Emittance Optimisation in the Drive Beam Recombination Complex at CTF3

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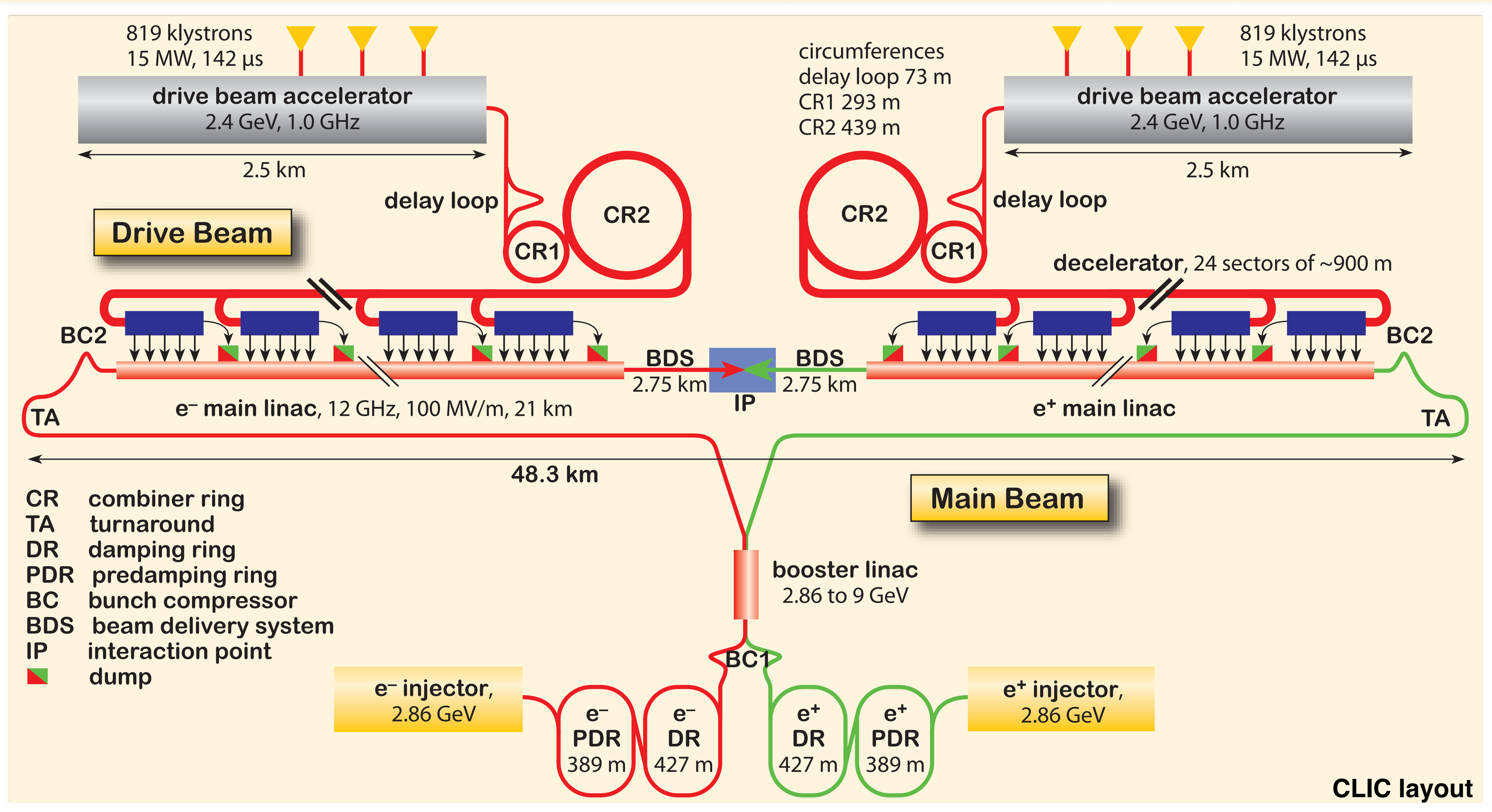
Introduction



CLIC:

- Design of a multi-TeV e^+e^- linear collider.
- Requires high acceleration gradient.
- Based on two-beam acceleration scheme.
- Besides the two colliding beams, it has two parallel high intensity Drive Beams.
  - Current and phase stability of these Drive Beams is crucial for luminosity.

