
CERN

TI2/8 momenta adjustment - proposal

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Energy matching SPS-LHC

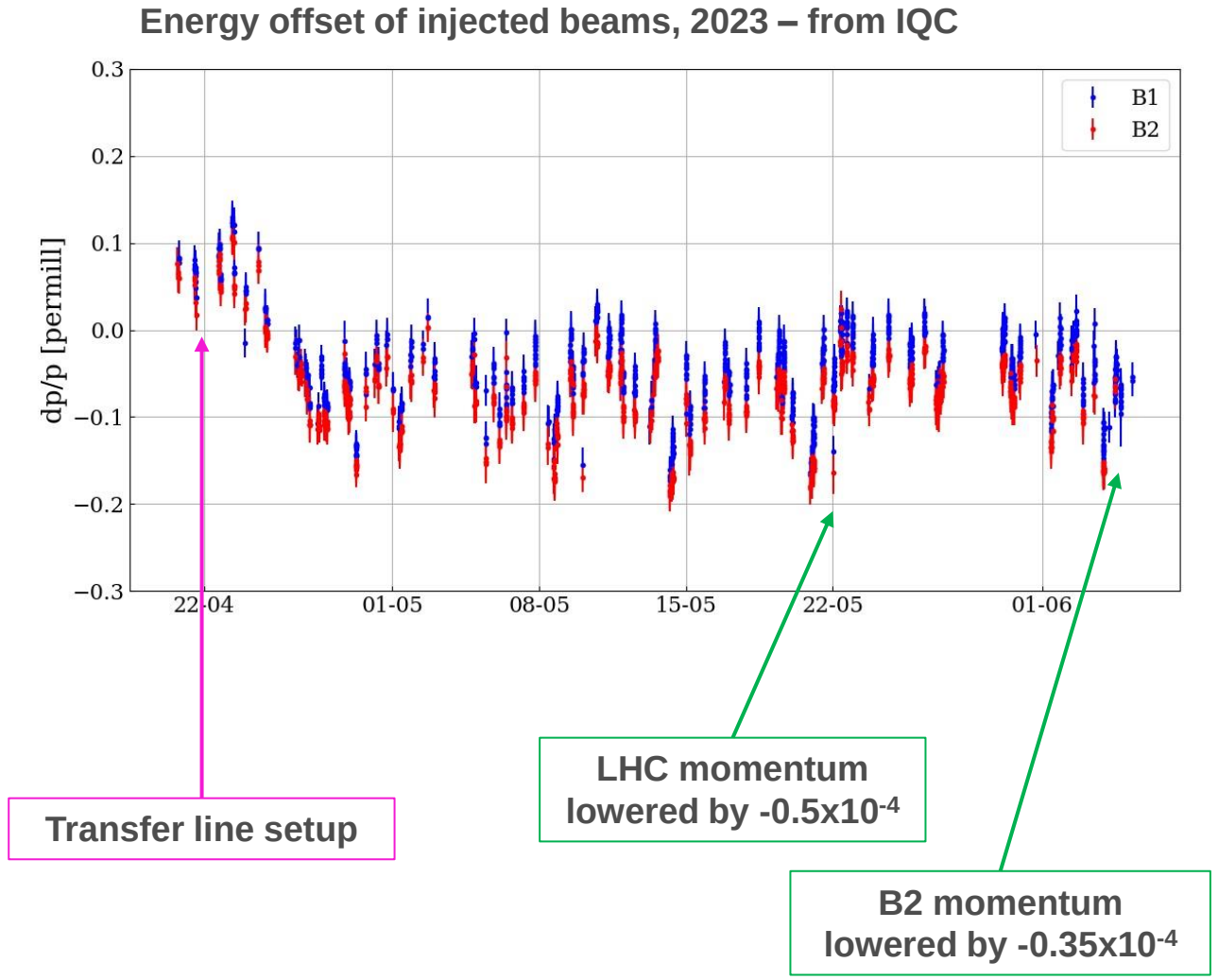
The energy offset of the SPS beams injected into the LHC is fluctuating over time during a run in a band of **dp/p = ± 2x10^{-4}**.

