

Highlights of the ATS MD part III

(Achromatic Telescopic Squeeze)

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Initial Goal:

→ **Demonstrate $\beta^*=10$ cm at IP1 and IP5** (w/o X-angle but with parallel separation)

Initial Plan & Results:

- a) Dry run (3h) → **Successful in 2.5 h (no trips, all knobs tested)**
- b) Pre-squeeze to 40 cm (4.5 h) → **Cancelled**
- c) Squeeze to 10 cm (6 h) → **beam lost after 4.5 h when starting the telescopic part at $\beta^*=40$ cm ... but 40 cm reached nevertheless at IP1&5 !**

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

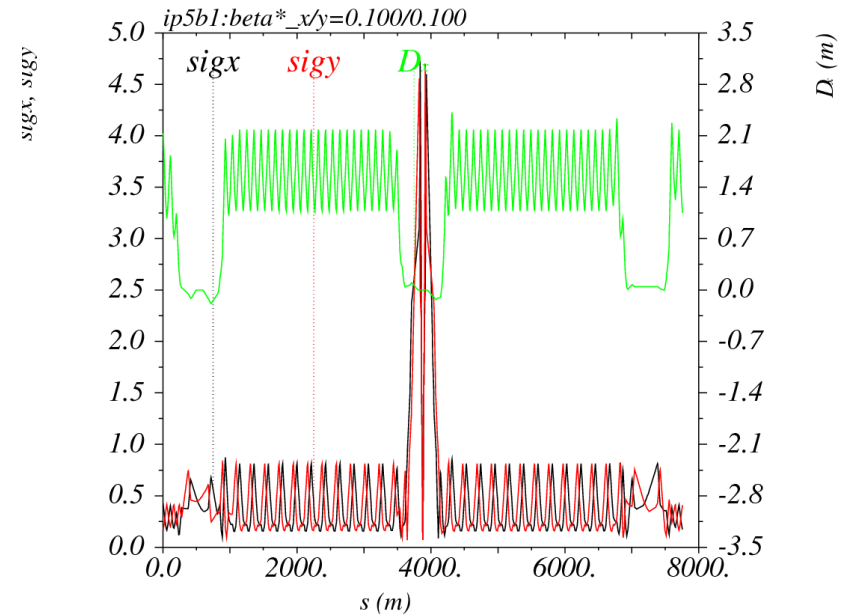
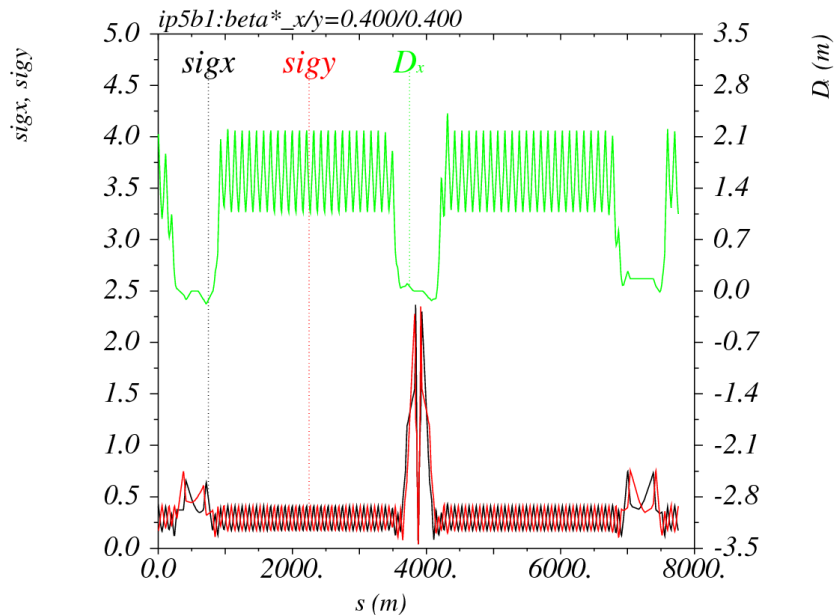
- **A squeeze procedure in two steps**

- 1) An “almost” standard squeeze, the Pre-squeeze, acting on the IPQs of IR1 and IR5.
- 2) A continuation of the squeeze, called Squeeze, acting on the IPQs of IR2/8 for squeezing IR1 and IR4/6 for IR5 and inducing β -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 β -beat, and more!)

- **For the July MD**, the **pre-squeezed β^* was chosen to 1.2 m**, and the telescopic part was activated to squeeze **IR1 only** and successfully reach **30 cm** (with 400% β -mismatch generated on purpose in arc 81 and 12).
- **For this MD**, the **pre-squeezed β^* was pushed to its limit of 40 cm**, and the plan was to activate the telescopic part **both for IR1 and IR5** in order to reach **10 cm**.



The IR5 pre-squeeze at $\beta^*=40$ cm

- $\beta_{\max}=6$ km in the triplet
- ($\sigma \sim 2.5$ mm @ 3.5 TeV, $\gamma\epsilon=3.5$ μ m)
- FODO β 's in arcs 45 & 56
- FODO dispersion

