Studies of Emittance Bumps and Adaptive Alignment method for ILC Main Linac

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Outline

- ✓ Static Beam-Based Alignment: Emittance Bumps
- ✓ Dynamic Alignment: Adaptive Alignment (AA) – Basic Principle & Performance
  - ➢ Ground Motion in Lucretia
  - ➢ AA in Perfect and Misaligned ML Lattices
  - ➢ Effect of BPM resolution
  - ➢ AA after Static Alignment (DFS)
- ✓ Summary

This is an Overview of Two Posters

THPMN107 - Study of Emittance Bumps in the ILC Main Linac

THPMN108 - Study of Adaptive Alignment as Beam Based Alignment in ILC Main Linac in the Presence of Ground Motion

Sources of Emittance Dilution

Single Bunch

- Dispersion from Misaligned Quads or Pitched cavities
- Transverse SR Wakefields: Misaligned cavities and CM
- XY-coupling from rotated Quads
- Transverse Jitter

Design Parameters

- 10.5 km length
- E_{acc}=31.5 MV/m in cavity @1.3GHz
- Injection energy = 15.0 GeV
- Extraction energy = 250 GeV
- Initial Energy spread = 150 MeV

Beam condition

- **Bunch Charge = 2 x 10^{10}**
- **Bunch length = 300 μm**
- **Norm. Y-emit. = 20 nm**
- **Norm. X-emit. = 800 nm**
- **ML budget for Y-emit. growth = 8 nm**

BCD

- Curved tunnel;
- Optics - FODO lattice, with β phase advance of 75^0 / 60^0 in x /y plane; 1 Quad / 32 cavities (changed to 1Q / 26 cav. in RDR – **THPMN109**)
- Each quad has a Cavity style BPM & Vertical Corrector magnet.

Tolerances

Nominal initial misalignments in ILC Main Linac

Tolerance	With respect to	XY- plane
Quad offset	CM	300 μm
Quad Rotation	CM	300 μrad
BPM Offset	CM	300 μm
BPM Resolution	--	1 μm
Cavity Offset	CM	300 μm
Cavity Pitch	CM	300 μrad
Cryostat Offset	Survey Line	200 μm
Cryostat Pitch	Survey Line	20 μrad

- Vertical emittance dilution in such a Linac >10000 nm*rad
- Needs Beam Based Alignment

Static Beam Based Alignment

One-to-One (1:1) Steering

- Find BPM readings to pass through the exact center of every quad and Use correctors to Steer the beam.
- One-to-One alignment generates dispersion which contributes to emittance dilution and is sensitive to the BPM-to-Quad offsets
- Typically reduce emittance from **~10000 nm to ~100nm**

Dispersion Free Steering (DFS):

- Aims to directly measure and correct dispersion in beamline.
- Measure dispersion (via mismatching the beam energy to the lattice). Calculate correction (via steering magnets) needed to zero dispersion. Apply the correction. Make few iteration
- Typically reduce emittance growth to $\Delta\varepsilon_y$***~5÷7 nm***

Emittance (Dispersion and Wake) Bumps:

- Global correction technique ***(NLC, CLIC, ILC)***
- Varying strength of the correctors in bump to minimize beam size at the Laser Wire Scanner monitor at the end of the linac.
- Can reduce emittance growth to $\Delta\varepsilon_y$***~2÷3 nm*** (X-Y coupling)

Emittance Bumps

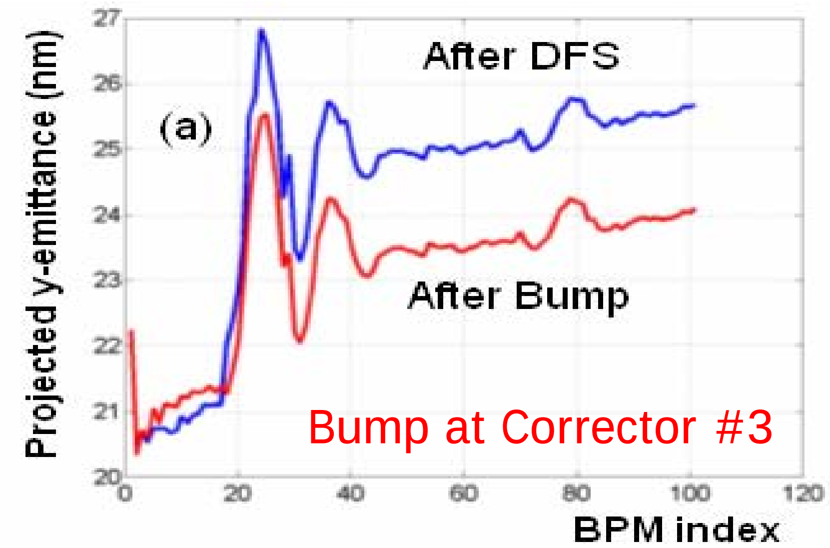
- Residual emittance growth (due to both dispersive and wakefield effects) after DFS. Thus, two different global bumps, Dispersion and Wakefield bumps, are considered for the present study.

- **Dispersion Bump:** Two sets of correctors 90º apart in betatron phase, each set consisting of two correctors 180º apart, with appropriate beam energy scaling between the two correctors. The corrector fields are then varied to minimize beam size at the end of Linac (laser wire monitors).

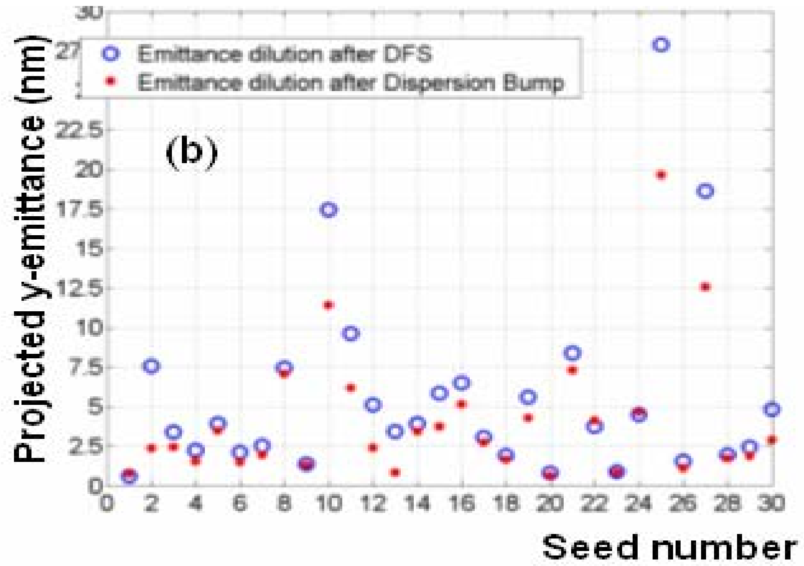
- **Wakefield Bump:** Two sets of correctors with 90º in apart, each set consisting of three correctors 180º apart to cancel both beam offset and dispersion.

