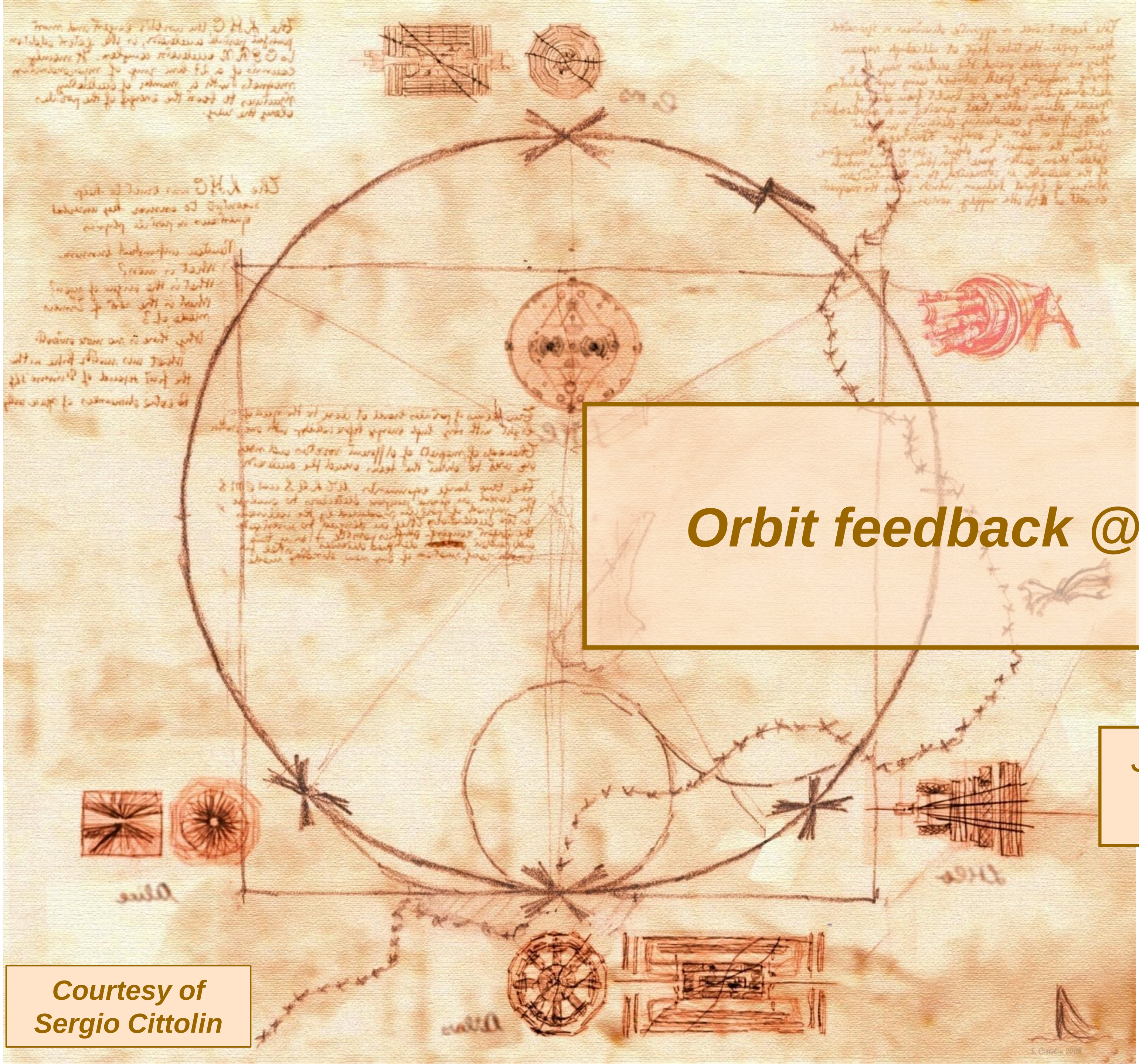


Orbit feedback @ LHC

J. Wenninger
BE-OP-LHC

Courtesy of
Sergio Cittolin

Back to the specs…

- The requirements for orbit stabilization were mostly driven by collimation (to preserve the collimator hierarchy).
  - *There was no operational experience of complex multi-stage cleaning systems → made the specs a bit tricky.*

