On-line dispersion free steering

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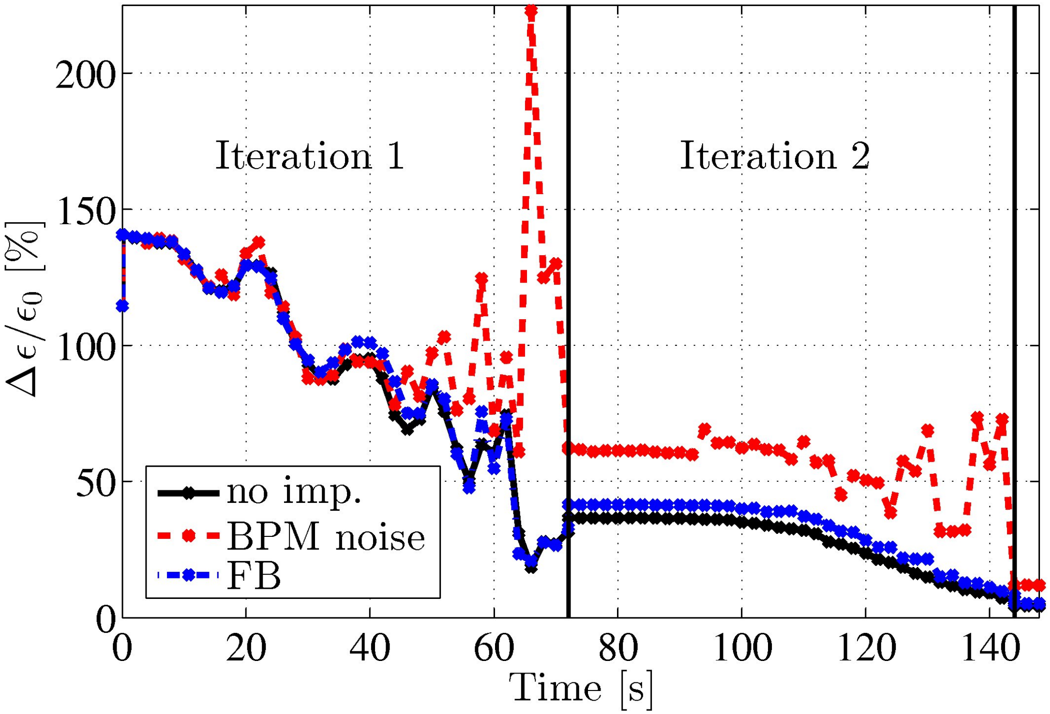

