TMCI in the SPS Q22 optics

Mario Beck – HSC section meeting - 26 February 2017

Thanks to: Hannes Bartosik, Kevin Li, Giovanni Rumolo, Michael Schenk,
The injectors operator teams

Introduction I

- Transverse Mode Coupling Instability (TMCI) is a single bunch instability caused by the transverse wake field.
- Theoretically the TMCI threshold can be described as seen below [1]:

$$N_{thr}^{TMC} = \frac{16\sqrt{2}}{3\pi} \frac{R|\eta|\varepsilon_z}{\beta_y e \beta^2 c} \frac{\omega_r}{|Z_y^{BB}|} \left(1 + \frac{Q'_y \omega_0}{\eta \omega_r}\right)$$

R : machine circumference
ε_z : longitudinal emittance
Q'_y : vertical chromaticity
η : slippage factor
$|Z_y^{BB}|$: Impedance of broad band resonator model
ω_r : resonance frequency of broad band resonator model
ω_0 : revolution frequency of the machine
β_y : betatron function of the machine

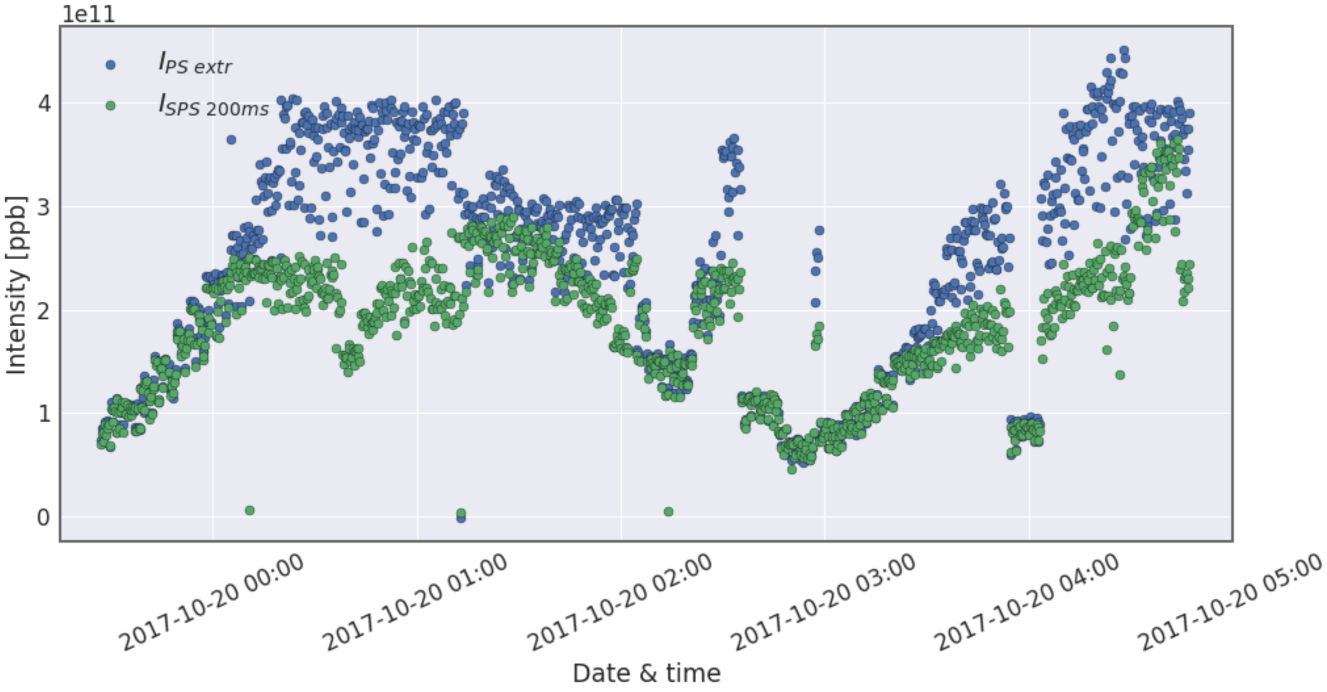
[1] H. Bartosik - Beam dynamics and optics studies for the LHC injectors upgrade

Introduction II

- The influence of the variable factors of the intensity threshold will be investigated.
- TMCI has been measured in the SPS in Q20 and Q26 optics before [1].
- Now the TMCI measurements in the SPS Q22 optics.
- TMCI represents an intensity limitation and is thus a potential issue for the LIU.

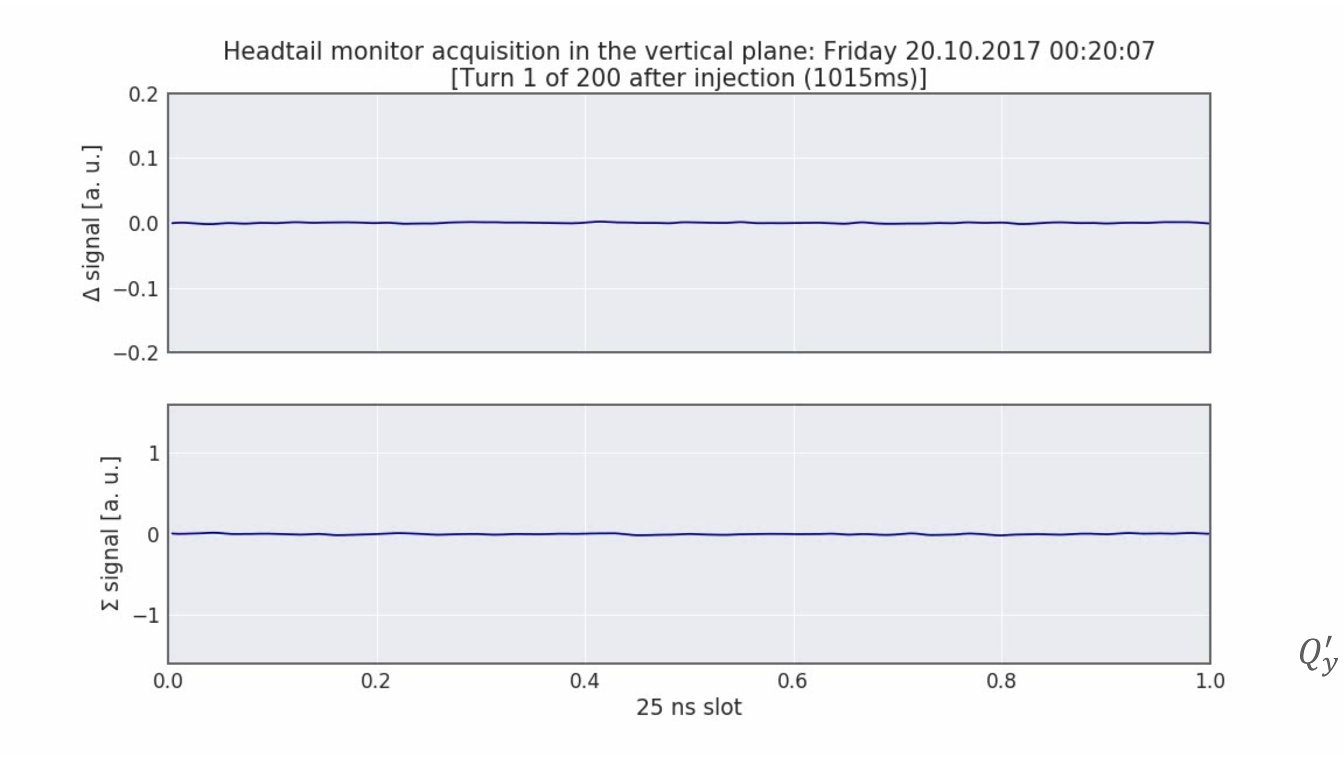
Overview over MD

- TMCI MD the 19th to 20th of October 2017.
- We observe high losses in the SPS.



Pattern of the losses

- But are the losses we see due to TMCI?

