Beam stability : an update

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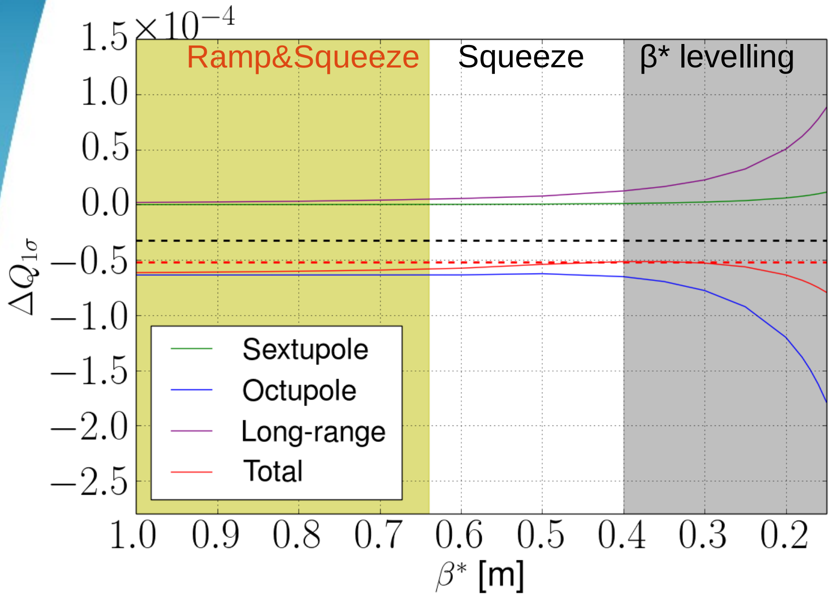
S.V. Furuseth, E. Métral

WP2 meeting – 12.06.2018

Content

- Coherent stability at top energy
  - Estimation of the telescopic index requirements
- Measured discrepancy and future tests
  - Decoherence and beam distribution
- Electron cloud effects at top energy
- Stability of coherent beam-beam modes

Tune spread through the HL-LHC cycle – Ultimate BCMS / 8b4e (Presented at Madrid)



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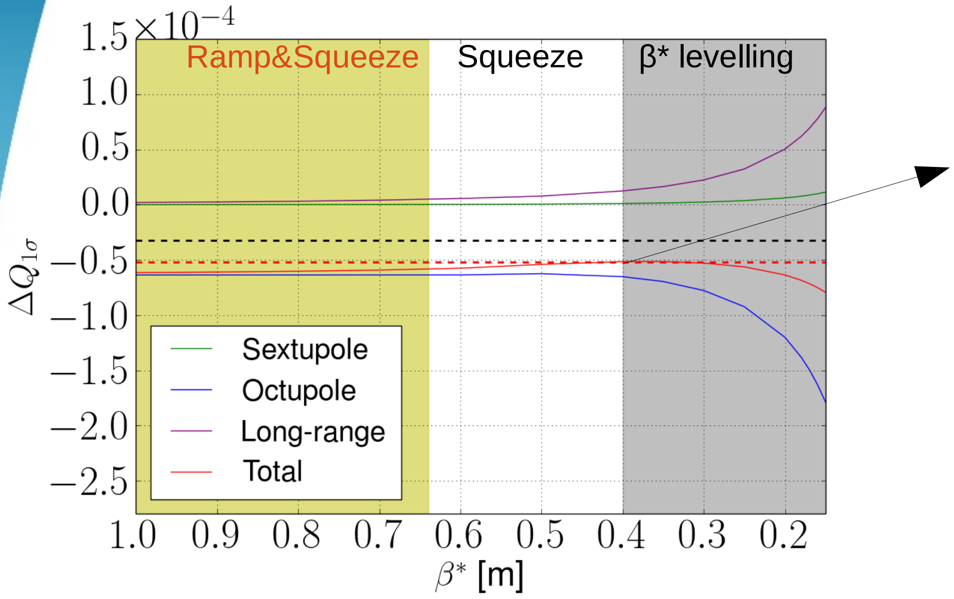

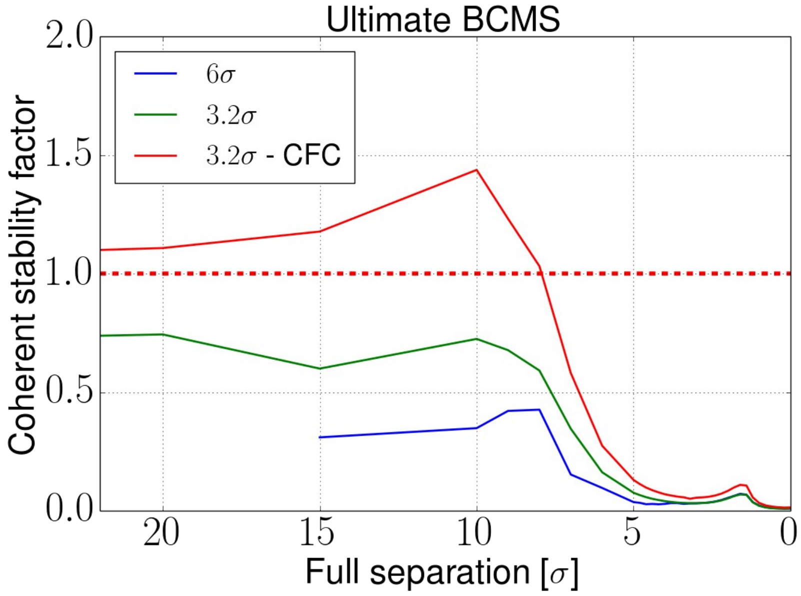

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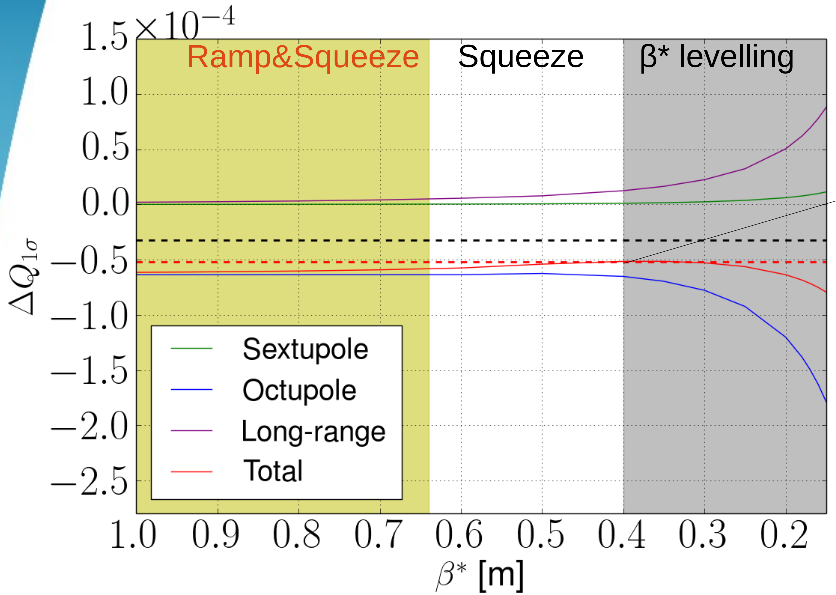
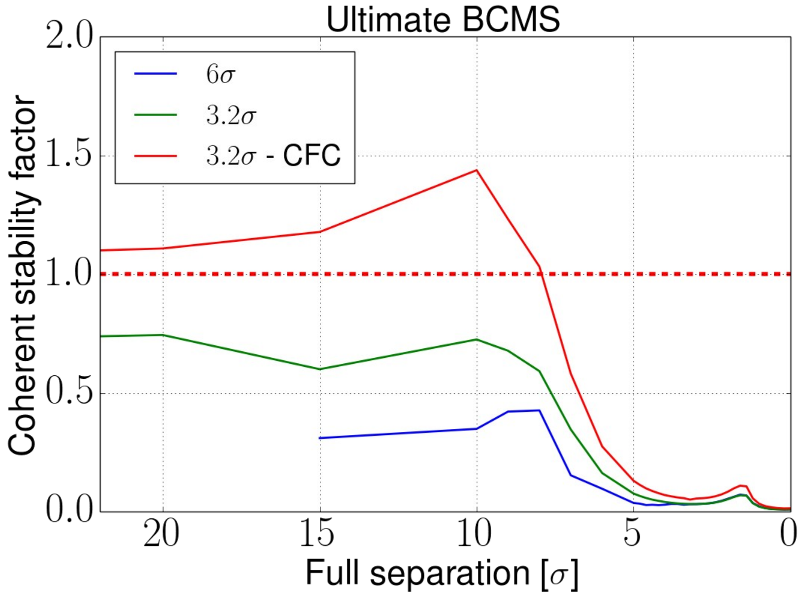
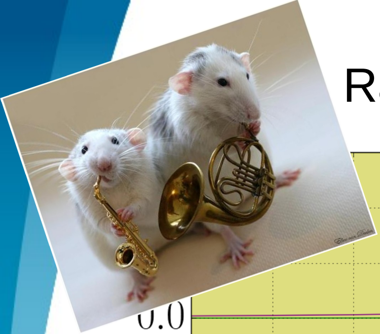
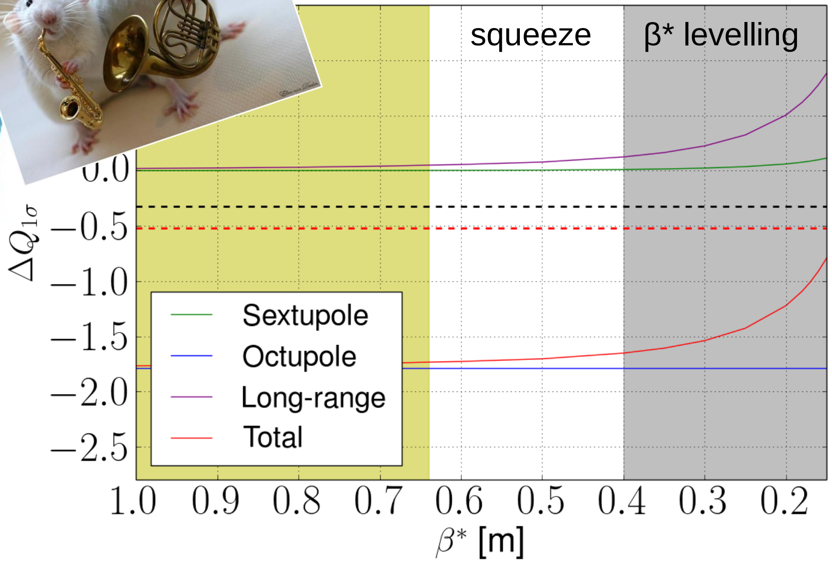


