Single bunch instabilities at DLS
Experimental and simulation studies

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Acknowledgements
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V. Smalyuk (BNL), K. Li (CERN)

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Collective effects

- Collective effects are important for the performance of an accelerator
- Its performance is usually limited by one collective effect
- Beam loss or degradation of beam quality can occur when the intensity is pushed above a certain threshold
- Small apertures of modern light sources

Single bunch instabilities

•Short-lived wakes affect the dynamics of a single bunch
•Coherent tune shift and bunch lengthening with increasing bunch current

Single bunch instability studies at DLS

Measurements

- Study of the transverse instability thresholds for
  - zero and positive chromaticity
  - different RF voltages
  - closed and open **I**nsertion **D**evices (**IDs**)
- Monitor the bunch lengthening with increasing current using the streak camera

Simulation

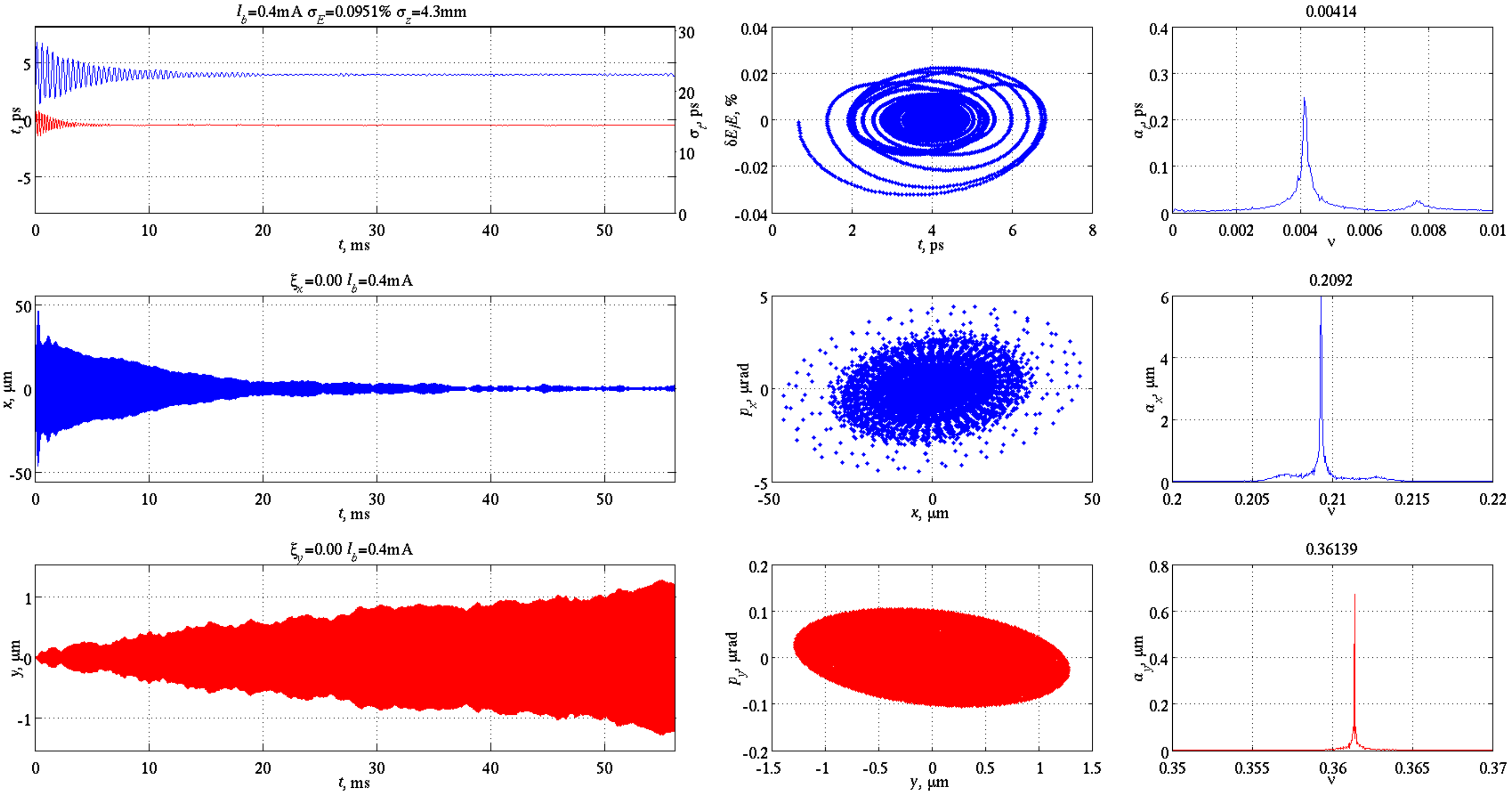
- Macro-particle tracking to reproduce the measured data
- Code development

Macro-particle simulation

- Measured single bunch instabilities are analysed using **sbtrack**
- Multi-particle 6-dimensional tracking code
- Originally written in C (R. Nagaoka)
- Matlab version available (J. Rowland)
- Collaboration between Diamond and SOLEIL on sbtrack/mbtrack codes
- Modifications in sbtrack@DLS:
  - ☐ Resistive-wall impedance (V. Smalyuk)
  - ☐ Non-linear maps (J. Rowland)
  - ☐ CSR, CSR with shielding (I. Martin)
  - ☐ THz radiation emission (R. Bartolini, J. Puntree)
  - ☐ arbitrary number of resonators (E. Koukovini-Platia)

sbtrack simulation examples ($\xi_{x,y}=0$)

