LHC transverse Damper
Observations versus expectations

W. Hofle
BE/RF/FB

CERN BE-RF team for ADT

L. Arnaudon, P. Baudrenghien, A. Butterworth, G. Cipolla, F. Dubouchet, D. Glenat,
W. Hofle M. Jaussi, G. Hagmann, F. Killing, *G. Kotzian*, R. Louwerse, J. Molendijk,
E. Montesinos, J. Noirjean, A. Pashnin, V. Rossi, *M. Schokker*, *D. Valuch,* U.Wehrle, F. Weierud

With participation of JINR, Dubna, E. Gorbachev, V. Zhabitsky et al.

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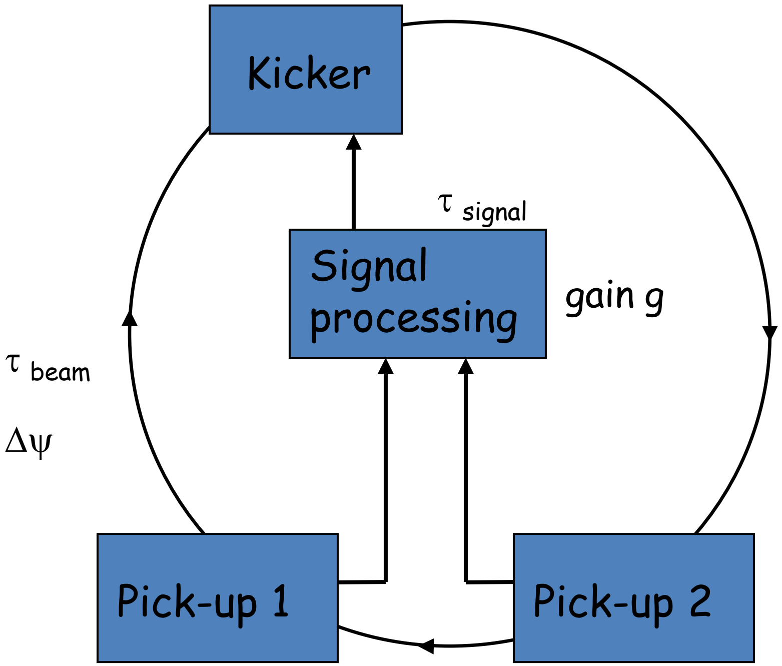
Overview

- what we designed for: brief system overview, expectations and limitations
- commissioning the damper feedback loop, tune shift
- diagnostics with damper signals
- hump control and tune measurement
- gain: performance (damping time) at injection and with colliding beams
- abort gap cleaning – pulse shape
- summary and plans for 2011

Transverse Damper / Feedback



need real-time digital signal processing

Match delays:
$t_{signal} = t_{beam} + MT_0$

T_0 : beam revolution time

M=1: very common ->
“One -Turn-Delay” feedback
But M>1 also possible

phase *and* delay adjustments

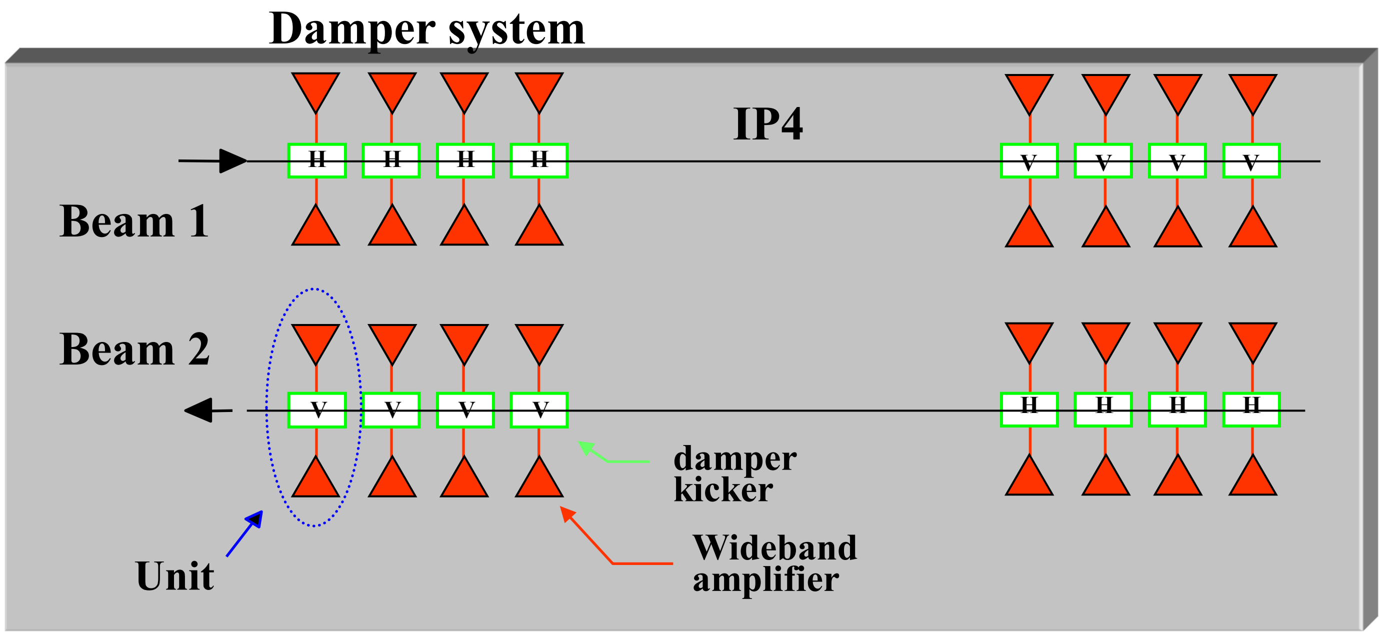
- damping: of transverse injection oscillations
- feedback: curing transverse coupled bunch instabilities
- excitation: of transverse oscillations, tune meas. / abort gap cleaning …

High expectations, facing the unknown

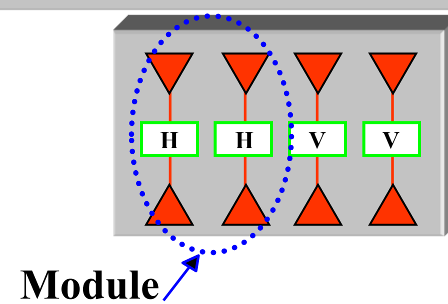
- injection damping requires strong kicks, 2 μrad @450 GeV/c, 900 kV
- LHC design report call for damping time of 4.1 ms (46 turns)
- plan: use damper during injection plateau and ramp, switch off during collisions
- during the design stage worried that due to noise damper could not be used
- 2010 run showed that we can use damper with colliding beams
- efforts put into designing electronics and software paid off
- thorough testing, power system running reliably since first commissioning in 2008
- mitigation of 2009 interference (8 kHz) !

The LHC Transverse Damping System high power part

Naming: #1 to #16 (power team), H1, H2, H3, H4, V1, V2, V3, V4 .B1/B2



- 26 kickers
- 16 wideband amplifiers, i.e. 32 tetrodes in total (RS2048 CJC, 30 kW)

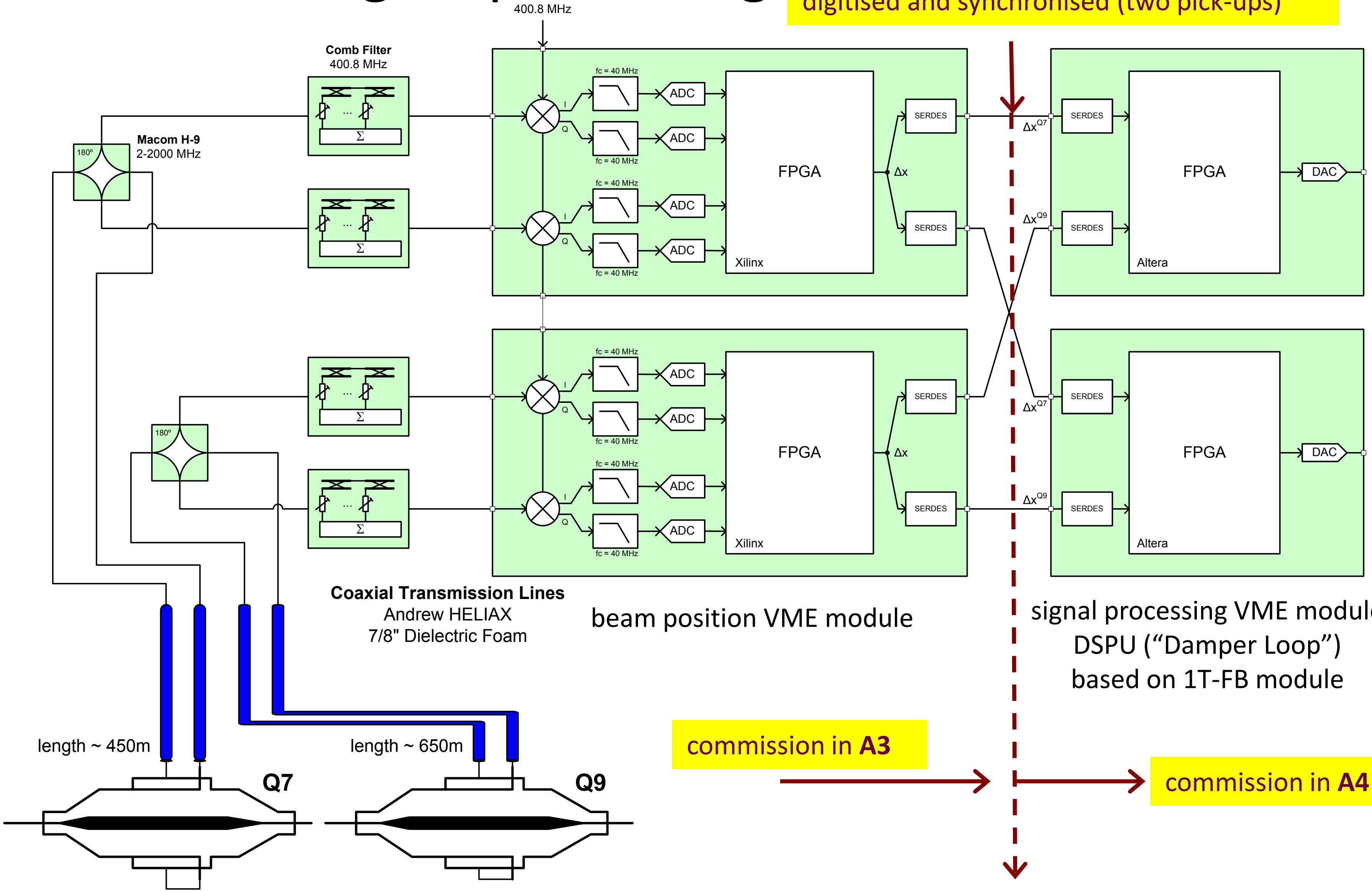


Module share common resources, power converters, LL


ADT amplifiers in tunnel point 4
RB44 and RB46

Overview of signal processing

intensity nomalised bunch position
digitised and synchronised (two pick-ups)



