IP positions and angles, knowledge and correction

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Orbit at LHC

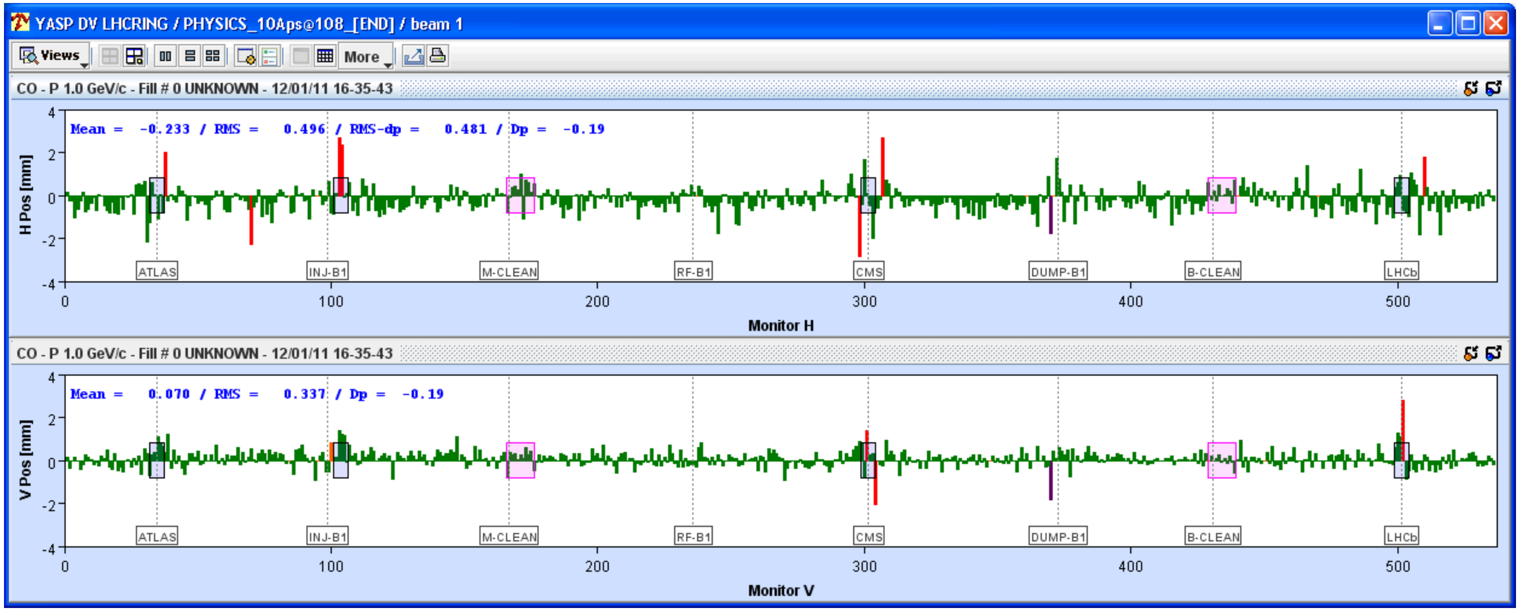
2010 was the first year of real operation, with a significant learning curve along the year.

- Orbit handling and orbit data quality improved along the run, sometimes hampered by ‘legacy’ effects (and lack of time to do fresh setups).

Orbit handling in 2011 (in 2010 only for part of the year):

- Define base reference orbit at injection with a flat machine.
  - Corrected orbit rms ~0.4 mm which is much better than design. Results an in aperture gain of ~ ±2 mm (>> β^* reach).
  - (so far) no special treatment of IRs (zero crossing angle).
- The same orbit is kept through the cycle, changing only the amplitudes of separation, crossing and lumi scan bumps.