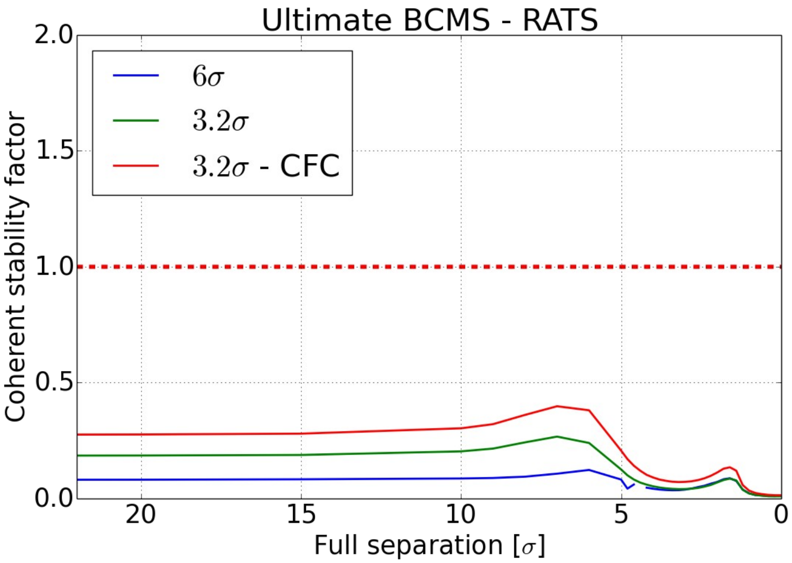


- The ultimate scenario with BCMS/8b4e beams is possible only with the upgrade of the collimators with low resistivity material (Mo+MoGR)
  - Despite the collimator upgrade, the stability margins remains above 0.5

Ramp and ATS (Presented at Madrid)







- The beneficial impact of the ATS on the stability margins can be fully exploited by anticipating the telescopic part at the earliest stage, i.e. during the ramp

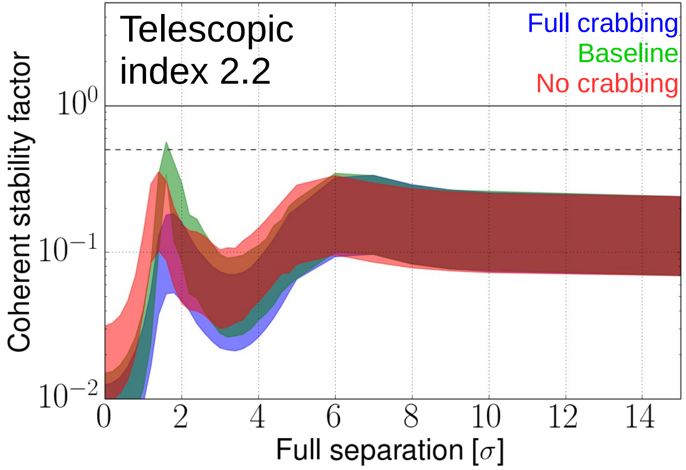
    → Significant improvement of the stability margin

See also : C. Tambasco, PhD Thesis, EPFL, 2017

HL-LHC requirement

- A telescopic squeeze is needed already at flat top to recover the stability margins of a factor 2, including the low impedance collimator upgrade (Ultimate BCMS scenario)

Low impedance collimator upgrade



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  - Limits of the RATS still need to be estimated and tested (Round ATS MD, S. Fartoukh, et al.)

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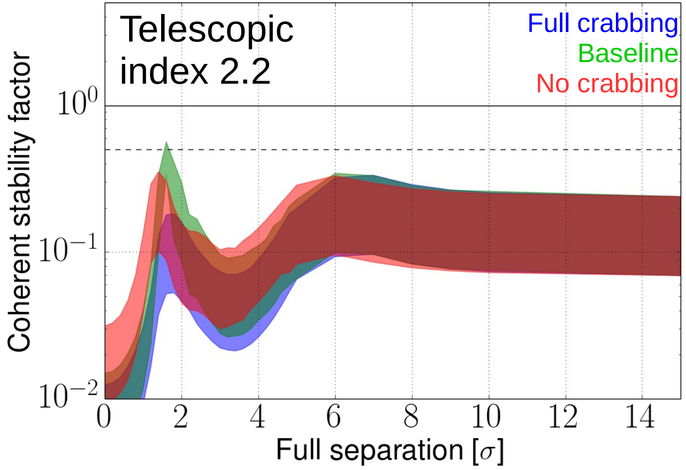
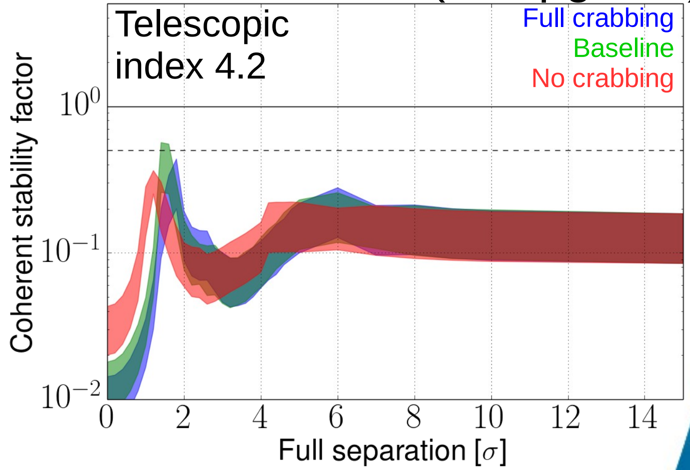


CFC collimators (no upgrade)



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  - The optimal at 6-10 σ is not necessarily the optimal at 1-2 σ

