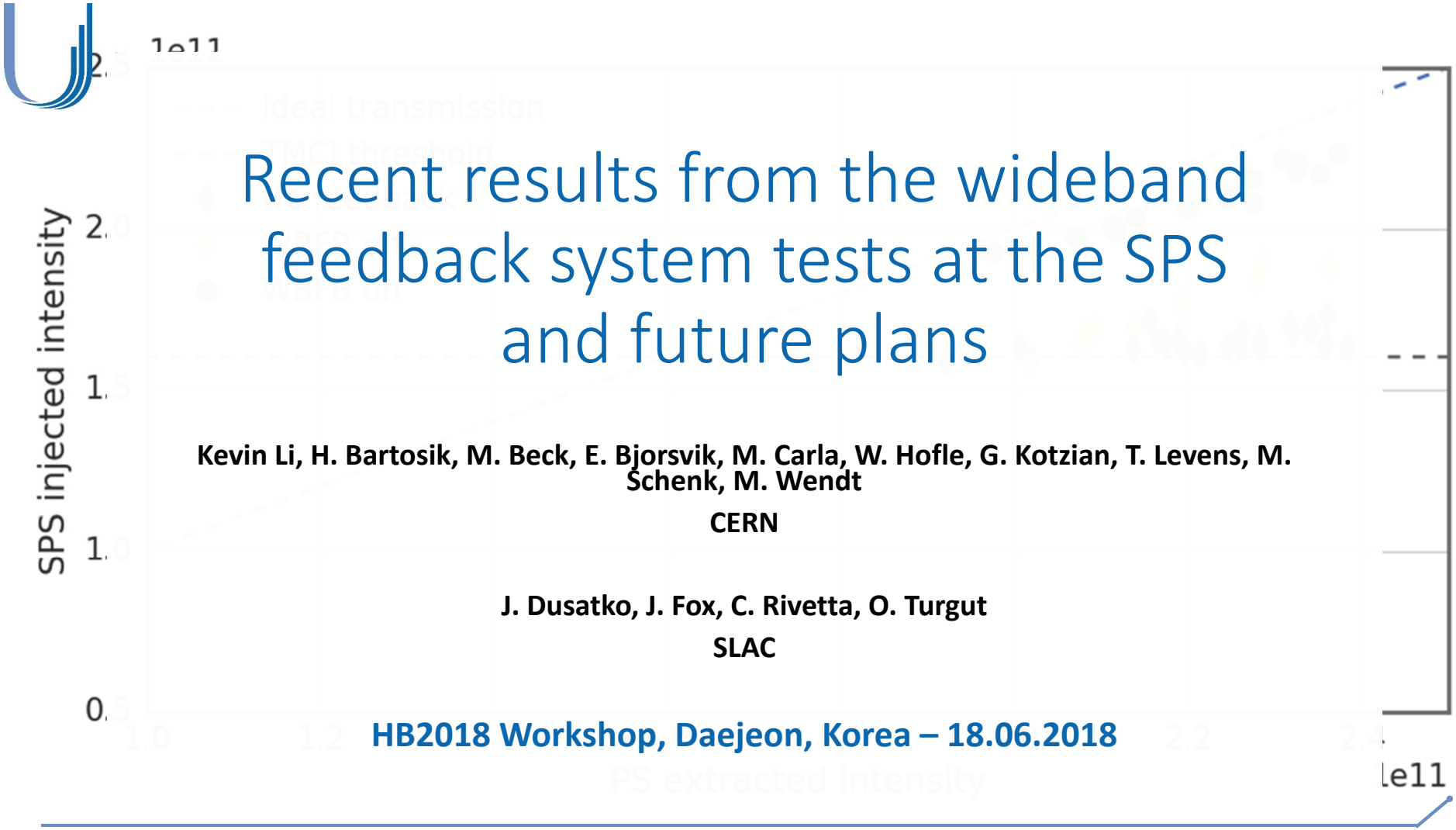


Recent results from the wideband feedback system tests at the SPS and future plans

Kevin Li, H. Bartosik, M. Beck, E. Bjorsvik, M. Carla, W. Hofle, G. Kotzian, T. Levens, M. Schenk, M. Wendt

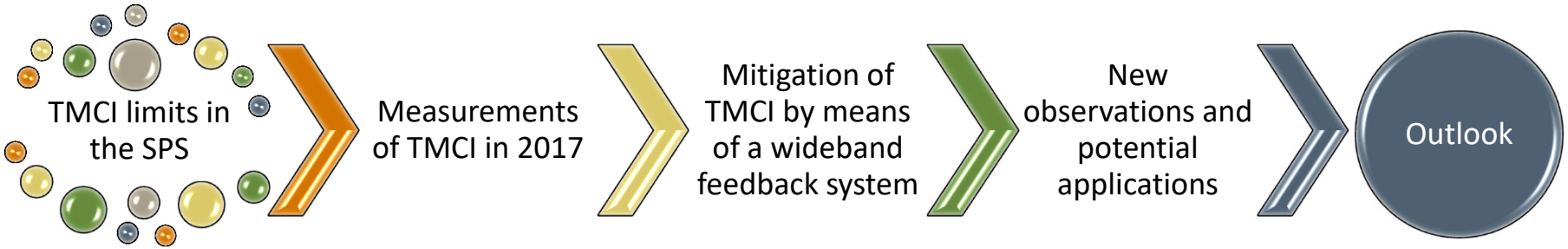
CERN

J. Dusatko, J. Fox, C. Rivetta, O. Turgut

SLAC

HB2018 Workshop, Daejeon, Korea – 18.06.2018

Outline


TMCI limits in the SPS
Measurements of TMCI in 2017
Mitigation of TMCI by means of a wideband feedback system
New observations and potential applications
Outlook

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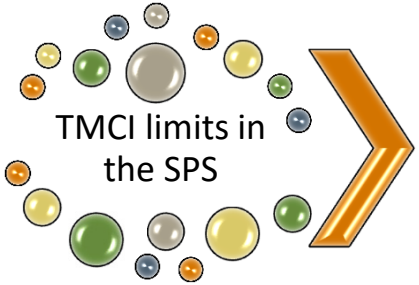

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Intensity limitation in the SPS

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- To deliver the required brightness for the HL-LHC era, the CERN injector complex **will undergo significant upgrades** under the LHC Injectors Upgrade project (LIU).

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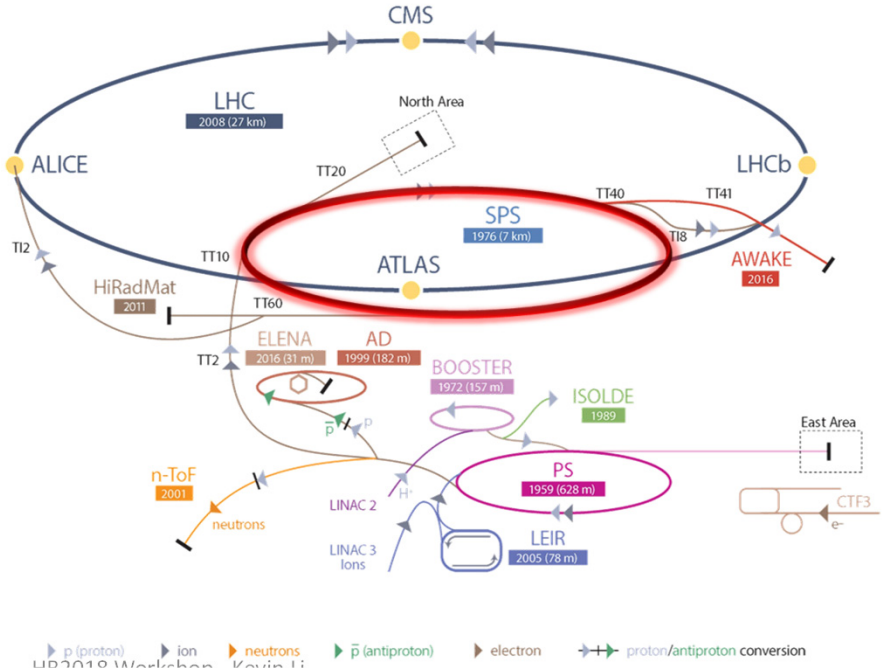

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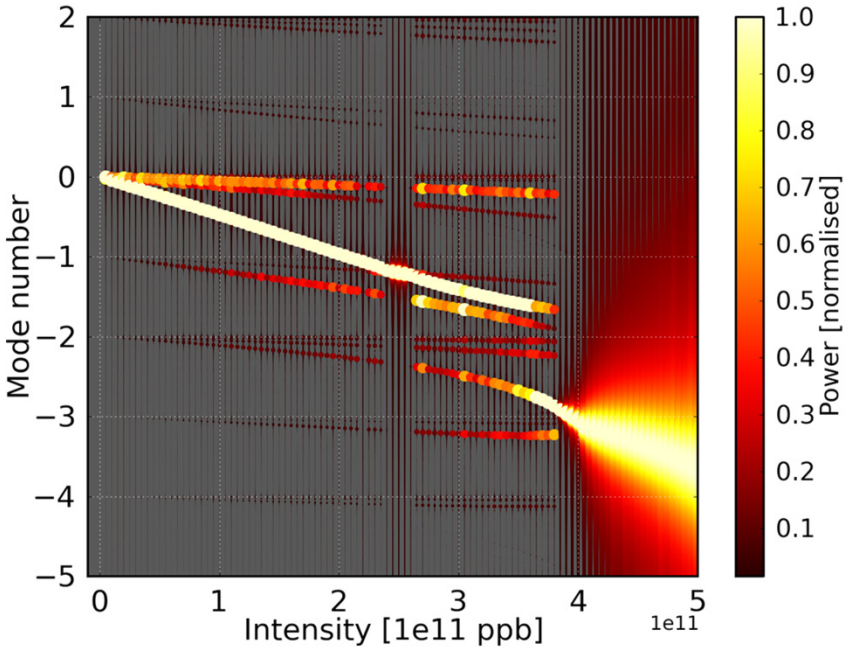
- One of the bottlenecks towards the high brightness beams are **intensity limitations in the SPS**.

- Transverse instabilities, in particular **TMCI and electron cloud instabilities**, have posed an intensity limit in the past. The SPS has the flexibility to accommodate **modified optics with lower transition energies**. The original optics with an integer tune of 26 – *Q26 optics* – has a **TMCI threshold at 1.4e11 ppb**. Other possible optics have an integer tune of 22 and 20 – *Q22 optics* and *Q20 optics* – with correspondingly higher TMCI thresholds. The **target injected intensity for LIU beams is 2.6e11 ppb**.

- To date, the SPS is operated using the Q20 optics. Recently, the **Q22 optics has become and interesting option** for LIU. For this reason, measurement have been carried out in the past year, to evaluate the potential and limitations of this optics.

Transverse mode coupling instability in the SPS

- TMCI in the SPS (modeled using a broadband resonator impedance at around 1.3GHz) for the case of Q20 optics.



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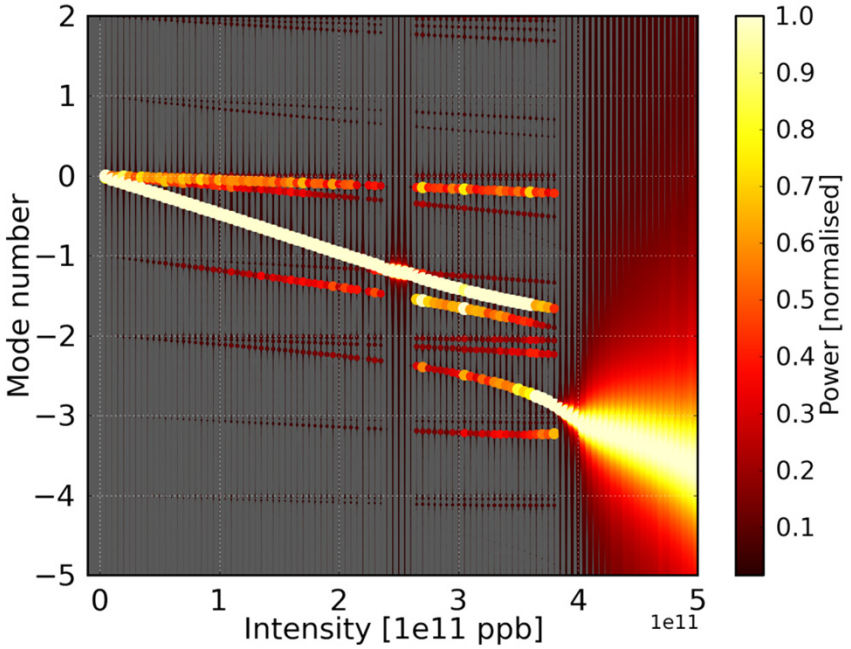

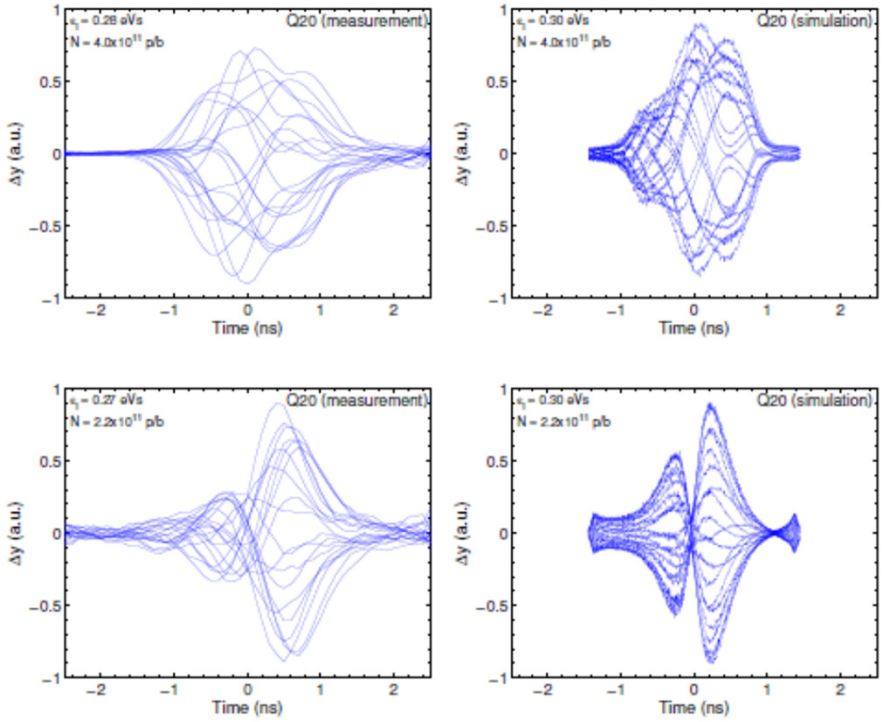

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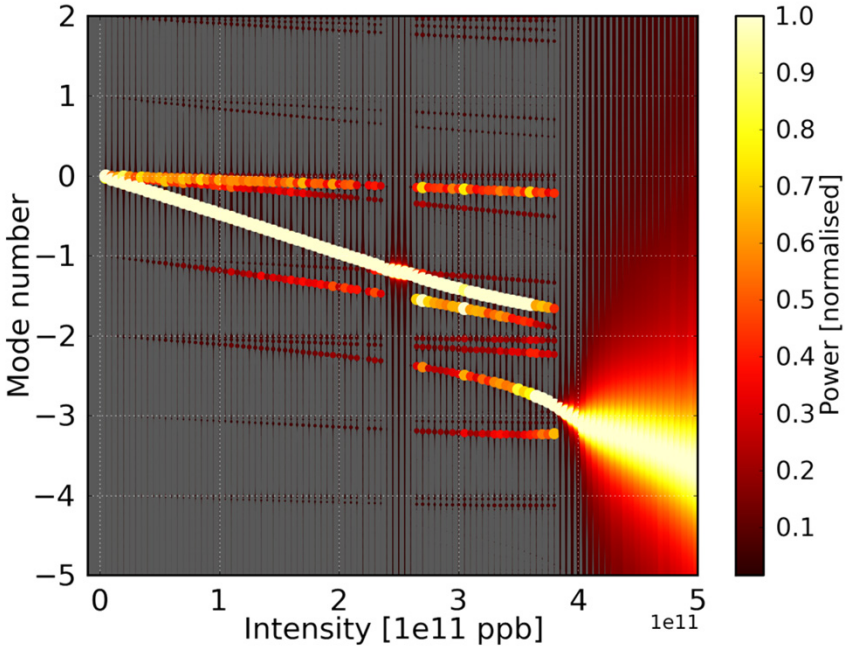

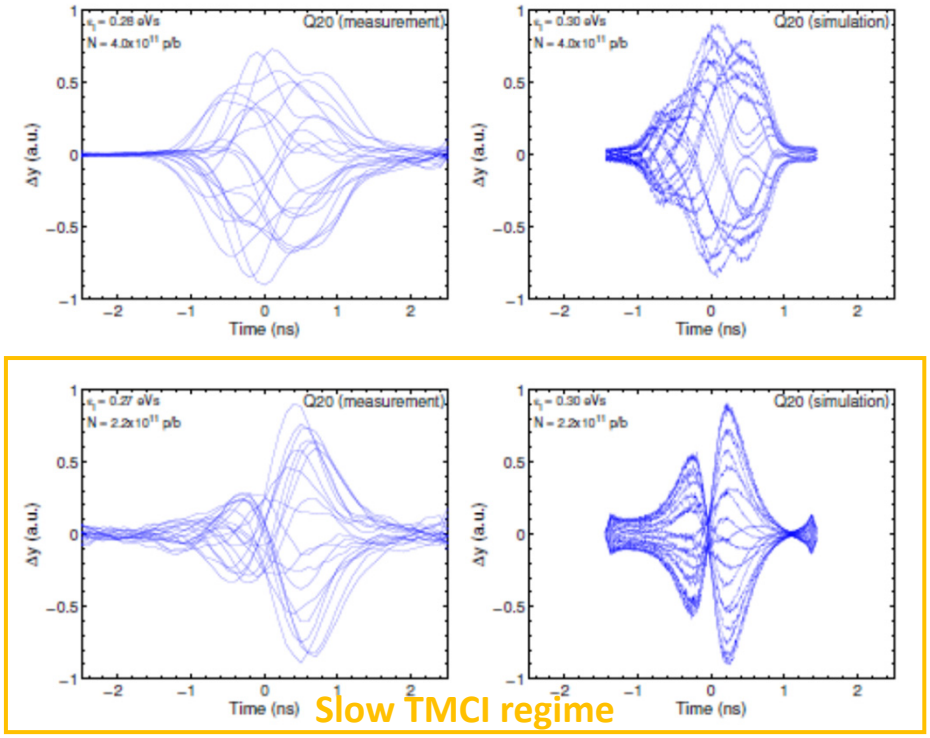

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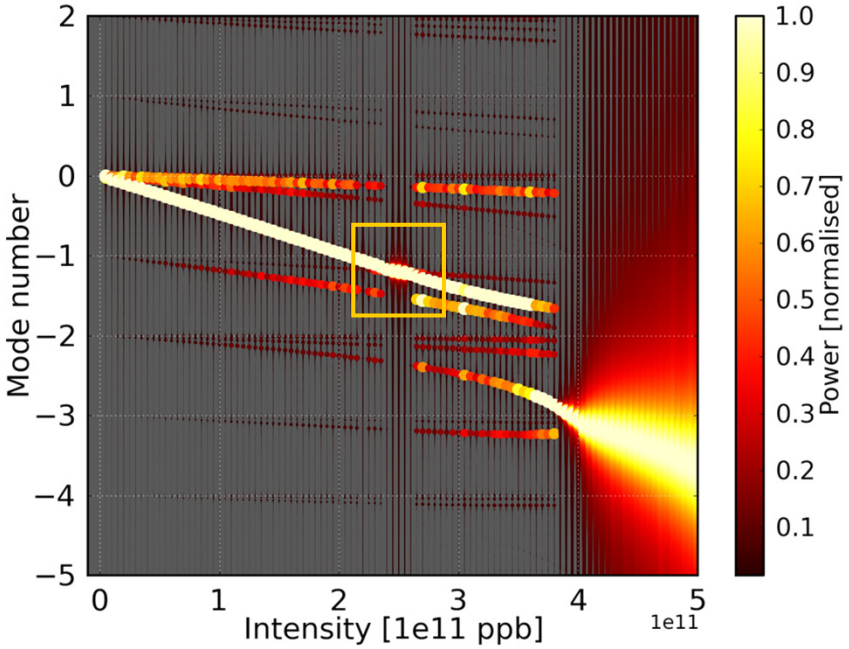

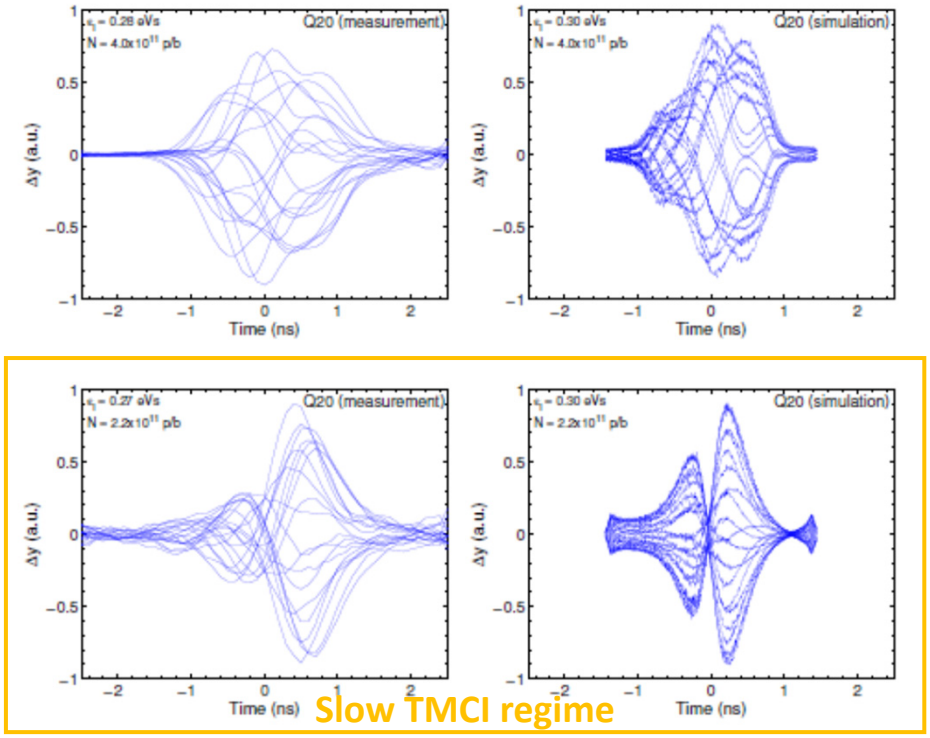

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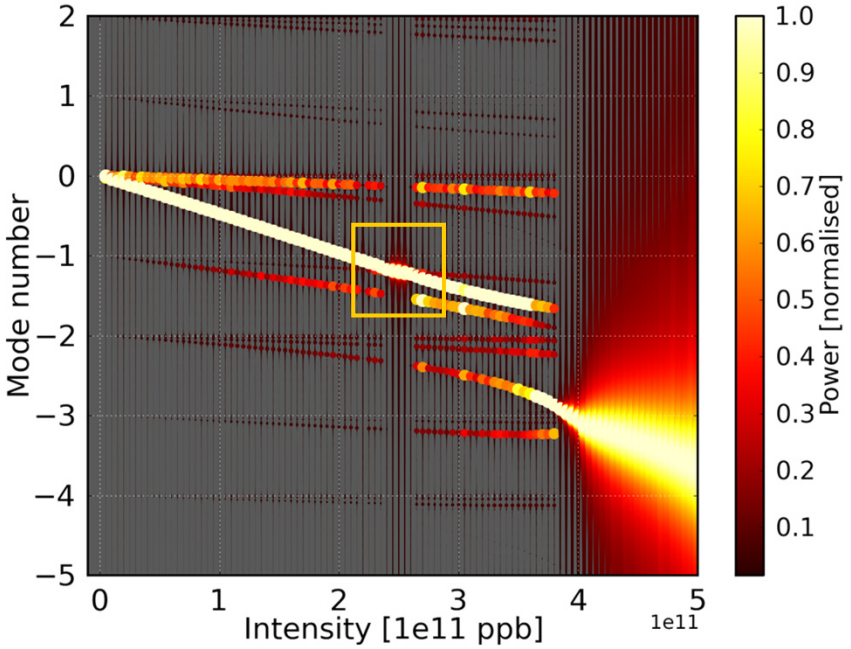

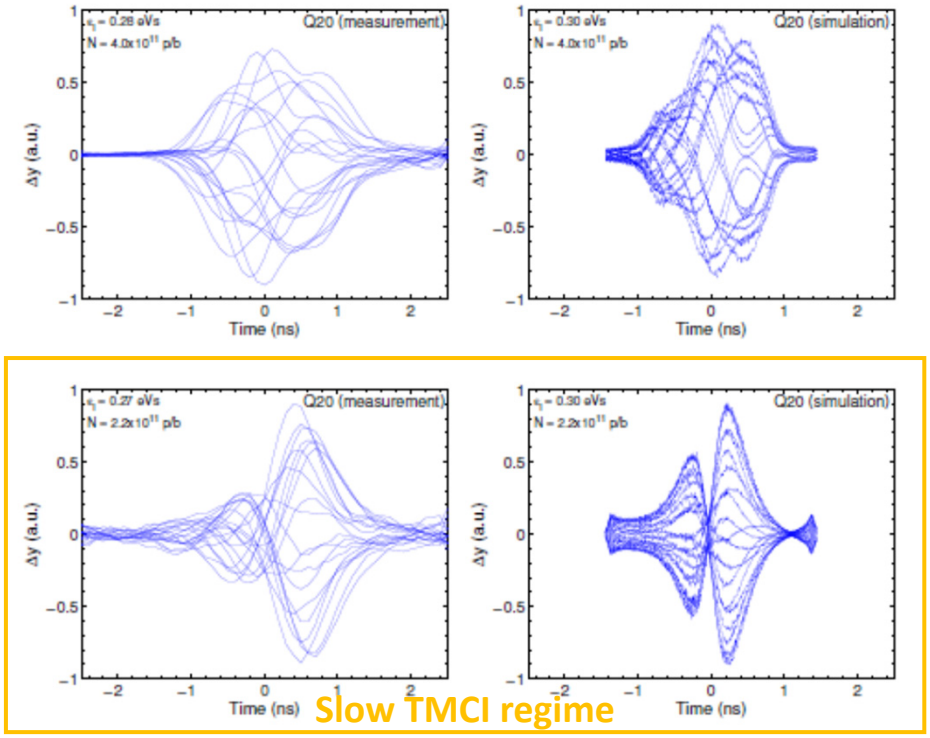

H. Bartosik - CERN-THESIS-2013-257

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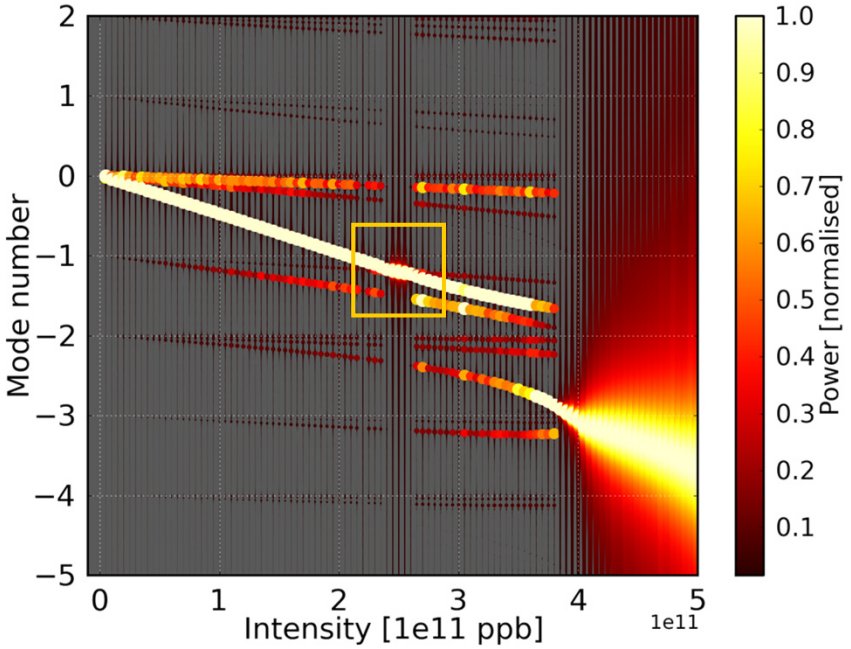

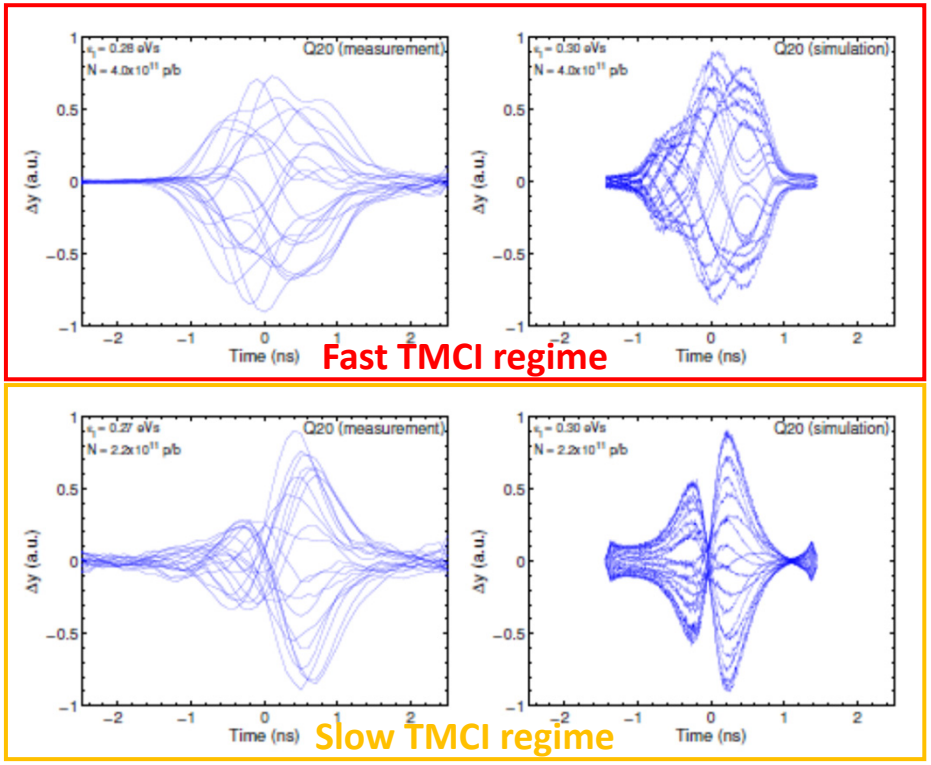

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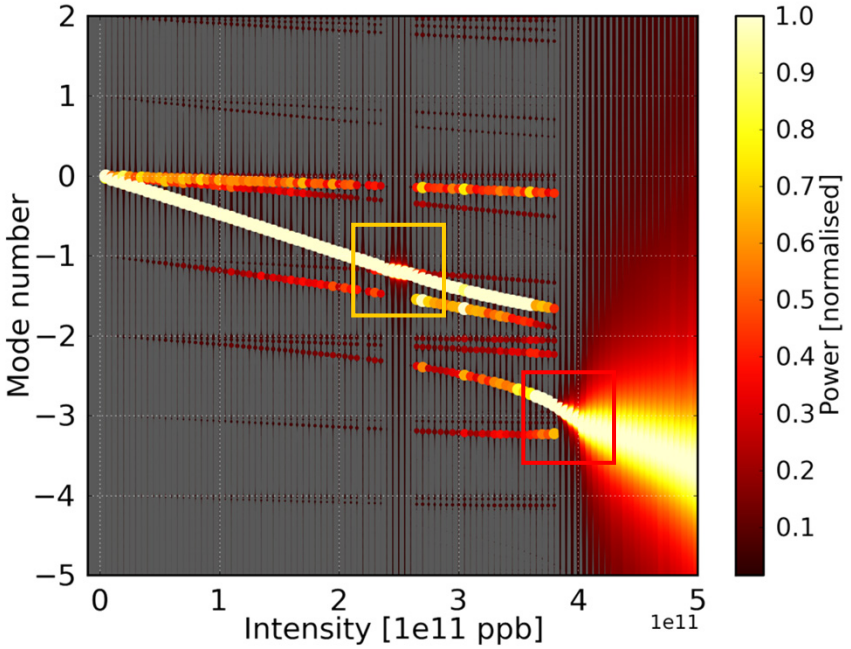
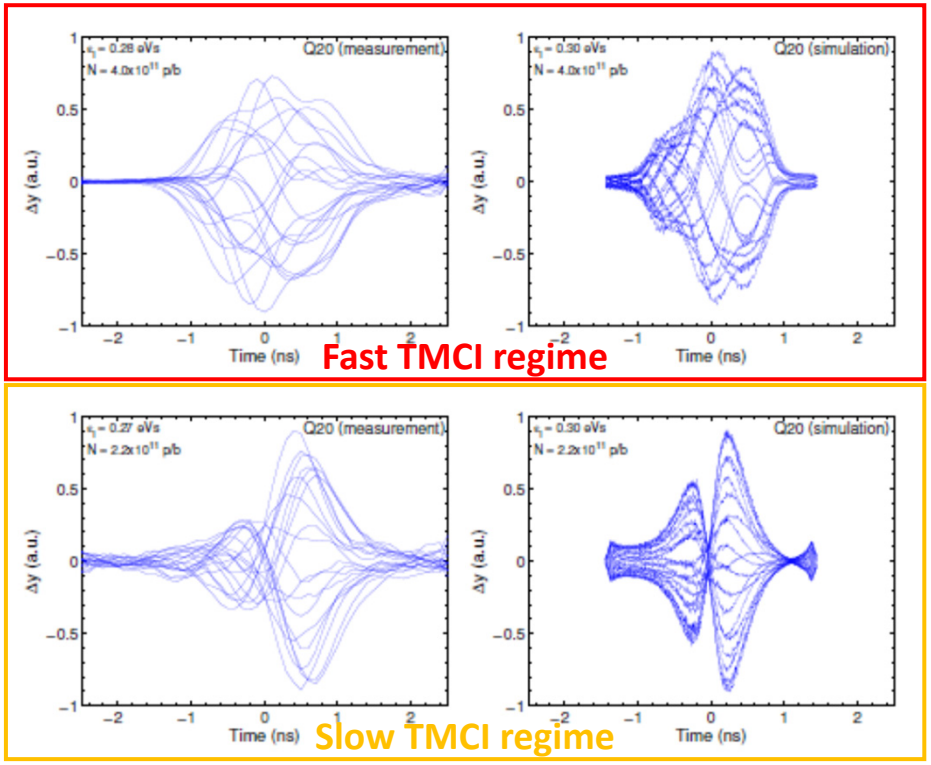
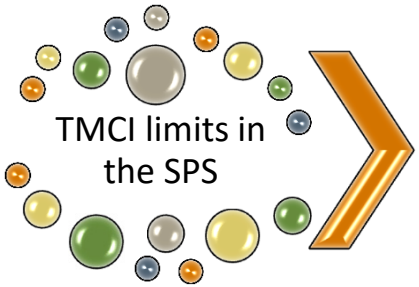




