LHC Base-Band-Tune (BBQ) and Q' Measurement Systems

Functionality and Use-Cases

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Outline

- Please, also have a look on recent Q/Q' CARE workshop, in particular the following presentations:
  - Base-Band-Tune (BBQ) principle:
    http://adweb.desy.de/mdi/CARE/chamonix/071212_chamonix_bbq.ppt
  - LHC PLL principle:
    http://adweb.desy.de/mdi/CARE/chamonix/LHC_PLL.ppsx
  - LHC Tune/Chromaticity (FB) Control:
    http://adweb.desy.de/mdi/CARE/chamonix/2007-12-12_Qp_workshop_Chamonix_FB_Architecture.pdf

Reminder: LHC Tune and Chromaticity Requirements

- The measurement and control of

  -- orbit, tune, chromaticity, energy and coupling --

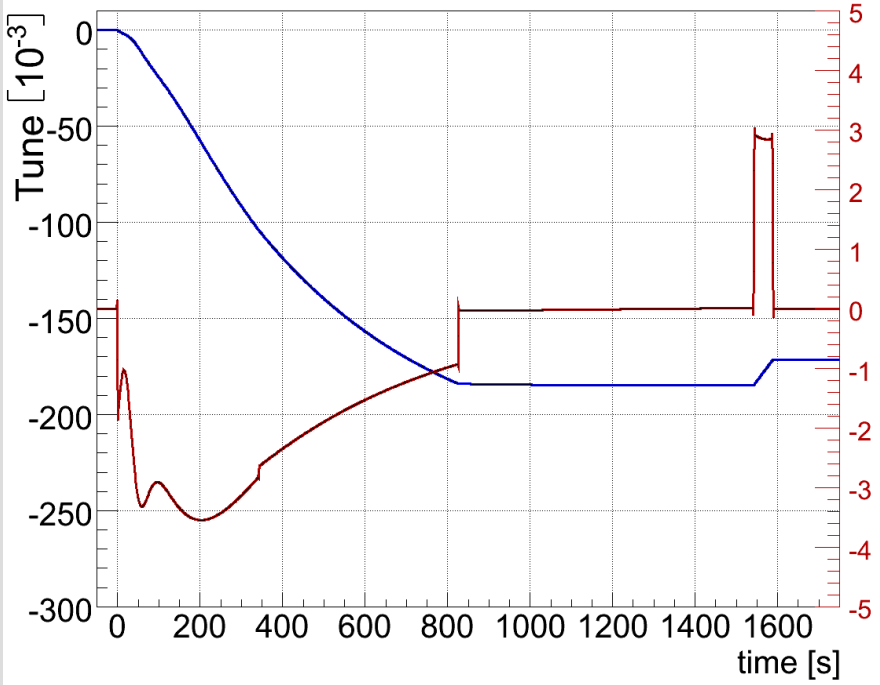
  will be an integral part of the LHC operation

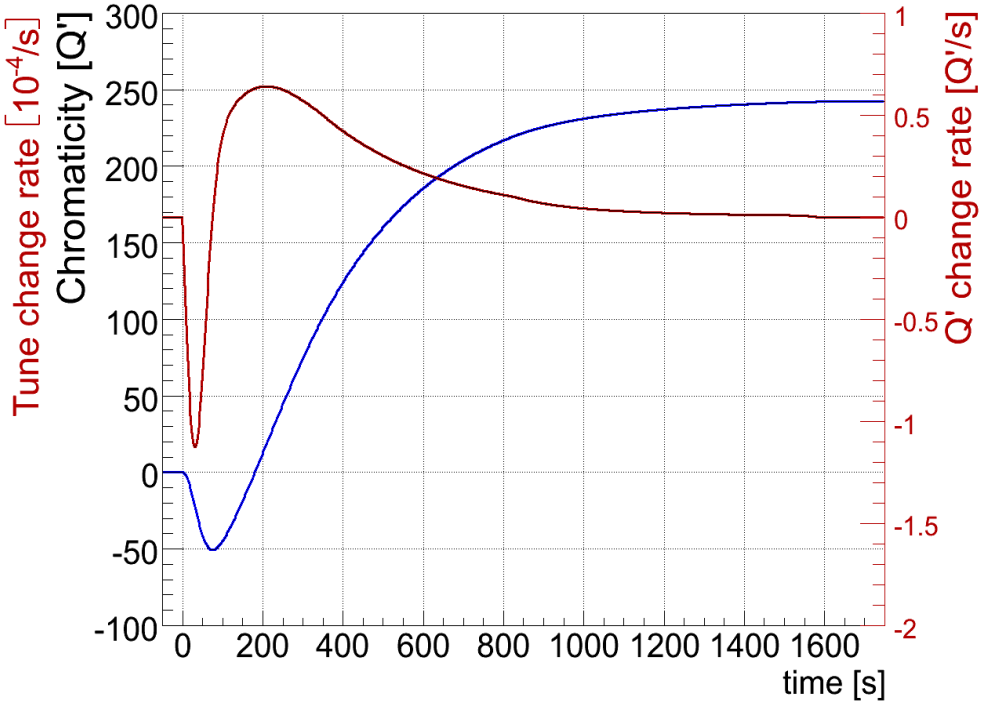
- Stability requirements summary (Chamonix'06):

	Orbit [σ]	Tune [0.5·f_{rev}]	Chroma. [units]	Energy [Δp/p]	Coupling [c_-]
Exp. Perturbations:	~ 1-2 (30 mm)	0.025 (0.06)	~ 70 (140)	± 1.5e-4	~0.01 (0.1)
Pilot bunch	-	± 0.1	+ 10 ??	-	-
Stage I Requirements	± ~ 1	±0.015→0.003	> 0 ± 10	± 1e-4	« 0.03
Nominal	± 0.3 / 0.5	±0.003 / ±0.001	1-2 ± 1	± 1e-4	« 0.01

- Naming convention:
  - 'one FFT measurement' = 'one FFT spectra based on <nbofAcq> turns'
    → after post-processing: →
    ≈ 'one Q_1, Q_2, Q_x, Q_y, $|C^-|$ measurement' = 'one PLL measurement'

Reminder Exp. Tune and Chromaticity Drifts during LHC ramp





- Exp. perturbations are about 200 times than required stability!
- however: maximum drift rates are expected to be slow in the LHC
  - Tune: $\Delta Q/\Delta t|_{max} < 10^{-3}\ s^{-1}$
  - Chromaticity: $\Delta Q'/\Delta t|_{max} < 2\ s^{-1}$ ← the critical/difficult parameter
- Requires active control relying on beam-based measurements

LHC Base-Line Q/Q' Diagnostics Overview - Q/C⁻

Tune/Coupling – Commissioning Phase A.3 (first circulating beam):

- FFT based acquisition (excite and analyse oscillation spectra) using either
  - 'RF transverse damper' or 'BQK' (aka. 'tune tickler'),
  - 'MKQA' (aka. 'tune' or 'aperture kicker') triggered through either
    - FESA/MTG (software) or
    - directly using a direct link between BBQ-DAB and MKQA electronics (TTL based, more robust, easy turn-adjustment)
  - or simply no excitation! - yields sufficient data for most cases...
    ...for the other: fall-back to one of above excitation based methods.
  - CON: slower tune (→ chromaticity) tracking, problematic with large Q'

- Phase-Locked-Loop (PLL) based acquisition
  - requires excitation using either the 'BQK' or 'RF transverse damper'

- FFT based acquisition using the LHC BPMs - Phase A.2 → V.Kain et al.
  - initial tune adjustments (first 100 turns, integer Q, local C⁻ correction etc.)

LHC Base-Line Q/Q' Diagnostics Overview – Q'

Chromaticity:

- Slow RF momentum modulation – Commissioning Phase A.3
  - Q' is proportional to momentum induced tune changes:

$$Q' = \frac{\Delta Q}{\Delta p / p}$$

the measured tune change

the RF induced momentum change (known)

  - momentum can be changed on the scale of 1-2 Hz (Δp/p error ~ 10^{-3})
  - Controllability of Q' depends on the ability to track the tune both accurately & fast (> 2++ times faster the Δp/p modulation)
- Kicked Head-Tail Phase-Shift – Phase A.3 (~ copy of SPS installation)
  - control method and massively used for beam stability analysis
  - N.B. required MKQA kicks too large to be used operationally for Q'
- Side-exciter based method – lower priority (end 2008/2009?)
  - needs further assessment/acceptance with LHC beam (parameters)
- Continuous Head-Tail Phase-Shift
  - under investigation (2009++)

