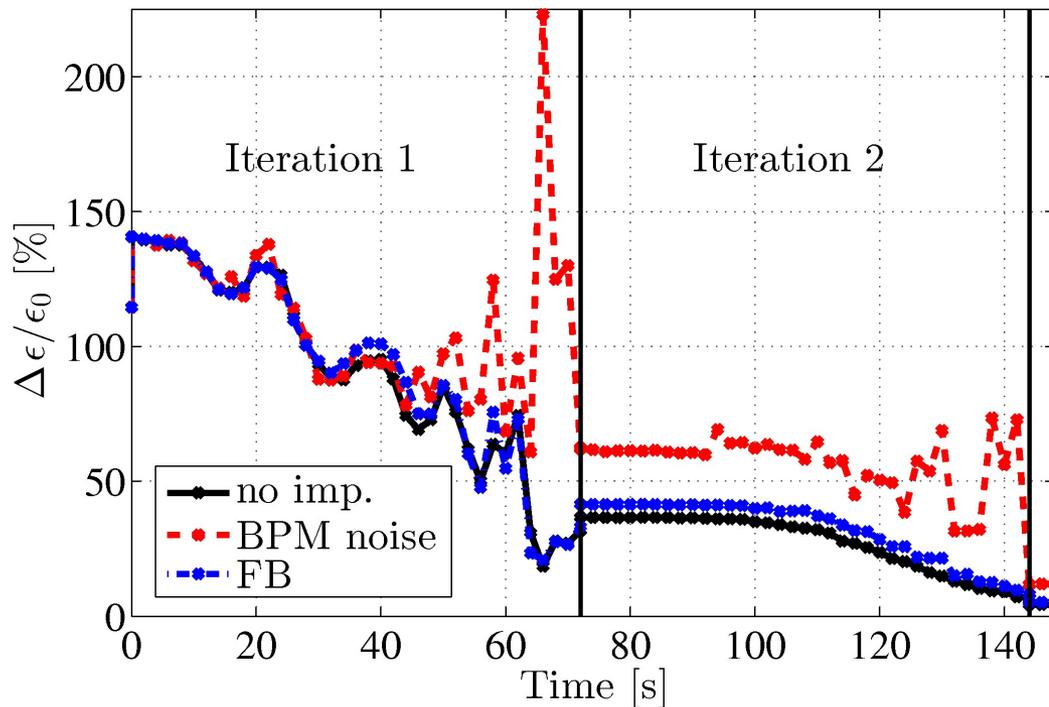# On-line DFS for the main linac of CLIC

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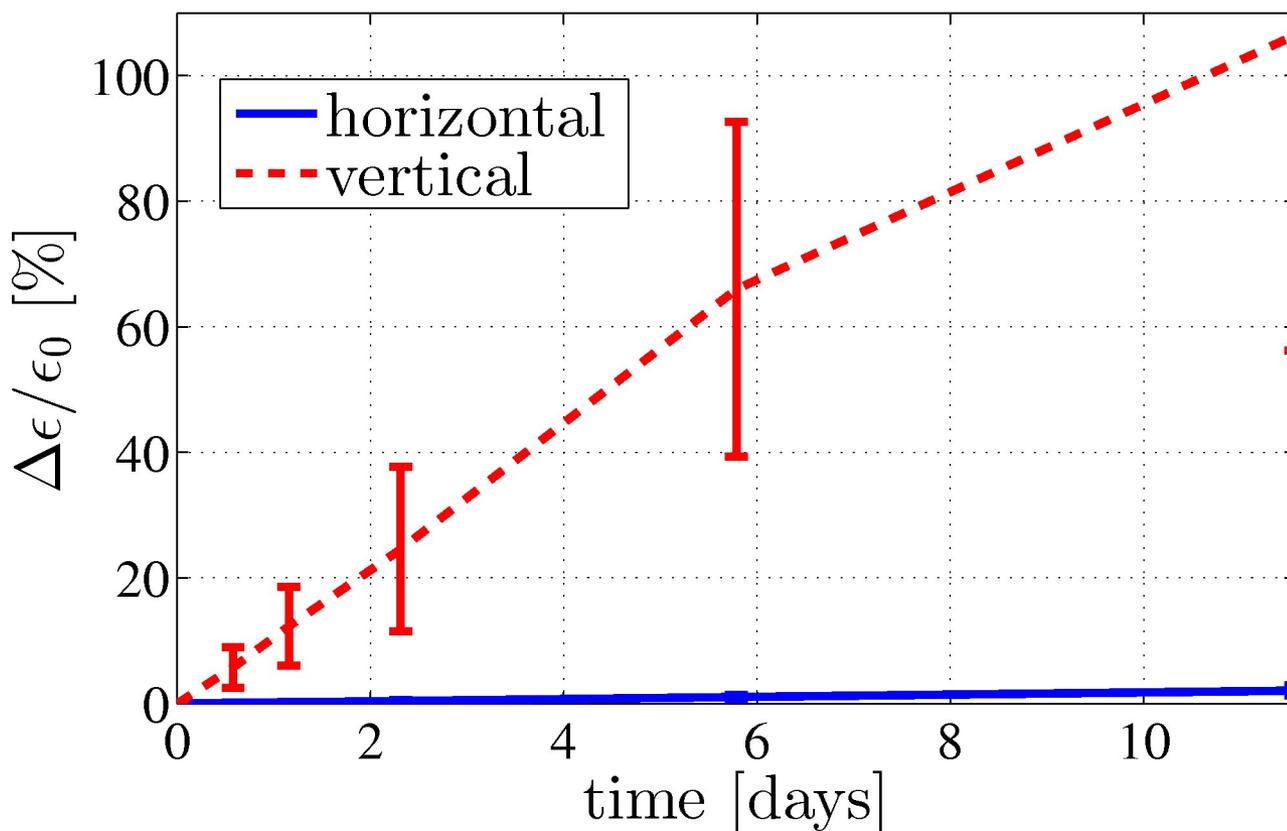
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1. Introduction

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:

$$
\begin{bmatrix} \boldsymbol{b} - \boldsymbol{b_0} \\ \omega(\boldsymbol{\eta} - \boldsymbol{\eta_0}) \\ \boldsymbol{0} \end{bmatrix} = \begin{bmatrix} \boldsymbol{R} \\ \omega\boldsymbol{D} \\ \beta\boldsymbol{I} \end{bmatrix} \boldsymbol{\theta}