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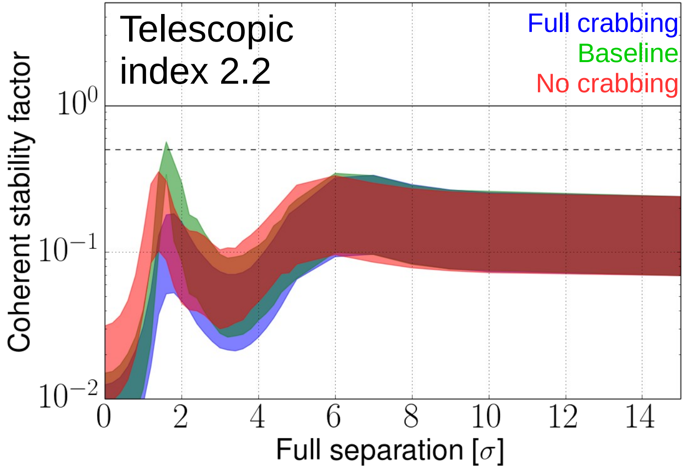

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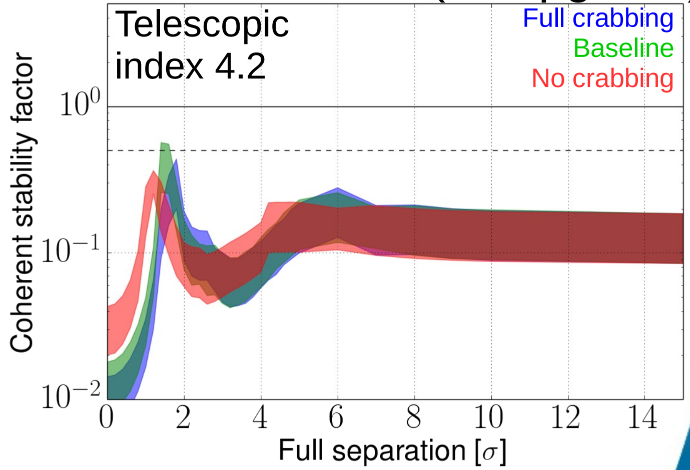

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- If those can be achieved, the beam stability would no longer be critical during offset luminosity levelling

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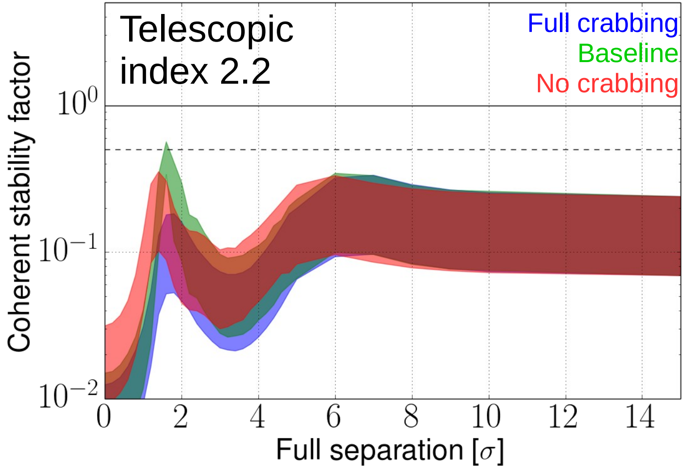

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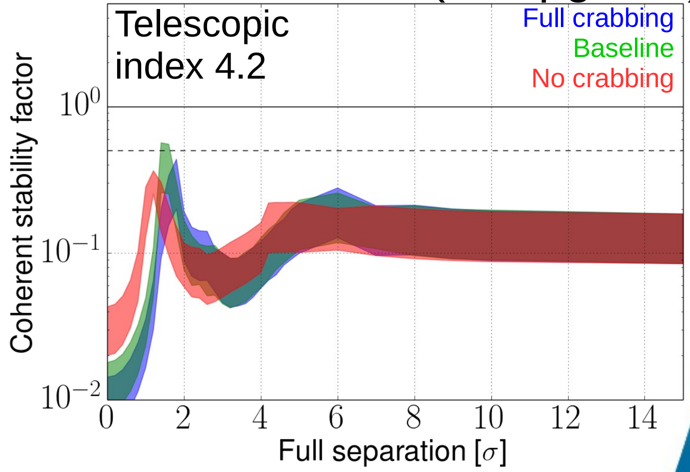

HL-LHC requirement

Separation [σ]	Equivalent octupole current [A] (Telescopic index)					
	Nominal			Ultimate		
	CFC	LS2 upg.	Full upg.	CFC	LS2 upg.	Full upg.
6-10	-1250 (2.6)	-1000 (2.2)	-750 (1.7)	-1020 (2.2)	-900 (2.0)	-780 (1.7)
1.5-2	-2500 (3.9)	-1000 (2.2)	-750 (1.7)	-2750 (4.2)	-900 (2.0)	-780 (1.7)

(a) $\varepsilon = 2.5\mu$m

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- The current target of a telescopic index of 3.3 at the end of the ramp covers all scenarios with at least the LS2 collimator upgrade

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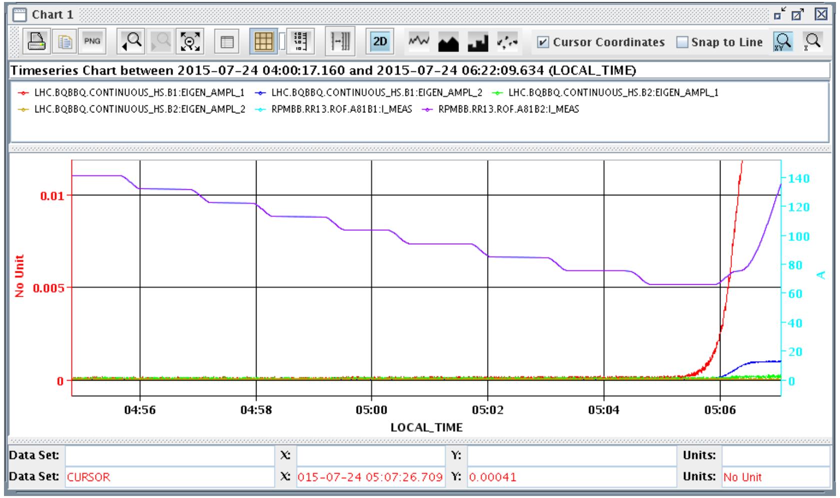
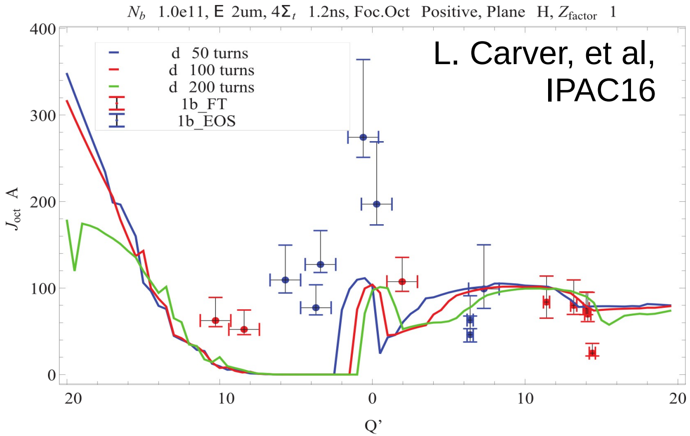
Octupole threshold in 2015 and 2016

- Measuring the stability threshold by reducing the current in small and short steps, the instability starts within 30s after the octupole change

→ Good agreement with DELPHI (at high chromaticity)

