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SPS: impedance model and instability in the transverse plane

C. Zannini, H. Bartosik, G. Rumolo, B. Salvant

Acknowledgments: M. Barnes, O.Berrig, F. Caspers, E. Chapochnikova, H. A. Day, G. Iadarola, E. Métral, N. Mounet, V.G. Vaccaro, J. E. Varela

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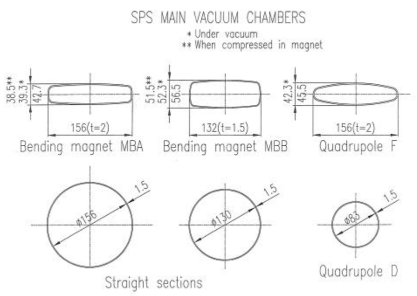
SPS transverse impedance model

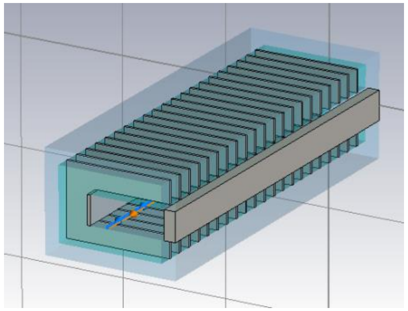
Elements included in the database:

- Wall impedance that takes into account the different SPS vacuum chambers (analytical calculations)
- Kickers (CST 3D simulations)
- RF cavities (200 MHZ and 800 MHz) without couplers (CST 3D simulations)
- Broadband impedance of step transitions (CST 3D simulations)
- Horizontal (BPH) and vertical (BPV) beam position monitors (CST 3D simulations)

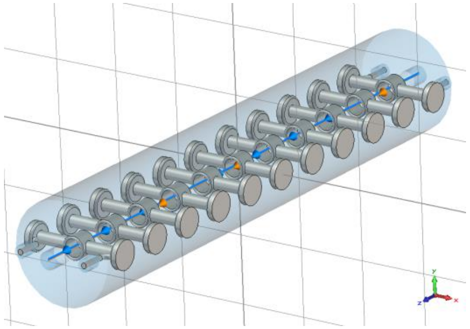
Beam pipe



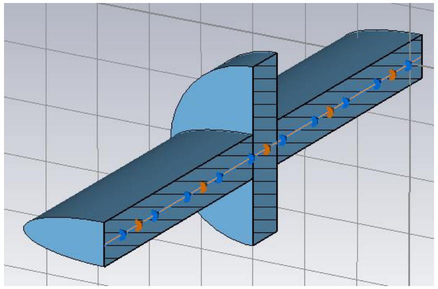
Kickers



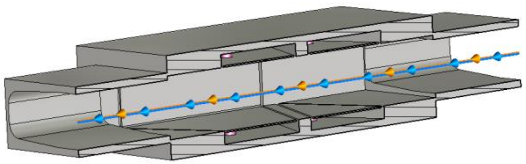
RF cavities



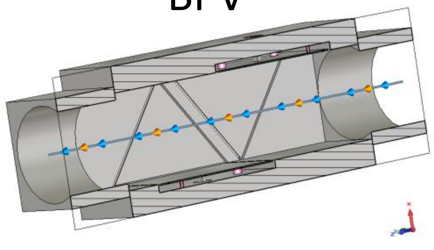
Step transitions



BPH

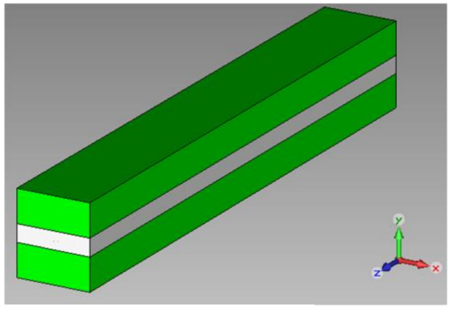


BPV

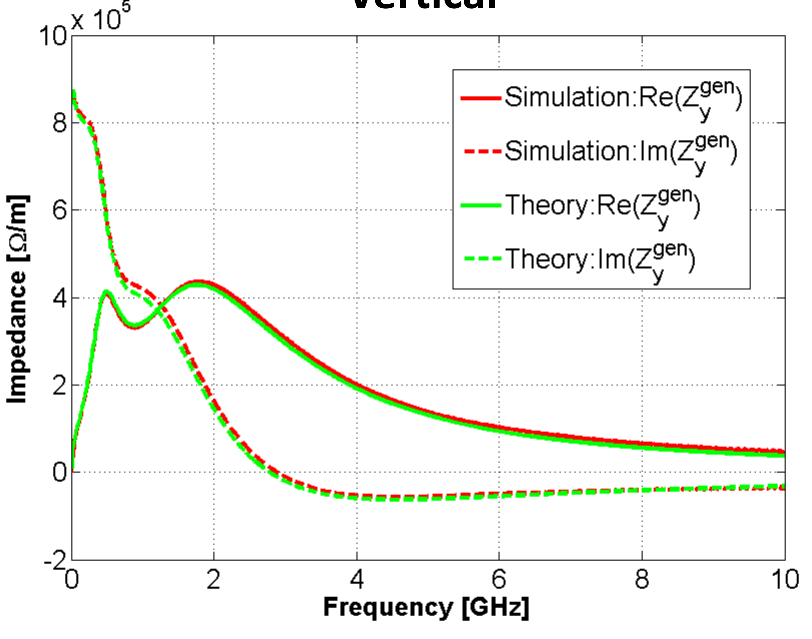


SPS kicker impedance model

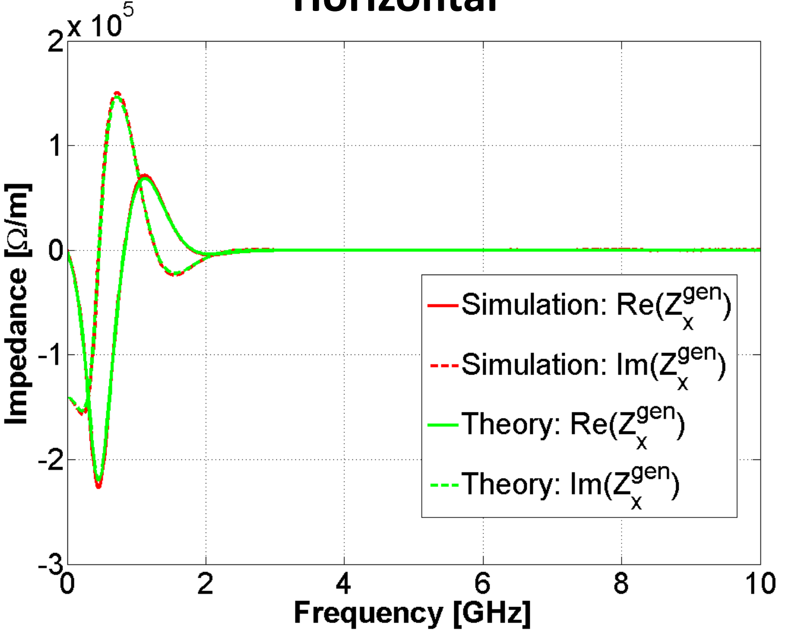
Tsutsui model



Vertical



Horizontal

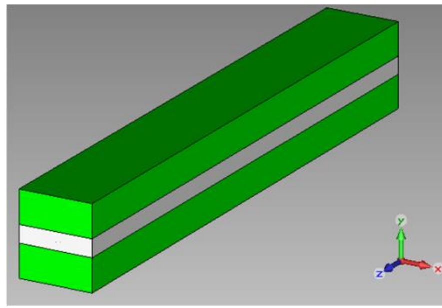


CST Particle Studio is found to be a reliable tool to simulate the impedance of ferrite loaded components

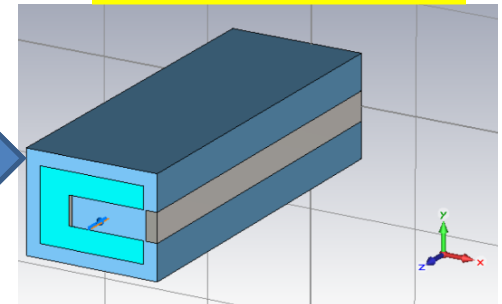
SPS kicker impedance model

SPS kicker magnet

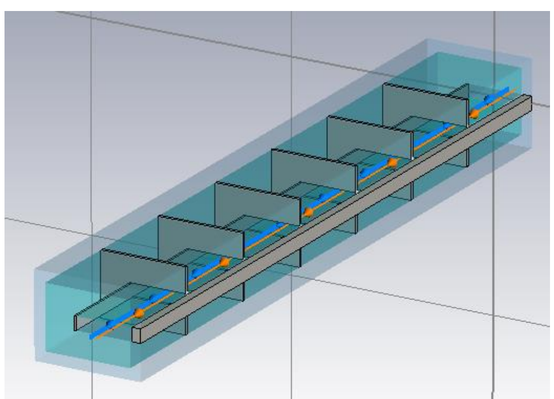
Tsutsui model

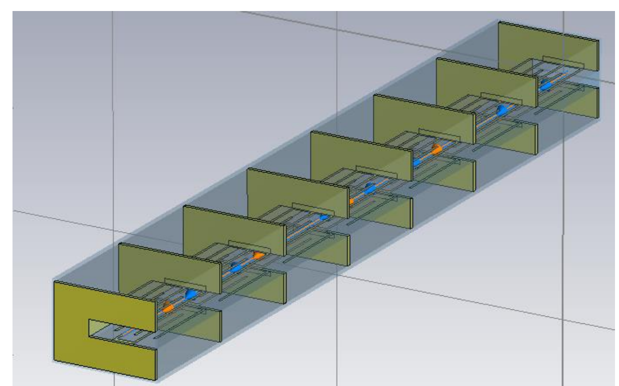


C-magnet model



Realistic models: longitudinal cell segmentation and serigraphy





SPS kicker impedance model: experimental benchmark

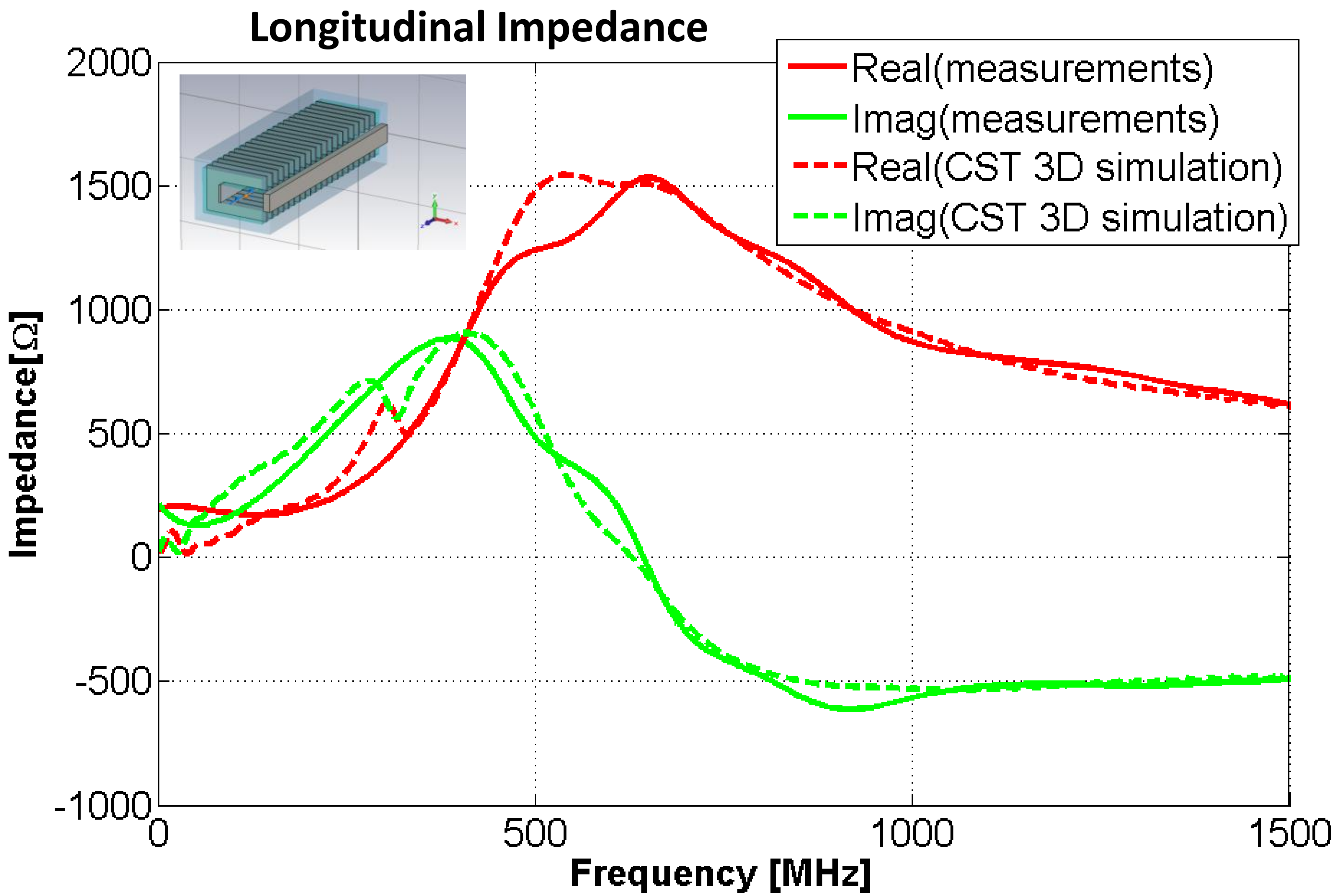
→ Beam induced heating measurements

- The impedance model of the SPS extraction kicker with and without serigraphy can explain the beam induced heating observed in the SPS machine

C. Zannini, *Electromagnetic simulations of CERN accelerator components and experimental applications*. PhD thesis, Lausanne, EPFL, 2013. CERN-THESIS-2013-076.

