Cavities Auto Recovery with Beam

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Outline

- ✓ ALBA Overview
  - ALBA Accelerators
  - RF plants of Booster and SR
  - LLRF Conceptual Design
- ✓ Automatic Recovery with beam
  - Automatic startup without beam
  - Automatic recovery with beam
  - Trips postmortem analysis
- ✓ Future Upgrade: Feedforward loops

ALBA Overview

ALBA Overview

ALBA is a 3rd generation synchrotron light source, located at 20 km from Barcelona, Spain.

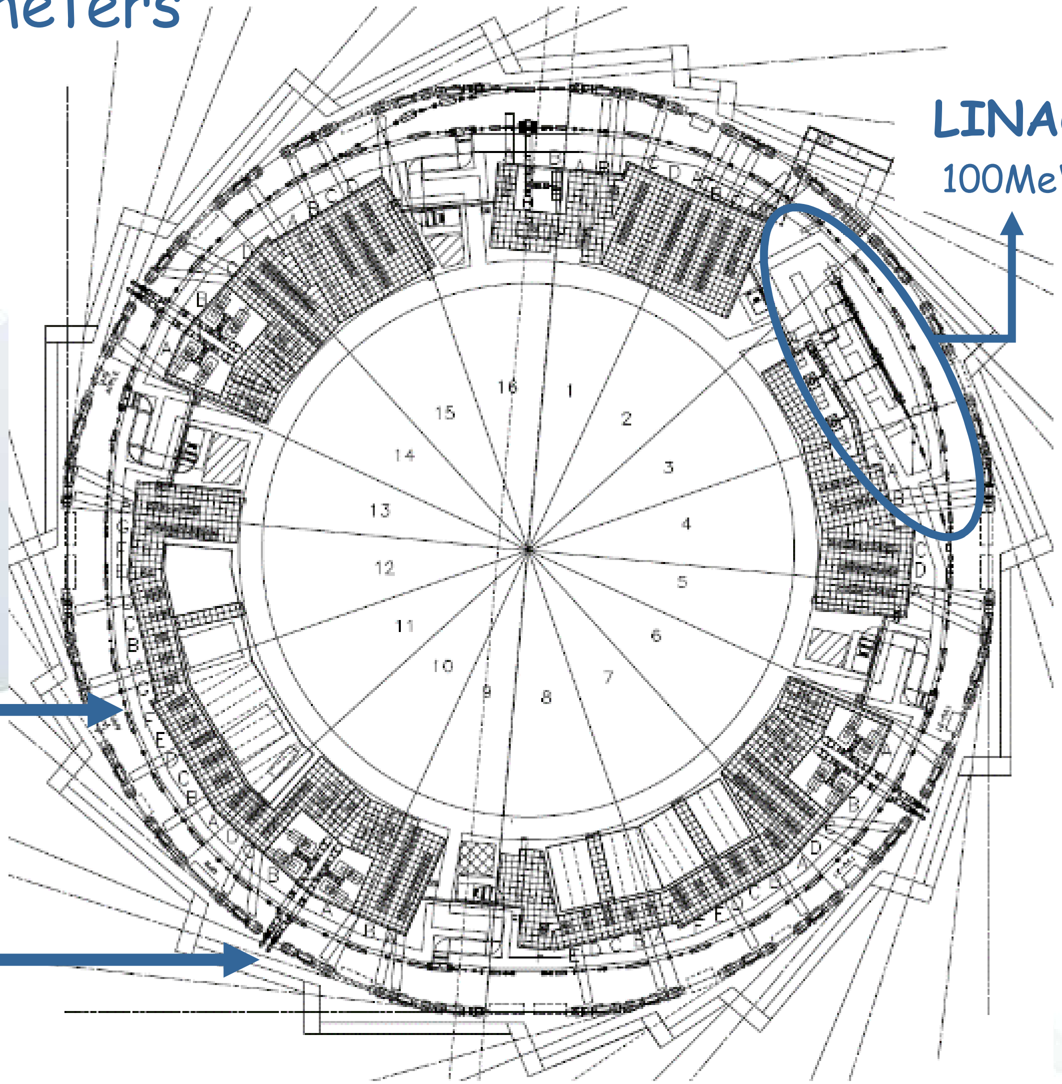
History

2004. Start Acc + Building design
2008 Linac Installation (turnkey system)
2009 Booster Installation
2010 Booster Commissioning and SR Installation
2011 SR Commissioning
2012 Operation with users

