# Issues with Static Alignment

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# 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

# BBA Algorithms

- 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    - Unpublished, lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/lcimu-20050325a.pdf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

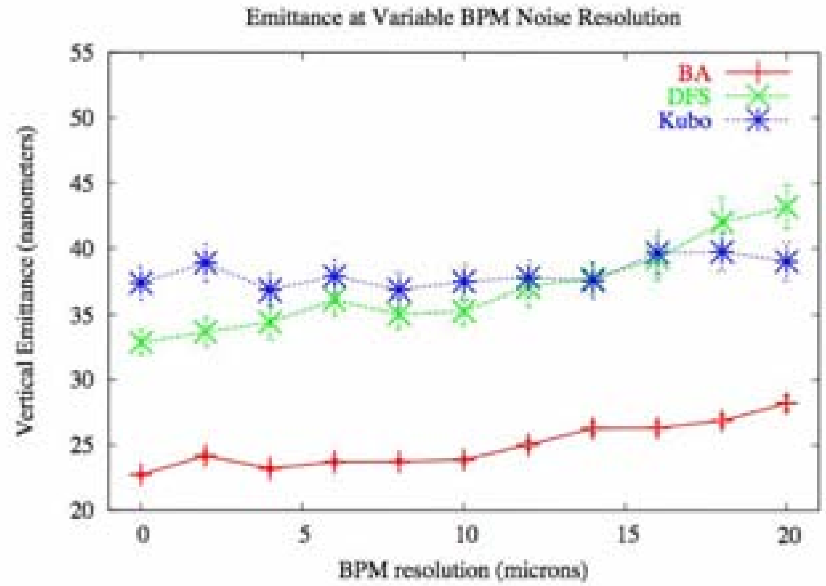
# Nominal Misalignments

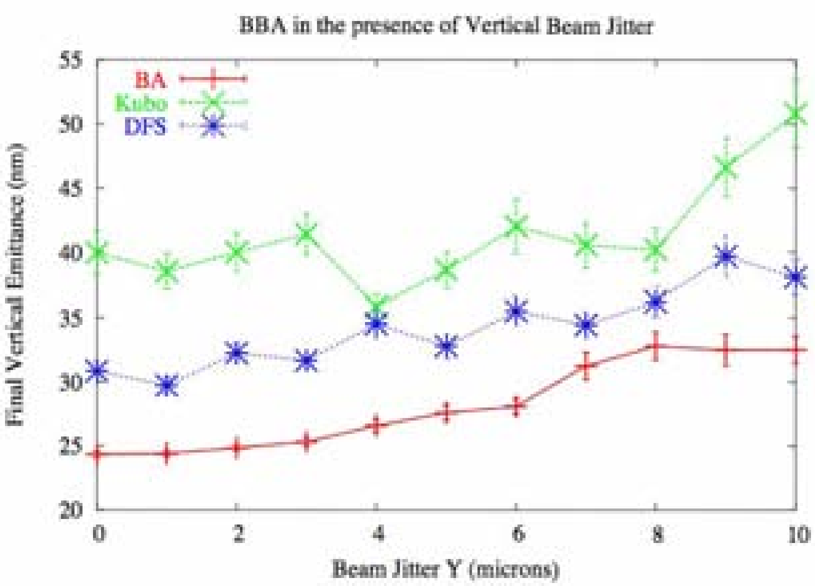
In all the following analysis, unless otherwise specified, these standard misalignments where used. The point of this analysis wasn't to find alignment tolerances but examine the effects of other issues in the presence of element misalignments.

| 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 and Jitter

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




Beam Jitter also found not to be a serious issue up to 1 sigma rms jitter.

# Stray Fields

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.

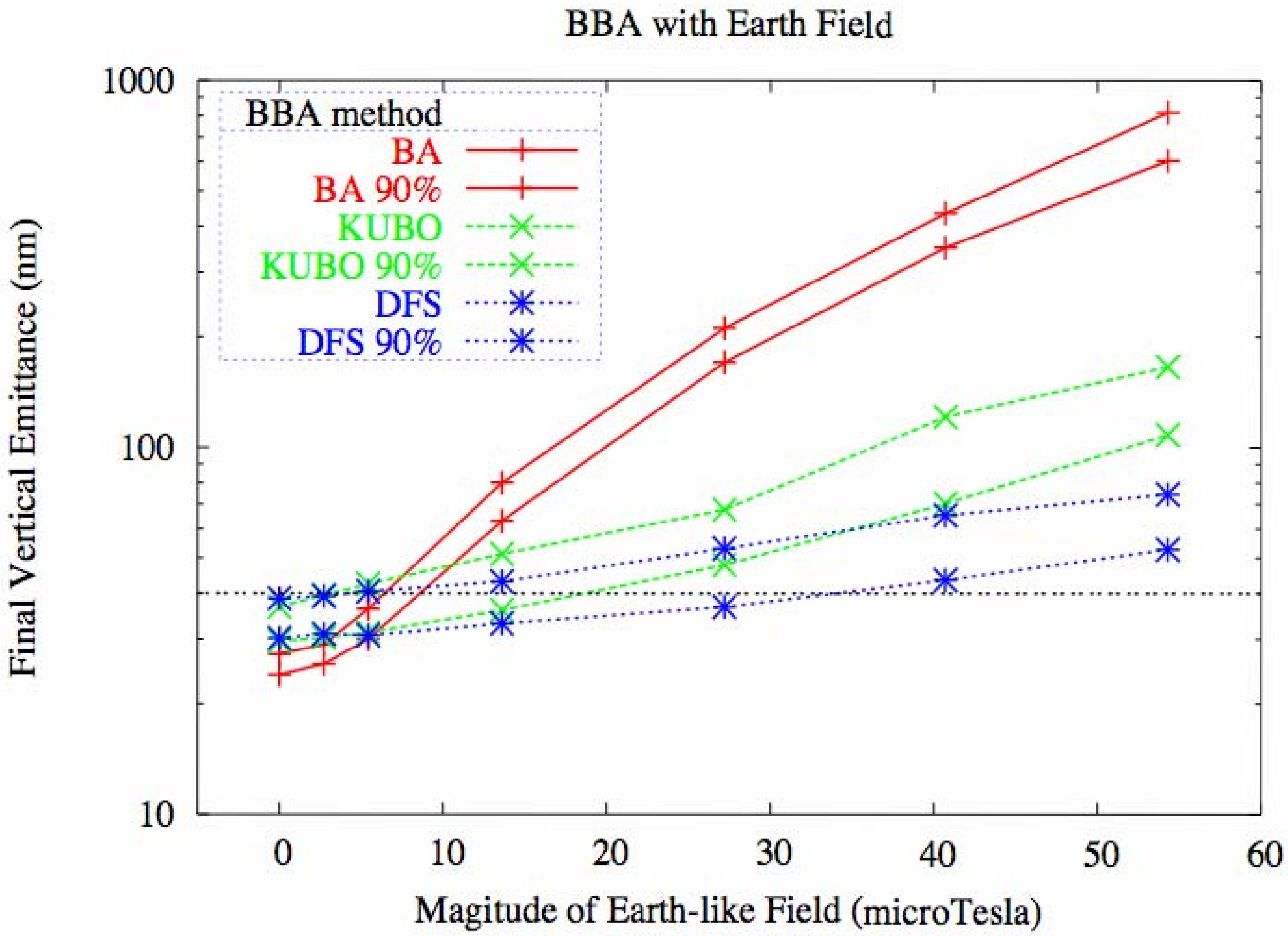
Since Earth's field is known, compensation should be possible, but this analysis will also give the effects of other unknown stray fields.