LHC orbit – no bumps



H

±4 mm

Beam 1

V

H

Beam 2

V

Orbit at LHC (2)

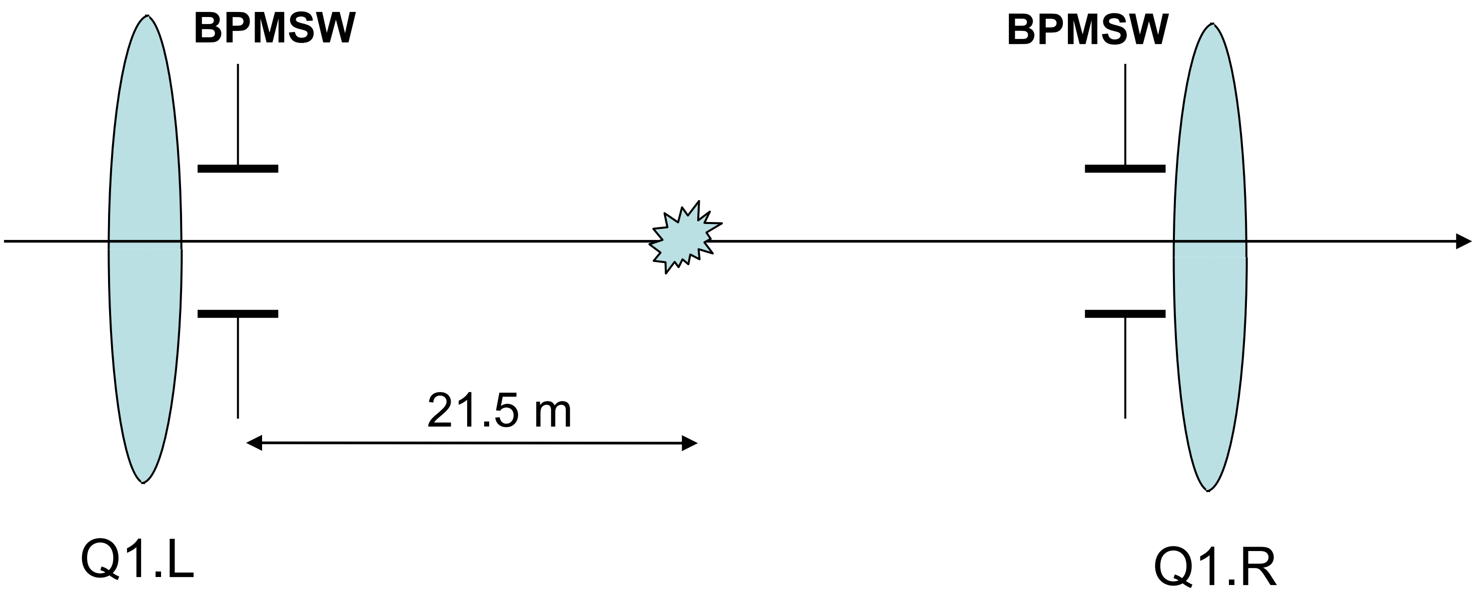
- Define base reference orbit at injection with a flat machine.
- The same orbit is kept through the cycle, changing only the amplitudes of separation, crossing and lumi scan bumps.
  - The bumps are ‘added’ on top of the base orbit.
  - Imperfections of the bumps (leakage outside the bump area from optics errors etc) are corrected experimentally.
  - Rough check of the measured crossing angle/separation (10%)
  - The residual variations (bumps excluded) through the cycle are at the level of 0.05-0.1 mm rms.

  >> maintain identical orbits in IR3/7 for collimation to minimize the setup time.

Intensity effects

- The LHC BPM has a sensitivity switch (auto-trigger threshold).
  - Low sensitivity range: ≥ 5-6e10 p.
  - High sensitivity range: < 5e10 p.
  - Residual intensity dependence.
- The base orbit is defined for bunches with a charge of ≥6e10 p.
  - The rms difference of orbit readings for a low intensity bunch (1e10p) and a nominal bunch (1e11p) injected one right after the other is ~150 μm.