ALBA Overview

Accelerators Main Parameters

Energy	3GeV
Circumference	268m
Beam Current	400mA
Emittance	4nm.rad
Lifetime	≈10h
RF Freq	500MHz
Beamlines	up to 34



RF Plants

Booster RF Plant

Ramping from 100MeV to 3GeV at 3Hz

	Injection	Extraction
Cavity voltage	55kV	1000kV
Energy loss	0.001keV/turn	627keV/turn
Cavity power	0.1kW	33kW
Beam Power	0kW	2.5kW
Sync. Freq	13.7kHz	9.4kHz

Petra Cavity type (5 Cells)

Normal Conducting

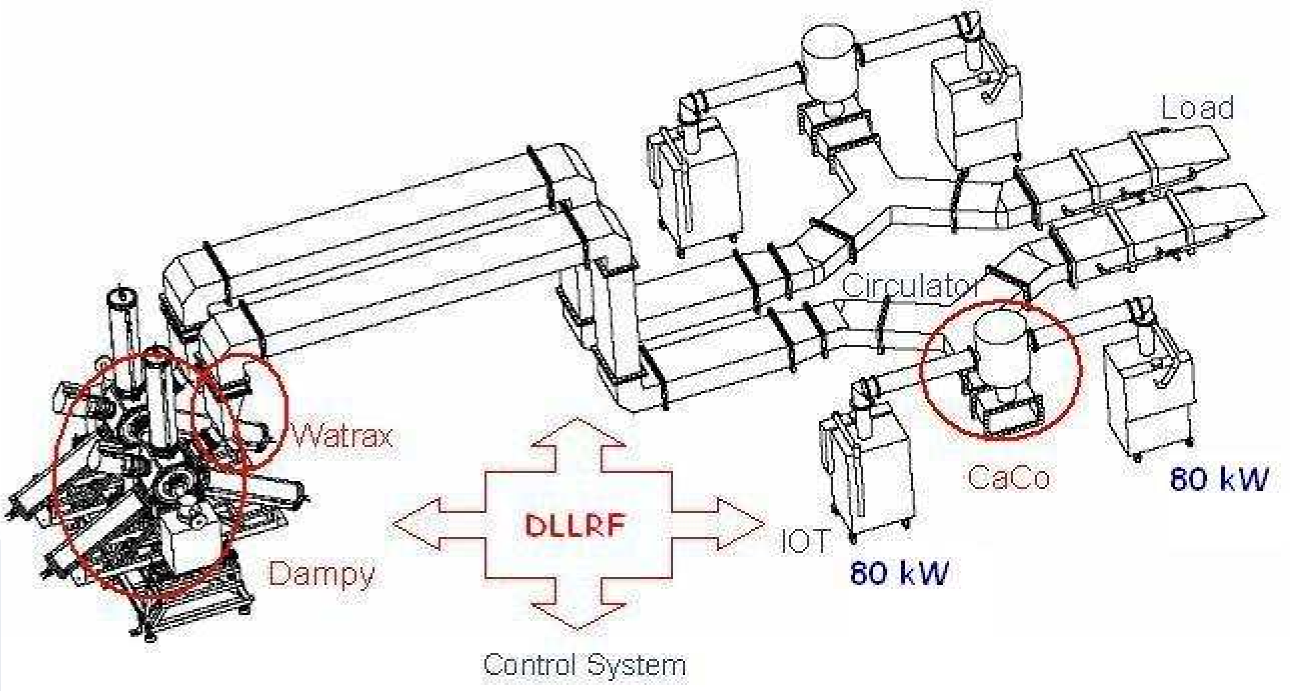
500MHz

80kW CW - IOT

Storage Ring RF Plants

RF Parameters

U_0	1.3MeV/turn
V_{total}	3.6 MV
q	≈ 2.5
f_s	≈ 9kHz
P_{RF}	960kW



6 RF Plants of 160kW at 500 MHz

2 IOT Transmitters per RF cavity. Power combined in CaCo

Dampy Cavity
- Normal Conducting