H. Bartosik - CERN-THESIS-2013-257

Outline



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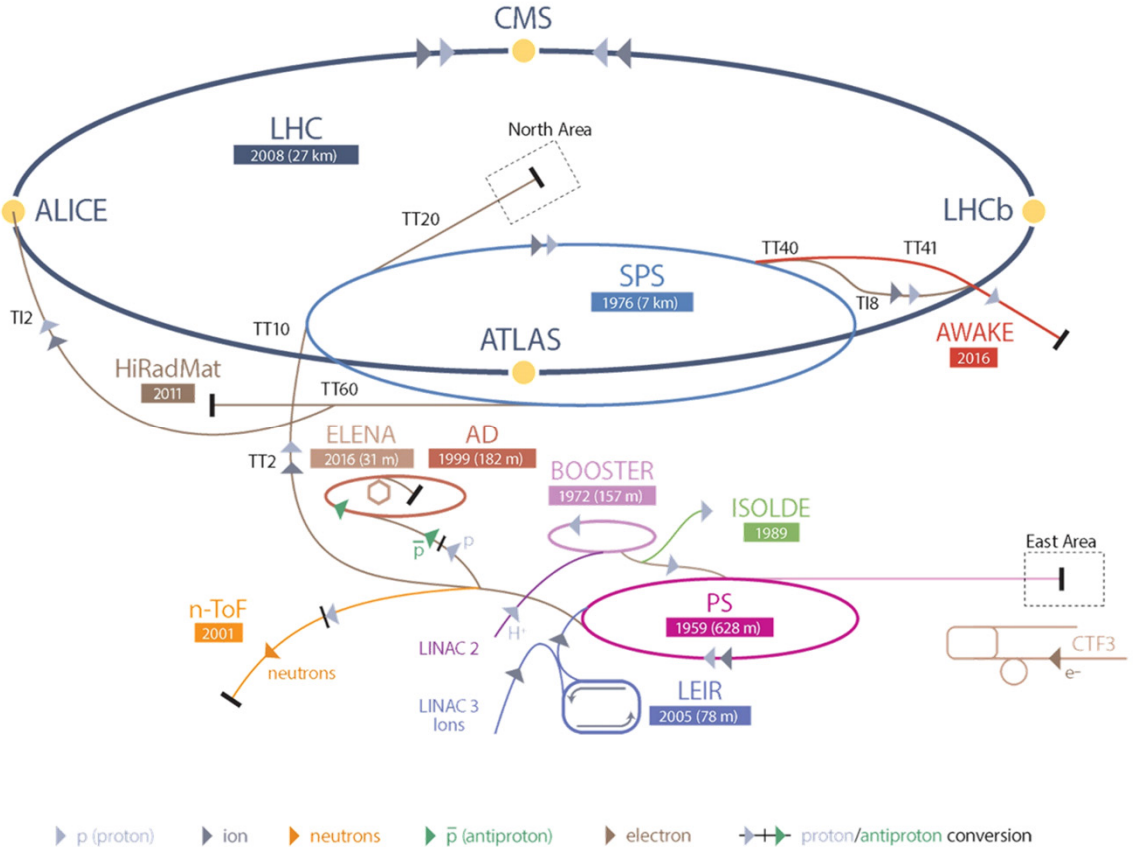

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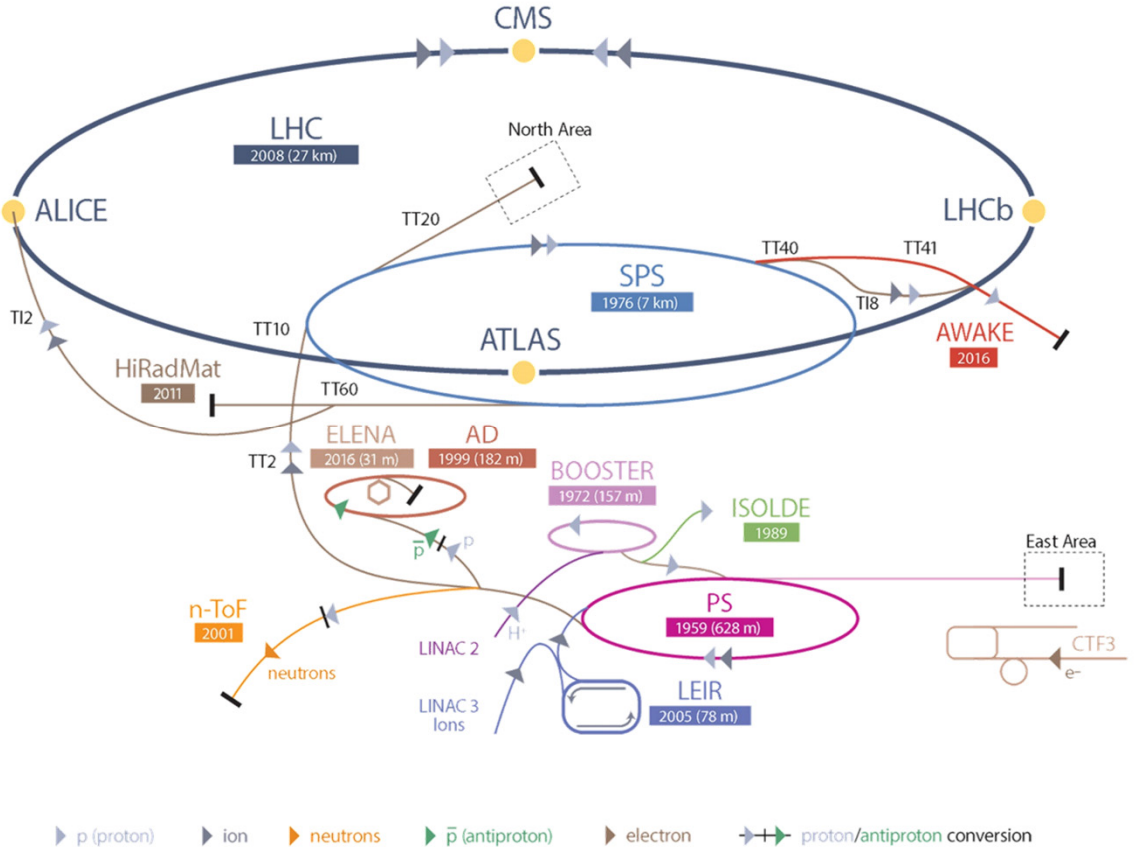

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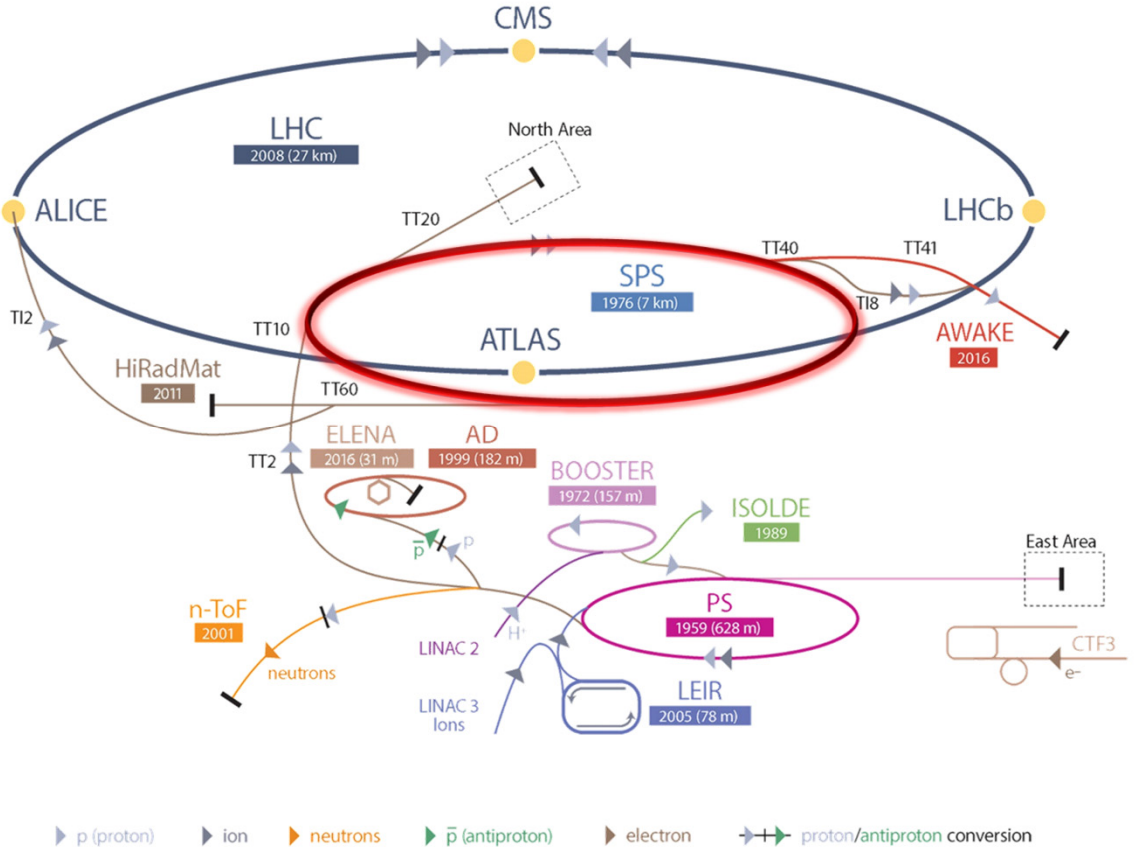

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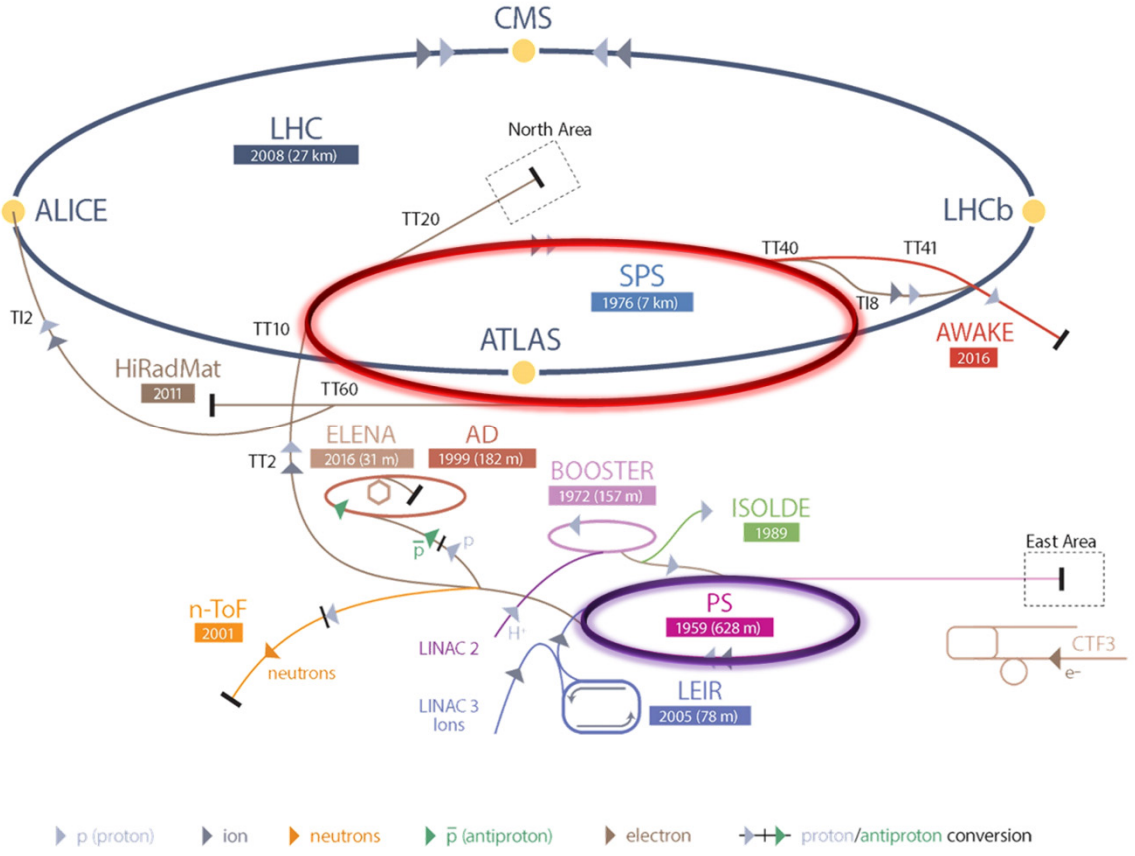

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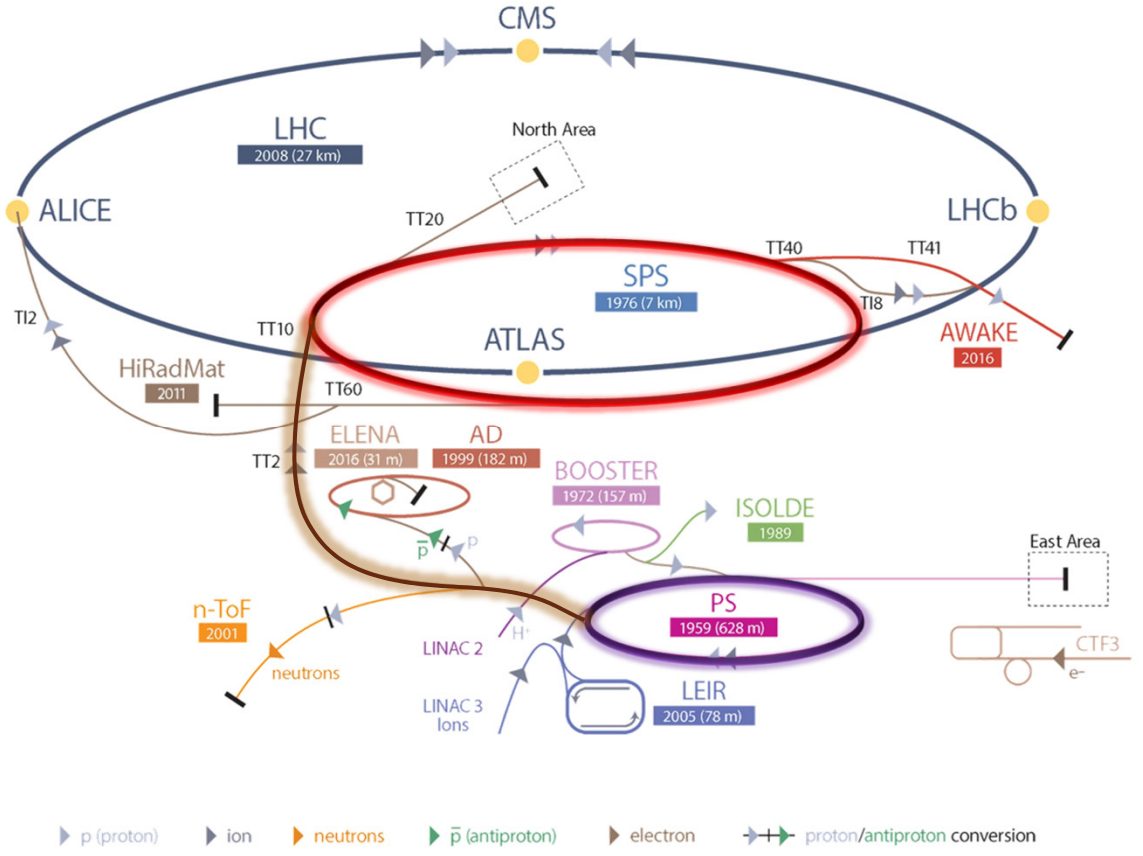
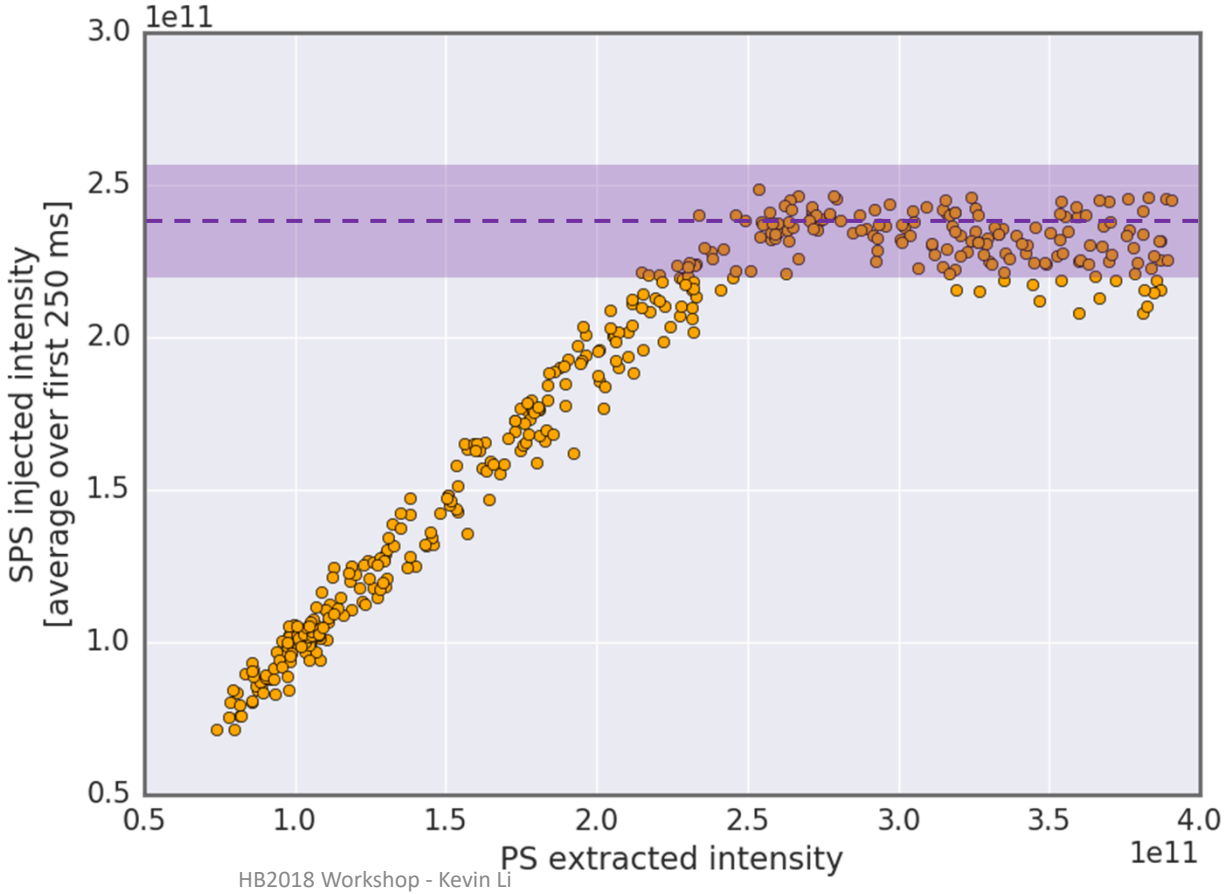


TMCI threshold from intensity scan in Q22 optics



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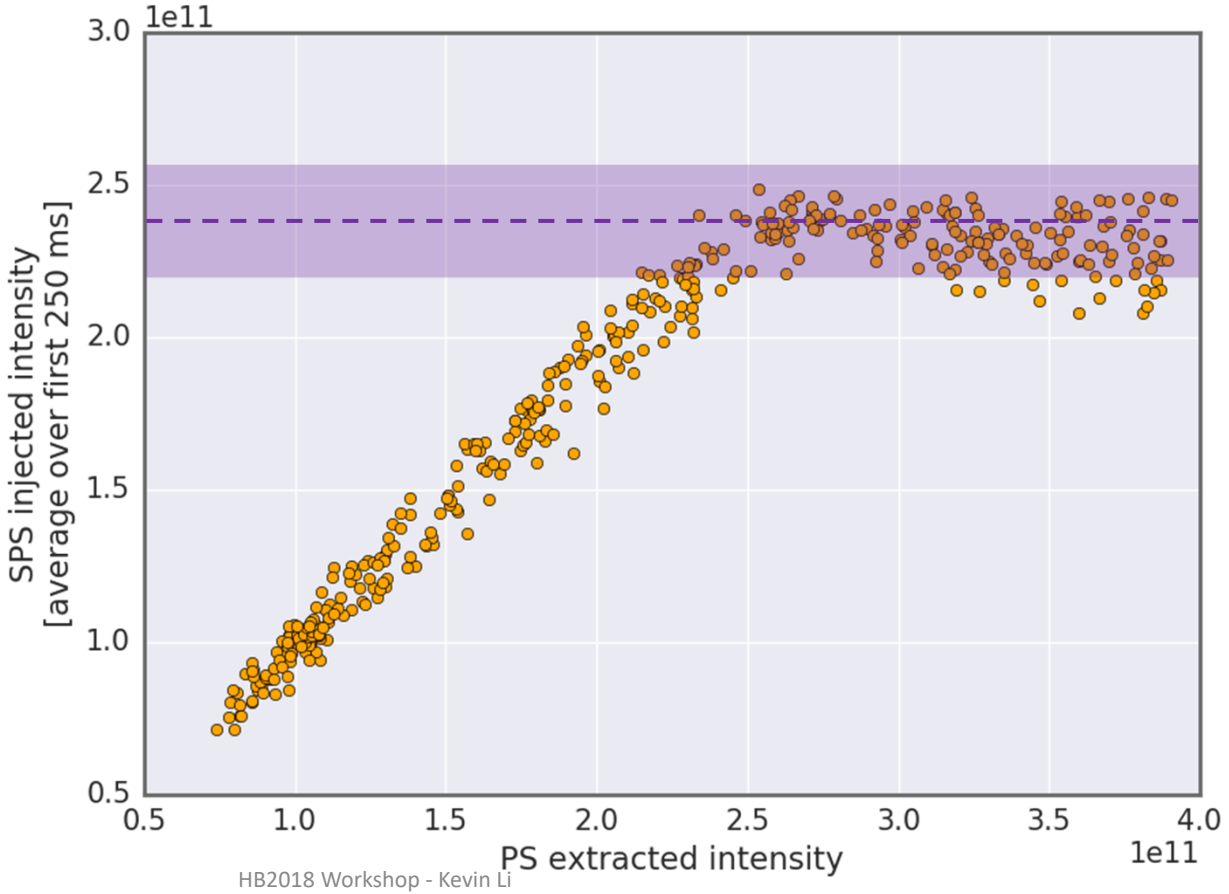

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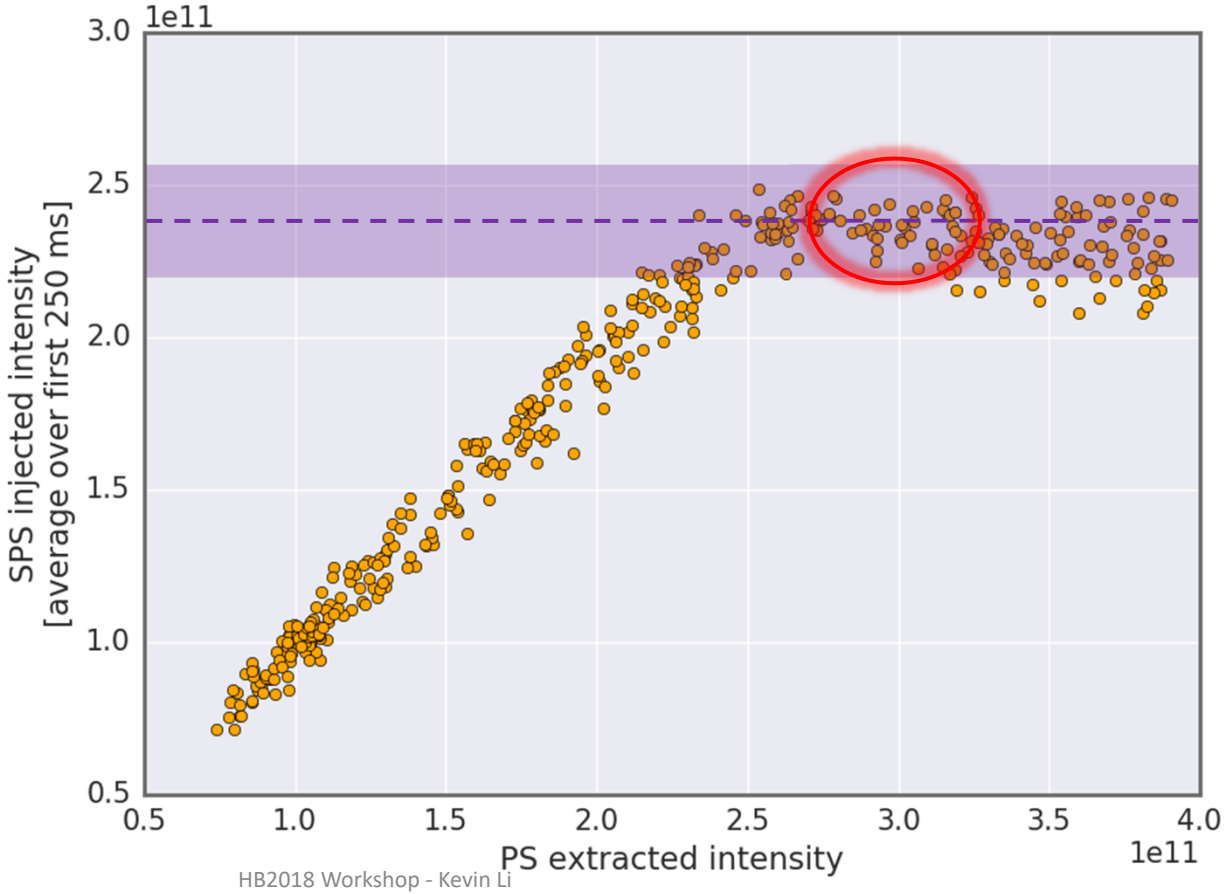

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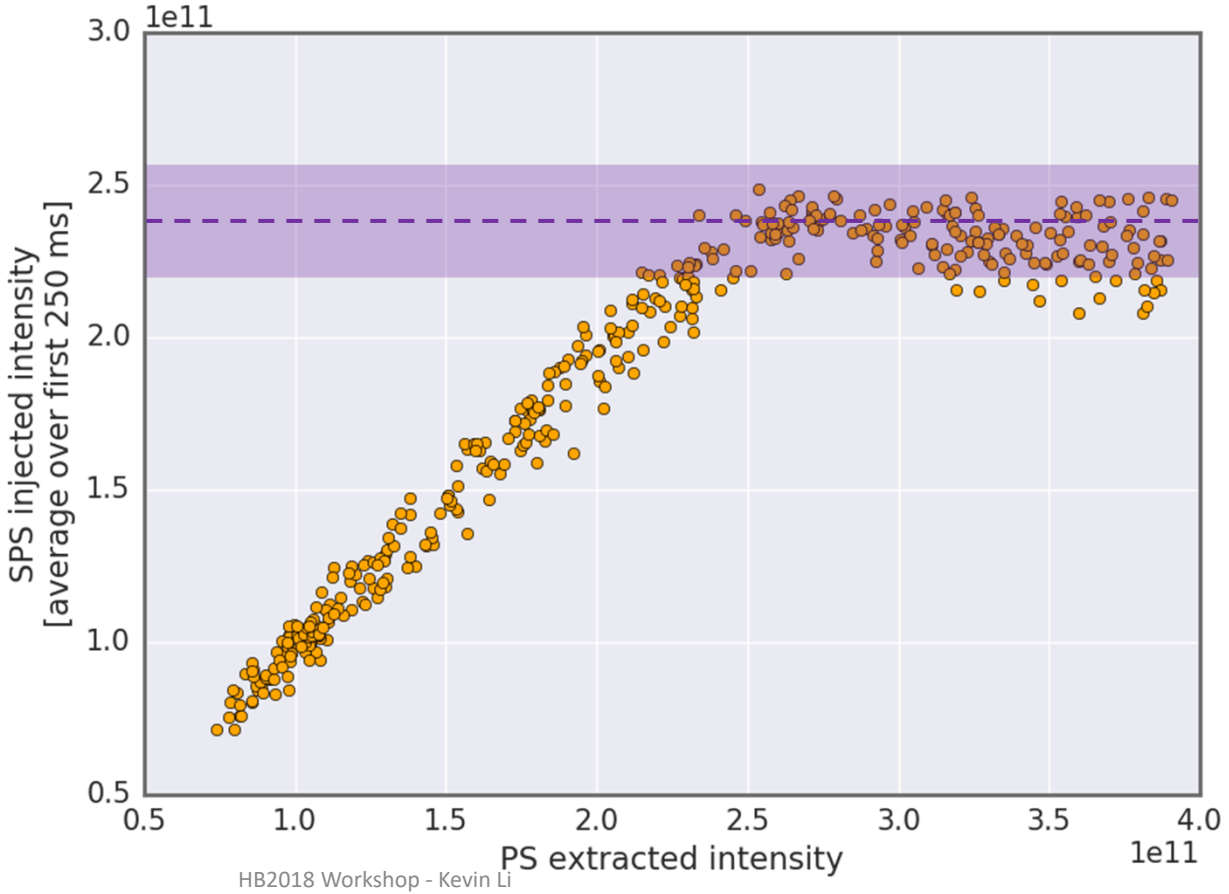

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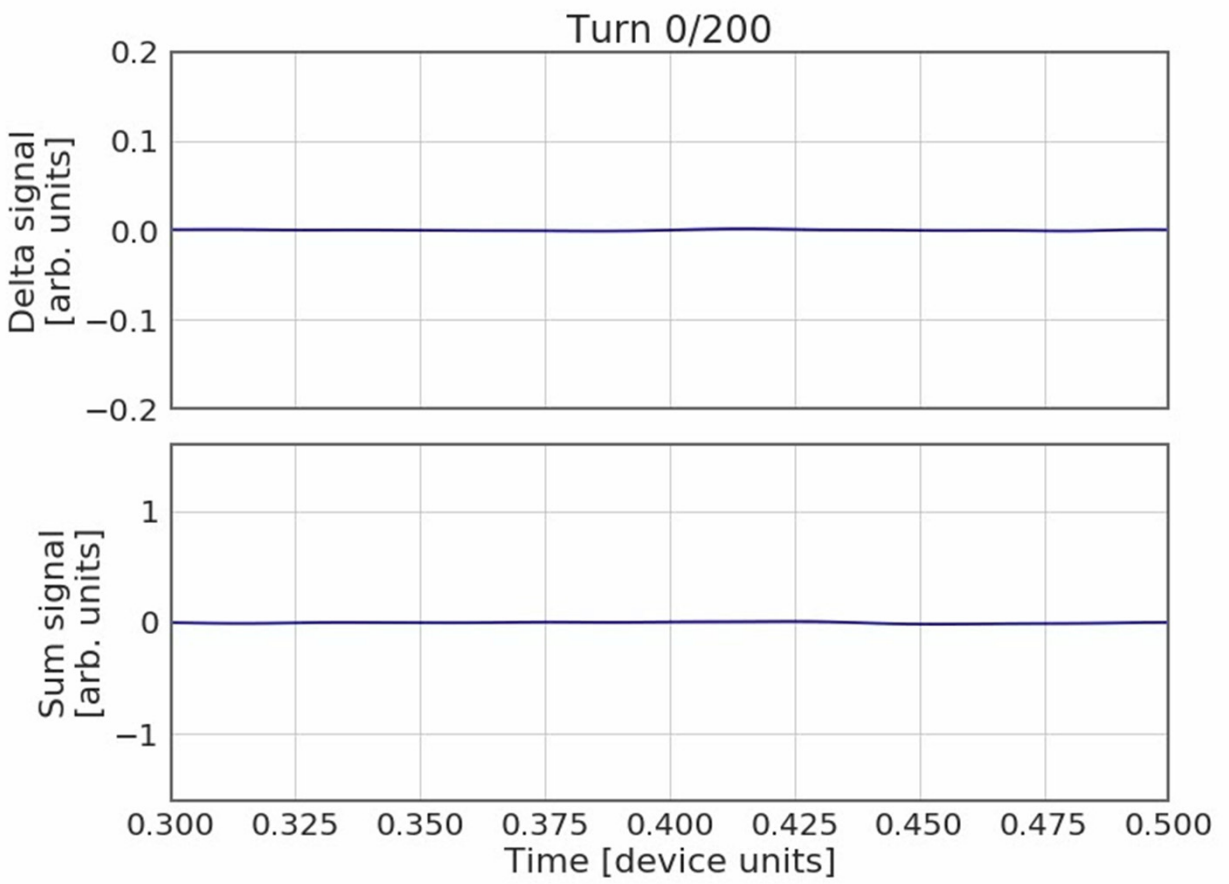

