REVIEW OF THE INSTABILITIES OBSERVED DURING THE 2012 RUN AND ACTIONS TAKEN

Elias Métral (20 + 10 min talk, 19 slides) for many people: G. Arduini, R. Assmann, O. Bruning, X. Buffat, A. Burov (LARP LTV), S. Fartoukh, W. Herr, W. Hofle, M. Lamont, N. Mounet, T. Pieloni, G. Rumolo, B. Salvant, R. Schmidt, E. Shapo-shnikova, D. Valuch, J. Wenninger, S. White (Toohig), F. Zimmermann and OP team (many thanks to all the coordinators and EICs), BI, RF, collimation team…

- **Introduction and main limitation at the end of the run**
- **Past predictions, new findings and actions taken**

  Effects of Landau octupoles (and other machine nonlinearities), chromaticity (1st and 2nd order), transverse damper (ADT): old and new bbb (flat) gain, bunch length, 1- and 2-beam impedances, Beam-Beam (BB) and e-cloud…
- **Conclusions and lessons learned from 2012**

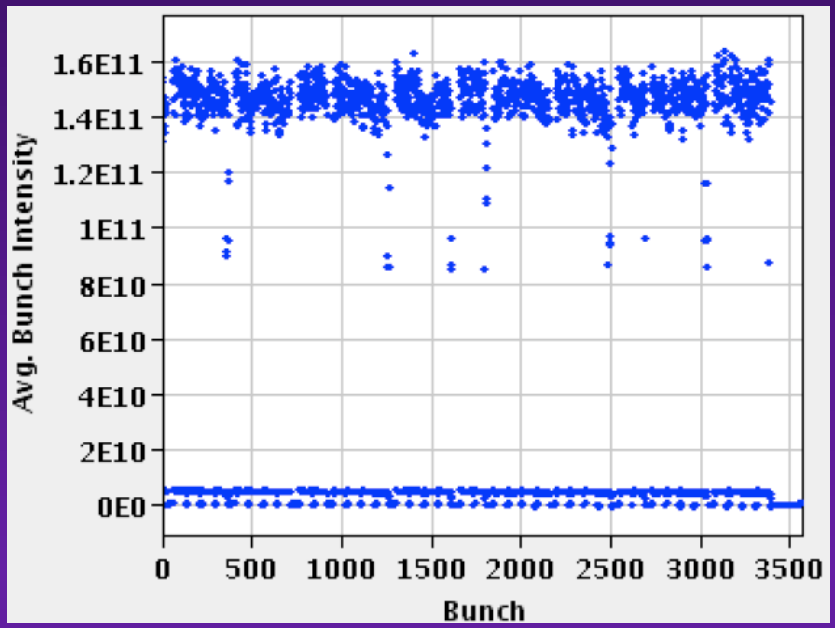
INTRODUCTION (1/6)

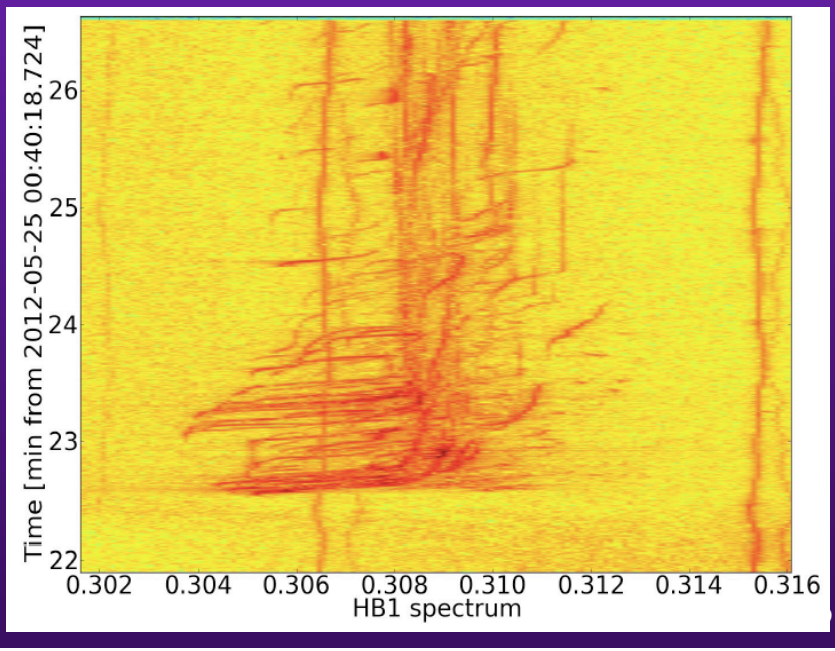
- **Considerable increase of LHC luminosity in 2011 and 2012**
  - *Peak luminosity record: ~ 7.7E33, i.e. 77% of design luminosity*
  - *4 / 7 = 57% of design energy*
  - *½ number of bunches (50 ns spacing instead of 25 ns): 1374 b*
  - *~ 1.6 10^{11} p/b within ~ 2.2 μm (transv. r.m.s. norm. emittance)*
  - **Bunch brightness: ~ (1.6 / 1.15) × (3.75 / 2.2) ~ 2.4 times larger than nominal**
  - **Tight collimators' settings in 2012 => Larger impedances and more critical instabilities (factor ~ 2.3 compared to 2011)**
- **However, 3 types of instabilities perturbed the intensity ramp-up**

INTRODUCTION (2/6)

- **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)

Xavier Buffat

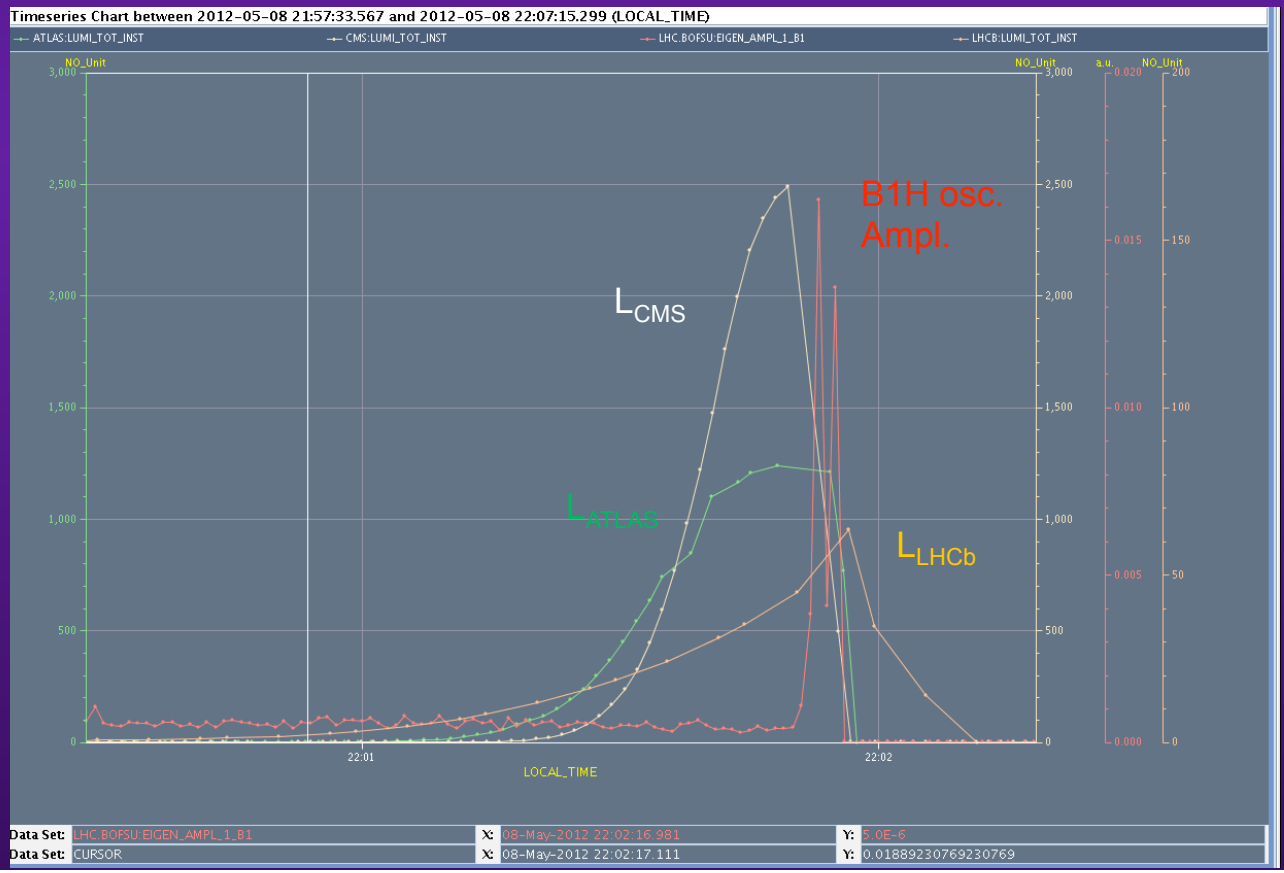




INTRODUCTION (3/6)

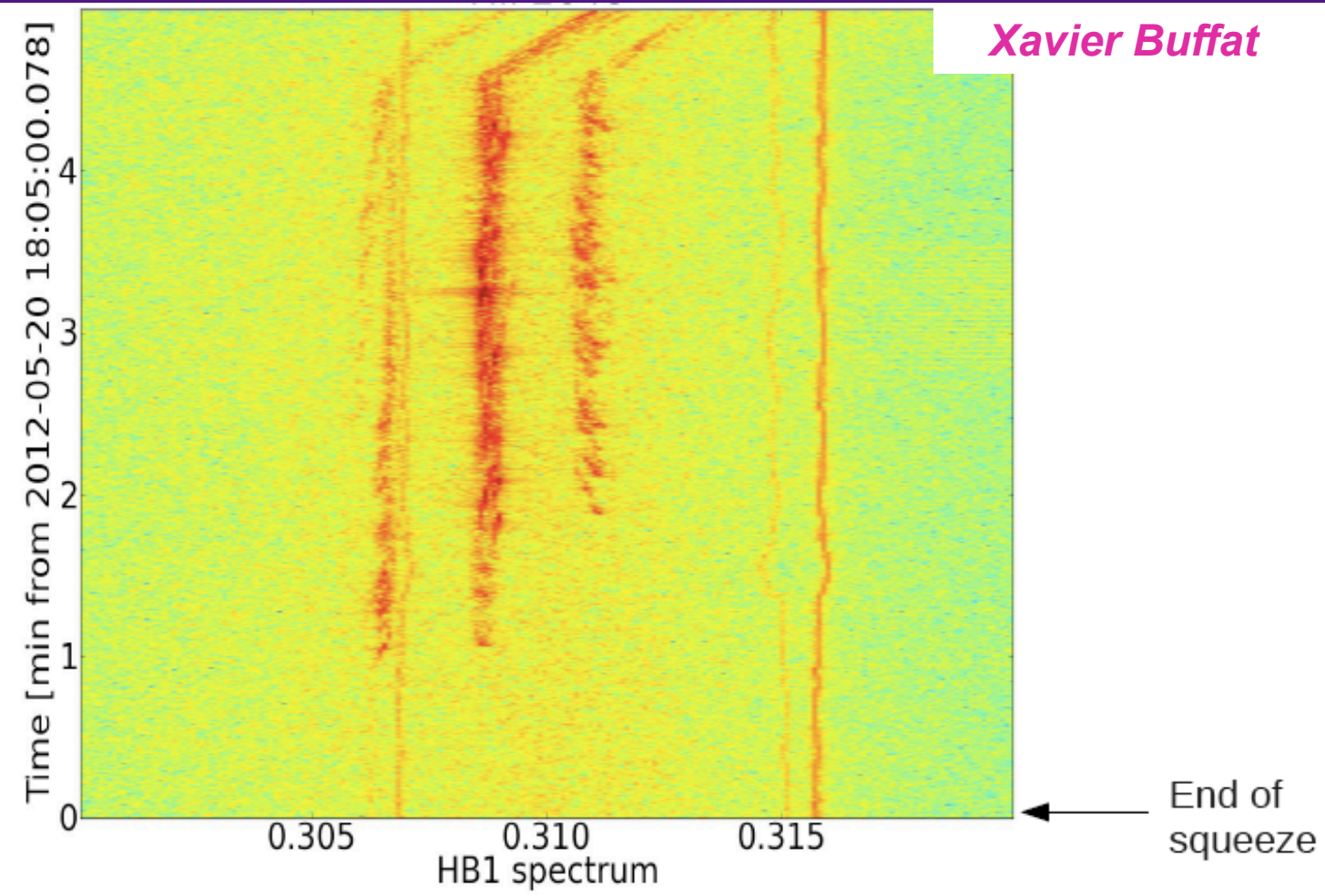
- **2) During the collapsing process (putting the beams into collision)**
  - **Example of instability at the end of the collision process (separation bumps collapsed) when ending with residual separation of ~ 2.1 sigmas in IP1 and ~ 1.2 sigmas in IP5 (estimated from luminosities at the moment of the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

