



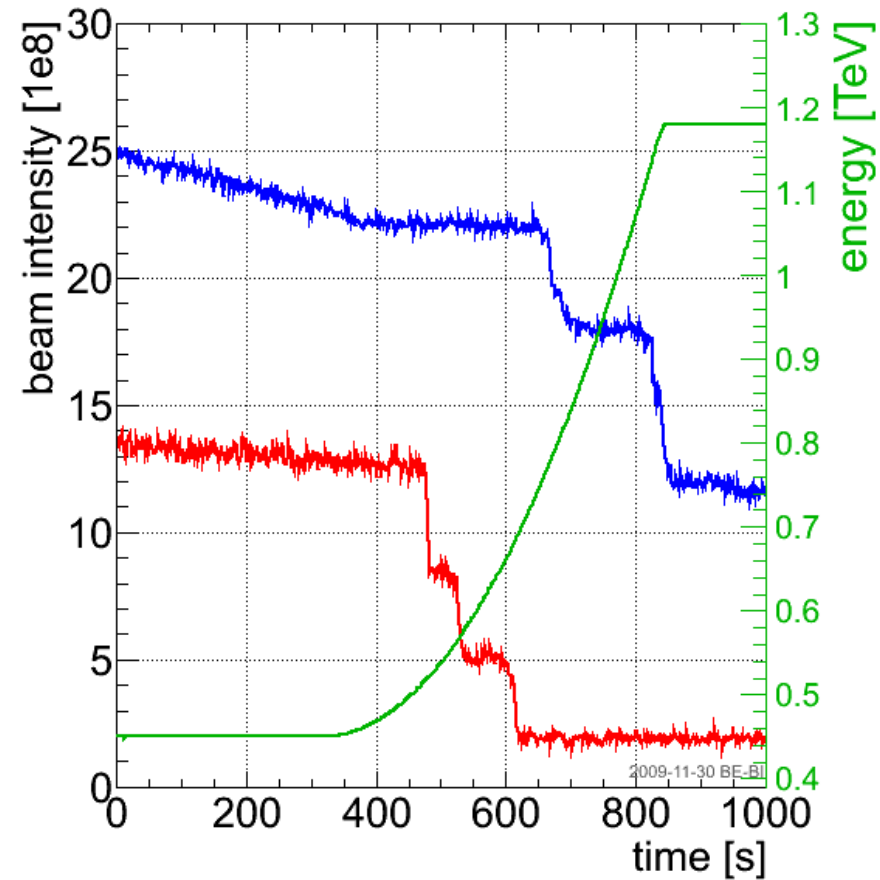
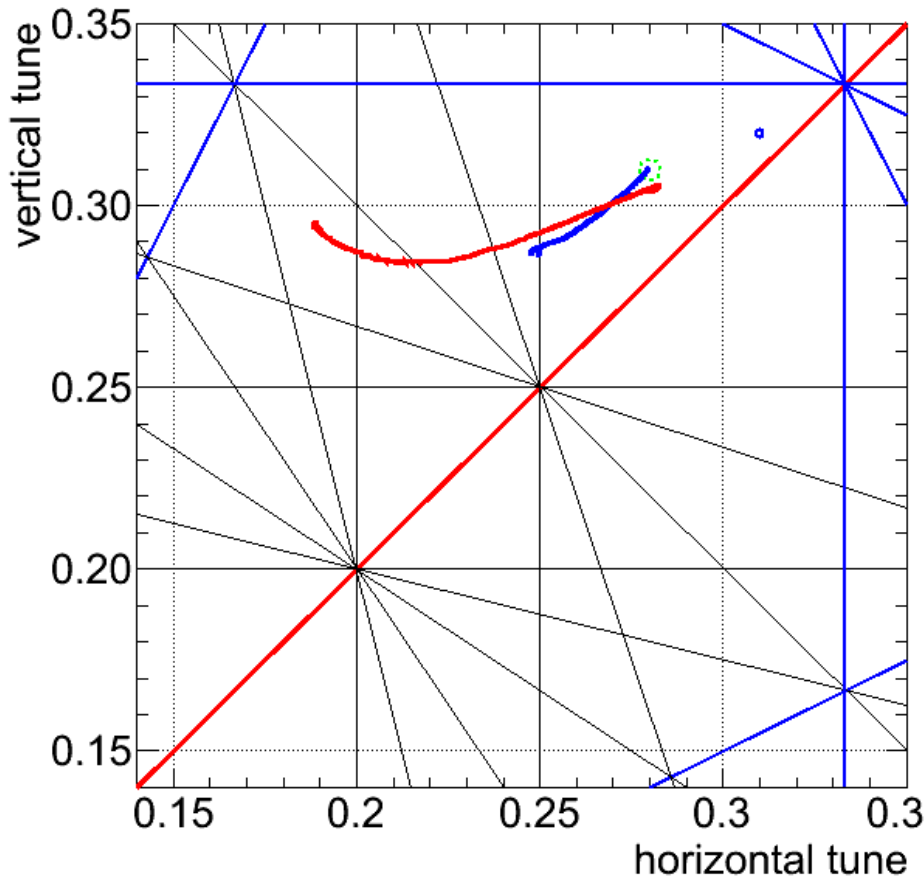
Q/Q' Diagnostics and Feedback Systems

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**for the BI-QP team: A. Boccardi, M. Gasior,
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- FFT & PLL operation
- Tune-FB and Radial Loop (De-)Modulation
- Beam spectrum issues affecting beam diagnostics and operation
 - Residual tune stability
 - 8 kHz line et Co.
 - broad frequency “hump” driven beam excitation

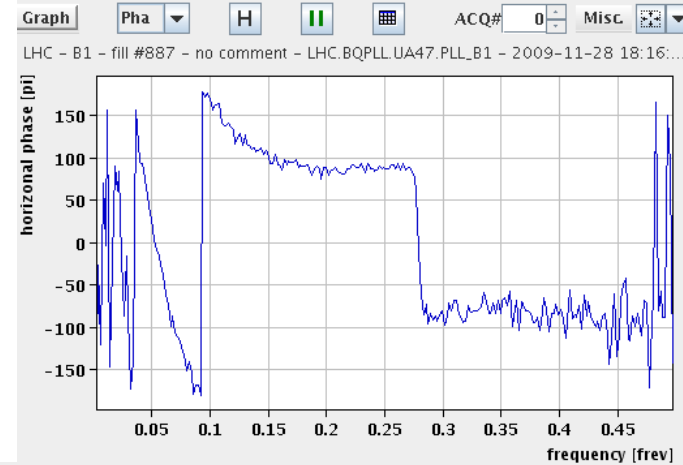
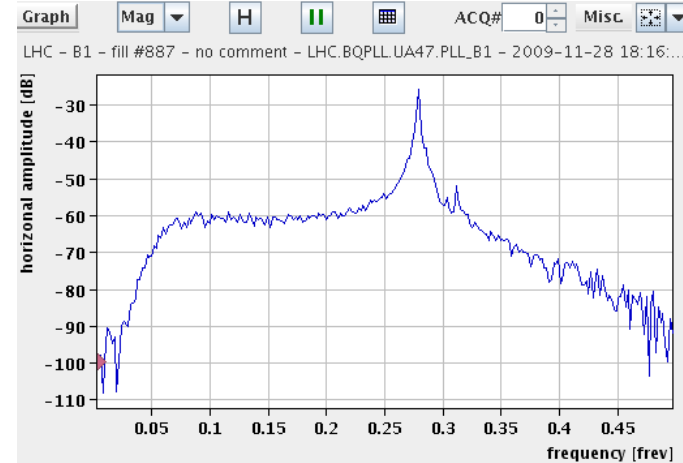
- The Base-Band-Tune (BBQ) system was work horse from LHC Day-I
 - No hardware, minimal software and only a few beam related issues



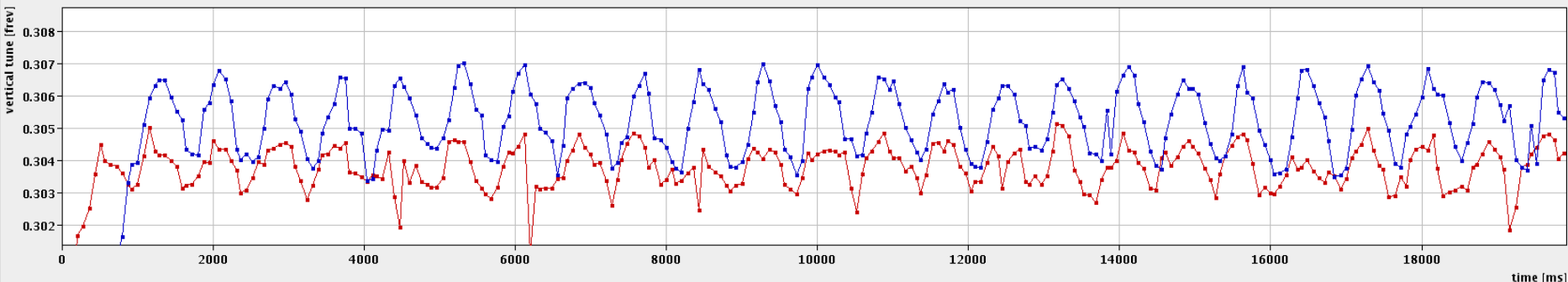
- Most measurements were done with residual beam excitation
- Typ, Q measurements resolution in the range of $10^{-4} \dots 10^{-5}$

