Issues with Static Alignment

Jeff Smith

Snowmass 2005

August 18th, 2005

Topics of Consideration

- Look at three Static Alignment Algorithms in the presence of the following:
  - BPM Resolution and Beam Jitter
  - Stray Fields
  - BPM and Steering Magnet Failure
  - Stronger Wakefields in Low Loss Cavities

The Computer Model

- Simulations performed in TAO using the BMAD library

- Using TESLA TDR Main Linac lattice
  - 23.4 MV/m gradient
  - 1 quad per 2 cryos first half, 1 quad per 3 cryos second half

- Beam Conditions
  - 250 particles, Gaussian distributed
  - 5.0 GeV initial energy
  - 3.0% initial energy spread, 0.3 mm bunch length
  - Only looking at single bunch effects

- Algorithms adapted from the following sources:
  - Ballistic Alignment, or "BA"
    - D. Schulte, N. Walker, "Simulations of the Static Tuning for the TESLA Linear Collider", PAC03 proceedings
  - Quad Shunting, or "Kubo"
    - Unpublished, lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/lcimu-20050325a.pdf
  - Dispersion Free Steering, or DFS
    - P. Tenenbaum, R. Brinkmann, V. Tsakanov, "Beam-Based Alignment of the TESLA Main Linac", EPAC02 proceedings

Nominal Misalignments

In all the following analysis, unless otherwise specified, these standard misalignments where used. The point of this analysis wasn't to find alignment tolerances but examine the effects of other issues in the presence of element misalignments.

Error	Tolerance	With Respect To…
Quad Offset	300 m	Cryostat
Quad Tilt	300 rad	Cryostat
BPM Offset	300 m	Cryostat
BPM Resolution	10 m	True Orbit
RF Cavity Offset	300 m	Cryostat
RF Cavity Pitch	200 rad	Cryostat
Cryostat Offset	200 m	Survey Line
Cryostatic Pitch	20 rad	Survey Line

BPM resolution was found to have a slight effect on the alignment algorithms. DFS being most sensitive, as expected.
No significant dependence on BPM tilt errors up to a large fraction of a radian

Emittance at Variable BPM Noise Resolution

BBA in the presence of Vertical Beam Jitter
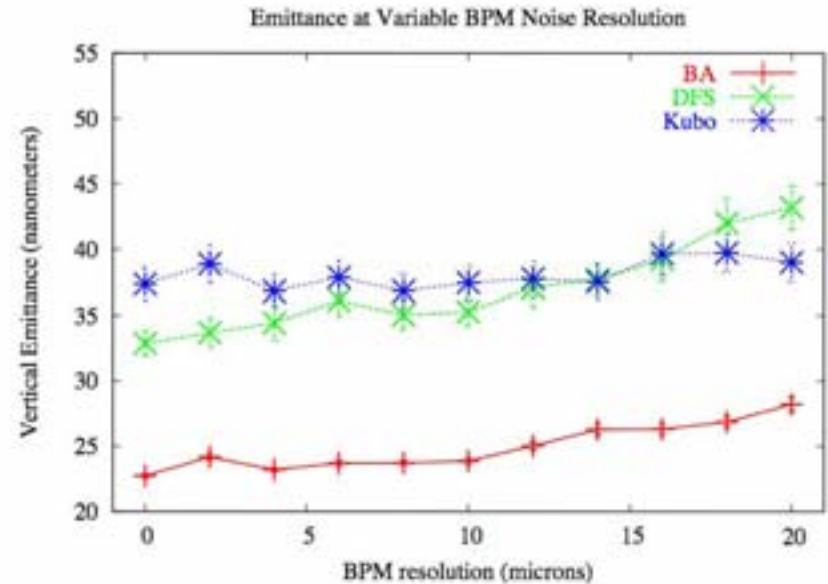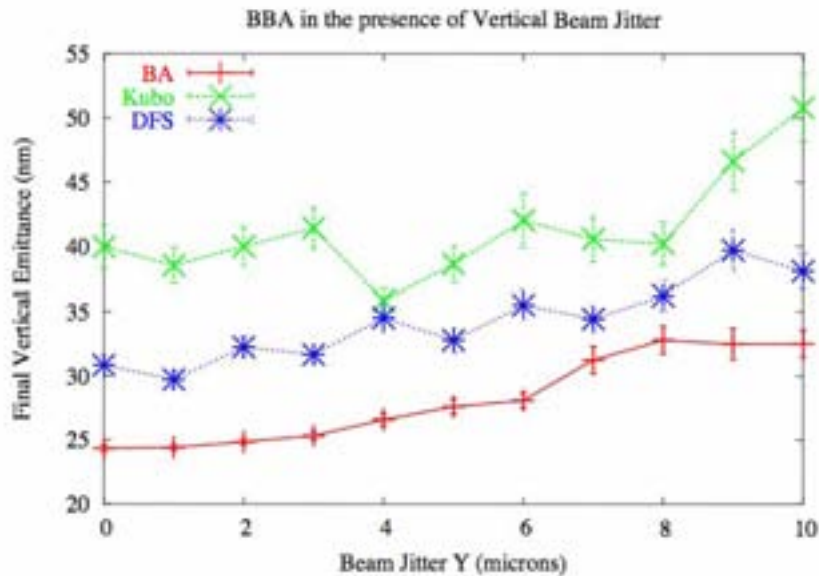
Beam Jitter also found not to be a serious issue up to 1 sigma rms jitter.

An Earth-like dipole field was applied over all unshielded components. The cavities were assumed to to be completely shielded and all other components not shielded.

Since Earth's field is known, compensation should be possible, but this analysis will also give the effects of other unknown stray fields.

The Earth field was varied from 0 to its full strength of 54.3 micro-Tesla.
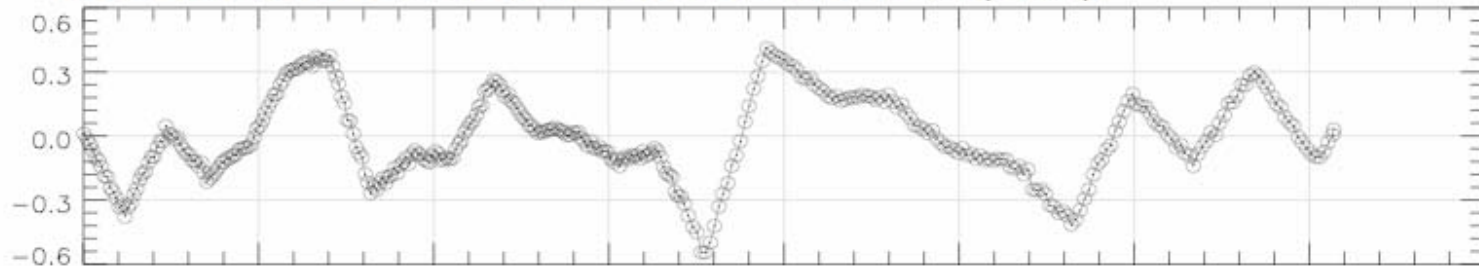
Earth's field in Ithaca, NY:

Field Component	Strength	Unit
Magnitude	54.3	microTesla
Declination	-12.2	Degrees West
Inclination	69.5	Degrees Down
Linac Orientation	90.0	Degrees East

