Tune System Performance with/without Gating

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Ralph J. Steinhagen[1], M. Gasior[1], S. Jackson[1], Thomas G. Lucas[1,2,3]

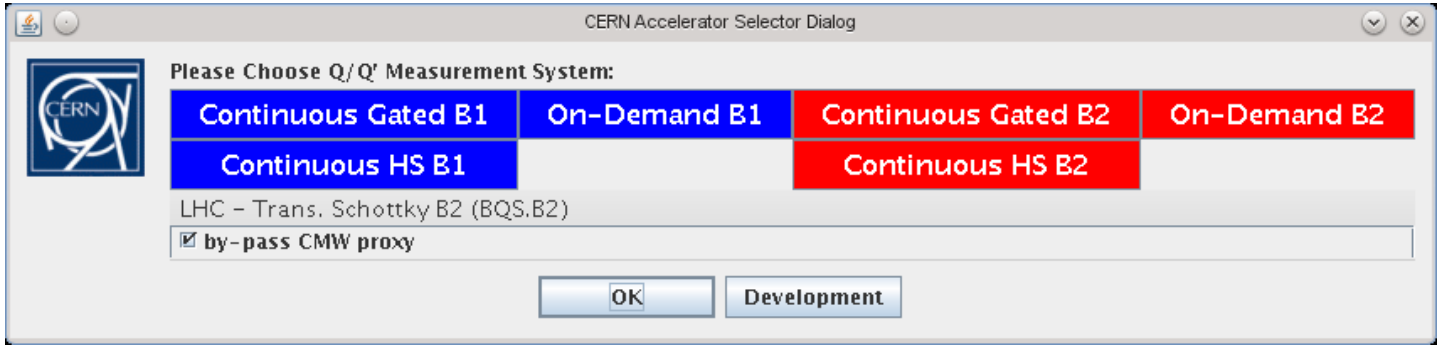
[1]Beam Instrumentation Group, CERN;

[2]ACAS, Australian Collaboration for Accelerator Science;

[3]School of Physics, The University of Melbourne;

- Total 9 front-ends involved in Q/Q' diagnostics (6 used by OP), functionally equivalent but grouped into two subsets:
  - Continuous FFT Systems: fixed acquisition settings, used by logging, postmortem and feedback systems
  - On-Demand FFT Systems: free-to-play, MD-type studies, Q/Q' via using the tune kicker, etc...
  - Development Systems: used by BI to validate new designs, SW & settings

- Quick-access in TuneViewer for OP devices, others in sub-menus:
  - N.B. GUI does not need to be active for the systems to send data to the tune feedback.

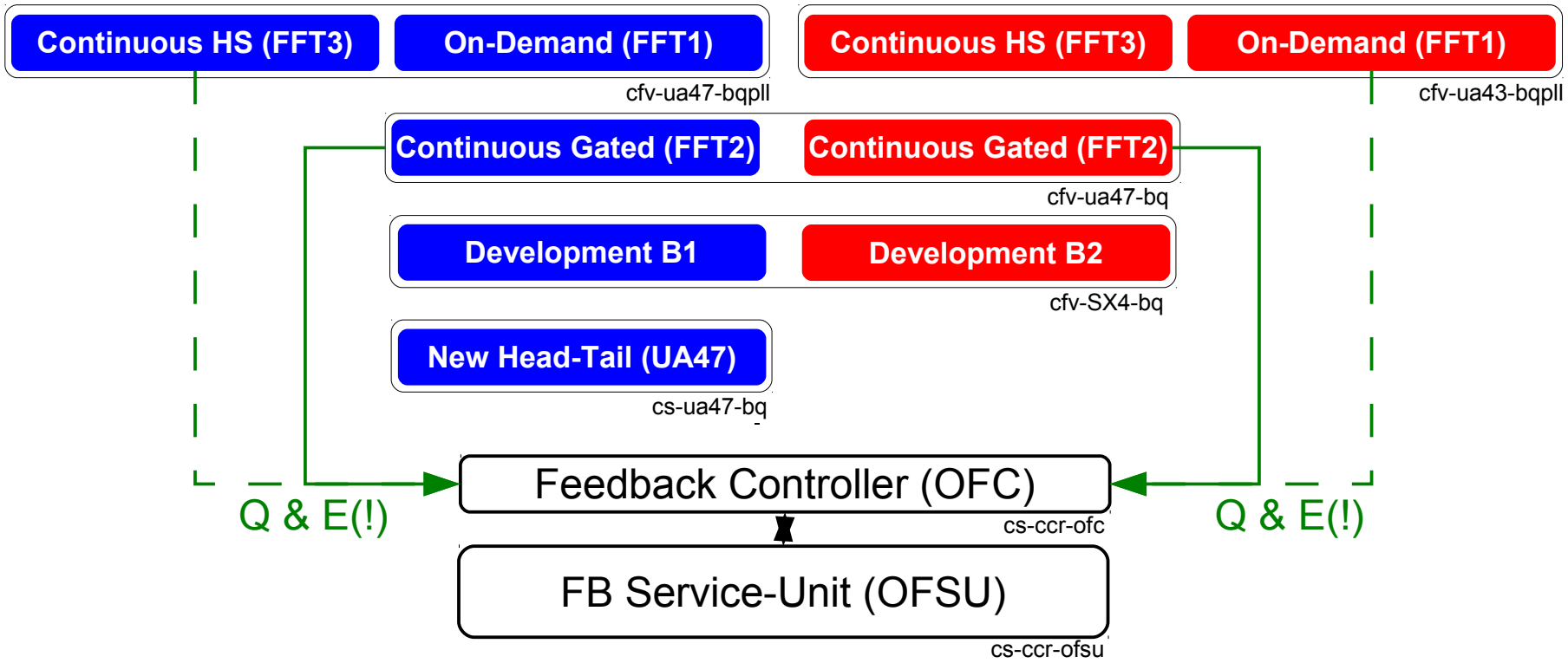


- Two new devices: copy/same AFE as as the On-Demand system (FFT1)
  - Continuous HS* → to be used with pilot, ion beams and few (<400) nominal bunches
  - Continuous Gated → nominal beam & when gating is required

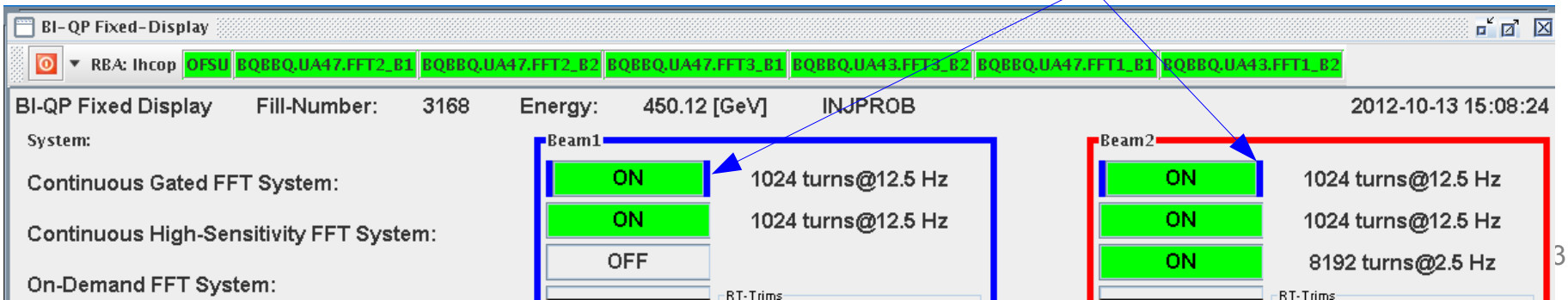
*Not being logged yet (tbd. this week with Chris)

Deployed LHC Tune Diagnostics Systems

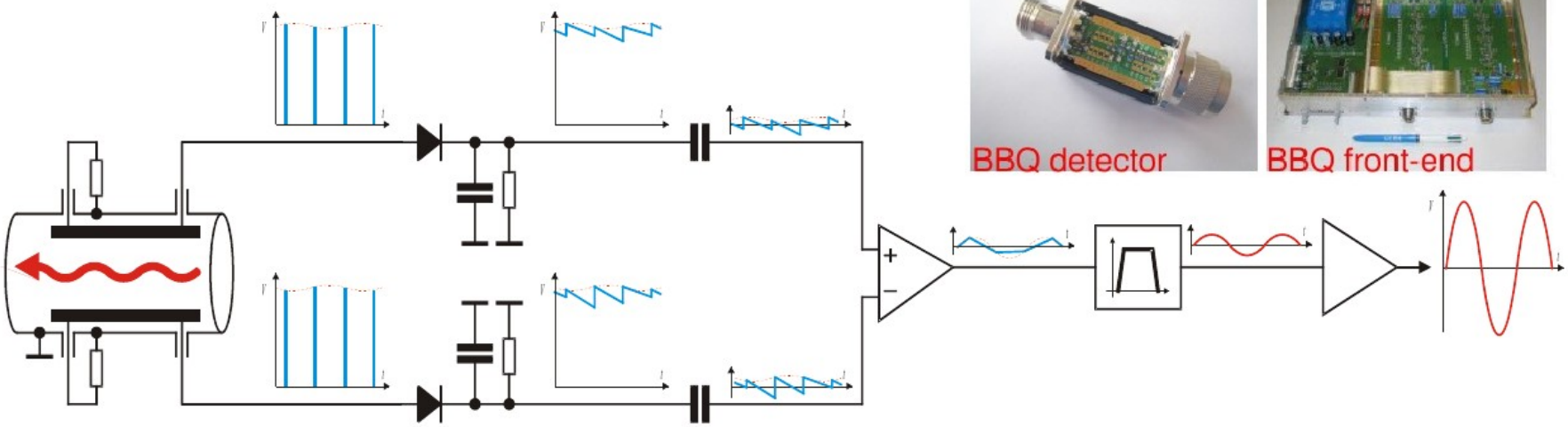
- Total 9 front-ends involved in Q/Q' diagnostics (6 used by OP)



