Topical Workshop on
Instabilities, Impedances and Collective Effects
TWIICE

Modeling of the single bunch detuning at ALBA

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CELLS/ALBA
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Introduction: ALBA Facility

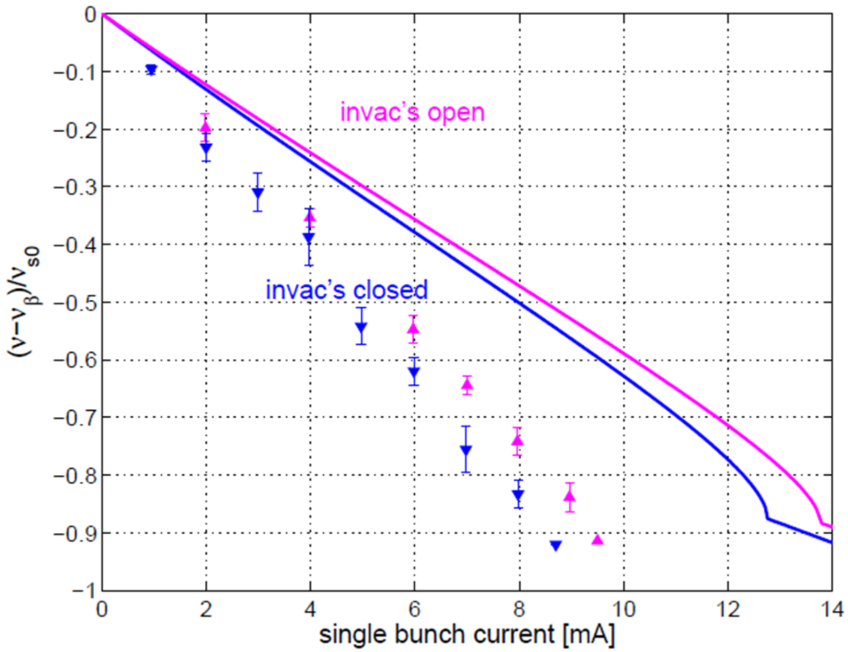
- ✓ Synchrotron Light Source in Barcelona
- ✓ Up to 30 beamlines (7 on Day-1)
- ✓ Full energy Booster for Top-up injection
- ✓ 3 GeV Storage Ring, 268m circumference
- ✓ Emittance: 4.6nm*rad (4.3 design value)
- ✓ Maximum design current: 400mA

- ✓ SR Commissioning started 8 March 2011
- ✓ BeamLine Commissioning Autumn 2011

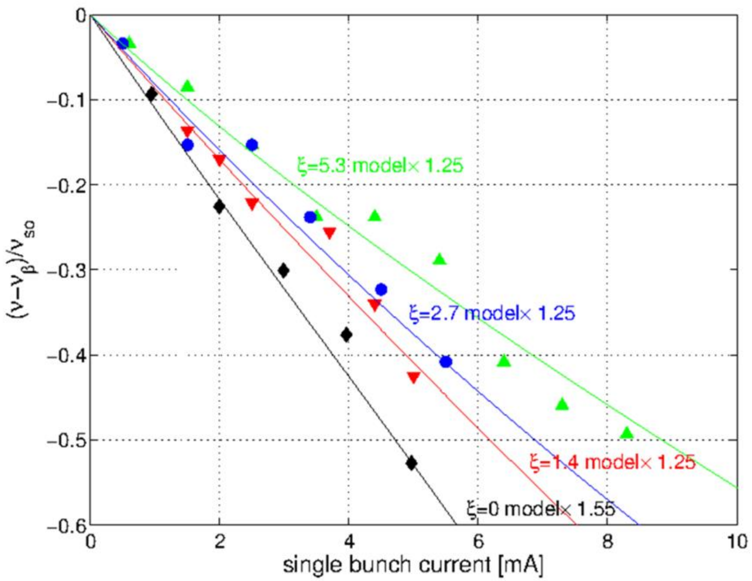
Outline:

- Motivation: the status of the trans. impedance modeling 2014
- Improvement of Wall and geometrical impedance modeling
- Bunch length parametrisation
- Results
- Laslett contribution
- Installation of the pinger
- Trans. Impedance from Turn-by-Turn measurements (M. Carla)
- Horizontal impedance
- Conclusions and Acknowledgements
- References

The status of the trans. impedance modeling 2014 [1]



Comparison of the measured detuning with the model given by MOSES[2]@ ξ_V=0, reproduction ~65%



detuning slope measurements at non-zero ξ_V show that most of the missing impedance is of low frequency

This low frequency impedance should be mostly located in the low-gap chambers

The modeling of the trans. impedance of low-gap chambers should be revised.

Doubts about the behaviour of the RW-impedance should be cleared => use IW2D

Large difference (50%)between the measured & calculated vert. impedance of the IVUs was found.

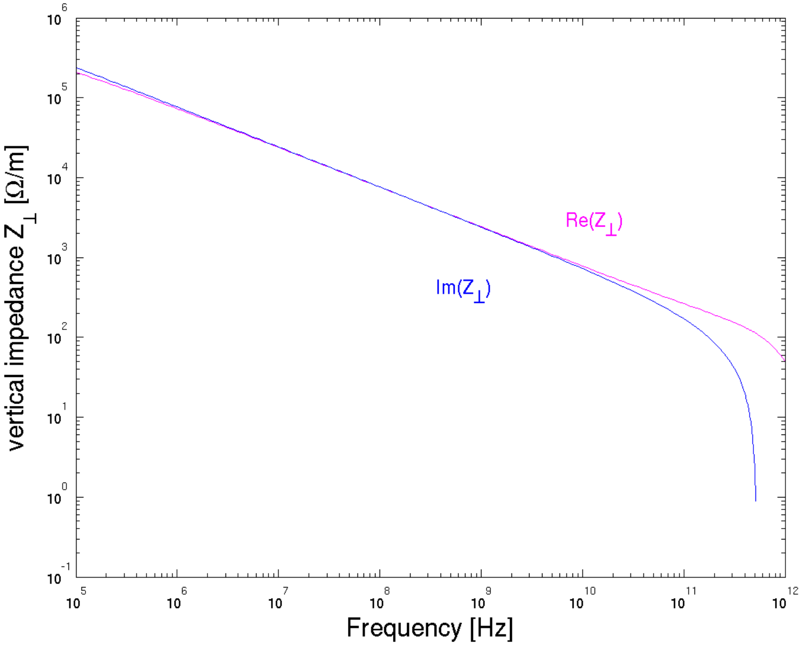
(Resistive) Wall impedance

Use a "state of the art" program to compute the wall impedance
ImpedanceWake2D (N. Mounet[3])

