LHC Beam Commissioning Workshop

Hilton and Palais Lumière, Evian, France

January 19th-20th, 2010

Betatron Squeeze:

Status, Strategy and Issues

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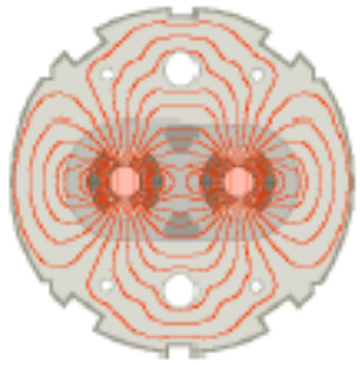
S. Redaelli, M. Strzelczyk

CERN - BE department



Acknowledgments

ABP	S. Fartoukh, M. Giovannozzi, W. Herr
Beat-beat team	**R. Tomàs**, **G. Vanbavinckhove**
Simulations	X. Buffat (EPFL, Lausanne, CH)
BI tune team	**M. Gasior**, **R. Jones**, R. Steinhagen
Controls	G. Kruk
FiDeL team	P. Hagen, E. Todesco
OP orbit team	K. Fuschberger, J. Wenninger

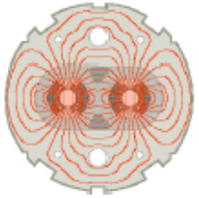
+ OP team on shift: **Laurette** & **Lasse**

bold = people in CCC during beam tests

Outline

- ☑ Introduction
- ☑ Squeeze handling
- ☑ Beam experience
- ☑ Conclusions

Introduction



Squeeze:

Change of optics done in the experimental regions to **reduce the beta functions** at the interaction points (β^*_x, β^*_y) and increase luminosity.

*7 TeV design for IP1/IP5: β^*_{inj} = 11 m → β^*_{coll} = 0.55 m ⇒ **20 x** in luminosity*

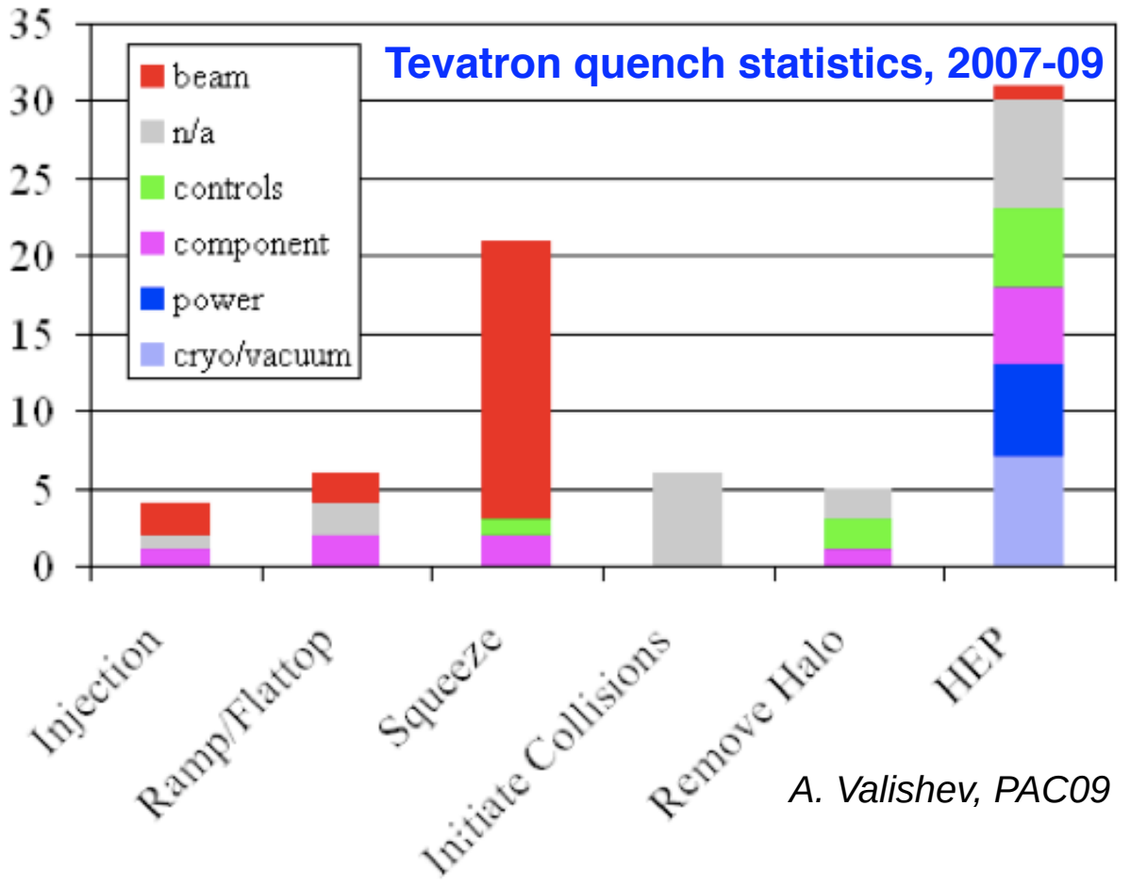
The squeeze is particularly **critical**:

- *Performed at top energy (highest damage potential)*
- *Reduces the machine aperture (triplets become the bottlenecks)*
- *Imposes tighter tolerances (orbit, optics, collimator settings, ...)*
- *Requires function-based settings*

*A squeeze test with beam was performed at the end of the 2009 run to test the squeeze **mechanics** and see the **first beam results**.*

This beam test was "squeezed" in < 2h so it is by far NOT complete...

On the other hand, we got first interesting results and important feedback on the available tools!

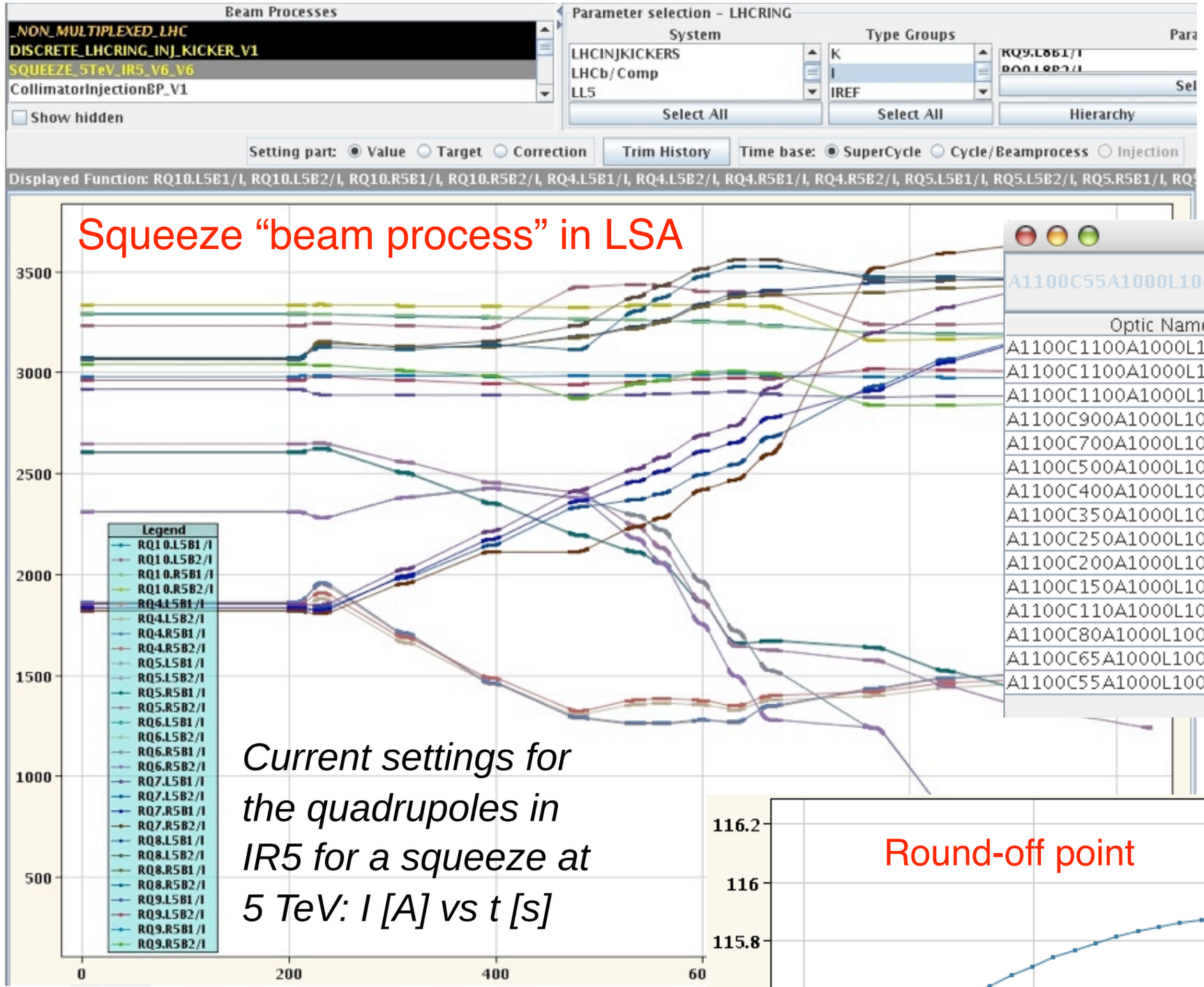


A. Valishev, PAC09

Outline

- Introduction
- **Squeeze handling**
  - **Controls implementation**
  - **2010 requirements**
- Beam experience
- Conclusions

Squeeze in the controls system

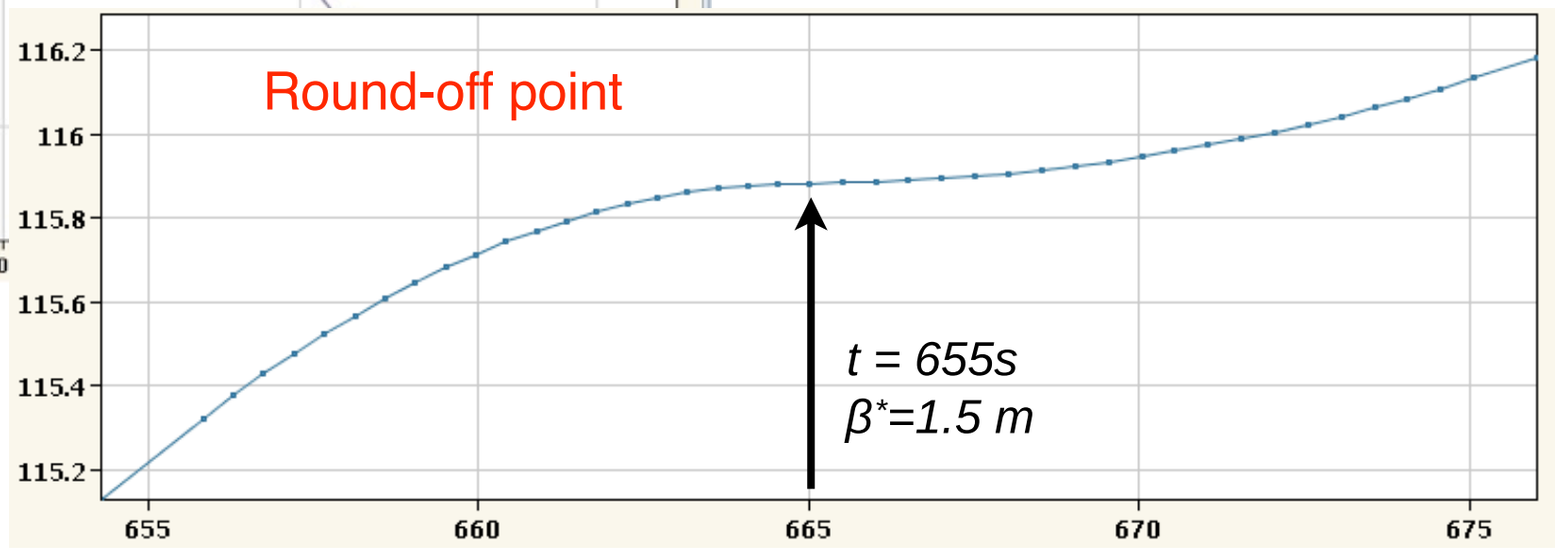


ABP matched optics

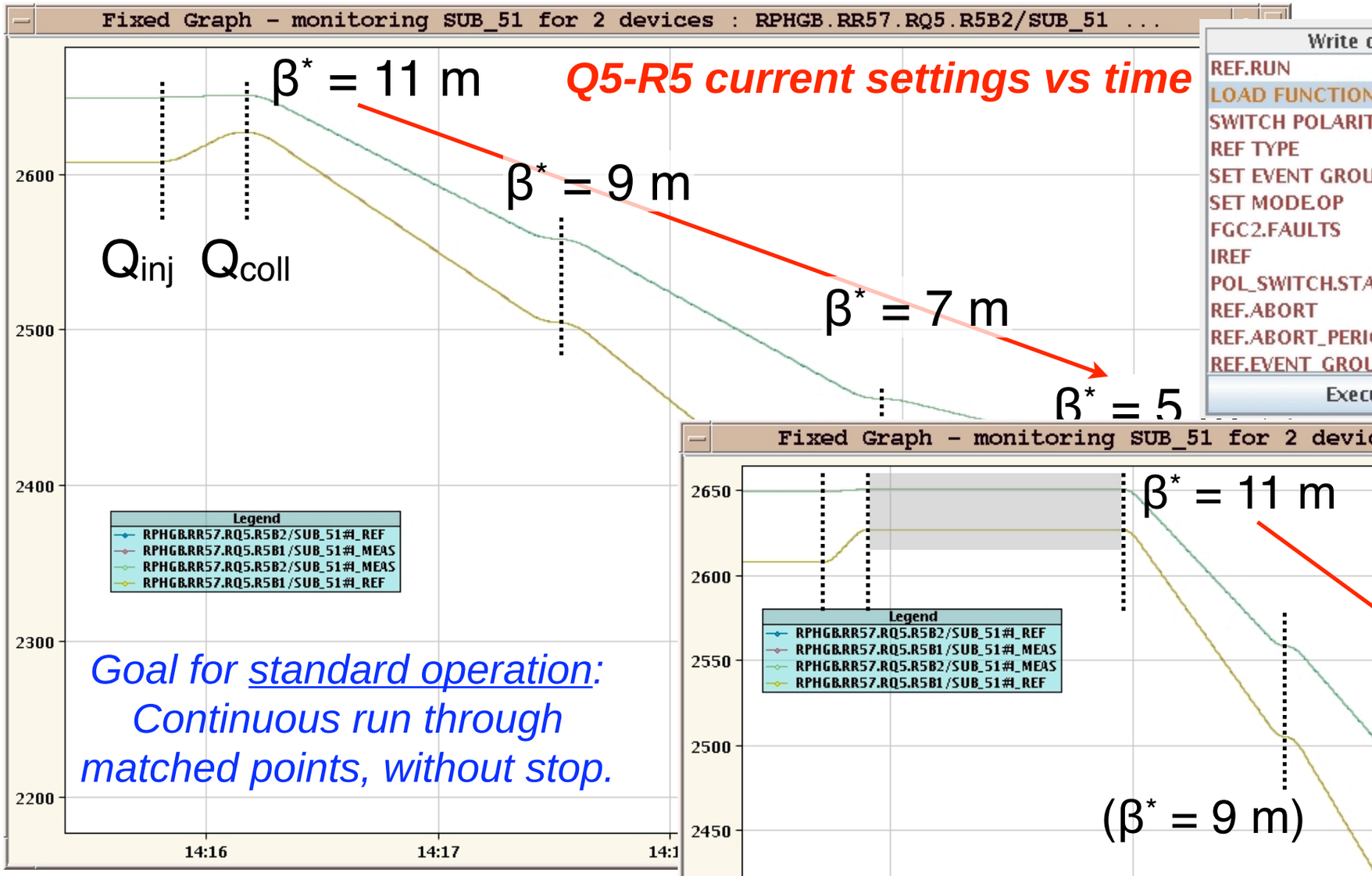
Optic Table Editor

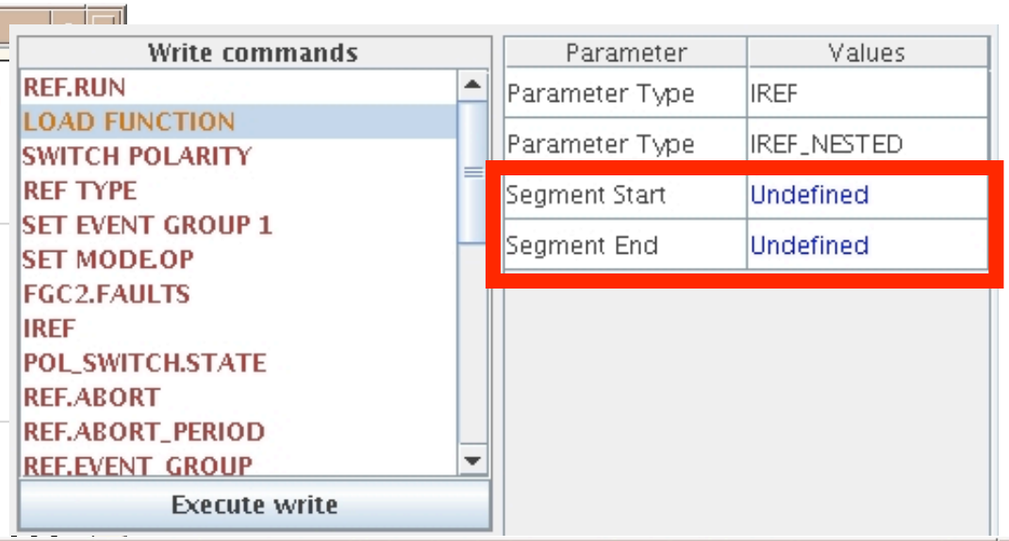
A1100C55A1000L1000 | Add | Remove

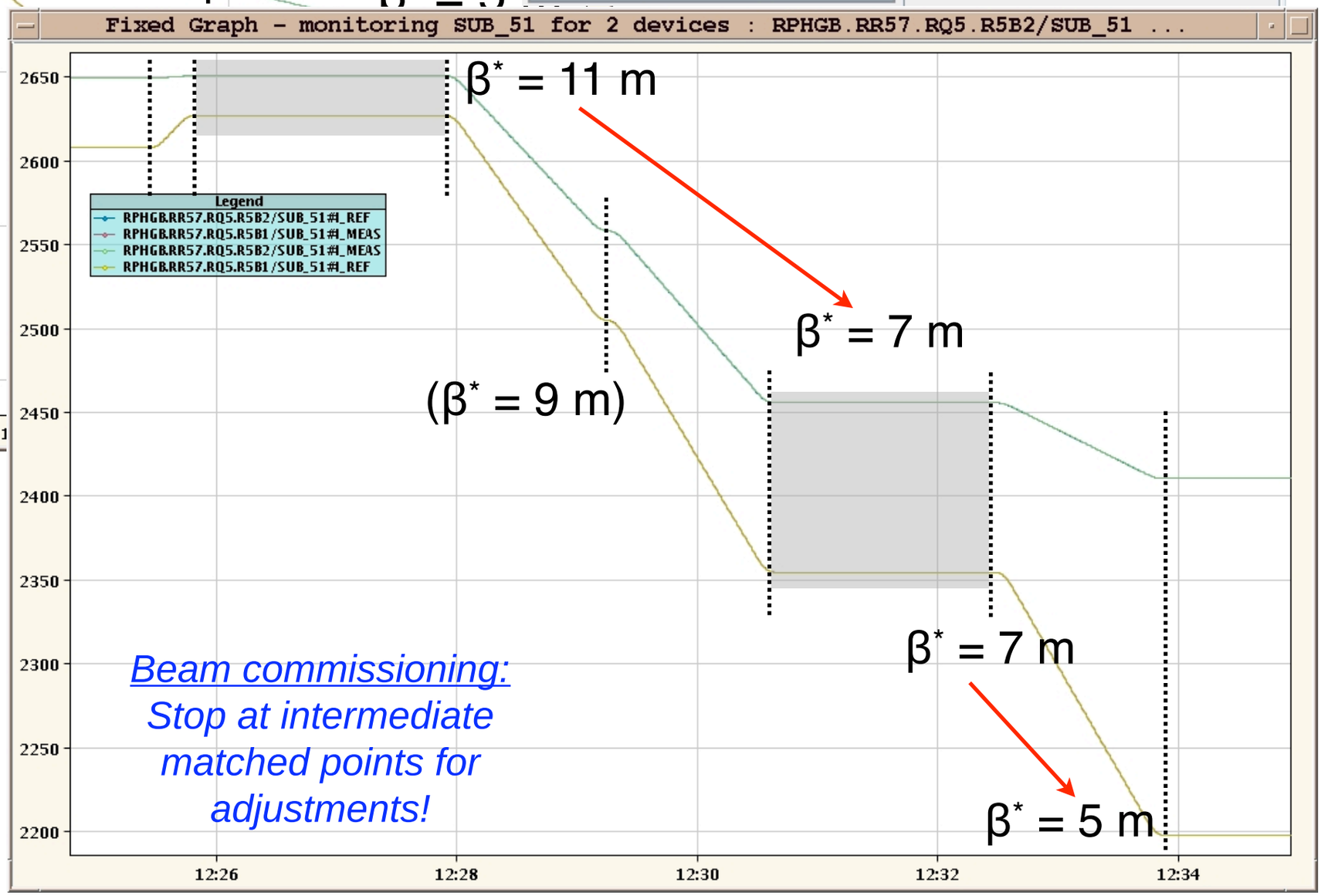
Optic Name	Energy	Time	Parabolic Fraction
A1100C1100A1000L1000P_INJ	5000.0	0	0.0
A1100C1100A1000L1000P_IR5	5000.0	209	0.047878
A1100C1100A1000L1000_IR5	5000.0	231	0.308478
A1100C900A1000L1000	5000.0	312	0.10033
A1100C700A1000L1000	5000.0	395	0.097534
A1100C500A1000L1000	5000.0	479	0.096855
A1100C400A1000L1000	5000.0	536	0.173941
A1100C350A1000L1000	5000.0	560	0.330357
A1100C250A1000L1000	5000.0	599	0.210644
A1100C200A1000L1000	5000.0	631	0.203919
A1100C150A1000L1000	5000.0	665	0.26938
A1100C110A1000L1000	5000.0	766	0.099674
A1100C80A1000L1000	5000.0	835	0.120635
A1100C65A1000L1000	5000.0	912	0.102405
A1100C55A1000L1000	5000.0	1033	0.063386



Stopping at matched optics







Goal for standard operation: Continuous run through matched points, without stop.

Required for commissioning!

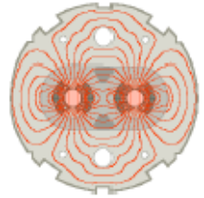
First implementation and tests without beam done this summer (S. Redaelli and G. Kruk at the LHCCWG of Aug. 4th, 2009).

Worked well for the first beam tests!

Beam commissioning: Stop at intermediate matched points for adjustments!

2010 optics requirements

see also talks by Werner (S3) and Massimo (S6); ***LHC-OP-ES-0020 rev. 1***



	β^*_{inj}	β^*_{min}
IP1 / IP5	**11 m**	**2 m**
IP2+	**10 m**	**3 m**
IP8+	**10 m**	**2 m**
IP5-TOTEM	***11 m***	***90 m***

+ *No pre-squeeze required for 2010.*

Required preparation in LSA (*Beam Processes, BPs*):

- Ramp with injection optics → 1 BP
- Squeeze one IP at a time (commissioning) → 4 BPs
- IP1 and IP5 together to β^*min → 2 BPs
- IP2 (IP8) with IP1 and IP5 at β^*min → 2 BPs
- IP8 (IP2) with IP1, IP5 and IP2 (IP8) at β^*min → 2 BPs
- *TOTEM un-squeeze in IP5* → *1 BP*

TOTAL of 12 beam processes with up to 30 optics each!