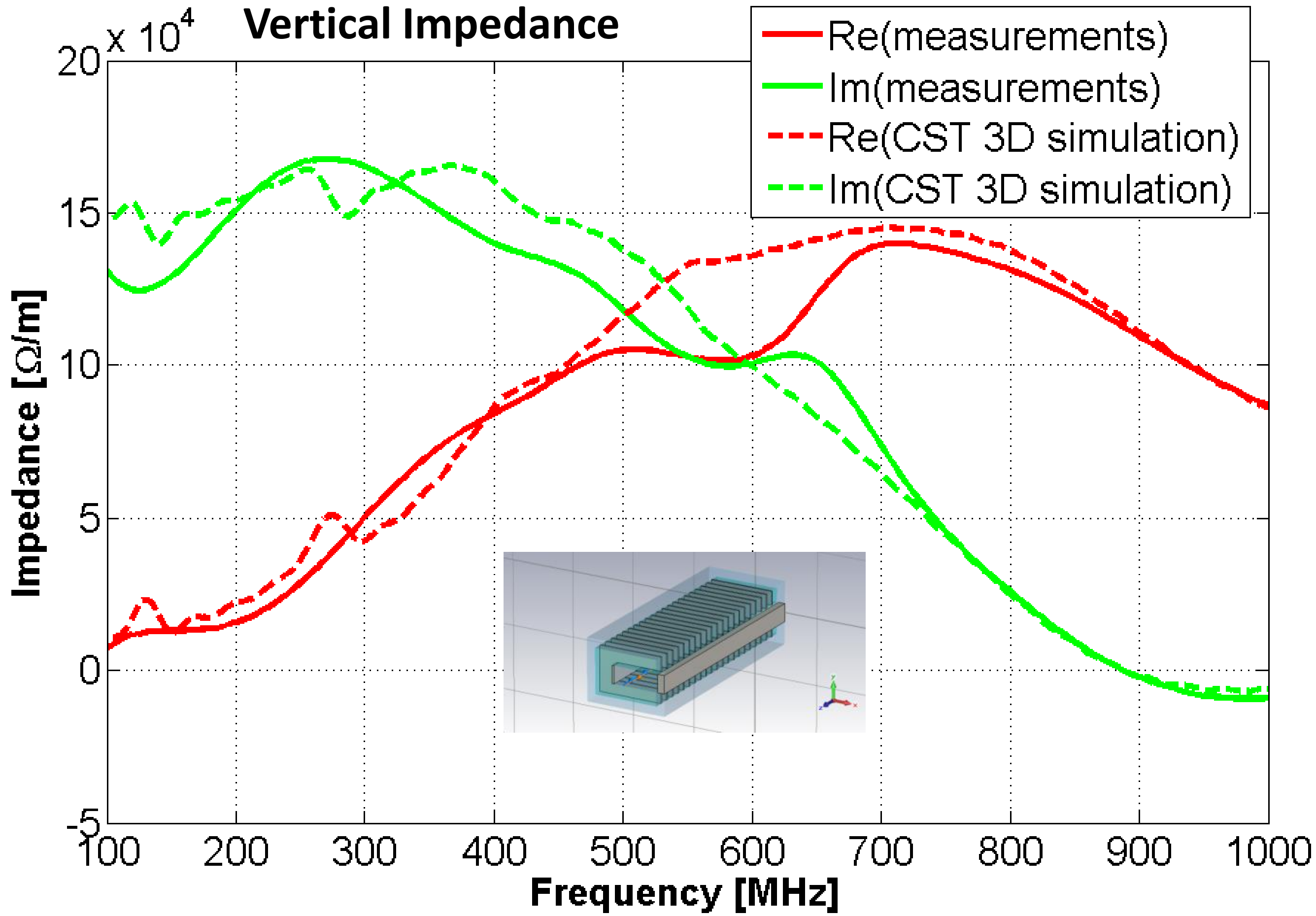
→ Bench impedance measurements (stretched wire method)

SPS kicker impedance model: comparison with bench measurements for the MKP11955 module



Confirmation of the 3D simulation model

SPS kicker impedance model: comparison with bench measurements for the MKP11955 module



Confirmation of the 3D simulation model

SPS transverse impedance model

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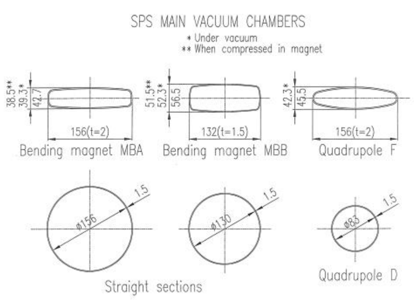
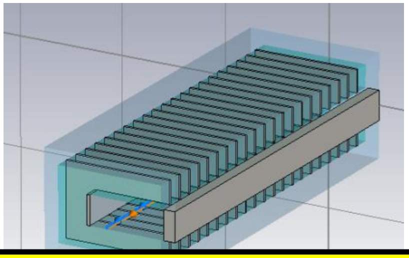
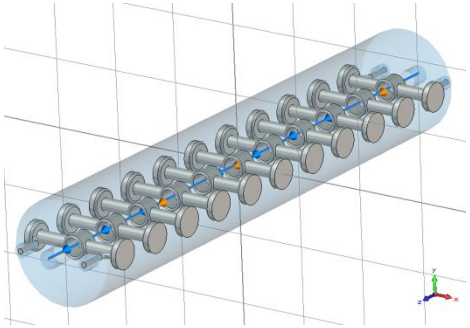
Beam pipe



Kickers

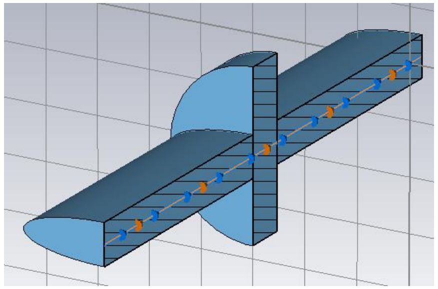


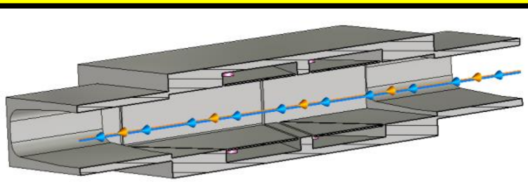
RF cavities



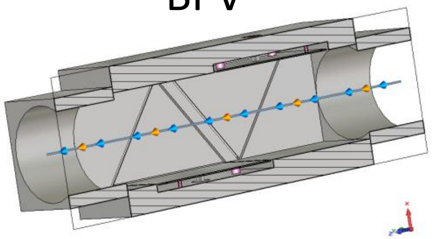
$$Z_{\perp}^{SPS}(f) = \sum_{i=1}^{N} \frac{\beta_{\perp}^{i}}{\langle \beta_{\perp} \rangle} Z_{\perp}^{i}(f)$$