BBA with Earth Field

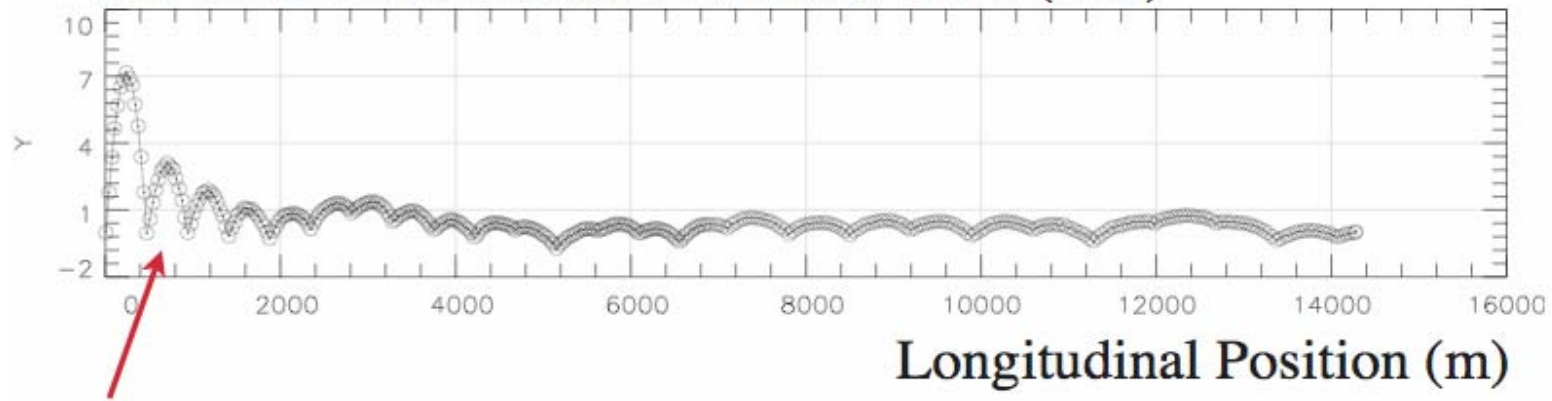CORNELL UNIVERSITY **LEPP**
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS
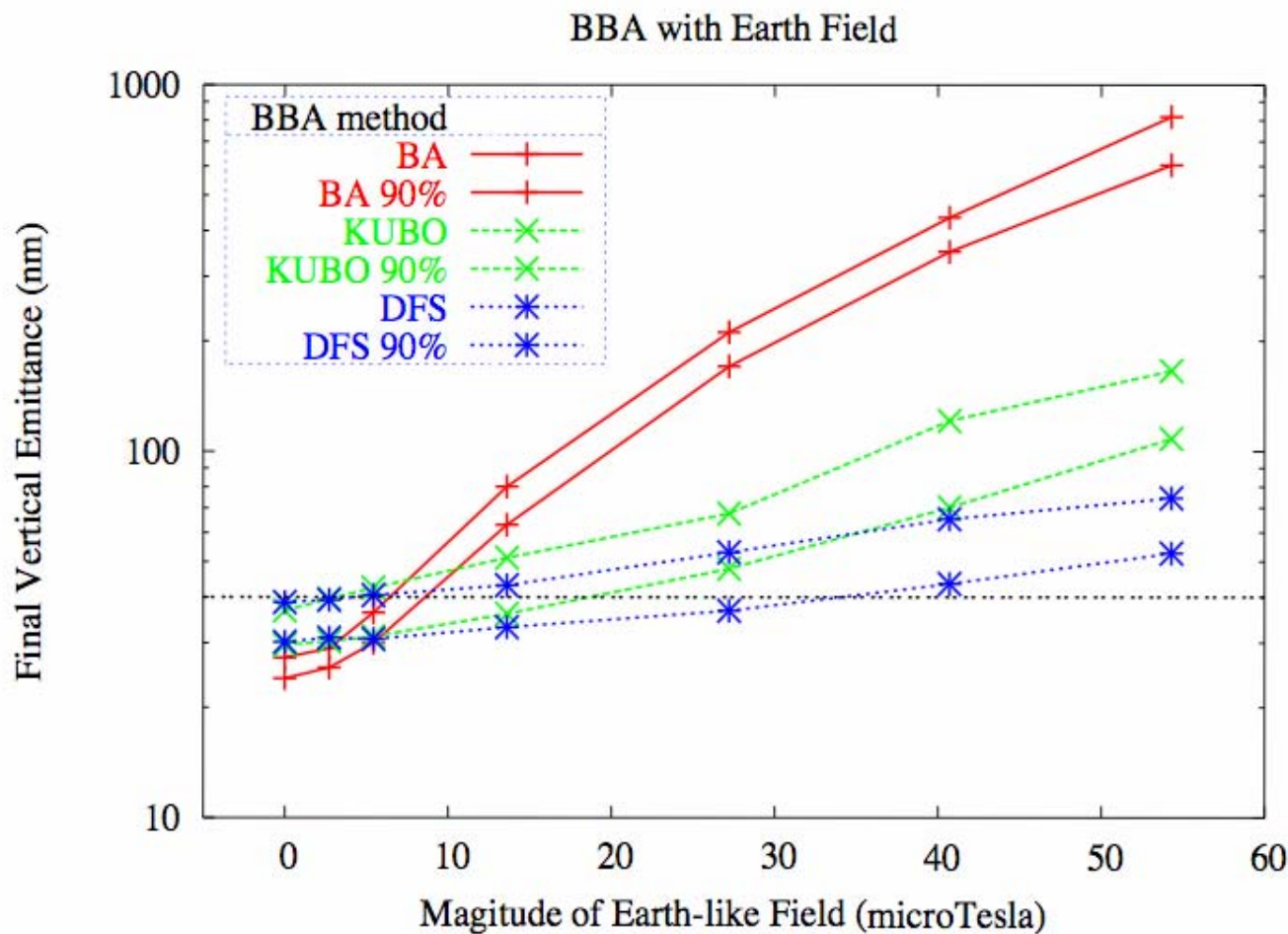
BA Vertical Orbit with no Earth Field (mm)

Longitudinal Position (m)

BA Vertical Orbit with Full Earth Field (mm)

Longitudinal Position (m)

Earth field effects mainly the first 1500 meters.

Here, the full 54.3 microTesla Earth-field is applied and shielding is extended to fill the entire linac up to the point on the horizontal axis.


BBA With More Shielding
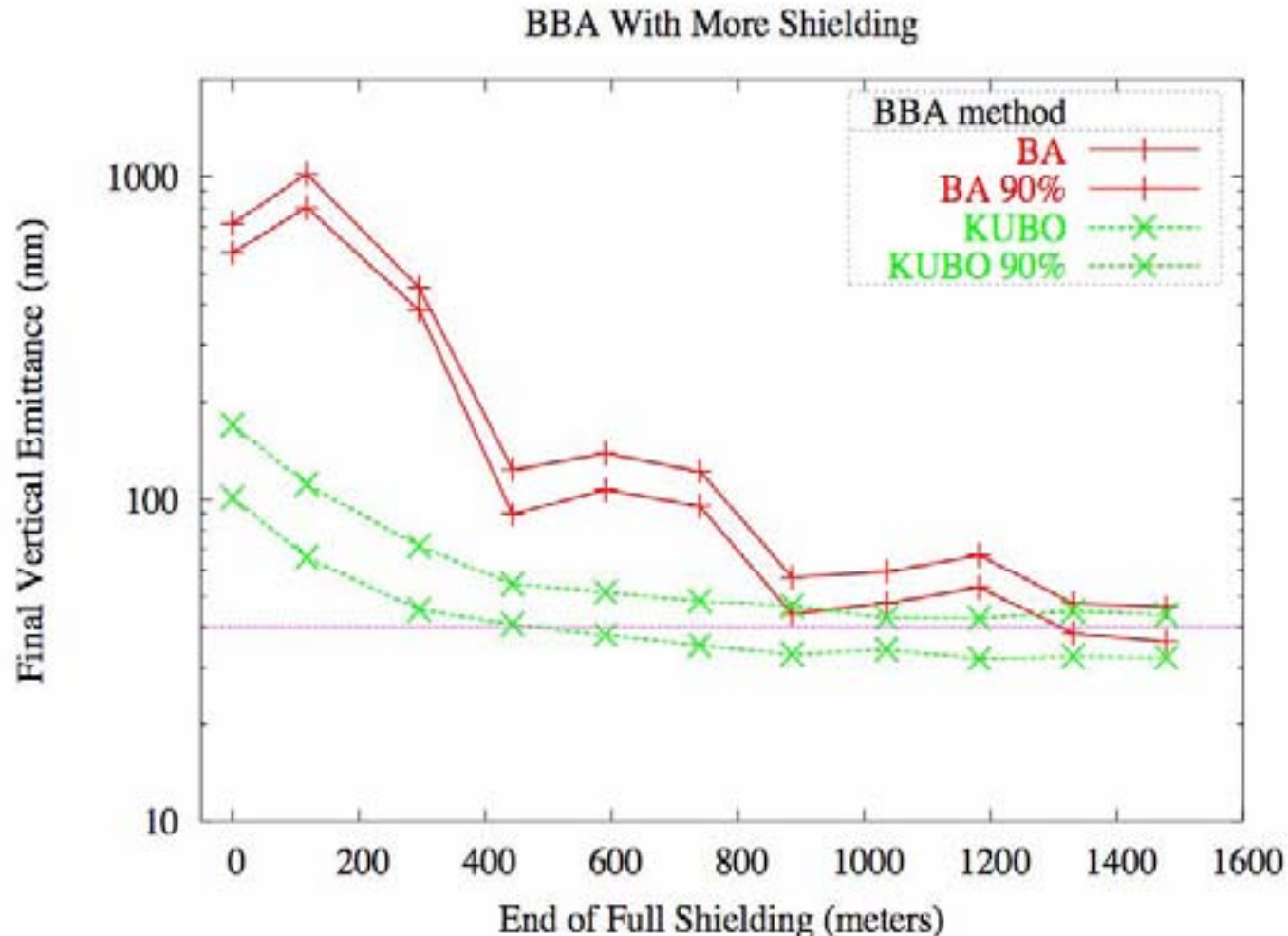
This analysis assumed the failed BPMs or steering magnets have been identified and "vetoed."

