Recent Achievements in the Dynamic Alignment of the CLIC Beam Delivery System

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Dynamic Effects

- During operation, three *dynamic effects* affect the machine performances
  - **pulse-to-pulse**: beam trajectory changes
  - **jitter and shift**: of the components
  - **noise**: in the diagnostics

$$\Delta L_{\text{total}} \approx \Delta L_{\text{systematic}} + \Delta L_{\text{residual}} + \Delta L_{\text{instrumentation noise}}$$

- Sources of vibration include
  - **natural seismic** motion
  - **man-made** (cultural) noise

$\Rightarrow$ The motion can be divided in three regimes

- **high frequency** no spatial correlation of the vibration
- **lower frequency** ground motion well correlated
- **slow drifts** where the motion is uncorrelated

Ground Motion Vibrations

- It is possible to simulate the ground motion vibration using experimental samples (A,B,C,K)
- but one can consider the two limiting extremes:
  1. uncorrelated high-frequency jitter
  2. slow drifts of components that can be described with the ATL model
- The ATL relation states that

$$< \Delta y^2 > \; = \; A \cdot T \cdot L$$

  - the misalignment of two points is proportional to their distance L and elapsed time T
  - A is a site/condition/geology specific parameter, typically in the range 0.1 to 100 $\mathrm{nm}^2/\mathrm{m/s}$

  ⇒ The T dependence has been confirmed in the minute to month time scale.

⇒ **High frequency** jitter can be used to estimate the motion of the beam centroid (offset), that will be compensated by **beam-beam correction**

⇒ **ATL-drifts** primarily result in increase of the beam emittance, that will be corrected by **component re-alignment**

Beam-Based Feedback

- tolerances on the alignment of beamline components require continuous beam-based feedback to counteract performance deterioration

- multi-layered approach on different time scales:
  - ⇒ "slow feedback"
    - corrects the beam orbit and compensate for slow ground motion
  - ⇒ **inter-pulse feedback**
    - straightens the train from pulse to pulse
  - ⇒ **intra-pulse feedback**
    - operates at high frequency and acts within a bunch train
    - removes the relative offset jitter at the IP by measuring the beam-beam deflection angle and steering the beams back into collision

Overview

⇒ static alignment

- dispersion free steering
- singular values analysis
- response to quadrupole and bpm misalignments, and to corrector strengths

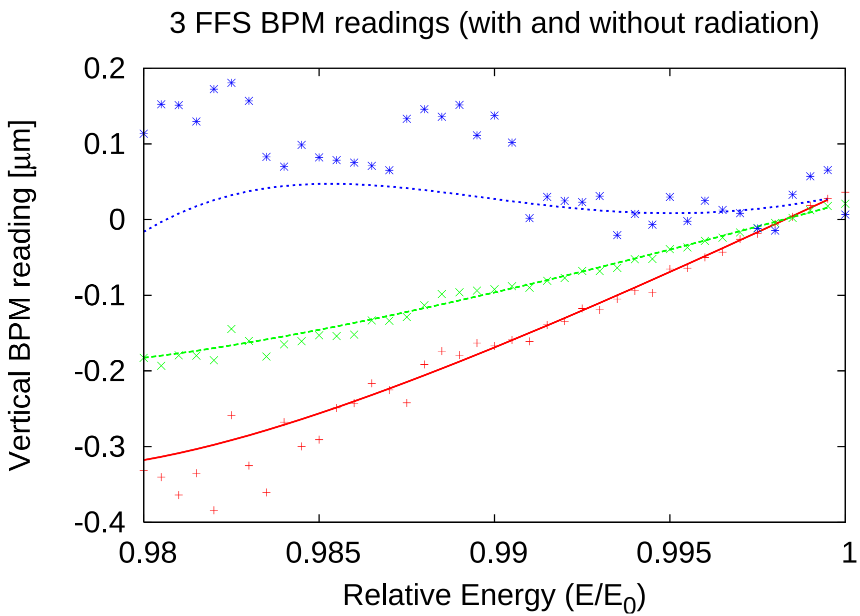
- (i) systematic noise
  - pulse-to-pulse motion → give a constraint to the orbit correction *gain*
  - uncorrelated quadrupole jitters → tolerance
- (ii) instrumentation noise
  - bpm noise on orbit correction → is 100 nm bpm resolution sufficient?
  - bpm noise and fast beam-beam feedback
- (iii) ATL slow motion:
  - orbit correction over a long time scale → how long can we run?
  - orbit correction algorithms comparison

