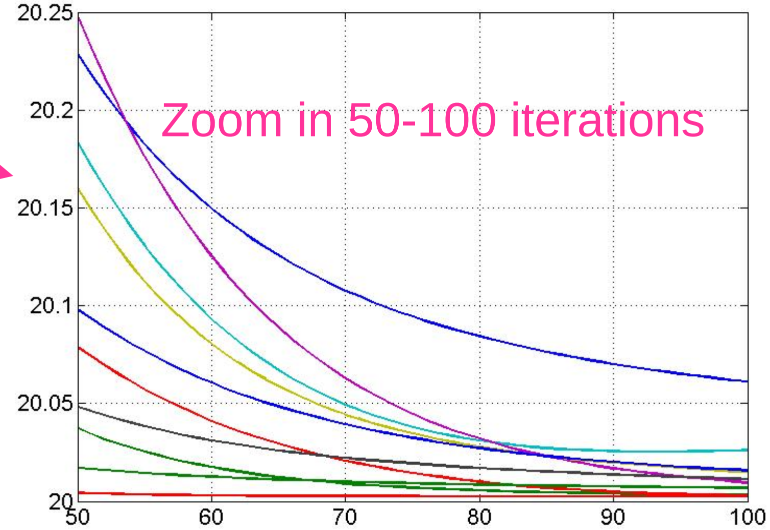


AA helps in keeping emittance dilution to minimum even after 1 hour of GM, which otherwise causes reasonable emittance growth

GM – Effect on Perfect Lattice

Y-emittance (nm) @ Linac exit vs. AA iteration for all 10 individual seeds



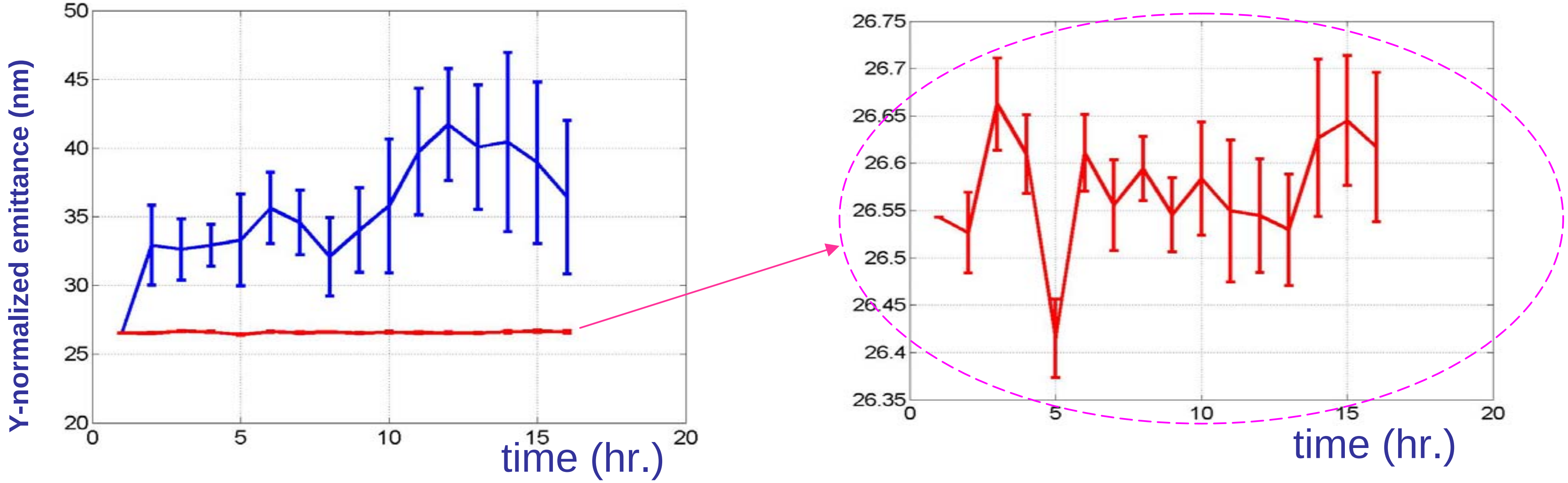


In all the seeds, AA converges towards small values of emittance

GM – Effect on Dispersion Free (DF) Steered Lattice

- ILC BCD Like Straight Lattice - Initial elements (quad, bpm, cavity, ycor) settings are those obtained after one particular DFS iteration. All errors (except BPM resolution) as in DFS
- 10 different GM seeds (GM – Model –C); In each seed
- GM of 15 hrs. in step of 1 hr.
- When AA incorporated: AA of 100 iterations after every one hr. (perfect BPMs, conv = 0.2)

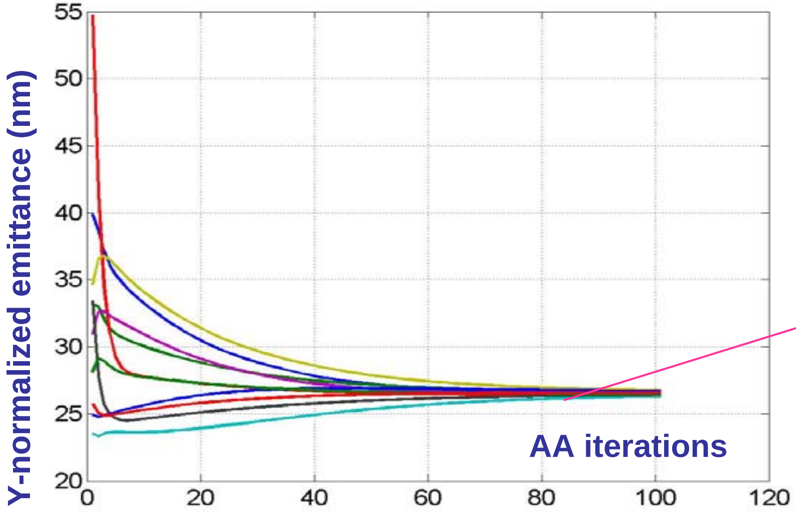
Y-emittance (nm) @ Linac exit vs. time (hrs.)
Mean of 10 random GM seeds

