miscellaneous slides, status and comments on:

LHC (Beam 2) Commissioning

- BPM, Q, Q'
Instrumentation and Diagnostics -

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Outline

For those who have been nice...

- Tune Measurements
- Coupling Measurements
- Chromaticity estimates
  - Injection tune shifts
  - Q resonance width & Q_s side-bands
  - ...

Something to think about/follow up...

- Residual LHC beam noise and misalignment estimates
  - BBQ and BPM resolution

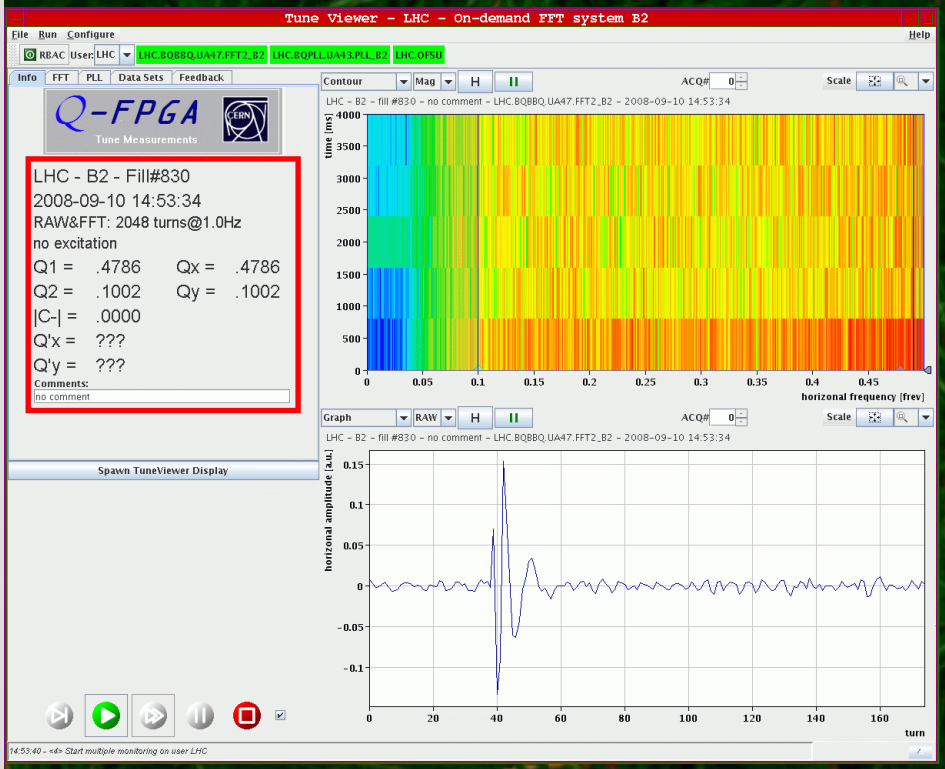
LHC Base-Line Q/Q' Diagnostics Overview – Q/C⁻ BBQ Use-Cases Abstraction

- Three independent BBQ Tune/Coupling diagnostic chains available per beam:
  - PLL based acquisition - commissioning pending!
    - one measurement at high/reduced acquisition frequency, targets:
      - 100 Hz for feedbacks (driven by need to reduce feedback latencies)
      - 1 Hz for general purpose logging
    - expert: high frequency data, event synchronised and buffered (post-mortem, PLL setup), typical length: 5 min ↔ < 1 MB of data
    - main use: monitoring/logging, feedbacks, fill-to-fill studies, ...
  - FFT based acquisition – 'periodic' (FFT1) – B2 fully commissioned
    - one measurement every 1 second starting from first-injection
    - intended use: monitoring/logging, (feedbacks), fill-to-fill studies, ...
  - FFT based acquisition – 'on demand' (FFT2) – B2 fully commissioned
    - n-measurements synchronised to an external event (BPM, BQ, ...)
    - intended use: expert diagnostics, detailed studies, ...

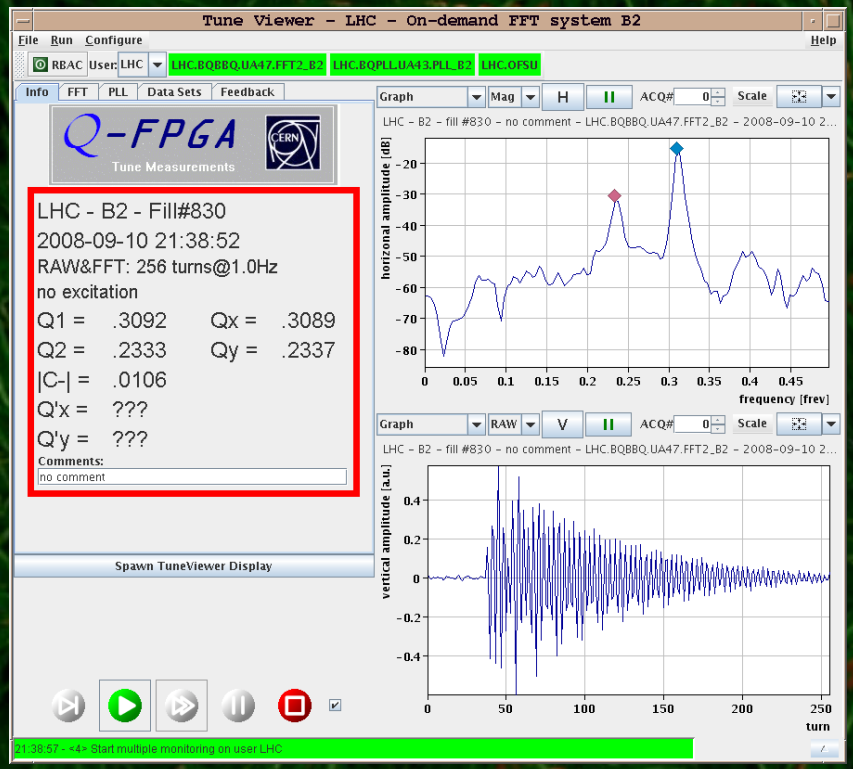
Present Commissioning State

- BBQ systems for B2 including excitation and correction commissioned
  - One important stepping stone in getting the beams circulating

Very first turn B2 (B1 similar)!



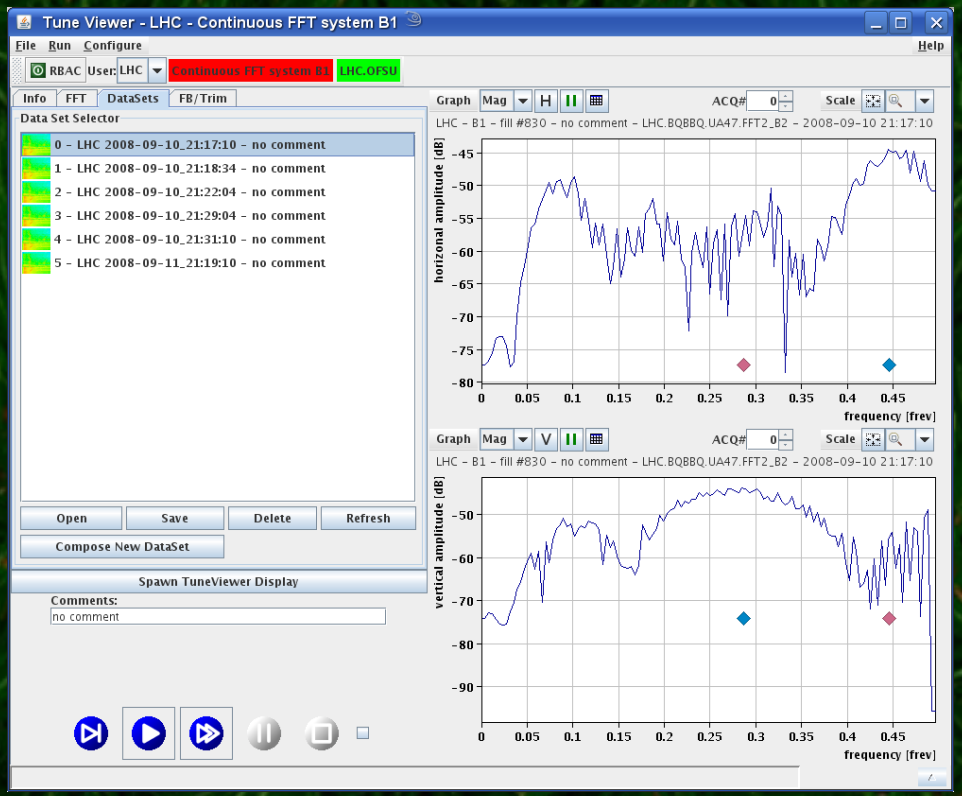
first circulating beam...

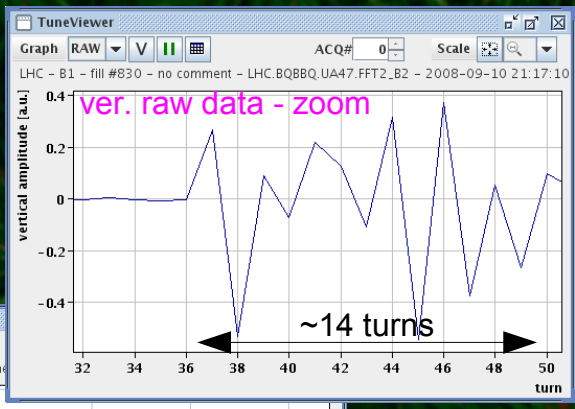


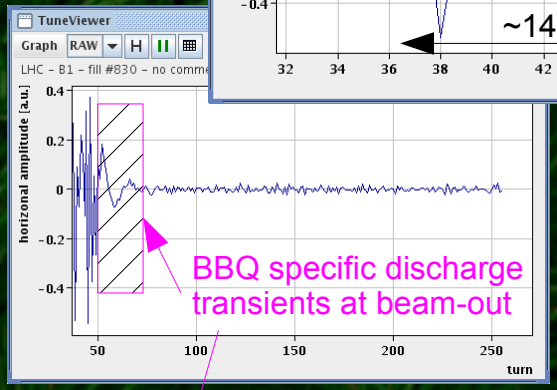
- Next few slides document how we got there...
  - N.B. Colour coding: **'blue frames' = B1 data** & **'red frames' = B2 data**

