Electron cloud report

22nd August 2011

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with contributions from G. Arduini, V. Baglin, S. Claudet, E. Metral and F. Zimmerman

Main topics

- Introduction

- Scrubbing run

- 50 ns beams in Physics

- Other vacuum induced effects

- Perspectives and limitations

- Closing remarks

Introduction

Introduction

- The electron cloud build-up:

Is a threshold phenomenon → bunch population
Is a threshold phenomenon → number of bunches in the train → Linear build-up

Is attenuated by the spacing between bunches and bunch trains and by satellite bunches

Depends highly on the Secondary Electron Yield (SEY): δ_{max}, $E_{\delta max}$, reflectivity

Is enhanced by the low energy electrons surviving the gaps between bunches

Is affected by many other parameters like:

Size of the beam vacuum pipe
Magnetic field (field free, dipole, quadrupole or solenoid field)
Gasses condensed on cryogenic beampipe walls

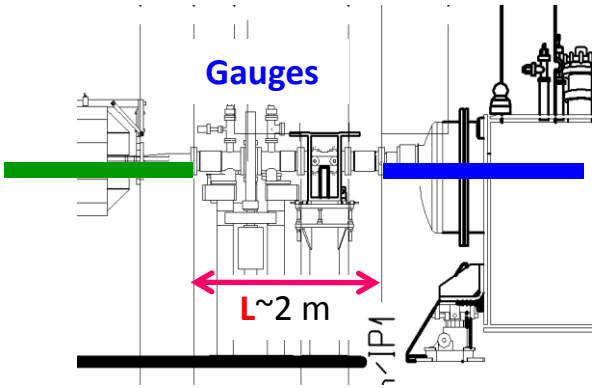
Introduction (2/4)

- The electron cloud induced limitation are:
  - Vacuum pressure rise
    - Resulting from electron stimulated desorption (ESD)
    - ΔP signal depend on the ratio: Multipacting length vs effective pumping speed
  - Cryogenic cooling capacity
    - Induced by the electron flux to the beam screen inner wall (heat deposition)
    - Heat load limited by the available cooling capacity (capillaries / cryoplants)
  - Beam instability
    - Depends on both the electron density and the integrated length over LHC ring
    - Can become a limiting factor for the scrubbing run (emittance blow-up and losses)
  - Beam-gas scattering induced radiation and beam losses
    - Depends on both the pressure bump amplitude and length (and on gas species)
    - Can become a limitation by increasing:
      - The single event probability and radiation to cables and electronics
      - The background to the Detectors

☞**LHC vacuum pressure interlocks are set to keep the beam-gas scattering negligible ; at least 1 order of magnitude of margin is available.**

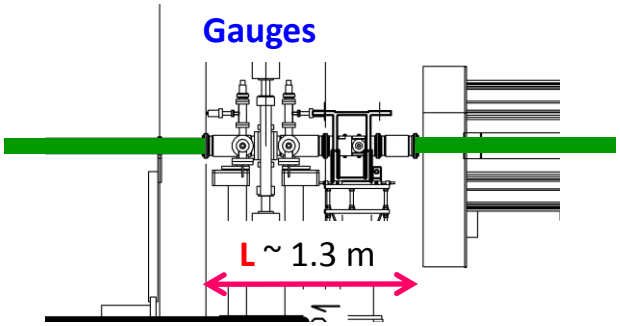
Introduction (3/4)

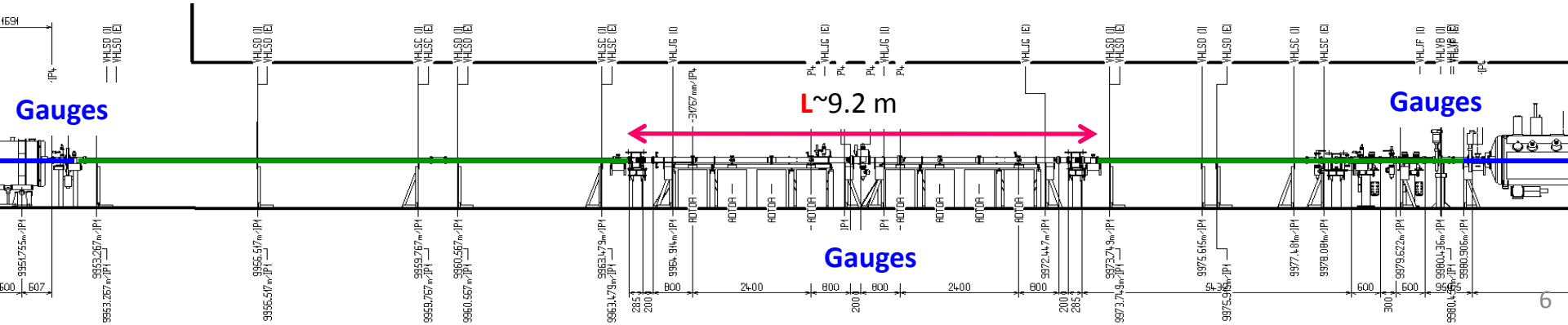
- The electron cloud induced pressure rise need a careful analysis since depending on:
  - Number of circulating beams, magnetic field conditions, beam pipe size, multipacting length, effective pumping speed and location and type of probe



