Top-Level Base-Band-Tune (BBQ) Measurement Functionalities as seen from the OP GUI

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Outline

- FESA interface properties:
  - 'Settings'
  - 'Acquisition' ('Measurements')
- Expected performance:
  - analogue BBQ front-end
  - digital acquisition board (DAB) and FESA server
- Why "operational knowledge" is required for a robust tune reconstruction
  - other-than-tune peaks, betatron coupling, chromaticity,
    fast longitudinal bunch operations/length variations, ...

FESA Interface for the BBQ DAB

- As seen from operation:
  - FESA server names: PSB: '*BR.BQSB*', PS: '*PR.BQSB'*, SPS: *'SPSBQSB'*
  - Main properties:
    - 'Settings': basic acquisition settings
    - 'Acquisition': the results
    - 'Measurement': as 'Acquisition' but on a sample-by-sample basis (used in case of coasting beam)
- Naming: 'one measurement' = 'one FFT spectra based on <nbofAcq> turns'
  - after post-processing: → one Q_1, Q_2, Q_x, Q_y, $|C^-|$ measurement
- Further details accessible through the FESA navigator:
  - http://wwwpsco.cern.ch/private/java/fesa/CURRENT_RELEASE/FNT.jnlp
  - or 'Tune Viewer' example application (all CERN accelerators): http://slwww/~pcrops/releaseinfo/pcropsdist/sps/sps-tuneviewer/PRO/

'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'

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

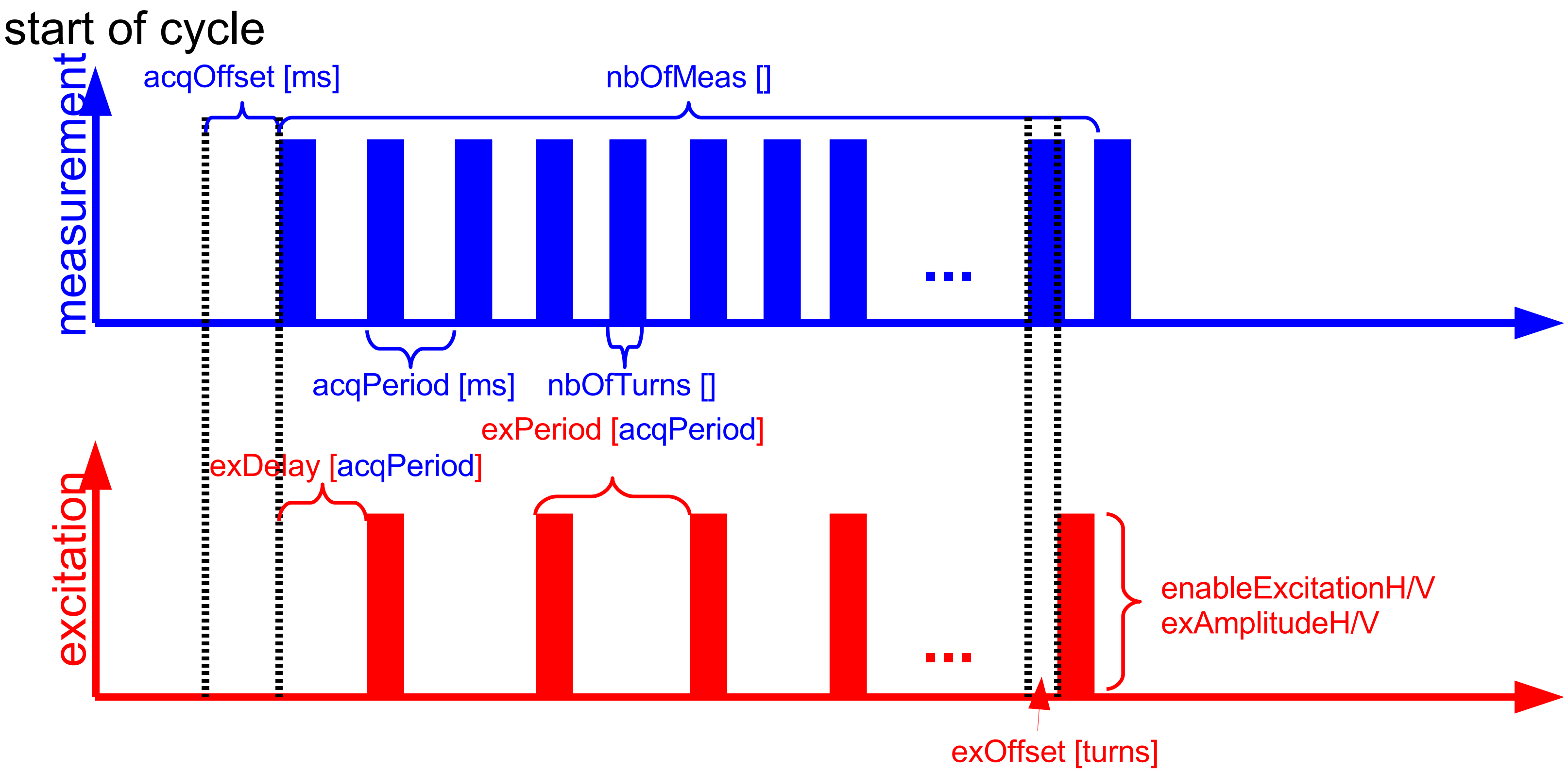
General excitation settings:

- 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:

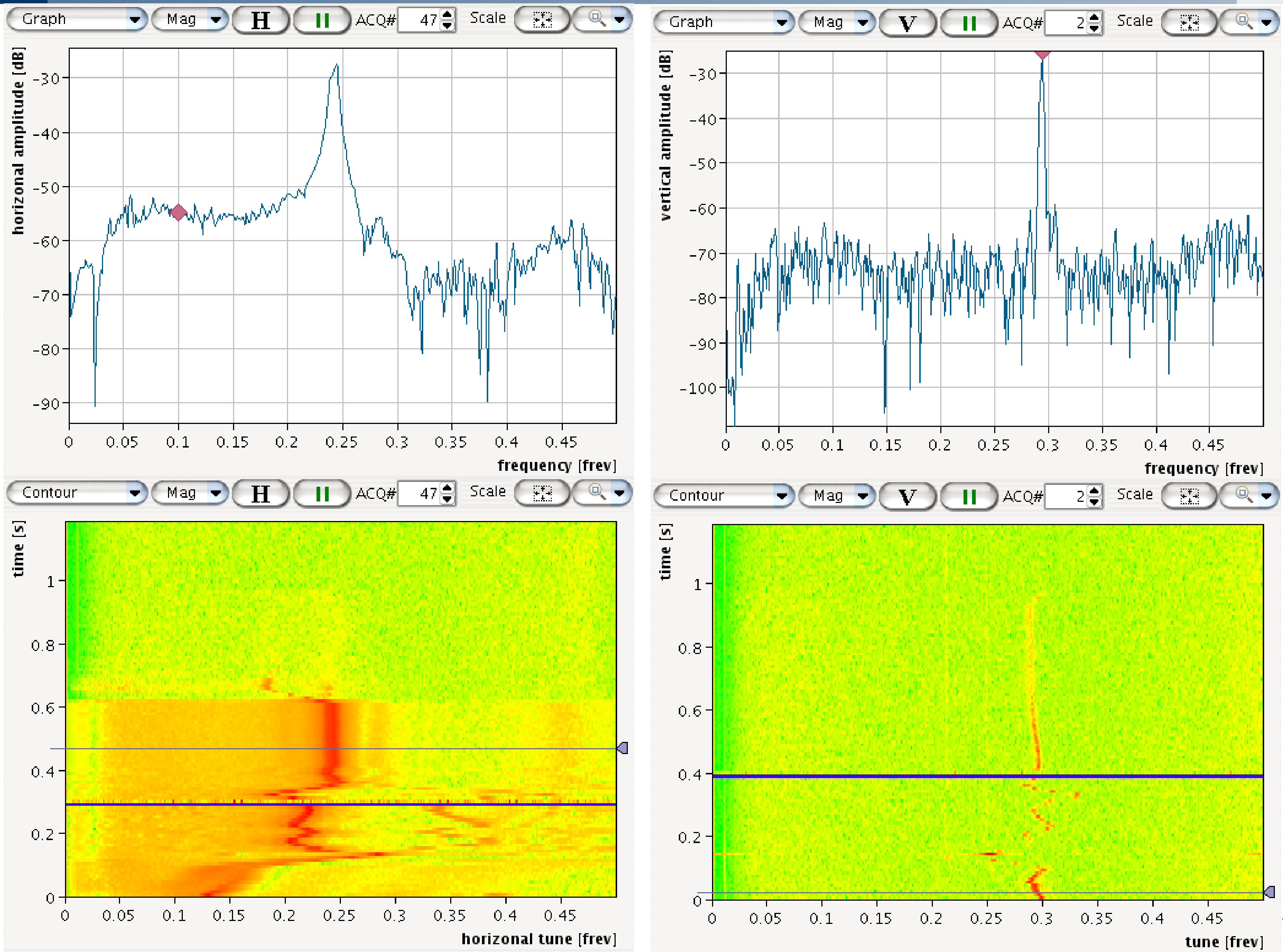
- exAmplitudeH, exAmplitudeV: <float> [defined by chirp/kick exciter]
  - N.B. hardware (kicker) to be modified for 2008 startup
- chirpStartFreqH, chirpStopFreqH, chirpStartFreqV, chirpStopFreqV: <float>
  - start/stop frequency ([f_{rev}]) of chirp excitation (usually:]0.0, 0.5])

