DFS(Dispersion Free Steering) in Curved(following Earth) ILC Main Linac

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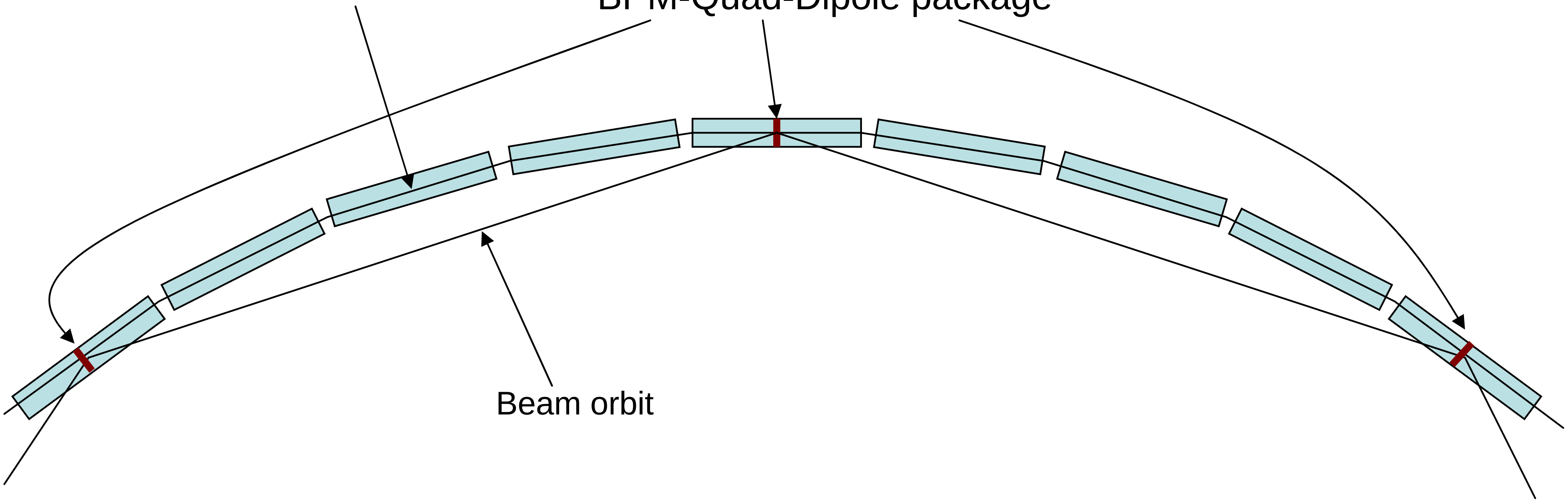
Lattice

- For Performance Study by P. Tenenbaum
  - one quad per four cryomodules
  - 75/65 degree phase advance per FODO cell

