

# Highlights of the ATS MD part II (pre-squeeze and squeeze)



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stephane.fartoukh@cern.ch

## The Achromatic Telescopic Squeezing (ATS) MD part II

S. Fartoukh, R. de Maria, G. Vanbavinkhove, D. Wollman, M. Albert, R. Giachino, B. Goddard, P. Hagedorn, W. Hoffe, V. Kain, M. Lamont, A. Macpherson, R. Miyamoto, G. Mueller, L. Normann, G. Papotti, P. Ponce, S. Redaelli, R. Steinhausen, M. Strzelczyk, R. Tomas, D. Valuch, J. Wenninger

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### Summary

This note describes the results obtained during the second pre-squeezed MD where the  $\beta^*$  record was reached at IP1 and IP5 with a “pre-squeezed”  $\beta^*$  of 1.2 m. In addition the correction of the chromatic aberrations induced (non-linear chromaticity, off-momentum beating). Then, the  $\beta^*$  of 30 cm targeted by the LHC Upgrade Phase I project was reached using the Achromatic Telescopic Squeezing techniques.

### 1 Introduction

The Achromatic Telescopic Squeezing (ATS) scheme is a novel concept enable to reach extremely low  $\beta^*$  values by correcting the chromatic aberrations induced by the inner triplet [1, 2]. This scheme is essentially based on a two-stage telescopic squeeze. First a so-called pre-squeeze is achieved by using exclusively, as usual, the matching quadrupoles of the high luminosity insertions IR1 and IR5. Then, in a second stage, the squeeze continues by acting only on the insertions on either side of IR1 and IR5 (i.e. IR8/2 for IR1 and IR4/6 for IR5). As a result, sizable  $\beta$ -beating bumps are induced in the two sectors adjacent to IP1 and IP5, but which are also necessary in order to improve, at constant strength, the chromatic correction efficiency of the lattice sextupoles.

One of the keystone of the scheme is the pre-squeezed optics, where specific matching conditions are imposed on the left and right phase advances of the low-beta insertions, and for which  $\beta^*$  has to be chosen within a certain interval. This interval depends on the detailed layout and gradient of the triplet, on the maximum operating current of the lattice sextupoles and on the beam energy. At nominal energy (7TeV/beam) and for the existing triplet (205T/m), the pre-squeeze  $\beta^*$  shall fulfill the following condition

$$40 \text{ cm} \leq \beta_{\text{pre-squeezed}}^* \leq 2 \text{ m}. \quad (1)$$

# What is the ATS scheme? ... A small recap.

- A squeeze procedure in two steps

1) An “almost” standard squeeze, called Pre-squeeze, acting on the IPQ circuits of IR1 and IR5.

2) A continuation of the squeeze, called Squeeze, acting on the IPQ circuits of IR2/8 for IR1 and IR4/6 for IR5 and inducing  $\beta$ -beating bumps in s81/12/45/56

$$\rightarrow \beta_{\text{Squeeze}}^* = \beta_{\text{Pre-Squeeze}}^* \times \frac{180}{\hat{\beta}_{\text{Arc}}}$$

- With **additional features** to warrant the correction of the chromatic aberrations ( $Q''$ ,  $Q'''$ , off-momentum  $\beta$ -beat)

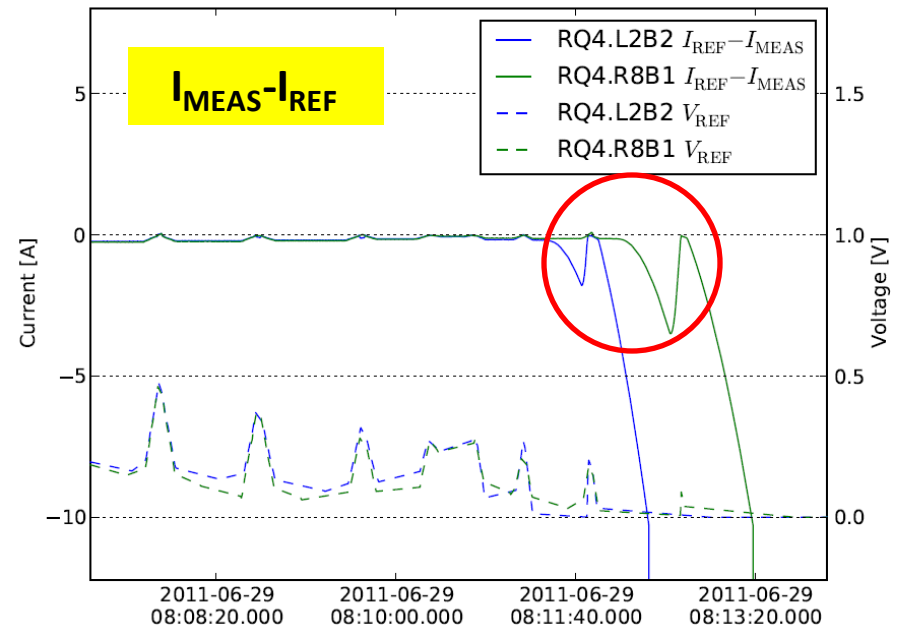
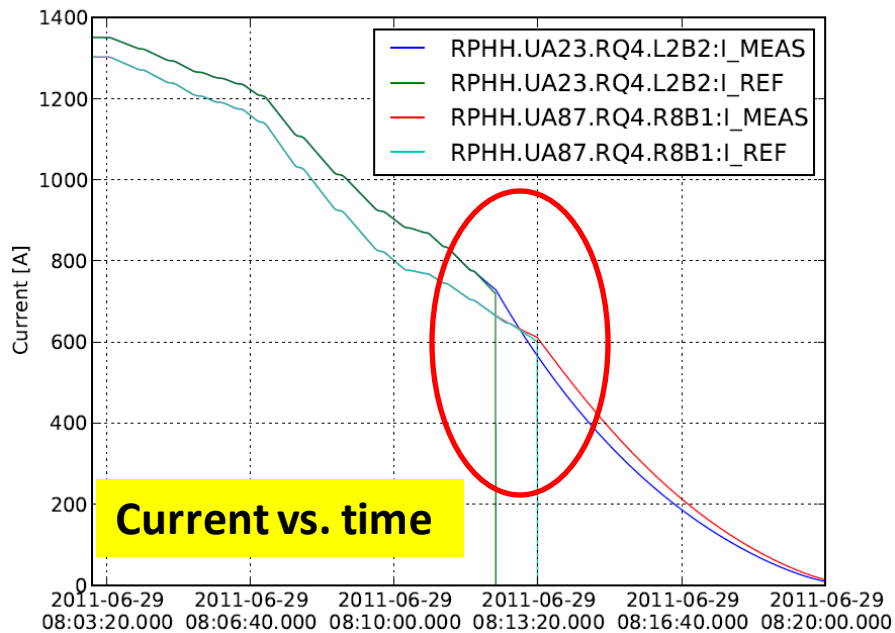
→ giving constraints for the choice of the pre-squeezed  $\beta^*$