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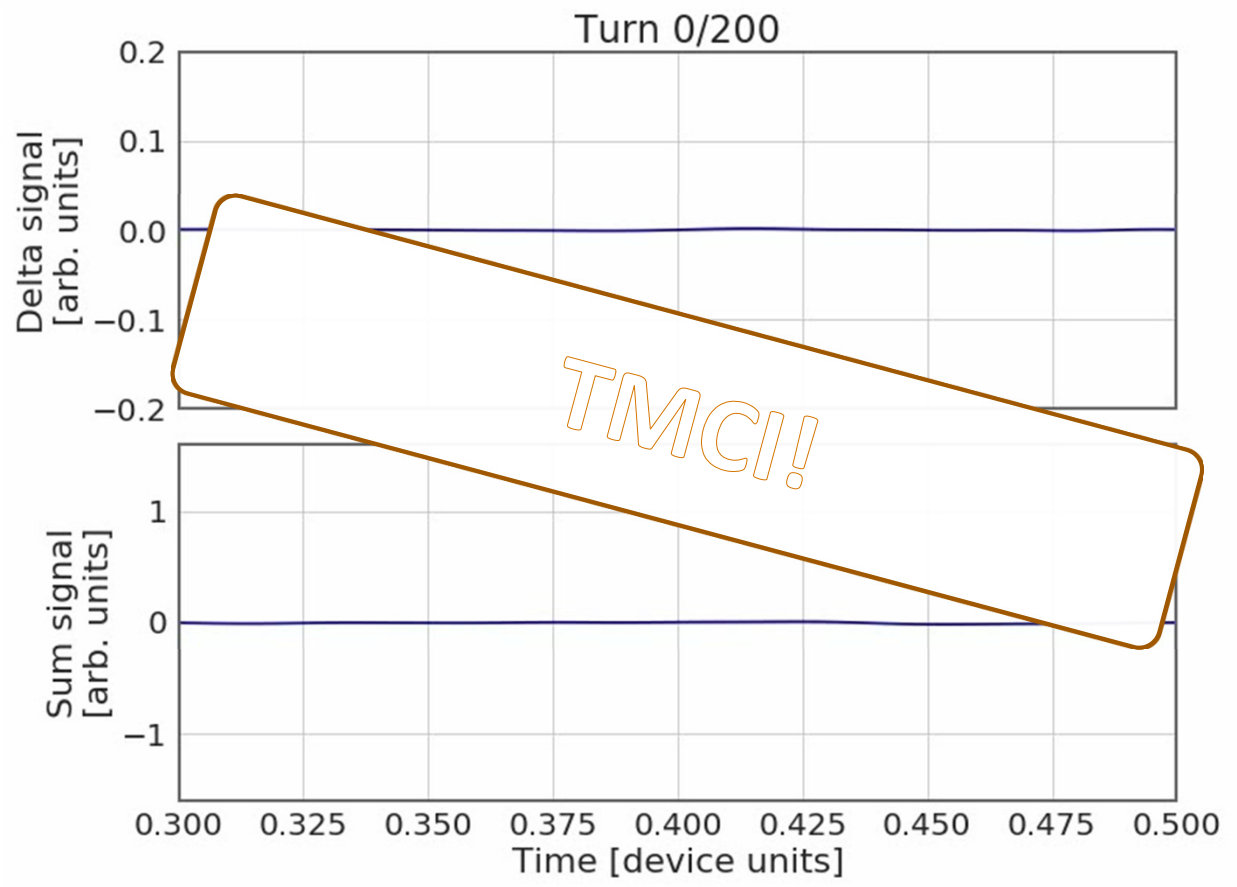

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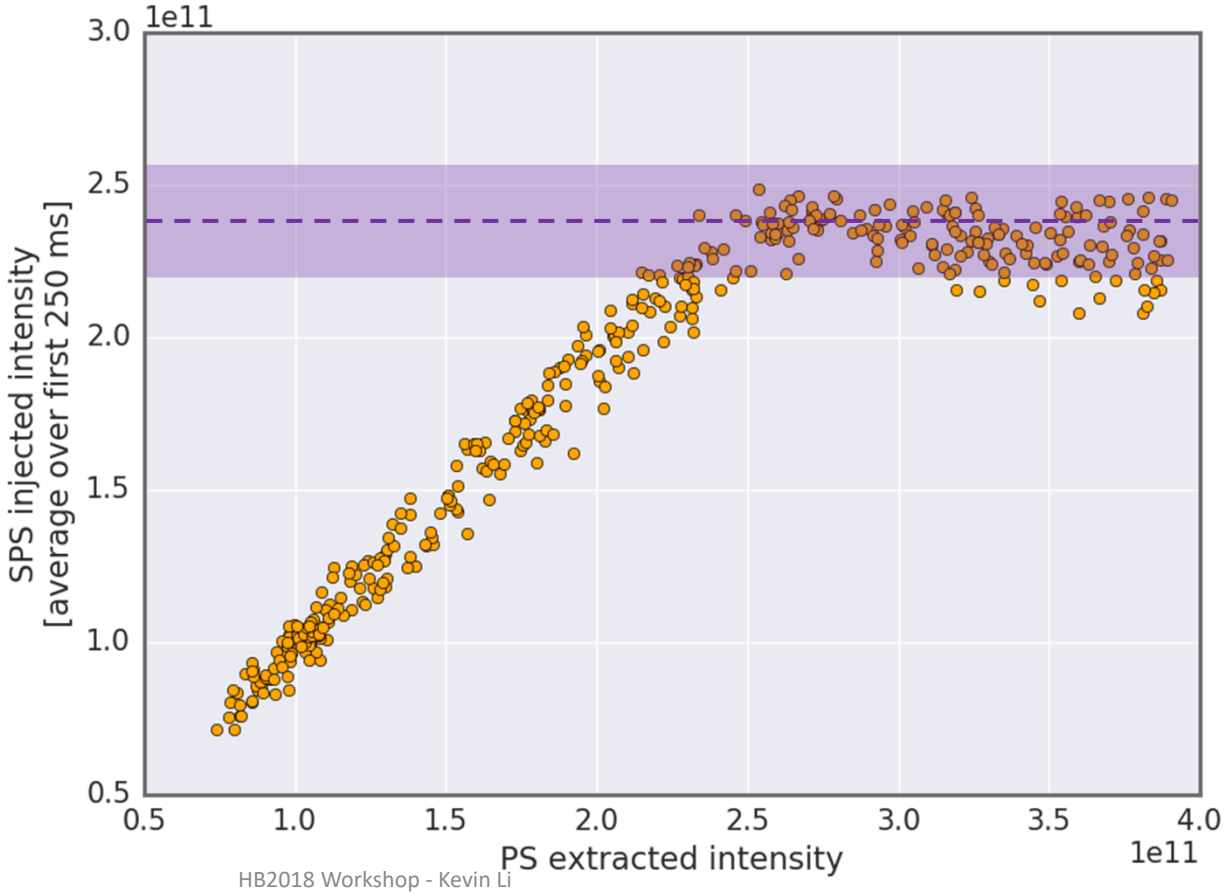

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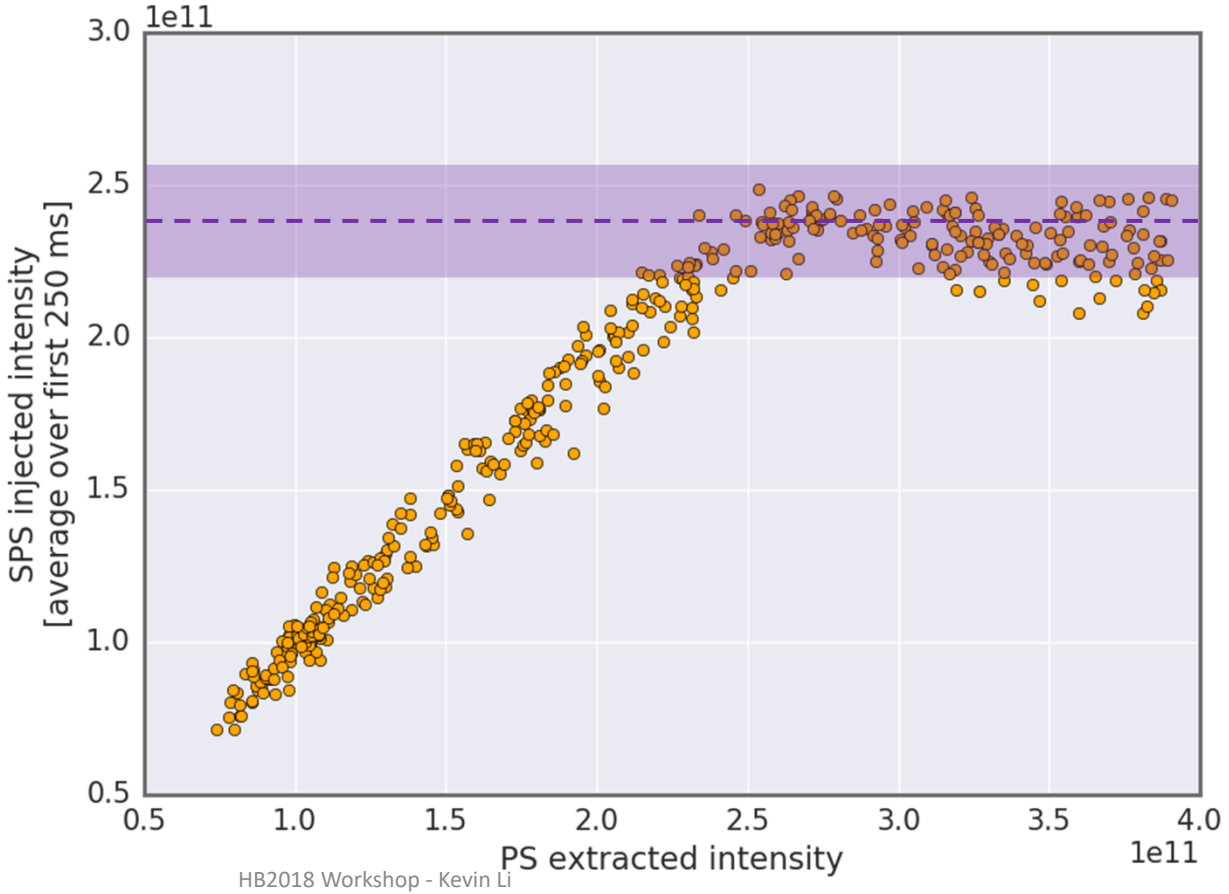

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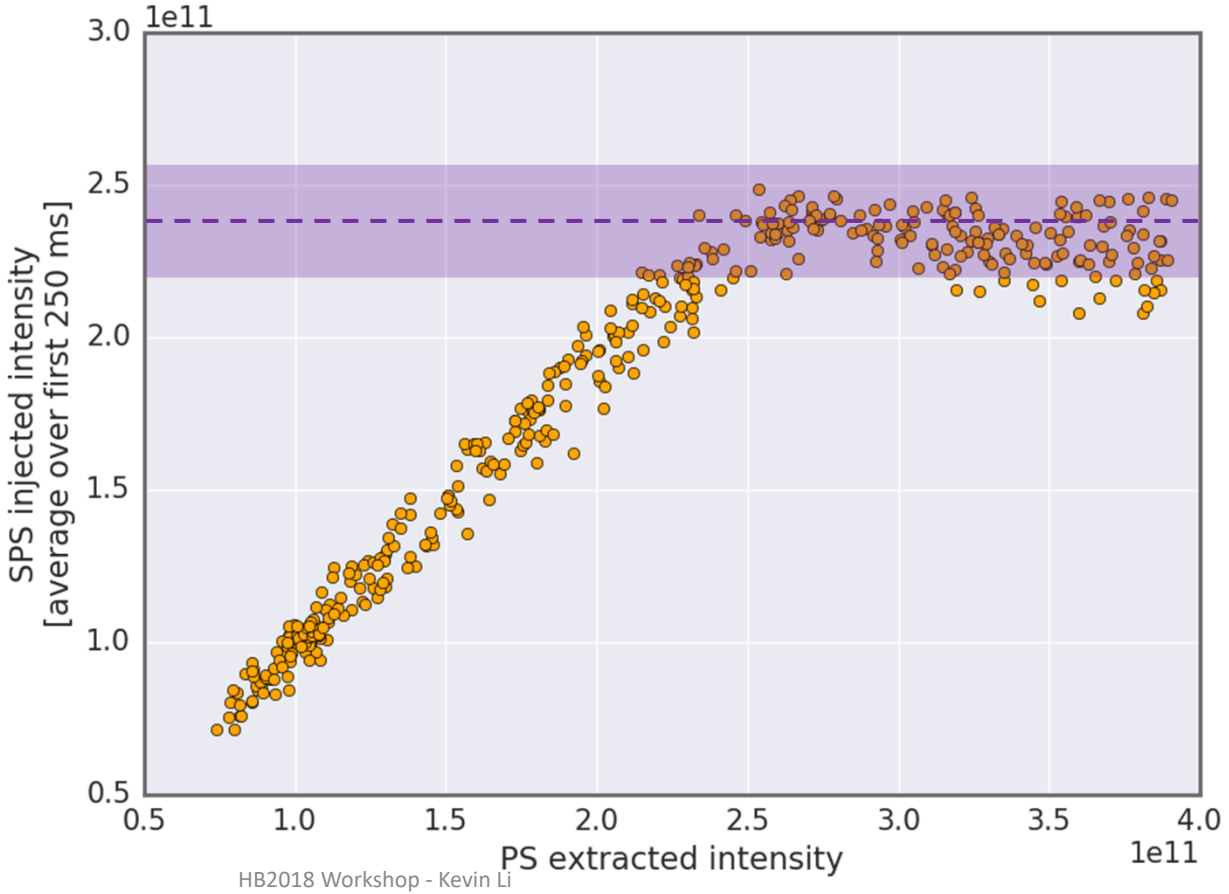

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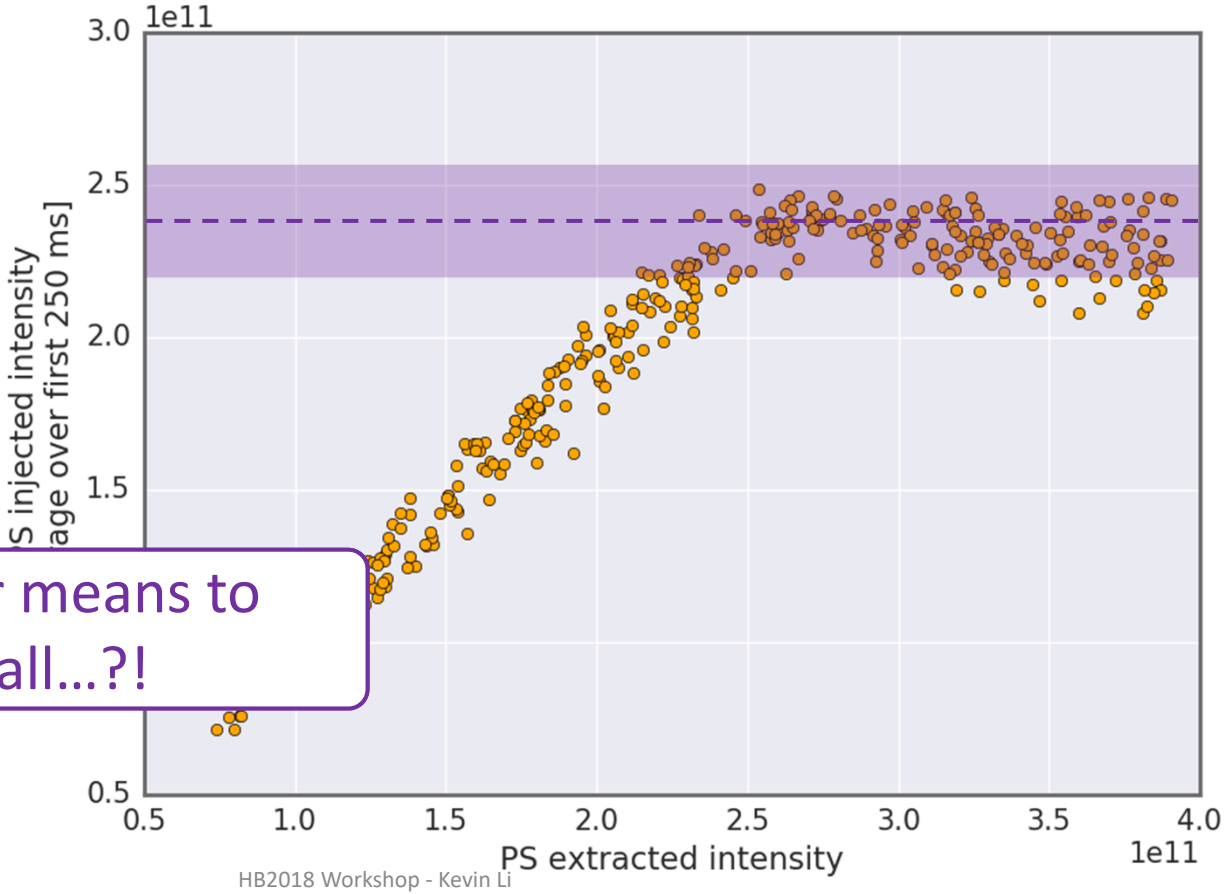

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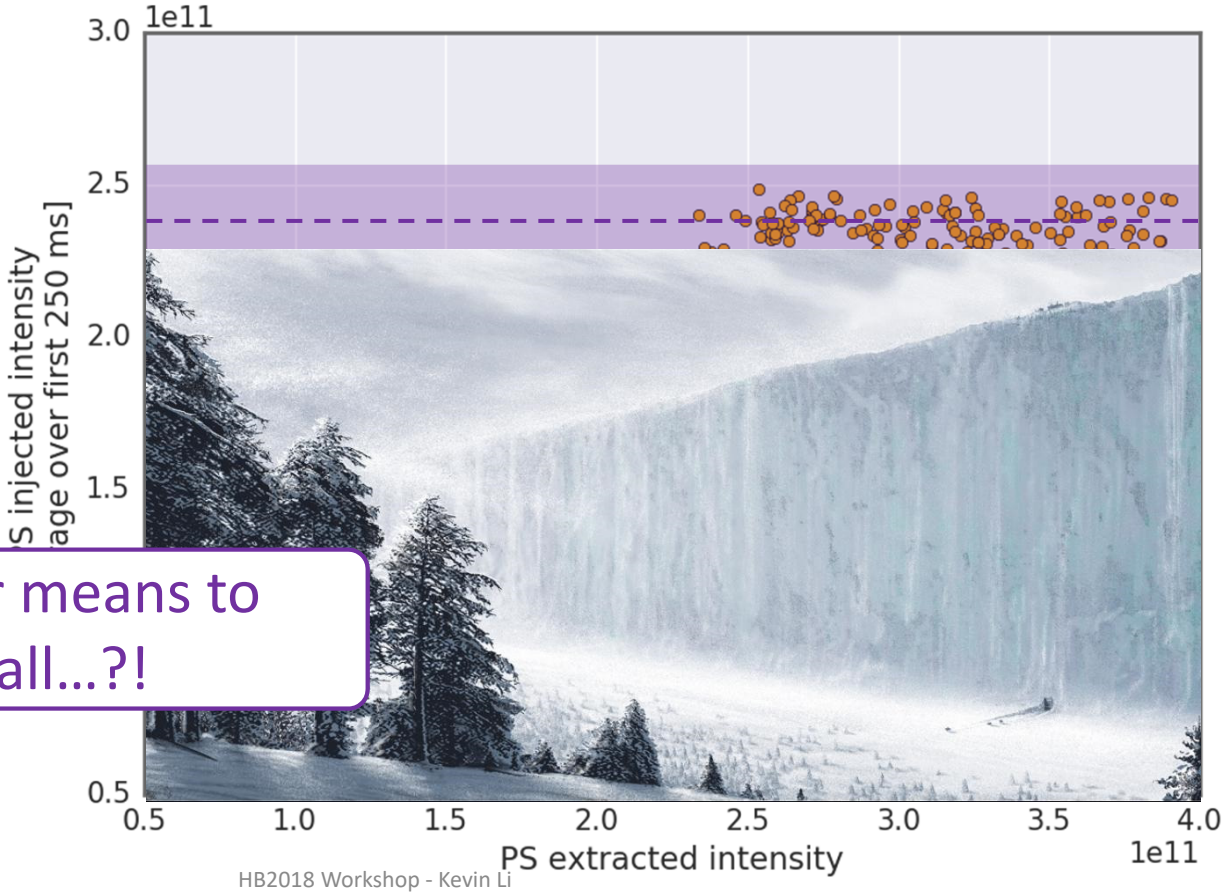

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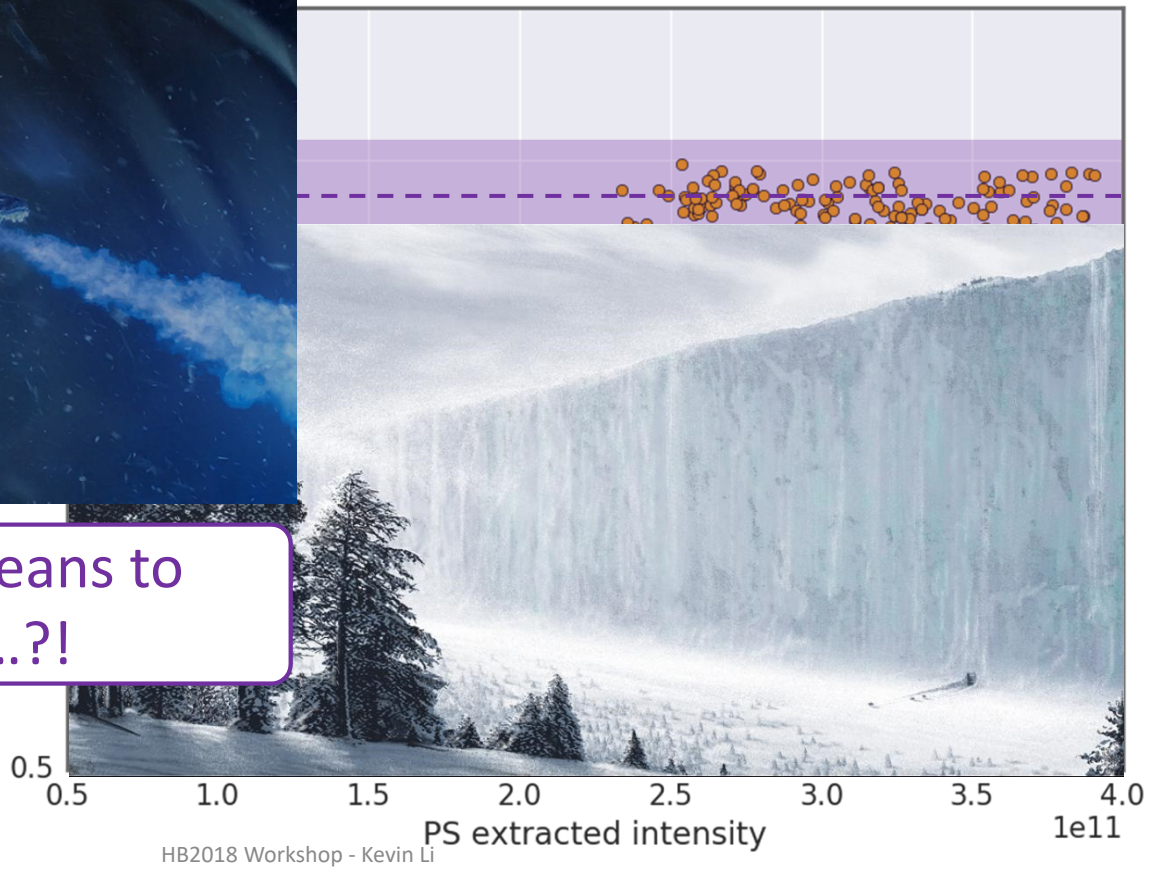

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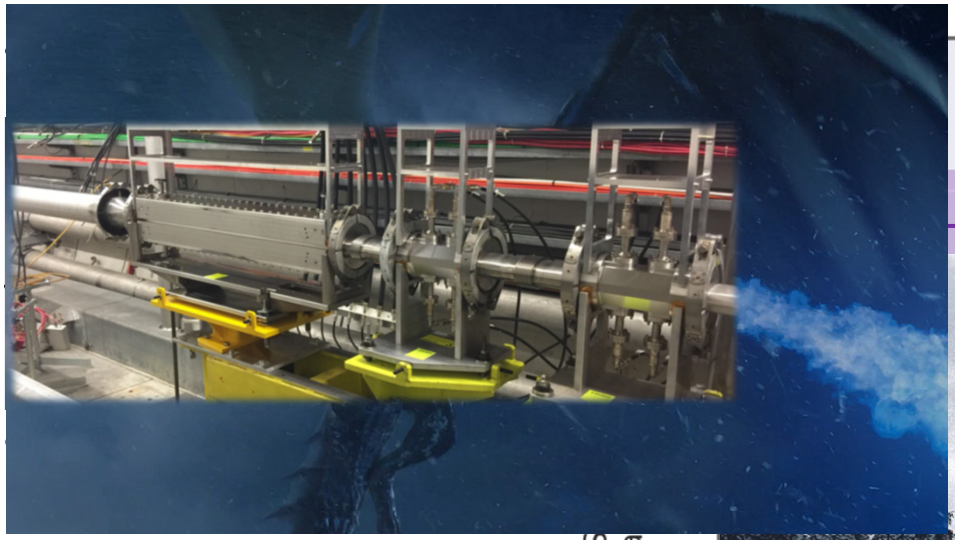

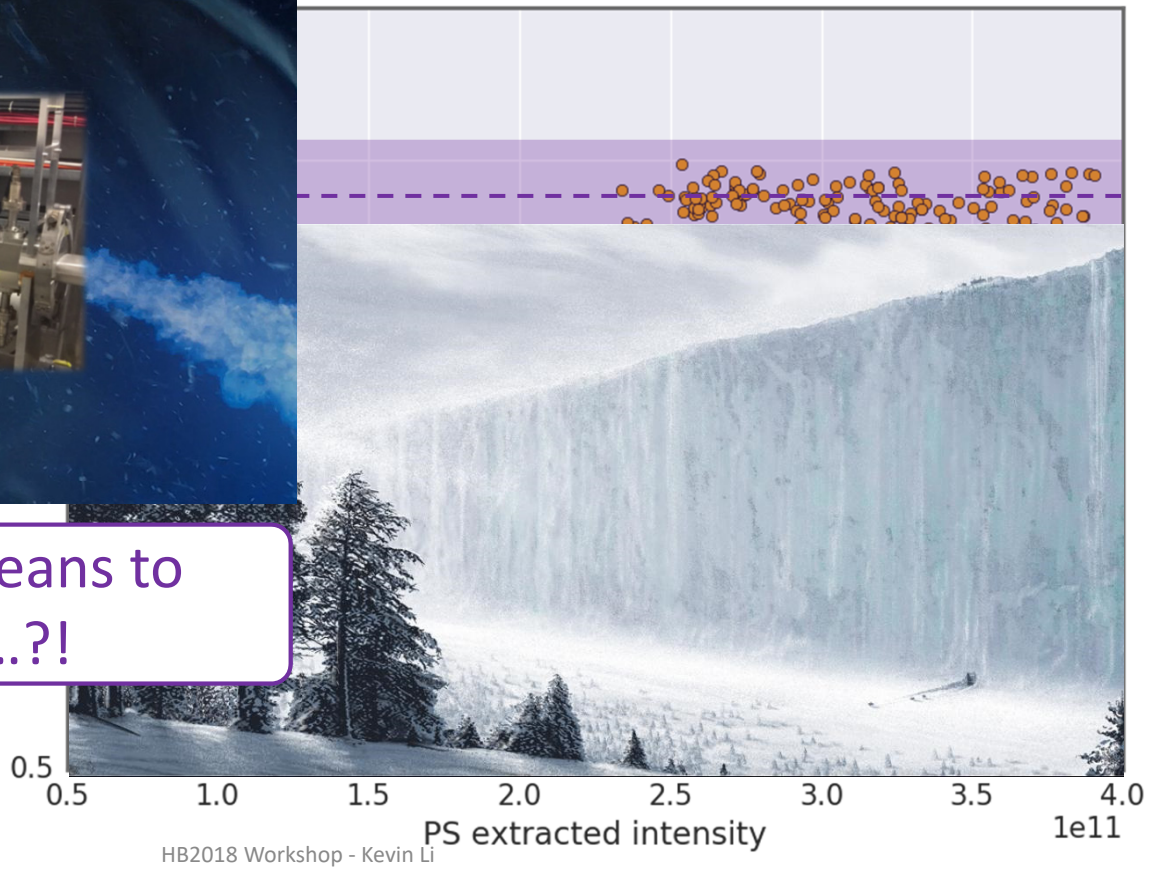

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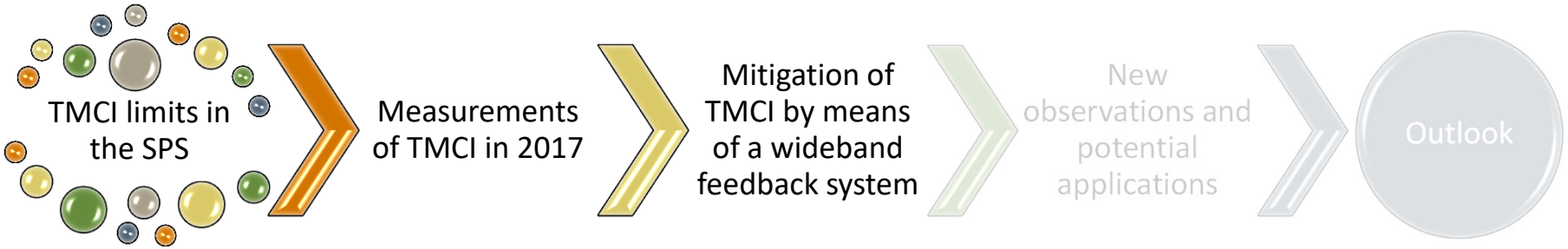
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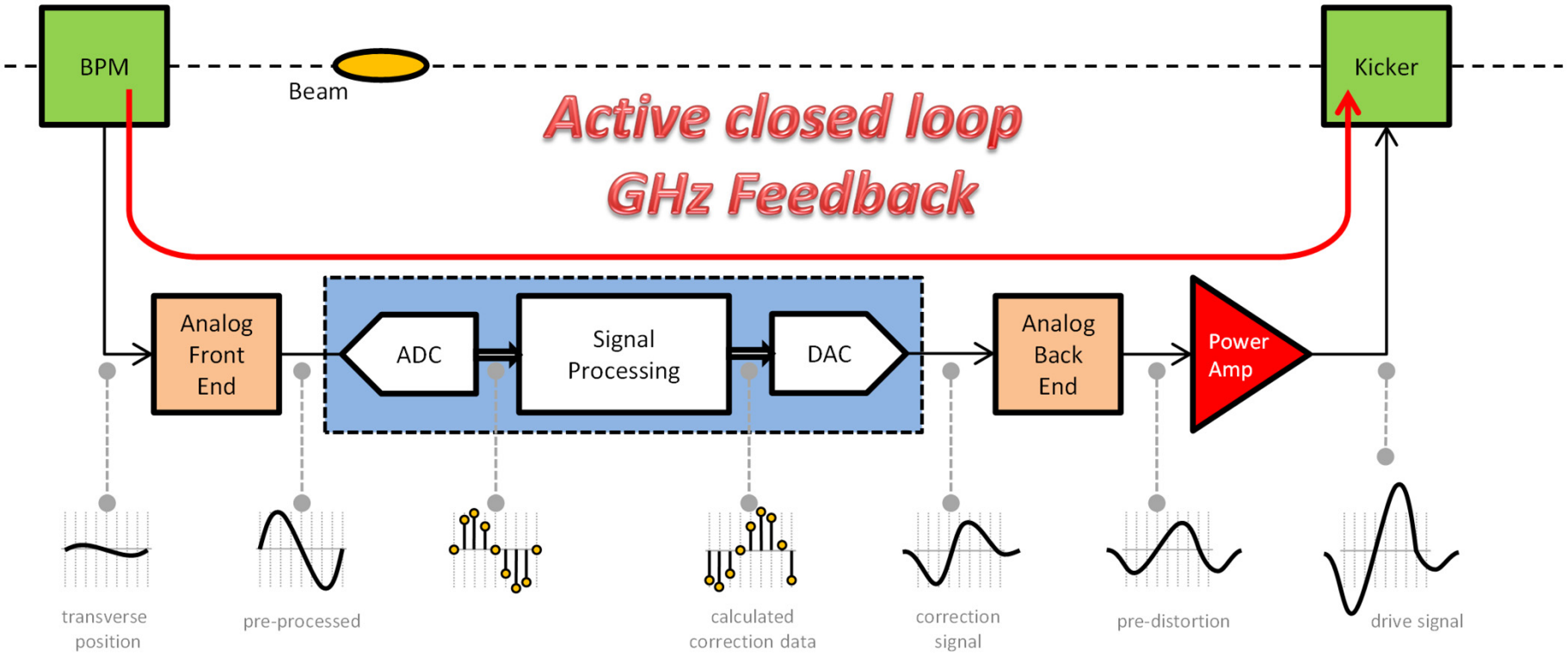
Wideband feedback system principle



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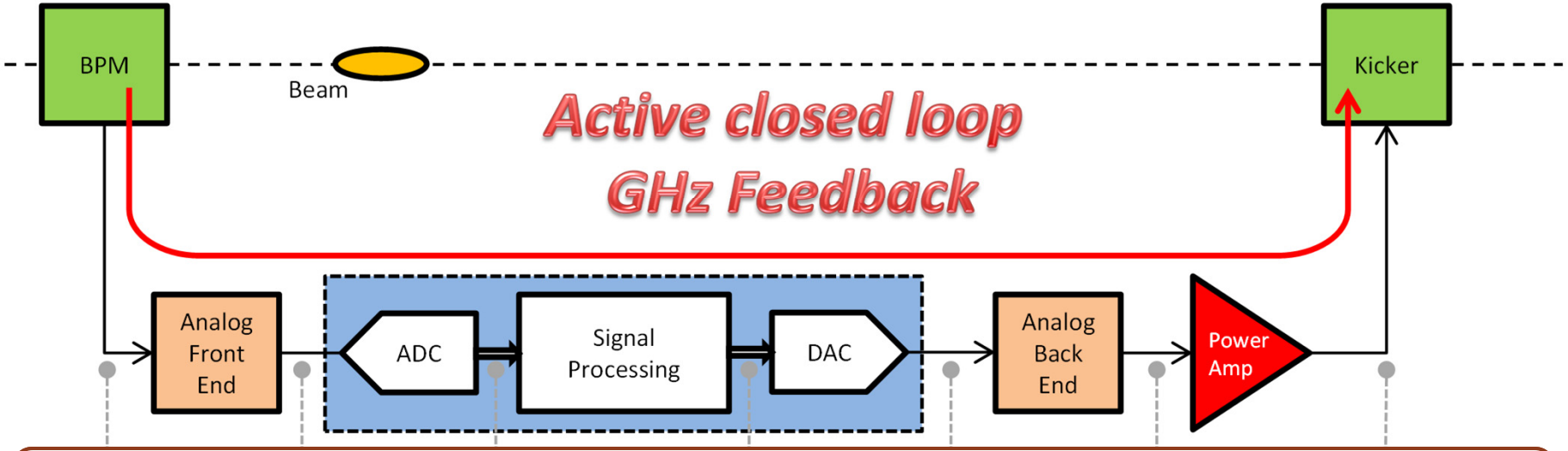

One of the potential mitigation schemes for TMCI and electron cloud instabilities in the SPS has been the design and the construction of a **wideband feedback system**. Such a system could become very interesting to make accessible a reliable operation of Q22 optics in the SPS.