Cold
NEG

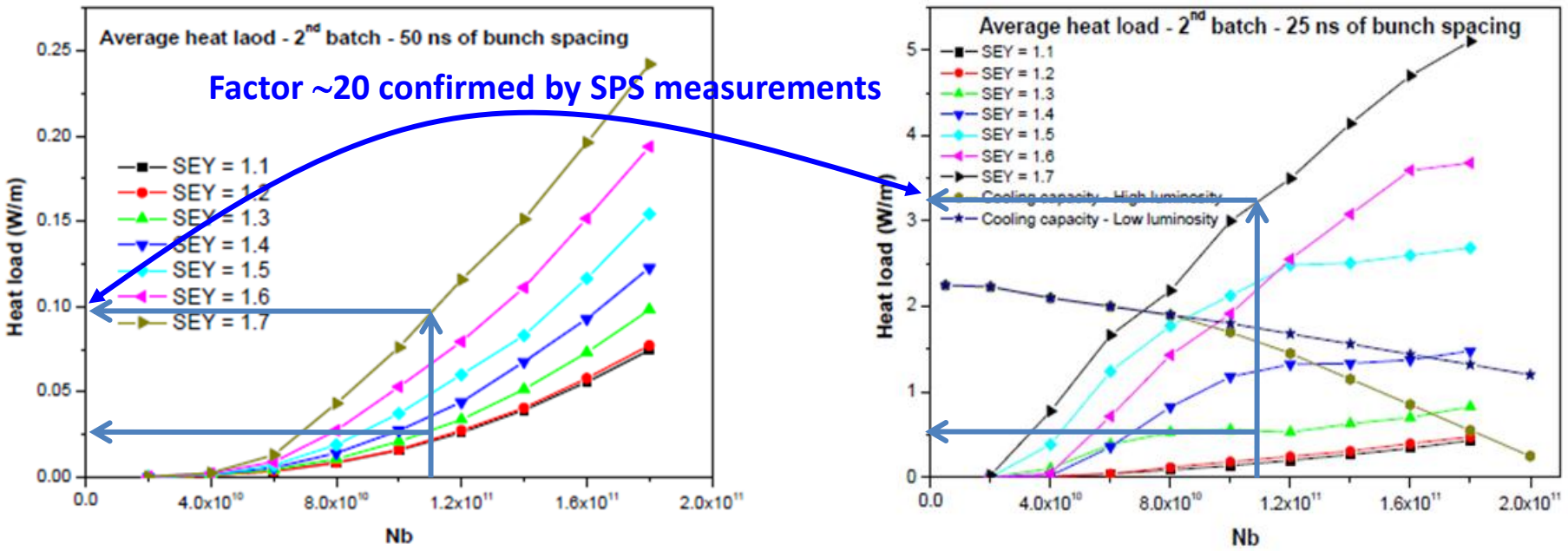
$\Delta P_{observed} \propto L$
Pumping speed ≈ cte





Introduction (4/4)

- The electron cloud induced heat load depends on:
  - Electron flux to the inner beam screen wall
  - Average energy of the electrons
  - Measurements integrated over a half period and for 2 apertures



M.H. Cuna, EuCARD-DIS-2009-002, Nov 2010

...assuming that beams limitations are not dominated by single bunch instabilities or pressure rise!

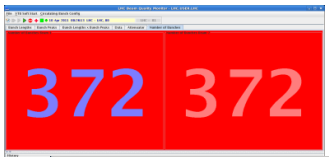
Scrubbing run

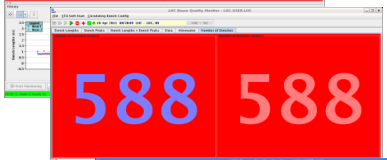
Scrubbing run (1/4)

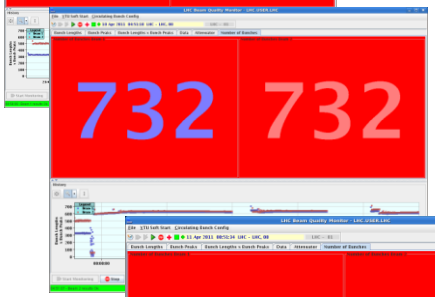
- A success story !

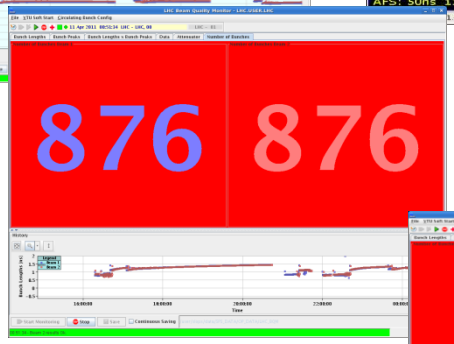
1020 bunches injected after only 15 hours of scrubbing run !

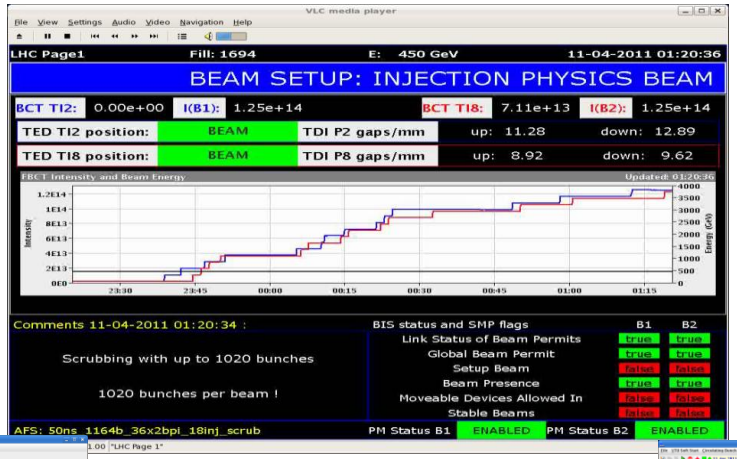
(@50 ns bunch spacing)

