Status of LHC Operations

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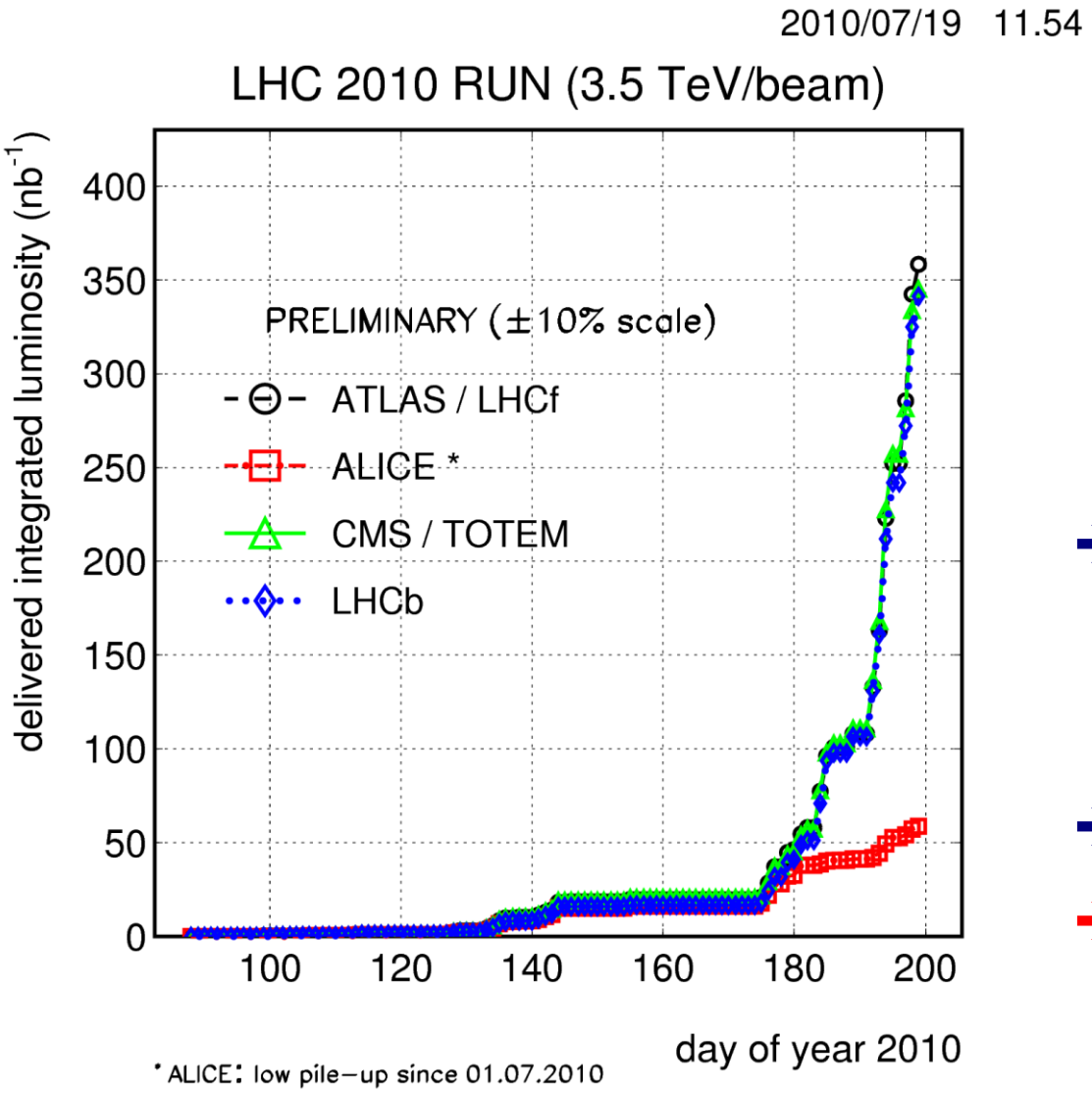
for the LHC commissioning team and LHC teams & groups

LPCC 23.7.2010

Outline

- Stable beams for requested 100 nb-1 plus more
- Increasing intensity to > 10^{12} p at injection
- Issues during stable beams
- Optimizing conditions in collision
- Analysis of record physics fill
- Intensity outlook
- Conclusion

Stable Beams for Requested 100 nb^{-1}



ca. 70 nb-1 in last fill!

➔ Approach with high bunch intensity paid off (investment of commissioning time)

➔ **9e10 p per bunch**

➔ **up to 13 bunches**

Collision Scheme (LPC, M. Ferro-Luzzi)

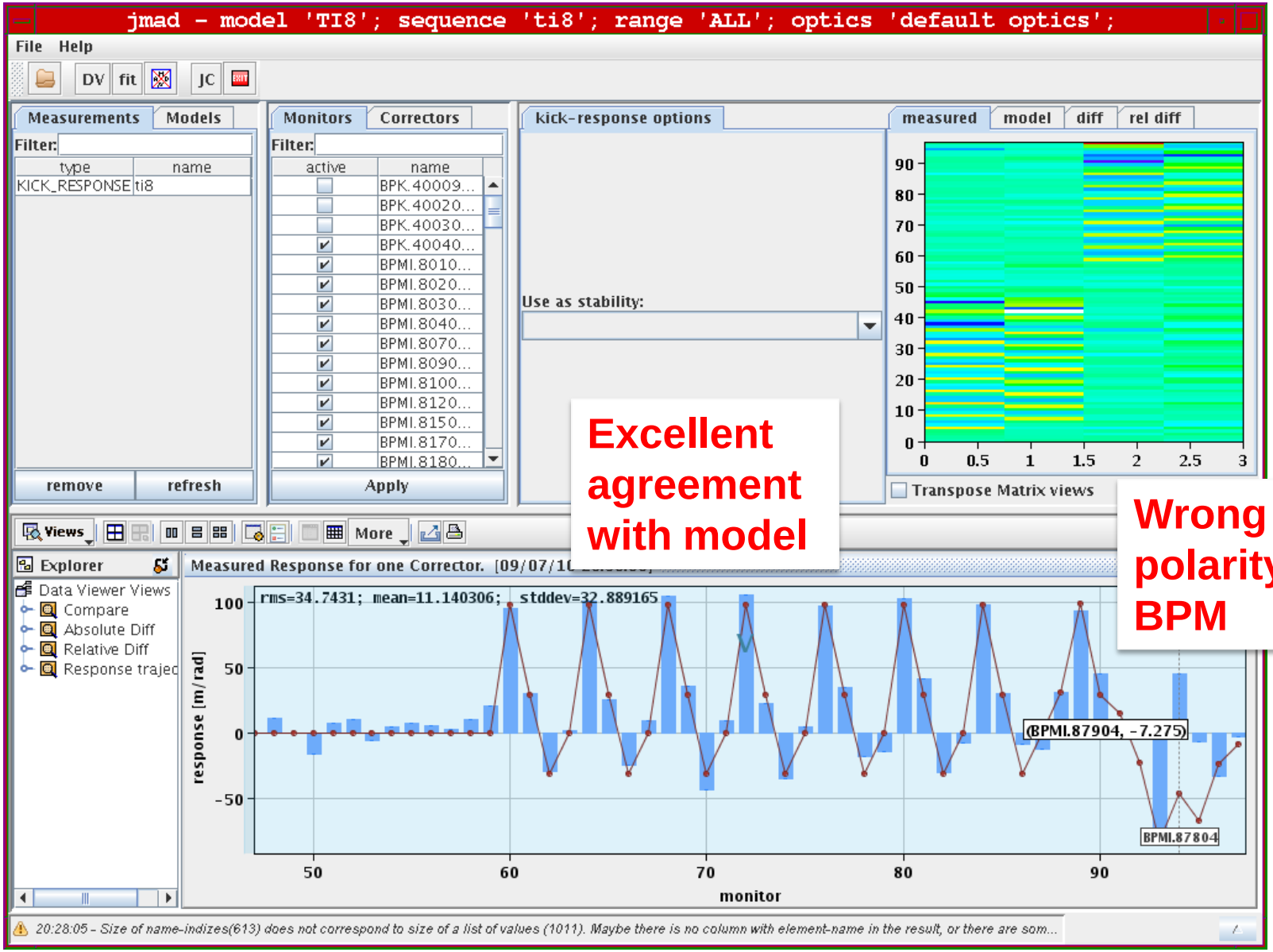
8 collisions per IP

	d	Beam1		Beam2
lision in IR1/5:	-11.25 m	bucket 8941	and bucket	8911
collision in IR1/5:	-11.25 m	bucket 9941	and bucket	9911
displaced collision in IR1/5:	-11.25 m	bucket 10941	and bucket	10911
displaced collision in IR1/5:	-11.25 m	bucket 11941	and bucket	11911
good collision in IR1/5:	0 m	bucket 1	and bucket	1
good collision in IR1/5:	0 m	bucket 1001	and bucket	1001
good collision in IR1/5:	0 m	bucket 2001	and bucket	2001
good collision in IR1/5:	0 m	bucket 3001	and bucket	3001
good collision in IR1/5:	0 m	bucket 17851	and bucket	17851
good collision in IR1/5:	0 m	bucket 18851	and bucket	18851
good collision in IR1/5:	0 m	bucket 19851	and bucket	19851
good collision in IR1/5:	0 m	bucket 20851	and bucket	20851
good collision in IR2:	0 m	bucket 1	and bucket	8911
good collision in IR2:	0 m	bucket 1001	and bucket	9911
good collision in IR2:	0 m	bucket 2001	and bucket	10911
good collision in IR2:	0 m	bucket 3001	and bucket	11911
good collision in IR2:	0 m	bucket 8941	and bucket	17851
good collision in IR2:	0 m	bucket 9941	and bucket	18851
good collision in IR2:	0 m	bucket 10941	and bucket	19851
good collision in IR2:	0 m	bucket 11941	and bucket	20851
good collision in IR8:	0 m	bucket 8941	and bucket	1
good collision in IR8:	0 m	bucket 9941	and bucket	1001
good collision in IR8:	0 m	bucket 10941	and bucket	2001
good collision in IR8:	0 m	bucket 11941	and bucket	3001
good collision in IR8:	0 m	bucket 17851	and bucket	8911
good collision in IR8:	0 m	bucket 18851	and bucket	9911
good collision in IR8:	0 m	bucket 19851	and bucket	10911
good collision in IR8:	0 m	bucket 20851	and bucket	11911
not colliding at all:		bucket 6001		
not colliding at all:				bucket 5001

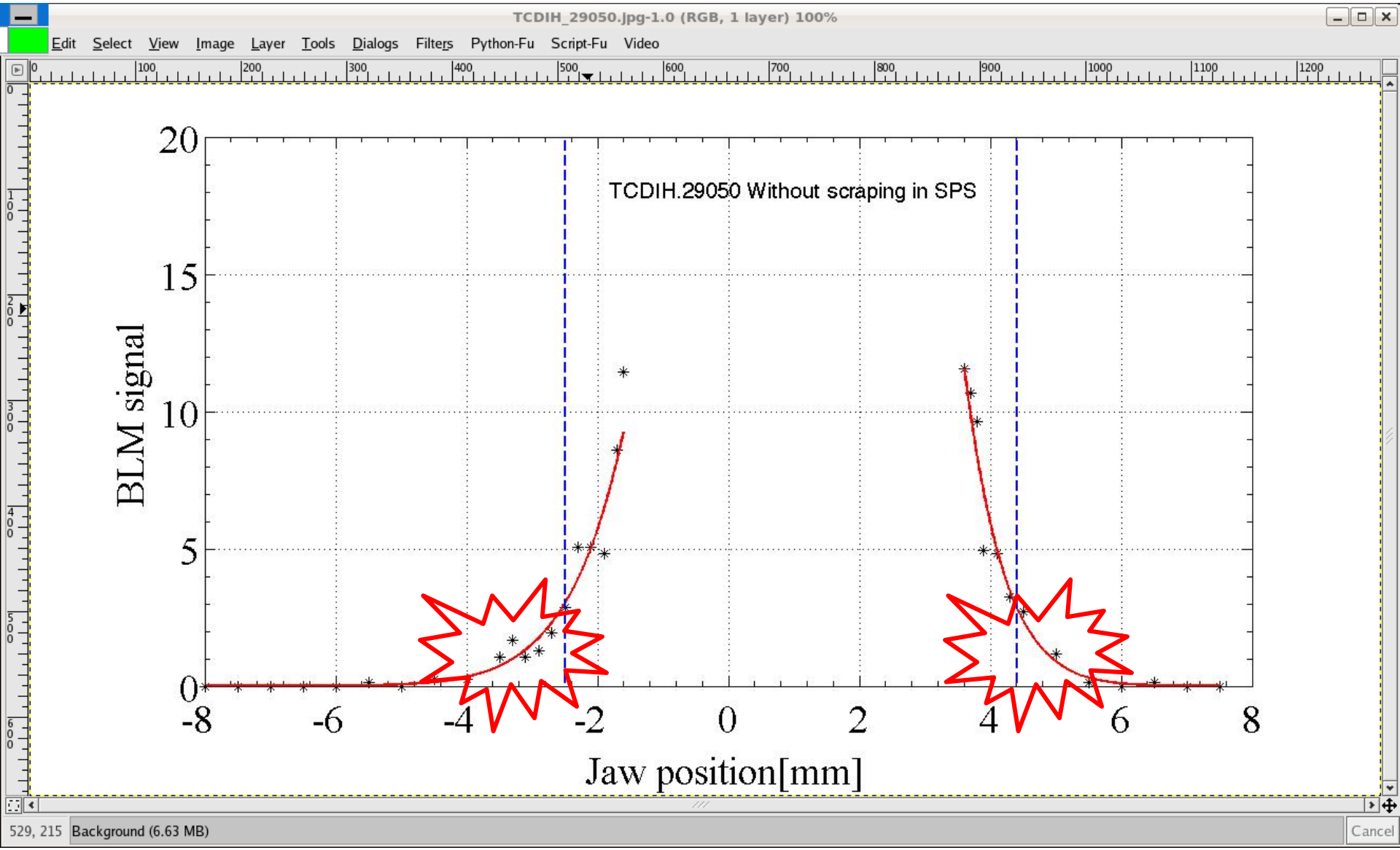
Increasing intensity to > 10^{12} p at injection

