Status and Prospects of Q/Q' measurements

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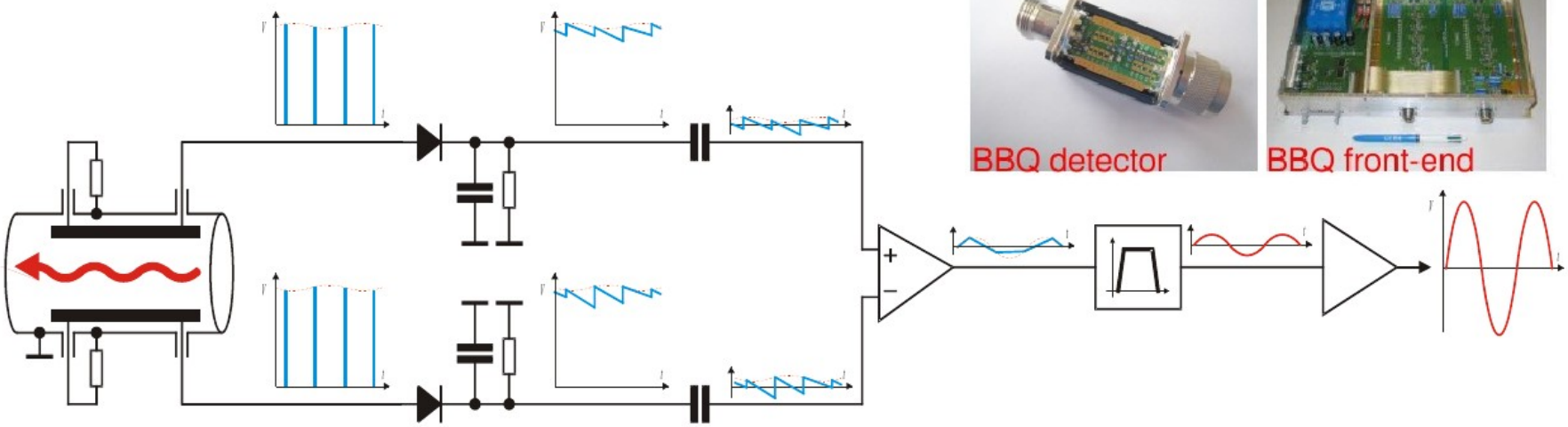
- Initial BBQ and Head-Tail design consideration, strengths and weaknesses
- New Head-Tail Electronics Prototype and Beam Measurement Examples
  - Head-Tail Instability Diagnostics
  - Gated- /bunch-by-bunch tune diagnostics
- Present planning for beam prototype tests after the next technical stop

Tune Diagnostics Instrumentation – RECAP
Direct-Diode-Detection

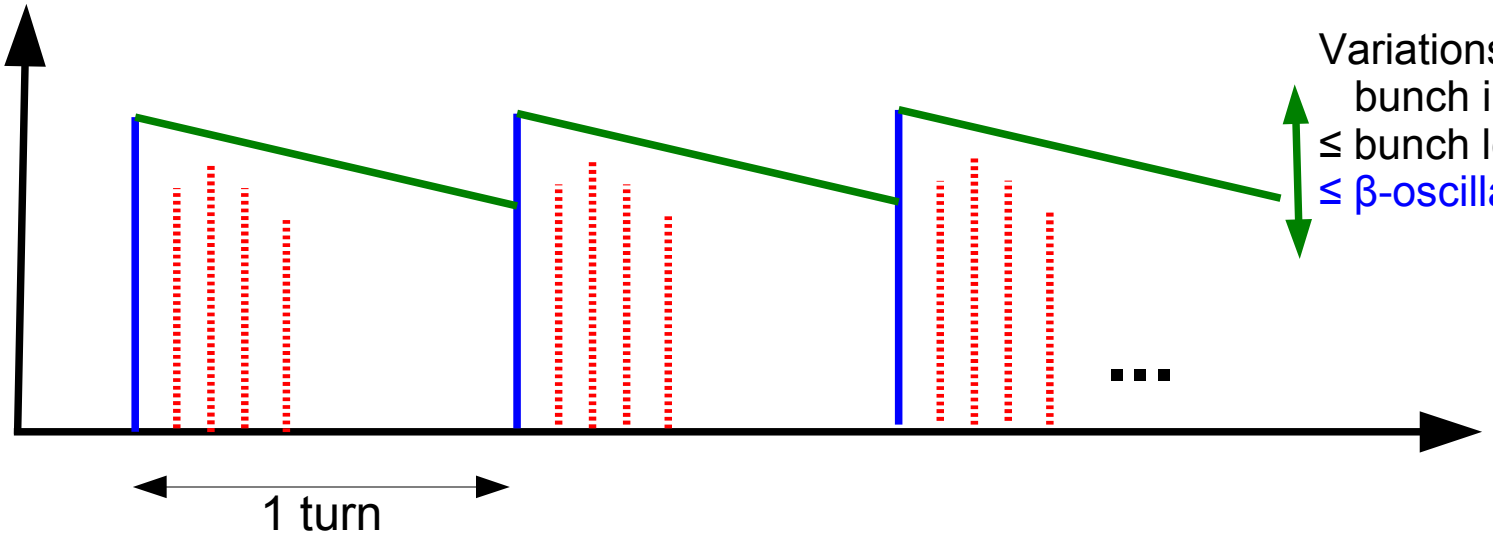


- Basic principle: AC-coupled peak detector[1]
  - intrinsically down samples spectra: ... GHz → kHz (independent on filling pattern)
    - thus 'Base-Band-Tune Meter' (aka. BBQ)
    - Base-band operation: very high sensitivity/resolution ADC available
    - Measured resolution estimate: < 10 nm → ε blow-up is a non-issue
  - AC-coupling removes common-mode → only rel. changes play a role
    - capacitance keeps the "memory" of the to be rejected signal
  - no saturation, self-triggered, no gain changes to accommodate single vs. multiple bunches or low vs. high intensity beam
- However: no specific bunch-by-bunch information (unless using gating)

[1]M. Gasior, *"The principle and first results of betatron tune measurement by direct diode detection"*, CERN-LHC-Project-Report-853, 2005

BBQ Working Principle

- … being essentially an 'RF Schottky (Peak) Detector'



- Which 'peak' is selected depends on a number of parameters

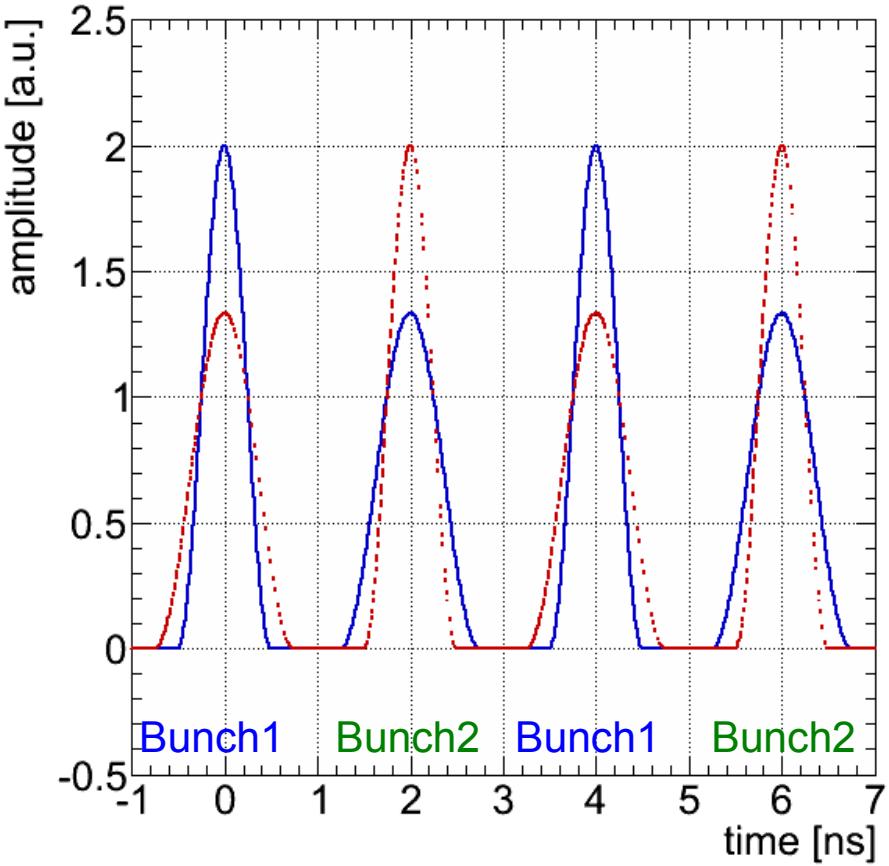
~700 V_p ~7 V_p ~few μV_p

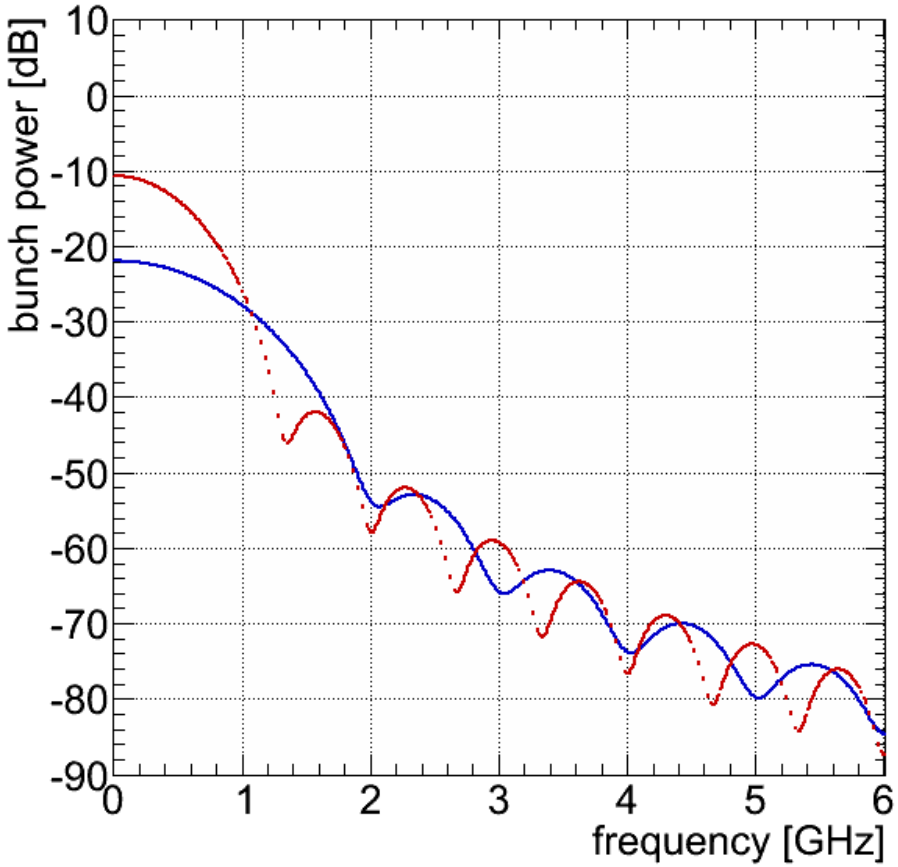
$$\Delta I_{button}(t) \sim \underbrace{\rho(\tau, t)}_{\tau \sim \sin(\omega_s t)} * \left[\frac{I_{cm}}{I_0} \right] + \frac{\Delta z}{R} \underbrace{\sin(\omega_Q t + \varphi)}_{dep.\ on\ Q',\ \Delta p/p,\ \omega_s,\ ..} + \left[h.o. \right]$$

bunch length oscillations | bunch intensity variations | Position dependent/ Betatron motion | i.e damping terms