Should remove uncertainty of the wall impedance of multi-layer structures

One program for all cases of RW impedance,
in particular:

chamber type	assumed layers
in-vac undulator(open/closed)	Cu/Ni/CoSm
NEG-coated Al-chamber	NEG/Al/Air
Ti-coated ceramic chamber	Ti/Al_2O_3/Air/Ferrit
wiggler chamber	Cu/Air
cavities	Cu/Air
different SS^2-chambers	SS/Air



Vert. impedance spectrum of std ALBA vac.chamber

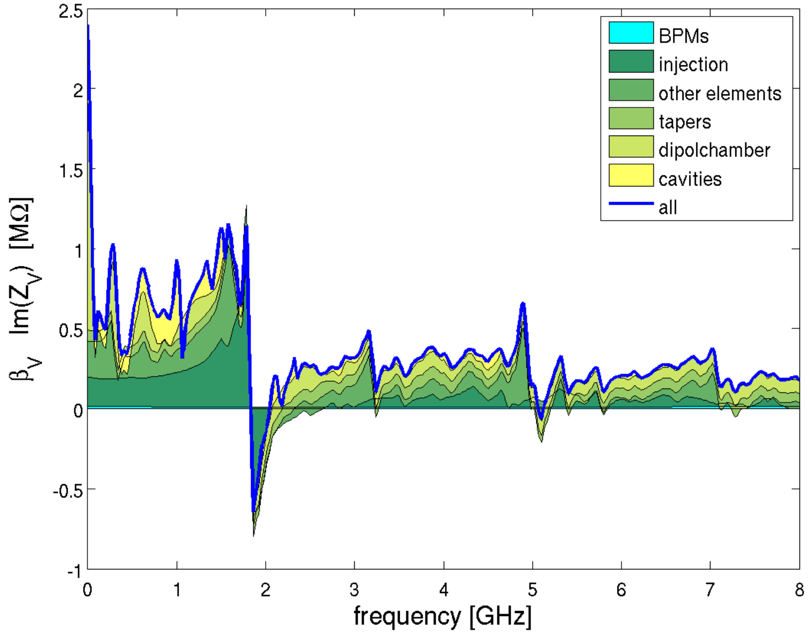
It turned out that the already developed models for multi-layer chambers agreed rather well with IW2D, apart from the high-frequency part which led to a smaller imaginary part than before.

Improvement of GdfidL-modeling

Revision of the geometrical models of the taper-dominated geometries and their surroundings with GdfidL[4]

chamber	Z_V[kΩ/m]	change
horizontal scraper & mesh	0.24	99.999%
cavity pipe & tapers	1.13	20%
wiggler chamber & tapers	6.08	9.50%
low-gap Al chamber & tapers	8.21	20.30%
in-vacuum undulators	21.75	34.60%
pinger chamber (NEW)	0.64	100%

shows porcentual gain of element impedance due to the revision



Imaginary part of the vert.broadband impedance

Highlight:
flanges at both ends of the 8mm chambers were discovered to be of 150mm diameter

Computation

This analysis will be essentially slope-based and not threshold-based:

$$\kappa_{\perp} = \frac{1}{\pi}\int_0^{\infty} Im(Z_{\perp}(\omega))e^{-(\sigma_{\tau}\omega)^2}d\omega$$

For the computation of the kick factors bunch lengthes are needed.

$$\Delta\upsilon_{\beta}(I) = \frac{I}{2\omega_0\left(E/_e\right)}\sum_i(\beta\kappa)_{\perp i}\,(\sigma_{\tau}(I))$$

A normalisation on the zero current υ_{s0} is applied in order to allow comparisons of data sets taken at different RF-voltage.

The advantage:

The normalized slope reflects the bunch length dependence of the effective impedance

$$\frac{\Delta\upsilon_{\beta}}{\upsilon_{s0}} = \frac{I_b\ \ (\beta Z)_{eff}(\sigma_{\tau}(I))}{4\sqrt{\pi}\left(\frac{E}{e}\right)\underbrace{(\omega_{s0}\sigma_0)}_{\text{const.}}g_V(I)}$$

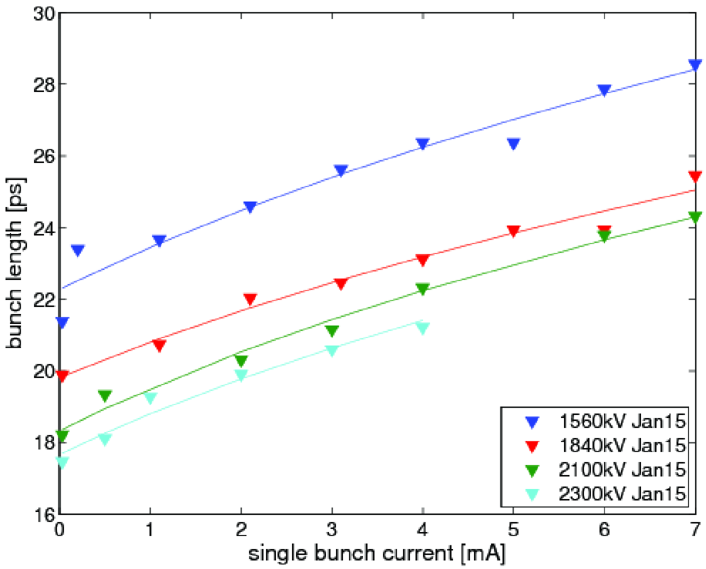
where we assume $\sigma_{\tau} = \sigma_0(V)g_V(\mathrm{I})$