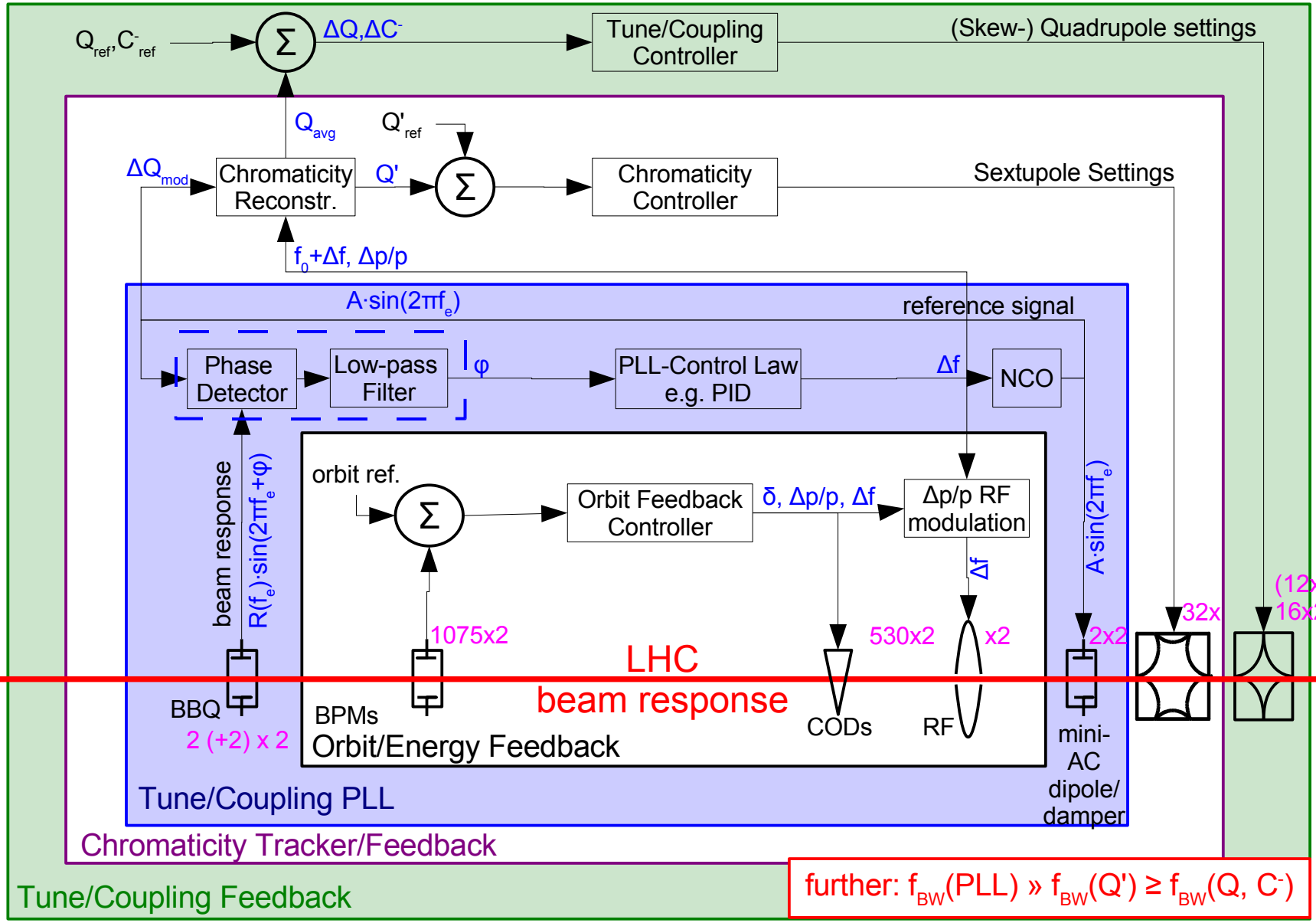
Use-Cases Abstraction

- From a controls software (/operational) point of view, tune diagnostic can be decomposed into three measurements can be grouped/abstracted to
  - PPL based acquisition of Q,Q'...
    - one measurement at high/reduced acquisition frequency
      - Proposed/required targets for feedbacks 100 Hz (driven by need to reduce latency) and 1 Hz for general purpose logging
    - expert: high frequency data that is event synchronised and buffered (post-mortem, PLL setup), typical length: 5 min ↔ < 1 MB of data
    - main users: monitoring/logging, feedbacks, fill-to-fill studies, ...
  - FFT based acquisition of Q,Q'... – 'periodic'
    - one measurement every 1 second starting from first-injection
    - main users: monitoring/logging, (feedbacks), fill-to-fill studies, ...
  - FFT based acquisition of Q,Q'... – 'on demand'
    - n-measurements that are synchronised to an external event
      - event sequence (MTG): arm → start acquisition → publish data
    - main users: expert diagnostics, detailed studies, ...

LHC Q/Q' System Overview

- LHC Q/Q' system: 5 racks, 9 VME crates, 10 DAB front-ends:
  - UA43-BY09 - initially: BQK kicker control (unused)
  - UA43-BY10 - support cavern left of IP4 [*CFV-UA43-BQB2~~PLL~~*]
    - PLL-B2 (operation): Q/C$^-$ Phase-Locked-Loop System Beam 2
      - connected to BQK.6R4 (aka. 'Q tickler')
    - FFT-B2 (operation): periodic acq., logging, fill-to-fill studies, Beam 2
  - UA47-BY06 - initially: BQK.B1 kicker control (unused)
  - UA47-BY07 - support cavern right of IP4 [*CFV-UA47-BQB1~~PLL~~*]
    - PLL-B1 (operation): as above but Beam 1
      - connected to BQK.6L4
    - FFT-B1 (operation) as above but Beam 1
  - UA47-BY12 [*CFV-UA47-BQ → CFV-UA47-BQFFT?*]
    - FFT-B1, FFT-B2: on demand FFT spectra acquisition
      - connected to RF damper system
      - software + hardware (TTL) link to MKQA
      - N.B. can be also used for periodic acquisition
    - (BQSHT-B1/B2: 'Head-Tail' acquisition system)
  - SX4-BY11 – surface building
    [CFV-SX4-*BQDEV~~PLL~~B1, CFV-SX4-BQDEV~~PLL~~B2*]
    - DEV-B1: LHC FFT/PLL/HT development system
    - DEV-B2: (Q: move to SPS? - “easier”/more available test-bed)
  - SX4-BY10 – new Q/Q' designs (continuous head-tail) [CFV-SX4-*BQ]*

Future Integration of Q/Q' Measurements for Q/Q' Control
Full LHC Beam-Based Control Scheme



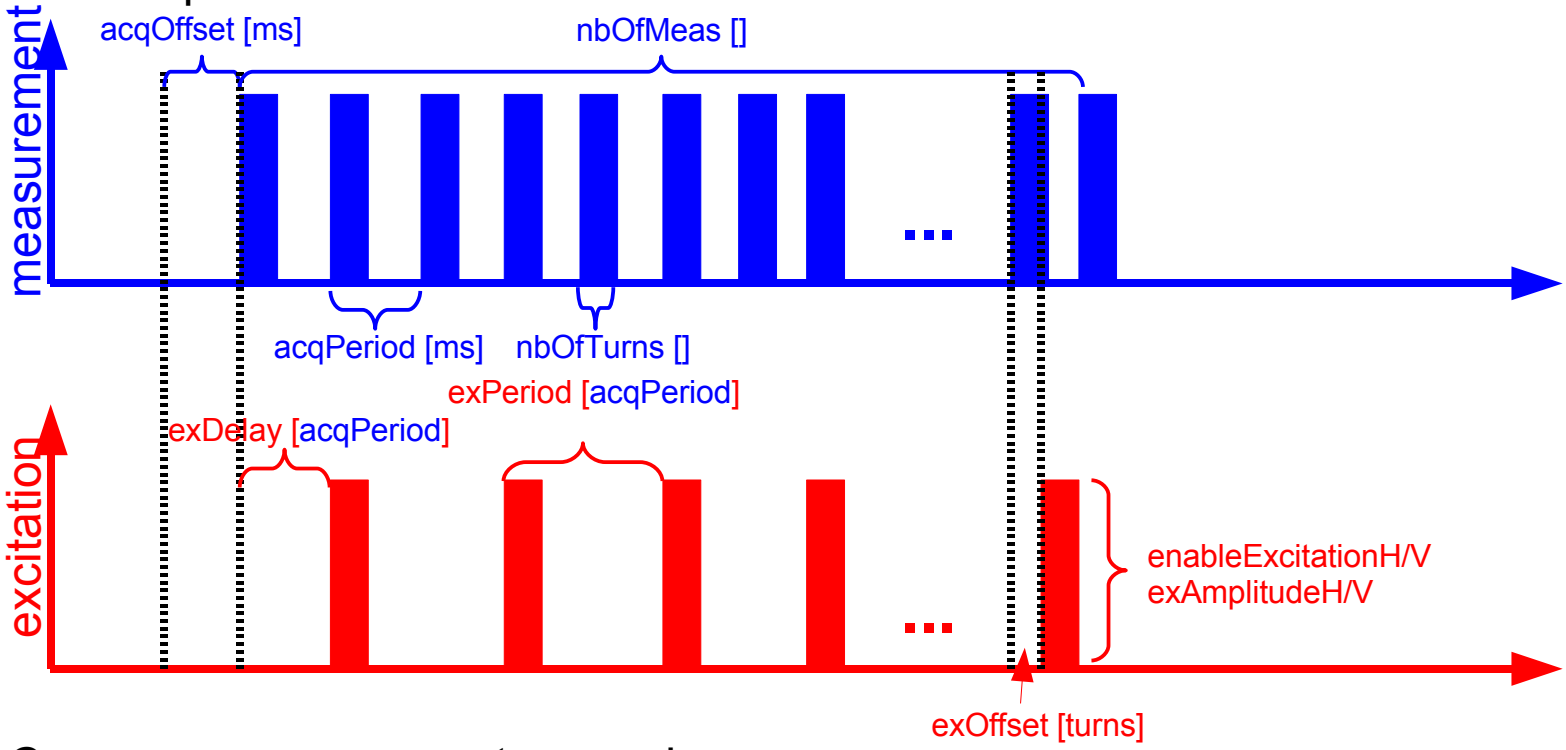
LHC FBs: 2158 input devices, 1136 output devices → total: ~3300 devices!

FFT Based Q Acquisition – 'On Demand'

- FFT based acquisition – 'on demand'
  - “acquire and publish N-measurements synchronised to a given event”
  - already implemented & tested at the PSB/CPS/LEI/SPS/...
  - SPS operation: mostly a “cycle-by-cycle” paradigm
    - traditional acquisition relies on a group of three events
      - “prepare/arm acquisition”
        - usually some 100 ms before acquisition (/injection)
      - “start acquisition” - usually user defined
      - “publish data” - usually at the end of the acquisition (/cycle)
    - event sequence & names are hard-coded in the SPS MTG