- Single cell, HOM damped
- 3.3 MΩ

Digital LLRF System based on IQ mod/demod

LLRF Conceptual Design

Main Characteristics

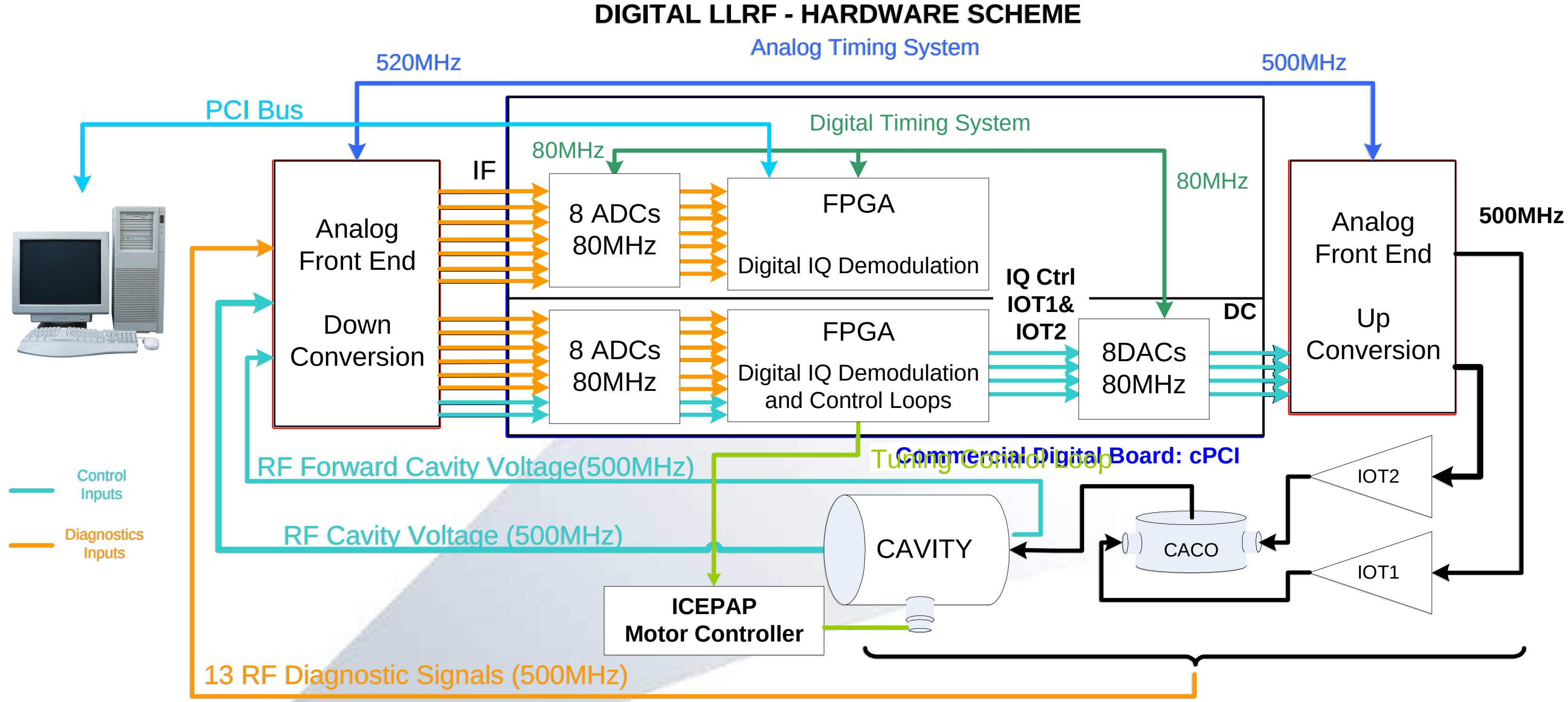
- ✓ Based on digital technology using a commercial cPCI board with FPGA
- ✓ Signal processing based on IQ demodulation technique
- ✓ Main loops: Amplitude, phase and tuning
- ✓ RF diagnostics: Circular buffer for post-mortem analysis (0.5s)
- ✓ Extra utilities
  - Automatic conditioning for cavities
  - Automatic soft start

Digital board: VHS-ADC from Lyrtech

Loops Resolution and bandwidth (adjustable parameters)

	Resolution	Bandwidth	Dynamic Range
Amplitude Loop	< 0.1% rms	[0.1, 50] kHz	30dB
Phase Loop	< 0.1º rms	[0.1, 50] kHz	360º
Tuning	< ± 0.5º	--	< ± 75º

