Observations and Analysis of Fast Beam-Ion Instabilities at SOLEIL

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C. Herbeaux, A. Bence, J.M. Filhol, L. Cassinari, M. Diop, M.P. Level, C. Mariette, R. Sreedharan, A. Loulergue, N. Béchu, M. Labat, M.E. Couprie, A. Nadji and other Machine Physics group colleagues, A. Rodriguez (student), V. Krakowski (student), Ph. Martinez and the SOLEIL Operation group members, …

1. Background

- Aims to achieve high average current (500 mA in 400 bunches)/high bunch current (1×15 mA, 8×12.5 mA)
- Choice of relatively small vertical aperture (*b* = 12.5 mm) for the standard chamber, and b=5mm for the ID chambers
- About 2/3rd of the ring NEG coated (Al vessels)
- Presence of many in-vacuum IDs [presently 7, (full gap)$_{\text{min}}$ = 5.5 mm]

Basic ion effects expected for SOLEIL:

- Ion trapping: Critical mass $A_c = \dfrac{N_b r_p \pi R}{n_b \sigma_y (\sigma_x + \sigma_y)}$ = 1.3 at 500 mA
- Fast Beam Ion Instability (FBII)

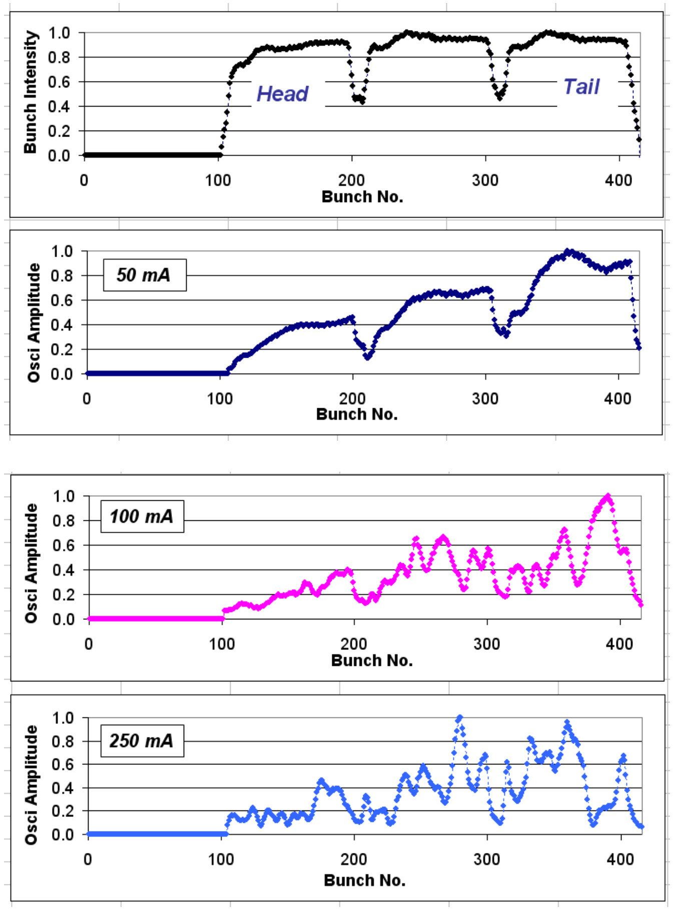
$$\tau^{-1}_{aymp,e^-}(s^{-1}) \approx \frac{N_b^{3/2} n_b^2}{\gamma} \times \left[5 p_{gas}(\text{Torr}) \frac{\beta_y r_e r_p^{1/2} L_{sep}^{1/2} c}{\sigma_y^{3/2} (\sigma_x + \sigma_y)^{3/2} A^{1/2}} \right]$$

= several μs at 500 mA

◊ Ion instability is being an important issue at SOLEIL, as it apparently prevents us from running the machine at 500 mA with zero chromaticity and a high RF voltage (i.e. the general conditions to improve the beam lifetime).

