Main Linac Emittance Preservation

with bonus material not found in plenary edition

Vancouver GDE Meeting 2006
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People Contributing to Talk

- Kiyoshi Kubo, *KEK*
- Peter Tenenbaum, *SLAC*
- Peder Eliasson, Andrea Latina, Daniel Schulte, *CERN*
- Jeffrey Smith, *Cornell*
- Freddy Poirier, Nicholas Walker, *DESY*

Areas touched on in this talk

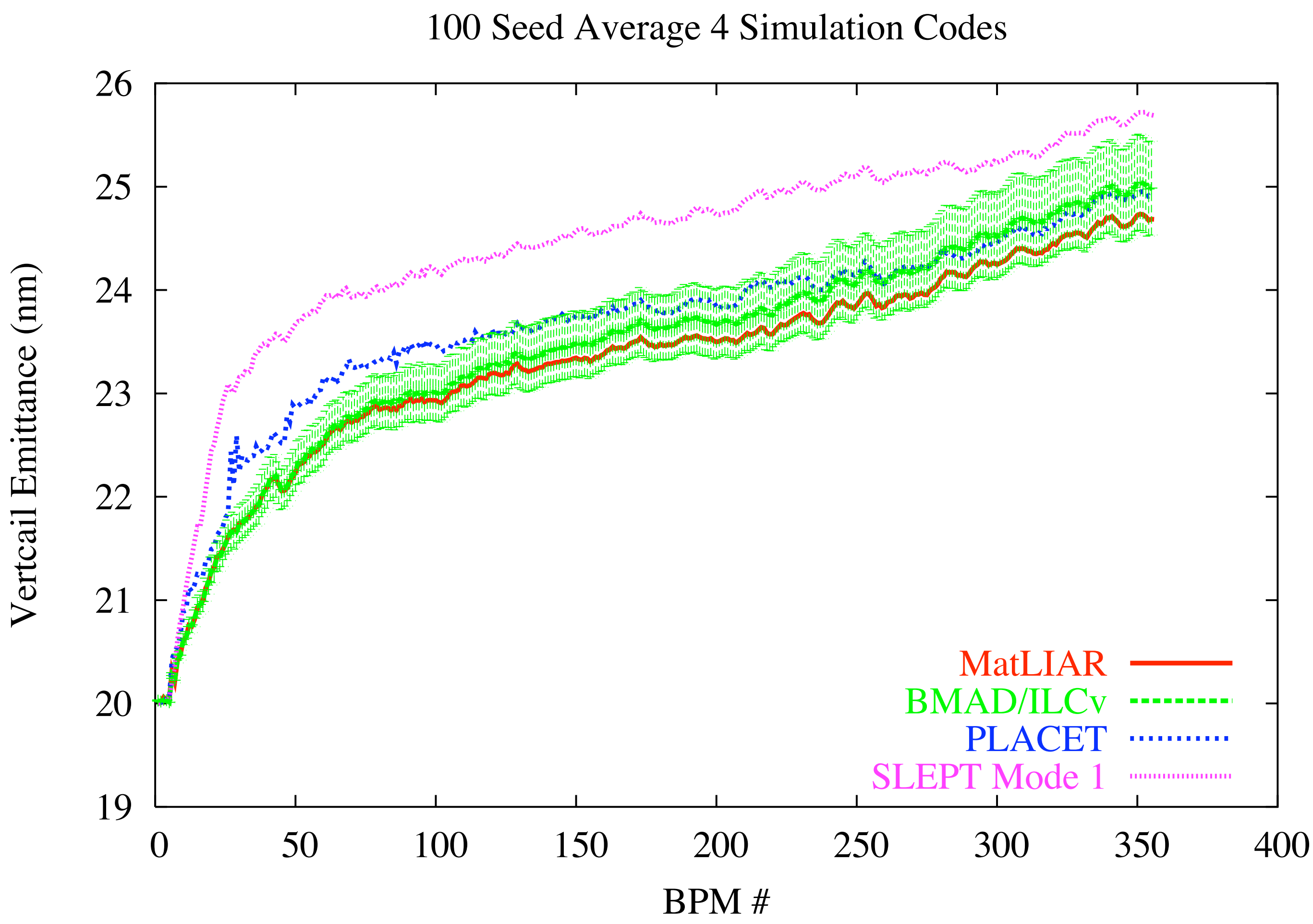
- Benchmarking/Crosschecking simulation codes
  - **In good shape, but more can be done**
- Analysis of SLEPT DFS modes in ILCv
- Dispersion bumps - Peder and Andrea
- Use BC for ML DFS - Andrea
- BPM scale errors - Peder and Andrea
- Dynamic Studies - Daniel
  - **beam jitter**
  - **quadrupole jitter**

Benchmarking/Crosschecking

- The Problem
  - **Different simulations codes get slightly (sometime grossly) different results when performing, in particular, Dispersion Free Steering**
  - **Is this due to differences in code, misalignments or algorithm?**
  - **Previous crosschecking studies were only performed with simple tracking simulations and not with a fully developed alignment algorithm**
  - **After successful completion, we will have a "benchmark" for all new simulation codes to compare to if beginning ILC LET work.**

Benchmarking/Crosschecking results

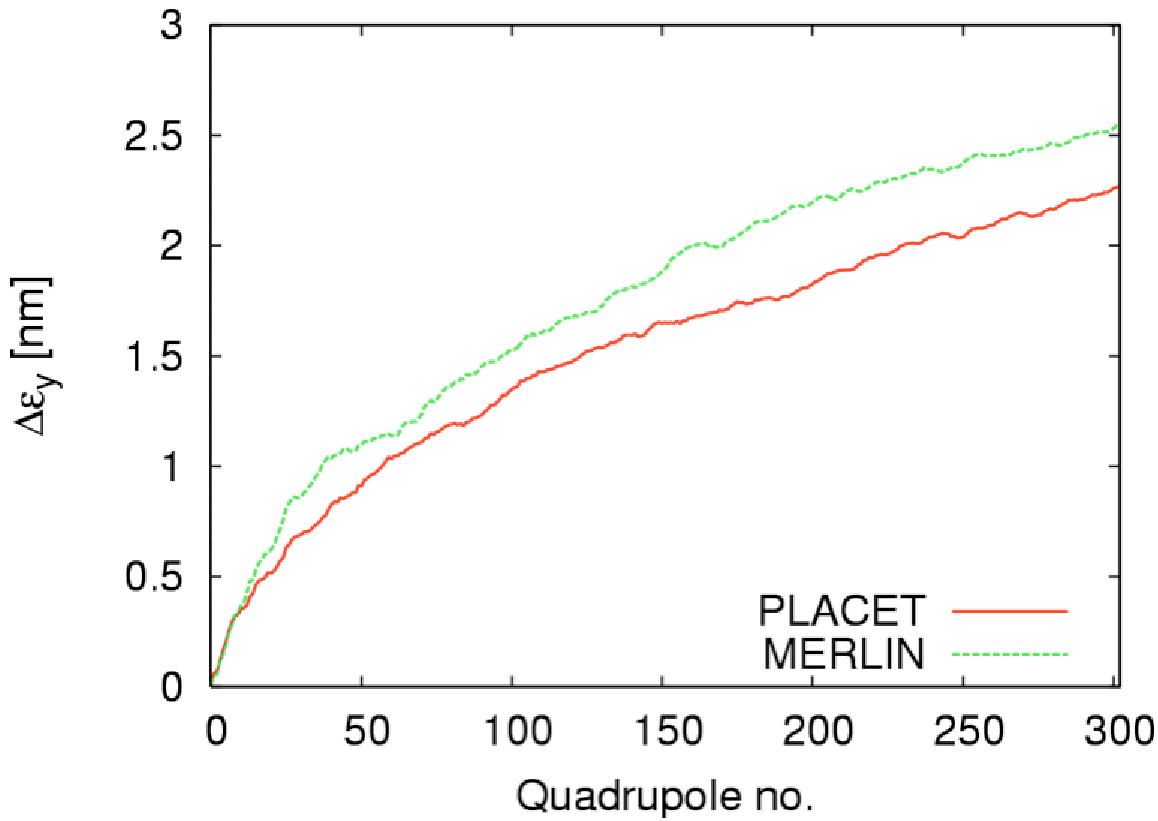
- After enough work we were able to get four codes to agree rather well.
- We now have 4 independent programs with 4 independent code bases performing very similarly with the same set of lattice conditions
- Still some disagreement between SLEPT and ILCv -- working on this...



Benchmarking/Crosschecking results

P. Eliasson, F. Poirier

- A separate comparison was made between PLACET and Merlin and agreement was found to quite good.
- We should get Merlin plotted on the previous plot...

