Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Fast feedback for DAFNE

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LER2010
Low Emittance Rings Workshop 2010
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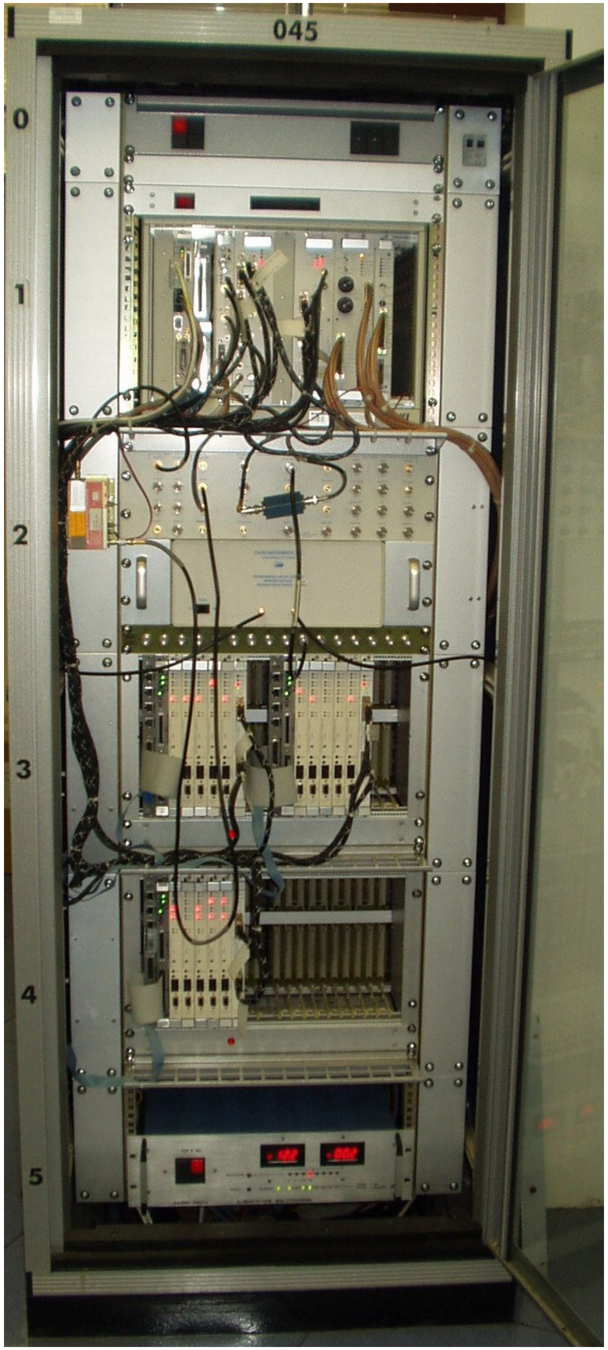
Main topics

- Evolution and continuity of the DAFNE bunch-by-bunch feedback systems
- Diagnostics through feedback systems: turn-by-turn **and** bunch-by-bunch powerful tools
- Considerations on the impact of feedback systems on low emittance beams
- DAFNE feedback upgrade plan for low emittance beams (looking to SuperB spec’s)
- Conclusions



Looking back: the first bunch-by-bunch FB

- This is the longitudinal feedback developed in the years 1992-1996 by a SLAC–ALS-DAFNE collaboration with J.Fox, S.Prabhakar, D.Teytelman, myself and many others
- Installed @ ALS, PEP-II, DAFNE, Bessy-II, Pohang
- Up to 4 VME backplanes: each VME processing board contains 4 DSP (Digital Signal Processors)
- The system can manage up to 80 DSP and each DSP can elaborate up to 32 bunches
- Still working at DAFNE in 2009 runs

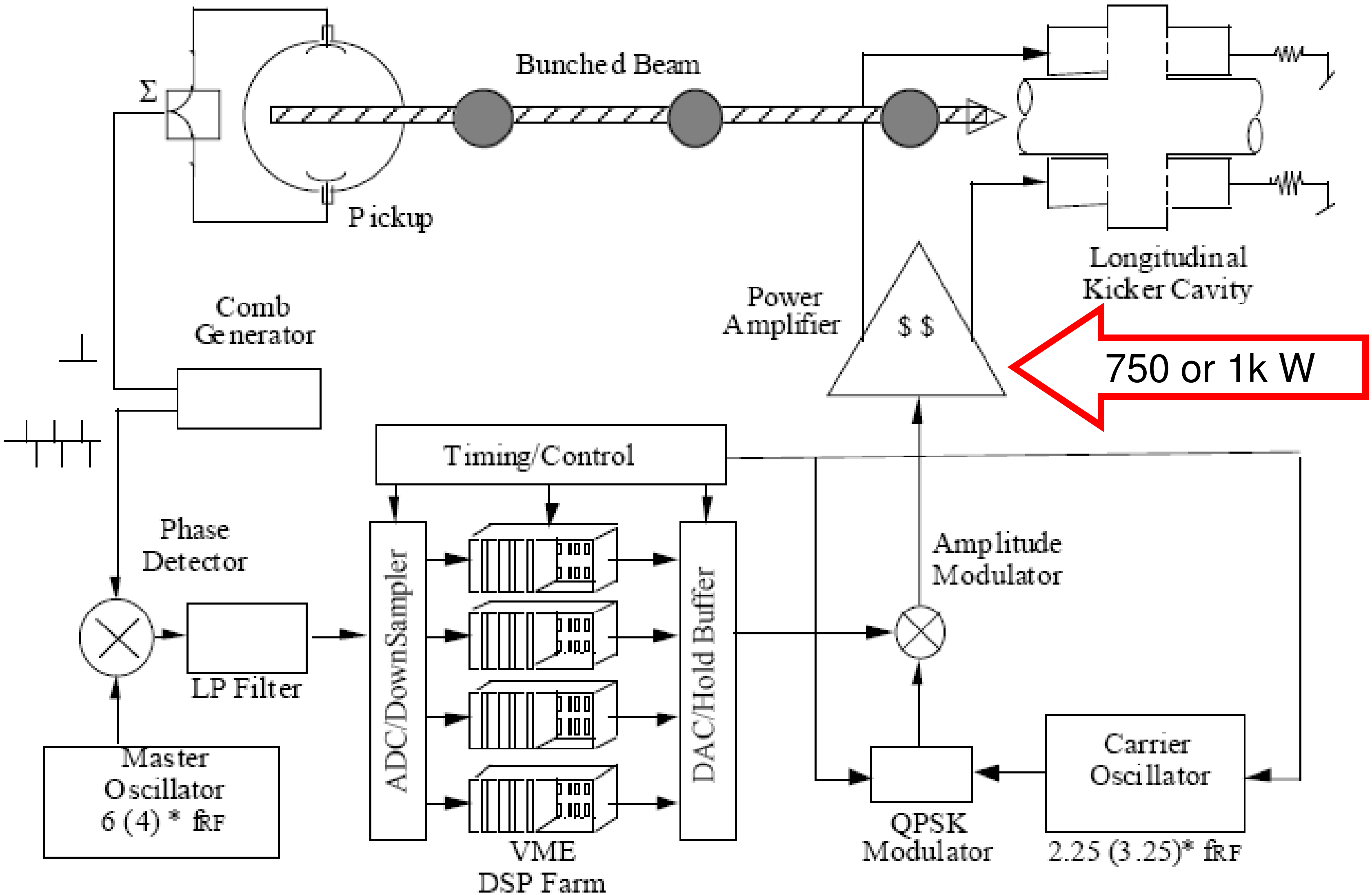


Figure 6: Basic architecture of the bunch-by-bunch longitudinal feedback system

Core of the feedback:
For each bunch the input signal is sent to a DSP that implement the code with IIR or FIR bandpass filter

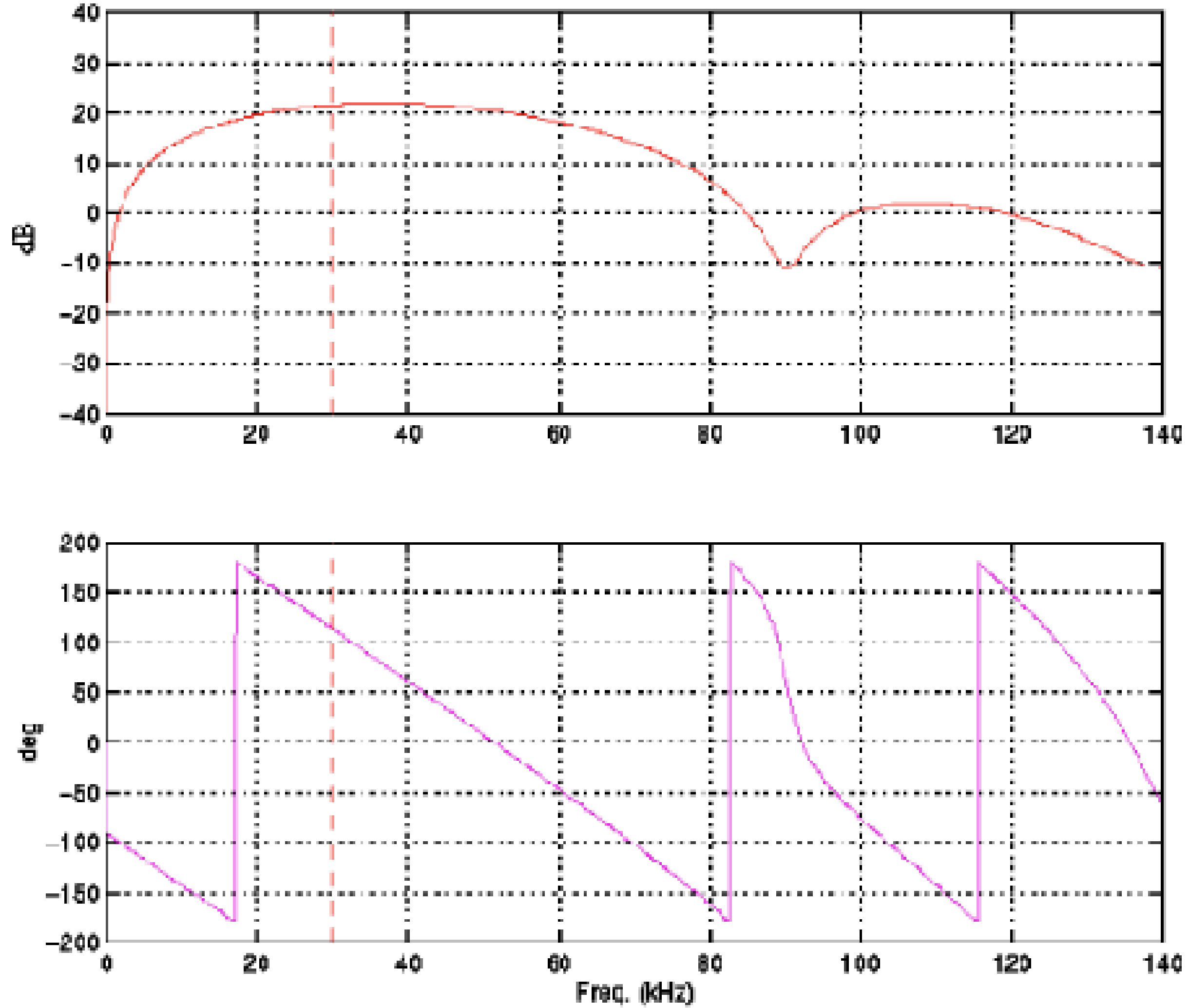
General form of IIR filter (infinite impulse response)

$$y_n = \sum_{k=1}^{N} a_k y_{n-k} + \sum_{k=0}^{M} b_k x_{n-k}$$

General form of FIR filter (finite impulse response)

$$y_n = \sum_{k=0}^{M} b_k x_{n-k}$$

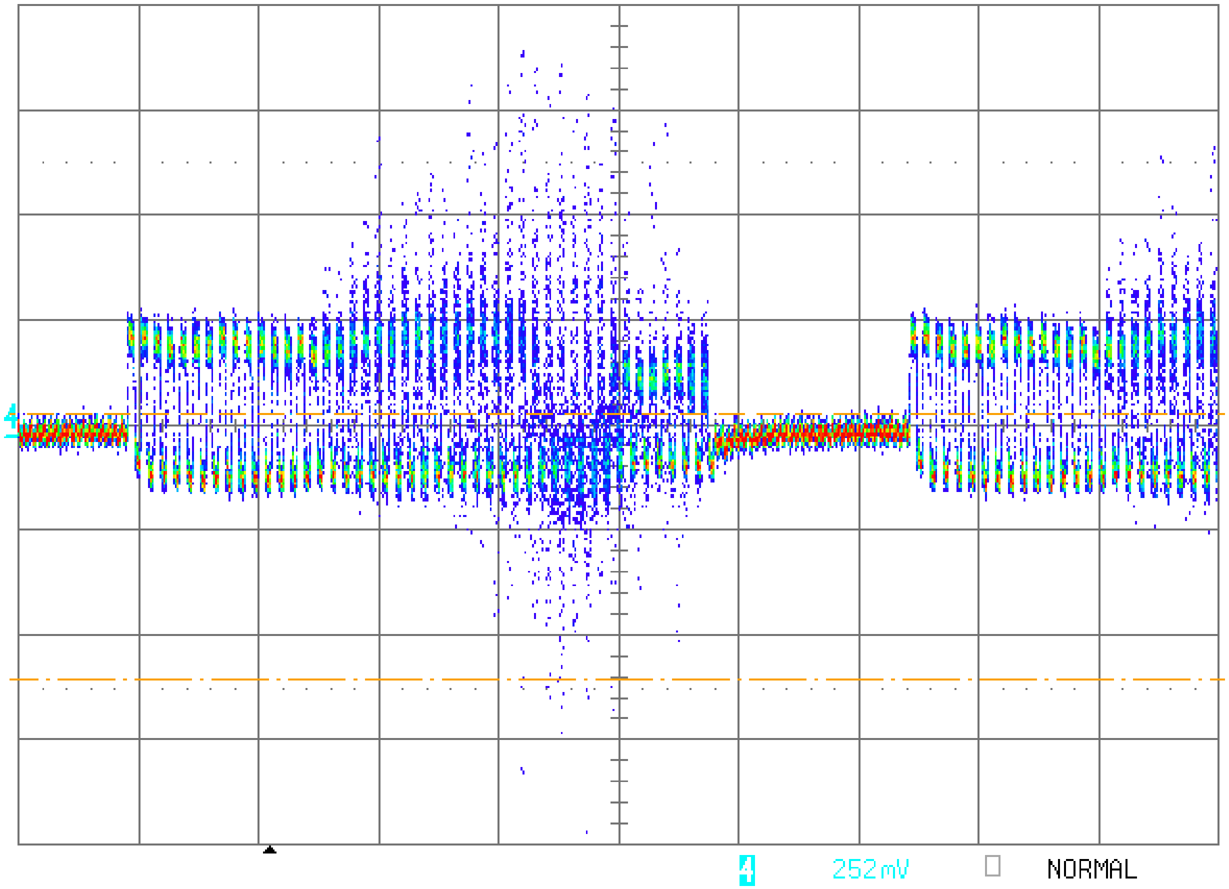
Amplitude and phase response versus frequency of a FIR filter implemented in the DSP farm for high current electron beams. Synchrotron frequency is by dotted line.



Transverse feedback motivations

- In the first years of DAFNE runs, the 120 buckets were non fully populated but, after each bunch, a space of 2 or 3 buckets was let empty (25 or 33 bunches in each ring)
- A gap of 20 bucket was always necessary to avoid ion trapping in the e- beam
- Trying to store and put in collisions more bunches, it was evident a strong vertical instabilities (for beam currents > 250 mA) in the last part of the bunch train limiting the total storable beam current
- This lead to the need of a vertical feedback and a couple of years later to the horizontal feedback

Vertical instability growing along the bunch train and limiting the beam current (year 2001 – both rings)



In single bunch mode, no current limits (>10 times design value)

WEAP048
physics/0111209

FAST ELECTRONICS FOR THE DAΦNE TRANSVERSE FEEDBACK SYSTEMS

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Vertical feedback first "simple" version (ICALEPCS 2001)

Abstract

Transverse feedback systems for controlling the vertical coupled-bunch instabilities in the positron and electron main rings are installed at DAΦNE. They started to be operative respectively from June and September 2000. For the horizontal plane, similar systems have been installed in summer 2001 with less kicker power. Design specifications and the basic system concepts are presented. Real time bunch-by-bunch offset correction is implemented using digital signal processors and dual-port RAM's. Fast analog to digital sampling is performed at the maximum bunch frequency (368 MHz). The system manages at full speed a continuous flow of 8-bits data and it has the capability to invert the sign or put to zero the output for any combination of bunches. A conversion from digital to analog produces the output correcting signal.