$$40 \text{ cm} \leq \beta_{\text{Pre-Squeeze}}^* \leq 2 \text{ m}$$

→ For the MD, the pre-squeezed  $\beta^*$  was chosen to 1.2 m at IP1 and IP5, and  $\beta^*$  of 30 cm was reached at IP1 quadrupling the peak  $\beta$ 's in s81 and s12

# The Dry Run (2.5h on the 29<sup>th</sup> June)

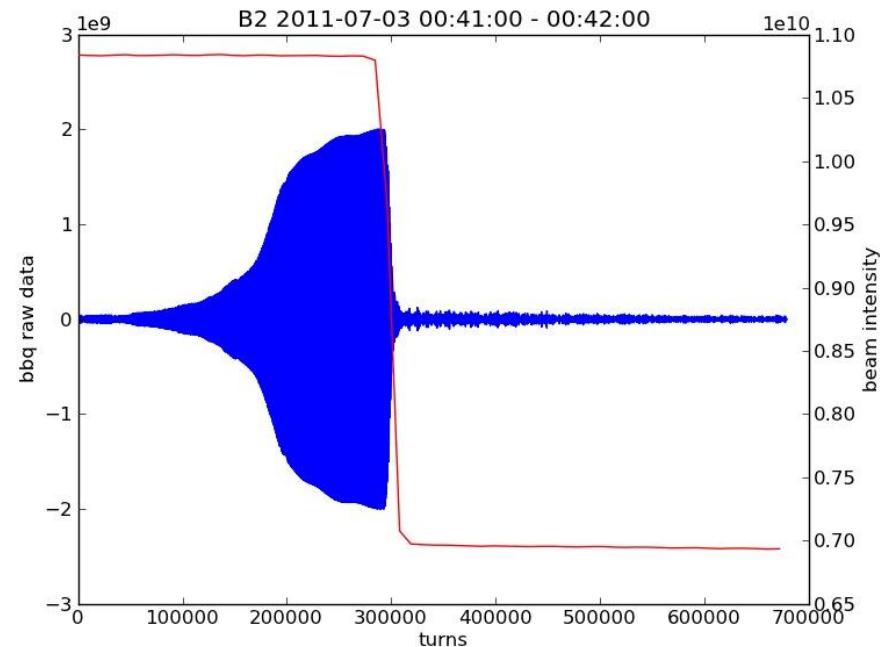
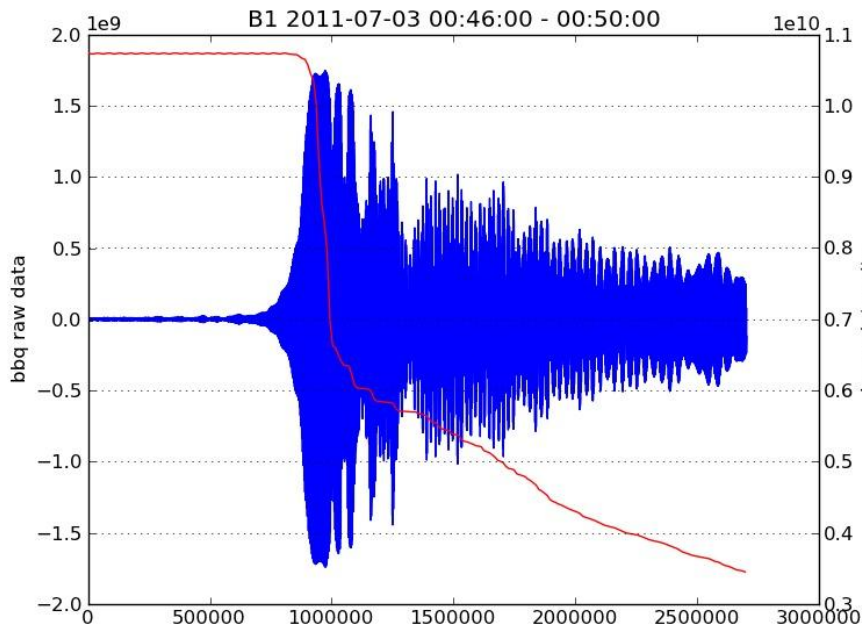
- Test the **full ATS hyper-cycle** (injection, ramp, pre-squeeze, squeeze)
- Standard and new ATS knobs tested, minor problems found and fixed but a **BIG problem identified: trip of RQ4.L2B2 & RQ4.R8B1**



- A new squeeze beam process was generated **doubling the time sep. between the last 3 matched points** ( $\beta^* = 42-36-30$  cm at IP1).

# MD with beam (8+2h in the Sat-Sun night)

→ **First ramp lost** due a bad incorporation of the Q' trim performed at injection and resulting to **a negative chroma in the ramp.**