Simulation Parameters

- CLIC parameters as defined in May
  - bunch charge : $4 \cdot 10^9$ particles
  - bunch separation : 0.667 ns
  - vertical emittance : 20 nm
  - repetition rate : 50 Hz
  - bunch length : 44 μm
  - bds lattice version : $L^\star = 4.3$ m
- In the BDS we have..
  - 67 quadrupoles
  - 67 dipole correctors
  - 79 beam position monitors

(Static) Alignment of the BDS

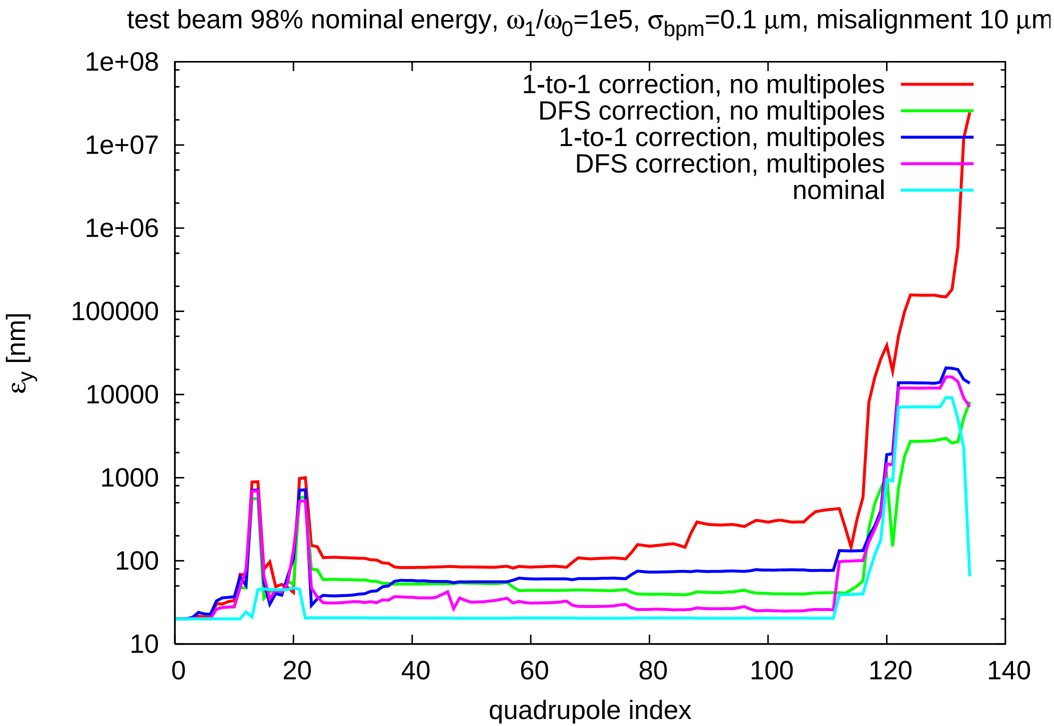
- the system is strongly non-linear
- it is better to align the collimation system and final focus independently
- the final focus is still an open problem...



⇒ We decided to calculate the response matrix R neglecting the synchrotron radiation emission

