Imperfection tolerances for on-line dispersion free steering in the main linac of CLIC

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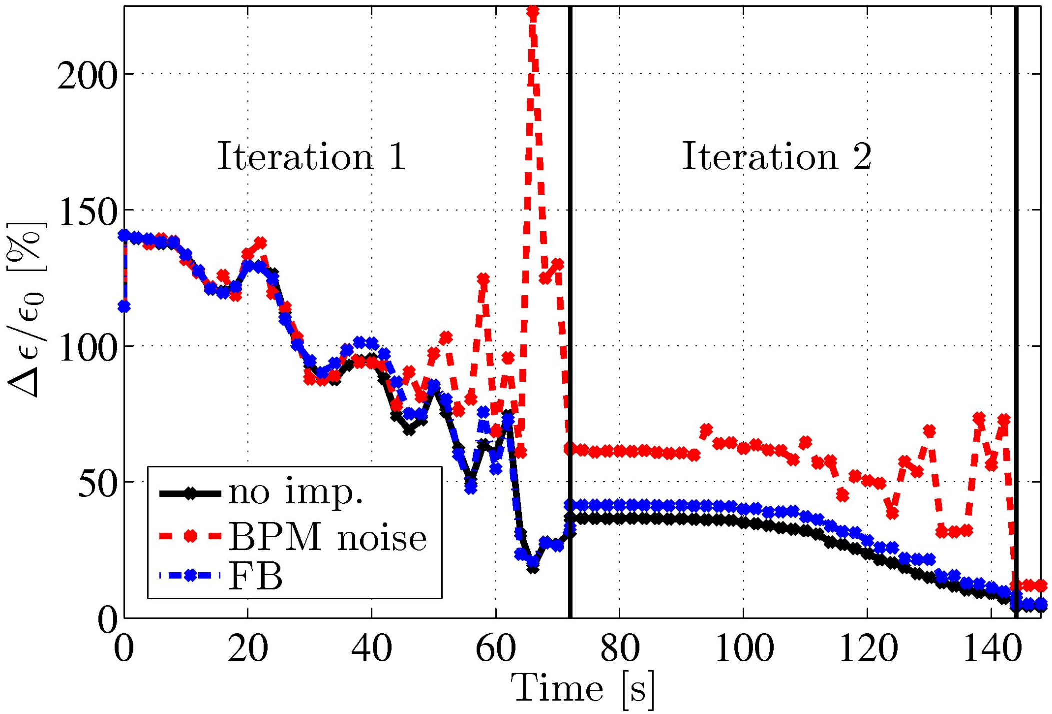