- Which system is being used by the FB is decided by the 'useByOFC' flag (set by sequencer):



Tune Diagnostics Instrumentation – RECAP
Direct-Diode-Detection

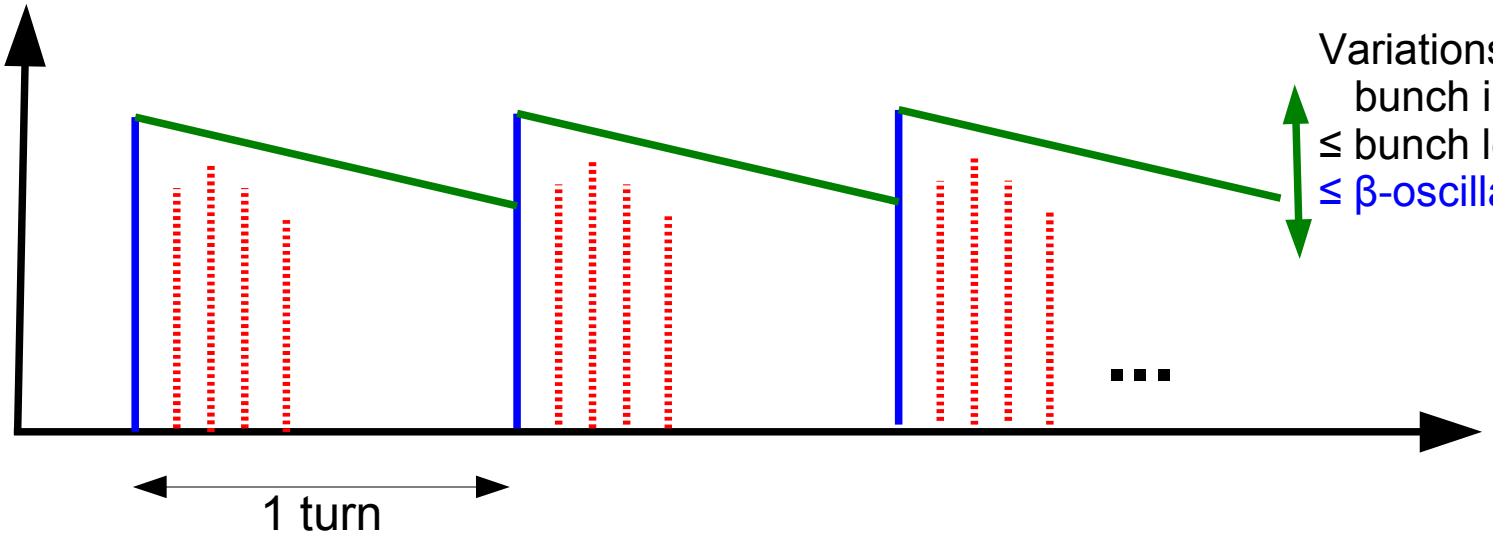


- Basic principle: AC-coupled peak detector[1]
  - intrinsically down samples spectra: ... GHz → kHz (independent on filling pattern)
    - thus 'Base-Band-Tune Meter' (aka. BBQ)
    - Base-band operation: very high sensitivity/resolution ADC available
    - Measured resolution estimate: < 10 nm → ε 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'



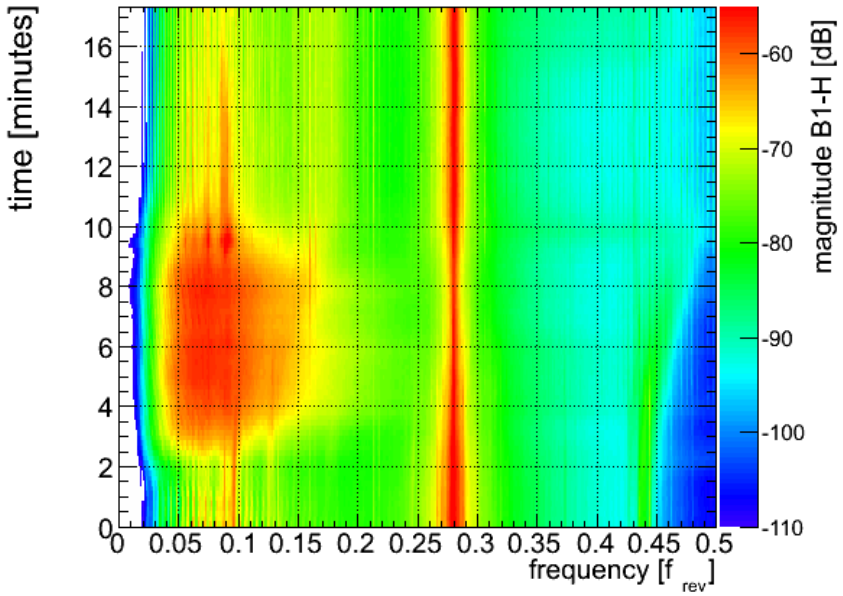
- Which 'peak' is selected depends on a number of parameters

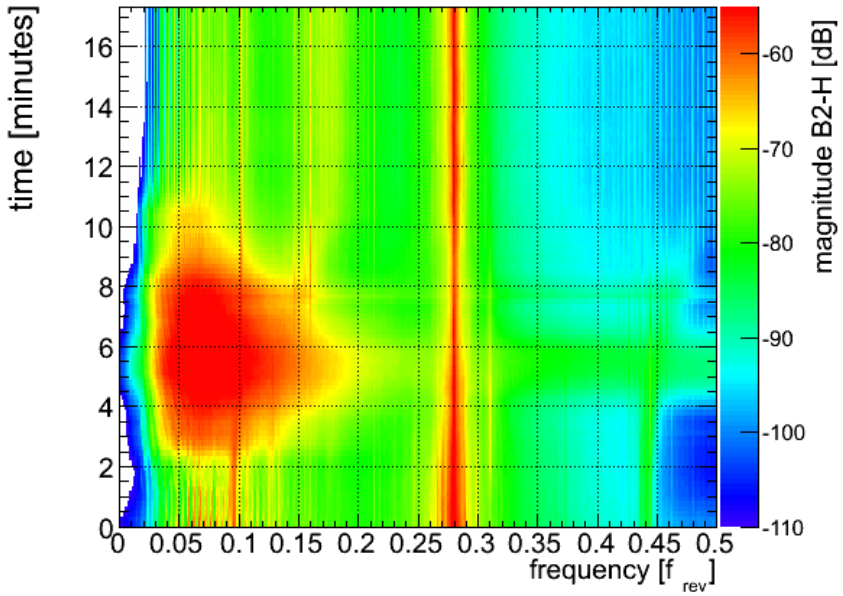
~700 V_p ~7 V_p ~few μV_p

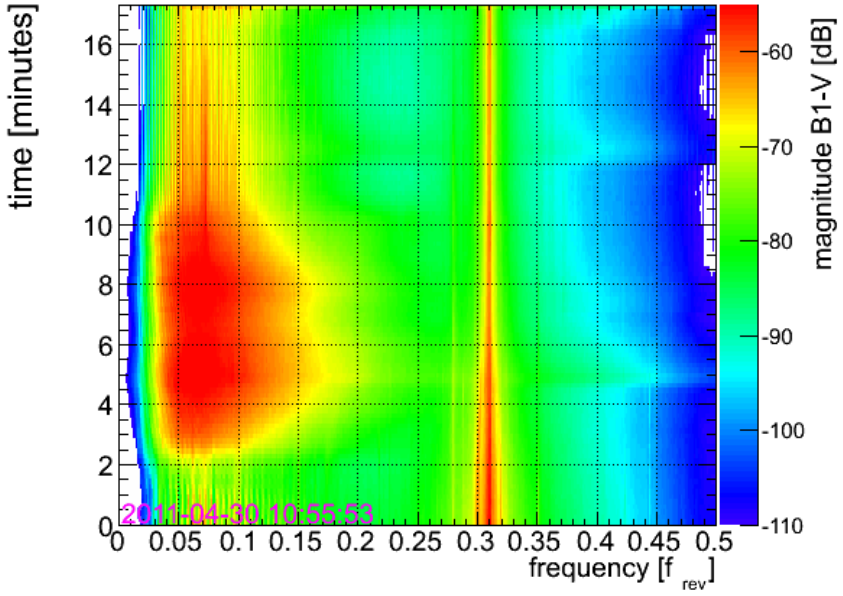
$$\Delta I_{button}(t) \sim \underbrace{\rho(\tau, t)}_{\tau \sim \sin(\omega_s t)} * \left[\frac{I_{cm}}{I_0}\right] + \left[\frac{\Delta z}{R}\underbrace{\sin(\omega_Q t + \varphi)}_{dep.\ on\ Q',\ \Delta p/p,\ \omega_s,\ ..}\right] + \left[h.o.\right]$$

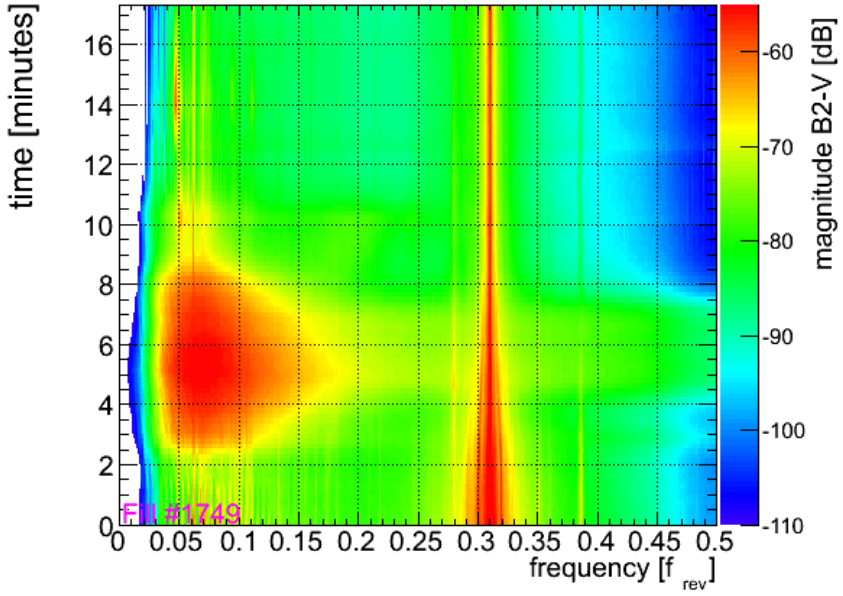
bunch length oscillations | bunch intensity variations | Position dependent/ Betatron motion | i.e damping terms

