LHC Injectors Upgrade

LHC Injectors Upgrade

PS: longitudinal instabilities and damper

Speaker: L. Ventura

Acknowledgments: H. Damerau, G. Favia S. Gilardoni , M. Migliorati, M. Morvillo, M. Paoluzzi, G.Sterbini

LIU day
11 April 2014

CERN

Outlook

- **The PS RF system**
- **Beam loading & cures**
  - Wideband negative feedback
- **Coupled-bunch instabilities measurements & simulations**
  - Feedback system and new longitudinal kicker
  - 10 MHz system impedance model and simulations
- **Summary and discussion**

Outlook

- **The PS RF system**
- **Beam loading & cures**

  Wideband negative feedback
- **Coupled-bunch instabilities measurements & simulations**

  Feedback system and damper

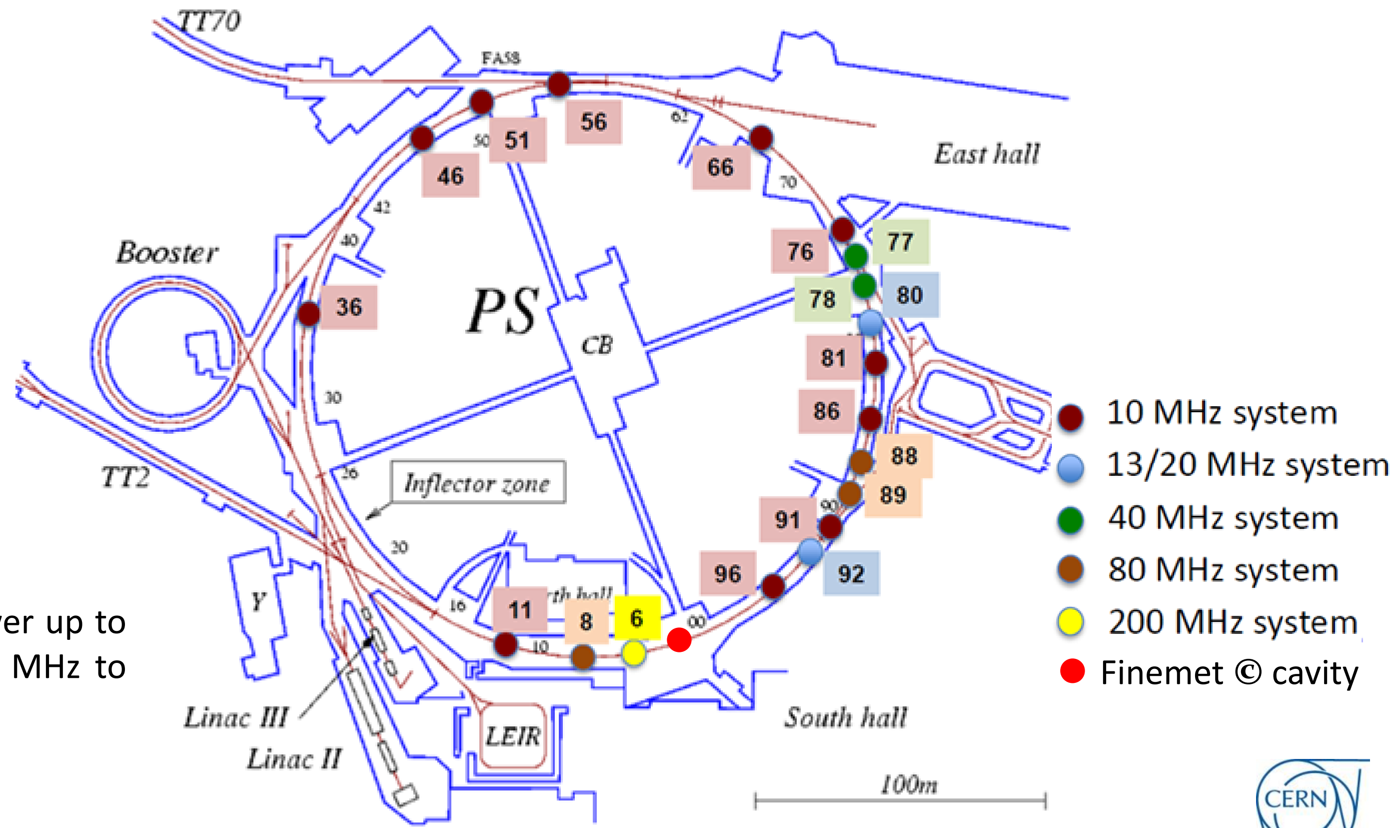
  10 MHz system impedance model and simulations
- **Summary and discussion**

The PS RF system

The PS machine contains cavities operating at different frequencies. The **10 MHz cavities** are the most important because they **accelerate the bunches** to the desired energy and **perform the triple splitting.**

The 10 MHz cavities (10+1 double gap cavities tuneable from 2.8 to 10 MHz) **are driven by amplifiers based on electron tubes** (vs solid state ones), for reasons of radiation hardness and power dissipation.

The **10 MHz cavity** with a power up to 20 kV, it is tuneable from 2.8 MHz to 10.1 MHz, h = [6...21].



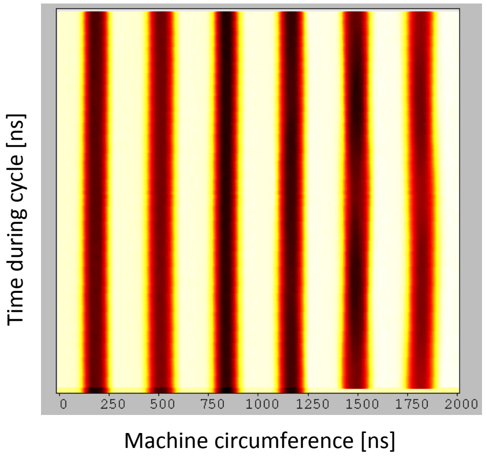
Courtesy of Carlo Rossi –[*http://indico.cern.ch/event/160434/contribution/11/material/slides/0.pdf*](http://indico.cern.ch/event/160434/contribution/11/material/slides/0.pdf)

Beam Instabilities

The PS has a **complex multi-harmonic system** which determines the longitudinal structure of the bunch train for LHC. The 25 ns LHC beam is prepared in the PS.

