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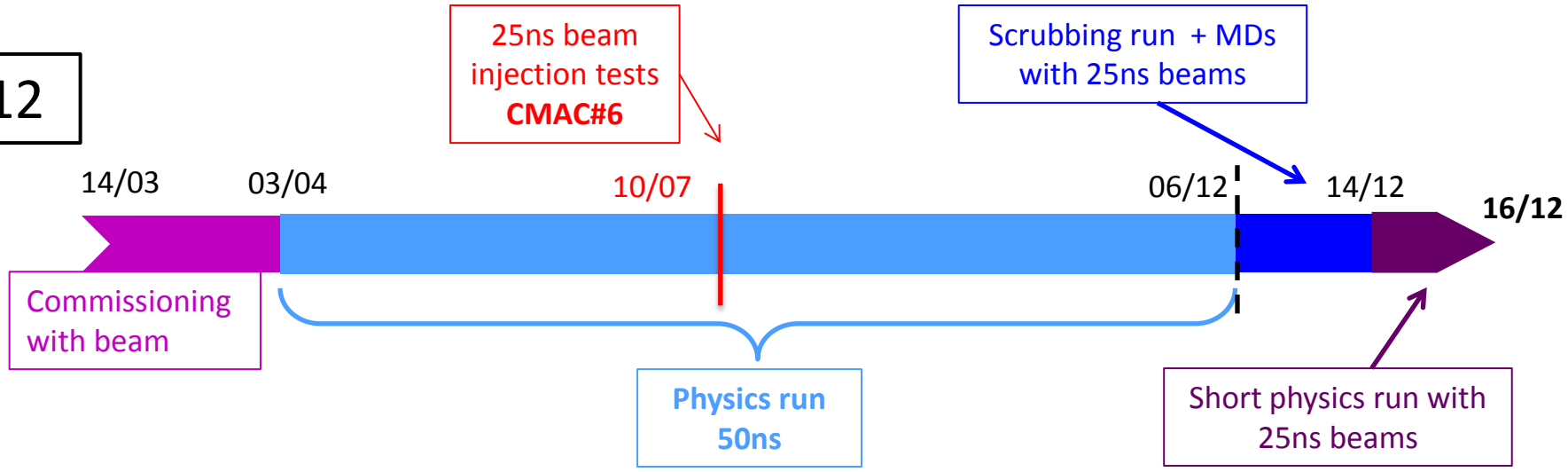
Electron cloud scrubbing run and strategy for 2015

G. Arduini, H. Bartosik, G. Iadarola, G. Rumolo
for *CMAC#7*, 14 March 2013

Many thanks to Cryogenics, Transverse Damper, EN/STI, Injection, Operation, Collimation, Vacuum teams +
Several ABP, RF and BI colleagues who contributed to the measurements

25ns beam in the LHC in 2012 at a glance …



→ Physics run with **50ns beam** from 3 March until 6 December, 2012. Intensity up to **1.6 x 10^{11} ppb** injected into LHC

→ 25ns injection tests. Slight deconditioning from 2011 observed in the arcs, but SEY quickly recovered

→ Scrubbing run & 25ns MDs (intensity **1.1 x 10^{11} ppb**, $\varepsilon_{x,y}$ **= 2.5 µm** at injection)

- ✓ Four days of dedicated scrubbing fills (**450 GeV**)
- ✓ Ramp to **4 TeV** with increasing number of bunches (**84, 156, 372, 804**)
- ✓ Additional tests at **450 GeV**

→ Physics run with 25ns beams

- ✓ Three useful fills with increasing number of bunches (**108, 204, 396**)
- ✓ Low emittance scheme used from injectors ($\varepsilon_{x,y}$ **= 1.4 µm** at injection)

- ☑ Brief memo of the LHC status (2011)
- ☑ Evolution of electron cloud observables during the 2012 scrubbing run
  - Achievements, new information
- ☑ Experience at 4 TeV
- ☑ Scrubbing strategy after LS1

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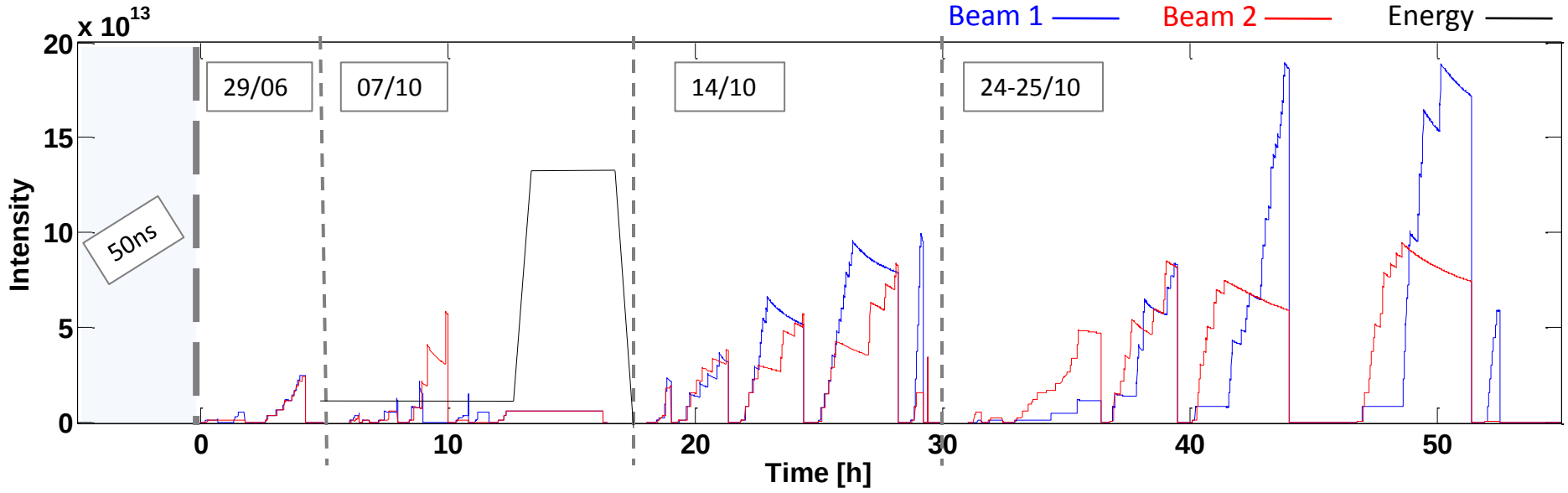
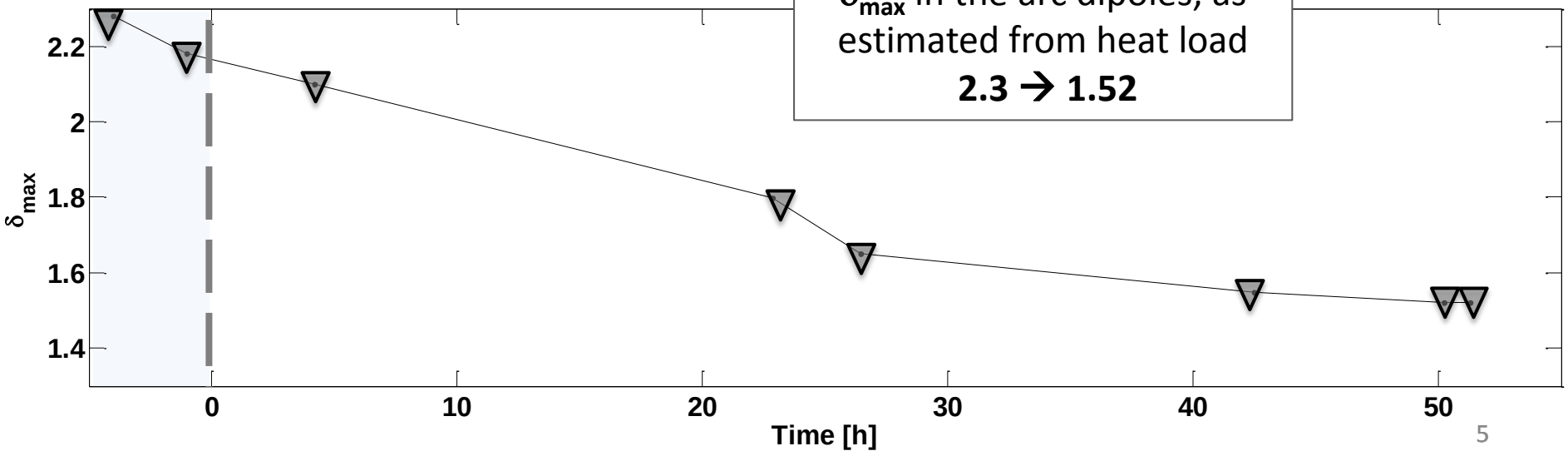
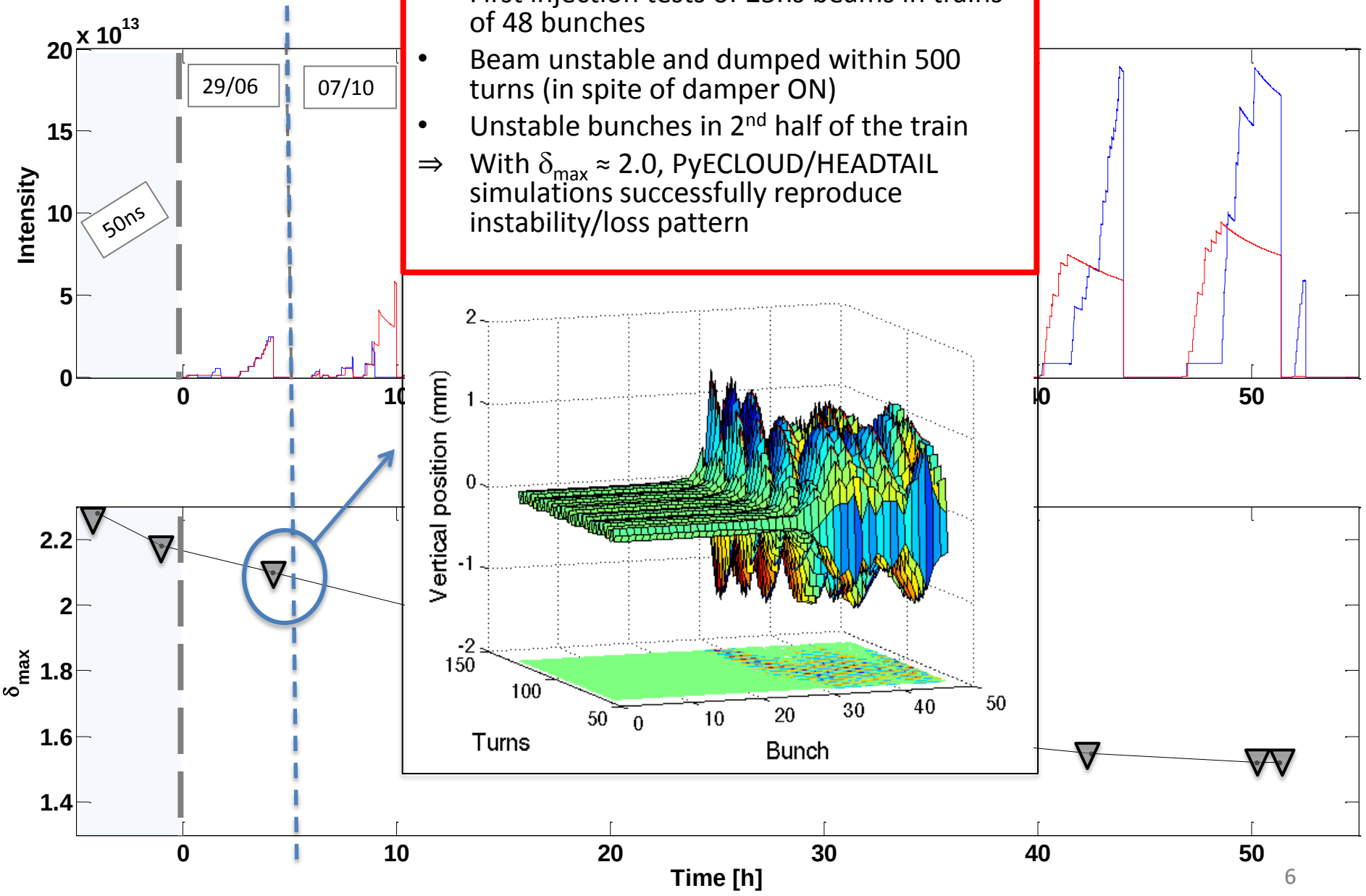
2011 scrubbing history of LHC arcs





- First injection tests of 25ns beams in trains of 48 bunches
- Beam unstable and dumped within 500 turns (in spite of damper ON)
- Unstable bunches in 2nd half of the train

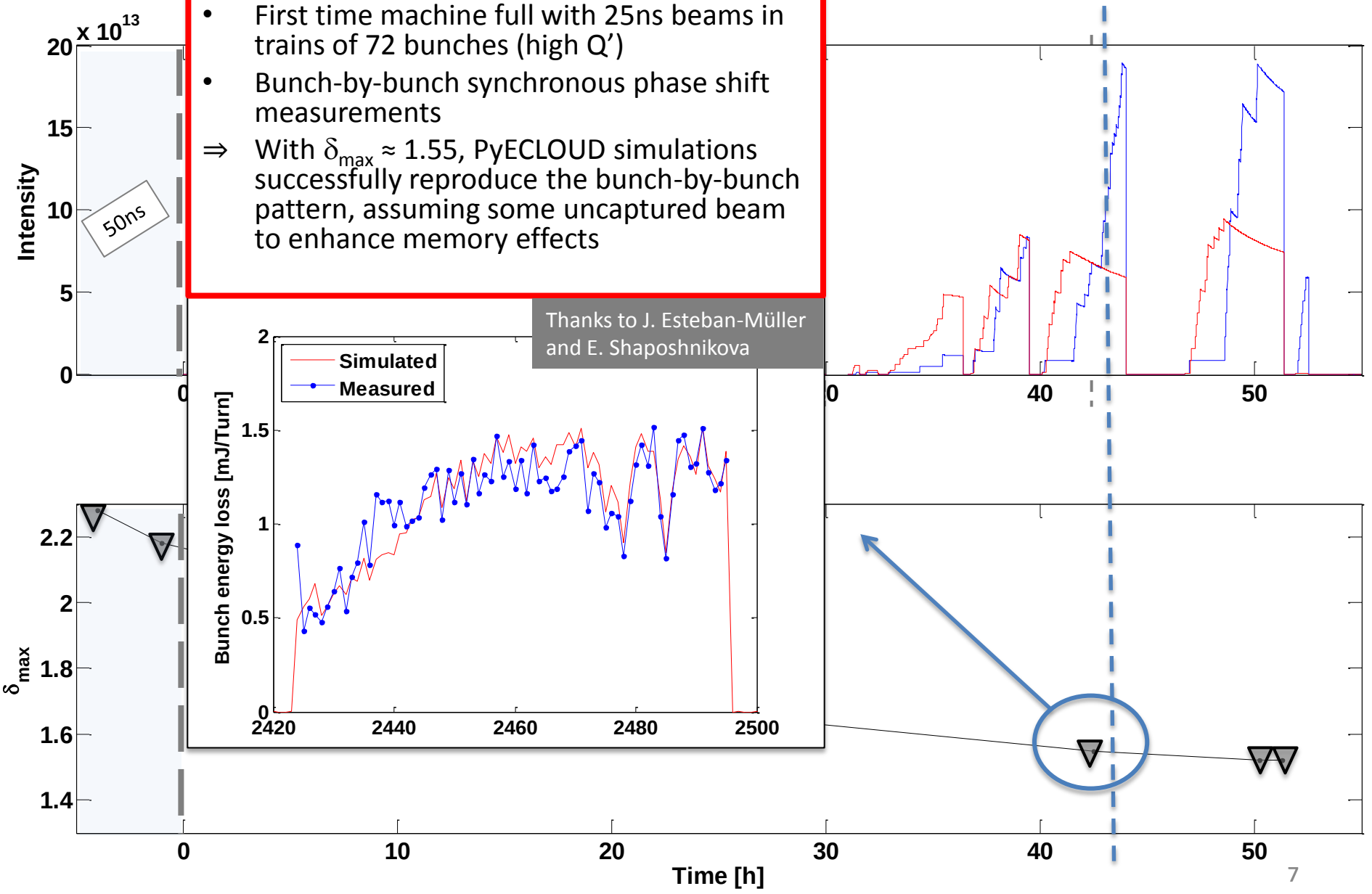
⇒ With $\delta_{max} \approx 2.0$, PyECLOUD/HEADTAIL simulations successfully reproduce instability/loss pattern



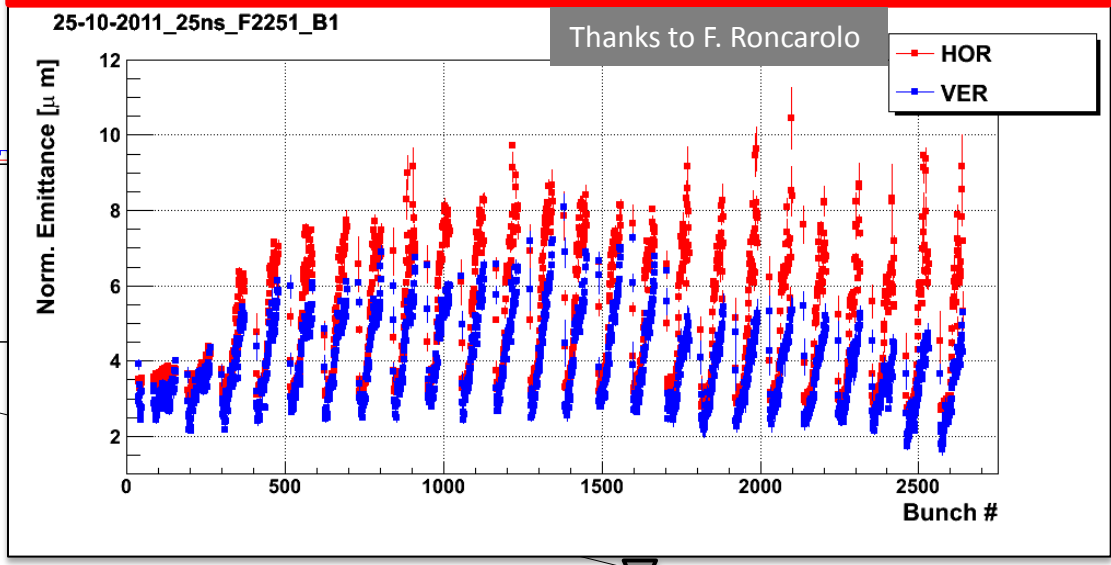
- First time machine full with 25ns beams in trains of 72 bunches (high Q')
- Bunch-by-bunch synchronous phase shift measurements

⇒ With $\delta_{max} \approx 1.55$, PyECLOUD simulations successfully reproduce the bunch-by-bunch pattern, assuming some uncaptured beam to enhance memory effects