CLIC Test Facility (CTF3):

- Proof-of-principle experiment to study CLIC feasibility.
- Main objectives:
  - Drive Beam production.
  - Drive Beam recombination.
  - RF power production.
  - Two-Beam acceleration.

Goal of this work:

- Identify the sources of emittance growth in the Drive Beam Recombination Complex (DBRC) of CTF3, and so spot possible issue to be corrected in the CLIC design.
- Implement a feedback algorithm to correct orbit and dispersion in the DBRC, and to optimise beam parameters in order to improve the Drive Beam recombination quality.

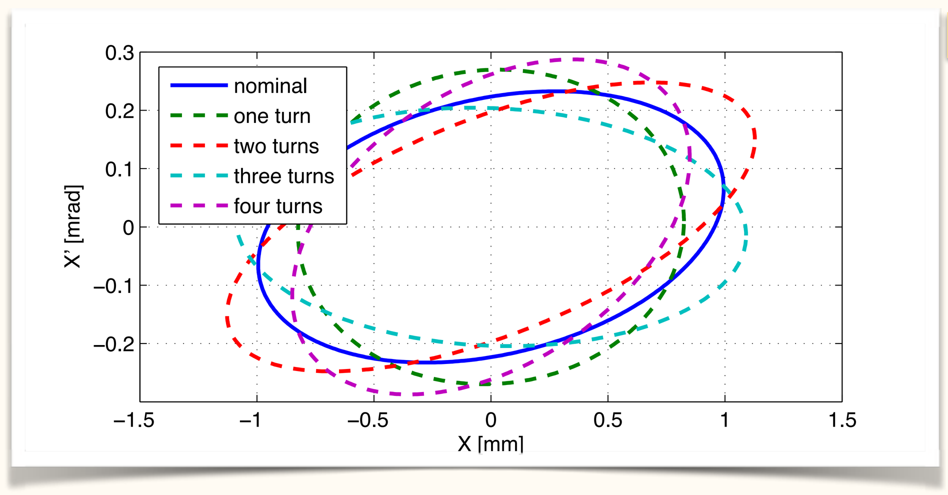
Simulations

One can define the emittance, ε, of an ensemble of particles in phase-space, x-x', as the determinant of the covariance matrix:

$$\Sigma = \begin{pmatrix} < x^2 > & < xx' > \\ < xx' > & < x'^2 > \end{pmatrix} \qquad \epsilon = \det(\Sigma) \qquad (1)$$

By means of Twiss simulations of monochromatic Gaussian beams one can obtain the covariance matrix from the Twiss parameters at any location along a machine.

One can merge many beams, either with different energies or different initial conditions, at one location and calculate the final emittance given by eq. (1).

