MICADO correction 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
- Effect of unavailable correctors & BPMs

MICADO

- Typically, ‘one-to-one 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 makes use of a $c \times b$ response matrix that relates the effect of all c correctors on all b BPMs
- Study performed on the 380 GeV main linac, with 576 correctors & 576 BPMs

MICADO

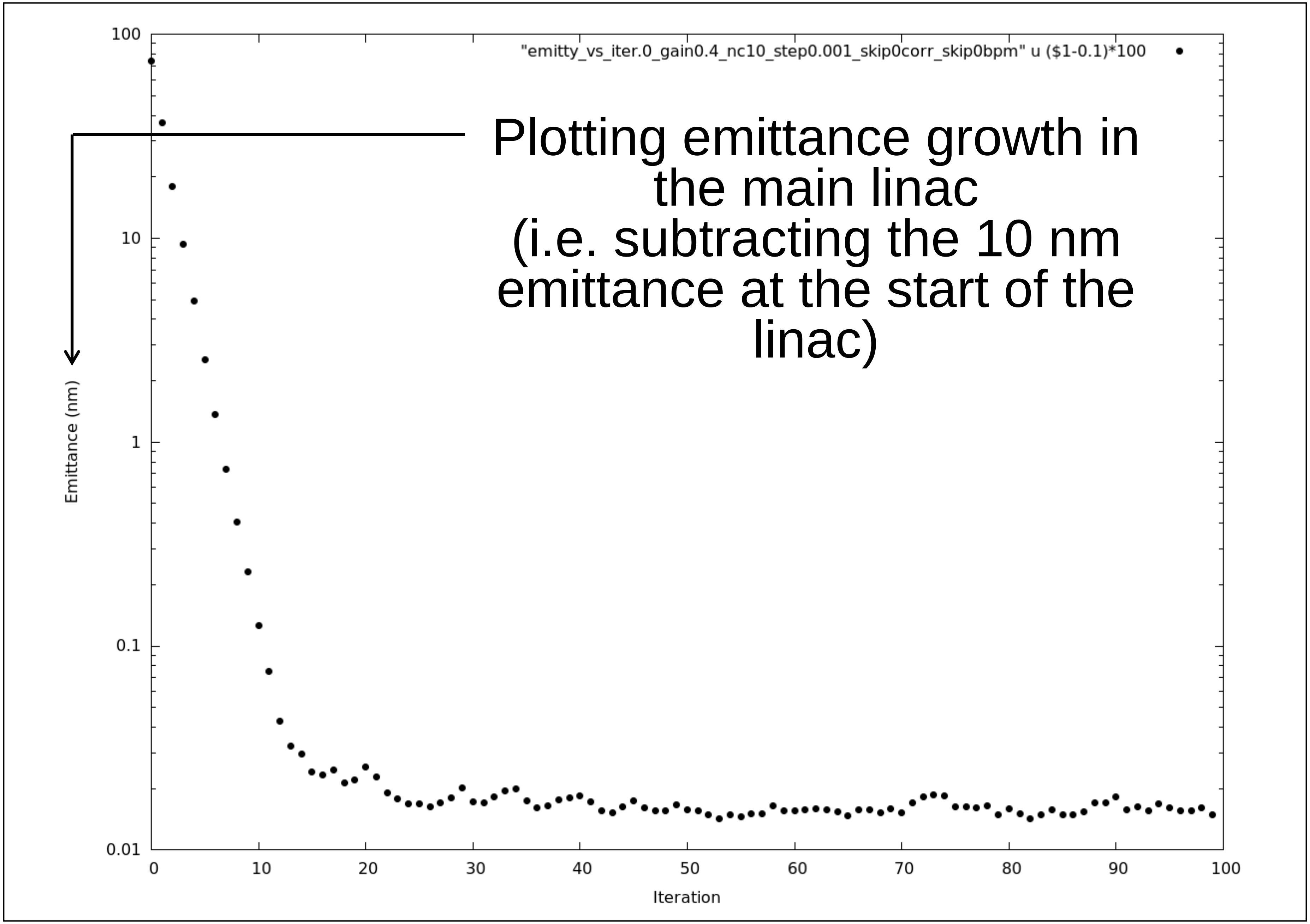
- Given the response matrix and the BPM measurements, the MICADO routine identifies the 10 correctors that best correct the distorted beam orbit
- The correctors are set and the MICADO routine is repeated for the next train, i.e., a new subset of 10 correctors is selected to perform the correction