Thanks to J. Esteban-Müller and E. Shaposhnikova

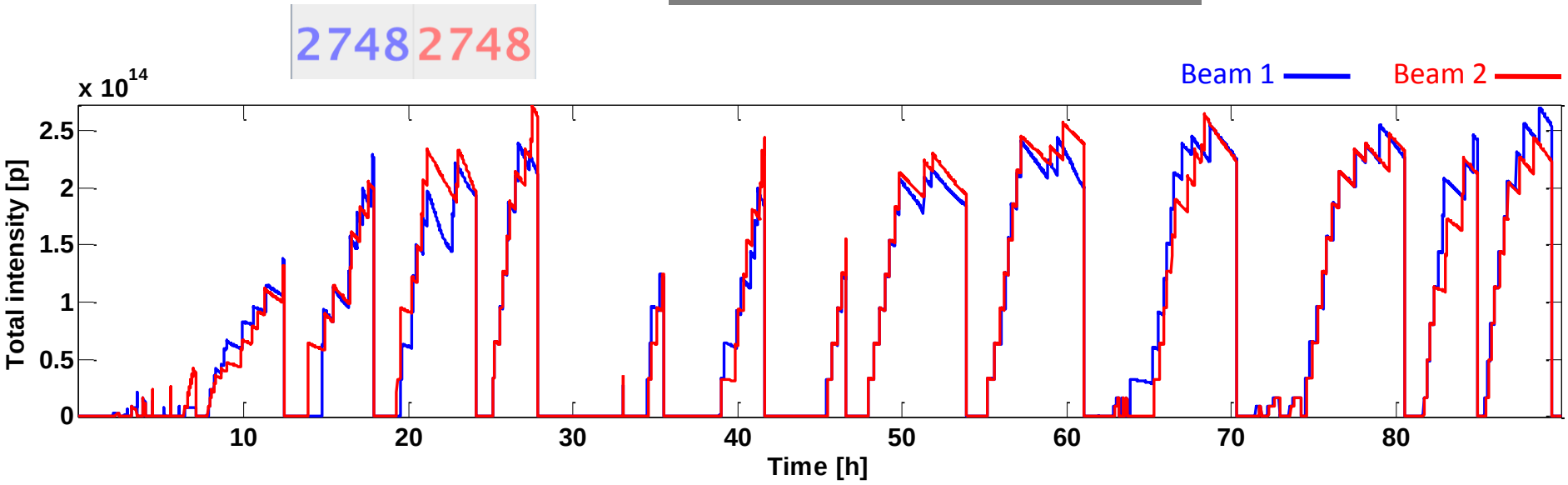


- Final estimated $\delta_{max} \approx 1.52$
- Still poor beam lifetime
- Degraded emittances in both planes along the 72-bunch trains and from train to train



- ☑ Brief memo of the LHC status (2011)
- ☑ Evolution of electron cloud observables during the 2012 scrubbing run
  - ☑ Achievements, new information
- ☑ Experience at 4 TeV
- ☑ Scrubbing strategy after LS1

Record intensity: 2.7 x 10^{14} p



→ After injection and transverse damper set up, **3.5 days** of **25ns beam** at **450 GeV** (6 – 9 December, 2012)

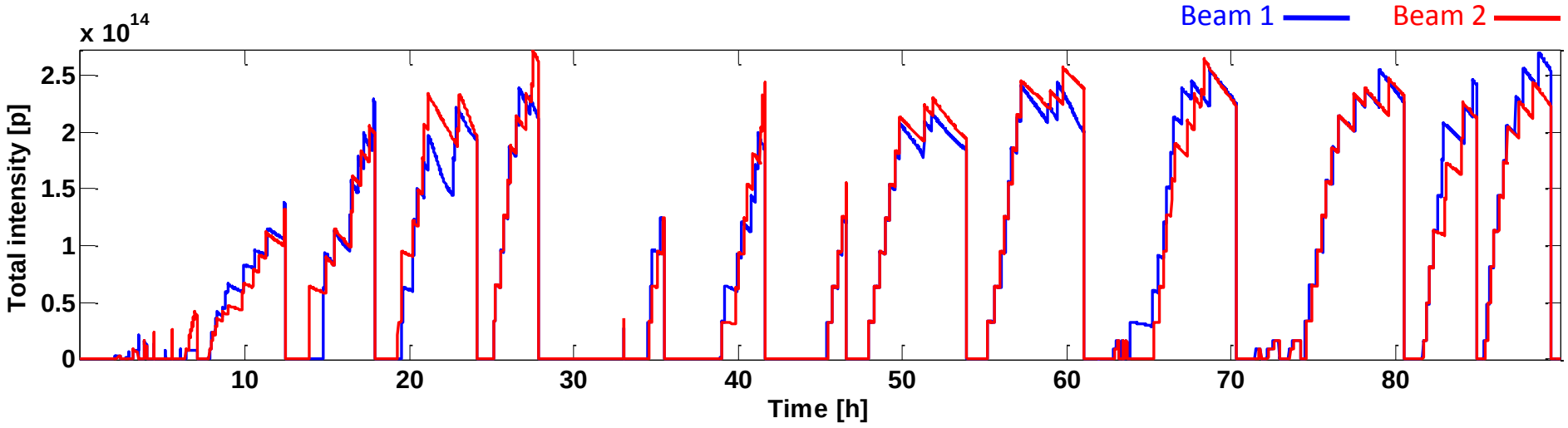
→ Fast intensity ramp up: only one fill with trains of 72 bunches, then trains of **288 bunches**

→ Several fills with maximum number of bunches (**2748**)

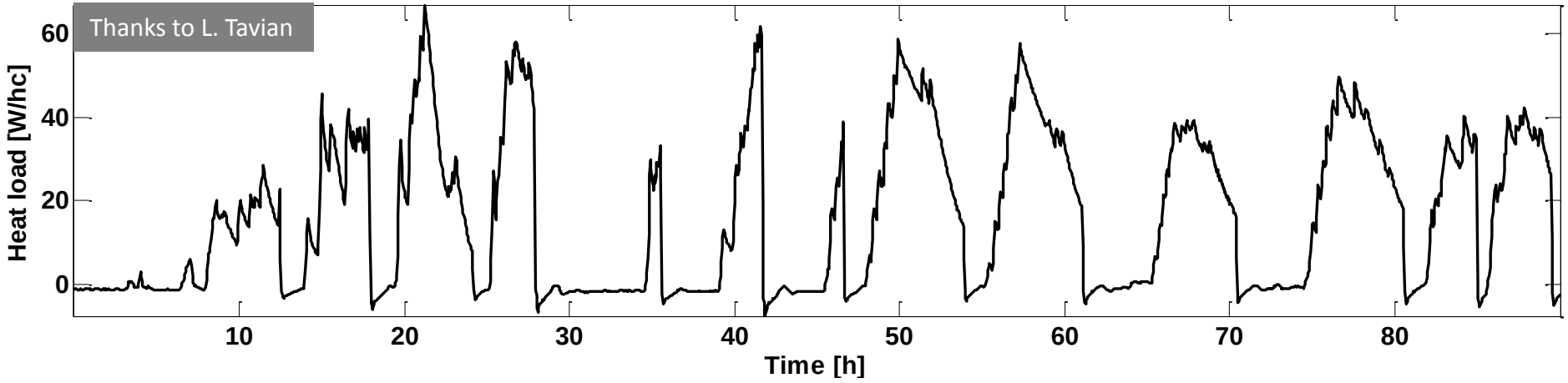
- ✓ Very good efficiency
- ✓ Injection time limited by vacuum in the MKI (beginning), then by time required by cryo to re-adjust to the increasing heat load

→ Electron cloud indicators (also used for the on-line monitoring of the scrubbing progress)

- ✓ Beam quality (lifetime, emittances)
- ✓ Heat load in the arcs

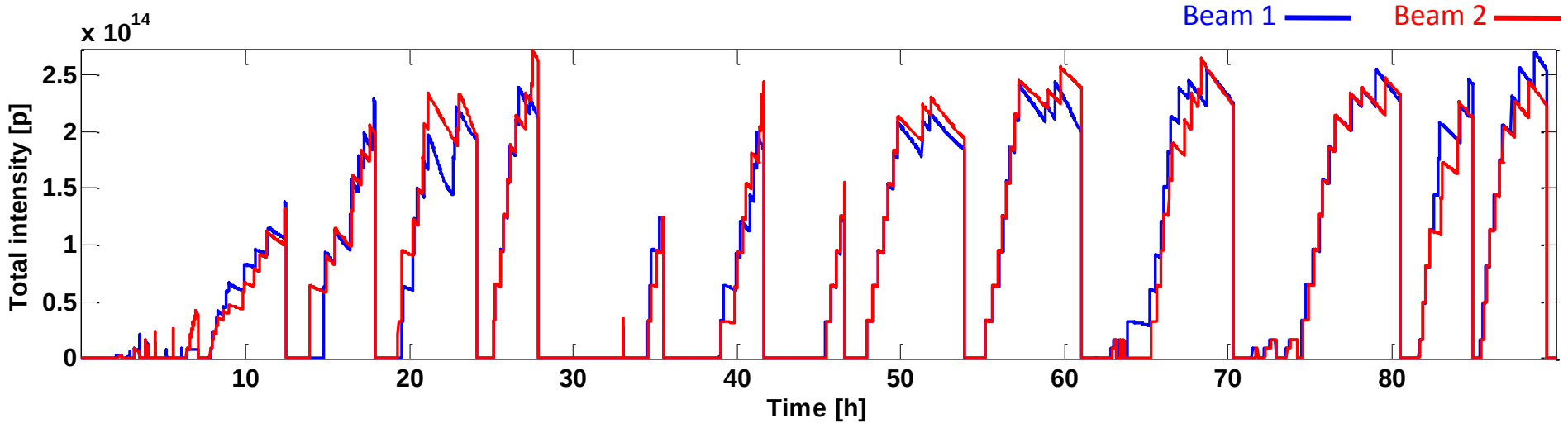


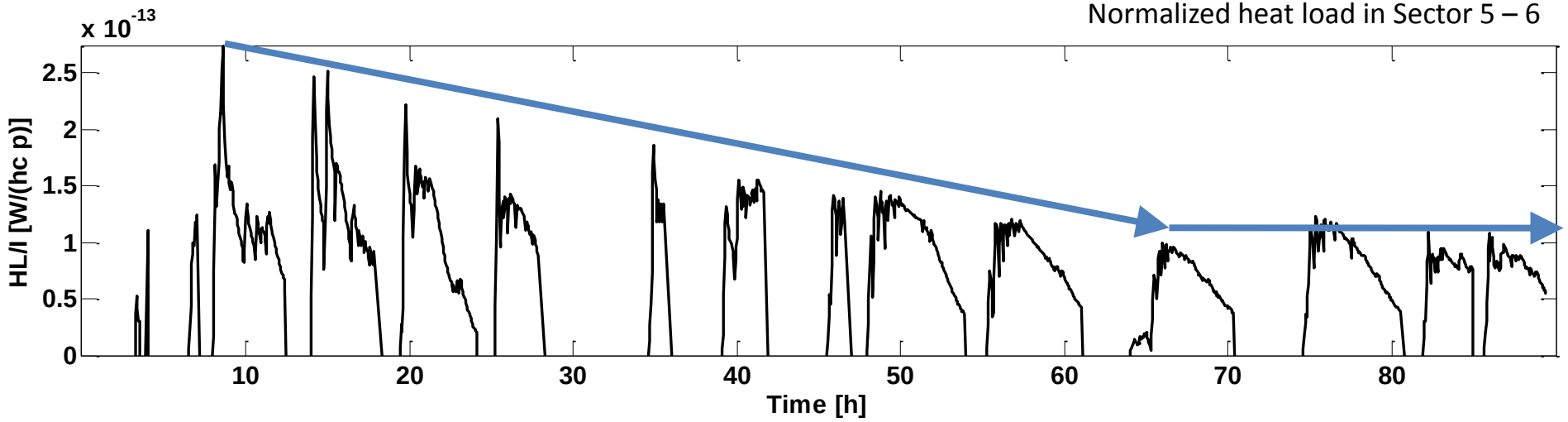
Heat load in Sector 5 – 6



→ Scrubbing progress from heat load

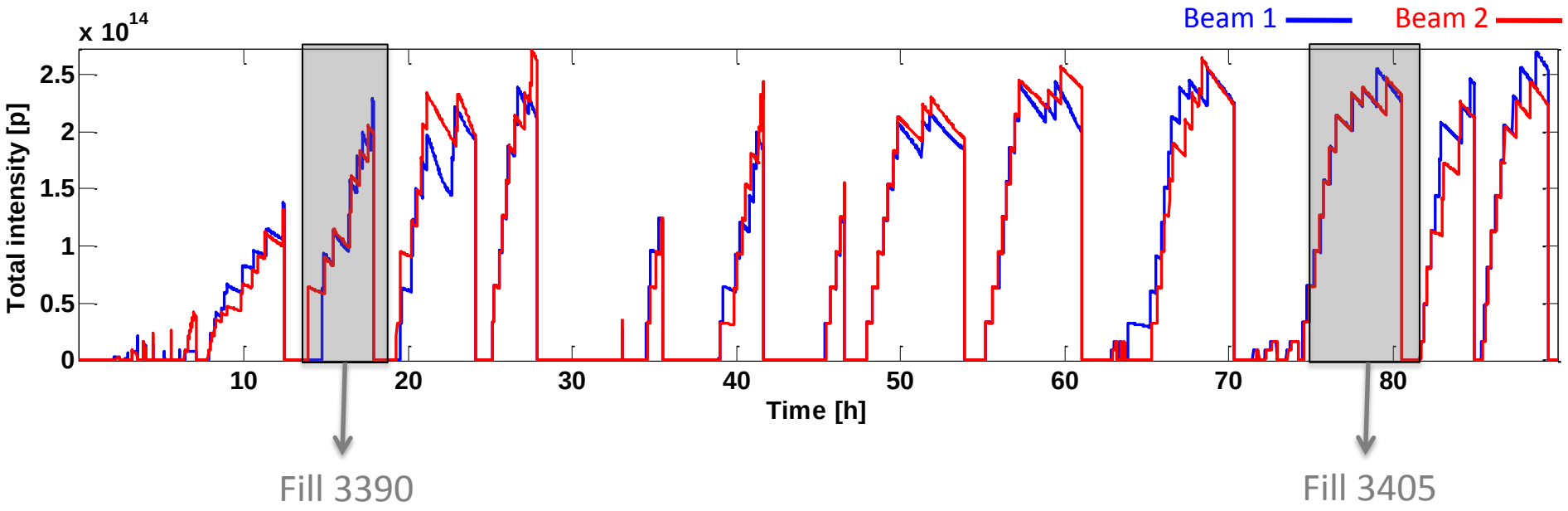
- ✓ Clear improvement during the first 60 – 70 hours
- ✓ Slow-down of the process in the last part of the scrubbing





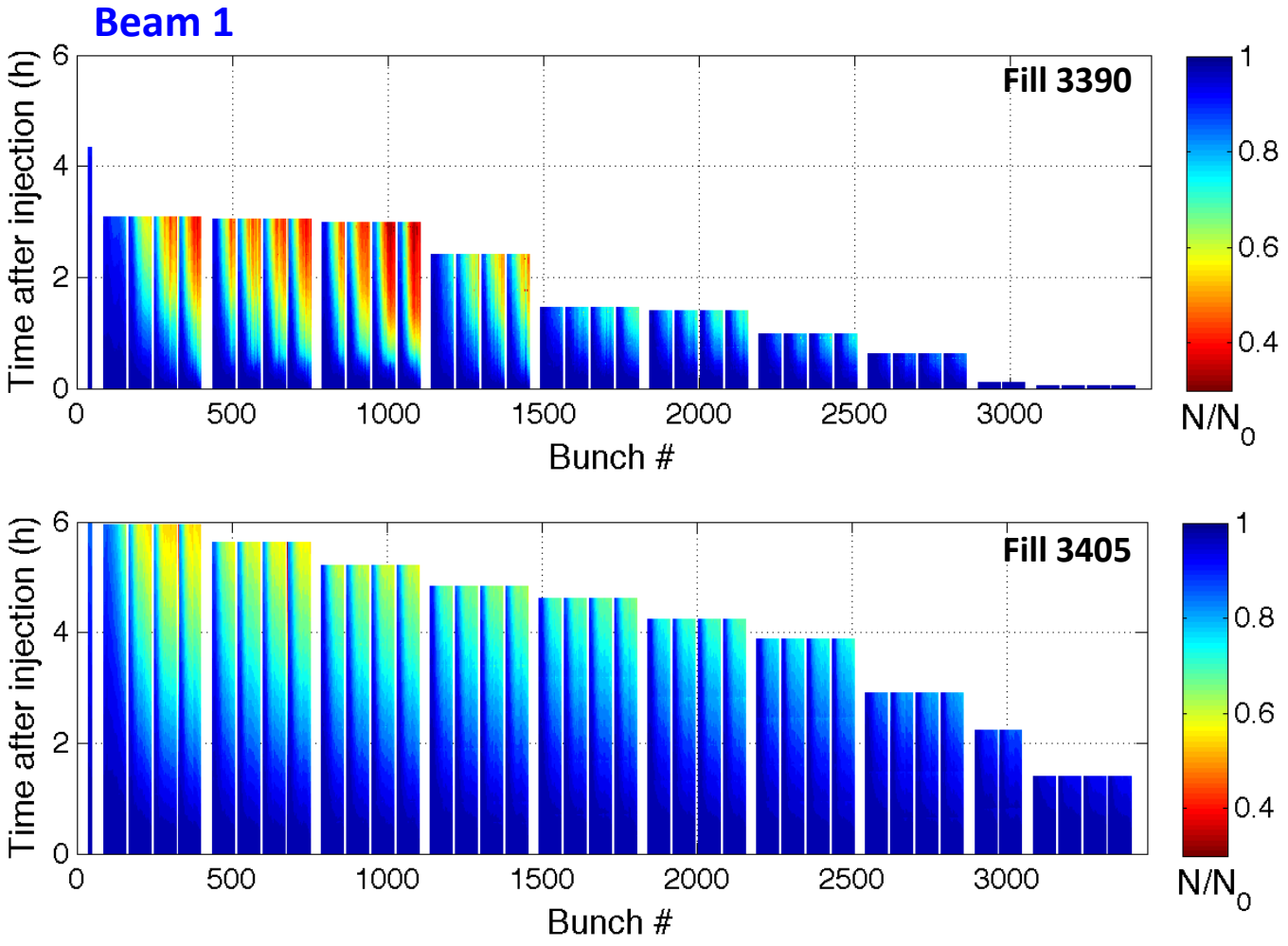
→ Beam quality evolution

✓ We first focus on two specific fills



→ Beam quality evolution (Beam 1)

