Orbit observations in 2016

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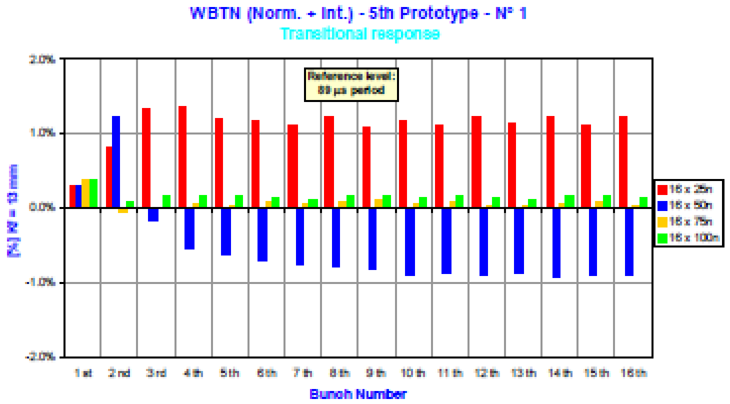
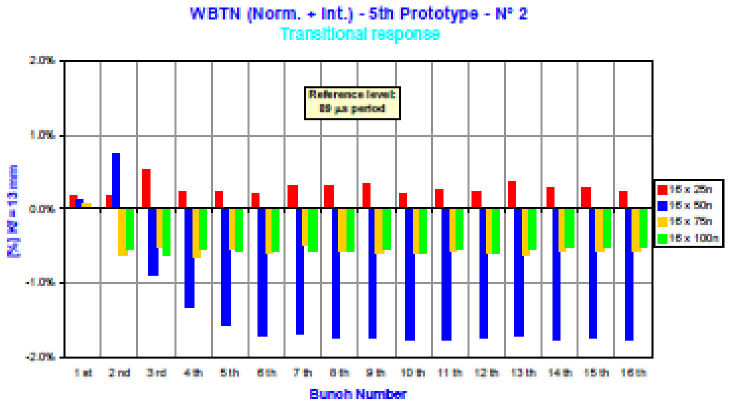
Introduction

- The response of the LHC BPM electronics depends on the bunch pattern – single bunches, 50ns, 25 ns etc – due to the response of the integrators.
- The effect can be mitigated by the calibration that mimics the bunch pattern (single bunch, 50 ns, 72b, 25 ns etc), but it is never perfectly compensated. The residual errors can reach ~**20-50 μm rms**, but **systematic shifts** are also observed.
  - *Ideally we should align all movable devices with the typical train pattern used for operation – currently 72b – and not with single bunches !*
  - *The systematic errors also depend on the details of the filling scheme like train lengths.*
- The situation is made more complex by the fact that the orbit feedback (OFB) can '*correct away*' some of the systematic patterns. This results in
  - *an **under-estimation of the orbit errors** when only the BPM readings are used to evaluate the stability / errors.*
  - *to a **real shift of the orbit** that is not visible from the BPM readings.*

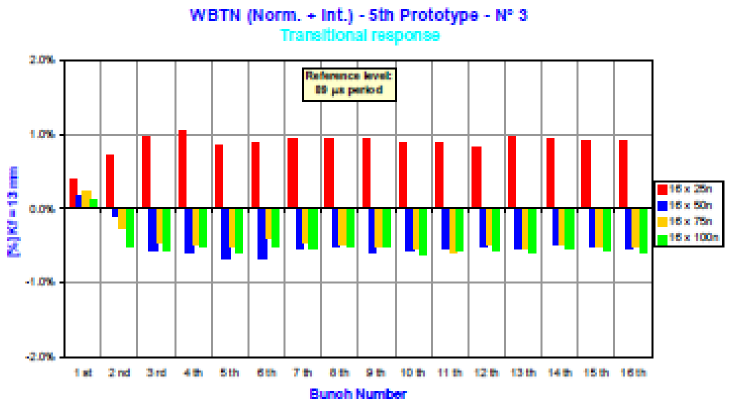
Calibration effects

- Systematic position shifts that depend on the filling pattern.
- Transients response over the first ~5 bunches.
- Each integrator card behaves slightly differently.
- The main effect is compensated by the calibration, but beam measurements show some residual effects at the level of ~50 μm rms.
- An **incorrect calibration** can bias the orbit by ~200 μm rms, with mean shifts > 100 μm.





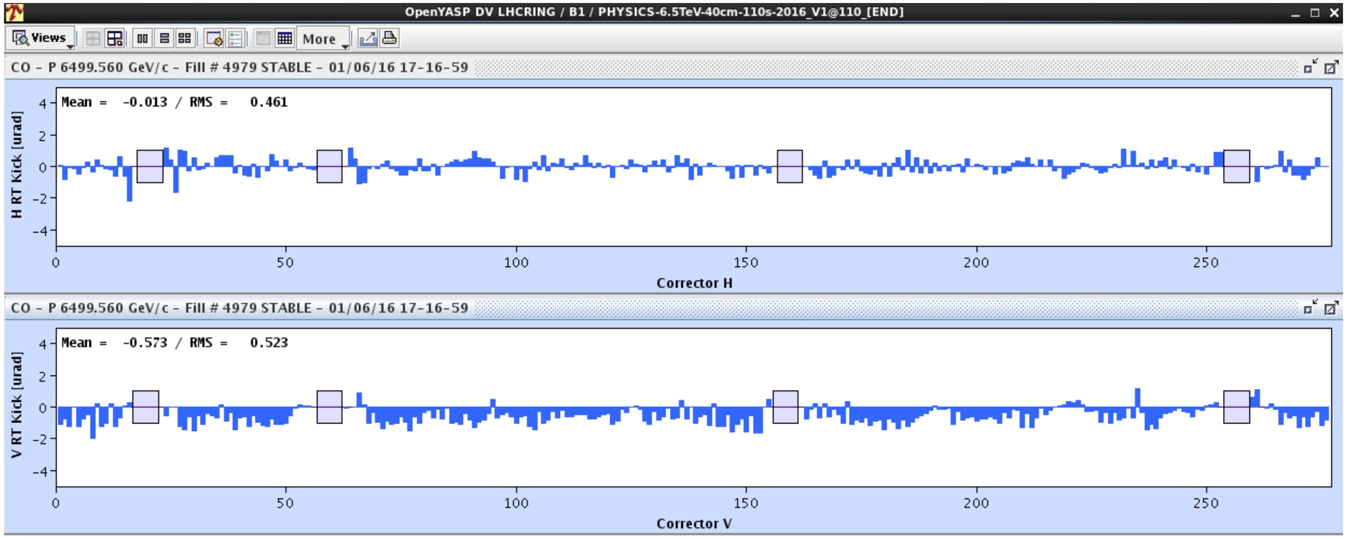
25 ns
50 ns
75 ns
100 ns



Systematic shifts (1)

