SPS TMCI with the Q22 optics

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HSC Section Meeting – 27.11.2017

Outline

Context:

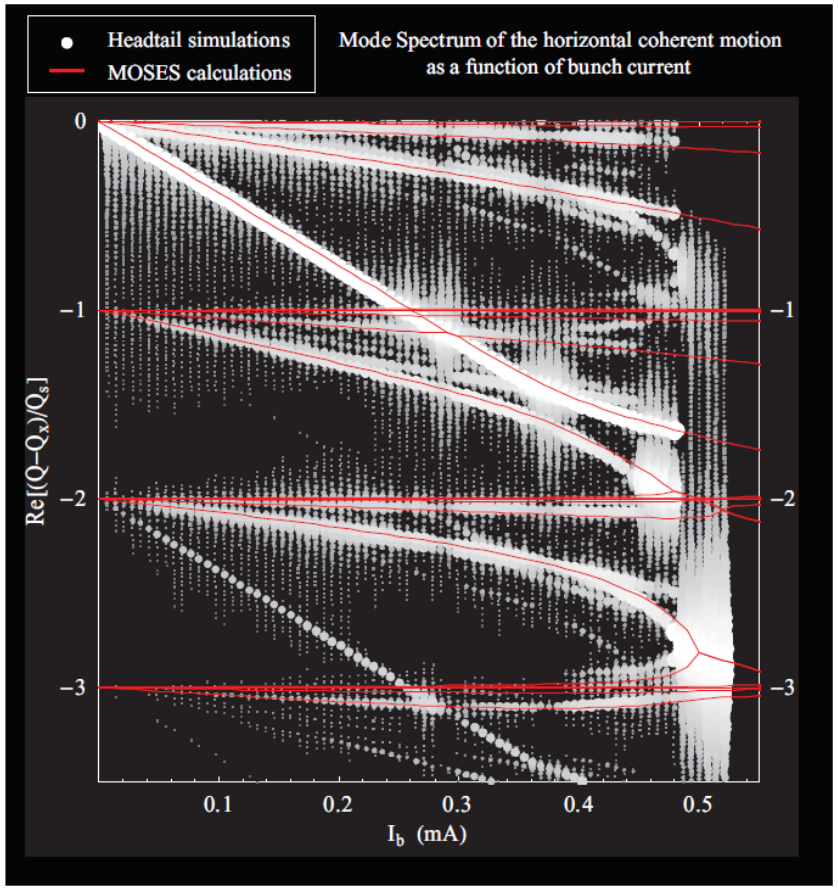
The **vicious transverse mode coupling instability** is one of the **fundamental intensity limitations** in the SPS. In the pre-Q20 era, this limit was set at around 1.4e11 ppb – way below the required 2.6e11 specified for LIU. With the Q20 optics the **threshold was raised to about 4.5e11 ppb**. An intermediate optics – **Q22** – was considered as alternative as it is less demanding in terms of RF power during certain parts of the cycle.

Outline:

- Measurement overview
- Identifying the TMCI threshold
- Voltage scans
- Mitigation of the TMCI

Preamble

- SPS TMCI has a long history of studies…
- It can be reasonably well reproduced using a broadband resonator impedance model at around 1.3GHz



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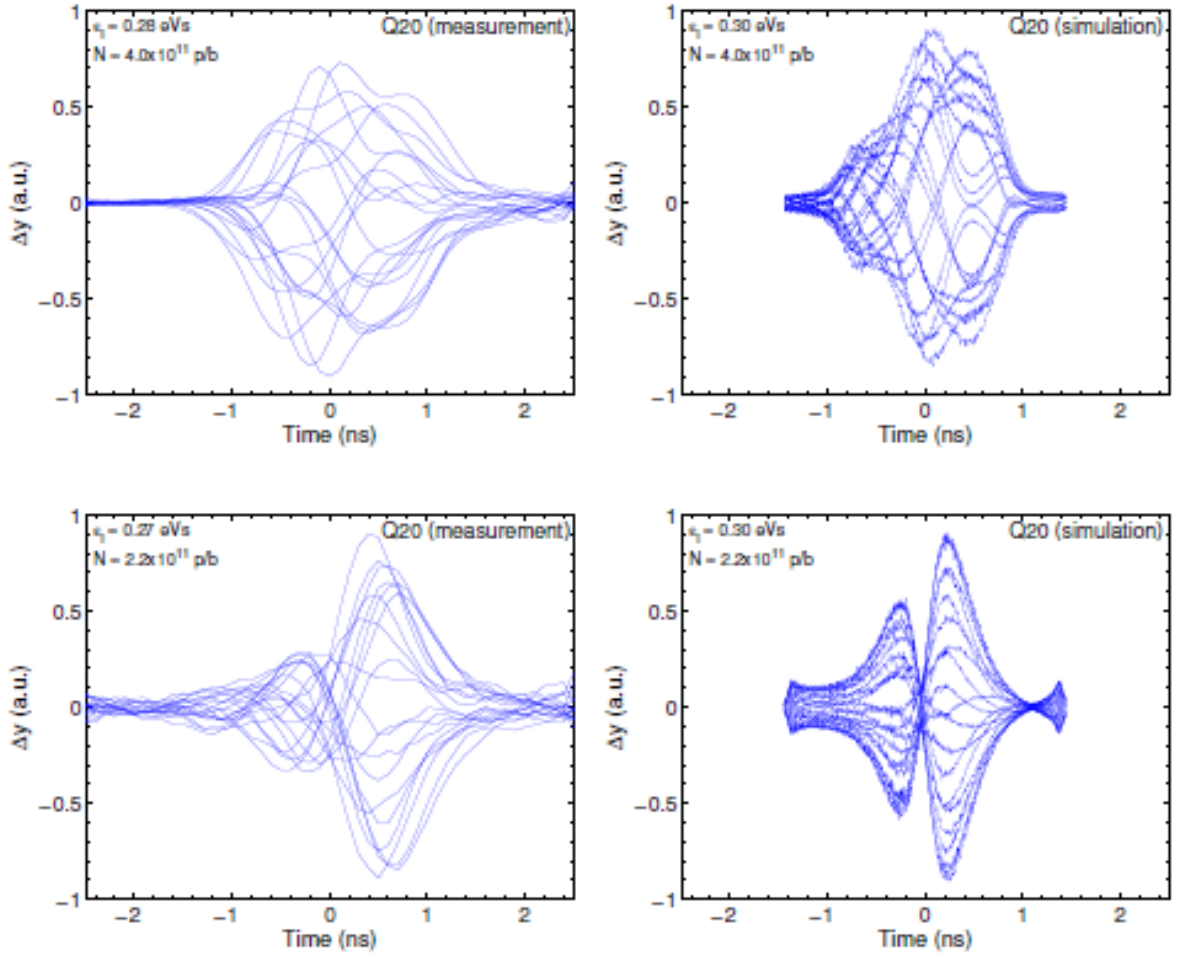
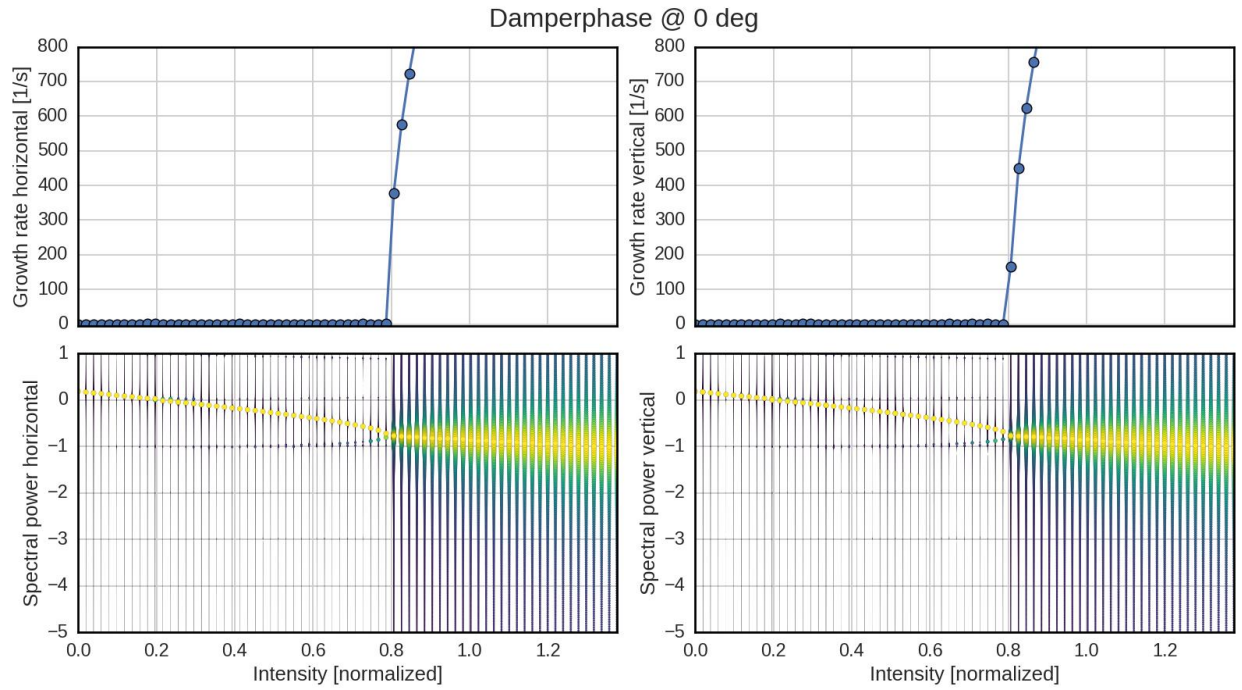
H. Bartosik

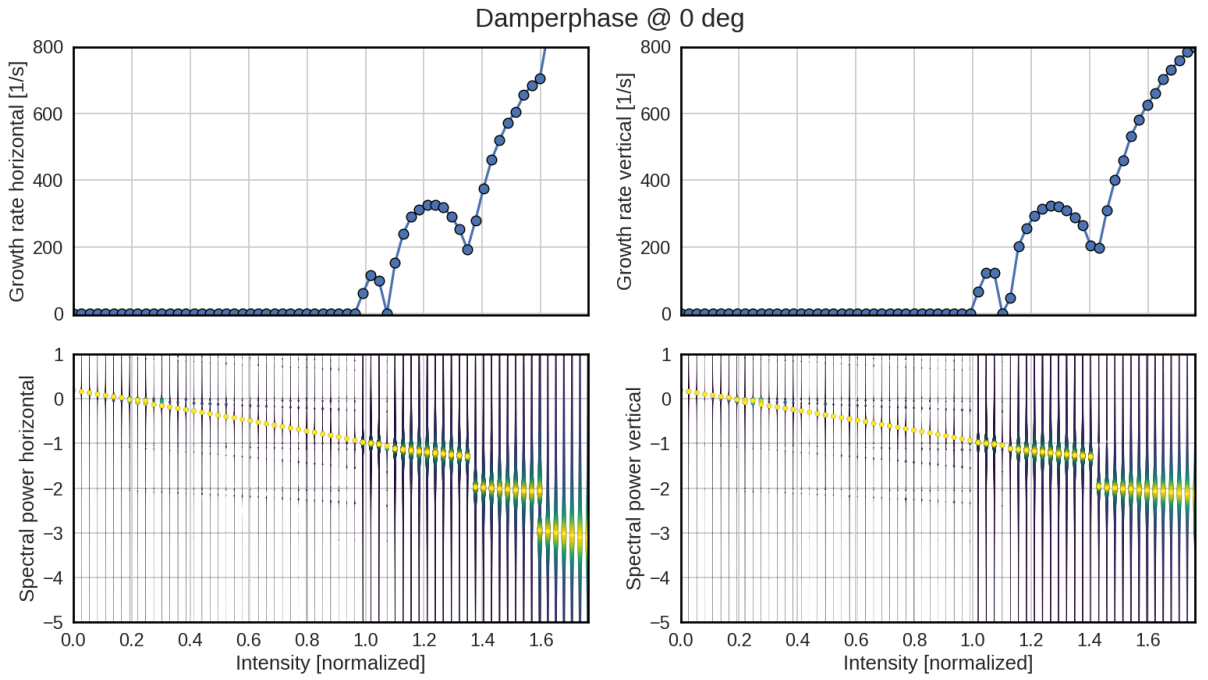


Preamble

- SPS TMCI has a long history of studies…
- Strong coupling takes place between mode -2 and -3