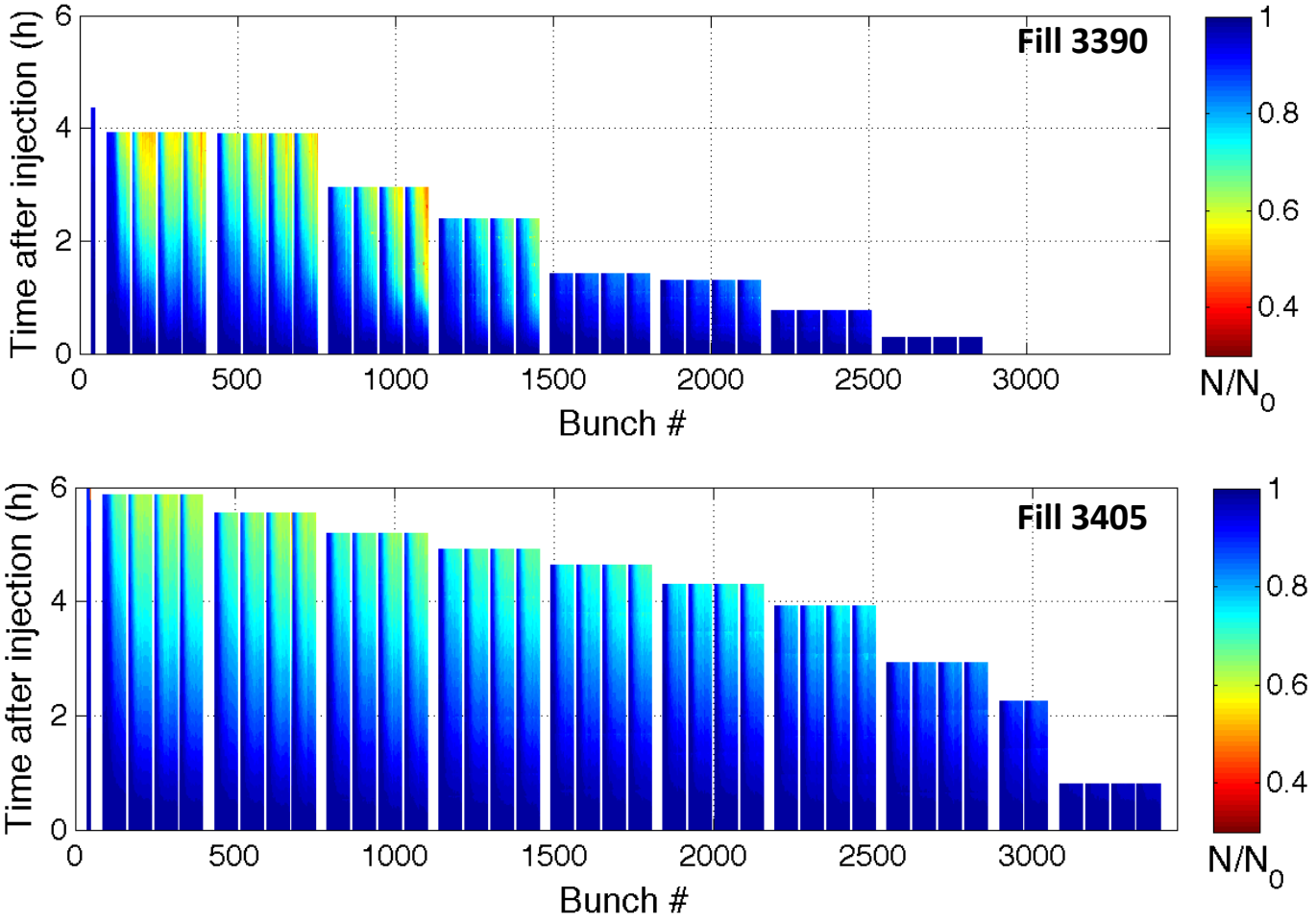
- ✓ **Fill 3390** → Losses up to 70% occur already in the first 3 hours of store for the bunches at the tail of the trains
- ✓ **Fill 3405** → Losses up to 40% appear after 6 hours of store for the bunches at the tail of the trains



→ Beam quality evolution (Beam 2)

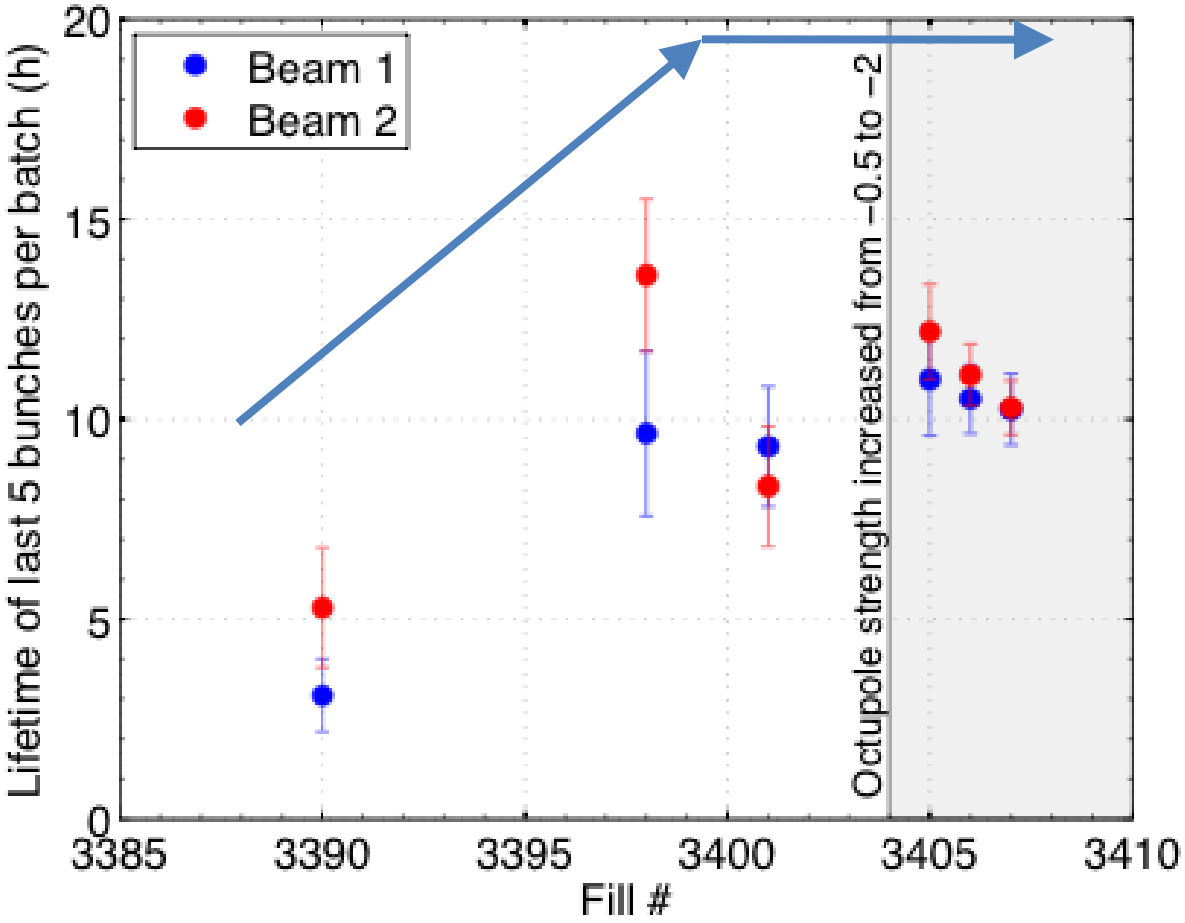
- ✓ **Fill 3390** → Losses up to 50% occur already in the first 3 hours of store for the bunches at the tail of the trains
- ✓ **Fill 3405** → Losses up to 30% appear after 6 hours of store for the bunches at the tail of the trains

Beam 2



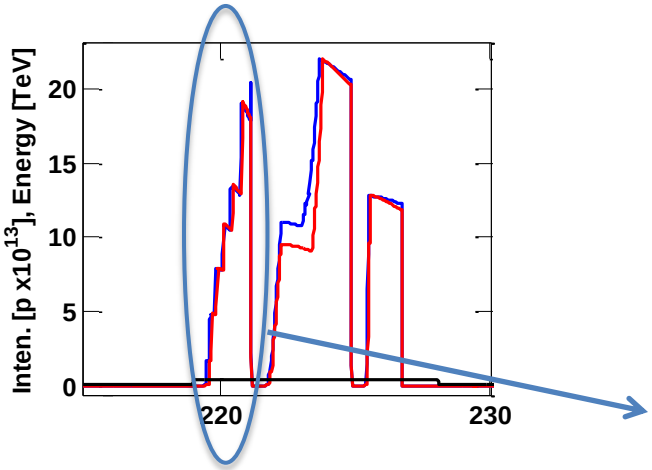
→ Beam quality evolution

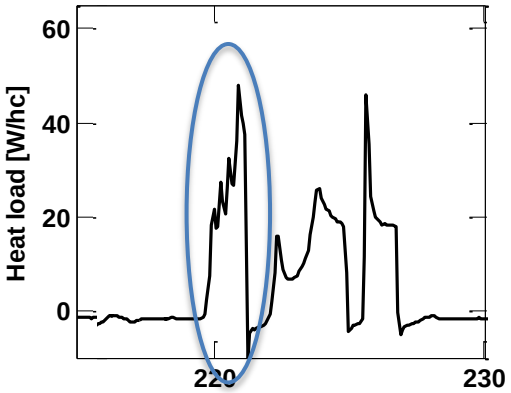
- ✓ Overview on lifetimes during scrubbing
- ✓ Also from the lifetimes, after a clear improvement at the beginning, the process seems to significantly slow down

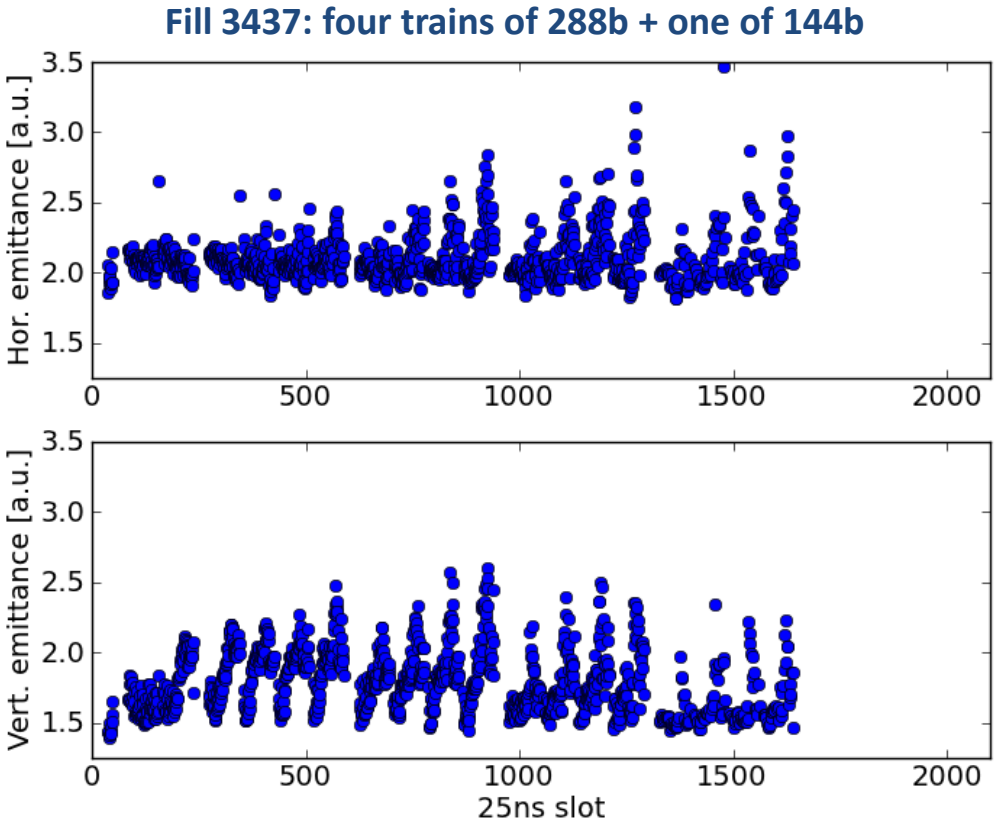


→ Beam quality evolution

- ✓ Between the test ramps at 4 TeV and the physics run, there were three more fills at 450 GeV (14 – 15 December, 2012)
- ✓ Heat load as high as in previous fills with 2748 bunches
- ✓ Emittance degradation still present with 288b fills



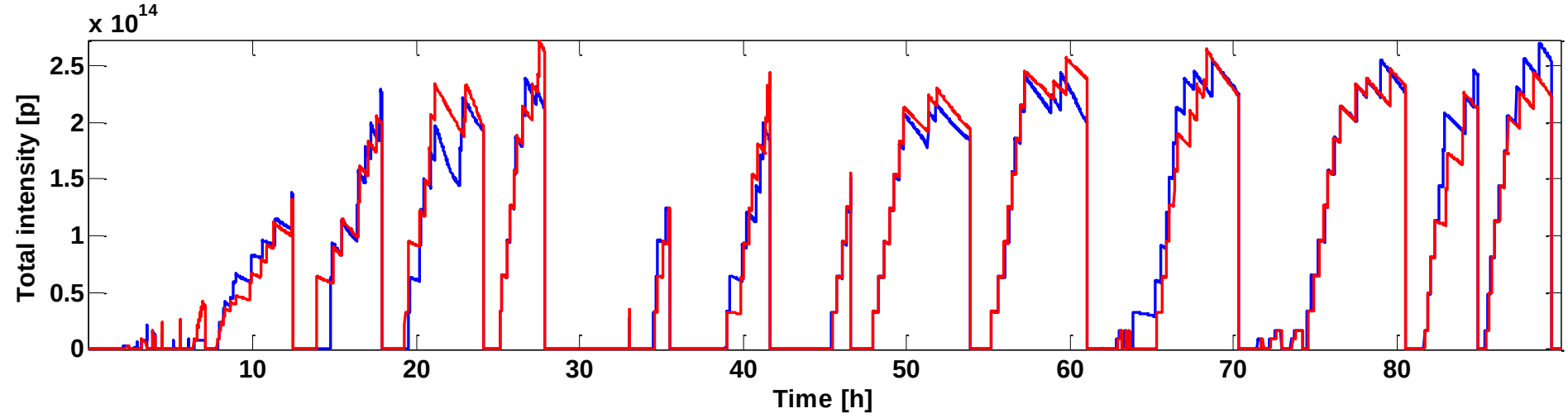


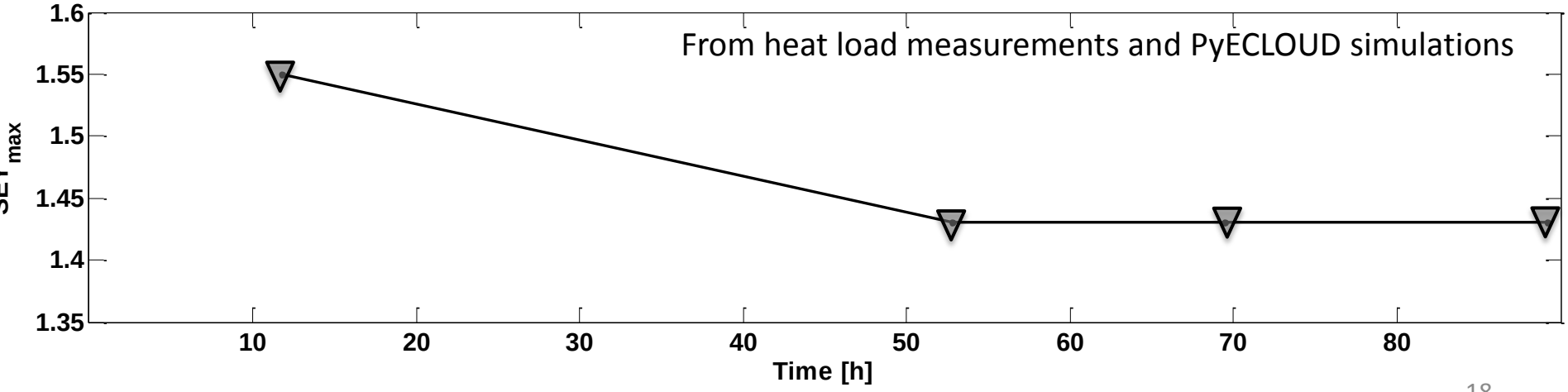


Thanks to T. Rijoff, H. Maury-Cuna

→ Reconstructing the SEY evolution during the scrubbing run

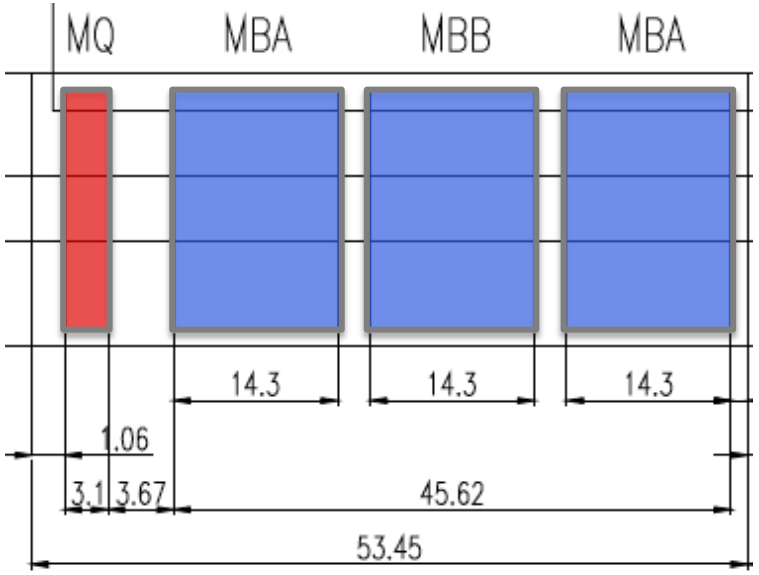
- ✓ Starting from an initial value of 1.55, the δ_{max} in the arc dipoles seems to quickly flatten at a value slightly below 1.45
- ✓ Unexpected leveling of the process

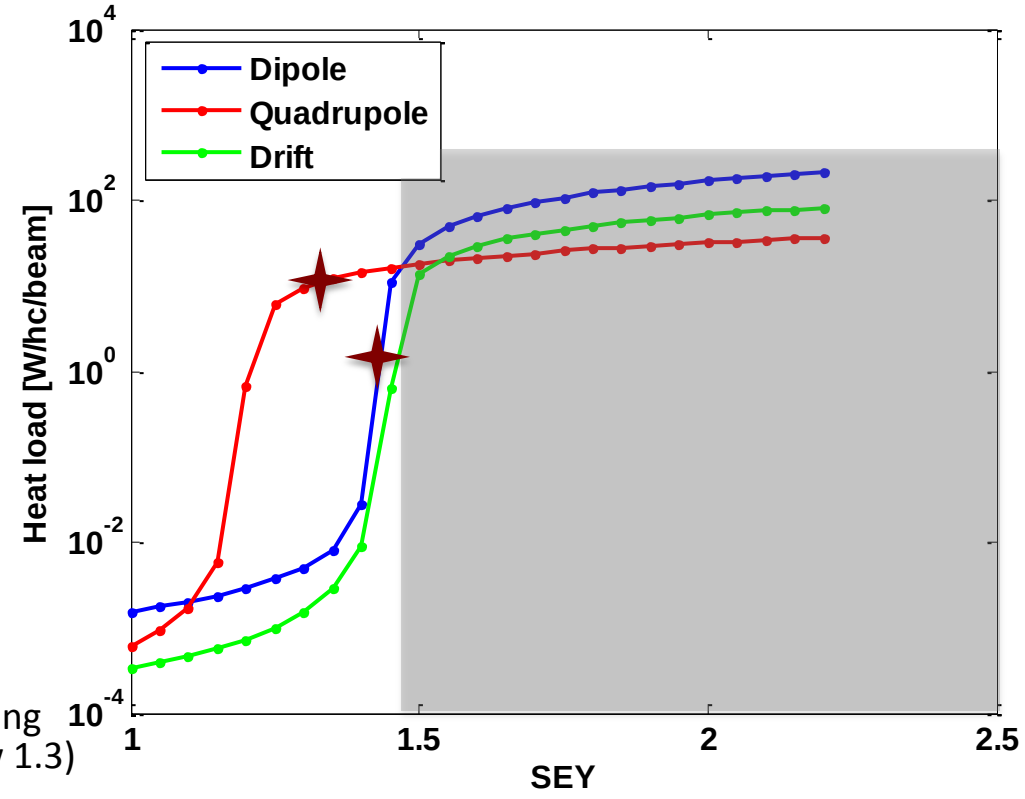




→ Possible interpretation

- ✓ Cells composed of 80% dipoles, but also 6% quadrupole + 14% drift & multipoles
- ✓ SEY thresholds are different in dipole/drift (1.45) or quadrupole (1.2)
- ✓ Electron cloud in dipoles is dominant (1-2 orders of magnitude) as long as $\delta_{max} > 1.5$ in dipole chambers
- ✓ But now quadrupoles (and multipoles?) could be dominant …





→ This could explain

- ✓ Saturation of scrubbing process (scrubbing curve becomes very steep for SEY below 1.3)
- ✓ Long memory between trains
- ✓ Horizontal blow up

