
CERN

LHC BPM calibration, offsets and new LSA parameters

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LHC BPM electronics response

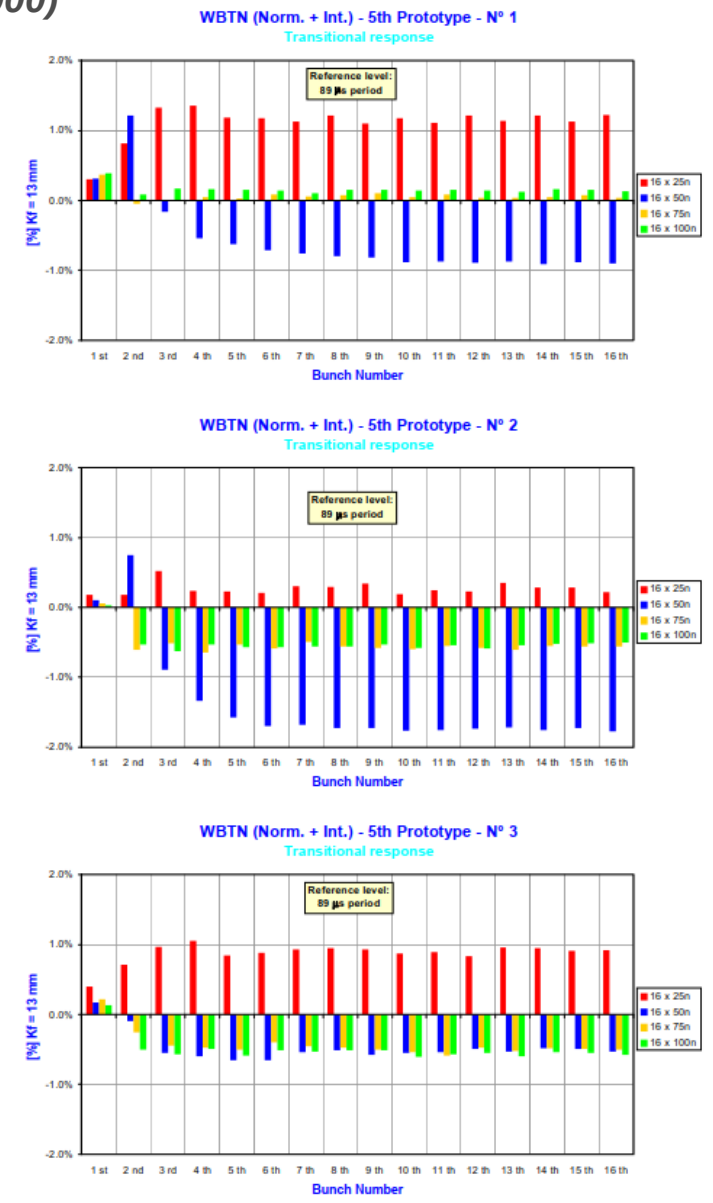
For an incoming train of bunches, the **response of the BPM electronics** (WB Time Normalizer + integrator) depends on the **bunch separation** and the **bunch position in the train.**

- Systematic error of up to ~0.25 mm, in general ~0.1 mm.
- Spread from one channel to another (see later).

Ideally the BPM calibration should take care of the error, but the available **calibration pulse trains** do **not match perfectly** our current filling schemes.

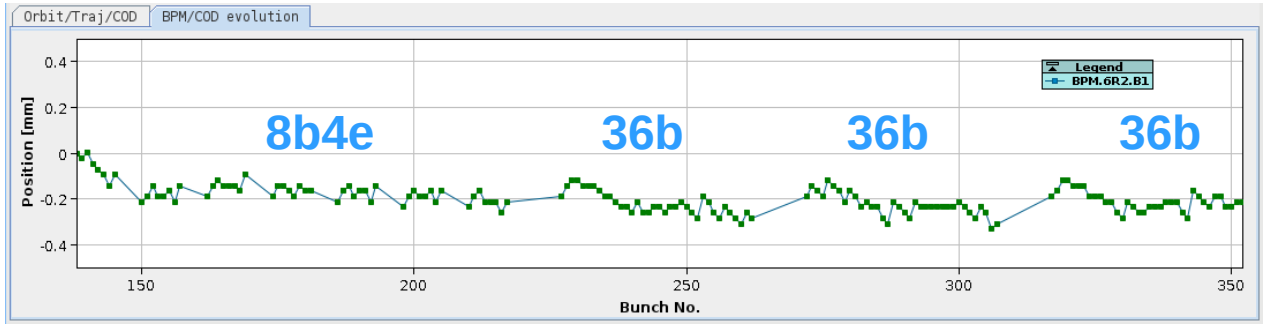
- **It is not possible to calibrate the BPM with a pulse sequence that mimics the actual filling scheme**: calibration patterns are hardcoded in an integrated circuit in the tunnel.
- Closest calibration type mimics a trains of 72 bunches.
- Calibration procedure works well for isolated bunches.