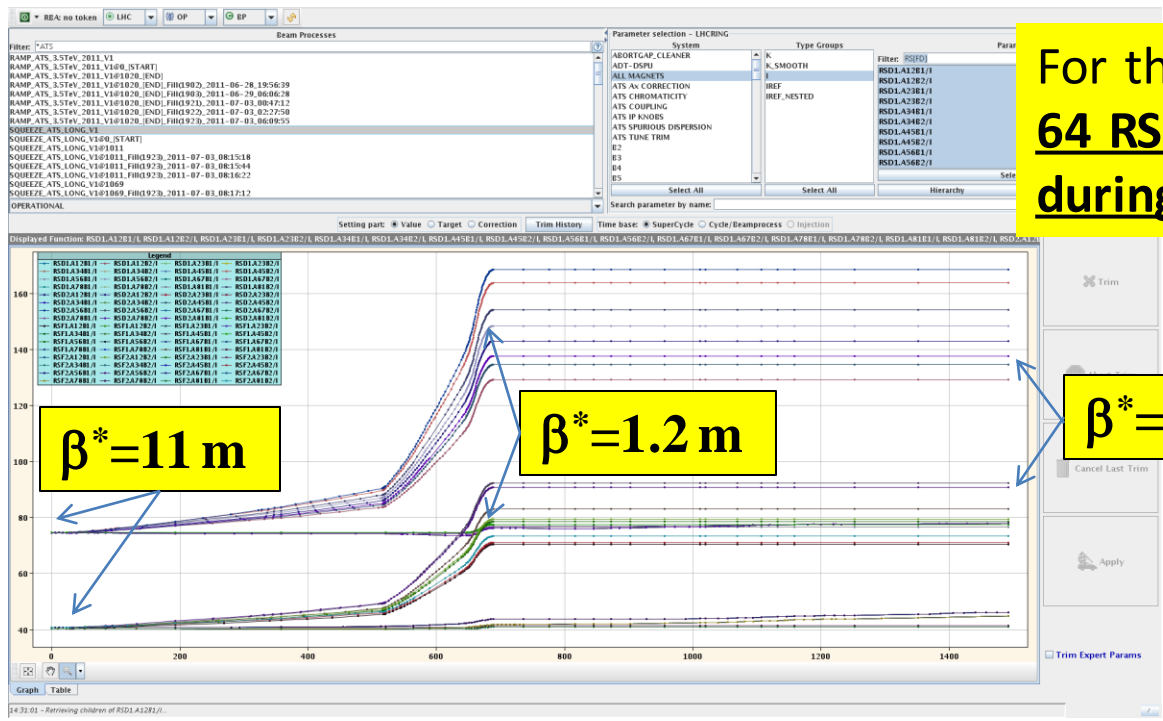


Beam1 (left) and Beam2 (right) BBQ data and intensity

→ Second ramp successful, start of pre-squeeze OK, but **Beam Dump triggered after the stop at  $\beta^* = 3$  m due to 2 RSD trips in s45 & s56.**

→ Why not observed during the dry run?

- 1) The dry run was performed with no stop between  $\beta^* = 11$  m and 1.2 m.
- 2) The LSA rounding in/out procedure is not applied for the sextupoles (only for IPQs).
- 3) The ramp speed  $dI/dt$  of the RS circuits is 4 times faster than nominal (will be 8 times faster at 7 TeV/beam) but still OK vs. 1.5 A/s specified.