{without taking into account the associated "ACTUAL" BPs!}

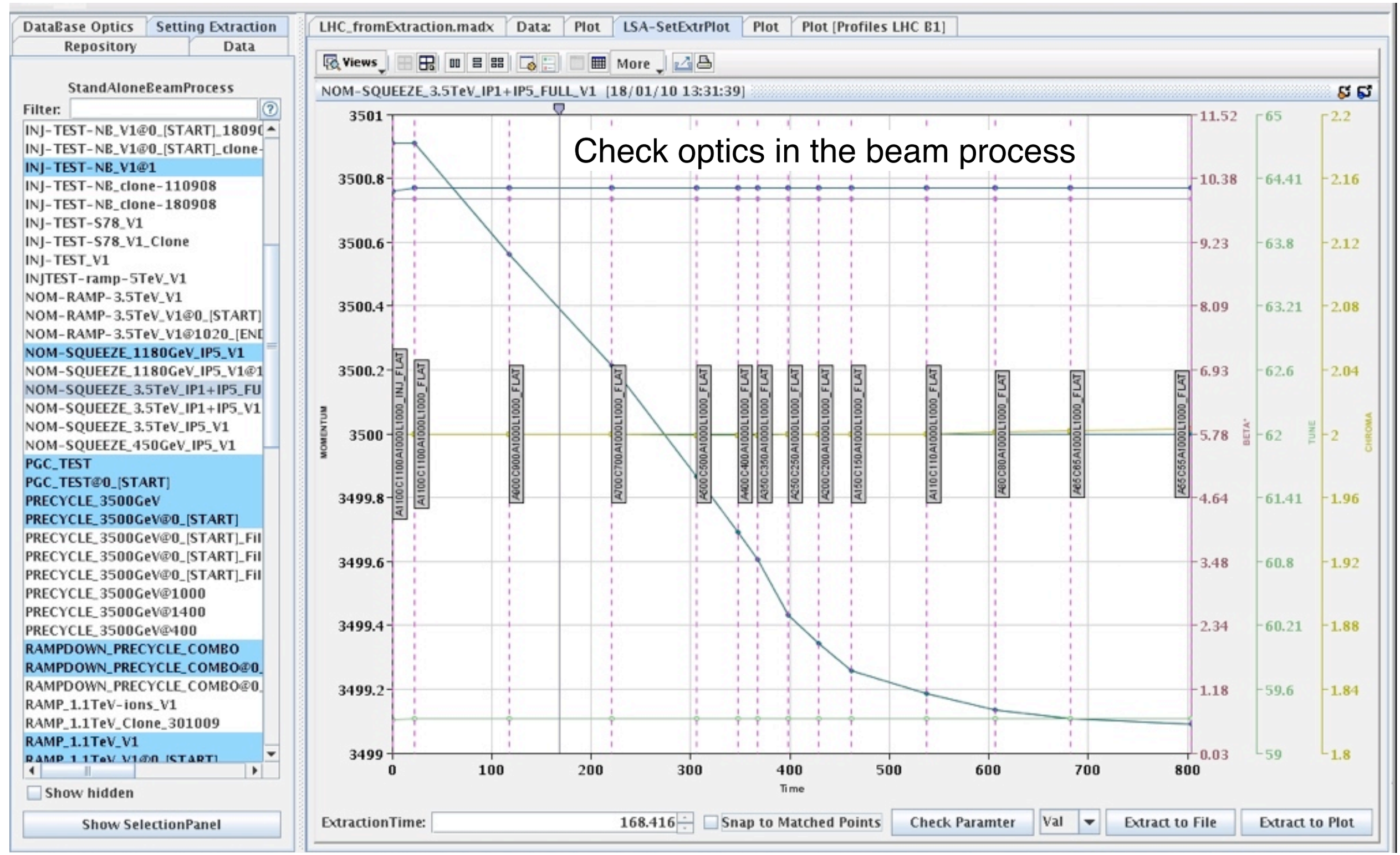
Status:

- All optics from ABP available and imported in the LSA database for latest layout of 2009

  Need to update them due to changes at the end of last year!
- Current settings tested with the power converters in simulations (except for IP2)
- The import into LSA highly automated within MADX-online
- Setting validation also available in MADX-online:

  Import and check knobs; verify K values calculated by LSA; check database optics
- TOTEM optics available since Oct. 2009 and not yet tested

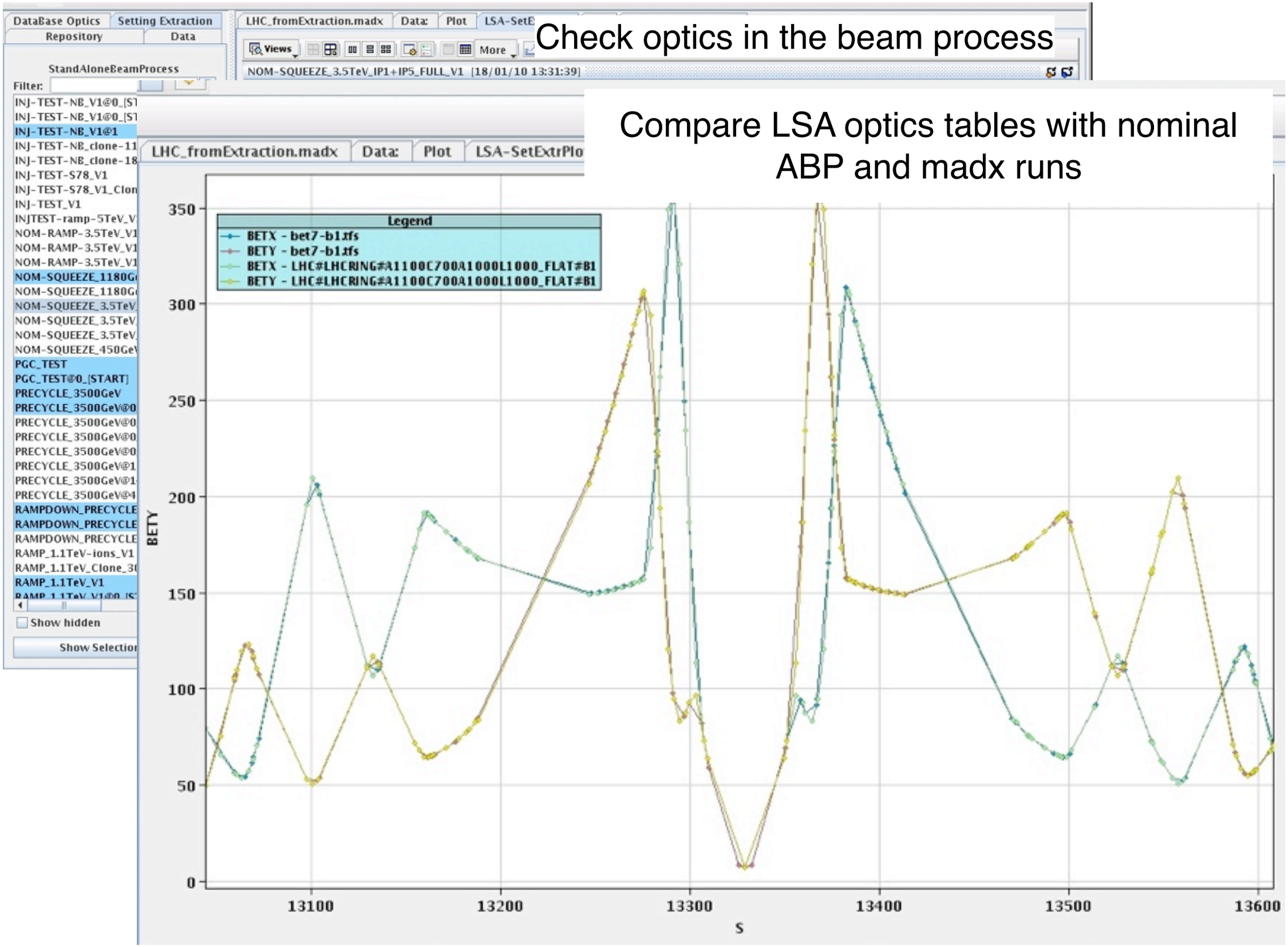
Setting checks with MADX online



Setting checks with MADX online

Check optics in the beam process

Compare LSA optics tables with nominal ABP and madx runs



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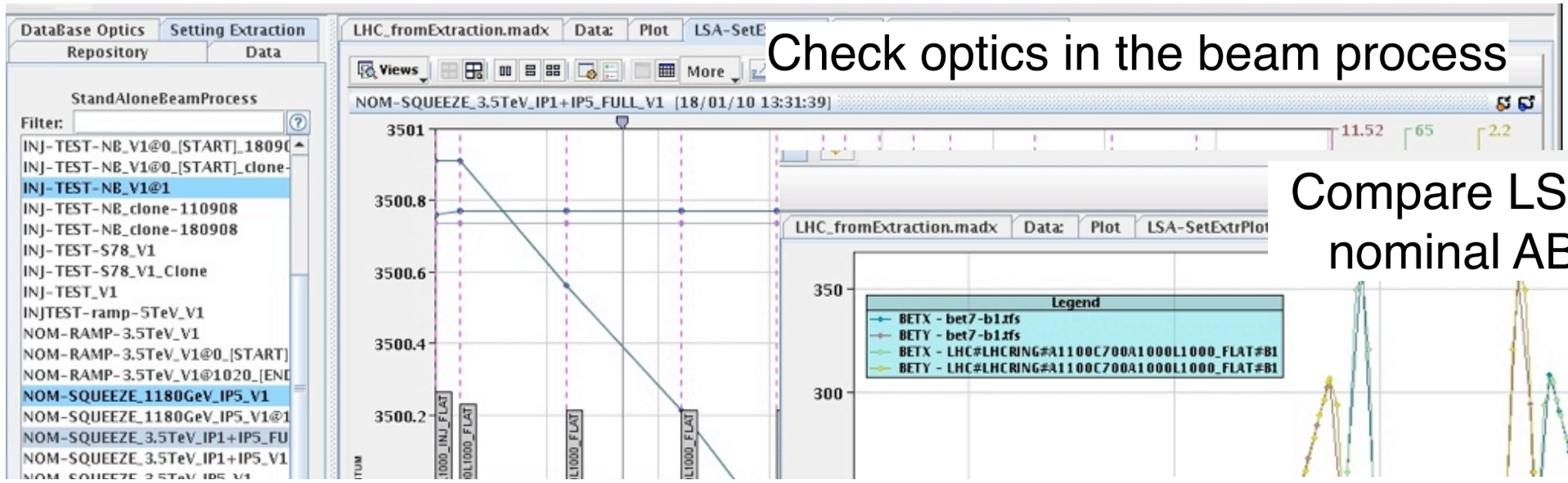

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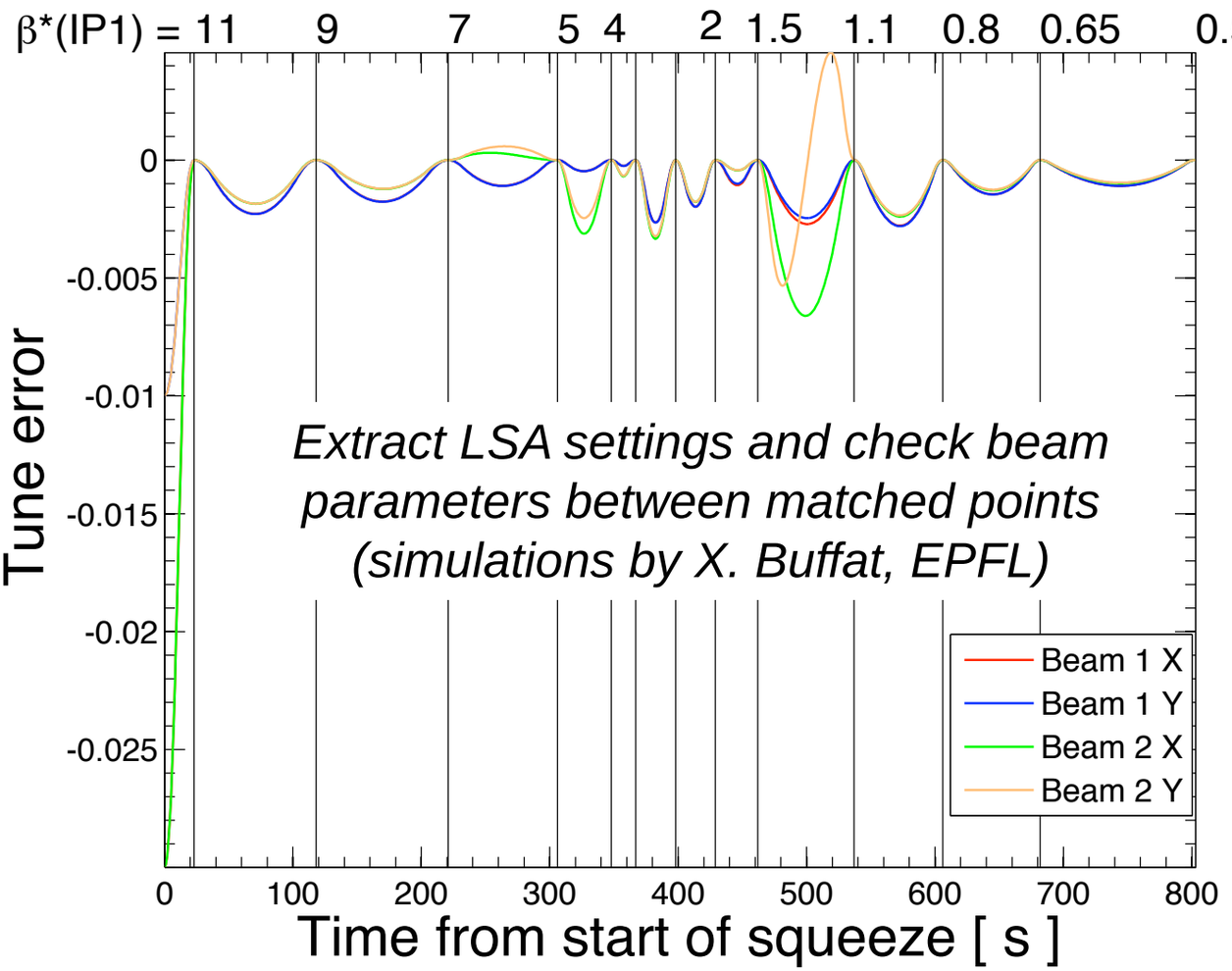
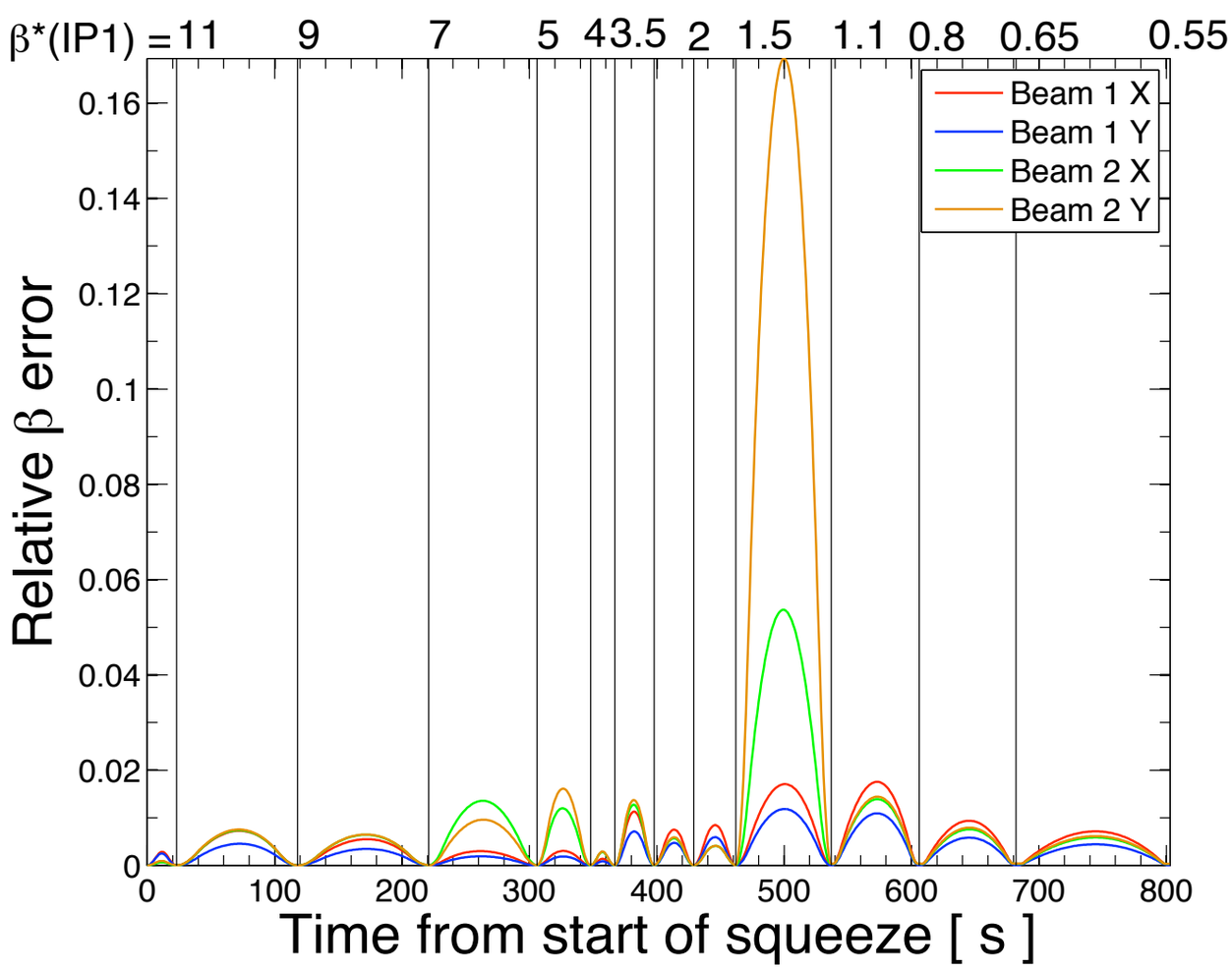


Extract LSA settings and check beam parameters between matched points (simulations by X. Buffat, EPFL)



Still not fail-safe: we managed to miss a few knob import for the squeeze test!

Outline

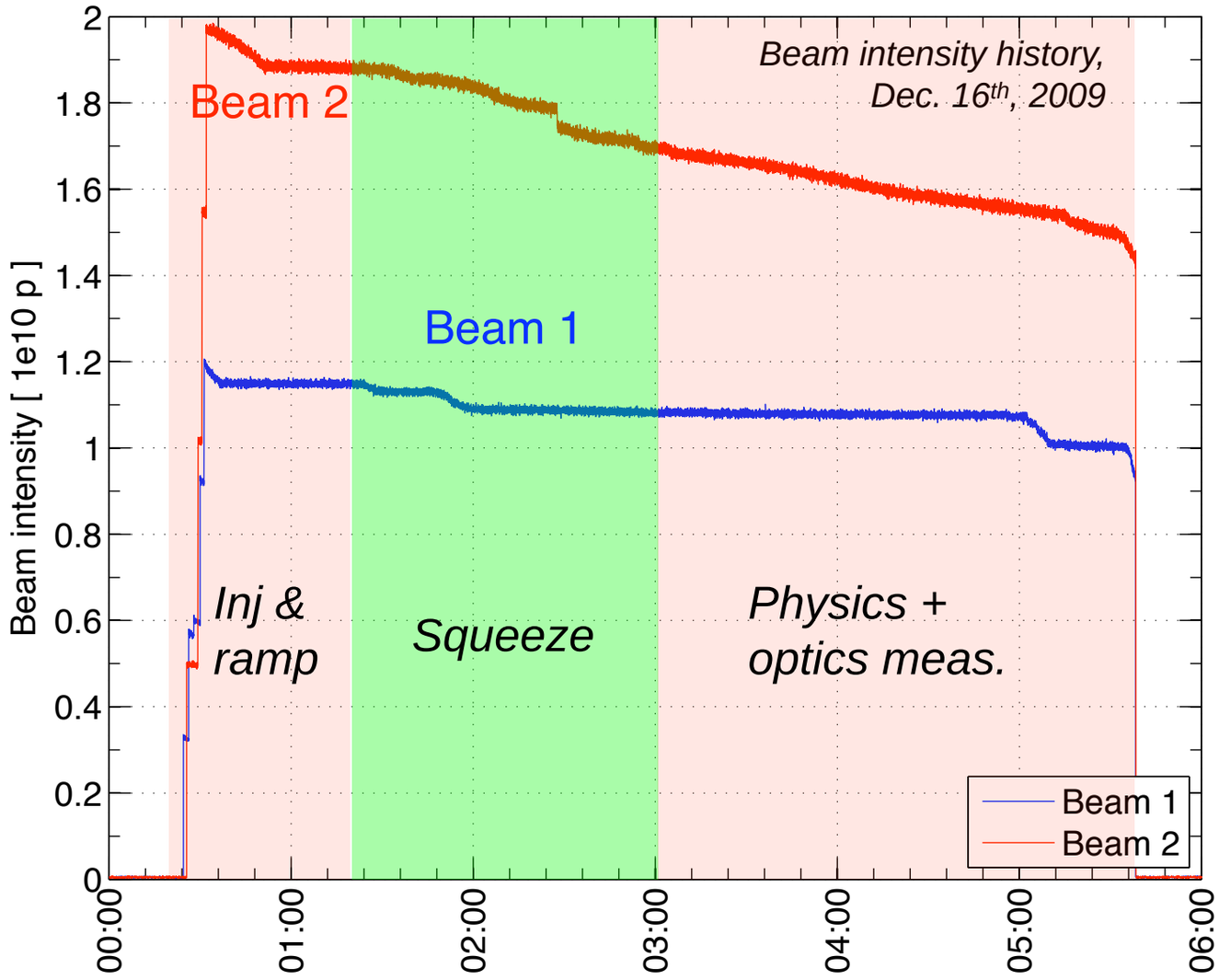
- ☑ Introduction
- ☑ Squeeze handling
- ☑ **Beam experience**
  - **Beam measurements**
  - **Some issues**
- ☑ Conclusions

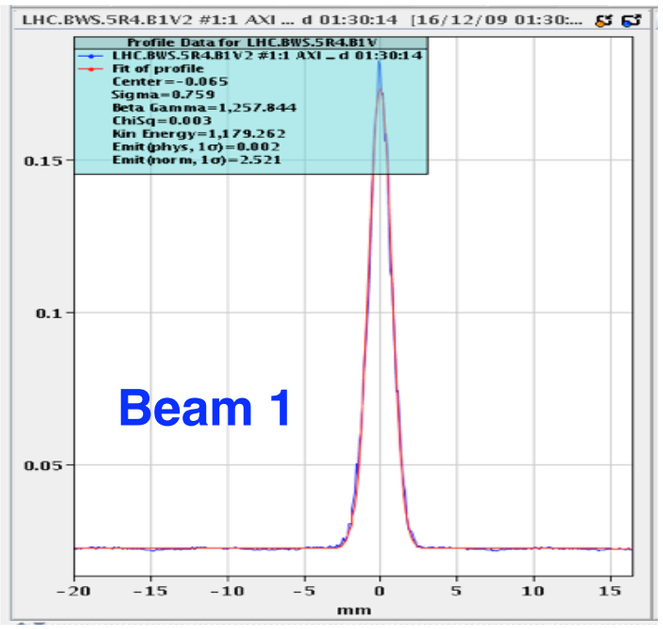
Conditions for beam tests

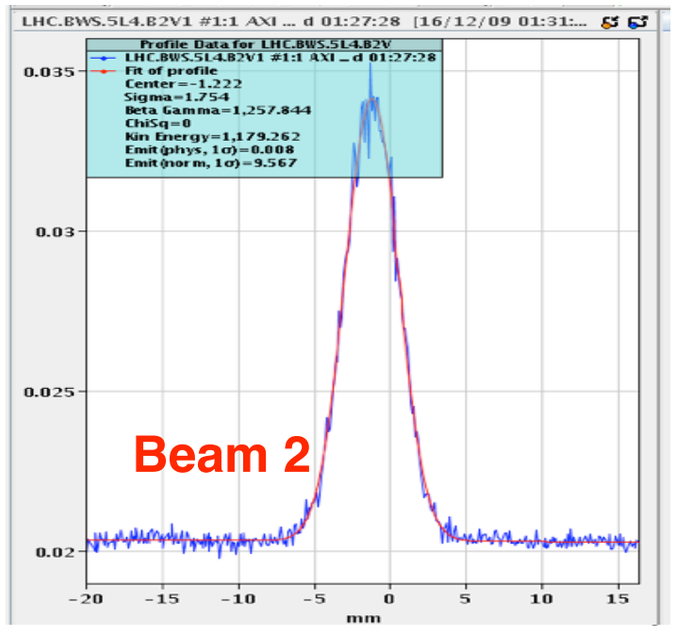
Beams:
- 1.18 TeV
- 4 bunches → $I_{B1} \sim 1 \times 10^{10}$ p
  $I_{B2} \sim 2 \times 10^{10}$ p
- Emittances: $\varepsilon_{x,y}^{B1} \sim 2.5$ µm
  $\varepsilon_{x,y}^{B2} \sim 4 / 9$ µm

Machine:
- End of ramp conditions
- Both beams circulating
- Separation OFF / Crossing OFF

Protection settings:
- Beam tests done with **SAFE BEAMS**
- Nominal collimator settings at 450 GeV:
  TCP / TCSG / TCDQ = 5.7 / 6.7 / 8.0 σ
- No energy scaling, fixed gaps in mm
  9.2 / 10.9 / 13.0 σ at 1.2 TeV
- Triplet protection: tertiary collimators (TCTs)
  at **± 15 mm** = 20 (H) / 30 (V) sigmas
  No detailed alignment around local orbit.
- IR and arc apertures ok.







