Application of MICADO technique in the CLIC main linac

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Contents

- Introducing the MICADO routine
- Emittance vs. MICADO iteration number
- Optimising gain, step size & number of correctors
- MICADO-style Dispersion Free Steering

MICADO

- Typically, one-to-one (1-to-1) correction uses all BPMs and all correctors
- However, the beam orbit only contains a few significant Fourier components
- The MICADO routine selects only a few correctors to perform a global orbit correction, thus reducing the number of setting errors and sources of noise

MICADO

- The correctors used for orbit correction are displaced quadrupoles (thus introducing dipole kicks)
- The MICADO routine uses an $n \times m$ response matrix that relates the effect of all n correctors on all m BPMs
- Study performed on the 380 GeV main linac, with 576 correctors & 576 BPMs

One MICADO iteration

- The residual orbit after the correction is:

$$\begin{pmatrix} r_1 \\ \vdots \\ r_m \end{pmatrix} = \begin{pmatrix} b_1 \\ \vdots \\ b_m \end{pmatrix} + A \; g \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}$$

residual orbit at m BPMs	position at m BPMs	response matrix	gain	settings of n correctors

- Find x_1 to minimise $\sum_{i=1}^{m} r_i^2$ (with $x_2 \cdots x_n = 0$)
- Then find for x_2, x_3, ... until ~10 correctors have been identified

MICADO iterations

- The ~10 correctors are set and the MICADO routine is repeated for the next train, i.e., a new subset of ~10 correctors is selected to perform the correction

MICADO literature

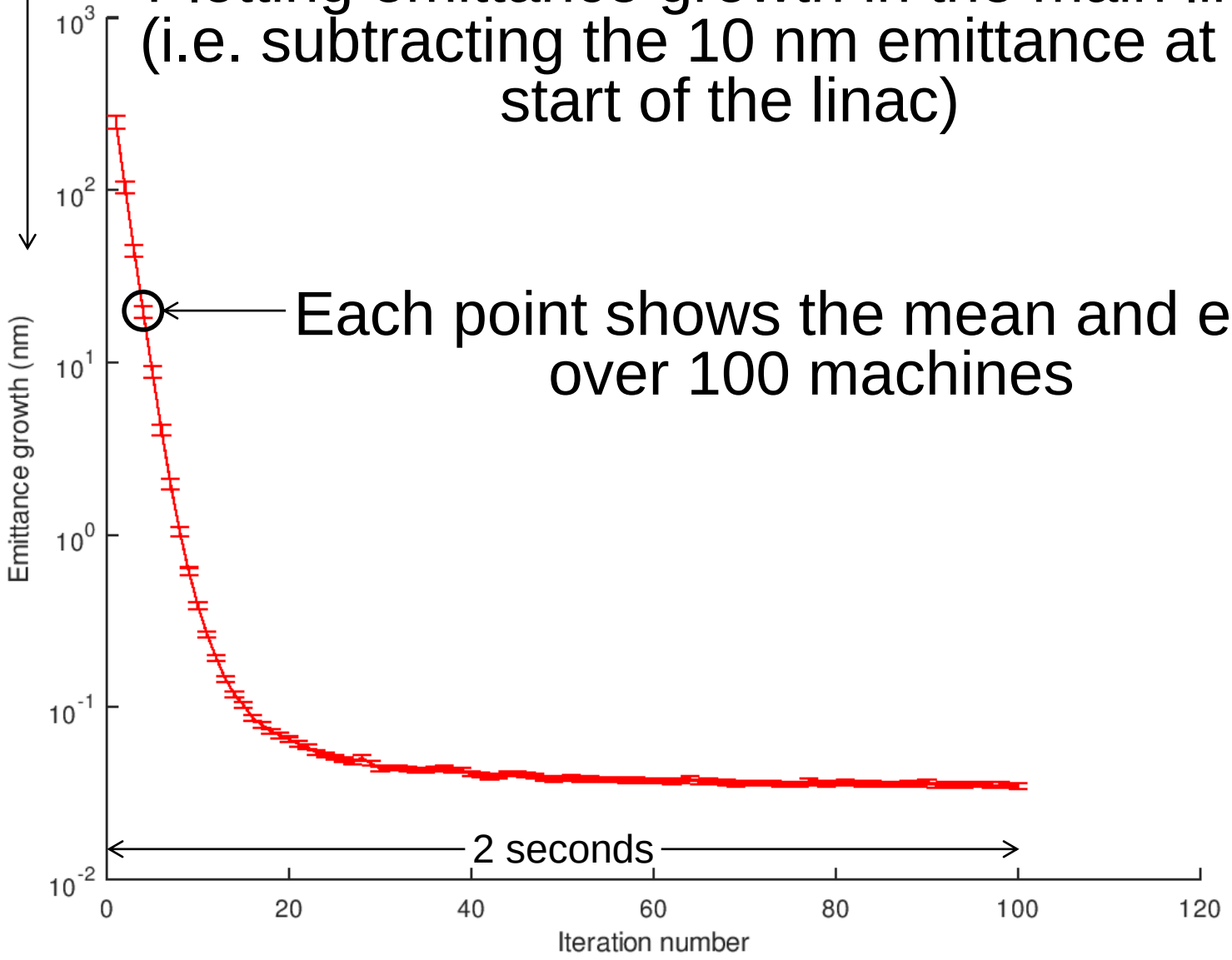
- MICADO routine:
  - B. Autin & Y. Marti, “Closed orbit correction of A.G. machines using a small number of magnets”, CERN-ISR-MA/73-17, 1973
- MICADO simulations for the ILC:
  - A. Latina, G. Rumolo, D. Schulte & R. Tomas, “Feedback studies”, proceedings of PAC 2007, Albuquerque, New Mexico, USA, pp. 2841–2843