Typ. LHC Ramp with Longitudinal Blow-Up

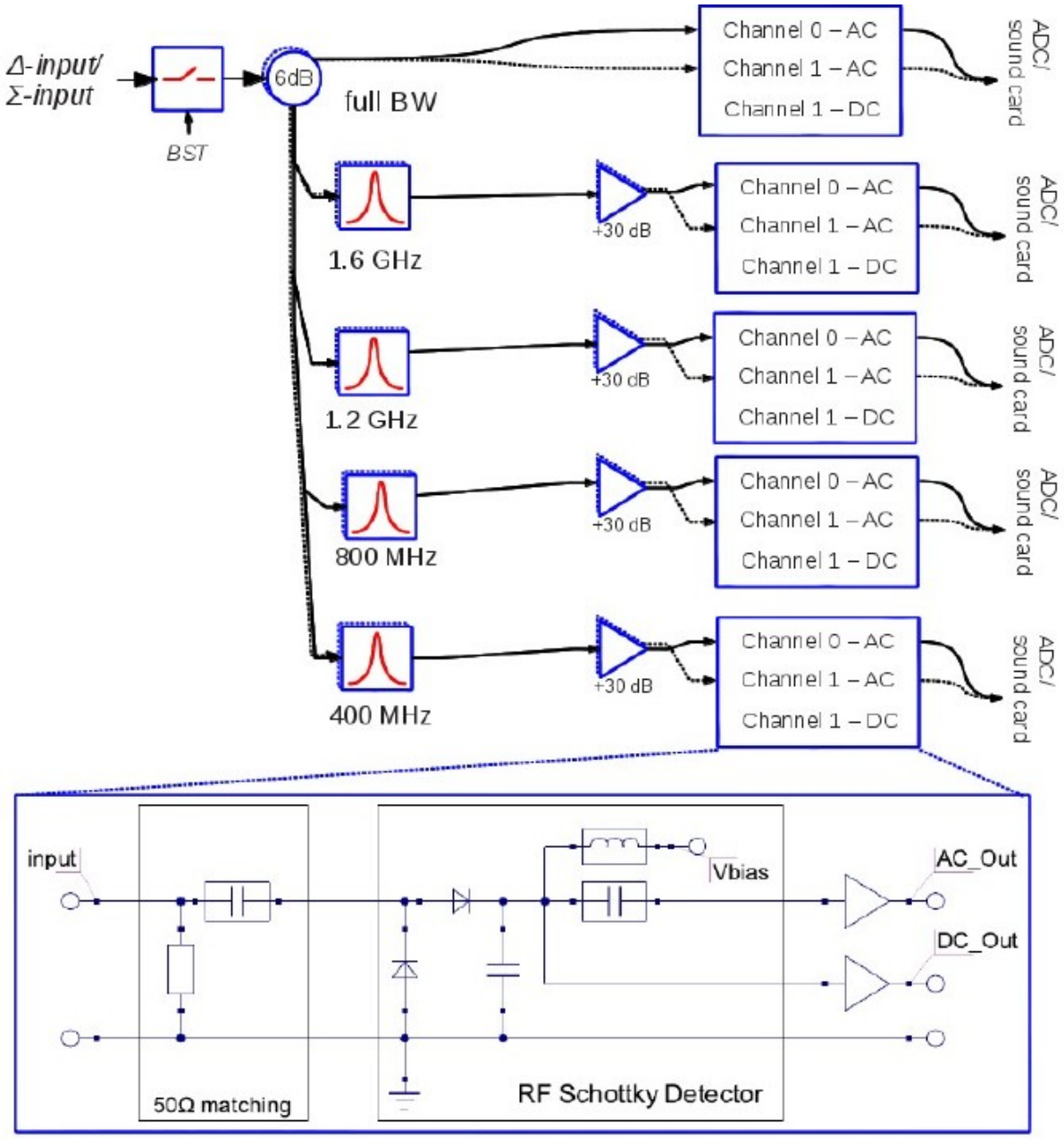






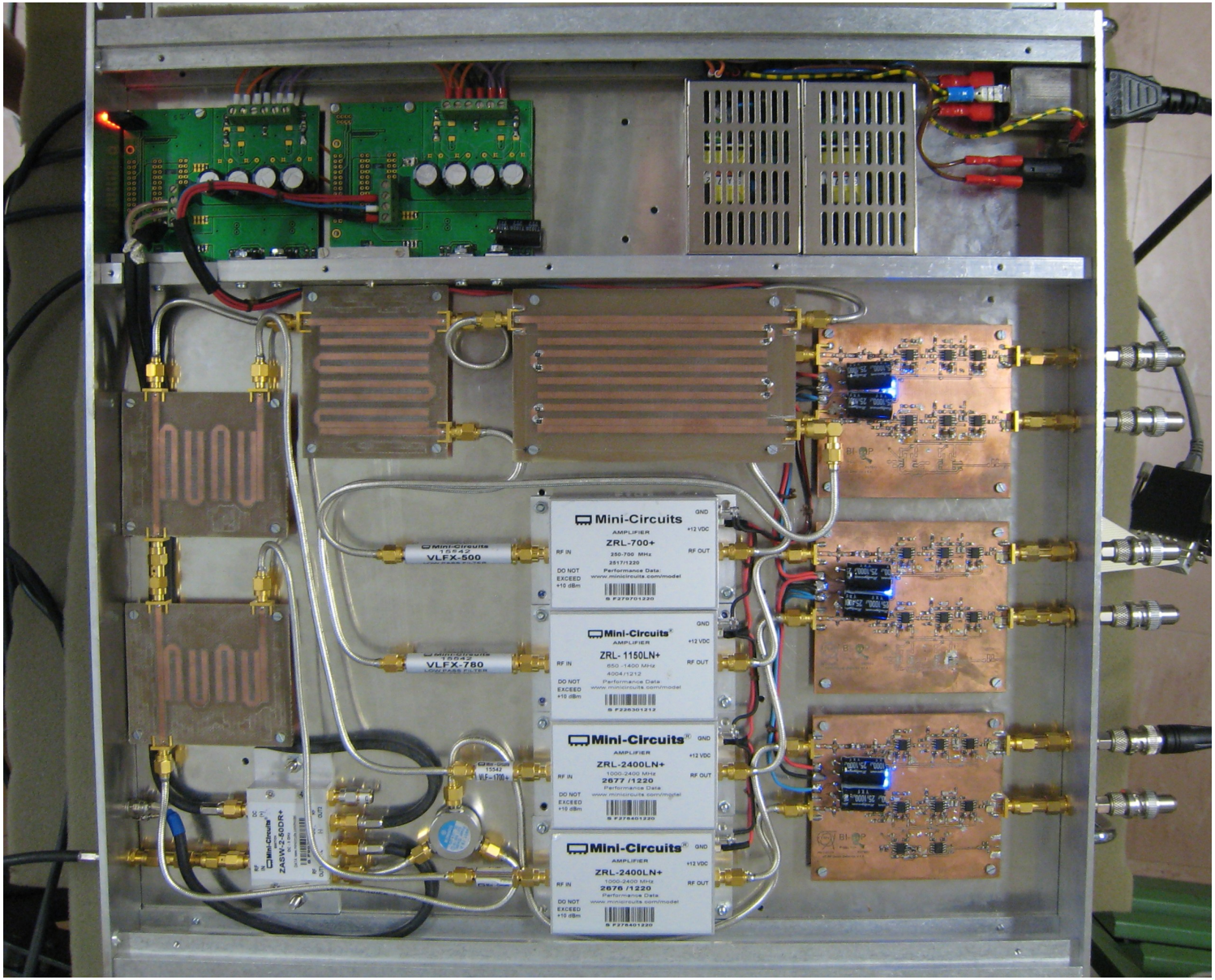


New Head-Tail Monitor
Multi-Band RF Schottky Diode Peak Detector



Channel functionally equivalent to 'Gated BBQ'

