IMPEDANCES, INSTABILITIES AND IMPLICATIONS FOR THE FUTURE

Elias Métral (20 + 10 min, 19 slides) for a big team: G. Arduini, R. Assmann, O. Bruning, X. Buffat, S. Fartoukh, W. Herr, W. Hofle, N. Mounet, T. Pieloni, G. Rumolo, B. Salvant, E. Shaposhnikova, F. Zimmermann, A. Burov (FNAL), M. Lamont, J. Wenninger and OP team (many thanks to all the coordinators and EICs), BI, collimation team…

- Introduction
- Reminder: Octupoles and transverse dampers are used
- Impedances
- Possible explanations (for the instabilities) and actions taken
- Conclusions and implications for the future

INTRODUCTION (1/4)

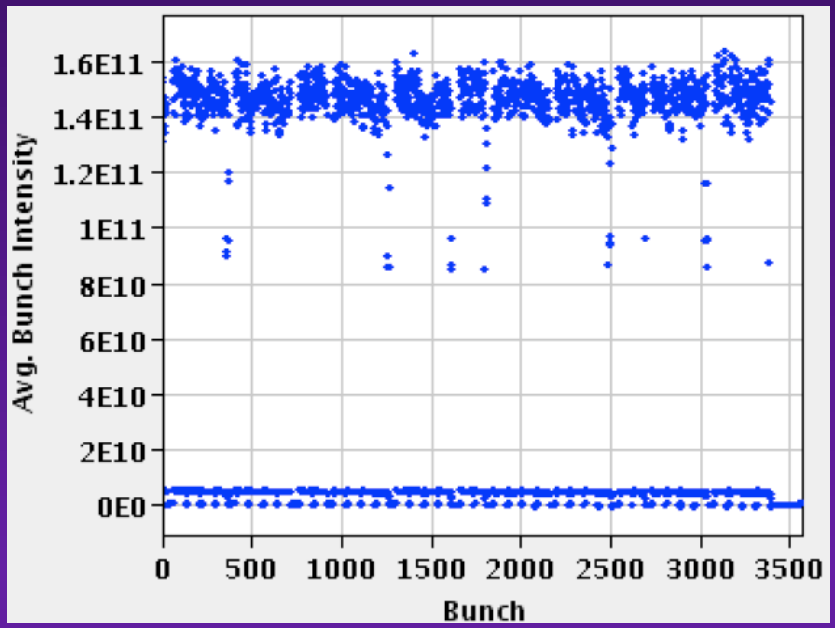
- **Reminder**
  - *New peak luminosity record few days ago: ~ 6.8E33, i.e. 68% of the design luminosity*
  - *4 / 7 = 57% of the design energy*
  - *½ number of bunches (50 ns spacing instead of 25 ns)*
  - **Bunch brightness: ~ (1.5 / 1.15) × (2.4 / 3.75) ~ 2 times bigger than nominal => ~ 2 times more critical for octupoles current**
  - **Tight collimators' settings => Larger impedances and more critical instabilities (factor ~ 2.3 compared to last year) => ~ 2.3 more octupoles needed**
  - **Recent change of octupoles sign (see later why) => ~ 65% more current needed (assuming Gaussian transverse distribution)**

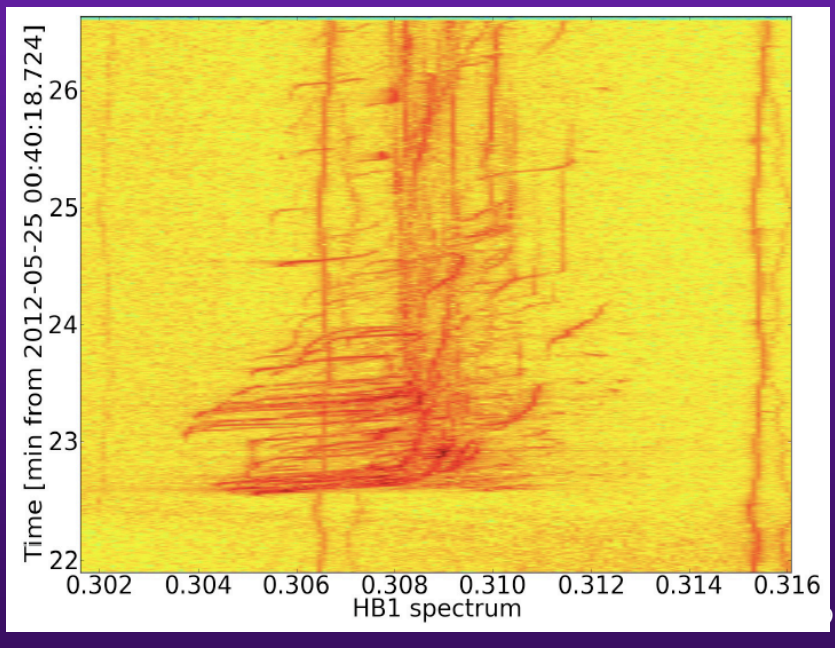
    => Factor ~ 7.6 more octupoles current needed!
- **3 types of instabilities perturbed the intensity ramp-up =>**

INTRODUCTION (2/4)

- **1) In collision => "Snowflakes"**
  - Always in H only (both beams)
  - Concerned initially only IP8 private bunches (=> Filling scheme was changed)
  - Happens on selected bunches with insufficient tune spread (and thus Landau damping) due to no HO collisions (or offsets)
  - See W. Herr's talk