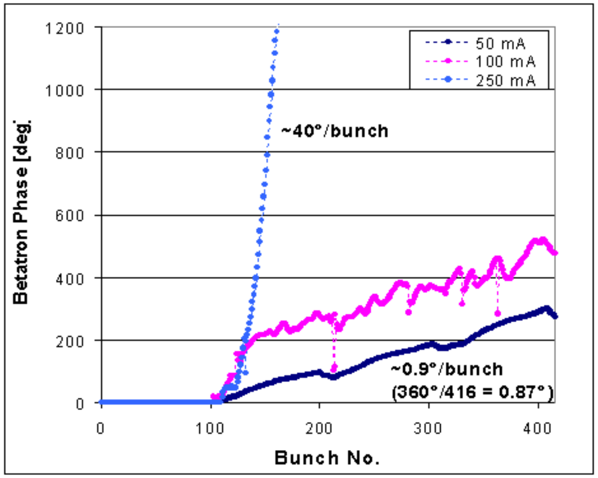
2. Early Observations

- *Example of ADC data analysis in 3/4th filling: (June 2007)*

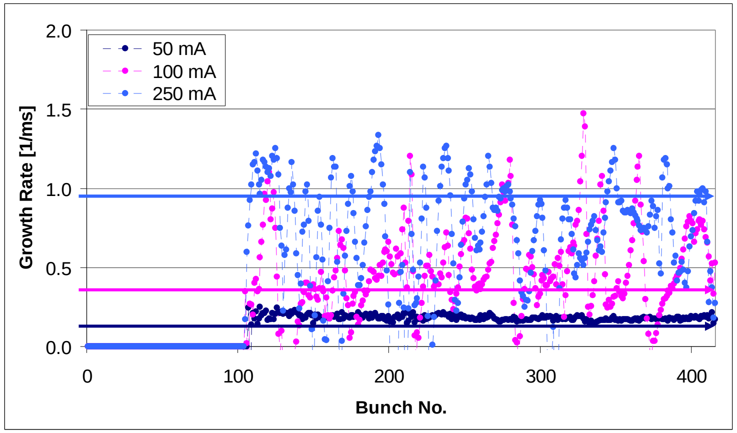


Top: Bunch intensity distribution

Lower 3: Oscillation amplitude distribution



Evolution of the betatron phase along the bunch train



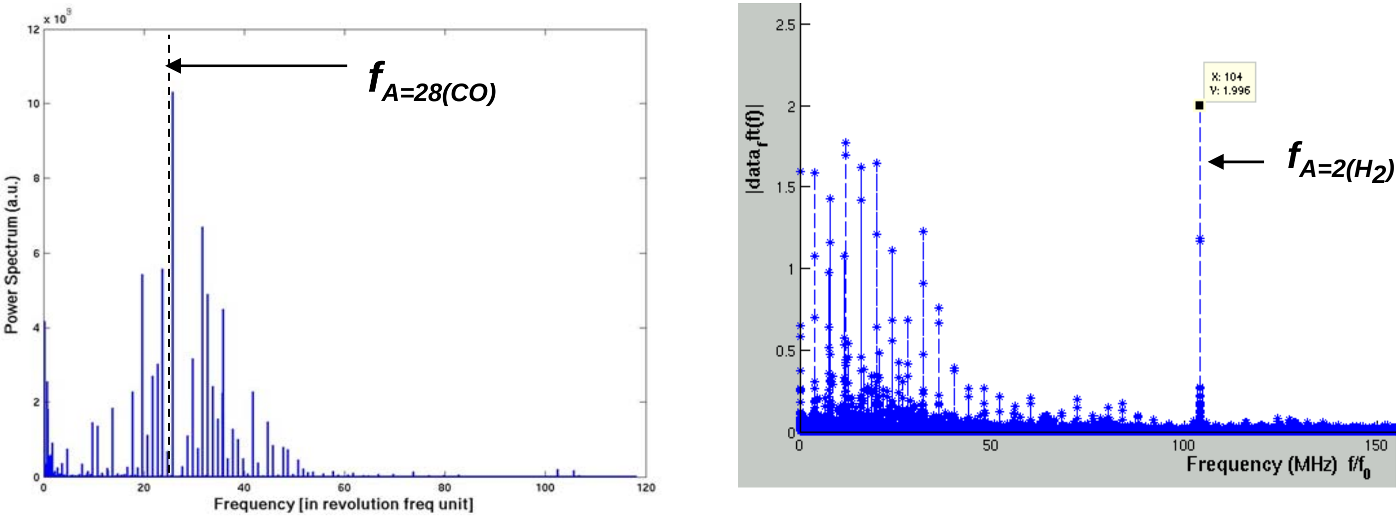
Fitted growth rate along the bunch train