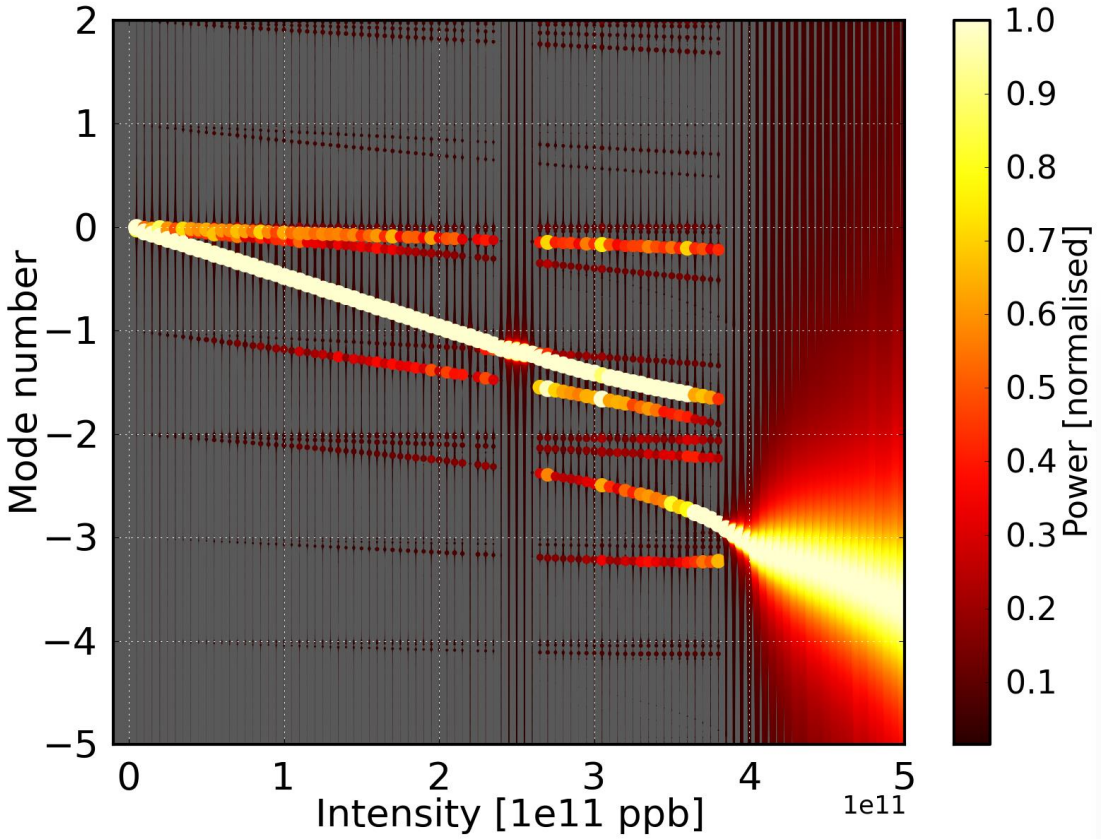
short bunch → **long bunch**

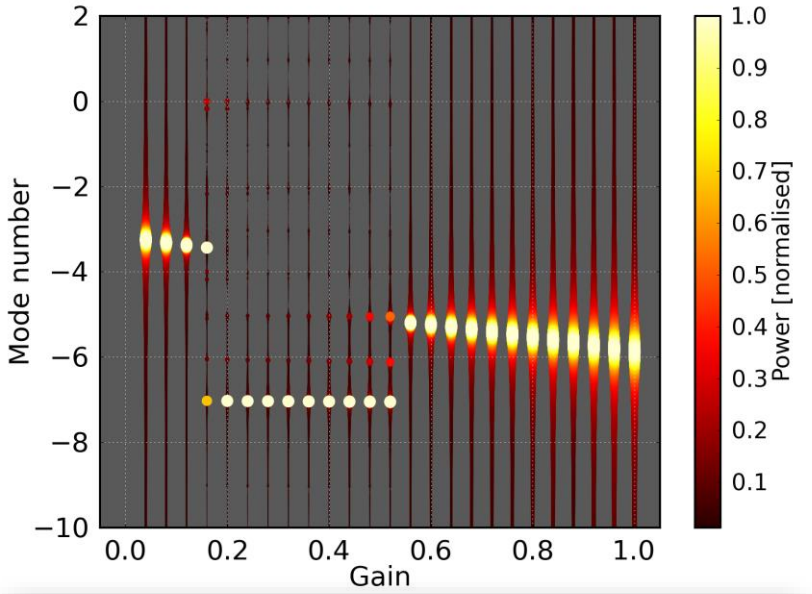


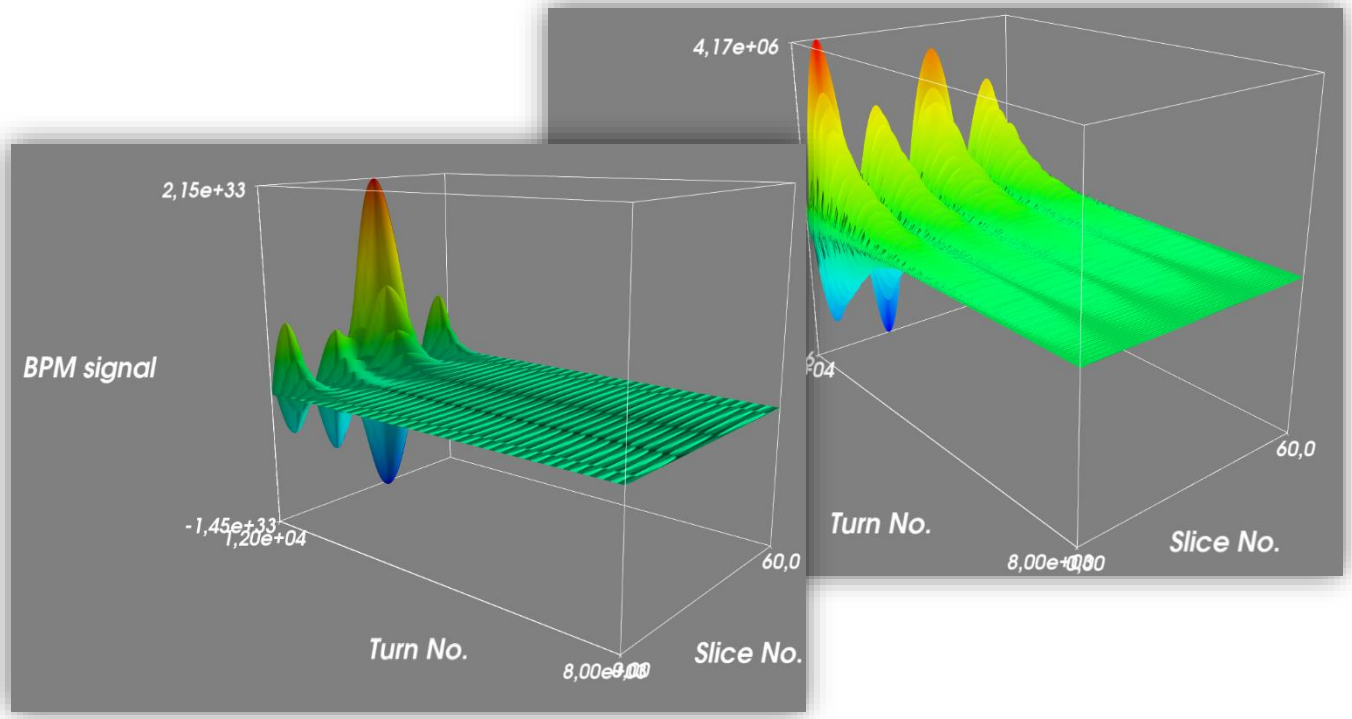


Preamble

- SPS TMCI has a long history of studies…
- Mitigation methods…







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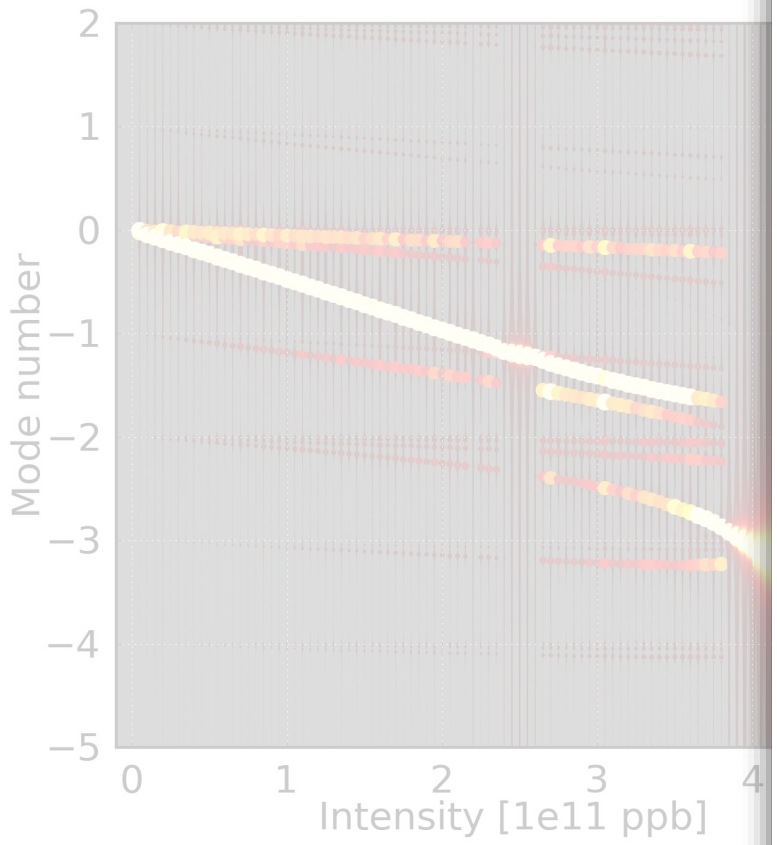
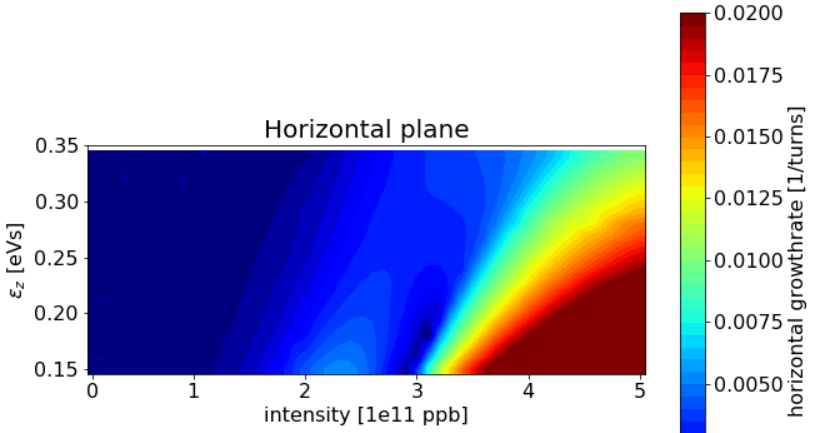
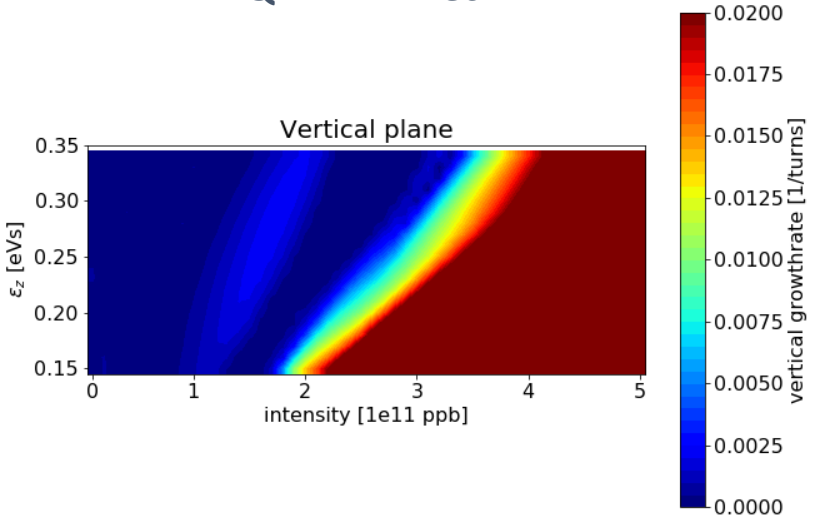
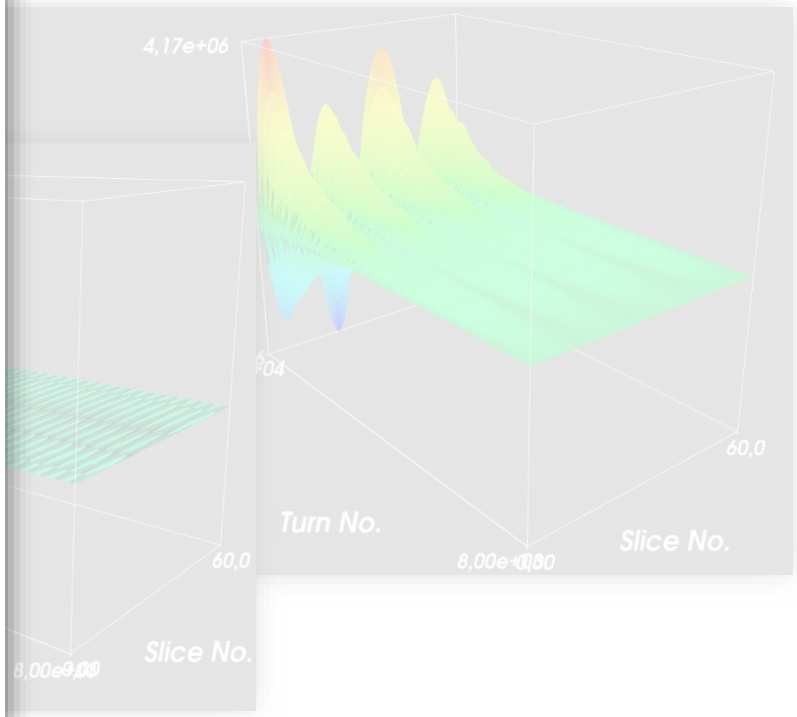