- Over 24 hours, the range is generally ± 0.5x10^{-4}.
- There is more and more evidence that the changes are **driven by the SPS**, even if small contributions from the LHC cannot be excluded.
- **B1 and B2 changes are always correlated**.

The offset is adapted periodically by adjusting the **LHC momentum using the hor. orbit correctors**.

- Easiest way…

Since the TI2/8 lines were set up in 2023, the relative momentum has dropped by ~ **–2x10^{-4}**



Small interlude on SPS and LHC momenta

Ingredients to the beam energy

The beam energies of SPS and LHC are defined by:

- The **main dipole field**,
- The **radial position of the orbit** (→ RF frequency) through the momentum compaction factor.

$$\frac{\delta p}{p} = \frac{1}{\alpha}\frac{\Delta R}{R} = \frac{-1}{\alpha}\frac{\Delta f_{RF}}{f_{RF}} \qquad \alpha_{sps} \approx 5\alpha_{LHC}$$

Due to the **requirement of synchronization** for SPS to LHC transfer the **SPS RF frequency is locked** at extraction to the LHC RF frequency:

$$f_{\mathrm{RFsps}} = f_{RFlhc}/2$$

LHC dipole field

The momentum of the LHC was **calibrated using p-Pb beams** taking advantage of the “large” RF frequency difference (difference in speed). We are slightly above 450 GeV:

$$P_{\mathrm{inj}} = 450.31 \pm 0.01(\mathrm{stat}) \pm 0.07(\mathrm{syst})\ \mathrm{GeV}/c.$$

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 081003 (2017)

Large Hadron Collider momentum calibration and accuracy

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(Received 1 March 2017; published 21 August 2017)

At injection there is **decay of the random b1 errors** (~1 unit = 1E-4 → closed orbit distortion), but the **systematic b1** (shift of momentum) is expected to be very small.

- Tested at injection during Run 1, with multiple injections spread over time for decay observation (assuming SPS more stable than LHC !!!) – no measurable decay observed.

Fill to fill changes of the dipole field would manifest by a **coherent shift of all tunes** (B1 & B2, H & V) in the same direction.

- Such fills exist, but no correlation with dp/p offsets of injection (2018 OP & RF study).

Changes of the LHC dipole field are not “visible” in TI2/8 since the SPS beam is not affected !

SPS dipole field

The momentum of the SPS was **calibrated using p-Pb and In beams** taking advantage of the “large” RF frequency difference (difference in speed). The real SPS momentum is lower than the setting:

Parameter	Value
Proton momentum P (GeV/c)	449.155 ± 0.136
Reference field B (T)	2.0251 ± 0.0002
Central orbit length C (m)	6911.5662 ± 0.0024