Tracking with BBR and RW impedance model (radiation damping and quantum excitation also included)



Impedance model

- Diamond has a stainless steel vacuum chamber (2 mm thickness)
- Average half-apertures: width=40 mm, height=12 mm (13mm for open ID's)
- In-vacuum devices (copper coated) close down to 5 mm

→ Resistive wall impedance (RW)

- The geometric impedance of the ring is approximated by a single broad-band resonator, characterized by Q, R and ω_r

→ Broad-band resonator impedance (BBR)

$$Z_{\parallel}(\omega) = \frac{R}{1 + jQ\left(\frac{\omega}{\omega_R} - \frac{\omega_R}{\omega}\right)}$$

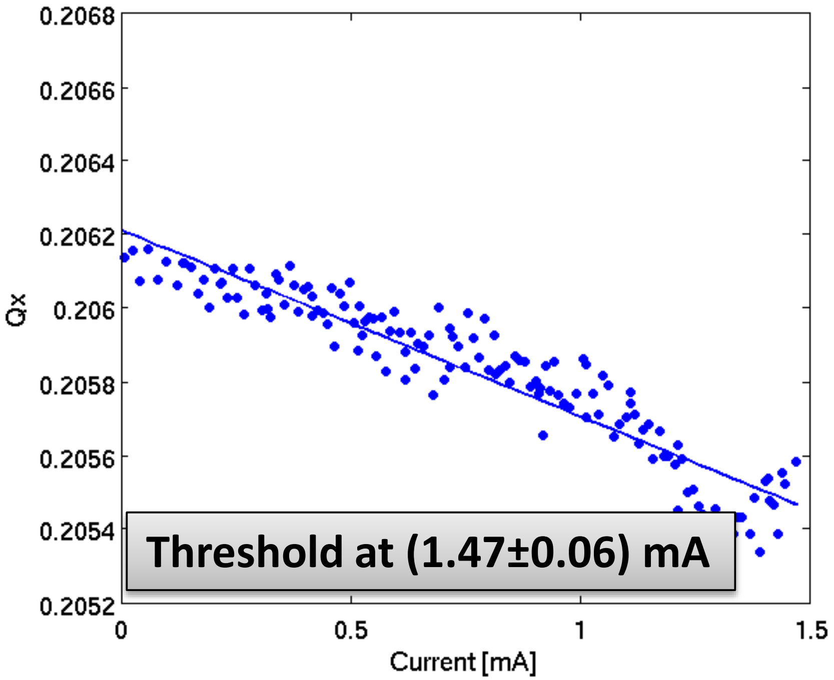
Diamond parameters

Energy (GeV)	3
Geom. emitt. x (nm.rad) (*)	2.66
Coupling (%)	0.3
Natural bunch length (mm) (*)	3.7
Momentum spread (*)	1.07×10^{-3}
Circumference (m)	561.6
Mom. compaction factor	1.6×10^{-4}
Tunes (x,y,s(*))	27.21/13.364/0.0042
Energy loss per turn (MeV) (*)	1.225
RF voltage (MV)	2.5
Average beta functions (x,y)(m)	10.65/12.84

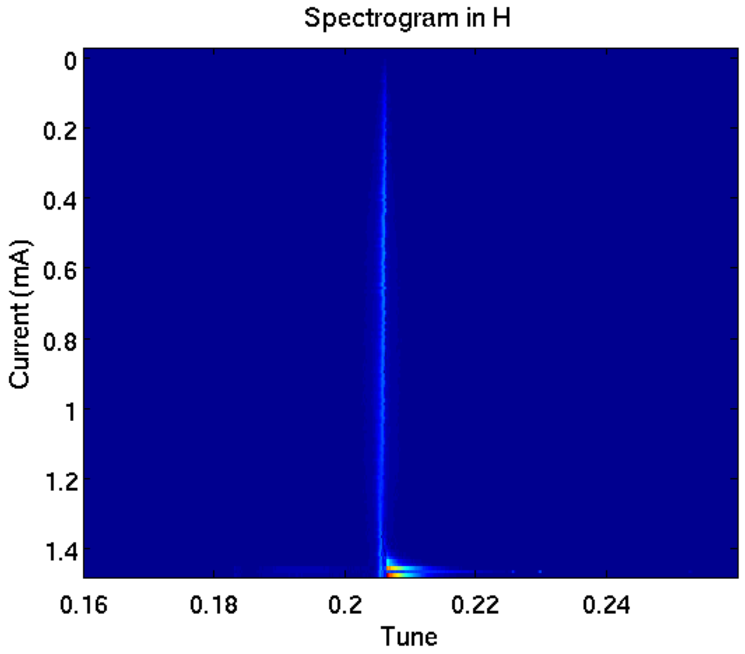
(*) values with wigglers on

Horizontal plane (Q’x=0, Q’y=3), V_{RF}=2.5 MV

- Excite the beam using the stripline kicker, part of the Transverse Multi-bunch Feedback system
- Measure the tune using the same system