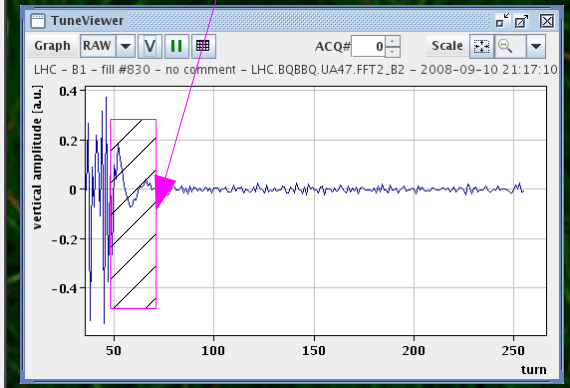
Sep. 10thBeam 2 Injection Tune – 14 Turn Data

- After adjusting first two turns (no RF, $Q_H \approx .44$, $Q_V \approx .28$)
  - Transient in raw (turn-by-turn) data:
    BBQ intrinsic discharging once beam is gone





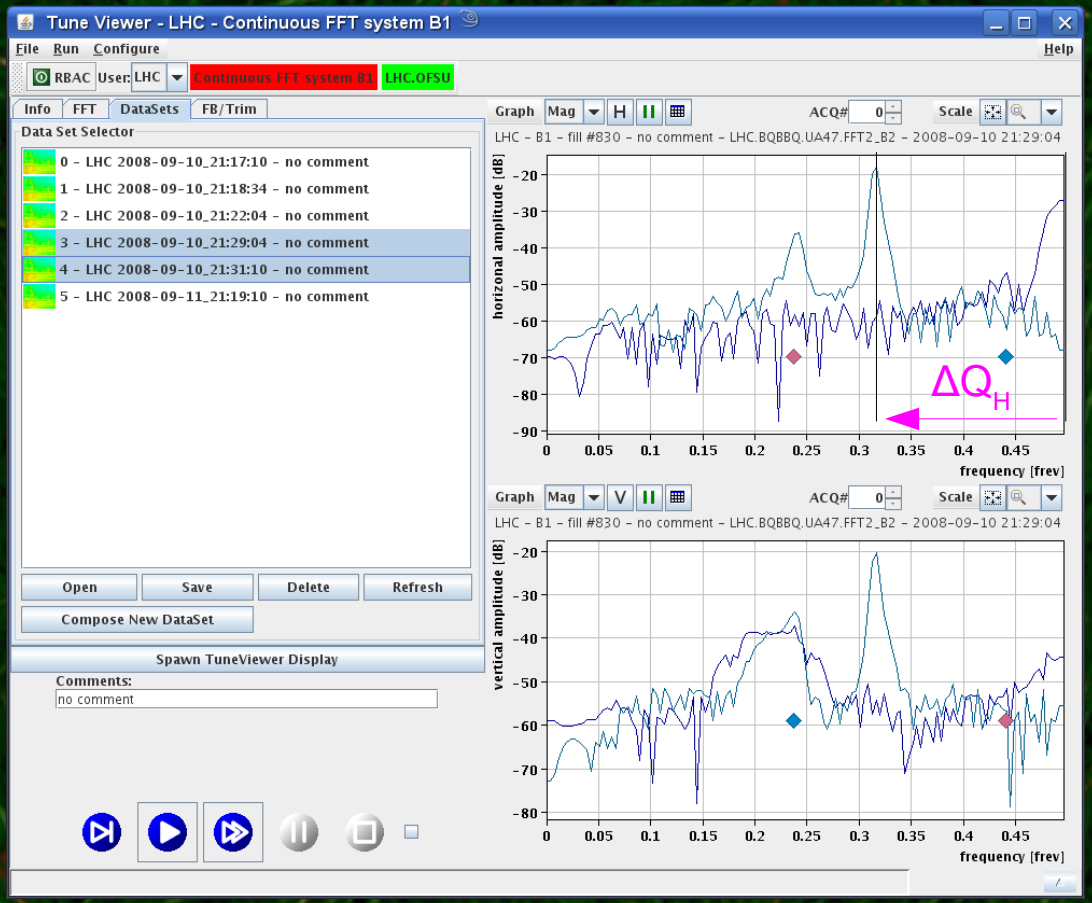


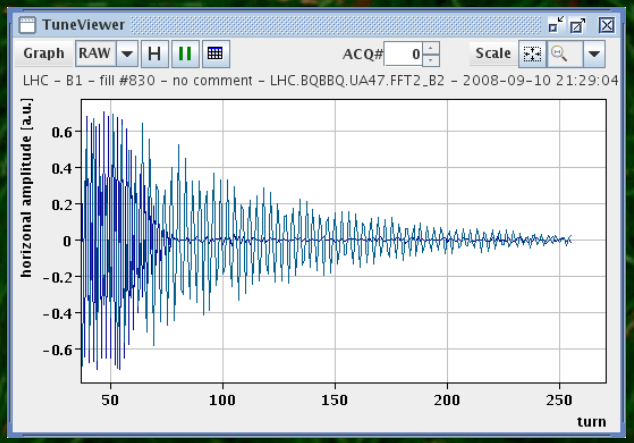


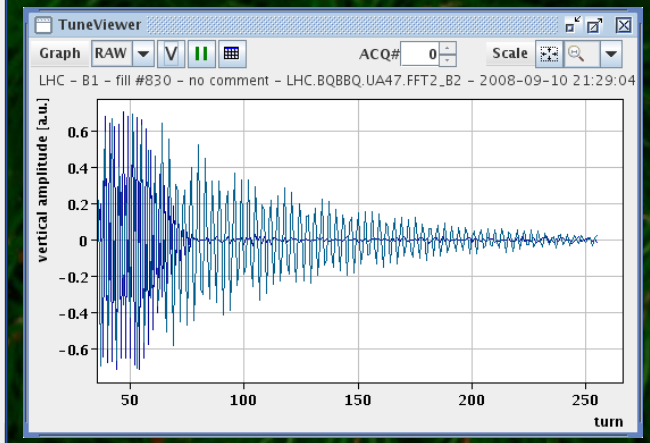
- Observations: only 14 turns – could the big spectra 'humps' indeed by the injection Q's?
  - vertical spectra is cleaner → decided to trim 'Δq_v=-0.1' and observe change

Beam 2 Injection Tune – 14 Turn Data – Q_v Trim

- no RF capture , $Q_H \approx .5 \rightarrow .315$, $Q_V \approx .24$, observation:
  - Programmed 'ΔQ_H=-0.2' seen as expected (LSA bug fixed, courtesy M. Lamont)
  - Moving from the half-integer resonance → 300+ turns (still no RF capture)