Beam process for squeeze in IP5

*Shift to **collision tunes**, done with IP1 and IP5:*
ΔQ_x=0.03
ΔQ_y=0.01

β^* = 11 m

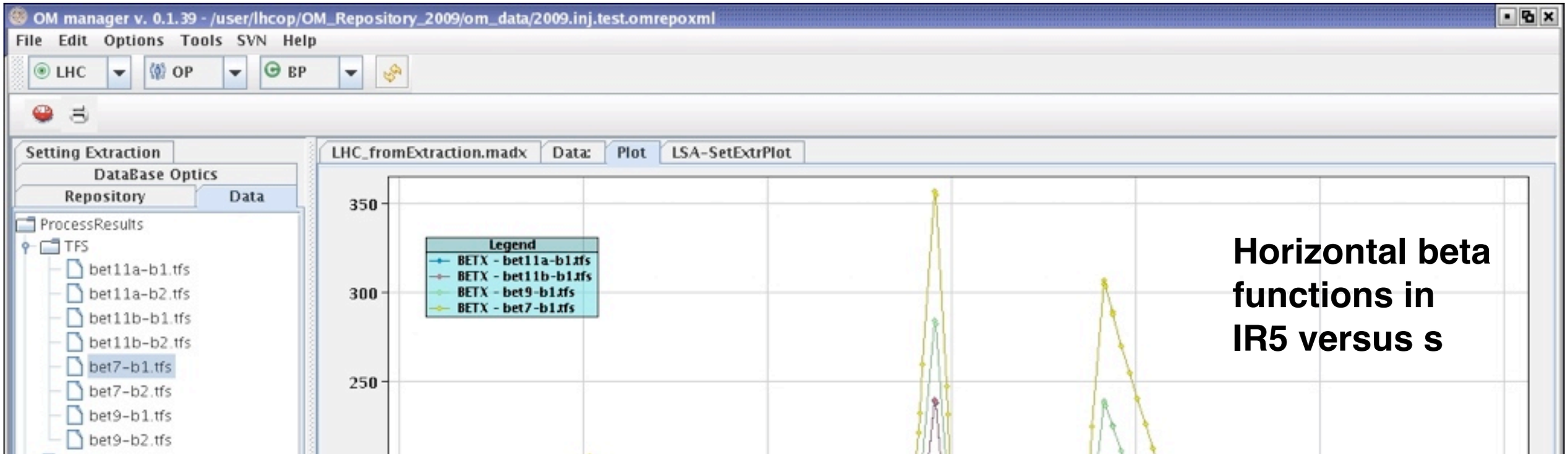
β^* = 9 m

β^* = 7 m

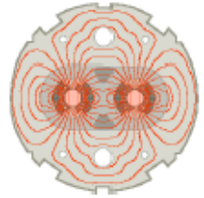
β^* = 5 m

We stopped there

Horizontal beta functions of beam 1



Recap. of commissioning procedure



From: http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA11/index.htm

Our general commissioning approach is the following (only for commissioning: the goal for routine operation is to have simultaneous squeeze of the IP concerned):

1. Start with a single pilot Beam 1 and squeeze IP1 without separation.
2. Verify squeeze of one beam with parallel separation.
3. Squeeze two separated pilot beams in IP1.
4. Squeeze IP5 with a single pilot Beam 1 simultaneously with IP1 squeeze - try with separation ON.
5. Try two beams in IP5 as well (IP1 squeezed in parallel).
6. Squeeze of IP8 follows (1), (2) and (3); then squeezed IP8 in parallel with IP1 and IP5.

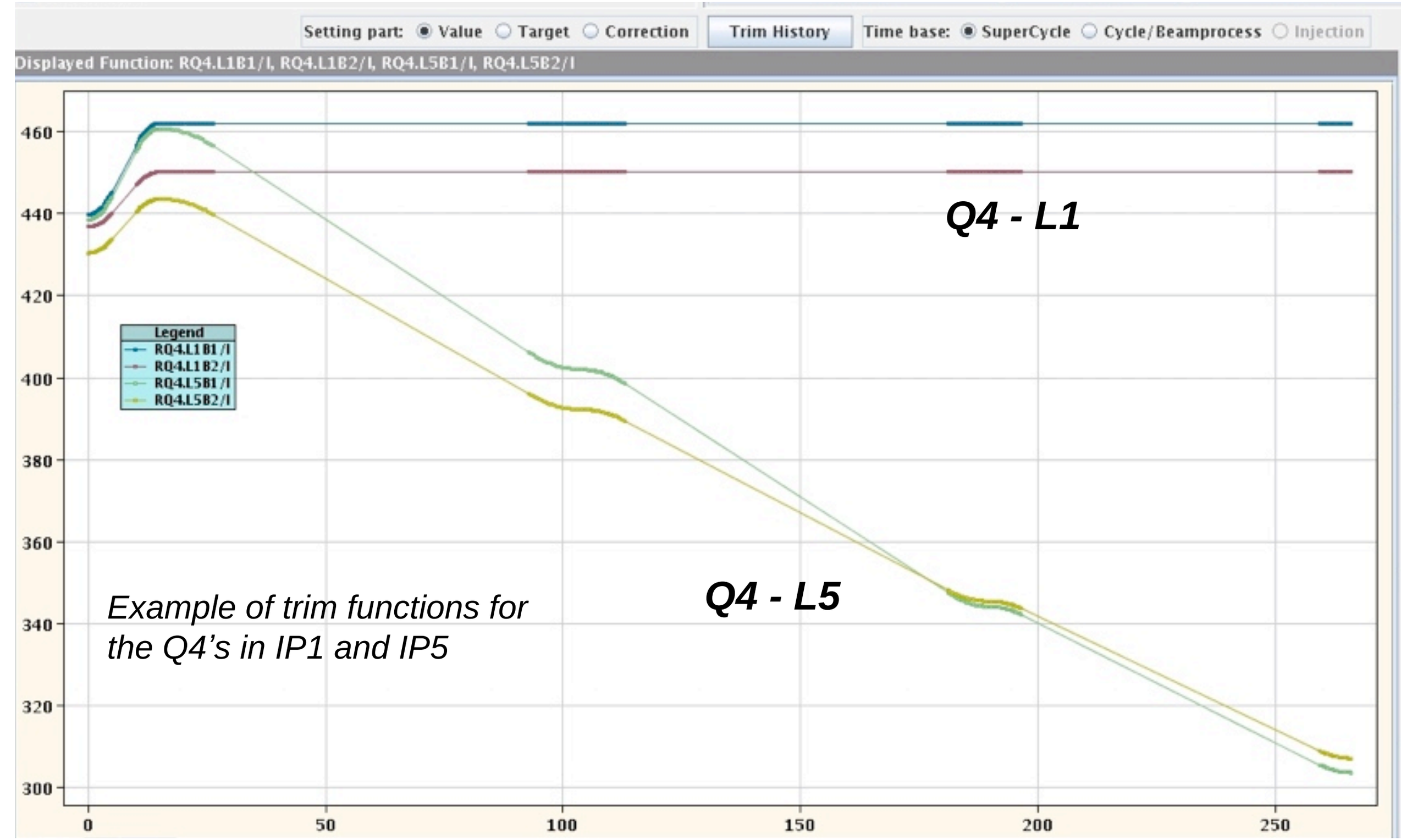
Having seen the remarkable machine quality, we proceeded as it follows (**SAFE beams**!):

1. Start directly with two beams in the machine;
2. Start with multi-bunches (I_{tot} = 1-2 x 10^{10} p) [pilot was meant for 7 TeV!];
3. One squeeze step done for IP1 and IP5 together at the first try;
4. Tests done with colliding beams (no separation, no crossing);
5. Tested the tune feedback during one squeeze step.

(1), (2), (3) and (5) can be incorporated in the procedure for the future (*keep previous strategy as a fall-back in case of problems at smaller β^*!*).

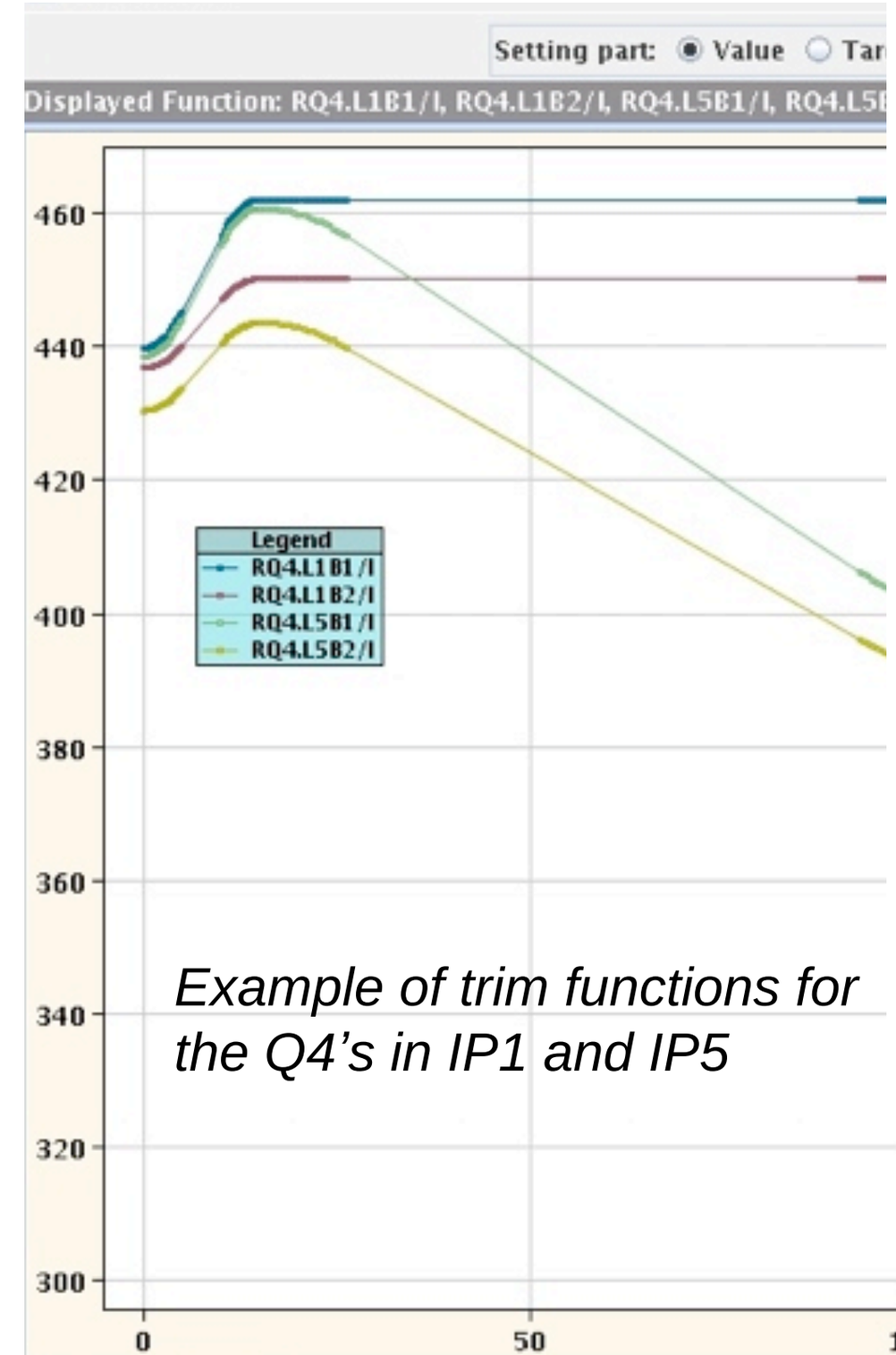
IP2 and IP8 will be done with squeezed IP1/IP5 in 2010.

PC currents and beam test procedure

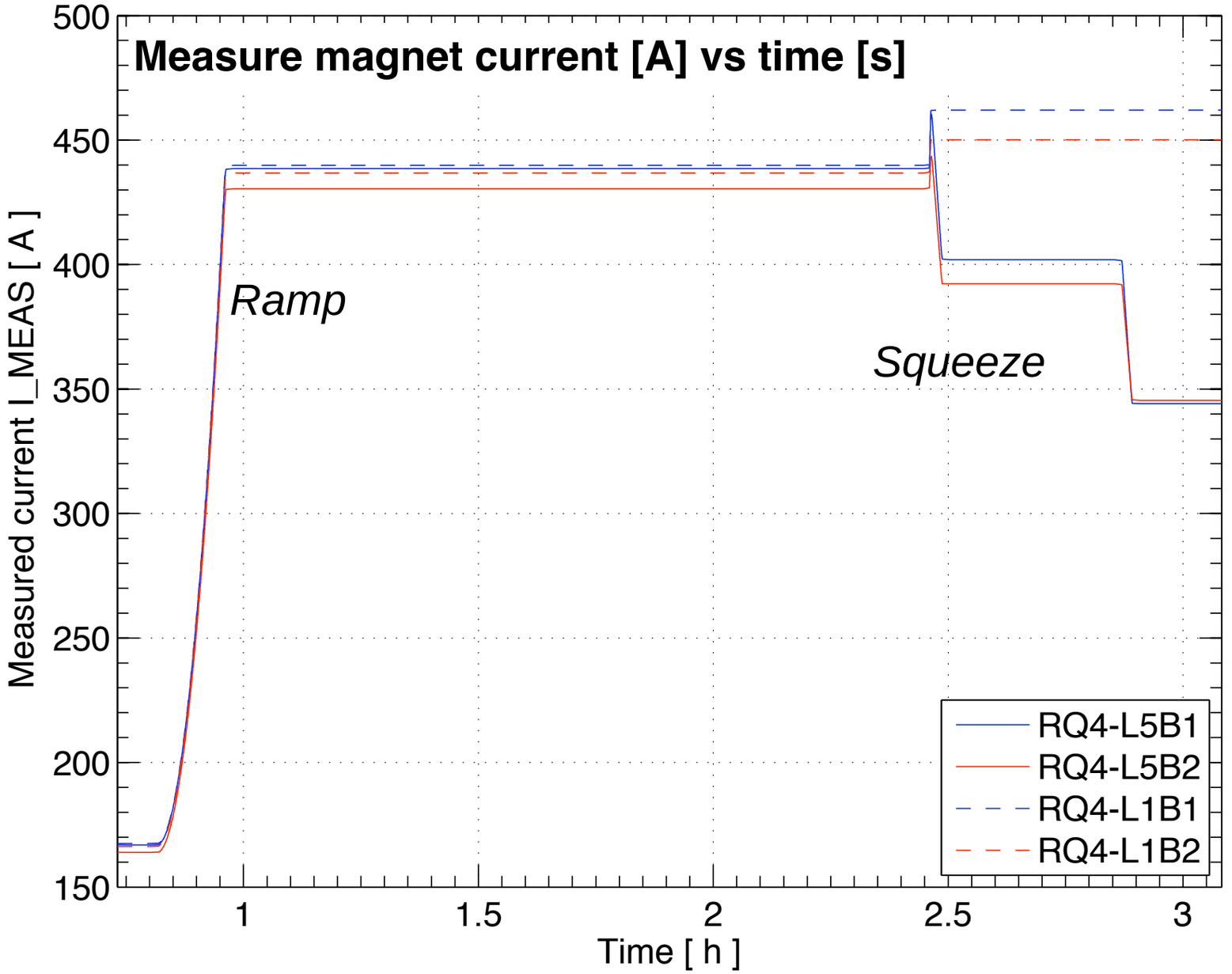


Example of trim functions for the Q4's in IP1 and IP5

PC currents and beam test procedure



Example of trim functions for the Q4's in IP1 and IP5



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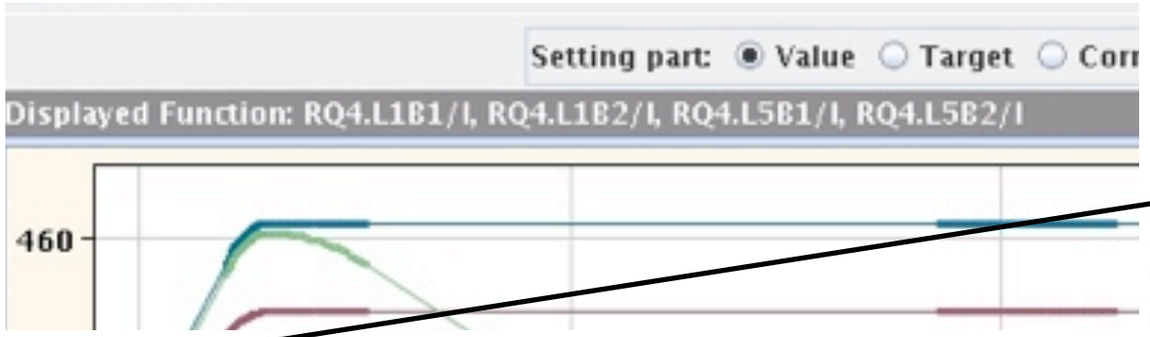
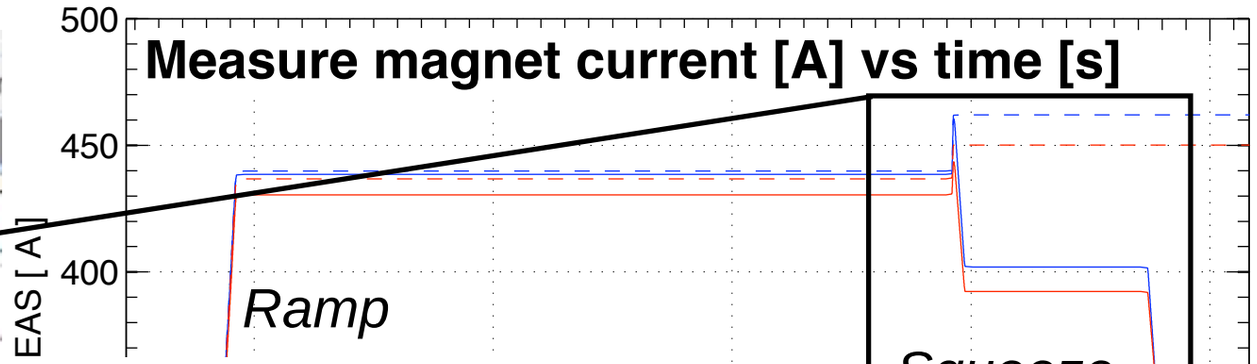
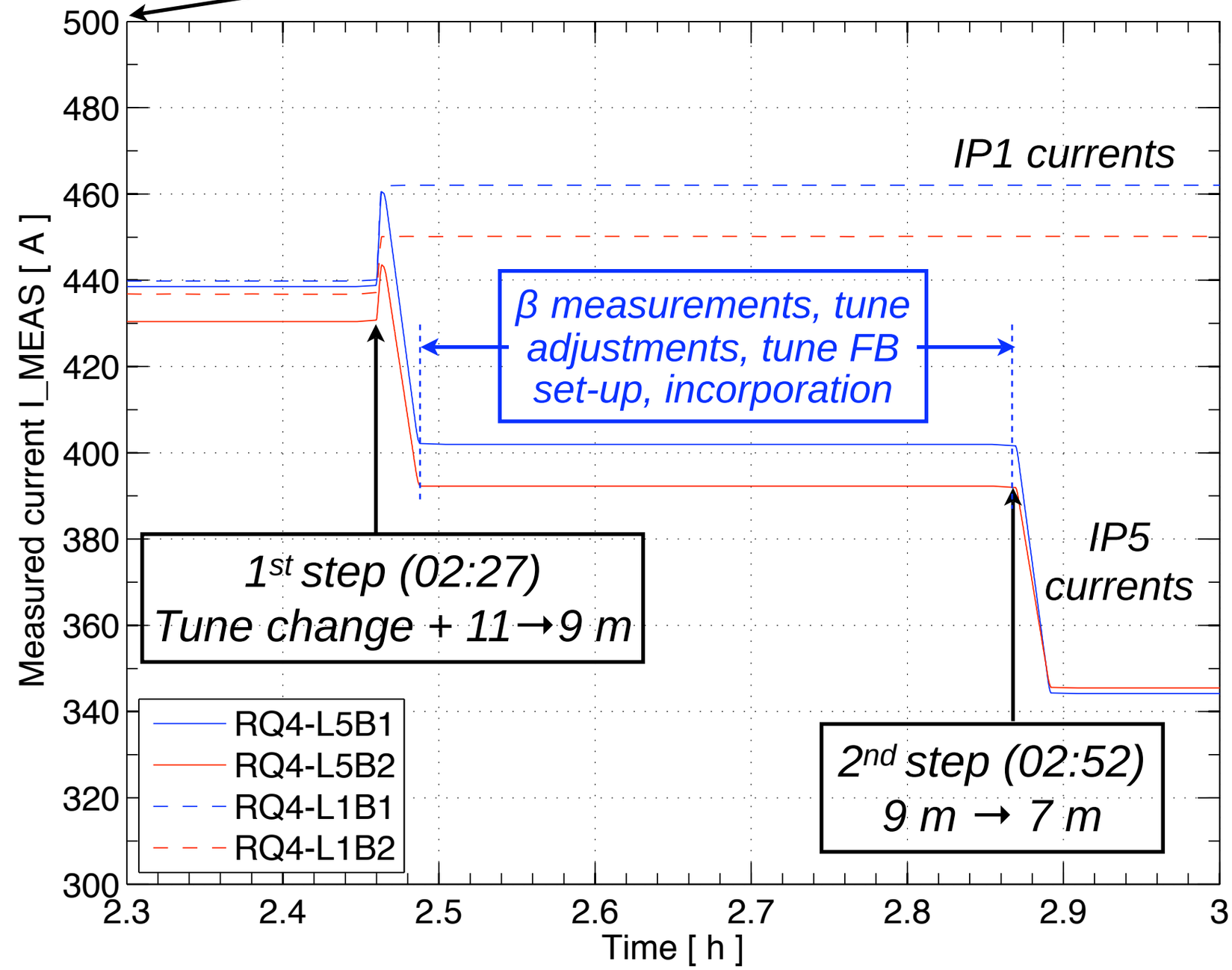
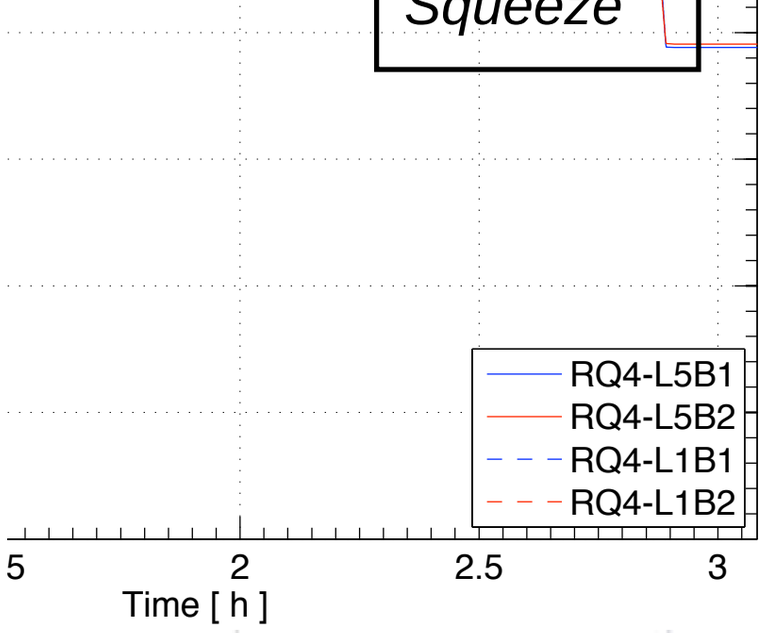








