Electron cloud and scrubbing in the LHC

G. Arduini, H.Bartosik, G. Iadarola, G. Rumolo

Many thanks to:
Many thanks to Cryogenics, Damper, EN/STI, Injection, Operation, Vacuum teams
Several ABP, BI and RF colleagues contributing to measurements

LHC Operation Meeting, Evian, 19/12/2012

Outline

- Introduction on electron cloud (EC) and scrubbing effects
- EC effects in the LHC: 50ns vs. 25ns
- Experience with 25ns beams:
  - Observations in 2011
  - The 2012 Scrubbing Run (450GeV)
  - 25ns beams at 4TeV
- Scenarios for post-LS1 operation
- Conclusions

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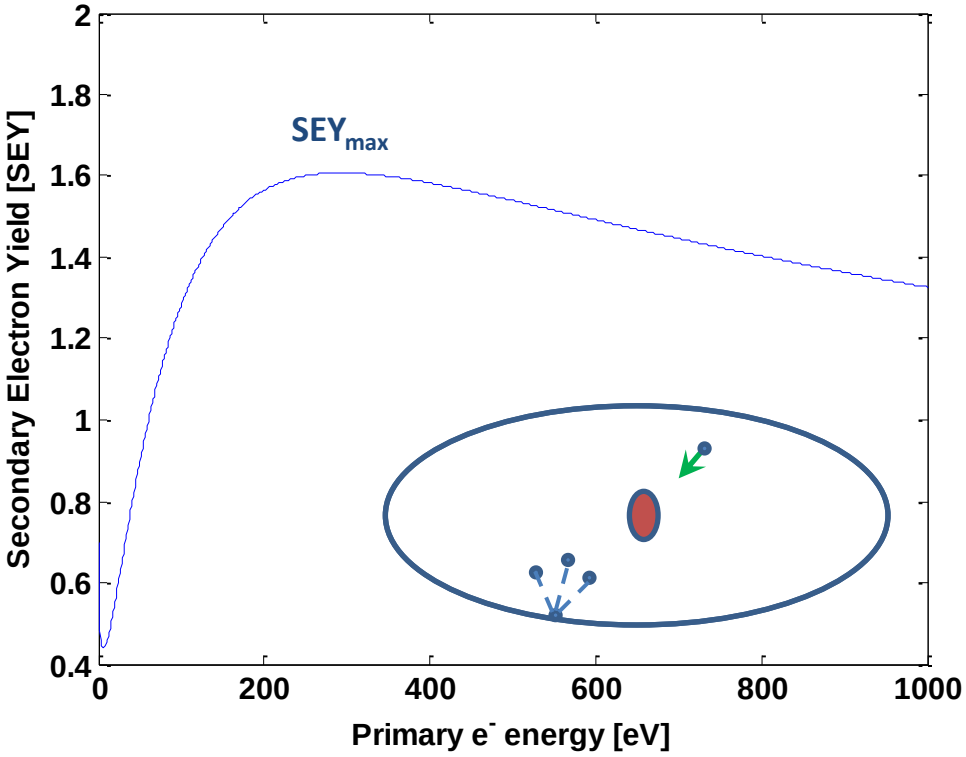
When the an accelerator is operated with close bunch spacing an **Electron Cloud (EC)** can develop in the beam chamber due to the Secondary Emission from the chamber's wall.



Secondary Electron Yield (SEY) of the chamber's surface:

- ratio between emitted and impacting electrons
- function of the energy of the primary electron

Introduction

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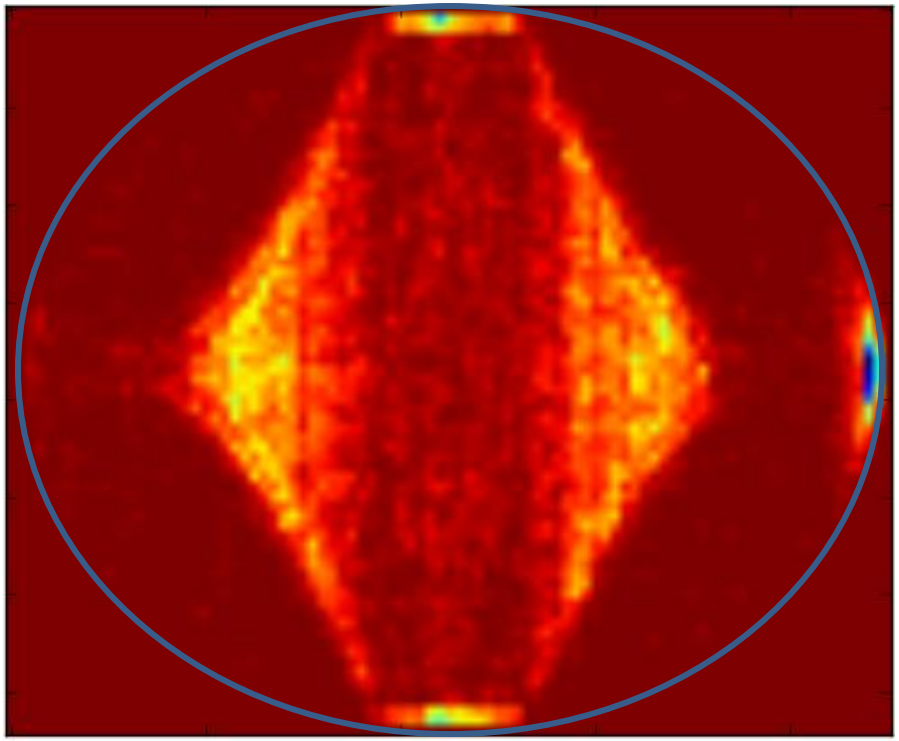
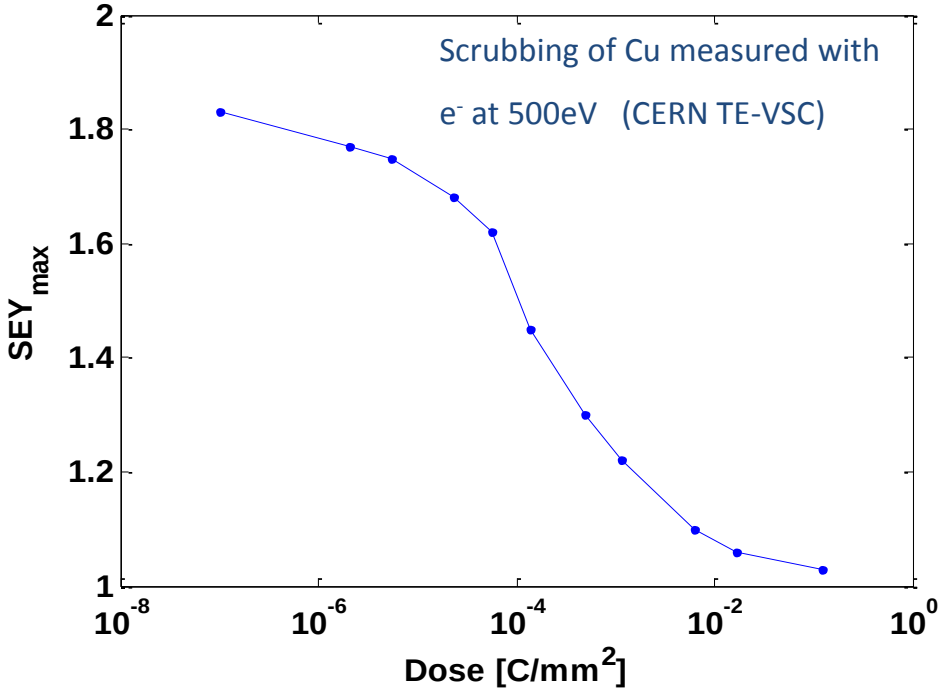
Dipole chamber @ 7TeV



- **Strong impact on beam quality** (EC induced instabilities, particle losses, emittance growth)
- **Dynamic pressure rise**
- **Heat load** (on cryogenic sections)

Introduction: electron cloud effects and scrubbing



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**

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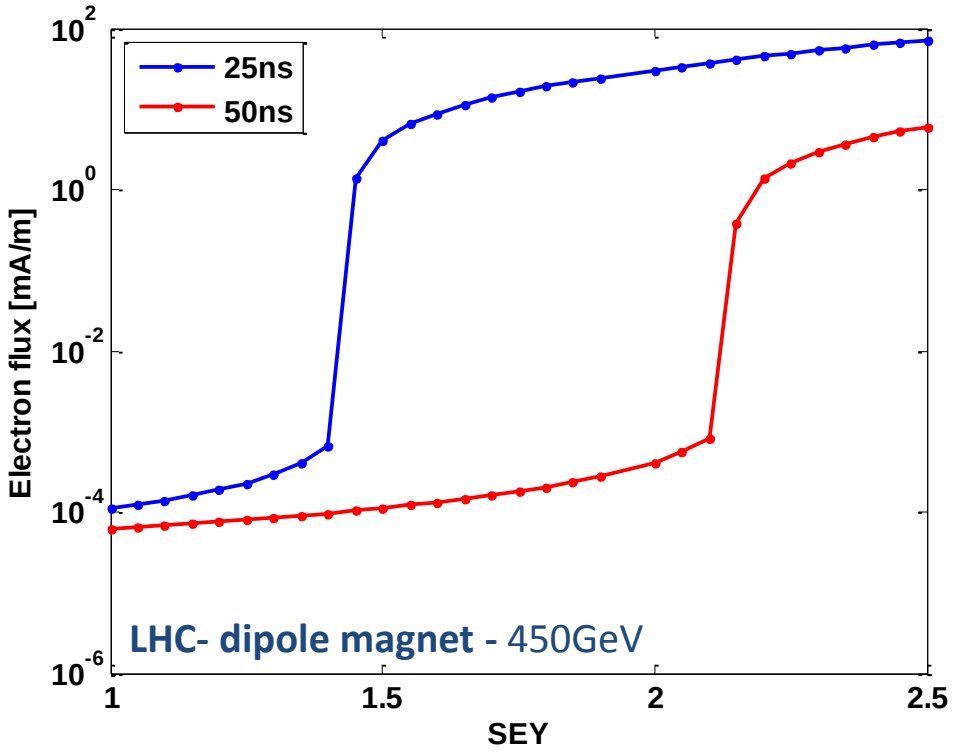
Electron cloud effects in the LHC dipoles: 50ns vs. 25ns