IP positions - BPMs



- **BPMSW** position monitors (strip line) can be used to interpolate the IP beam positions and angles.

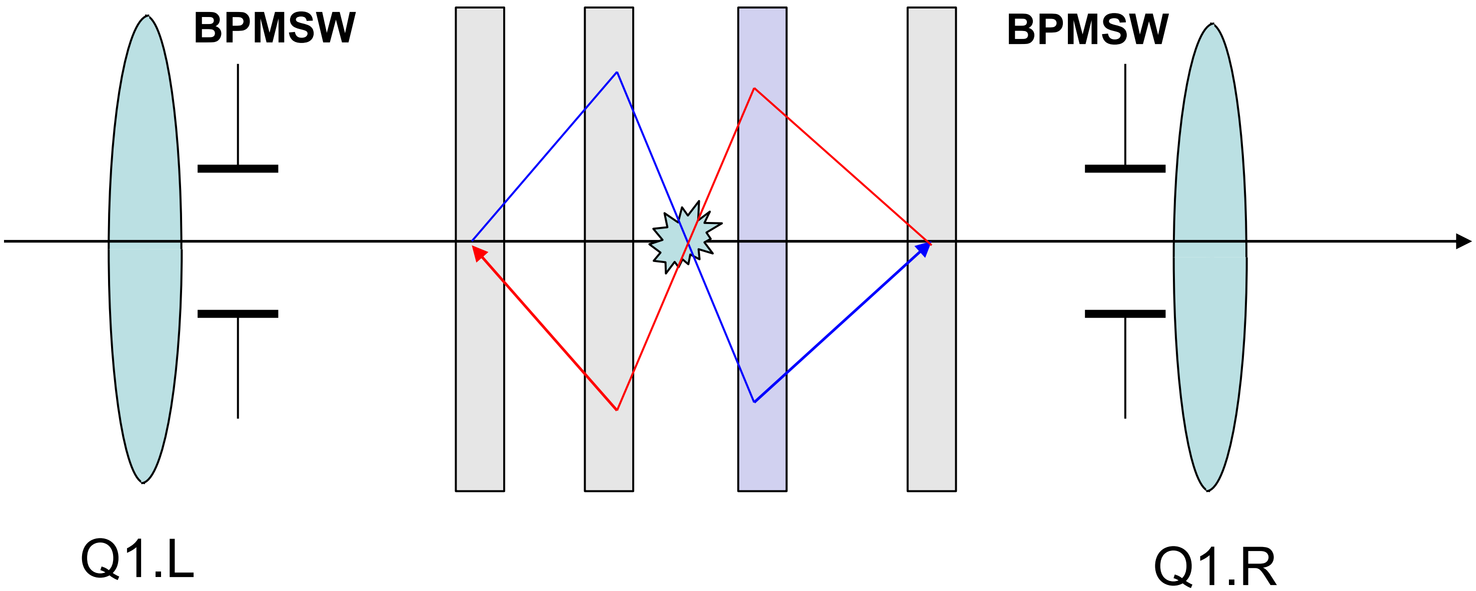
  Independent readouts for b1 and b2 → increased syst. errors.

- In IR1and IR5 there is an additional button monitor **BPMWF** (21.7 m) with common readout for b1 and b2.

  Requires timing information to disentangle the beams.

  Usable only with large bunch separation.

Spectrometer bumps



The internal crossing angles due to the spectrometer bumps (ALICE & LHCb) cannot be measured with machine BPMs.

We (machine) are effectively blind. We can only deduce it from the magnet settings and the external crossing angle bumps.

Requires measurements with beam-gas events a la LHCb…

BPM issues : temperature

- Long term stability limited by ambient temperature dependence
  - Systematic offset in the position measurement
  - Average value: 2.2 ADC bins/deg C (ARC BPM = **~50 um/deg C**).
  - ΔTemp in 24h varies from day to day but can be up to **6^0C**.