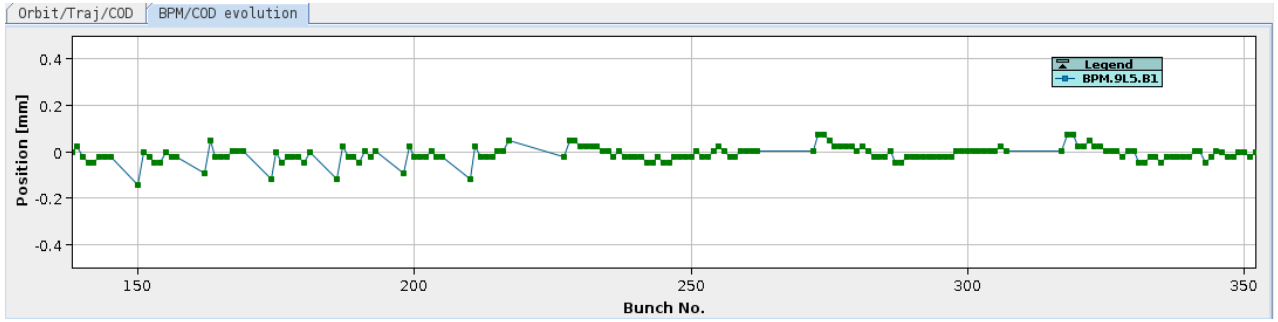
Example of responses of prototypes (around 2000)

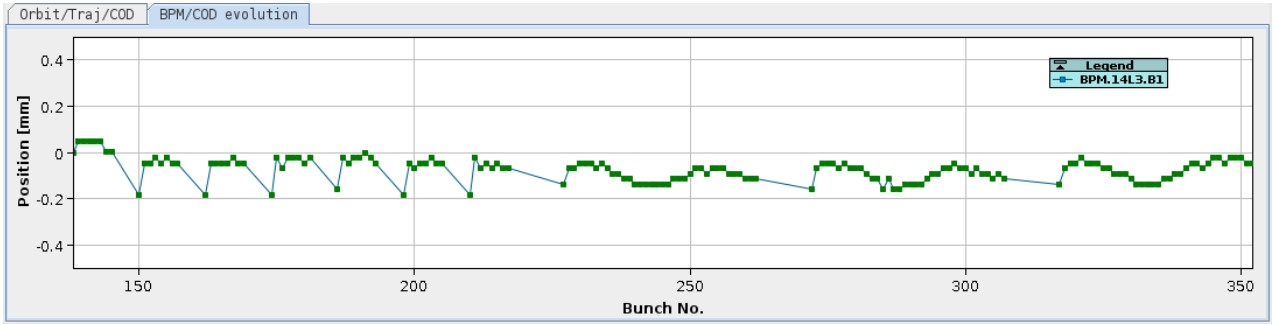


Example of responses

- Measurement of the response at injection for a mixed filling scheme 8b4e + n x 36b.