beam position VME module

signal processing VME module
DSPU ("Damper Loop")
based on 1T-FB module

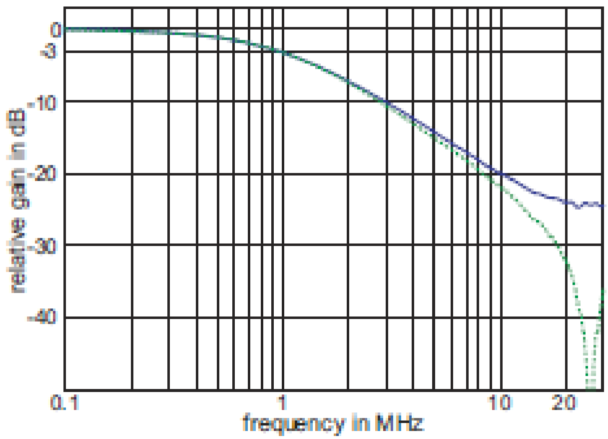
commission in **A3**

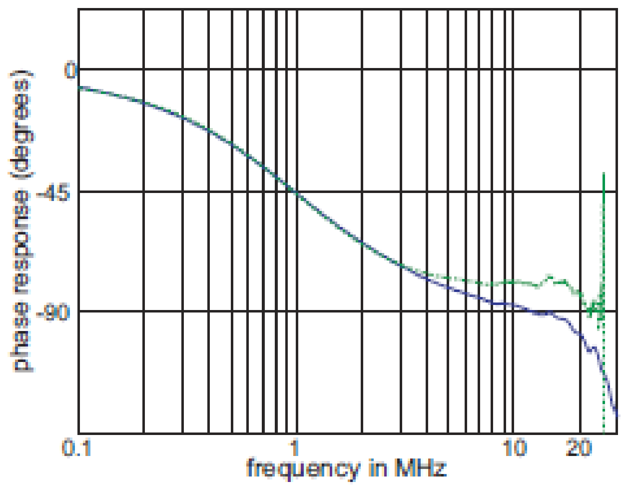
commission in **A4**

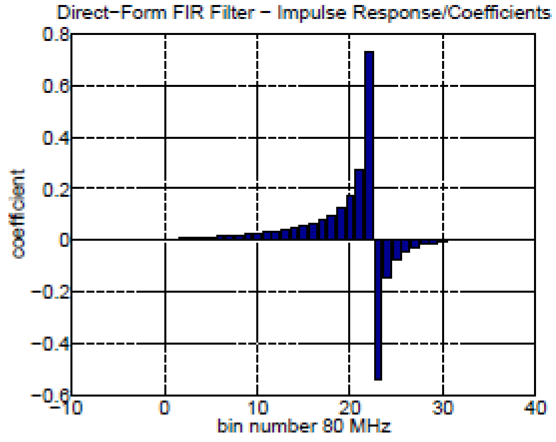
4 x i.e. one system per beam and plane

Limitation

roll-off of kick strength and gain towards 20 MHz (7% at 20 MHz)







phase response compensated by a digital filter

adapting required gain to bunch spacing

needs some tuning for 2011

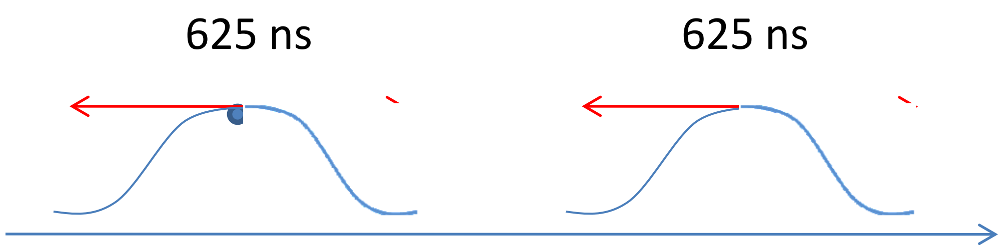
→prepare set of filters for different bunch spacings

25 ns: 20 MHz, 50 ns: 10 MHz, 75 ns: 6.7 MHz

Limitation: ADT and bunch spacing

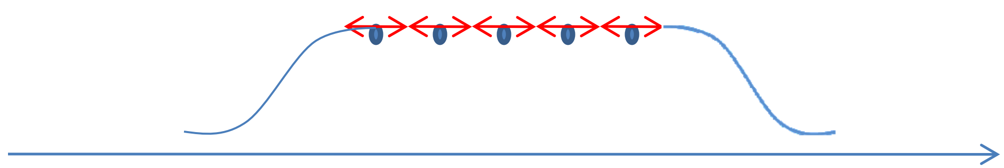
issue: full kick strength only available for frequencies up to 1 MHz
→ need to play some "tricks"

scheme for large spacing



best for bunch spacing > 625 ns

what we want (ideally)

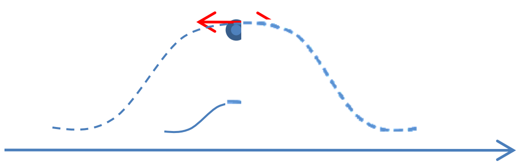


injection damping for bunch trains

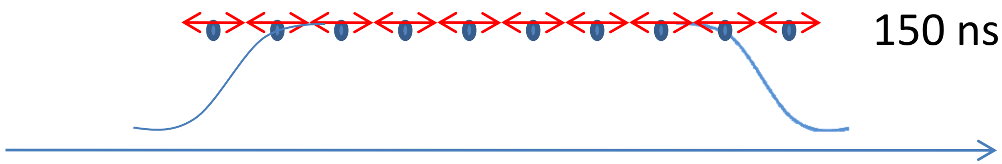
were somewhat surprised by the volatility of the filling schemes
→ only 25 ns slots allowed !

Example: 150 ns peak hold scheme

150 ns peak hold



less gain when operated
with isolated bunches
(used first in fill 1305)



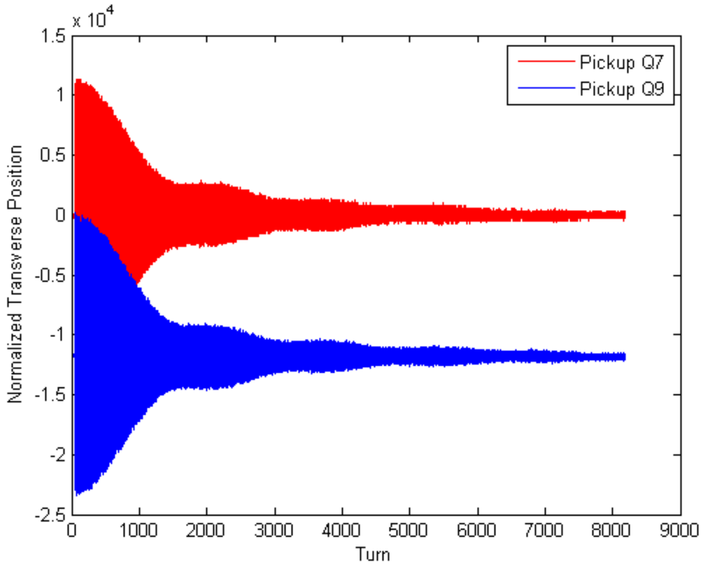
150 ns bunch trains

less gain for bunches at edge of batch
but similar , i.e. full gain for center of batch
[assuming common error of batch]
later adapted this to 75 ns and 50 ns spacing

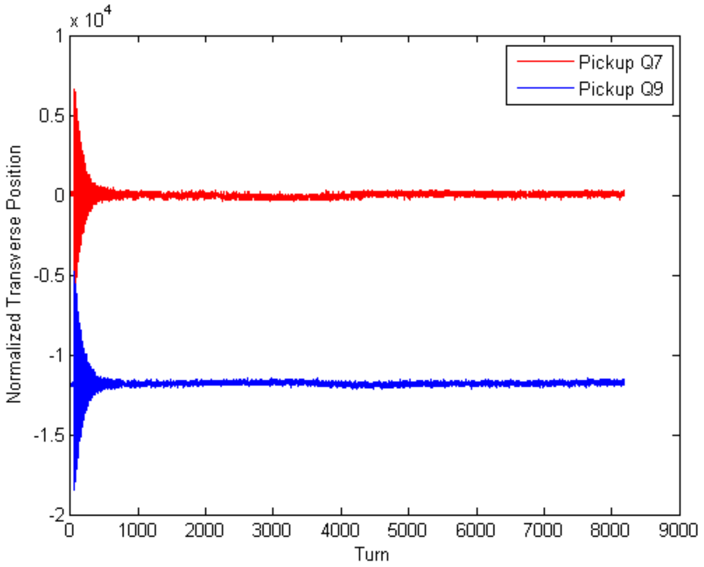
2011: preparation of settings for different bunch spacings