$$

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:

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

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

- 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 constant with alternating sign.
- Highest frequency for the orbit controller, which will damp this frequency strongly.
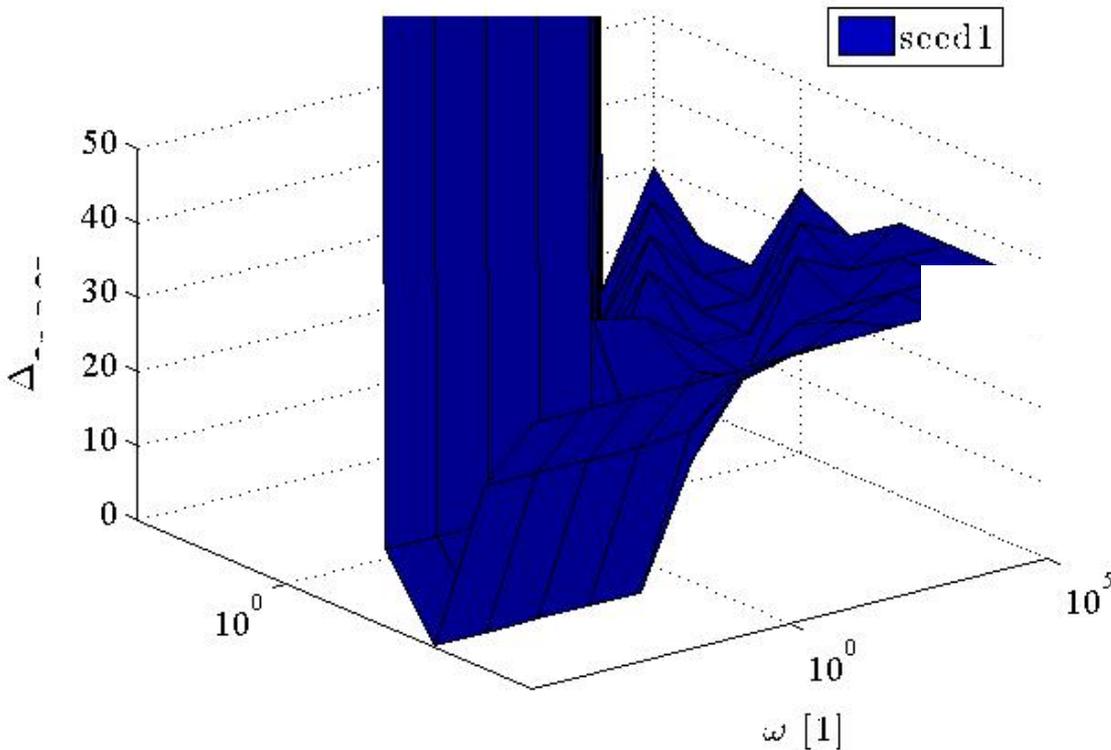
Steering correction:

- 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 damned by correctors downstream
- The use of only the next correctors in the bin for all2all-steering is sufficient:

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

3. Results

Parameter choice

- Weight ω not chosen as a constant, but as

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

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

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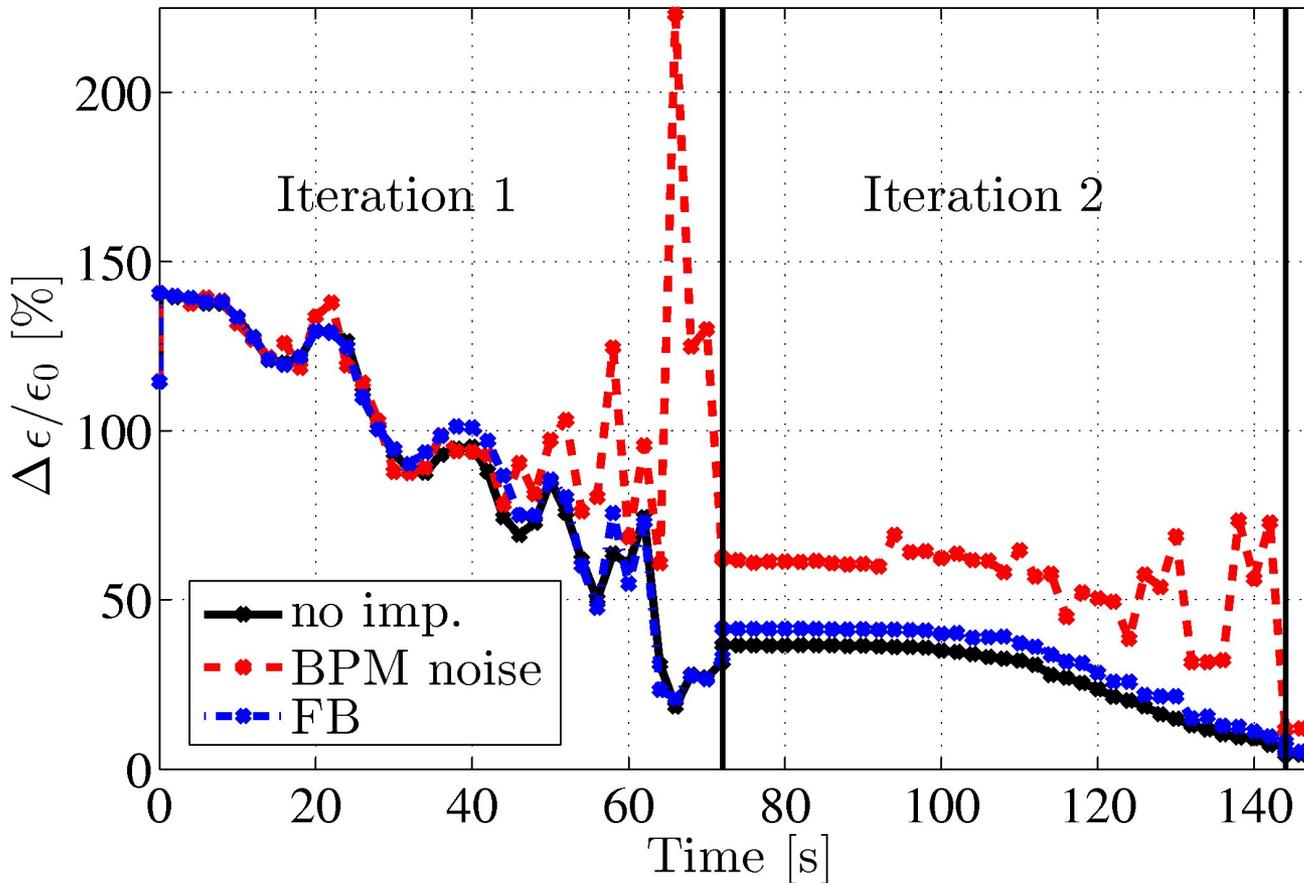 - β = 10^{-3}