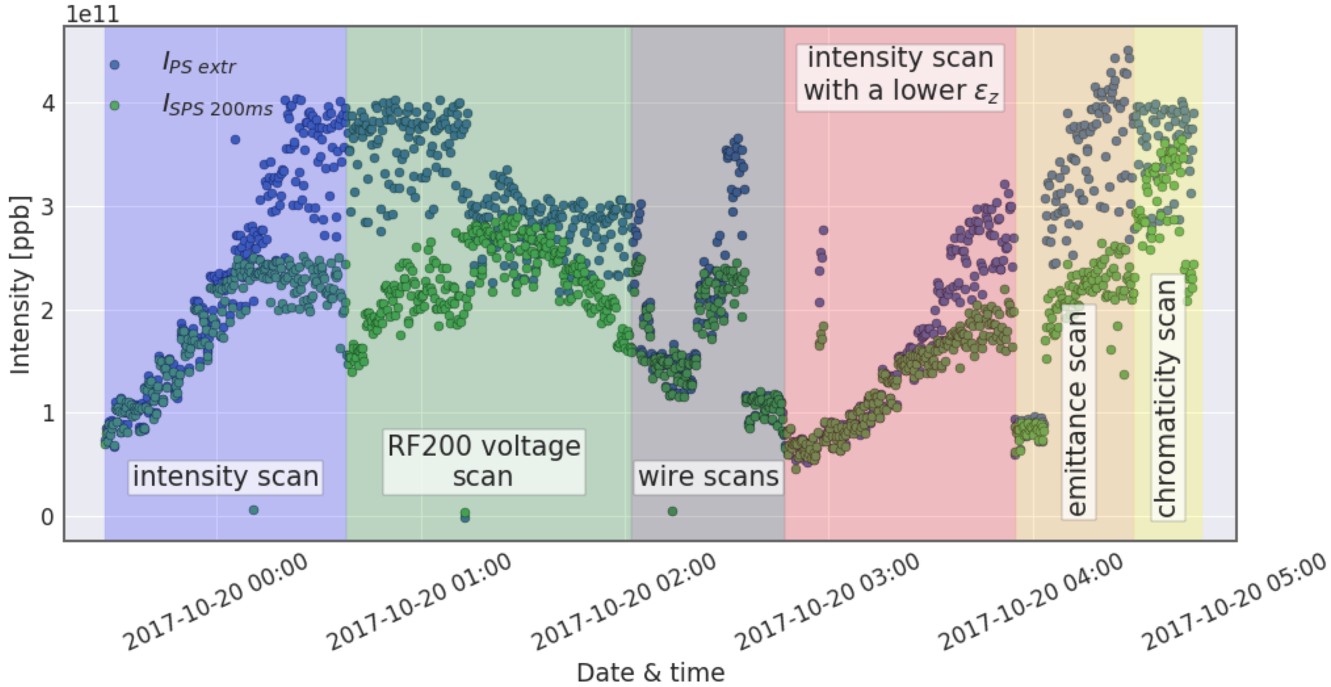


$Q'_y \sim 0.7$

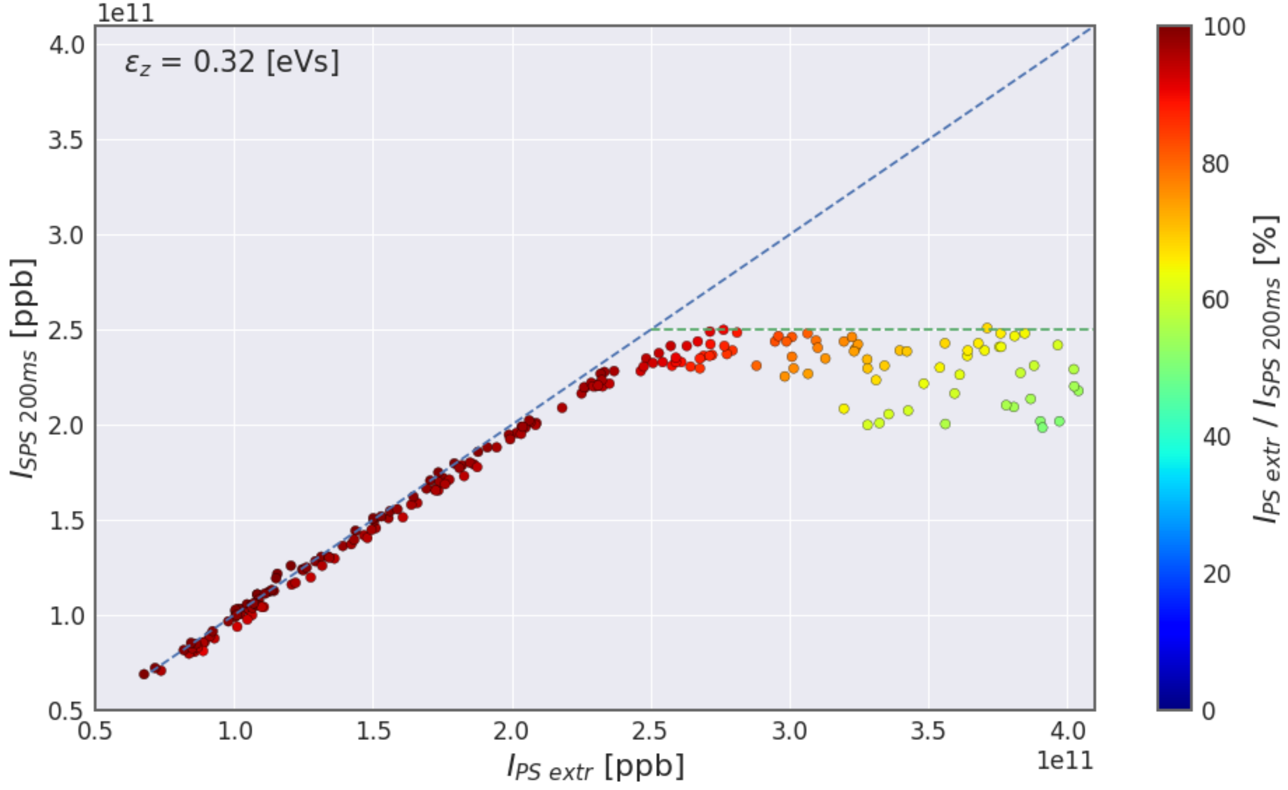
YES! => we observe the traveling wave pattern typical for TMCI.

Overview over MD II

- To see effects of different parameters on the TMCI threshold, scans were done.