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

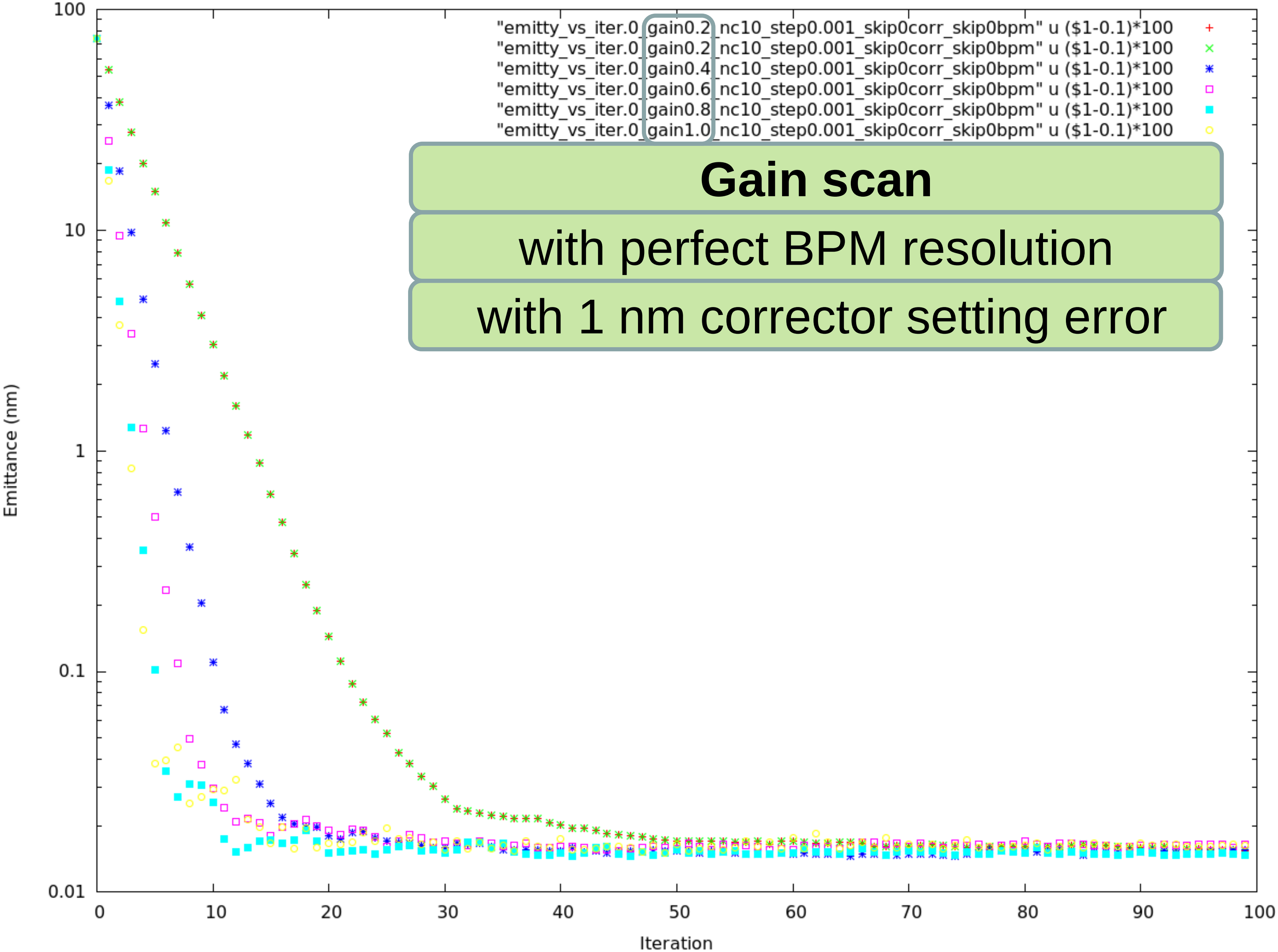
Running MICADO

- Run ATL motion for 1 hour starting from a perfectly aligned machine
- Run MICADO for 100 consecutive iterations assuming no additional ground motion during this period
- Figure of merit is the reduction in the emittance growth in the linac versus MICADO iteration number


"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
Plotting emittance growth in the main linac
(i.e. subtracting the 10 nm emittance at the start of the linac)
Emittance (nm)
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100
Iteration