The one-to-one alignment algorithms (BA and Kubo) are highly sensitive to BPM and Steering magnet failure since the corresponding dispersive quadrupole kick is not compensated at all.

Given an isolated failed BPM it may be possible to apply a steering magnet kick and compensate the corresponding dispersive quadrupole kick. Or, turn off the quadrupole and retune machine. (feasibility of these hasn't been tested yet)
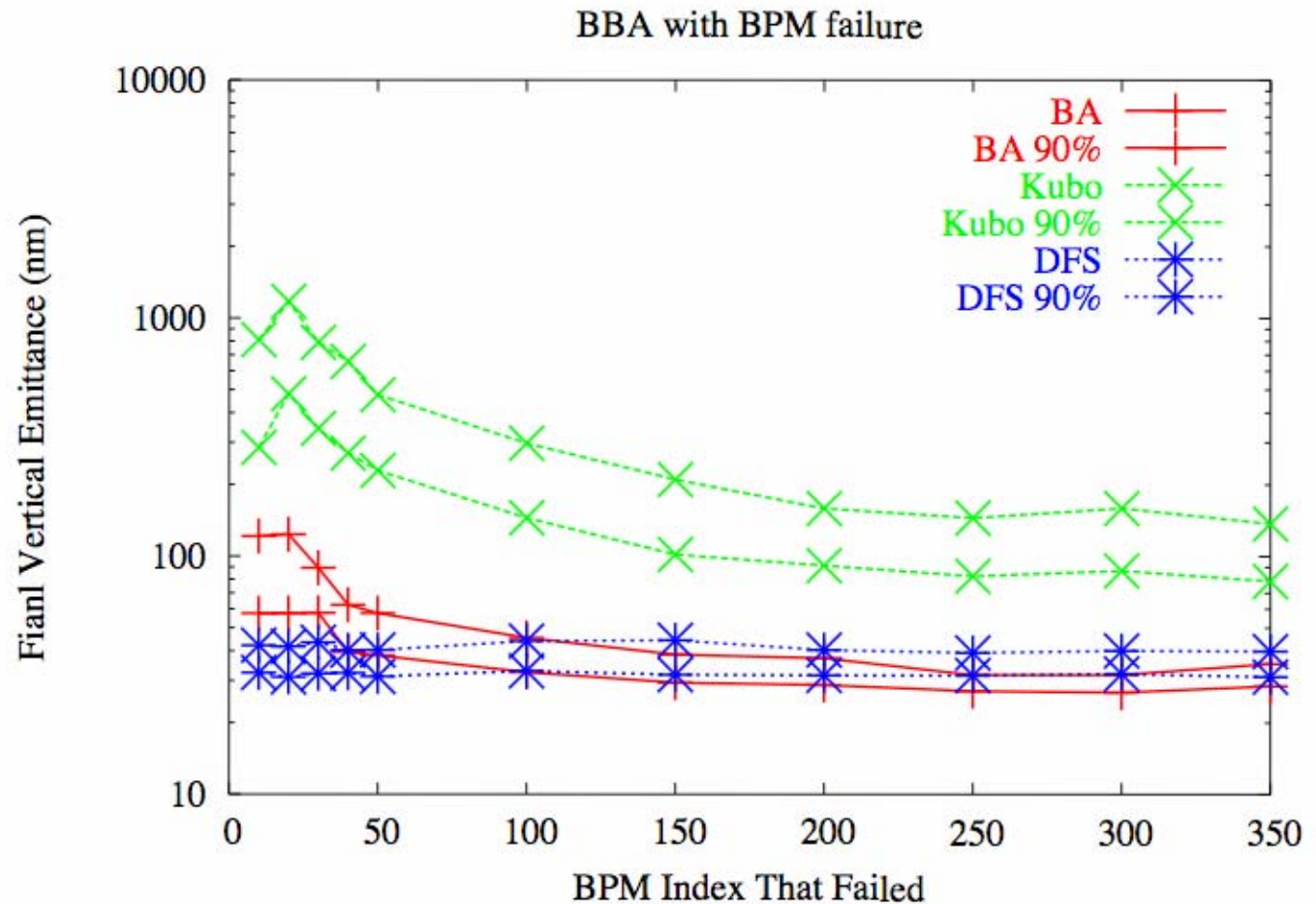
Kubo and BA very sensitive to even a single failed BPM. DFS is very robust.
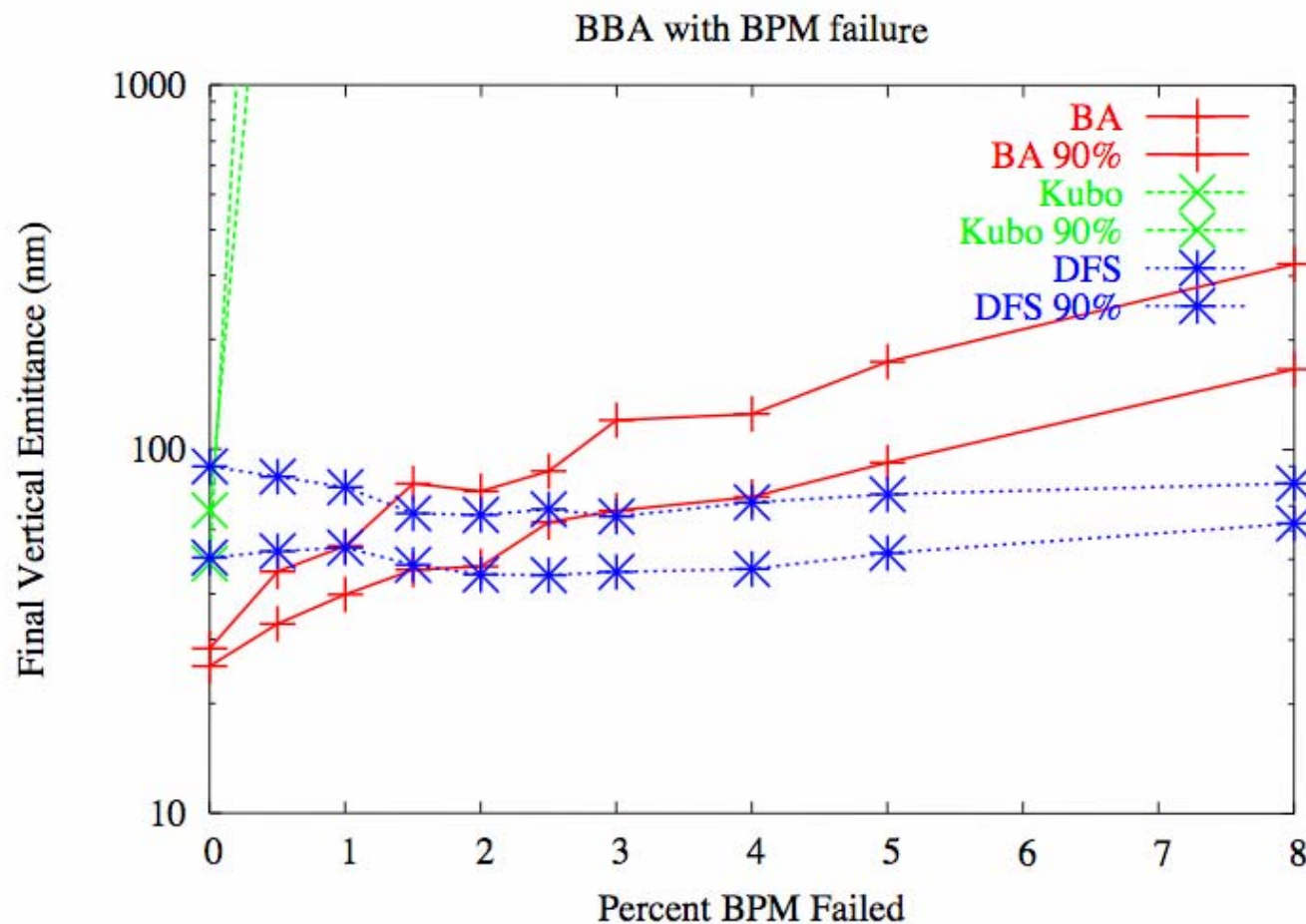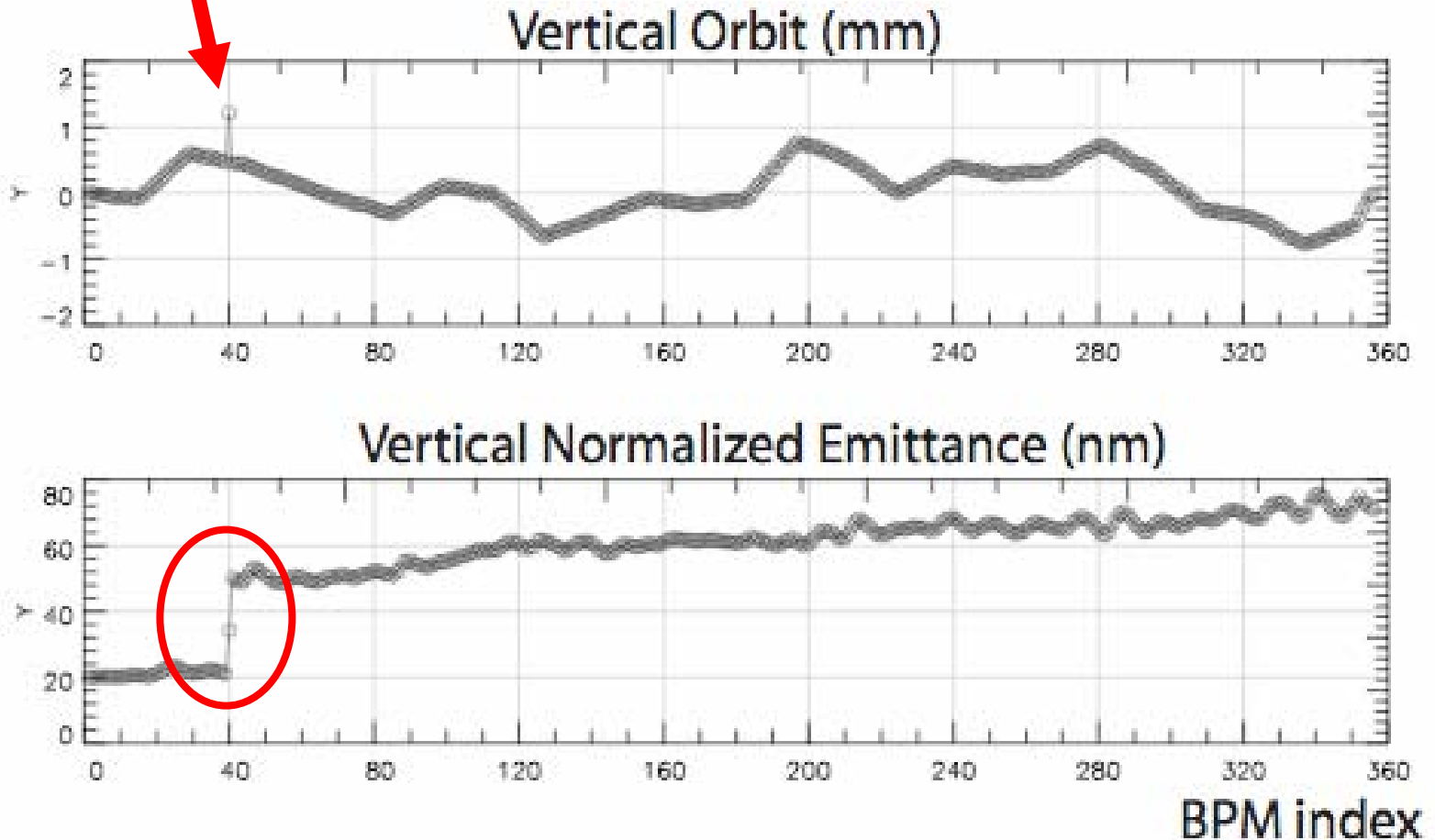