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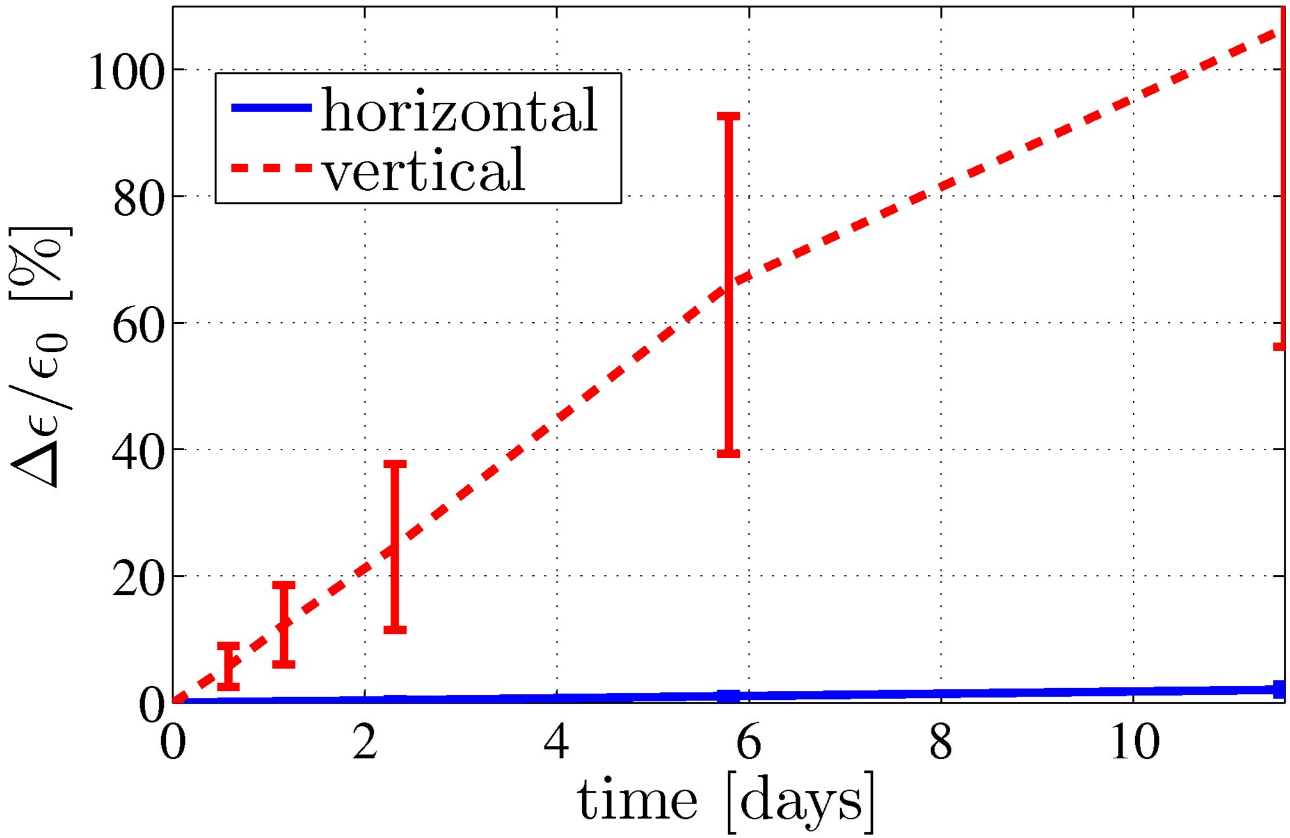
1. Introduction

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:

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

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.

Wakefields

- **Observation:** When no noise sources are considered:
  1.) DFS works better with larger induced energy change (e.g. 10%). It should work better for energy change in the order of the beam energy spread.
  2.) Results for small energy changes get better with 2 or 3 iterations where always a cavity alignment is included.
  3.) Fast convergence if an initial cavity alignment is performed.
- **Guess:**

  For very small energy variations the dispersive orbit is very small and wakefield effects can perturb the measurement.

-> Therefore always an initial cavity alignment is performed.

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.

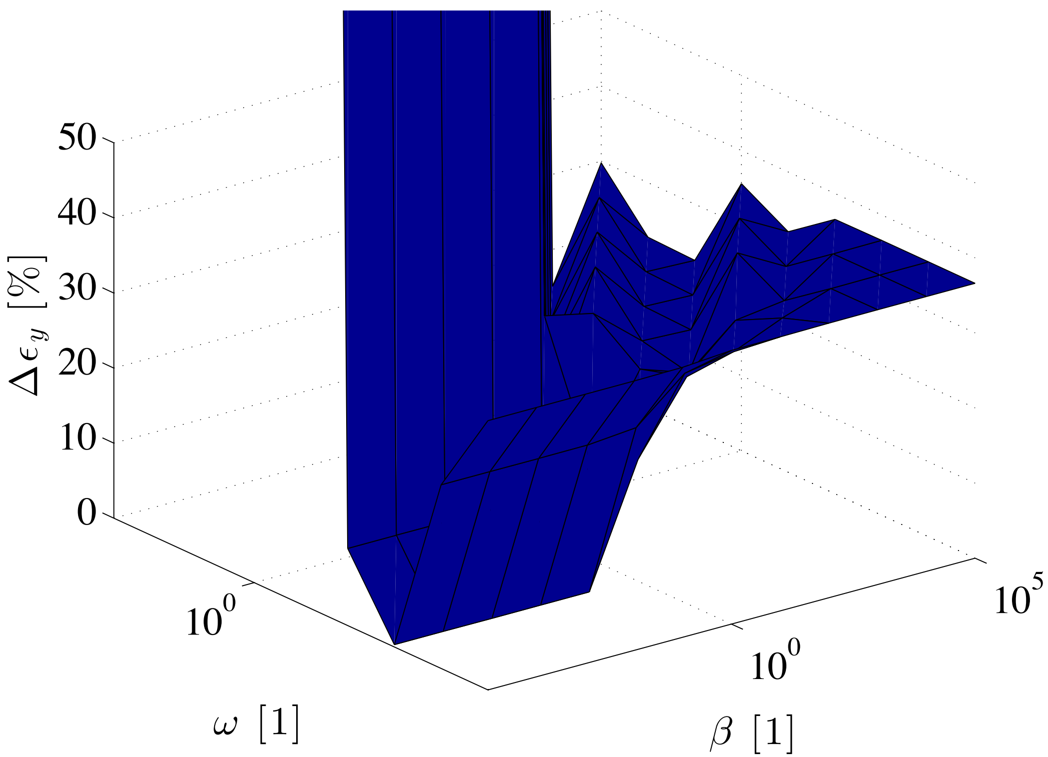
Steering correction:

- 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. Results

Parameter choice



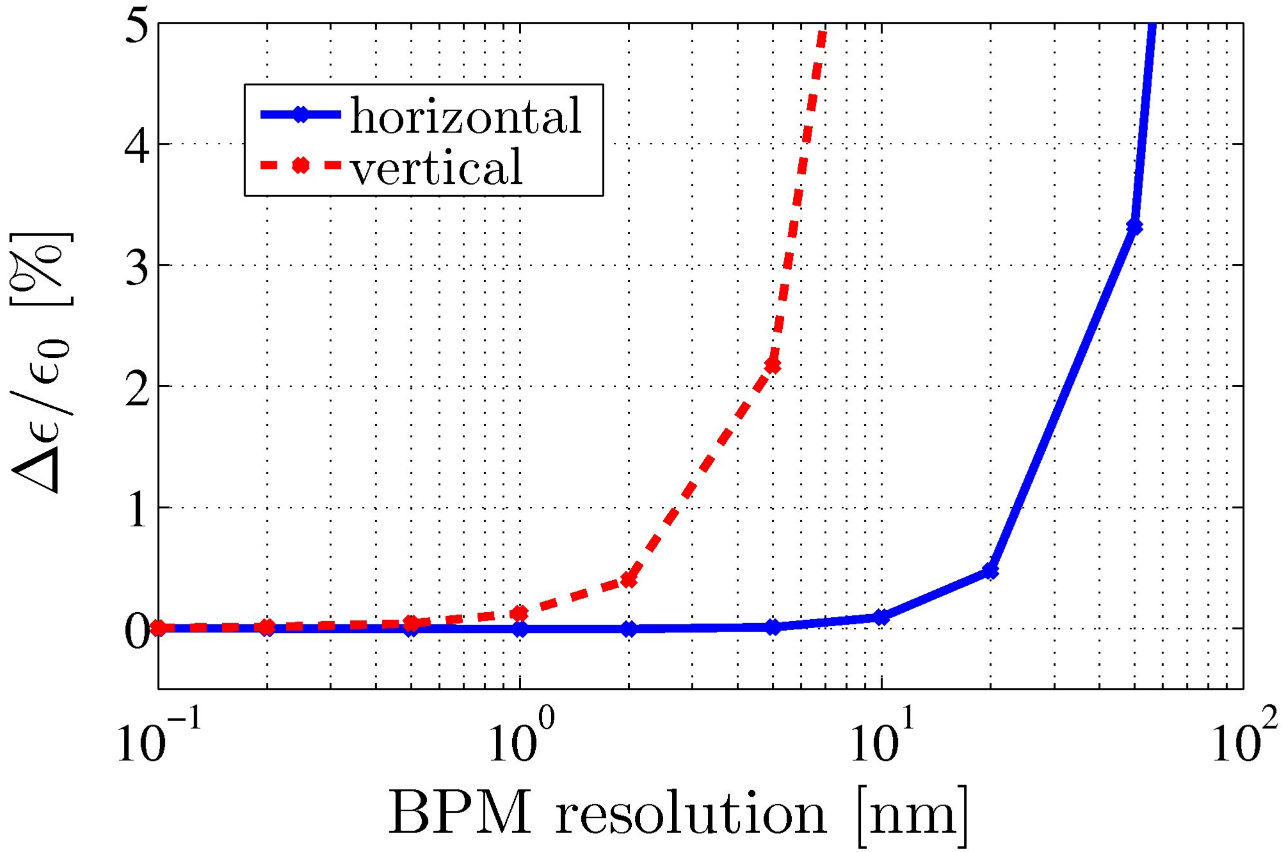
- Weight ω not chosen as a constant, but as