Gianluigi Arduini



INTRODUCTION (4/6)

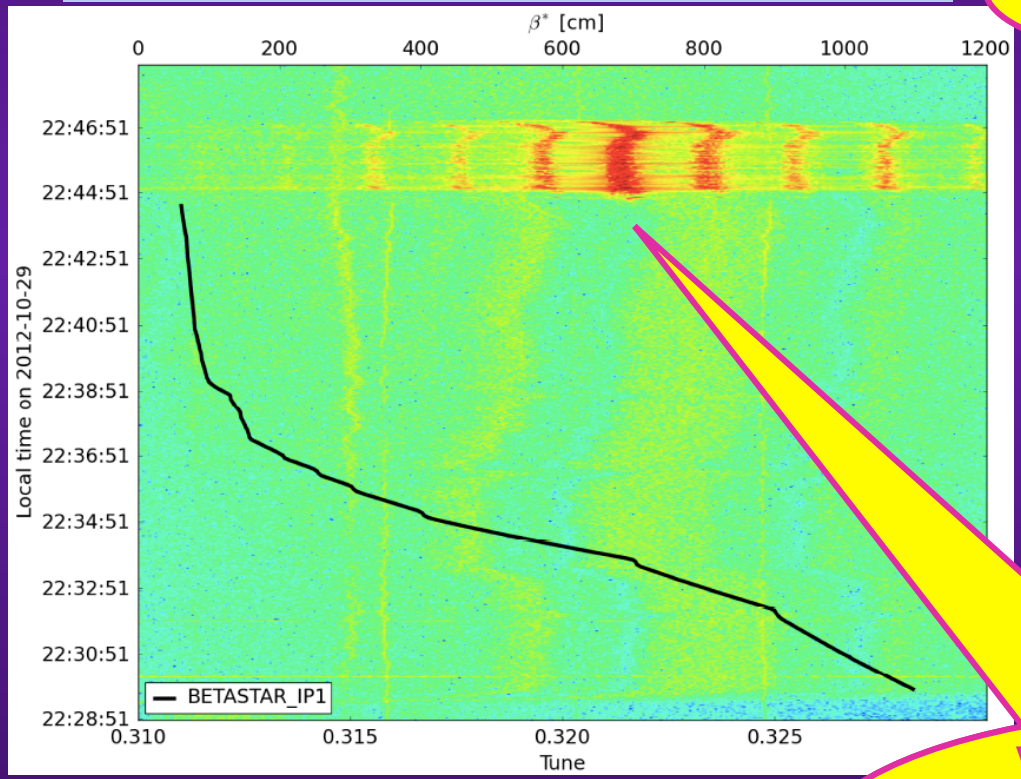
- **3) During or at the end of the squeeze process => EOSI**
  - **In H also**



INTRODUCTION (5/6)

- 1) and 2) disappeared with change of oct. sign (from < 0 to > 0 detuning) in August (7th, fill # 2926). Chromas and ADT gain also increased
- 3) remained with ~ max. octupole, max ADT gain and chromas of ~ 15-20

Fill 3238 (Monday 29/10 evening)

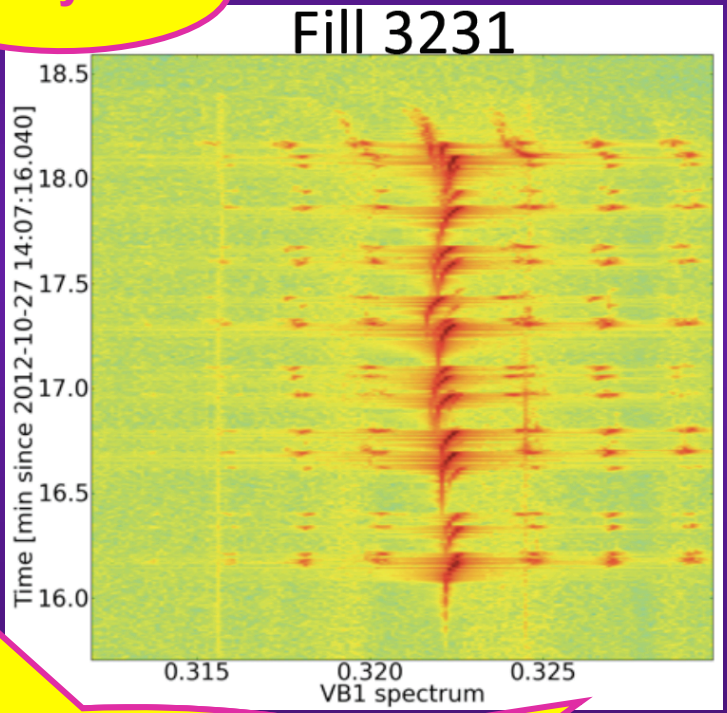


Nicolas Mounet

Mostly B1V

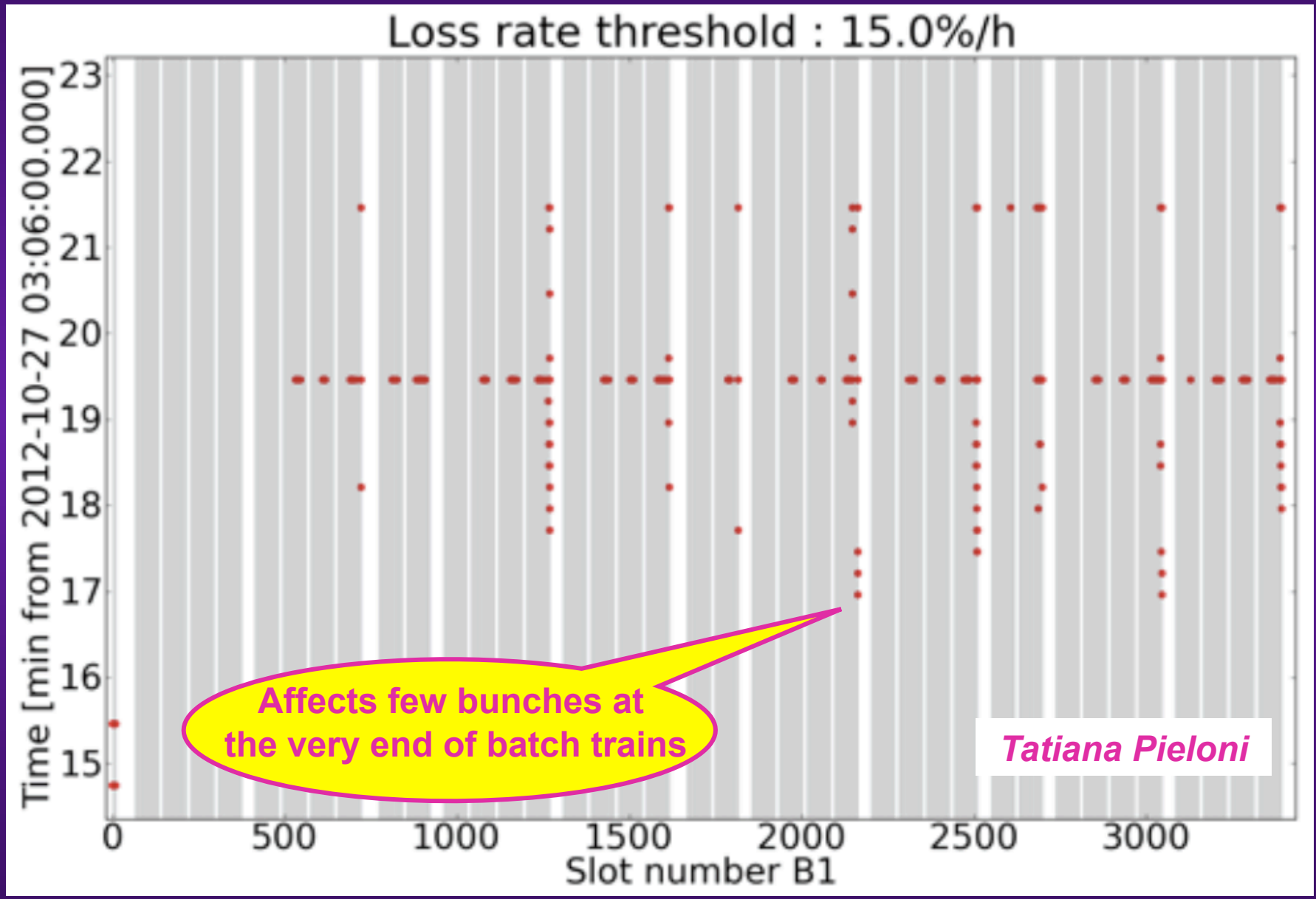
Tatiana Pieloni

Fill 3231



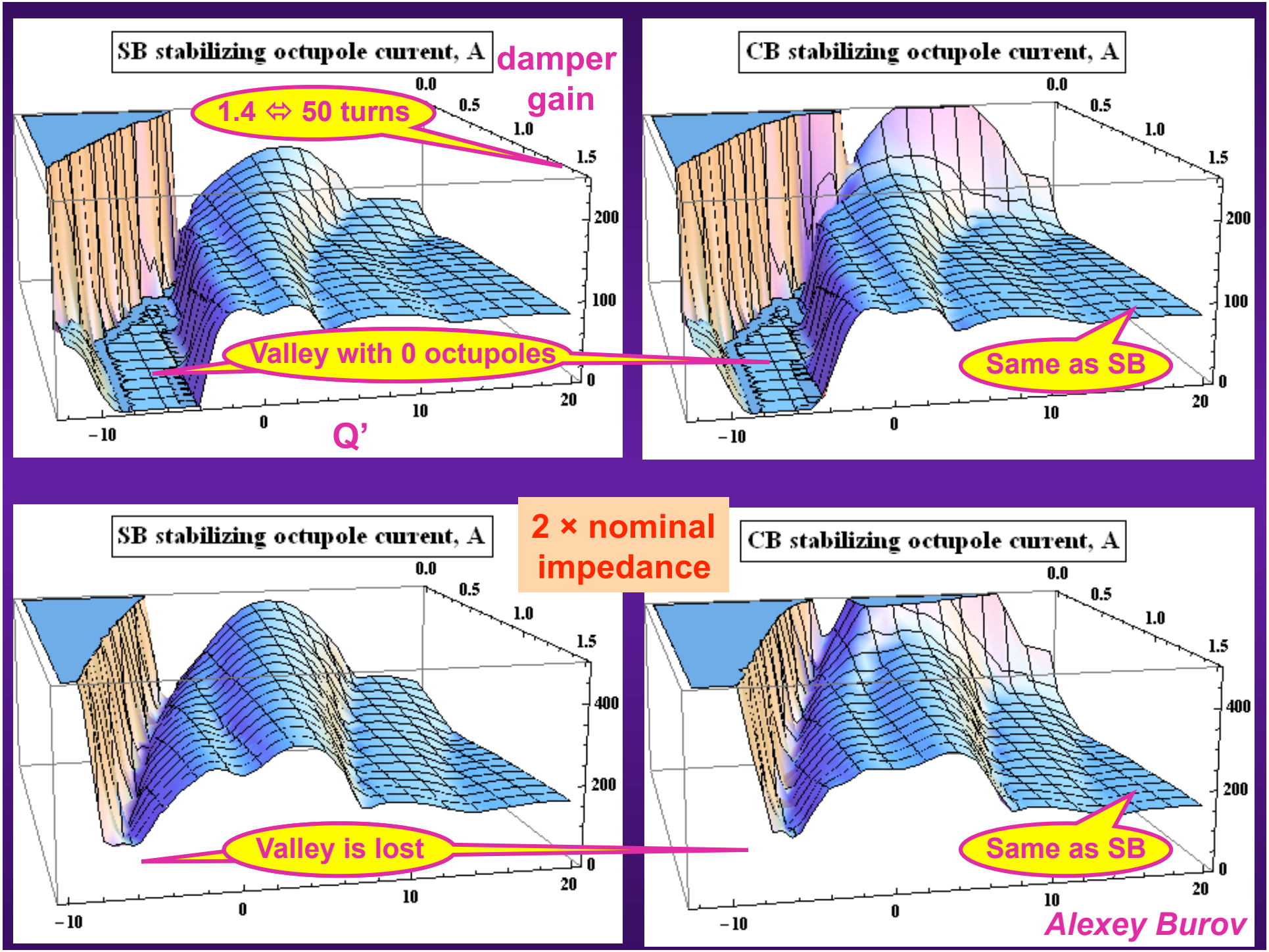
Very reproducible
=> At the end of the squeeze (β* = 0.6 m), after ~ 16 min from the start of the squeeze