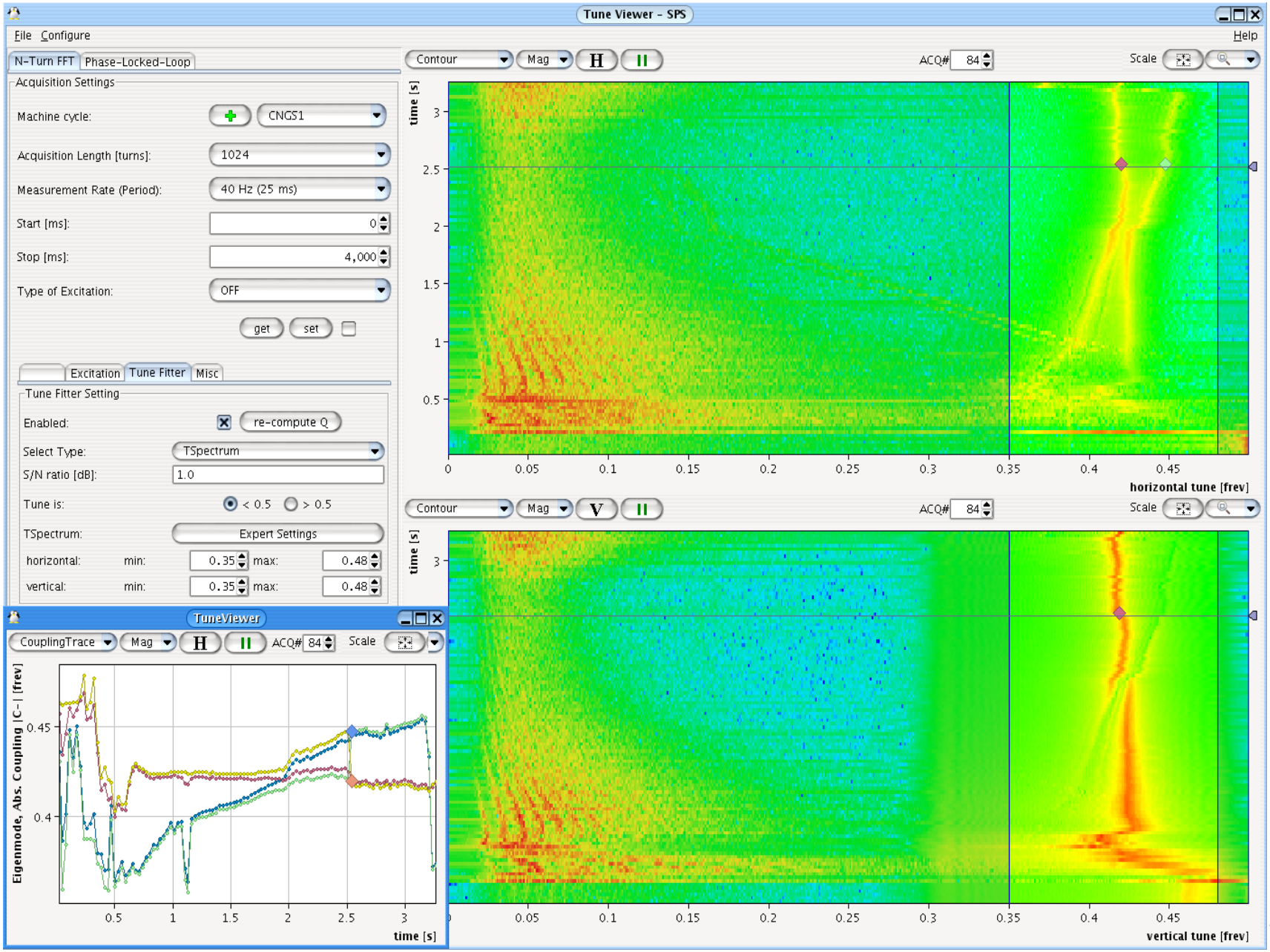
- Further details accessible through the FESA navigator:
  - http://wwwpsco.cern.ch/private/java/fesa/CURRENT_RELEASE/FNT.jnlp
  - or 'Tune Viewer' expert (/OP) application (all CERN accelerators):
    http://slwww/~pcrops/releaseinfo/pcropsdist/sps/sps-tuneviewer/PRO/

FFT Based Q Acquisition – 'On Demand'
FESA 'Settings' Property



- Common measurement scenario:
  - measure (acqState=on) from injection (acqOffset=0) every 10 ms (acqPeriod=10) till 900 ms (nbOfMeas=floor(900/acqPeriod)) while kicking the beam every measurement (exDelay=0) in the vertical plane (exMode=KICK, enableExcitationH = true, enableExcitationV = false)
- Example application: 'Tune Viewer' : http://slwww/~pcrops/releaseinfo/pcropsdist/sps/sps-tuneviewer/PRO/

FFT Based Q Acquisition – 'On Demand'
Example: Tests at the SPS - Real-Beam Data



SPS vs. LHC Timing Event Generation

- SPS operation(mostly) based on a “cycle-by-cycle” paradigm... LHC?

Based on discussion with M. Lamont et al.:

- LHC timing scheme could/will implement similar event structure:
  - hard-coded MTG table replaced by a user-definable event sequence
  - GUI/server programmes/modify the tables prior acquisition
  - Actual DAB FFT (/PLL) acquisition can be started via software (FESA event) or through an external input (hardware)

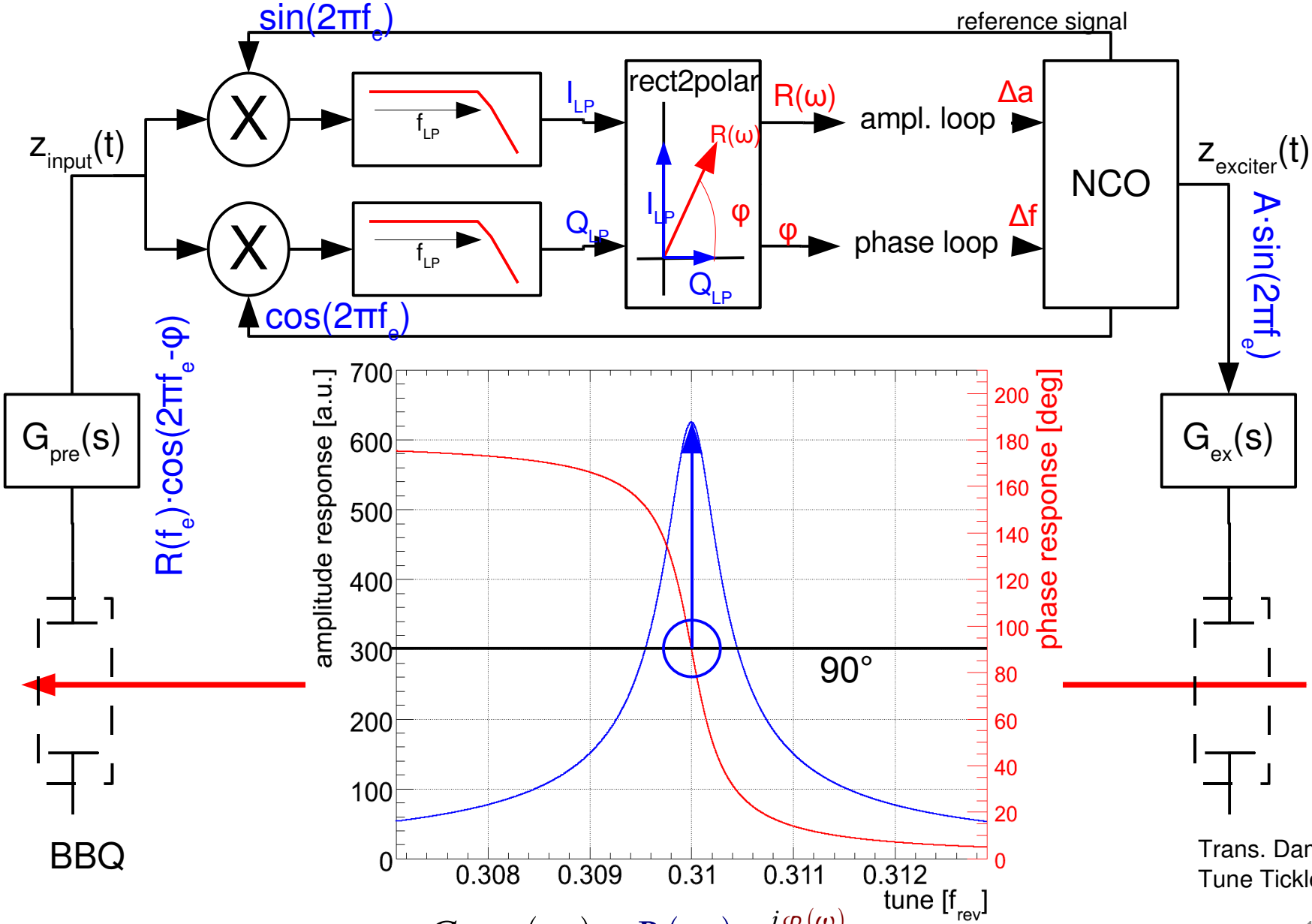
- There is no evident need to branch off a LHC-specific BBQ Tune FESA server
  - could/will be used to mimic the “three-event” sequence
    - could we drop the “publish” and “arm” event (they are redundant)??
  - profit of having the same diagnostic tools across all accelerators
    - easier maintenance, broader OP acceptance, ...

FFT Based Q Acquisition – 'Periodic'

- FFT based acquisition – periodic
  - measurements are published immediately
  - LHC: significantly lower data rates: ~ 80 KBytes@1Hz (UTC second)
  - event sequence: first injection (or software start) → beam extraction
    - 'on-demand' & 'periodic' are mutually exclusive operation
      → distributed on two separate systems
  - main issue: to be implemented in the FESA server (for both LHC & SPS)
    - N.B. TuneViewer already supports continuous input

