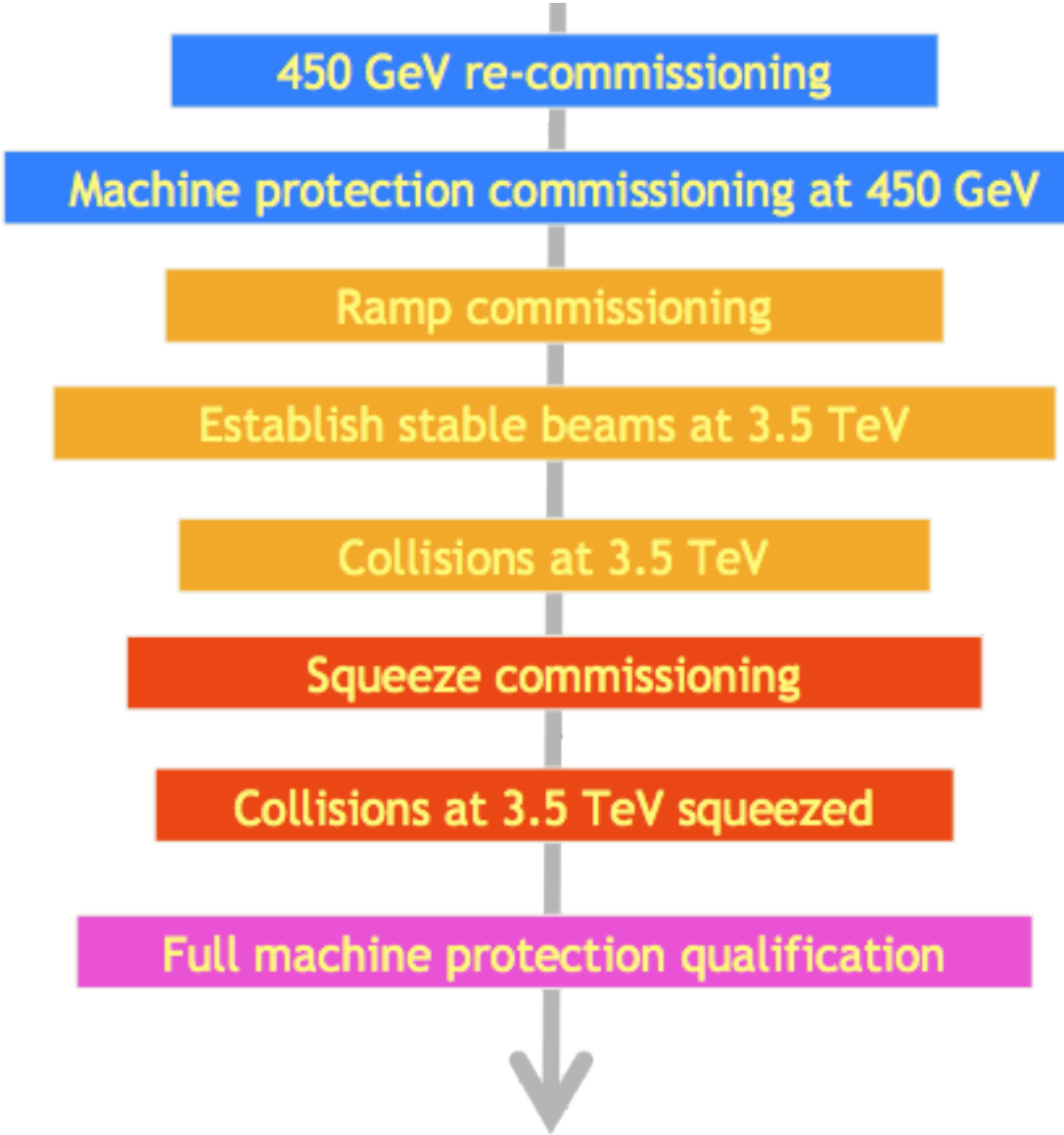
Status of LHC Operations

R. Assmann

for the LHC commissioning team and LHC teams & groups

LPCC 23.4.2010

Commissioning Strategy Last Weeks



Mike Lamont et al

Outline

- The squeeze story: Getting all 4 IR's squeezed to 2m
  - IR1 and IR5
  - IR8
  - IR2
  - All 4 IR's at once
  - Qualification tests for machine protection
- Higher intensity
  - Storing 10 bunches at injection
  - Storing nominal bunch charge
- Feedbacks, emittance and operational issues
  - Feedbacks
  - "Hunt the Hump"
  - Multiple beam-induced quench
- Conclusion

PART I – Squeeze IP Beam Size @3.5 TeV

… a long story but with a happy ending…

This is one of the most complex stages of operation!

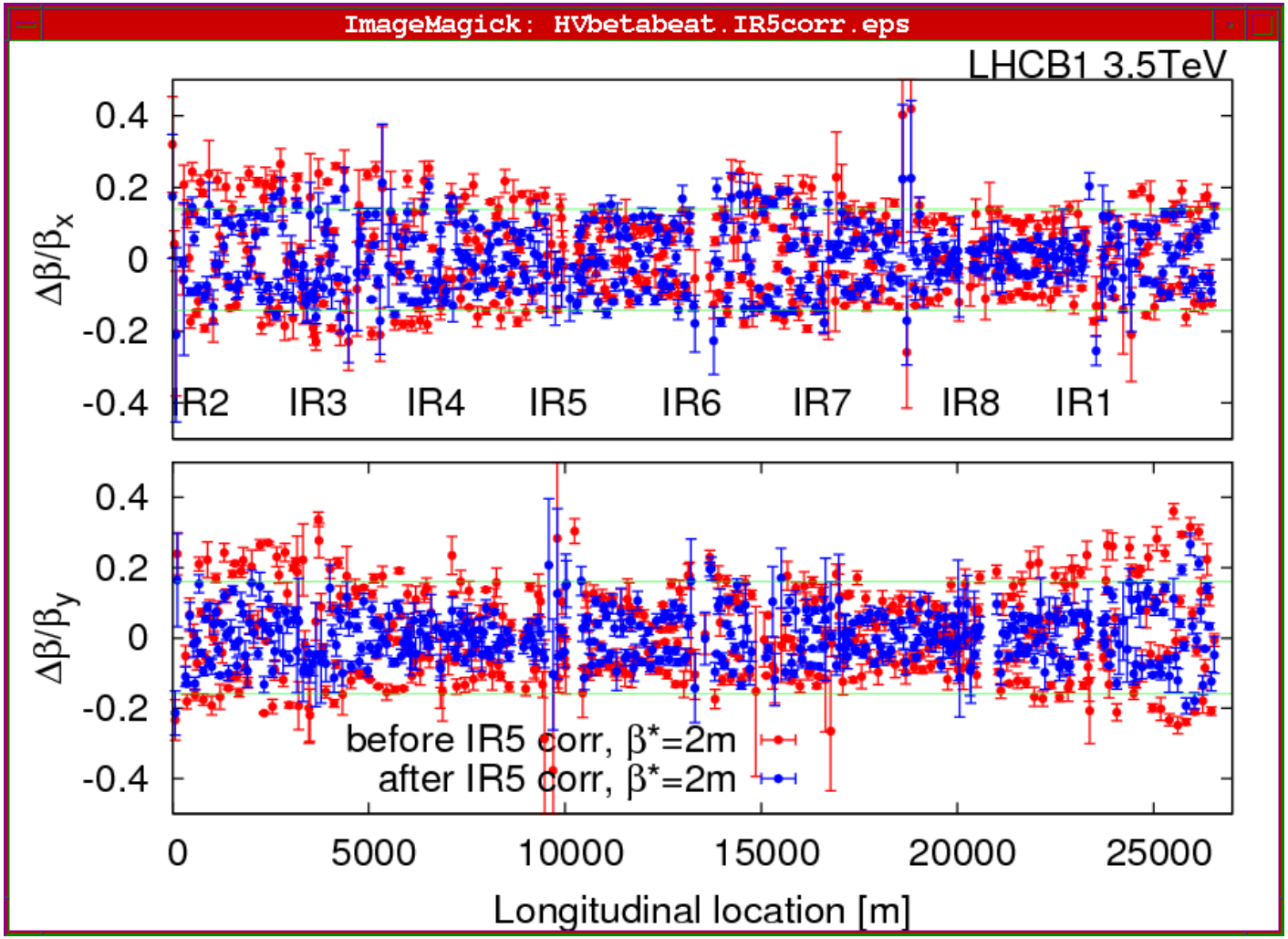
- **Change of beam optics to reduce beam size at the interaction points.**
- Goal for 2010 beam size reduction: factor ~2.2 for each plane (factor 5 in IP beta):

  ➔ factor 5 higher luminosity
- This is a change in β^* by a factor ~5! Complex control of all IR power converters plus precision corrections.
- At the same time the beam size at the triplets around the experiments increases significantly:

  ➔ triplets become aperture bottlenecks
- Protection of triplets and experiments against beam loss must be carefully verified before stable beams.

Step 1: Squeezing and correcting IR1 & IR5

- β-beat for Beam1 @ β^* = 2m after correction using IR5 Q2:



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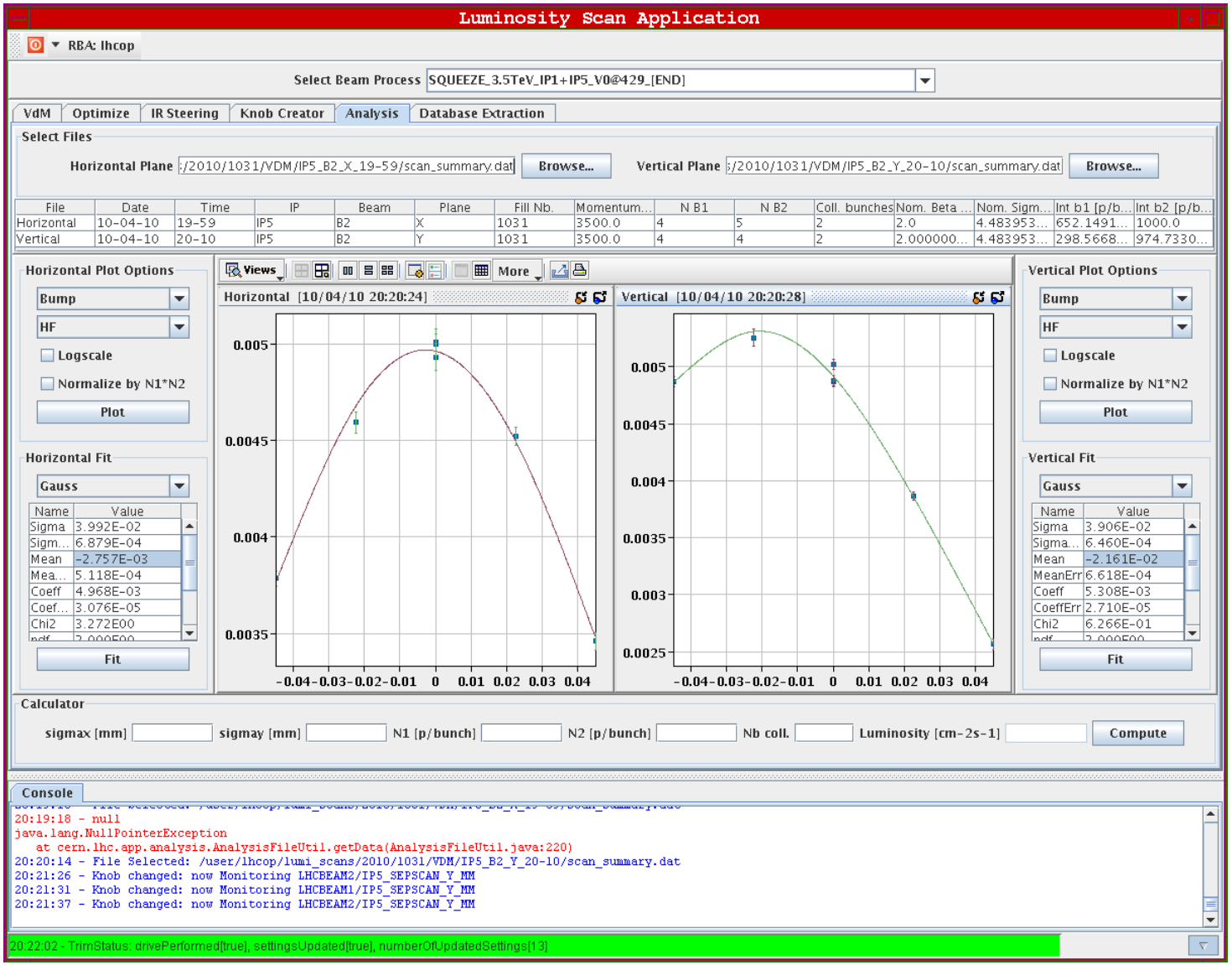
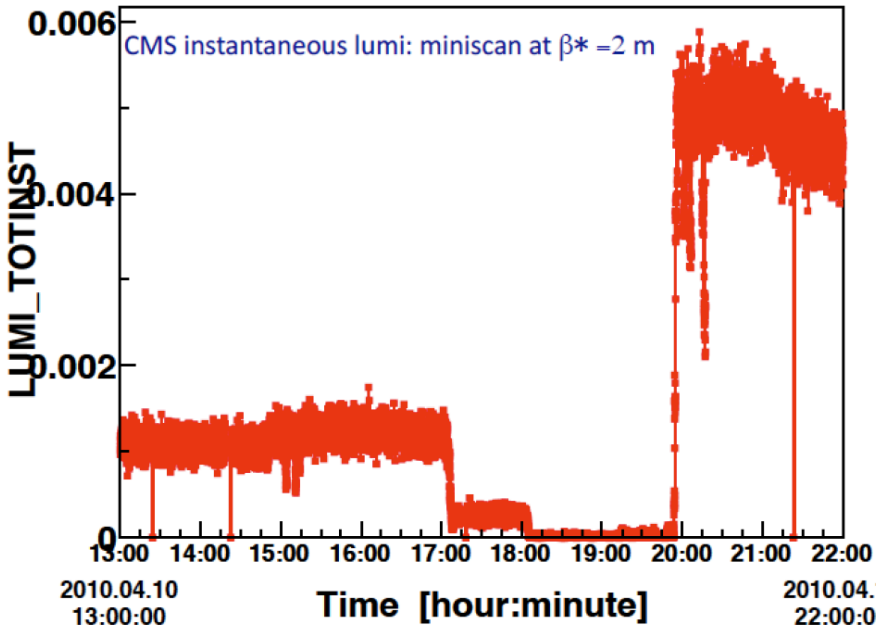
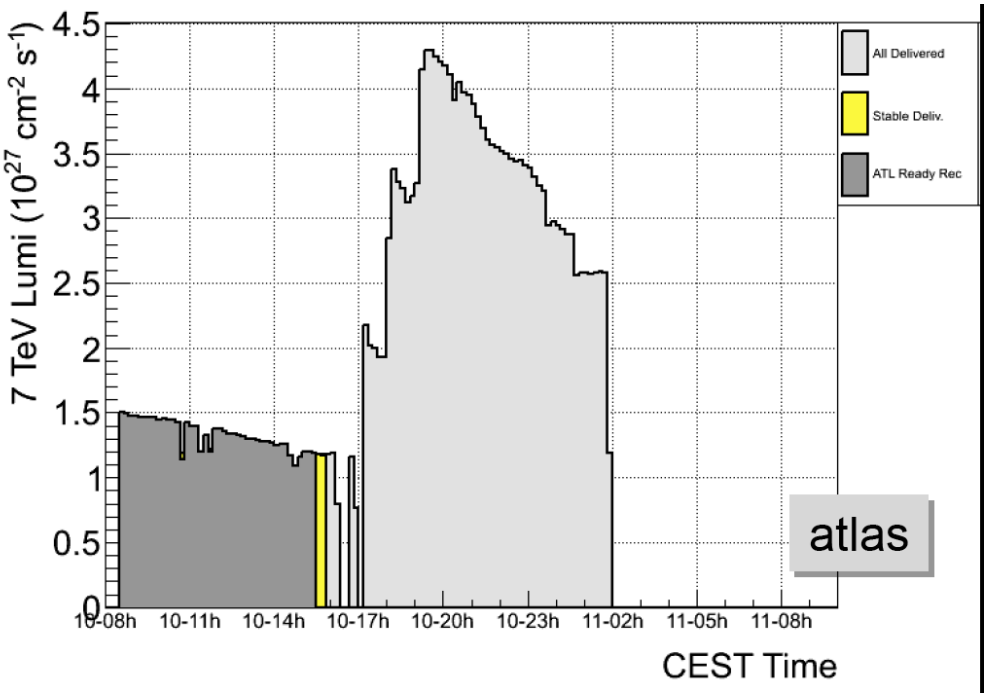
Example: CMS Luminosity Optimization



S. White

ATLAS and CMS Improvement





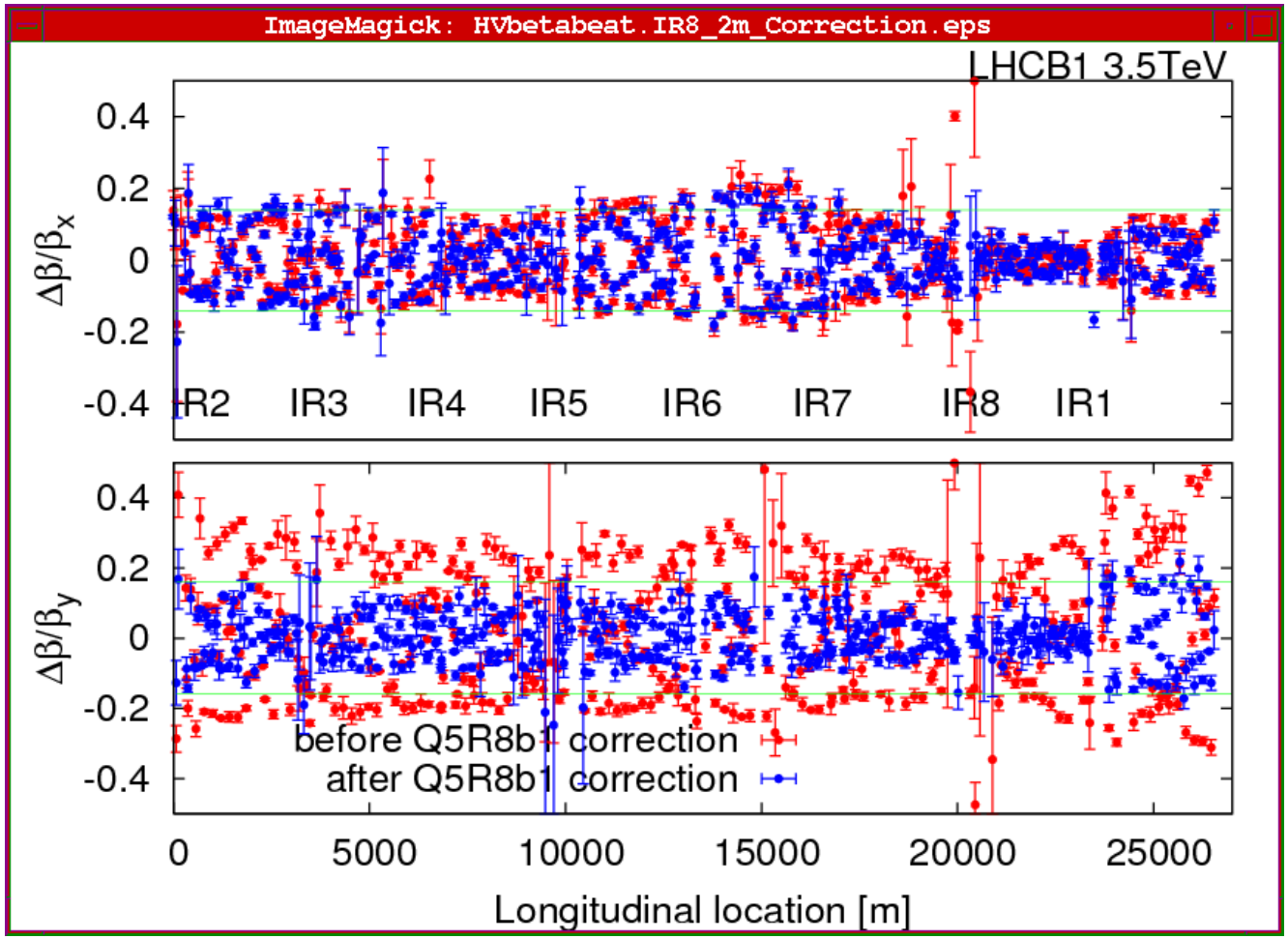
M. Ferro-Luzzi

Increase after squeeze: Factor 4-4.5 (to be compared with expected factor 5)

Luminosity up to 5×10^{27} cm^{-2} s^{-1}.

Step 2: Squeezing and correcting IR8

- β-beat for Beam1 after squeeze and @ β^* = 2m in IR8 after correction of Q5:



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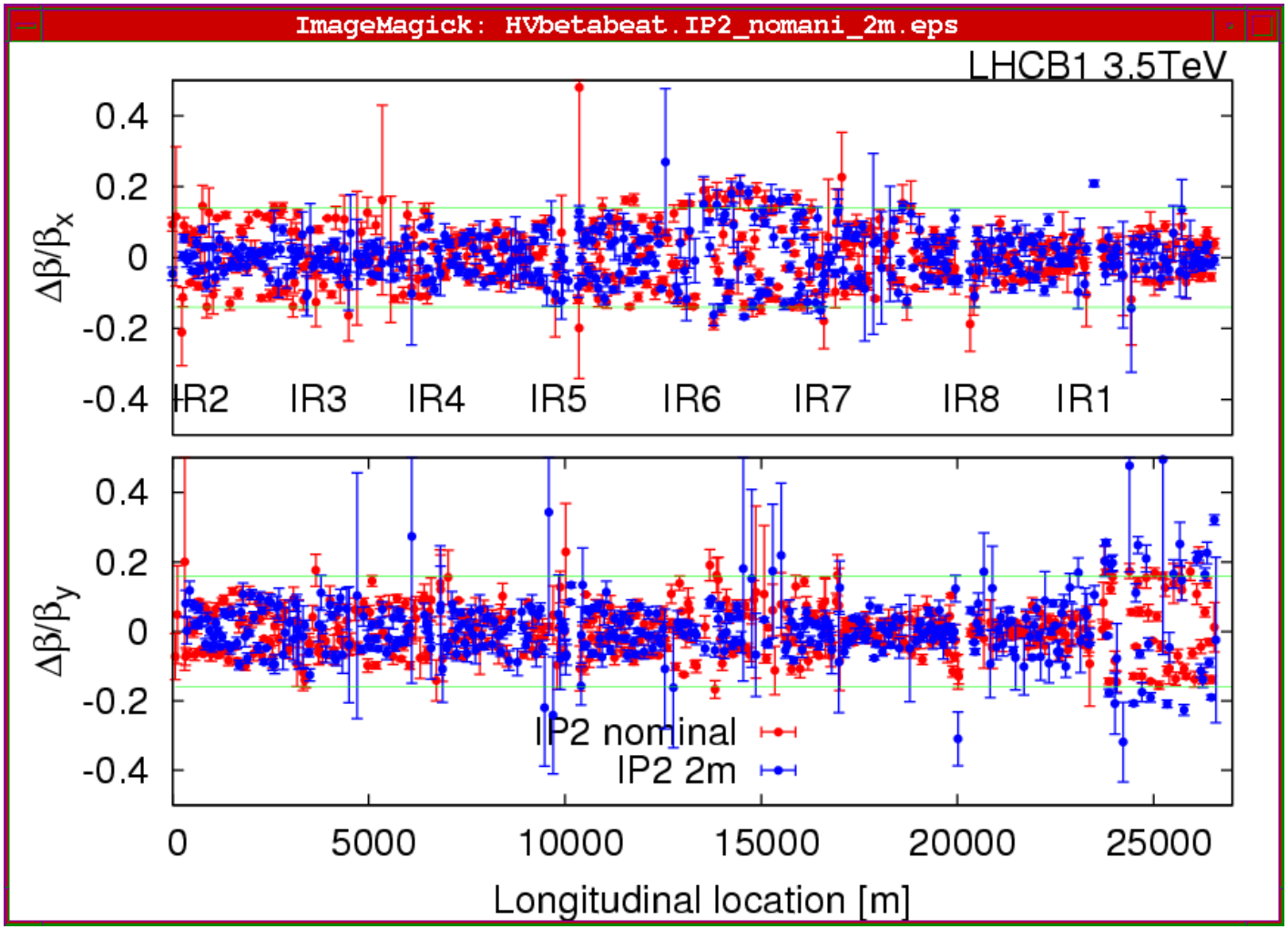
Step 3: Squeezing and correcting IR2

- β-beat for Beam1 at β* = 2m in IR2 (all other IPS at β* = 2m):