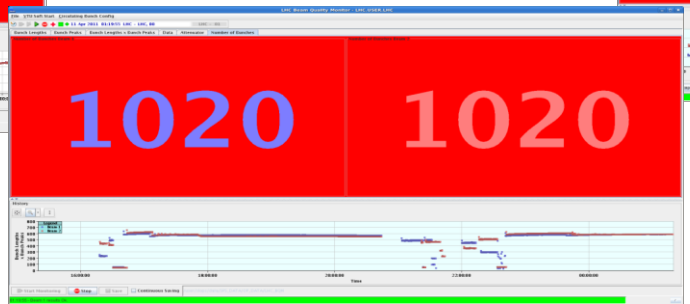


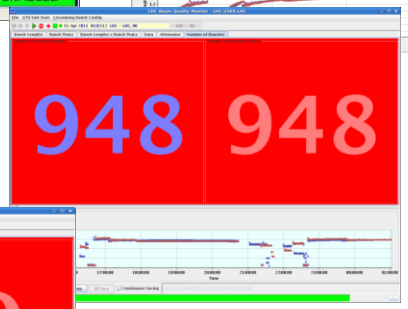


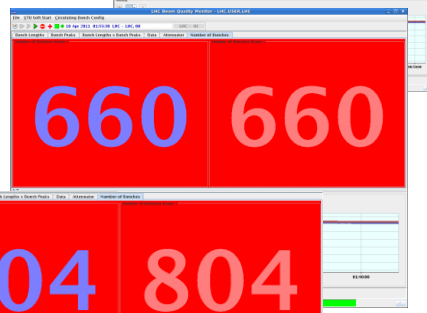


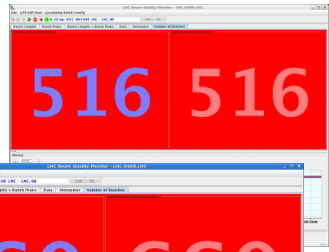






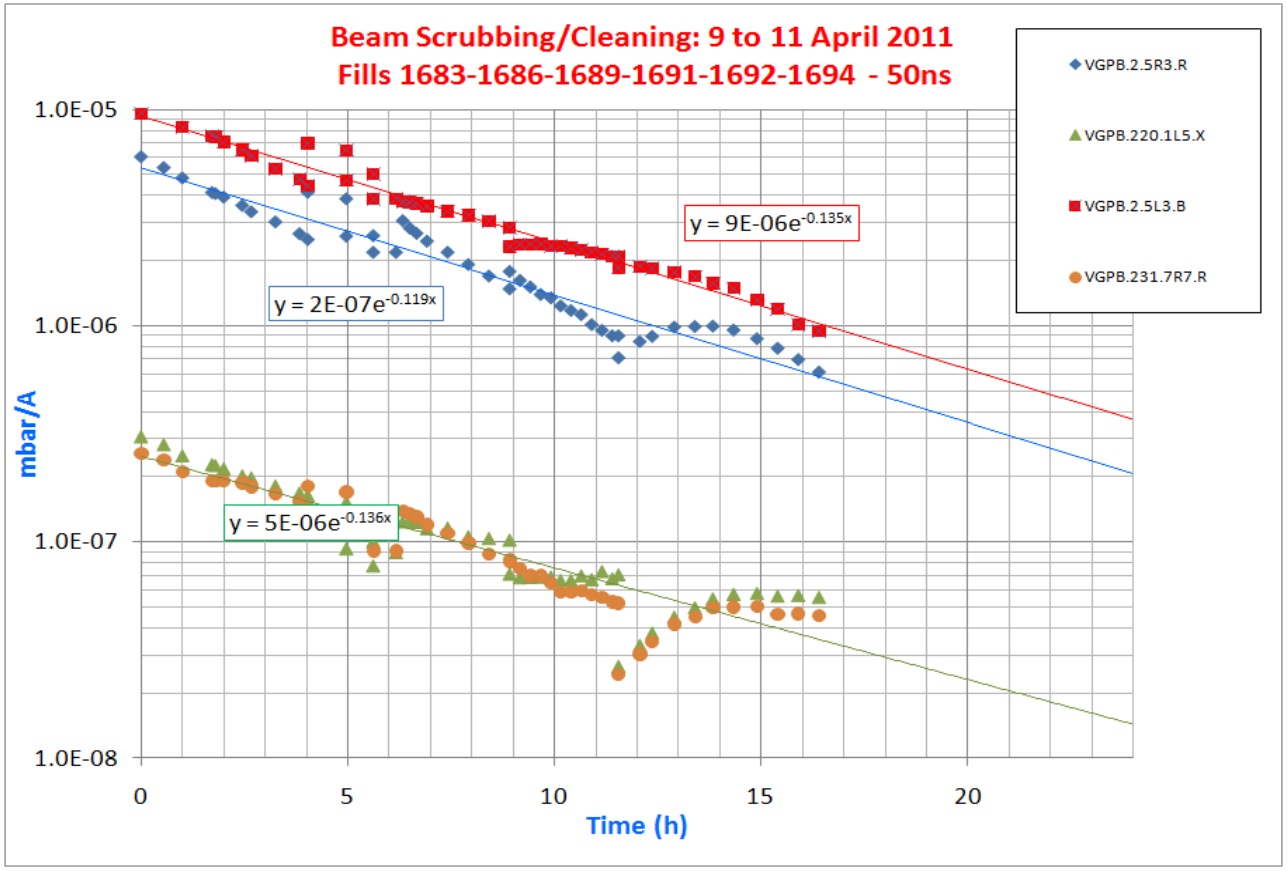






Scrubbing run (2/4)

- The decrease results simultaneously from the decrease of the electron cloud activity ($\delta\searrow$) and to the vacuum cleaning ($\eta\searrow$)



Today, LHC runs with 1380 bunches and pressure rise stay in the 10^{-8} mbar range...