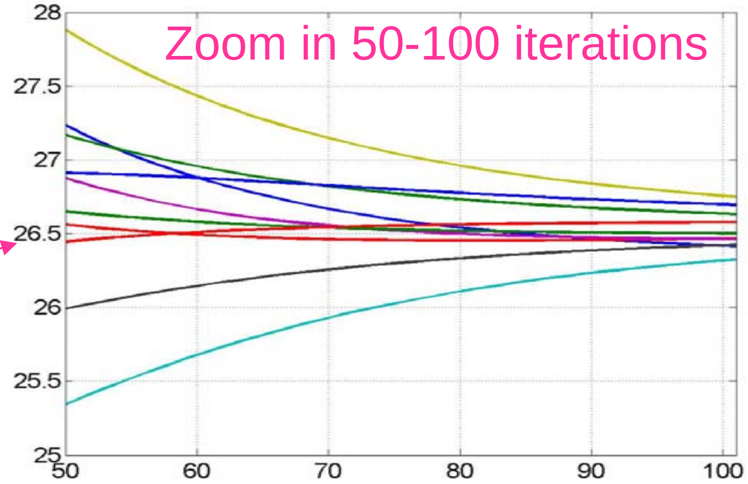


Starting from DF steered Lattice, AA helps in keeping emittance dilution to minimum (obtained after DFS) after 1 hour of GM, which otherwise causes reasonable emittance growth

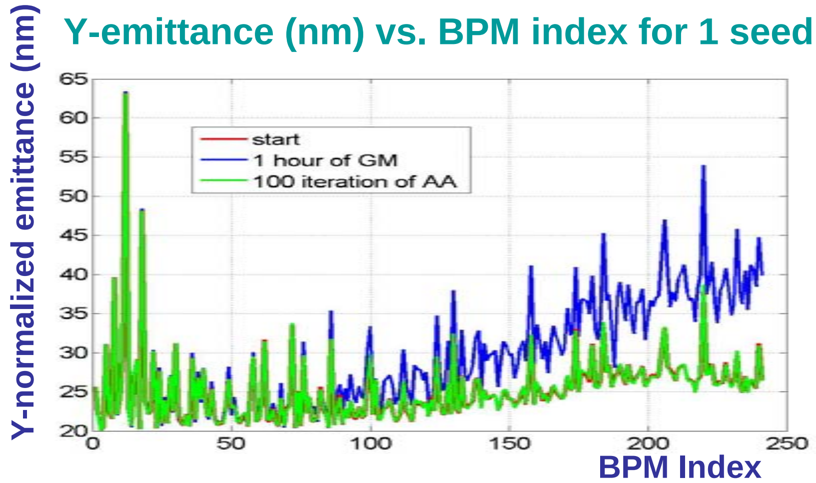
GM – Effect on Dispersion Free (DF) Steered Lattice