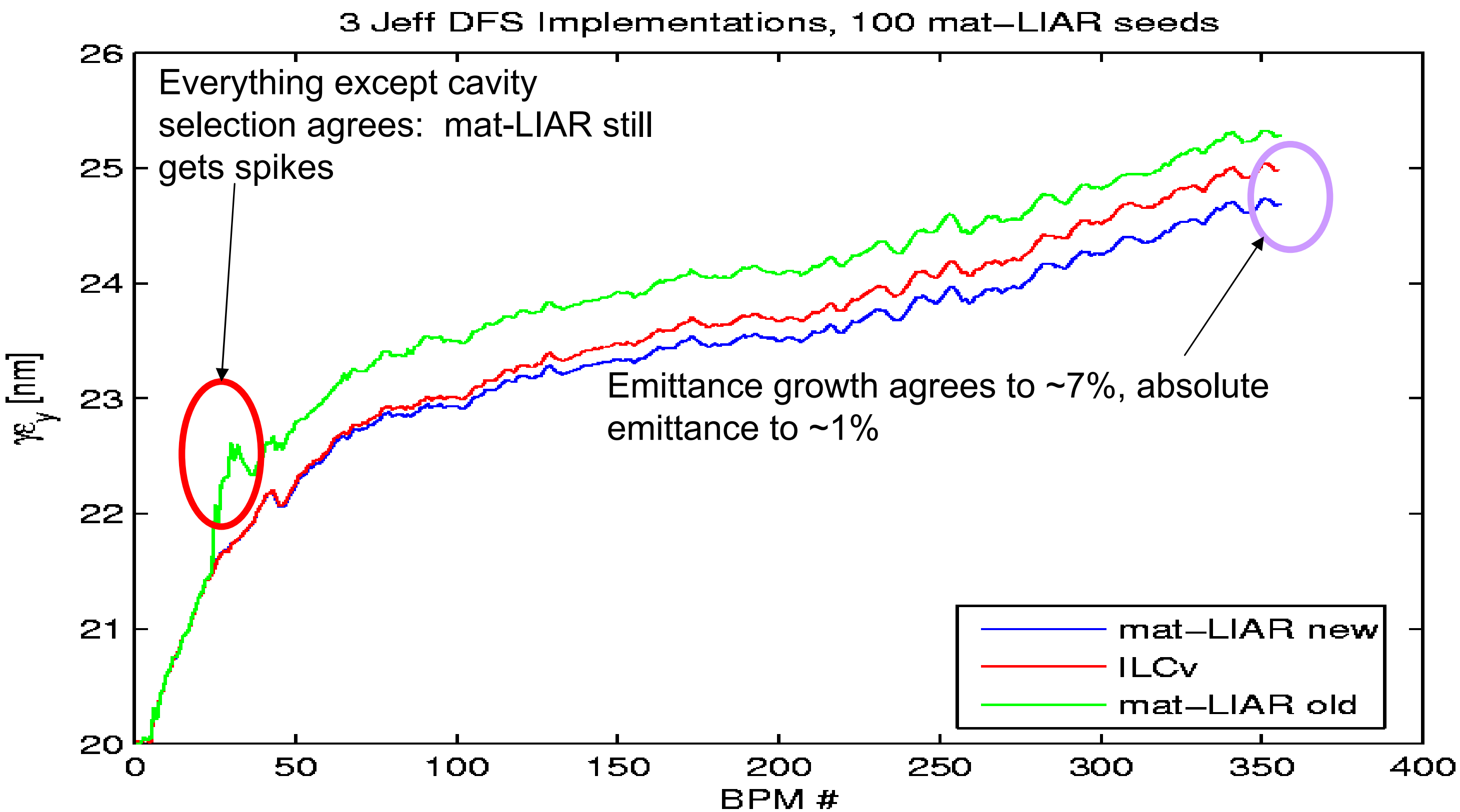


MatLIAR Spikes

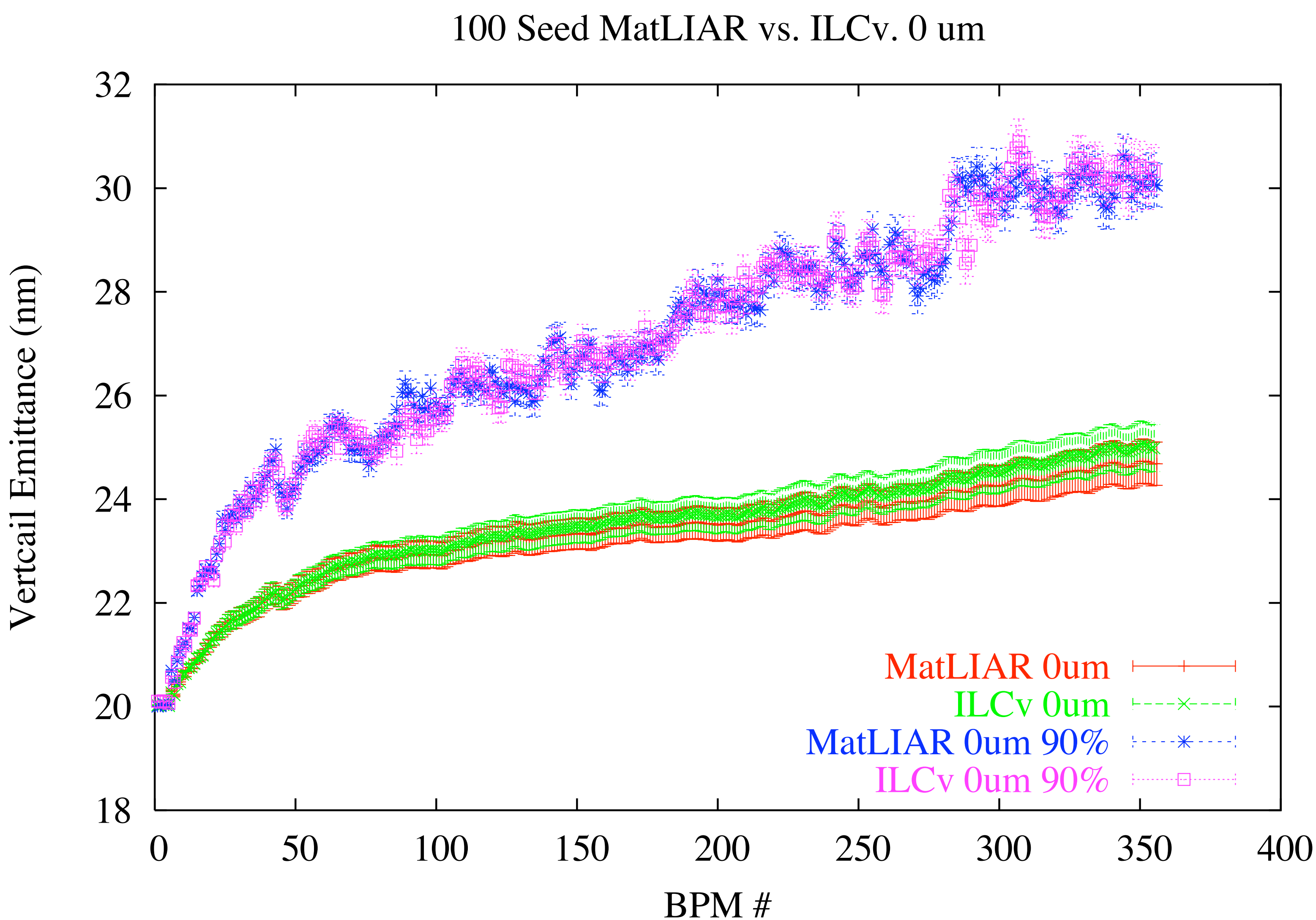
- MatLIAR produces spikes in emittance at beginning of linac, ILCv does not.
  - **Most of this was due to the method used to resteer the beam upstream of the first DFS region**
    - But… there still was a residual bump near the beginning
  - **Two different methods were used to resteer the beam. MatLIAR was converted to use the ILCv method.**
    - But… there still was a residual bump near the beginning
  - **Slight differences in how the regions were defined and precisely which cavities were switched off were the main causes of the bump.**
  - **I began to create a slide giving the details of the ILCv DFS algorithm but stopped after realizing there were way too many relevant details to fit on one slide, likewise with MatLIAR's original algorithm. This all should be explained in a paper.**

Spikes Elliminated!

- Precisely which cavities to turn on and off and where the regions begin and end have an effect on DFS performance

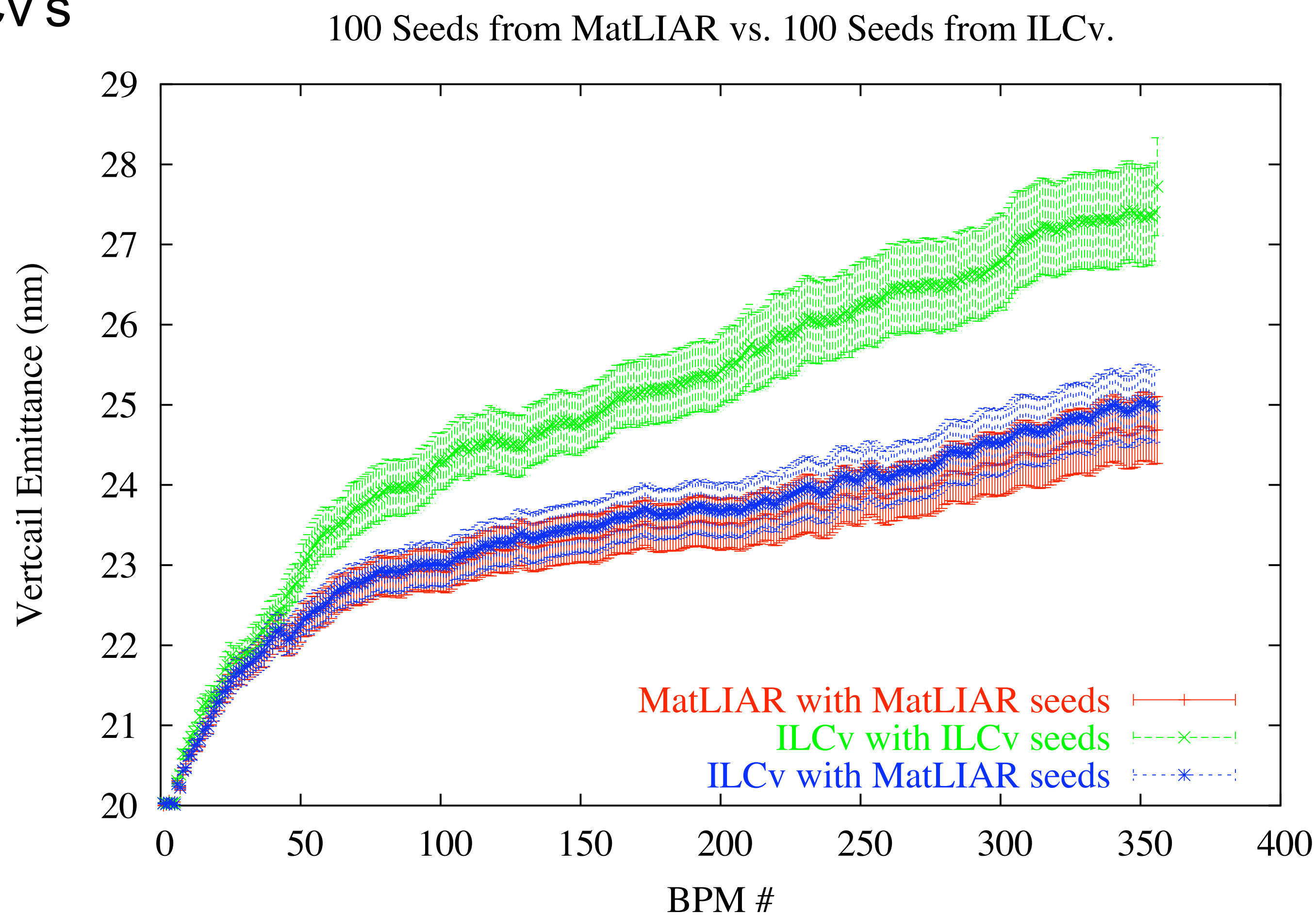


Agreement very good even for 90% confidence level



Must use the same 100 seeds for this comparison

I can't imagine that this large difference is due to two 100 seed gaussian distributions. It must be due to slight differences in MatLIAR's and ILCv's generators.



SLEPT modes analysis in ILCv

- SLEPT has three "modes" of DFS.
- Implemented SLEPT's three modes in ILCv
- Main difference from ILCv DFS:
  - **It changes the energy by scaling all cavities by a constant value versus turning off an appropriate set of cavities (like MatLIAR and ILCv)**
- Not completely the same DFS algorithm:
  - **Re-steering method is a little different, SLEPT uses two upstream BPMs ILCv uses three.**
    - kept ILCv method
  - **Also SLEPT changes incoming beam energy**
    - not performed in ILCv (just perfectly aligned first 9 cryomodules so this difference should not be important)

SLEPT DFS modes:

Simulated Algorithm of DFS, mode 0

One-to-one orbit correction (BPM reading zeroed)
Divide linac into sections (can be overlapped) and in each section:
(1) Measure orbit with nominal beam energy. ($y_{0,i}$ at i-th BPM)
(2) Reduce initial beam energy and accelerating gradient in entire linac by a common factor δ (e.g. 10% or δ= -0.1).
(3) For the second section or downstream, orbit adjusted at the two BPMs just before the section to make the position at the BPM

$$y_\delta = y_0 + \delta\eta$$

(y_0 is the position with nominal energy, η the dispersion at BPM.)
(4) Measure orbit. ($y_{\delta,i}$ at i-th BPM)
(5) Set dipole correctors in the section to minimize

$$w\Sigma(y_{\delta,i} - y_{0,i} - \delta\eta_i)^2 + \Sigma(y_{0,i} - y_{des,i})^2$$

(η_i is the dispersion, $y_{des,i}$ the designed orbit at i-th BPM. w is the weight factor, chosen as w=5000.).
(6) Iterate from (1) to (5).
(7) Go to next section.

Simulated Algorithm of DFS, mode 1

One-to-one orbit correction (BPM reading zeroed)
Divide linac into sections (can be overlapped) and in each section:
(1) Measure orbit with nominal beam energy. ($y_{0,i}$ at i-th BPM)
(2) Reduce initial beam energy and accelerating gradient from the linac entrance to the entrance of the section by a common factor δ (e.g. 10% or δ= -0.1).
(3) For the second section or downstream, orbit adjusted at the two BPMs just before the section to make the position at the BPM

$$y_\delta = y_0 + \delta\eta$$

(y_0 is the position with nominal energy, η the dispersion at BPM.)
(4) Measure orbit. ($y_{\delta,i}$ at i-th BPM)
(5) Set dipole correctors in the section to minimize

$$w\Sigma(y_{\delta,i} - y_{0,i} - \Delta y_{cal,i})^2 + \Sigma(y_{0,i} - y_{cal,i})^2$$

($\Delta y_{cal,i}$ is the calculated orbit difference, $y_{cal,I}$ the calculated orbit, without errors, at I-th BPM. w is the weight factor, w=5000.).
(6) Iterate from (1) to (5).
(7) Go to next section.

