Summary of instability observations at LHC and implications for HL-LHC

X. Buffat, D. Amorim, S. Antipov, S.V. Furuseth, G. Iadarola, E. Métral, N. Mounet, B. Salvant, A. Oeftiger

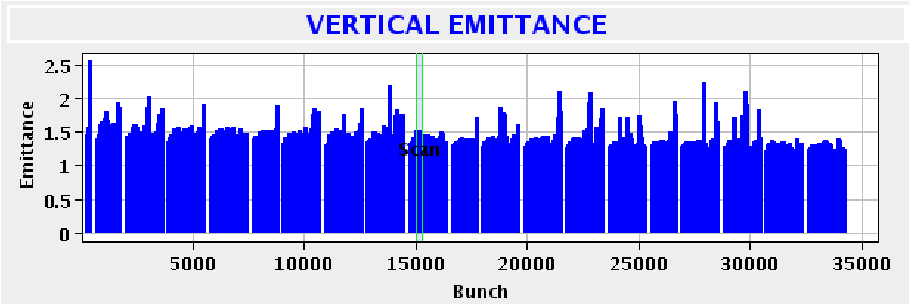
WP2 meeting – 09.07.2019

Content

- Injection
- Ramp
- Flat top
- Offset collision

Injection

- Weak instabilities affecting bunches at the end of trains were observed regularly in 2018, despite I_{oct}~40 to 50A, Q'~15 to 20, regular coupling corrections and Laslett tune shift correction



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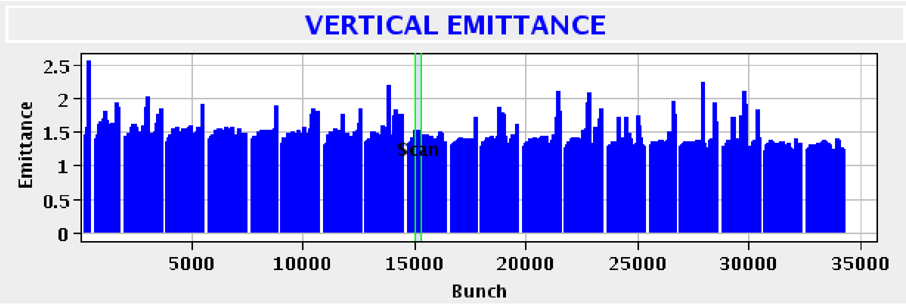
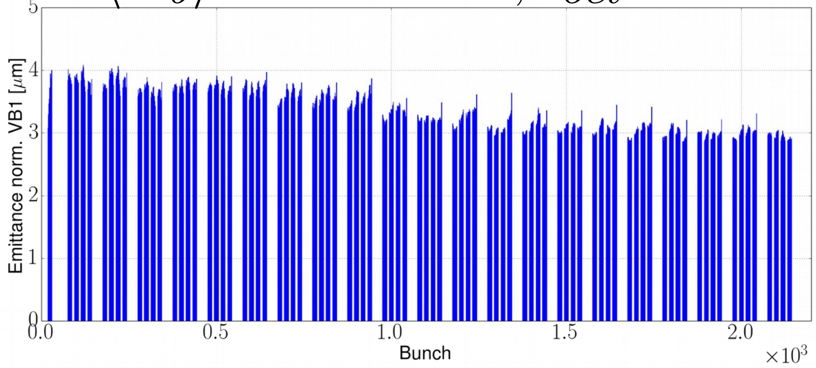
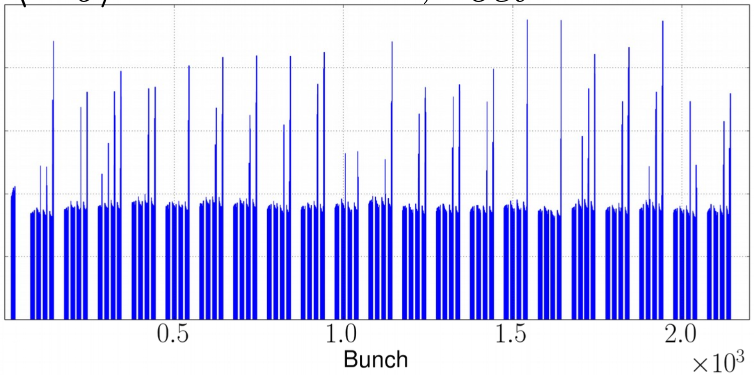


$$\langle N_b \rangle \approx 1.8 \cdot 10^{11}, I_{oct} = 0$$



$$\langle N_b \rangle \approx 0.7 \cdot 10^{11}, I_{oct} = 56A$$

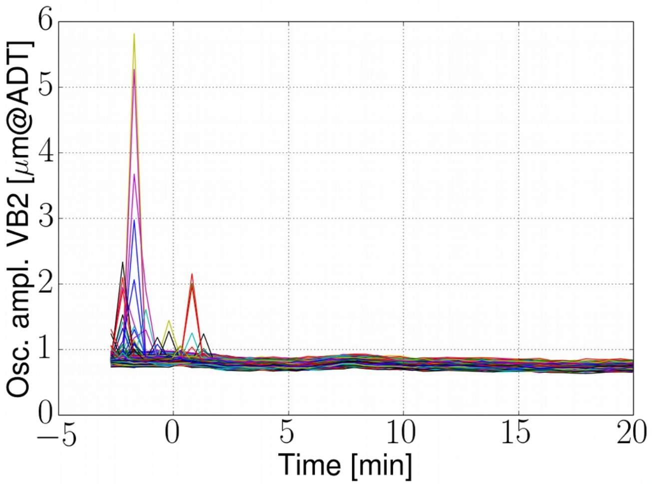


- Expected improvement of the stability with high bunch intensity* was observed experimentally → Detailed (heavy) simulations are ongoing to validate the HL-LHC scenario

*A. Romano, et al., Phys. Rev. Accel. Beams 21, 061002 (2018) and G. Iadarola, et al., Digesting the LIU high brightness beam: is this an issue for HL-LHC?, Chamonix 2018

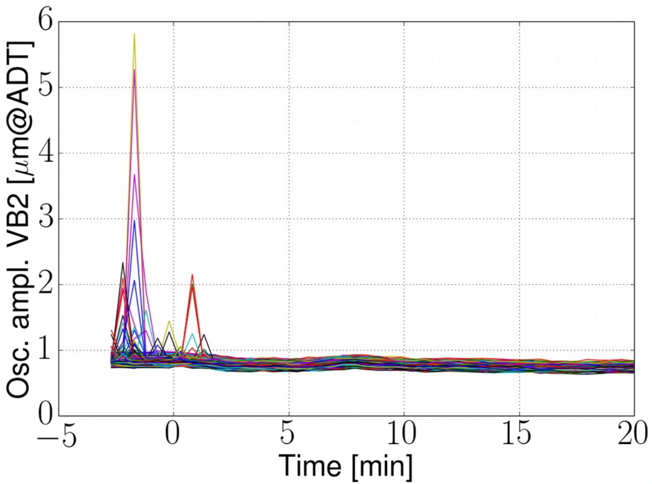
Ramp

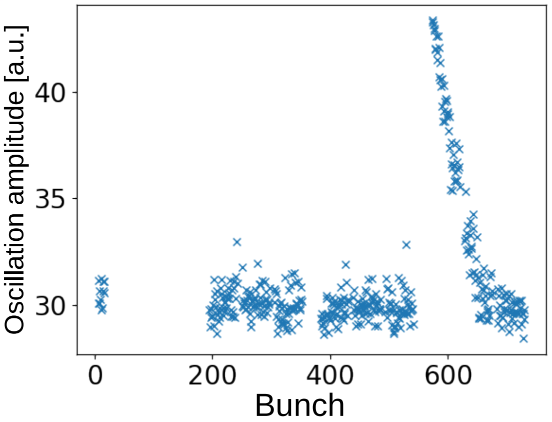
- Weak instabilities were observed at the start of the ramp, they seem to be of the same nature as the injection instabilities

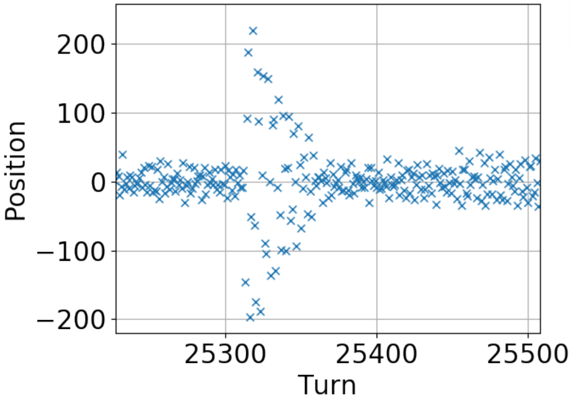


Ramp

- Weak instabilities were observed at the start of the ramp, they seem to be of the same nature as the injection instabilities
- At three occasions in 2018, coherent oscillations were observed, with ‘kick-like’ pattern rather than instability-like



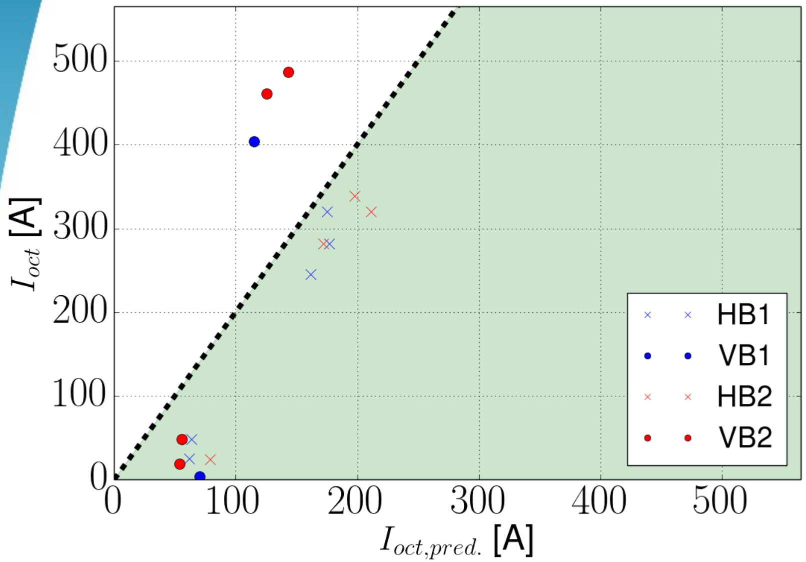




- There was no measurable degradation of the quality of those bunches
- A hardware failure within the ADT cannot be exculded with the existing internal diagnostics