- No interlock masking allowed at high intensities, even at injection.
- Transfer line trajectories drifting away.
- Incoming tails from SPS.
- **Improved setup of transfer lines, injection protection and collimation required.**
- B. Goddard, C. Bracco, M. Meddahi and team

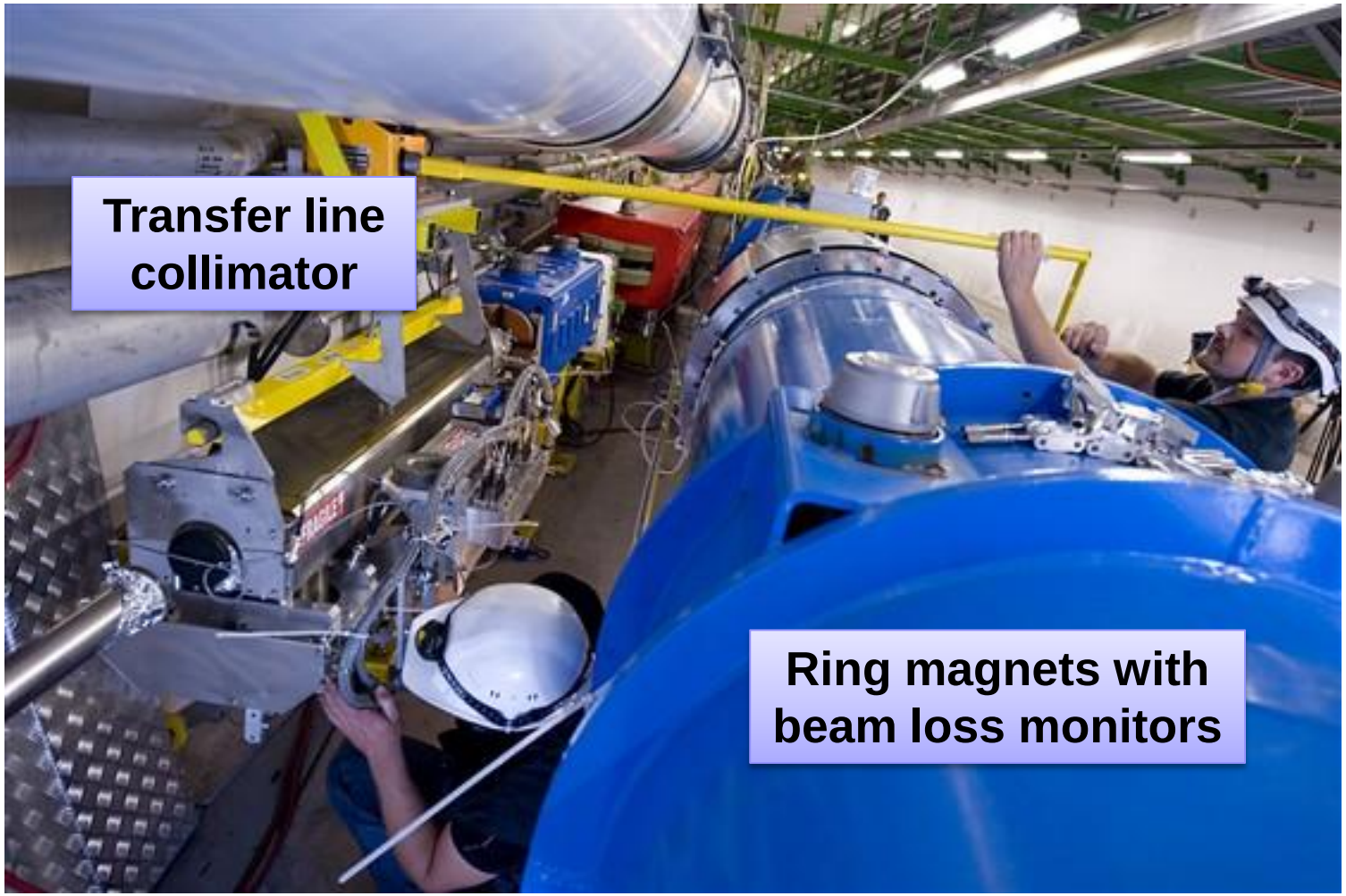
Increasing intensity to > 10^{12} p at injection



Increasing intensity to > 10^{12} p at injection

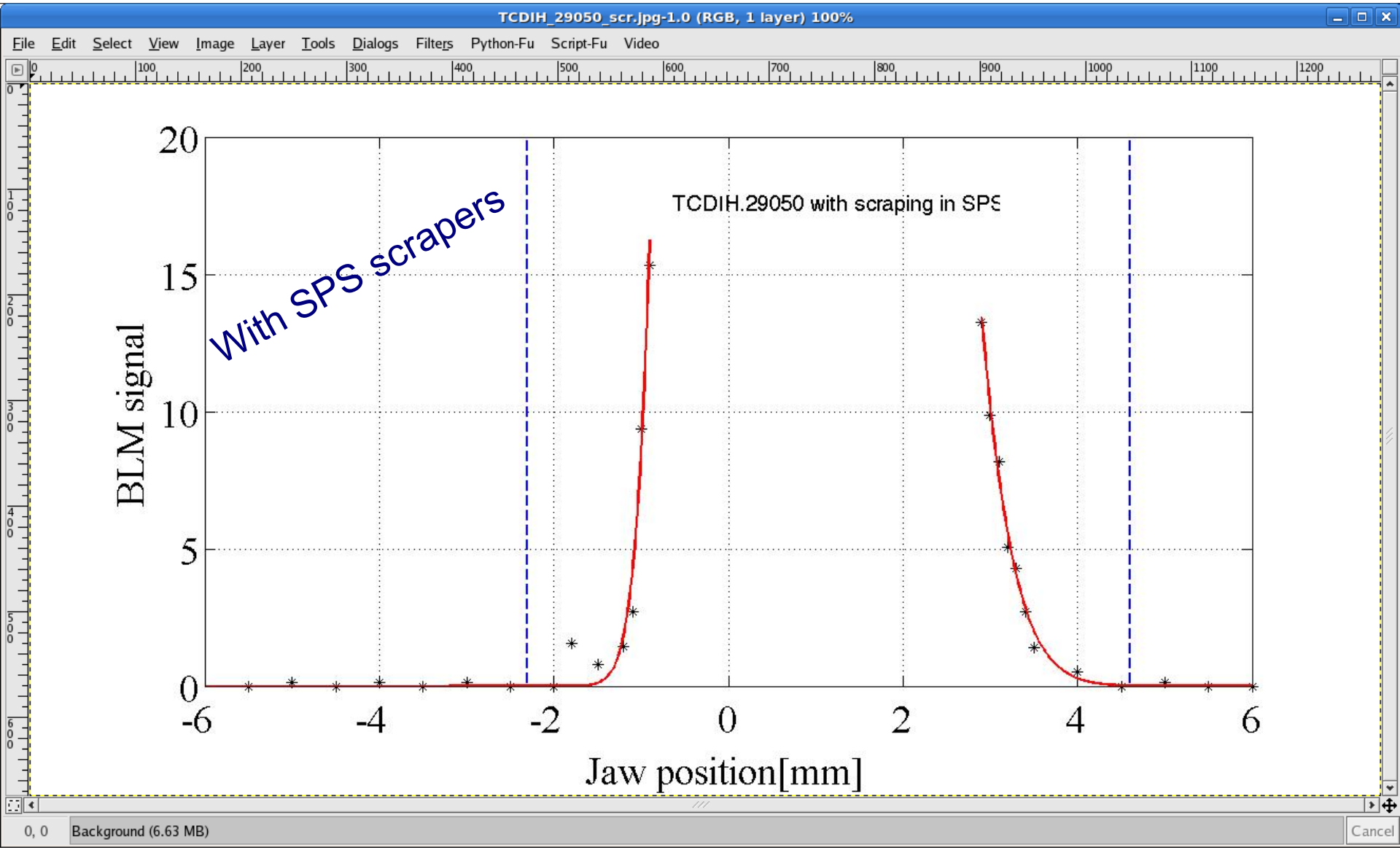


Tunnel View



Collimation Team

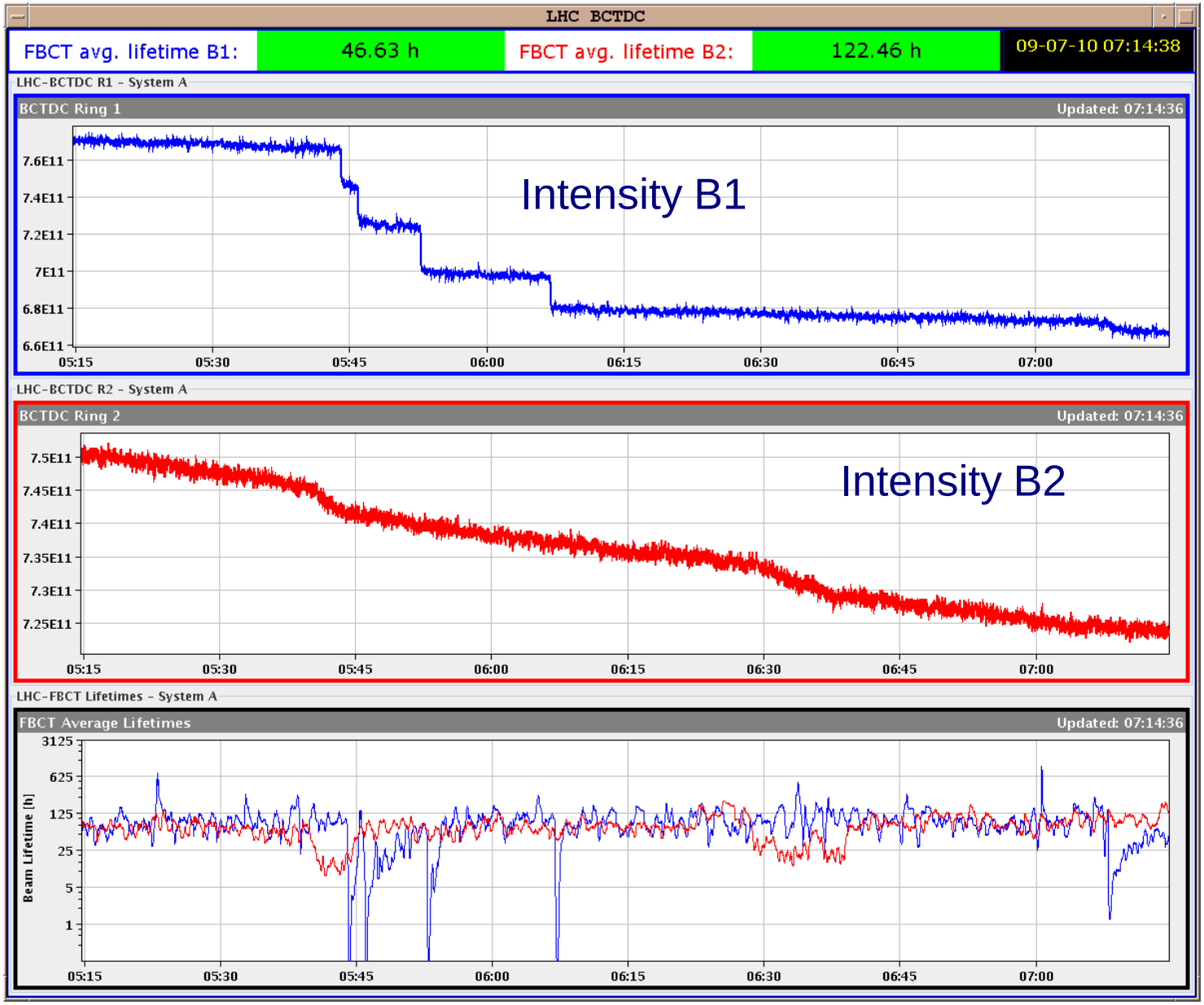
Increasing intensity to > 10^{12} p at injection