Simulated Algorithm of DFS, mode 2

One-to-one orbit correction (BPM reading zeroed)
Divide linac into sections (can be overlapped) and in each section:
(1) Measure orbit with nominal beam energy. ($y_{0,i}$ at i-th BPM)
(2) Reduce initial beam energy and accelerating gradient from the linac entrance to the entrance of the section by a common factor δ (e.g. 10% or δ= -0.1).
(3) (No upstream orbit adjustment)
(4) Measure orbit. ($y_{\delta,i}$ at i-th BPM)
(5) Set dipole correctors in the section to minimize

$$w\Sigma(y_{\delta,i} - y_{0,i} - \Delta y_{cal,i})^2 + \Sigma(y_{0,i} - y_{cal,i})^2$$

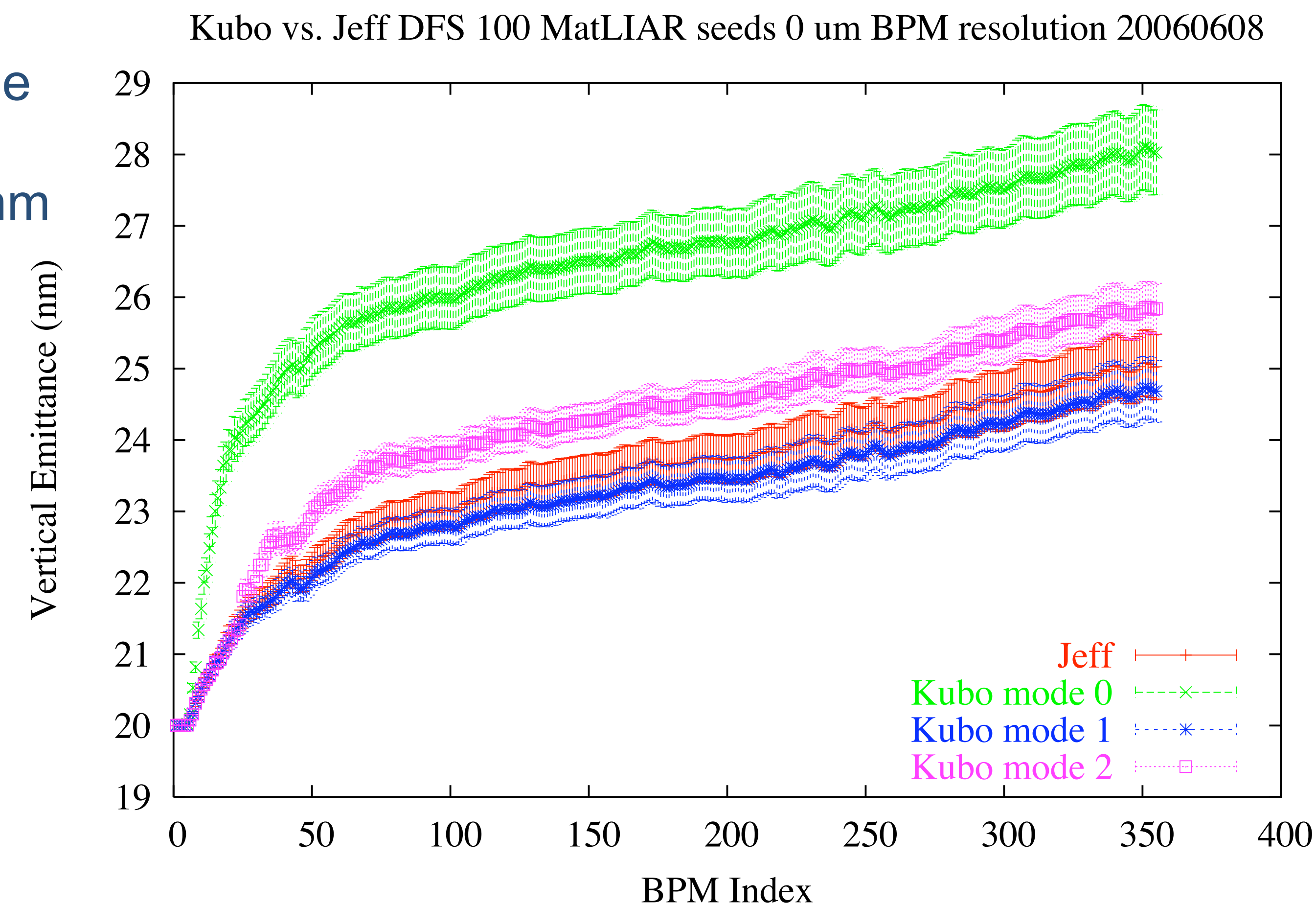
($\Delta y_{cal,i}$ is the calculated orbit difference, $y_{cal,I}$ the calculated orbit, without errors, at I-th BPM. w is the weight factor, w=5000.).
(6) Iterate from (1) to (5).
(7) Go to next section.

ILCV DFS mode

- No separate 1-1 orbit correction (this is already effectively performed with DFS algorithm)
  - **Extra 1-1 correction before DFS found not to make a difference**
- Divide linac into DFS regions: 20 quads per region half overlapped with previous region (there's subtle details here being glossed over)
- Take on-energy orbit
- Reduce energy by 20% or 18 GeV, whichever is less, for the beam entering the DFS region by turning off appropriate number of upstream cavities starting with first cavity upstream of DFS region (again, as found with MatLIAR comparison there are a devil in the details)
- Take new orbit and resteer incoming beam to on-energy orbit using three upstream BPMs
- Take off-energy orbit
- Minimize both on energy orbit and difference orbit, appropriately weighted using the same Chi-square as SLEPT stated on previous slide.
- Option available to also weight the corrector strenghts.
- Iterate 5 times
- Got to next region

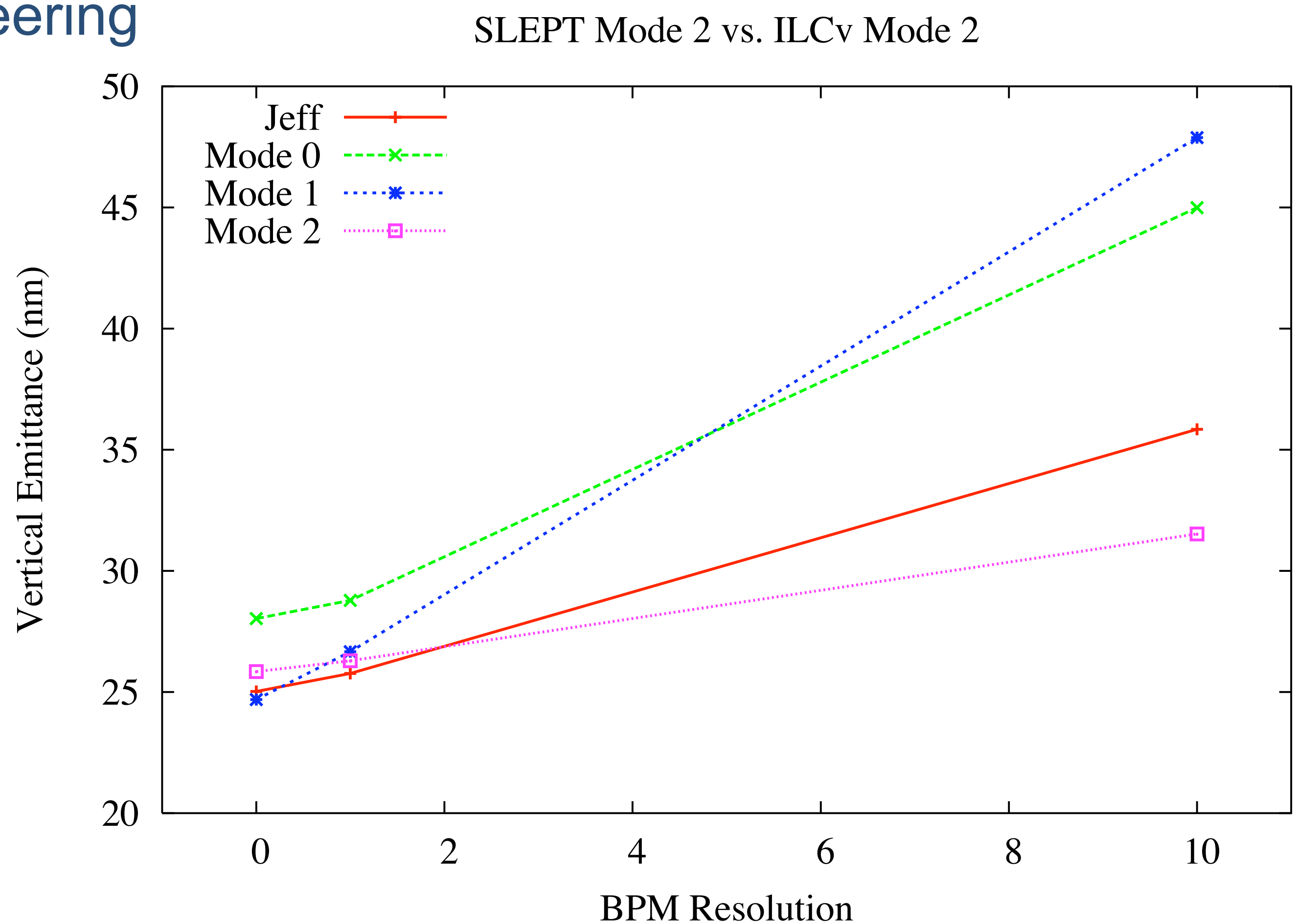
100 same seed average

- All simulations performed in ILCv
- If using same 100 seeds, “Jeff” mode behaves most similarly to mode 1
- This is the mode most similar to “Jeff” in algorithm



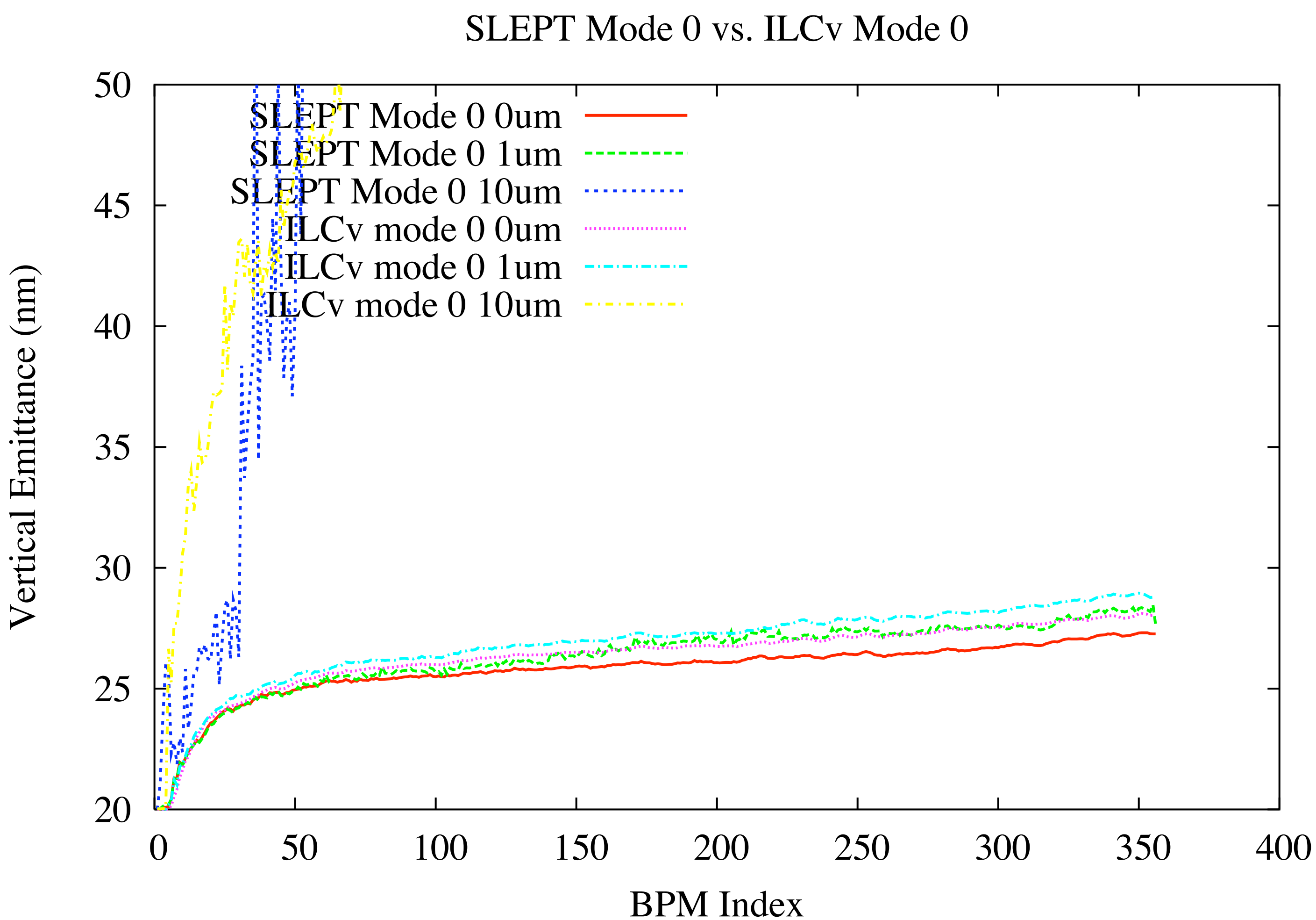
Different BPM resolution dependence

- Different dependence on BPM resolution
- Not surprising Mode 2 least dependent considering it does not perform re-steering
- However, should investigate why modes 0 and 1 are more sensitive to BPM resolution than “Jeff” mode.