Bunch Shape Oscillation

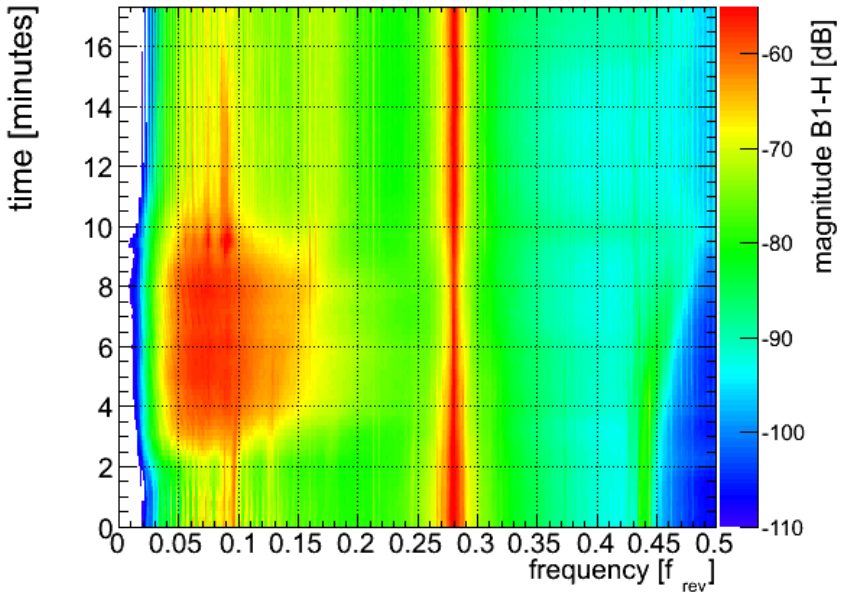
- Mechanism of issue:

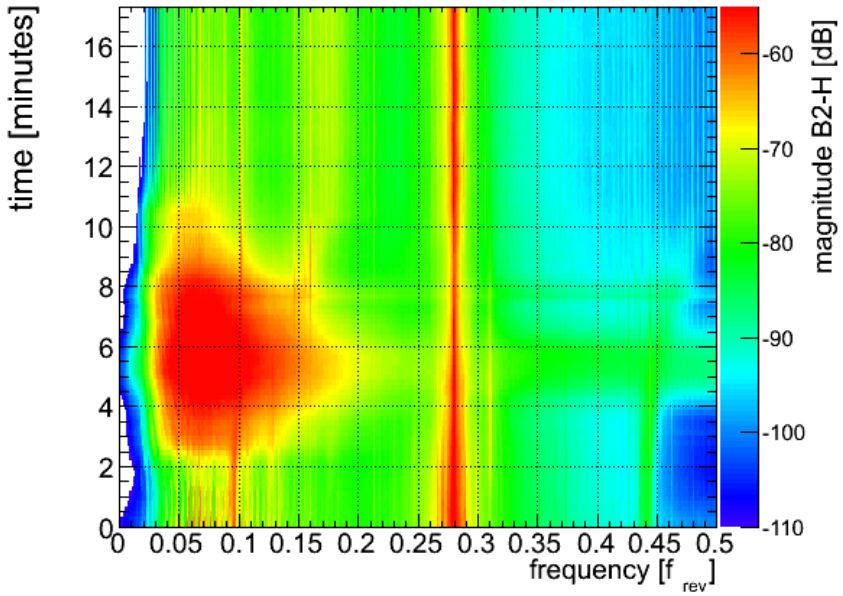


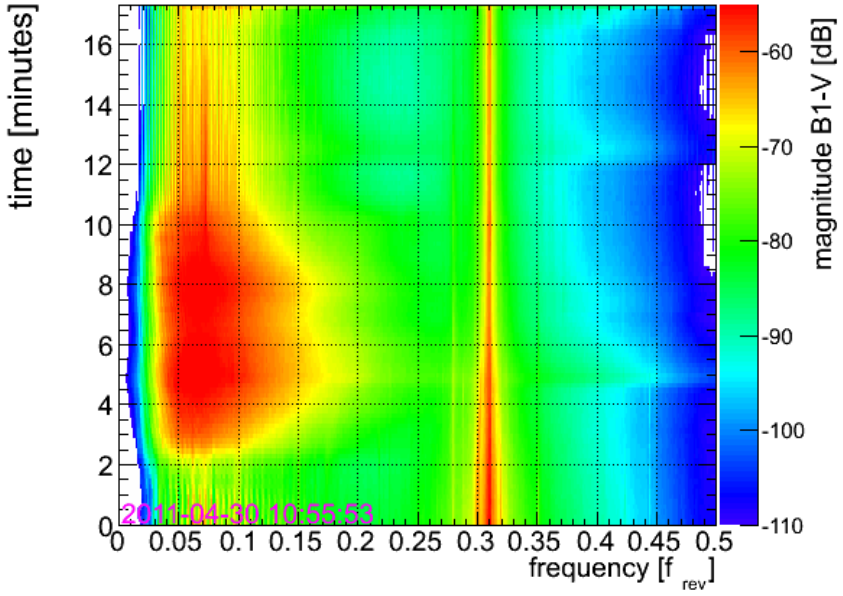


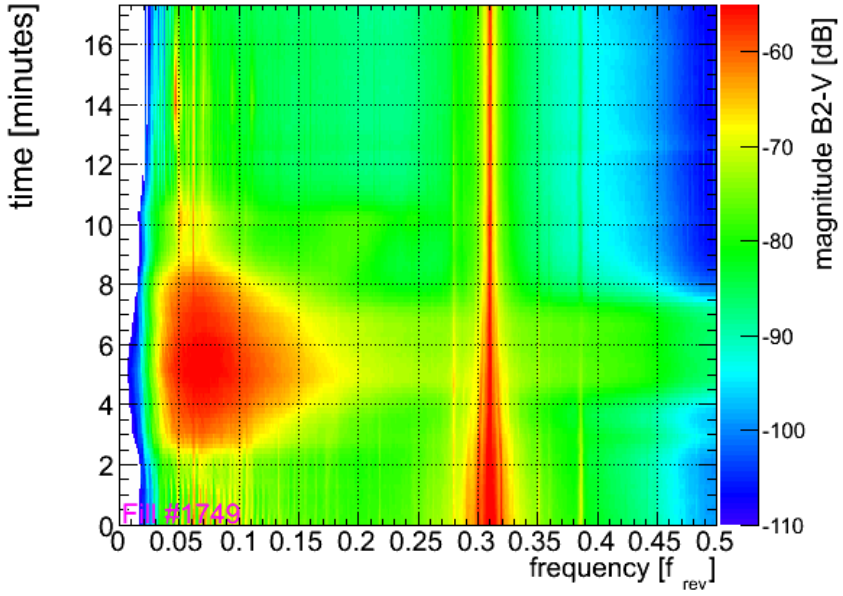
- Observables: Q_s side-bands & convoluted/noisy tune lines

