Transverse Feedbacks at DAFNE for Low Emittance

Alessandro Drago
INFN-LNF, Frascati

ALERT 2014
Advanced Low Emittance Rings Technology

IFIC - Institut de Fisica Corpuscolar
Valencia, May, 5th-6th, 2014

Preliminary Considerations

- *DAFNE is a PHI factory operating at LNF - Laboratori Nazionali di Frascati - since 1997. The PHI particle (1.02GeV) is unstable and decays in a very short time into other lower energy particles, mostly K mesons.*
- *DAFNE has two symmetric rings storing electron and positron beam at 510MeV energy with one or two interaction points for different experiments (KLOE, Finuda, Dear, Siddartha) and few IR, UV and softX beamlines. DAFNE has not low emittance, even if, with the "Crab-Waist" layout implemented today, the emittance is lower than in the past.*

Preliminary Considerations

•*DAFNE is a PHI factory operating at LNF - Laboratori Nazionali di Frascati - since 1997. The PHI particle (1.02GeV) is unstable and decays in a very short time into other lower energy particles, mostly K mesons.*

•*DAFNE has two symmetric rings storing electron and positron beam at 510MeV energy with one or two interaction points for different experiments (KLOE, Finuda, Dear, Siddartha) and few IR, UV and softX beamlines. DAFNE has not low emittance, even if, with the "Crab-Waist" layout implemented today, the emittance is lower than in the past.*

So - why this presentation ?

Preliminary Considerations

- *DAFNE is a PHI factory operating at LNF - Laboratori Nazionali di Frascati - since 1997. The PHI particle (1.02GeV) is unstable and decays in a very short time into other lower energy particles, mostly K mesons.*
- *DAFNE has two symmetric rings storing electron and positron beam at 510MeV energy with one or two interaction points for different experiments (KLOE, Finuda, Dear, Siddartha) and few IR, UV and softX beamlines. DAFNE has not low emittance, even if, with the "Crab-Waist" layout implemented today, the emittance is lower than in the past.*

So - why this presentation ?

The reason is that in the last 5/6 years, LNF has received R&D funds to design a new collider, the SuperB Factory (project now cancelled), and, under my responsability, the DAFNE transverse feedback systems have been modified and upgraded to be compatible with low emittance beams as foreseen for the SuperB

DAFNE parameters (Apr/14)

		DAFNE	
Parameter	Units	e+	e-
L calc/L Meas		2.1	
L Measured	$cm^{-2}\ s^{-1}$	7.30E+31	
LUMINOSITY	$cm^{-2}\ s^{-1}$	1.56E+32	
Pinch effect Shatilov		1.64E+32	
Energy	GeV	0.51	0.51
Circumference	m	97.59	
X-Angle (full)	mrad	51.4	
β_x @ IP	cm	27	27
β_y @ IP	cm	0.9	0.9
Coupling (full current)	%	3.3	1.9
Emittance x (from model)	nm	280	280
Emittance x (with blow-up)	nm	311	331
Emittance y	pm	10263	6289
Bunch length (zero current)	mm	10	10
Bunch length (full current)	mm	12	13
Beam current	mA	732	729
Buckets distance	#	1	
Ion gap	%	33	
RF frequency	Hz	3.69E+08	
Revolution frequency	Hz	3.07E+06	
Harmonic number	#	120	
Number of bunches	#	80	
N. Particle/bunch	#	1.86E+10	1.85E+10
σ_x @ IP	microns	289.8	298.9
σ_y @ IP	microns	9.6	7.5
$\sigma_{x'}$ @ IP	microrad	18.2	13.8
$\sigma_{y'}$ @ IP	microrad	183.3	190.8
Piwinski angle	rad	1.06	1.12
σ_x effective	microns	423.23	448.38
Σ_x	microns	416	
Σ_y	microns	12.2	
Σ_x effective	microns	617	
Hourglass reduction factor		*0.87*	
Tune shift x		0.0198	0.0231
Tune shift y		0.0292	0.0247
Longitudinal damping time	msec	17	17.0
Energy Loss/turn	MeV	0.009	0.009
Momentum compaction		1.90E-02	1.90E-02
Energy spread (zero current)	dE/E	4.00E-04	4.00E-04
Energy spread (full current)	dE/E	*6.00E-04*	*6.00E-04*
CM energy spread	dE/E	4.24E-04	
SR power loss	MW	0.01	0.01
RF Wall Plug Power (SR only)	MW	0.03	

The basic R&D ideas to adapt the DAFNE transverse bunch-by-bunch feedback systems for low emittance beams are the followings:

1) Less noise
2) More sensitivity
3) Larger dynamic range
4) Better use of power signals
5) Better beam diagnostics
6) Adaptive control

Looking inside these points we can observe that they are strongly correlated, in particular for the first 4 items

The basic R&D ideas to adapt the DAFNE transverse bunch-by-bunch feedback systems for low emittance beams are the followings:

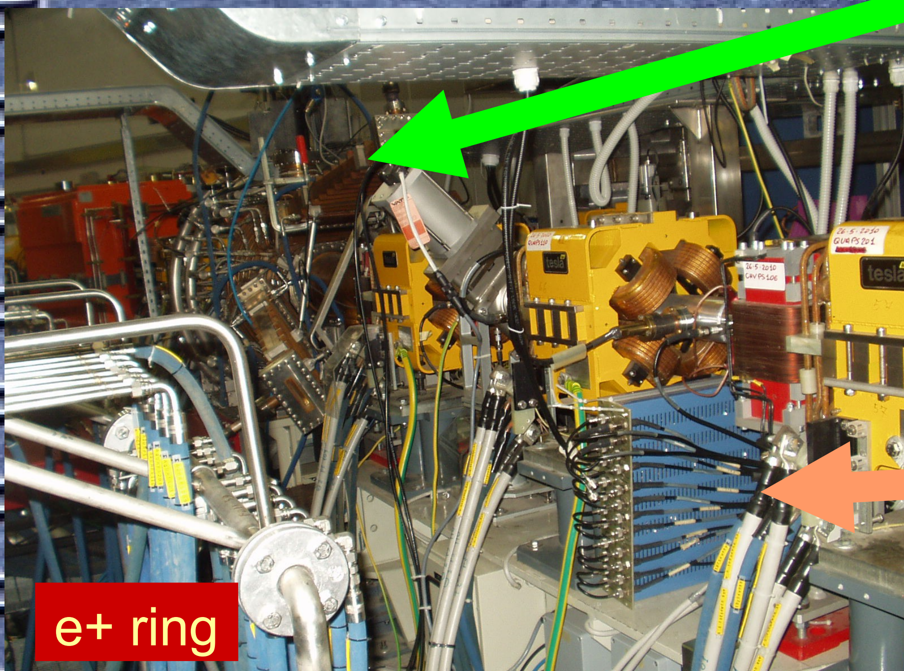
1) Less noise ==> low noise analog fe, ADC & DAC @ 12/16/20 bits
2) More sensitivity ==> low noise analog fe, ADC & DAC @ 12/16/20 bits
3) Larger dynamic range ==> ADC & DAC @ 12/16/20 bits
4) Better use of power signals ==> new kickers
5) Better beam diagnostics ==> bunch-by-bunch tune monitor
6) Adaptive control ==> automatic vertical gain control

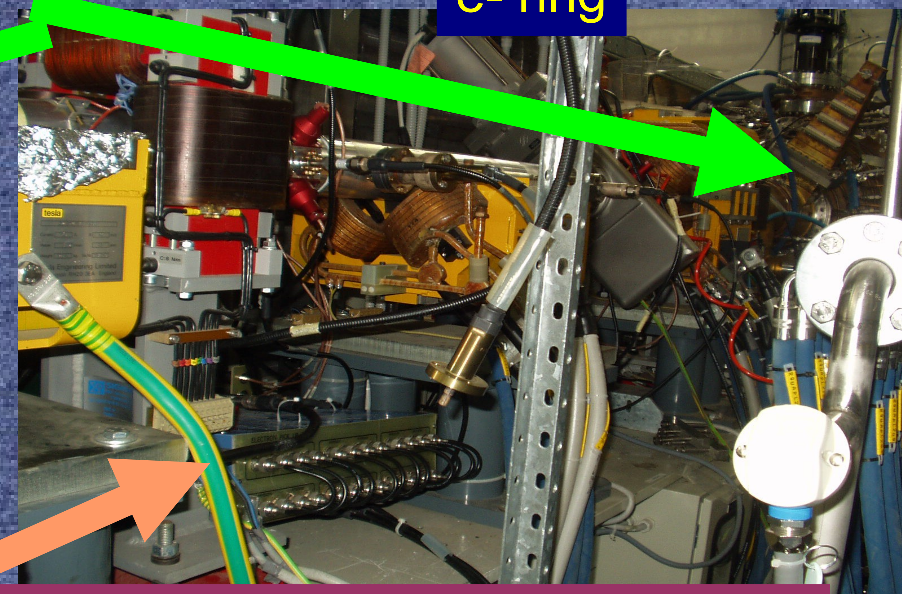
Looking inside these points we can observe that they are strongly correlated, in particular for the first 4 items

Low noise front-end R&D

In DAFNE main rings, to decrease the environmental noise effects, it has been proposed to move the parts of the circuits that are very close to the pickup, outside the hall with the vacuum chamber, far away from fringe fields coming from magnets and RF klystrons.