'Settings' Property VI/VI - Summary

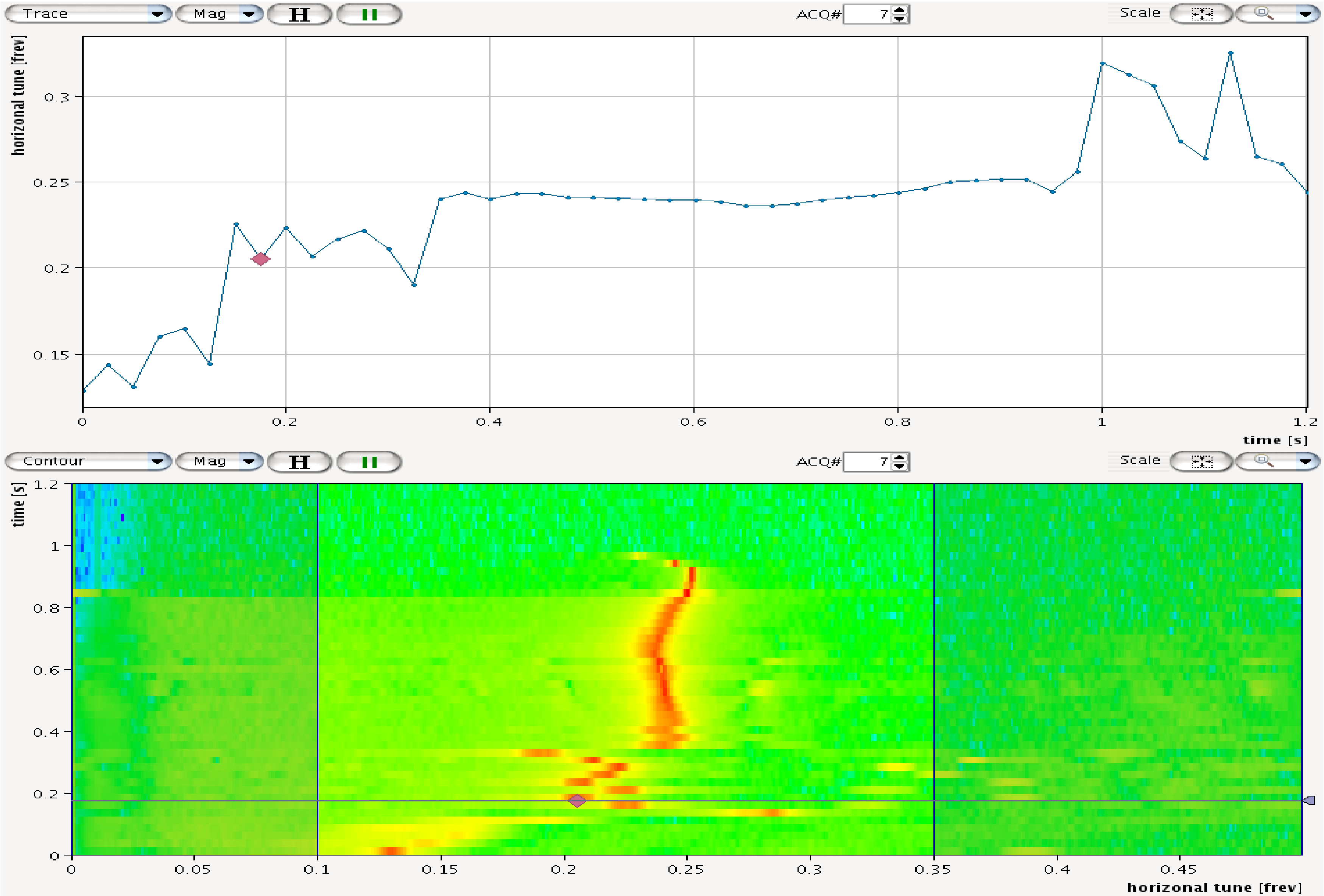


- Common measurement scenario:
  - measure (acqState=on) from injection (acqOffset=0) every 10 ms (acqPeriod=10) till 900 ms (nbOfMeas=floor(900/acqPeriod)) while kicking the beam every measurement (exDelay=0) in the vertical plane (exMode=KICK, enableExcitationH = true, enableExcitationV = false)
-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

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



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



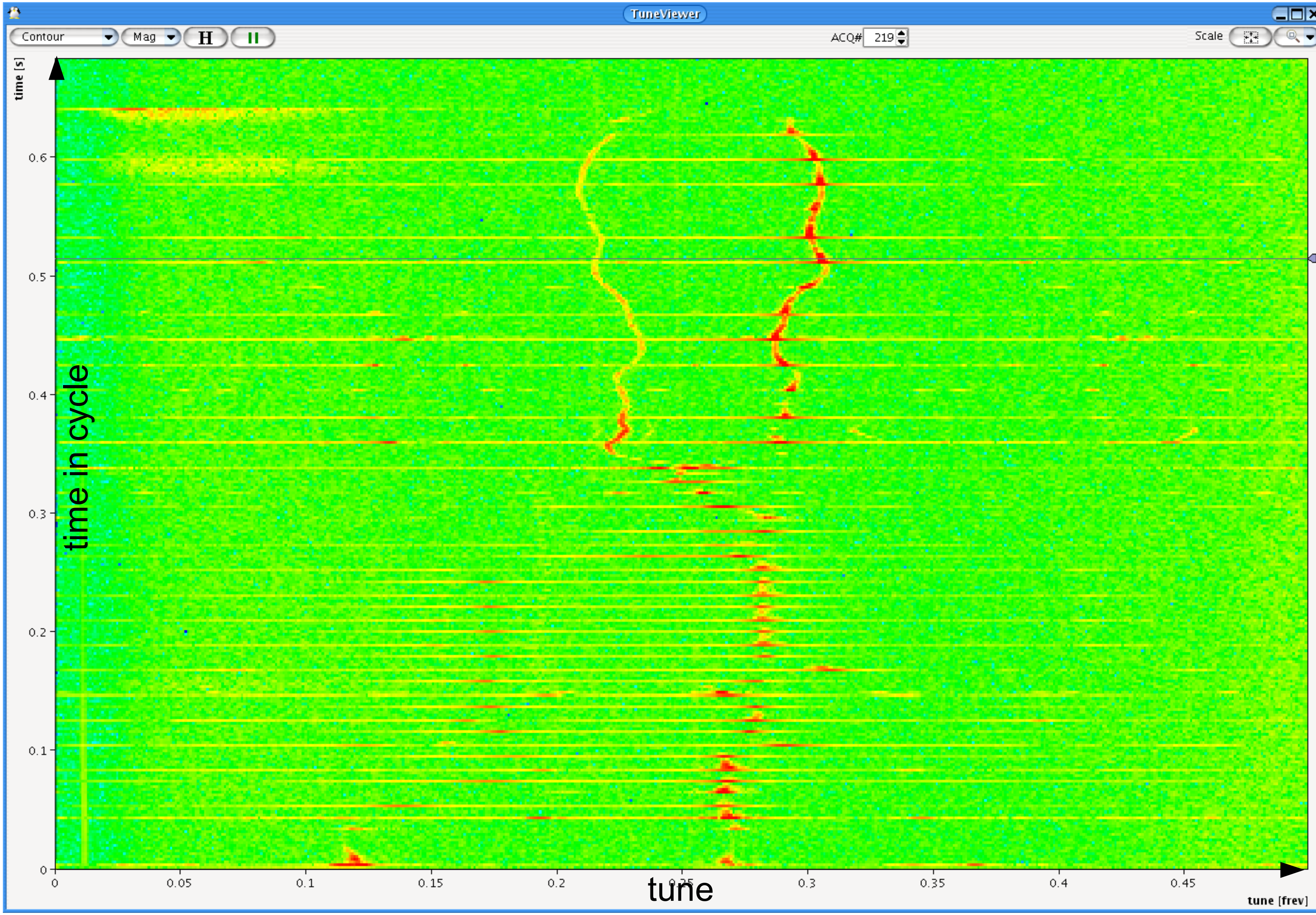
- Simple peak detection: “highest peak” or “highest S/N ratio”