- There were a number of other local requirements, and not too well defined demands from machine protection (for example).
  - *The LHC parameters were so much pushed wrt existing machine that it was not always easy to know what would be really required !!*

- LEP experience + LHC simulations:
  - *RT feedback required for ramp and squeeze.*
  - *In other (stable) phases of the LHC cycle, orbit changes are very slow – uncritical. Ground motion not a big issue (was not at LEP).*

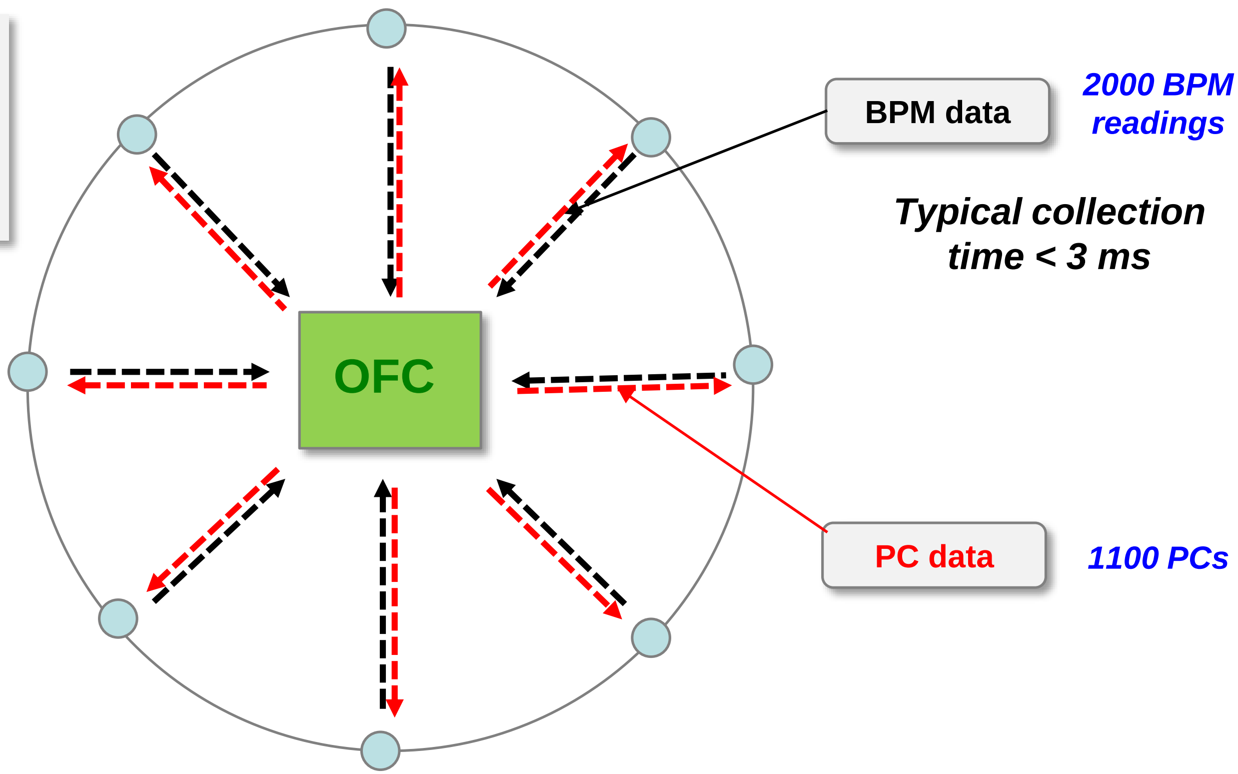
→ closed-loop FB bandwidth of ~ 1 Hz sufficient