First Damping of Injection errors

damper off



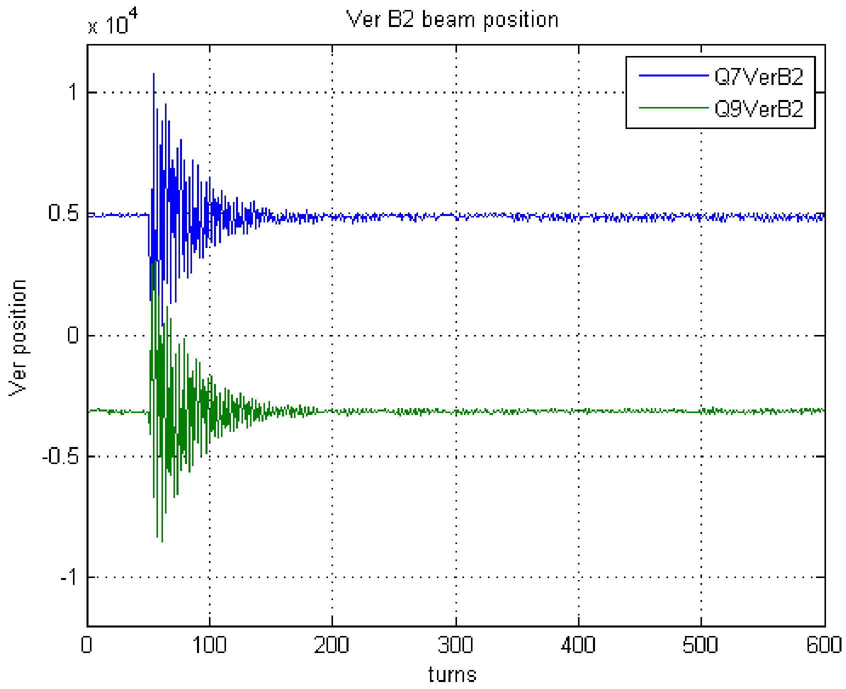
damper on



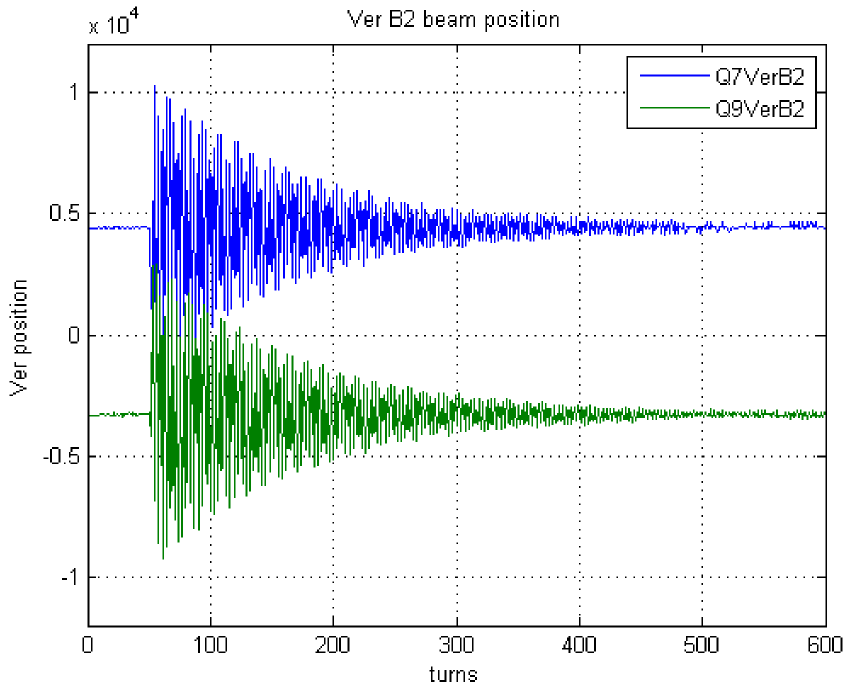
22.04.2010

Surpassing Design Specifications

High gain



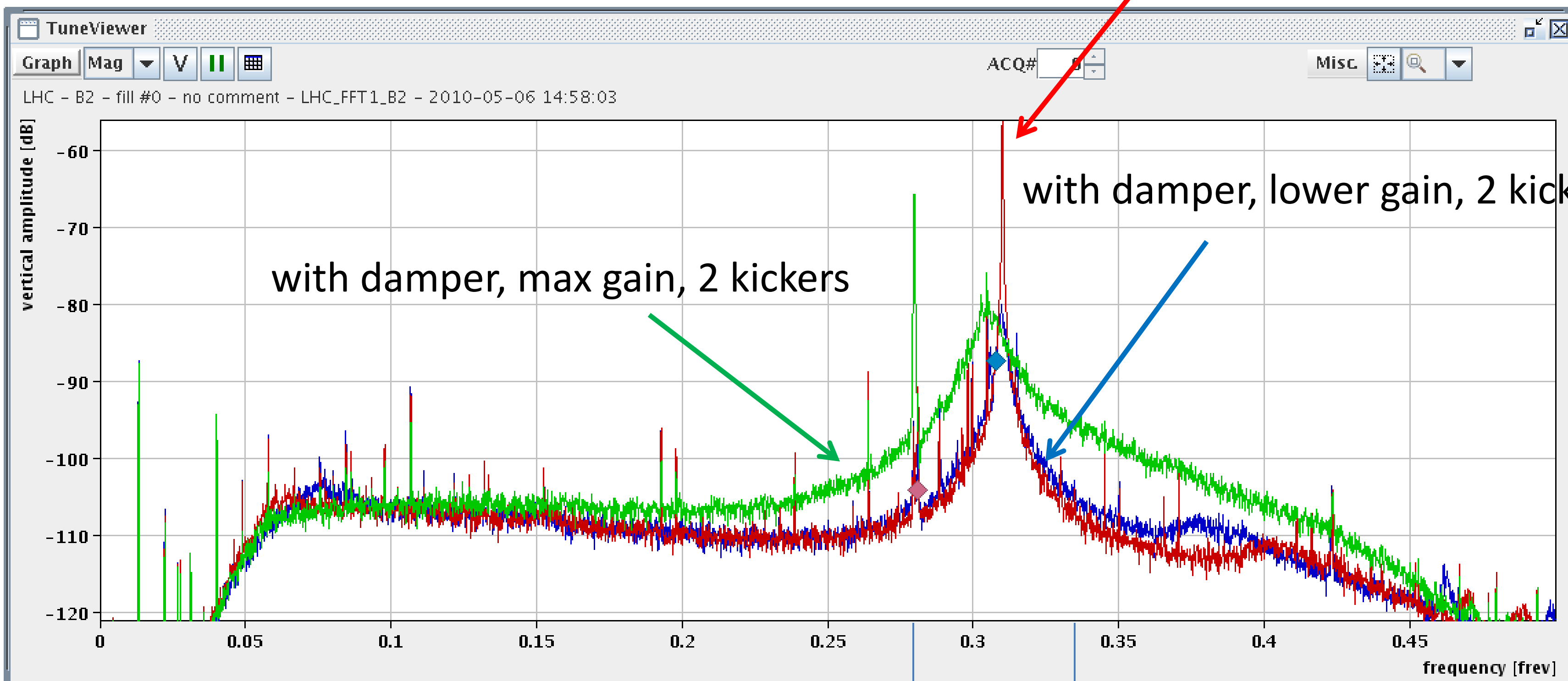
Lower gain



40 turns damping achieved

Tune peak broadens

without damper



plot:
R. Steinhagen

less broadening with lower gain
reduction of tune peak, i.e.
residual oscillations by more than 20 dB

range were FB works well
(limits 45 degrees phase error)

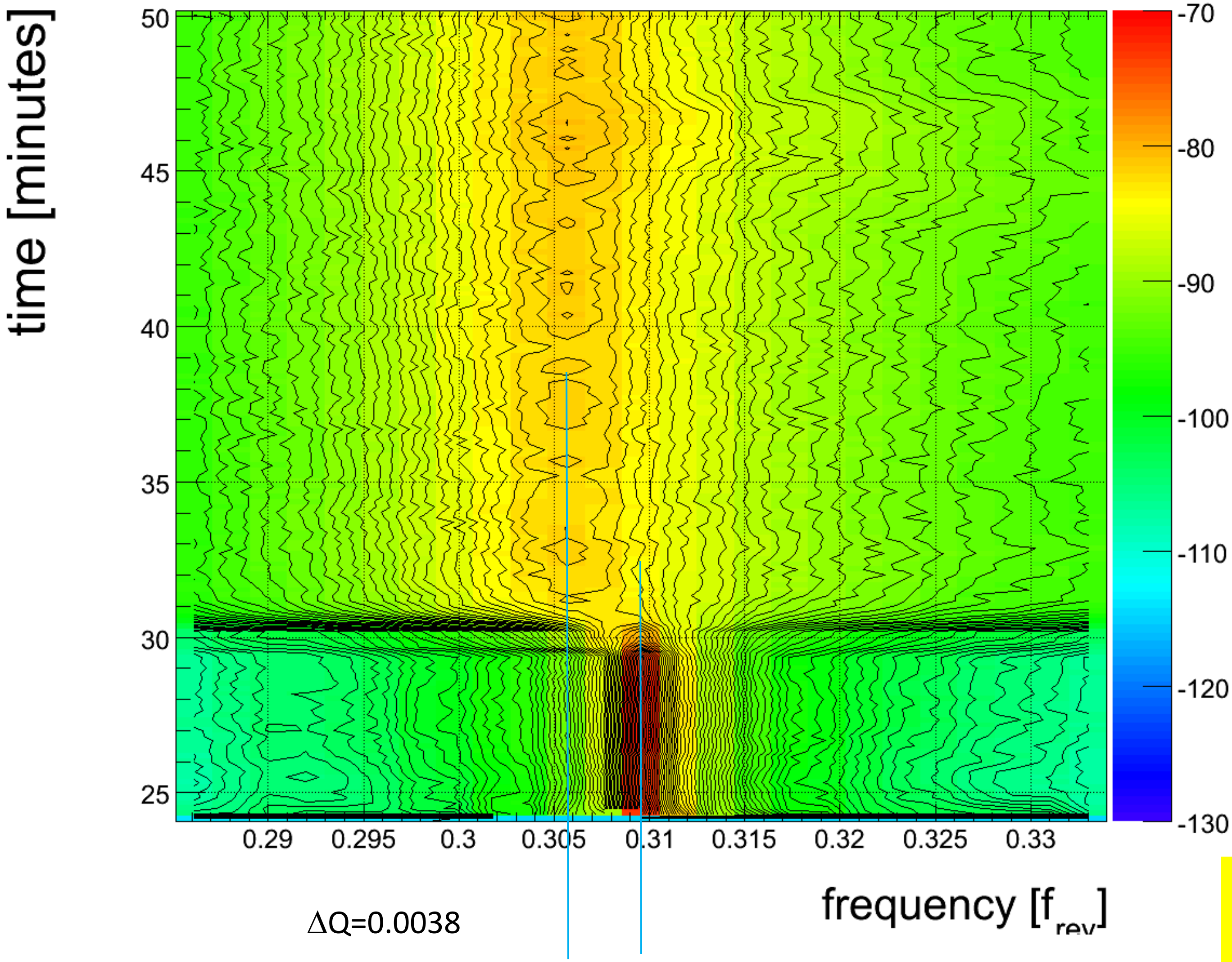
Vector sum versus FIR phase shifters

- currently a 7-tap FIR filter is used to adjust the feedback phase
  → introduces 3 turns additional (group) delay in processing;
  together with 1-turn delay and notch: 4.5 turns delay
  → phase error from tune change → 4.5 x 2π x ΔQ
  disadvantage: FB only works within a relatively narrow tune range, +/- $\pi/4$ for +/- 0.028
  advantage: processing gain (both pick-ups used with full amplitude, good for S/N)
  easier to set-up (both pick-ups can work independently)

- vector sum: three times less sensitive to tune variations
  disadvantage: loss of S/N

2011: keep FIR, but maybe test vector sum and evaluate S/N

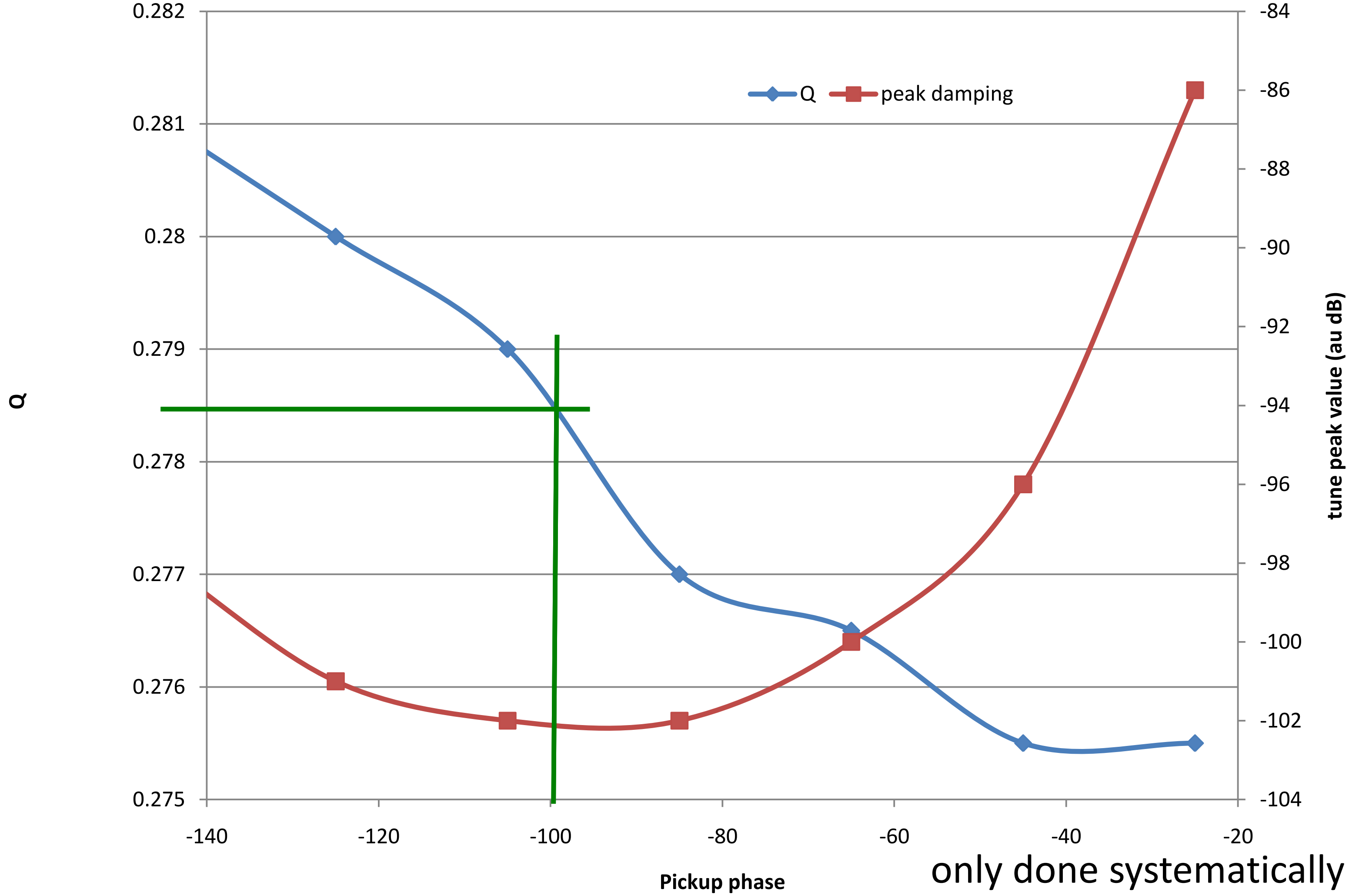
Tune shift



plot:
R. Steinhagen

estimate that phase adjustment overall better than 30 degrees
improvement possible in 2011 using tune shift method