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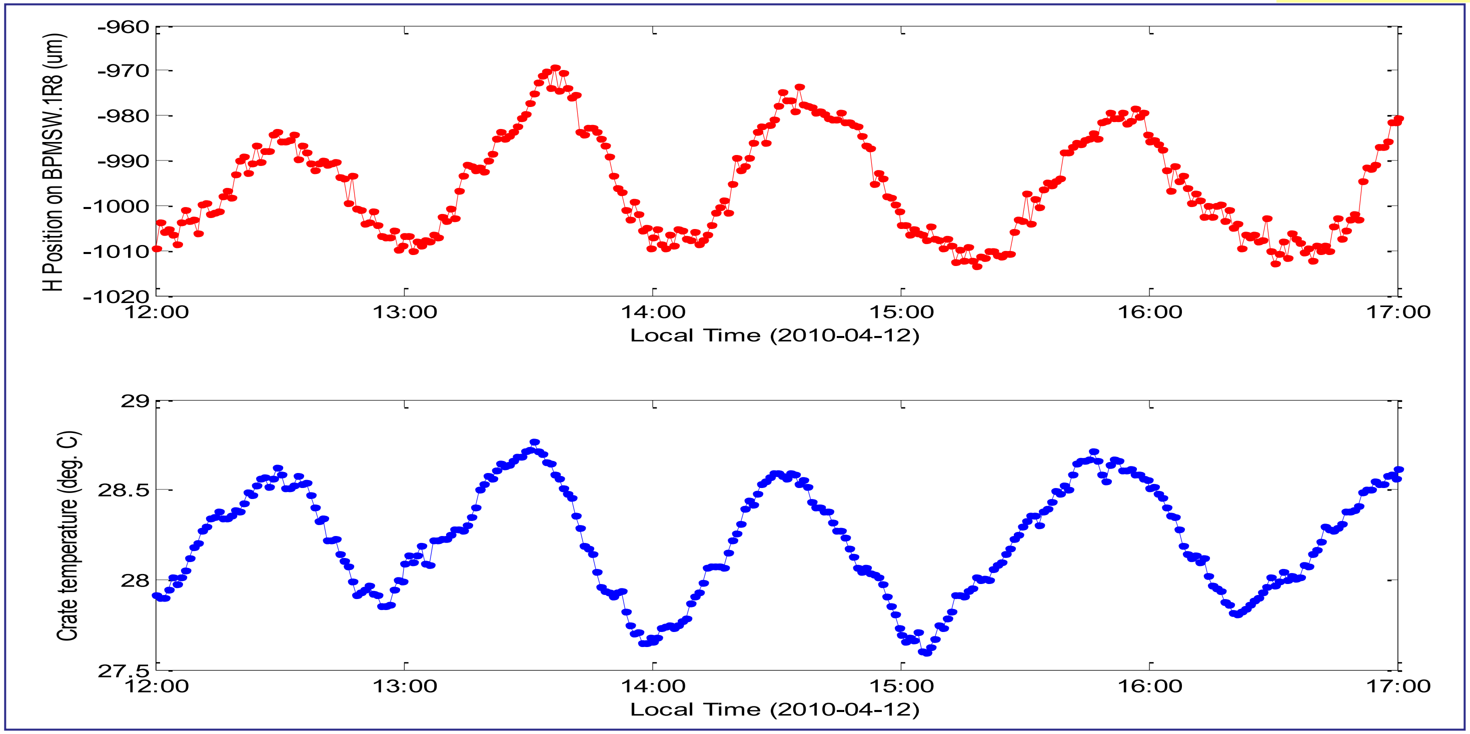