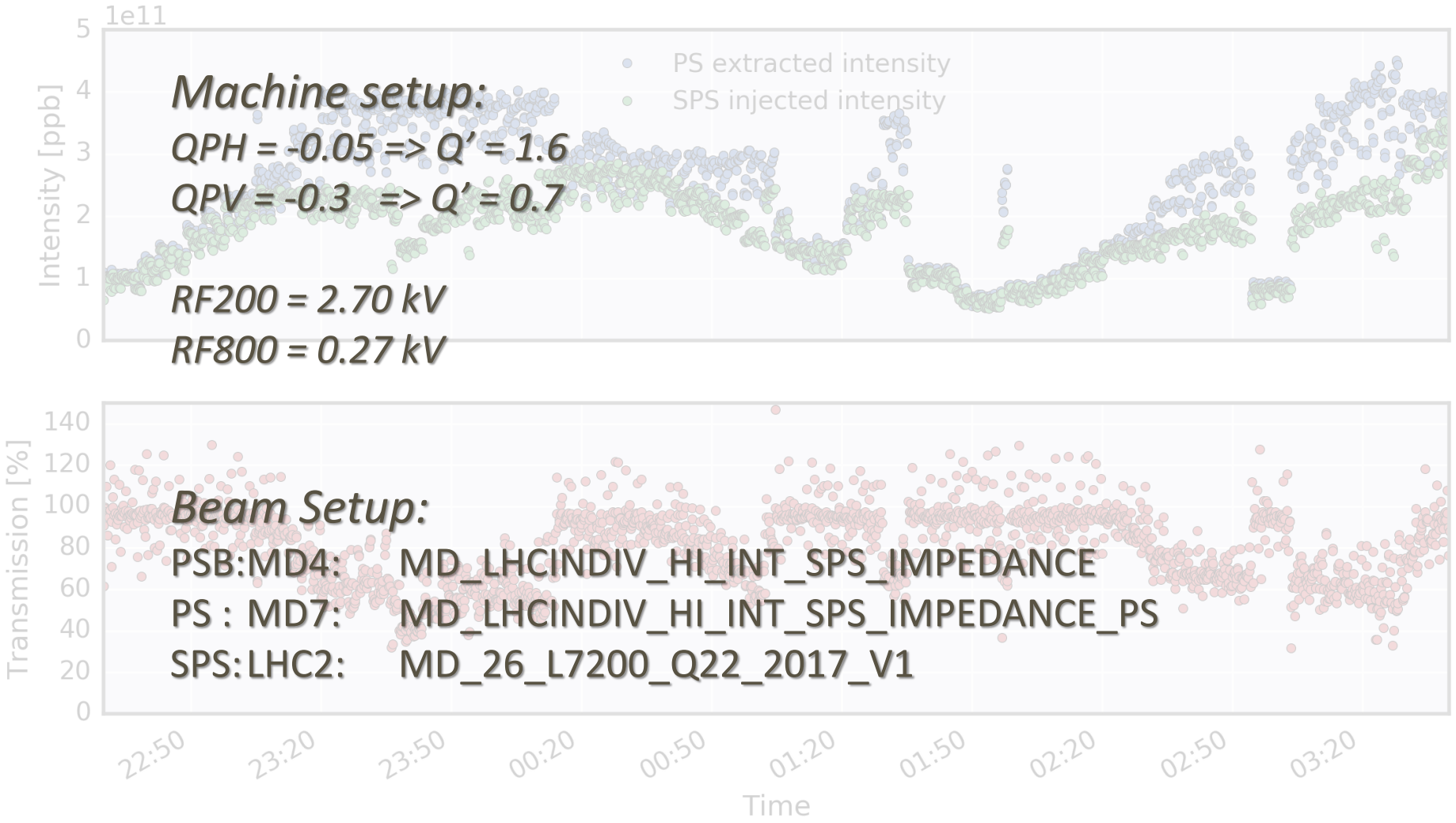


Q22 – M. Beck

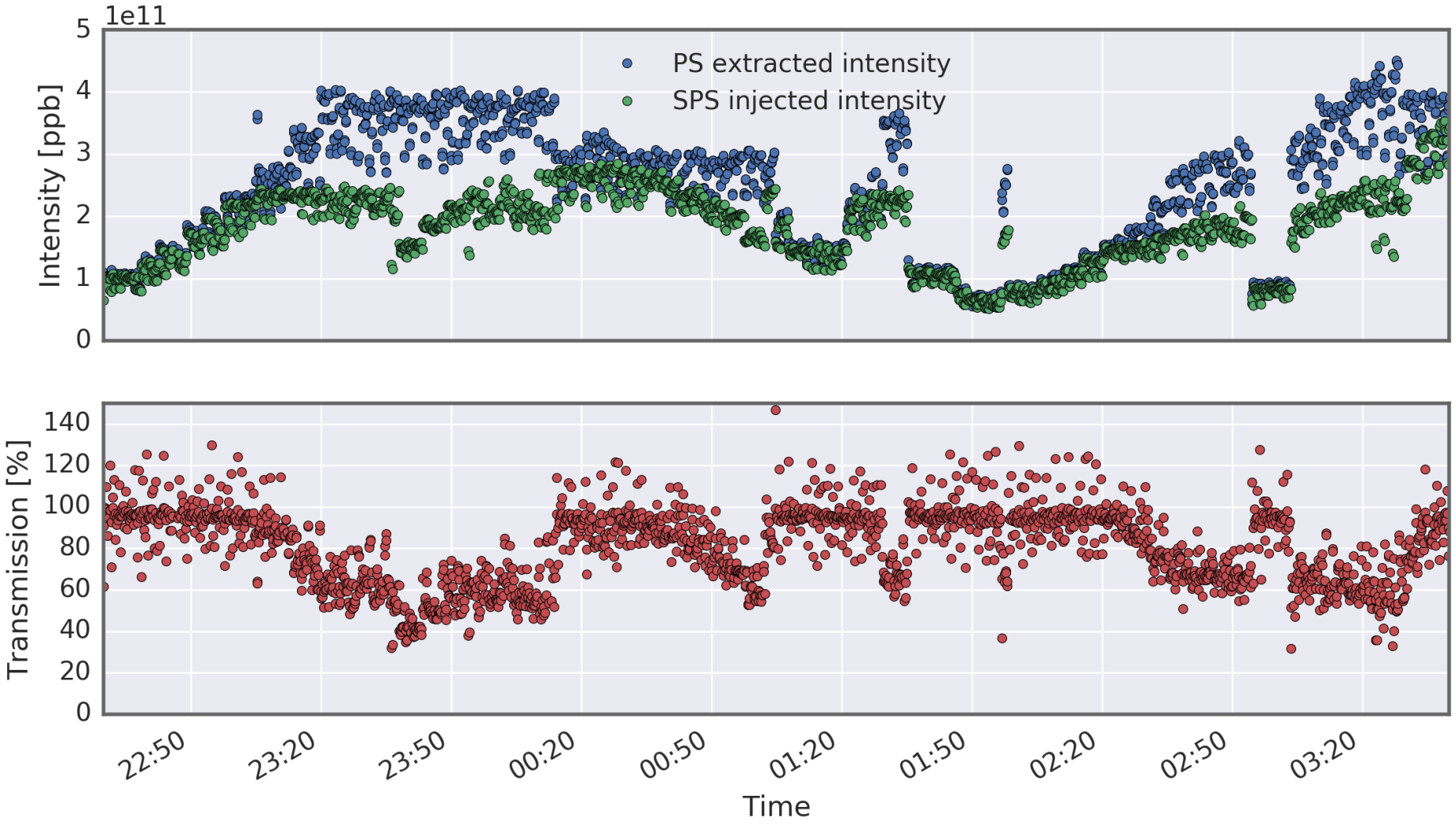




MD overview


1e11
5
4
3
2
1
0
Intensity [ppb]
PS extracted intensity
SPS injected intensity
Machine setup:
QPH = -0.05 => Q' = 1.6
QPV = -0.3 => Q' = 0.7
RF200 = 2.70 kV
RF800 = 0.27 kV
140
120
100
80
60
40
20
0
Transmission [%]
Beam Setup:
PSB:MD4: MD_LHCINDIV_HI_INT_SPS_IMPEDANCE
PS : MD7: MD_LHCINDIV_HI_INT_SPS_IMPEDANCE_PS
SPS:LHC2: MD_26_L7200_Q22_2017_V1
22:50
23:20
23:50
00:20
00:50
01:20
01:50
02:20
02:50
03:20
Time

MD overview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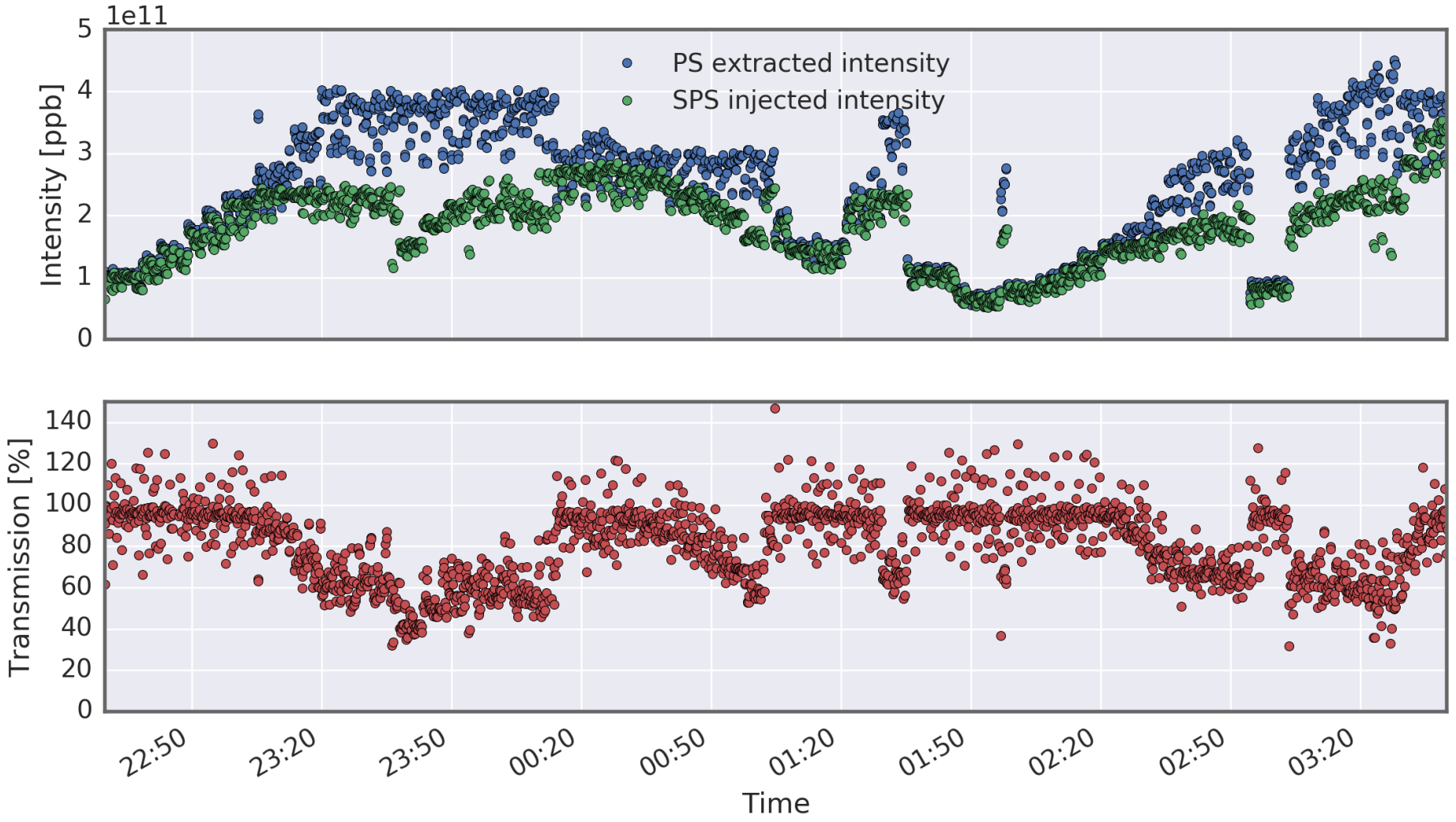
Transmission [%]
22:50
23:20
23:50
00:20
00:50
01:20
01:50
02:20
02:50
03:20
Time

MD overview

- Injection from the PS into the SPS – **monitoring of the extracted vs. the injected intensity**



MD overview

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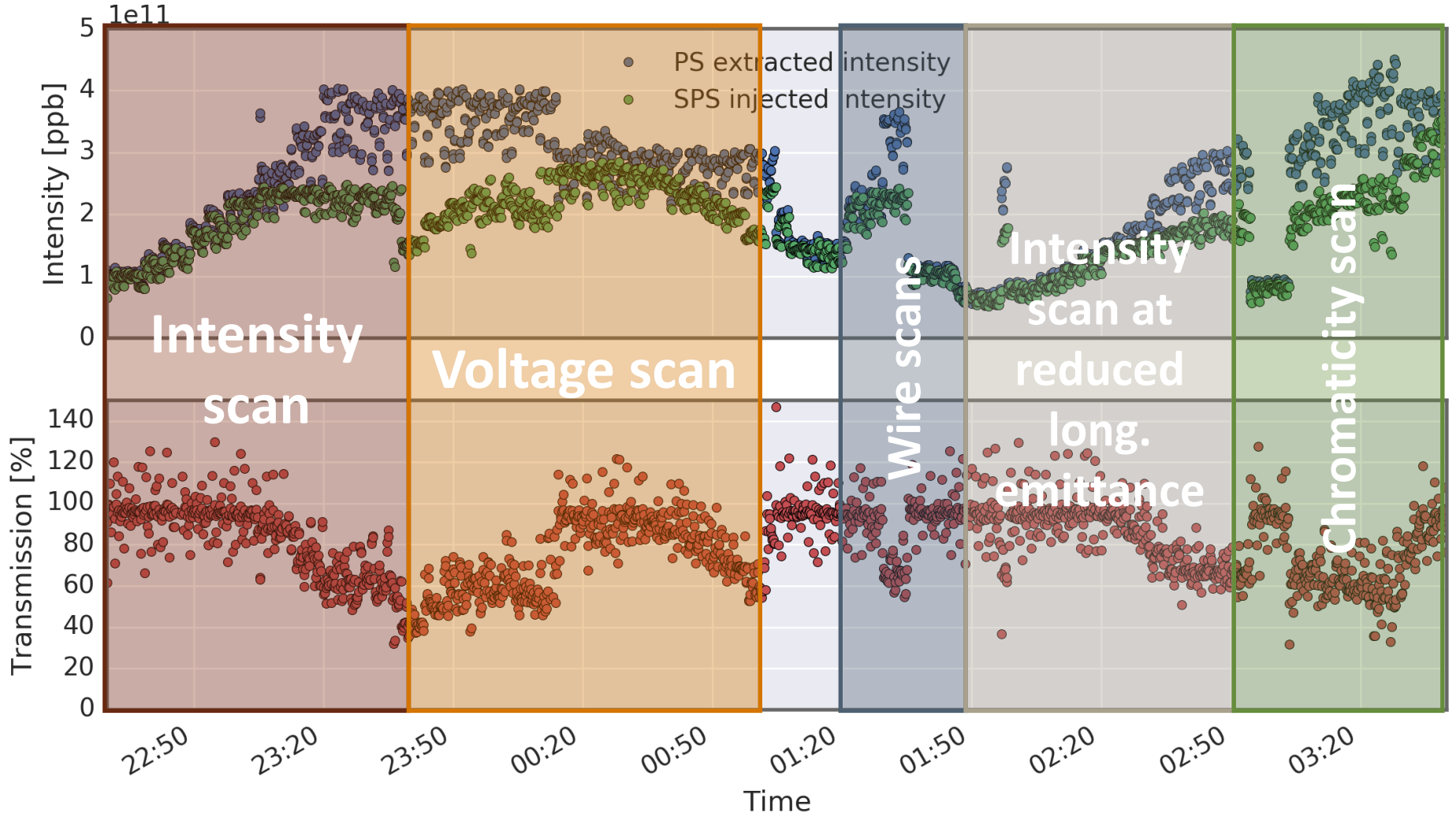
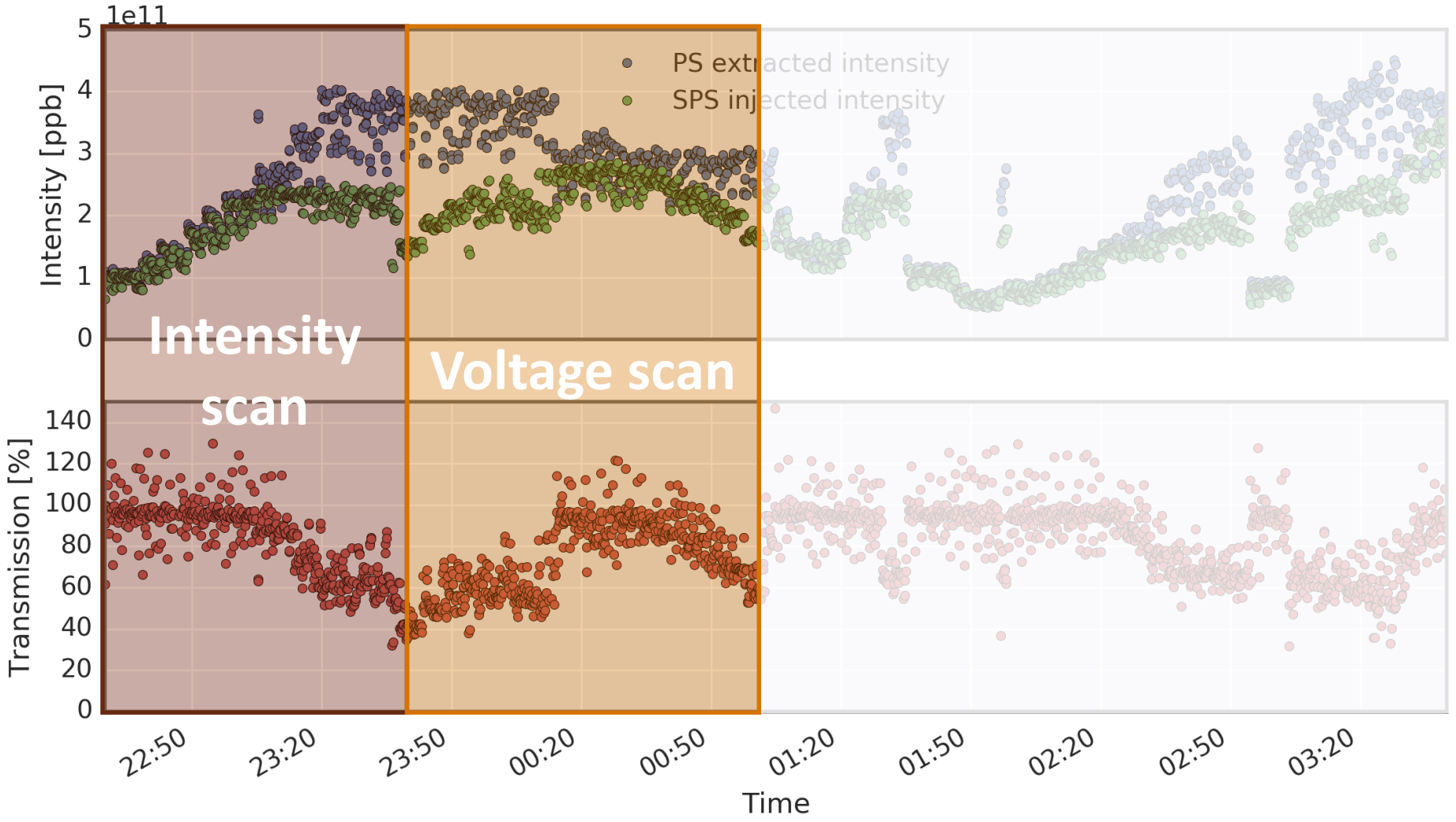