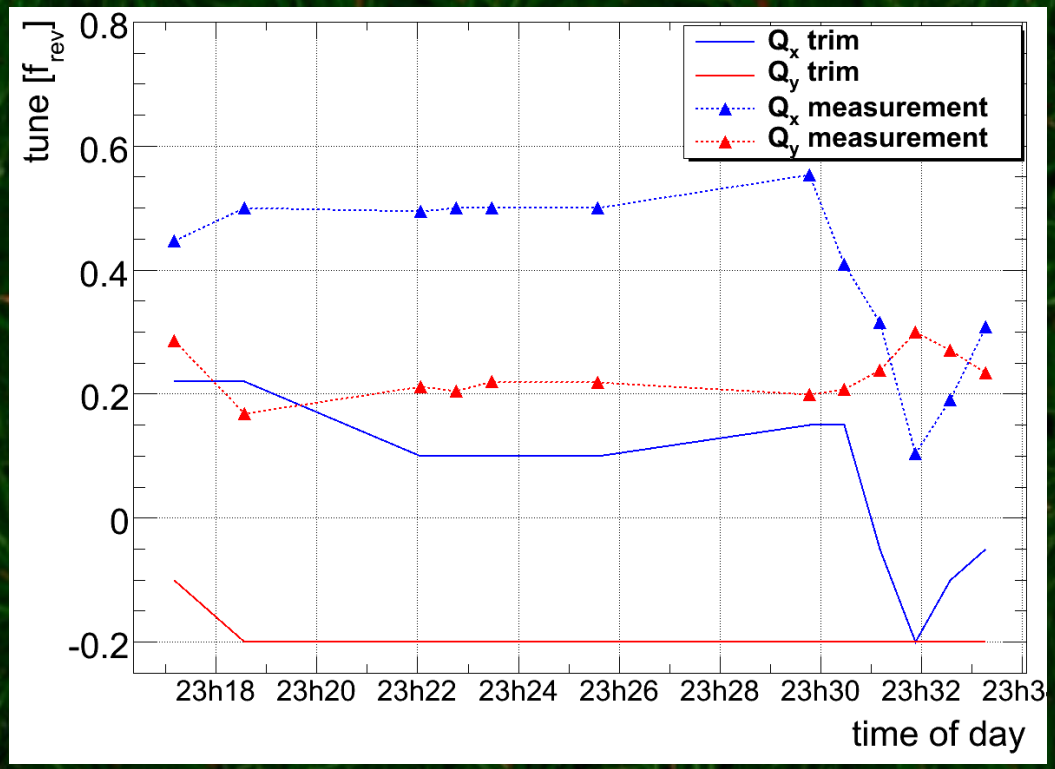


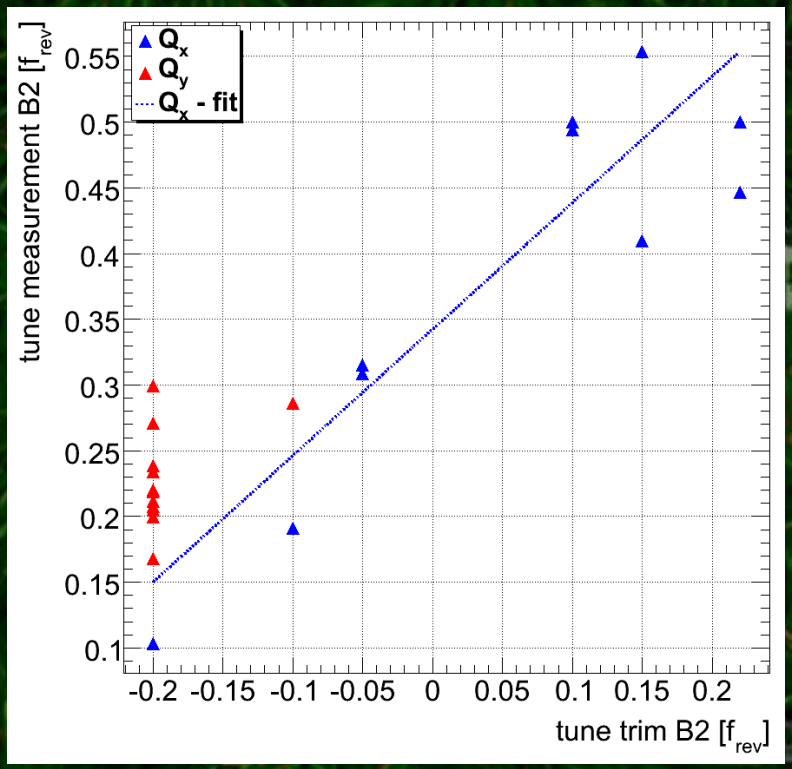




- LSA Settings (= deviation from reference): ΔQ_H = - 0.05, ΔQ_V = - 0.2

Beam 2 Injection Tune vs. Trim History

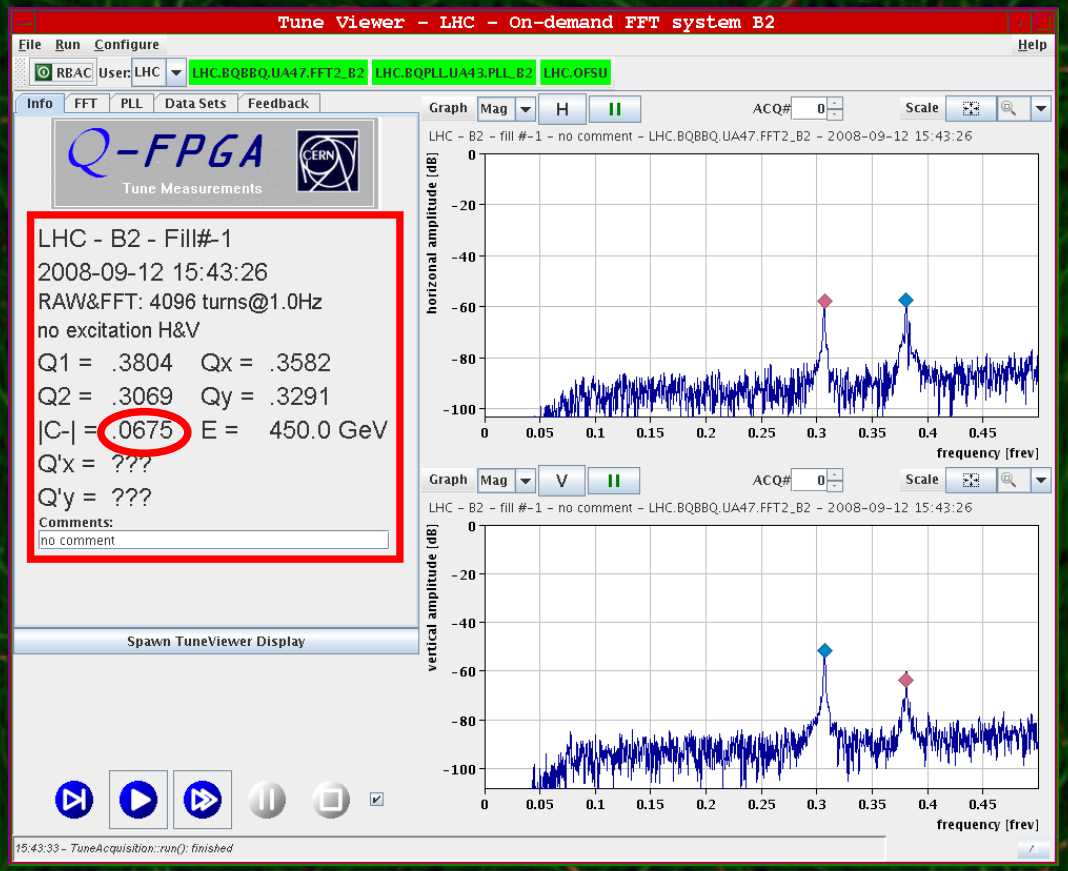


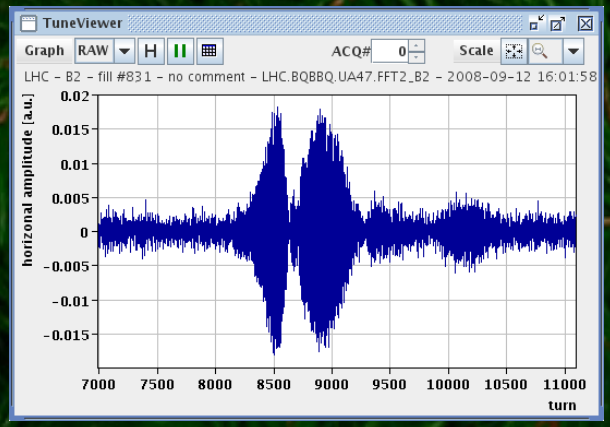


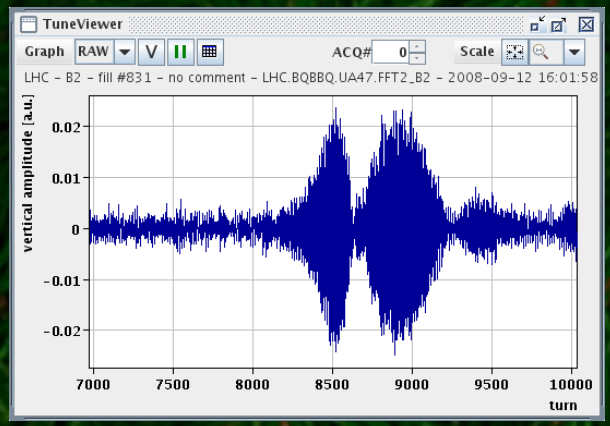
- Tune trim vs. measurement fits (w.r.t. Q_x=0.32 & Q_y=0.28):
  - Horizontal correlation: $\Delta Q_x = (0.96 \pm 0.16) \cdot Q_x(\text{trim}) + (0.03 \pm 0.03)$
  - Vertical correlation: $\Delta Q_y \approx X \cdot Q_x(\text{trim}) + 0.16$
    - Scaling 'X' off due to QD polarity error (fixed by Mike the same day)
- N.B. significant discrepancy in between individual data sets
- 'Space Domain' commissioning of feedback control loop (RealTime & TuneViewer)
  - time-domain pending (quadrupole circuit time constants, etc.)

Present Commissioning State
... lots of first: coupling measurement

- Measured coupling |C-| ≈ 0.07
  - Compatible with the assumed magnetic field error model at that time (0.06)



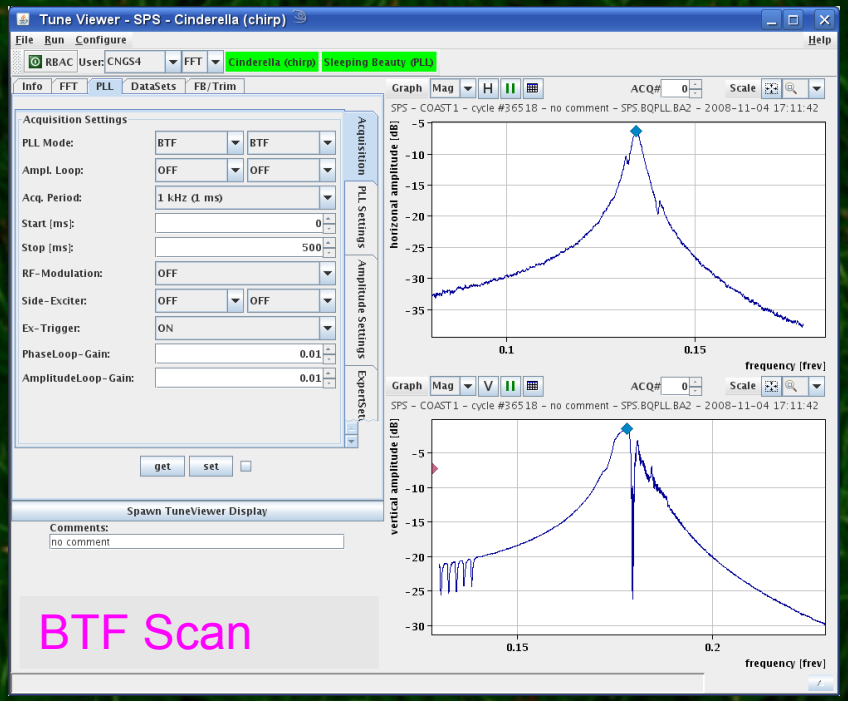


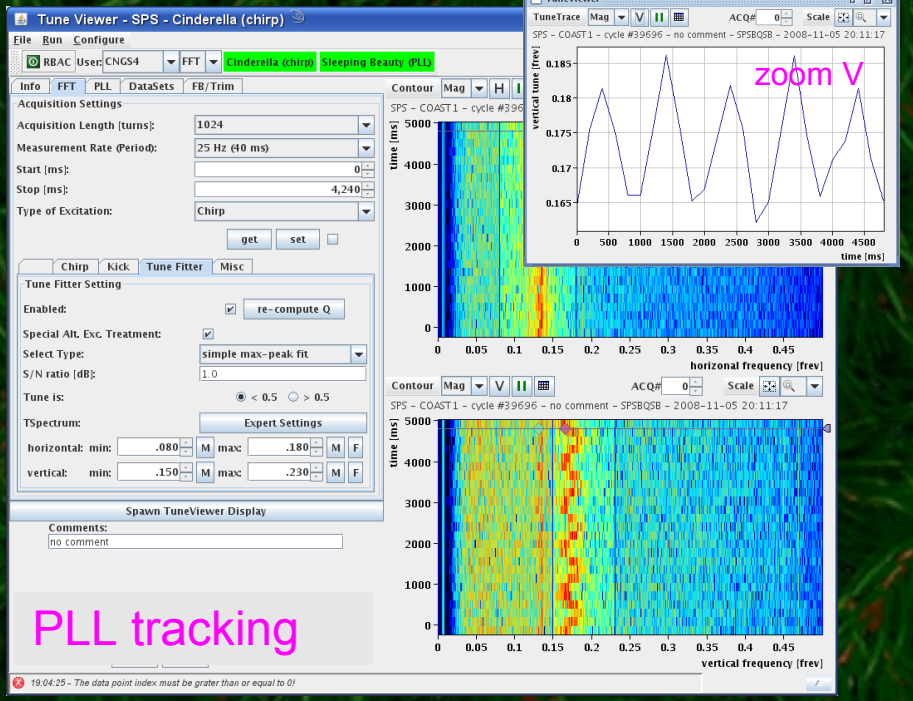


- Coupling wasn't corrected though...
  - Needed for nominal injection tunes (Q_x = 0.28, Q_y = 0.31)

Present Commissioning State
... Tune Phase-Locked-Loop Commissioning

- … made the best of the absence of beam in the LHC → used the LHC-PLL installation in the SPS for further tests
  - same interfaces/controls/server/operational GUI as LHC
  - Verified Beam-Transfer-Function (BTF) measurement and PLL logic