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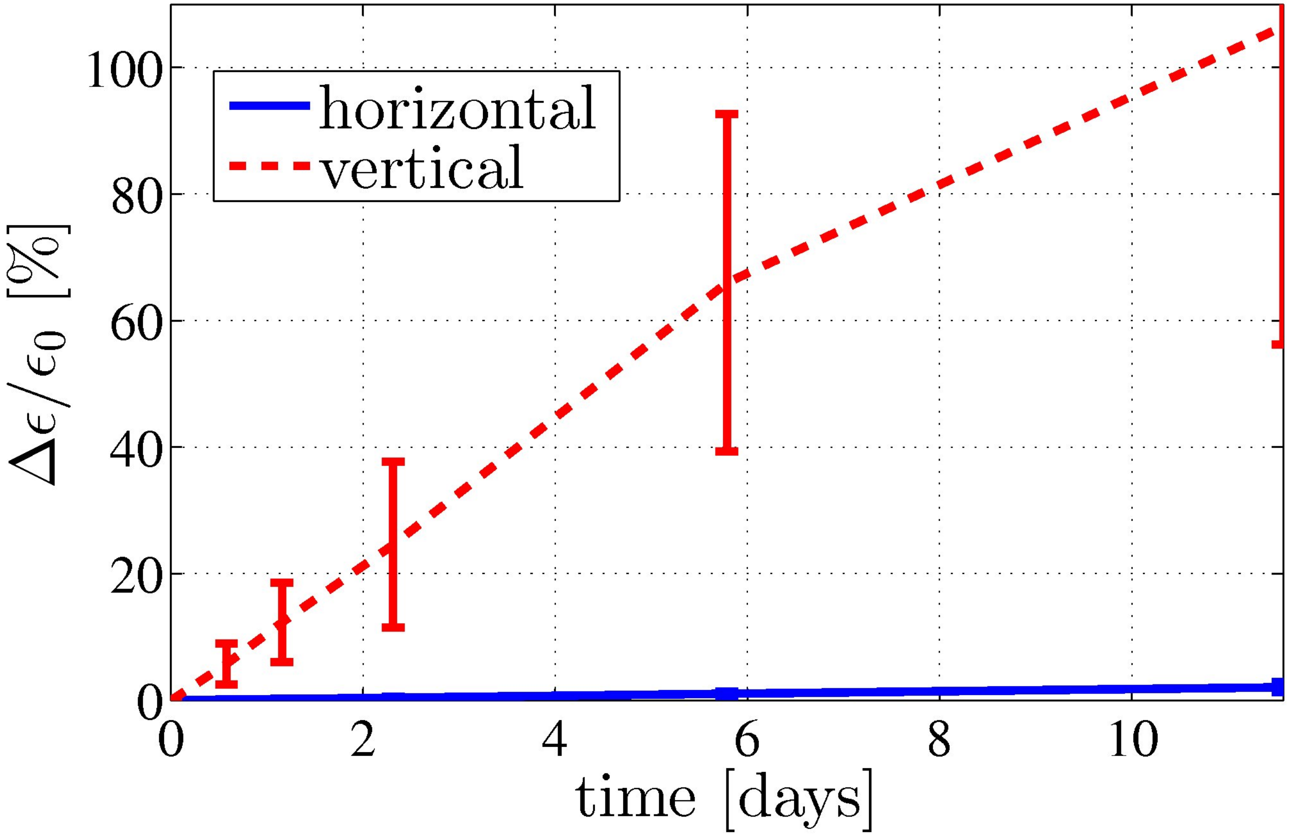
1. Introduction

Long-term ground motion in the main linac



Start from perfectly aligned machine

ATL motion and 1-2-1 correction applied

ε_x = 600nm
ε_y = 10nm

10 samples

On-line DFS

Long-term ground motion effects

- BPMs gets misaligned by ground motion
- ATL model used
- Orbit feedback steers in centres of BPMs
- New orbit is not optimal and results in emittance increase
- Problem is chromatic dilutions due to dispersion

Strategy: On-line DFS

- Additionally to orbit feedback that corrects orbit -> second system that corrects on-line the dispersion
- Dispersion Free Steering algorithm (DFS) can be used, but has to be modified for continuous operation
- Main problem calculation of the dispersion

2. On-line DFS algorithm

Dispersion Free Steering (DFS)

DFS algorithm consists of 2 steps:

1. Dispersion measurement:
The dispersion $\boldsymbol{\eta}$ at the BPMs is measured by varying the beam energy.

2. Dispersion correction:
Corrector actuation $\boldsymbol{\theta}$ are calculated such that at the same time the measured dispersion $\boldsymbol{\eta}$ as well as the beam orbit $\boldsymbol{b}$ are corrected. The corrections are calculated by solving the linear system of equations:

$$\begin{bmatrix} \boldsymbol{b} - \boldsymbol{b}_0 \\ \omega(\boldsymbol{\eta} - \boldsymbol{\eta}_0) \\ \boldsymbol{0} \end{bmatrix} = \begin{bmatrix} \boldsymbol{R} \\ \omega \boldsymbol{D} \\ \beta \boldsymbol{I} \end{bmatrix} \boldsymbol{\theta}$$

DFS is usually applied to overlapping sections of the accelerator (for this simulations: 36 sections with full overlap).