Curved Linac, 1-quad/4-cryomodules

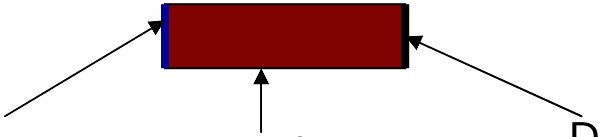


Alignment line

BPM-Quad-Dipole package

Beam orbit

BPM-Quad-Dipole package

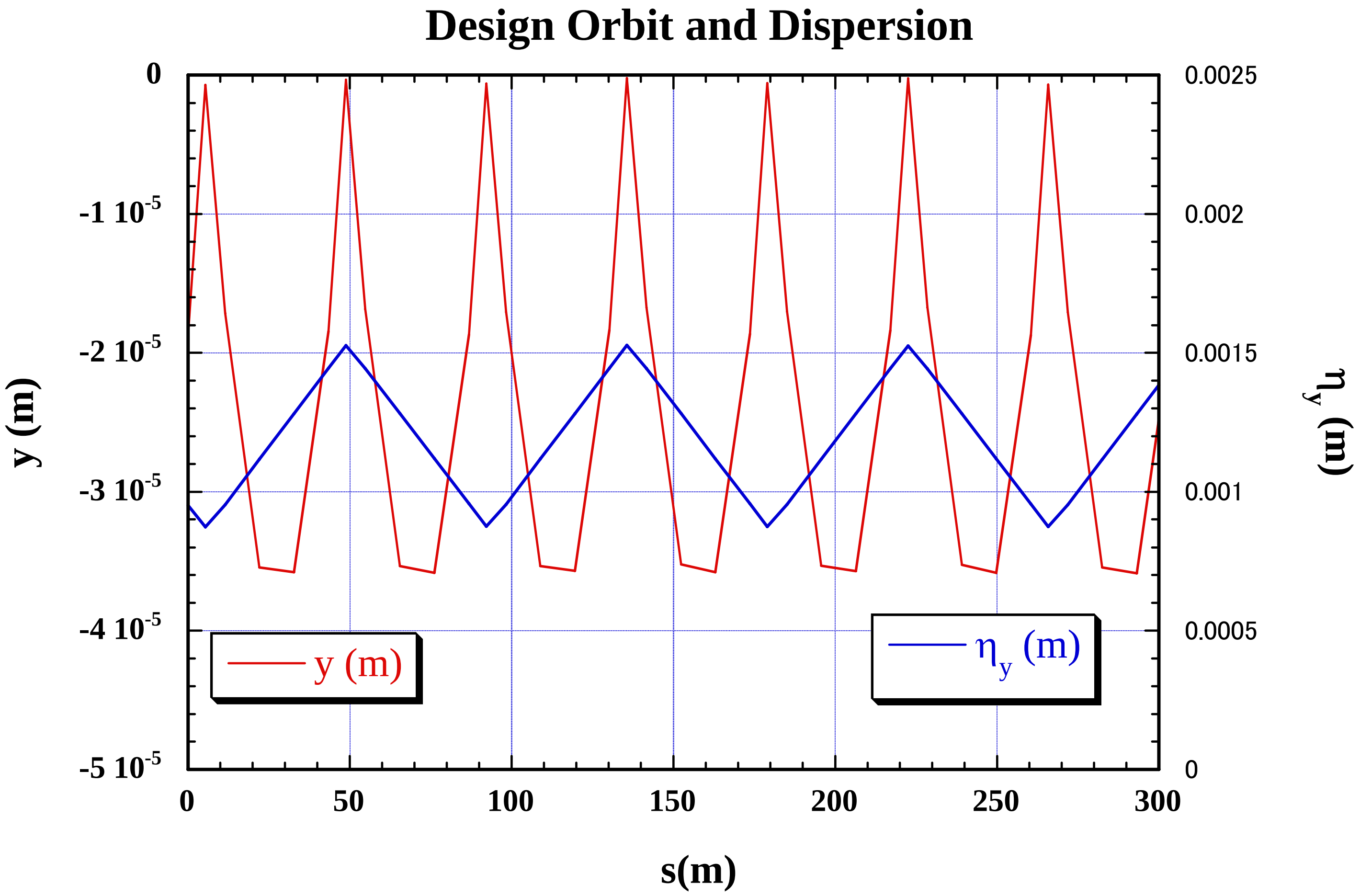


BPM
(zero length)