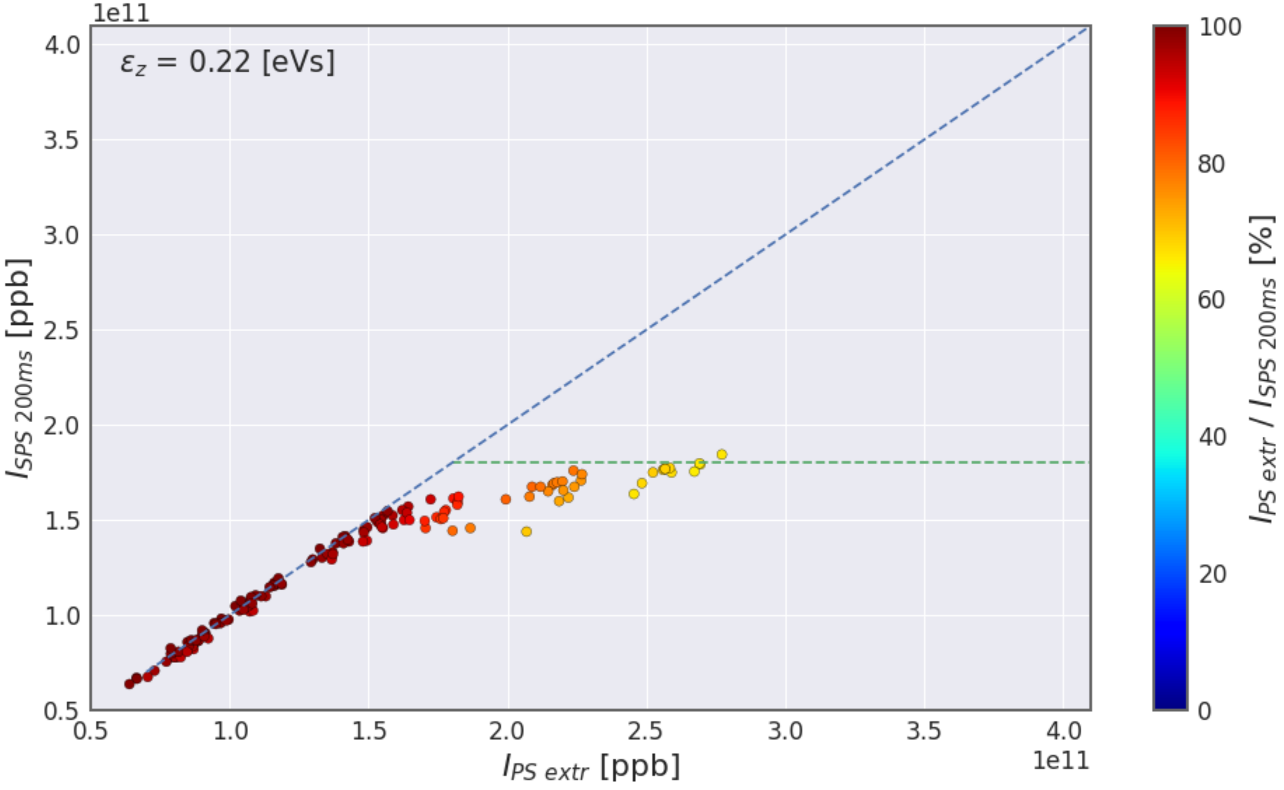
Intensity scan I



RF200 at 2.7 MV
Q'_y ~ 0.7
ε_z ~ 0.32 [eVs]

$\Rightarrow$ We observed a TMCI threshold of 2.5e11 ppb in the SPS.

Intensity scan II (smaller ε_z)



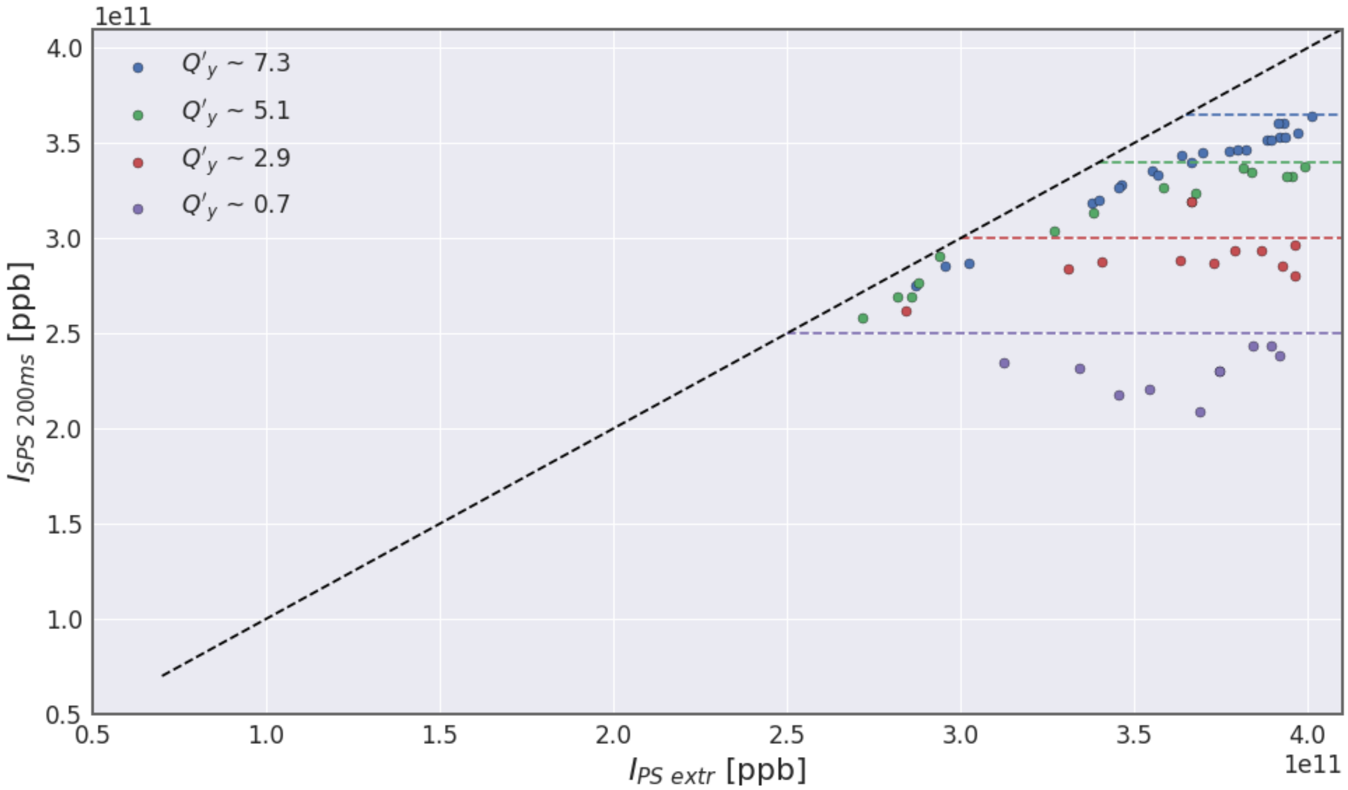
RF200 at 2.7 MV

Q'_y ~ 0.7

ε_z ~ 0.22 [eVs]

$\Rightarrow$ We observed a lower TMCI threshold of 1.8e11 ppb as expected.

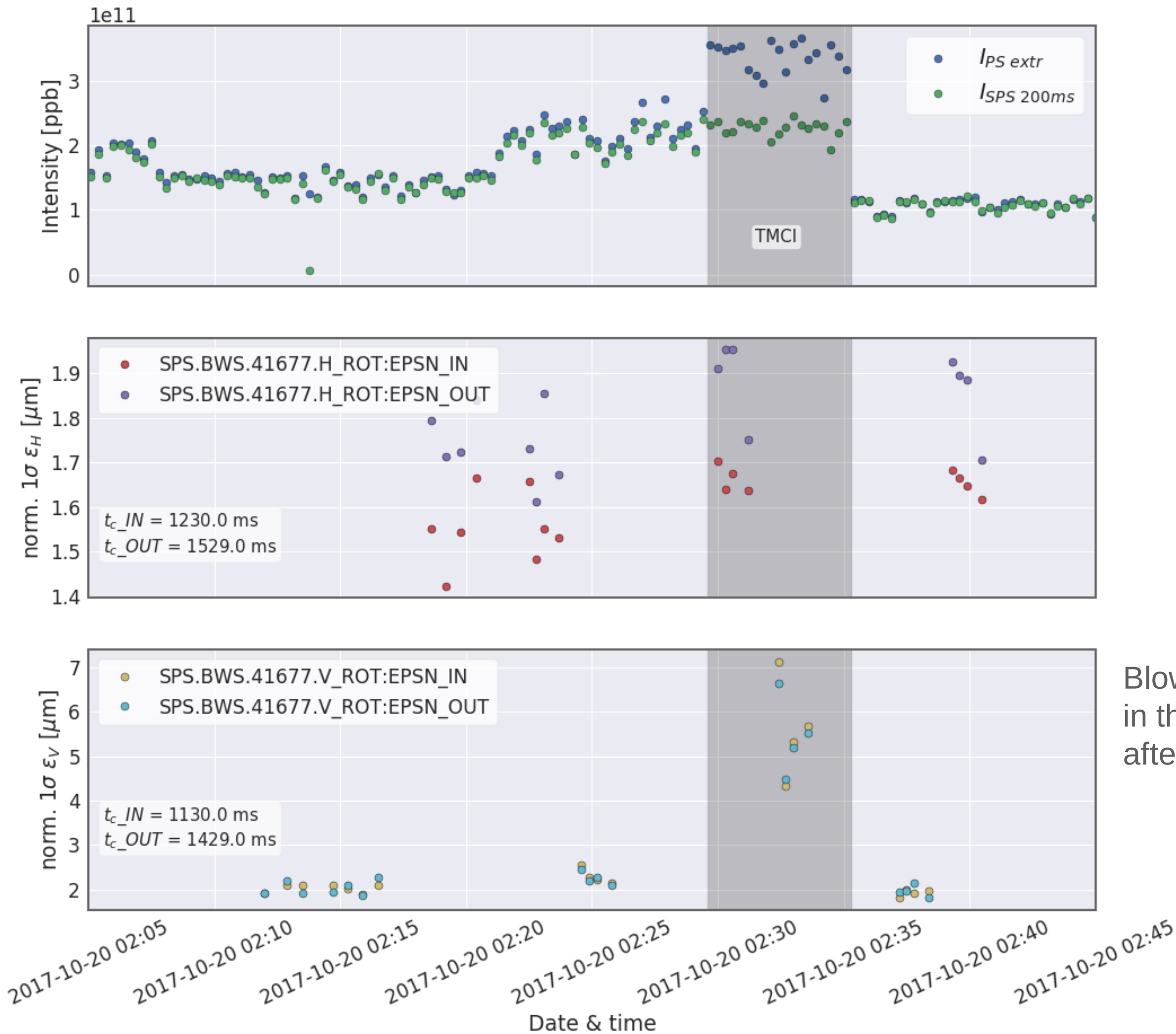
Chromaticity scan



ε_z ~ 0.32 [eVs]
RF200 at 2.7 MV

$\Rightarrow$ As expected; higher chromaticity leads to a higher TMCI threshold.