1 INTRODUCTION

DAΦNE is a φ–factory, mainly dedicated to the study of CP violation, currently in operation at Frascati (Italy). It has achieved a peak luminosity of ~5*10[31] cm[-2]s[-1] in the Kloe detector interaction region. Moreover, maximum currents of 1411mA in the electron ring and 1150mA in the positron one have been stored. In Table 1, some DAΦNE parameters are shown.

Table 1: DAΦNE parameters

Ring	e- / e+
Energy	0.510 GeV
Circumference	97 m
RF frequency	368.29 MHz
Harmonic #	120
Rev. frequency	3.069 MHz
Betatron tune x	5.1170 / 5.1615
Betatron tune y	5.1623 / 5.2244
Horizontal freq.	360 / 495 kHz
Vertical freq.	498 / 689 kHz
Max bunch curr	~44.1 mA
Bunch distance	2.7 nsec
Typ. fill pattern	47 stepped by 2

At the beginning of 2000, during commissioning, it was decided to install vertical feedback systems on the two main rings. Similar devices have been successfully used in other colliders or synchrotron light sources [1 - 7], however the design of our system is peculiar under some aspects. The design of the system developed at the Frascati laboratory was stepped in two phases: the first one was made operative in June 2000 and at the begin of 2001 the power of the back end stage was increased [8]. The e+ system is shown in figure 1.

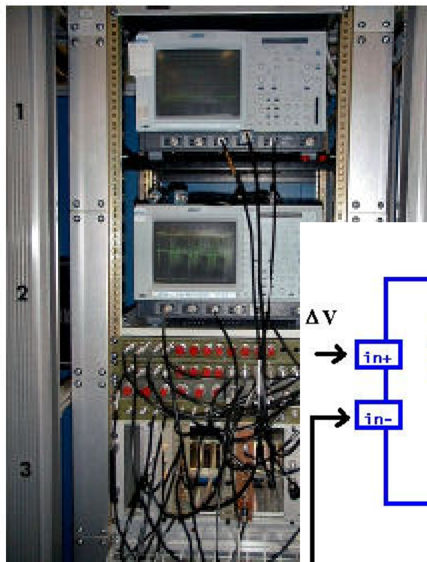
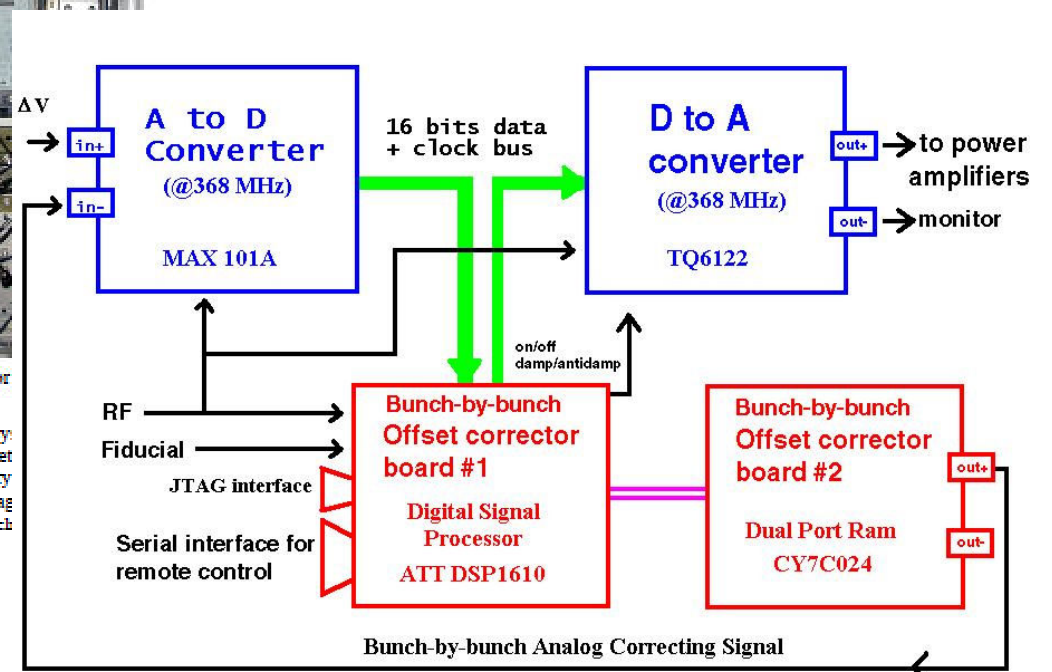


Figure 1: Vertical Feedback running for

In the second phase, the feedback sy modules added to the first version set under test. It can allow more flexibility a better performance of the power stag more efficient signal by a bunch correction scheme.



G-proto collaboration:

since **Oct.2005**, a prototype installed on DAFNE, horizontal e+ fb, tested @ PEP-II and KEK

Vmic 7750 (VMEbus) connected by 2 USB i/f

EPAC'06 Poster THPCH103

Design and testing of Gproto bunch-by-bunch signal processor *

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A. Drago, LNF-INFN, Frascati, Italy
J. Flanagan, T. Naito, M. Tobiyama, KEK, Tsukuba, Japan

Abstract

A prototype programmable bunch-by-bunch signal acquisition and processing channel with multiple applications in storage rings has been developed at SLAC. The processing channel supports up to 5120 bunches with bunch spacings as close as 1.9 ns. The prototype has been tested and operated in five storage rings: SPEAR-3, DAΦNE, PEP-II, KEKB, and ATF damping ring. The testing included such applications as transverse and longitudinal coupled-bunch instability control, bunch-by-bunch luminosity monitoring, and injection diagnostic. In this contribution the prototype design will be described and its operation will be illustrated with the data measured at the above-mentioned accelerators.

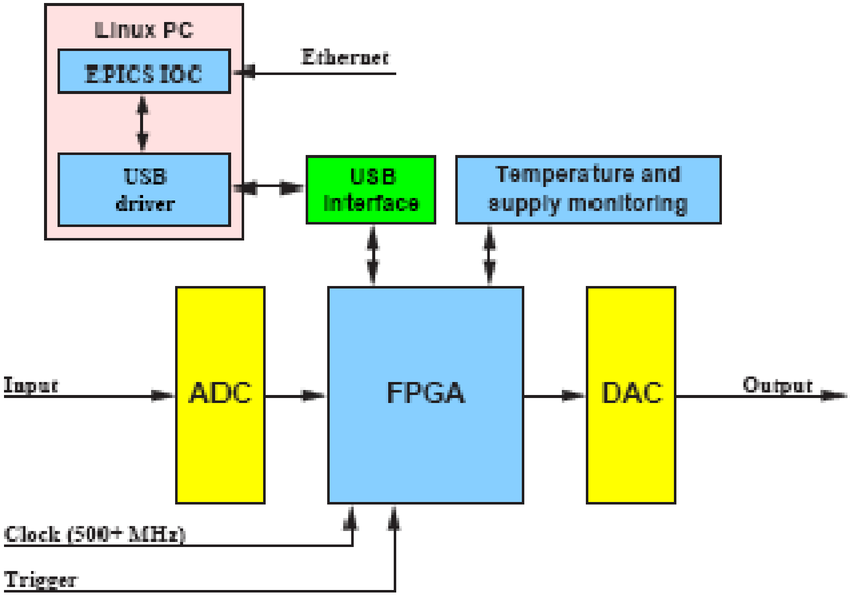
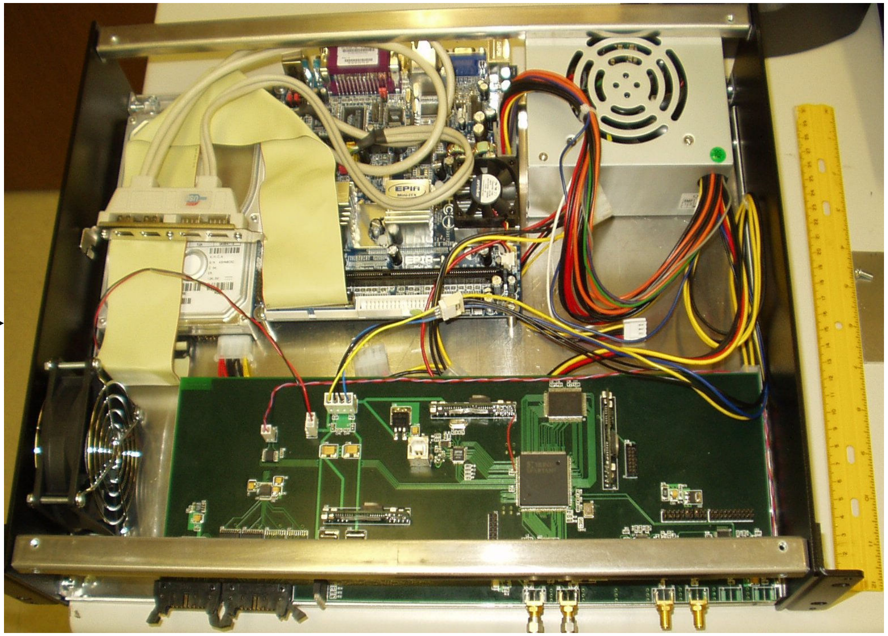


Figure 1: Gproto block diagram

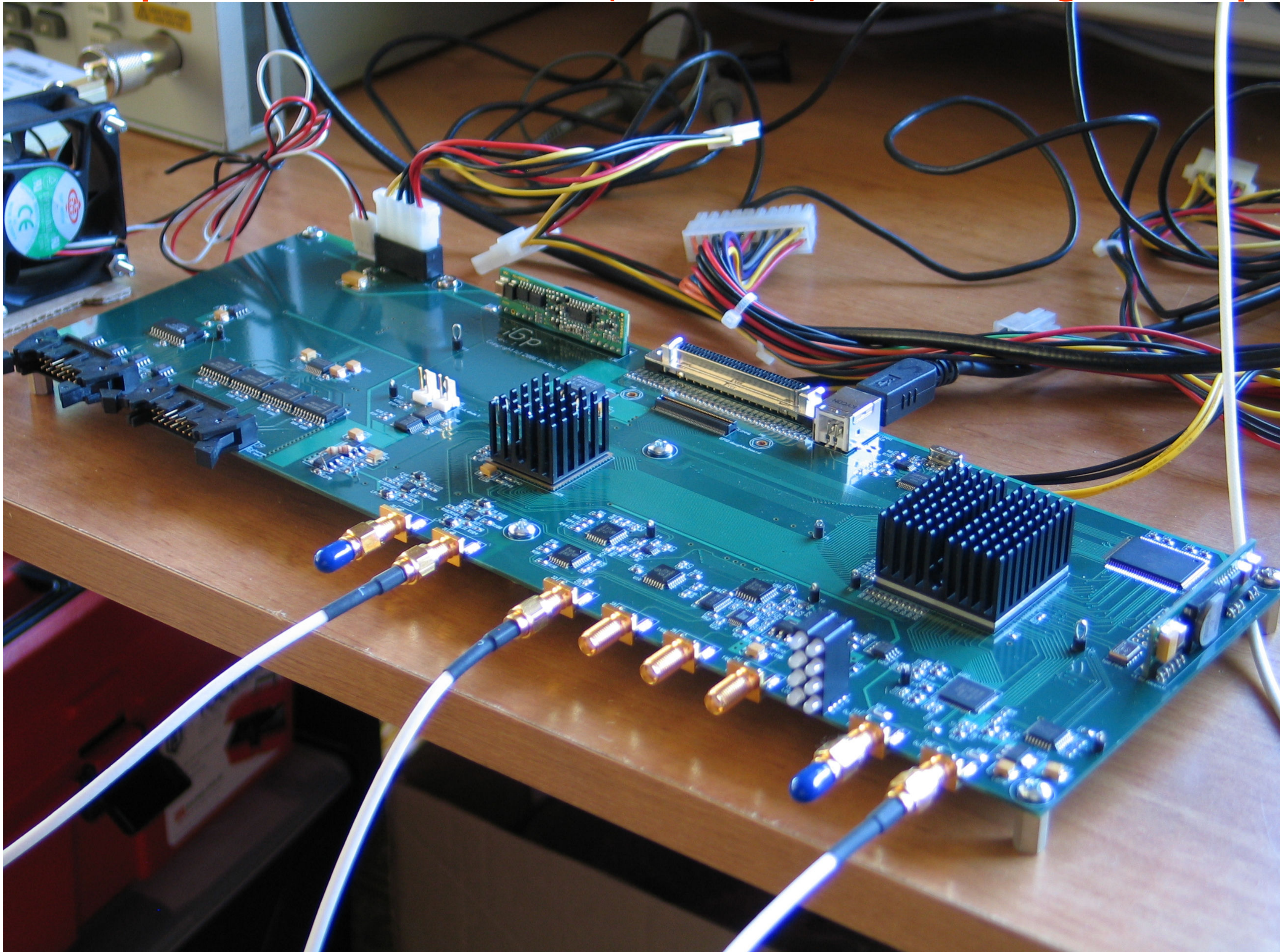
Since May 2006 a more recent and compact version: the **iGp** feedback (integrated Gigasample processor) - Tested or installed at KEK, SLAC, and DAFNE. Later installed also in ALS, CESR-TA, and other accelerators

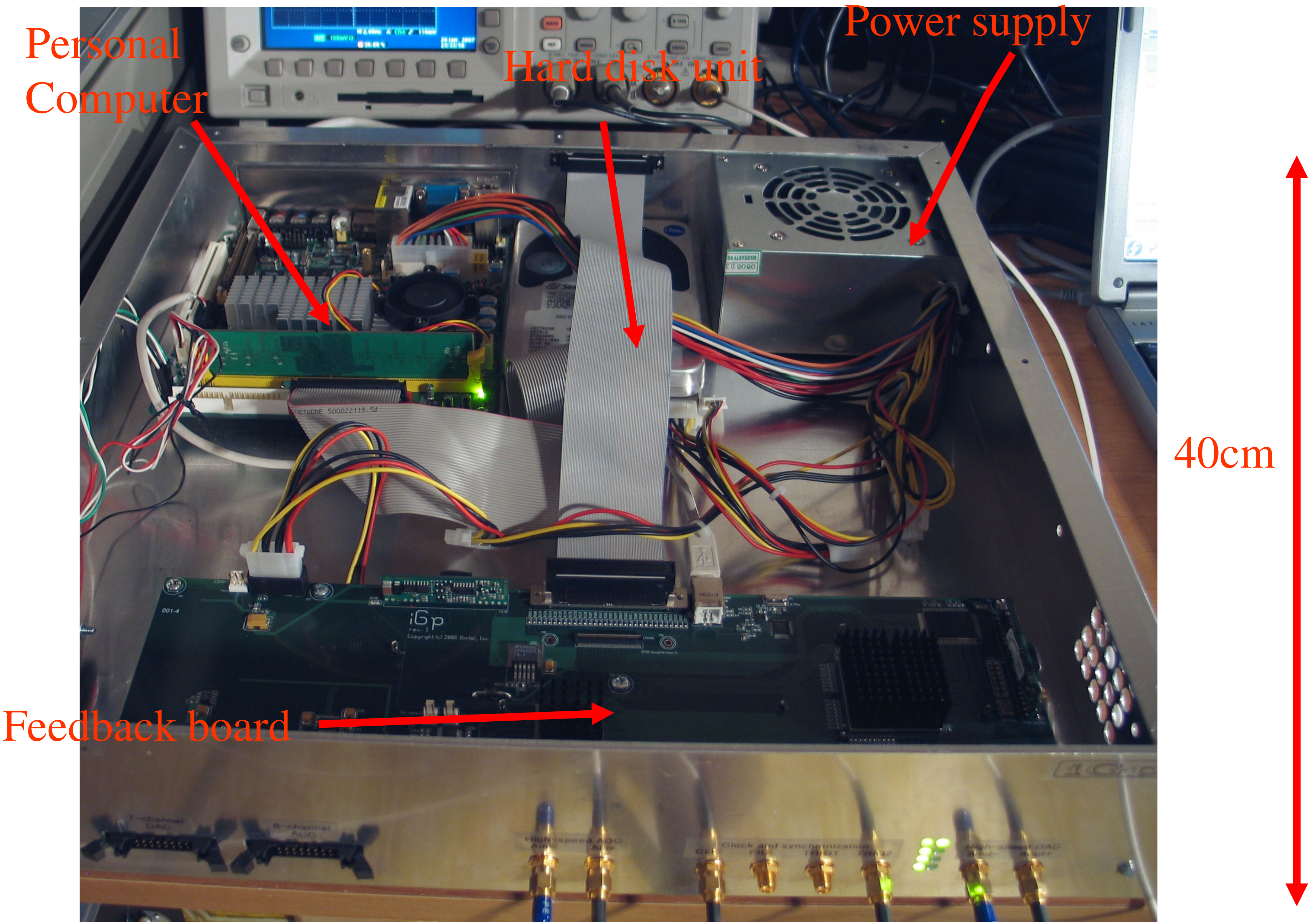


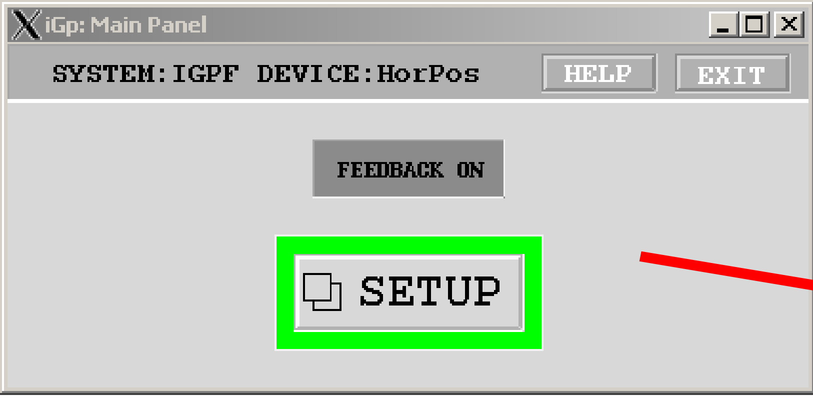
II generation digital bunch-by-bunch feedback designed for SuperB factories by a collaboration KEK-SLAC-LNF [EPAC2006, WEPB28].