The IR5 squeeze at $\beta^*=10$ cm

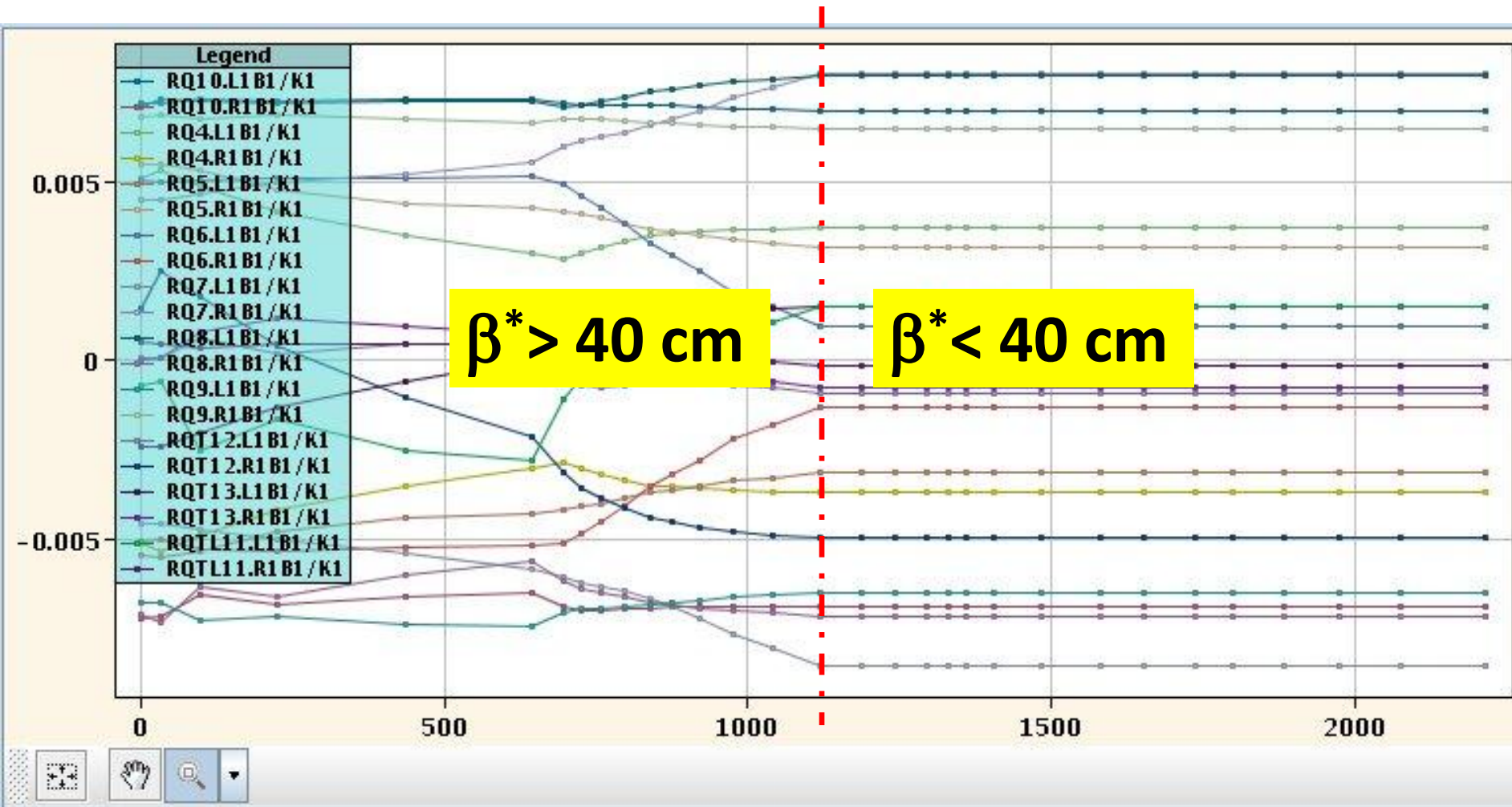
- $\beta_{\max}=24$ km in the triplet
- ($\sigma \sim 5$ mm @ 3.5 TeV, $\gamma\epsilon=3.5$ μ m)
- 400% β -mismatch in arcs 45 & 56
- FODO dispersion

The Dry Run (2.5h on 30th of October)

A tedious preparation work: the key for success

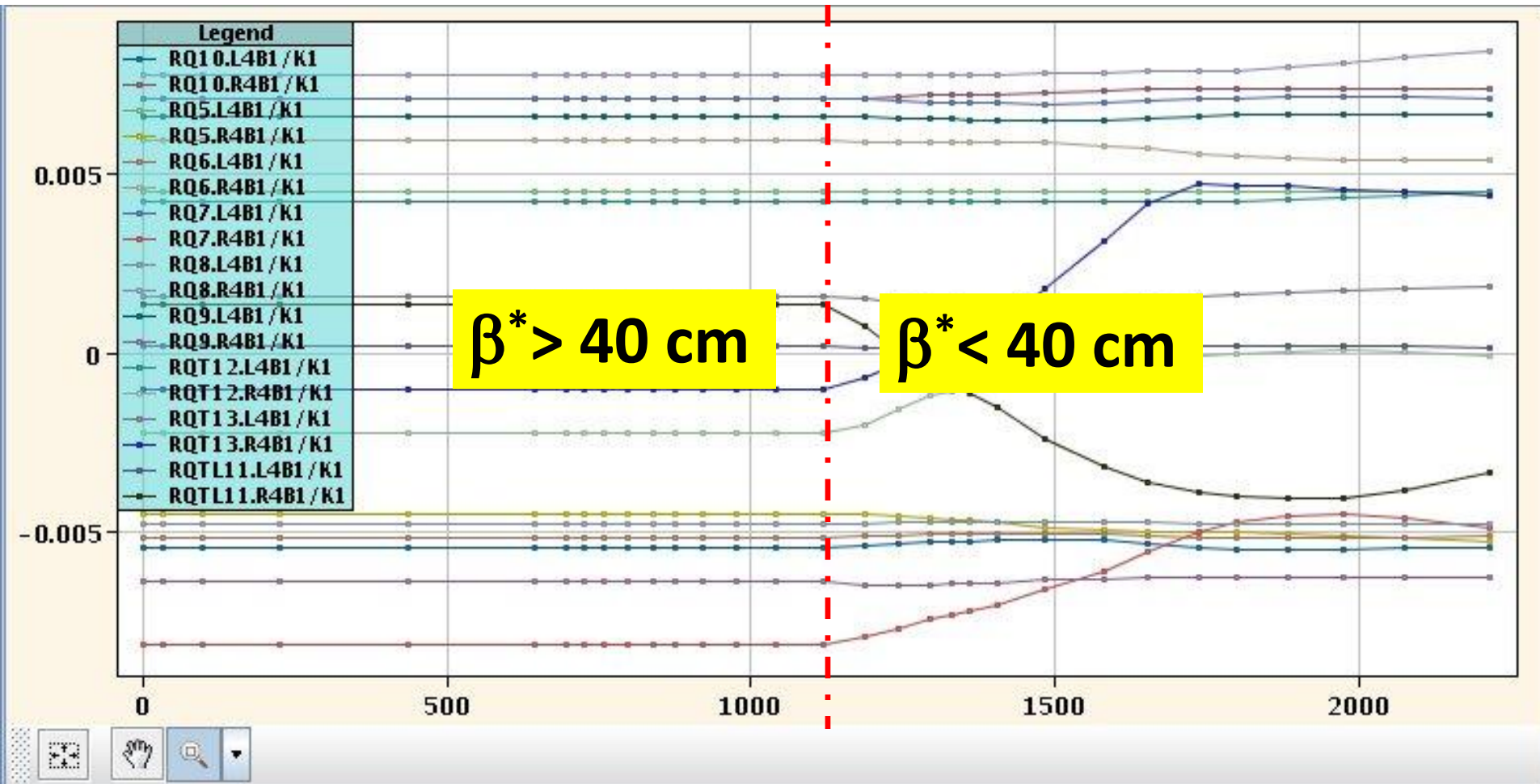
- Optics work : compared to last MD, pre-squeeze pushed down to 40 cm, squeeze transition calculated for IR4 and IR6 (taking into account Brennan's constraints)
- Full ATS hyper-cycle & sequence using the already commissioned ATS ramp and the new ATS squeeze beam process.
- Some modifications needed & implemented in LSA Pro version and other software with statements like *if beam-process-name contains “_ATS_” do it differently*
 - a) PLP procedure also applied for the setting generation and trims of sextupoles.
 - b) Artificially doubling the MQY decay time to avoid trip at low current during the squeeze (affect the duration of the few last segments only).
 - c) Two sets of knobs (Q, Q', coupling) to be used above and below the pre-squeeze β^* , and the *possibility to switch the QFB from one knob to the other ... at least we thought ... unfortunately this functionality was not tested during the dry run!*