2015 : Step length ~ 1 min





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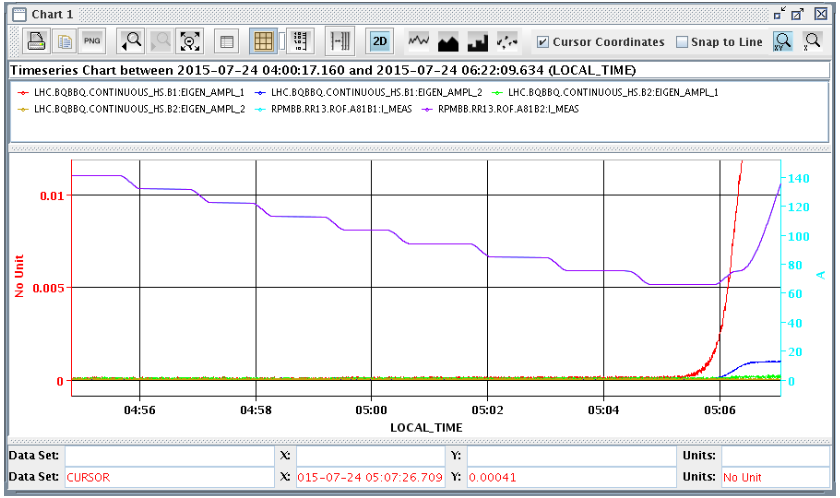
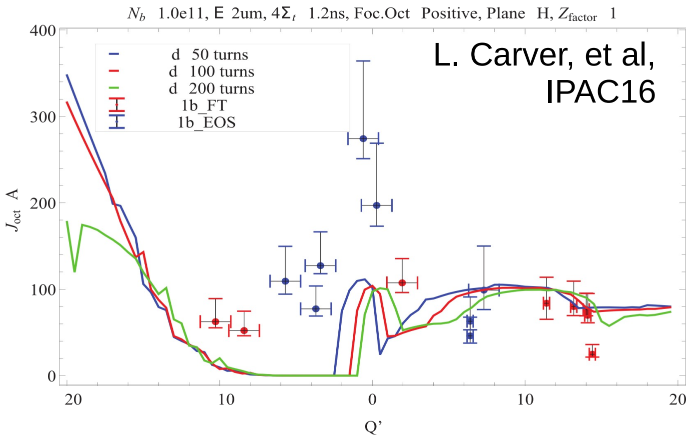
- Several instabilities were observed during ADJUST in 2016 (mainly during the execution of the TOTEM bump) with **490 A**

  → Large difference between experimental setup and operational configuration

2015 : Step length ~ 1 min



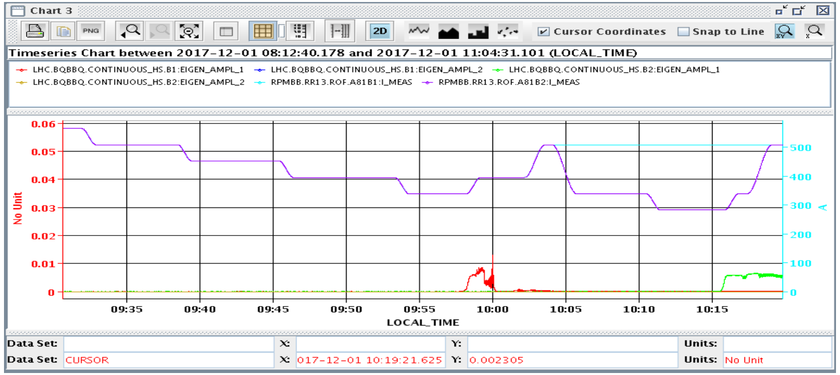


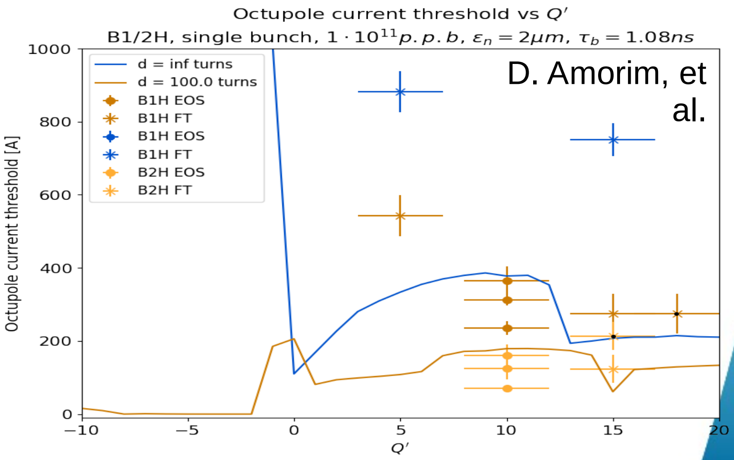
Octupole threshold in 2017

2017 : Step length ~ 8 min

- The instability started 4 minutes after the octupole current change

  → Disagreement with DELPHI also at high chromaticity by a factor ~2





Octupole threshold in 2017

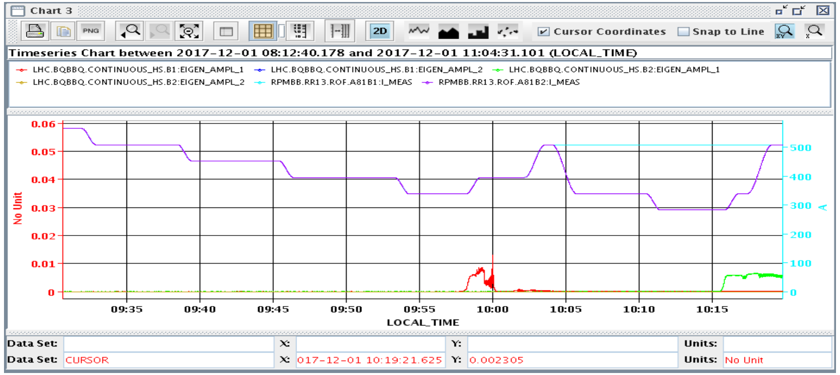
2017 : Step length ~ 8 min

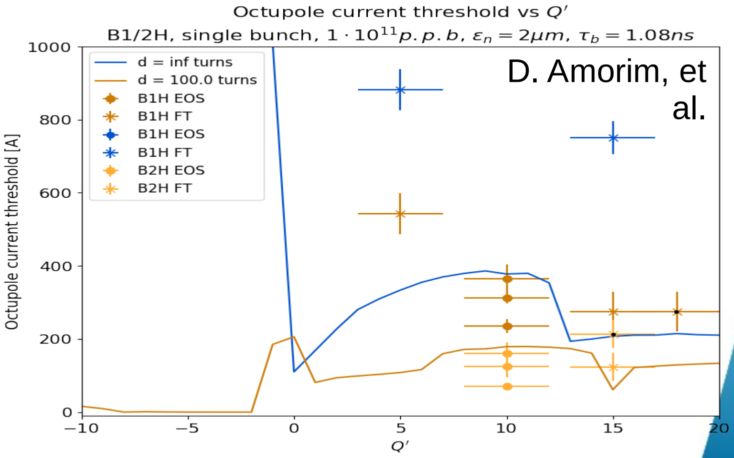
- The instability started 4 minutes after the octupole current change

  → Disagreement with DELPHI also at high chromaticity by a factor ~2

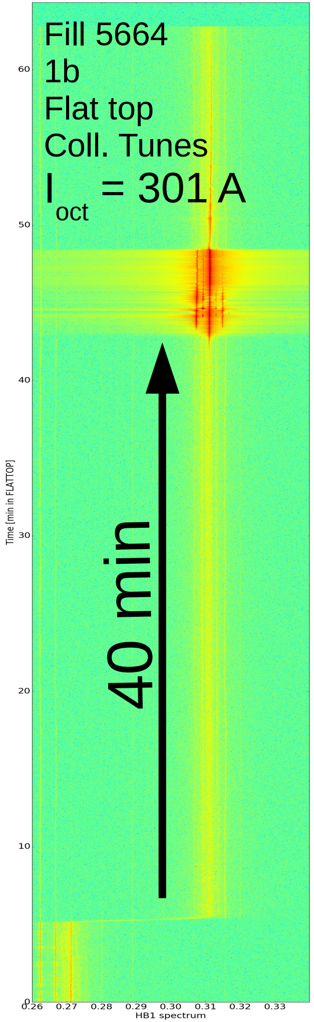
- The discrepancy with the model is also found in operational data