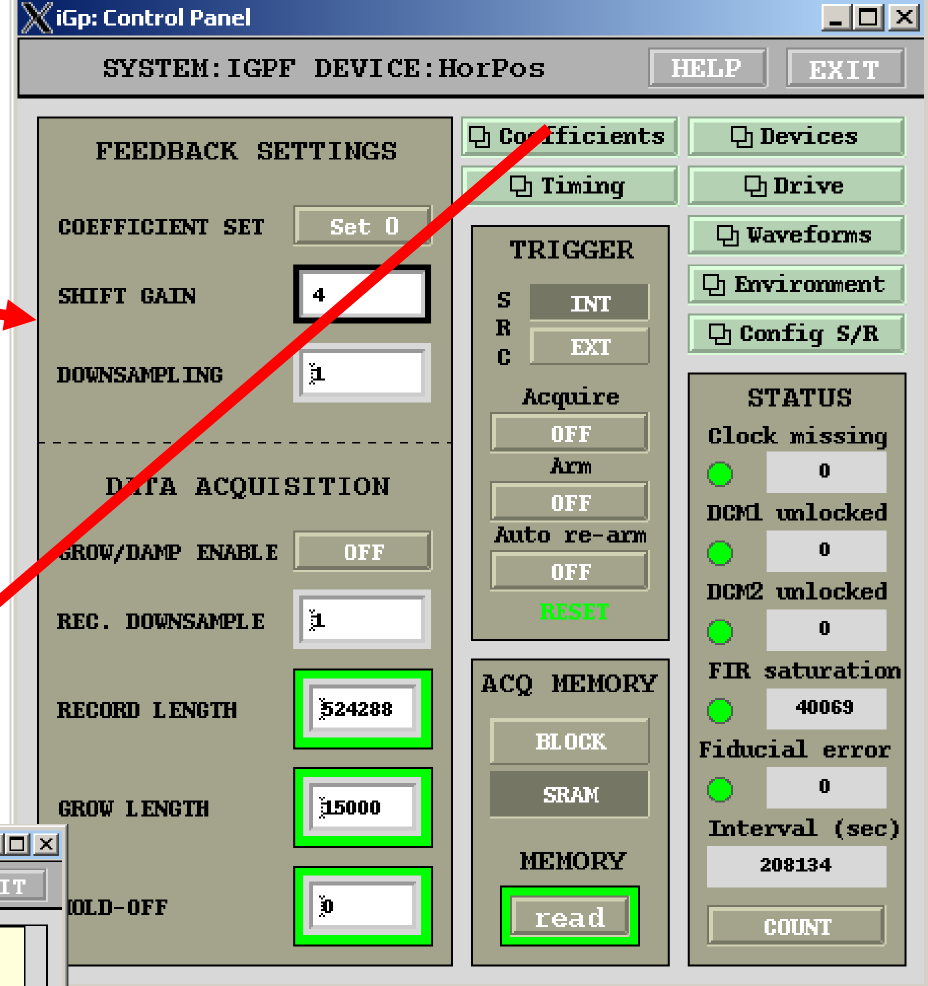
- Features:
  - even more compact
  - gain & phase digital by remote control
  - possibility to manage **any** betatron or synchrotron tunes
  - robust response to big oscillations @ injection (FIR filter 8/16 taps)
  - real time parameter monitoring
  - powerful beam diagnostics (legacy from the previous system)
  - main DSP loop based on FPGA (Field Programmable Gate Array)

iGp: the feedback (almost) in a single chip

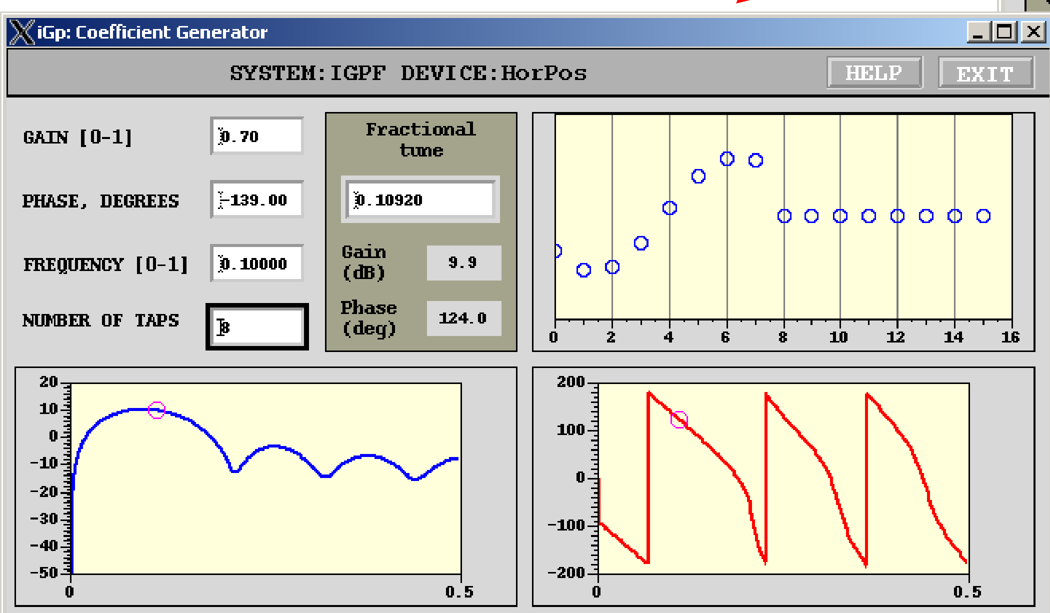



Personal Computer
Hard disk unit
Power supply
Feedback board
40cm
iGp





How to build a new real time FIR filter



User-friendly operator interface

Present feedback status

- DAFNE has seven bunch-by-bunch feedbacks currently running.
- On the e+/e- transverse planes there are 4+1 “iGp” feedback units.
- On the longitudinal planes the old “DSP-based” system is still used.
- From 1997 to now DAFNE has progressively increased the beam current to 2.4A (for e-) and 1.4A (e+)
- Total feedback power = (750+500+500)x2+500W = 4000 W !!!
- And we have bought 2 new 500W amplifiers…

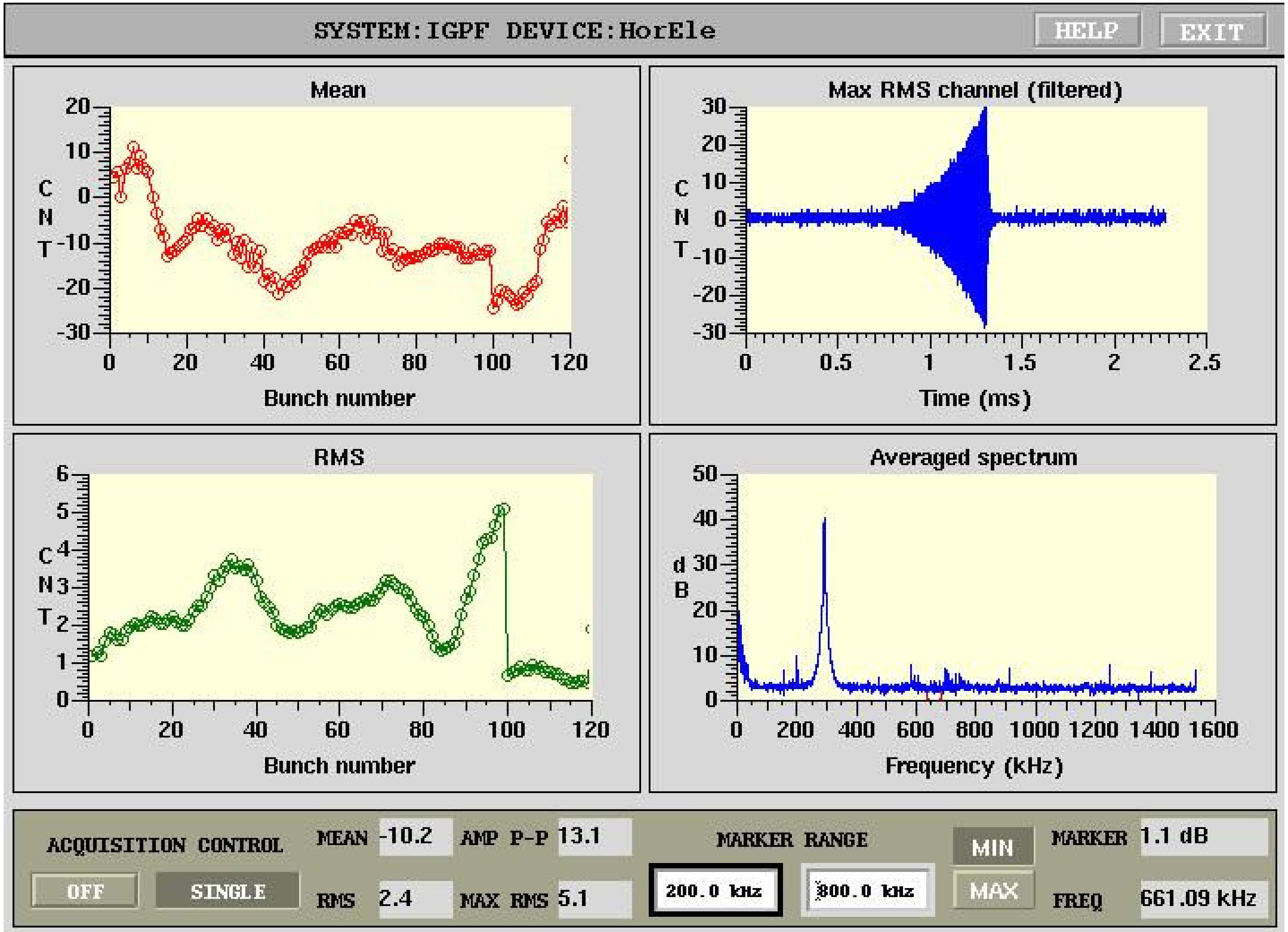
Diagnostic tools inside the feedback system:

- Input signal record with trigger from operator
- Growth / damping record with trigger from operator
- Record on injection with injection trigger from the timing system
- Store of recorded data in a time-stamped database
- Off-line analysis on the database
- Beam modal analysis (mode numbers and growth rates)
- Injection data analysis to study the injection kicker performance
- Bunch-by-bunch tune spread analysis

DAFNE grow rates studies done by diagnostics inside the feedback

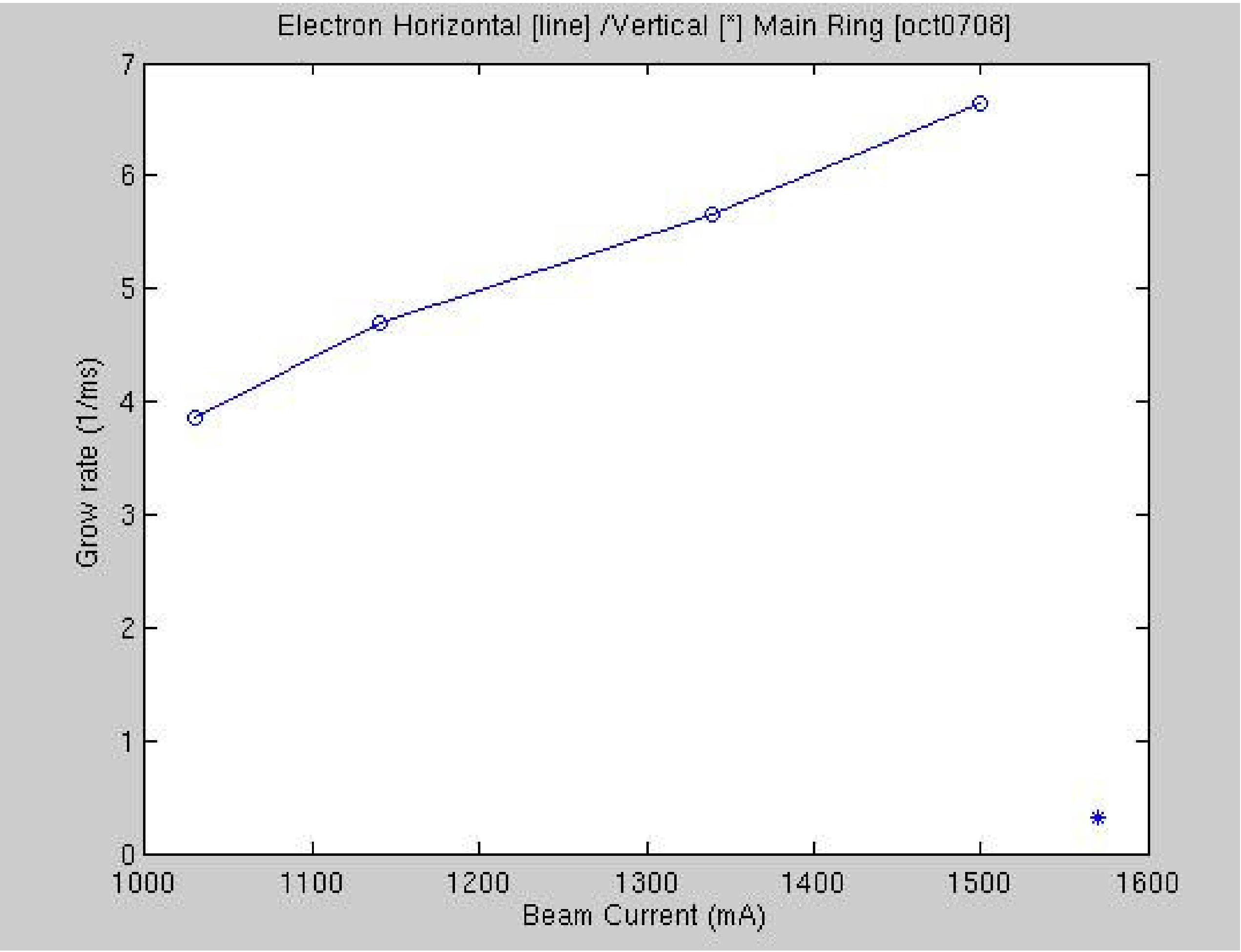
- Asymmetric behavior between e+ and e- maximum current in main rings
- In the past years, no evident limit for the e- current ($I^- > 2.4A$), while the positron current limited a strong horizontal instability to ~1.1A (single beam), or <1.4 A (in collision)
- After the June'08 shutdown, e+ current limited to less than 800mA, much worse before
- Measurements versus different optics parameters
- Comparison versus e-cloud simulations

e- beam, I=1140mA, 100/120 bunches [October 7, 2008]