- This year we observe a systematic shift of the BPM readings with 72b trains <u>even when the correct calibration is used</u>.
- The OFB consequently tends to shift the orbit in the opposite direction since it tries to zero those offsets.
  - *The offset is visible as a <u>systematic shift of the vertical orbit corrector kicks</u> between single bunch and 25 ns train operation.*
    - In the horizontal plane the error is compensated with the RF frequency.
  - *The shift of ~ -0.5 μrad corresponds to ~ -100 μm.*

Kick difference 25ns-single bunch



Systematic shifts (2)

- In the arcs the systematic shifts are not critical as they correspond to 0.1σ at injection, and at 6.5 TeV we have a lot of aperture..
- In the insertions the situation is more complex because the optics is not regular, leading to more complex patterns.
- It is expected that the shift improves with longer trains but…
- It is not possible to switch reference orbits with bunch pattern to take into account this effect (full orbit FB settings regeneration needed).
- One might consider *replacing the current single bunch reference with a 25ns reference*, but this would require a very careful measurement of the difference, plus checks.
  - *Multiple calibration and beam measurement sequences with nominal bunches and 25 ns trains.*
  - *I currently see no strong incentive to make this change since the difference is very modest.*

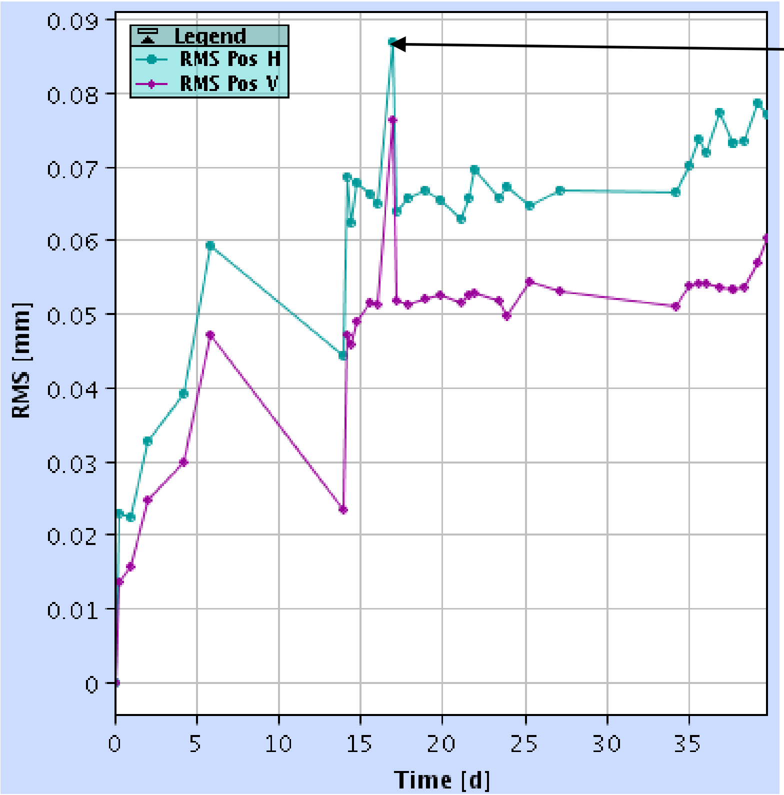
Orbit feedback

- The OFB is active in the following phases:
  - *Injection of probe and nominal.*
    - but it is only switched on ~ minute to correct.
  - *Ramp, tune change, squeeze, TOTEM bump swap.*
  - *Stable beams.*
    - Once all experiments are at or close (levelling) to target lumi.
- The OFB is not used for the 2 collisions BPs (45s and 160s long).
- The configuration in stable beams is much softer that for rest of the cycle:
  - *40 versus 390(H)/420(V) eigenvalues (max = ~510).*
    - Provides good global orbit corrections without interfering with levelling and luminosity optimisations.
  - *Gain a factor 10 lower.*
  - *In stable beam the global orbit is stable to* ***20 μm rms over 8 hours****.*