Xavier Buffat

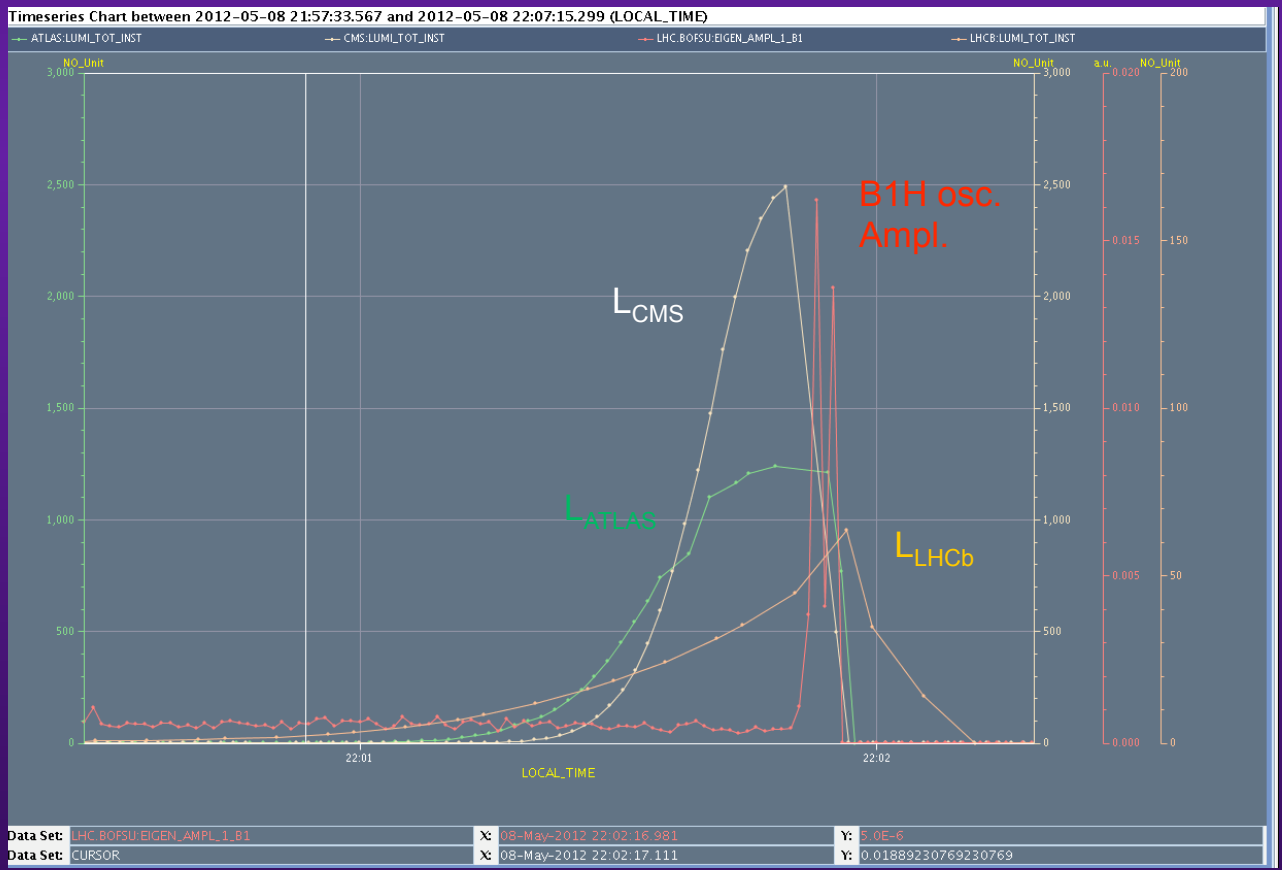




INTRODUCTION (3/4)

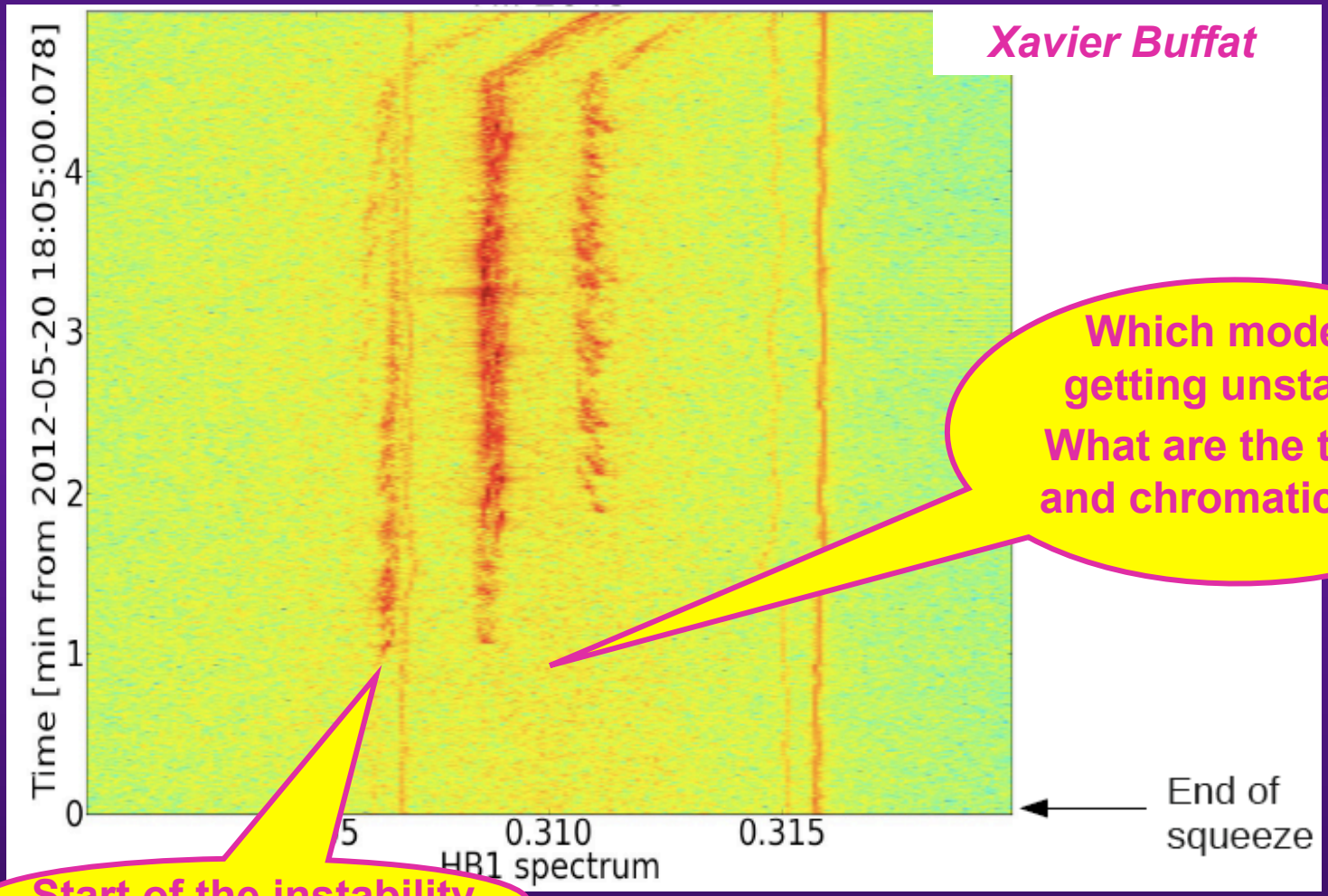
- **2) During collision process**
  - **Example of instability at the end of the collision process (separation bumps collapsed) when ending with residual separation of ~ 2.1 sigmas in IP1 and ~ 1.2 sigmas in IP5 (estimated from luminosities at the moment of the dump) => In H also**