Single Dispersion bump

50 FODO cells. Nominal Misalignments. 30 seeds
The linac is first tuned using one-to-one and DFS



Emittance growth after DFS and then a dispersion bump near the entrance



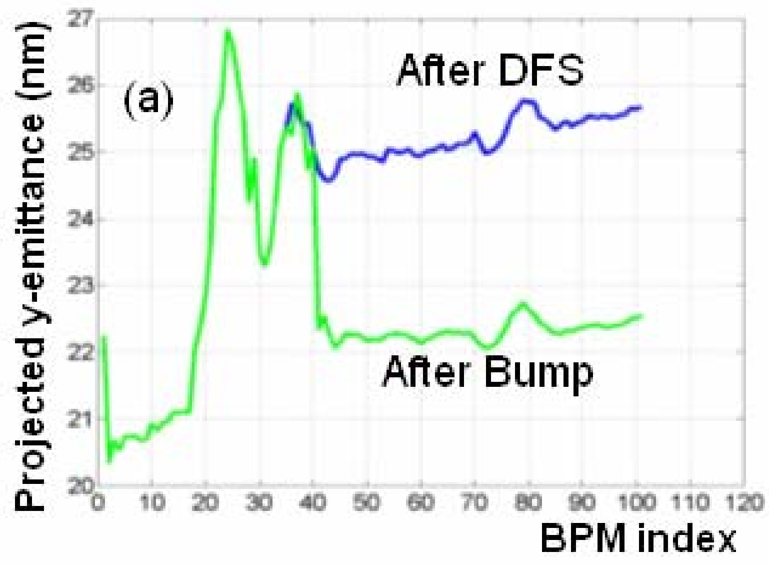
Results for the individual machines.

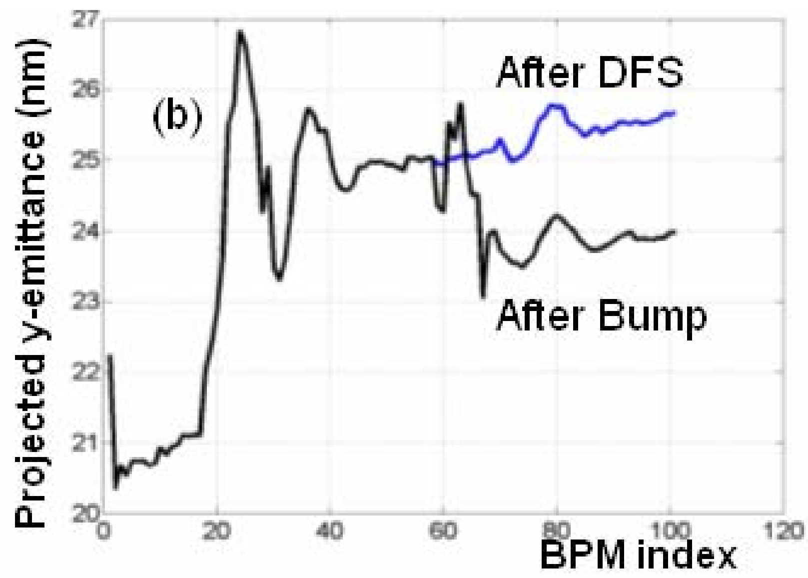
- A single dispersion bump placed near the entrance of the linac helps to significantly reduce the emittance growth when implemented after DFS
- Helps in limiting the emittance growth for all the seeds. For “”bad” seeds effect of the bump is bigger.

Location of the dispersion bump

Bump at corrector #36

Bump at corrector #59.



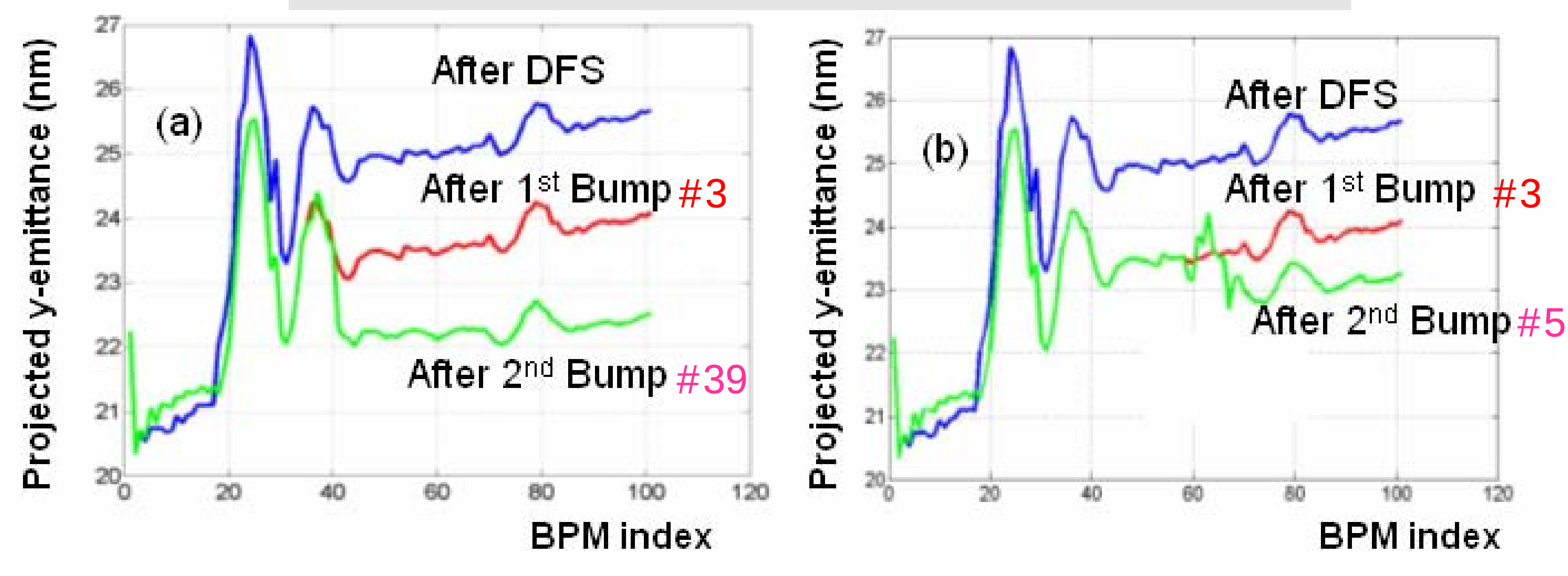


Average (30 seeds) emittance growth after DFS and then implementing a Dispersion bump. Location is chosen randomly

Effect of single Bump is different. Optimization of the Bump locations is important