(⇔ digital FB loop must operate at ≥ ~ 25 Hz)

Architecture of the orbit FB

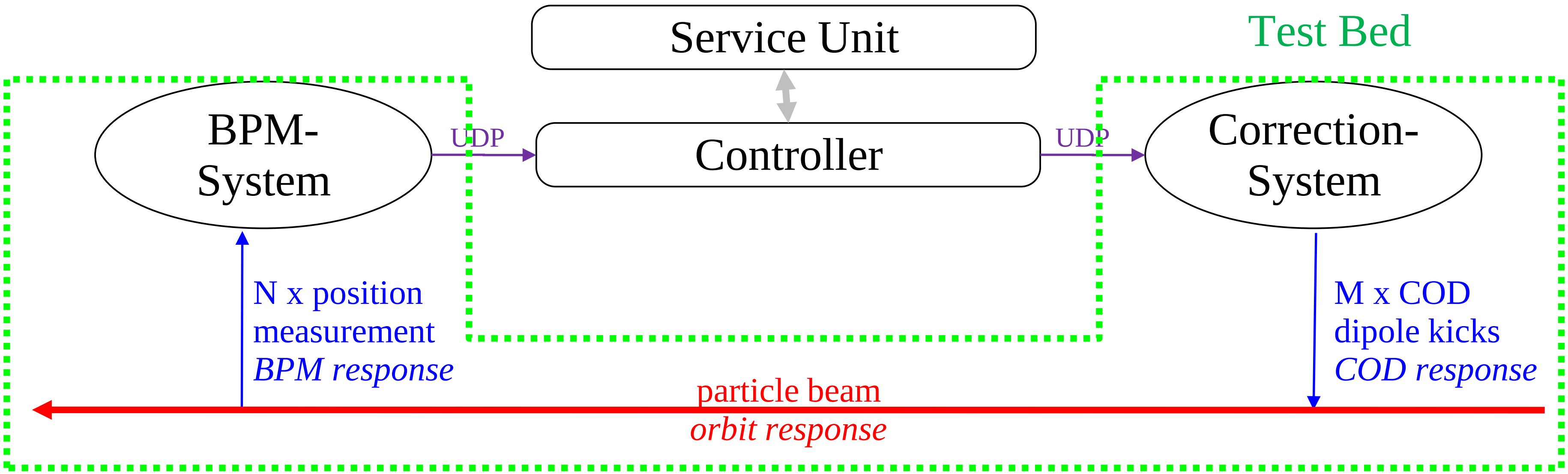
- A **FB Controller** (**OFC**) is running in the control room where all information is concentrated, processed and dispatched again.
- The beam position monitors ('sensors') and the PCs ('actuators') that feed the magnets are distributed around the LHC rings.
  - The sensor data is centralized in 70 front end crates (FECs) installed in all 8 LHC points.
  - The actuators data is dispatched to ~40 FGC FECs installed in all 8 LHC points

Data is transmitted over Gigabit Ethernet (Technical Network) with the UDP protocol



FB central control

- The central processing of the digital FB is performed on 2 multi-core servers in the CCR (soft real-time Linux).
- The **FB Controller** (**OFC**) process is collecting the data, calculating the corrections and sending the trims out to the FGC gateways.
  - Orbit data is currently sampled **at 25 Hz**.
- The **FB service unit** (**BFSU**) handles FB settings and dispatches data to clients (orbit data). It serves as a proxy to protect the OFC from the outside world.