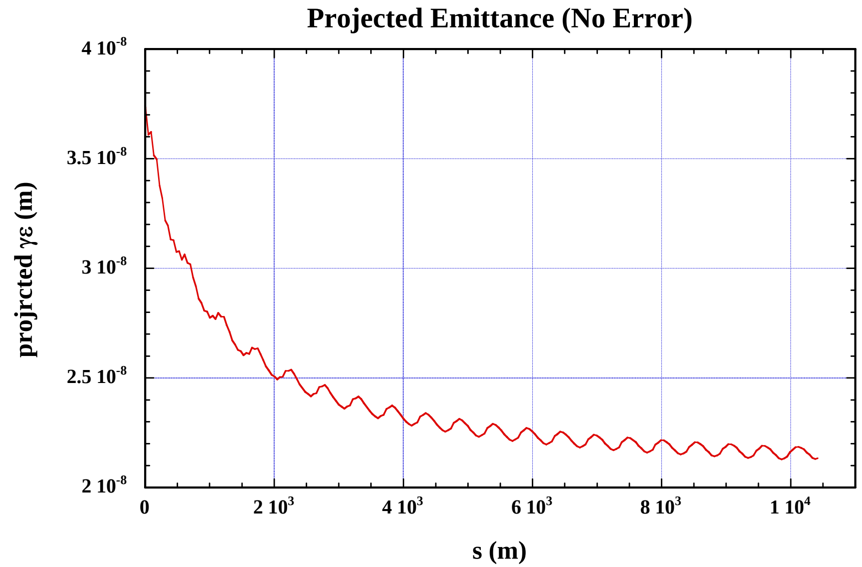
Quad magnet
(0.66 m)

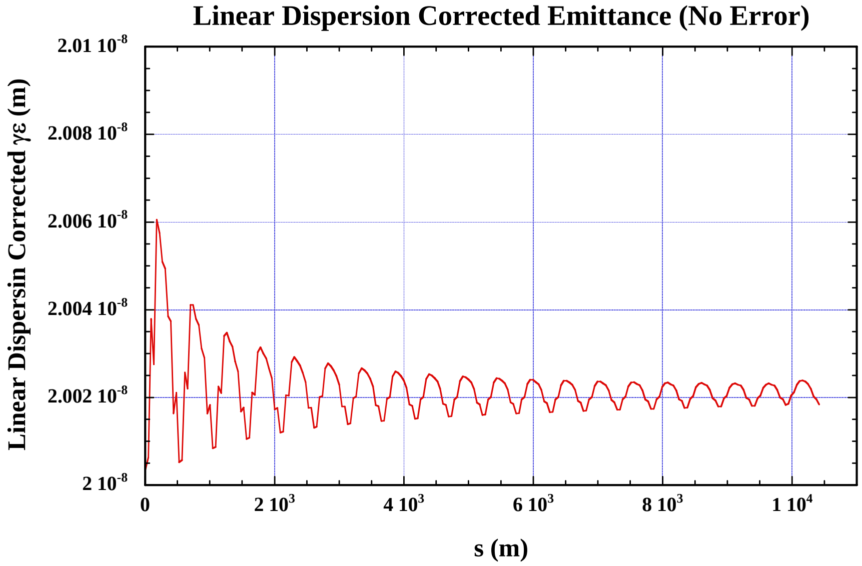
Dipole corrector
(zero length)

Design orbit and dispersion



Emmitance without errors


Projected Emittance (No Error)


Linear Dispersion Corrected Emittance (No Error)

Definition of
Projected emittance and
Linear Dispersion Corrected emittance

Projected emittance

$$\equiv \sqrt{(<y^2>-<y>^2)(<y'^2>-<y'>^2)-(<yy'>-<y><y'>)^2}$$

Linear Dispersion Corrected emittance

$$\equiv \sqrt{(<(y-\eta\delta)^2>-<y-\eta\delta>^2)(<(y'-\eta'\delta)^2>-<y'-\eta'\delta>^2)-(<(y-\eta\delta)(y'-\eta'\delta)>-<y-\eta\delta><y'-\eta'\delta>)^2}$$

y: Vertical offset, y': Verticale angle

δ: Relative energy deviation

$\eta \equiv (<y\delta>-<y><\delta>)/(<\delta^2>-<\delta>^2)$, $\eta' \equiv (<y'\delta>-<y'><\delta>)/(<\delta^2>-<\delta>^2)$

$<>$: Average over all macro - particles

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 $\delta = -0.1$).