WORK in PROGRESS

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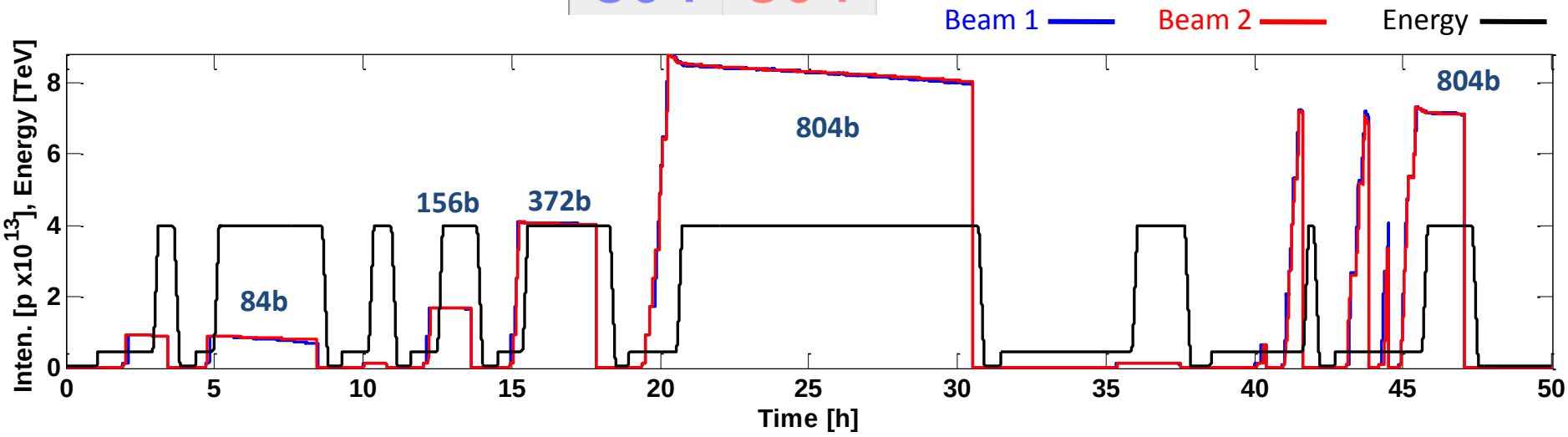
804 804



→ Test ramps with trains of 72 bunches to avoid excessive emittance degradation at injection energy, **2 days** of **25ns beam** at **4 TeV** (12 – 14 December, 2012)

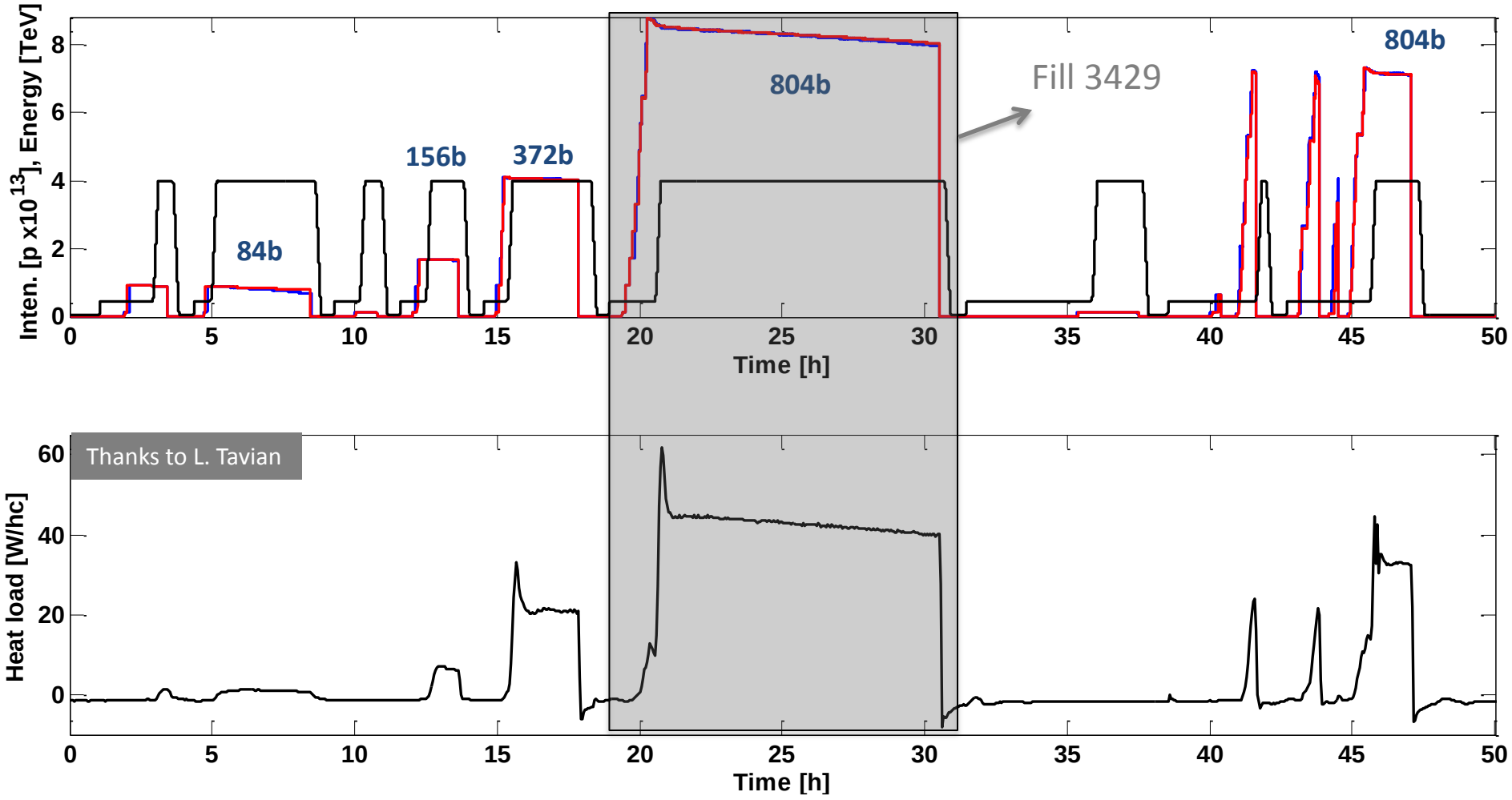
→ First fill (**84 bunches**) was used for a long-range beam-beam MD (changing the crossing angle)

→ Intensity ramp up (**156, 372 bunches**) with short stores and then finally one long store with **804 bunches** for scrubbing

→ One short store with **804 bunches** at lower intensity per bunch (around **9 x 10^{10} ppb**)

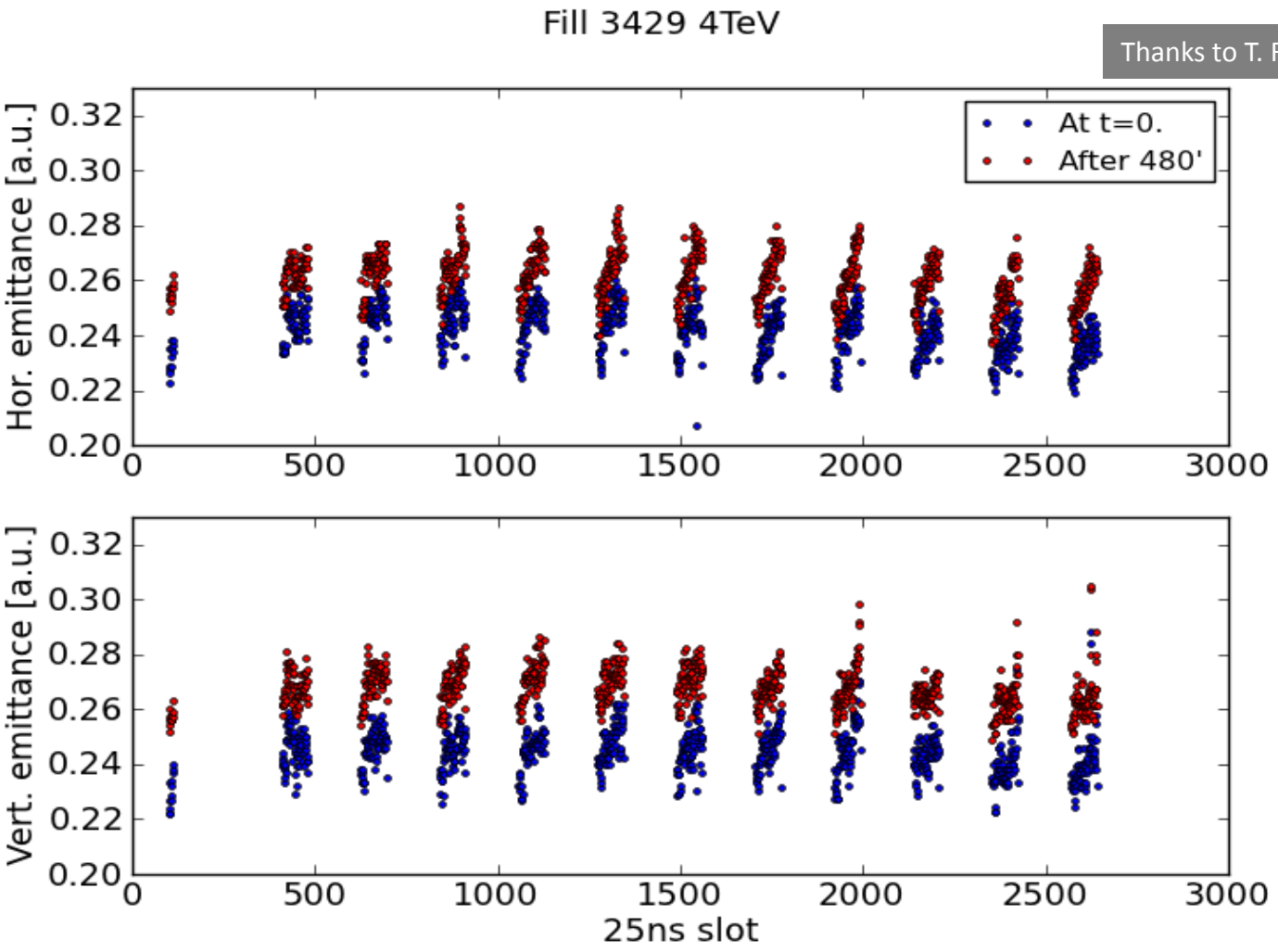
→ Heat load in the arcs when ramping up the energy

- ✓ Enhanced heat load probably due to photoelectrons (804 bunches at 4 TeV produce the same heat load as 2748 bunches at 450 GeV)
- ✓ Violent transient during the ramp (limit of the # of bunches)
- ✓ Not much additional scrubbing visible …



→ Transverse emittances at top energy

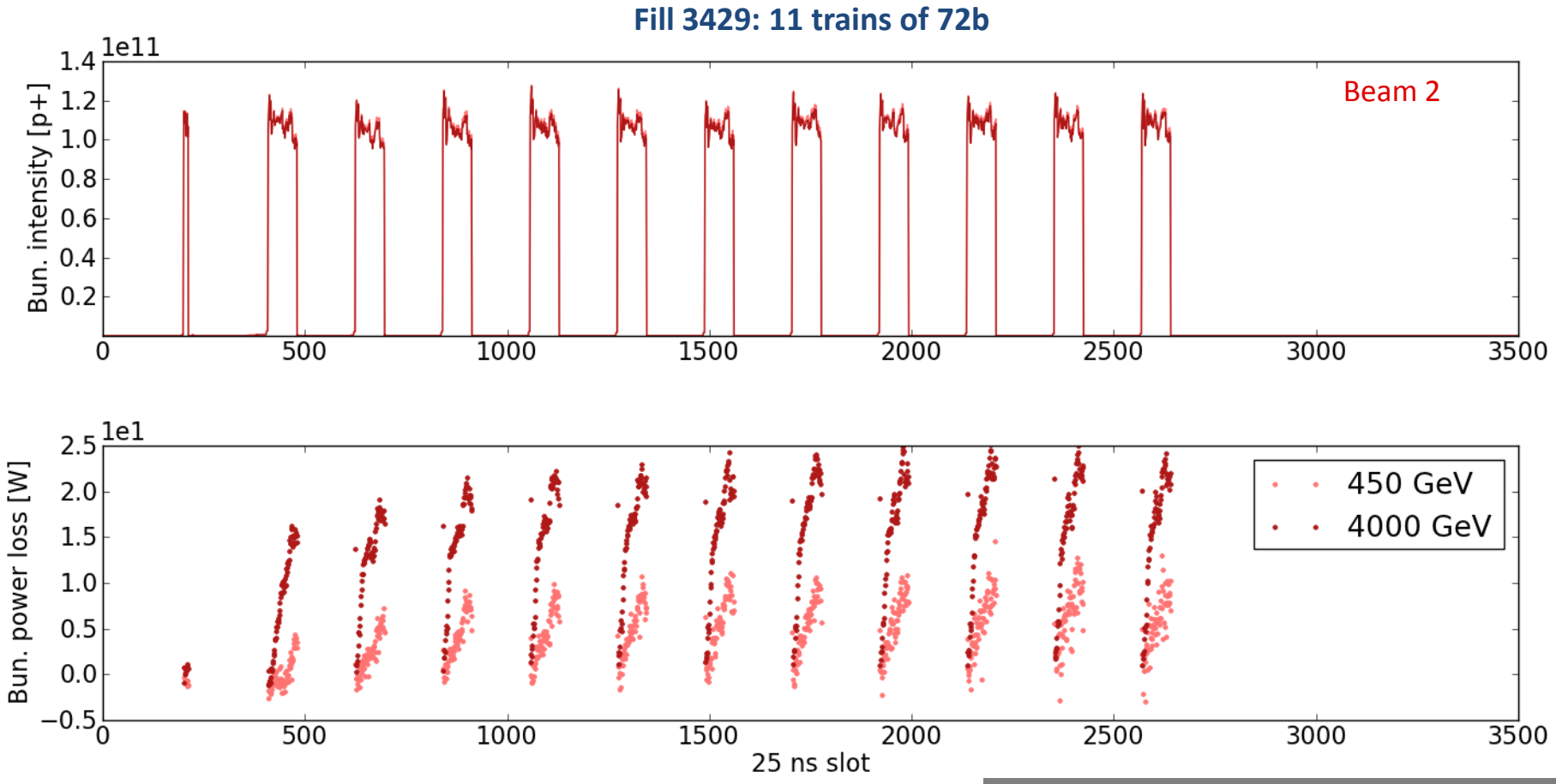
- ✓ Little effect of emittance blow up along trains of 72 bunches
- ✓ Uniform emittance blow along the beam by about 10% over 8h store
- ✓ Emittances are essentially determined at injection energy



Thanks to T. Rijoff, H. Maury-Cuna

→ Bunch-by-bunch stable phase shift

- ✓ Factor 2-3 larger at 4 TeV than at 450 GeV
- ✓ Clear intra-train pattern with possibly memory between trains
- ✓ Probably effect of photoelectrons



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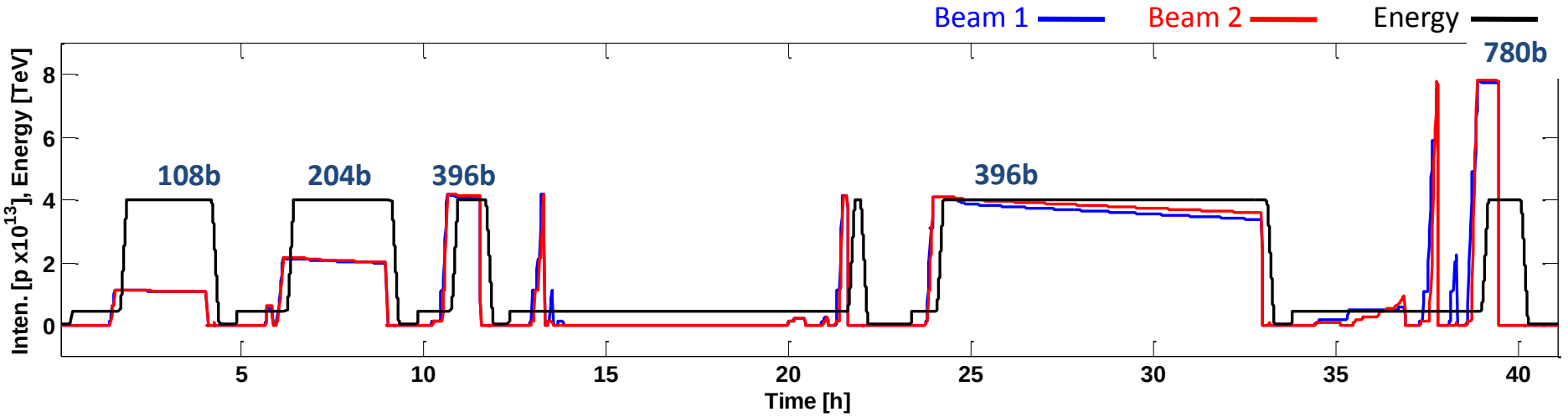
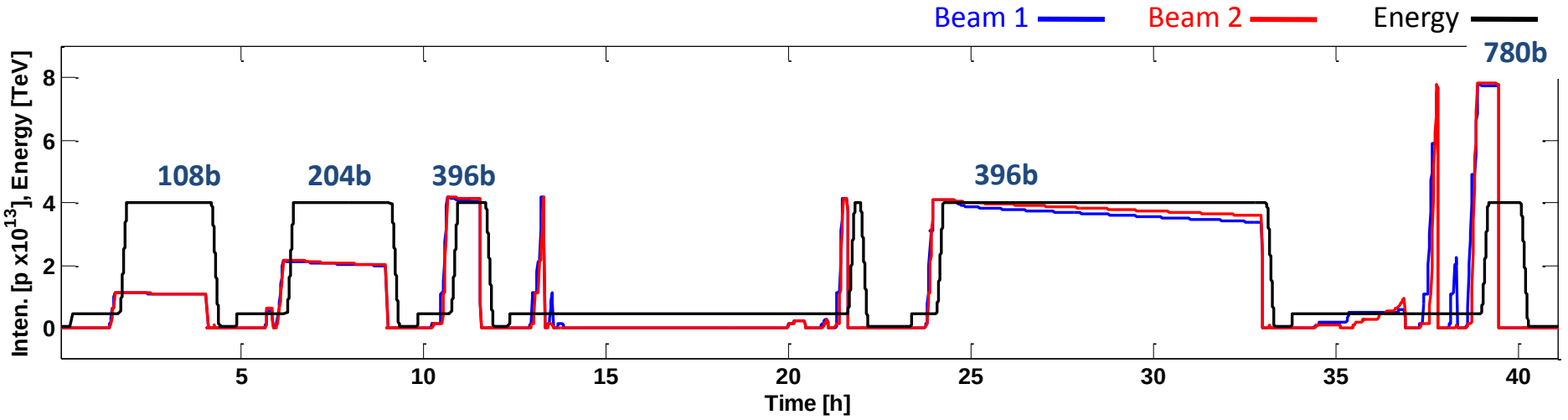
End of the 2012 proton run: physics with 25ns beams

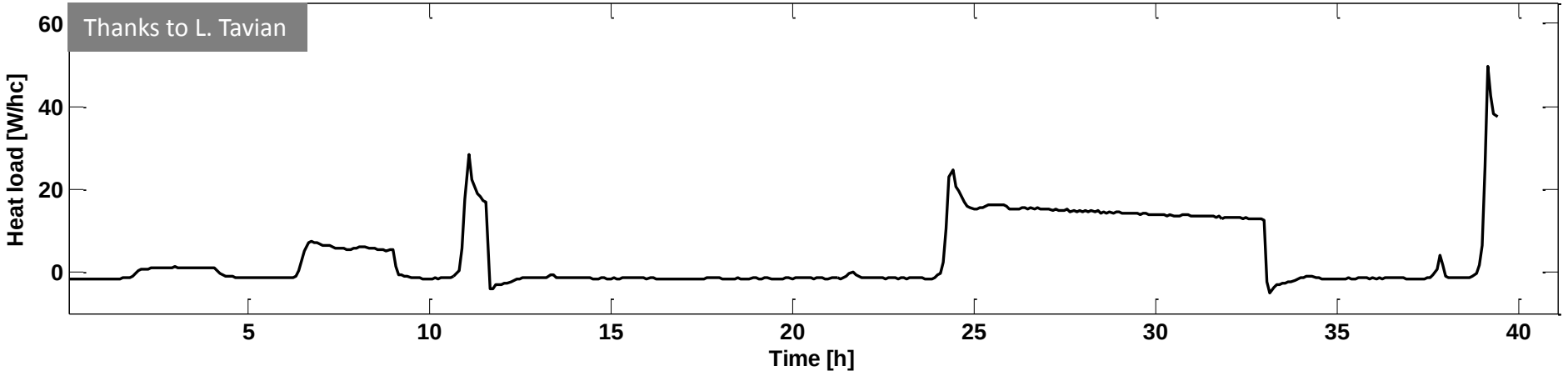


- → Physics run with 25ns beams, almost **2 days** of **25ns beam** at **4 TeV** (15 – 17 December, 2012)
- → Low emittance beams (BCMS production scheme) used from injectors and injected into LHC in trains of **48 or 2x48 bunches**
- → Intensity ramp up (**108, 204, 396 bunches**) with increasingly long stores to collect data for the experiments
- → Last fill with **780 bunches** → beam went through ramp and squeeze, then had to be dumped because of the end of the run!