For the full analysis bunch lengthes and synchrotron tune at zero current were measured

Thereby we also gain information about the potential well distortion

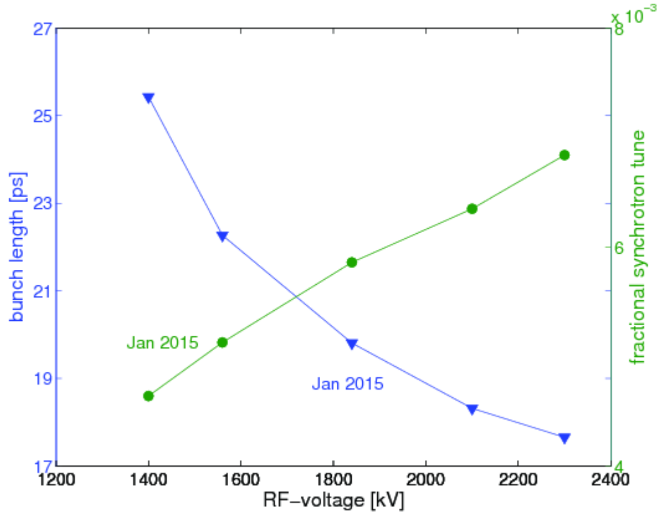
Bunch length parametrisations

Fitting of the bunch lengthening



Jan' 15 data

bunch length(I=0) & synchrotron tune vs. RF-voltage



fit function f: $\left(\frac{\sigma}{p_1}\right)^3 - \left(\frac{\sigma}{p_1}\right) = QIp_2$ acc. to [5,6]

Fit parameter:
$p_1 = \sigma_0 := \sigma(I=0)$ $p_2 = |Z/n|$
Q=const.

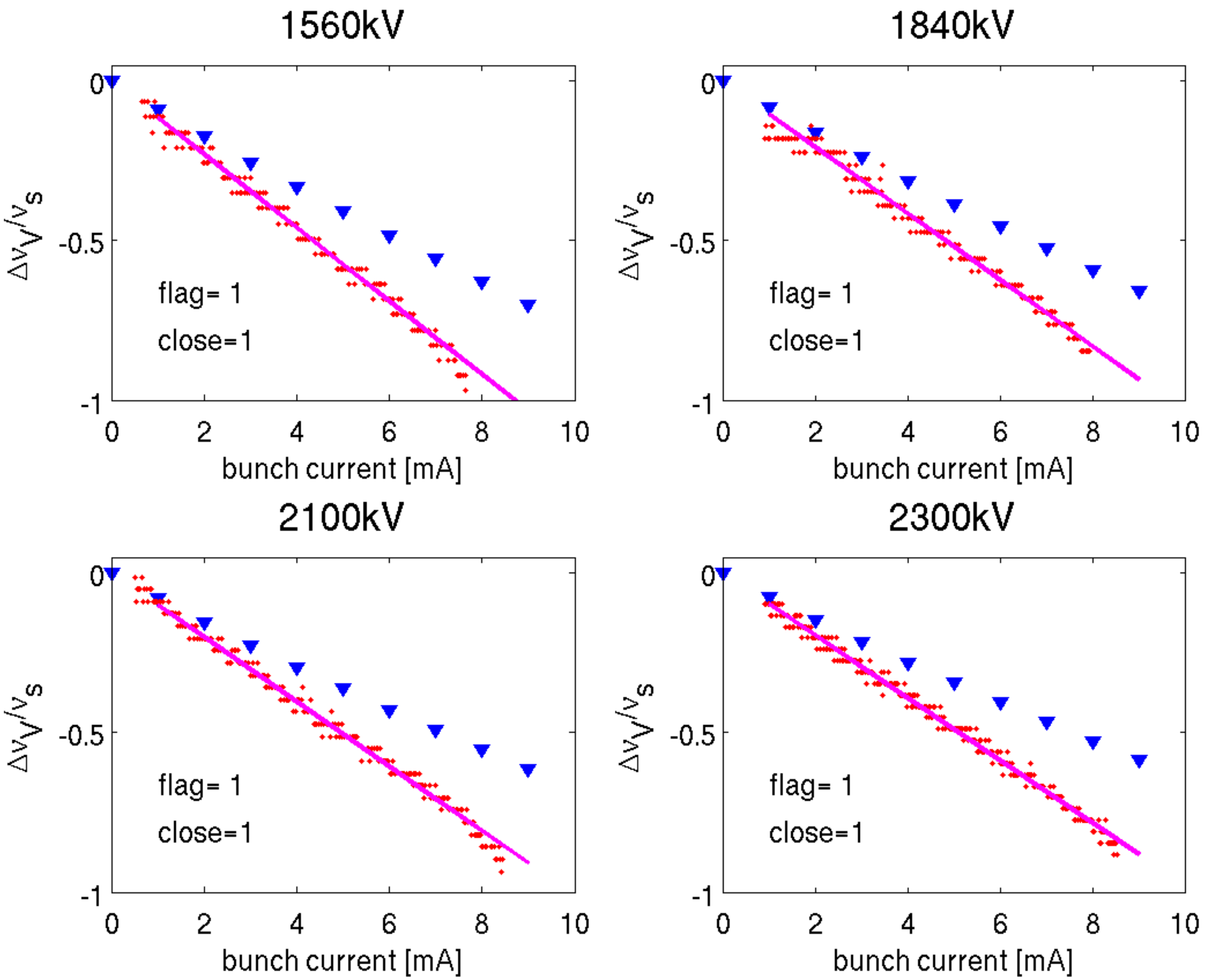
|Z/n|=[132,109,134,123]mΩ

We expect more or less: $\upsilon_{s0}\sigma_0 = \frac{\alpha\delta}{\omega_0}$ for different RF-voltages

In that respect the data from the same day (Jan'15) look rather nice.