Simulations show that a wideband feedback system in principle **can mitigate** both TMCI and e-cloud driven instabilities.

Wideband feedback demonstrator system

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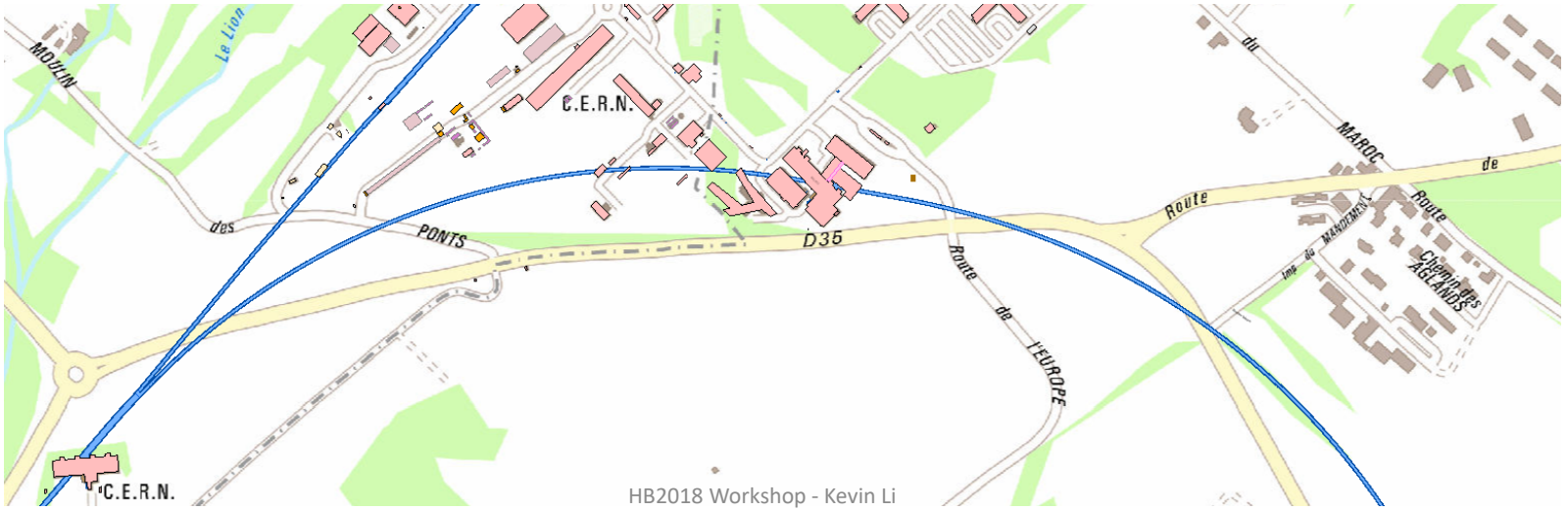
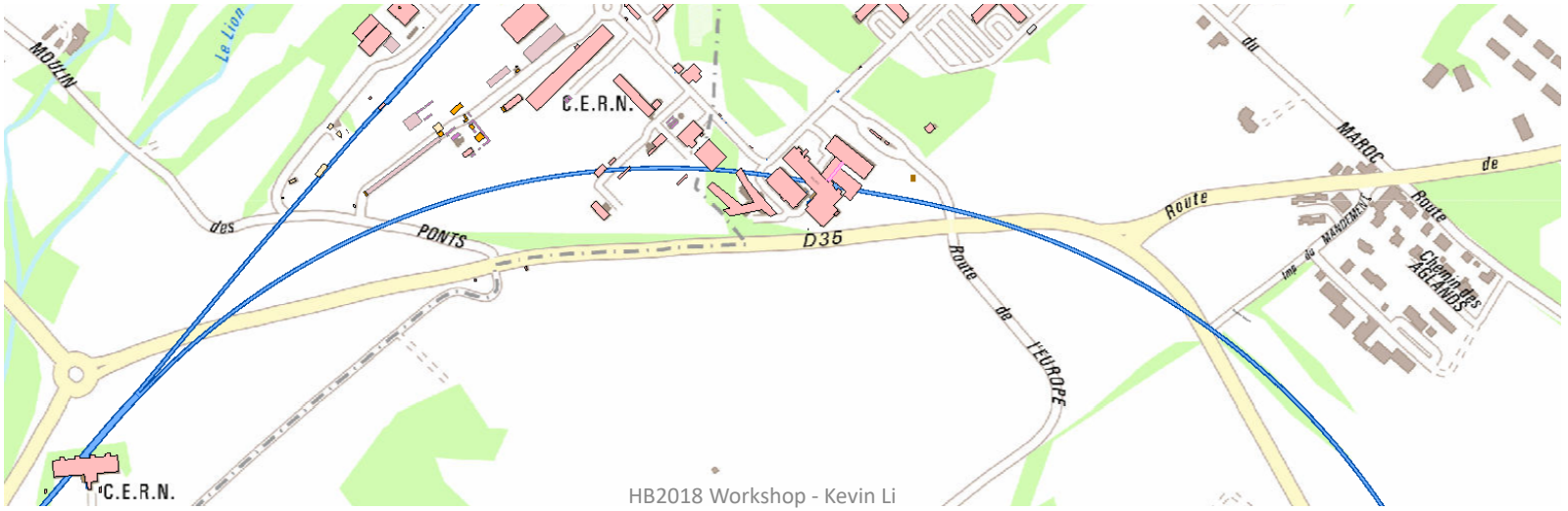


Wideband feedback demonstrator system

- A wideband feedback demonstrator system has been developed over the past years in a SLAC – CERN collaboration under the USLARP framework and within the LIU project.
- The system features:
  - A complete processing channel from pickups through kicker, running a **digital reconfigurable system up to 4 GS/s** (running at in the SPS at 3.2 Gs/s). The system also includes multi-bunch processing of up to 64 bunches in any configuration.
  - 2 stripline kickers with a **frequency reach up to 700 MHz**, each powered by a set of 2 amplifiers at 250 W and a bandwidth of 5 – 1000 MHz
  - Augmented by a **slotline kicker with a frequency reach beyond 1 GHz**.



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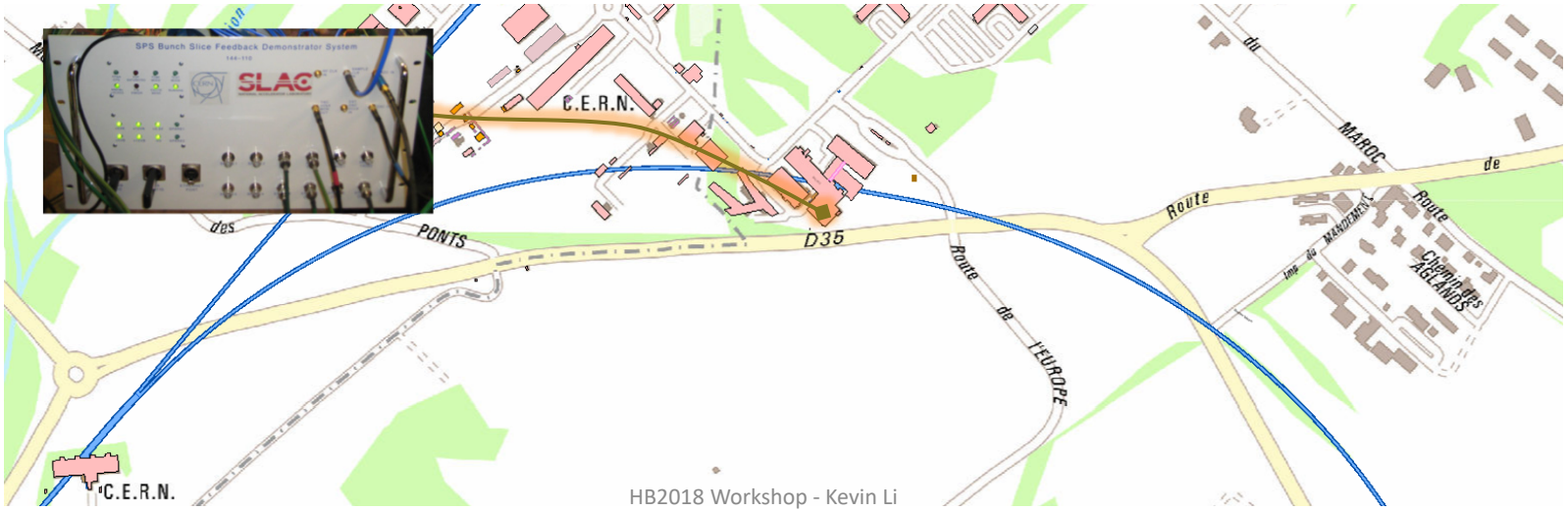

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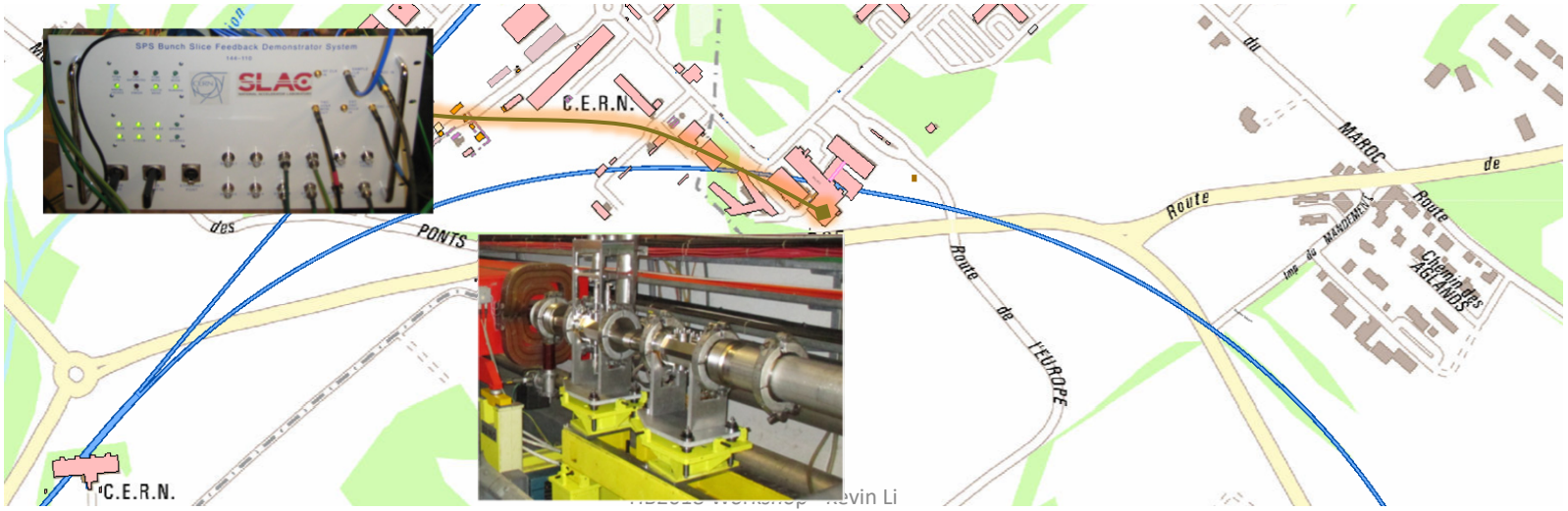

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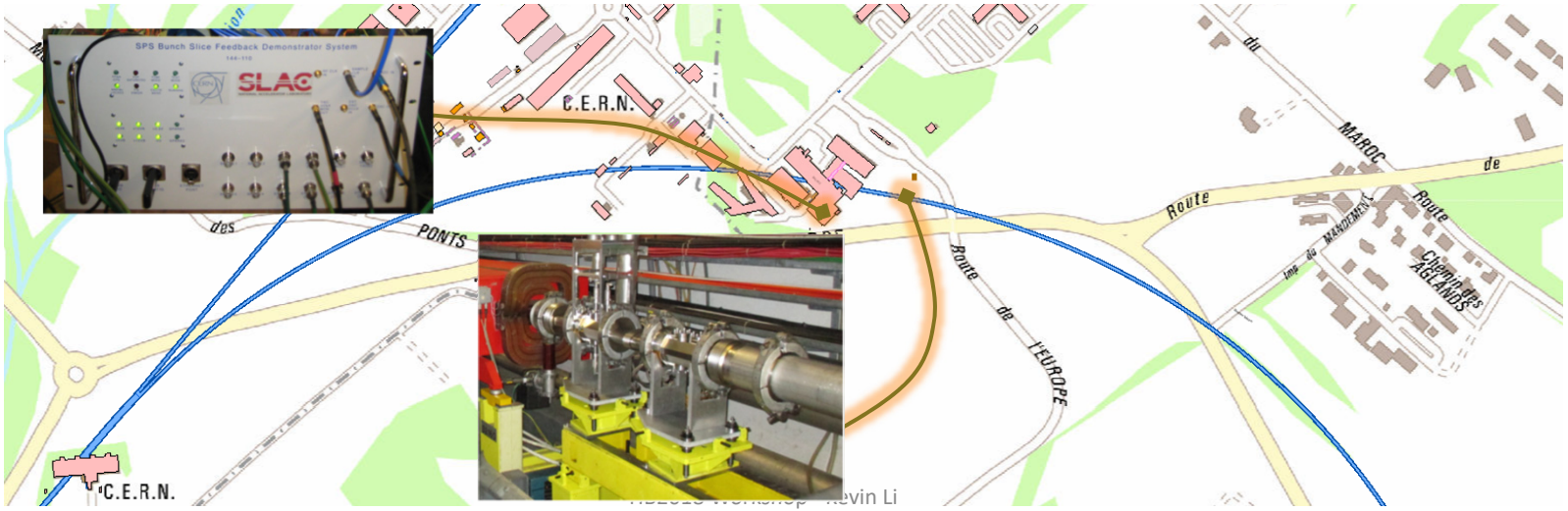

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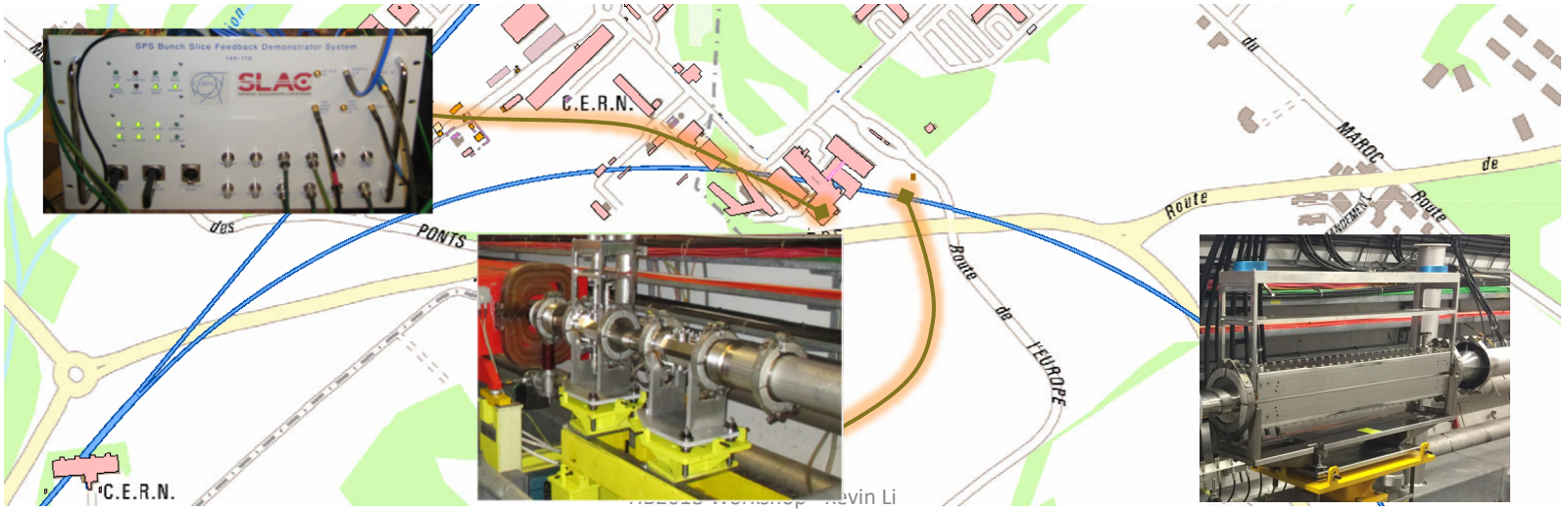

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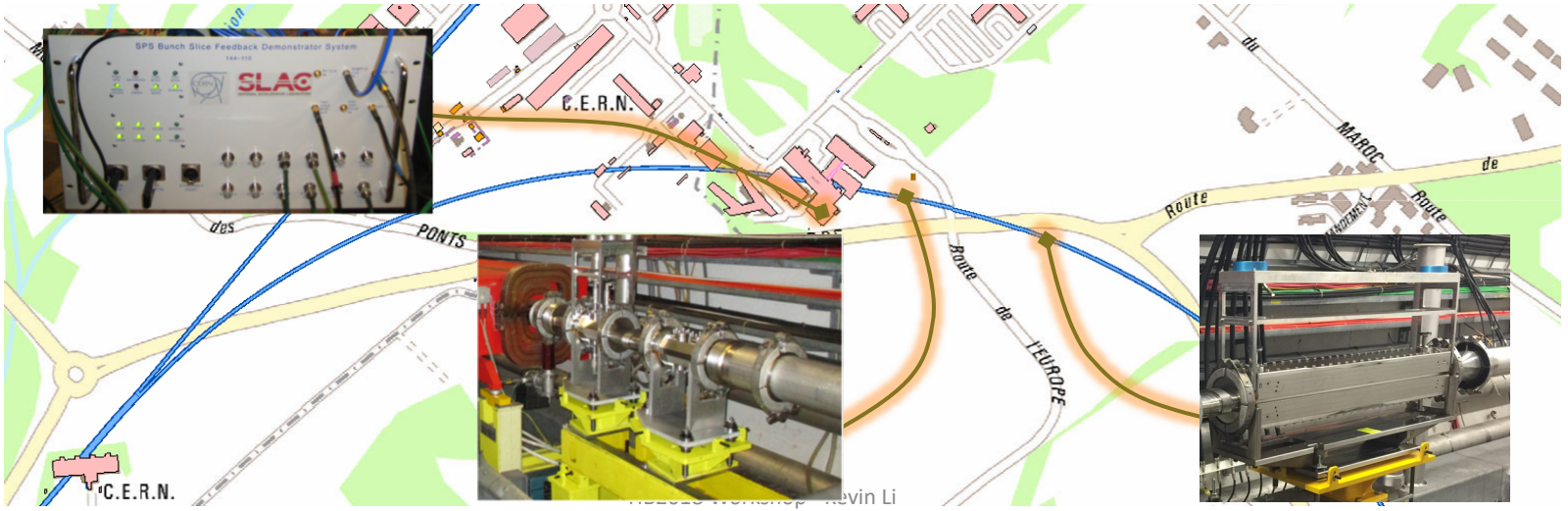
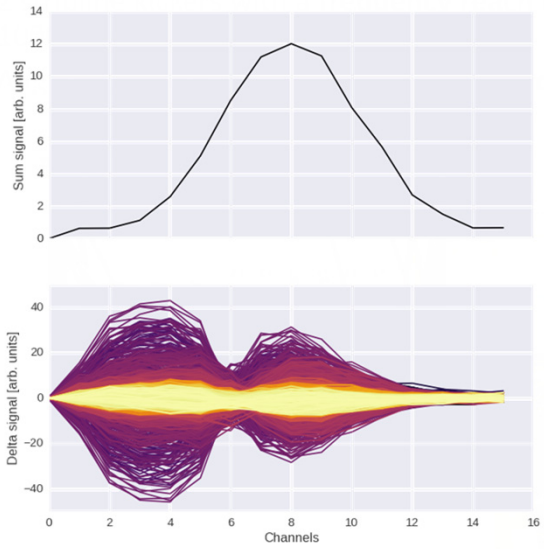


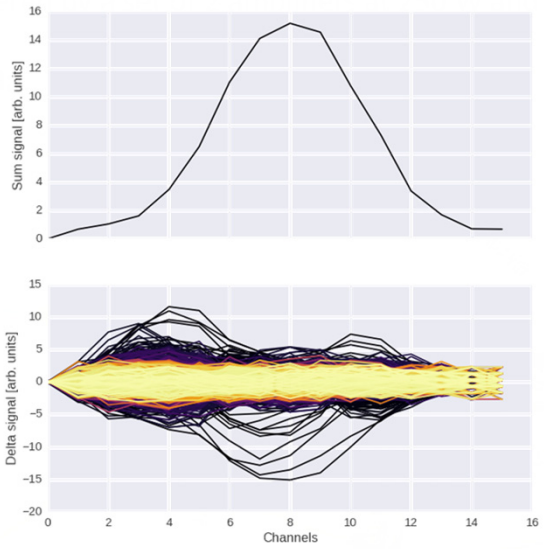
Wideband feedback demonstrator system

- In the past years, the wideband feedback demonstrator system was able to **successfully show control of intra-bunch motion** for the nanosecond scale bunches in the SPS. This was done in **the slow TMCI regime**.

Open loop

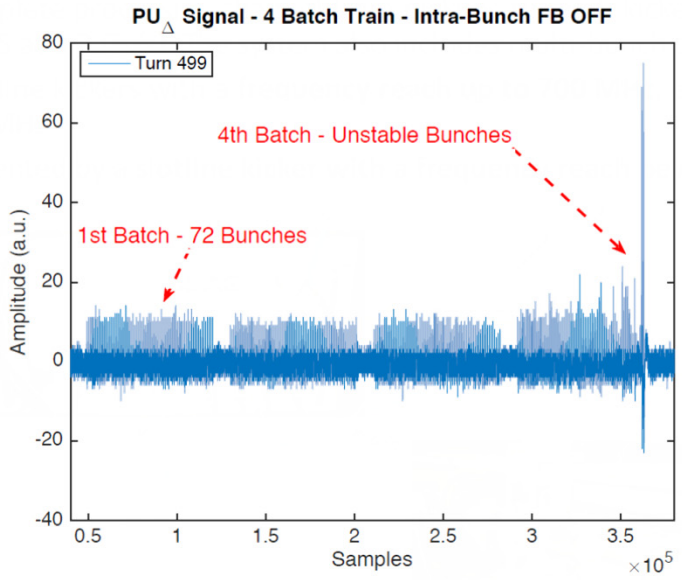


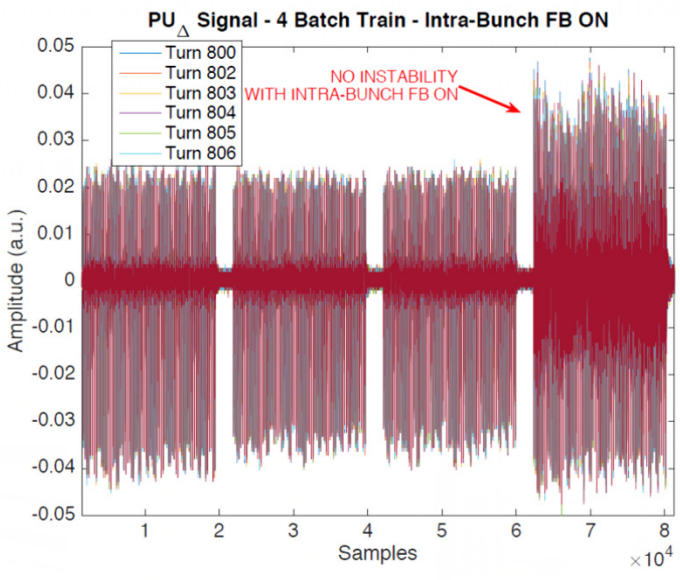
Closed loop



Wideband feedback demonstrator system

- It was also able to **show control of individual bunches** within a bunch train. This was done for Q20 optics **in an e-cloud susceptible regime**.





- So far, the wideband feedback system has **never been used, to breach the fast TMCI limits**.

Wideband feedback demonstrator system

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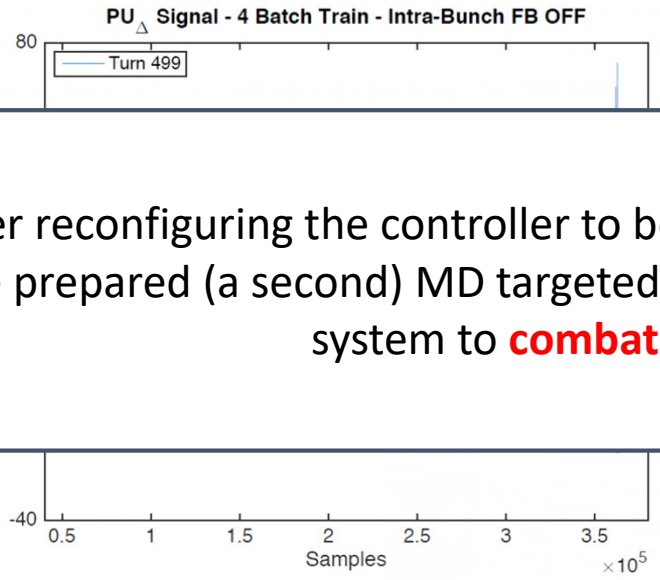
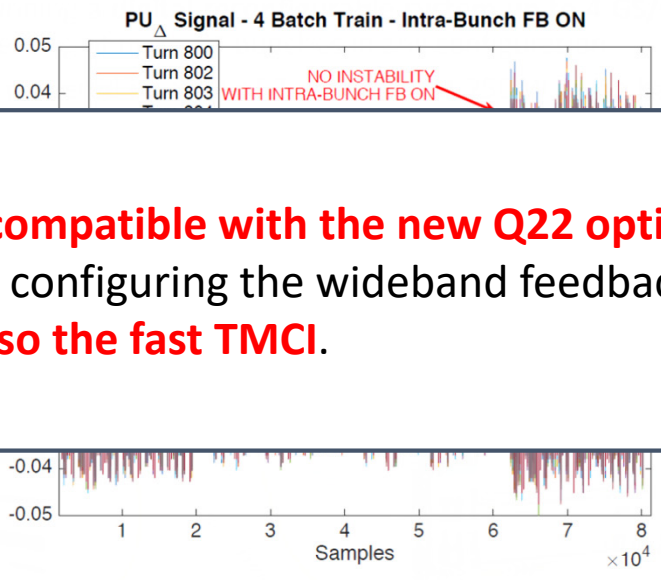
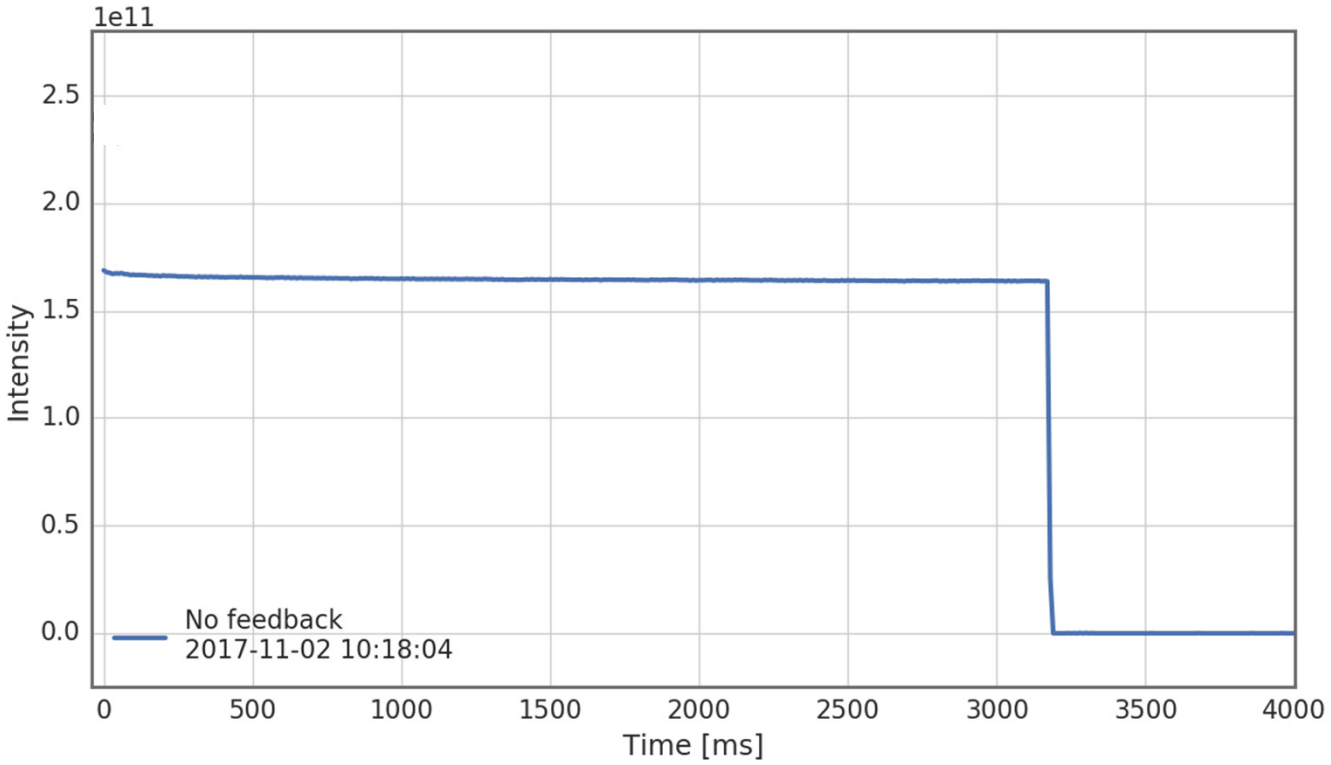




After reconfiguring the controller to be **compatible with the new Q22 optics**, we prepared (a second) MD targeted in configuring the wideband feedback system to **combat also the fast TMCI**.

- So far, the wideband feedback system has **never been used, to breach the fast TMCI limits**.

Intensity scan



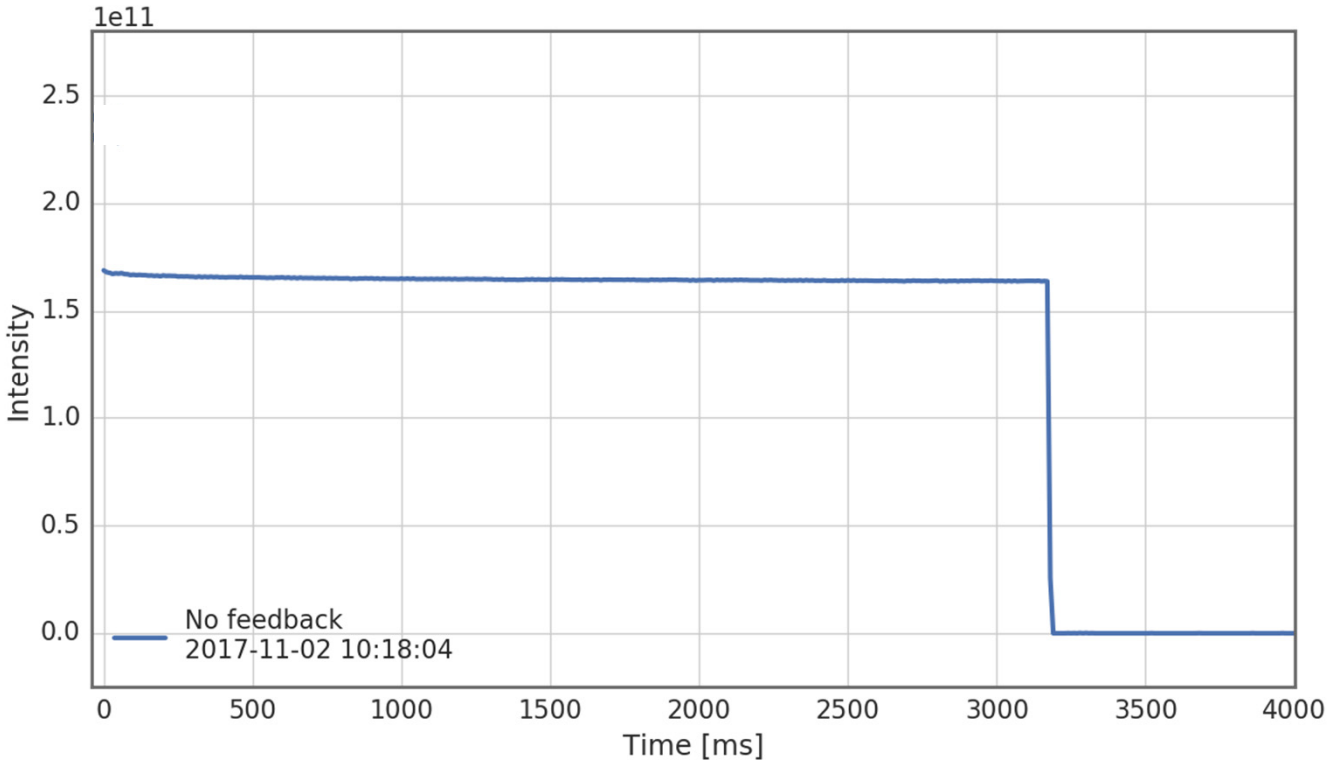
Intensity scan

- 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**.