Dispersion Estimation

- **Problem:** Only very small beam energy variations can be accepted
- For studies only 0.5 per mil are used: initial beam energy and gradient var.
- Measurement are strongly influenced by BPM noise and usual energy jitter. Therefore, many measurement have to be used and averaged.
- Use of a Least Squares estimate (pseudo-inverse), which can be significantly simplified by the choice of the excitation:

$$\eta_N = (\boldsymbol{E}^T \boldsymbol{E})^{-1} \boldsymbol{E} \boldsymbol{b} = \frac{T_N}{N \Delta E} \quad \text{with}$$

$$\boldsymbol{E} = \begin{bmatrix} -\Delta E \\ +\Delta E \\ \dots \\ -\Delta E \\ +\Delta E \end{bmatrix} \quad \text{and} \quad T_N = \sum_{i=1}^{N} (-1)^i b_i$$

- Choice of ***E*** is also of advantage for the interaction with the orbit feedback.

Other on-line issues

Integration with orbit feedback:

- Orbit feedback will "see" the orbit changes due to the energy variation and will react on them
- This will influence the estimation result

- To decouple the two systems: Energy excitation is chosen to be a constant value with alternating sign.
- Highest frequency for the orbit controller, which will damp this frequency strongly.

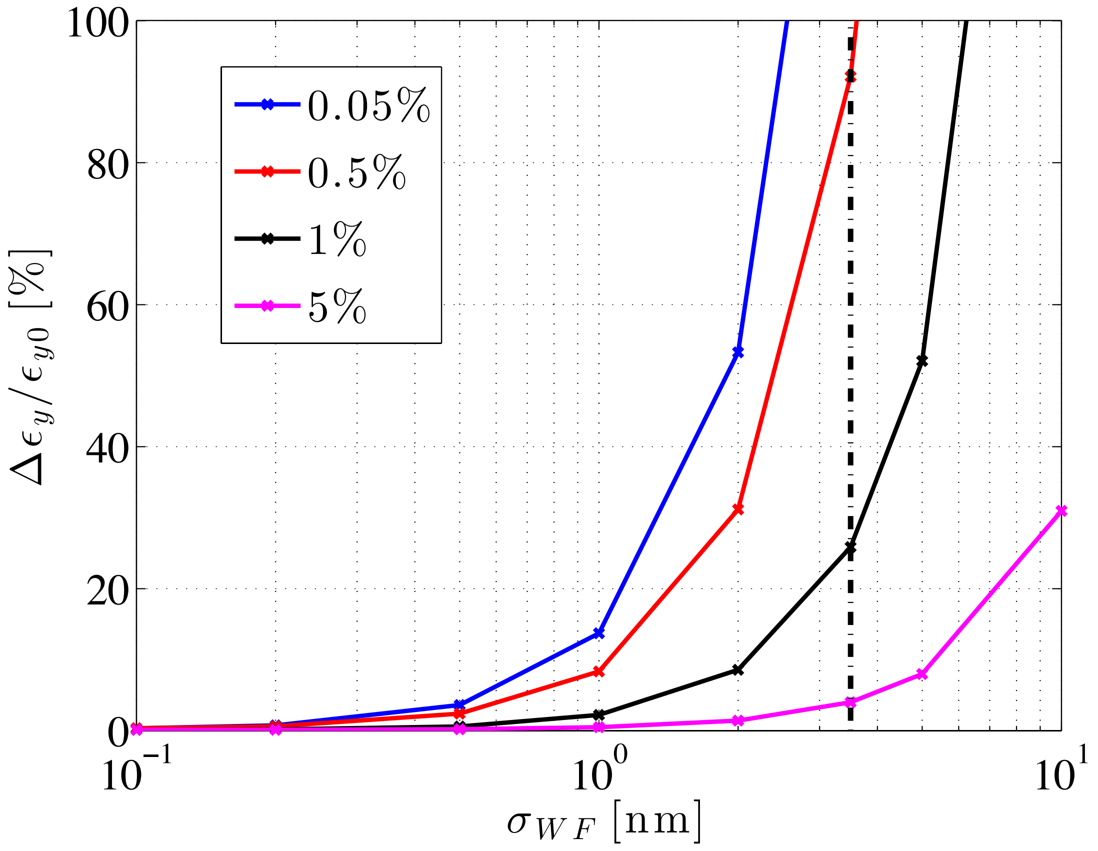
Steering correction:

- After moving the QPs due to DFS the BPMs have to be "moved" to the new reference orbit. Otherwise the OFB steers beam back.
- DFS correction in a bin will create beam oscillations downstream
- This oscillations have to be damped by correctors downstream
- The use of only the next correctors in the bin for all2all-steering is sufficient:

$$-\begin{bmatrix} \hat{\boldsymbol{b}} \\ \boldsymbol{0} \end{bmatrix} = \begin{bmatrix} \widehat{\boldsymbol{R}} \\ \beta_0 \boldsymbol{I} \end{bmatrix} \hat{\boldsymbol{\theta}}$$

3. Wake field problem

Resolution of wakefield monitors

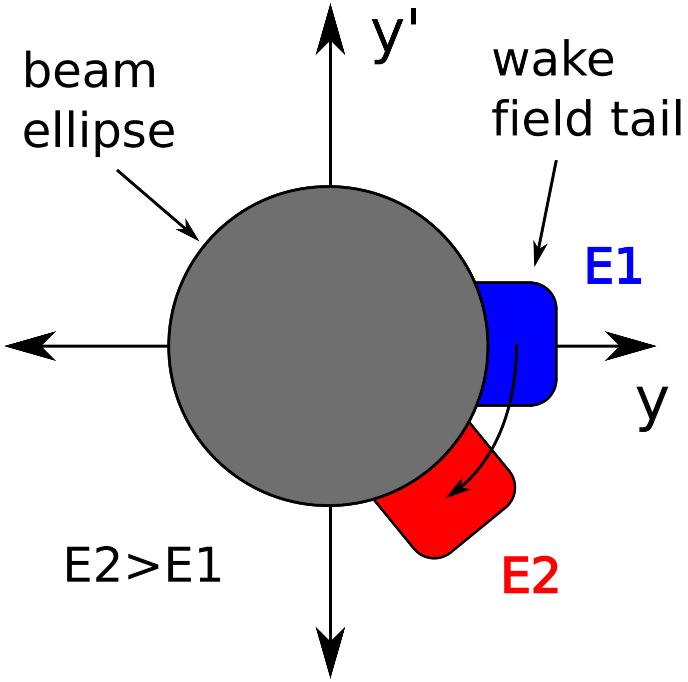


- Very strong sensitivity to wakefields
- Algorithm has to be made more robust
- We have tried:
  - recalculation of R
  - shorter Bins
  - parameter scan
  - no smoothing

=> nothing helped

Wake field tail motion and DFS

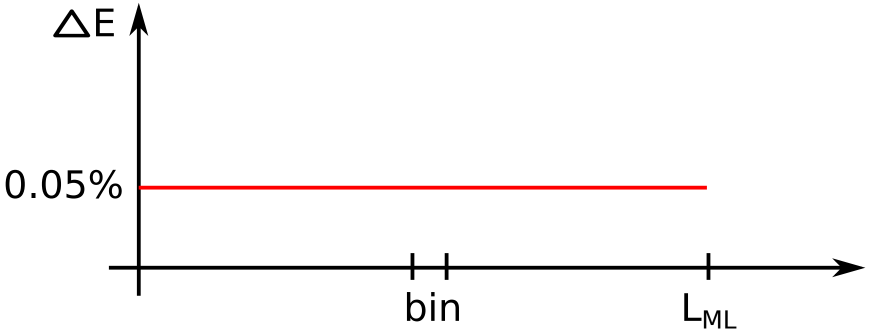
- If beams have different energies they rotate differently fast in phase space.
- If beams are symmetric, different energy does not cause beam centre shift.
- But if the beams are asymmetric (e.g. wake field tail) the beam centres are shifted for different energies.
- Even if the bin to be corrected has no (local, linear) dispersion, this nonlinear "wake field dispersion" from upstream will be measured.
- The on-line DFS tries to compensate this "wake field dispersion", but the result is not satisfactory.