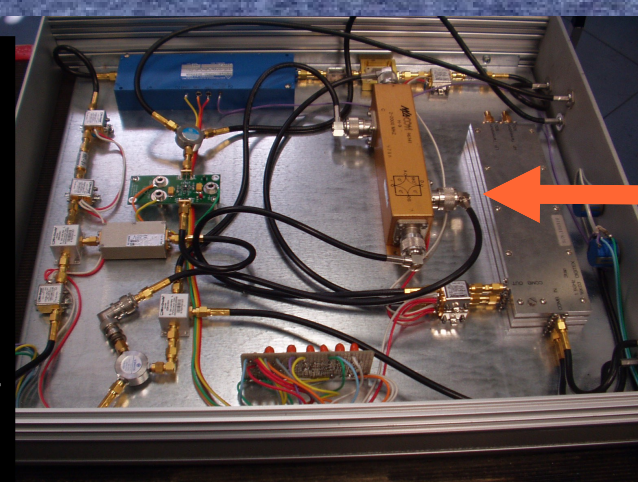
RF cavities





Faraday cages with H9 hybrids inside (the hybrids are parts making pulse addition & difference)

- The proposal brought to a completely new FE design working at 4*RF (1.4 GHz), tested at DAFNE in March 2011 and Jan/Feb 2012 in collaboration with KEK (Makoto Tobyiama).
- These tests done in DAFNE were positive but not conclusive because needing higher beam currents and very flat colliding bunches. In Jan/14 DAFNE finally gets the desired operative conditions



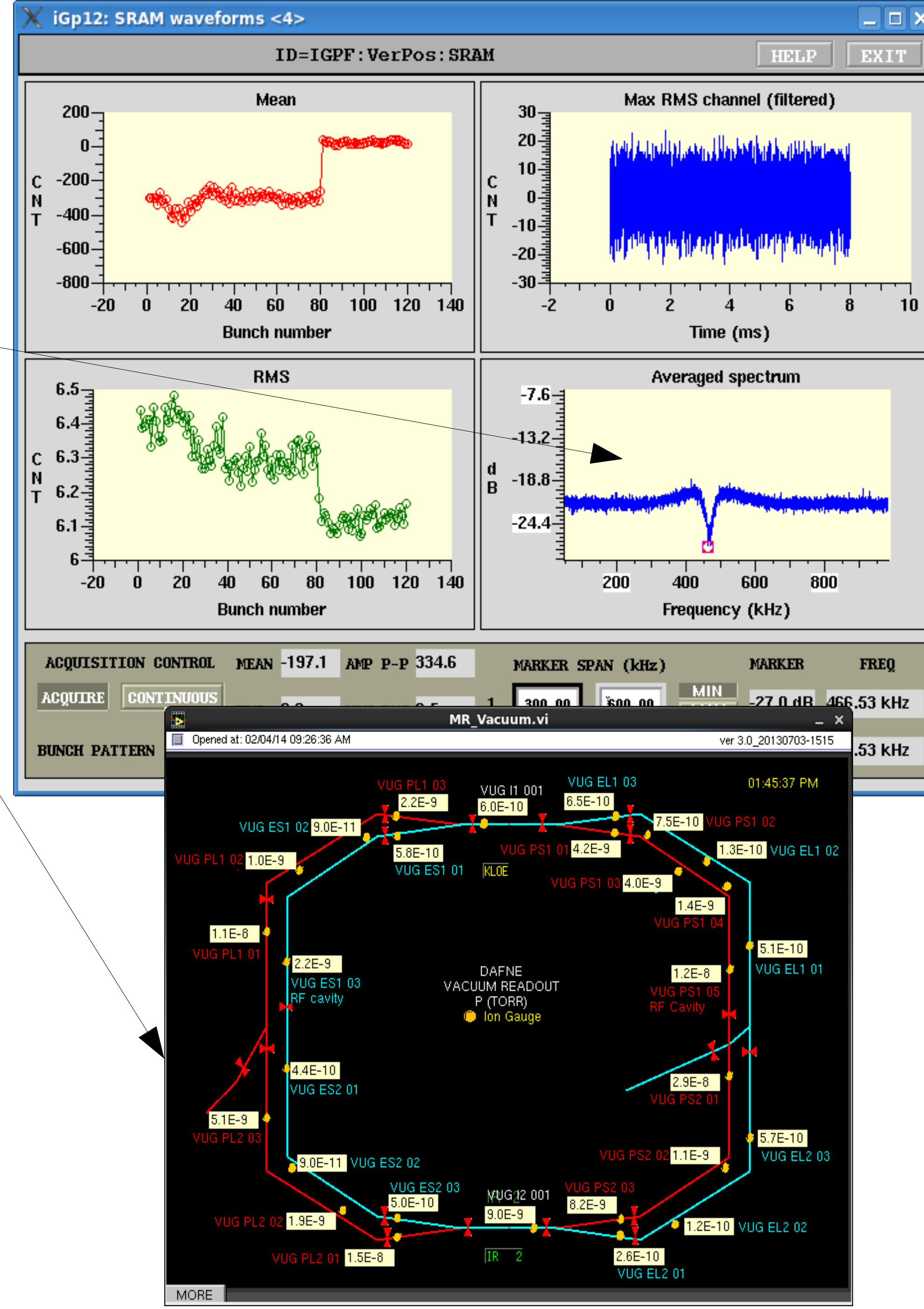
H9 Hybrids have been moved from DAFNE hall to the front end box in the instrumentation hall

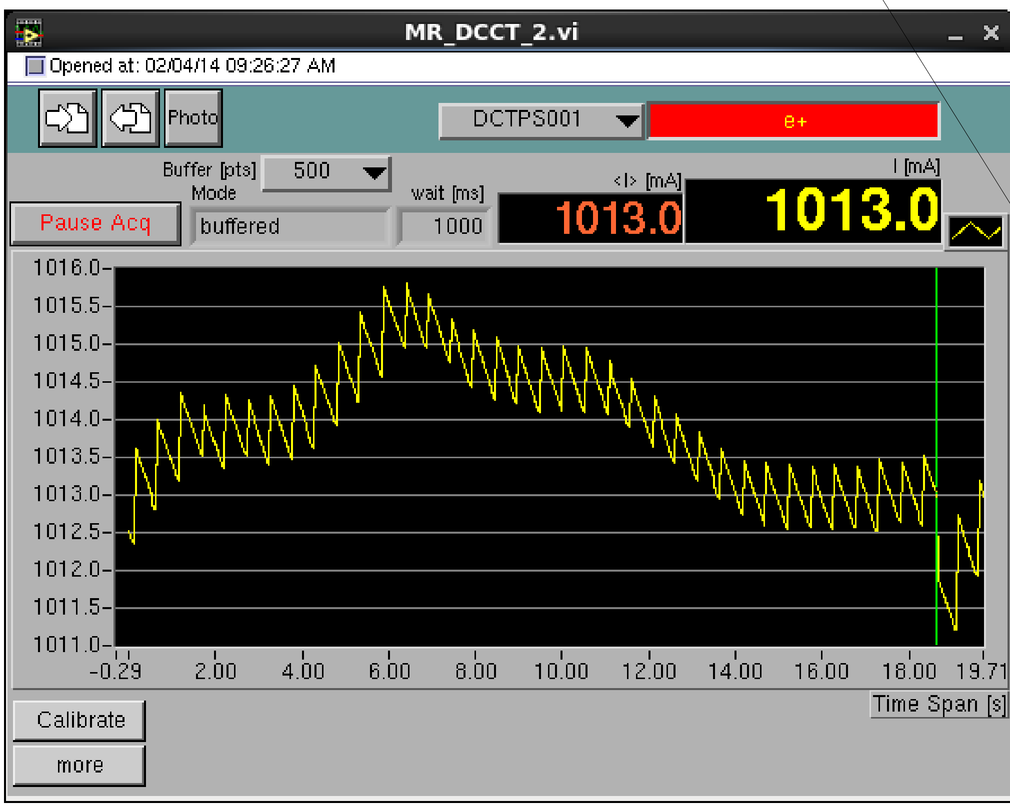
•Low noise analog front end tests completed in Jan/14:

a) no noise

b) positron current > 1 A

(limited only by vacuum at 10-8 mBar)