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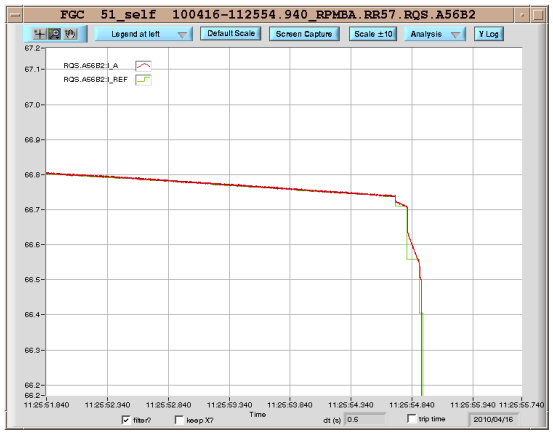
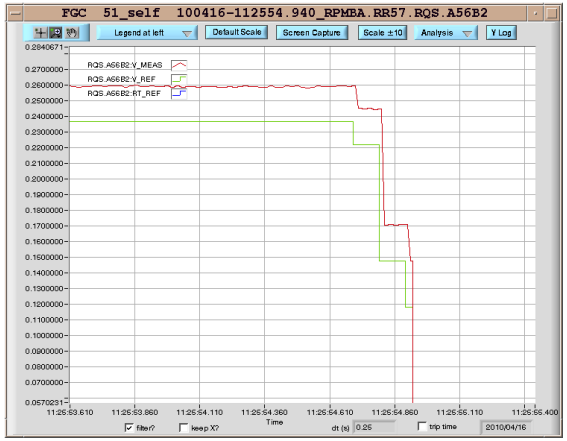
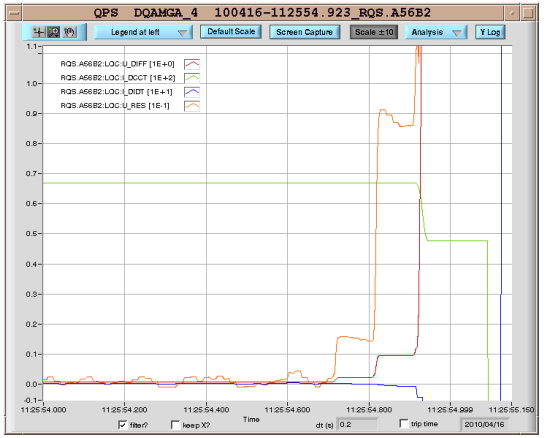
Problem Example I: Too steep current requests

- RQS.A78B2 (17/04) tripped 3 times due to steep current-ramp requests.
- RQS.A56B2 (16/04) tripped once for the same reason
- QPS inductive compensation does not have time to react.
- V_REF translates directly into U_RES which goes above threshold.
- Functions need to be adjusted / smoothened.

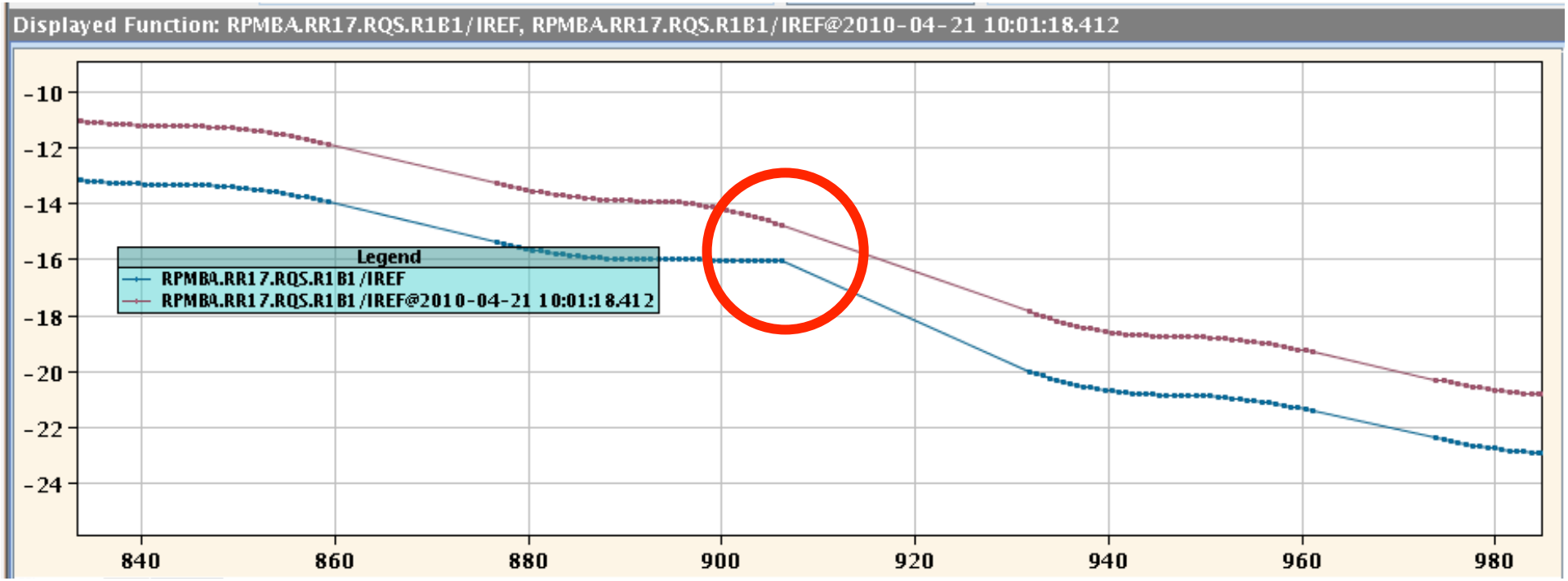






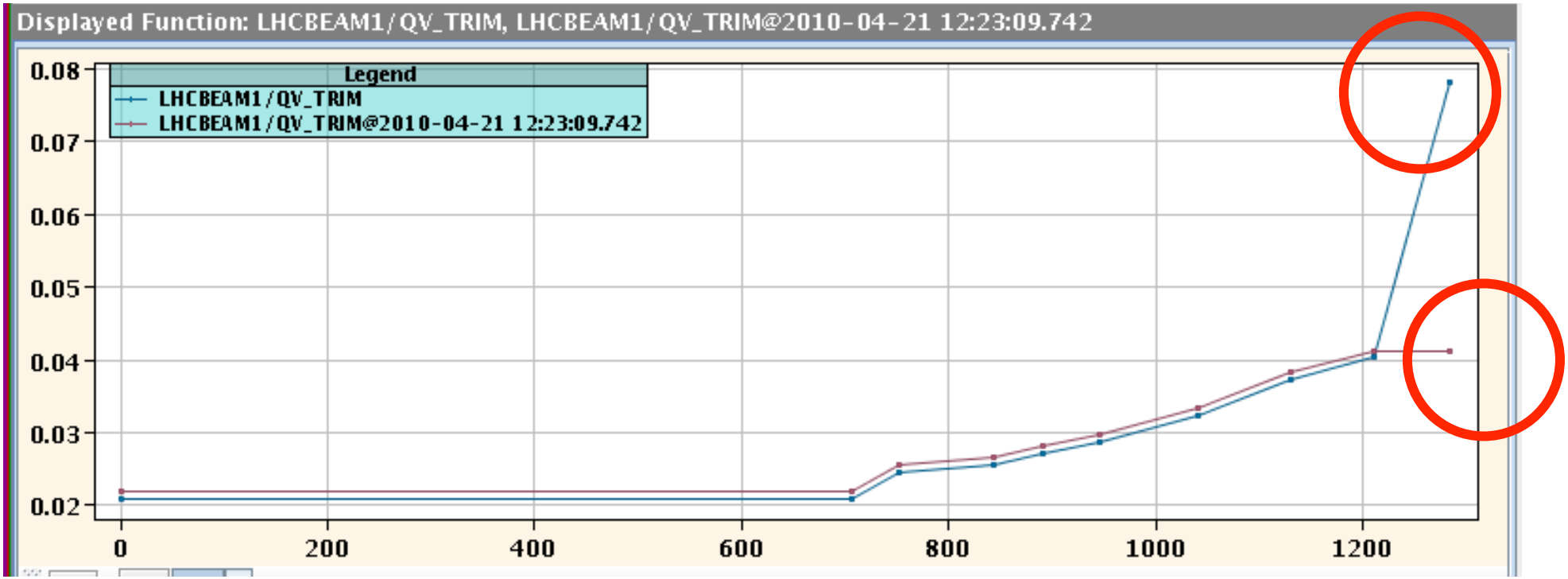
- Fixed as found…
- Thanks to crucial help from MP3 team on shift!

Problem Example II: Discontinuities after incorporation



➔ Fixed by new software

Problem Example III: Leftover trims incorporated



➔ Fixed by procedure…

Many small issues that require to be found and fixed. Each little issue costs 5-6 hours!

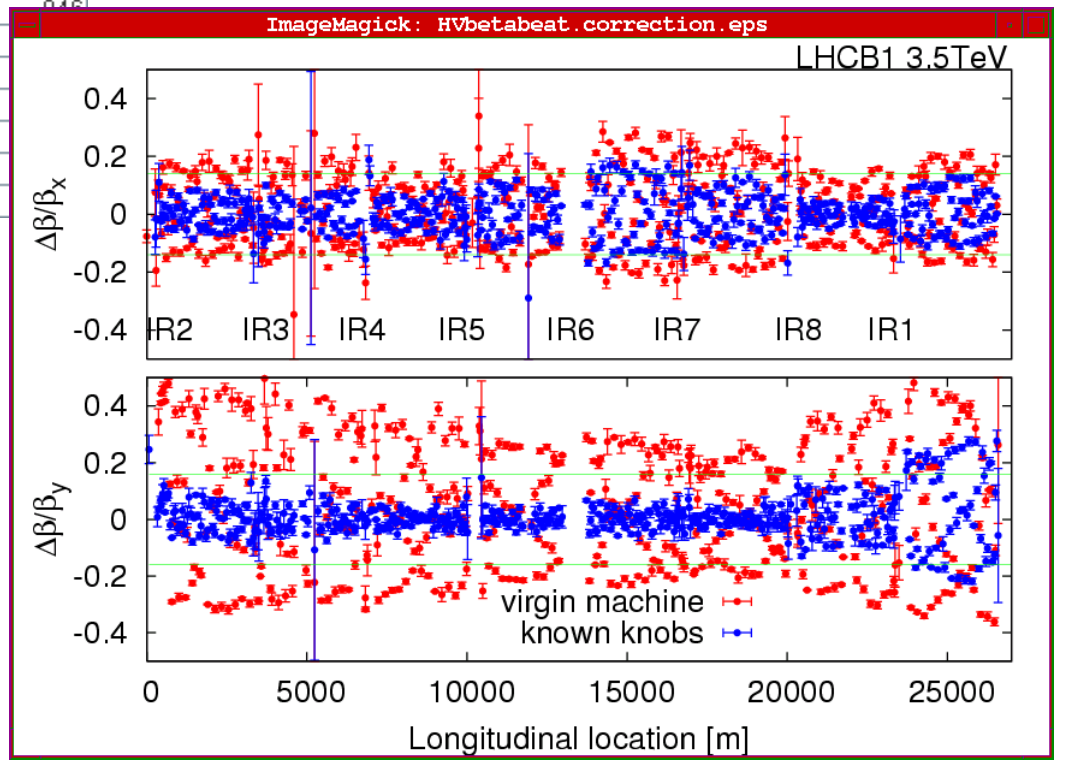
Step 4: Squeezing and correcting all 4 IR's

A1100C1100A1000L1000_FLAT_INJ	3500.0	0
A1100C1100A1000_0.00951L1000_0.00951_FLAT	3500.0	23
A1100C1100A982_0.00941L1000_0.00951_FLAT	3500.0	110
A1100C1100A950_0.00928L950_0.00949_FLAT	3500.0	185
A900C900A900_0.00915L900_0.00949_FLAT	3500.0	280
A900C900A850_0.00907L850_0.00945_FLAT	3500.0	354
A900C900A800_0.00901L800_0.00942_FLAT	3500.0	418
A900C900A750_0.00897L750_0.00932_FLAT	3500.0	486
A700C700A700_0.00893L700_0.00923_FLAT	3500.0	589
A700C700A650_0.00891L650_0.00915_FLAT	3500.0	659
A700C700A600_0.00889L600_0.00909_FLAT	3500.0	705
A700C700A550_0.00889L550_0.00904_FLAT	3500.0	752
A500C500A500_0.00889L500_0.00900_FLAT	3500.0	844
A500C500A450_0.00889L450_0.00896_FLAT	3500.0	892
A400C400A400_0.00889L400_0.00893_FLAT	3500.0	
A400C400A400_0.00889L375_0.00888_FLAT	3500.0	
A350C350A350_0.00889L350_0.00882_FLAT	3500.0	
A350C350A350_0.00889L325_0.00878_FLAT	3500.0	
A350C350A300_0.00889L300_0.00875_FLAT	3500.0	
A250C250A250_0.00889L250_0.00872_FLAT	3500.0	
A200C200A200_0.00889L200_0.00872_FLAT	3500.0	