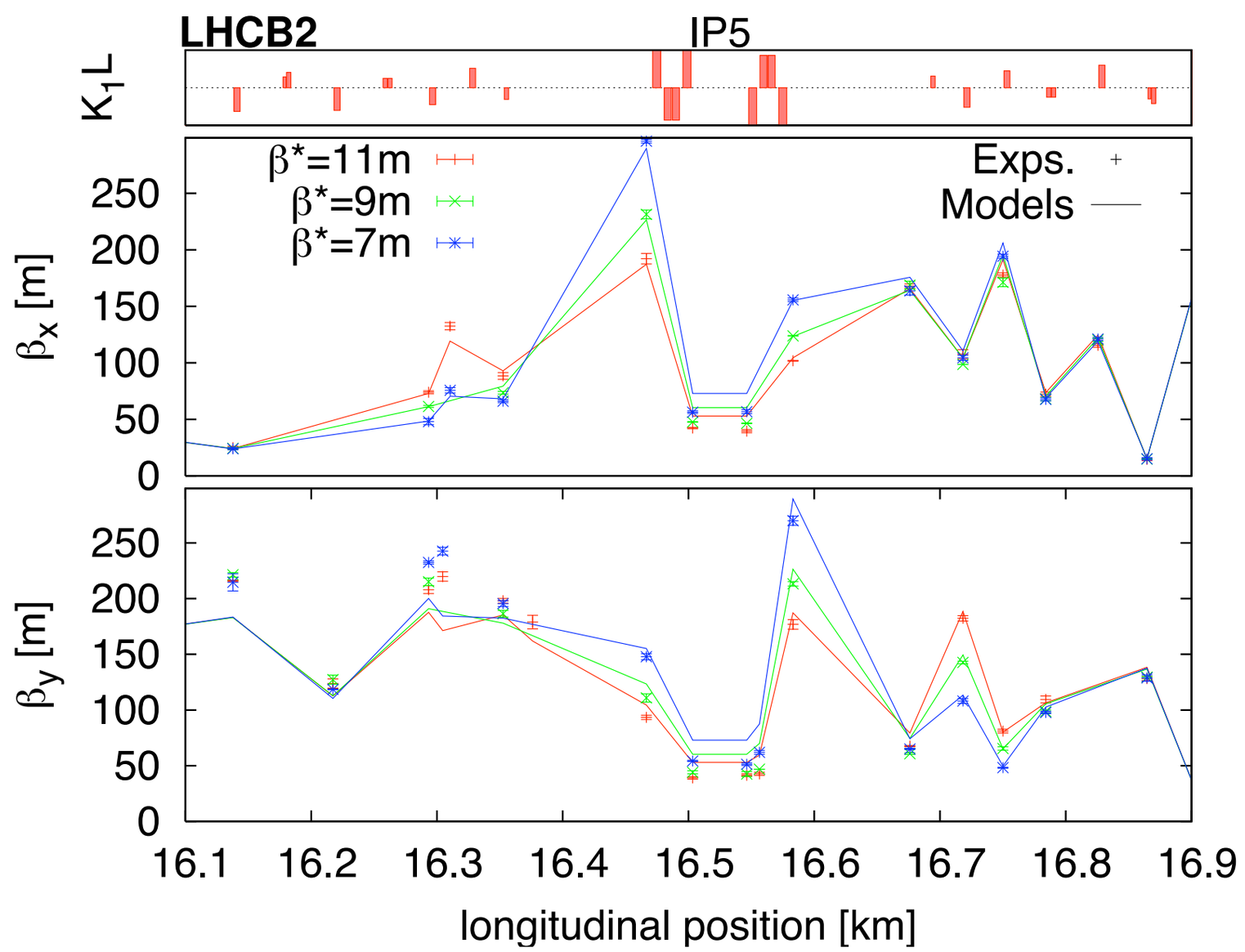
Operational procedures:
- Step for tune change (IP1/5) and jump from 11 m to 9 m (IP5 only) with tune FB OFF
- Jump from 9 m to 7 m in IP5 with feedback ON
- Incorporation of chromaticity settings as of end-of-ramp

Results

Online measurements, as of logbook:

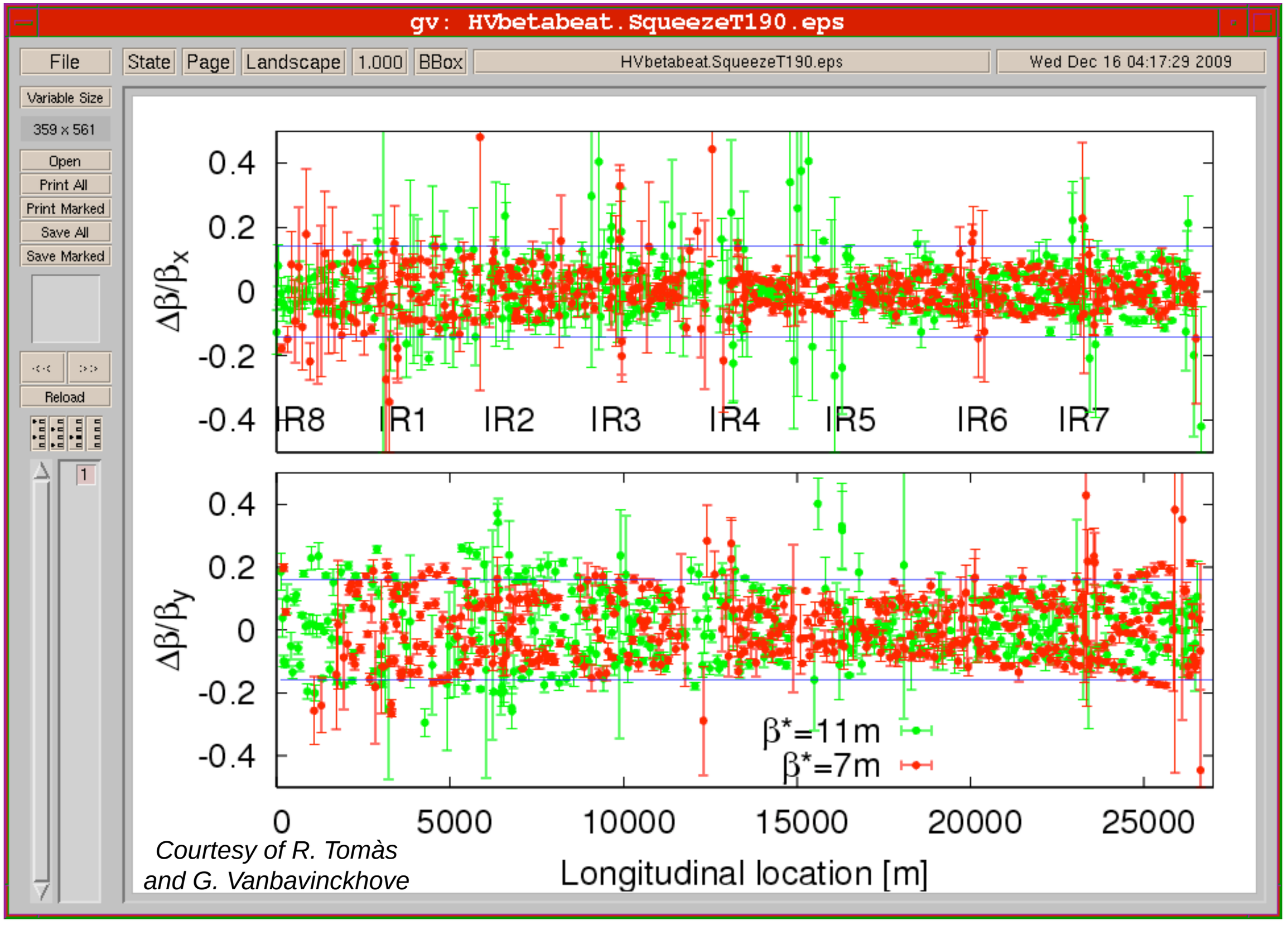
42	03:22	IP5 Beta* summary from the on-line measurement: H V 0step (11m) 10.2 +- 1.0 11.8 +- 1.0 1step (9m) 8.8 +- 1.0 11.7 +- 3 2step (7m) 6.8 +- 0.3 7.5 +- 0.5

Measured beta functions in IP5 for the various steps.



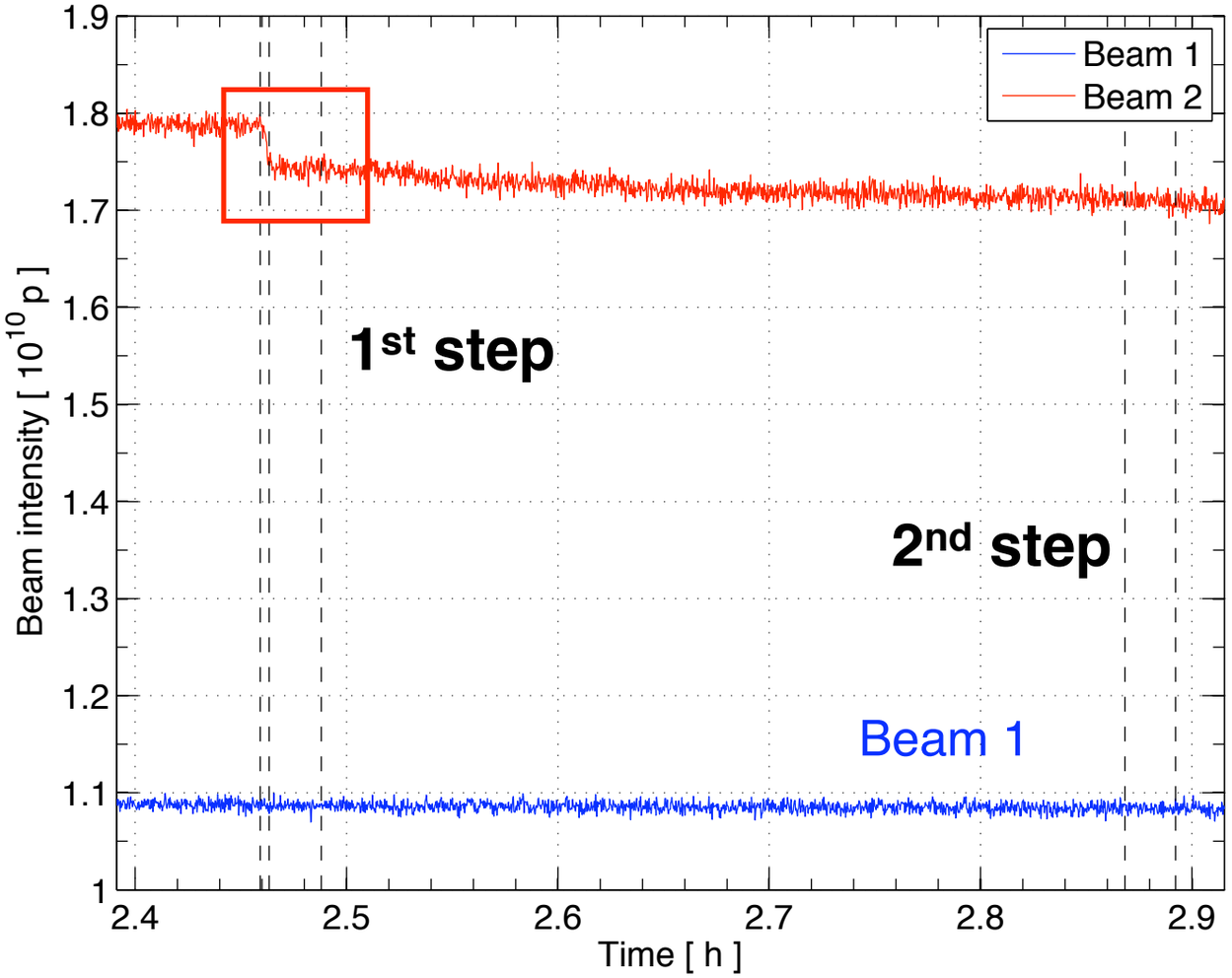
Courtesy of R. Tomàs and G. Vanbavinckhove

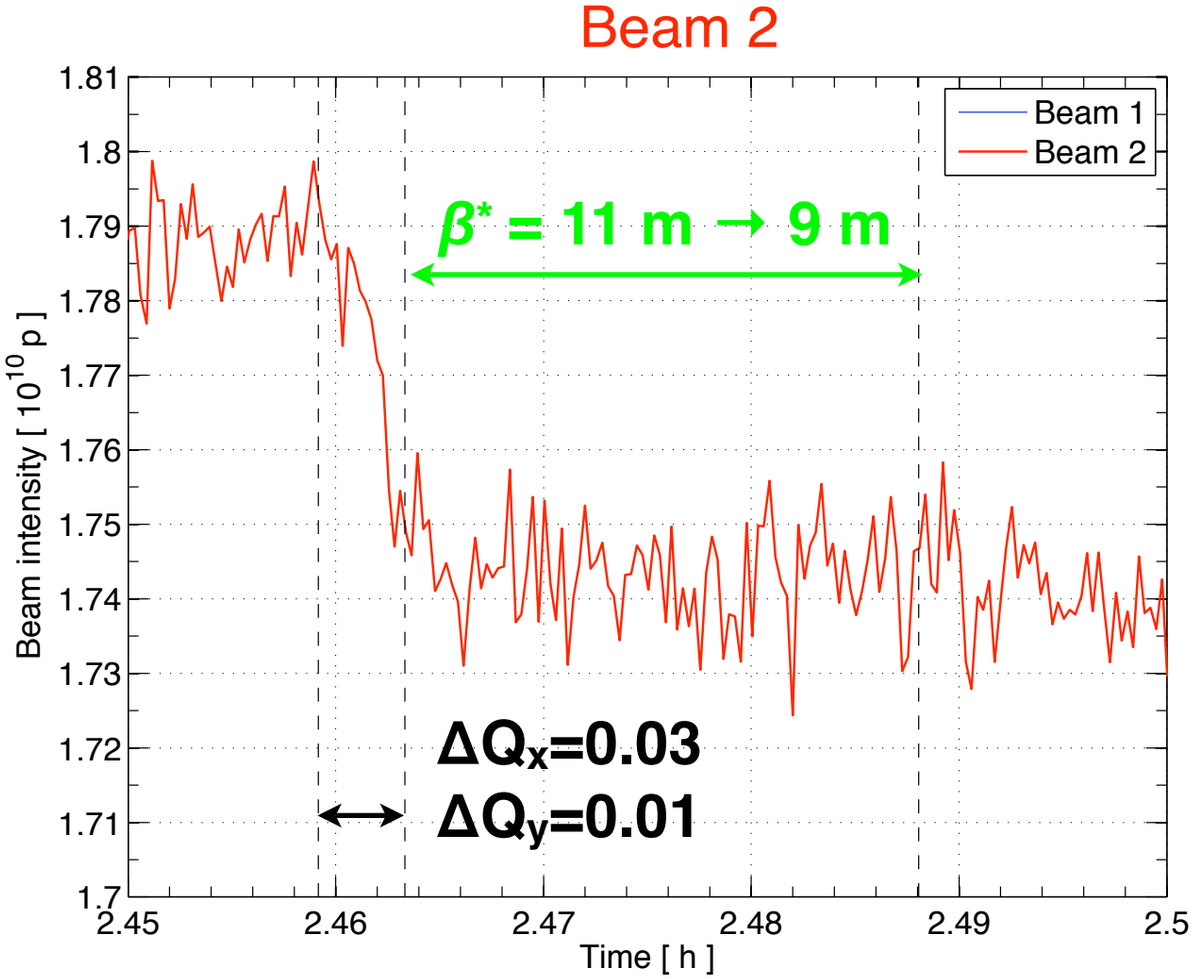
Squeeze improves the β-beat??



Courtesy of R. Tomàs and G. Vanbavinckhove

Beam losses: beam current





About **3%** of **beam 2** lost during the 1st squeeze step (11 m → 9 m); no losses of beam 1.

Second squeeze step (9 m → 7 m) was clean for both beams.

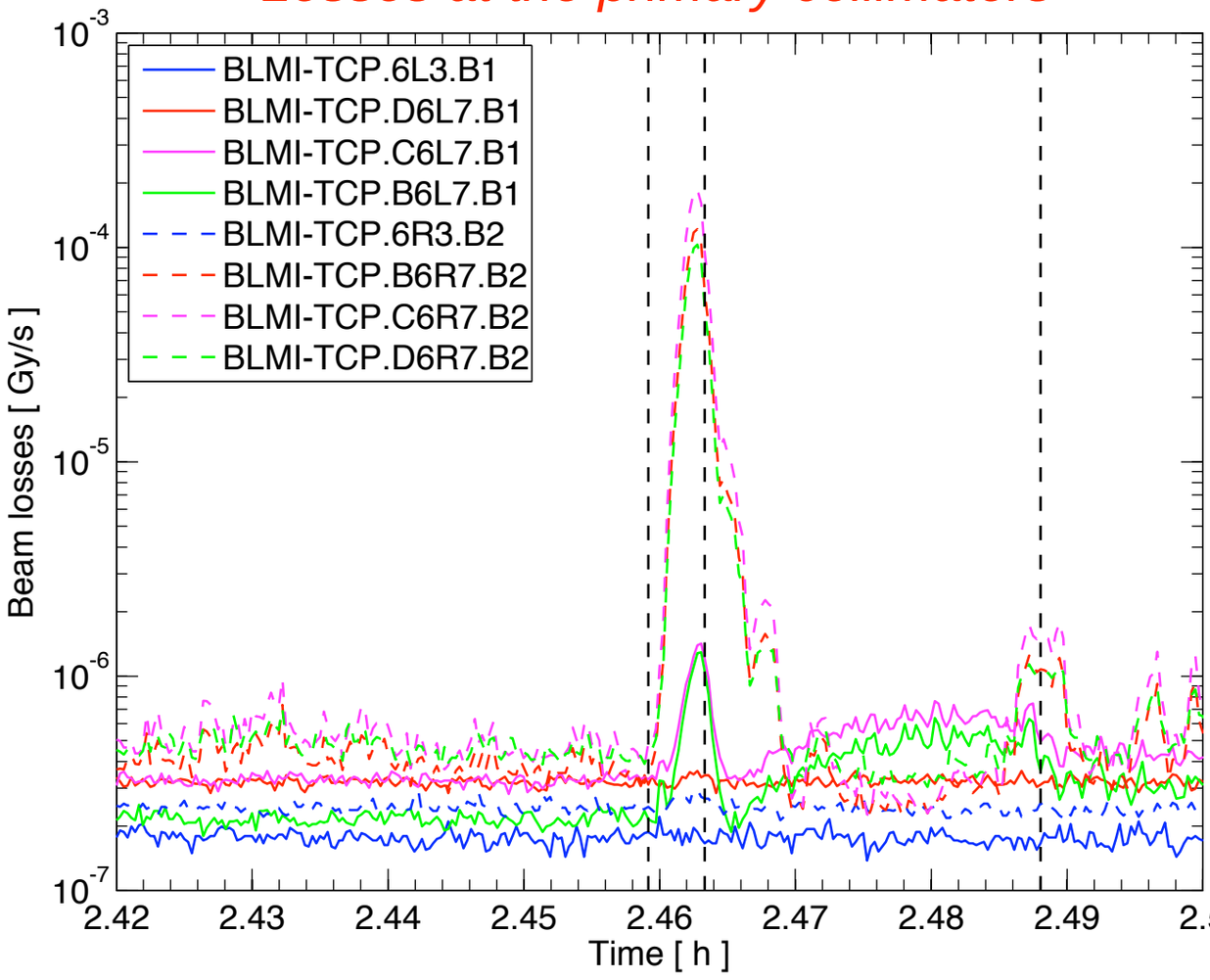
The losses occur ***during the tune transition (15 s)***, not during the beta changes.

No systematic for both beams (B2 emittance was larger).

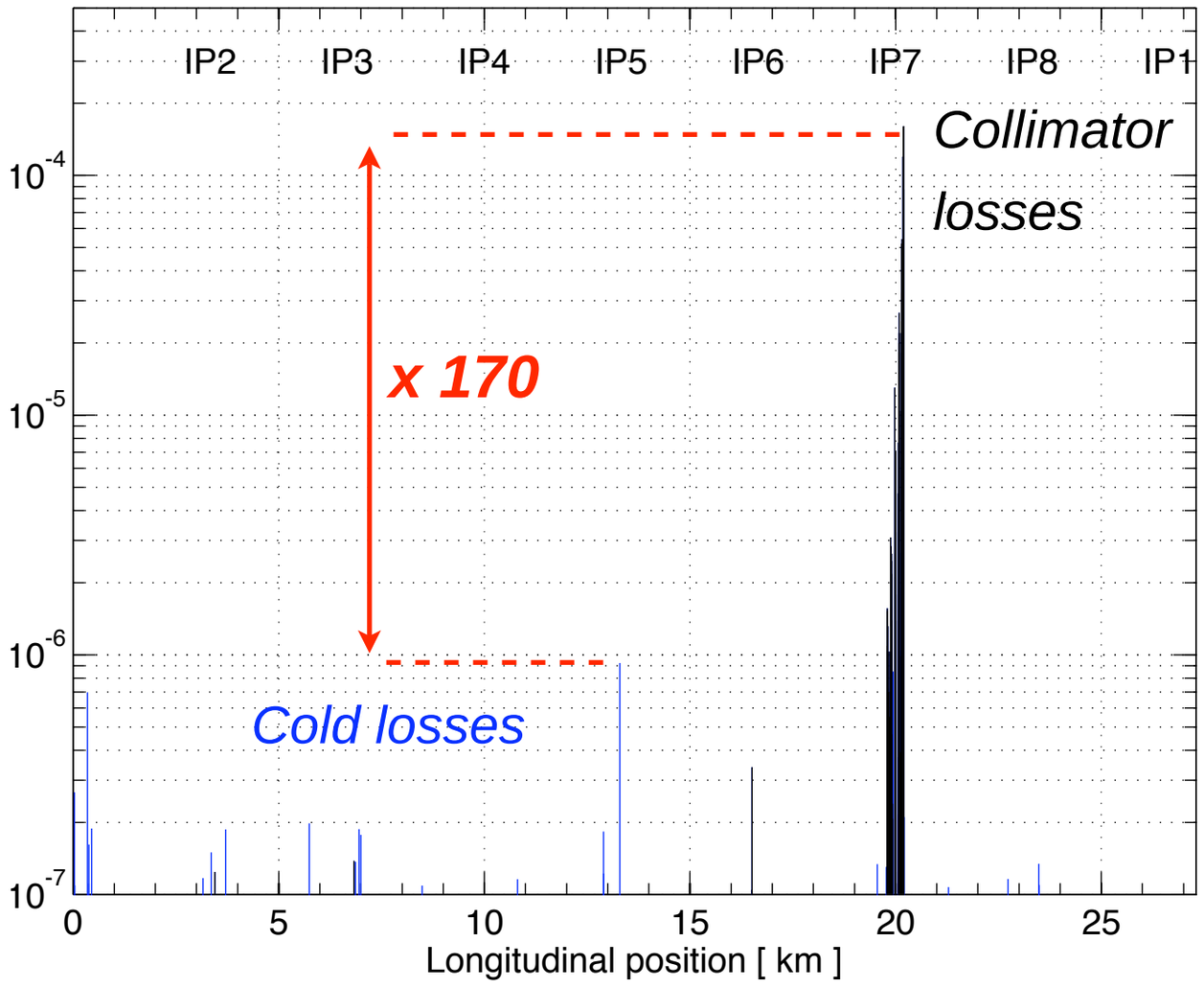
No indications that different optics have different lifetimes.