Systematic shifts of up to ~300 μm have been observed

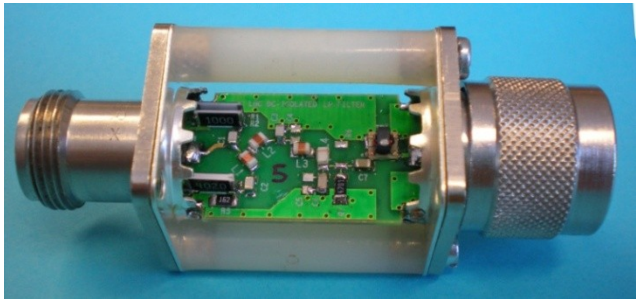
Temperature drift mitigation

- Calibration procedure in place for the temperature coefficient.
  - Temperature changes induced by reducing fan speed of VME crate while sending calibration pulses.
- In 2011 we plan to systematically calibrate the BPMs (not the T coefficient) at the start of each fill (not done in 2010).
  - Minimize accumulated temperature errors.
- Proper solution with temperature regulated racks in preparation (long shutdown).

BPM issues: 'Missing' channels (3%)

E. Calvo – Evian WS

- 75% correspond to BPMs close to the IR
  - Long coaxial cables (deported electronics)
  - Coupled noise and/or ground loops
- **Cable adapters** will be installed this XMAS stop
- Expect to reduce RMS noise in many channels



Strip line monitor issues with low bunch charge (< 4e10):

- Beam directivity smaller than sensitivity of electronics (~20 dB vs 35dB).
- With I_{beam}>2e10 p/bunch, B1 bunches can trigger B2 channels and vice versa. (LHC BPM front-end electronics auto-triggered, no timing signals in tunnel).
- During 2011 commission **Synchronous orbit mode** (bunch mask) will reduce this problem.

The IR BPMs are not out best BPMs – situation expected to improve in 2011 (lower noise and bunch mask for orbit acquisition).

IP position/angle from BPMSW

For the collision orbit (where by definition we know that we collide), **interpolations from the BPMSW**:

- Beam offsets: according to the interpolations the beams should miss each other in 3 out of 4 IPs, with offsets of up to 500 μm.

  Large systematic errors (they are rather constant).

  Rely on luminosity scans to determine optimum beam overlap. LHC-OP never uses the BPMs to optimize beam overlap (except when desperate !).

  The offsets can be measured using so-called K-modulation – tested, but not done systematically (lack of time/interest).

- The measured external crossing angles agree with expectations within some 10-20 μrad.

  Matches the expected accuracy of ~20 μrad (from observed BPM errors).

IP crossing angle from BPMWF

- For the crossing angle much lower systematic errors should be achievable because both beams are handled by the same readout.

  BPMWF only work with fillings based on isolated bunches (OK for 90+ m β running & VdM configurations).*

  → BPMWF are not part of normal orbit data.