$\rightarrow$ Impovements are foreseen for run III

Octupole threshold measurements at flat top in 2018



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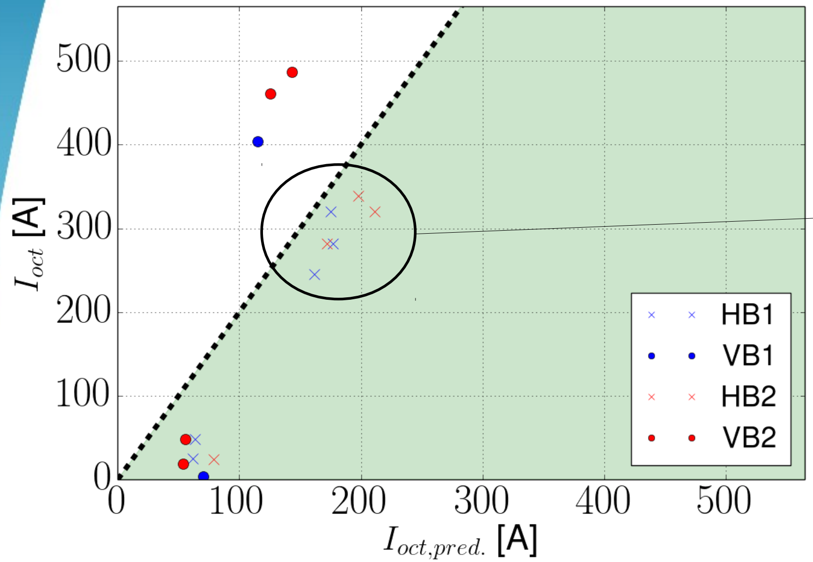

$$\text{std config} \rightarrow \frac{I_{oct}}{I_{oct,pred}} \approx 1.8$$

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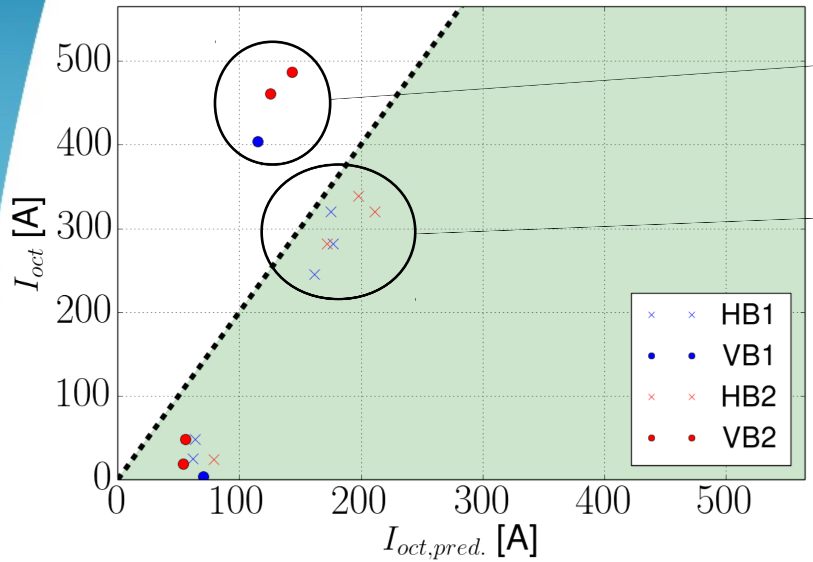

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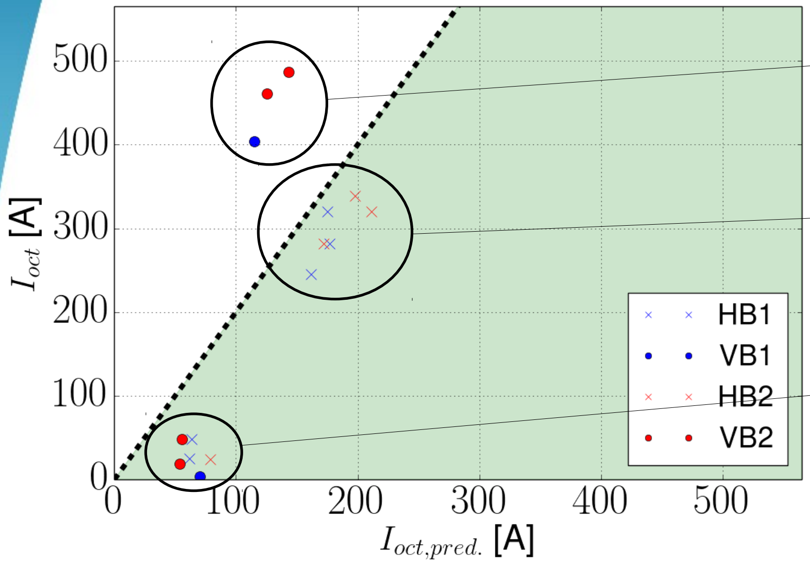

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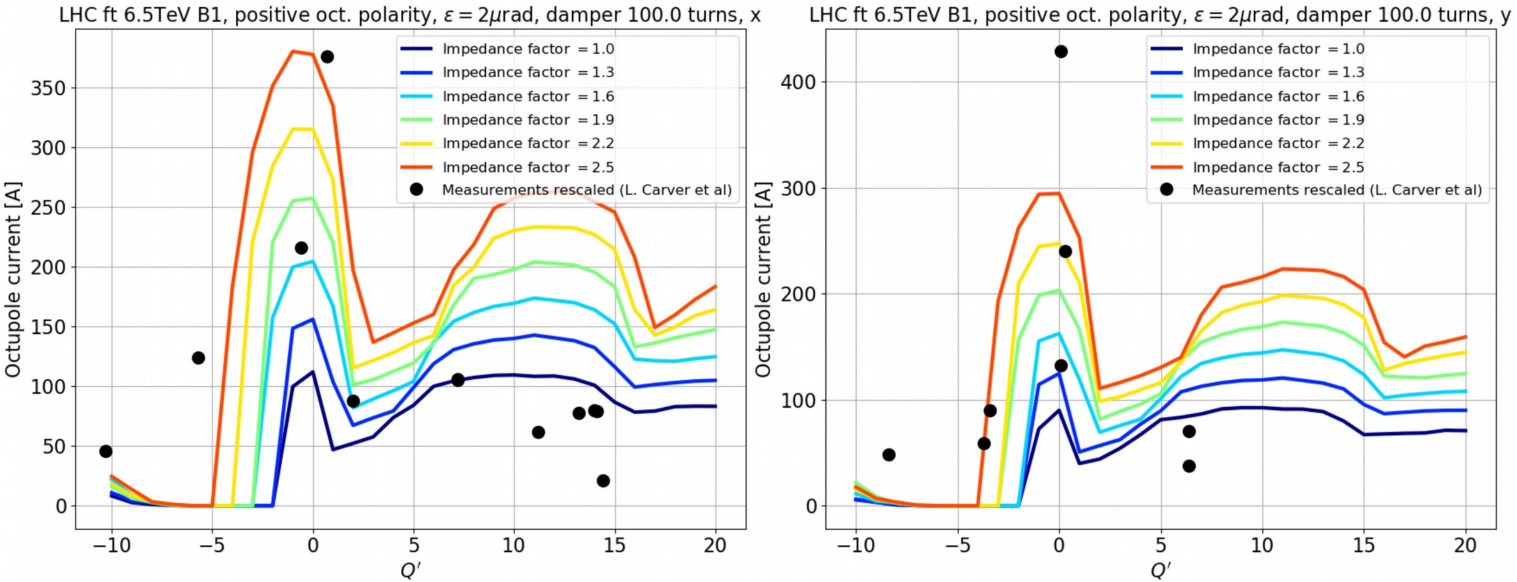
Round ATS MD
→ r_{ATS} = 3.1

- Octupole scans with 10 minutes steps show a threshold at about twice the expected current in the standard configuration (ADT damping time ~ 50 turns, Q'~15)
  - Without ADT the relative disagreement increases to almost 4
  - With the negative polarity and a large telescopic index, the measured threshold matches expectation, possibly an effect of high tail population (see E. Metral and A. Verdier, CERN-AB-2004-019-ABP)

Reviewed octupole threshold measurement from 2015 (See N. Mounet @ HSC 18.02.2019)



- In 2015 (and 2016), octupole scans with ~1 minute steps showed thresholds equal or lower than expected for Q'>2