Loss maps around the rings

Losses at the primary collimators



Loss pattern at peak loss rate



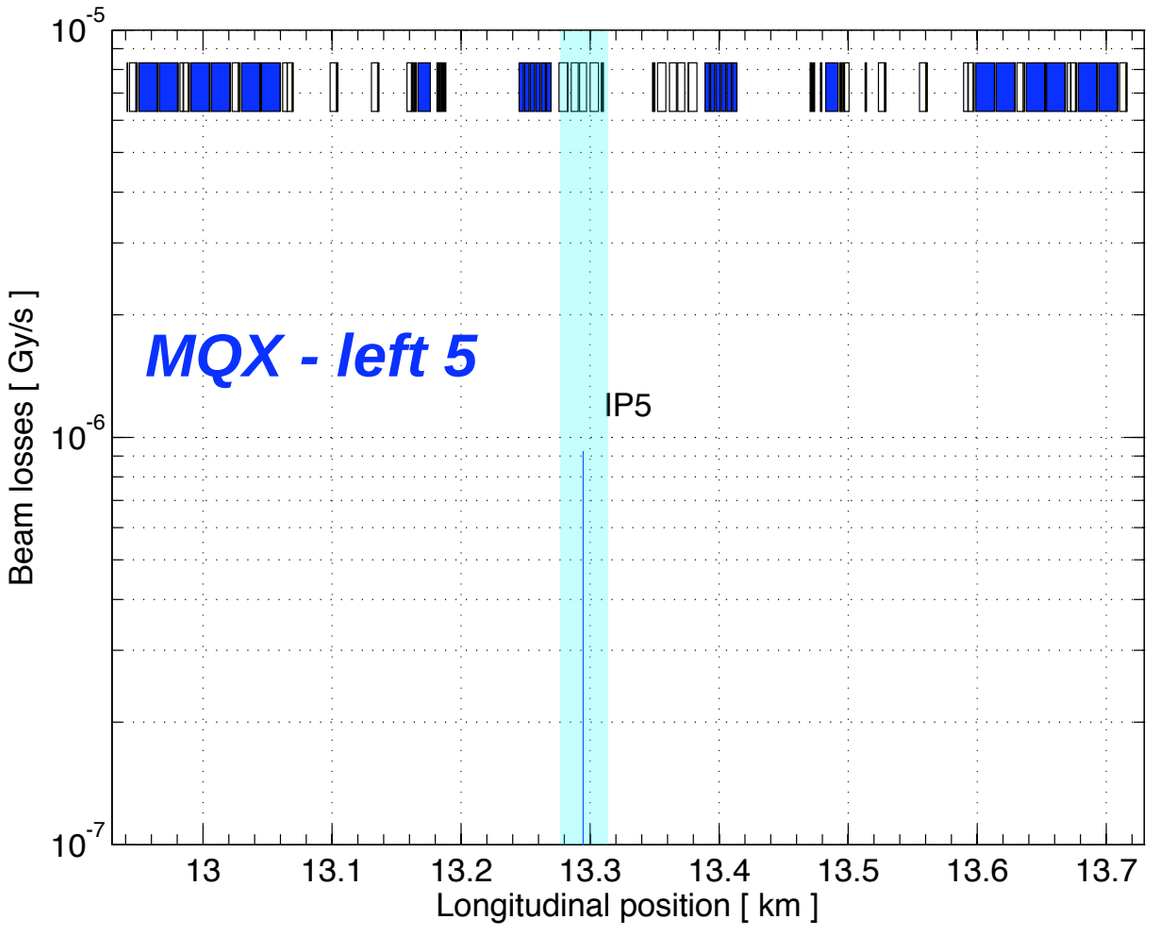
Highest loss peaks at the primary collimators of IR7, as expected!

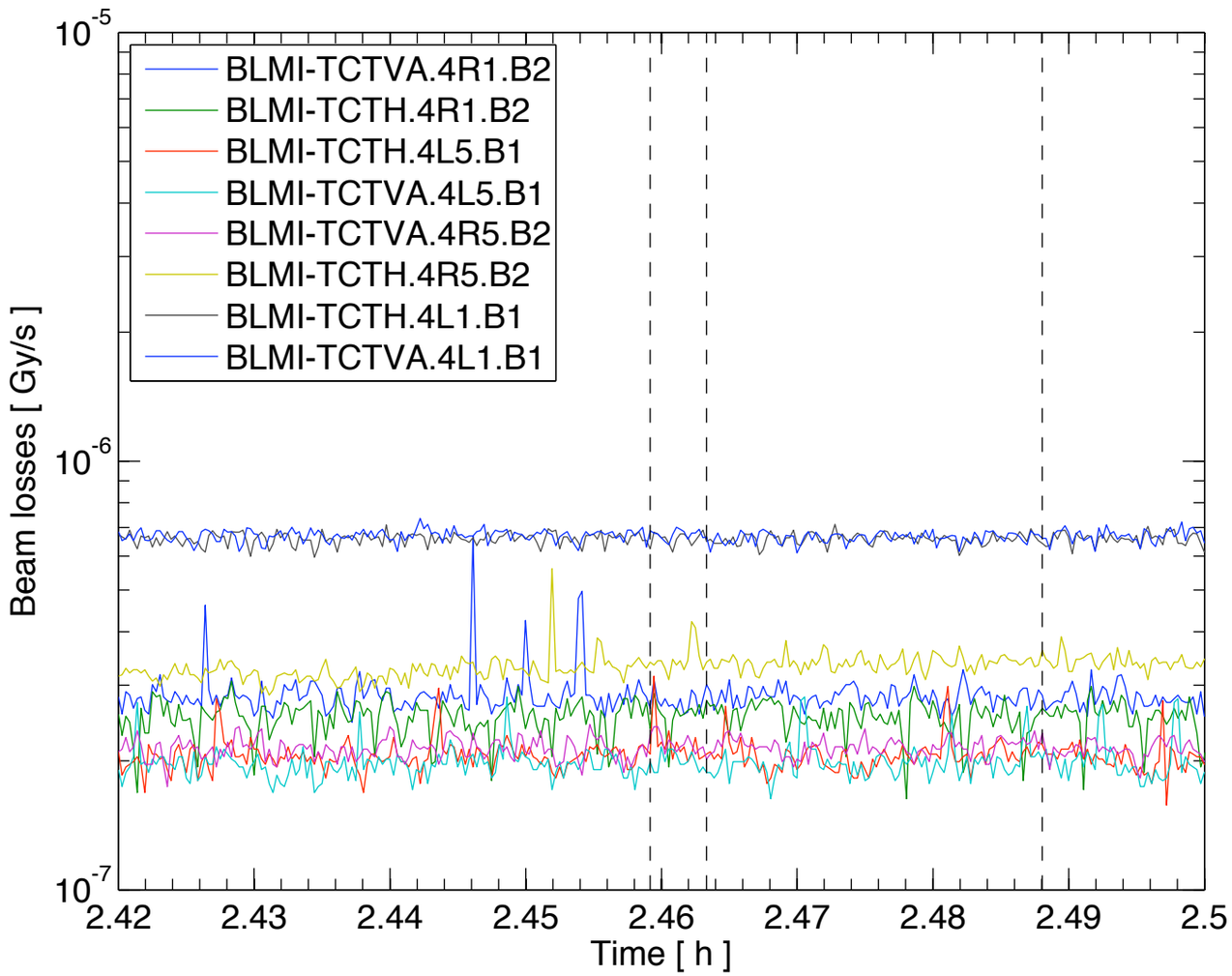
Cleaning efficiency much reduced with respect to the values at injection *(see C. Bracco's talk).*

Note that the collimation system WAS NOT SET-UP IN THESE CONDITIONS!

Optics and orbit changed with respect to the references at 450 GeV used for collimator setup!

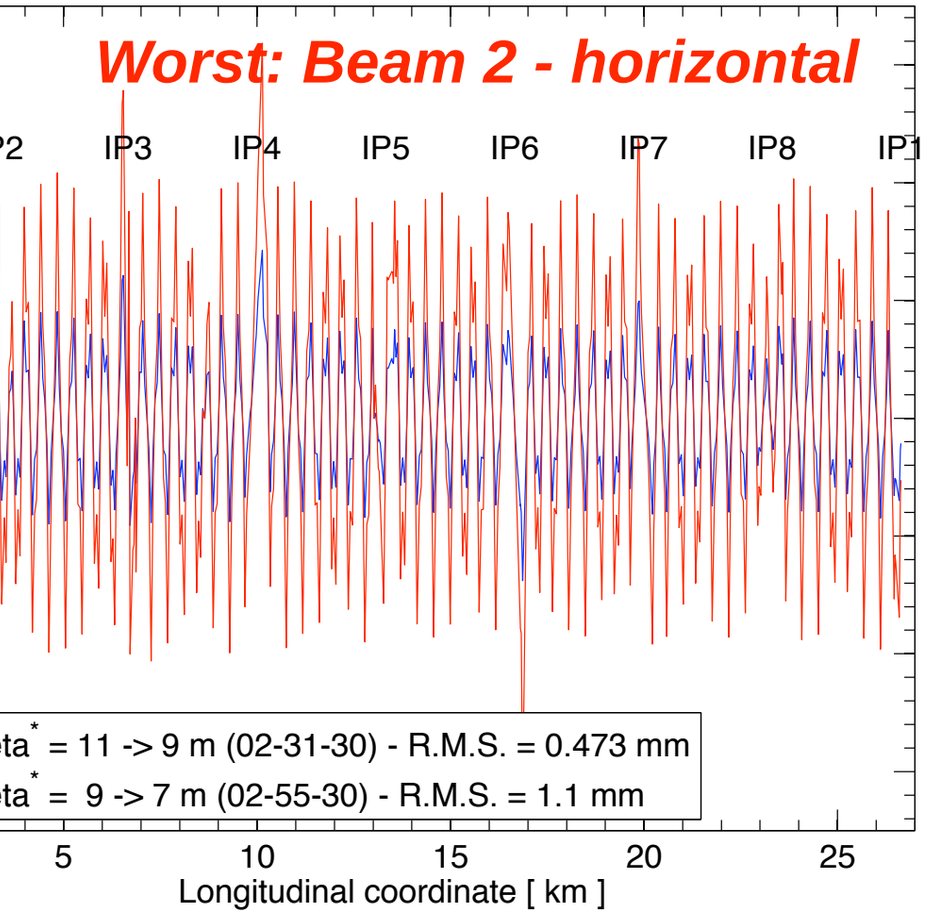
Details of losses in IP5

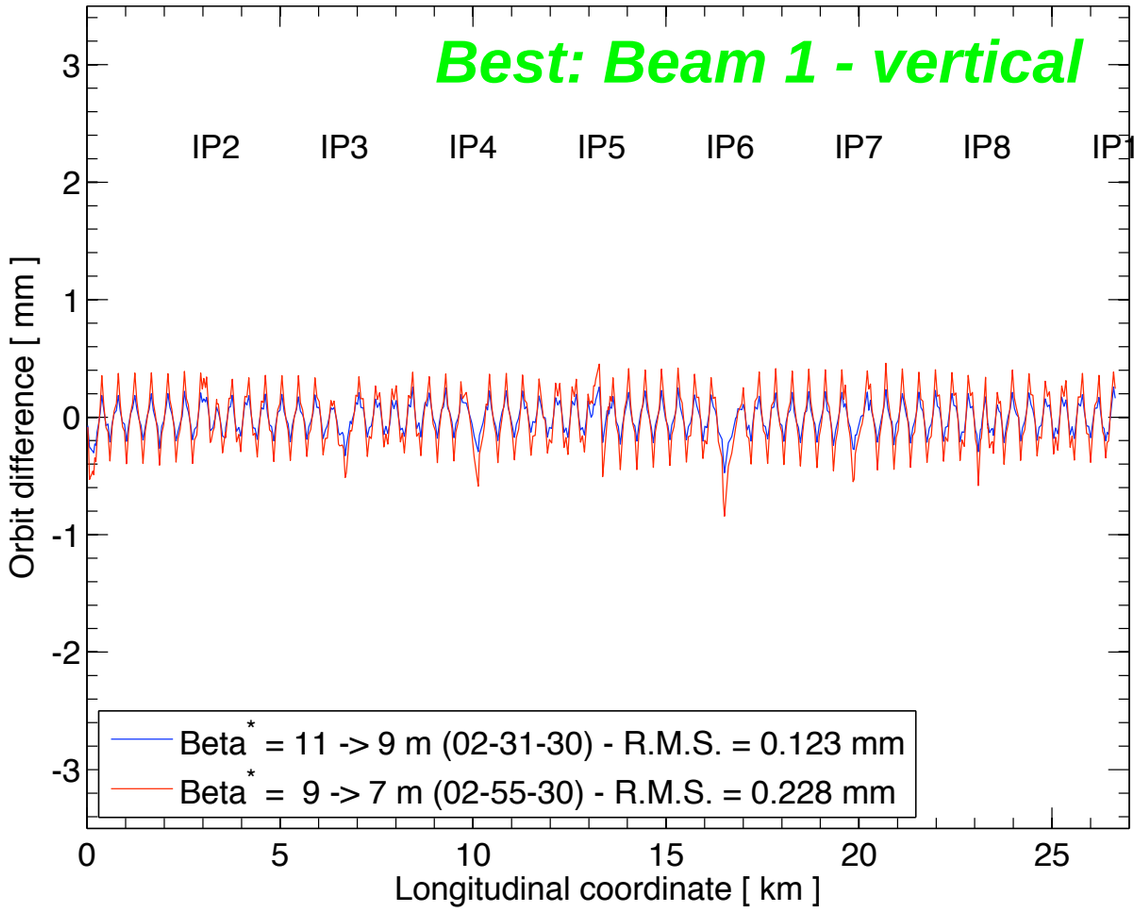




Losses in the triplet left of IP5 that are not caught by the tertiary collimators!

Orbit drift during the squeeze





Orbit errors induced by the change of gradient in the IP5 quadrupoles.

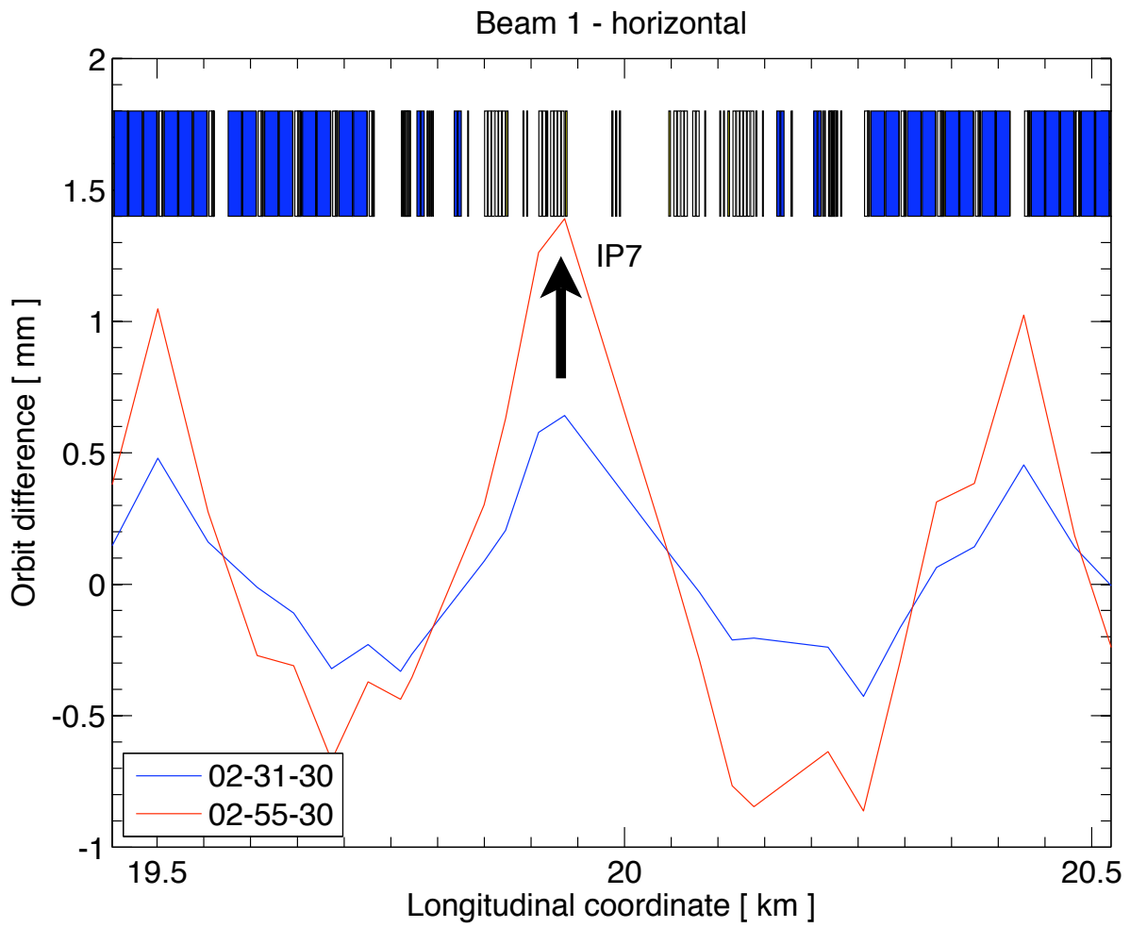
"Easy" to correct for a static machine but not while squeeze is being executed.

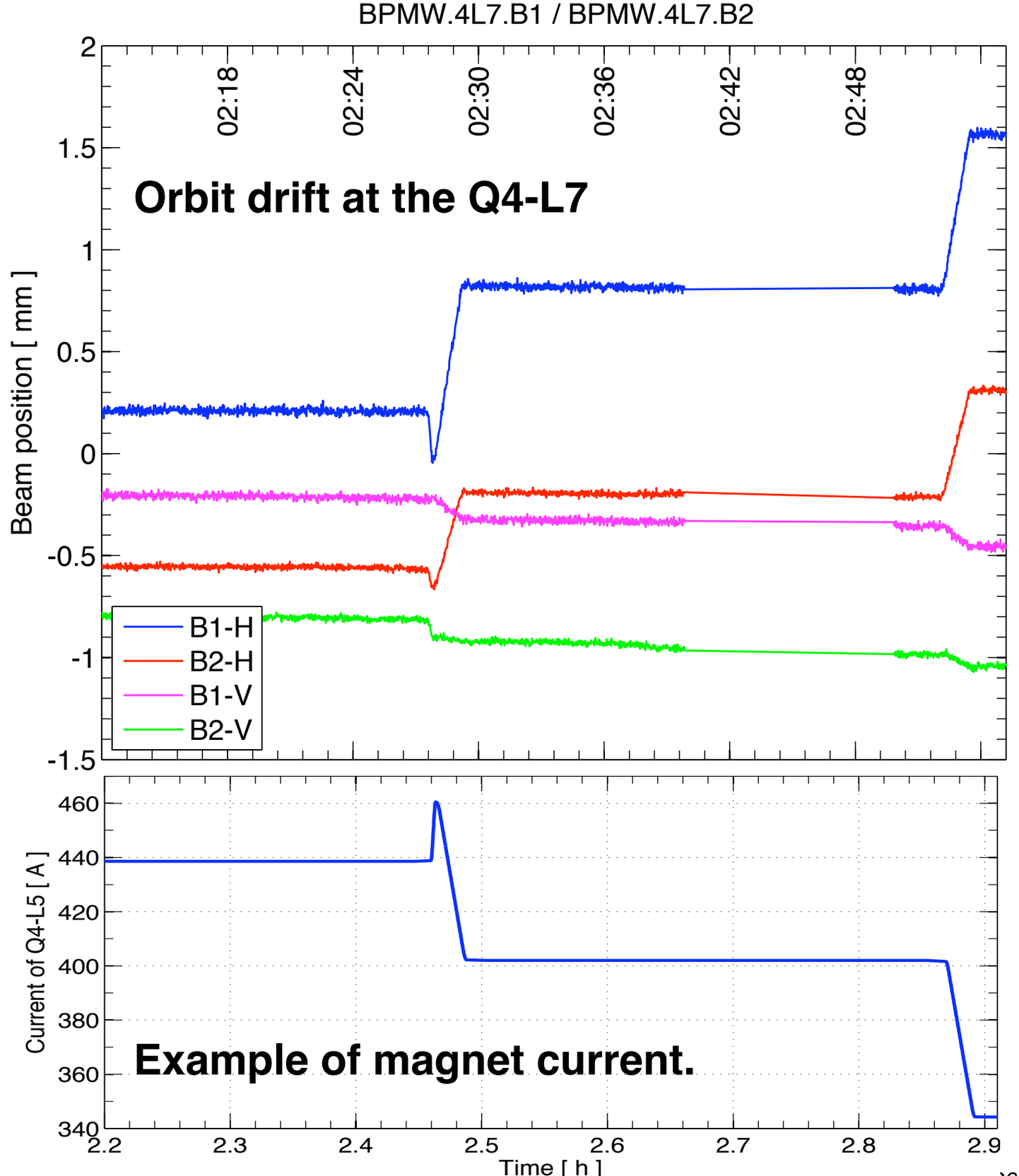
Solutions:

- Orbit feedback!
- Additional matched points
- Feed-forward?

		Orbit RMS (peak) in mm	
		$\beta^* = 11 \rightarrow 9$ m	$\beta^* = 9 \rightarrow 7$ m
Beam 1	H	0.245 (0.769)	0.589 (1.690)
	V	0.123 (0.472)	0.228 (0.842)
Beam 2	H	0.473 (1.430)	**1.100 (3.280)**
	V	0.132 (0.353)	0.283 (0.79)

Orbit drifts in IP7

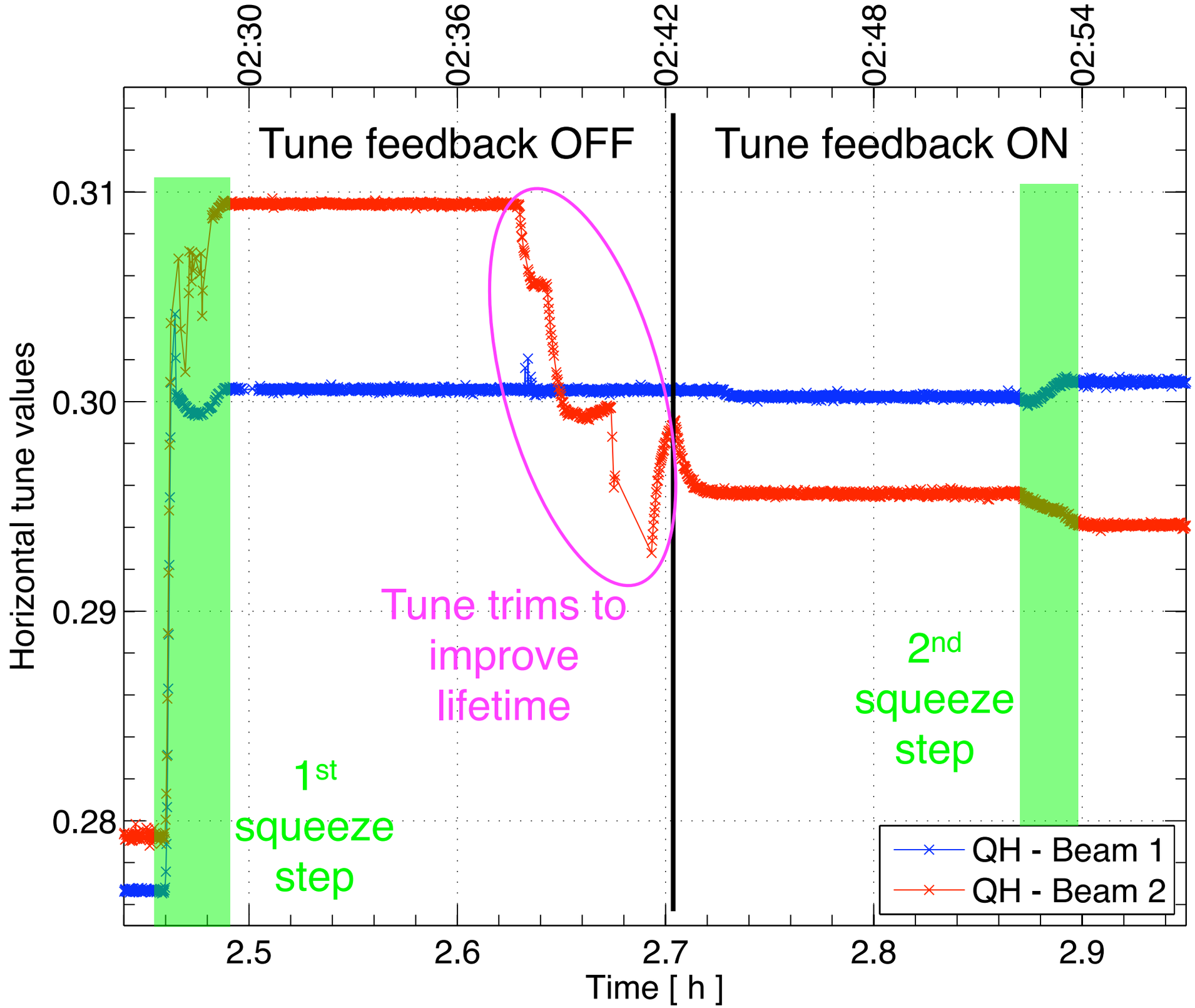




Closer look at orbit drifts in time in the betatron cleaning (IP7).