LLRF Conceptual Design



Conceptual Design and Prototype

Analog Front Ends for Downconversion (RF to IF) and Upconversion (DC to RF)

Digital Commercial Board: cPCI with 16 ADCs, 8 DACs and Virtex-4 FPGA

Timing systems: 520MHz (500 + 20 MHz) for downconversion synchronized with digital 80MHz clock for digital acquisition

Automatic Recovery with Beam

One cavity -out of six- trips

Beam is not lost

One wants to recover the tripped cavity with heavy beam loading

RF Autorecovery with beam

✓ **Automatic Start up – Initial version:**

- When RF trips → LLRF Standby:
  - *Low RF drive*
  - *Disable tuning*
  - *Open loops (I&Q)*
- When RF ON → LLRF smooth startup
  - *Minimum RF Drive (low power to avoid high reflected power)*
  - *Tuning enabled*
  - *Amplitude and phase loops closed*
  - *Smooth power increase*

✓**Main Inconvenients when applying this startup with beam:**

- After a trip, the cavity remains tuned → it steals power from beam and in some cases make it unstable
- Recovering the cavity with beam, when tuning the cavity, the beam induces more voltage in the cavity than the IOT → Tuning loop becomes crazy

RF Autorecovery with beam

✓ **New Automatic Start up – to take into account beam loading:**

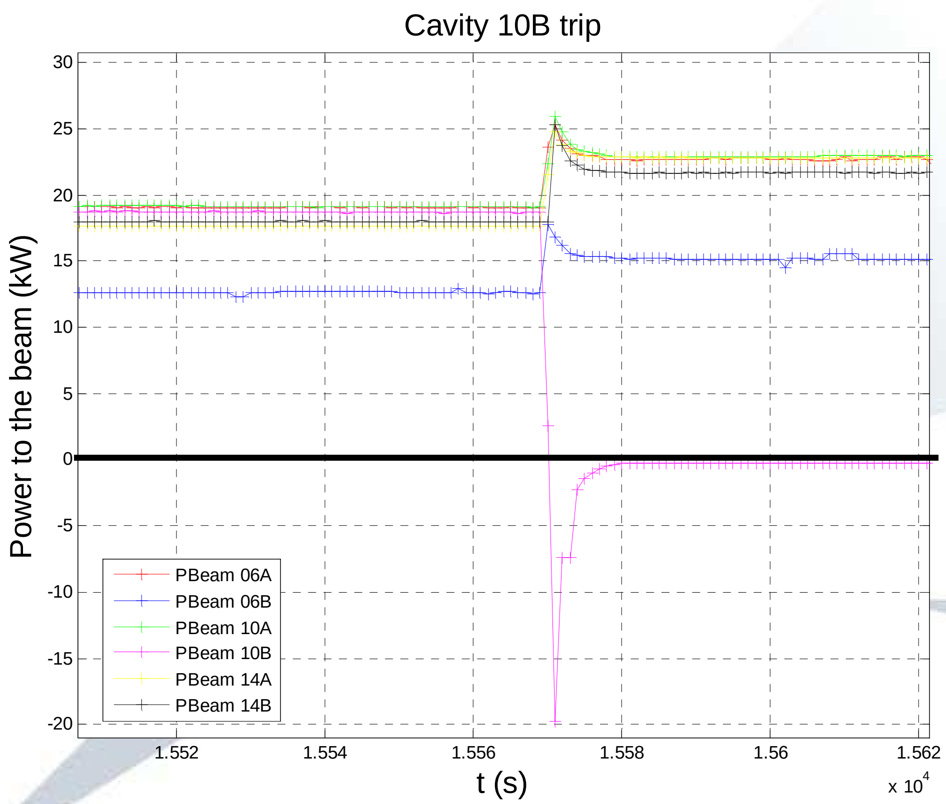
- When RF trip
  - *Open loops (I&Q)*
  - *Disable tuning*
  - *Detune cavity (parking) by moving the plunger 30,000 steps up*

- When RF ON:
  - ***IOT power high enough*** *to induce more voltage in the cavity than the beam loading after unparking*
  - *Amplitude and phase loops open because cavity is completely detuned*
  - *Phase and amplitude of LLRF adjusted to have very similar conditions in open loop and close loop*
  - *Plunger moved back 30,000 steps to tune cavity (unparking)*
  - *Tuning enabled*
  - *Amplitude and phase loops closed*
  - *Smooth power increase*