Running MICADO

- Run ATL ground motion for 10 hours starting from a perfectly aligned machine
- Run MICADO for 100 consecutive iterations assuming no additional ground motion during this period
- Run for 100 machines and average results
- Figure of merit is the reduction in the emittance growth in the linac versus MICADO iteration number

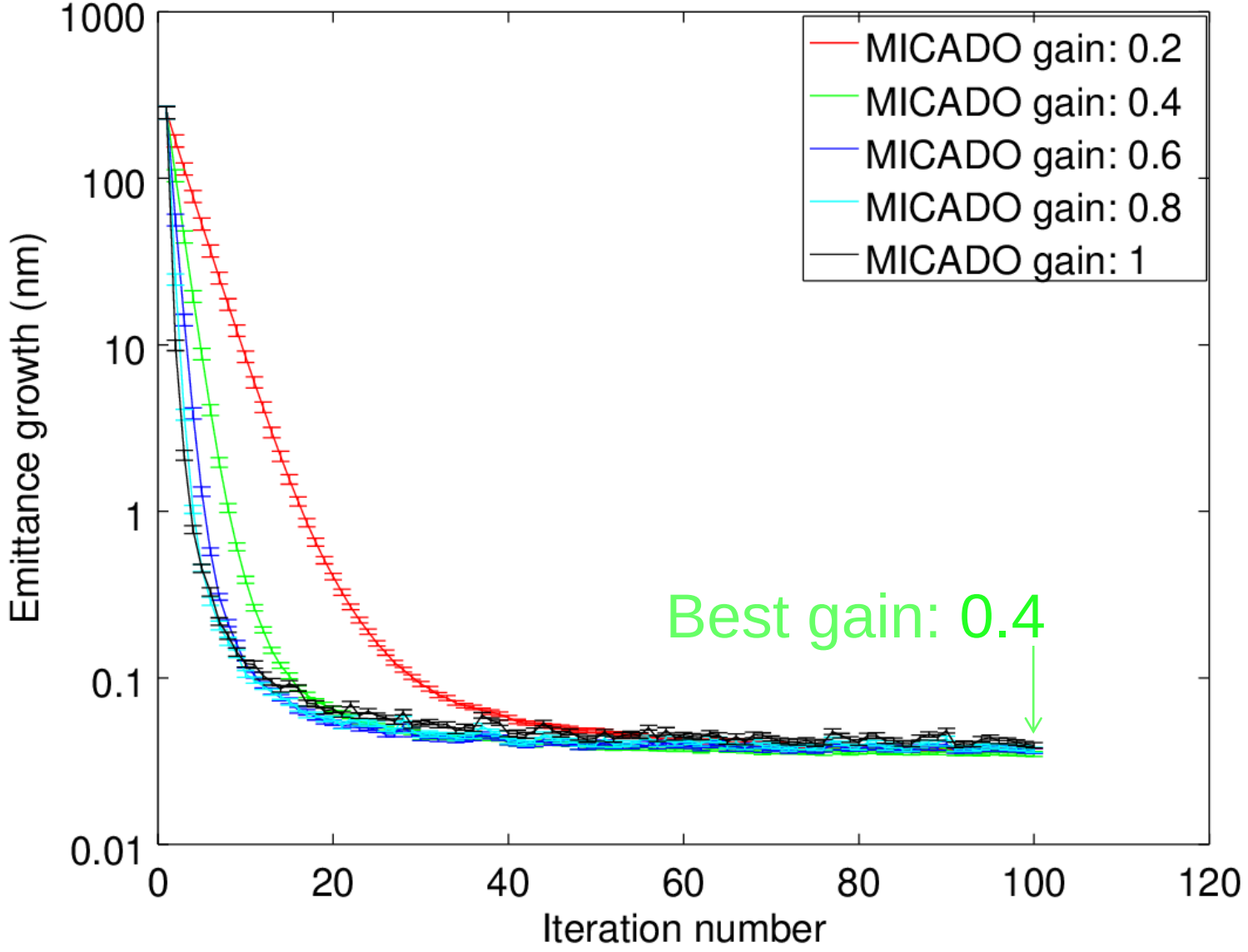
Plotting emittance growth in the main linac (i.e. subtracting the 10 nm emittance at the start of the linac)