MD overview

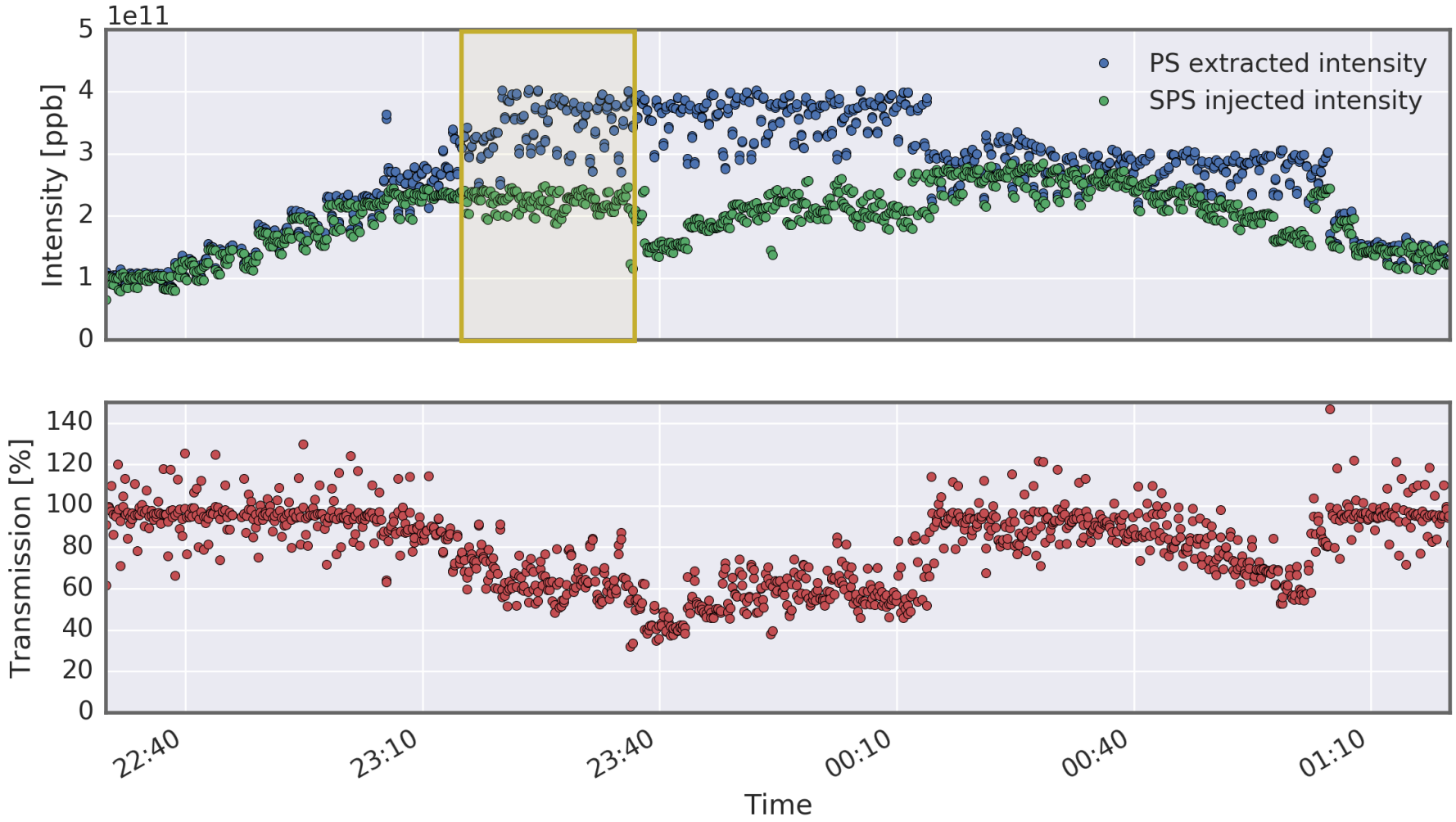
- Injection from the PS into the SPS – **monitoring of the extracted vs. the injected intensity**

- We will look at the **intensity scan in order to identify the TMCI** threshold at a voltage of 2.7 MV and a long. emittance of around 0.3 eVs



Intensity scan

- Scanning the injected intensity into the SPS we **notice a sudden decrease of the transmission** at around 23:10



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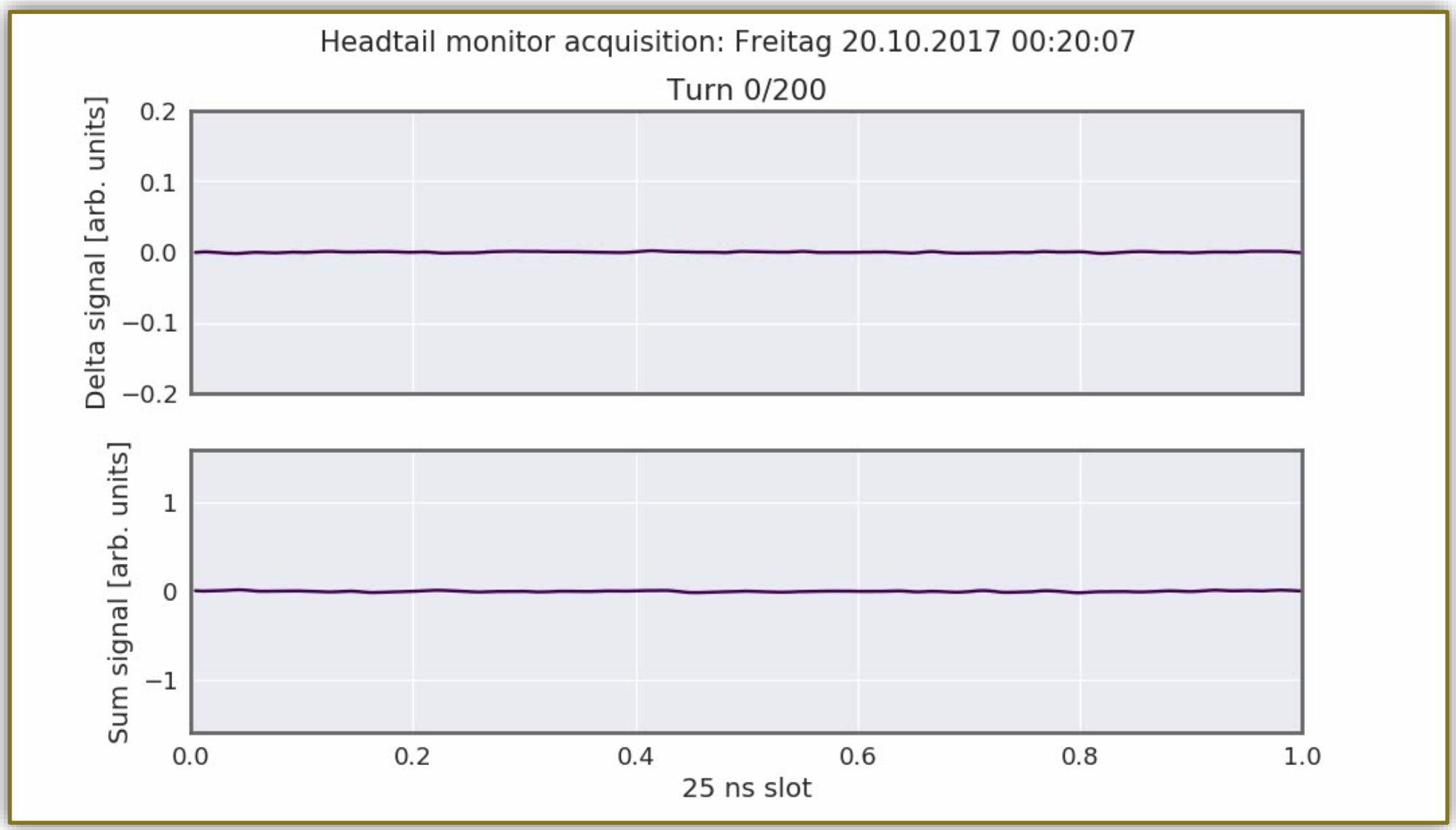
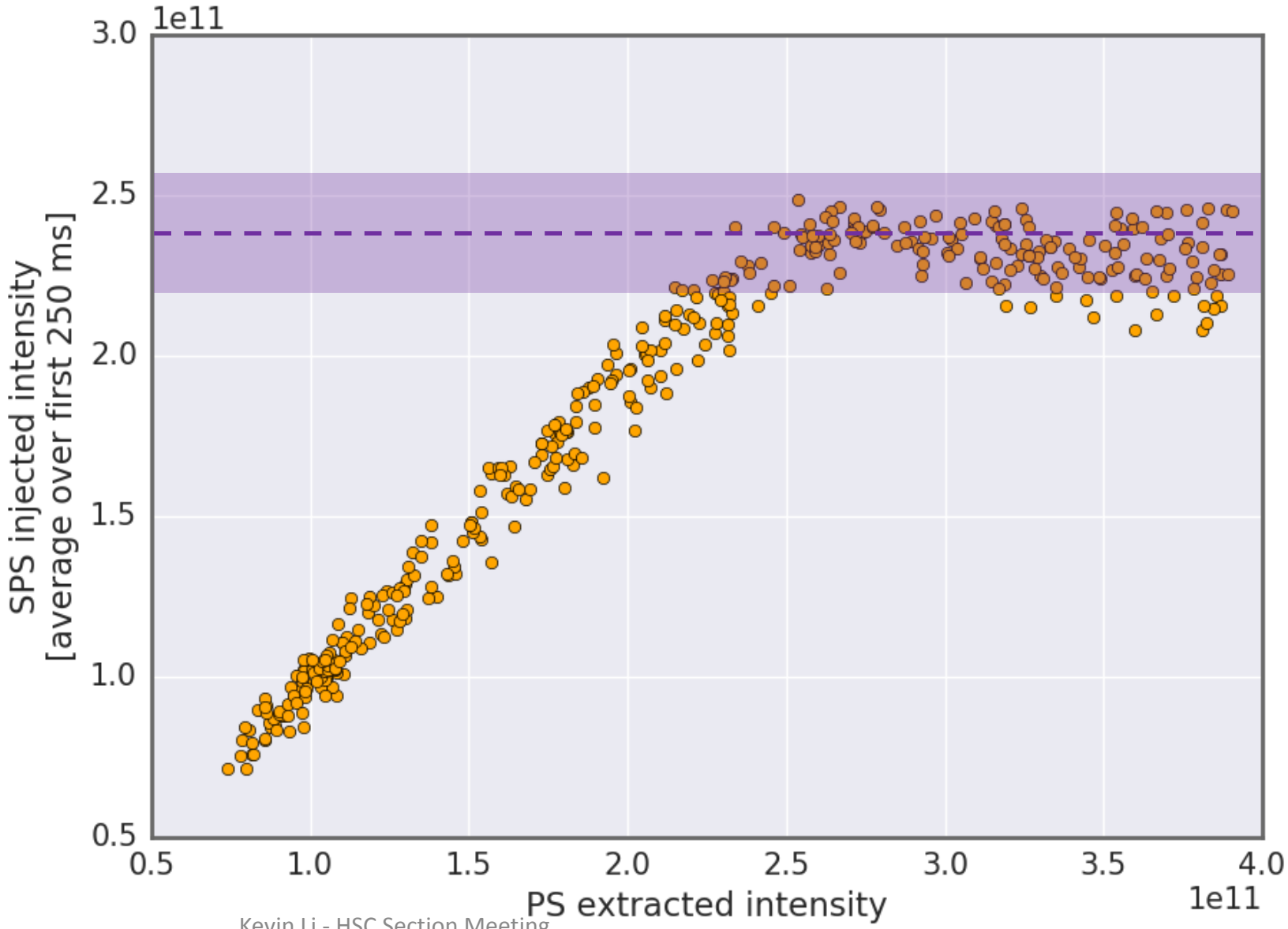