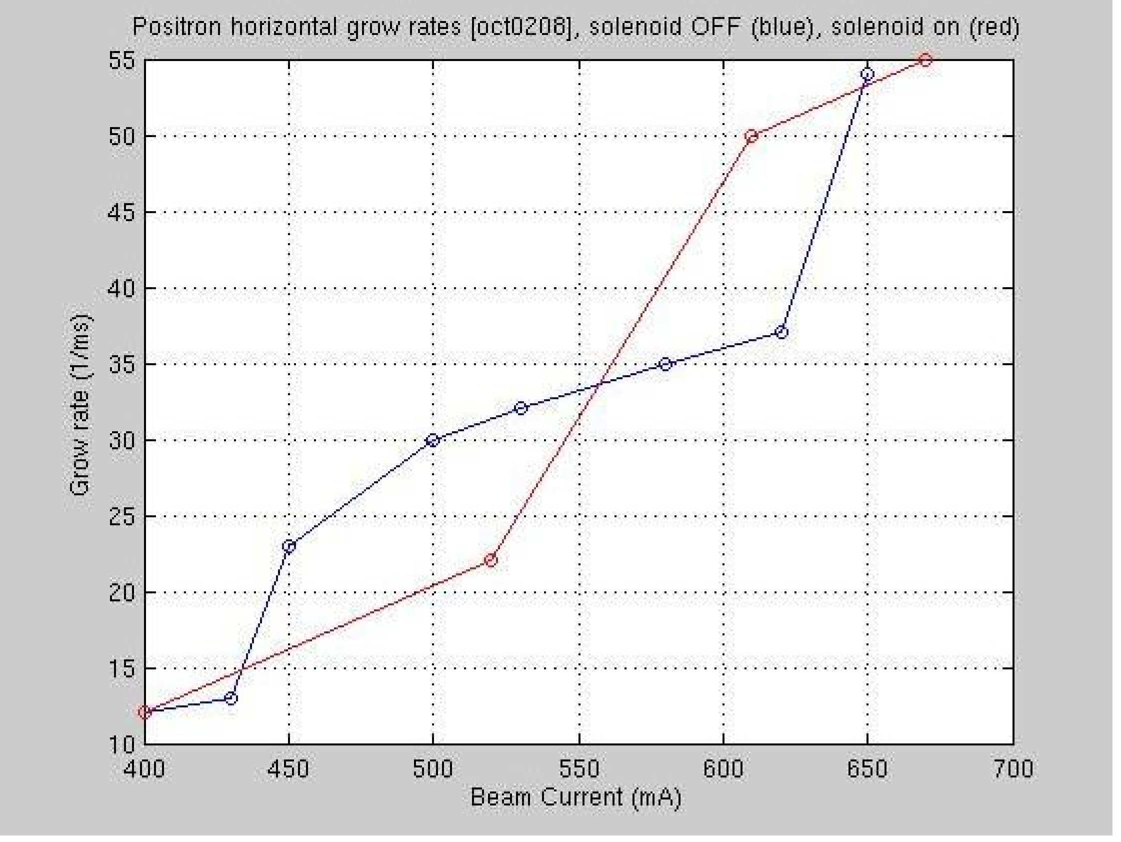
Real time waveform plot by the "iGp" feedback system

DAFNE e- ring, Imax=1.5 A, 100/120 bunches [October 7, 2008]



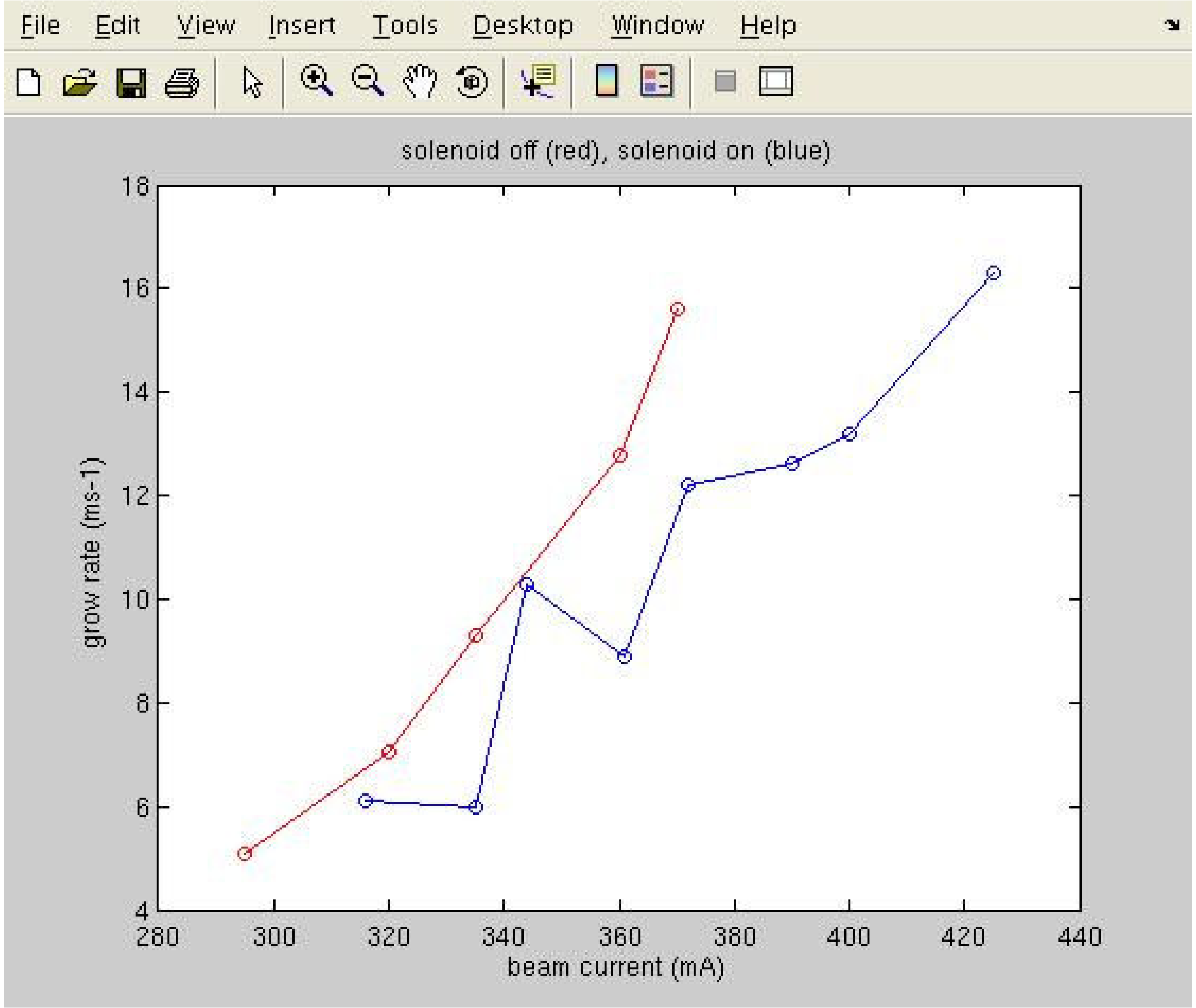
Slow unstable mode compared with e+ beam

DAFNE e+ horizontal instability behavior switching solenoids off (blue) & on (red)



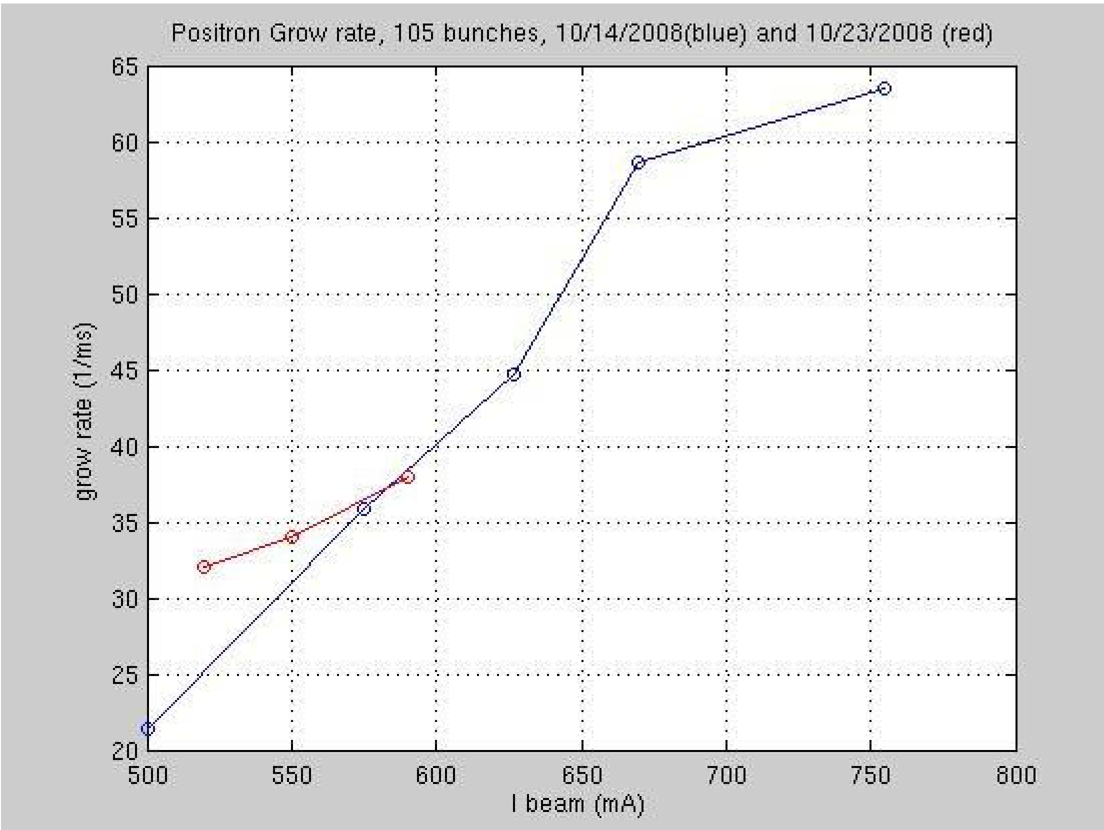
- Switching off the solenoids installed in the positron ring the grow rates of the e+ instability does not change

DAFNE e+ vertical instability behavior switching solenoids off (blue) & on (red)



- e+ vertical grow rates (ms-1) versus beam current
- Solenoids are useful for the vertical plane making slower the growth rates

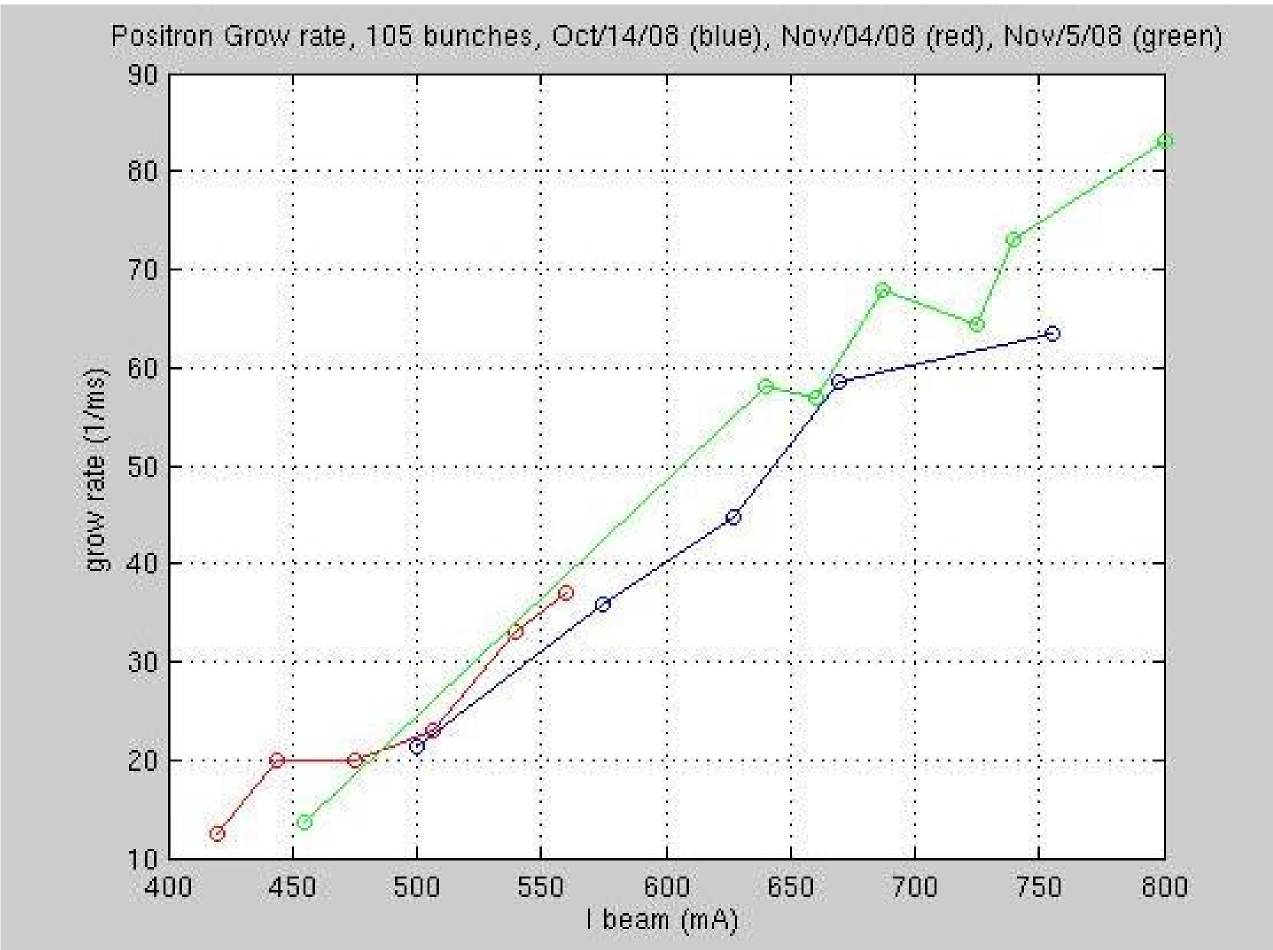
DAFNE e+ instability grow rates by halving βx in the RF cavity



- OPTICS for collision (blue)
- βx 4 [m] -> 2 [m] in the RF cavity (red)
- $\nu+_x = 6.096$,
- $\nu+_y = 5.182$
- $\Delta\nu+_x$ between the Wigglers unchanged

Conclusion: the instability does not depend on hypothetical high order mode in the e+ RF cavity

DAFNE e+ instability grow rates versus Δνx in PS1-PS2 and RCR



OPTICS:

- Collision

  mode m = -1 (blue)

- Δνx = + 0.5 (PS1÷PS2)

  νx = νy

  mode m = 0 (red)