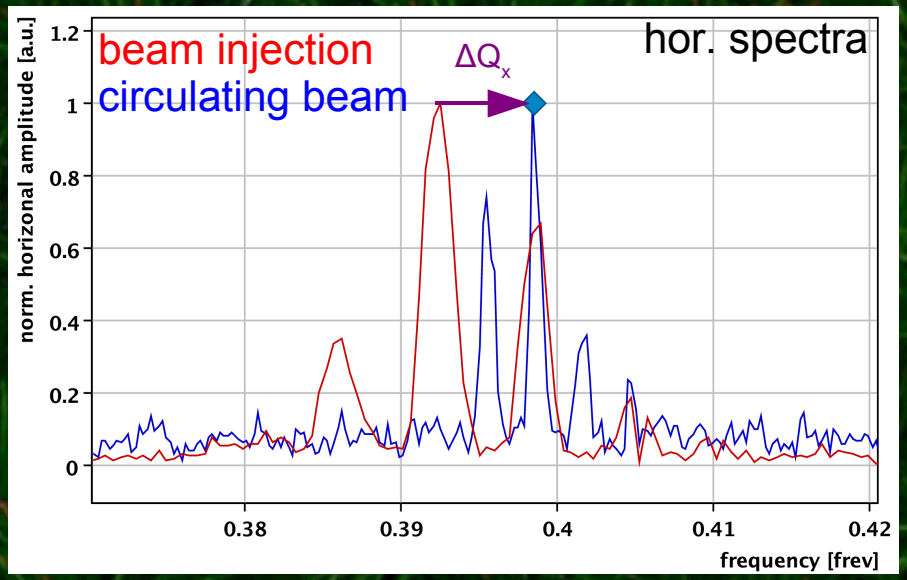


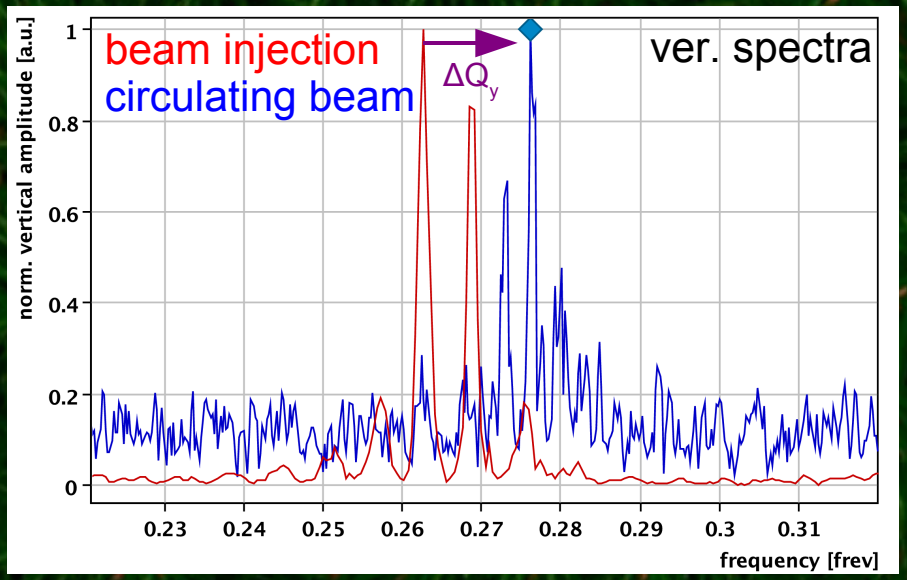


- To be tested: real-time display for PLL, LHC-RF interfaces (radial modulation)
- Since BBQ HW is fine for B2 (B1) and that the logic is correct (SPS test): remaining PLL commissioning should take less than one shift/beam.

Chromaticity via Injection vs. Circulating Tune Shift

- Continuous radial modulation (trim) was not fully available/commissioned
- Re-use measured SPS-to-LHC injection energy mismatch !?
  - Measured tune shifts 2009-09-12 (inj. 01:03:52 & circ.: 02:17:46)
    - $\Delta Q_x = +0.006$ & $\Delta Q_y = +0.014$
  - ΔQ & side-bands incompatible with earlier meas. $\Delta p/p \approx 10^{-3}$ (2008-09-10)
    - details on sector-to-sector difference and evolution over time → Jorg





Chromaticity via Tune Resonance Width I/II

- Some comments on Q', modulation index and tune width of the BTF
  - Turn-by-turn oscillations can be approximated by (n: turn)

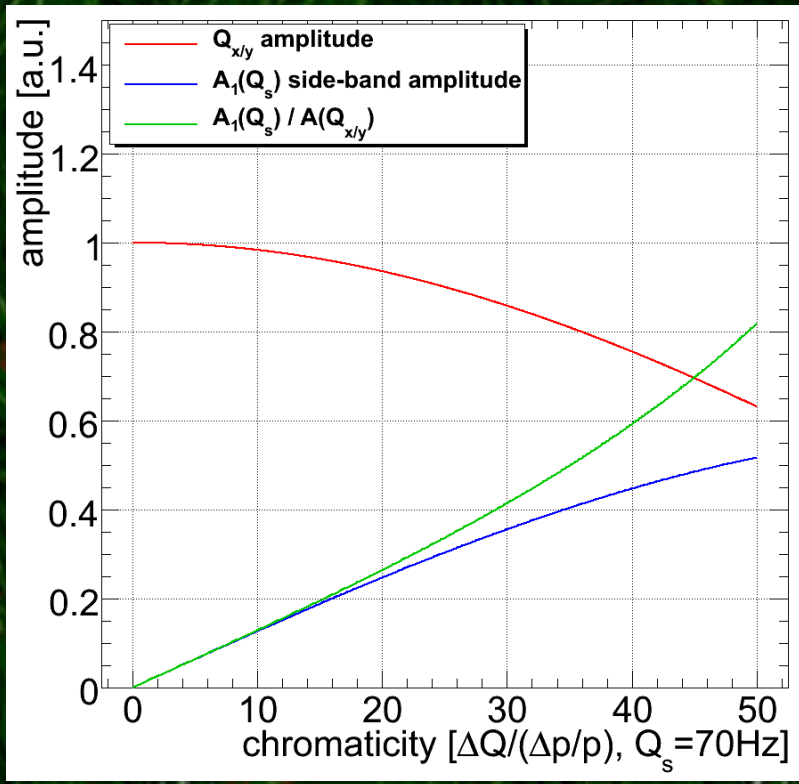
$$\Delta z(n) = z_0 \cdot \sin\left(2\pi \cdot \left[Q_0 \cdot n + \frac{Q'}{\omega_s}\frac{\Delta p}{p} \cdot \sin(\omega_s n) \right] + \varphi_\beta \right)$$

$$\cos(\omega_c t + B\sin(\omega_m t)) = \sum_{n=-\infty}^{+\infty} J_n(B) \cdot \cos((\omega_c + n\omega_m)t)$$

- Tune/Qs side-band amplitude (J_n: Bessel f.):

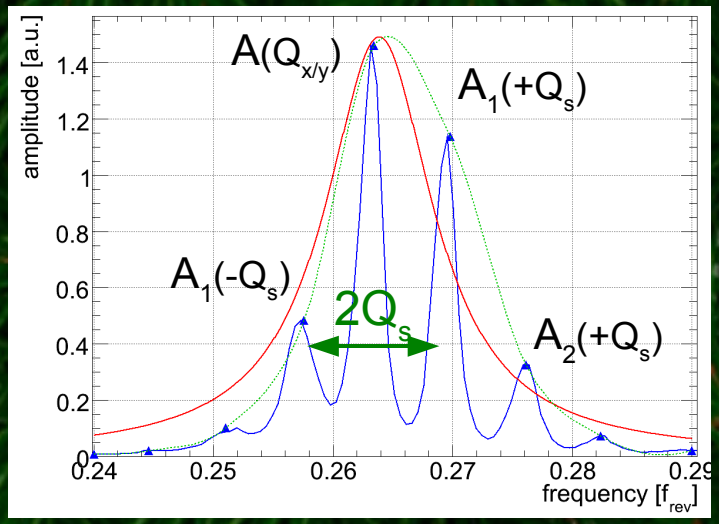
$$S_n(Q') = J_n\left(\frac{Q'}{\omega_s}\frac{\Delta p}{p}\right)$$

  - linear over a wide range of Q'
  - However: Q_s not always visible
    → only upper limits in this case
  - Simple estimates for non-linearities
    - ω_s: direct spectra observable
    - $\Delta p/p \approx 10^{-3}$: from bunch RF length (courtesy T.Bohl)

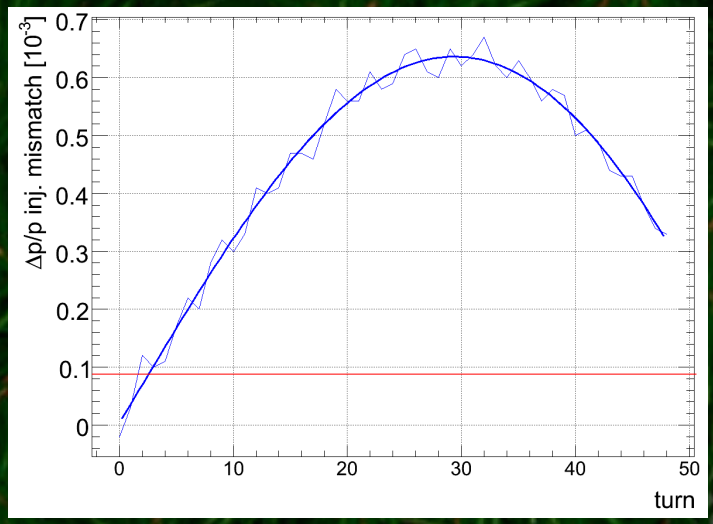


Chromaticity via Tune Resonance Width II/II

- 2008-09-12 (01:03++)
  - Q_s = 70 ± 2 Hz (f_{rev} = 400.788963 Mhz, U_T = 8 MV)
  - Estimates: $Q'_H \approx Q'_V \approx 34$
    - Settings: $Q'_H = 2.0$, $Q'_V = -30$
    - Asymmetry due to amplitude detuning anti-symmetric (left/right avg.)
  - ~ consistent over several injections
  - N.B. AB-RF found Q_s to be 60 Hz (difference unclear, same spectra)
- changed drastically from Thursday to Friday (machine was magnetically recycled)