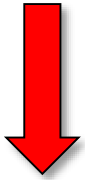


Actuation – PC control layer

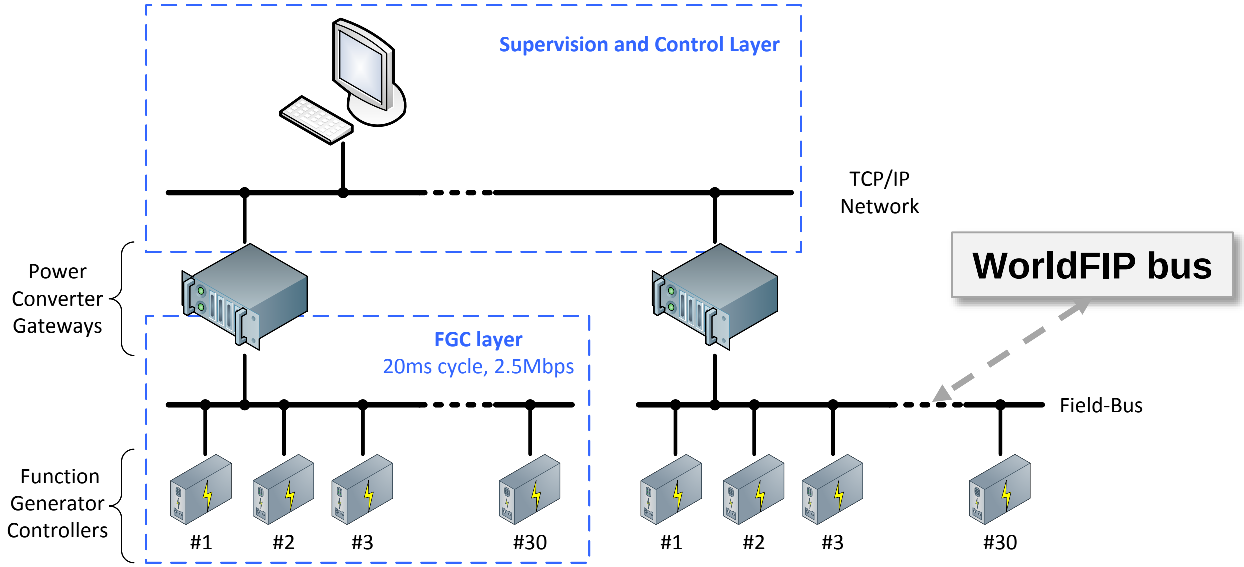
- The LHC PCs have digital control system – FGC (Function Generator Controller)
- Local gateways (by LHC point) receive control input (functions, state commands, **RT inputs**) through the Technical Network.
- Data is exchanged between gateways and FGC units (1 FGC ⇔ 1 PC) by a **Worldfip** bus operated at **50 Hz**.

Max. digital loop frequency is 50 Hz

FGC period for orbit correctors is currently 80 ms (12.5 Hz)



Max. closed loop BW ~0.5 Hz



Status and limits

- The LHC OFB is currently running with a period of 80 ms (12.5 Hz):
  - *Limits the BW to ~0.5 Hz,*
  - *In general the BW is adjusted to ~0.1-0.2 Hz.*
- With the current hardware and some effort, it is possible to push the period to 20 ms (50 Hz).
  - *Push the BW towards **~1-2 Hz**.*

→ No way to control oscillation frequencies of 50-100 Hz

- To fight oscillations at 100 Hz the digital FB loop must operate above **2 kHz**, ideally at **10 kHz** – the LHC revolution frequency !!!
- All components in the loop must be upgraded to operate at that speed.

kHz orbit FB

- For perturbations arising only in the triplet area (and vicinity) of ATLAS and CMS it is probably sufficient to include **a few dozen BPMs on each side of the 2 IRs**.
- For nominal beams, the **resolution of the orbit** is in the μm range even at that frequency with the current acquisition (WBTN) – **OK**.
  - *But commissioning with very low intensity may not work.*
- The BPM system needs a **new readout system** (split BPM signals?) that can readout and publish the data in less than **1 ms**.
- The orbit data of IR1 and IR5 has to be concentrated over a fast Gigabit Ethernet in less than **1 ms** – **sort of OK**.
  - *One may need a private network, but QoS (Quality of Service) with priority routing may also be OK.*
- Processing of the data will (may) have to be done 'in hardware' (**FPGA**) and not in a real-time Linux system.
  - *Filtering to remove slow orbit changes and only act on frequencies > 1-5 Hz.*
  - *Decouple from the current slow OFB in frequency domain.*

kHz orbit FB (2)

