# Tune and Orbit Feedbacks

L. Ponce

Thanks to J. Wenninger, K. Fuchsberger, S. Jackson and OP team

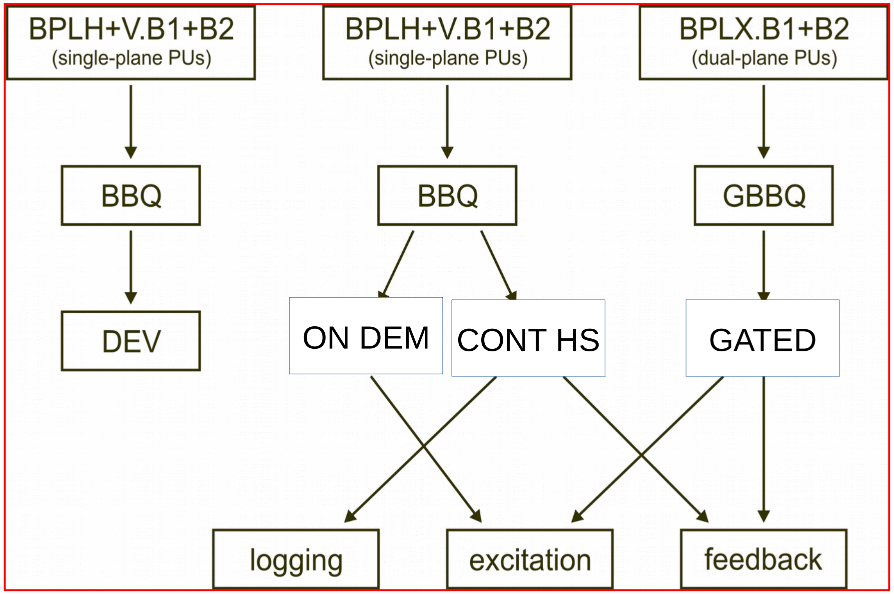
# Outlines

- New feedbacks for 2015
- Operational usage of the Feedbacks
- Main issues during 2015
- Orbit Feedback performances
- Changes for 2016

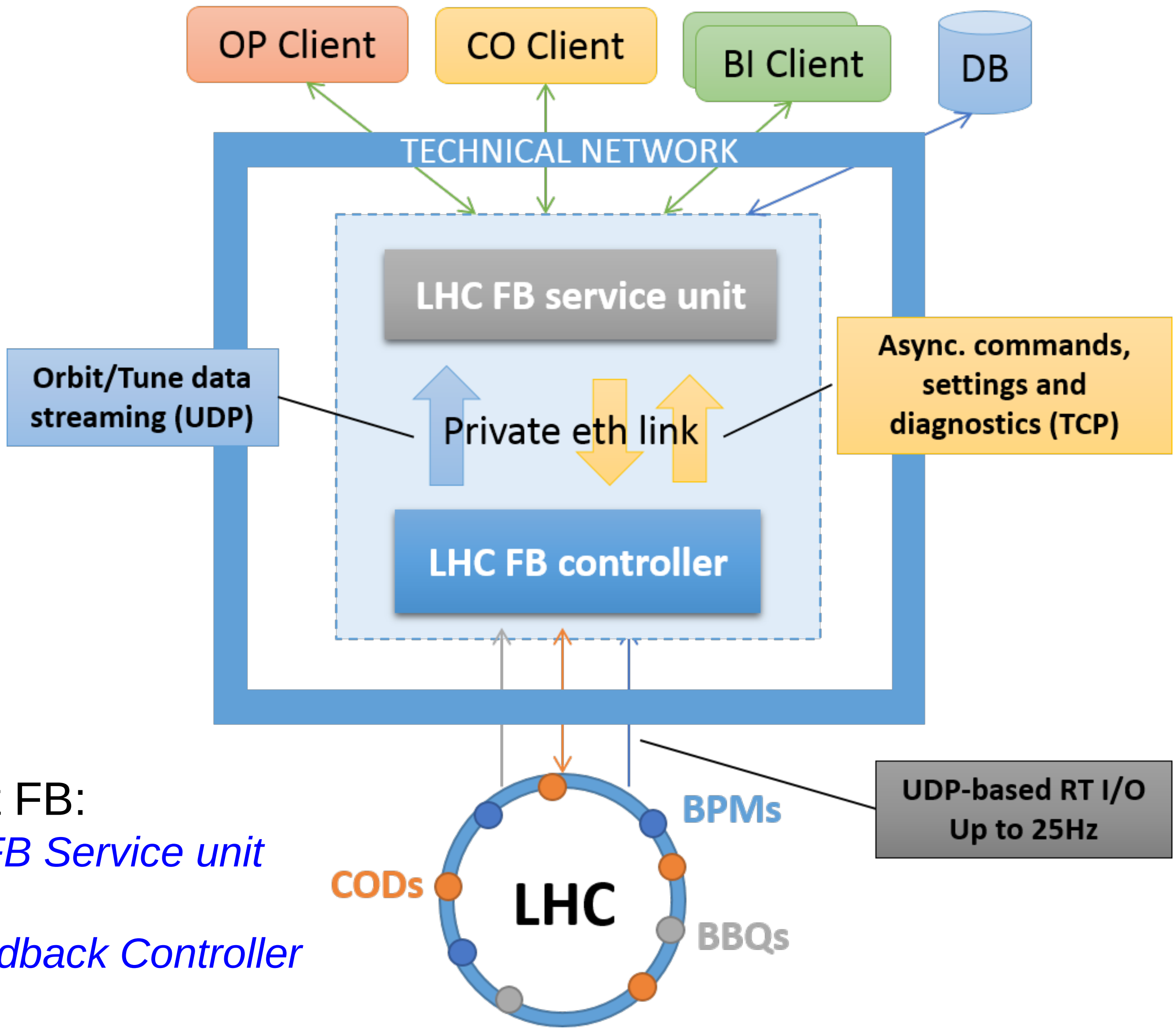
# TUNE Systems

- 4 independent acquisition systems are used:
  - *"On demand" used to perform measurements requiring changes in the acquisition settings or beam excitation*
  - *"Continuous GATED"  and*
  - *"Continuous High Sensitivity" used for nominal bunch intensity beam for Feedback and continuous tune measurement*
    - *Feedback functionality implies that acquisition settings are fixed*
    - *Continuous sees all bunches- e.g. observed beam instabilities*
  - *DEV system used for beam studies (also used as hot spare)*

- Tune Feedback system is only part of it



# Orbit Feedback Systems




- 2 parts in Orbit FB:
  - *BFSU= LHC FB Service unit (old OFSU)*
  - *OFC Orbit feedback Controller*