→ Heat load in the arcs

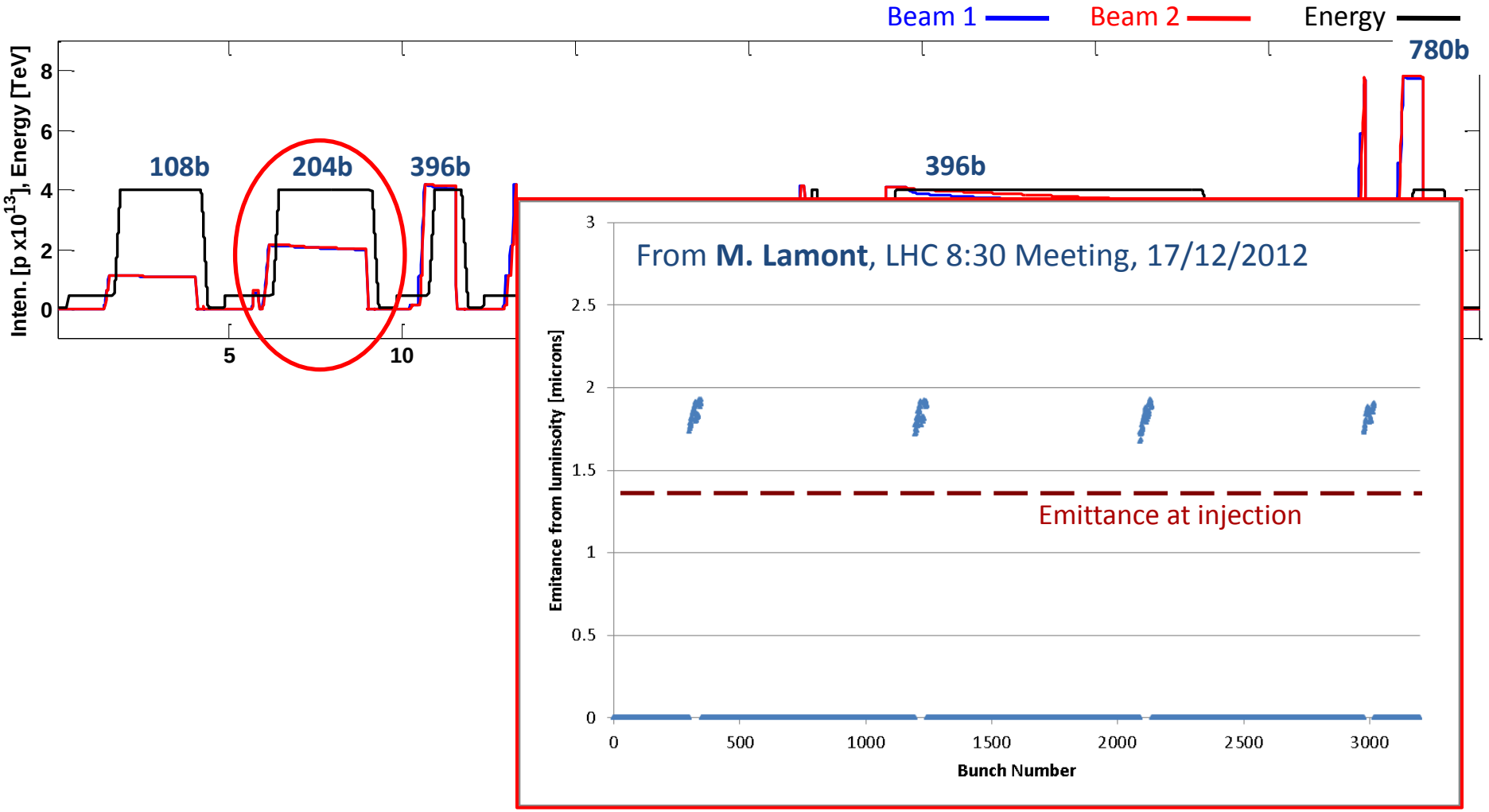
✓ Lower heat load than in previous stores with comparable currents: effect of scrubbing or train structure or lower emittance?





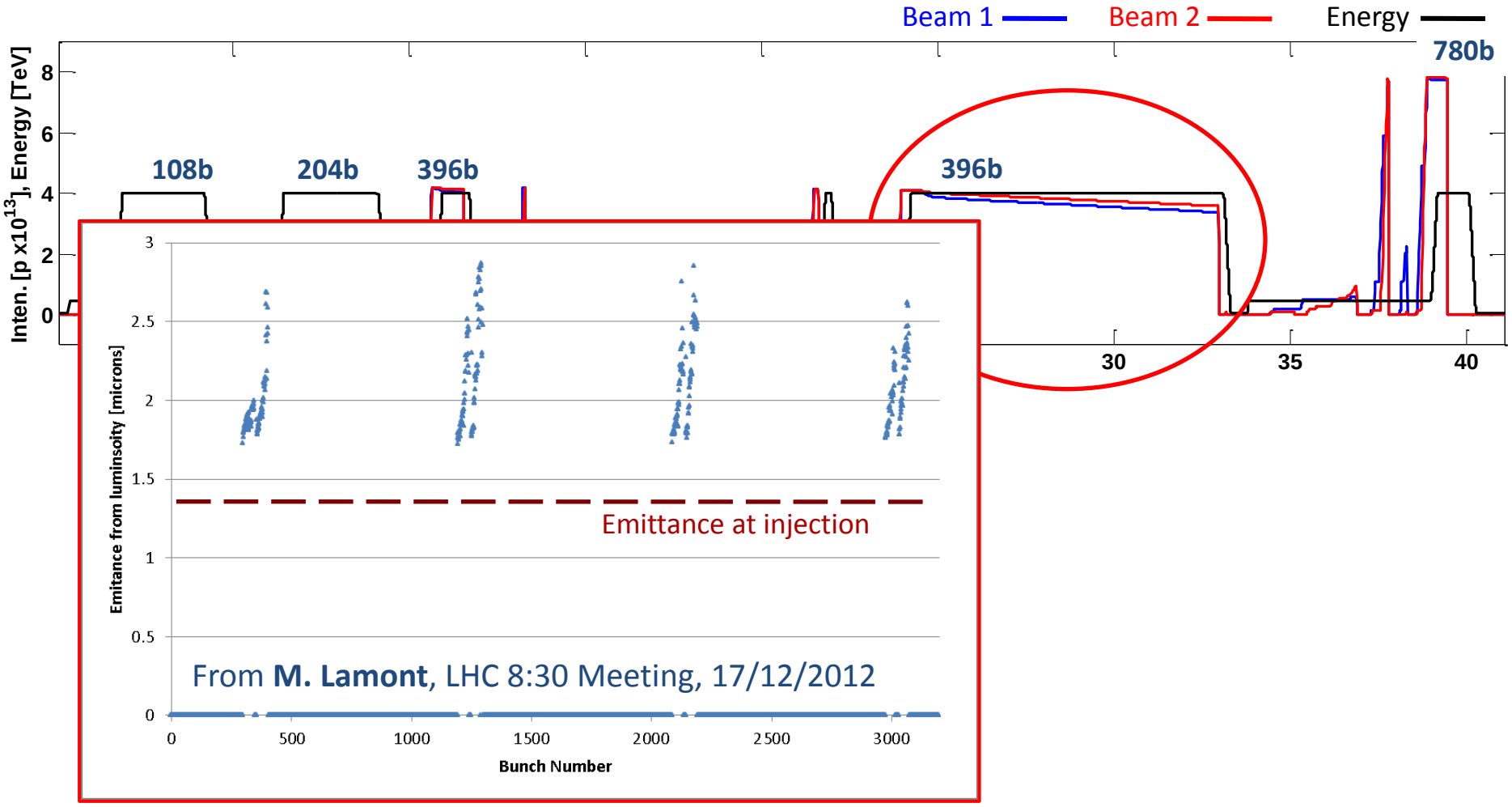
→ Transverse emittances

- ✓ Measured from luminosity
- ✓ 30% higher than at injection
- ✓ 10% spread over each train length (48b)



→ Transverse emittances

- ✓ Measured from luminosity
- ✓ Strong e-cloud shaped structure along the trains of 2 x 48b
- ✓ Memory between trains in spite of long distance



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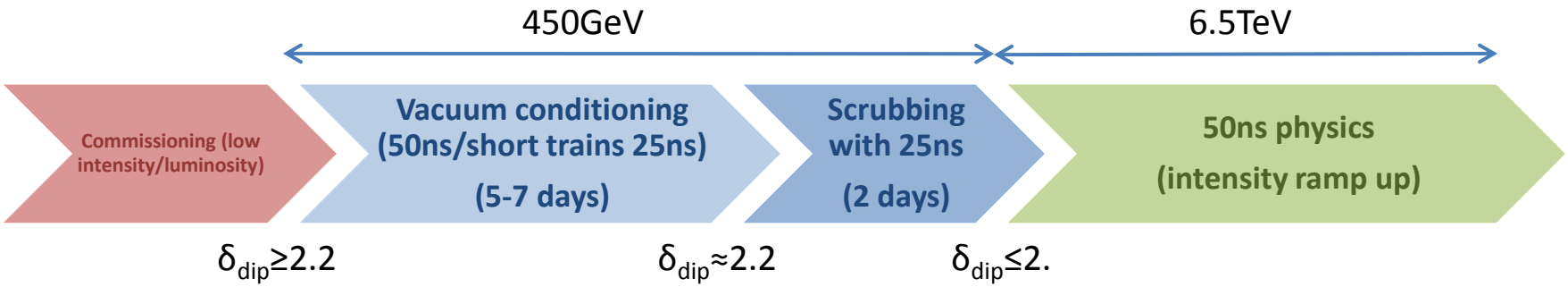
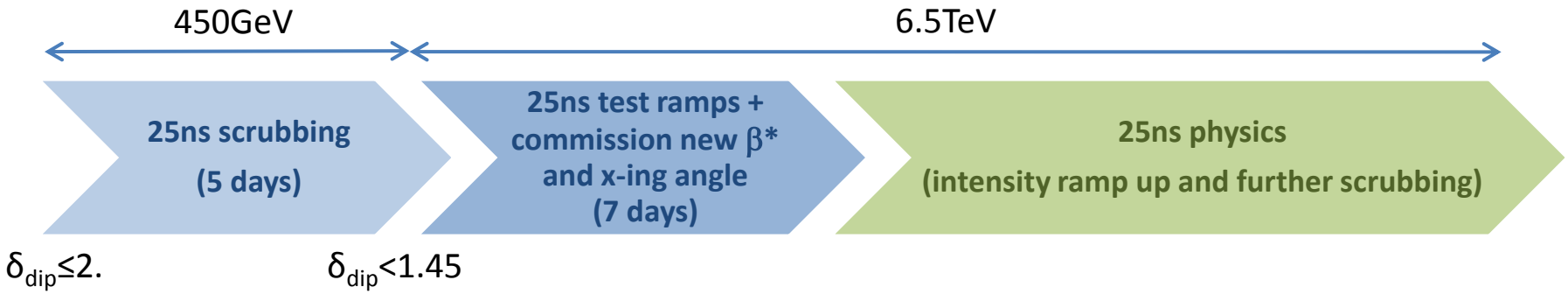
Requirements for operation with 50ns beams (to the pile up limit):



Further requirements for operation with 25ns beams:



Operation with 25ns will have the following implications:

⇒ **Co-existence with electron cloud effects**, at least for some time (especially heat load, emittance blow up and low lifetime) → slow intensity ramp up

⇒ **Deconditioning** occurring after longer stops (might require few hours scrubbing after each TS)

⇒ Close monitoring of **UFOs** and **beam induced heating**

Summary and conclusions

⇒ 3.5 days scrubbing run at 450 GeV
- Several fills with full machine (**2748 bunches per beam**), record intensity **2.7 x 10^{14} p**
- Improvement of heat load and beam lifetime over the first **≈70 hours**, then sharp slow-down of the scrubbing process (likely due to low SEY threshold in quads)
- Emittances still **blown up** during the injection process for long enough trains of bunches

⇒ Experience at 4 TeV (2 days test ramps + 2 days physics run)
- Fills with **up to 804 bunches** per beam stored for several hours
- Heat load and stable phase shift indicate a **steep increase of the power loss** when ramping to 4 TeV, probably due to photoelectrons
- Significant **blow up** of transverse emittances occurring only at injection energy
- Pilot **physics run** with **up to 396 bunches** per beam (780 squeezed)

⇒ Future scenarios (2015)
- After LS1, **≈1 week** vacuum conditioning & scrubbing for 50ns run, then **1 more scrubbing week + 1 week** for high energy commissioning needed to get into physics with 25ns beams
- **Co-existence with electron cloud** probably inevitable at least in the first part of the physics run


Thank you for your attention !

- ☑ Brief memo of the LHC status (2011)
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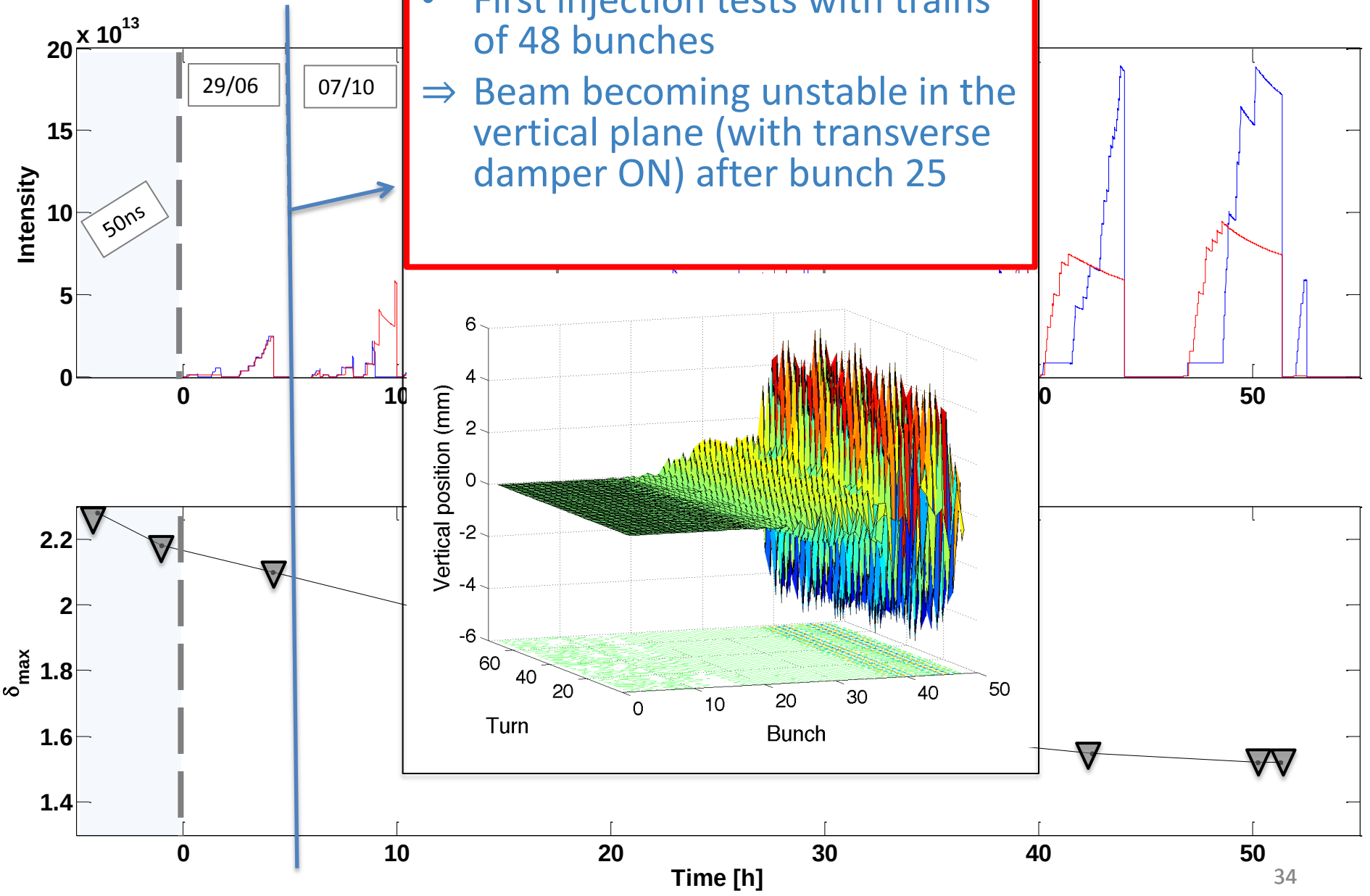
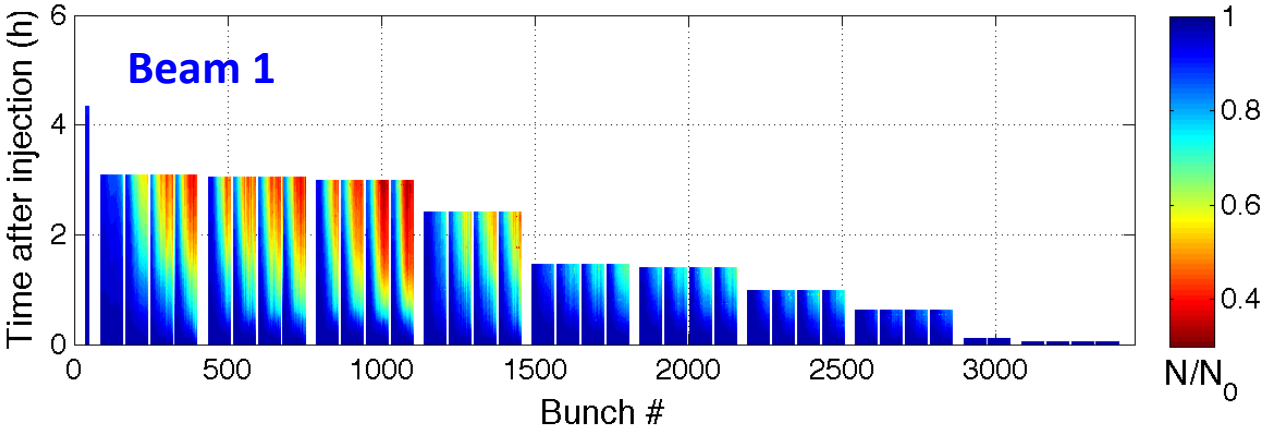
- First injection tests with trains of 48 bunches