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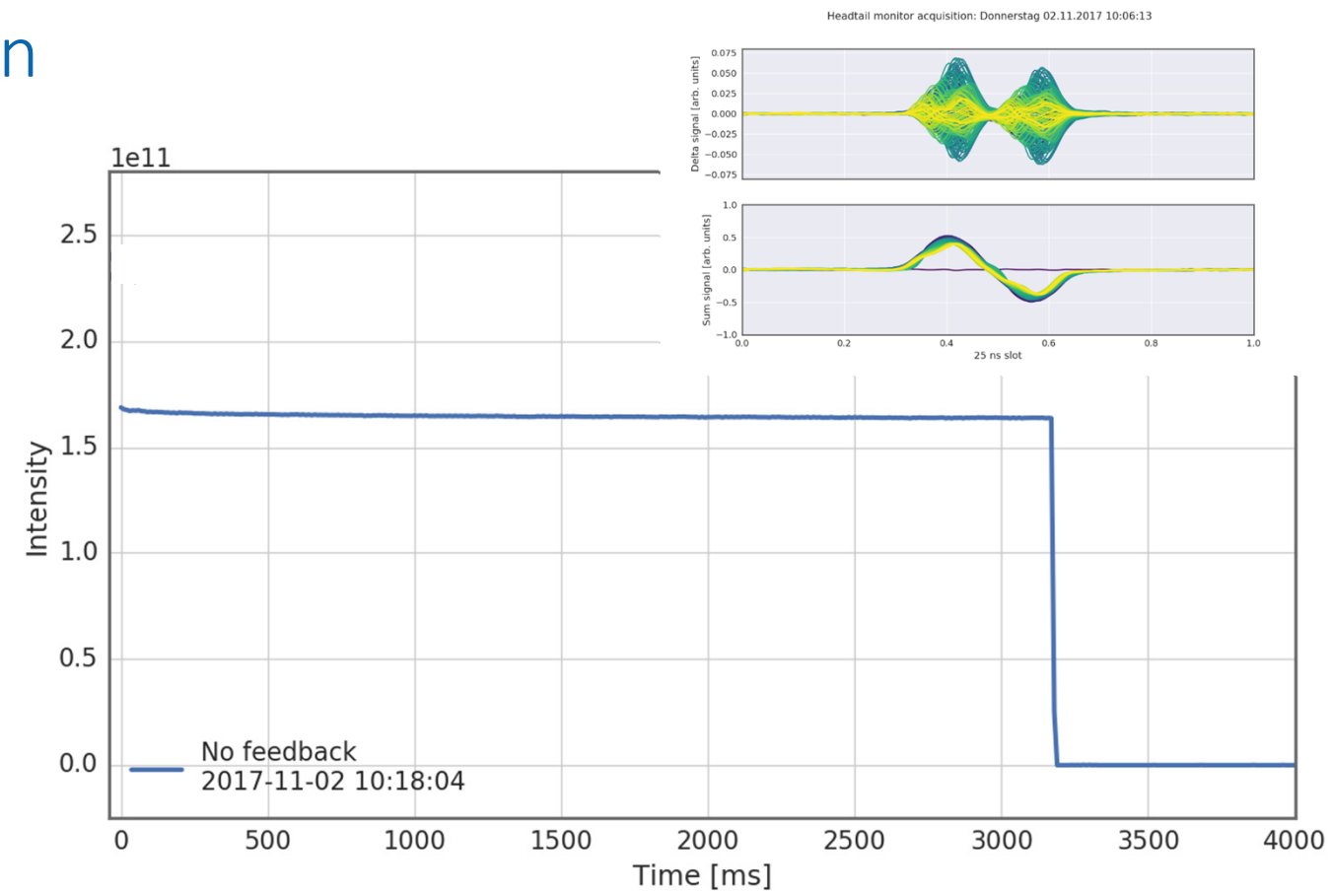

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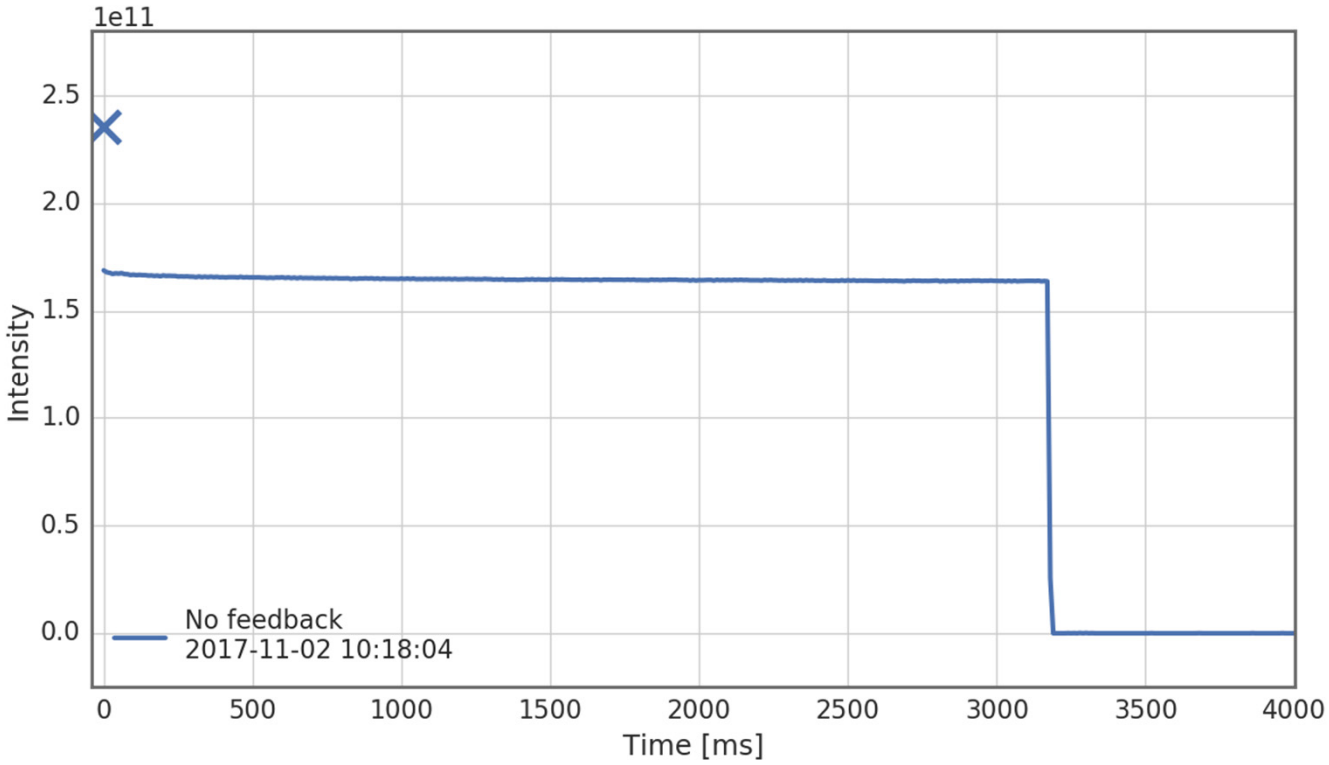

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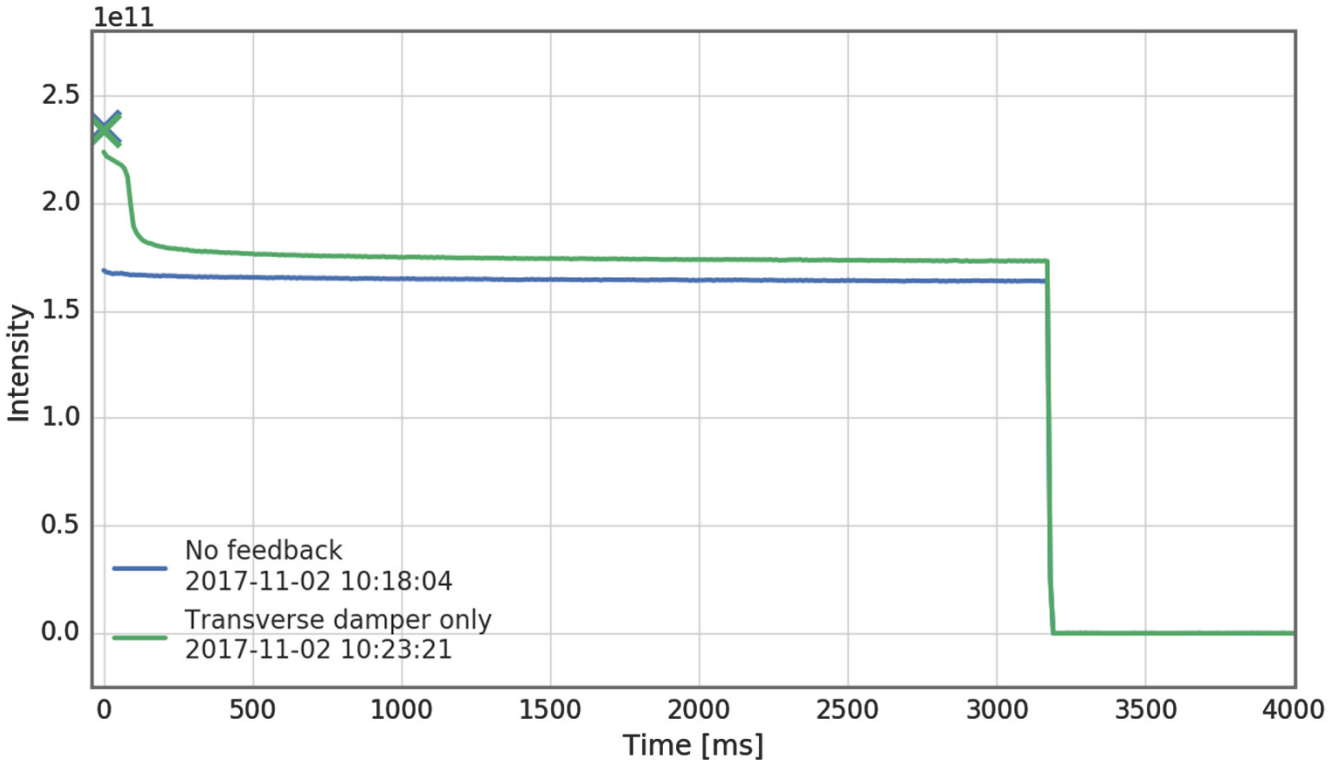
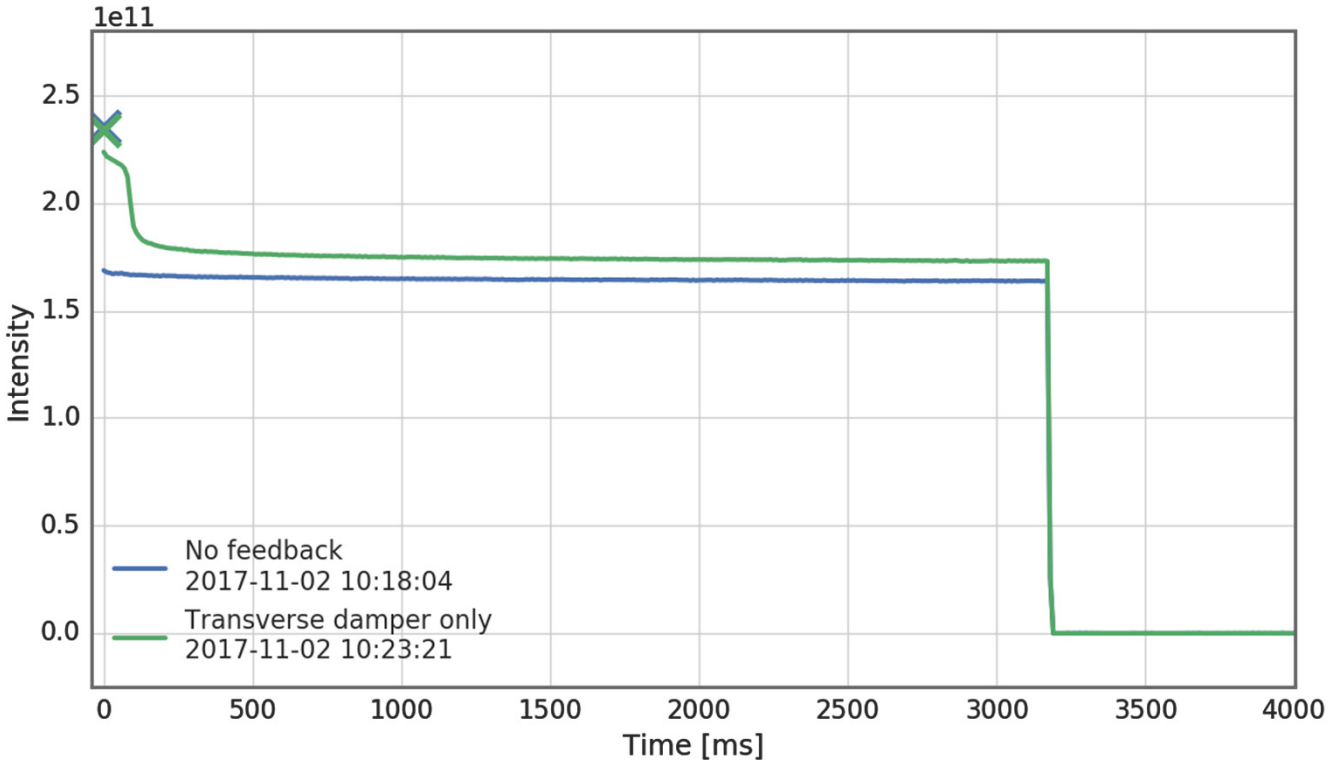


Intensity scan

- The **standard 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.



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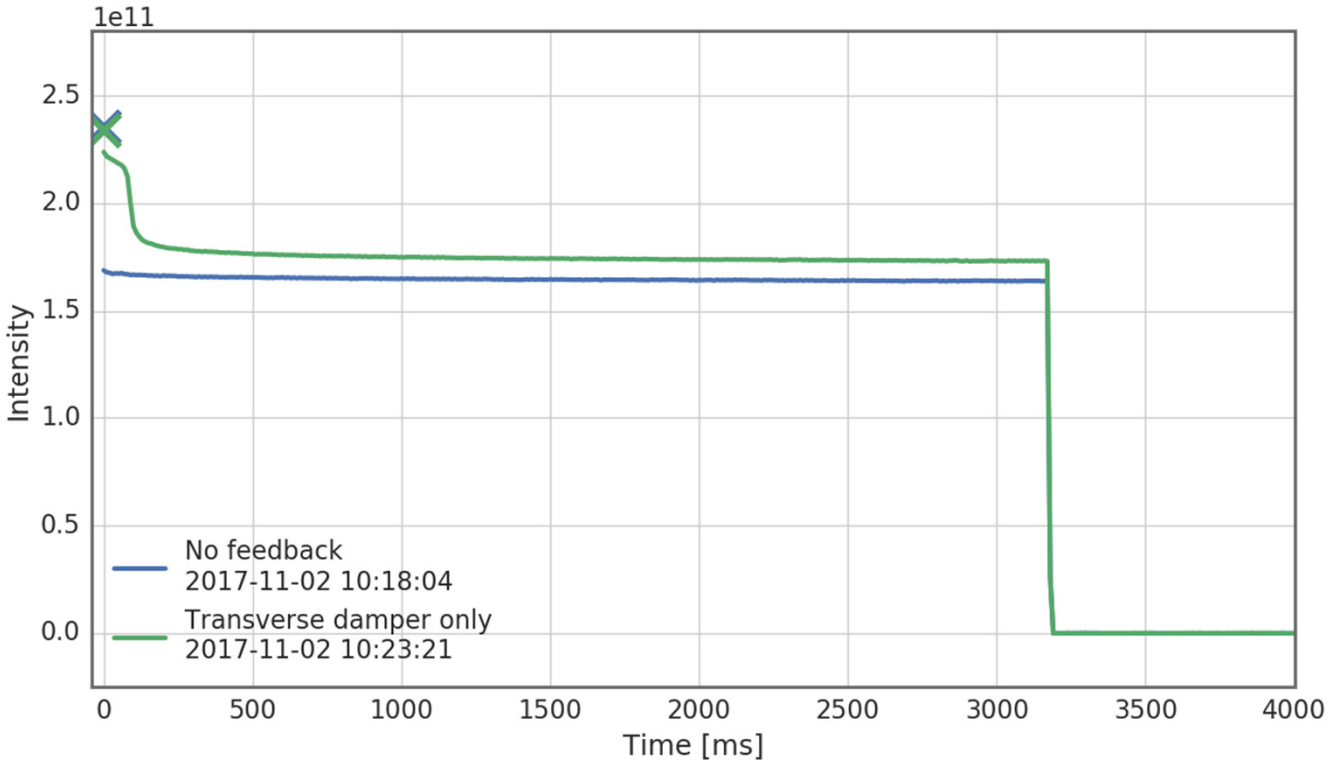
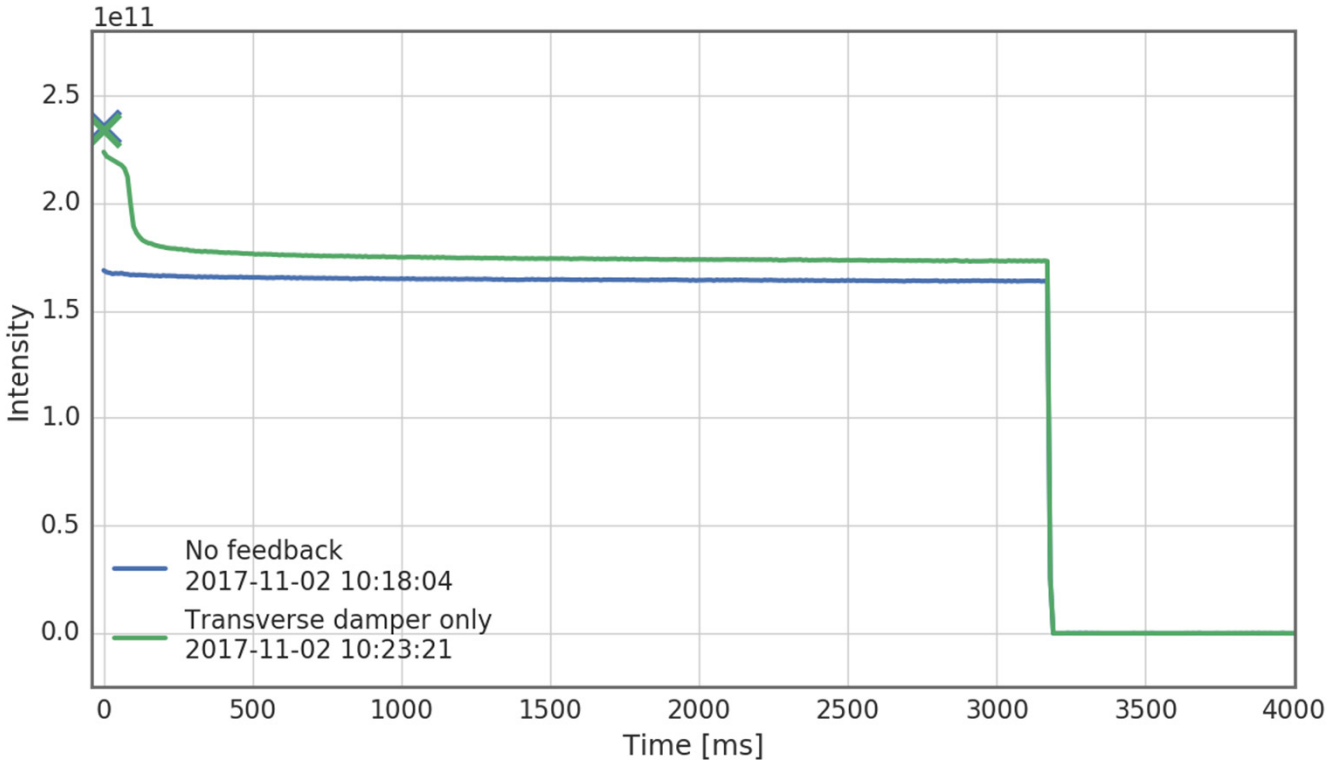


Intensity scan

- 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 to prevent saturation of the ADCs which would otherwise render the wideband feedback system ineffective.
- With the **two systems active**, the **losses are significantly reduced** and comparable to what is observed in absence of TMCI.



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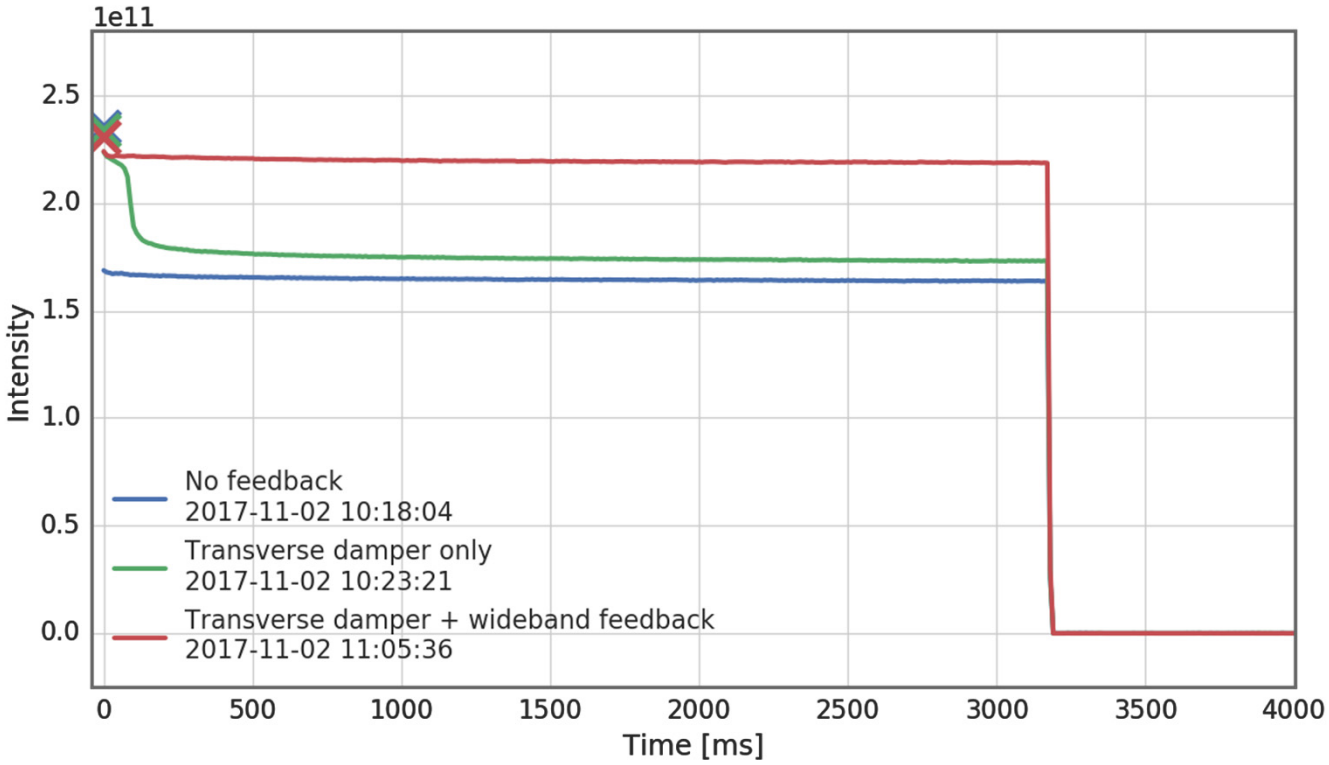
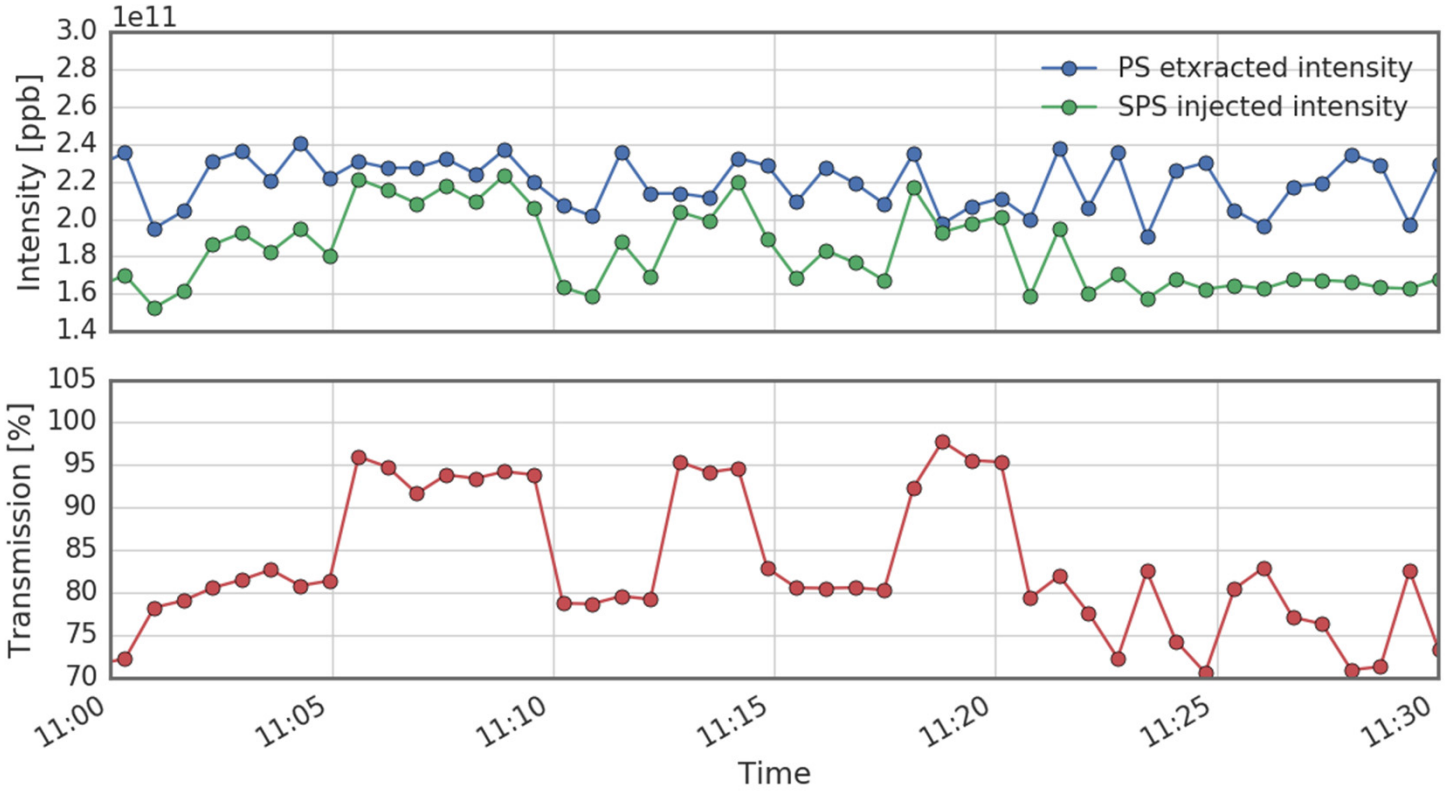


Intensity scan

- 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.



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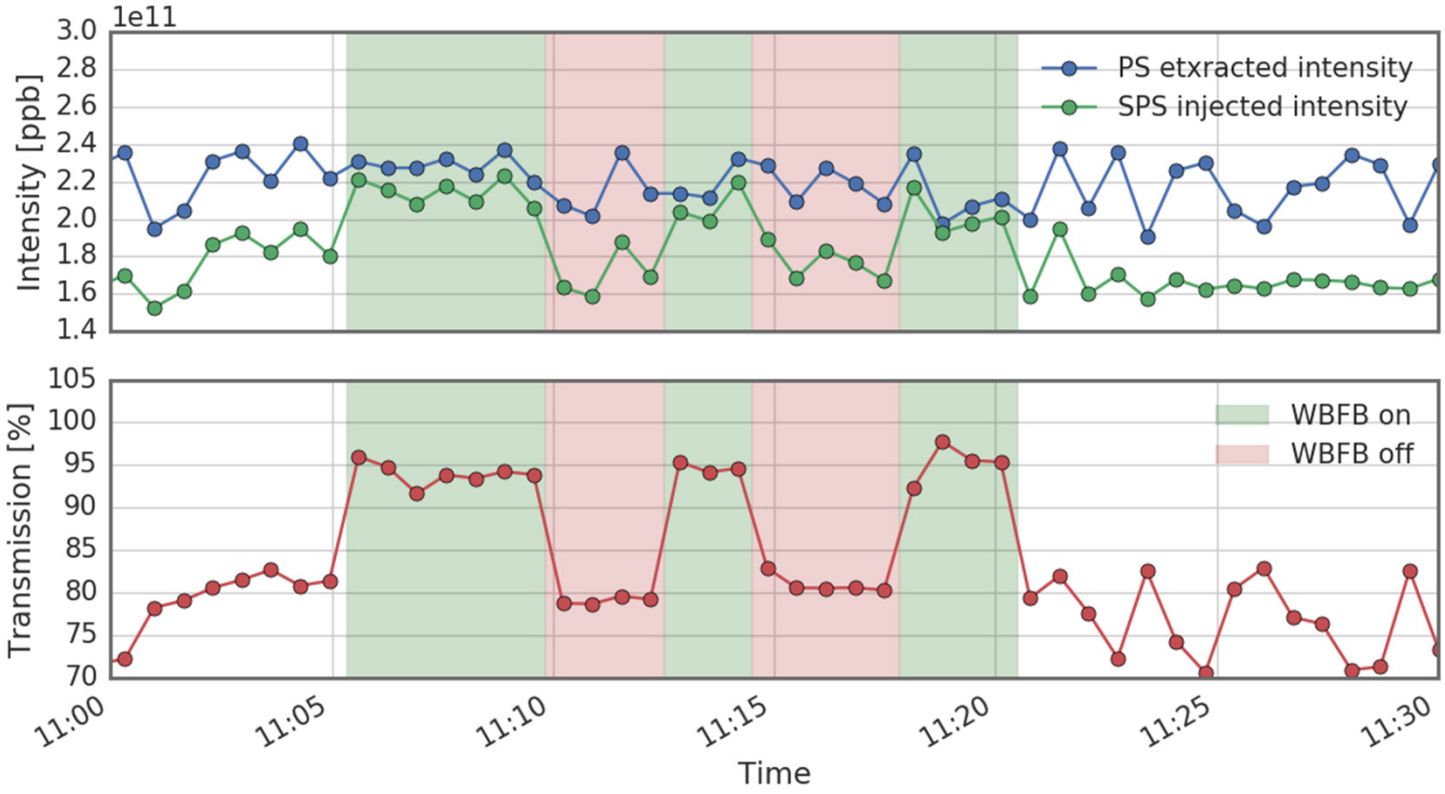
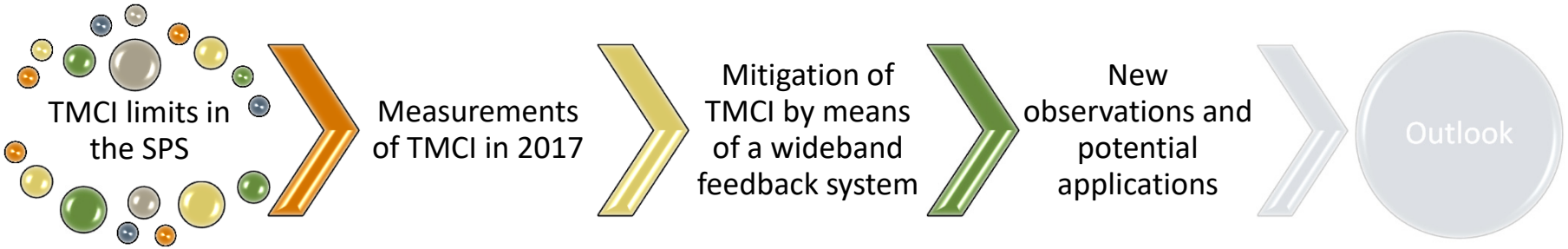
- There is a **clear correlation** between transmission and open/closed loop configuration.