Dispersion Free Steering in the BDS

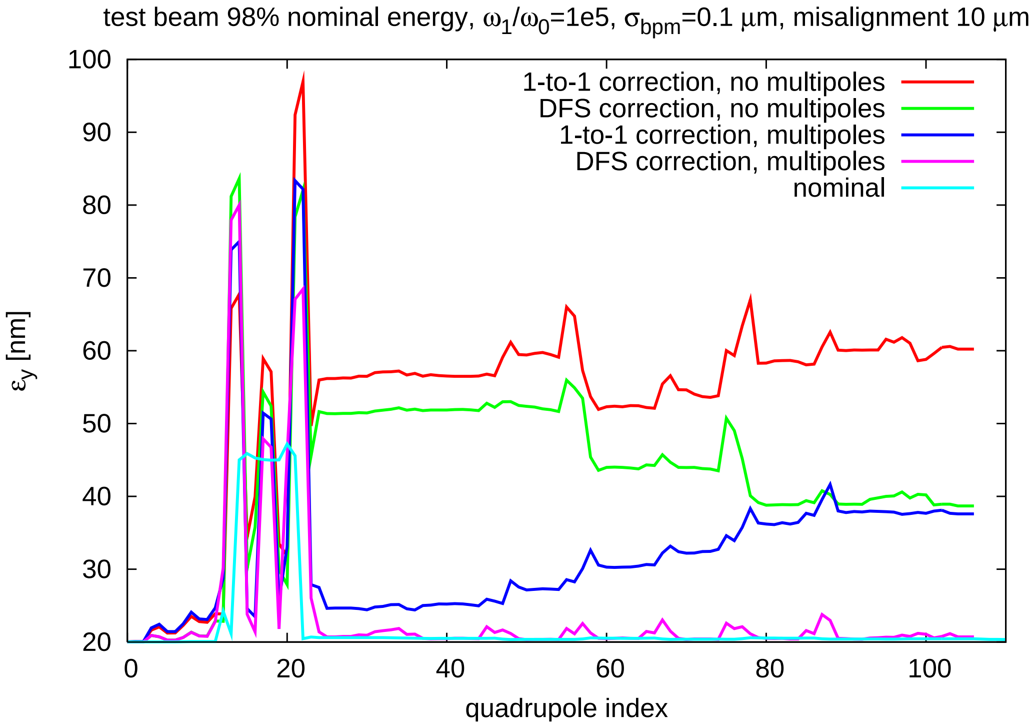
- using a test beam with energy $E = 98\% \ E_0$
- alignment in 4 steps...



$\Rightarrow$ the final emittance is enomous

Dispersion Free Steering in the Collimation System

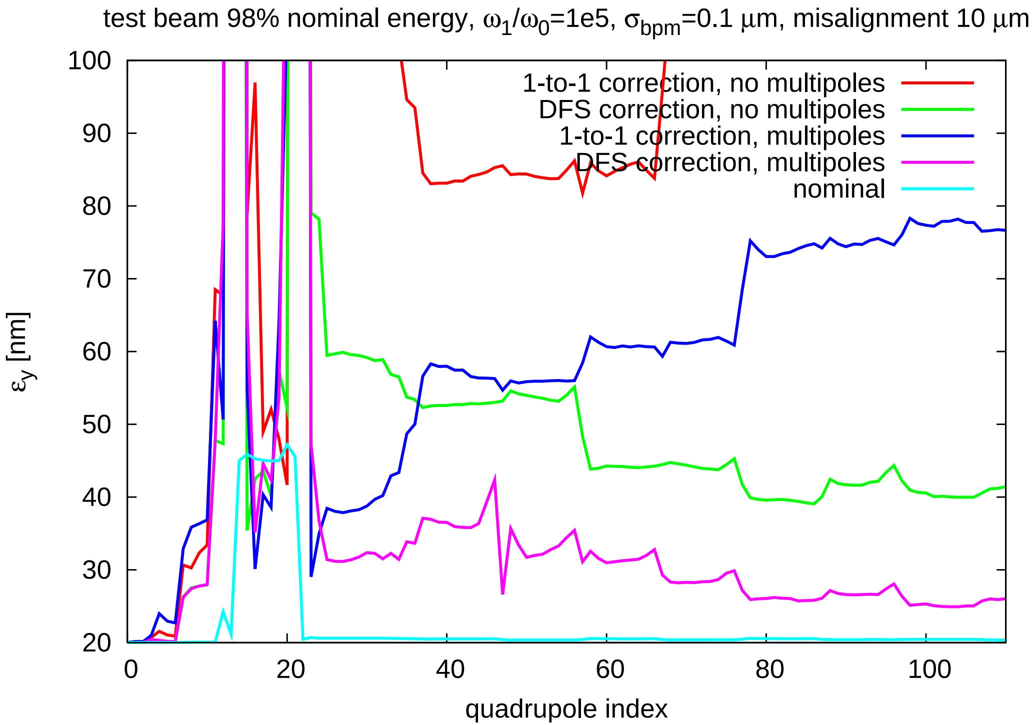
- using one test beam with $E = 98\% E_0$
- alignment in 4 steps...