Wire scans



Blown up emittance in the vertical plane after TMCI

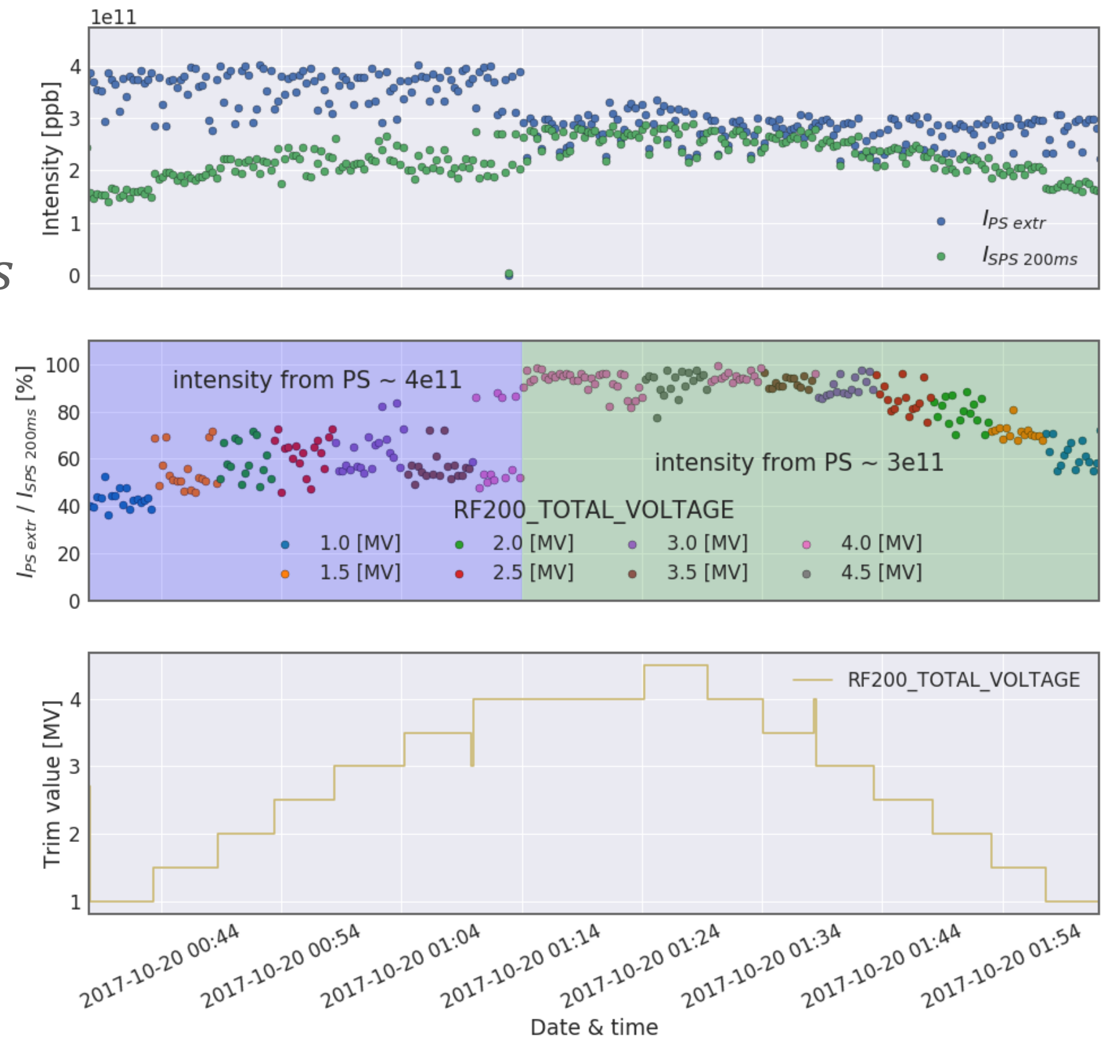
RF200 voltage scan I

ε_z ~ 0.32 [eVs]
Q'_y ~ 0.7

- As the TMCI threshold also depends on Q_s we changed the RF200 voltage [3].

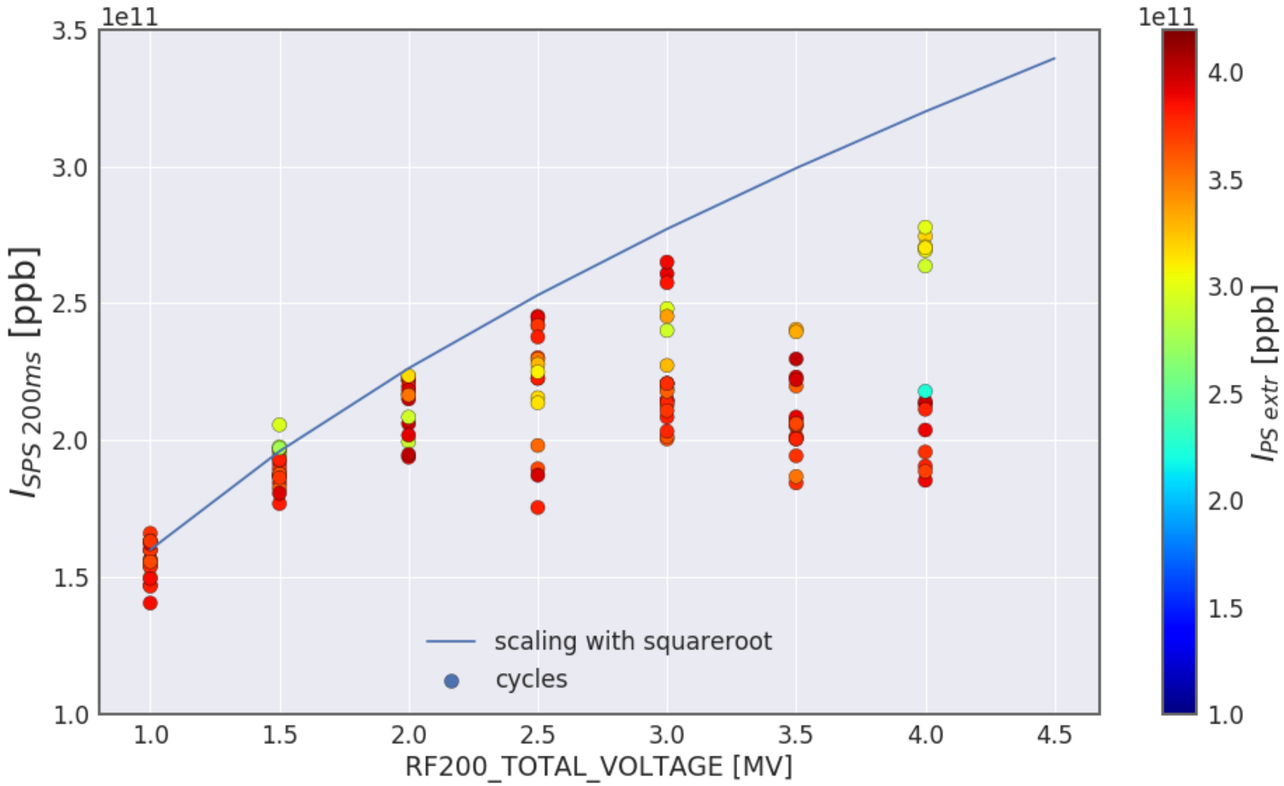
$$Q_s = \frac{\omega_s}{\omega_0} = \sqrt{\frac{eV\eta h}{2\pi E_0 \beta^2}}$$