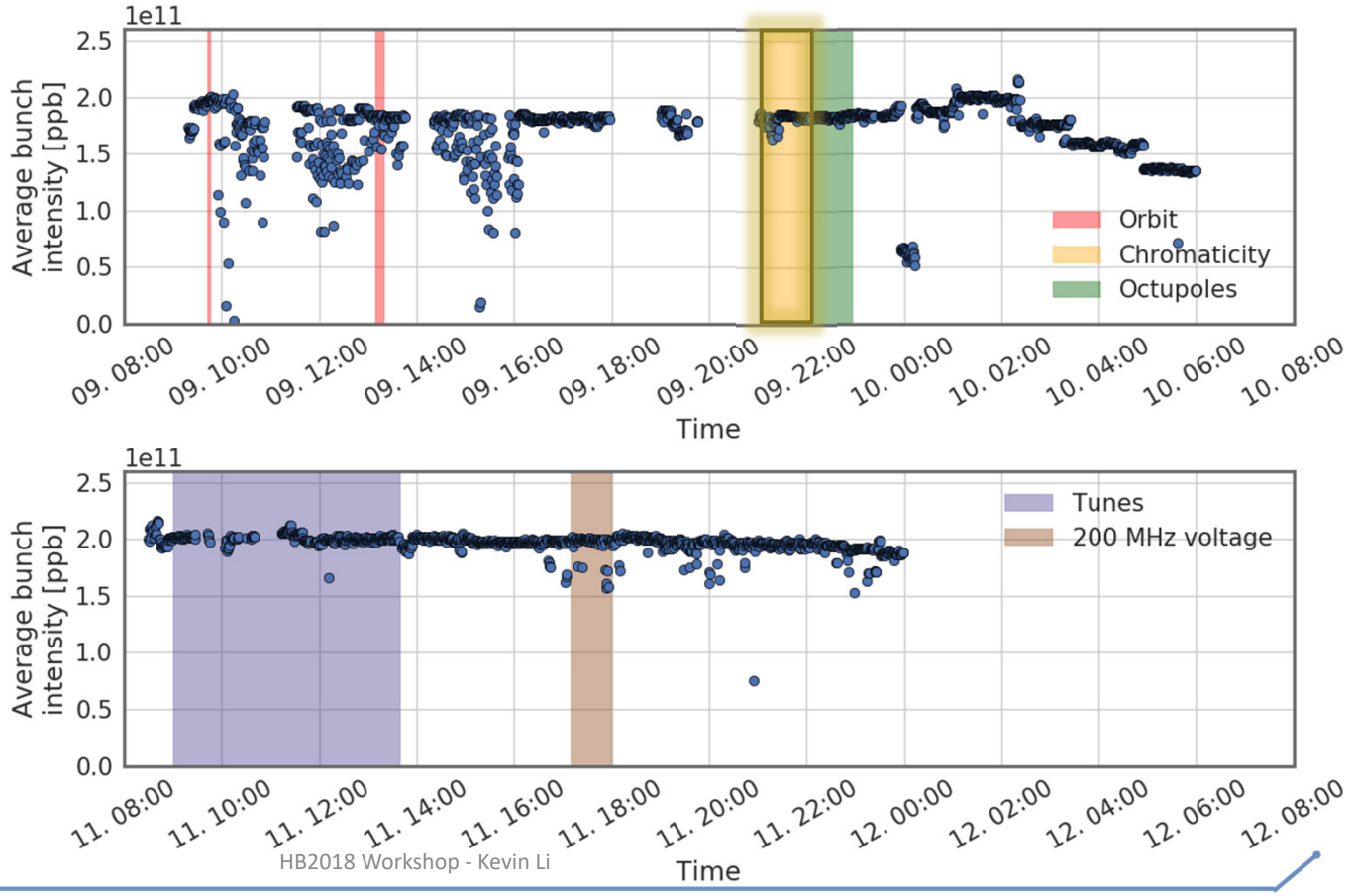
Outline


TMCI limits in the SPS
Measurements of TMCI in 2017
Mitigation of TMCI by means of a wideband feedback system
New observations and potential applications
Outlook

Observations during the 2017 high intensity run

- Investigation beam stability and incoherent losses as a function of chromaticity for high intensity beams.

- BCMS beam – 4 x 48 bunches



Observations during the 2017 high intensity run

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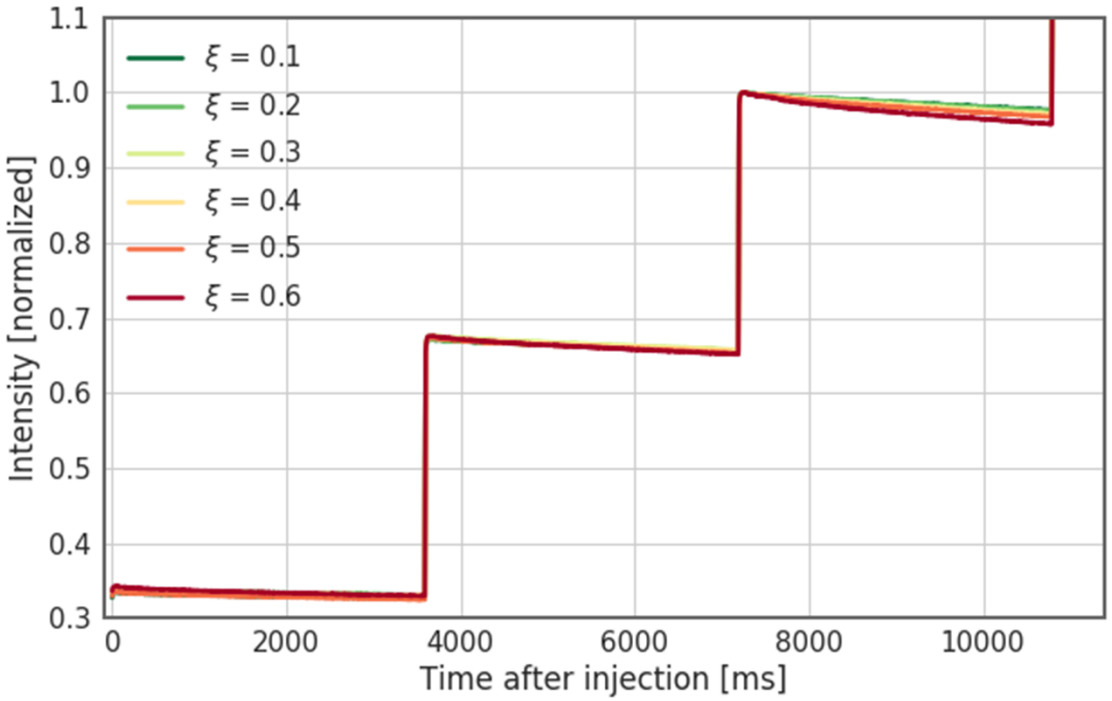

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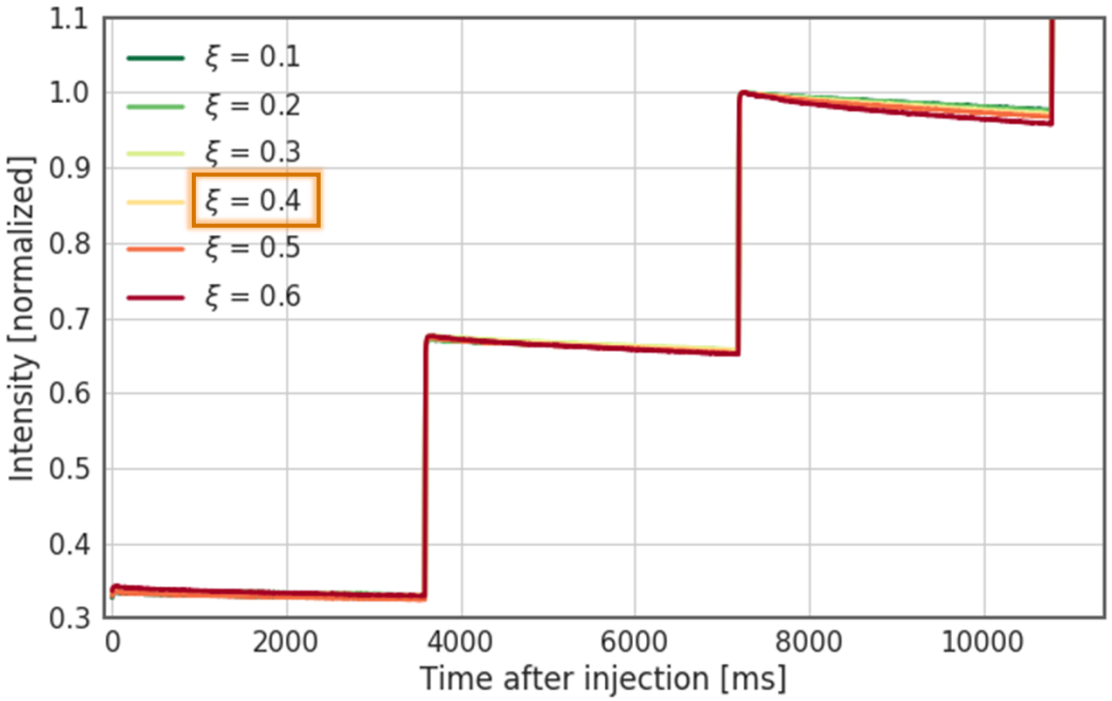

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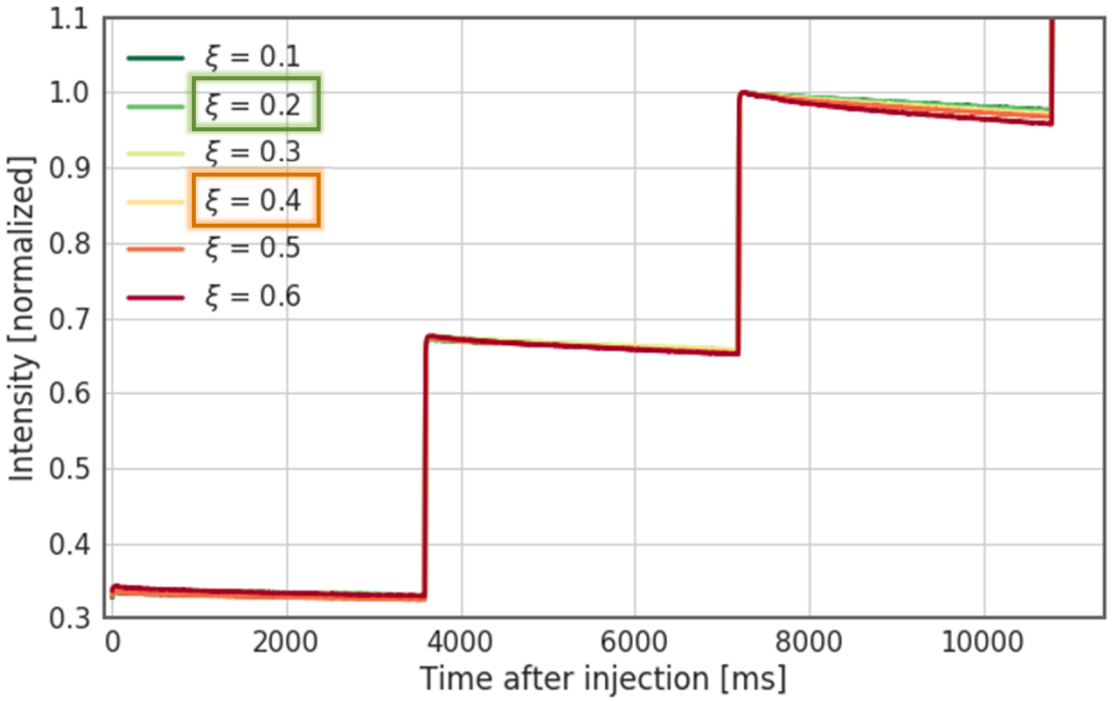

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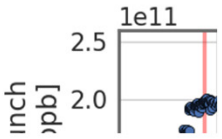

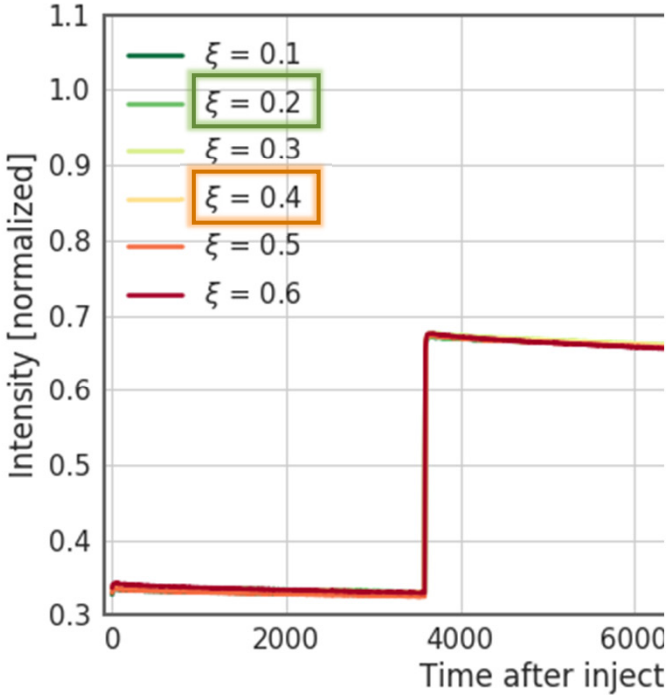

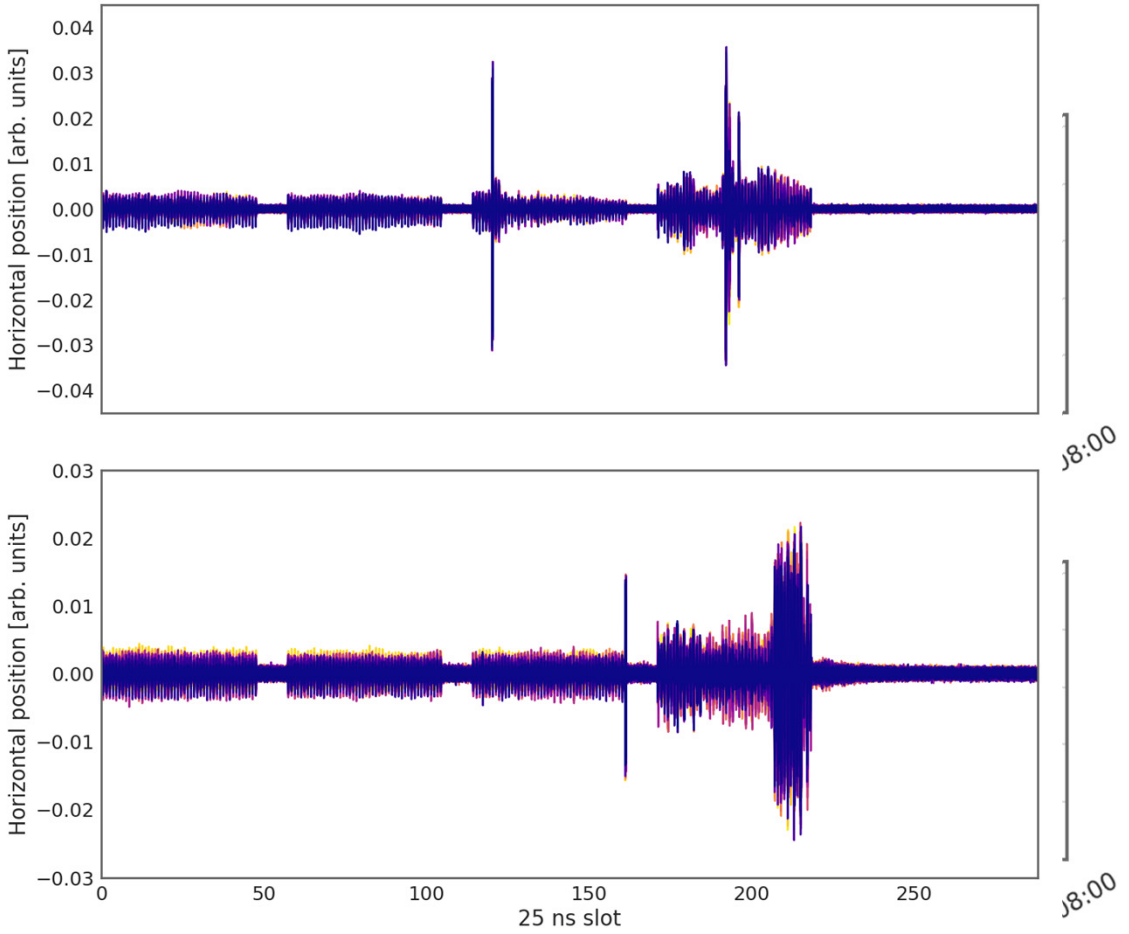

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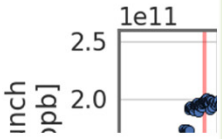

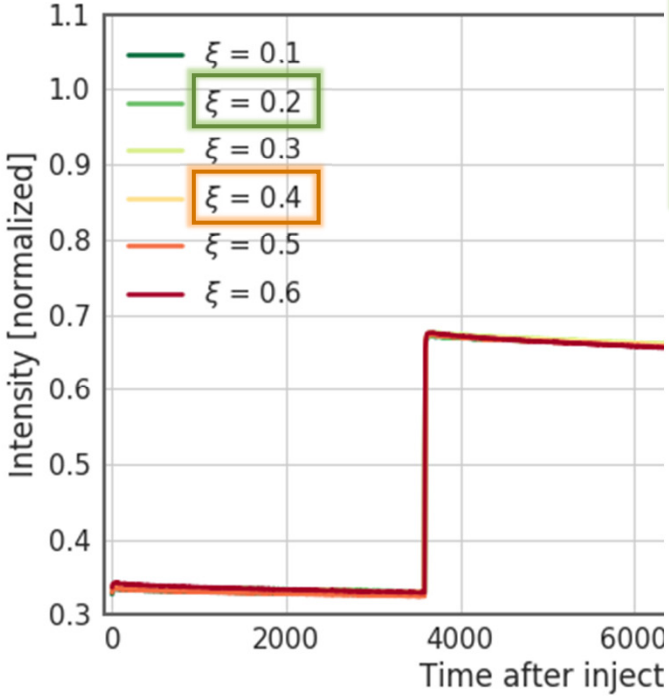

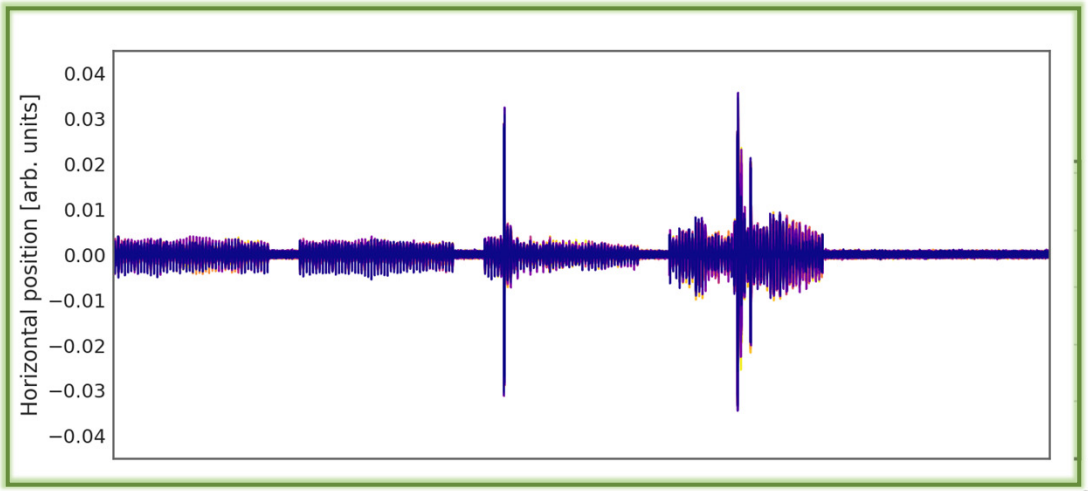

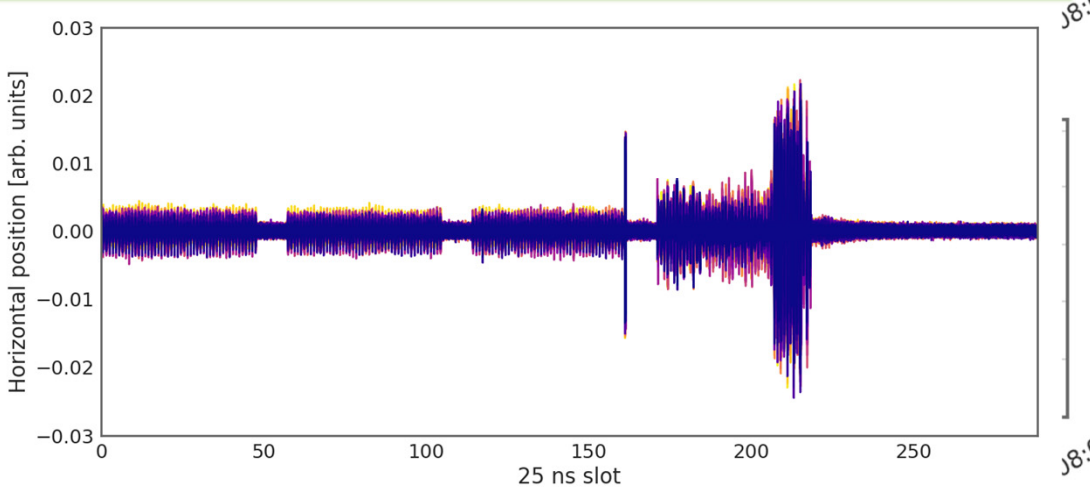

Time

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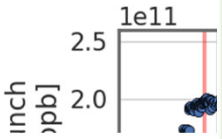

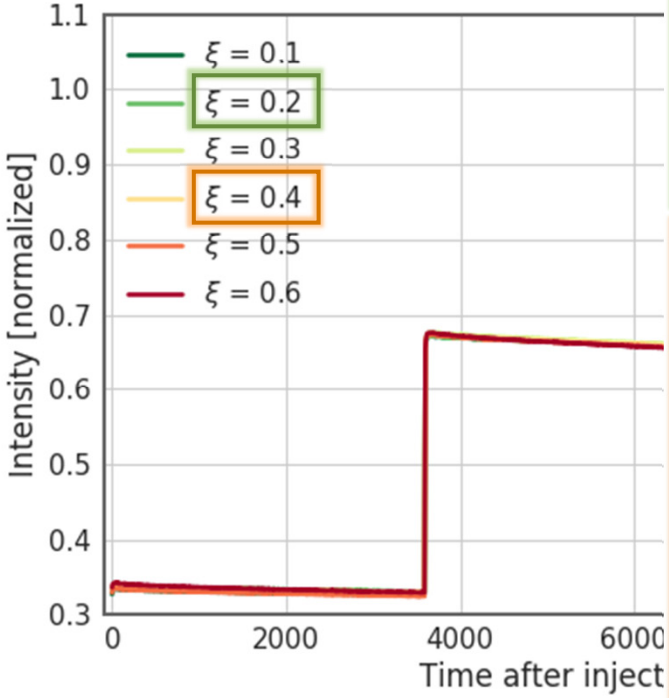

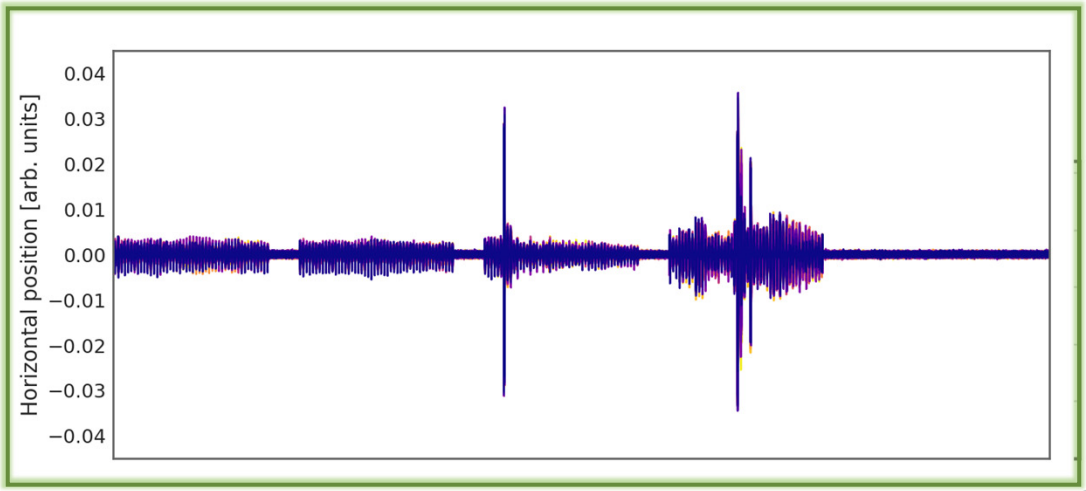

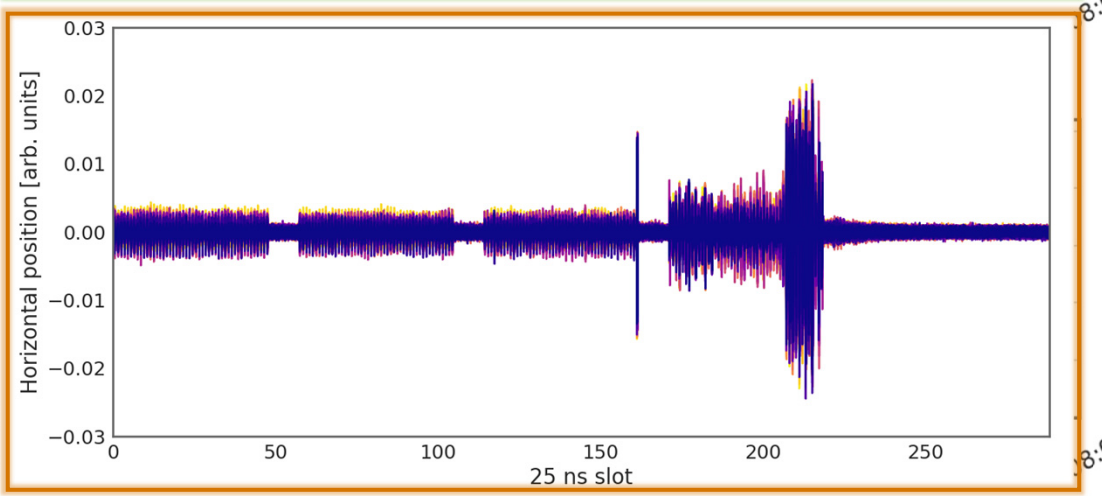

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Time

Observations during the 2017 high intensity run

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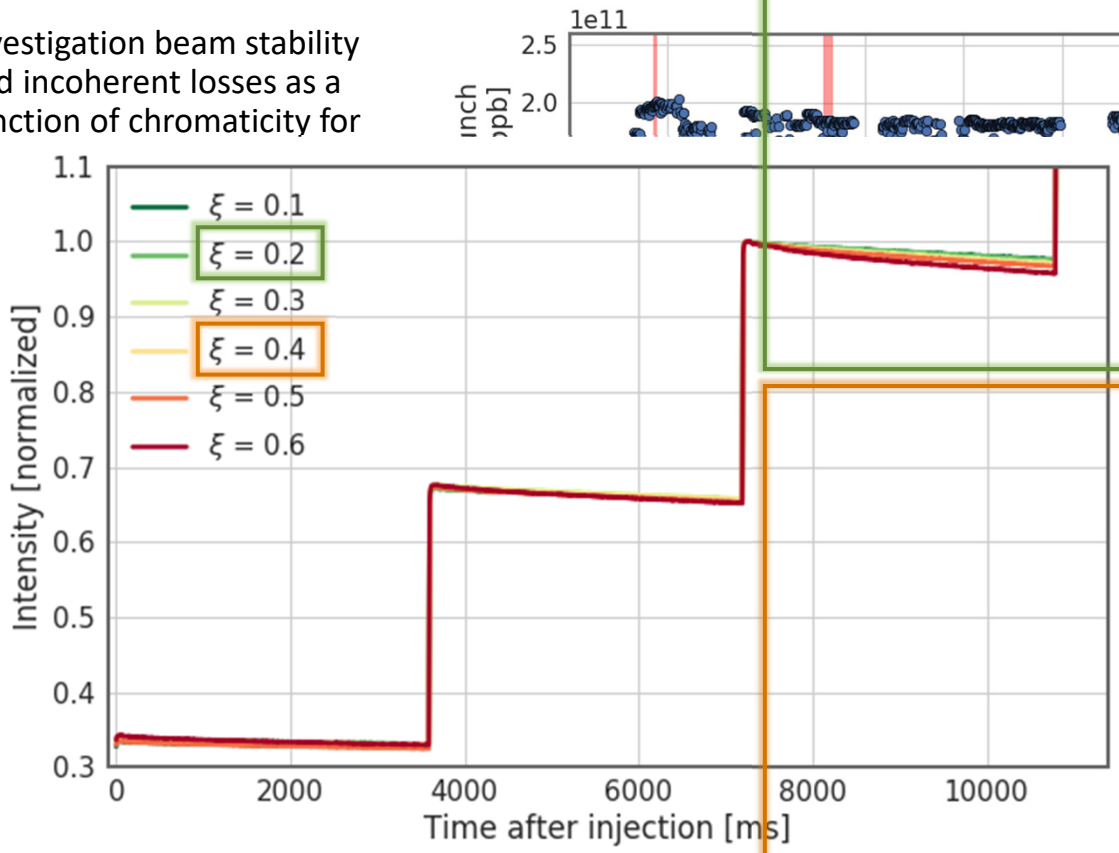

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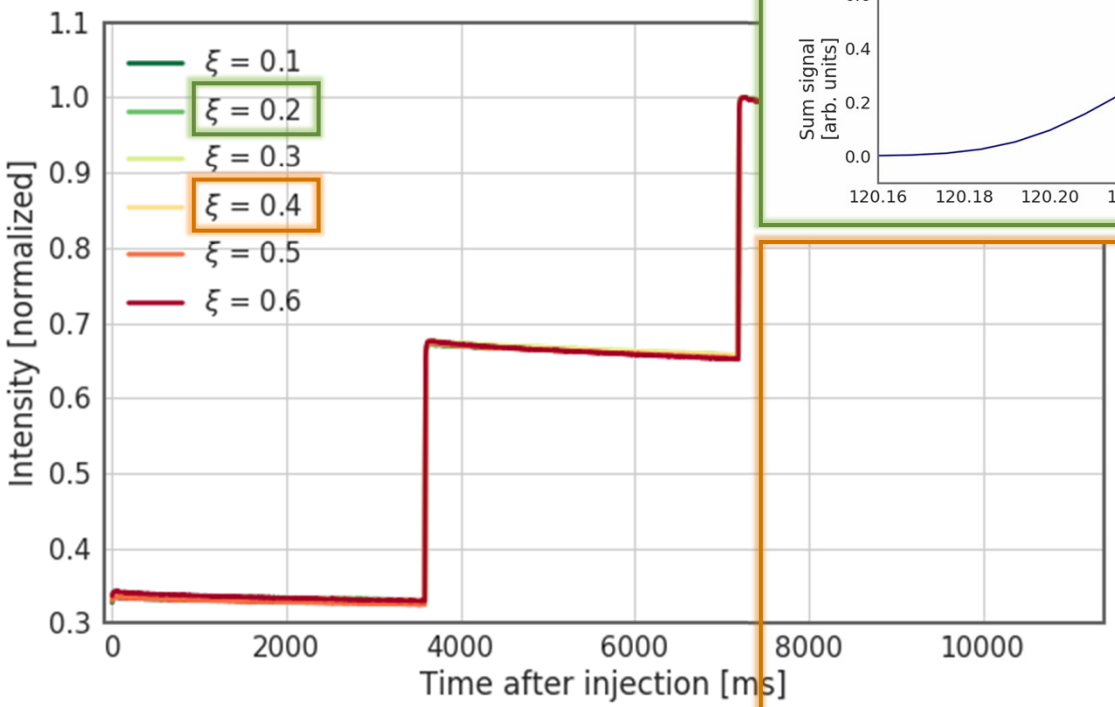

