Beam optics measurements: tools and procedures at CTF3

CLIC Workshop 2015 - CERN - 27/01/2015

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Outline

- The CLIC Test Facility (CTF3)
- Orbit:
  - Generic slow feedback application.
  - Orbit control and correction: an example.
- Dispersion:
  - Measurement.
  - Correction: two first results.
  - Future improvements.
- Work in progress: transverse optics verification.
- Conclusions.

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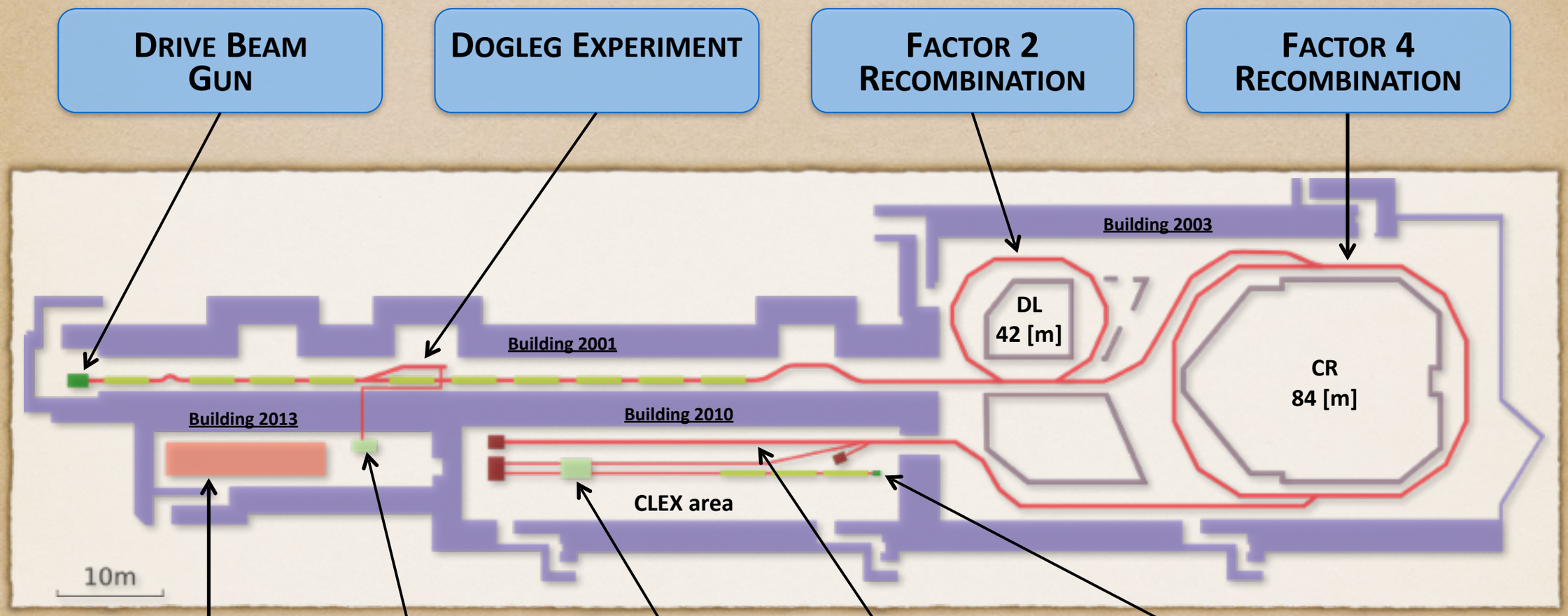
CTF3 - The CLIC Test Facility



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Orbit control

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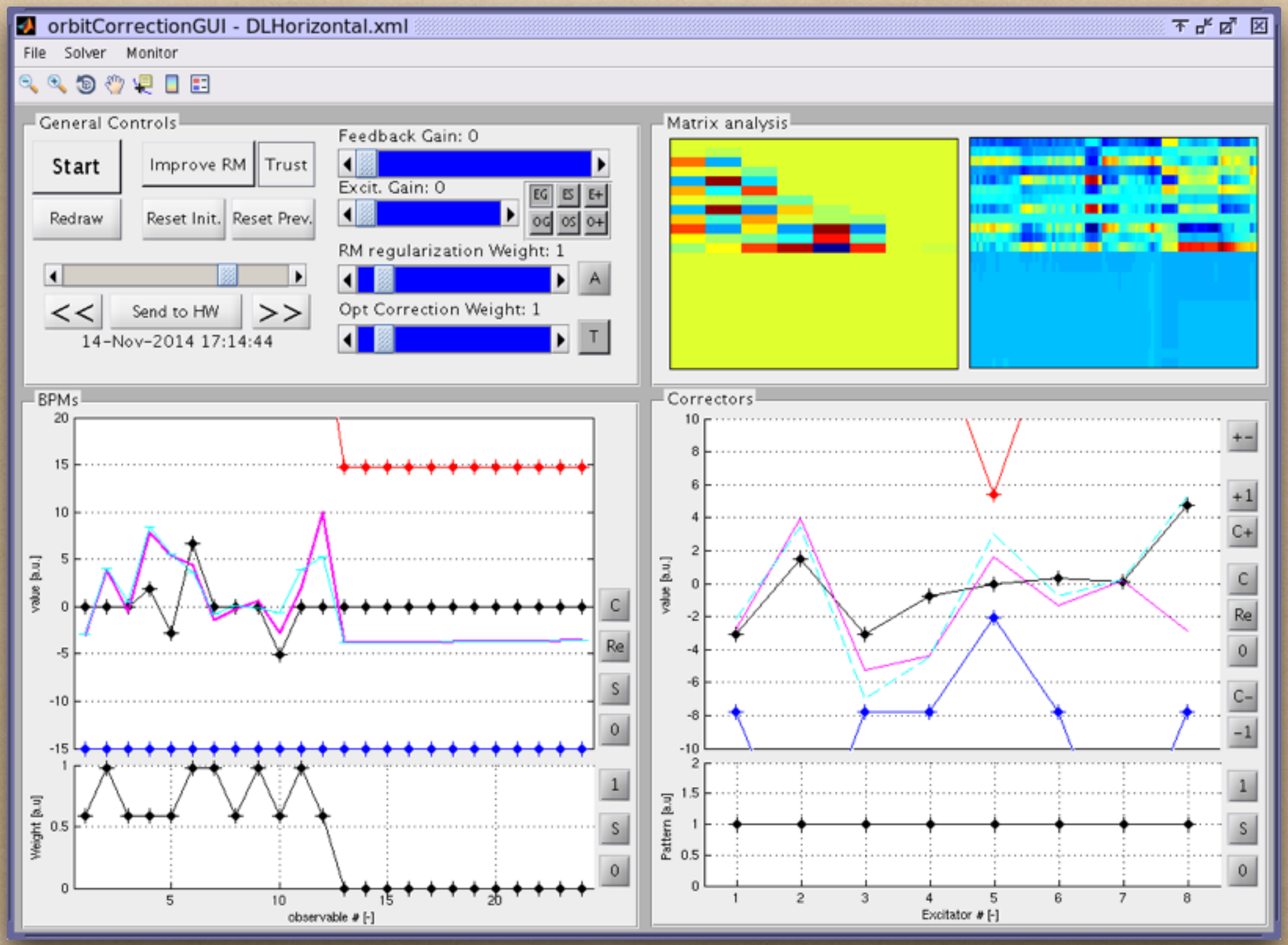
Orbit: Slow feedback tool



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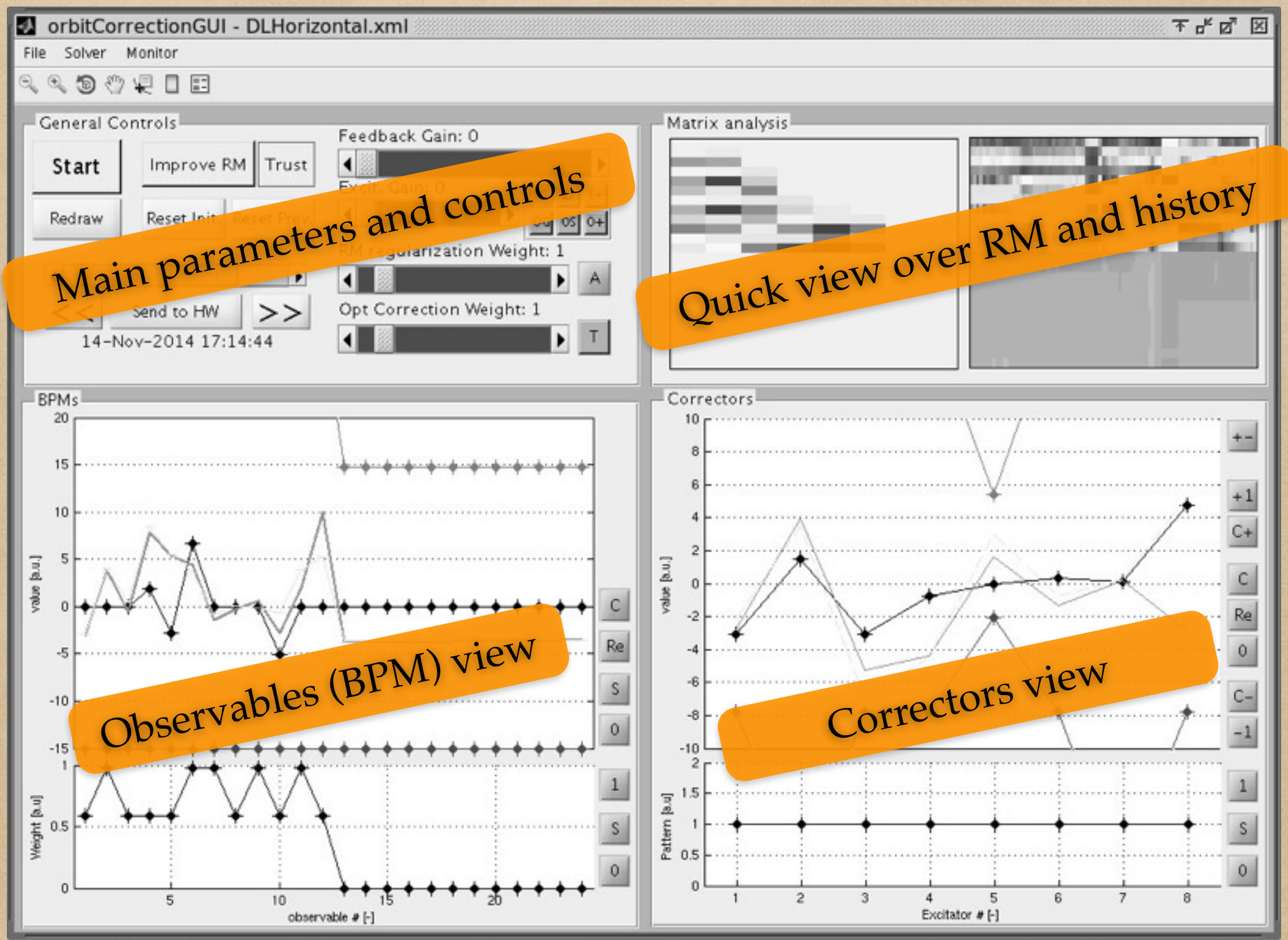
Orbit: Slow feedback tool



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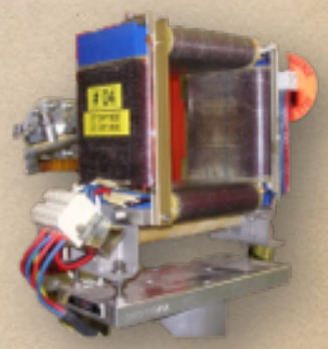
Feedback tool: what is behind

Wanted orbit

Classic response matrix

Correctors settings

$$\begin{pmatrix} \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{pmatrix} \\ \lambda \begin{pmatrix} t_1 \\ t_2 \\ \vdots \\ t_m \end{pmatrix} \end{pmatrix} = \begin{bmatrix} \begin{bmatrix} R_{1,1} & R_{1,2} & \dots & R_{1,m} \\ R_{2,1} & R_{2,2} & \dots & R_{2,m} \\ \vdots & \vdots & \dots & \vdots \\ R_{n,1} & R_{n,2} & \dots & R_{n,m} \end{bmatrix} \\ \lambda \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & 1 \end{bmatrix} \end{bmatrix} \begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ a_m \end{pmatrix}$$



Weighted Target correction

Weighted Identity matrix

- If **λ = 0**, we are back in the classical situation.
- If **λ != 0**, then the full Response Matrix is **always over-constrained**.
  - Solution cannot explode.
- If **λ >> 0**, then the classic response matrix is just “noise”. Solution will be identical to the target correction required.

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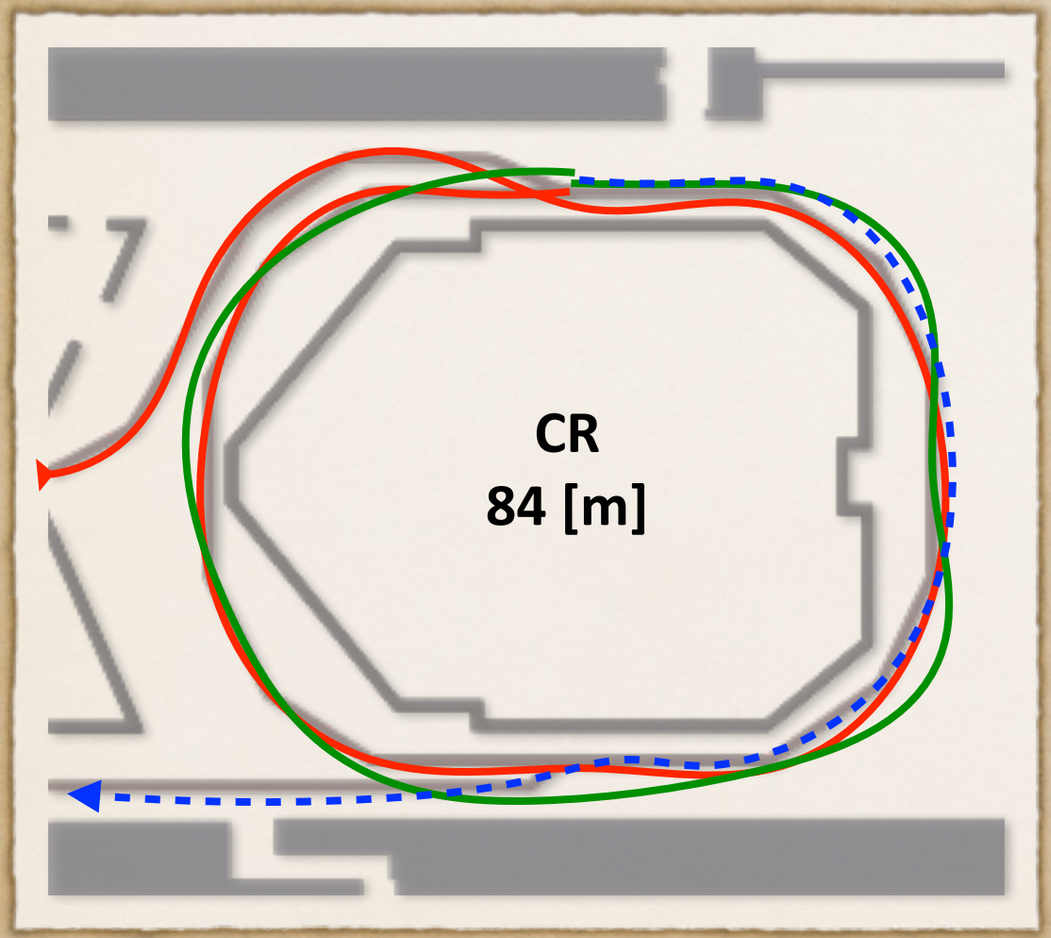
Orbit correction: special case of slow feedback

- The tool has an **XML configuration file** that allows the use of the same tool for different parts of the machine and, a priori, not only for orbit.
- It has the **possibility to measure the Response Matrix** with different strategies, and to **keep it updated** by improving it meanwhile applying a correction.