Each point shows the mean and error over 100 machines



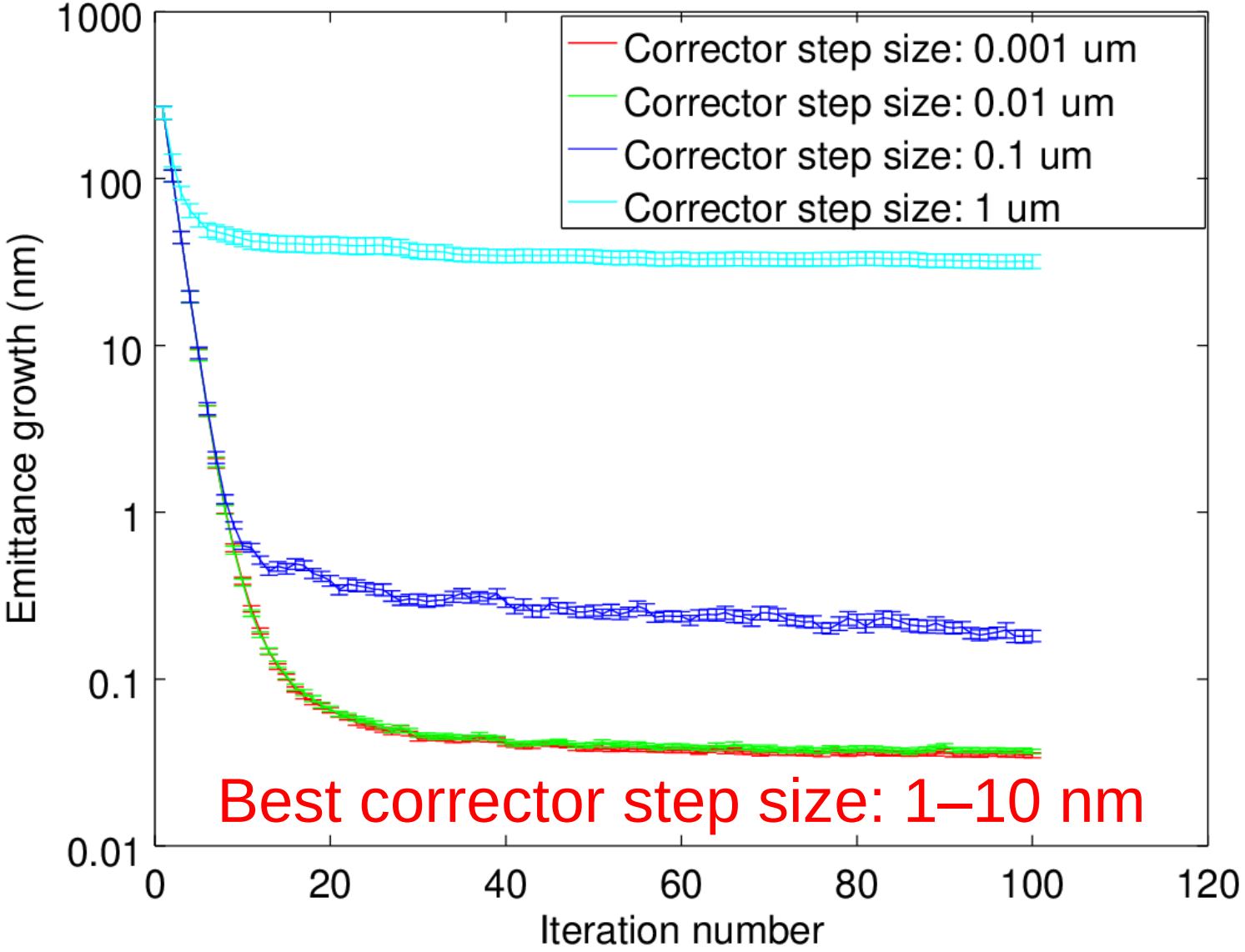
Correction gain

- A gain of 1 leads to the reduction in beam emittance in the fewest iterations, at the risk of introducing too much noise from BPM and corrector errors
- Assume 100 nm BPM resolution and 1 nm error in the corrector setting


1000
100
10
1
0.1
0.01
Emittance growth (nm)
0
20
40
60
80
100
120
Iteration number
MICADO gain: 0.2
MICADO gain: 0.4
MICADO gain: 0.6
MICADO gain: 0.8
MICADO gain: 1
Best gain: 0.4