Front-End Prototype



full-range

0.4 GHz

0.8 GHz

1.2 GHz

1.6 GHz

full-range

Δ-Signal

Pros and Cons of Gating the BBQ Signals

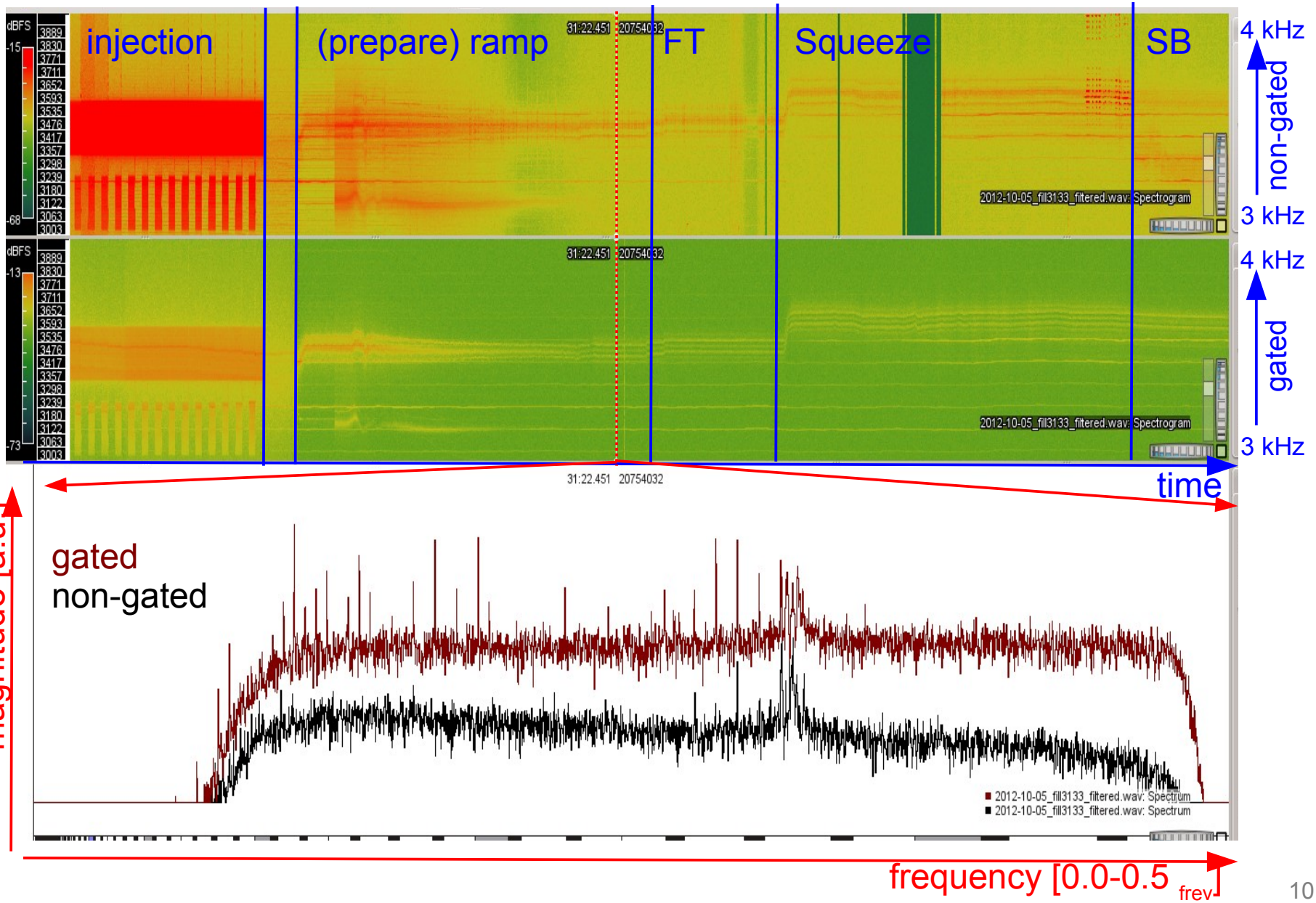
Without gating:

- More robust/less inter-system dependencies
- One system can cover a wide range of beam intensities ($10^9 \rightarrow 10^{14}$ protons) with one setting
- trigger/measure any bunch that becomes potentially unstable
- more sensitive to bunch length oscillations
- Mixes signal of different bunches that oscillate with same frequency but typically difference phase

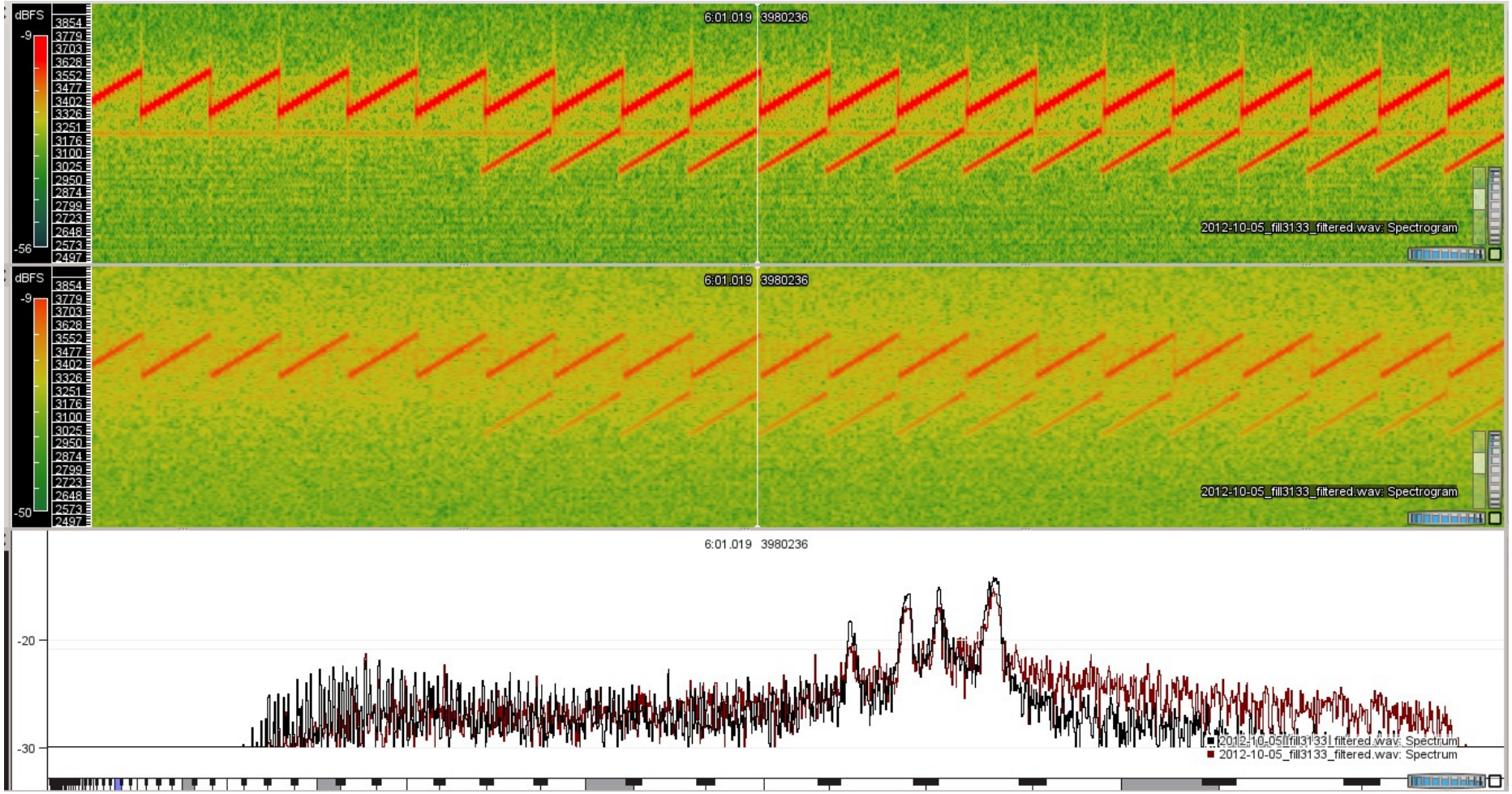
With gating

- Decouples ADT-gains from Q/Q' diagnostic signal requirements
- trigger/measure one specific bunch, no mixing → cleaner spectra
- Allows gain or beam-beam effect studies on selected bunches during physics
- Reduced duty-cycle/signal levels for the RF diode detector
- Less signal if selected bunches are stable
- Another free parameter: gating must be properly set-up (sequence, SW, ...), otherwise: no signal