Step transitions

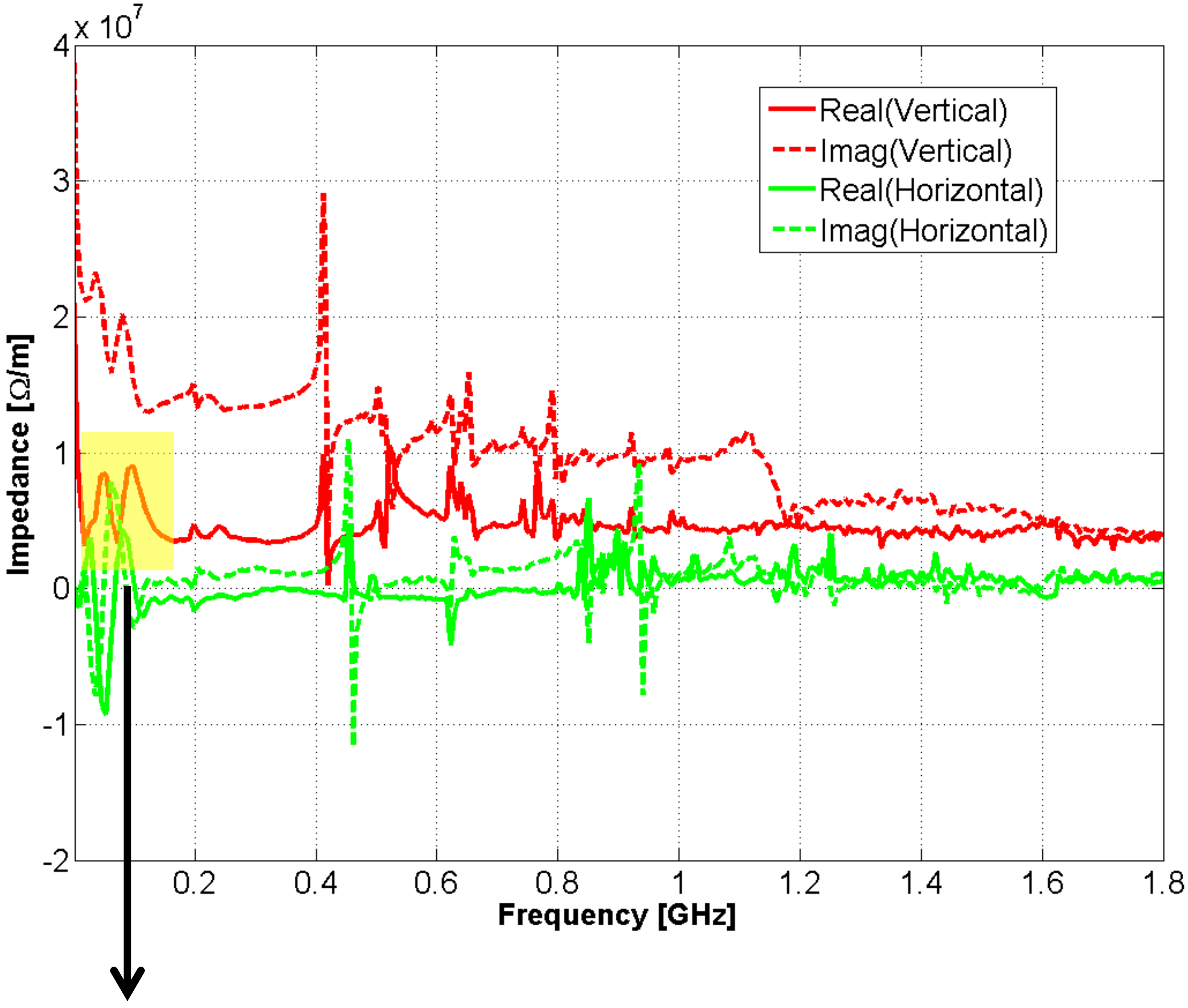




BPV

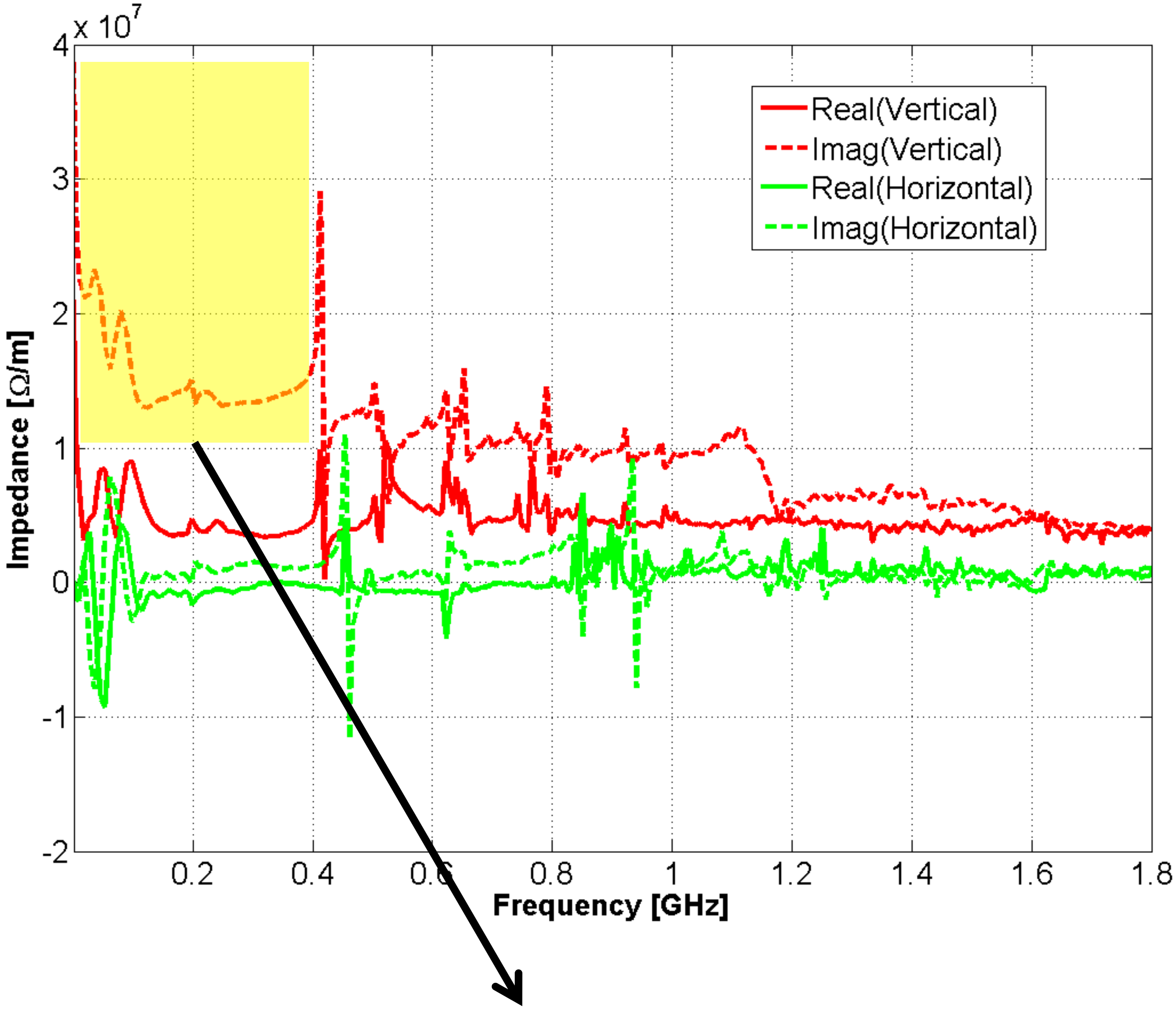


SPS transverse impedance model



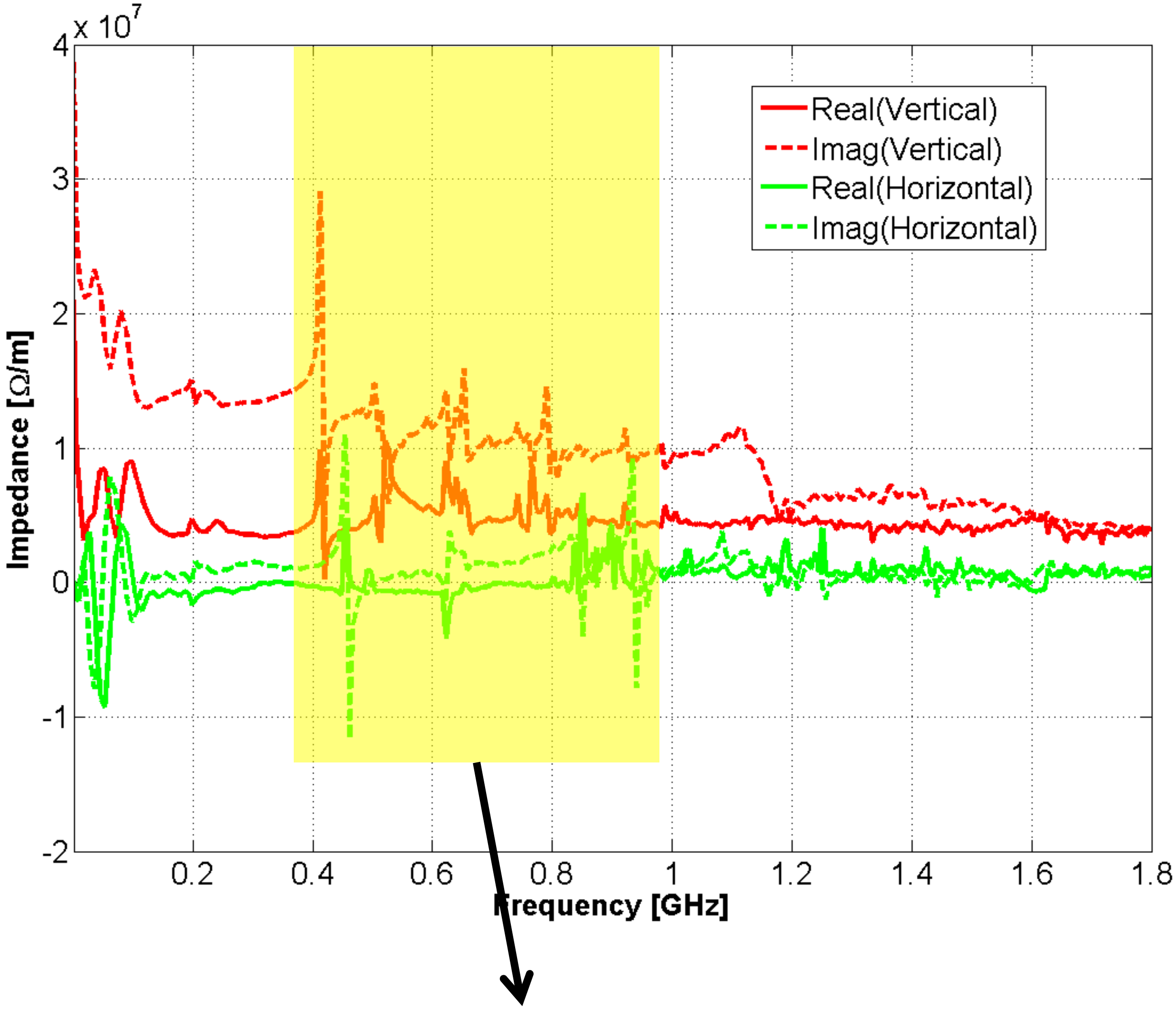
Peaks due to the serigraphy of the extraction kickers