INTRODUCTION (6/6)



PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (1/10)

- **Initial recommendations at the beginning of the run**
  - **Chromas: ~ 1-2 units (test < 0 during MDs)**
  - **Octupoles: ~ - 450 A (~ - 200 A used at end 2011 and impedance increased by ~ 2.3)**
  - **Bunch length: from 9 cm rms (1.2 ns total) to ~ 10 cm (~ 1.35 ns total) => RF heating reason but should be better for 1-beam instability**
  - **ADT gain: reduce it as much as we can**
- **Change of octupoles' sign as BB and octupoles fought against each other (LR and HO, IP8 and nom. bunches) => Stephane Fartoukh**
- **New values for ADT gain, chromas and octupoles suggested after new analytical approach (Nested Head-Tail Vlasov Solver) developed by Alexey Burov => Initial implementation by Nicolas Mounet and Alexey Burov. Next slide for 50 ns beam, ~ 1.5E11 p/b within ~ 2 microm**


SB stabilizing octupole current, A
damper gain
1.4 ⇔ 50 turns
Valley with 0 octupoles
Q'
CB stabilizing octupole current, A
Same as SB
2 × nominal impedance
SB stabilizing octupole current, A
Valley is lost
CB stabilizing octupole current, A
Same as SB
Alexey Burov

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (3/10)

- **Conclusion of all 1-beam studies**
  - Current model seems consistent and disagreements were never > factor ~ 2 (for impedance model or Landau damping) => Most of the time now we consider the impedance as being a factor 2 bigger than nominal
    - Was already obtained in the past in several studies without ADT (Nicolas Mounet)
    - Seems to be confirmed this year including the ADT with the NHT model (Alexey Burov)
  - It happened several times that the situation was much better than predicted => Can be explained by larger transverse tails (for previous negative octupoles' polarity) or longitudinal tails

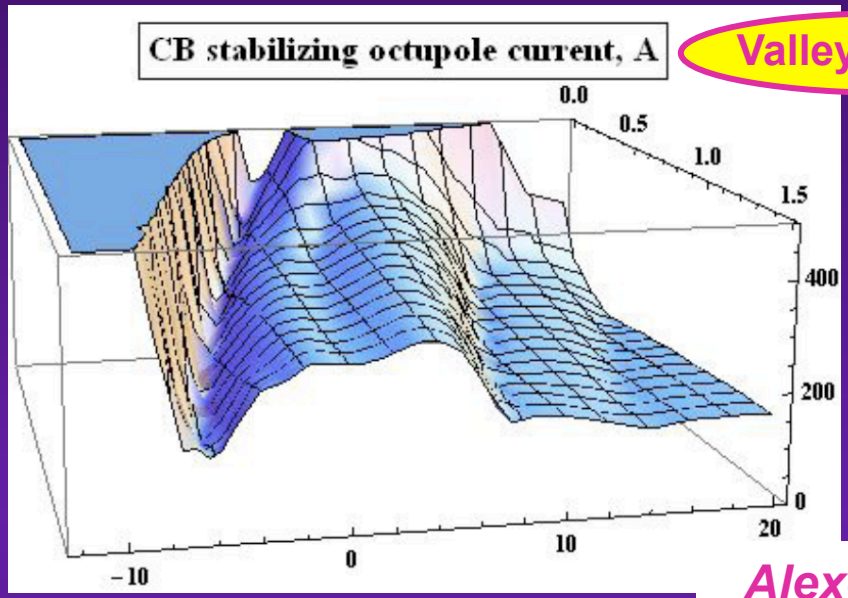
- **The problem(s) come with 2 beams (below a beta* of few m)!!!**
  => We need much more octupoles' current than for 1 beam: ~ max. now and we might be limited at higher energies…

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (4/10)

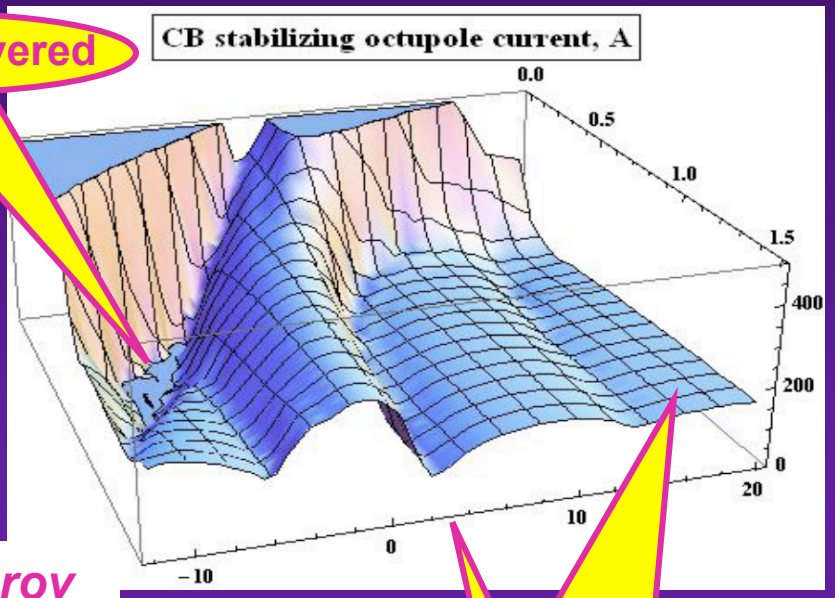
- Do we understand well the ADT? => See next
- Do we lose Landau damping due to interplay with other mechanisms?
  - Because the stability diagram is modified (shifted, deformed, collapsing etc.) due to other nonlinearities:
    - Beam-beam (LR and/or HO) => Seems cannot explain EOSI (Xavier Buffat and BB team)
    - Machine nonlinearities => Seems cannot explain EOSI
    - e-cloud in IRs? Recent hypothesis from Alexey Burov (with simplified model). Others?
  - Because the coherent tune shift (of some modes) is underestimated:
    - 2-beam impedance => Seems not (cogging MD, StephaneF)
    - Beam-beam coherent modes (mode coupling) => See next
    - e-cloud in IRs? Recent hypothesis from Alexey Burov (with simplified model). Others?

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (5/10)

- Old ADT



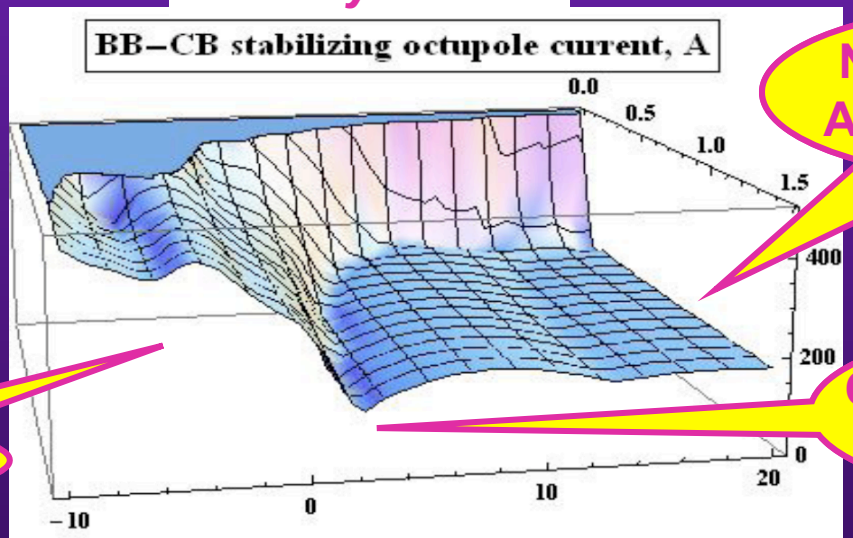
New (bbb – flat gain) ADT



Valley recovered

Alexey Burov

New (bbb – flat gain) ADT + Beam-Beam



incoherent $dQ_{bb}/Q_s\big|_{IR1,5} = \pm 1.1;\quad d\phi_{15} = \pi$

No difference on AlexeyB's plateau

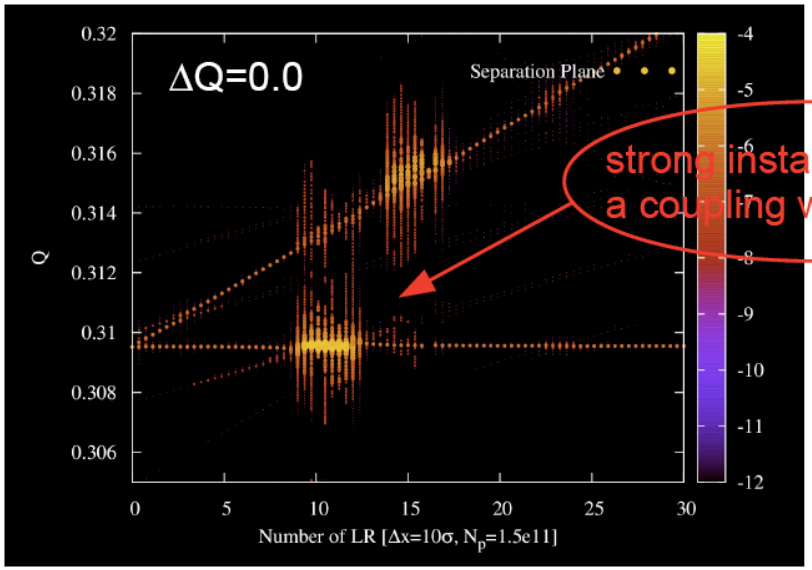
Valley lost again…

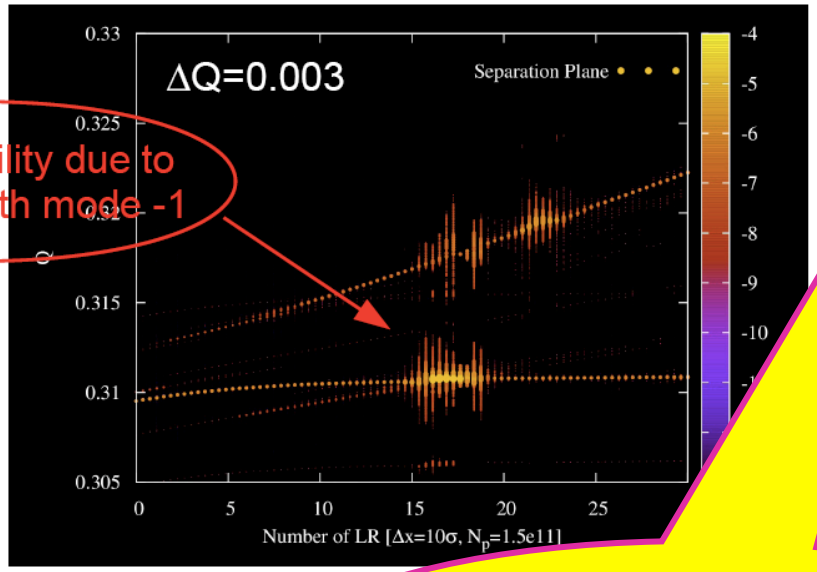
Chroma. of ~ 2 units good again…

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (6/10)

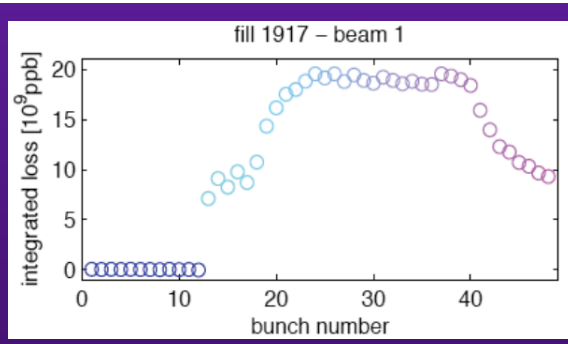
- **Interplay between impedance and beam-beam coherent modes => Mode coupling**