The Earth field was varied from 0 to its full strength of 54.3 micro-Tesla.

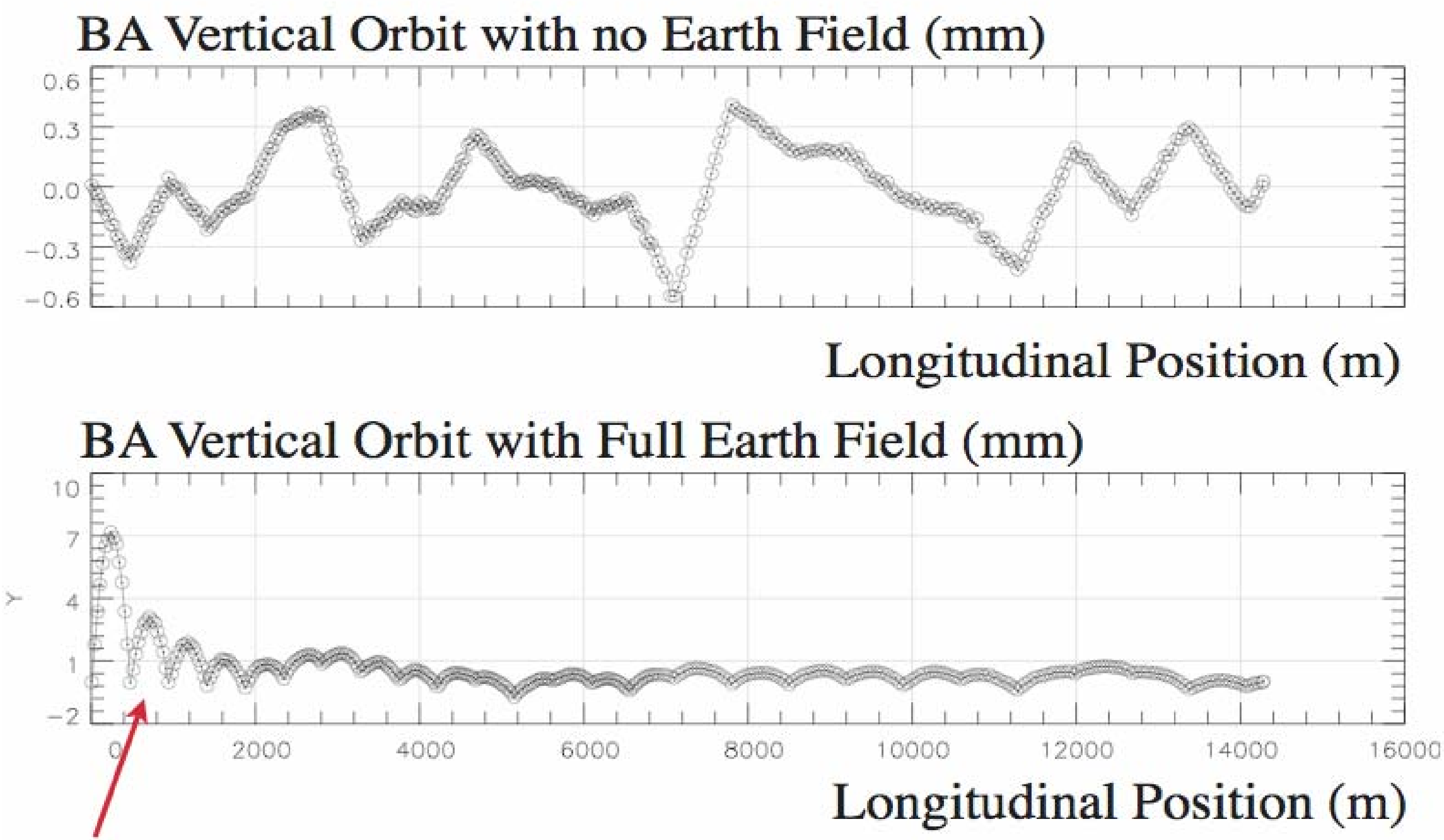
Earth's field in Ithaca, NY:

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

# Effects of an Earth-like Field



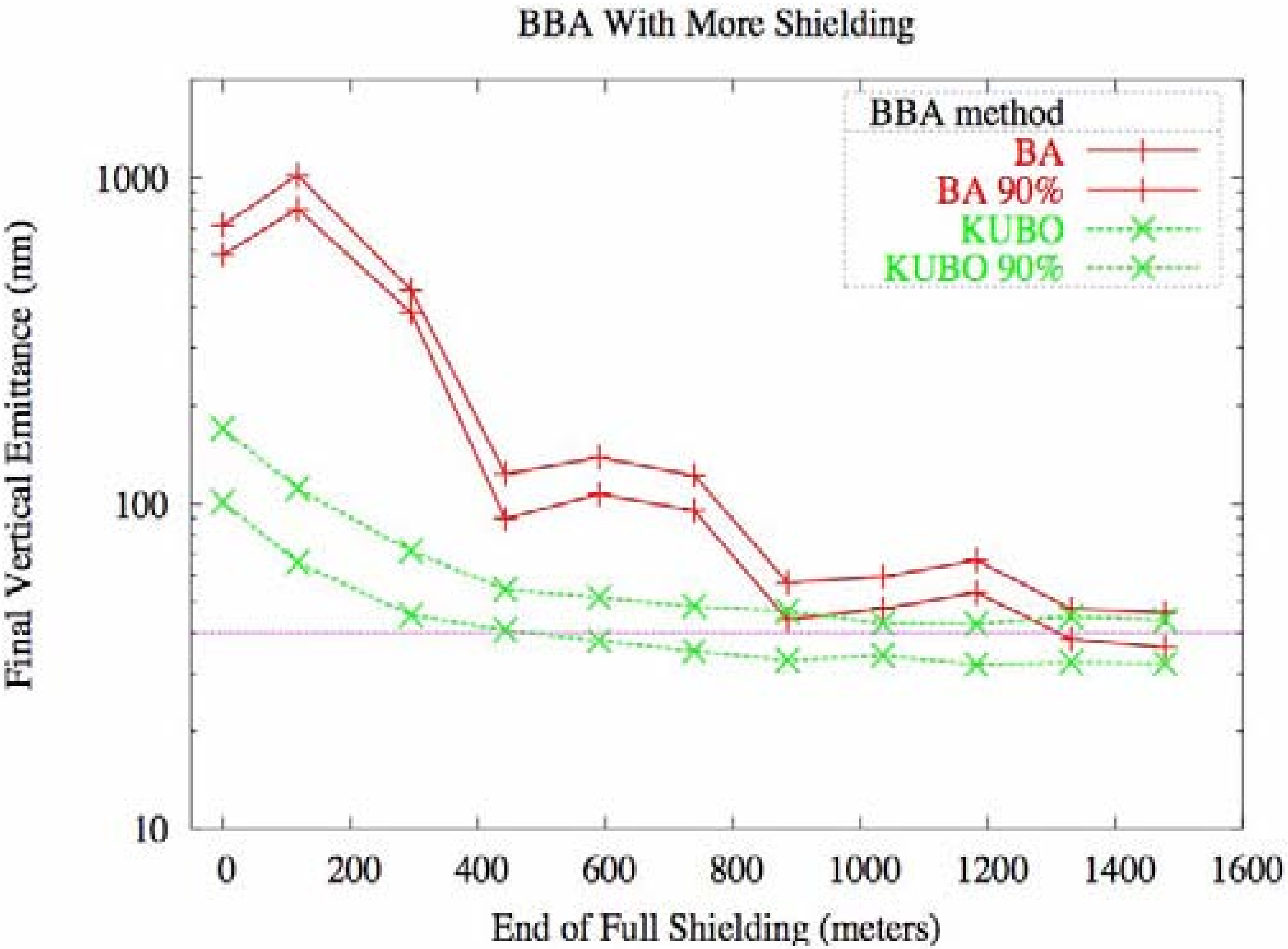
# More Shielding




Earth field effects mainly the first 1500 meters.