- <u>Two solutions to the problem:</u>
  1. Higher energy change
  2. Local excitation scheme

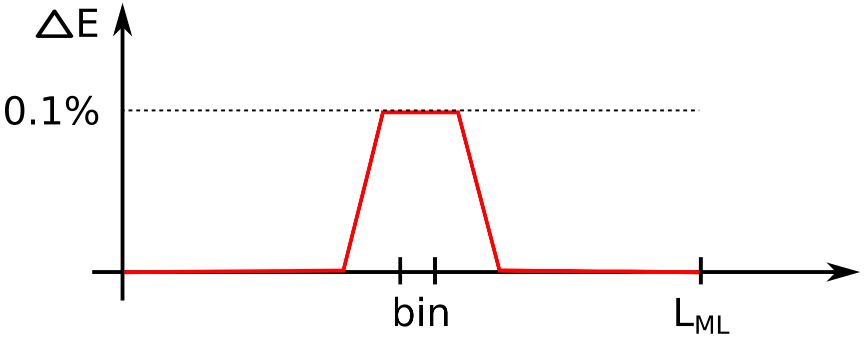
Global vs. local excitation scheme

1. Global excitation scheme:



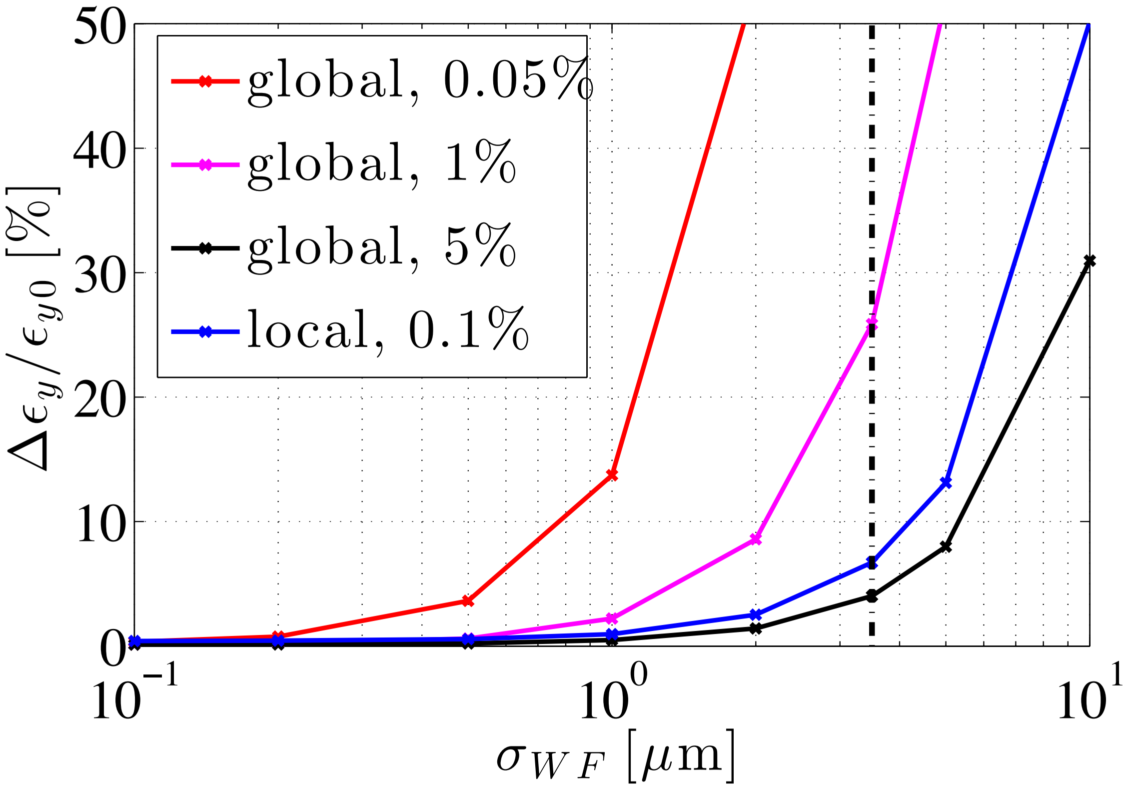
- Simple, since all acceleration gradients are changed equally