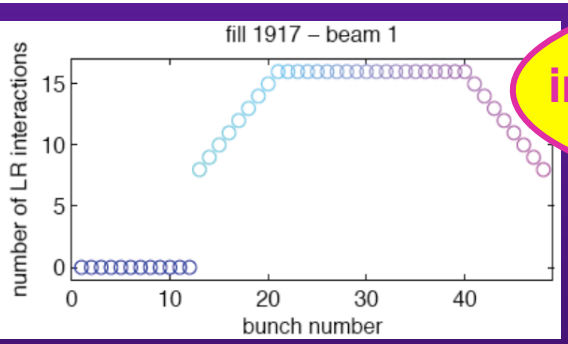
S. White





strong instability due to a coupling with mode -1





Who included the LHC impedance model (N. Mounet) on BeamBeam3D code

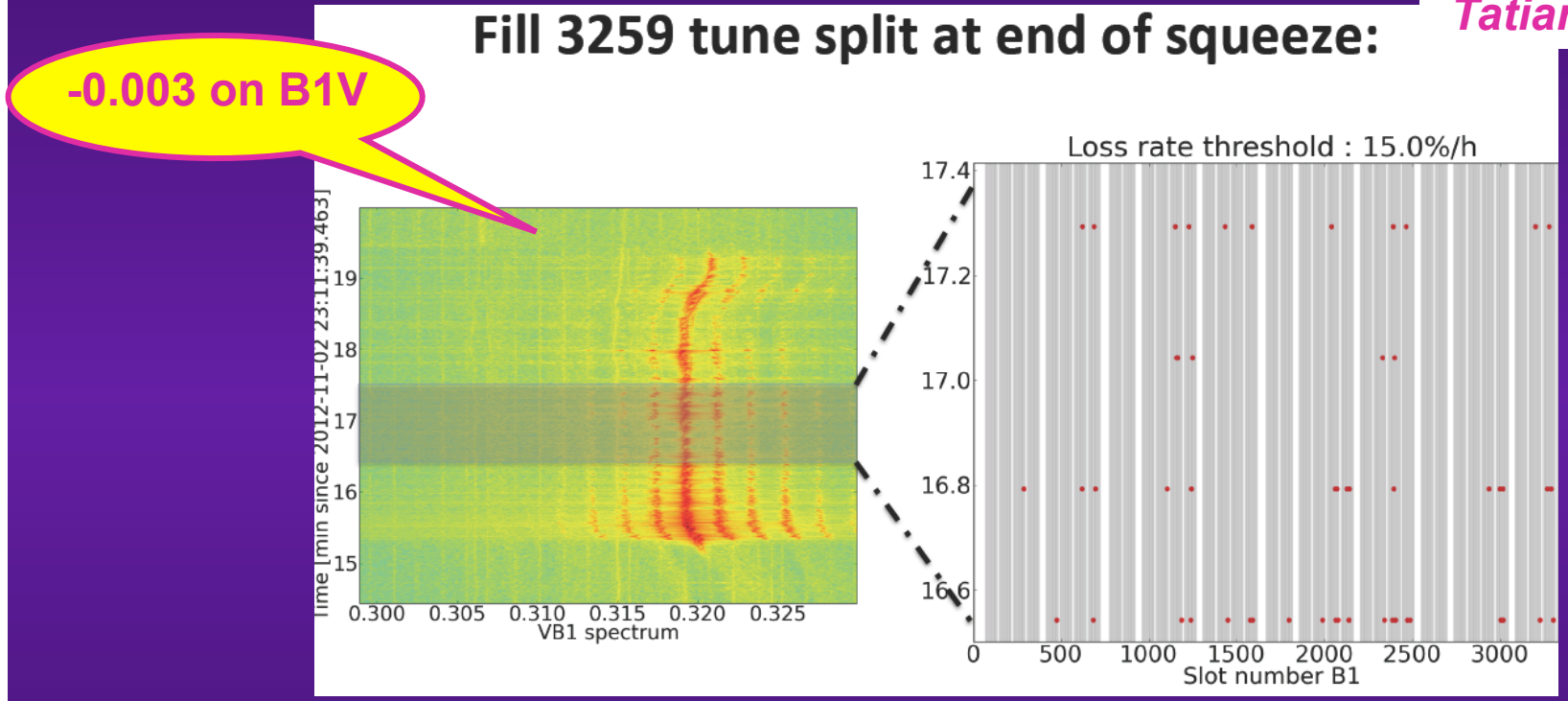
G. Papotti, W. Herr et al.

- **Solution: tune split (between the 2 beams) to decouple the machine. Some studies started with fill # 3259**

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (7/10)

- In some studies the unstable bunches seemed to move from tail to centre (as expected by SimonW)

Tatiana Pieloni



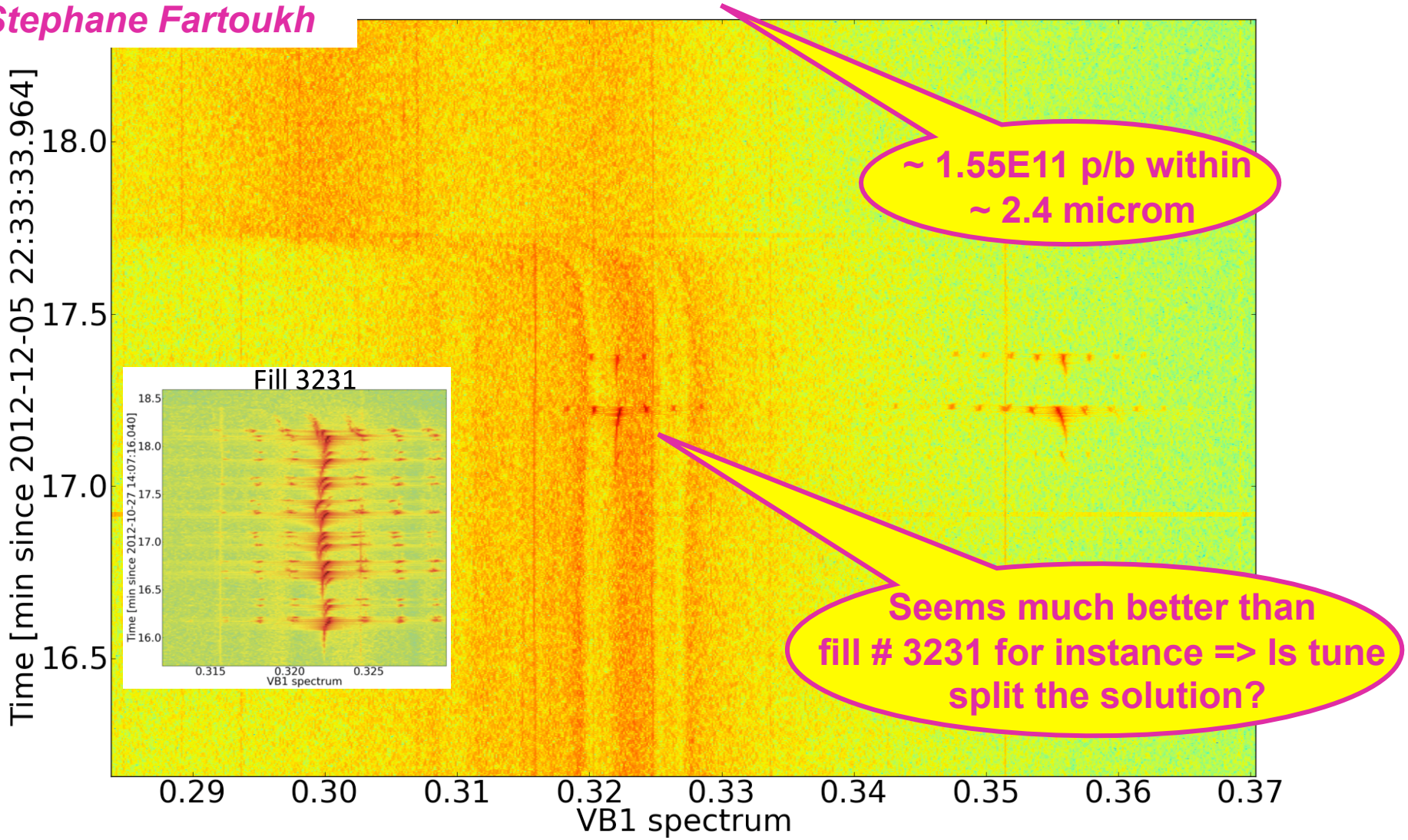
- Note: this instability should be suppressed by ADT (in simplified cases studied by AlexeyB and SimonW) => Tune split should even not be needed: is it true in reality? Still to be followed-up with multi-bunch study from Xavier Buffat and BB team

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (8/10)

Fill # 3378 => Tune split: -0.005 on B2H and B2V

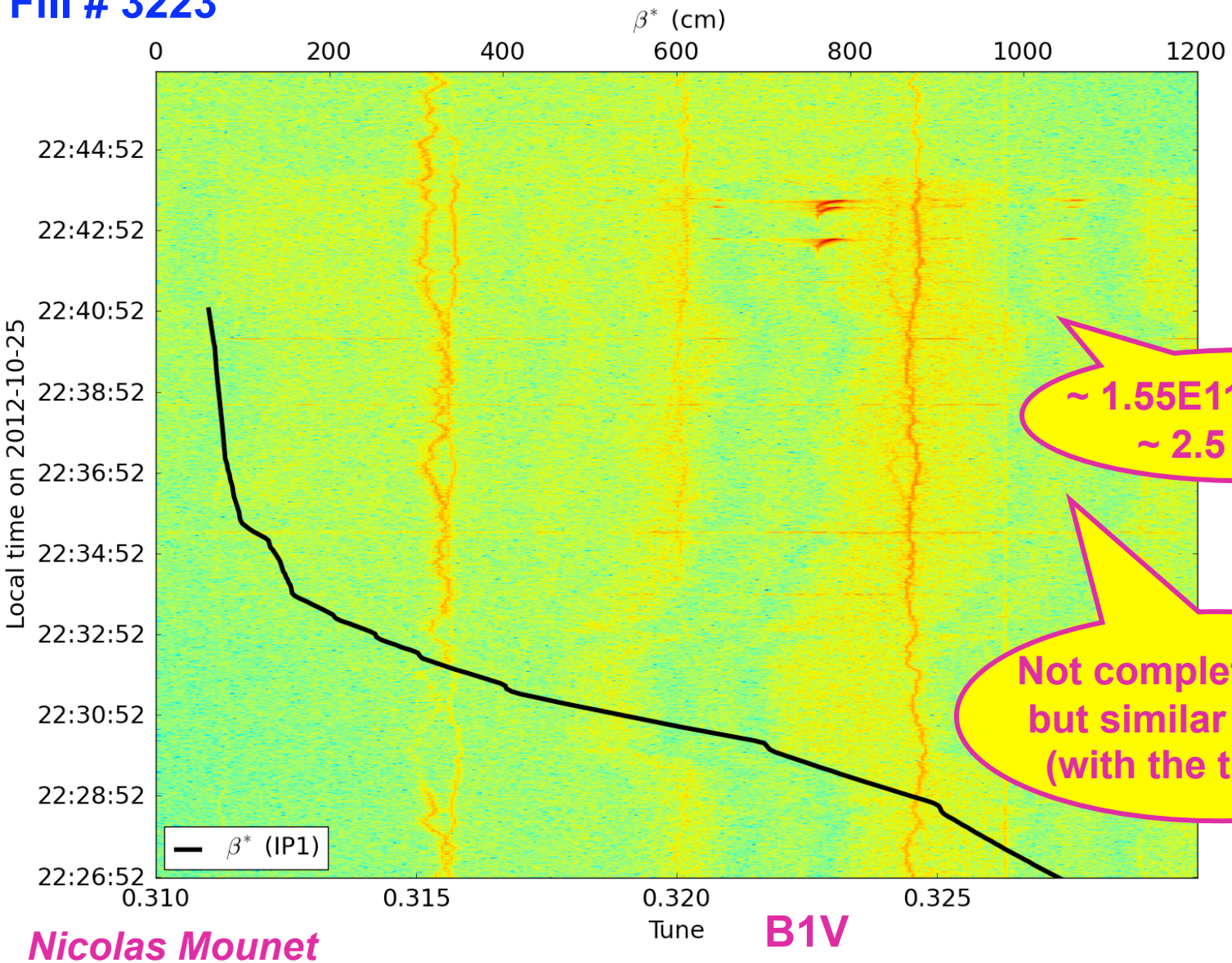
Tatiana Pieloni

Stephane Fartoukh



PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (9/10)