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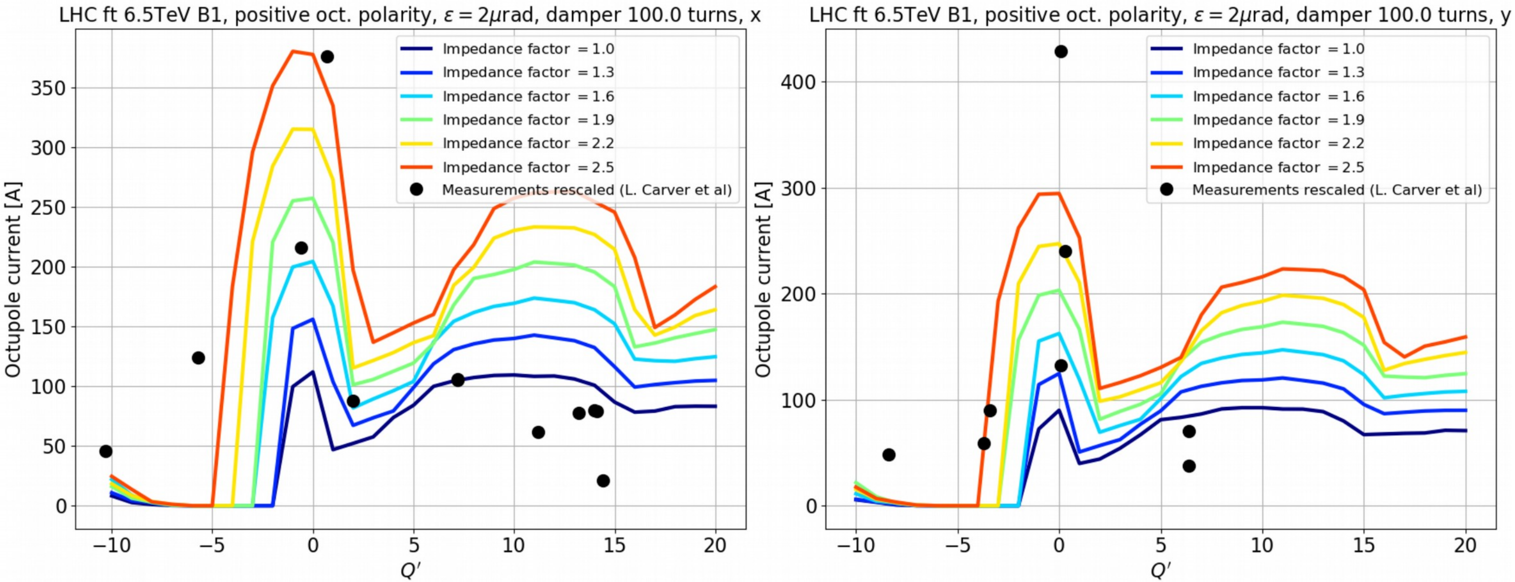

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- The difference w.r.t. 2018 (and 2017) is attributed to an additional stabilisation by Q'' with non-ATS optics (See M. Schenk, et al., Phys. Rev. Accel. Beams 21, 084401 (2018)) and to the instability latency (see X. Buffat, et al., @ 8th HL-LHC collaboration meeting, CERN, 2018)

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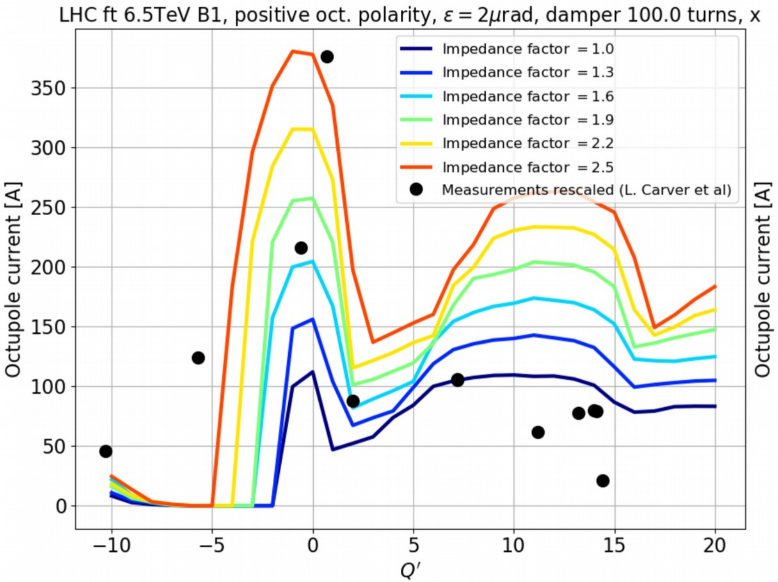

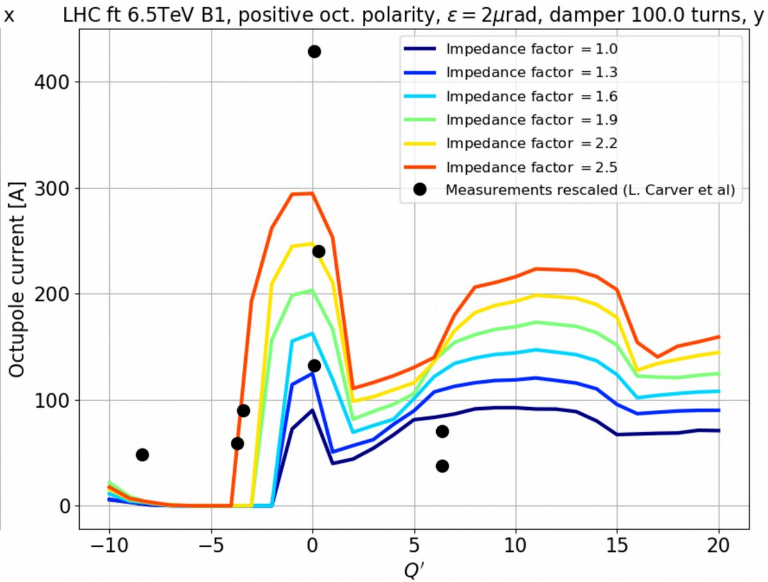

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- The avarage value and the variablity of the measurement at Q'~0 does not match the model

  → Impact of the longitudinal distribution (see A. Oeftiger @ WP2 16.04.2018 and H. Timko, et al., CERN-ACC-NOTE-2019-0021)

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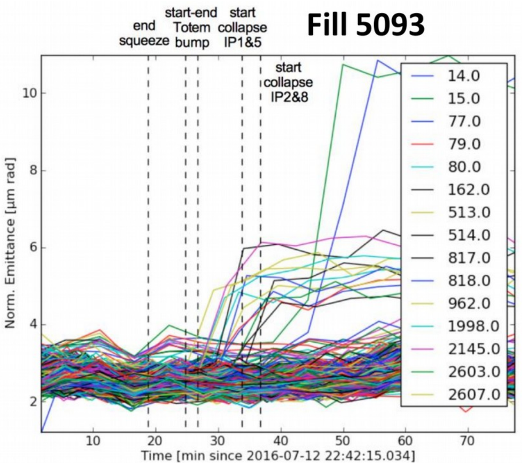
Optics correction

- In 2016, instabilities during orbit manipulation in the IRs (TOTEM bump) suggest that uncontrolled feed down (detuning terms and/or linear coupling) lead to loss of Landau damping
  (see L. Carver @ Evian 2016)



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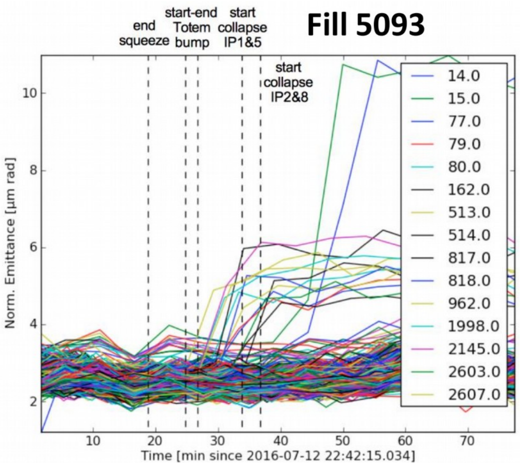

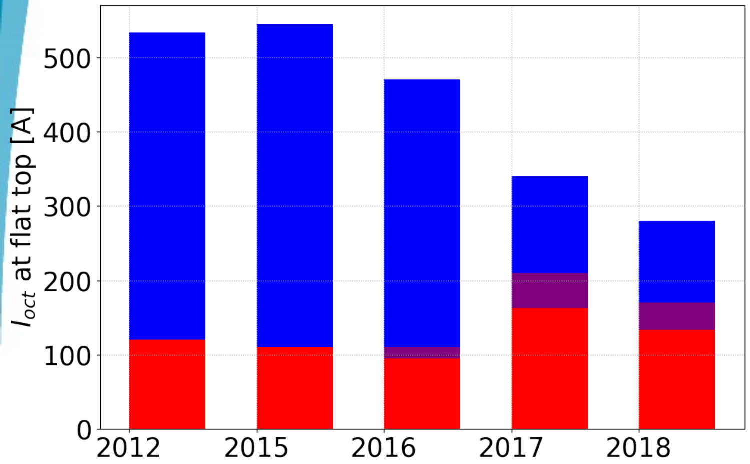

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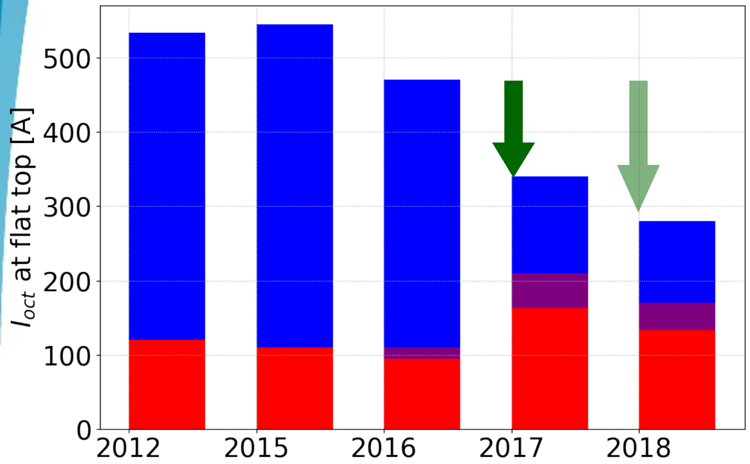
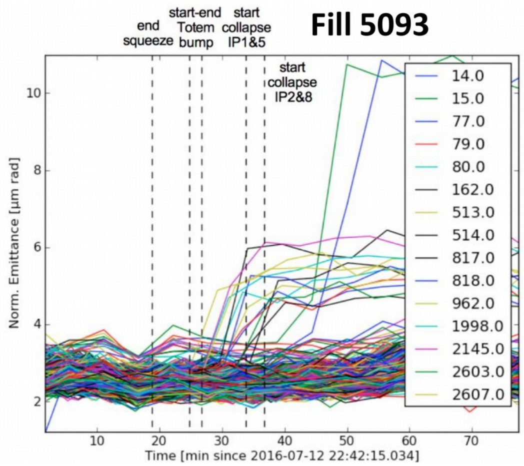
- Non-linear optics correction during commissioning