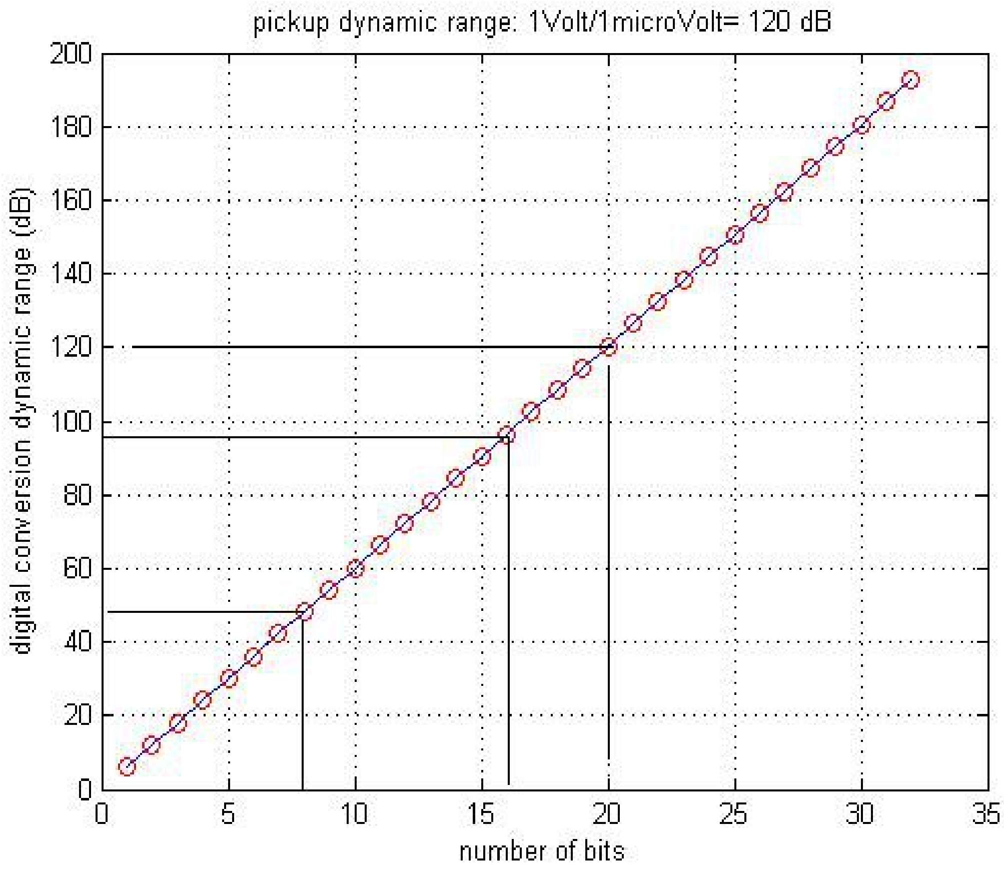
A complete discussion on this approach with pro's and con's is beyond the goal of this talk, nevertheless we can summarize that:

- Up and down button signal are brought from high beta pickup in DAFNE hall to instrumentation hall by long cables
- Up and down signal are managed separately by trombone delays and two comb filters are used to make 3 replicas for each bunch.
- The 1.5GHz 3 taps Comb Filter Component uses microwave PCB substrates in Diclad880 (Woven fiberglass/PTTE; Er=2.17@10GHz) with thickness:1.6mm Cu:18um/18um.
- Orbit offset correction is done by a dedicated mixer for eventual manual correction by using a simple knob
- 4*RF is generated inside the front end and it is put in phase by using an other knob
- Amplitude detection is made at 4*RF

Digital conversion and processing

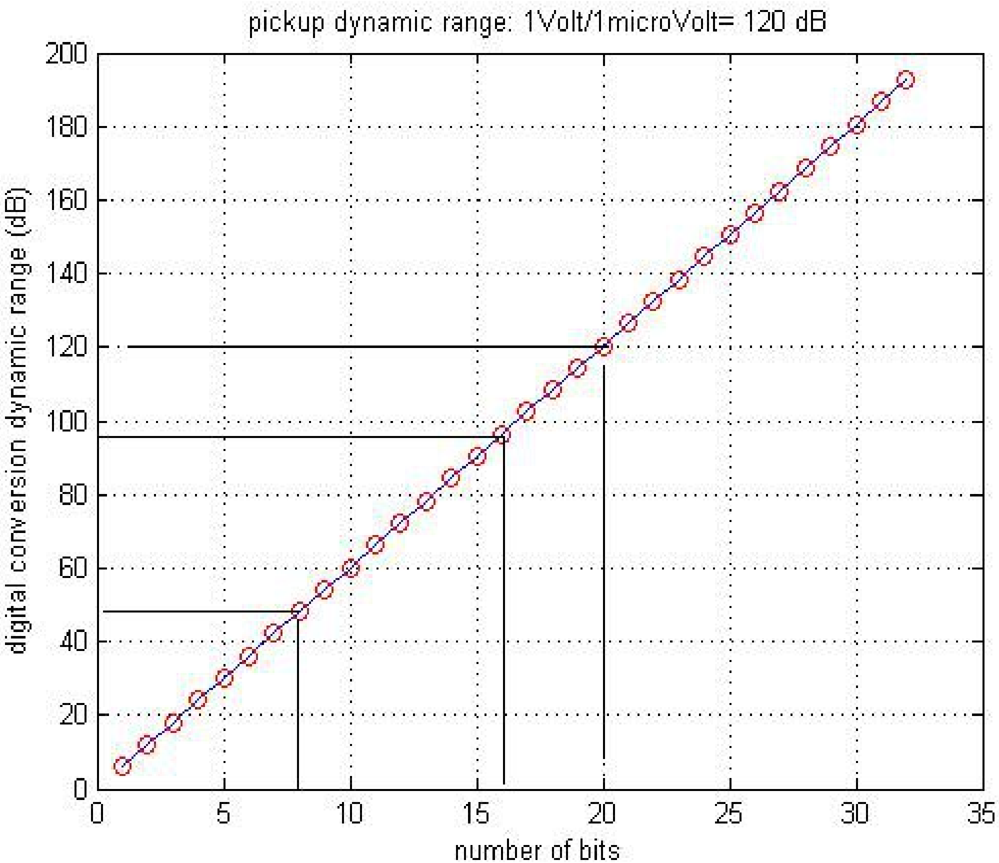
- The second key-point to eliminate or to attenuate strongly the noise inside the feedback loop is the quantization noise.
- The question is: in the analog to digital conversion how many bits are the right choice ?
- This is also related to the dynamic range of the feedback loop that is basically given by three active blocks: frontend, digital processing unit (included ADC and DAC), and backend power amplifiers.
- Evaluating in my lab the power amplifiers (commercial devices by Amplifier Research) that we use at DAFNE I have measured about 90-95 dB of dynamic range
- Of course the block with the lowest dynamic range plays as bottleneck, and typically this is the digital block that include ADC, individual FIR filters for each bunch signal and DAC.