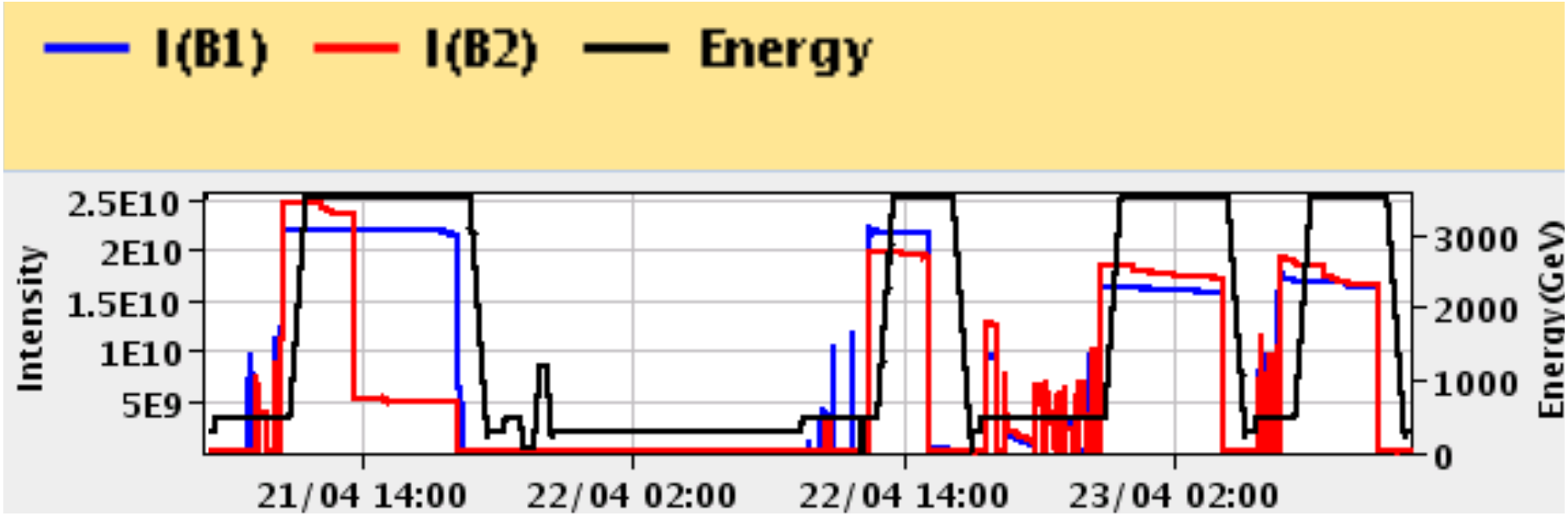
21 optics steps!

Mike Lamont
Gabriel Muller
Marek Strzelczyk
Stefano Redaelli
Xavier

Rogelio Tomas et al



Squeeze now starts working smoothly!



Look at 4 most recent fills in last 48 hours!

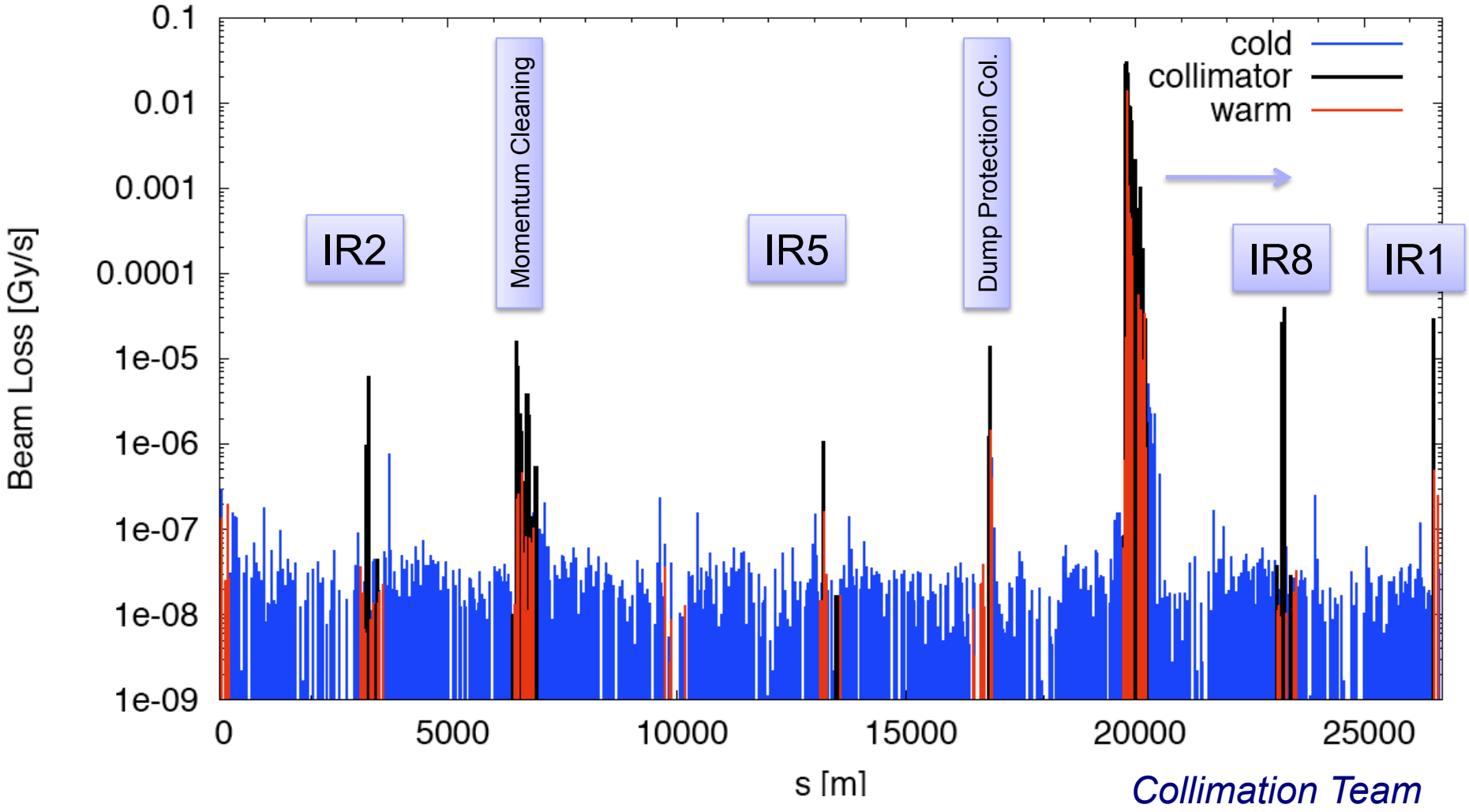
All these fills made it to 3.5 TeV and 2m β^*!

First two still affected by bugs (intensity loss) but used for qualification study!

Last two fills without any problem, very smooth!

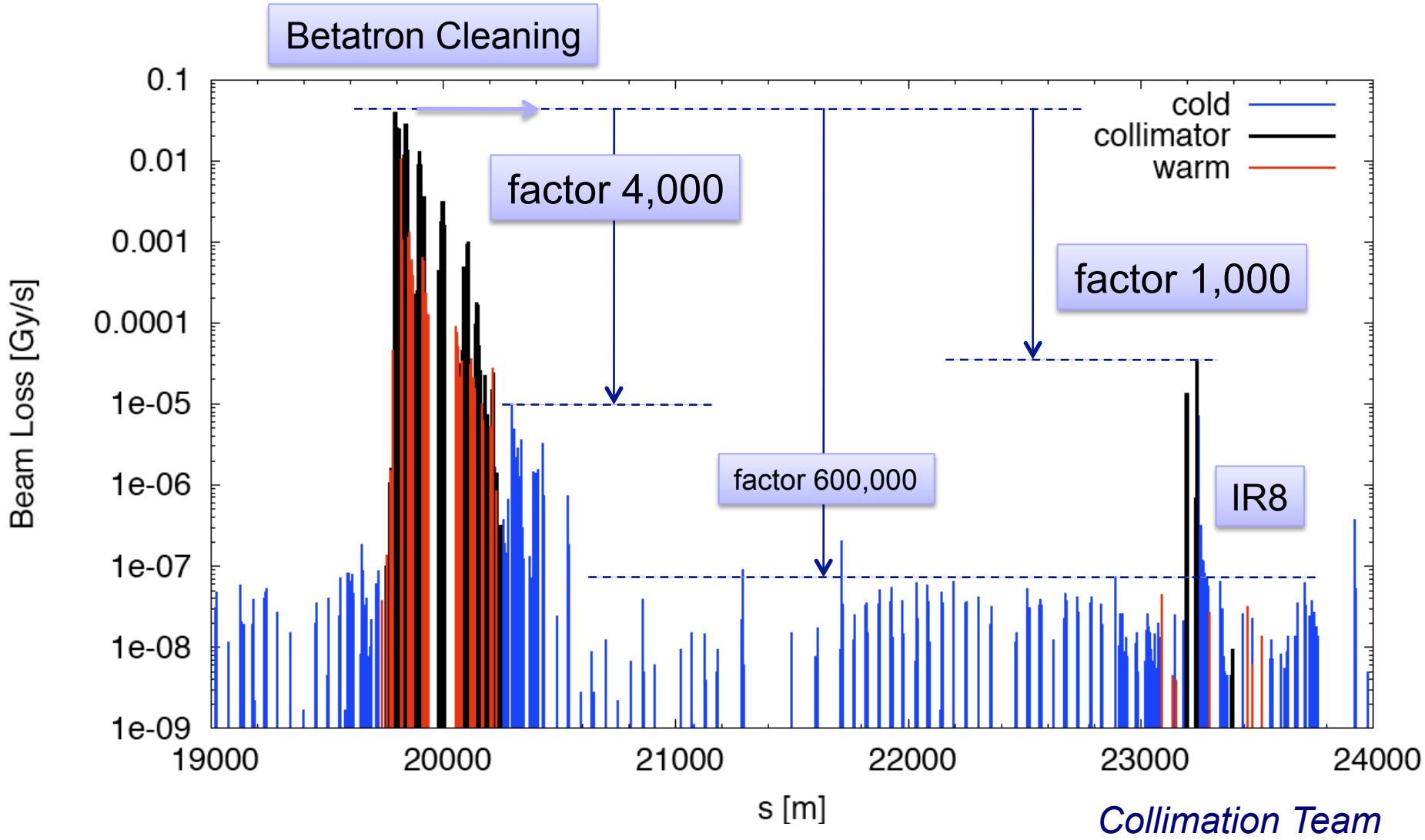
Used for provoked loss tests in preparation for stable beams!

Provoked vertical beam loss on beam 1



2m optics exposes IR's as expected! Protected by tertiary collimators.