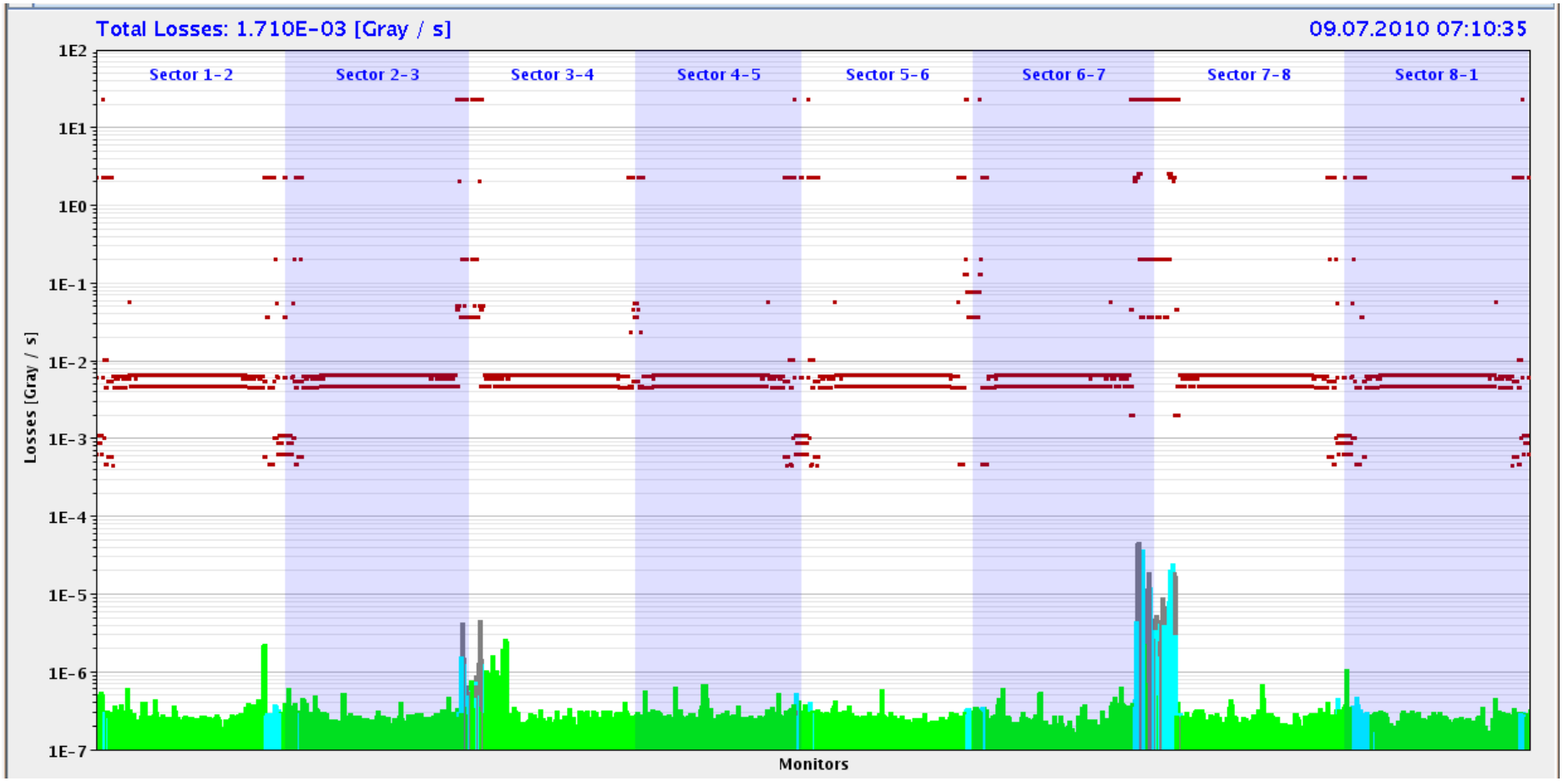
Issues During Stable Beams

- We are learning continually and solver issue after issue:
  - Losses during stable beams
  - Orbit
  - Transverse damper
  - RF noise

Losses during stable beams (9.7.)



Losses during stable beams (9.7.)

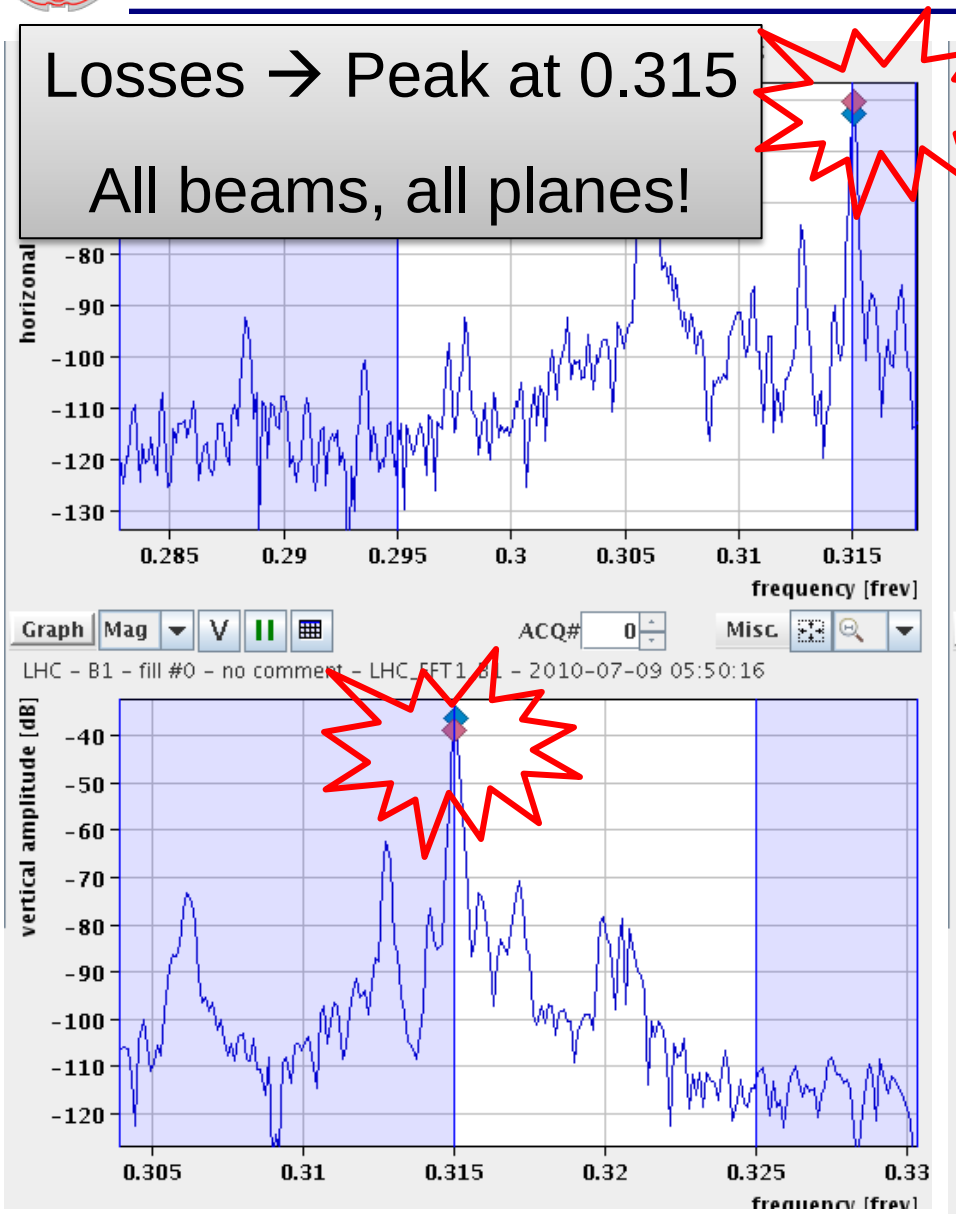


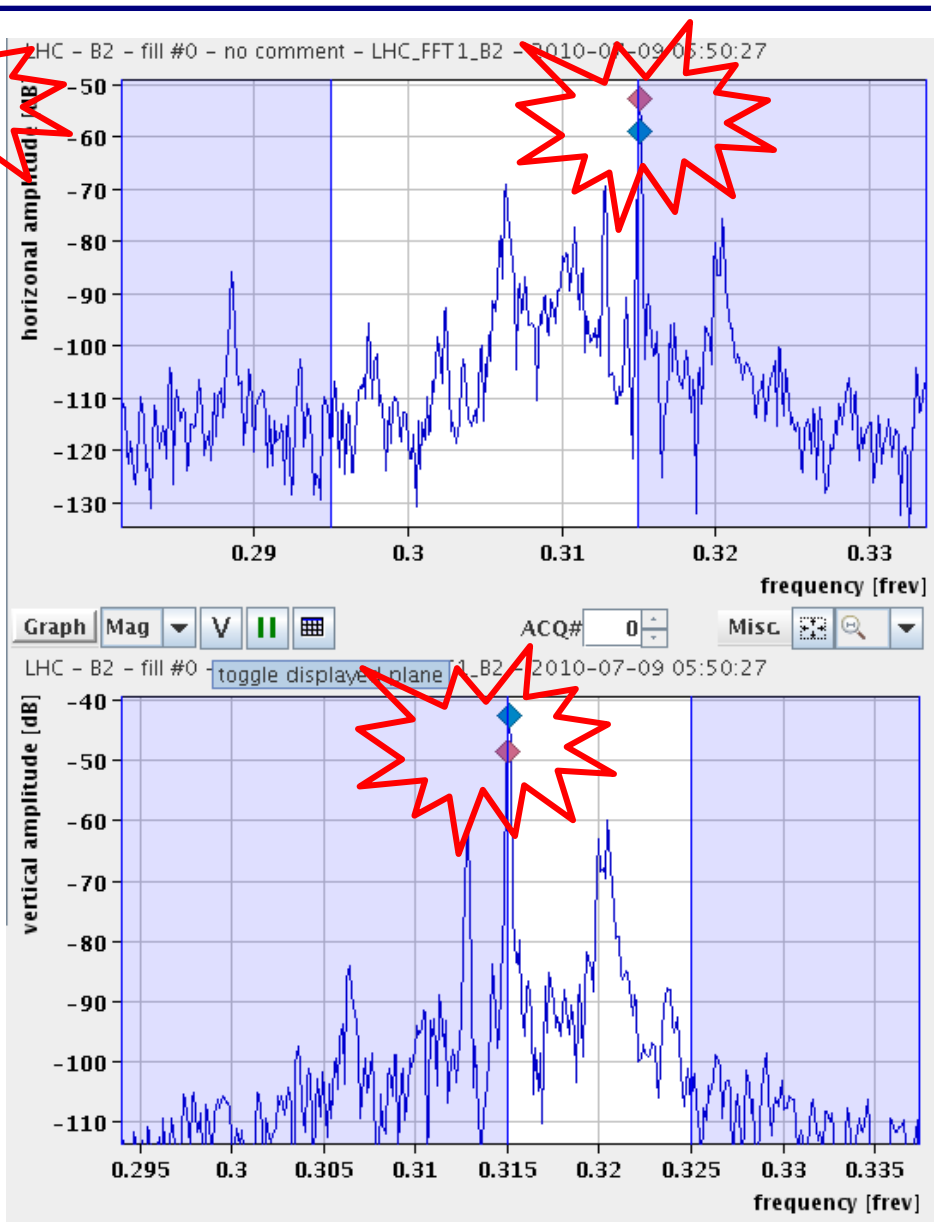
Takes place at collimators in cleaning insertions → OK

Losses during stable beams (9.7.)