# Extending Shielding

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.



# BPM and Steering Failure

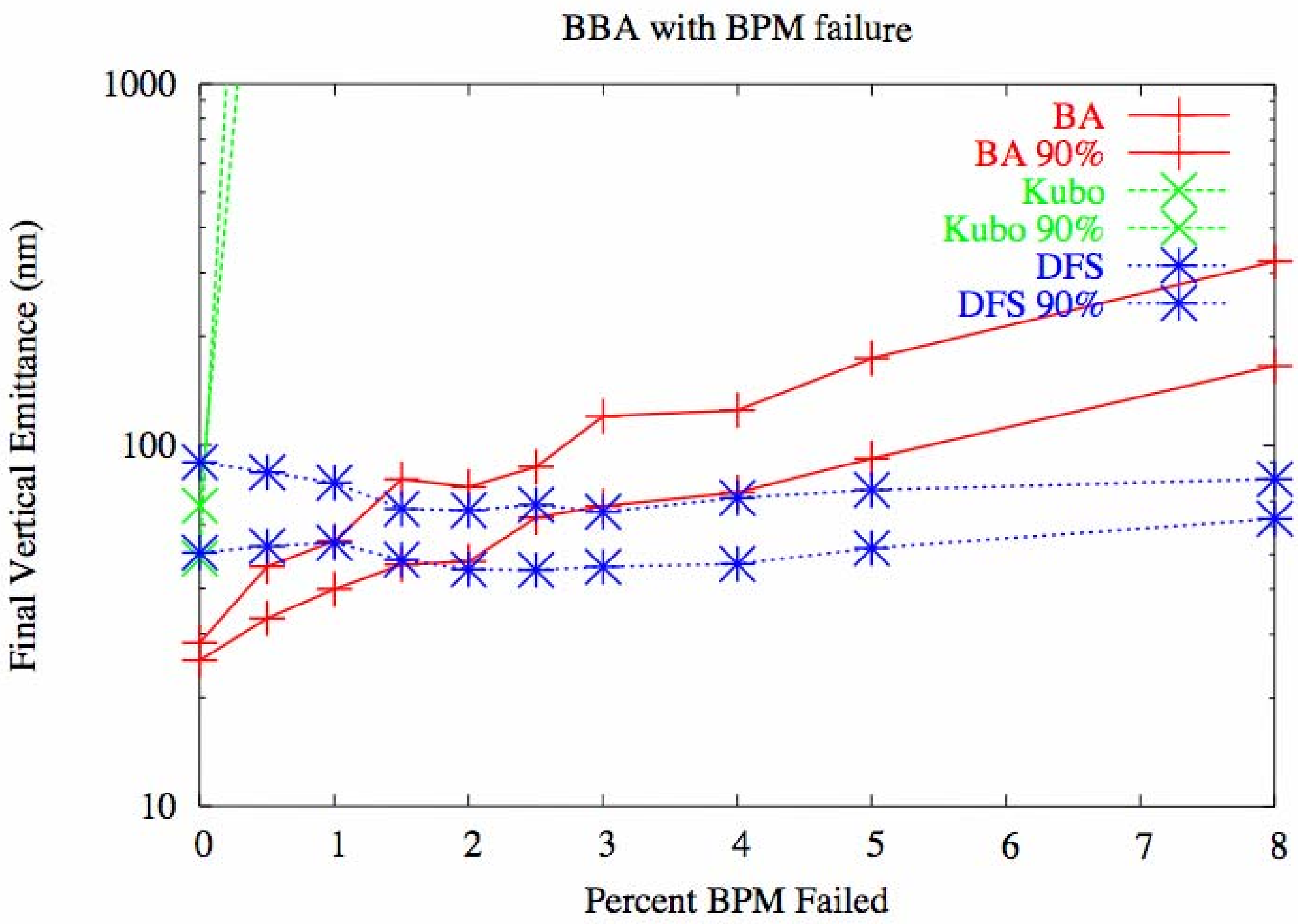
This analysis assumed the failed BPMs or steering magnets have been identified and "vetoed."

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)