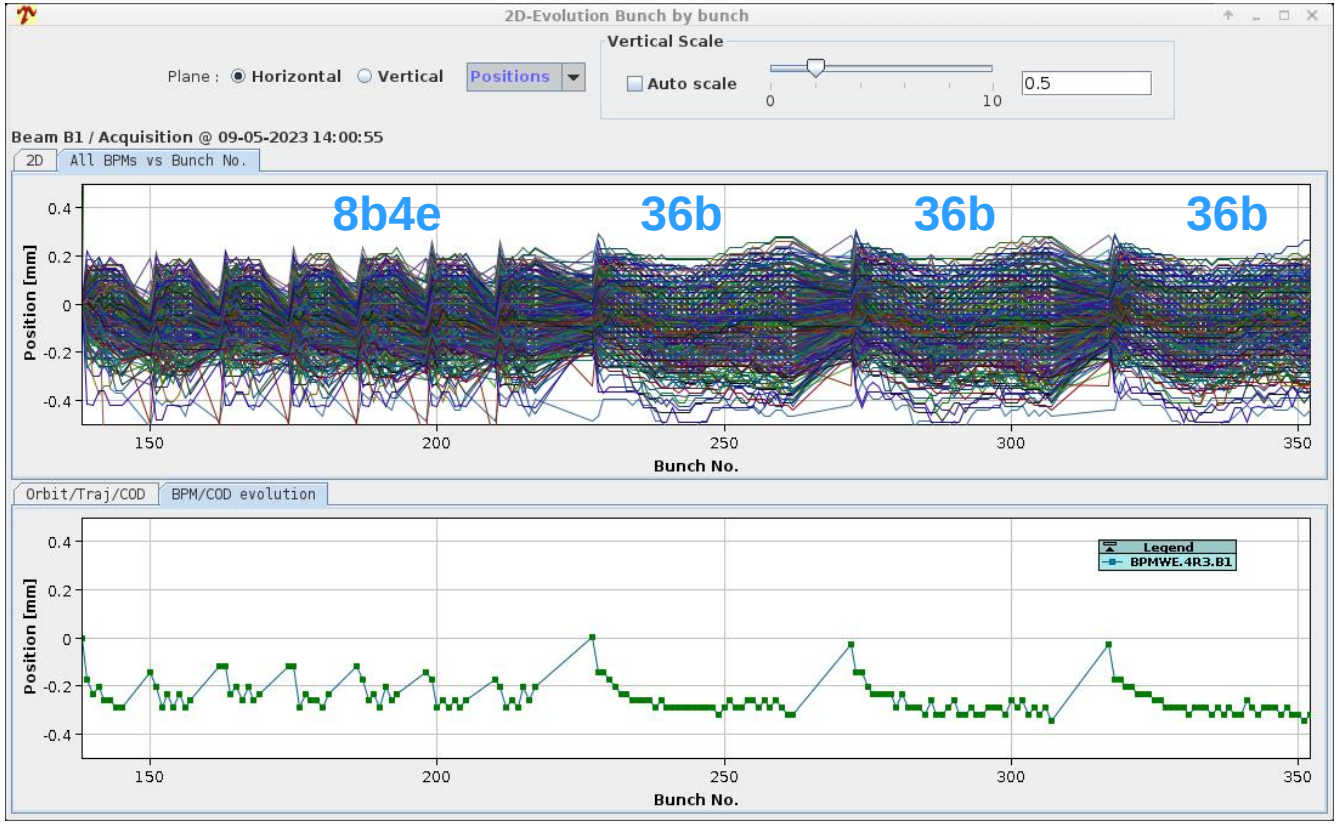


Bunch response examples for 3 BPM planes, 8b4e and 36b trains

Example of responses (2)

Measurement of the response as a function of bunch for a mixed filling scheme 8b4e + n x 36b.

- Response of most channels within ± 0.2 mm.