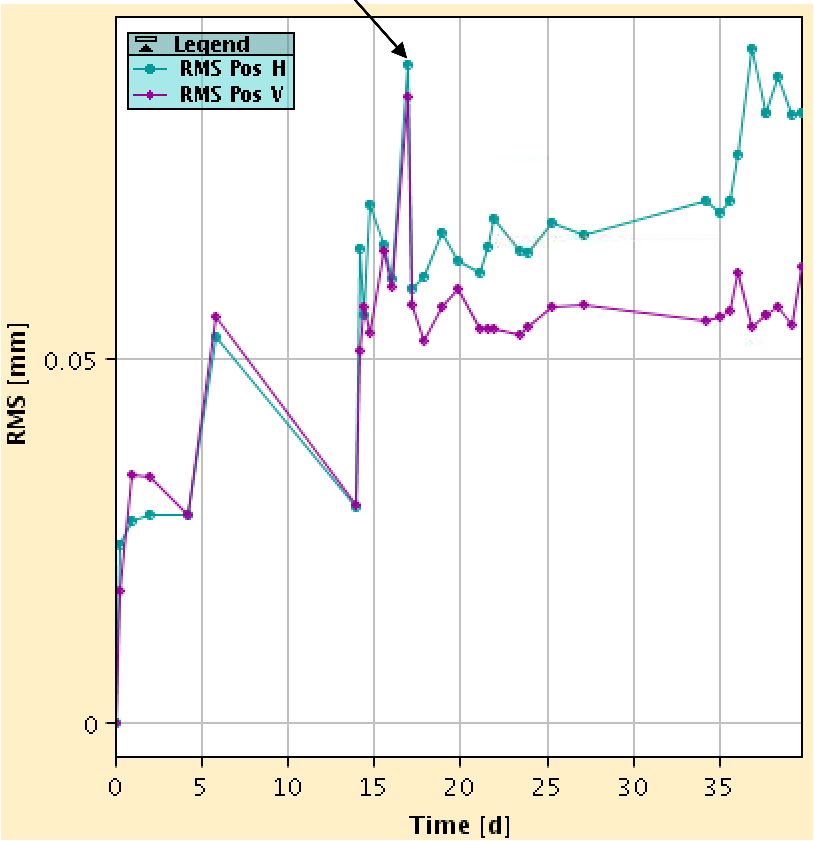
- The TOTEM BPMs (BPMWT) are currently not used in the OFB because a) they were not working properly in the start-up weeks and b) in order not to overweight the cell Q5-Q6 (too high BPM density) for correction.
  - *Plan to enable one of the 4 per beam for the OFB.*

Reproducibility - overall

- Orbit reproducibility wrt to the first stable beams fill (3bx3b).



Wrong calibration (single bunch instead of 72b)

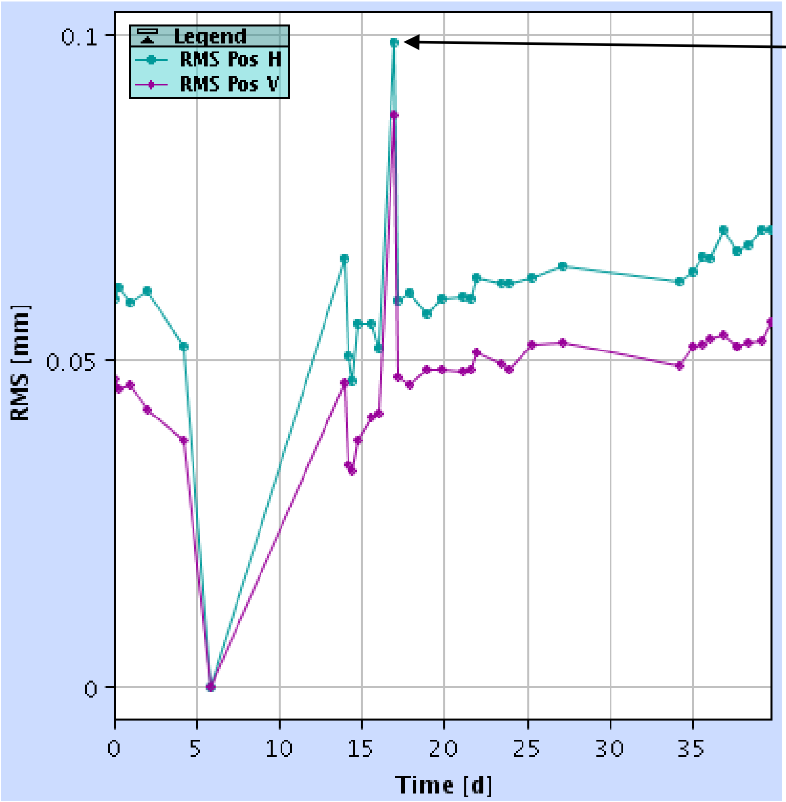


Vertical plane ~60 μm

Horizontal plane ~80 μm – ALICE levelling, triplet movements..

Reproducibility – overall 25ns

- Orbit reproducibility wrt to the first stable beams fill with 25 ns.



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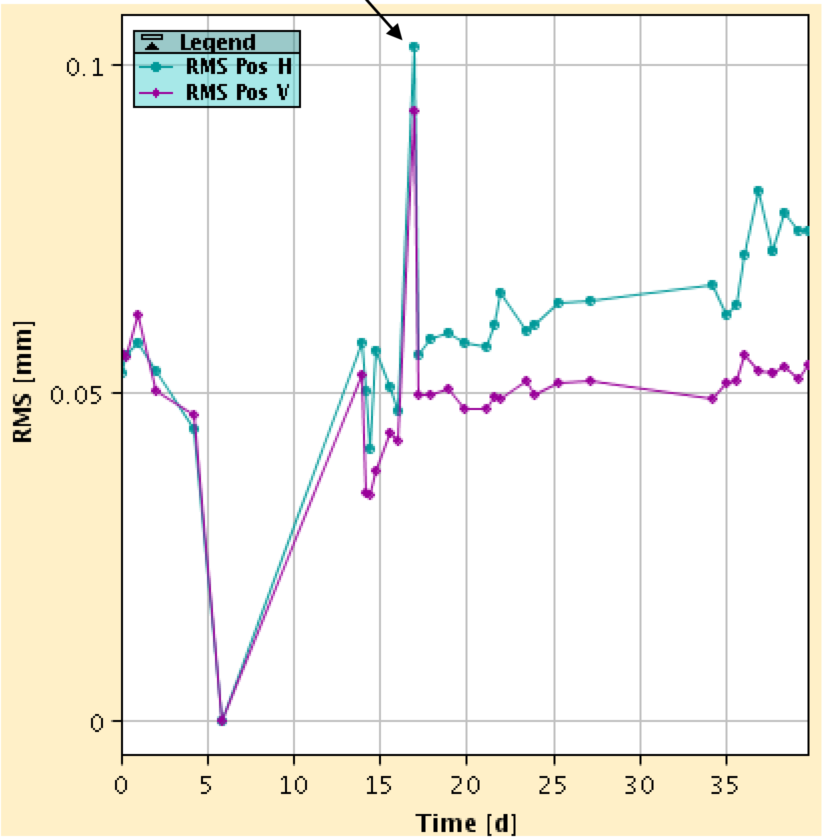