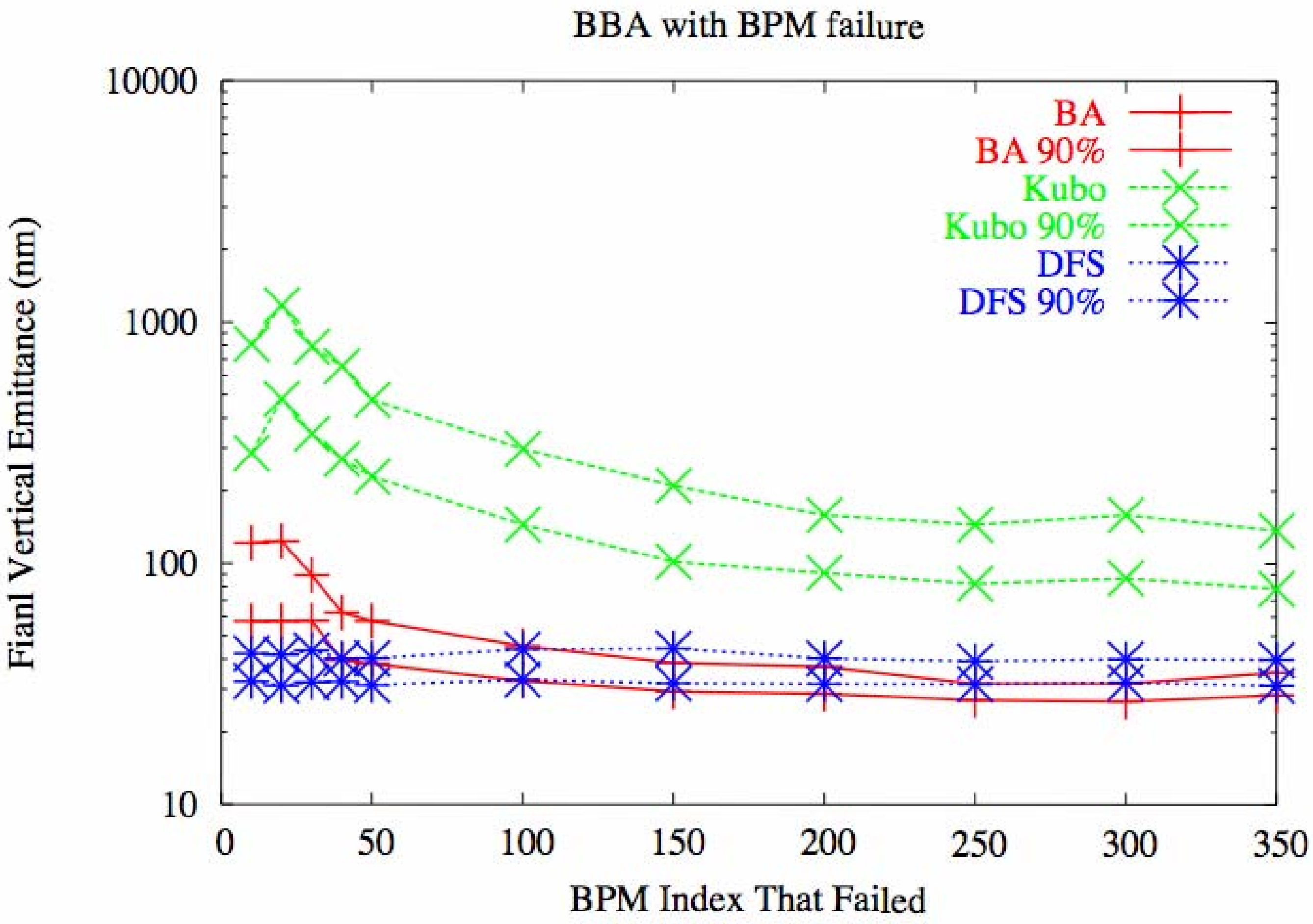
# BPM failure

Kubo and BA very sensitive to even a single failed BPM. DFS is very robust.



# BPM failure

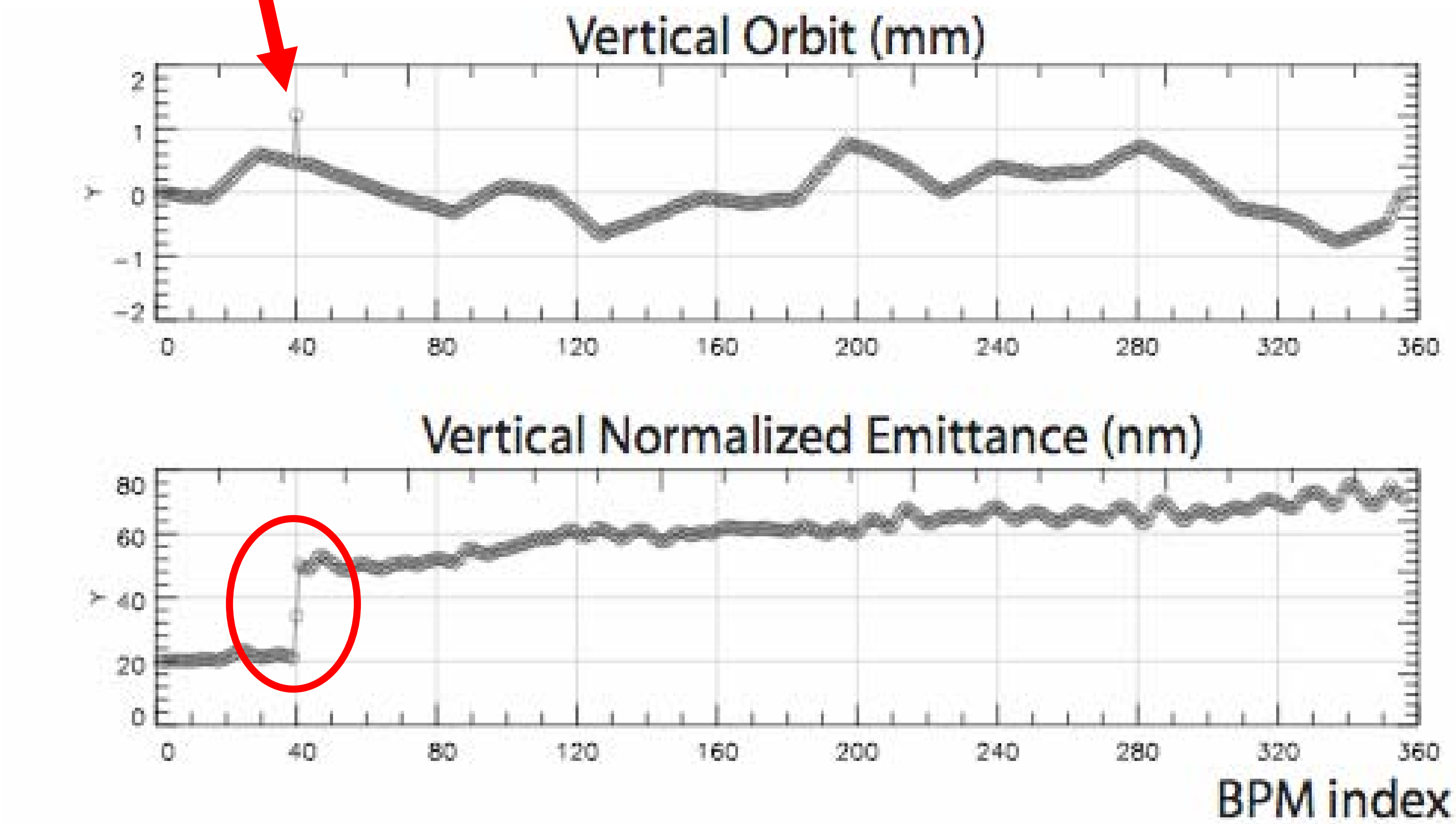
Kubo is sensitive all the way to the end of Linac. This is due to the beams having a very large orbit after correction.



# BA with BPM failure

Single failed BPM

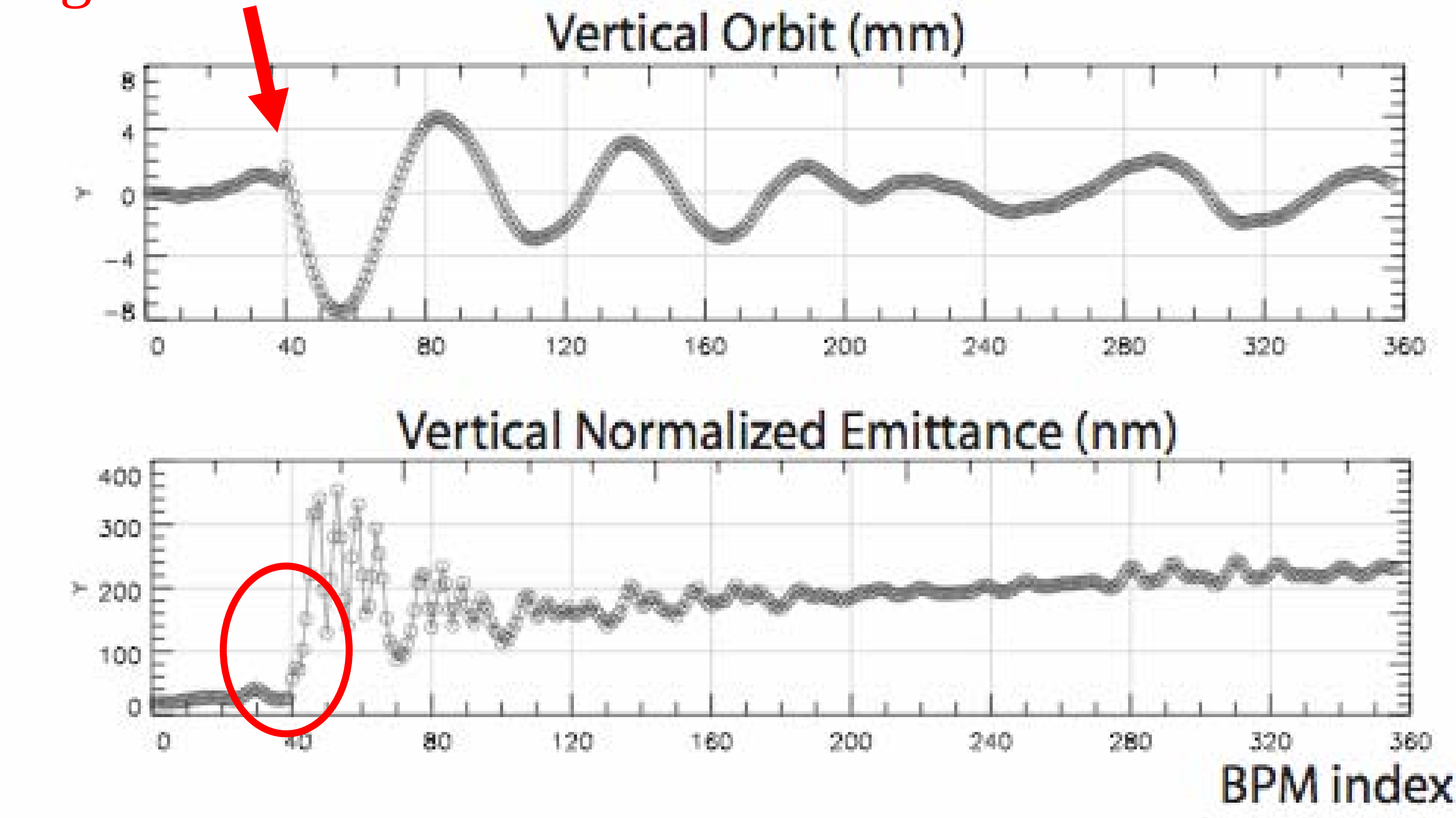
This failed BPM is ignored in the BA algorithm.