- Example of its use: **Vertical Closure of CR orbit:**



1. Send a **short (< 280 ns) beam** in the CR.
2. Let it circulate for at least **two complete turns**.
3. Define as "**observable**" **the difference in orbit between the first and second turn**.
4. **Measure** the Response Matrix that relates changes of correctors strength in the CR with changes of observables.
5. Try to **minimise** the observables (i.e. close the orbit of CR).

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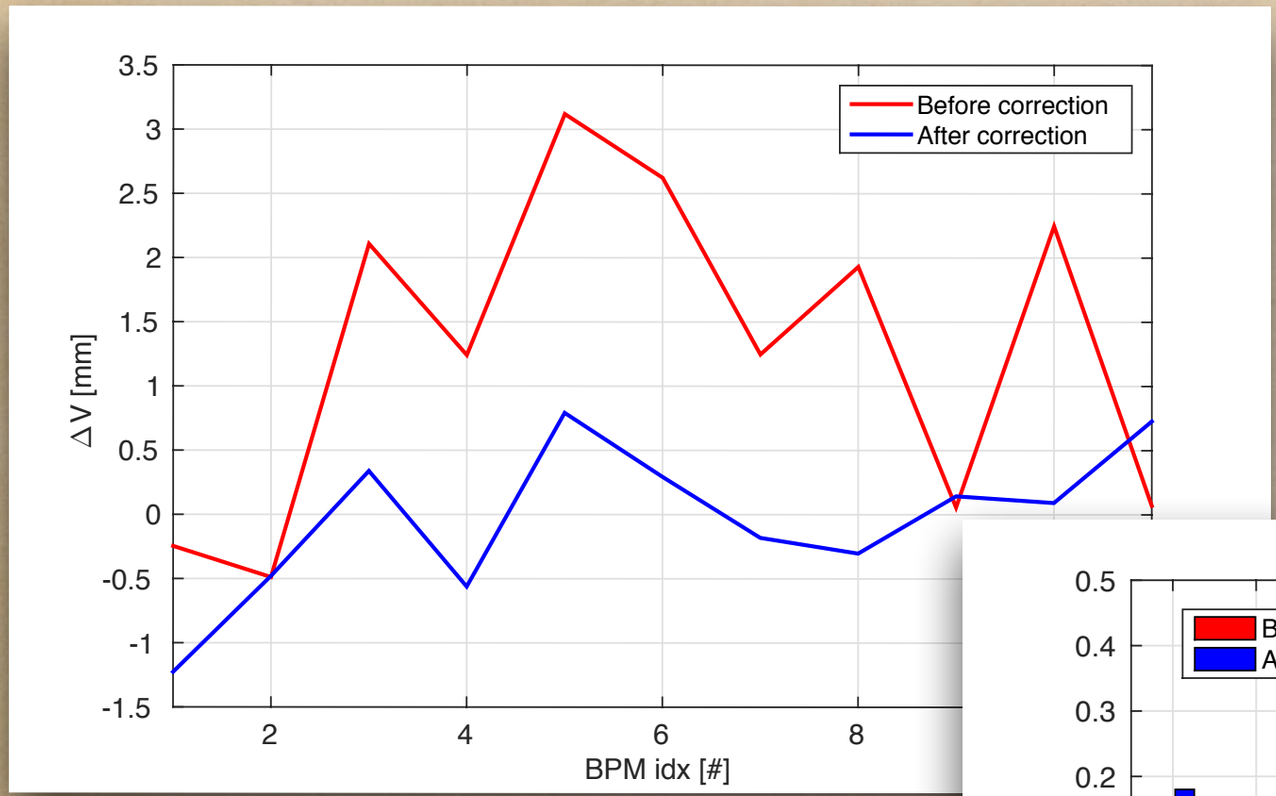
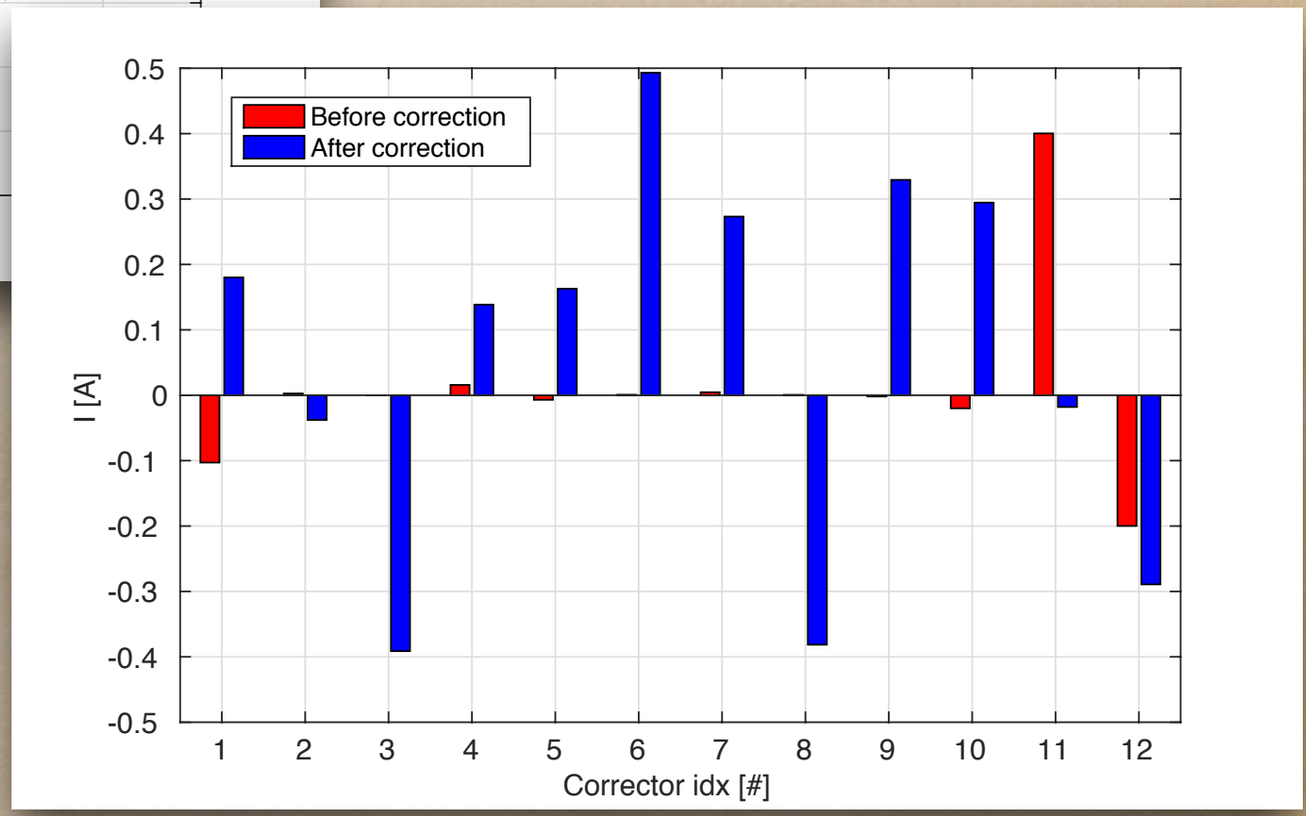
Orbit correction: vertical closure of CR.



Observables (i.e. differences between one turn and the next one on the mostly trusted BPMs of CR) before and after correction.

Further improvements mainly limited by losses.



Strength of the vertical correctors in the CR before and after the correction.

- **Similar results has been obtained for horizontal closure, as well as general orbit correction in other parts of CTF3.**

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Dispersion control

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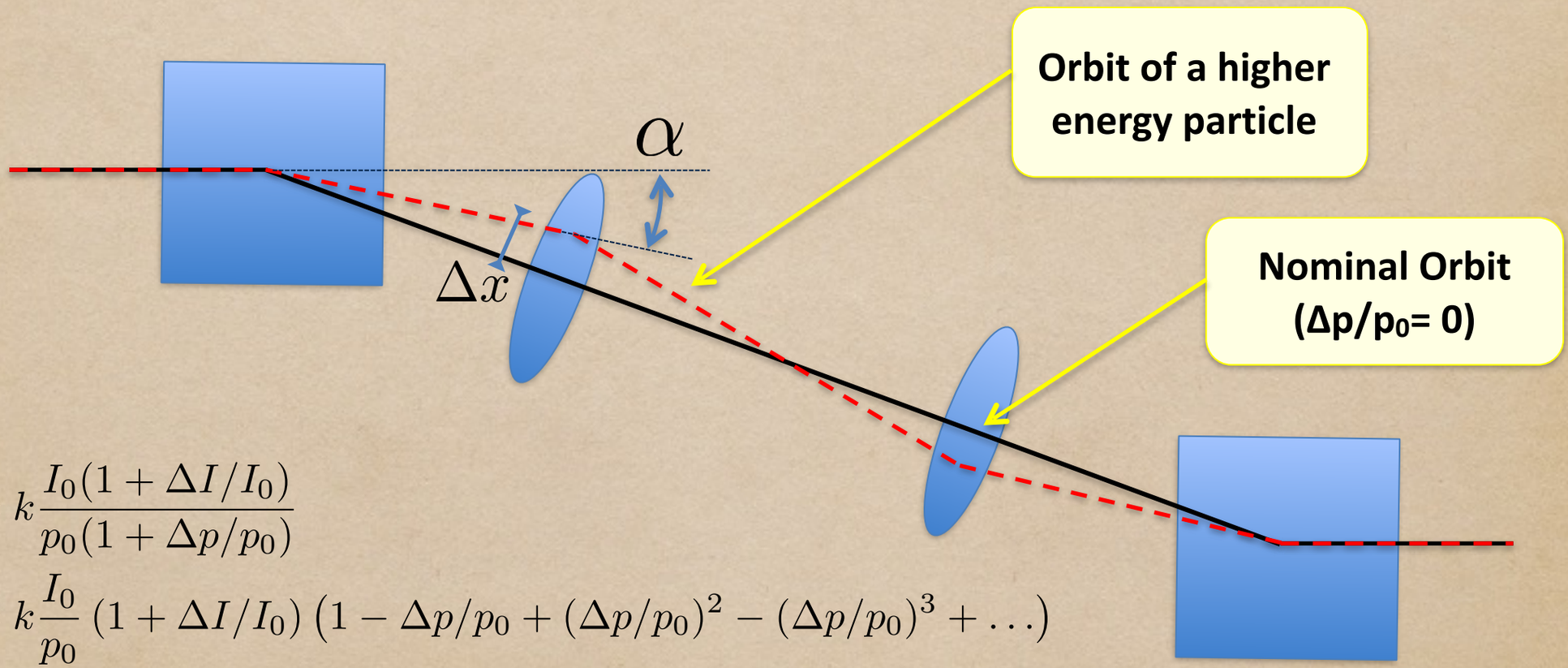
Linear dispersion:

$$D_x \frac{\Delta p}{p_0} = \Delta x$$

- By definition it is the linear coefficient between energy error and the observed transverse displacement of the beam respect to the nominal (0) orbit.
- **Main source** of dispersion in CTF3 are **dipoles**.
  - Dispersion introduced by correctors and misalignments is normally smaller.



$$\alpha = k\frac{I_0(1+\Delta I/I_0)}{p_0(1+\Delta p/p_0)}$$
$$= k\frac{I_0}{p_0}(1+\Delta I/I_0)\left(1-\Delta p/p_0+(\Delta p/p_0)^2-(\Delta p/p_0)^3+\ldots\right)$$
$$\approx k\frac{I_0}{p_0}(1+\Delta I/I_0)(1-\Delta p/p_0)$$

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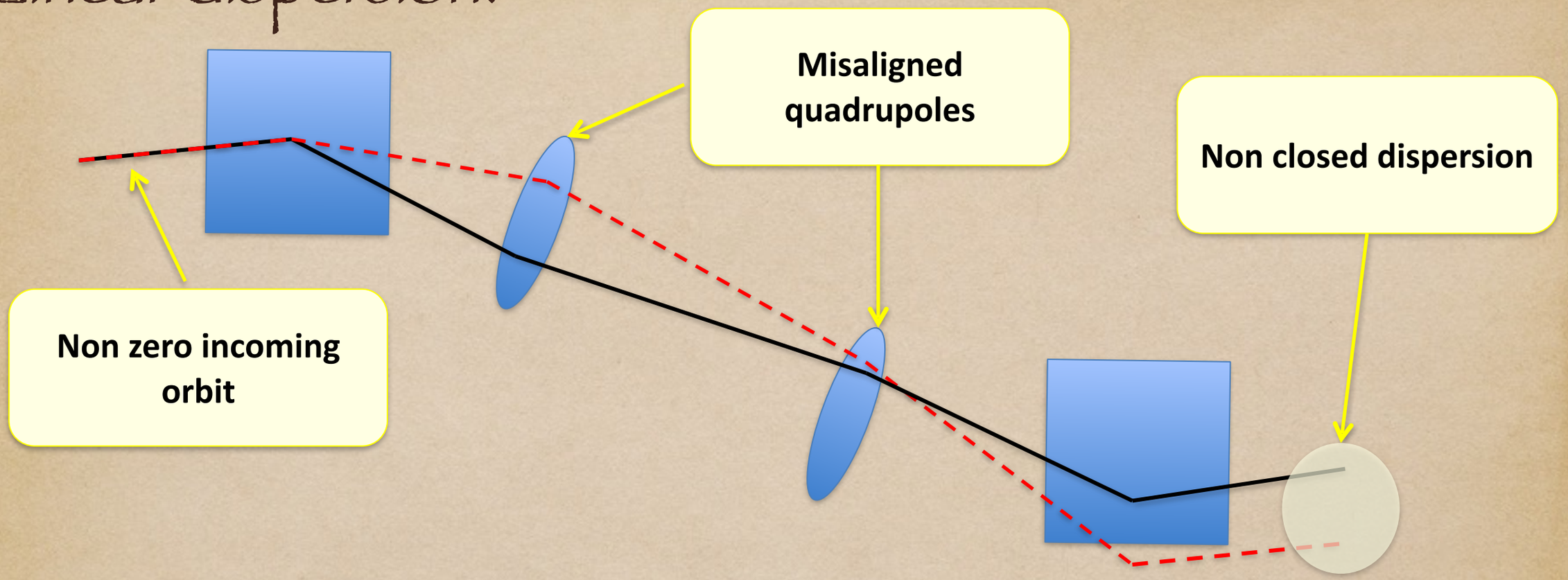
Linear dispersion:



- The orbit response due to a change of the bendings, doesn't depend on the initial orbit and misalignments (at least in first approximation).
- Scaling the bending of 1% is equivalent (at first order!) to change the the beam energy of -1%
  - **i.e. We can use the response to bendings scaling as measurement of the "nominal" dispersion.**
  - **This can give us the target dispersion for a later Dispersion Target Steering.**
- If two consecutive shots have slightly different mean energies, the observed orbit difference is the actual dispersion (eventually at any order!) of the line.
  - **i.e. Beam energy jitter reveals the actual dispersion taking into account all misalignments and incoming orbit at any order.**

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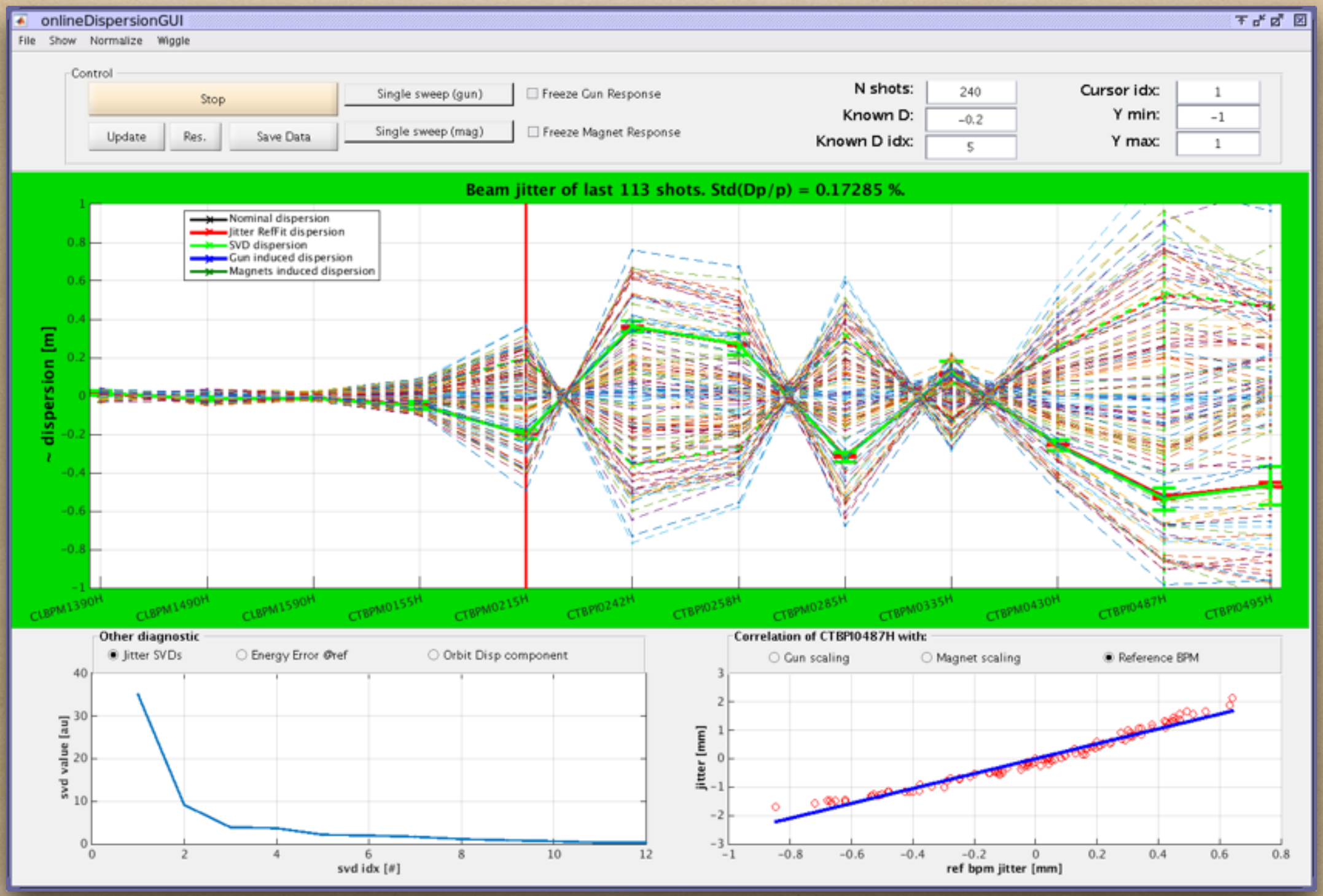
Dispersion: Measurement tool



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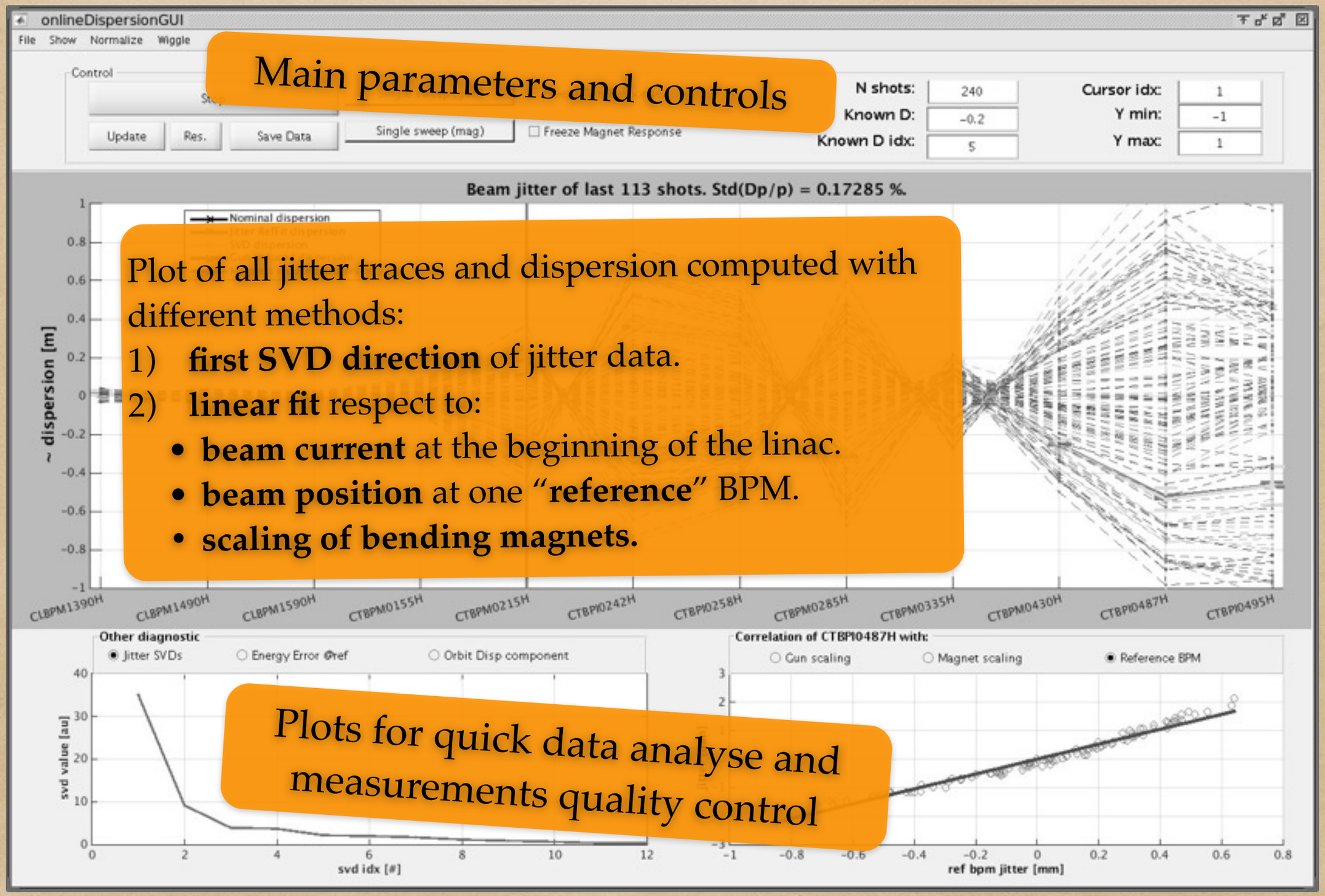
Dispersion: Measurement tool



Main parameters and controls

Plot of all jitter traces and dispersion computed with different methods:

1) **first SVD direction** of jitter data.
2) **linear fit** respect to:
   - **beam current** at the beginning of the linac.
   - **beam position** at one "**reference**" BPM.
   - **scaling of bending magnets.**

Plots for quick data analyse and measurements quality control

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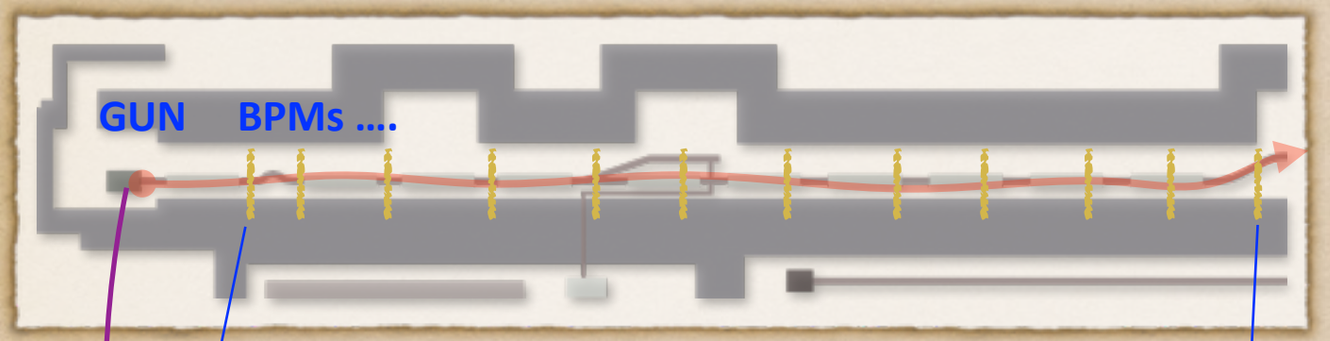
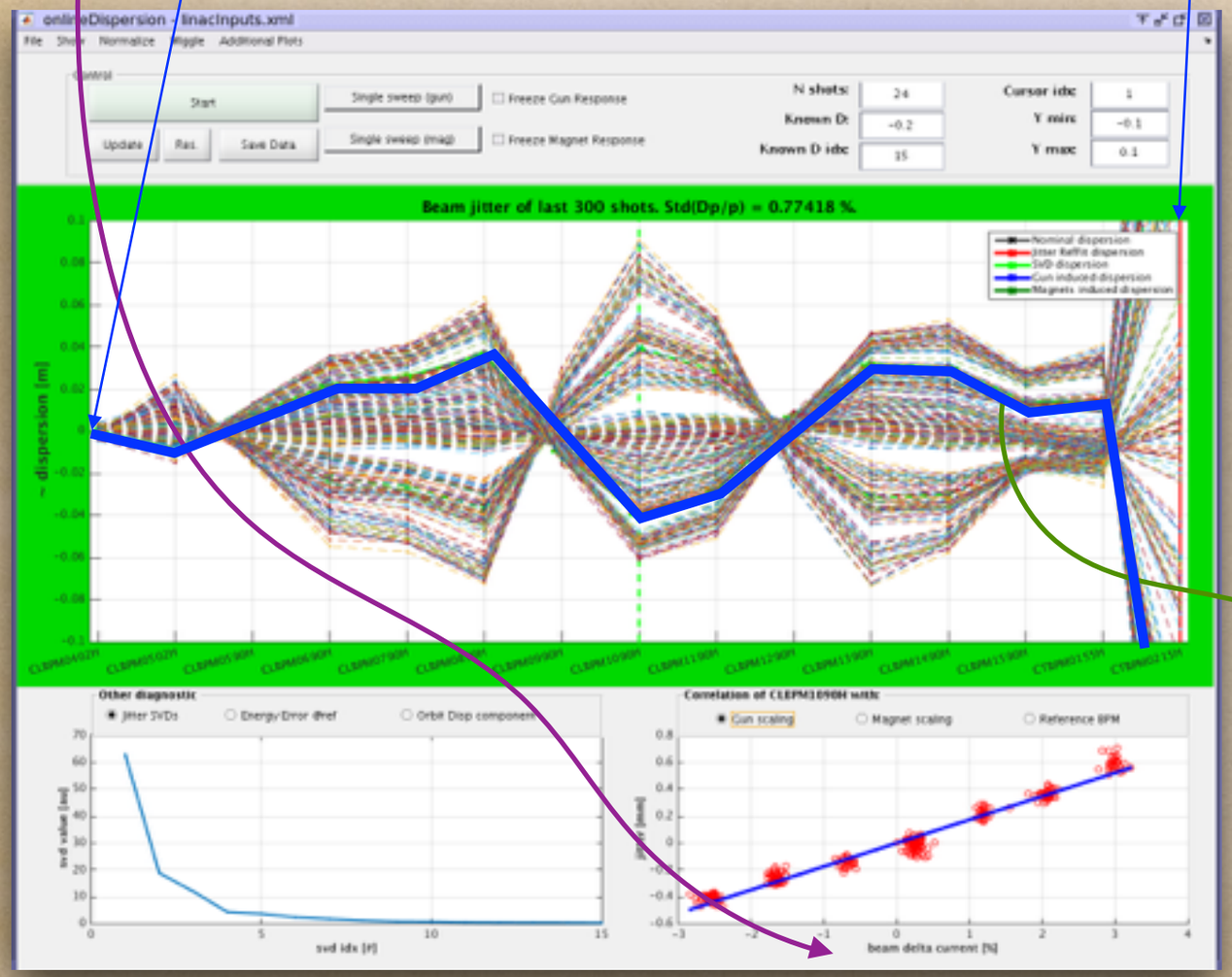
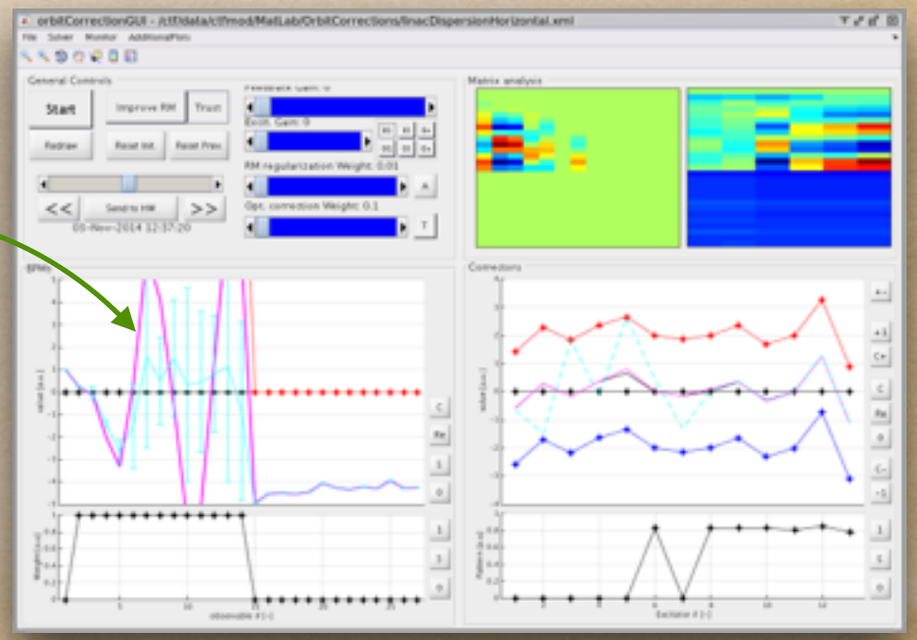
Dispersion free steering in the LINAC