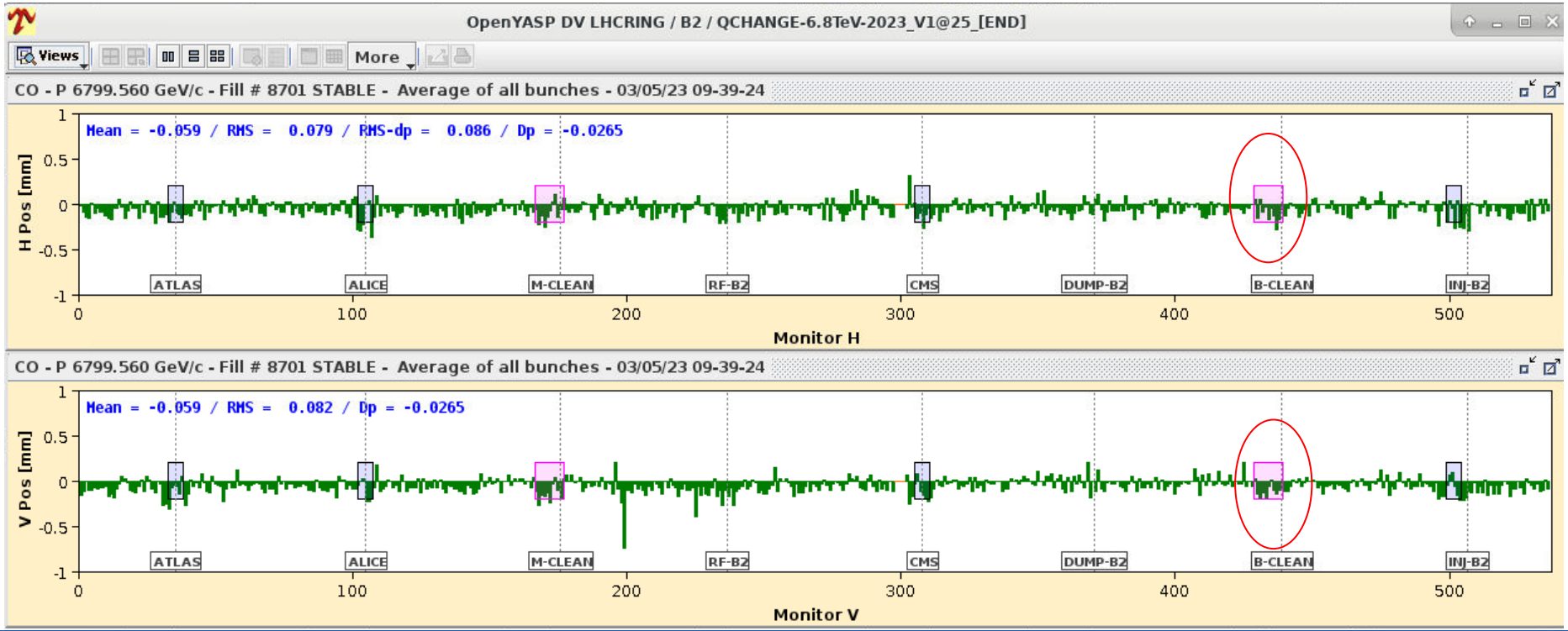


Bunch responses for all B1 horizontal BPM channels, 8b4e and 36b trains

Global orbit shifts due to response

Example for beam 2: orbit reading difference for a mixed train wrt a single bunch due to the BPM electronics response (without compensation by calibration).

- Shown here: **orbit for mixed train – orbit indiv (= orbit of first bunch in train)**.
- **Mean shift ~60 microns, rms of ~80 microns**.
- Important to compensate this shift with the calibration, else the **resulting systematic orbit shift will be 'corrected' by the orbit FB** (in H: adjust RF frequency, corrected residual – in V: bump orbit up, correct residuals.



BPM calibration procedure

Before every injection phase, the BPMs are **calibrated** with **a sequencer task**.

- Calibration types for **low sensitivity**: **single bunch**, **72b train**, 40 MHz (continuous train), 50 ns.
- For the **high sensitivity** setting (probe bunches, ions) **the calibration is always 40 MHz**.
  - The issue of the calibration failures for other type is understood – issue with signal reflections. Work in progress OP-BI.

The results of the calibration are sent to the BPM FECs and stored in LSA (with full history).

When the BPMs are switched between high and low sensitivity during filling, **tunnel HW and FEC settings** must be **updated independently**.

- There is currently no communication between FEC and tunnel HW.

To switch between calibrations, the FECs must be informed about the sensitivity of the tunnel HW and must be switched between high and low sensitivity (FESA class setting).

Calibration procedure (2)

During the LS2 software renovation, the **update of the FEC settings was accidentally suppressed: since LS2 the FECs have always operated in high sensitivity → calibration of probe bunches is applied to all beams.**

This means that since LS2 we have set up the machine with **nominal bunches** using the **40 MHz probe calibration**.

- **RMS error due to the calibration is ~0.1 mm**, small compared to the **residual flat orbit RMS of ~0.3 mm**.
- Not clean, but no impact on machine aperture.

Whenever trains are (were) injected, **the calibration is (was) never switched to 72b train** (low sensitivity) the orbit shift presented previously is therefore present in every fill since LS2.

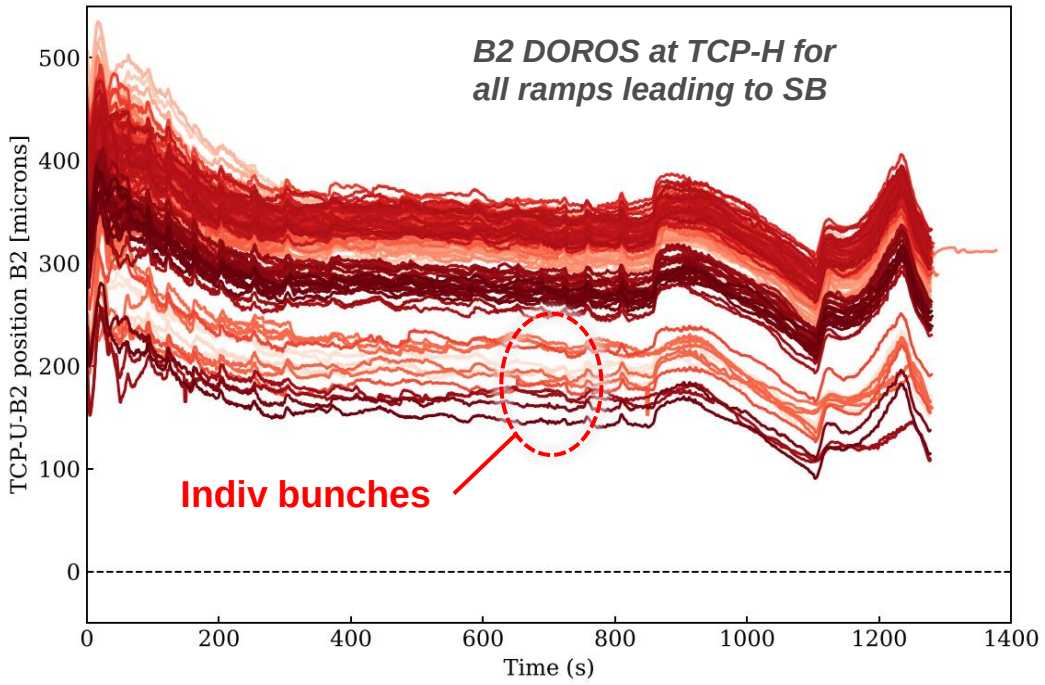
- Even if 72b train calibration is not 'ideal', it would have mitigated the shift.
- Explains **the shifts observed with DOROS BPMs at the collimators** equipped with BPMs: the orbit FB was compensating the BPM response effect.