SPS transverse impedance model



Broadband impedance mainly from kickers, step transitions and wall

SPS transverse impedance model



Peaks due to the RF system and BPMs

Benchmark with beam measurements

- Coherent tune shift
- Instability behavior

SPS transverse impedance model

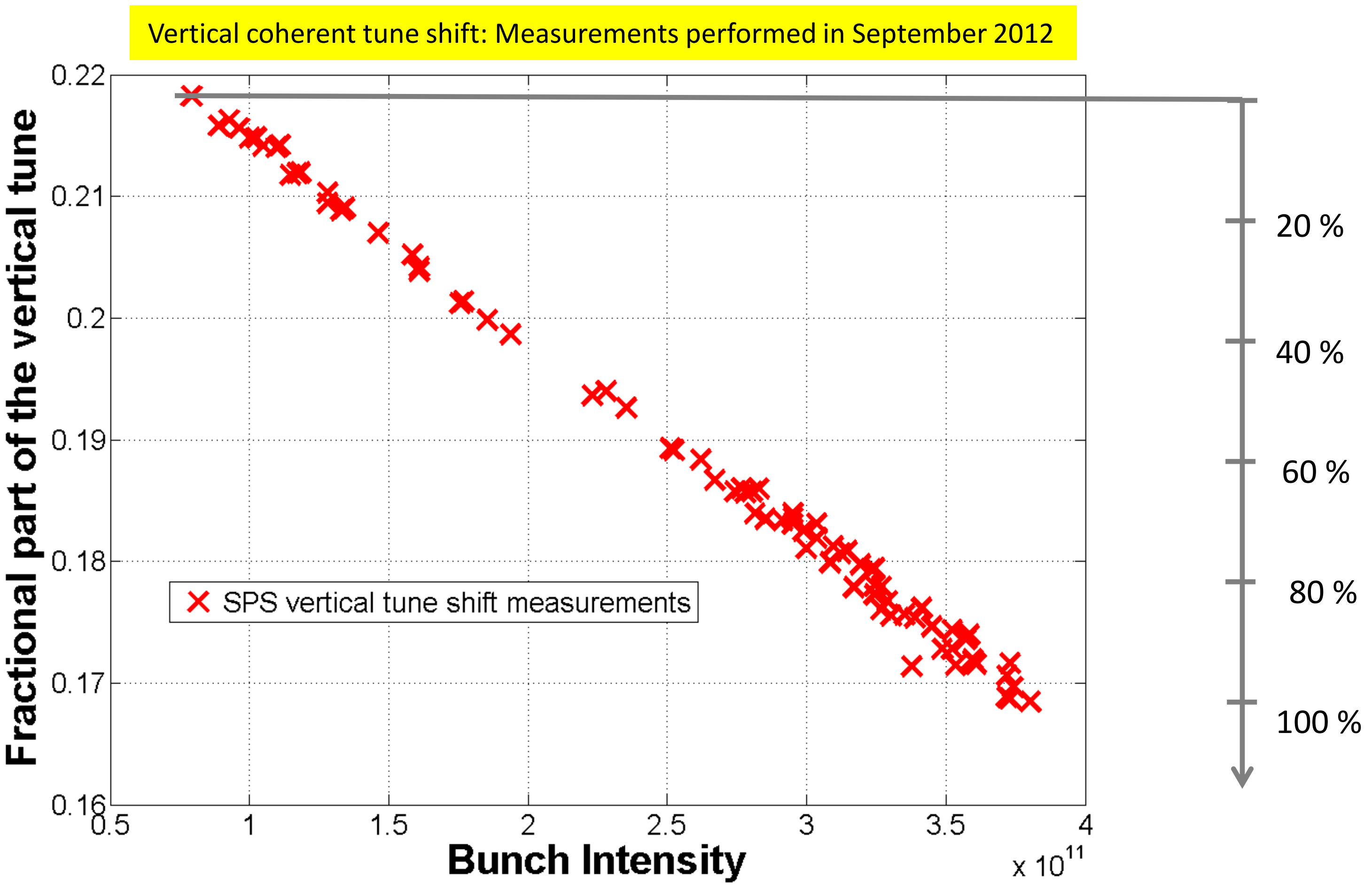
Benchmark with beam measurements

- Coherent tune shift
- Instability behavior

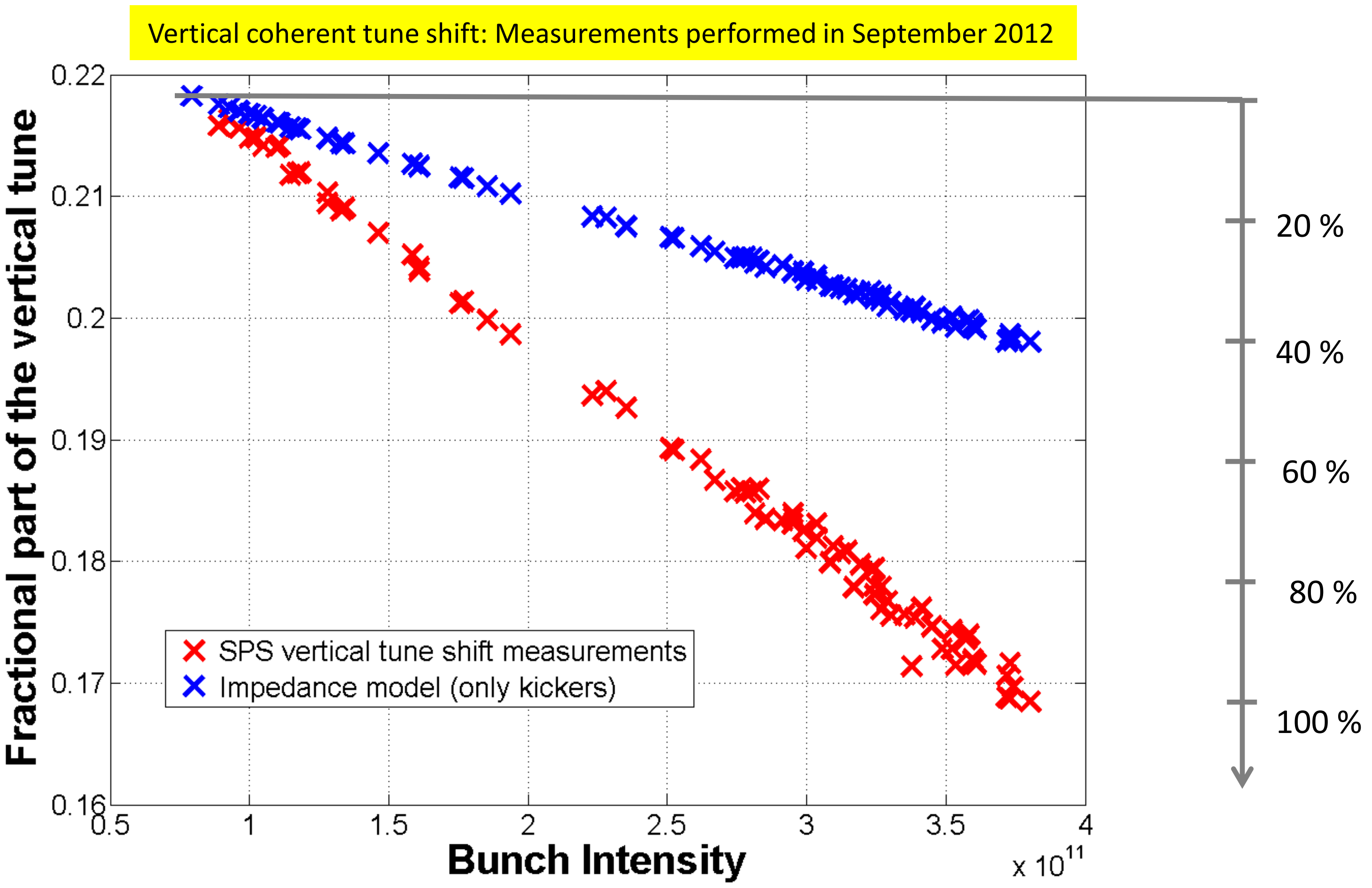
A. W. Chao, Physics of collective beam instabilities in high energy accelerators

$$\Delta Q_{\perp}(N) = -\Gamma\left(\frac{1}{2}\right)\frac{\mathrm{Im}[Z_{\perp}^{eff}]N r_0 c^2}{8\pi^2\gamma\omega_\beta\sigma_z}$$