How does it look like in practice (IR1/5)



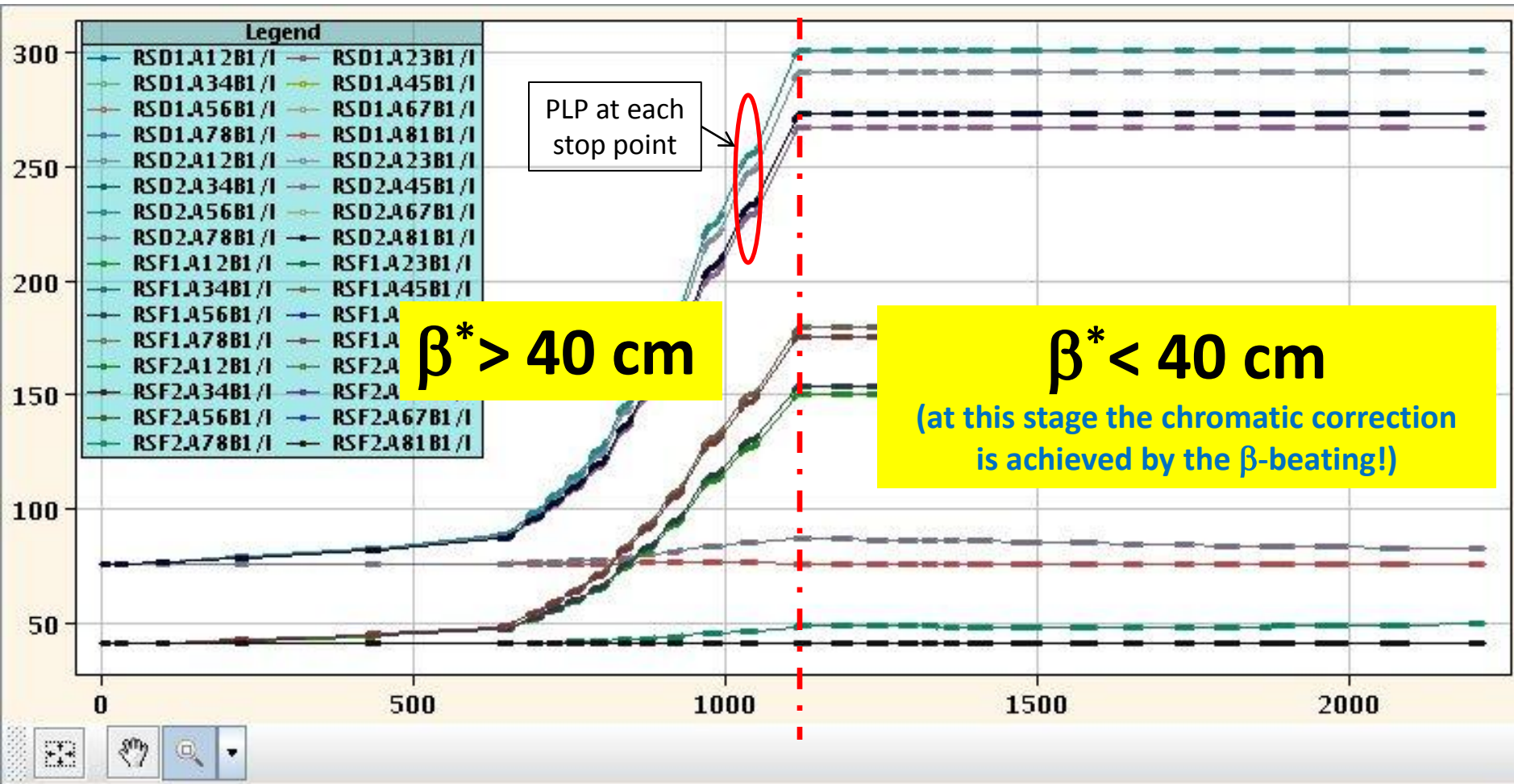
→ The IPQ settings are changing in **IR1 and IR5** down to the pre-squeezed β^* , then stay constant.