Tune shift versus phase setting



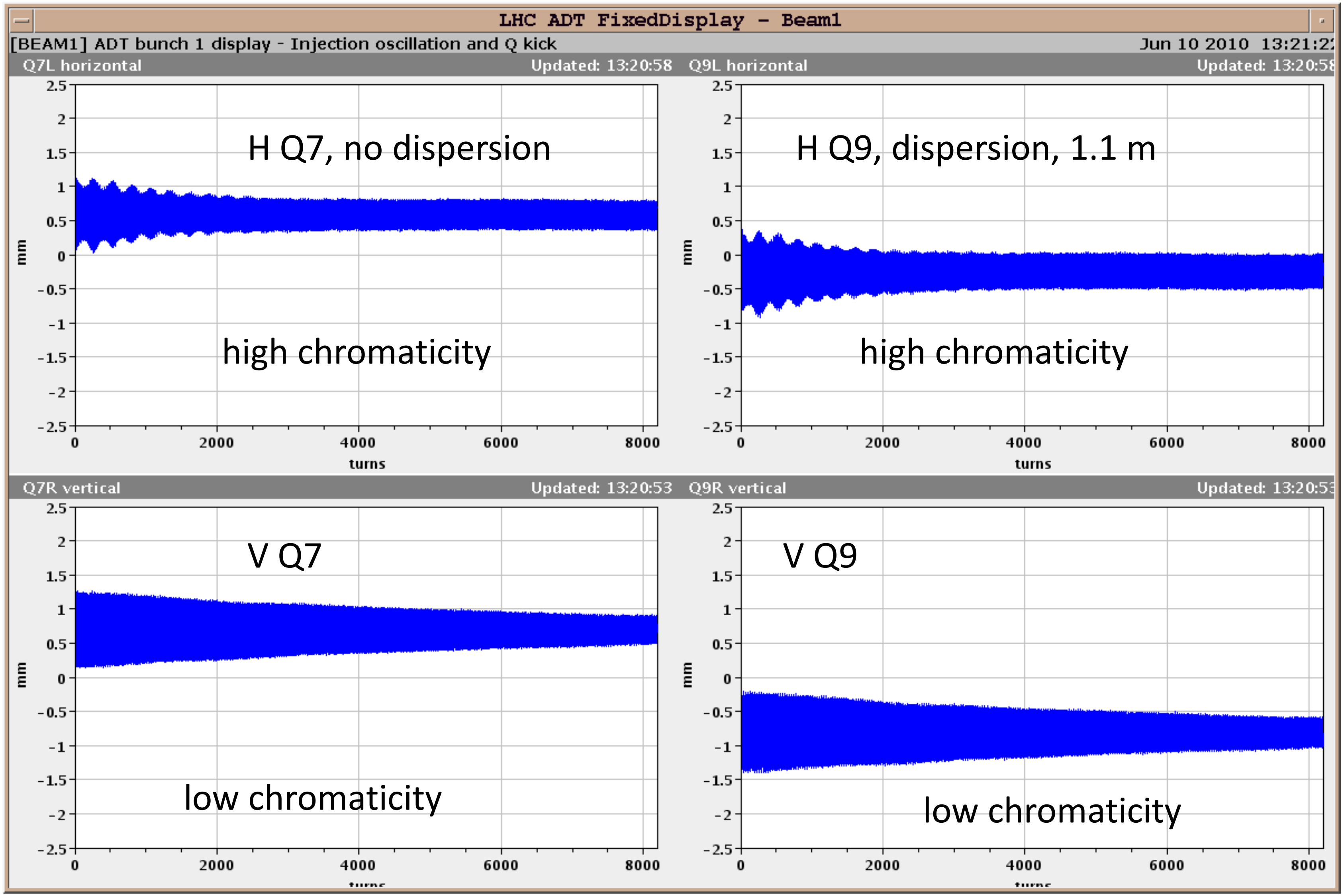
D. Valuch, U. Wienands

only done systematically for one damper module
due to a lack of time

Diagnostics: the fixed display

Damper off

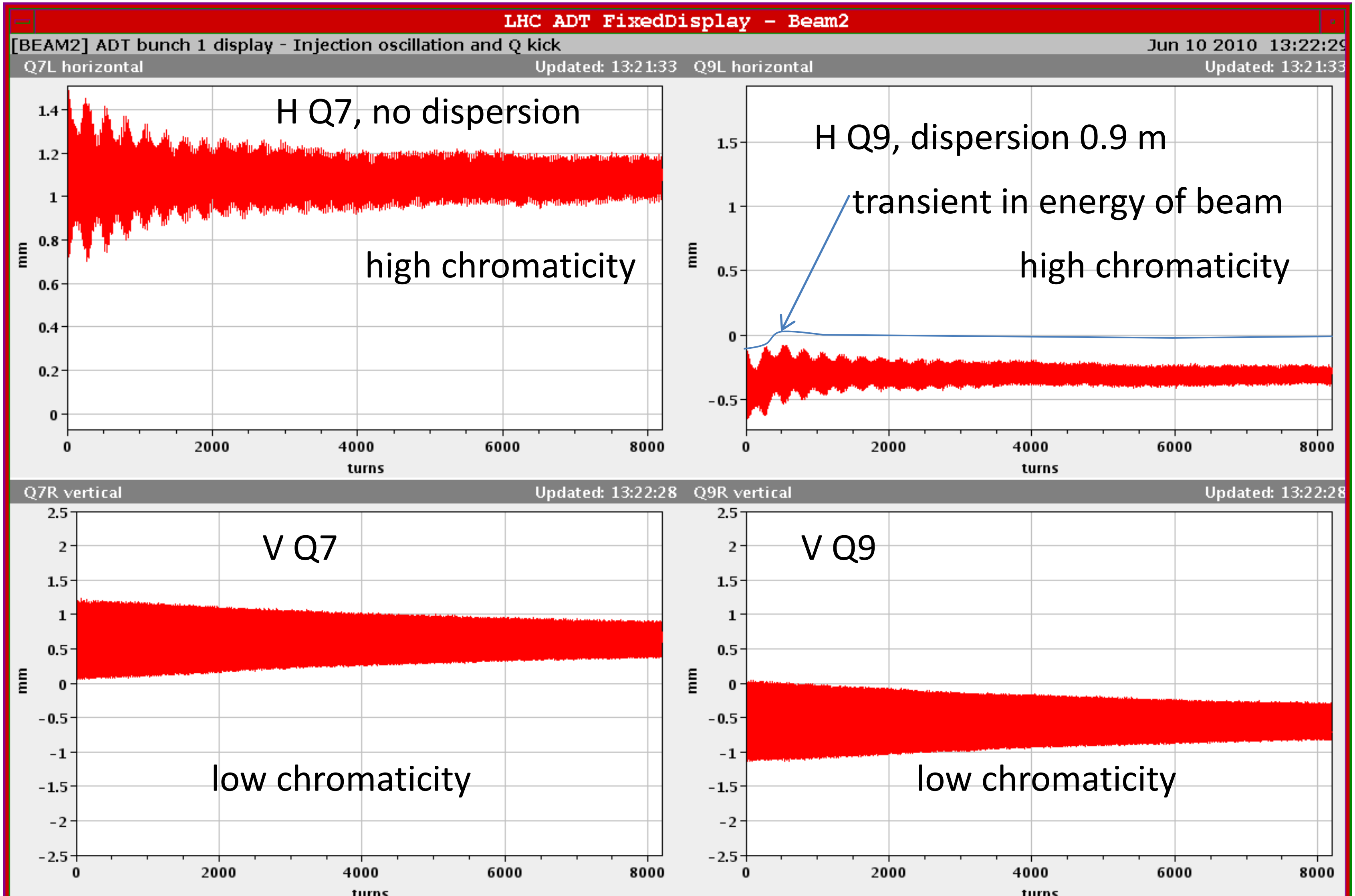
Beam 1: Transverse injection transient, pilot, Thursday, 10.06.2010, 13:12