- Zero dispersion expected.
- The small chicane after the injector might leave some unclosed dispersion.
- We have big aperture, so we can afford to heavily scale the beam current without losses.
- **If we can measure something reasonable, we can correct it…**



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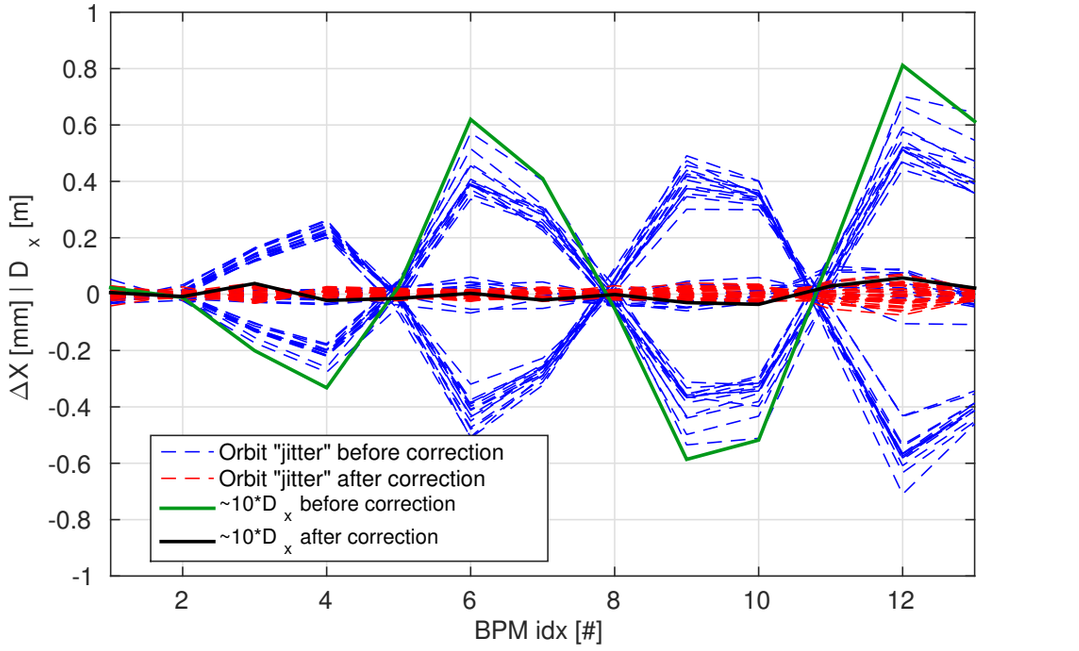
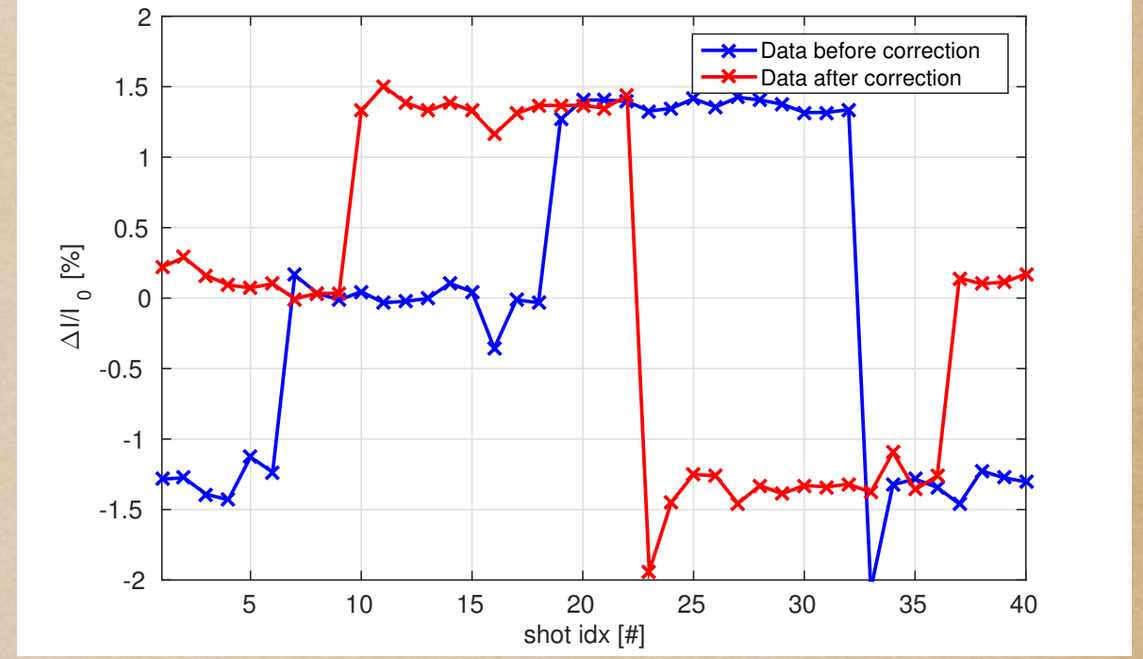
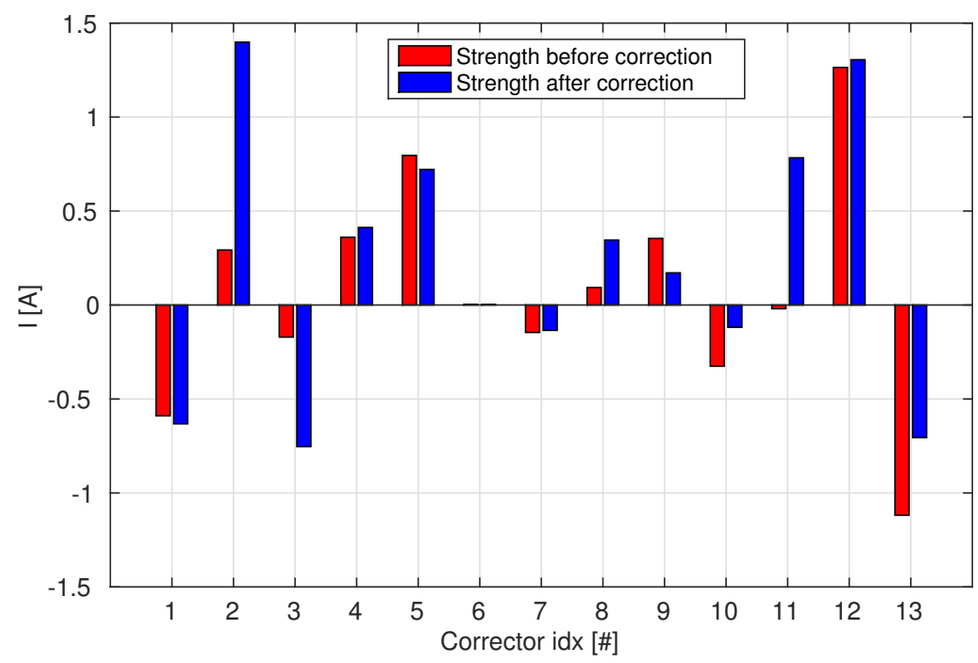
Dispersion free steering in the LINAC

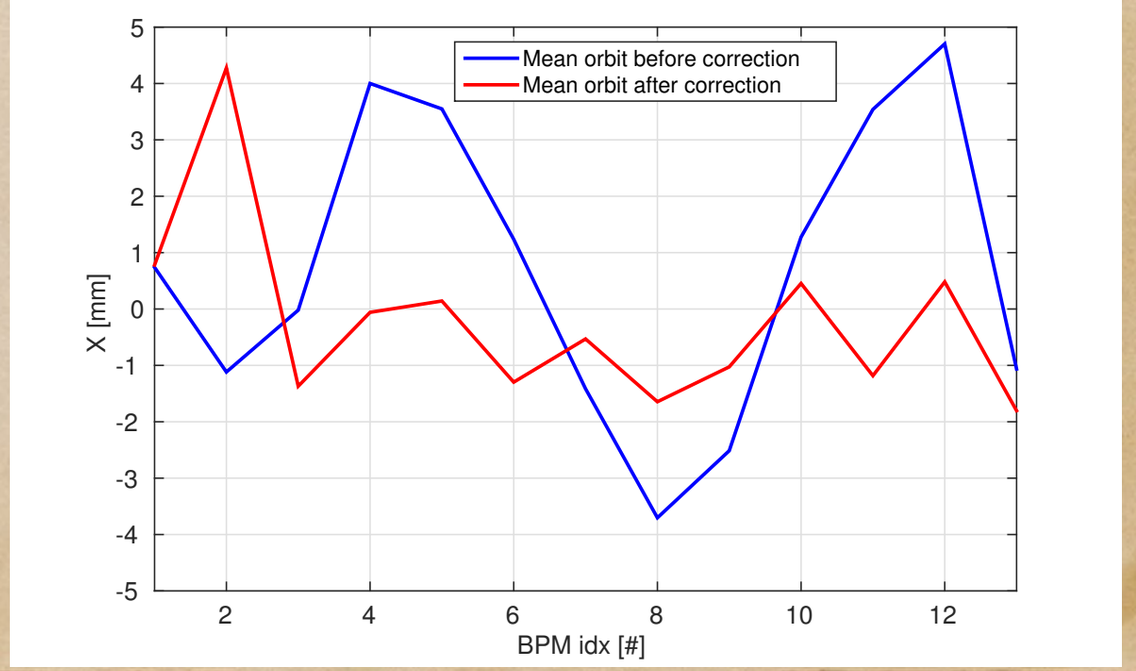
- **Observables: 40 consecutive shots at different GUN current settings (scaling up/down of ~1.5% than nominal).**





- **Main correction is at the beginning of the linac. This reduces not only the dispersion, but also the orbit.**