Fill # 3223

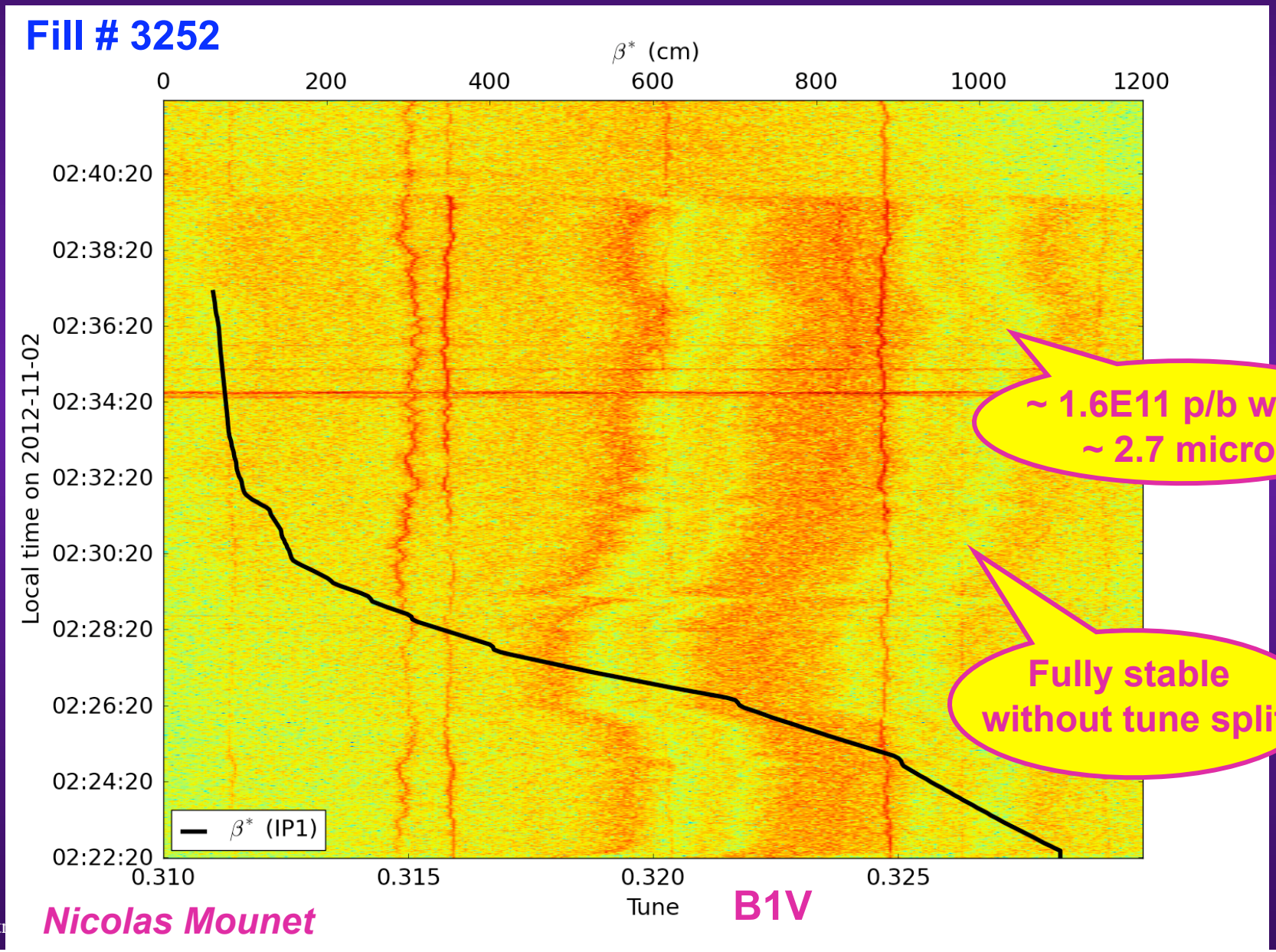


~ 1.55E11 p/b within ~ 2.5 microm

Not completely stable but similar as # 3378 (with the tune split)

Nicolas Mounet **B1V**

PAST PREDICTIONS, NEW FINDINGS, ACTIONS TAKEN (10/10)



CONCLUSIONS AND LESSONS LEARNED IN 2012 (1/2)

- 1-beam is ~ OK with our current model (at max. within a factor ~ 2 with impedance model) => New model including ADT
- 2-beam operation needs much more octupoles than predicted => Why?
  - Many studies performed but not understood yet…
  - Study carefully PACMAN bunches
  - …
- Clear observations
  - Instabilities observed only for beta* < few m
  - Increasing octupoles' current helps => Can we have more?
  - Increasing chromaticities helped a lot (but plateau now)
  - Once in collision, no instability anymore due to large BBHO tune spread => See also talk from Xavier Buffat
  - No beam dumps anymore as observed with the old (<0) Landau octupoles' polarity (and lower chroma and ADT gain)

CONCLUSIONS AND LESSONS LEARNED IN 2012 (2/2)

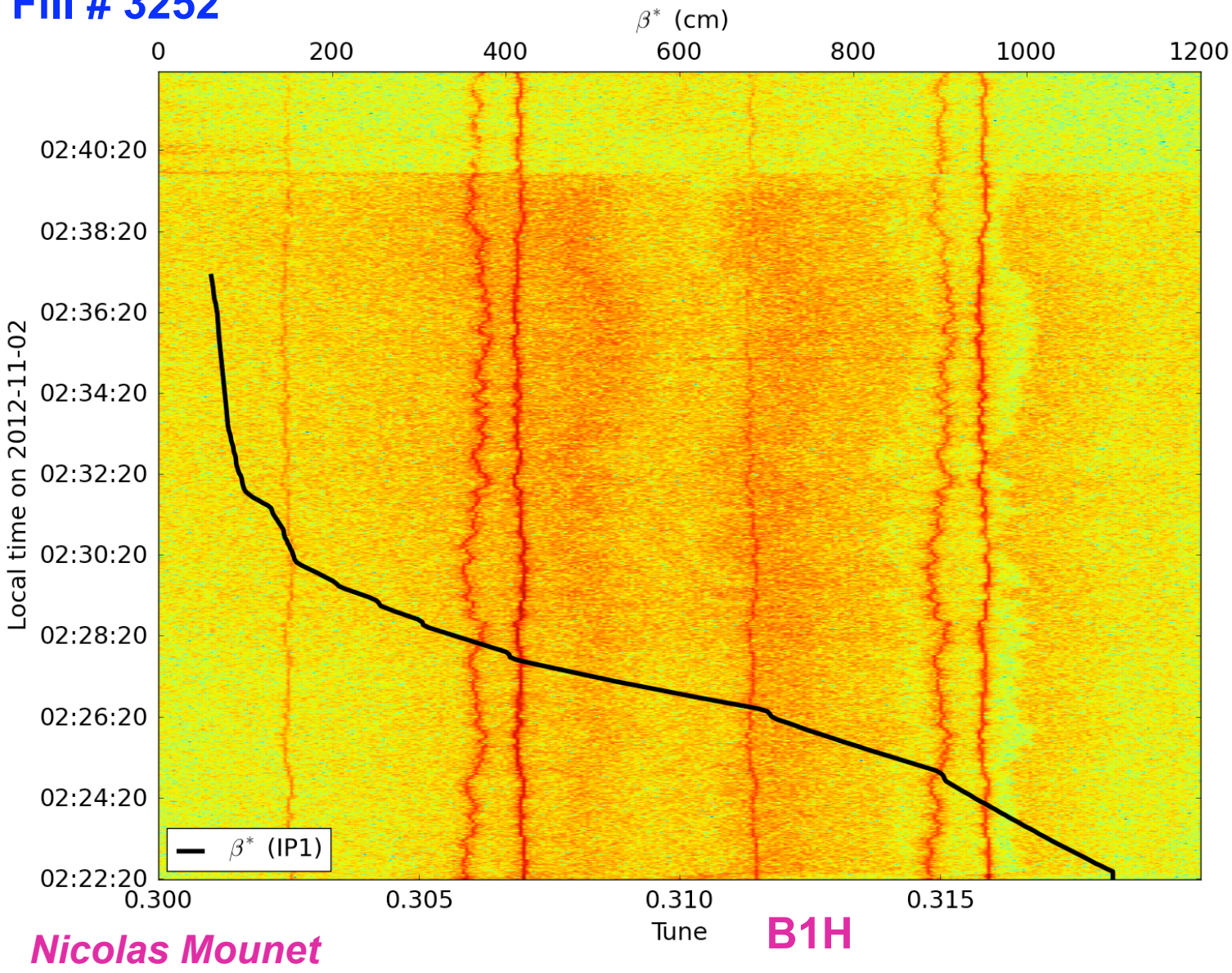
- **Need to understand / work more on interplays between different mechanisms (incoherent and coherent)**

  => Impedance, nonlinearities (machine and Landau octupoles), space charge (at low energy), ADT, longitudinal bunch distribution, beam-beam when the beams start to see each other, e-cloud…

- **Need to understand better how the ADT works**
- **Benchmark the NHT results with tracking codes => Already started and to be continued**
  - **Including ADT in HEADTAIL (ongoing) => Nicolas Mounet**
  - **Including Impedance and ADT in COMBI (ongoing) => Xavier Buffat**