Gianluigi Arduini



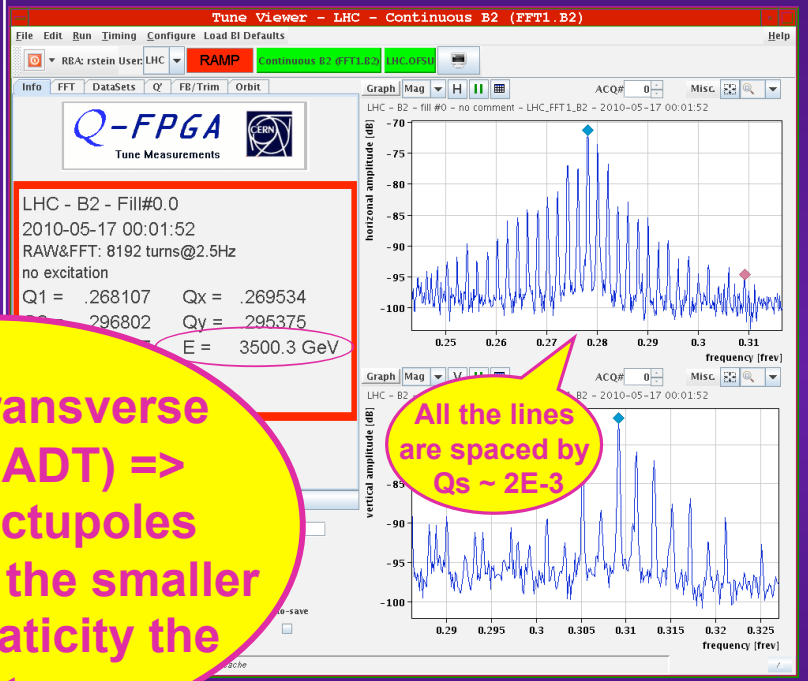
INTRODUCTION (4/4)

- **3) During / at the end of the squeeze**
  - **In H also**



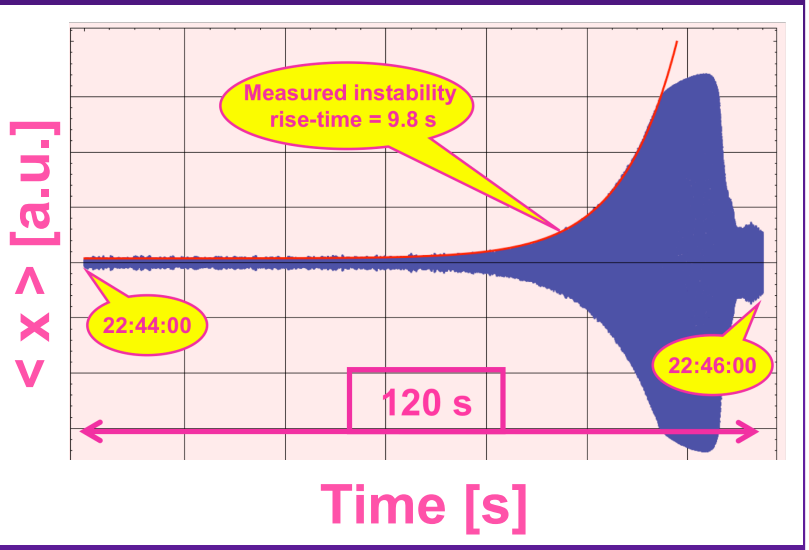
REMINDER: Octupoles and transverse dampers are used (1/2)

- **Single-bunch head-tail instability m = - 1 without Landau octupoles (for Q' ~ 6) on LHC flat-top**

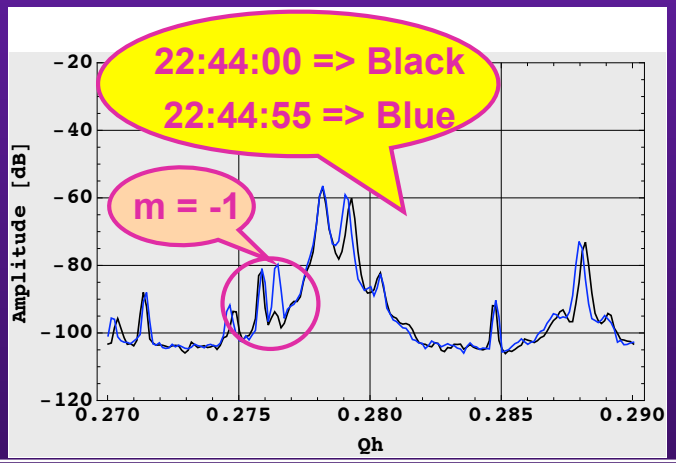


Without transverse damper (ADT) => Landau octupoles needed and the smaller the chromaticity the better