Results (only impedance)

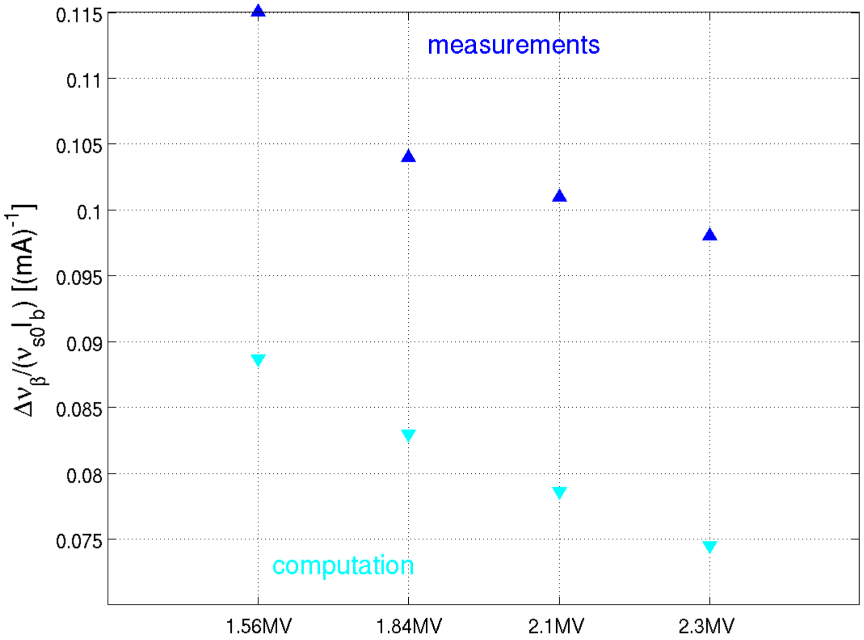
Data taken during injection applying shot-by-shot tune measurements



Up to 75% of the measured slope could be reproduced.

Results

Comparison of measured and computed detuning slopes ALL single bunch data



Jan'15

The theoretical and measured slopes of Jan'15 data follow more or less $\sim\sigma_0^{0.8}$ according to a fit, i.e. $Z_{eff}\sim\sigma^{0.8}$

Actually it's close to $Z_{eff}\sim\sigma_\tau$

$$\frac{\Delta\upsilon_\beta}{\upsilon_{s0}} = \frac{I_b\ \ (\beta Z)_{eff}}{4\sqrt{\pi}\left(\frac{E}{e}\right)(\omega_{s0}\sigma_0)g_V(I)}$$

Thus the dependence on $g_V(I)$ is rather weak

Actually, to a large extent the behaviour of the data points reflects the synchrotron tune dependence on voltage

Laslett contribution

Normally direct and indirect space charge effects are not considered in synchrotrons classified as either incoherent or as too small.

B.Zotter writes 1975[8]:
Ordinary non-magnetic metallic vacuum chamber walls cause only an electric image force for coasting beams, while a magnetic image is formed by the pole-pieces of the magnets surrounding chamber.
For bunched beams, however, also the magnetic image is formed by the [vacuum] chamber walls, and a strong cancellation of the image forces results.

However, the cancellation for bunched beams is not complete,
some non-zero coherent tune shift remains (non-penetrating case):

$$\Delta \upsilon_\beta = \frac{2RI_{tot}}{ec\beta_{rel}} < \beta > \frac{r_e}{\gamma}\left(\frac{\epsilon_1}{h^2} + \frac{\epsilon_2}{g^2} + \cancel{\frac{\xi_1 \cdots 1}{h^2\gamma^2 B^2}}\right)$$

h: vacuum chamber half-gap
g: magnetic half-gap
ε_1: electric Laslett coefficient
ε_2: magnetic Laslett coefficient

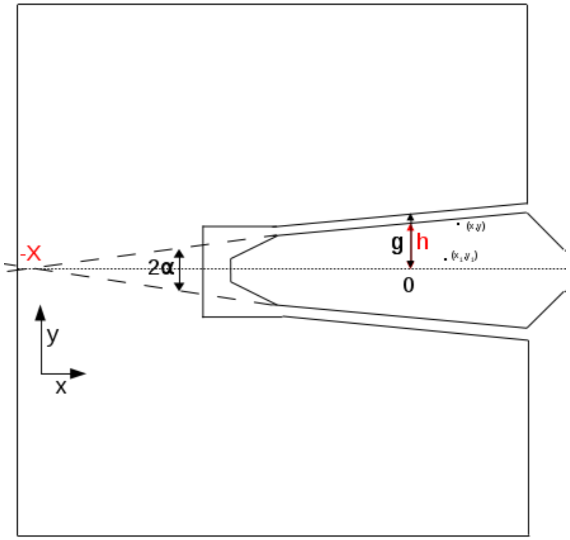
I don't think that it is considered in IW2D, above all because it is not an impedance driven effect.

It was considered on top of the impedance for the tune shift of the PS/CERN [9]

It is not so small compared to RW: $\Delta\upsilon_{Las}/\Delta\upsilon_{RW} \sim h\omega_0$ γ does not appear in the scaling!

Laslett computation

Take most chambers as parallel plate (even if they are elliptical or racetrack or octogonal)



however, the ALBA dipole chamber is oblique.