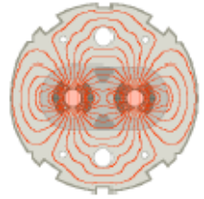
Note that the initial orbit in IP5 was NOT optimized!

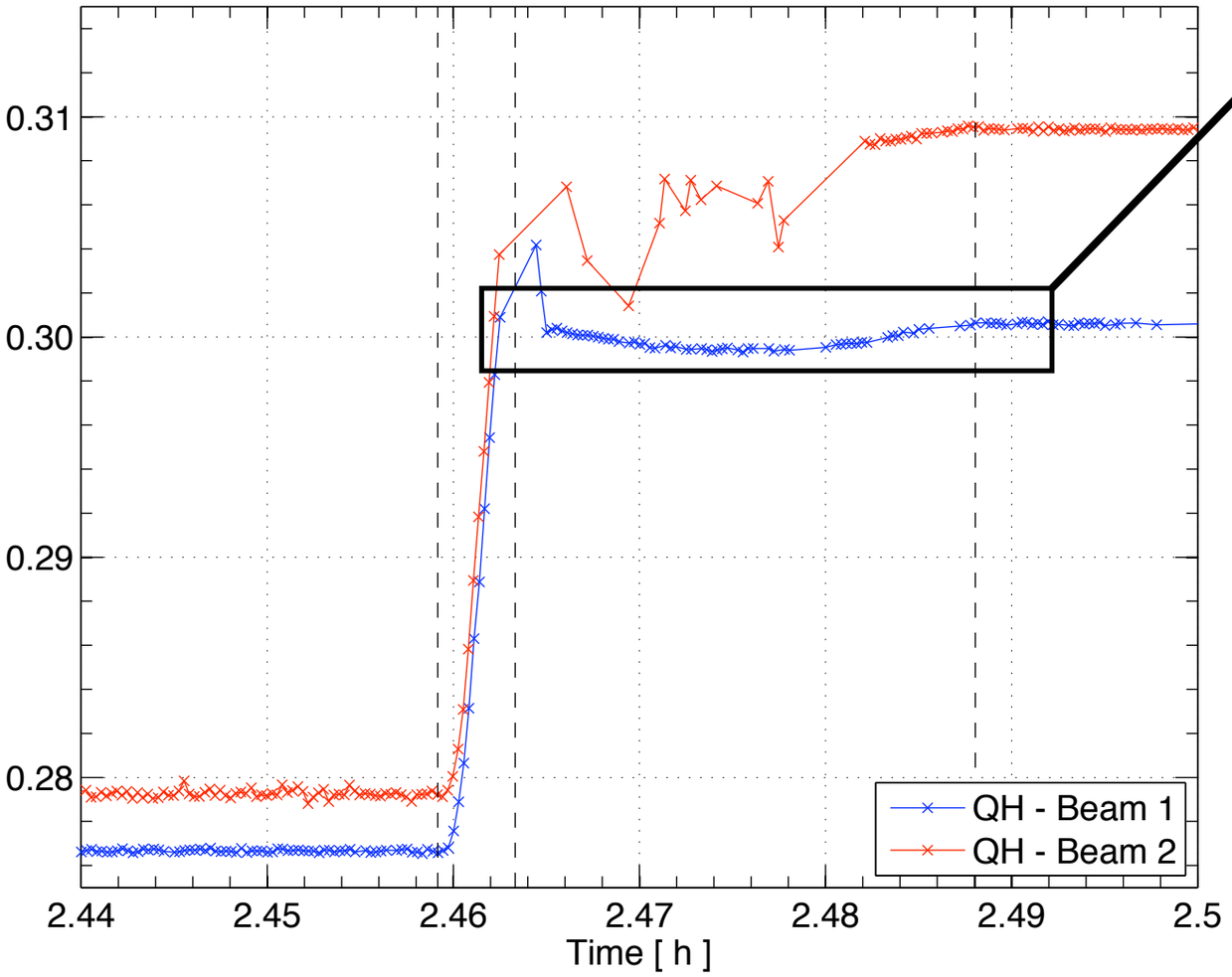
Tune (H) variation during squeeze

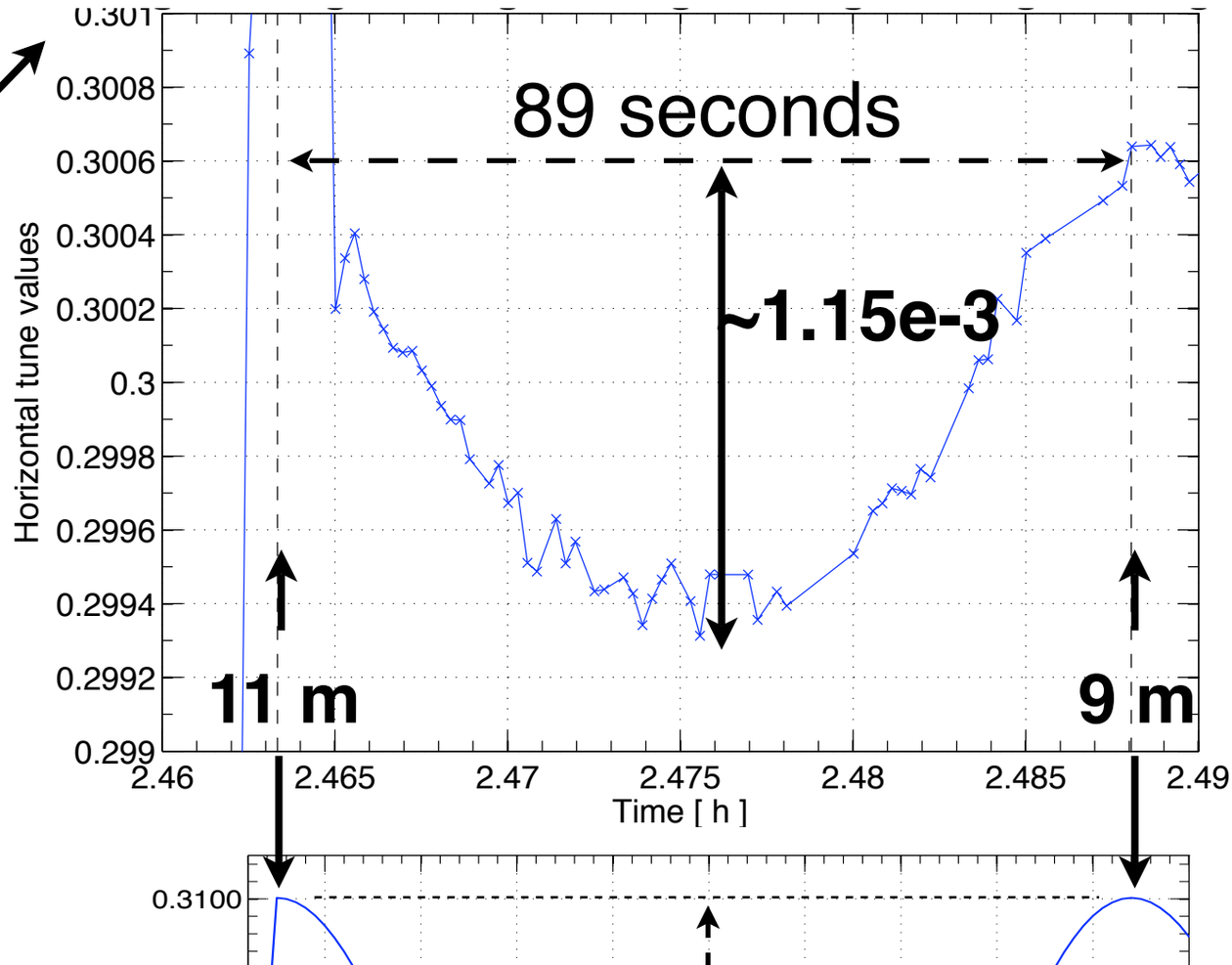


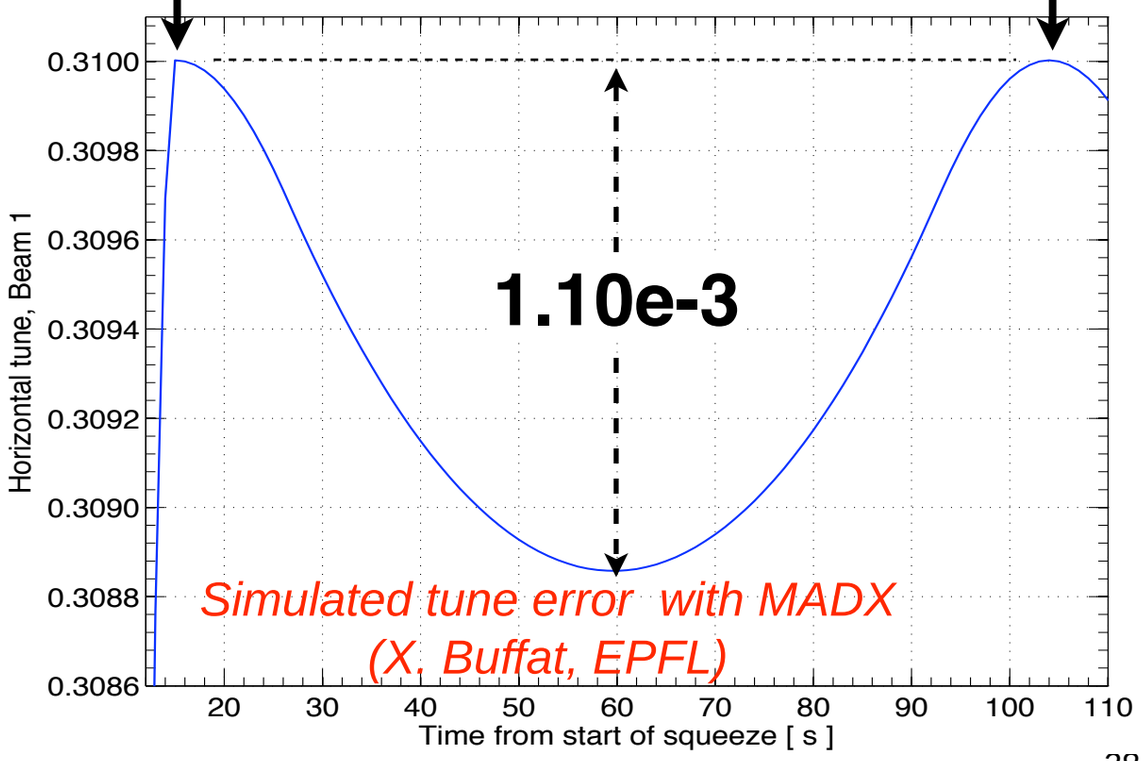
Look in some details of the first squeeze step...

Tunes during first squeeze step (FB OFF)







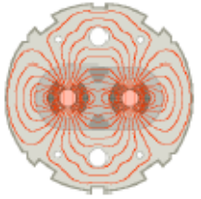


Note the remarkable precision of tune measurements!

Measured tune error between matched points agrees well with the simulations that use MADX + LSA settings!

See also M. Giovannozzi at LHCCWG, Nov. 2006.

Miscellaneous



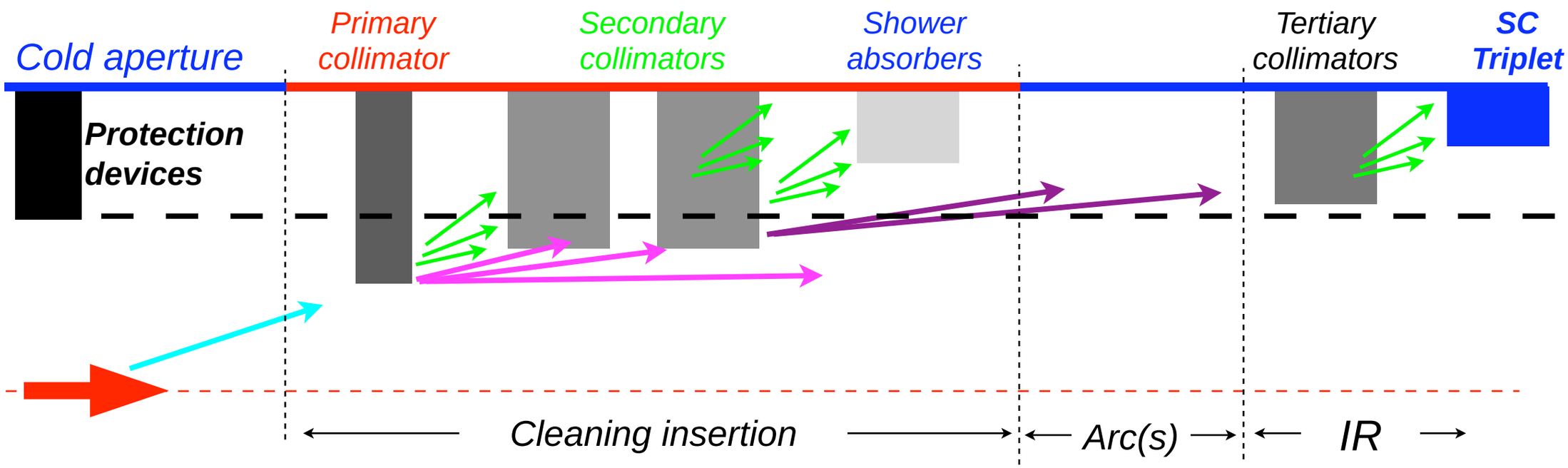
Problems / issues encountered during the beam tests:

1. Machine at the end of the ramp not fully optimized: coupling, B2 lifetime, ...
2. Missing tune/chromaticity knobs for the required optics.
3. Limited accuracy in beta measurements:
   - *Small kicks with tune kicker; will be worst at higher energy!*
   - *Measurements affected by missing BPM acquisitions.*
4. Incorporation of settings did not work reliably for all parameters.
5. Maintenance/handling of the many beam processes for functions and stopping points is an issue that requires well debugged methods.

Required implementations not yet tested:

1. Automatic optics change during squeeze for the feedback matrices.
2. Trims in intermediate points between matched times not optimized.
3. Stopping point implementation does not work for critical properties.
4. Beta squeeze factor will not be available in 2010.

Collimation during the squeeze



The triplets become the aperture bottlenecks for *β* values below 6-7* (3.5 TeV simulations by A. Rossi).

Tertiary collimators (TCT's) are now installed in all IPs, both planes: no constraints in any IPs.

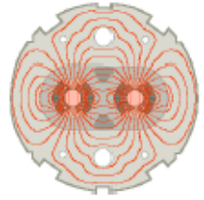
The setting hierarchy must be respected between cleaning (IR7), protection (IR6) and TCT's.
- *Collimator settings must be updated for each new beta* value!*

Operational settings established for the 3.5 TeV operation (R. Assmann, A. Rossi)
- *"Tolerance relaxed" settings established to ease the initial operation.*
- *Implementation issue: stepping points for critical limit thresholds.*

The machine protection requires the definition of limits as a function of *β* ("**betatron squeeze factor**")* that is not presently available in the SMP.

Operation with small collimator gaps will require to establish procedures for octupole operation, if impedance is a concern (R. Assmann, LHCCWG Nov. 2006).

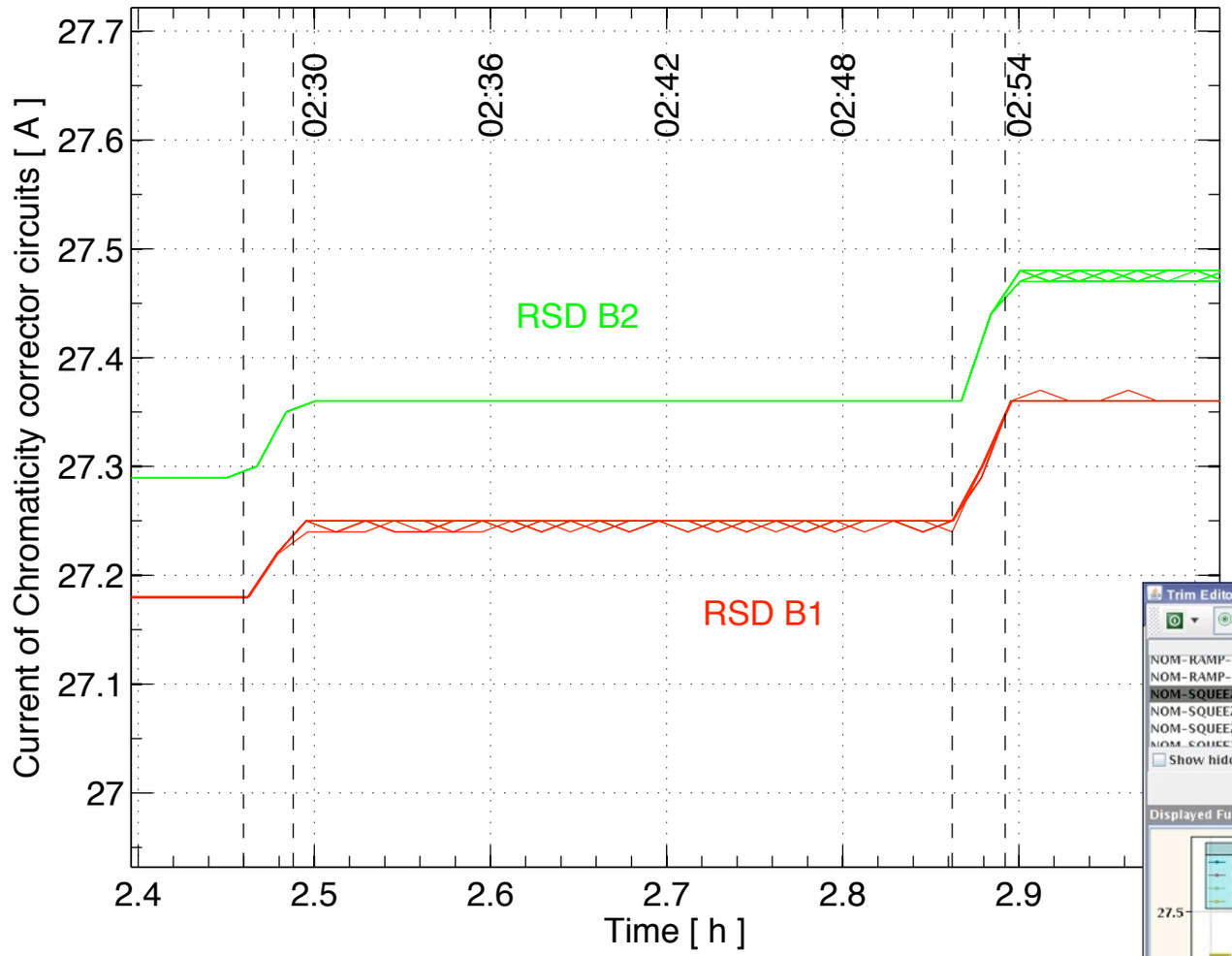
Conclusions



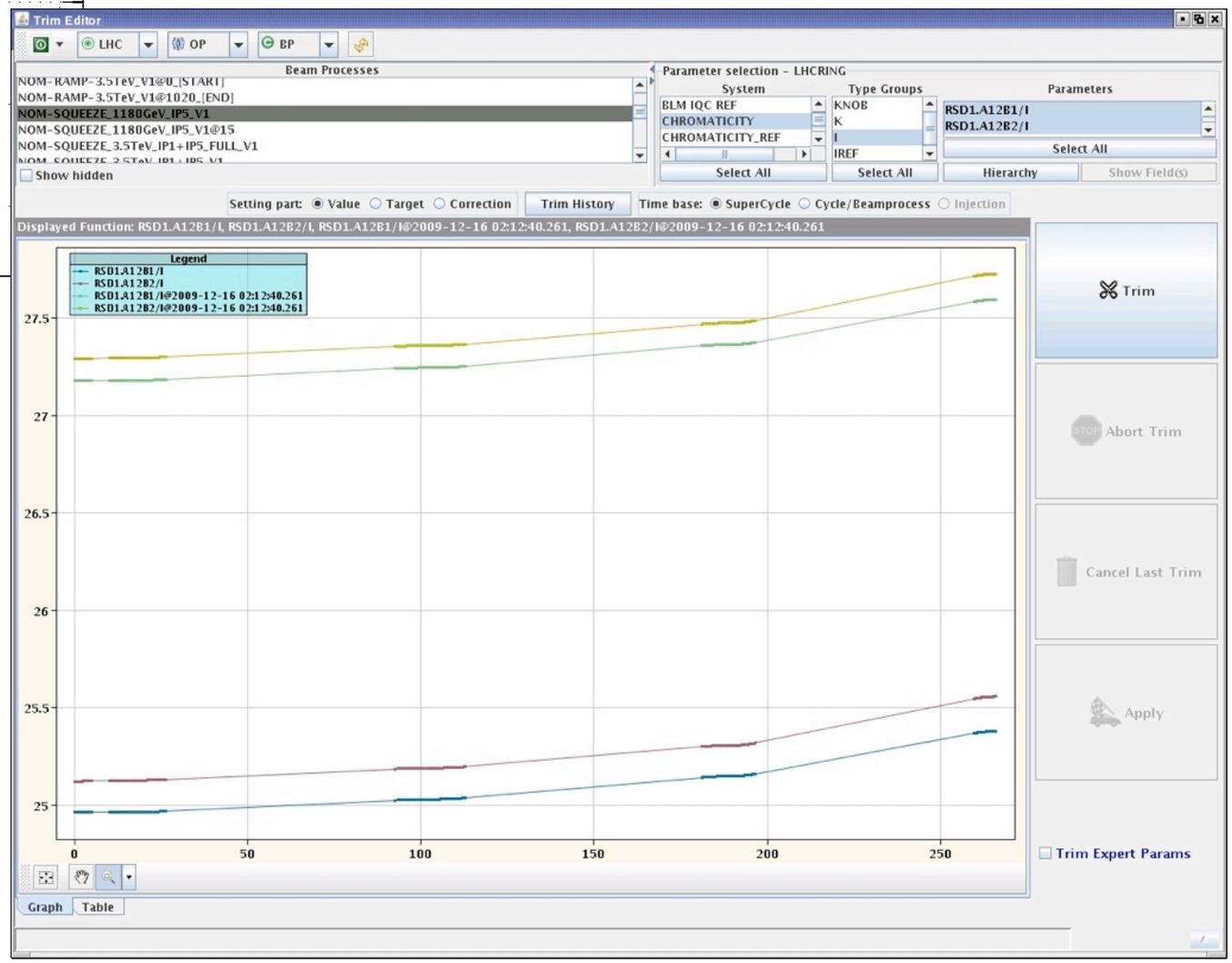
- **First beam tests of betatron squeeze were successful!**
  - The mechanics of the squeeze works well.
  - We achieved a good agreement with the expected beta values.
- **Some issues were identified and are being addressed**
  - Improve further LSA implementation (incorporation, BP handling)
  - New functionalities: change of optics matrices for orbit feedback; handle stop points for critical properties (collimators).
- **Feedbacks (preliminary):**
  - Orbit control would be highly appreciated, as expected!
  - If simulations are confirmed, tune feedback seem less critical.
- **Proposed an updated of commissioning procedures**
  - Conservative baseline kept in case of problems with smaller β^*.