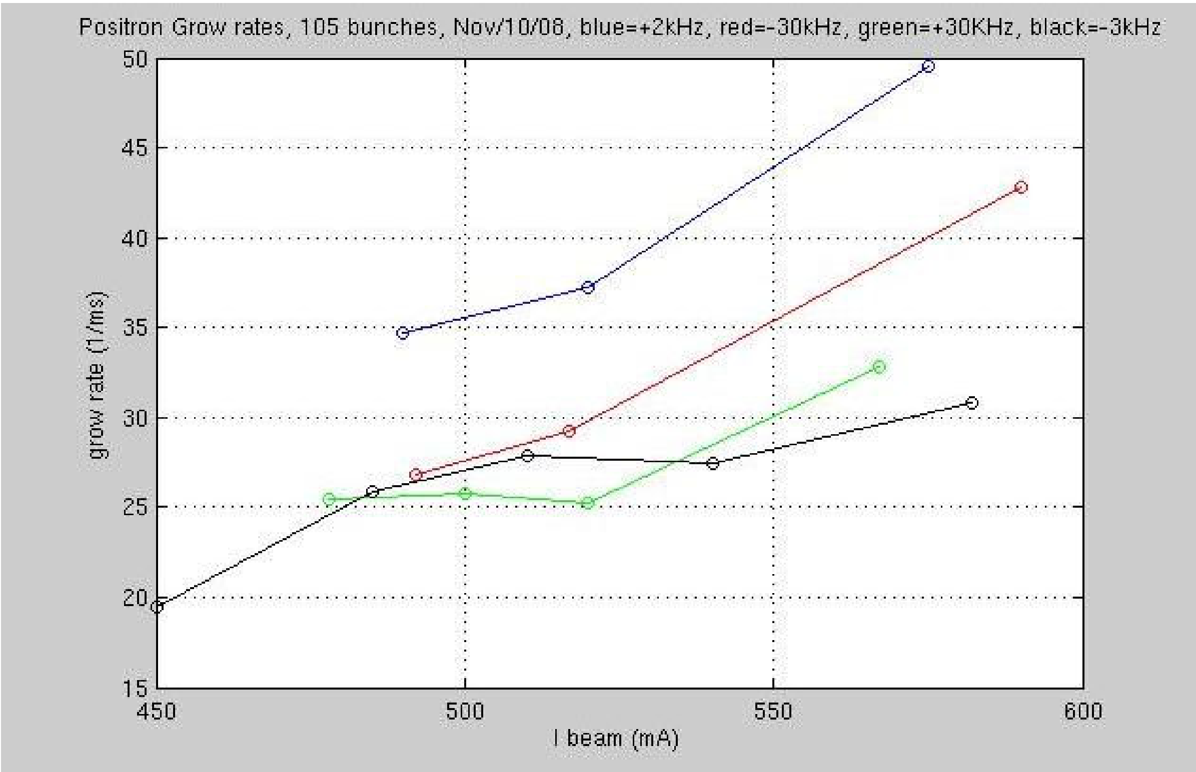
- Δνx = + 1.0 (0.5 in PS1÷PS2 0.5 in RCR)

  νx = νy

  mode m = -1 (cyan)

This is to study the e+ instability as a function of the relative phase advance between the WGLs

DAFNE e+ instability grow rates versus orbit in the main ring dipoles

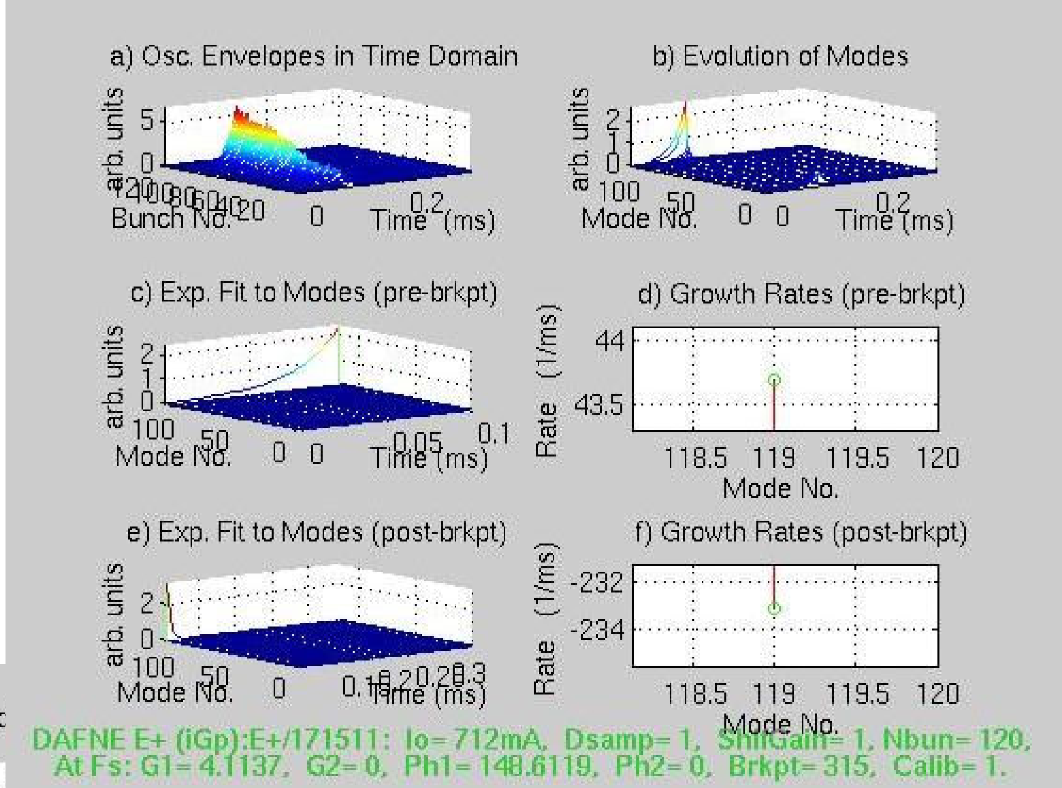


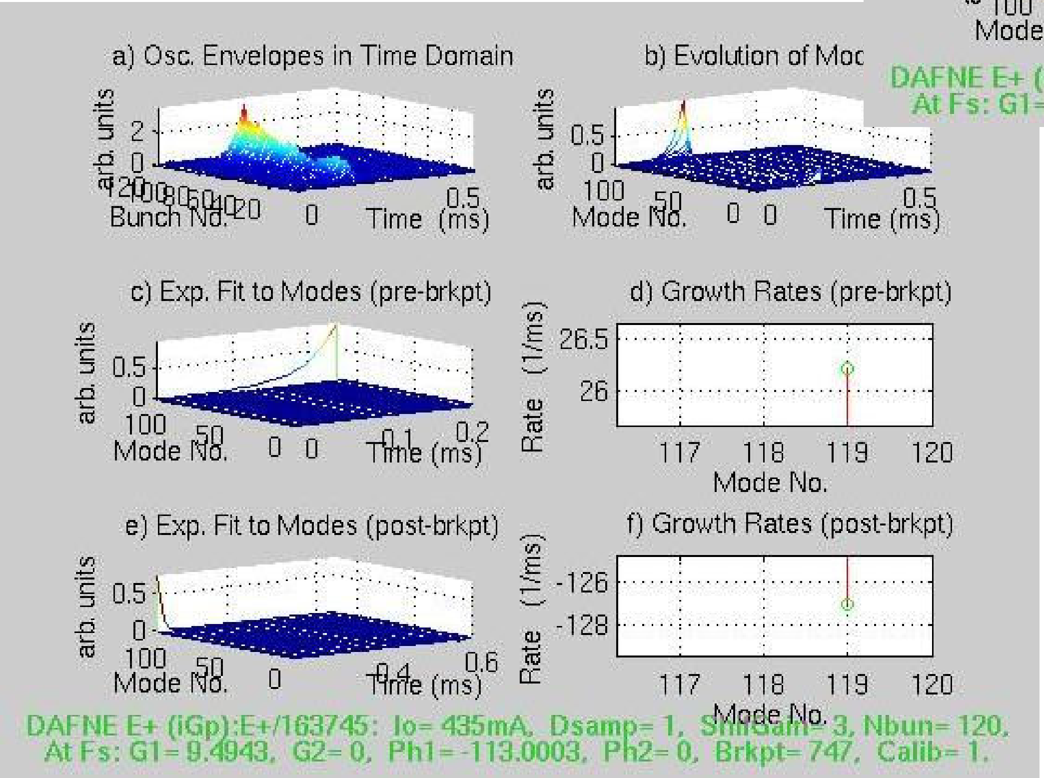
- The orbit variation shows **<u>important differences</u>** from the point of view of understanding the instability source
- but not to solve completely the e+ current threshold

Positron beam trouble on the horizontal plane

- Double feedback in the same oscillation plane to use at the best the power output
- A proved example of the scalability advantages
- Possibility to have and manage easily more than one feedback in a single oscillation plane
- Capability to damp coherent high order modes even if faster than foreseen

DAFNE, single horizontal feedback:
I=560mA, mode -1 [=119] , grow=34.5 (ms-1), damp=-127(ms-1)





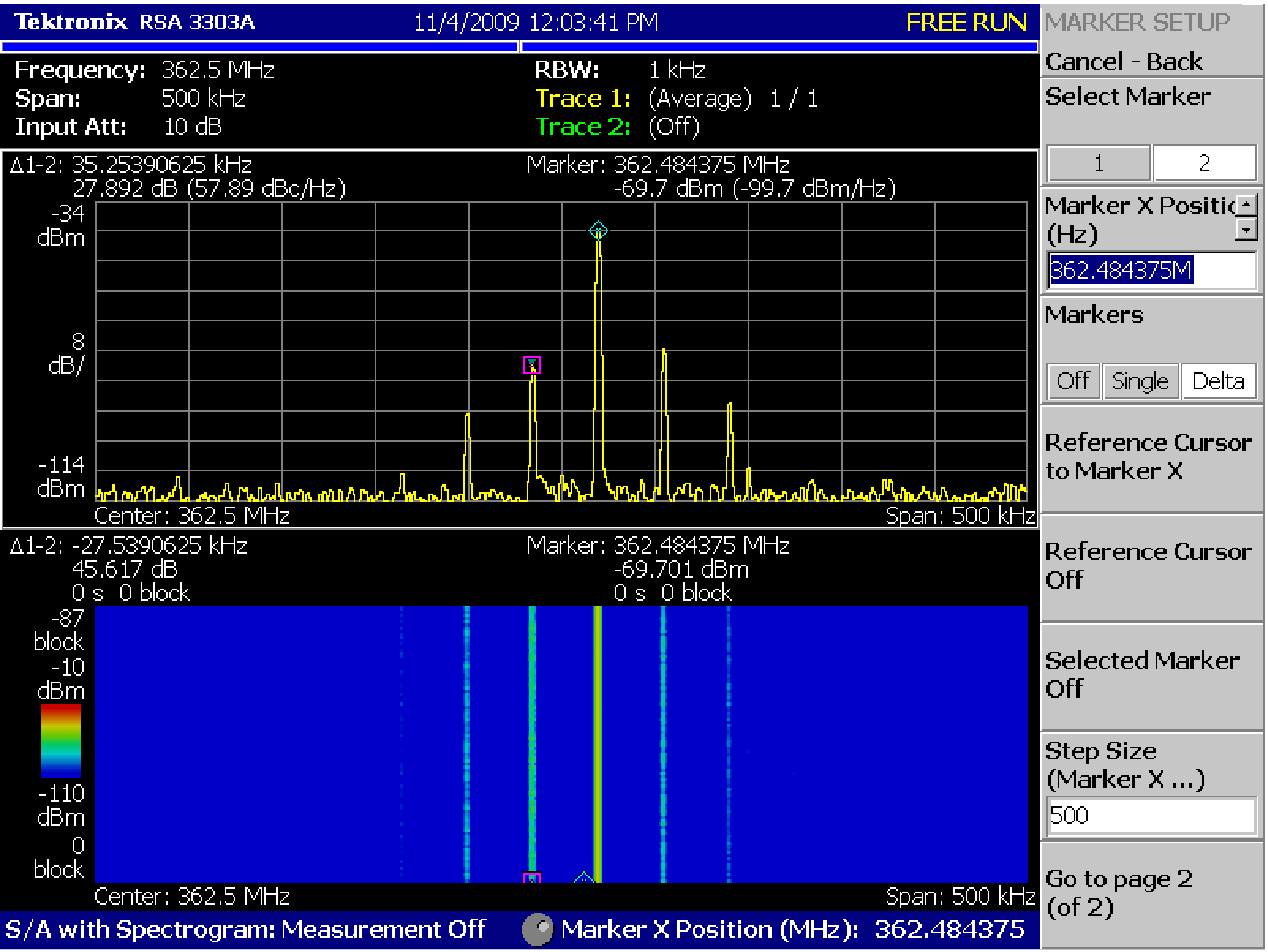
DAFNE, double horizontal feedback:
I=712mA, mode -1 [=119] , grow=43.7(ms-1), damp=-233 (ms-1)

Damping time
in 4.3 microsecond
i.e. in ~13
revolution turns

Beam-beam longitudinal damping studied through the feedback diagnostics

Longitudinal sidebands in e+ beam

(set of measurements recorded at DAFNE in 11/2009)