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
- Start first assuming perfect BPM resolution and only 1 nm error in the corrector setting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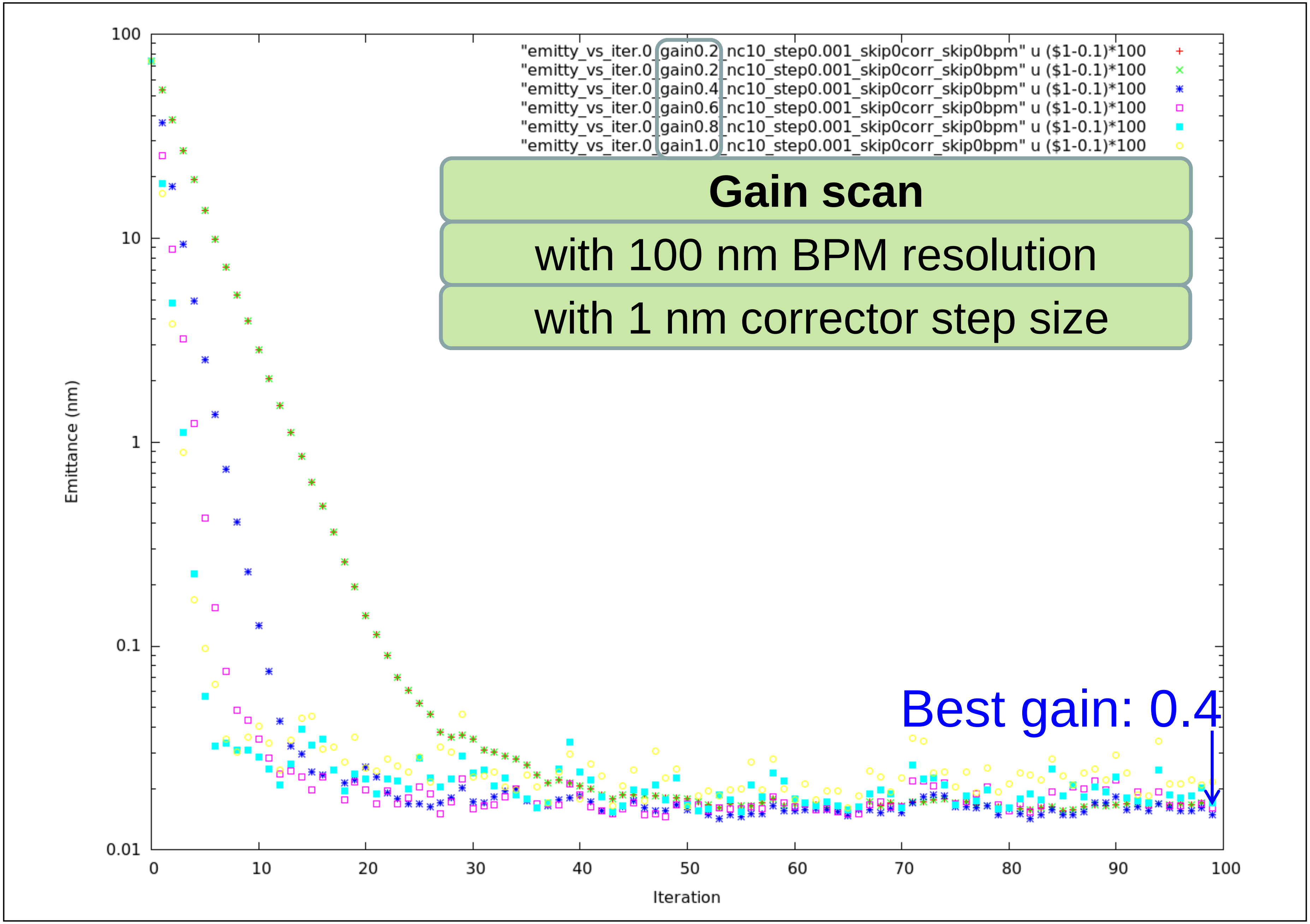
"emitty_vs_iter.0_gain1.0_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
Gain scan
with perfect BPM resolution
with 1 nm corrector setting error
Emittance (nm)
Iteration
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100

Correction gain

- Assume now a more realistic 100 nm BPM resolution
- A gain of 0.4, giving the lowest emittance after 100 iterations, is selected for subsequent studies



Gain scan
with 100 nm BPM resolution
with 1 nm corrector step size
Best gain: 0.4
"emitty_vs_iter.0_gain0.2_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
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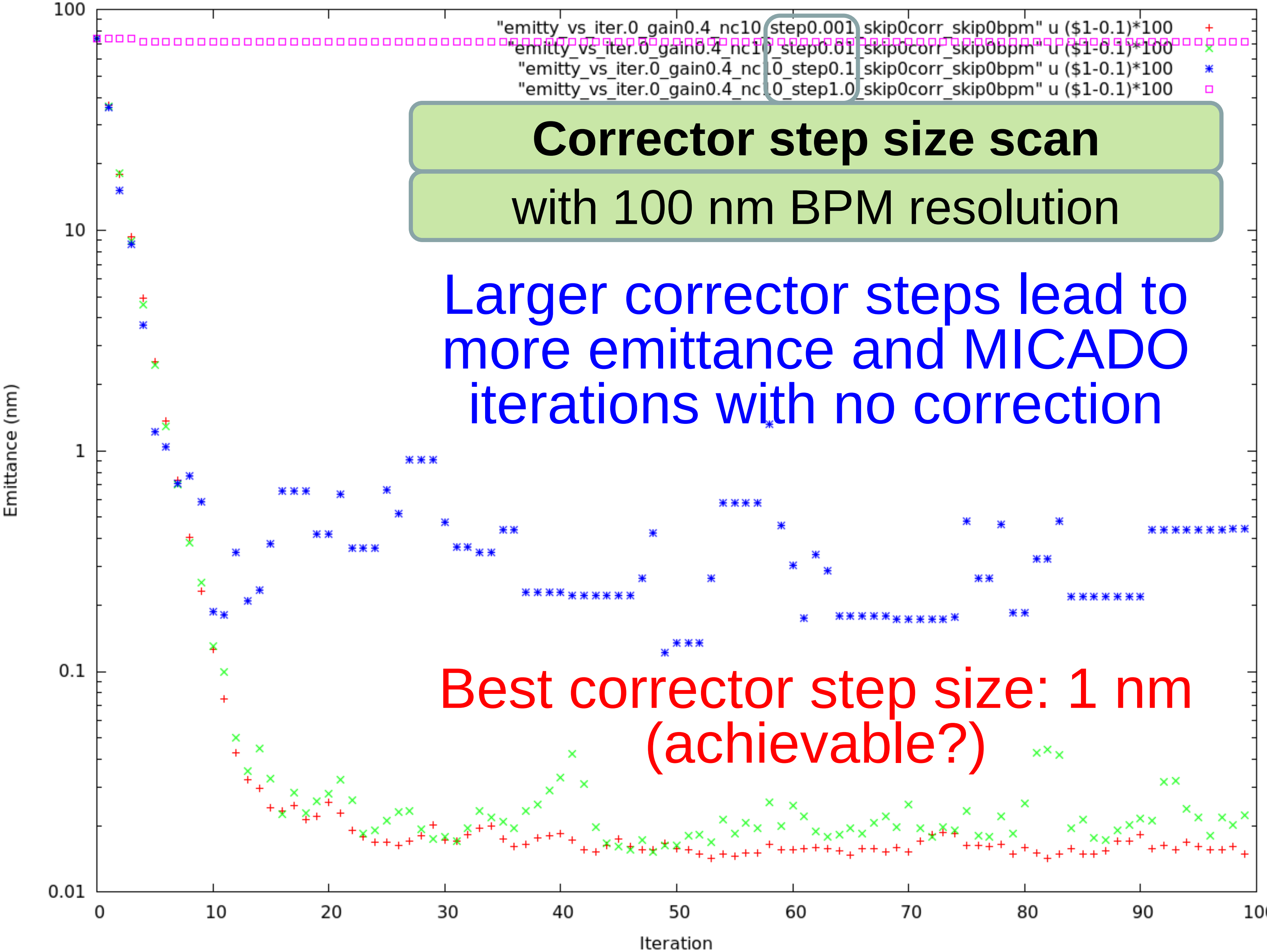
"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.6_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.8_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain1.0_nc10_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
Emittance (nm)
Iteration