Diagnostics: the fixed display

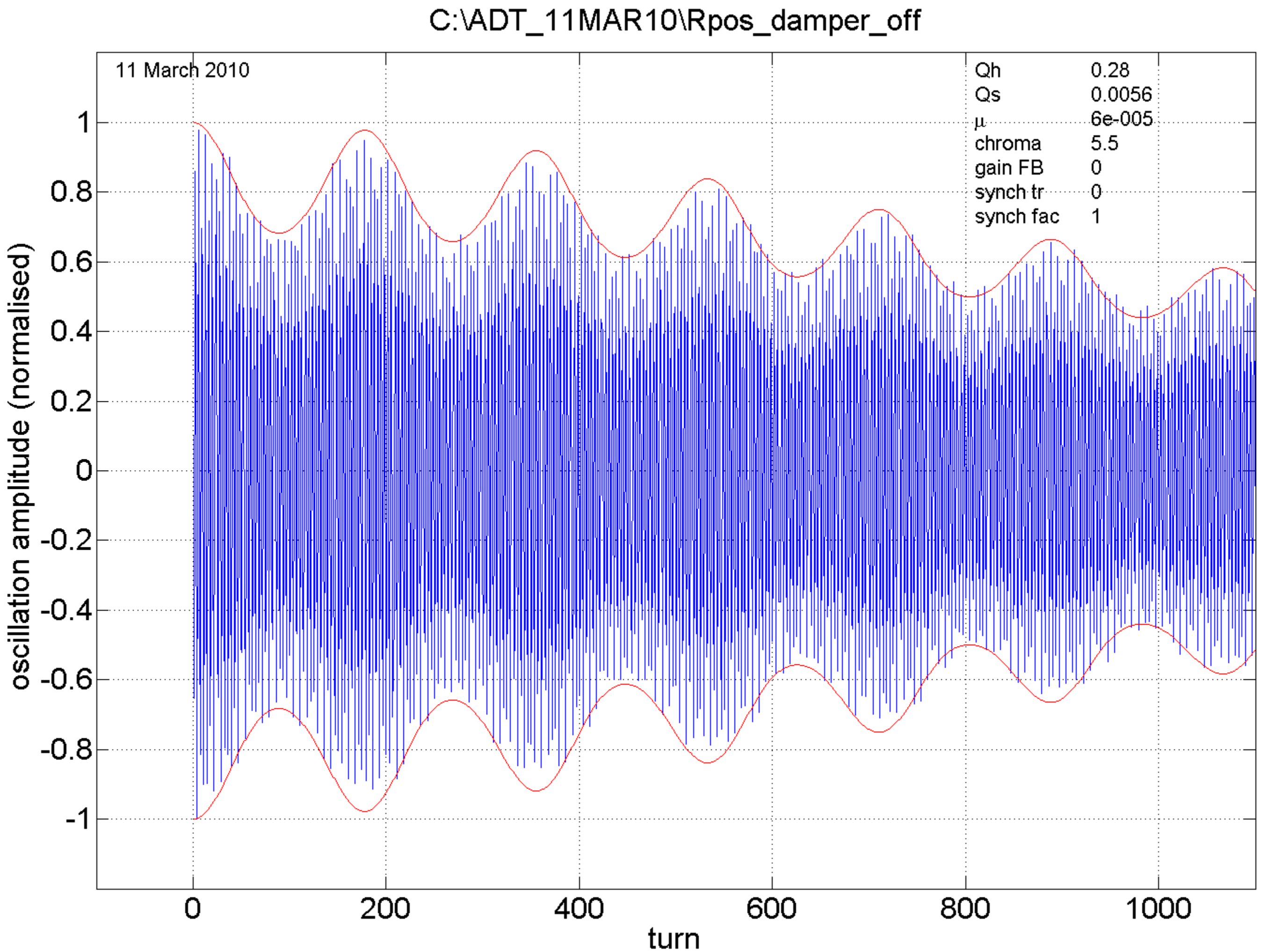
Damper off

Beam 1: Transverse injection transient, pilot, Thursday, 10.06.2010, 13:12



Offline analysis

Damper off

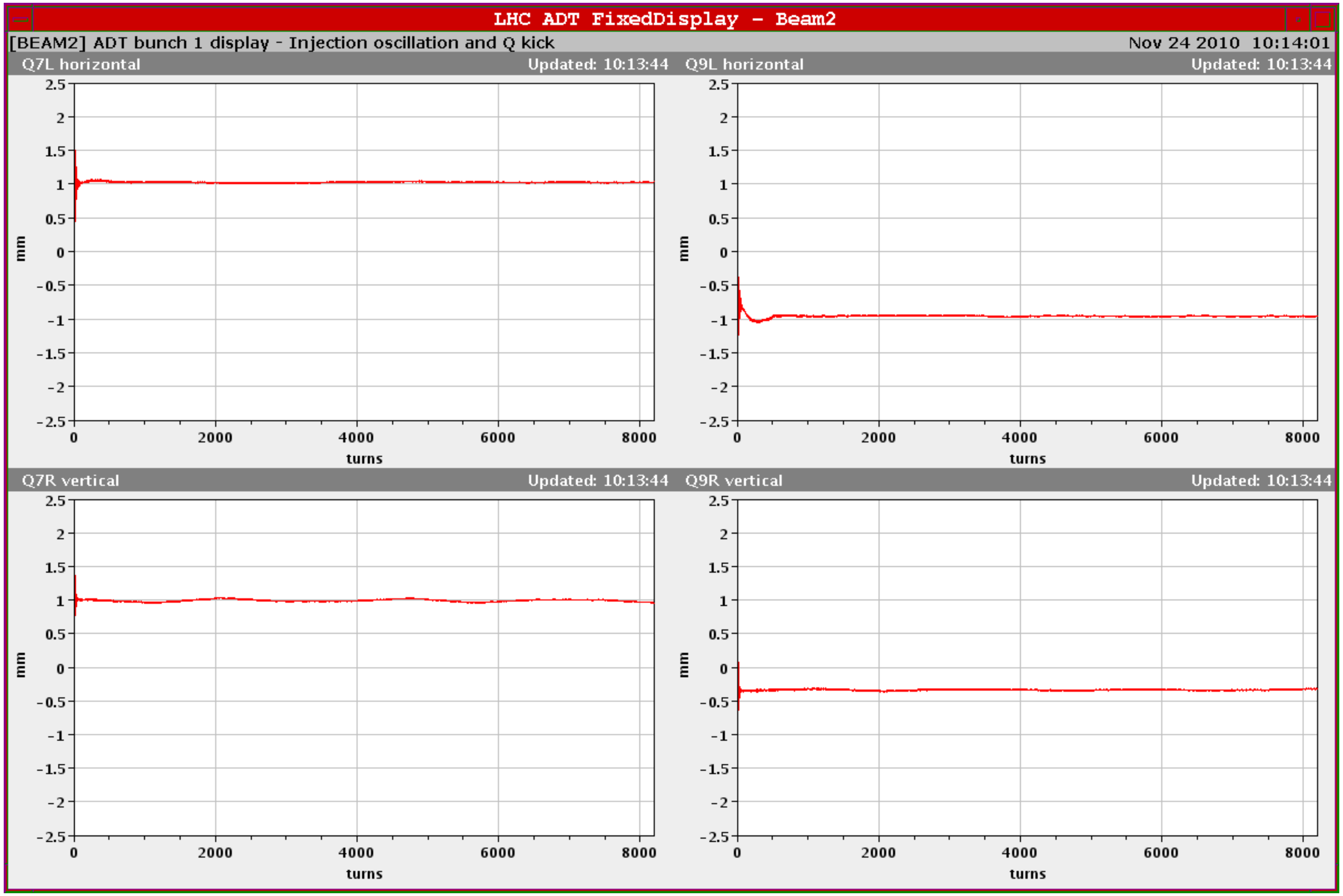


fit: Q'=5.5, $\mu = 0.6 \times 10^{-4}$, $\Delta x = 0.5\ \sigma$, $Q_H=0.28$, $Q_S=5.6 \times 10^{-3}$, no damper

Can this be made a tool for chromaticity estimation (from pilot injection) ?

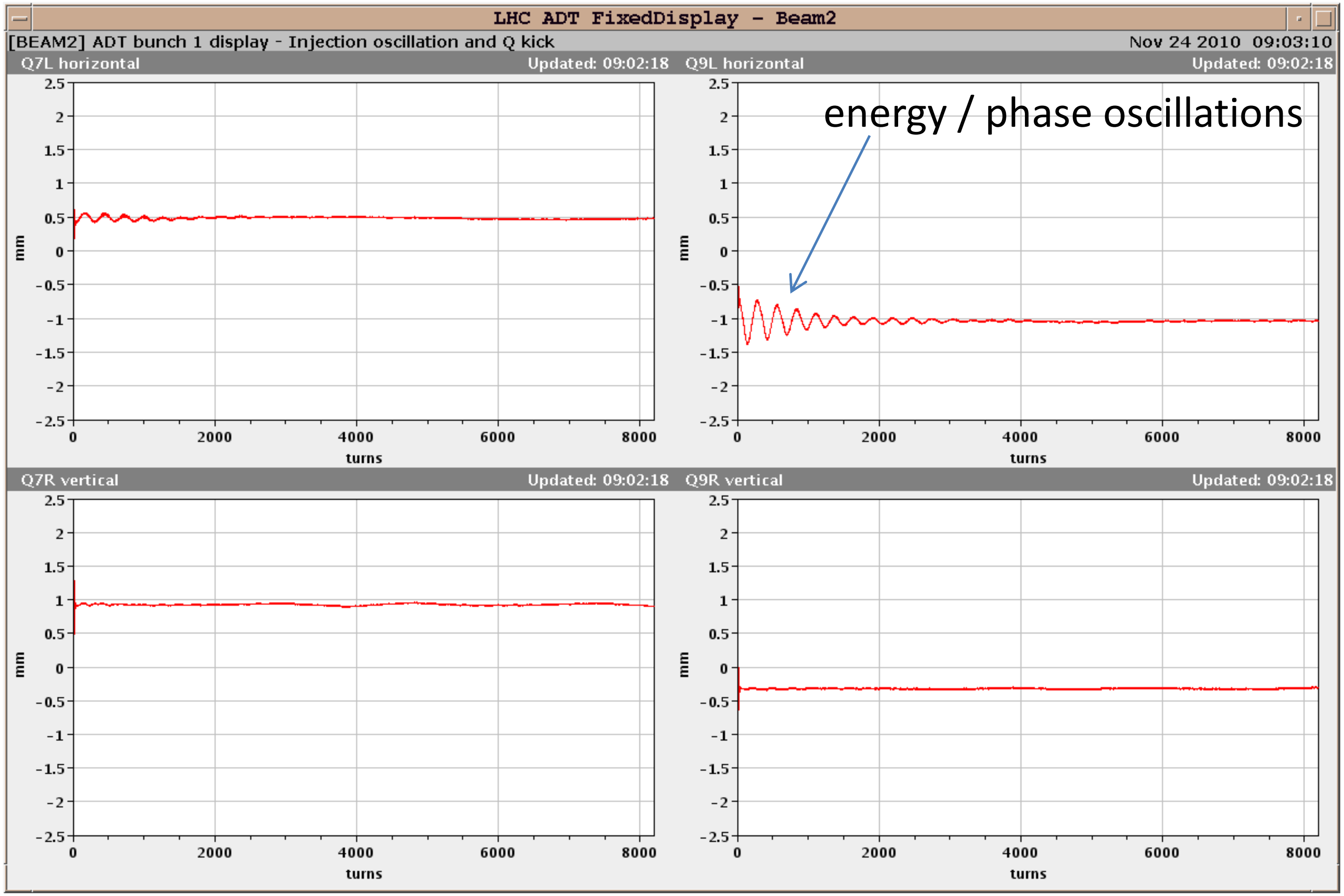
Needs ppm change of damper settings from pilot to nominal, plus some programming

Damping with ions, 1st injection



Less than 20 turns damping

Damping with ions, last injection



Less than 20 turns damping

Reducing effect of external perturbations using the transverse feedback
“hump control”

assuming hump is an external perturbation (not an instability)

→ a high gain is required in the feedback to reduce effects on the beam

for off-tune perturbation using the PU vector sum should be more efficient, but lower S/N

but closed loop transfer function for the noise suppression contains BTF !

on the other hand, if hump is off-tune its effect on the beam emittance is probably small,

while contribution at the tune frequency (if any) is cured by feedback

→ performance improvements for S/N will help and permit tests with vector sum!

Tune measurement options

BBQ → relies on residual oscillations on the beam that are not controlled

Schottky → relies on residual oscillations

BBQ + excitation → with damper quite strong excitation necessary (blow-up ?)