For details → Walter's presentation

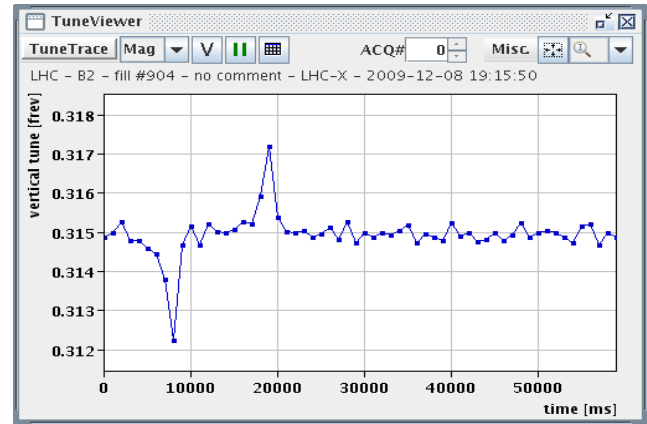
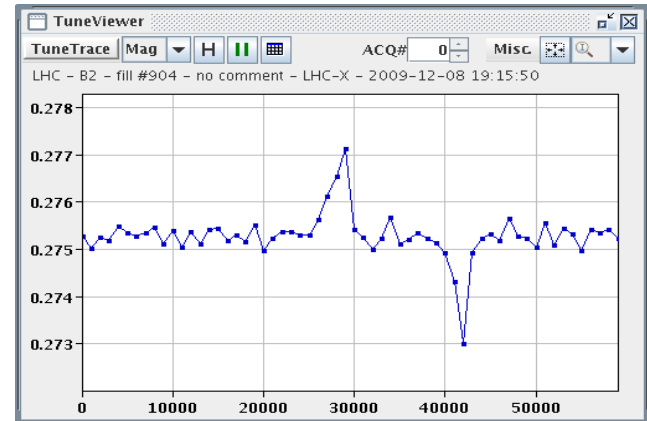
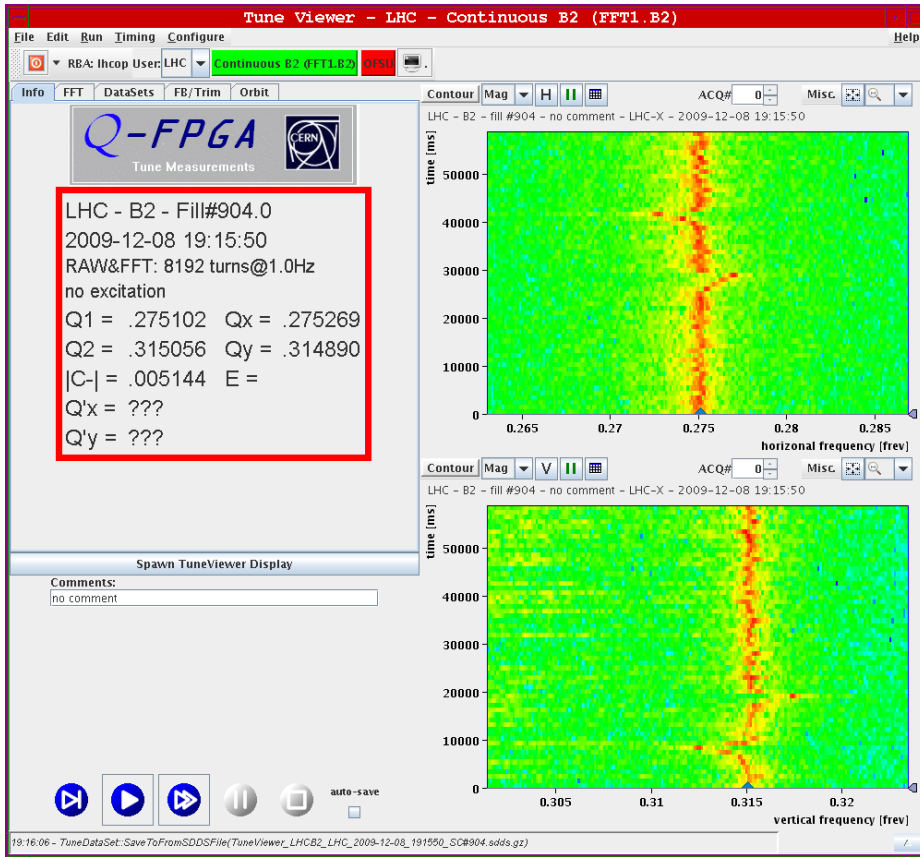
- Same BBQ as 'Continuous FFT' system (logging)
- Gain relations and BTF agree with model
 - typical tune resolution: 10^{-5}
 - Op. range w/o retuning: 0.15 ... 0.5
- Deploy BQK for missing planes once available
- some software issues pending but otherwise essentially ready for next ramps
- Example: $Q'_v = 15$ (blue, $dp/p = 10^{-4}$ @2.5 Hz)
 $\rightarrow Q'_v \text{ trim}) = -10 \rightarrow Q'_v = 10$ (red)



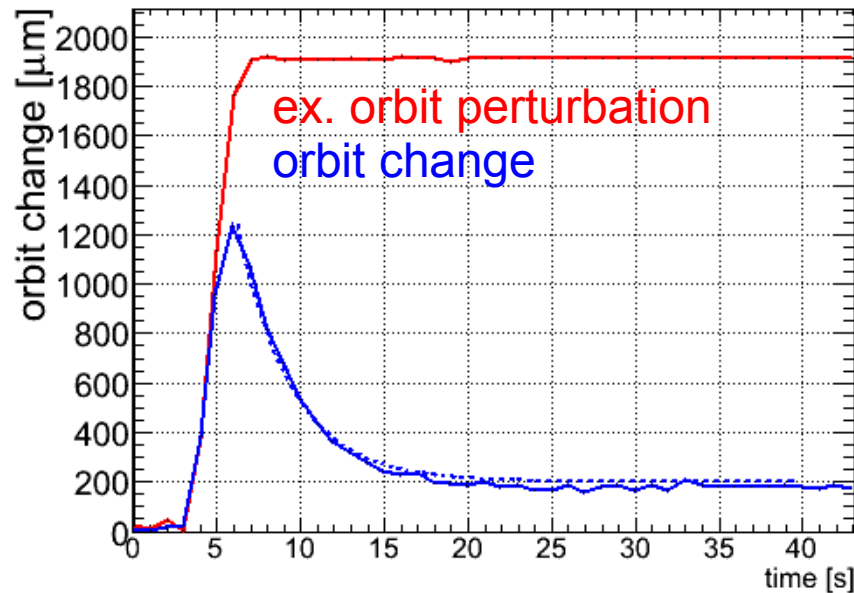
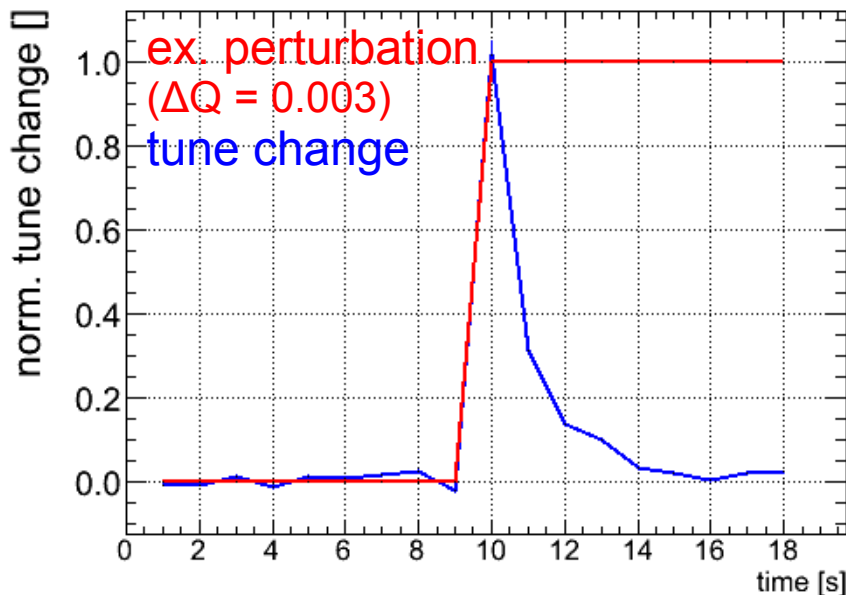
LHC - B1 - fill #888 - no comment - LHC.BQPLL.UA47.PLL_B1 - 2009-11-29 02:24:25



- Quick Q-FB sanity check, here with $\Delta Q_{\text{trim}} = \pm 0.003$ (via LSA) with Q-FB 'on':



- Any weak link/sub-system error would break the feedback chain, or (reverse logic) since FB was stable \leftrightarrow sub-systems work according to model
 - same applies a priori to Q'-FB
 - weak link: reliability/availability of measurement



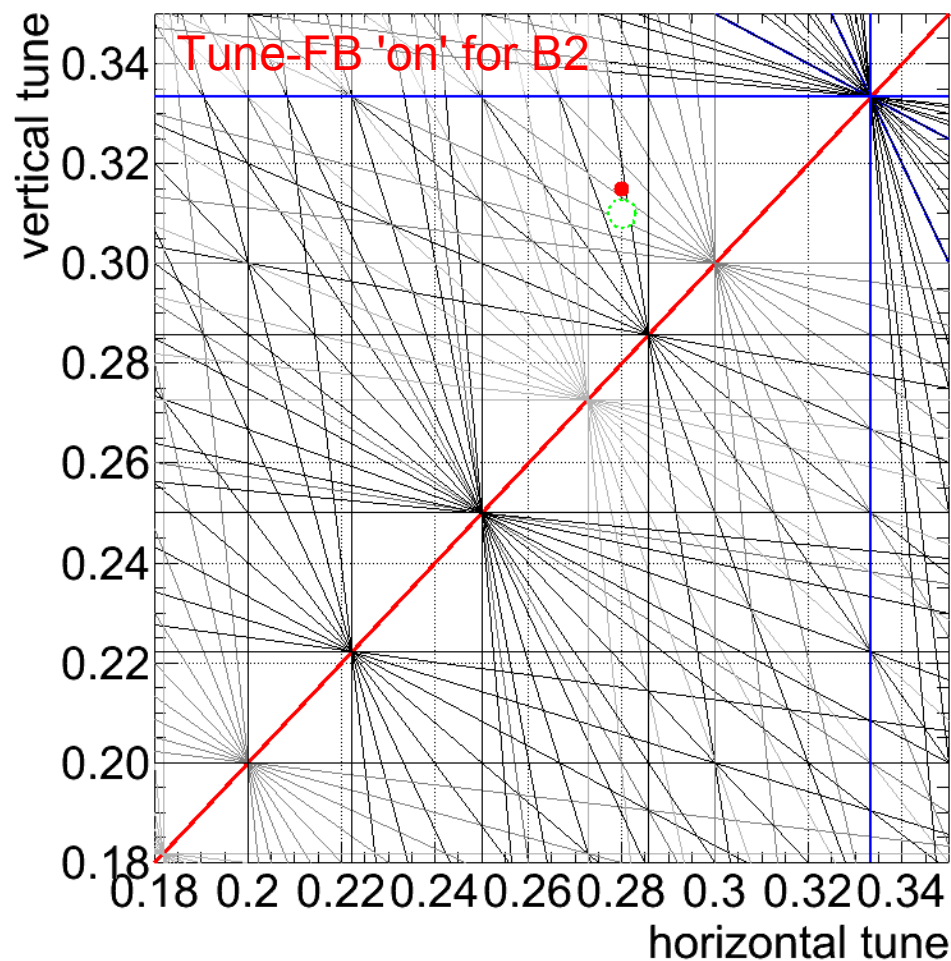
- FB response 1/e - time constants:

- Tune: 1..2 s \leftrightarrow \sim 0.1..0.3 Hz BW (depending on fitting limits)
 - peak-to-peak tune stability 10^{-3} (known from other measurements)
 - from Q-FB point-of-view: choice between FFT vs. PLL is transparent
- Orbit-FB & Radial-loop: 3.3 s \leftrightarrow 0.1 Hz BW
 - 200 μm steady-state error due to using only 400/520 eigenvalues
 \rightarrow next step: “SVD++” algorithm (FB-BW dependence on global/local control)
- In good agreement with model!
 \rightarrow Going to 0.5 or 1 Hz BW should not pose (big) problems

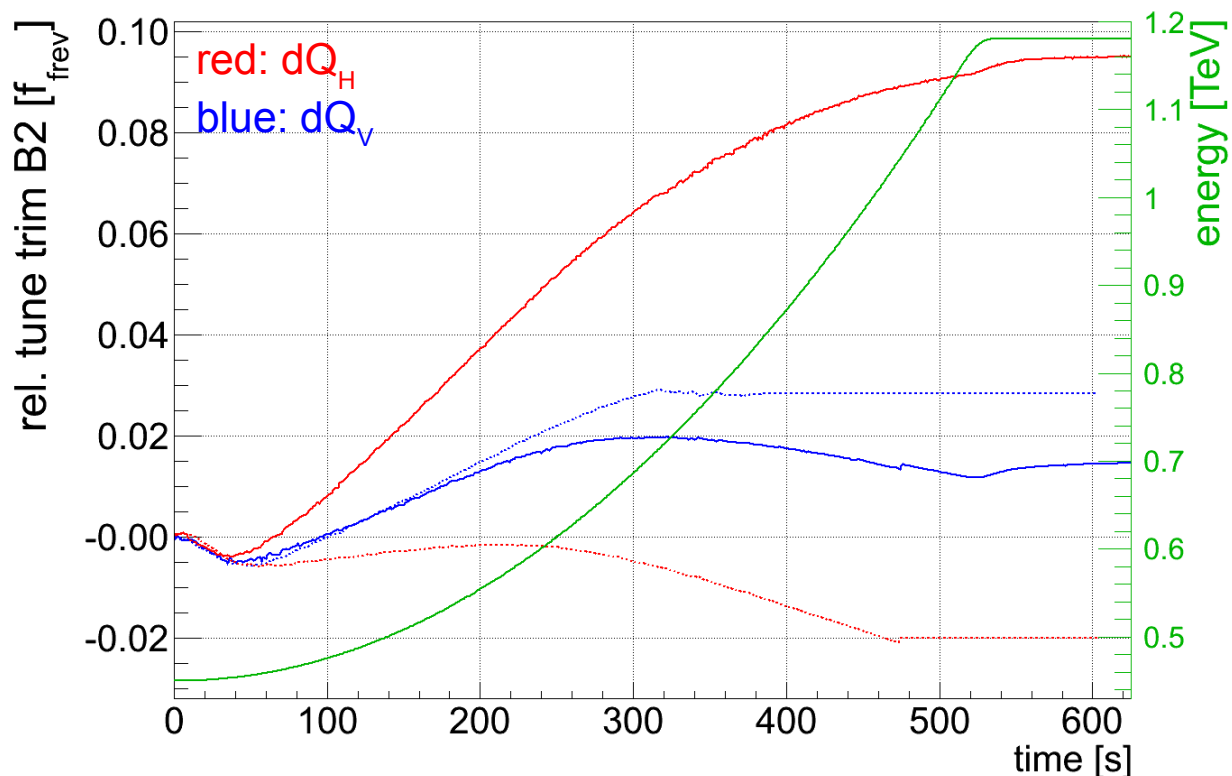


2009-12-08 @21:30 Ramp #4 ... a night to remember

- The “best/worst” case scenario to test the Q-FB function due to a sign-error in the B2 feed-forward correction
- N.B. Logging of equipment failed due to server problems
→ only B2 data useful for further analysis using MQT[D/F] currents
- Caught certain operational faults:
 - wrong feed-forward function,
 - Q-shifts due to Q' trims and “accidental” quadrupole trims
 - ...
- Q-FB established further ramps
 - Tune stability typically $< 10^{-4}$
 - off-line analysis of corrections
→ incorporation into LSA's feed-forward trim function



- From trim circuits reconstructed relative tune trims:



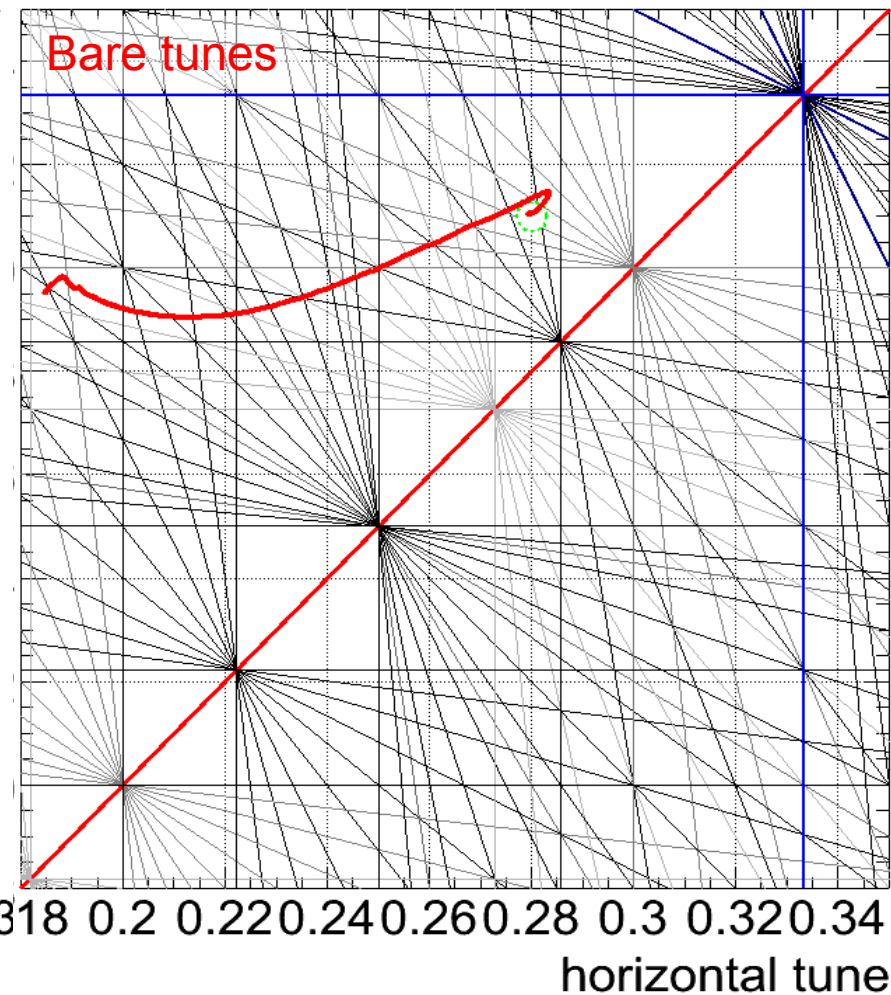
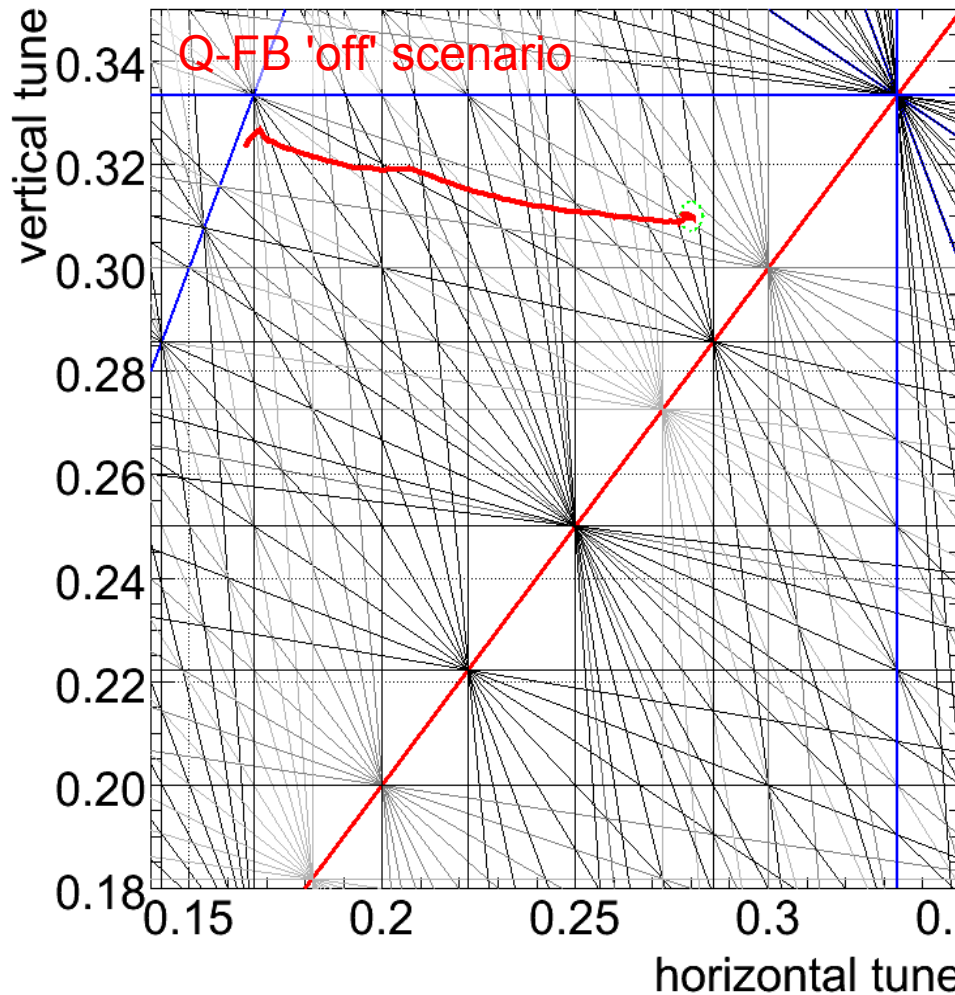
- Drift parameter reconstruction and source for tune drift are unclear:
 - Is it a b1 vs. b2 energy mismatch/lag,
 - a 'true' b2 snap-back and persistent currents decay, or
 - b3 feed-down caused by an off-centre orbit in the MBs & MSs... ?