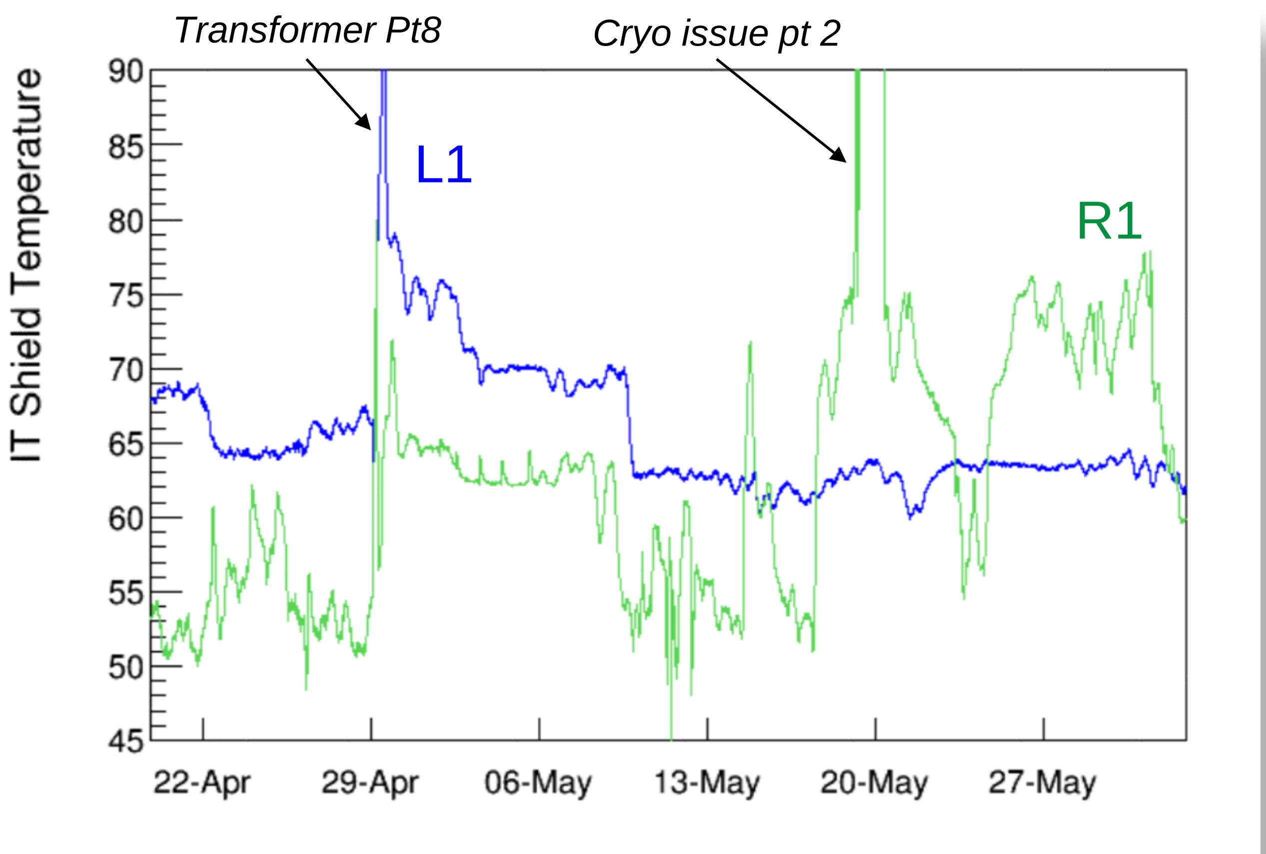
Reproducibility ~50 μm in V, slightly more in H – very typical, was the same in 2015.

Triplet movements

- We know since last year that we are sensitive to the temperature of the IT thermal shields (50k-80K).
- Temperature variations lead to radial displacements of the triplet magnets of **~10's of μm** that in turn induce orbit drifts and separations of the beams at the IPs.
  - *Mitigated by using the OFB in stable beams.*
  - *The OFB mitigates well the impact of a triplet movement on the machine, but it cannot correct locally the IP shifts very well. Regular re-optimizations must be performed at the concerned IP.*
- The knobs that are used to steer the beams back are **closed before the TOTEM RP stations** – there is no interference between lumi optimizations and TOTEM RPs.
  - *For the TCTs, the movement TCT and IP are equal within a factor ~2 , but the beam size is ~100 x larger at the TCT.*