$\Rightarrow$ final emittance growth is $\boxed{\Delta\epsilon = 0.7 \text{ nm}}$

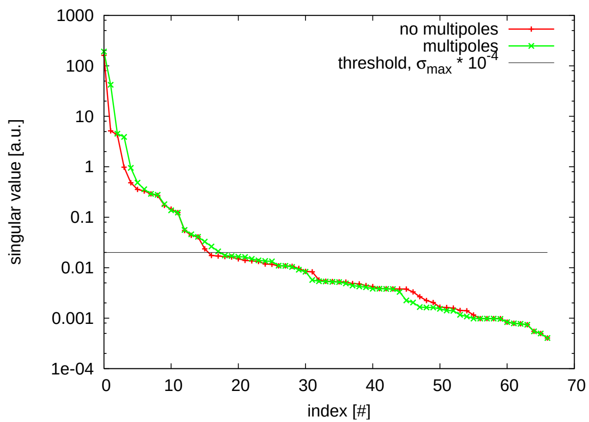
Dispersion Free Steering in the Final Focus

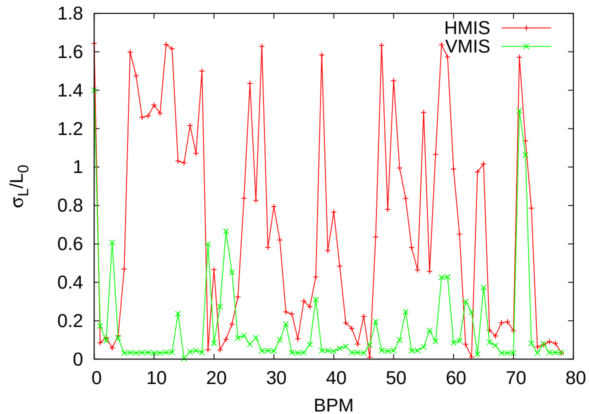
- assuming a perfect collimation system and $E = 98\% E_0$ for the test beam
- alignment in 4 steps...

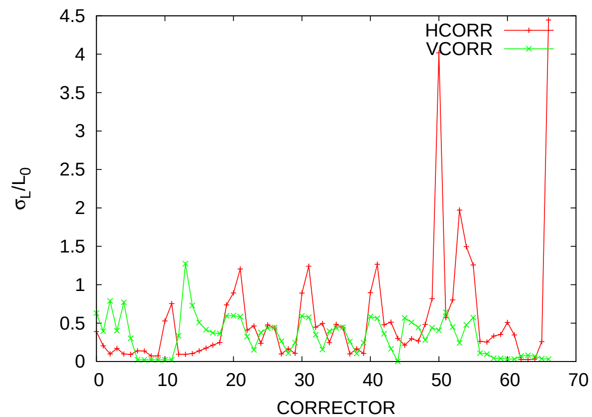


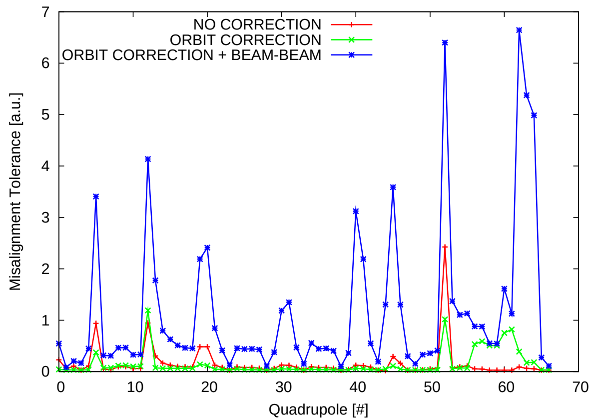
⇒ the alignment of the final focus is an open problem

SVD Analysis of R and Weight of the Components









Luminosity Loss due to Pulse-to-Pulse Motion

$\Rightarrow$ lower limit for the slow orbit feedback gain

- ground motion model B (medium noise)
- (ideal implementation of an) orbit correction algorithm

$$y_{n+1} = \Delta y_n + (1-g)\, y_n$$

  - Δy_n ground motion vibration at time step n
  - g gain of the orbit feedback
  - y_n element position at time step n, for each element.