◊ Observation of ion frequencies on the beam spectra (from the ADC data)

An electron beam interacting with ions having an oscillation frequency f_i would exhibit in its spectrum, an envelope proportional to

$$\left|\frac{\sin 2\pi(f \pm f_i)T_0}{2\pi(f \pm f_i)T_0}\right| \qquad \text{with } f_i \text{ given by} \qquad f_i = \frac{c}{2\pi}\left[\frac{2N_b r_p}{A s_b \sigma_x \sigma_y}\right]^{1/2}$$

(*G. Stupakov and S. Heifets*)



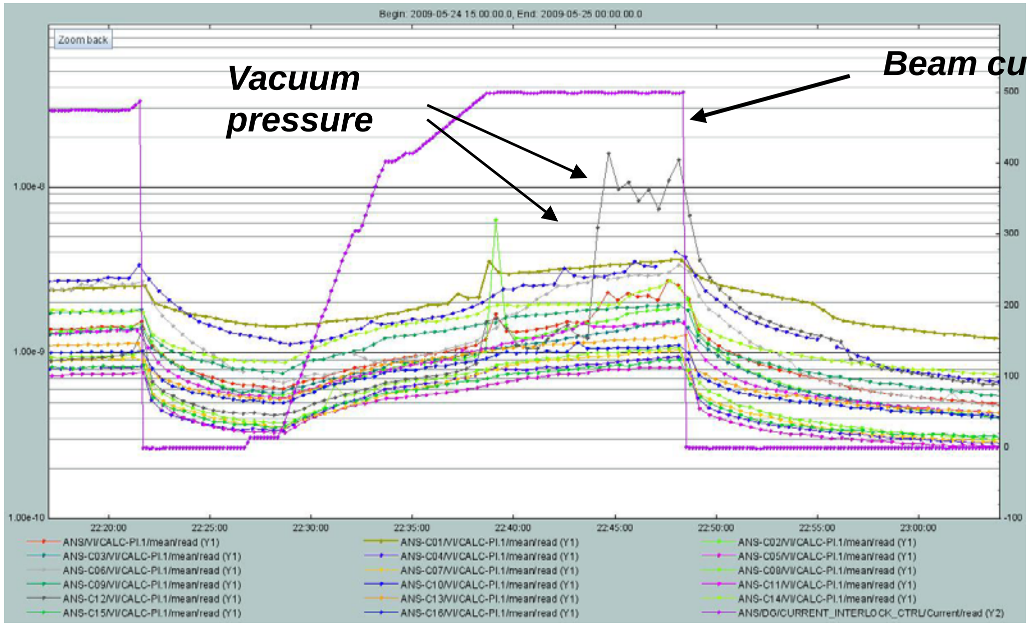
Ion frequencies observed in the ADC data

3. Up to Achieving the Final Goal of a Stable 500 mA Beam

- In reaching high beam current (> 400 mA), TFB manages to keep the beam stable at its nominal size, but frequently the beam gets lost completely after ~10 minutes.

- In many of such cases, we saw local vacuum pressure bursts prior to beam losses.

- Pinhole images and Post-mortem data indicated that the beam gets lost vertically with signature of ions.