All the lines are spaced by Qs ~ 2E-3

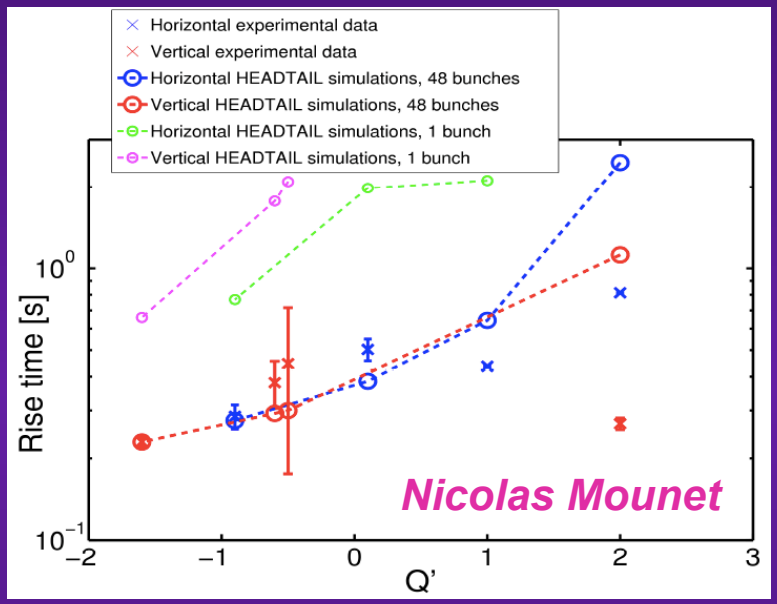


- **Rise-time and Landau octupoles' current for stability (between 10 and 20 A) within factor ~ 2 with predictions**



REMINDER: Octupoles and transverse dampers are used (2/2)

- **TCBI rise-time studies (for mode 0) with 48 bunches (12 + 36)**
  - **Good agreement at 450 GeV**



ADT needed

  - **~ 2-3 faster rise-times observed at 3.5 TeV (but uncertainty on chromaticities)**
  - **Landau octupoles' current for stability at 3.5 TeV within factor ~ 2 with predictions (less than predicted => Studies with Q" ongoing)**

Studies done and beneficial effect in H

IMPEDANCE (1/2)

- **Longitudinal (with Elena Shaposhnikova)**
  - Long. impedance meas. started this year with stable phase shift, Schottky spectrum and direct observation of Loss of Landau damping during ramp and on flat top
  - LHC impedance very small => Very high accuracy required
  - Promising results from phase meas. which indicate a resistive impedance larger than in the impedance model by factor ~ 2
  - Loss of Landau damping puts a limit on the minimum longitudinal emittance at 4 TeV flat top which is around 1.1 eVs
  - Heating issues:
    - Longer bunches but not too long (reduction of luminosity geometric factor + reduction of single-beam lifetime)
    - LRFF Task Force (2012) to review equipments with RF fingers (VMTSA issues in 2011 solved in 2012)
    - MKI8D => Will be changed soon (19 instead of 15 strips)

IMPEDANCE (2/2)

- **Transverse**
  - With all the measurements done (tune shifts, rise-times, stability with octupoles etc.), the transverse impedance is within a factor ~ 2 (factor ~ 3-4 at injection for tune shifts => TDI issues?… not a problem for the moment)

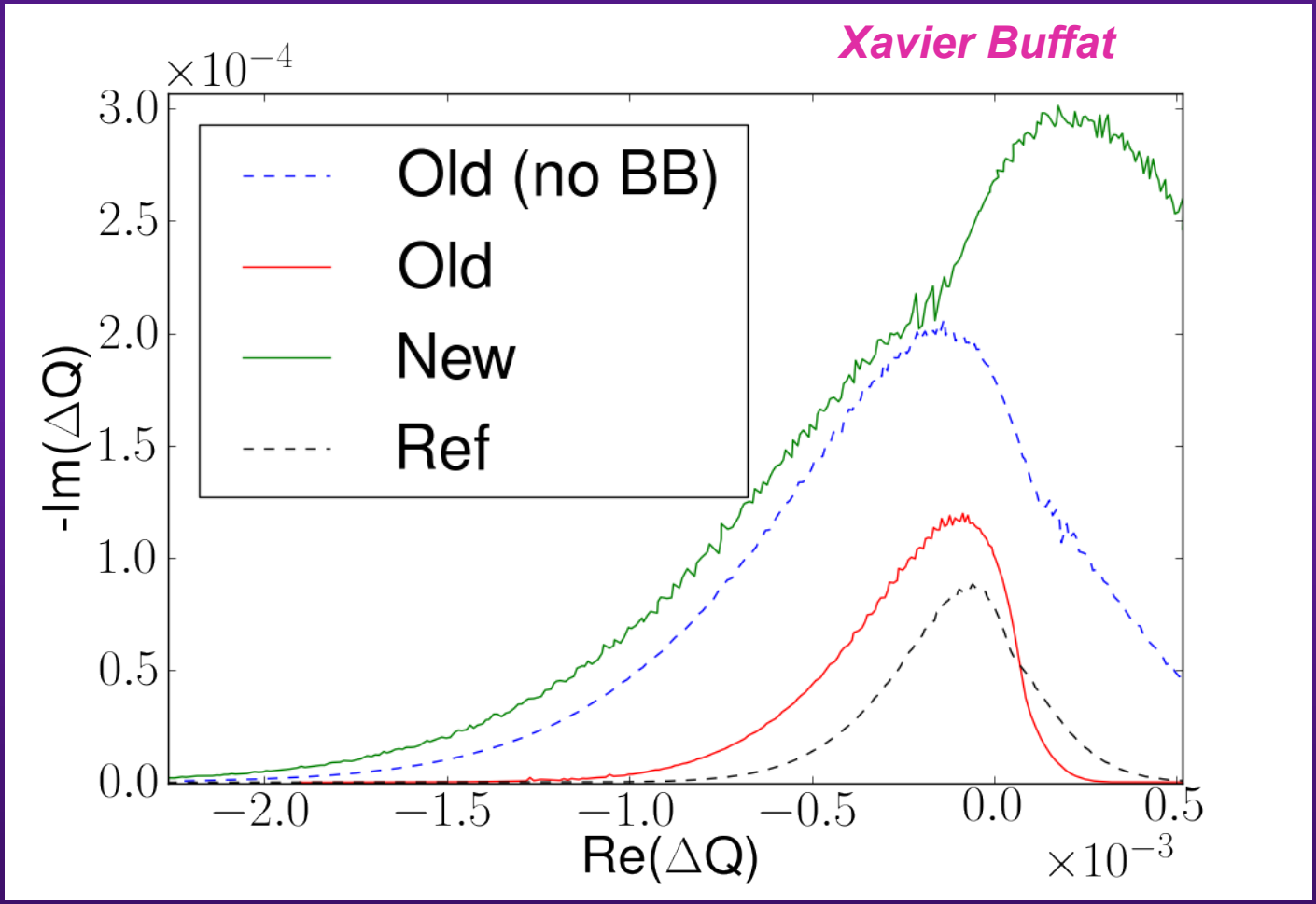
POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (1/7)