Threshold at (1.47±0.06) mA



Simulation with sbtrack

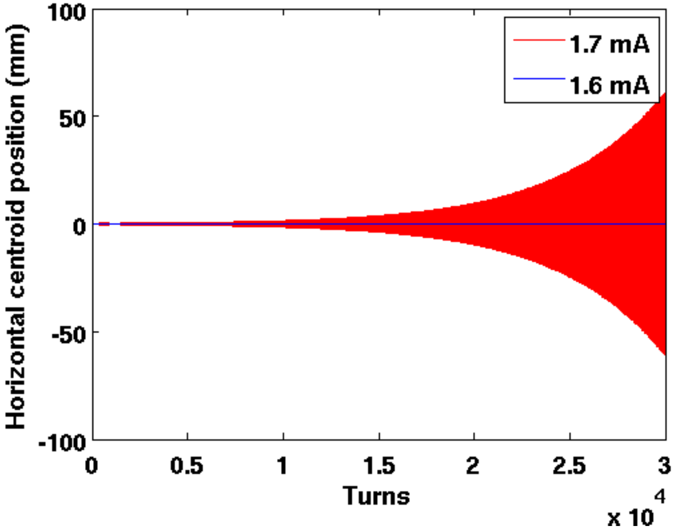
Horizontal impedance model

BBR impedance model in x plane:

$Q = 1$, $R = 0.10\ \mathrm{M\Omega/m}$, $f_r = 8.3\ \mathrm{GHz}$

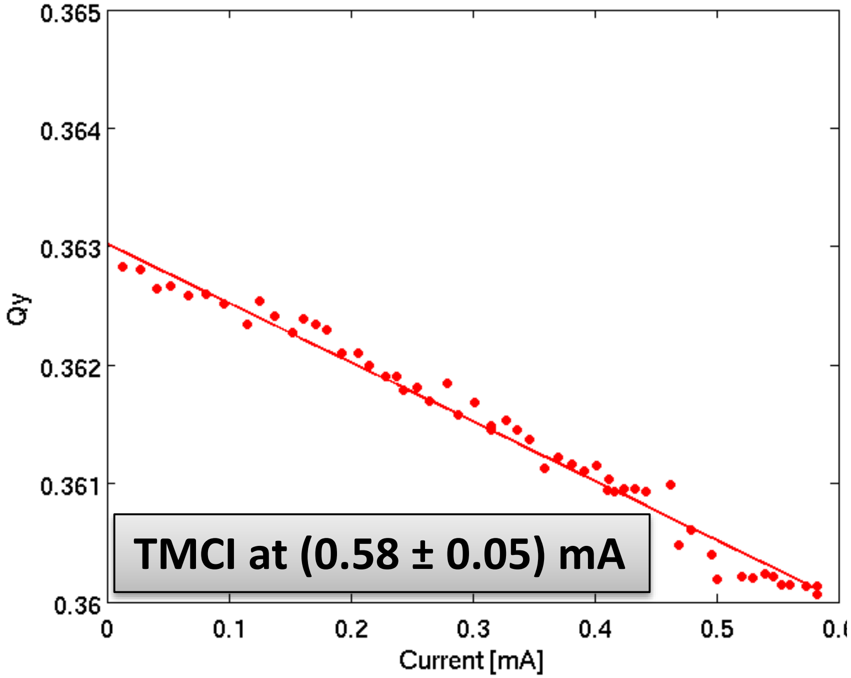
RW impedance with stainless steel chamber:

$\sigma_{StSt} = 1.37\times10^6\ \mathrm{S/m}$, a=40 mm, b=12.1 mm

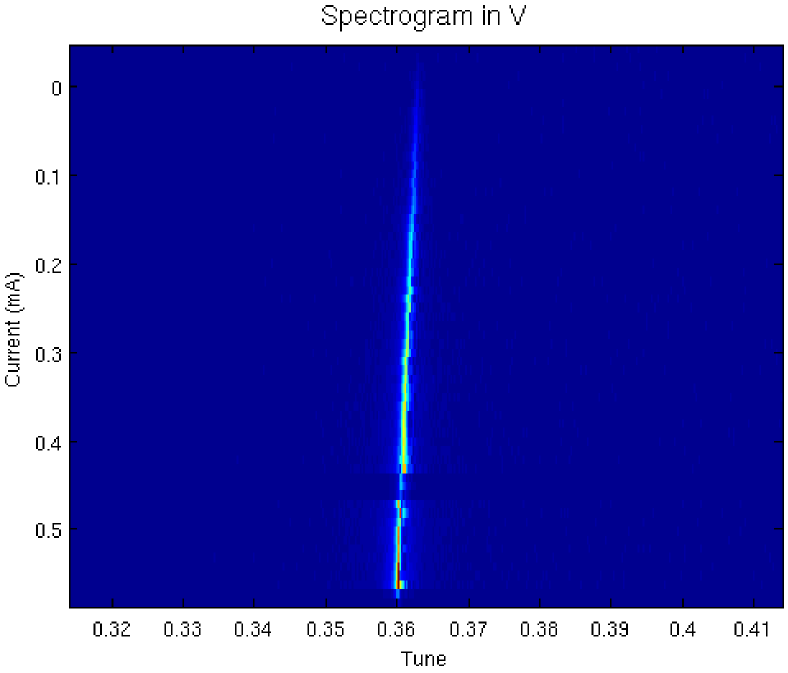


Measured TMCI threshold (1.47±0.06) mA
sbtrack: 1.6-1.7 mA

Vertical plane (Q’y=0, Q’x=3), V_{RF}=2.5 MV



TMCI at (0.58 ± 0.05) mA



Simulation with sbtrack

Vertical impedance model

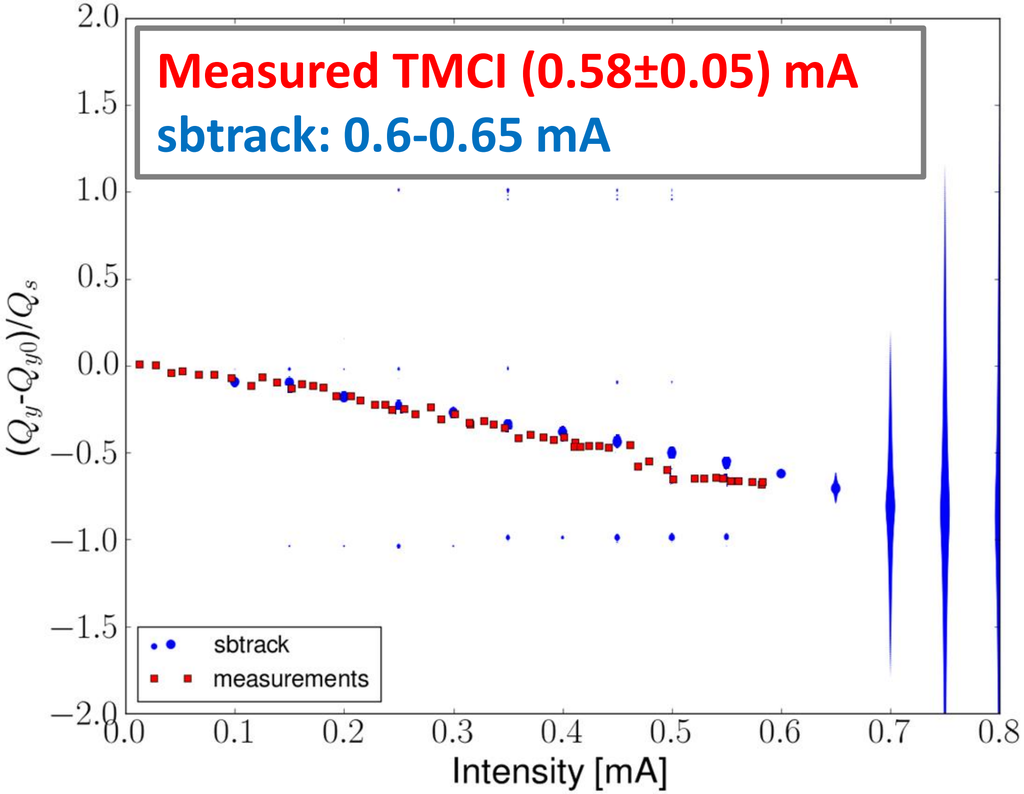
BBR impedance in y:

Q = 1, R = 0.25 MΩ/m,

f_r = 8.3 GHz

RW impedance:

σ_{StSt} =1.37x10^6 S/m, a=40 mm,
b = 12.1 mm (average half gap for closed ID's)



Measured TMCI (0.58±0.05) mA
sbtrack: 0.6-0.65 mA

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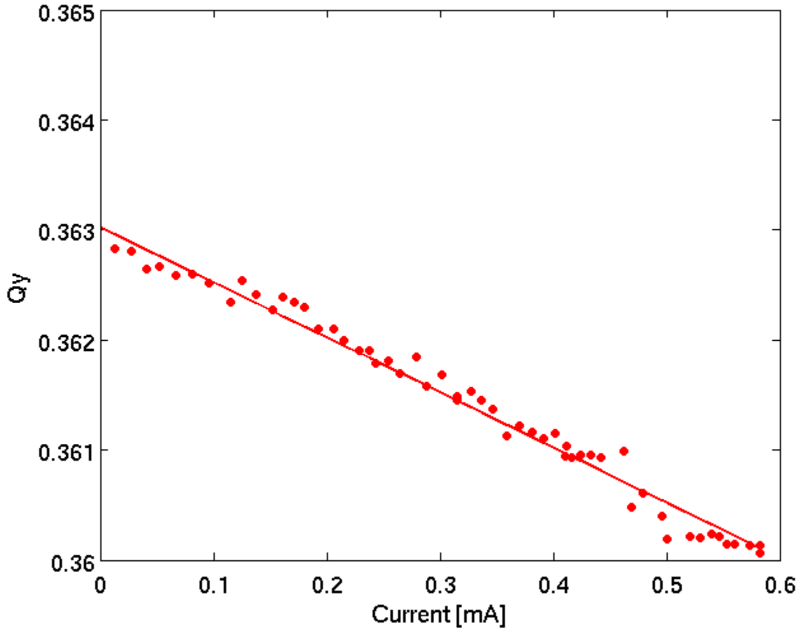
Imaginary effective vertical impedance