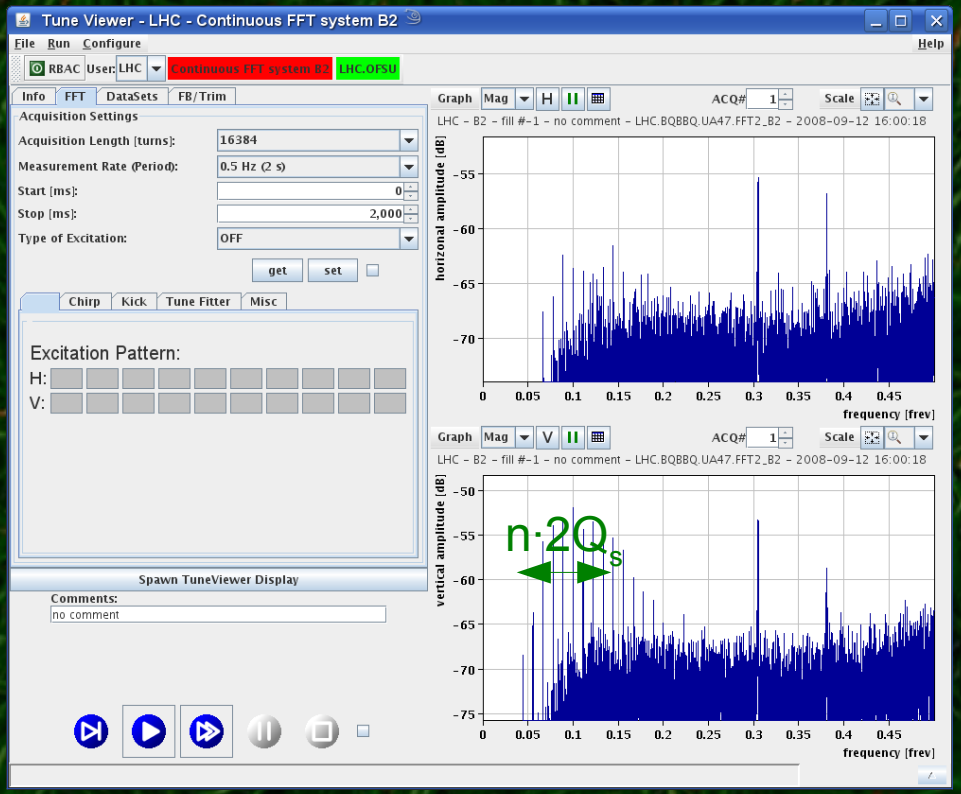


- Injection mismatch fit:
  - Injection mismatch is likely < 10^{-4}
  - Compatible with above Q' estimates and observed tune shifts (previous slides)
  - further analysis pending (SDDS data)



Beam 2 - Typical Circulating Beam Spectra

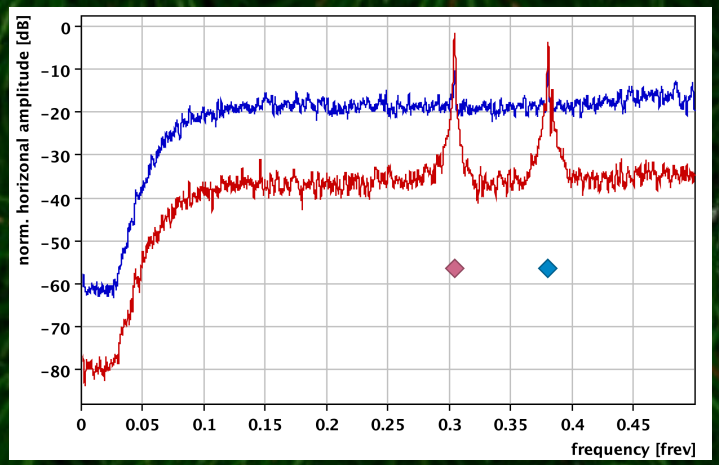
- Horizontal and vertical tunes were usually seen without further excitation
  - Typical signal-to-noise: 10-20 dB
    - FFT1 (continuous system, logging) was slightly more sensitive (+ ~ 5 dB)
  - Sufficient for monitoring & steering for the given beam configuration (single pilot)

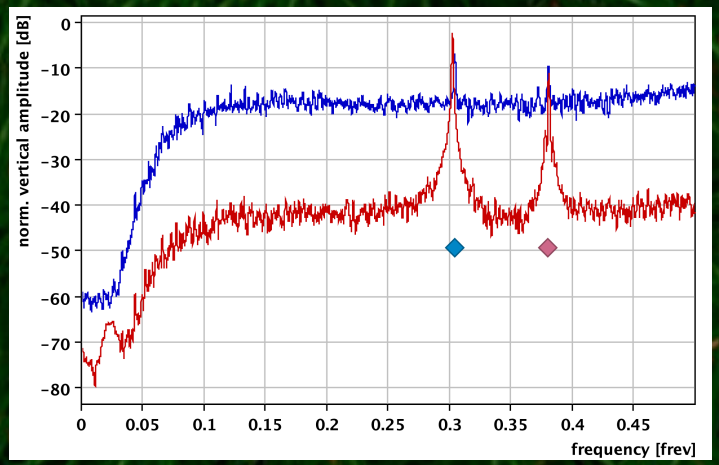


- Actually, this was a bit of a surprise...

LHC Beam Noise & BBQ Resolution Estimate

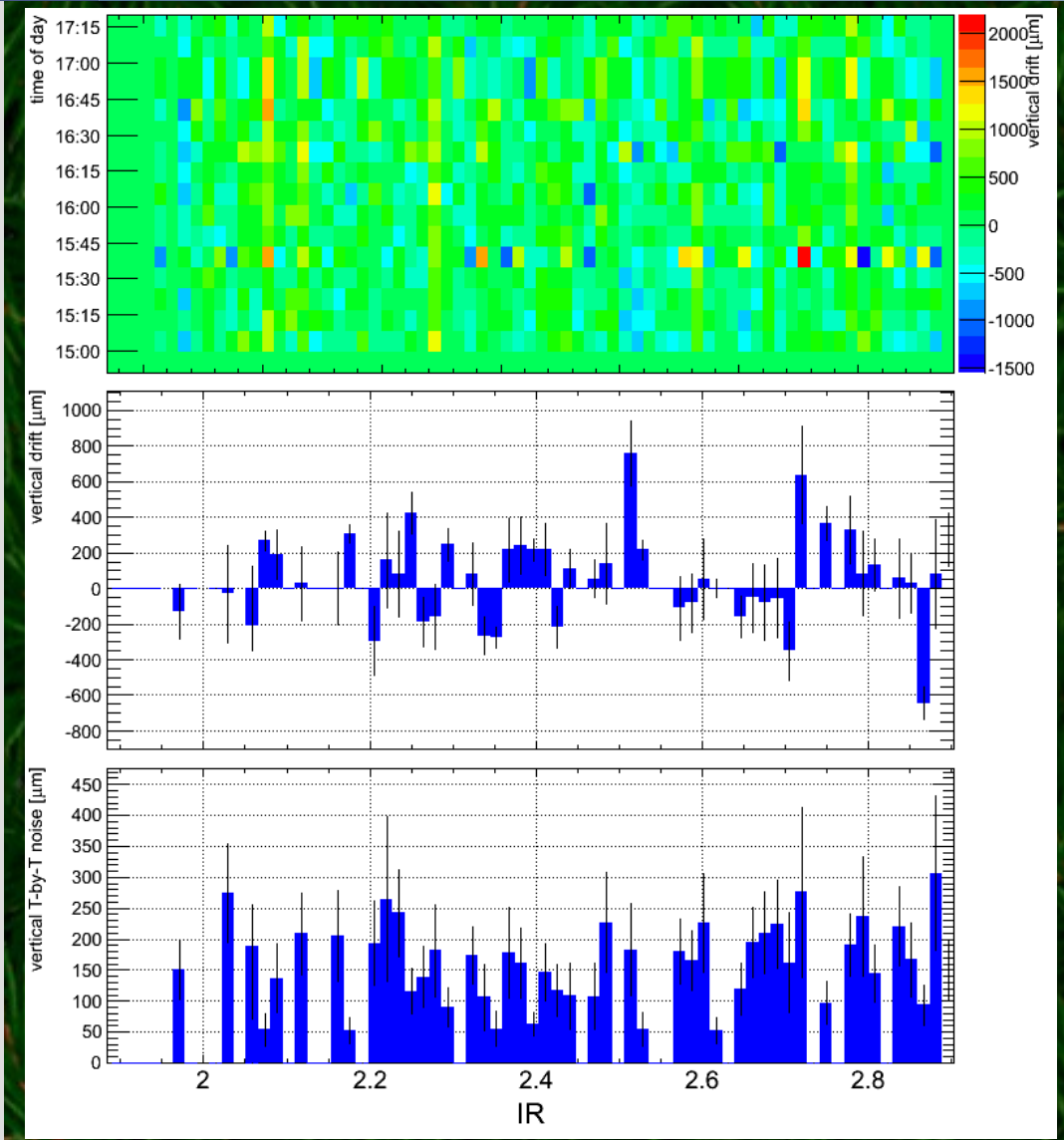
- Difference
  - $S/N_H \approx 36$ dB, $S/N_V \approx 42$ dB (16382 turns)
    - FWHM ≈ 0.0007 → Amplification = 227
      - $Q'_H \approx Q'_V < 12$
  - Damper kicker (2.5% of 2 μrad @450GeV)
    - Hor. tune amplitude ≈ 185 μm
    - Ver. tune amplitude ≈ 200 μm





- → BBQ noise floor estimates ($2 \cdot 10^9$ p/bunch):
  - horizontal: < 3 μm
  - vertical: < 2 μm
- → Residual tune oscillations (quite large):
  - horizontal: ≈ 30 μm (sources?)
  - vertical: ≈ 15 μm (sources?)
- Note: BBQ resolution scales with bunch intensity (1st order)
  → noise floor expected to be ≤ 10 nm for nom. bunches (based on SPS exp.)
  - N.B. Need to correlate this with absolute BPM amplitudes

LHC Beam Position Monitor – Turn-by-Turn Stability - B1 Injection Test on 2008-08-10



No obvious time structure from one injection to the next
→ dominated by the 'white noise' floor of the BPM acquisition electronic