**For the ATS optics only 16 out the 64 RS circuits are moving and only during the pre-squeeze**

**$\beta^* = 30$  cm**

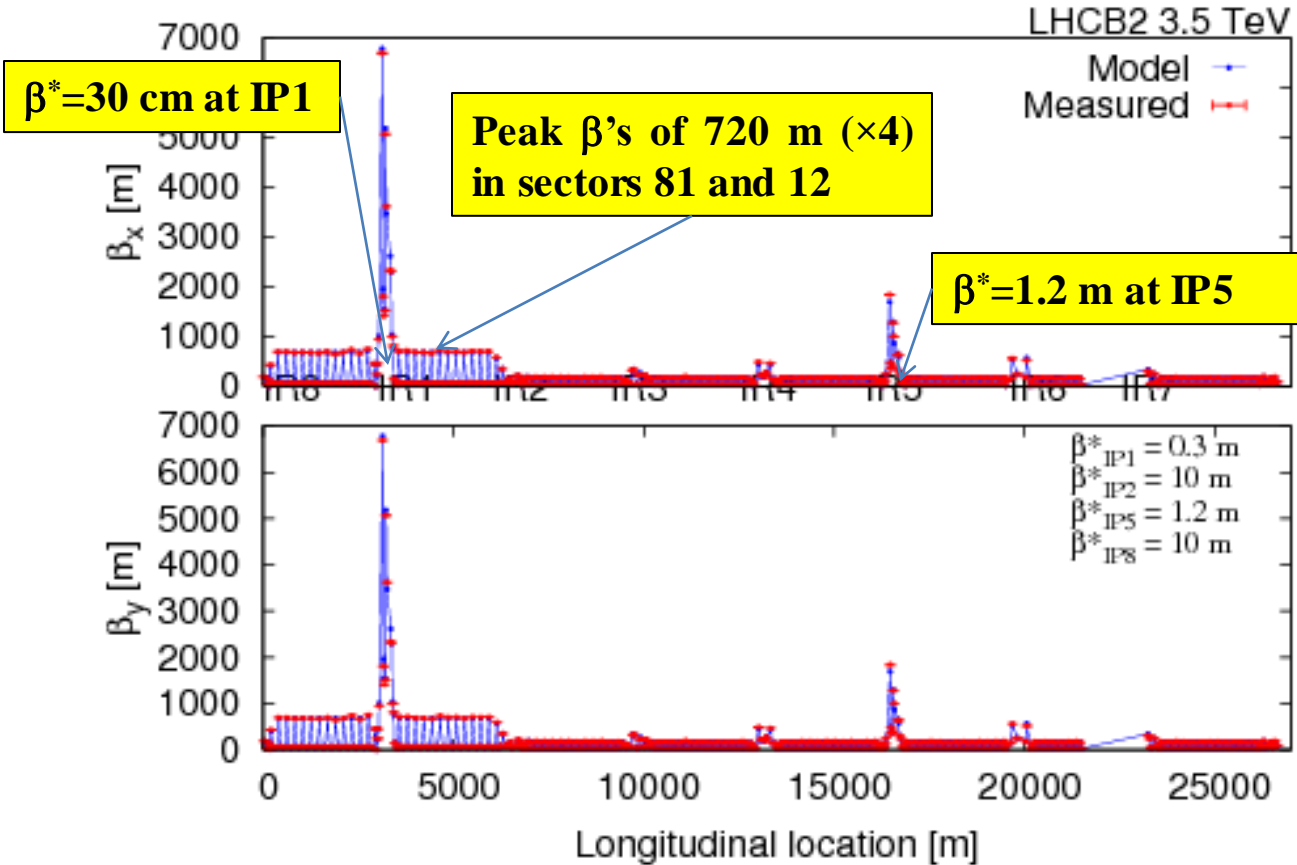
**$\beta^* = 11$  m**

**$\beta^* = 1.2$  m**

**4) But too big deceleration/acceleration for the QPS before/after a stop.**

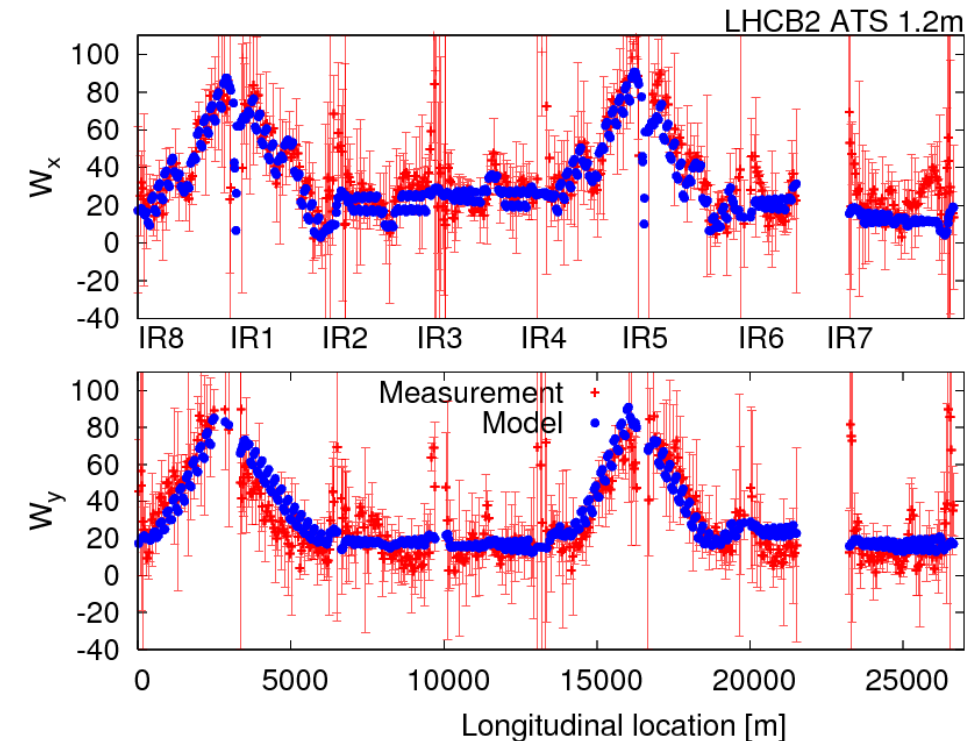
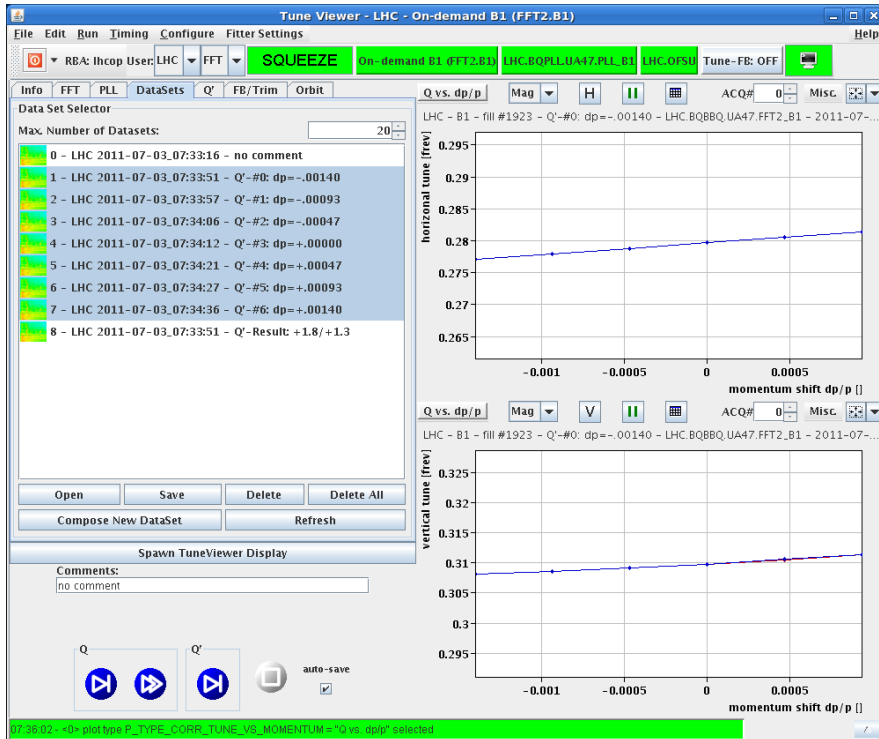
→ **Third attempt finally successful from 6H10 to 9H09:**

- 1) With **only one stop at  $\beta^*=6\text{ m}$**  during the pre-squeeze.
- 2) Following all the stop points (but the last) for the squeeze below  **$\beta^*=1.2\text{ m}$**
- 3) .. And reaching  **$\beta^*=30\text{ cm at IP1}$**  (with  $\beta^*=1.2\text{ m}$  at IP5)



...Some highlights:

→ Chromatic properties of the pre-squeezed optics ( $\beta^*=1.2$  m).