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
- The corrector step size limits the correction performance, but a small step size of 1 nm will be assumed subsequently to make other contributions visible



Corrector step size scan

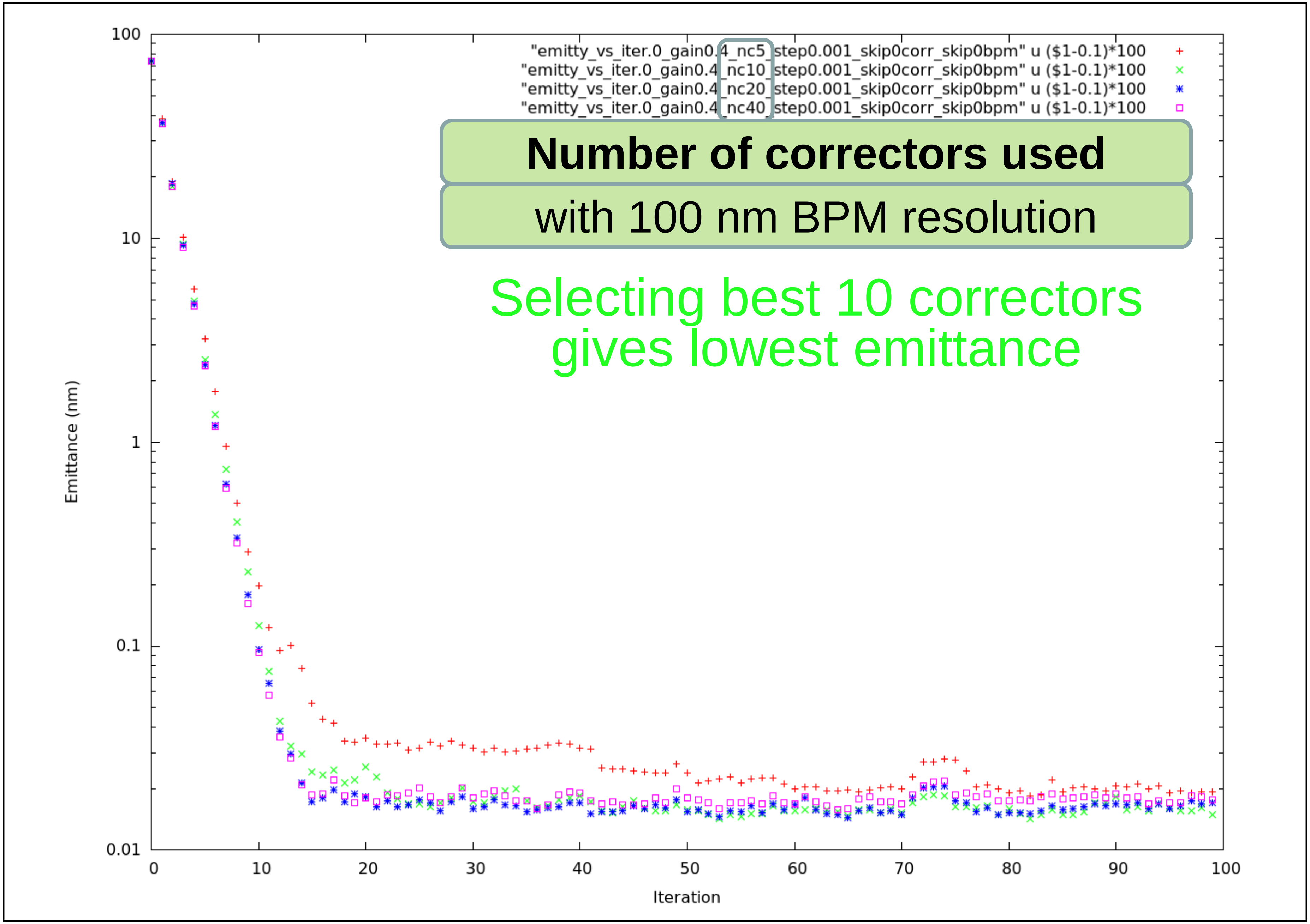
with 100 nm BPM resolution

Larger corrector steps lead to more emittance and MICADO iterations with no correction

Best corrector step size: 1 nm (achievable?)

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



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"emitty_vs_iter.0_gain0.4_nc40_step0.001_skip0corr_skip0bpm" u ($1-0.1)*100