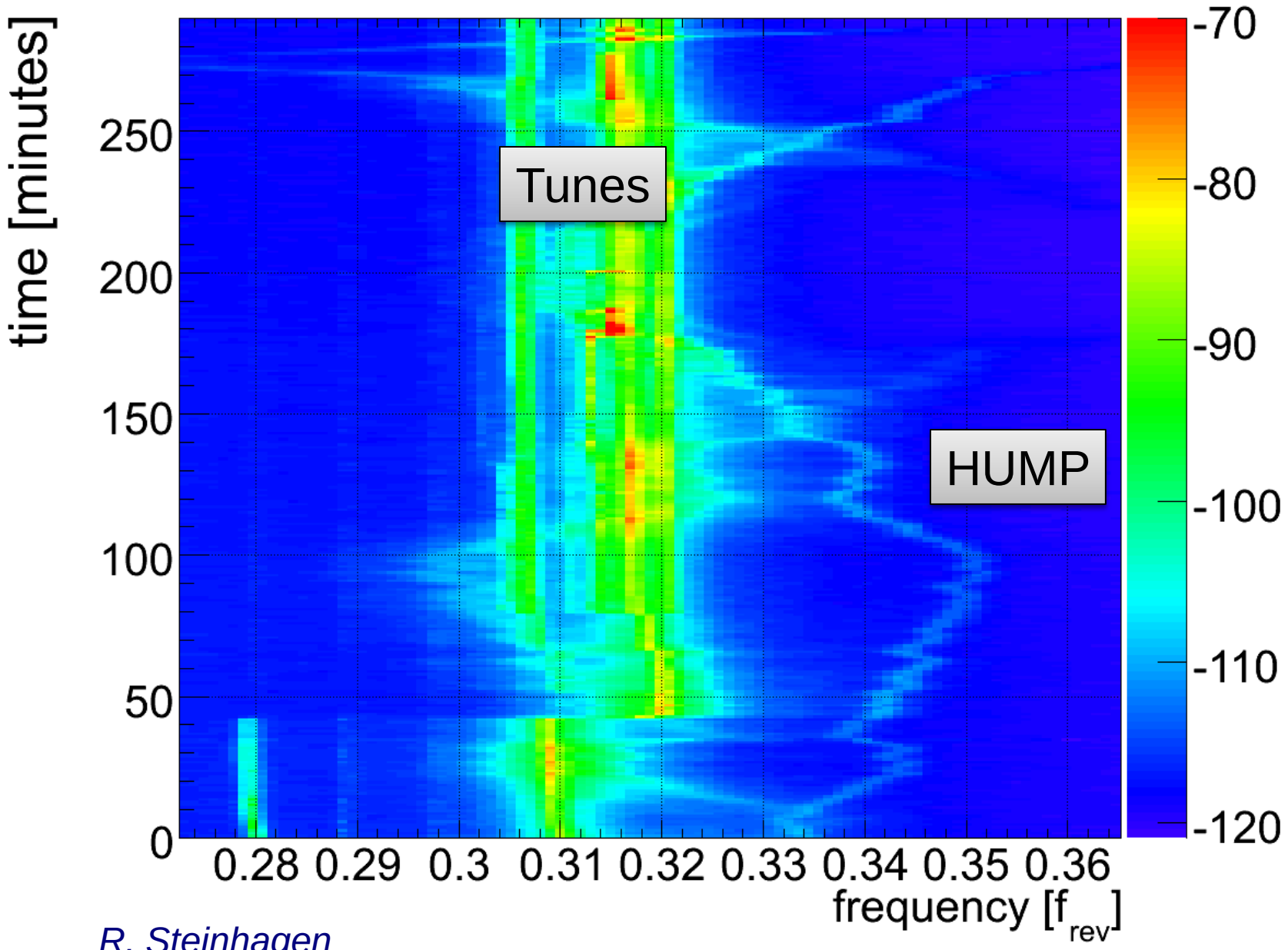
Losses → Peak at 0.315

All beams, all planes!



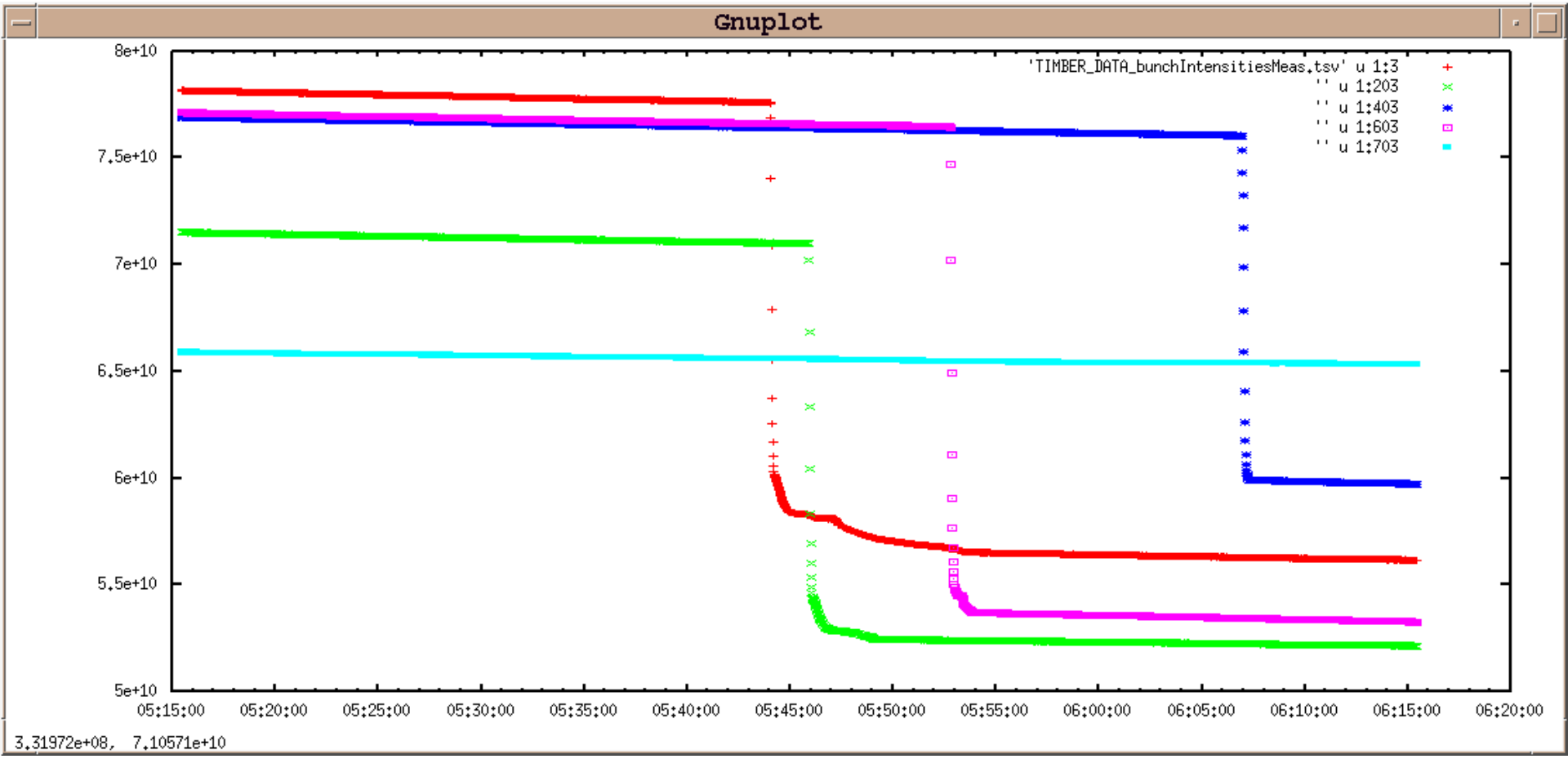


Losses during stable beams (9.7.)



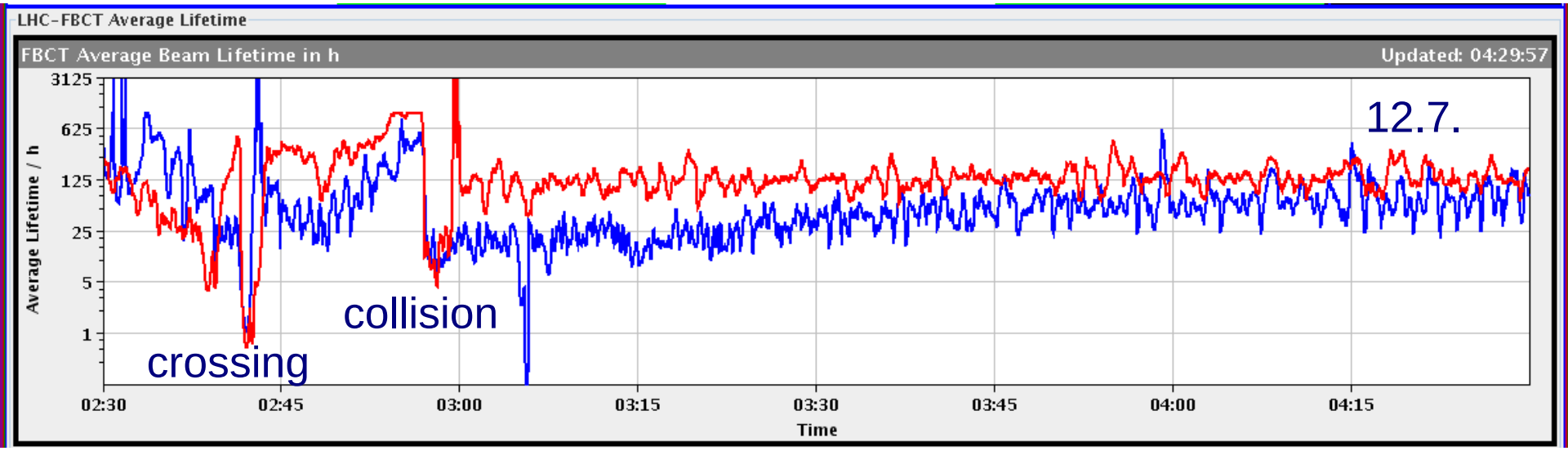
R. Steinhagen

Losses during stable beams (9.7.)



Losses only in first 4 bunches from bucket 1 onwards!

Lifetime 12.7. – “Regular” Drops



Not easily avoidable losses in operation…

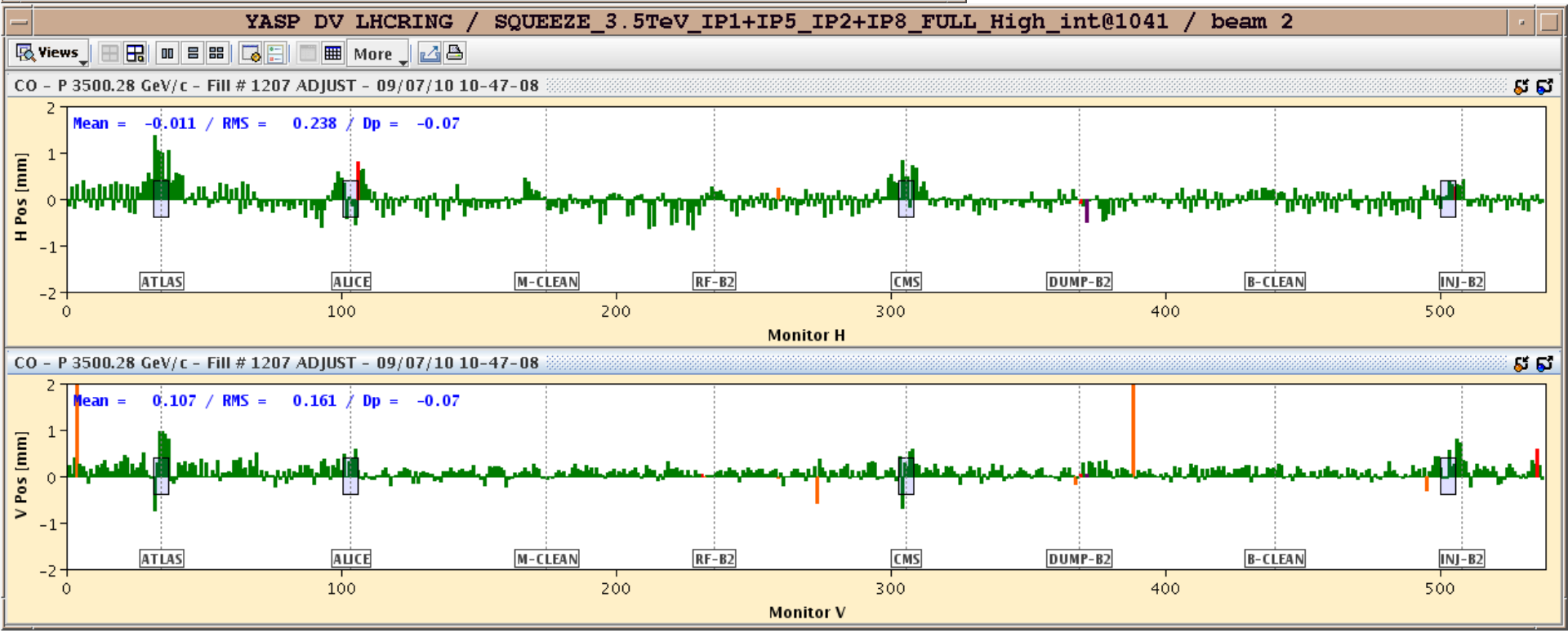
Orbit control in IR: After normal correction

Bumps in IR's

Real?