Digital conversion and processing



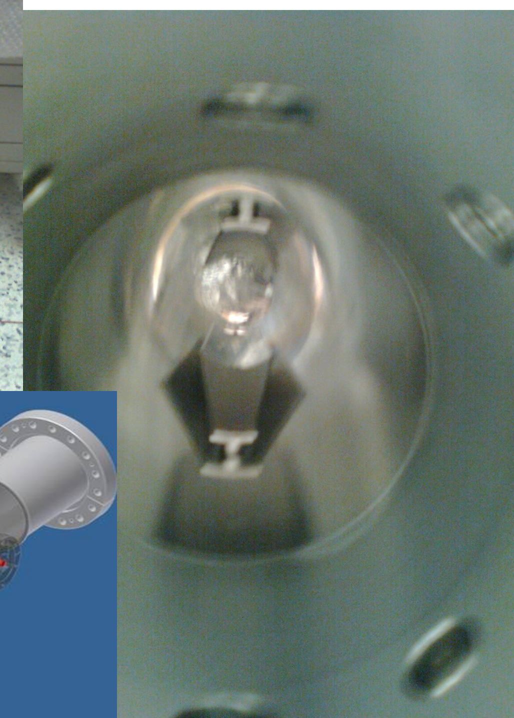
- Possible options in the choice of the best number of bits to have both low quantization noise and large dynamic range are:
- 8 bits = 48 dB (used in the past at DAFNE for transverse feedback)
- 12 bits = 72 dB (used at DAFNE after the upgrade of the transverse feedback)
- 16 bits = 96 dB
- 20 bits = 120 dB

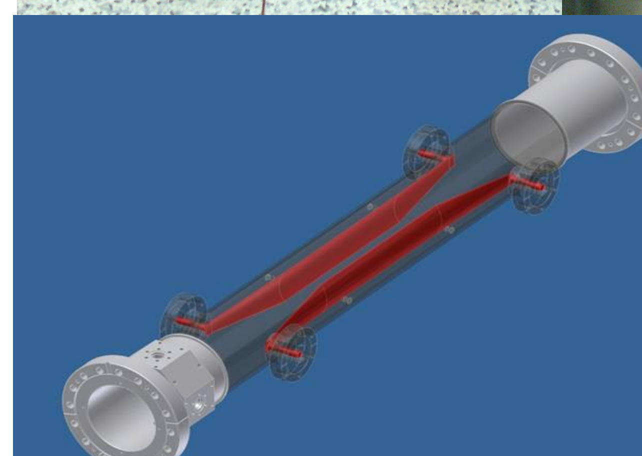
Digital conversion and processing



- In base at what I have shown, the best or more convenient choice would be a conversions by 16 bits, but for many reasons (both technological and related to the compatibility with previous feedback system versions), the R&D efforts has stopped after the upgrade at 12 bits (that are much much better than 8 bits).
- This, in my opinion, is not sufficient for ultra low emittance beam

New horizontal kickers to have stronger beam deflection without increasing the noise from power amplifiers and digital gains





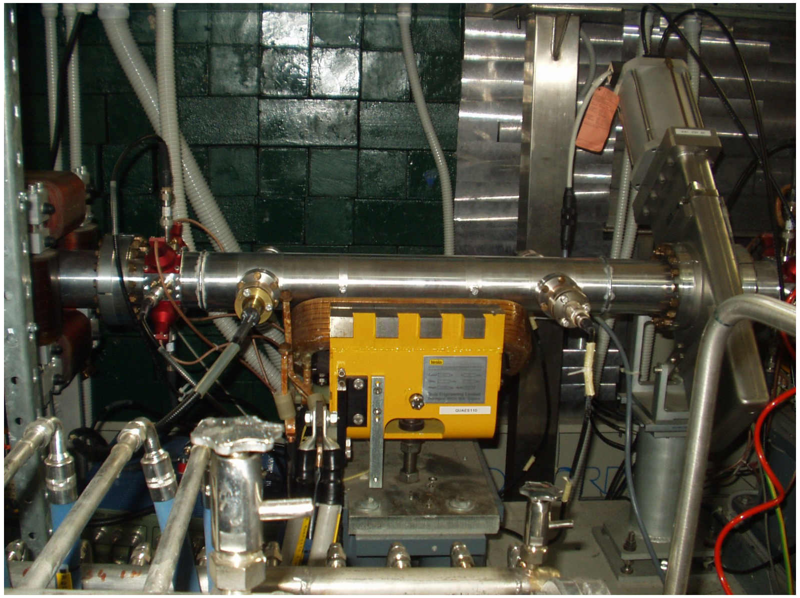
New horizontal kickers (design at LNF by D.Alesini, A.Zolla & G.Fontana) have been installed in DAFNE main rings having:

Tapered and double length striplines (close to bucket length);

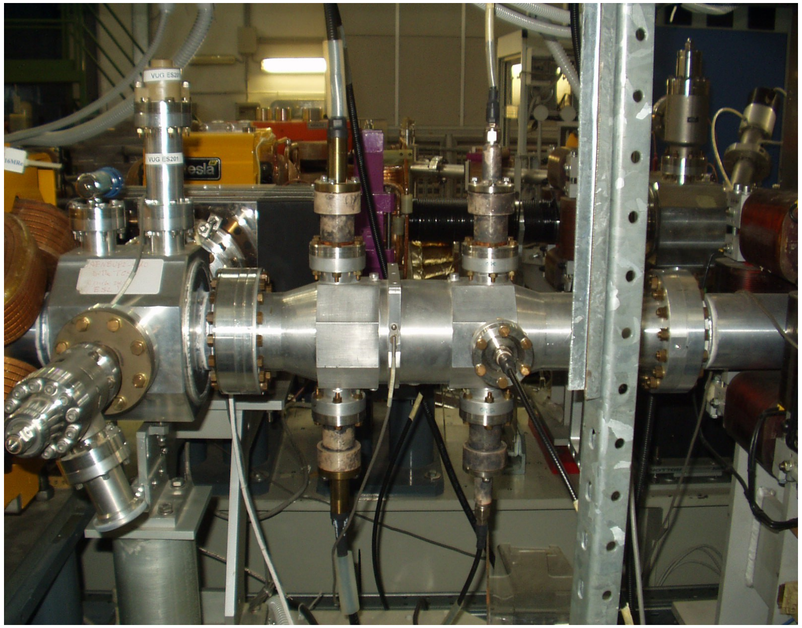
reduced striplines separation in the horizontal plane (88 mm -> 60 mm);

much better shunt impedance.