- **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

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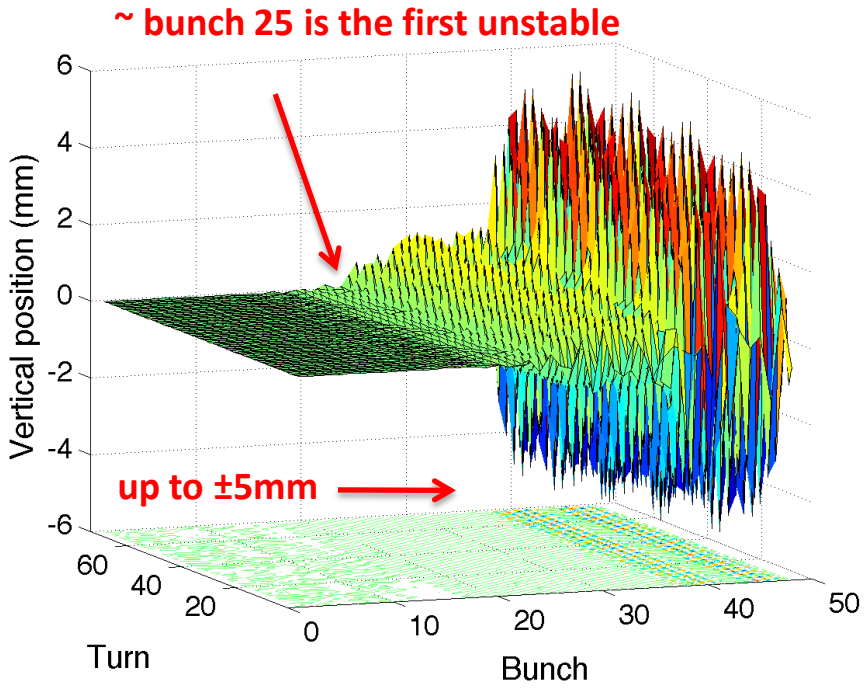
Electron cloud effects with 25ns: flashback into 2011

First injection tests with a train of 48b. on 26/08/2011:

- Beam **unstable** right after injection (dump due to losses)
- Probably driven **by e-cloud in the dipoles** (mainly vertical motion, trailing bunches of the train)
- Beam stable with **high chromaticity settings (Q'=15)**



Thanks to **W. Höfle** and **D. Valuch**

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- Probably driven **by e-** bunches of the train)
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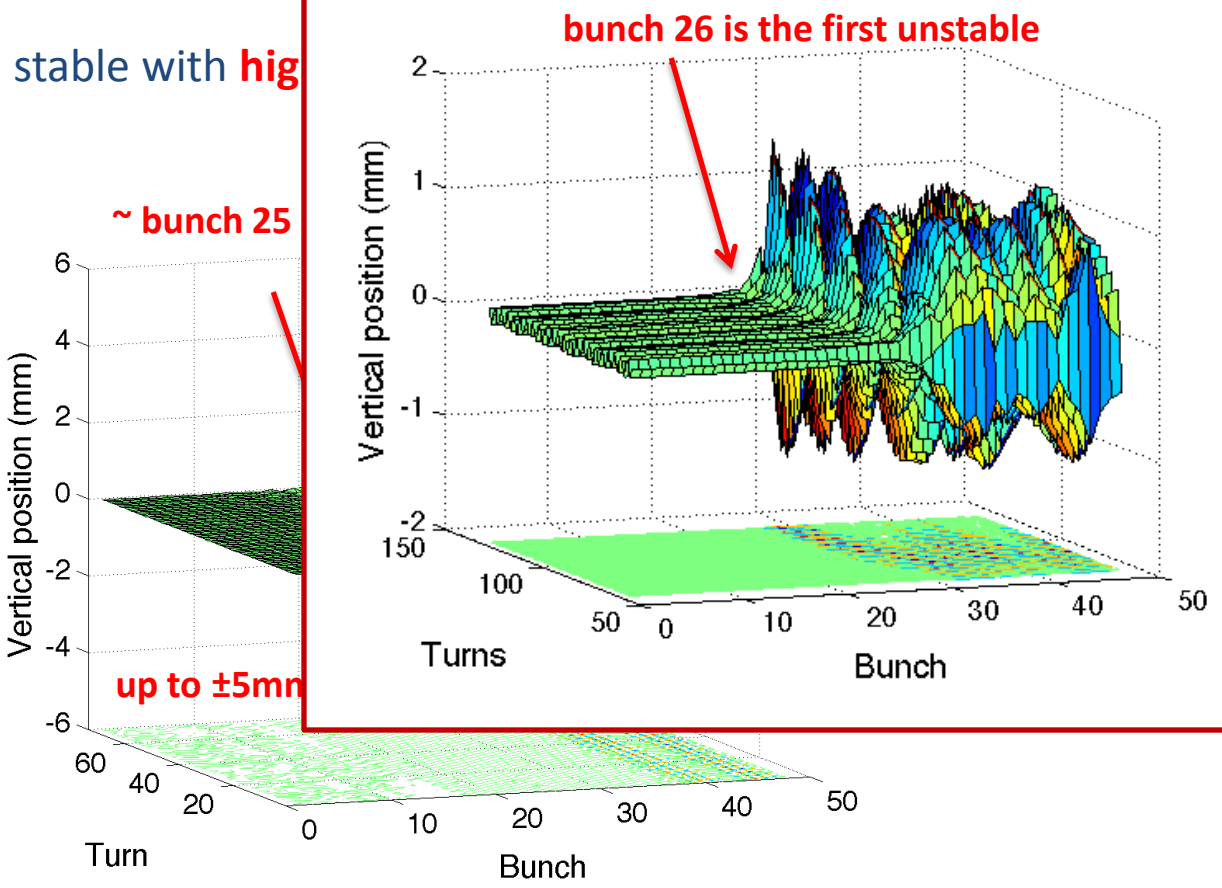
The instability could be **successfully reproduced in HEADTAIL simulations** (with electron distributions from PyECLOUD)



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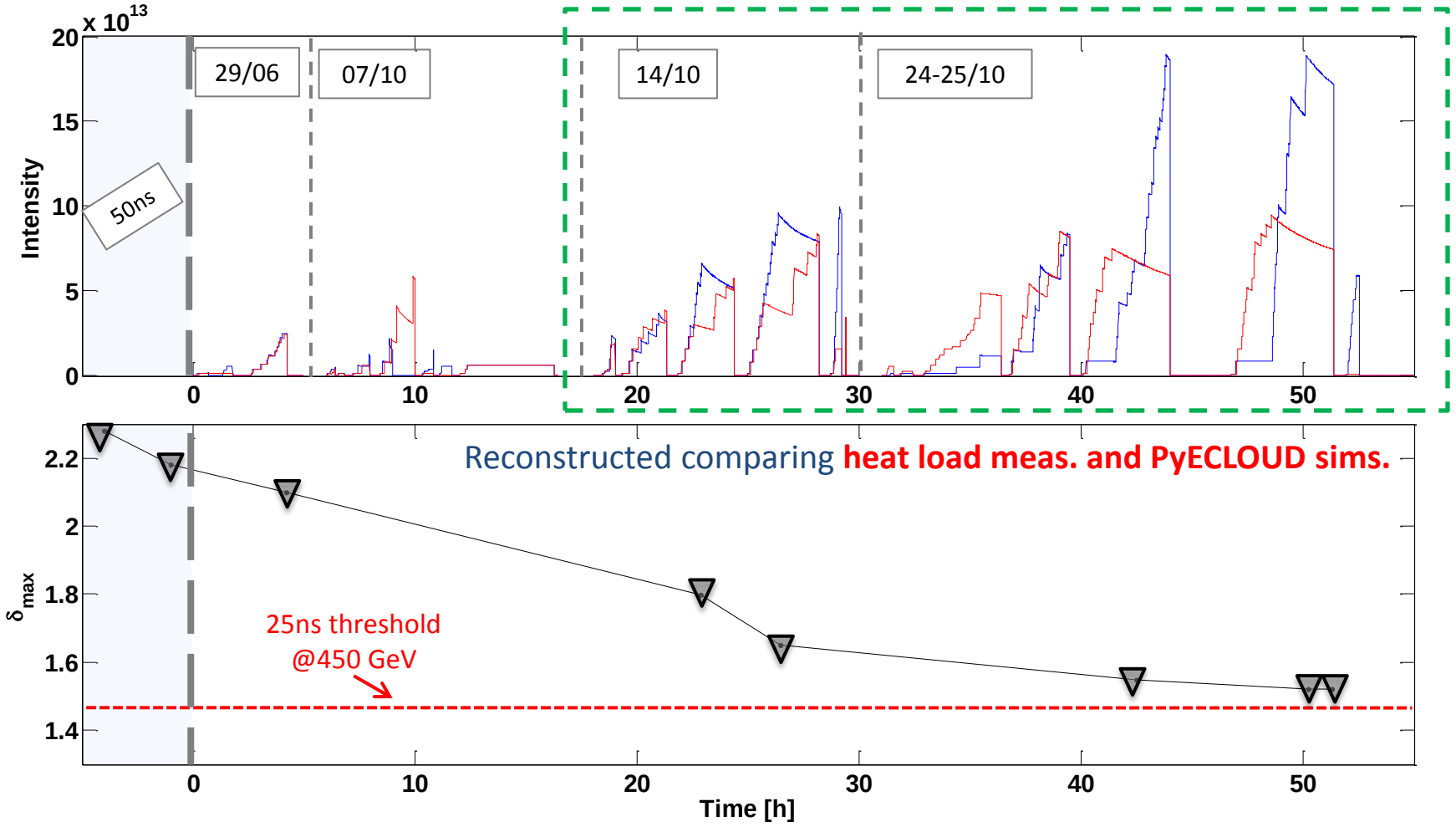
Electron cloud effects with 25ns: flashback into 2011

First scrubbing tests with 25ns (14 & 24-25 Oct. 2011):

- Injected up to **2100b.** for B1 and **1020b.** for B2
- SEY in the arcs could be decreased down to **1.52**