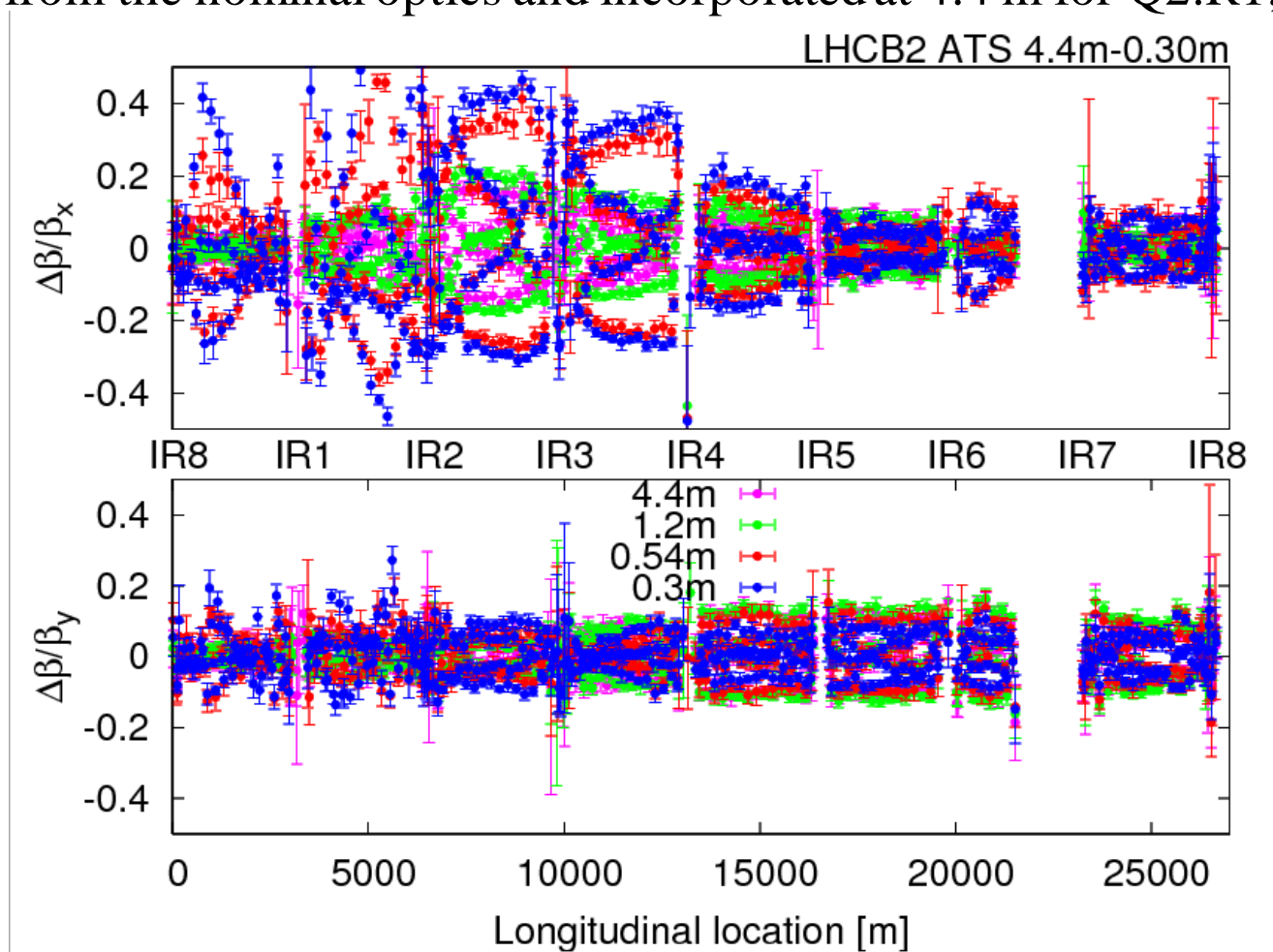


The Tunes are linear vs.  $\delta_p$  over a momentum window of +/- 1.5 permil

The off-momentum  $\beta$ -beating wave induced by the IT is contained in s81/12/45/56 (i.e. IR3 and IR7 are preserved)



→  $\beta$ -beating measurement at  $\beta^* = 4.4, 1.2, 0.54$  and 30 cm (only 3 trims, extracted from the nominal optics and incorporated at 4.4 m for Q2.R1, Q2.L/R5).

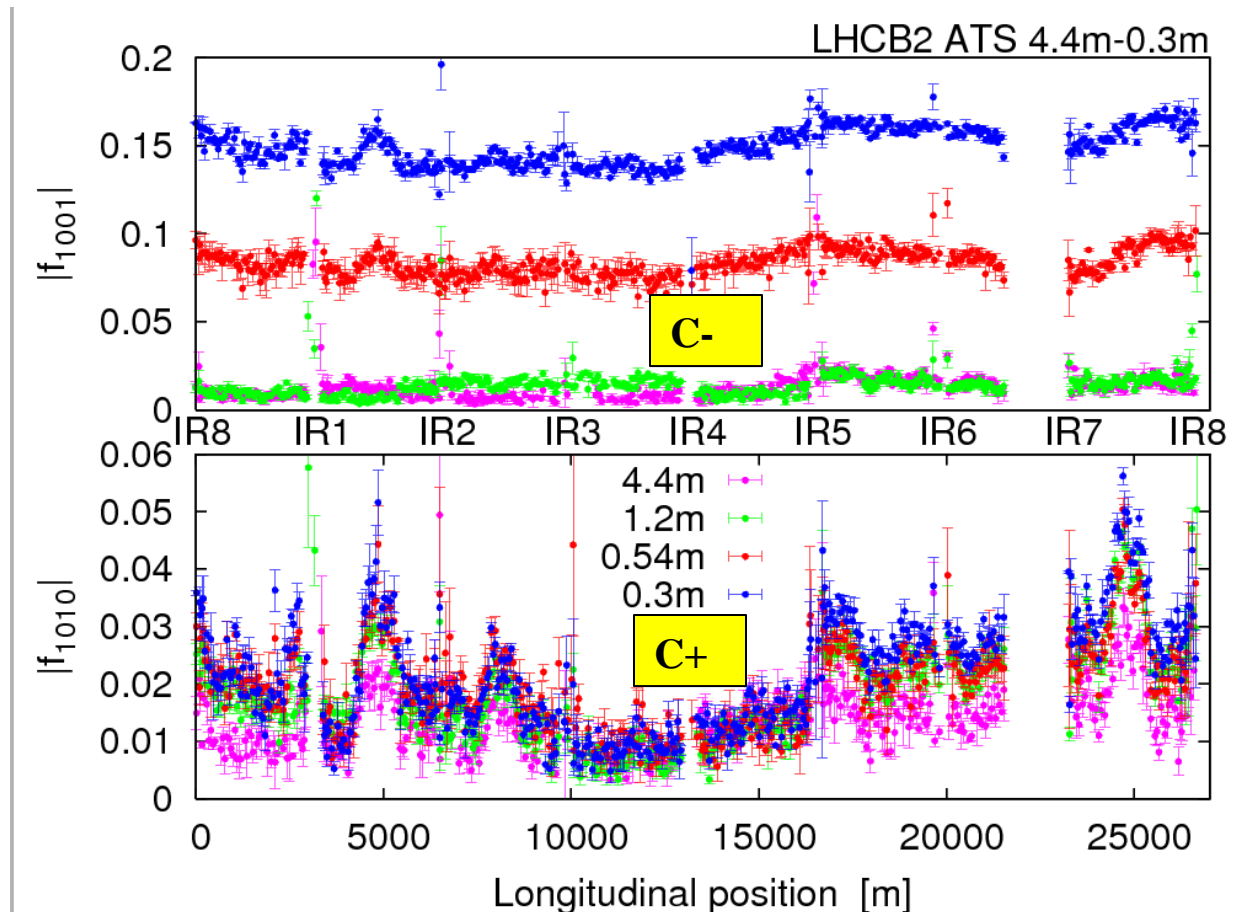


→ Could have been much worse with a  $\beta_{\max}$  of 7 km in IR1 and by increasing by 4 the  $\beta$ 's in s81 and 12 (thank to SSS sorting!).