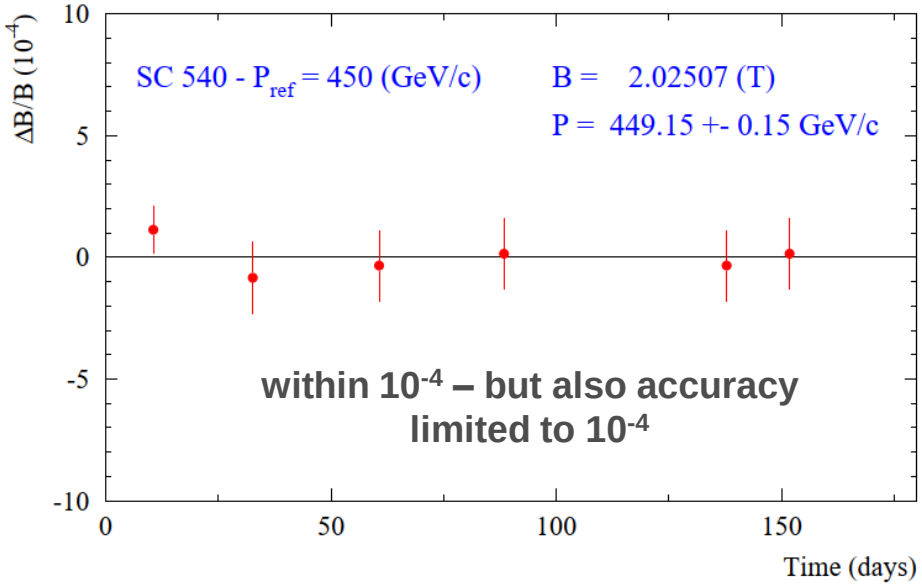
AB-Note-2003-014 OP

for setting = 450 GeV

AB-Note-2003-091 OP

Due to those “errors”, the **SPS momentum LSA setting at FT is 451.15 GeV for LHC cycles**.

SPS stability – 2003 (ref magnet NMR)



LHC circumference changes

LHC circumference changes are mainly driven by **periodic tides** and **“slow” circumference changes**.

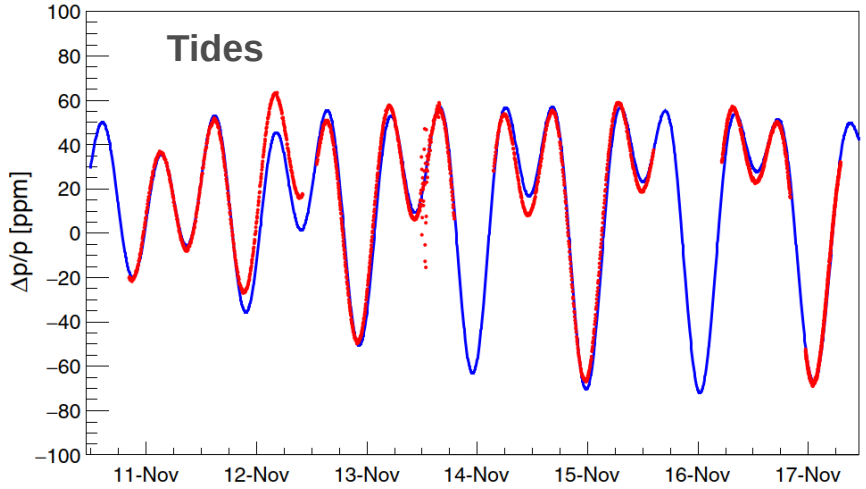
- **Already observed at LEP !** The ring expands in the summer, contracts in the winter.
- Similar amplitudes of tides and slow changes.
- If left uncorrected, **dp/p range ~2x10^{-4}**.

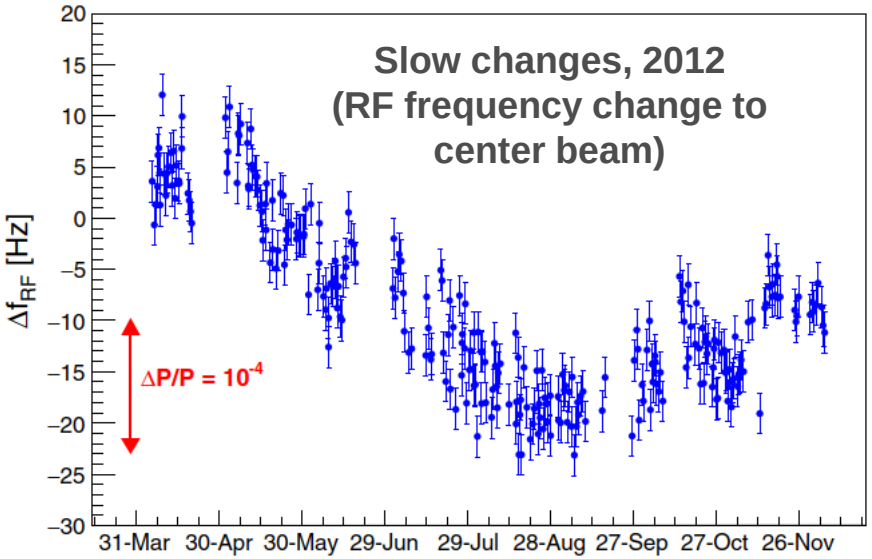
The shift crew / OFB **center the beams** on the same reference orbit with a f_{RF} trim → **no dp/p on LHC beam**.