... too many free parameter → FBs would help to pin-down some of them



2009-12-08 @21:30 Ramp #4 B2 reconstruction – “What if ... “ Analysis

- ... the Q-FB would have been 'off'
- ... the Q-FB would have been 'off' and no correction been applied → “bare tunes”, later used to compare different ramps



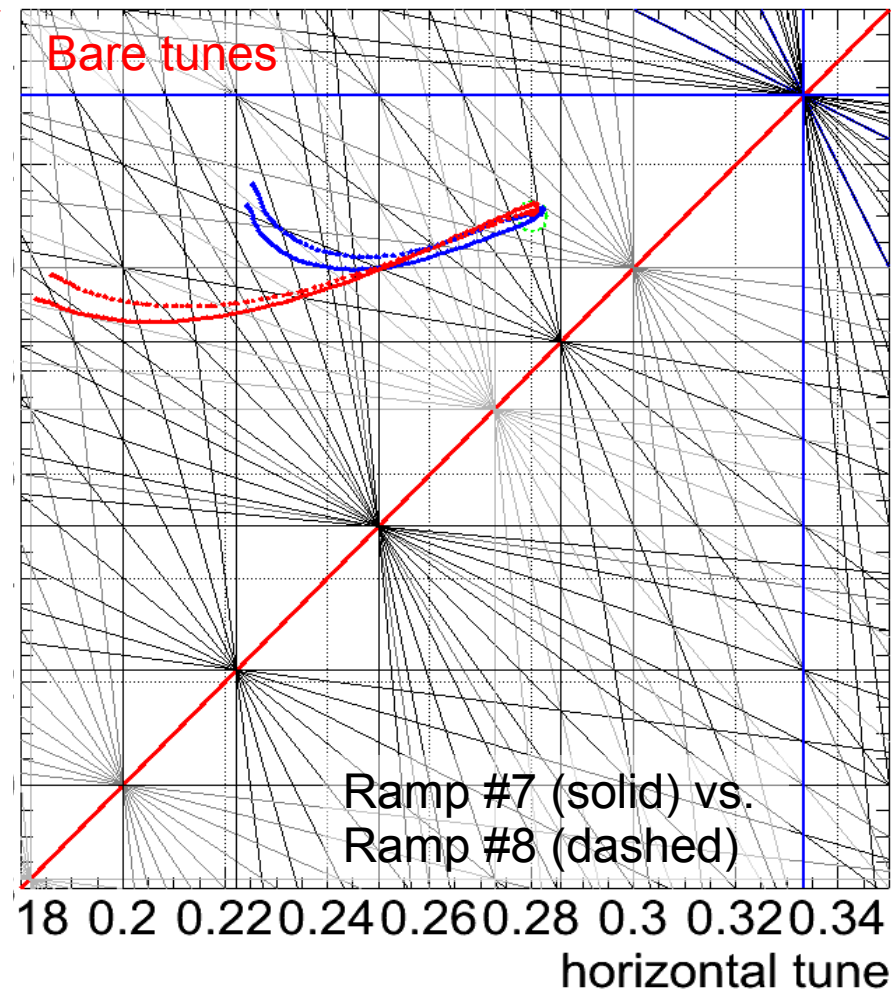
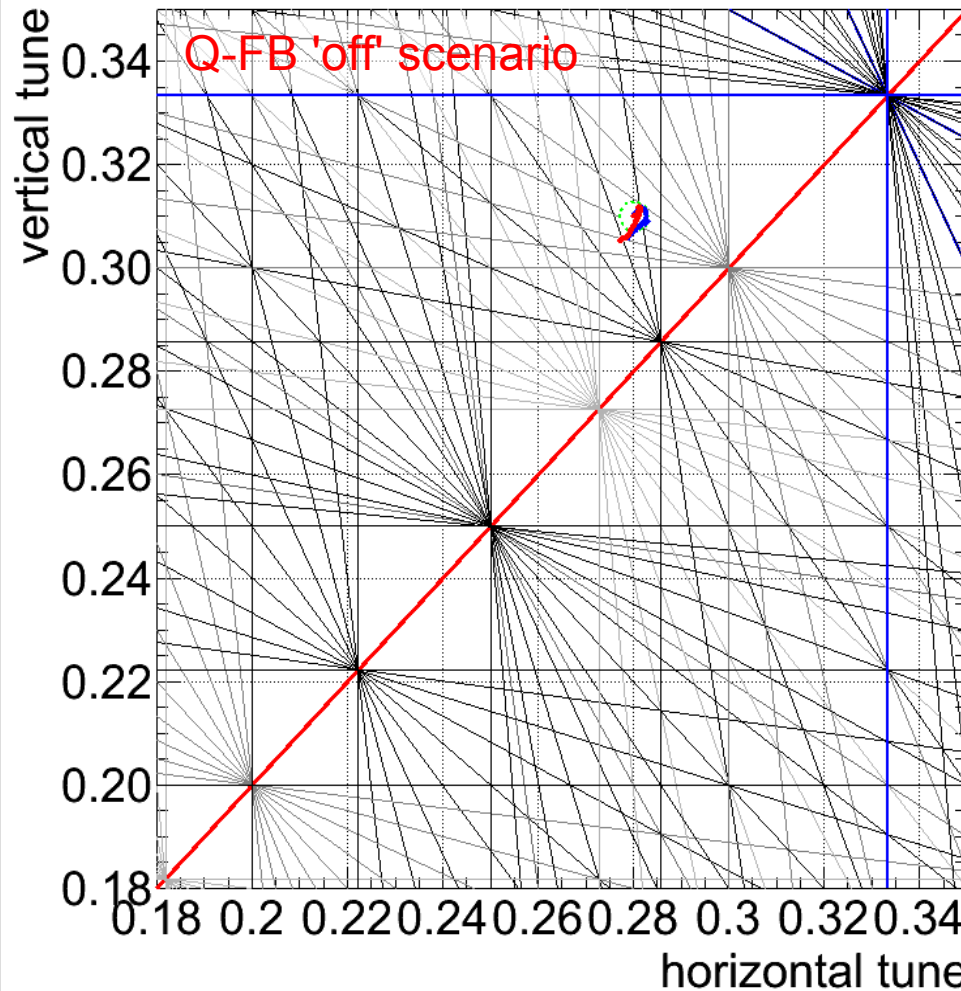


2009-12-15 @21:00 – Ramp #7

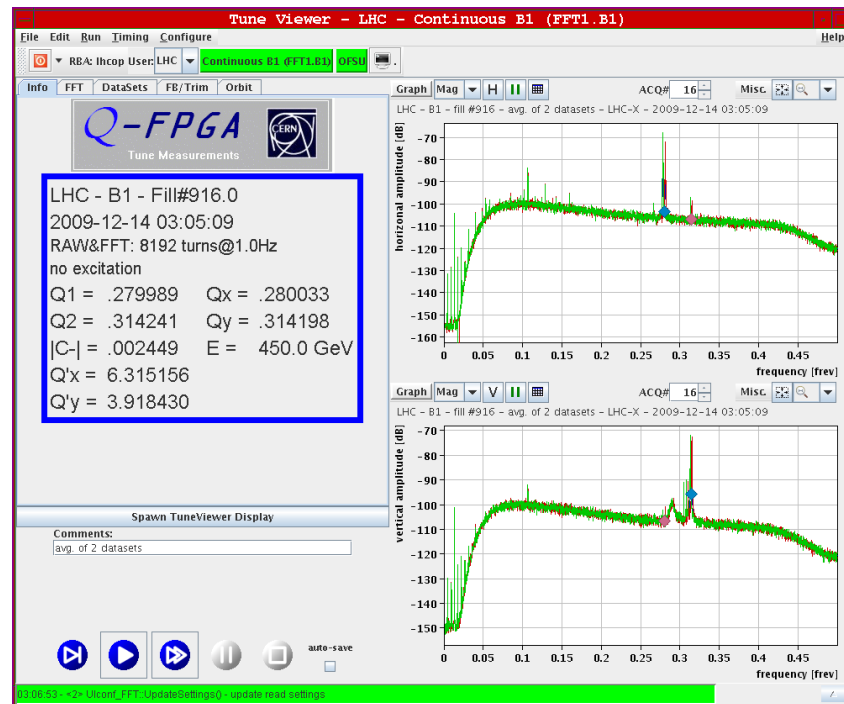
2009-12-16 @00:40 – Ramp #8

- Feed-Forward eventually converged with Feedback corrections
 - short-term tune stability of about $5 \cdot 10^{-3}$ between successive ramps