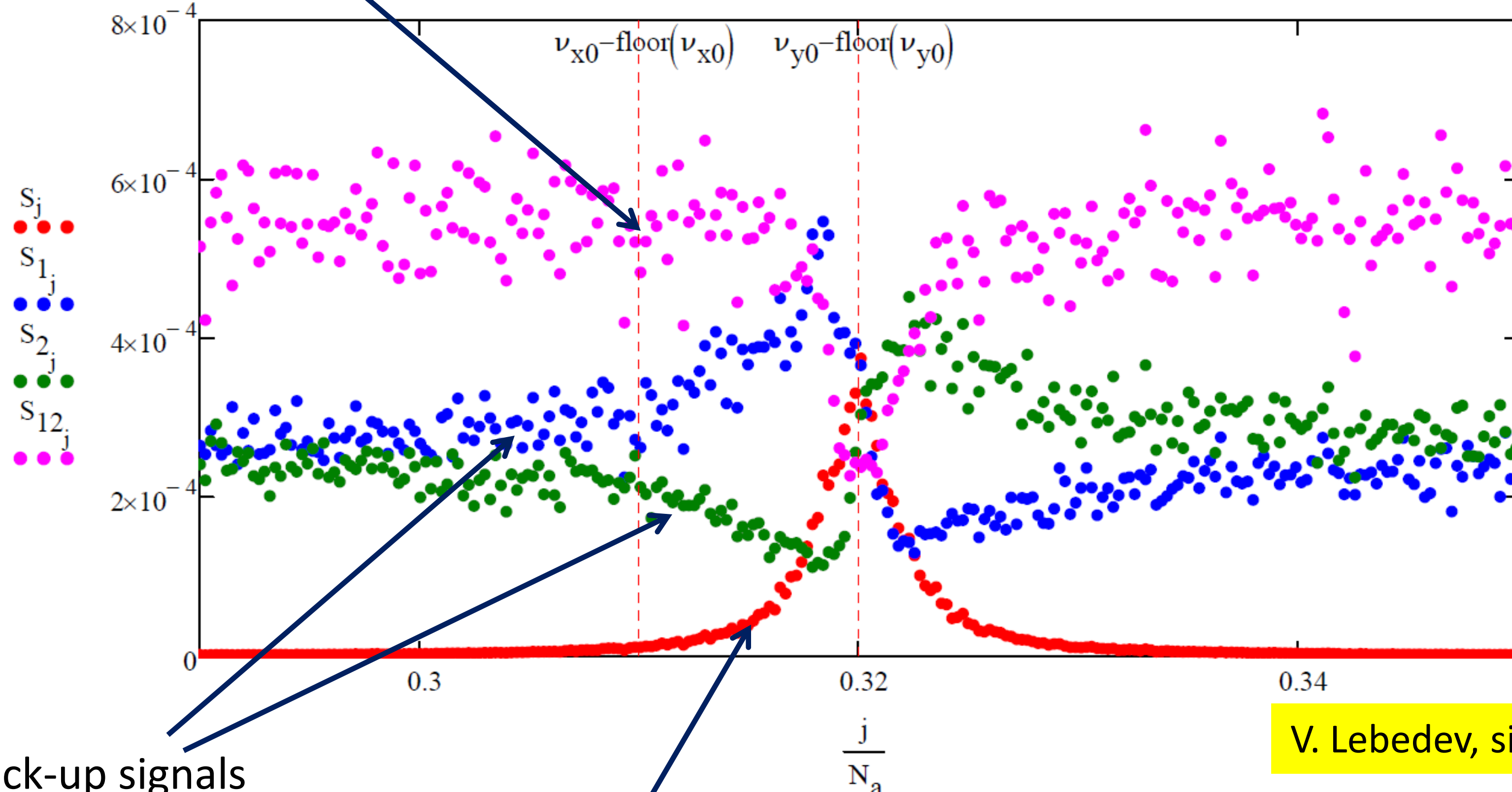
PLL + damper → cleaner spectrum with FB on,
blow-up to be checked
calibration of PLL depends on damper settings

stop band → should be equivalent to higher noise in damper hence more blow-up, do this on witness bunch ?

tune from FB → we are checking the feasibility, 10^{-3} accuracy seems possible, long lead time for development

What we should see on damper (feedback on)

damper signal, FB on, correctly phased (resistive FB)



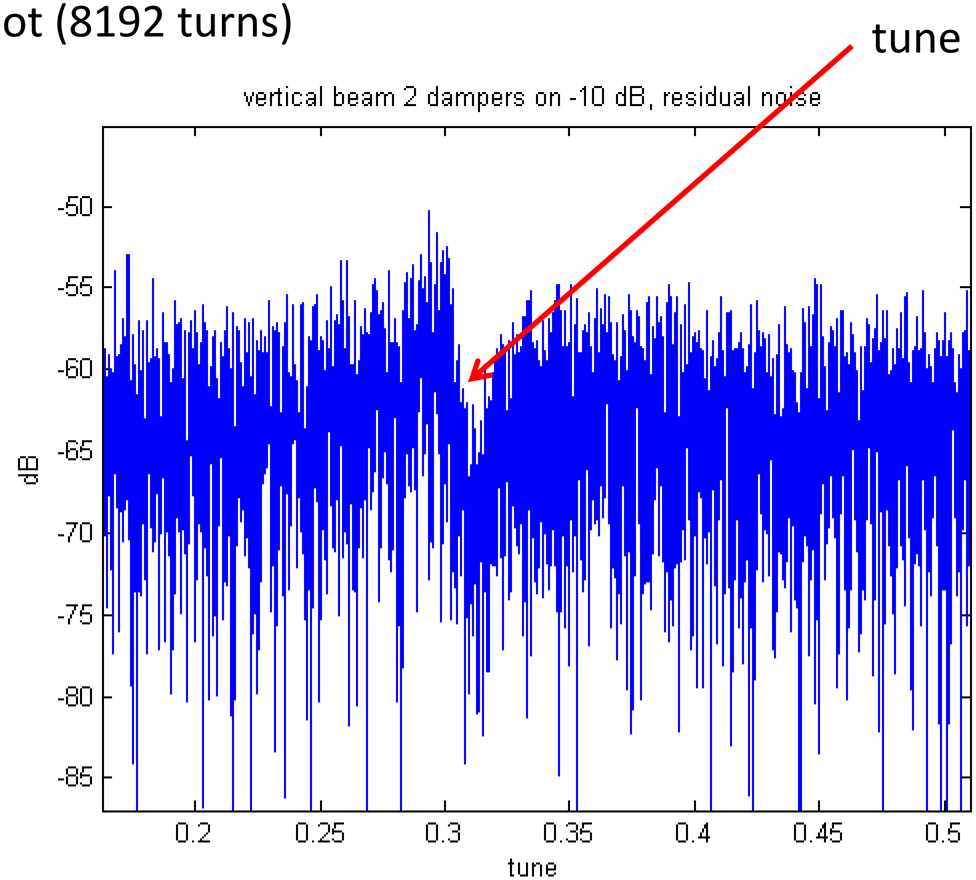
V. Lebedev, simulation

pick-up signals
with phasing not equal
to $\pi/2$ with respect to kicker

residual beam oscillation *below* noise level
(not visible on damper signals !)

Damper signals measured

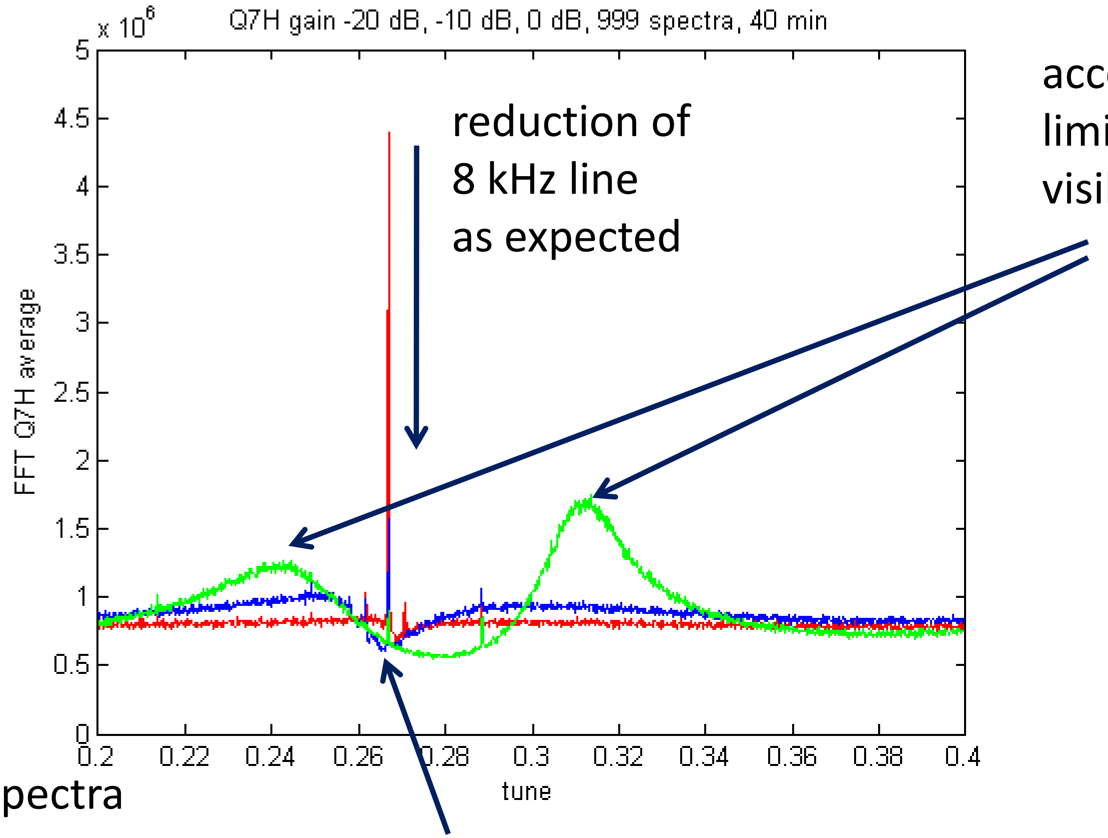
Single shot (8192 turns)



28. May 2010

best method of averaging the spectra needs to be studied
dip less pronounced at nominal intensity

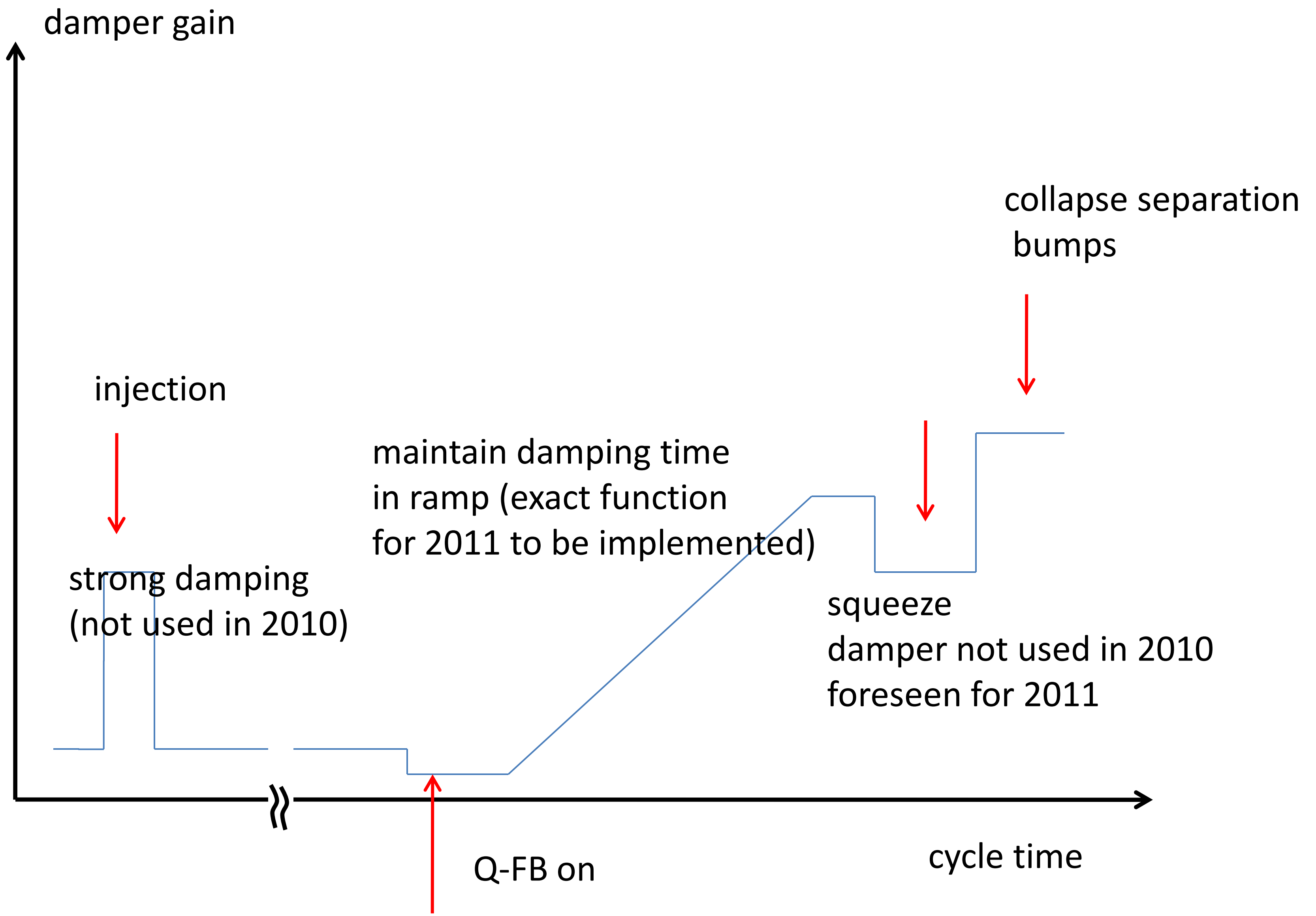
Measurements of September 5, 2010
(beam 1 horizontal as function of damper gain)



average of 999 spectra
from damper
(1 bunch !)