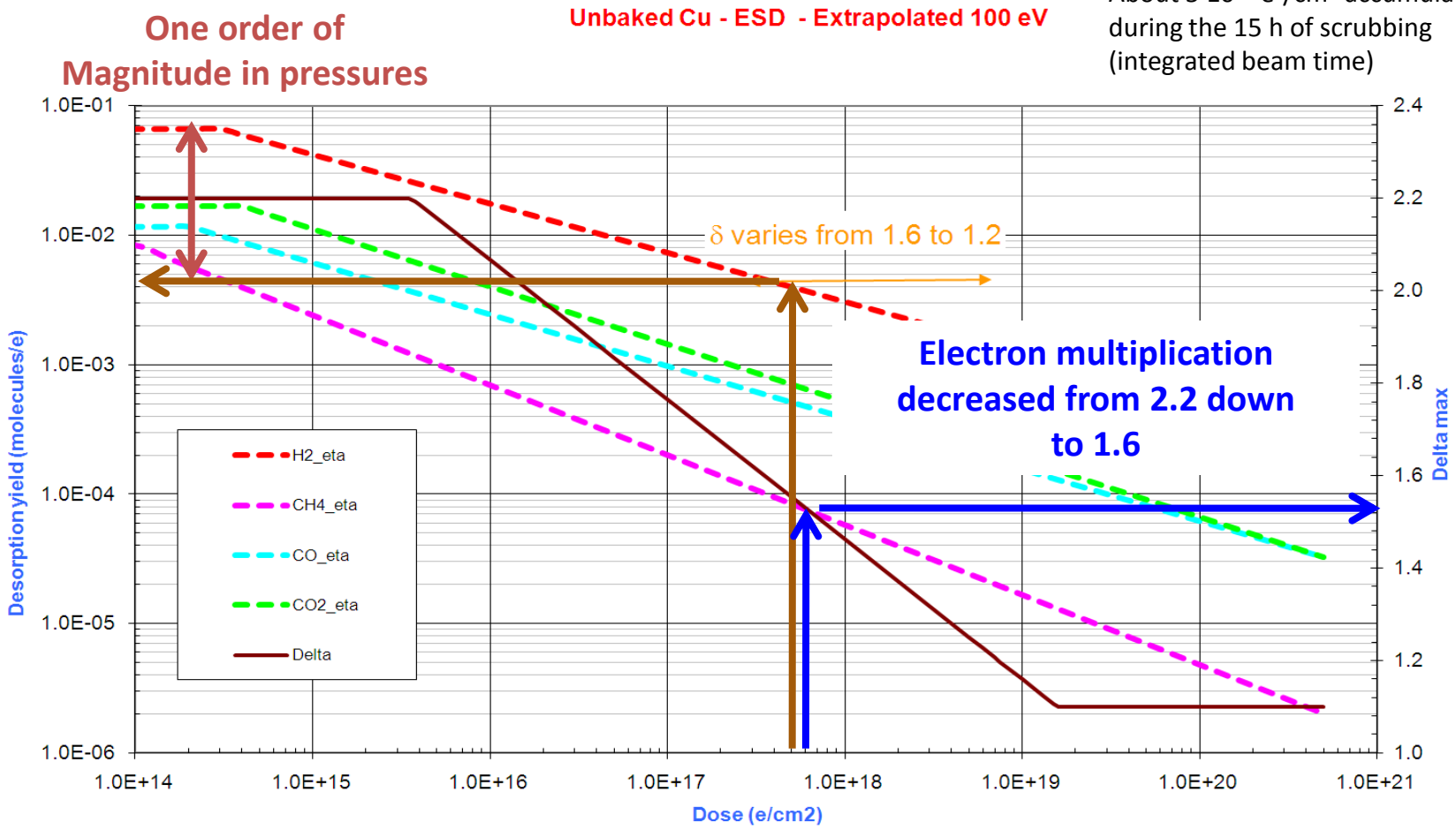
More than 3 orders of magnitude below with 1380 bunches as compared to runs with 588 b (April)!

No electron cloud in arcs (50 ns bunch spacing) and in NEG coated beampipes, as expected.

Scrubbing run (3/4)

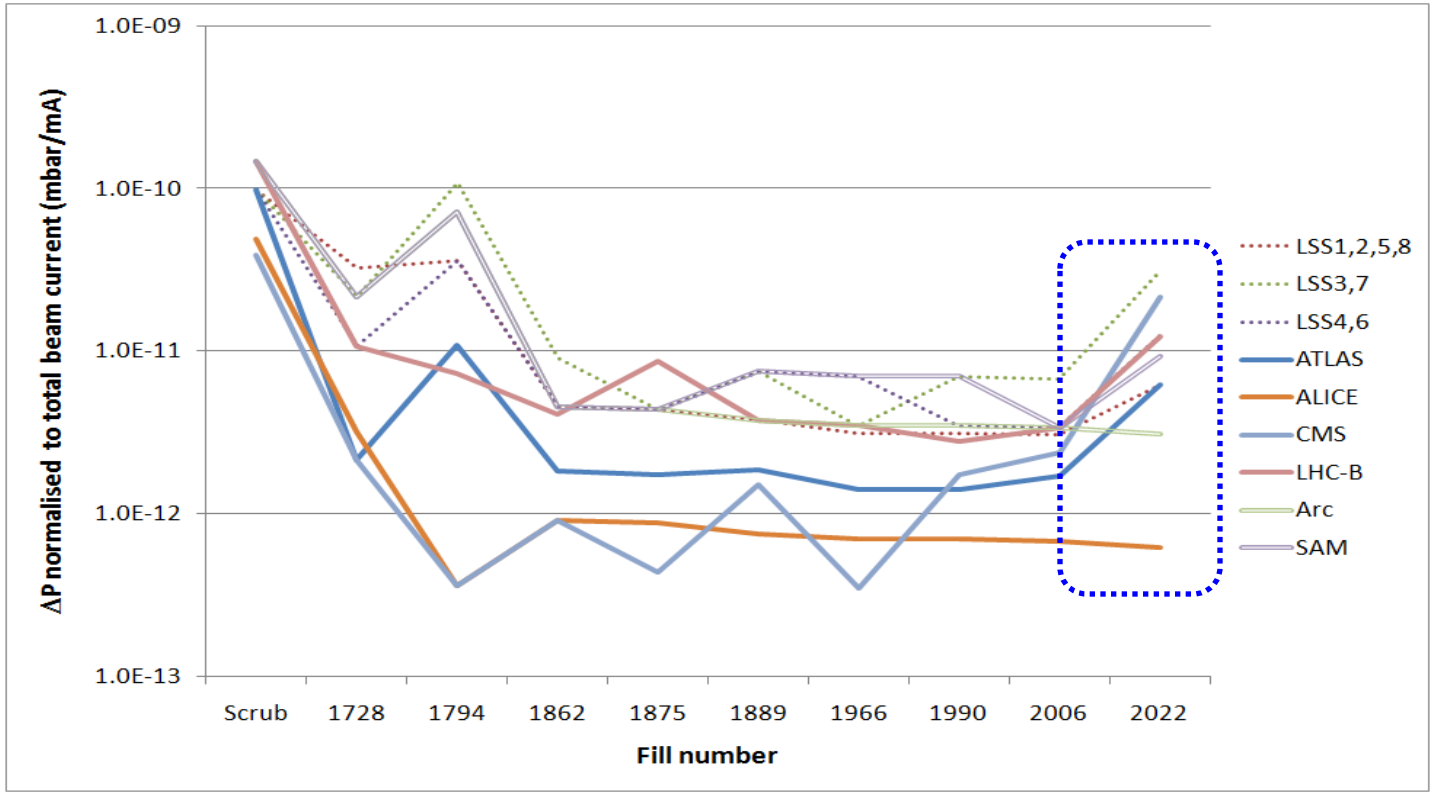
- Decrease of δ and η as a function of dose

Assuming 20 mW/m induced heat load (10^{15} e-/m/s or 2 10^{16} e-/cm^2/h). About 5 10^{17} e-/cm^2 accumulated during the 15 h of scrubbing (integrated beam time)