- Horizontal kicker

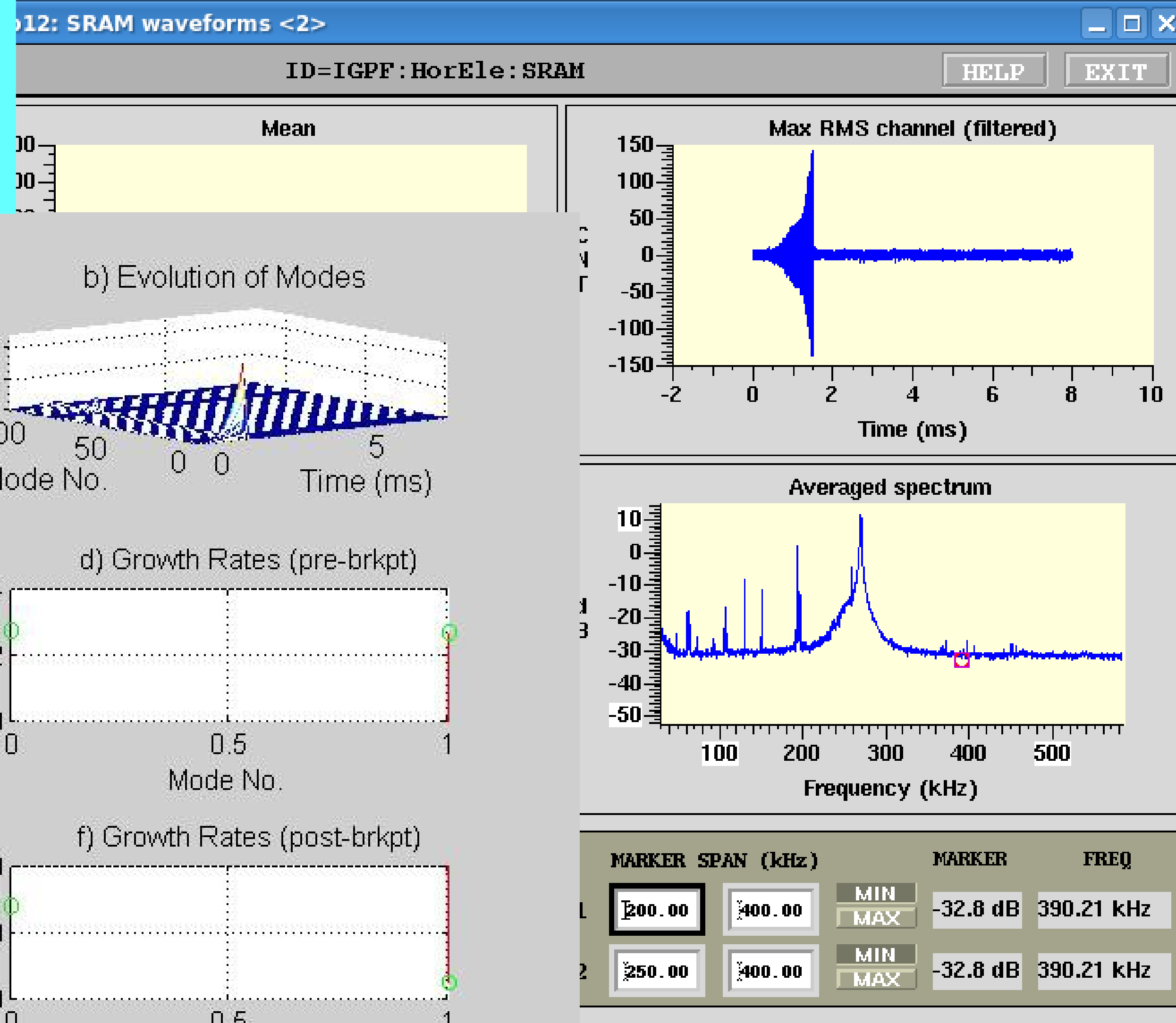


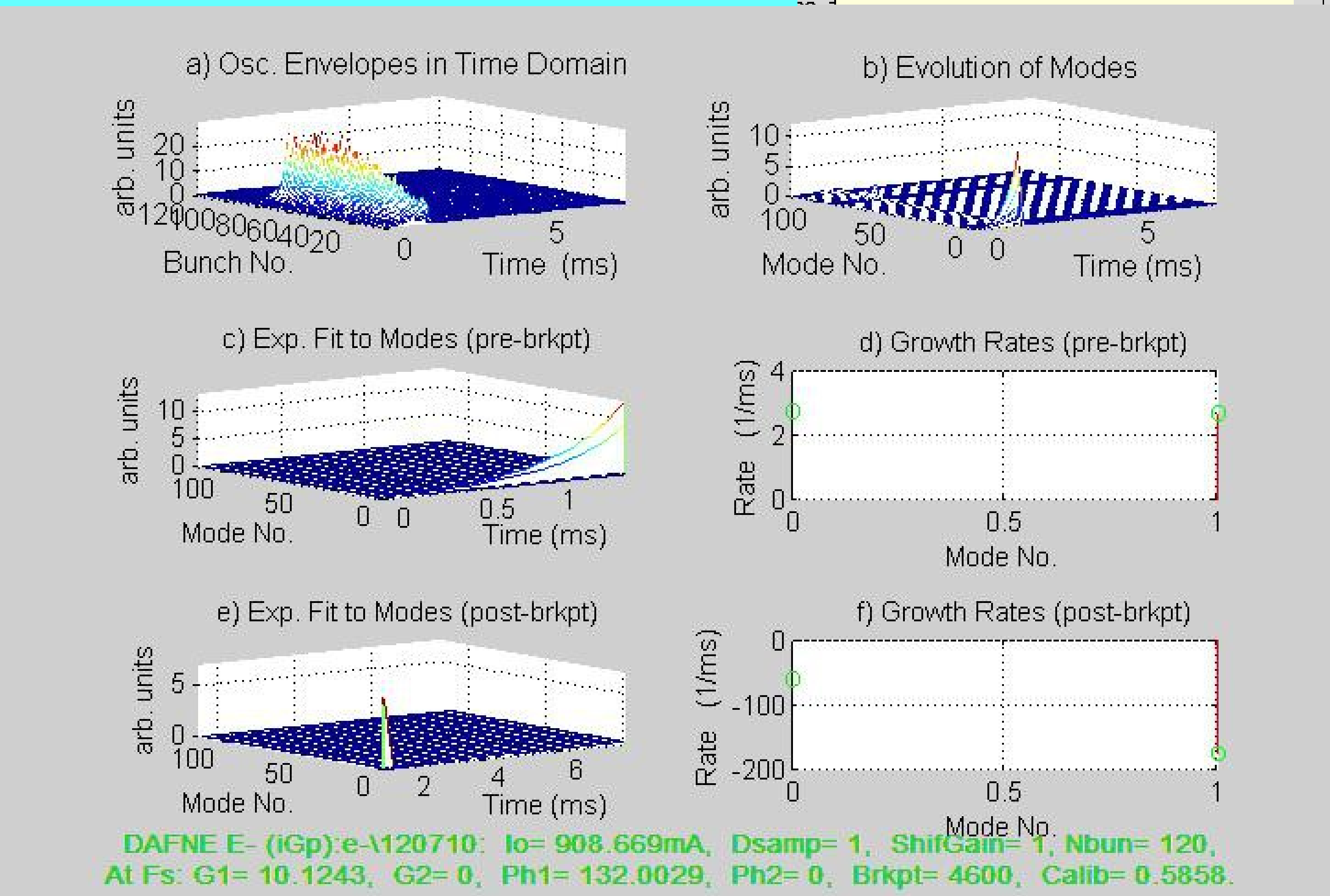
Horizontal versus vertical kickers:
the new horizontal kicker is much longer than the vertical one