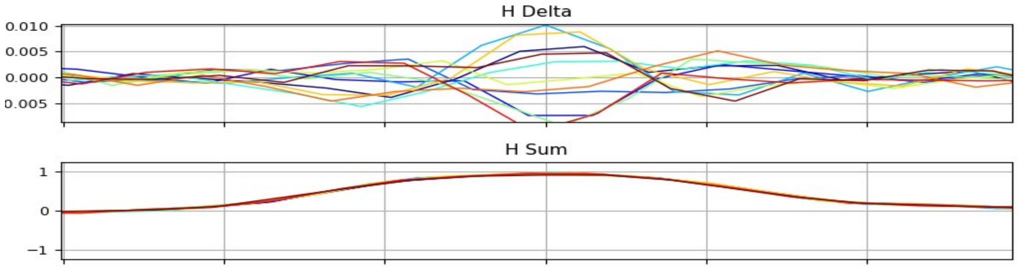
  → To represent operational conditions, sufficient time as to be spent at each step of the octupole scan due to the instability **latency**

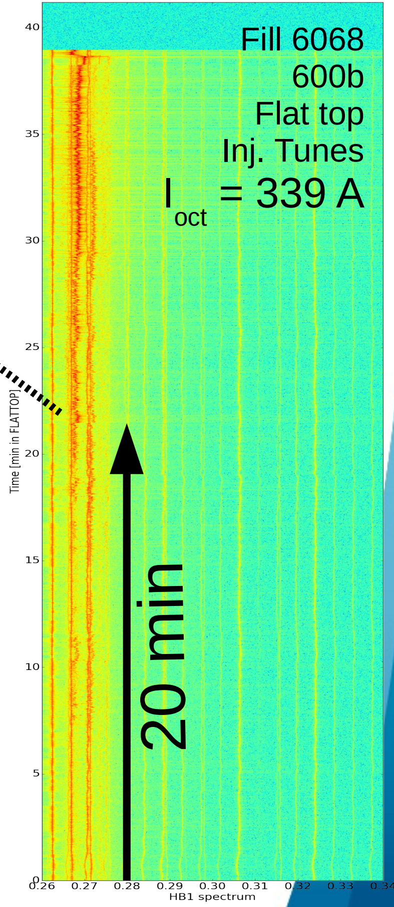




Two observations of high latency at flat top in 2017







- At two occasions, single bunches became unstable when the beam was left untouched for tens of minutes

  → Is an external excitation (hump-like) triggering the instability ? If so, what amplitude is needed ? (BTF MD, C. Tambasco, et al.)

  → Are some machine parameters drifting without control ?

  → Is the latency a fundamental aspect missing from our beam dynamics models ? (Latency MD)

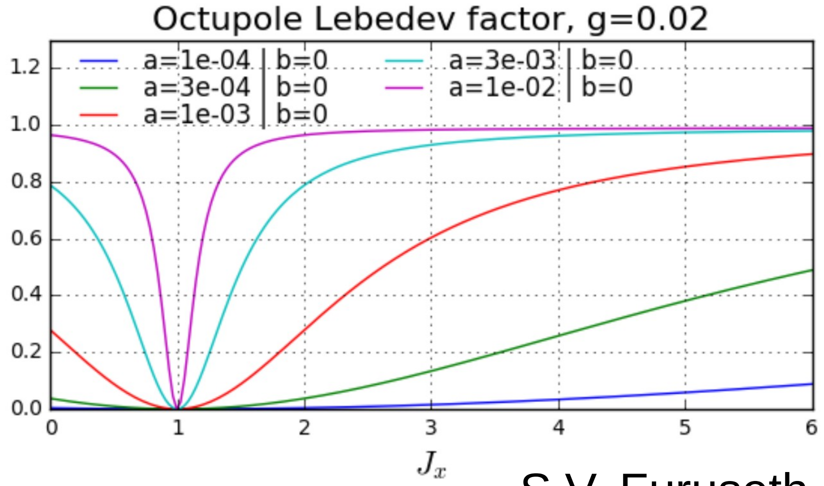
Decoherence and beam distribution

- Past simulations showed that a change of the distribution occur during the latency and could be the cause of a loss of Landau damping

  → Numerically heavy and prone to artefacts due to numerical noise

  → Absence of fundamental understanding

$$\frac{\Delta\epsilon(J)}{\Delta\epsilon_0}$$



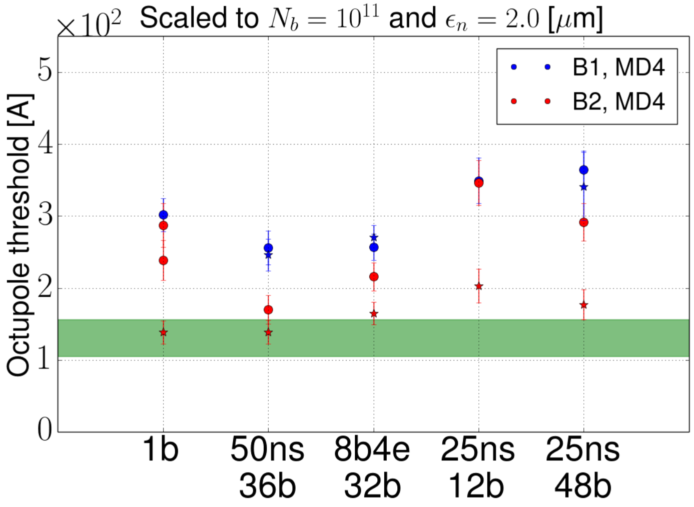
S.V. Furuseth

- Extending Lebedev's model for decoherence in the presence of linear detuning (octupoles), transverse feedback and noise, it is possible to show that the diffusion is non-uniform in phase space, leading to distortions of the distribution

→ Next step : consider consistently the effect of the impedance, within Vlasov perturbation theory

Electron cloud effects at flat top

- The bunches at the end of 25ns trains is more critical than others, also at top energy
  - The scaling of this contribution with higher bunch intensities is unclear (→ Dedicated MD with 12b trains)
  - A semi-analytical model based on the CMM was developed by E. Gottlob (EPFL) in order to address this type of weak electron cloud effects at top energy



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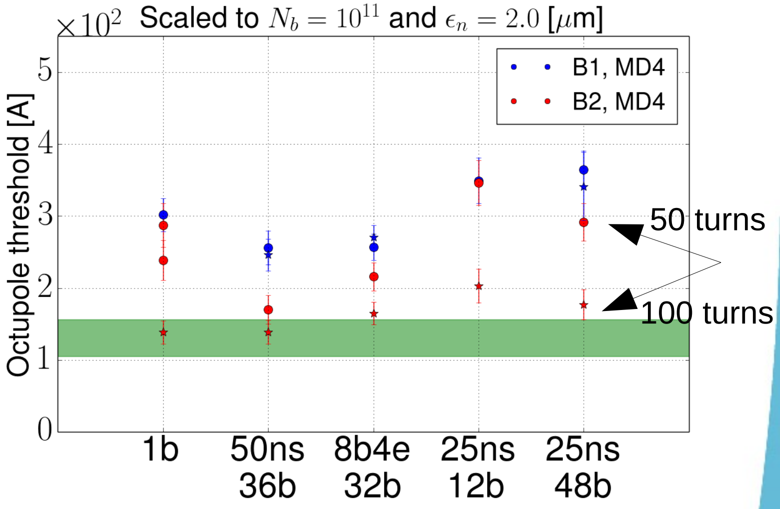