In *h*=21, with 100 ns bunch spacing -> cross-talk of bunches which are coupled with the longitudinal impedance of the PS -> **LONGITUDINAL INSTABILITY OF THE BEAM**

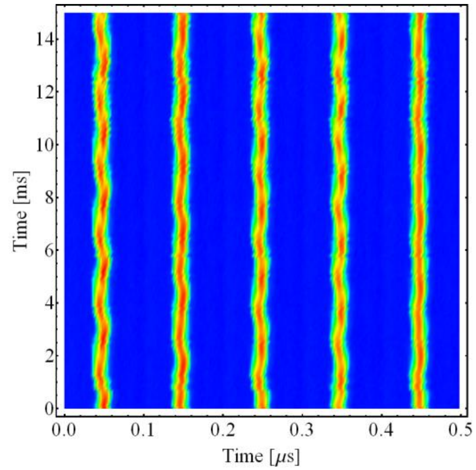
STABLE



Injection

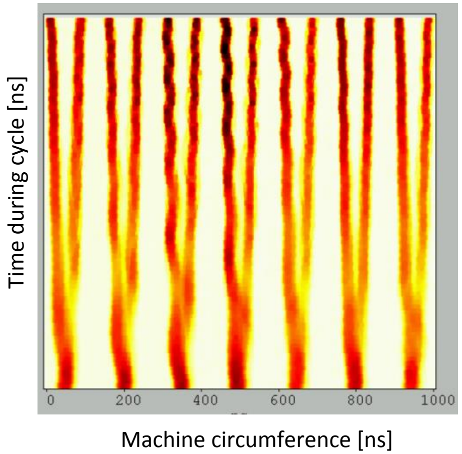
Impedance interaction

UNSTABLE



After triple splitting and transition

Not a correct population of the bucket



Double splitting at high energy

New LHC beam planned for the **LIU project** -> Increased intensity -> $1.8 \cdot 10^{11} \rightarrow \mathbf{2.7 \cdot 10^{11}}$ ppb at extraction

Increased voltage in the cavity induced by the beam

Beam instabilities

Beam instabilities & Feedback system

BEAM LOADING

Action: Reduce the impedance seen by the beam

Cures:
- Wideband negative feedback
- 1-turn delay feedback (see D.Perrelet talk)

REDUCE

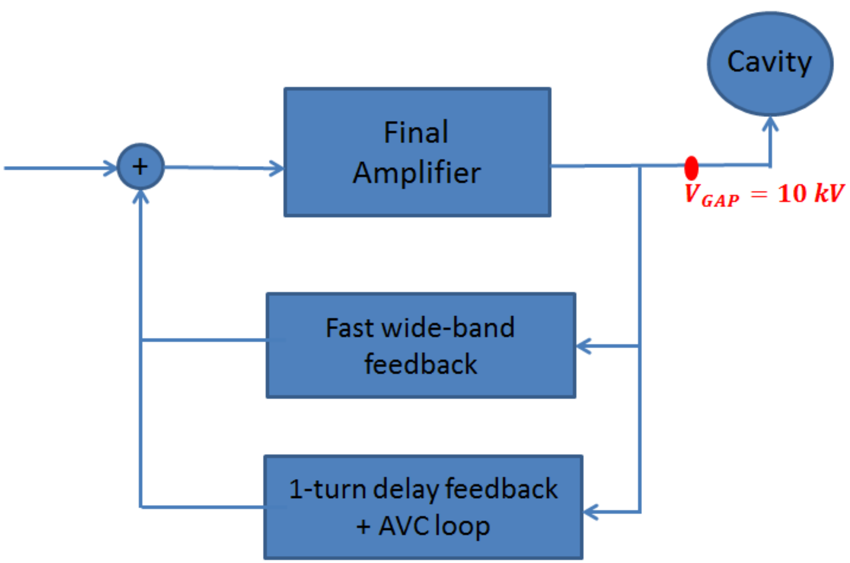
COUPLED-BUNCH INSTABILITY

Action: damp unstable oscillation modes caused by the 10 MHz cavities (as found in measurements and simulations)

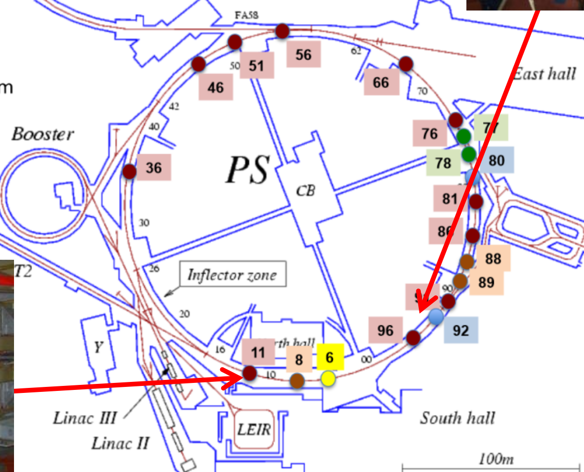
Cures:
- Coupled-bunch feedback
- New longitudinal kicker -> Finemet © cavity

COMPENSATE

1) Wideband Feedback acts on the voltage sent to the cavity



2) Coupled-bunch Feedback acts on the beam



Outlook

- The PS RF system
- **Beam loading & cures**

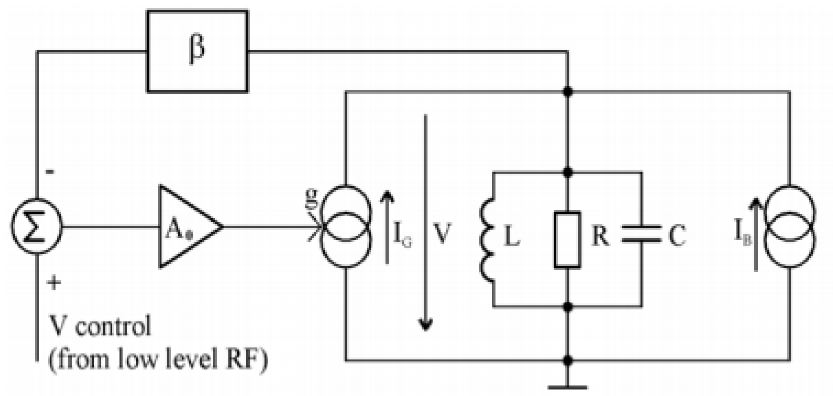
  Wideband negative feedback
- Coupled-bunch instabilities measurements & simulations

  Feedback system and damper

  10 MHz system impedance model and simulations
- Summary and discussion

Beam loading & wideband negative feedback

Any **cavity** close to its fundamental mode can be represented as a **parallel RLC resonator**. The beam and the RF amplifier are modelled as ideal current generators.



