Beam Instability Observations
and
Analysis at SOLEIL

At 22nd PAC Conference, June 25-29, 2007 Albuquerque, USA
R. Nagaoka on behalf of the SOLEIL team

Outline:

1. Introduction
2. Multibunch Instabilities
3. Development of a Multibunch Tracking Code
4. Single Bunch Instabilities
5. Conclusion

Acknowledgement

to the People Who Specially Contributed to this Work:

Instability Measurements:

M.P. Level, M. Labat, M.E. Couprie, L. Cassinari, A. Loulergue, A. Nadji, J.M. Filhol and the SOLEIL commissioning team members

Development of a Multibunch Tracking Code:

A. Rodriguez (student), Ph. Martinez, W. Bruns (GdfidL)

Development of a Transverse Bunch by Bunch Feedback System:

C. Mariette, R. Sreedharan, T. Nakamura (SPring-8), K. Kobayashi (SPring-8)

1. Introduction

SOLEIL is the French third generation light source ring commissioned in 2006 and starting its user operation this year.

Energy [GeV]	2.75
Circumference [m]	354.097
Nominal current [mA]	500, 8×12
Harmonic number	416
Betatron tunes Q_H/Q_V	18.2/10.3

Machine characteristics related to beam instability:

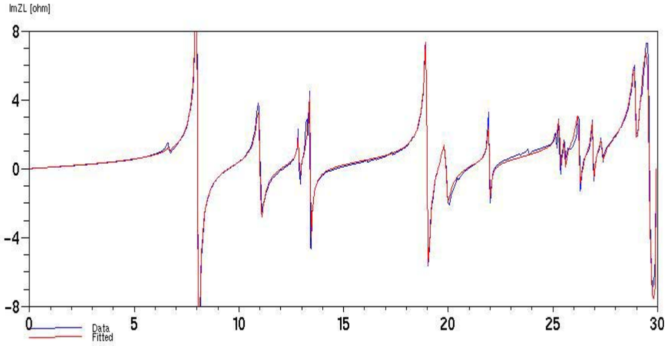
- Aims to achieve high average/bunch current
- Choice of relatively small vertical aperture (b = 12.5 mm) for the standard chamber
- Commissioned the machine equipped with ID low gap chambers (b = 5 & 7 mm)
- About half of the ring NEG coated (Al vessels)
- Presence of in-vacuum IDs [presently 3, $(\text{full gap})_{\text{min}}$ = 5 mm]

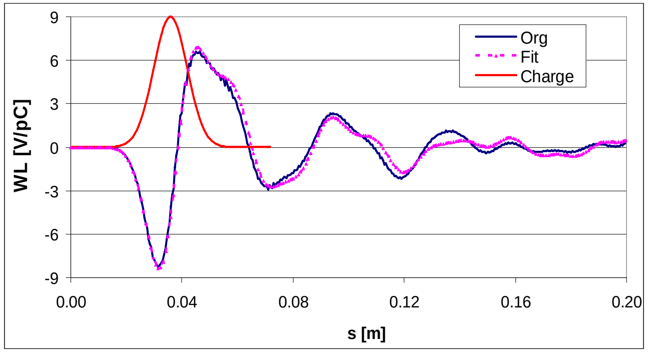
- Impedance induced instability expected to be significant
  - Evaluation/minimization of geometric impedance with 3 & 2D codes (*GdfidL/ABCI*)
  - Evaluation of RW (resistive-wall) impedance (ρ, chamber cross section, thickness, layers)

Object	Number	Loss factor [V/pC]	(P)500mA [kW]	$\Sigma\|Z_L/n\|$ eff [mΩ]	(ZV)eff [kΩ/m]	$\Sigma\beta v^*(ZV)$eff [kΩ]	(ZH)eff [kΩ/m]	$\Sigma\beta h^*(ZH)$eff [kΩ]
Shielded bellows	176	8.72E-03	**1.17**	**48.30**	(0,03 0,14)	**(52,8 246,4)**	(0,01 0,06)	**(15,8 112,6)**
Flange	332	4.67E-04	0.12	11.65	(0,00 0,01)	(0,7 42,3)	(0,00 0,01)	(9,1 46,8)
Dipole chamber	32	1.64E-04	2.63E-03	0.48	(0,00 0,00)	(0,2 0,7)	(0,00 0,03)	(0,1 0,8)
SOLEIL cavity	1	2.20	**1.55**	9.30	(0,29 0,44)	(0,8 1,3)	(0,17 0,44)	(0,8 2,0)
BPM	120	3.31E-03	0.28	12.80	(0,02 0,04)	(22,4 37,2)	(0,0 0,0)	**(0,0 0,0)**
Medium section tapers	10	1.76E-03	1.24E-02	9.31	(1,35 3,41)	**(85,5 215,9)**	(0,01 0,56)	(0,4 33,7)
Long section tapers	3	7.32E-04	1.55E-03	1.52	(0,43 1,13)	(14,9 39,2)	(0,00 0,24)	(0,1 9,2)
In-vacuum ID tapers	4	0.25	0.76	**18.92**	(0,50 1,42)	(6,0 17,0)	(0,13 0,50)	(9,4 36,0)
SOLEIL cavity outer tapers	1	0.17	0.13	6.70	(0,49 1,56)	(2,6 8,3)	(0,01 0,29)	(0,0 1,6)
Resistive-wall	-	7.31	**5.17**	**85.50**	(21,8 101,5)	**(135,2 743,5)**	(7,1 51,7)	**(34,8 376,3)**
Injection zone	1	1.86E-03	1.42E-03	0.09	(0,00 0,01)	(0,0 0,1)	(0,10 0,72)	(1,2 8,7)
Pumping slots (at quadrupoles)	128	< 1,0E-07	< 1,0E-07	0.01	(0,00 0,00)	(0,0 0,0)	(0,00 0,00)	(0,0 0,5)
Total	-	-	**9.20**	**204.6**	-	**(321,1 1351,9)**	-	**(71.7 628.2)**