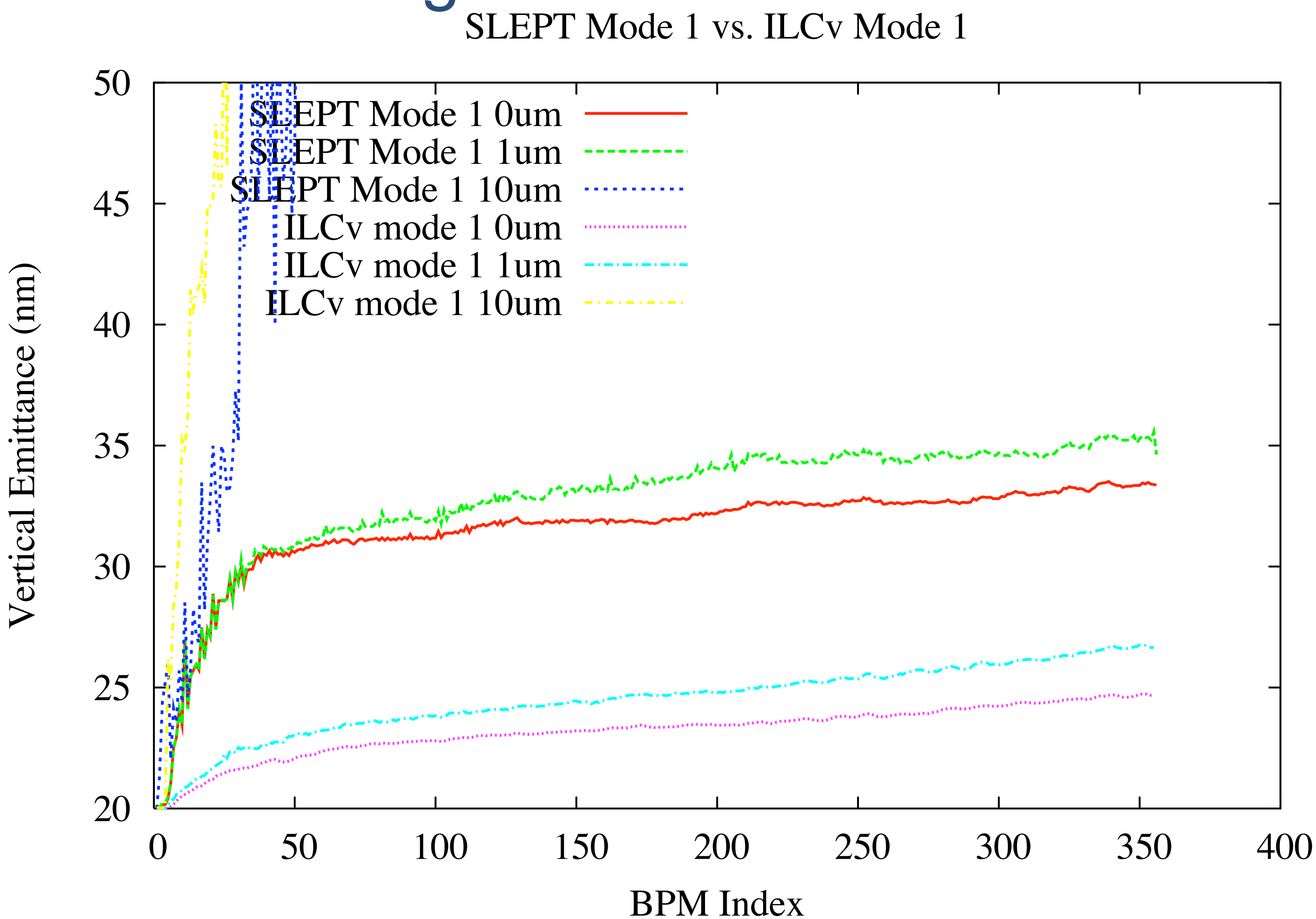
ILCv vs SLEPT mode 0

- Curves agree well



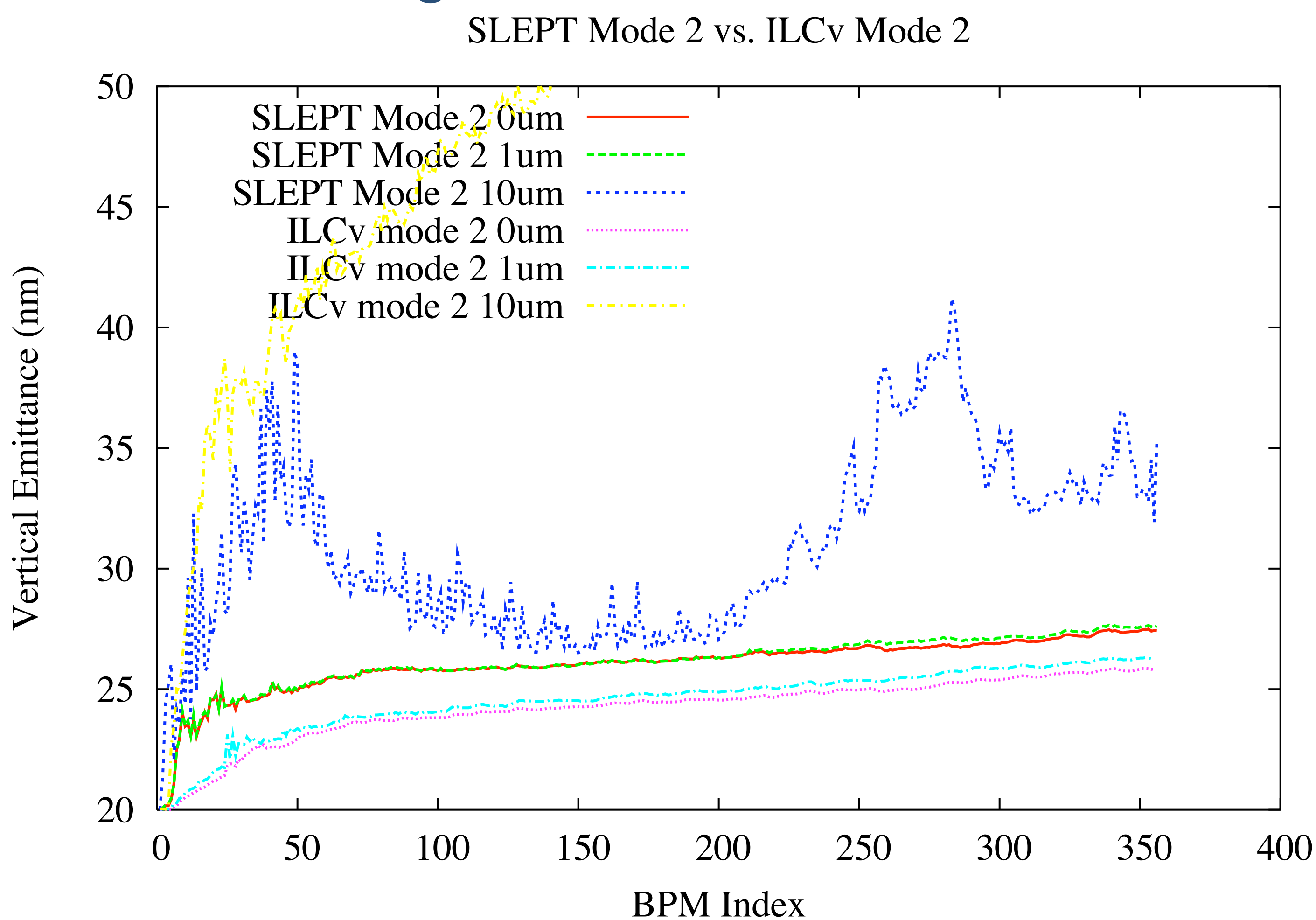
ILCv vs SLEPT mode 1

- Curves don’t agree



ILCv vs SLEPT mode 2

- Curves don't agree



Now moving on to developments at CERN

Work by:

Dnaiel Schulte

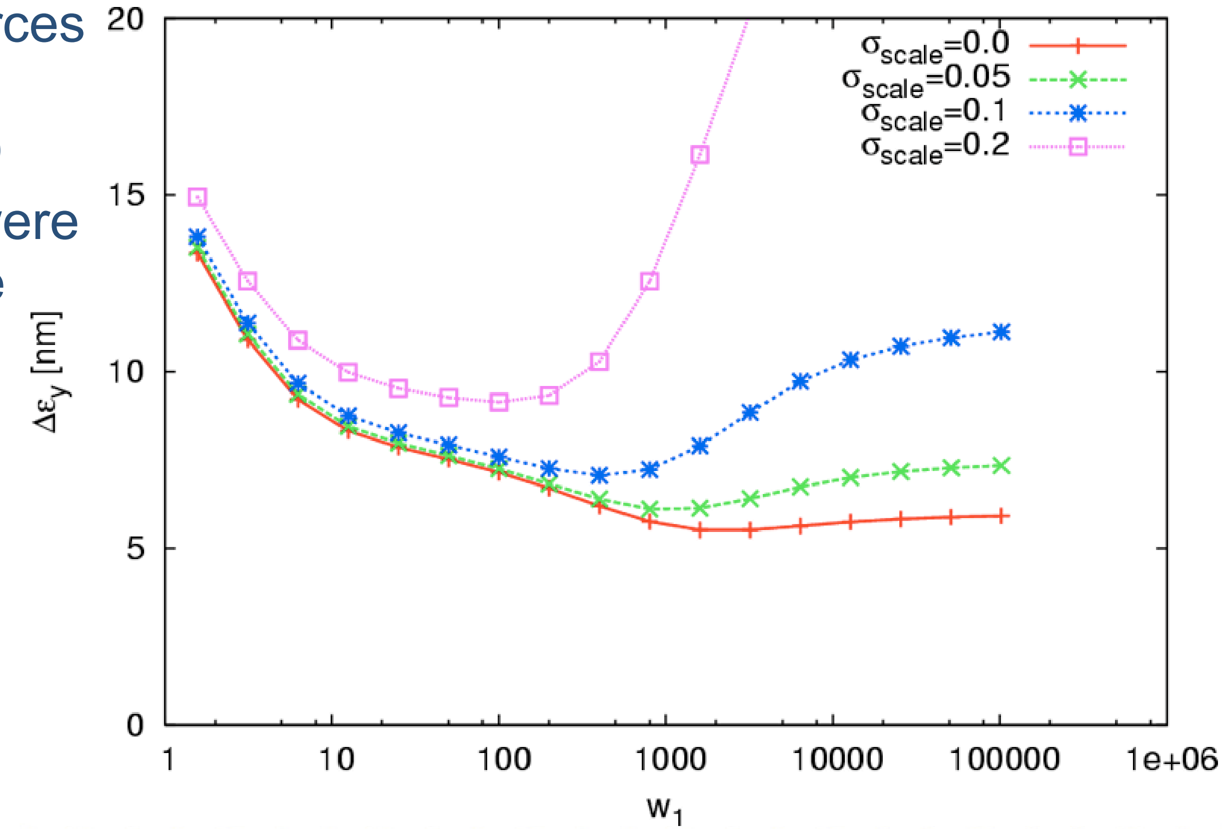
Peder Eliasson

Andrea Latina

Curved Linac and BPM Scale Errors

P. Eliasson

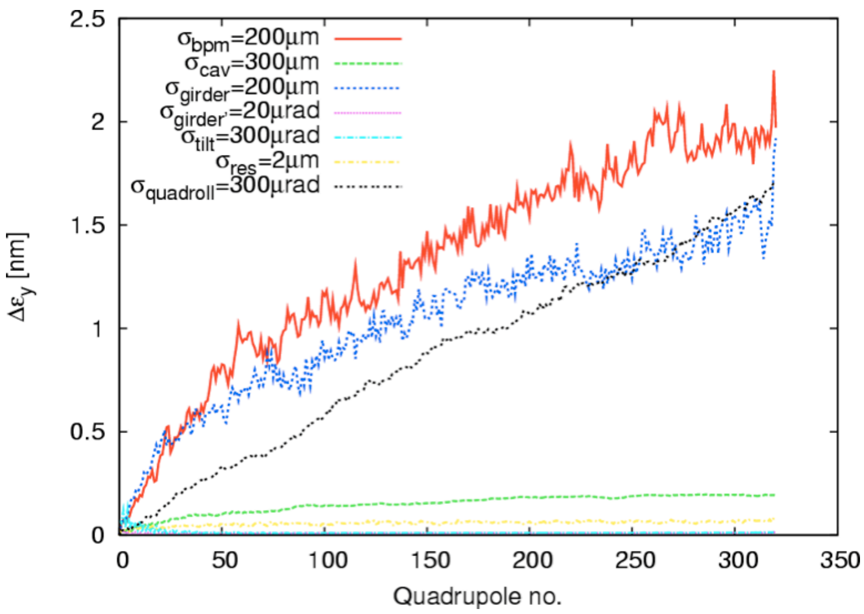
- BPM scale errors: $x_{\text{reading}} = a\, x_{\text{real}}$
- Without calibration, the scale errors could be as large as 20%
- This plot shows the effect the scale error has on DFS performance. A 20% scaling error dramatically decreases DFS performance and forces a lower DFS weight (more 1-1 less DFS)
- Dispersion bumps were found to mitigate the effects (explained below).
- The horizontal axis is the weighting function for DFS



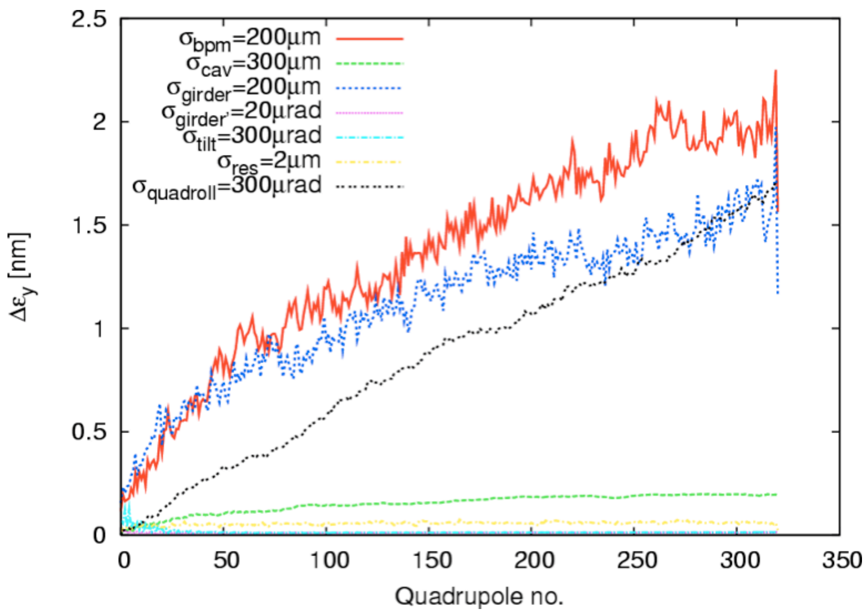
The Schulte, Eliasson, Latina (SEL?) solution to BPM Scale Error

- With no scale errors, it is best to not change the gradient in each DFS region
- That way, with large weighting in DFS all principle components of emittance growth are corrected.
- In this case, dispersion bumps do not improve performance over DFS by much

DFS only.



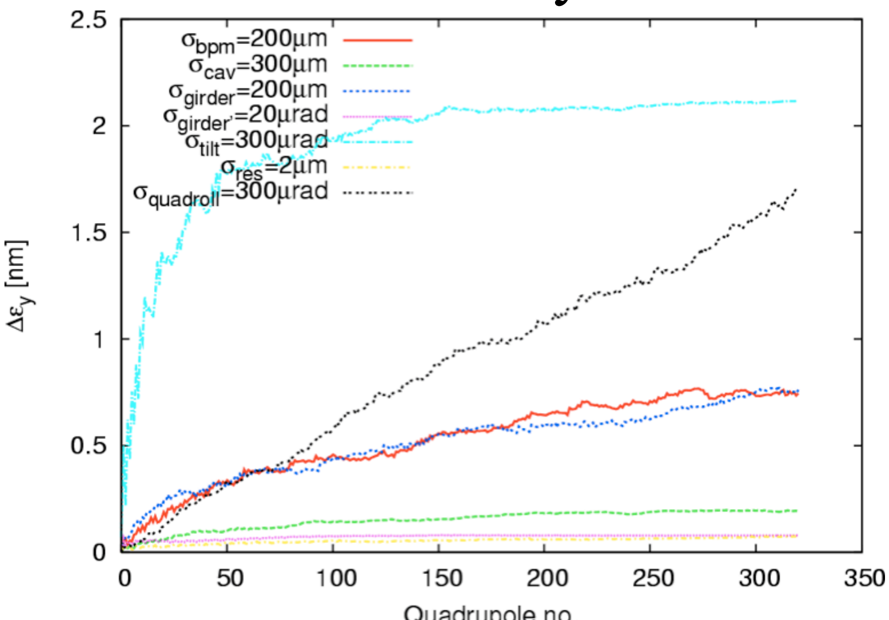
DFS + 2 dispersion bumps.



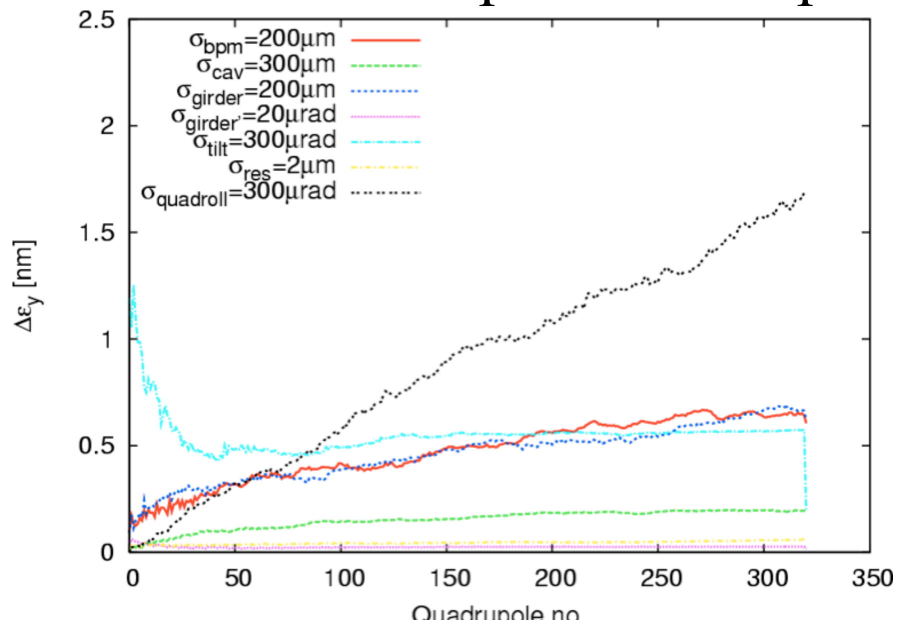
The Schulte, Eliasson, Latina (SEL?) solution to BPM Scale Error

- However, with scale errors, DFS cannot be weighted as strongly
  - lower weighting results in larger emittance growth due to BPM and Girder offsets
  - These effects can be reduced by scaling the cavity gradient in the DFS region,
    - But this increases growth due to cavity tilts
  - Dispersion bumps works well against cavity tilts

DFS only.



DFS + 2 dispersion bumps.

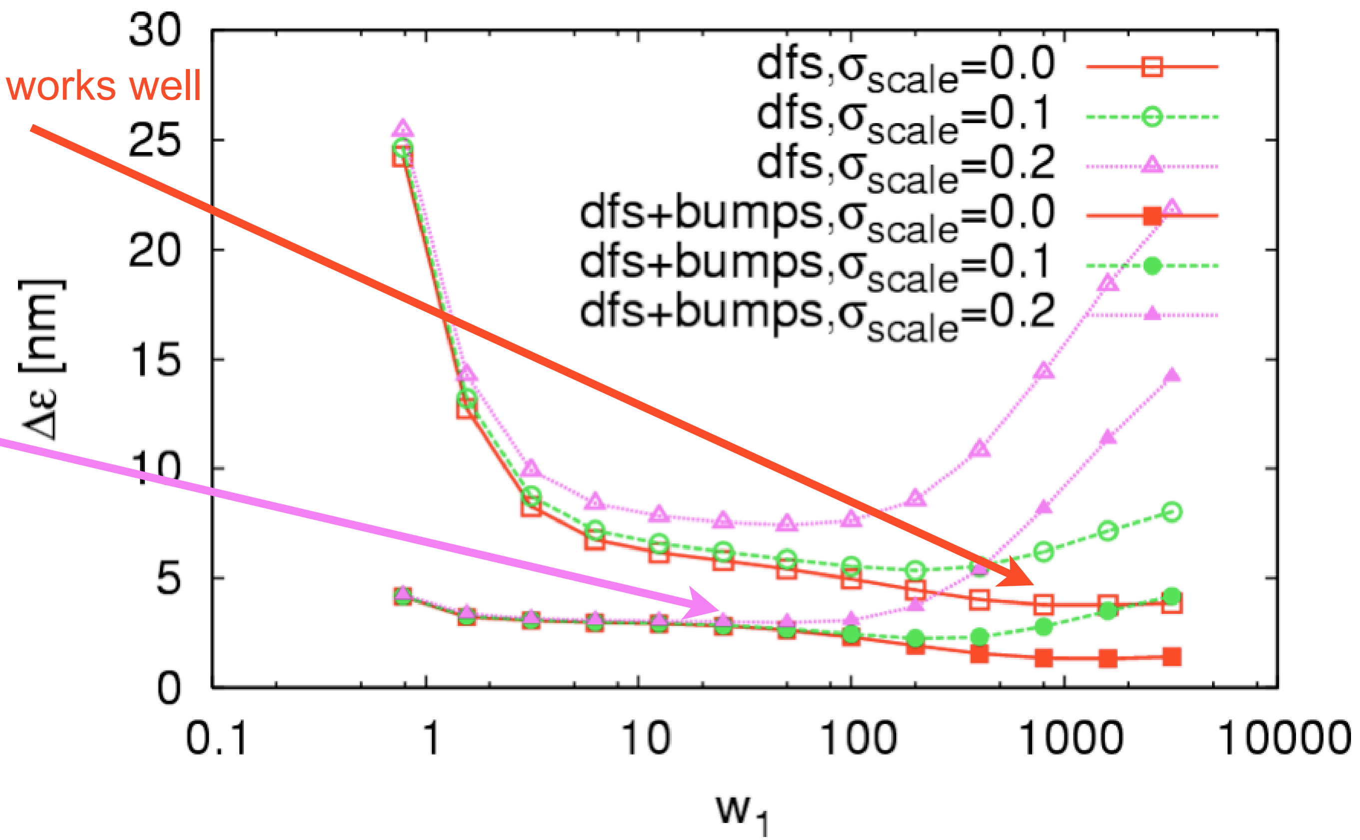


The Schulte, Eliasson, Latina (SEL?) solution to BPM Scale Error

- Combination of DFS and Bumps works well even when BPM scale error is included in model