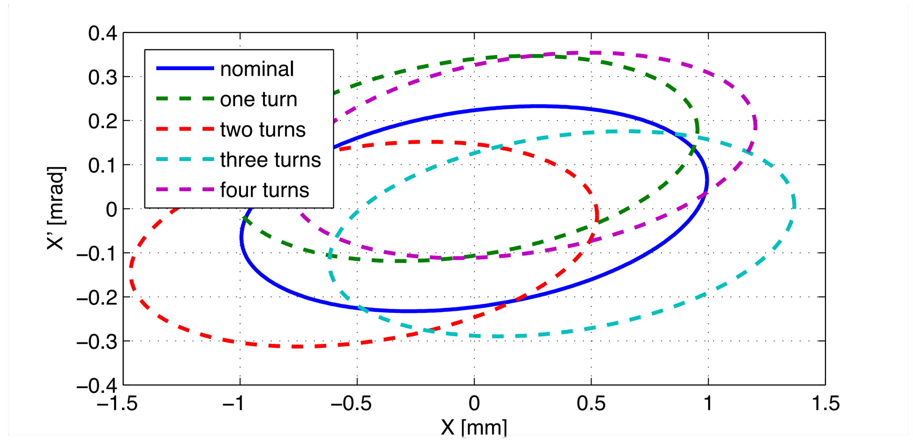


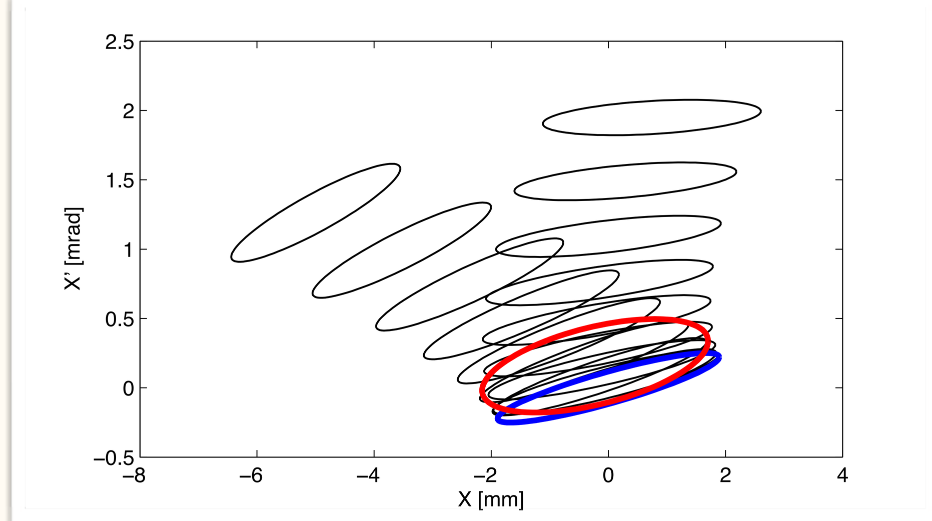
Beta mismatch

Transverse phase-space ellipses of monochromatic Gaussian beams injected with an initial β, 1.5 times the nominal closed solution, after several turns in the Combiner Ring (CR) at CTF3.
The ellipses turn in phase space according to the tune of CR.
Given the nominal emittance of 50 µm, the final projected emittance growth of the 4 recombined beams is 10%.

Orbit error

Transverse phase-space ellipses of monochromatic Gaussian beams injected with an orbit error of 0.5 mm, after various number of turns in the Combiner Ring (CR) at CTF3.
The shape of the ellipses is not perturbed, but the centres of the ellipses move in phase space.
Given the nominal emittance of 50 µm, the final projected emittance growth of the 4 recombined beams is 10%.