# Feedbacks after LS1

- Major refactoring of BFSU/OFC during LS1 + new developers

- New hardware:
  - *New machines: 24xCore, 64-bits, SLC 6*
    *+ extra CTR timing receiver on Controller (OFC)*

- Migration to FESA3:
  - *> 35k lines of code ported mostly by hand (migration tools not mature at that time)*
  - *Major effort (3-4 months) for BE/BI team*

- Improved diagnostics:
  - *Replaced ROOT based logging with standard syslog (CO tools)*

- Stability improvement:
  - *Code cleaning: bugs fixing, suppress unneeded heavy functionalities*
  - *Less reliance on FESA persistancy: moved critical settings into LSA*
  - *Overloading of the Ethernet (resulting in FESA queues being exhausted) solved by restructuring data exchange and reducing data structure size*

# FB Testing Framework

- Motivated by new team for controlled testing outside operational environnement → less impact on operation!
- Inject tests through UDP layer → language could be chosen freely
- Implemented in JAVA (Junit test) with following advantages
  - *Bigger community to write tests*
  - *Easy interaction with other parts of controls system (LSA)*
  - *Gaining first experience*
- Identified (and implemented) types of test:
  - *FESA mechanics: Setting a value in one property has the desired effect in another. In principle very simple, but most frequently required.*
  - *Communication:  send some more predefined values for an orbit and check if the values are correctly processed through layers*
  - *Control loop behaviour: send a constant orbit verifying the resulting corrections. From an operational viewpoint these are the most interestinf tests, as they highlight instabilities and allow error predictions*

# TestBed: Fruitful Intersectional Collaboration

- BE-OP, BE-BI and BE-CO collaboration:
  - *Very focused work during 3 iterations of 3 weeks each (Scrum Sprints)*

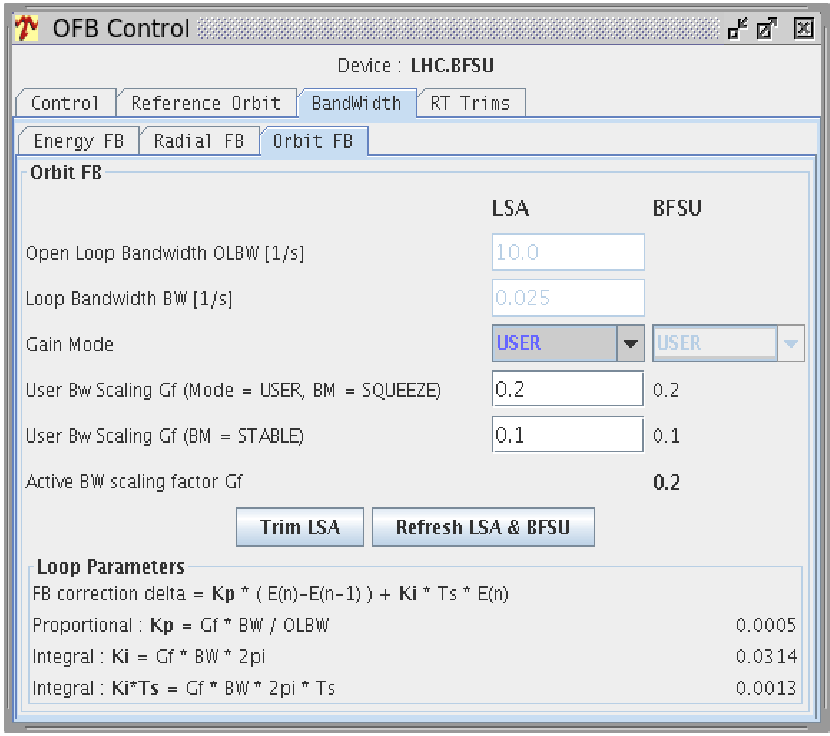
- BI will use the FB testBed model in 2016 when migrating other big classes to FESA3 (BPM, BLM)

# Interface with Operation

- Functionalities used/needed by operation:
  - *On/Off command of the FBs via sequencer and application*
  - *Loading of references and optics (= set to BFSU)*
  - *Dynamic change of the reference (ramp/Qchange/Squeeze)*
  - *Critical dependance on BFSU when timing is needed*

- Experts setting became operational (now stored in LSA):
  - *Eigen values, bandwith, gains (via YASP and sequencer)*
  - *BPM status*

- Both tune and orbit references set in 2 different properties of the BFSU class
  - *Critical dependance on BFSU when timing is needed*

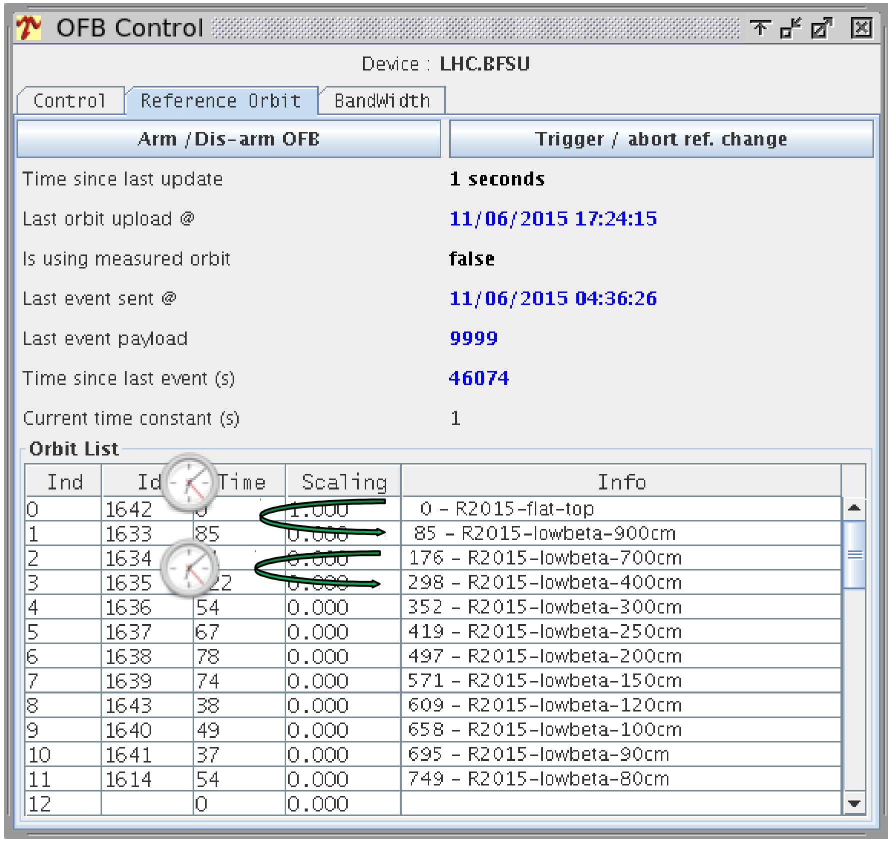


# Change of reference

- Needed during the ramp, Qchange and squeeze, following PC functions
- Settings stored in LSA and tasks executed via sequencer
- Linear interpolation between actual settings and requested settings over a time set by the task (*timeConstant*)
  *=> BFSU is not playing a function*
- Change triggered by timing events send to BFSU