Zoom (vertical loss beam 1)

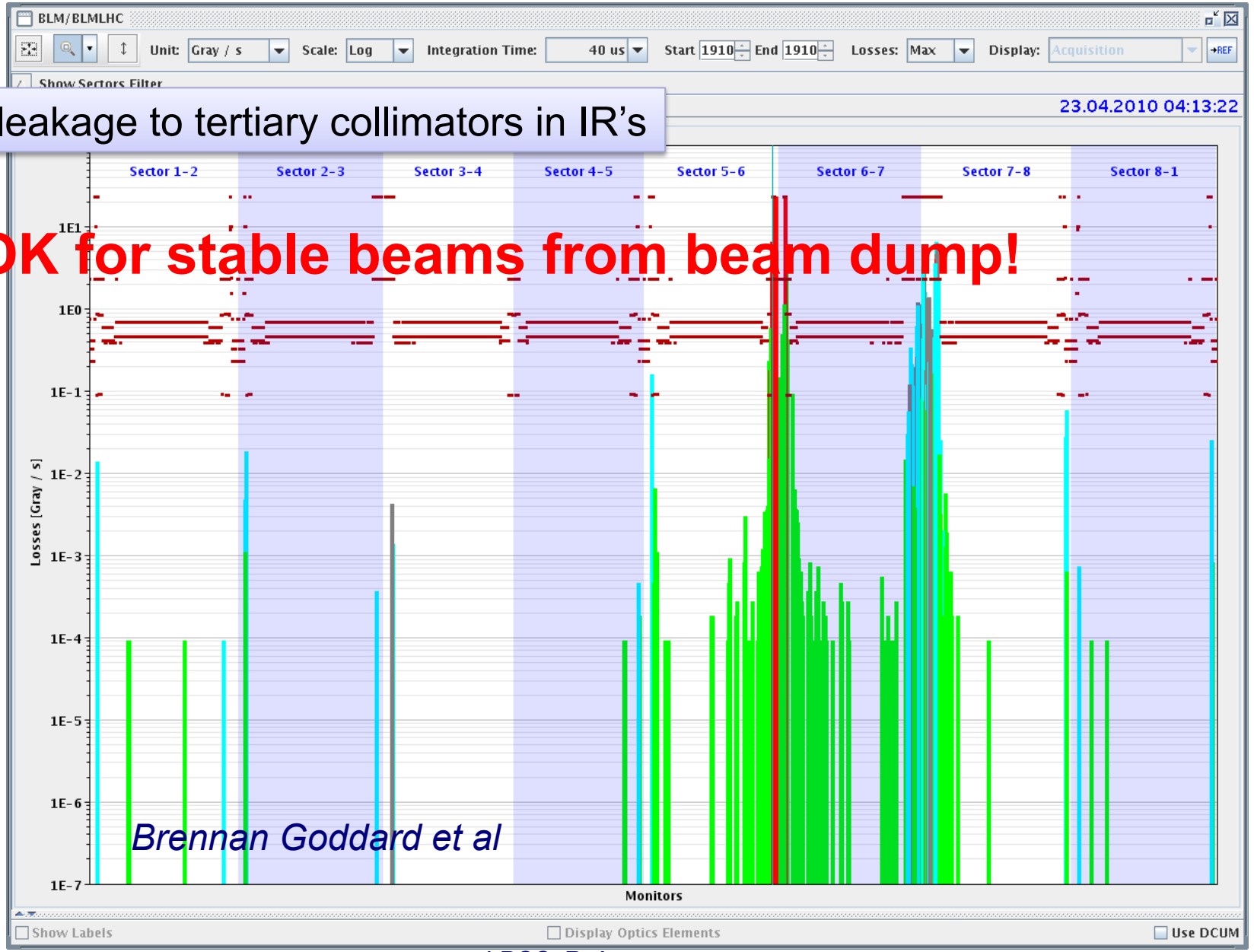


➔ **OK for stable beams from collimation!**

Provoked asynchronous beam dump

1e-3 leakage to tertiary collimators in IR's

➔ **OK for stable beams from beam dump!**



Status and Outlook Squeeze

- Squeeze to 2m for all 4 IR's established.
- All IR's steered into collision.
- Golden orbit established.
- All 16 tertiary collimators adjusted.
- Squeezed optics fully qualified for protection.

- Next: intensity from 2e10/beam to 3.5e10/beam
- Next: **Stable beams with 10 times luminosity:**

10^{28} cm^{-2} s^{-1} in reach

- Still a lot to go but first steps are most difficult!

PART II – Increasing Intensity at 450 GeV

… will be a long story but so far very happy…

This will be the challenge of LHC!

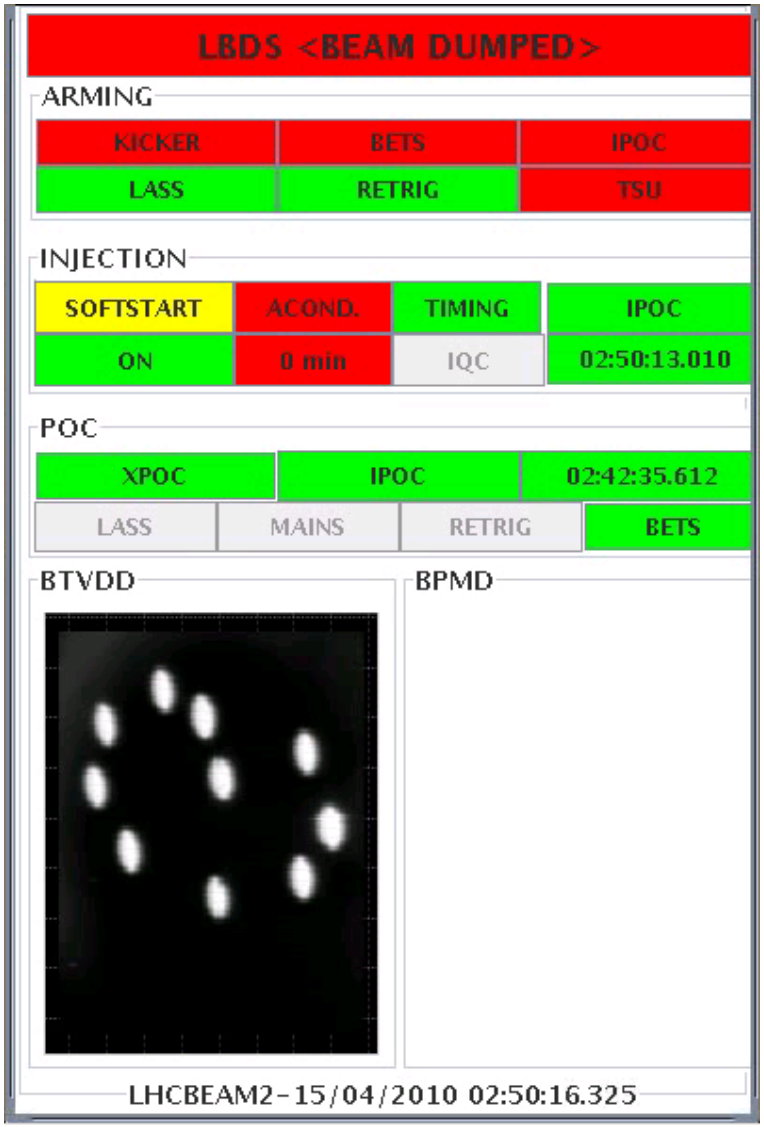
Goal: Factor 10 at injection.

Increase Intensity: Number of Bunches

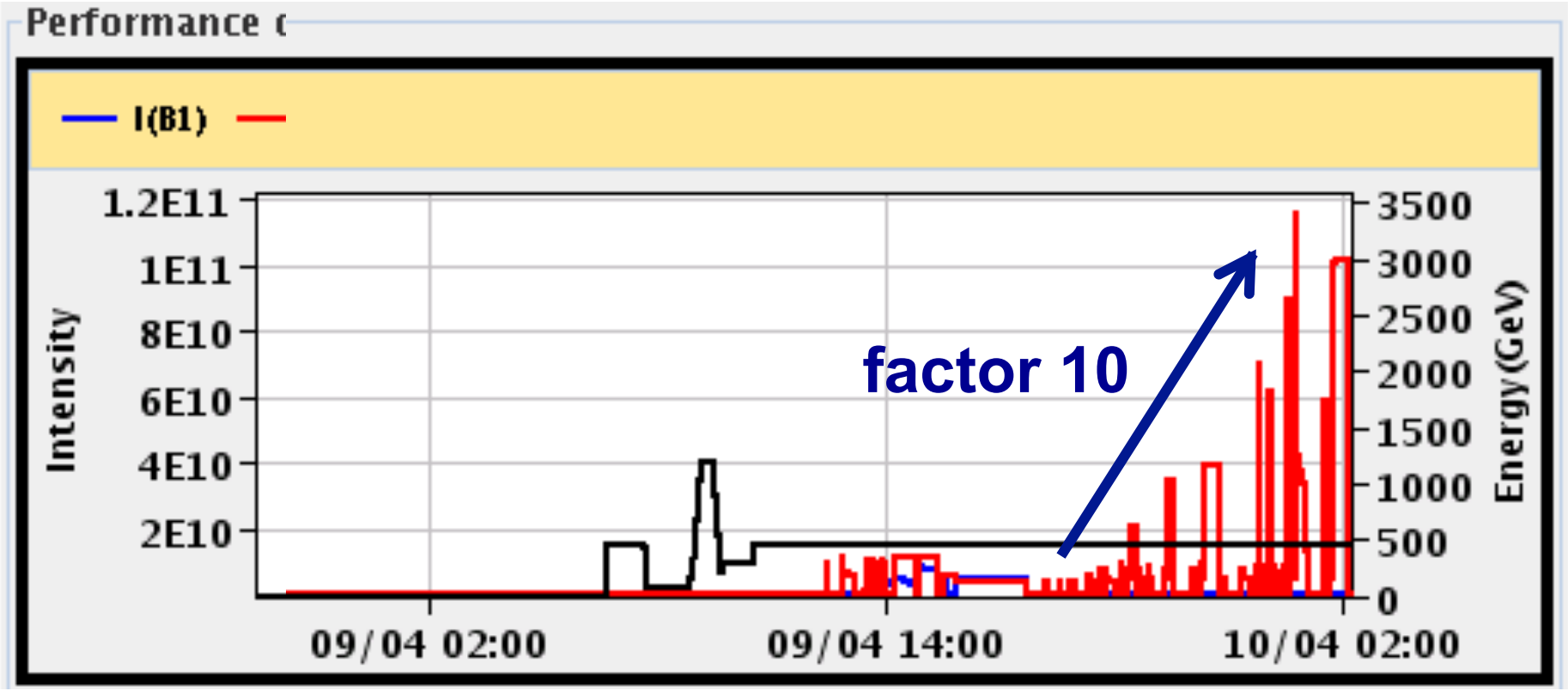
Dump of the 10 bunches

factor 10

Brennan Goddard et al



Increasing bunch intensity

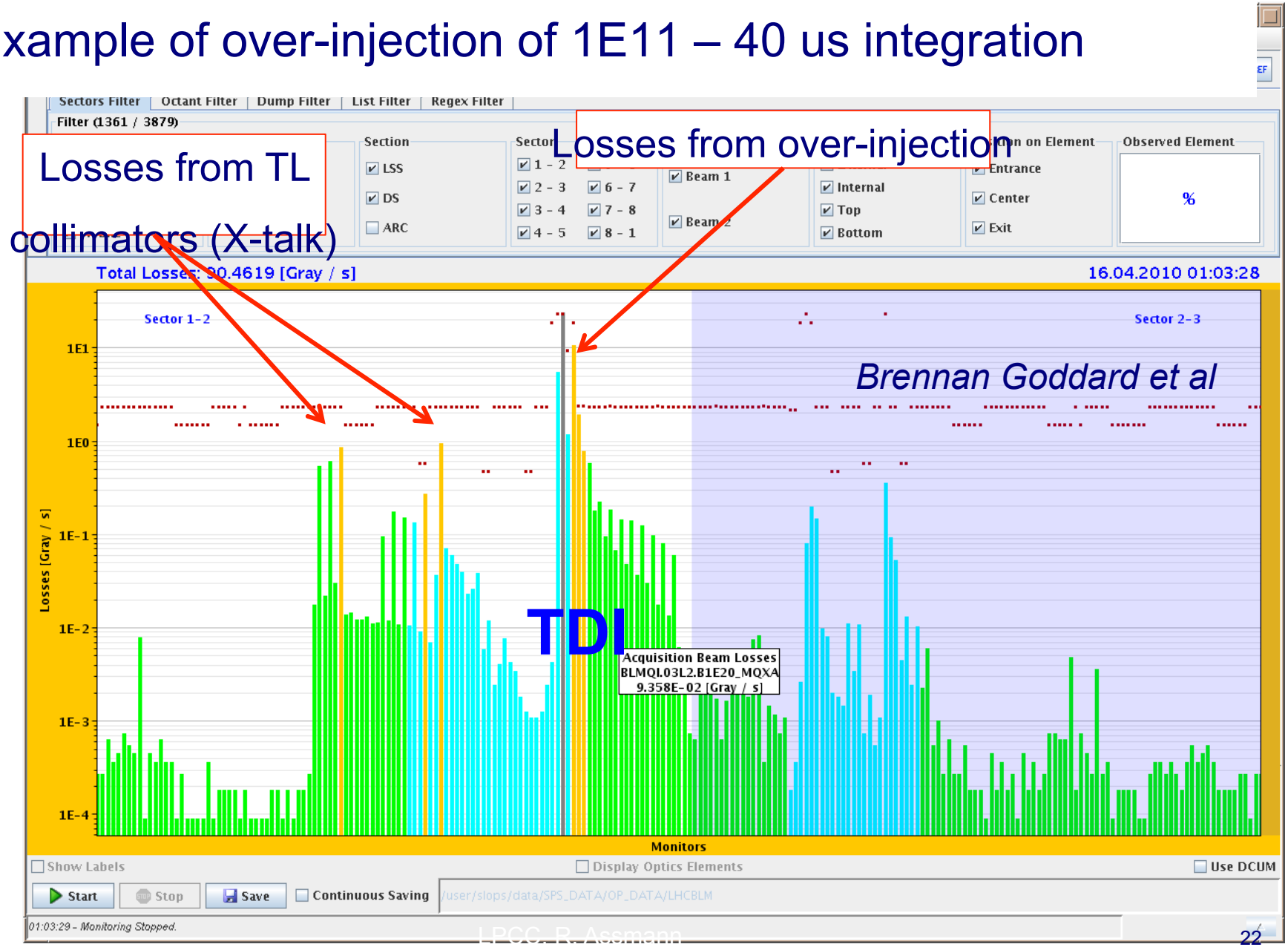


Major success for LHC: **Nominal bunch charge at 450 GeV!**
25 hours beam lifetime!