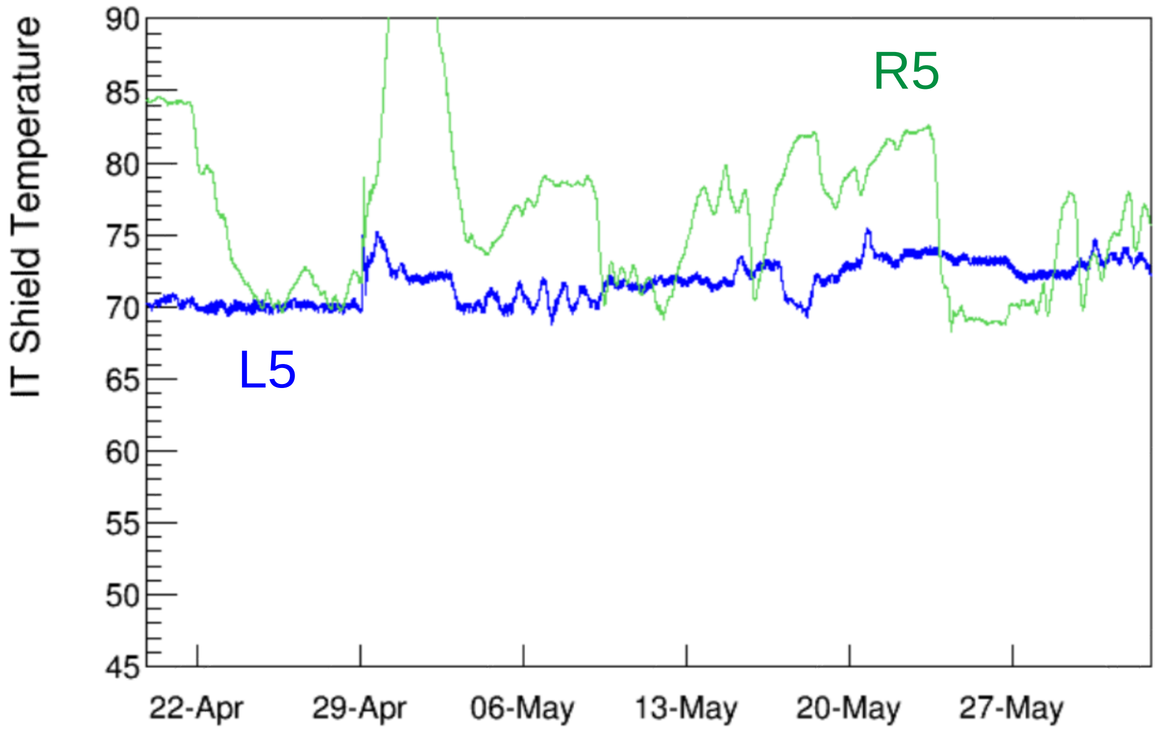
Triplet thermal shield – IT1

- IP1 triplet thermal shield temperatures vary significantly over time, in particular in **R1**.
- IT **L1** was mainly affected by the 'fouine' transformer event: large pressure wave and high temperature that led to a transverse movement of ~170 mm of one the magnets.
  - *Magnet moved back with motorized jacks. Remaining errors corrected with manual trims along the cycle (mainly affecting 3m-40cm part).*



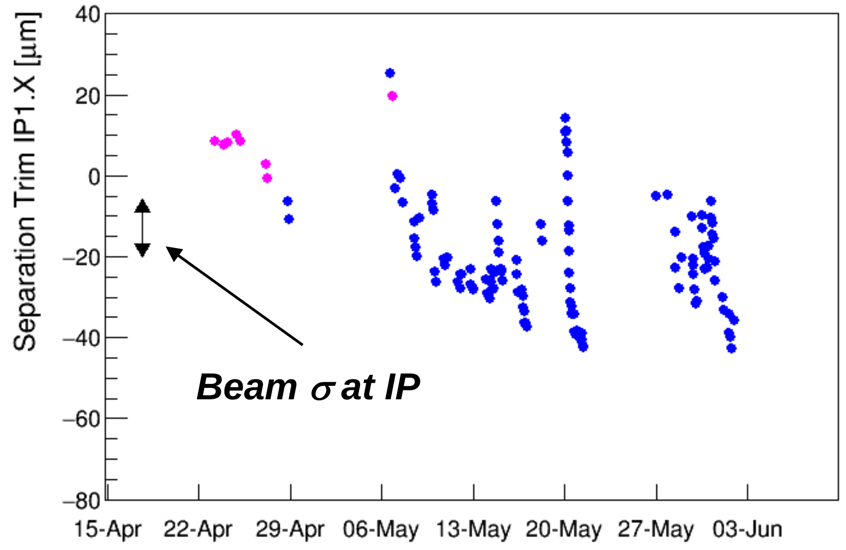
Triplet thermal shield – IT5

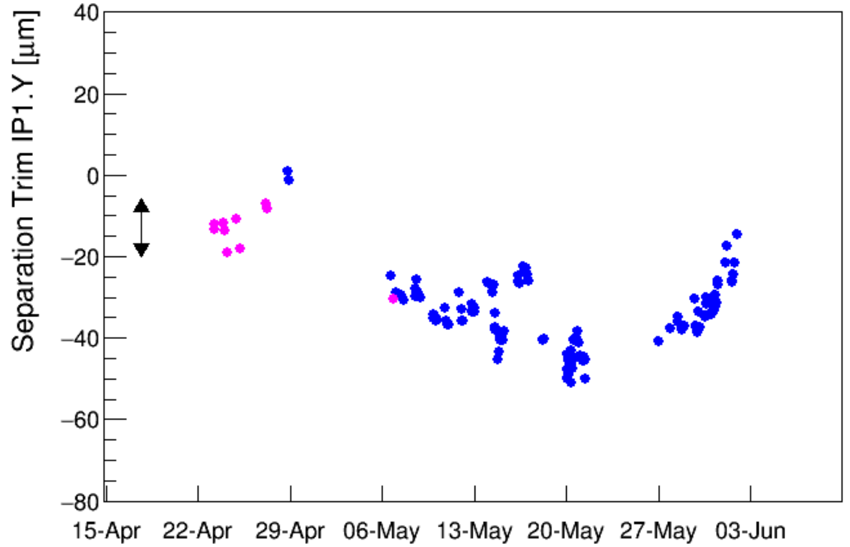
- Same information for triplet in IR5.
- Quieter, but also much higher temperature.
  - *Same scales for IT1 and IT5 !*