Reserve slides

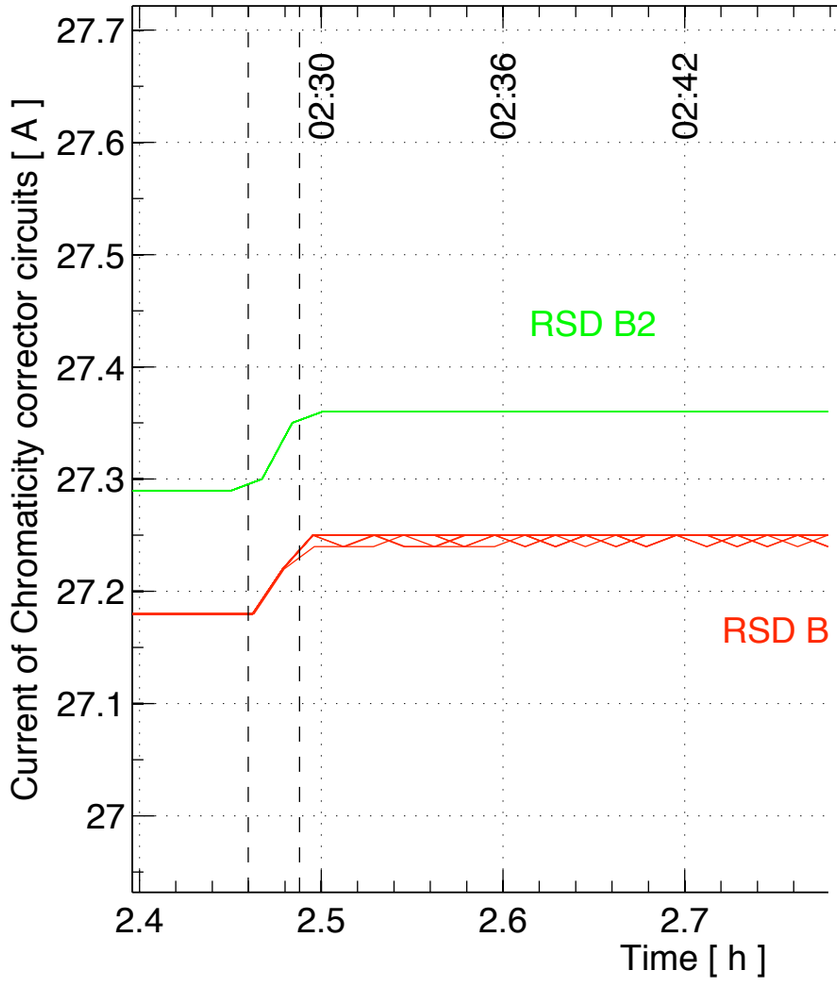
Chromaticity incorporation

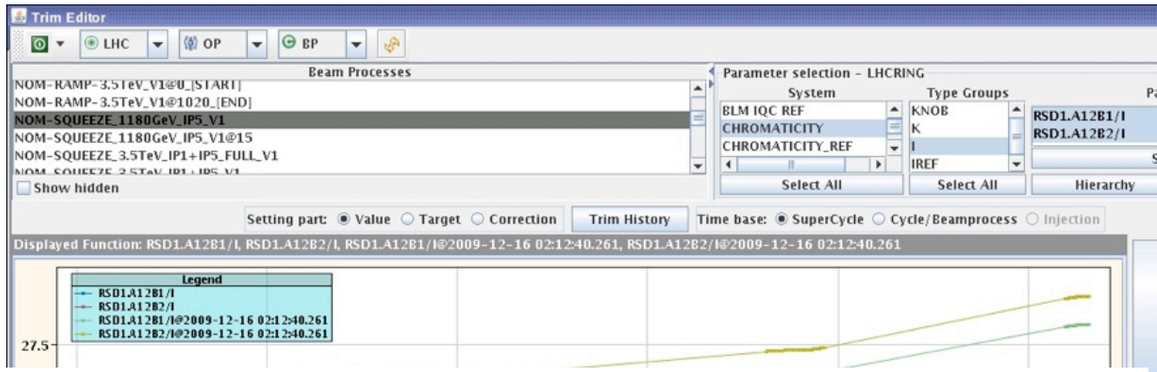


Initial setting with correction of chromatic aberrations from squeeze.



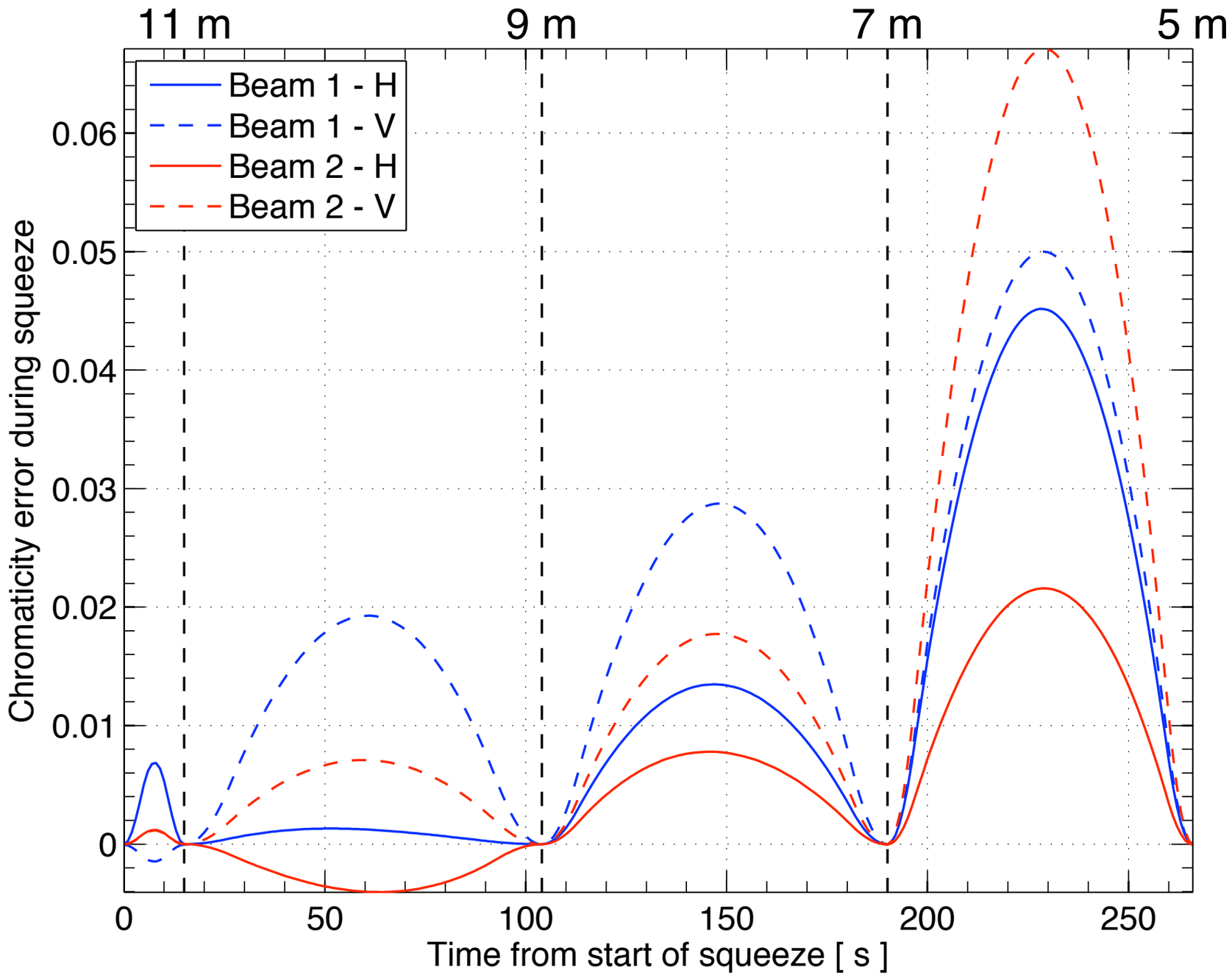
Chromaticity incorporation



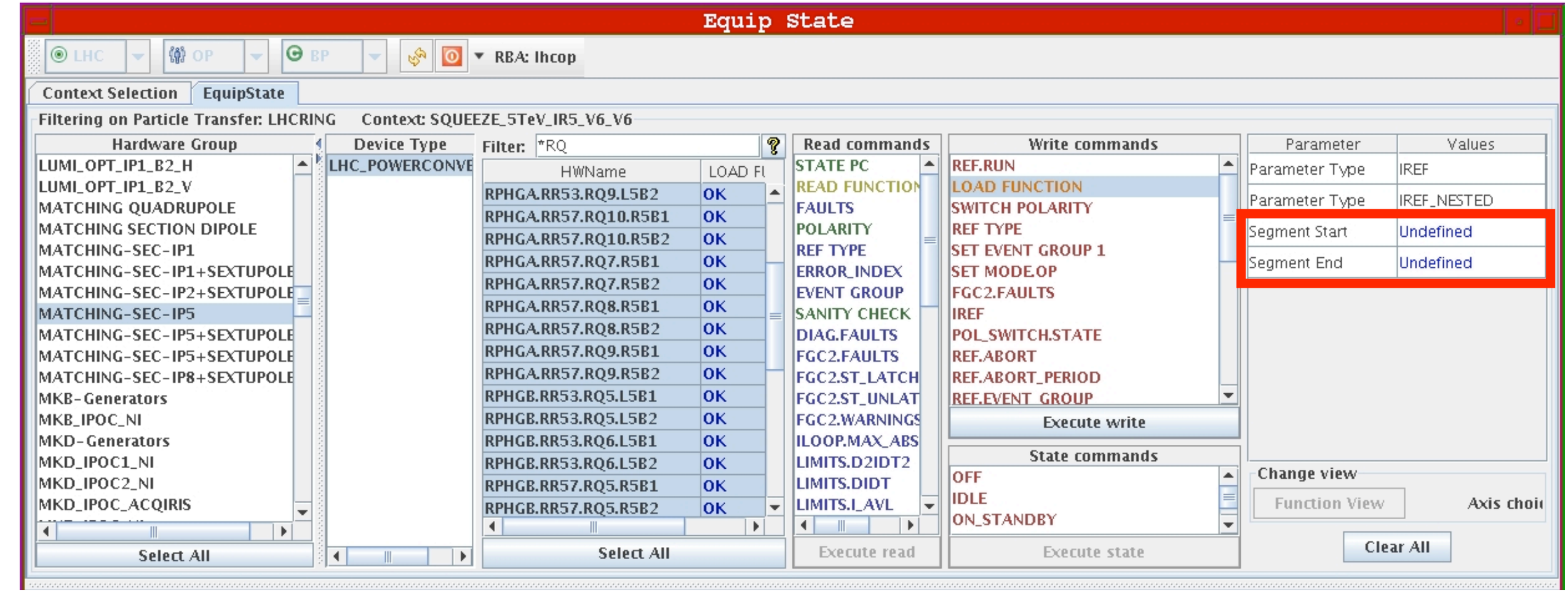


Initial setting with correction of chromatic aberrations from squeeze.

Predicted chromaticity variation versus time.

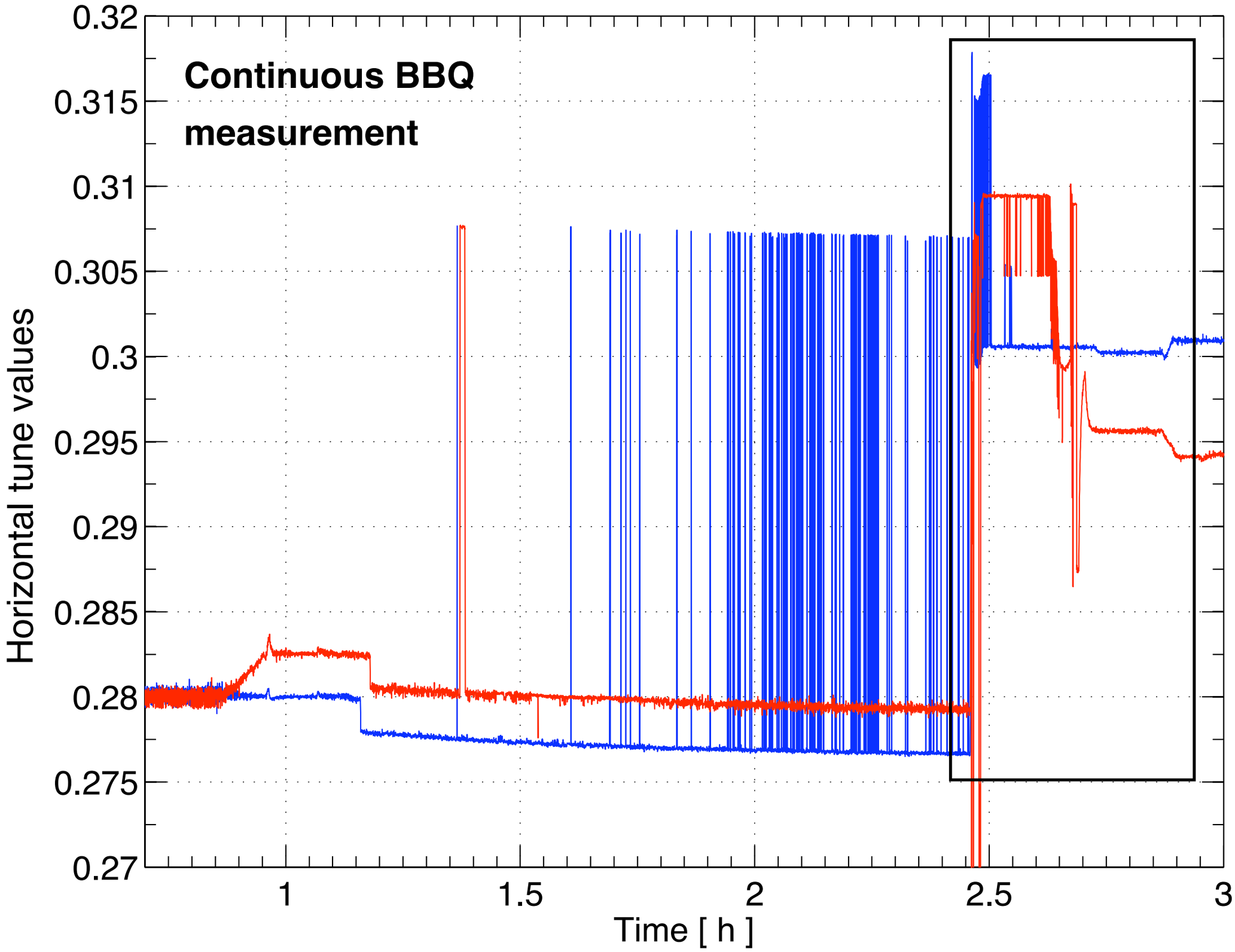


Squeeze segments - implementation

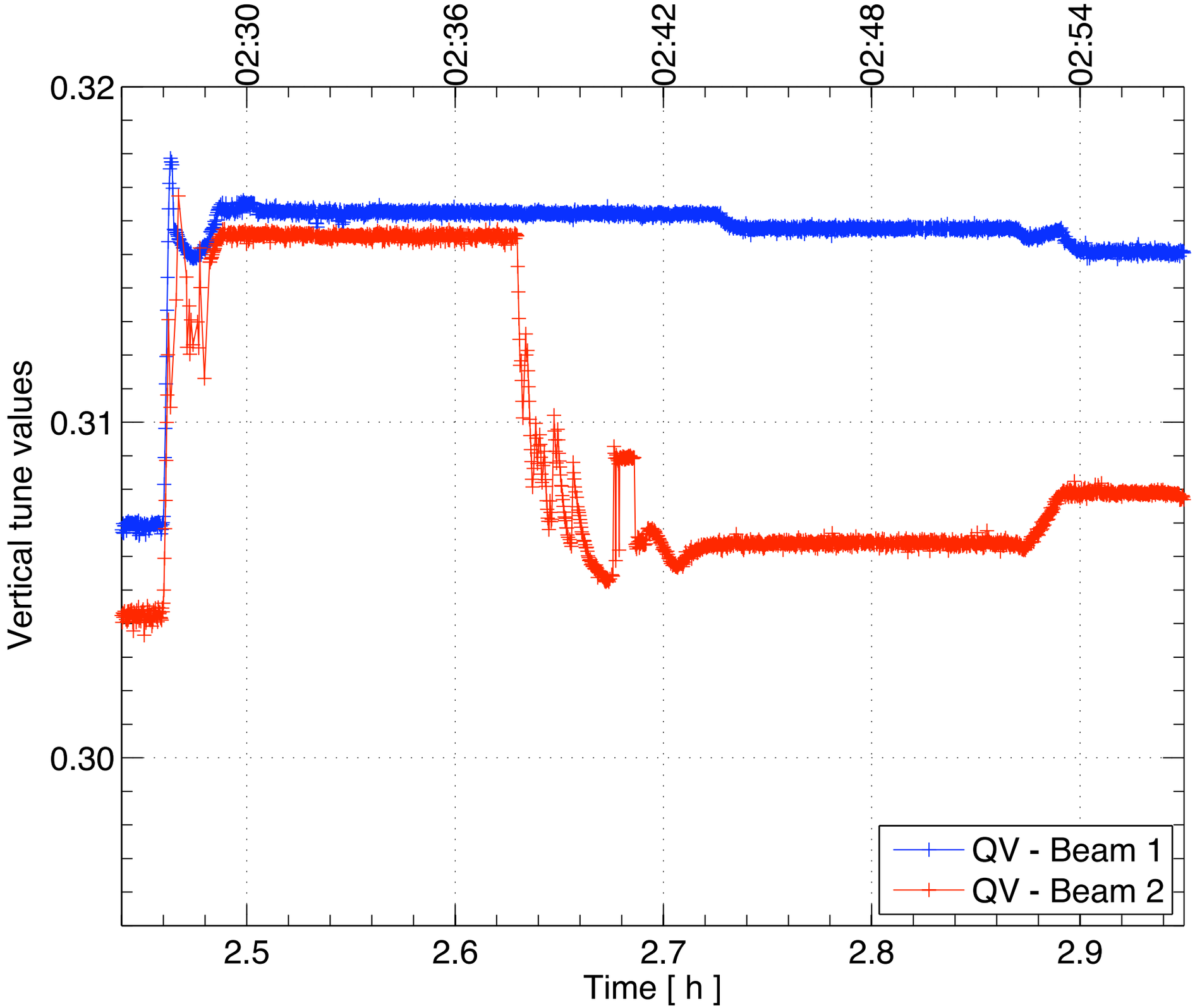


- Can specify t_start and t_end of any segment when **loading** the functions (parameters of the hardware command).
  Standard **triggers** can then be used (software, timing)
- For PC's, get an exception if t_start and t_end do not correspond to times of matched optics
- Protection: If one sends segments that are not adjacent, HW will give a first-point-mismatch exceptions. *(Other checks could be added...)*

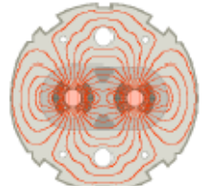
Raw tune signals

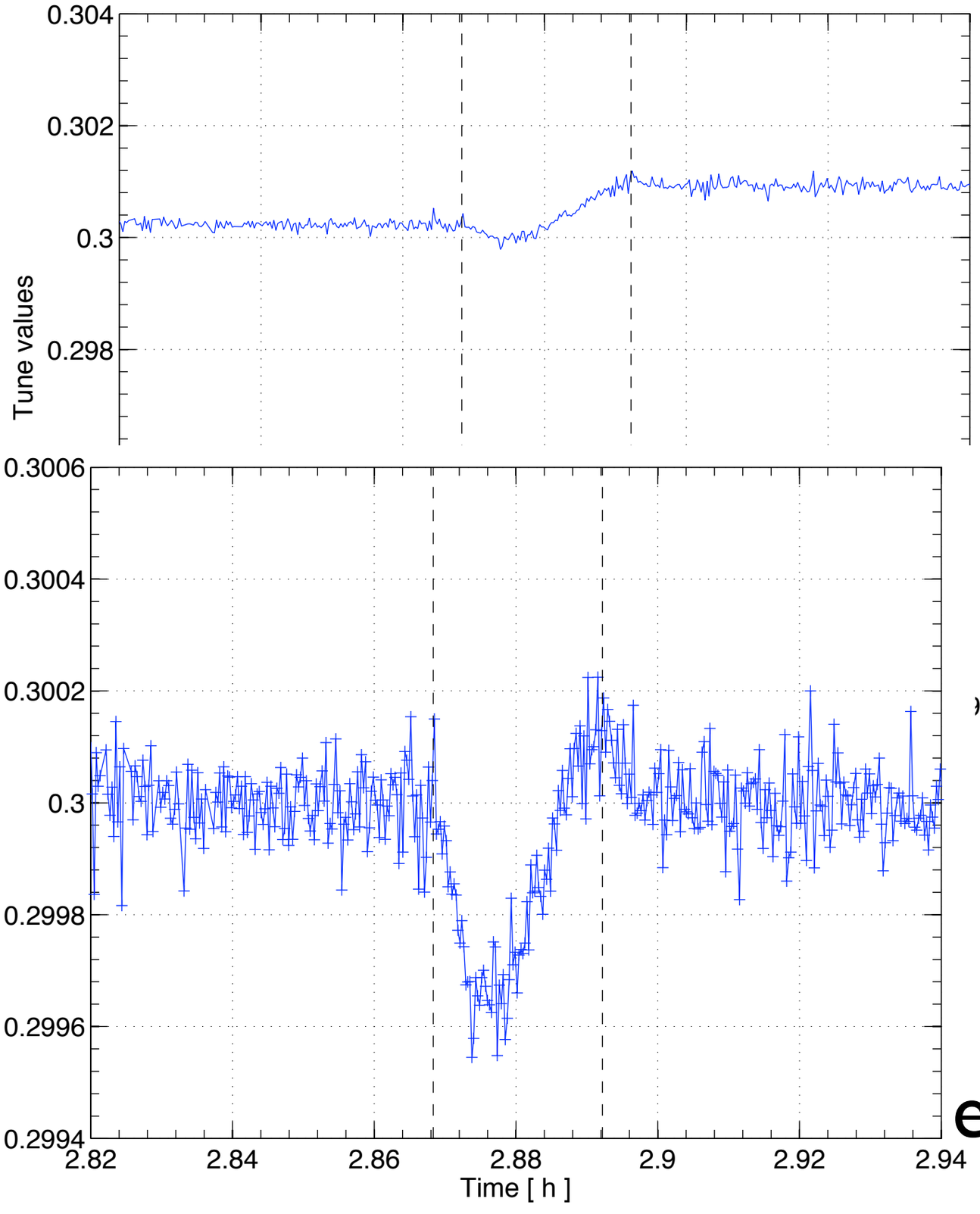


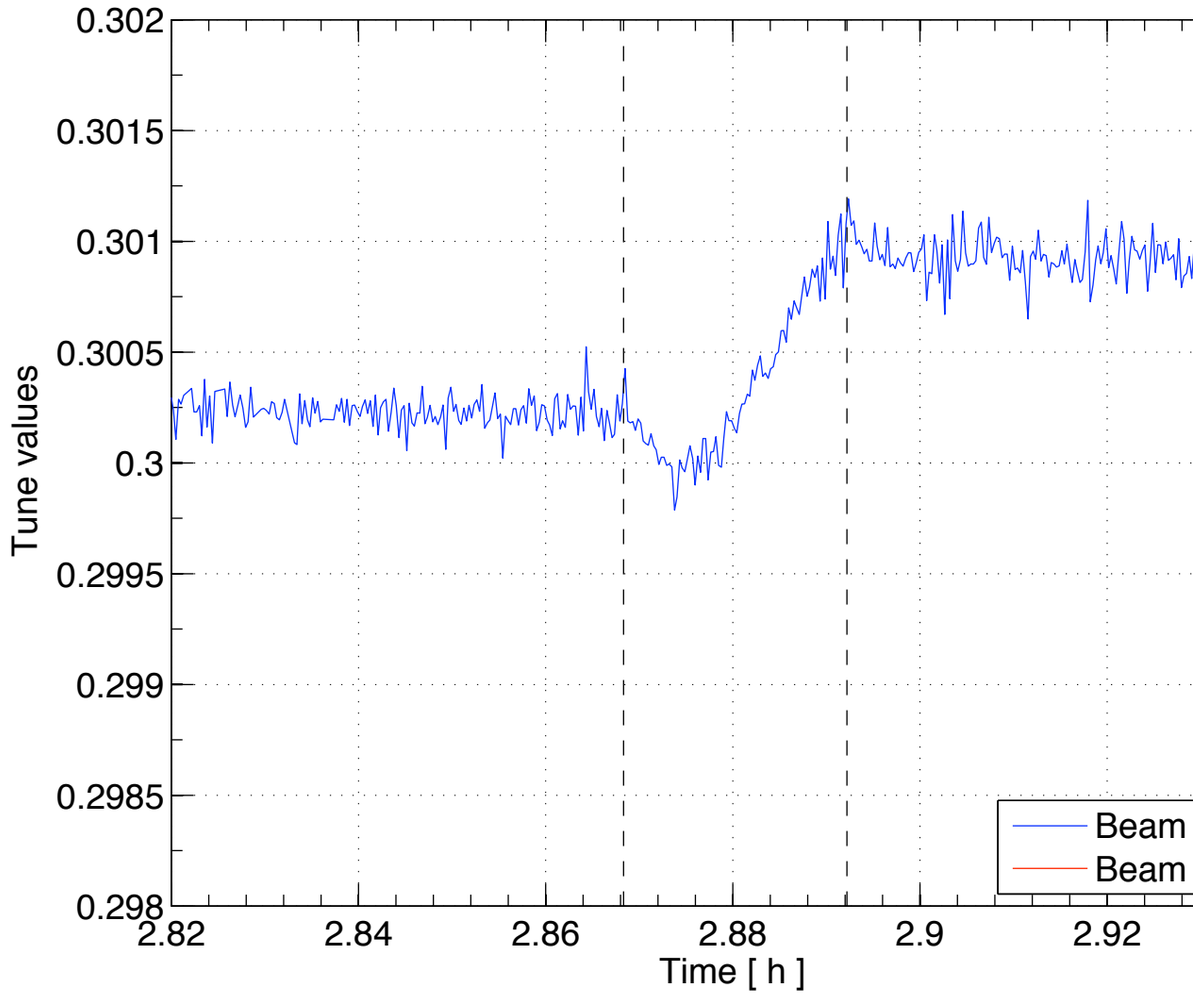
Tune variation during squeeze - V



Tune during second step (FB ON)