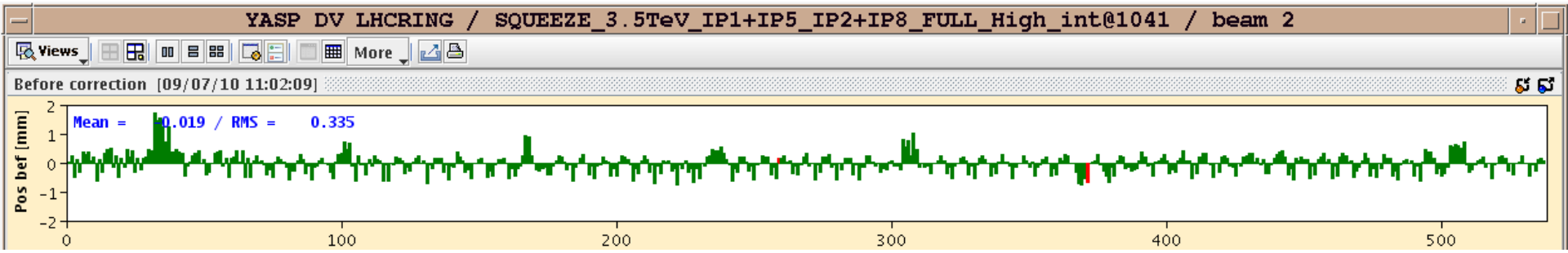
YES → Correct

NO → Leave it in



Orbit control in IR: H correction IR1

30% of correction sent

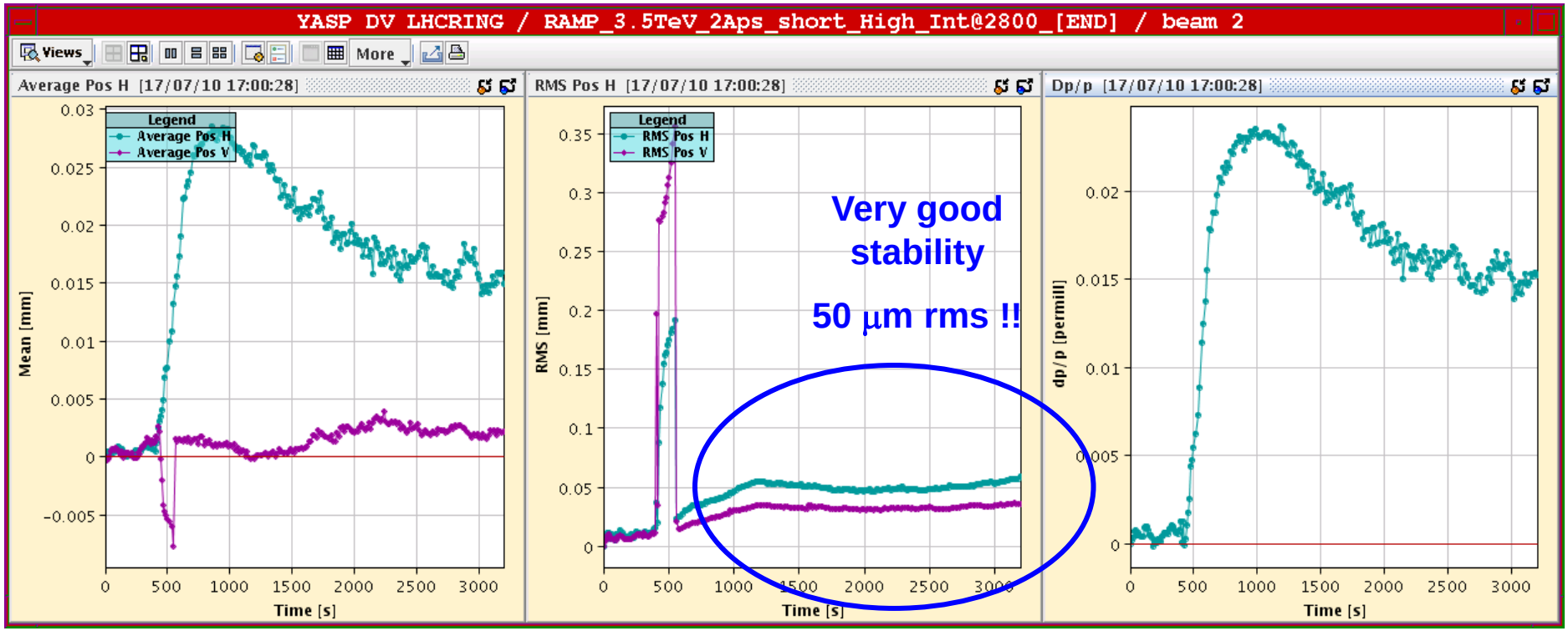


Orbit control in IR: Problem with Crossing Angle

➔ Non-closure when putting crossing angle…

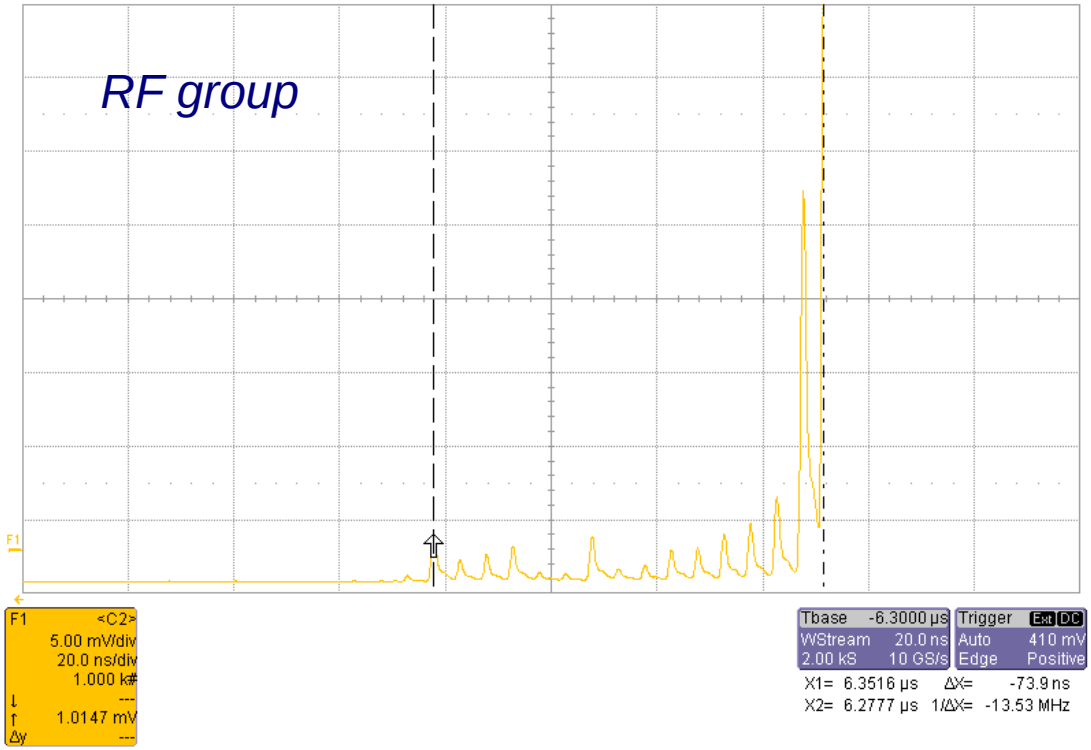
Orbit in the ramp fill 1232

- Orbit correction became unstable – seemed to be coming from IR4.
- Orbit FB switches off.
- Switch on worked, instability disappeared!