Typ. LHC Ramp with Longitudinal Blow-Up

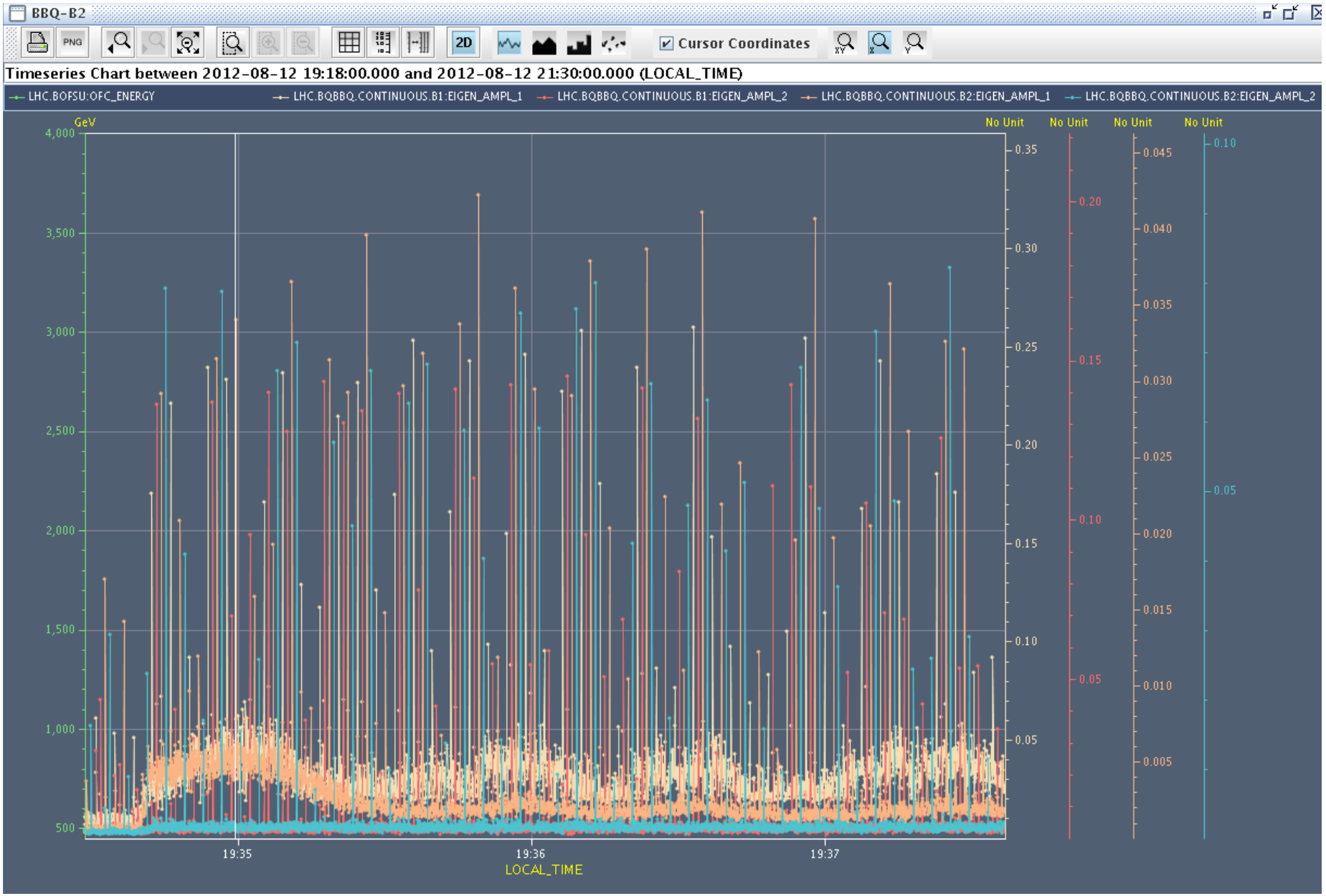




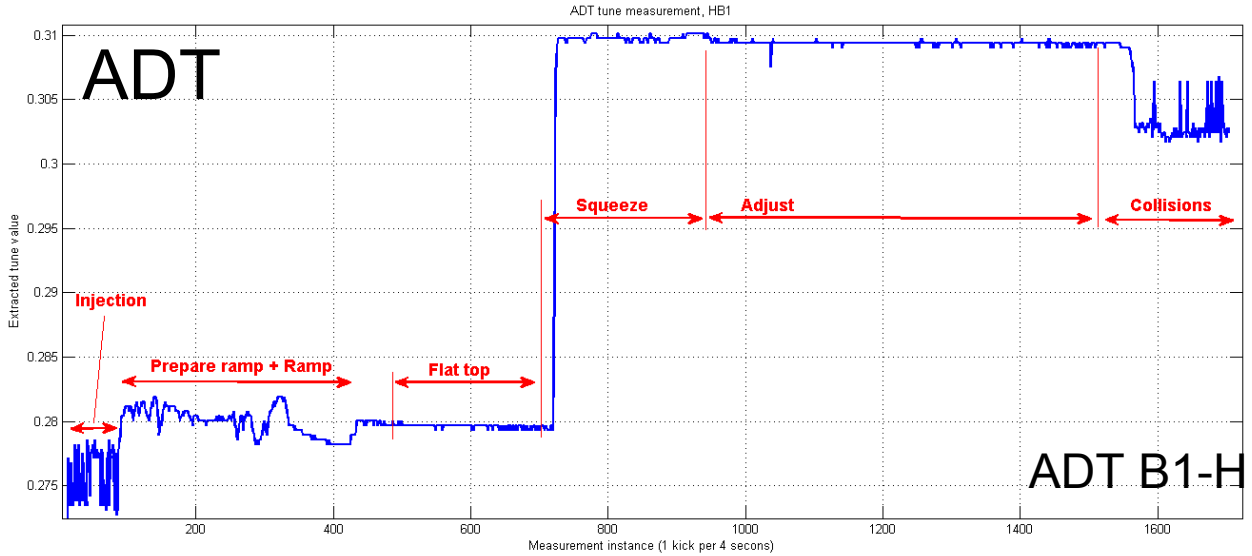


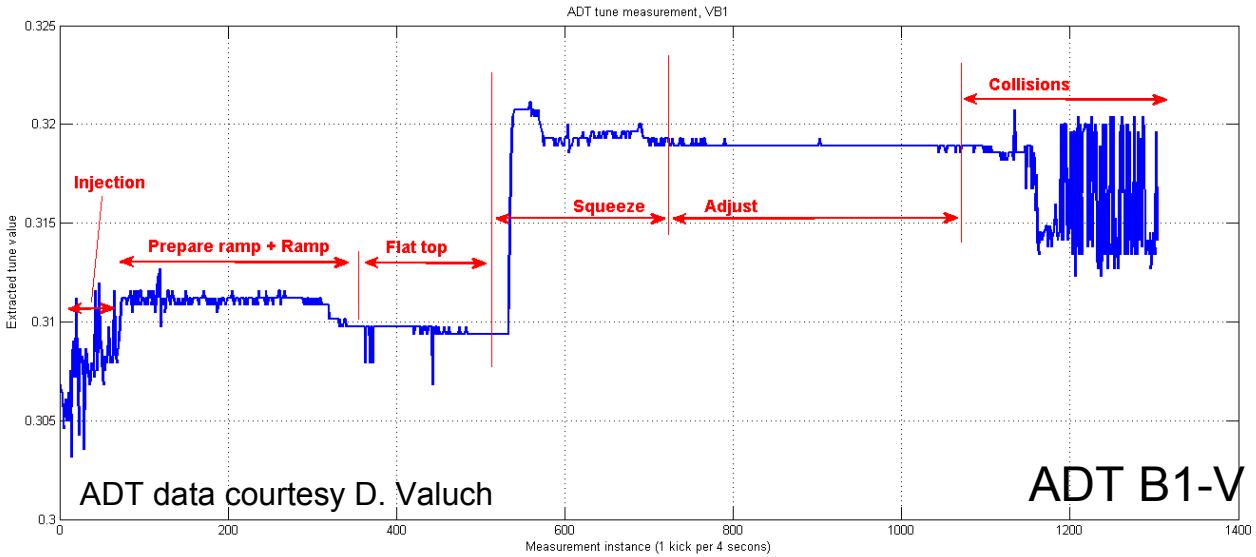


Corresponding BBQ Eigenmode Amplitude – ZOOM
Kick@0.25Hz visible increason S/N ratio by up to 40 dB



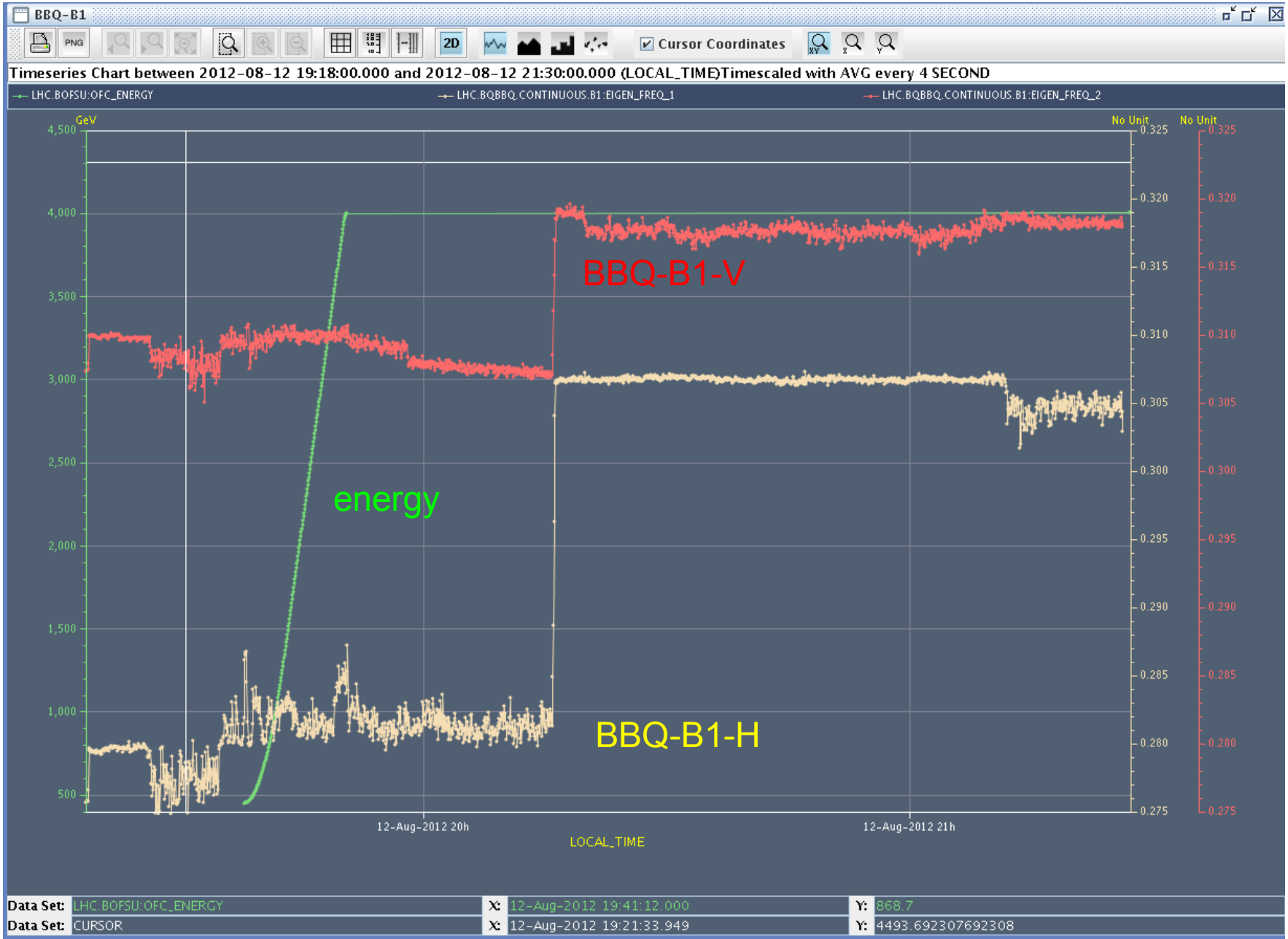
2012-08-12 19:15 – 22:00
Comparison between 'gated ADT' and 'BBQ' based Q diag.