- Same mechanics for the Tune feedback references changes

- All timing events for a given BP are generated in a dynamic timing table which is played at the same time as the start ramp table:
  - *11 events sent for the squeeze to 80 cm*

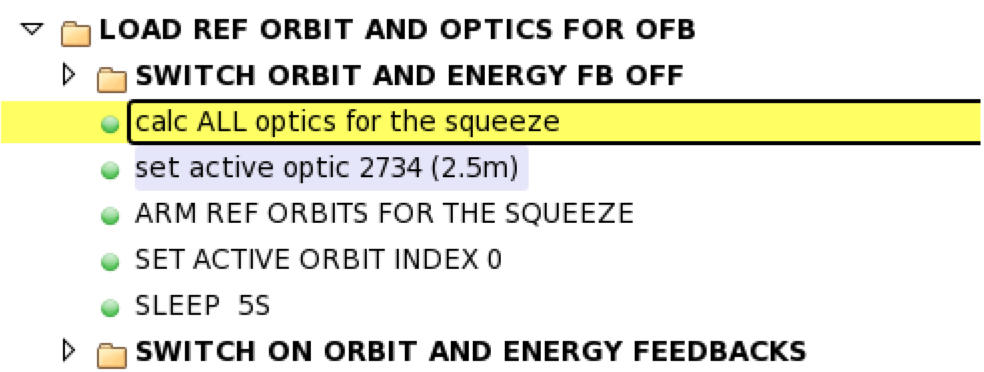


# Change of Optics

- The SVD matrix should in principle be recomputed for each optics:
  - *Quite a long process: Take between 1 and 2 minutes (11 optics during squeeze!)*

- Dynamic change of the optics during the squeeze is implemented, never used in nominal operation:
  - *Reduced list of optics to avoid crash of BFSU*
  - *Never tried to re-compute with OFB ON*
  - *Re-computation time versus squeeze segments length maybe a problem?*

- Only used for squeeze in a discrete mode:
  - *FB stopped, optics recomputed and sleep time before switching ON again*
  - *Intermediate optics used for the whole squeeze*



# FB usage

- Without Beam: preparing settings
  - *Fetching all optics for full cycle*
  - *Calculation with default matrix (ignoring statuses)*
  - *Selection of tune device for pilot*
  - *Settings: OFB Gain =1, Eigen Values 390-420, Radial loop gain 0.5*
- Injection:
  - *OP crews correct tunes back to reference (by hand).*
  - *Orbit corrected back to reference with OFB*
  - *Switch between different BBQ systems according to intensity*
- Ramp:
  - *OFB and QFB switched on at end of filling for the ramp.*
  - *Constant reference for tune FB*
  - *Change of orbit reference (crossing + separation) at 2 TeV*
  - *Settings: OFB Gain =2, Eigen Values 390-420, Radial loop gain 0.5*
- Q Change
  - *Dynamic change of tune reference and tune fitters*
  - *OFB on with constant reference*

# FB usage

- Squeeze
  - *Calculation of intermediate optics before starting the squeeze*
  - *QFB and OFB on.*
  - *Change of orbit references following change of bump shapes with optics*
  - *Settings: OFB Gain =1, Eigen Values 390-420, Radial loop gain 0.5*
- To collisions
  - *Collapsing of separation bumps and ramping of crossing done in few minutes (IP 1 and 5 first, then 2and 8).*
  - *Functions only, FBs off but change of reference display*
  - *Manual correction towards physics reference*
- In Collisions
  - *Due to orbit drift in IP8 (triplet movements) and very good stability, Orbit Feedback used in STABLE BEAMS with reduced gains and number of Eigen values.*
  - *Reference orbit is the active one, OFB switch ON after optimization*
  - *Settings: OFB Gain =0.2, Eigen Values 40-40, Radial loop gain 0.02*

# Main issues with Feedbacks systems

- Problem with Tune Feedback: 3 dumps at flat top
  - *Automatic switch off due to signal quality: loosing peaks, noise peaks*
  - *QFB locked on noise peak and push real tune towards resonnance*
  - *Interference with transverse dampers*

- Problems with orbit Feedback: teething problems, no dump
  - *Missed timing events to change reference orbit: critical in the ramp*
  - *Wrong orbit reference during Beam Setup/MD: always recovered*

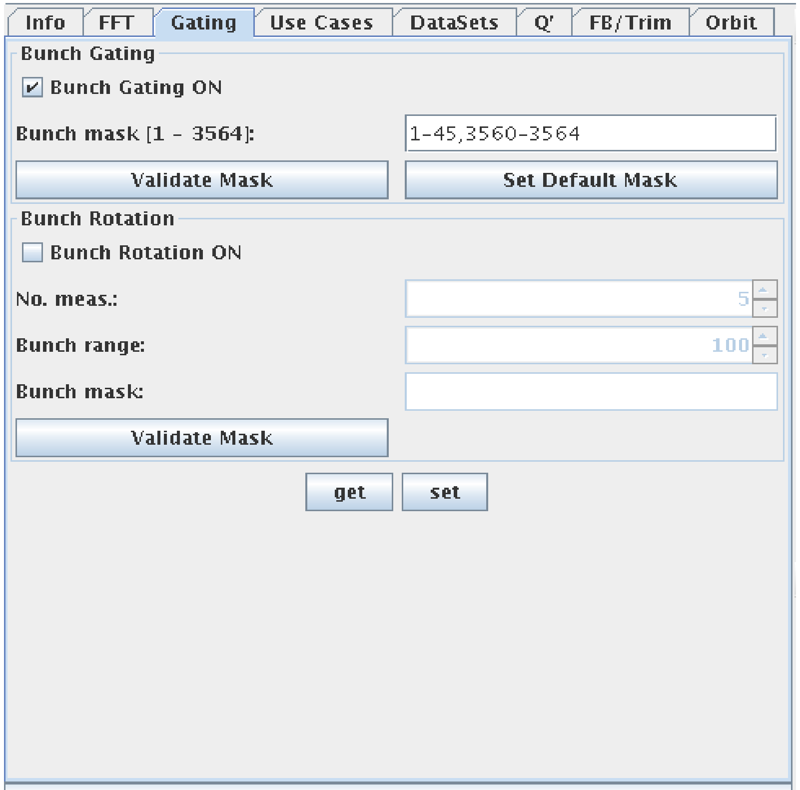
# Tune measurement quality

- Saturation problem solved by using 2 different devices for pilot and nominal intensity beams:
  - *Switch between devices in the nominal sequence*
- Co-existence with transverse dampers solved with GATED device: gating on first few bunches with a lower ADT gain
  - *ADT witness gain on first 400 bunches (factor 100 below NOMINAL gain)*
  - *GATED device can be configured by OP*
    *=> optimization during intensity ramp-up*