- Small effect from BPM calibration issue, dp/p ~2x10^{-5}.

For tides SPS and LHC should be similar, no impact on SPS beam momentum (LHC correction compensates SPS). For **long term changes of the cirfumference, expect SPS & LHC to be completely different**:

LHC dp/p ~2x10^{-4} → SPS dp/p ~4x10^{-5}





From LEP

The LEP BPM system was slow, but **very accurate and stable** – resolve structures in the periodic circumference changes.

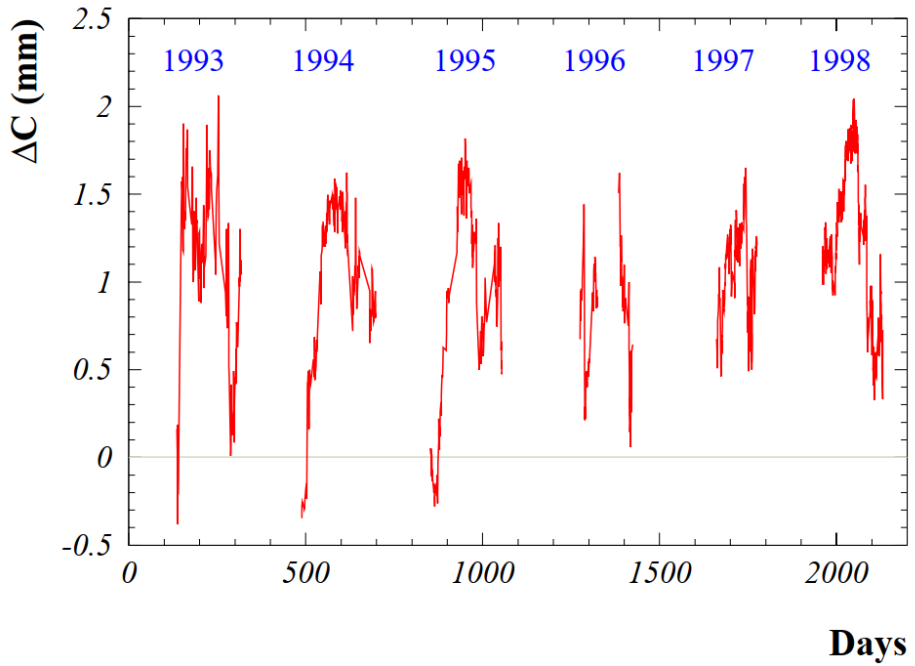
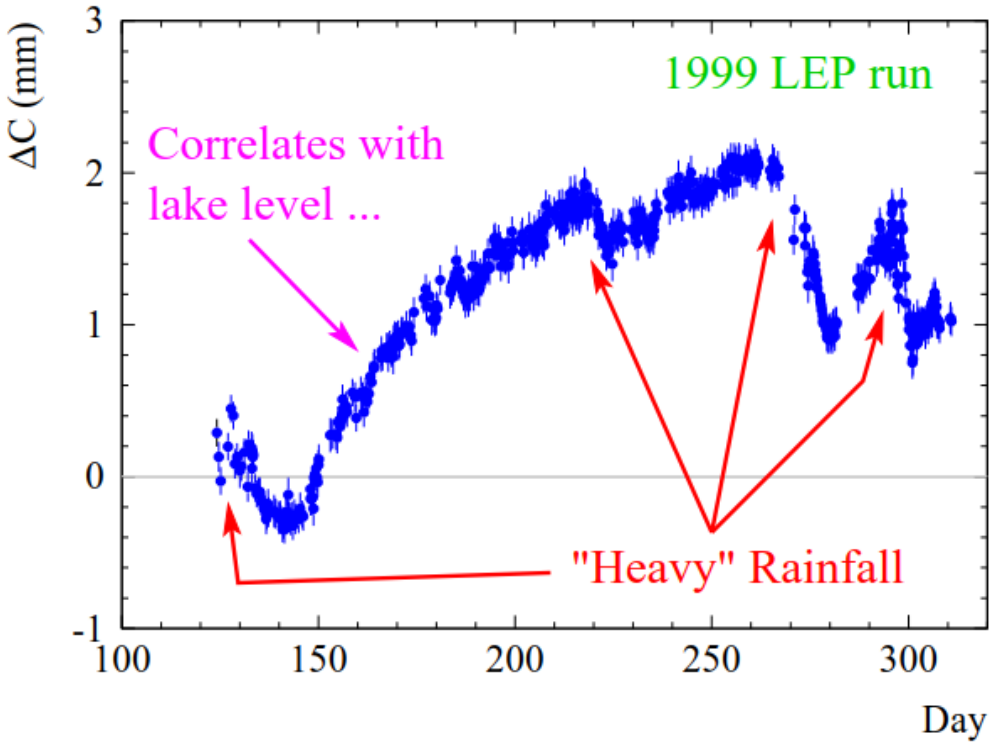