Guaranteed Performance and Robust Tune Detection or: ... "not all that glitters is gold"

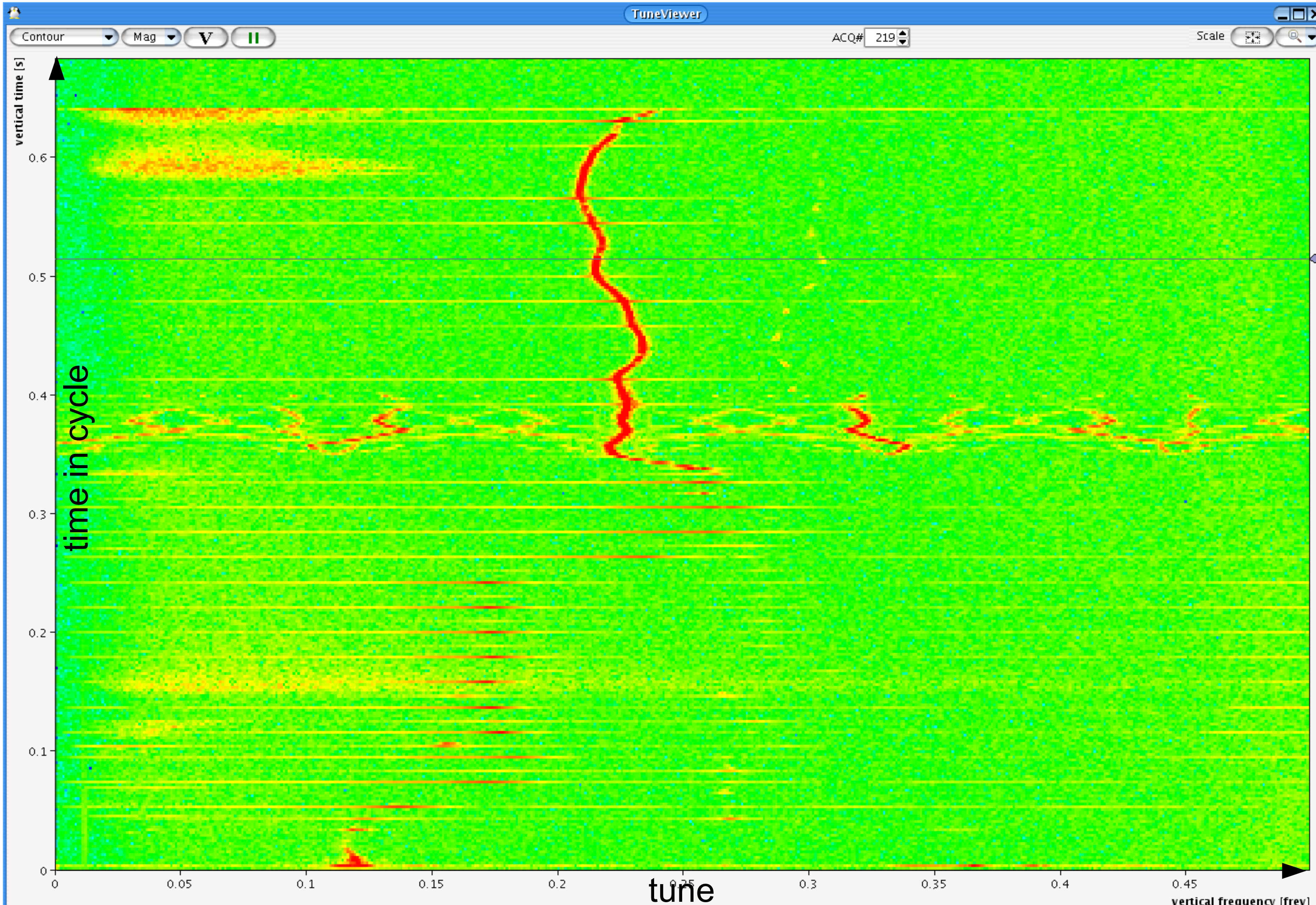
- DAB/FESA provides for the PS/PSB:
  - transverse FFT spectra based on 1024 turns every 5 ms for one nominal CPS cycle (1.2 seconds)
    - both planes! (old system: either H/V@5ms or H&V@10ms)
    - memory bandwidth limit: 'acqPeriod'·'nbOfTurs' = const.)
  - some cycle do not require excitation. However, there is no guarantee for that (monitor only)

- "Highest peak" or "highest S/N ratio" does not guarantee that only the tunes are detected, robust detection depends on:
  - operational tune range and working point ($Q < 0.5 \vee Q > 0.5$)
  - expected tune drifts
  - whether cycle requires full or no betatron-coupling
  - knowledge of RF operation
  - a rough estimate of the machine chromaticity (→ to steer excitation strength)

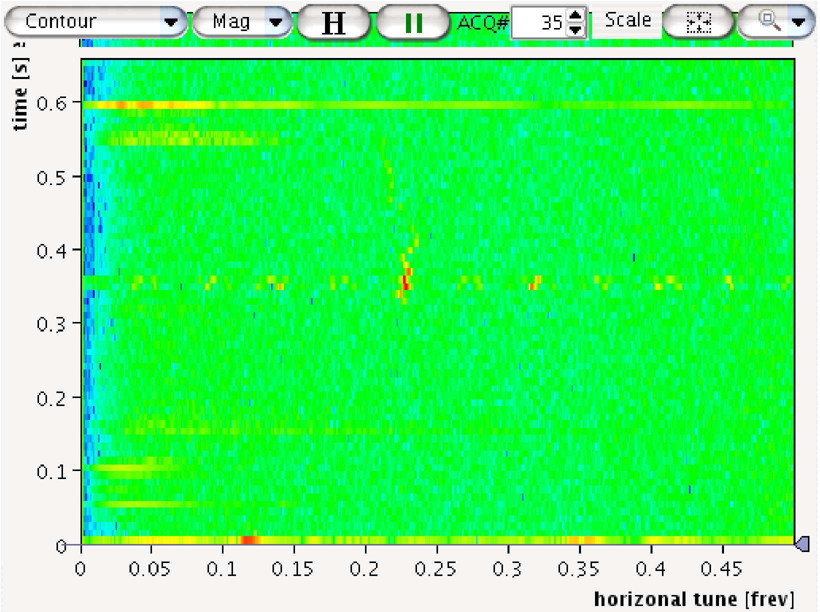
PS-SFTPRO cycle, back-to-back acquisition, H/V kicks every 5 ms, horizontal plane, “back-to-back”