Q_s: synchrotron tune
V : RF voltage
E_0: reference energy



[3] K. Li – USPAS longitudinal beam dynamics - 2015

RF200 voltage scan II



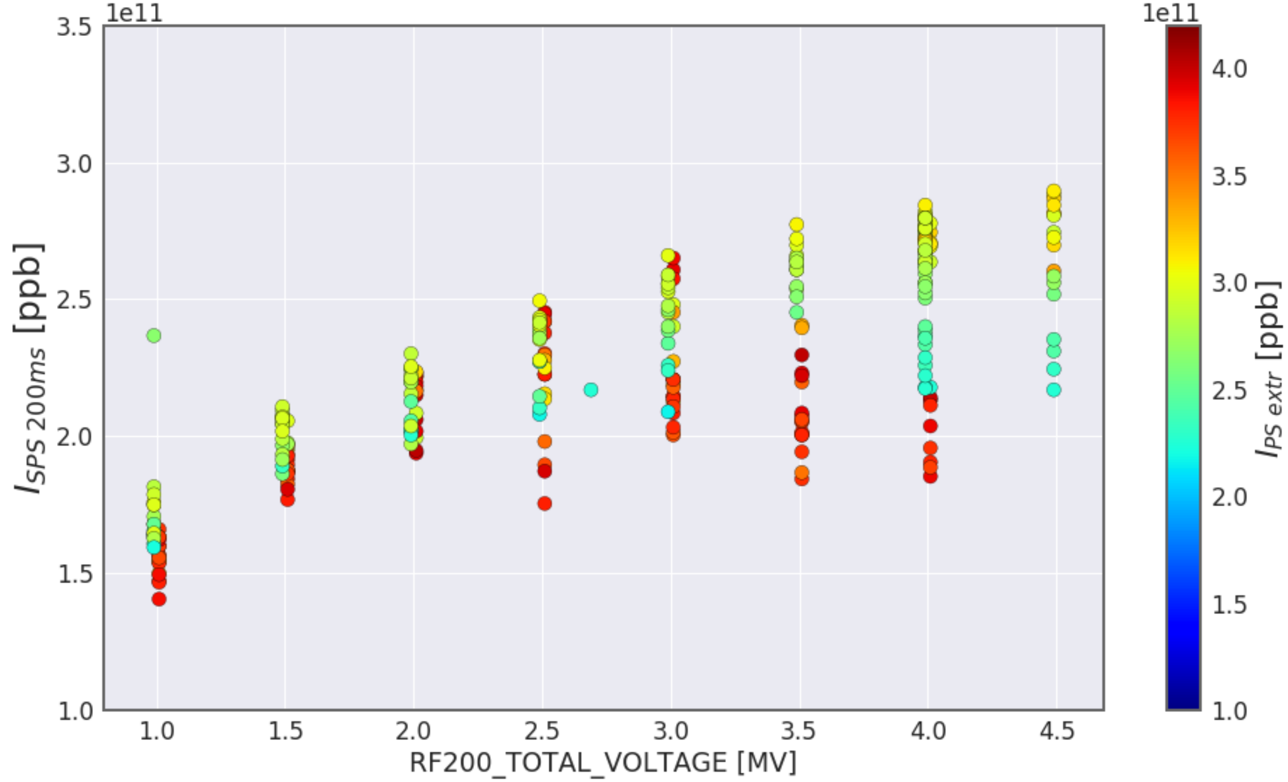
$$Q_s = \frac{\omega_s}{\omega_0} = \sqrt{\frac{eV\eta h}{2\pi E_0 \beta^2}}$$

Q_s: synchrotron tune
V : RF voltage
E_0: reference energy

Q'_y ~ 0.7
ε_z ~ 0.32 [eVs]

$\Rightarrow$ The intensity scales as expected with $\sqrt{V}$ (until losses take over)

RF200 voltage scan III



Q'_y ~ 0.7

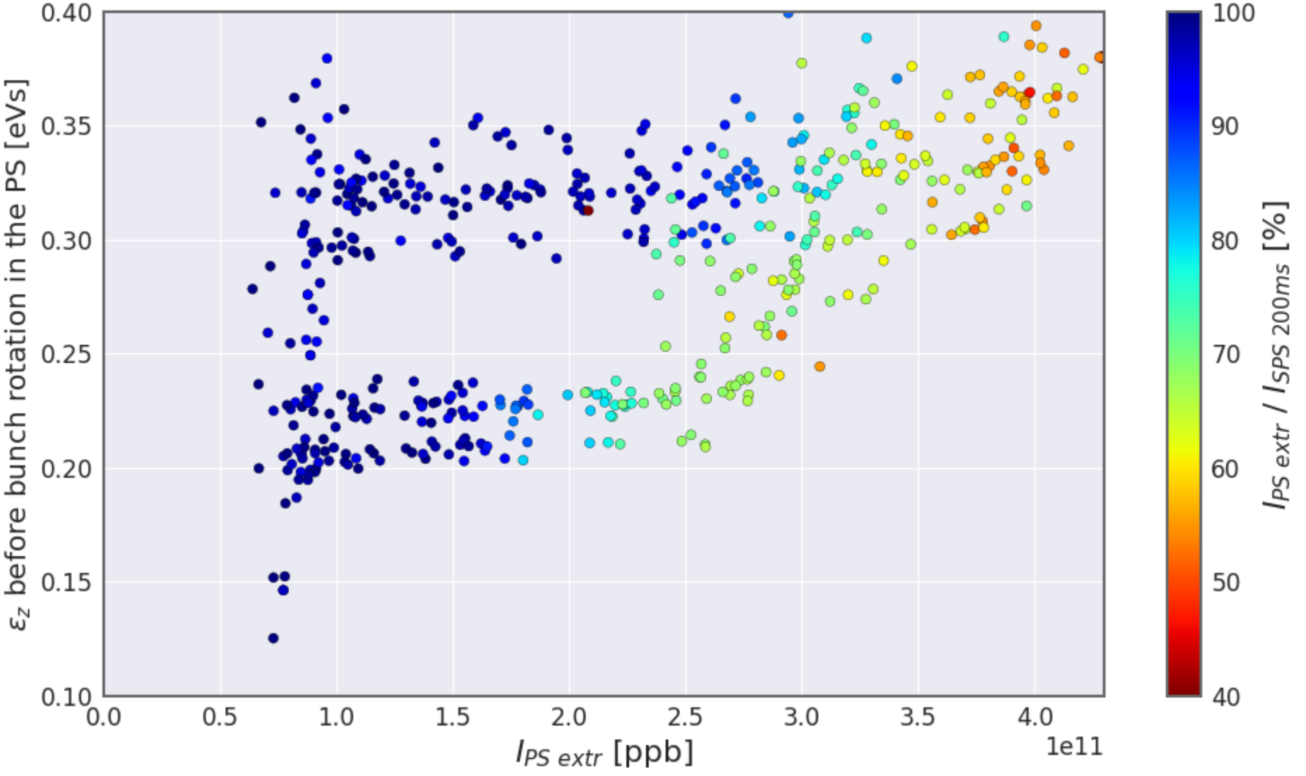
ε_z ~ 0.32 [eVs]

⇒ Injecting less intensity seems to avoid the fast TMCI losses.

⇒ The threshold seems to be further approached.

⇒ But is the beam blown up?