Figure 6: Relative change of the LEP circumference ΔC between 1993 and 1998.

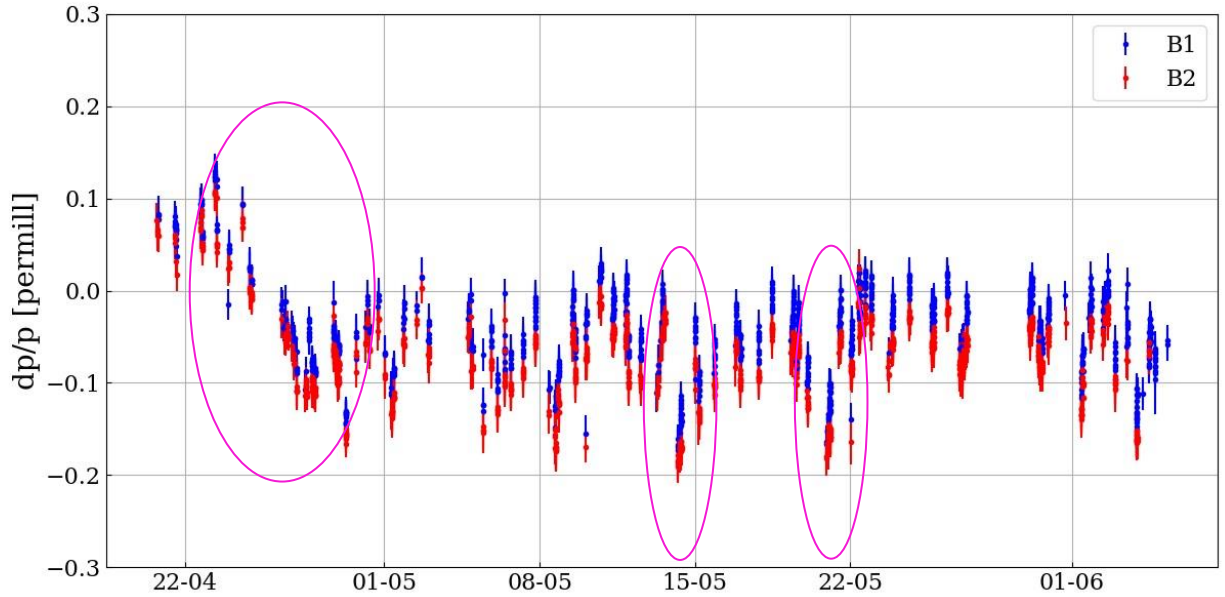
Paper on LEP tides @ PAC99



Short summary

We know / are able to monitor some effects that impact the SPS & LHC energies, but none of them explains the steps and structures that we are observing… Missing some information.

But the signature on the side of the TI2/8 lines seems to point to the SPS energy at extraction as an important ingredient.