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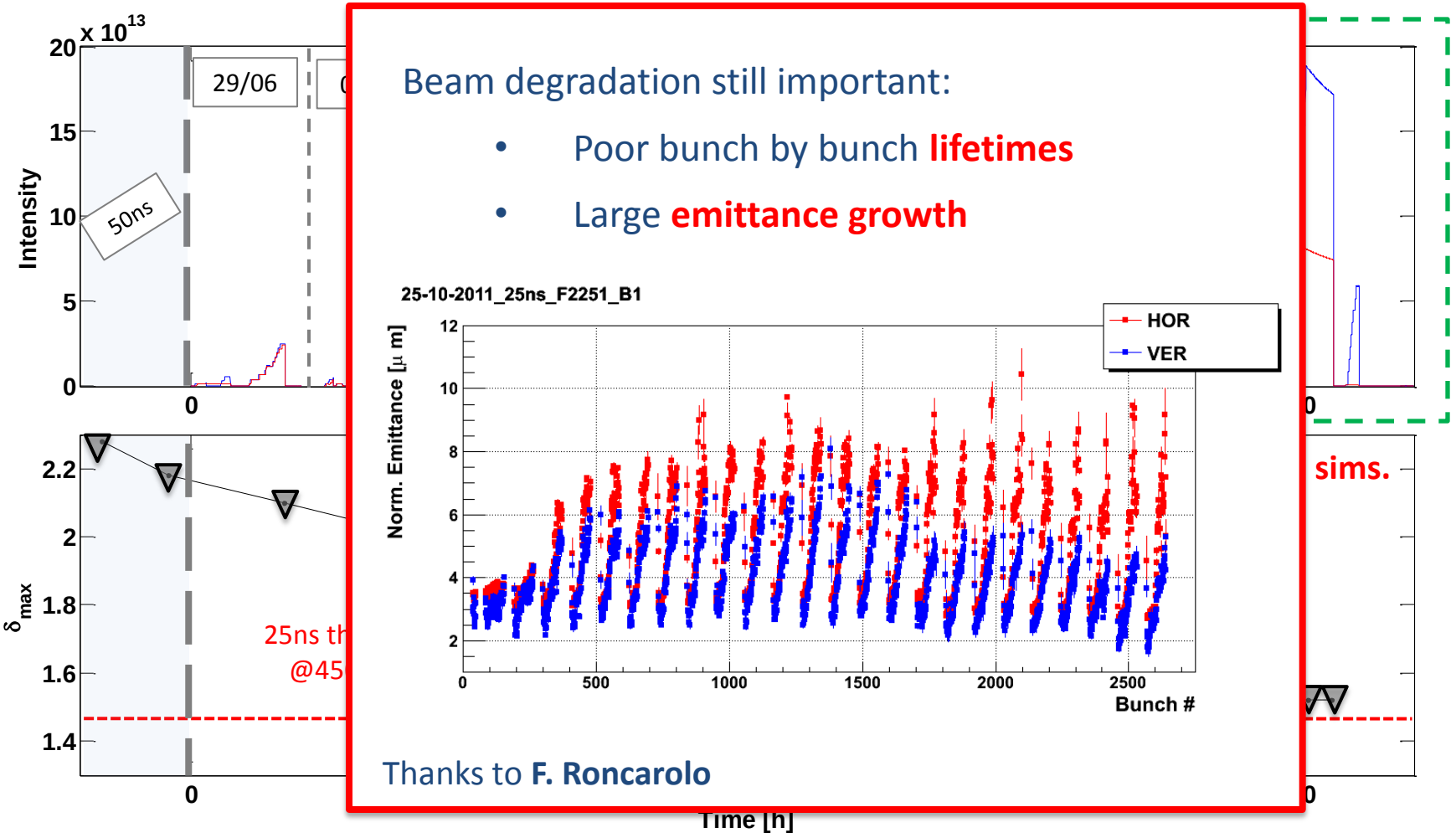

Beam degradation still important:

- Poor bunch by bunch **lifetimes**
- Large **emittance growth**

Thanks to **F. Roncarolo**

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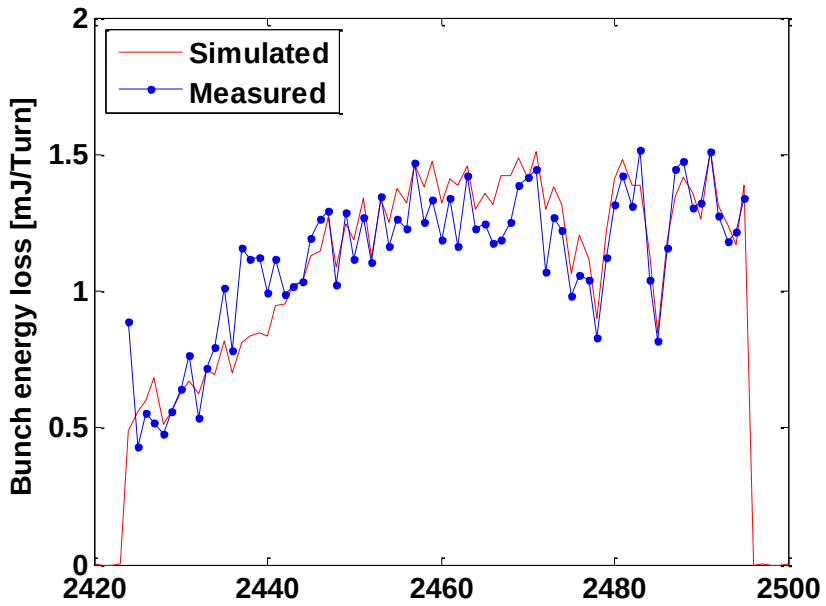
An important benchmark for our models came from **bunch by bunch energy loss estimation** based on **stable phase measurements.**



Thanks to **J. Esteban-Müller and E. Shaposhnikova**

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Preliminary!

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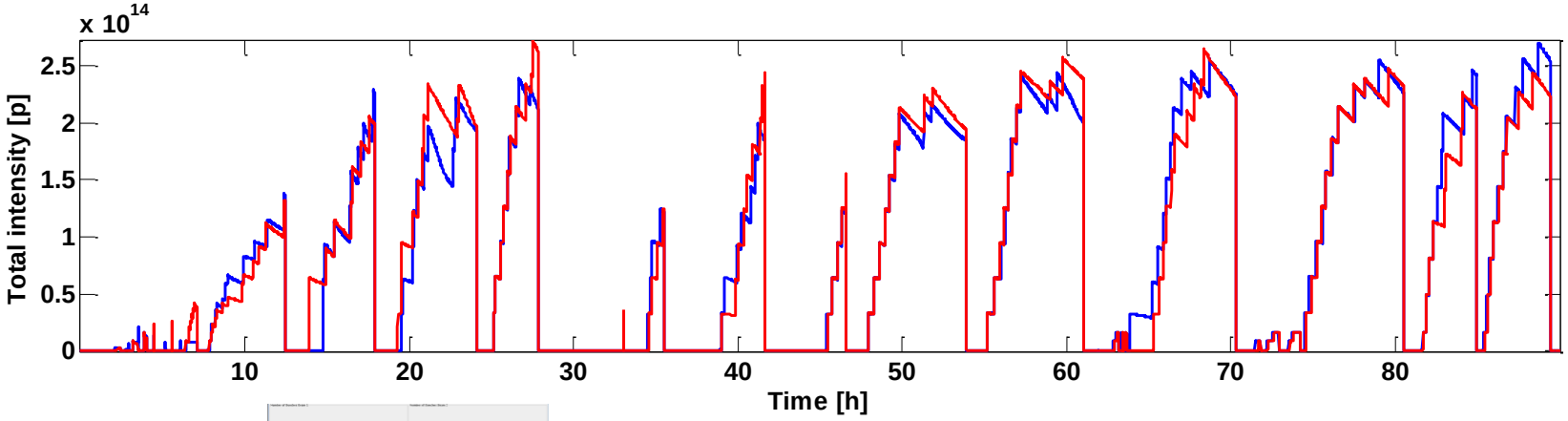
The 2012 scrubbing run

3.5 days of scrubbing with 25ns beams at 450GeV (6 - 9 Dec. 2012):

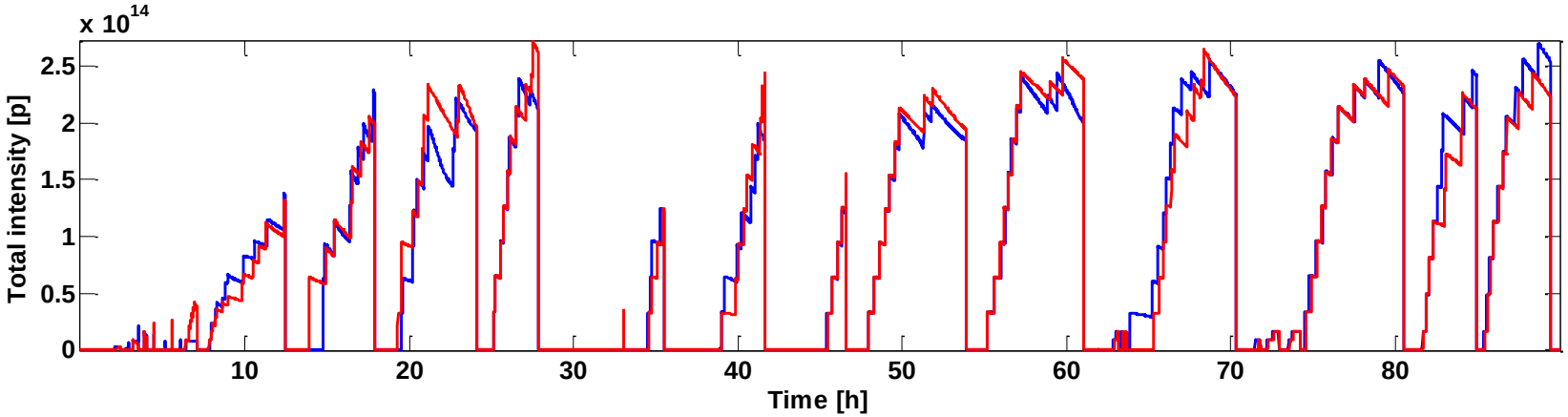
- Regularly filling the ring with up to **2748b.** per beam (up to **2.7×10^{14} p**)
- Overall **very good efficiency:** injection rate determined by MKI vacuum interlocks (in the beginning) and by time required by the cryogenic system to adapt to the increasing heat load (mainly in stand alones)

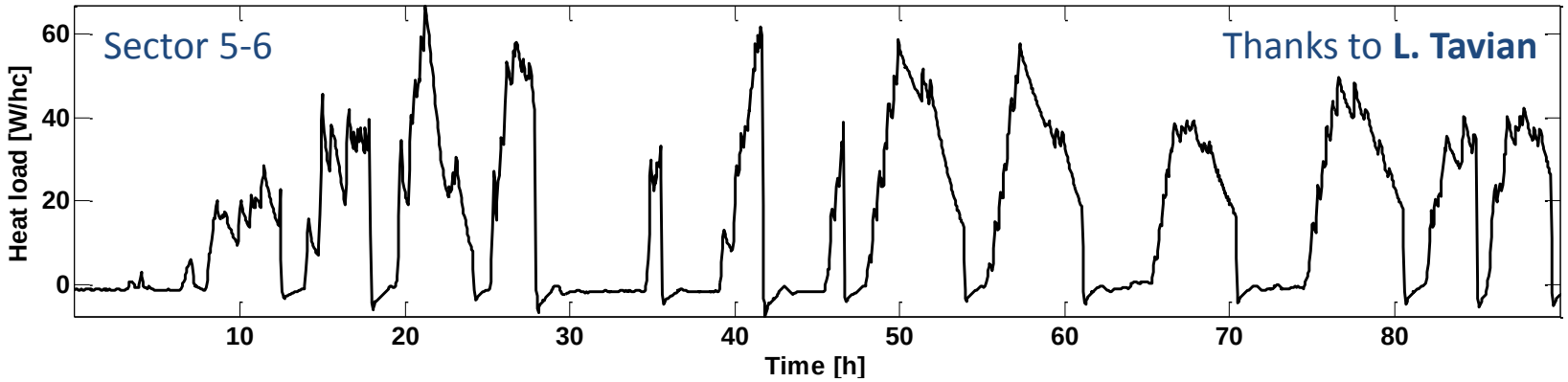


2748 2748

Scrubbing effects in the arcs:

- Quite **rapid conditioning observed in the first stages**
- The **SEY evolution significantly slows down** during the last scrubbing fills (more than expected by estimates from lab. measurements and simulations)





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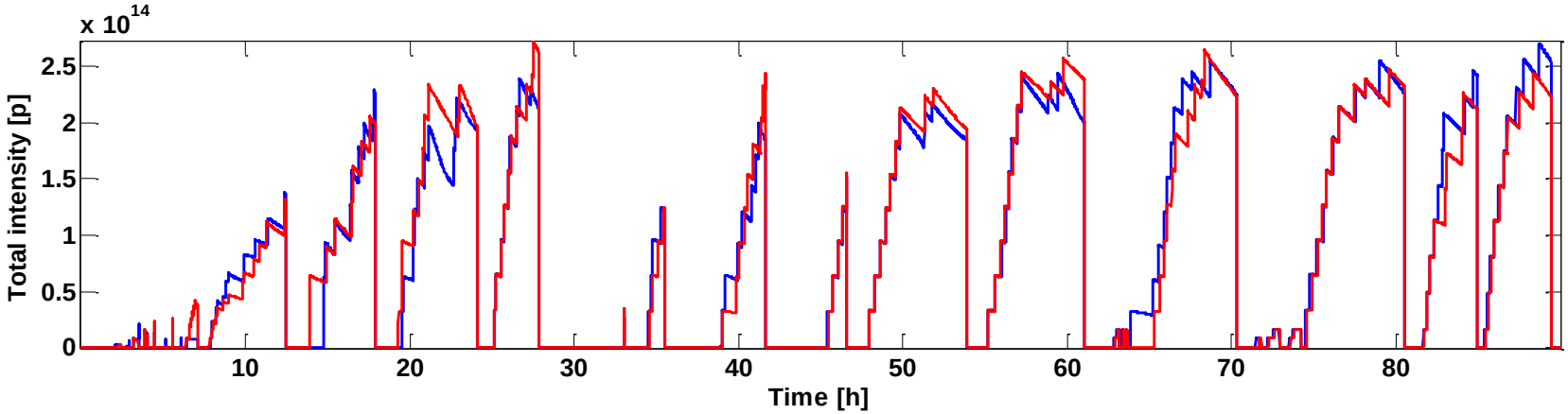

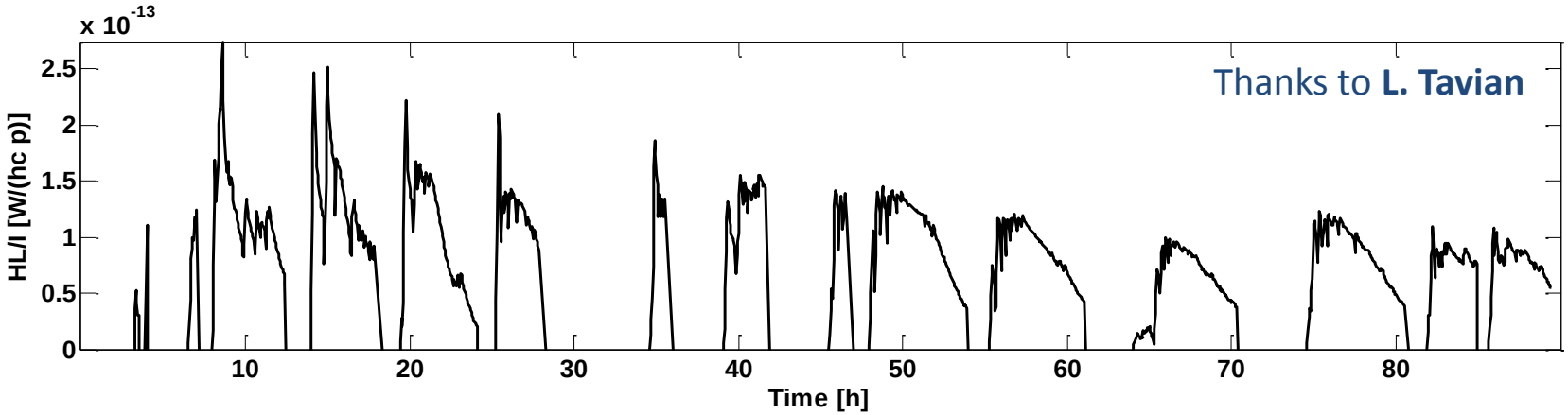

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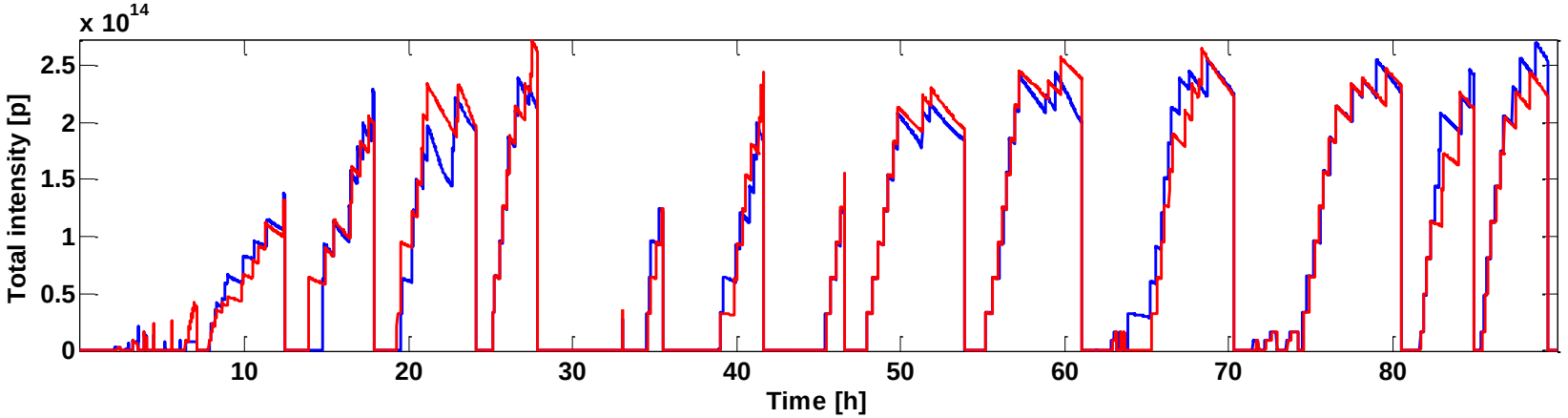