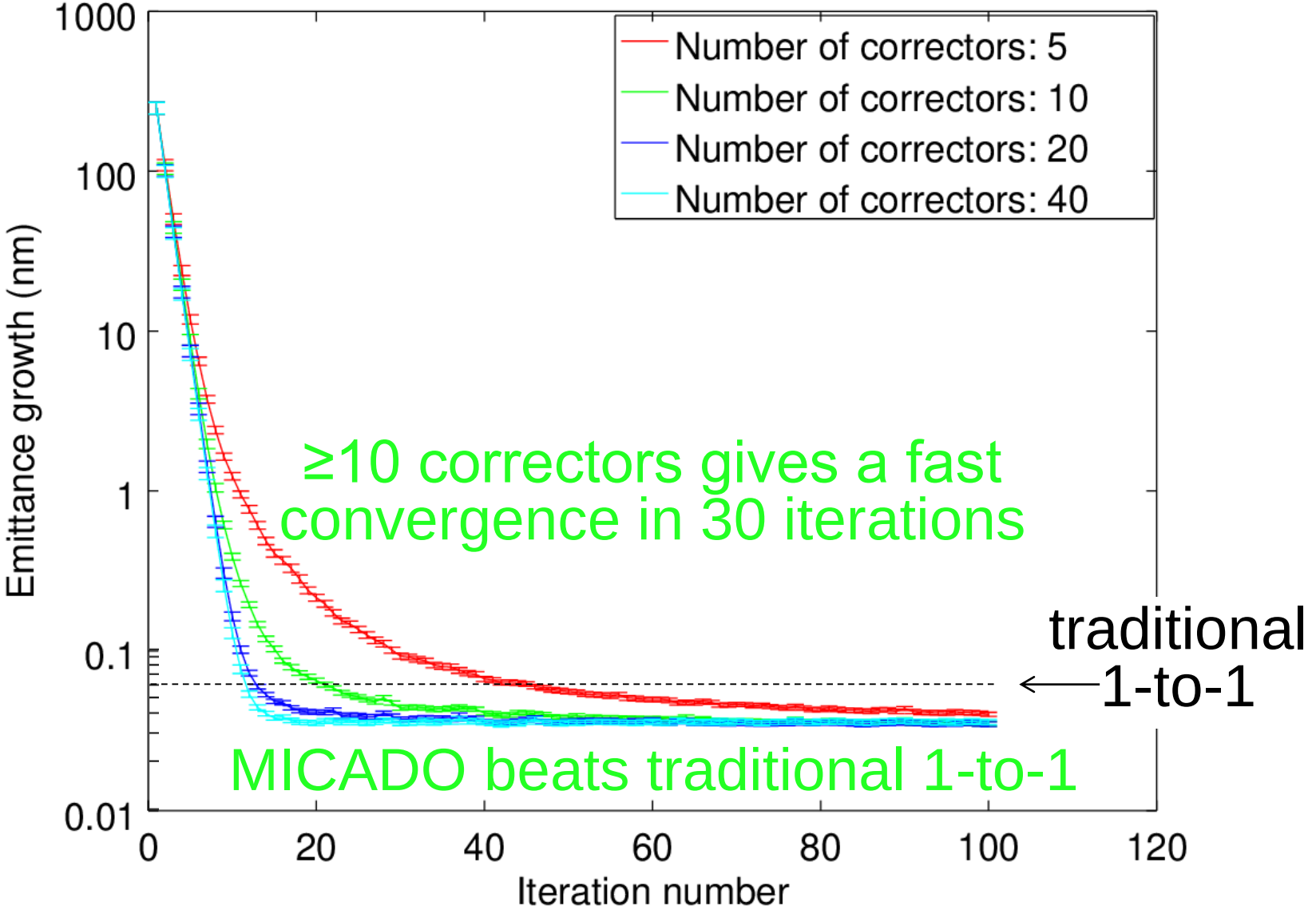
Corrector step size

- The corrector step size can be set, such that the corrector setting is rounded the nearest corrector step
- It is used to simulate the resolution with which the corrector position can be set


Corrector step size: 0.001 um
Corrector step size: 0.01 um
Corrector step size: 0.1 um
Corrector step size: 1 um
Emittance growth (nm)
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
120
Iteration number
Best corrector step size: 1–10 nm

Number of chosen correctors

- The number of correctors chosen by the MICADO routine, e.g. 5, 10, 20 or 40, can be varied to find the optimum number


Number of correctors: 5
Number of correctors: 10
Number of correctors: 20
Number of correctors: 40
Emittance growth (nm)
Iteration number
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
120
≥10 correctors gives a fast convergence in 30 iterations
traditional 1-to-1
MICADO beats traditional 1-to-1

Number of chosen correctors

- Starting with the same initial conditions, emittance growth in main linac:
  - ~0.04 nm after 30 MICADO iterations
  - 0.061 nm using traditional 1-2-1 correction
- As a smaller number of correctors reduces the effect of corrector setting errors, 10 correctors are chosen for each MICADO iteration for the subsequent studies

DFS

- Dispersion Free Steering (DFS) consists in correcting both orbit and dispersion
- The beam is steered to minimise both:
  - the offsets of the nominal-energy beam from the BPM centres
  - the differences of the trajectories of beams at different energies
- DFS overcomes systematic errors due to BPM offsets

MICADO-DFS

- MICADO-style DFS procedure uses two beams with energies E_0 and $E_1 = 0.95E_0$
- The residual orbit being minimised is:

$$\begin{pmatrix} r_1 \\ \vdots \\ r_m \\ r_{m+1} \\ \vdots \\ r_{2m} \end{pmatrix} = \begin{pmatrix} b_1^{E_0} \\ \vdots \\ b_m^{E_0} \\ w(b_1^{E_0} - b_1^{E_1}) \\ \vdots \\ w(b_m^{E_0} - b_m^{E_1}) \end{pmatrix} + A \; g \; \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}$$