- The corrections must be send to a **new PC control system** that can operate in the kHz regime → need a new field-bus (not WorldFip) or direct Ethernet connection.
    - *Such systems are foreseen as future FGC upgrades (LS3?) at least up to ~kHz.*
- Finally one needs a few magnets / IR (and space) that can operate at 100 Hz and the associated PC (with sufficient voltage).
- The overall loop delay must be limited to ~ 1ms.

Summary

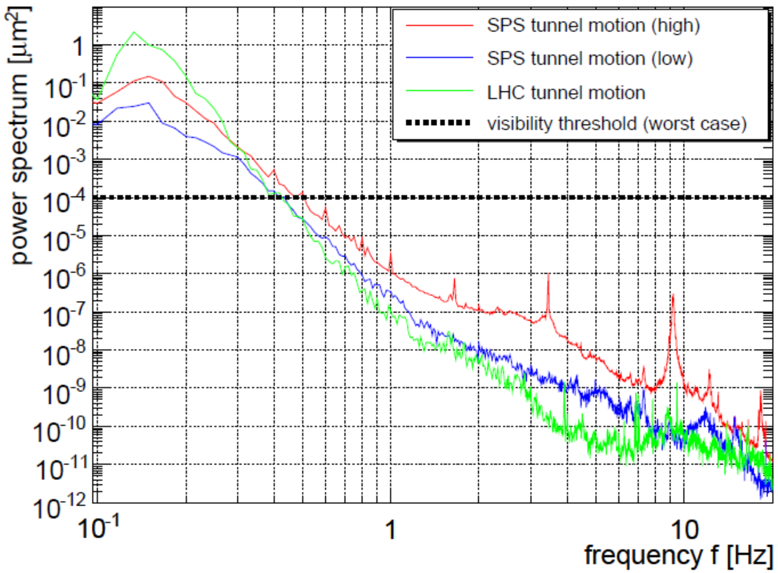
- The current orbit FB cannot be used for vibrations of the triplet – too high frequency for that system.
- A FB loop operating at ~1 kHz (⇔ max 50 Hz bandwidth) looks feasible but requires:
  - *A new kHz BPM acquisition system for ~ 50 BPMs,*
  - *Possibly a dedicated Gigabit/Fast Ethernet network,*
  - *A new kHz FGC/PC control system (radiation tolerance !),*
  - *Adequate magnets and PCs.*

  All numbers + performance to the confirmed !
- Pushing the operating frequency much higher looks a lot more challenging (on the LHC scale)…