Y-emittance (nm) @ Linac exit vs. AA iteration for all 10 individual seeds





Y-emittance (nm) vs. BPM index for 1 seed

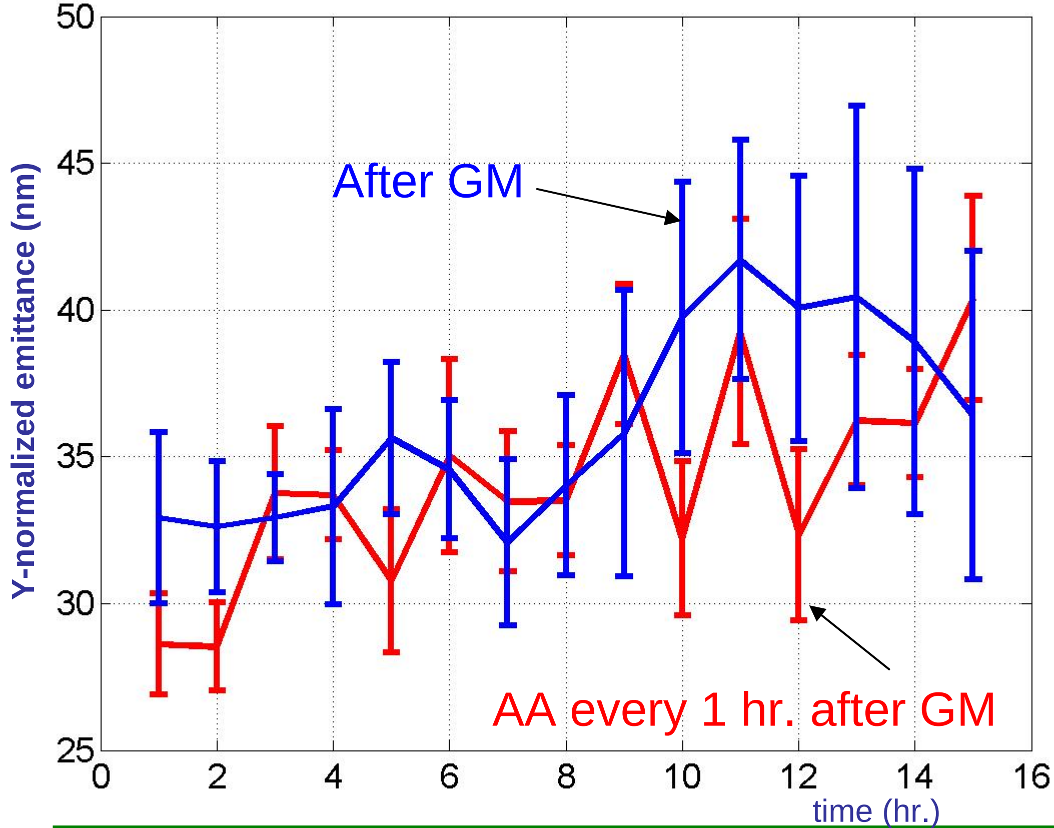


In all the seeds, AA converges towards small values of emittance

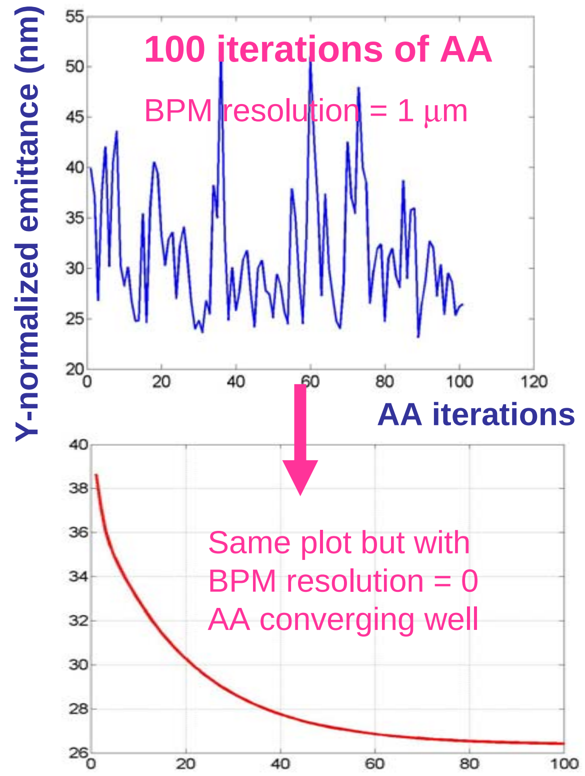
GM – Effect on Dispersion Free (DF) Steered Lattice

- DF Steered Lattice + 1 μm BPM resolution

Y-emittance (nm) @ Linac exit vs. time (hrs.)
Mean of 10 seeds



Y-emittance at the Linac exit(nm) vs. AA iterations

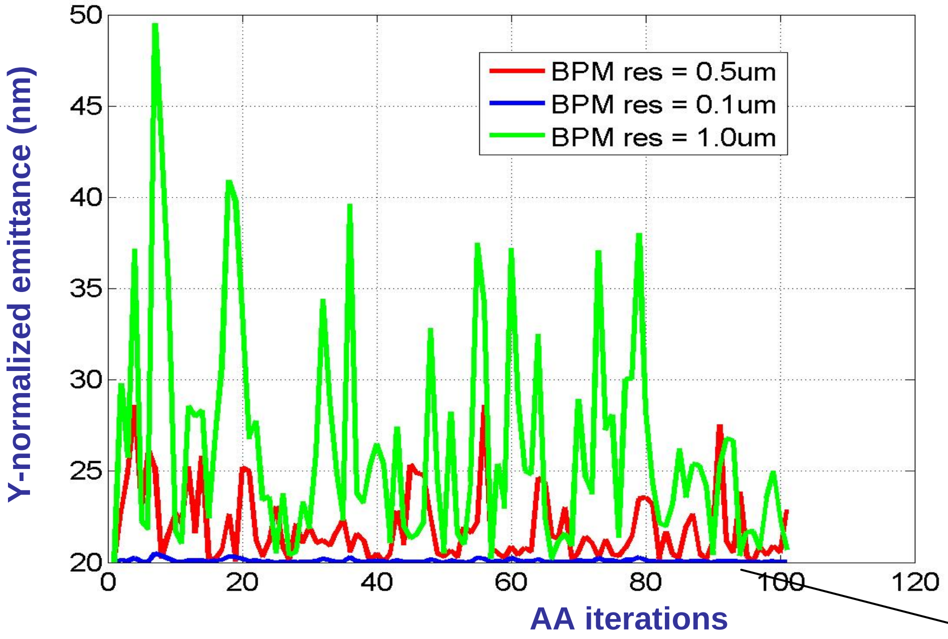


BPM resolution of even 1um plays very detrimental role on AA performance. Starting from DF steered Lattice, AA is unable to keep emittance dilution to minimum after 1 hour of GM. Similar effect in Perfect Linac also.

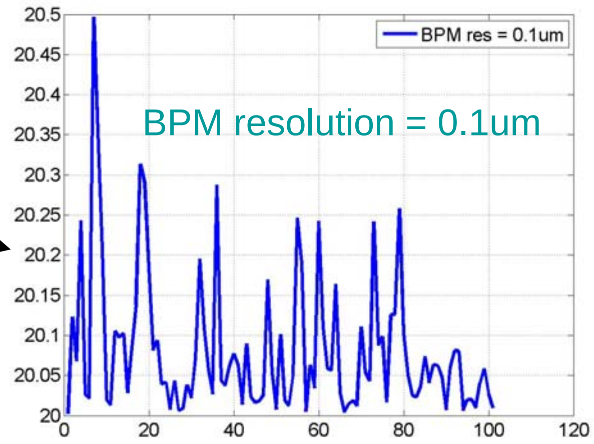
AA and BPM resolution

- ILC BCD Straight lattice: Perfect; No ground motion
- 100 iterations of AA (conv. = 0.2) just in the presence of BPM resolution

Y-emittance at the Linac exit (nm) vs. AA iterations



AA preseves the same emittance.