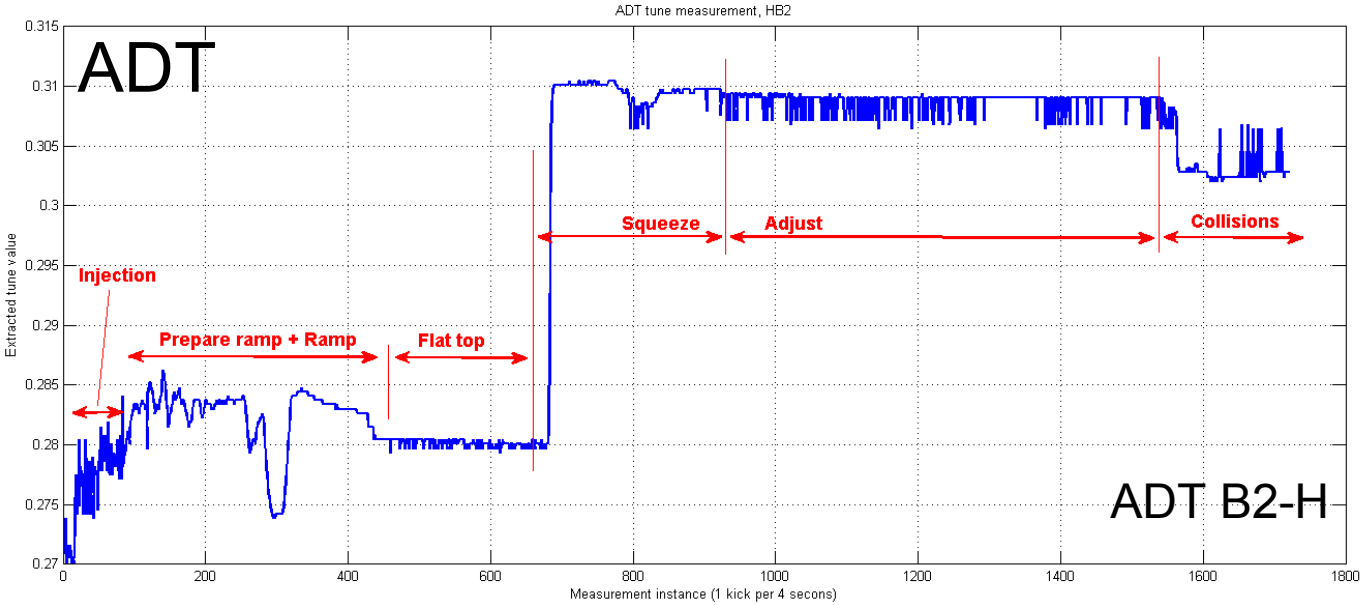


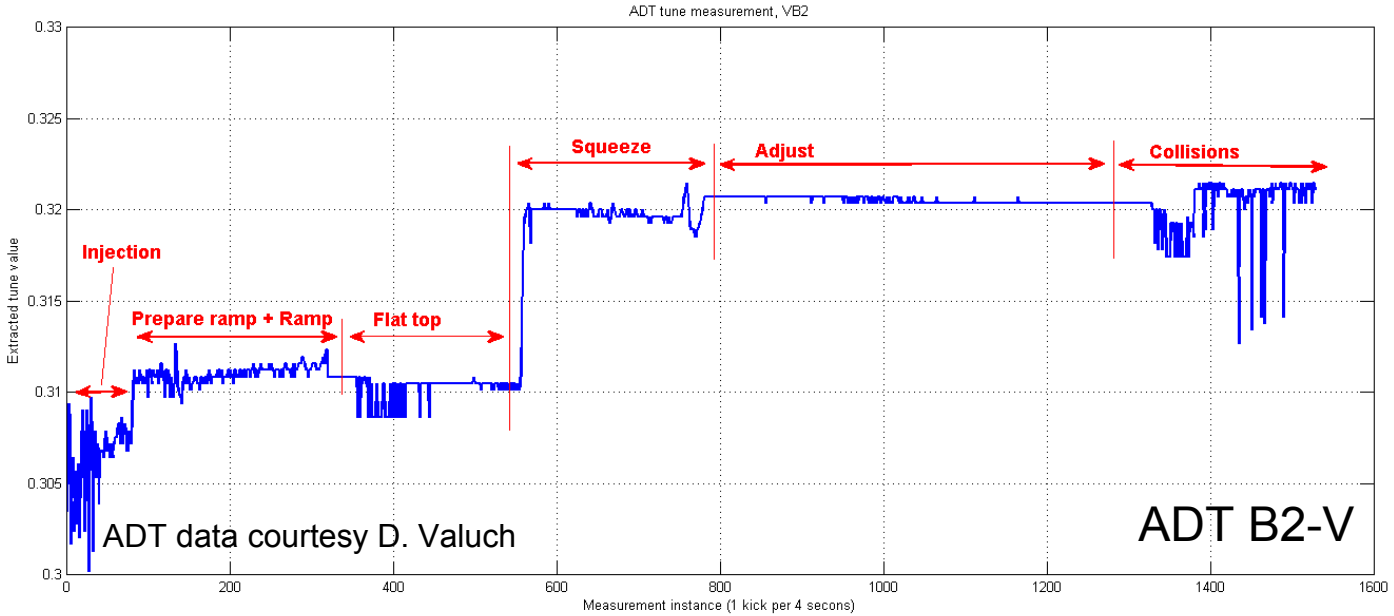
N.B. 100 um level kick every 4 seconds

2012-08-12 19:15 – 22:00
Corresponding BBQ Signal B1



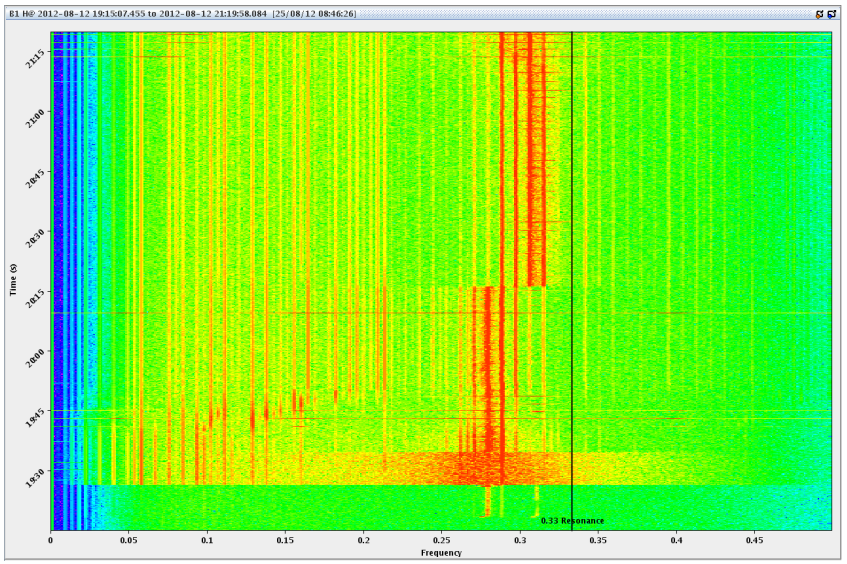
2012-08-12 19:15 – 22:00
'gated ADT' for B2

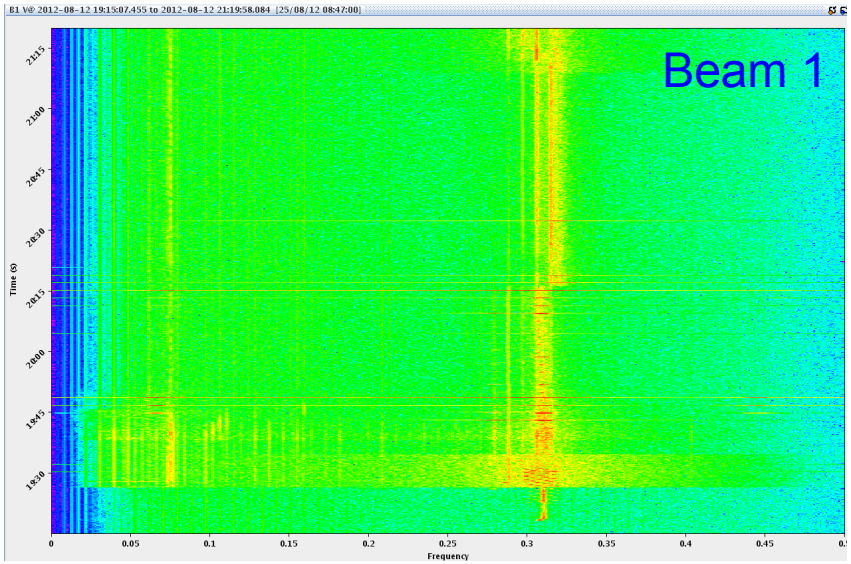


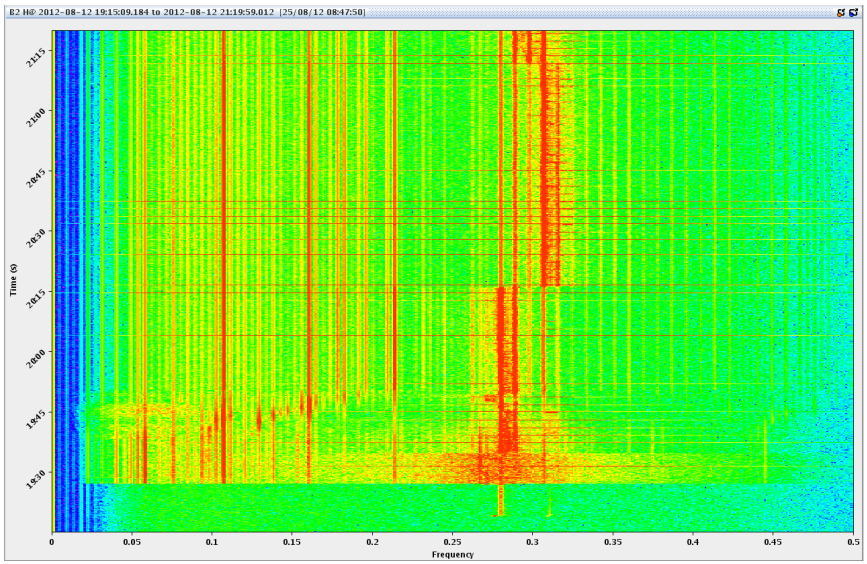


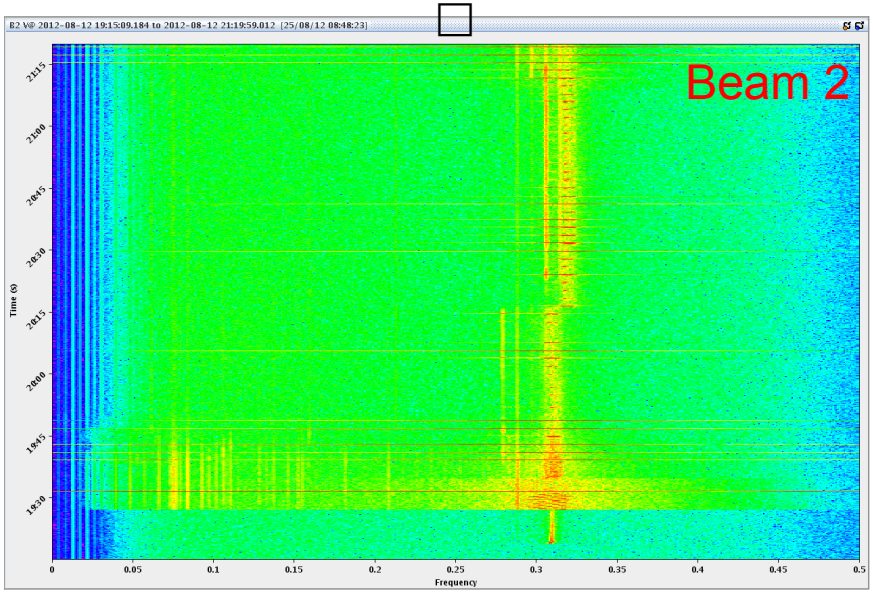
2012-08-12 19:15 – 22:00
Corresponding BBQ Signal B2