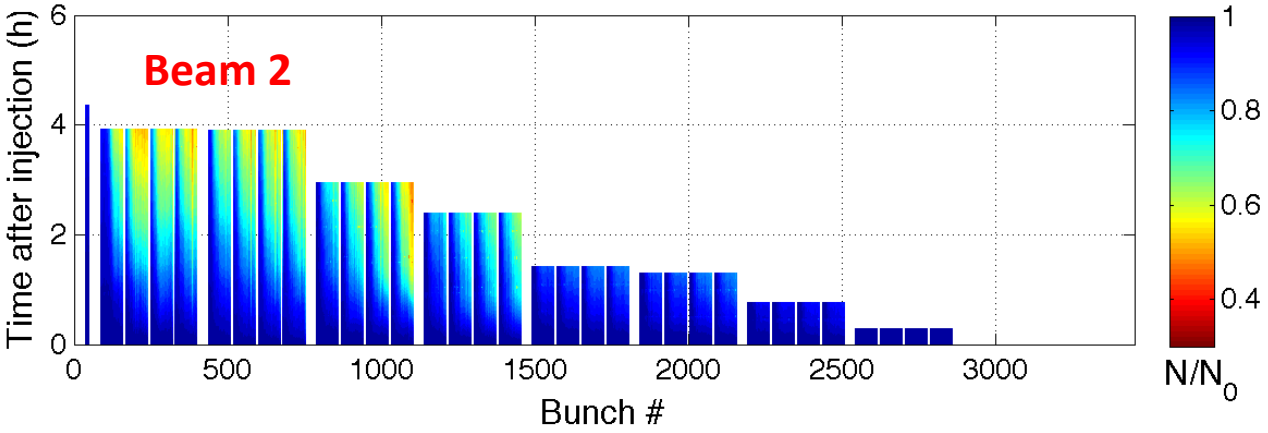
⇒ Beam becoming unstable in the vertical plane (with transverse damper ON) after bunch 25



→ Beam quality evolution

- ✓ Fill 3390: beginning of the scrubbing run
- ✓ Losses of ~70% occur already in the first 3 hours of store for the bunches at the tail of the trains





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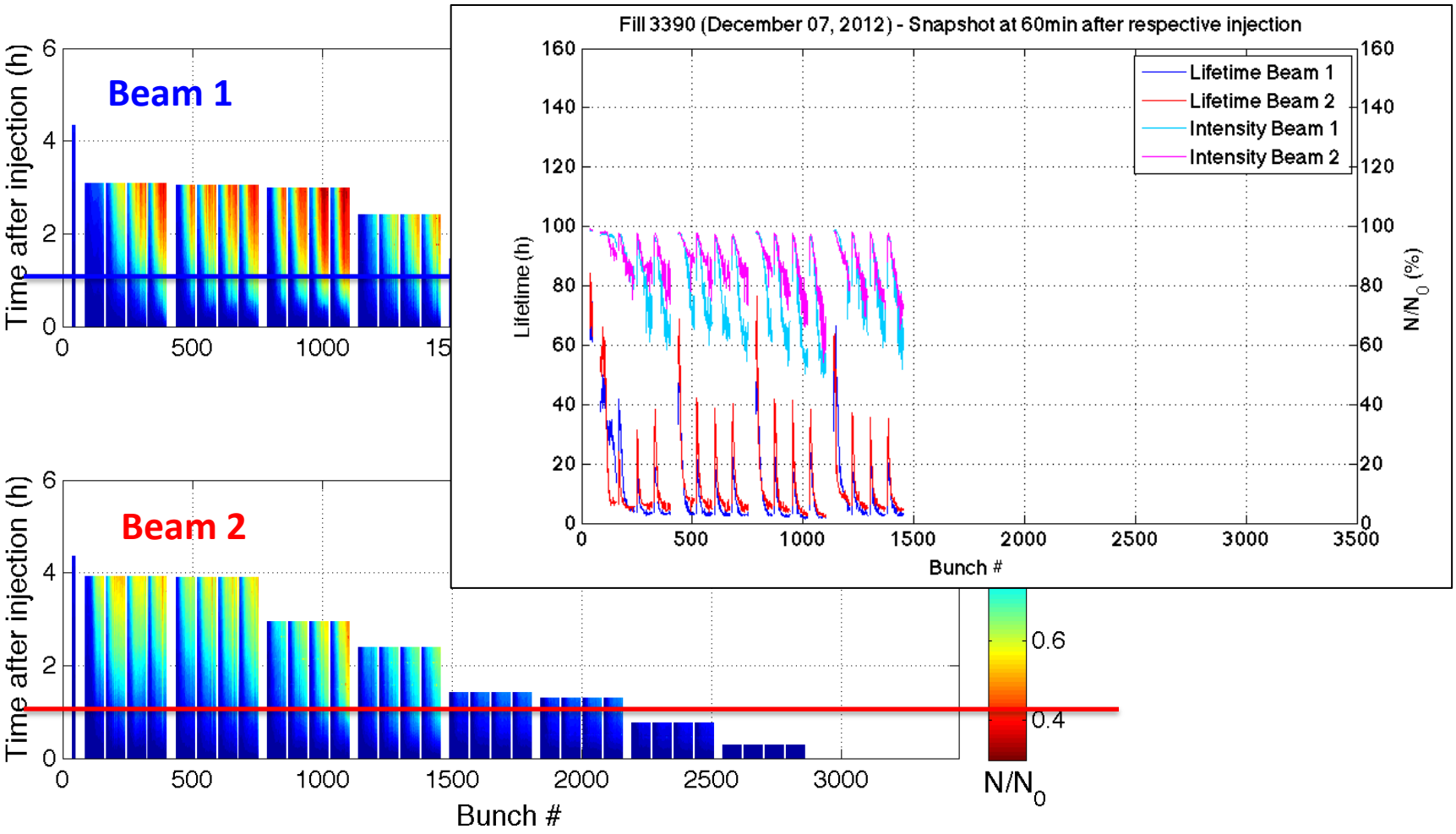
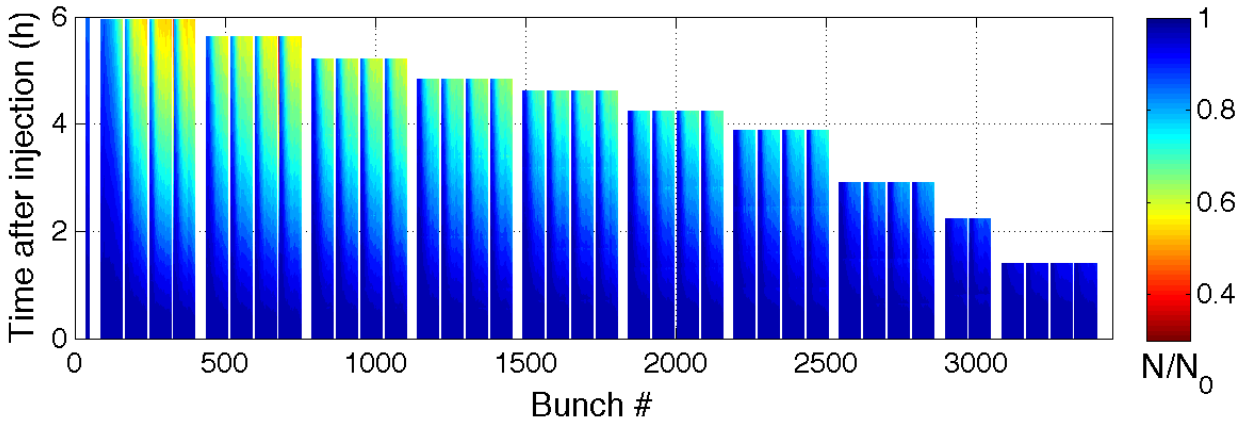


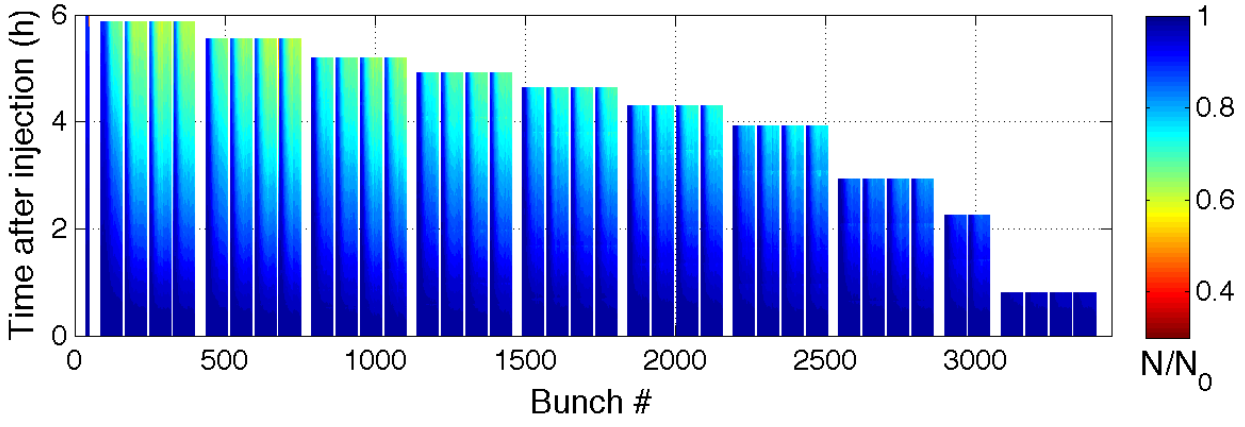
→ Beam quality evolution

- ✓ Fill 3405: end of the scrubbing run
- ✓ Losses of ~50% appear after 6 hours of store for the bunches at the tail of the trains

Beam 1



Beam 2



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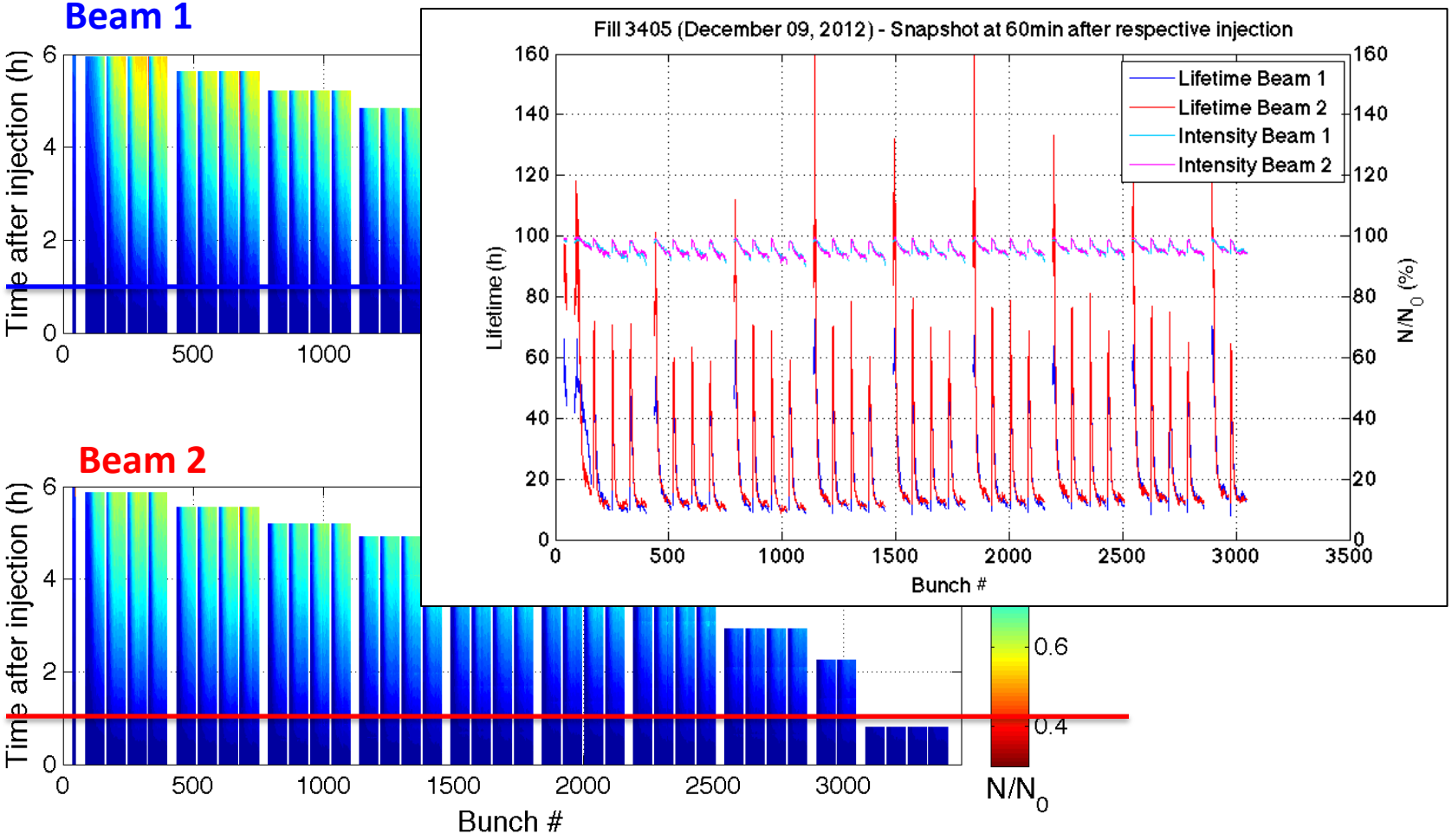
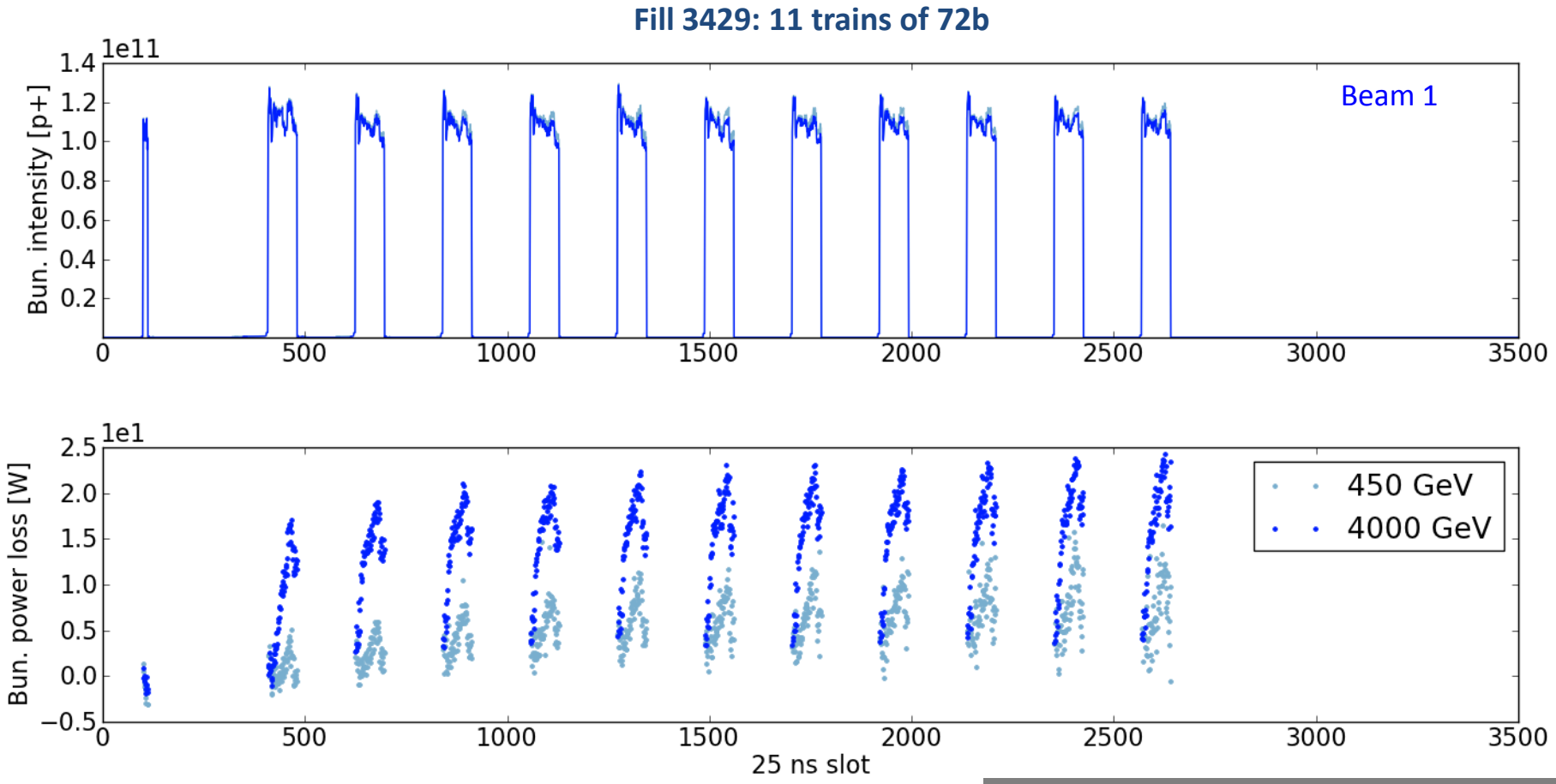
- ✓ Losses of ~50% appear after 6 hours of store for the bunches at the tail of the trains