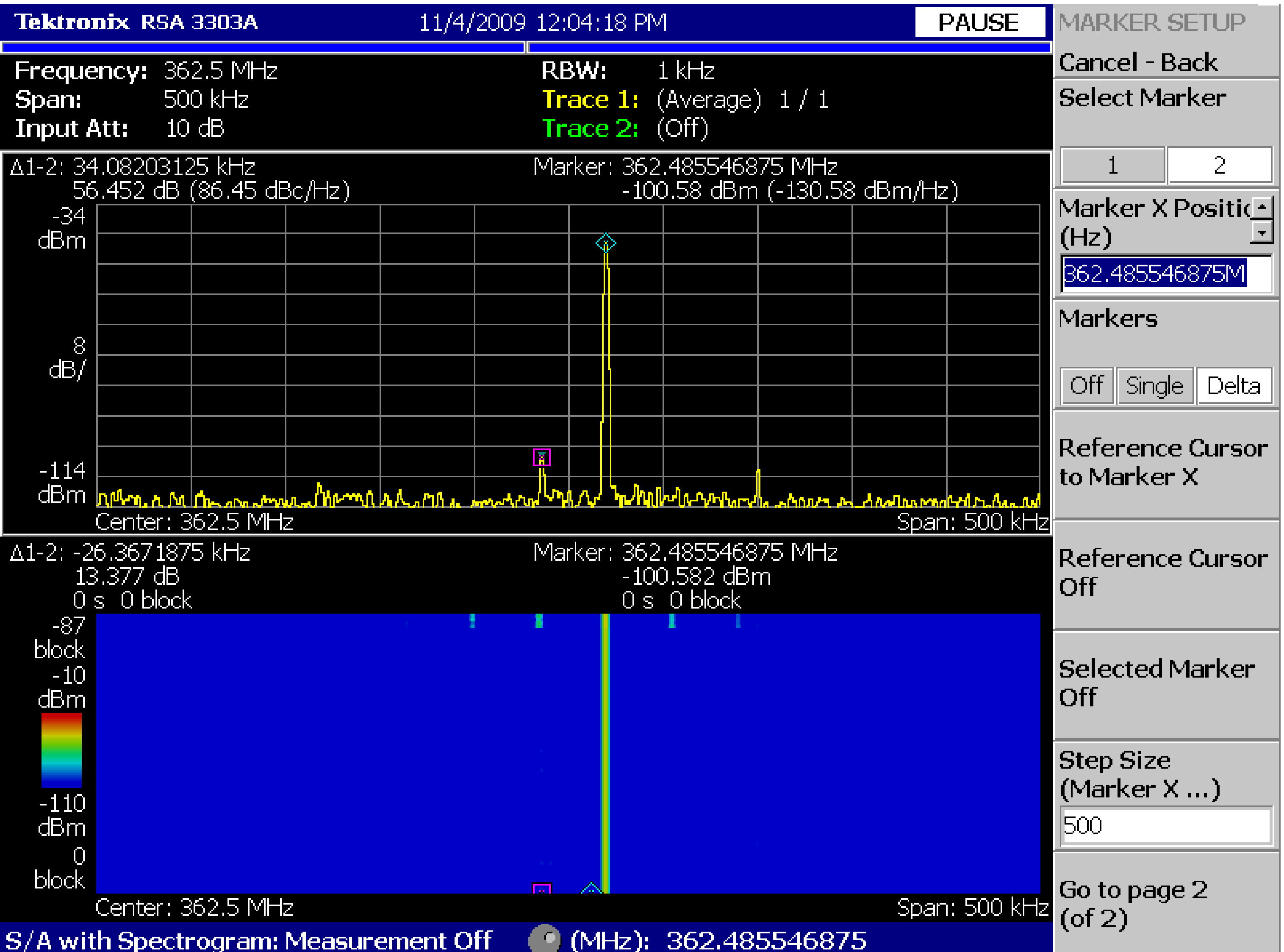


I+ = 200mA

e+ longitudinal feedback off

No collisions at the IP

Longitudinal sidebands in e+ beam in collision with e- beam



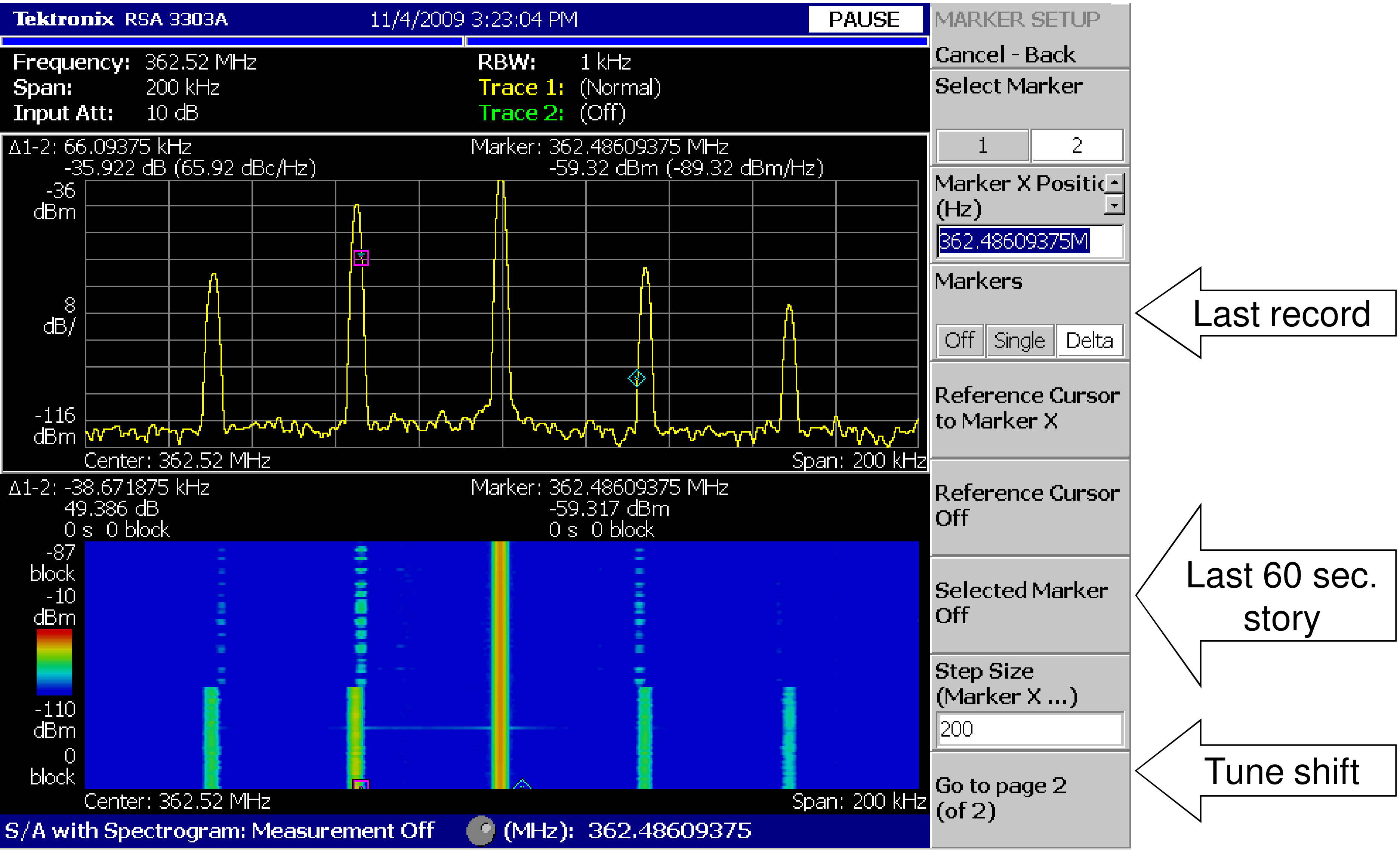
I+beam = 200mA

Longitudinal feedback off

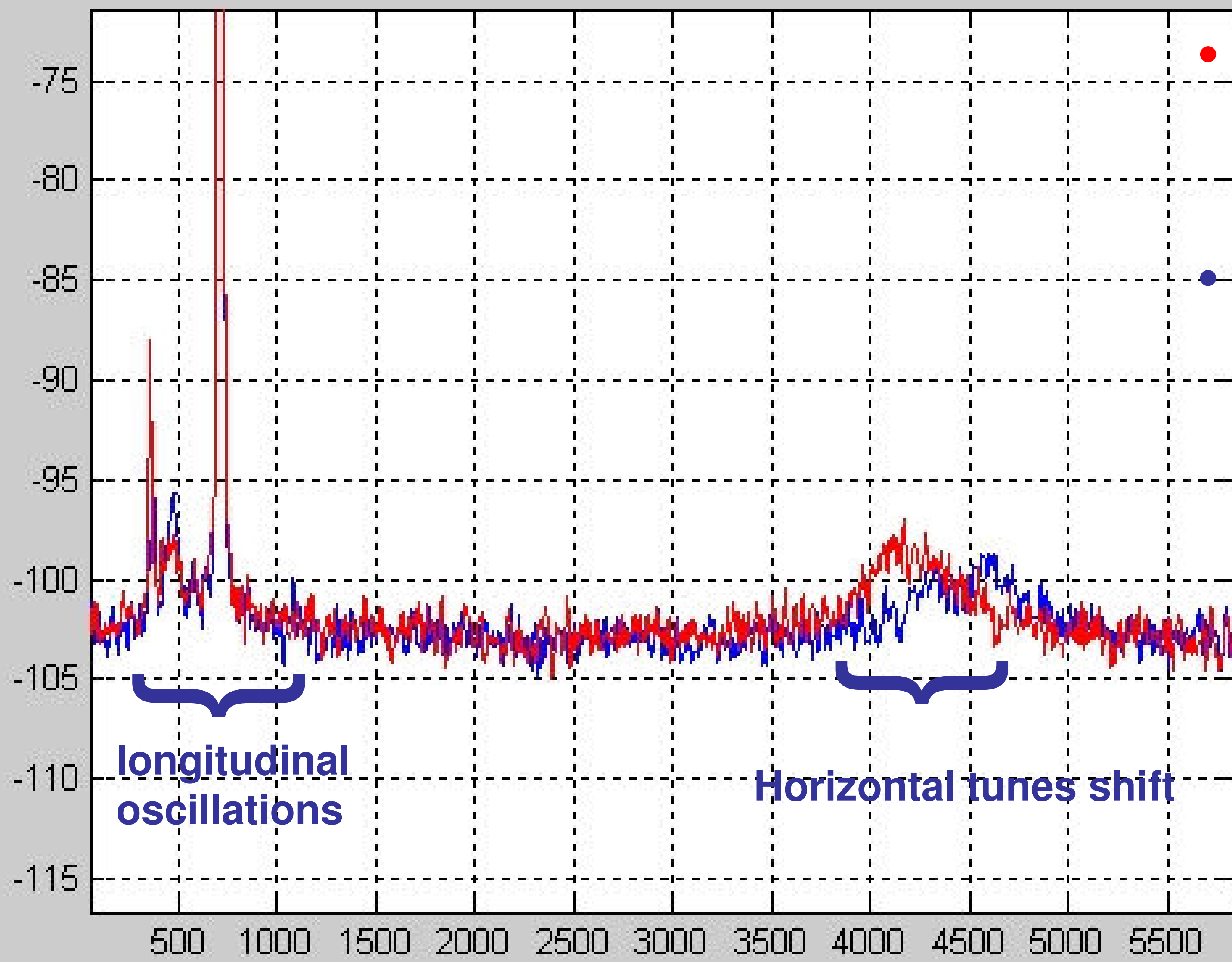
collisions at the IP with the e- beam

Record by Tektronix S.A. 3303

In collision ←→ out of collision

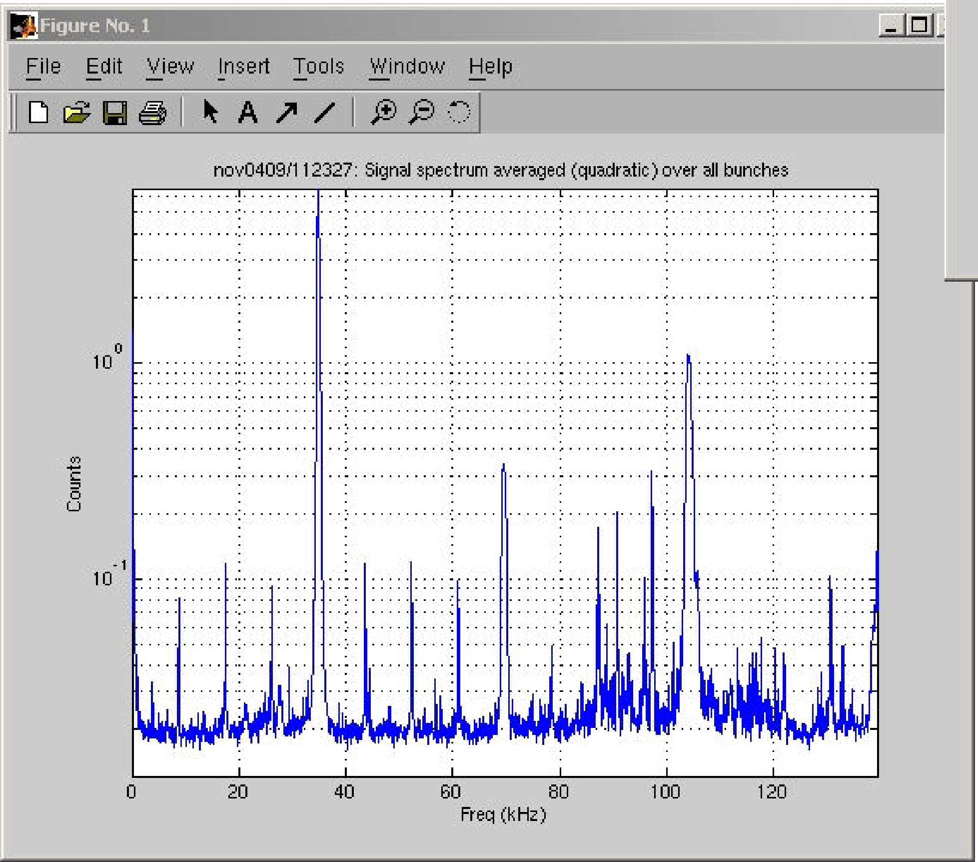


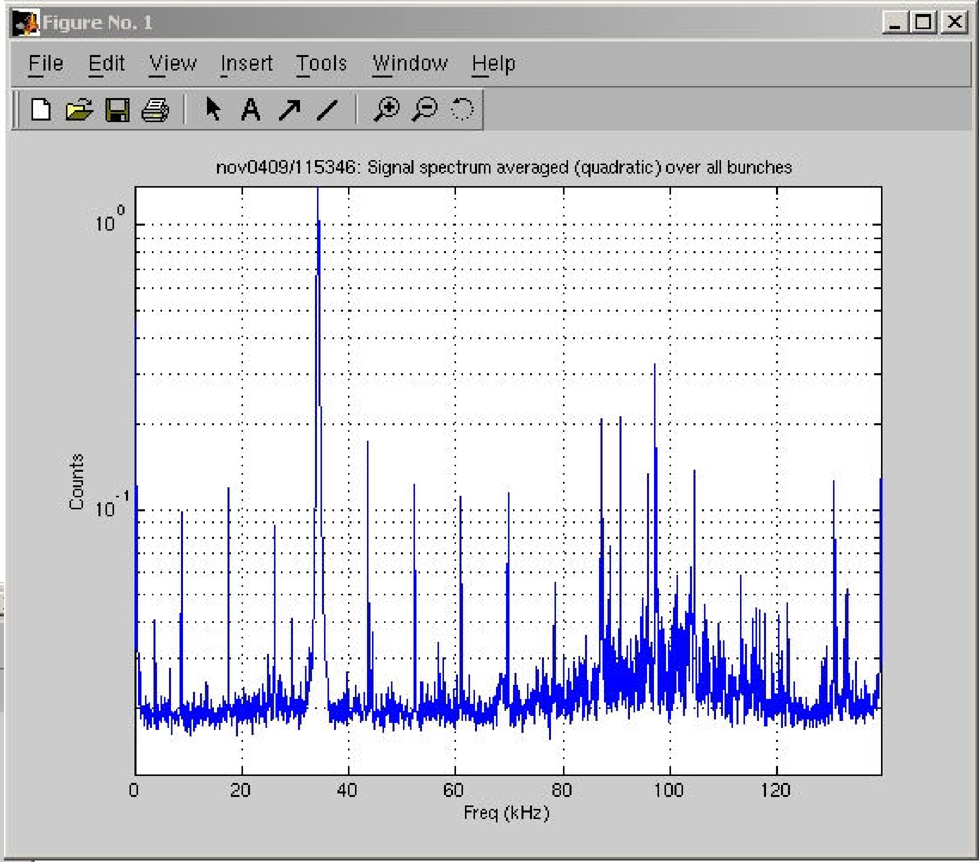
Diagnostics by longitudinal feedback



- Red trace: no collisions
- Blue trace: beams in collisions

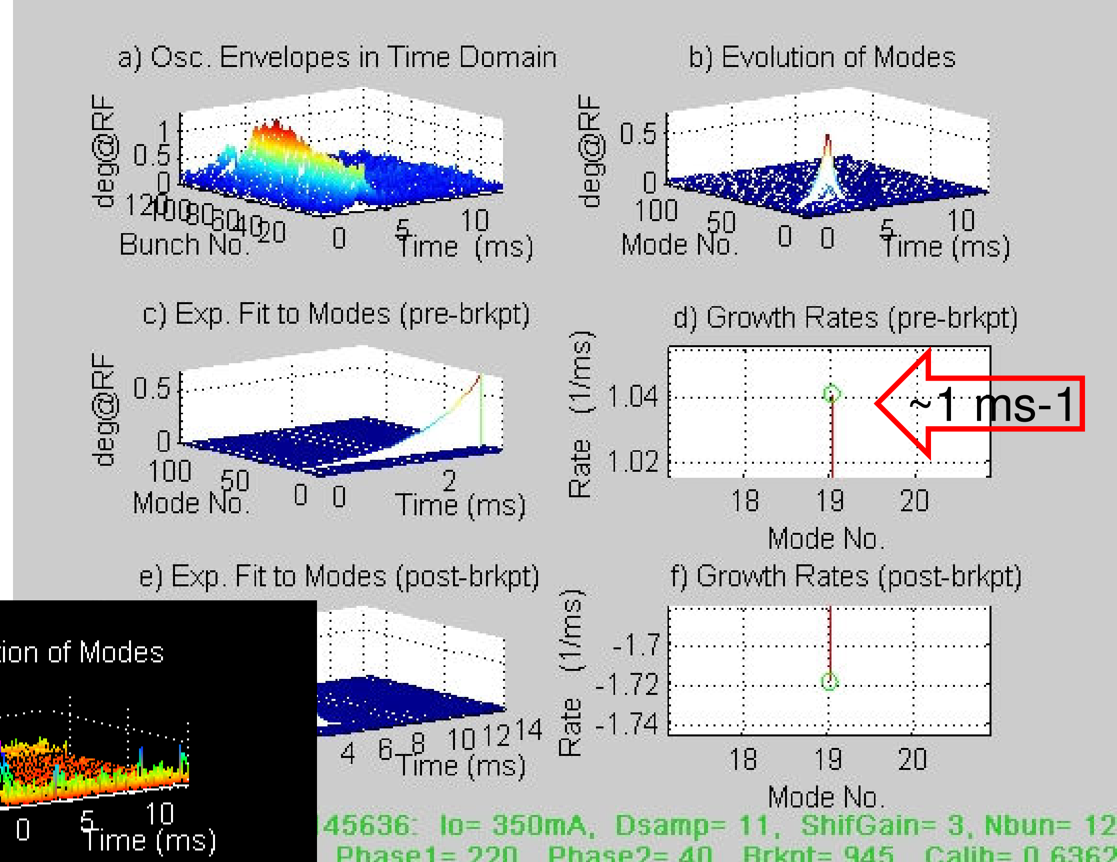
Out of collision



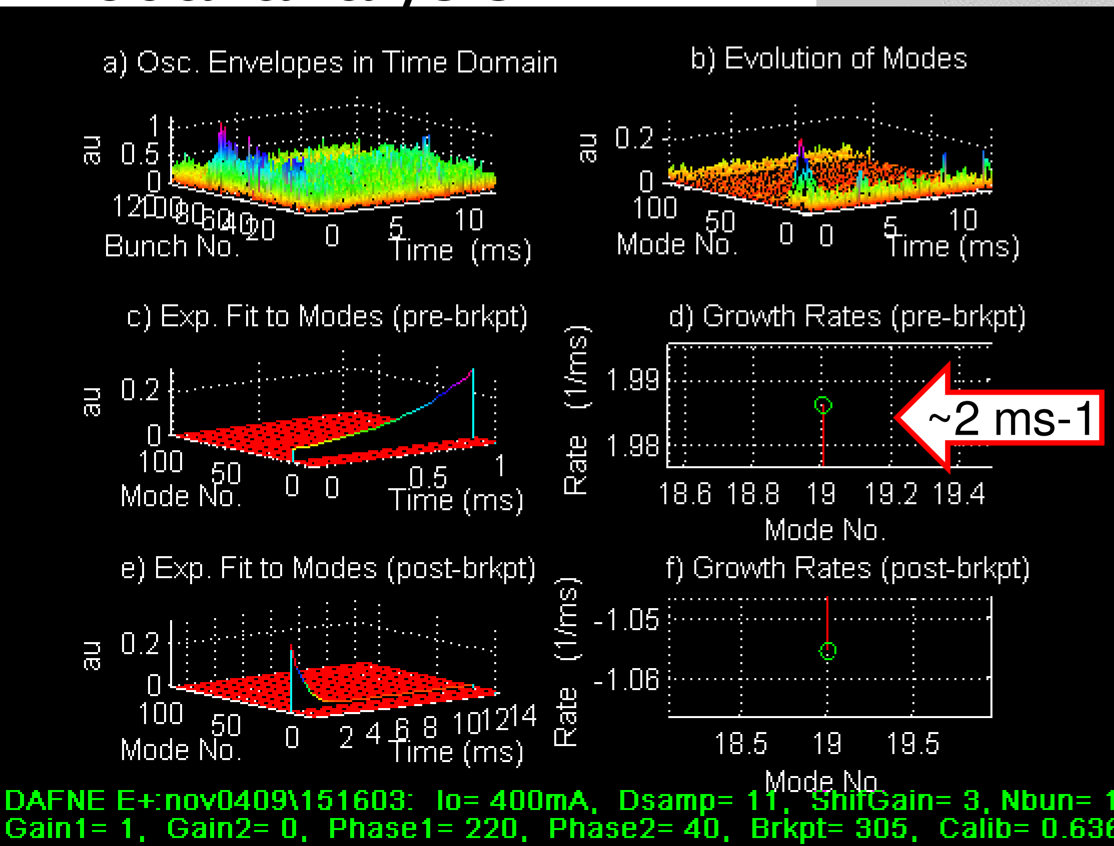


In collision

In collision e+ long. modal analysis

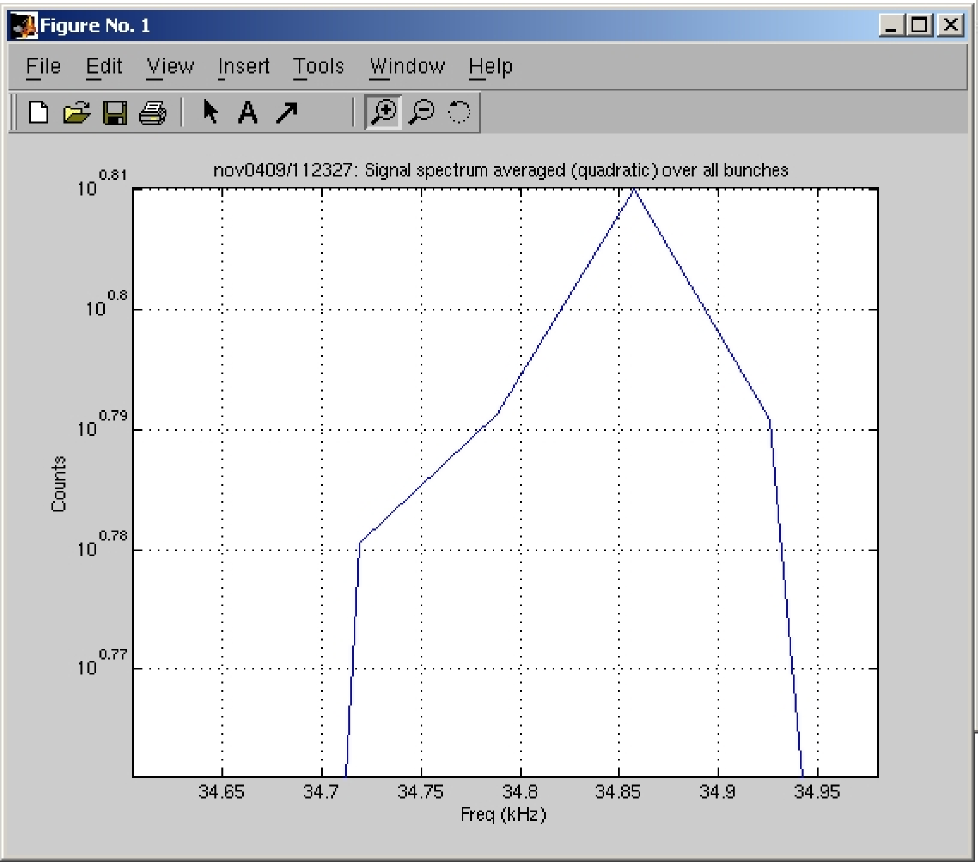


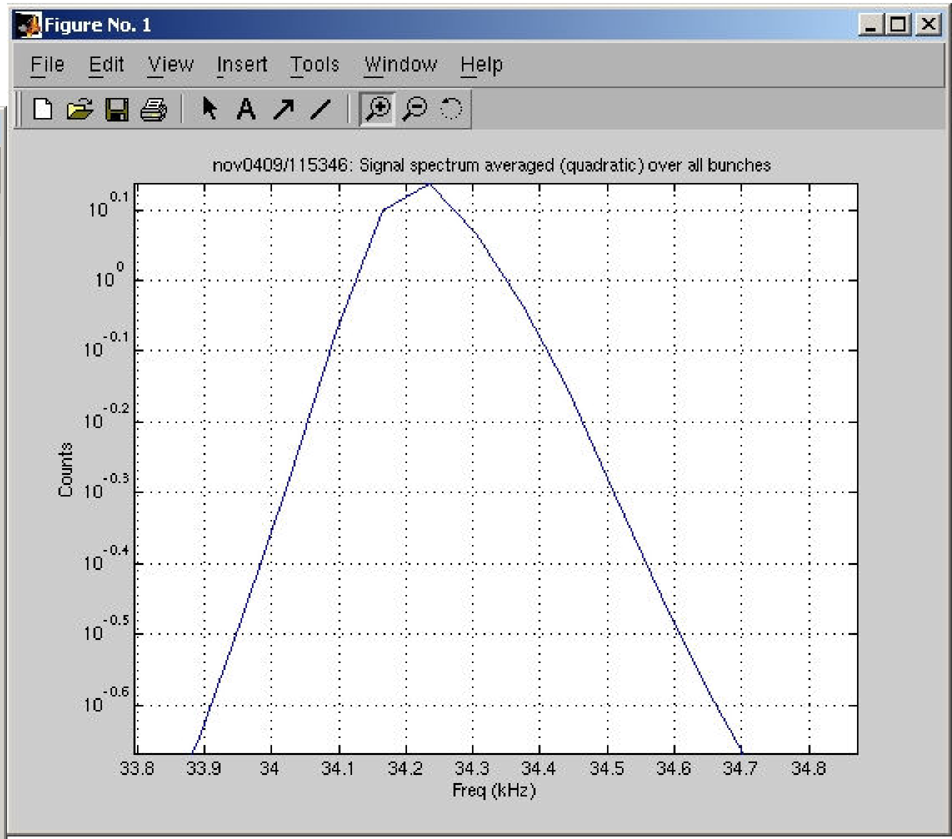
Out of collision longitudinal modal analysis



Difference=~-600Hz

Out of collision:
f_sync=34.8 kHz





In collision:
f_sync=34.2 kHz

Abstract submitted at IPAC'10

SYNCHROTRON OSCILLATION DAMPING DUE TO BEAM-BEAM COLLISIONS

A.Drago, M.Zobov, P.Raimondi.

In DAFNE, the Frascati e+/e- collider, the crab waist collision scheme has been successfully implemented in 2008 and 2009. During the collision operations for Siddharta experiment, an unusual synchrotron damping effect has been observed. Indeed, with the longitudinal feedback switched off, the positron beam becomes unstable with beam currents in the order of 200-300 mA. The longitudinal instability is damped by bringing the positron beam in collision with a high current electron beam (~2A). Besides, we have observed a shift of ≈600Hz in the residual synchrotron sidebands. Precise measurements have been performed by using a commercial spectrum analyzer and by using the diagnostics capabilities of the DAFNE longitudinal bunch-by-bunch feedback. This damping effect has been observed in DAFNE for the first time during collisions with the crab waist scheme. **Our explanation is that beam collisions with a large crossing angle produce a longitudinal tune shift and a longitudinal tune spread, providing Landau damping of synchrotron oscillations.**

Low emittance beams ask for small impact feedback design.

Horizontal and vertical emittances can be calculated using the following formula:

$$\sigma_i^2 = \beta_i \, \varepsilon_i + (\eta_i \, \sigma_\varepsilon)^2$$