(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 $\delta = -0.1$).

(3) (No upstream orbit adjustment)

(4) Measure orbit. ($y_{\delta,i}$ at i-th BPM)

(5) Set dipole correctors in the section to minimize

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

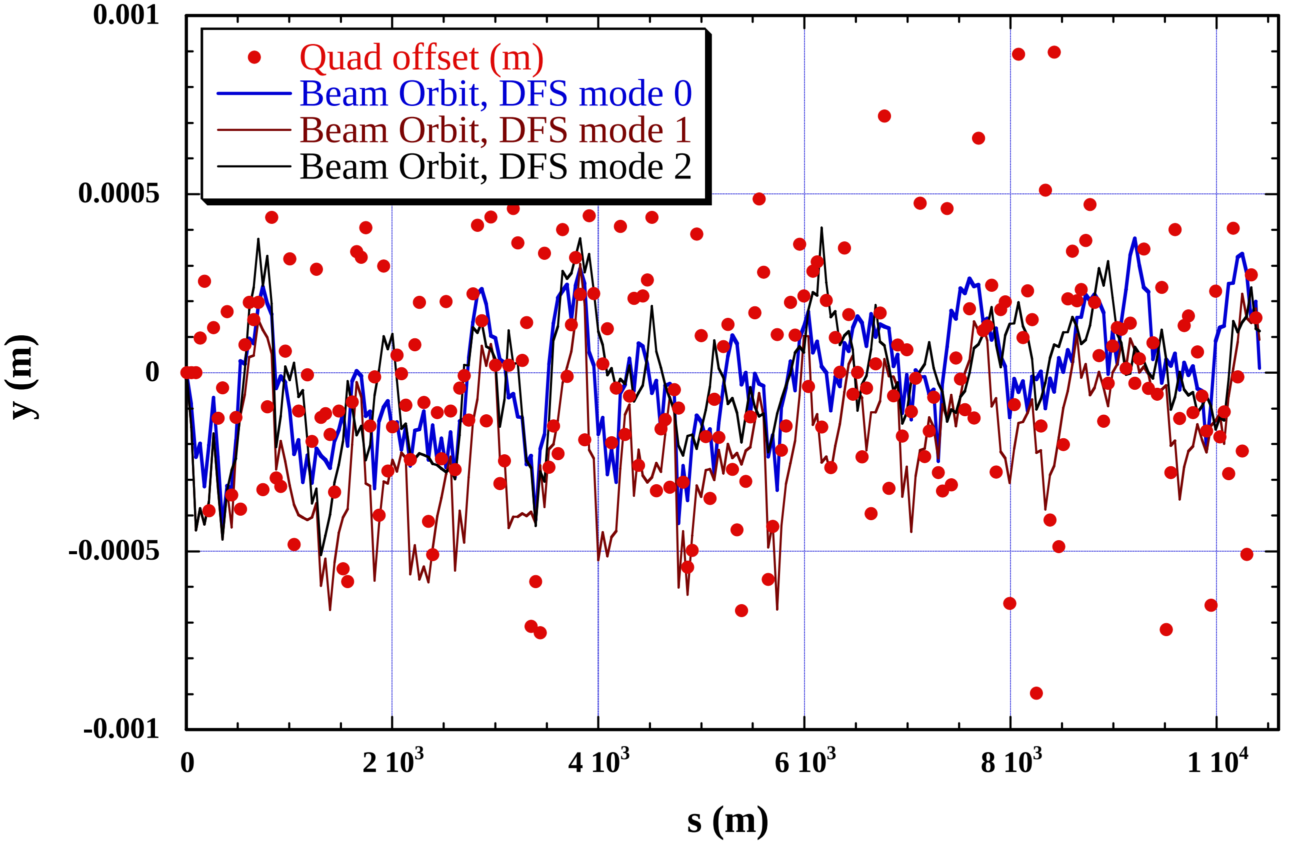
($\Delta y_{cal,i}$ is the calculated orbit difference, $y_{cal,I}$ the calculated orbit, without errors, at I-th BPM. w is the weight factor, w=5000.).