$2m$ residuals

weight

m positions & m position differences

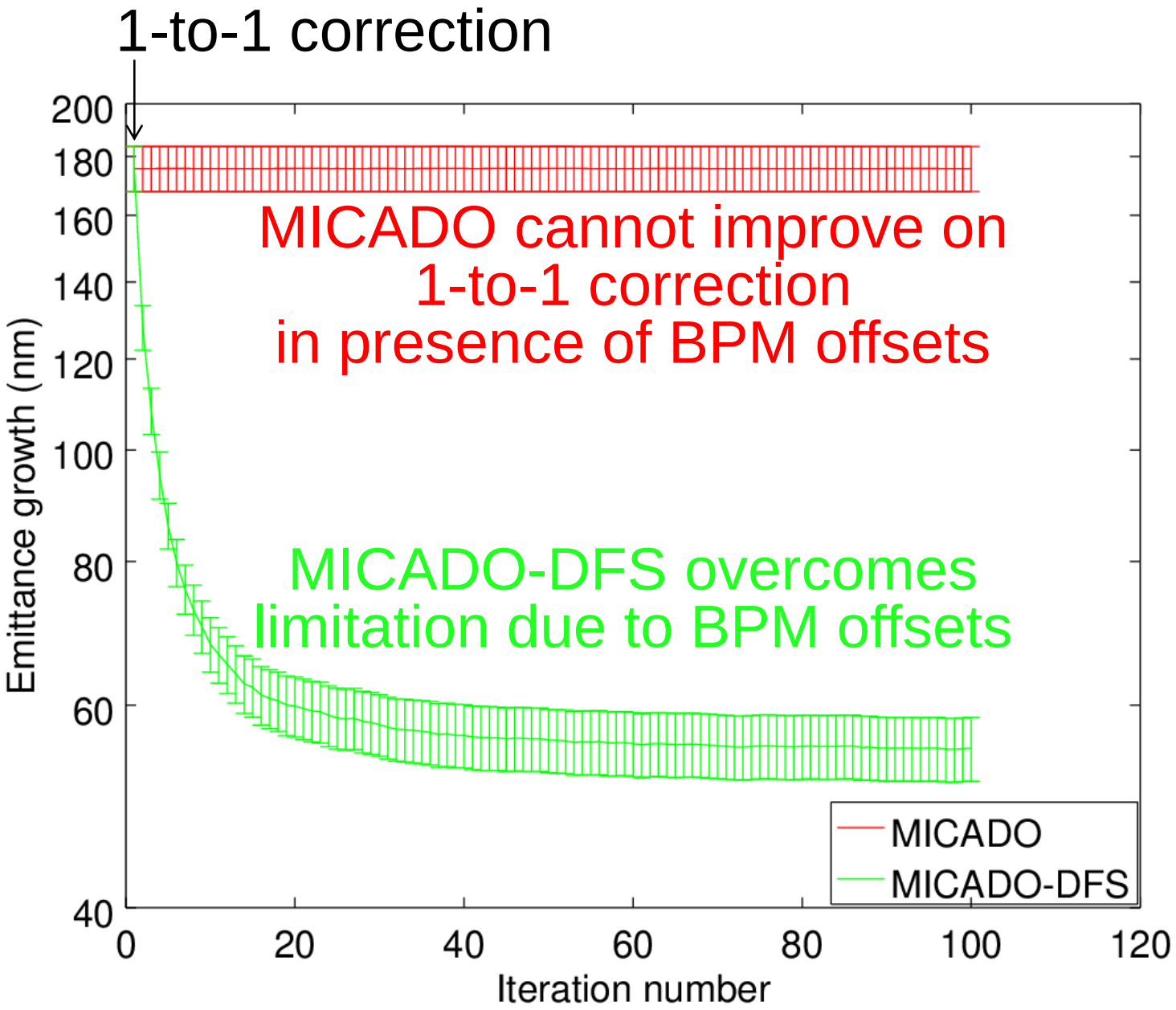
response matrix

gain

settings of n correctors

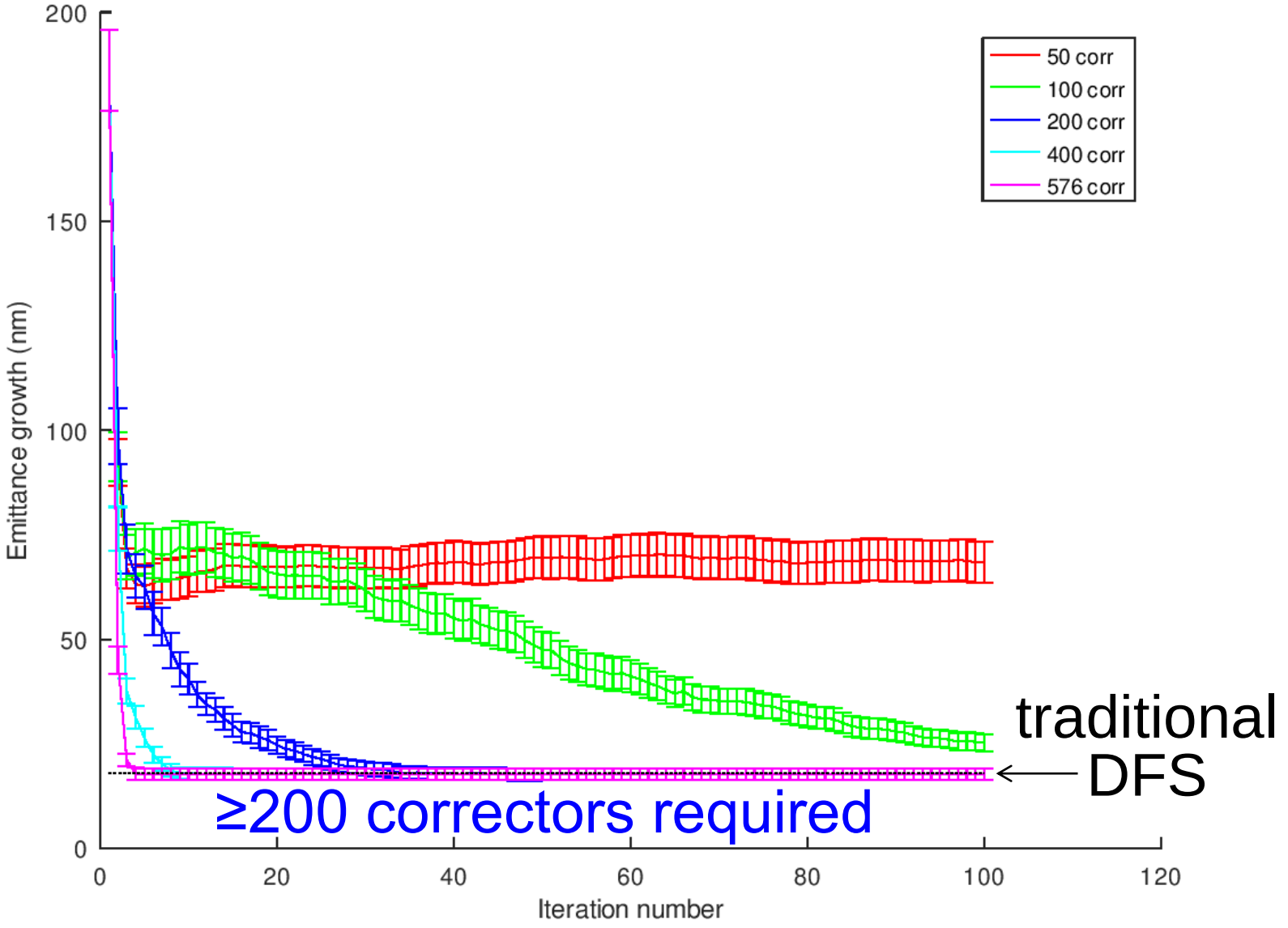
MICADO-DFS

- Instead of applying the ATL motion, the BPMs have been randomly vertically offset to demonstrate the DFS performance
- 1-to-1 steering is performed before doing either MICADO or MICADO-DFS


1-to-1 correction
MICADO cannot improve on
1-to-1 correction
in presence of BPM offsets
MICADO-DFS overcomes
limitation due to BPM offsets
Emittance growth (nm)
Iteration number
MICADO
MICADO-DFS
200
180
160
140
120
100
80
60
40
0
20
40
60
80
100
120

MICADO-DFS

- Emittance growth reduced to under 60 nm
- Traditional DFS would yield 16 nm
- Investigate by using perfect conditions (perfect BPM resolution, no corrector setting error, gain of 1)
- Vary number of correctors selected by MICADO


200
150
100
50
0
Emittance growth (nm)
0
20
40
60
80
100
120
Iteration number
50 corr
100 corr
200 corr
400 corr
576 corr
traditional
DFS
≥200 correctors required

MICADO-DFS

- MICADO-DFS matches traditional DFS performance but requires at least around a third of correctors to converge

Conclusions

- The MICADO routine selects the best 10 correctors (from 576) for orbit correction
- Starting with the same initial conditions, emittance growth in main linac:
  - ~0.04 nm after 30 MICADO iterations
  - 0.061 nm using traditional 1-2-1 correction
- MICADO-DFS matches traditional DFS performance but requires at least around a third of correctors to converge