Benchmark of the SPS transverse impedance model: tune shift measurements

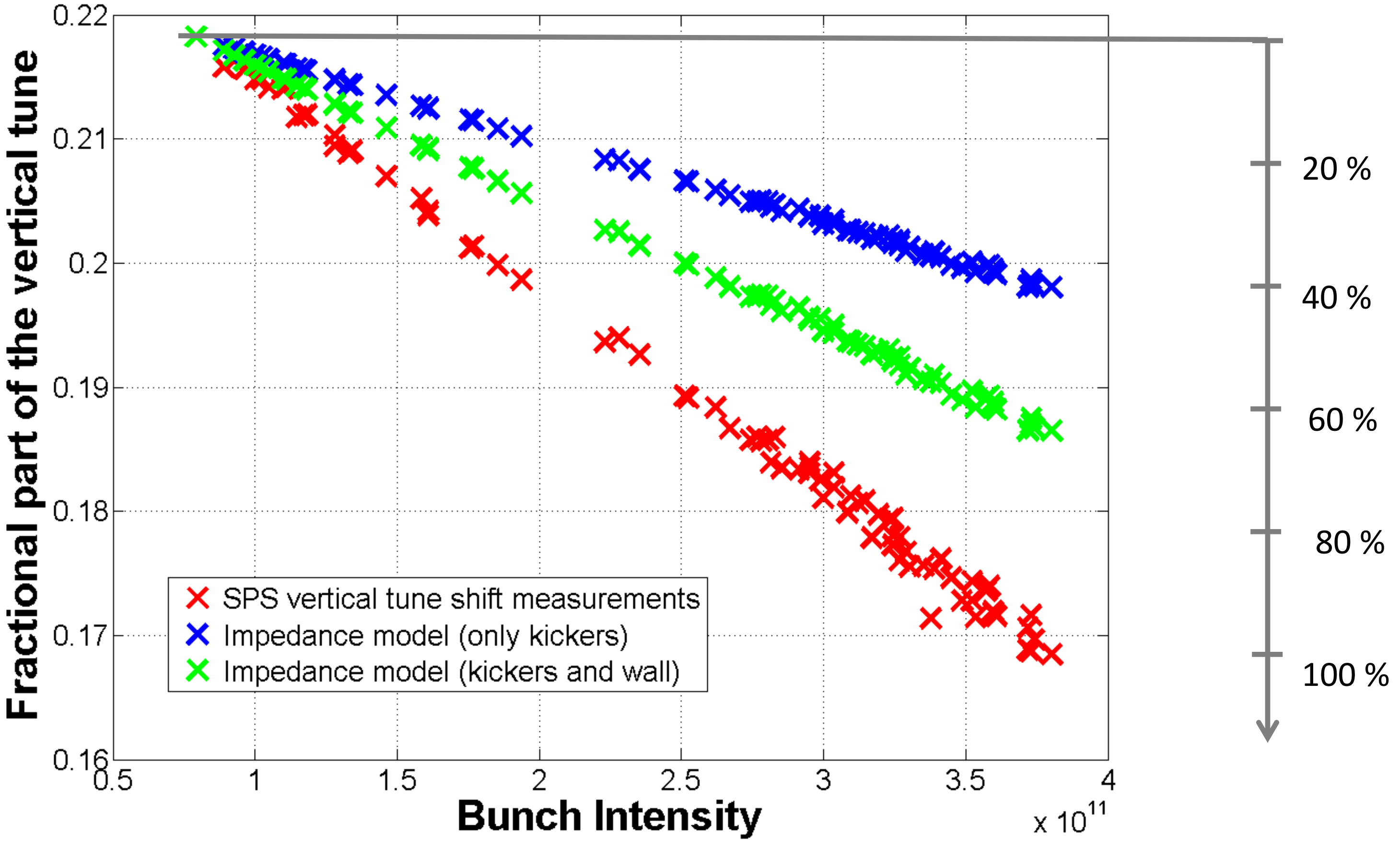


Benchmark of the SPS transverse impedance model: tune shift measurements

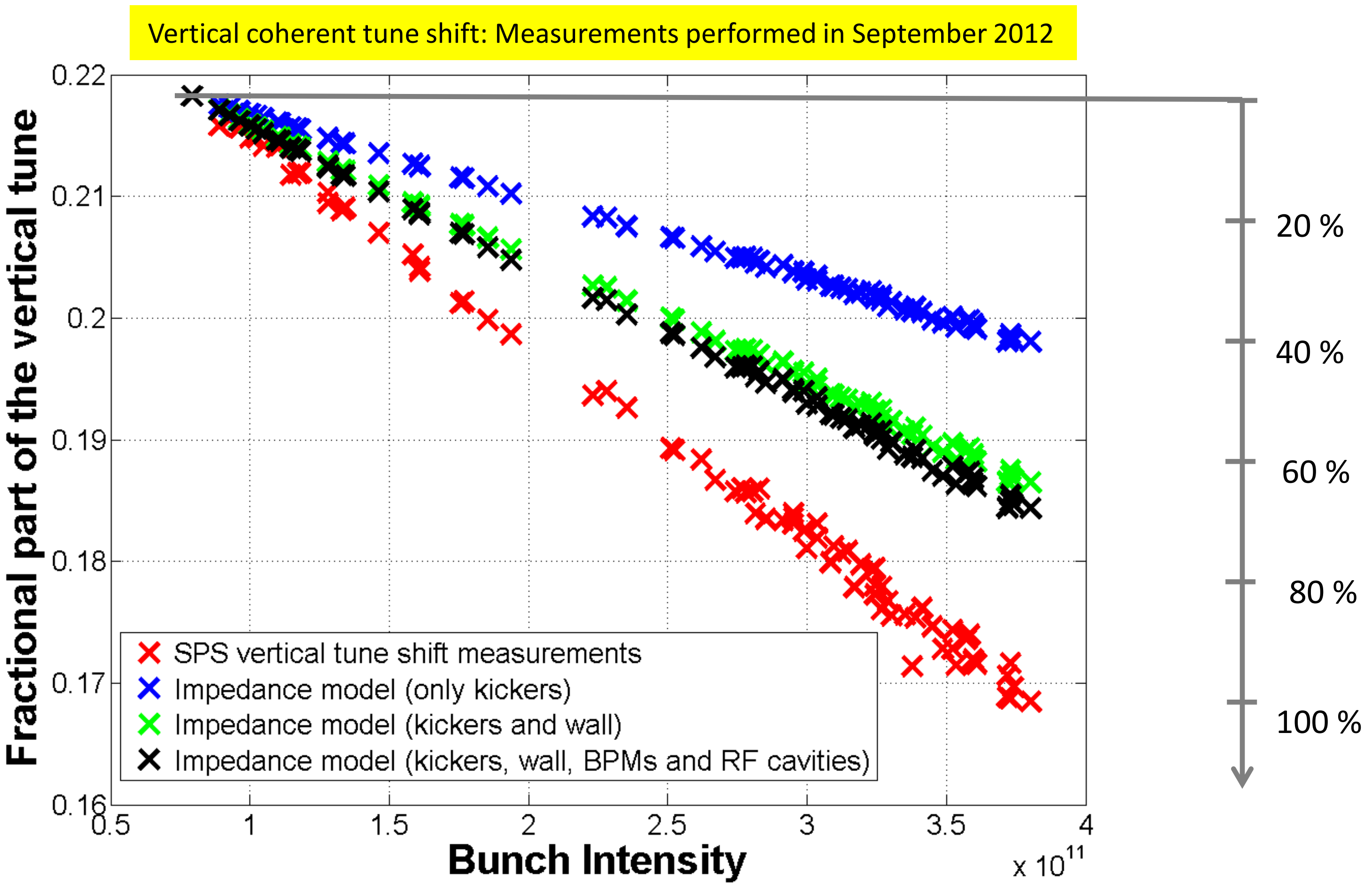


Benchmark of the SPS transverse impedance model: tune shift measurements

Vertical coherent tune shift: Measurements performed in September 2012



Benchmark of the SPS transverse impedance model: tune shift measurements



Benchmark of the SPS transverse impedance model: tune shift measurements

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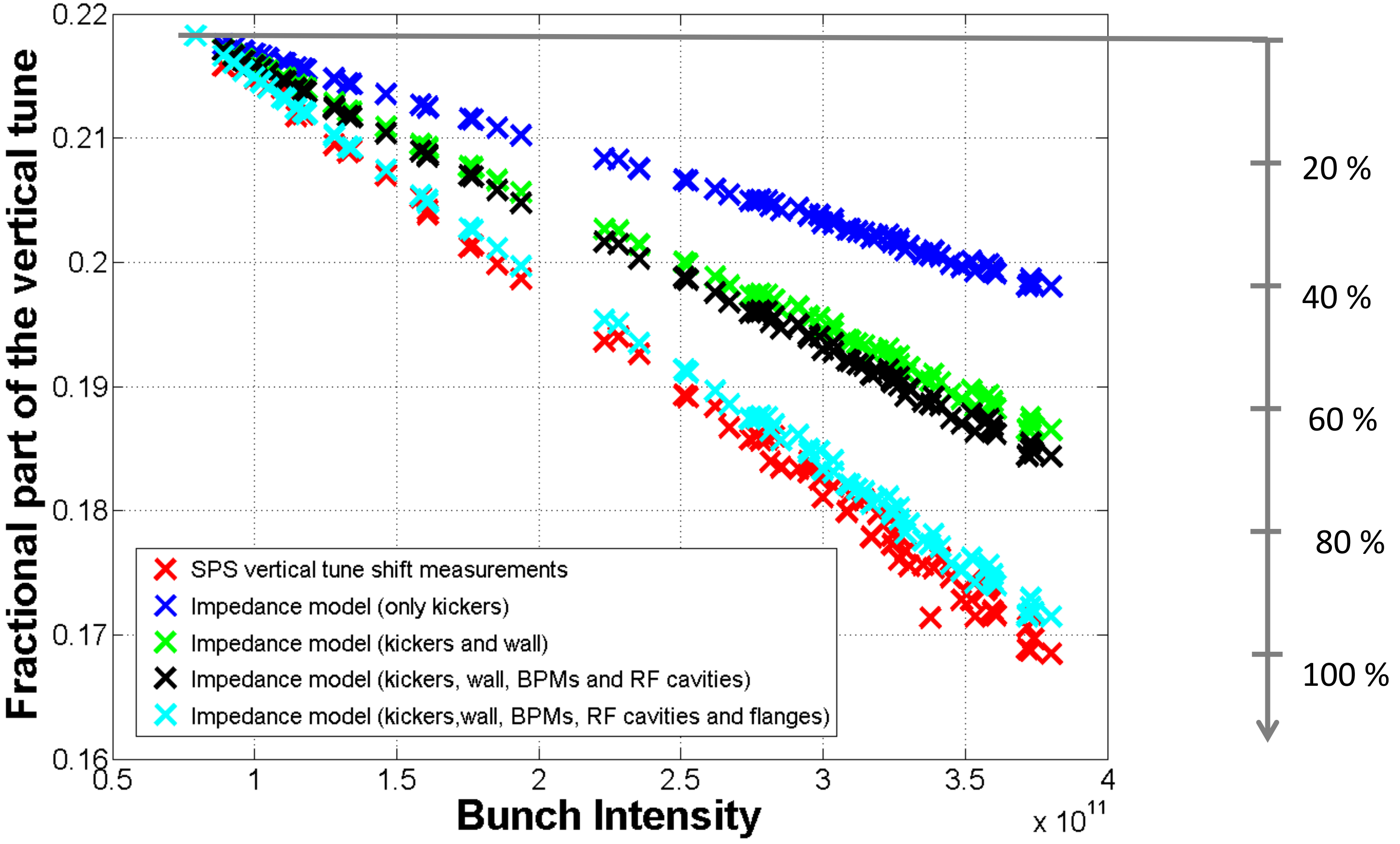
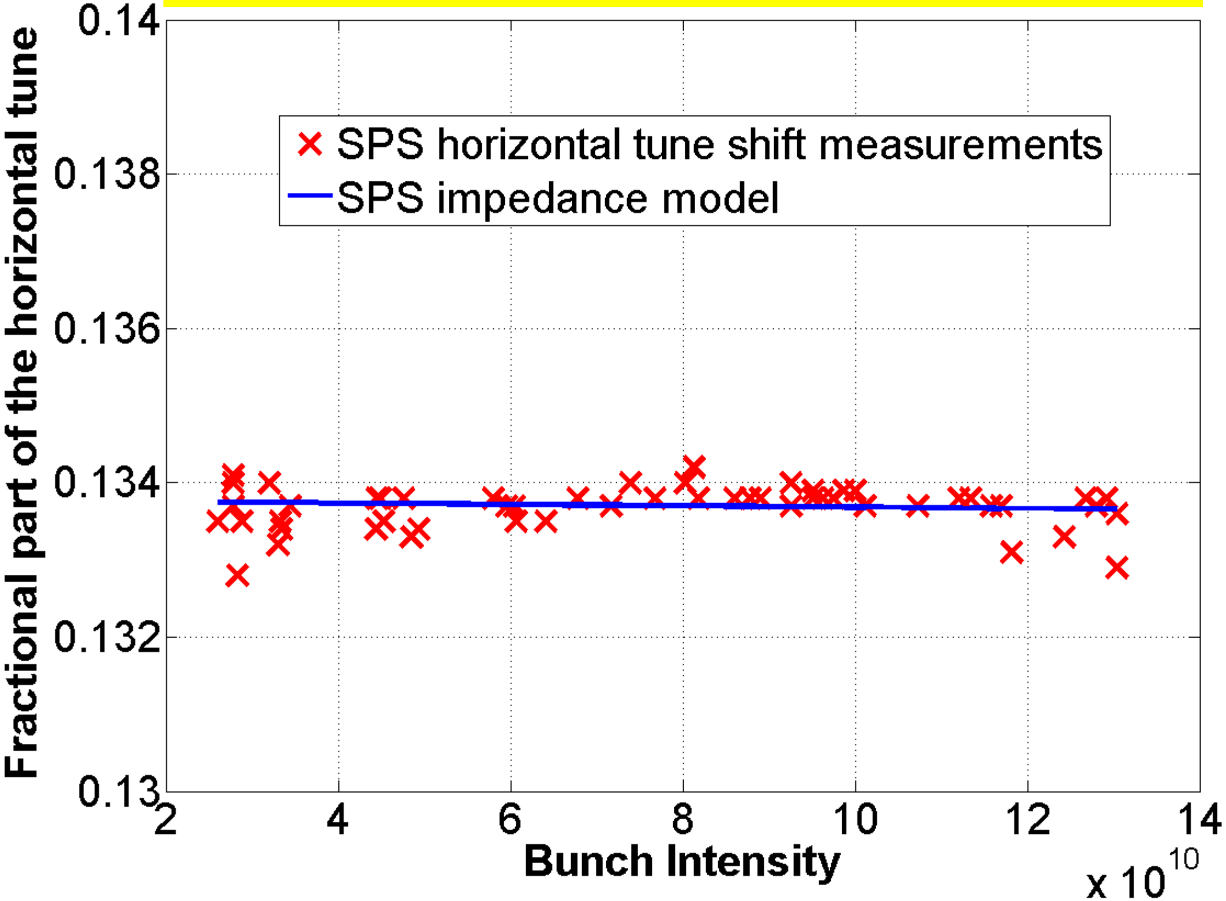


The SPS impedance model explains more than 90% of the measured vertical coherent tune shift

Benchmark of the SPS transverse impedance model: tune shift measurements

Horizontal coherent tune shift: Measurements performed in February 2013



The SPS impedance model predicts a very small horizontal tune shift (almost flat) in agreement with the measurements

SPS transverse impedance model

Benchmark with beam measurements

- Coherent tune shift
- Instability behavior

Benchmark of the SPS transverse impedance model: instability behavior

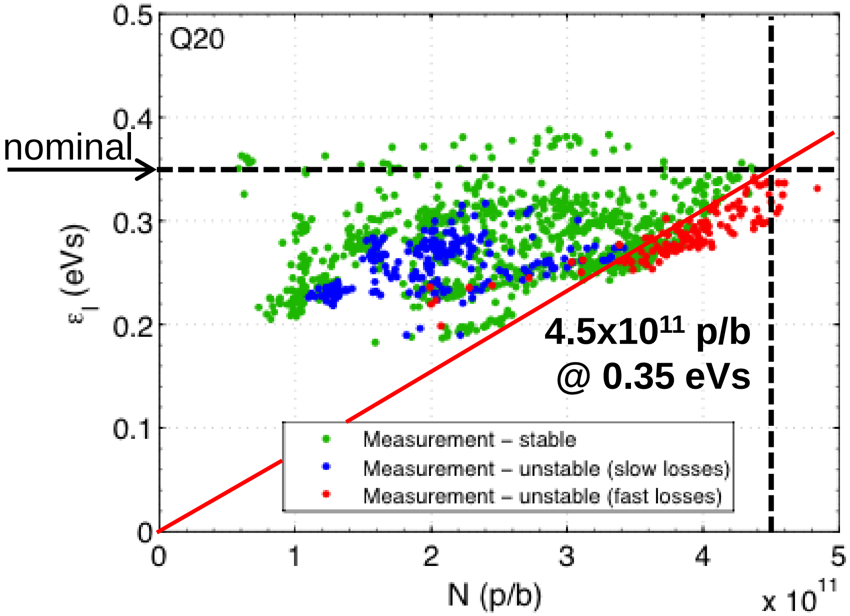
Two regimes of instability in measurements

- Fast instability threshold with linear dependence on ε_l
- Slow instability for intermediate intensity and low ε_l

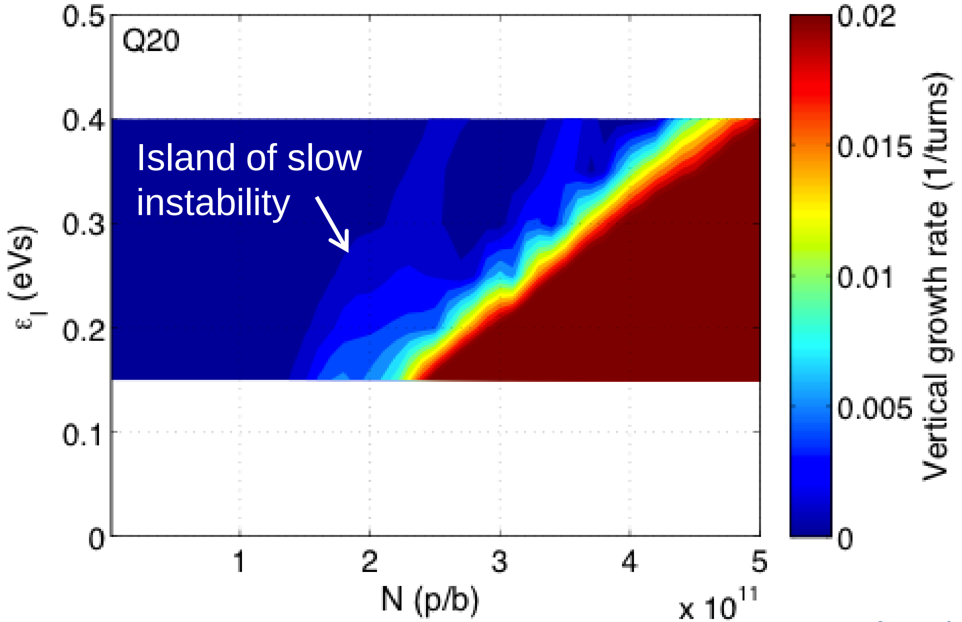
Very well reproduced with HEADTAIL simulations

- SPS impedance model includes kickers, wall, BPMs and RF cavities
- Direct space charge not included