2012-10-05 – Fill 3133

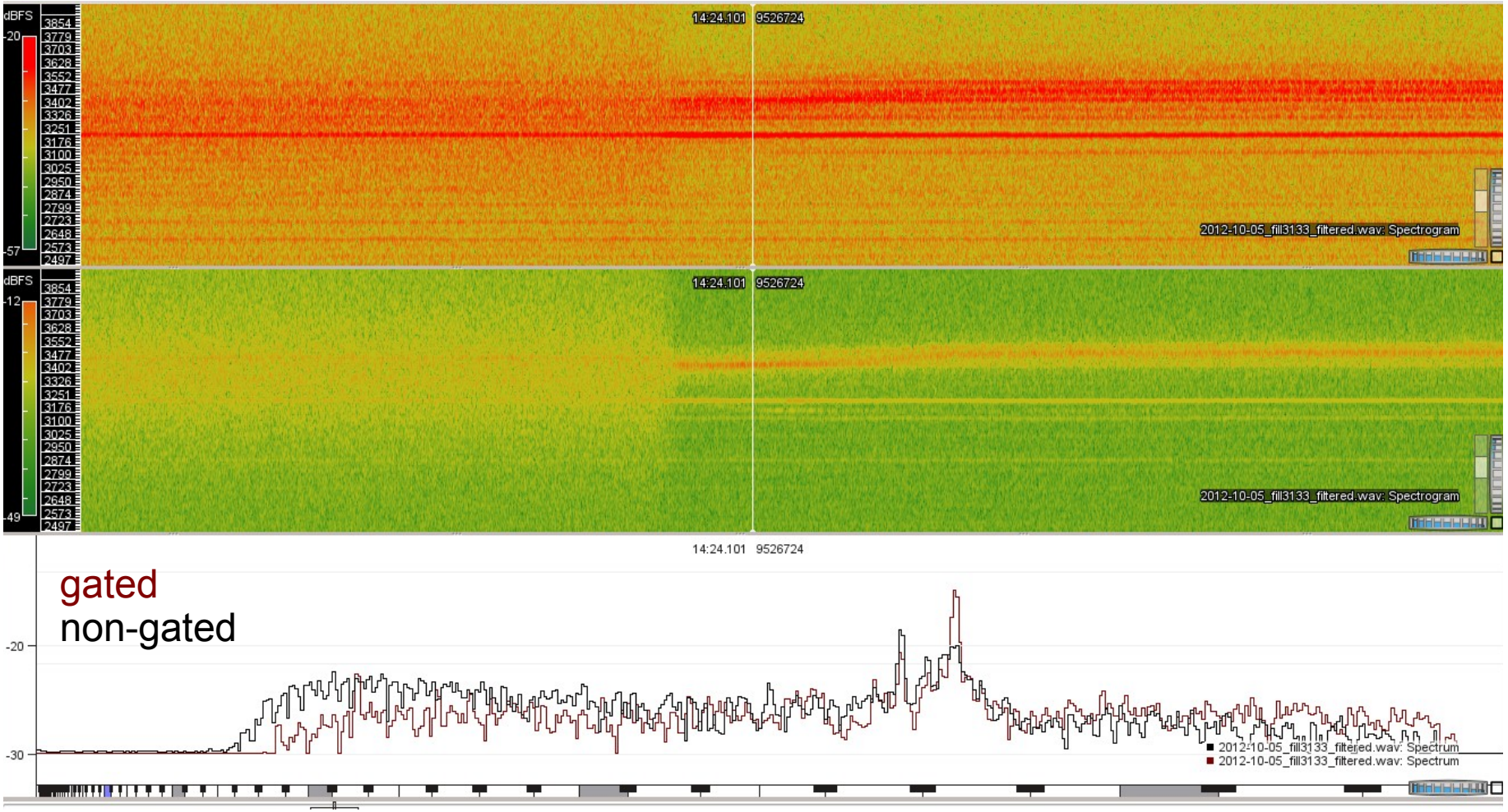


2012-10-05 – Fill 3133: Injection



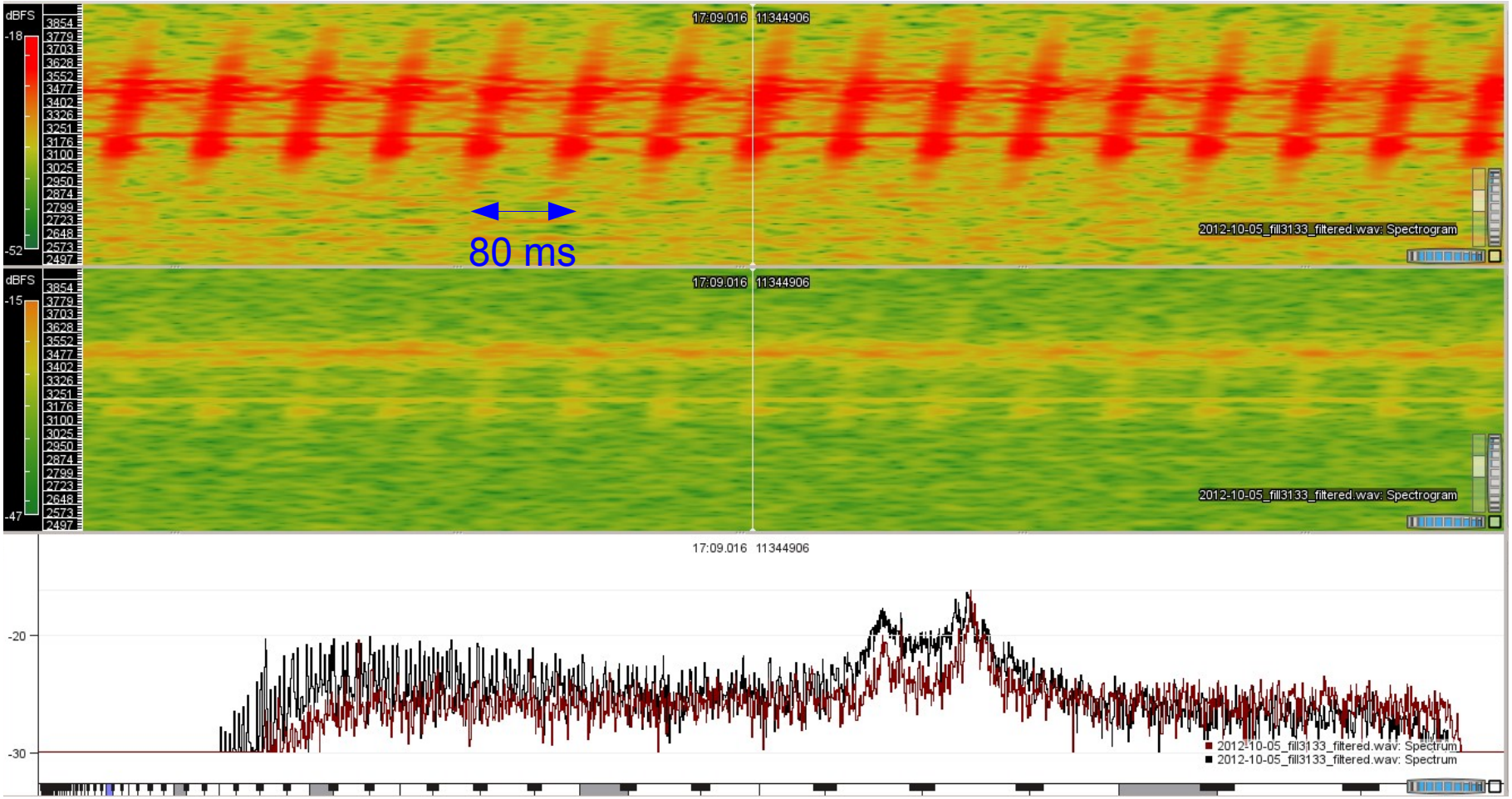
- Abort gap and injection cleaning visible on first six bunches

2012-10-05 – Fill 3133: Prepare Ramp



- 10 dB damper gain reduction for the first six bunches

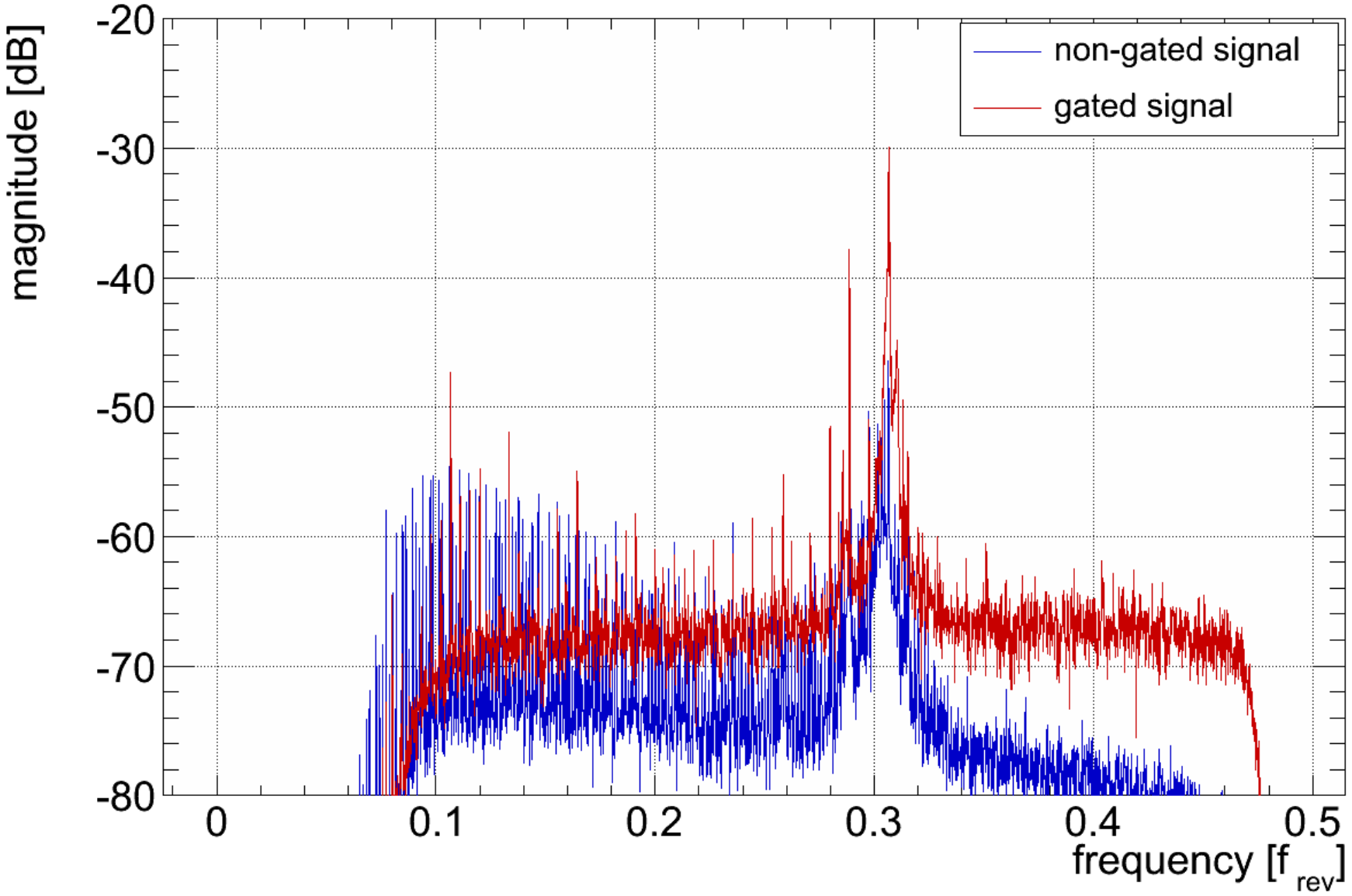
2012-10-05 – Fill 3133: Ramp Start & Chirp



- Inherent cross-talk w.r.t. 'chirping' and using with a high-gain ADT
  → often measure rather the feedback loop response rather than the tune
  → before 'chirping' on should reduce the gain, an OP parameter?