where σ_i is the measured beam size in the horizontal or vertical plane (i= x, y), β_i and η_i are respectively the betatron and dispersion functions at the source point in the corresponding plane; and ε_i and σ_ε are the emittance and the relative energy spread of the e+ / e- beam.

From the above formula, it is evident that an increment of the beam size leads directly to an emittance growth.

The feedback systems, that send the correction signals by powerful amplifiers, can increase the beam size, in particular the vertical one, pumping undesired noise even if minimal.

Analog to digital conversion quantization error

- 8 bit ADC ➔ +/- 128 levels
- Supposing +/-1 mm max displacement, the measure will be affected by an error up to 7.8 micron
- Supposing +/-2 mm max displacement, the measure will be affected by an error up to 15.6 micron
- These values are <u>not very compatible</u> with low emittance beams

Analog to digital conversion quantization error

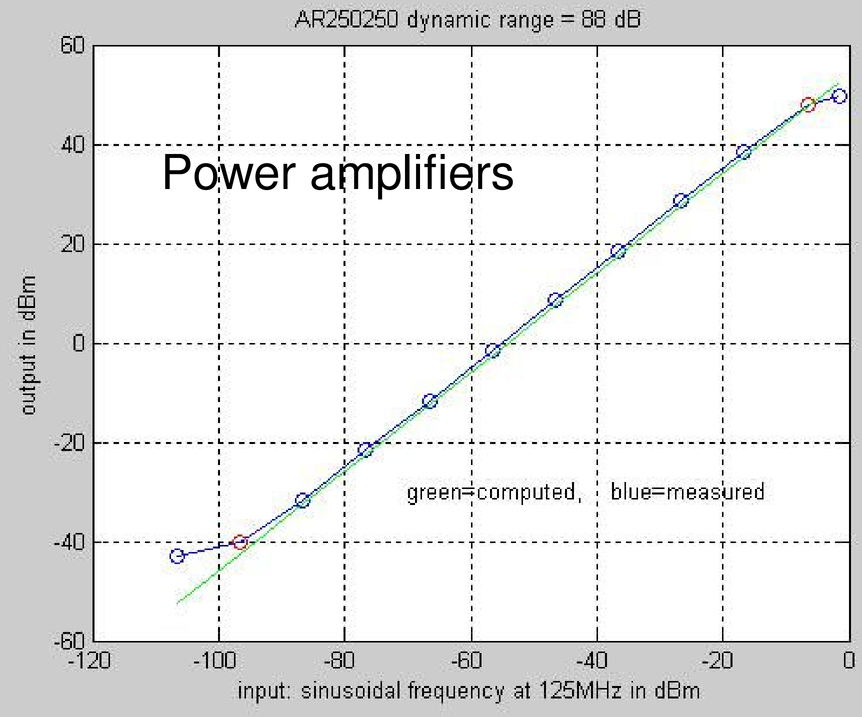
- 12 bit ADC ➔ +/- 2048 levels
- Supposing +/-1 mm max displacement, the measure will have an error up to ~.5 micron
- Supposing +/-2 mm max displacement, the measure will have an error up to ~1 micron
- These values seem <u>compatible</u> with low emittance beams also in the vertical plane if pickups are in a point of the orbit with large beta

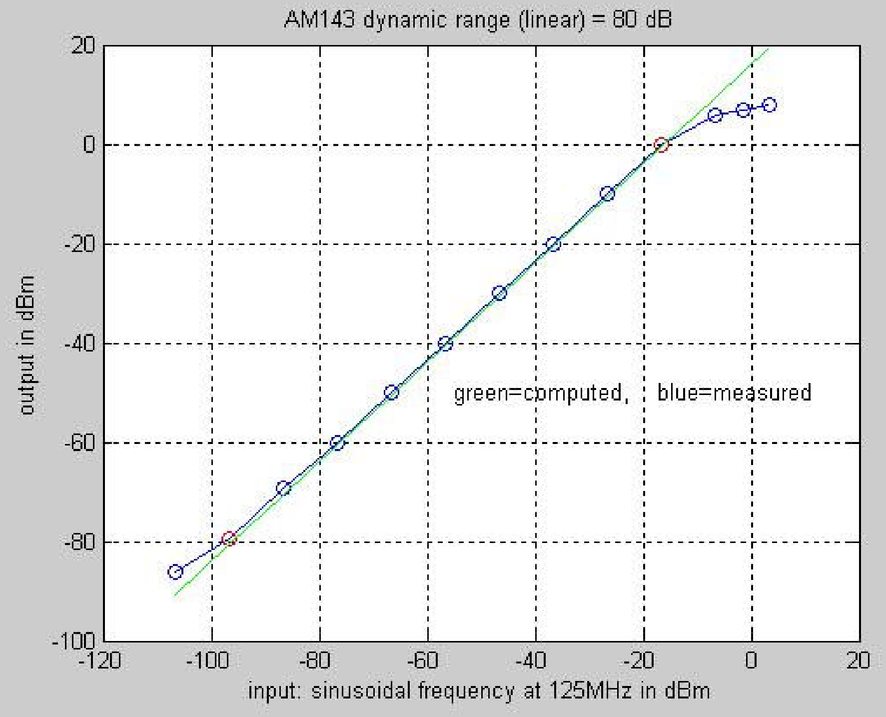
SuperB LER/HER	Unit	June 2008	Jan. 2009	March 2009	LNF site
E+/E-	GeV	4/7	4/7	4/7	4/7
L	$cm^{-2}\ s^{-1}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$
I^+/I^-	Amp	1.85 /1.85	2.00/2.00	2.80/2.80	2.70/2.70
N_{part}	$x10^{10}$	5.55 /5.55	6/6	4.37/4.37	4.53/4.53
N_{bun}		1250	1250	2400	1740
I_{bunch}	mA	1.48	1.6	1.17	1.6
$\theta/2$	mrad	25	30	30	30
β_x^*	mm	35/20	35/20	35/20	35/20
β_y^*	mm	0.22 /0.39	0.21 /0.37	0.21 /0.37	0.21 /0.37
ε_x	nm	2.8/1.6	2.8/1.6	2.8/1.6	2.8/1.6
ε_y	pm	7/4	7/4	7/4	7/4
σ_x	μm	9.9/5.7	9.9/5.7	9.9/5.7	9.9/5.7
σ_y	nm	39/39	38/38	38/38	38/38
σ_z	mm	5/5	5/5	5/5	5/5
ξ_x	X tune shift	0.007/0.002	0.005/0.0017	0.004/0.0013	0.004/0.0013
ξ_y	Y tune shift	0.14 /0.14	0.125/0.126	0.091/0.092	0.094/0.095
RF stations	LER/HER	5/6	5/6	5/8	6/9
RF wall plug power	MW	16.2	18	25.5	30.
Circumference	m	1800	1800	1800	1400

Analog to digital conversion quantization error

- Why not more bits in ADC ?
- feedback systems based on 14-bit need (for technological reason) to have 3 or 4 ADC chips for the conversion because they are not commercially available for clocks >200MHz
- Jitter on the sampling clock limits the analog to digital converter performance