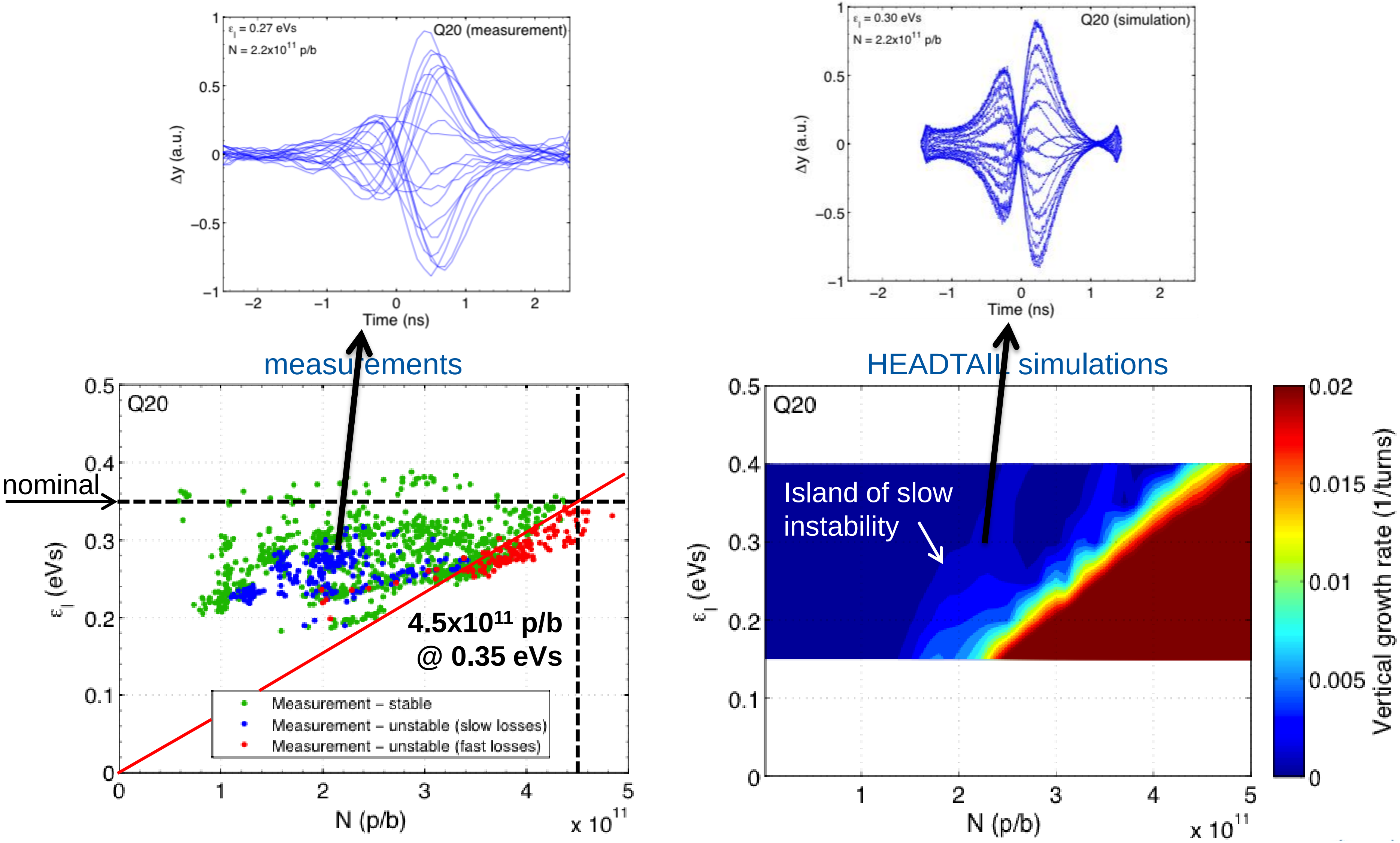
measurements



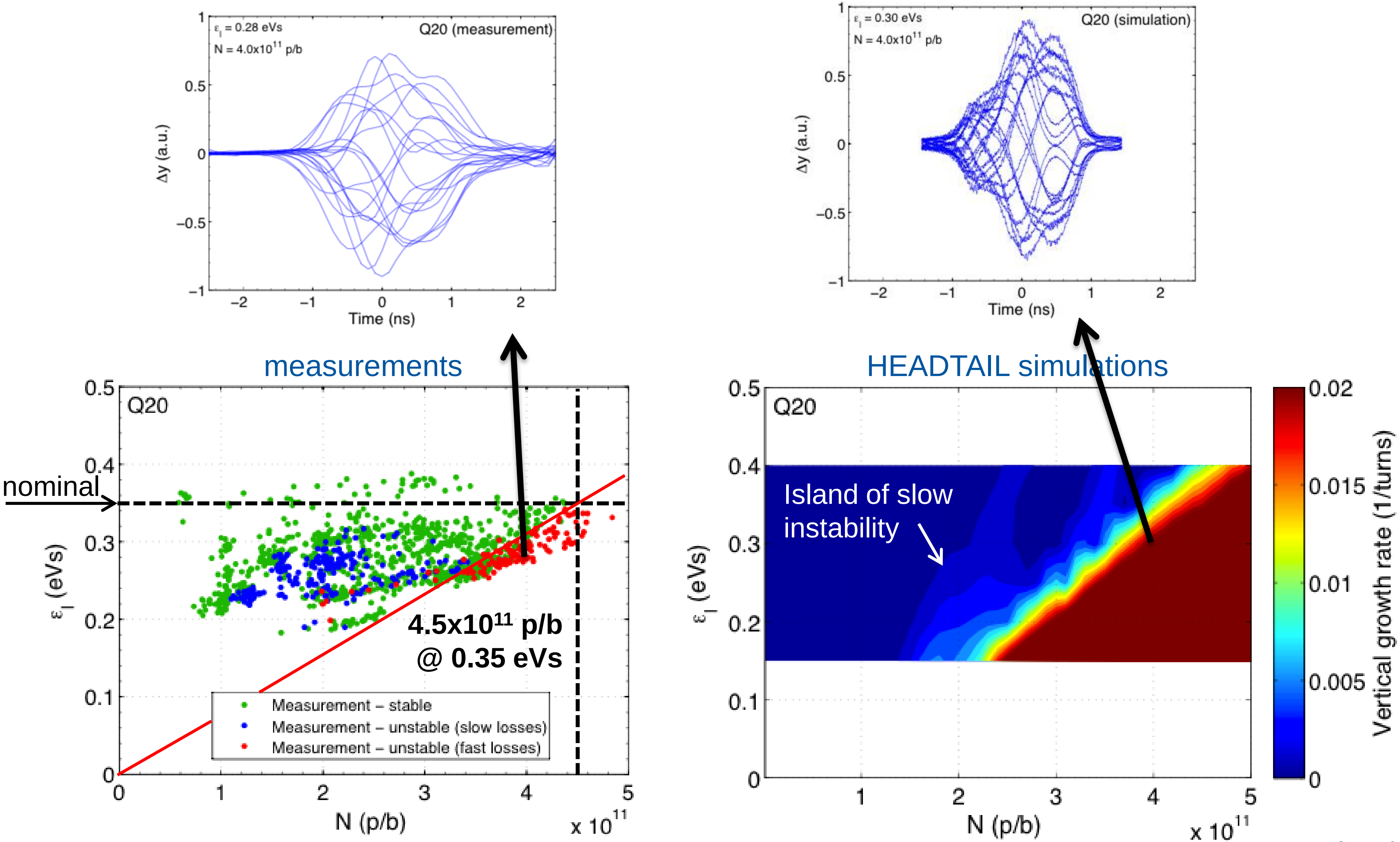
HEADTAIL simulations



Benchmark of the SPS transverse impedance model: instability behavior



Benchmark of the SPS transverse impedance model: instability behavior



New elements to be added in the model

Simulations are ongoing or must be finalized

- Septa
- Wire scanner
- Non standard elements (special transitions, valves)

Update due to future installations and modifications

- New wire scanner
- New kicker for high bandwidth feedback system
- New MSI-V septum
- Serigraphy of the last MKE (7/8 were already serigraphed in the 2012)

Summary

The present SPS transverse impedance model includes kickers, wall, cavities, BPMs and step transitions

- The kickers are the main contributors to the SPS broadband impedance (about 40% of the measured coherent tune shift)

- The present SPS impedance model explains more than 90% of the measured coherent tune shift

- HEADTAIL simulations based on the SPS impedance model reproduce very well the instability behavior

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Thank you for your attention

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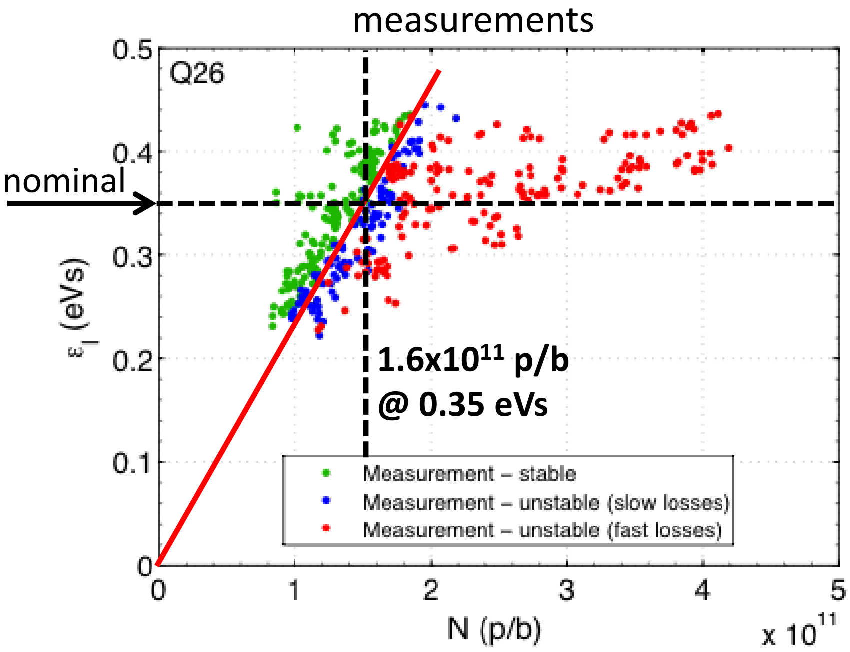
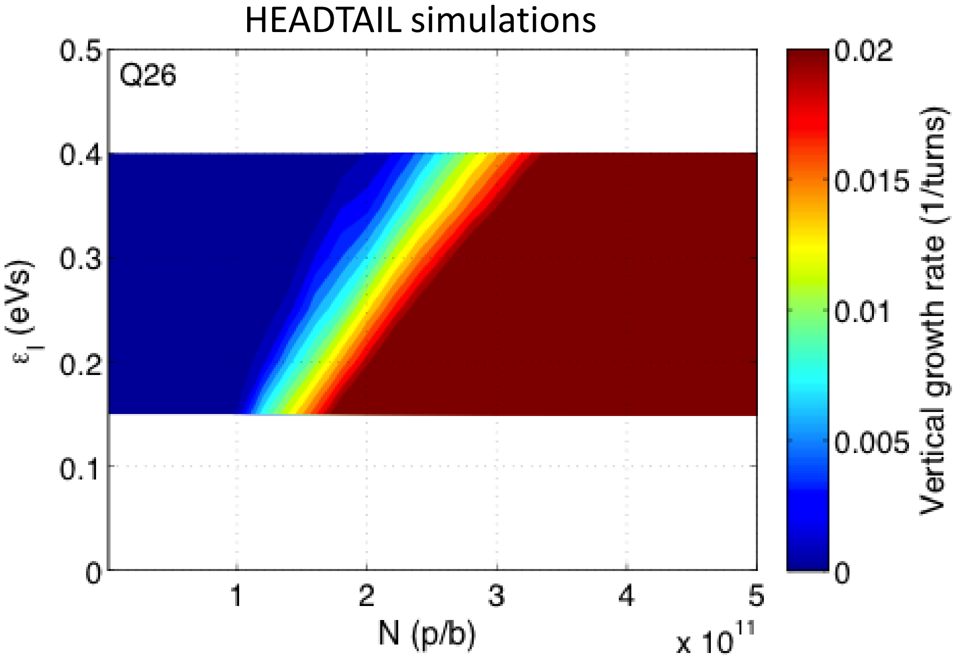
Stability diagram: Q26

- Measured onset of instability linear in ε_l
  - As expected, slower losses (lower growth rate) slightly above threshold
- Linear dependence and instability thresholds reproduced in HEADTAIL
  - SPS impedance model includes kickers, wall, BPMs and RF cavities

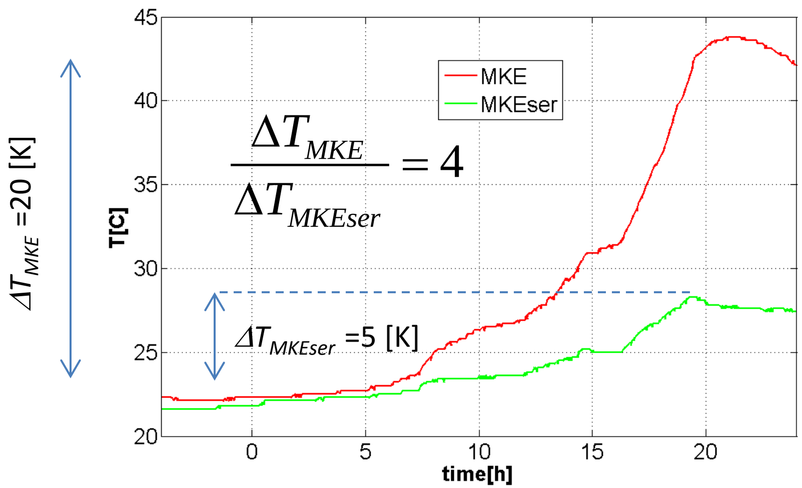




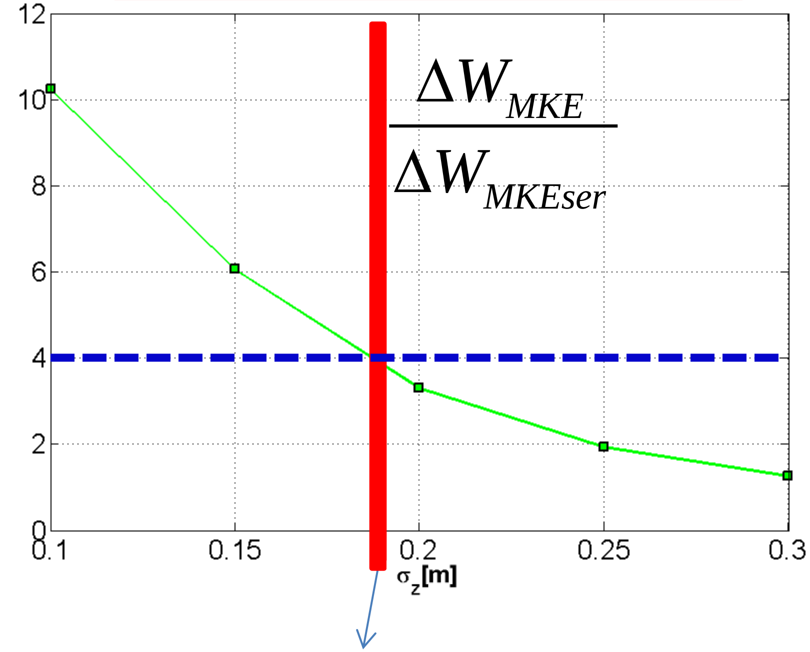
SPS kicker impedance model: comparison with beam induced heating observation (MKEs)

$$\Delta W = (f_0 e N_{\mathrm{beam}})^2 \sum_{p=-\infty}^{p=\infty} \left(\left| \bar{\Lambda}(p\omega_0) \right|^2 \mathrm{Re}\left[Z_{||}(p\omega_0) \right] \right)$$