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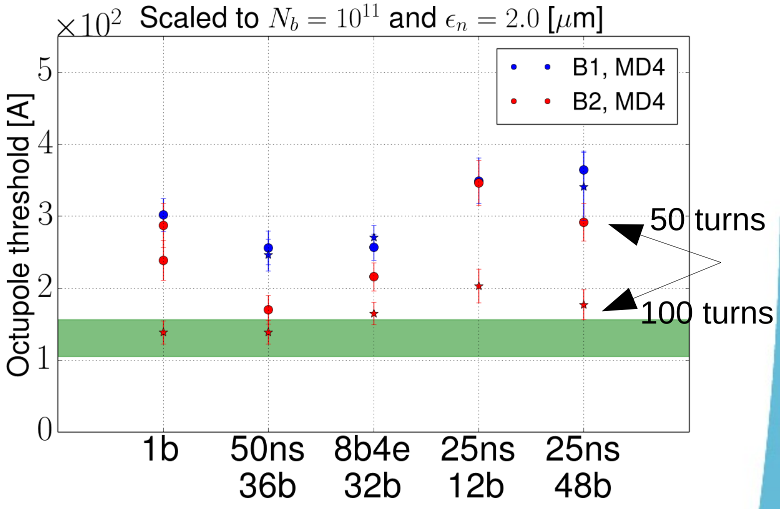
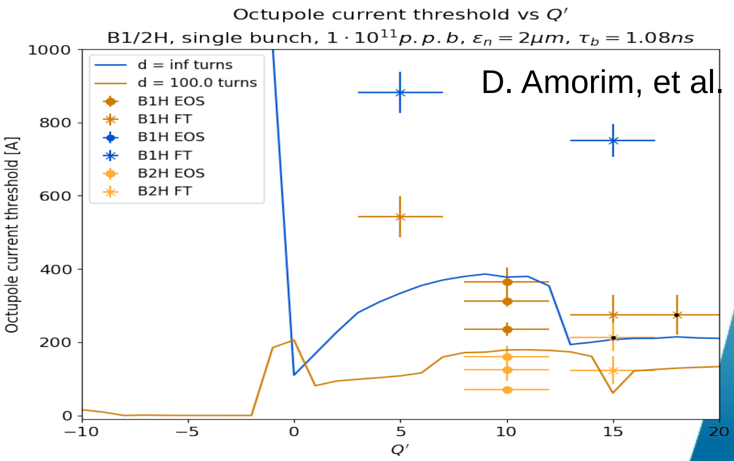
- A lower threshold was measured with a reduced ADT gain
  - From single bunch MDs, it is also clear that the low ADT gain regime is not well understood

→ Optimum to be determined / understood in MDs

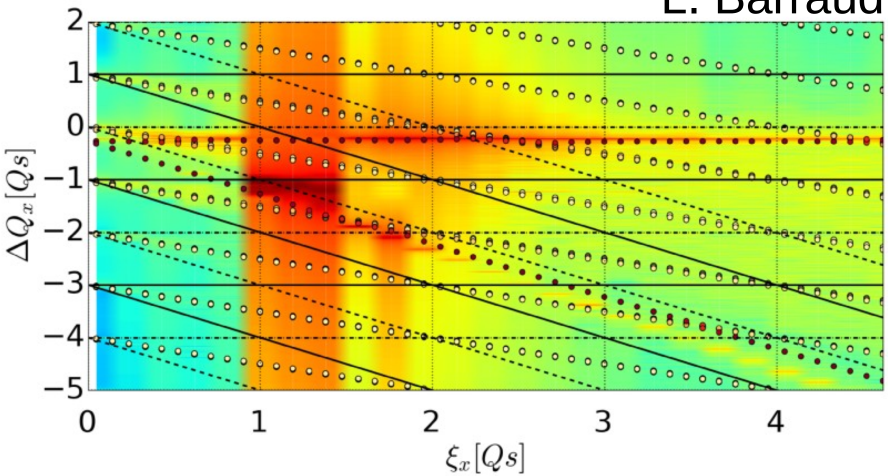




Mode coupling instability of colliding beams

L. Barraud

- Varying the beam-beam tune shift, keeping the impedance effect constant (constant intensity), a coupling instability is observed when the coherent beam-beam mode frequency reaches the head-tail mode frequencies
  - Within the Yokoya factor and Landau damping, the BimBim and COMBI gives compatible results
  - This effect was observed in MDs (S. White, et al, PRSTAB 2013)



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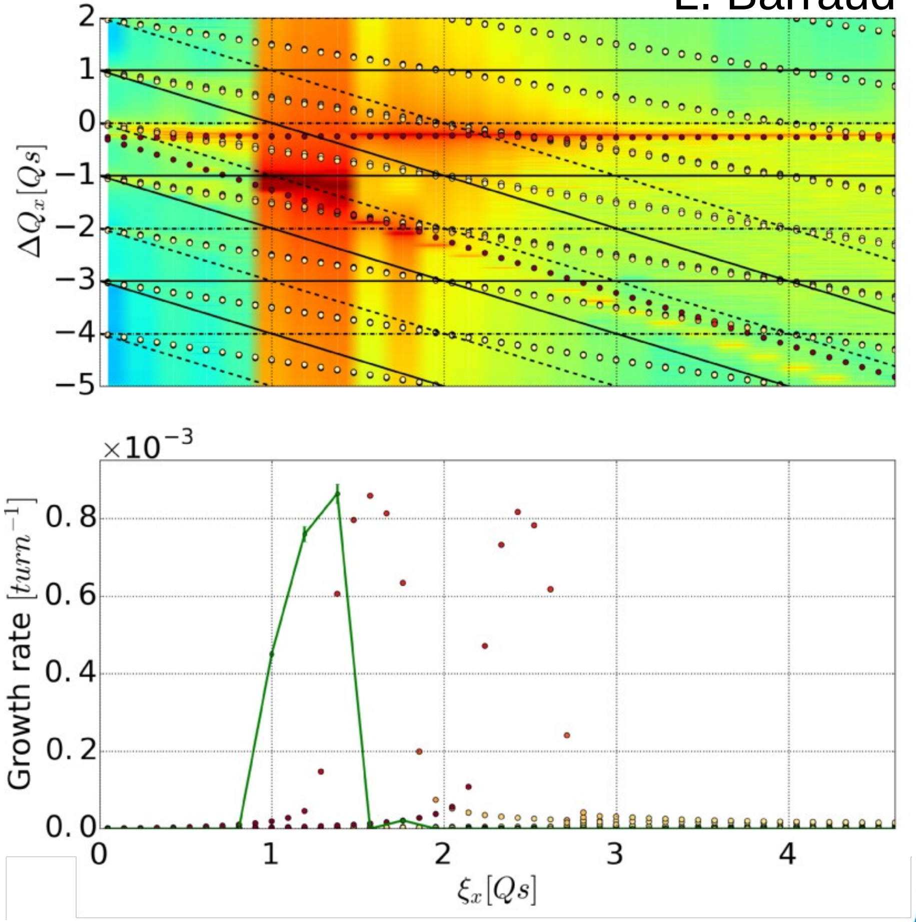
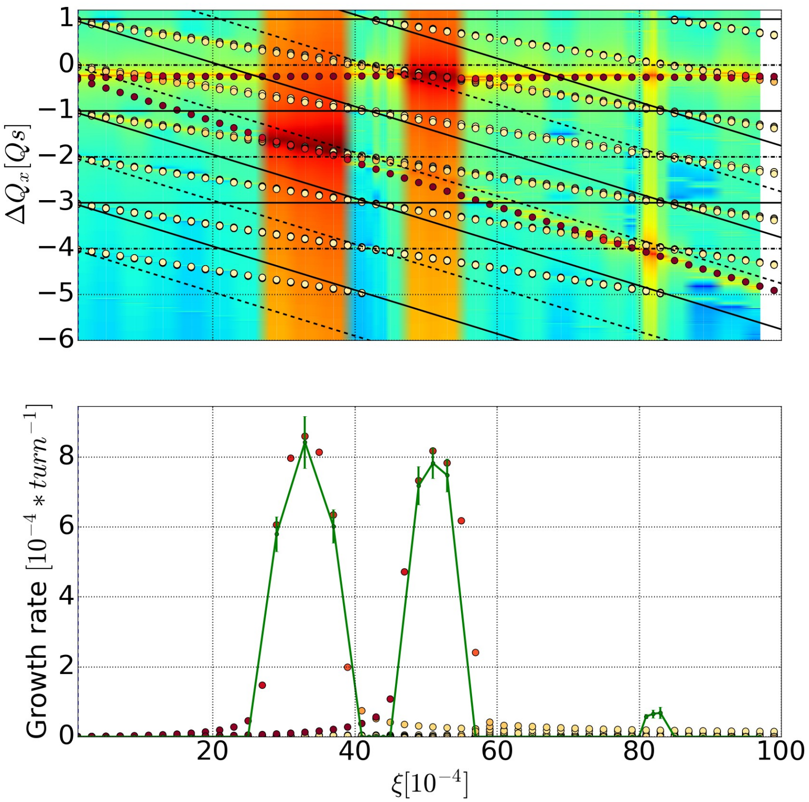


Landau damping of the mode coupling instability of colliding beams

L. Barraud

- Introducing a weak-strong beam-beam interaction in COMBI (e-lens like) to compensate the incoherent effect, leaving the coherent beam-beam effects