=> 2 main ideas

- 1) 1st idea [Beam-beam team, Stephane Fartoukh, others]: Octupoles and beam-beam (HO and LR) fight against each other with the sign of the octupoles used until now (- for LOF and + for LOD) => Can lead to smaller tune spreads (and stability diagrams) when beam-beam is involved (i.e. starting near the end of the squeeze)
  - Sign changed last week (in steps, as chromaticities depend on octupoles current; larger tune footprints when effects of octupoles and beam-beam add, etc.)
  - Should be good for all instabilities observed BUT it makes the situation worse for the stability of a single-beam as more current is needed in the octupoles

POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (2/7)

=> Indeed, it is better for this: (1) larger stability diagram during and at the end of the squeeze (shown here)



POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (3/7)

=> It should also be better for this: (2) avoid very critical situation during the collision process (still under investigations)

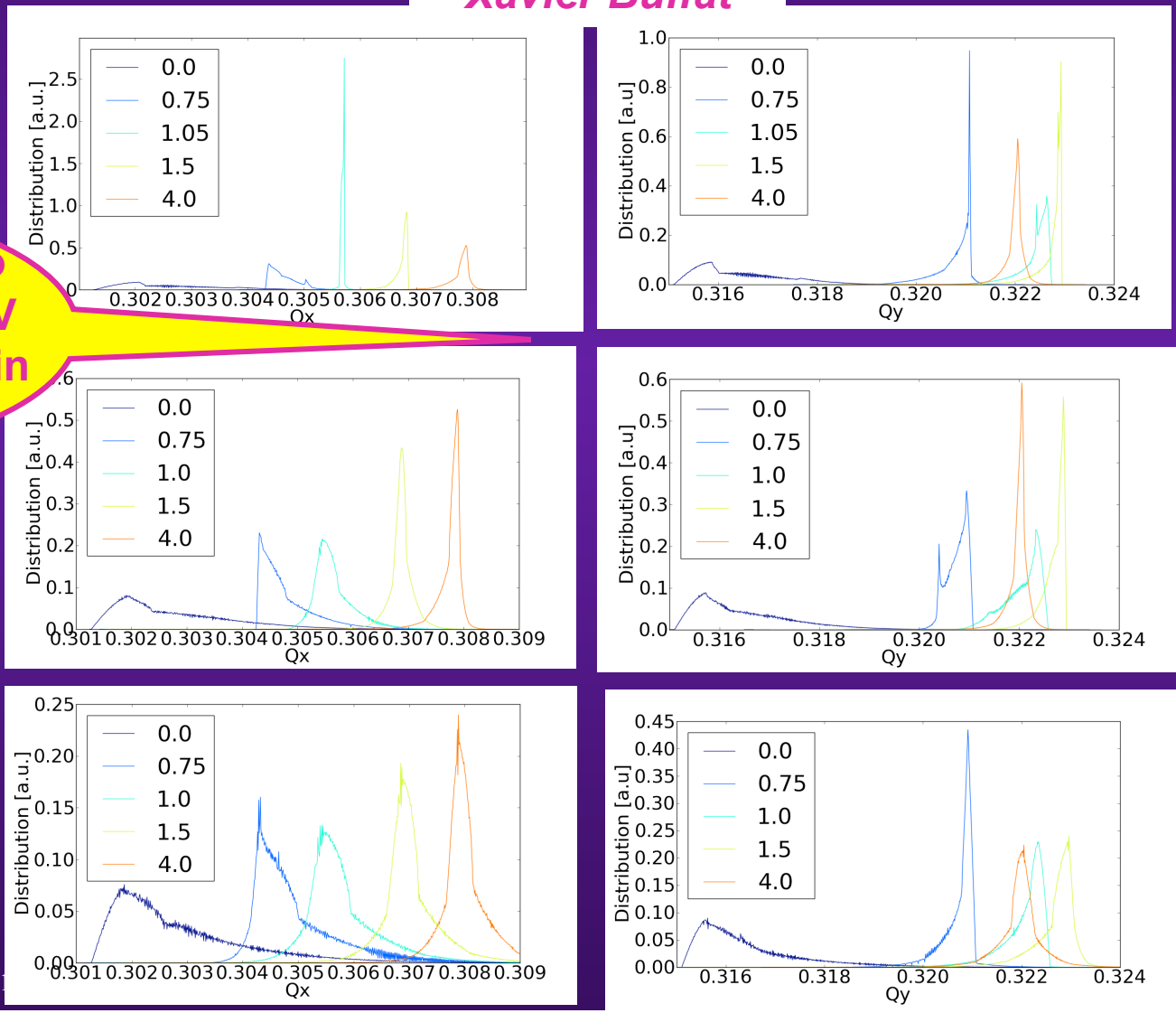
Xavier Buffat

< 0 sign

Was "1 possibility" to try and explain the H/V asymmetry observed in instabilities