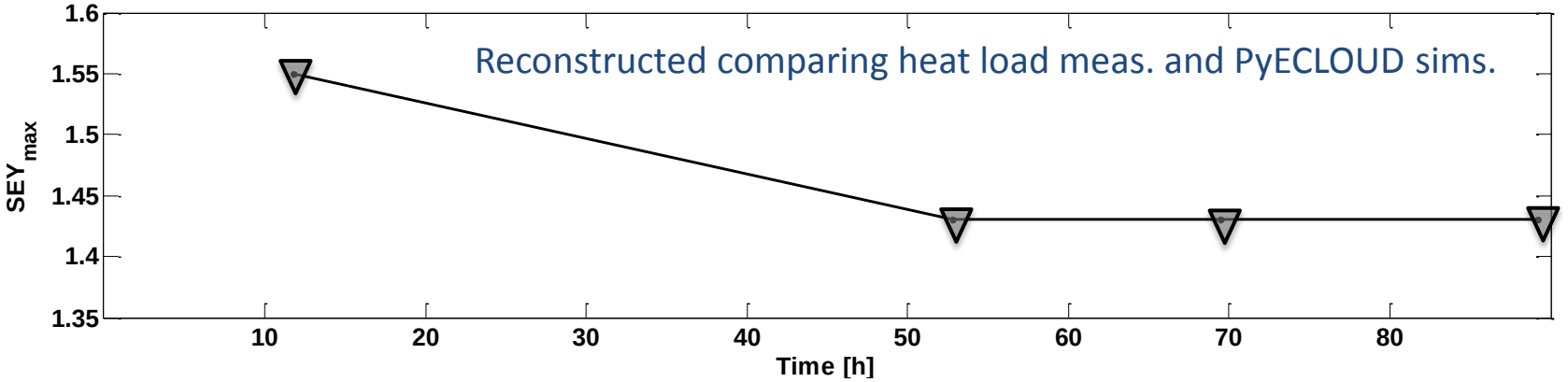

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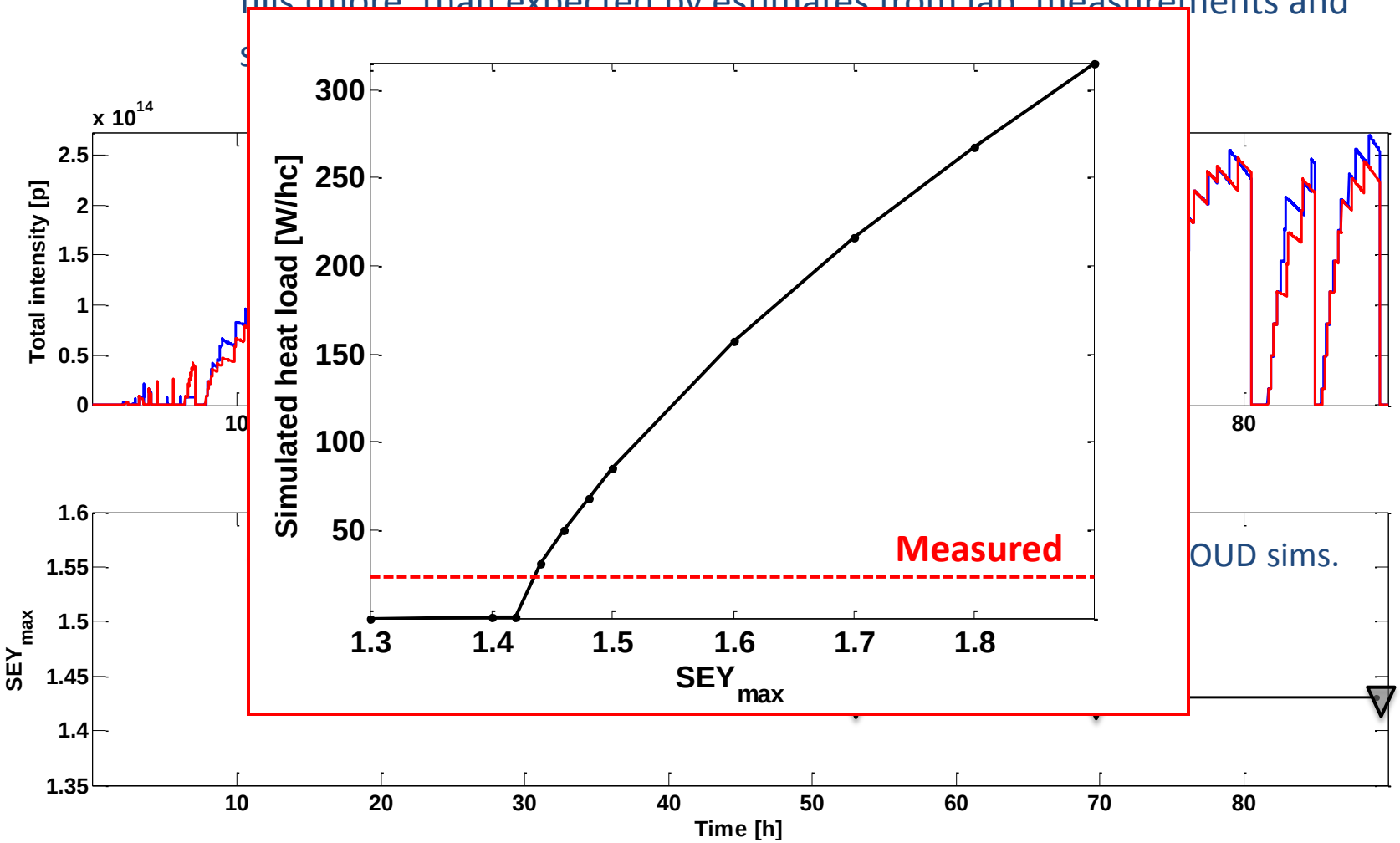
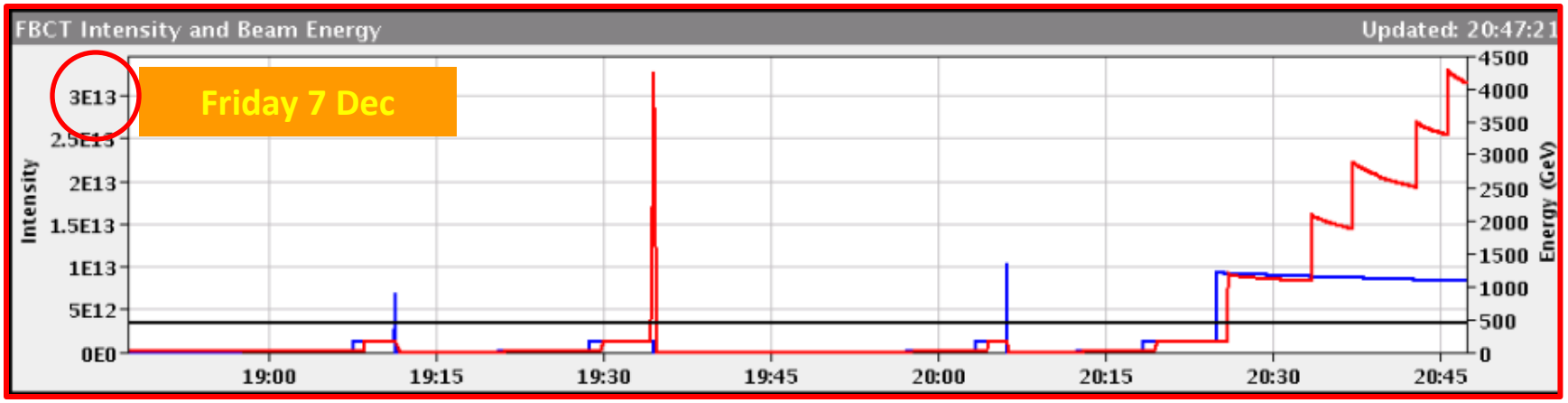
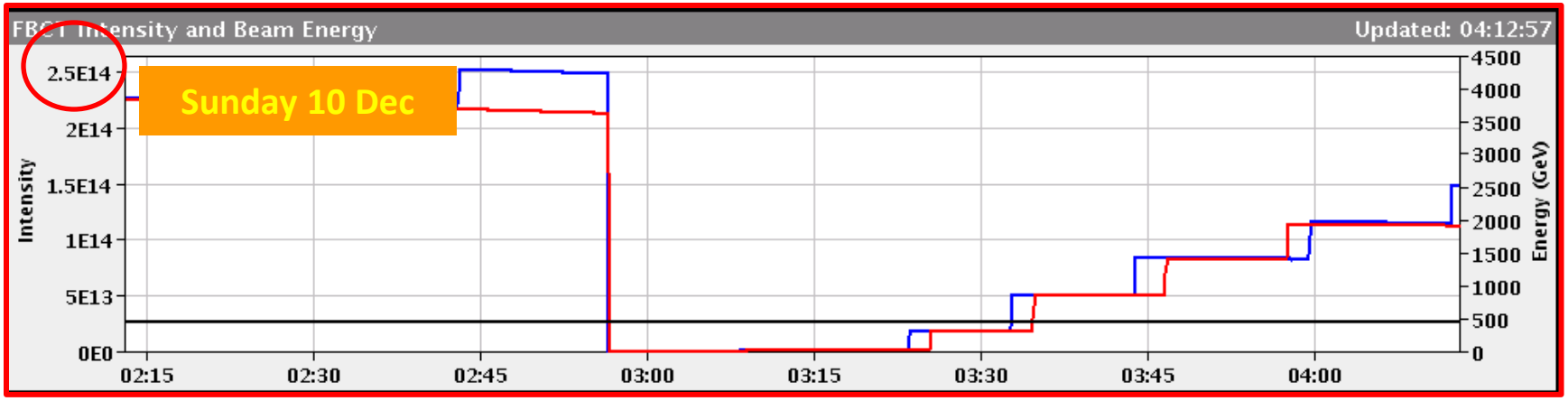


OUD sims.

Scrubbing effects:

- Evident improvement on **beam lifetime**





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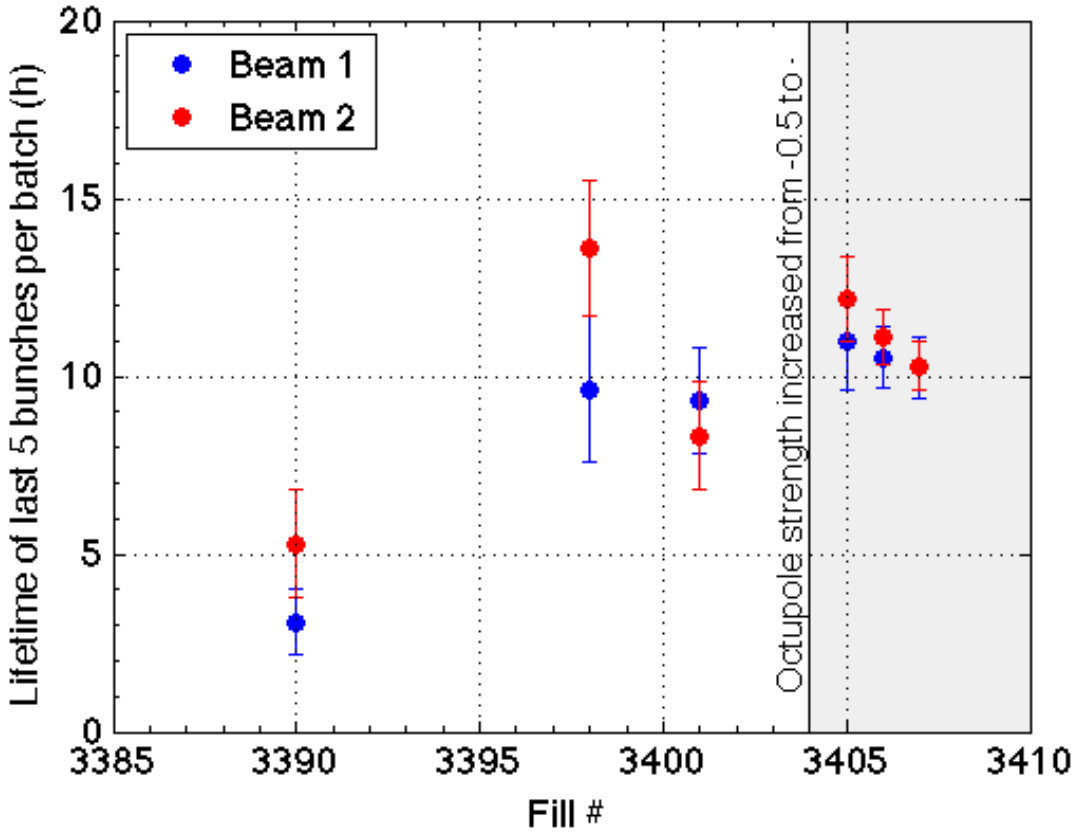

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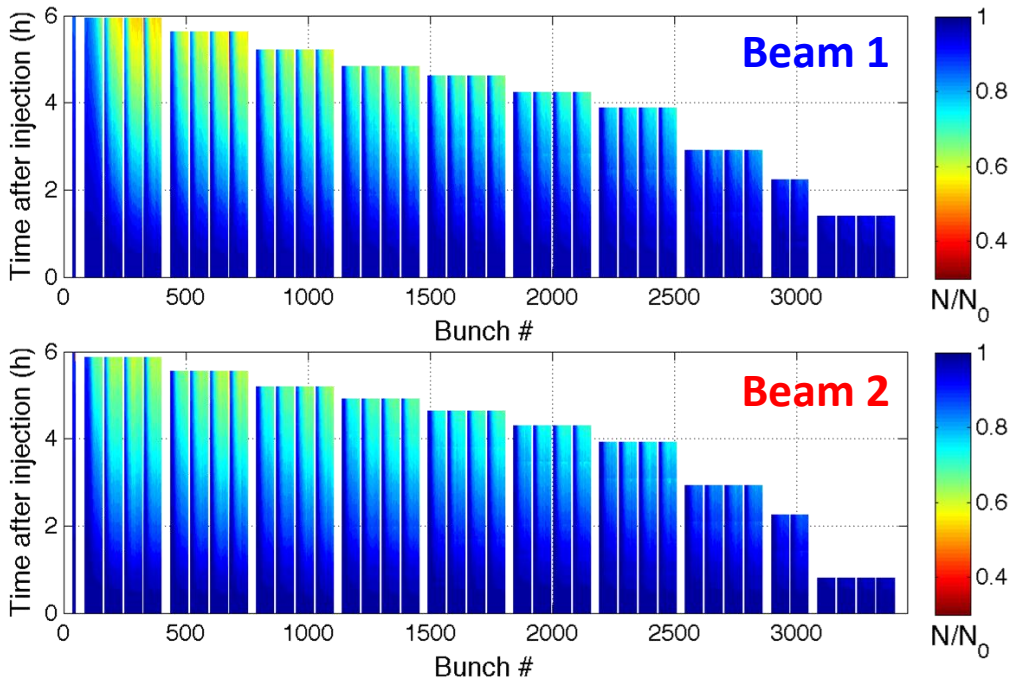
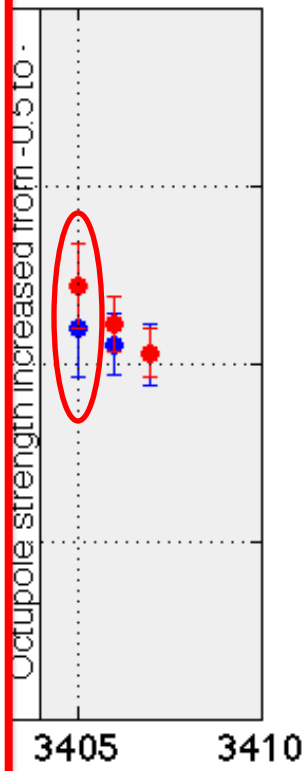