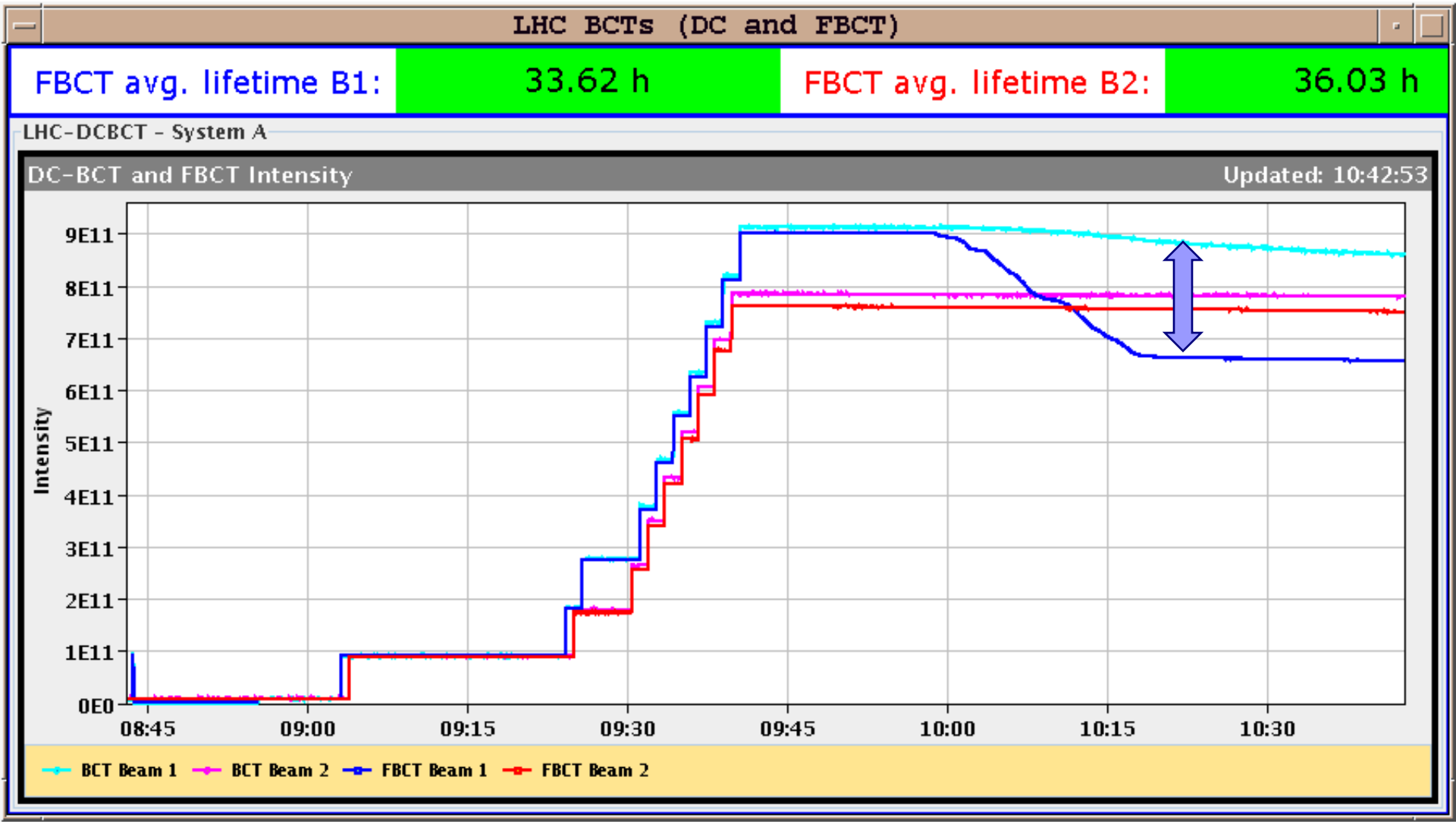


Ghost bunches

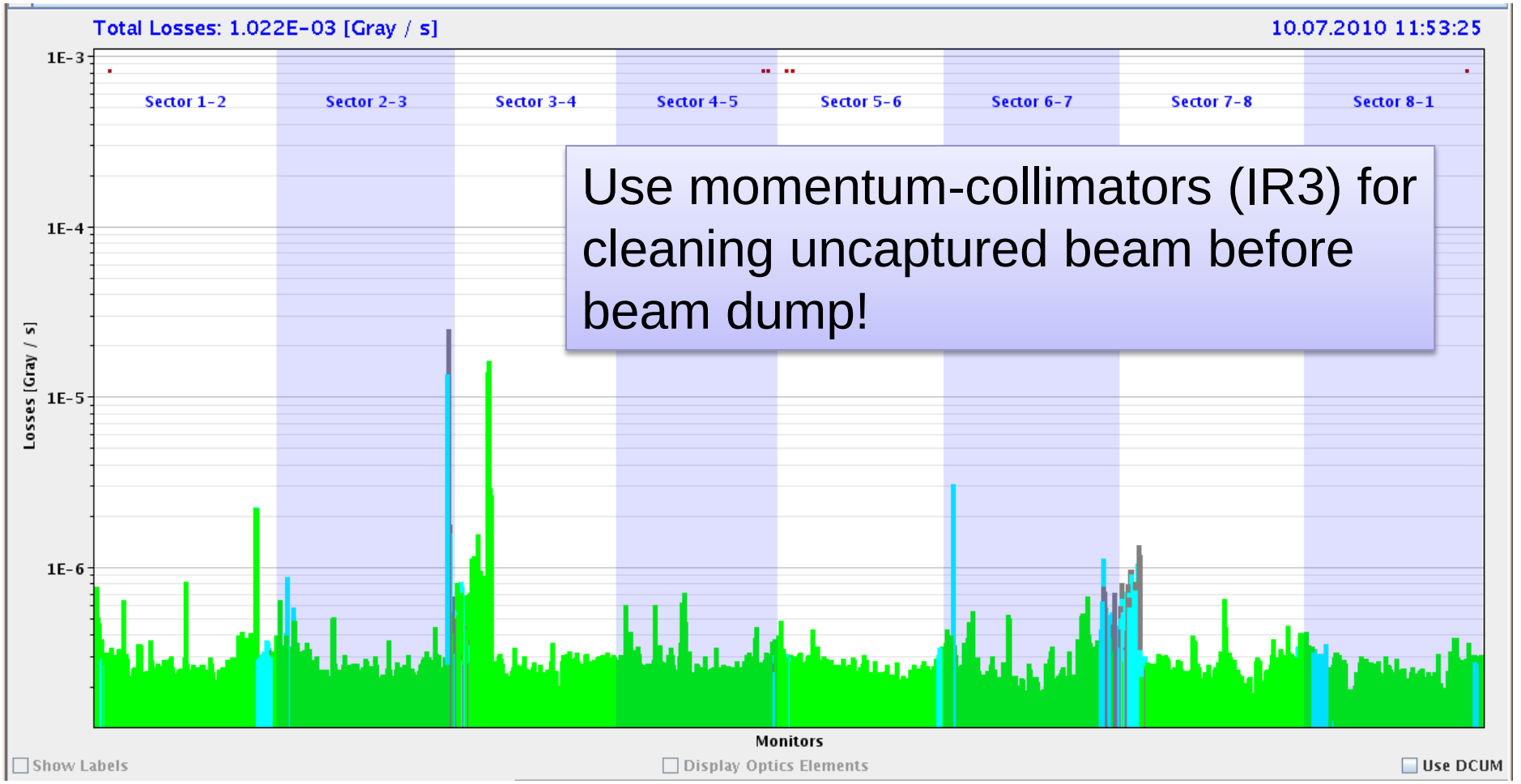
- Small ghost bunches around main bunches reported by the experiments.
  - Intensity at the level of 0.1% of the main bunch.
- Ghost bunches confirmed measurements of the RF group.
  - Bunches extend up to ≈ -80 ns. Spacing is 5 ns.
  - Abort gap population is below 5E6 p/bucket (excep for messy 80 ns).
- Problem: Collision of ghost bunches with one of nominal bunches