How does it look like in practice (IR8/2/4/6)



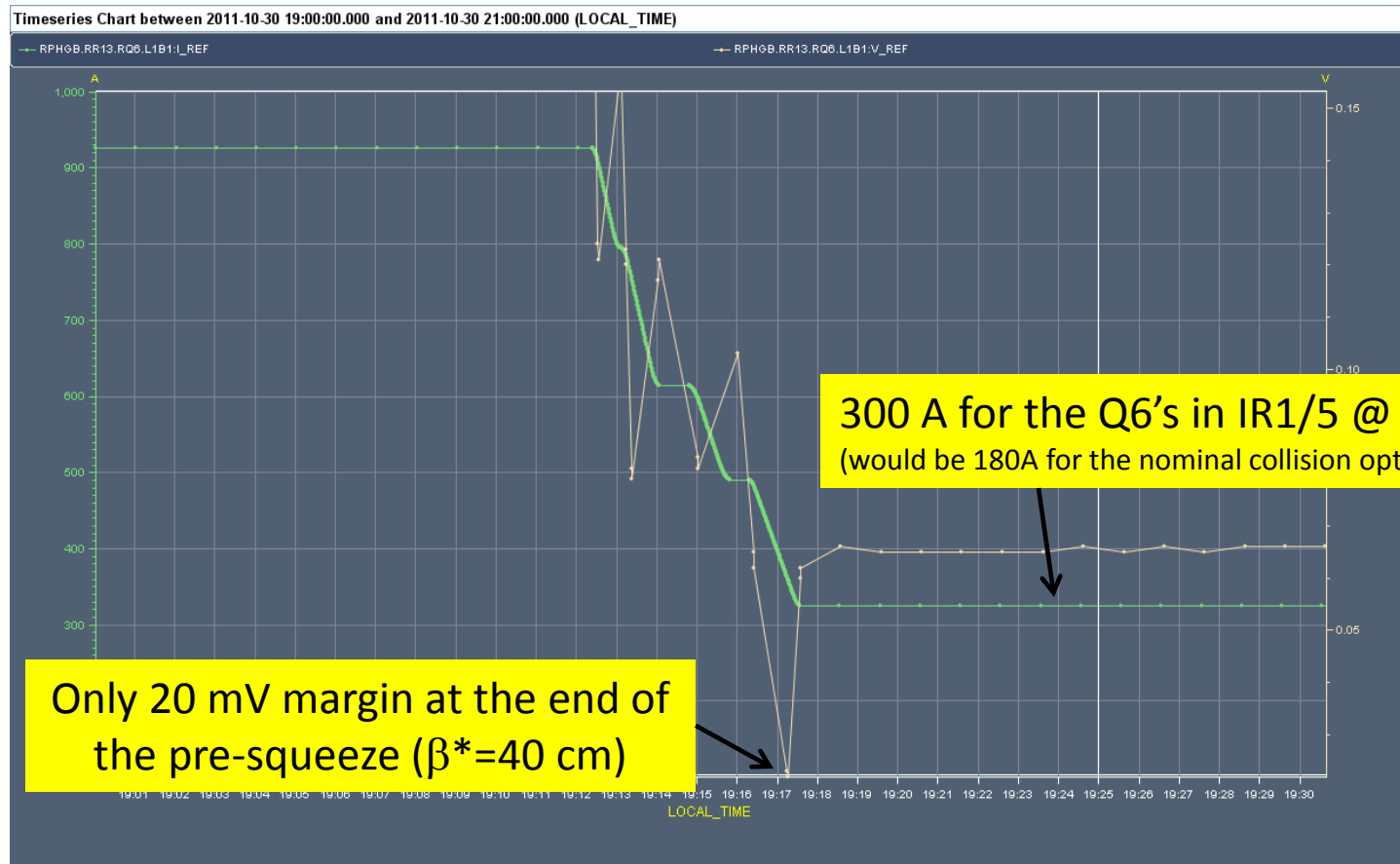
→ The IPQ settings are constant in **IR8/2/4/6** down to the pre-squeezed β^* , then start to move.

How does it look like in practice (sextupole)



→ Only 25% of the **RS circuits** actively participates to the chromatic correction.
 They are the limiting circuits during the pre-squeeze (except for the last segment)
 → Note that **300A** is reached for some RSDs at 3.5 TeV/beam (i.e. max current reached at 7TeV).

How does it look like in practice (Q6 in IR1/5)



- The only big uncertainty was the RQ6 circuits (MQML) in IR1 and IR5, reaching very low current ($\sim 300\text{A}$) at the end of the pre-squeeze.
- **However these circuits did not trip ... with only 20 mV margin left in Vref**

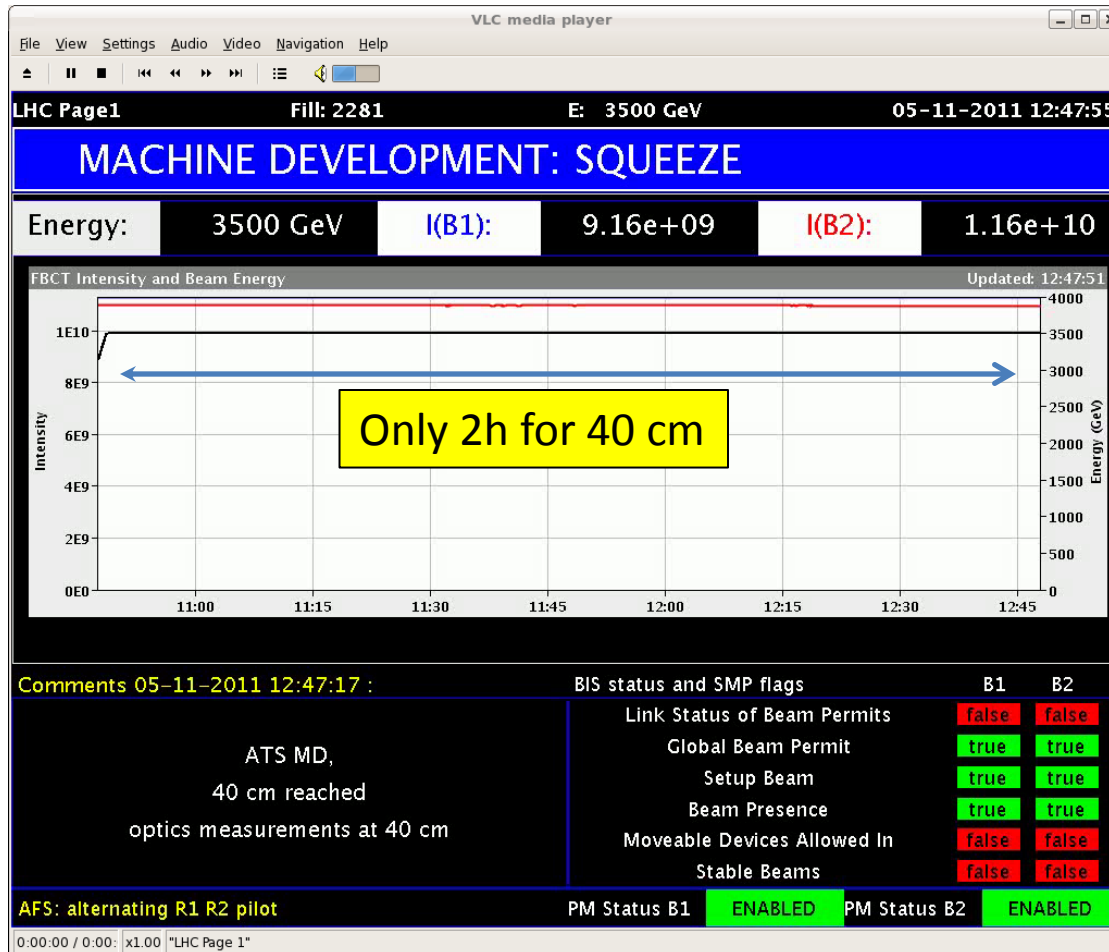
The MD with beam (5th of November)