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

(for ξ=0 and l=0)



$$\boxed{Im(Z_{eff})=(334.2\pm0.5)\ k\Omega/m}$$

***** To be compared to the DLS impedance database – *in progress*

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Vertical threshold measurements for several V_{RF}

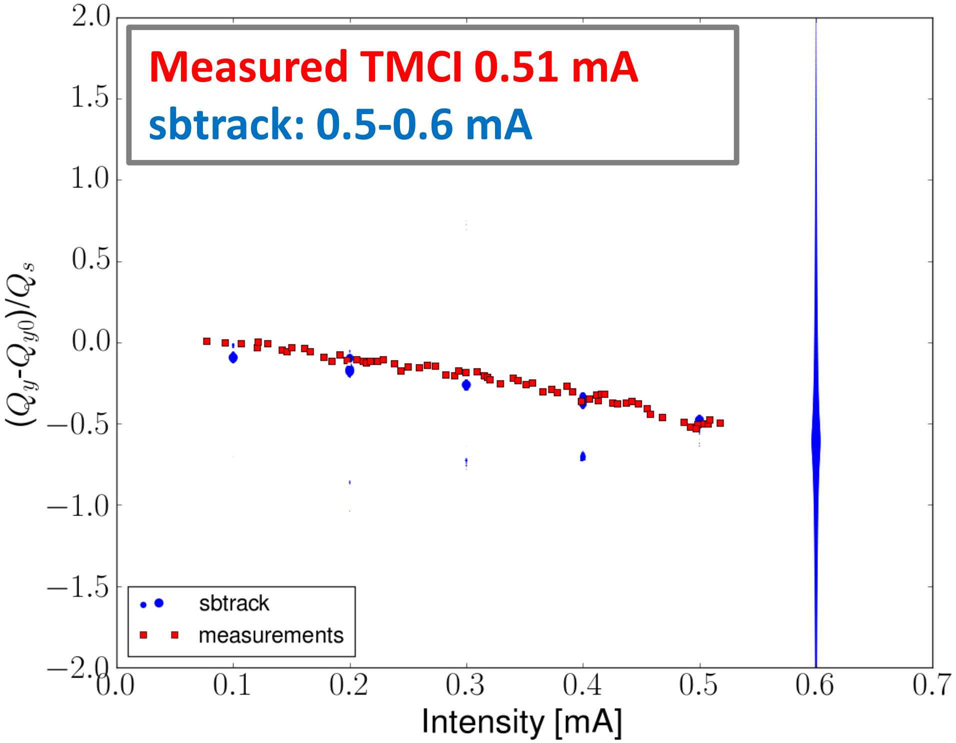
Lower RF voltage → lower synchrotron tune and a longer bunch length

- For lower RF voltage, the measured TMCI threshold is lower
- For higher RF voltage, the measured TMCI threshold is higher

RF voltage [MV]	**TMCI threshold in y [mA]**
1.7	0.51
2	0.54
2.5	**0.58**
2.8	0.61
3.4	0.64

Vertical plane (Q’y=0, Q’x=3)

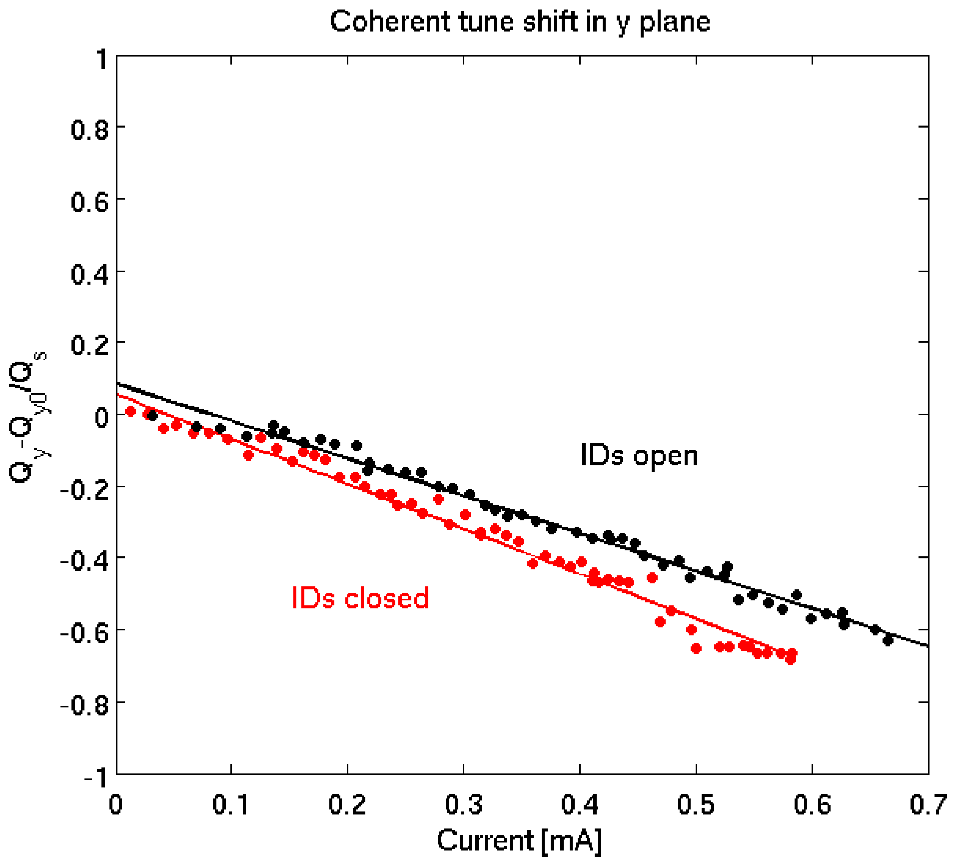
- Same impedance model: BBR: Q = 1, R = 0.25 MΩ/m, f_r = 8.3 GHz and RW: σ_{StSt} =1.37x10^6 S/m, a=40 mm, b = 12.1 mm
- V_{RF}=1.7 MV