(Impedance budget presented at EPAC2004)

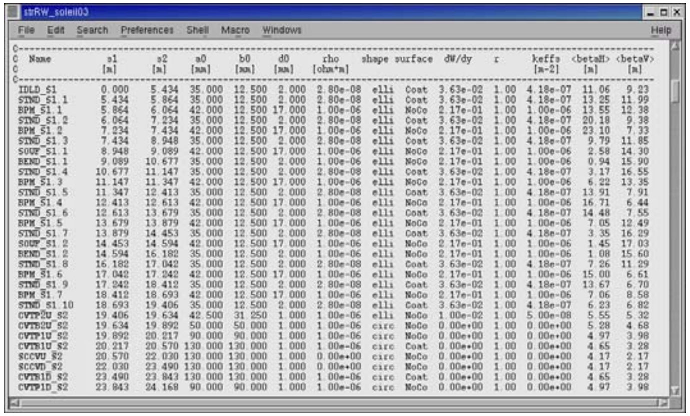
◊ Instabilities (RW, TMCI, head-tail, microwave, bunch lengthening,…) estimated using time and frequency domain simulation codes





Calculated impedance (GdfidL/ABCI) is decomposed into pure inductance & BBRs

Original wake potentials are reconstructed with corresponding wake functions



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C-------------------------------------------------------------------------------------------------------------------
C  Name          s1      s2      a0       b0      d0      rho     shape surface  dW/dy     r      keffs  <betaH> <betaV>
C               [m]     [m]     [mm]     [mm]    [mm]  [ohm*m]                                    [m-2]    [m]     [m]
C-------------------------------------------------------------------------------------------------------------------
 IDLD_S1       0.000   5.434   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  11.06    9.23
 STND_S1.1     5.434   5.864   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  13.25   11.99
 BPM_S1.1      5.864   6.064   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06  13.55   12.38
 STND_S1.2     6.064   7.234   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  20.18    9.38
 BPM_S1.2      7.234   7.434   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06  23.10    7.33
 STND_S1.3     7.434   8.948   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07   9.79   11.85
 SOUP_S1.1     8.948   9.089   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   2.58   14.30
 BEND_S1.1     9.089  10.677   35.000   12.500   2.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   0.94   15.90
 STND_S1.4    10.677  11.147   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07   3.17   16.55
 BPM_S1.3     11.147  11.347   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   6.22   13.35
 STND_S1.5    11.347  12.413   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  13.91    7.91
 BPM_S1.4     12.413  12.613   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06  16.71    6.44
 STND_S1.6    12.613  13.679   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  14.48    7.55
 BPM_S1.5     13.679  13.879   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   7.05   12.49
 STND_S1.7    13.879  14.453   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07   3.35   16.29
 SOUP_S1.2    14.453  14.594   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   1.45   17.03
 BEND_S1.2    14.594  16.182   35.000   12.500   2.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   1.08   15.60
 STND_S1.8    16.182  17.042   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07   7.26   11.29