- Easy injection (c.o., tune, coupling, chroma,..).
- Excellent transmission during the ramp.
- Smooth “pre-squeeze” down to 40 cm (6.2 km β_{\max} in the triplet) reached in 2h:
“3 km/h in terms of β_{\max} ” including a pause at $\beta^*=1\text{m}$ for optics measurement!
- Successful on-line β -beating measurement and correction at 40 cm (<20%).
- **Beam lost due to trips of several 600A circuits, triggered by QPS, when preparing the telescopic part towards 10 cm.**

When switching the QFB to the new tune knobs, the real time trims of the RQT & RS were sent to zero in S45/56/81/12 (the 4 sectors where the β 's are supposed to increase), and trying to redistribute them in S23/34/67/78 (the 4 sectors where the β 's are always kept nominal).

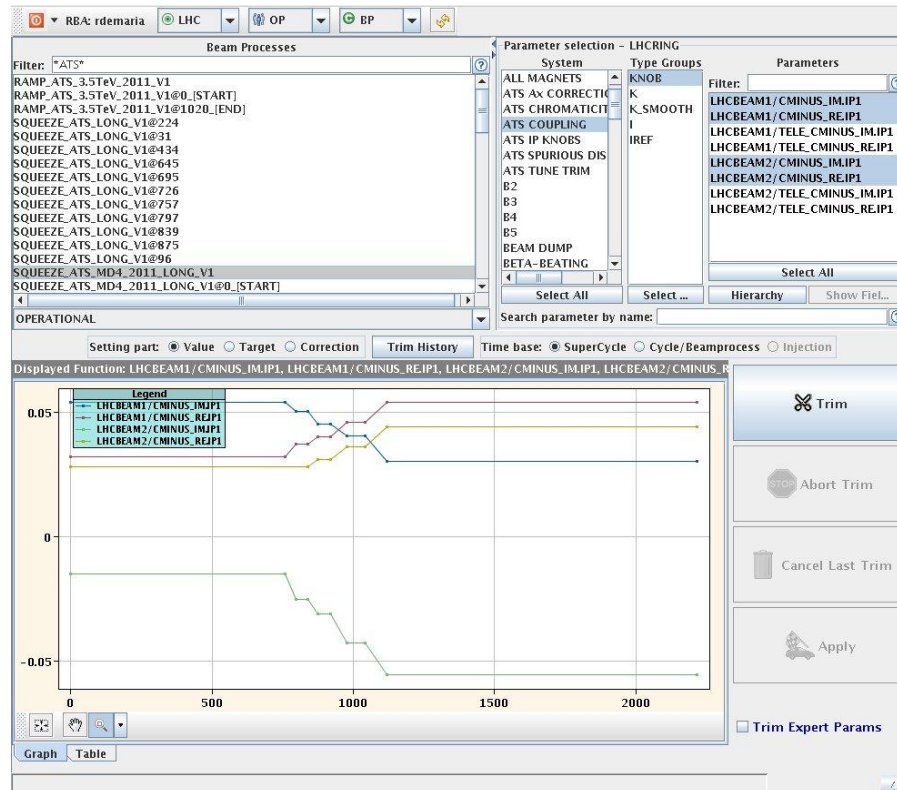
Highlights of the MD with beam

- Excellent transmission during ramp and fast pre-squeeze “mini-commissioning”.