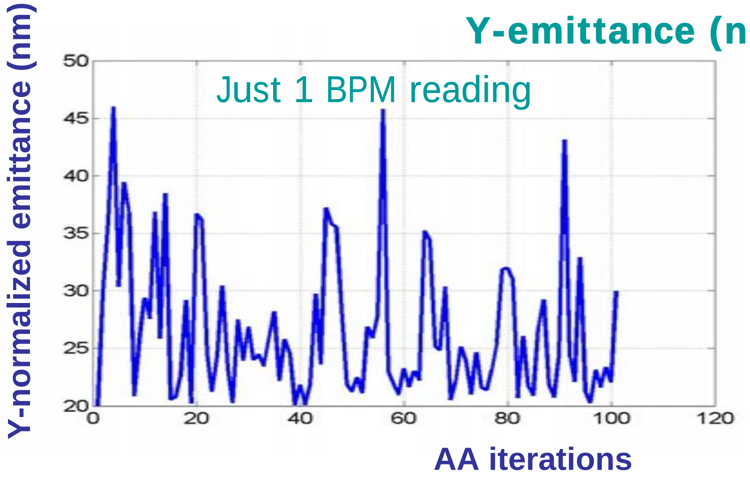


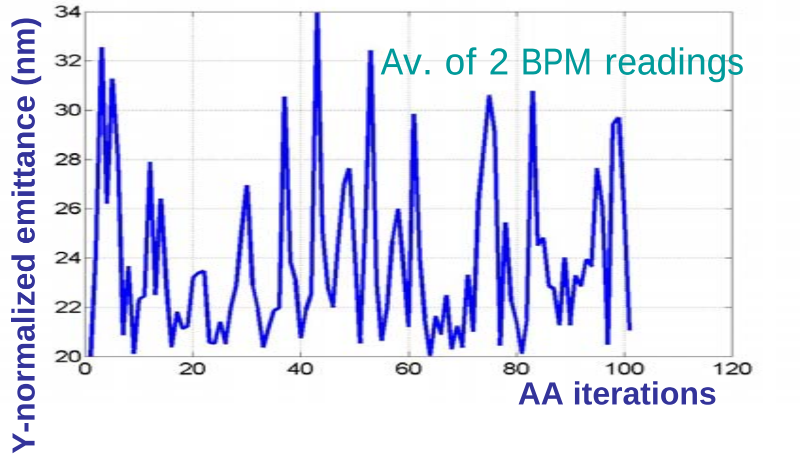
Sensitive to BPM resolution; Results o.k. for 0.1 μm
AA gets confused even for 1um BPM resolution.

AA and BPM resolution

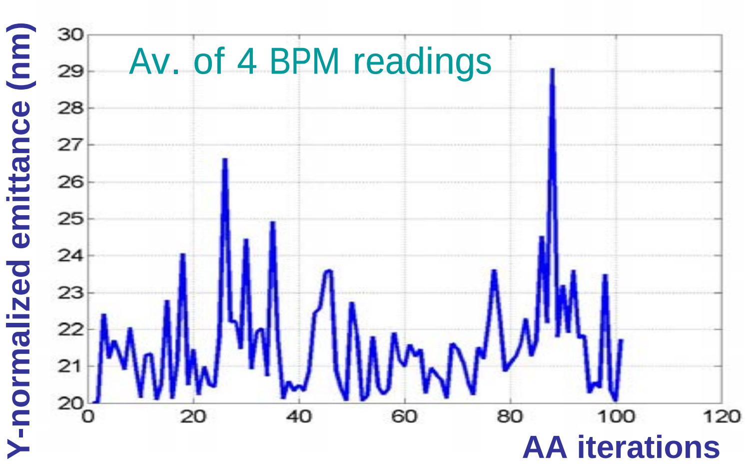
Assuming single-bunch BPM resolution to be 1um, we can average over few bpm readings for our purposes? With perfectly aligned lattice

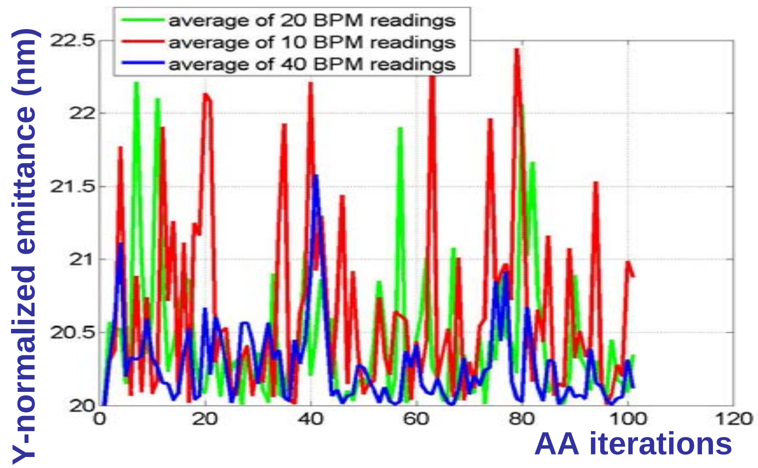
Y-emittance (nm) at the Linac exit vs. AA iterations