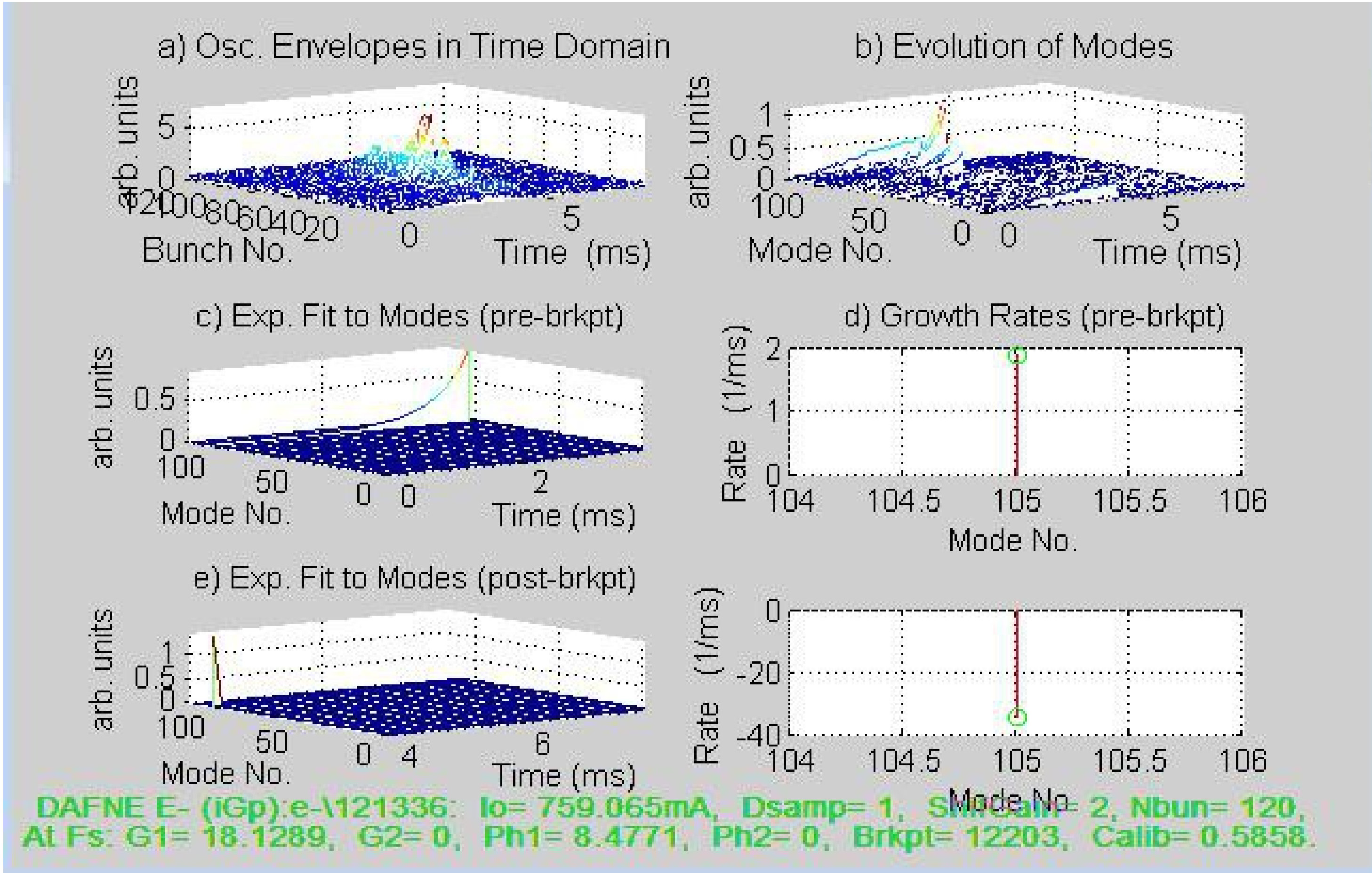
- Vertical kicker

•Horizontal e- grow-damp measures @DAFNE (10/15/13) with 908 mA beam current in 90 bunches





In the horizontal case the unstable mode is #1 and growth rate is 360 μs. The feedback damping rate, using same power (2x250W) of the vertical system and the new kicker, is 5 μs (i.e. 15 revolution turns)



For the vertical plane, this is a growth/damping measurement done at DAFNE by the feedback on Oct/2013 with e- beam current=759mA and bunches=90.

The unstable mode is #105 and the growth rate is 500 μs.

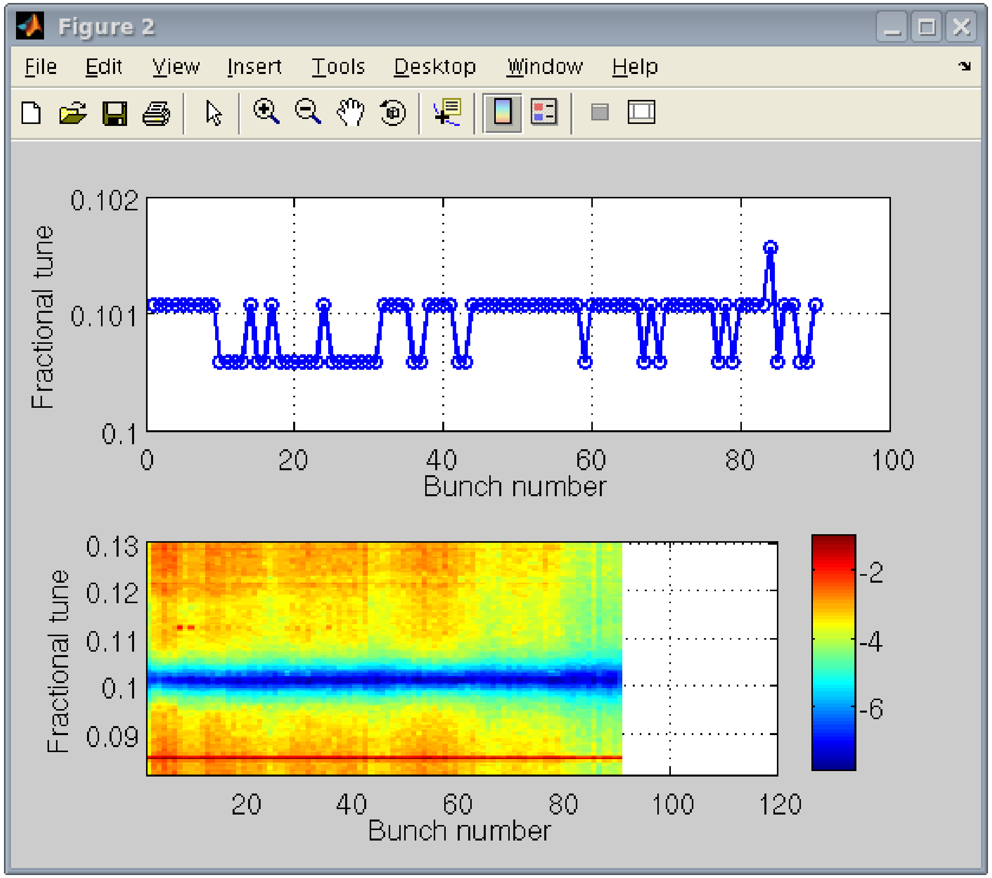
The feedback damping rate, using same power (2x250W) of the horizontal system and the “old-type” kicker is 25 μs.

Bunch-by-bunch diagnostics by bunch-by-bunch feedbacks

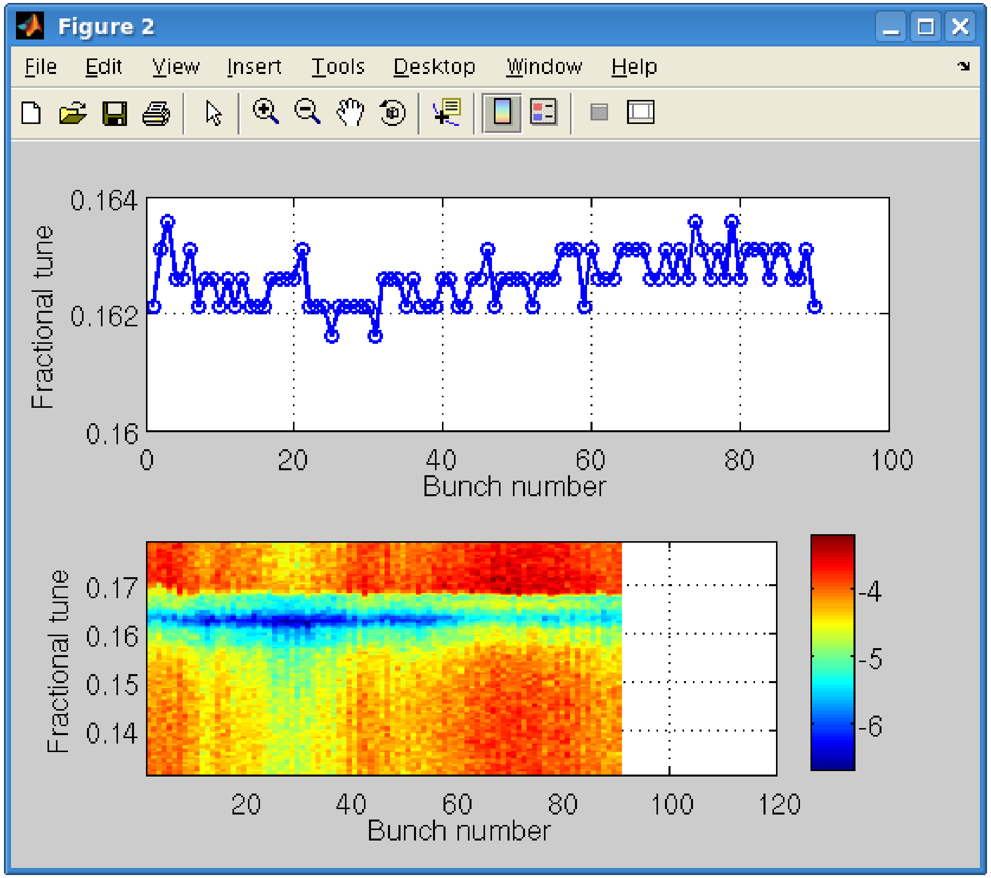
- Bunch by bunch diagnostics is a promising field where can be useful to focus the R&D efforts for the circular accelerator especially looking to low emittance ring
- Feedback system, being bunch-by-bunch, allows such diagnostics during the beam runs without stopping the regular performance
- Mostly used measurement tools :
  - coherent instability growth rates
  - bunch-by-bunch transverse tune spreads