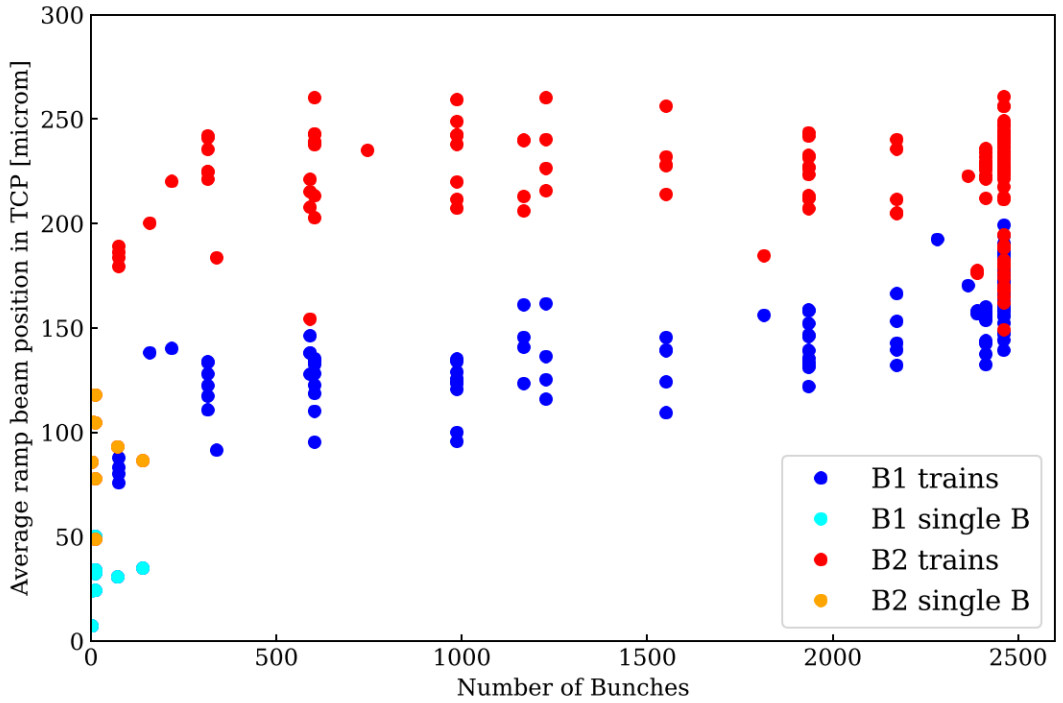
Shift at DOROS BPM on collimators

The DOROS BPMs are not affected by the systematic effects, they are good **witnesses** for the effect.

See LBOC presentation on orbit in the ramp (Jan 2023) and presentations by B. Lindstrom (CollWG).

- Orbit shift at TCPs with trains: **+100-150 microns**. Sign is consistent with the shift on slide 6 (orbit is shifted down → feedback is pushing up/out → positive orbit shift).





Offset correction – current situation

Two fields are available in the OFB FESA class to set **BPM offsets and scale calibration factors**.

- **Offsets are used for the Q1/Q2 K-modulation offsets.**
- Calibration are all = 1.
- Settings of those fields are already in LSA.

OP concept to be able to apply beam type dependent corrections is to use the same parameter/fields but build a **hierarchy above those parameters** to **inject beam dependent offsets**.

- Bias the base orbit to compensate missing/imperfect calibrations.
- Can be useful even after restoring more appropriate calibrations.