- Tested in all cavities at **130mA**

RF Autorecovery with beam

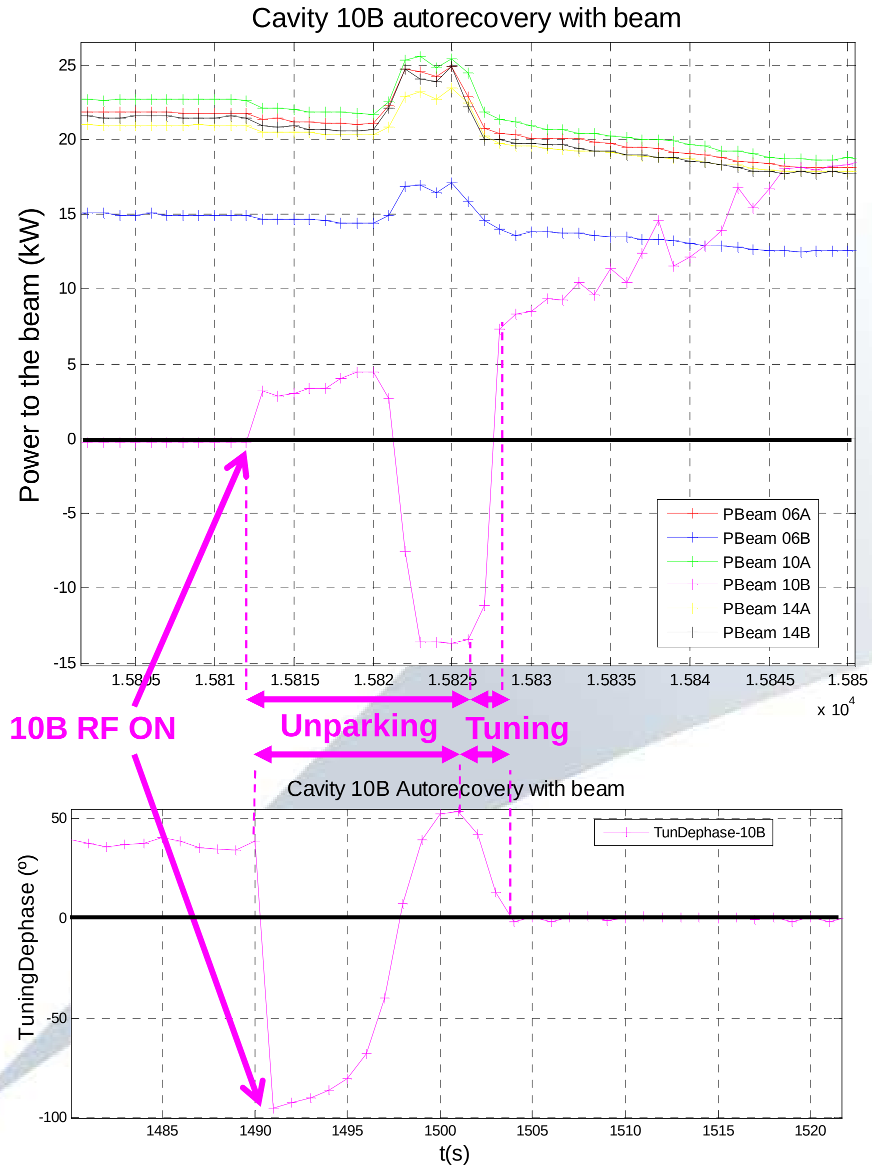
There are 6 cavities: 06A - 06B – 10A – 10B – 14A – 14B



Cavity 10B trip:

- ✓ Other 5 cavities increase power
- ✓ 10B steals -20kW power to the beam
- ✓ After trip **Parking Process** starts
- ✓ After 15s, 10B power = 0kW

RF Autorecovery with beam



Cavity 10B autorecovery

- ✓ RF ON in 10B: some power to the beam
- ✓ **Unparking Process** starts
- ✓ After unparking, 10B steals power to the beam
- ✓ Tuning Loop Enable (10B power > 0kW)
- ✓ Amplitude and phase loop enable and power increased