Vacuum pressure

Beam current

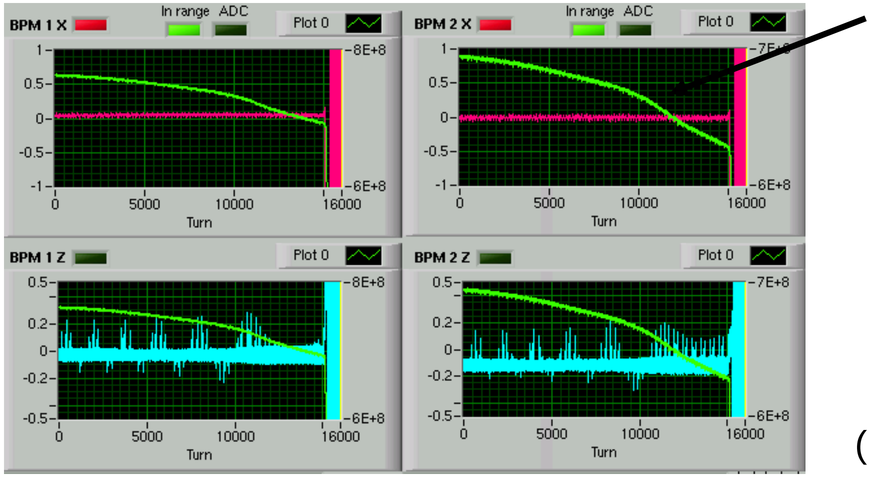
Courtesy C. Herbeaux

A local vacuum pressure rise followed by a beam loss encountered at 500 mA (24 May 2009).

- Empirically, we called this ~10 minutes the « *charging time of the ions* », which was interpreted as the time required for the locally heated vacuum components (due to longitudinal wakes) to surpass a threshold of « *outgassing* ».

(*discussions with C. Herbeaux*).

- The big question remained: Why the complete beam losses, while the theory of FBII only predicts a vertical blow up of $1\sigma \sim 2\sigma$ (phenomenon of saturation)



Beam current

BPM post-mortem data during a vertical beam loss

(*Courtesy L. Cassinari*)

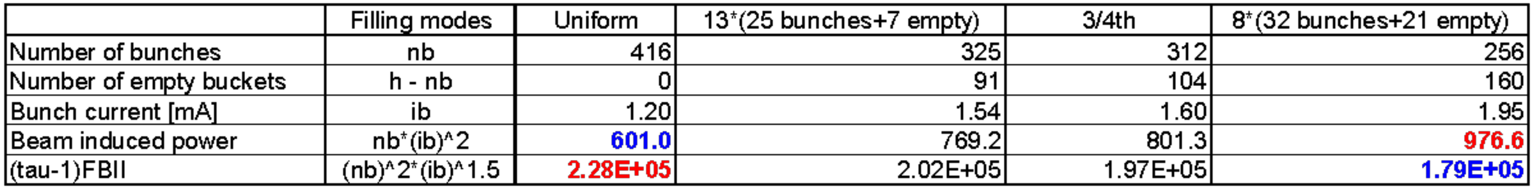
⇨ A closer look into the BPM post-mortem data indicated that the beam was scraped on the chamber wall and was interlocked by the RF system.

- Why the beam blows up to several <u>mm</u> instead of several <u>tens of μm</u> is yet to be seen.

- To alleviate the effect of FBII, different beam fillings were tried:

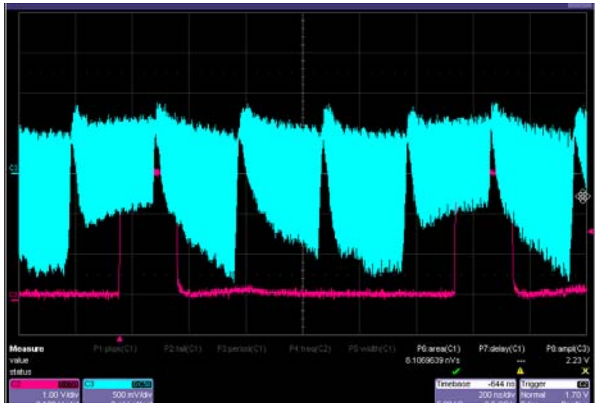
  There are 2 opposing effects:

  - FBII growth rate that scales as $n_b^{\,2} \cdot i_b^{\,3/2}$
  - Beam-induced heating that scales as $n_b \cdot i_b^{\,2}$



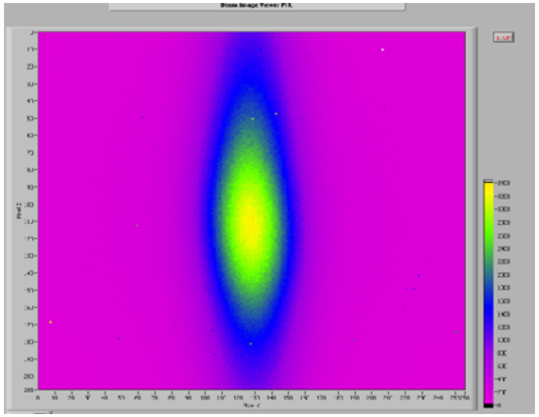
	Filling modes	Uniform	13*(25 bunches+7 empty)	3/4th	8*(32 bunches+21 empty)
Number of bunches	nb	416	325	312	256
Number of empty buckets	h - nb	0	91	104	160
Bunch current [mA]	ib	1.20	1.54	1.60	1.95
Beam induced power	nb*(ib)^2	**601.0**	769.2	801.3	**976.6**
(tau-1)FBII	(nb)^2*(ib)^1.5	**2.28E+05**	2.02E+05	1.97E+05	**1.79E+05**

- Tests of different fillings showed that the one with smaller current per bunch tends to give better stability ⇨ « Modulated » 4/4 filling was chosen.



« Modulated » 4/4 filling employed at 500 mA

- In parallel, we saw that an increase of chromaticity from ξ_z = 2.6 to 3.5 allows us to keep the beam at 500 mA without being lost (thanks to Landau damping).



Vertically blown up beam (ε_V > 100 pm) at 500 mA with ξ_z = 3.5

- The blown up beam was completely stable and TFB could even be switched off!

- Finally, by pushing further the idea of minimising the beam-induced heating by lowering the RF voltage (4 → 3 MV), 500 mA could be stored (*6 April 2010*) without any blow up and all the in-vacuum undulator gaps could be closed to minimum values.

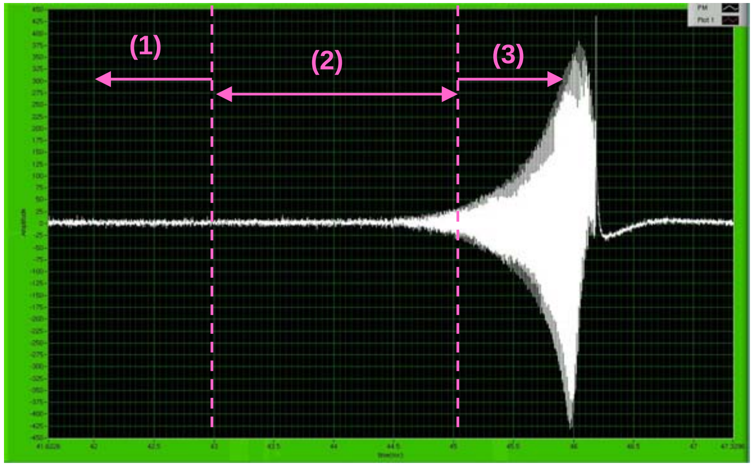
- The bunch lengthening introduced may in addition alleviate directly the FBII (to be pursued).