Number of dispersion bumps

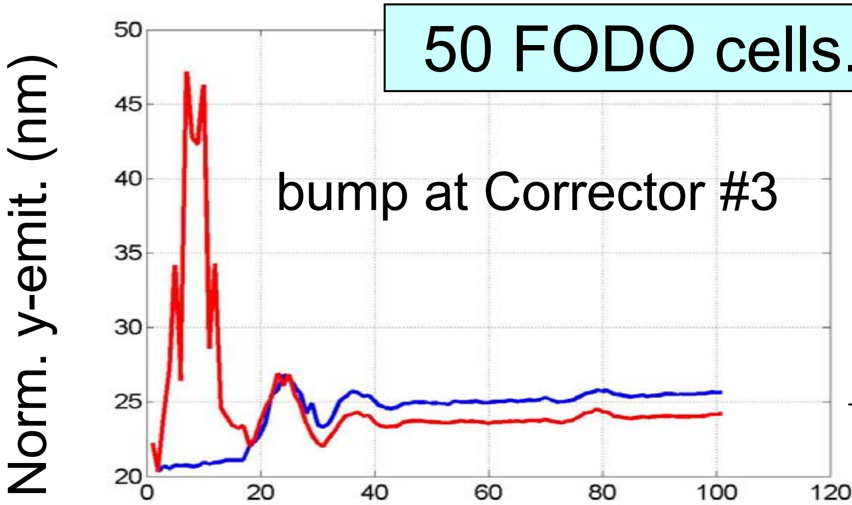
50 FODO cells. Nominal Misalignments. 30 seeds
The linac is first tuned using one-to-one and DFS

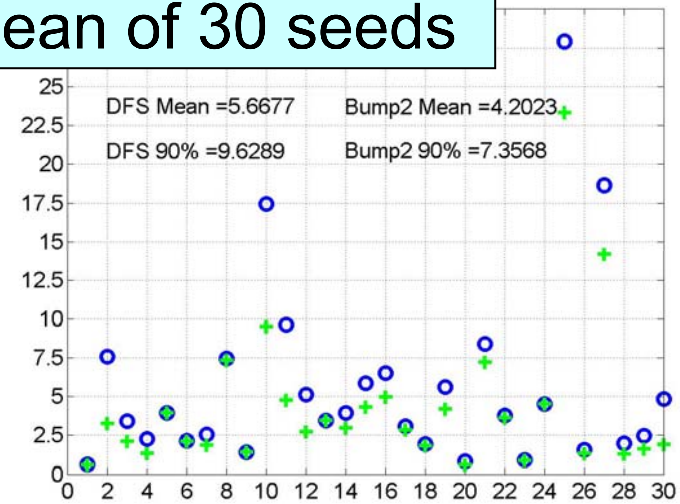


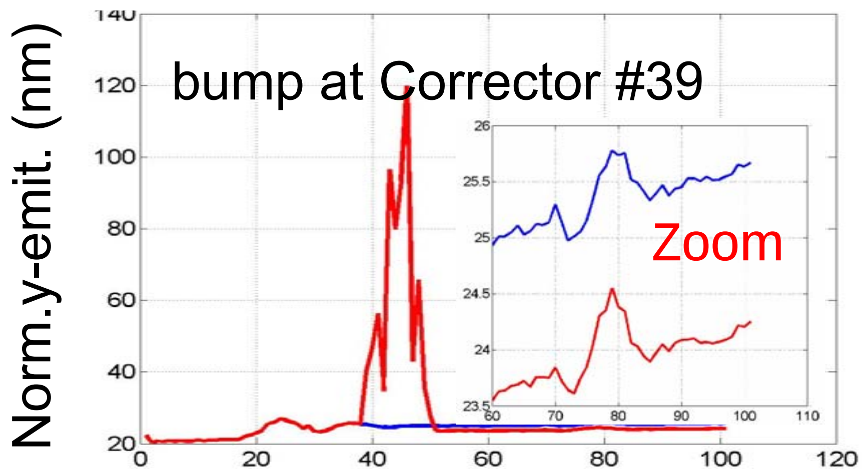
- **It is found that the placement of the dispersion bump is crucial to get the optimal result.**
- **No significant improvement in the emittance growth was observed after using three or more bumps; however, a detailed study is in progress for further results.**

Single Wake bump

50 FODO cells. Mean of 30 seeds



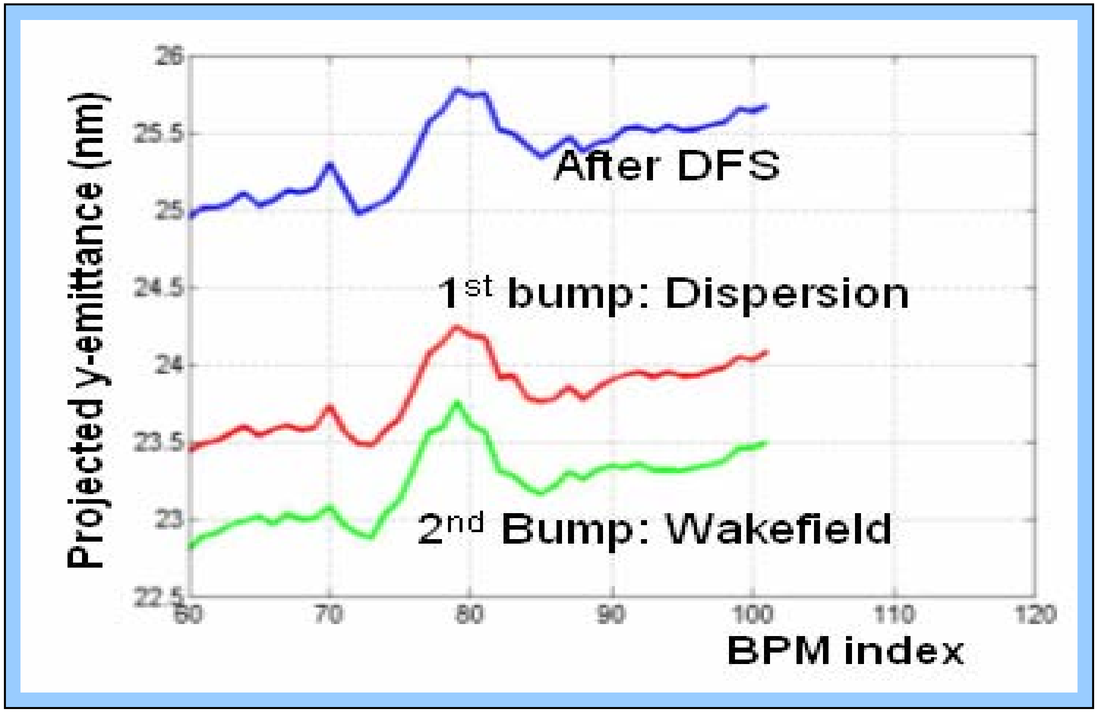




Single Wake bump can reduce dilution of the normalized Y-emittance by ~1.5 nm

Wakefield bumps are useful in limiting the emittance growth after DFS, indicating the presence of residual wakefield based emittance growth in the linac after static tuning.