 BPM_S1.6     17.042  17.242   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06  15.00    6.61
 STND_S1.9    17.242  18.412   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07  13.67    6.70
 BPM_S1.7     18.412  18.693   42.000   12.500  17.000 1.00e-06  elli  NoCo  2.17e-01  1.00  1.00e-06   7.06    8.58
 STND_S1.10   18.693  19.406   35.000   12.500   2.000 2.80e-08  elli  Coat  3.63e-02  1.00  4.18e-07   6.23    6.82
 CVTP2U_S2    19.406  19.634   42.500   31.250   1.000 1.00e-06  elli  NoCo  1.00e-02  1.00  5.00e-08   5.55    5.32
 CVTB2U_S2    19.634  19.892   50.000   50.000   1.000 1.00e-06  circ  NoCo  0.00e+00  1.00  0.00e+00   5.28    4.68
 CVTP1U_S2    19.892  20.217   90.000   90.000   1.000 1.00e-06  circ  NoCo  0.00e+00  1.00  0.00e+00   4.97    3.98
 CVTB1U_S2    20.217  20.570  130.000  130.000   1.000 1.00e-06  circ  Coat  0.00e+00  1.00  0.00e+00   4.65    3.28
 SCCVU_S2     20.570  22.030  130.000  130.000   1.000 0.00e+00  circ  NoCo  0.00e+00  1.00  0.00e+00   4.17    2.17
 SCCVD_S2     22.030  23.490  130.000  130.000   1.000 0.00e+00  circ  NoCo  0.00e+00  1.00  0.00e+00   4.17    2.17
 CVTB1D_S2    23.490  23.843  130.000  130.000   1.000 1.00e-06  circ  Coat  0.00e+00  1.00  0.00e+00   4.65    3.28
 CVTP1D_S2    23.843  24.168   90.000   90.000   1.000 1.00e-06  circ  NoCo  0.00e+00  1.00  0.00e+00   4.97    3.98
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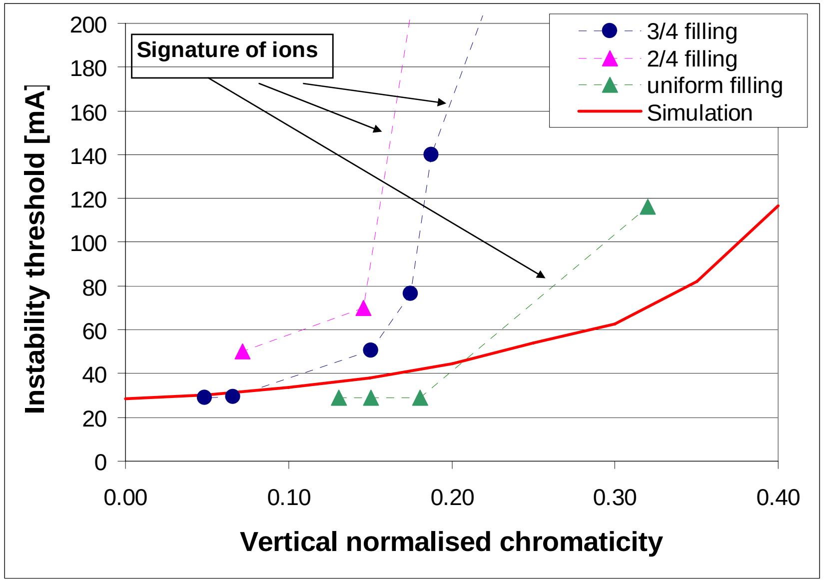
Total RW impedance is constructed from a data base of the ring

⇨ Simulation codes read BB decomposition coefficients & RW data base to construct impedance and wake potentials

2. Multibunch Instabilities

- Mixture of RW and ions induced instabilities in both V & H planes.
- No instability observed in the longitudinal plane (HOM free SOLEIL SC cavities).



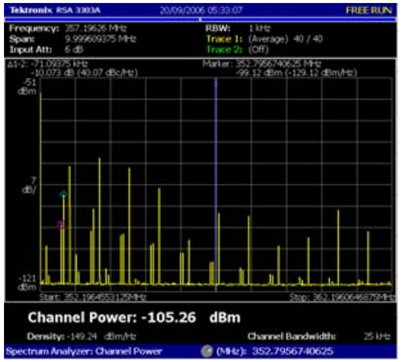
- Ion-induced instability depends much on the beam filling

- $(I_{th})_V$ at low chromaticity in rather good agreement with prediction

- $(I_{th})_H$ much lower than expected

(← Measured when beam dose was ~20 A·h)

- Characterization of instability in terms of beam spectra



Tektronix RSA 3303A 20/09/2006 05:33:07 FREE RUN

Frequency: 357.19626 MHz
Span: 9.999609375 MHz
Input Att: 6 dB
RBW: 1 kHz
Trace 1: (Average) 40 / 40
Trace 2: (Off)

Δ1-2: -71.09375 kHz
-10.073 dB (40.07 dBc/Hz)
Marker: 352.7956740625 MHz
-99.12 dBm (-129.12 dBm/Hz)

Start: 352.1964553125MHz Stop: 362.1960646875MHz

Channel Power: -105.26 dBm
Density: -149.24 dBm/Hz Channel Bandwidth: 25 kHz
Spectrum Analyzer: Channel Power (MHz): 352.7956740625

← “RW dominated”

→ “Ion-induced dominated”

Tektronix RSA 3303A 20/09/2006 00:10:07 FREE RUN

Frequency: 357.19626 MHz
Span: 9.999609375 MHz
Input Att: 6 dB
RBW: 1 kHz
Trace 1: (Average) 40 / 40
Trace 2: (Off)