→ Optimization still needed (IR8, IR4 and arc by arc fine-tuning of the b2 correction)

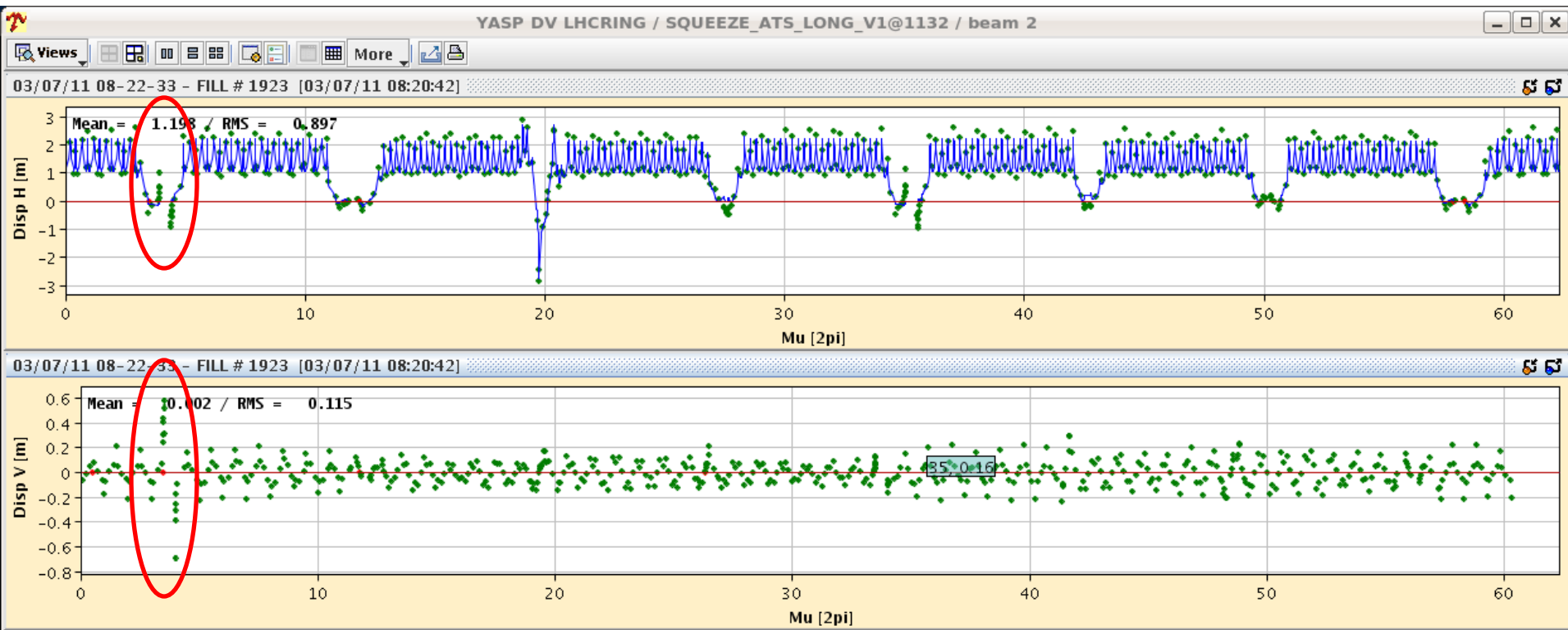


→ Coupling measurement at  $\beta^* = 4.4, 1.2, 0.54$  and 30 cm (“nominal” RQSX trims implemented at 450GeV, no time for global correction below 1.2 m).