APPENDIX

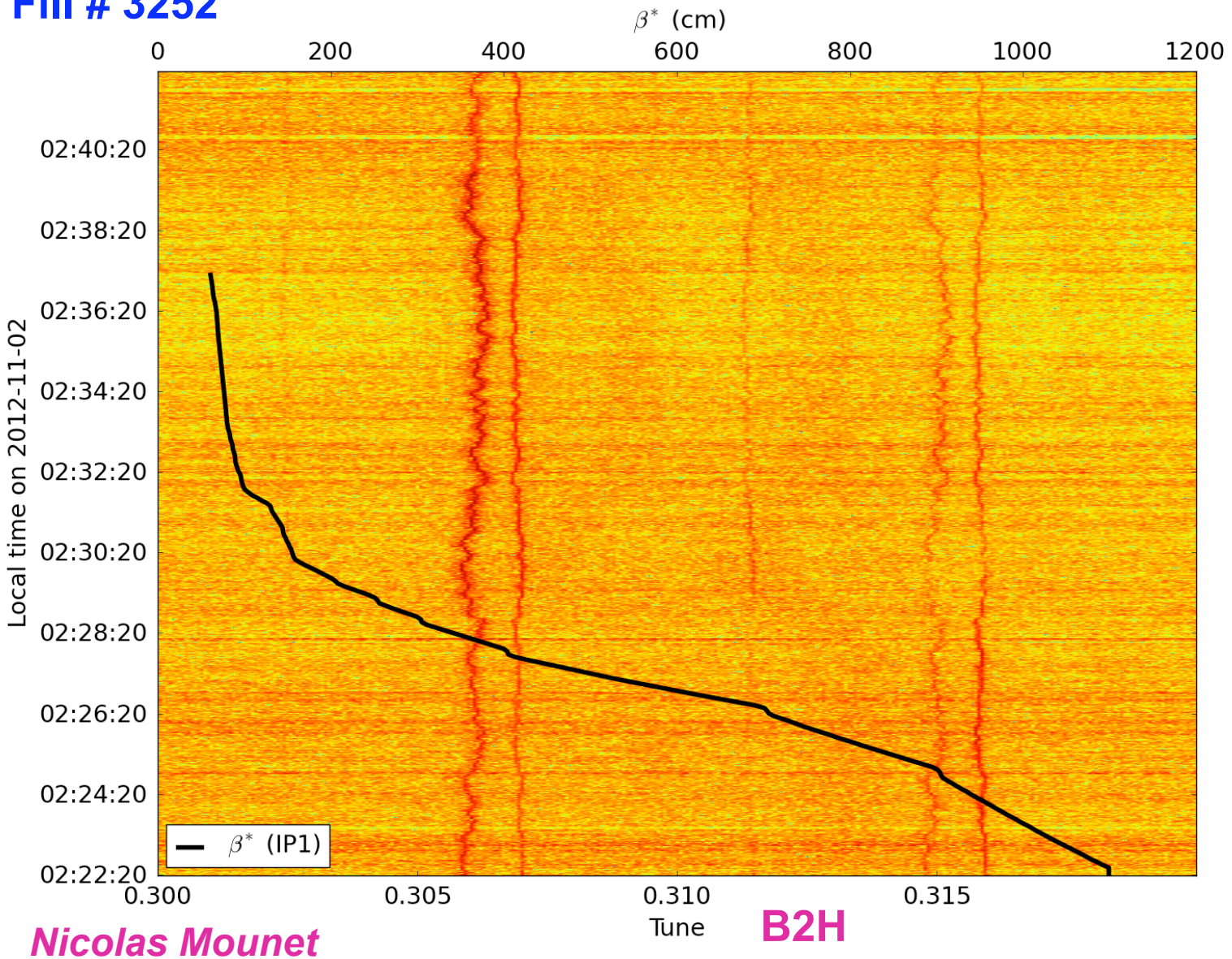
Fill # 3252



Nicolas Mounet

B1H

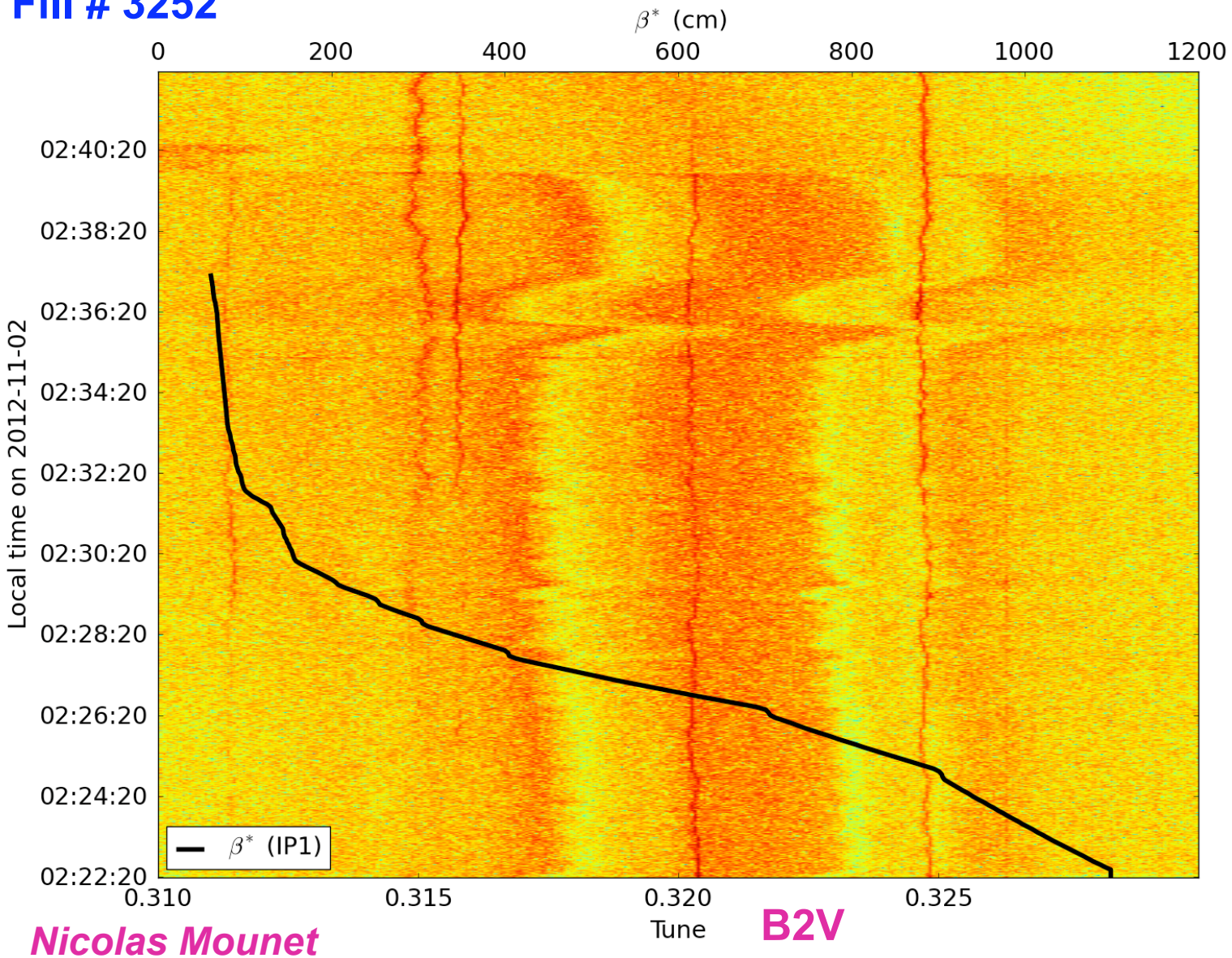
Fill # 3252



Nicolas Mounet

B2H

Fill # 3252



Nicolas Mounet

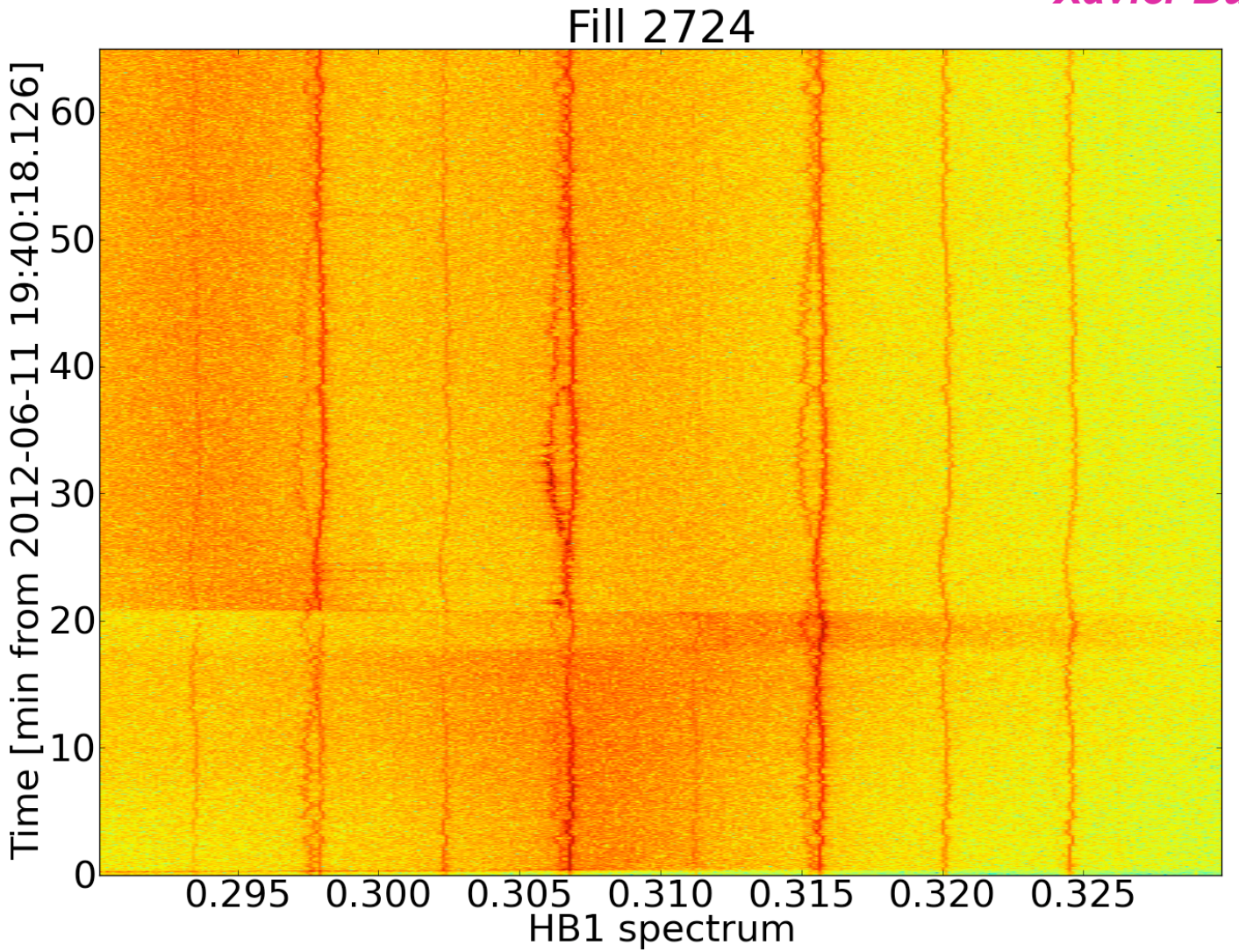
B2V

SOME EXAMPLES OF FILLS WITHOUT INSTABILITY WITH OLD OCTUPOLES' POLARITY (1/3)

- **Stable fills 2717 – 2718 – 2719 – 2720 – 2723 – 2724 – 2725 – 2726 – 2728 – 2729 => With intensities per bunch between 1.47E11 and 1.51E11 p/b**
- **They came after good chromaticities' measurements and increases**
- **In the next plots, the time starts at the beginning of the squeeze and therefore minute 15 is ~ the end of the squeeze**

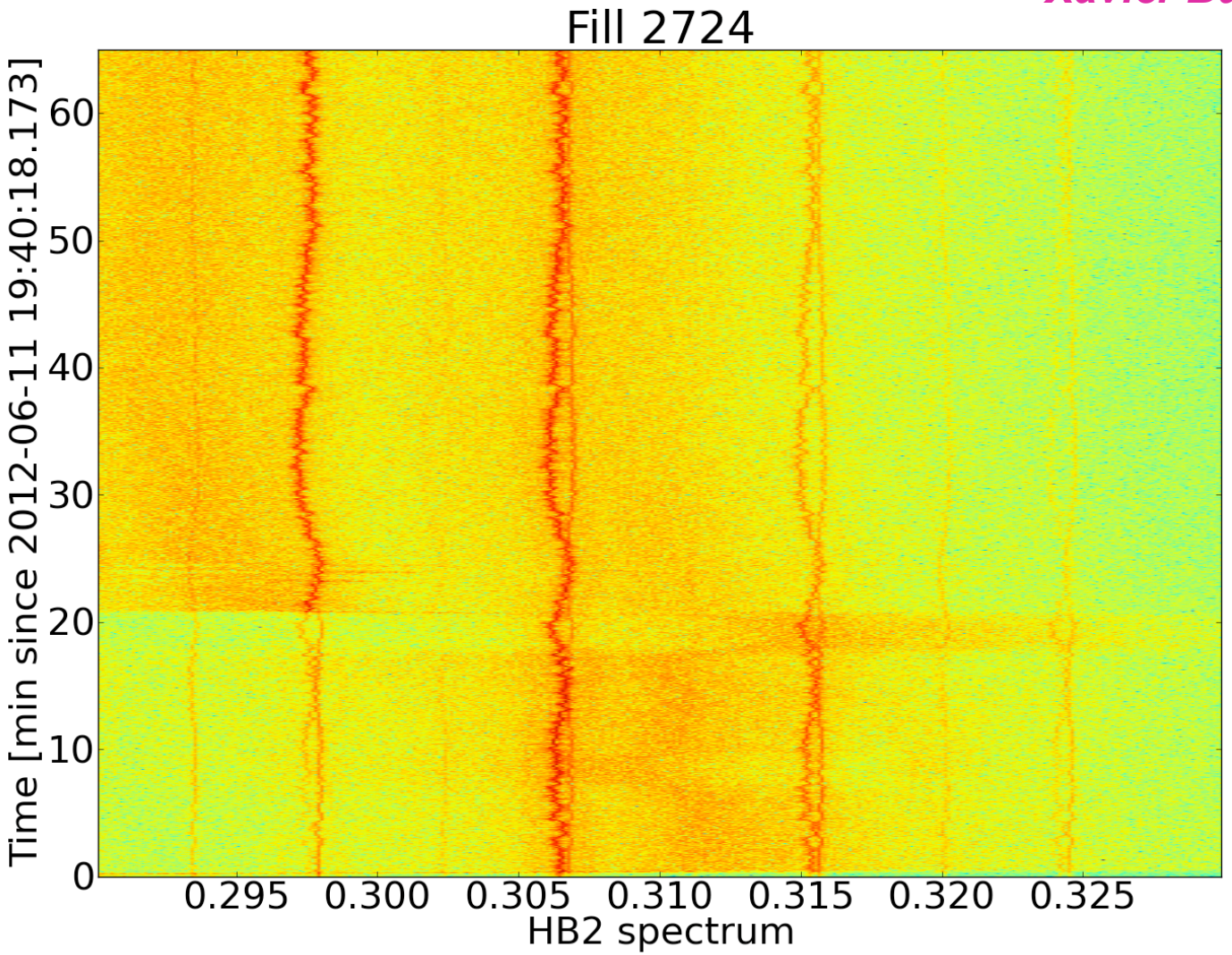
SOME EXAMPLES OF FILLS WITHOUT INSTABILITY WITH OLD OCTUPOLES' POLARITY (2/3)