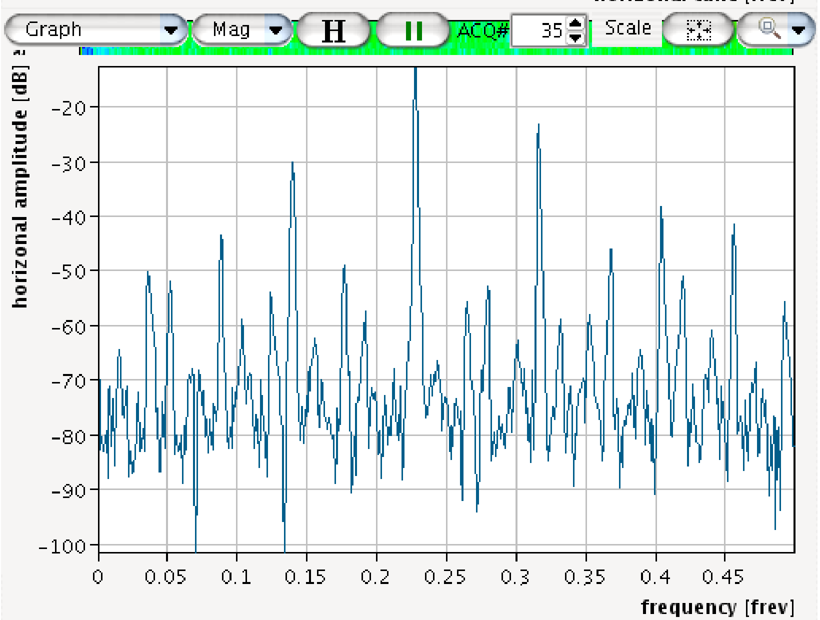


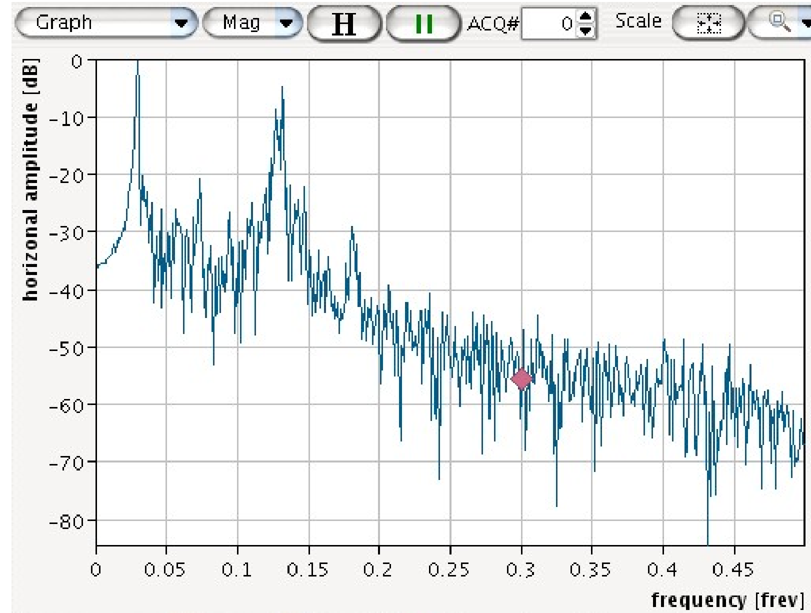
PS-SFTPRO cycle, back-to-back acquisition, H/V kicks every 5 ms, vertical plane