2. Local excitation scheme:



- Change of only the gradients in the decelerators before, at and after the bin to correct
- Beam travels only over a short distance with different energies
- Remove ΔE after corrected bin
- A higher ΔE can be used

Wake field sensitivity with local excitation

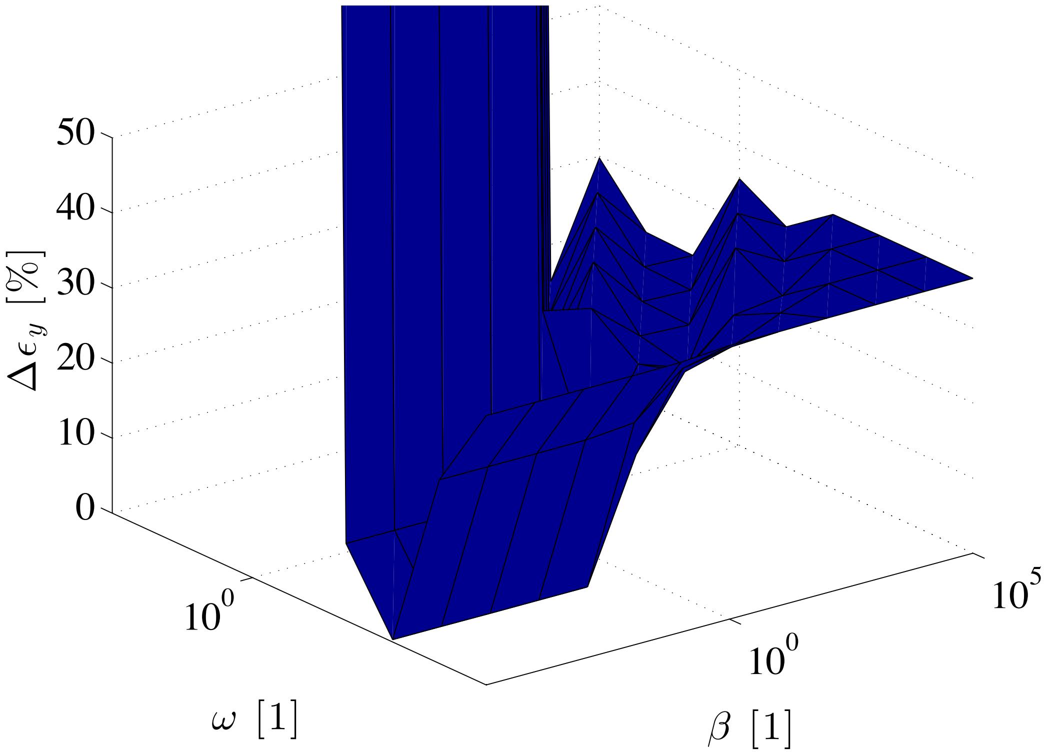


- Local scheme with 0.1% shows similar behaviour than global excitation with 5%

- The increase of emittance due to the nominal CLIC wake field monitors resolution is about 6%.