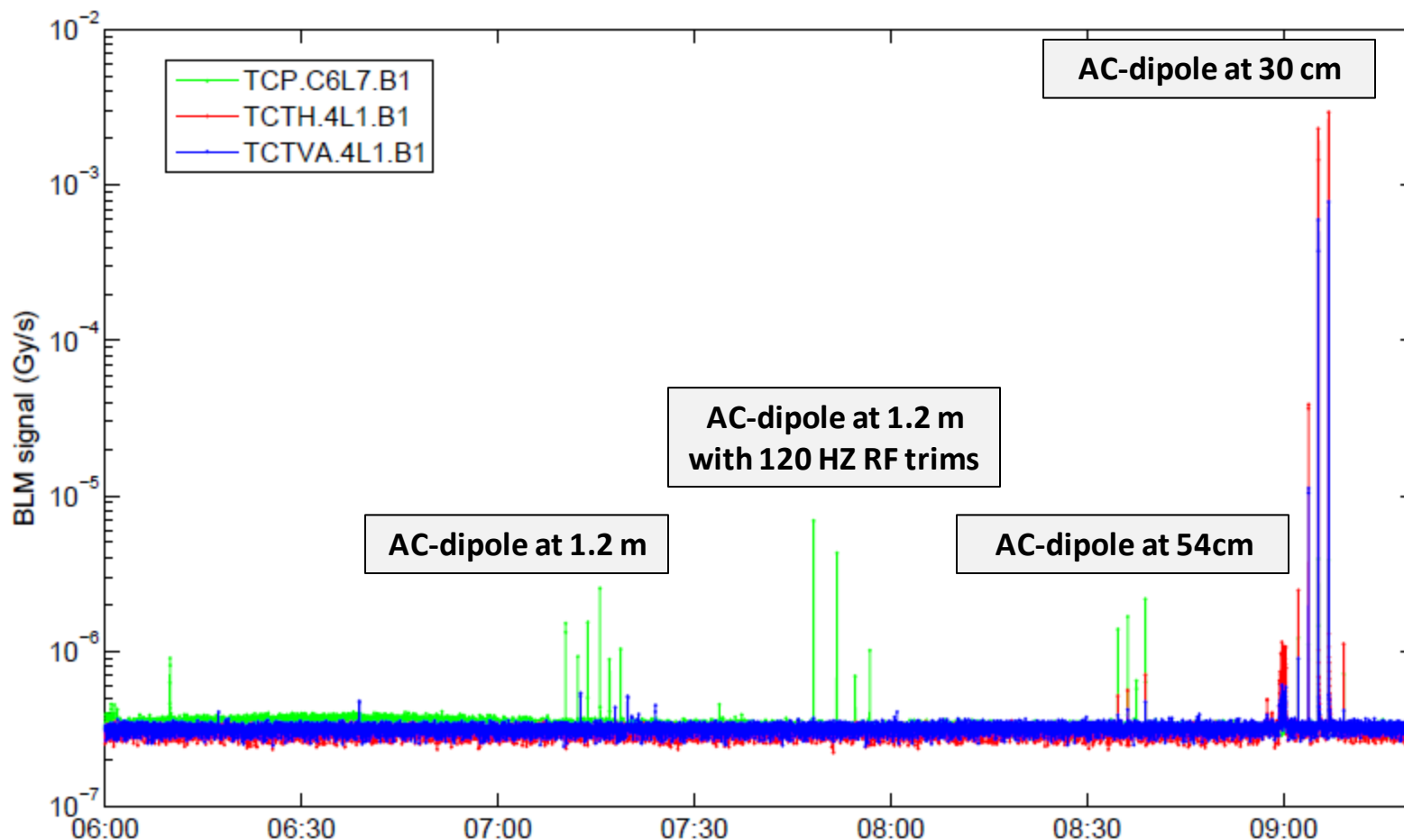
→ We were prudent enough **to work with the injection tune, i.e. a tune split of 0.03** (0.36 in  $f_{1001}$  units), by compensating with the QFB the tune jump at the beginning of the pre-squeeze.  
 → **Optimization still needed**: global correction during squeeze with sector by sector a2 correction in particular in s81/12/45/56

→ Dispersion measurement at  $\beta^* = 4.4$  m, 1.2 m and 54 cm. The “worst” case of Beam 2 at 54 cm is showed.



- Dy less than 15-20 cm in the arcs (thanks to MB sorting on a2!)
- Dx worst by a factor 2 in the arcs but still in spec (not optimized in the SSS sorting strategy)
- Dx and Dy magnified with  $\sqrt{\beta}$  in the triplet but no exceeding 1m (Dx) compared to 3 m specified for the nominal 55 cm collision optics → a good  $\sigma$  gained for the IT aperture of IR1

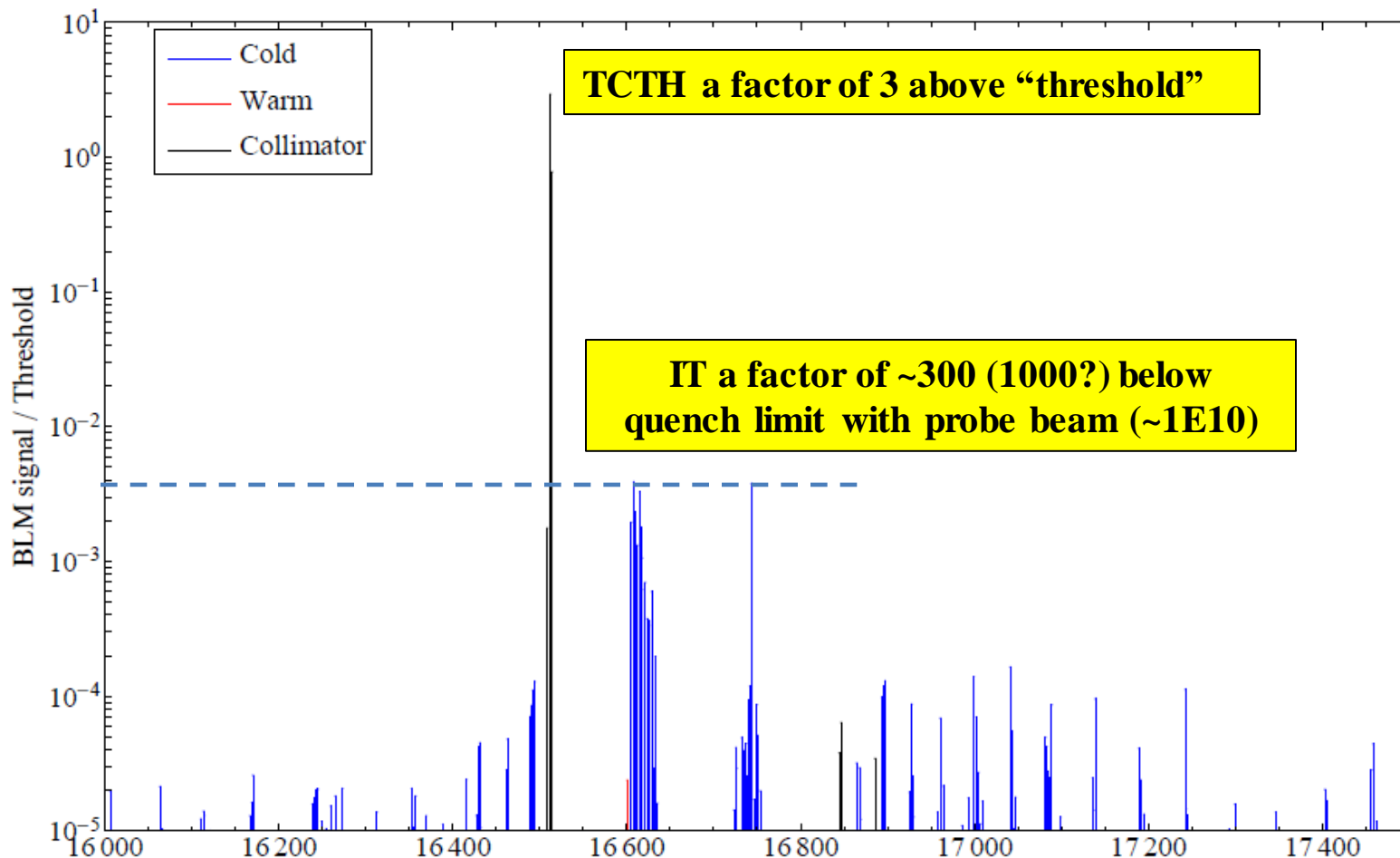
→ Losses (hystory over the last 3 hours): TCPH/V set at  $\sim 9$  sigma in IR7, TCTH/V set a  $\pm 12/10$  mm in IR1 and 5.