End of interlude

Steering issue

Since a long time (also previous runs), observation that un-correctable structures appear in the lines. In TI2 it is impossible to remove **horizontal trajectory offsets** in the **collimation (TCDIL) region** (grey box).

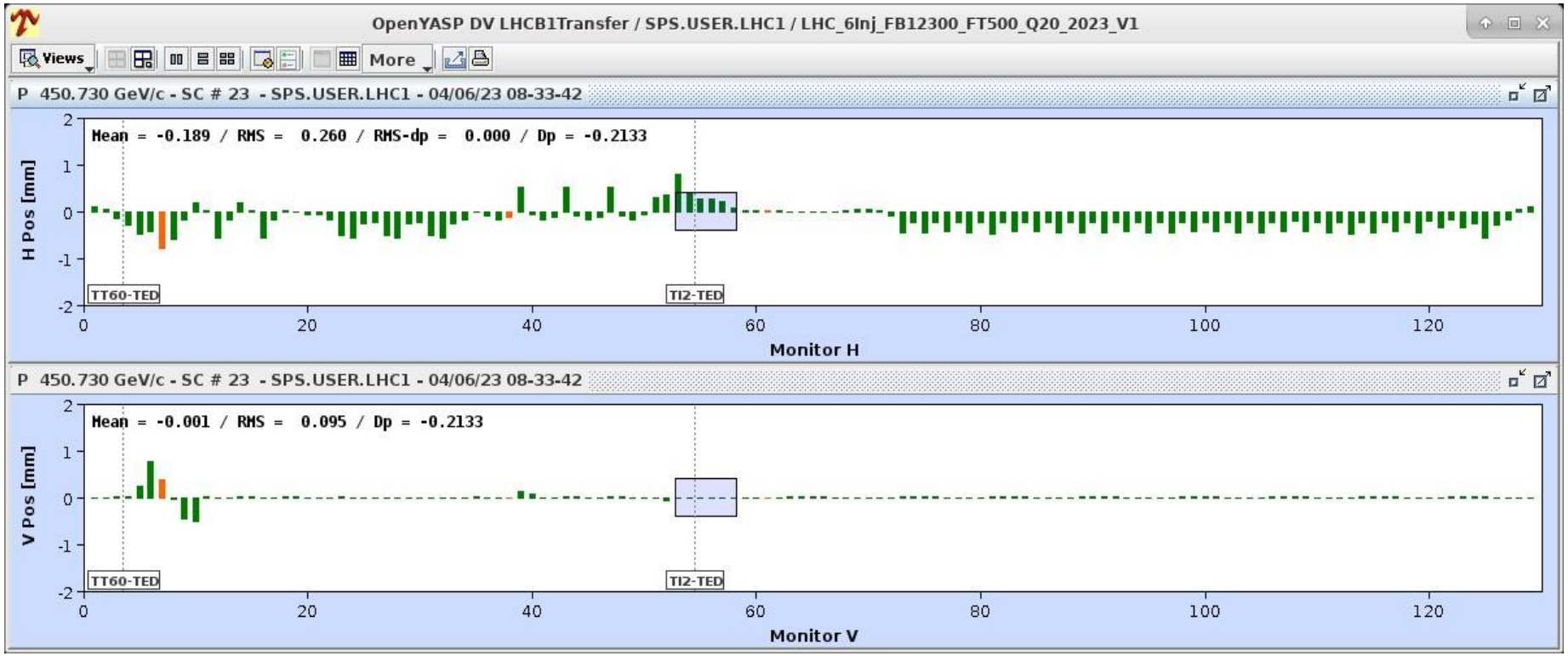
- Beam sizes at collimators ~0.4-0.8 mm (nominal emittance).