R= final resistance of the amplifier and cavity losses
I_G = provided by the power RF amplifier
I_B = current due to the beam producing a voltage in the cavity called **Beam loading voltage V_B**
V = total voltage in the cavity (V_{GAP})

Maintain V constant, (in the limit of the input signal), **minimizing the effect of I_B** -> **minimize V_B**

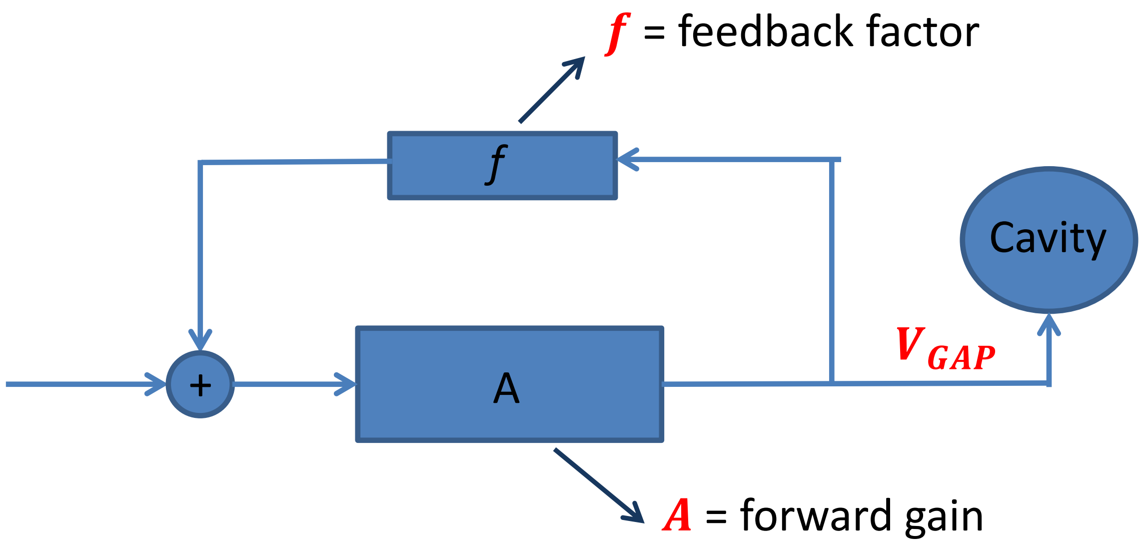
BEAM LOADING VOLTAGE

$$V_B = I_B \cdot Z_{BEAM}$$

Reduce the impedance seen by the beam

Wideband negative feedback in the 10MHz cavity

G.Favia, V. Desquiens, M. Morvillo



Reduce the impedance seen by the beam:

$$Z_{BEAM} = \frac{Z_{CAV}}{1 + G_L}$$

Increase the loop gain

$$G_L = A \cdot f$$

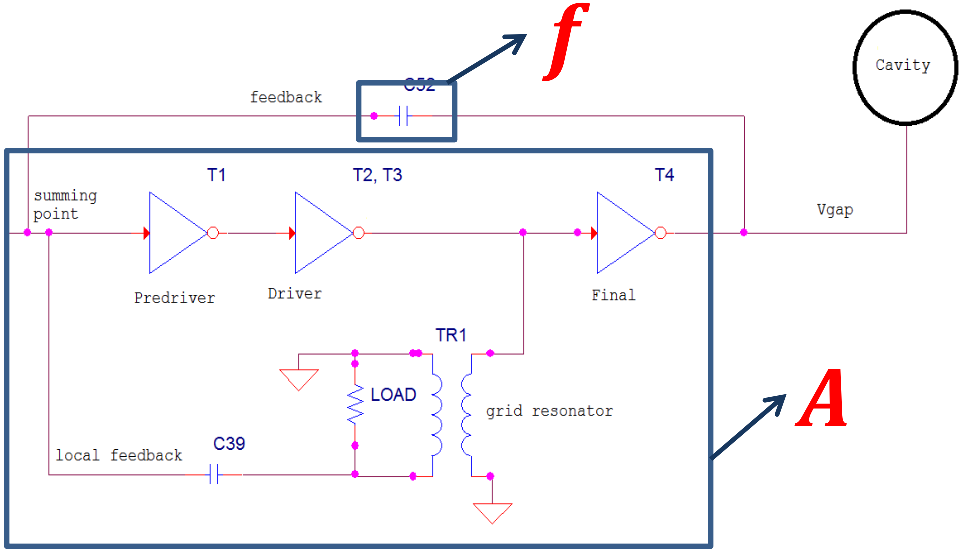
Why don't increase just f ? ⟹ **Closed loop gain** $G \cong 1/f$

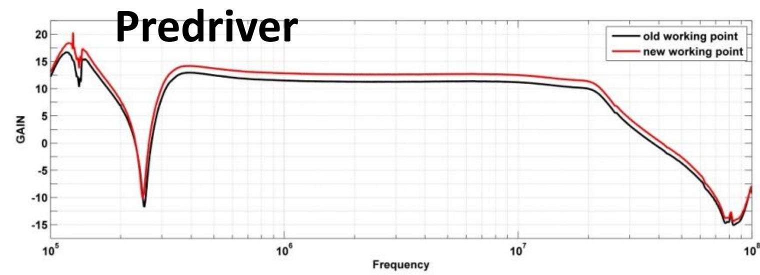
Not able any more to give to the cavity the $V_{GAP} = 10\ kV$ per gap

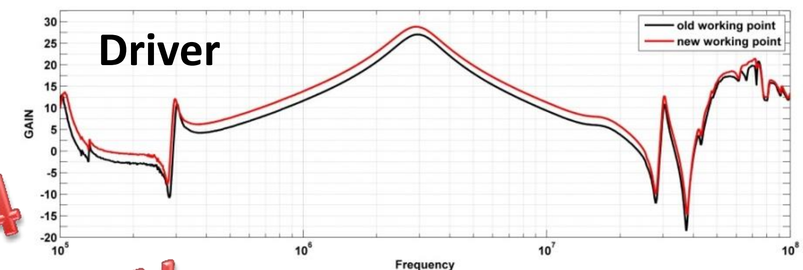
Actual situation in the 10 MHz cavity
$G_L \sim 23dB$

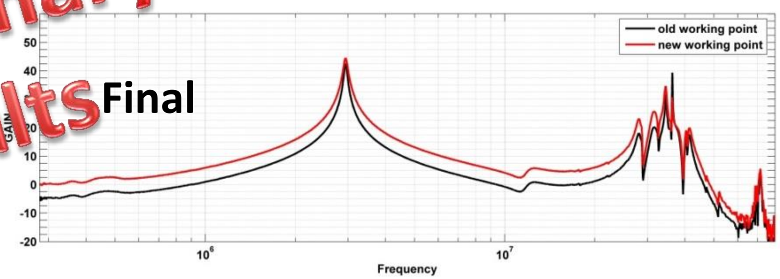
⟹ **OBJECTIVE: INCREASE OF G_L UP TO ~29dB (in the limit of stability)**

Work in progress: change the working point of the electron tubes









STAGE	GAIN Old configuration	GAIN Change of tubes working point
Predriver	11.1 dB	12.76 dB
Driver	27 dB @3MHz 24.35 dB @10MHz	28.8 dB @3MHz 25.9 dB @10MHz
Final	42.5 dB @3MHz 38.8 @10MHz	44.6 dB @3MHz 42.17 dB @10MHz

2014 preliminary results

TO DO NEXT -> verify that with the new working points the amplificator (in the limit of stability and respecting the phase and gain margin) give to the cavity 10 kV per gap.