Xavier Buffat



SOME EXAMPLES OF FILLS WITHOUT INSTABILITY WITH OLD OCTUPOLES' POLARITY (3/3)

Xavier Buffat

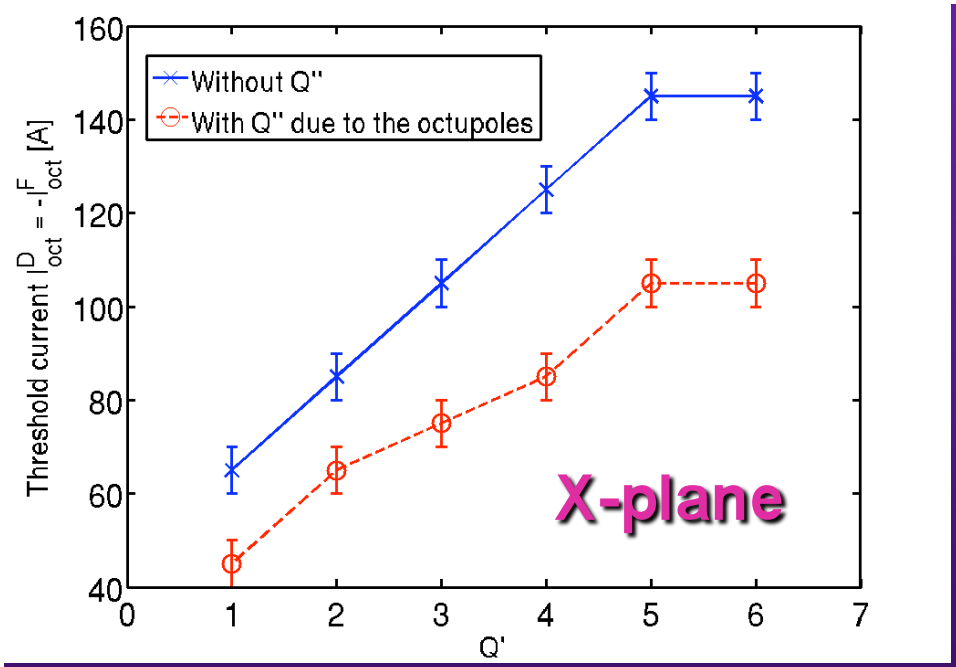


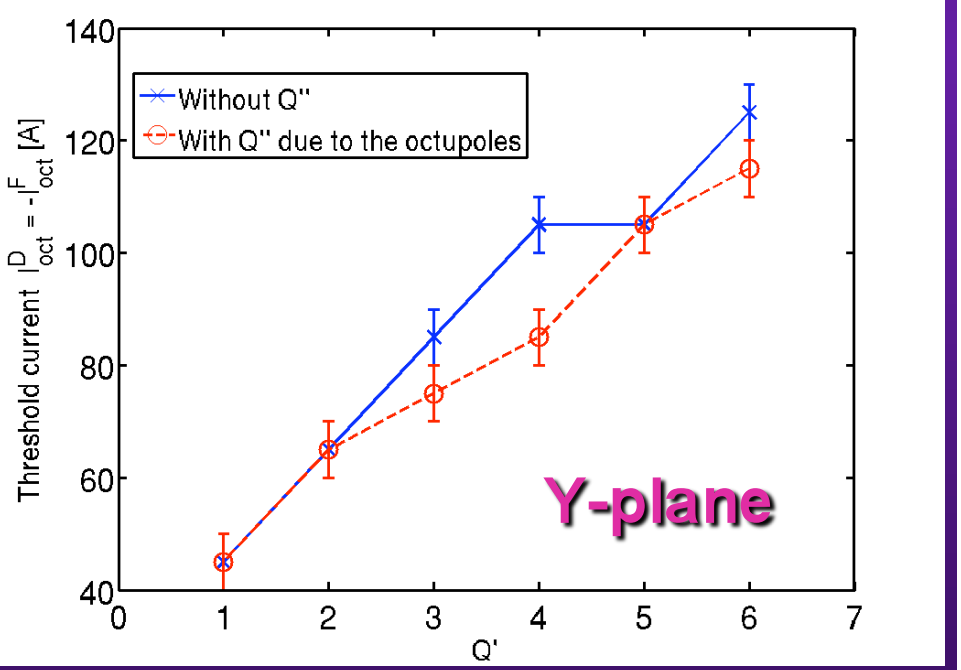
- A 4th type of instability was also observed at injection (leading to transverse emittance blow-ups of some injected batches)
  - Reason why 6.5 A is used in the octupoles at injection (not optimized)
  - Octupoles increased even more (factor 4) during 25 ns scrubbing run => Maybe not optimized but to be looked at in detail for the future
- A 5th type of instability was also observed at flat-top before the squeeze in some cases
  - Expected 1-beam instability to be more critical with the current (positive) sign of Landau octupoles (for transverse distribution with tail: e.g. factor ~ 1.6 for Gaussian)

- **2nd order chromaticity**
  - Q_x" = - 36000 for 450 A in the (D) octupoles at 4 TeV
  - Q_y" = + 15000 for 450 A in the (D) octupoles at 4 TeV

=> HEADTAIL simulations for a single-bunch at 4 TeV/c, with tight collimator settings, rms bunch length of 9 cm, dipolar impedances only, linear bucket, ultimate intensity 1.7e11 p/bunch, transverse emittances (rms. norm.) of 2 microm