Measured TMCI 0.51 mA

sbtrack: 0.5-0.6 mA

Effect of closed and open IDs in the vertical plane



TMCI threshold for **closed** IDs (gap 5 mm): **0.58 mA**

TMCI threshold for **open** IDs (gap 30 mm): **0.74 mA**

Simulation with sbtrack for open IDs

BBR impedance in y

Q = 1, R = 0.25 MΩ/m,

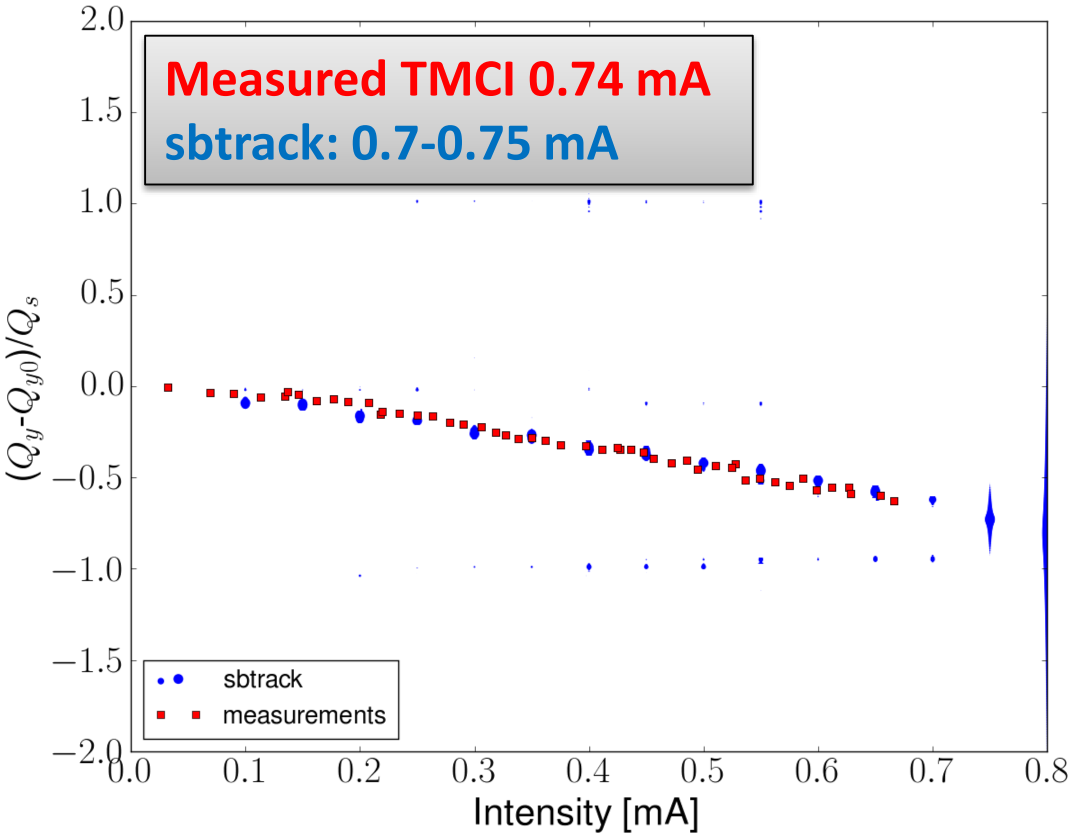
f_r = 8.3 GHz

RW impedance

σ_{StSt} =1.37x10^6 S/m,

a=40 mm, b=13 mm

The effect of open ID's at DLS is sufficiently explained by resistive wall impedance