Outlook

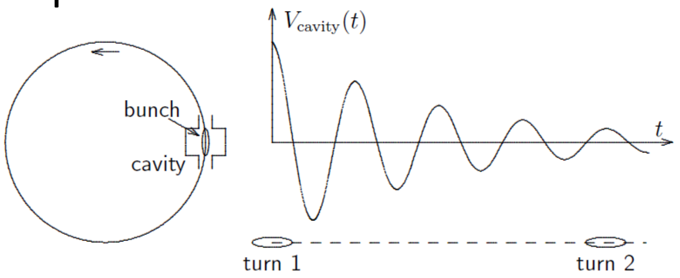
- The PS RF system
- Beam loading & cures
- Wideband negative feedback
- **Coupled-bunch instabilities measurements & simulations**

Feedback system and damper

- 10 MHz system impedance model and simulations
- Summary and discussion

Coupled-bunch instabilities

- Beam in a synchrotron ring made of bunches of charged particles.

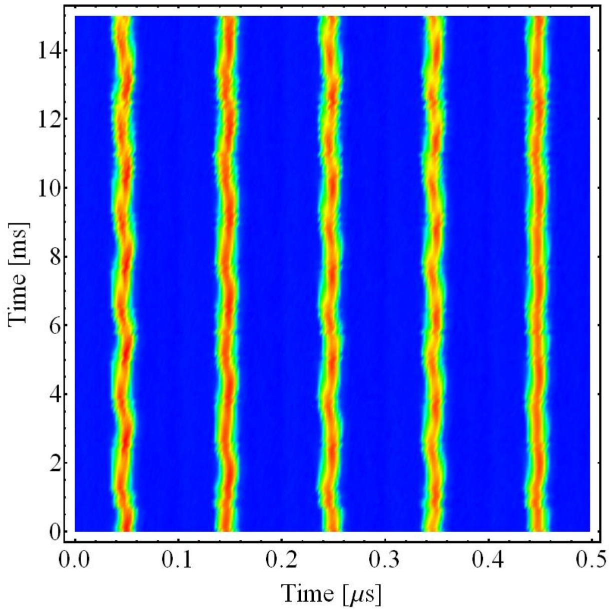


- Transverse (betatron) and longitudinal (synchrotron) oscillations normally damped by natural damping.

- Interaction of the particles with cavity-> **wakefields**.

- Wake fields act back on the beam and produces growth of oscillations.

Example of an n = 12 mode



- **If the growth rate is stronger than the natural damping the oscillation gets unstable.**

Since wakefields are proportional to the bunch charge, **instabilities are current dependent.**

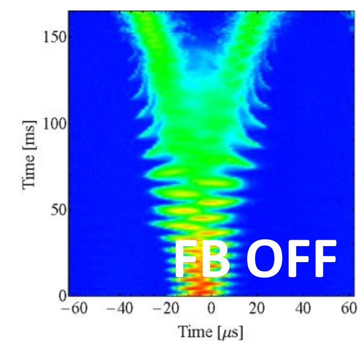
'Theory and performances of the longitudinal active damping system for the CERN PS Booster' F.Pedersen and F.Sacherer

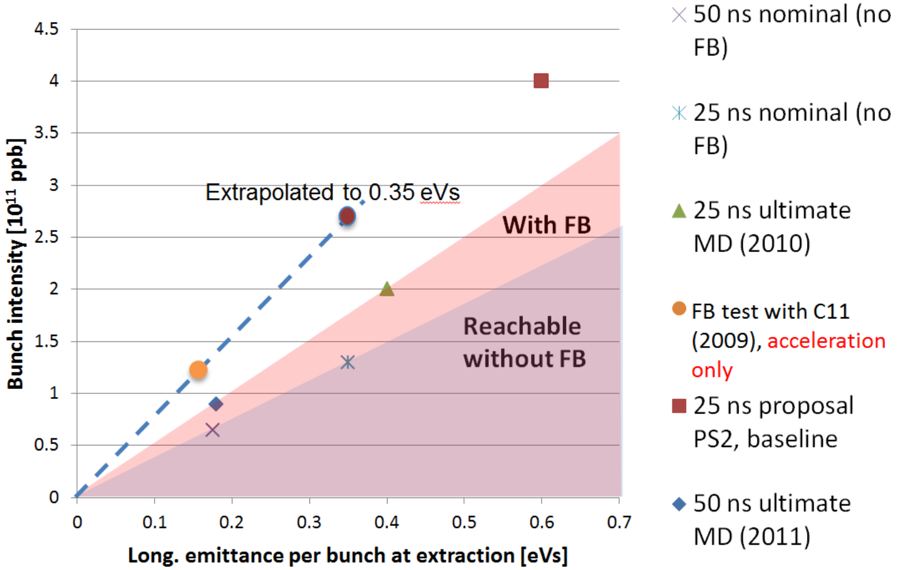
State of the art of coupled-bunch instabilities in the PS

- Longitudinal coupled-bunch instabilities are observed in the CERN PS **during acceleration (above transition energy) and on the flat-top**.

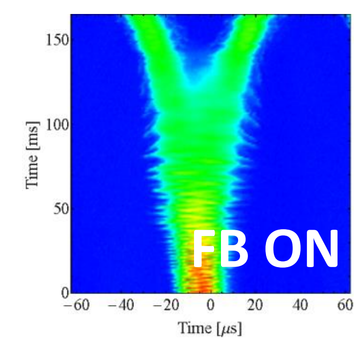
- For LHC-type of beam in the PS with bunch spacing below 100 *ns* only **the motion of the centre of mass of the bunches** has been observed.

- Up to present intensities (achieved $1.8 \cdot 10^{11}$ ppb at extraction) coupled-bunch instabilities are damped using a feedback system limited to the first two dominant oscillation modes, but it will become insufficient for the beam parameters planned within the LHC upgrade ($2.7 \cdot 10^{11}$ ppb at extraction).



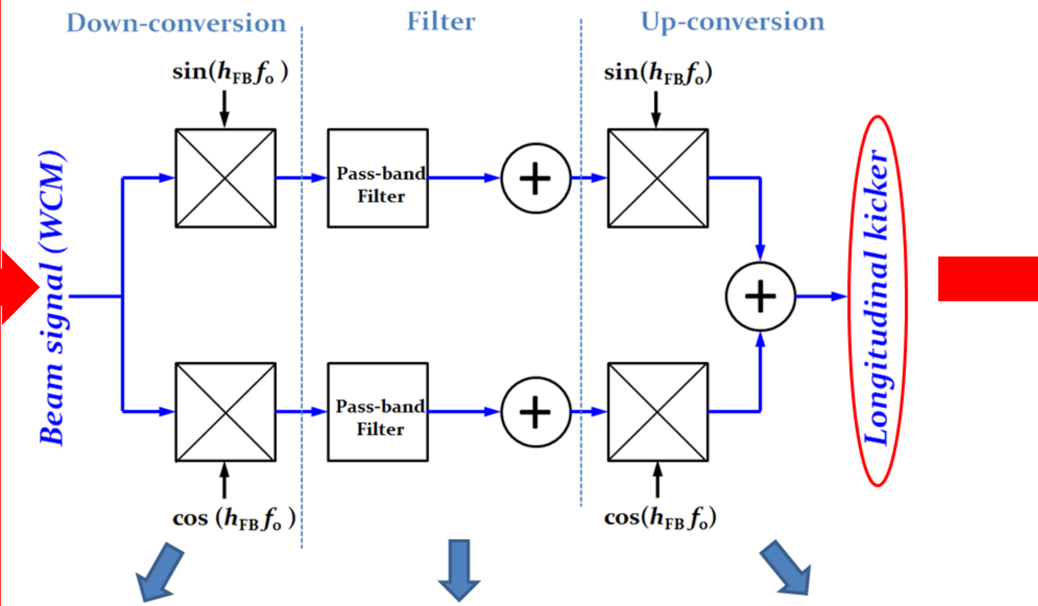


New coupled-bunch feedback system based on the 1-turn delay scheme



Coupled-bunch feedback & measurements

H. Damerau



Pick up f_s sidebands at harmonic of f_o .