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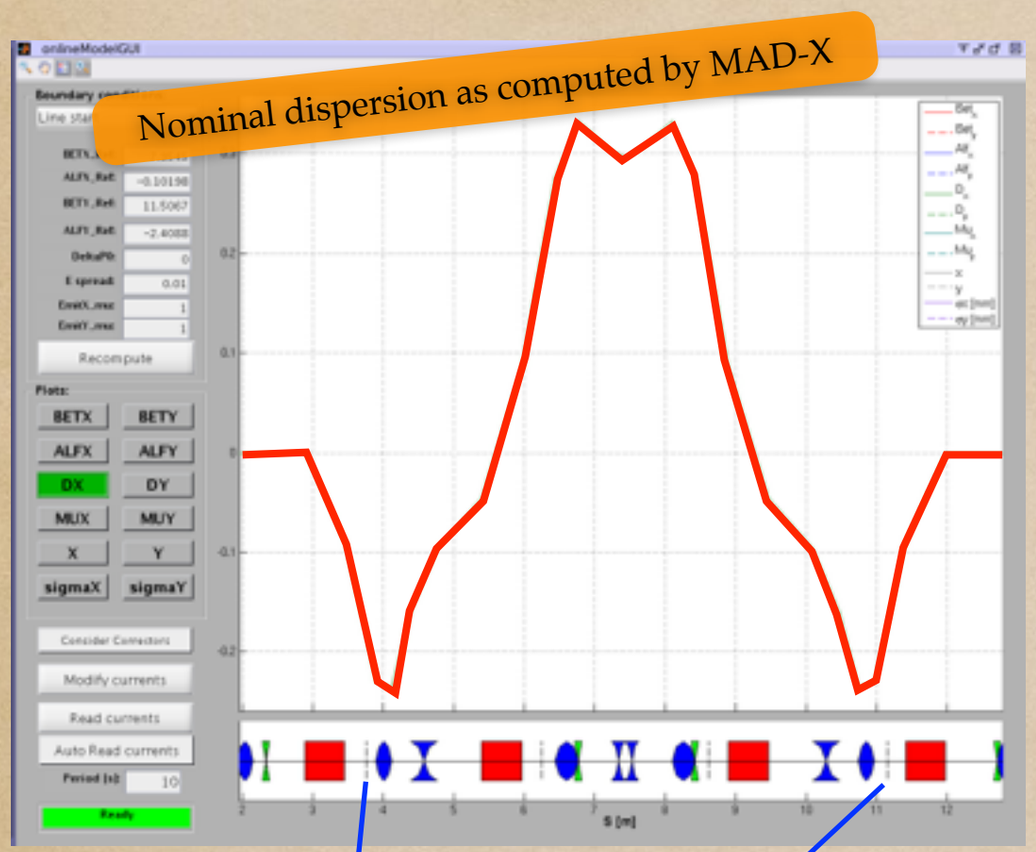
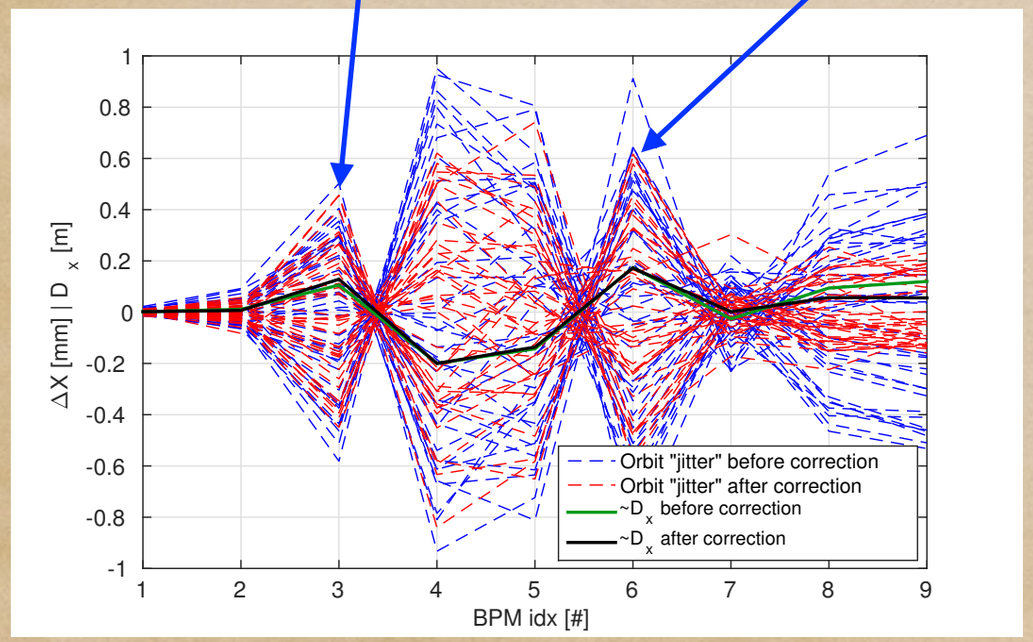
Dispersion Target Steering in Frascati Chicane.





- In this case we need to target the designed dispersion.
- We can have this information from our MADX model.
  - **First issue:** **calibration error of BPMs** are not important for dispersion free steering (we anyway need to measure “zero” at the end), but **extremely important for Dispersion Target Steering**.
- If we don’t trust calibration of BPMs, we can try to just impose zero dispersion in the region where no dispersion is expected.
- **First Results:** not very effective when scaling beam current.
  - Partially effective using natural jitter of beam energy and using first dispersive BPM as “energy meter”.

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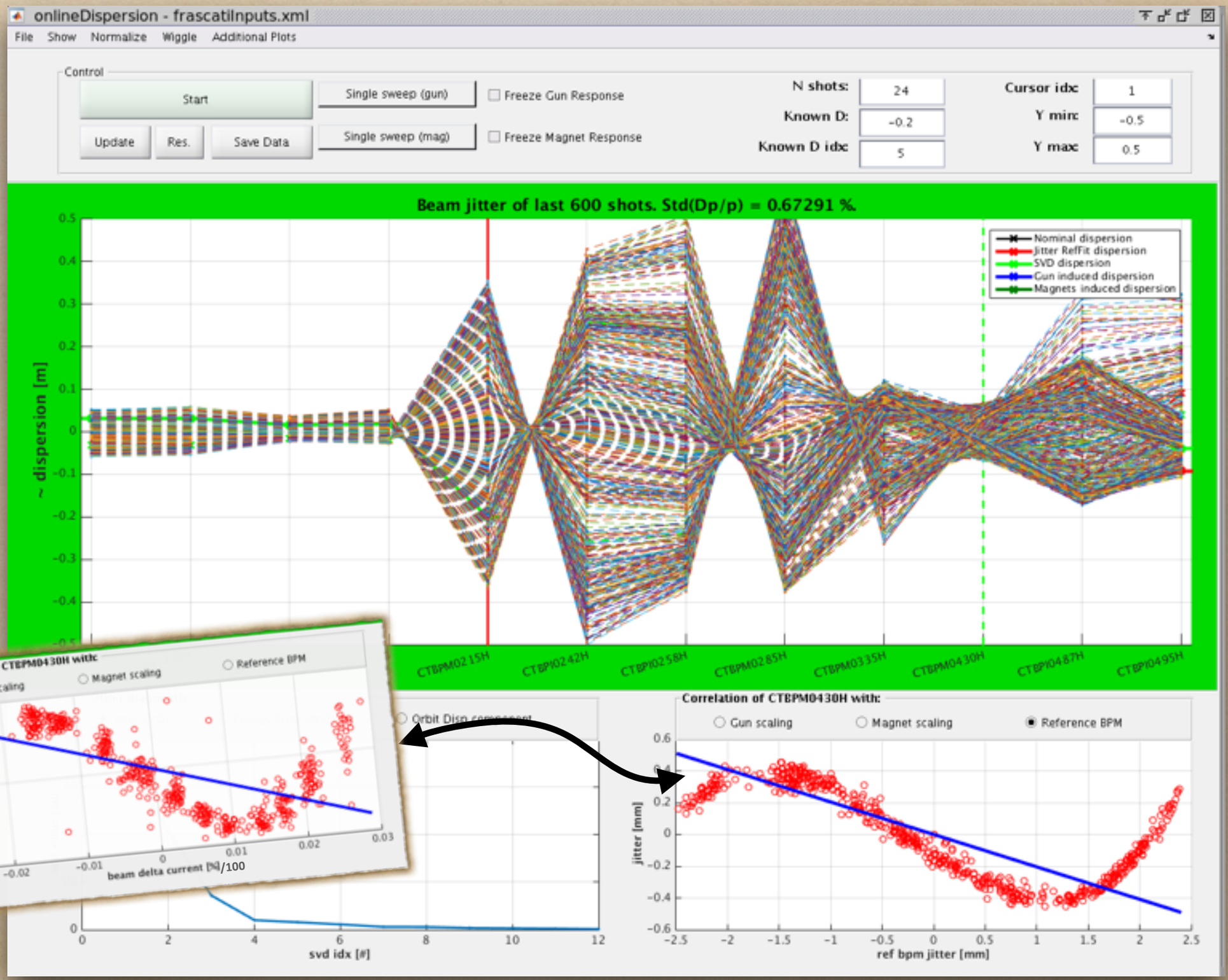
Dispersion in Frascati Chicane: a closer look.



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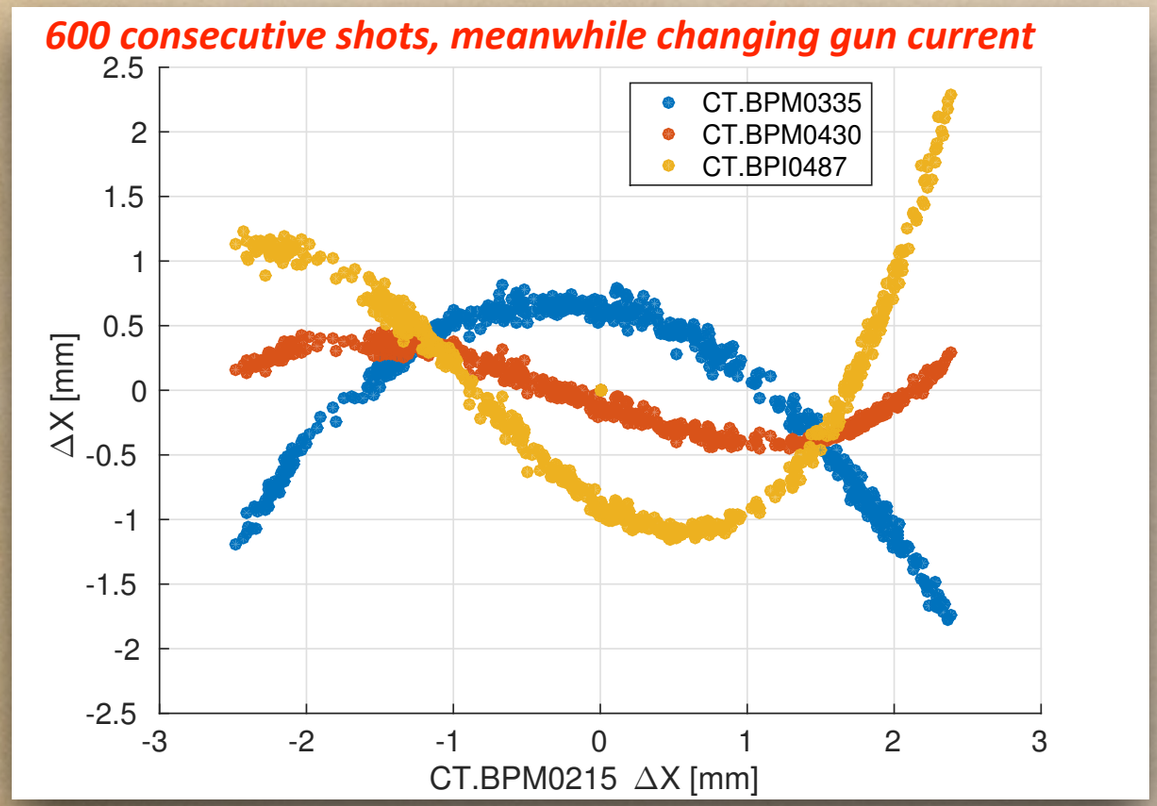
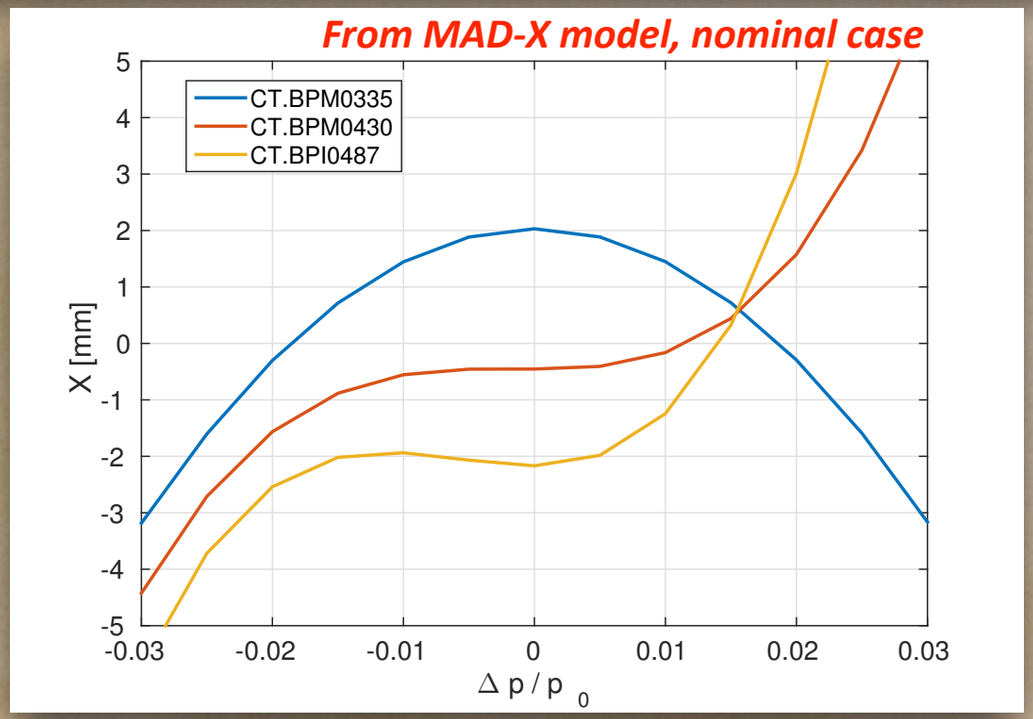
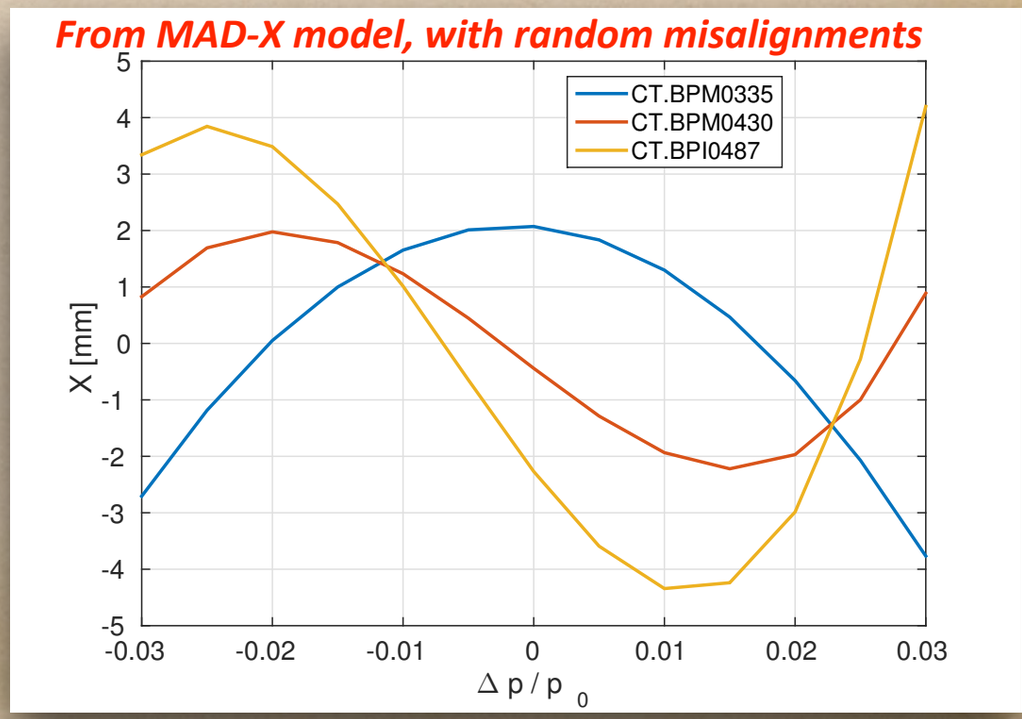
Dispersion in Frascati Chicane: a closer look.