Electron beam with 1 Ampere stored in 90 bunches

horizontal tunes

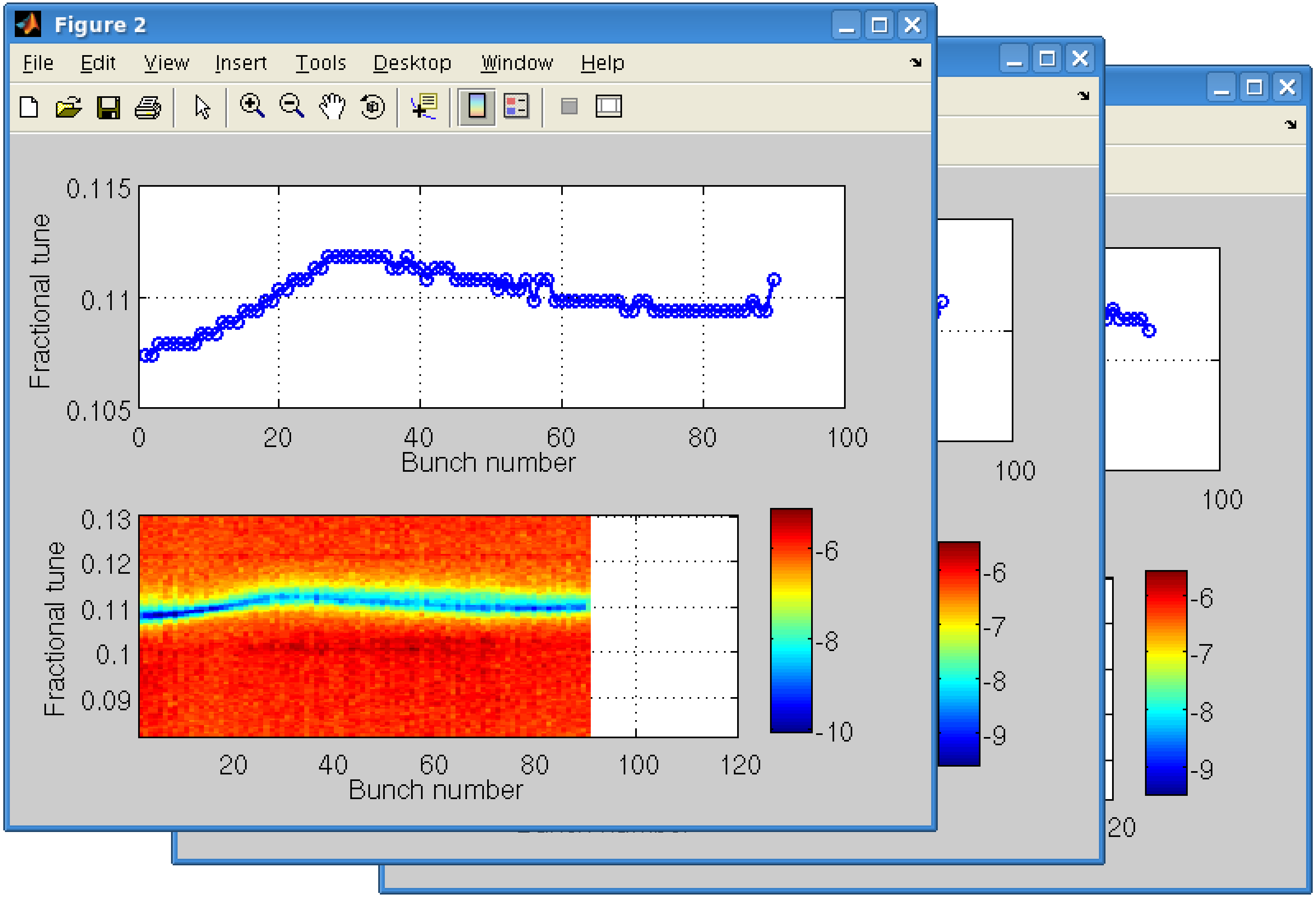


vertical tunes



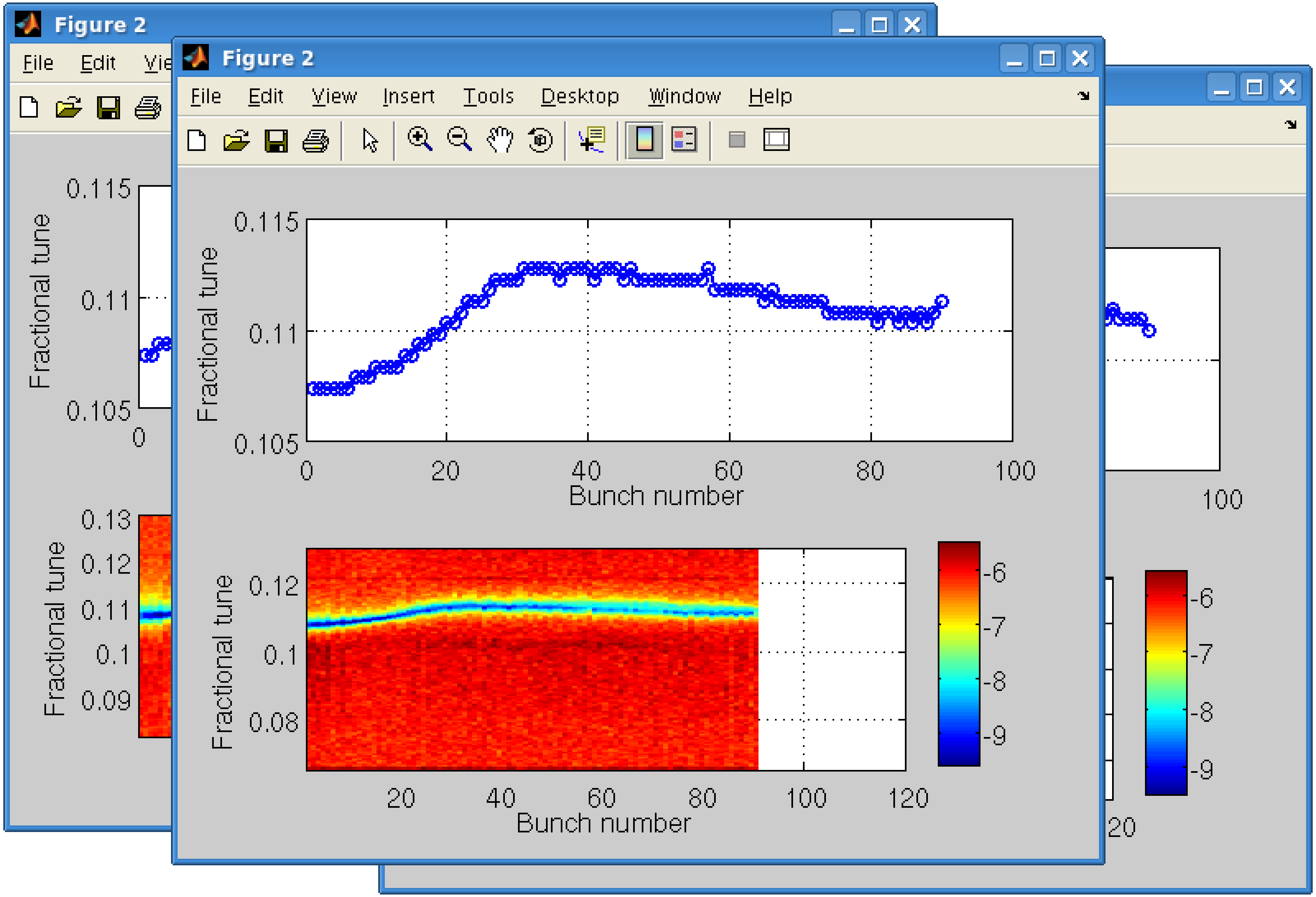
Positron beam with 0.7 Ampere stored in 90 bunches

horizontal tunes with e-cloud clearing electrodes on at full voltage (8 inside bending magnets, 2 inside wiggler magnets)