Scrubbing run (4/4)

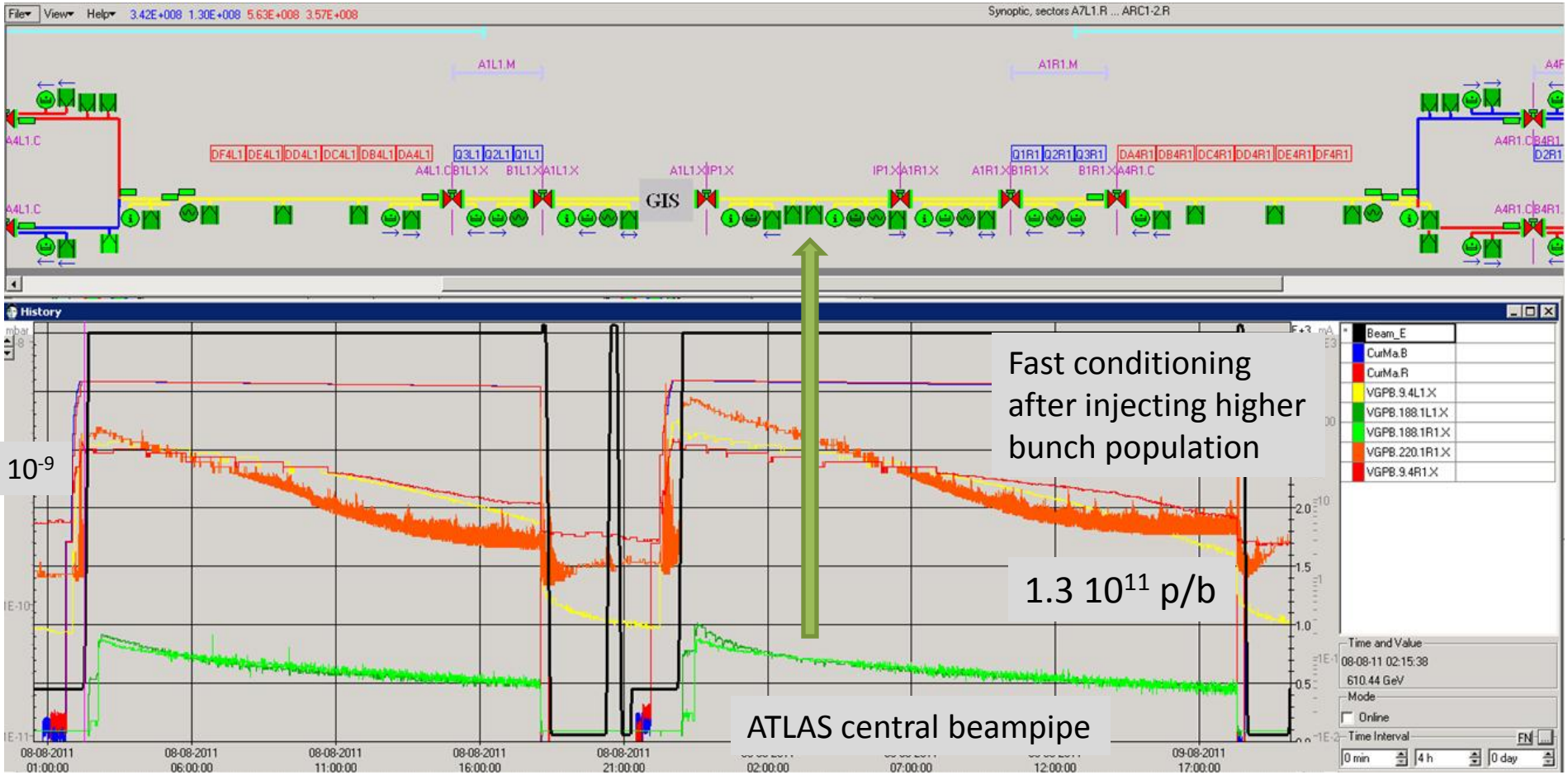
- Limits of the Scrubbing run
  - A log conditioning can be observed (as expected)
  - Runs above the scrubbing threshold induce pressure rise



50 ns beams in Physics

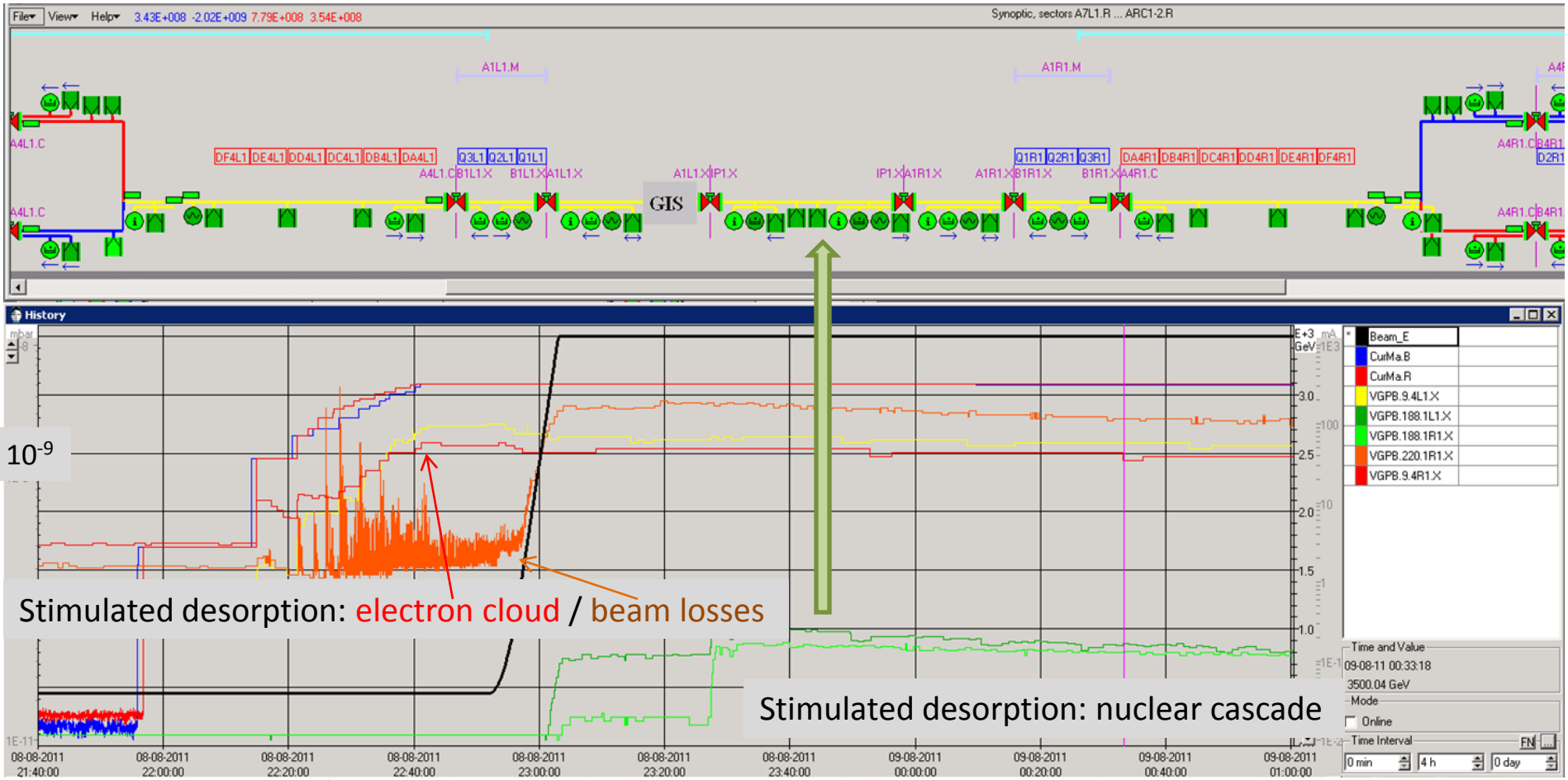
50 ns beams in Physics (1/4)