  → Both the Yokoya factor and Landau damping are suppressed, leaving a perfect agreement between the two approaches



Synchrobetatron coupling

- While 4D effects were well studied, a good understanding of 6D effects (hourglass, crossing angle) was lacking
  - Y. Alexahin predicted Landau damping from synchrotron sidebands
  - Mode coupling instability of high order head-tail modes are possible due to synchrobetatron coupling

→ Implementation of a 6D coherent beam-beam kick in COMBI (+heavy usage of EPFL and CERN's HPC facility)

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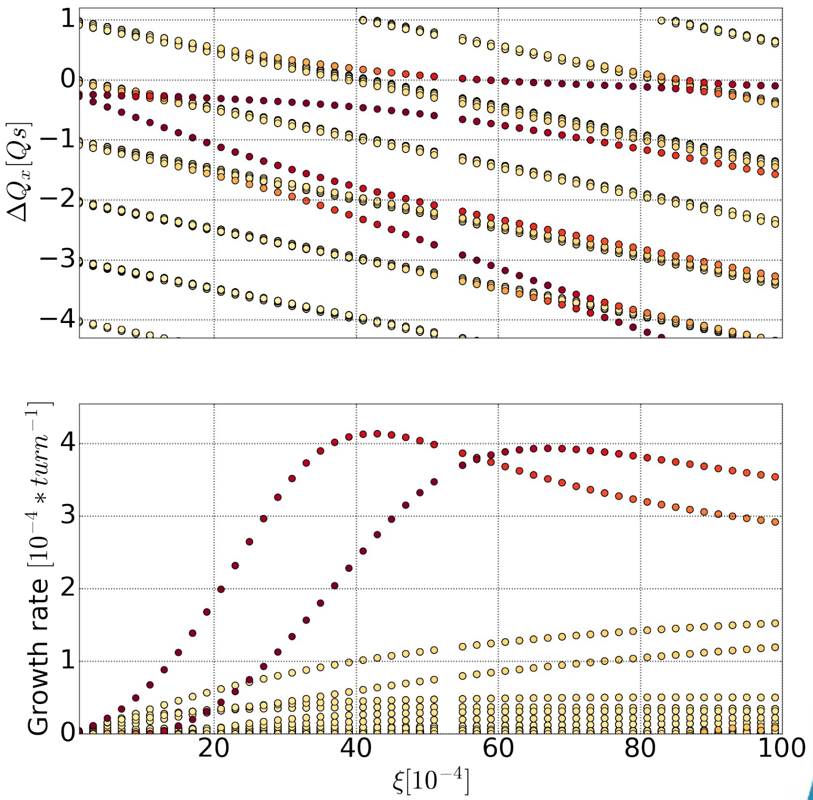

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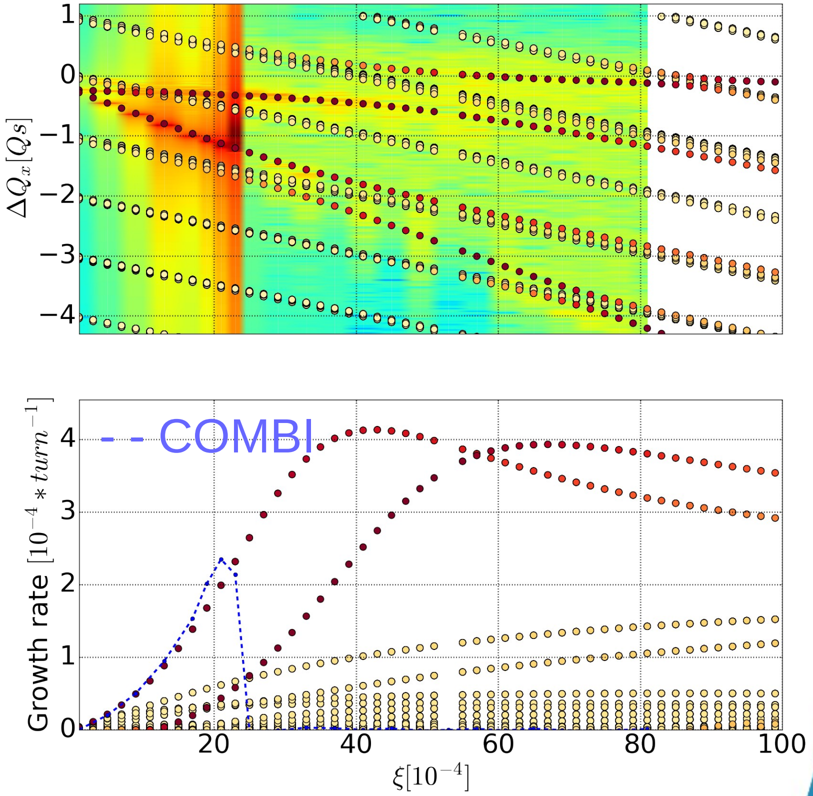

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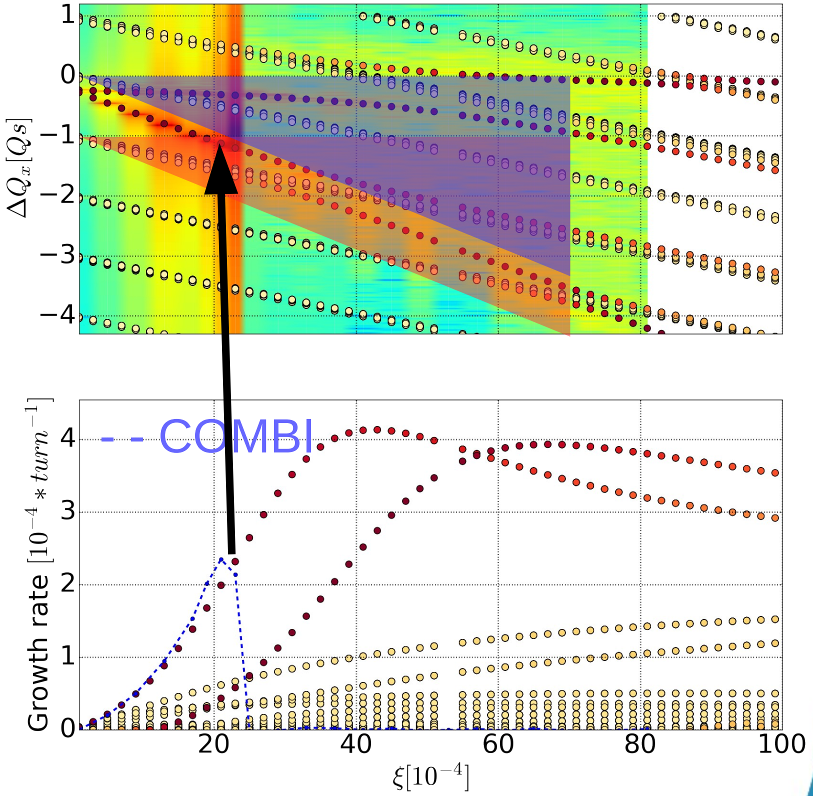
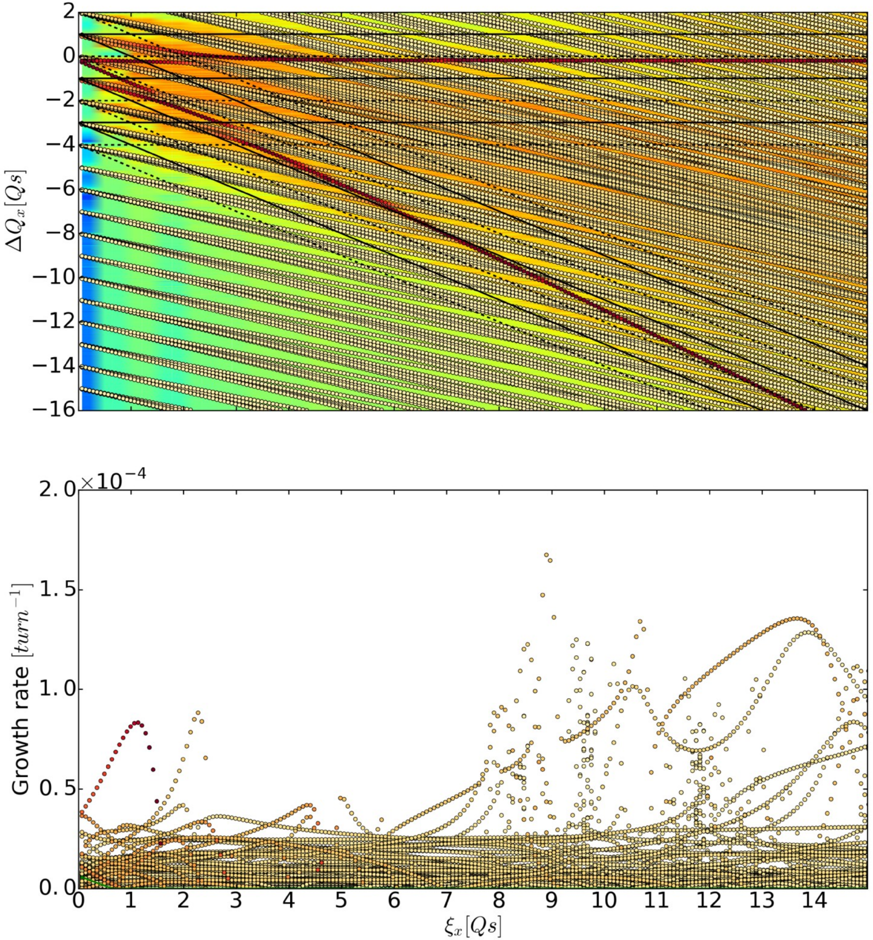