Emittance vs. intensity scan

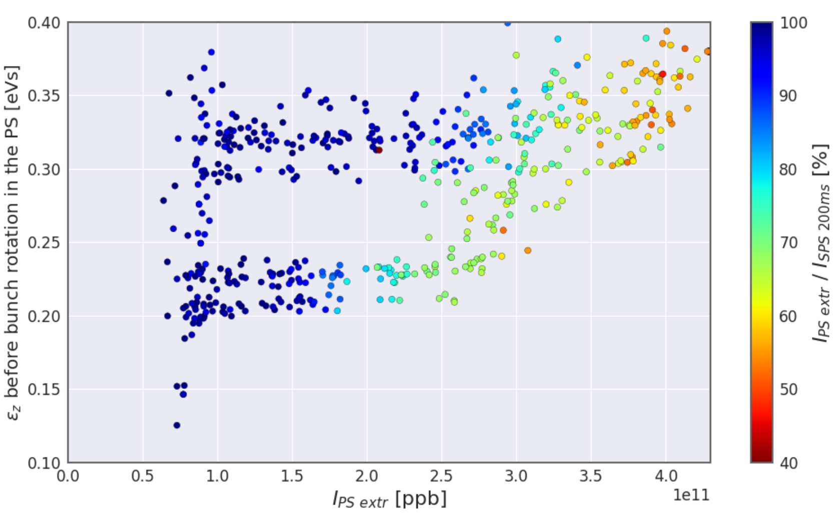


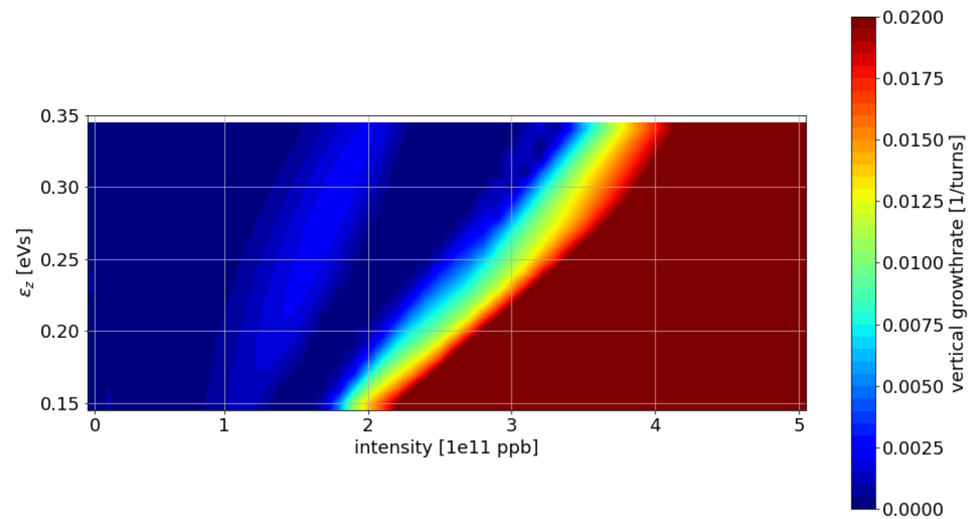
RF200 at 2.7 MV
$Q'_y \sim 0.7$

$\Rightarrow$ The dependency on intensity and longitudinal emittance are clearly observed.

Compare to Simulations

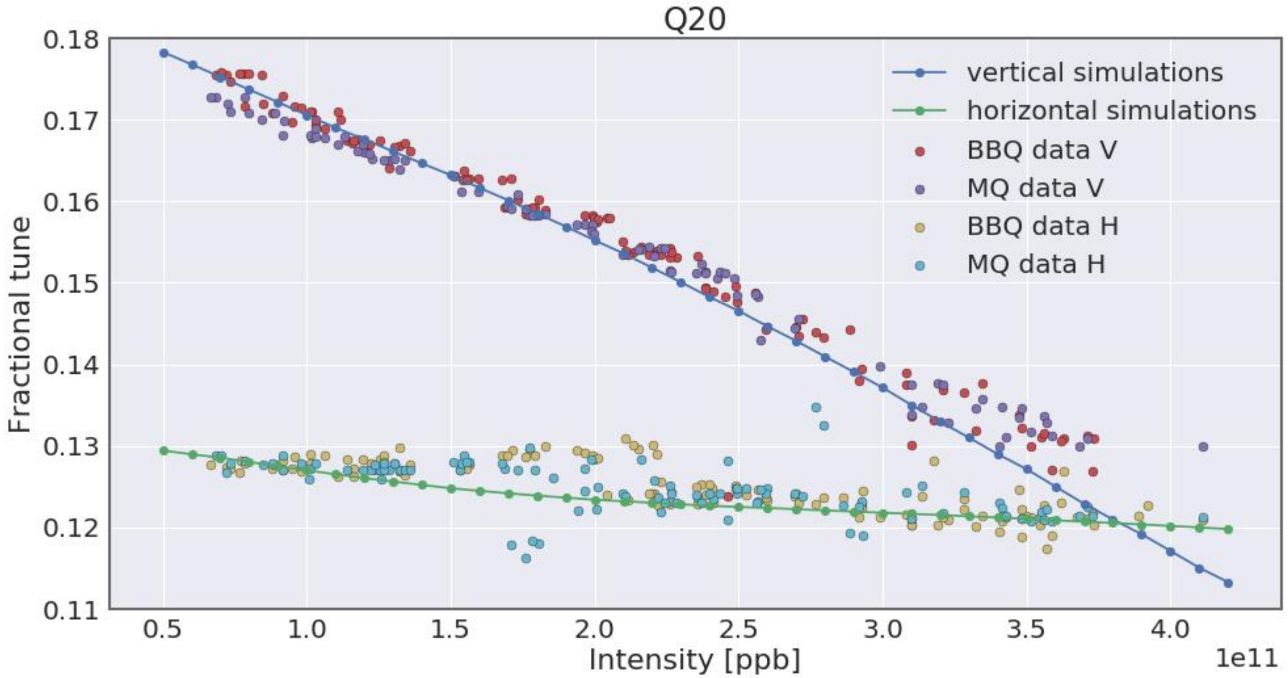
- As no turn by turn data of the first turns is available, the growth rate of the measured data is represented by the losses from PS to SPS.
- PyHEADTAIL was used for the simulations.





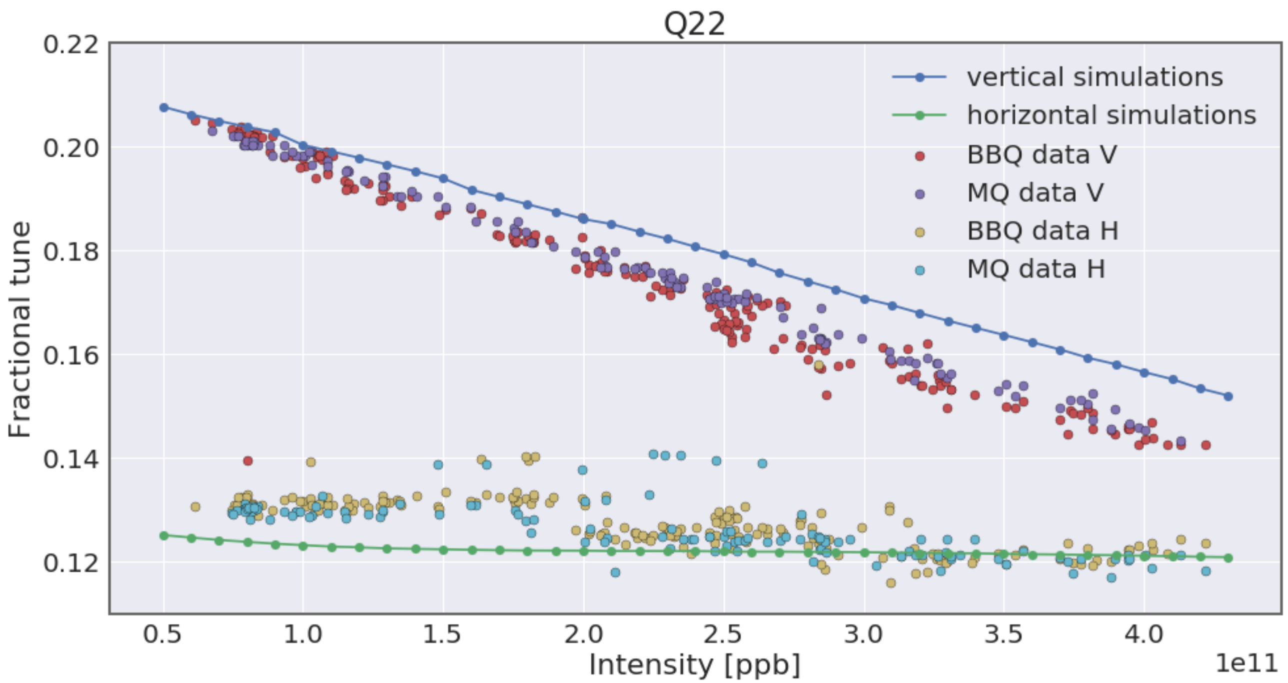
Tune vs. intensity scan in Q20

- In Q20 the simulated results are in agreement with the measurements



Tune vs. intensity scan in Q22

- In Q22 there is a bigger difference between simulations and measurements
- Problem with measurement or simiulations?