- ATLAS zone (1/2)



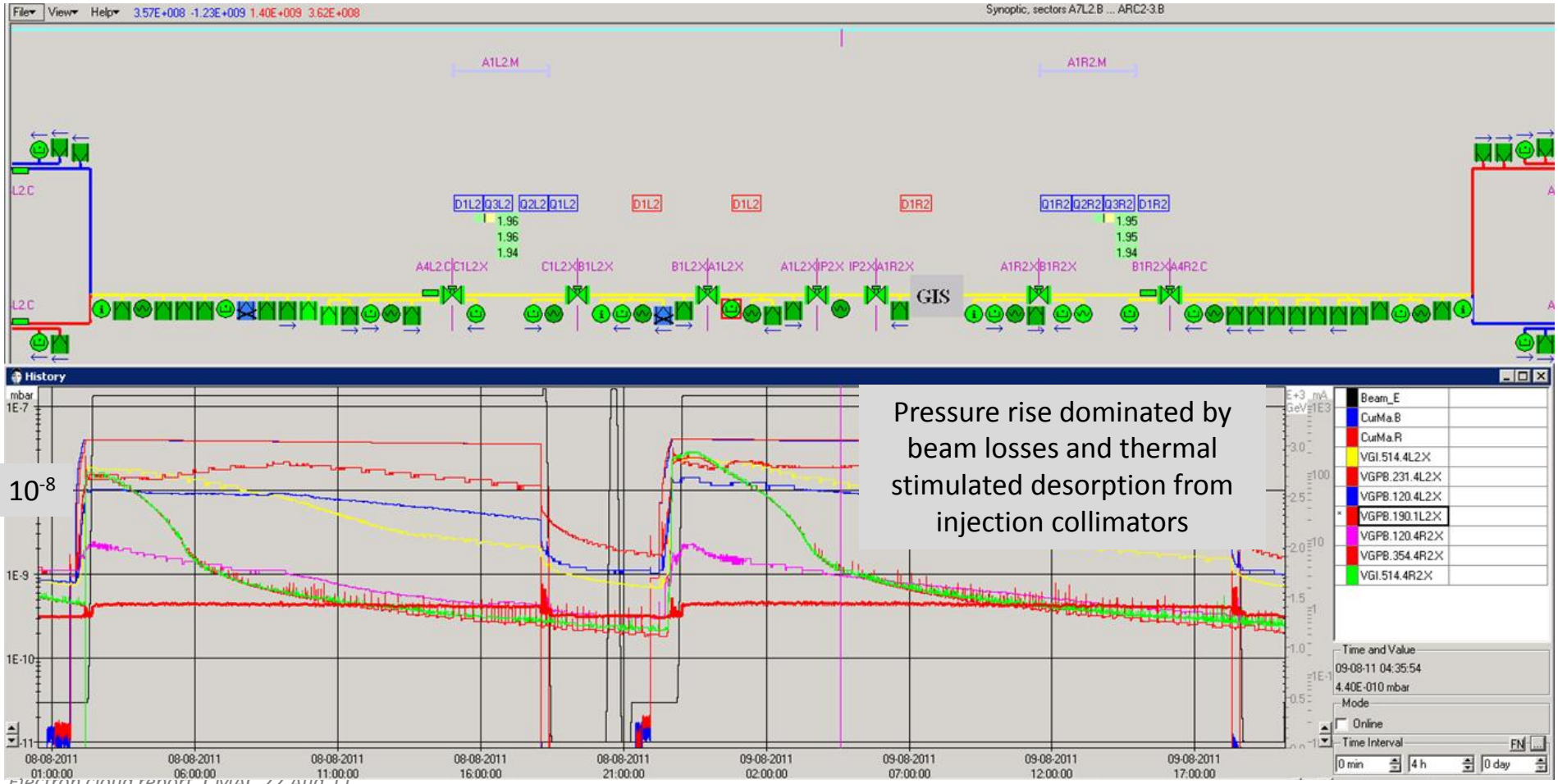
50 ns beams in Physics (2/4)

- ATLAS zone (2/2)



50 ns beams in Physics (3/4)