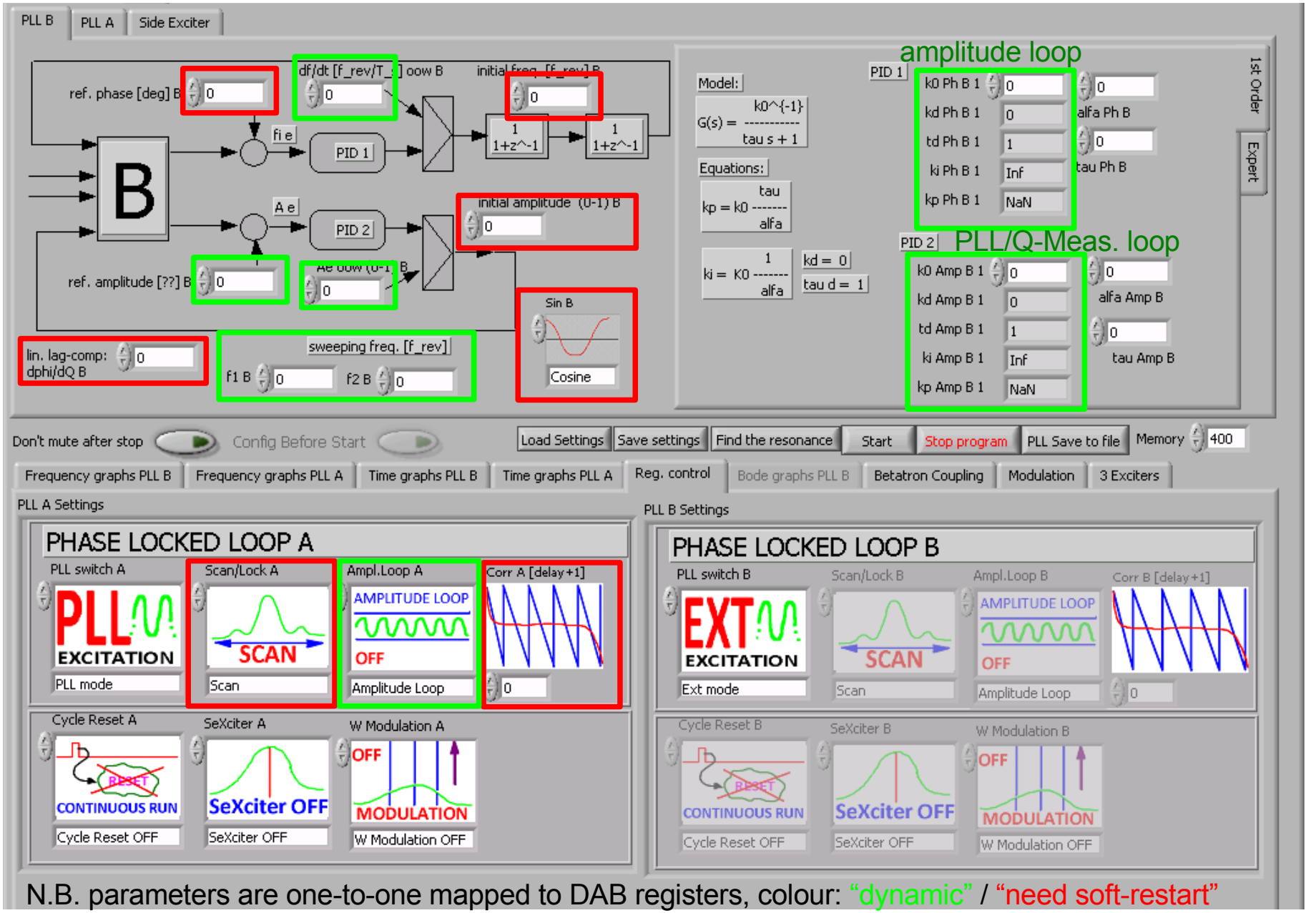
- Again, since the systems are quite similar across the CERN accelerators:
  - leverage and re-use
    - the same FESA design
    - the same expert/operational monitoring application

PLL based Q/Q' tracking
Simplified LHC Phase-Locked-Loop Scheme



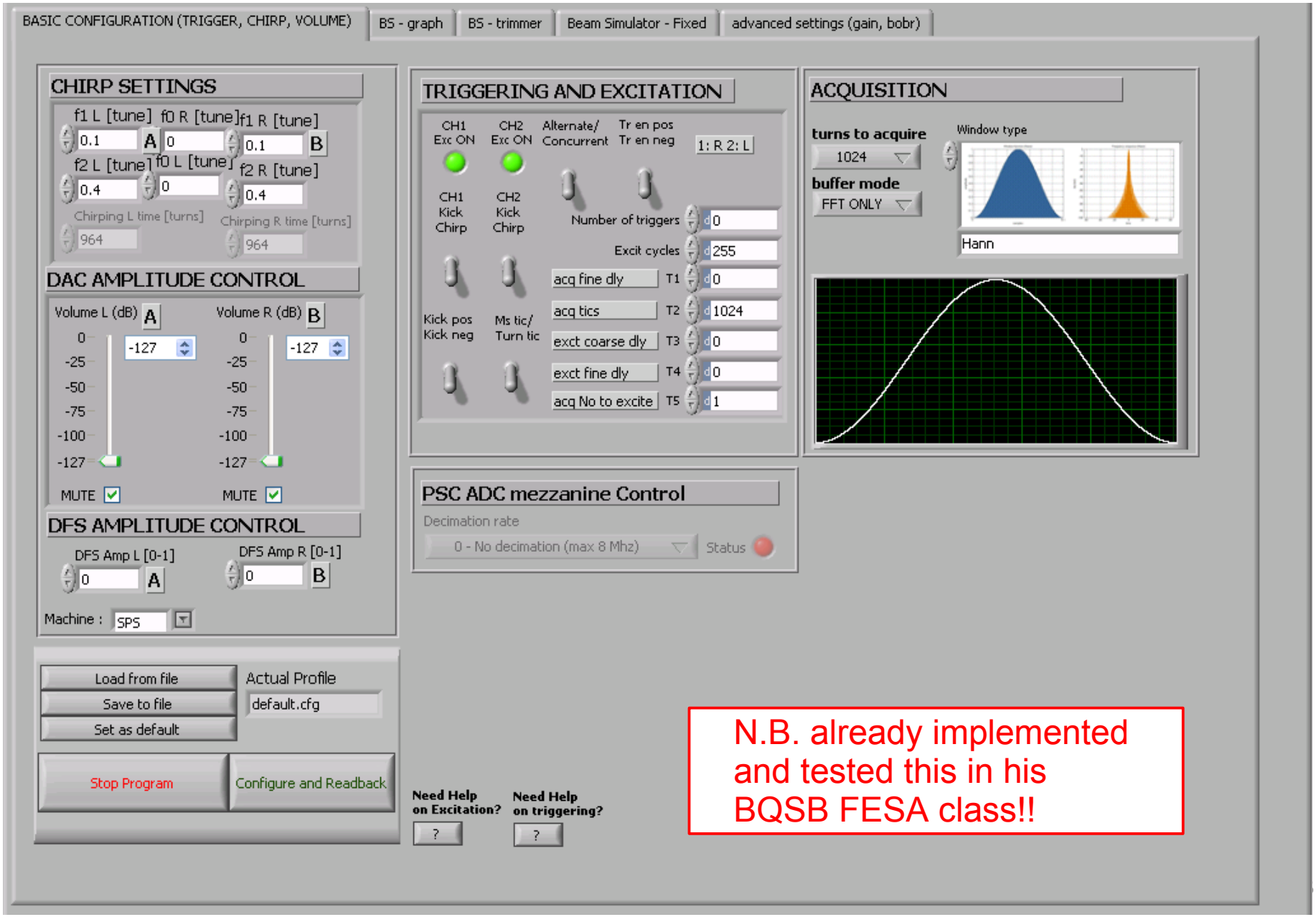
$$G_{Beam}(\omega) = R(\omega) \cdot e^{i\varphi(\omega)}$$

LHC PLL Prototype in the SPS
LabView Interface I/II



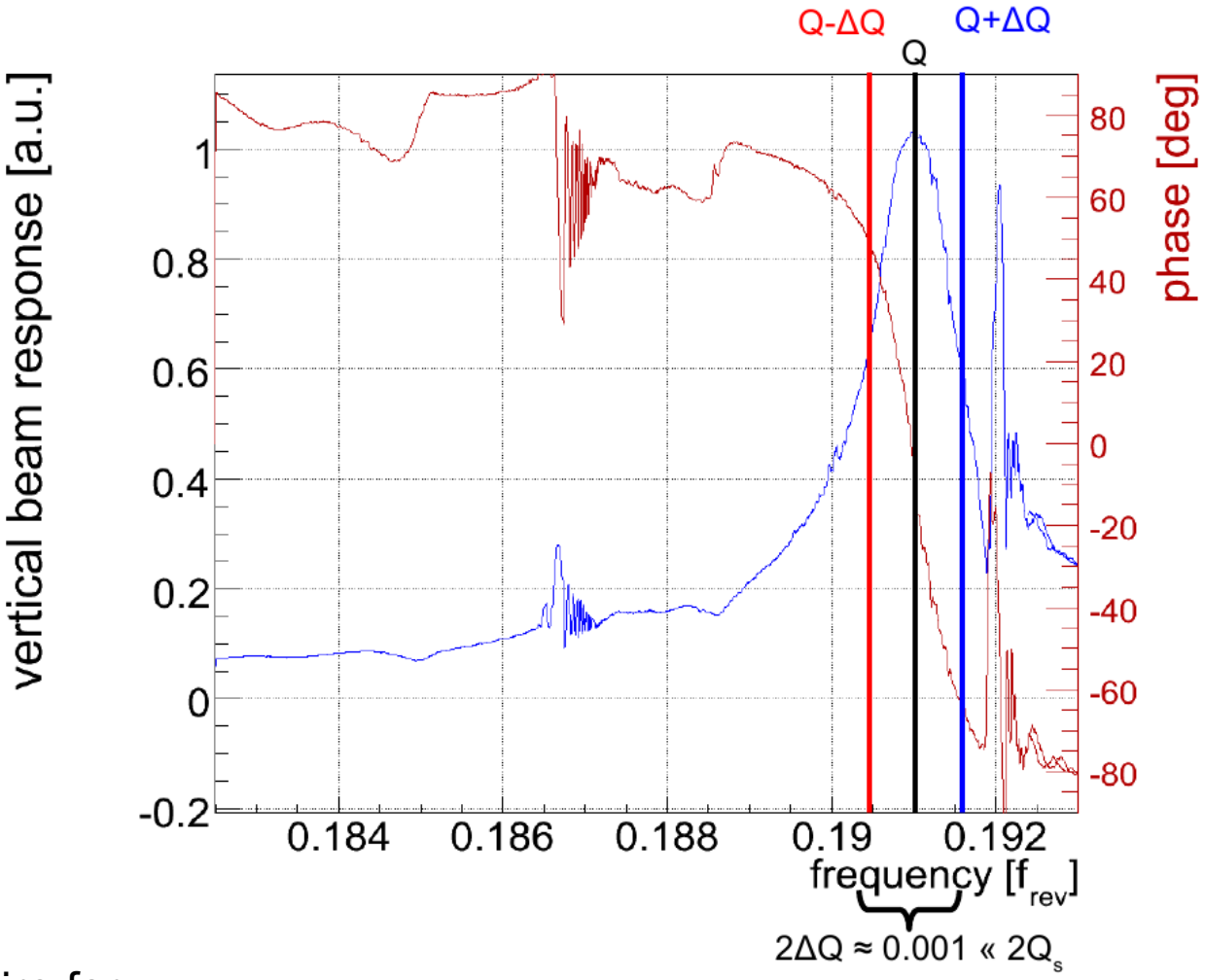
N.B. parameters are one-to-one mapped to DAB registers, colour: "dynamic" / "need soft-restart"