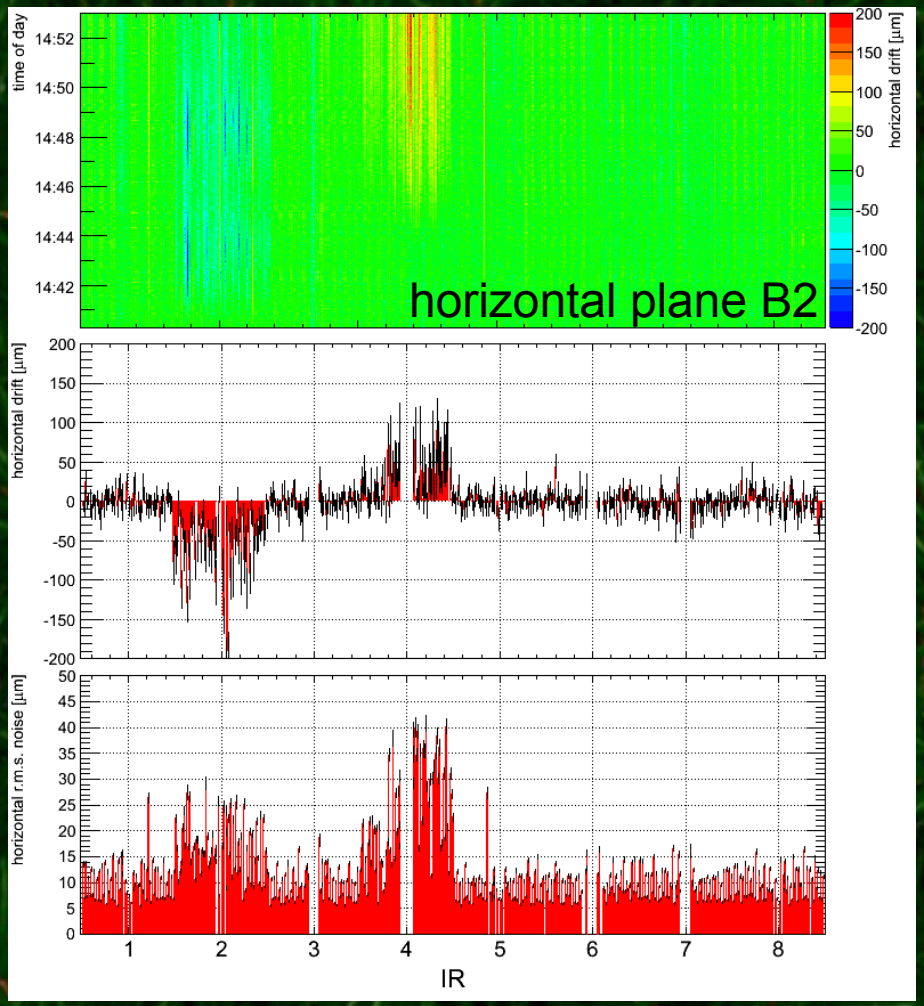
Residual min/max trajectory drift is compatible with BPM noise estimate (see below).

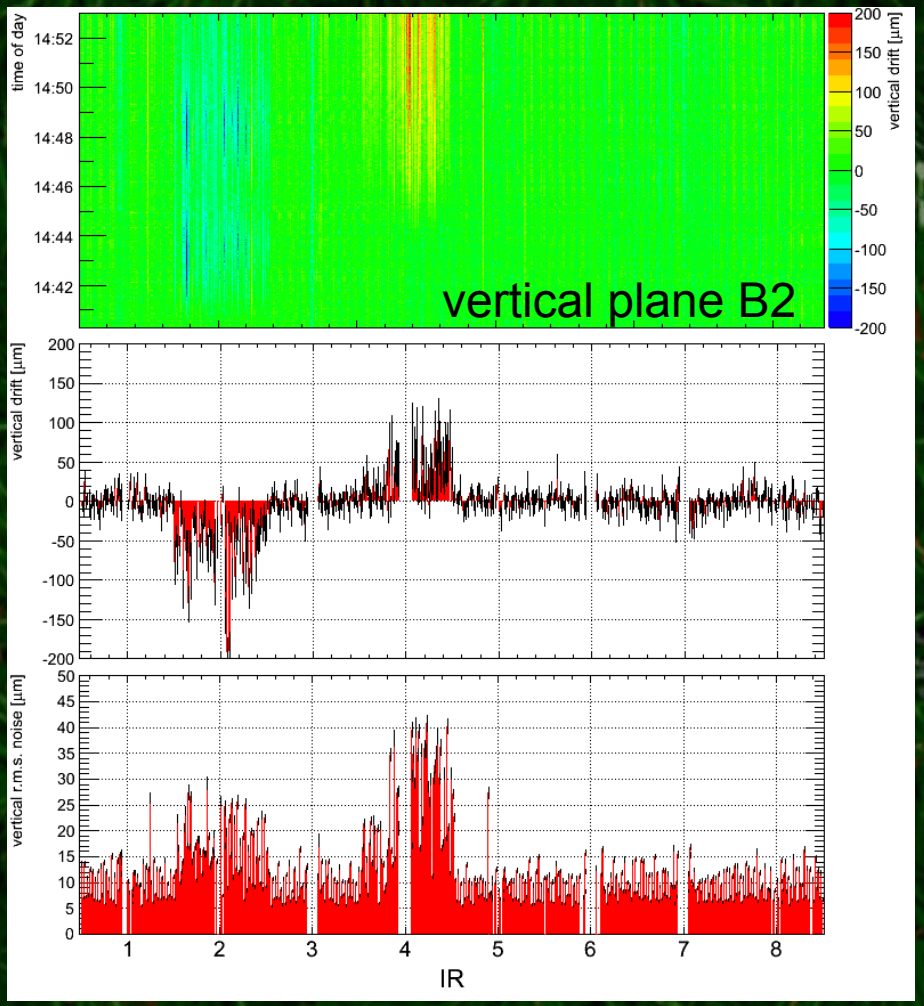
r.m.s. turn-by-turn noise: ≈ 200 µm
- as expected from lab and electronic design for the given intensity ($2 \cdot 10^9$ protons/bunch)

- Found 2 (B1)/ 12(B2) polarity/mapping errors – fixed immediately once spotted
  - no additional erroneous BPMs found with circulating beam (injection test paid off)

LHC Beam Position Monitor – Orbit Stability B2 – LHC Day 1

- Residual injection orbit stability (orbit feedback/radial loop off)

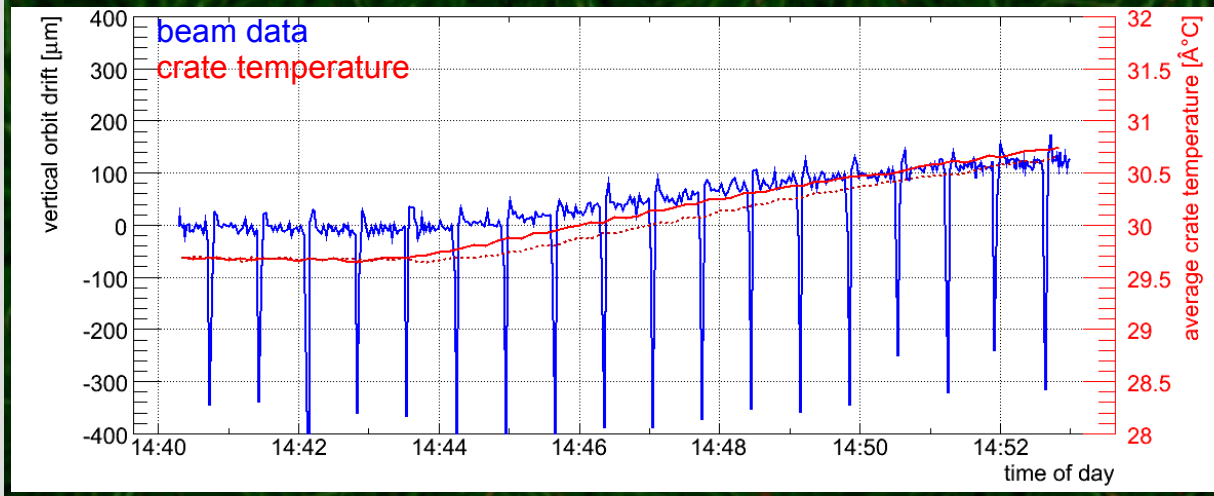


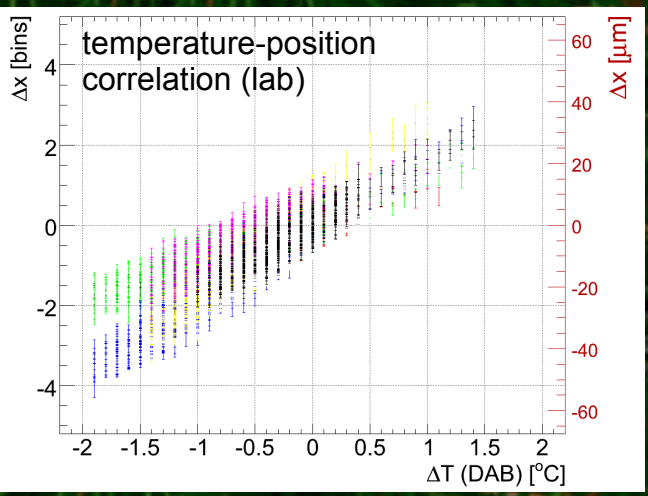


- Effective LHC B2 orbit stability about 5 um → understood (next slide)
- Small oscillations/drifts in point 2 and 4 → also understood (next slide)

LHC Beam Position Monitor – Orbit Stability B2 – LHC Day 1
Residual Noise Sources

- Effective LHC B2 orbit stability about 6 µm, two known sources:
  1. turn-by-turn noise predicition → orbit r.m.s.: ≈ 6 µm (150-200µm, 1024 turns average)
     - However: should be the same for all arc BPMs (same aperture)
  2. Residual noise of the COD power supplies, expectation: 5-10 µm orbit r.m.s.
- Small drifts in point 2 and 4 → thermal drifts (switched off SX4 climatisation)
  - Known from earlier lab measurements
  - Fix: 'somebody' gets a scarf for Christmas & local crate temperature control