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
$N = 100$ ->
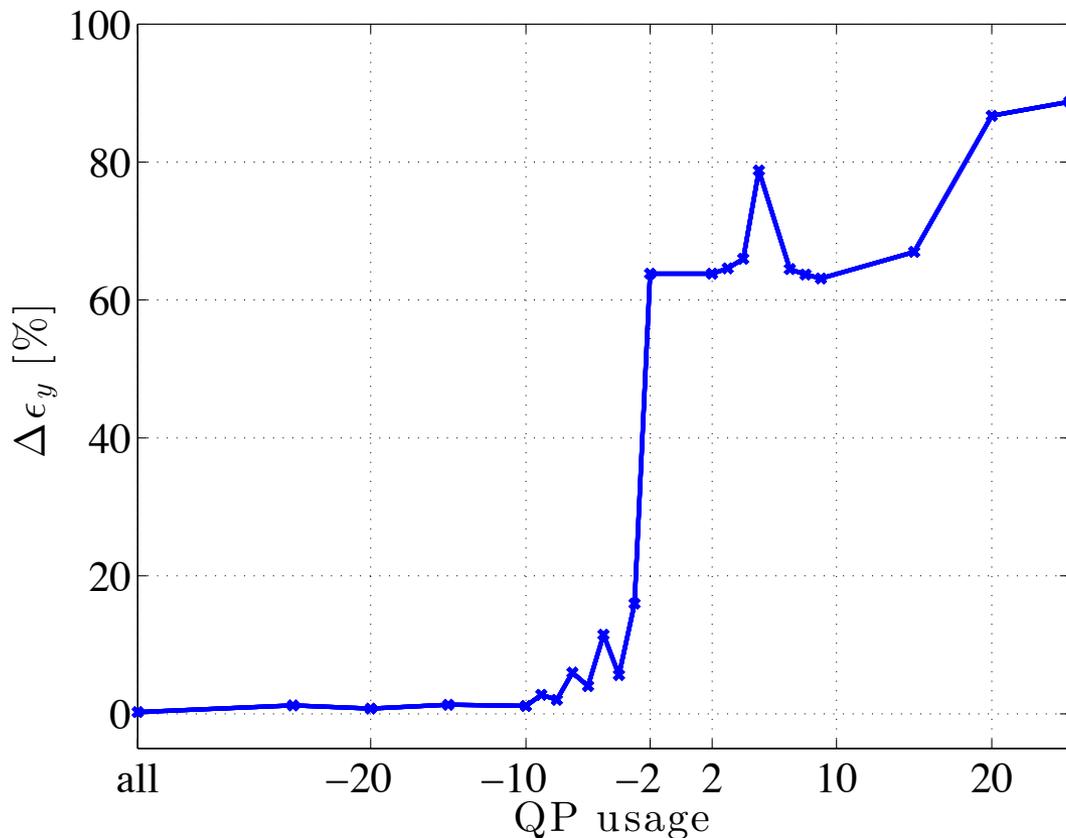$T \approx 2$min