0 octupoles

> 0 sign

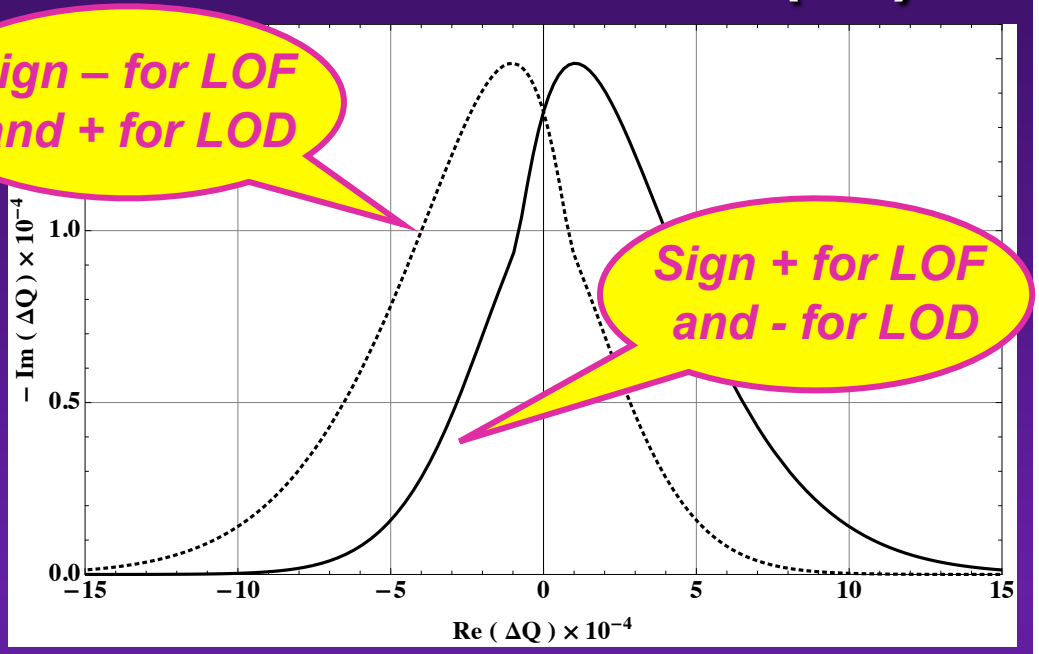


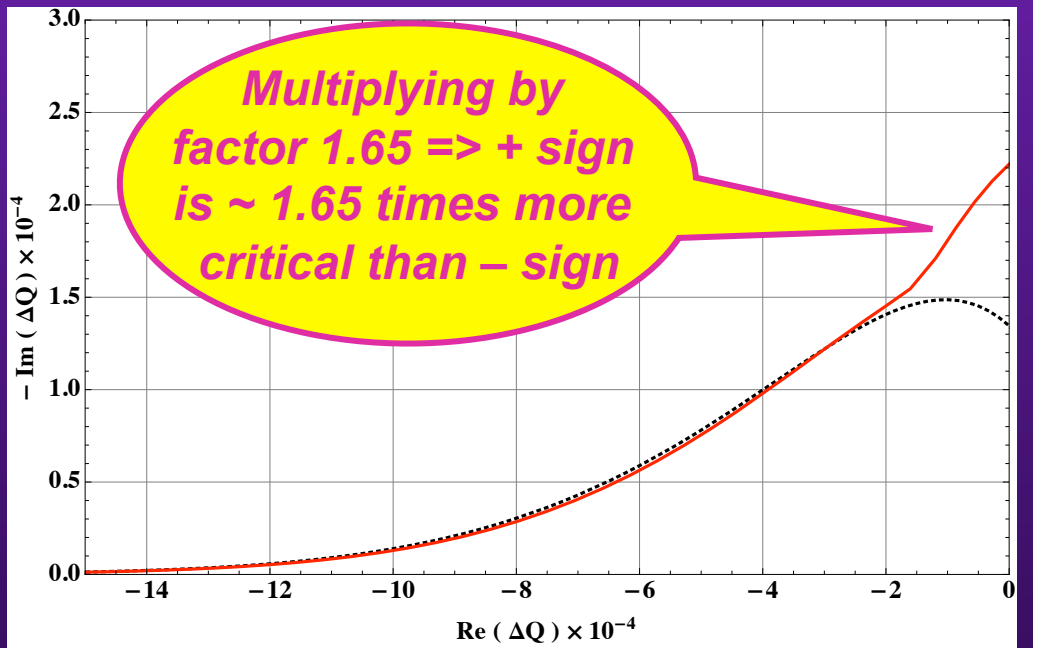
POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (4/7)

=> BUT, it is worse for this: stability diagram with octupoles only (i.e. before the squeeze)

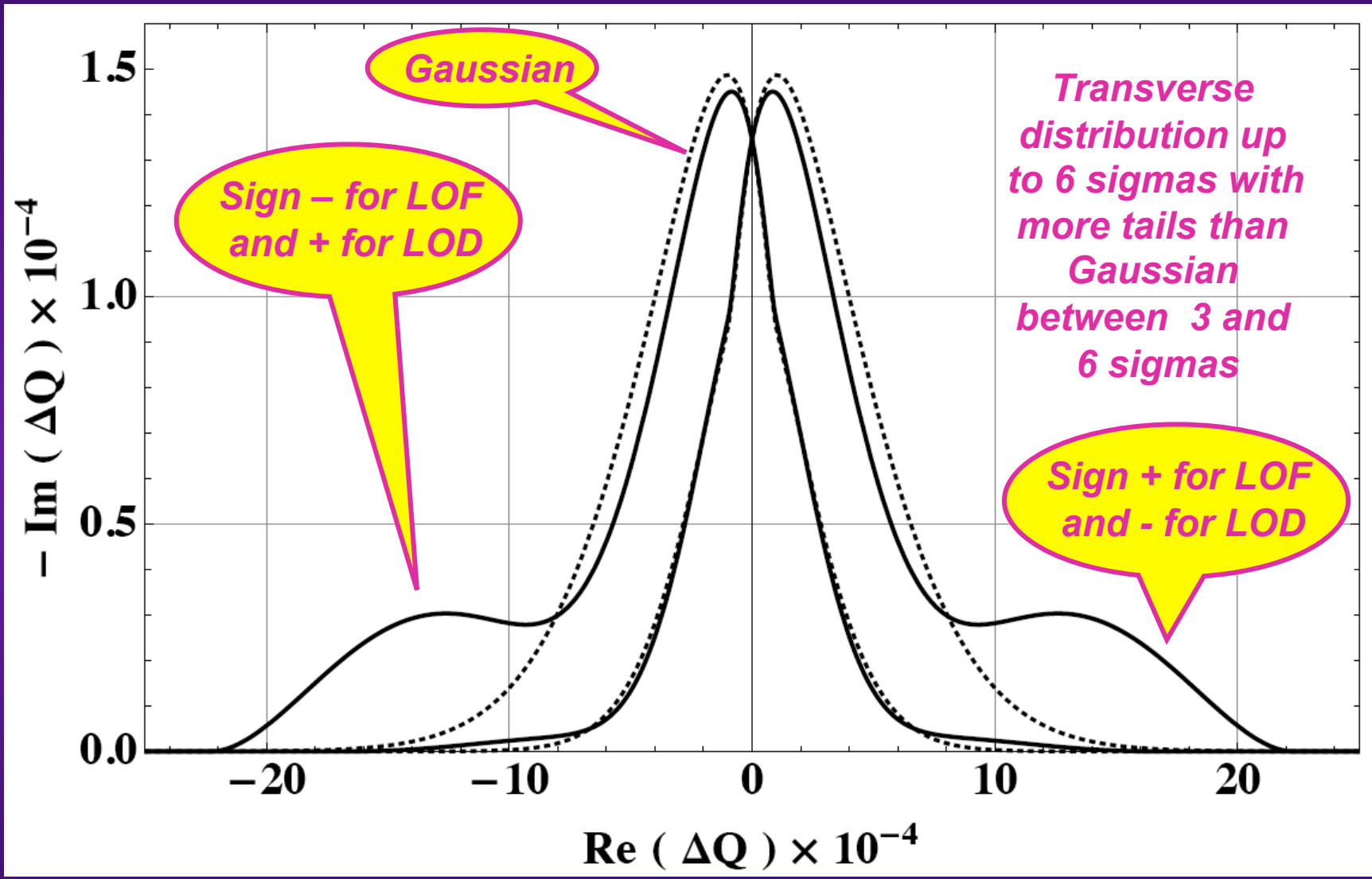
Gaussian transverse distribution assumed here