Corresponding BBQ Spectra – down-sampled to 0.1 Hz
Strong periodic kicks visible

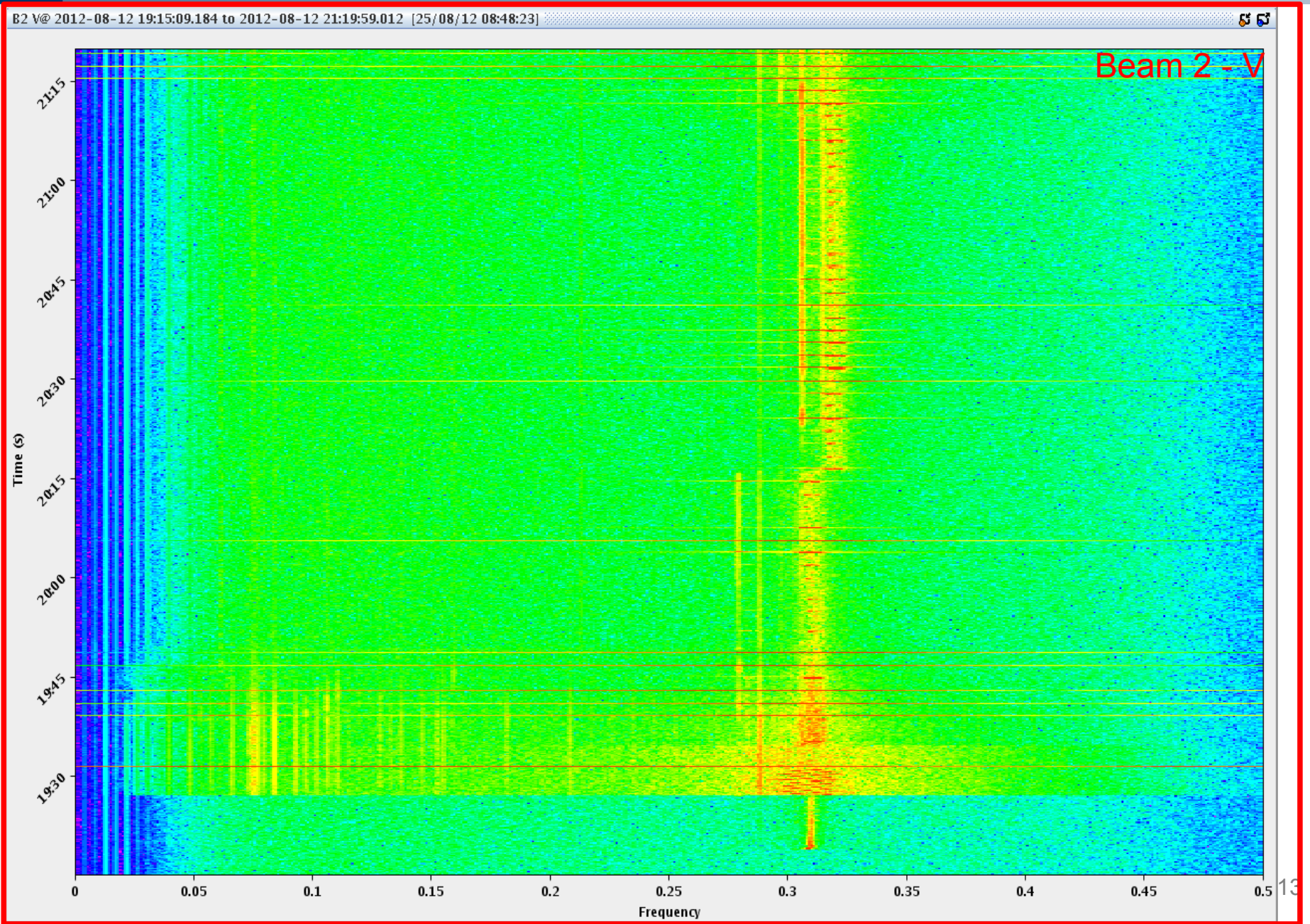






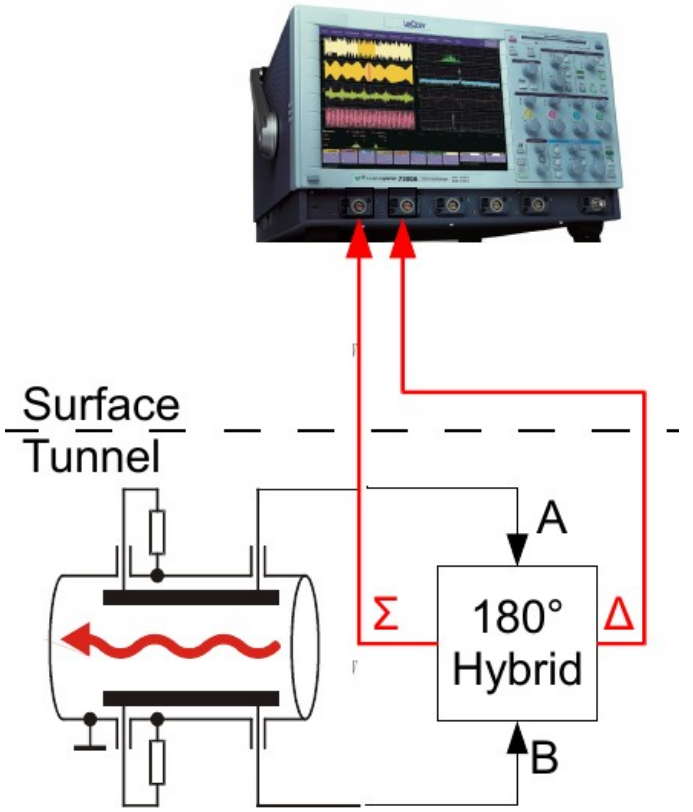


Corresponding BBQ Spectra – down-sampled to 0.1 Hz
Strong periodic kicks visible – ZOOM B2V



Classic Head-Tail Detection Scheme

- Limit: Fast-sampling to resolve bunch structure
  - ~ ns bunch length → GHz bandwidths

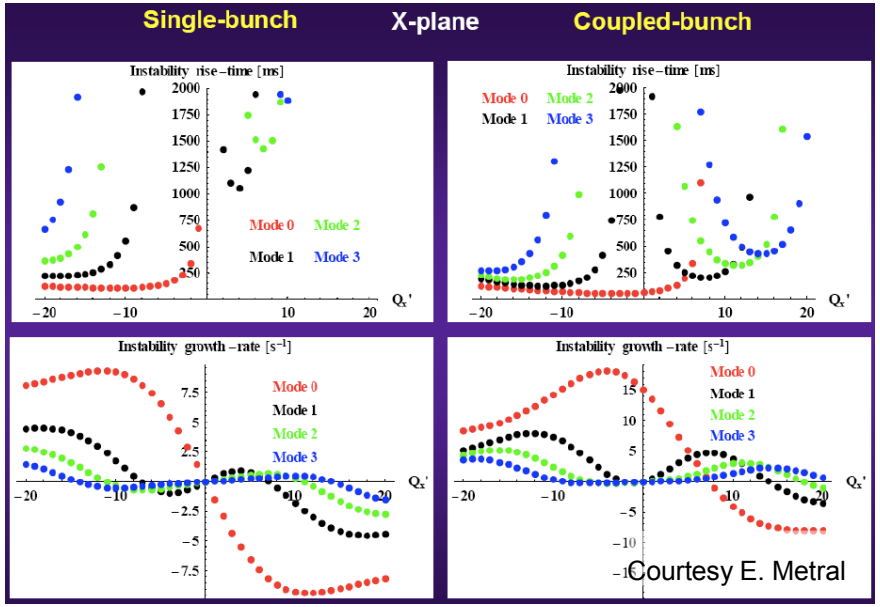


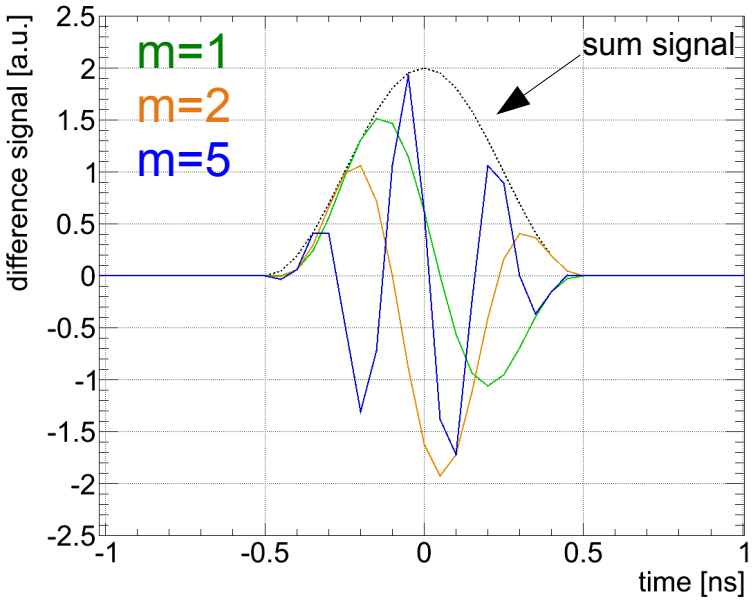
- Limitations:
  - Resolution: sampling limited to 8/~6.3 ENOB → limits resolution to the 100 um range
    - Beam typ. lost before visible with HT
  - Power limitation → issue of protection of analogue FE
  - damping: synchrotron radiation, impedance, amplitude de-tuning and other high order effects driving HT instabilities
  - Similar to all BPM/ADT/kick based Q diagnostics: kick amplitudes (1..2 σ) → emittance blow-up

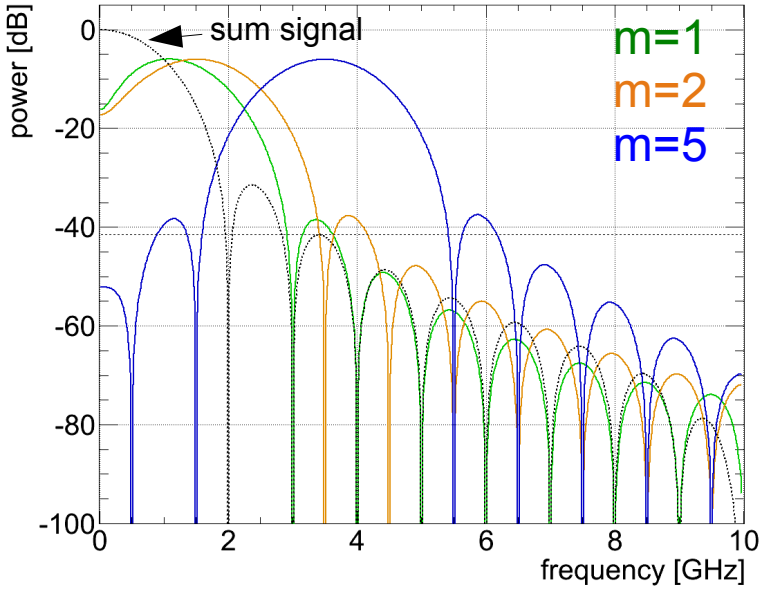
Head-Tail Motion Signal-Spectra Simulation

Can be detected e.g. via:

- time-domain: counting number of zero-crossing, rising/falling-edges
- freq.-domain: standard peak search, provides also indication for
  - mixed modes & HT mode strengths
  - much++ higher dyn. range & S/N