- In this case the "**cleaner**" measurement is the **correlation with the first dispersive BPM** (CT.BPM0215).
- Clear non-linearities visible on the dispersion free BPMs after the chicane.
- **Similar results** can be obtained by simulating different beam energies with MAD-X in the **nominal case** and with random quadrupoles **misalignments** (σ=0.2 [mm]).





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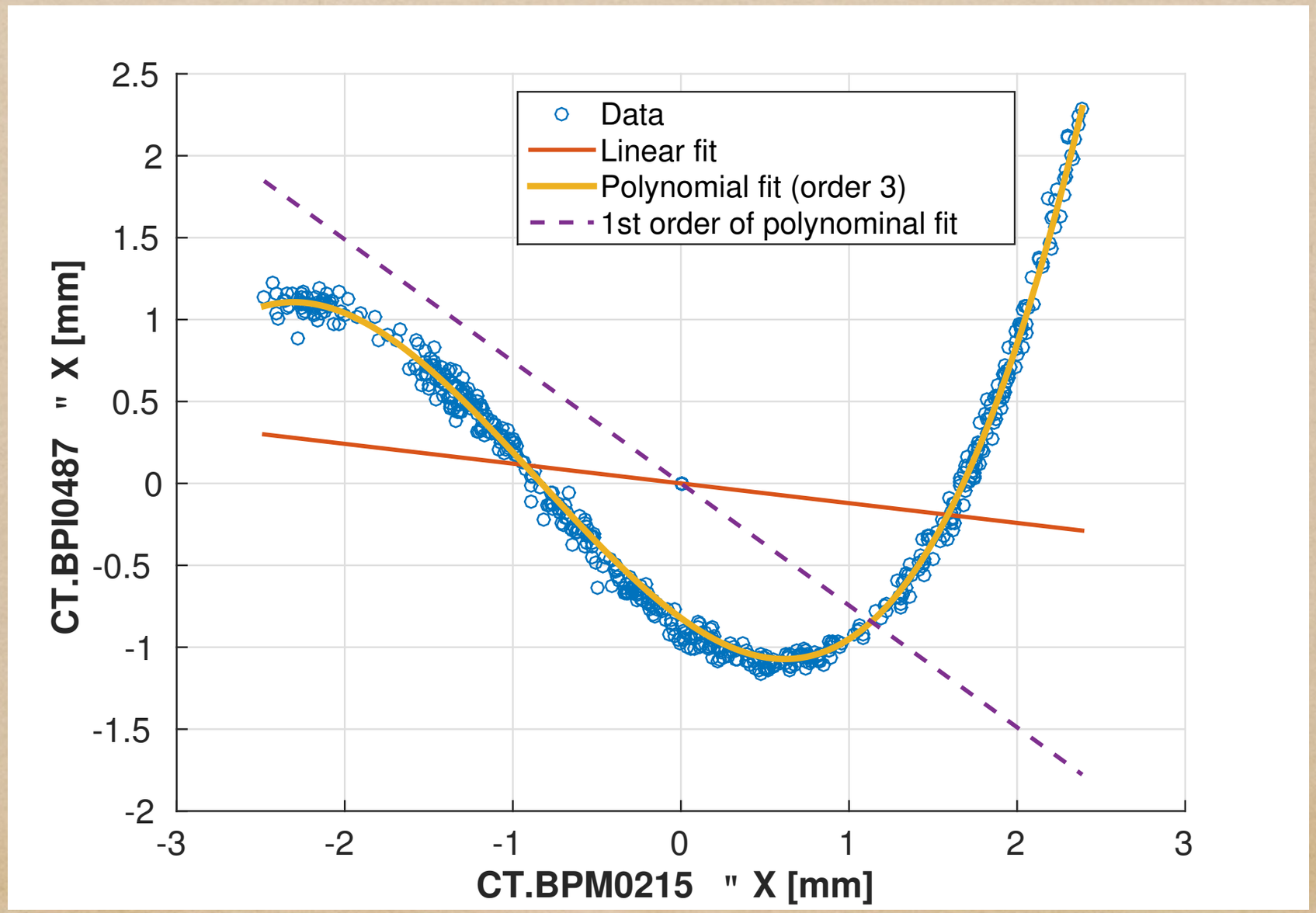
Dispersion control: future improvements

1. To **get rid of BPMs calibration** in Dispersion Target Steering, use the measurement of "nominal" dispersion computed by **scaling the main bending magnets**.
2. Instead of a linear fit, compute a **polynomial fit** and then take as measurement the derivative in zero (i.e. the first order coefficient).



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Work in progress: transverse optics control

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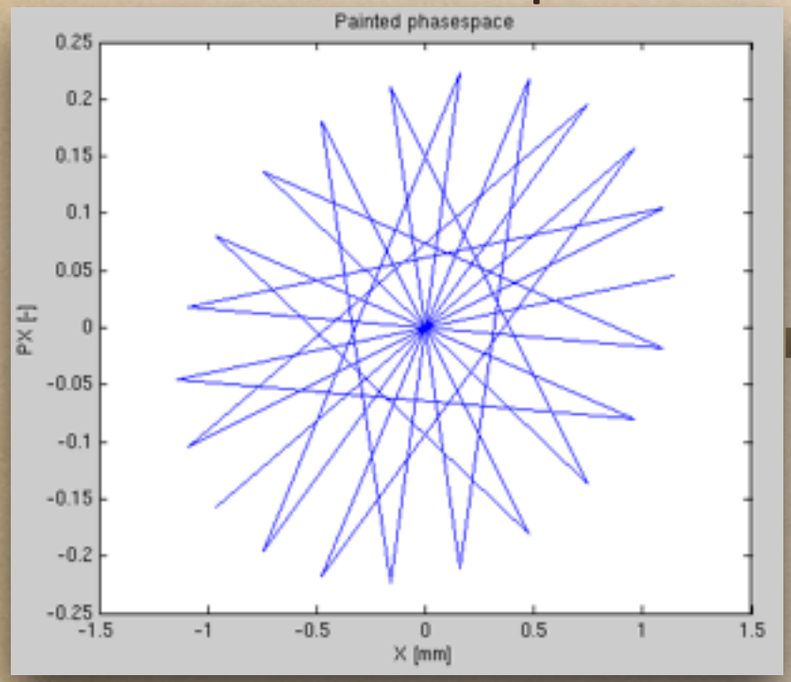
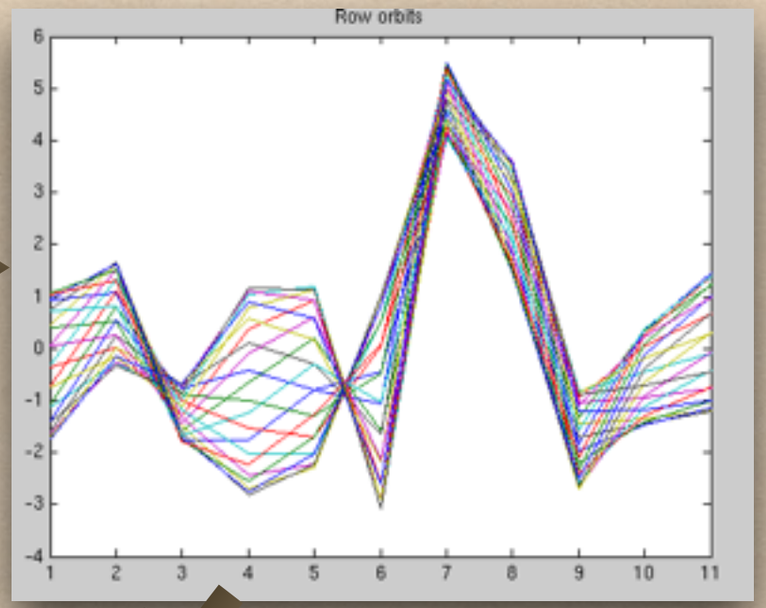
Phase Space Painting.

By P. Skowronski

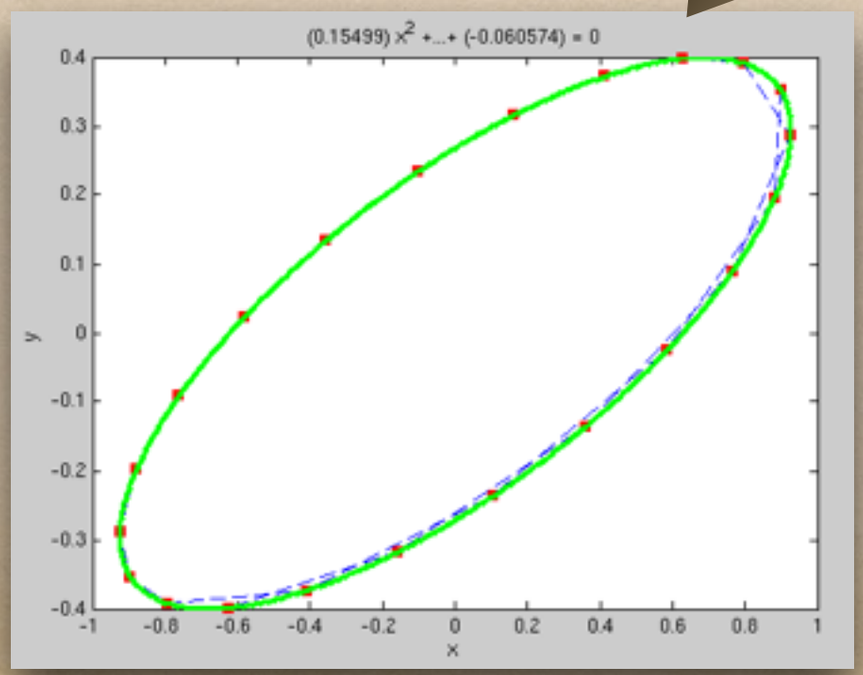
1. **Use two correctors to paint a reasonable phase space.**



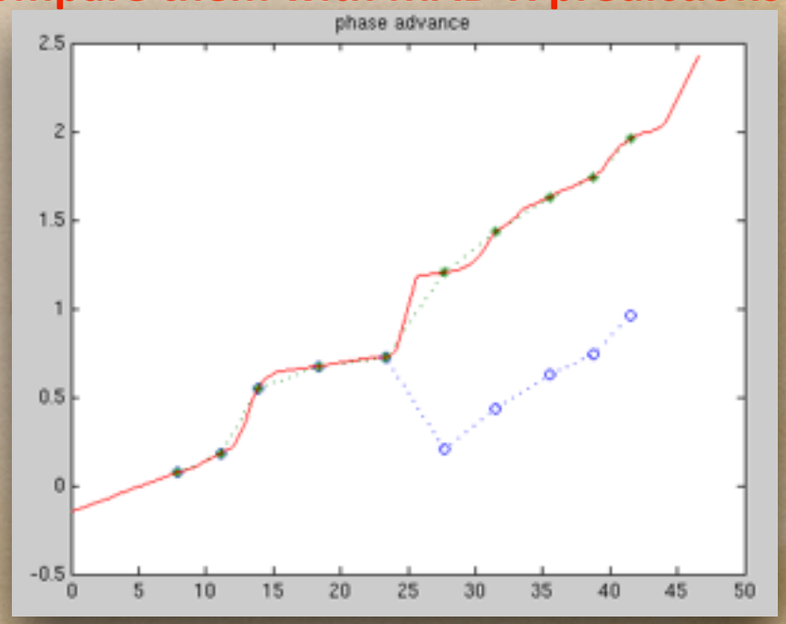


2. **Trace the orbit downstream.**

3. **Reconstruct the transformed phase space at each BPM location**



4. **Compute optics parameters and compare them with MAD-X predictions**



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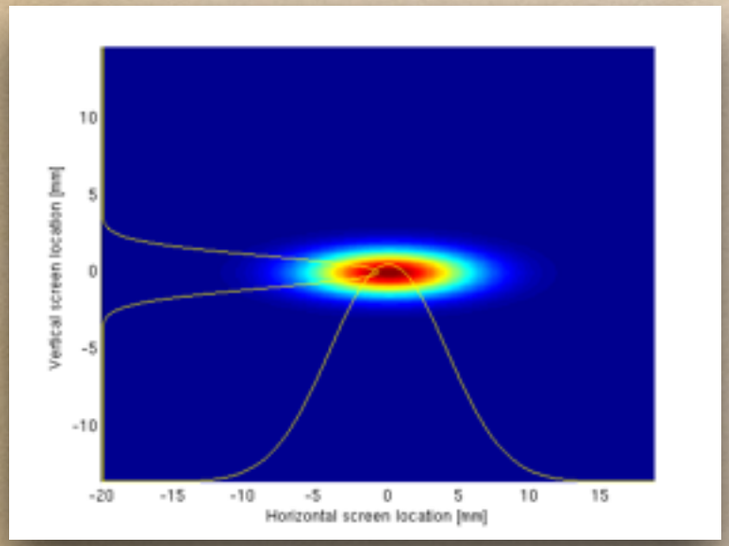
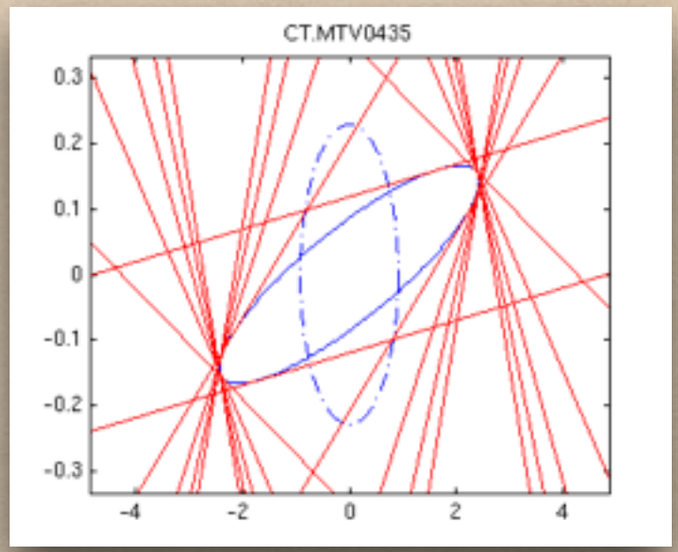
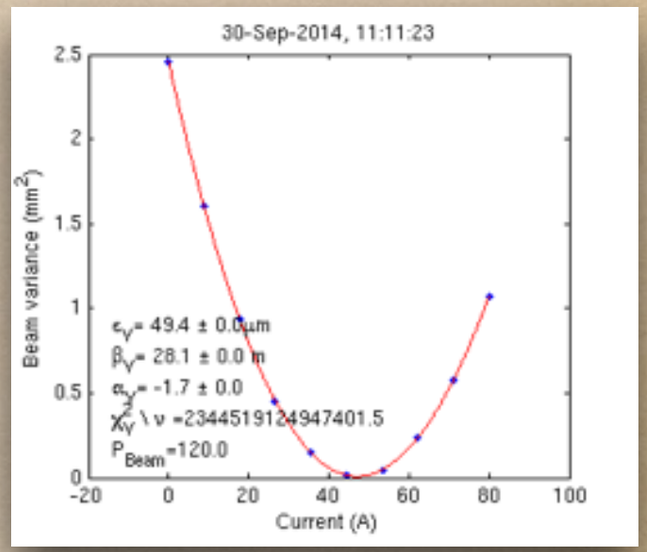
Quadscan: simulation mode

By R. L. Lillestøl

Quadscan are used for machine setup. Sometimes “strange” results suggested us to develop a simulation mode of our application to better investigate what happens.