IP1 beam separation

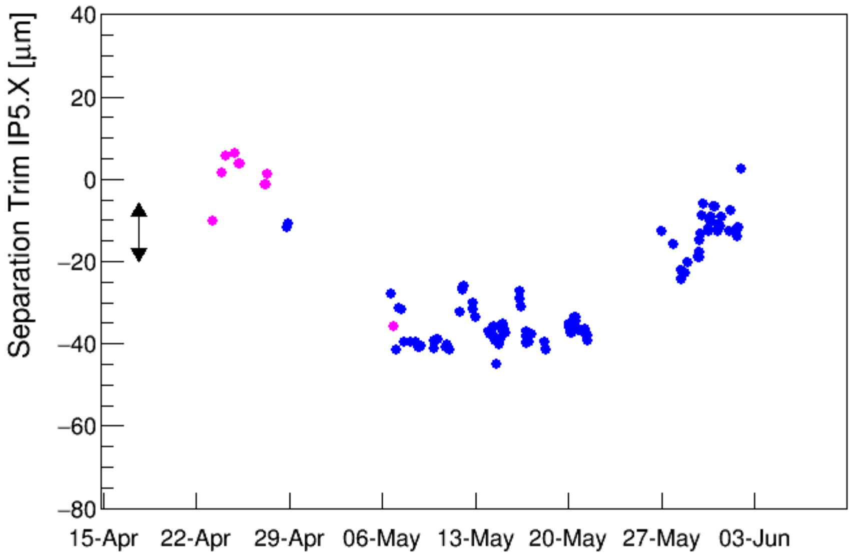
- In IP1 the beam separation is quite 'unstable' in the horizontal plane as the L1 side triplet is the most unstable in terms of thermal screen cooling.
  - *Reason for the frequent drifts and re-optimizations of the ATLAS luminosity.*
- The vertical plane exhibits slower long term drifts, probably due to ground motion etc.

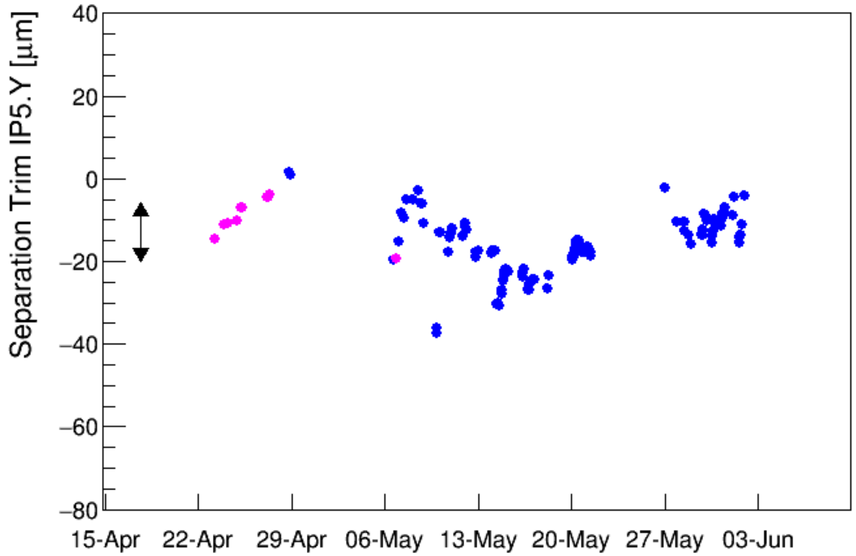




IP5 separation

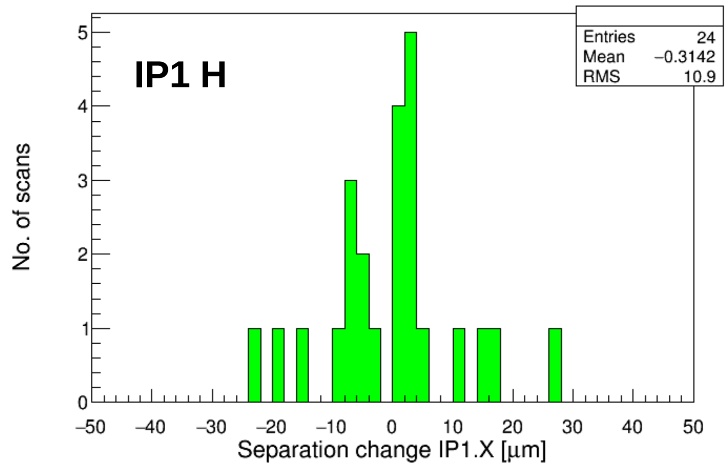
- IP5 is much quieter, triplet thermal screen cooling is also better.
  - *No convincing correlation with IT temperatures.*
- The vertical plane exhibits modest long term drifts.