Beam induced heating: measurements (25/04/2012)



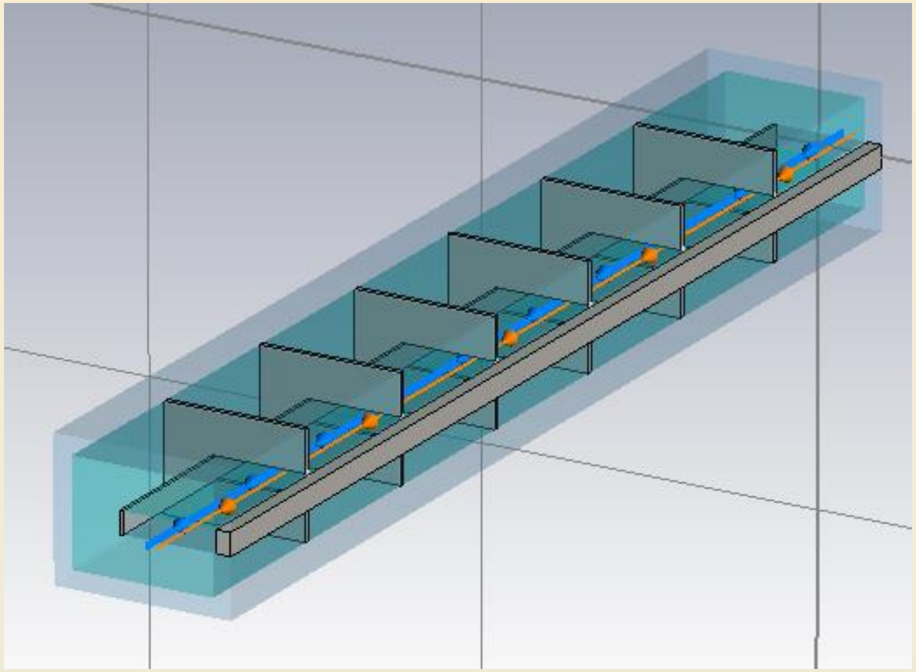
Power loss from the impedance model

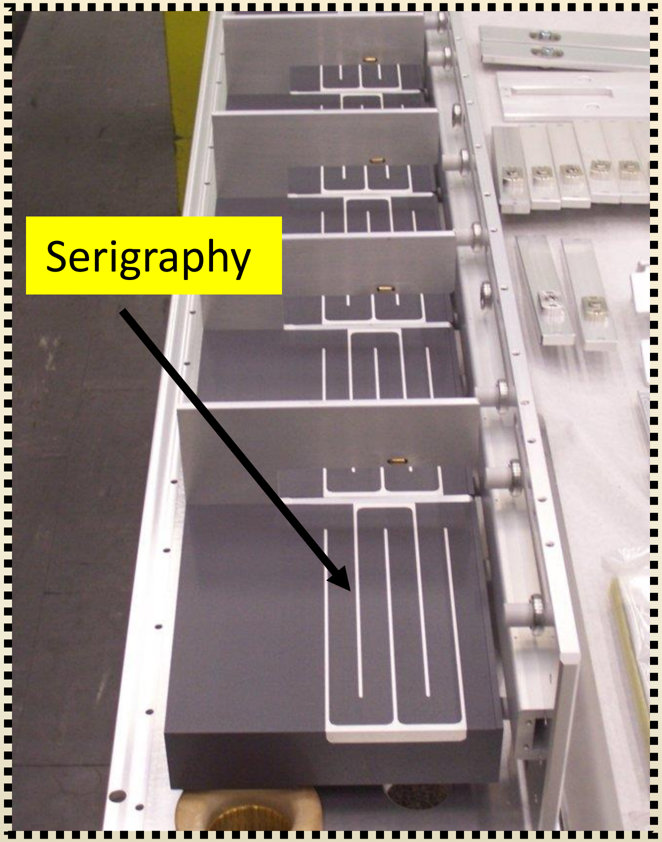


Bunch length during the experiment

$$\frac{\Delta T_{\mathrm{MKE}}}{\Delta T_{\mathrm{MKEser}}} = \frac{\Delta W_{\mathrm{MKE}}}{\Delta W_{\mathrm{MKEser}}}$$

Realistic models: SPS extraction kicker (MKE-L)





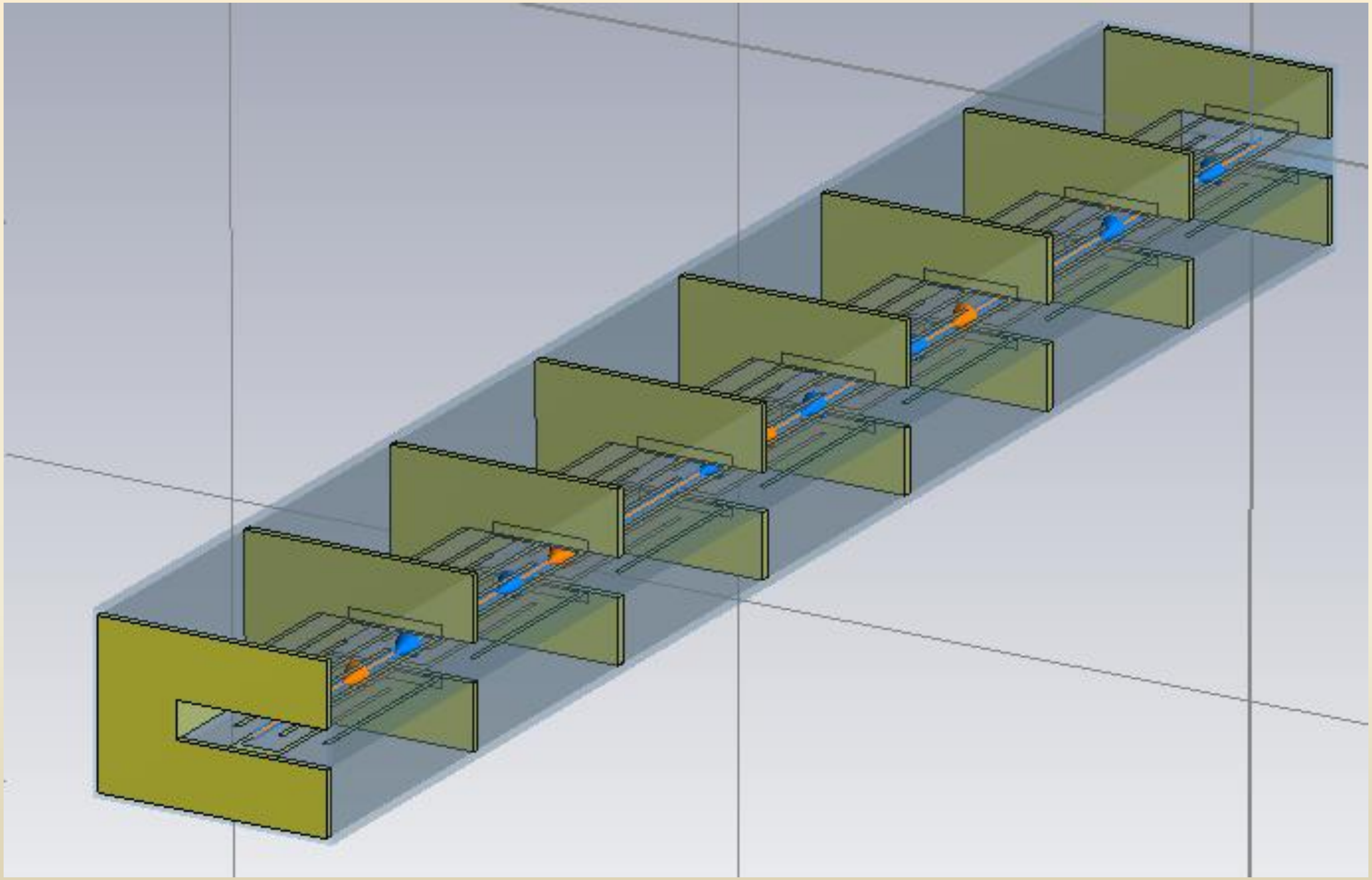
Seven out of eight SPS extraction kickers have been serigraphed

F. Caspers, T. Kroyer,
M. Barnes, E. Gaxiola et al.

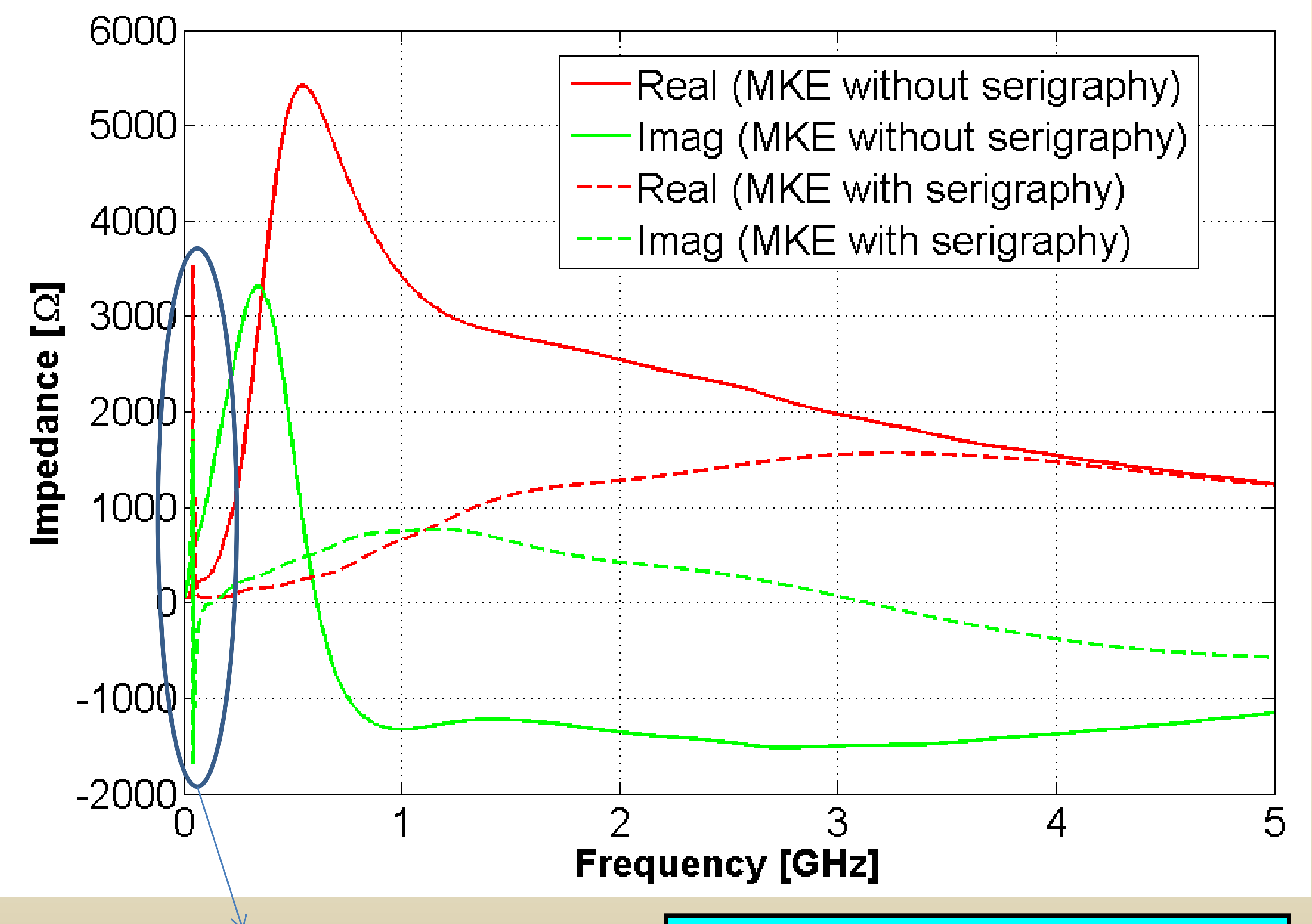
Evolution of the extraction kickers in the SPS

year	MKE (incl. MKESer)	MKESer
2001	0	0
2003	5	0
2006	9	0.5
2007	8	1.5
2009	8	3
2011	8	5
2012	8	7
Post-LS1 2014	8	8