Δ1-2: -600.5859375 kHz
56.879 dB (86.88 dBc/Hz)
Marker: 352.79704125 MHz
-107.15 dBm (-137.15 dBm/Hz)

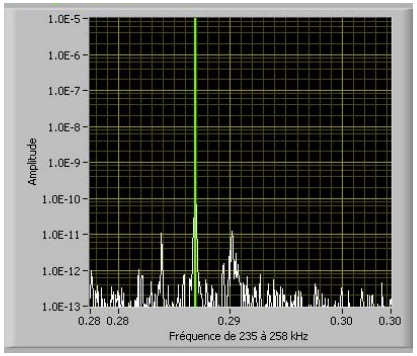
Start: 352.1964553125MHz Stop: 362.1960646875MHz

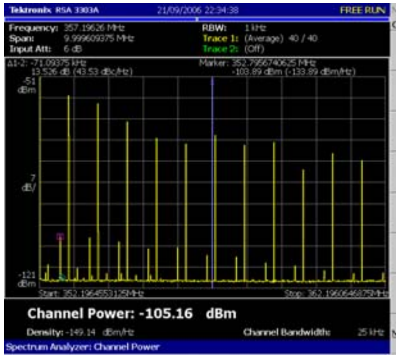
Channel Power: -105.27 dBm
Density: -149.25 dBm/Hz Channel Bandwidth: 25 kHz
Spectrum Analyzer: Channel Power Center Freq (MHz): 357.19626

(Observations in ¾ filling)

- However, influence of ions on “RW dominated” cases not yet clear
- Stabilisation of *m*=0 occurs at chromaticity of ~0.2 in vertical
- As expected, shift of chromaticity excites higher-order head-tail modes
    - → Bunch-by-bunch transverse feedback (TFB) used at zero chromaticity

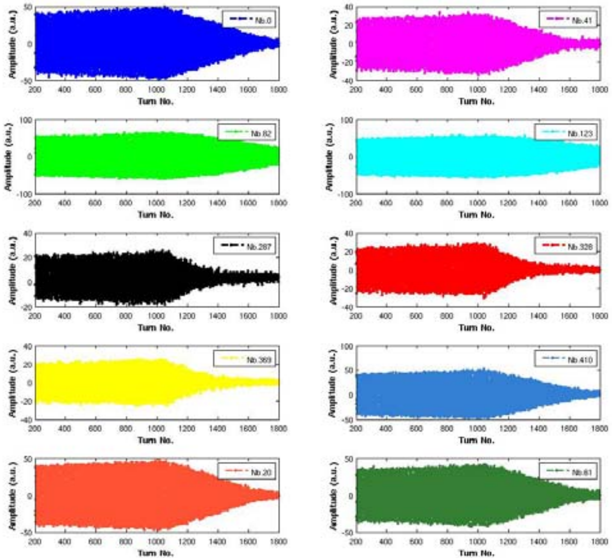
m=-1 excitation
at 250 mA, ξ_v=0.3
in ¾ filling



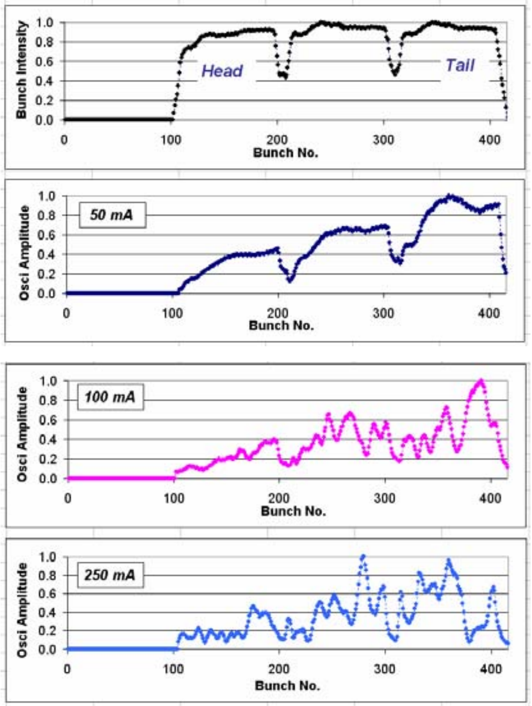

Tektronix RSA 3303A 21/09/2006 22:34:38 FREE RUN
Frequency: 357.19626 MHz
Span: 9.999609375 MHz
Input Att: 6 dB
RBW: 1 kHz
Trace 1: (Average) 40 / 40
Trace 2: (Off)
Δ1-2: -71.09375 kHz 13.526 dB (43.53 dBc/Hz)
Marker: 352.7956740625 MHz -103.89 dBm (-133.89 dBm/Hz)
Start: 352.1964553125MHz
Stop: 362.1960646875MHz
Channel Power: -105.16 dBm
Density: -149.14 dBm/Hz
Channel Bandwidth: 25 kHz
Spectrum Analyzer: Channel Power