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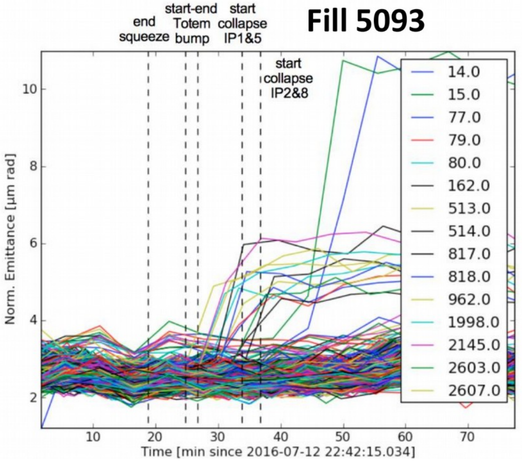

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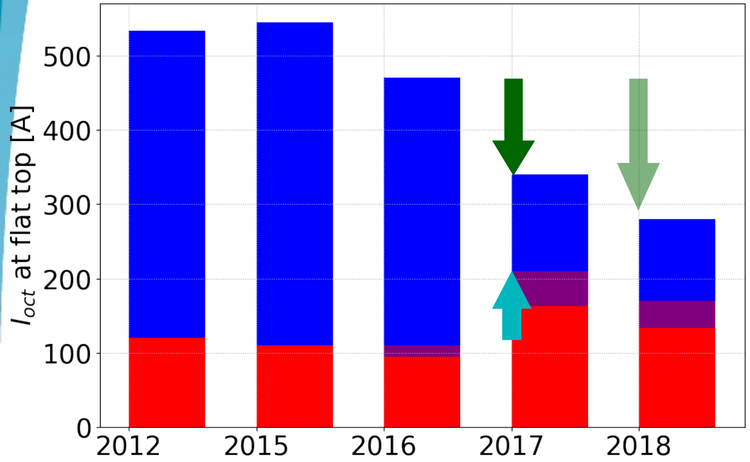

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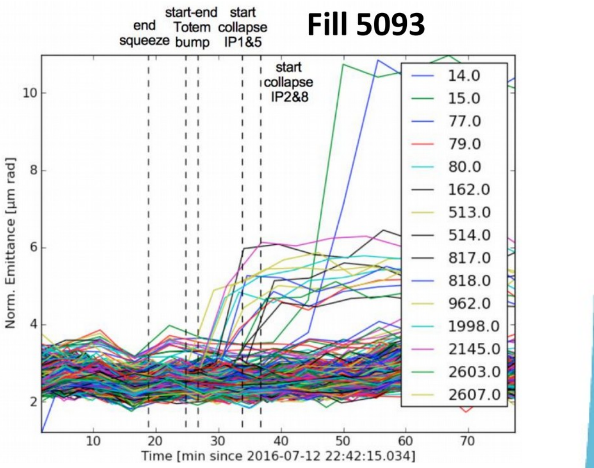

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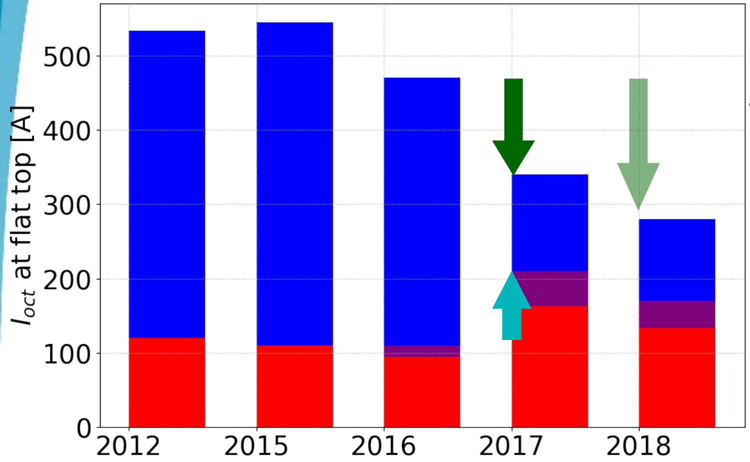

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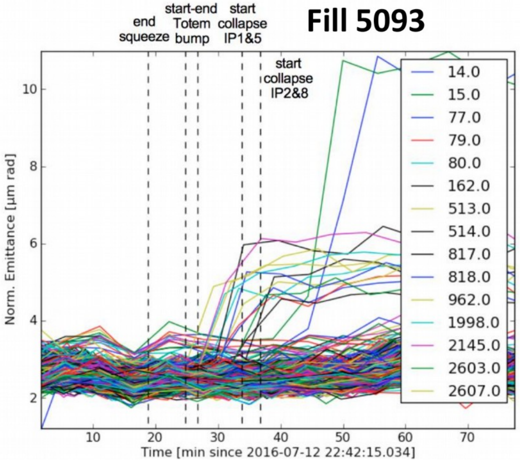

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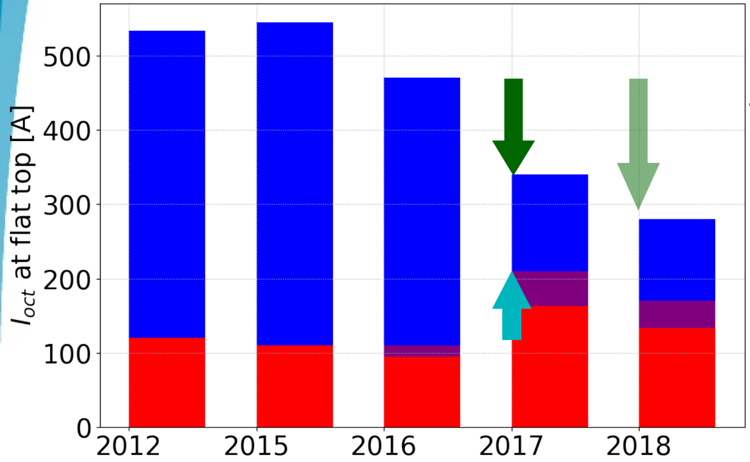

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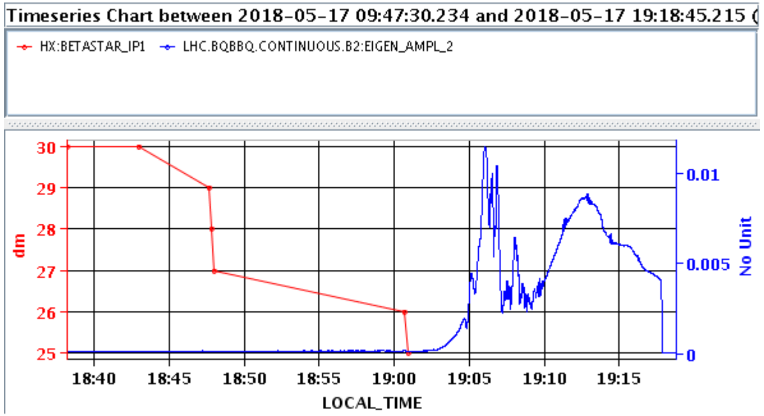
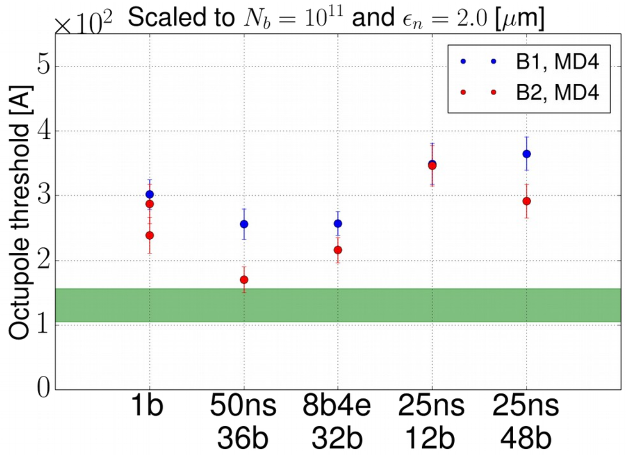


- In 2018, some effect was still visible at the end of β* levelling, on non-colliding bunches

Stability of 25ns bunch trains at flat top



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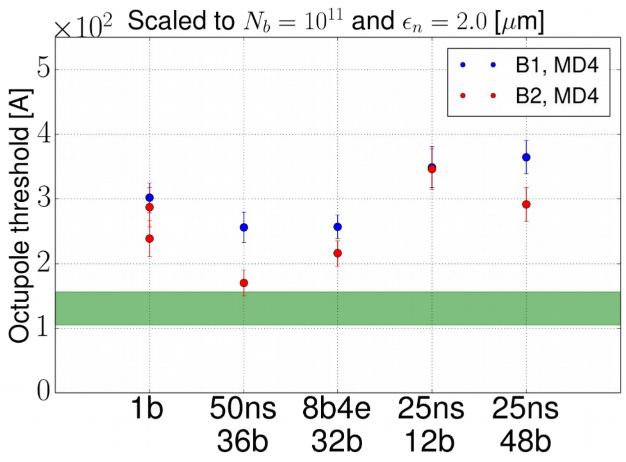
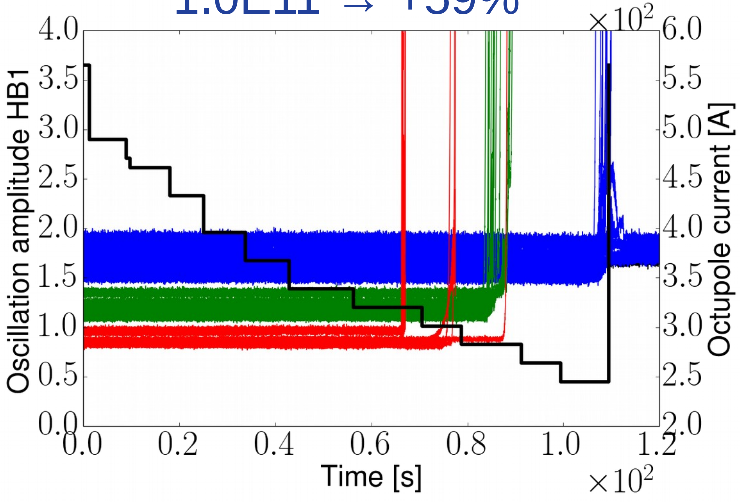