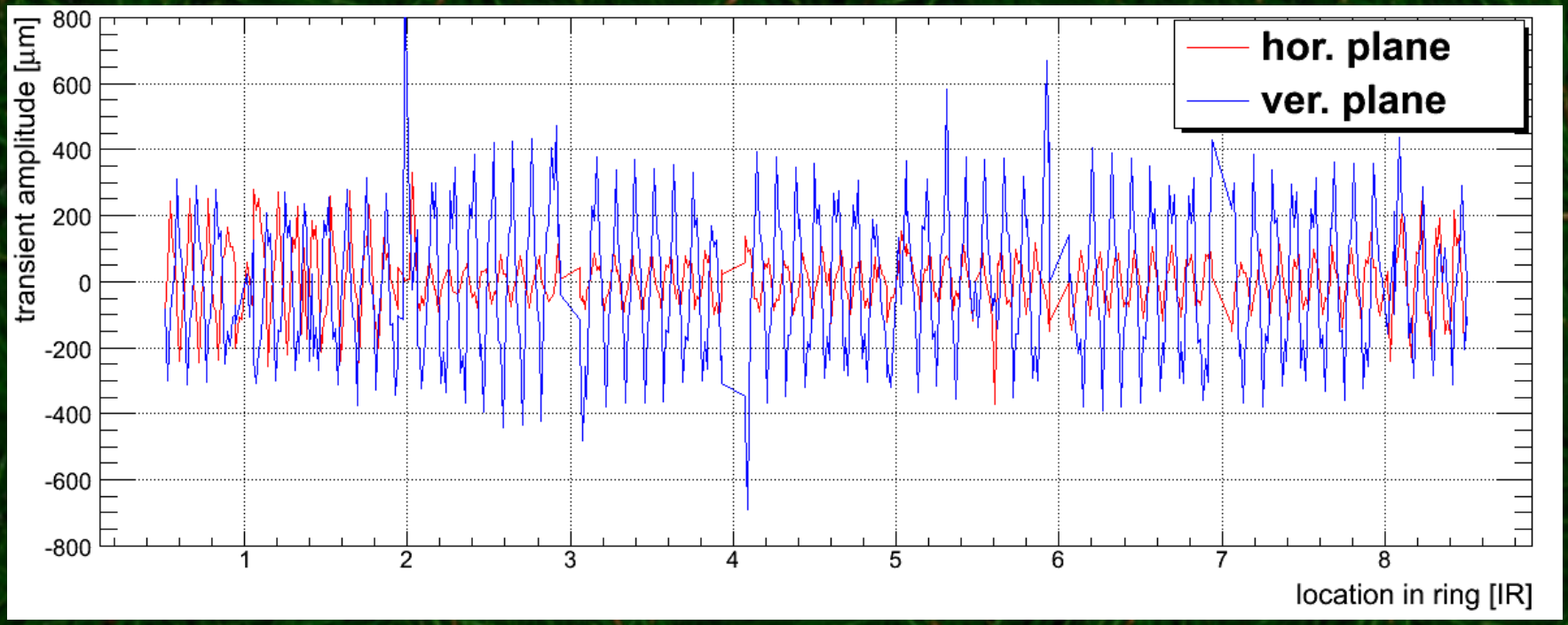


- Exact source of the transient orbit spikes is unknown
  - lasts up to two seconds
    - → too slow for an BPM electronics related spike (visible on the whole LHC)
    - (maybe) to fast for COD power-converter transients
  - a forgotten injection/tune/...? kicker magnet?

LHC – Orbit Stability – Systematic Transient

- ..at two culprits, one in IR2 the other in IR8 (betatron-oscillation beating)

  N.B. appears to be triggered by the SPS super cycle



- Some likely but excluded sources:
  - individual CODs: fit requires to many sources to explain the seen pattern
  - Injection septa: only one per beam and either in IR2 or IR8 (B2!)

Conclusions I/III – Things done

- Base-line FFT tune acquisition commissioned for B2
  - used to establish circulating beam
  - tested polarities, gains, timing, all detectors alive
  - tested RF damper polarities, rough amplitude calibration
    - Now LHC's baseline exciter for Q measurements
  - tested semi-automatic Q and Q' correction schemes (via LSA)
  - tested MKQ trigger & kicker response (synchro-delay adjustments pending)

- BPMs/Orbit Feedback:
  - good BPM readings, permitting fast commissioning of circulating beam
    - practically all BPM triggered with intensities down to ≈$2 \cdot 10^9$ protons
    - noise floor: COD power supplies (5-10 um), residual BPM 'white noise' (6 um), thermal BPM drifts (~35 um/°C, to be fixed)
    - Only few calibration & mapping errors found after injection tests!
      - We are lucky and should probably play the lottery more often!
      - Few noisy pick-ups electronic chains remain to be check/replaced
  - Data concentration and error/fault filter operational
  - Commissioned/tested about 250/1060 CODs with beam (ongoing)

Conclusions II/III
- Things to be (Re-) Done

- Full commissioning of B1 FFT1 & FFT2 BBQ systems
  - first turn works (all detectors alive), plane pending
  - otherwise same procedure as for B2:
    - damper polarities, amplitude calibration, ...
- Full commissioning of B1 and B2 BBQ Phase-Locked-Loop Systems
  - pre-requisite for first ramp! However: if no surprises: < shift/beam
- Test of (semi-) automated Q' & C^- measurement and correction procedures
  - after SPS tests: LHC-RF radial modulation
- Feedbacks
  - 750/1060 COD polarity and optic checks with beam pending
  - Quadrupole & sextupole circuit mapping/polarity checks with beam
  - test of > 1300 power-converter real-time inputs (AB/PO)

  → Semi- (or even fully) automated FB on Q/C^- is probably fastest/easiest to setup
- Training of LHC operators & EIC's

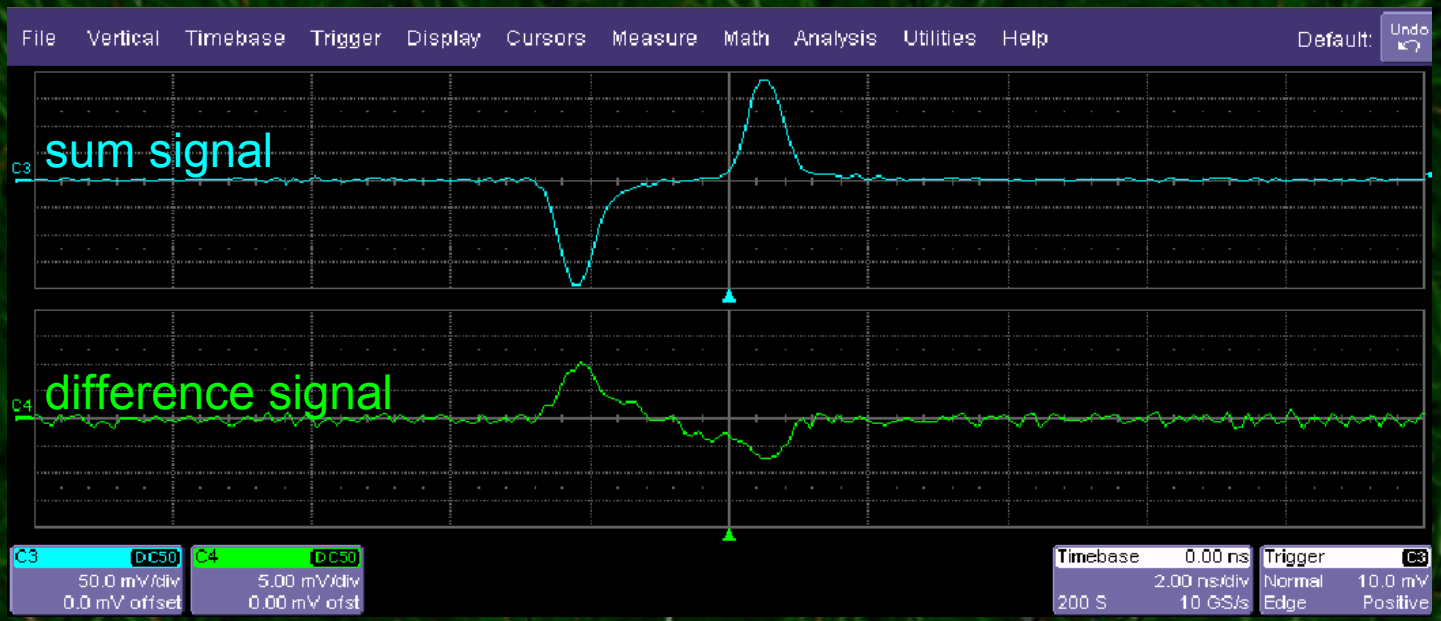
(ongoing, some have never seen/measured/corrected Q/Q' and even less C-)

Merry Christmas and a Happy New Year!!!

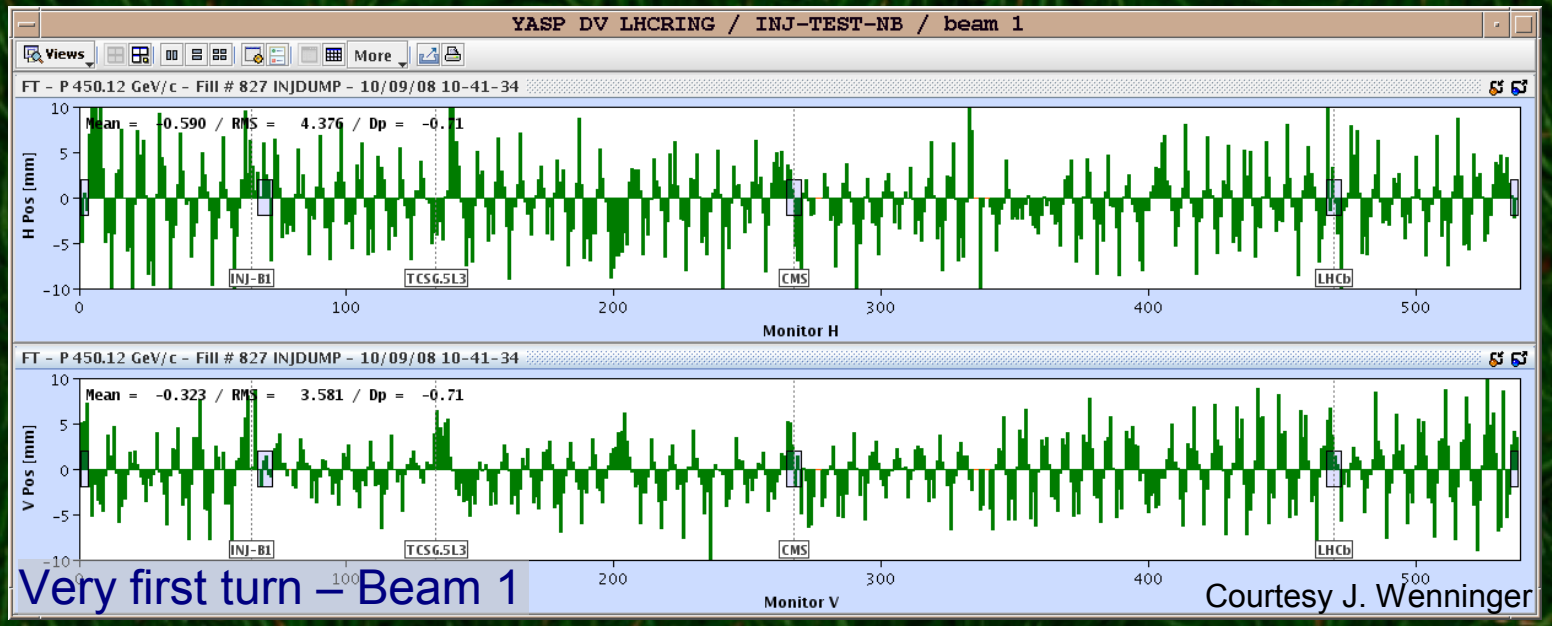

additional supporting slides

BI's Wall-Current and Head-Tail Monitor

- Tested that detectors are alive and trigger on given timing event
  - Some software tests/adjustments pending
    - one full acquisition presently results in about 1 GByte of data
    - optimisations in the pipe-line
      - optimised memory usage (Java/JDataViewer)
      - optimised/simplified GUI for the WCM
    - Otherwise: same functionality/state as SPS Head-Tail system (bunch length, intensities, HT modes, chroma estimates, ...)