BBA with BPM failure

Kubo is sensitive all the way to the end of Linac. This is due to the beams having a very large orbit after correction.
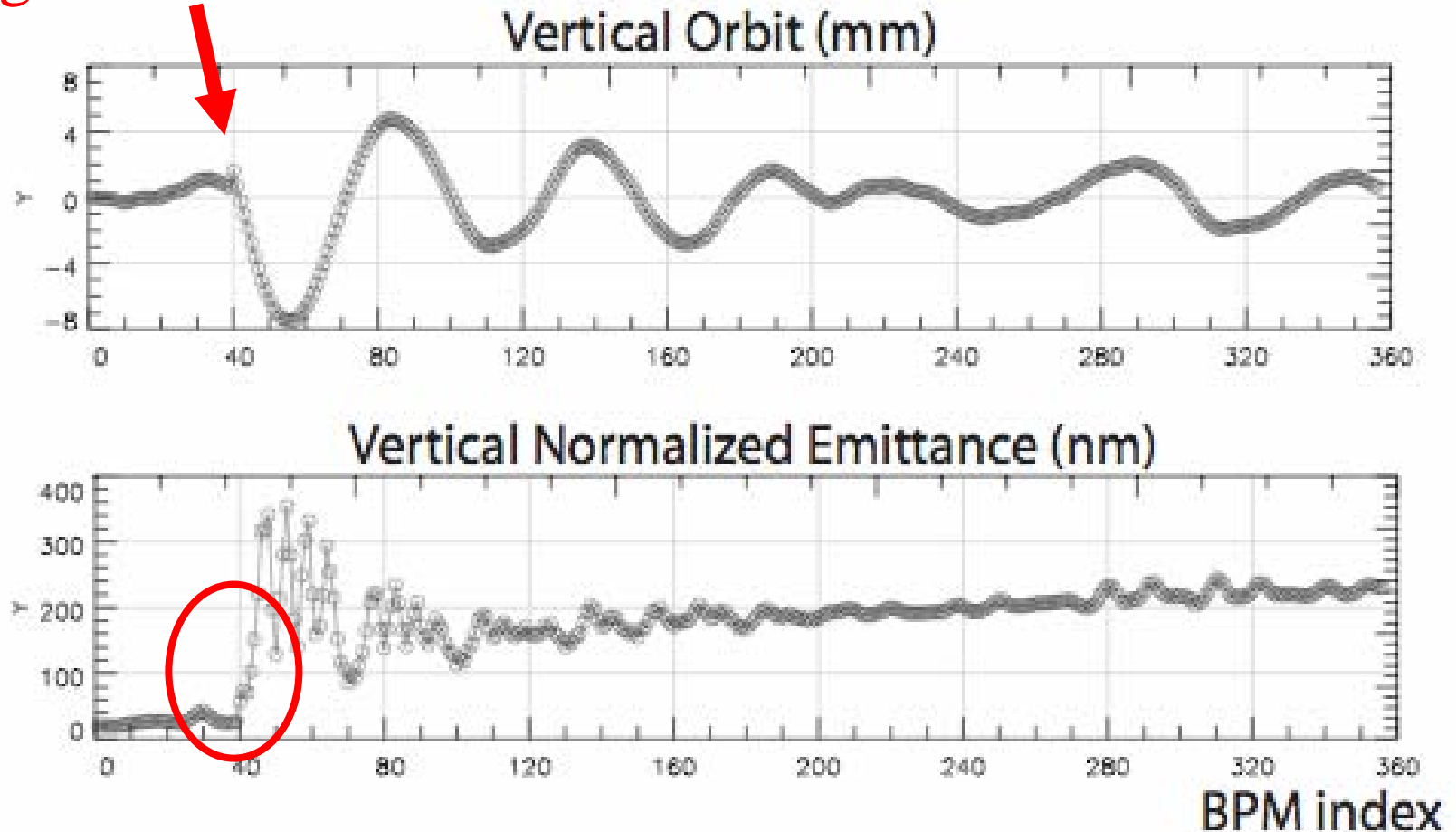