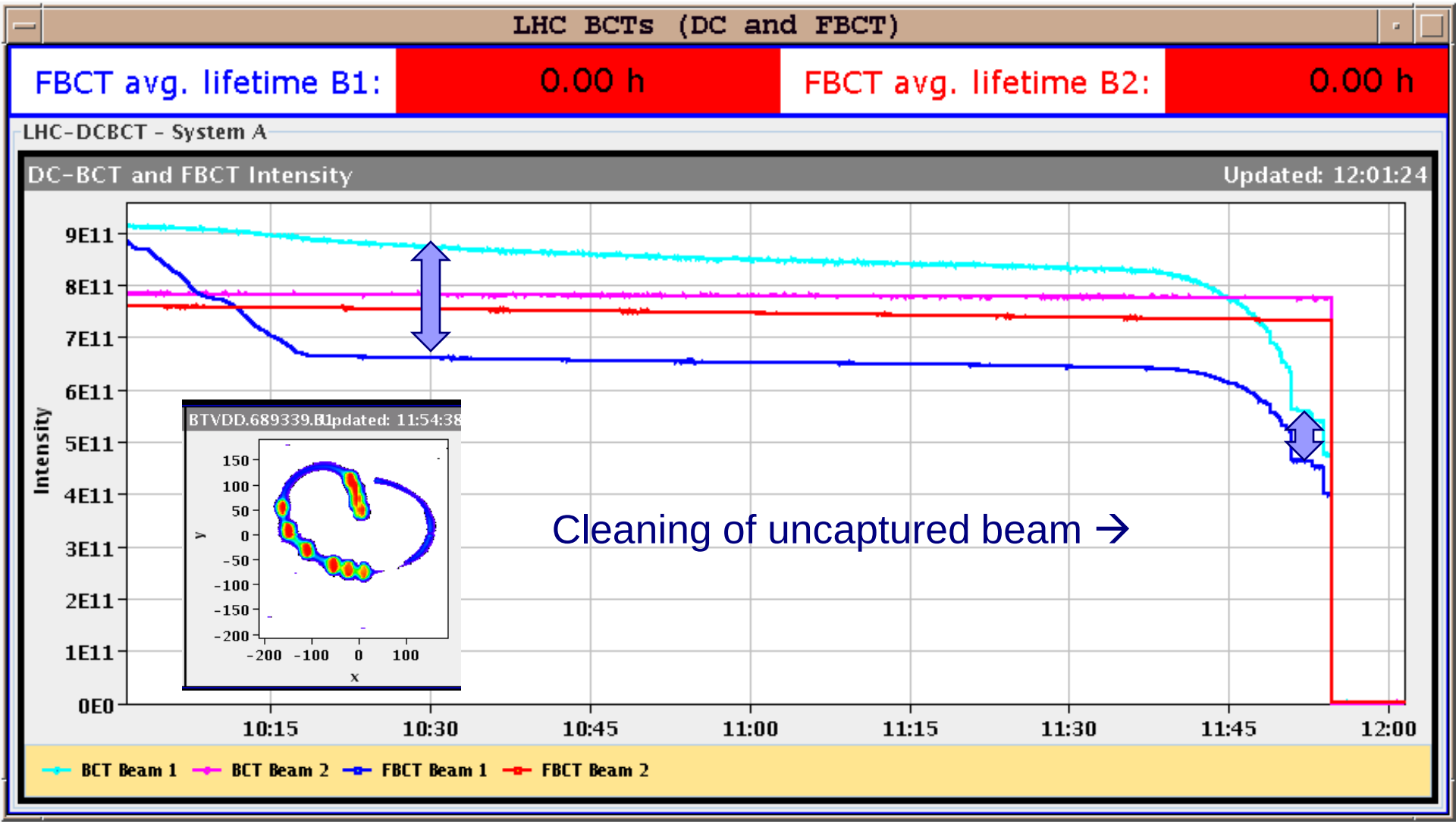
Losses from RF bucket



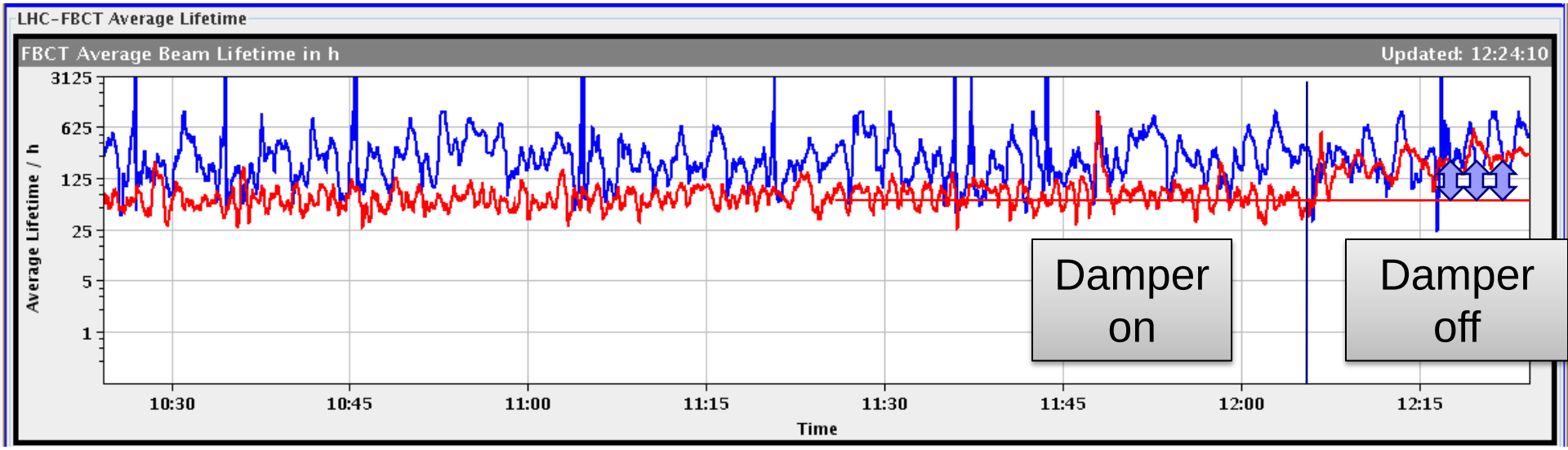
Losses from RF bucket



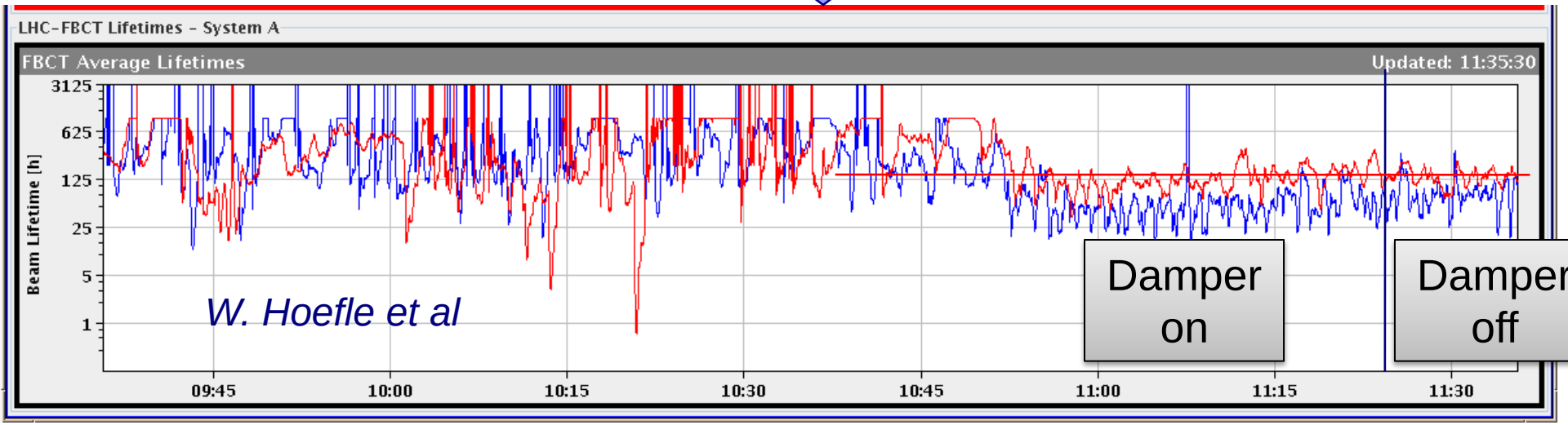
Losses from RF bucket



Transverse Damper in Stable Beams



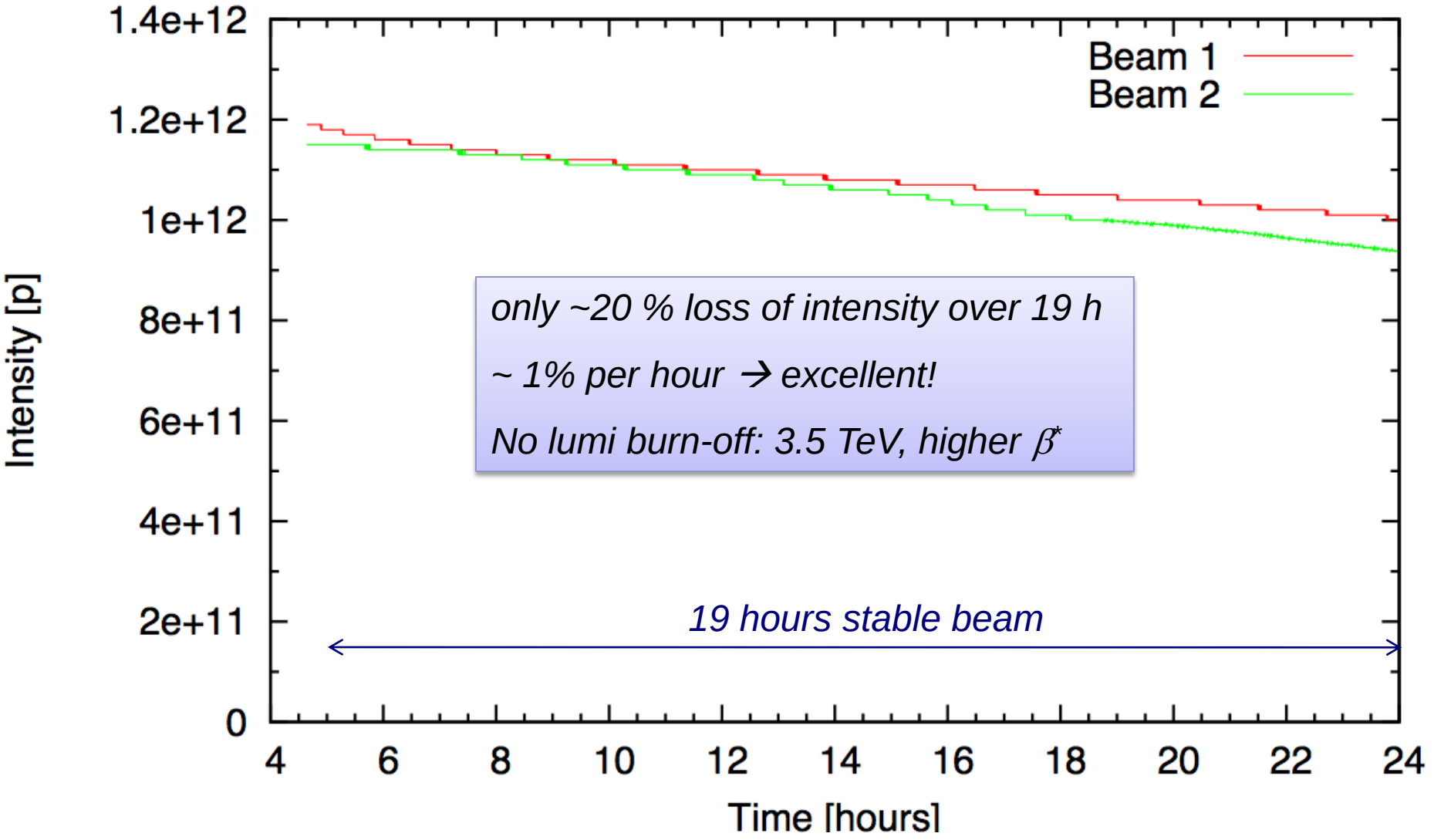
Damper noise reduction beam 2



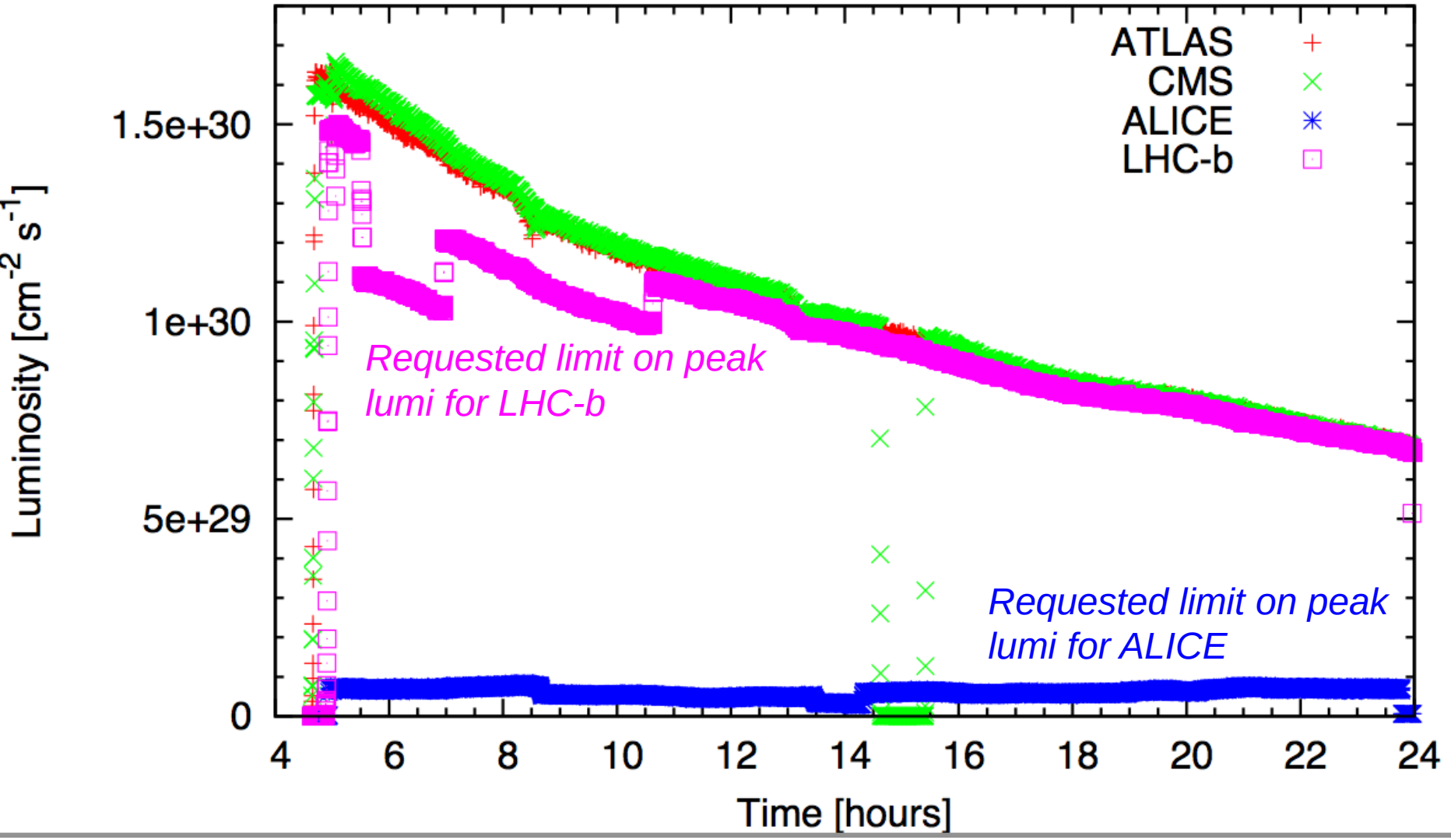
Optimizing conditions in collision

- Various measures done in parallel…
- Beam-beam investigation ongoing.
- Equalize beam parameters:
  - Blow-up of longitudinal emittances to have nominal values.
  - Blow-up of transverse emittances to have nominal values.
  - Equalize bunch currents and B1/B2 currents by more stringent injection process, good 450 GeV orbit correction.
  - Minimize losses at flat top (crossing angle in steps, skip chromaticity measurement for best fill, only manual IP scans, …).
- Use of transverse damper with reduced noise at 3.5 TeV.
- Increased B1/B2 tune split: 0.003 → 0.005