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

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

- Parameter scan over ω and β for different seeds and with some imperfections:
  $\omega = 10^{-2}$
  $\beta = 10^{-3}$

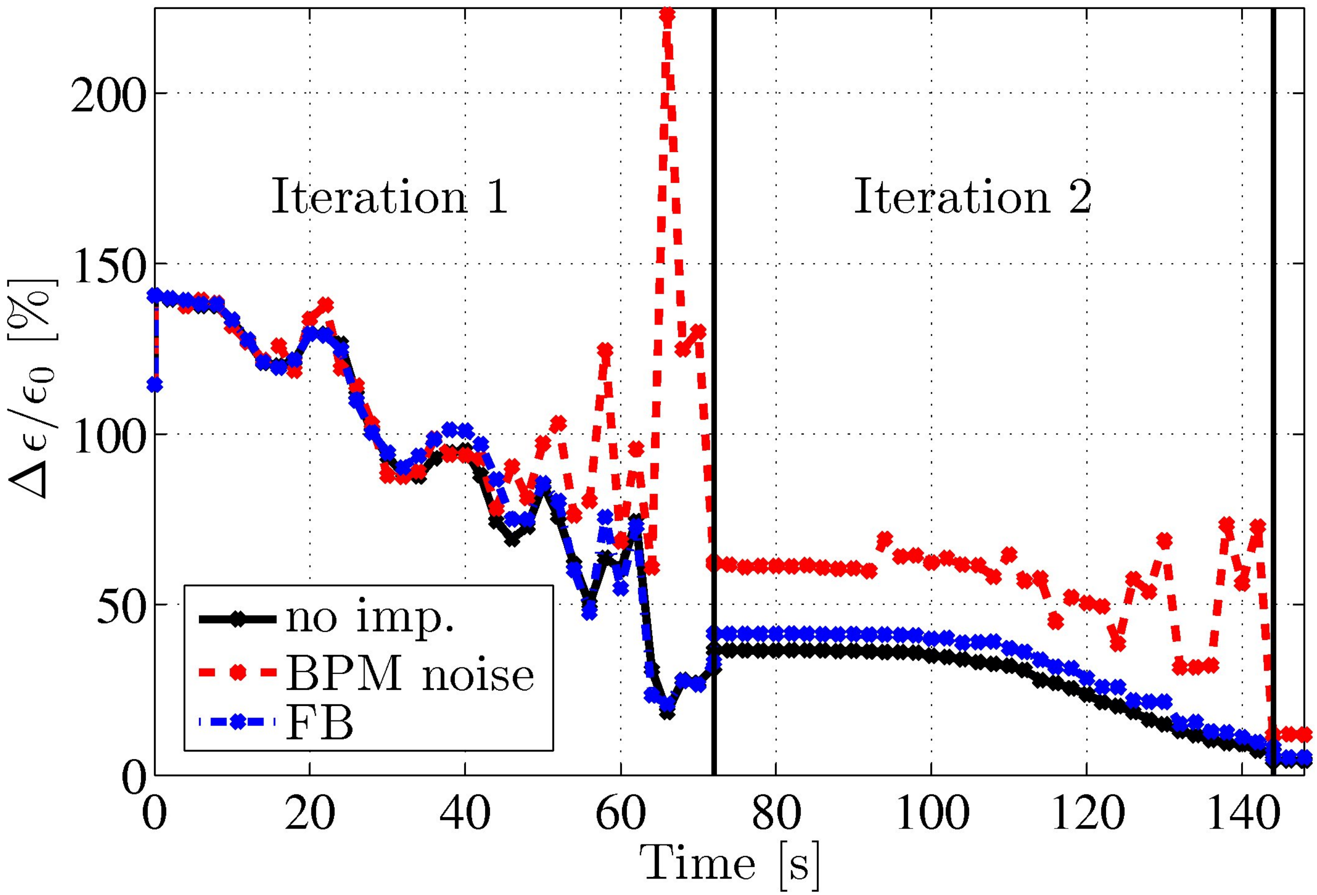
Necessary averaging time



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

For $\Delta\varepsilon_y$ < 2% ->
σ_{BPM} < 5nm ->
Reduction of 20 ->
N = 400 ->
T = 0.02*400*36*2
≈ 10min