LHC PLL Prototype in the SPS
LabView Interface II/II



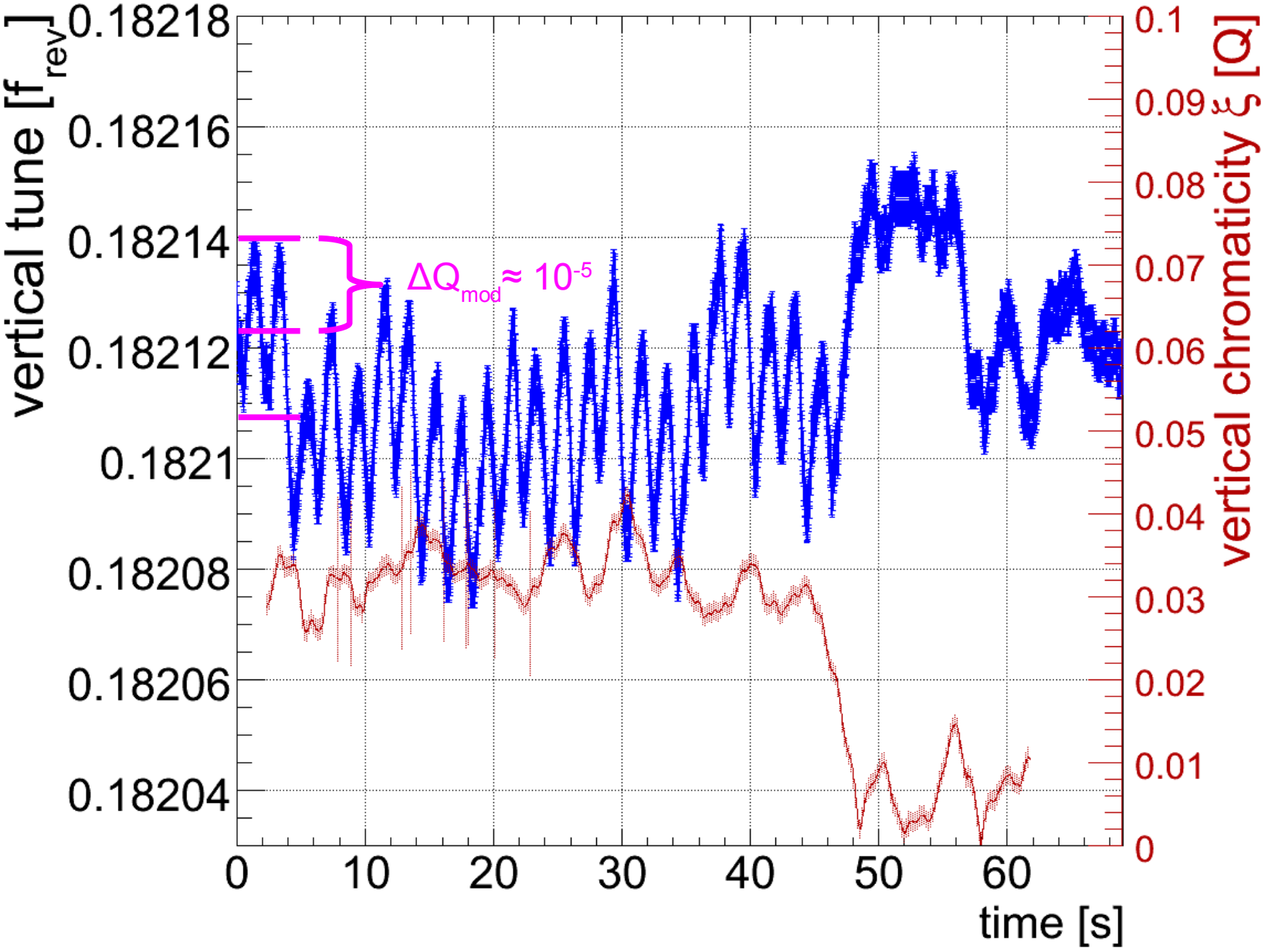
N.B. already implemented and tested this in his BQSB FESA class!!

PLL based Q/Q' tracking study at the SPS Beam-Transfer-Function

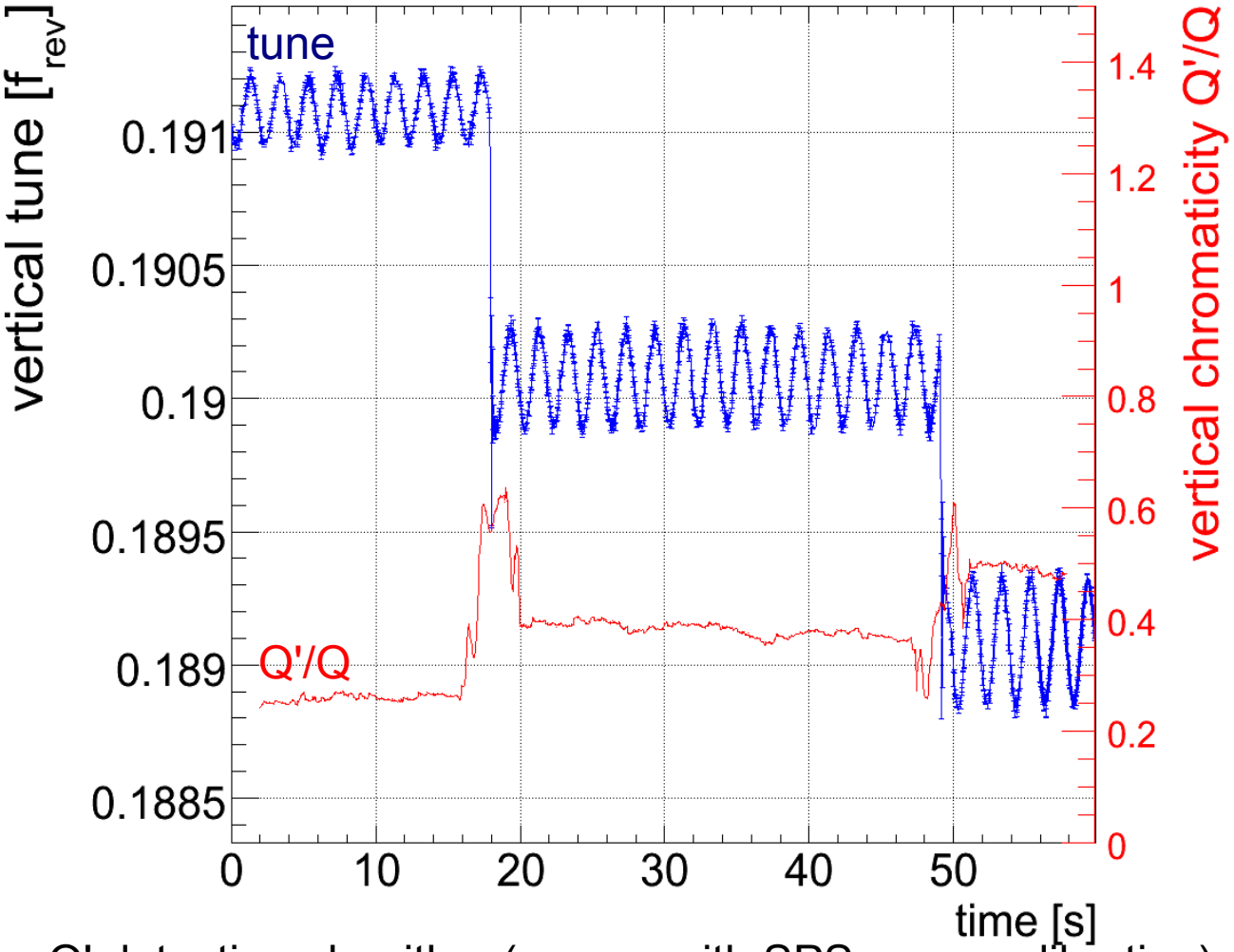


- Require for:
  - PLL setup and re-calibration: phase/amplitude adjustments, ...
  - Impedance, Q', Q'', Q''', other advanced beam measurements, ...

PLL based Q/Q' tracking study at the SPS
Radial RF modulation dp/p=1.6·10^{-5}, set ξ := 0.05



PLL based Q/Q' tracking study at the SPS
Radial RF modulation: $\Delta p/p \approx 1.85 \cdot 10^{-5}$



- real-time Q' detection algorithm (agrees with SPS cross-calibration):
  - Q' resolution better than 1 unit (nominal performance)
  - N.B. tracking transients: ΔQ' feed-down on ΔQ (non-centred orbit)
    - $\Delta Q/\Delta t \gg \Delta Q'/\Delta t \rightarrow$ SPS specific, LHC: $\Delta Q/\Delta t|_{max} < 10^{-4}$/s

PLL Based Q Acquisition

Distinguish/require two types of acquisition:

- Continuous re-publishing of PLL measurements (normal operation)
  - high sampling @ 100Hz for Q' tracker & Q/Q' feedback operation (~30 bytes/sample)
  - logging @ 1 Hz (average + buffer of high freq. data ~ 3Kb/sample)

- Buffered - 'on demand' (setup diagnostic & post mortem)
  - triggered by state change (two states: PLL Lock ↔ SCAN) and/or software event
  - required buffer length < 5 MB (↔ ~5 minutes)

- Most of the settings
  - some static (f_{rev}, phase corr., reference phase, LOCK/SCAN state, ...)
  - some dynamic (controller gains, reference amplitude, ...)
  - However: Most are one-to-one mapping to DAB registers

additional supporting slides

'Settings' Property I/VI

Acquisition trigger settings:

- acqState: <on,off>:
  - enables or disables the acquisition
  - default: 'off', also switches 'off' once 'single' acquisition is finished
- acqMode: <SINGLE, CONTINUOUS>
  - 'SINGLE': perform 'nbOfAcq' measurements and then switch to state '*acqState*=off' (fail-safe mechanism)
  - 'CONTINUOUS': 'coast mode' (ignores cycle alignment)
- externalStartTrigger: <true, false>
  - switches 'start first acquisition' between external HW based (BST-Master) trigger or CTRP timing card (e.g. 'cycle start') trigger
  - required to synchronise with external events such as collimator movements or RF that are not aligned to CERN's UTC 'ms' clock.
  - default: 'false'

'Settings' Property II/VI

Acquisition trigger settings:

- nbOfTurns: <T256, T512, T1024, ..., T262144>
  - length of acquired data window(s) in turns.
  - default: CPS/PSB/SPS: 'T1024'; LHC: 'T8192'
- nbOfMeas: <int>
  - number of requested measurements (N.B. '0' → '1')
  - default: '1' (maximum limited by available memory)
- acqOffset: <int>
  - offset of the first measurements in 'ms'
  - default: CPS/PSB: '10', SPS: '25', LHC: '1000'
- acqPeriod: <int>
  - distance in between measurements in 'ms'
  - special mode 'acqPeriod == 0': 'back-to-back' acquisition (BI experts/MD type acquisition)
  - default: CPS/PSB: '10', SPS: '25', LHC: '1000'

'Settings' Property III/VI

Excitation trigger settings:

- exDelay: <int>
  - number of measurements to perform before first excitation [acqPeriod]
  - default: '0'
- exOffset: <int>
  - turn delay of excitation (kick) w.r.t. to individual acquisition start
  - default: '0'
- exPeriod: <int>
  - number of non-excited measurements (gap) in between measurements with excitations. e.g. excitationGap = 3 → every fourth measurement contains excitations
  - unit: [acqFrequency]
  - default: '0'

'Settings' Property IV/VI

Data pre- and post-processing:

- dataMode: <RAW, FFT, MAG, RAW_AND_FFT>
  - RAW: raw oscillation data (N.B. the BBQ ≠ a BPM: oscillation frequencies below $0.1f_{rev}$ are attenuated by a significant amount)
  - FFT: Fast-Fourier-Transform spectrum (contains real- and imaginary part)
  - MAG: magnitude spectrum (no phase information)
  - default: PSB/CPS: 'MAG', SPS/LHC: 'RAW_AND_FFT'
- windowFunction: <RECTANGULAR, HAMMING, HANN, BLACKMAN, NUTTALL, BLACKMAN-HARRIS, BLACKMAN-NUTALL, FLAT_TOP>
  - apodisation function of the FFT routine (N.B. the 'RAW' data is unaffected by this)
  - default: 'HANN'

'Settings' Property V/VI

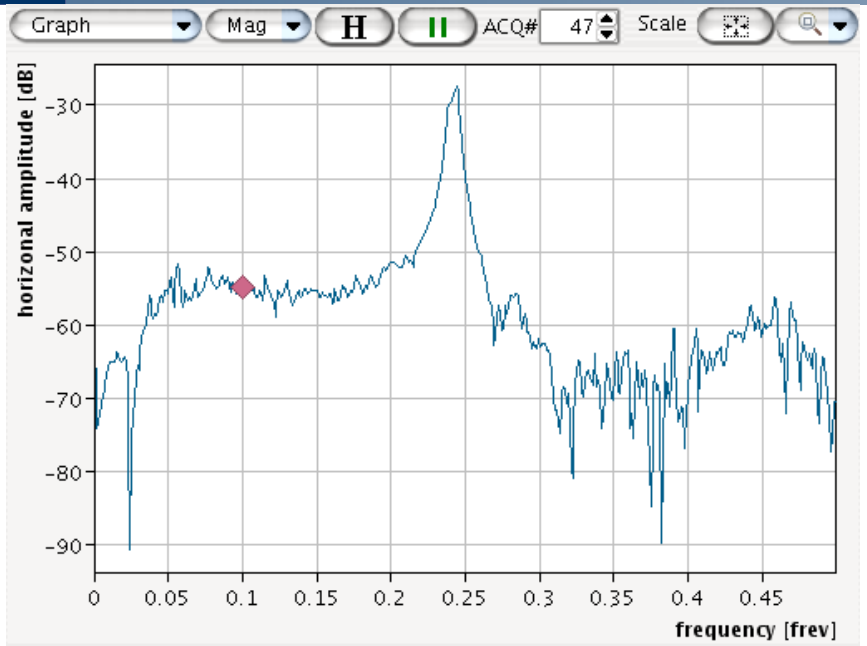
General excitation settings:

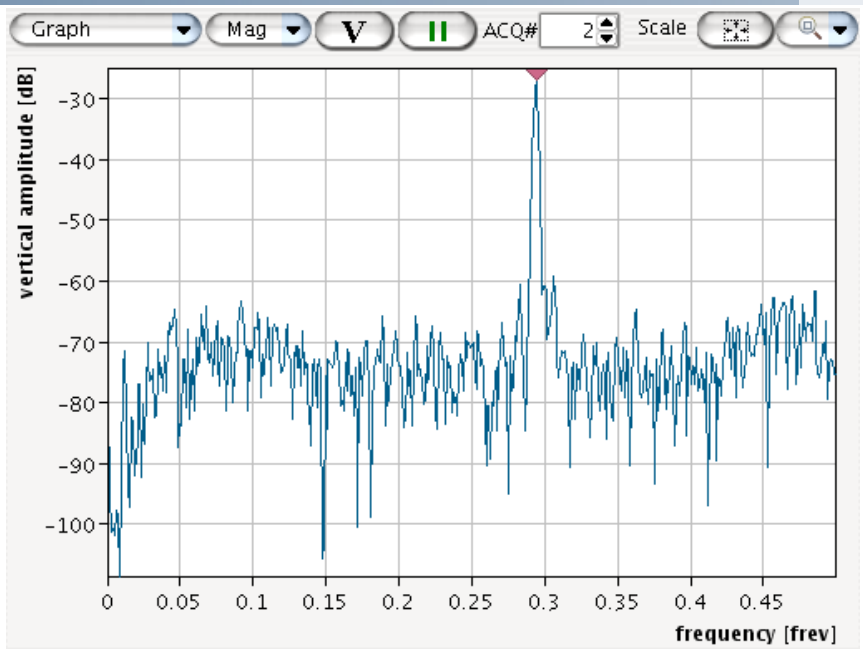
- exMode: <NOEXCITATION, CHIRP, KICK>
  - chooses the excitation source
  - default: 'NOEXCITATION'
    - Lots of diagnostic possibilities (tune, chromaticitiy, RF problems, instabilities ....). However: no guarantee that the tune is always visible without excitation
- enableExcitationH, enableExcitationV: <true/false>
  - default: 'false' (fail-safe)
  - N.B. <true, true> → forces alternating of chirp in H/V plane

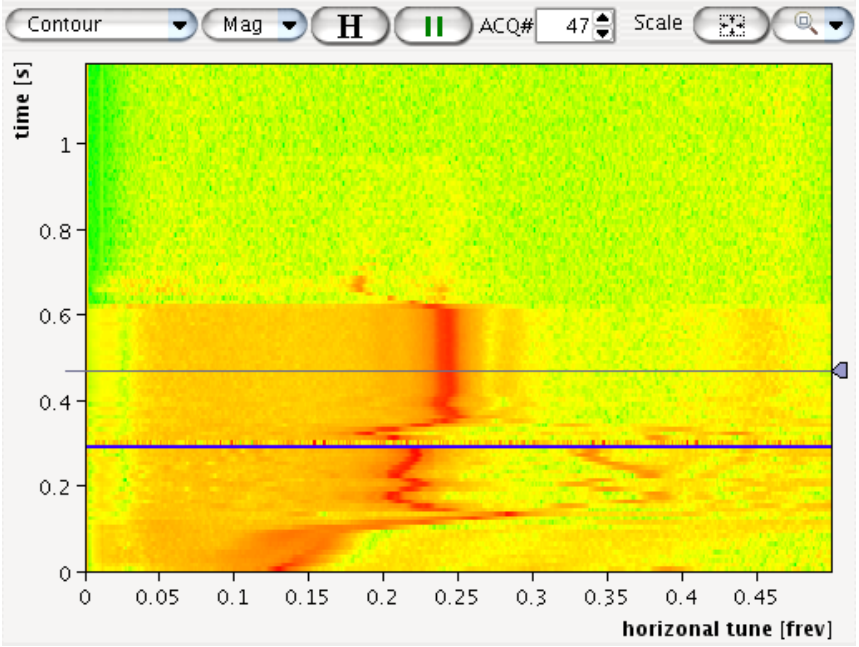
Chirp related settings:

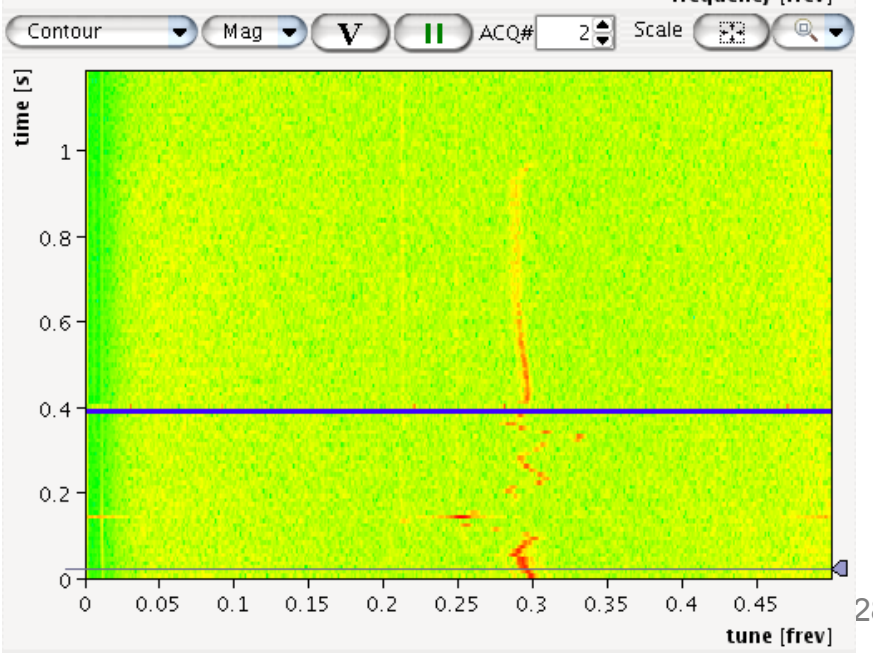
- exAmplitudeH, exAmplitudeV: <float> [defined by chirp/kick exciter]
  - N.B. hardware (kicker) to be modified for 2008 startup
- chirpStartFreqH, chirpStopFreqH, chirpStartFreqV, chirpStopFreqV: <float>
  - start/stop frequency ([f_{rev}]) of chirp excitation (usually:]0.0, 0.5])