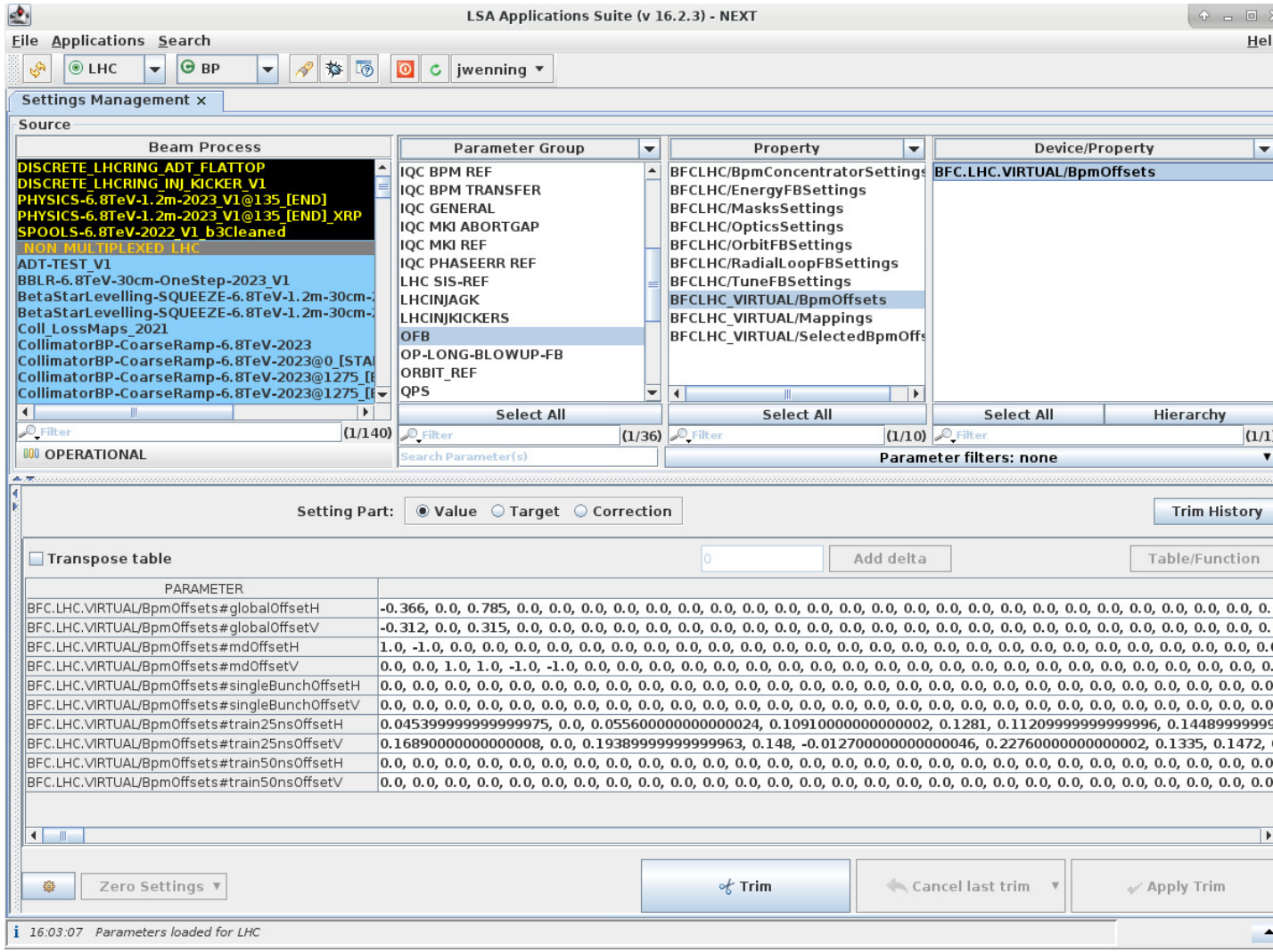
LSA parameter for offset correction

A set of parameters have been prepared to stored corrective offsets for different use cases / beam types.

5 pre-defined categories:

- **Global** : for static (k-modulation offsets),
  - Already used in OFB.
  - Always added to the other types.
- **Single Bunch**
- **25 ns**
- **50 ns**
- **MD**