Intensity scan

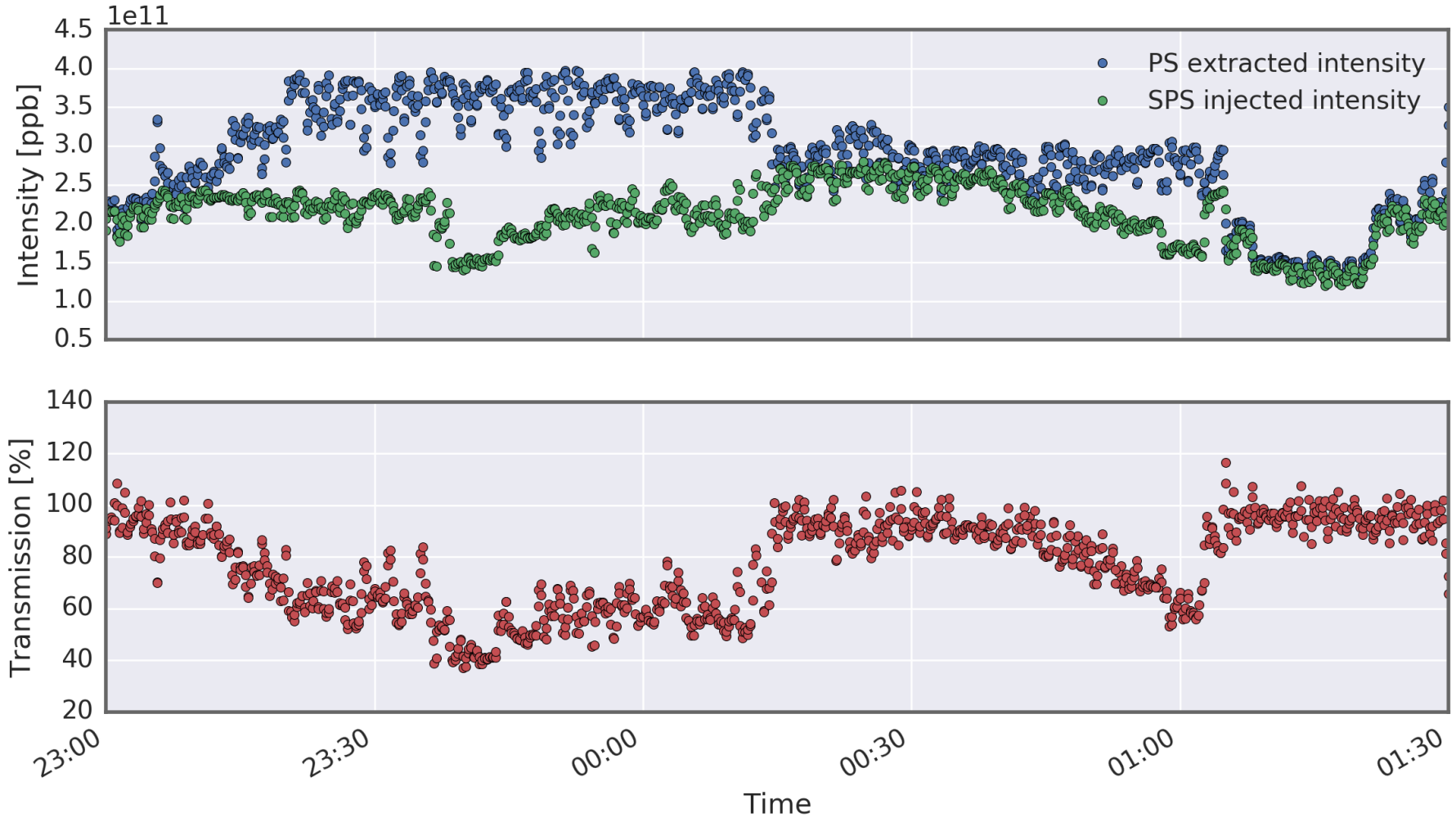
- Scanning the injected intensity into the SPS we **notice a sudden decrease of the transmission** at around 23:10

- Plotting it slightly differently – **where is the TMCI threshold… :D?**



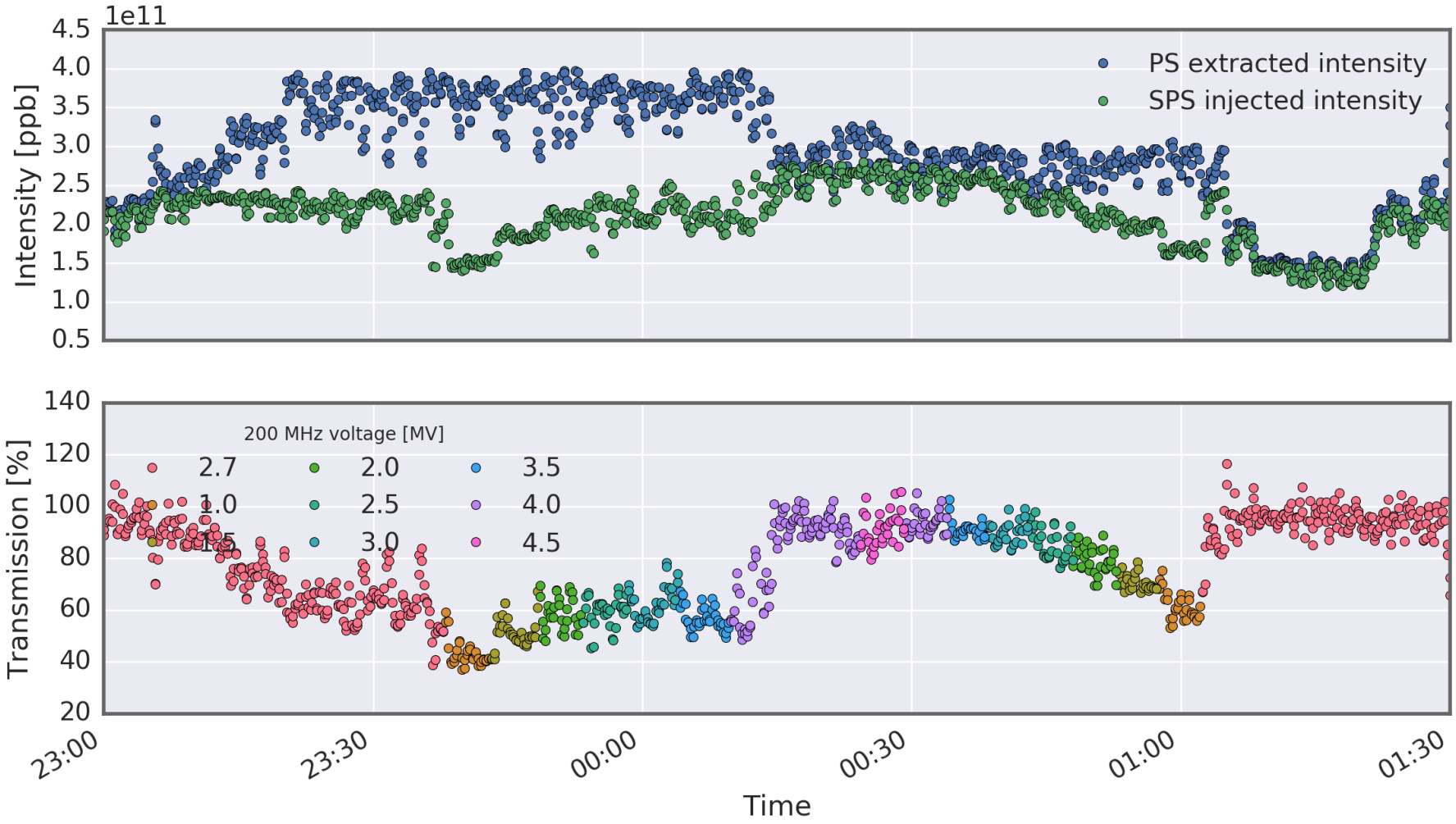
Intensity scan

- After identifying the TMCI threshold via the intensity scan, we did a **voltage scan at a fixed injected intensity**, at around 4e11 ppb.



Intensity scan

- After identifying the TMCI threshold via the intensity scan, we did a **voltage scan at a fixed injected intensity**, at around 4e11 ppb.
- Increasing the voltage did not show any clear improvement… still to be understood.
- At lower intensity, a dependence on the RF voltage is seen.

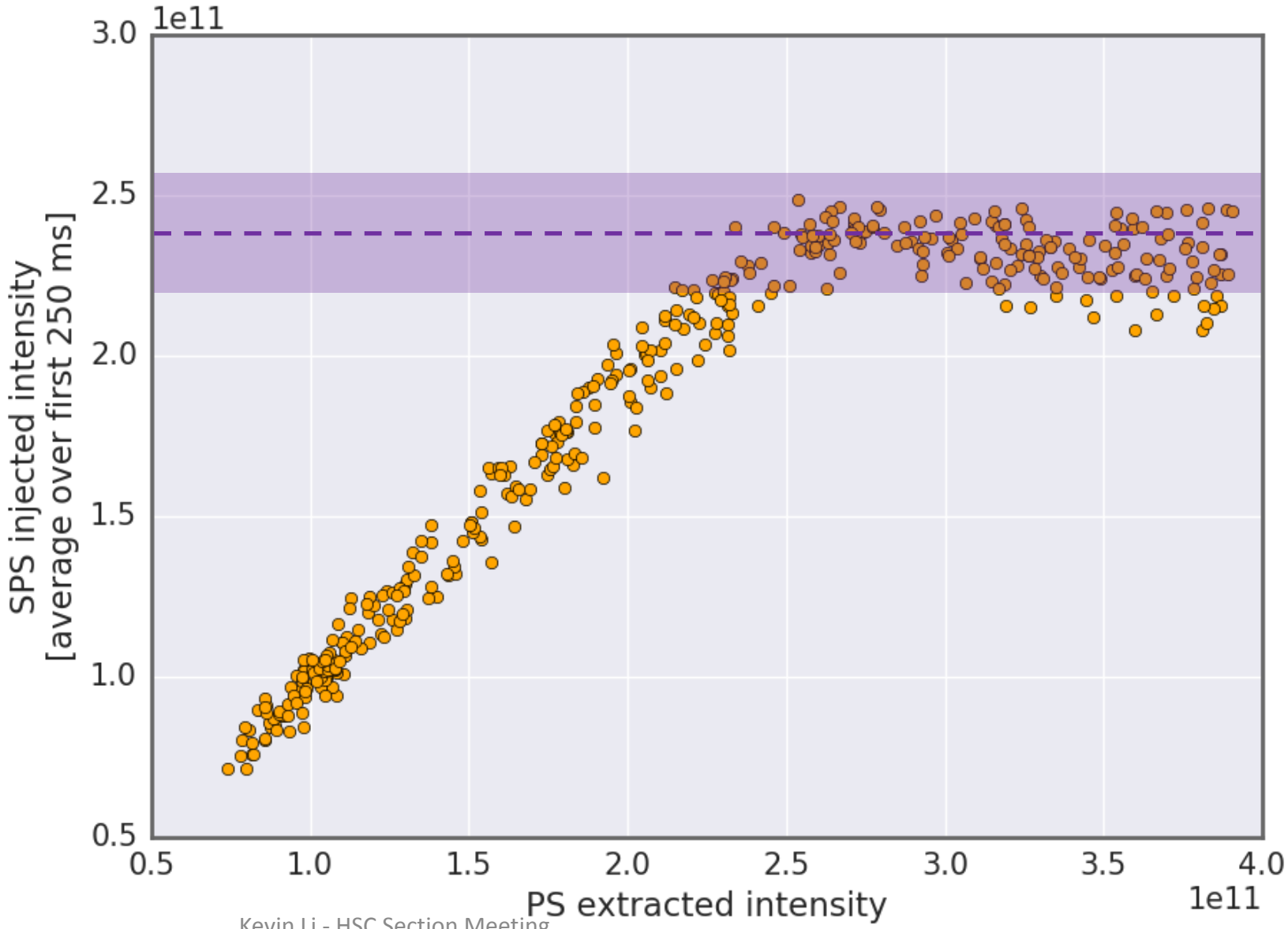


TMCI threshold

- The TMCI threshold in the SPS for Q22 at a voltage of 2.7 MV and a long. Emittance around 0.3 eVs is at 2.4e11 ppb!

- LIU requires an injected intensity of 2.6e11 ppb.

- **Does this mean Q22 is excluded as potential alternative for LIU?**



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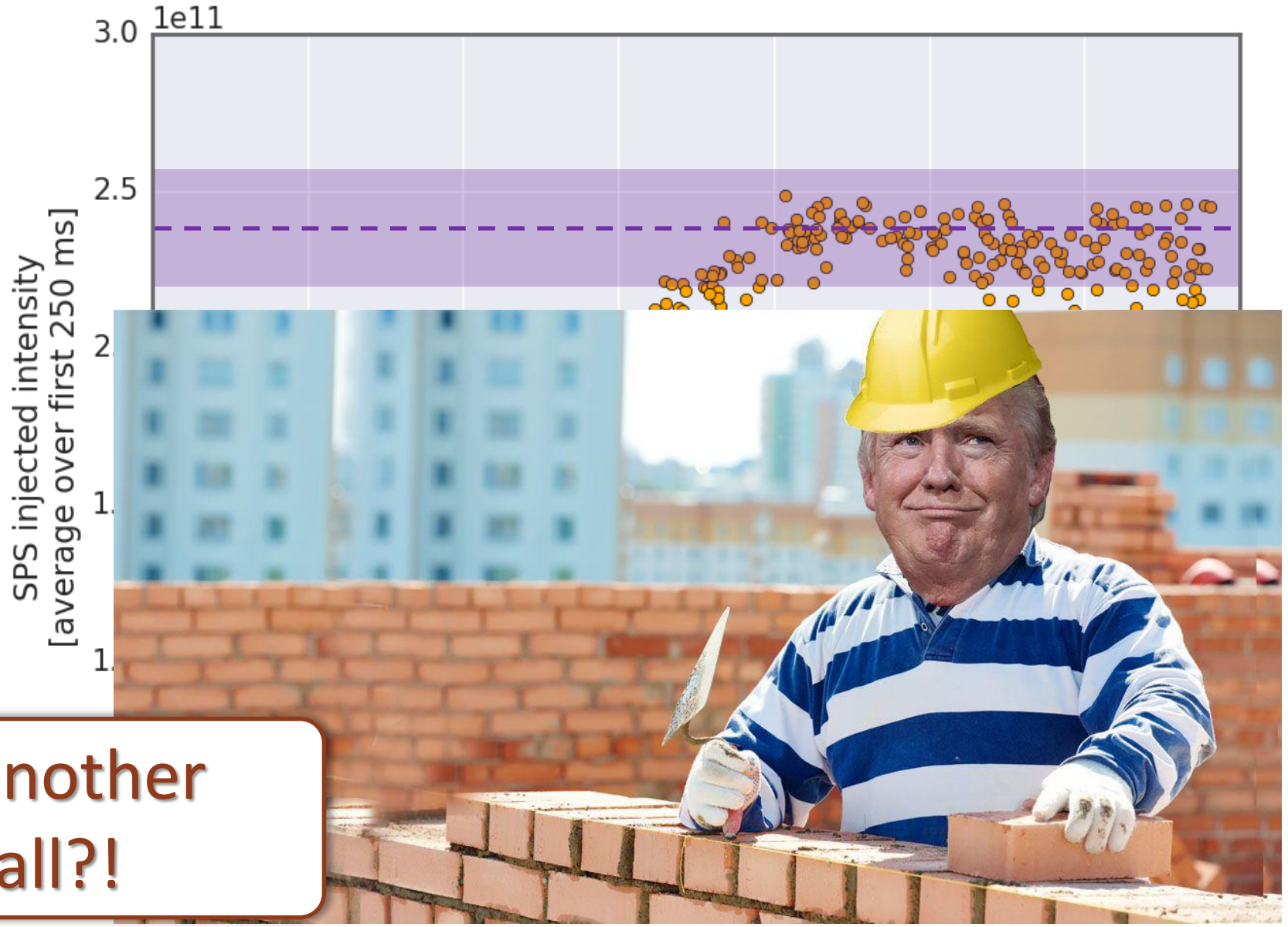

Yet another wall?!