Laslett also computed coefficients for combined function dipoles but only the magnetic coefficient[10]

Compute magnetic res. electrical field via conformal mapping from the vector res. scalar potential

$A_{z=}$-2I [log|z-z_1|+log |z-$\bar{z}_1$|]

φ=-λ [log|z-z_1|-log |z-$\bar{z}_1$|]

magnetic Laslett coefficient

$$\epsilon_2 = \frac{\pi^2}{24}\left[1 - \frac{6}{\pi}\alpha + \left(\frac{2}{3} + \frac{5}{\pi^2}\right)\alpha^2\right]$$

ϵ_2=.3576

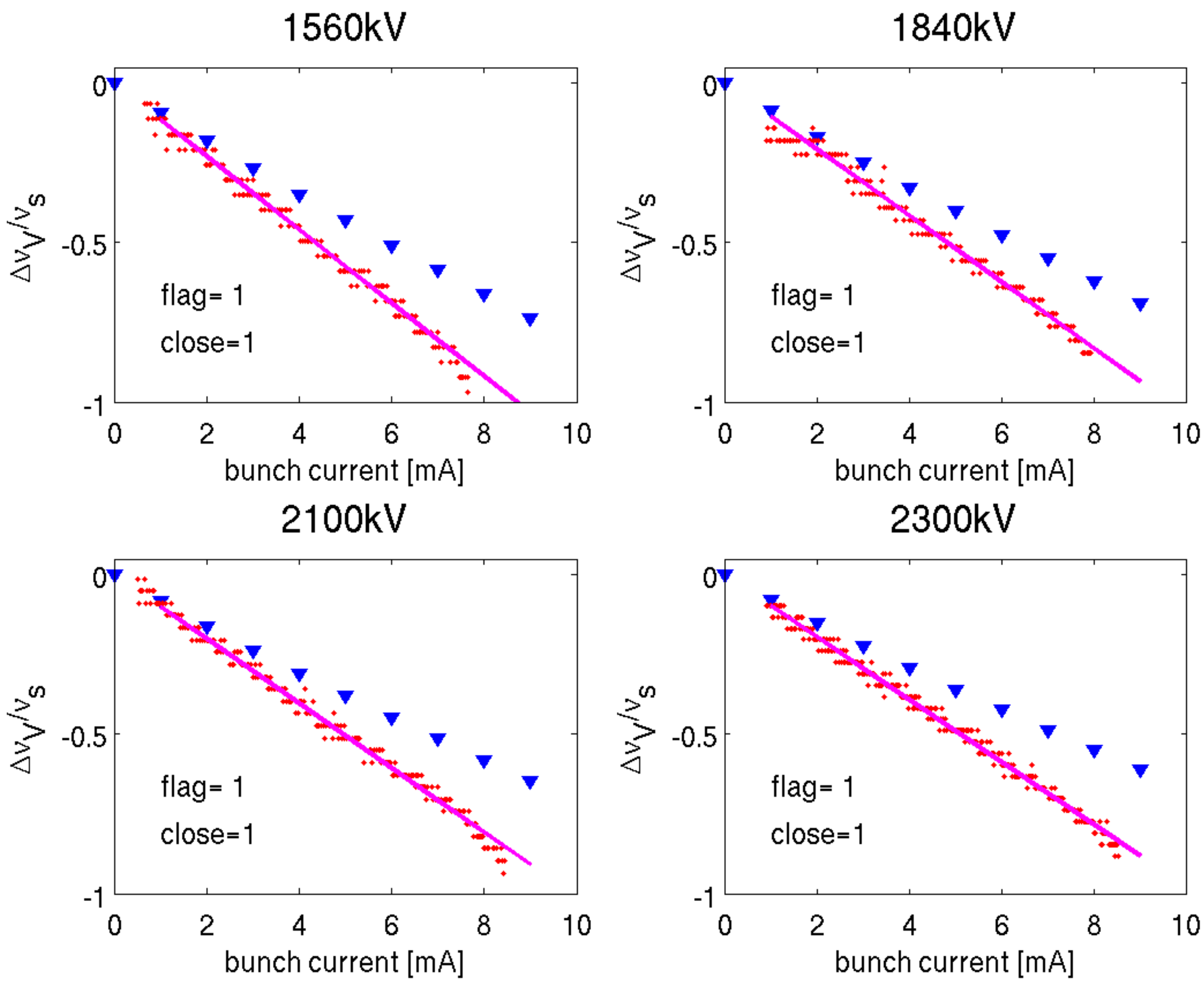
electric coefficient

$$\epsilon_1 = \frac{\pi^2}{48}\left[1 - \left(\frac{10}{\pi^2} - \frac{2}{3}\right)\alpha^2\right]$$

ϵ_1=.2053

$$\Delta\upsilon_{Las}/\upsilon_{s0} = 0.0033$$

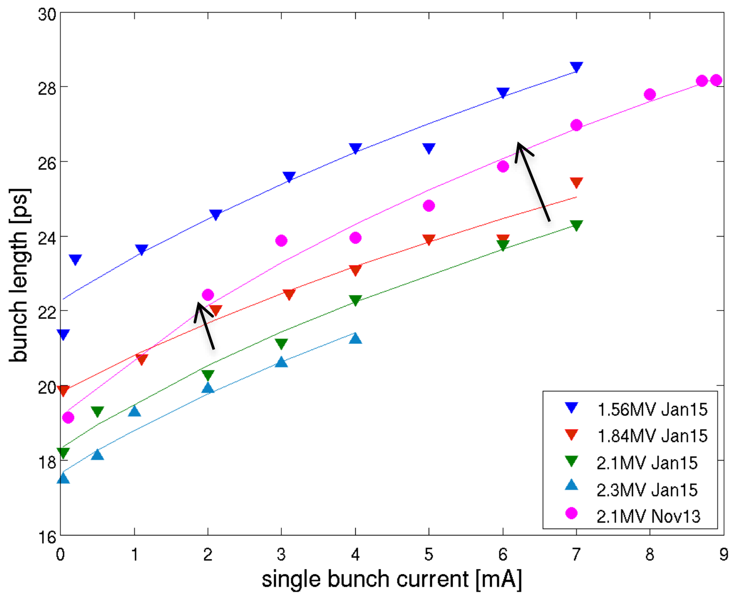
Results (Impedance+Laslett)