Conclusion

- The TMCI has been observed an investigated during measurements in the Q22 optics.
- The theoretical dependencies have been shown in measurements.
- A good setup of the machines can lead to a TMCI threshold which might just be sufficient for LIU.

Outlook

- Investigation of the Q22 SPS impedance model. How can the difference be explained?
- Investigate if the higher intensities in the machine with lower PS injection are blown up.
- Test the effect of the damper and the transverse wideband feedback on LIU intensity TMCI [2].

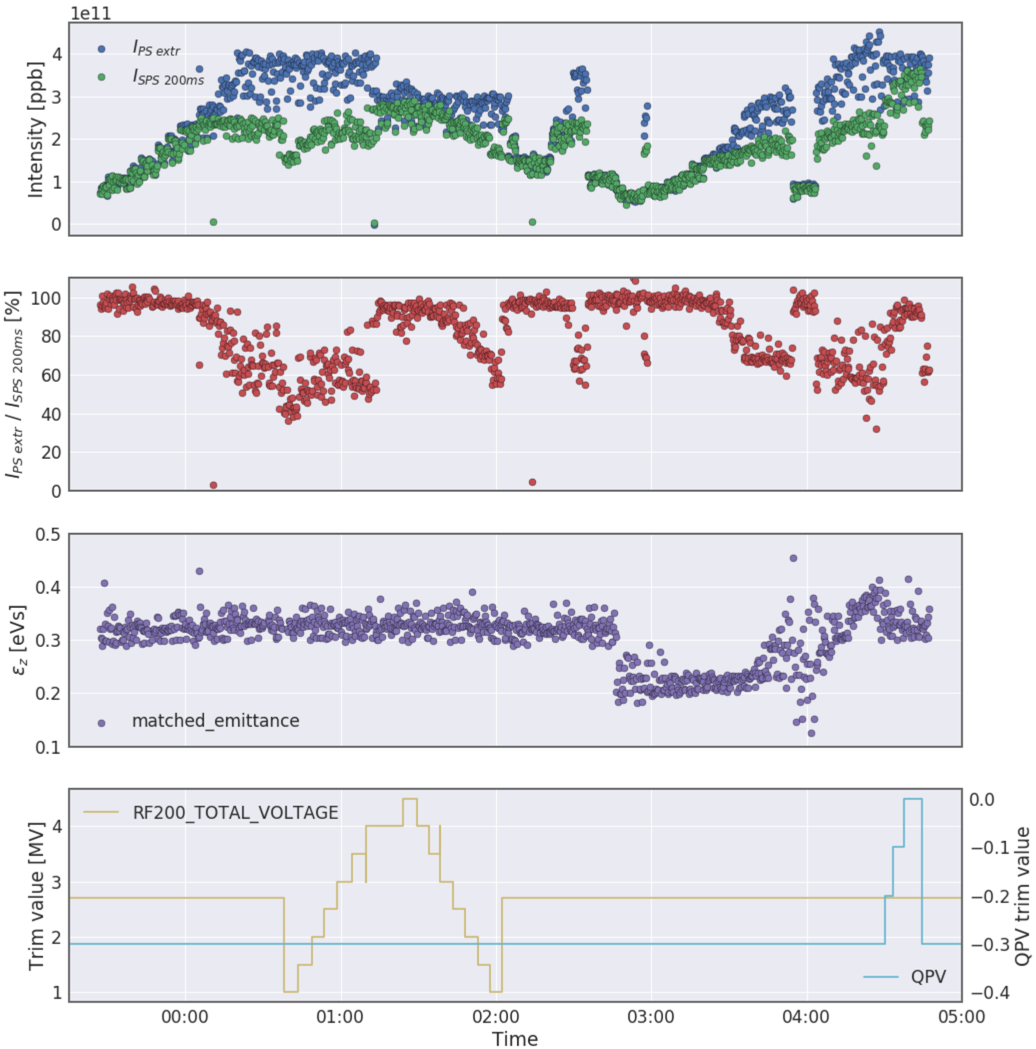
[2] K. Li - SPS TMCI with the Q22 optics – HSC section meeting – 27.11.2017

Thank you for your attention!

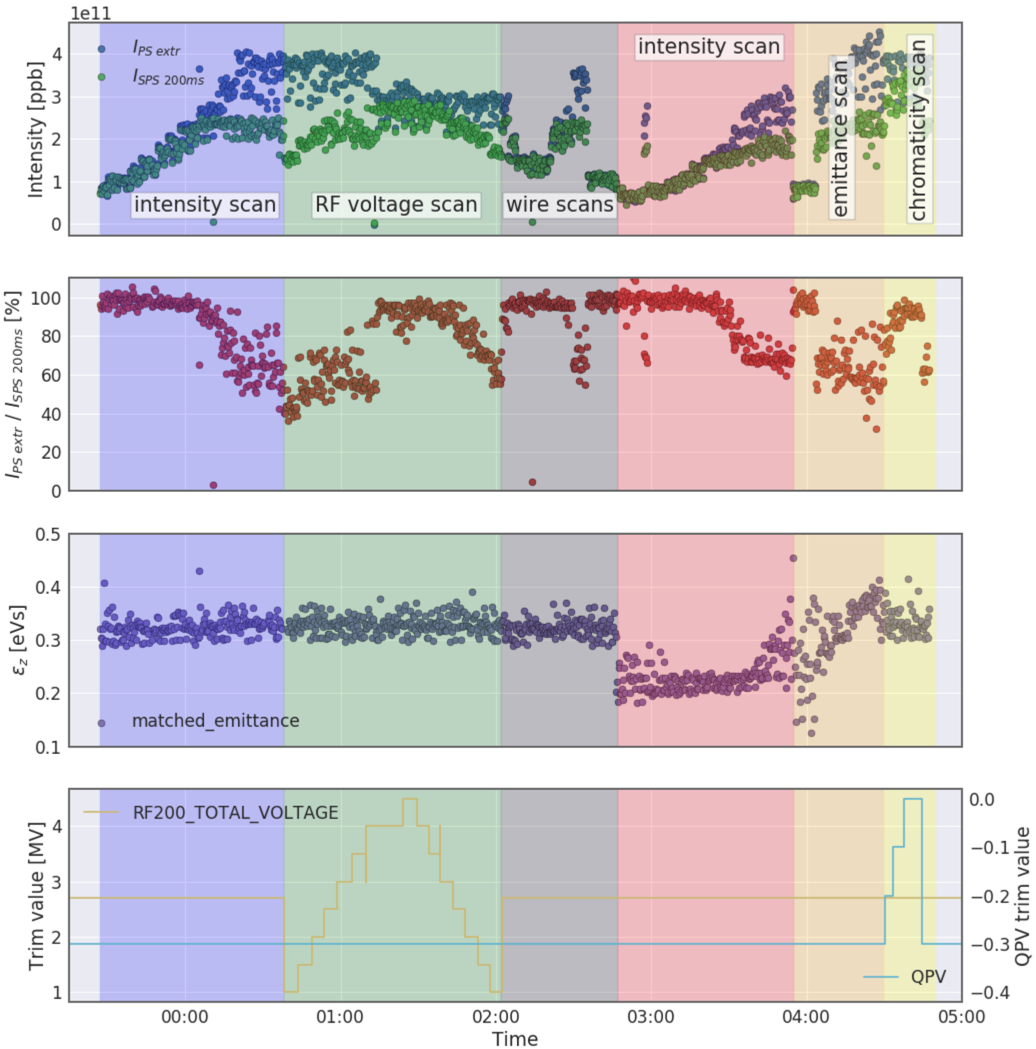
Questions?