Dispersion + Wakefield Bumps

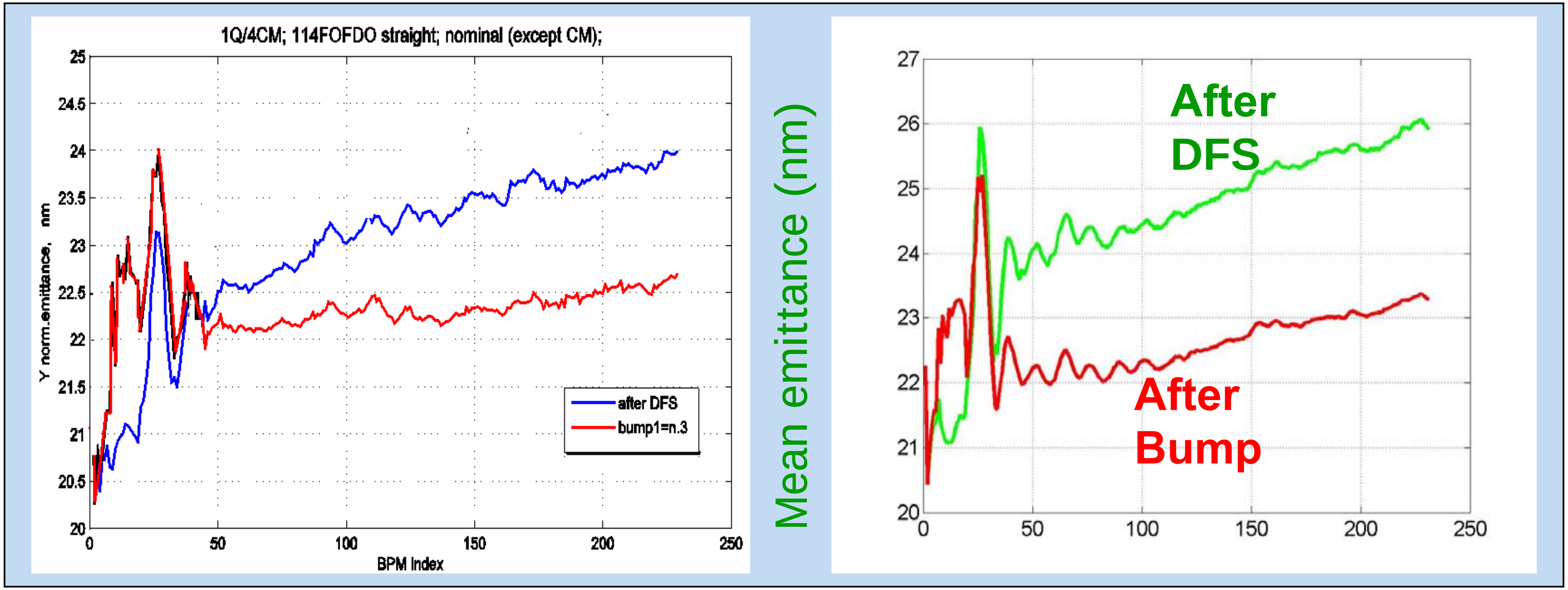


Average emittance growth in a after DFS and then implementing one dispersion bump at corrector #3, and one wakefield bump at corrector #39.

Because of the presence of residual dispersive and wakefield related emittance growth after DFS, the combined results of the two emittance bumps are beneficial.

Entire ML Lattice

114 FODO cells. Single Bump at energy = 16.16 GeV



Straight Linac.

Average y-emittance growth after DFS, and then implementing one dispersion bump at corrector #3.

Curved Linac.

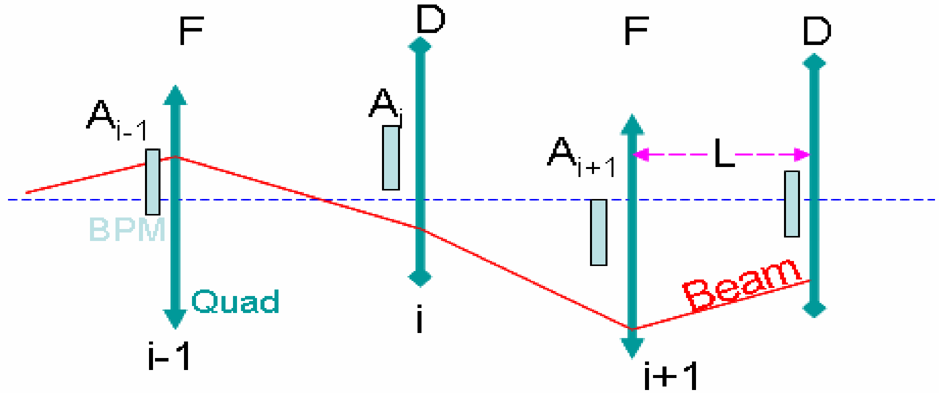
2% resolution assumed for the beam size measurement

Summary of Bump studies

- Because of the presence of residual emittance growth from dispersion and wakefield related emittance growth after static tuning, these global bumps are found to be very important to further limit the emittance growth.
- Two different emittance bumps, dispersion and wakefield, are studied. Both of them are found to be important; however, a careful optimization of the number of these bumps and their location are crucial.
- Further studies to optimize these bumps for the realistic ILC machine is in progress

Adaptive Alignment as a Beam Based Dynamic Alignment Algorithm for the ILC Main Linac

Proposed by Vladimir Balakin in 1991 for VLEPP project



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

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

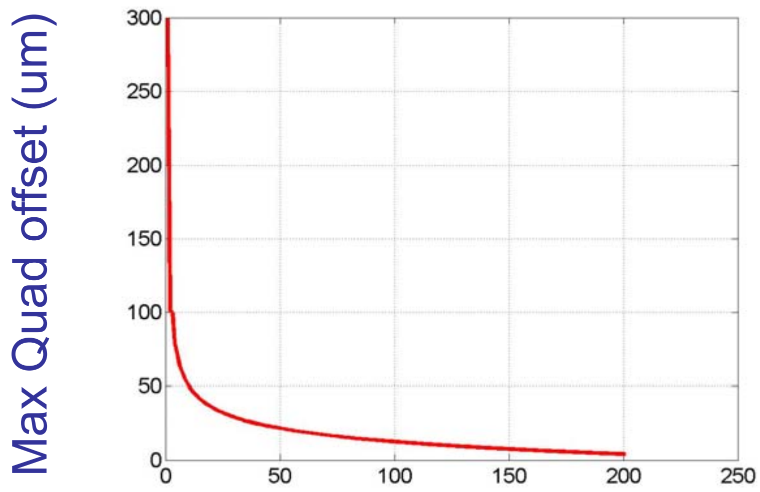
conv : Speed of convergence of algorithm
A_i : BPM reading of the central quad and so on
K_i : Inverse of quad focusing length
L : Distance between successive quads (assuming same distance b/w quads)
ΔE : Energy gain between successive quads
E : Beam Energy at central quad