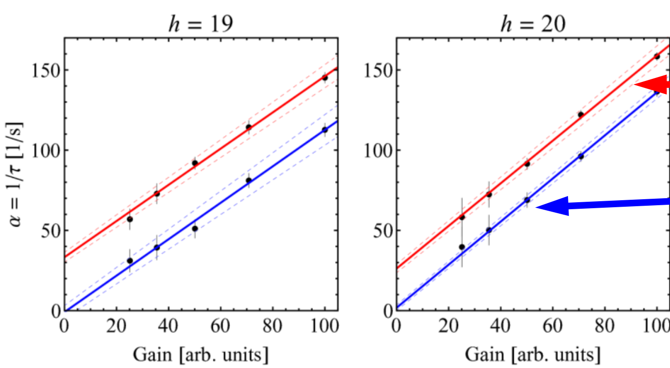
Demodulation and baseband filtering are used to remove the component at the f_o harmonic.

The synchrotron sidebands filtered are then amplified and re-modulated.

Spare 10MHz cavity

Finemet © cavity

A **large amount of measurements** has been done to **check the behaviour of the coupled bunch instabilities** in the machine **with the feedback system**, studying the damping rate vs many parameters like gain, intensity, emittance and cycle time.



Measured damping rate with **feedback on**

Corrected for natural damping

→ **Zero damping at zero gain**

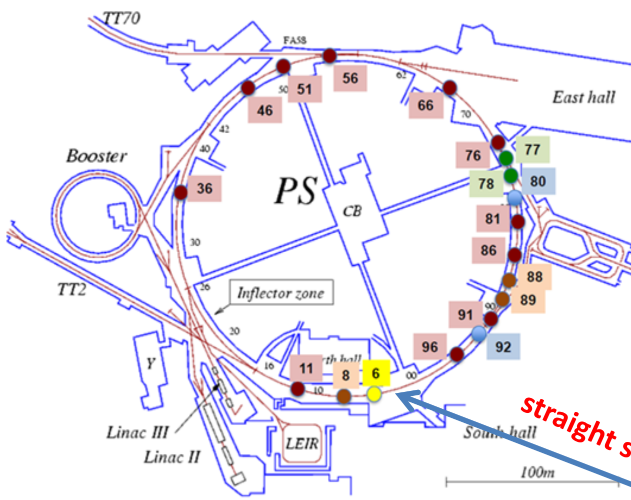
→ Natural damping independent from gain

New PS longitudinal kicker cavity

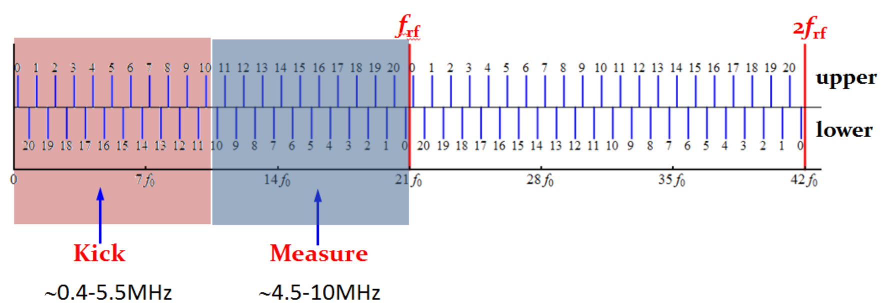
M. Paoluzzi

During the first long shutdown (LS1) in 2013-2014, a **new digital feedback** has been installed, covering all coupled-bunch modes with a new longitudinal cavity based on the wideband frequency characteristics of **Finemet** © magnetic alloy and **driven by solid-state amplifiers.**

Finemet cavity used in LEIR but to accelerate



Feedback kicker requirements	
Frequency range	0.4-5.5 MHz
RF voltage per sideband, V_{mode}	~ 1kV
Maximum total RF voltage, V_{max}	~5kV
Un-damped shunt impedance at $n \cdot f_{rev}$	<200Ω



Outlook

- The PS RF system
- Beam loading & cures
- Wideband negative feedback
- Coupled-bunch instabilities measurements & simulations
- New feedback system and damper
- 10 MHz system impedance model and simulations
- Summary and discussion

Coupled-Bunch Simulations

Measurements done in 2013 before LS1 : coupled-bunch feedback and the spare cavity have been used to excite and damp coupled-bunch oscillation.

Need of **SIMULATIONS** to:

- Study and deeply understand these instabilities
- Predict the beam behaviour with the new LIU parameters

Longitudinal Coupled-Bunch simulation code

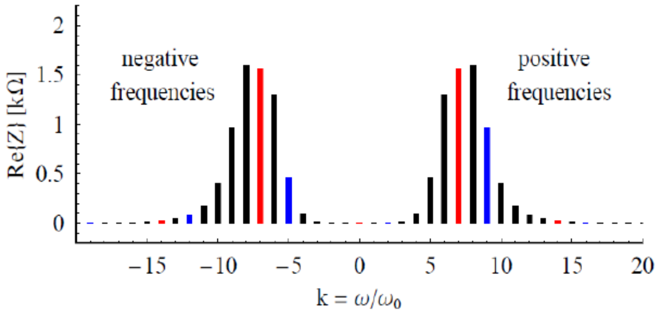
Tracks the **longitudinal centre of mass motion** of all the bunches, by including wakefields effects.

The **feedback system** in the code has been implemented according with the PS installation.