BPM Resolution = 1 um

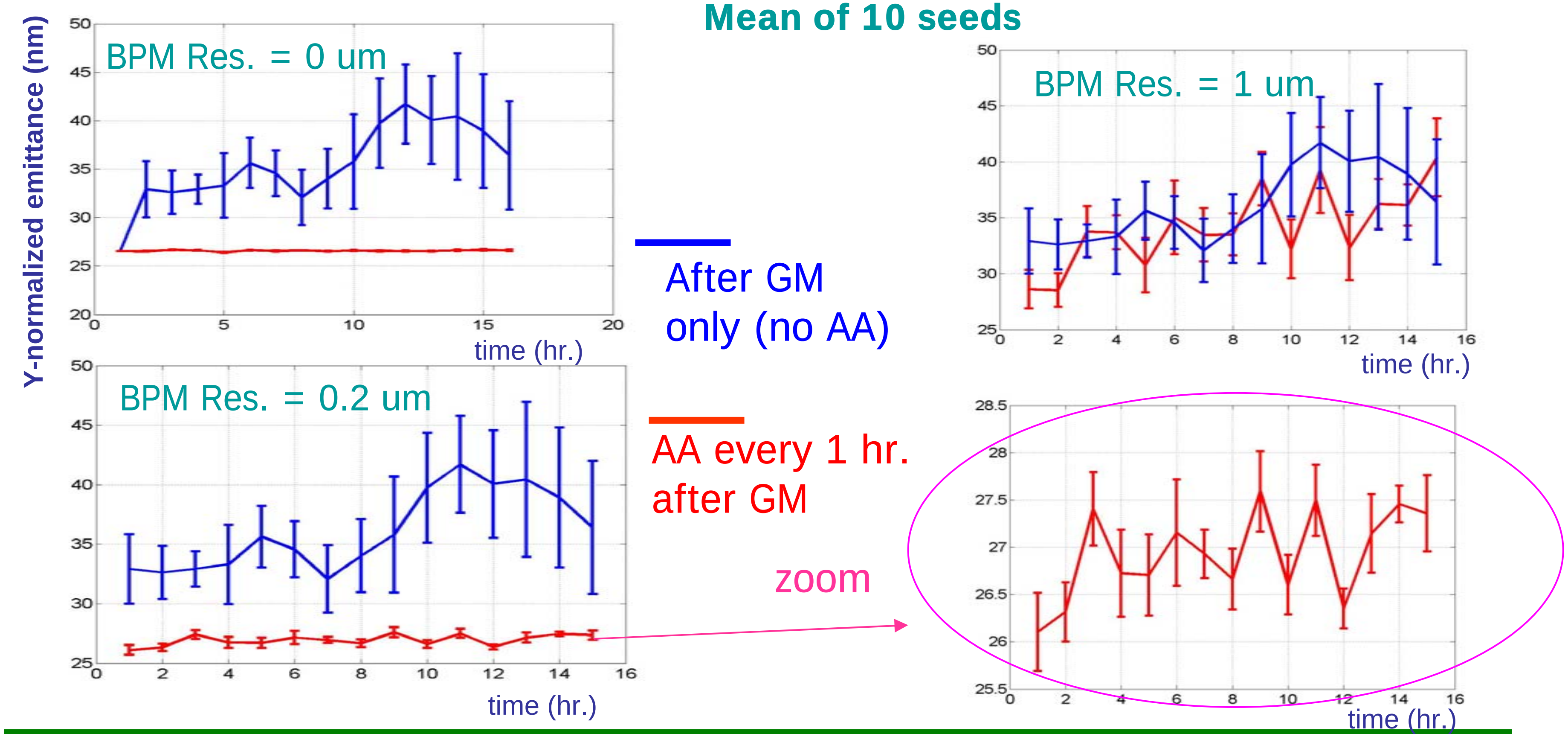




If we average over 25 bunches, we get much improved results. In ILC train there are 1000-6000 bunches in a single pulse which we can average

- Straight lattice: DF steered
- 10 different GM seeds; GM of 15 hrs. in step of 1 hr.
- When AA incorporated: AA of 100 iterations after every one hr. (convergence = 0.2)