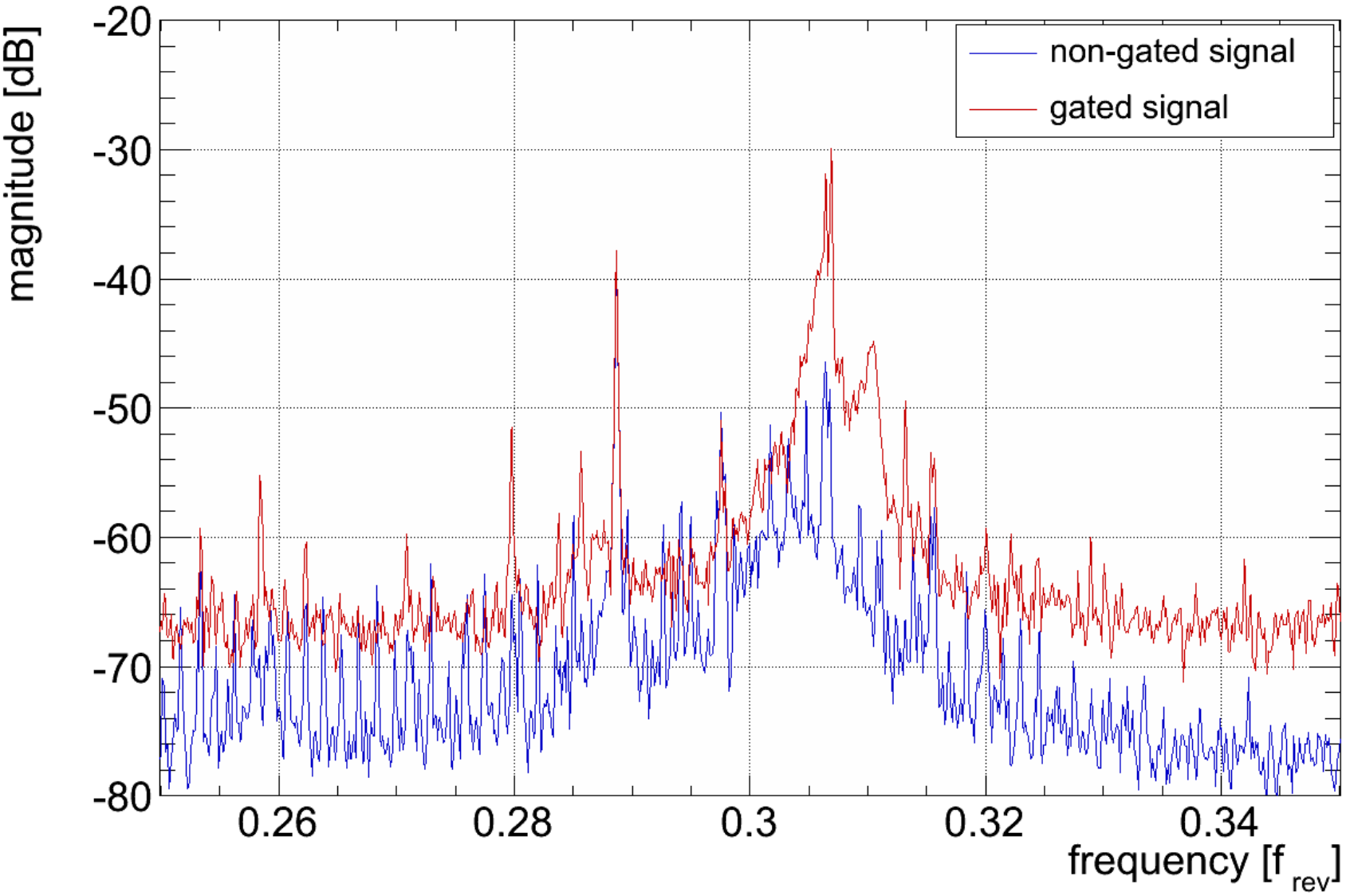
2012-10-05 – Fill 3133: Start of Ramp

- Q_s side-bands around f_{rev} visibly reduced:



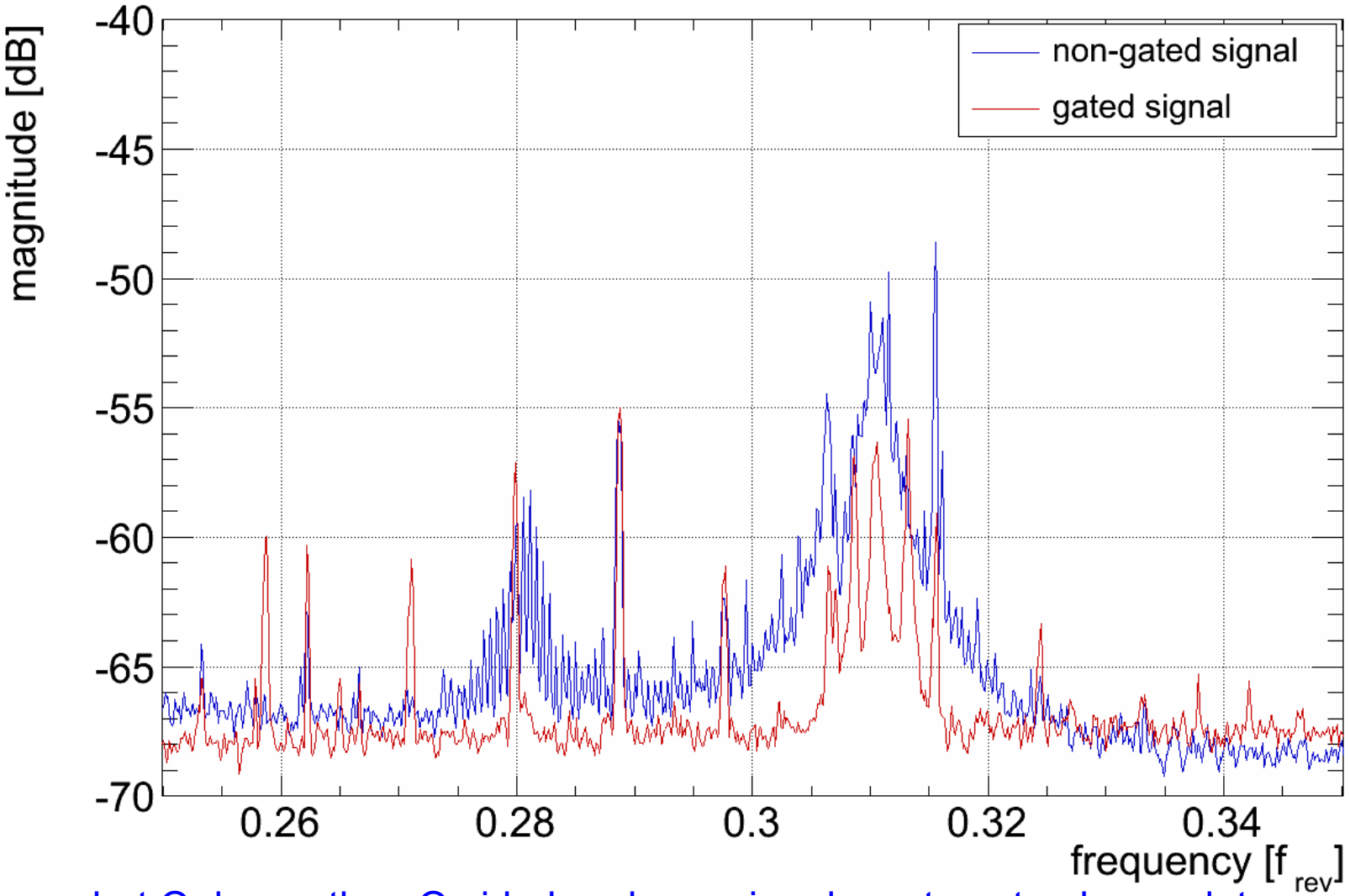
2012-10-05 – Fill 3133: Start of Ramp – ZOOM

- > 30 dB S/N ratio in some cases (particularly during start of the ramp)



2012-10-05 – Fill 3133: End of Ramp

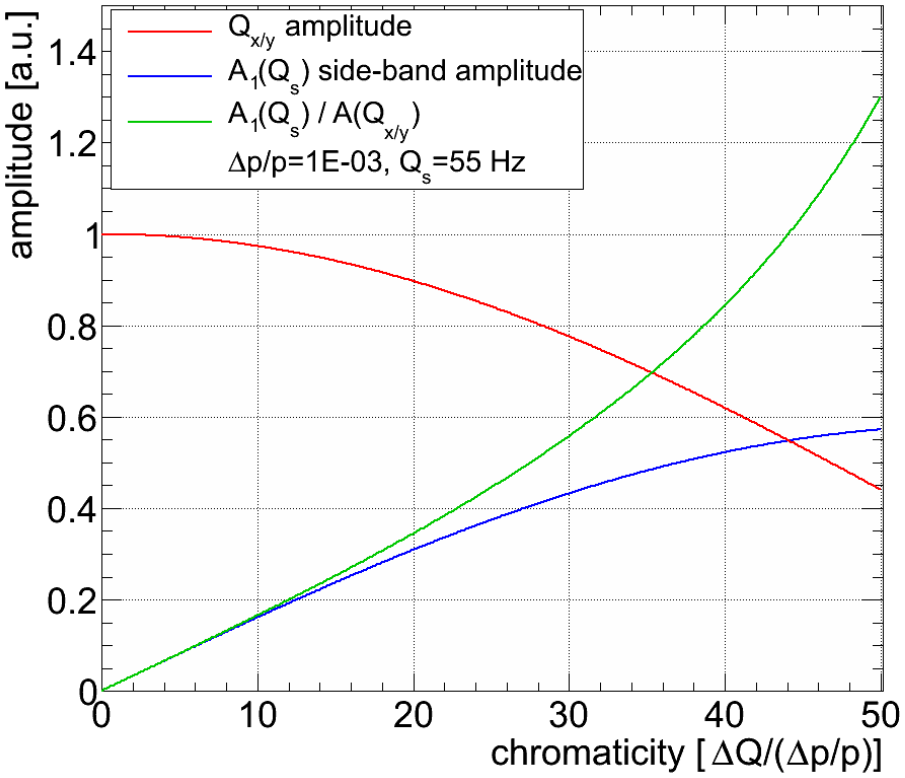
- Q_s around main Q-peak more pronounced → enables rough Q' estimate