◇ Recent analysis using TFB and its ADC data:

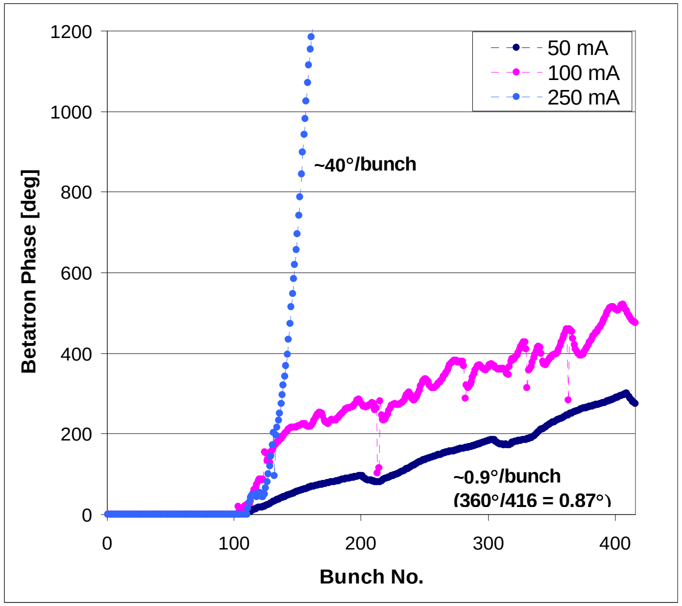
TFB is switched off temporarily over several milliseconds to follow the instability bunch by bunch