=> TUNE signal improved:
almost no problem with protons

- *More difficult for ions (GATED system not recalibrated for ions intensity)*

- Co-existence with abort gap cleaning still a problem:
  - *Cannot switch On Abort gap cleaning during squeeze*



# Loss of timing event

- Traced back to a configuration problem of the O/S in the processing of interrupts: 2 timing events were sent too close
- Several mitigation methods put in place after the events:
  - *Configuration of the BFSU machine corrected*
  - *Introduced a delay between the timing event to change the optics and the one to trigger the change of reference*

*=> No more missing event observed after the change*

| MTG tables |
|---|
| rampdown |
| injection |
| BLM_capture_test |
| optics_orbit_changes |
| precycle |
| Injection_BI |

**SELECTED MTG TABLE DETAILS**

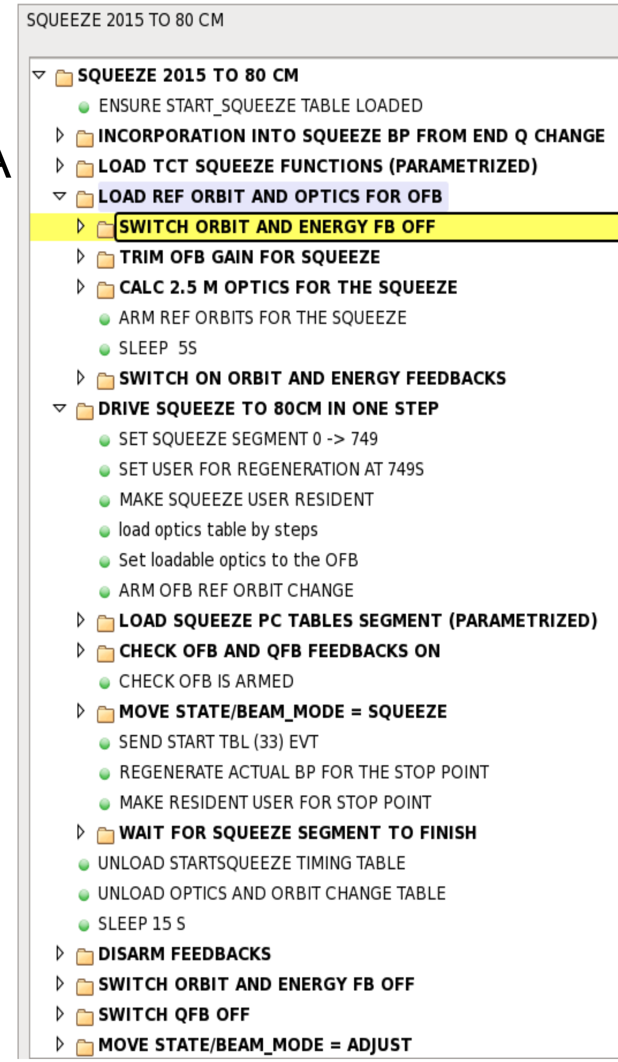
| | | |
|---|---|---|
| TABLE NAME (no space) | optics_orbit_changes | |
| START EVENT | HX.START-TBL-CT (33) - Start table(s) | Set start Event |
| RUN COUNT | -1 | |

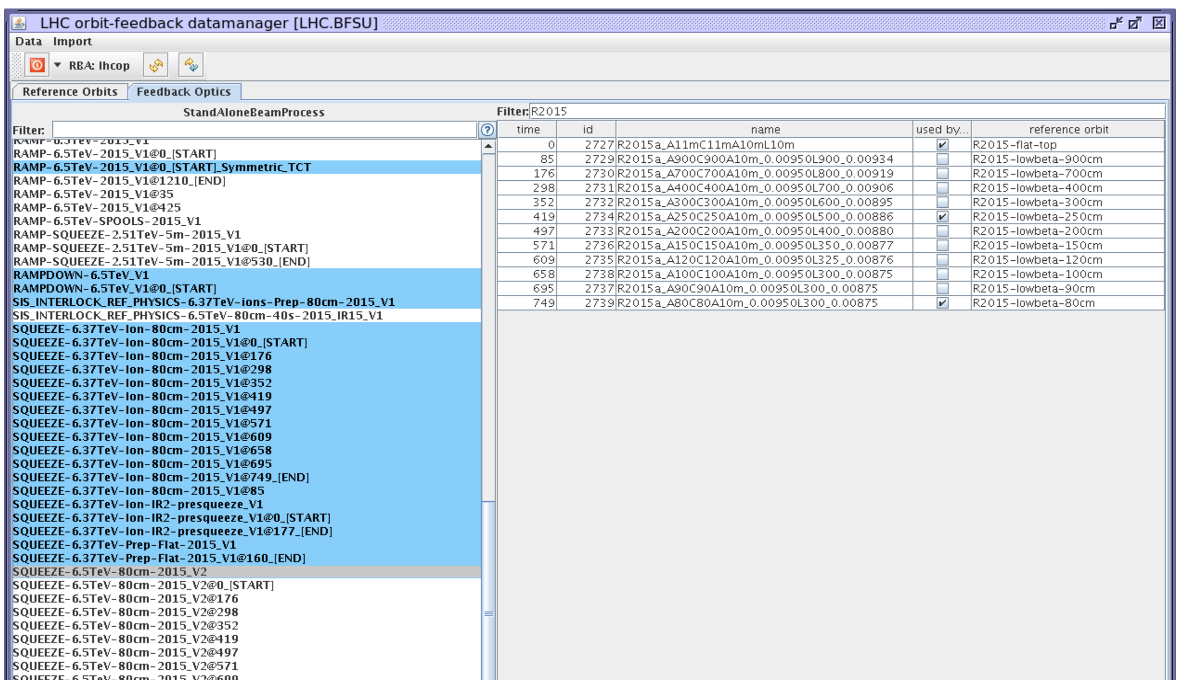
| EVENT NAME | PAYLOAD | OFFSET (ms) | EVENT DESCRIPTION |
|---|---|---|---|
| *HX.FBOREF-CT* | 1 | 0 | Start Orbit Feedback reference change |
| *HX.SIS-SSQU-CT* | 283 | 0 | Start SQUEEZE for PC intlck |
| *HX.OPTID-CT* | 2727 | 500 | Optics Identifier |
| *HX.FBOREF-CT* | 2 | 65000 | Start Orbit Feedback reference change |
| *HX.OPTID-CT* | 2770 | 65500 | Optics Identifier |
| *HX.FBOREF-CT* | 3 | 108000 | Start Orbit Feedback reference change |
| *HX.OPTID-CT* | 2768 | 108500 | Optics Identifier |