Y-emittance (nm) @ Linac exit vs. time (hrs.)
Mean of 10 seeds

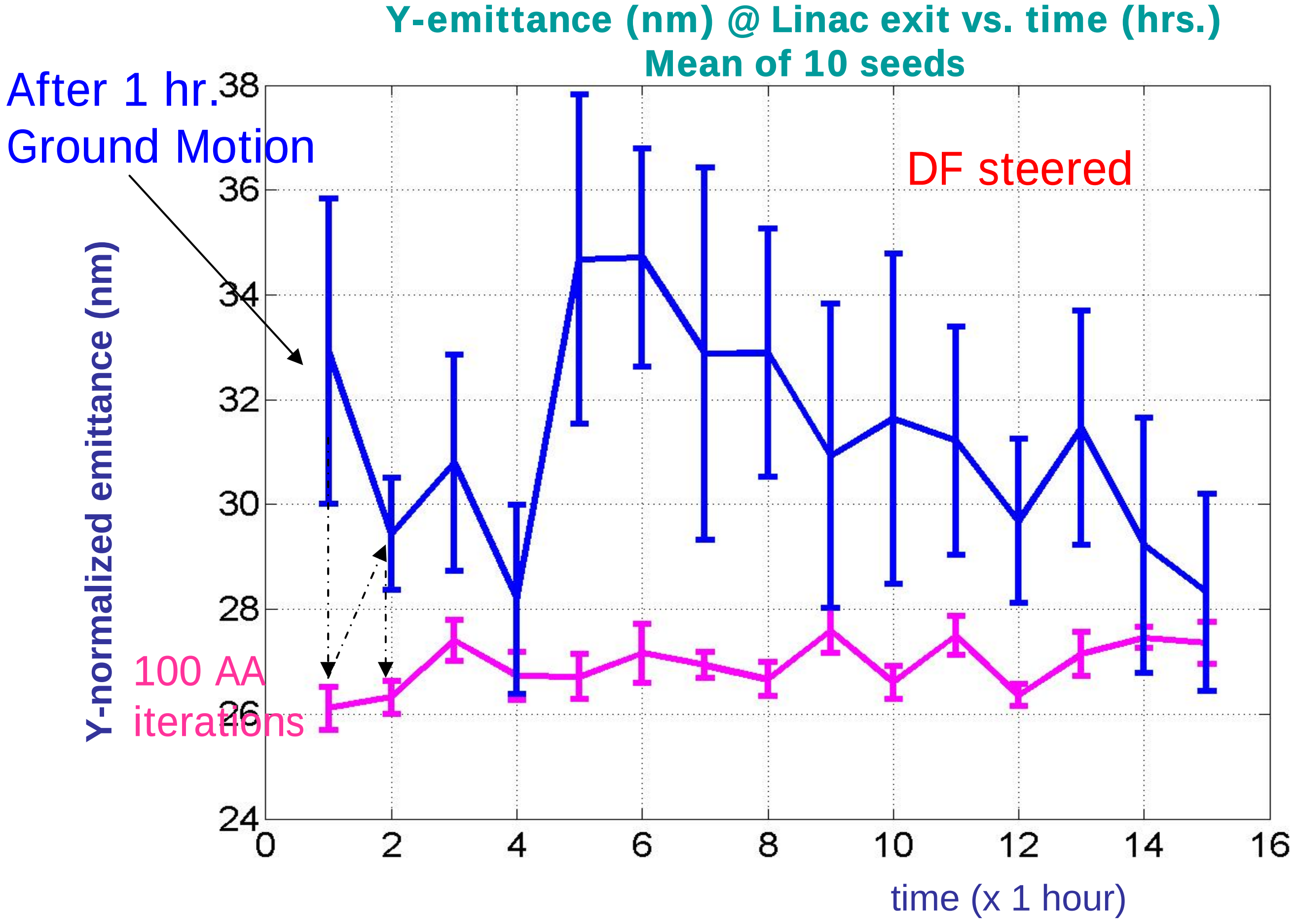


Assuming effective BPM resolution to be 0.2 μm by, say, summing over say 25 bunches, then the results from AA are much better

GM – Effect on Dispersion Free (DF) Steered Lattice

By how much amount the emittance dilution increases in an hour after 100 iterations of AA ?

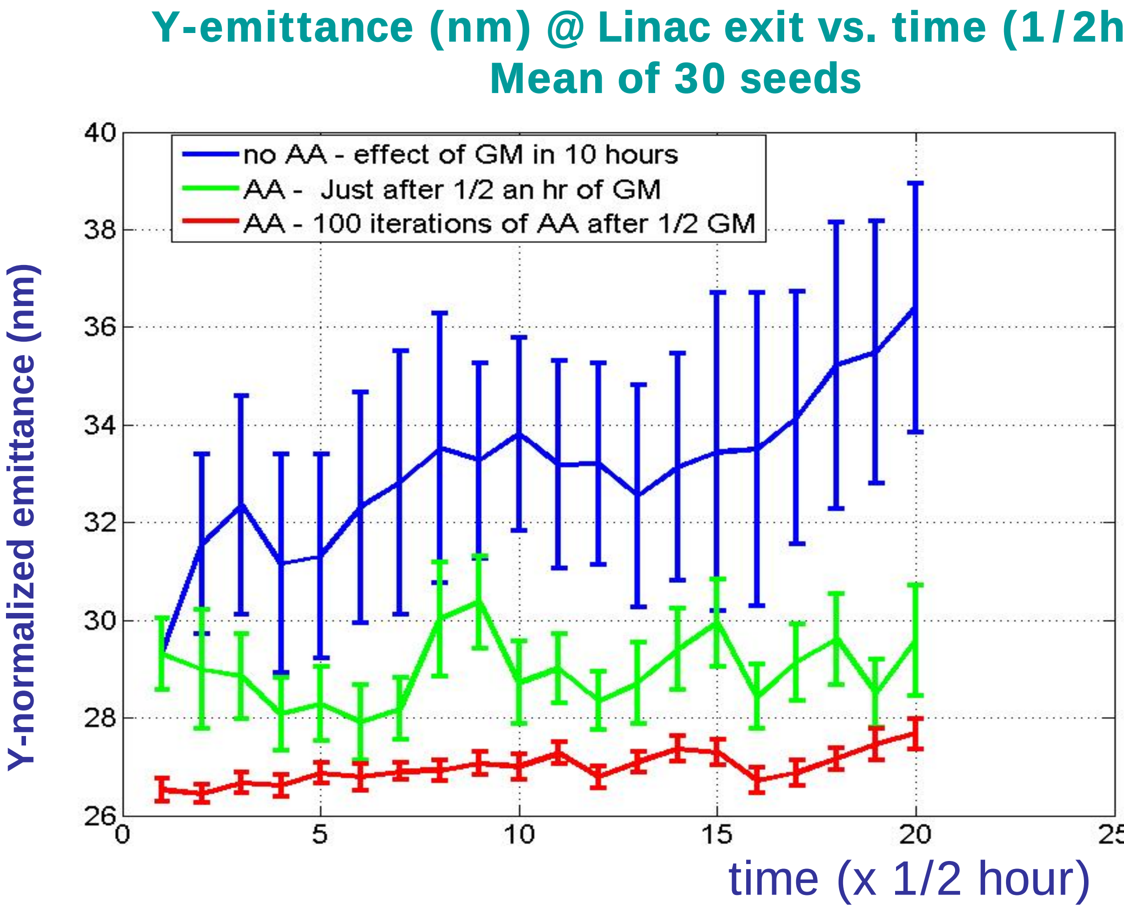
- 10 different GM seeds
- GM of 15 hrs. in step of 1 hr.
- When AA incorporated: AA of 100 iterations after every one hr. (convergence = 0.2)



In one hour of GM, emittance dilution increases by as much as 10 nm between the subsequent AA iterations, which implies that AA will have to be done more often than an hour!