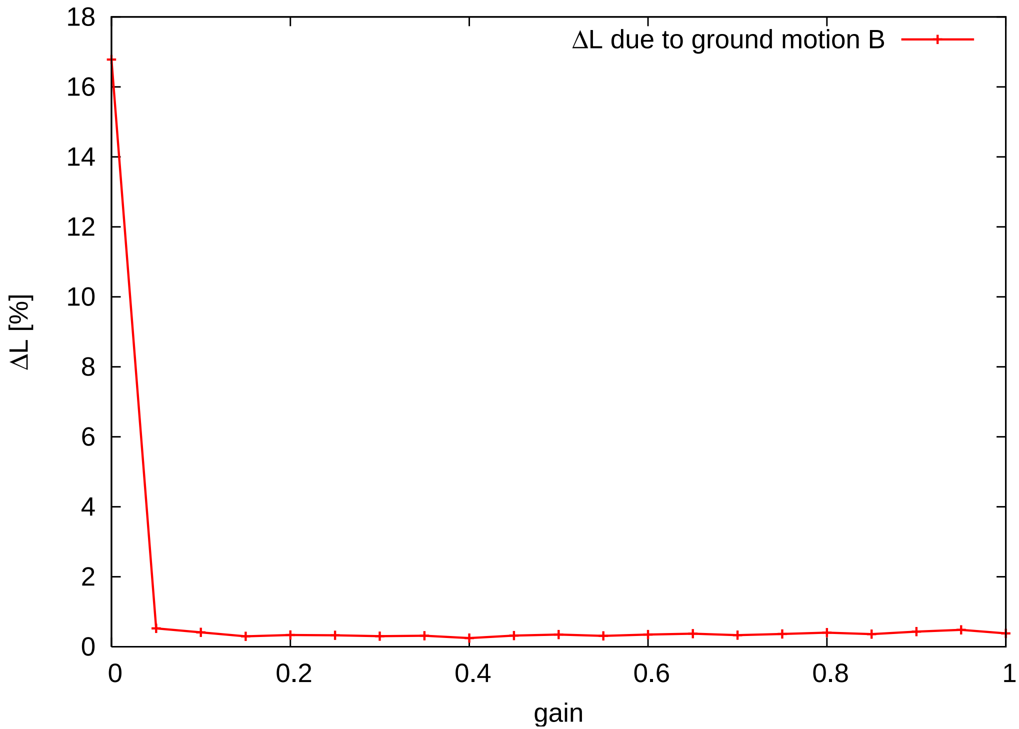
- final doublet is stabilized
- beam-beam feedback to correct beam offset at the IP

- Simulation

  1. ground motion
  2. the orbit feedback runs until stability is reached
  3. the beam-beam runs to correct the offset

Loss due to Pulse-to-Pulse Motion

- lower limit for the orbit feedback gain



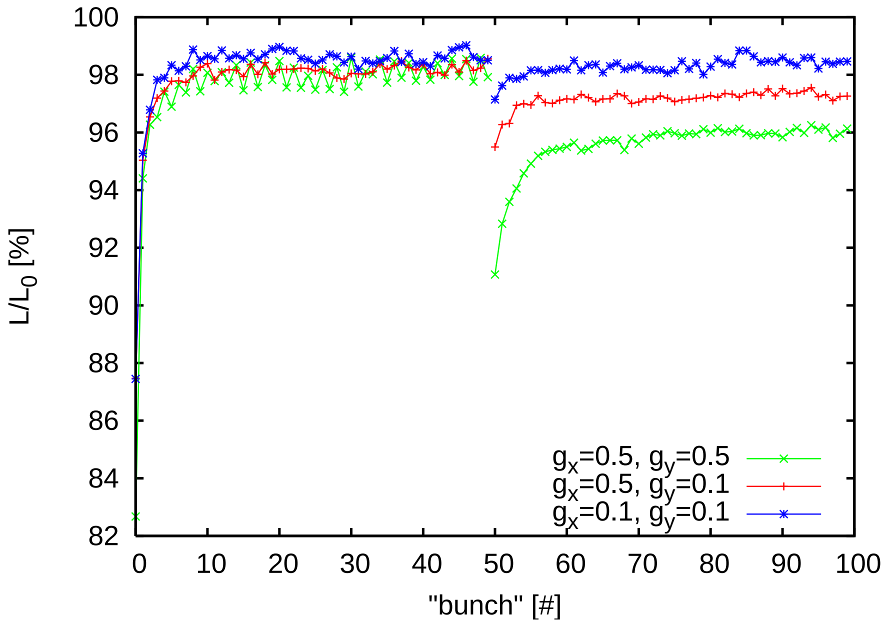
$\Rightarrow \Delta L < 2\%$ for: $\boxed{g_y \; > \; 0.05}$

Luminosity Loss due to Bpm Resolution

- we want to study the effect of the instrumentation noise
- perfectly aligned BDS
- realistic orbit correction, using...
  - all bpms
  - all correctors (svd cut in the singular values)