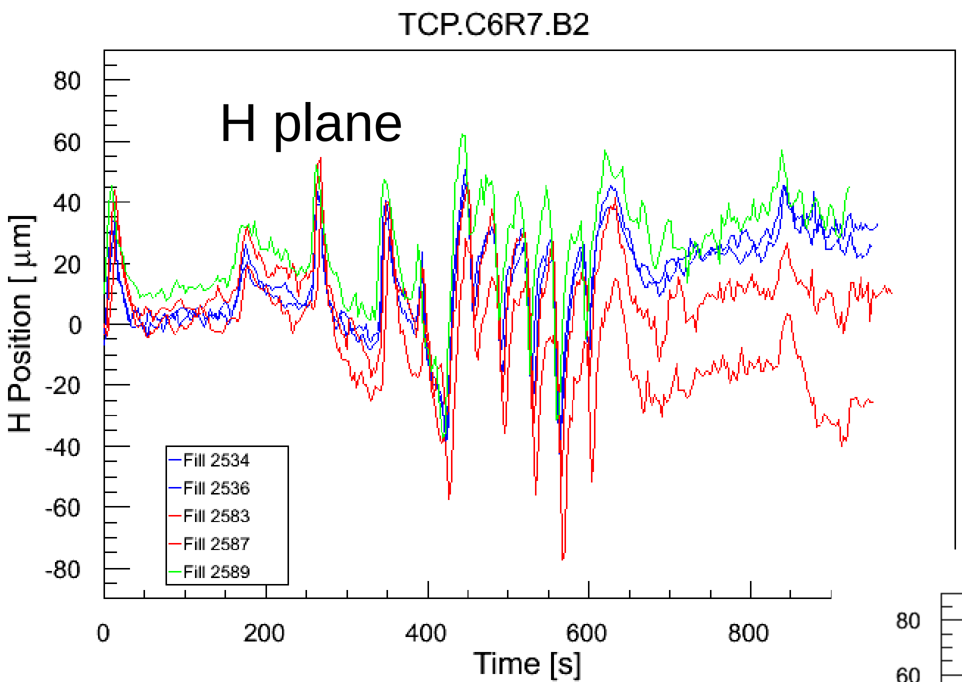
Ground Motion

- Ground motion has a large frequency spectrum, for the LHC orbit we are mainly concerned by changes on time scales of minutes to months.

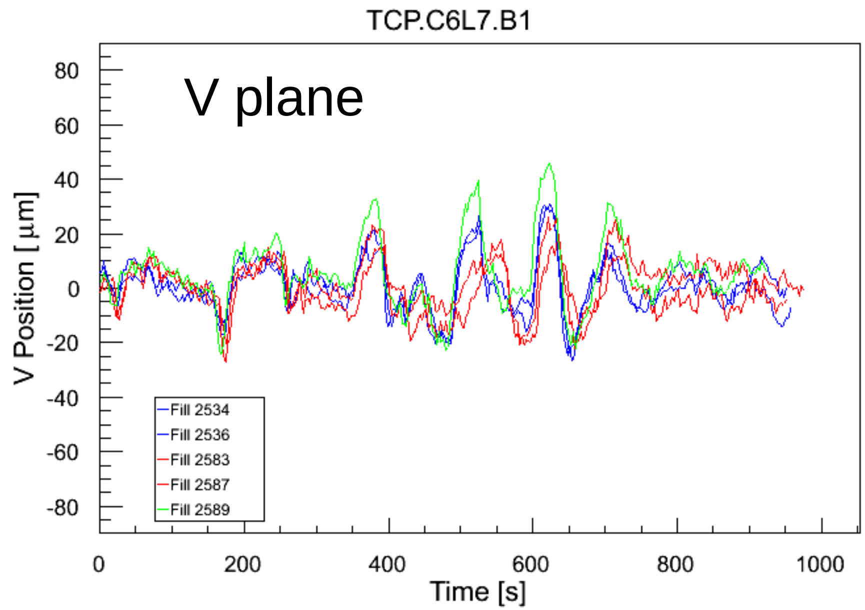
Ground motion spectrum (CERN-AB-2005-087)



- The drift over one year of typical machine elements is ~0.1 mm.
  - Depends on location, can be much larger close to geological faults.
- The drift on the time scale of **1 day** to **1 week** is sufficiently small to be able to inject the beam with magnet settings based on the last orbit correction and then to correct the resulting orbit.
  - Drifts are at the level of 1 mm rms or less.