- Alice



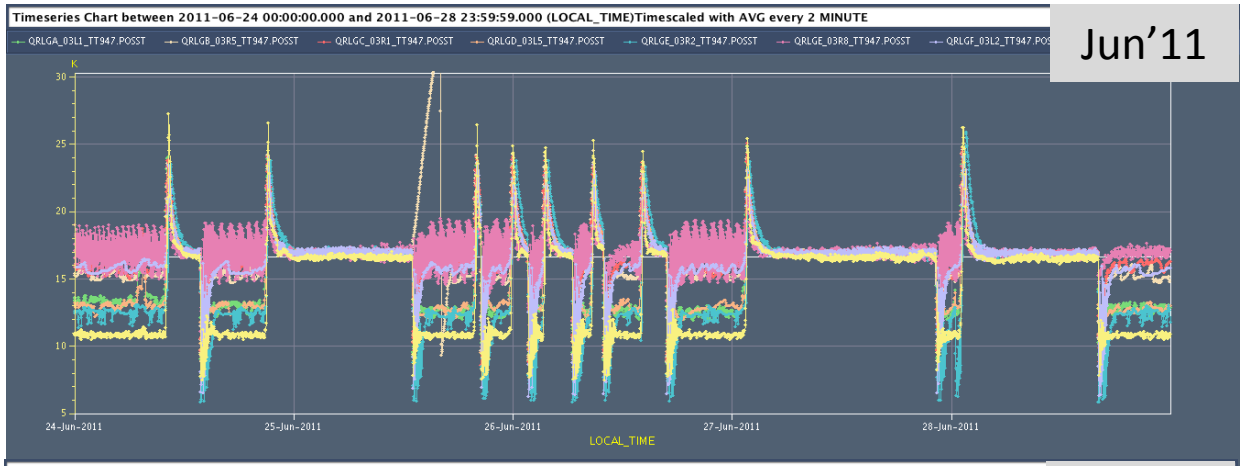
50 ns beams in Physics (4/4)

- Summary
  - Pressures in experimental beam pipes are factor 10 below the specified values (LHC Design Report)
  - Upstream and downstream electron cloud activity at cold/warm transitions in recombination areas (2 circulating beams) is still visible. Nothing where only 1 beam circulates in beam pipe.
    - Operation close to the electron cloud threshold and gas recycling during stoppage of cryogenics (partly solved)
  - Fast pressure spikes observed:
    - At injection, during the ramp in energy, simultaneously with beam tuning and orbit optimisations
  - Situation more favorable in ATLAS and CMS:
    - Warm D1 with NEG coatings,
    - Not an injection point,
    - No collimator to protect the cold D1,
    - Vacuum layout at D1 more favorable (to be modified at LS1).

Other vacuum induced effects

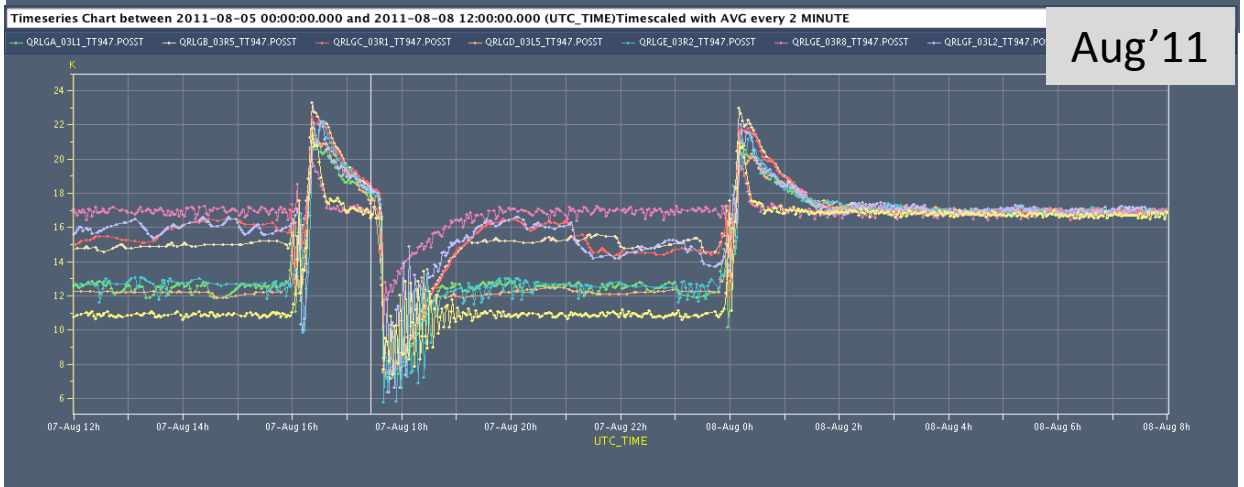
Other vacuum induced effects (1/4)

- Temperature dependence of the cryo-beam vacuum: Procedure to optimise the Beam Screen temperature stability