BBA with BPM failure

Single failed BPM

This failed BPM is ignored in the BA algorithm.

Vertical Orbit (mm)

Vertical Normalized Emittance (nm)

BPM index
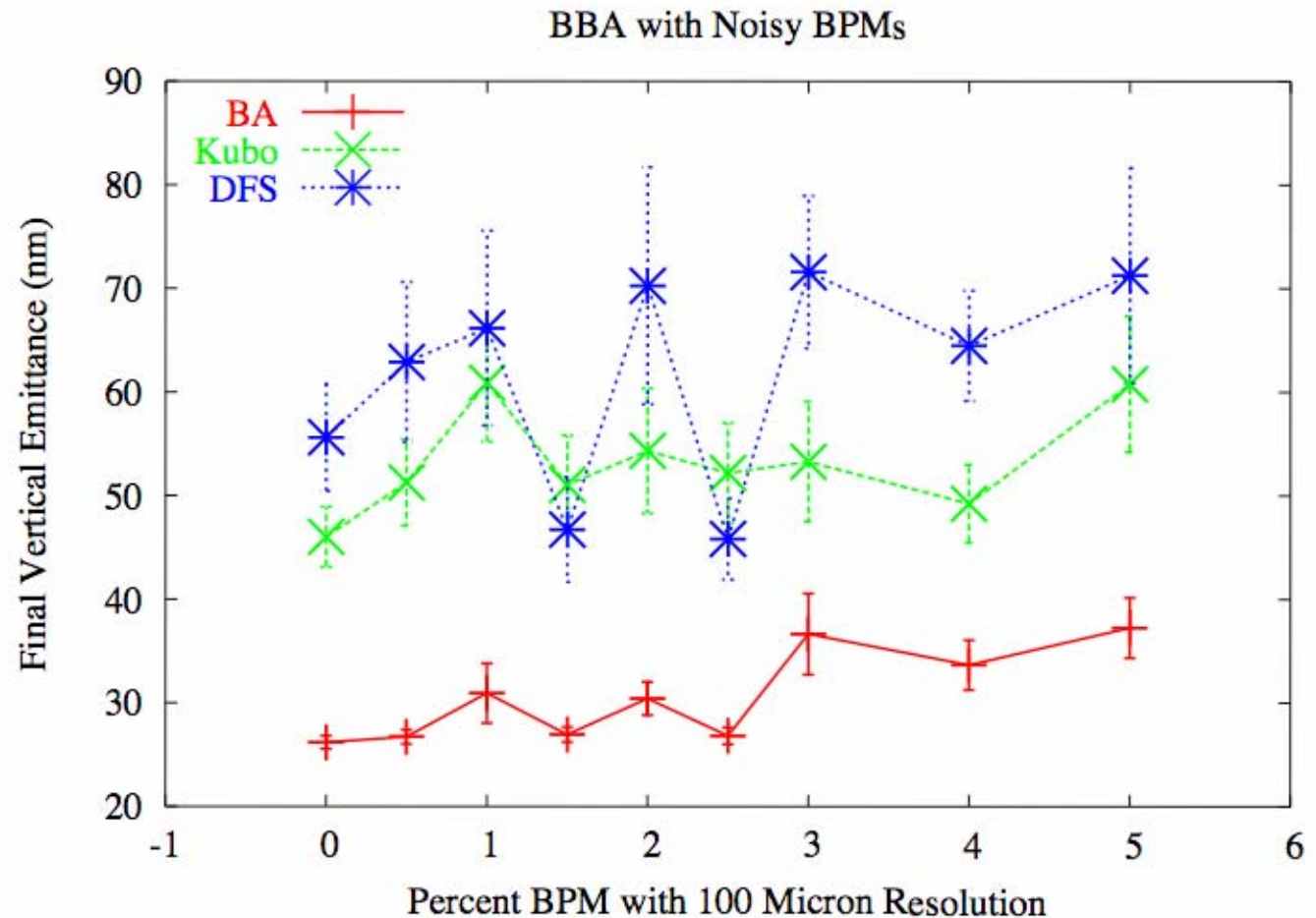
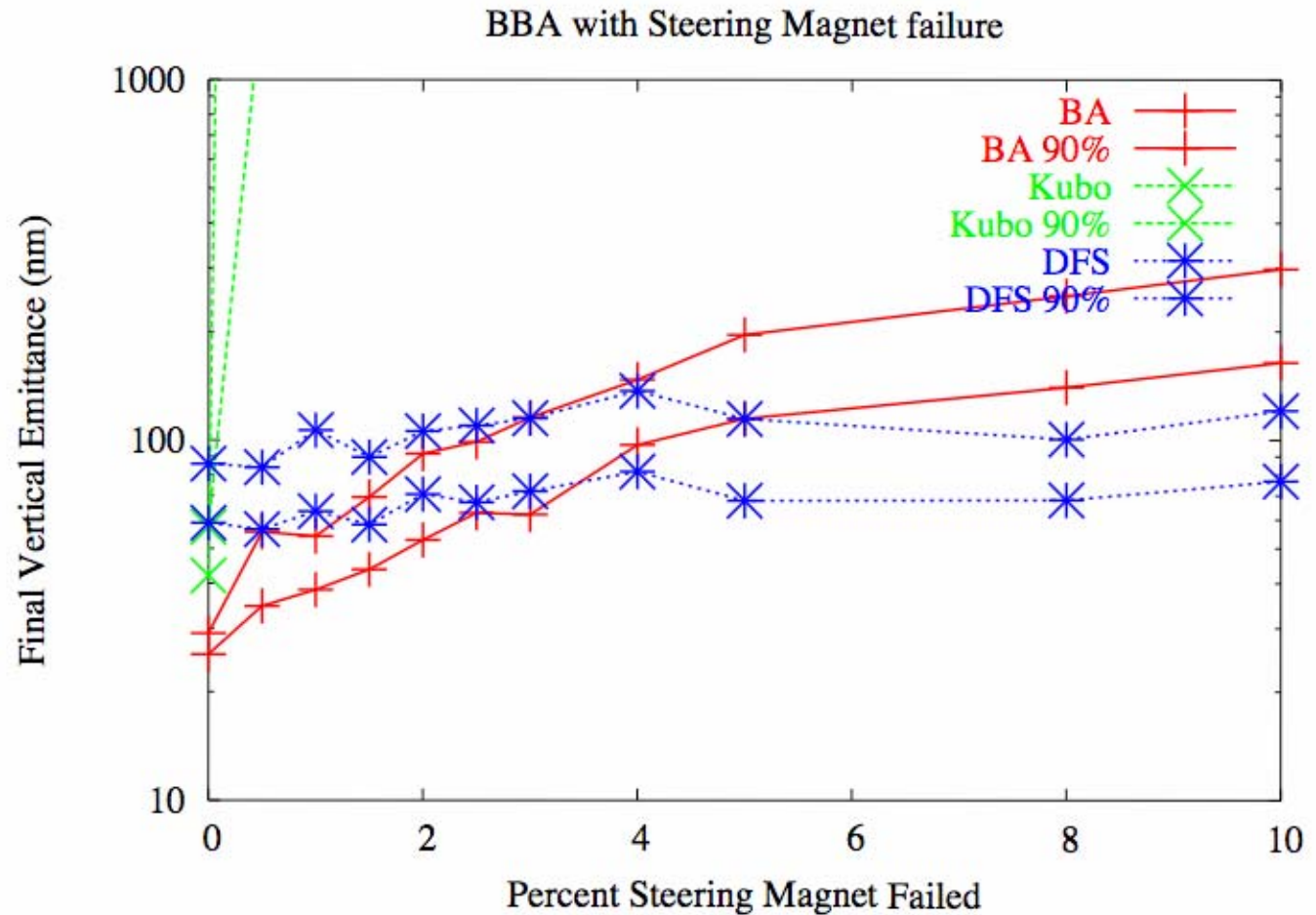This failed BPM is ignored in the Kubo algorithm.