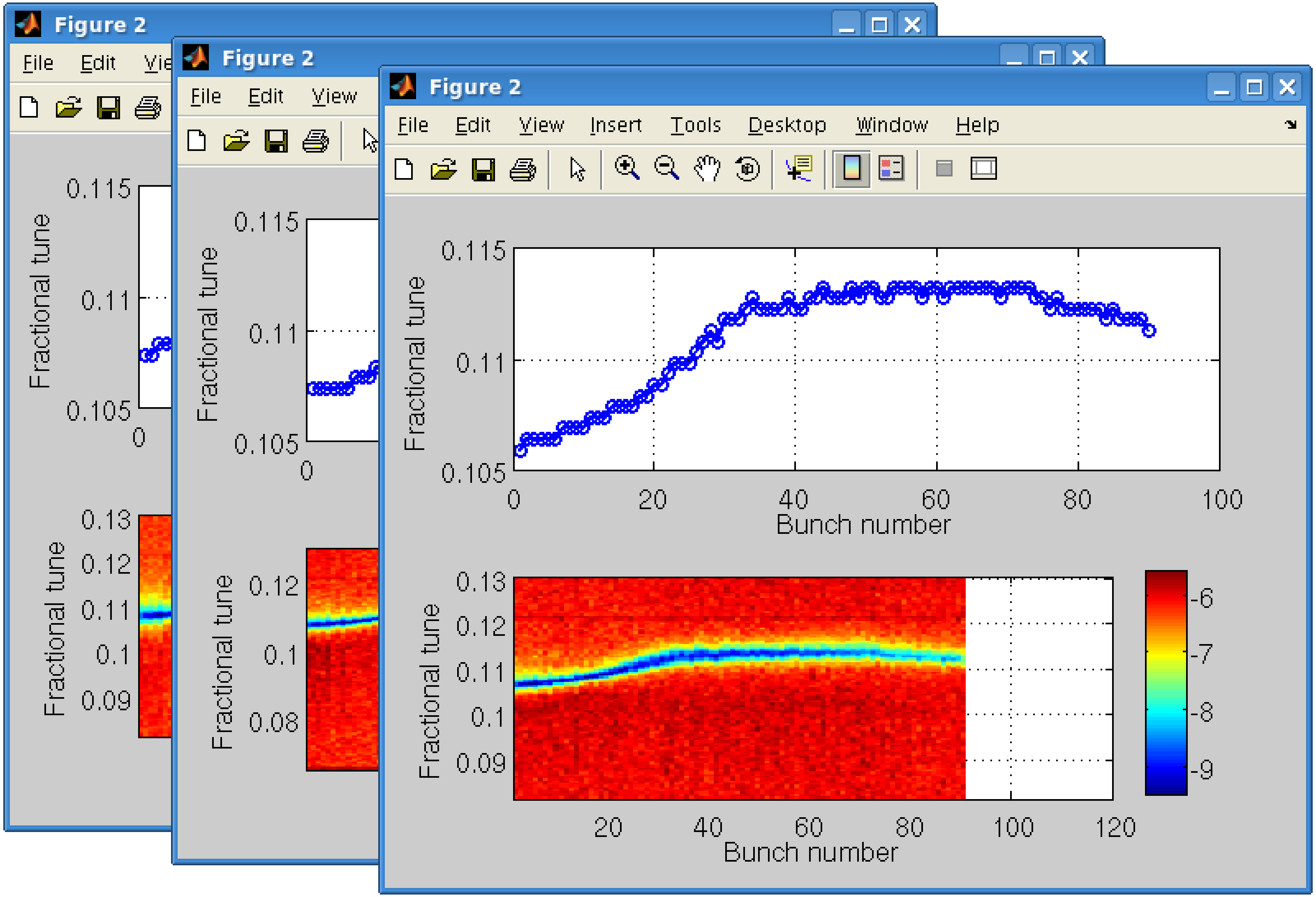
Positron beam with 0.7 Ampere stored in 90 bunches

horizontal tunes with e-cloud clearing electrodes on at full voltage (only the 8 inside bending magnets)



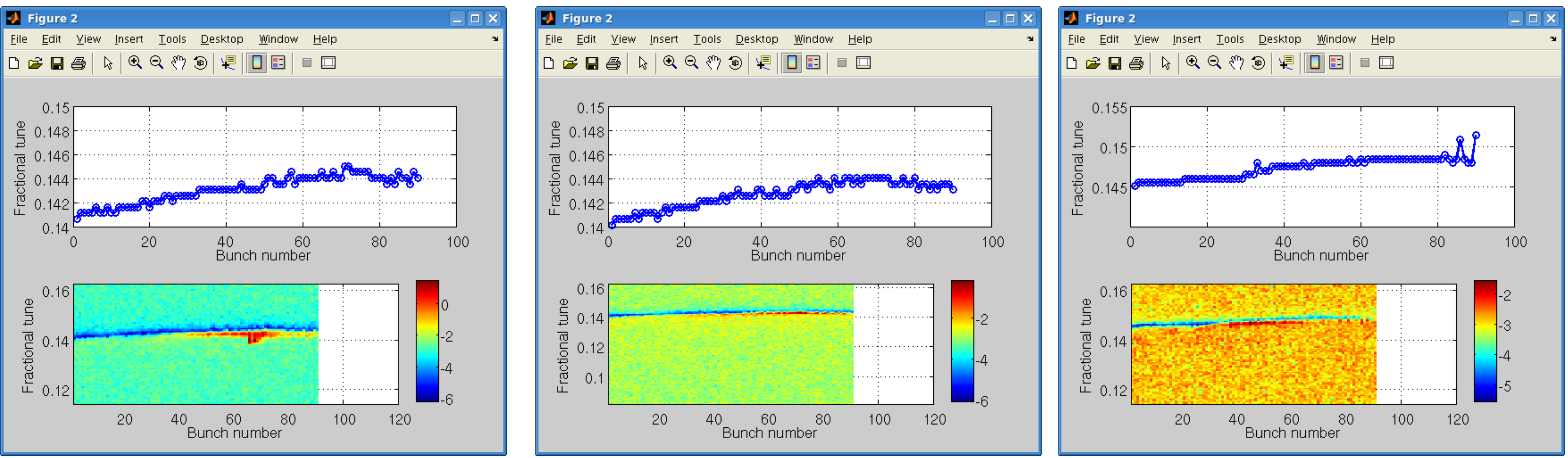
Positron beam with 0.7 Ampere stored in 90 bunches

horizontal tunes with all e-cloud clearing electrodes off



Positron beam with 0.7 Ampere stored in 90 bunches

vertical tunes with all e-cloud clearing electrodes on (8bm +2wm), on (only 8 bm) and all off:
in the three cases no big differences are shown...



Note that the damping effect on the vertical instability is mainly due to the solenoids in the straigth section of the vaccum chamber that in this measurements are all on !

Adaptive gain control/1

- An **<u>expert system</u>** is under study to control automatically the feedback setup
- The program is written in Matlab with LCA system calls to interface the feedback EPICS realtime database (including beam currents and tunes)
- It is made by a continuous loop with three blocks followed by a wait (from 1 to 30 s)
- First block reads the EPICS database to evaluate correctly the machine status that could be:
  - Machine off (zero currents in both rings)
  - e+ or e- injection
  - Beams colliding (with e- current > e+ current)
  - Beams colliding (with e+ current > e- current)
  - Only e- beam is stored and the current value is acquired
  - Only e+ beam is stored and the current value is acquired

Adaptive gain control/2

- The second block has rules to infere conclusion to decide the goals and the actions to achieve the goals
  - The rules can be easily changed
  - The rules can be rewritten in base at the collision setup and considering that a setup for a better peak luminosity can be different from a setup for a large integrated luminosity
  - Oscillation amplitudes can be measured (from EPICS panels) to have a better control of the feedback gain even if the oscillation evaluation can bring to short periods of beam instability
- The third block makes the actions to implement the goals
  - Typically the goal consists in increasing or to decreasing the e+ vertical feedback gain
  - The gain of the other feedback systems can be also changed even if it not seems necessary with the present DAFNE setup
  - Note that the operators in the control room are NOT always happy if a stupid program can modify the peak luminosity without any advice........!

Conclusions

- In the last years, at LNF, R&D efforts have been carried on for the SuperB project, a low emittance collider that has been cancelled by the Italian government
- Nevertheless the feedback system upgrade is very useful also for DAFNE, a low energy e+/e- collider where the crab-waist scheme is under test with the present strong solenoidal fields
- A strong collaboration with the SuperKEKB feedback team is in progress with very fruitful results and new ideas to be checked in both colliders