GM – Effect on Dispersion Free (DF) Steered Lattice

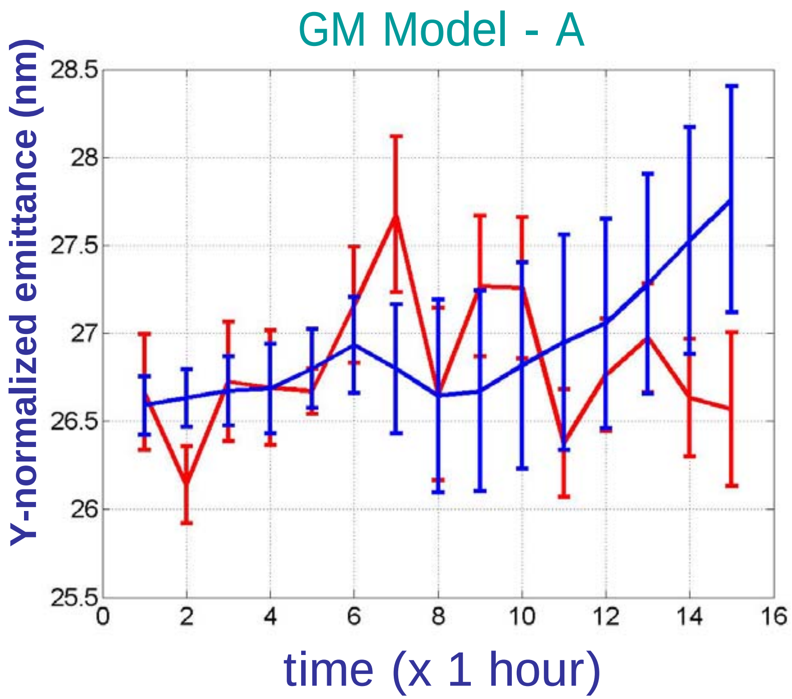
- 30 different GM seeds
- **Case2**: GM of 10 hrs. in step of 1/2 hr.
- When AA incorporated: AA of 100 iterations after every one hr. (convergence = 0.2)

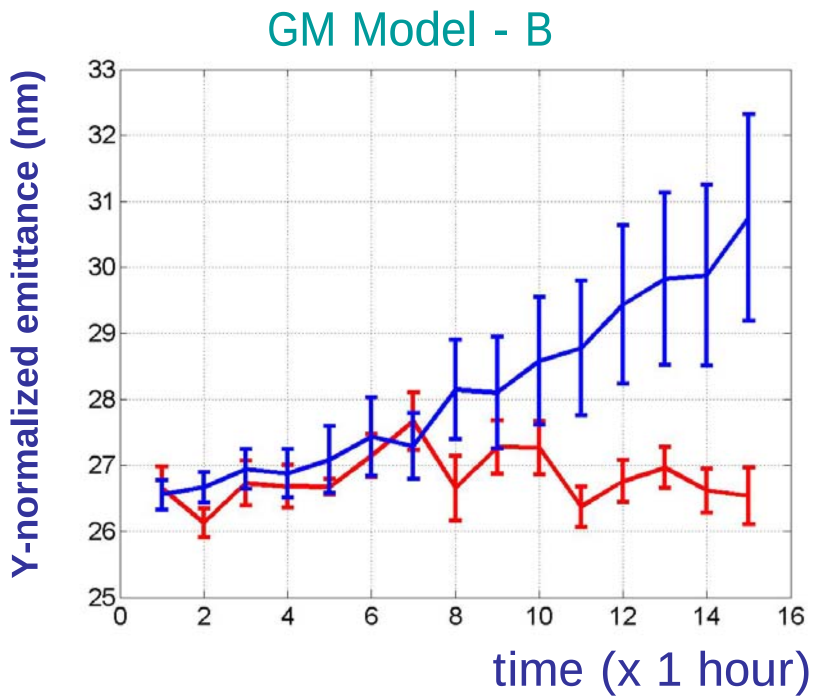


In half an hour of GM, emittance dilution increases by as much as ~ 5 nm b/w the subsequent AA iterations, which implies that AA will have to be done at least of this order or better!