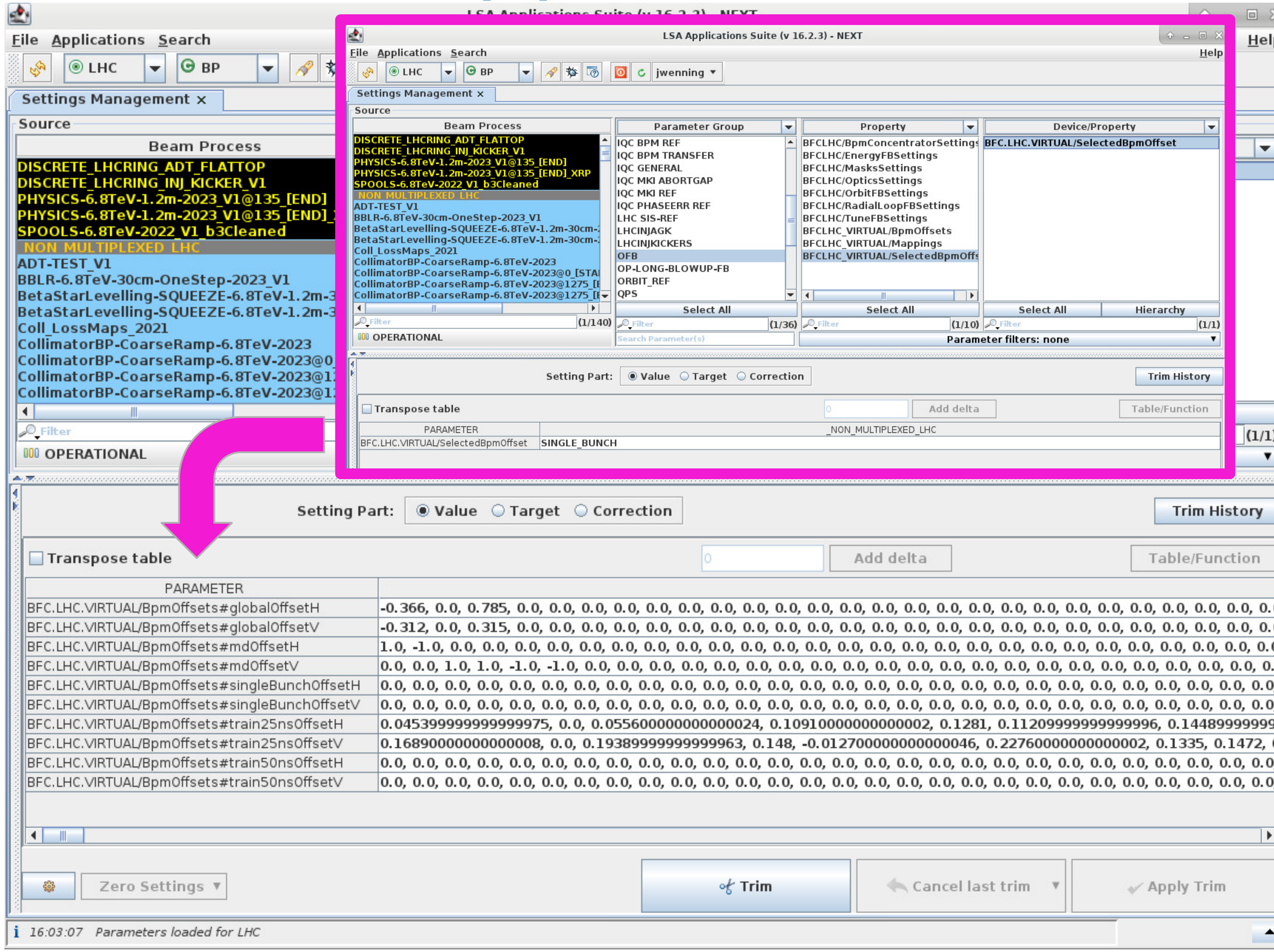
Parameters will be made critical to avoid mishaps.



LSA parameter for offset correction (2)

A **separate parameter** is used to **select** which use case to apply at a given time.

- Triggers a re-calculation of the **total offset = Global + selection → applied to the OFB offset field**.
- Very similar to selecting a BPM calibration type.