→ The TCTs becomes “very relaxed primary” (i.e.  $\cong 9\sigma$  settings +  $2\sigma$  AC dipole kick in both planes!) only at  $\beta^* \sim 54$  cm, i.e. the nominal collision  $\beta^*$  (but w/o crossing angle)

→ **What are we waiting for to go to nominal  $\beta^*$  (or slightly above)?**

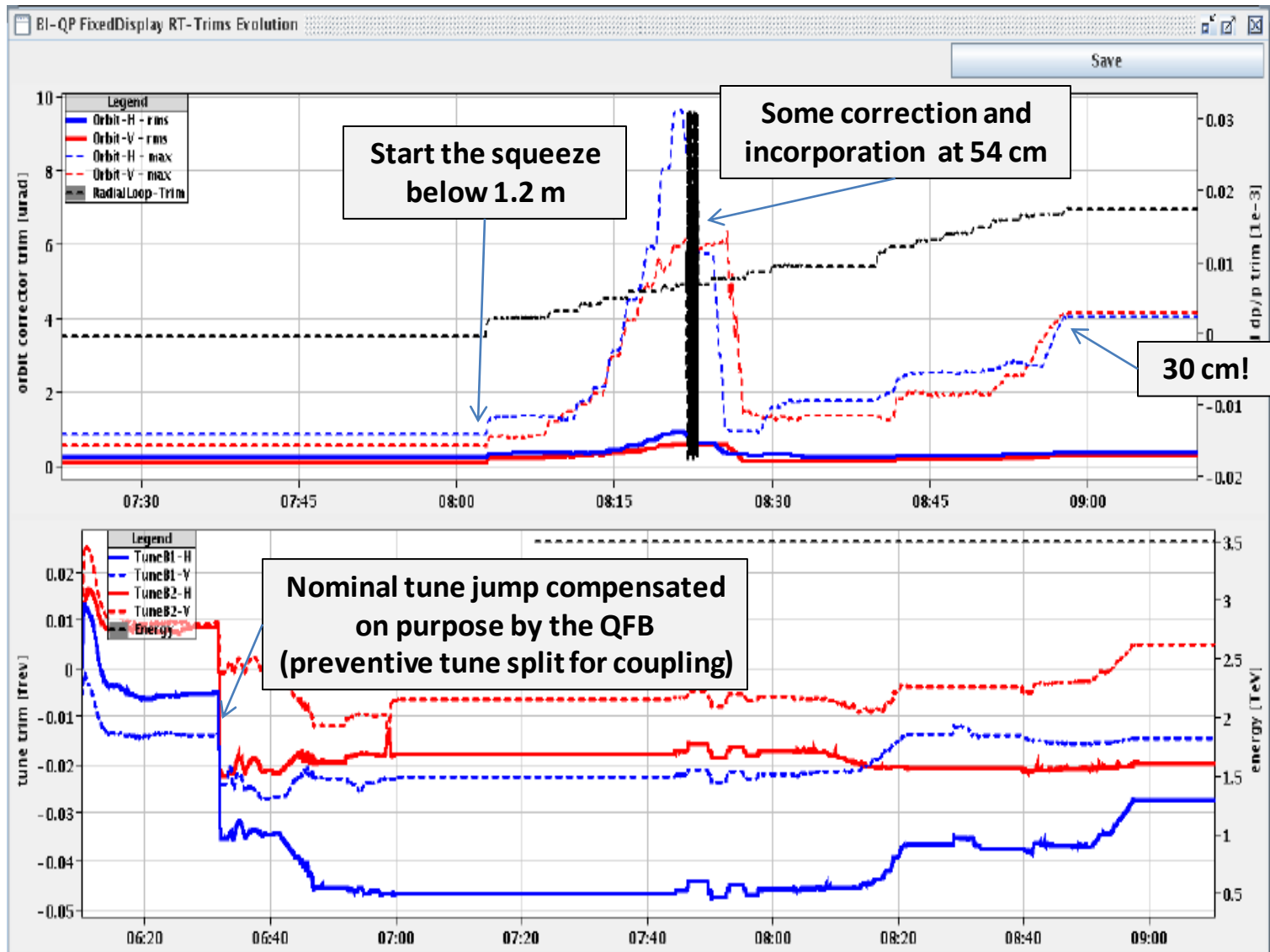
→ Losses vs. threshold at  $\beta^*=30$  cm (with AC-dipole measurements)  
at the **TCTs** and **IT BLMs** (quench limit with a factor of 3 margin).



... We could have AC-kicked 30 (100?) nominal bunches at  $\beta^*=30$ cm (while I would not have tried that at the first attempt!).

# → Feed-backs (trim history over the last hours)

→ It swallowed the squeeze of a 7 km long low- $\beta$  insertions!



# Conclusions and possible next steps

- An incredible success!
- The bar is too high,.. better to skip the next MD 😊
- ... Also waiting for decisions on priorities (mini-Chamonix, LHC 2012, HL-LHC, other applications)
- The next steps could be
  - **Nominal LHC**: Pushing the pre-squeeze down to 40 cm (i.e. w/o beta-beating yet in the arcs but with correction of the chromatic aberrations).
  - **HL-LHC**: Clean up (i.e. correct) the existing ATS collision optics and reiterate for squeezing IR5 (using IR4 and IR6).
  - **BOTH**: Production of flat optics (e.g. 1m/25cm) and collide.
  - **Miscellaneous**: Generalise the principle for an Achromatic Telescopic Un-Squeezing (ATUS) scheme for very high  $\beta^*$  ... still nothing serious, i.e. at the level of a simple idea.
- But, for most of these items we are only partially or not all ready and priorities / resources shall be agreed.