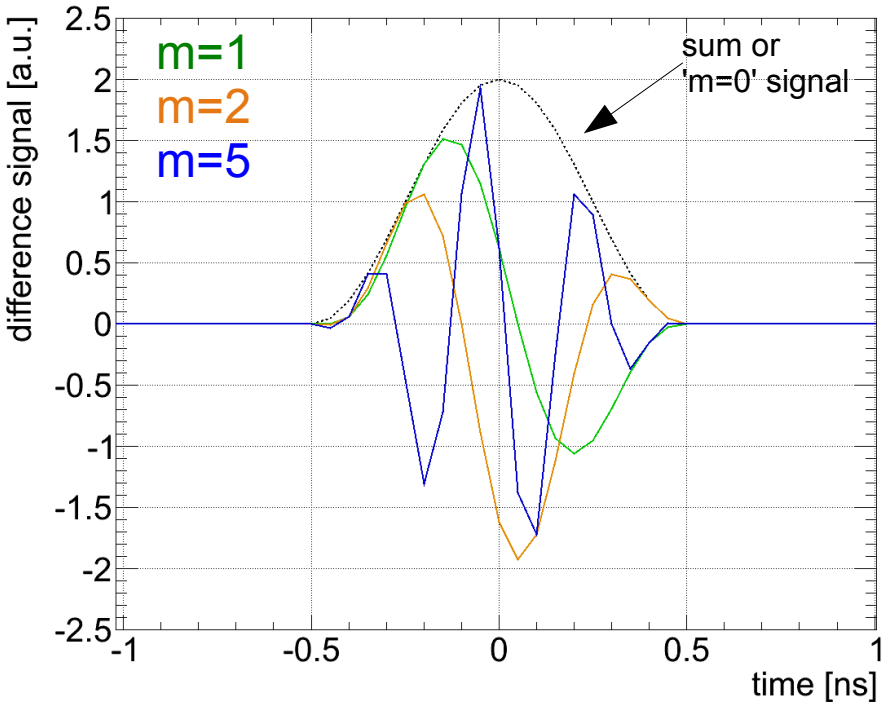


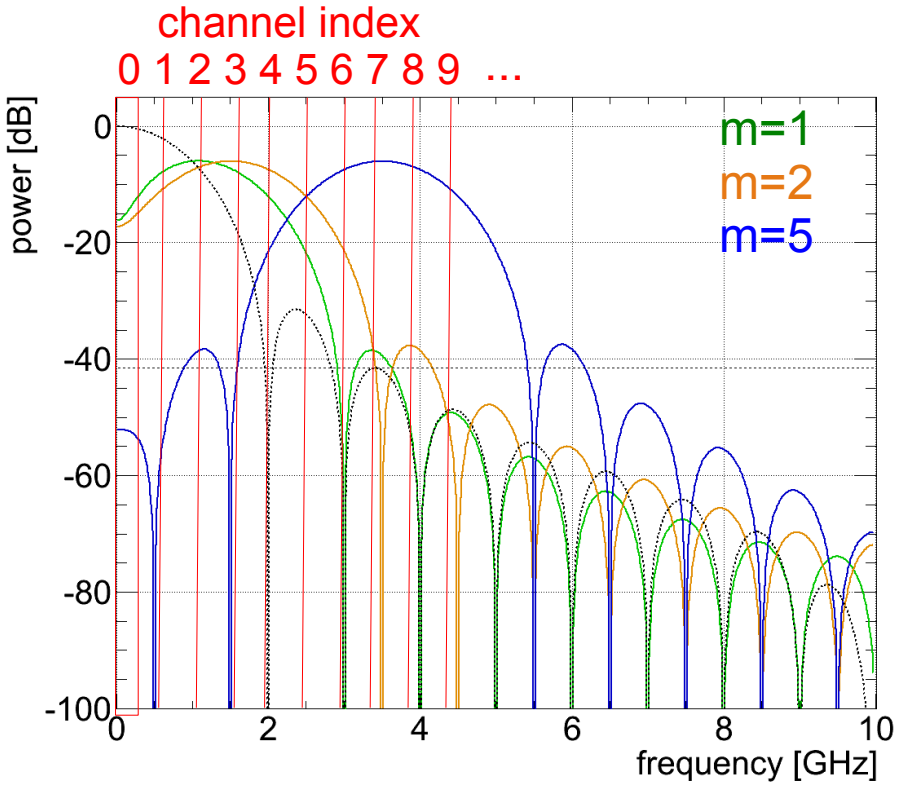




Head-Tail Motion Signal-Spectra Simulation

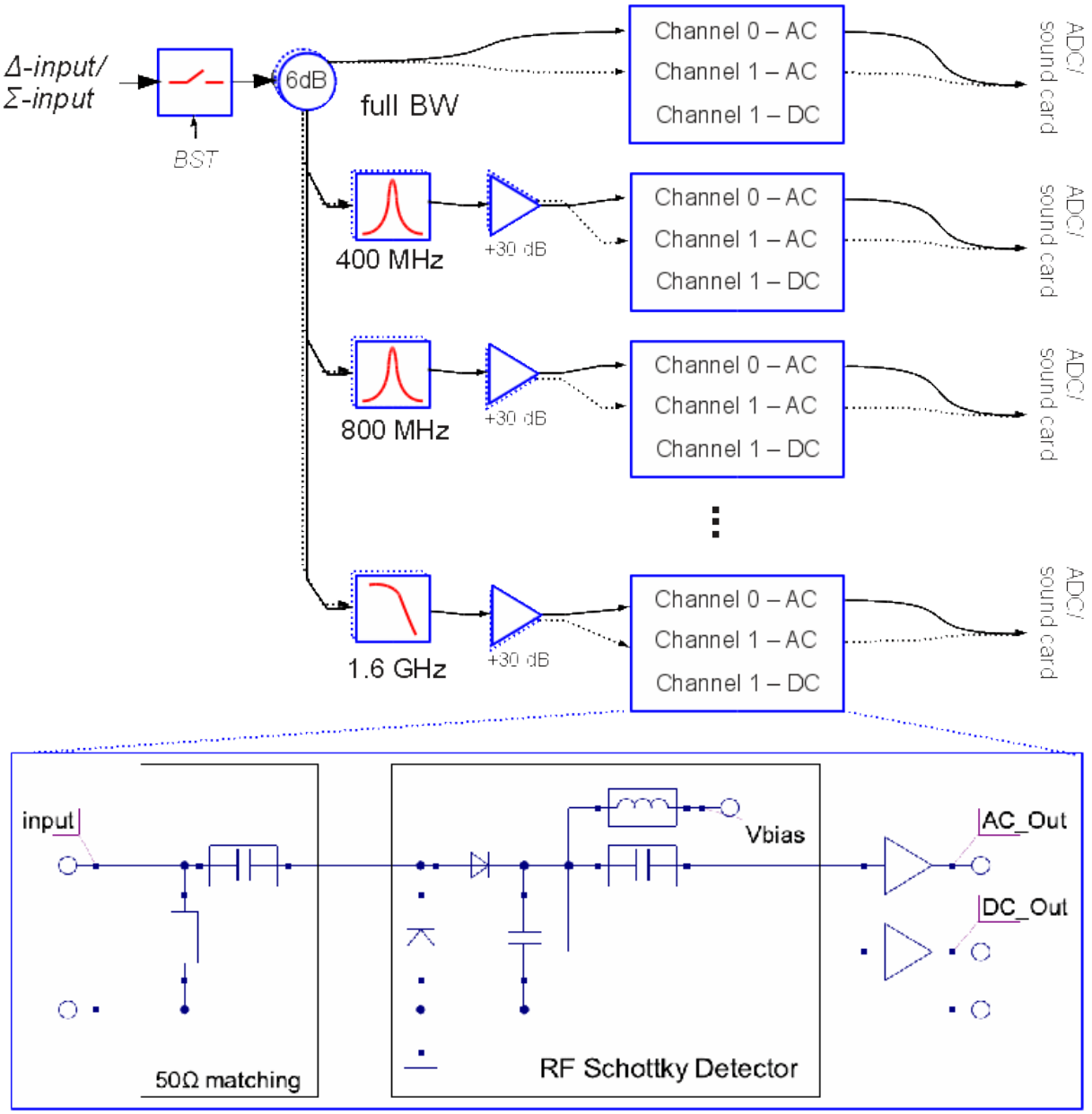
- Basic idea: exploit system using a ...



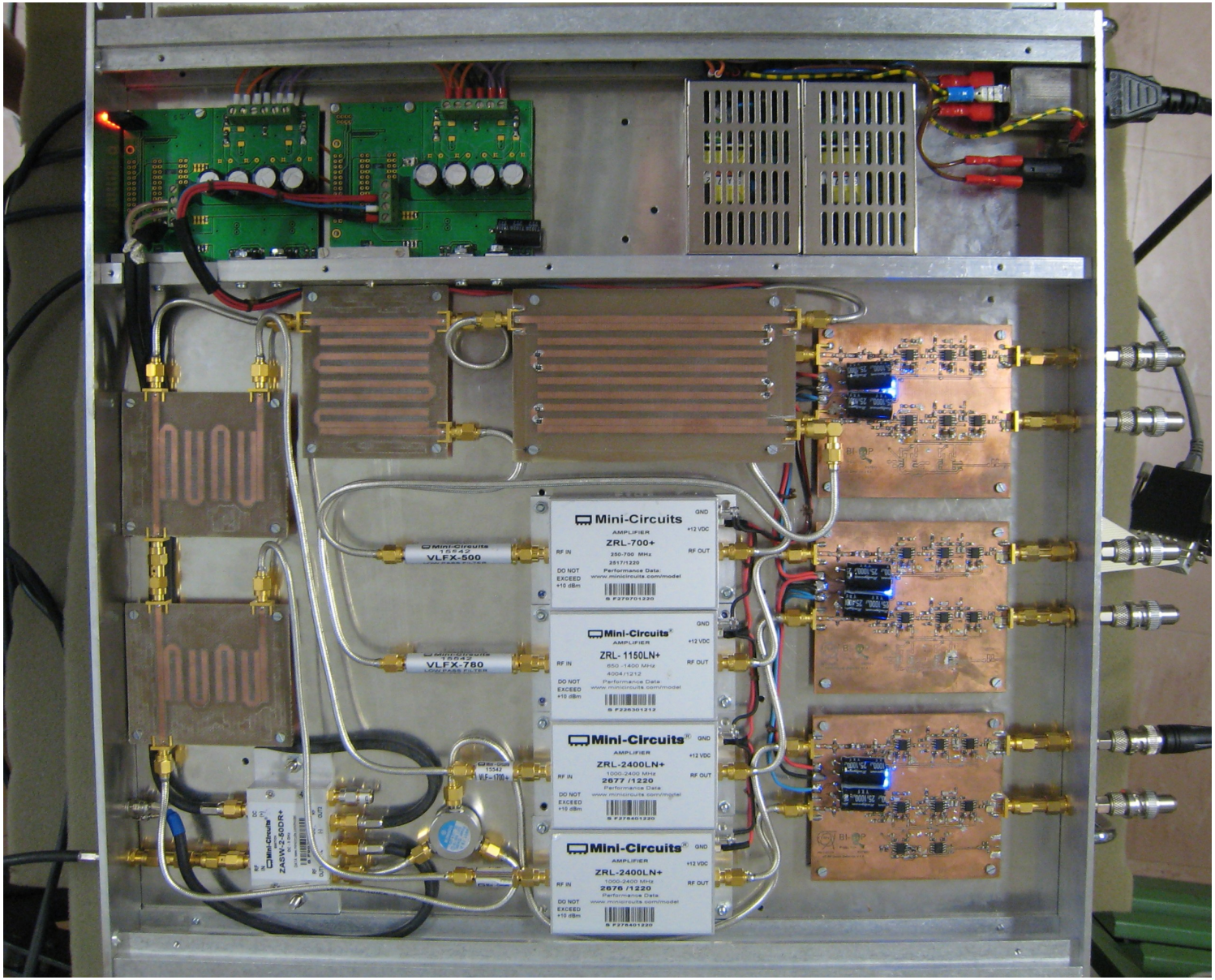


- …parallel spectrum analyser via multi-channel direct down-conversion scheme (N.B. need a better system name)
- Example: if the there is more power in 'CH n≥1' → head-tail instability