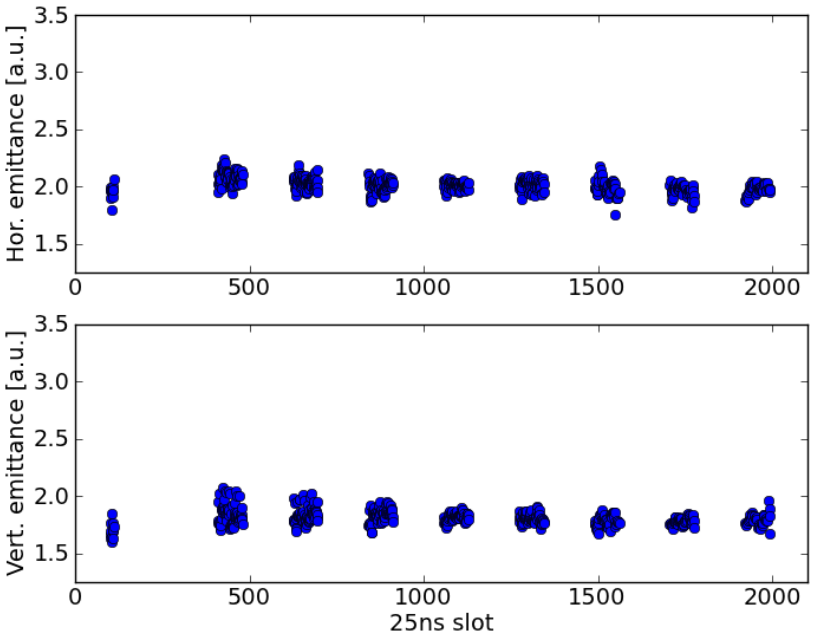
- Important losses do no appear **before 1h after injection**



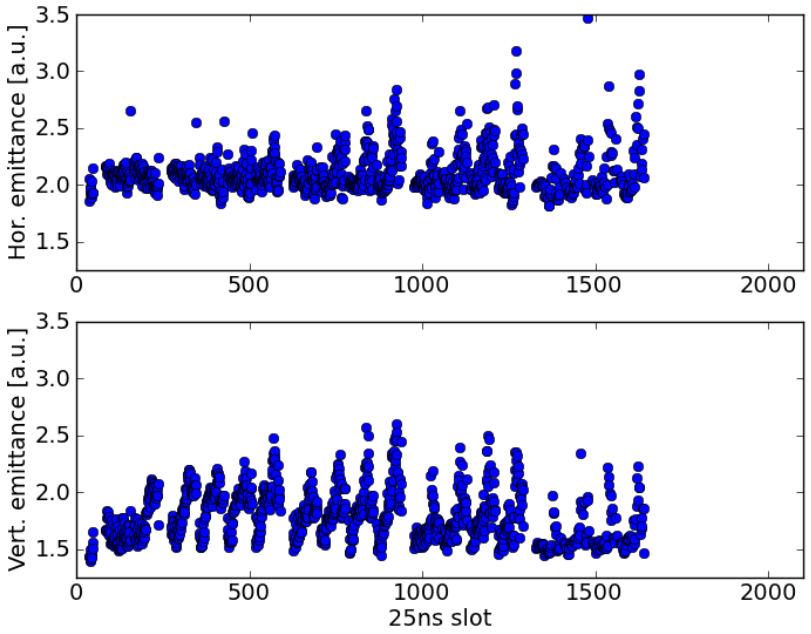
Scrubbing effects:

- Evident improvement on **beam lifetime**
- After the scrubbing, **emittances** are ok for trains of 72b. (3.6μs spacing) but a significant blow-up is still visible when longer trains are injected

Fill with trains of 72b.



Fill with trains of 288b.



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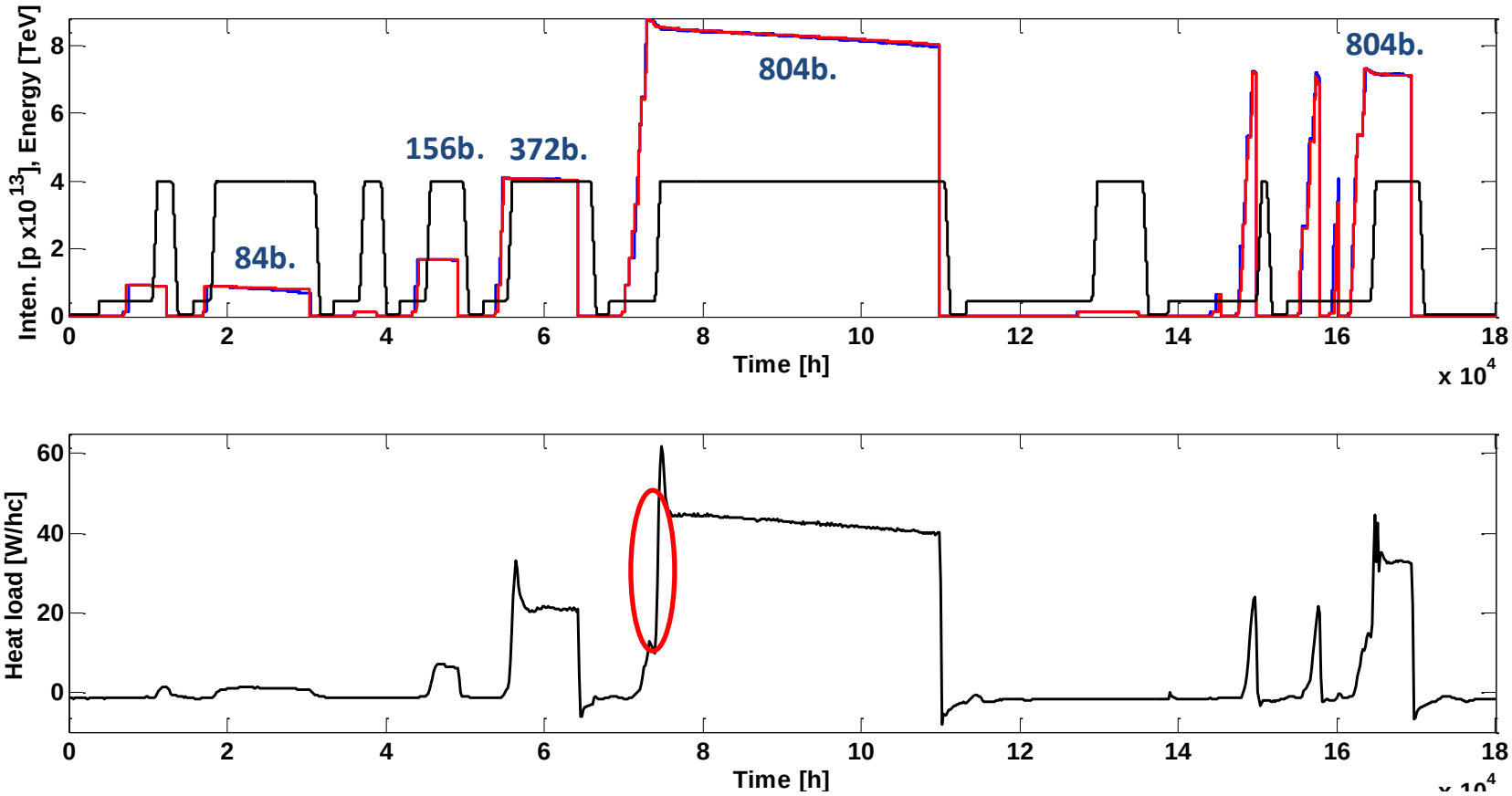
Electron cloud observations at 4TeV

After Scrubbing Run **machine studies with 25ns beams at 4TeV were possible**. Main observations:

- The heat-load strongly increases during the ramp since the **EC is enhanced by the photoelectrons** due to synchrotron radiation → This violent **transient on the heat load in the arcs** limits the number of bunches which can be accelerated



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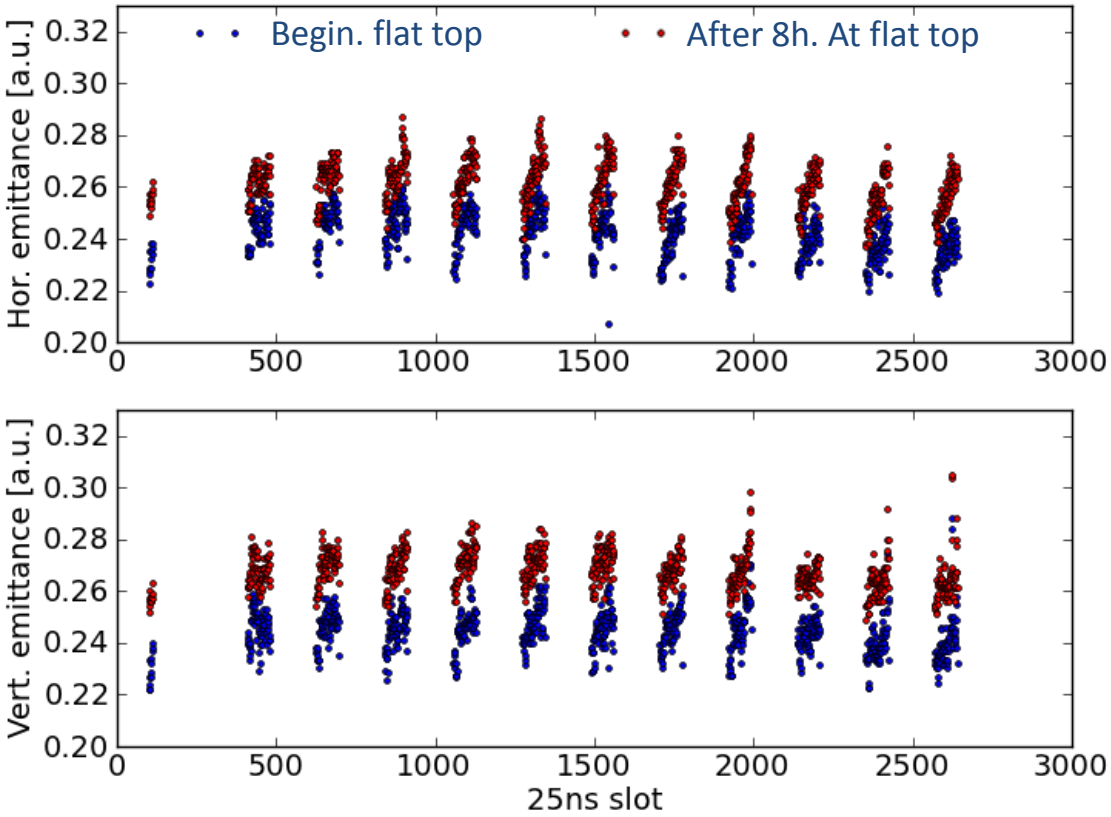
Main observations:

- Despite the larger number of electrons, at high energy the beam becomes **less affected by EC** → the beam quality achievable at collisions is determined by the EC effects at 450GeV



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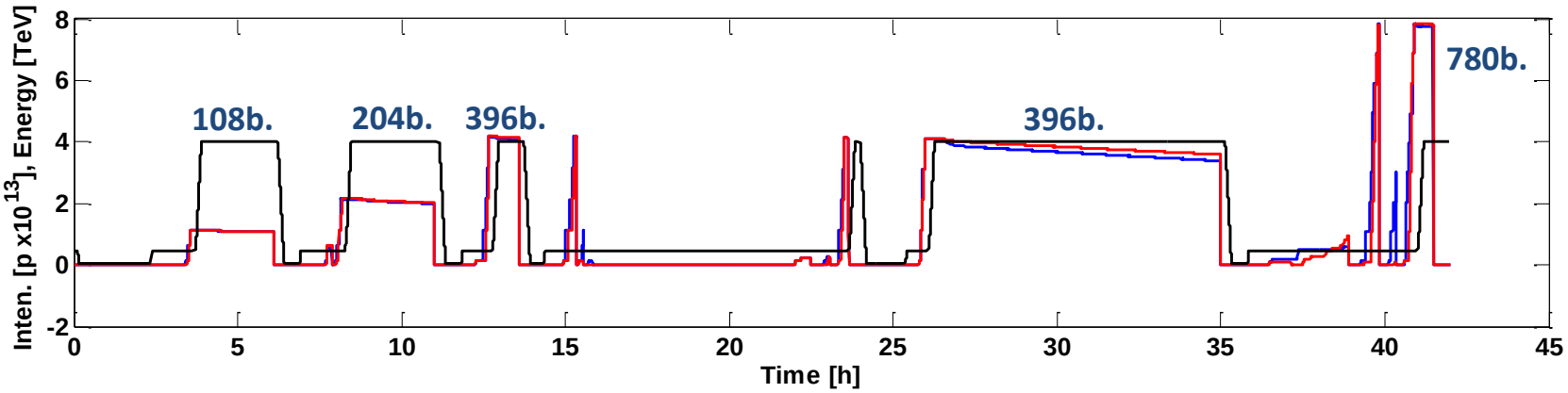
Electron cloud observations at 4TeV

A **pilot physics run** with 25 ns beams took place in the last two days of the 2012 run:

- High brightness **BCMS 25ns beam** from the injectors (batches of 48 bunches 1.1e11ppb within transverse emittances of ~1.4µm)
- Stable beams with 396b. (squeezed up to 780b.)



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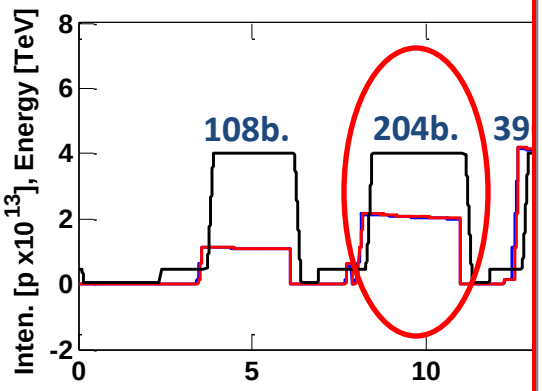
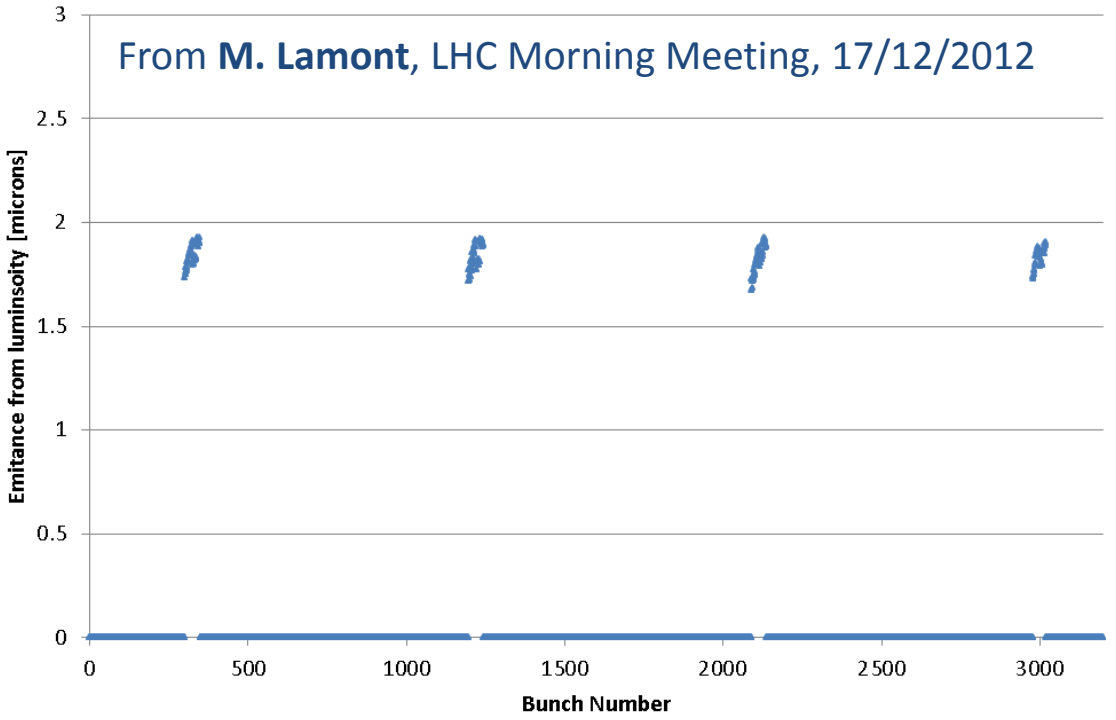


From **M. Lamont**, LHC Morning Meeting, 17/12/2012



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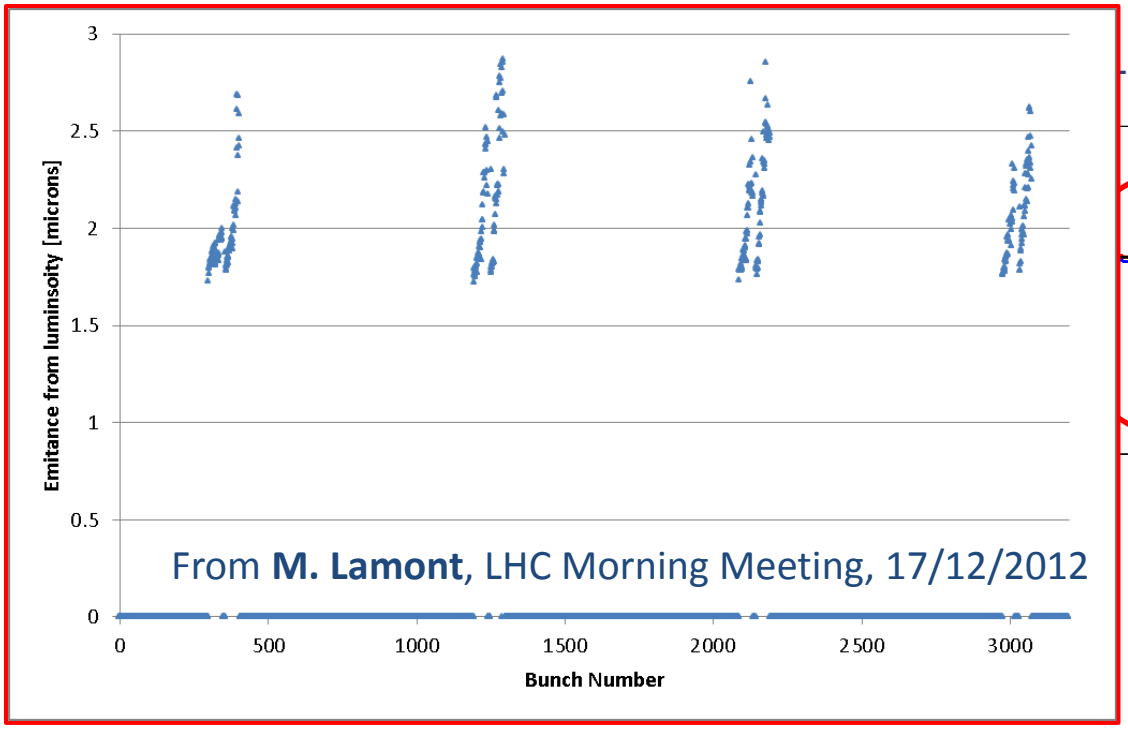

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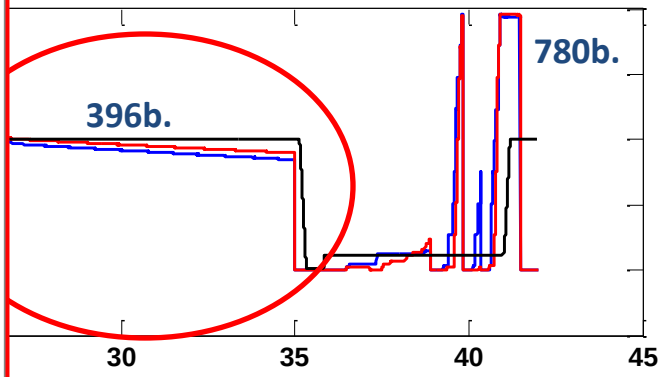