# Kubo with BPM Failure

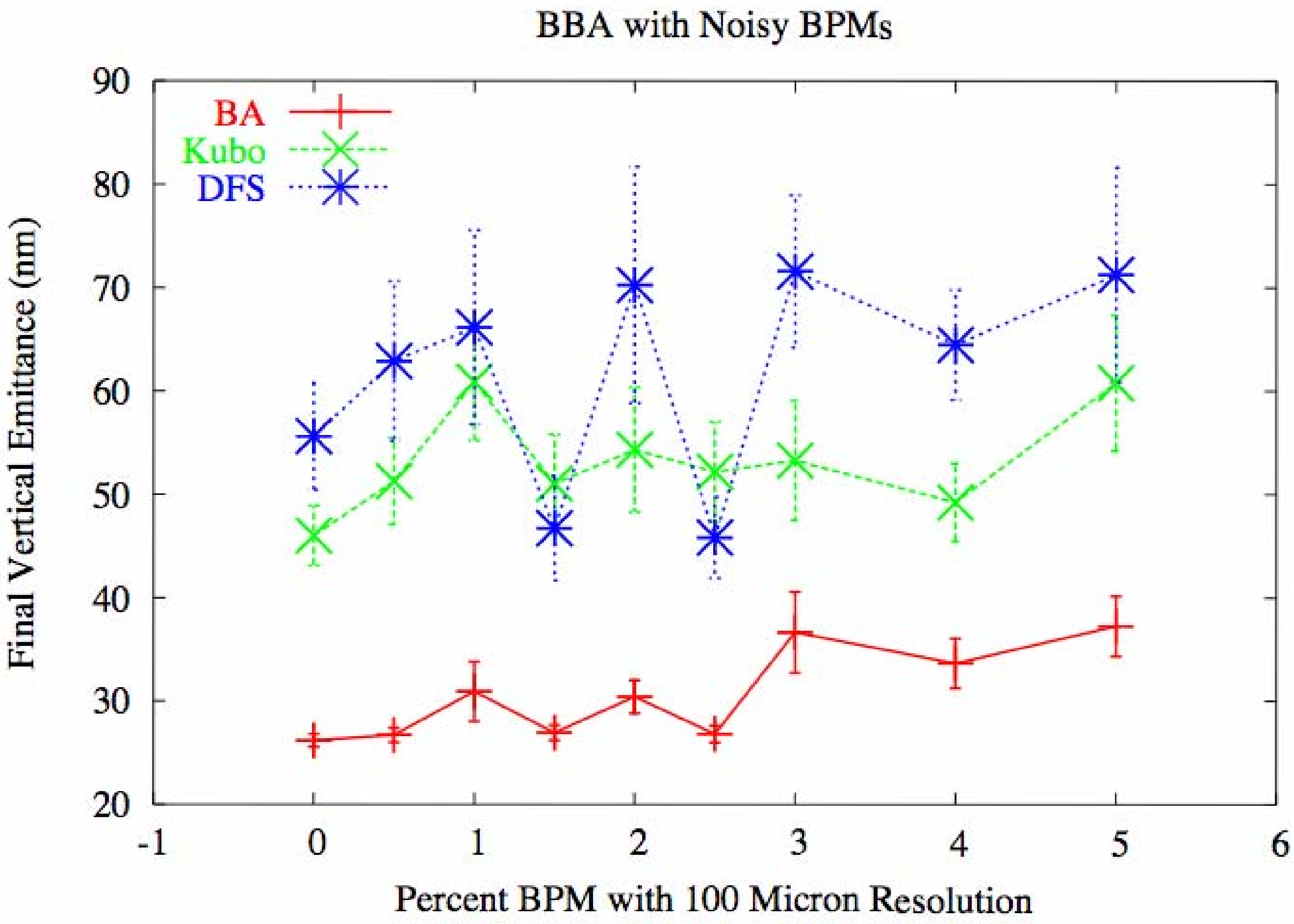
This failed BPM is ignored in the Kubo algorithm.