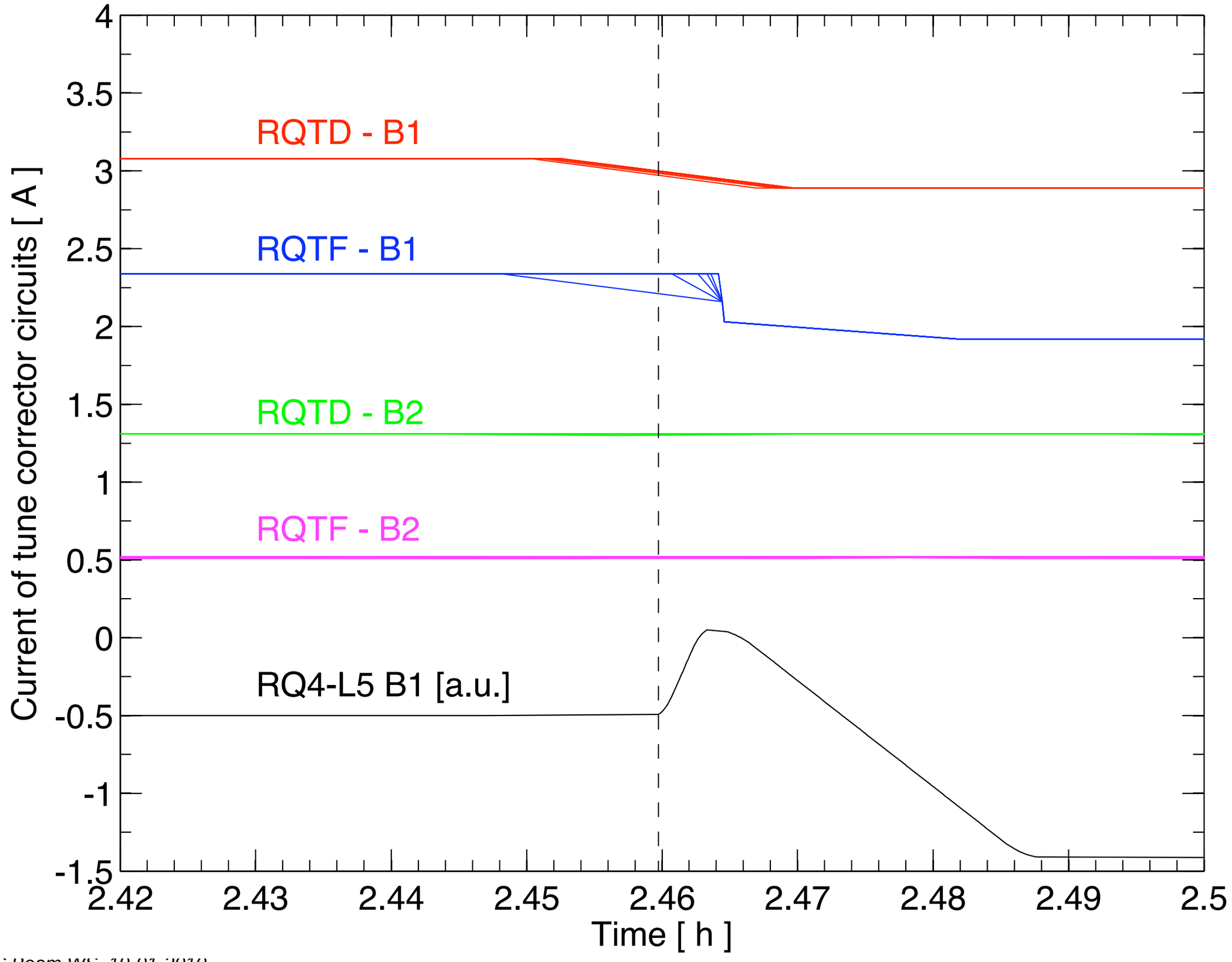




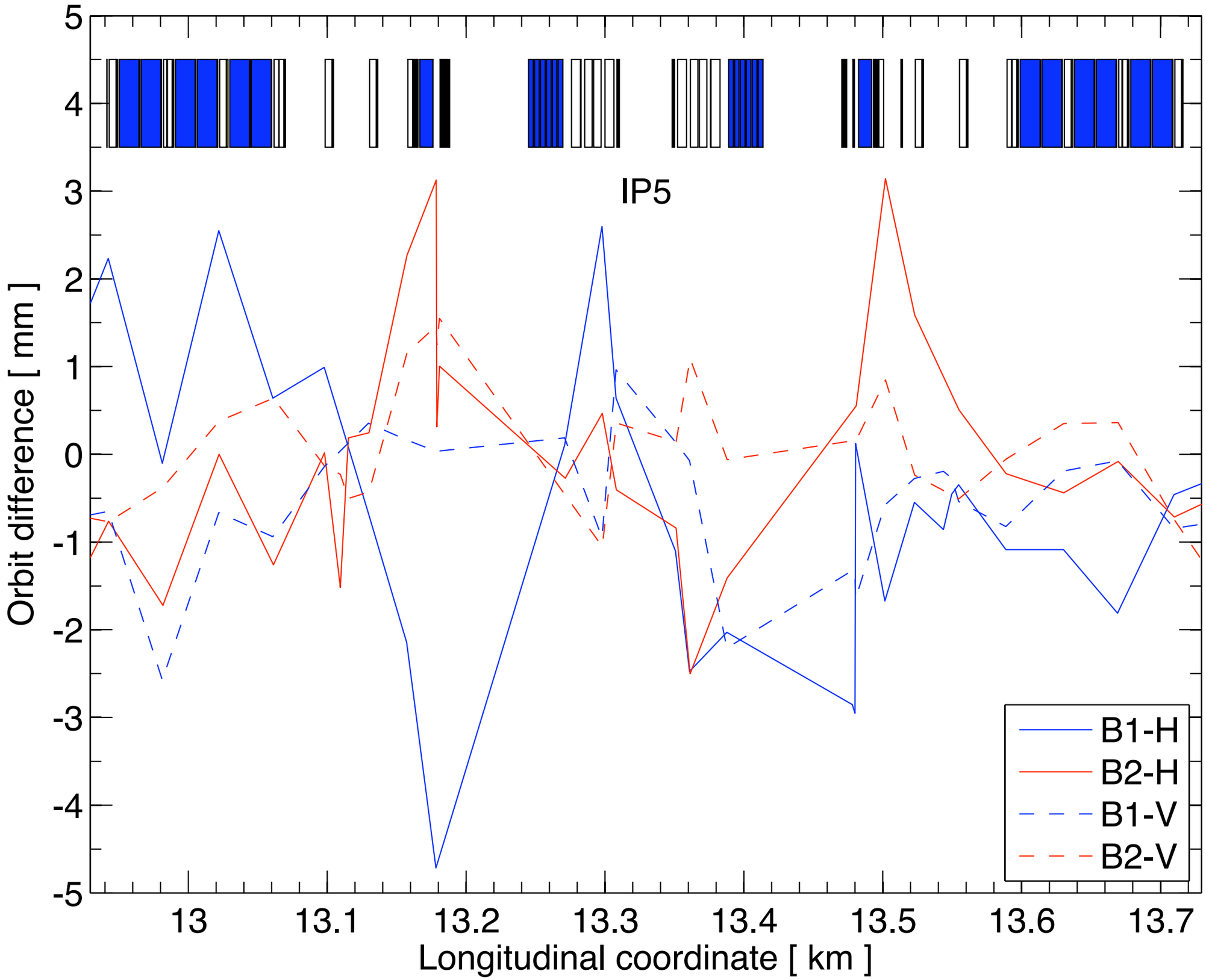


Tune FB locked on tune eigenvalues without coupling corrections

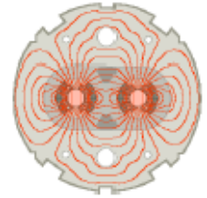
Un-expected tune change for B1



Initial orbit in IP5



Squeeze combined with ramp



Pro's: save time (by overcoming PC limitations); beams less dangerous at lower energy.

Con's: add complication to ramp; mechanical aperture limits the minimum β* (see WH talk); critical steps only possible at 7 TeV; beam-beam is worst (parasitic crossing).

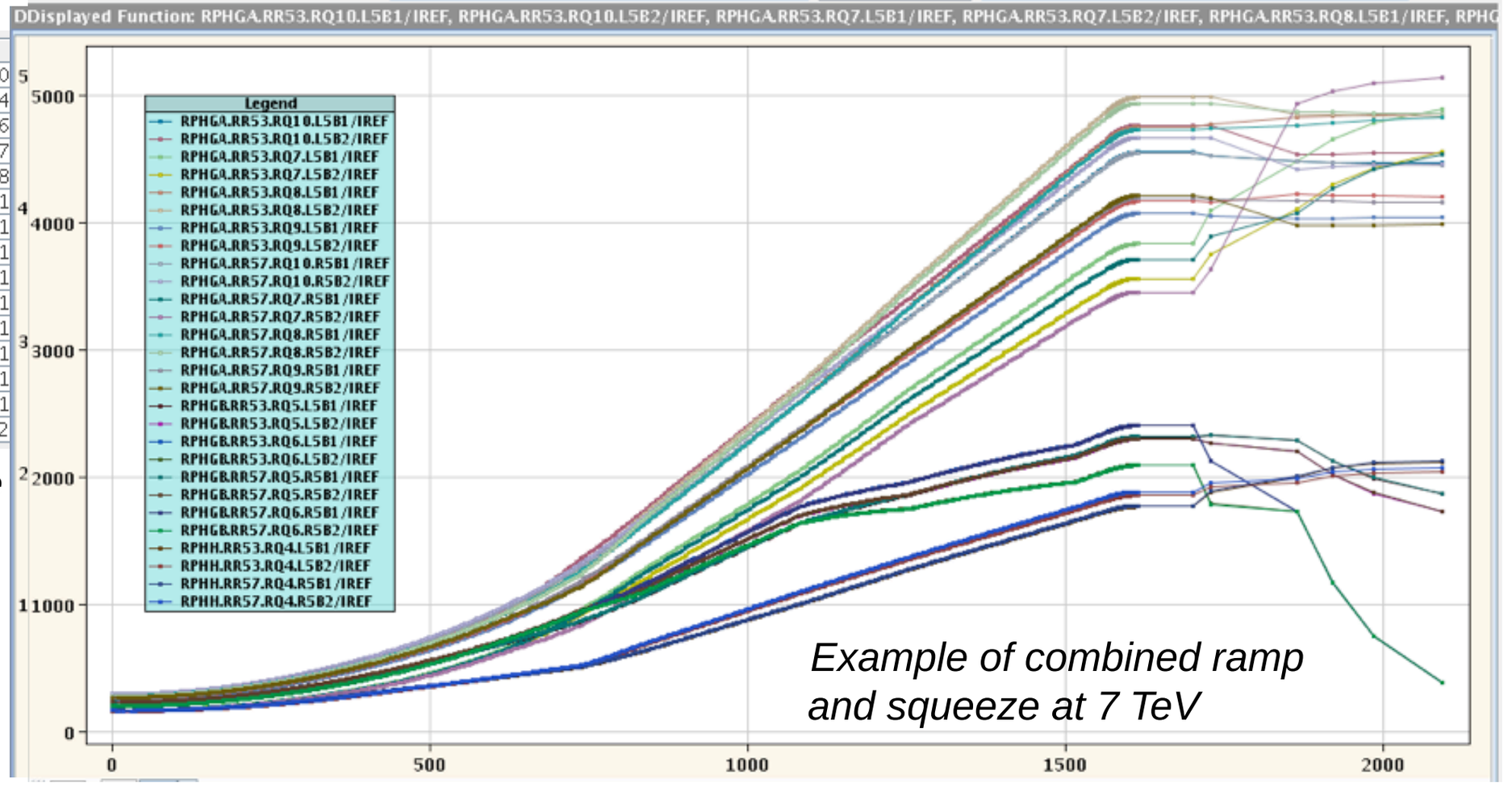
LSA gives all the flexibility needed to combine ramp and squeeze!

Baseline for operation:

- *only do it if really needed.*
- *only do it on a commissioned ramp, after we have mastered well the squeeze.*

Optic Name	Energy	
A1100C1100A1000L1000	450.0	0
A1100C900A1000L1000	1000.1676	4
A1100C700A1000L1000	1505.2014	6
A1100C500A1000L1000	1996.0389	7
A1100C400A1000L1000	2505.8593	8
A1100C350A1000L1000	3997.9646	1
A1100C250A1000L1000	4992.7014	1
A1100C200A1000L1000	6555.8593	1
A1100C200A1000L1000	7000.0	1
A1100C200A1000L1000	7000.0	1
A1100C150A1000L1000	7000.0	1
A1100C110A1000L1000	7000.0	1
A1100C80A1000L1000	7000.0	1
A1100C65A1000L1000	7000.0	1
A1100C55A1000L1000	7000.0	2

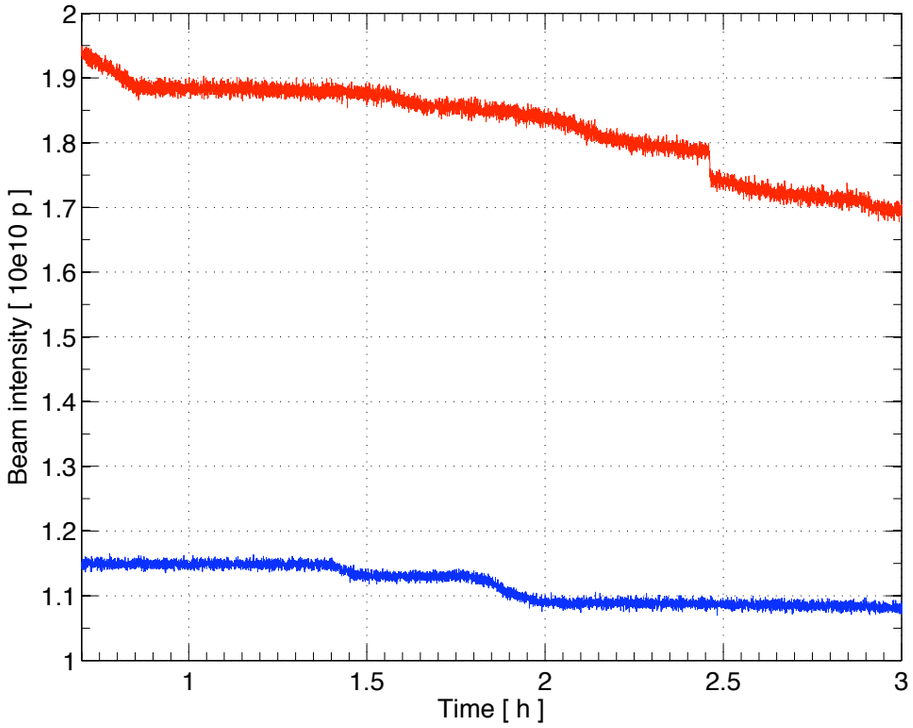
Tests ongoing with G. Kruk, S. Page

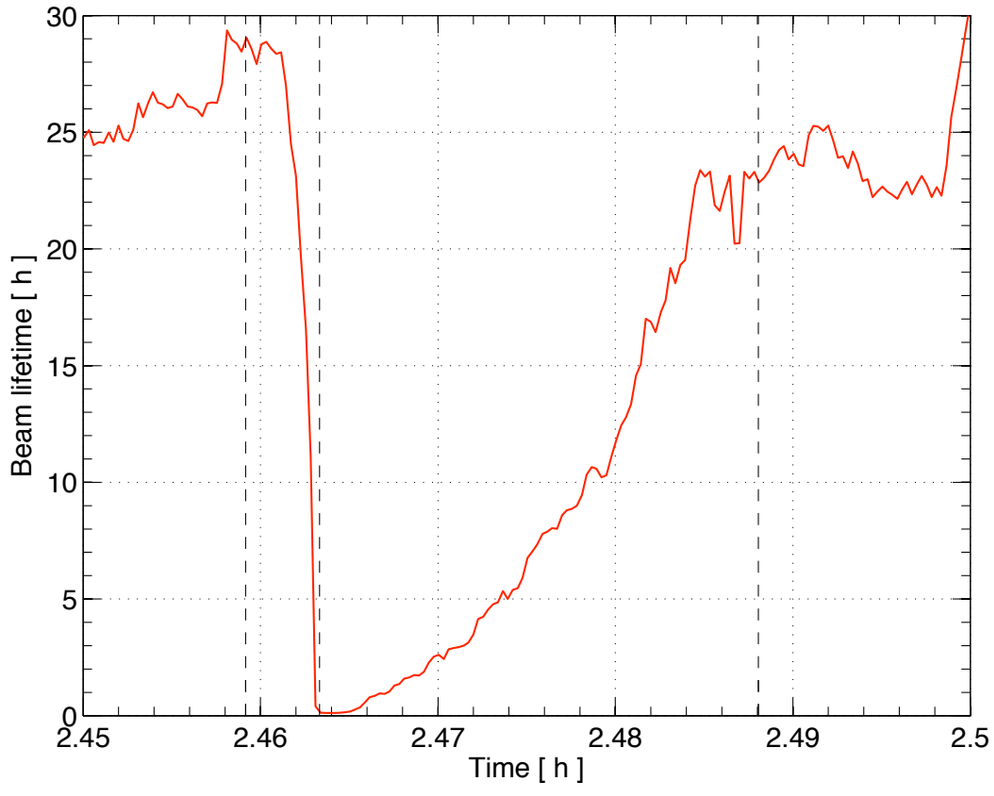


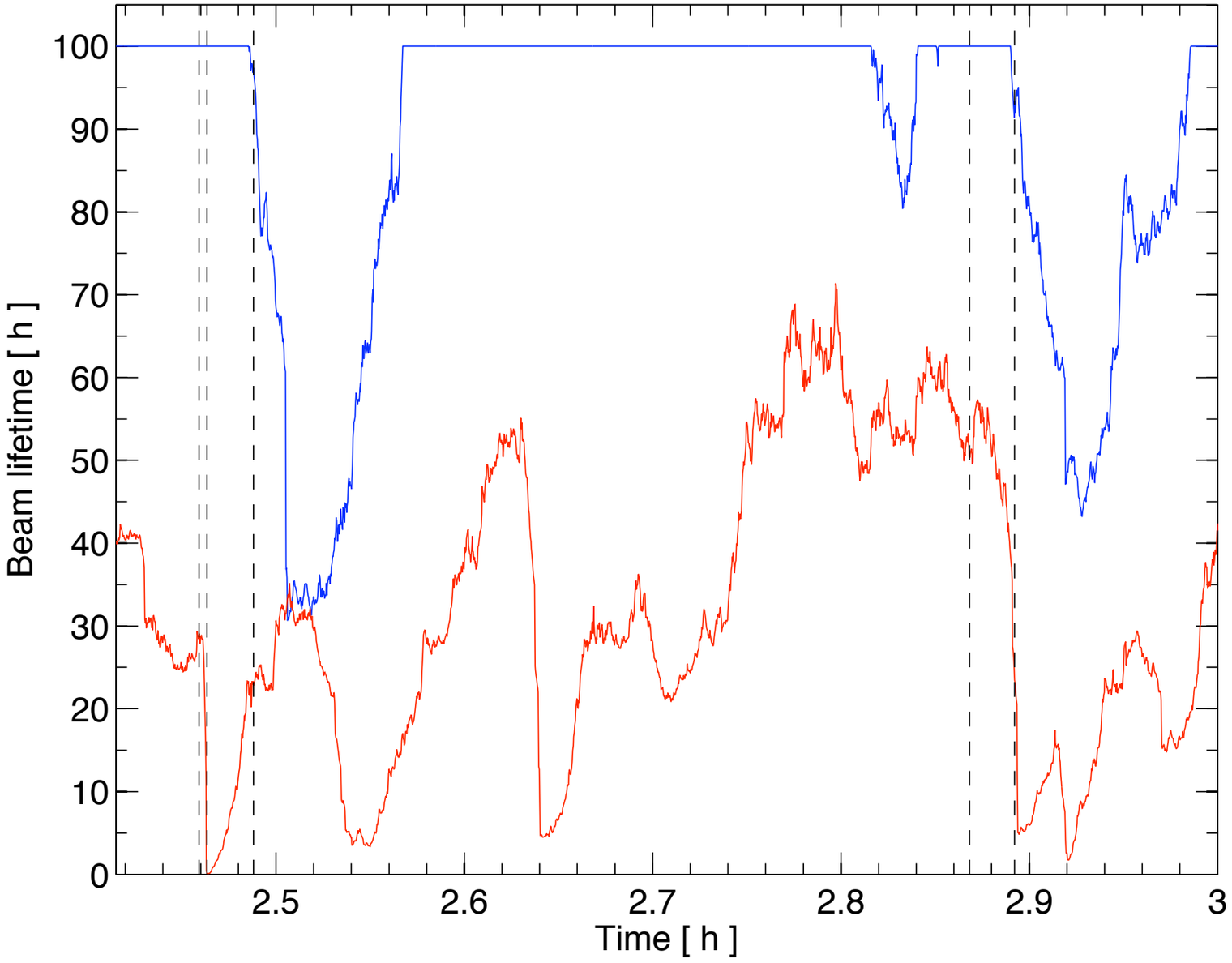
Example of combined ramp and squeeze at 7 TeV

Reminder: pre-squeeze required anyway for IP2 and 8 at energies above 6.6 TeV!

Beam intensity and lifetime







History of power converter currents