With no scale error DFS works well

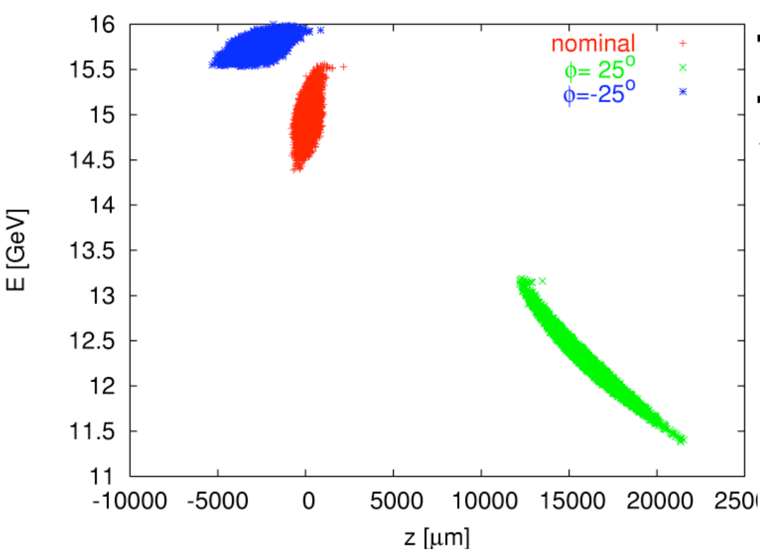
With scale error Disp. Bumps reclaims performance



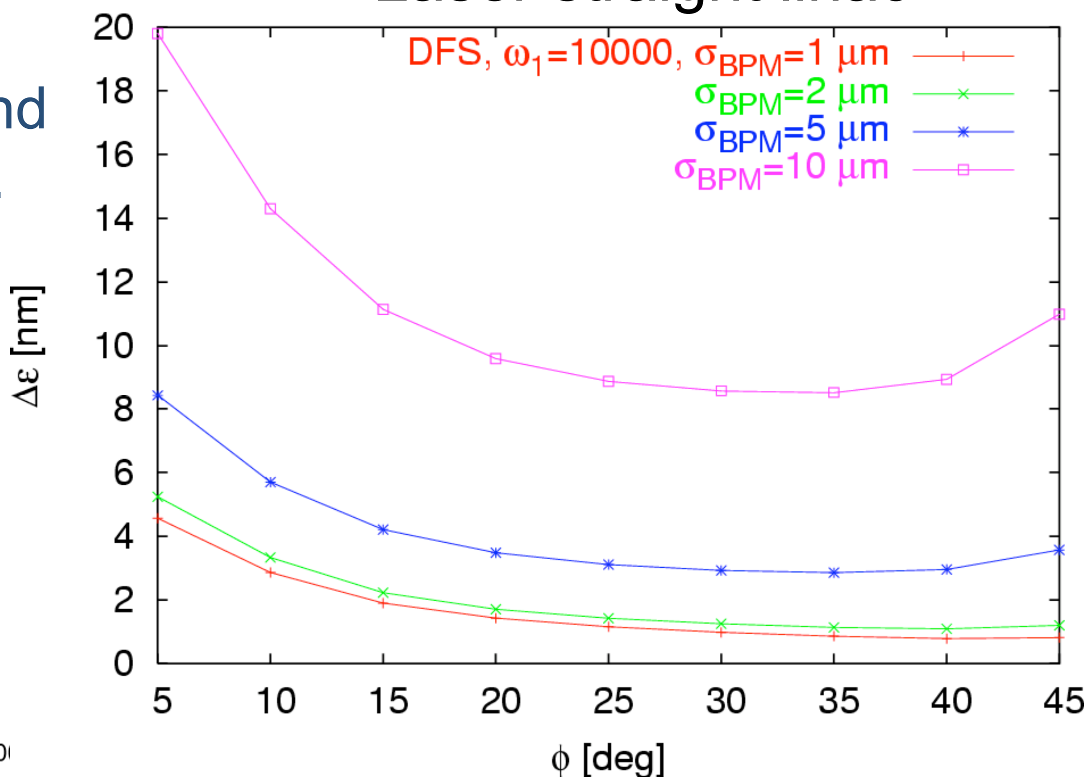
Using Bunch Compressor for DFS

A. Latina

- Off-phase beams in BC gain different energies, so these beams can be used for DFS instead of changing ML cavity gradients.
- With a phase offset of about 25 degrees, this method was found to be very promising.



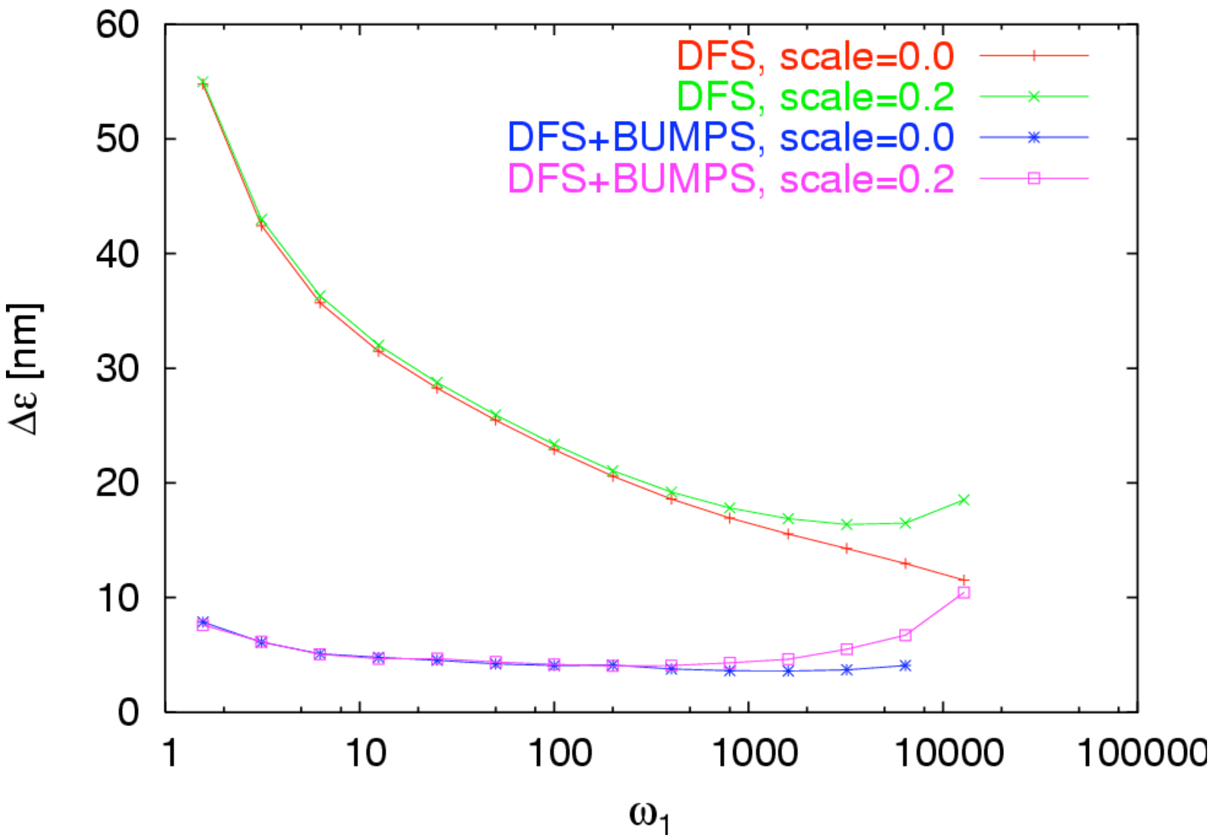
Laser straight linac



Using Bunch Compressor for DFS

A. Latina

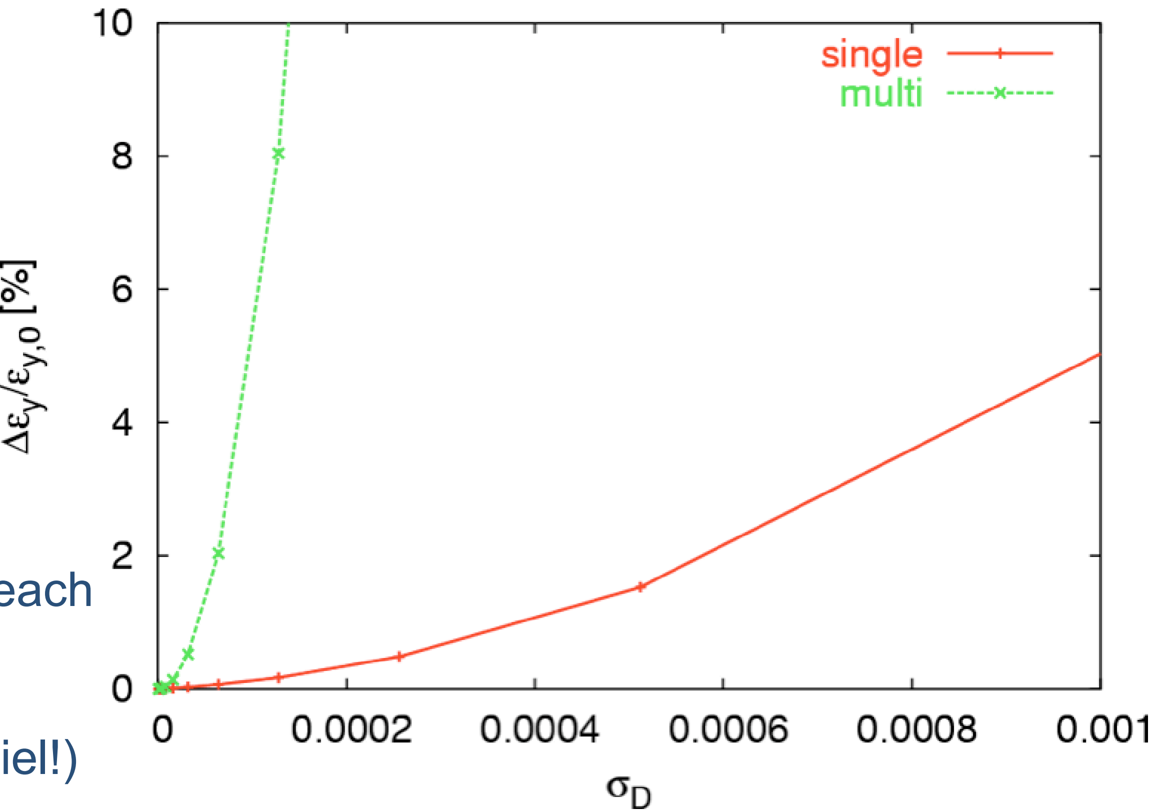
- With curved linac the BPM scale errors prevents the use of large weighting on DFS and spoils the performance
- However, dispersion bumps save the day (as explained above)!