Single failed BPM



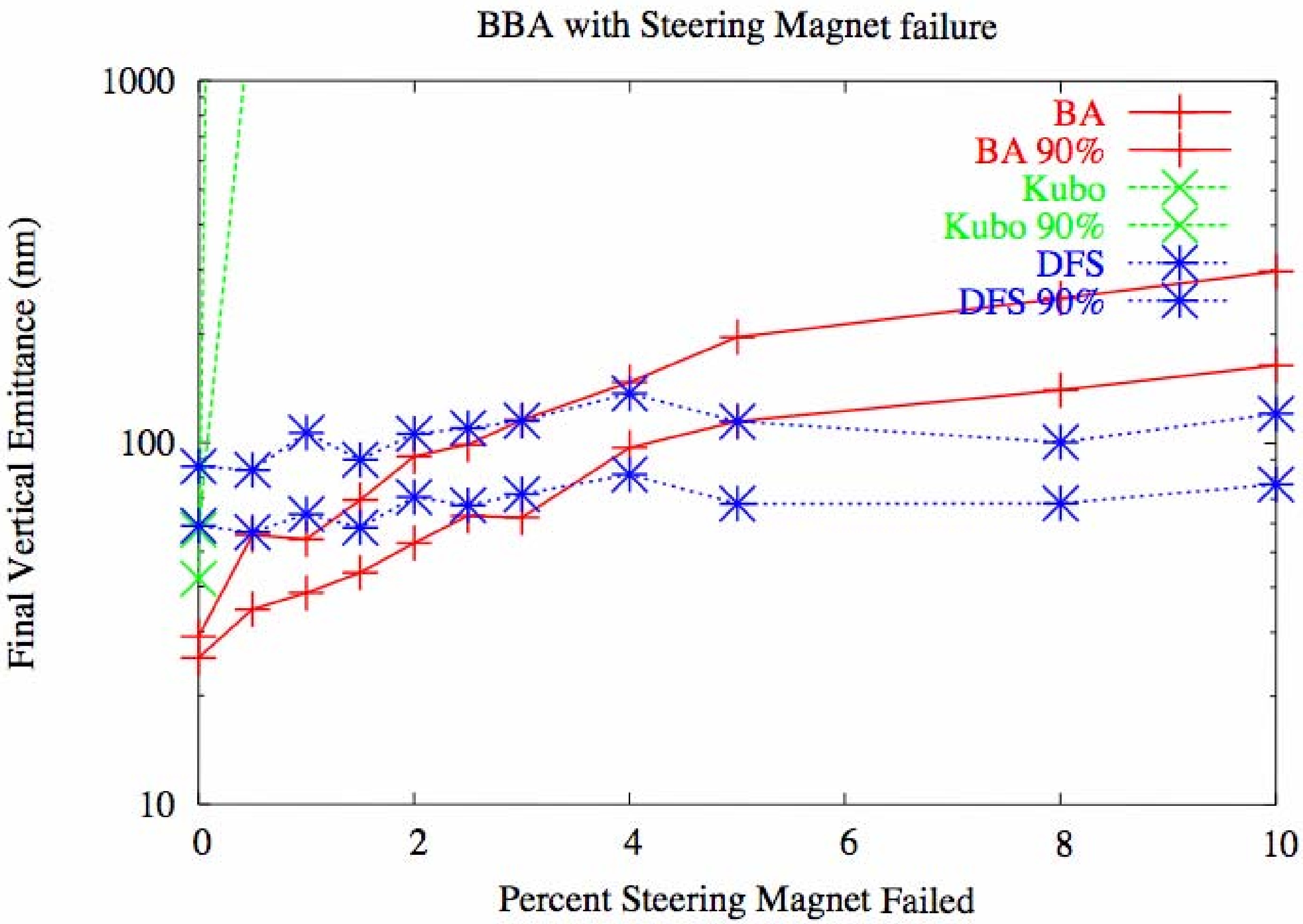
# Noisy BPMs

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.



# Steering Magnet Failure

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

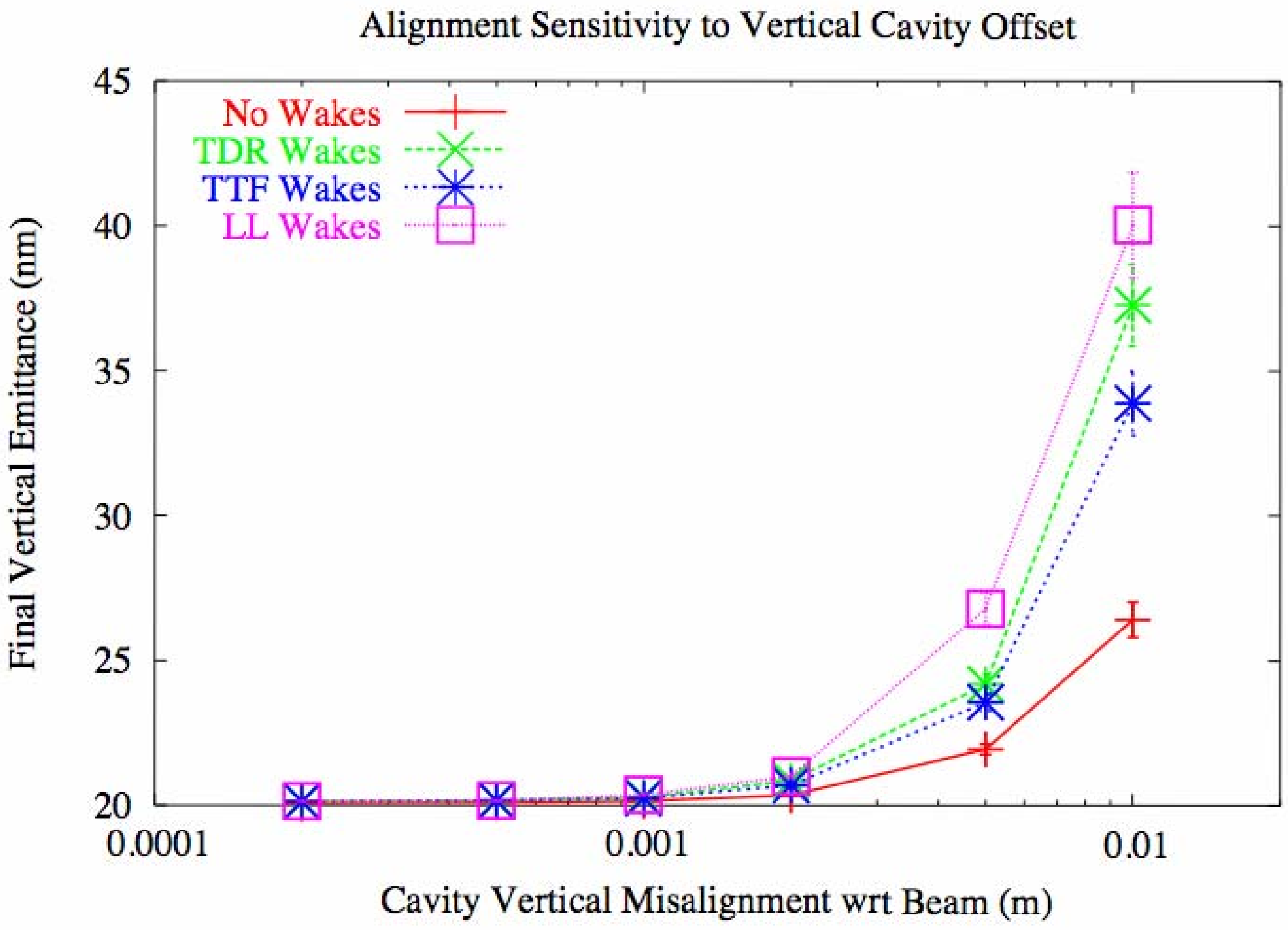


# Low Loss Cavities

- 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%
    - $K_{||}$ 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%.