... end of 2009 LHC commissioning with beam

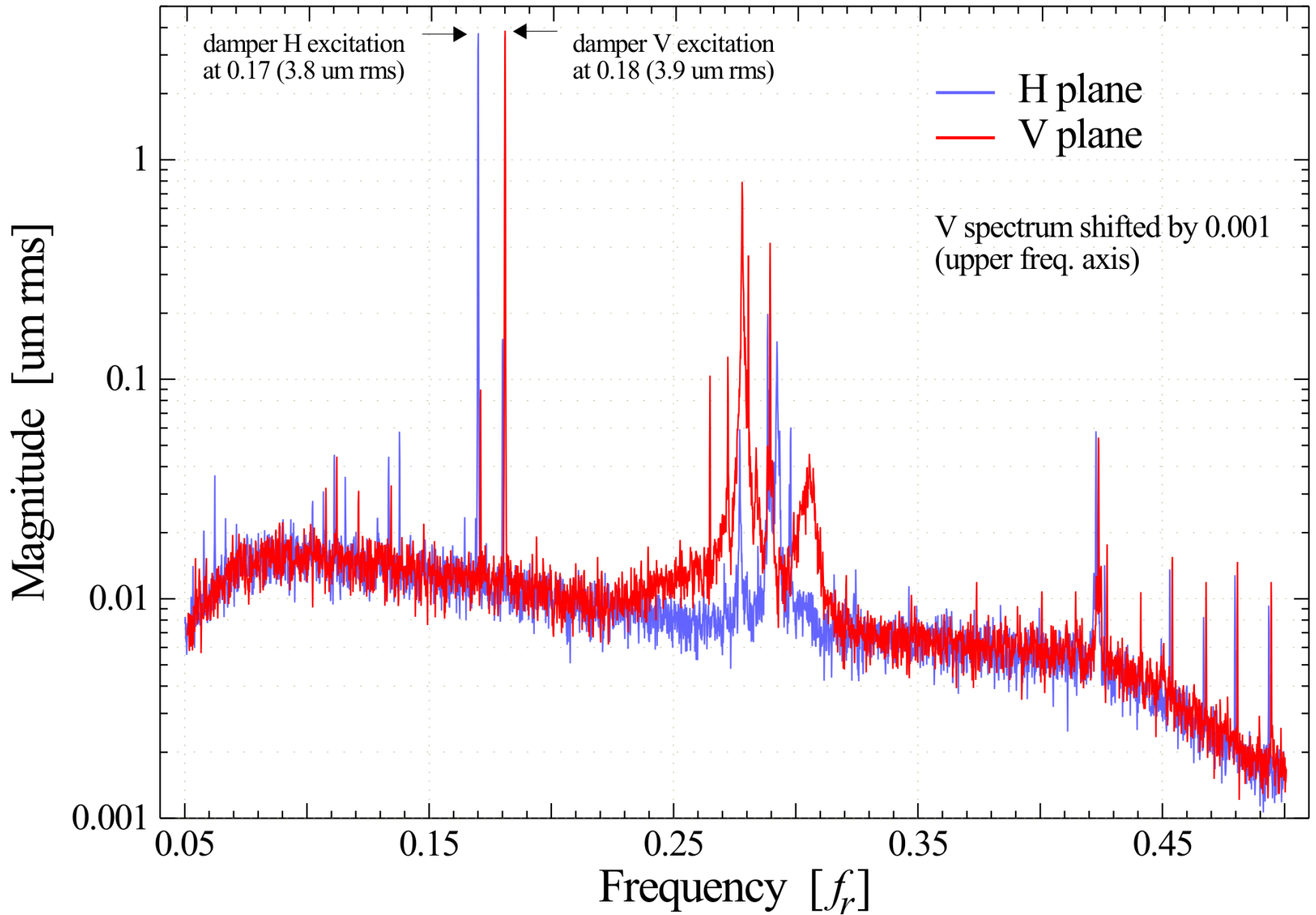


- Principal Q' diagnostics based on manual RF frequency trims while monitoring the corresponding tune shifts
 - some assistance by TuneViewer GUI
 - more automation foreseen for Q'
 - ... pending GUI improvements in view of day-to-day operation
 - **However: limited use while ramping**
→ the Q'-PLL use-case



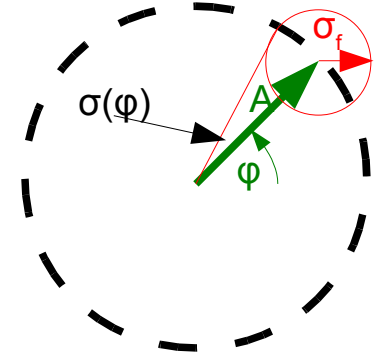
- Some mod. require more experience with beam but in any case:
→ **Thanks for the OP feedback!**
- In response to "Is the Feedback 'On'?" & 'What the ... is ... doing?':
 - A fixed-display type GUI and logging of FB 'on/off' & reference states for all Q/Q' and FB systems is under preparation... suggestions are welcome!

- Any feedback is only as good as its model and the measurement it based on!
- Identified issues:
 - Residual um-amplitude tune oscillations:
 - PRO: beneficial for the FFT-based systems!
 - CON: bad for beam life-time and Q-PLL operation
 - Residual tune jitter:
 - Implies larger required $\Delta p/p$ modulations for the Q'-Tracker operation
 - 8 kHz line, broad frequency “hump”, and other spectra perturbations:
 - Reduction of beam life-time, emittance blow-up, ...
 - Potential to perturb FFT-based Q-Tracker (N.B. PLL less sensitive to this)
- Effects not (yet) seen or of less importance in 2009:
 - Beam-Beam: effects on BTF & interpretation of coherent Q spectra
 - Coupled bunch-effects and damper operation: effects on BTF (Q-PLL)



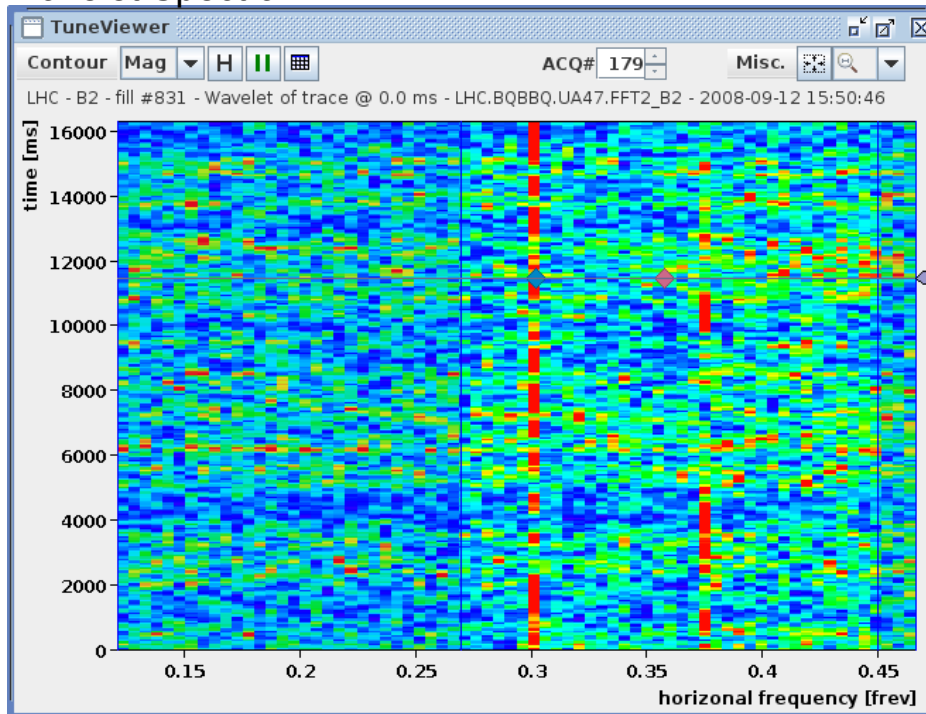
- add vectorial to the carrier signal:
 - excitation amplitude (carrier signal): A
 - noise in time (frequency) domain: σ_t (σ_f)
 - equivalent number of turns: N

$$\sigma(\varphi) \leq \arcsin\left(\frac{\sigma_f}{A}\right) = \arcsin\left(\sqrt{\frac{2}{N}} \frac{\sigma_t}{A}\right) \approx \sqrt{\frac{2}{N}} \frac{\sigma_t}{A}$$