# Wrong orbit references

- Both Orbit and Tune feedback are sequencer driven via TIMING USER
- Reference Orbits stored with optics table in LSA
- Most of the errors came when cloning hypercycles for MDs or re-using Beam Processes (e.g FlatOrbit)
  - *References stored by BP type*

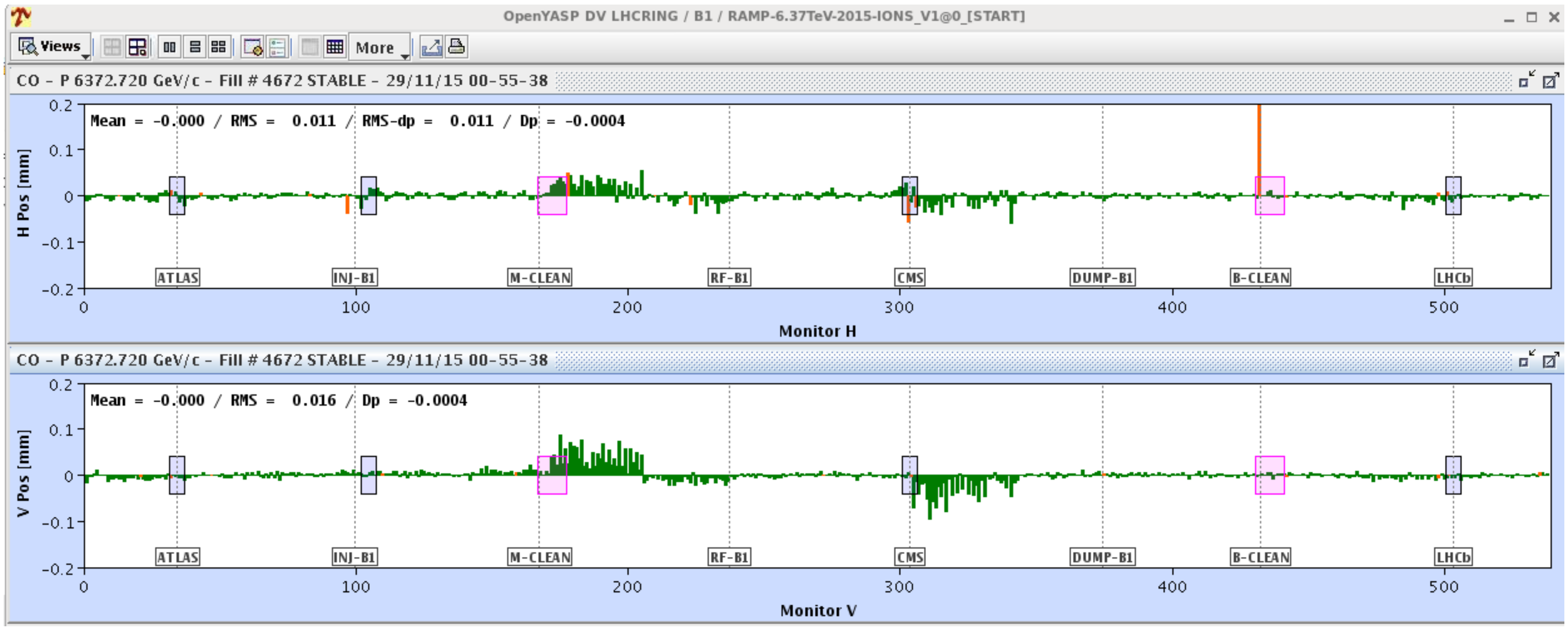
=> need to be improved



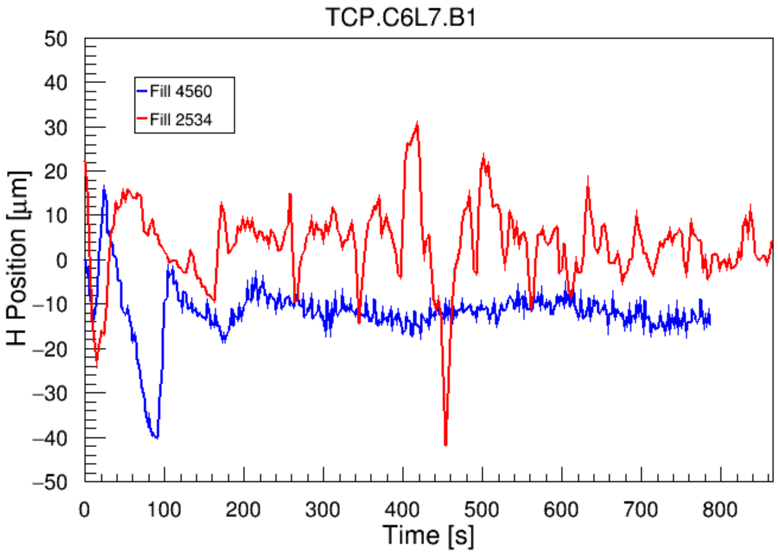
# Systematic orbit errors

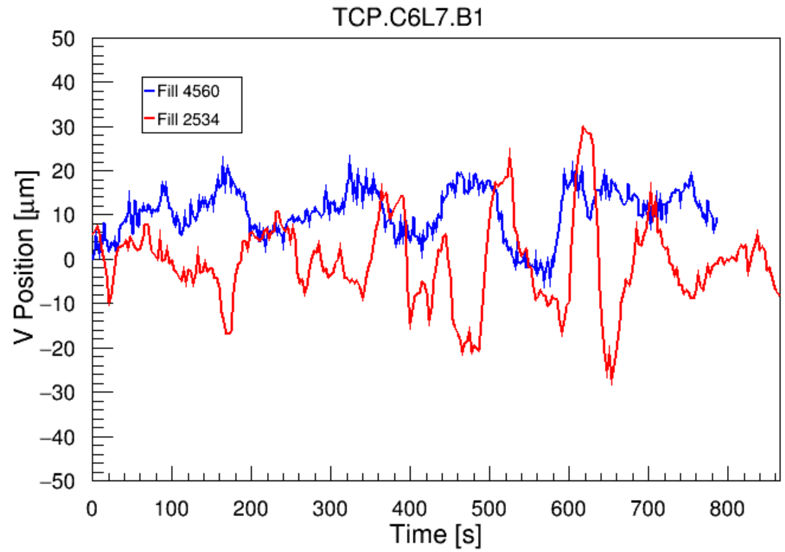
- The orbit quality was improved a lot with the rack cooling. There are remaining effects, smaller by factor ~5-10 wrt Run 1.
  - *This improvement allowed us **to run the OFB in SB !***