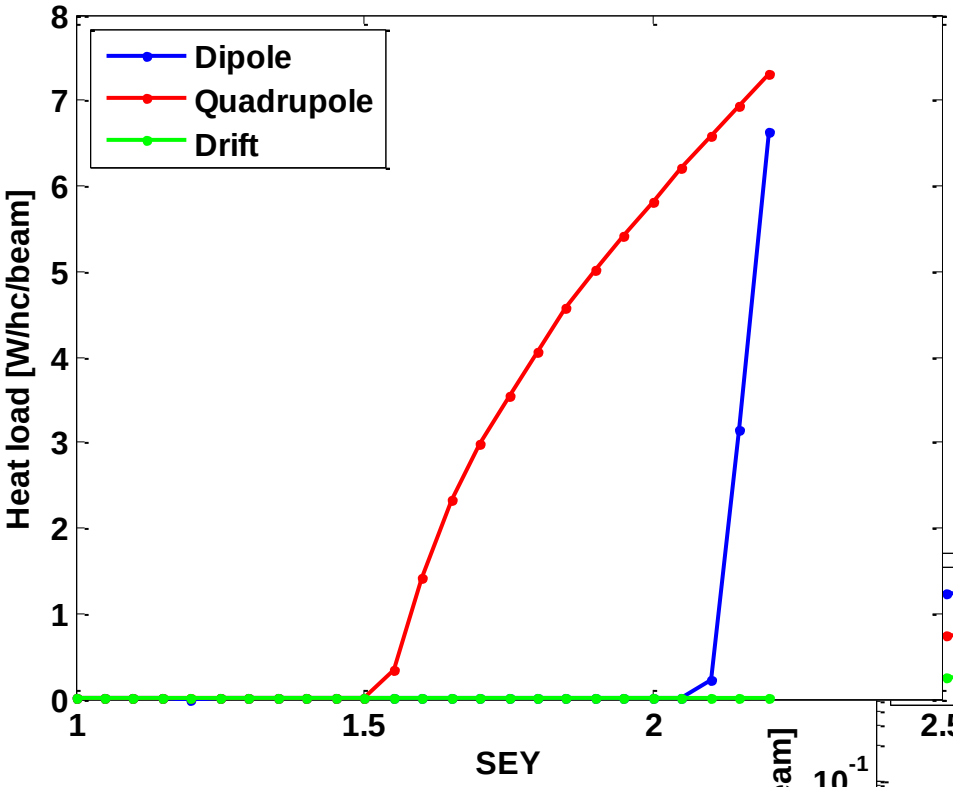
→ Bunch-by-bunch stable phase shift

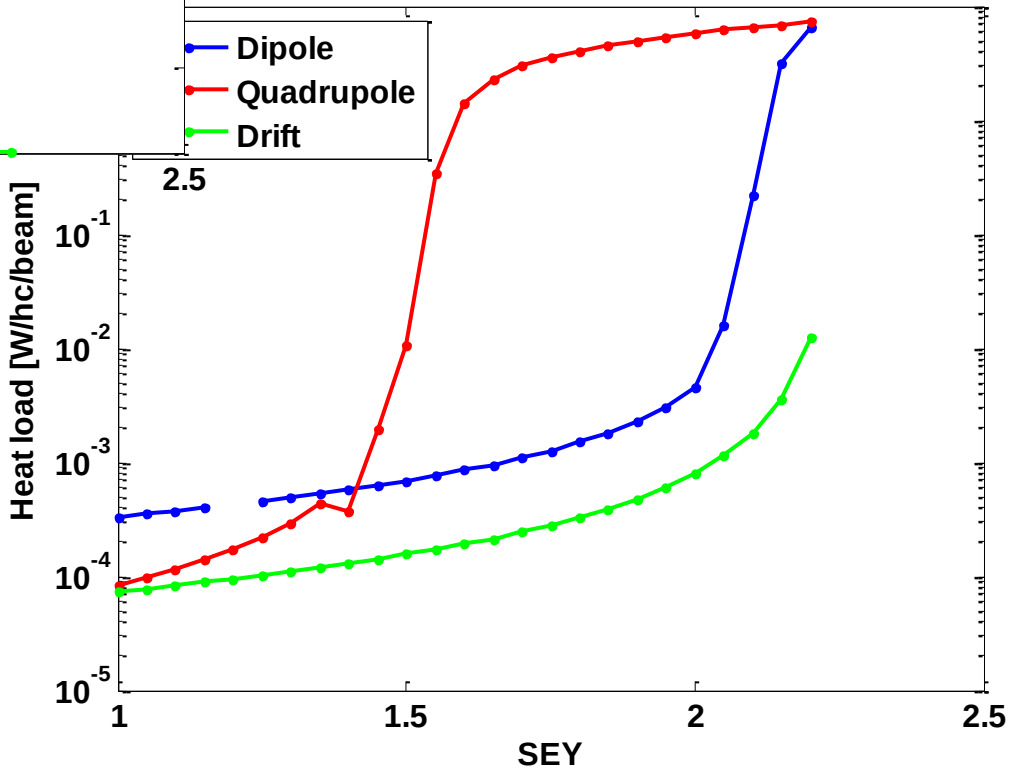
- ✓ Factor 2-3 larger at top energy than at injection energy
- ✓ Clear intra-train pattern with possibly memory between trains
- ✓ Probably effect of photoelectrons



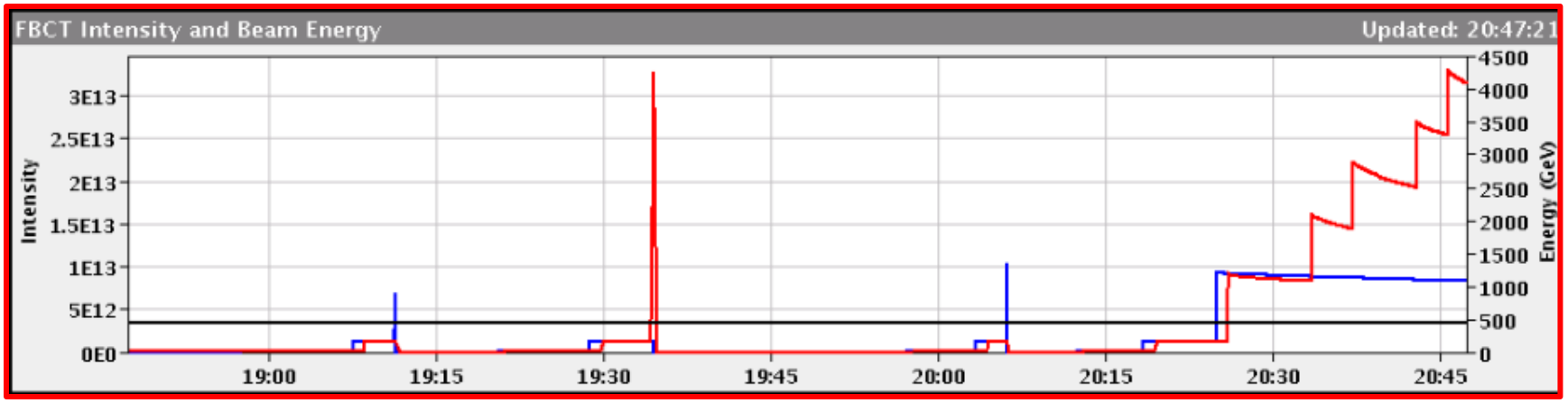
Thanks to J. Esteban-Müller, E. Shaposhnikova

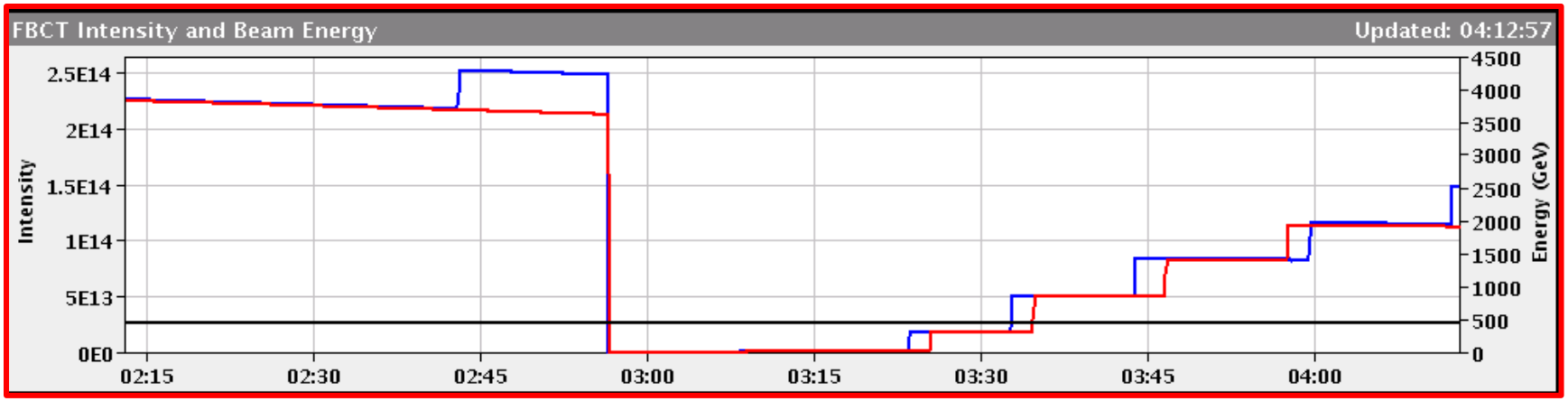
50ns

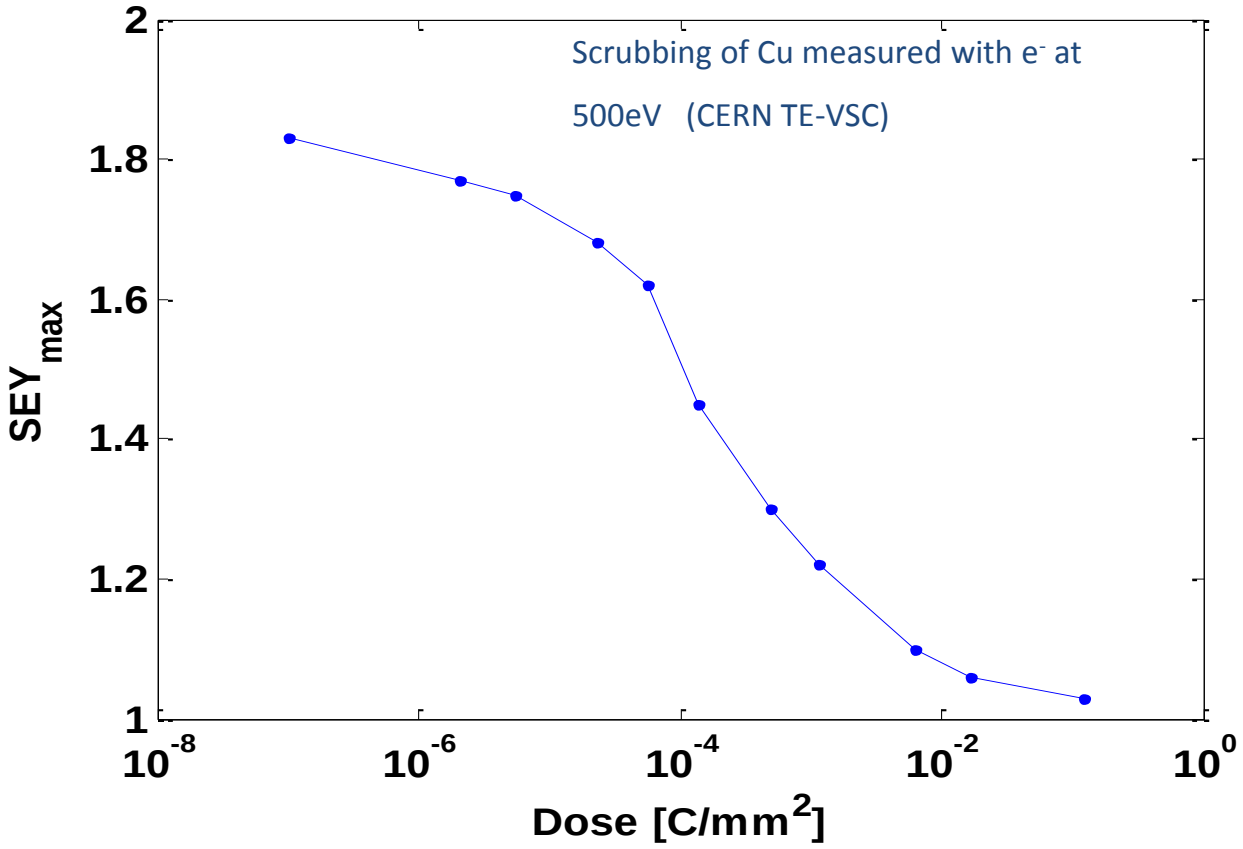

Dipole
Quadrupole
Drift
Heat load [W/hc/beam]
SEY
0
1
2
3
4
5
6
7
8
1
1.5
2


Dipole
Quadrupole
Drift
Heat load [W/hc/beam]
SEY
10^-1
10^-2
10^-3
10^-4
10^-5
1
1.5
2
2.5

Beam lifetime (CCC monitoring)



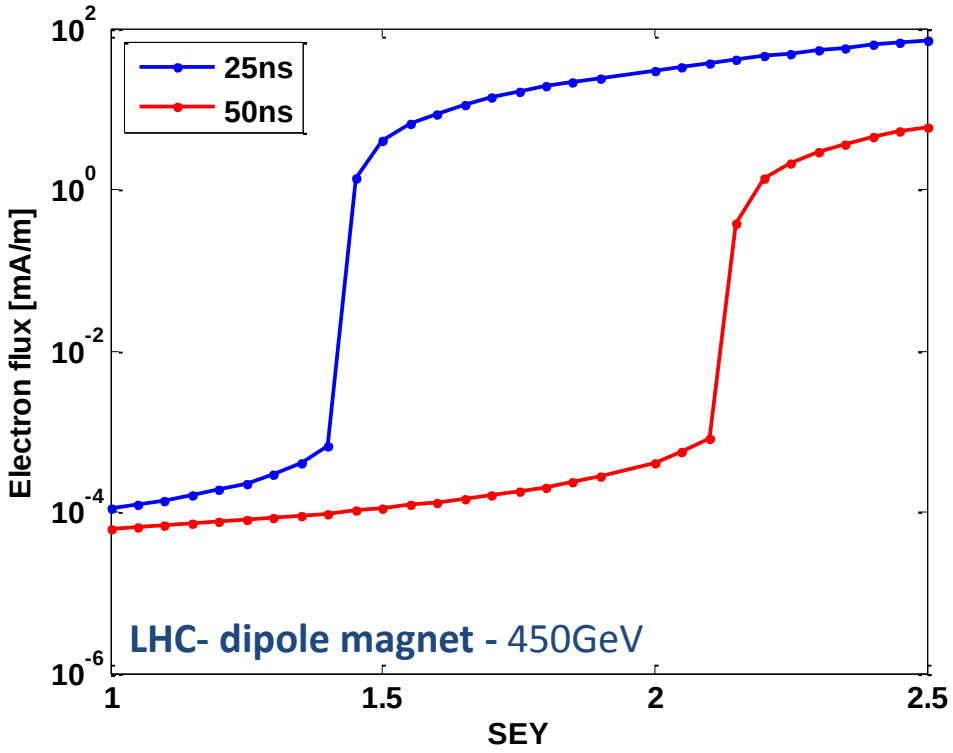




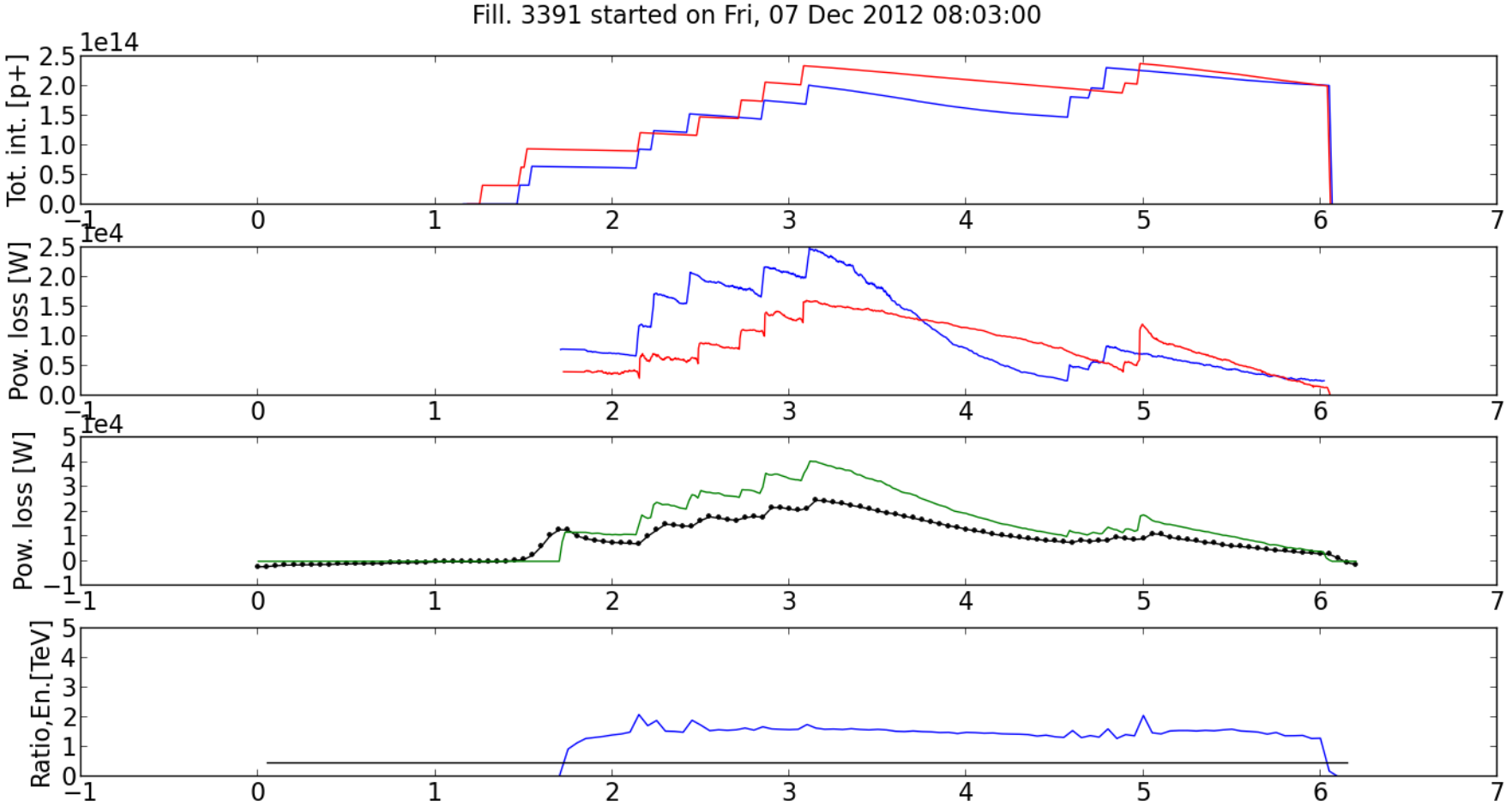
Scrubbing is a mitigation for the e-cloud effects:

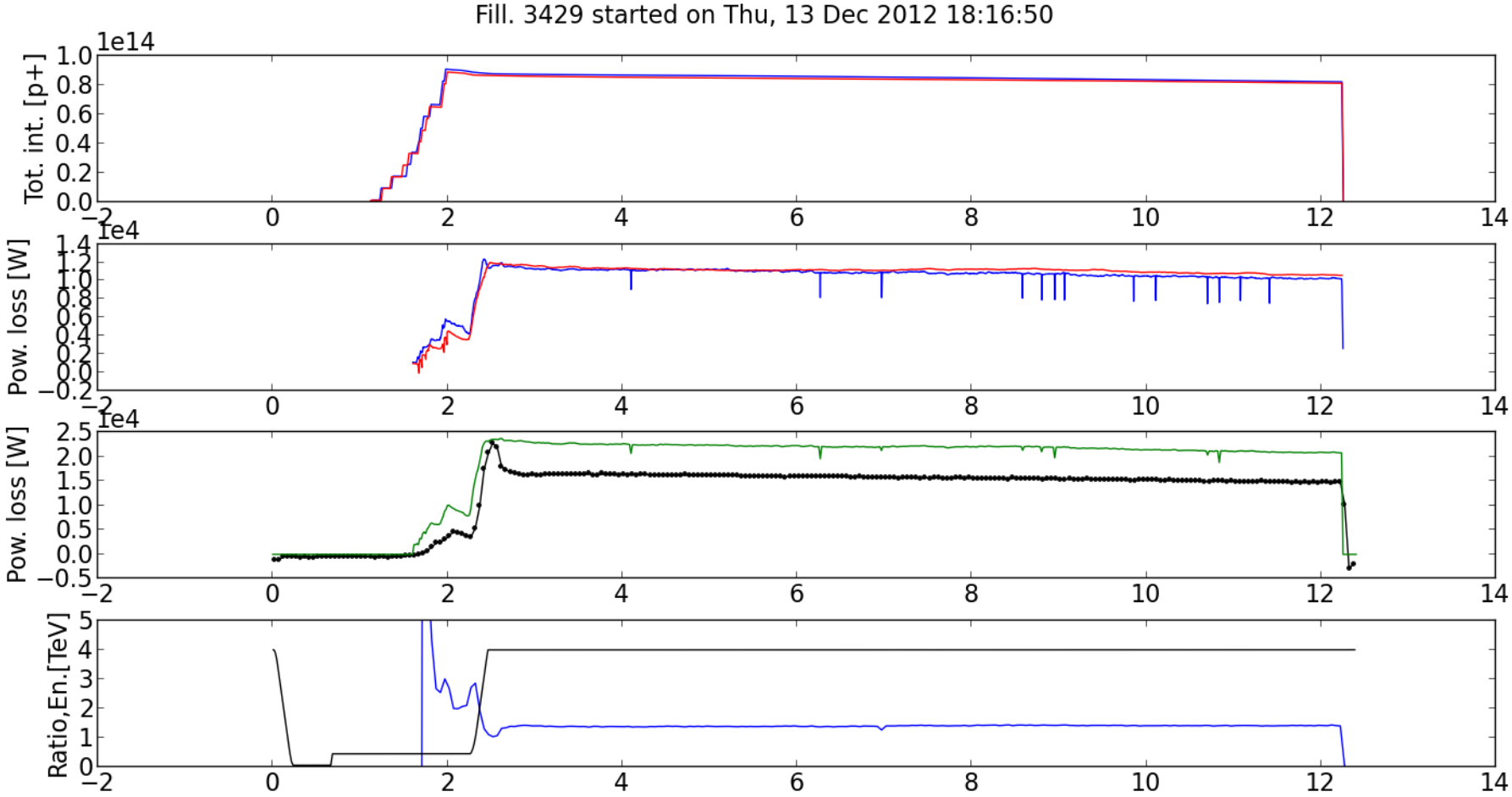
- ☺ Keeping a significant e- flux **on the chamber's walls causes a decrease** of the SEY (and hence the e-cloud)
- ☹ The dependence of the SEY on the accumulated dose **is logarithm - like**