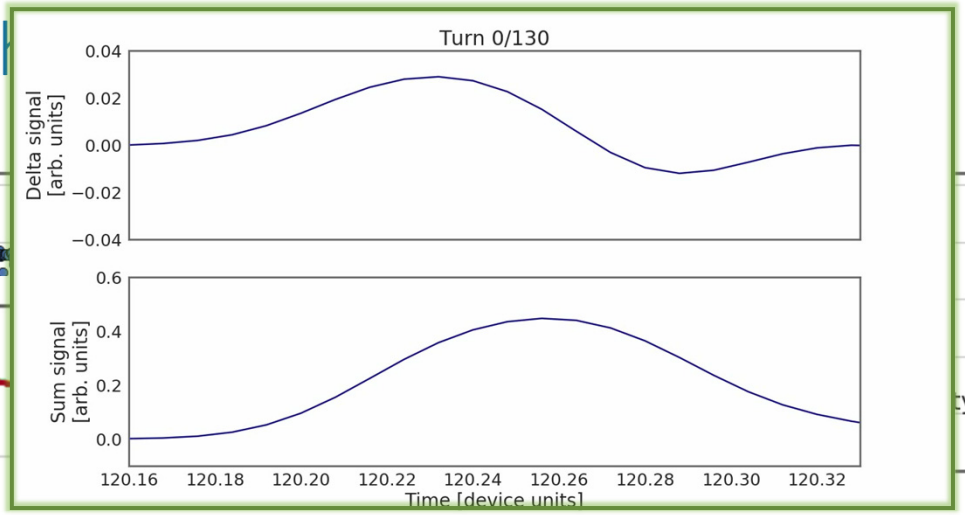

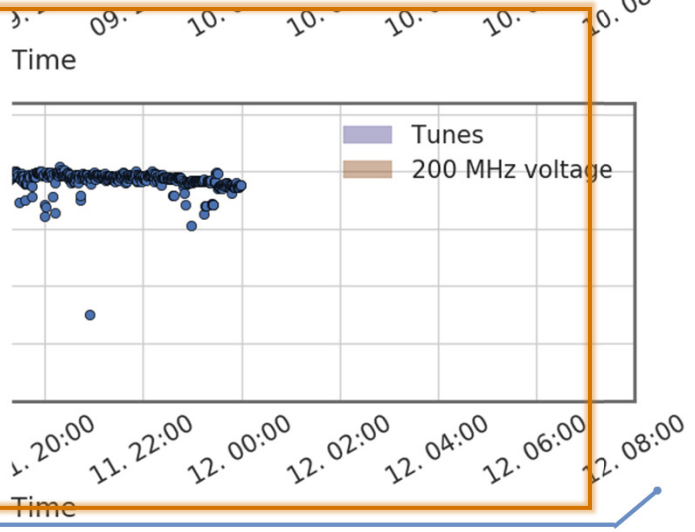

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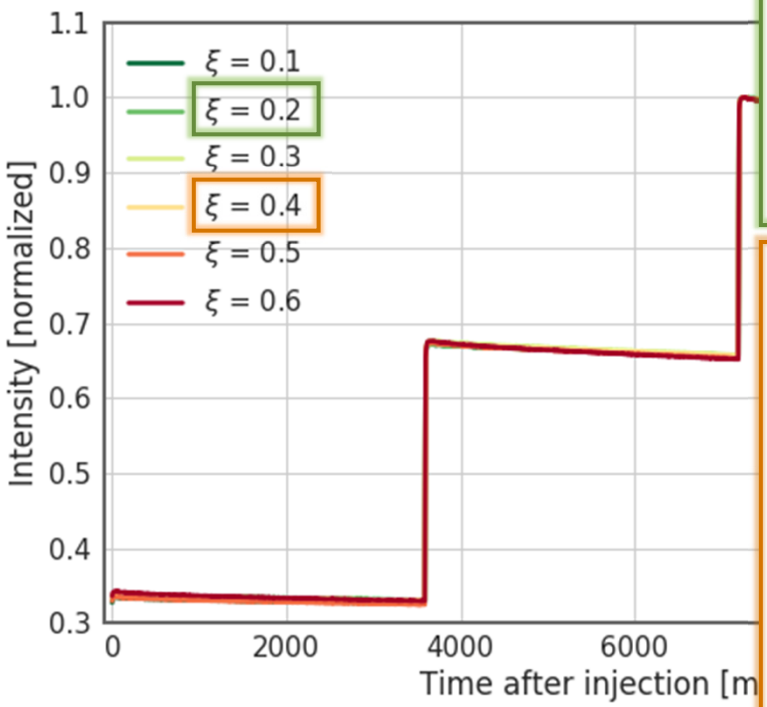

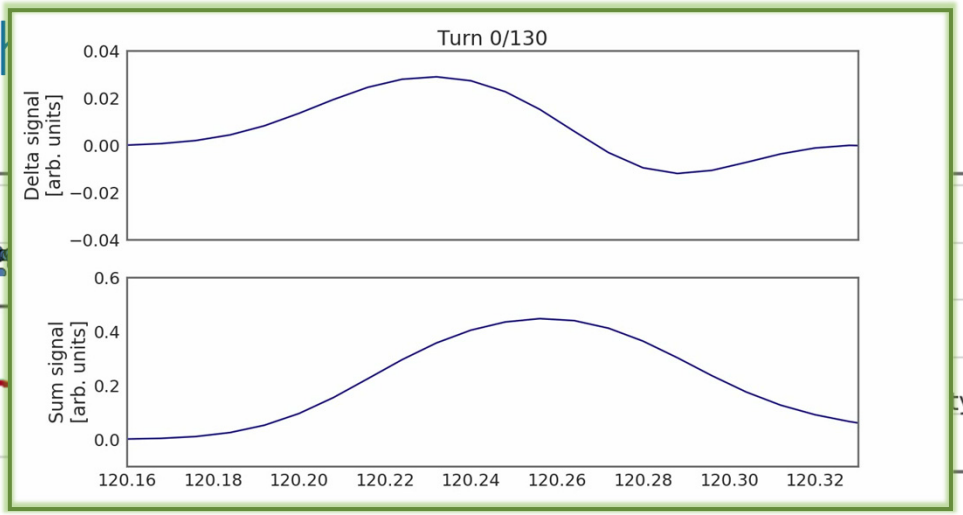

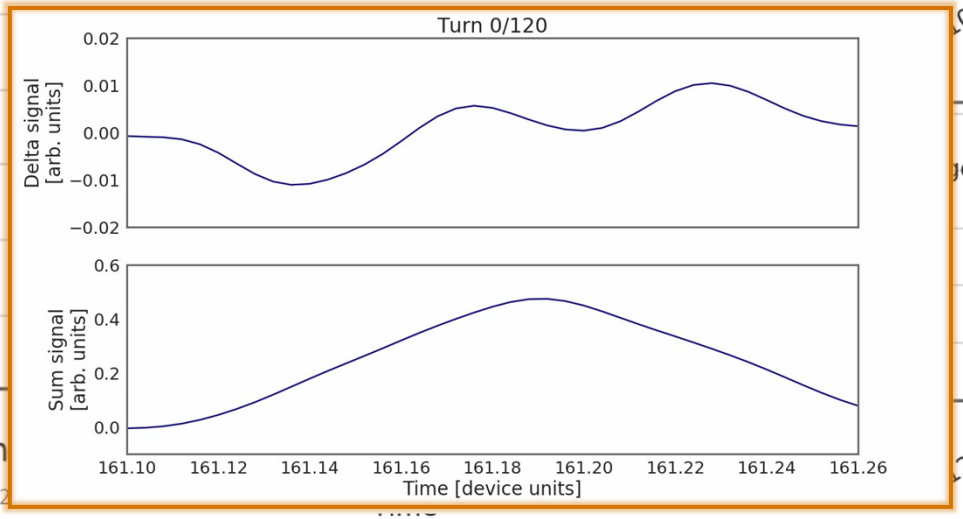

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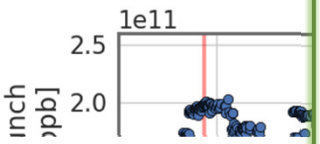
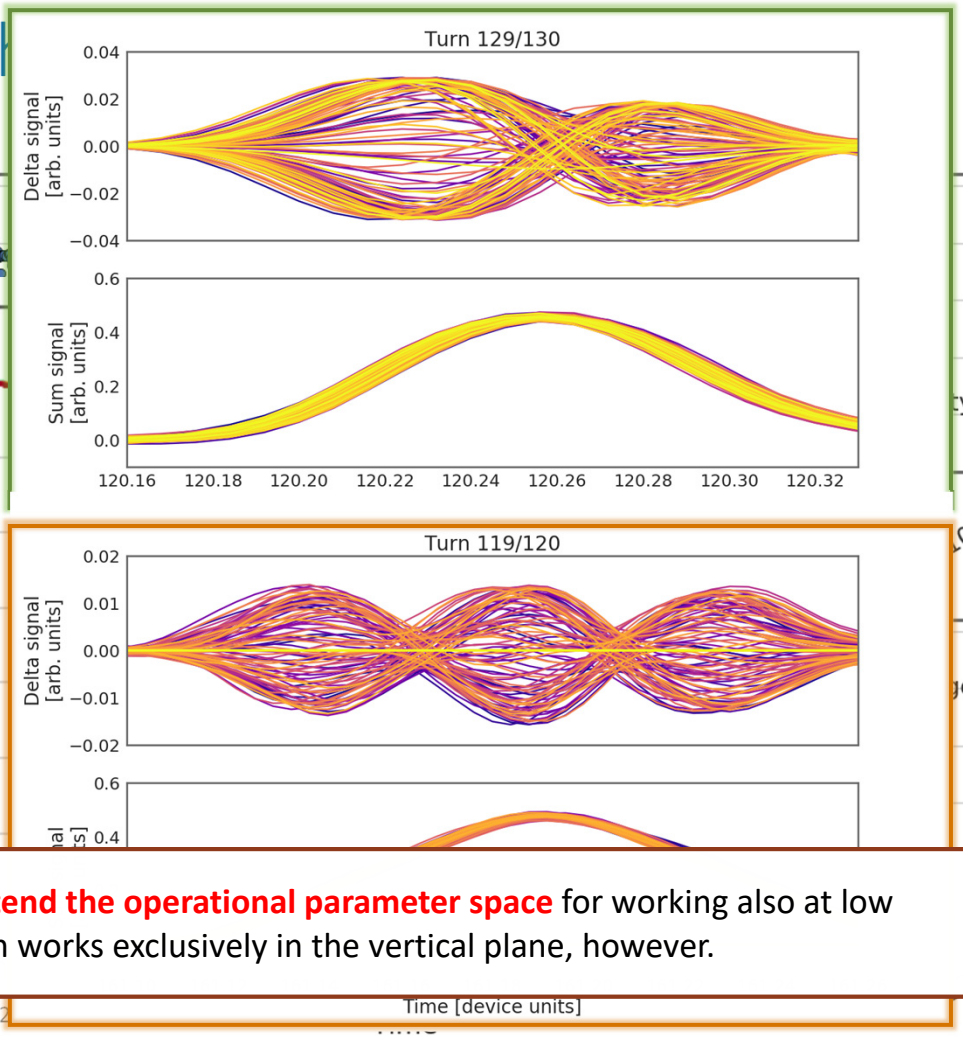
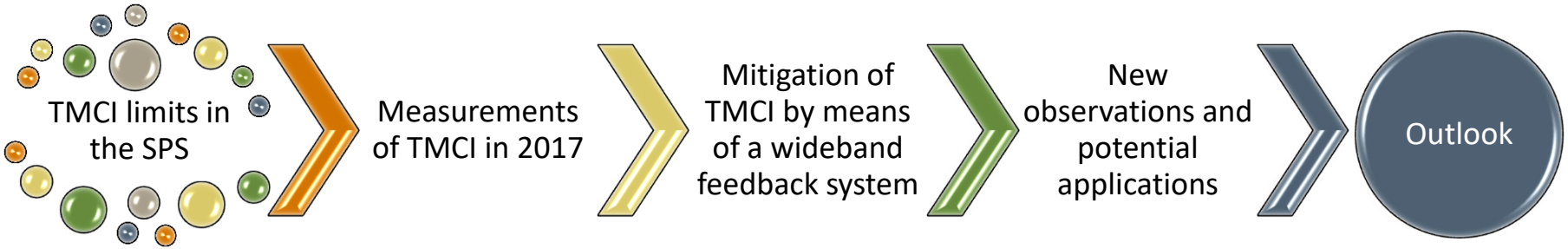
- BC





Clearly, a wideband feedback system could **extend the operational parameter space** for working also at low chromaticities. The present system works exclusively in the vertical plane, however.

Outline


TMCI limits in the SPS
Measurements of TMCI in 2017
Mitigation of TMCI by means of a wideband feedback system
New observations and potential applications
Outlook

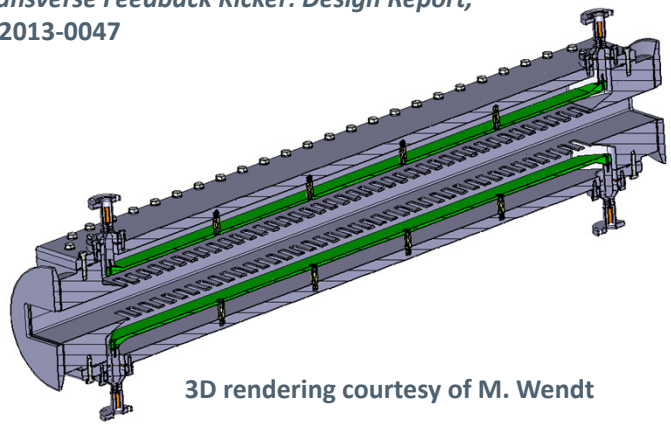
Outlook – using the slotline kicker

	N_{mod}	N_{amp}	P_{amp} (W)	P_{tot} (W)	$V_\perp$ (kV)				
					100 MHz	250 MHz	500 MHz	750 MHz	1000 MHz
Striplines	4	8	500	4000	7.6	7.3	6.3	4.9	3.2
Striplines	44	88	100	8800	37.3	35.9	31.1	23.9	15.5
Slotline	1	2	500	1000	3.2	3.3	3.6	4.2	4.6
Slotline	1	2	2000	4000	6.4	6.6	7.2	8.4	9.3
Slotline	6	12	300	3600	14.8	15.3	16.7	19.4	21.5

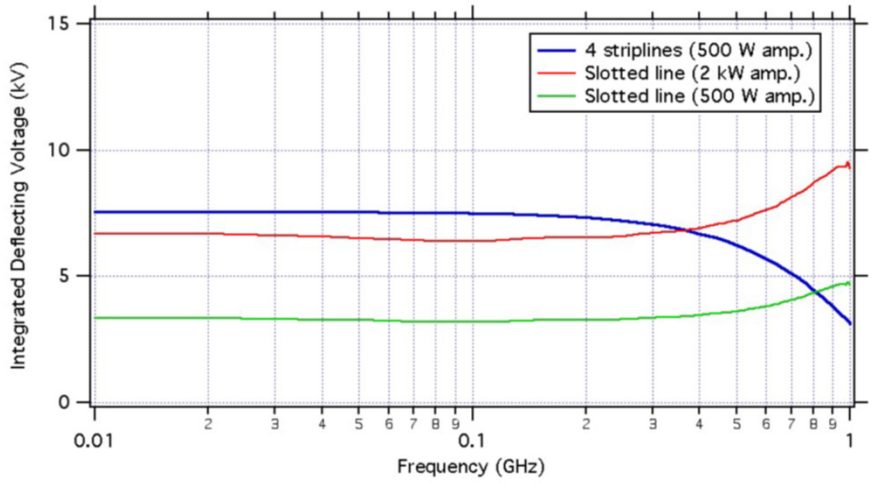
$$\Delta x' \propto \frac{eV_\perp}{E}$$

- Stripline – 10 cm
- Slotline – 1 m
- +- 5 m on each side

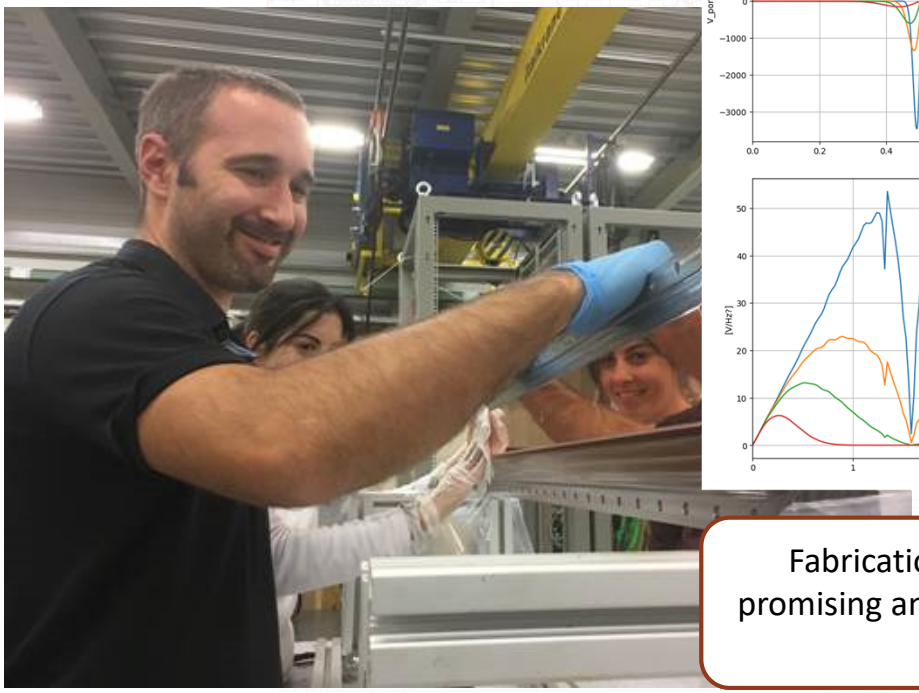
J. Cesaratto et al.:
SPS Wideband Transverse Feedback Kicker: Design Report,
CERN-ACC-NOTE-2013-0047

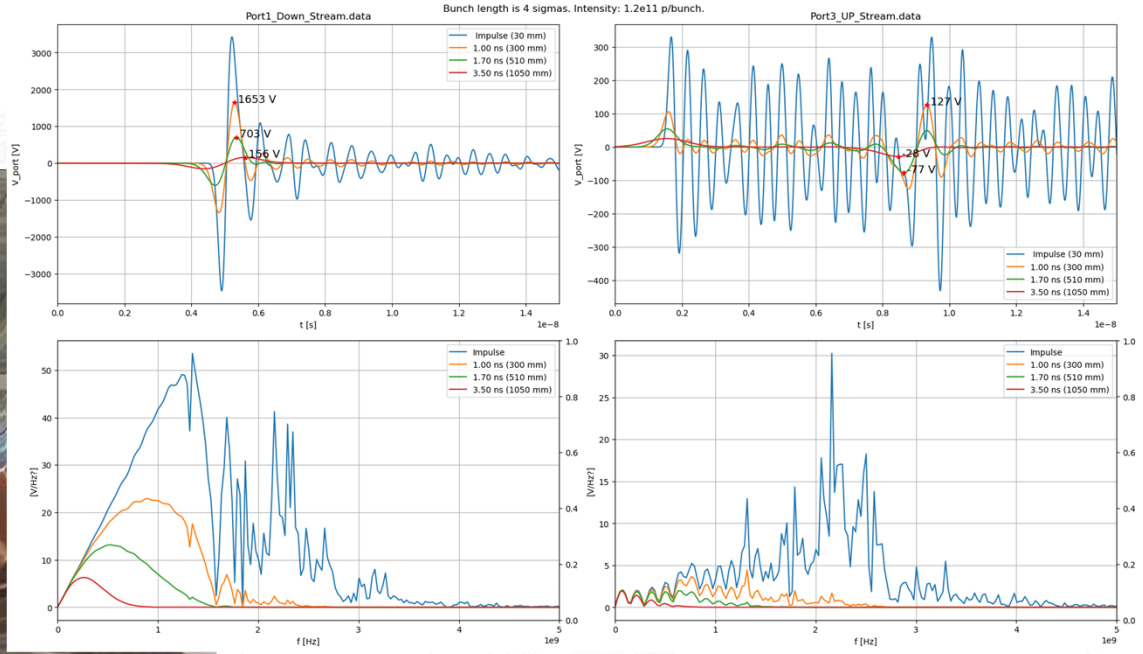


3D rendering courtesy of M. Wendt



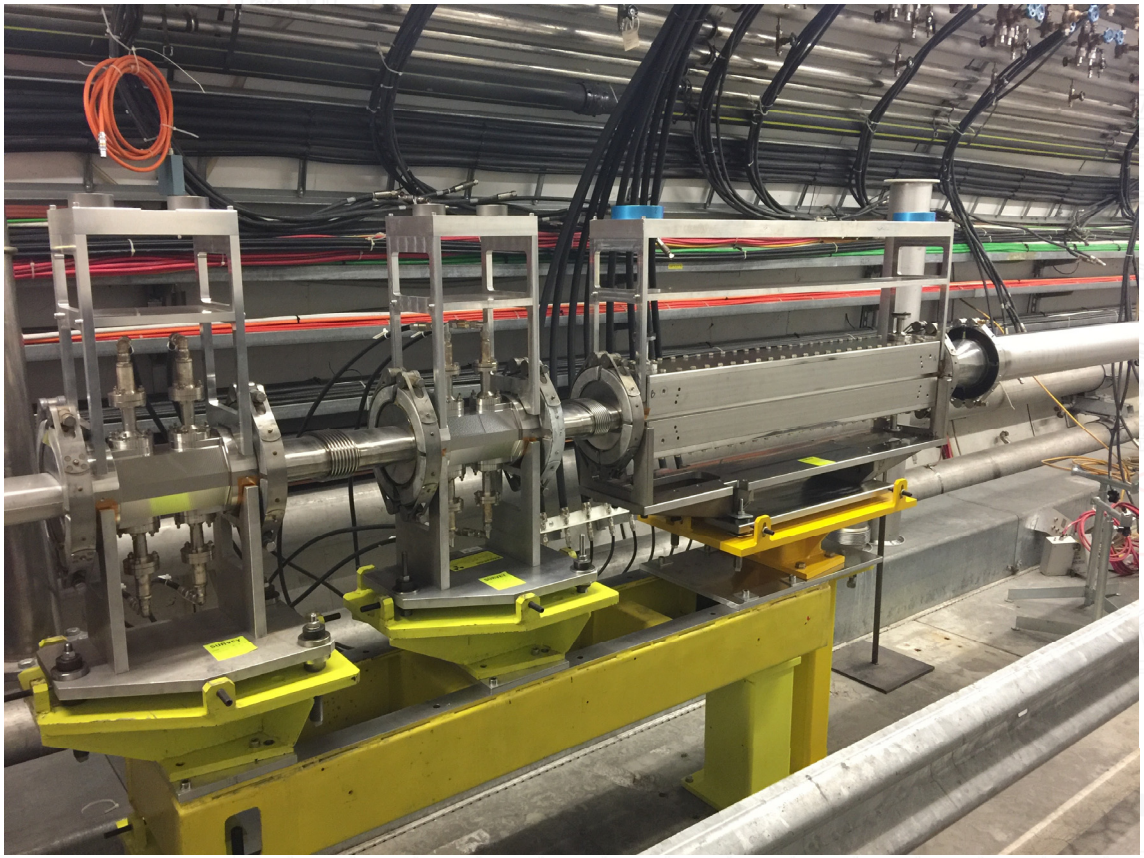
Outlook – using the slotline kicker





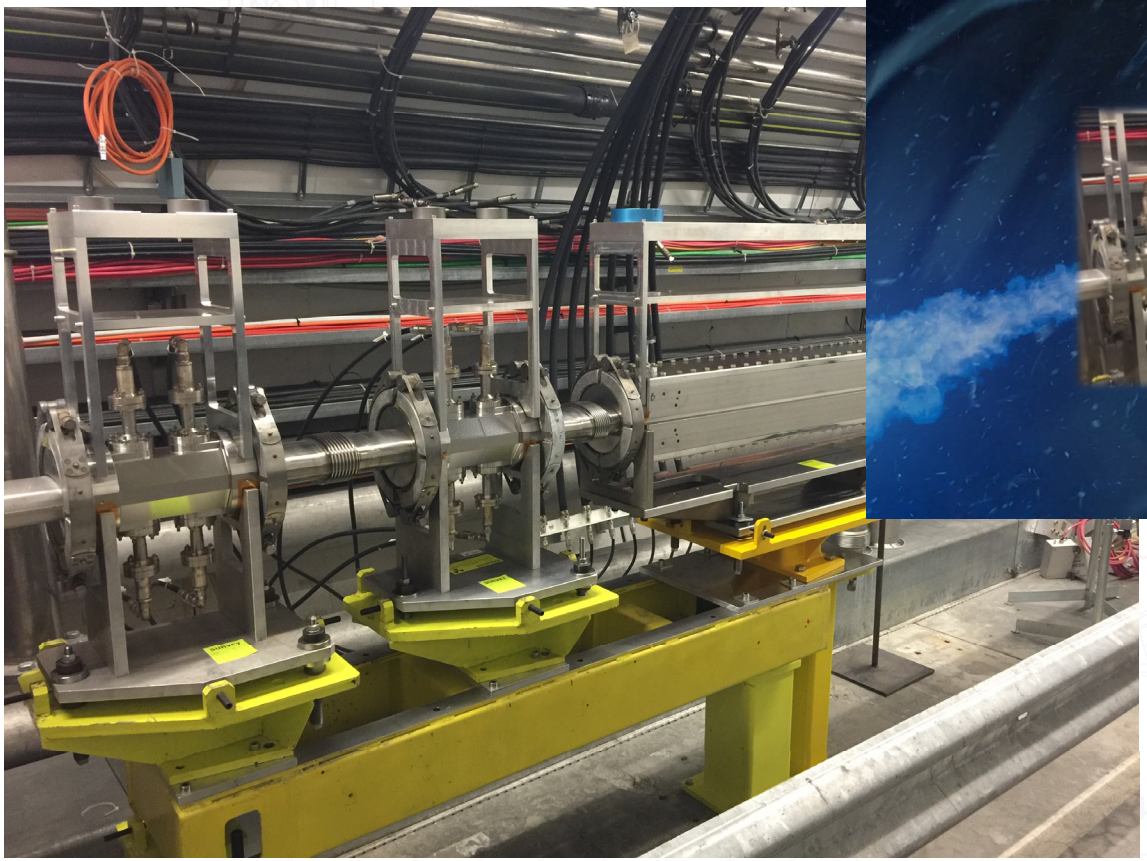
Fabrication and installation ready. Lab/tunnel measurements look promising and match well with the simulations. 50 Ohm matching is very good.

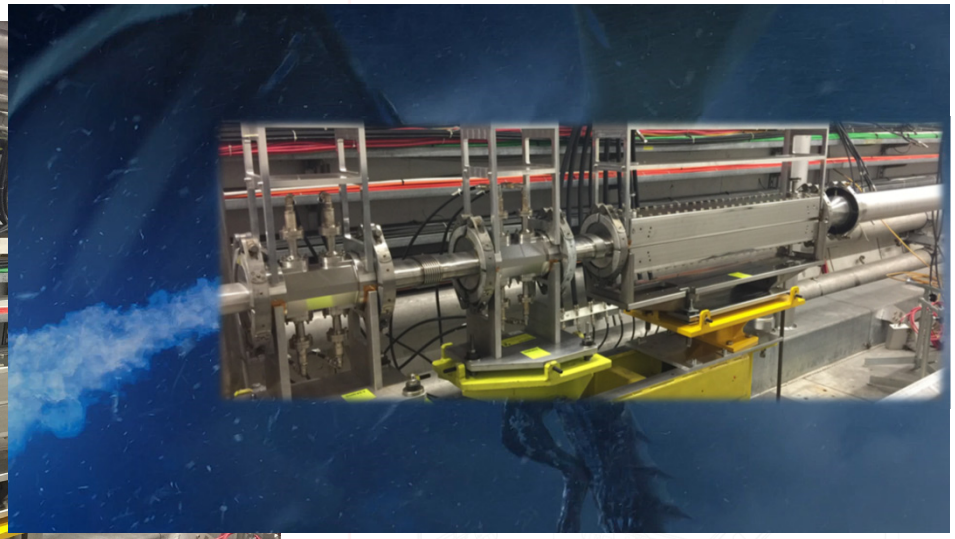
Outlook – using the slotline kicker



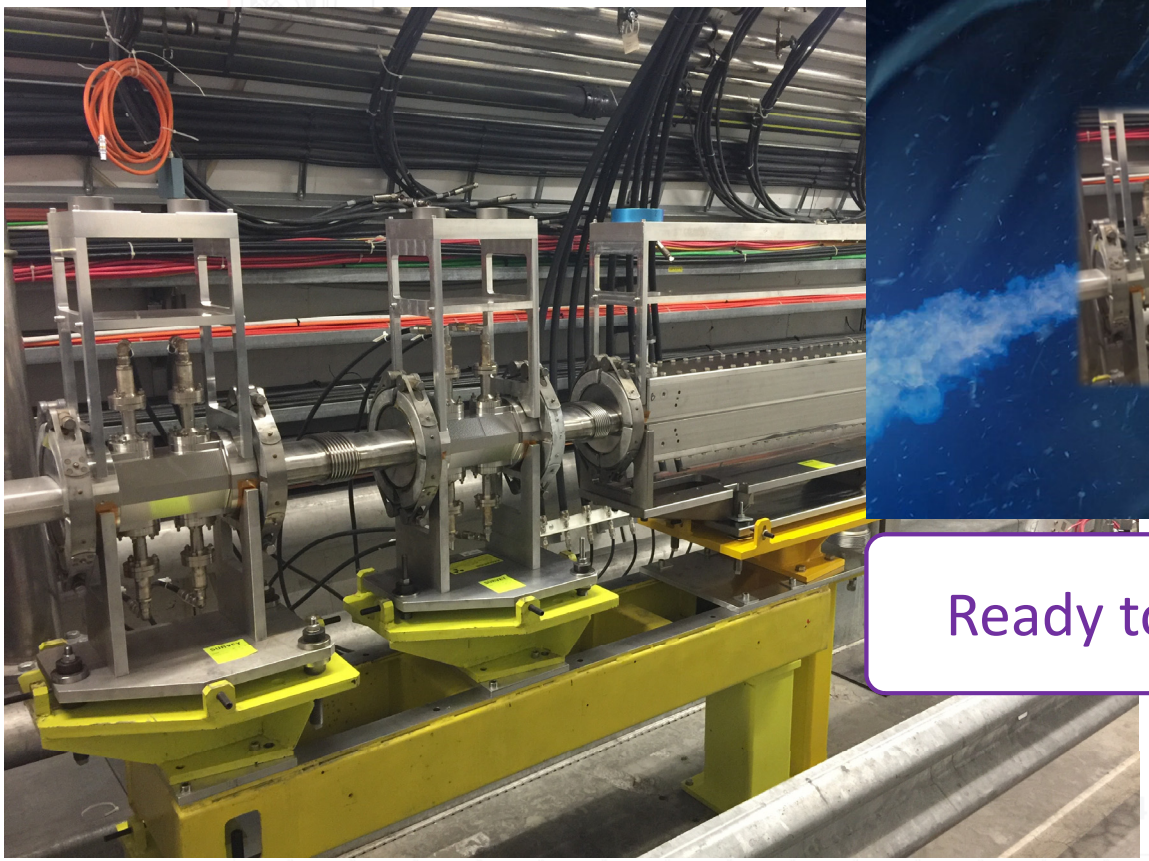
Some space (~ 5m at each side of the ADT) was already foreseen for a possible damper upgrade

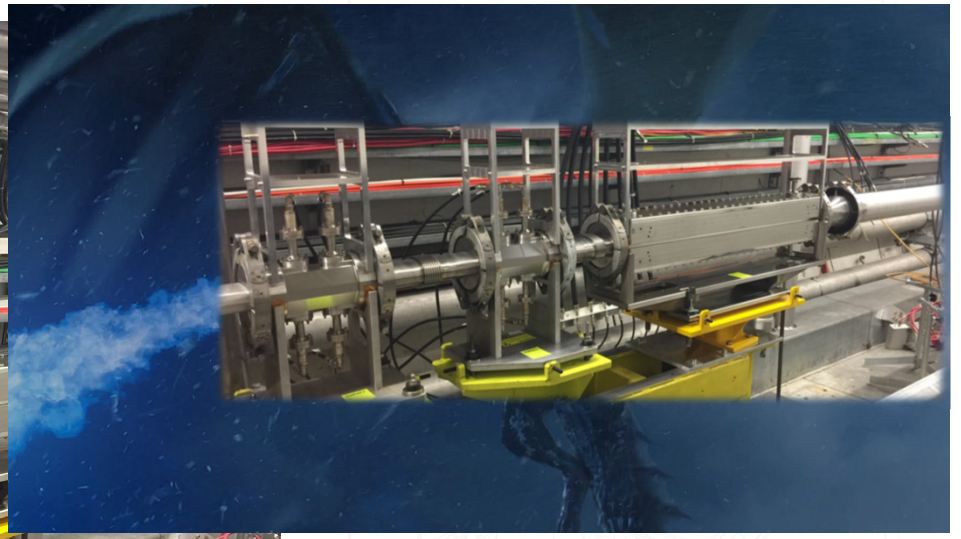
Outlook – using the slotline kicker





Outlook – using the slotline kicker





Ready to explore new realms!