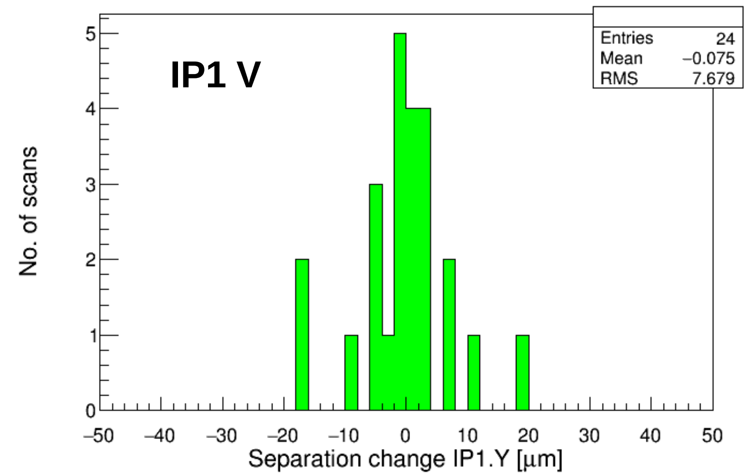


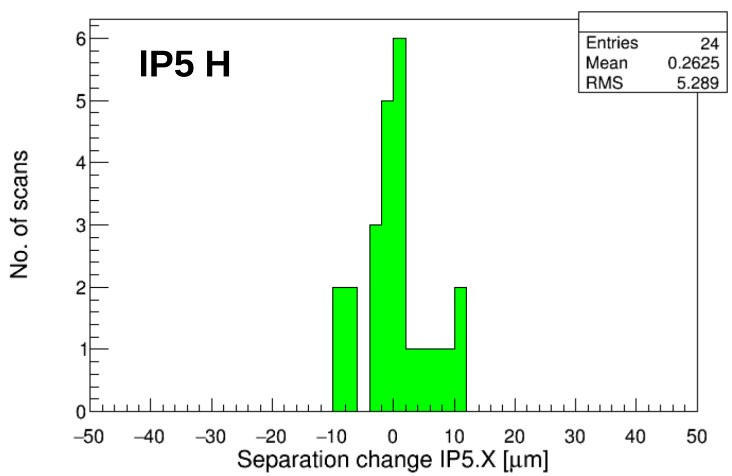


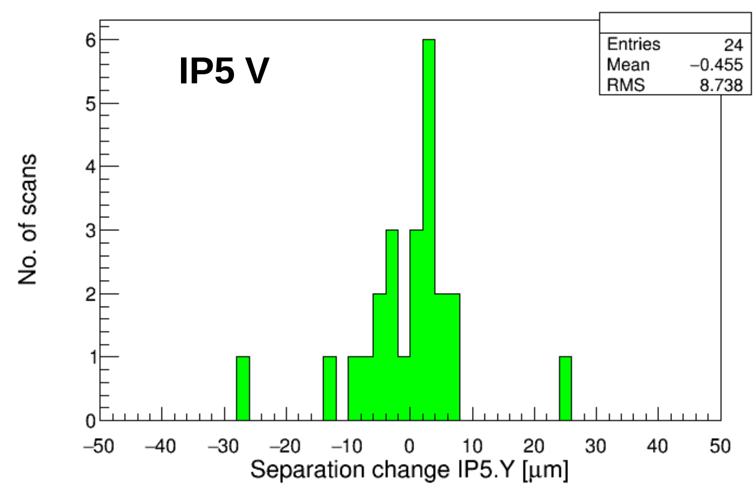
Fill-2fill

- Change of separation from one fill to the next for fills that start <u>within 5 days</u> of each other – typical change ~ 8 μm.



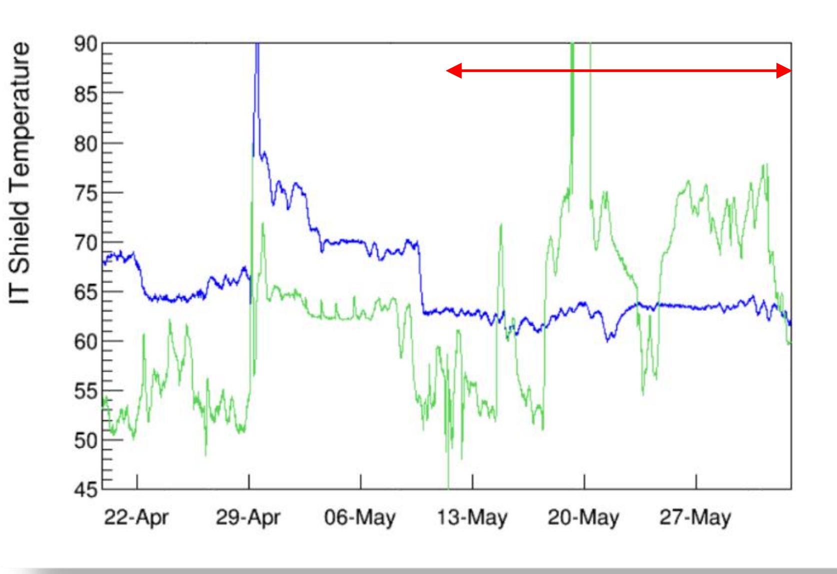






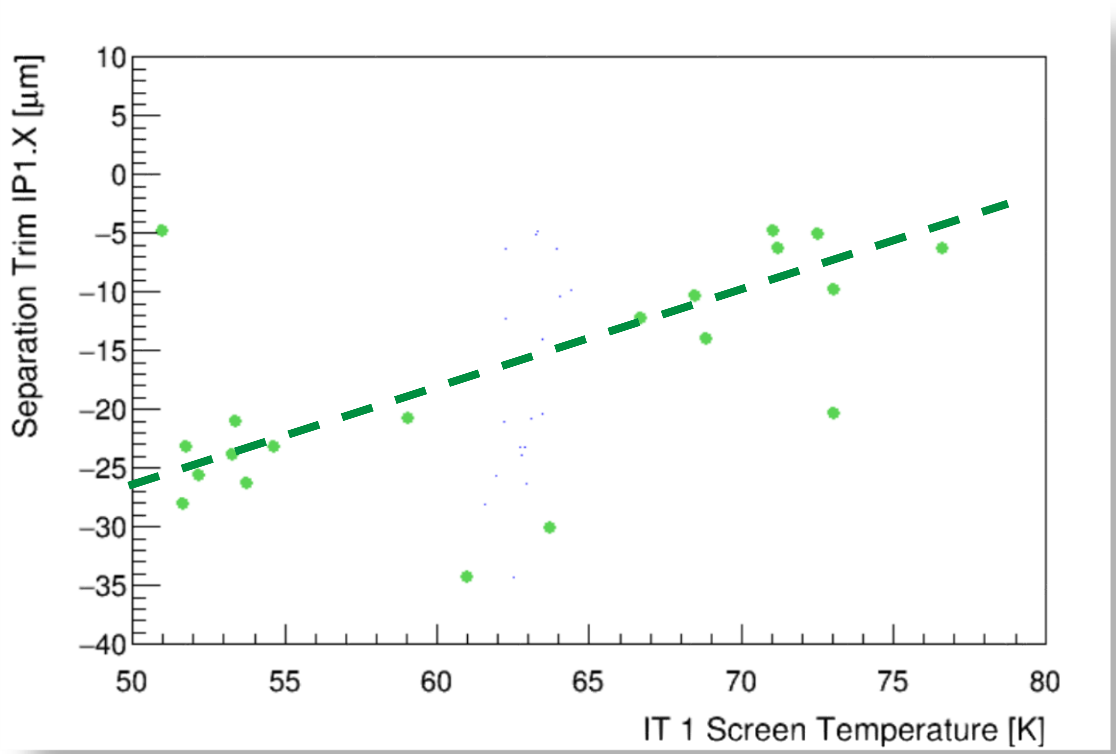
Triplet T – beam separation

- To establish a correlation between triplet thermal shield T and beam separation is not straight-forward:
  - *The transformer event led to important re-steering around IR1, including the triplet orbit correctors → breaks the correlation between pre- and post-fouine time period.*
  - *During the cycle the OFB has a more aggressive configuration than during stable beams → correlation changes due to the different impact of the OFB.*
- The data was therefore filtered to include only the start of fill optimizations after the transformer event (~10.05).
  - *In that period IT L1 was stable ~60-65K.*