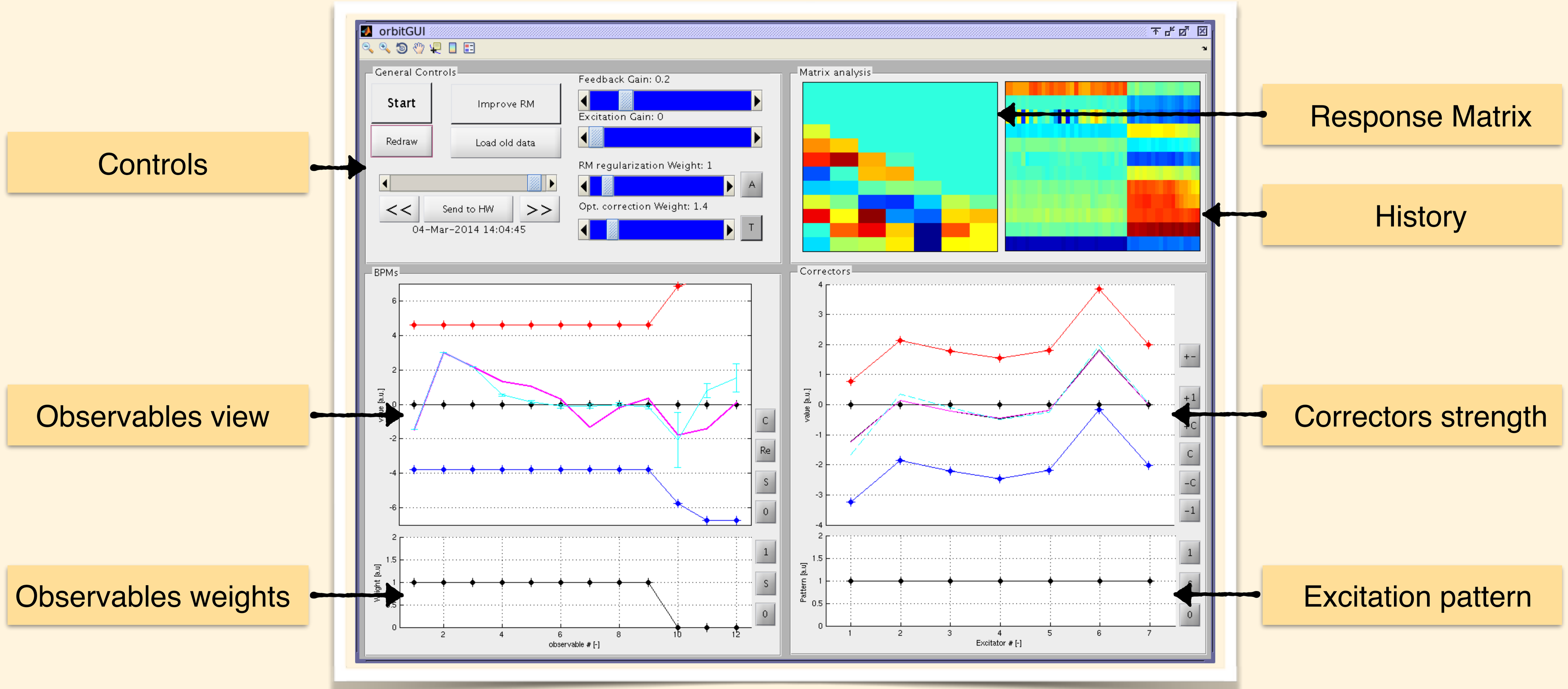


Energy spread

Transverse phase-space ellipses of monochromatic Gaussian beams after one turn in the Delay Loop (DL) at CTF3. The initial Twiss parameters are identical for all the beams, but they have different energies (equally spaced from -2% to +2%).
The blue ellipse represents the nominal condition (emittance of 50 µm, nominal 115 MeV energy).
The red ellipse is the weighted average of all the simulated ellipses.
Considering a Gaussian energy profile with sigma 0.5%, the emittance growth is more than 100%.

Linear Feedback Implementation

- Generic implementation in MATLAB®:
  - Interfaced with any parameter/observable available in the accelerator control system.
- Able to measure the response matrix based on Regularised Linear Regression.
  - It is not needed to excite one actuator at a time.
  - It is possible to keep the response matrix updated while correcting.