'A time domain simulation code of the longitudinal multibunch instabilities', M.Bassetti, A.Ghigo, M.Migliorati, L.Palumbo, M.Serio

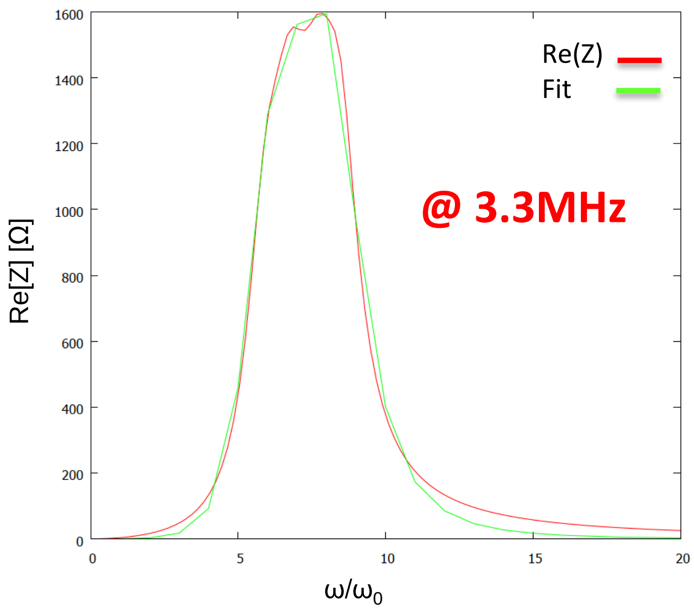
Impedance model of the 10 MHz RF system

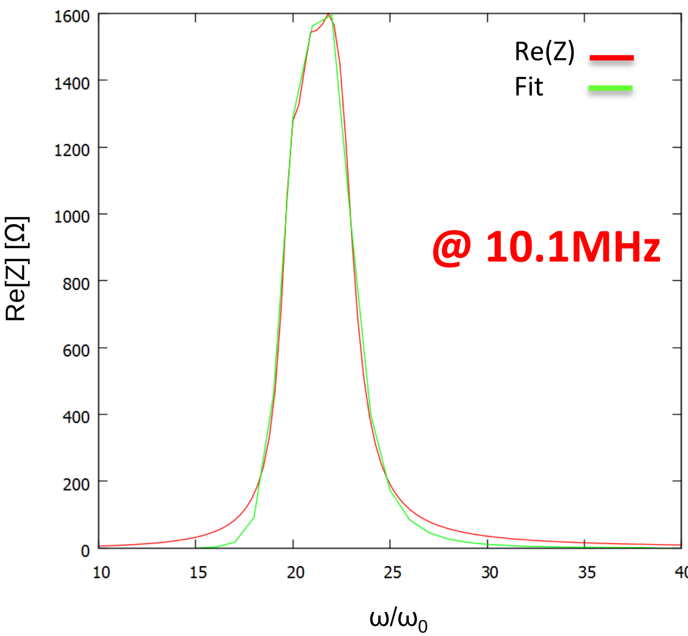
Real part of the total impedance of the 10 MHz cavities at the revolution harmonics @ 3.3MHz



Coupled-bunch growth rate obtained by theoretical approach

Mode number	$\mu = 1$	$\mu = 2$	$\mu = 3$
Growth rate $1/\tau$	$2.5s^{-1}$	$3.0s^{-1}$	$1.0s^{-1}$

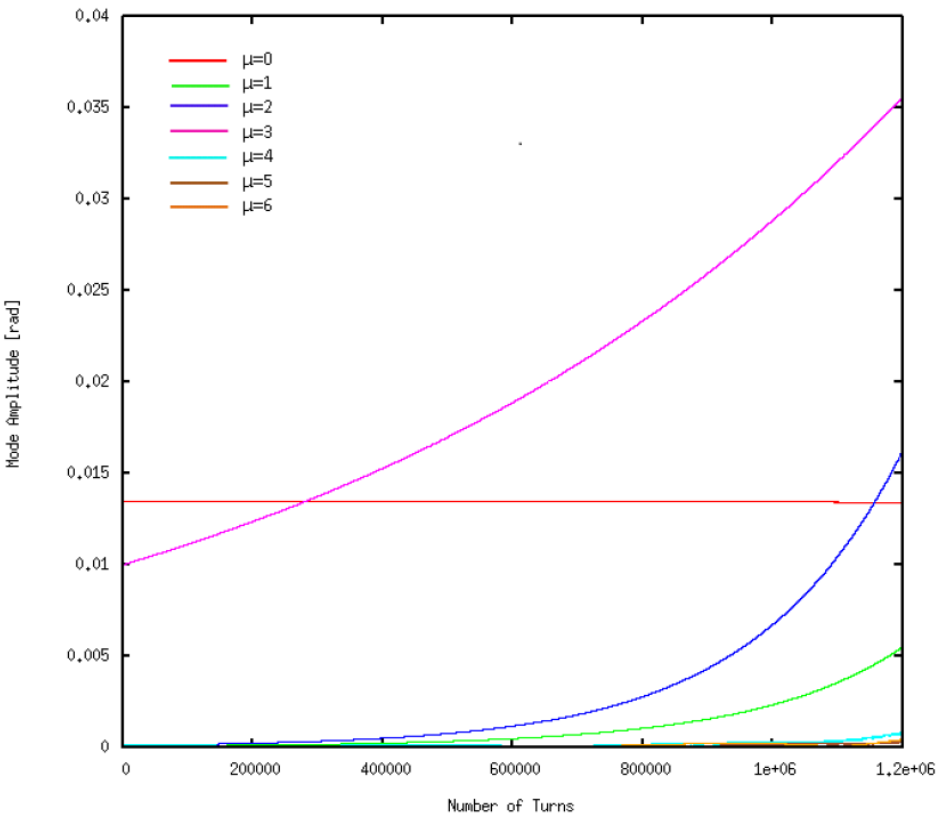




Simulations vs. stability data in h=7 (3.3MHz)

Parameters	Value
Beam energy (GeV)	13
RF voltage (kV)	165
Synchrotron frequency (Hz)	230
Total beam intensity (ppp)	9×10^{12}

We compare the rise time of the instability obtained with simulations with the CB growth rate from the eigenvalues system (PAC07).