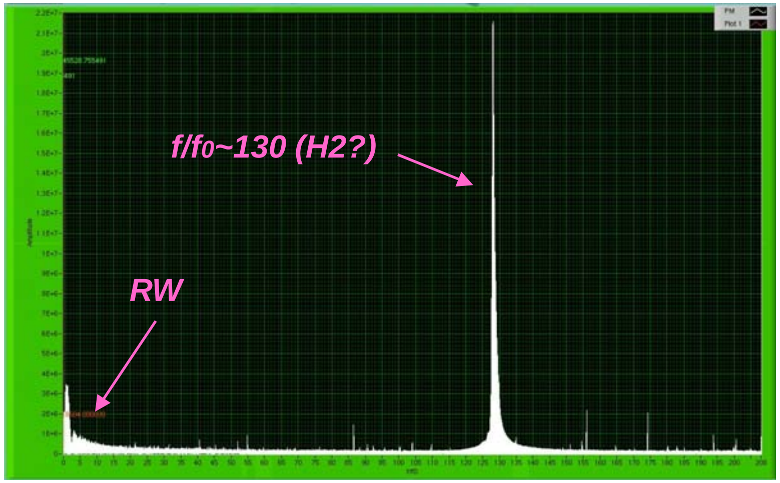
4. Recent Experimental Results

◊ Features at 500 mA

- V_{rf} = 4.2 MV and $(\xi_H, \xi_V) = (0, 0)$

(Measured on 11 October 2010)





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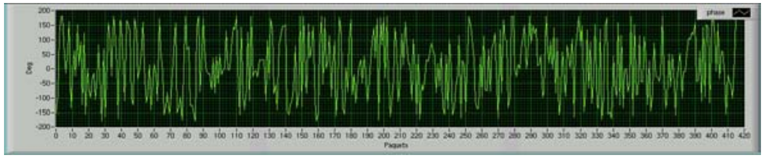

No phase correlation: Stable regime

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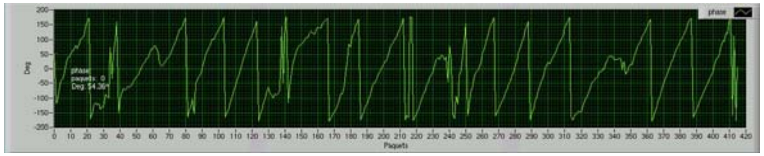
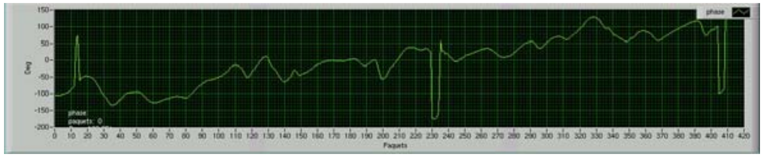


FBII like regime

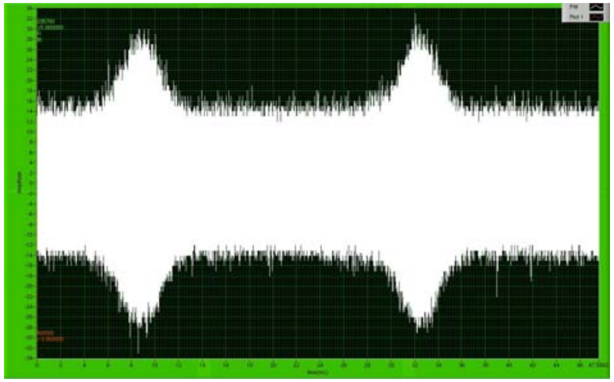
(3)