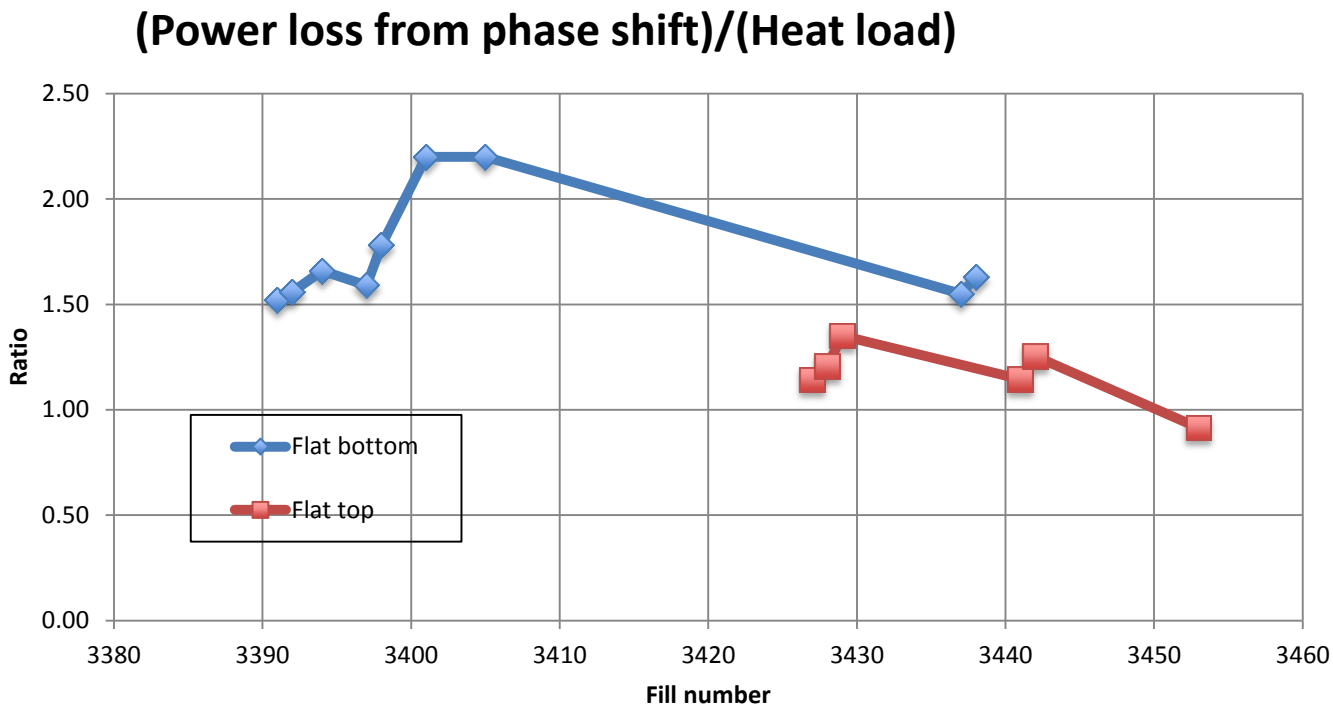
- **Main focus on the dipole magnets** (~60% of the machine) → they determine the performance in terms of beam quality



- The **"multipacting threshold"** for 25ns beams is significantly lower than for 50ns
- In 2011, 4 days of scrubbing with 50ns beams + 2 days of tests with 25ns beams have **lowered the SEY in the arcs well below 2.0** allowing an "EC free" operation also in 2012

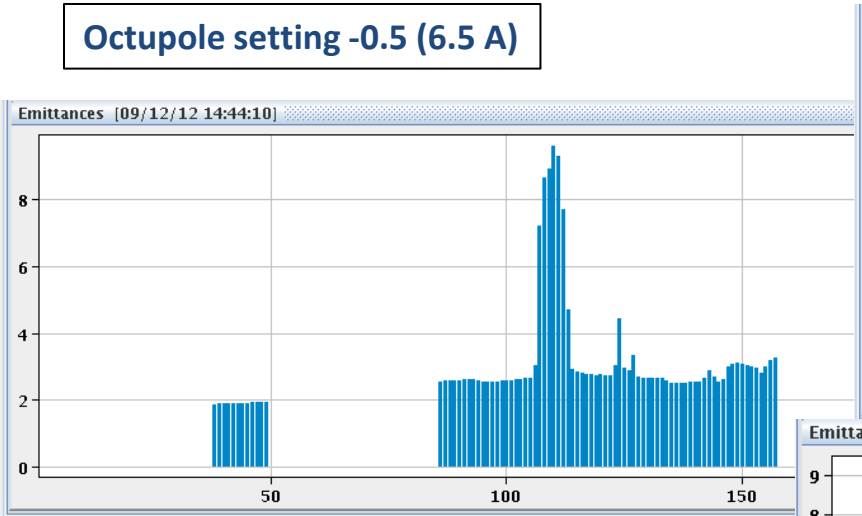

Fill. 3391 started on Fri, 07 Dec 2012 08:03:00
1e14
Tot. int. [p+]
1e4
Pow. loss [W]
1e4
Pow. loss [W]
Ratio,En.[TeV]

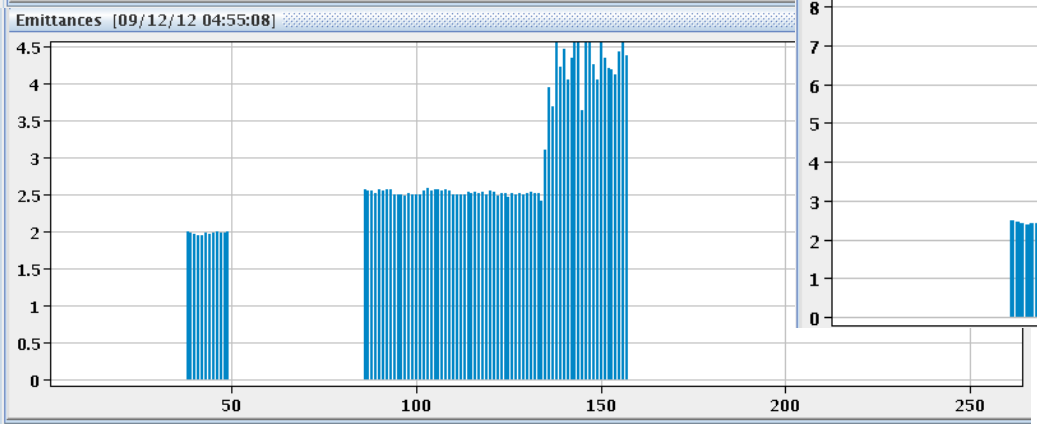

Fill. 3429 started on Thu, 13 Dec 2012 18:16:50
1e14
Tot. int. [p+]
1e4
Pow. loss [W]
1e4
Pow. loss [W]
Ratio,En.[TeV]

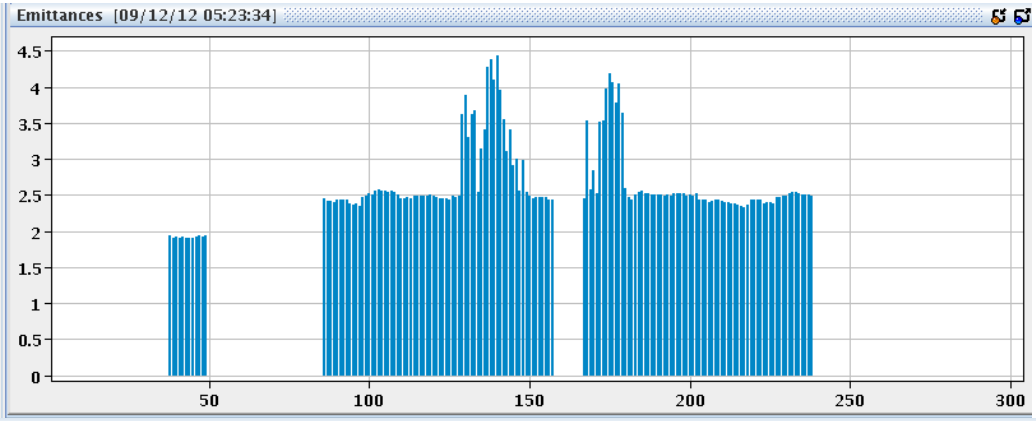

(Power loss from phase shift)/(Heat load)
2.50
2.00
1.50
1.00
0.50
0.00
Ratio
3380
3390
3400
3410
3420
3430
3440
3450
3460
Fill number
Flat bottom
Flat top

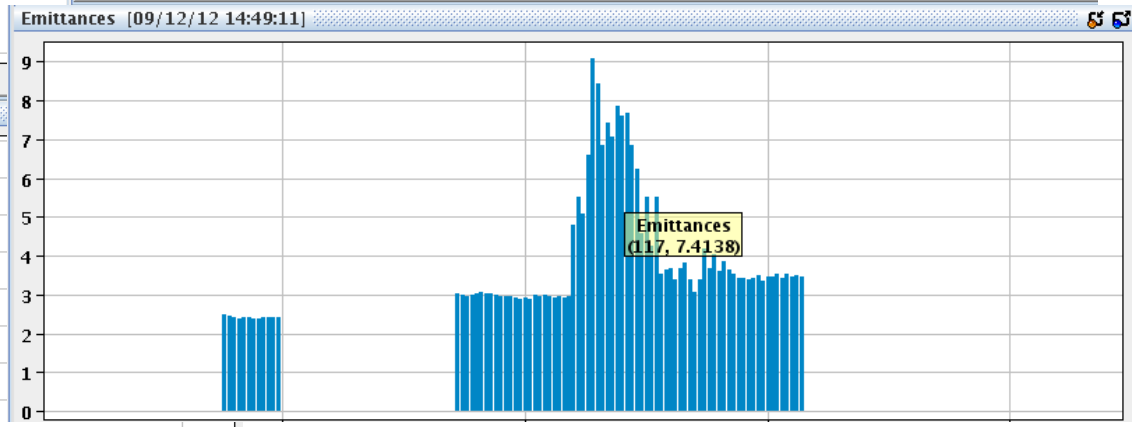
- **Important transverse emittance blow up**
  - → Typically affecting only some bunches of the first injected train
  - → Seen with BSRT, confirmed with WS, both planes
  - → Corrected by increasing the octupole current (setting to -2 → 26 A)

Octupole setting -0.5 (6.5 A)



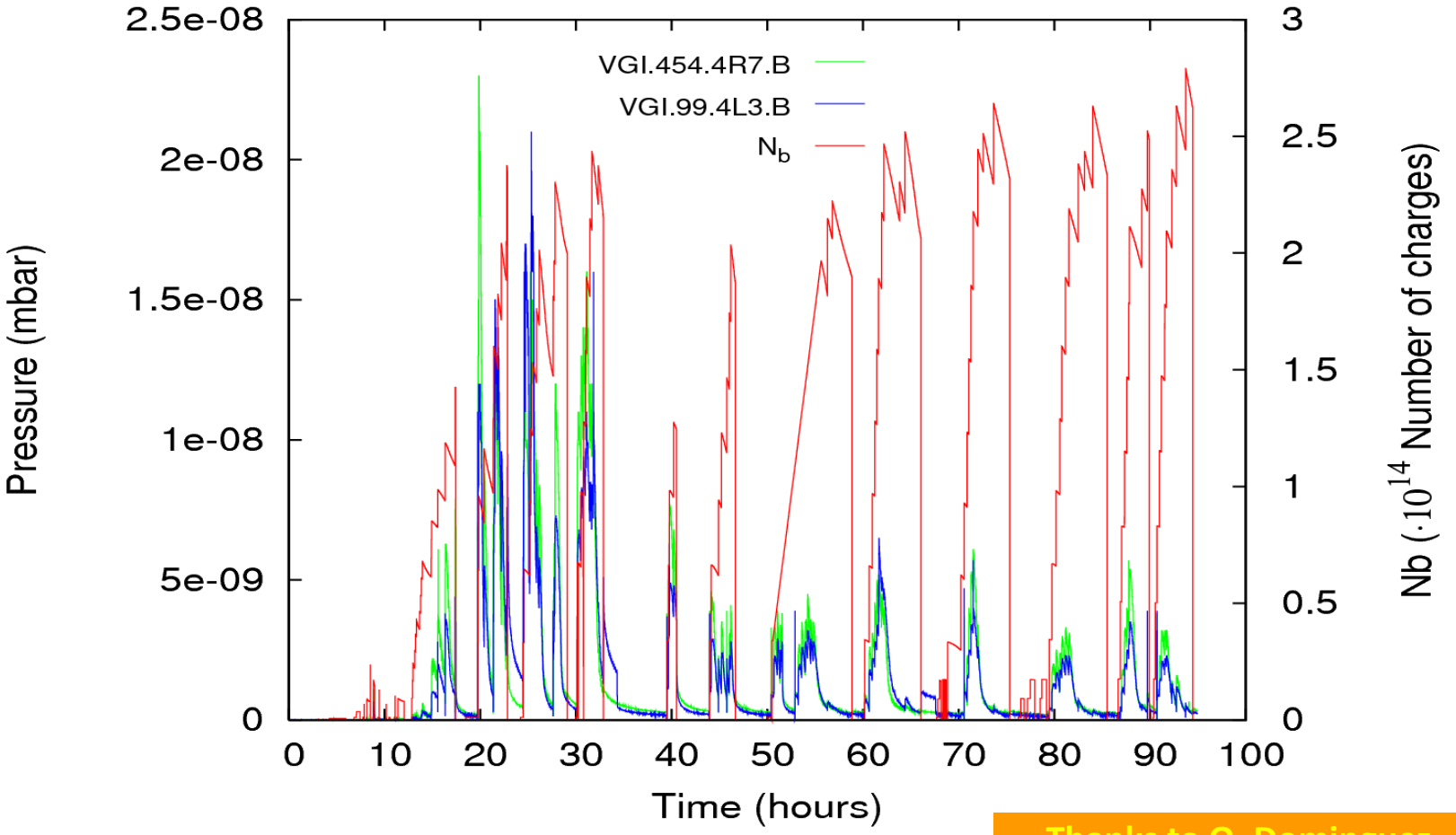






Vacuum evolution (I)

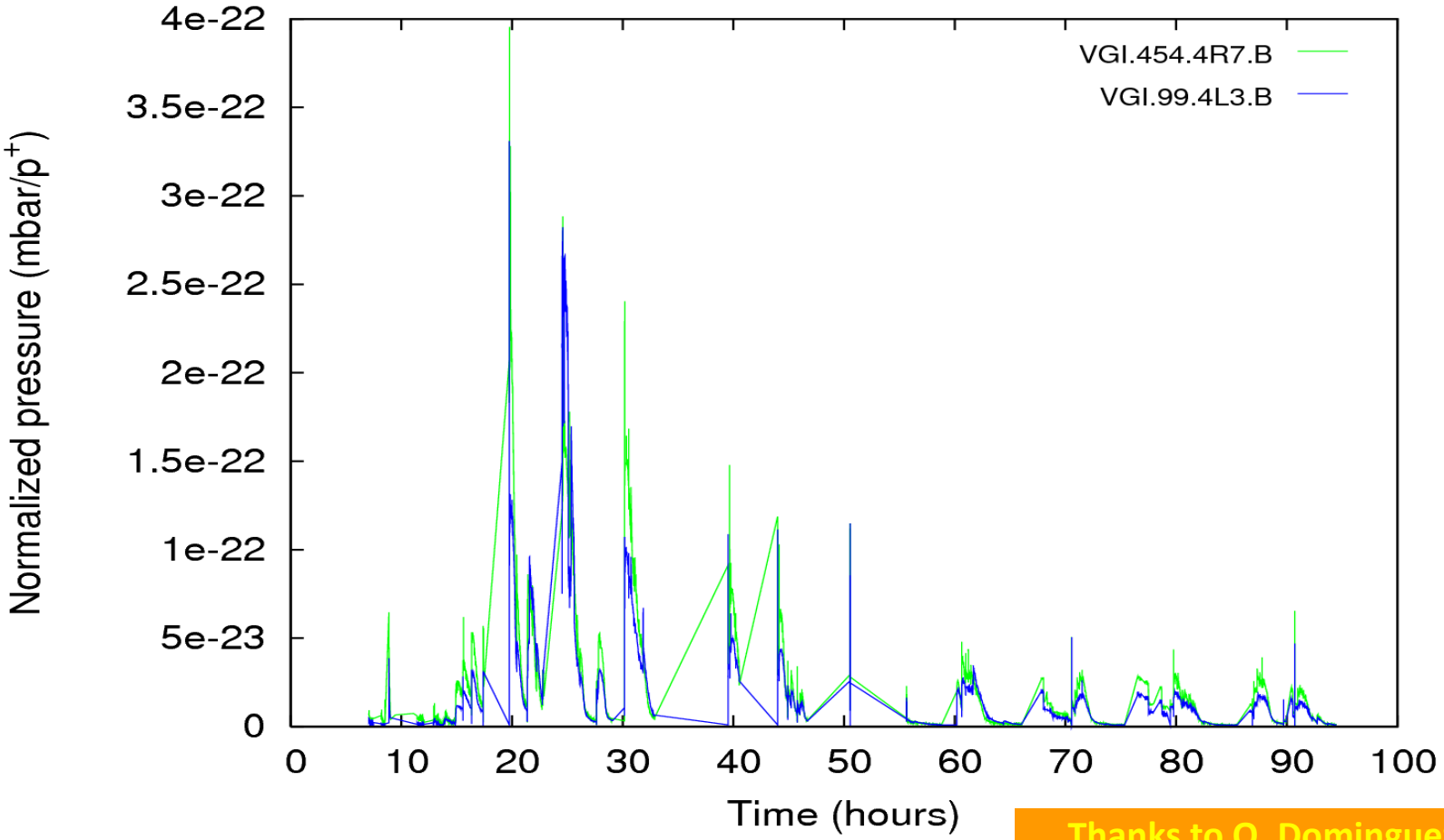
- **Significant improvement seen in the** vacuum (pressure gauges used for the SEY analysis in the LSS).



Thanks to O. Dominguez, V. Baglin

Vacuum evolution (II)

- **Clearer trend in terms of normalized pressure**(pressure gauges used for the SEY analysis in the LSS).



Thanks to O. Dominguez, V. Baglin