The dynamic range in DAFNE feedback analog blocks is in the range 78 dB – 88 dB





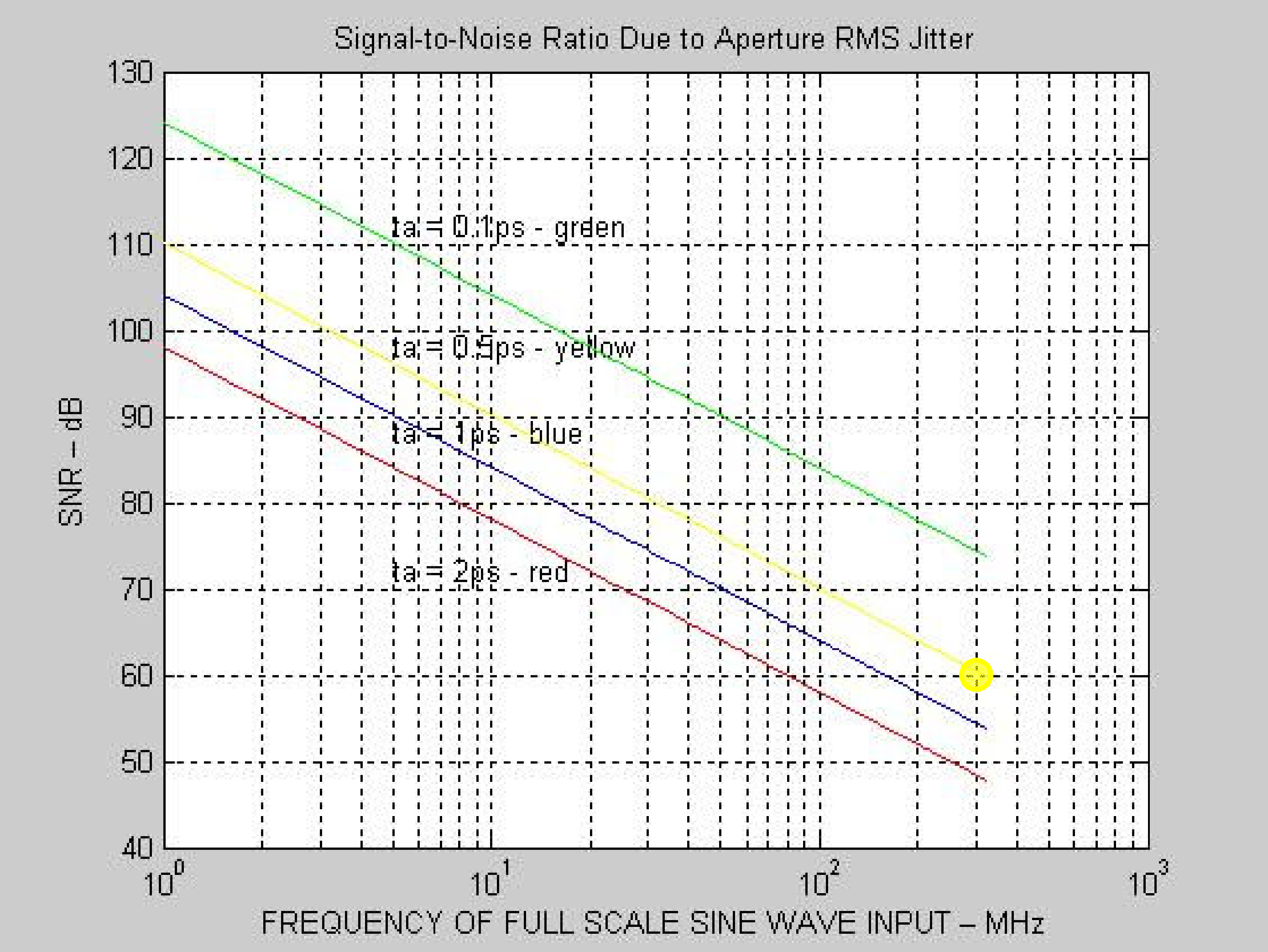
- ADC dynamic range versus # of bits

- 7.5_bit ADC_= 45.15 dB } very poor
- 8_bit ADC _ = 48.16 dB } very poor
- 10_bit ADC _= 60.20 dB
- 12_bit ADC _= 72.25 dB
- 14_bit ADC _= 84.29 dB
- 15_bit ADC _= 90.31 dB [best value considering the analog blocks!]
- 16_bit ADC = 96.33 dB
- 24_bit ADC = 144.49 dB

A factor liming the effectiveness of the ADC is the sampling clock jitter. I can suppose that a realistic value of the RMS jitter for the timing signal will be ~0.5 ps

This value must be included in SuperB Timing specifications

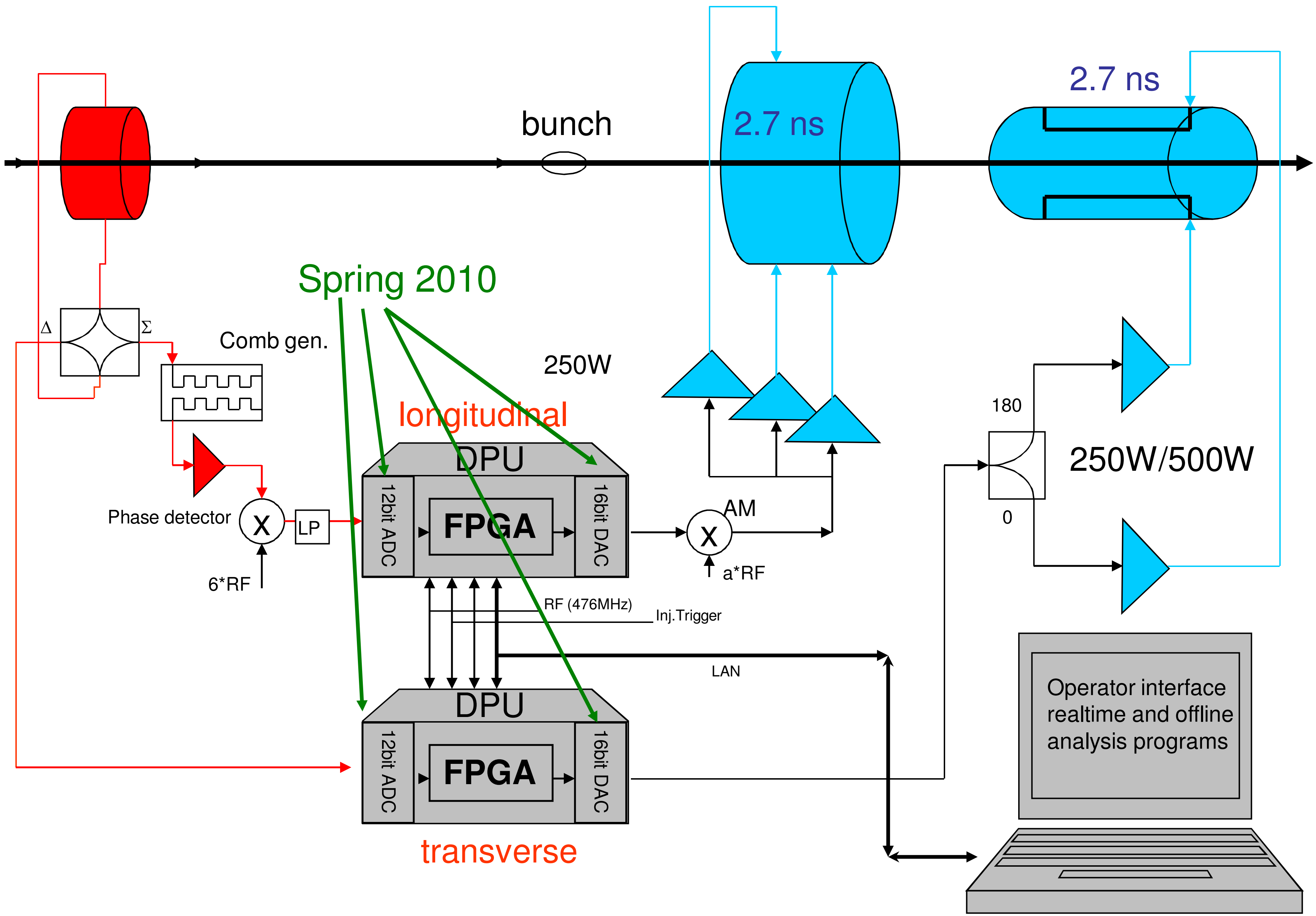
- In this case (yellow trace), the ADC dynamic range should be better than 60 dB (10bits)



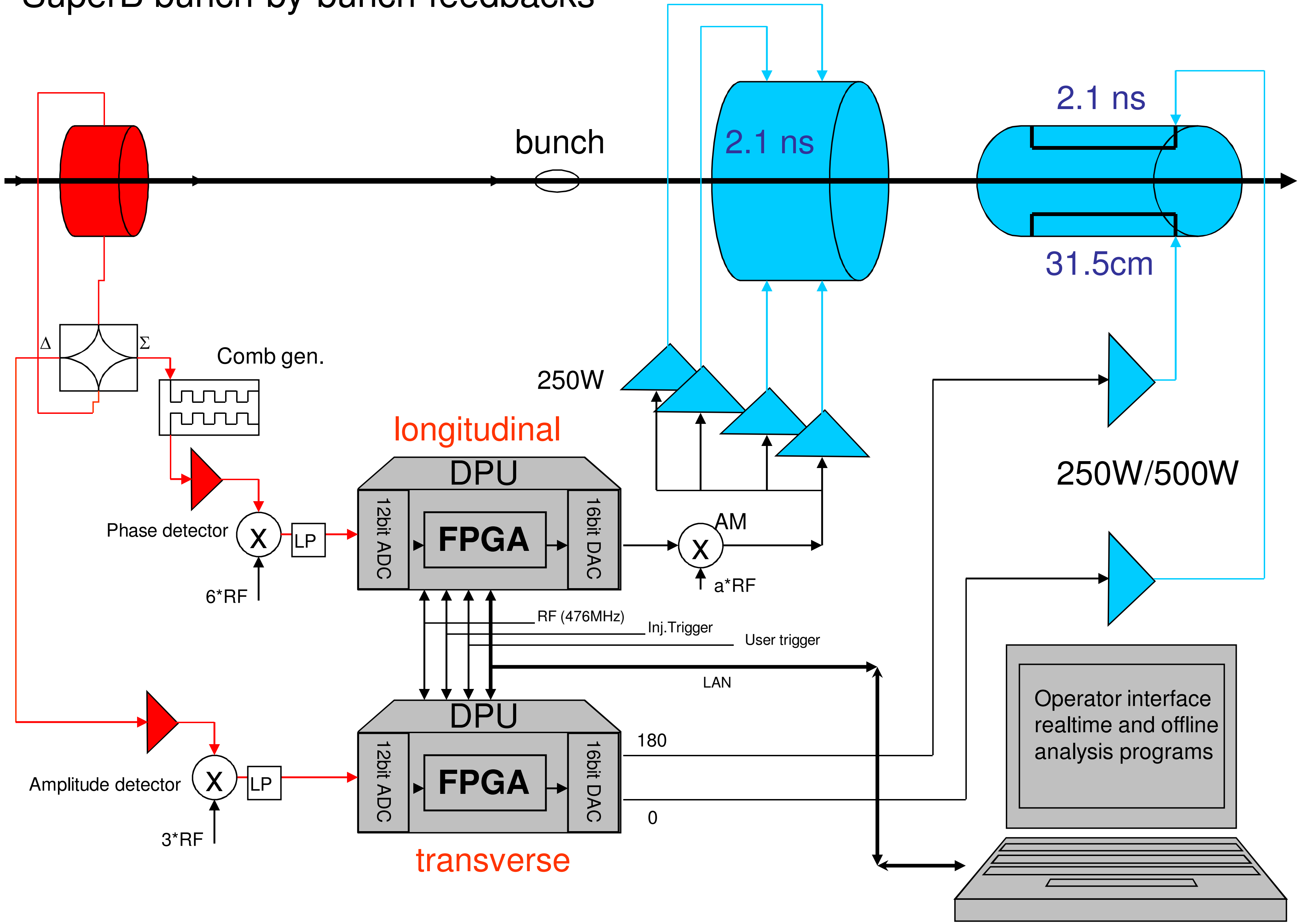
DAFNE feedback upgrade plan for low emittance beams (looking to SuperB spec’s)

- Upgrade all the systems from 8-bit ADC to 12-bit (by installing the new iGp-12)
- Maintain noise level and bunch crosstalk inside the feedback loop below 60 dB
- Simplify and make even more compact the feedback design to have the capability to add as many system as necessary

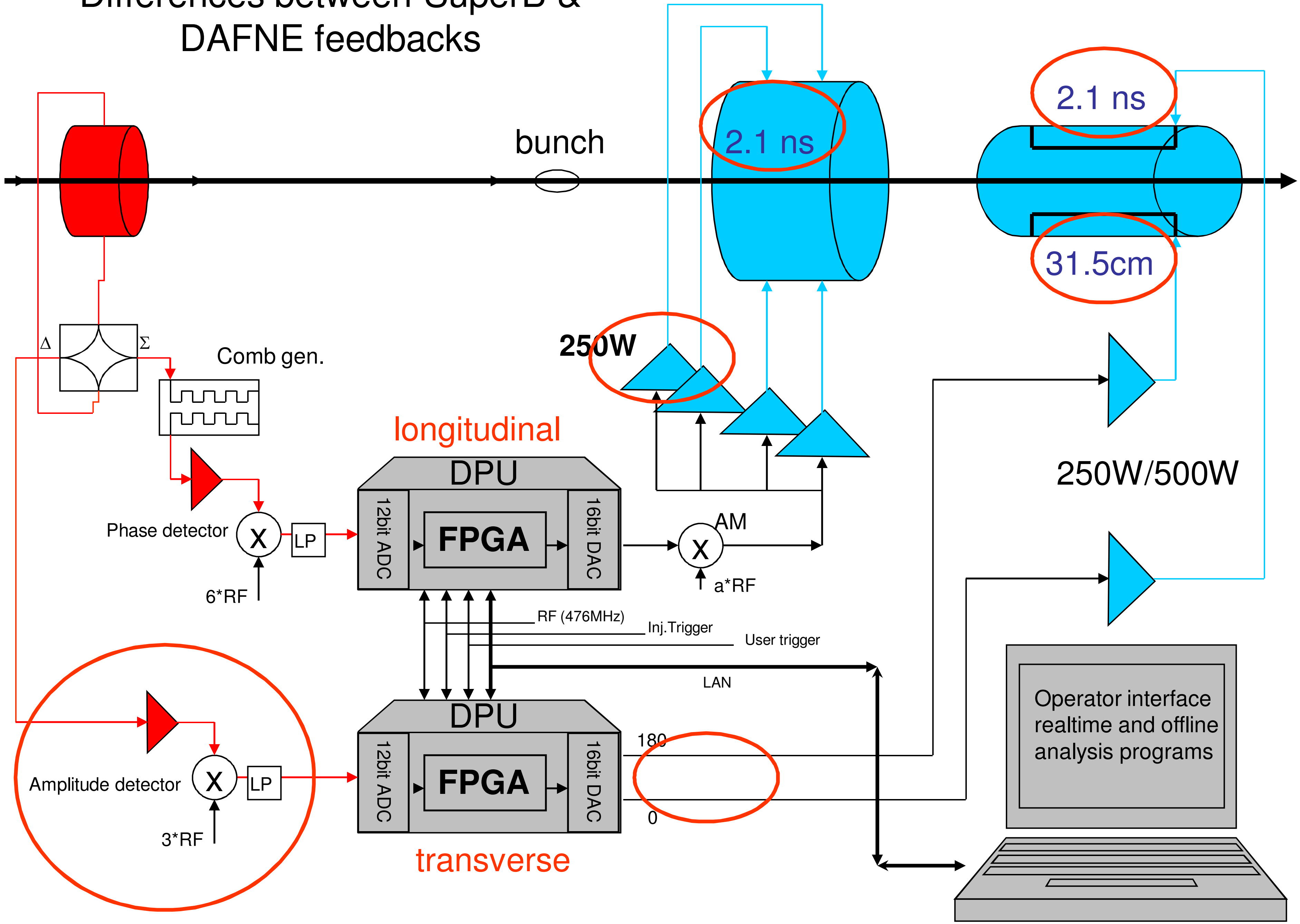
DAFNE (2010) bunch-by-bunch feedbacks



SuperB bunch-by-bunch feedbacks



Differences between SuperB & DAFNE feedbacks



Conclusions

- The last 10-15 years have seen great improvements in the (DAFNE) feedback system
- DAFNE still looks for upgrade the feedback system to achieve e+ current design value (2A), up to now 1.4A, while e- beam can store 2.4A
- Diagnostics through feedback system is very powerful and helps to have the right working setup but also to understand beam behaviour
- Upgrade for low emittance compatible feedback systems is in progress looking to SuperB specifications