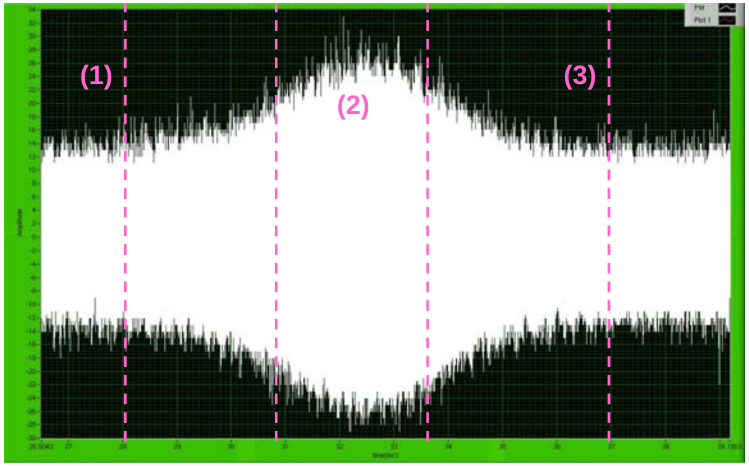


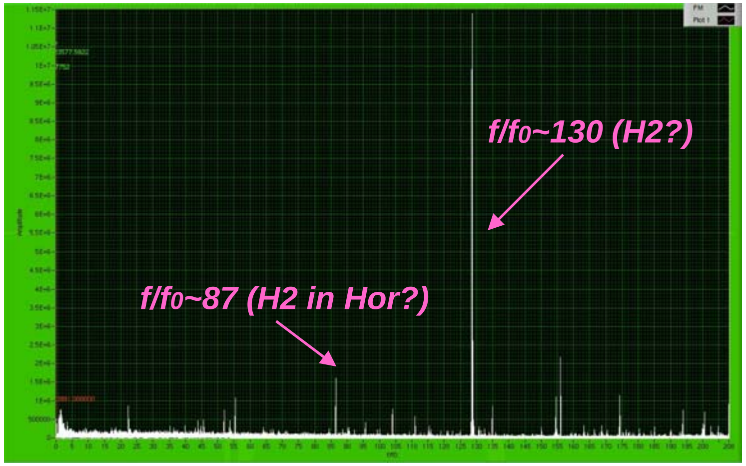
Resistive-wall (*RW*) *like regime*
(the observed exponential growth time of ~0.27 ms is close to expected from RW instability)

- V_{rf} = 4.2 MV and (ξ_H, ξ_V) = (0, **4**) (*Measured on 11 October 2010*)

  … No beam loss, but periodic vertical explosions







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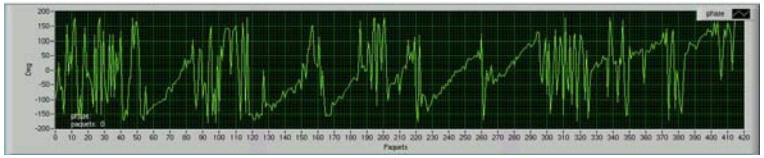
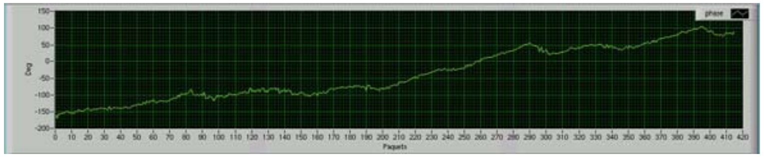


FBII-like

(2)



RW-like

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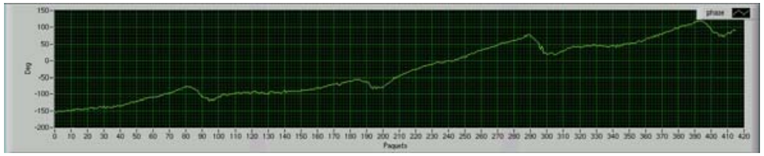

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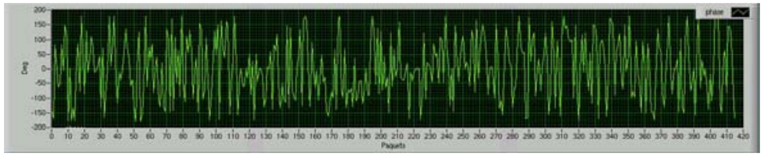

Stable

5. Summary

- The ion effects strongly seen since the commissioning times at SOLEIL on top of the classical impedance originated instabilities were identified to be the Fast Beam Ion Instability (FBII).

- Although with improvement of the vacuum, the relative contribution of FBII diminished, beam losses due to FBII persist at high multibunch current.

- To achieve a stable beam at 500 mA, lowering of the RF voltage turned out to be effective, most likely due to suppression of ions by reducing the beam-induced heating of vacuum chambers.

- However, the mechanism of beam blow ups leading the beam to be scraped against the chamber walls remains to be understood, in particular the reason of transverse feedback remaining ineffective.

- In addition to experiments, analytical and simulation studies should be made to answer the open questions.