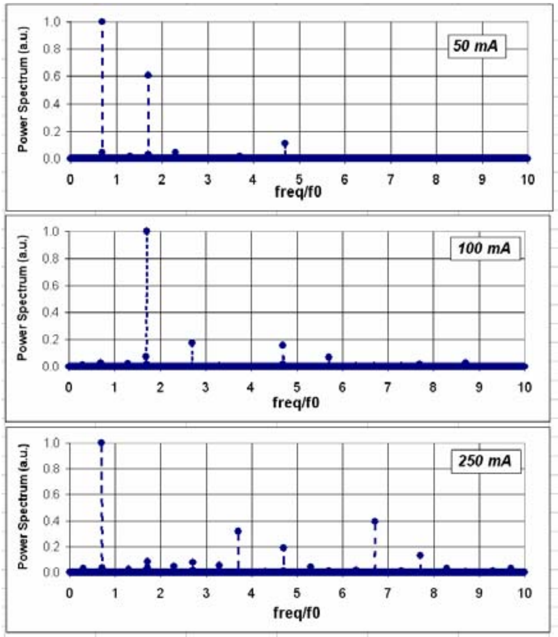
Observations in ¾-th filling



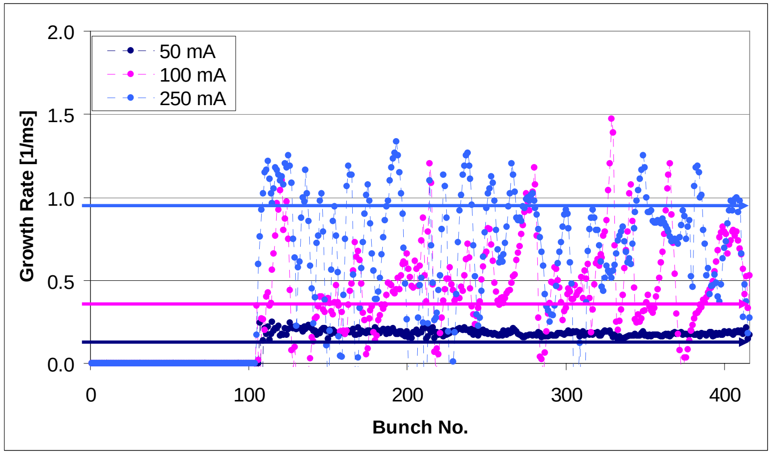
Oscillation amplitude



Oscillation phase



Beam spectra

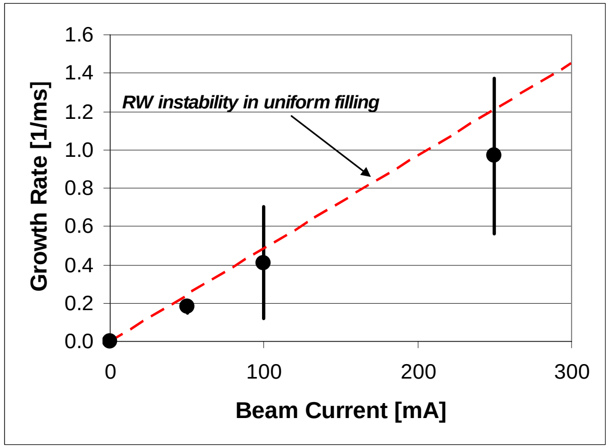


←

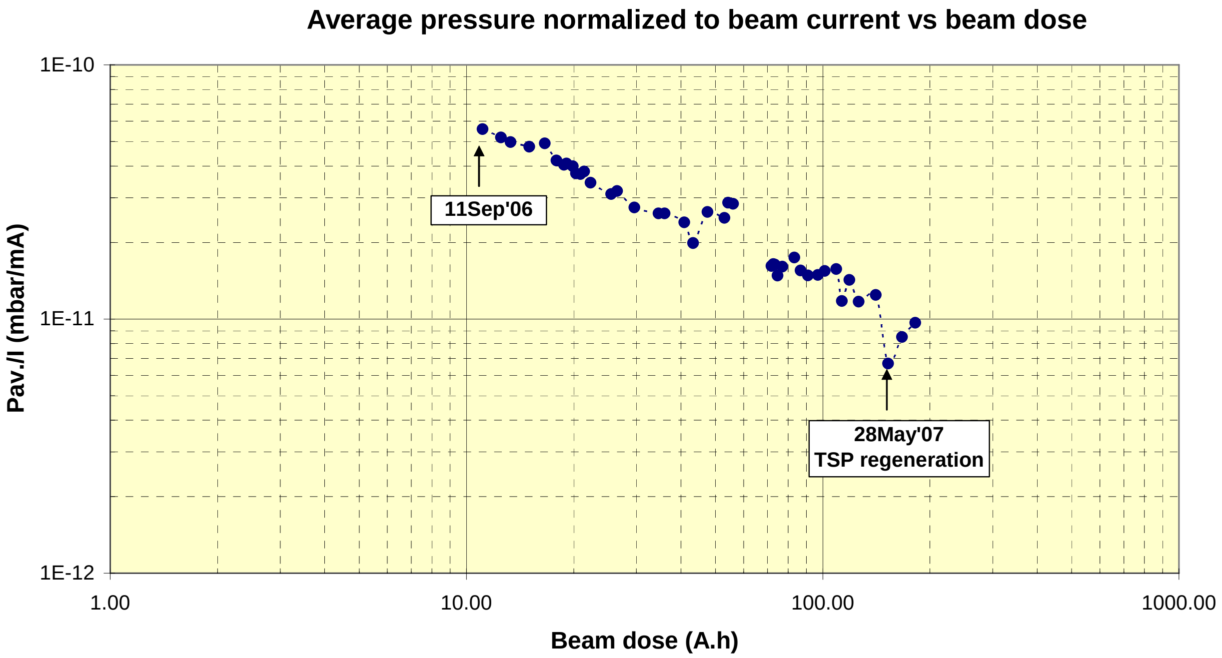
Growth rate vs bunch

→

Averaged growth rate vs beam current



◇ Dependence of the instability on the vacuum level:



Courtesy
C. Herbeaux

- Average pressure is still improving as a function of beam dose (lowered by a factor of ~5 since early instability measurement)

- Vacuum level several times higher locally in in-vacuum IDs

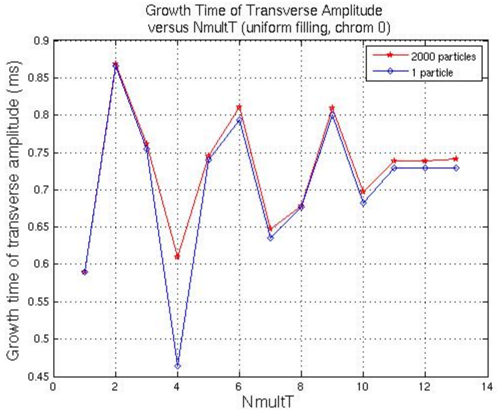
- Recently, it became difficult to measure the threshold without beam loss (tail part)

(Overall beam-ion interaction triggered RW instability & avoided beam losses?)

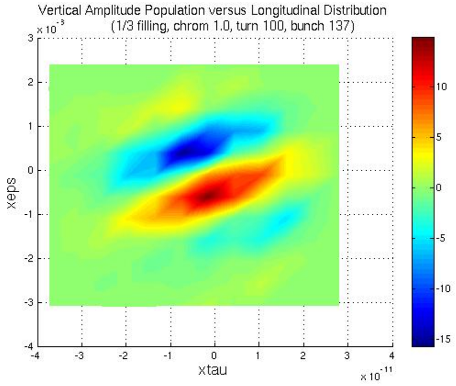
3. Development of a parallel-processed multibunch tracking code

- To analyze RW & Ions driven transverse multibunch instability.
- To able to treat different beam fillings, incoherent tune spread, beam-ions interactions.