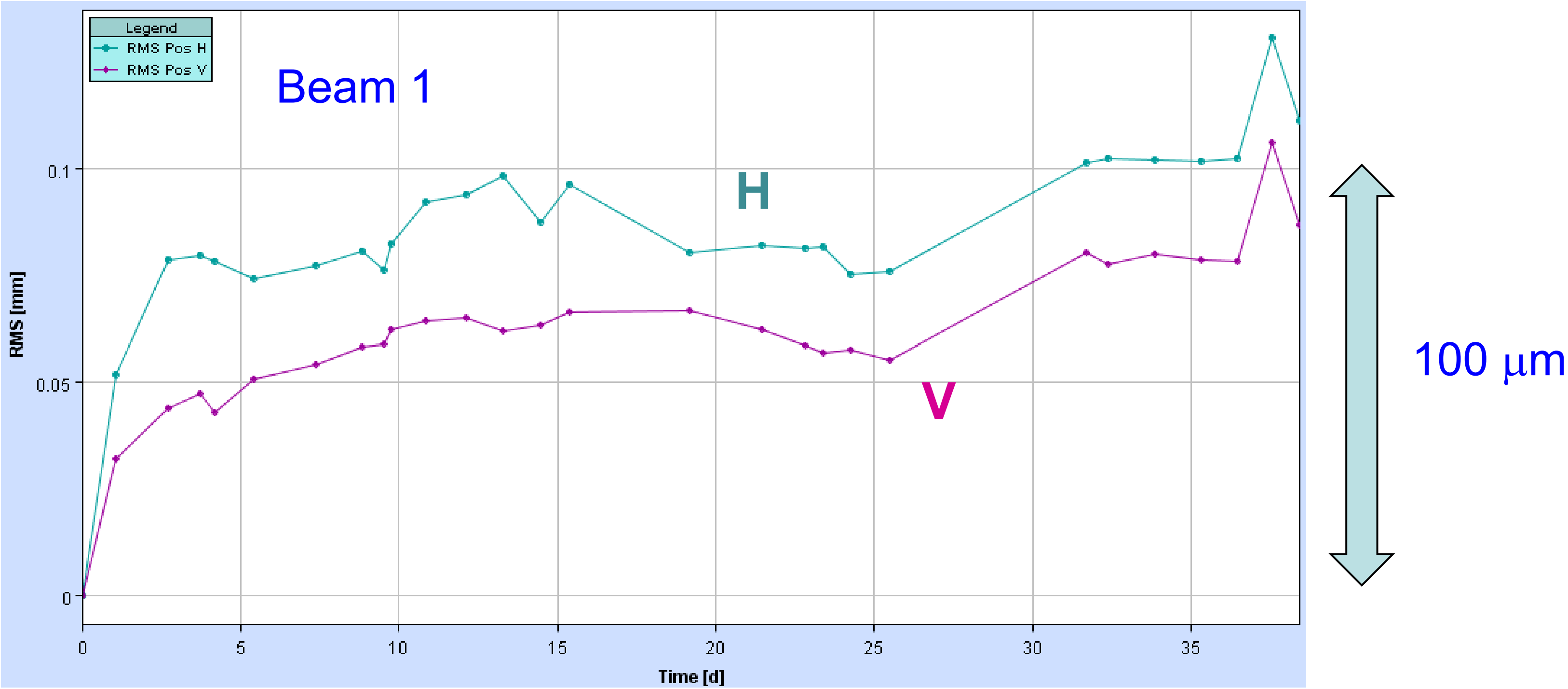
- In 2010 the BPMWF were used occasionally in 'expert' mode.
- In 2011 bunch-by-bunch orbits will become available (@ 0.1 Hz), it is planned to include the BPMWF.
  - *BPMWF information will be available for tuning and diagnostics (not for trains).*
  - *Systematic uncertainties to be estimated in 2011 (TOTEM & ALFA). It should be possible to reach the μrad scale.*

Reproducibility & stability

- Beam position changes due to:
  - Ground motion (random walk).
  - Earth tides (radial beam movement).
  - Magnet reproducibility.
  - Position measurement errors (→ wrong corrections).
- Changes counteracted by:
  - Orbit and radial position feedback (ramp & squeeze). We are considering extending this into the stable beams period.
  - Manual luminosity scans to optimize the beam overlap.

At high intensity the OP crews have instructions to stick as closely as possible the reference orbit – machine protection. Beams are dumped in case of excessive excursion (even if no beam loss !)

Stability fill-to-fill



Global orbit rms change during 150 ns operation (wrt first fill).