Tuning Dephase during autorecovery

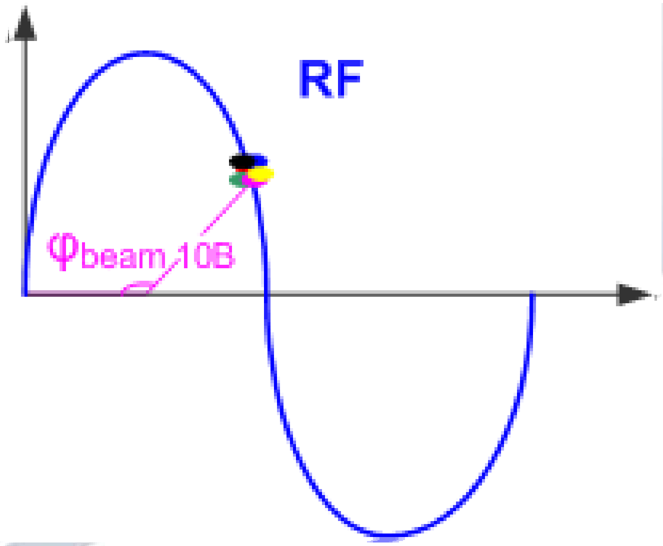
- ✓ RF ON : TuningDephase = -90º
- ✓ **Unparking Process** starts → Tuning dephase approaching 0º and then overpasses this value

RF Autorecovery with beam

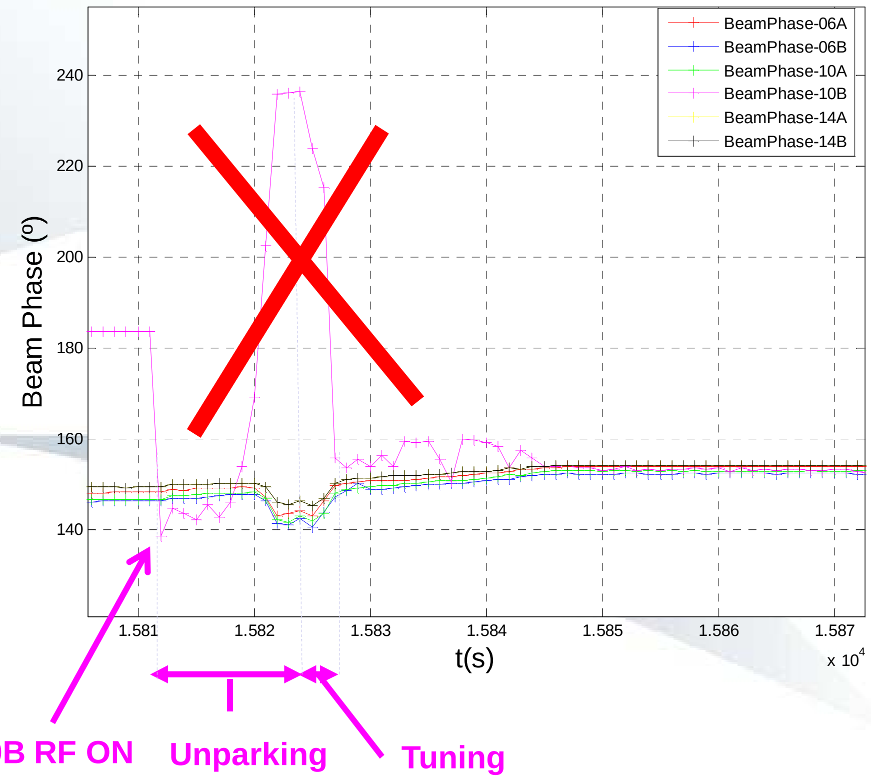
Cavity 10B autorecovery

- ✓ RF ON: 10B Beam phase ~ 140º
- ✓ **Unparking Process** finishes: 10B Beam phase ~ 230º
- ✓ **Conclusion**: the unparking process should move the plunger less steps than the parking process