Number of correctors used
with 100 nm BPM resolution
Selecting best 10 correctors
gives lowest emittance
Emittance (nm)
Iteration
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100

Unavailable correctors & BPMs

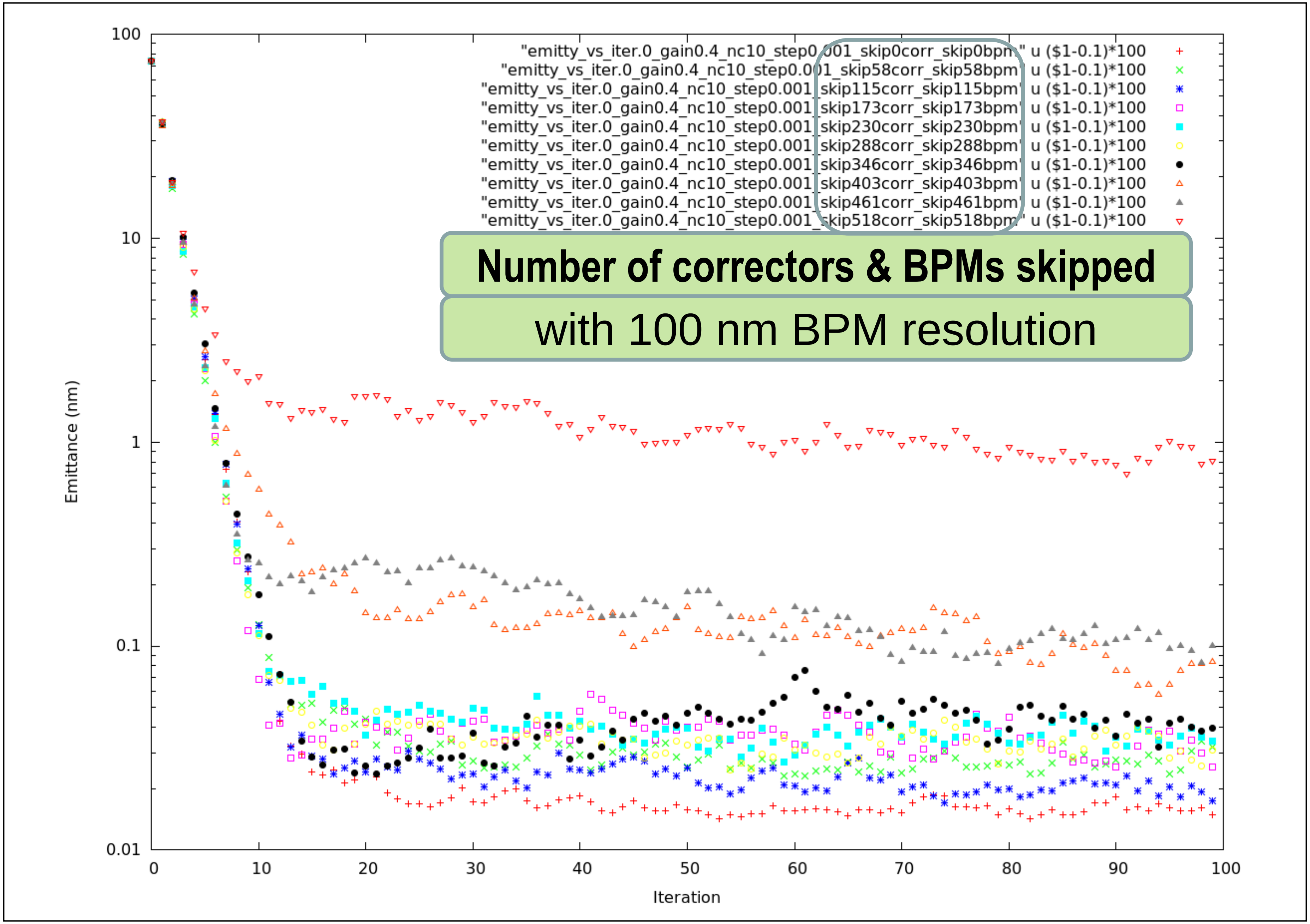
- Given that we have a technique which only uses a subset of the 10 best correctors from a total of 576, we can investigate what happens if a fraction of the correctors & BPM are unavailable (e.g. due to failure)
- We assume that the unavailable correctors & BPMs are known and can be removed from the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