IT R1 correlation

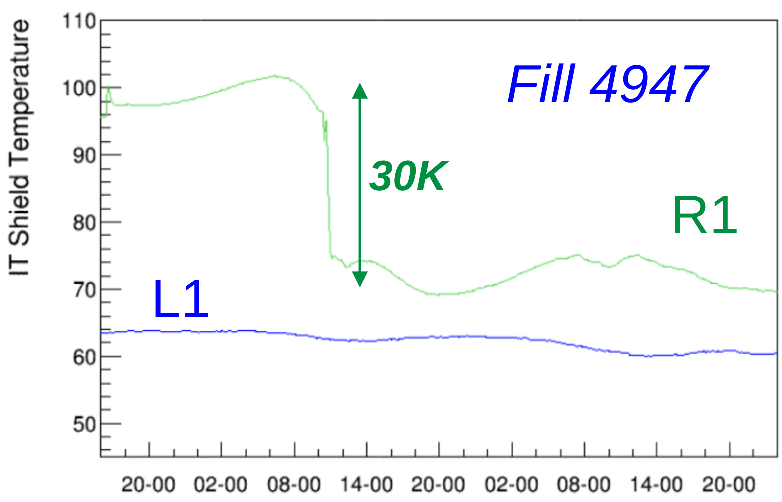
- Reasonable correlation between start of fill separation data and R1 triplet temperature after mid-May.
  - *Some outliers – to be checked.*
- There seems to be a slope of ~ **0.8 μm / K**.

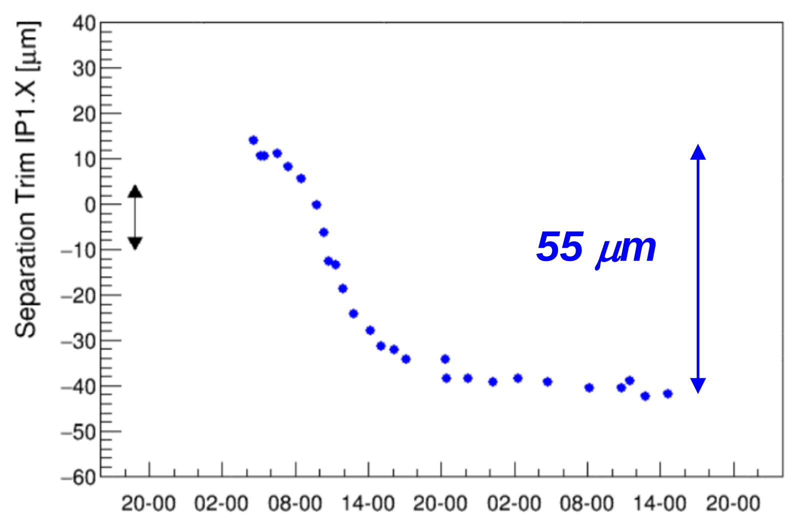


Record fill – for length and IT1

- During the record 36 hour fill, the IT R1 was brought back to its ~nominal temperature during the fill (post cryo plant problem).
- The correlation between temperature and separation is not perfect – possibly because the IT support was not in thermal equilibrium?
- The overall change of 55 μm for 30K (**1.8 μm/K**) is a factor two larger than the slope of the previous slide.
  - *The difference could come from the OFB configuration.*

Rule of thumb: ~1-2 μm / K





Wrap up - TOTEM

- The <u>global orbit rms</u> is reproducible within **~50 μm** for 25 ns operation.
- There is a <u>shift</u> of up to **~100 μm** between the real orbit for single bunches and for 25 ns beams due to the BPM systematics.
- The triplet movements in IR5 are small, no / negligible impact at the locations of the TOTEM RPs.
  - *Luminosity optimization knobs are decoupled.*
- For the TOTEM RPs a <u>margin</u> of 3 x 50 μm + 100 μm ~ **250 μm** covers the present orbit stability + systematic errors envelope.
  - *Orbit around IR5/TOTEM is reproducible within ±200 μm.*
  - *For the RPs with the smallest beam size (~100 μm) the envelope leaves a margin of ~3.5σ out of the 6σ margin wrt TCTs (15σ – 9σ).*

What if the orbit is not as expected?

- An important question concerns deviations of the orbit from the currently observed stable situation.
- We clearly do not want to dump the beam because the orbit is out of tolerance when a RP is in beam → extract the RP !
  - *Currently not possible to implement such an extraction from SIS (according to my last discussion with M. Deile).*
- As an alternative a ‘warning interlock’ is available in SIS:
  - *Vocal message is send out when RPs are in beam and the orbit is not within tolerance, for example 2 or 3 out of the 5 BPMs in the cell (standard + TOTEM) are out of tolerance.*
  - *The reference settings are identical to the ones used by SIS for the global orbit interlocks.*
  - *Never used so far !*
- The same warning is available in the steering application with details on the readings.
  - *Check before inserting the RPs.*
- In case a warning / check approach is adopted, what limits should one set ?

Summary

- I see no problem to move to 15σ RP settings.
- The orbit is sufficiently well controlled, we have ~3σ margin wrt the bare minimum for the smallest RP taking into account current uncertainties / reproducibility.
  - *Considers that the absolute limit is when the RP is at the same distance to the beam than the TCTs.*
- A warning / pre-insertion check should probably be considered to avoid problematic situations.

Record fill

- The correlation temperature – separation is not perfect for fill 4947.
  - *Possible transient effect, the return temperature may not be representative for the temperature of the support feet??*