TI2 steering Saturday night

Momentum offsets and steering

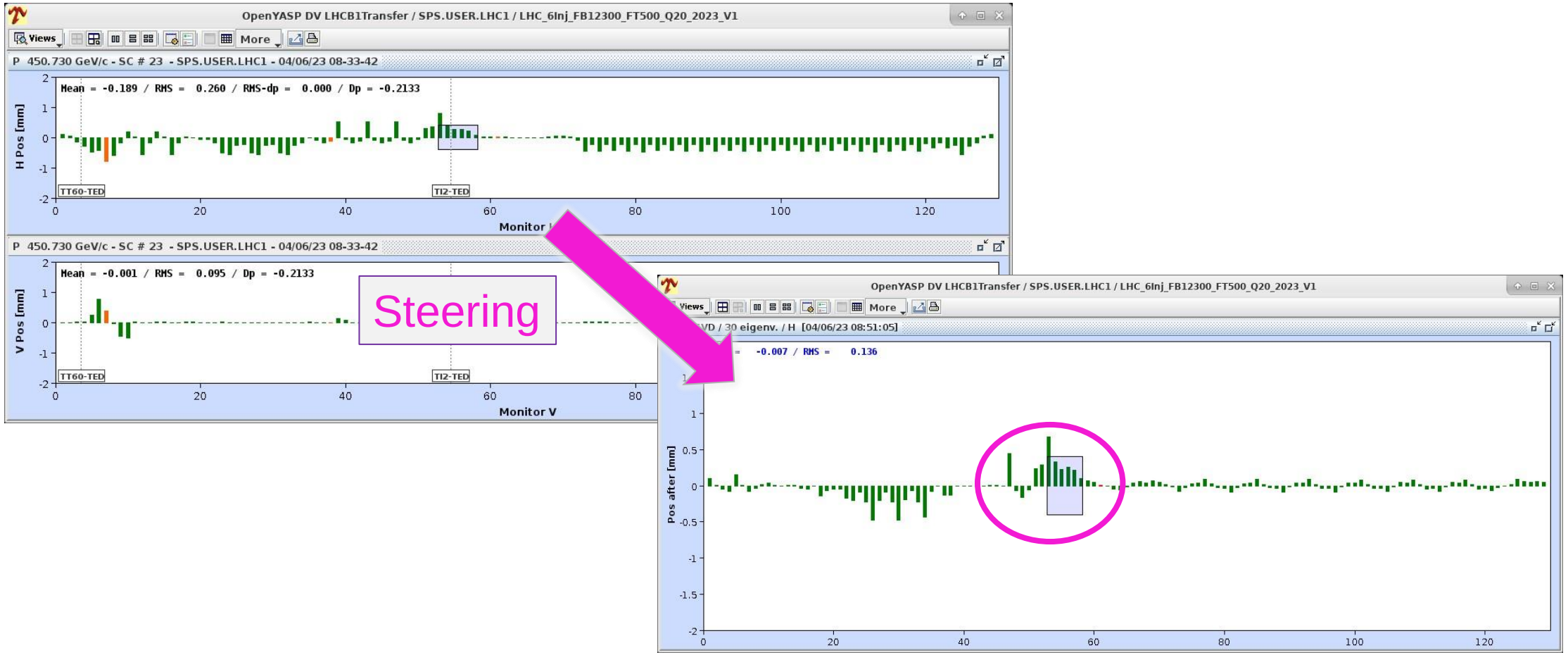
A momentum change in the SPS adds a dispersive trajectory component, which is **simulated** below for a momentum change of ~ **-2×10^{-4}.**

This dispersive component adds to the other trajectory drifts and is difficult to disentangle on a daily basis when relative changes are small.