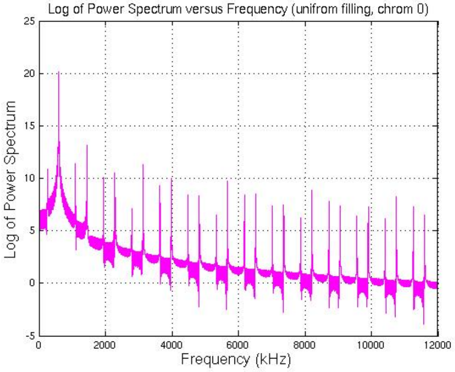
- Master-children structure using *pvm*. Each child performs single bunch tracking.
- Master stores CM motions of all bunches. Each child then takes into account long-range (RW) forces of all bunches over multiple turns.



Multi-turn effects



Bunch internal motion



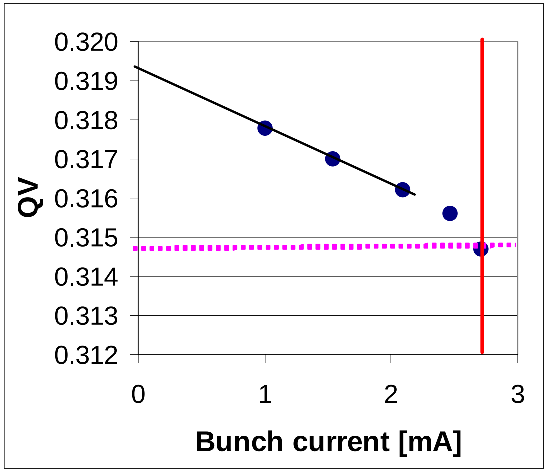
Beam spectrum

- At SOLEIL, 1000 turn tracking of 138 bunches (1/3 filling) with 2000 particles/bunch:

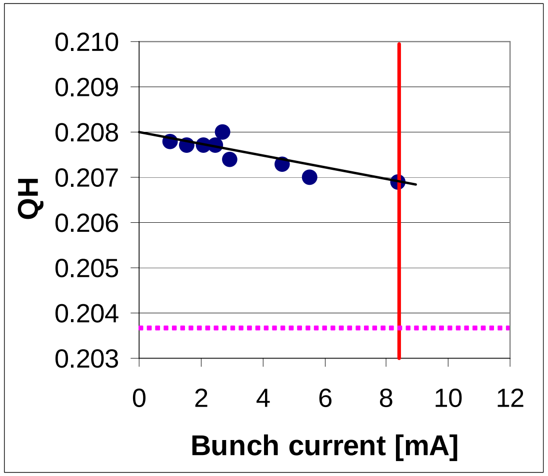
  Takes ~ ¼ hour with 16 processors

3. Single Bunch Effects

- Mode detuning and TMCI threshold



Vertical detuning



Horizontal detuning

: Measured threshold

Cancellation between the coherent and incoherent tune shifts seen in H.

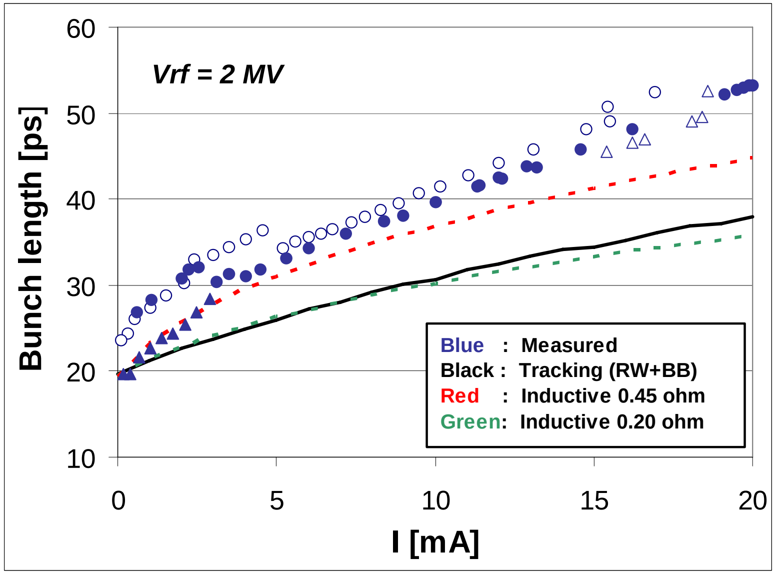
- Comparison of impedance using

$$\frac{df_\beta}{dI} = -\frac{\beta}{8\pi^{3/2}\sigma_\tau E/e}\cdot \mathrm{Im}\left(Z_\perp\right)_{eff}$$