- bpm noise
  - $\sigma_{\text{bpm}} = 100$ nm

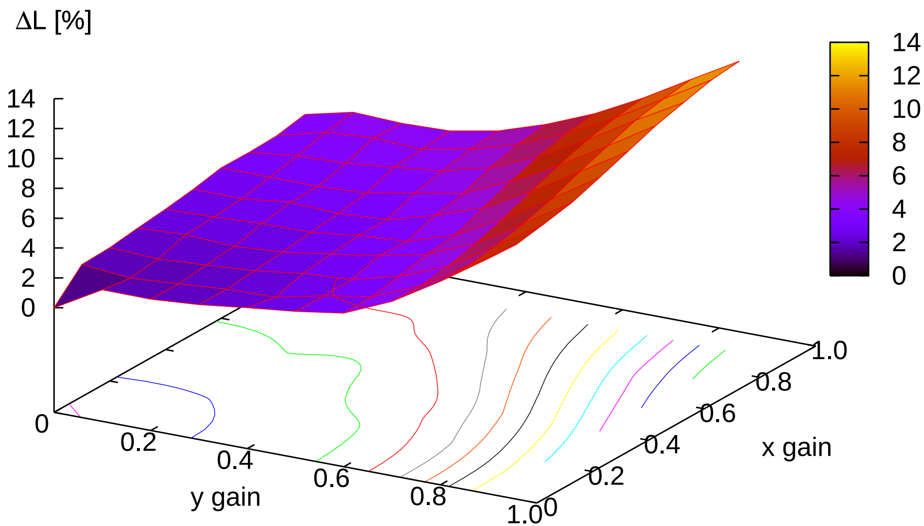
$\Rightarrow$ high gains g amplify the noise



Luminosity Loss due to Bpm Resolution

⇒ to find the upper limit for the gain

- scan of the x and y gains

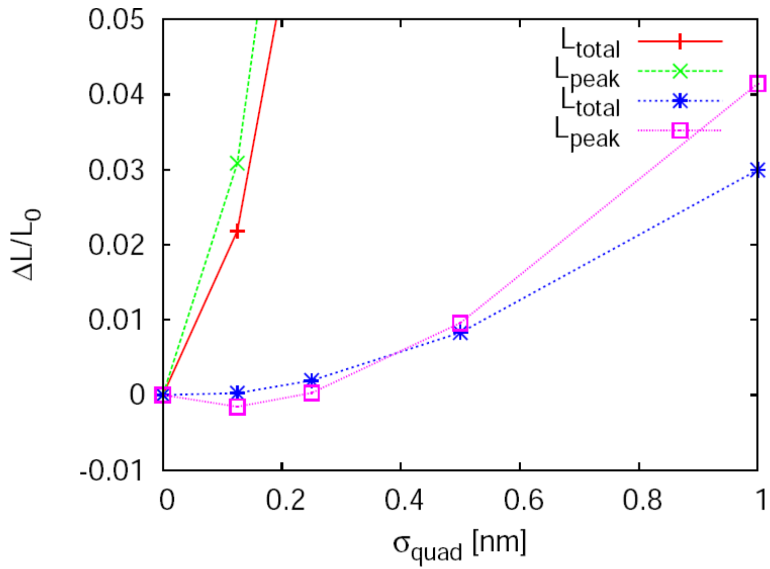


⇒ $\Delta L < 2\%$ for:

1.	g_x	$<$	0.2
2.	g_y	$<$	0.3

Quadrupole Jitter Tolerance

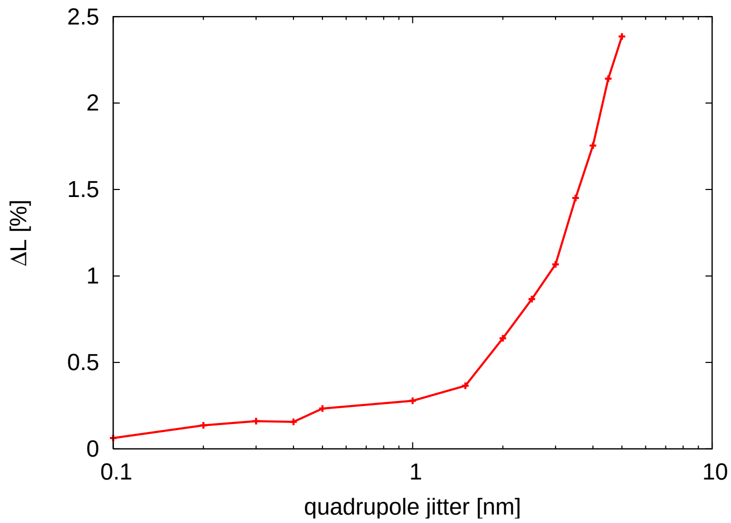
- Two cases
    1. all quadrupoles jitter
    2. final doublet stabilized
- beam-beam feedback is running
- old parameter set : $\epsilon_y = 10$ nm