Front-End Prototype – Parallel Spectrum Analyzer
Multi-Channel Homodyne Receiver



Front-End Prototype



full-range

0.4 GHz

0.8 GHz

1.2 GHz

1.6 GHz

full-range

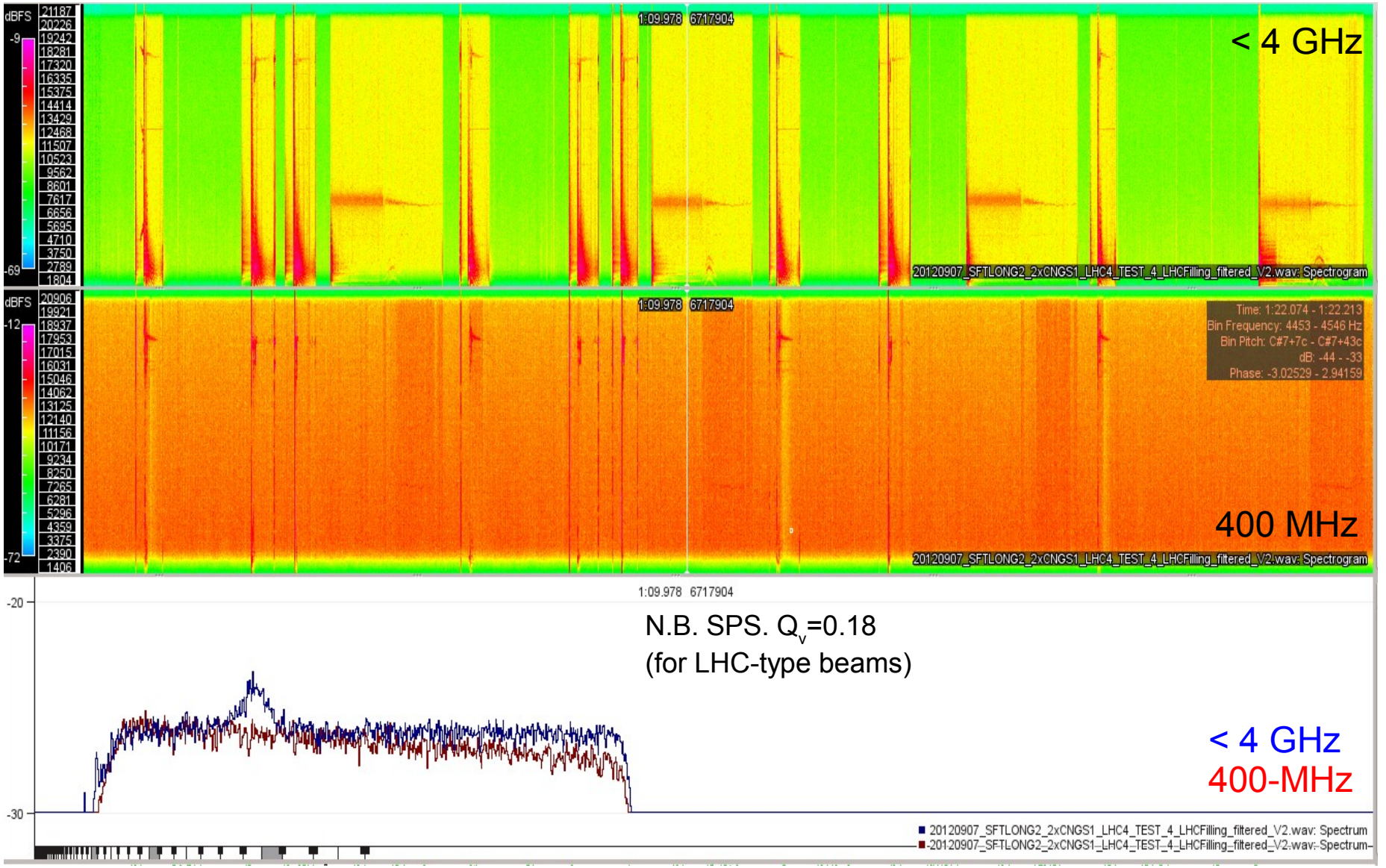
Δ-Signal

Testing using SPS Head-Tail installation – ECA4

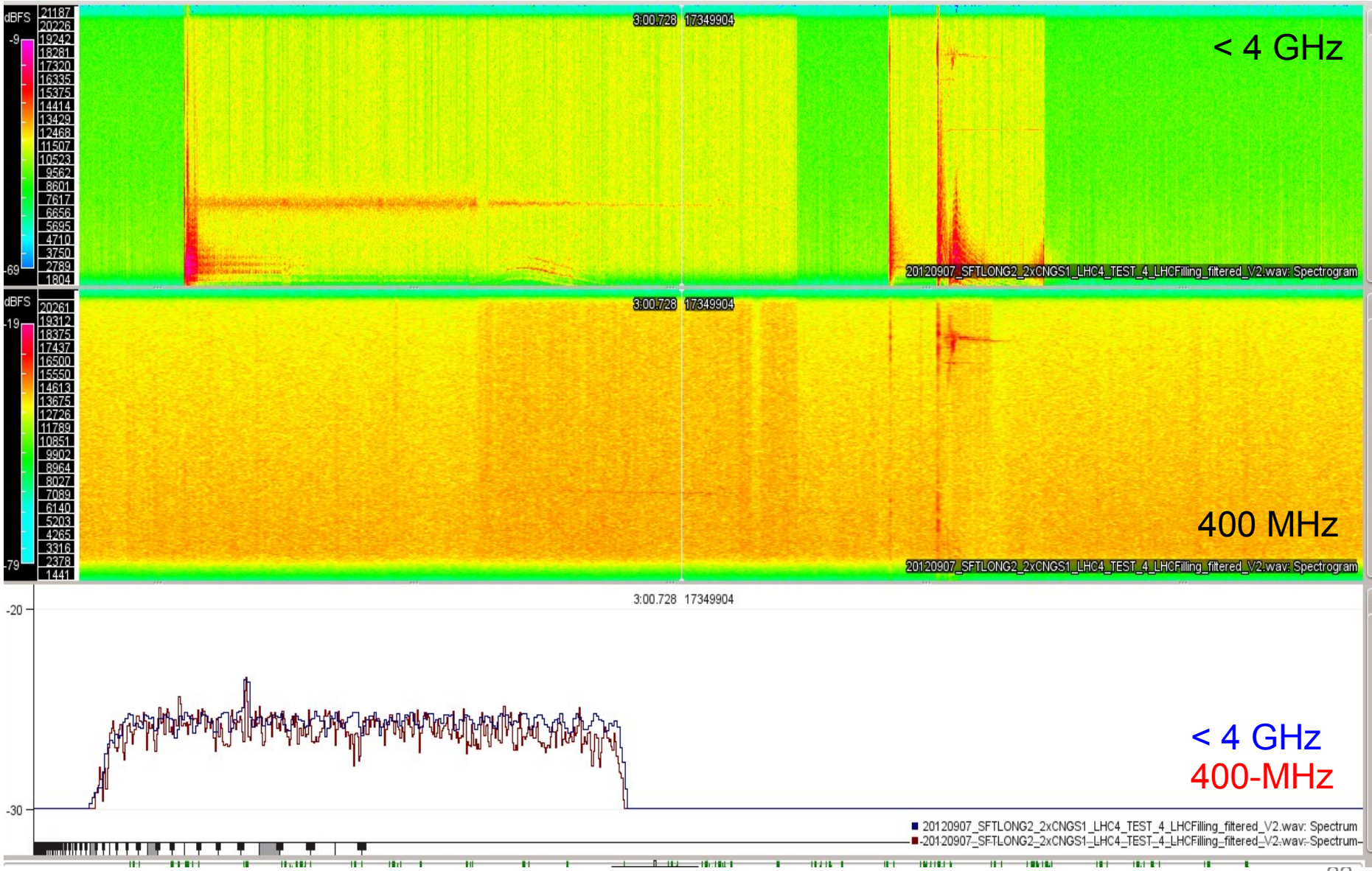
Sophie Dawson Thomas Lucas

Installed today in LHC
– Split Δ-Signal from regular B1-V Head-Tail Monitor

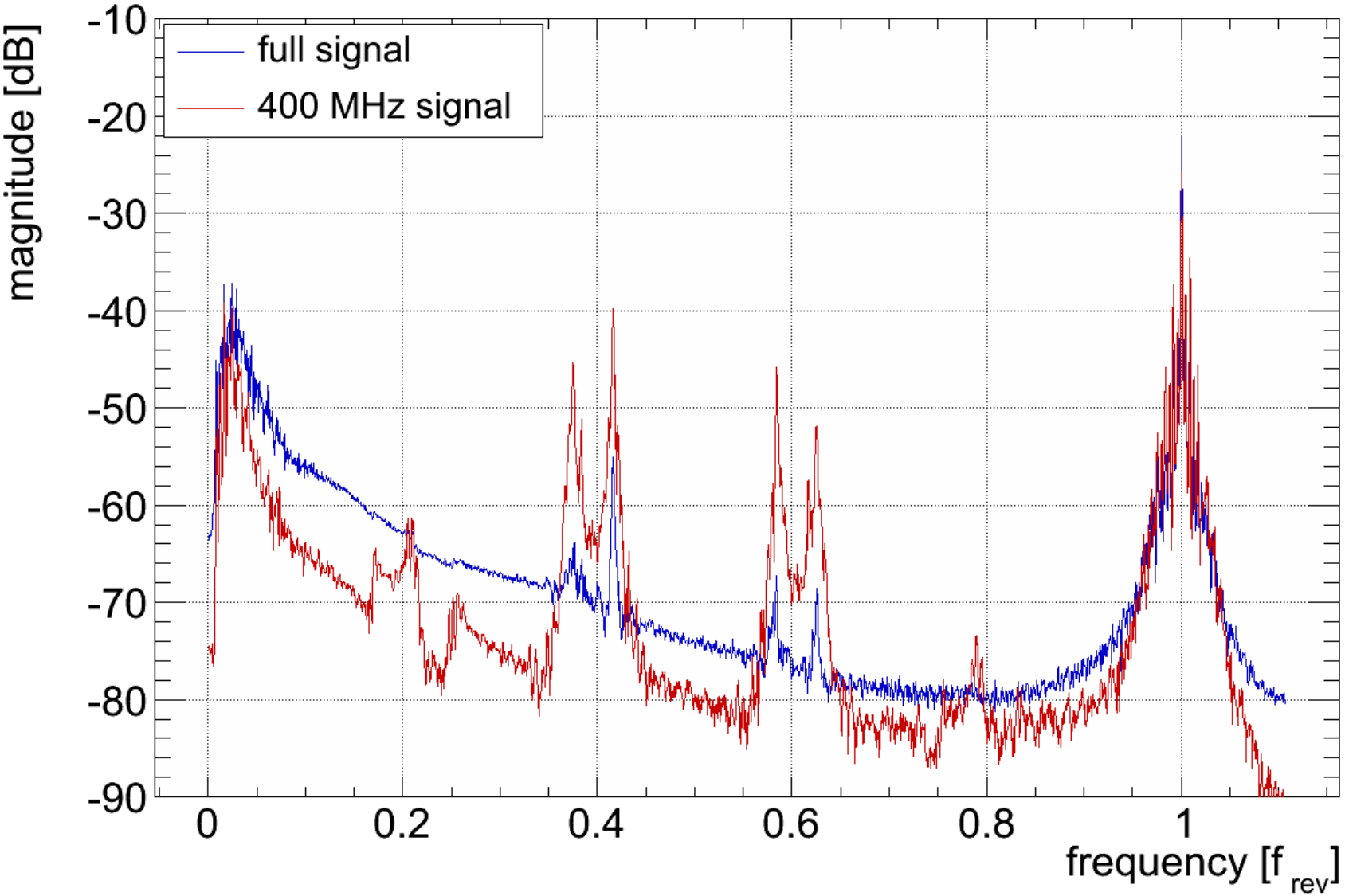
Example: LHC filling in the SPS



Example: LHC filling in the SPS
HT-Instability during ramp in 400 MHz band visible



- High modulation-index @ 400 MHz → indicates 'm≥1' head-tail motion



Further Exploitation – Chromaticity via Q_s Side-bands

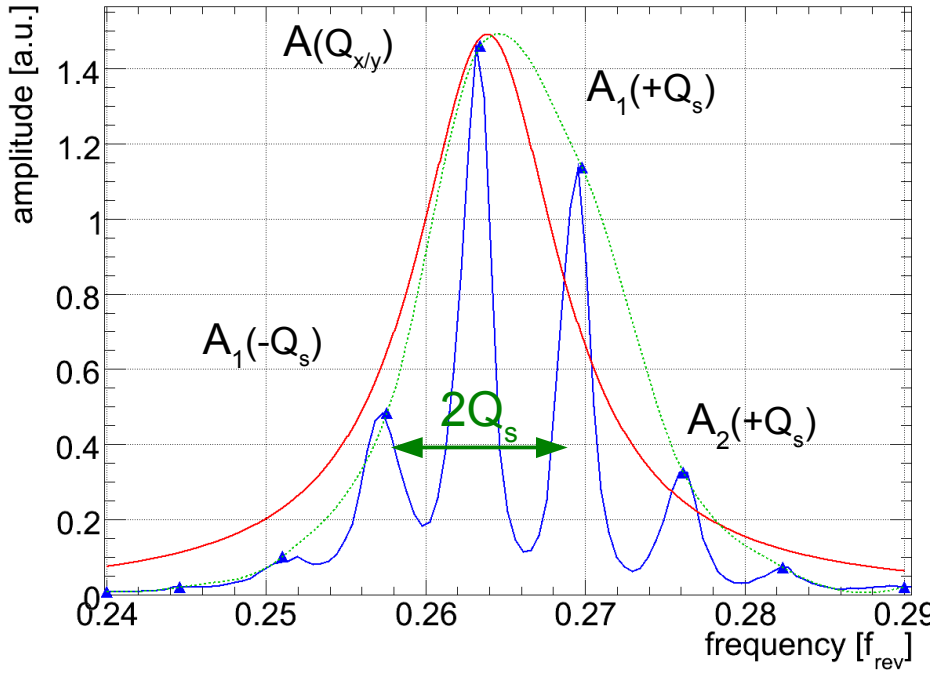
- Some comments on Q', modulation index and tune width of the BTF
  - Turn-by-turn oscillations can be approximated by (n: turn)