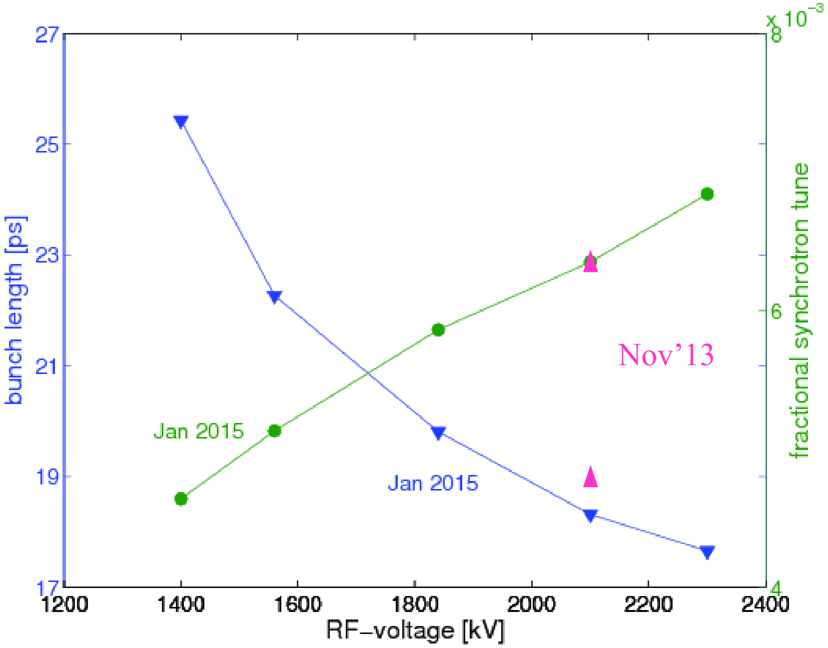


Up to almost 80% of the measured slope could be reproduced.

Bunch length parametrisations

However, bunch length behaviour in Nov.13 looks rather different, both @2.1MV though





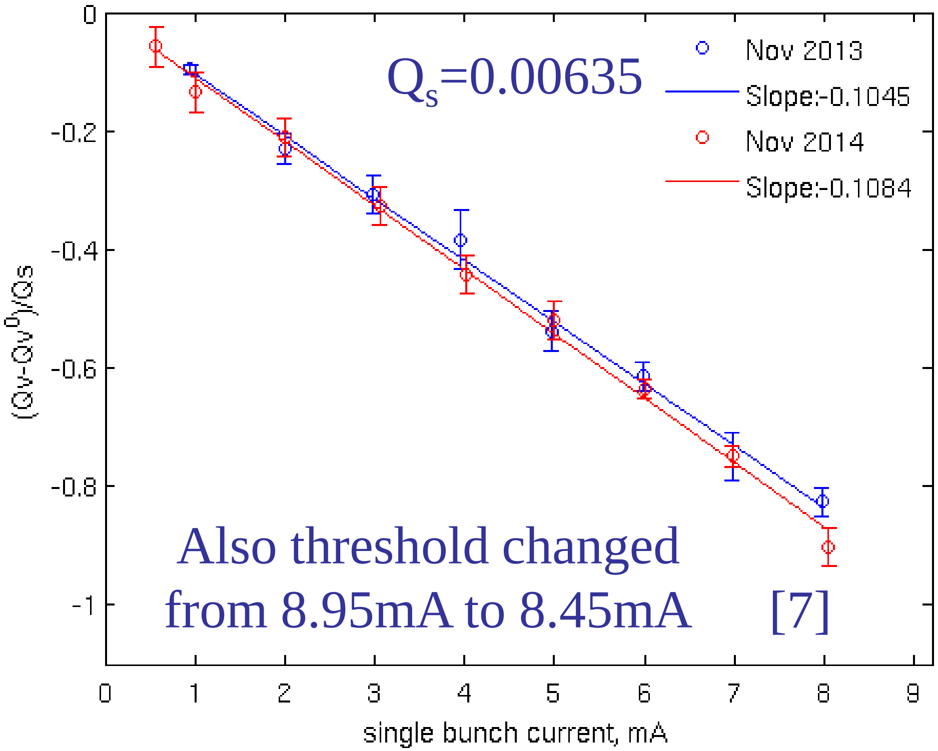
fit parm: σ_0=19.15ps & |Z/n|=181mΩ much larger than |Z/n| of Jan'15 data

$$\nu_{s0}\sigma_0 = \frac{\alpha\delta}{\omega_0}$$ seems to be not well fulfilled, at least not with the same αδ as Jan'15

For the time being we assume that the bunch length data are valid although we don't understand neither their RF-voltage nor |Z/n|–behaviour well.

Installation of the pinger[7]

Between the 1. and 2. reasonable TMCI measurement a pinger was installed in ALBA.



The pinger is like a injection kicker, above all a multi-layer structure RW can be computed with IW2D

The Ti-coating was suspected to be smaller (0.1μm) than assumed (0.4μm) But no extraordinary heating was observed.

Slope difference led to a Im(Zeff)=(14.5±4)kΩ/m

Computation provided only Im(Zeff)=2.92kΩ/m@22ps

Unfortunately the bunch length of the 2. measurement set were unusable.

The red slope (at same RF and υ_{s0})in Jan'15 got already weaker than the one of Nov'14. However, the TMCI-threshold with pinger installation is still lower.

Effect of in-vacuum undulators compared to the one of the pinger

Opening and closing of the in-vacuum undulators

The invac-undulators were opened & closed during the same measurement campaign

Measured effect: $(\beta Z_V)=256k\Omega$ Computed effect: $(\beta Z_V)=158k\Omega$ (62% reprod.)

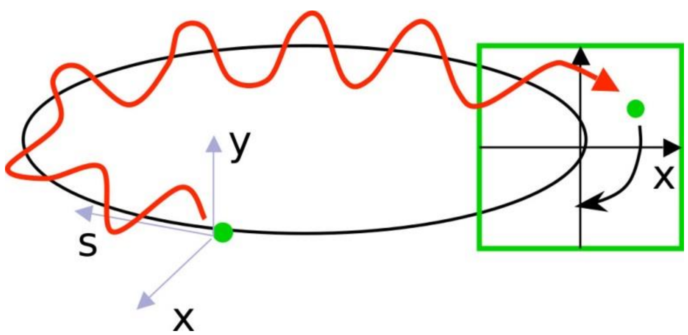
Pinger

To compare 2 data sets which might have rather different bunch length parametrisations, taken in one year's difference time the conclusion is less sure.