Typical correction



Full estimation simulations for one seed

Reduced estimation time to speed up simulations: only
N = 100 ->
$T \approx$ 2min

σ_{BPM} = 100nm

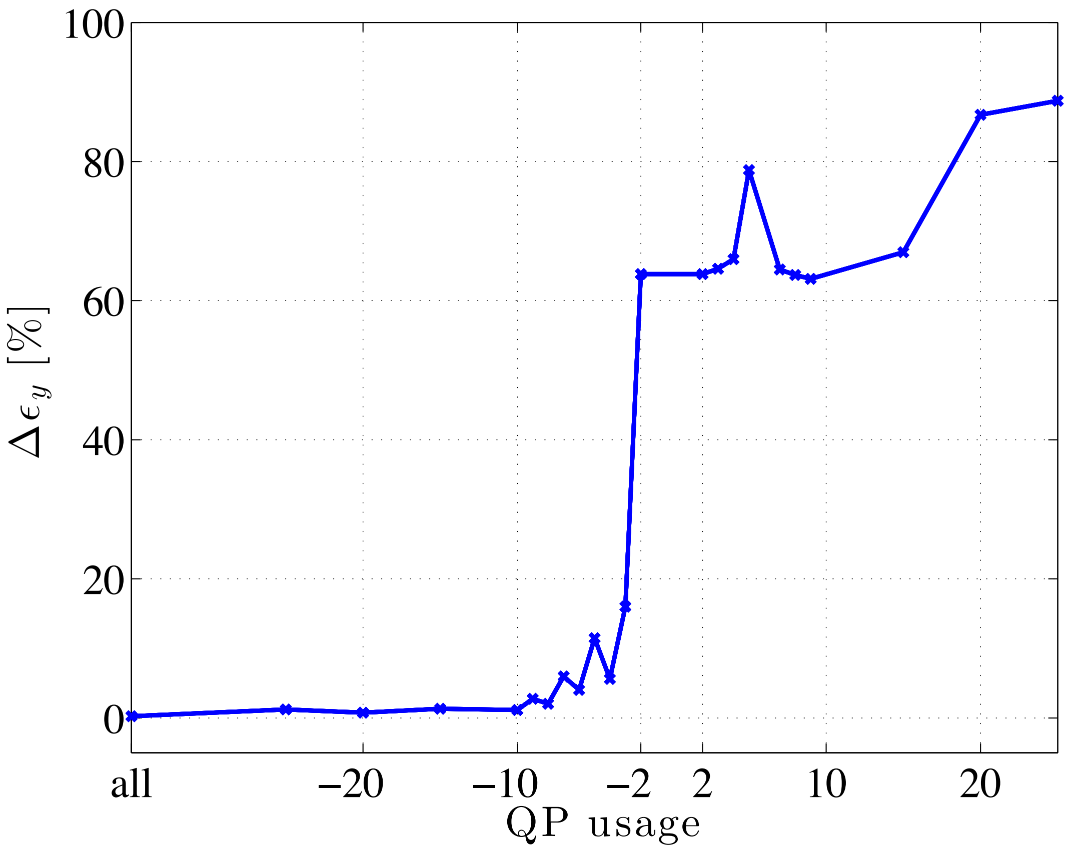
No imp: 4%
FB : 5%
BPM noise: 12%

Averaged results and imperfections

- **Averaged results** of full simulations (20 seeds) with *N* = 100 and 2 iterations:
  - About 11 days of CLIC ATL motion -> 1-2-1 steering -> 107%
  - No imperfections: 2.8%
  - With OFB on: 3.7%
  - BPM noise: 10.4% (no controller)