DAB based BBQ acquisition: PS examples
PS-MD2, H/V kicks

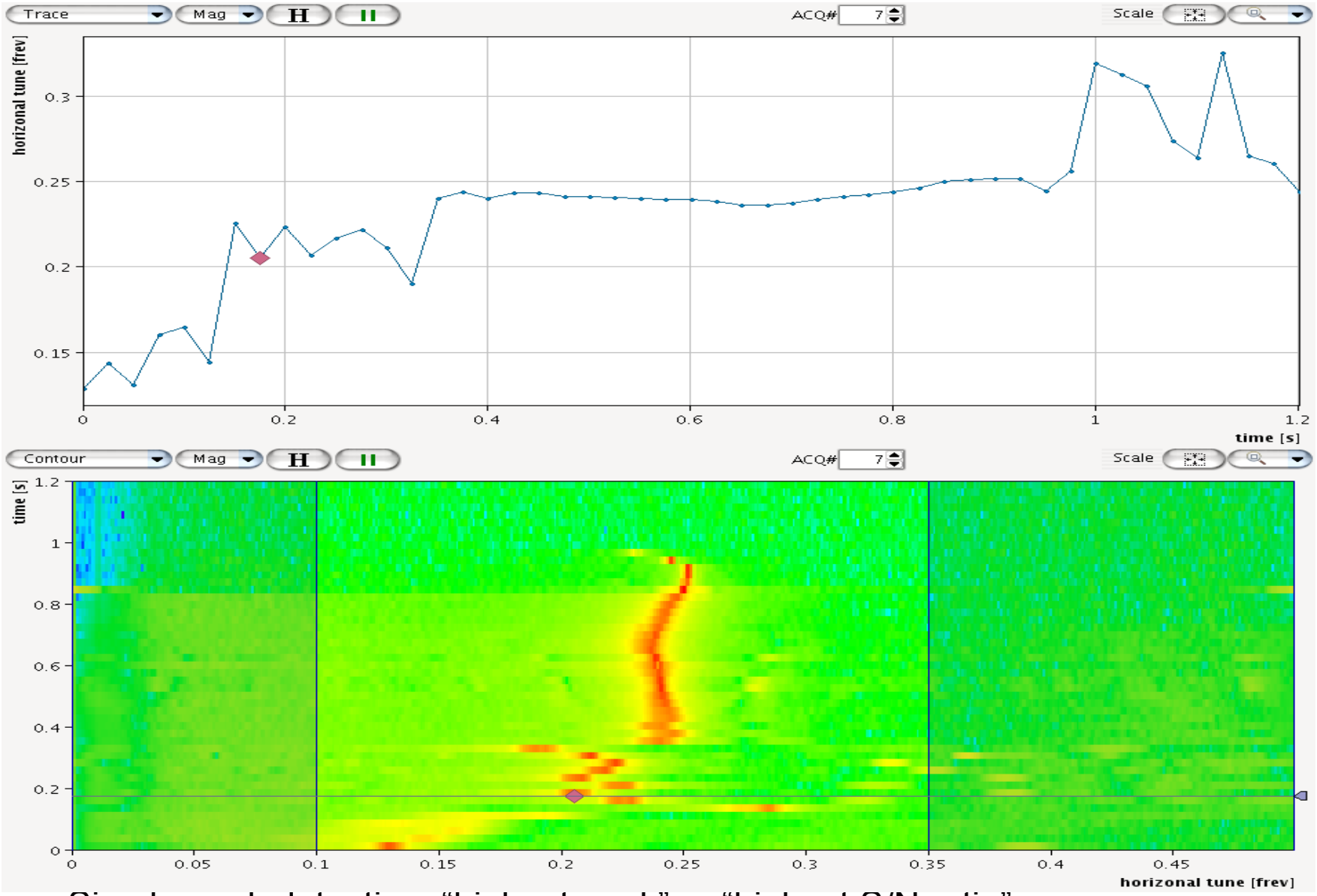






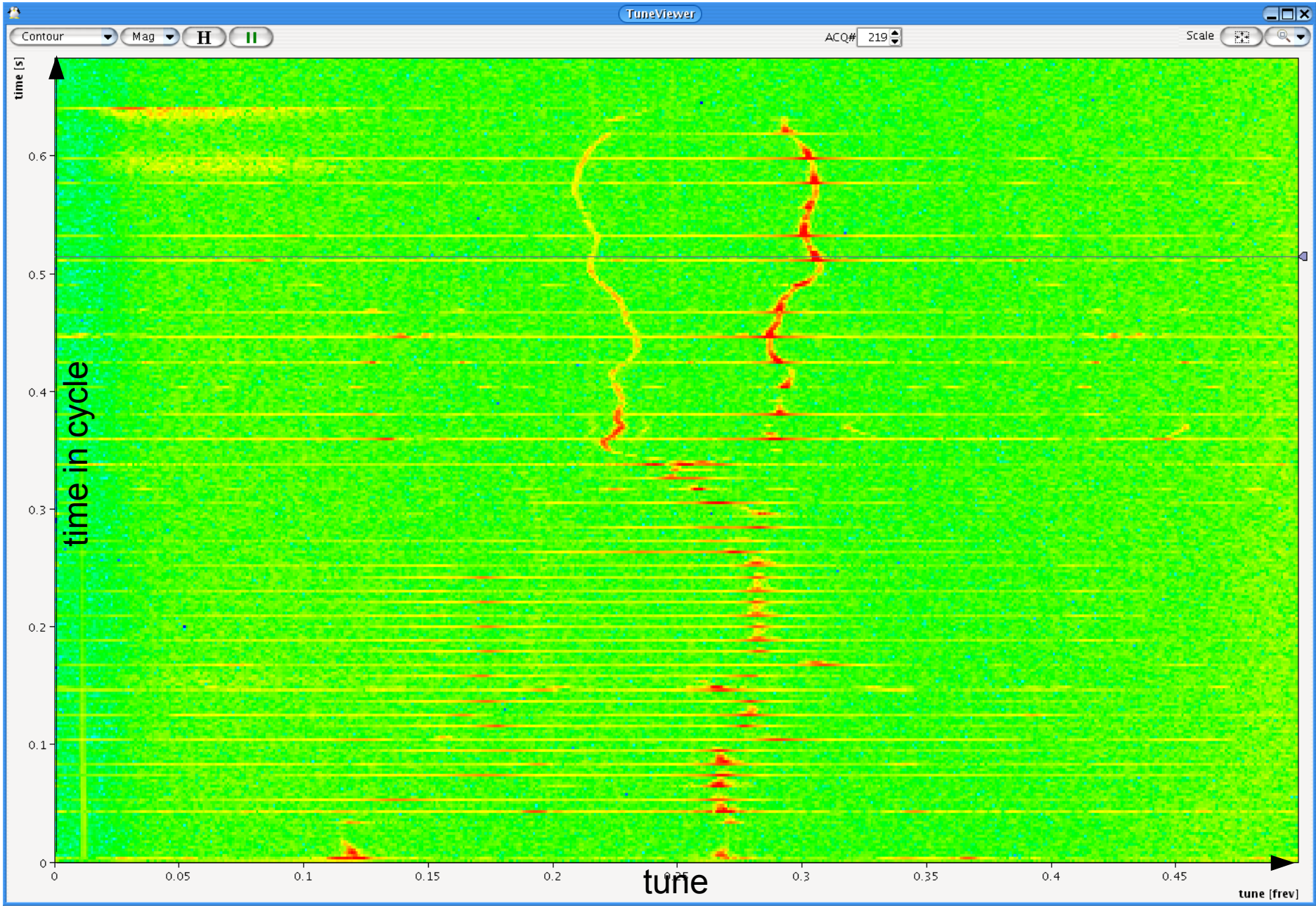


DAB based BBQ acquisition: PS examples SFTPRO, H kicks only,

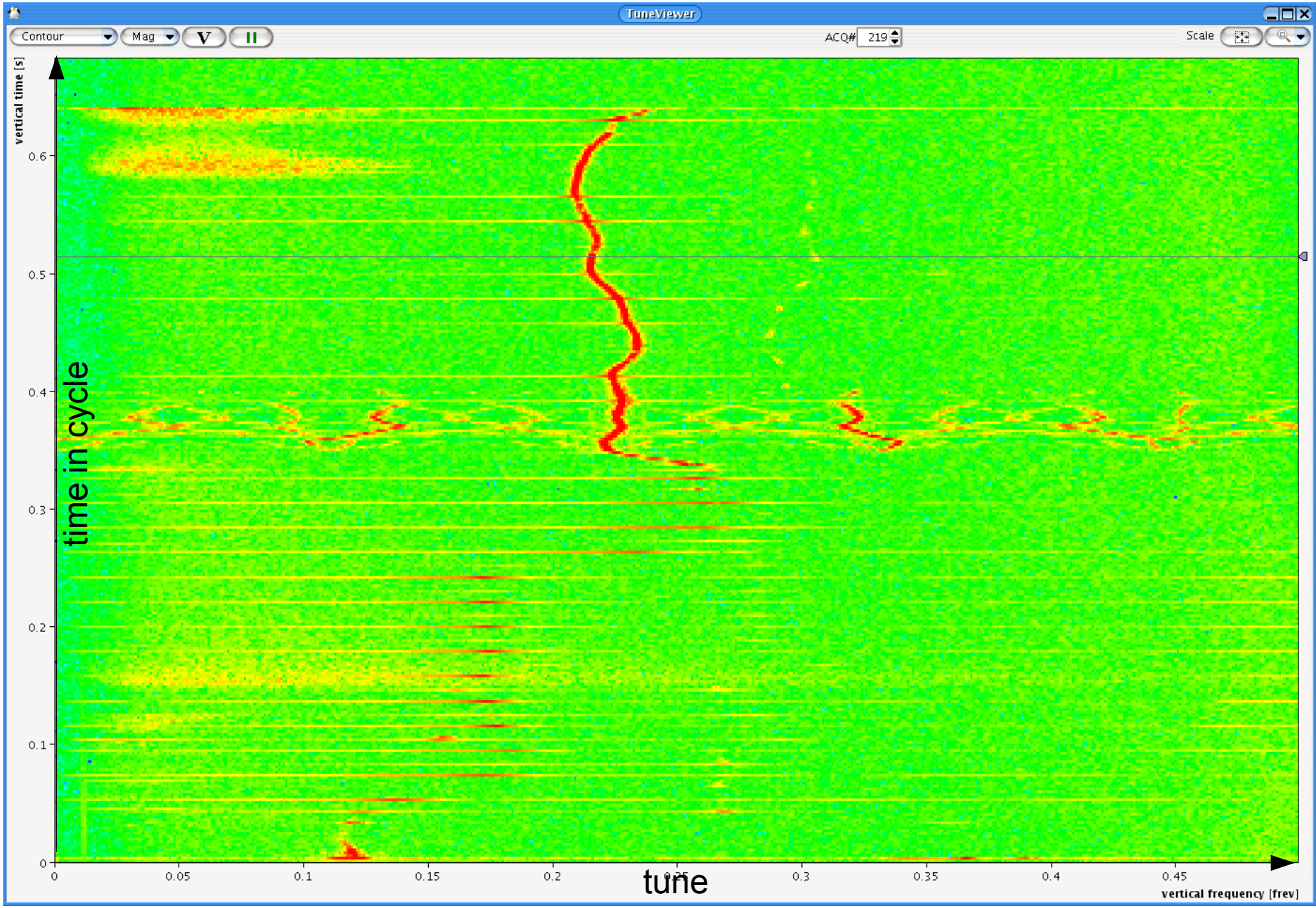


- Simple peak detection: “highest peak” or “highest S/N ratio”

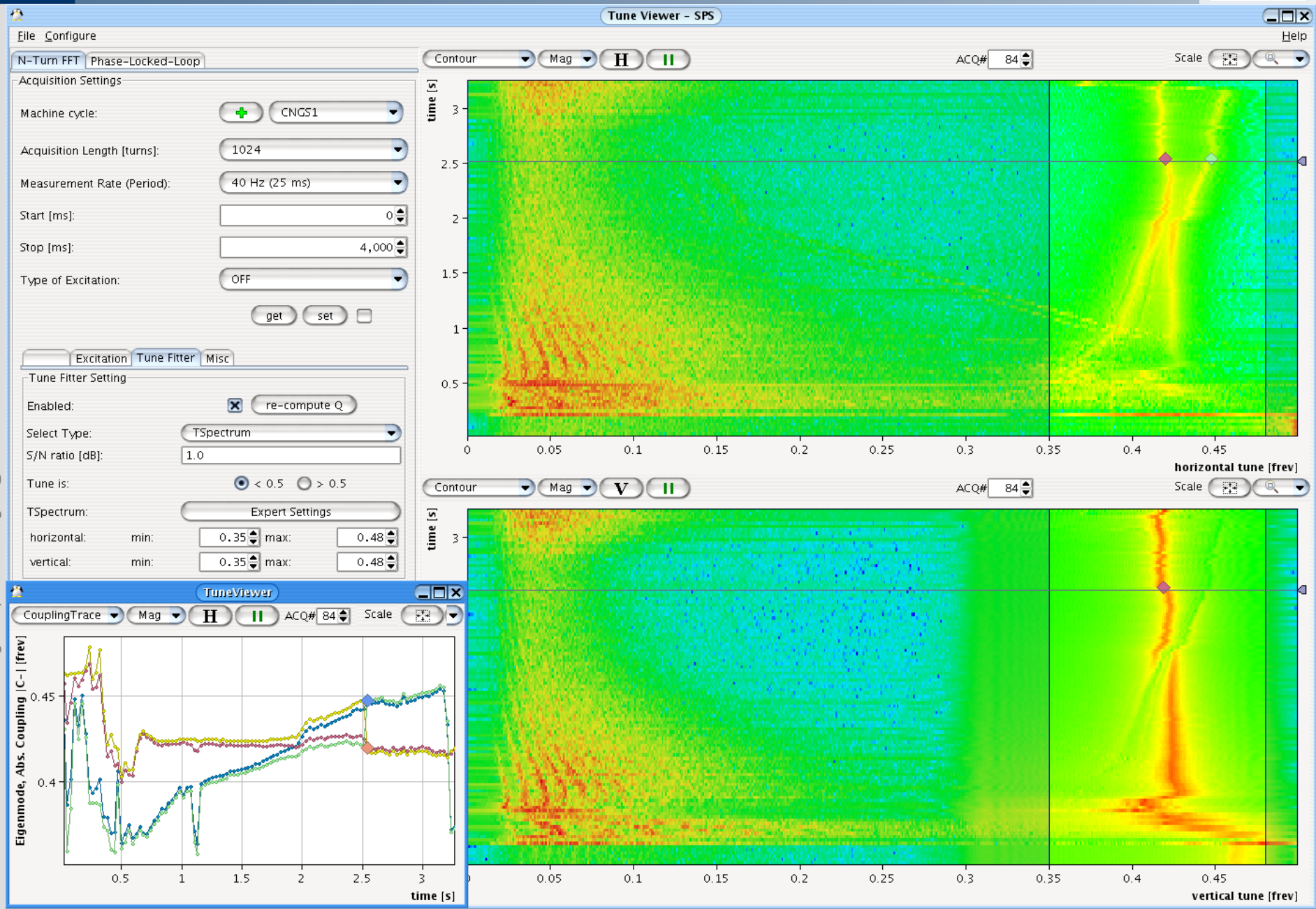