Mode coupling instability of colliding beams in the HL-LHC

- Nominal configuration at the end of the squeeze with full intensity (pessimistic scenario)

  → Due to both hourglass effect and the remaining crossing angle at the IP, a forest of coherent modes appear



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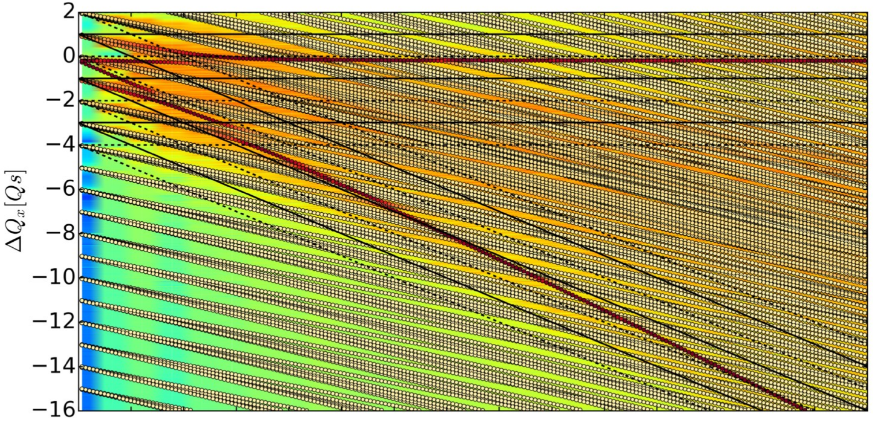

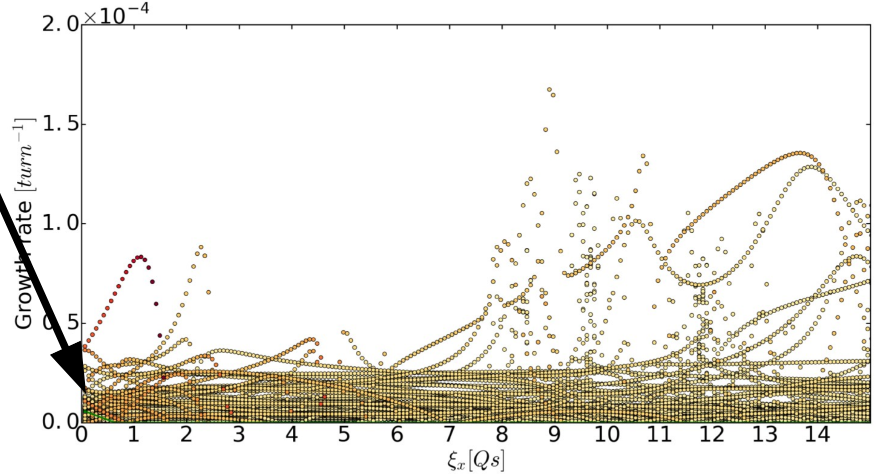

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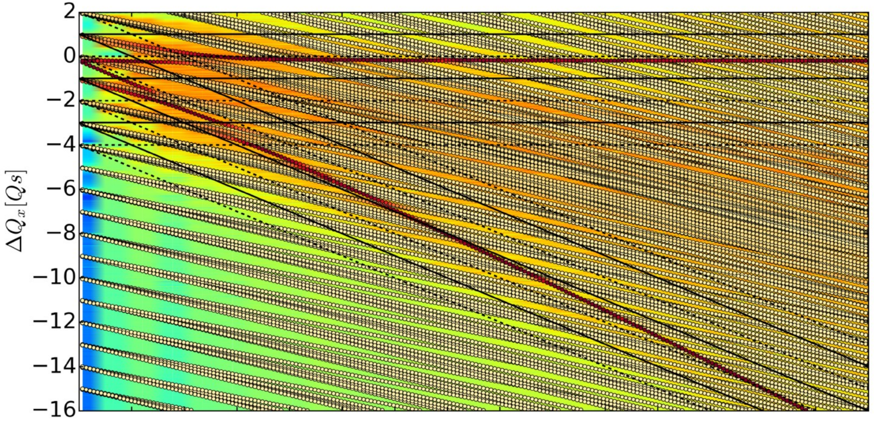
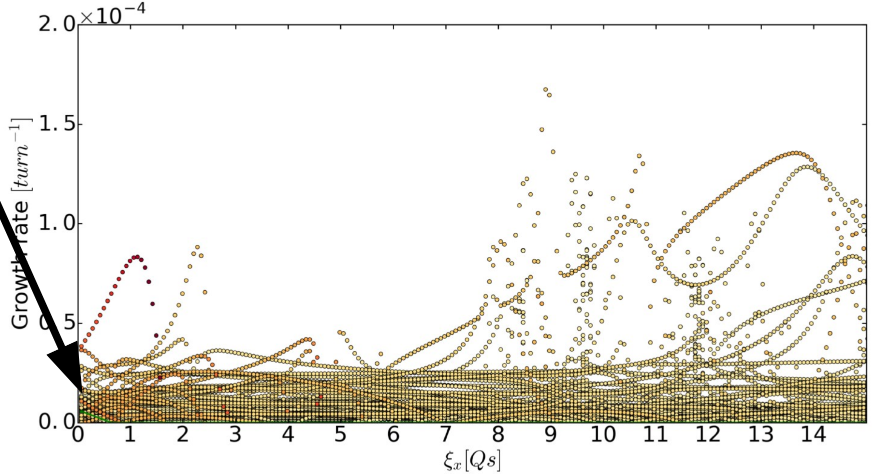
- Despite the pessimistic assumptions, the mode coupling instability of colliding beams is always well damped by the head-on tune spread, for ξ>Qs
  - The weak beam-beam parameters are achieved only with a reduced intensity → not an issue for the operational scenario
  - To be kept in mind for offset levelling **at low β***





Summary

- A significant telescopic index is needed during the ramp / pre-squeeze to maintain the beam stability
  - The current target of 3.3 ensures the beam stability through the whole cycle with the negative octupole polarity for all scenarios with at least the LS2 collimator upgrade
  - In principle offset levelling in the main IPs becomes also a possibility in such a configuration
- Based on LHC experience, the design relies a factor 2 margin in amplitude detuning w.r.t. the predictions of the model
  - Without understanding of the cause, the scaling to HL-LHC parameters is not fully robust → Experimental studies are planned and theoretical / numerical investigations ongoing
- The scaling of electron cloud effects at top energy remains unclear

  → In principle a test with a high intensity 12b 25 ns train is possible
- The mode coupling instability model was extended to include 6D effects
  - The strength of Landau damping for the mode coupling instability of colliding beams was found sufficient for all scenarios of HL-LHC