Steering Magnet Jitter

D. Schulte

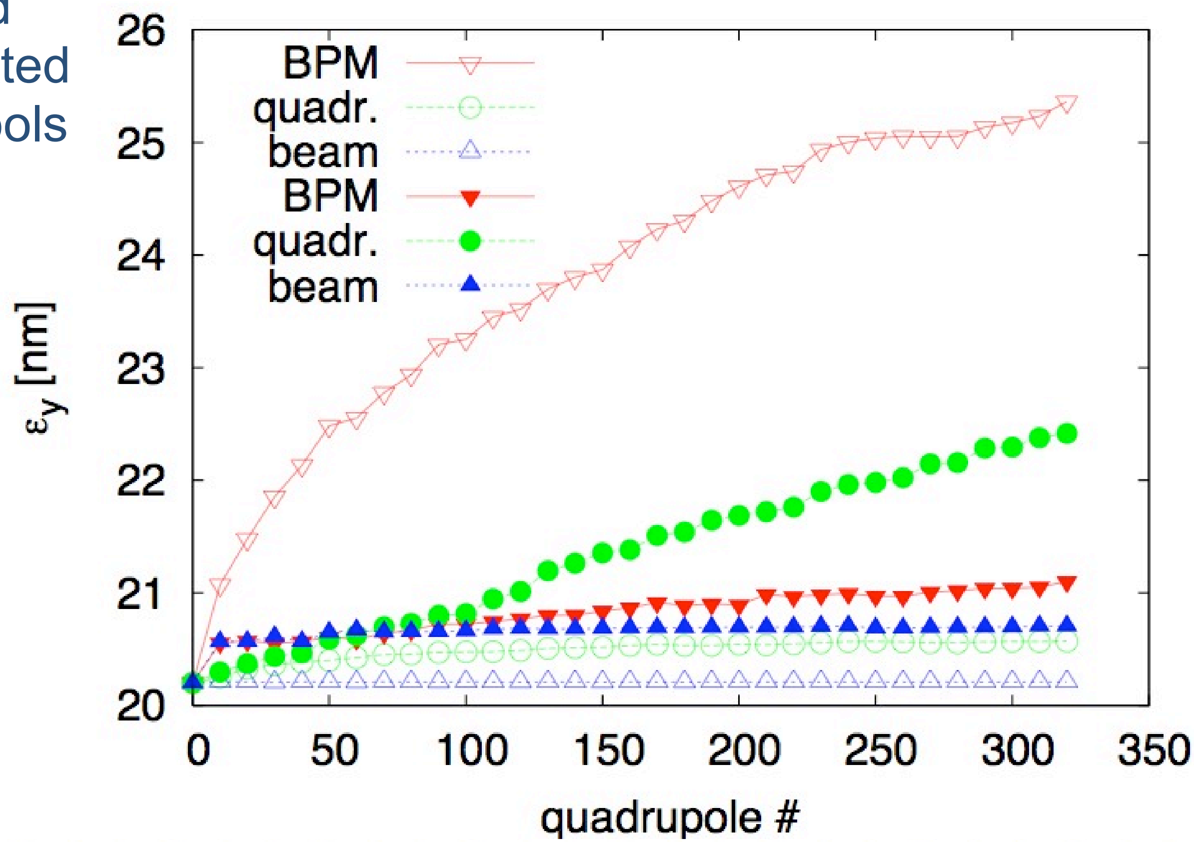
- For single bunch effects, steering magnet power supply jitter appears to not be a problem and the required stability of a few 10^-4 is well within capability.
- Here, perfectly aligned machine with just steering magnet jitter
- If there is no intra-pulse feedback then multi-bunch effects can result in significant average emittance dilution.
- Red Curve: emittance of each iteration is averaged, this "simulates" intra-pulse feedback (according to Daniel!)
- Green Curve: emittance of each iteration is overlayed, this "simulates" no intra-pulse feedback (according to Daniel!)



Dynamic Effects During DFS

D. Schulte

- Beam and magnet jitter during DFS can be partially “fitted out” using upstream BPMs and model prediction
- This was found to require very good BPM resolution.
- To the right, the solid symbols are for unfitted data, the open symbols are after the fitting.
- Each dynamic effect was analyzed separately
  - **BPM resolution**
  - **Quad jitter**
  - **Beam jitter**

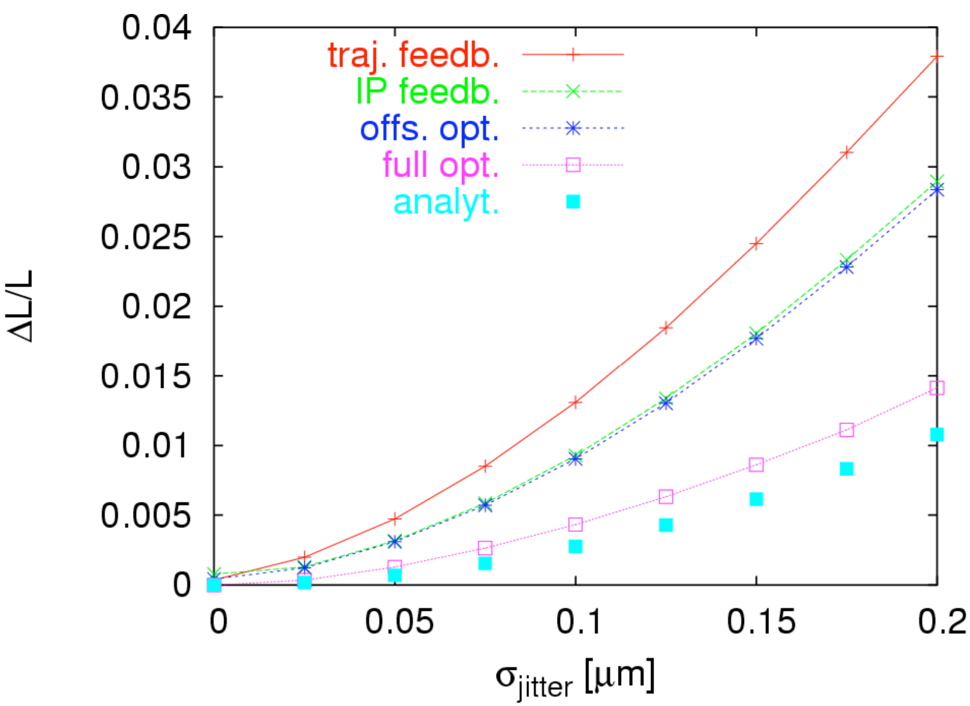


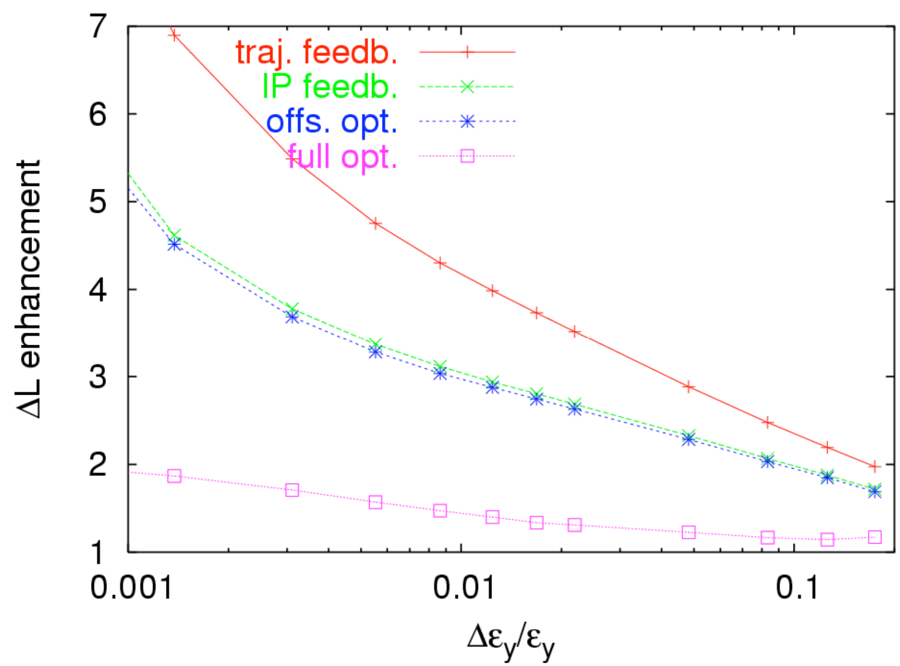
- Quadrupole jitter leads to luminosity loss not just from emittance growth but from beam IP jitter
- Several methods to regain luminosity in presence of jitter:
  - **intra-pulse trajectory feedback at end of main linac**
  - **intra-pulse IP beam-beam offset feedback**
  - **beam-beam offset optimization at IP**
  - **beam-beam offset and angle optimization at IP**
- In following plots, Main Linac simulations performed in PLACET with a matrix for the BDS (no BDS jitter).
- Beam-Beam done in GUINEA-PIG

Quadrupole Jitter

D. Schulte

- With no optimization, a jitter of 100 nm leads to 1% luminosity loss
  - **With optimization this decreases to 0.5%**
- Plot on left shows total luminosity reduction.
- Plot on right shows luminosity reduction over and above that simply due to emittance growth

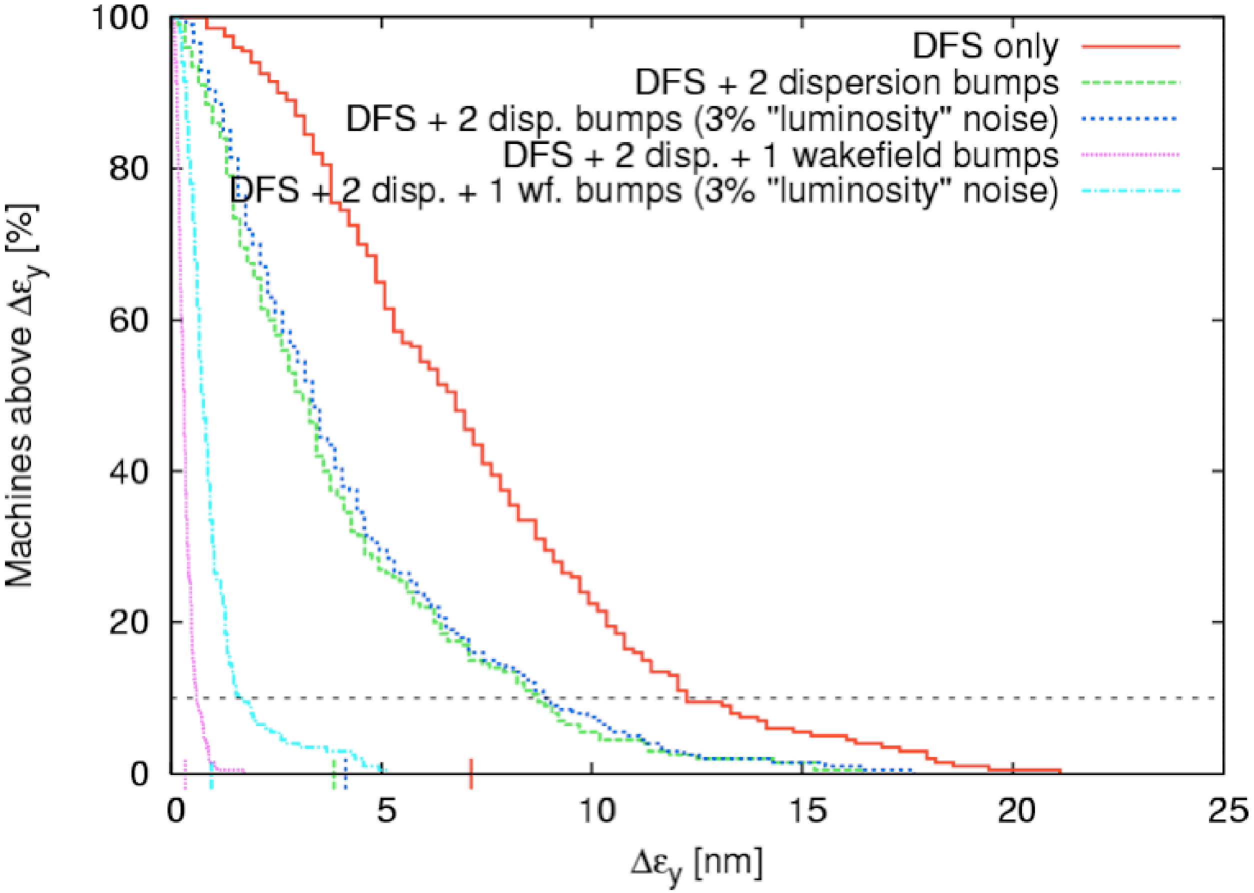




Dispersion and Wakefield Bumps with DFS

P. Eliasson

- Using Dispersion and Wakefield Bumps in conjunction with DFS has been found to be very effective in emittance preservation.
- Even when including all significant sources of emittance dilution, this combination preserves emittance very well.
- Only the laser wire signal noise remains as a significant source of emittance dilution.