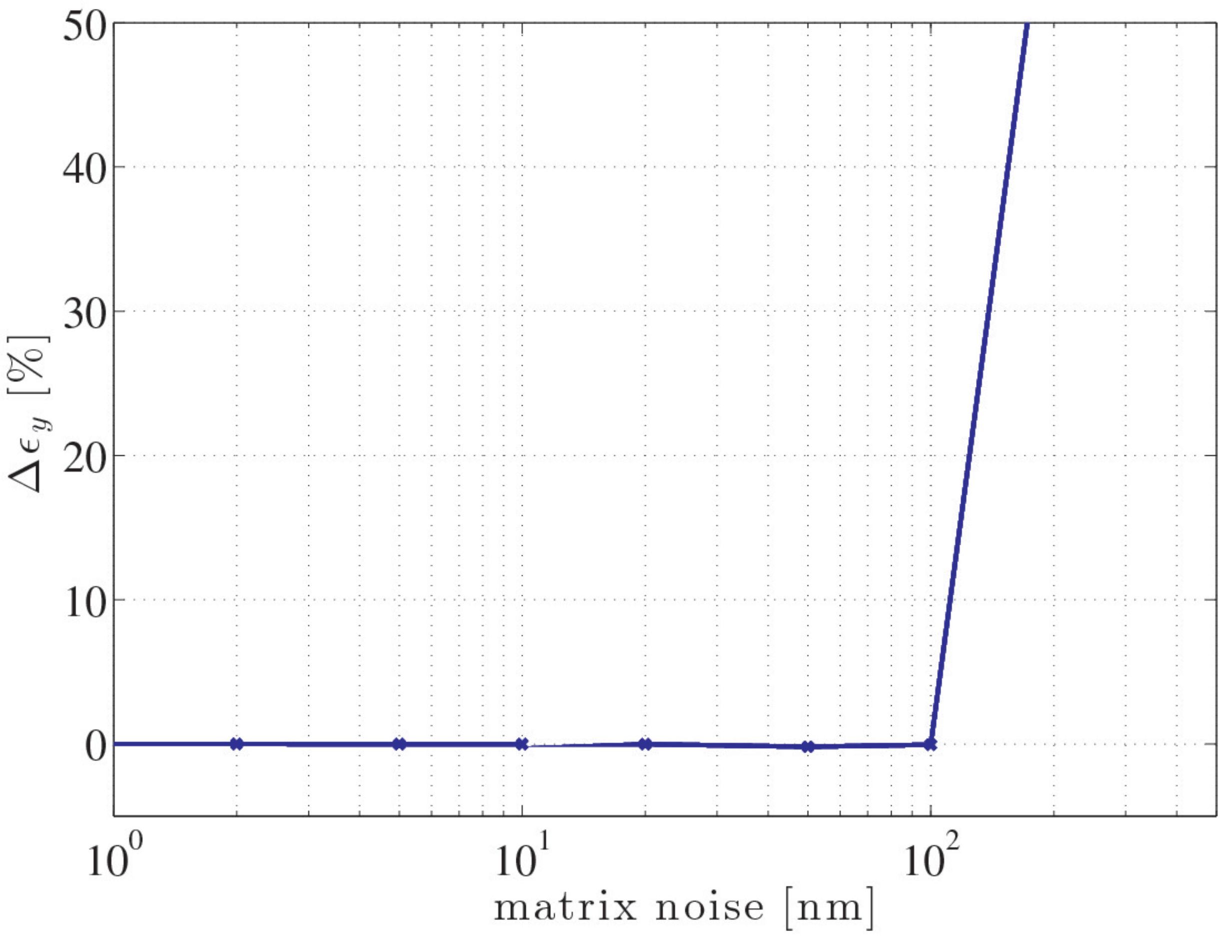
- **Other tested imperfections:**
  - Short-term ground motion (model B) with dispersion simulations: very small effect.
  - Jitter of acceleration gradient (per decelerator): only small effect up to the maximal specification of 0.5%.