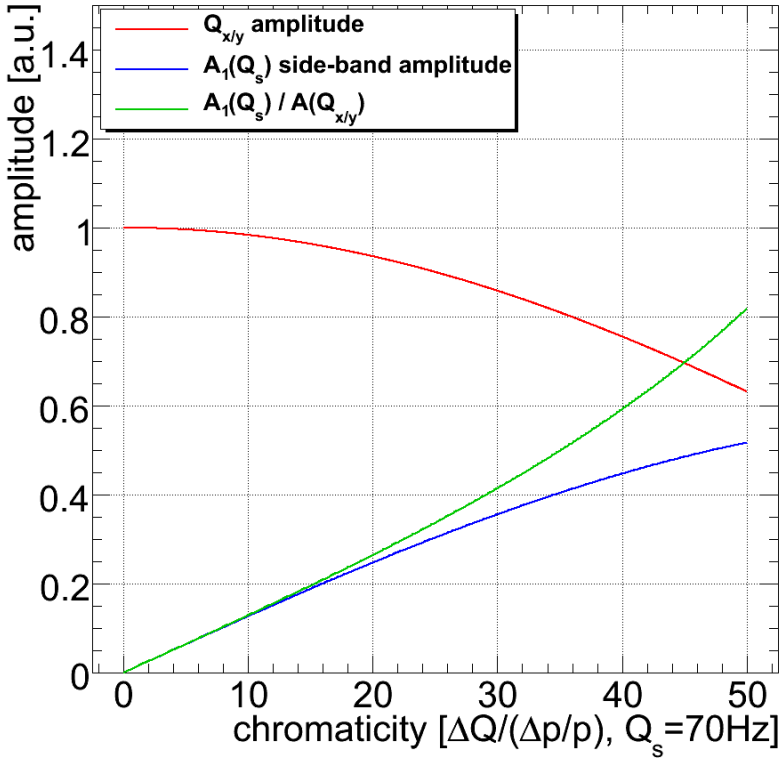
$$\Delta z(n) = z_0 \cdot \sin\left(2\pi \cdot \left[Q_0 \cdot n + \frac{Q'}{\omega_s}\frac{\Delta p}{p} \cdot \sin(\omega_s n)\right] + \phi_\beta\right)$$

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

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

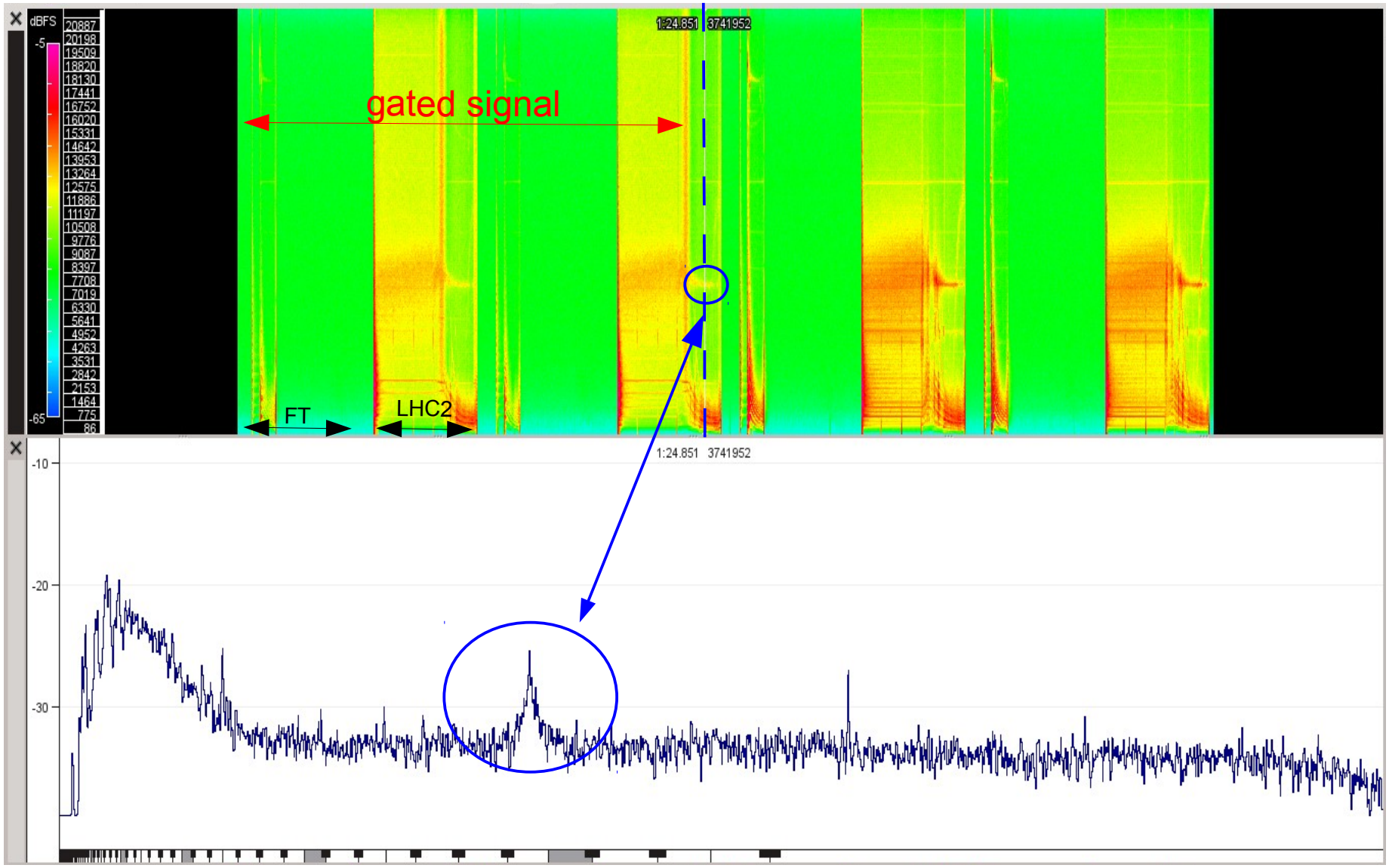
- Tune/Qs side-band amplitude (J_n: Bessel f.): linear over a wide range of Q'





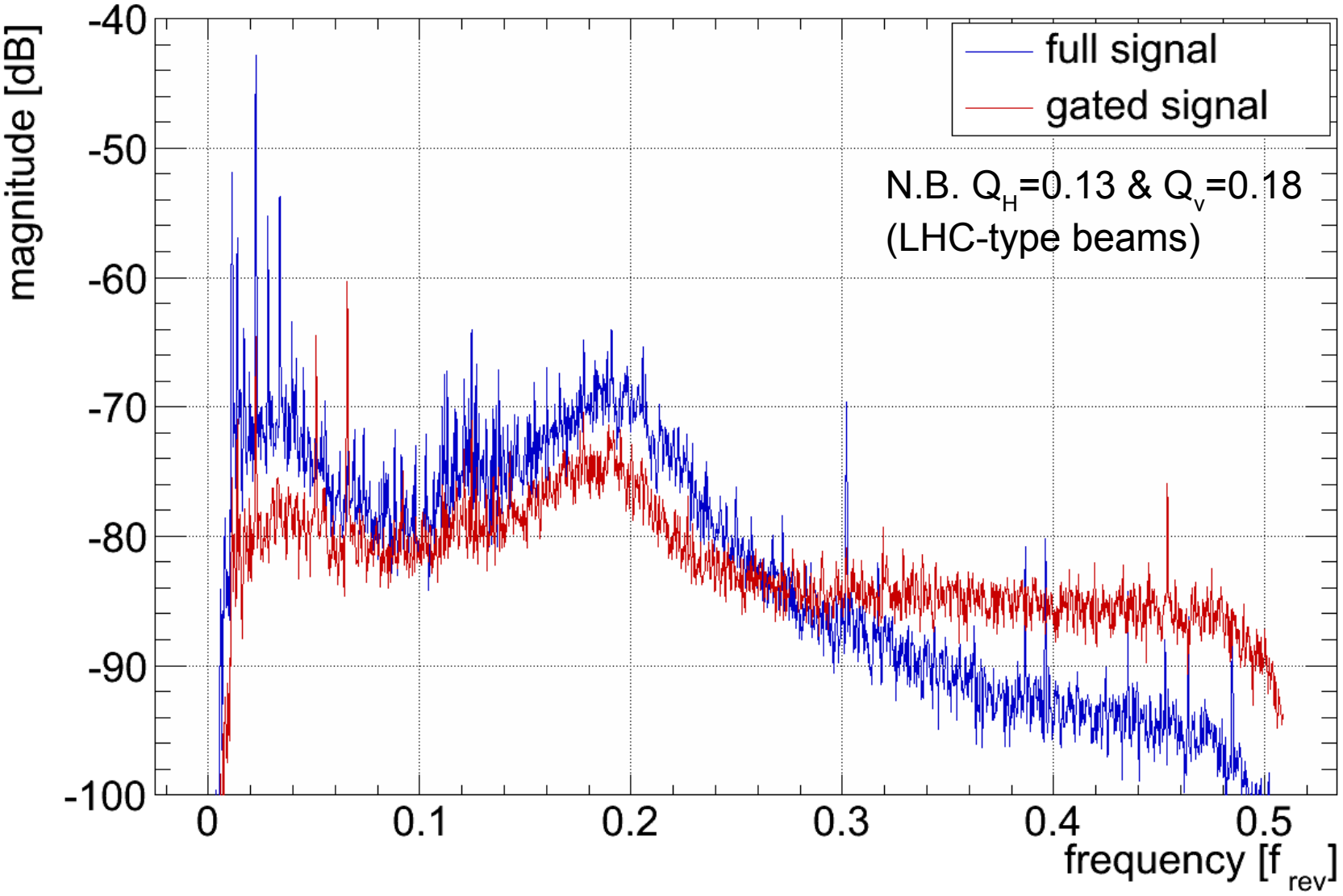
BBQ Spectra Comparison with & w/o Gating I/II

- Example: fixed-target (SFTLONG2) and 1 nominal LHC batch (LHC1)



BBQ Spectra Comparison with & w/o Gating II/II

- Suppression of Q_s harmonics visible for gated signal:



Summary

- New head-tail measuring <enter-name-here> system has been tested at the SPS and since this morning is deployed in the LHC (B1-V)
  - First glance on the results looks very promising
  - Can gate and/or operate outside of the ADT band-width, lots of options:
    - monitoring/exciting at 600 or 800 MHz
    - Tune lines narrow/clean >400 MHz
      → re-opens Q' via Δp/p modualation or side-band amplitudes
    - Default proposal: first reduce ADT gain for selected bunch(es?)

- A similar prototype replacing the 'Continuous B1' (BPLX) BBQ system is being prepared, should a priori deliver similar results and will be installed during the next technical stop → planned to drive the Tune-FB

- Both systems are gate-able with the existing BOBR infrastructure
  - For 2012, bunch-by-bunch diagnostics will need to be based on a rotation-based scanning (BQBBQLHC automatisation only after TS)
  - 'True'/instantaneous b-by-b being investigated and tested during the year
- Apropriate MD-time to calibrate and test the system during operation would be appreciated (particularly for Q')
- Your questions, comments and suggestions...