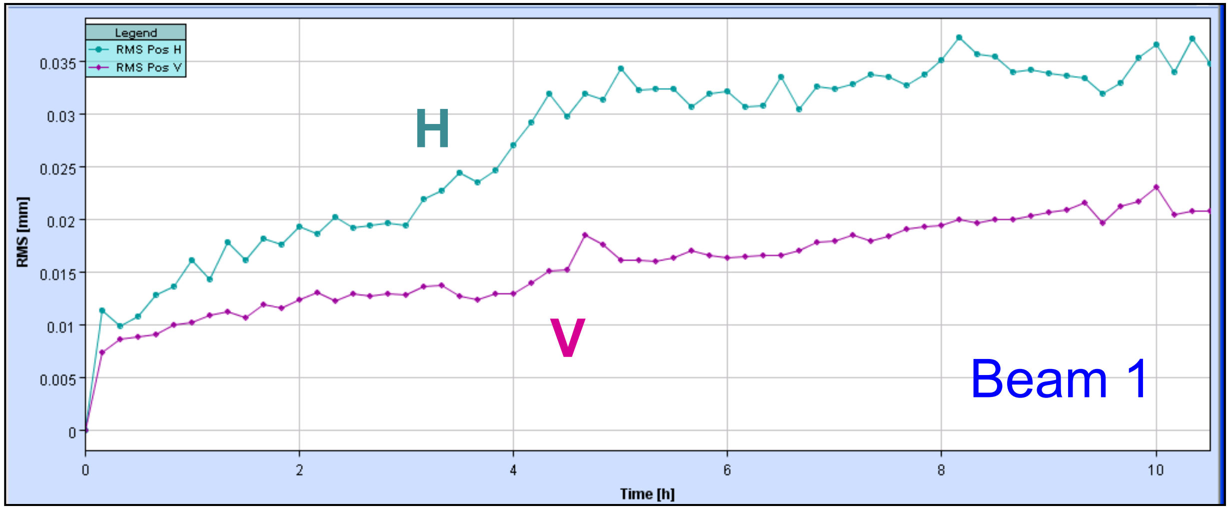
Residual AFTER correction (5 mins into a fill).

Uncorrected orbit change would have been ~0.5 – 1.5 mm rms.

Stability in a fill

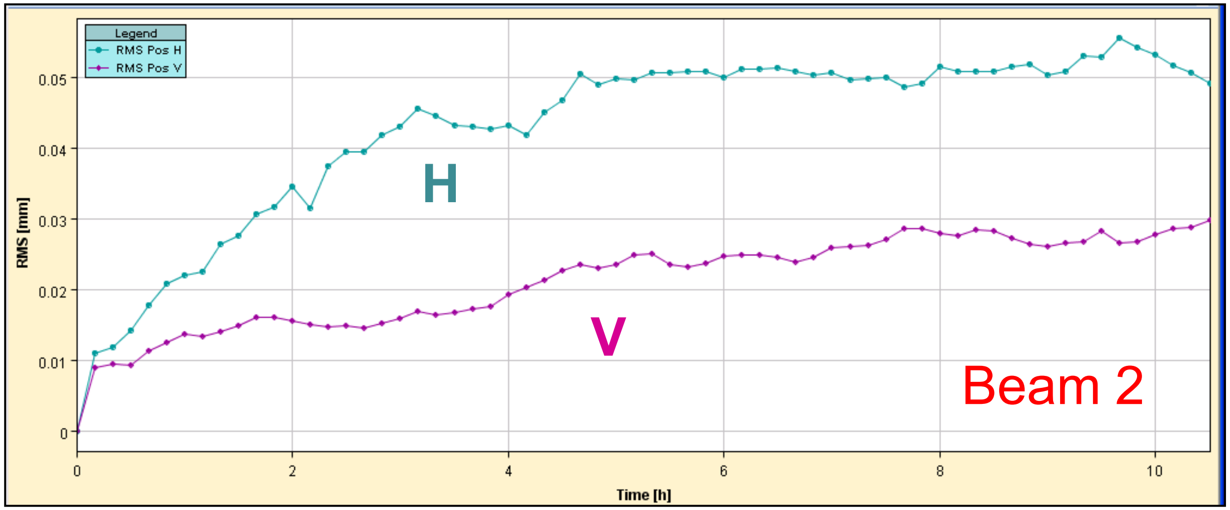
A rather typical example…

30 µm



In stable beams Earth tides are often the dominant perturbation !