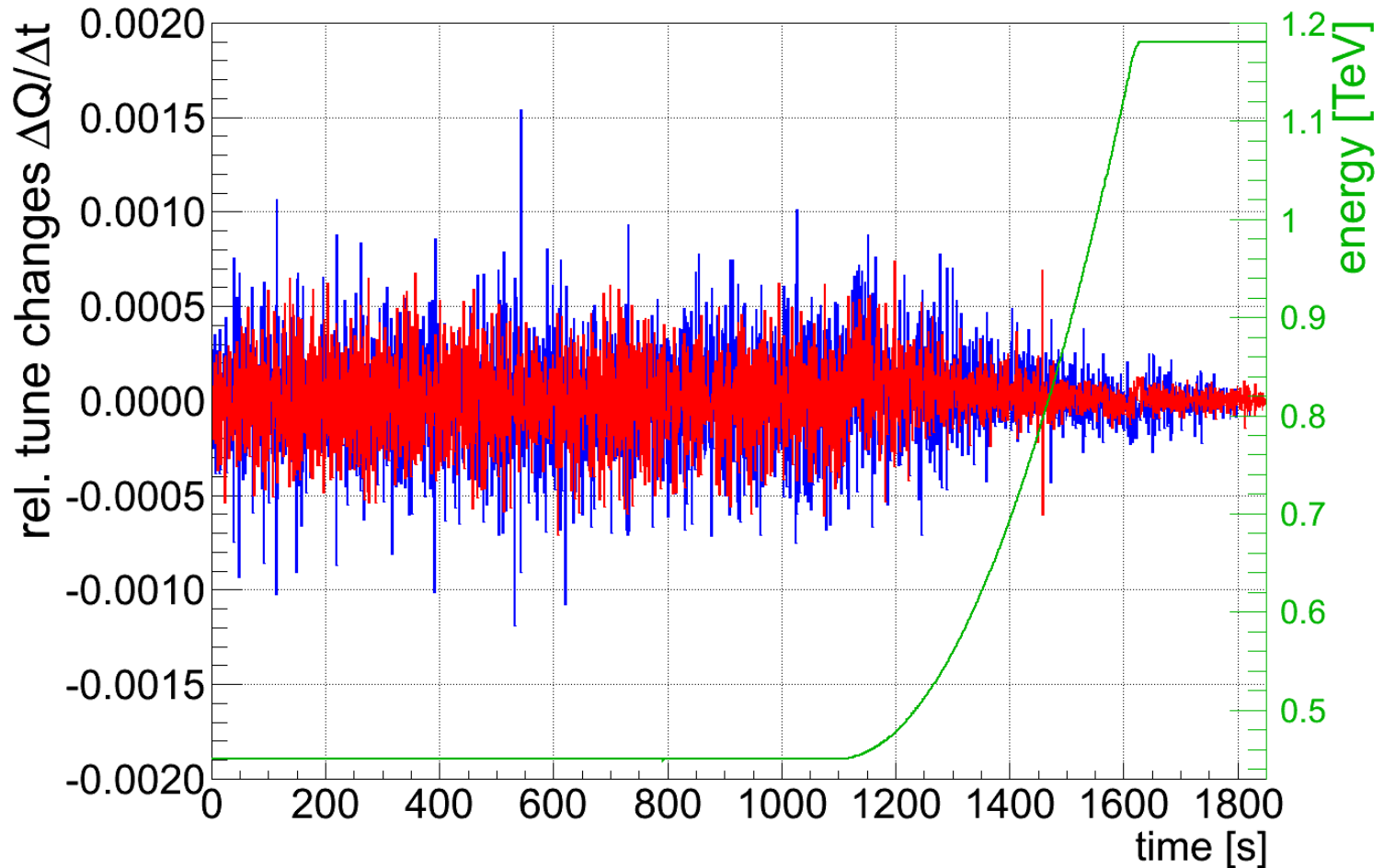


- PLL excitation needs to be larger than the non-PLL driven oscillation!

Wavelet Spectra:



- Example (3. ramp 2009-11-30 @00:15):



- Residual tune stability $\Delta Q \approx 5 \cdot 10^{-4}$
 - no particular frequency dependence \rightarrow 'white noise'
 - Little/no Q' but energy dependence \rightarrow power converter noise?



Residual LHC Tune Stability

– Source #1: RQT[D/F] Circuit Noise

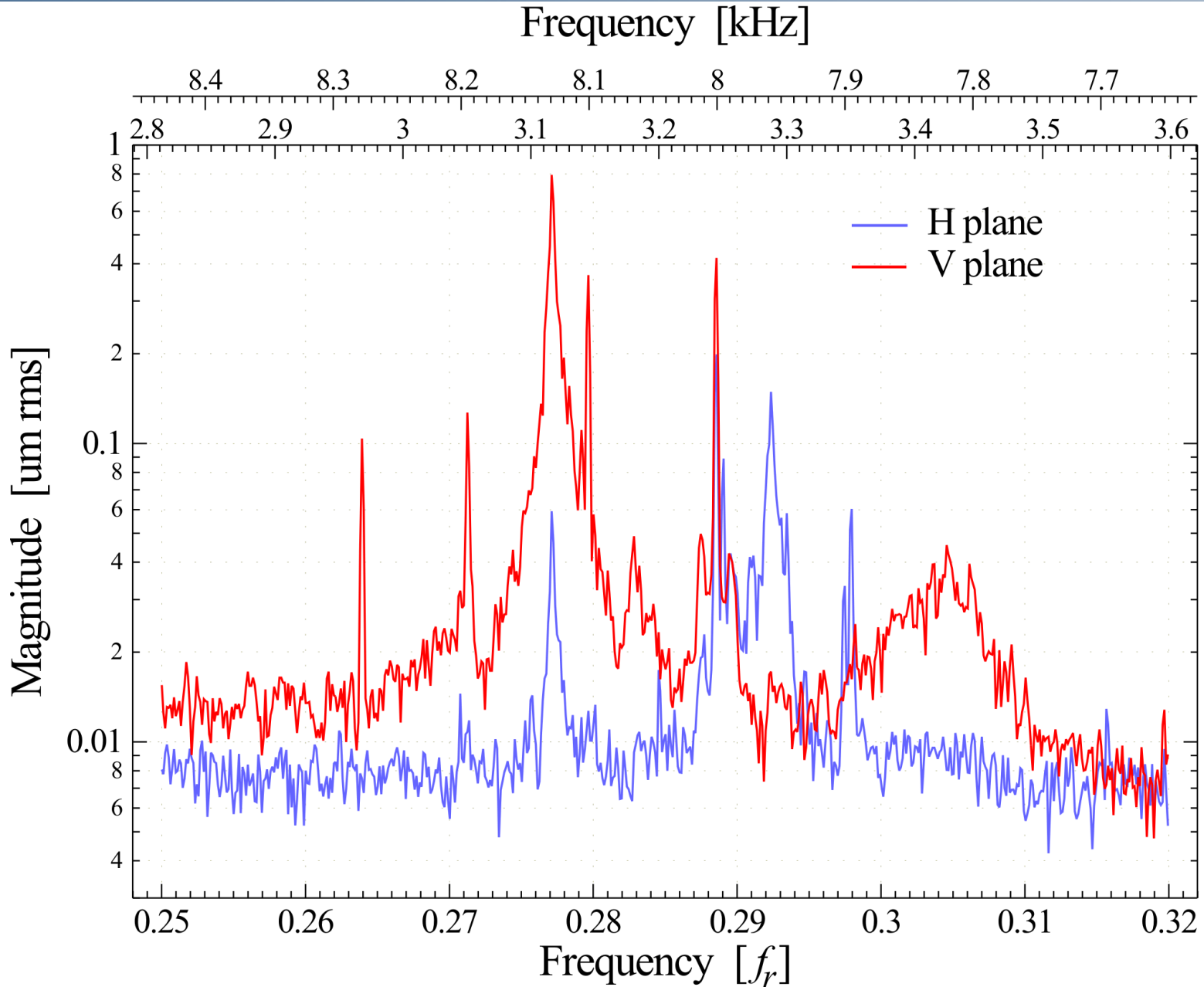
- Jitter hampers Q'-tracker operation with targeted mod. amplitudes of $\sim 10^{-5}$
 - The “easy/naive” solution of increasing the dp/p modulation to $> 10^{-4}$ to compensate for this effect is (probably) impractical for every-day operation!
 - While the 1.18 TeV spectra are much cleaner, Q'-Tracker is most needed at 450 GeV (b3 during ramp diagnostics)!

- Trim quadrupoles as one of the possible sources:

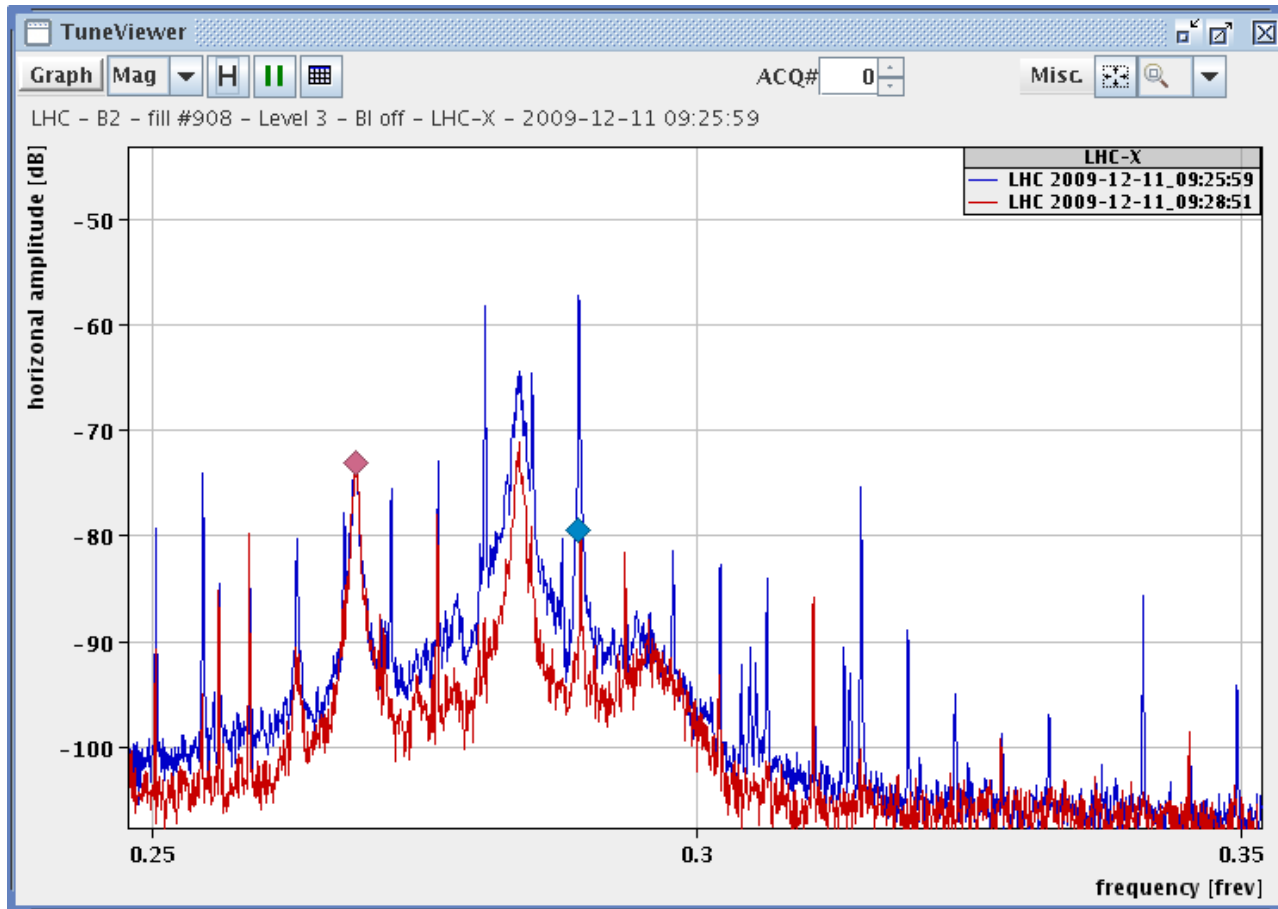
$$\begin{pmatrix} \Delta I_{RQTD} [A] \\ \Delta I_{RQTF} [A] \end{pmatrix} \approx \frac{p [GeV]}{450 GeV} \cdot \begin{pmatrix} +4.3 & +22.2 \\ +22.7 & +3.9 \end{pmatrix} \cdot \begin{pmatrix} \Delta Q_H \\ \Delta Q_V \end{pmatrix}$$

- Some numbers: $\Delta Q_H = 10^{-4}$ @450 GeV $\rightarrow \Delta I_{RQTF} = 2.2$ mA & $\Delta I_{RQTD} = 0.4$ mA !!
 - Specified nominal current stability over 0.5 h: $\Delta I = 10^{-5} \cdot 600$ A = 6 mA
 - Some RQT[D/F] circuits have short-term jitter of ~ 1 mA
 - Why do some other jitter by up to 10 mA? Other important circuits?
- Actual trims were tiny \rightarrow switch them 'off' and re-measure effect @450 GeV?