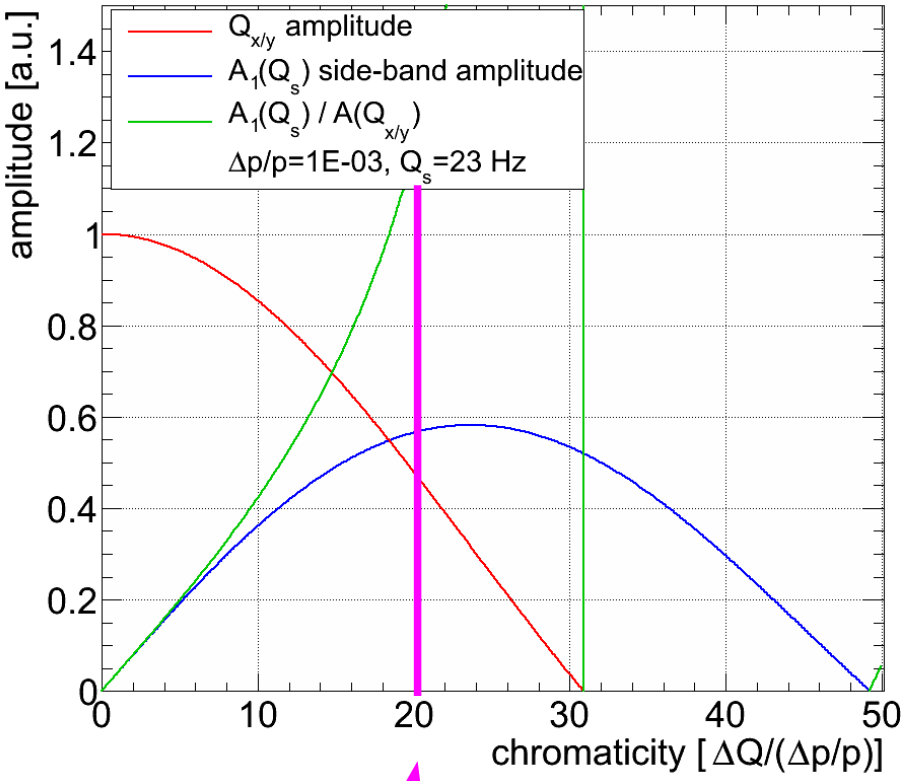
- … but Q_s larger than Q side-bands require also a tune tracker update.

Further Exploitation – Chromaticity via Q_s Side-bands II/II

- LHC start-ramp:



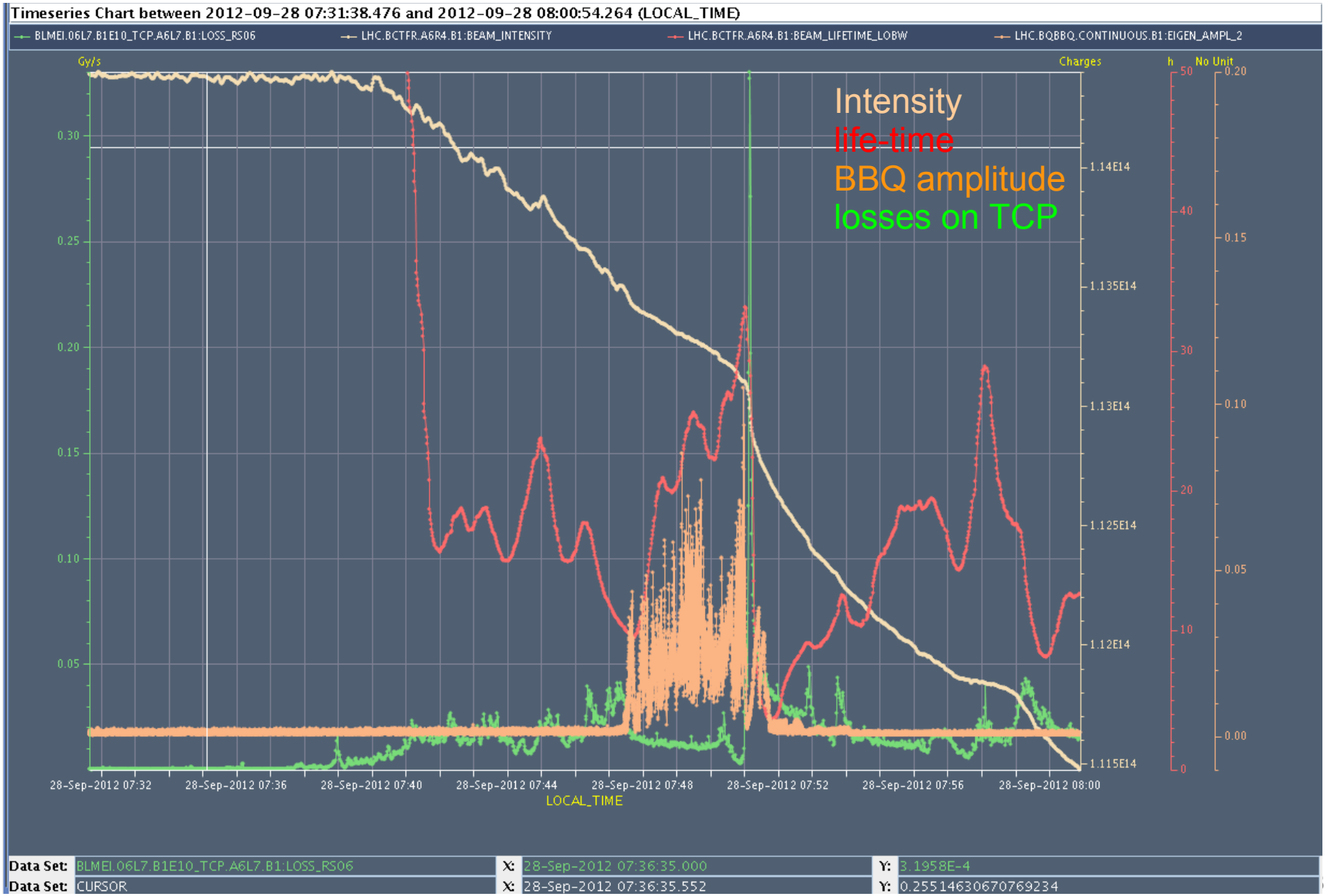
- LHC flat-top:



we presently operate here

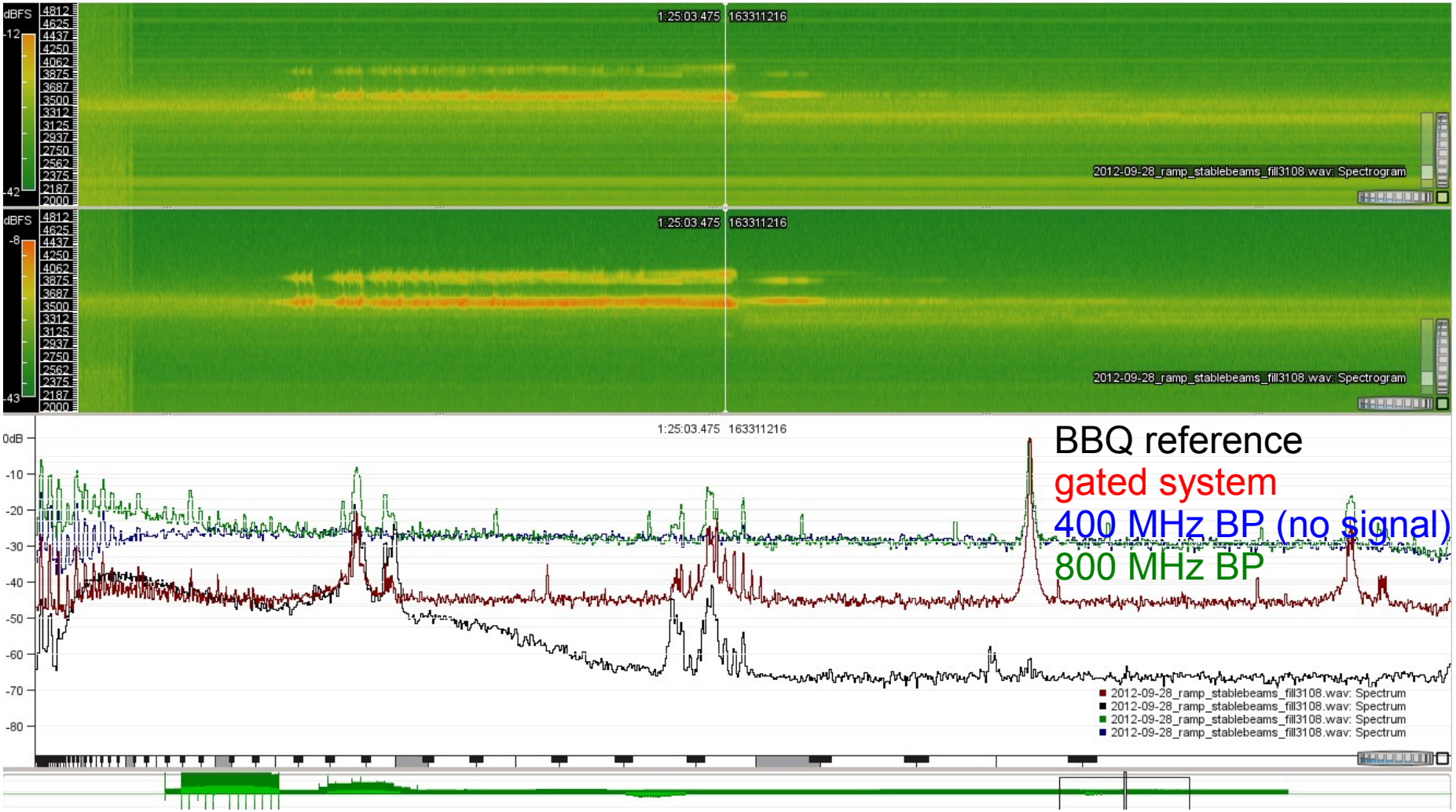
N.B. Q_s and Δp/p numbers approximate

Instabilities detected by BBQ at β*=60 cm I/II



Instabilities detected by BBQ at β*=60 cm II/II

- Signal not seen on first six bunches



- Q-amplitue-to-f_{rev} ratio larger at 800 MHz than <400 MHz → intra-bunch motion