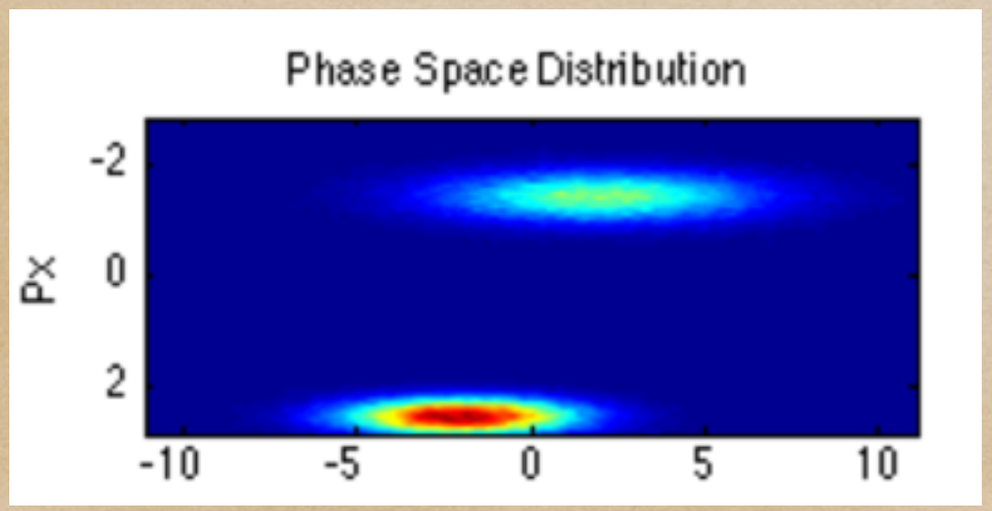


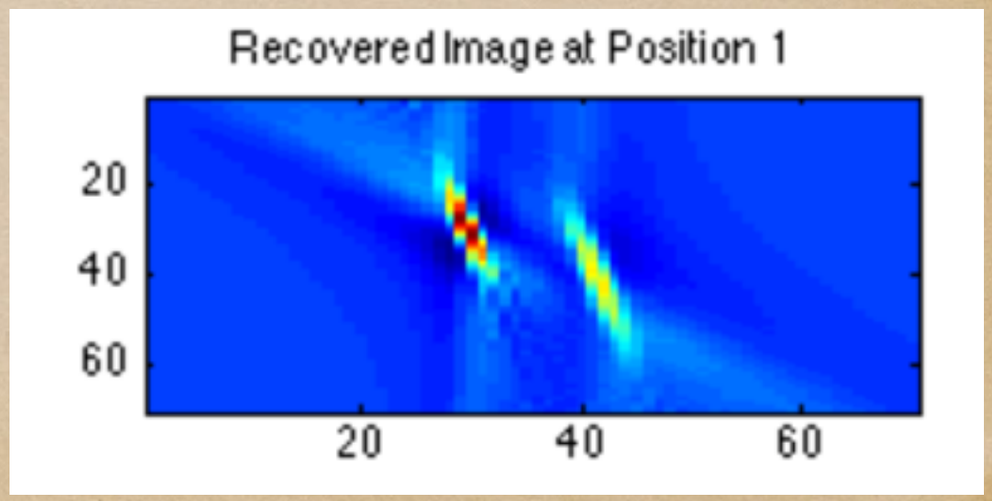


Quadscan: phase-space tomography

By A. Rollings

In a similar way to quadscan, we can reconstruct the phase-space using the quadscan projections and applying tomography algorithms. (**For the time being only at a proof of principle stage.)**





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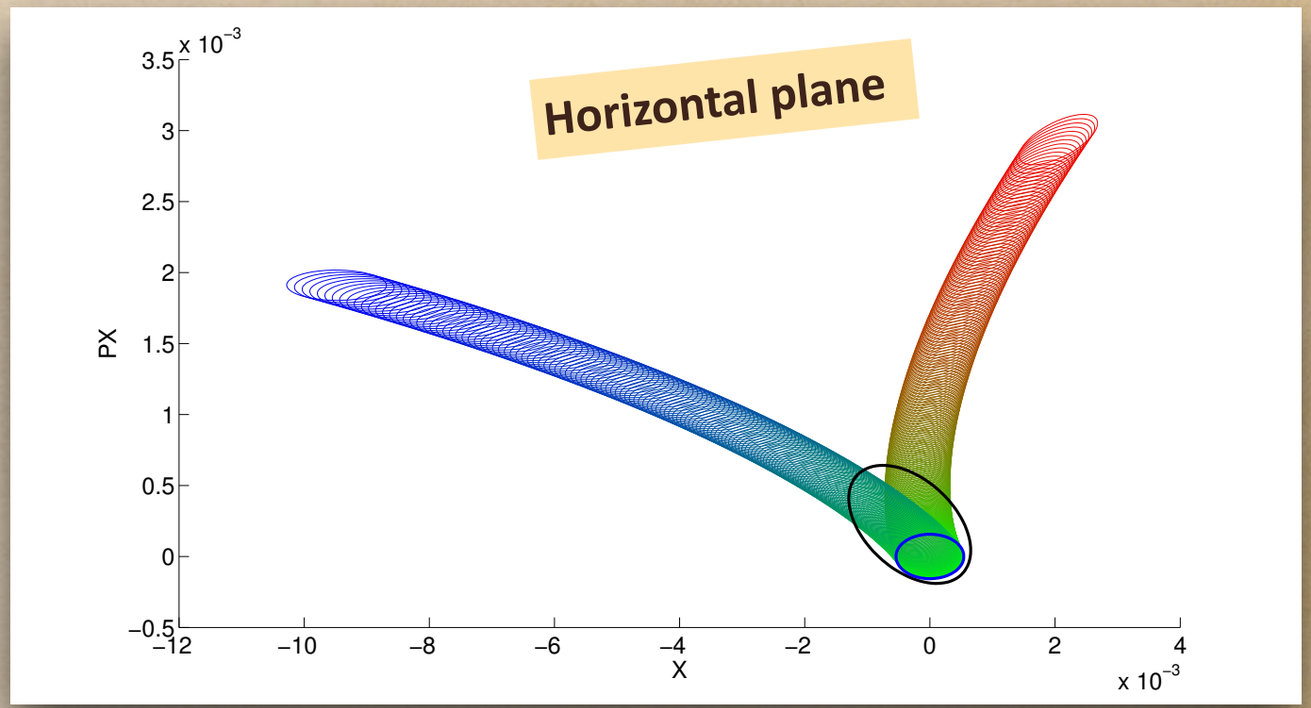
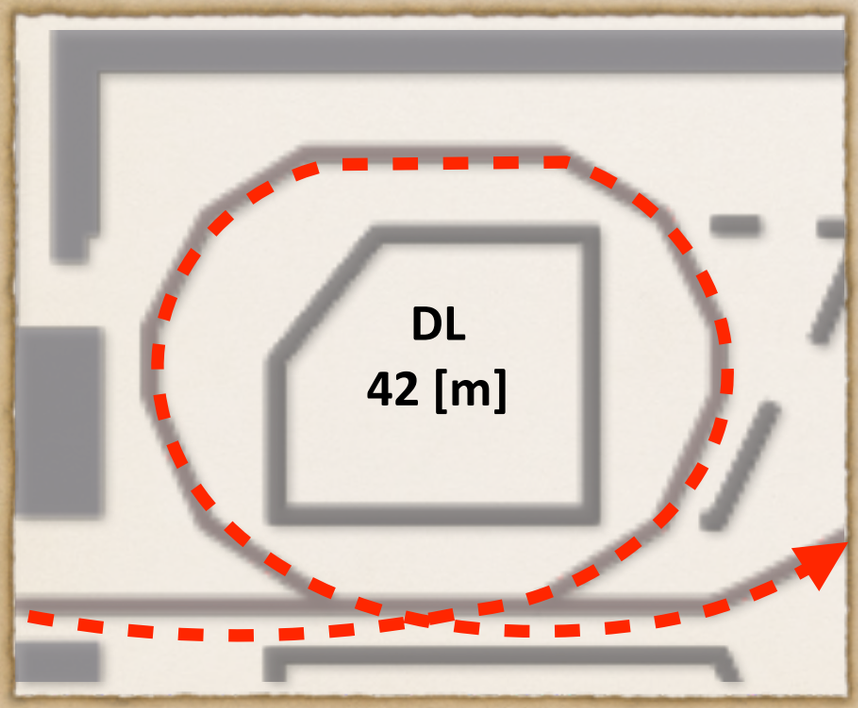
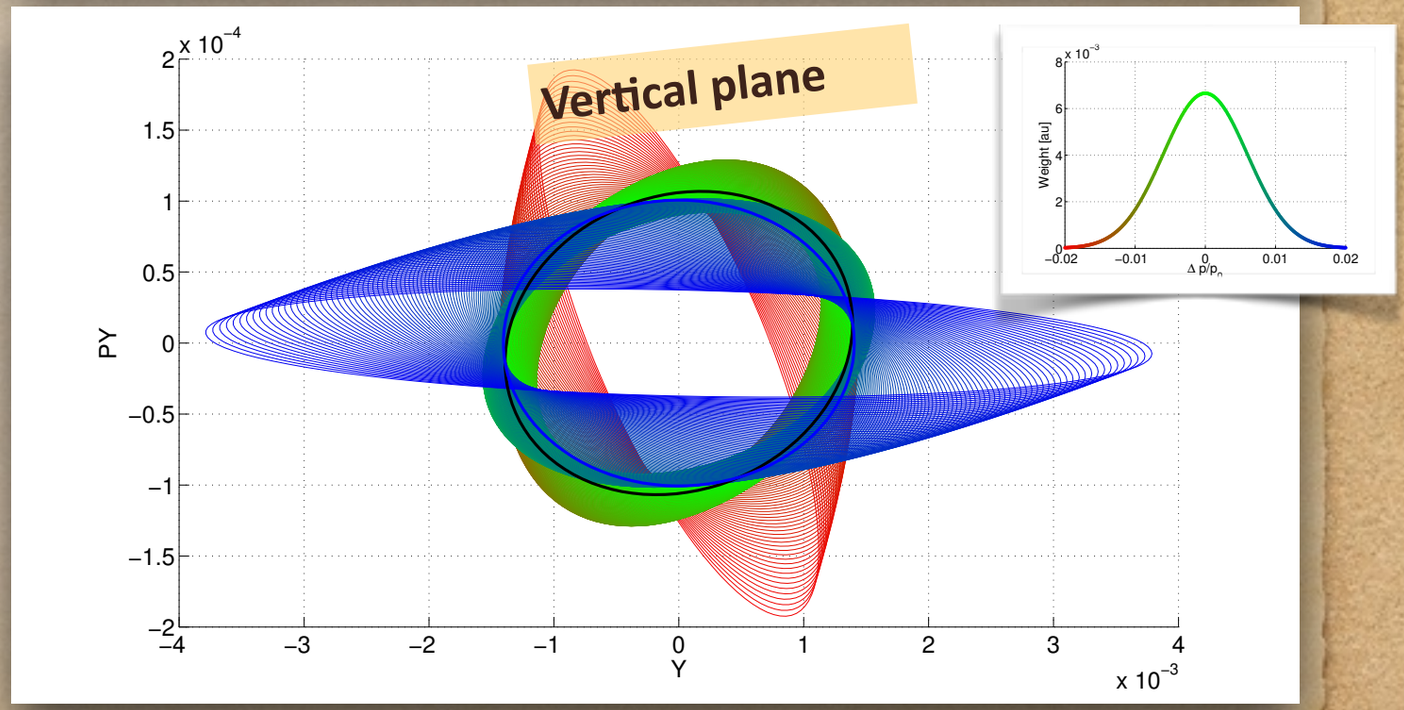
Emittance growth simulations with MAD-X

- One can simulate emittance growth due to non linear dispersion by means of phase-spaces propagation at different energies.
- Here some simulations for Delay Loop installed in CTF3.
  - Horizontal emittance growth > 100% after one single passage.