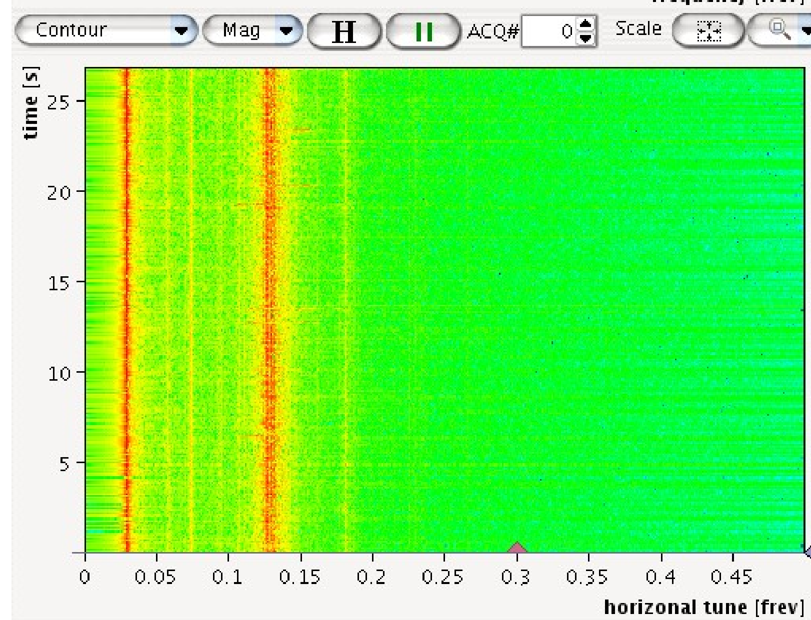


PS-SFTPRO(1) cycle

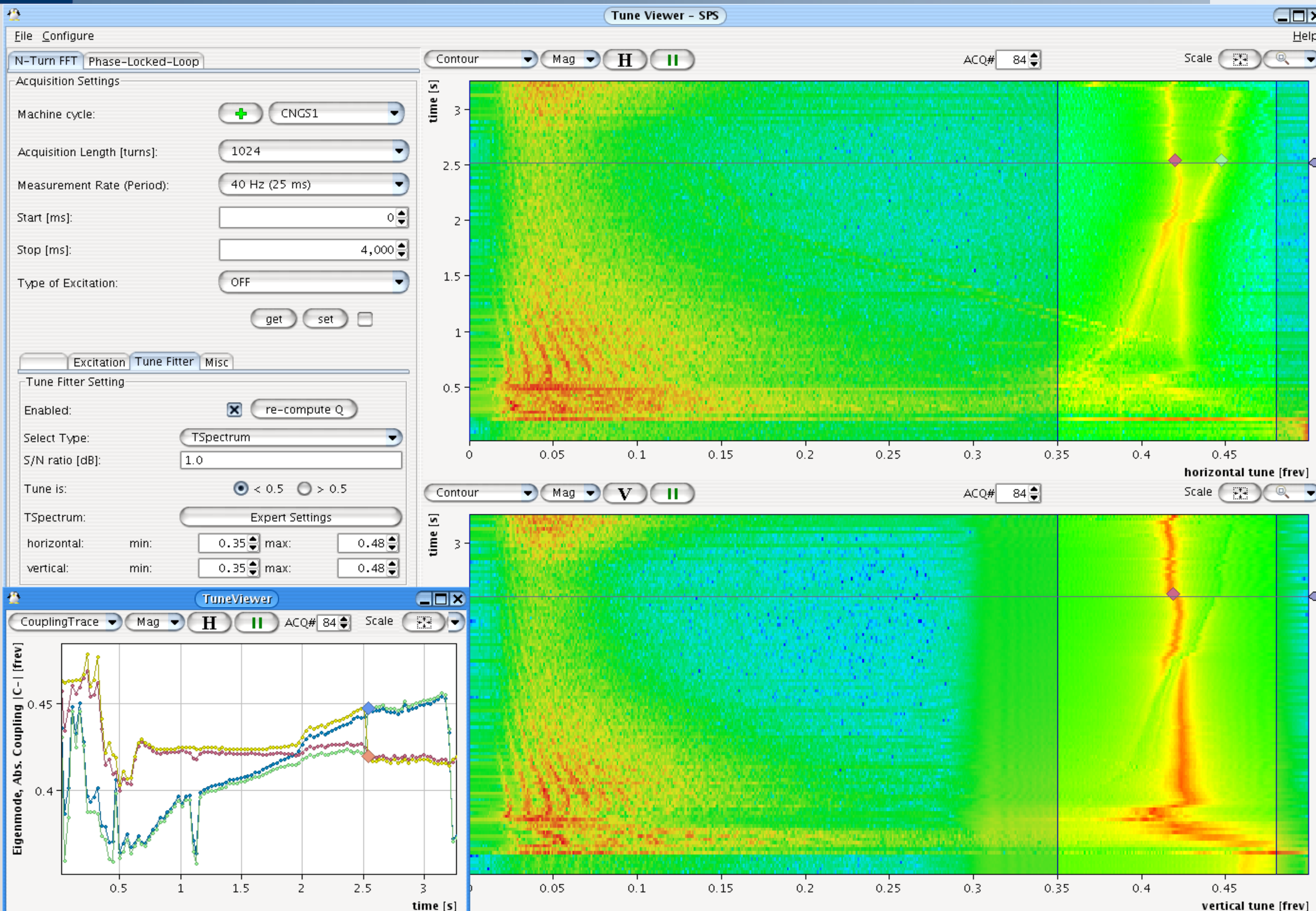




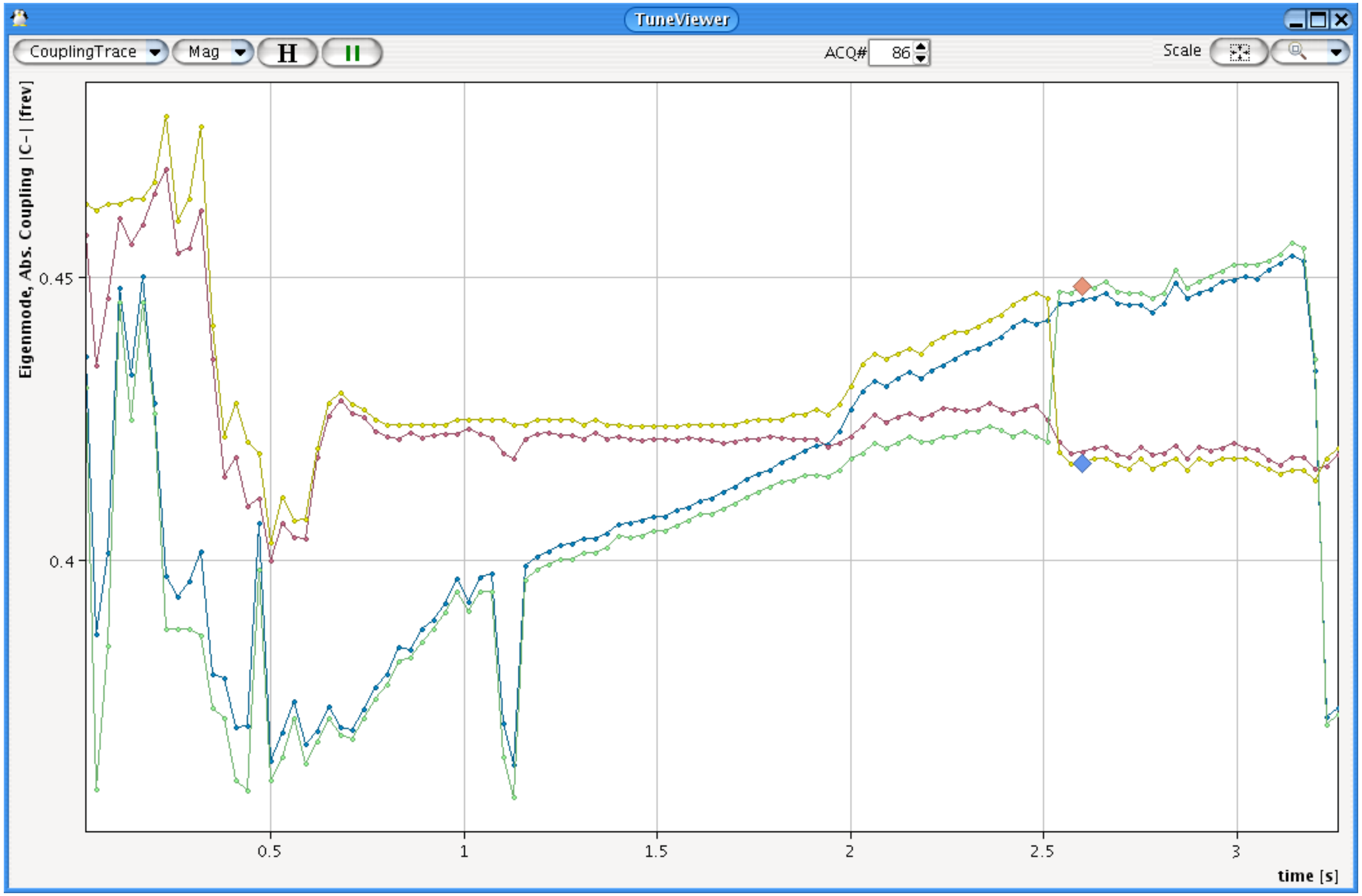




Betatron-Coupling: SFTPRO1 I/II

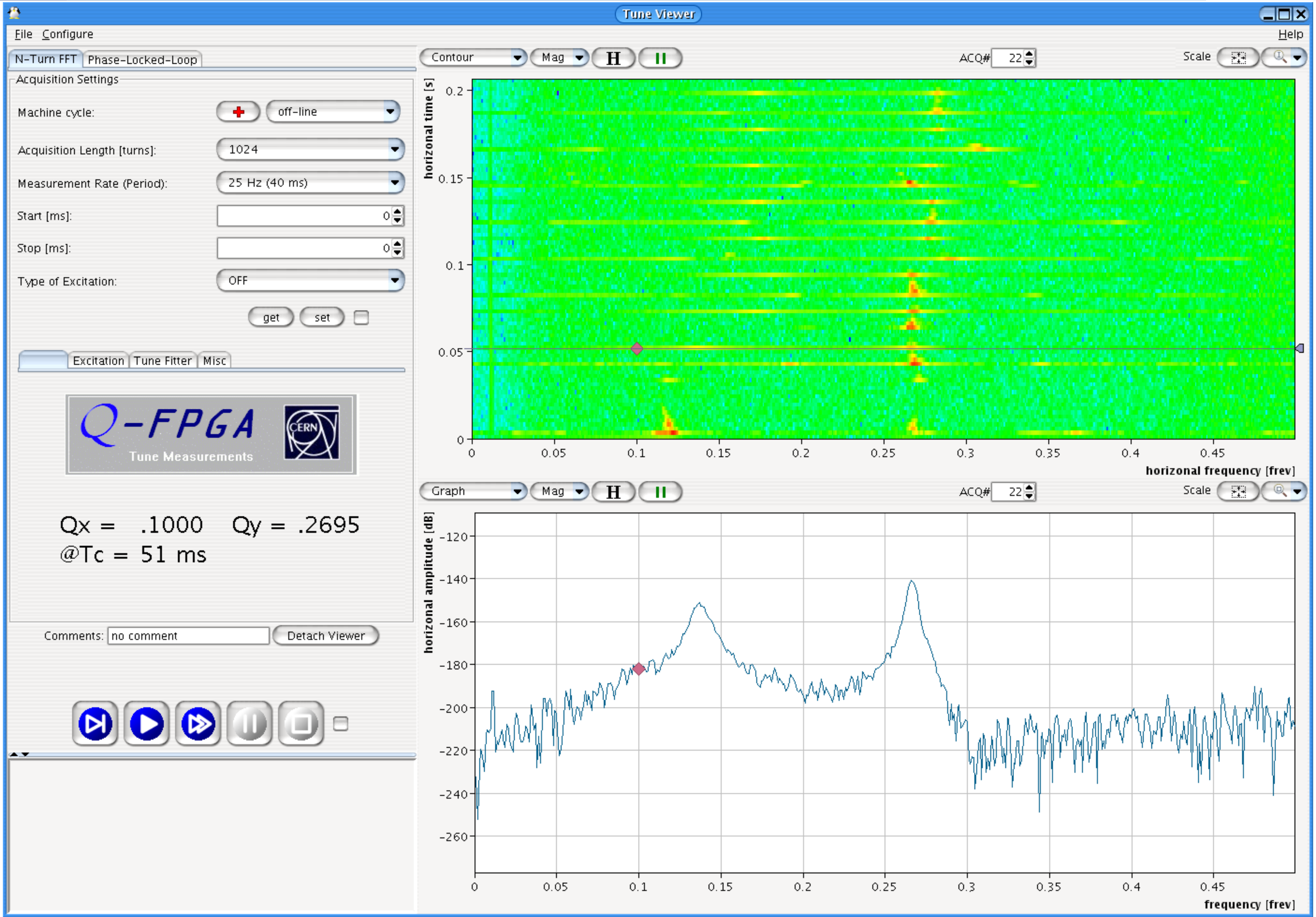


Betatron-Coupling: SFTPRO1 II/II after reconstruction



- Tracking of eigen-modes:
  -

PS-SFTPRO cycle
Betatron-Coupling after Injection



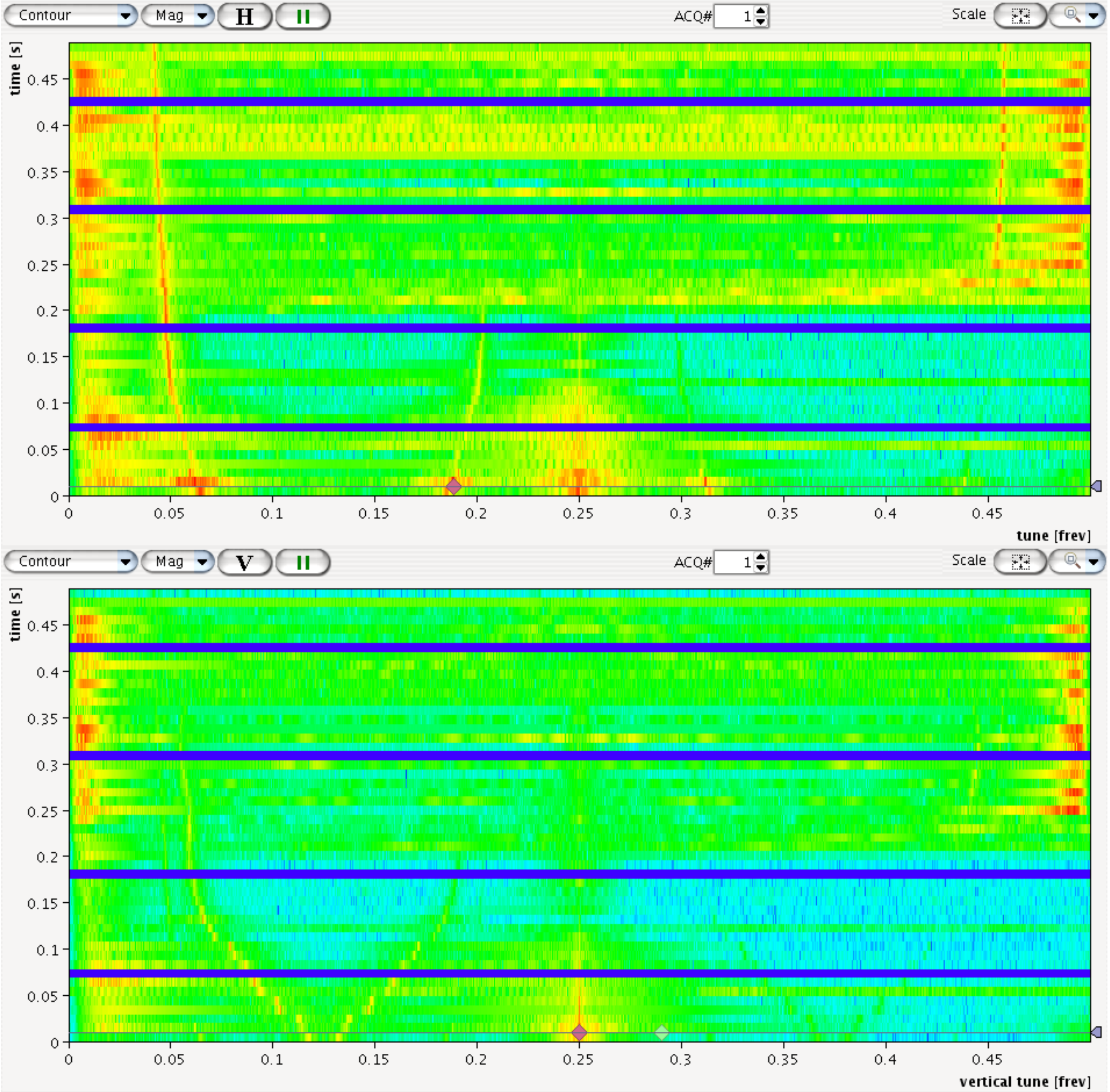
Preliminary Conclusions

- Our target:
  - same (/similar) low-level front-end electronic, the same digital acquisition electronic for all CERN accelerator
  - > 80% of common DAB/FESA functionality