Was observed after the change of the octupoles sign





POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (5/7)



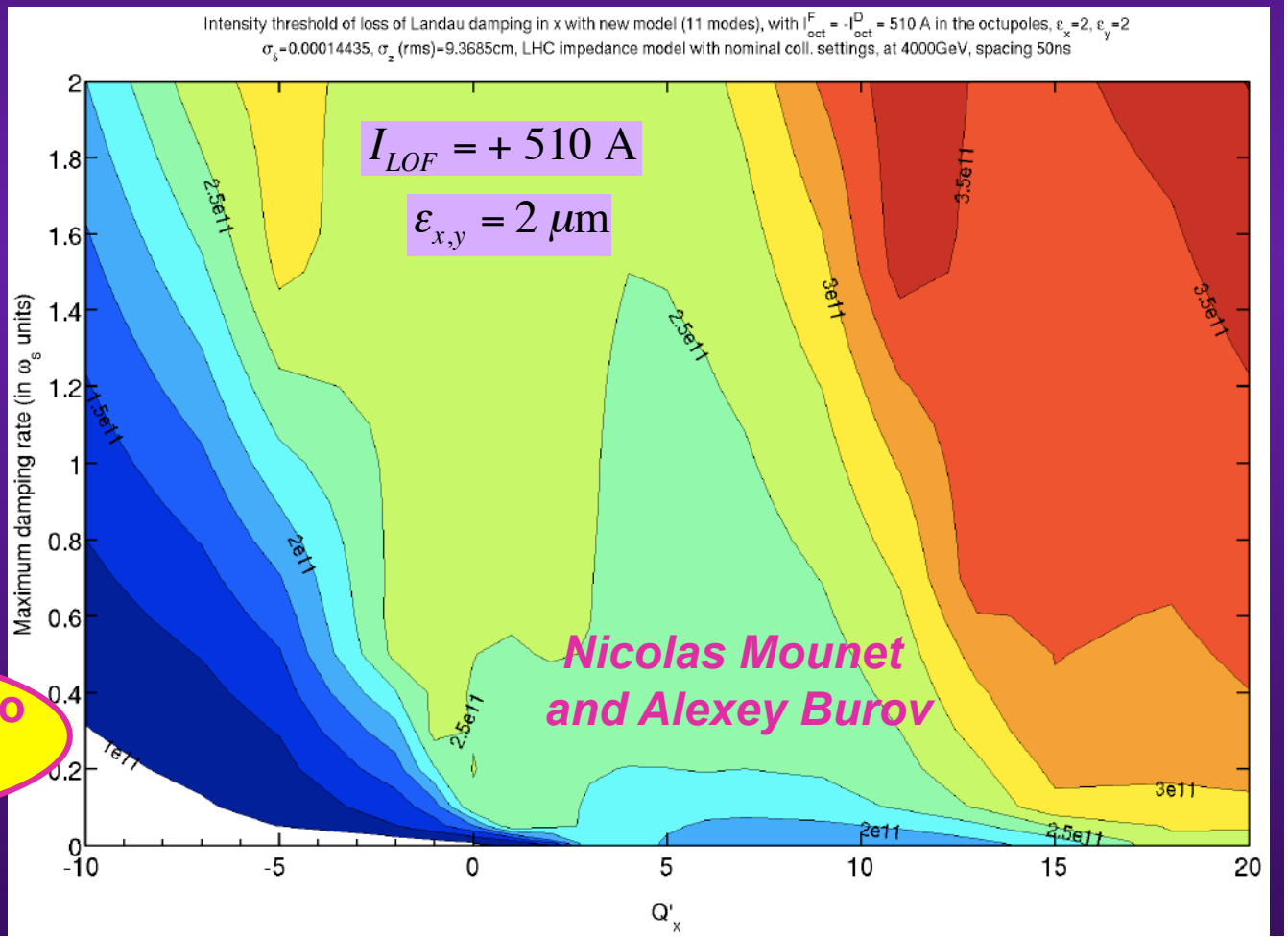
=> With the new (+) sign, large tails would not be useful anymore (as negative tune shifts are expected)

POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (6/7)

- **2) 2nd idea [Alexey Burov and Nicolas Mounet]: transverse damper and coupling of the different head-tail modes should be included in the computation of the complex tune shifts of the different modes => Preliminary (radial modes still to be included), but very promising!**