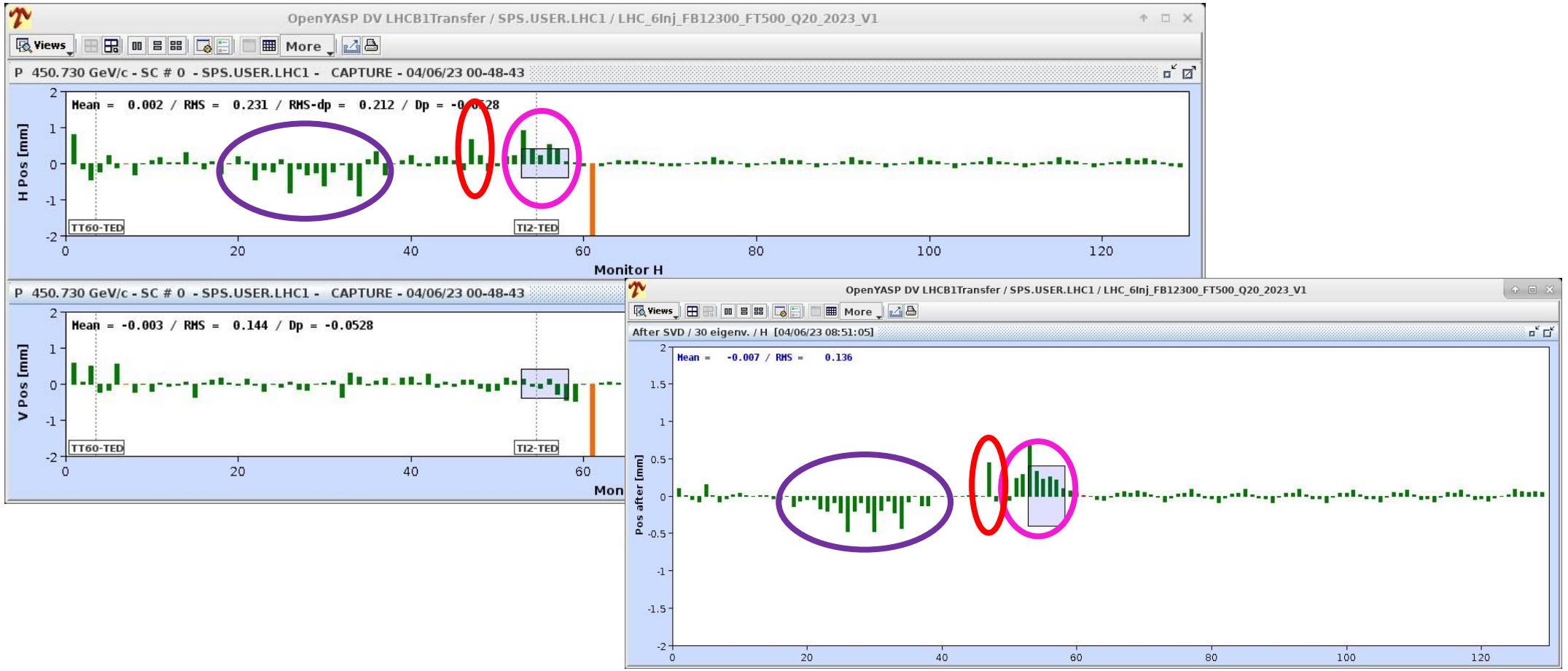
Momentum offsets and steering (2)

Steering away the dispersive trajectory is not possible due to the distribution of orbit correctors in the line.
A residual structure is left over, in particular in the TCDIL region.



Momentum offsets and steering (3)

Striking similarity !



Better steering

The steering could therefore be improved with more consistent settings.

- Adapt the momentum at the level of the SPS FT – a bit tricky due to the rounding. But to be followed up. Would clearly be the cleanest solution if this is the real source of change.
- **Adapt the momentum of TI2/8 at the same time the momentum of the LHC is adjusted**.

Adapting the momentum of TI2/8 would make the situation more consistent !

The changes are at the level of 10^{-4}, proposal would be to only **follow the "long term" trends** to maintain the error within say $\pm 0.5 \times 10^{-4}$. Do not expect more than one change / month.

The trims would be small, at the level of 10^{-4}.

Impact on interlocking

A test of trimming the TI2/8 momenta by -2x10^{-4} was done Monday with probes.

Good results, the structure do indeed disappear. Linear optics works…

Impact on FEI (PC current interlocks):

- Quad tolerances ~0.5% → no impact.
- COD tolerances ~10 microrad → no impact.
- Dipoles tolerances ~few 10^{-4} → only impact for **RBI.221** (tolerance just below 2x10^{-4}).
  - Adapting the tolerance of RBI.221 by 30% would provide the required margin.