1.8E11 → +83%
1.4E11 → +71%
1.0E11 → +59%



- In 2017, an experiment revealed a difference between the stability threshold of single bunches and bunch trains, possibly linked to electron clouds (bunches at the end of the trains were affected)
- A weak dependence of the train instability threshold on the bunch intensity was observed in 2018, but it remains compatible with single bunch thresholds
  - Additionally, no electron cloud pattern was identified in the single bunch oscillation, as opposed to the 2017 experiement

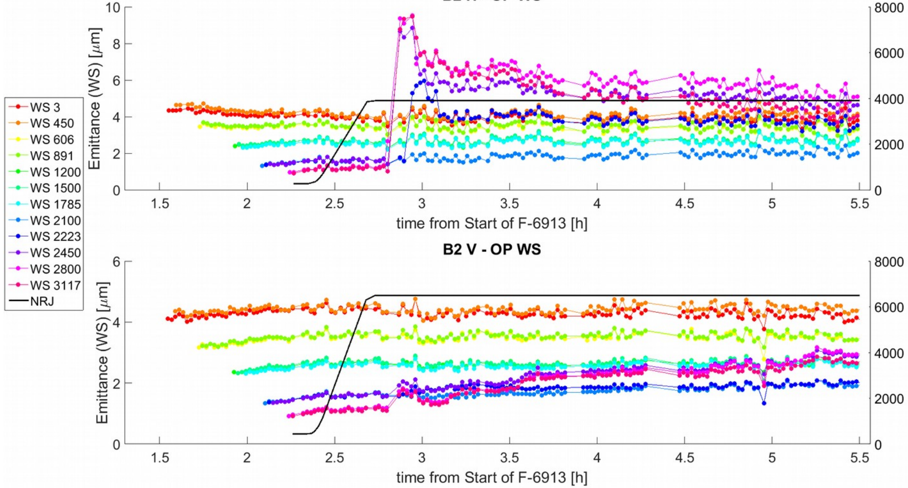
Reproducibility of the measurement : an example

Fill number	6699	6913
Intensity [10^{11}]	1.34	1.16
Emittance (WS) [μm]	1.7/1.5	1.9/1.7
Bunch length [ns]	1.11	1.08
Recommended octupole current [A]	613	481
Octupole current [A]	452	452

- The first BSRT calibration in 2018 featured high brightness bunches, the octupole current was lower than recommended (i.e. less than twice the modelled value), **yet no instabilities were observed**
- The second calibration featured slightly less bright bunches, but an instability was observed

→ One or more critical parameters are not fully under control

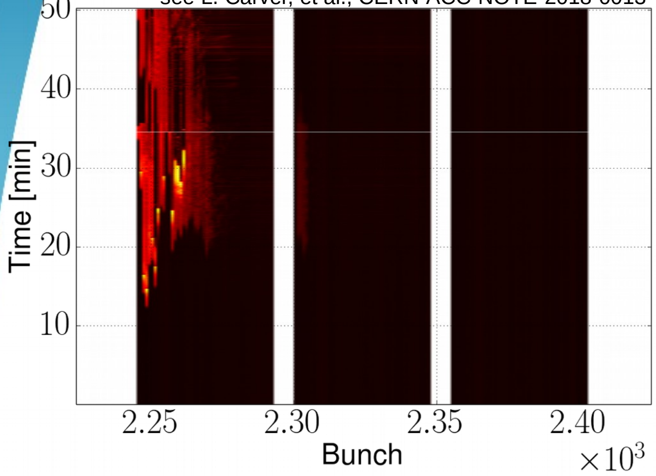
E. Bravin @ LMC 15.08.18



Ghost instabilities

Ghost train instability (2017)

see L. Carver, et al., CERN-ACC-NOTE-2018-0013



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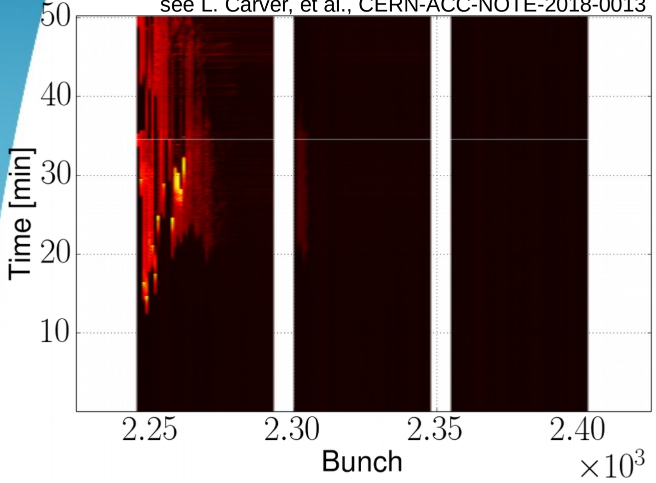
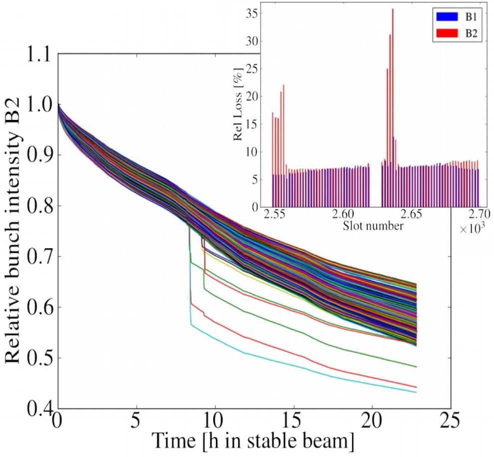


Fill 2692 (2012)
(Colliding bunches)



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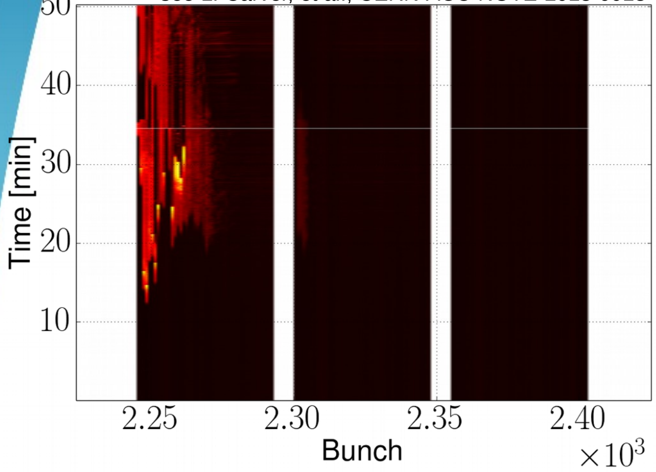

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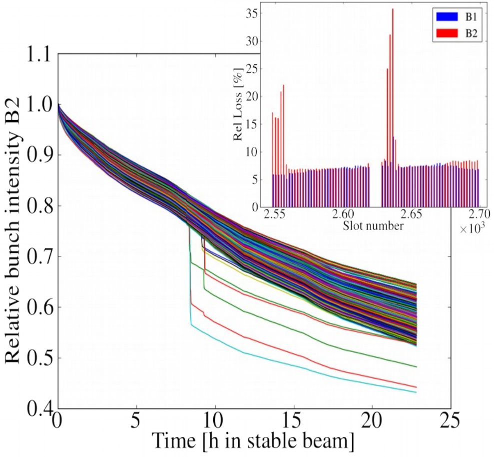

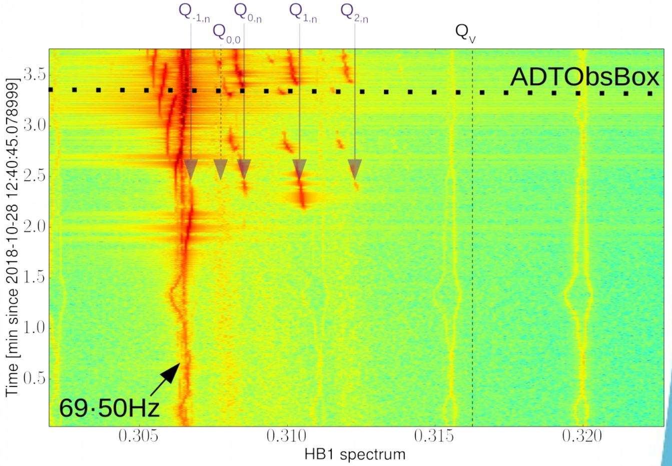

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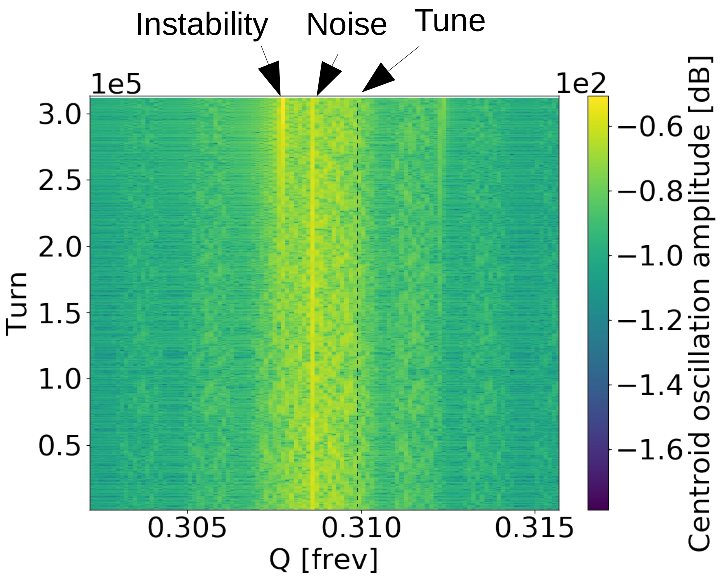
- At three occasions in 2012, instabilities affected colliding bunches at the head of trains (**~10 times** more Landau damping than needed according to the model).
- In 2018, single high intensity bunches became unstable with the maximum octupole current and a tele-index of 3.1 (**~10 times more** Landau damping than needed accroding to the model)