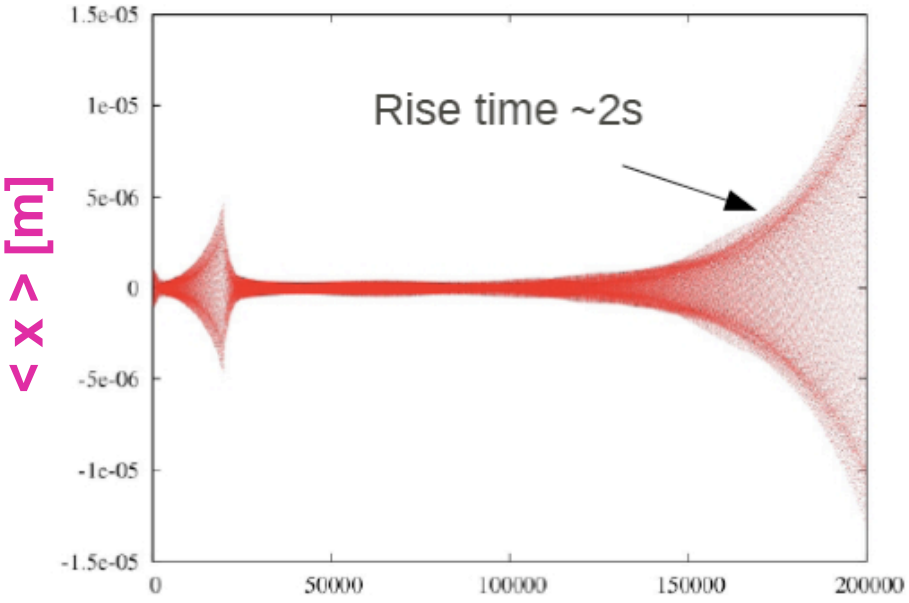
$$G_D = \frac{1}{2\,\pi\,Q_s\,n_D}$$

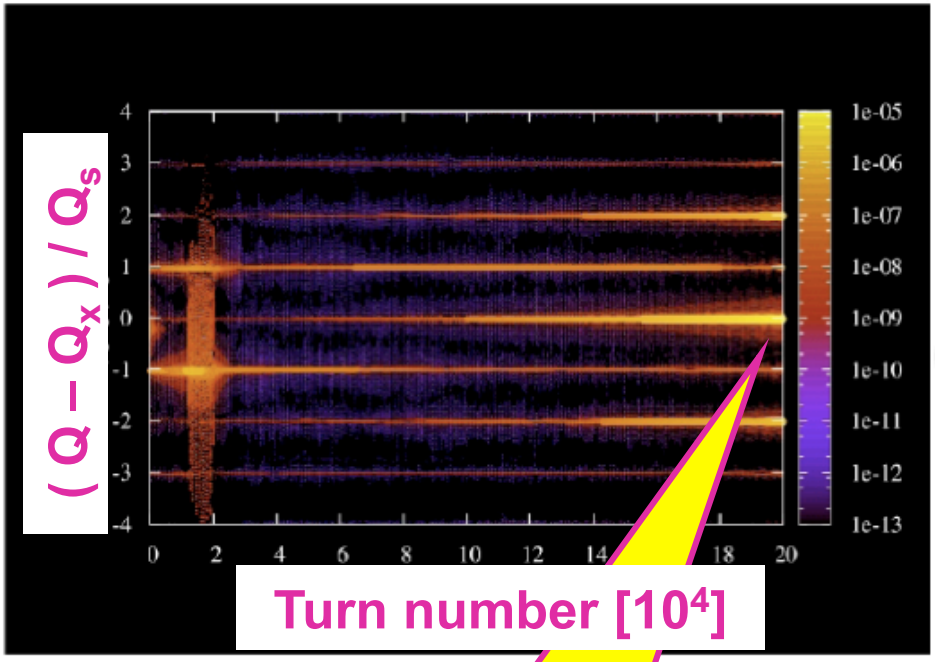
G_D = 1.4 corresponds to n_D ~ 50-turn damping



POSSIBLE EXPLANATIONS AND ACTIONS TAKEN (7/7)

Simon White





- Initially mode – 1 (more than + 1)

- Damped by damper

- Then other modes unstable (similar to new theory)

Radial mode 02? => 2 nodes… => Would be very important to have the HEADTAIL monitor to check that!

CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE (1/3)

- Several instabilities observed with the old (-) sign of the octupoles (end of the squeeze, during collision process and in collision) => Should be better with the new (+) sign
- But new (+) sign makes the situation more difficult before the squeeze (1-beam issues) => New theory (with ADT & mode coupling) should explain many (if not all) observations!
- Preliminary recommendations (but under verifications, including the radial modes etc.):
  - Increase as much as we can the ADT gain (we/I wanted to do the opposite in the past…). Flatten the gain vs. *f* (W. Hofle)?
  - Increase as much as we can the chromaticities (we/I wanted to do the opposite in the past…) => How far can we go?
  - Such that we can run with an octupoles current below ~ 300 A (to be able to run at 7 TeV with similar other parameters)

CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE (2/3)

- Going from 4 TeV to 7 TeV => Factor 7/4 = 1.75 in energy
- With the same settings for the collimators (in mm)
  - Impedance will be the same and the transverse instabilities will be ~ 1.75 times less critical
  - BUT, the effect of the octupoles will be (7/4)^2 ~ 3.1 times more critical

    => The overall situation should be 1.75 more critical. As 550 A is the maximum octupoles' current, it means that it corresponds to a maximum value of ~ 300 A at 4 TeV
- For collimators closer to the beam => Situation will be worse!
- For higher brightnesses (intensities / emittances) => Situation will be worse!

CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE (3/3)

- In the future, if we have sufficient octupoles current (depending on possible chromas, ADT gain, impedances from collimators etc.) => Should be fine like this and we should have to fight only against the single-beam instability before the squeeze (as seen now)
- But if we can't have enough octupoles current (ATS optics could help - Stephane Fartoukh), we might want to come back to the previous sign to solve this issue => In this case the critical situations during / at the end of the squeeze and during collision process should come back => To solve this, several possibilities:
  - Reduce the time during which we have the critical situations => Go faster through the processes (IP8 tilting after colliding IP1 & 5…)
  - Increase the chromaticities and ADT during critical situations
  - Beta star leveling (See W. Herr's talk) => To be studied in detail
  - Optimize collimators settings and beta star (see R. Bruce's talk) => Could also be done with other sign of octupoles …