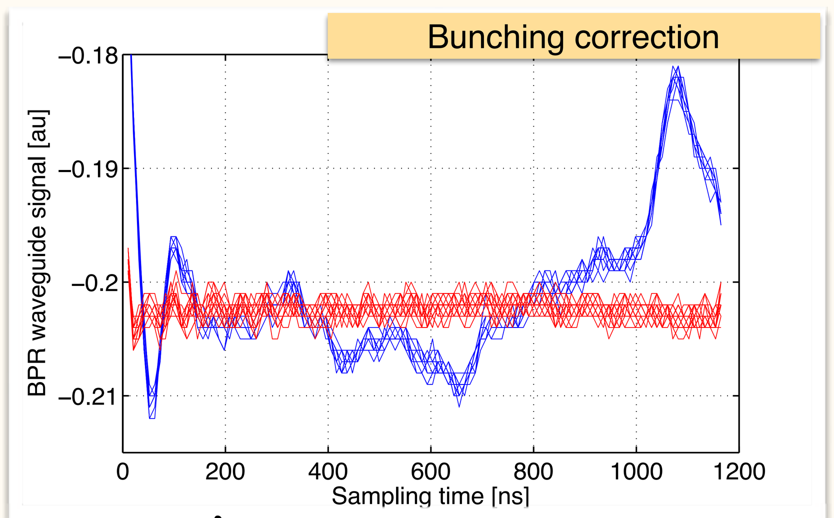


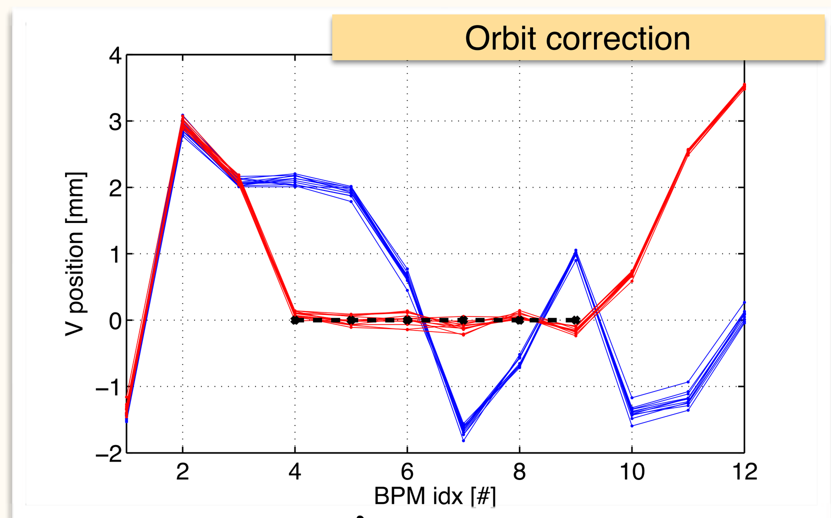
Experimental Results at CTF3

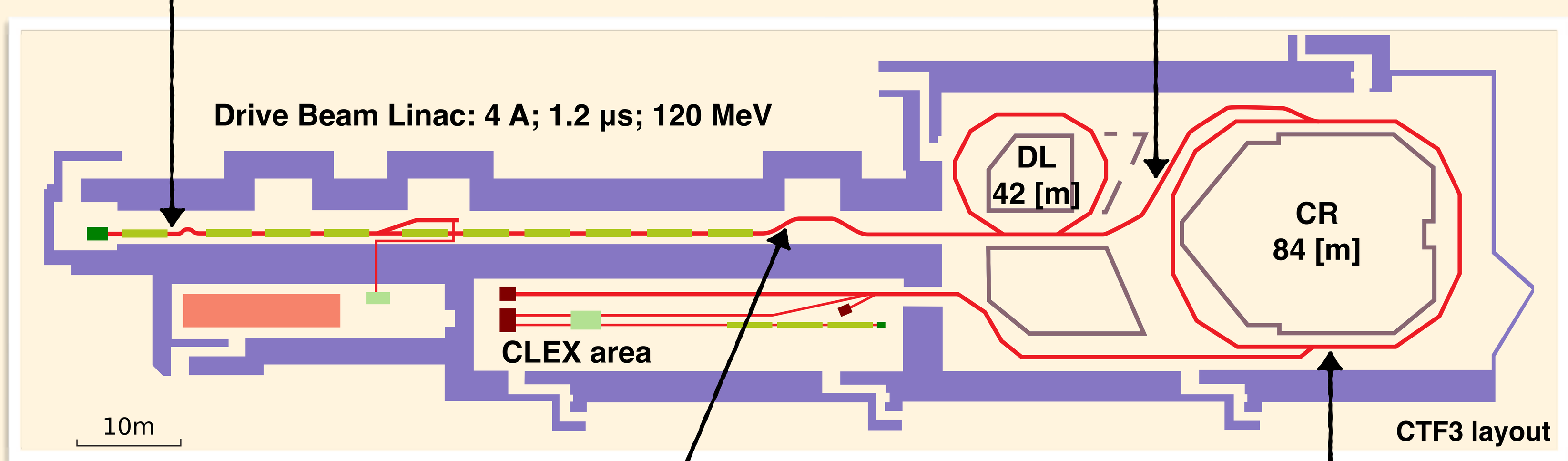
- Using the developed linear-feedback application.