Single failed BPM

If, instead, we have flaky BPMs (with 100 micron resolution) then BA and Kubo behave much better. Now, DFS degrades in performance since it is more sensitive to BPM resolution.

Similar results
for steering
magnet failure.
It's essentially
the same issue.

- Current TTF cavities optimize $E_{peak}/E_{acc} = 2$ which limit the E_{acc} to ~43 MV/m

- Low Loss cavities optimize $B_{peak}/E_{acc} = 3.61(mT/MV/m)$ which limits E_{acc} to ~50 MV/m

  – Allows for operation at higher gradients

  – Allows for operation at lower cryogenic load, 20% less

  – But, for us emittance police, Wakefields are larger

    - k increases by 65%

    - $K_{\parallel}$ increases by 18%

    - Full studies of the functional form of the wakefields appearently have not been undertaken, so, this analysis just scaled the TTF wakes by 65% and 18% .

Here, each RF cavity was vertically misaligned relative to the beam orbit and all quadrupoles were perfectly aligned to the beam orbit. This should give the sensitivity of vertical emittance to RF cavity vertical misalignements alone.

Alignment Sensitivity to Vertical Cavity Offset
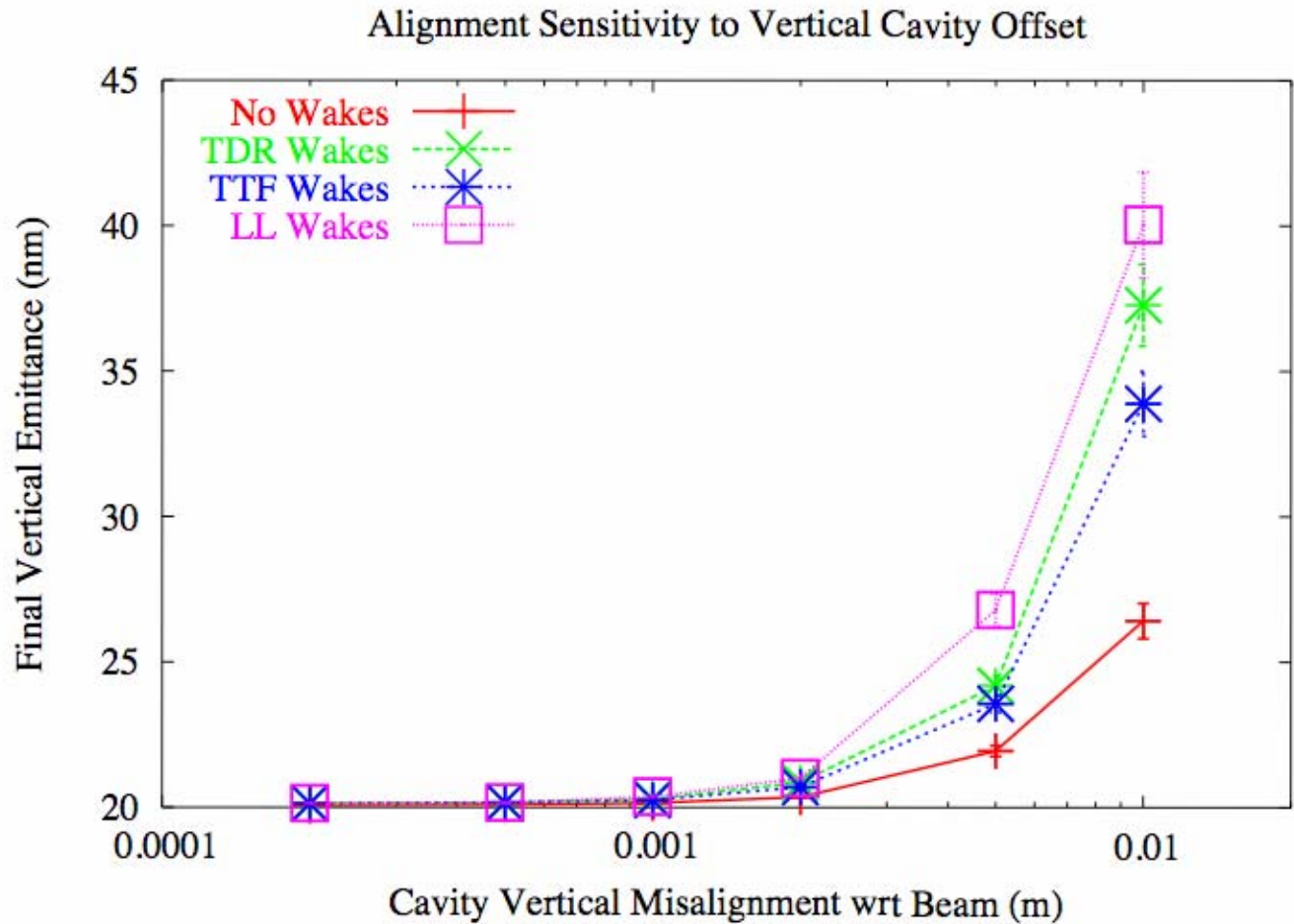
The effects on BBA is not as simple as the alignment sensitivities on the previous slide would suggest. DFS seems to be most sensitive to Wakefields whereas BA is barely effected at all.
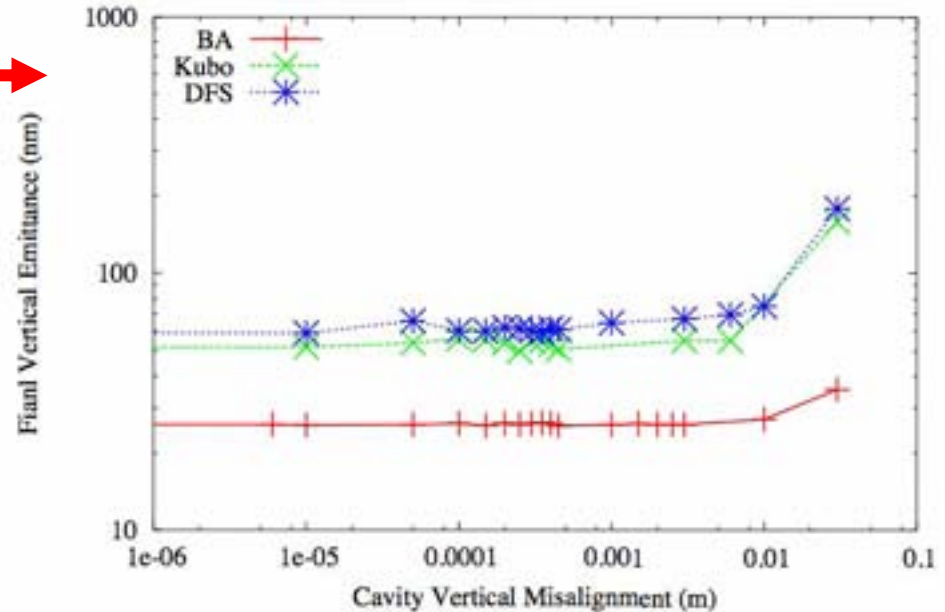