Future Work

- Look into benchmarking with other alignment algorithms (DFS most complex so we started there)
- Static studies rather well progressed so we should ramp up work on dynamic studies
- Fully integrated Emittance preservation studies
  - **RTML, ML and BDS tuned separately**
  - **Start studies from DR extraction to IP**
- Even though benchmarking not totally complete I want to stop using dated TESLA lattice even though we agreed on that for benchmarking
  - **Now that it's in a more finalized state, use current lattice design instead**
  - **No need to use something different for benchamrking**

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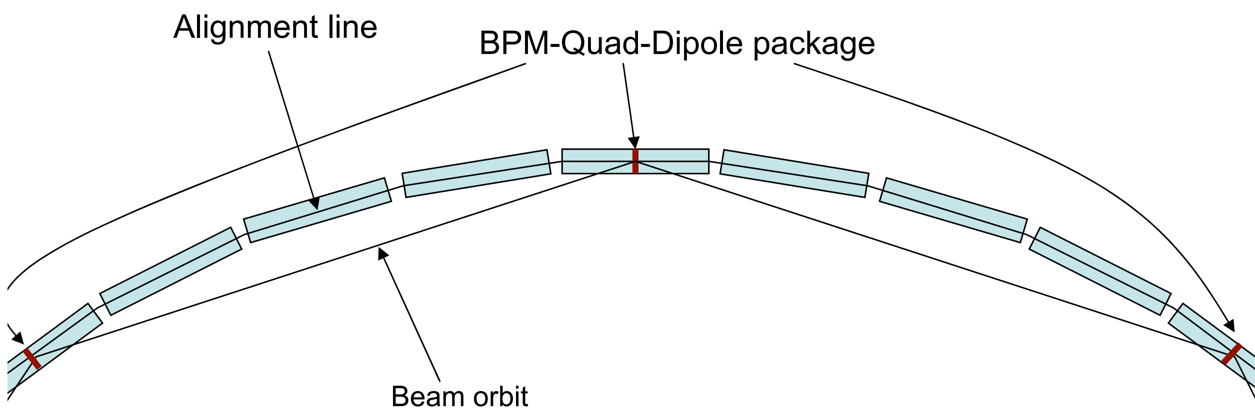
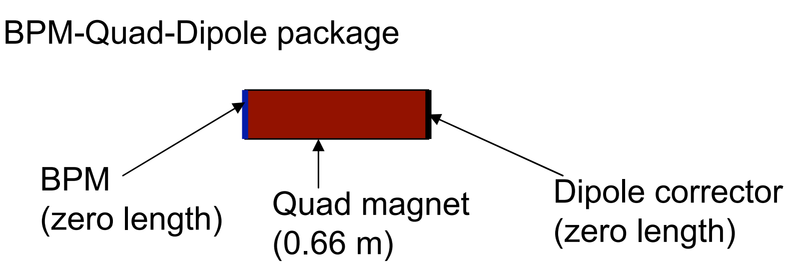
Curve Linac Anaylsis

K. Ranjan, F. Ostiguy, N. Solyak, K. Kubo, P. Tenenbaum, P. Eliasson, A. Latina, D. Schulte

- Laser straight best for emittance preservation
- Earth curvature following best for cryogenic system and helium distribution, and possibly for civil engineering.
  - **But what about emittance preservation?**

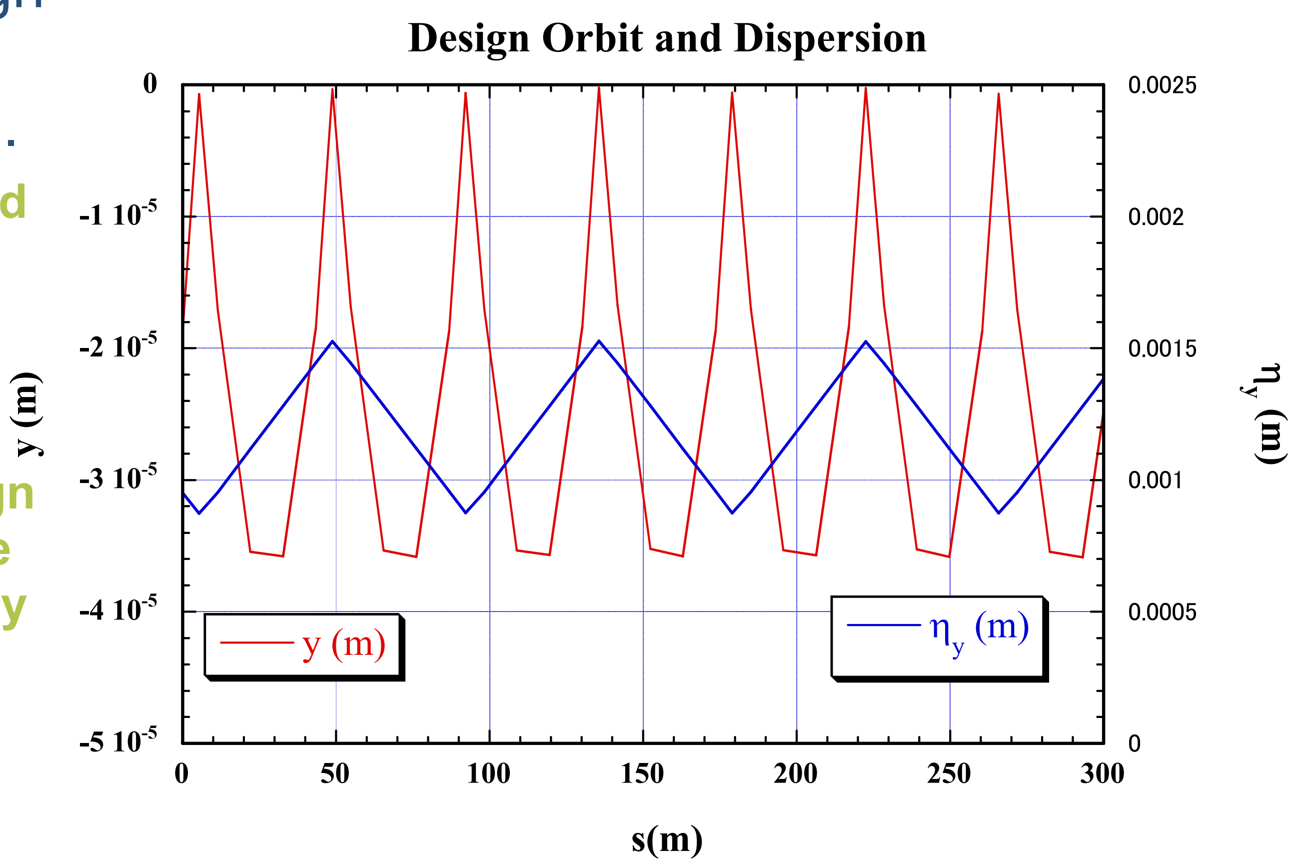
Curved Linac, 1-quad/4-cryomodules





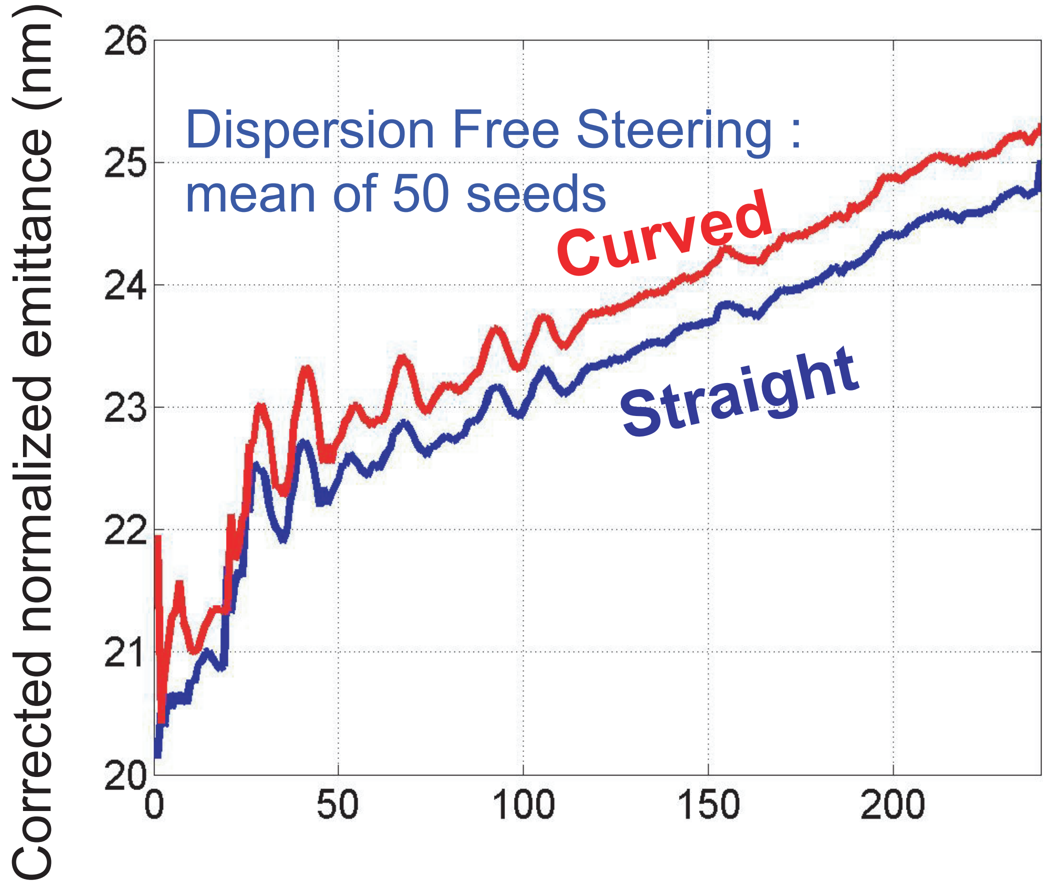
Curved Linac Considerations

- With a curved linac there is now a design non-zero vertical orbit and dispersion.
  - The orbit was found to make an insignificant contribution to emittance growth.
  - However, the design dispersion must be compensated for by injecting a dispersive beam into the main linac



Curved Linac Analysis Results

- Using similar component misalignments but not including BPM scale errors, all participants found insignificant difference in DFS performance between straight and curved linacs.
- MatLIAR results to the right



DFS parameters not optimized for Curved Linac

Failure Mode Analysis

K. Ranjan, F. Ostiguy, N. Solyak, J. Smith

- Examined faulty BPMs and Steering Magnets.
- Effects on DFS:
  - DFS performs well even in the presence of several (few %) failed BPMs and steering magnets, provided the faulty BPMs and magnets can be identified. This is true even if there are several failed BPMs and steering magnets back to back (decrease in performance begins when about 4 or more consecutive components fail).
  - However, if DFS is performed while being unaware of faulty components then the emittance dilution is significant
  - Compared to other alignment algorithms, DFS is very robust to BPM and Steering Magnet failure. It's much more of a serious issue for BA and KM.
  - However, in the presence of noisy, but still operational, BPMs and steering magnets DFS performs more poorly than BA and KM

Number of BPMs

K. Ranjan, F. Ostiguy, N. Solyak

- The nominal design has BPMs only in the Quadrupole package
- Increasing the number of BPMs results in only a slight decrease in average emittance for DFS.
- However, the spread in performance over different seeds is smaller.