Unavailable correctors & BPMs

- Start by assuming a corrector step size of only 1 nm to make the impact of corrector & BPM removal visible
- Expect a poorer emittance reduction when more correctors & BPMs are unavailable



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"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip230corr_skip230bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip288corr_skip288bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip346corr_skip346bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip403corr_skip403bpm" u ($1-0.1)*100
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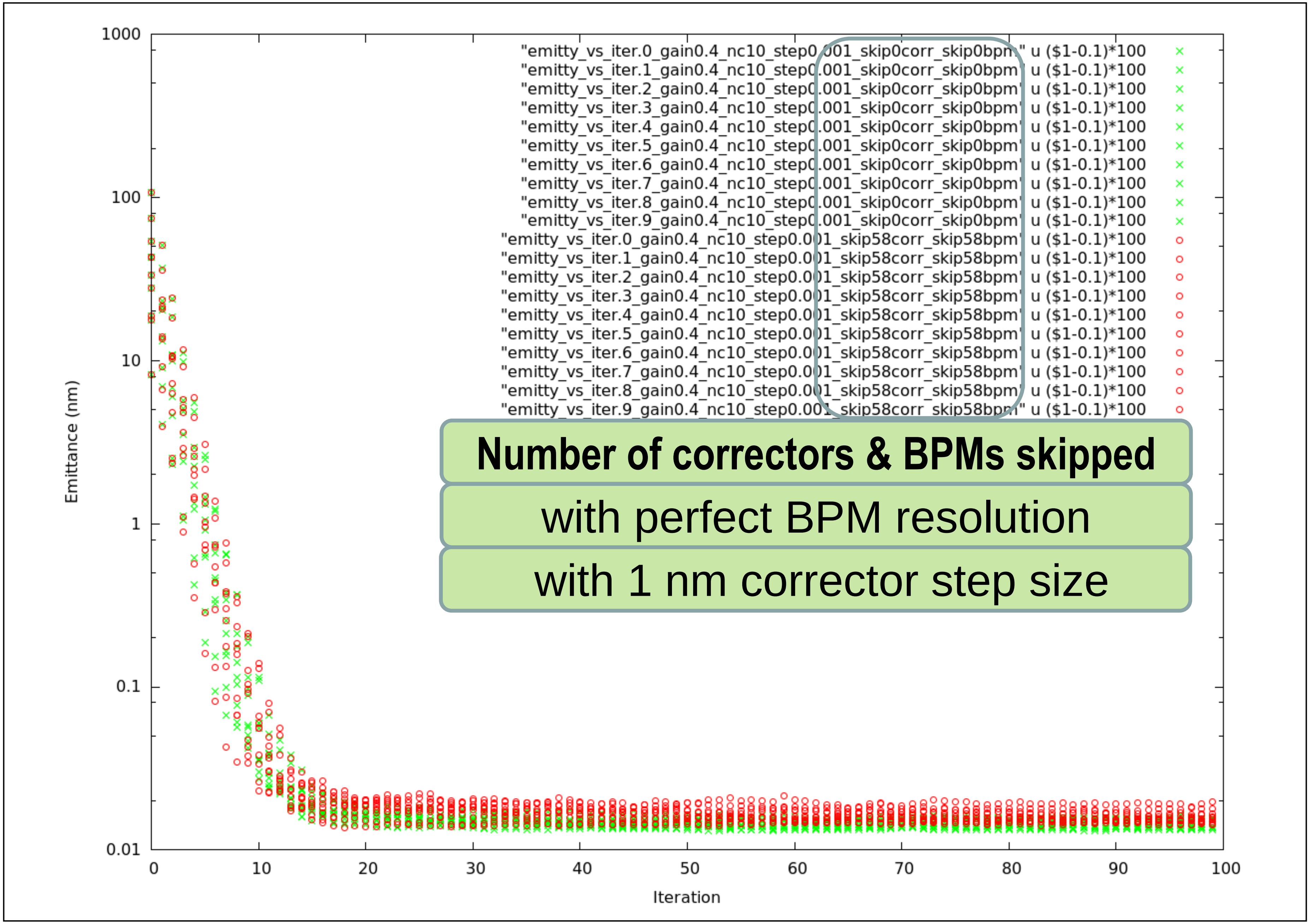
"emitty_vs_iter.0_gain0.4_nc10_step0.001_skip518corr_skip518bpm" u ($1-0.1)*100
Number of correctors & BPMs skipped
with 100 nm BPM resolution
Emittance (nm)
Iteration
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100