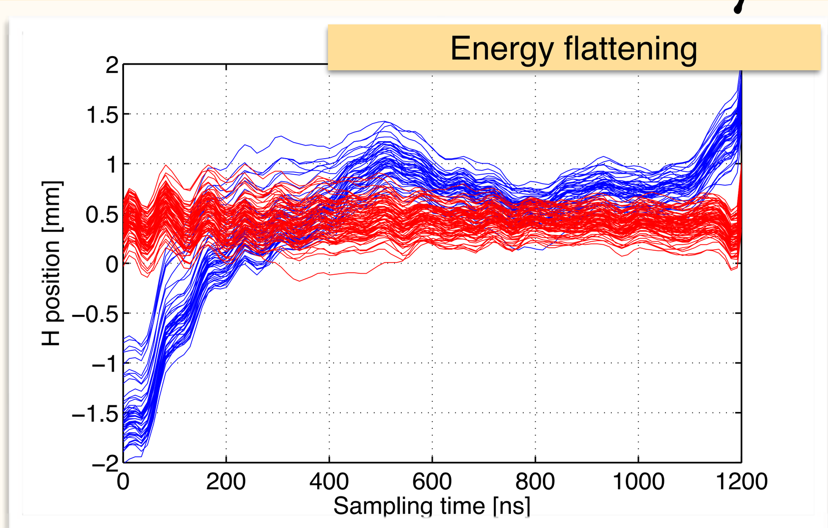
Flattening of BPR waveguide signal acting on the buncher klystron phase.
Each line represents a single 1.2 µs long pulse.
Red are shots after correction.

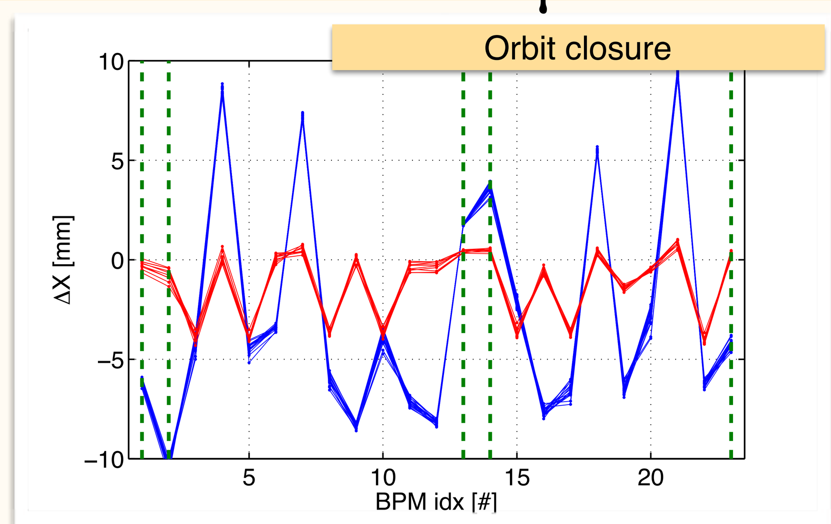
Vertical orbit correction in the Transfer Line 1 (TL1).
Each line represents the orbit averaged over 5 pulses.
In black, where present, the target orbit.
Red are shots after correction.











Horizontal beam profile at the end of the linac in a dispersive BPM for different single shots. The blue lines are before energy flattening correction, the red lines after the correction.

Difference between the first and second turn horizontal orbit in the CR. Each line represents an average over 10 pulses. The red differences are obtained after minimising the closure on the green-marked BPMs.

Conclusions and Outlooks

DONE:

- Developed software to implement linear feedbacks for parameter optimisation.
- Performed preliminary simulations of emittance growth in the DBRC.
- Proven the ability to control beam orbit, and to correct bunching and energy features along the pulse.

TO DO:

- Prosecute simulations to better characterise the emittance growth sources.
- Implement a Dispersion Matching Steering algorithm.
- Further improve the orbit closure of Delay Loop and Combiner Ring.
- Measure the emittance improvement after the Recombination Complex.

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