Measured effect: $\mathrm{Im}(Z_{eff})=(14.5\pm4)k\Omega/m$ Computed effect: $\mathrm{Im}(Z_{eff})=2.92k\Omega/m$

Michele Carla et al.

Transverse impedance results among the other effect in a small bunch charge dependent optical function distortion.



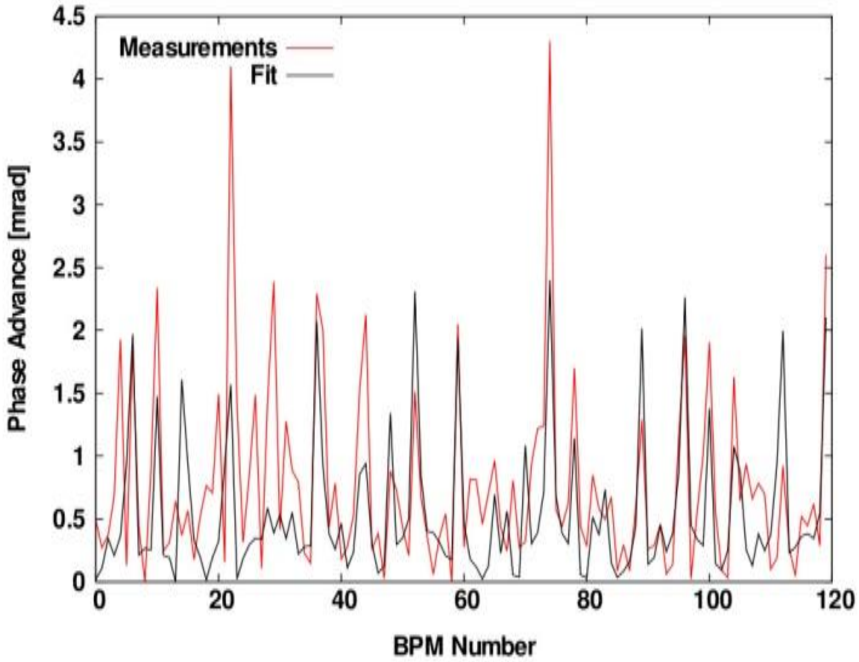
- Betatron motion is excited by means of a fast kicker
- 120 BPM measure the transverse beam position turn after turn
- Machine optical function are obtained from spectral analysis [phase advance]

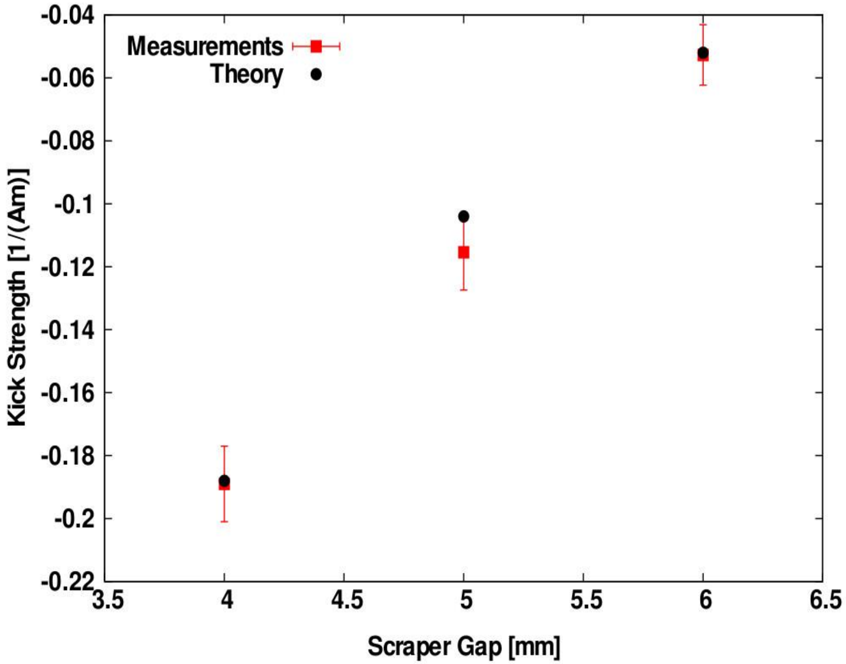
Final precision is defined by BPM and machine stability since no magnetic element is changed during the process!

Scraper

Michele Carla et al.