  - *Some crates could still be improved, mainly around points 3, 4 and 5.*



# Squeeze

- Orbit corrector function are now all forced to follow PLP segments. Trim and FF only at the matched points. Smoother orbit in the squeeze without need of high gain for OFB.

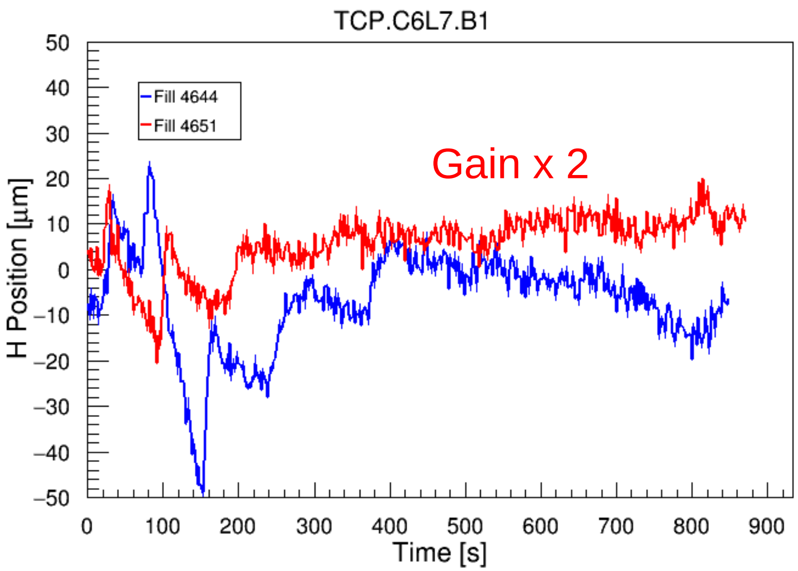


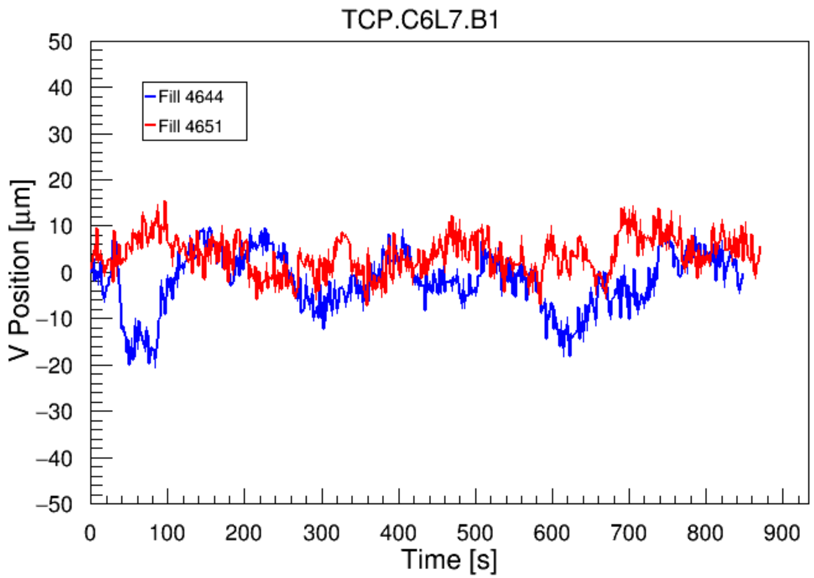




*2012*: after heavy FF following a special high gain OFB pass through the squeeze.
*2015*: simple FF at matched points. Horizontal transients remain between start of squeeze and first matched point (85 s). Operating at ~2 higher gain could bring down the orbit excursion < 20 um.

# Squeeze – more gain

- Residual perturbations can be improved with higher OFB gain.