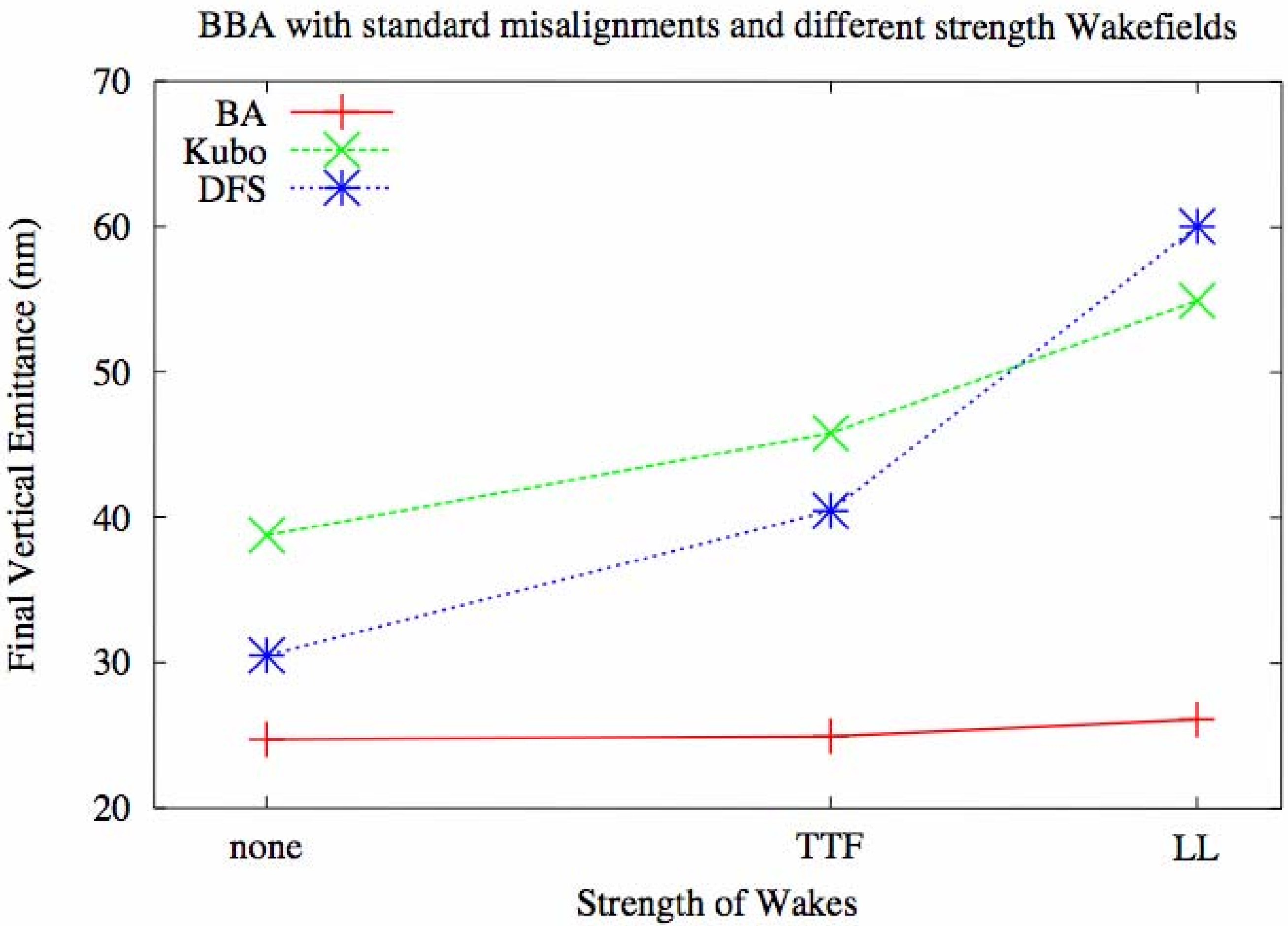
# Alignment Sensitivity

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.



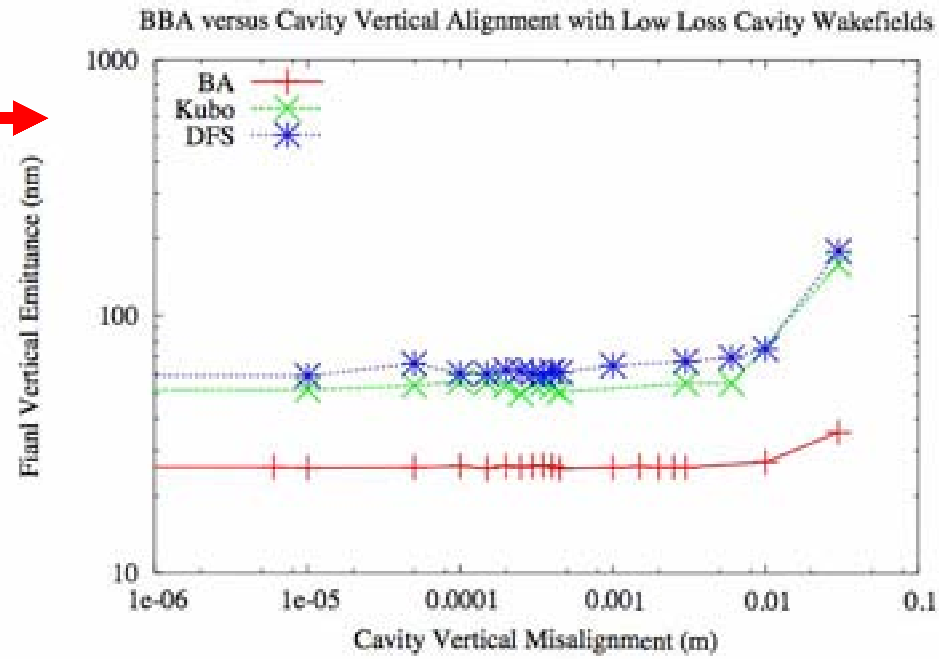
# Effects of Stronger Wakes on BBA

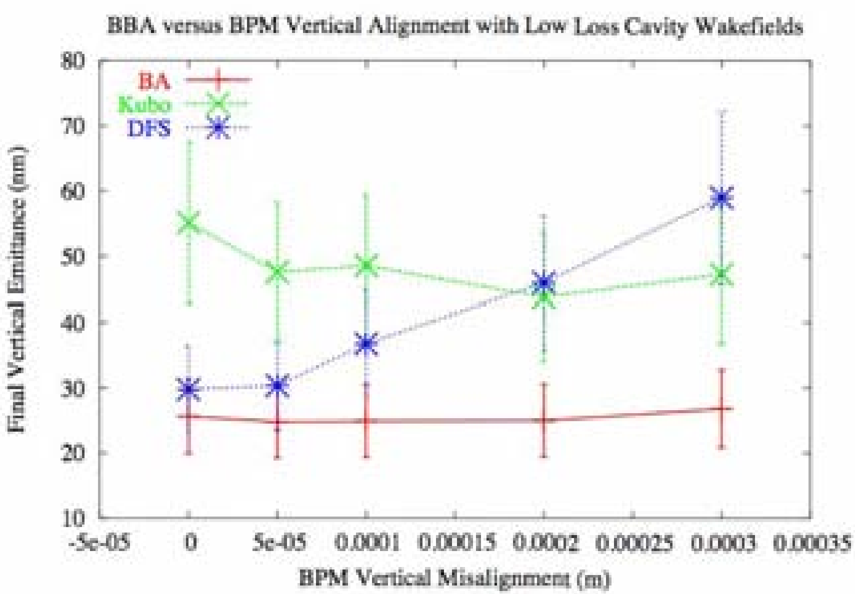
The effects on BBA is not as simple as the alignment sensitivities on the previous slide would suggest. DFS seems to be most sensitive to Wakefields whereas BA is barely effected at all.



# Compensation with Tighter Alignment Tolerance

Tighter alignment tolerances on cavity vertical offset will not compensate for stronger wakefields!