Summary and conclusions

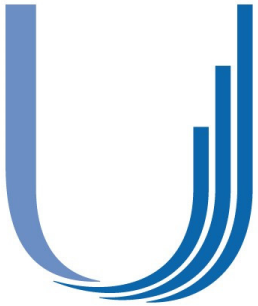
Summary and conclusions

- **Measurement of the TMCI thresholds for Q22 optics in the SPS:**
  - **Required intensities for LIU are around 2.6e11 ppb injected**
  - **Q22 TMCI threshold measured at around 2.4e11 ppb for nominal machine and beam parameters**

- **Achievements with the wideband feedback demonstrator system for far**
  - **Demonstration of control of intra-bunch motion in the slow TMCI regime**
  - **Demonstration of control of multi-bunch centroid motion**
  - **Demonstration of mitigation of fast TMCI in combination with a conventional transverse damper**

- **Other potential applications:**
  - **During high intensity runs we observe the emerging of higher order headtail modes in the horizontal plane at intermediate chromaticities; these are not mitigated by the conventional transverse damper**
  - **A wideband feedback system could stabilize these headtail modes and considerably extend the operational parameter space**

- **Installation of slotline kicker:**
  - **Installation during these YETS – matching to 50 Ohm is very good**
  - **Presently cabled for observation of beam induced signals (validation of impedance)**
  - **Possibility to power with 2x250 W at 5-1000 MHz (at penalty of not powering one stripline)**



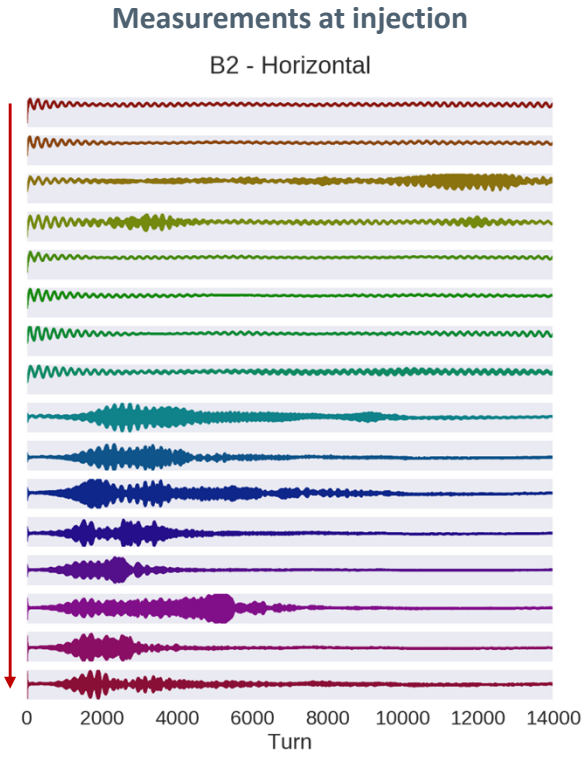
LHC Injectors Upgrade

Electron cloud in the LHC

When moving to **multi-bunch** or **multi-batch** operation, **electron clouds** in the LHC form one of the hardest limits for the number of bunches that can be injected, ramped and stored

Electron cloud in the LHC

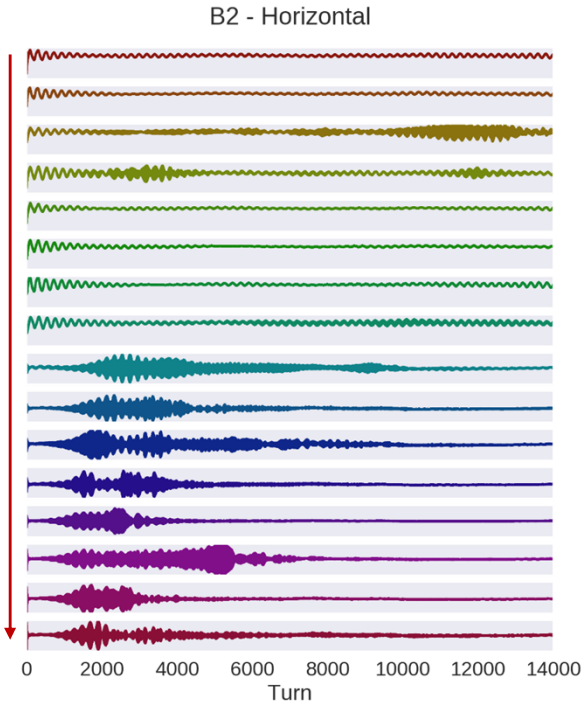
When moving to **multi-bunch** or **multi-batch** operation, **electron clouds** in the LHC form one of the hardest limits for the number of bunches that can be injected, ramped and stored



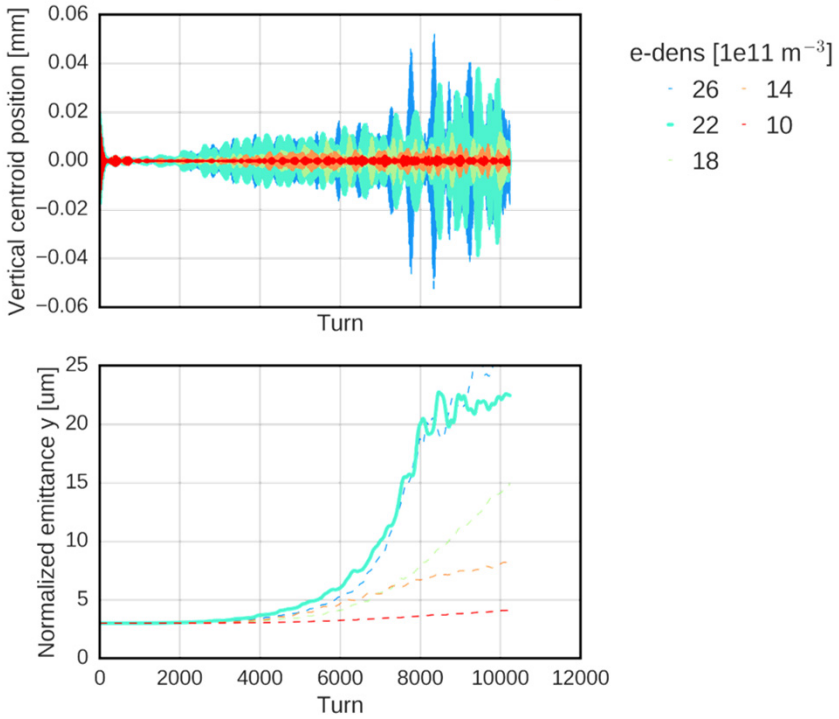
Electron cloud in the LHC

When moving to **multi-bunch** or **multi-batch** operation, **electron clouds** in the LHC form one of the hardest limits for the number of bunches that can be injected, ramped and stored

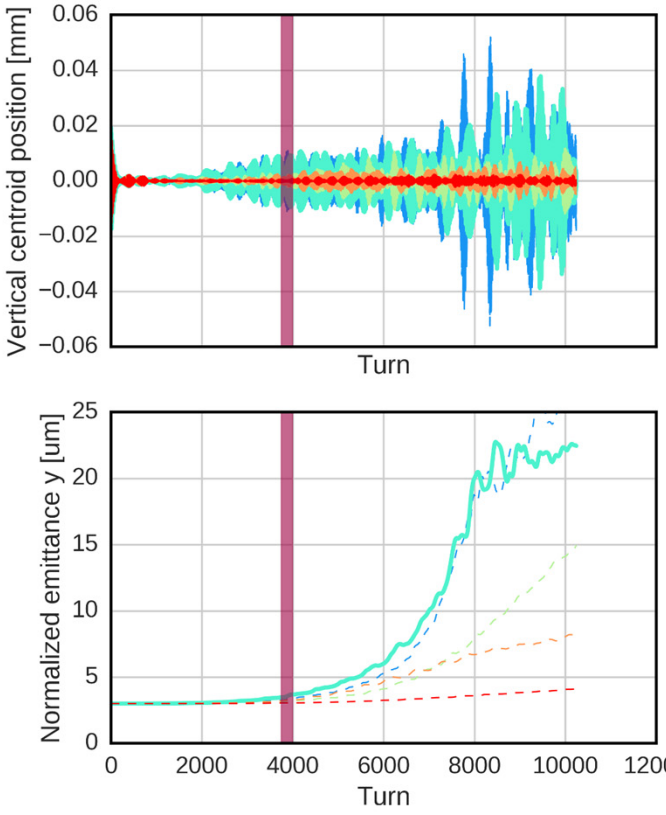
Measurements at injection

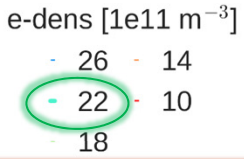


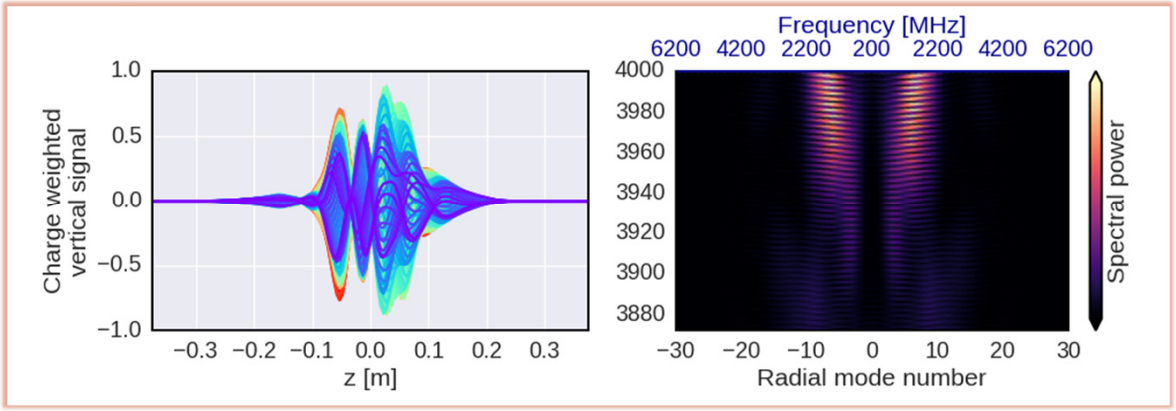
Simulations at flat top



E-cloud at 6.5 TeV







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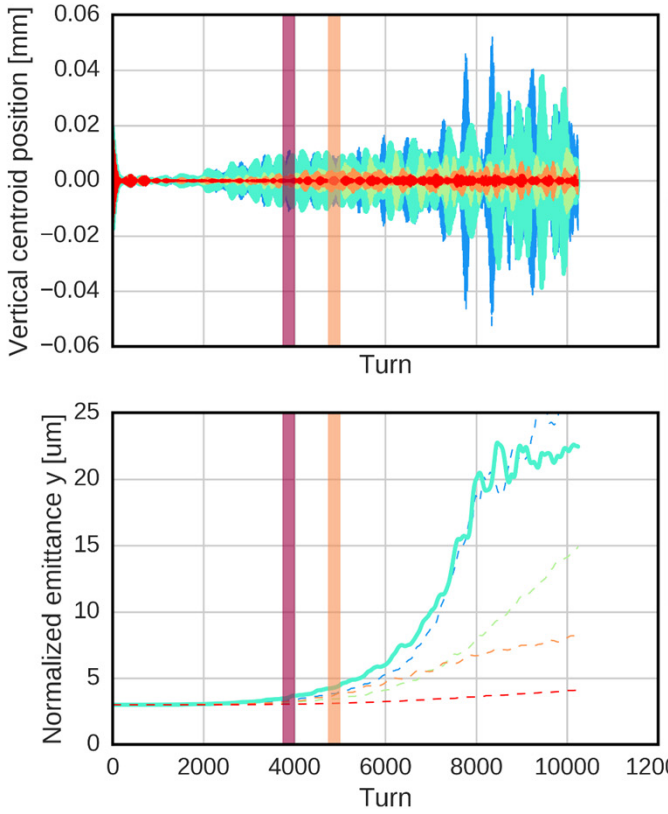
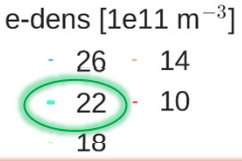
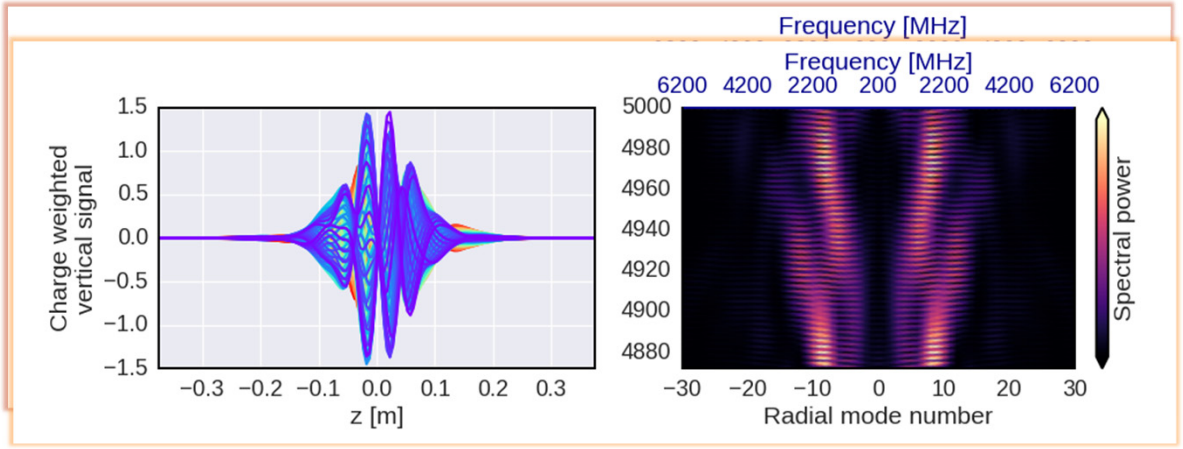
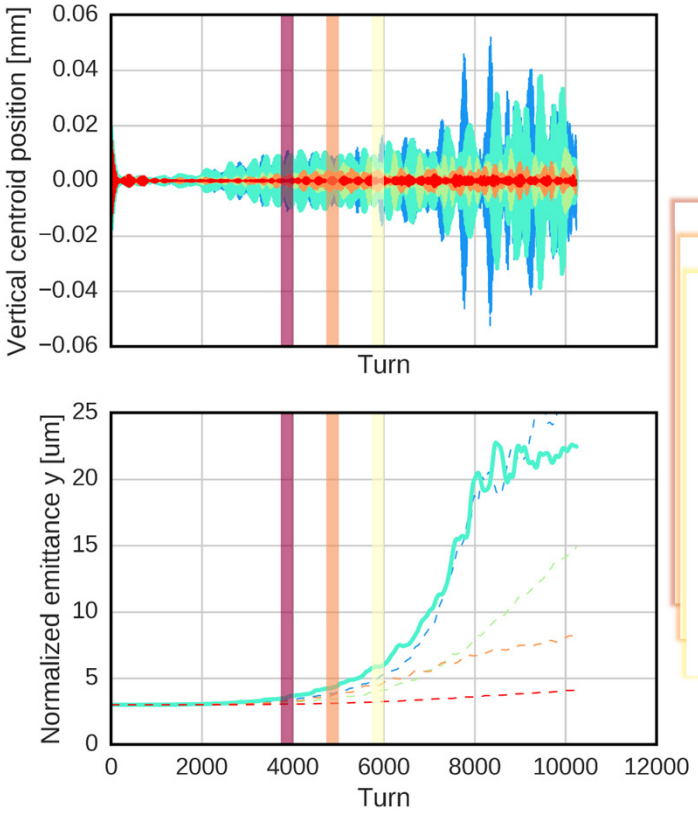
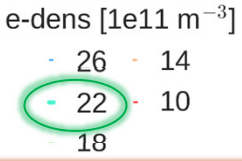


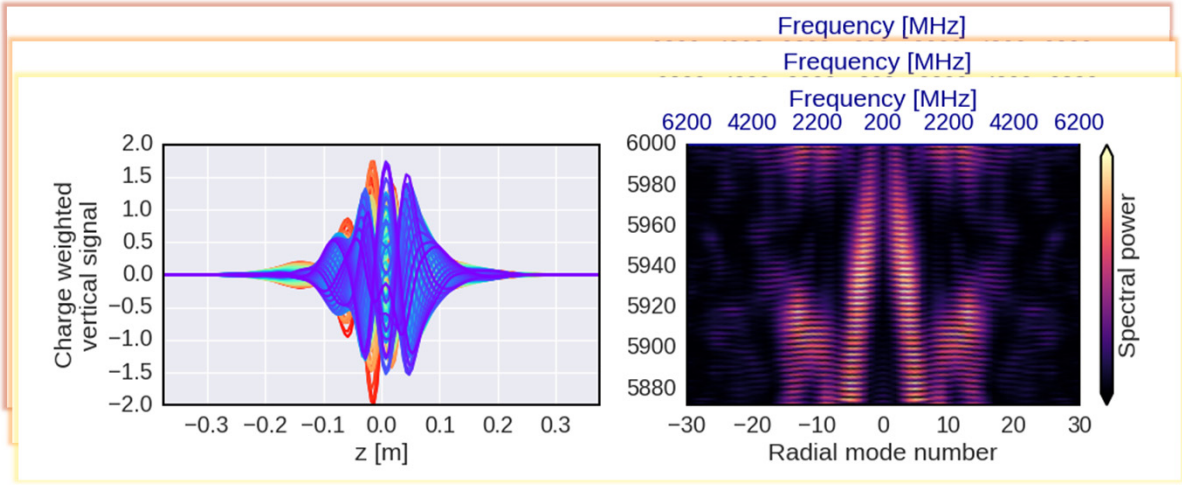




E-cloud at 6.5 TeV







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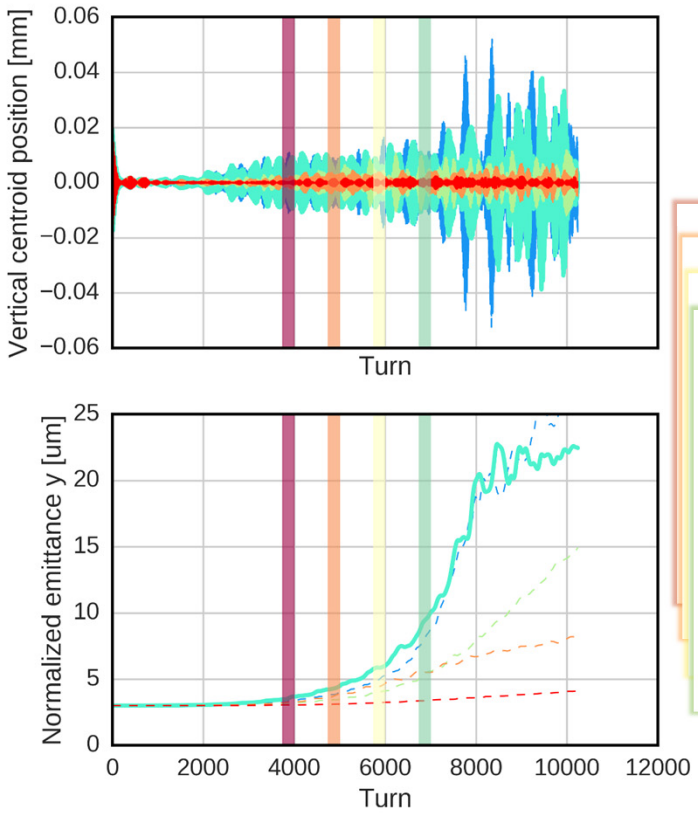

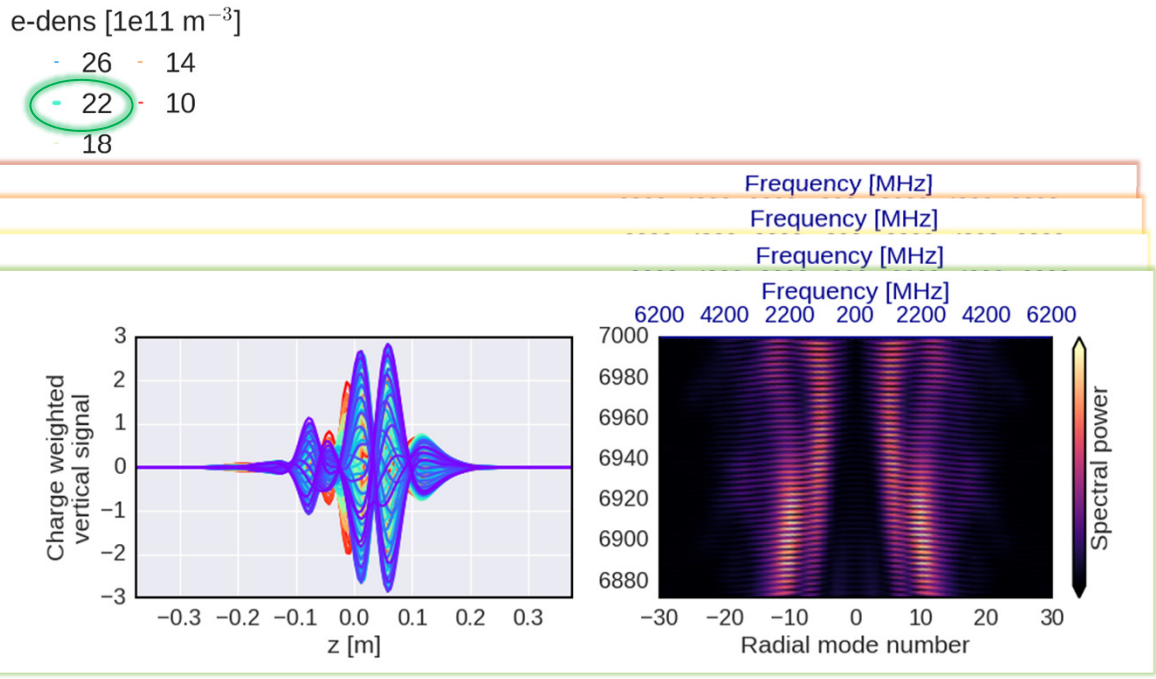

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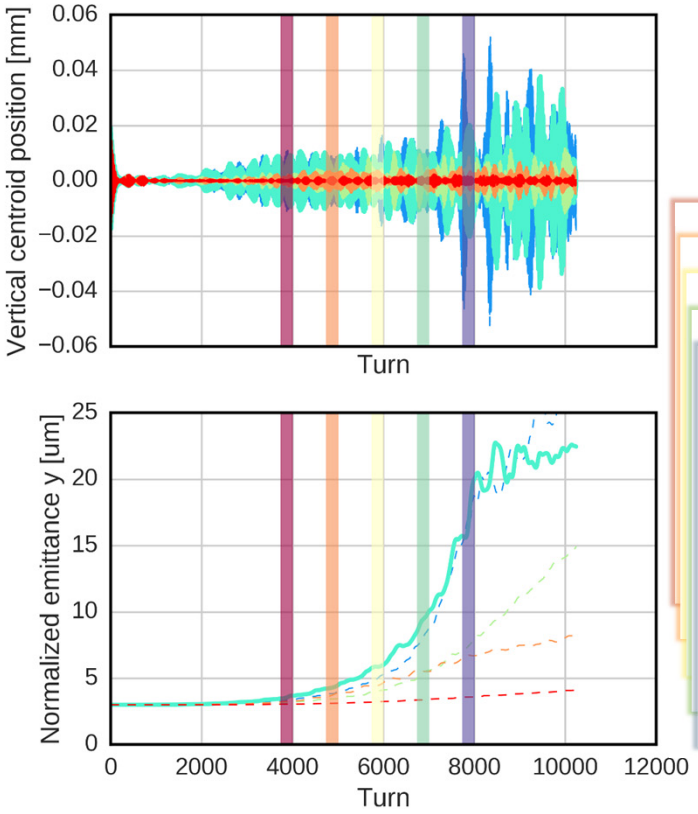

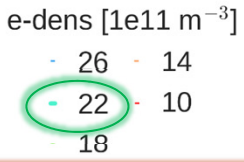

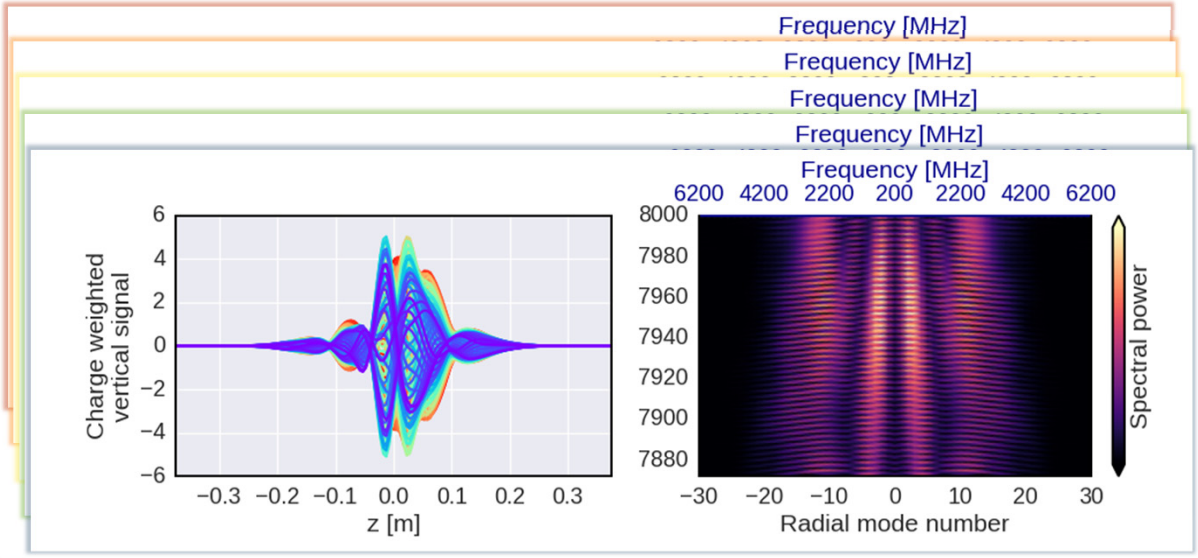

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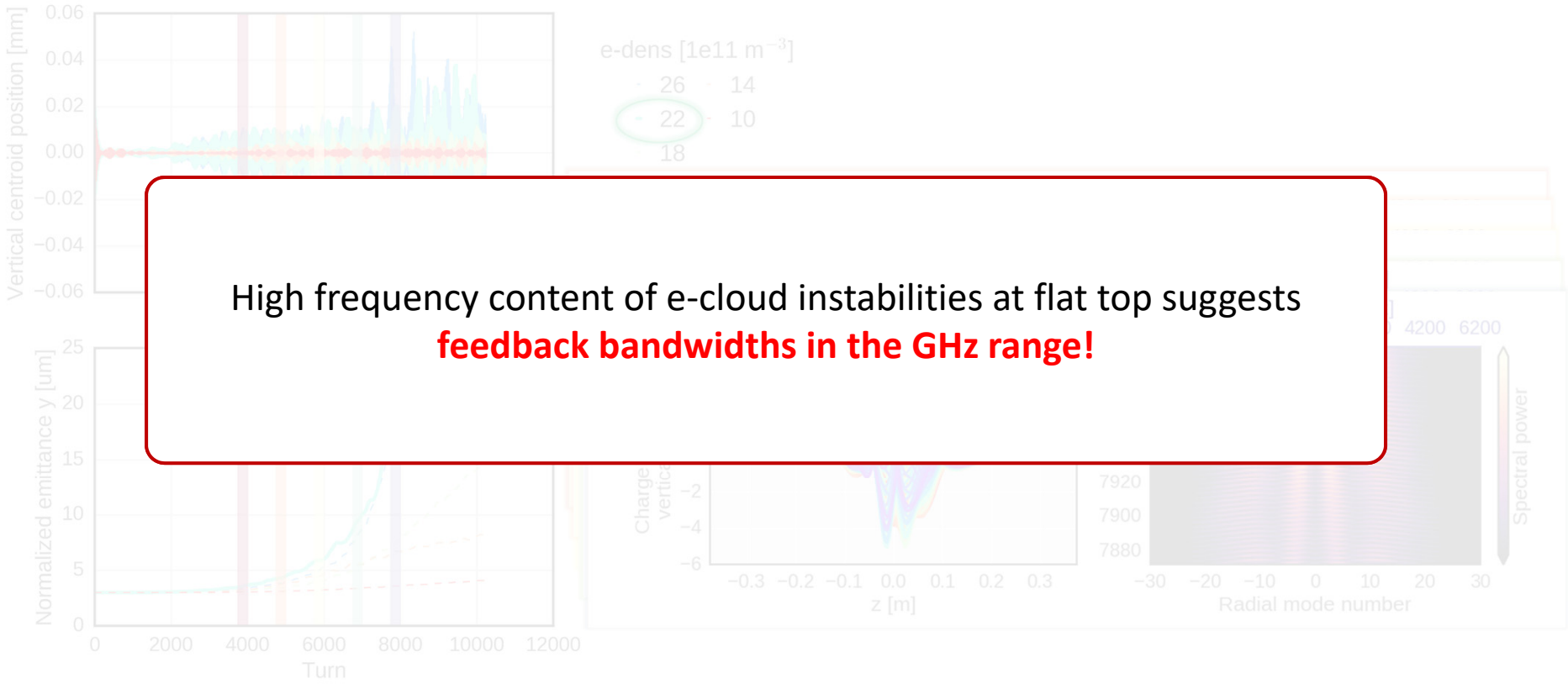
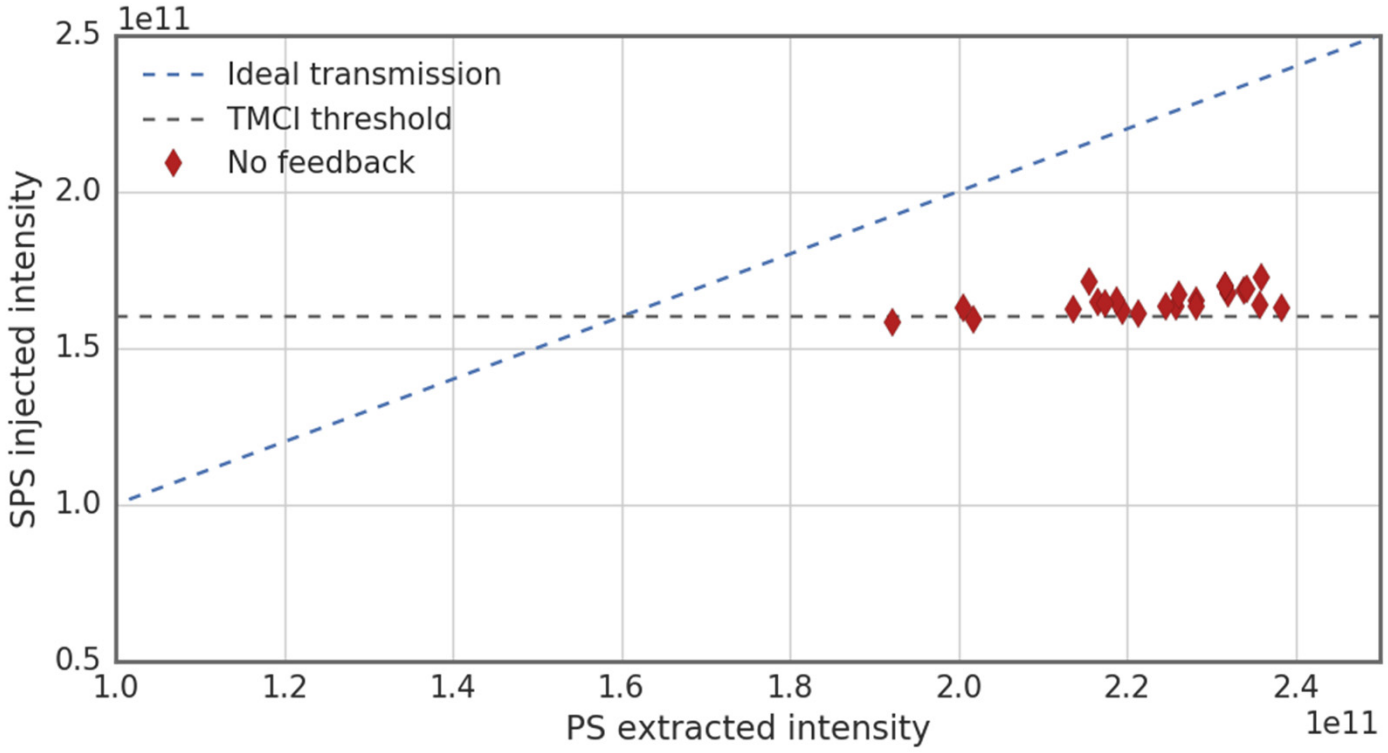


High frequency content of e-cloud instabilities at flat top suggests **feedback bandwidths in the GHz range!**

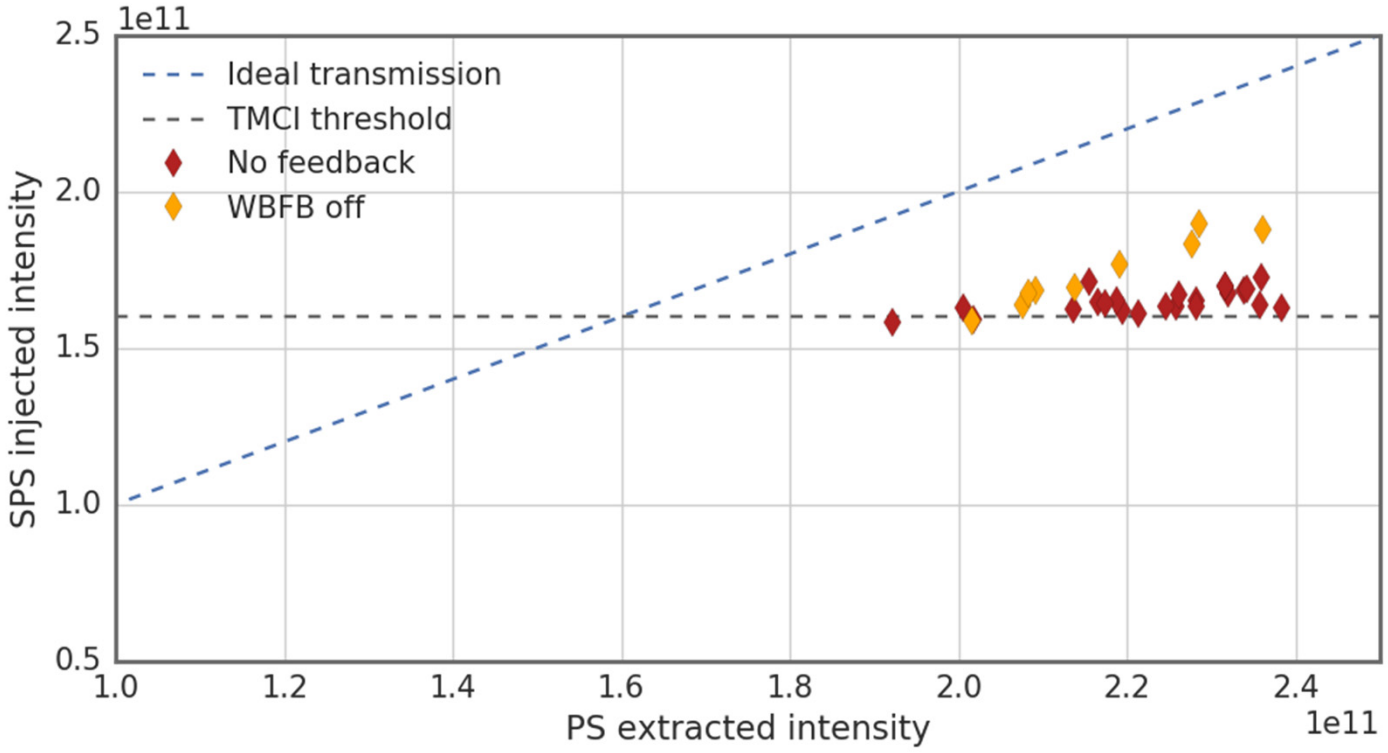
Intensity scan

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



Intensity scan

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



Intensity scan

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