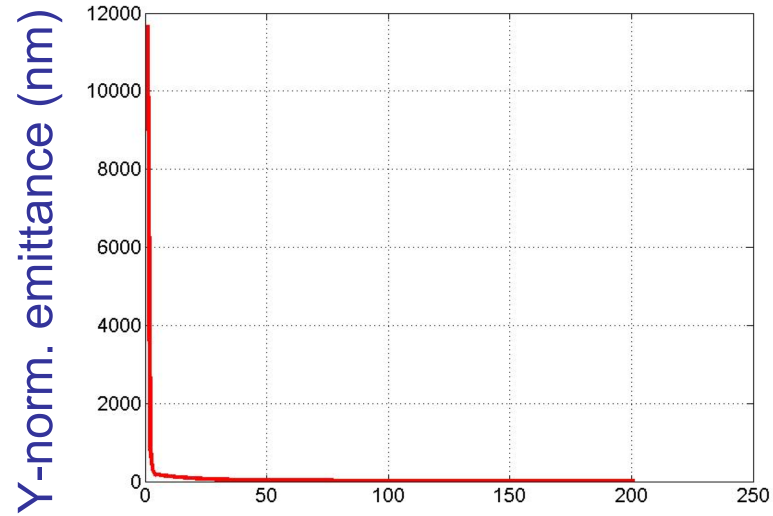
New position of quad & BPM:

$$y_i = y_i - \Delta y_i$$

The procedure is iteratively repeated

Examples of AA performance, no GM

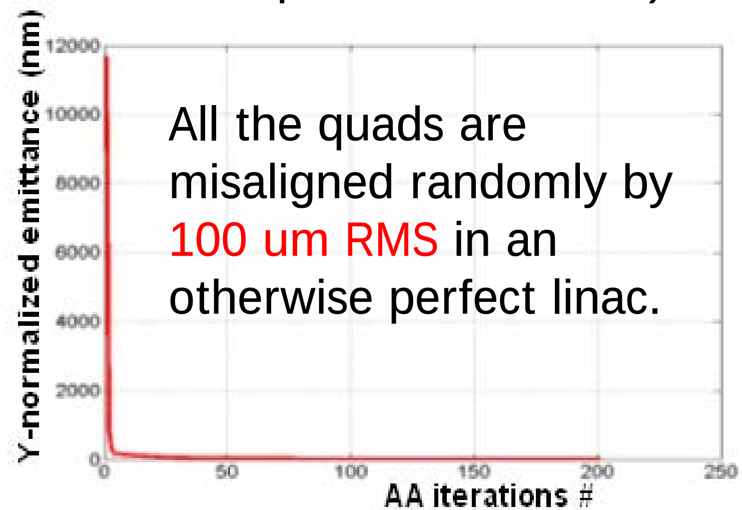




ILC BCD Like Lattice – Straight – Only one quad at 10th position is misaligned by 300um (BPM's are perfectly aligned with Quads, and have perfect resolution)

- AA procedure smoothes out the beam thrusts, and decreases the emittance growth significantly from ~12000nm to ~20nm (initial)

- **Sensitive to BPM-Q offset and BPM resolution**



Ground Motion (GM) in LIAR and Lucretia

A.Seryi et.al., " Recent developments of LIAR Simulation Code", EPAC 2002

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

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

Diffusive corrected "ATL"

Isotropic plane wave motion

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

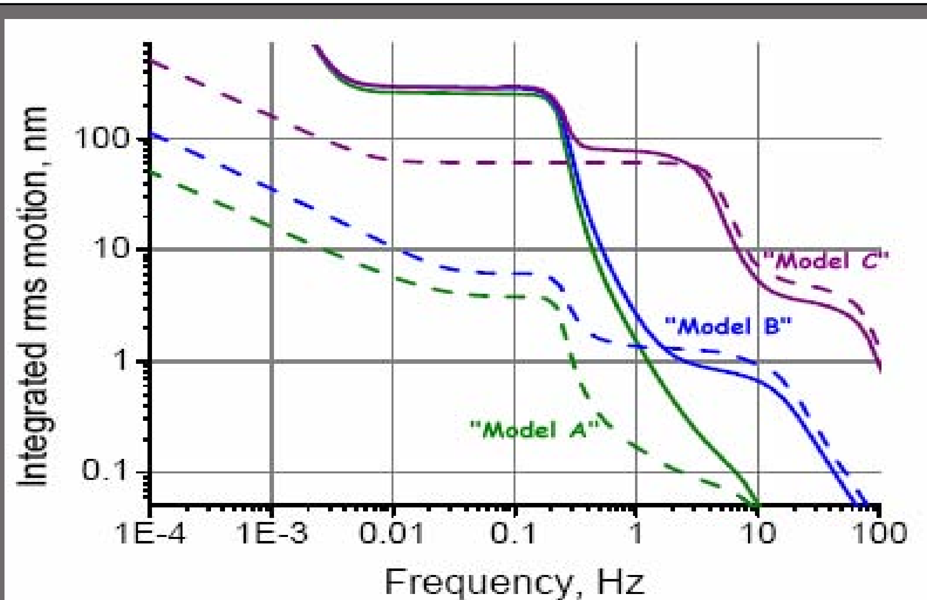
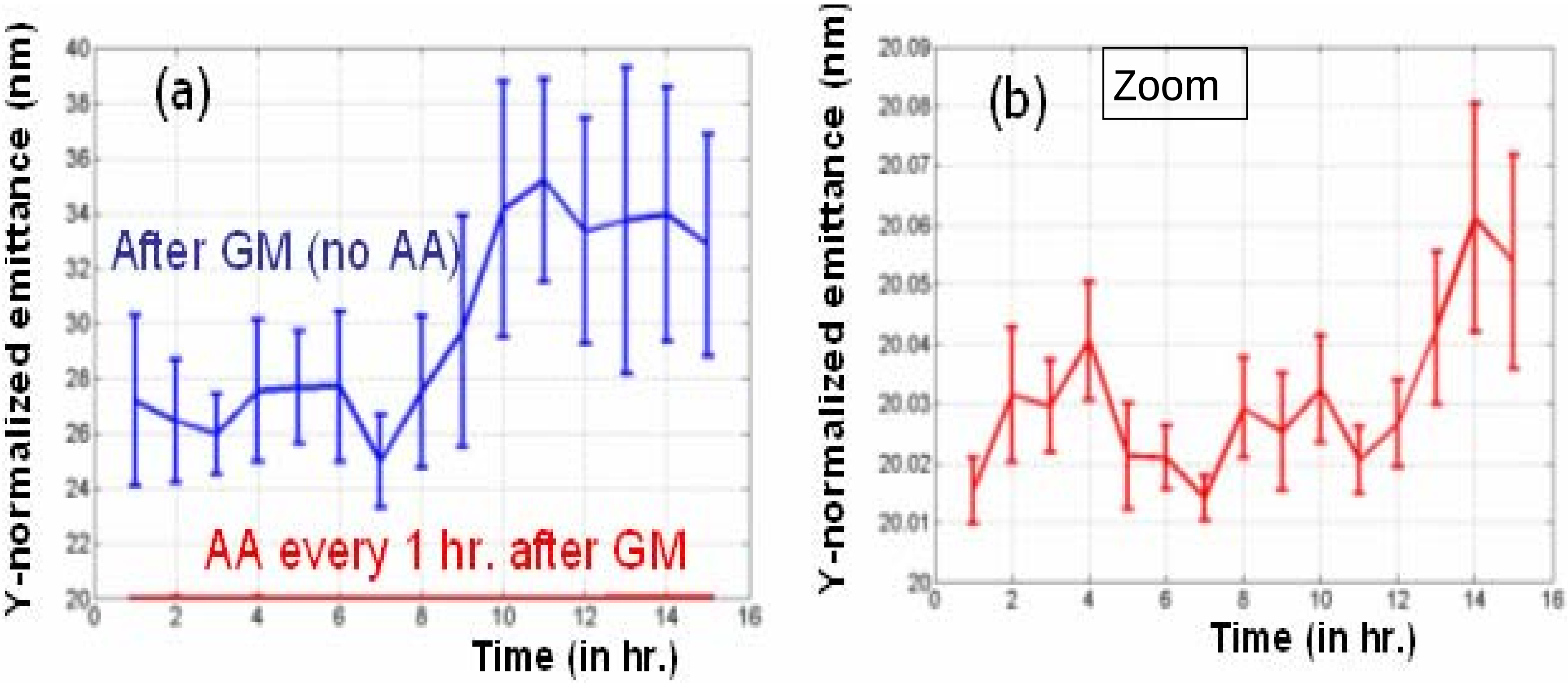