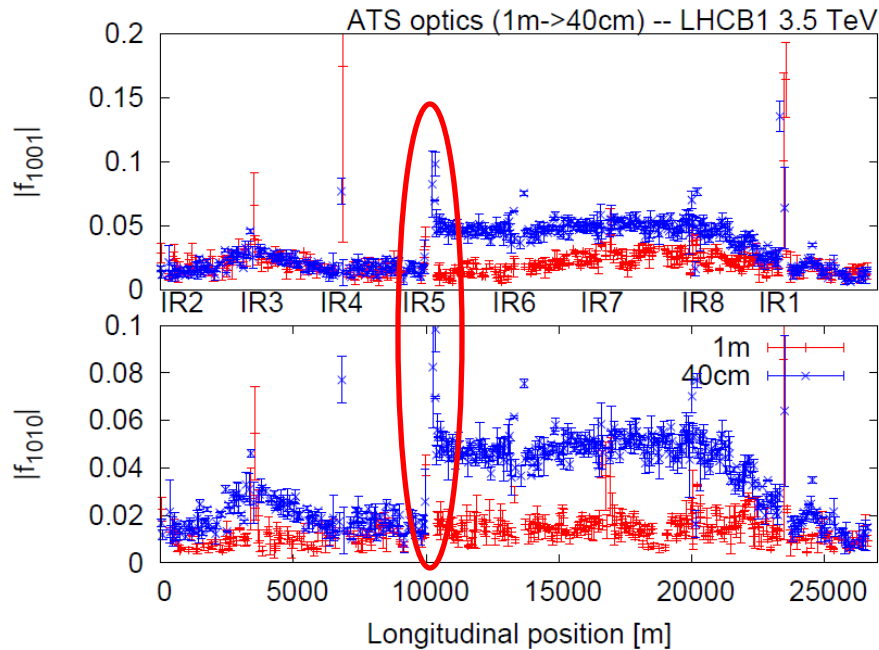


Highlights of the MD with beam

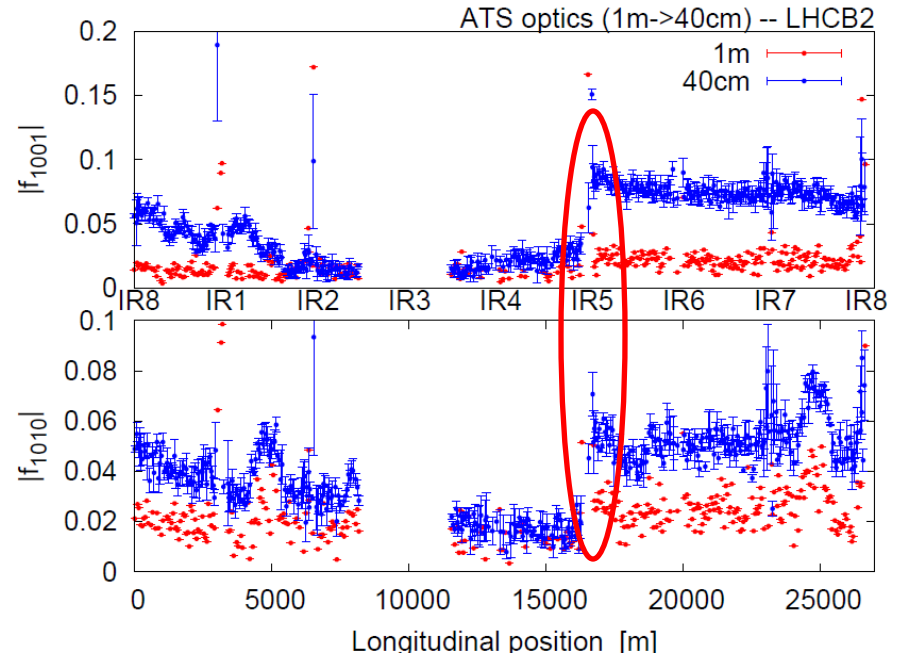
- **Rather constant Q'** during the pre-squeeze (with stop points possible w/o tripping the RS circuits thank to the “If ATS” in the control softs).
- **Coupling easily corrected** with global knobs, but some trend visible
→ Fine tuning of the RQSX's needed in IR1/5 and rebalancing the arc a2 correction (see next slides).



Highlights of the MD with beam



Beam1

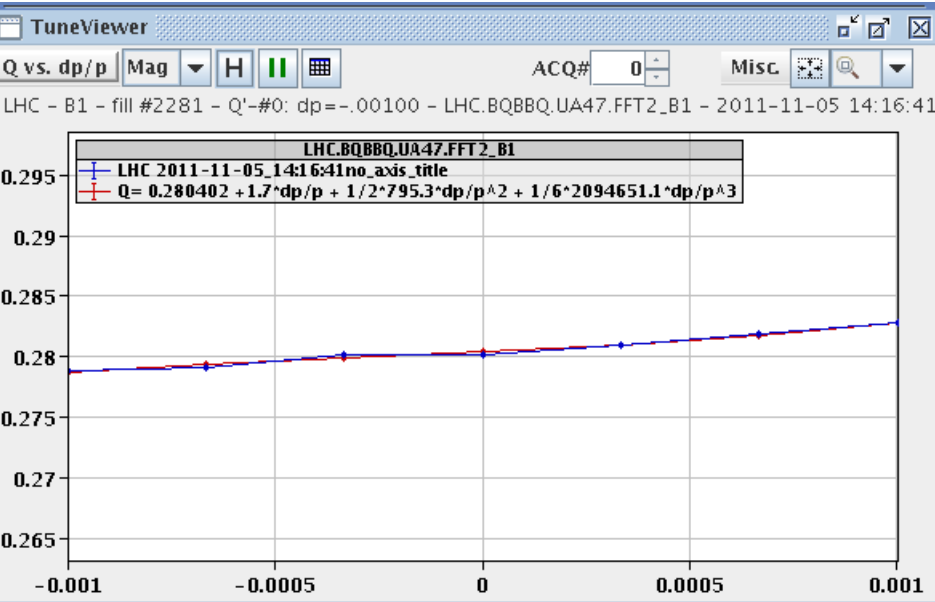


Beam2

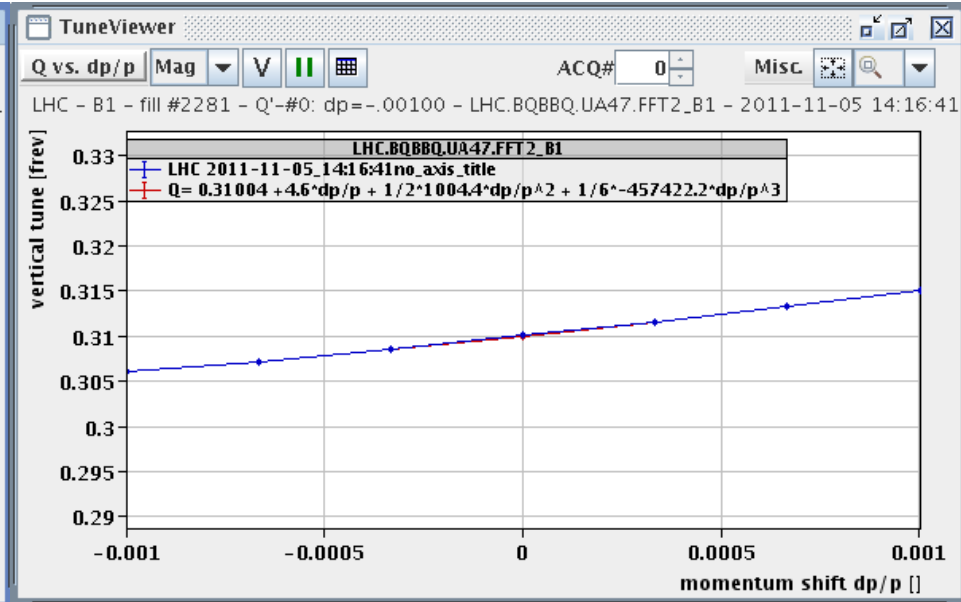
- Clear source of coupling errors in IR5 while IR1 looks OK ... but at 10 cm who knows?
- Certainly, RQSX pre-settings to be re-adjusted in IR5.
- Sector by sector a2 correction to be re-optimized accordingly, mainly in S81/12/45/56 to already prepare the telescopic part of the ATS. Idem for the arc by arc b2 correction (not showed here).