A potential mechanism for non-reproducibility (and possibly ghost instabilities)

- COMBI :
  - Linear transfer map with amplitude detuning
  - Damper
  - Impedance
  - Harmonic excitation with finite coherence time (colored noise)



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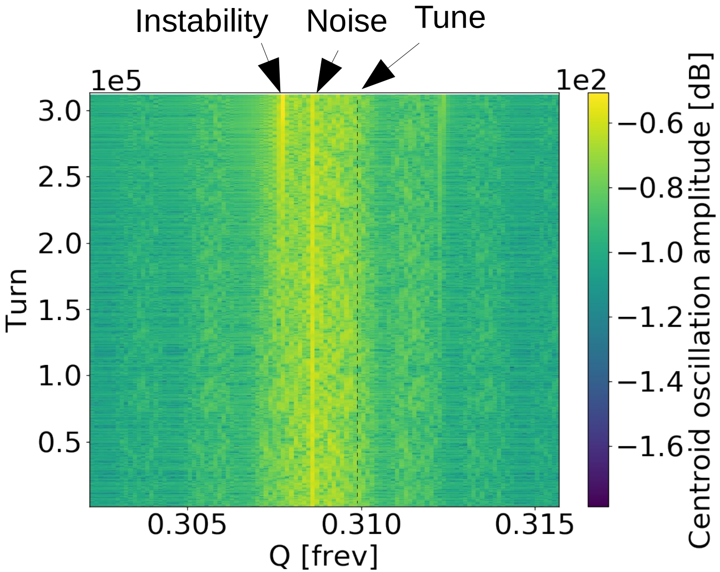

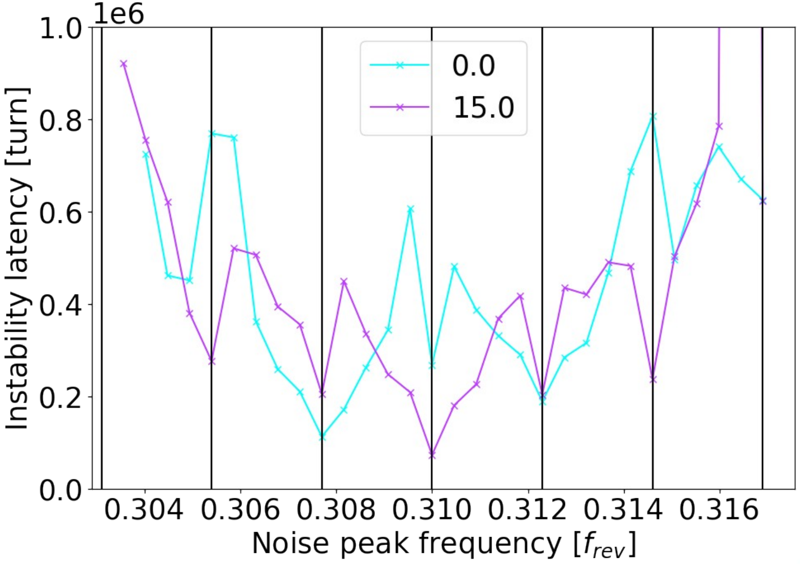

- Introducing a *weakly* colored noise (ΔQ_{noise} = 0.002) peaked at different frequencies we observed large differences in the instability latency
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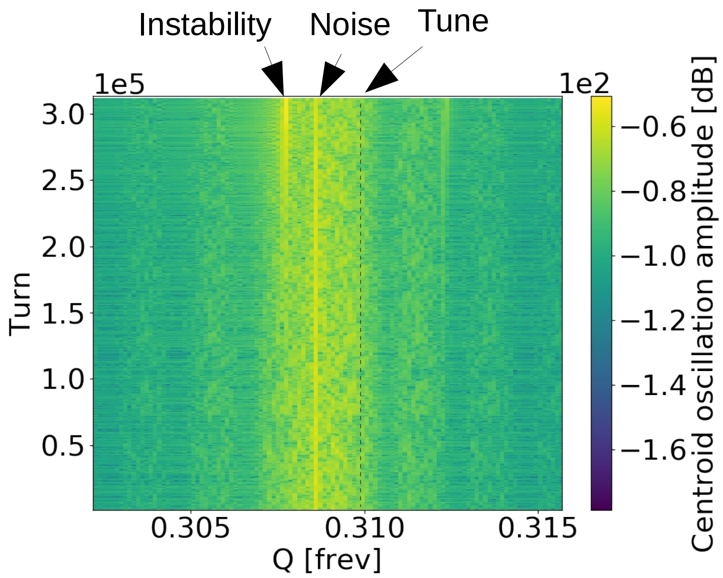

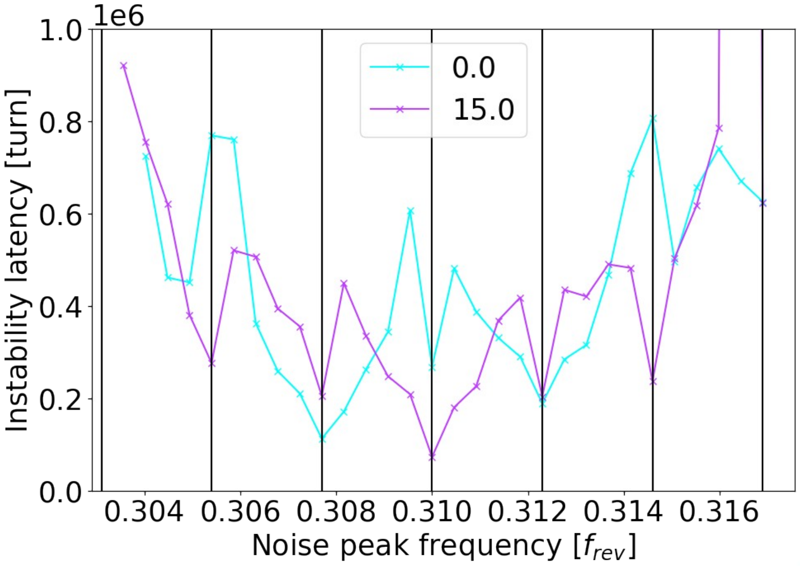

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→ 50Hz lines have a narrower spectral width ($\Delta Q_{noise} \sim 10^{-4}$), one may expect larger differences for peaked noise (parameteric study ongoing)

Implication on the strategy for the HL-LHC

- Experimentally the current operational point with Q'~15 and damping time ~50 turns seems most robust
- Linear coupling should be corrected to $\Delta Q_{min} < |Q_x - Q_y|/10$
- The correctability of non-linear optics should be taken into account in the arc octupole requirement
- For long term stability (more than ~10 minutes), an octupole current twice as much as modelled is needed
  - → Given the rôle of the latency, it might be advisable to collide directly at the end of the ramp also in the ultimate scenario
  - → The lack of reproducibility in the threshold could be linked to the presence of narrow noise lines (→ 50Hz)
  - → Few instabilities were observed with very high octupole currents, they remain unexplained
- The single threshold measurement performed with the negative polarity of the octupole did not exibit the factor two w.r.t. the model, potentially due to the beneficial impact of overpopulated tails in this configuration (to be confirmed experimentally)
  - → This beneficial impact is not considered for HL-LHC since active tail cleaning is envisaged
- No clear differences between the instability threshold of single bunches and 25ns bunch trains could be established experimentally at flat top

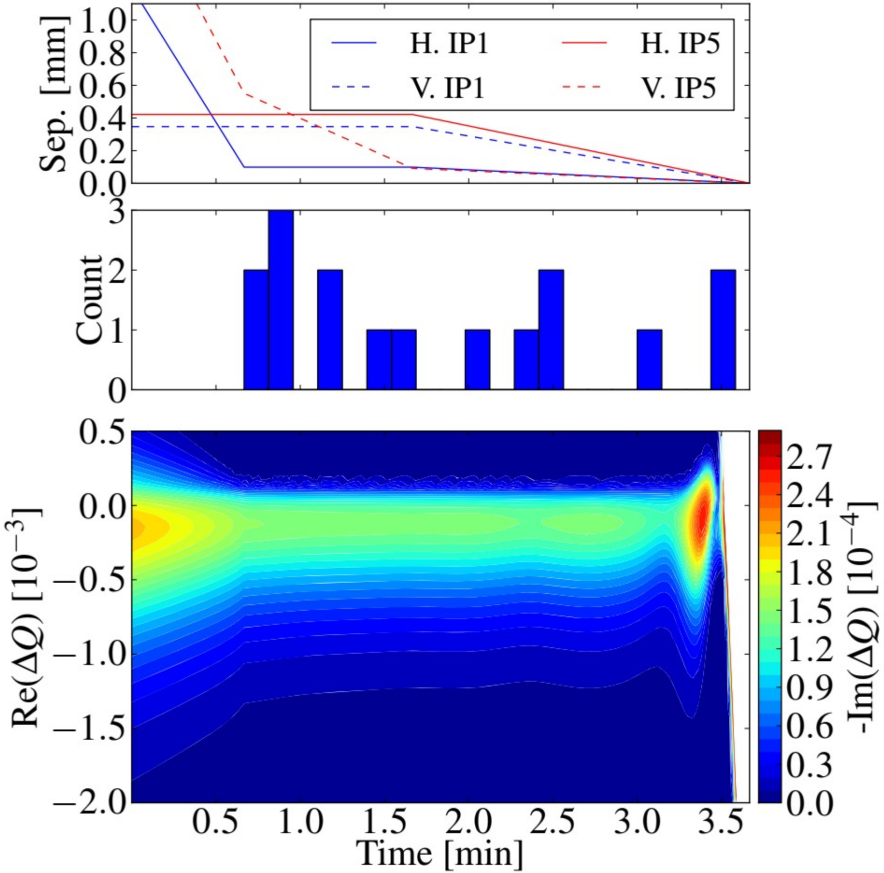
Colliding beams : The 2012 issue

- Several instabilities occured when collapsing the separation bump in a steady phase with separation > 5σ (I_{oct} < 0)