Beam Phase respect to RF ~ 150º



Cavity 10B autorecovery with beam



Trips Post Mortem Analysis

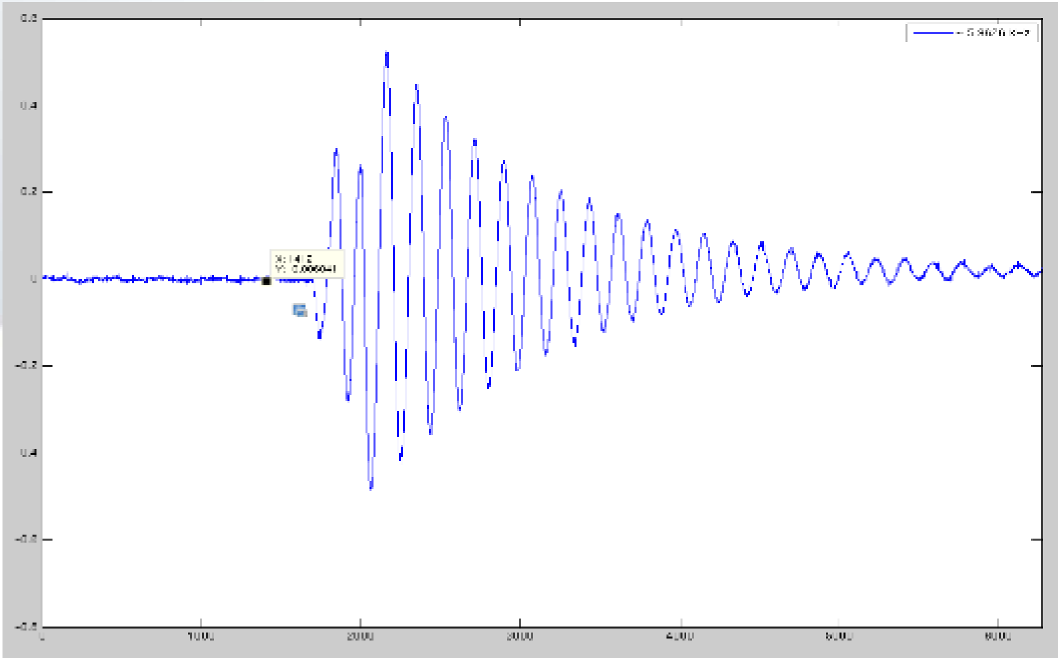
✓ **Sometimes beam does not survive after RF trip**

- The less # of cavities, the more likely to have beam dump due to RF trips
- The higher the current, the higher reflected power in other cav. after a RF trip

✓ **Will the beam survive at 400mA after a RF trip?**

Behaviour of 06B after a trip in 10B and no beam dump (61mA)

- ✓ Power to the beam increases
- ✓ Beam phase gets reduced
- ✓ Frequency oscillations ~ 6kHz (synchrotron freq)
- ✓ Stabilization time ~ 3ms (longitudinal damping time)

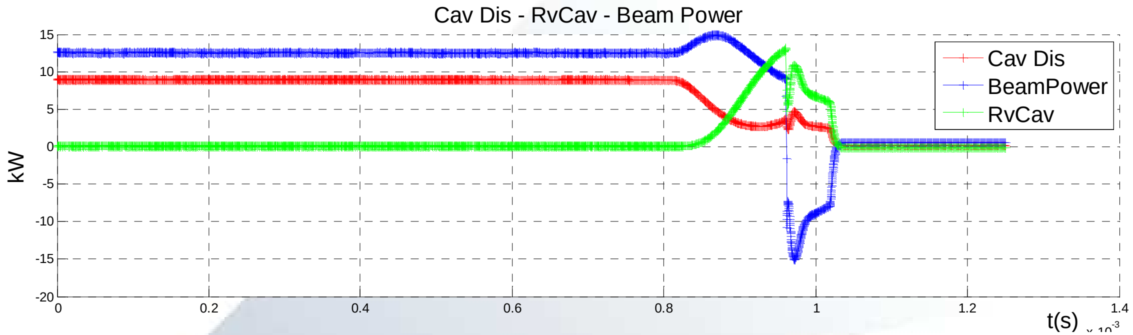


Effect on beam trajectory (BPMs reading after RF ITCK – Data provided by A. Olmos)

Trips Post Mortem Analysis

Behavior of 06B after a trip in 10A and Beam Dump (100mA)

- ✓ Power to the beam starts to increase
- ✓ Beam phase starts to get reduced
- ✓ BUT Reflected power reaches interlock level: 16kW



Provisional solution:

- ✓ Reflected power interlock level increased up to 23kW
- ✓ Cavities detuned to avoid Robinson instability and to reduce the amplitude of reflected power in active cavities when one RF cavity trips

Maximum reflected power calculated when working at 400mA (data provided by Bea Bravo)

- ✓ Cavities β adjusted to have minimum reflected power at 400mA
- ✓ Working with 6 Cavities, 600kV/cav, 400mA → RF trip causes:
  - ✓ Reflected Power transient of 73kW per cavity