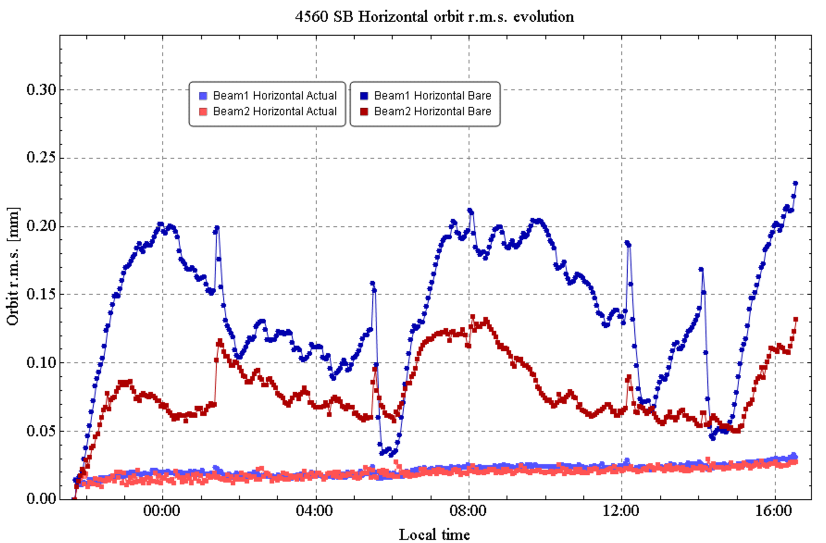


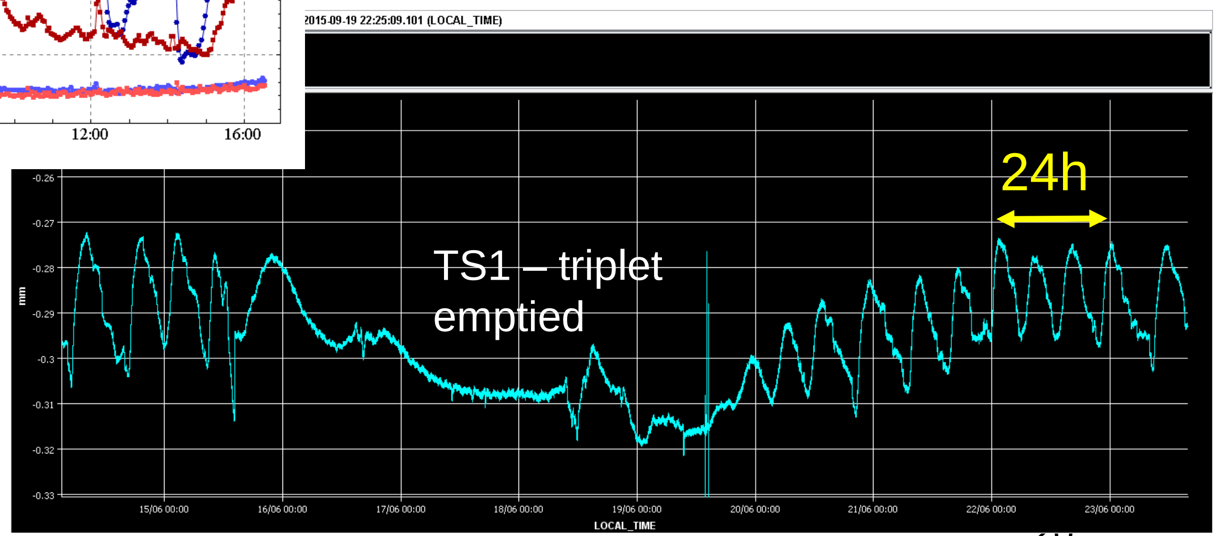

- Source of perturbations between start and first 2 matched points to be analysed – suspect IR8.

# Stable beams

- The triplet movement in R8 leads to orbit drifts of up to ~0.2 mm rms, period of ~ 8 hours. Present as soon as triplet is filled with Helium. Cause is not understood.
  - *Compensated by OFB in stable beams (gentle correction, not interfering with lumi scans…).*

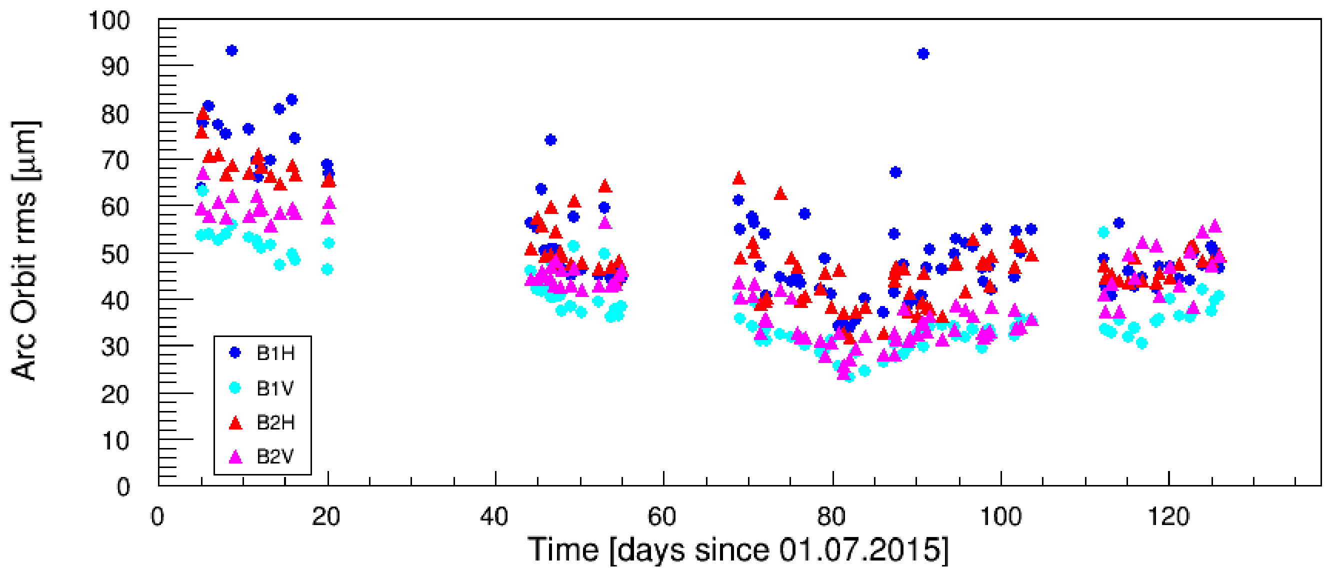



- Nice correlation with the triplet WPS readings.



# Long term orbit reproducibility

- The evolution of the orbit rms excluding the areas close to IR1, IR2, IR5 and IR8 is an indicator of the long term reproducibility of the orbit – includes BPM errors, ground motion, OFB corrections etc




rms over all healthy BPMs except IR1, IR2, IR5, and IR8 bump regions wrt reference orbit

reference fill in 25 ns period (t ~ 85).

1 point / fill, ~5 mins after start of SB.

The orbit reproducibility is ~50 µm over 3 months.
Long and short term reproducibility are quite similar.
Slightly worse reproducibility in H plane ⇔ IR8 triplet issue.

# Few ideas for 2016

- Implementation of functions for gain:
  - *For more flexible operation*
  - *Gain could be pushed on the first 120 seconds of the ramp where we observed the largest orbit & tune perturbation, similar for the start of the squeeze etc.*
- For the QFB a factor 2 could be gained by moving from 4k turns at 4 Hz to 2k turns at 8 Hz.
- Future plan for the testBed:
  - *Add more tests to increase code / use-case coverage*
  - *'Closing the loop' (ambitious):*
    - *Capture controller magnet corrections*
    - *recalculate (simulate) LHC reaction*
    - *send response back to BFSU. Could explore dynamic stability limits*
  - *Automated builds to test on every change + additional reports (e.g. Test coverage, Code quality)*
- Refactoring of the reference orbit construction and storage based on knob (on-going)