Summary

- Preliminary results confirm the viability of a gated BBQ measurement:
  - more narrow peak and suppression of Q_s harmonics around DC
  - side-bands are much more pronounced around main Q peak
    - scale with and permits rough check on Q'
    - May need to update the Q tracker for large Q'
- First six bunches more stable than the rest of the beam and perturbed by the abort gap and injection cleaning (i.e. BBQ does not trigger on un-captured beam)
- Observed instability once reaching β*=60 cm, identified to be related to intra-bunch beam motion of a few selected bunches. To be followed-up...
- Based on this data, could we adjust the following two things:
  - ramp without chirping (at least for B1, the signals are very much sufficient without and the chirp perturbs the first bunches unnecessarily)
  - keep the gain modulation throughout flat-top, squeeze, adjust and possibly also during the physics beam process? (only first six bunches of B1)
- Need a short access to UA47 to modify/decouple the BBQ gating signal
  - After that, could time-in the two system independently/deploy sys. for OP
- Provided there is an ~2h access, could deploy a gated BBQ system for B2

Further Exploitation – Chromaticity via Q_s Side-bands I/II

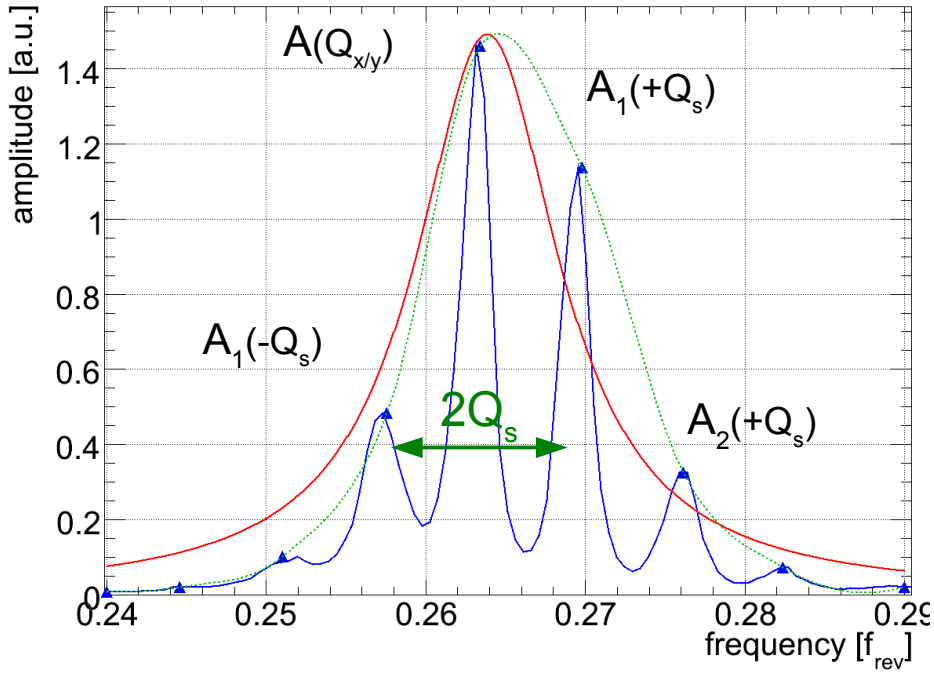
- Some comments on Q', modulation index and tune width of the BTF
  - Turn-by-turn oscillations can be approximated by (n: turn)

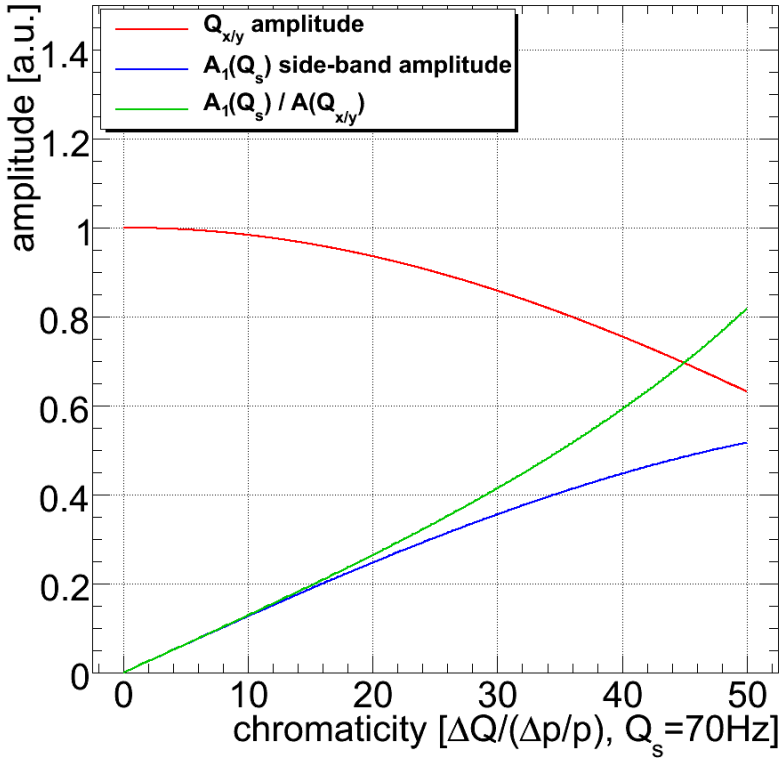
$$\Delta z(n) = z_0 \cdot \sin\left(2\pi \cdot \left[Q_0 \cdot n + \frac{Q'}{\omega_s}\frac{\Delta p}{p} \cdot \sin(\omega_s n)\right] + \phi_\beta\right)$$

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

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

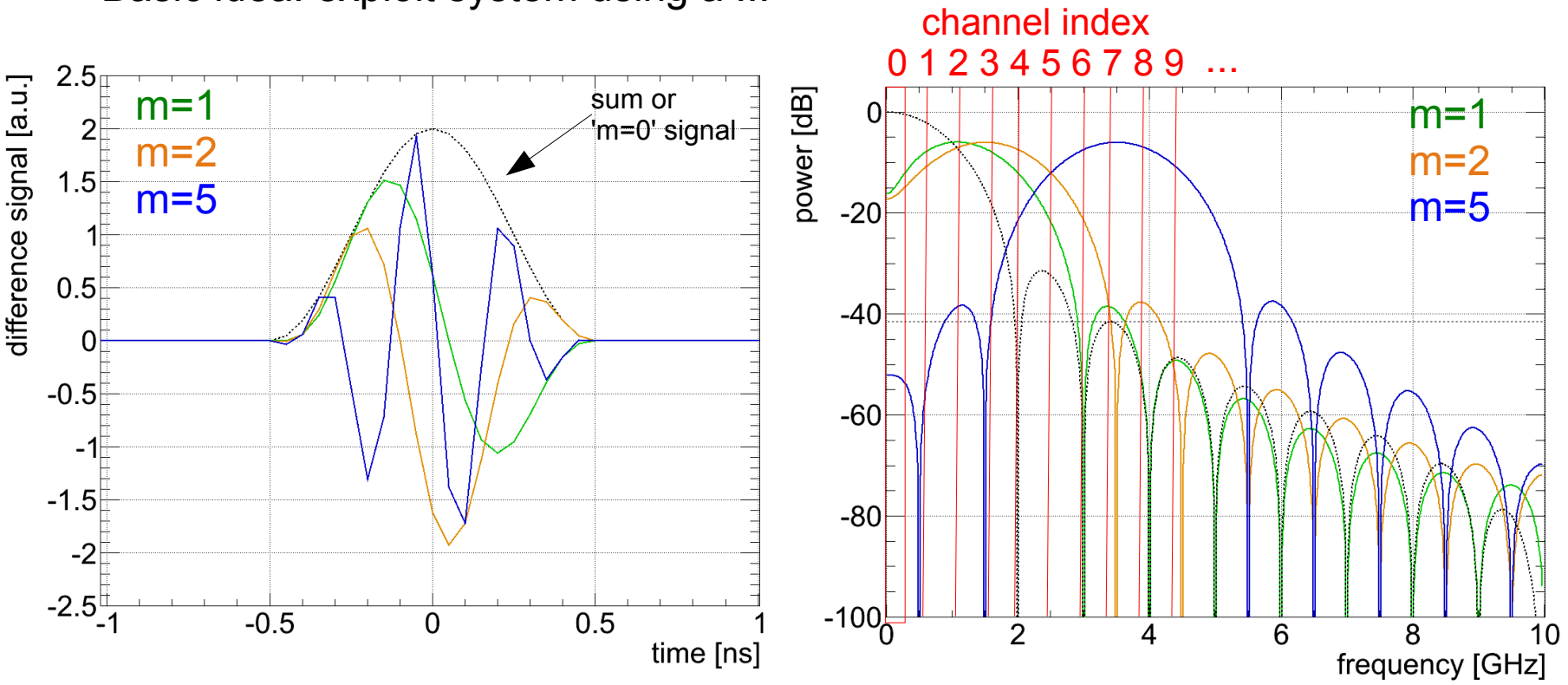
- Tune/Qs side-band amplitude (J_n: Bessel f.): linear over a wide range of Q'





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