PS-SFTPRO cycle, back-to-back acquisition, H/V kicks every 5 ms, horizontal plane, “back-to-back”



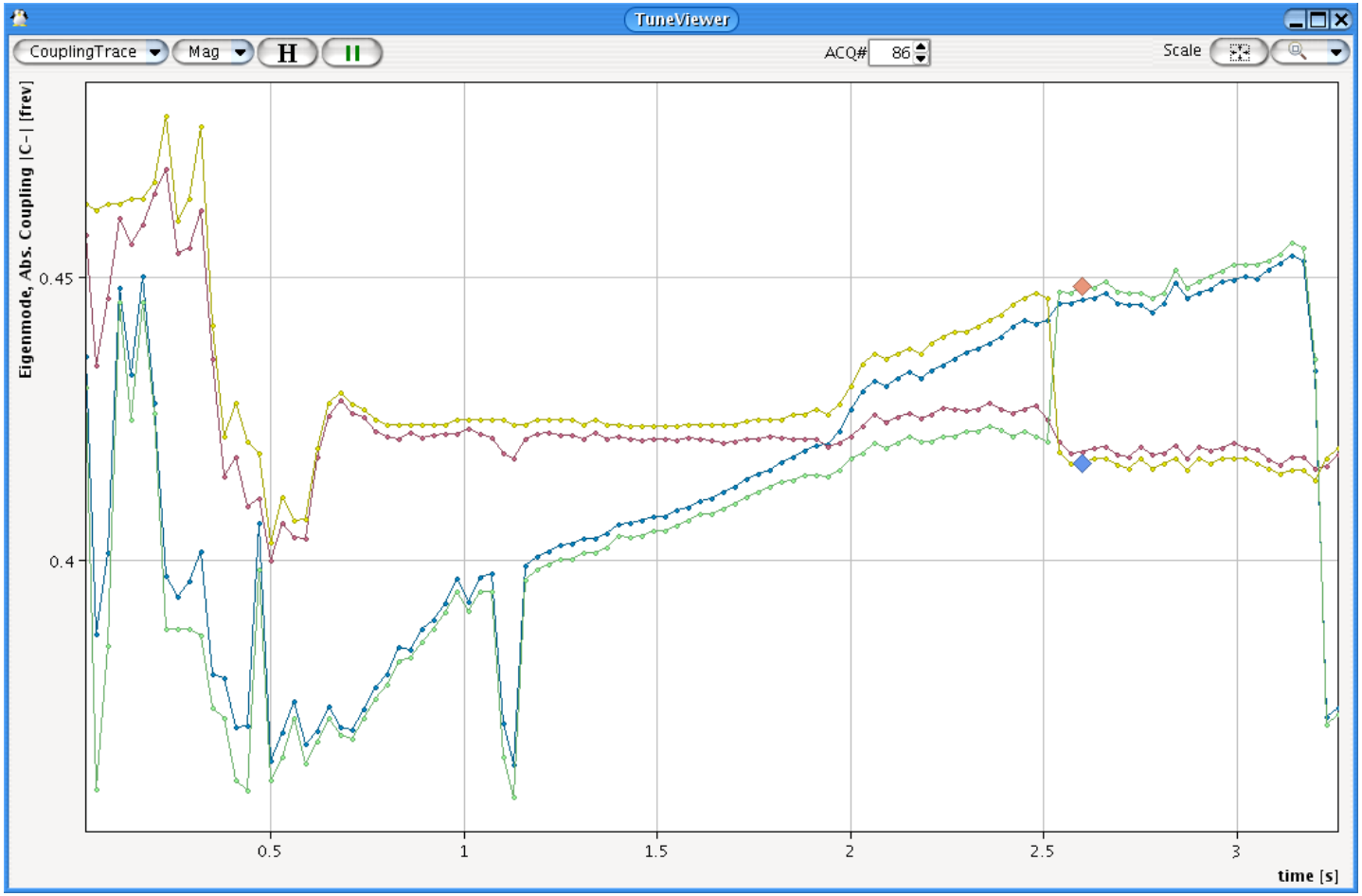
PS-SFTPRO cycle, back-to-back acquisition, H/V kicks every 5 ms, vertical plane



Betatron-Coupling: SFTPRO1 I/II



Betatron-Coupling: SFTPRO1 II/II after reconstruction



- Tracking of eigen-modes:

PS-SFTPRO cycle
Betatron-Coupling after Injection