The 8 kHz Line & Frequency “hump”

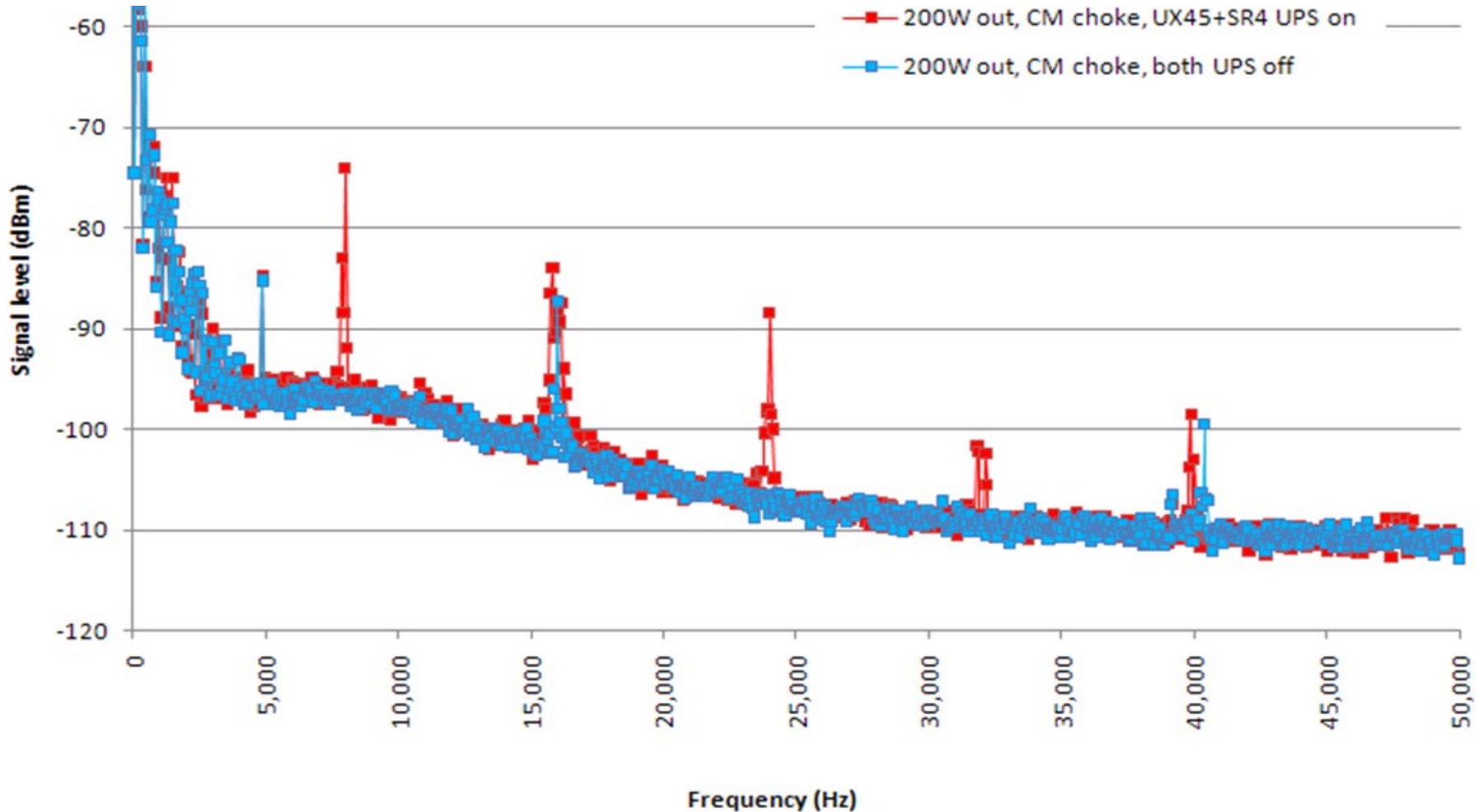


- ADT 'Level 3' (damper 'on', blue) vs. 'Level 2' ('off', red): Horizontal Plane

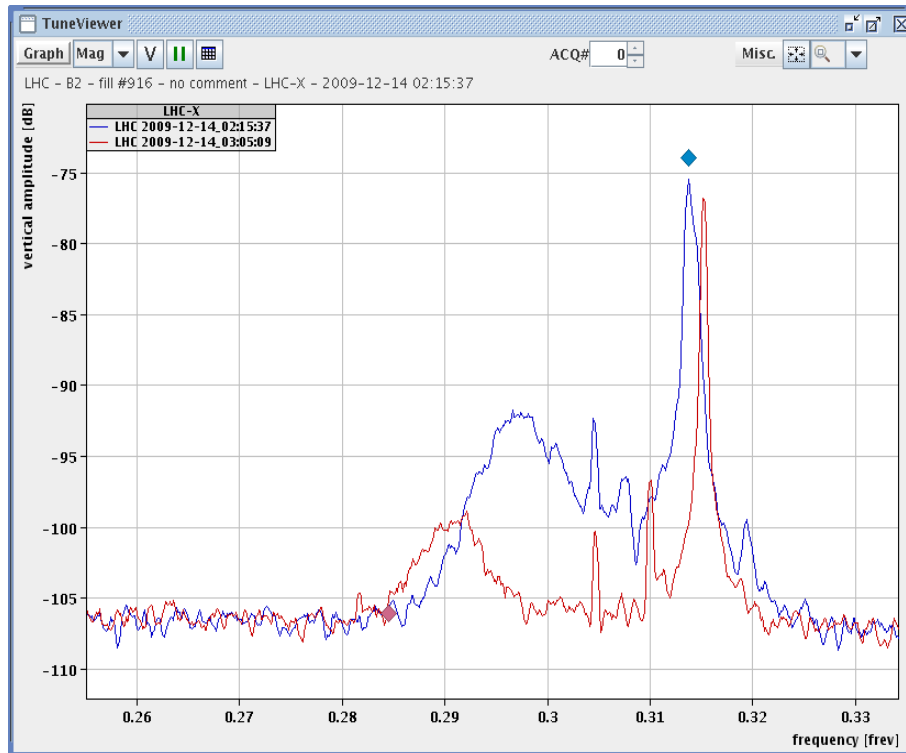


- Features: 'white noise' driving the tune resonance, some lines are specific to ADT but some remain even if the damper is switched 'off'
 - Residual 8 kHz confirmed to be due to the UPS!

- Damper 200W driver output spectrum, UPS 'on' vs. 'off' (courtesy W. Höfle):
 - 8 kHz vanishes if UPS is by-passed, some other lines remain

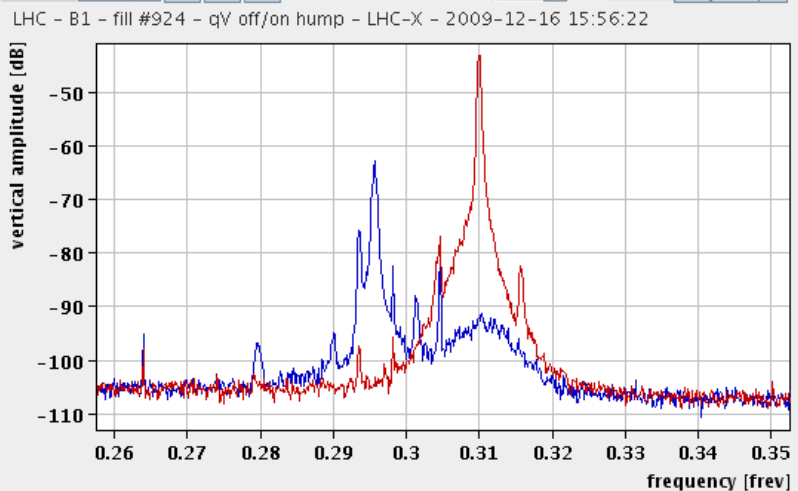
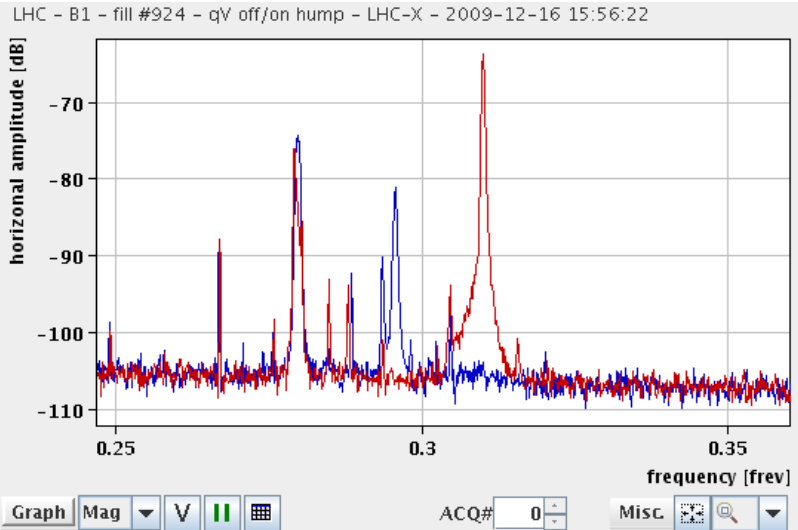