Figure 1: The integrated absolute ground motion spectra (solid lines) and the integrated relative motion of 2 objects separated by 50 m (dashed lines)

Different GM Models in LIAR/Lucretia

Parameter	A Model	B Model	C Model	KEK (4AM)	KEK (10AM)
A (m/s)	1E-19	5E-19	1E-17	1E-17	1E-17
B (m^2/s^3)	5E-19	1E-18	5E-18	5E-18	5E-18
Resonances Freq. (Hz) ω_i	0.001 0.2 5	0.001 0.2 4.5	0.14 2.5 50	0.012 0.22 0.5 3.0 10.0 20.0	0.012 0.22 1.1 2.0 3.0 10.0 20.0
Amplitude (m^2 s) a_i	1E-9 3.5E-13 1E-21	1E-9 3.5E-13 2.5E-20	1E-11 1E-15 1E-19	1E-10 1E-11 5E-15 5E-16 1.5E-18 1.3E-20	3E-10 1.5E-13 2.0E-15 1.5E-15 5.0E-15 1.8E-17 5.0E-19
"d" (~1/width) d_i	1.0 3.5 1.3	1.0 3.5 0.35	5 1.5 1.5	1.0 5.5 2.0 8.5 3.5 3.0	0.7 6.5 7.0 3.0 8.0 5.5 4.0

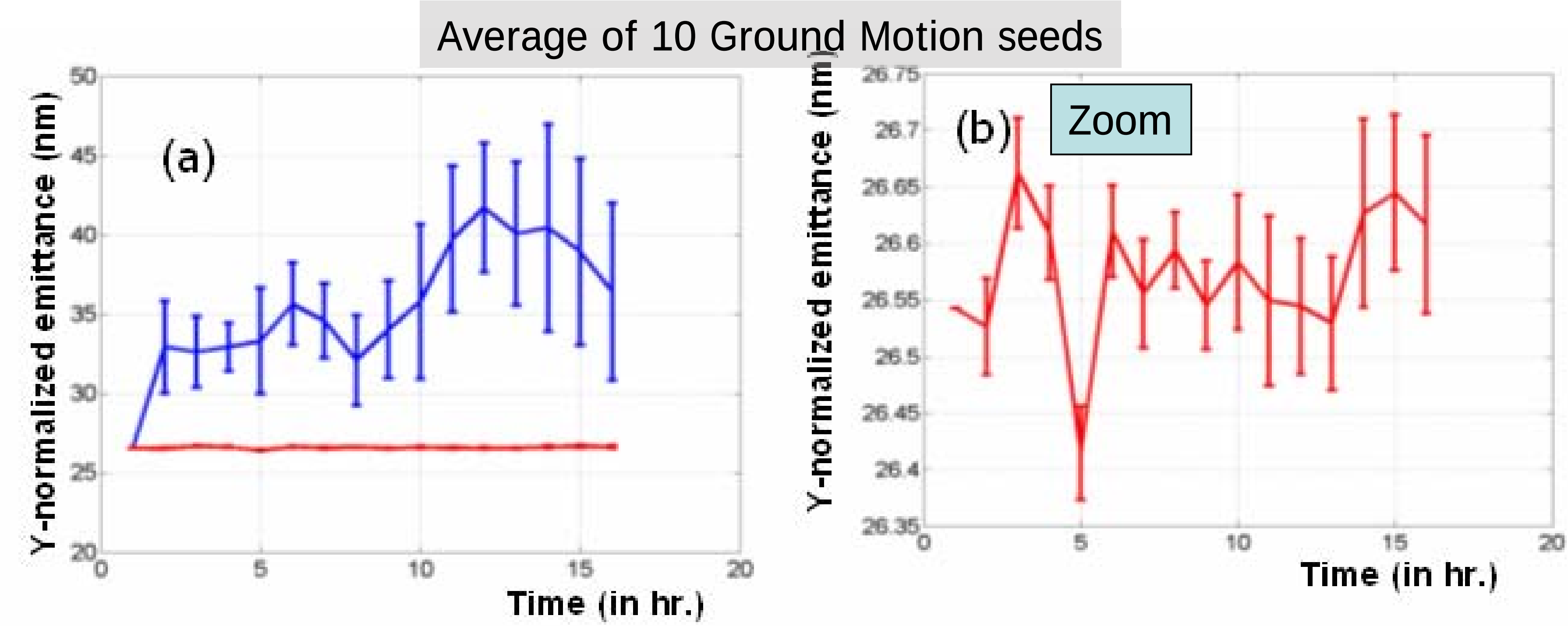
AA in presence of ground motion



(a) Normalized vertical emittance vs. time in a perfectly aligned linac. AA of 100 iterations and 0.3 convergence factor is implemented after every one hour of GM model 'C'.

(b) A blown-up portion of the plot after adaptive alignment.