    - the 'missing 20%' likely used during MDs (all CERN) and LHC

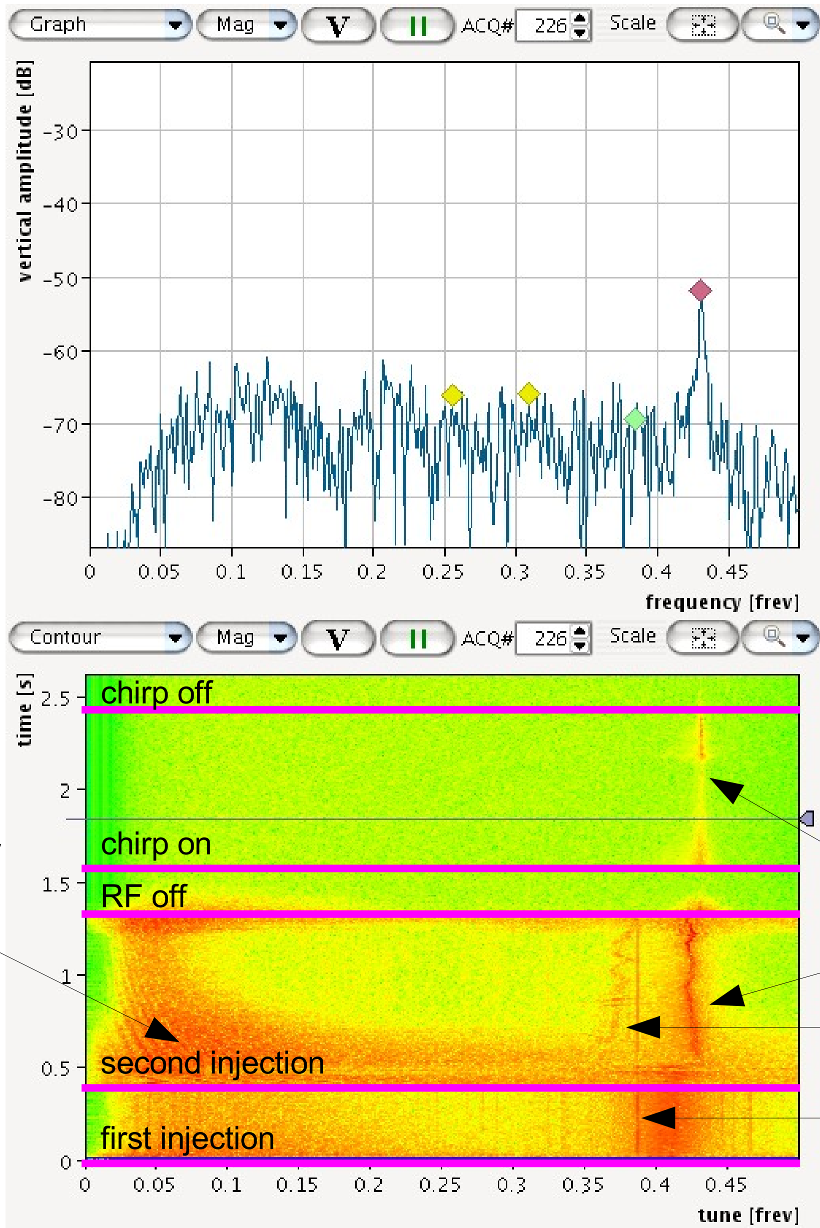
- The robust tune reconstruction for all possible operational machine and beam condition requires estimates and previous knowledge on
  - operational tune range and working point ($Q < 0.5$ v $Q > 0.5$)
  - expected tune drifts
  - whether cycle requires full or no betatron-coupling
  - a rough estimate of the machine chromaticity (→ to steer excitation strength)

additional supporting slides

PSB - SFTPRO
four-times oversamples ('tune =1.0' = 4_{frev})