  → The main causes (linear coupling, long-range beam-beam interactions) are now taken into account in the stability estimations

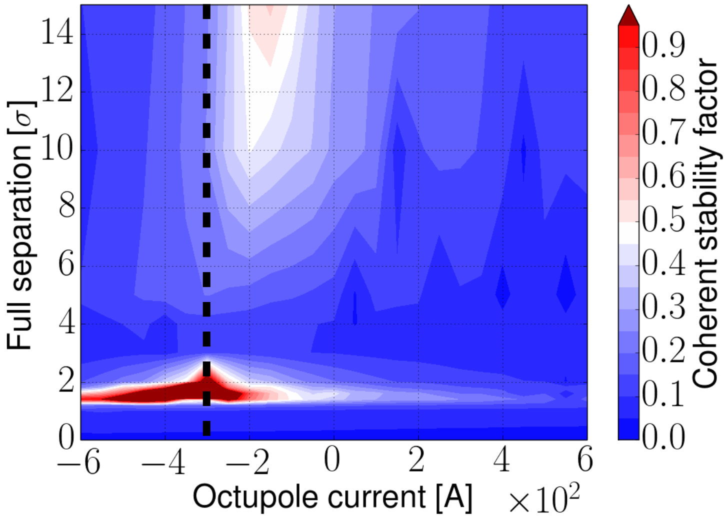
- Several instabilities occured with beams separated by ~ 1.5σ when levelling the luminosity in IP8 with a separation (private bunches) and during the collapse of the separation

  → It is now recommended to have at least one head-on collision elsewere for bunches colliding with an offset in IPs 2 or 8

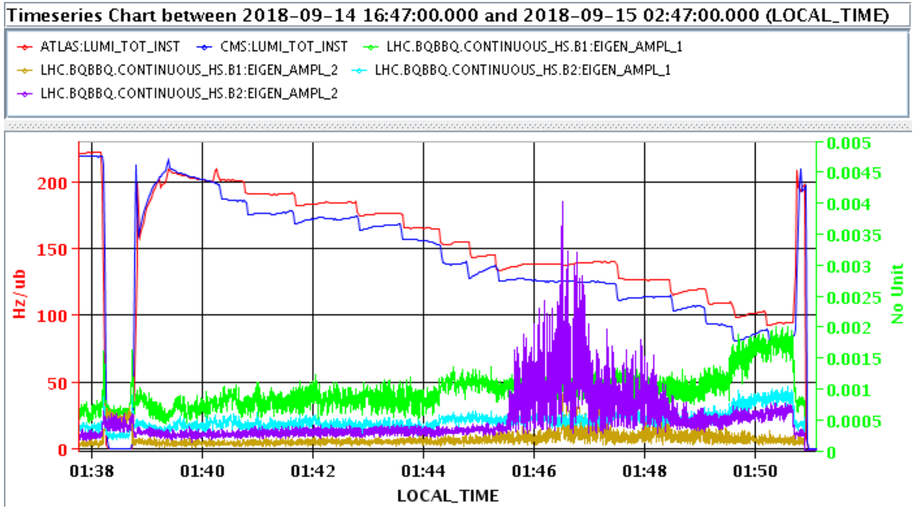


Offset collision

- The loss of Landau damping with offset collisions could be reproduced in controlled conditions in ATS MDs with high tele-index (3.1)



ATSMD 2017 and 2018 (See S. Fartoukh, et al., CERN-ACC-2018-0032 + note in prep. for 2018 round ATS MDs)



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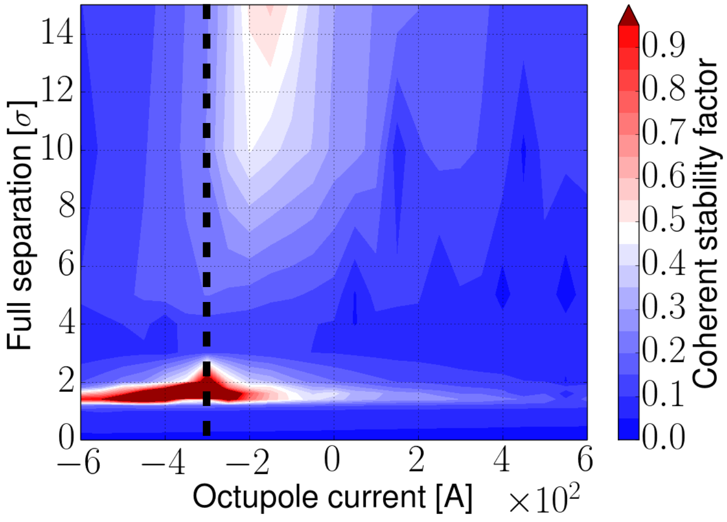

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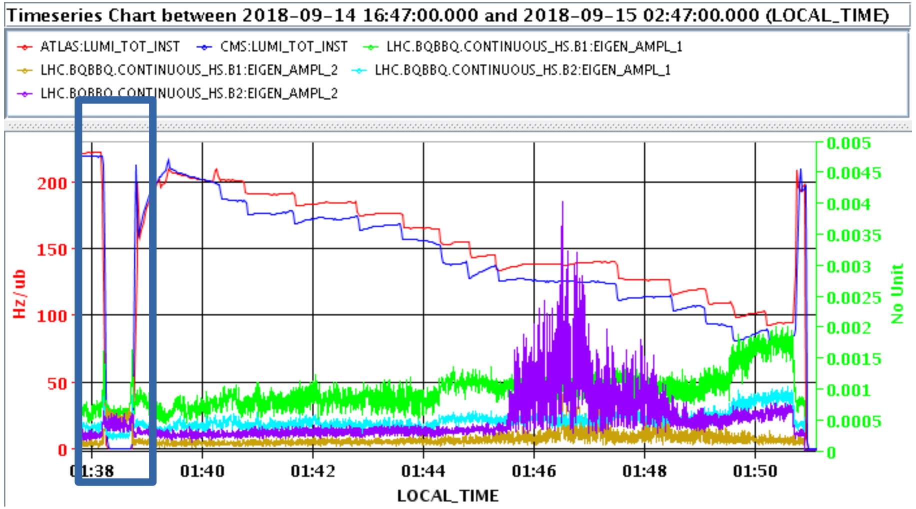

- The instability was not observed when collapsing the separation bump in on go

Offset collision

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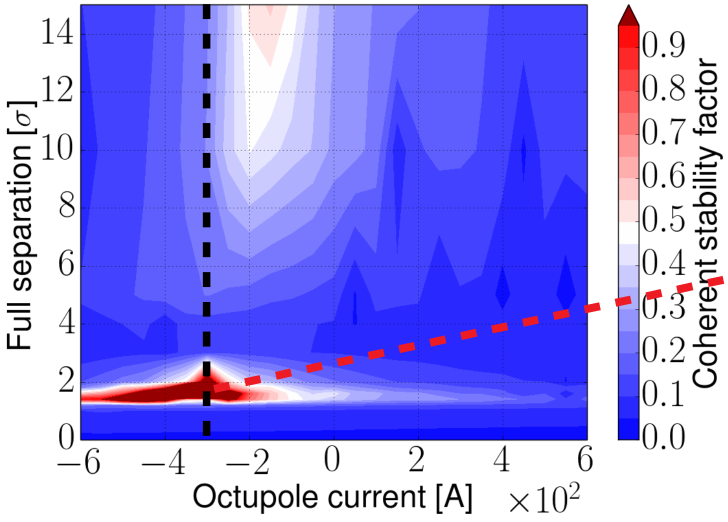
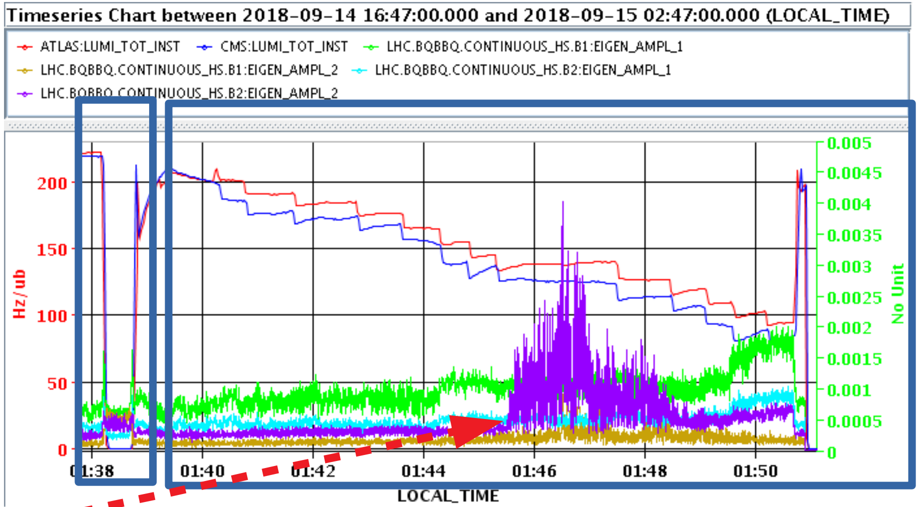
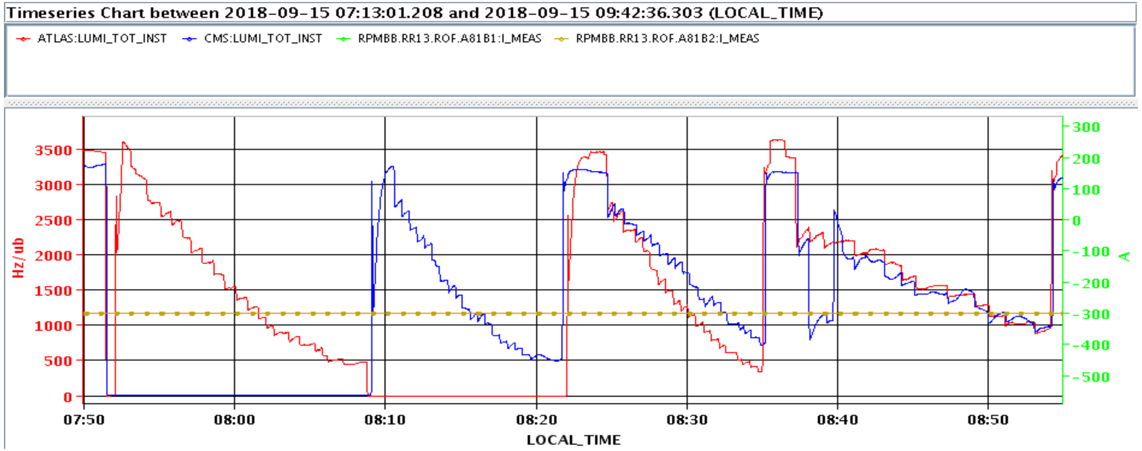