Taking advantage of the ability to switch on and off the scraper contribution



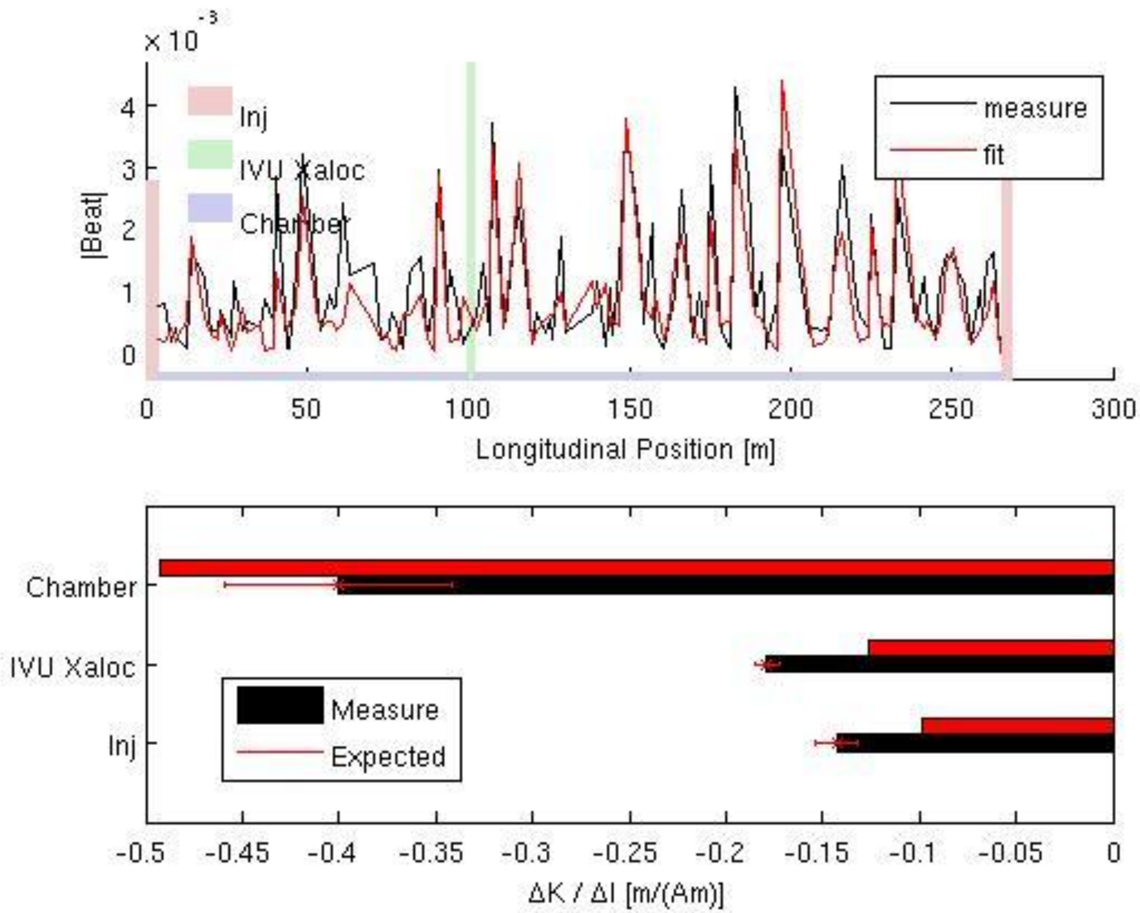


- One measurement with scraper in [at different gaps].
- One measurement with scraper out.
- The impedance model is fitted to reproduce the difference between the two measurements.

Global Measurement

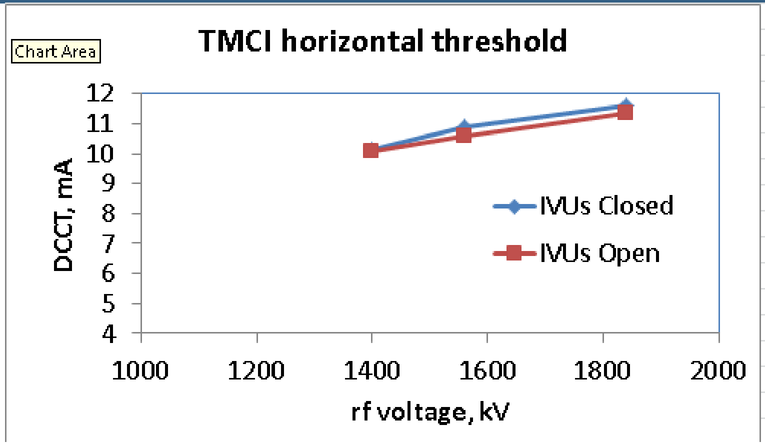
Michele Carla et al.

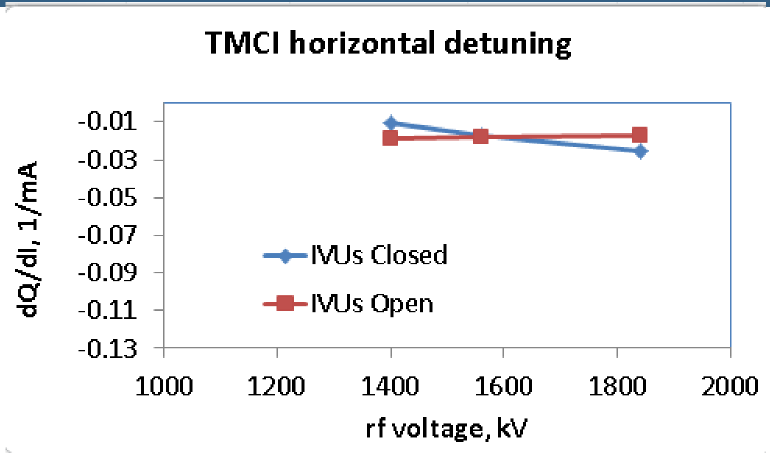
We can not switch on and off every other impedance source, but we can change the bunch charge!



- One measurement low bunch charge.
- And one with high bunch charge.
- The impedance model is fitted to reproduce the difference between the two measurements.

Horizontal TMCI





The horizontal TMCI-threshold changes with RF-voltage.

The horizontal detuning is very small compared to the vert. plane

Assumption : $(\beta Z)^{H}_{eff} \sim B + W\sigma_0^{0.5} = B + (C\,W)V^{-0.25}$

$$I_{thres} \approx \frac{4\sqrt{\pi}(\frac{E}{e})(\omega_{s0}\sigma_\tau)}{(\beta Z)_{eff}} \approx \frac{4\sqrt{\pi}(\frac{E}{e})(\omega_{s0}\sigma_\tau)}{B}[1-\frac{CW}{B\sqrt[4]{V}}]$$

The threshold is increasing with the RF-voltage weakly.

The decrease of the threshold with opened IVUs might create a large horizontal cavity, a source of impedance.

Next time we'll try with the horizontal scraper

Conclusions

- With the inclusion of the Laslett tune shift we can explain almost 80% of the measured single bunch tune slope of the Jan'15 data.
- The analysis depend sensibly on a good bunch length parametrisation, probably due to lack of this we encountered difficulties with the impedance characterisation of the pinger magnet.
- The missing ~20% have to be searched in the still unsufficient impedance reproduction of different types of low-gap chambers.
- It is now time to study more thoroughly the horizontal impedance.
- New experimental techniques will allow us, as already at other synchrotrons, get more experimental data on the localisation of big chunks of trans. impedance.

References

[1] T.F.Günzel et al., “Analysis of single bunch measurements at the ALBA storage ring”, IPAC’14, TUPRI052

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[9] S.Aumon et al.,”Trans. low frequency broadband impedance measurements in the CERN PS” CERN-ATS-2011-089

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