Tune Measurement with slowly-extracted un-bunched Beam in the SPS



RF + damper noise

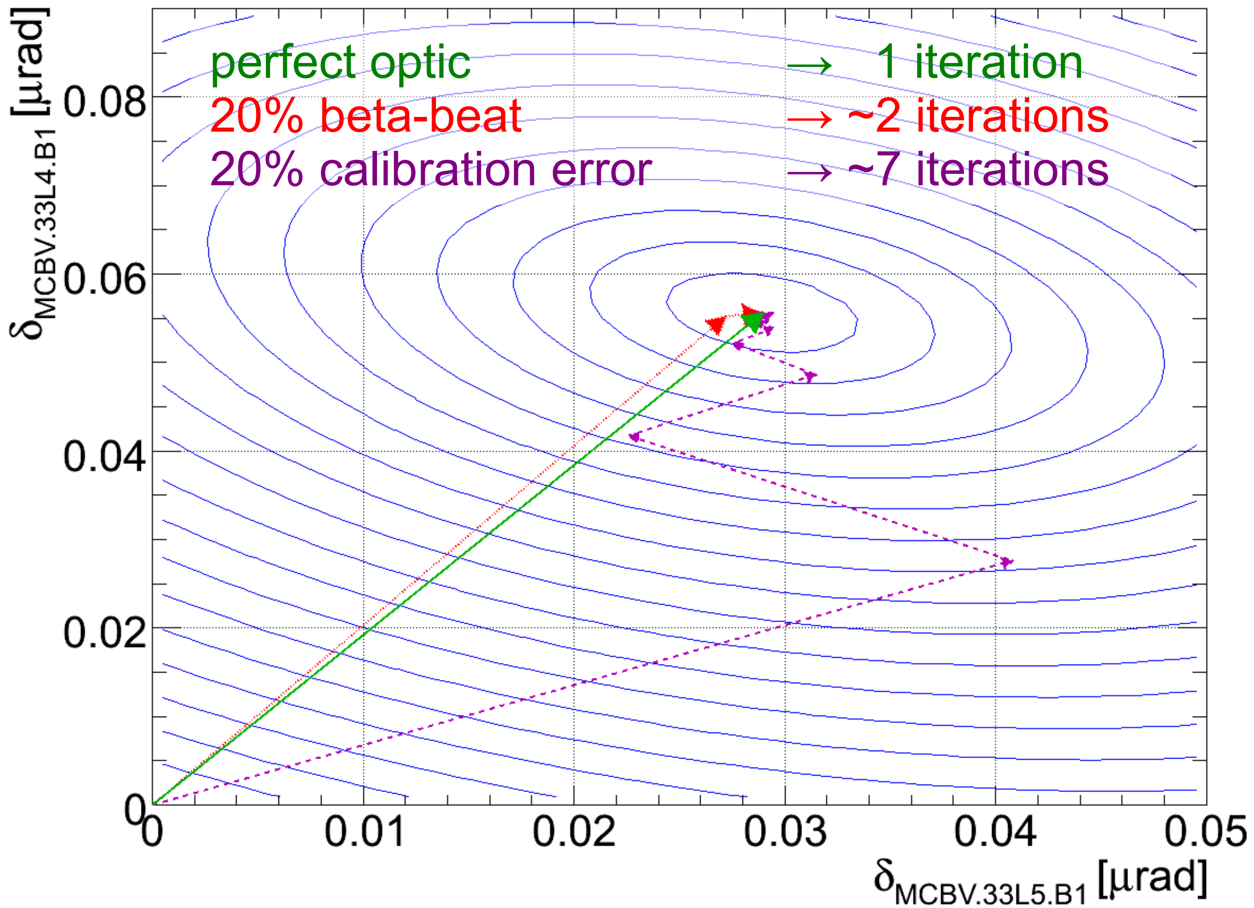
vertical tune

horizontal tune

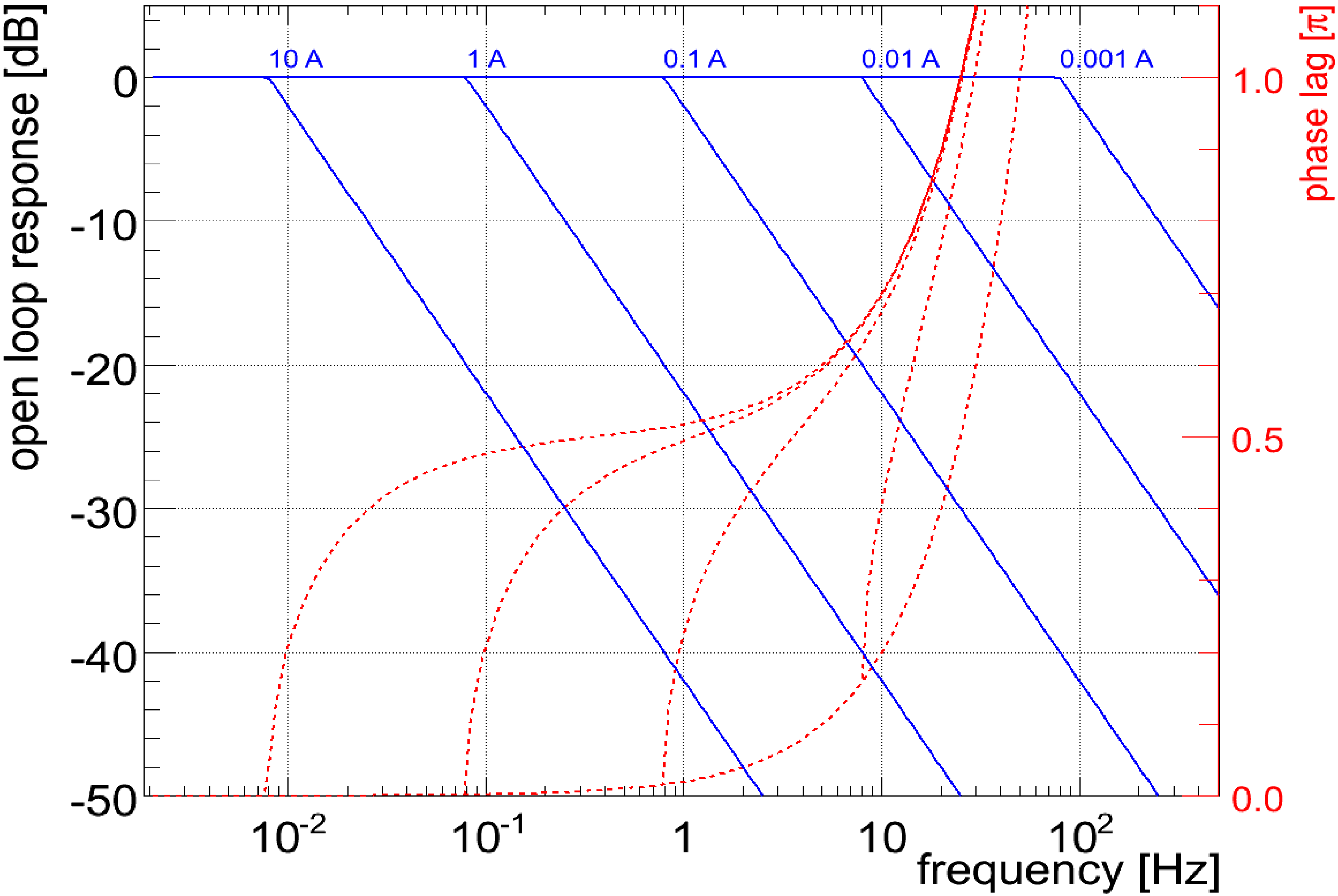
damper noise

Q/ξ Beam Response Matrix Uncertainties

- Uncertainties in the beam response matrix reduced the effective control/feedback bandwidth but does not affect the steady-state precision
- E.g. LHC orbit feedback:



Non-linear Slew-rate Limited Exciter Response

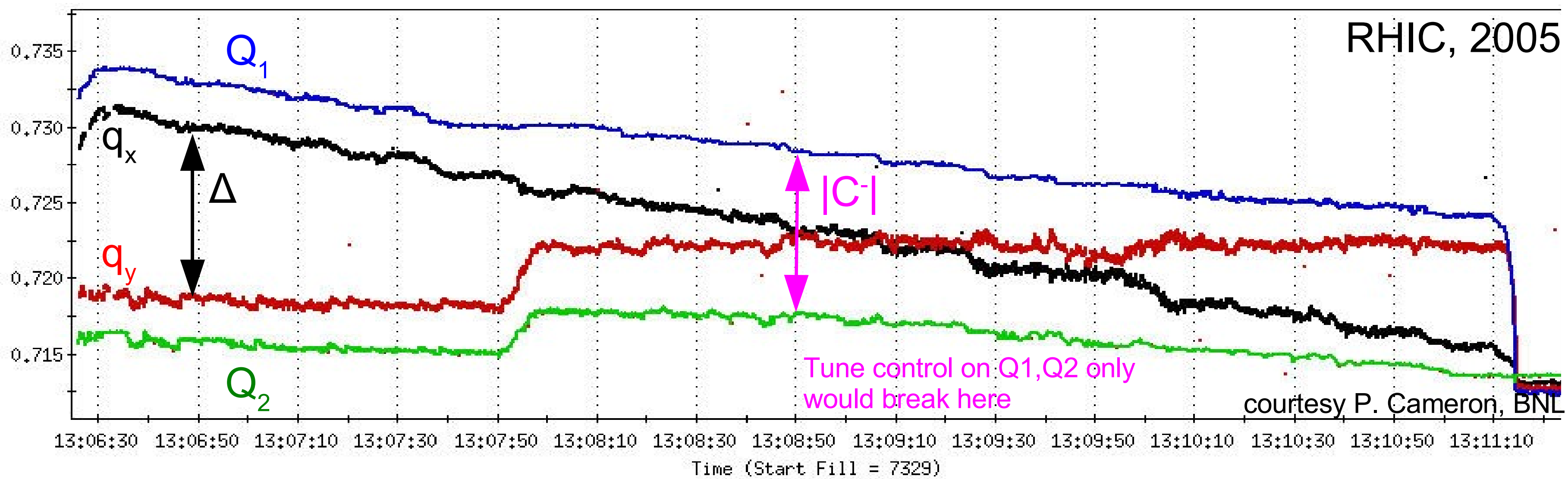


LHC orbit dipole corrector: ΔI=0.01 ↔ Δx ≈ 15 μm @7TeV

Cross-Dependability and Constrains of FB Loops II/III - Coupling I/II

- Strictly speaking: PLL measures eigenmodes (Q_1, Q_2) which in the presence of coupling may be rotated w.r.t. unperturbed tunes (q_x, q_y, $\Delta = |q_y - q_y|$):