$\Rightarrow$ stability of 0.5 nm for quadrupoles and 0.1 nm for final doublet quadrupoles

Quadrupole Jitter Tolerance

- new parameter set
- all quadrupoles jitter
- beam-beam feedback is running
- no jitter within the train



- average of 40 seeds

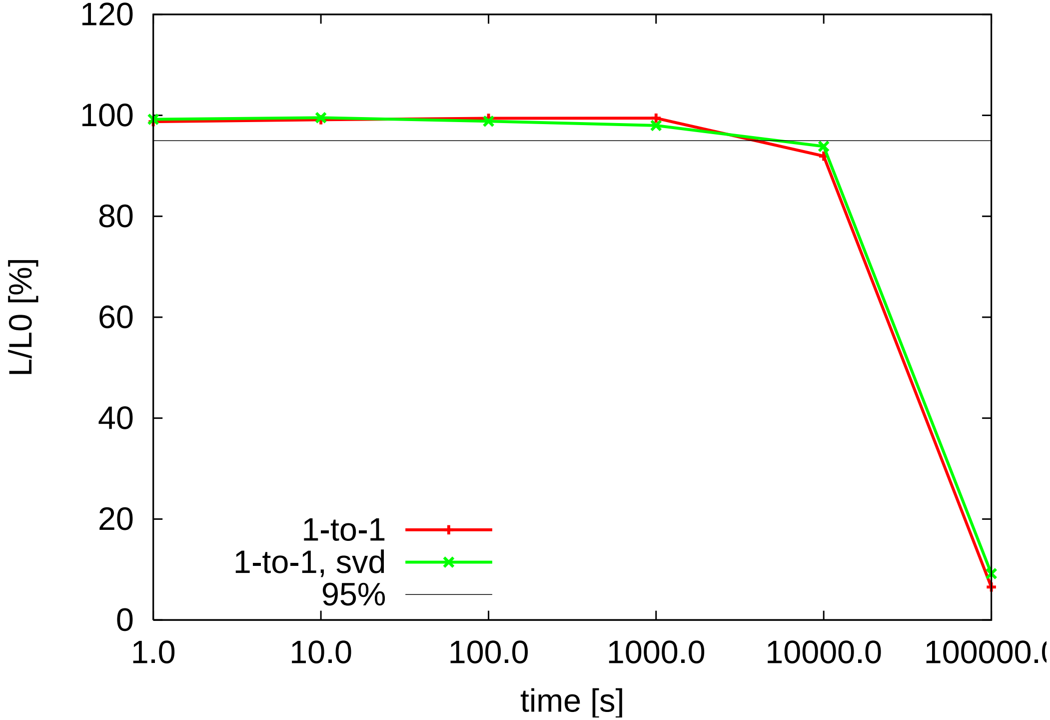
Luminosity preservation over long time scales

⇒ Shows how long we can run with this feedback loop

- ATL ground motion
- orbit feedback
  - all correctors (w/o svd)
  - all correctors with bpm and corrector weights
  - MICADO: picks out the best correctors
- beam-beam feedback to correct beam offset