4. Simulation results

Parameter choice



- Weight ω not chosen as a constant, but as

$$\boldsymbol{\Omega} = diag\left(\sqrt{\frac{\boldsymbol{\sigma}_{BPM}^2 + \boldsymbol{\sigma}_{off}^2}{2\boldsymbol{\sigma}_{BPM}^2}}\right)\omega$$

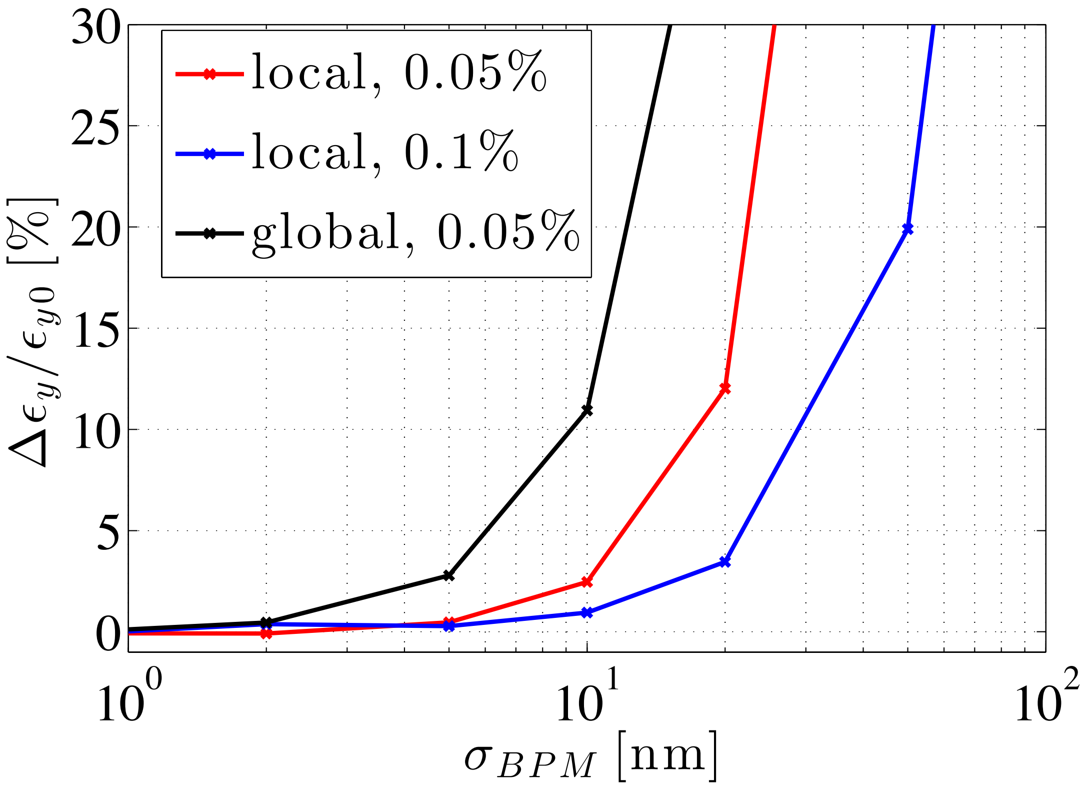
$$\boldsymbol{\sigma}_{off}^2 = AT\boldsymbol{\Delta L}_{BPM}$$

- Parameter scan over ω and β for different seeds and with some imperfections:

  $\omega = 10^{-2}$

  $\beta = 10^{-3}$

Necessary averaging time

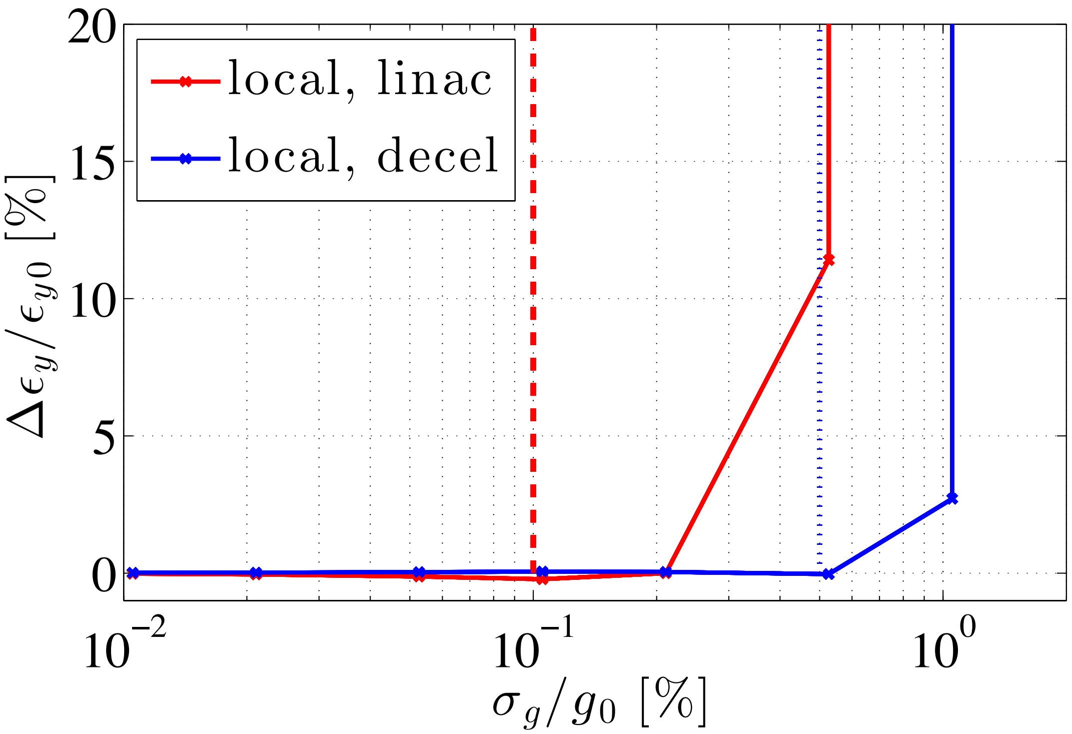


Not full estim. but only real dispersion is disturbed by noise.

For $\Delta\varepsilon_y < 2\%$ ->
$\sigma_{BPM} < 10$nm ->
Reduction of 10 ->
$N = 100$ ->
$T = 0.02*100*36$
$= 72$s

With global scheme about 10 minutes

Effect of gradient imperfections



- Jitter coherent for the whole linac or only for the decelerators
- Vertical lines indicate CLIC specifications (0.1% linac, 0.5% per decelerator).
- Surprisingly robust

Other tested imperfections

- Integration with the orbit feedback: hardly any effect visible
- Linearity errors of the BPMs: up to 10% linearity error no significant emittance growth
- Quadrupole mover breakdown: up to a 1/3 of all movers could break down without any strong impact (2-4% increase of emittance)

- Errors in the used correction matrices (orbit response matrices with different beam energies):
    1. BPM noise: pretty robust no averaging necessary
    2. Energy errors: some averaging at measuring will be necessary, but no severe problem

4. Conclusions

- On-line DFS seems to be capable of correcting chromatic dilutions
- Corrections are applied in a parasitic way with an energy change of 0.1 per mil, which is transparent (apart from last bin) for the BDS and IP.
- It is not necessary to operate all the time, but just to switch on the corrections for a few iterations.
- An sensitivity to the resolution to the wake field monitors has been overcome by adopting a local excitation scheme.
- The time necessary to correct the chromatic dilutions below 10% emittance growth is 72 sec compared to 10 min with the global excitation scheme (not including the time for 2 cavity alignments).
- Full-scale simulations performed.
- Influence of many imperfections has been tested and no serious problems have been observed.

Thank you for your attention!