Use of less correctors



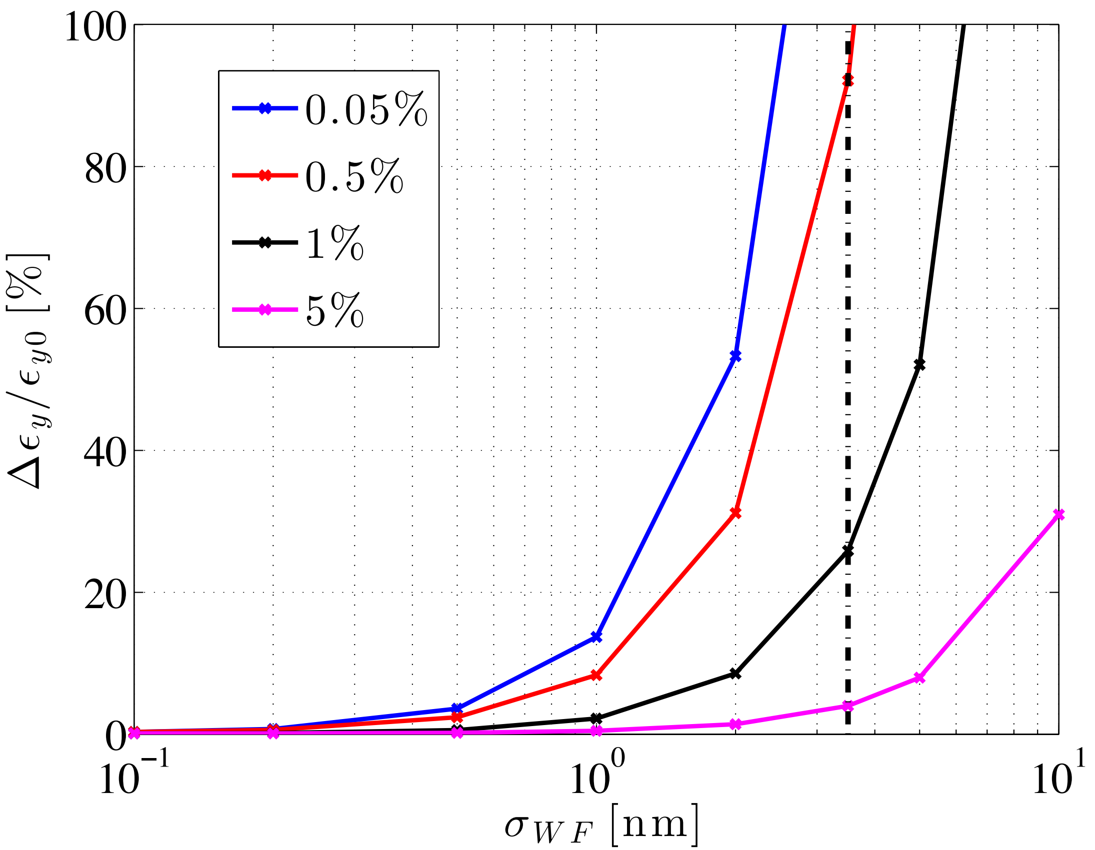
- Pos. numbers on x-axis correspond to using each nth corrector.
- Neg. numbers on x-axis correspond to leaving out each nth corrector.
- Averaged over 10 seeds. Behaviour between different seed varies strongly
- Reduction of a factor 2 causes already strong performance loss

Noise in DFS matrices



- Artificial noise in the matrices used for the DFS
- Averaged over 5 seeds
- Result stays the same for noise below 100nm

Resolution of wakefield monitors



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

-> nothing helped
-> open issue

Is it the same with usual DFS?

4. Conclusions

- In general, on-line DFS seems to be capable of correcting chromatic dilutions
- Corrections are applied in a parasitic way with an energy change of 0.5 per mil.
- It is not necessary to operate all the time, but just to switch on the corrections for a few iterations.
- The time necessary to correct the chromatic dilutions below 5% emittance growth is about 10 minutes (2 iterations) not including the time for 3 cavity alignments.
- Full-scale simulations performed with reduced estimation time show that the algorithm can correct the dispersion to the expected level.
- The influence of the orbit controller (without noise), energy jitter and short-term ground motion seems to be small or even negligible.
- But a high sensitivity with respect to wake field has to be resolved!!!

Thank you for your attention!