Highlights of the MD with beam

- **Linear chromatic variations of the tunes at $\beta^*=40$ cm**
→ No or small Q'' & Q''' which is a signature of a **well-controlled off-momentum β -beating** (.. unfortunately no time for measuring the W 's for a direct confirmation).



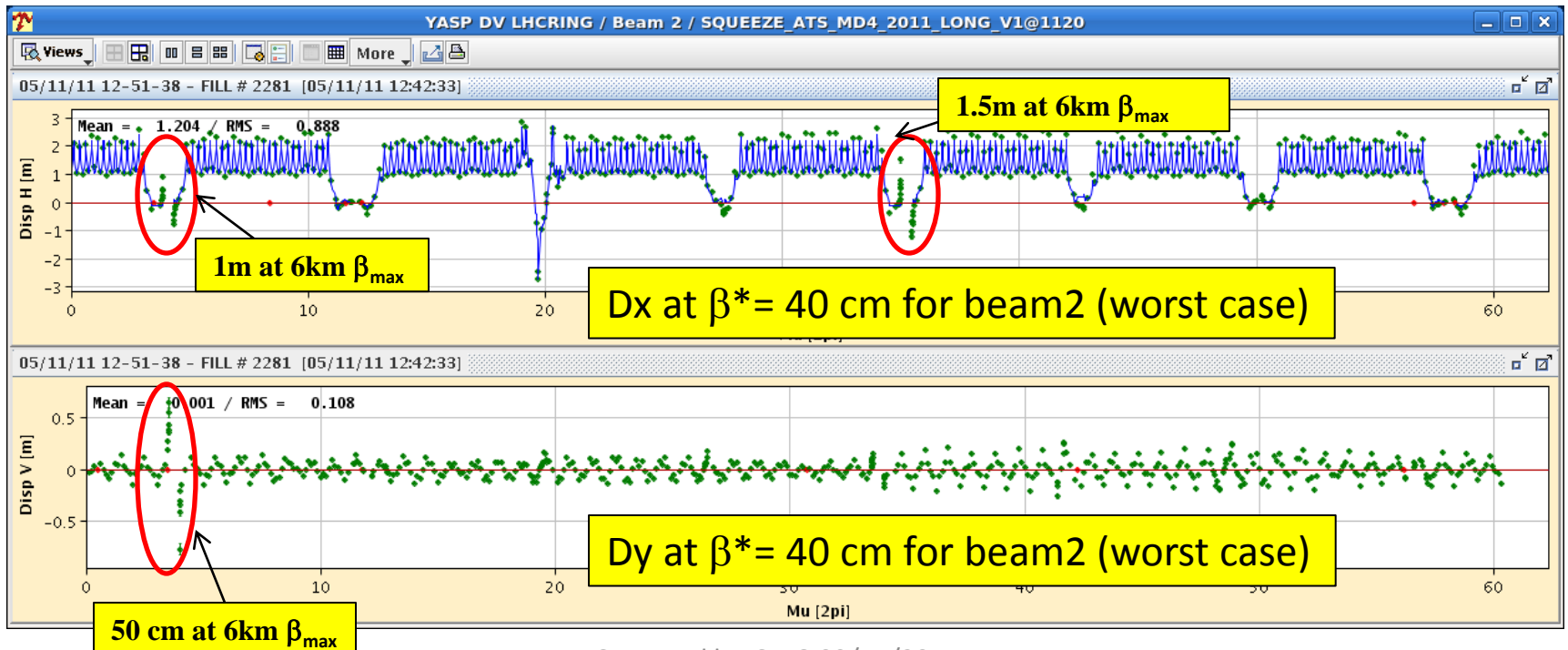
$Q_x(\delta)$ at $\beta^*=40$ cm



$Q_y(\delta)$ at $\beta^*=40$ cm

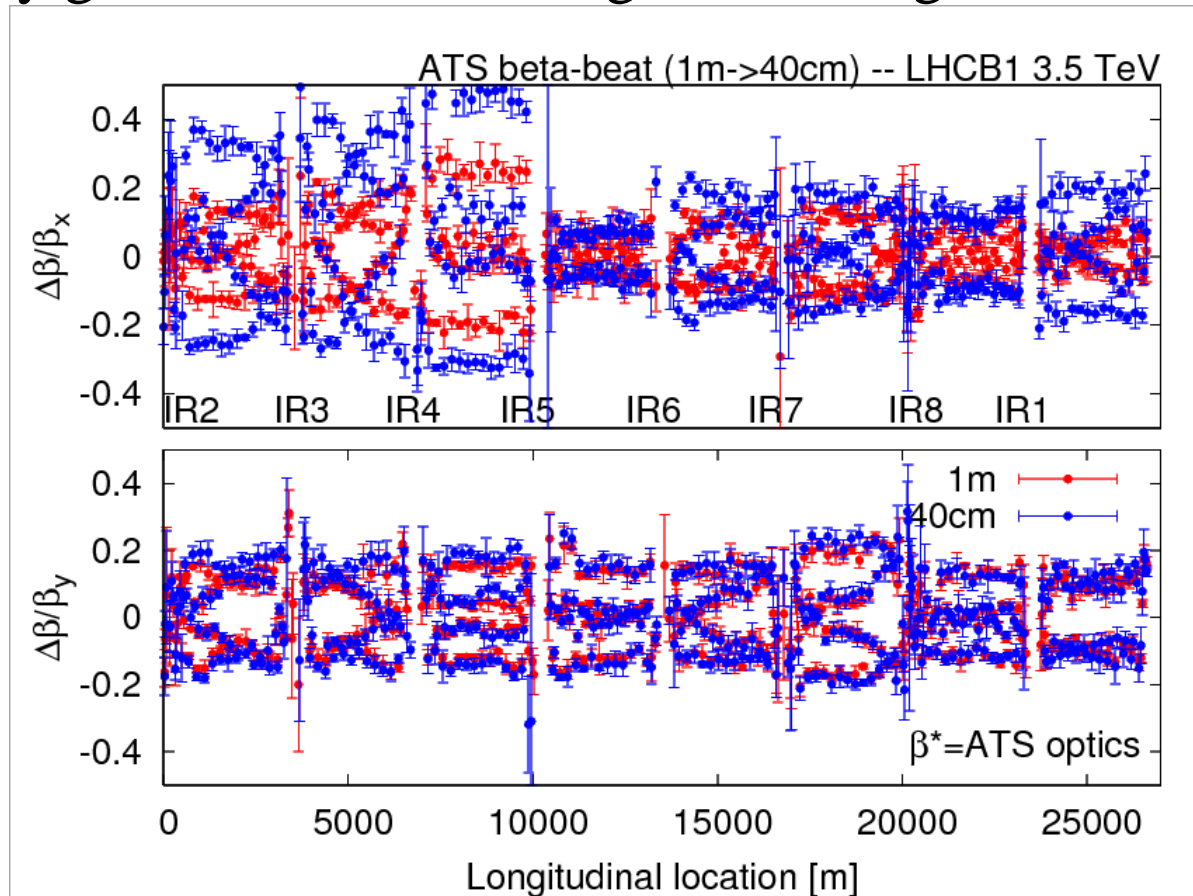
Highlights of the MD with beam

- The **linear imperfections coming from the arcs** start to show up!
 - **Dy still more than acceptable**: sorting on random a2 for the MBs.
 - **Dx starts to be worrying, but a priori correctable**: the MQ sorting was optimized for β -beating only (too many SSS types)



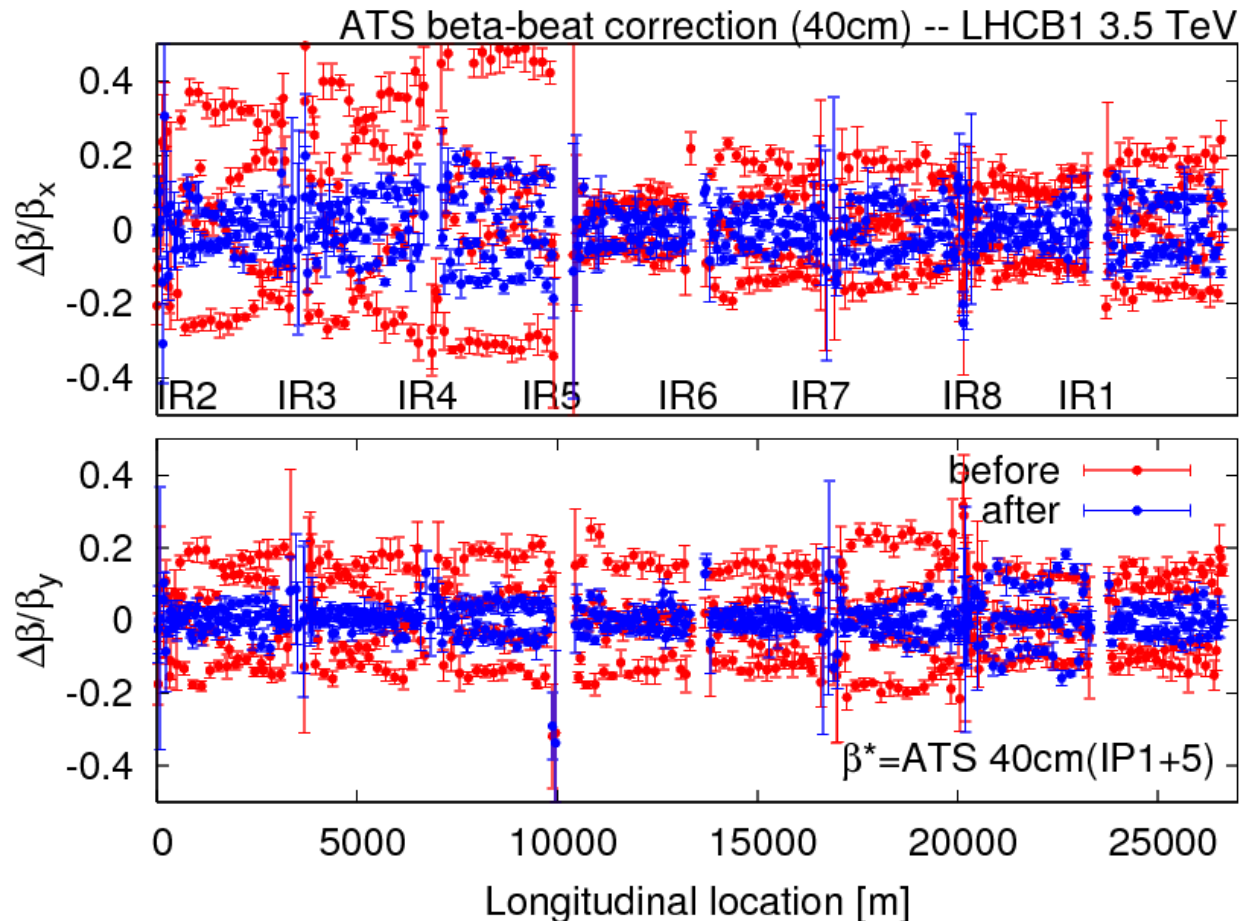
Highlights of the MD with beam

- **20 → 50% level achieved for the β -beating at $\beta^*=1\text{ m} \rightarrow 40\text{ cm}$ with only 3 empirical trims applied for 3 Q2's (around ± 10 units)**
→ mostly generated in IR5: longitudinal alignment of the triplet??



Highlights of the MD with beam

- **15-20% level reached (for beam1) after one single correction iteration** (using only the IPQs of IR1 and IR5).



Conclusions

- Certainly a BIG success for the LHC: $40 < 55!$
- Certainly a BIG success for the “A” of the ATS (Achromatic).
- Let us wait for some MD time next year in order to validate the “T” (Telescopic)
 - ... even if already demonstrated with the last MD but only for one IP (the easiest one IP1) and starting from a less aggressive pre-squeezed optics (1.2 m).