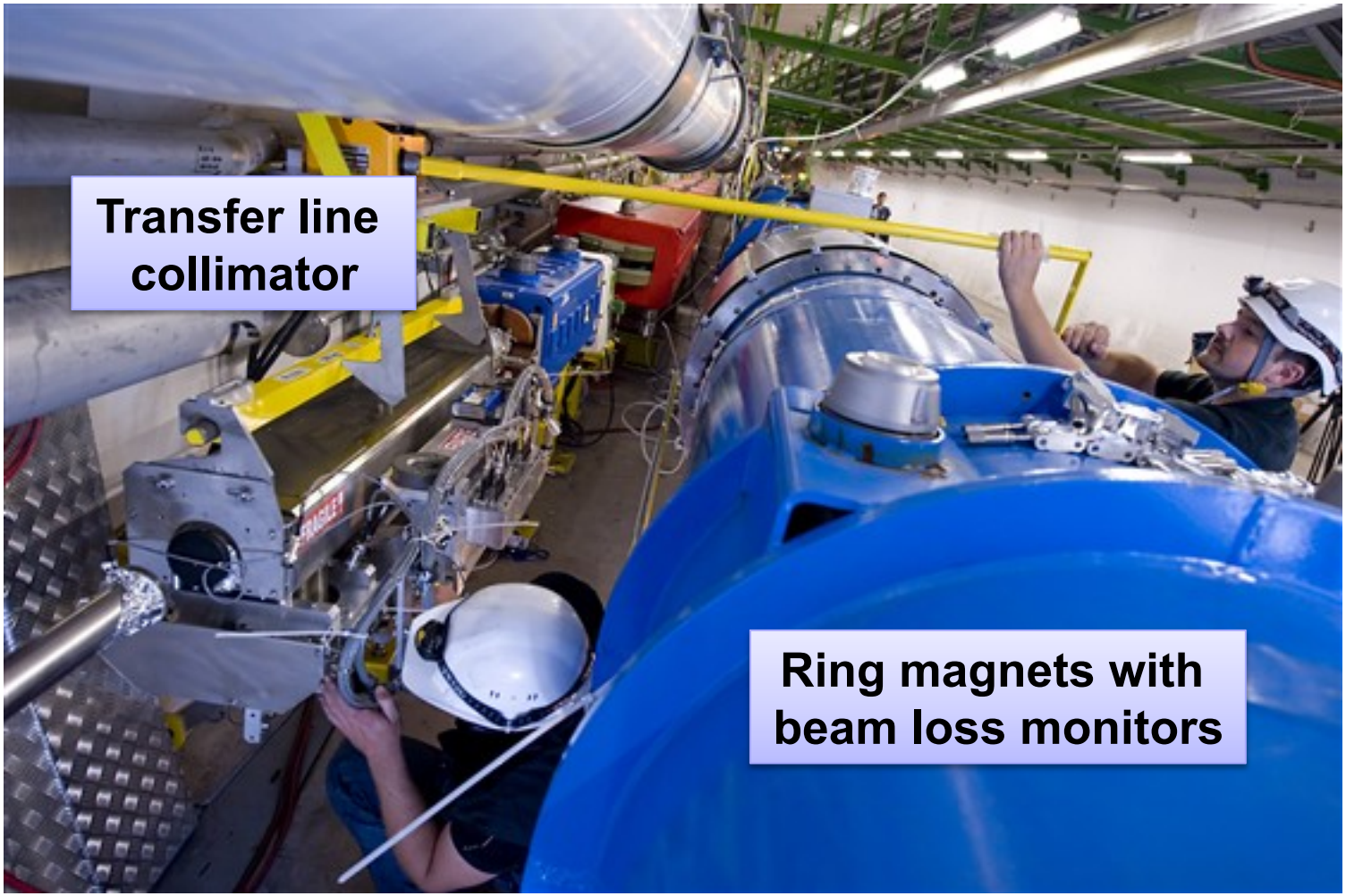
Means: No single bunch show stoppers from dynamic aperture, instabilities, …

Increase Intensity: Over-Injection

- Example of over-injection of 1E11 – 40 us integration



Tunnel View

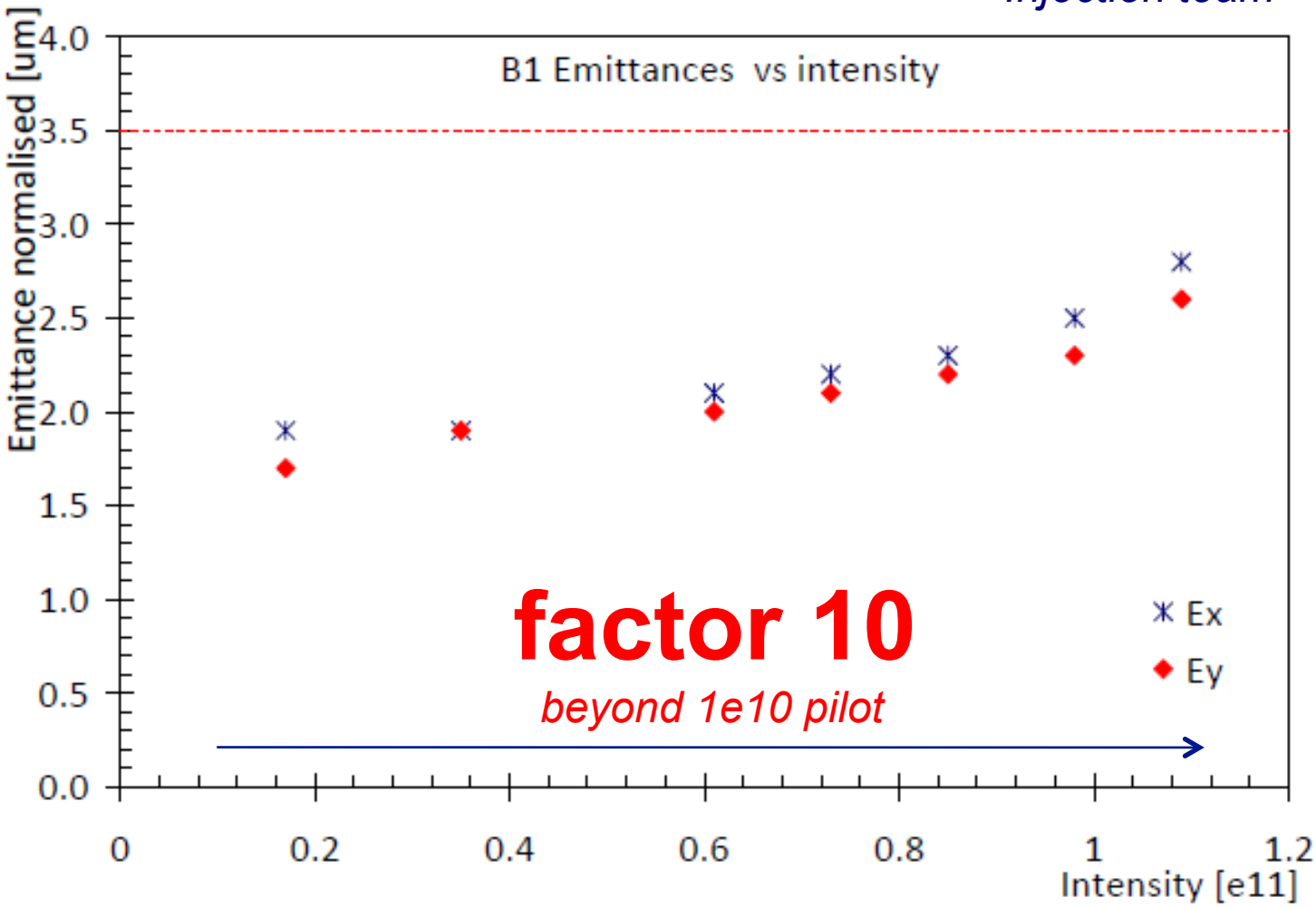


Collimation Team

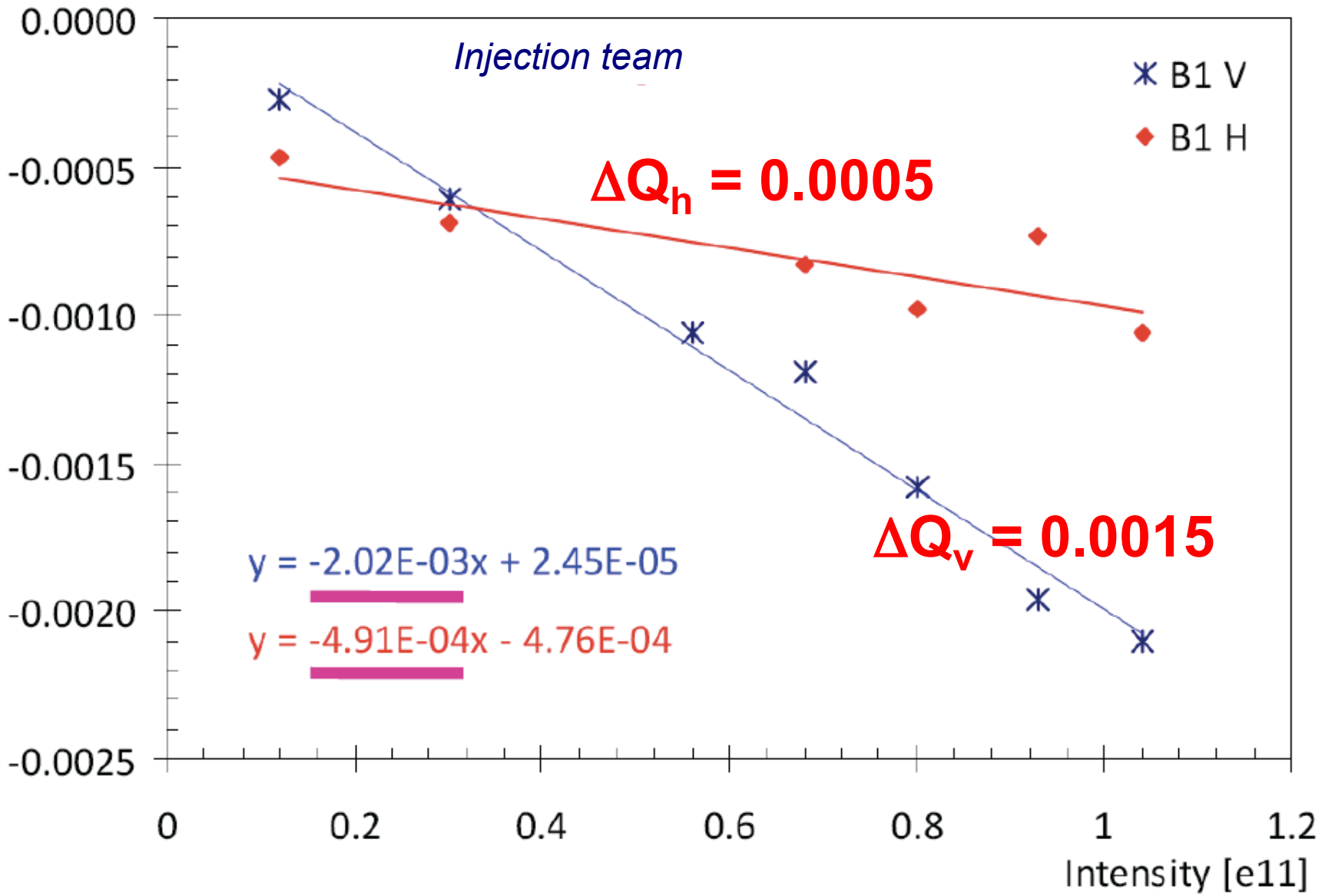
Increase Intensity: Emittance

- Emittances versus bunch intensity:

Injection team

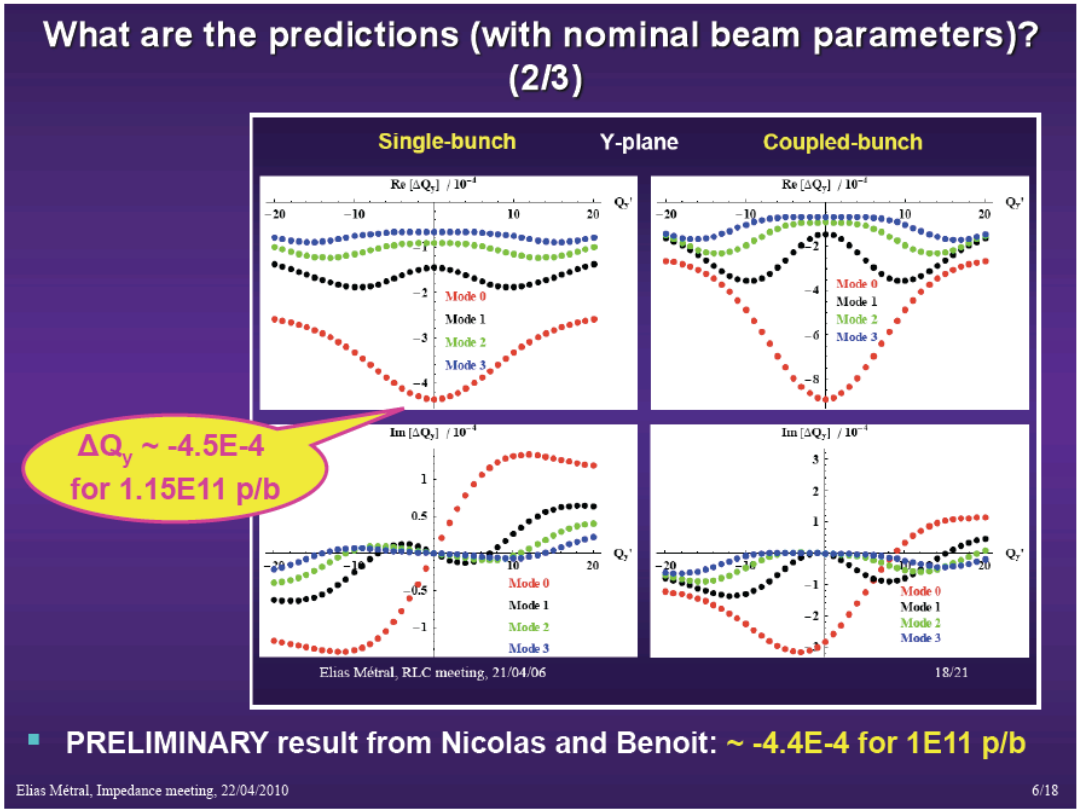


Increase Intensity: Tune Shift Beam 1



Tune shift: Measured versus Expected

	B1 meas	B2 meas	Expected
Q_h tune shift	5e-4	1.5e-3	
Q_v tune shift	**1.5e-3**	**2.0e-3**	**4.5e-4**



for 1e10 to 1e11 p

to be studied systematically:

impedance vs. collimator settings

other source?

Elias Metral et al

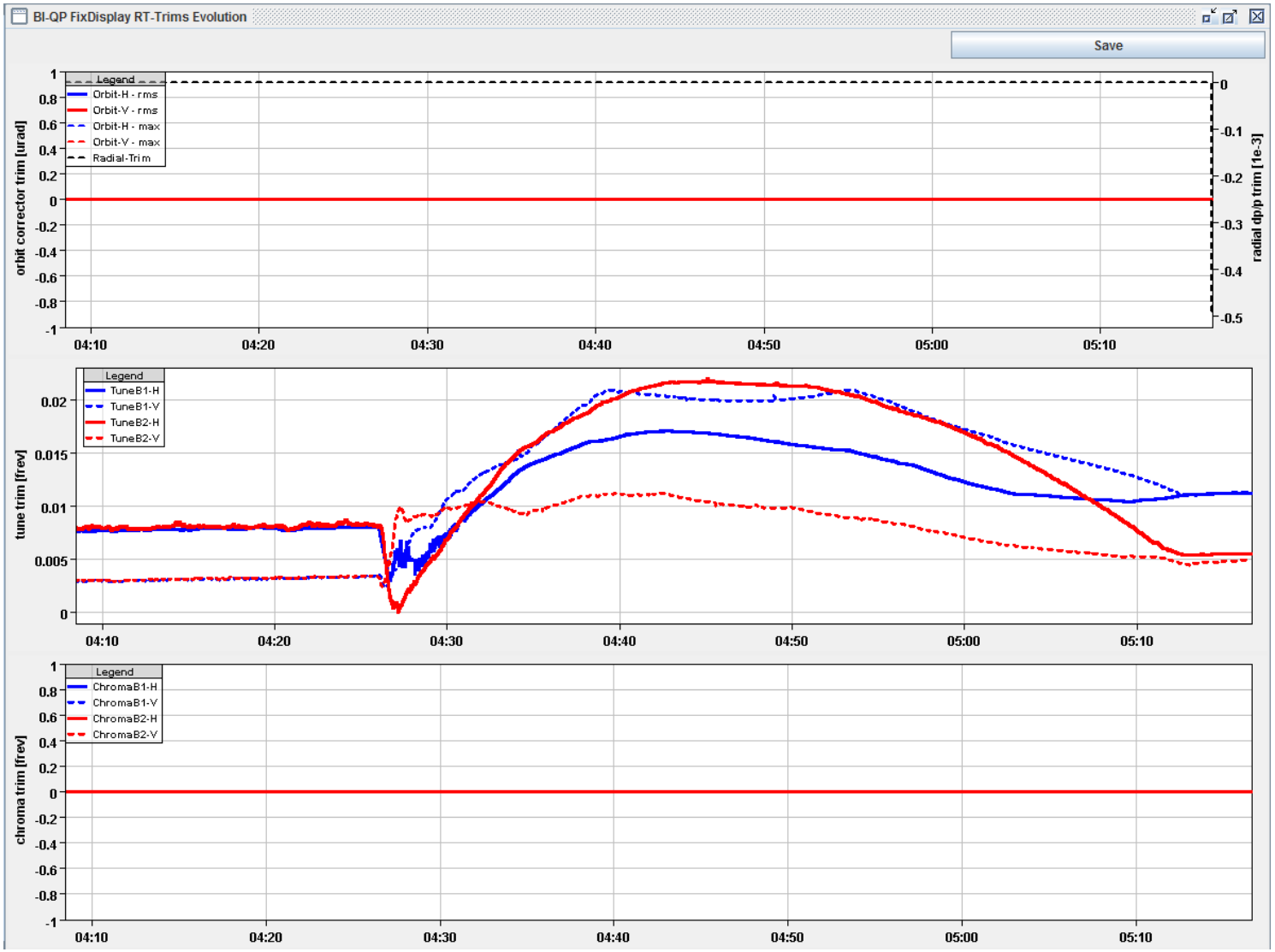
PART III – Feedbacks, Emittance & OP Issues

…the cure, some issues…

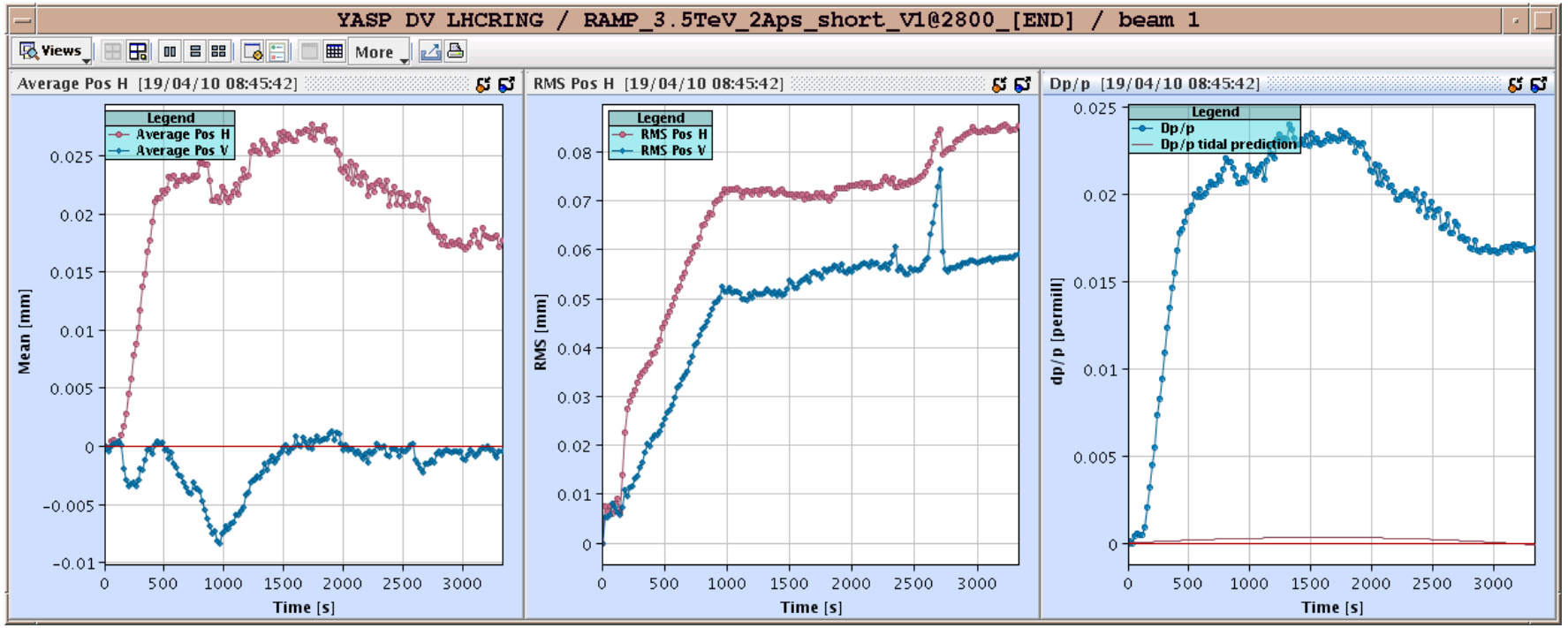
Tune Feedback in Operation

- Tune feedback during ramp:

Ralph Steinhagen et al



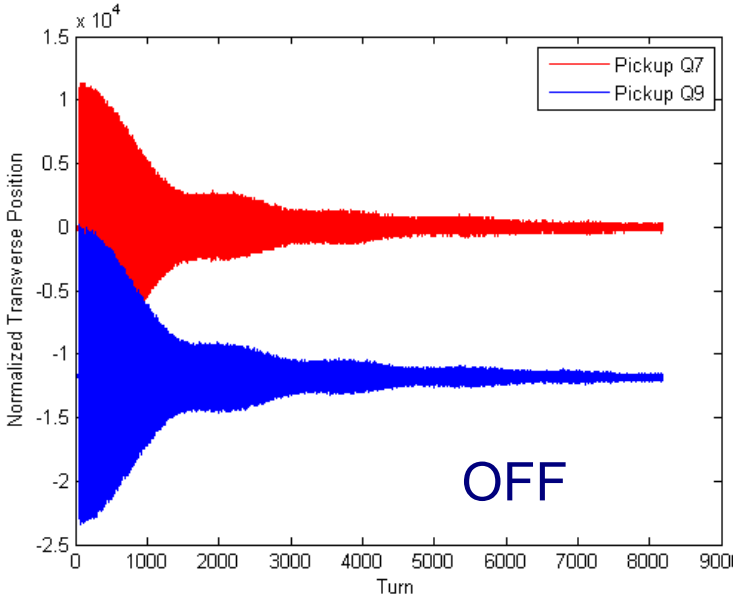
Orbit Feedback in Operation



Maximum orbit change during energy ramp: **0.08 mm**

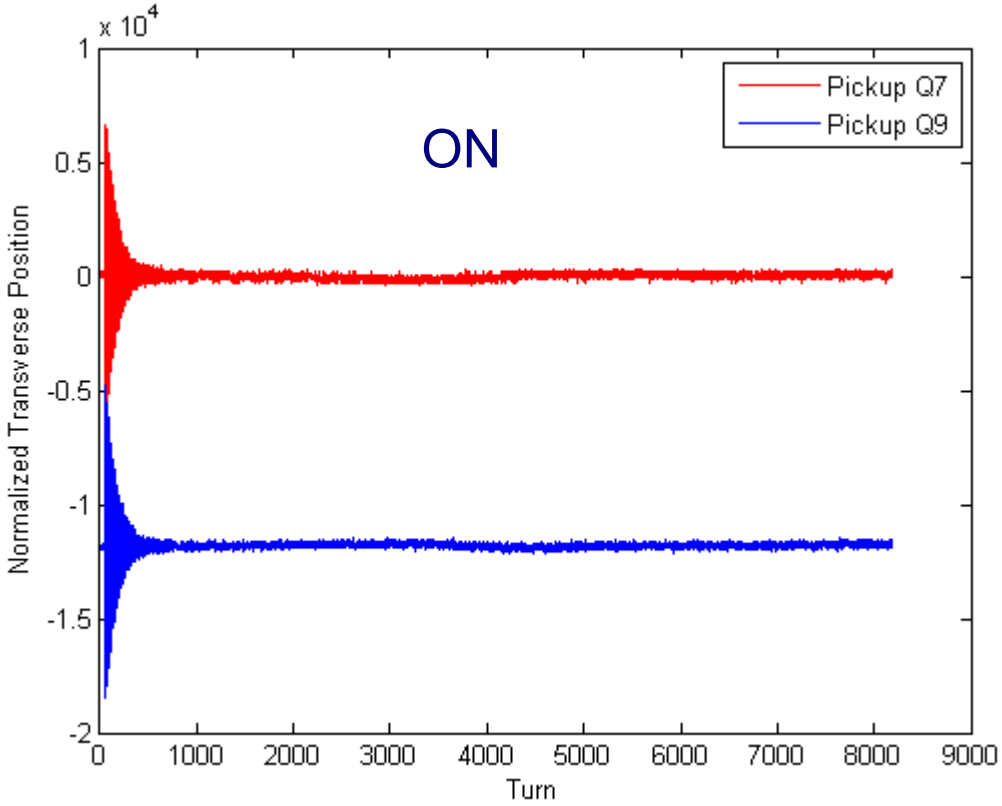
Ralph Steinhagen et al

Transv. Damper: Damping Beam Excitations

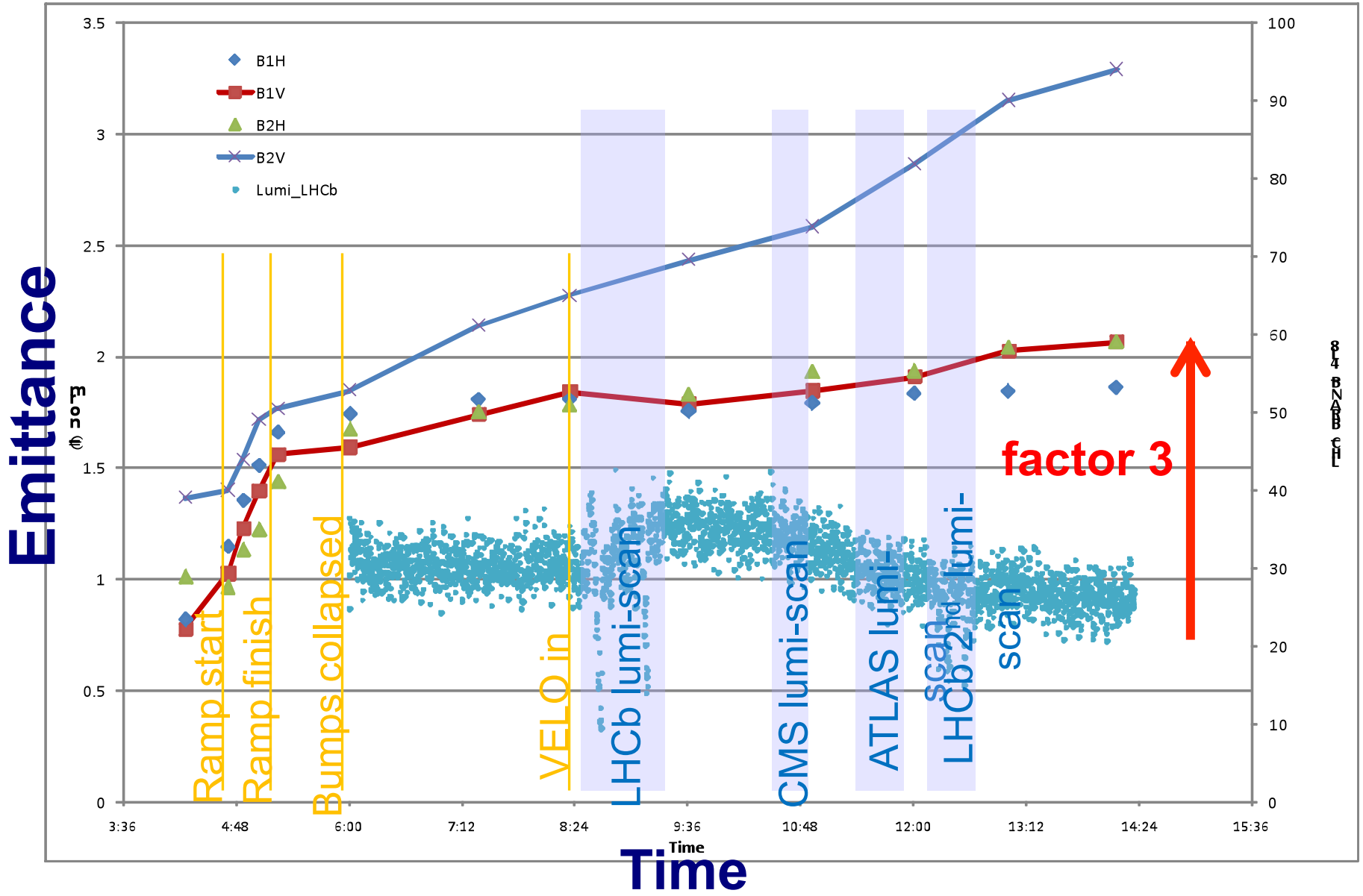


Crucial device to keep emittance growth under control!

Wolfgang Hoefle et al



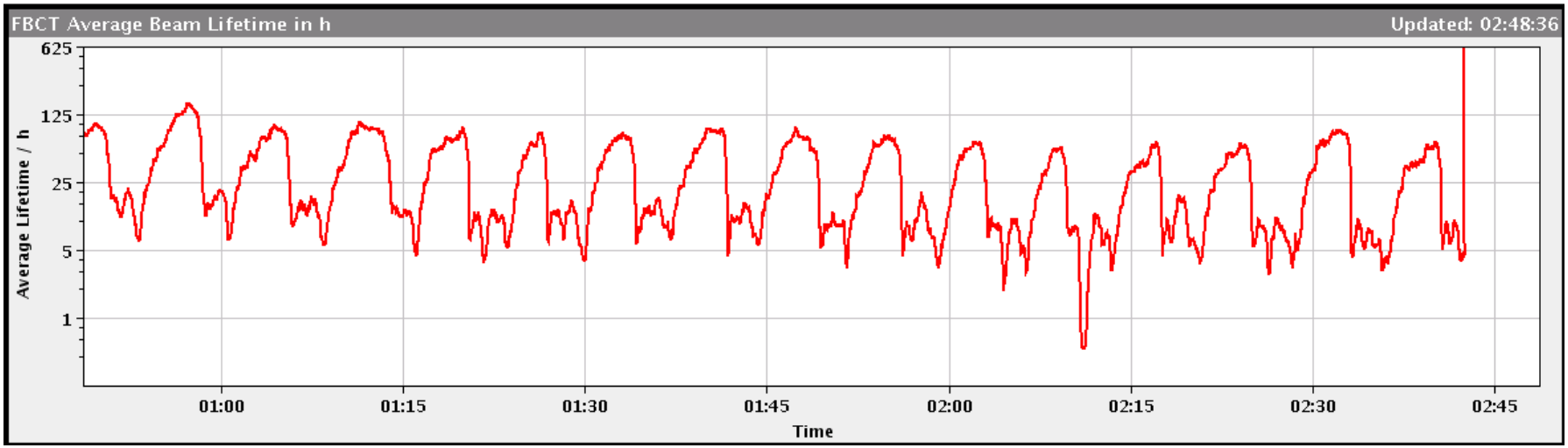
Emittance Growth: Still a Problem



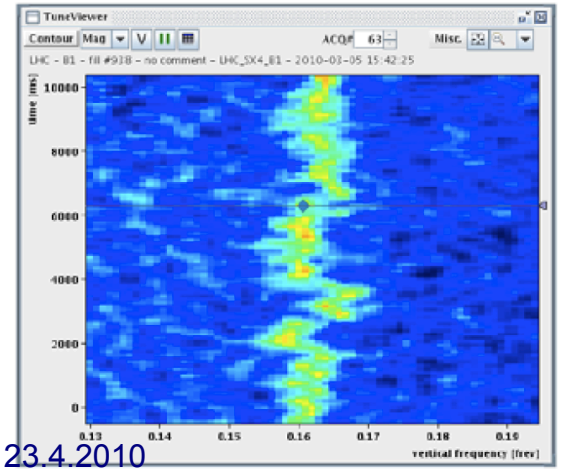
Mirko Pojer

Lifetime Drops with “Quiet” Beam

- Our friend the hump on the lifetime - ~ 7 minute period



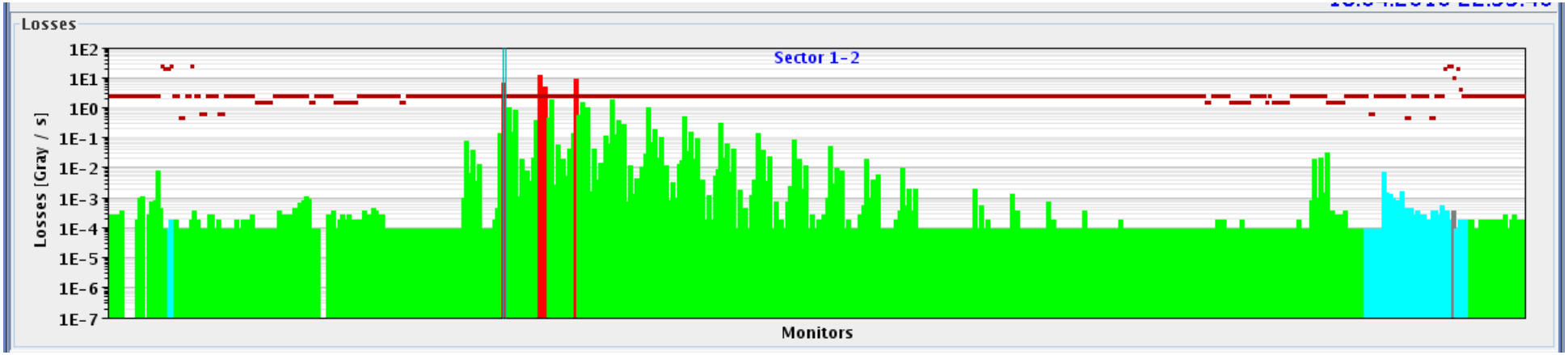
Hunt the Hump!



The hump is a vertical excitation on the beam that has a fast frequency component (therefore visible as “hump” in the tune spectrum and a slow moving frequency component (7 min).

4 Magnet Quench from Injected Pulse

- Losses in Sector12 at 450 GeV injection (1e10 p):



First injection into machine with some magnets mis-powered.

First injection always with pilot beam to exclude damage.

Collimation cannot protect for strong local kicks!

- Debugging of operational procedures…

Conclusion

- Our “baby” (the LHC) learns walking surprisingly fast:
  - Routine ramps with 2e10 p to 3.5 TeV (just below safe beam limit).
  - Squeeze in all 4 IR’s to 2m β^* starts to run smoothly (smallest 2010).
  - Squeezed optics fully qualified for protection ➔ IR’s protected by collimation as foreseen.
  - Tonight/tomorrow:
    Stable beams: **unsafe 3.5 TeV beam, all IR’s squeezed to 2m β^*.**
    Luminosity at **10^{28} cm^{-2} s^{-1}.**
- In parallel important progress towards higher intensities:
  - Stored nominal bunch intensity at 450 GeV with excellent lifetimes.
  - Multiple bunches stored.
  - Various feedbacks running. Instrumentation, RF, cryo, … very good!
  - Seeing and addressing issues: emittance growth, hump, thresholds, impedance, operational issues, …
- Remember, LHC is still a baby (for beam). So we try to guide it carefully the first steps… (we do not want to fall)

Thank you for your attention!