Simulations results			
Mode Number	1	2	3
Growth Rate	544ms	467ms	1.91s

Paper results			
Mode Number	1	2	3
Growth Rate	400ms	333ms	1s

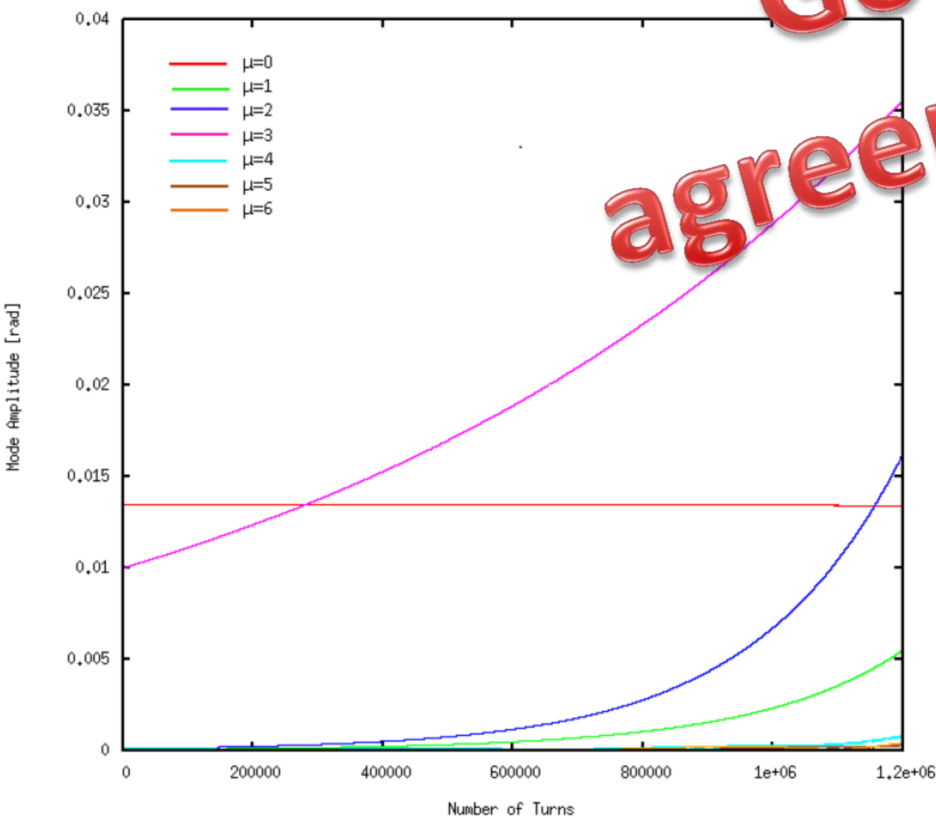
Longitudinal coupled-bunch instabilities in the CERN PS
H.Damerau,S.Hancock,C.Rossi,E.Shaposhnikova,J.Tuckmantel,J.-L. Vallet

Simulations vs. stability data in h=7 (3.3MHz)

Parameters	Value
Beam energy (GeV)	13
RF voltage (kV)	165
Synchrotron frequency (Hz)	230
Total beam intensity (ppp)	9×10^{12}

We compare the rise time of the instability obtained with simulations with the CB growth rate from the eigenvalues system (PAC07).

Good agreement!!



Simulations results			
Mode Number	1	2	3
Growth Rate	544ms	467ms	1.91s

Paper results			
Mode Number	1	2	3
Growth Rate	400ms	333ms	1s

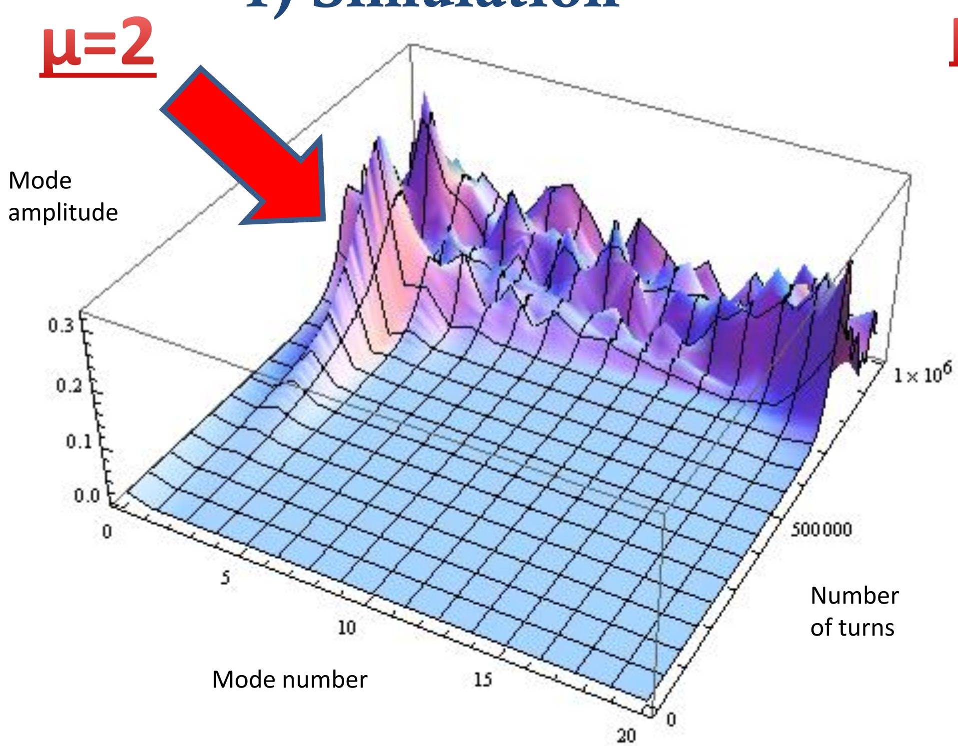
The code is a good tool to simulate coupled-bunch instabilities

Longitudinal coupled-bunch instabilities in the CERN PS
H.Damerau,S.Hancock,C.Rossi,E.Shaposhnikova,J.Tuckmantel,J.-L. Vallet

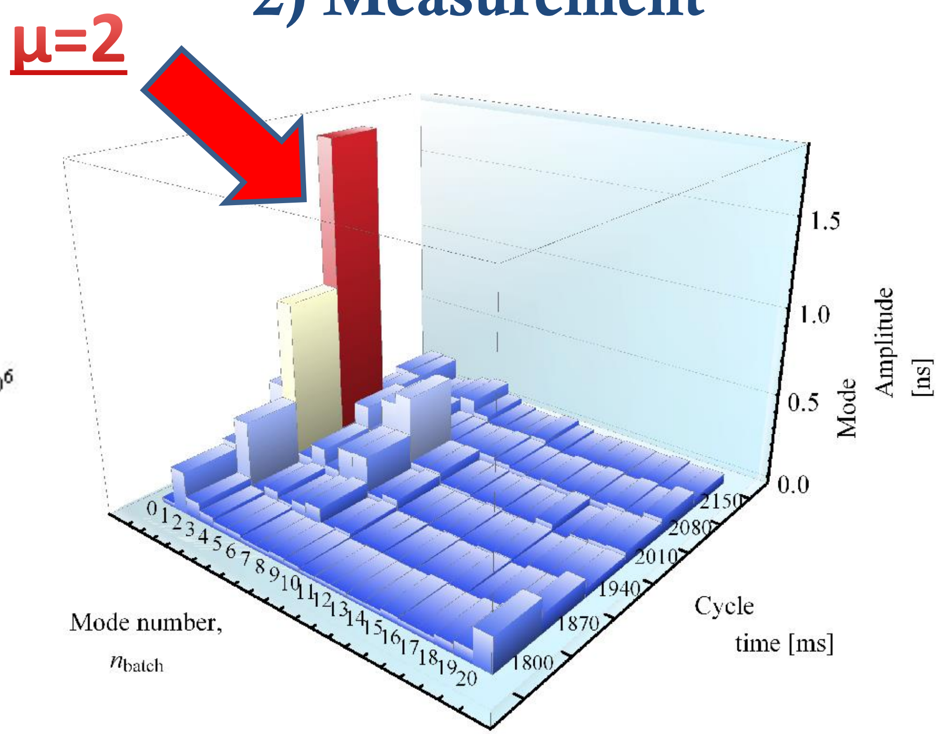
2013 measurements vs. simulations in h=21 (10.1MHz)

Pattern of the oscillation modes at 10 MHz compared with measurements done in 2013 which show the evolution of the mode spectra for LHC50ns beam during acceleration for a full machine (21 bunches). The 'mode pattern' depends on the initial conditions and the oscillation amplitude depends on the bunch number in the train.