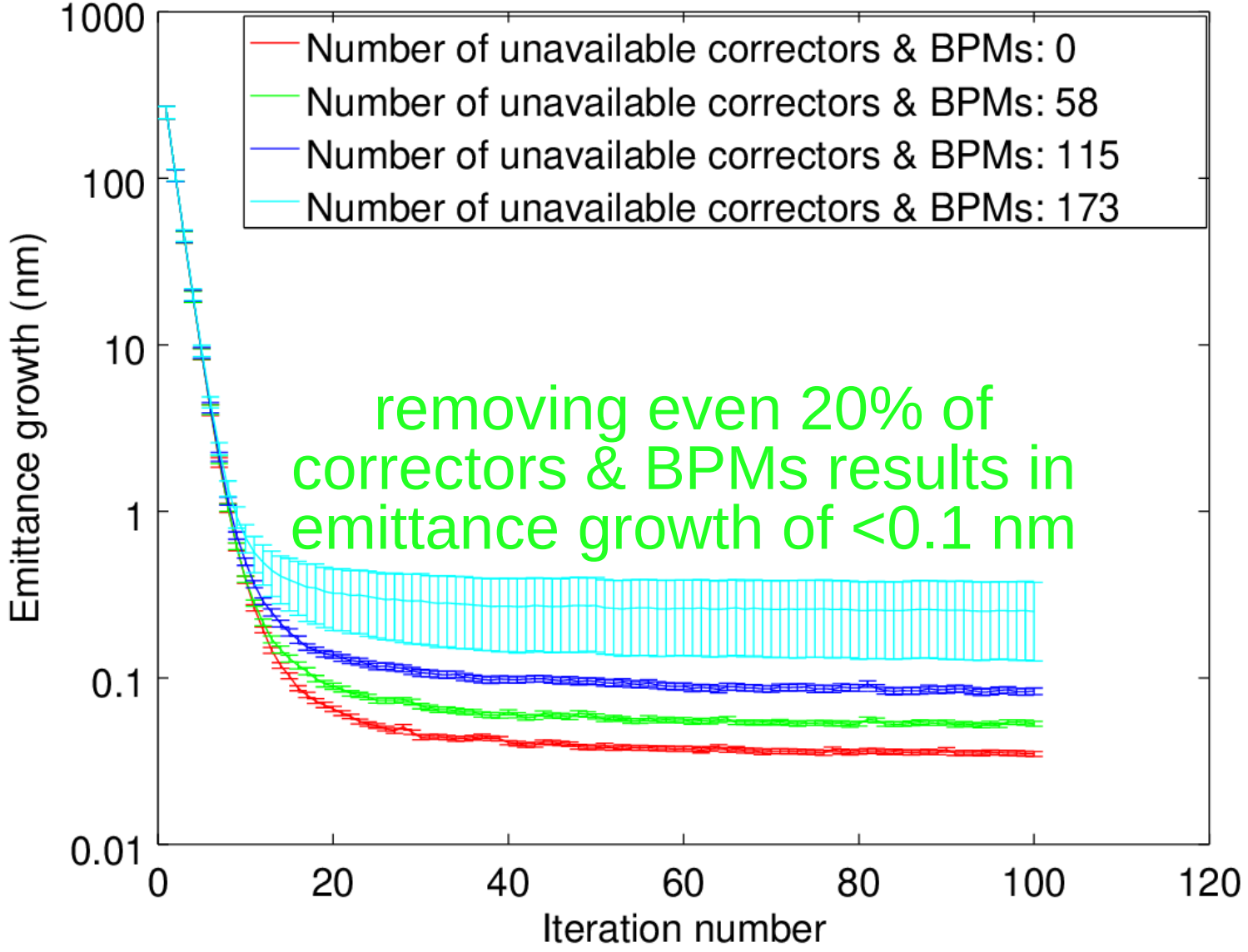
Thank you for your attention!

Unavailable correctors & BPMs

- Given that we have a technique which only uses a subset of the 10 best correctors from a total of 576, we can investigate what happens if a fraction of the correctors & BPM are unavailable (e.g. due to failure)
- We assume that the unavailable correctors & BPMs are known and can be removed from the lattice model

Unavailable correctors & BPMs

- The effect is simulated by removing randomly, say, 10% of the correctors and, independently, 10% of the BPMs
- The response matrix is made smaller by removing the relevant rows & columns
- The vector of BPM measurements has the relevant entries removed
- The MICADO routine is run with this reduced system


Number of unavailable correctors & BPMs: 0
Number of unavailable correctors & BPMs: 58
Number of unavailable correctors & BPMs: 115
Number of unavailable correctors & BPMs: 173
removing even 20% of correctors & BPMs results in emittance growth of <0.1 nm
Emittance growth (nm)
Iteration number
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
120