Nicolas Mounet

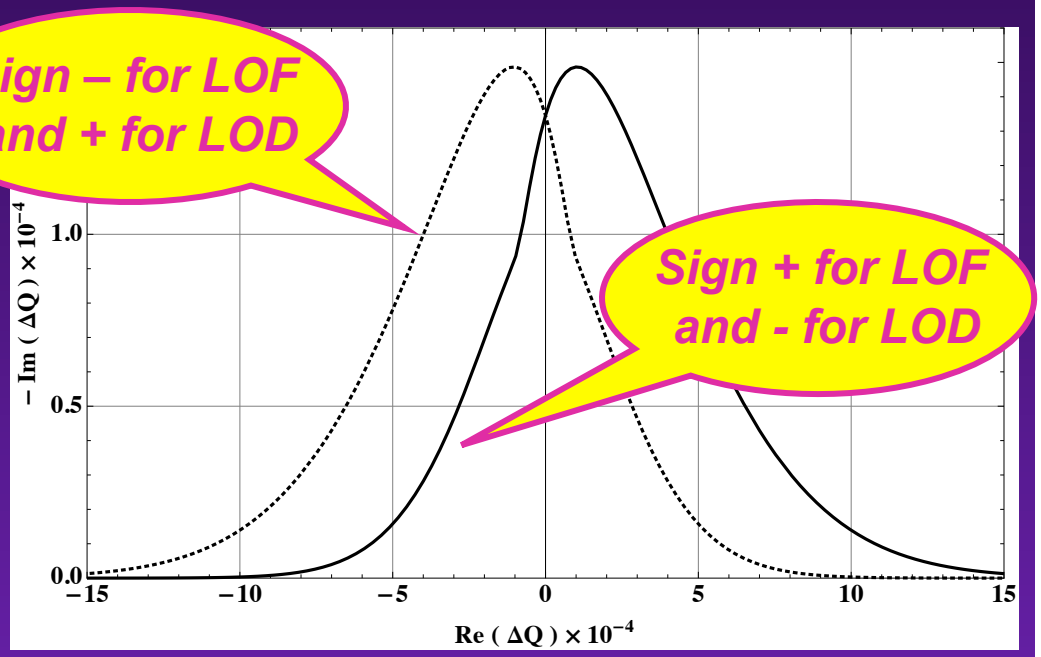


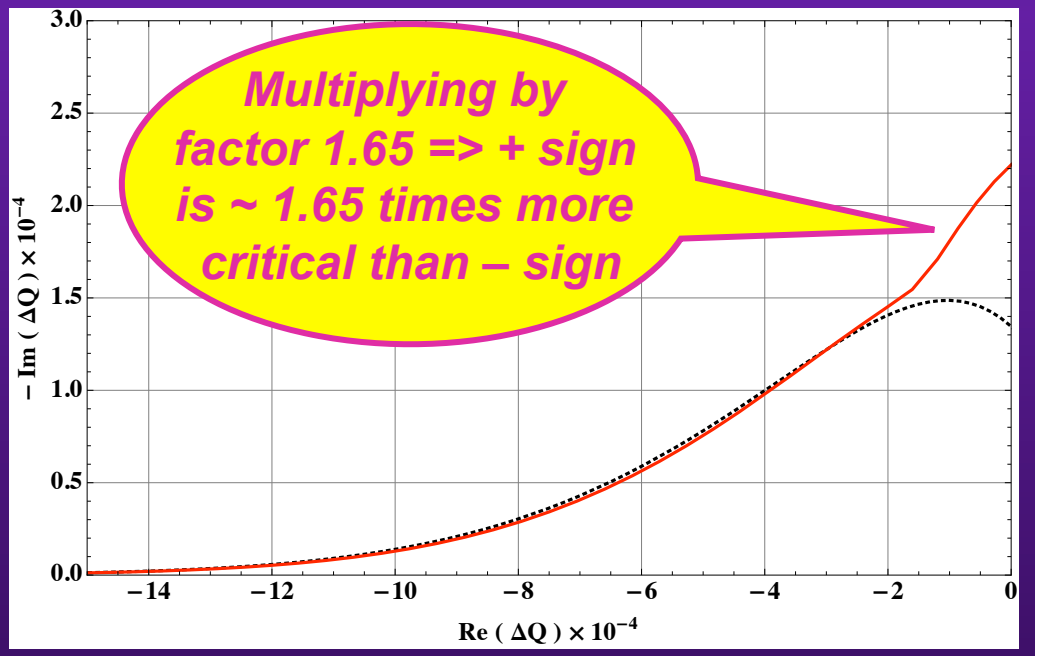


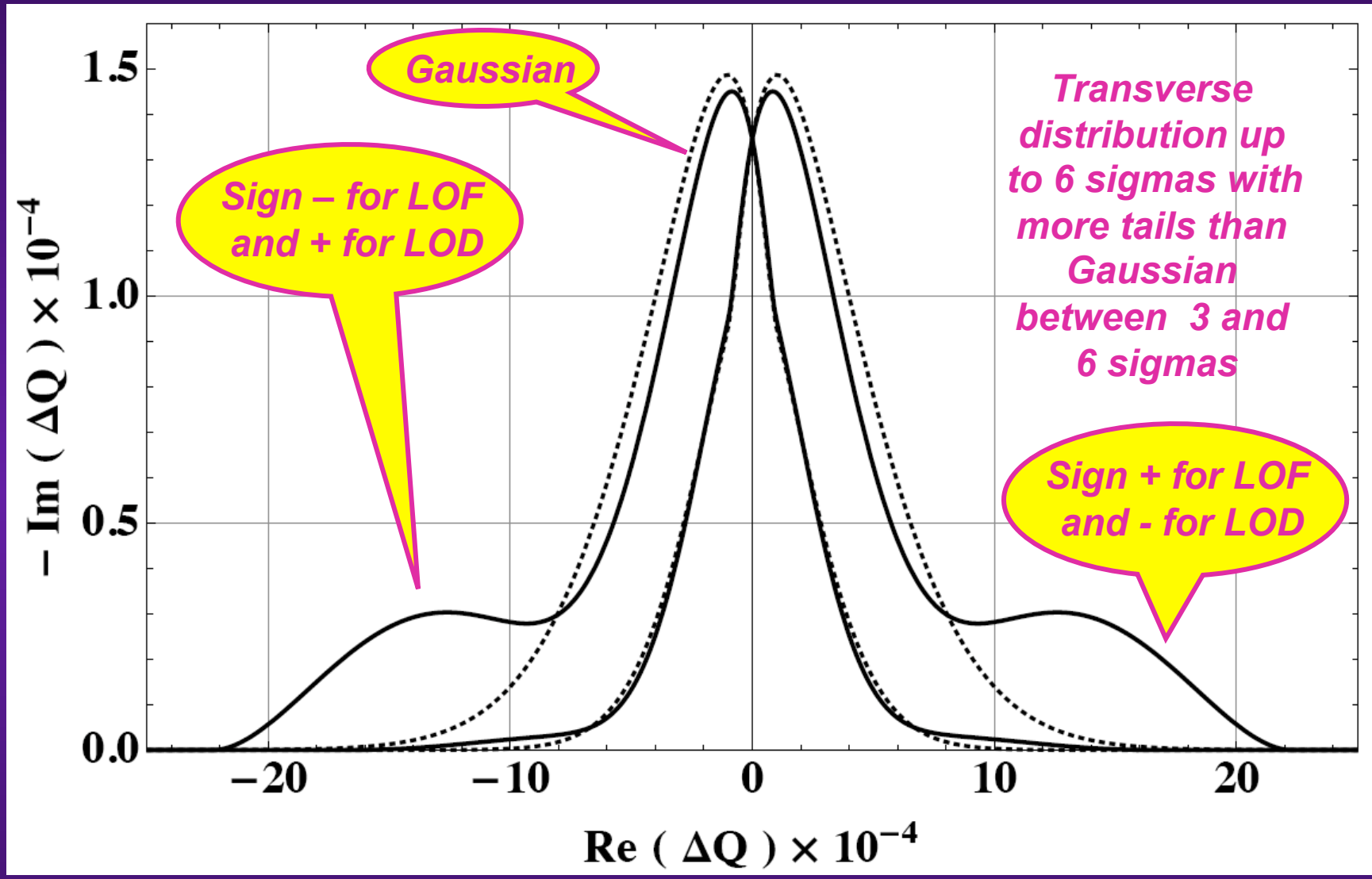
=> BUT, it is worse for this: stability diagram with octupoles only (i.e. before the squeeze)

Gaussian transverse distribution assumed here

Was observed after the change of the octupoles sign

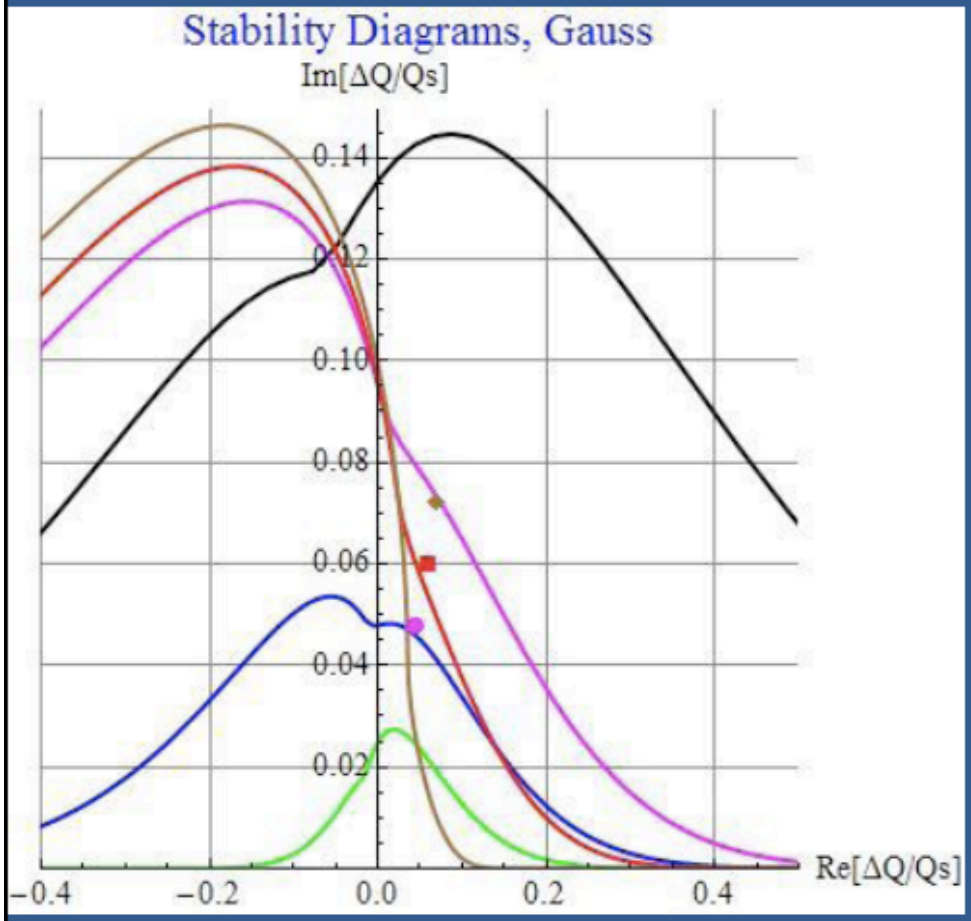






=> With the new (+) sign, large tails would not be useful anymore (as negative tune shifts are expected)

- **Interplay between impedance, beam-beam and e-cloud**



LO=140A – computed threshold

BB only, LO=0

BB and LO=500A

BB, LO=500A, dQe0=6.0E-4

BB, LO=500A, dQe0=8.0E-4

BB, LO=500A, dQe0=1.0E-3

Markers – MUMs, colors correspond

$\Delta Q_e^{(0)} = 8 \cdot 10^{-4} \Leftrightarrow N_e = 1.3 \cdot 10^{10}$ total

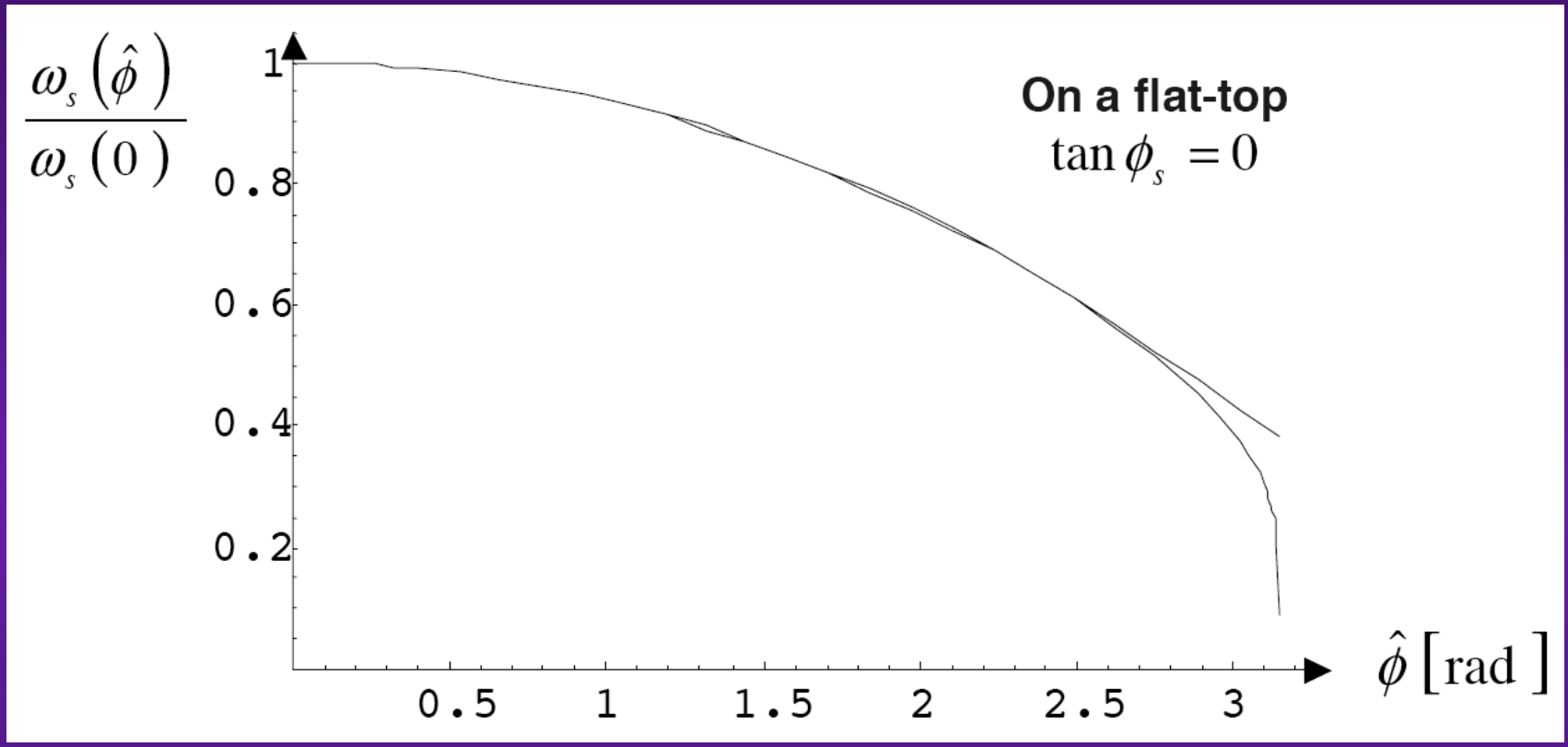
3

Alexey Burov

… to be followed-up (very simplified model)…

If confirmed => Suppress IRs e-

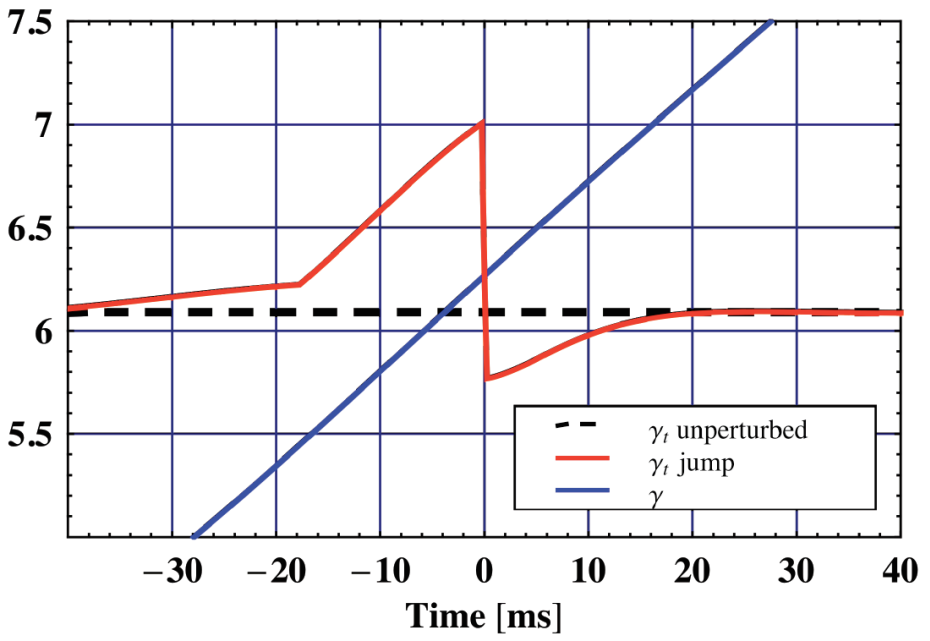
- **Effect of bunch length**



=> Interplay with Q'' studied (NHT method => To be confirmed by HEADTAIL simulations) which should provide more stability for longer bunches (complex tune shifts smaller and more tune spread)

=> No clear beneficial effects observed during some studies (6 MV)

- **Is crossing a 0 (small) - tune spread a problem? => Yes, can be, but depends on the times of the different processes**
  - **For instance, the PS machine is crossing a 0-tune spread every cycle**



$$\eta = \gamma_t^{-2} - \gamma^{-2}$$

  - **Solutions (if this is really a problem)**
    - **Don't cross 0 (what was implemented in LHC)**
    - **Cross faster and/or cleaner (e.g. IP1&5 first and then IP8 => Already implemented by beam-beam team)**