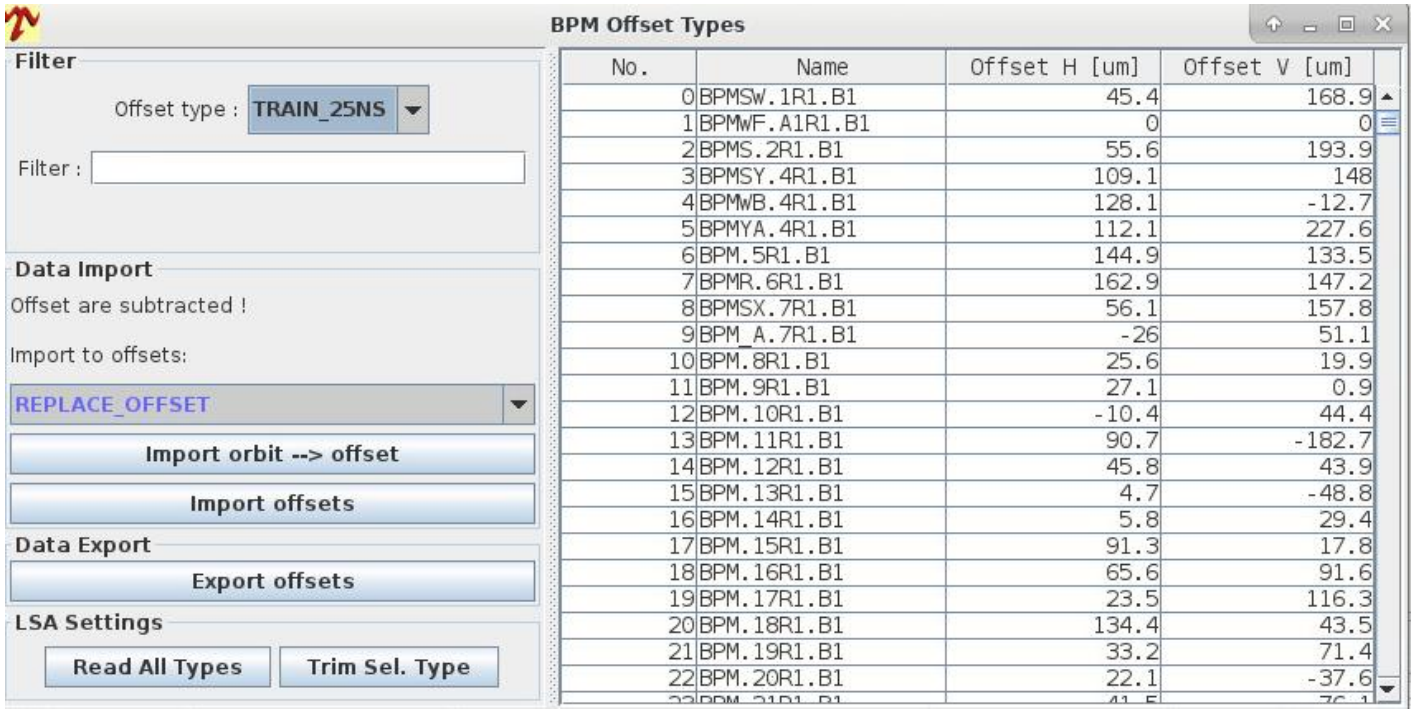


LSA parameter for offset correction (3)

Special YASP panel to read, display, trim, import offsets etc.

Editing offsets is/will remain an **expert action**.

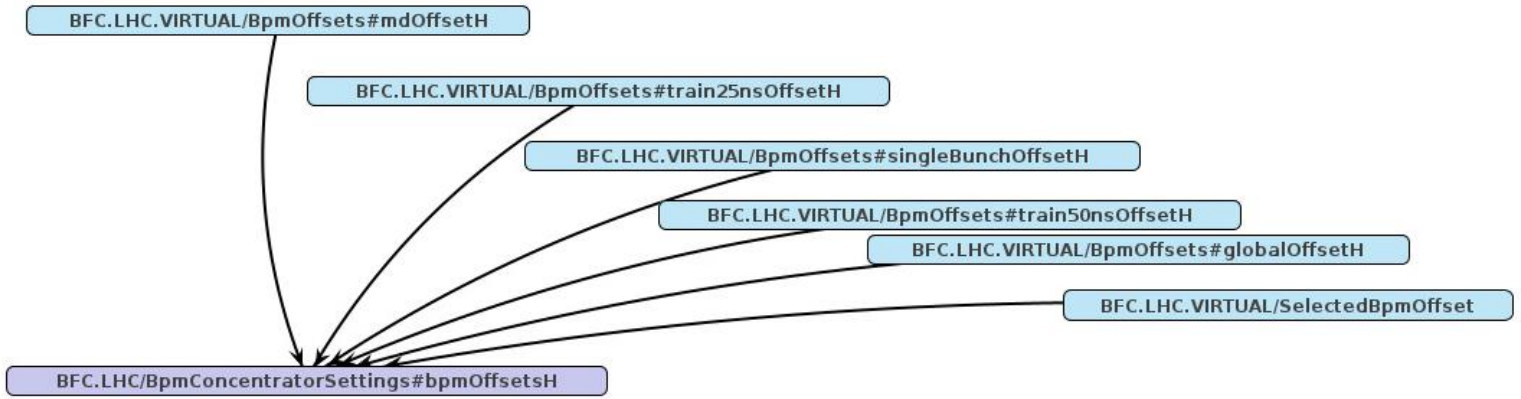
Work in progress…



LSA parameter status

Parameters and make rules
deployed in LSA NEXT and PRO.

YASP interface **tested in NEXT**.



Next steps:

- **Test offsets at injection** with single bunch versus trains, verify DOROS readings on TCPs.
- **Perform a test ramp** with one train 8b4e + n(=3,4,5)x36b, verify DOROS readings on TCPs.

Deploy corrections after TS1.

- **As long as all offset type parameters except global = 0 → no difference to what we have now !**

Summary and outlook

BI will modify the FEC software to ensure that the **FECs switch automatically** to the correct sensitivity without need of an external synchronization.

- Easiest to implement during YETS 23-34 to provide adequate time for testing.

To ensure that we remain in the same situation and that we do not accidentally apply the correct calibration, a **software interlock** was added to check that all **FECs are in high sensitivity at injection**.

- Temporary until we restore a correct sensitivity switching.

The **orbit shift** due to the BPM response and non-application of the correct calibration can be **corrected** by **biasing the reference orbit for trains** with the measured difference (slide 6).

- See previous slides.
- The parameter change is deployed, we currently operate without beam type offsets (= status quo).
- To be **usable after TS1**, we should perform **tests asap**. We should use it during the ramp up if we decide to go ahead.