TMCI threshold

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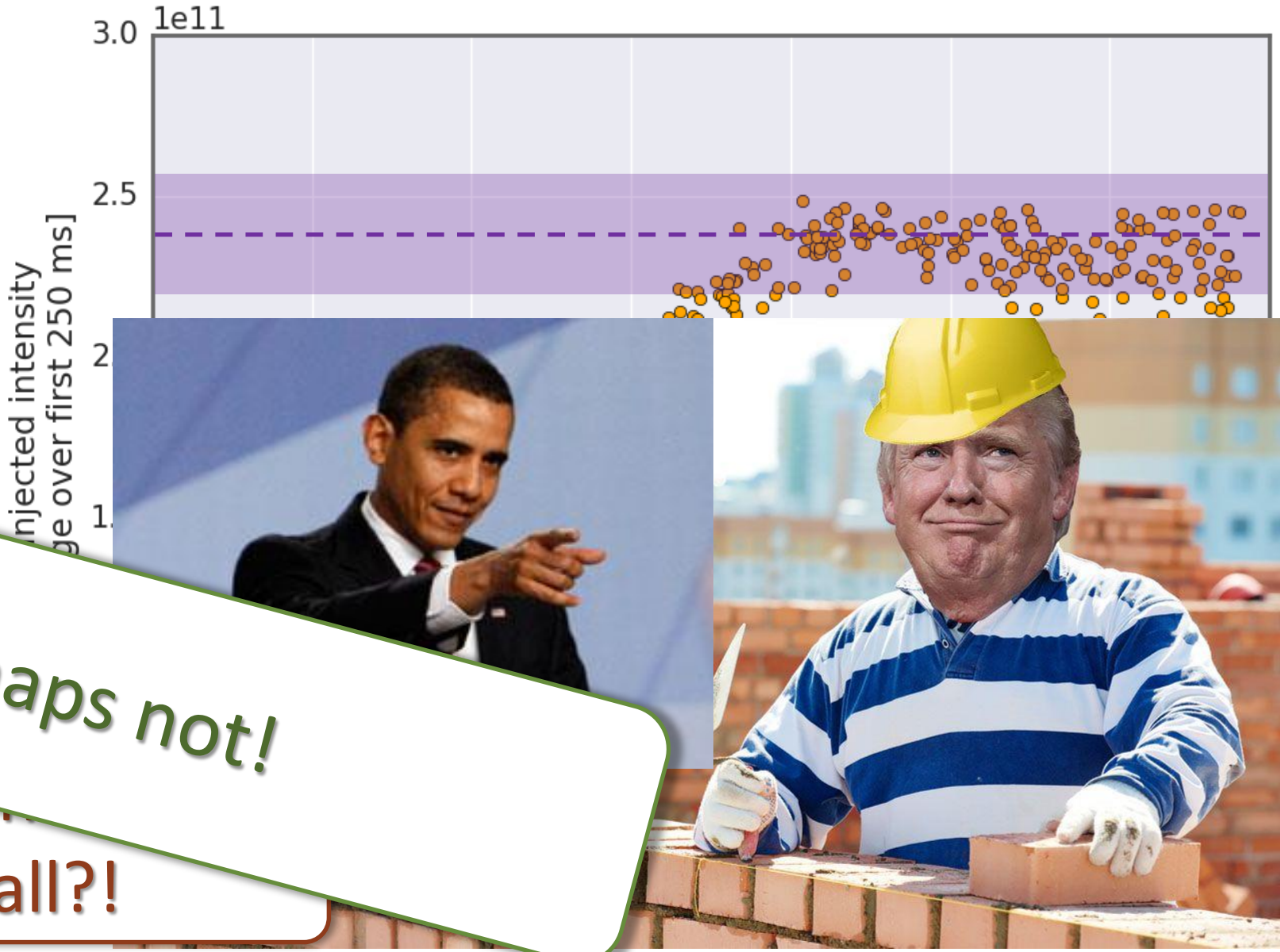
- **Does [illegible] is excluded as p[illegible]?**



Wideband feedback system components

Pickup → Equalization → Closed orbit rejection → **Digital signal processing system** → Pre-distortion → **Power amplifiers** → **Wideband kickers**

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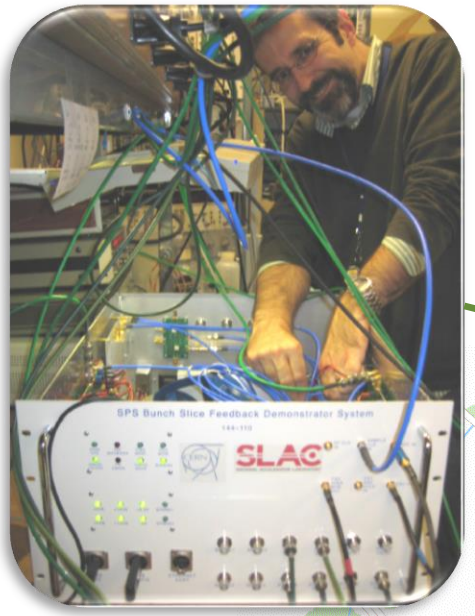
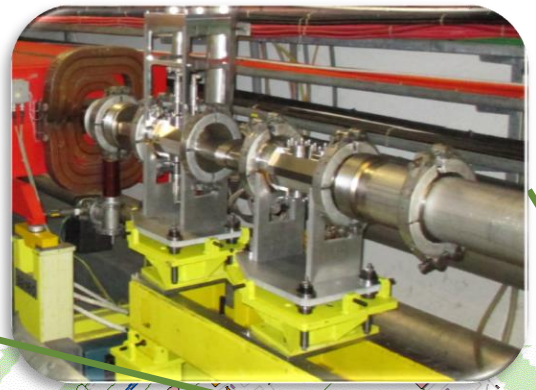
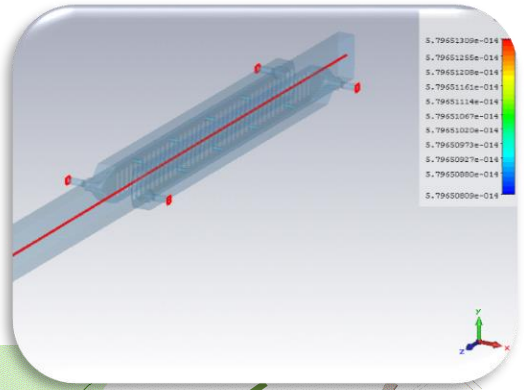
- Complete processing channel from pickups through kicker, running a digital **reconfigurable system up to 4 GS/s** is installed and ready for use at 3.2 Gs/s. Now includes **multi-bunch processing** of up to 64 bunches in any configuration.
- Actuators:
  - 2 stripline kickers
  - 2 x 2 power amplifiers with 250 W, frequency range: 5 – 1000 MHz
  - Augmented by a slotline kicker in 2018







Wideband feedback system components

Pickup | Equalization | Closed orbit rejection | **Digital signal processing** | Pre-distortion | **Power amplifiers** | **Wideband kickers**

This system has been demonstrated to be **effective against TMCI in the slow risetimes** regime. As a demonstrator system, it **runs at limited power** with, hence, reduced capabilities. We prepared a second MD targeted in configuring the wideband feedback system to **combat also the fast TMCI**.

- with 250 W, frequency range: 5 – 1000 MHz
  - Augmented by a slotline kicker in 2018

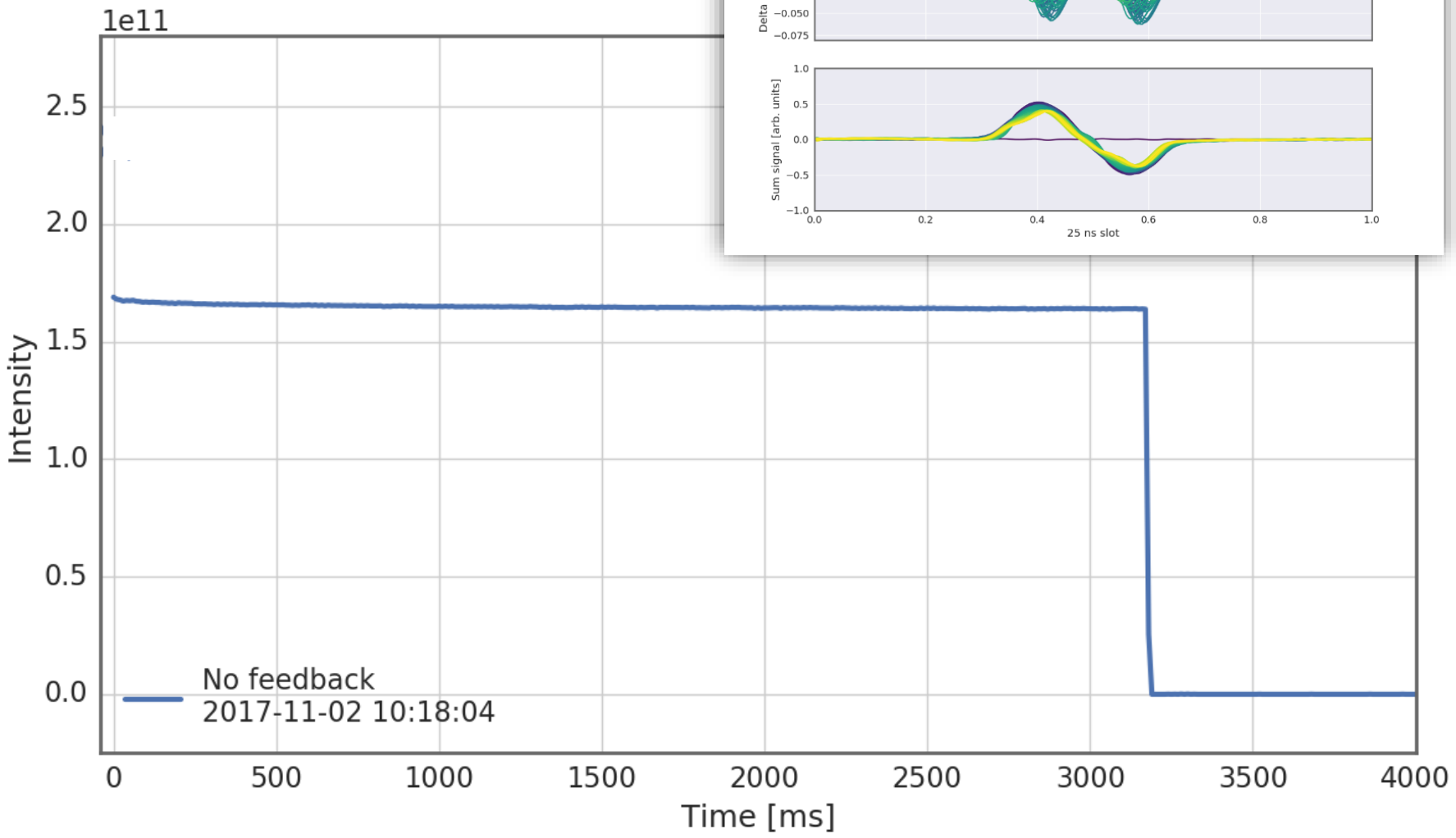
Intensity scan

- Due to limitations imposed by the ions cycle the injected intensity had to be reduced → the RF voltage was reduced adequately to obtain TMCI at a lower intensity.

- First test… looking at the BCT, **a constant signal** is observed all along the cycle.

- To be noted that we are **injecting high intensity beams** (~2.5e11 ppb) → TMCI induced losses occur before the first BCT sampling point!

- A look into the HEADTAIL monitor **just after injection reveals the TMCI**.

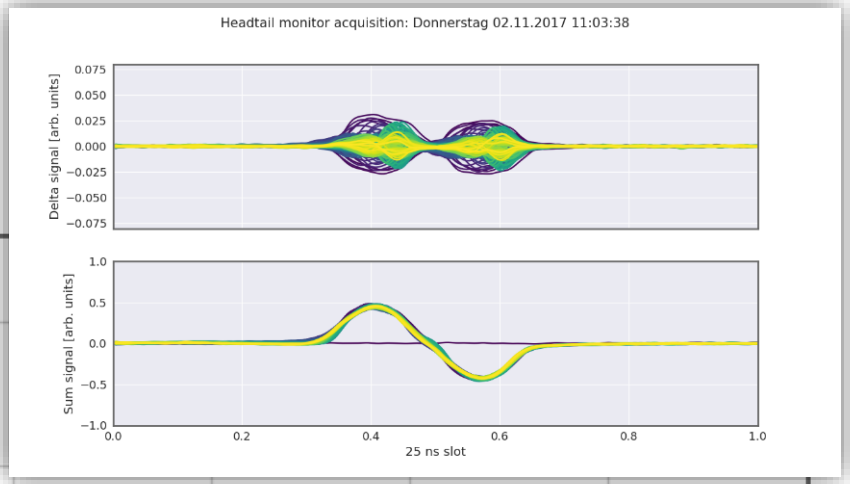


Intensity scan

- The **transverse damper** was set up and put into operation in an attempt to mitigate the instability.

- The fast growth was reduced but **could not be stopped**. The losses are ultimately comparable to running without the transverse damper.

- This is expected **due to the bandwidth limitations** of the transverse damper… the high frequency content of the instability remains unaffected.