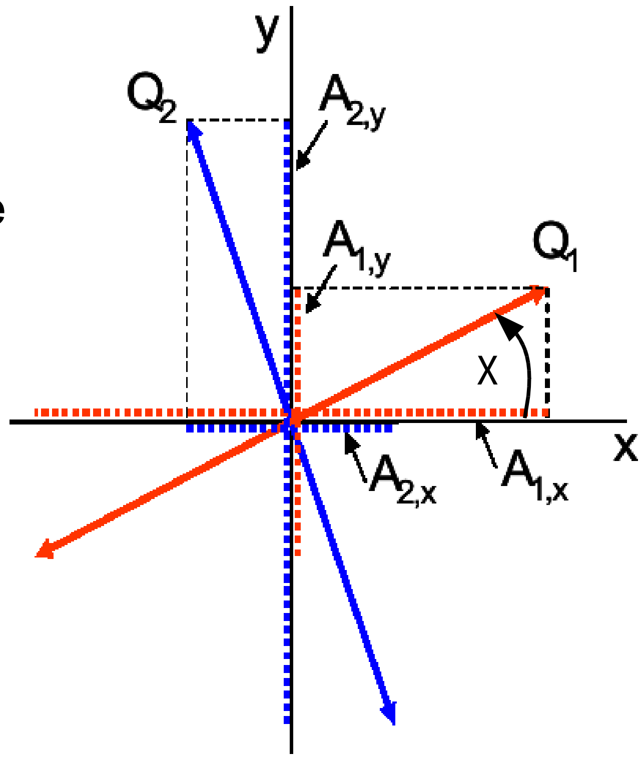
$$Q_{1,2} = \frac{1}{2}\left(q_x + q_y \pm \sqrt{\Delta^2 + \left|C^-\right|^2}\right)$$



- Possible improvement:
  - optimise tune working point (larger tune-split),
  - vertical orbit stabilisation in lattice sextupoles,
  - active compensation and correction of coupling

Cross-Dependability and Constrains of FB Loops II/III - Coupling II/II

- Measure ratio between regular and cross-term:
  - $A_{1,x}$: “horizontal” eigenmode in vertical plane
  - $A_{1,y}$: “horizontal” eigenmode in horizontal plane



$$r_1 = \frac{A_{1,y}}{A_{1,x}} \quad \wedge \quad r_2 = \frac{A_{2,x}}{A_{2,y}}$$

$$\Rightarrow \quad \left|C^-\right| = \left|Q_1 - Q_2\right| \cdot \frac{2\sqrt{r_1 r_2}}{(1 + r_1 r_2)} \quad \wedge \quad \Delta = \left|Q_1 - Q_2\right| \cdot \frac{(1 - r_1 r_2)}{(1 + r_1 r_2)}$$

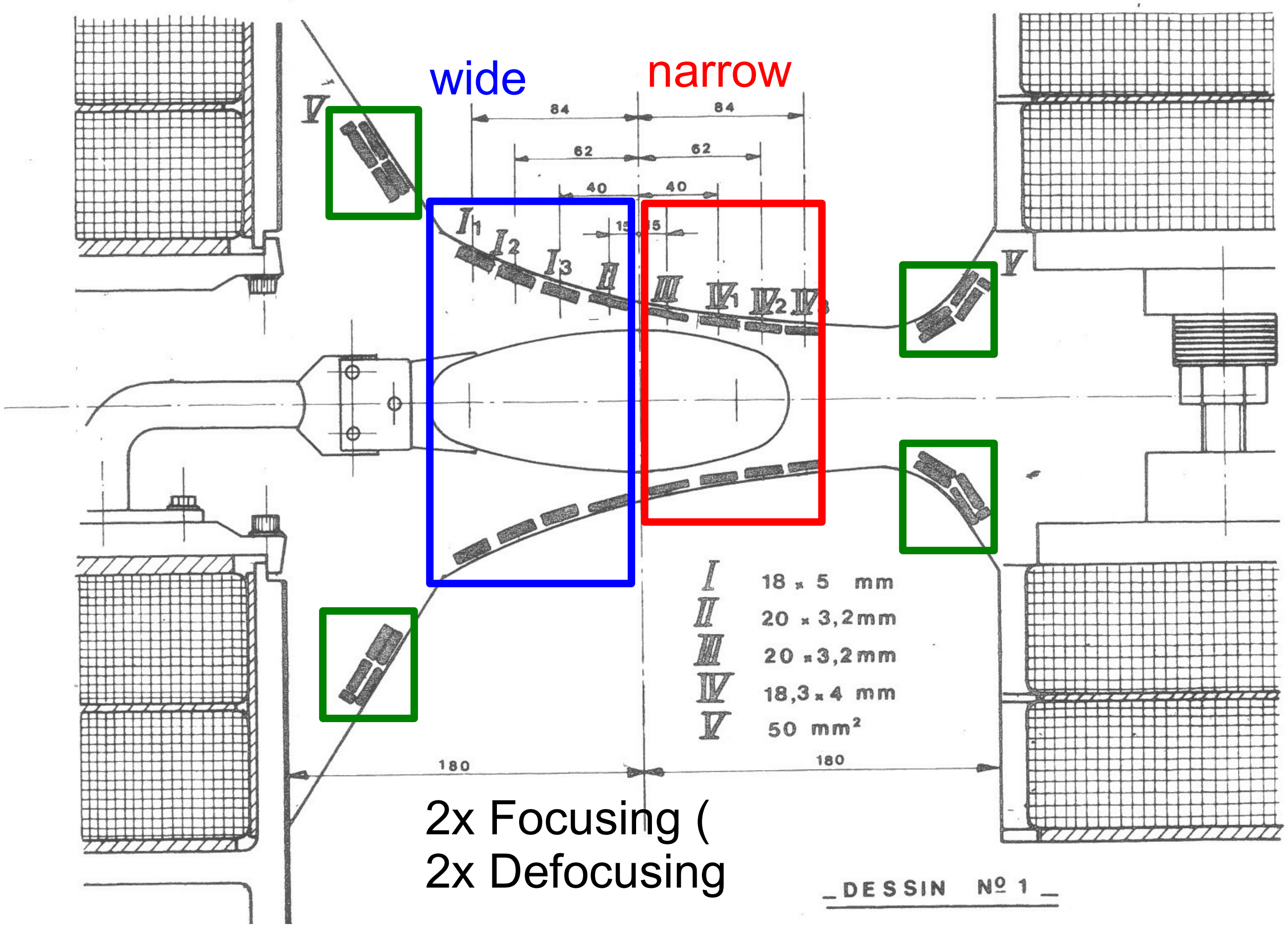
- Decoupled feedback control
  - q_x, q_y → quadrupole circuits strength
  - $|C^-|$, χ → skew-quadrupole circuits strength

implemented and tested at RHIC

R. Jones e.al., “Towards a Robust Phase Locked Loop Tune Feedback System”, DIPAC'05, Lyon, France, 2005
P. Cameron, this workshop's Poster Session

Controllability -
PS' Combined Function Magnets

- Main Dipole's Pole-Face-Winding (PFW) Schematic (before 1978)



- 1x Focus. (FW, FN), 1x Defocus. (DW, DN), 8-loop (~octupole) → 3 circuits

HOT: SPS Q' tracking study
Radial RF modulation $dp/p=1.6\cdot10^{-5}$, set $\xi := 0.05$