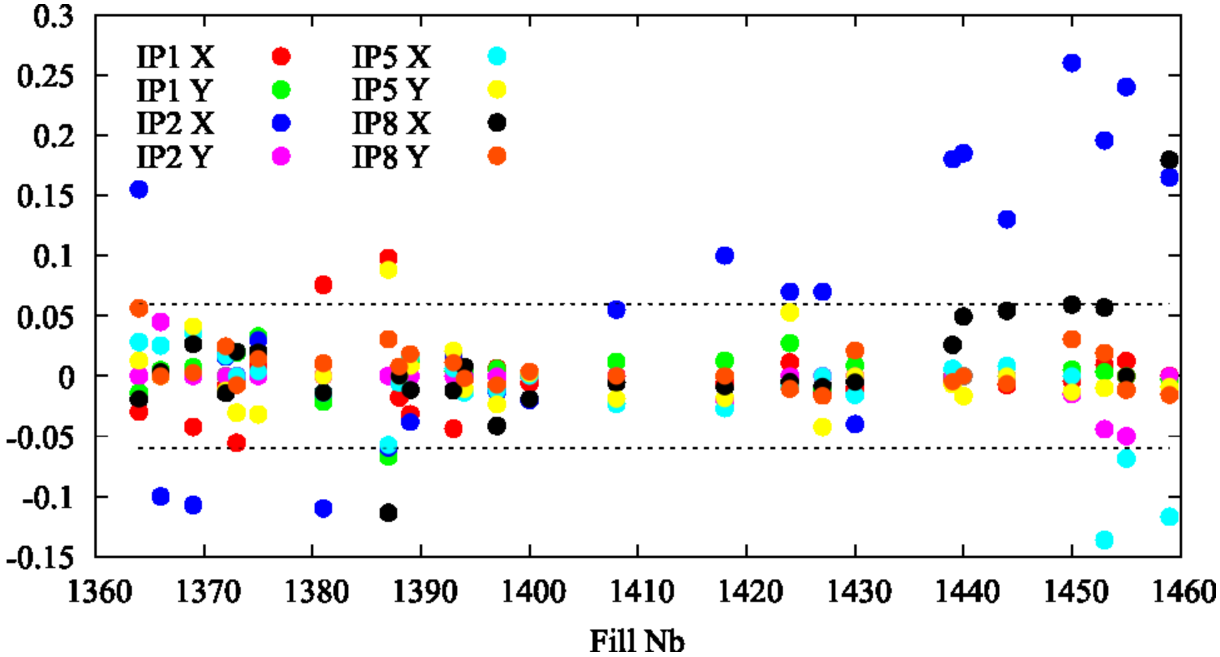
30 µm



10 hours

S. White – Evian WS

- **Amplitude of the corrections (B1-B2) applied. Fills since 10A/s ramp:**



Statistics over all fills excluding IP2:

Δx_{rms}	41 μm
Δx_{max}	180 μm
Δy_{rms}	21 μm
Δy_{max}	90 μm

⇒ **Fill-to-fill reproducibility: in general within +/- 60 μm. Sufficient to find collision point with actual beam parameters (σ ~ 60 μm).**

⇒ **Horizontal plane worse than vertical plane.**

⇒ **IP2: large differences due to offset collisions.**

2011

- In 2011 a new base orbit will be defined.
  - The machine will be bootstrapped from that base.
- We hope to see improvements in several areas.
  - BPM data quality: temperature correction, calibration procedure.
  - BPM offset determination using K-modulation (matter of priority…).
  - Fine tuning of the correction strategy.
  - Smoother switching between low and high intensity bunches.
- We will also start to investigate more systematically the (non-) reproducibility of the machine orbit, in particular collision offsets.
- A large amount of work ahead to understand systematic effects for total cross-section measurements by TOTEM/ALFA.