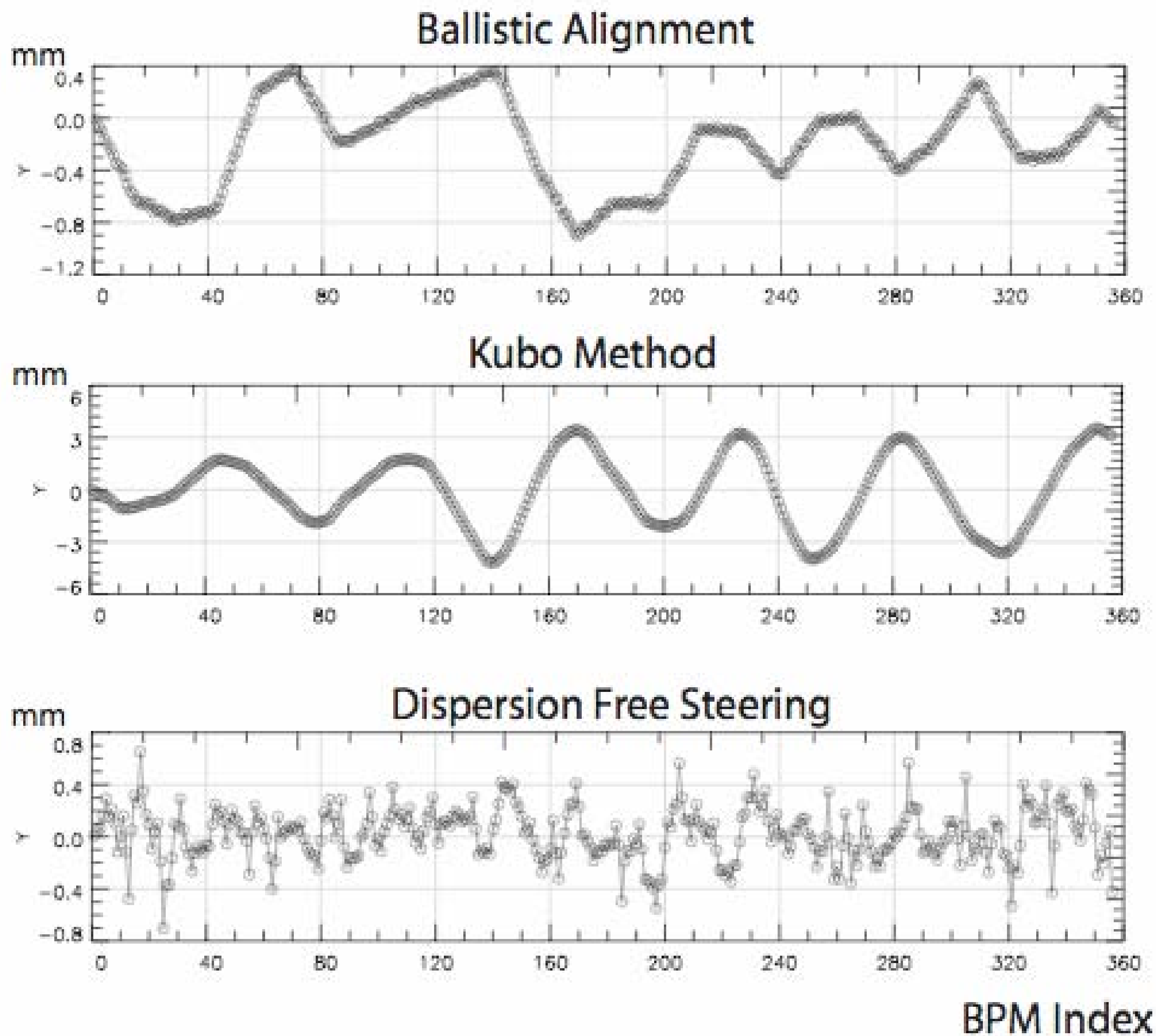



Increasing the alignment tolerances on the quads and BPMs is what helps. In this case, BPM alignment was increased.

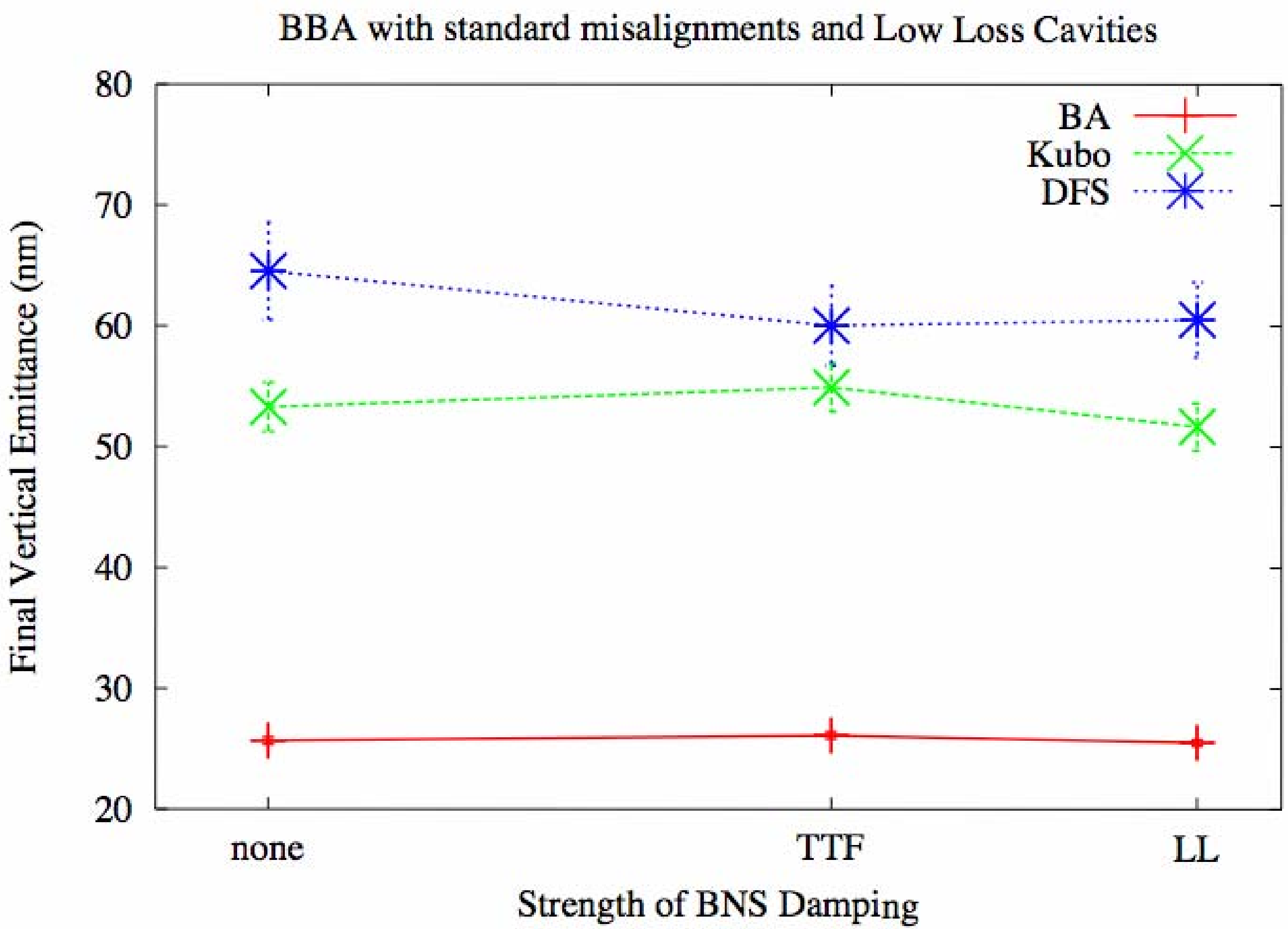
# Reducing the Effects of the Stronger Wakes

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.



# What about BNS Damping?

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.



# 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 $_{y}$ 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

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