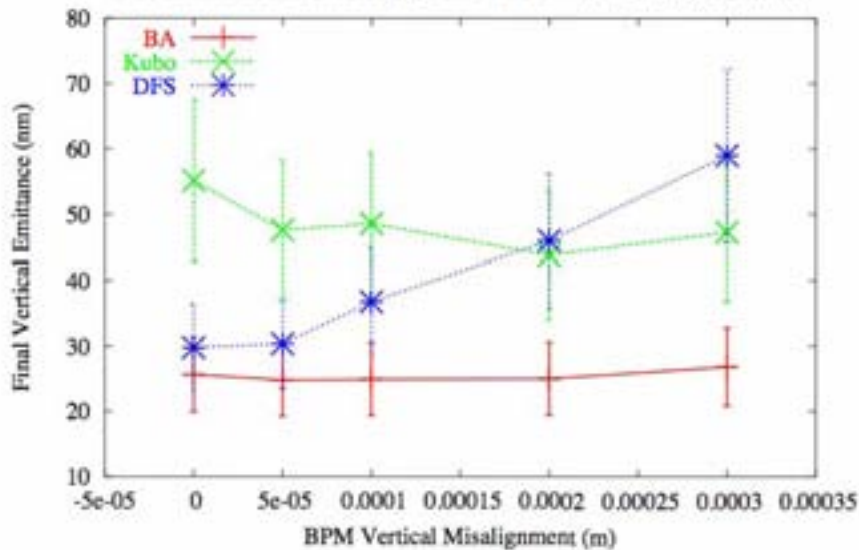BBA with standard misalignments and different strength Wakefields
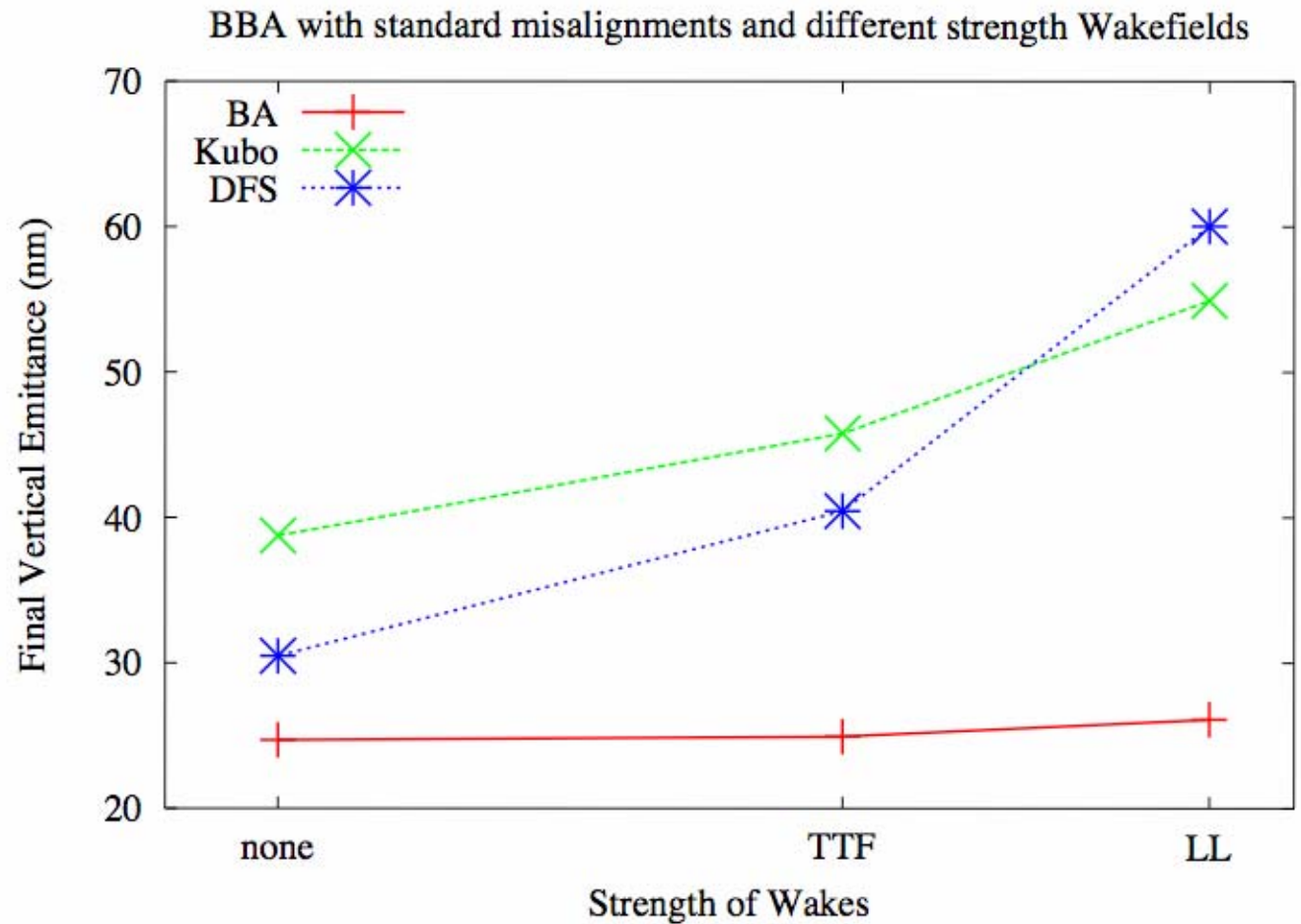
Tighter alignment tolerances on cavity vertical offset will not compensate for stronger wakefields!

BBA versus Cavity Vertical Alignment with Low Loss Cavity Wakefields

BBA versus BPM Vertical Alignment with Low Loss Cavity Wakefields

Increasing the alignment tolerances on the quads and BPMs is what helps. In this case, BPM alignment was increased.