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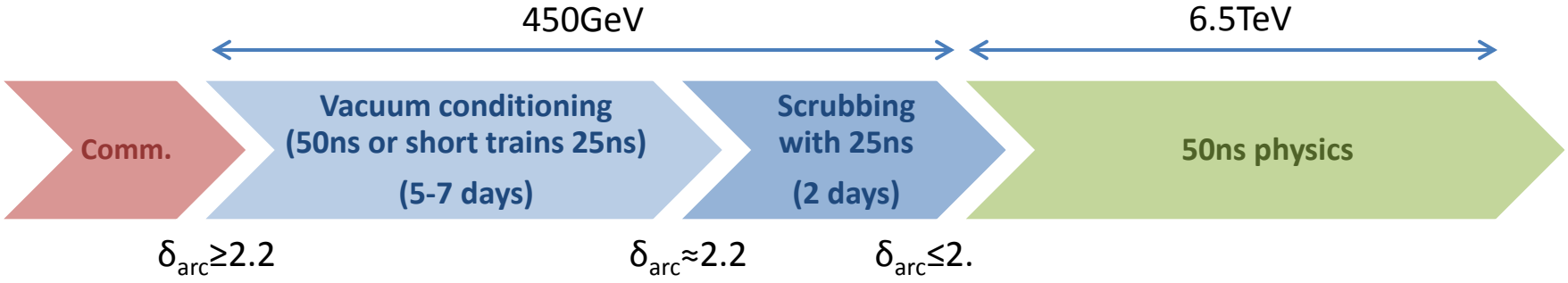
Possible scrubbing scenarios for 2015

Requirements for operation with 50ns beams:



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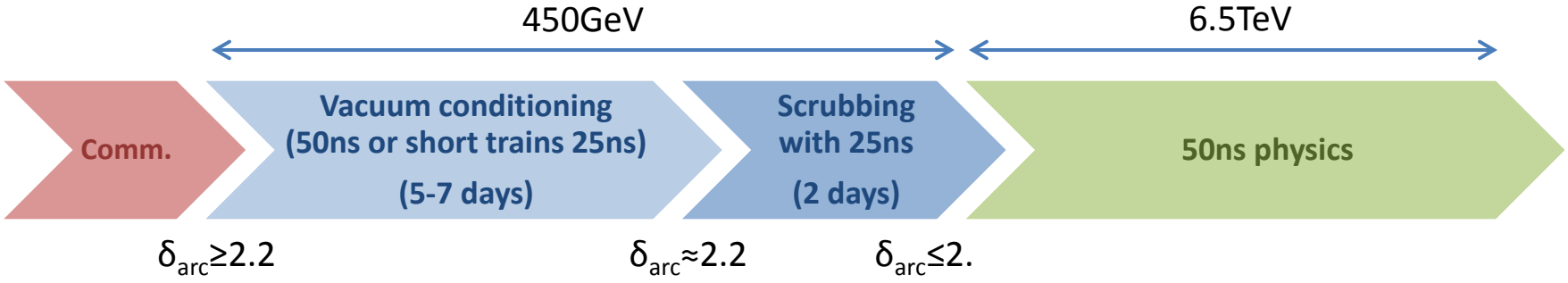
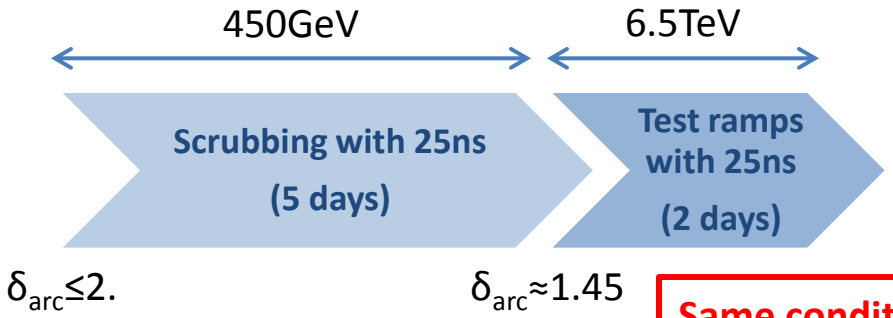


Further requirements for operation with 25ns beams:



Same conditions as in 2012 pilot physics run but with enhanced heat load due to higher energy

Possible scrubbing scenarios for 2015

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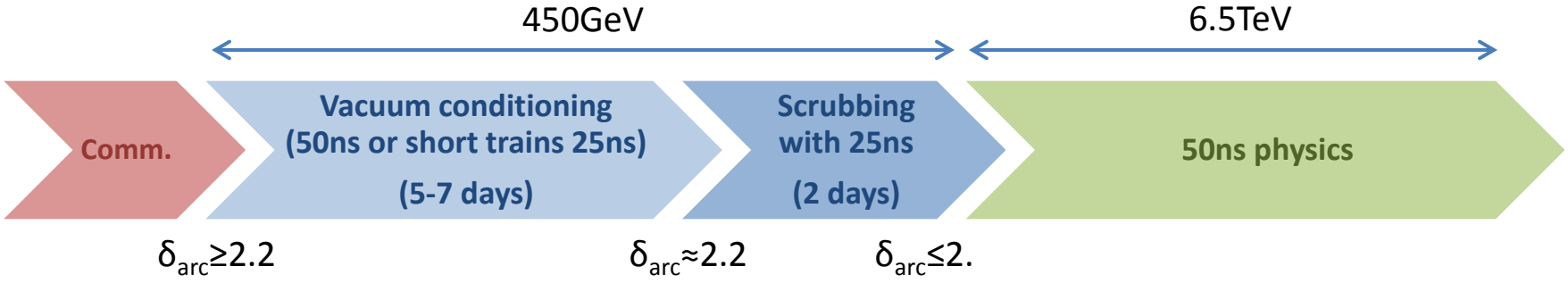

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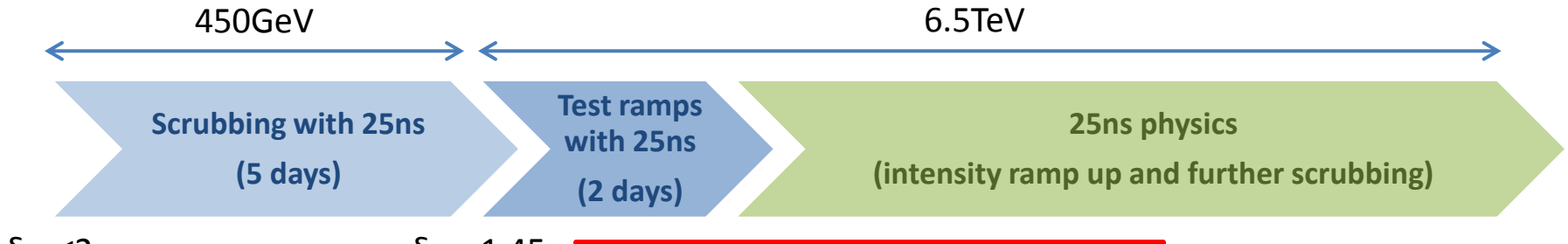

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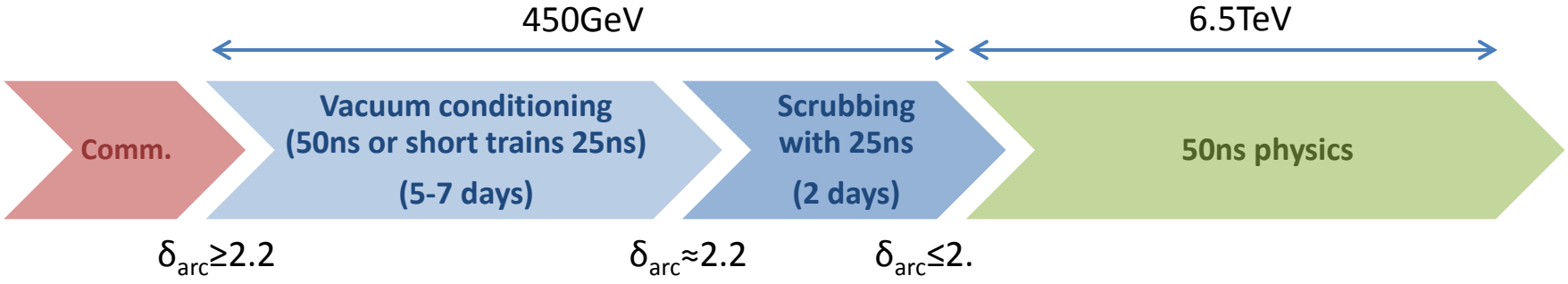

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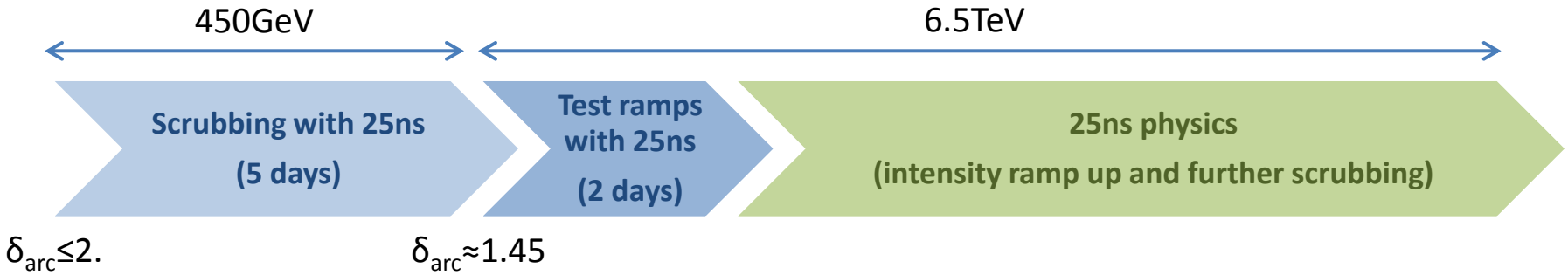


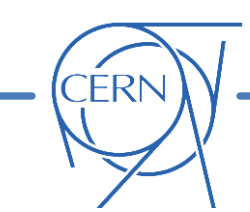
Remark:

In case of long periods without beam **de-conditioning** is likely to take place:

- **No action needed for 50ns beams** (due to margin taken by scrubbing with 25ns beam)
- **Few hours reconditioning required for 25ns beams**

Summary

- The 2012 Scrubbing Run has lowered the **SEY in the arcs to less than 1.45** resulting in a **reduced heat load** as well as **improved beam quality** (lifetime, emittances)
- In spite of the high heat loads, close to the cryogenics limit, **the second part** of the Scrubbing Run and the ramps to 4 TeV **did not exhibit any clear improvement** in the conditioning state of the arcs (to be investigated with additional simulations and lab measurements)
- **Emittance blow-up ascribable to EC is still observed** at injection energy with **long and closely spaced trains**
- **At 4TeV, no indication of further emittance deterioration** driven by EC
- A concentrated scrubbing run will be likely to **be insufficient to fully suppress** the EC from the arcs for 25ns beams in future operation.



Thanks for your attention!