GM – Different Models

BPM resolution = 0.2 μm



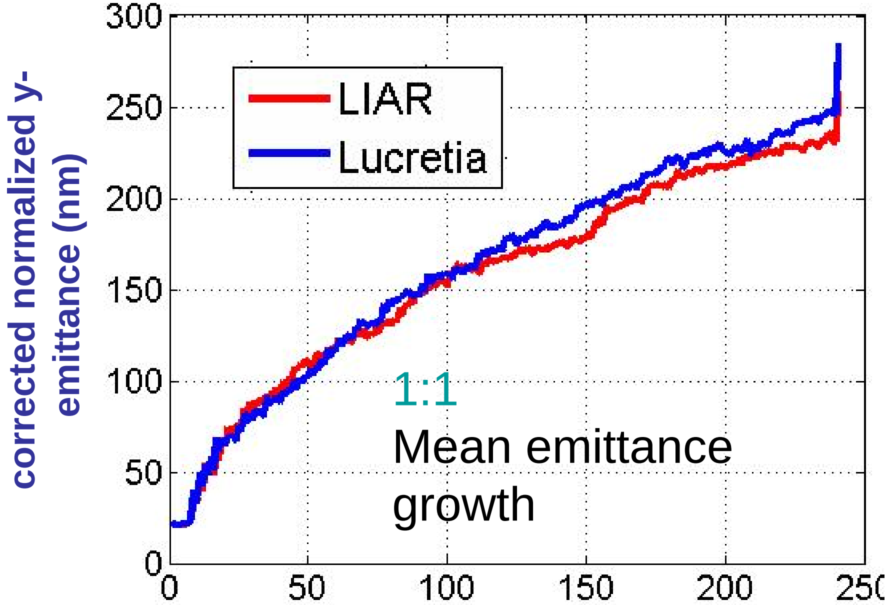


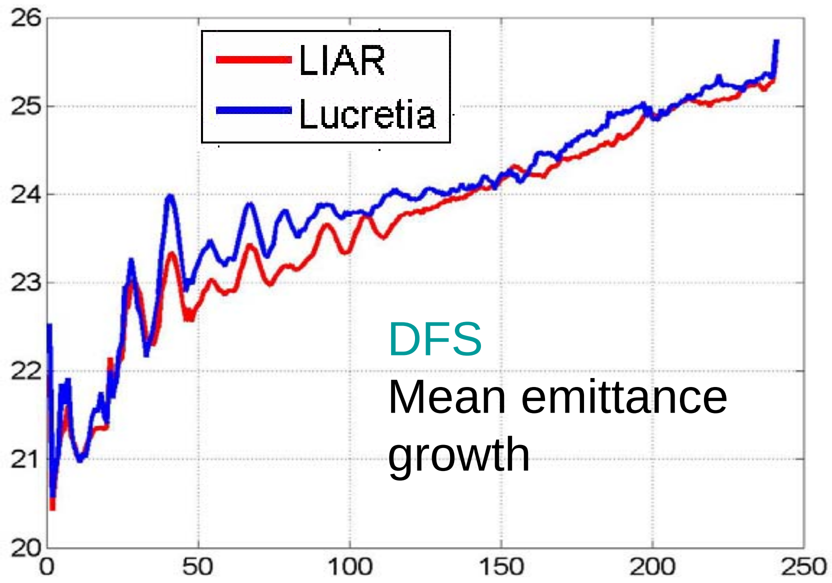
Lucretia – DFS Implementation

1:1/DFS implementation in Lucretia – Identical implementation in LIAR & Lucretia

Curved ILC BCD Lattice with GKICK, All nominal misalignments (including Girder Pitch),
1st 7 BPMs have 30mm offset w.r.t. survey line; **50 seeds**

Normalized corrected emittance vs. BPM index





LIAR → Lucretia transition - getting ready for the Cradle-to-grave simulation

Summary

✓ Effect of Adaptive Alignment (AA) has been studied – AA is extremely helpful in reducing the emittance dilution in case of Quad offsets

✓ AA is sensitive to large value of BPM offsets w.r.t. Quad, Cavity Pitch and BPM resolution

✓ In the presence of Ground Motion, AA is very helpful in keeping emittance dilution sufficiently low, both for perfect lattice or Dispersion Free Steered Lattice

✓ AA is sensitive to BPM resolution, but if we average over sufficiently large bunches, then we can still get very good performance from AA after GM

✓ Further work with the understanding of

- for how long can we run with AA before restoring to Gold Orbit
- Comparison with regular 1-to-1
- Other dynamic effects

SPOTSIZE STABILIZATION STUDIES FOR THE TESLA BEAM DELIVERY SYSTEM

PAC-97

A. Sery

The qualitative dependence of the beam dispersion when the "one-to-one" orbit correction is applied

$$\langle \eta^2 \rangle \propto (\sigma_{\rm bpm}^2 + A\,T\,L)\,N \;+\; A\,\Delta T\,L\,N^3$$

where N is the number of quadrupoles in the linac, L is the quadrupole spacing, T is the time since the moment of perfect alignment, ΔT is the time interval between successive corrections, $\sigma_{\rm bpm}$ is the BPM resolution. From the other hand, if the adaptive alignment is applied, we have

$$\langle \eta^2 \rangle \propto (\sigma_{\rm bpm}^2 \;+\; A\,\Delta T\,L)\,N^3$$

We see the obvious fact that for the "one-to-one" orbit correction the beam dispersion grows with time, since the algorithm does not realign quadrupoles, in contrast to the adaptive alignment where the beam dispersion does not increase with time.

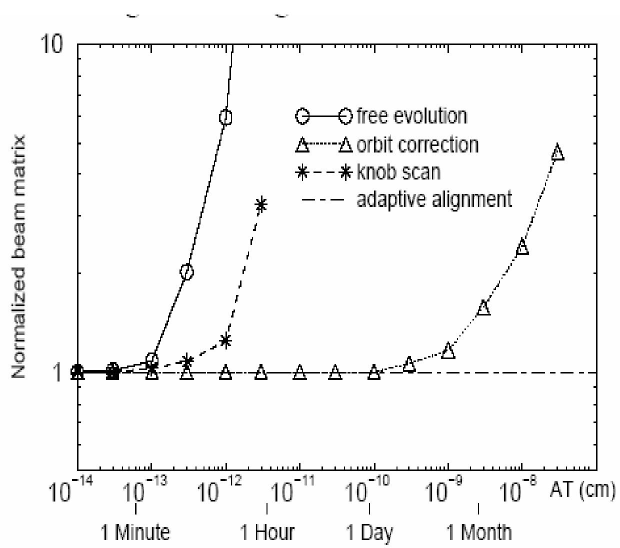


Figure 4: Normalized vertical beam size $(\sigma_{yy})_n$ for the TESLA BDS versus AT for different procedures applied solely. The second axis assumes $A = 10^{-5}\ \mu{\rm m}^2{\rm s}^{-1}{\rm m}^{-1}$.