ATSMD 2017 and 2018 (See S. Fartoukh, et al., CERN-ACC-2018-0032 + note in prep. for 2018 round ATS MDs)



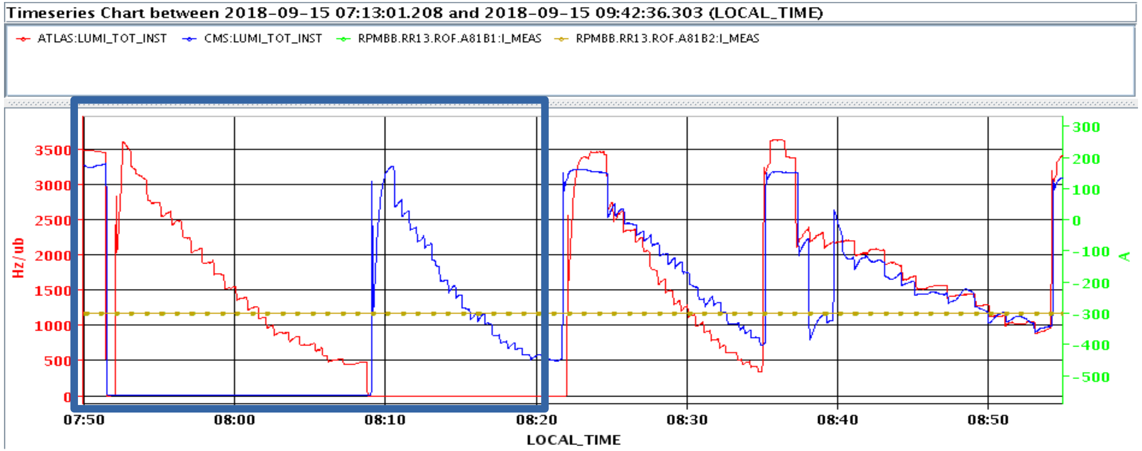
- The instability was not observed when collapsing the separation bump in on go
- The instability was observed when steady for ~5 seconds with 1.6σ separation between the beams

Offset collision



Offset collision

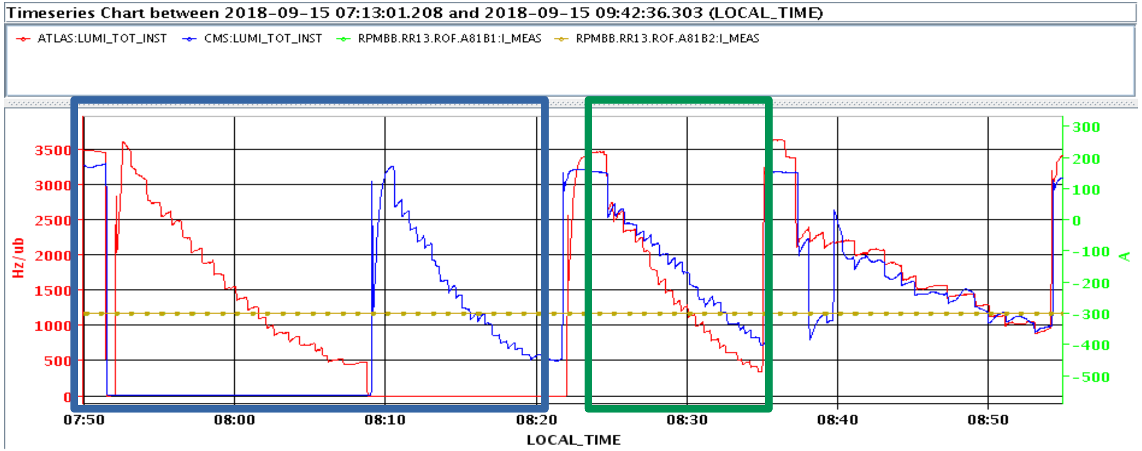
Asynchronous → Stable



Offset collision

Identical separation plane
→ Stable

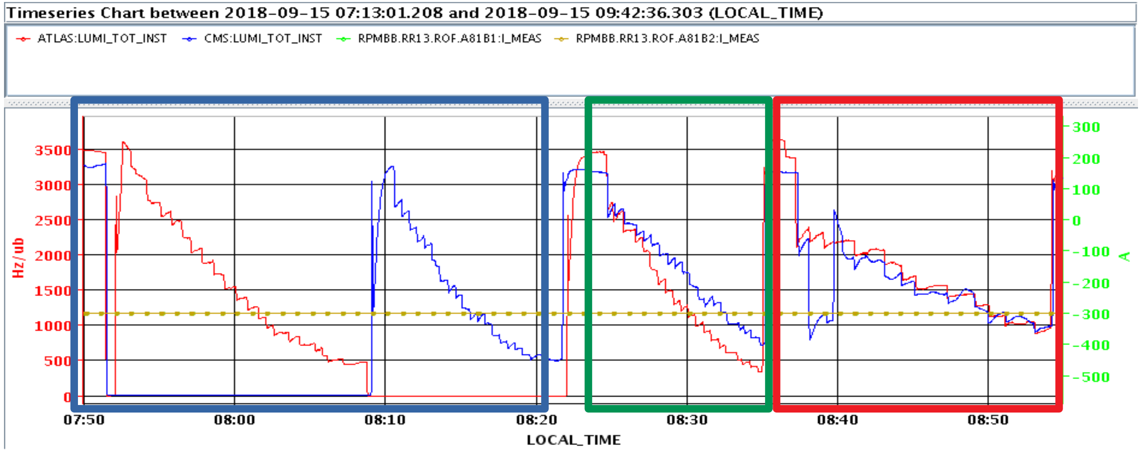
Asynchronous
→ Stable



Offset collision

Identical separation plane
→ Stable

Asynchronous
→ Stable

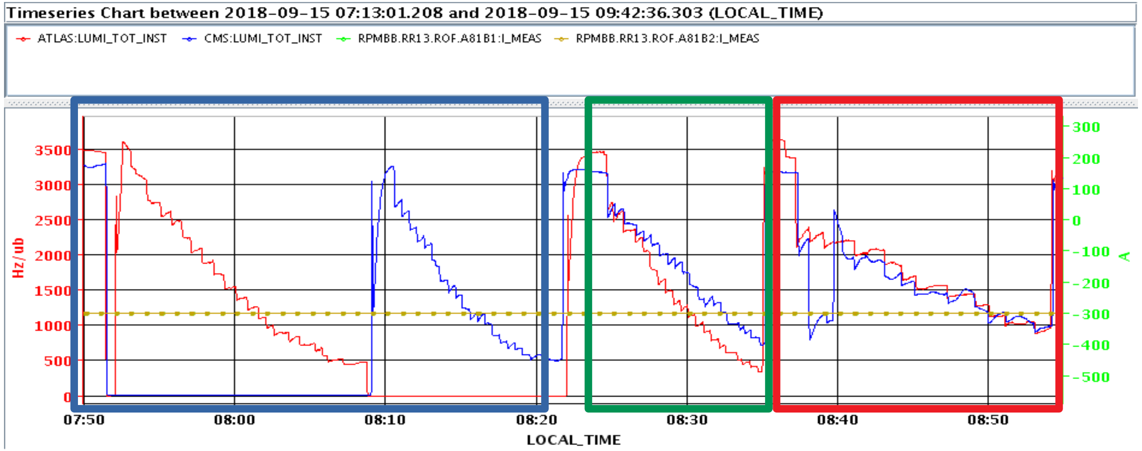


Alternating separation plane in IPs 1 and 5
→ Unstable at 1.6σ
(consistently with previous test)

Offset collision

Identical separation plane
→ Stable

Asynchronous
→ Stable



Alternating separation plane in IPs 1 and 5
→ Unstable at 1.6σ
(consistently with previous test)

- Variations of the process were efficient to mitigate the instability, as predicted with PySSD
(see X. Buffat @ WP2 21 Aug. 2018)

Implication for HL-LHC

- The current strategy based on DELPHI and PySSD, including an empirical factor 2, seem robust for the estimation of the loss of Landau damping with offset beams in a steady configuration, which may occur if :

  → The reproducibility of the separation bump exceeds 1σ at initial β*

  → The orbit drifts at the IP during β* levelling exceeds 1σ

  → Luminosity levelling by more than 20 % with a transverse offset is needed simultaneously in IPs 1 and 5

- The mitigation of the instability by collapsing the separation bump faster than the instability rise time was found effective in MD

  → Currently the recommendation on the speed of the collapse is 2→0σ in less than 3s at initial β*, comparing to expected instability rise times of ~8s*

*with LS2 collimator upgrade (would be ~3s without)

More details in X. Buffat, et al., Strategy for Landau damping of head-tail instabilities at top energy in the HL-LHC, CERN-ACC-NOTE-2019 (in perp.)