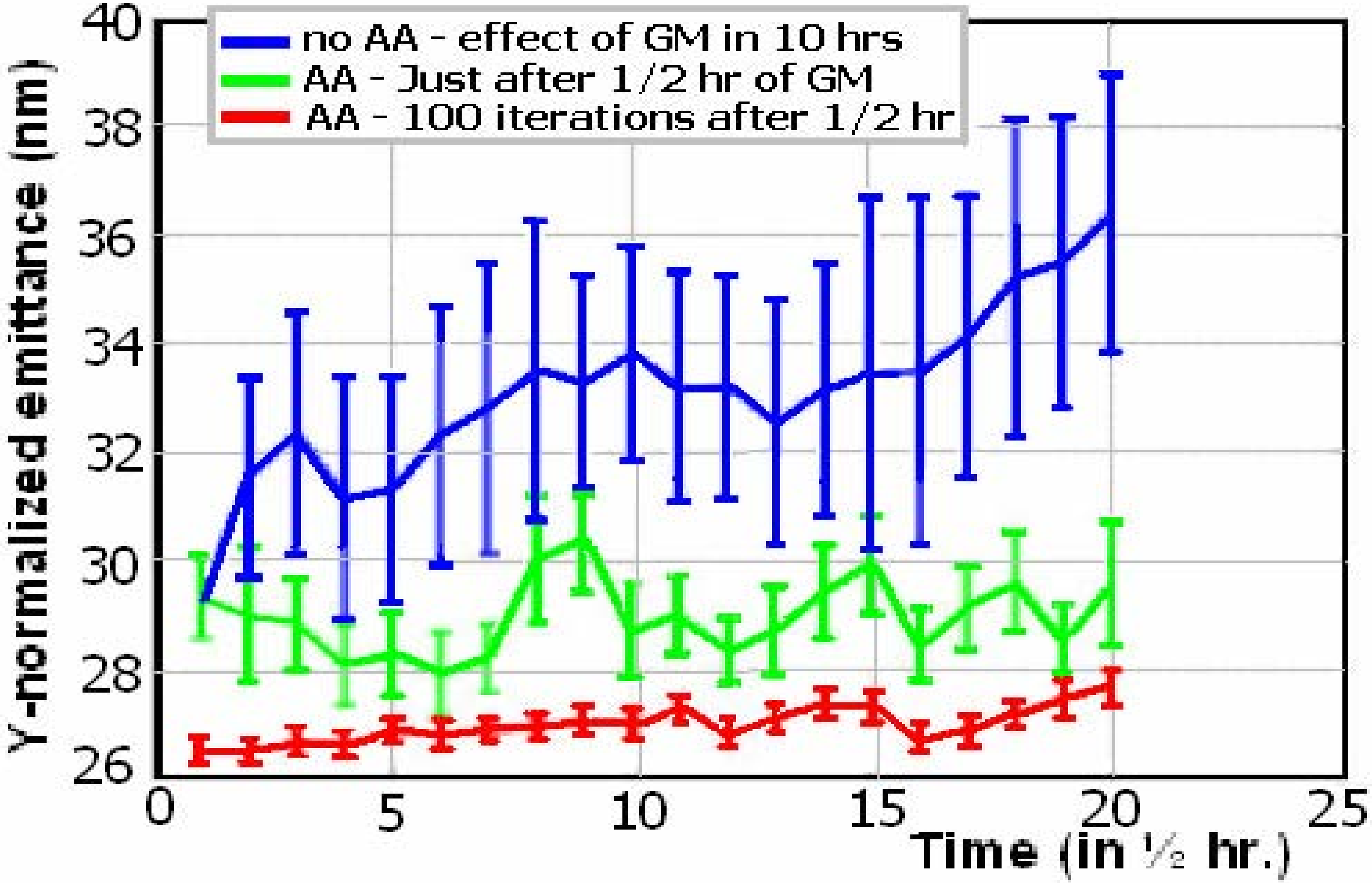
AA with Ground Motion after DFS



(a) Normalized vertical projected emittance vs. time in a dispersion-free steered linac. AA is implemented after every hour of GM model 'C'.
(b) A blown-up portion of the plot after 100 AA iterations, gain=0.3.

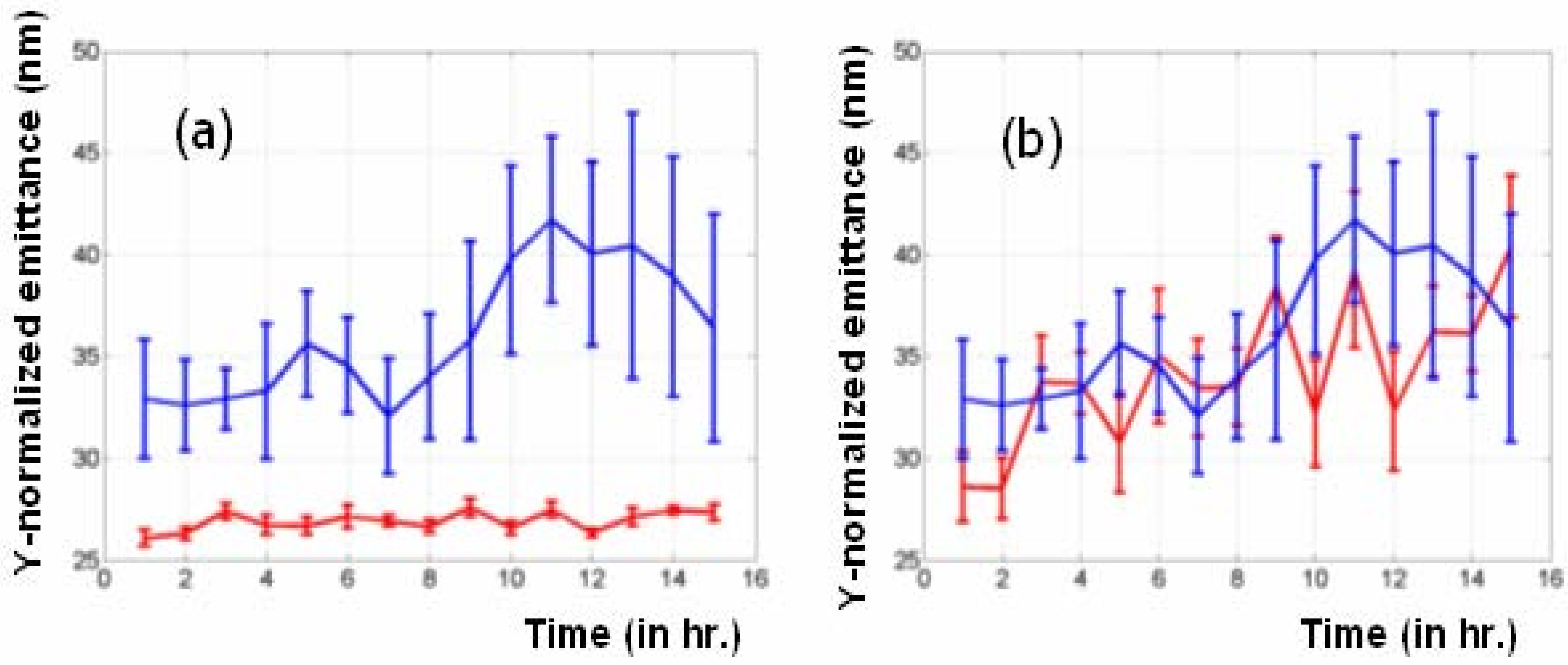
Orbit after DFS is used as a reference, in this case AA is not sensitive to BMP-to-Quad offsets