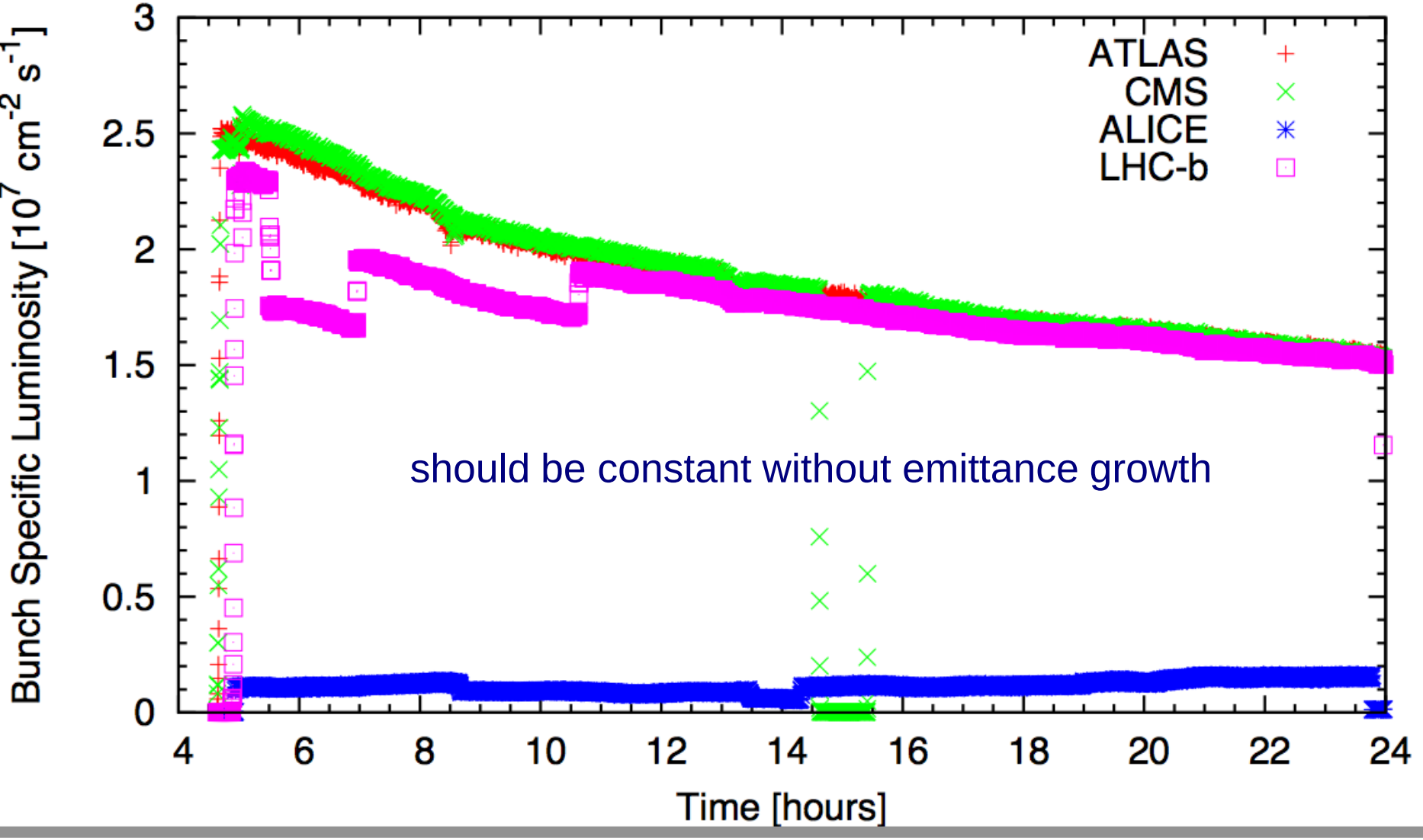
Record physics fill: Intensities



Record physics fill: Peak luminosity



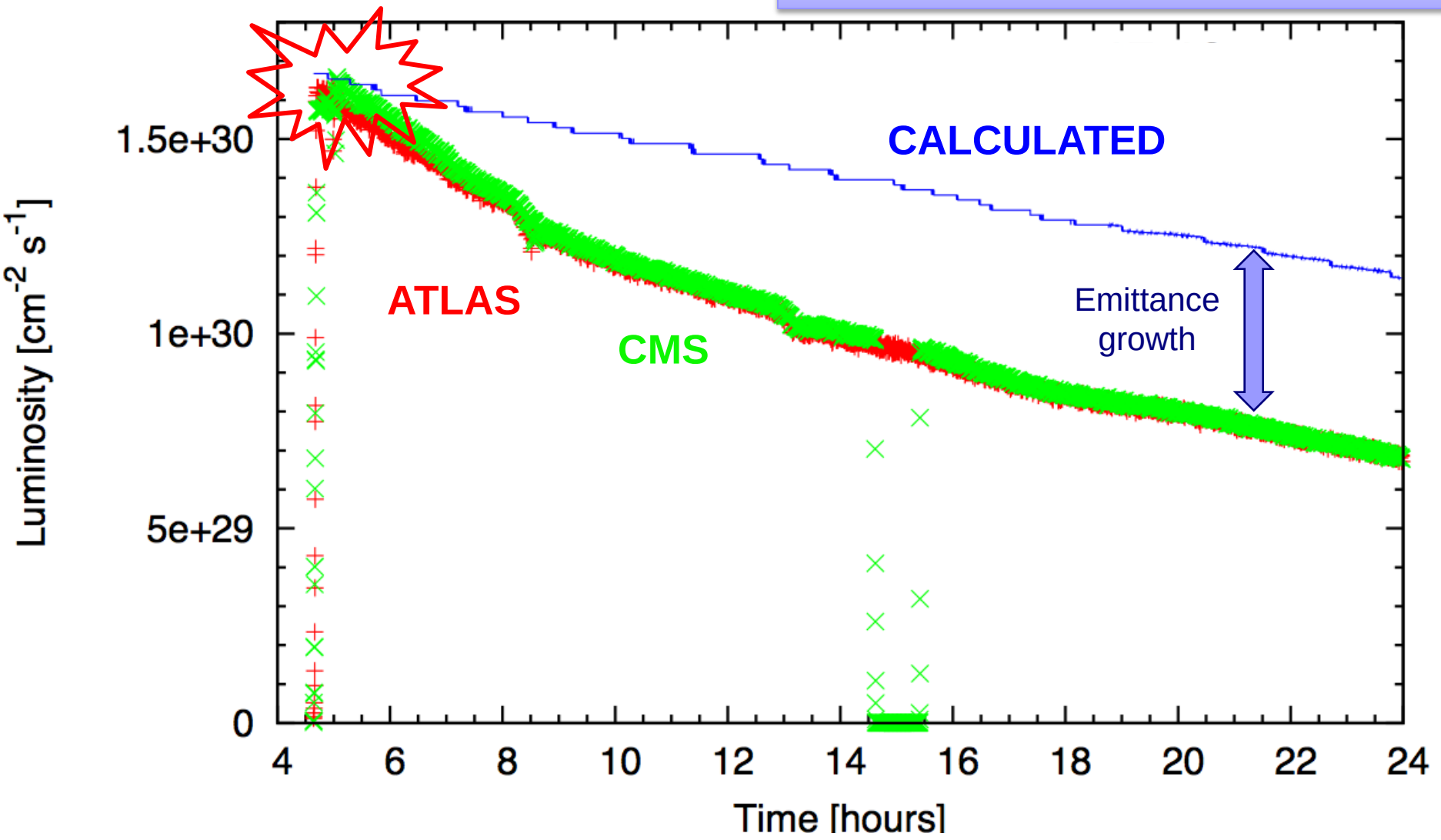
Record physics fill: Bunch Specific Luminosity



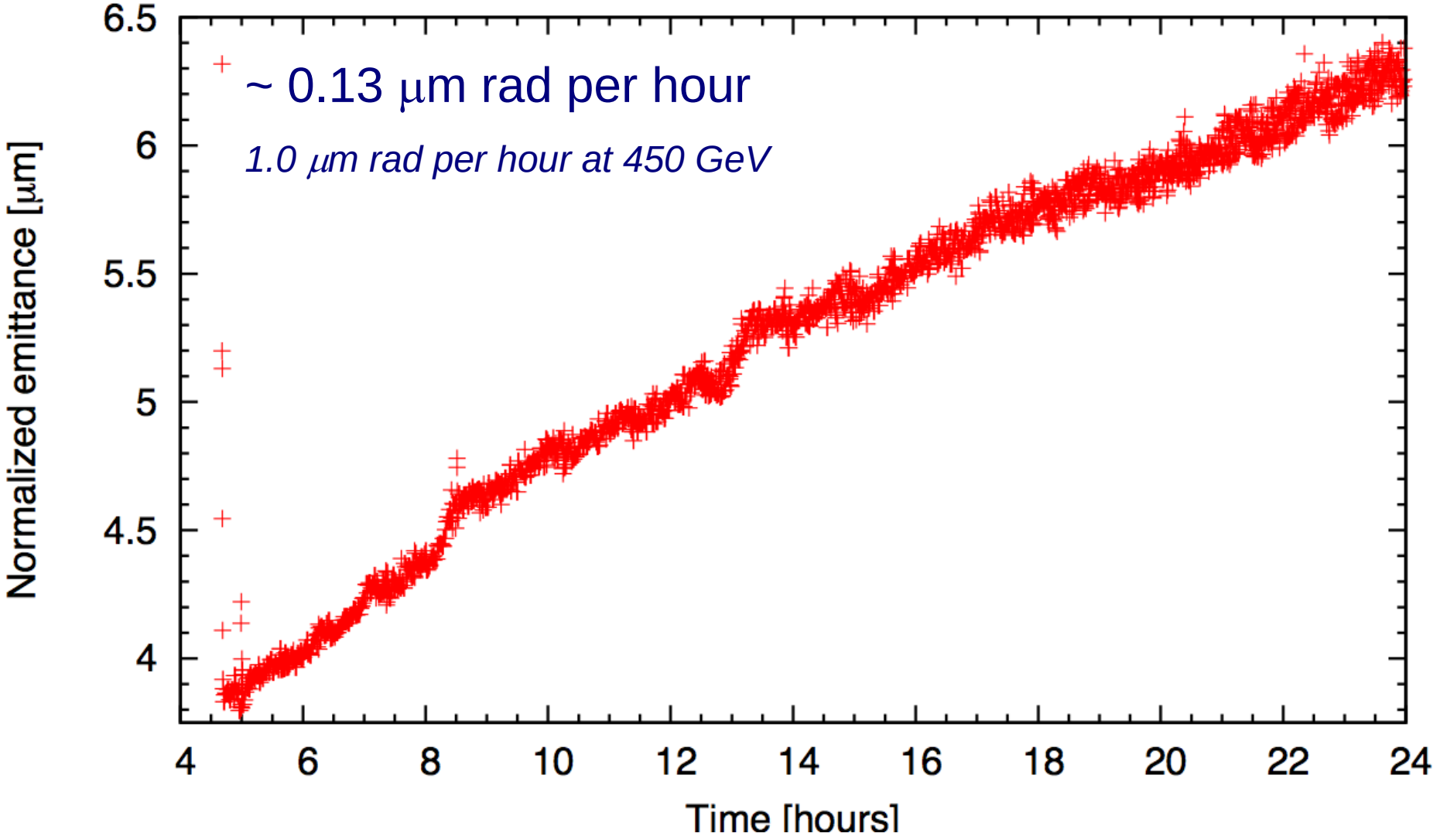
Record physics fill: Lumi Measured & Calculated

Machine parameters very well controlled!

calculated with measured bunch intensity, nominal $\gamma\varepsilon$ = 3.75 μm and β^*=3.5m



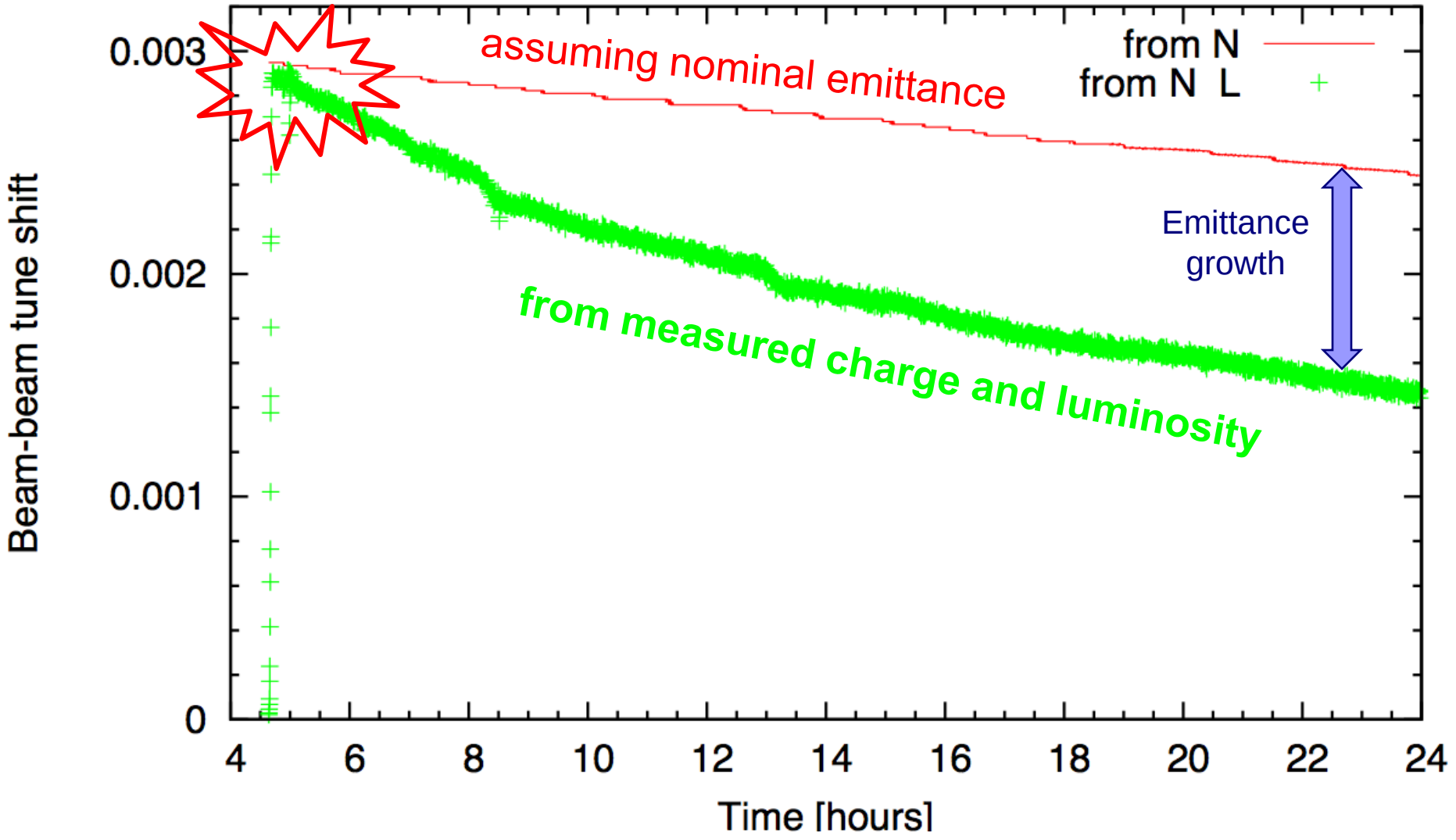
Effective Average Emittance Growth



Beam-beam parameter

$$\xi = \frac{r_p \cdot N}{4\pi \cdot \varepsilon_n}$$

~ design beam-beam parameter!



Intensity outlook

- LHC performs already outstanding…
- We are high already:
  - Presently we have established**: ~ 0.7 MJ**
  - Remember: Beams are much smaller at LHC and 3.5 TeV!
  - Transverse energy density is already **~ 7 MJ/mm^2** at some relevant locations. Far beyond previous CERN experience (ISR), HERA and Tevatron!
- We want to increase from **0.7 MJ to 1.4 MJ** the next days.
- Then plan for multi-week stable period without changes!
- What limits the increase in intensity?
  - No immediate danger, otherwise we would have to drop intensity.
  - I have shown that we have still frequent non-conform issues.
  - Use stable period to sort them out and then push ahead!
  - Must always be prepared for infrequent problems (irregular dumps)!

Conclusion

- LHC operation has made significant progress:
  - Optimized working point for physics.
  - All performance parameters well known and controlled!
  - Record fill with expected luminosity, very small intensity losses and very small emittance blow-up!
  - Can run at design beam-beam parameter!
  - LHC stored energy is at ~ 0.7 MJ: about 30% of world record!
  - LHC stored energy density is at ~ 7 MJ/mm^2 → this is ~3 times world record. Highly destructive beam!
- Push intensity up factor ~2 in next days/week.
- Still issues:
  - learning with highly destructive beams!
  - Regularly see and solve non-conform issues (orbit, procedures, …).
  - Want stable run period (~4 weeks) for solving them.
- Then push into 10-30 MJ regime!

Thank you for your attention!