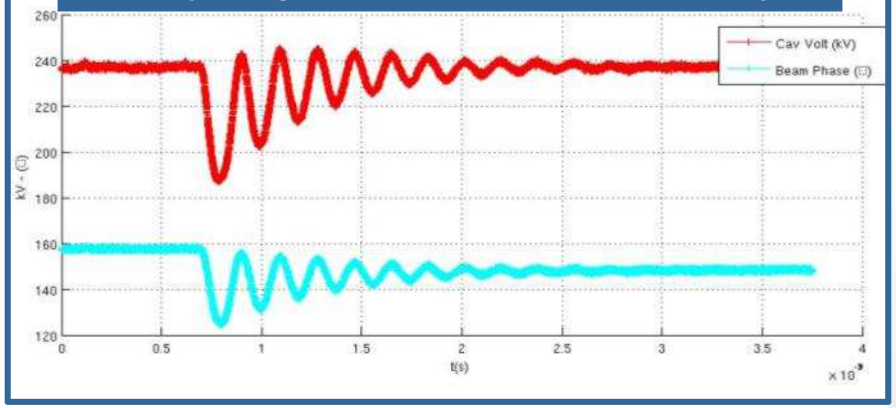
Will beam survive at 400mA after RF trip? Still don't know, but not likely

Future upgrade: Feedforward loops

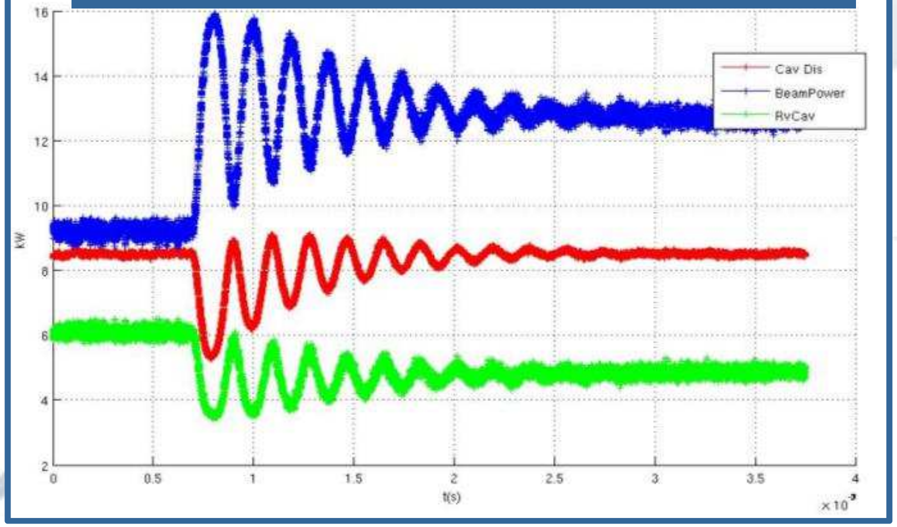
Feedforward Loop

Feedforward loop to compensate transient when RF cavity trips

Cavity Voltage & Beam Phase transient after RF trip



Cavity voltage, Power to Beam and Cavity Reverse Power



✓When cavity trips

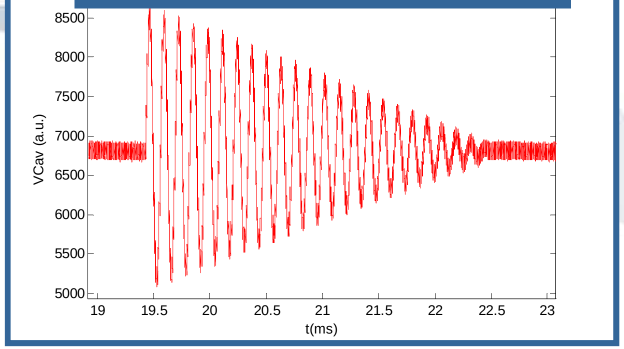
- Cavity Voltage oscillates with frequency equal to synchrotron tune
- Transient time equal to damping time of machine

✓Compensation

- Amplitude modulation triggered when one cavity trips
- Frequency, amplitude and phase of modulation are adjustable parameters

✓ Tests with beam still pending

Amplitude Modulation of Cavity after fake interlock



Thanks for your attention

Questions?