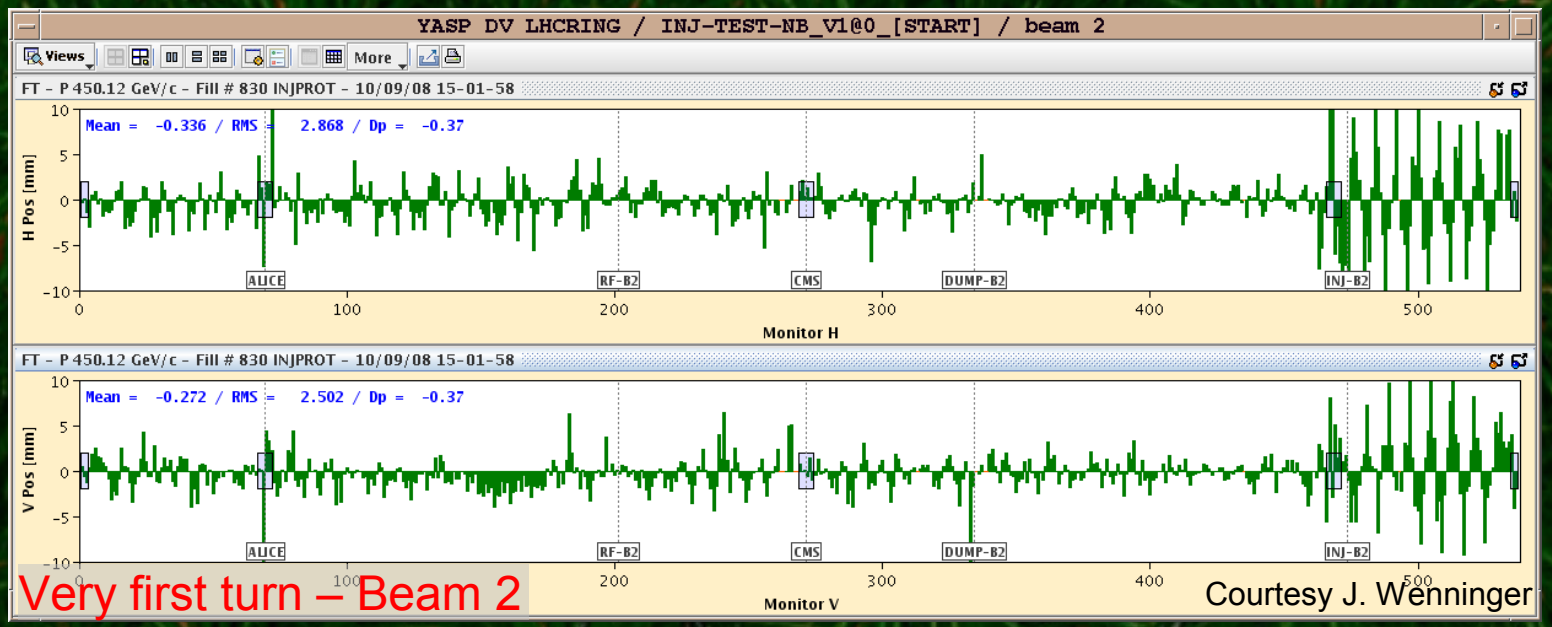


LHC Beam Position Monitor – LHC Day 1
The LHC BPM System at It's Best I/II



Very first turn – Beam 1

Courtesy J. Wenninger

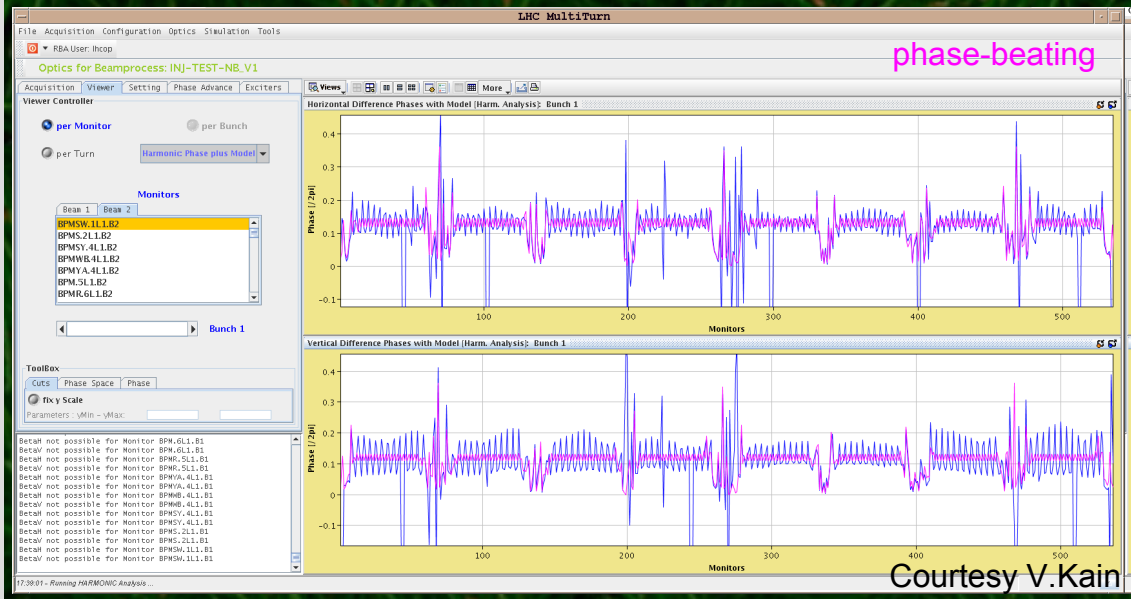


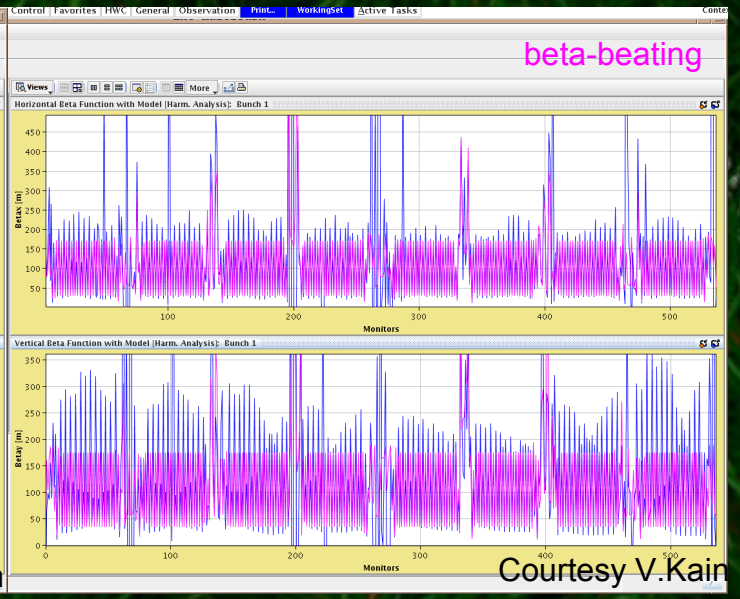
Very first turn – Beam 2

Courtesy J. Wenninger

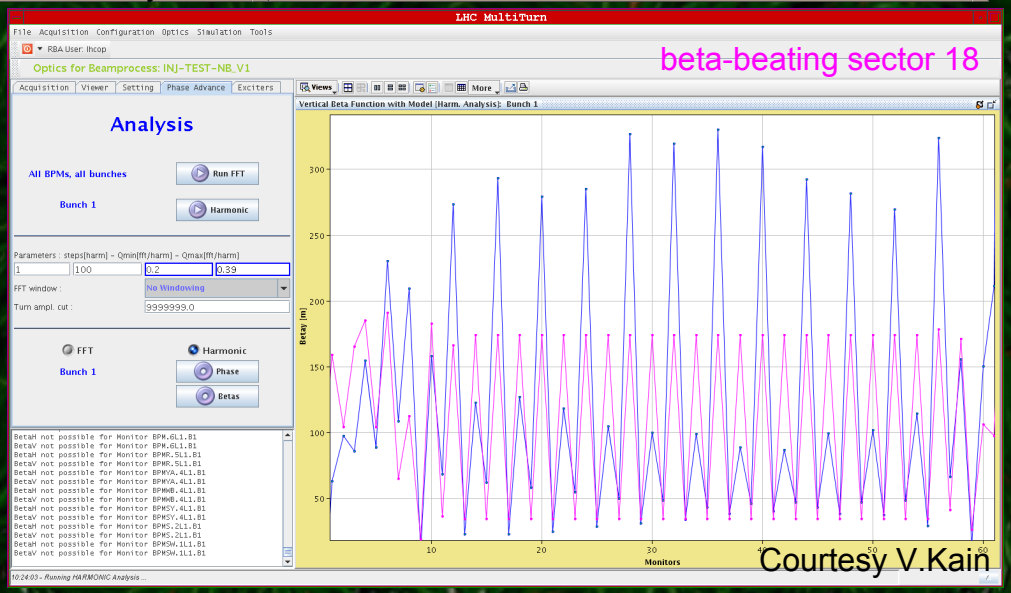
LHC Beam Position Monitor – LHC Day 1
The LHC BPM System at It's Best II/II

- Could reconstruct LHC B1 optic on the few 10% level using only 50 turns





- Nearly all BPM triggered and gave useful readings
  - LSA concentrator hick-ups relying on FIFO read-out using
- Vertical beta-beat (blue) vs. model (pink)
  - Surprisingly large: 100%
  - further analysis/correction proposal pending (R. Tomas)



LHC Orbit Feedback Controller & Service Unit

- Tested data concentration of 120 front-end systems, mapping, etc....
  - Worst case latencies shown to be less than 20 ms (small cross-talk with LSA's CMW-get call)
- Tested first-order BPM error/fault detection scheme
- Now default data source for YASP (orbit, CODs, statuses) and 100k turn GUI (statuses)
- Example: B2 sector test – beam as seen/published by the OFC