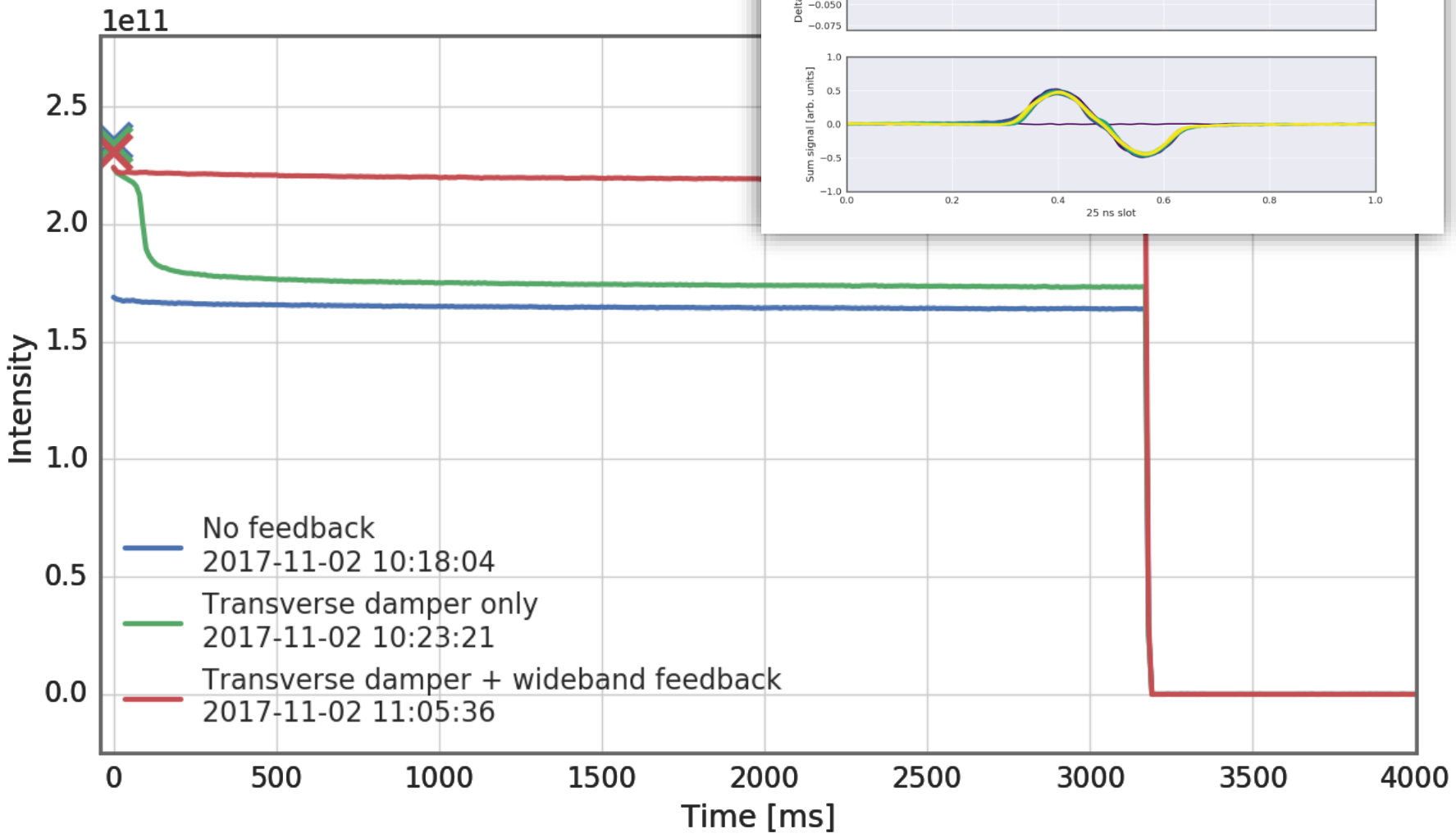


Intensity scan

- Finally, the **wideband feedback system** was time aligned, configured and activated by closing the loop over the observed instability.

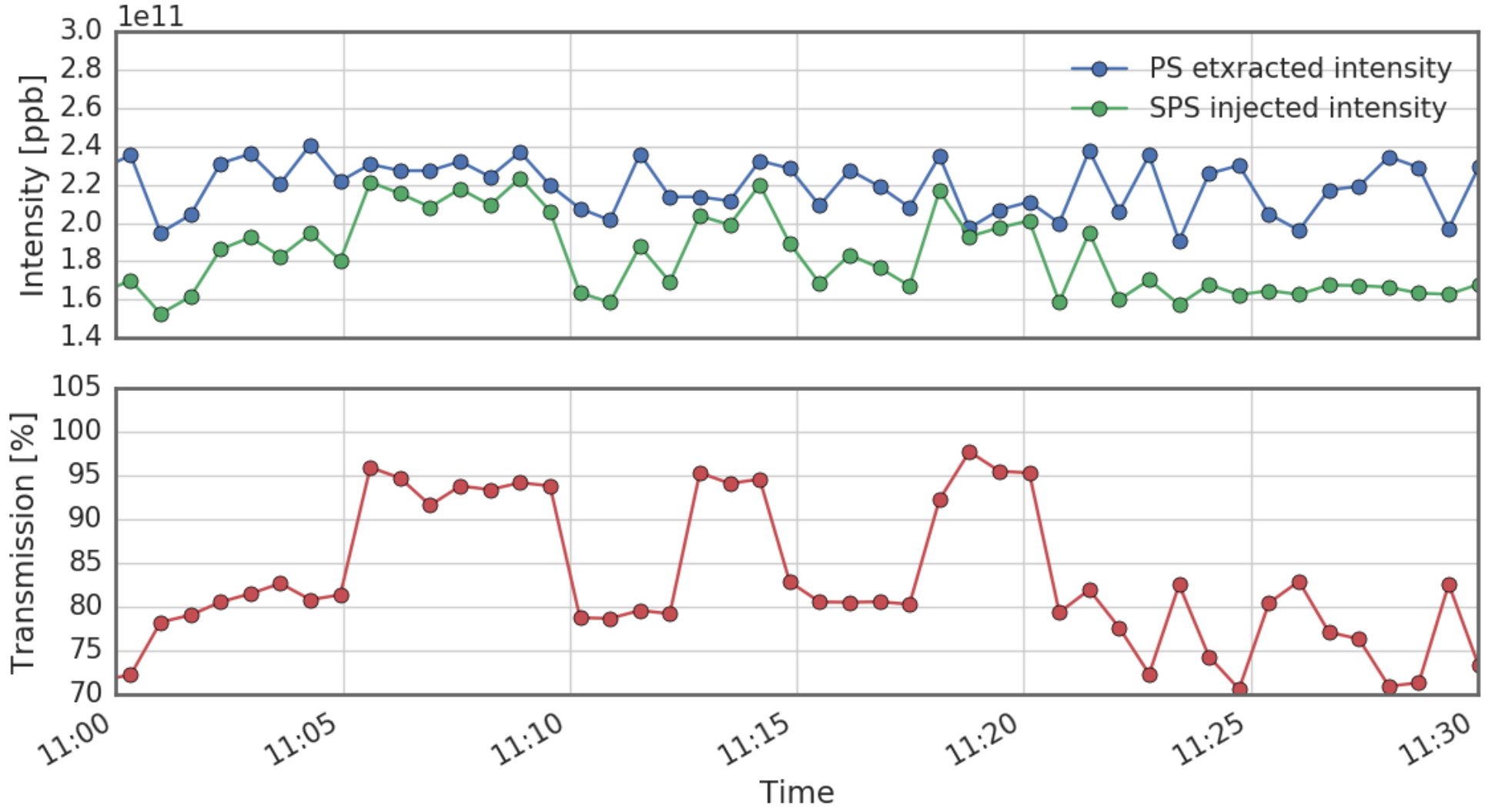
- The **transverse damper** was kept active to control the large amplitude low frequency motion and prevent saturation of the ADCs rendering the system ineffective.

- With the **two systems active**, the **losses are significantly reduced** and comparable to what is observed in absence of TMCI.



Intensity scan

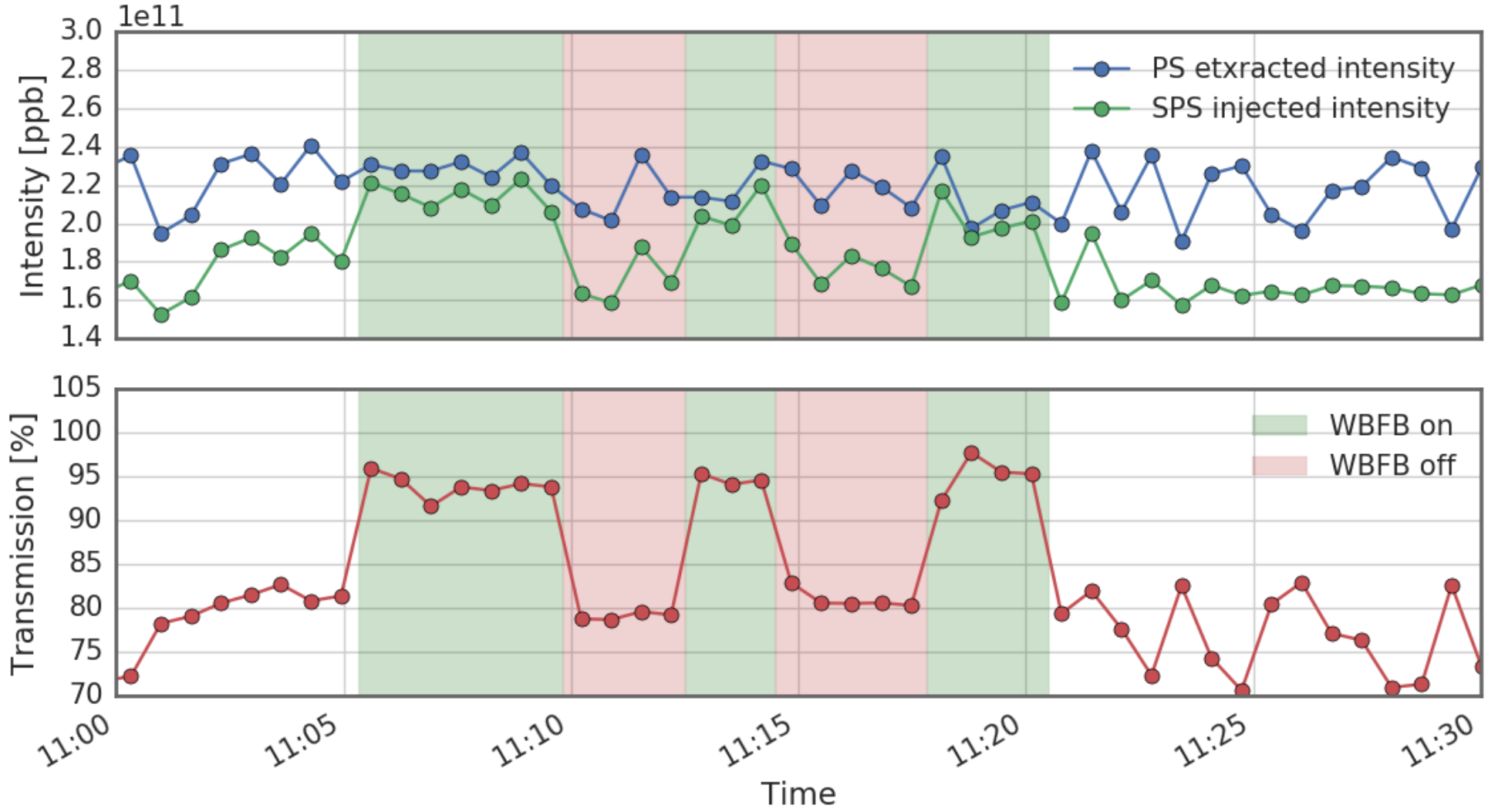
- The wideband feedback loop **was closed and opened several times** over a period of half an hour **to ensure reproducibility** of both the TMCI and the stabilization of the latter.



Intensity scan

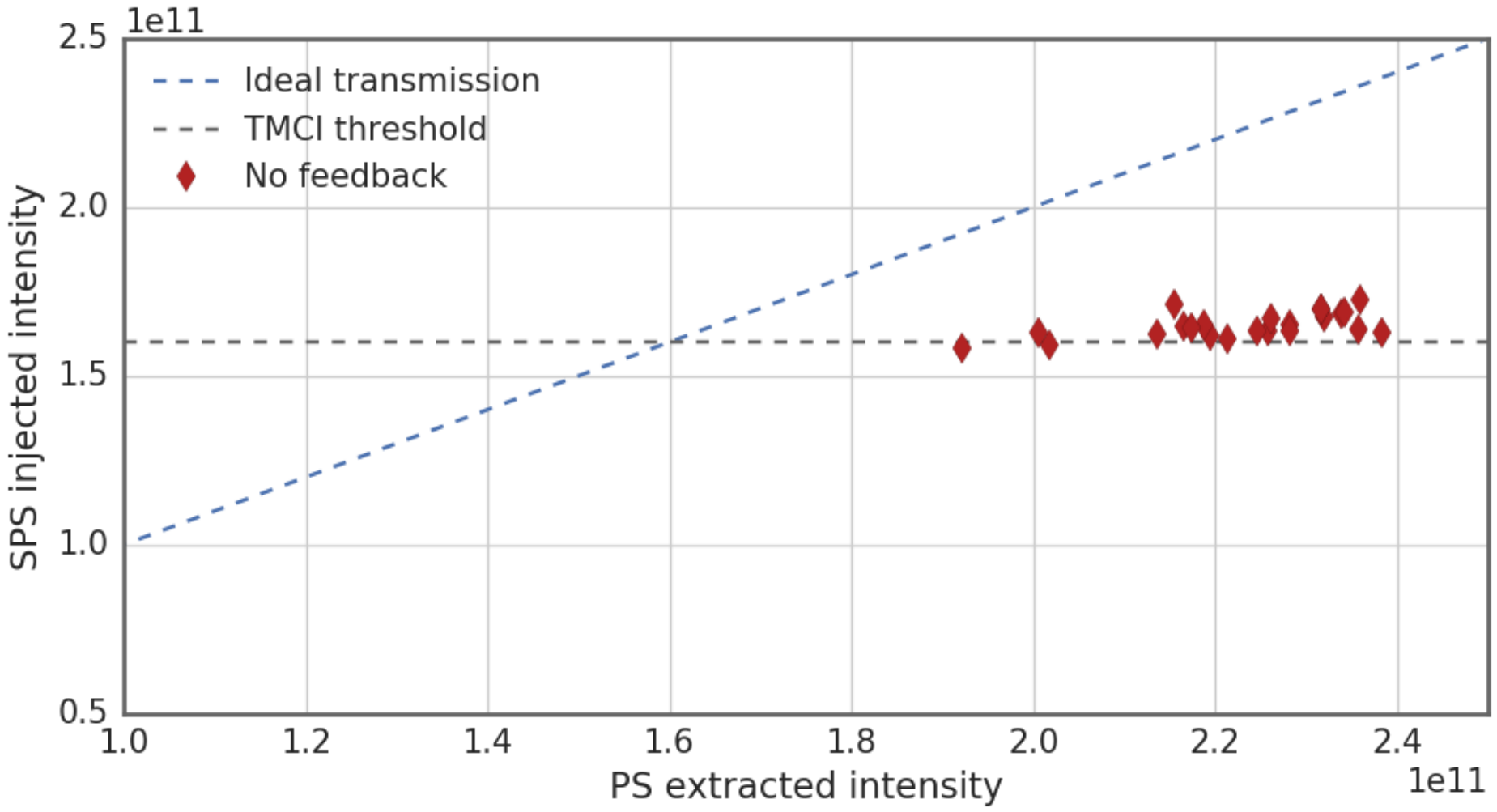
- The wideband feedback loop **was closed and opened several times** over a period of half an hour **to ensure reproducibility** of both the TMCI and the stabilization of the latter.