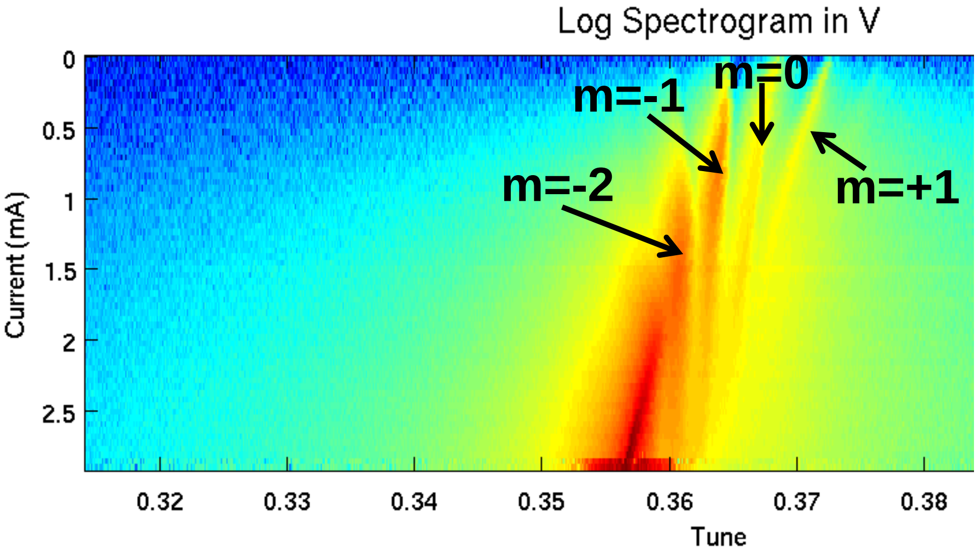


Measured TMCI 0.74 mA

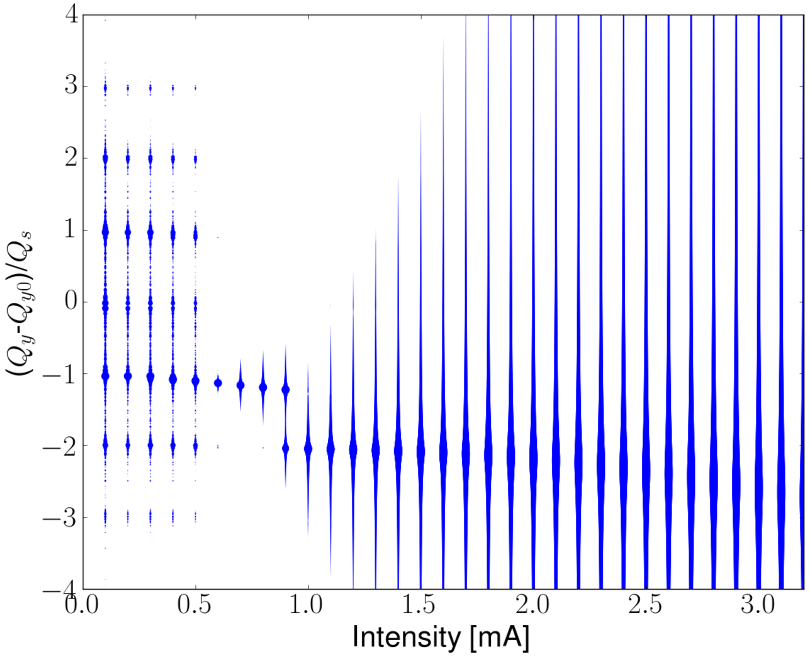
sbtrack: 0.7-0.75 mA

Head-tail instability with Q’y=3.5 (Q’x=3)

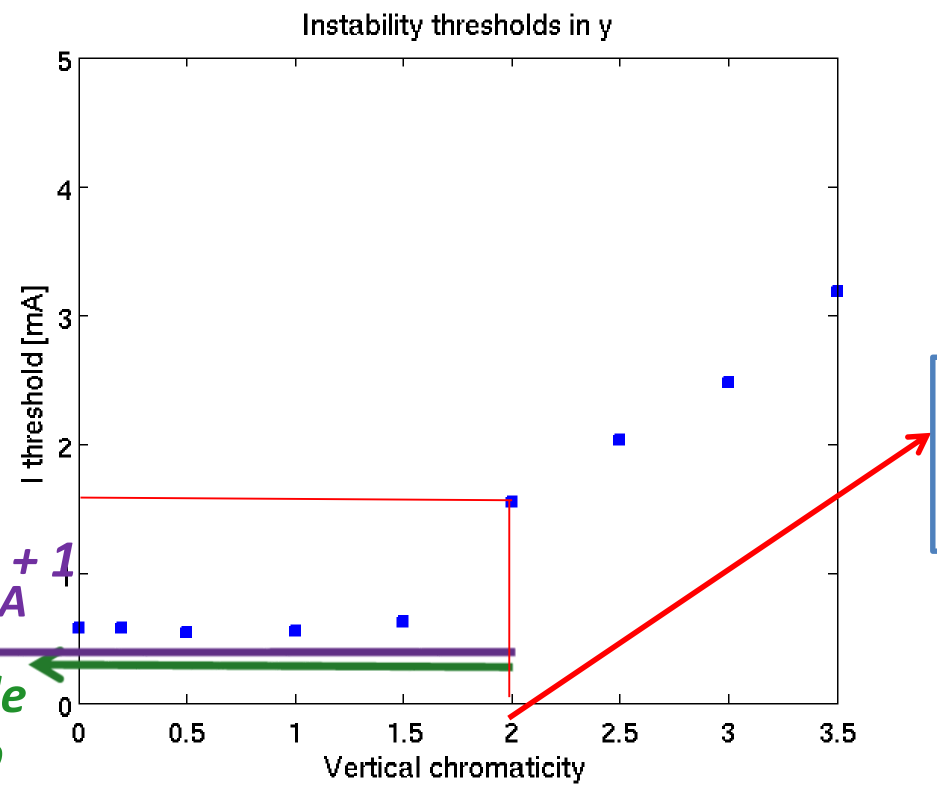
Measurements



sbtrack



Summary of thresholds in the vertical plane (closed ID’s)