$\sigma_{BPM} = 100$nm

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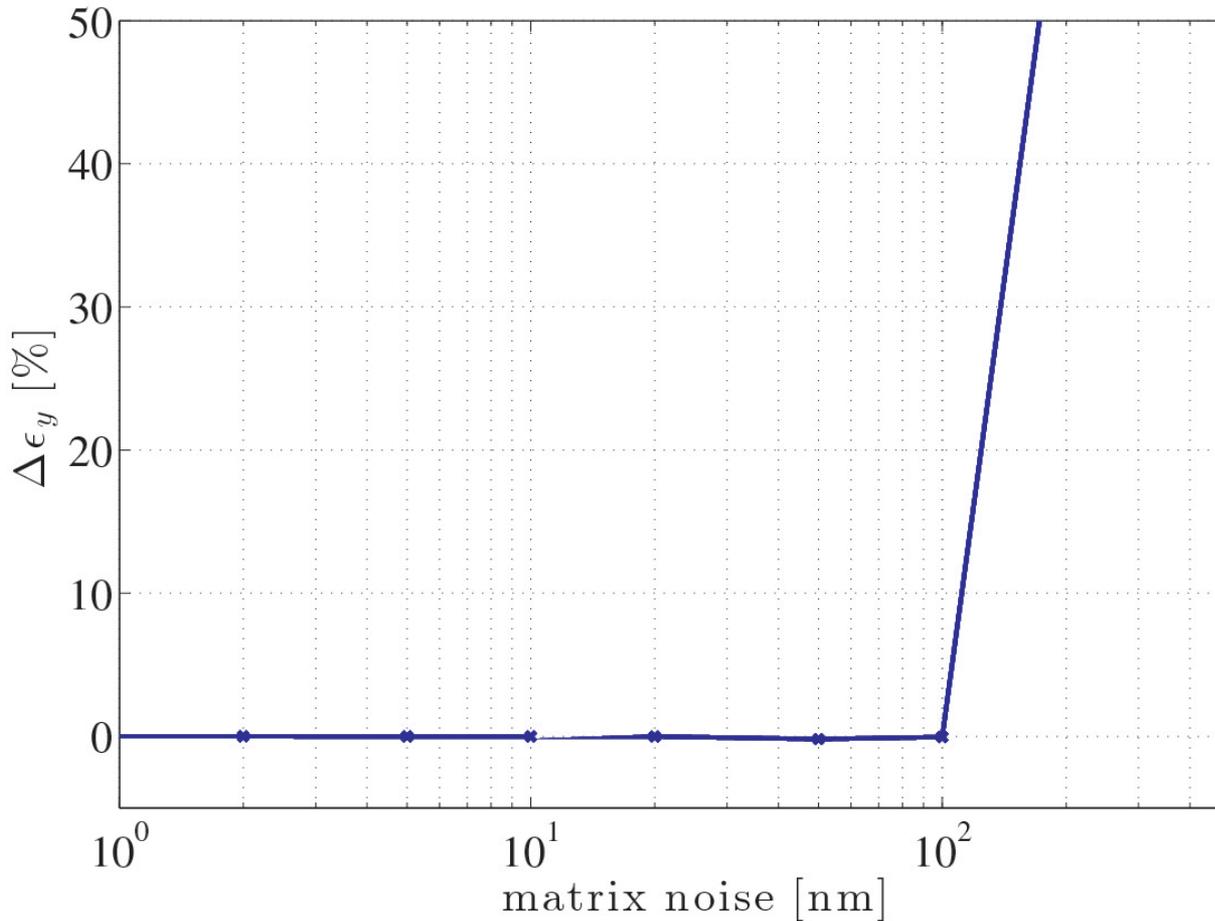FB : 5%
BPM noise: 12%

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

4. Conclusions

• On-line DFS seems to be capable of correcting chromatic dilutions

• Corrections are applied in an 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.

Open issues and discussion

• How is the bahaviour of the algorithm over longer time periods (several iterations)?

• Should other imperfections also be tested, e.g. noise in the cavity alignment and the wakefield monitors was set to zero at a the moment?

• How long will the cavity alignment take? How does the procedure looks like?

• Orbit correction after DFS at the end of the linac seems to be not very good. Guess: less BPMs used and therefore noise cannot be averaged so well by all-2-all steering weight. Better choice of weight could improve the results. Also important for transient emittance behaviour.

Thank you for your attention!