- There is a **clear correlation** between transmission and open/closed loop configuration.



Intensity scan

- One can now make a comparison of the intensity reach (average over first 250 ms) in the different configurations:
  - **No feedback**



Intensity scan

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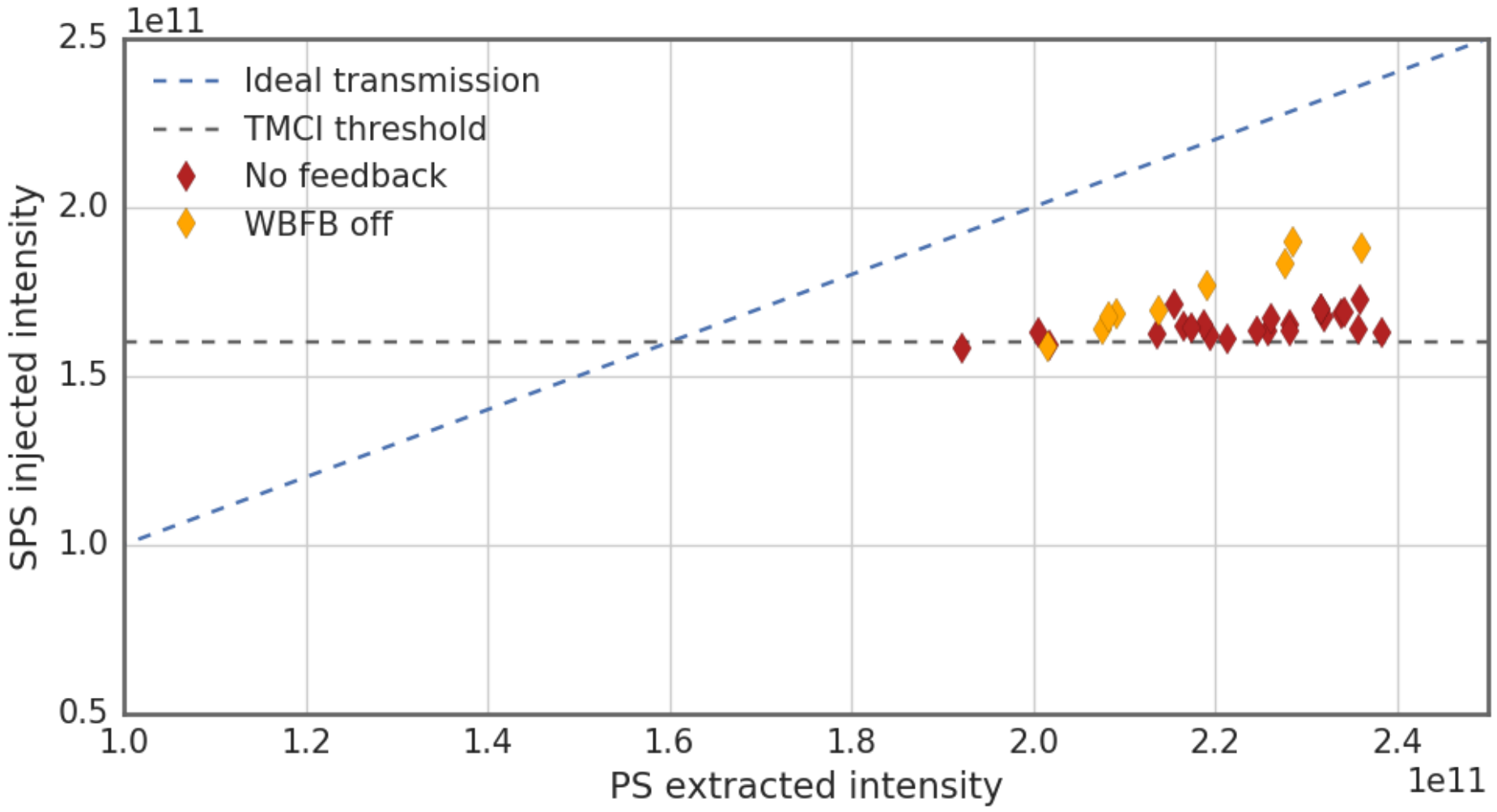
  - **No feedback**
  - **Transverse damper**



Intensity scan

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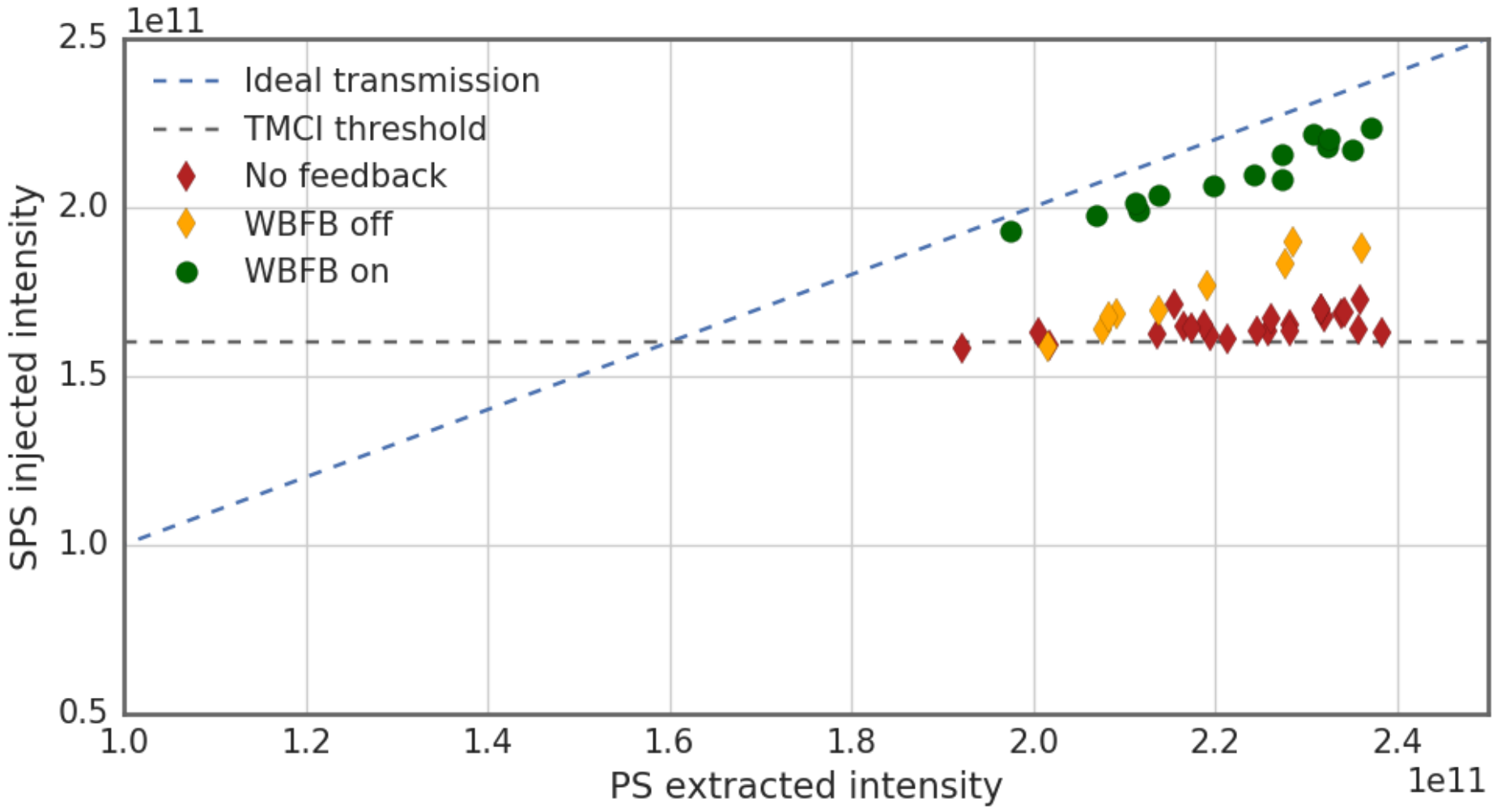
  - **No feedback**
  - **Transverse damper**
  - **Transverse damper + wideband feedbacl**

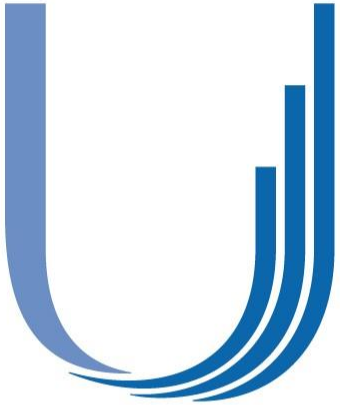


Conclusions

- The **transverse mode coupling instability** has been identified and measured in Q22 optics in the SPS. The instability threshold is higher than for Q26 ad lower than for Q20 optics.

- The instability threshold is close to the 2.6e11 ppb required for LIU beams. There is little or no margin for operating at these intensity values.

- A configuration was found with the transverse damper operating in conjunction with the wideband feedback system having led to a successful mitigation of the TMCI.



LHC Injectors Upgrade

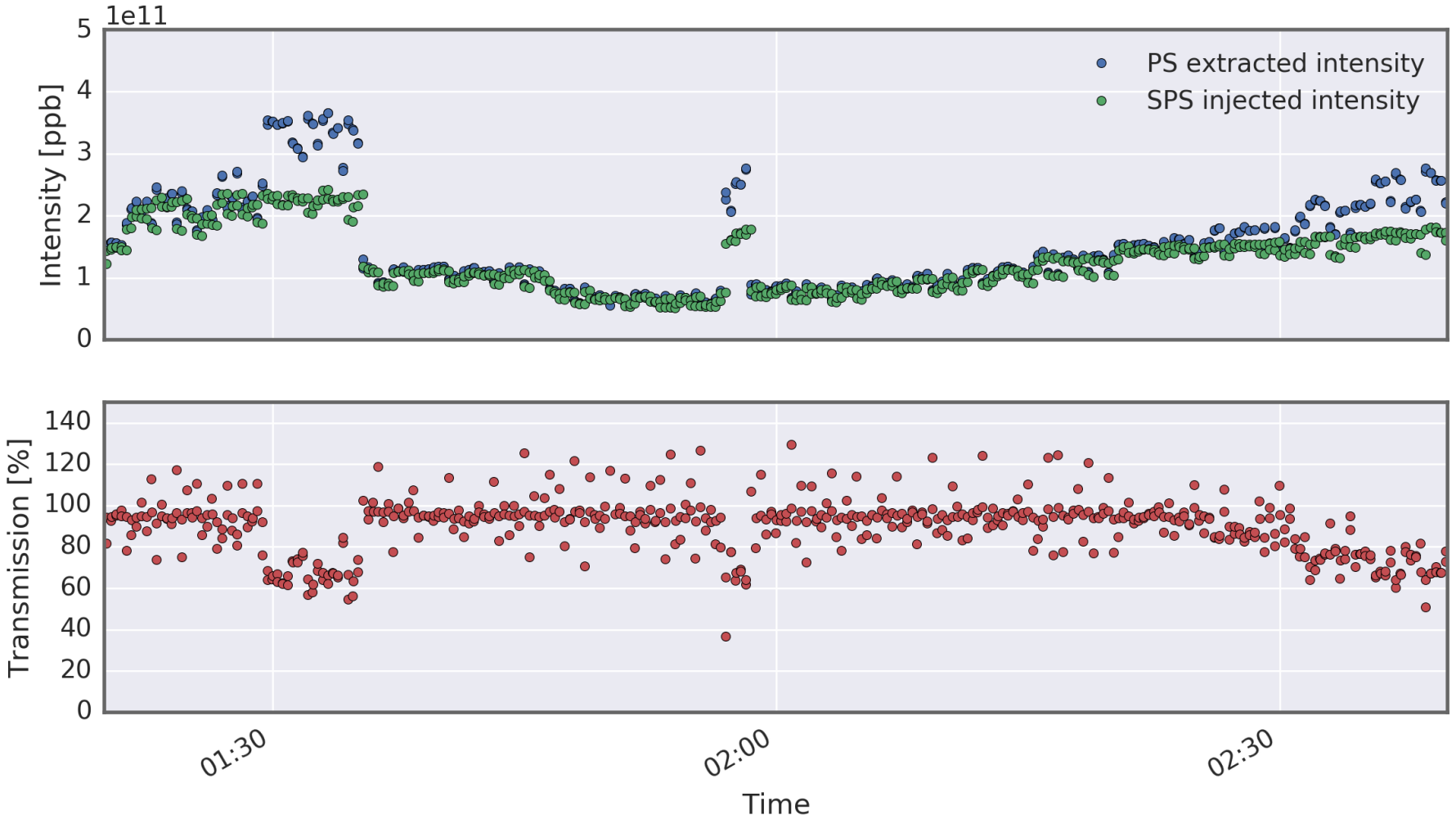
Framework and potential gains

- Transverse instabilities limit beam quality and machine performance and must be avoided.
- There are roughly two to three types of instabilities:
  - Slow headtail – no threshold; usually cured by machine non-linearities
  - Fast headtail (TMCI) – threshold effect usually determines the maximum intensity reach
  - Coupled bunch – usually low frequency and taken care of by the transverse feedback system
- In the SPS, to date, the first two types of instabilities could pose potential problems

Fast headtail

- Poses intensity limit – mitigated by moving to alternative optics (Q20, Q22) with faster synchrotron tunes
- Modified optics has implications – also for RF power
- Mitigation of fast headtail could open new options for the choice of optics and substantially widen the considerable parameter range

What are the gains obtained by the freedom to move to different optics without having to worry about TMCI?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