LCWS2014 - http://agenda.linearcollider.org/event/6389/session/10/contribution/111

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Summary

- We have an **advanced implementation of a slow feedback tool** that has been demonstrated over a wide range of corrections. *(here only discussed orbit and dispersion, but also energy, bunching, gun current,…)*
- **Orbit correction** is not an issue by itself, but:
  - Steering to "zero" orbit is normally not achievable: losses.
  - In some conditions (e.g. 1.5 GHz beam) the behaviour of some BPMs is unclear.
  - Interface not yet user-friendly enough for every-day use.
- **Dispersion measurement** tools is very useful; able to reveal interesting non-linearities.
- **Dispersion Free Steering** in the LINAC is "easy".
- **Dispersion Target Steering** is more complex:
  - **non-linearities** of dispersion comes in when trying to enhance energy jitter.
  - increasing **losses** downstream in the machine **make the measurement very unstable**.
- **Transverse beam optics** is in general under control, but:
  - Still some issues (e.g. TL2).
  - Emittance measurements shows unphysical increase/decrease.
  - Under study/implementation new tools to better diagnose optics issues along the different lines:
    - **Quadscan simulations.**
    - **Phase-Space tomography.**
    - **Phase-Space painting and reconstruction.**
    - **Emittance growth simulations.**
    - **…**

Thank you for your attention

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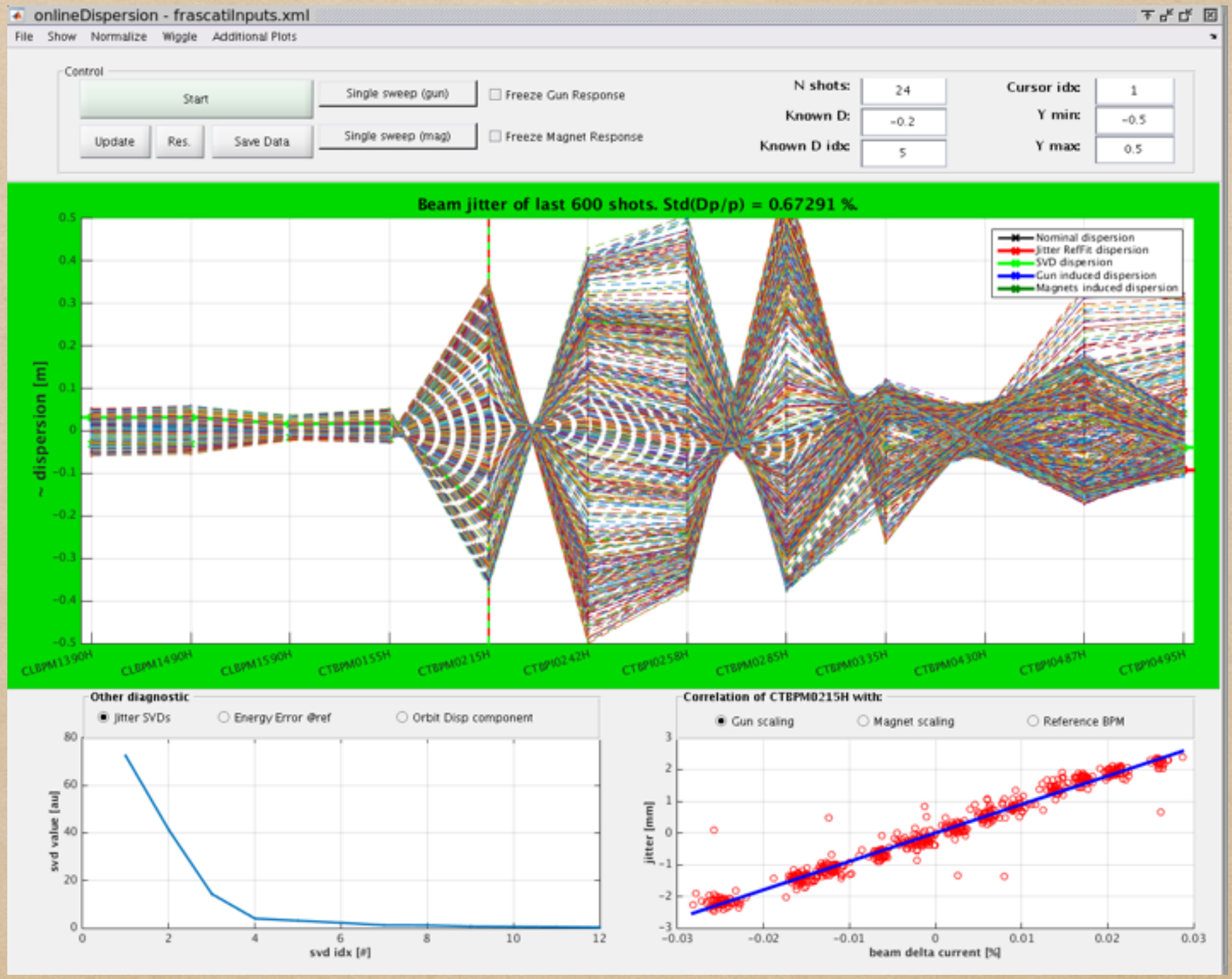
Dispersion: is BPM215 linearly respond to gun current?



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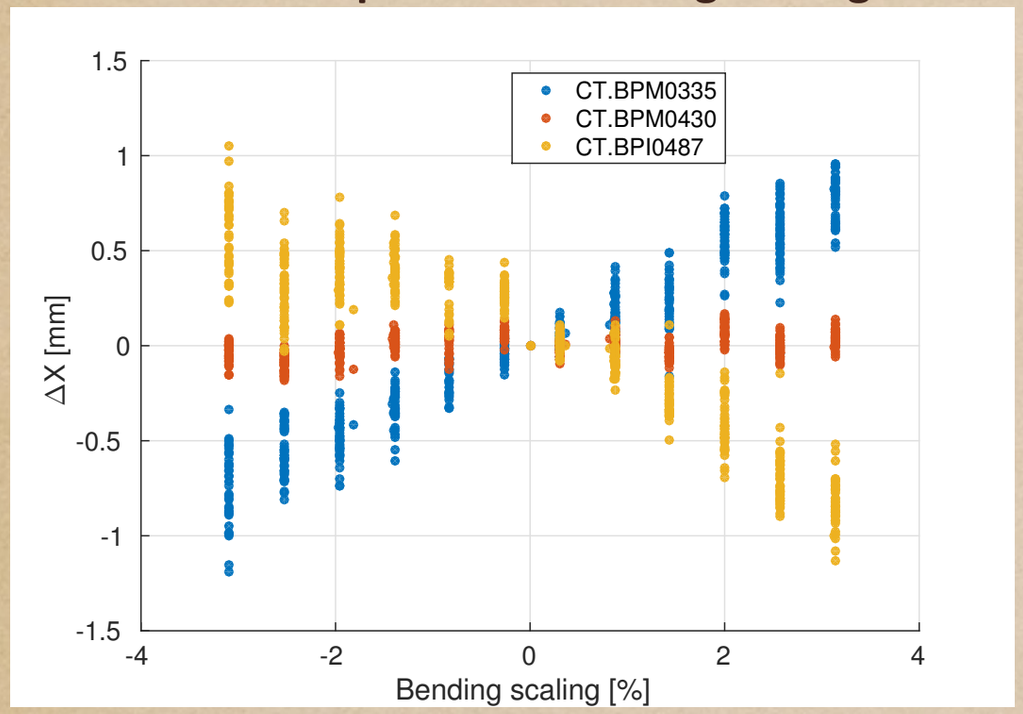
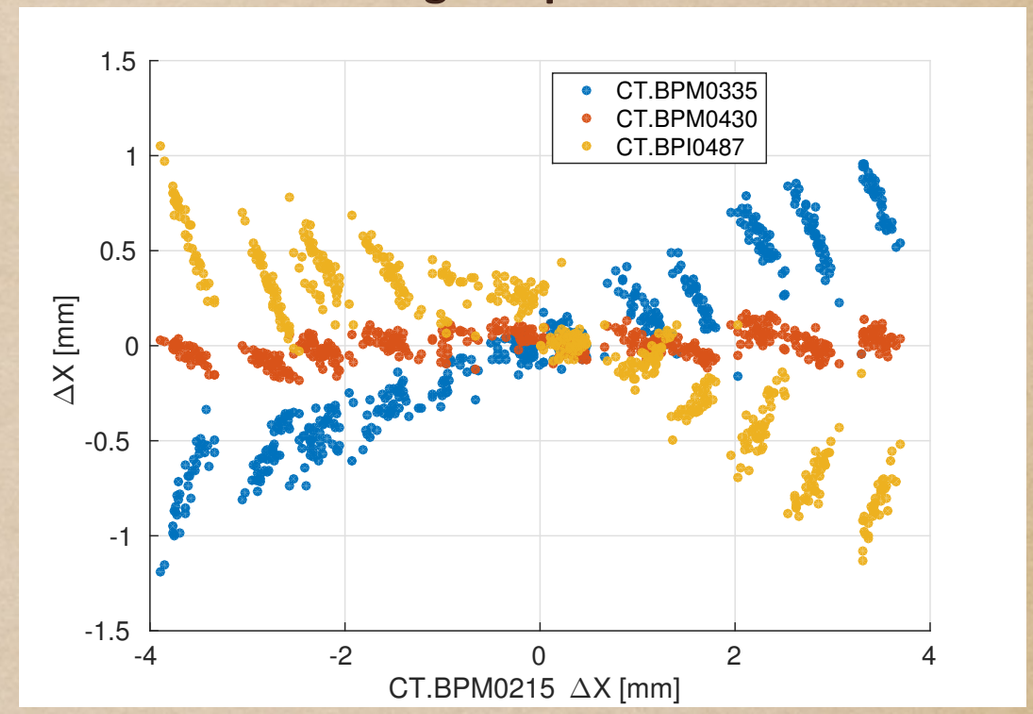
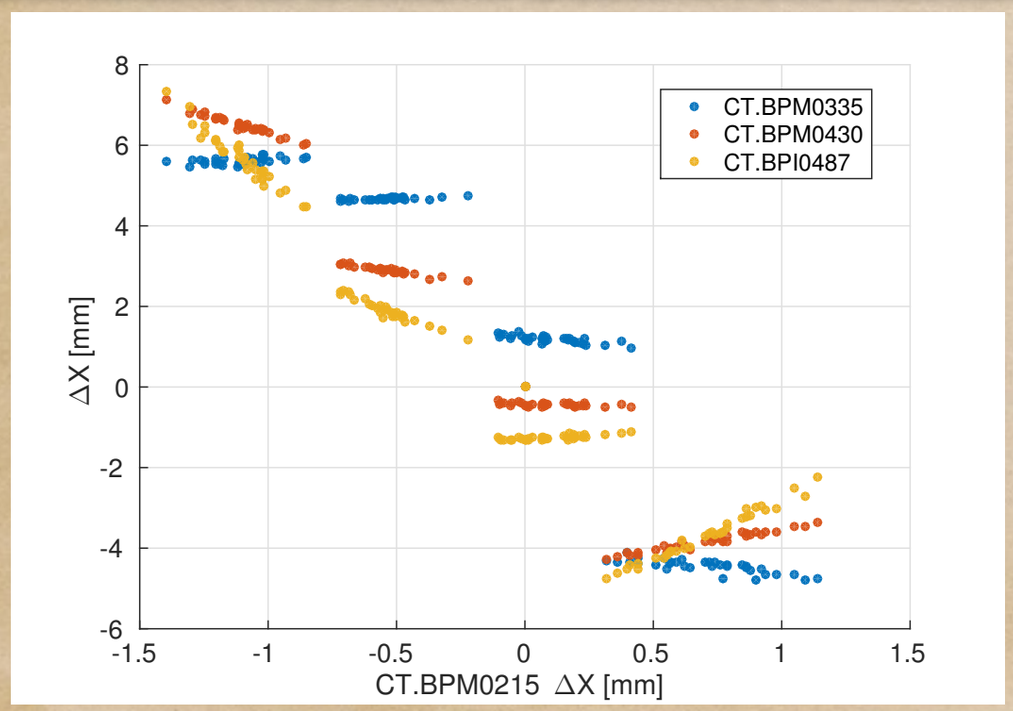
Dispersion: check that everything works…

- **Is the orbit response to bending scaling linear?**



- **Does it also change dispersion?**





- **Does a corrector change dispersion?**
  - **each subset of points differ from each other only by a different corrector strength at the beginning of frascati chicane.**
  - **To be noticed the different slope of correlation with first dispersive BPM in frascati chicane. Position jitter is due to natural energy jitter acquired along the linac.**

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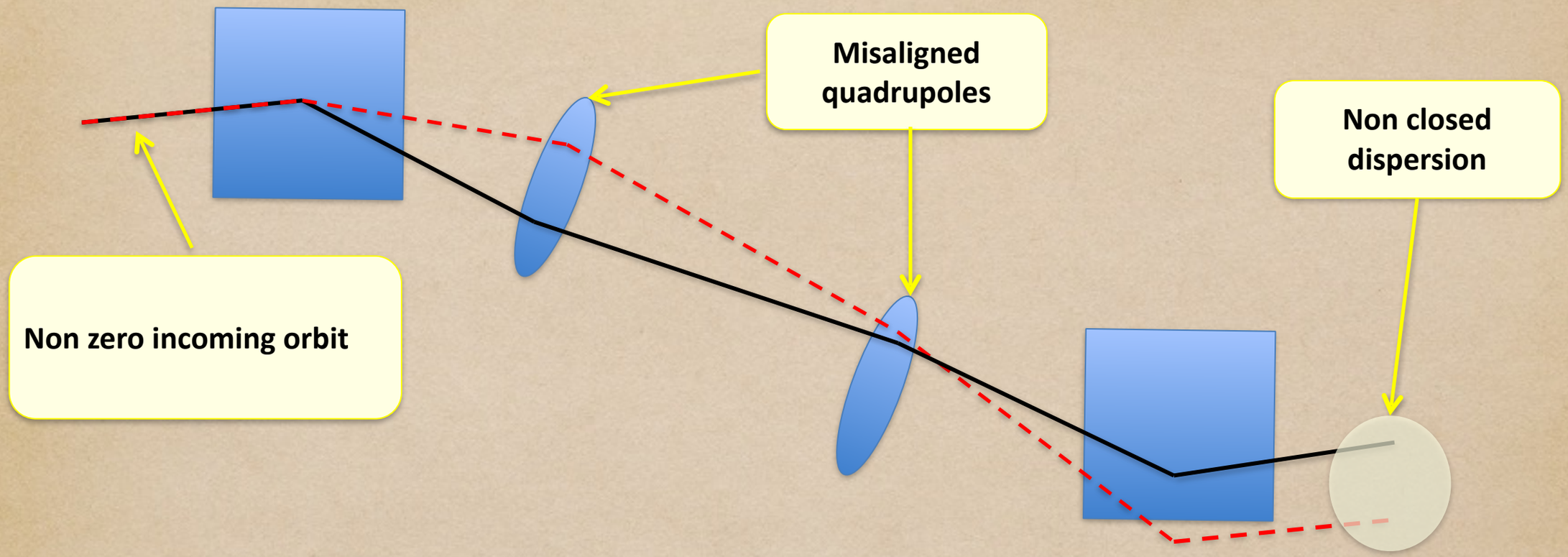
Linear dispersion: some order of magnitude



- A bending magnet (at CTF3) **typically** bends the beam of $\alpha_0 = \pi/10 = 0.314$ [rad].
  - After 1 [m] it generate a dispersion of 0.314 [m].
  - A **bending error of 1%** would generate a 0.00314[m] dispersion error.
- An **energy error of 1%** would mean to add a kick of ~ **π/1.000 [rad] = 0.00314 [rad]**.
  - Dispersive quadrupoles has to "respond" with kicks of the same order of magnitude.
- **Correctors** (when in use) kick the beam of similar order of magnitude (~ **π/1.000 [rad]**).

$$\alpha \approx \alpha_0 \left(1 - \Delta p / p_0\right)$$

Misalignments and correctors generate dispersion of the order ~ π/1.000 [m] after 1 [m].

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