Backup slides

Q22 TMCI MD 19/20 October 2017



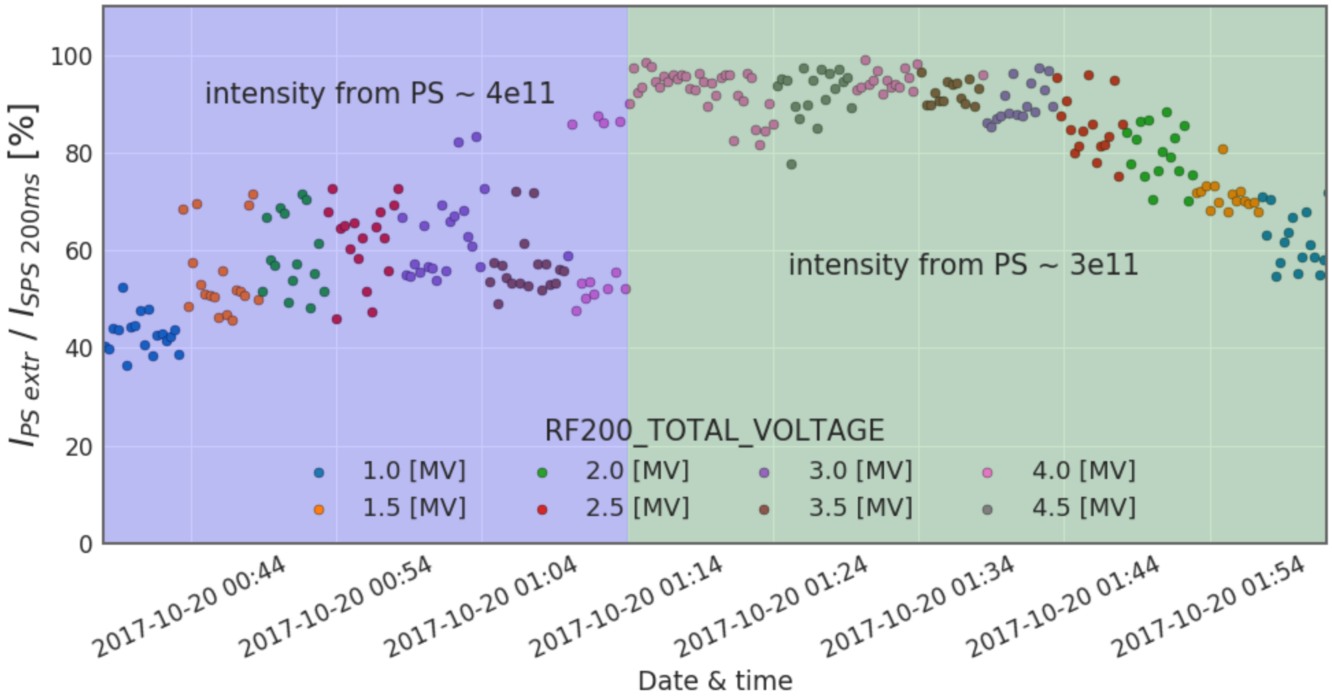
Q22 TMCI MD 19/20 October 2017



Introduction

- TMCI (**T**ransverse **M**ode **C**oupling **I**nstability) also called fast head tail instability.
- Instability created due to the transverse wake.
- The leading (transverse offset) particles create a transverse wake which excites the trailing particles.
- The particles exchange their positon every half synchrotron period; the faster the synchronous motion is the higher the instability threshold gets.

RF200 voltage scan II



N_{thr}^{TMC} should scale with $\sqrt{V}$:

2e11 with 1.5 MV
$\Rightarrow$ for 3MV:

$$2e11 \cdot \sqrt{\frac{3MV}{1{,}5MV}}$$
$$= 2.8e11$$

Correct!

$\Rightarrow$ We observe a principal scaling with the RF voltage.
$\Rightarrow$ But also a higher intensity in the SPS when injected less from the PS.

Connecting Q_s to N_{thr}^{TMC} [1, 2]

$$Q_s = \frac{\omega_s}{\omega_0} = \sqrt{\frac{eV\eta h}{2\pi E_0 \beta^2}}$$

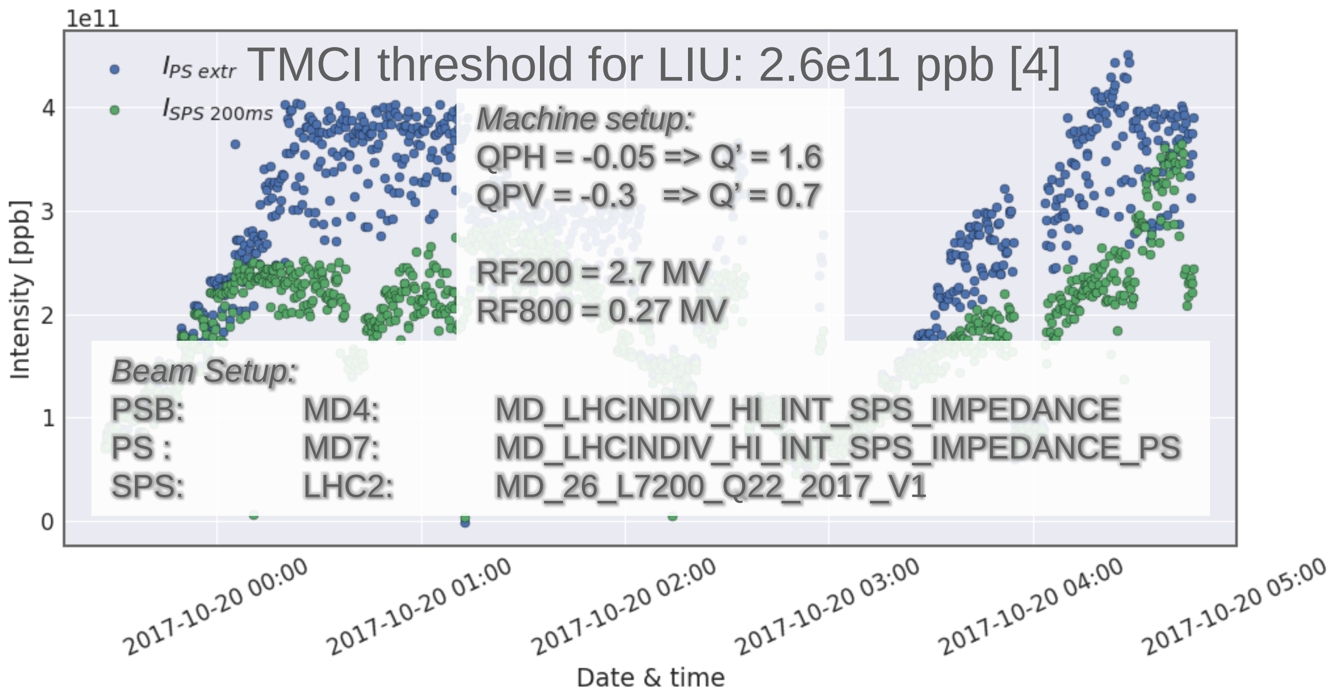
$$\varepsilon_z = 4\pi \frac{Q_s}{\eta R} p_0 \sigma_z^2$$

$$N_{thr}^{TMC} = \frac{16\sqrt{2}}{3\pi} \frac{R|\eta|\varepsilon_z}{\beta_y e \beta^2 c} \frac{\omega_r}{\left|Z_y^{BB}\right|} \left(1 + \frac{Q_y' \omega_0}{\eta \omega_r}\right)$$

Q_s : synchrotron tune
V : RF voltage
E_0 : reference energy
p_0 : reference momentum
σ_z : longitudinal bunch length
R : machine circumference
ε_z : longitudinal emittance
Q_y' : vertical chromaticity
η : slippage factor
$\left|Z_y^{BB}\right|$: Impedance of broad band resonator model
ω_r : resonance frequency of broad band resonator model
ω_0 : revolution frequency of the machine
β_y : betatron function of the machine

Overview over MD

- TMCI MD the 19th to 20th of October 2017.
- In Q22 optics, single bunch, no acceleration.



[4] H. Bartosik – Q22 optics - SPS injection losses review, 30 November 2017