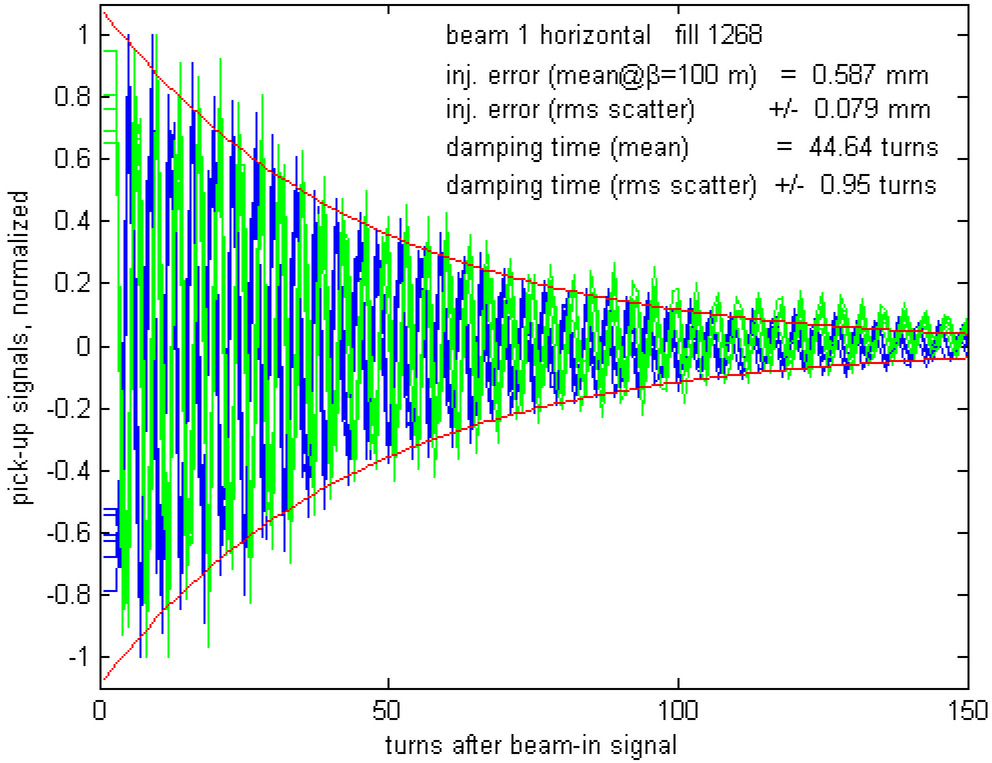
→ should get same in one shot from 999 bunches, but streaming the data is an issue

Scenario for the gain



450 GeV: What was the gain / damping time ?

Injection damping fill 1268 (August 9, 2010)



data logged since summer, but no automatic tool to compute damping time / inj. error

3.5 TeV: Kicking non colliding bunch with damper on (20 August 2010)

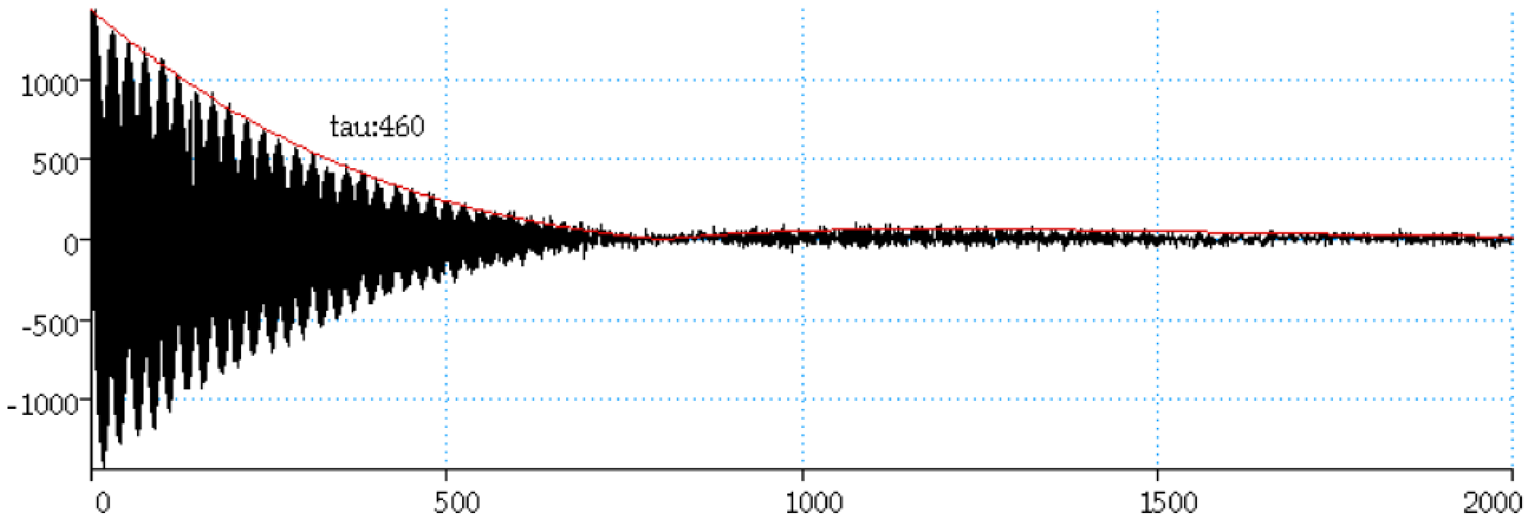
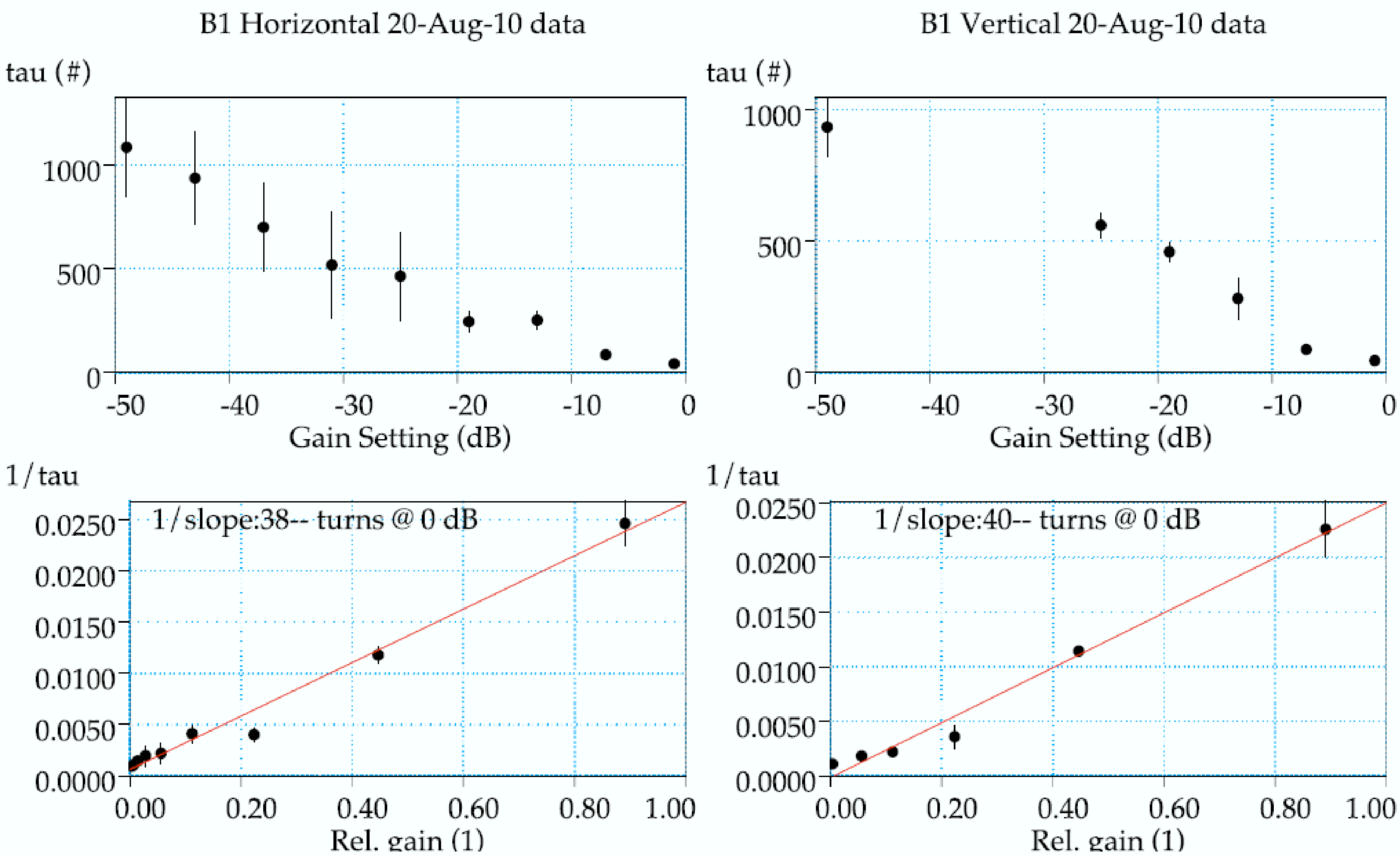


Figure 1.2: Envelope fit example for Beam 1, Q7 data, -19 dB gain setting.