3.8%: 686 bunch mode + 1

0.43 mA/b + 1.6 mA

74.7%: 900 bunch mode

0.33 mA/b

Machine usually operates with Q’x,Q’y=2

- We need sufficiently high positive chromaticity to relax the intensity limitation

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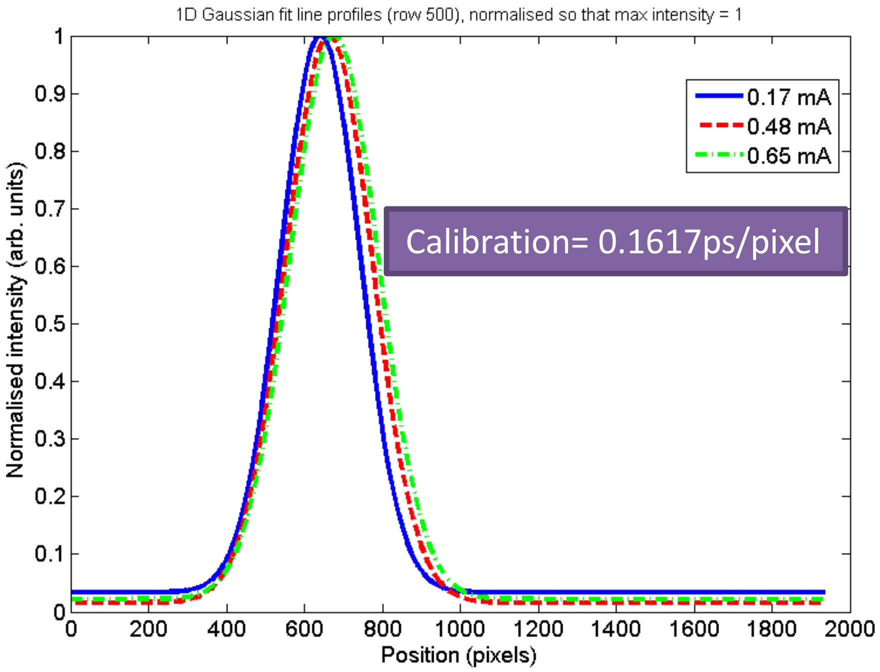
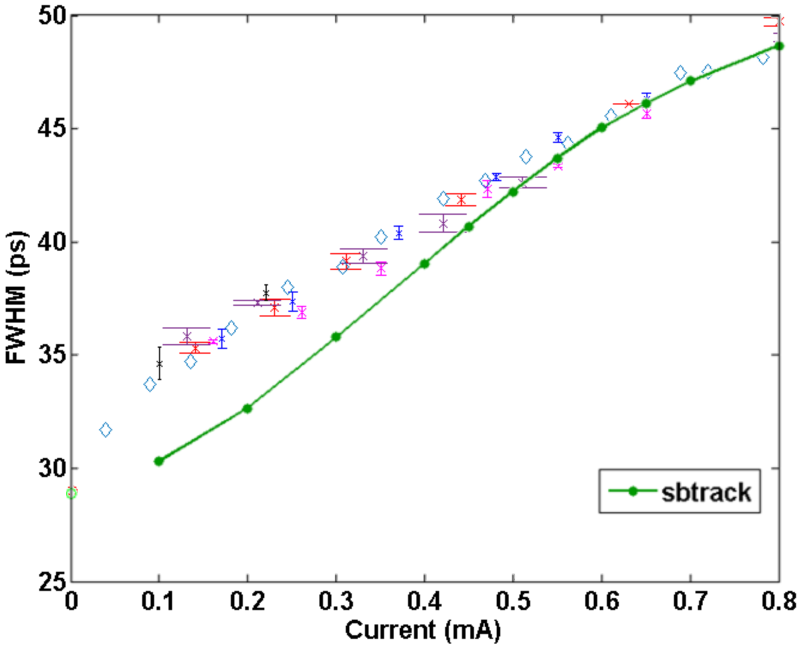
Bunch lengthening measurements

- The bunch profile is measured using a streak camera
- V_{RF}=2.5 MV
- Longitudinal BBR parameters: Q=1, f=22 GHz, R=8 kΩ (V. Smalyuk)



Calibration= 0.1617ps/pixel

work in progress



Courtesy L. Bobb

Summary

- As a first approximation, an impedance model consisting of a BBR and RW impedance is found to match well the transverse measured tune shift and the bunch lengthening for
  - zero/positive chromaticity
  - different RF voltages
  - closed and open ID’s

Work in progress

- Fit several broad-band resonators to the calculated total transverse and longitudinal impedance (DLS impedance database from CST, analytical formulas etc)
- Macro-particle tracking with several broad-band resonators → compare simulation with measurements
- Comparison of measurements with simulation for ultra-low alpha operation

Thank you for your attention!