- The 'hump' seemed to be more apparent since 2009-11-28 – 2009-12-03
 - Predominantly seen in vertical plane
 - beam gets resonantly excited if tune in the vicinity of this frequency → emittance blow-up as nicely documented by the BSRT
- Amplitude seems to approximately scale with energy (-8dB reduction)
 - tune spectra before (450 GeV) and after (1.18 TeV) the ramp #6:

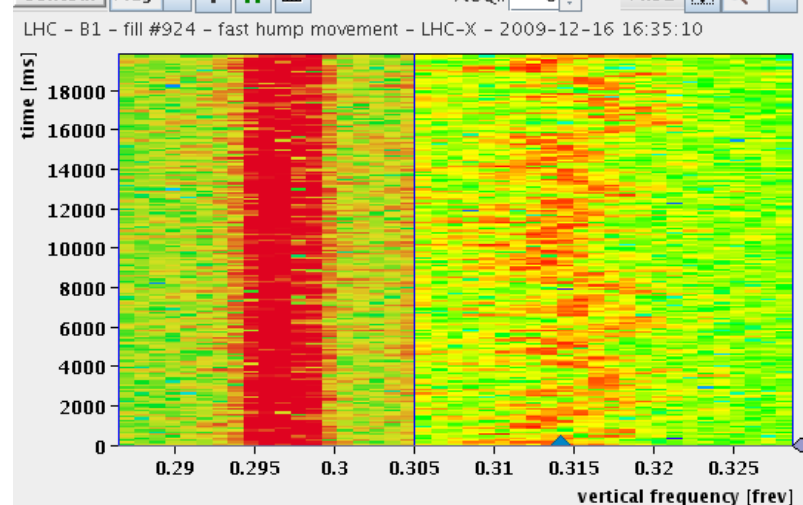
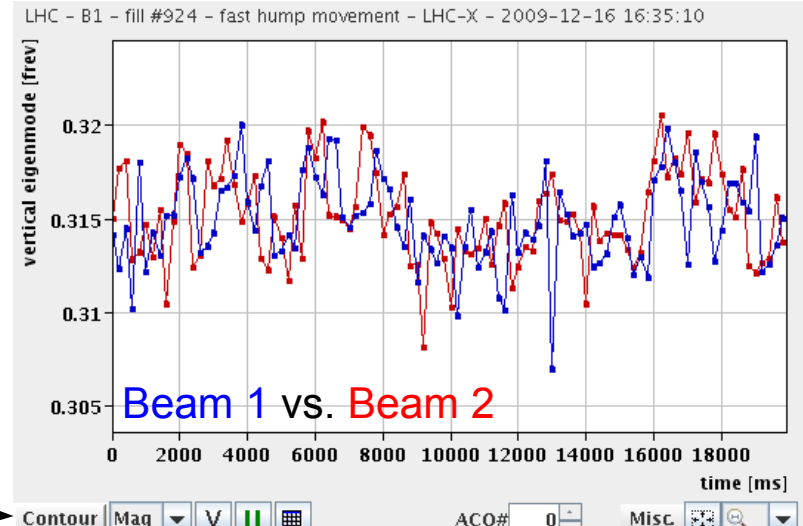


- Initially identified has 'hump' but actually a fast frequency shifting oscillation with the mean drifting slowly between $0.25...0.32 f_{rev}$

Example: Q_v being shifted onto the 'hump'



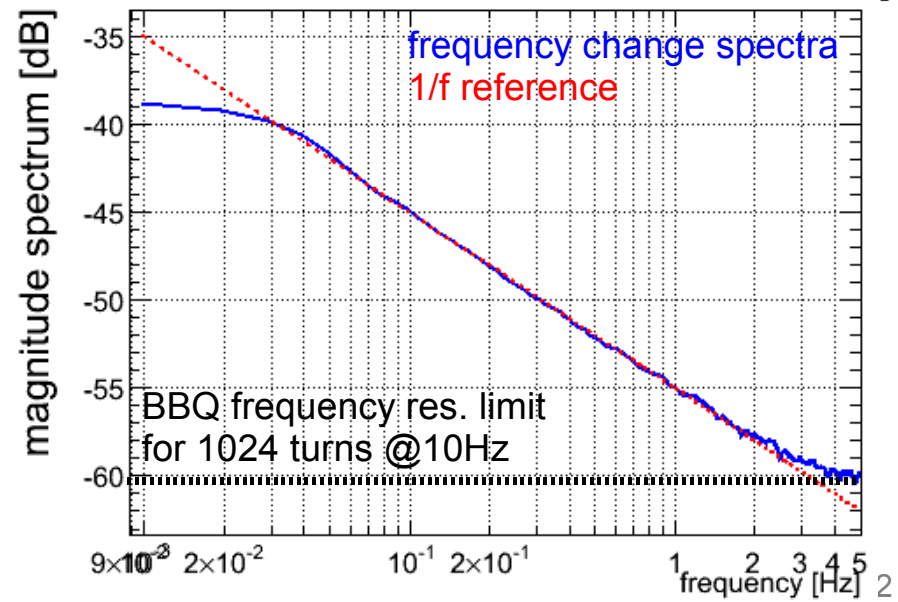
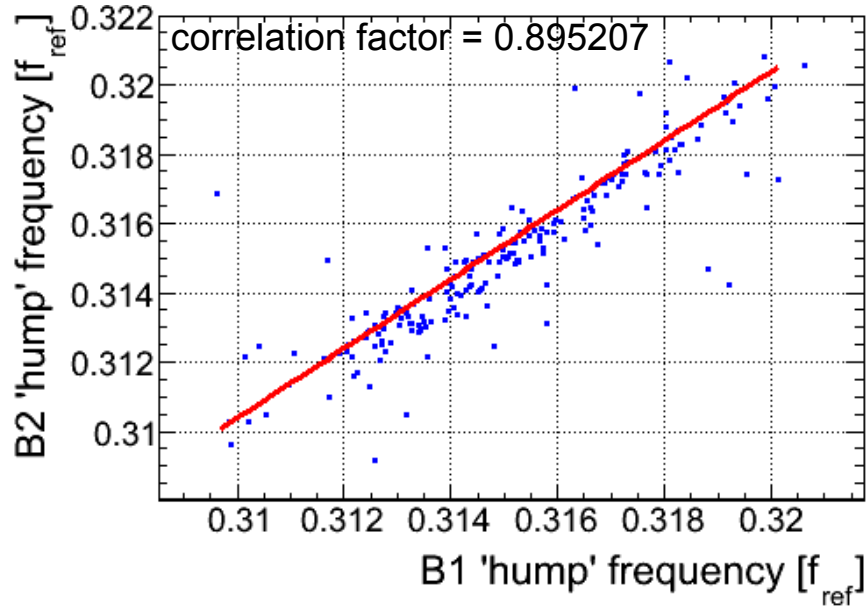
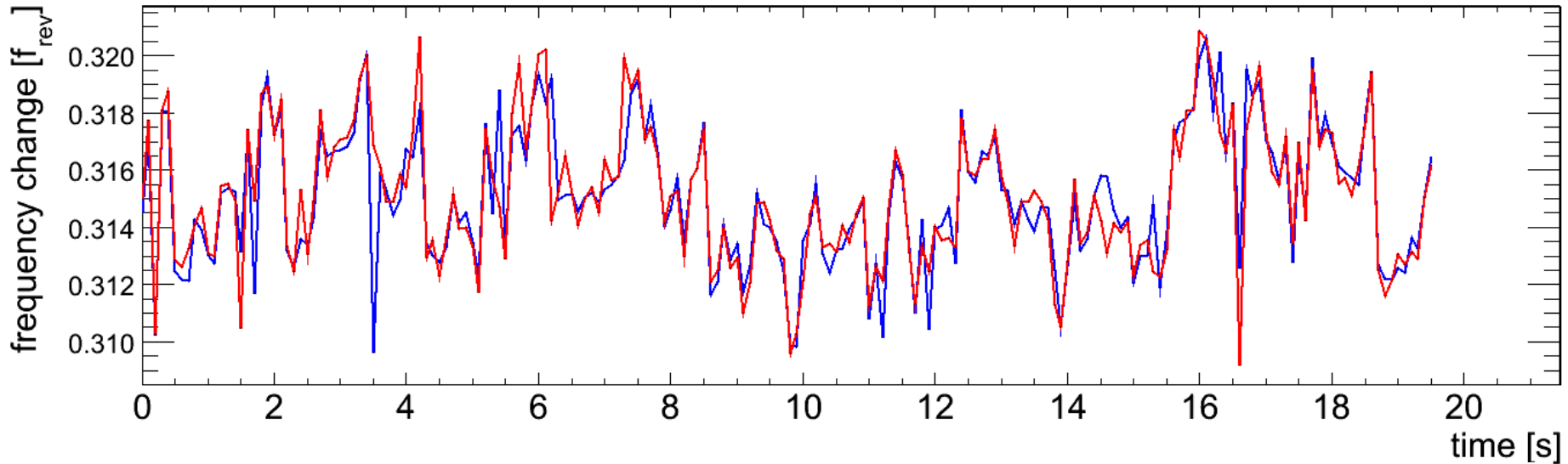
Time-resolved 'hump' structure:





Shifting Frequency Dune → LHC's 'Hunchback' III/III Correlation and Frequency Characteristics

- Hump on Beam 1 is correlated with the one in Beam 2:



- Ramping the LHC seems to work only during the night (21:30 ↔ 2:28)
→ we should try whether we can do this also e.g. after 8 o' clock
- BBQ/Q-FB stability promising & better than residual LHC reproducibility
→ envisage Orbit & Q' FB to eliminate/pin-down some of the 'unknowns'
- Some identified issues/remaining questions:
 - Residual um-amplitude tune oscillations → life-time & Q-PLL operation
 - Residual tune jitter → Q'-Tracker operation
 - Can the MQT[D/F] corrector circuits' stability be improved?
 - 8 kHz line & broad frequency “hump” → beam stability & FFT Q-Tracker
 - UPS/Damper may be 'one' but not the sole perturbation source.
 - Other sources and origin of the non-8kHz lines?
 - to 1st order unlikely effects causing the 'hump' (tested with beam):
 - ADT, MSI, CODs, ...?



Reserve Slides

Visible through out the LHC