(6) Iterate from (1) to (5).

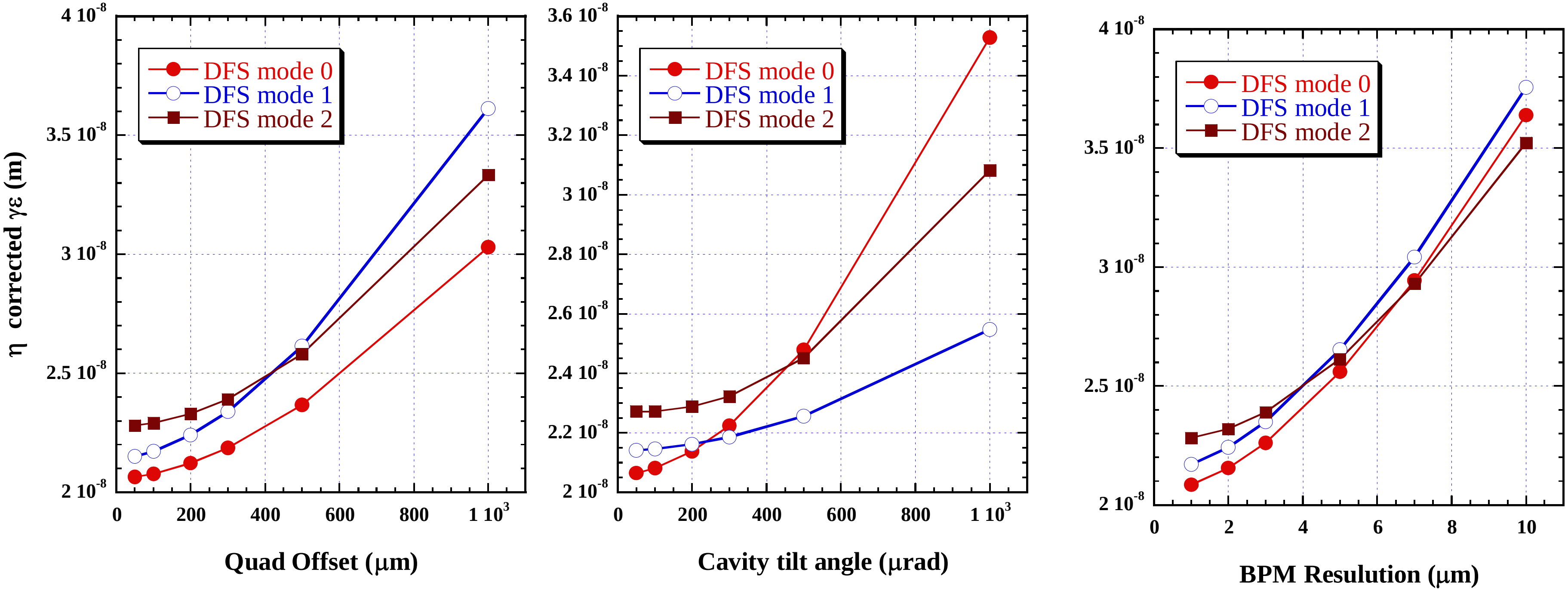
(7) Go to next section.

Example of beam orbit after DFS

Quad offset 0.3 mm, Cavity offset 0.5 mm, Quad-BPM offset 0.2 mm, Cavity tilt 0.5 mrad, BPM resolution 3 micron. (example of one particular seed.)