All three alignment algorithms result in a beam orbit on the order of a millimeter or greater, so aligning the RF cavities to greater than a millimeter will do little to reduce the wakefield effects. Considering the very good performance of BA, it appears that having the beam travel in a straight line also mitigates the effects of wakefields.
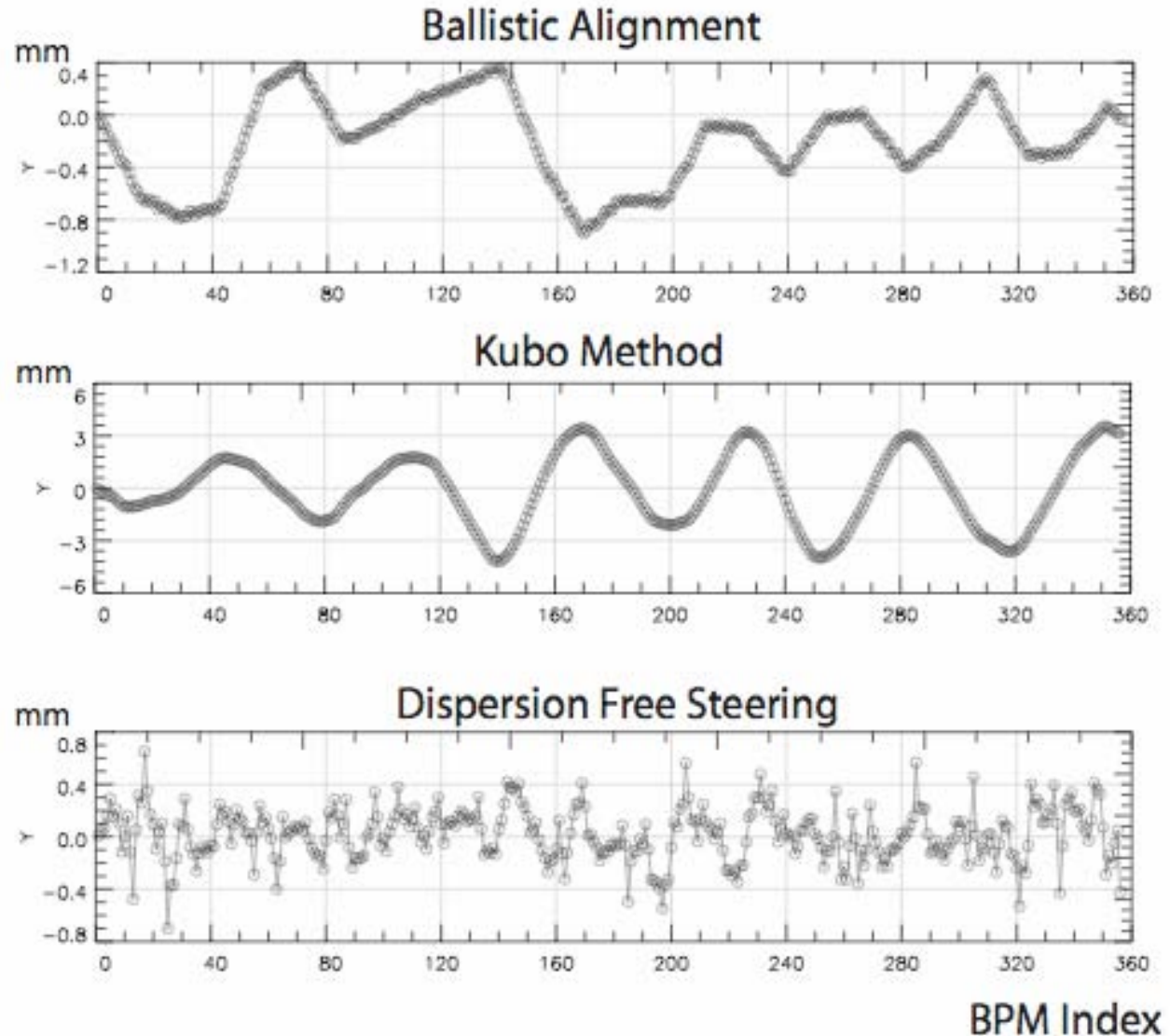
Varying the strength of the BNS Damping also doesn't seem to compensate for the stronger wakefields. Not surprising considering BNS damping corrects for coherent oscillation effects, not the random effects of misaligned structures.

BBA with standard misalignments and Low Loss Cavities

Summary
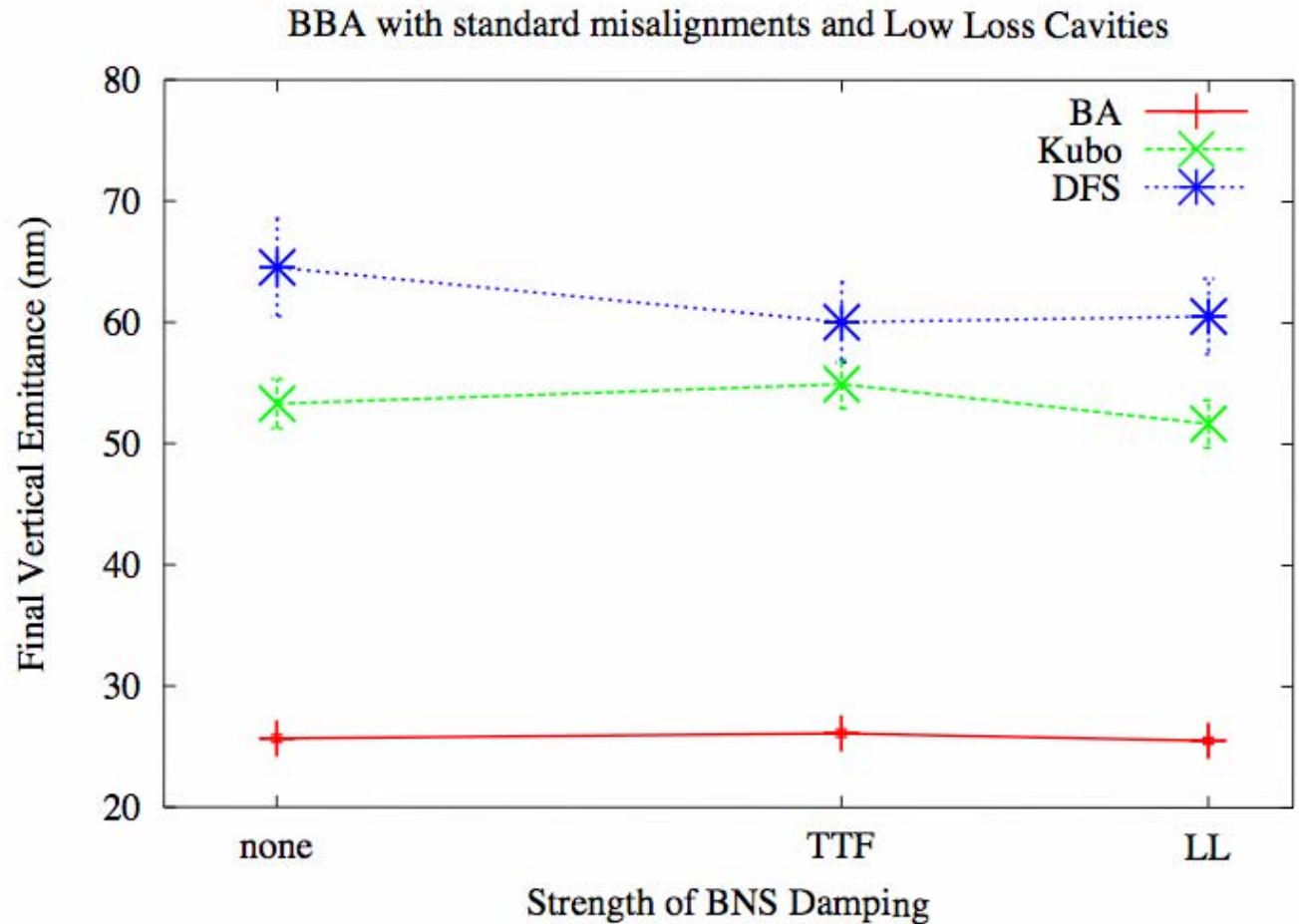
- Increasing BPM resolution from 10 microns to 1 microns has little improvement in performance (of static alignment algorithms)

- Beam jitter was found to have little effect (on static alignment algorithms) up to about 1 σ_y jitter

- Stray Fields have a significant effect on all three algorithms but extending shielding through the first 1500 meters of linac will remove effects (for the TESLA TDR lattice).

- Essentially, a single failed BPM can be detrimental to Kubo and BA. DFS is robust to failed BPMs. However, the opposite is true for noisy BPMs.

- The greater Wakfields of the Low Loss Cavities cannot be mitigated with tighter tolerances of the RF Cavities. *Emittance preservation is tied to quadrupole and BPM alignment*.

Thank You

Special Thanks to:

Theodor Brasoveanu, Gerry Dugan, Kristin Kopp, Kiyoshi Kubo, David Rubin, David Sagan, Jacek Sekutowicz, Peter Tenebaum, Nick Walker, Andy Wolski