1) Simulation

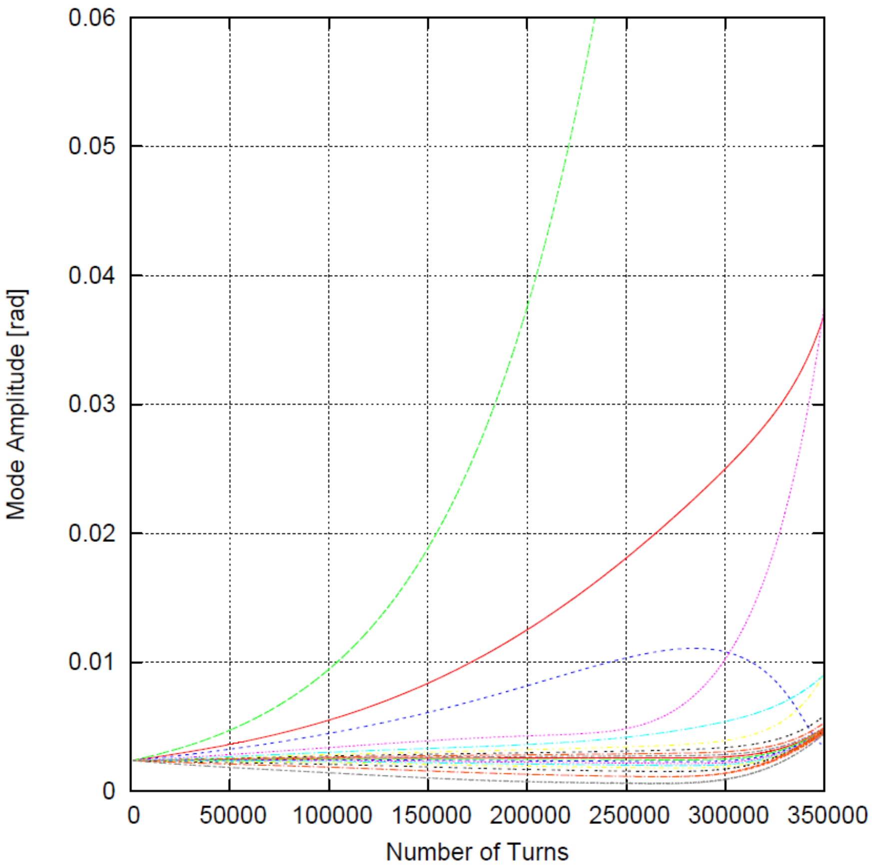


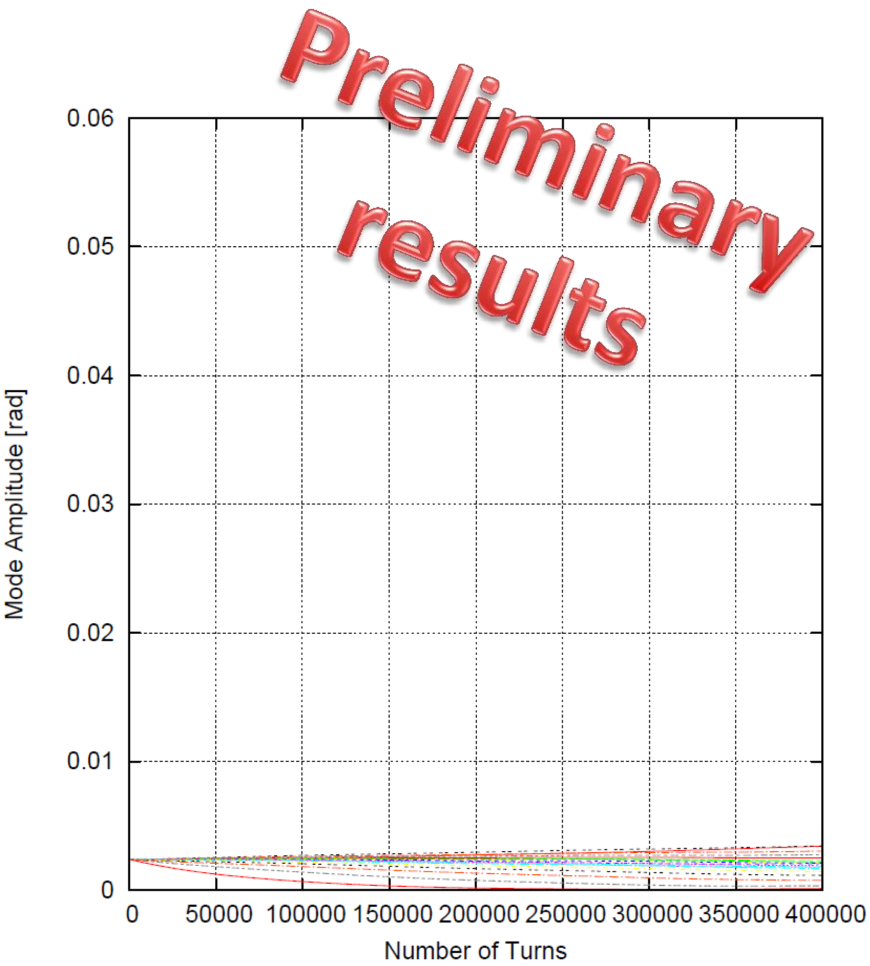
2) Measurement



Simulations predict oscillation mode μ=2 as the stronger one before knowing the measurements results!!

Simulations with LIU intensity





Simulations performed with 21 bunches IN h=21 with an intensity of $2.7 \cdot 10^{11}$ ppb at extraction.

Outlook

- ➢ The PS RF system
- ➢ Beam loading & cures
- ➢ Wideband negative feedback
- ➢ Coupled-bunch instabilities measurements & simulations
- ➢ New feedback system and damper
- ➢ 10 MHz system impedance model and simulations
- ➢ **Summary and discussion**

Summary

- 10MHz RF system behaviour with new LIU parameters: beam loading and coupled-bunch instabilities.
- Modified the working point of the tubes into the amplifier to increase the loop gain and so reduce the impedance seen by the beam.
- **In measurements done in 2013 before LS1** coupled-bunch feedback and the 10MHz spare cavity have been used to damp coupled-bunch oscillation.
- **Finemet © cavity** as new longitudinal kicker in the coupled-bunch feedback.
- **New feedback** also to operate in the frequency domain, similar signal processing as existing feedback, but digital and covering all harmonics simultaneously **based on hardware developed for the 1-turn feedback.**
- **First test with the beam after the startup in 2014**
- **10 MHz cavities impedance model implemented in the simulation code** and crosschecked either with theory and measurements
- Simulations with PS-LIU beam parameters with longitudinal feedback to find the maximum required feedback voltage (preliminary results)

LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

CERN