Effect of tuning intervals



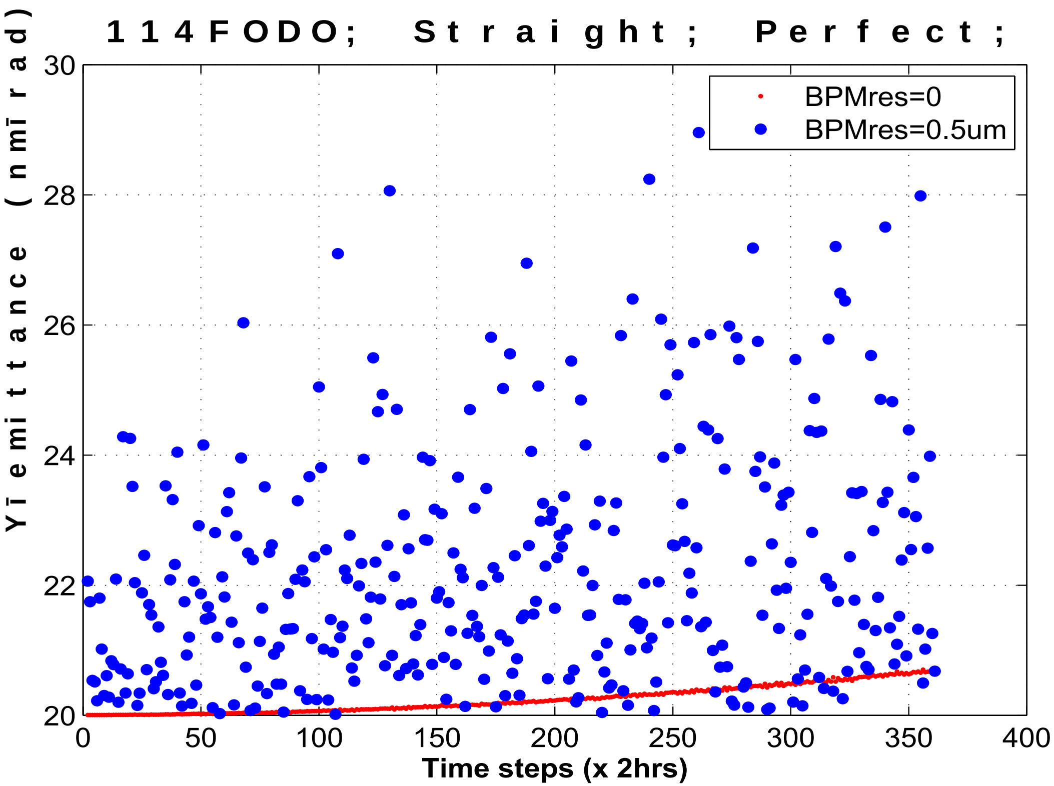
Normalized vertical emittance vs. time in a DFS linac. AA of 100 iterations and convergence factor 0.2 is implemented every half hour of GM of model 'C'.

Effect of BPM resolution



Normalized vertical emittance vs. time in a DFS linac. AA of 100 iterations and convergence factor 0.3 is implemented after every 1 hour of GM of model ‘C’

(a) BPM resolution of 0.2 um (b) BPM resolution 1 um.



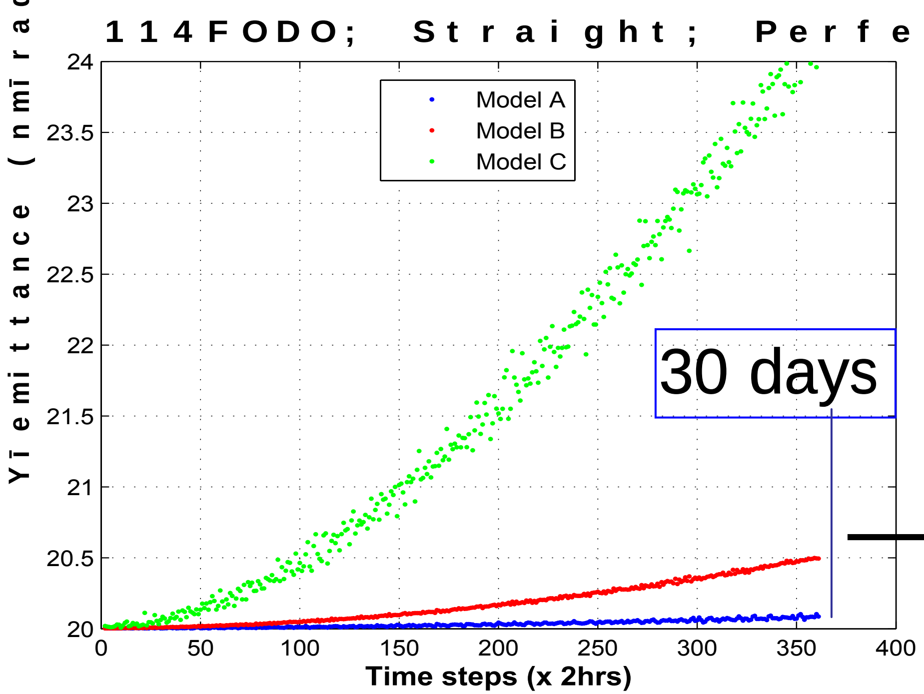
Full ML Lattice

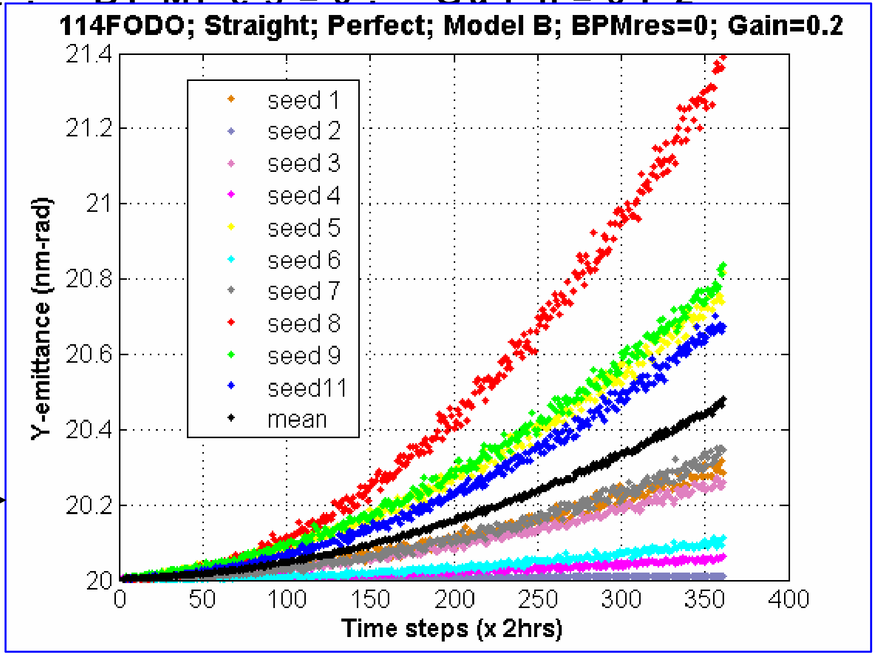
Normalized vertical emittance growth for GM of model 'B' for different BPM resolutions; 100 AA iterations.

The effect of BPM resolution for AA correction can be significantly reduced by averaging information from all bunches in one train or even by using information from a number of previous pulses. This was confirmed in simulations done for short lattice.

AA in entire Main Linac (114 FODO)

Y-emittance (nm) @ Linac exit after 100 AA iterations for different GM models 'A', 'B' and 'C'. Total period - one month, time step - 2 hours





Average of 10 GM seeds for each model Convergence = 0.2;

Individual GM seeds for model B.

Individual variation for different seeds & GM models can affect substantially on beam emittance

Summary of AA studies

- In the absence of any dynamic steering Ground Motion can severely limit the emittance dilution performance;
- Adaptive Alignment algorithm can be helpful as a dynamic tuning technique to stabilize the emittance performance in a perfect or Dispersion Free Steered linac for ~months time scale (site dependant)
- We expect to implement this algorithm every few pulses; however, a time interval of more than half hour between iterations can cause significant growth in emittance, particularly in GM model 'C'.
- A detailed study of GM on the main linac is in progress.