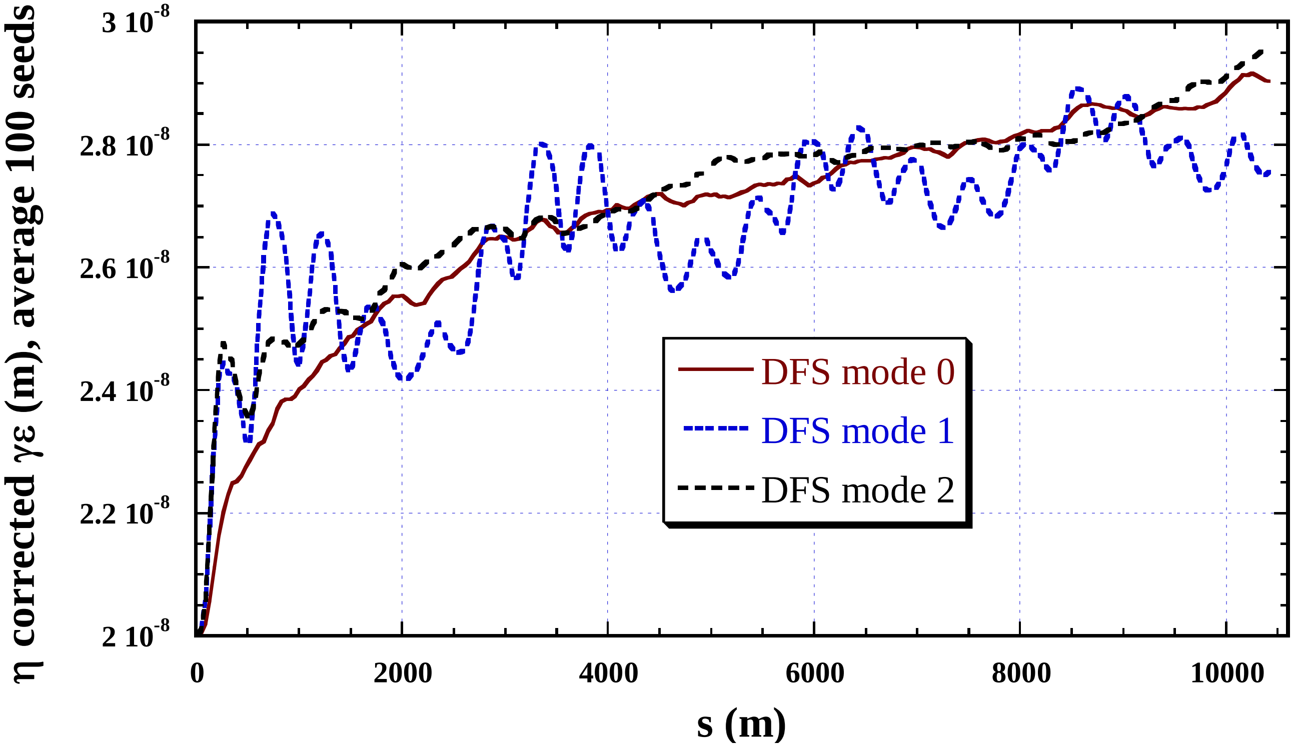


Sensitivity of final (linear dispersion corrected) emittance to various errors
(Average of 25 random seeds. No other errors in each figure.)



Emittance vs. s

Quad offset 0.3 mm, Cavity offset 0.5 mm, Quad-BPM offset 0.2 mm, Cavity tilt 0.5 mrad, BPM resolution 3 micron. (Average of 100 random seeds.)



Mode 1 shows clear structure due to division into sections.

Summary and comments

- DFS (Dispersion Free Steering) is effective in slowly curved (following earth) linac.
- Three different algorithms of DFS were tested.
  - Result of mode 0 is most sensitive to cavity tilt error, as expected.
  - Averaged emittance of the three looked similar for the combined errors: Quad offset 0.3 mm, Cavity offset 0.5 mm, Quad-BPM offset 0.2 mm, Cavity tilt 0.5 mrad, BPM resolution 3 micron.
    - About 40% to 50% vertical emittance dilution. (w.r.t. 2E-8 m)
- The results seem to depend on how the linac is divided into sections. (not shown here)