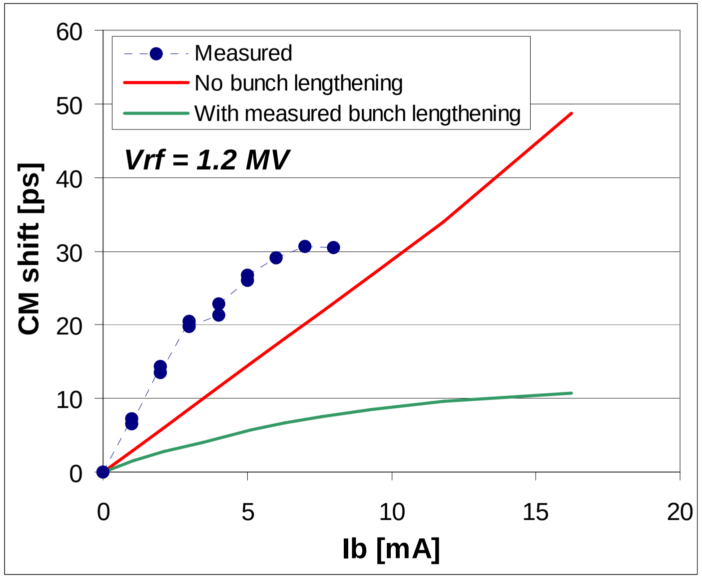
(Horizontally, df_β/dI is deduced as $-f_0 Q_s/I_{th}$.)

	$(df\beta/dI)$meas [kHz/mA]	β*Im$(Z_\perp)_{eff}$ [MΩ]	[β*Im$(Z_\perp)_{eff}$]*budget* * [MΩ]	ratio *(meas/calc)*	$(I_{TMCI})_{meas}$ * [mA]	$(I_{TMCI})_{calc}$ *** [mA]	ratio *(calc/meas)*
Vertical	-1.34	2.45	1.35	**1.8**	2.8	5.0	**1.8**
Horizontal	-0.44	1.05	0.63	**1.7**	8.4	14.0	**1.7**

- Bunch lengthening (streak camera)



- Synchronous phase shift (streak camera)



- Energy spread widening

Both measurement and simulation show no substantial widening up to 20 mA

◊ Measured data seem to indicate that Im*Z* is larger than expected by a **factor of ~2** in all H, V and L planes.

◊ Measured $|Z/n|_{eff}$ is still less than 0.5 Ω.

◊ Could the ImZ discrepancy be due to roughness of the NEG coating?

- Reports exist that NEG coated Al chambers have granular surface roughness.
- Anomalous increase of ImZt observed at ELETTRA when NEG coated Al chambers installed.

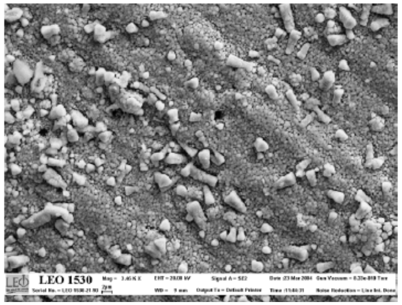
→ For precaution NEG coating thickness reduced (1 → 0.5 μm) at SOLEIL

- Estimates using the roughness impedance theory:

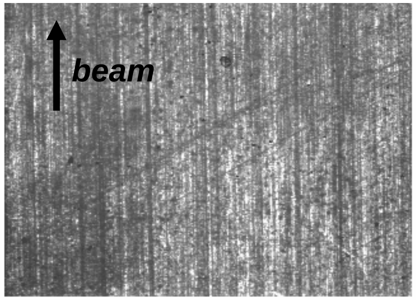
- G. Stupakov's small angle model applied to the measured substrate → Δ(ImZ) negligible
- K. Bane et al.'s model applied to a granular surface (a ~1 μm) → Δ(ImZ) ~ discrepancy

However, NEG coating carried out for SOLEIL chambers did not degrade the roughness

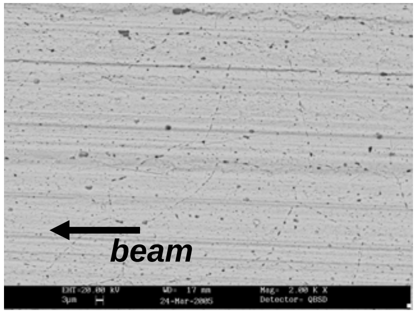
→ The observed Δ(ImZ) should not be attributed to the roughness



Measured at the ESRF
(bumps ~μm)
Courtesy T. Perron



SOLEIL extruded Al chamber
(rms ~0.3 μm)
Courtesy SOLEIL's Metrology Lab.



NEG coated SOLEIL extruded
Al chamber
Courtesy SAES Getters

4. Conclusion

- There appears to be a strong influence of beam-ion interactions on the multibunch, on top of impedance (RW) effects.

  Better understanding of the dynamics is required for the good control of the beam instability.

  Up to the present maximum current of 300 mA in 3/4th filling, TFB manages to keep the beam stable at zero chromaticity in both H & V planes.

- The origin of discrepancy on the broadband impedance (measured vs calculated) must be clarified