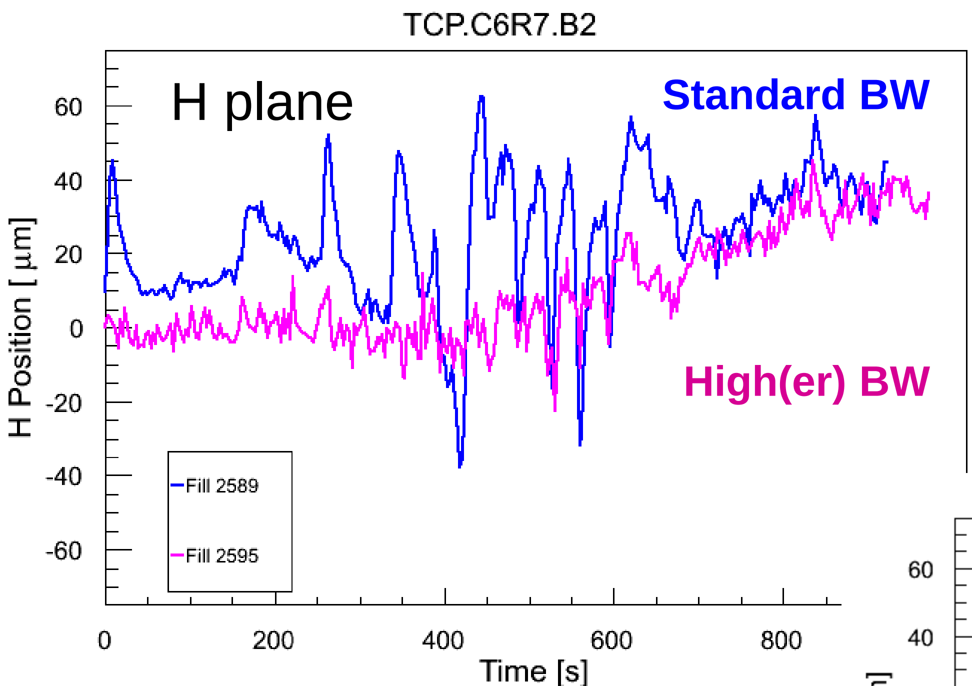
- 5 fills in April/May.
  - ***Good example for the typical F2F reproducibility.***
- Residual spikes at the matched optics points: smoothing in LSA and too coarse optics changes.
- At LEP the squeeze was practically unpredictable !



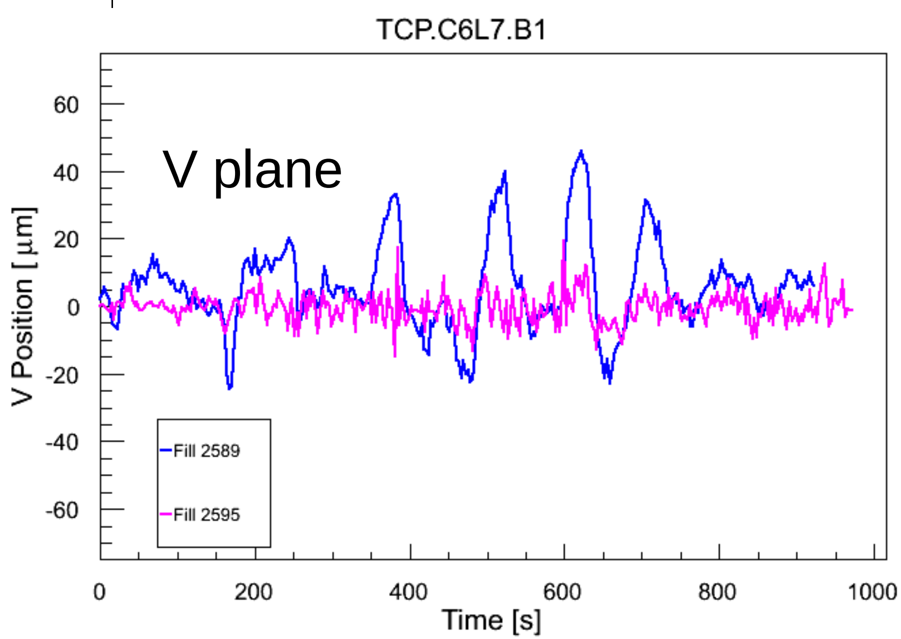
Better than specs !

But not good enough with tight collimators…

Performance – squeeze 2012 (2)



- Test with higher bandwidth to cure residual spikes - makes a difference !
- Feed-forward (FF) of the high bandwidth fills very successful.
  - ***FF preserves quality.***
  - ***After FF back to normal BW.***



Much better than the specs !