More statistics

- So far, only 1 machine was simulated in each case
- Simulating 10 machines each with independent ATL evolutions for:
  - No missing BPMs or correctors
  - 10% missing BPMs & 10% missing correctors
- Assume perfect BPM resolution & 1 nm corrector step size to reduce spread of results



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"emitty_vs_iter.4_gain0.4_nc10_step0.001_skip58corr_skip58bpm" u ($1-0.1)*100
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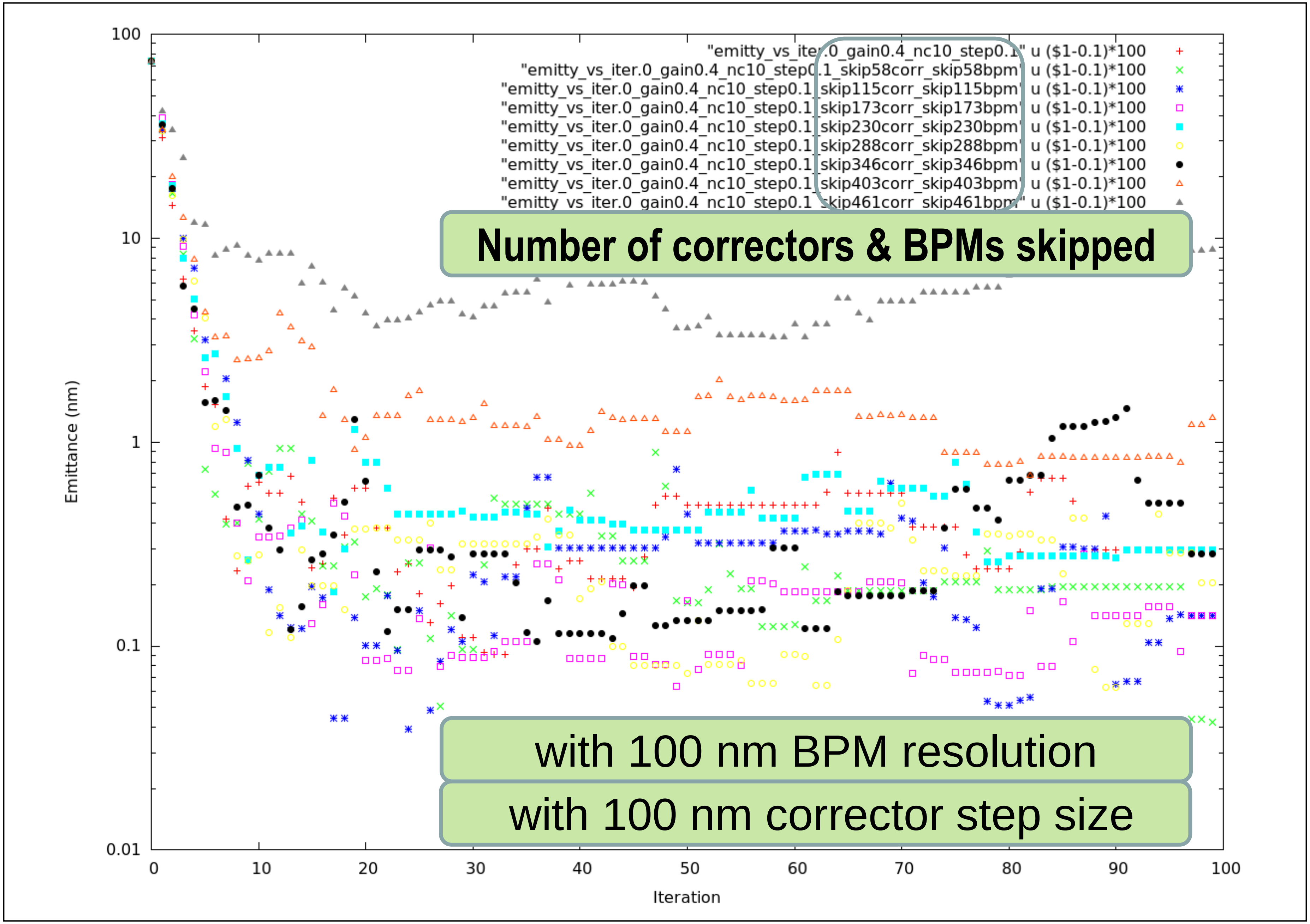
"emitty_vs_iter.9_gain0.4_nc10_step0.001_skip58corr_skip58bpm" u ($1-0.1)*100
Number of correctors & BPMs skipped
with perfect BPM resolution
with 1 nm corrector step size
Emittance (nm)
1000
100
10
1
0.1
0.01
Iteration
0
10
20
30
40
50
60
70
80
90
100

Results

- The emittance degrades by <0.01 nm on losing 10% of the BPMs and 10% of the correctors
- This small effect is clear given the small ~0.01 nm emittance growth in the main linac obtained for perfect BPM resolution and 1 nm corrector step size
- Introducing 100 nm BPM resolution and 100 nm corrector step size…