Realistic models: MKE kicker with serigraphy



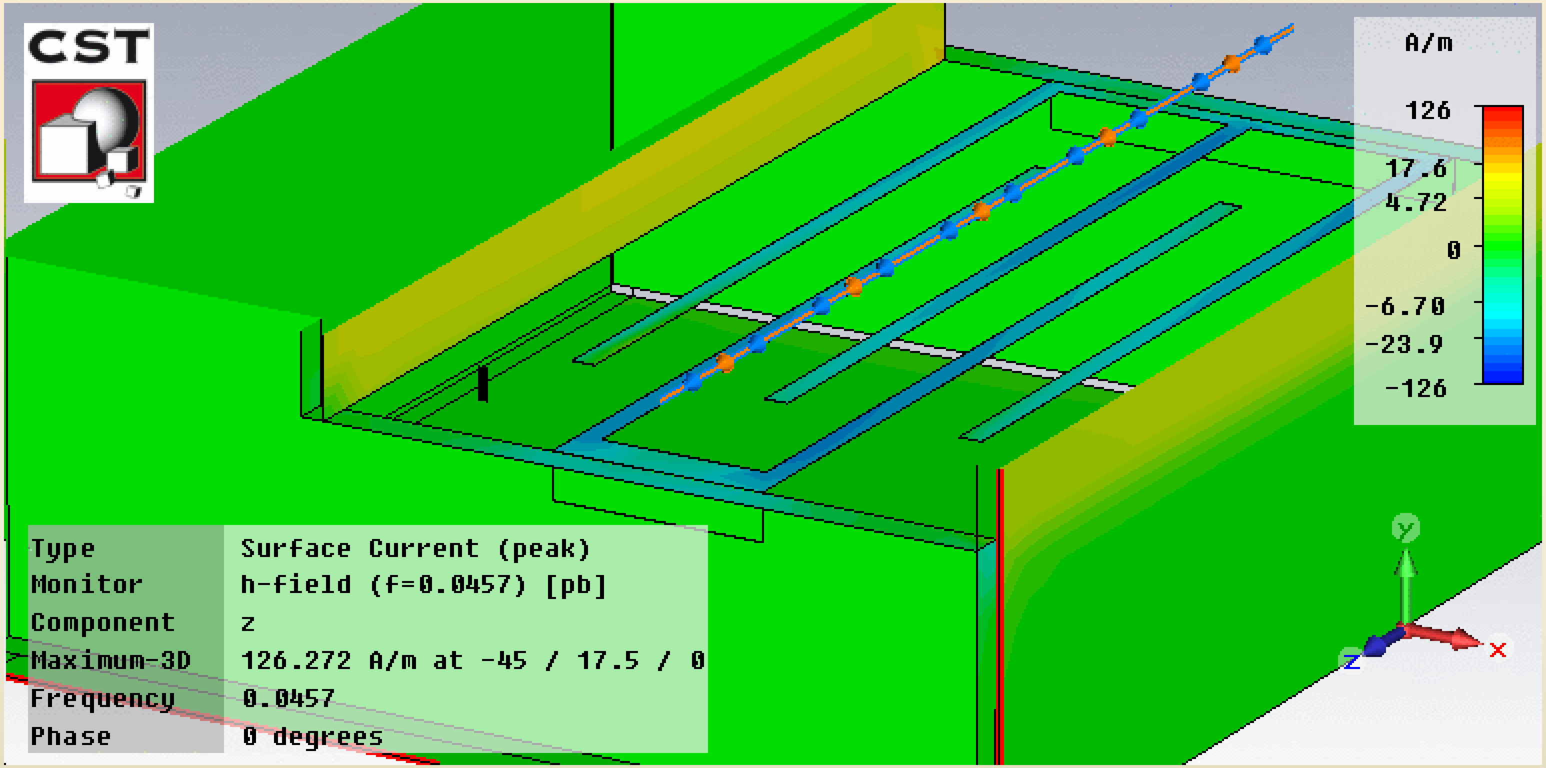
Comparing MKE with and without serigraphy



f=44 MHz

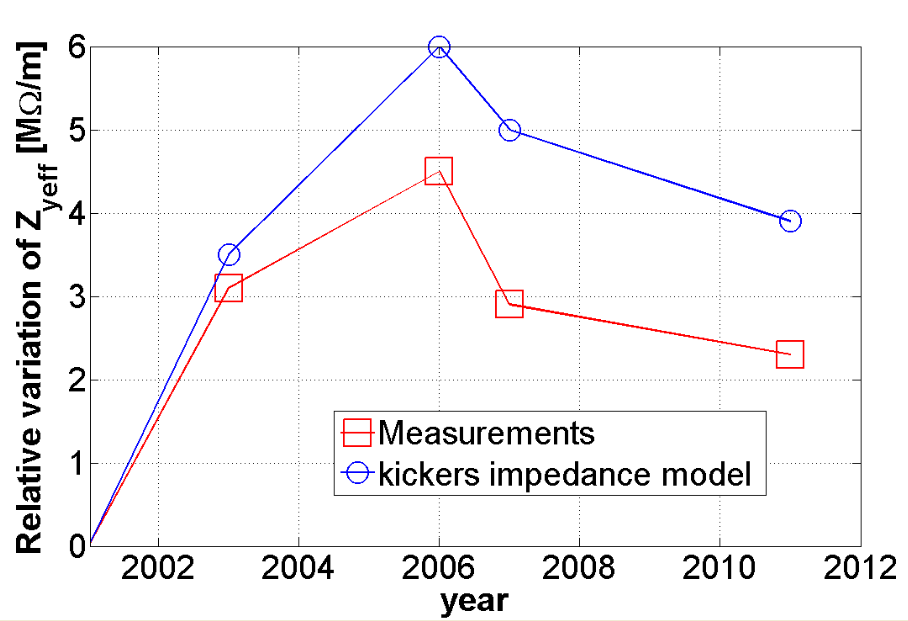
$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}\,\mu_{eff}}} \cong 0.78\,m \cong 4L_{finger}$$

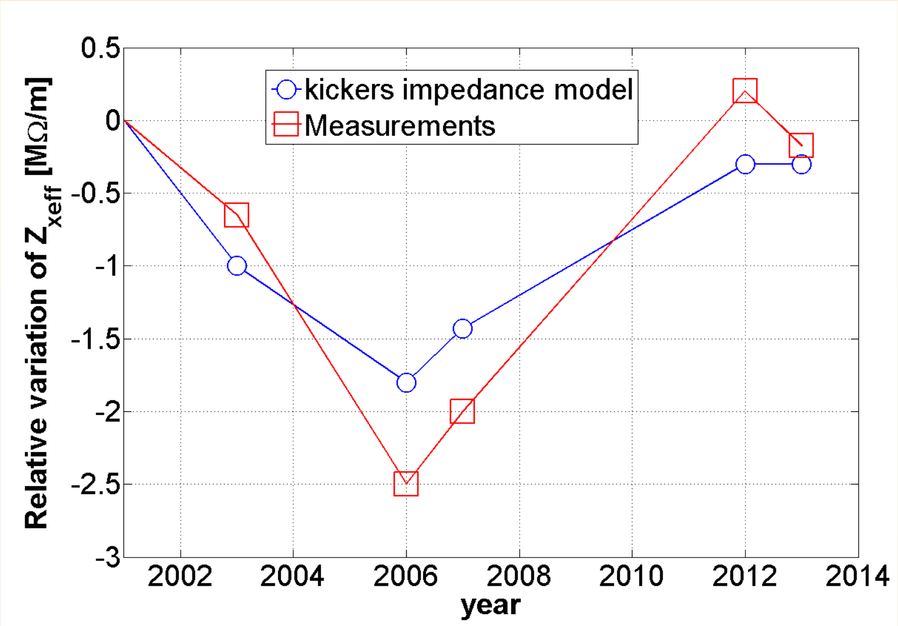
Comparing MKE with and without serigraphy



The peak observed in the MKE with serigraphy is a quarter-wavelength resonance on the finger length

History of the extraction kickers in the SPS





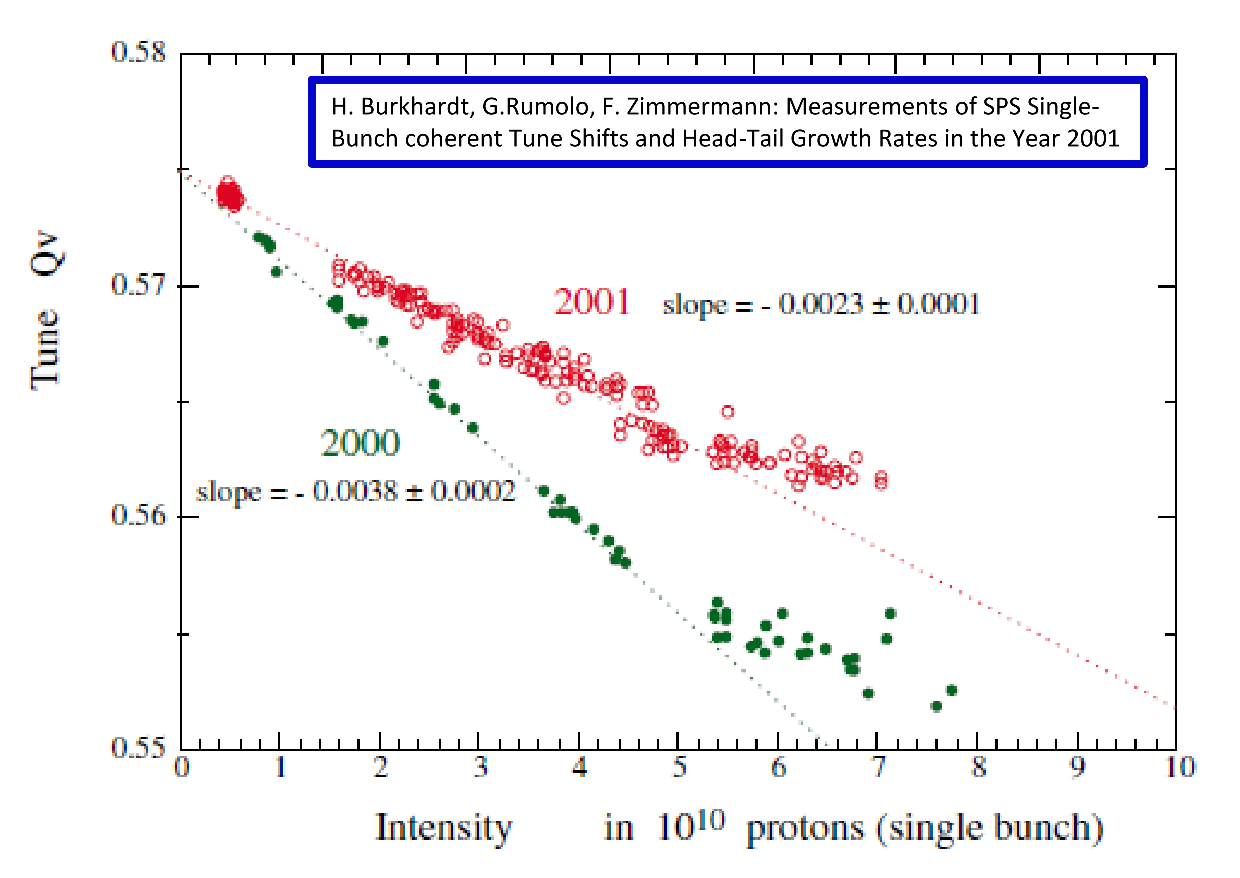
The trend of the transverse effective impedance along the last 10 years is in good agreement with the expected changing of the kicker impedance model

Kickers play a major role in the SPS total impedance

Pumping ports

2000 ⟶ Impedance reduction campaign: shielding of the pumping ports, lepton cavities etc.)

$$\Delta = Z_{2000}^{y_{eff}} - Z_{2001}^{y_{eff}} = 13.1\, M\Omega / m$$



The broadband impedance due to step transitions can give significant contribution to the coherent tune shift