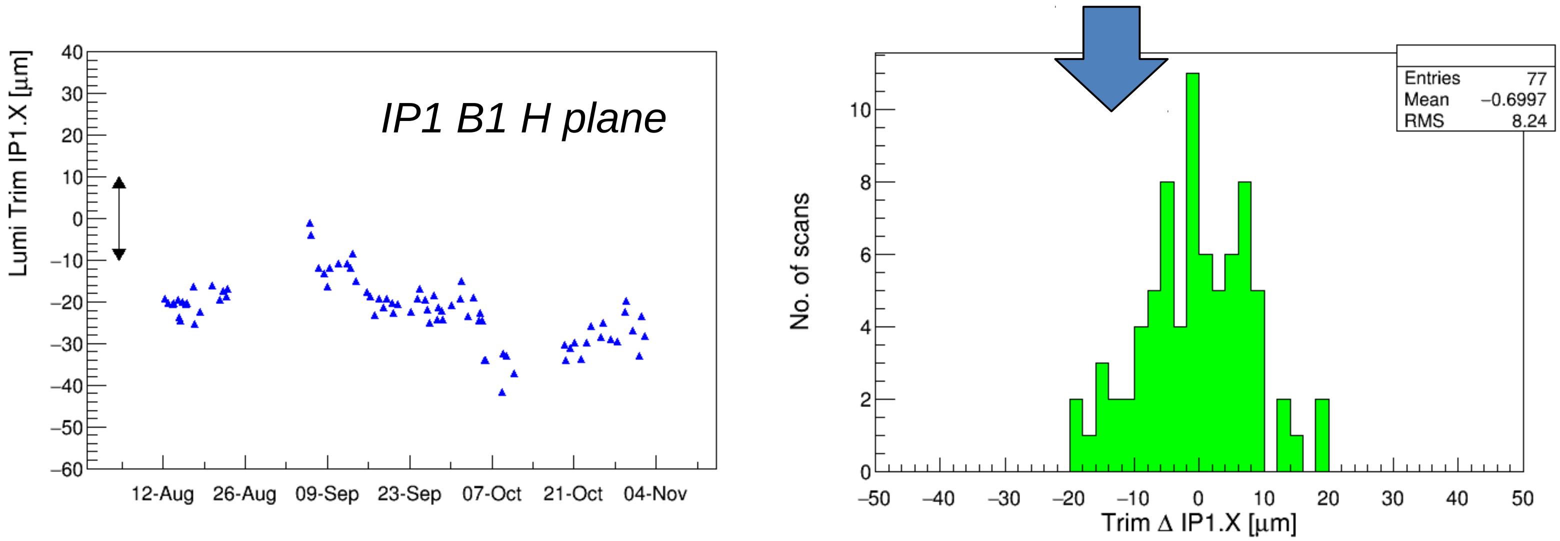
# Summary

- Major refactoring of OFB during LS1 improved stability and operability
- More experts settings available for setting-up ease the commissioning of the systems
- No major problem with Feedbacks during the nominal operation: Tune feedback used all along the proton run
- For orbit feedback we moved from the “DISABLE RT TRIMS” mode to 24h of STABLE BEAMS with FB ON.
- Some improvement in the management of the reference orbit and management of the gains are planned for next year

- Spare slides

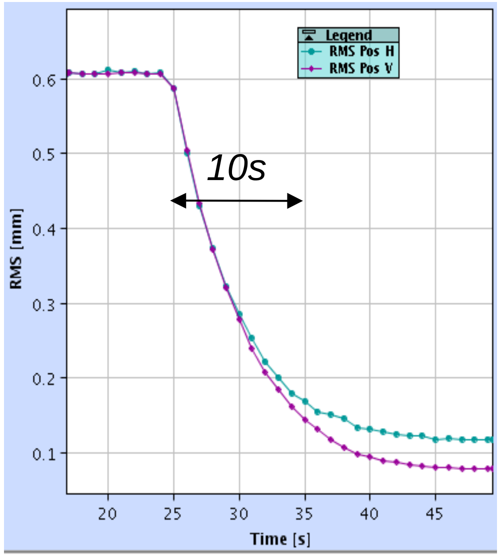
# Collision offsets

- Fill-2-fill offsets in collision are better than in 2012.
  - *Typical fill-2-fill B1-B2 offset rms is 8 $\mu m < \sigma/2$.*



# FB gain factors

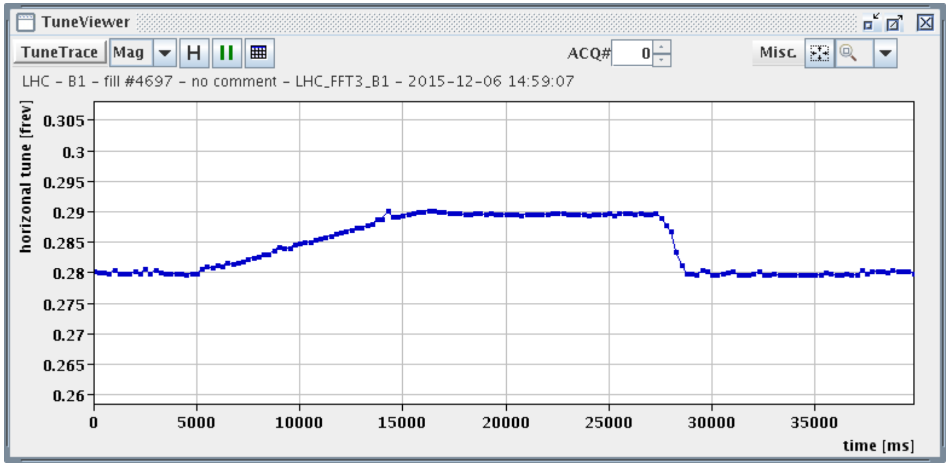
- Gain factors and FB responses




OFB gain factor (GF) = 1 => T ≈ 12 s.

2015 settings:

- Ramp: GF = 2,
- Squeeze: GF = 1,
- Stable beams: GF = 0.2.




OFB gain factor = 1.5
=> T ≈ 12 s.

2015 settings:

- Ramp: GF = 1.5,
- Squeeze: GF = 0.5.

# Writing test is easy!

- Framework based on JUnit testing framework -> execution, assertions and reports out of the box.
- Java embedded DSL to formulate readable tests on different levels:
  - FESA mechanics
  - Sending orbits and verify reaction

```
public class ExampleFeedbackTest extends AbstractFeedbackTest {
    @Test
    public void assertThatSomeValueIsCorrect() {
        /* Test Code goes here */
    }
}
```

```
String opticsName = from(OPTICS).doGet().getActiveOpticsName();

to(ACTIVE_OPTIC).partially().setFetchOFC_object(true);
```

```
prepareSendingOf(zeroOrbit()).andStart();
MultibeamOrbit acquiredOrbit = from(MultibeamOrbit.class).
                                        skip(1).and().awaitNext();
awaitLastSending(); /* assertion here */
```