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"emitty_vs_iter.0_gain0.4_nc10_step0.1_skip230corr_skip230bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.1_skip288corr_skip288bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.1_skip346corr_skip346bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.1_skip403corr_skip403bpm" u ($1-0.1)*100
"emitty_vs_iter.0_gain0.4_nc10_step0.1_skip461corr_skip461bpm" u ($1-0.1)*100
Number of correctors & BPMs skipped
with 100 nm BPM resolution
with 100 nm corrector step size
Emittance (nm)
Iteration
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100

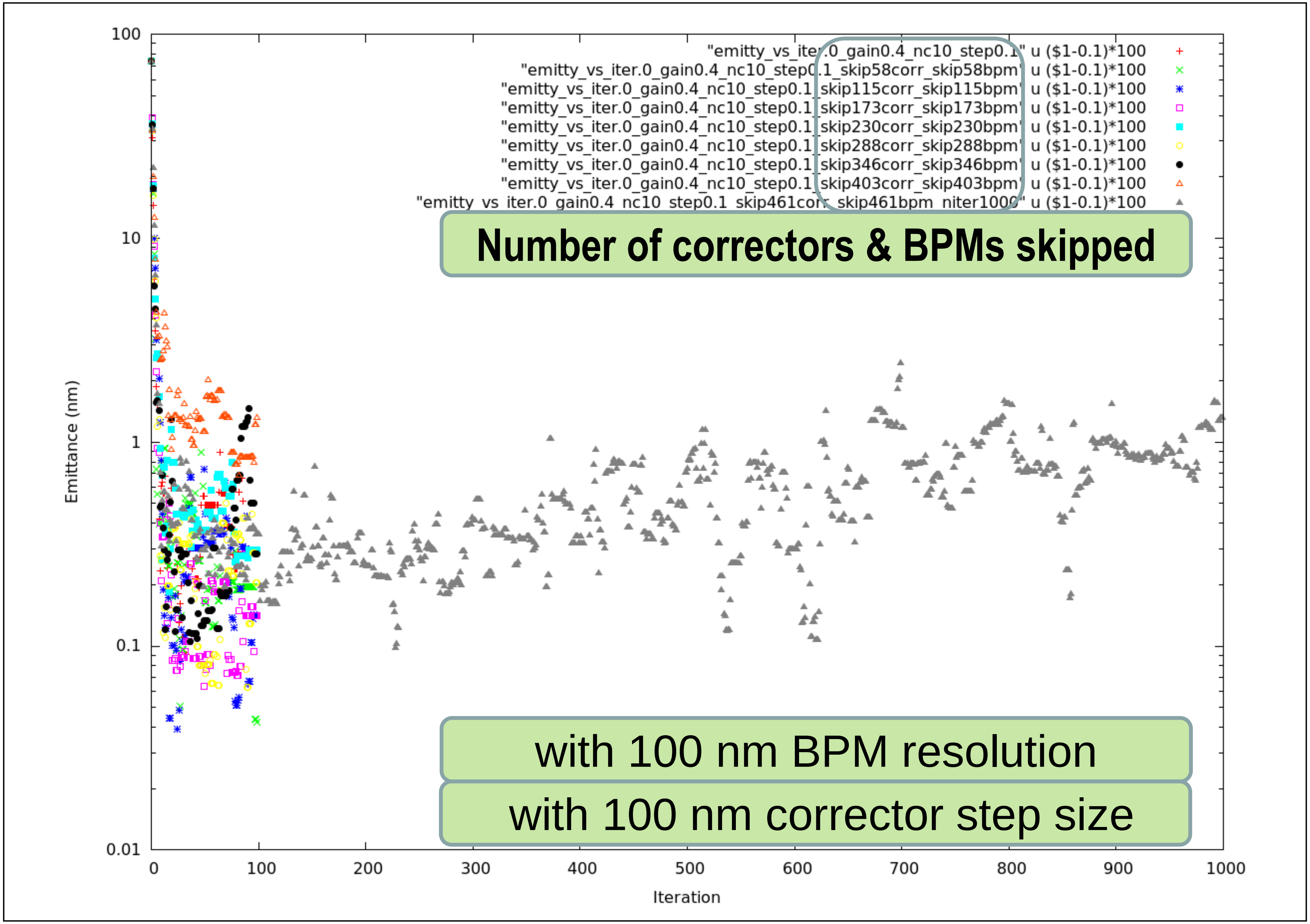
Results

- With 100 nm corrector step size & 100 BPM resolution, the emittance growth in the main linac is an order of magnitude larger at 0.1 nm
- The effect of losing 10% of the BPMs and 10% of the correctors is imperceptible

Conclusions

- The MICADO routine selects the best 10 correctors for a global orbit correction
- Results converge after ~15 iterations
- Correction limited by corrector step size:
  - Order 0.1 nm ε growth for 100 nm step size
  - Order 0.01 nm ε growth for 1 nm step size
- Losing 10% of the correctors & 10% of the BPMs leads to order 0.01 nm ε growth

Thank you for your attention!



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Number of correctors & BPMs skipped
with 100 nm BPM resolution
with 100 nm corrector step size
Emittance (nm)
Iteration
100
10
1
0.1
0.01
0
100
200
300
400
500
600
700
800
900
1000