U. Wienands

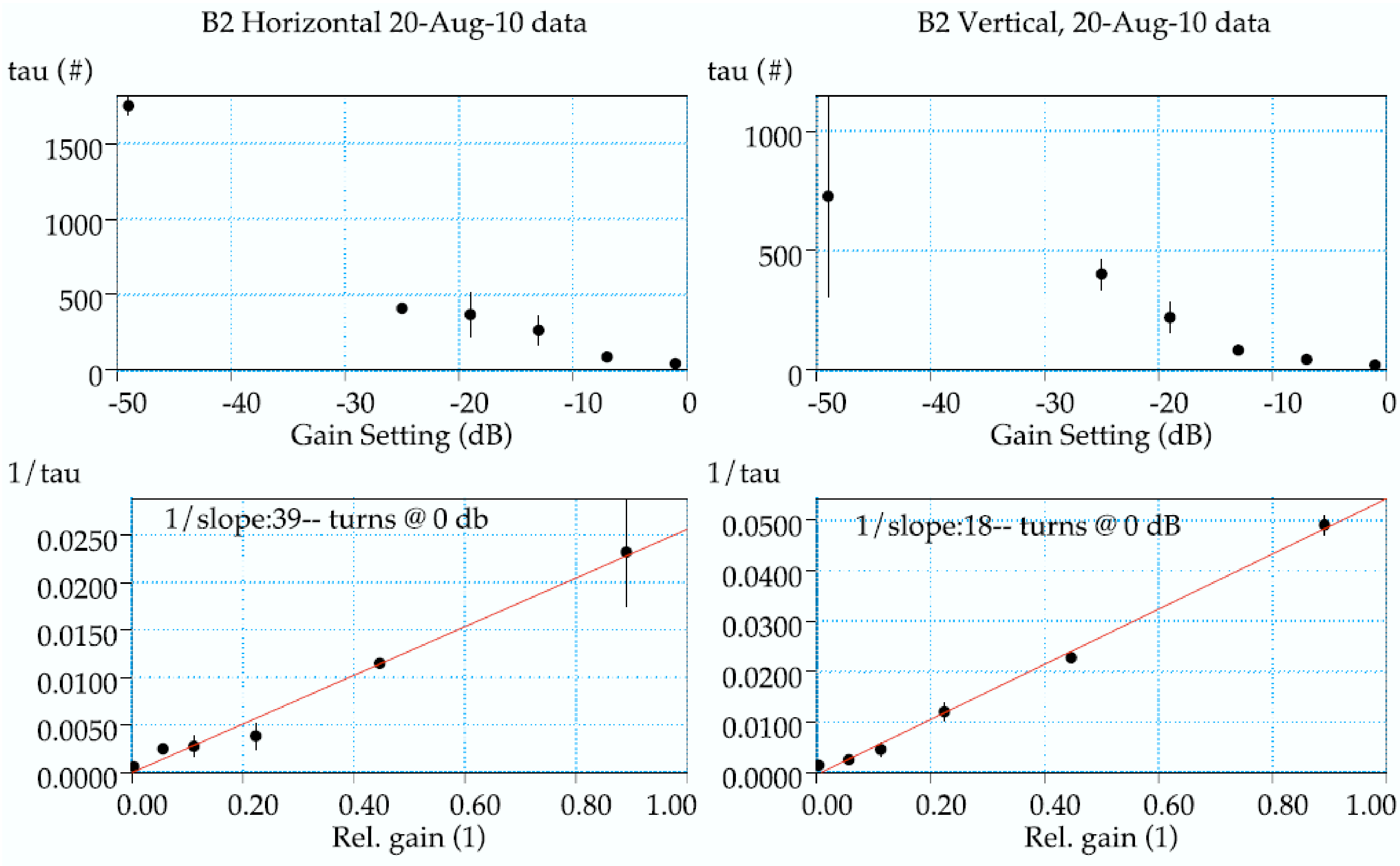
used Qkicker and synchronised observation with damper

Damping time versus gain at 3.5 TeV



U. Wienands

Damping time versus gain at 3.5 TeV



U. Wienands

→ suggests practically no or very little damping at zero gain

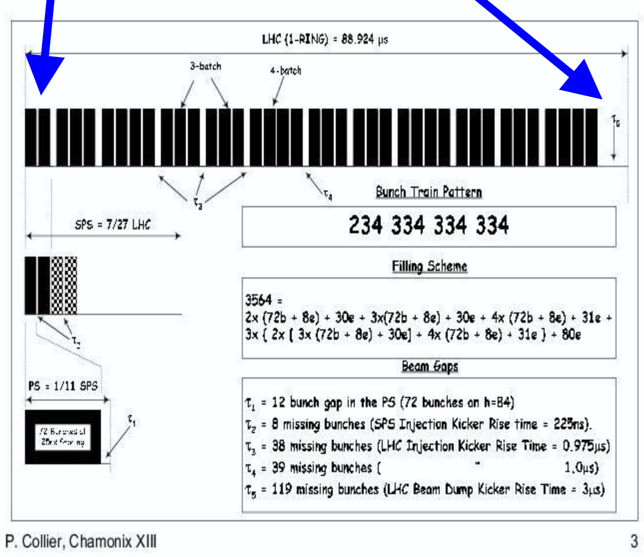
Principle of Abort Gap Cleaning

resonant excitation of transverse oscillations
capture of beam by aperture limit
(collimators)

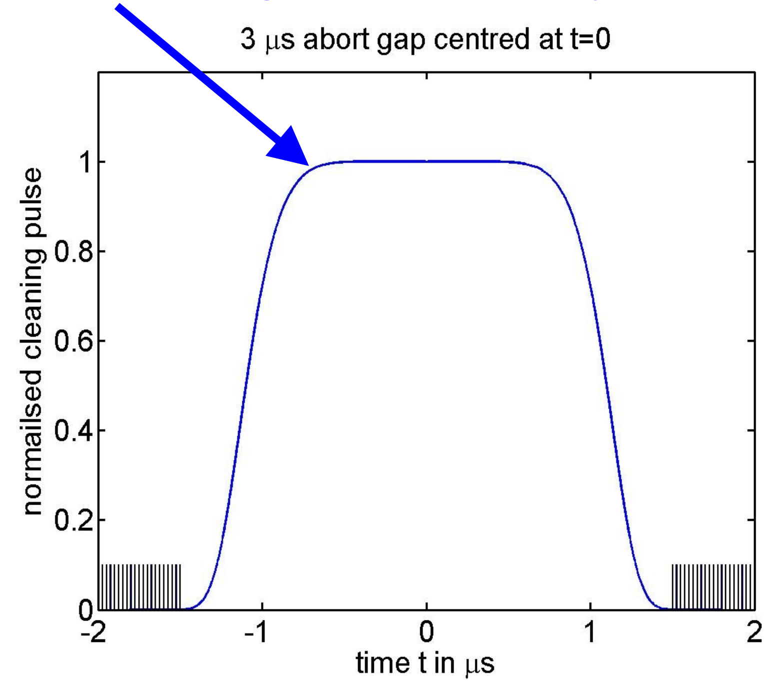
amplitude modulated at frequency
close to betatron tune
(covers a range of tunes in steps)

1st injected batch

abort gap
(119 missing bunches)

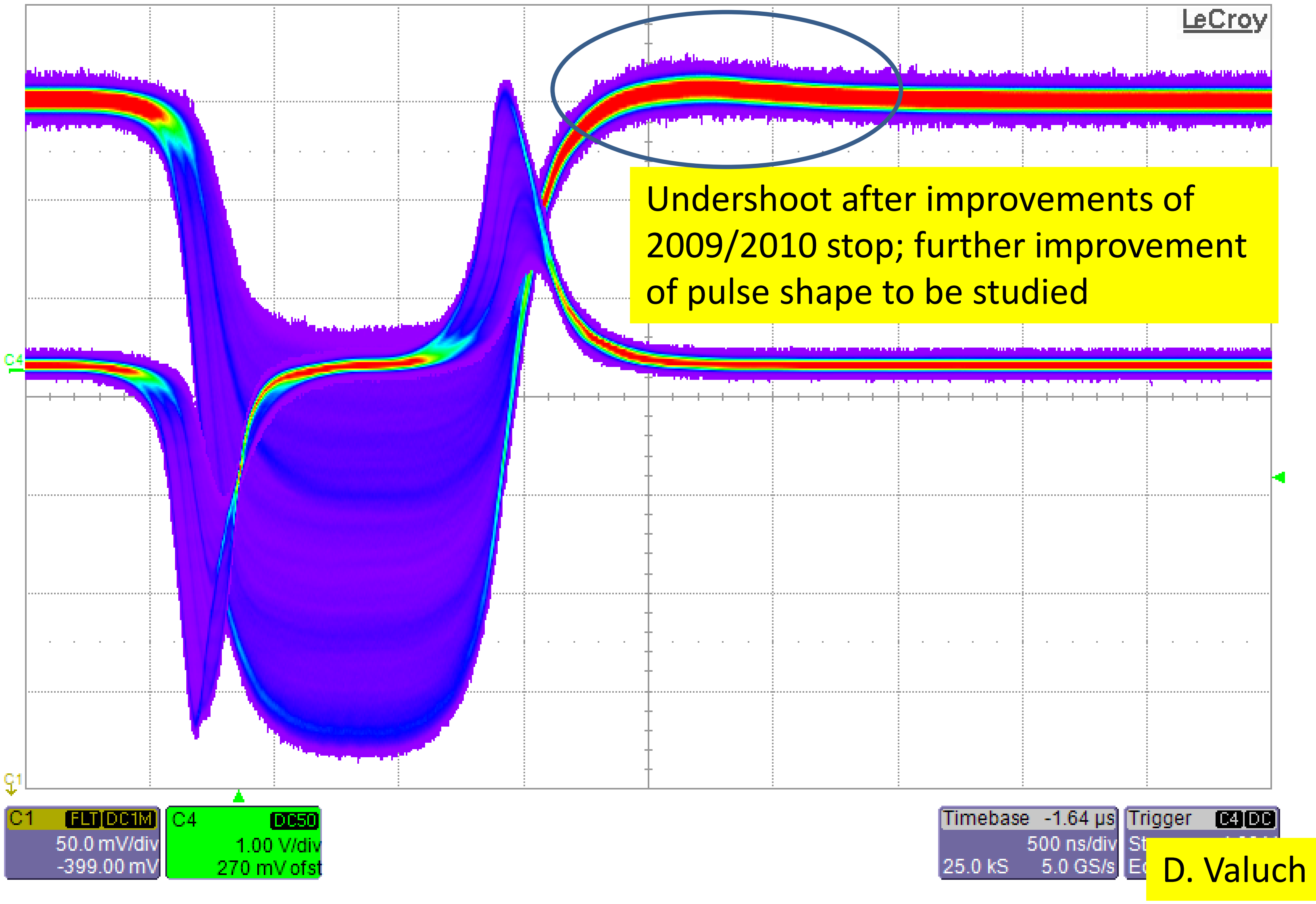


LHC nominal bunch pattern
2808 bunches



cleaning pulse (gate) centered in abort gap
modulation of pulse with betatron frequency
full amplitude up to ~ 1 MHz possible

Abort Gap Cleaning Pulse



Summary of 2010

- ✓ commissioned damper at 450 GeV, during ramp and with colliding beams
- ✓ nominal damping rate reached and surpased
- ✓ commissioned operation with bunch train
- ✓ commissioned damper for ions at 450 GeV and with colliding ion beams
- ✓ abort gap cleaning and injection slot cleaning successfully used
- ✓ diagnostics (logging, fixed display, multi-bunch acquisition) available

- (in)compatibility with tune measurement somewhat surprised

Plan for 2011

- "ppm" loading of settings for different operation mode (trains, intensity)
- improving filters, best frequency response for given bunch spacing
- fine adjustment of phase and delay
- vector sum ?
- program gain via a normalised function (scale with energy), in physical unit τ
- improve multi-bunch acquisition (more than 8 bunches)
- post mortem logging (?!)
- move to standard operation the beam cleaning (abort gap / injection slot)
- improvements in abort gap cleaning pulse shape, investigate
- commission damper in squeeze
- study noise and propose improvements (2012 more pick-ups, Q8, Q10 ??)
- work on compatibility with tune feedback (witness bunches ?)
- study feasibility of tune determination from residual FB signal