Luminosity preservation over long time scales

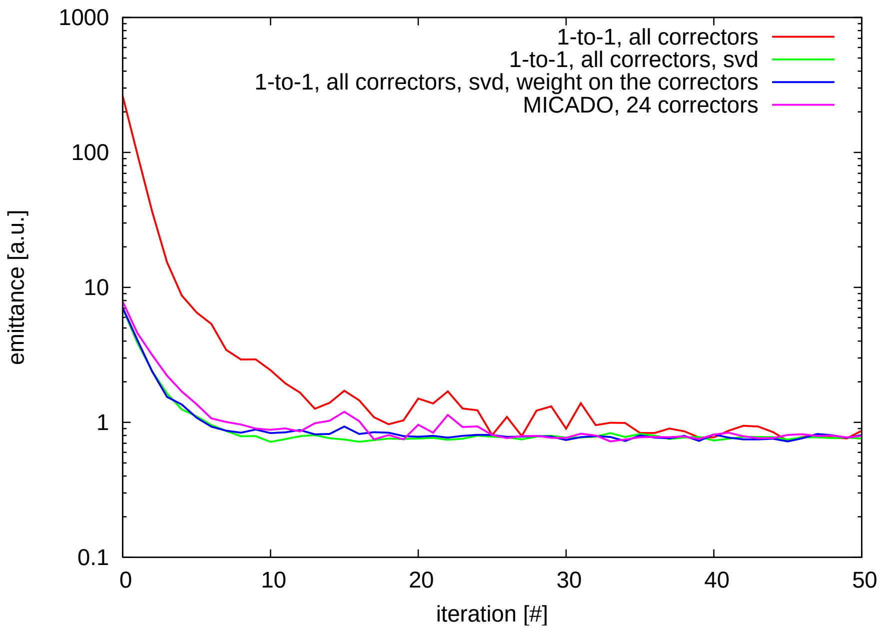
- 1-to-1 correction + beam-beam



⇒ the luminosity can be preserved for about 10000 seconds

Orbit Correction Convergence

- ATL motion for 1000 seconds



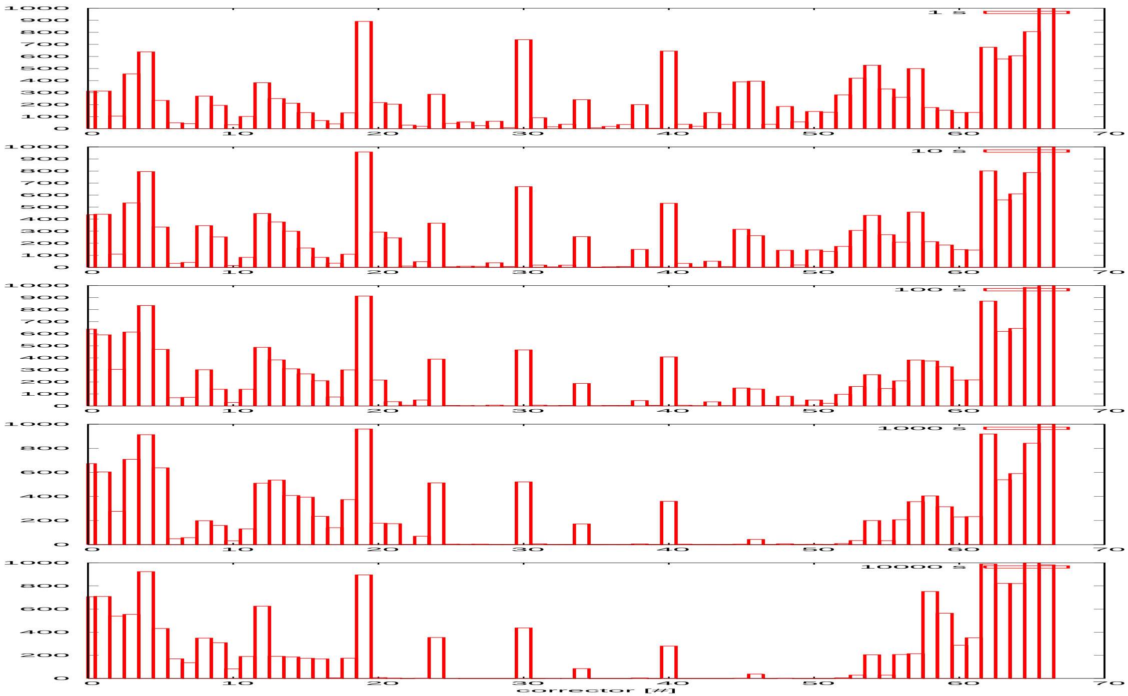
⇒ 1-to-1 correction, with no cut in the singular values shows poor performance

⇒ 1-to-1 correction, with cut in the singular values show good performance

⇒ MICADO, with 24 correctors, does not seem to improve particularly

MICADO Patterns

- 16 correctors selected
- histograms for t=1, 10, 100, 1000, 10000, 100000 seconds (top to bottom)



corrector [#]

Conclusions (for $L^\star = 4.3$ m...)

- the tools to perform these integrated simulations have been provided by placet-octave and guinea-pig
- static alignment

  1) collimation system aligned using dispersion free steering

  2) final focus still to be aligned
- dynamic alignment

  1) it has been proved that

  $\Rightarrow$ quadrupole jitter tolerances are relaxed

  $\Rightarrow$ 100 nm bpm resolution seem to be sufficient

  2) the optimal gains for the orbit correction feedback have been found

$$? < g_x < 0.2$$

$$0.05 < g_y < 0.3$$

  3) long time scale simulations show that slow orbit correction and fast beam beam allow to run for ≈ 10000.0 seconds without further corrections