Jun'11

Peaks 25-27K



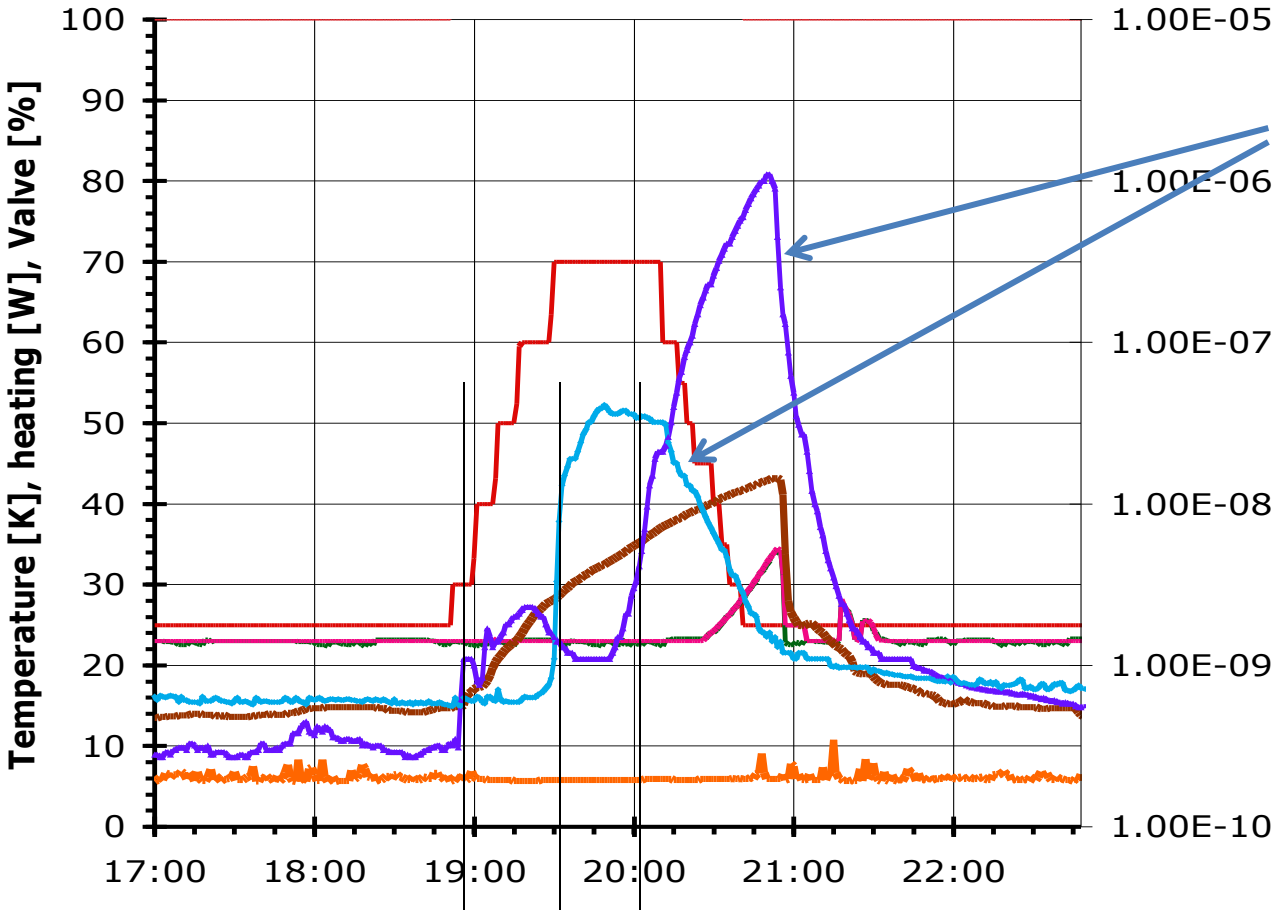
Aug'11

Peaks 22-23K

Automatism now in place
Lower peak values, reproducibility

Other vacuum induced effects (2/4)

- Temperature dependence of the cryo-beam vacuum: Procedure to flash gas from Beam Screen to Cold Bore

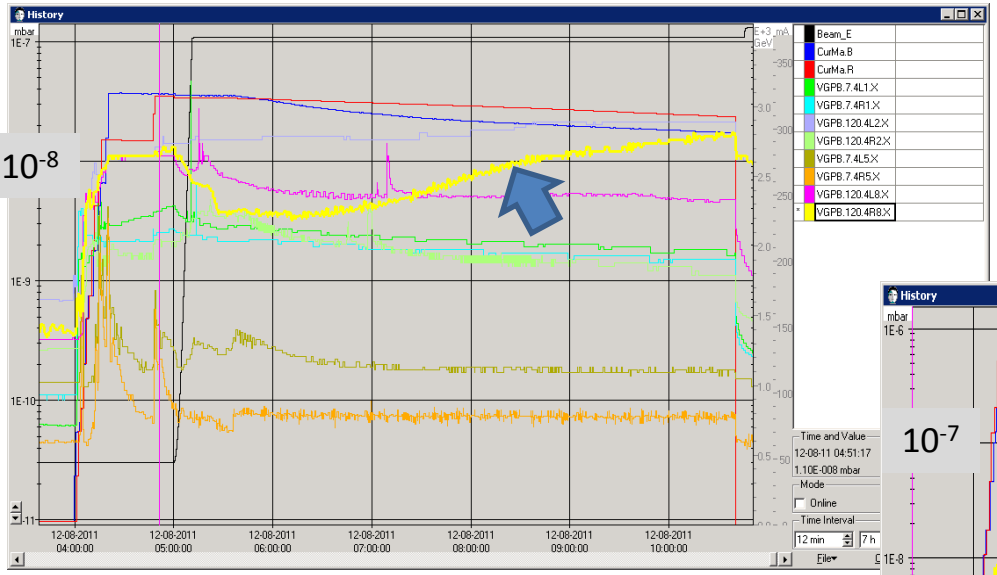


Gas redesorbed from BS and "flashed" to the CB which is always kept at a lower temperature

Inner triplets IR8R

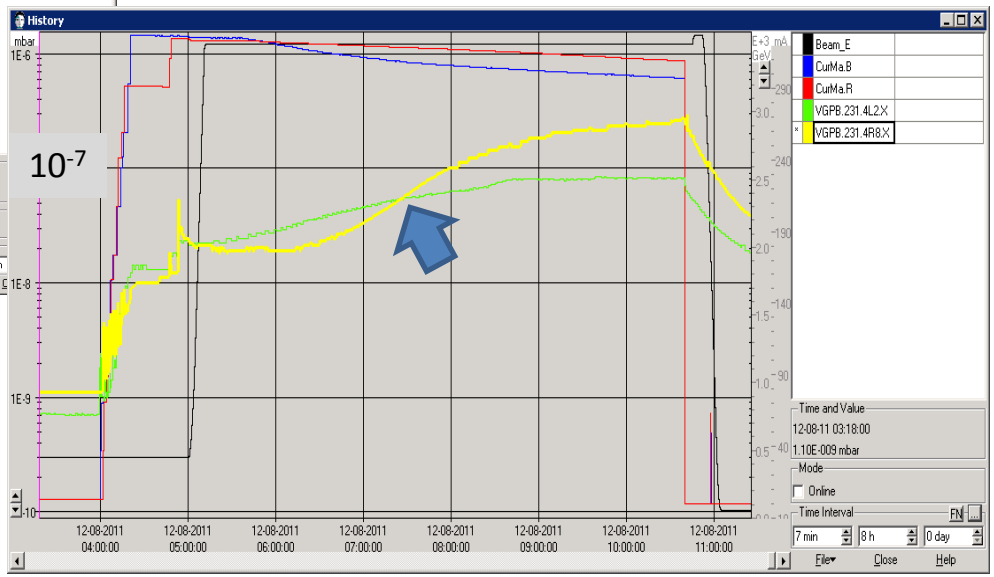
Other vacuum induced effects (3/4)

- Injection collimators operated as “active” collimators and no longer as passive absorbers?



10^{-8}

...could become an issue for Alice and LHCb background !
Already some complains



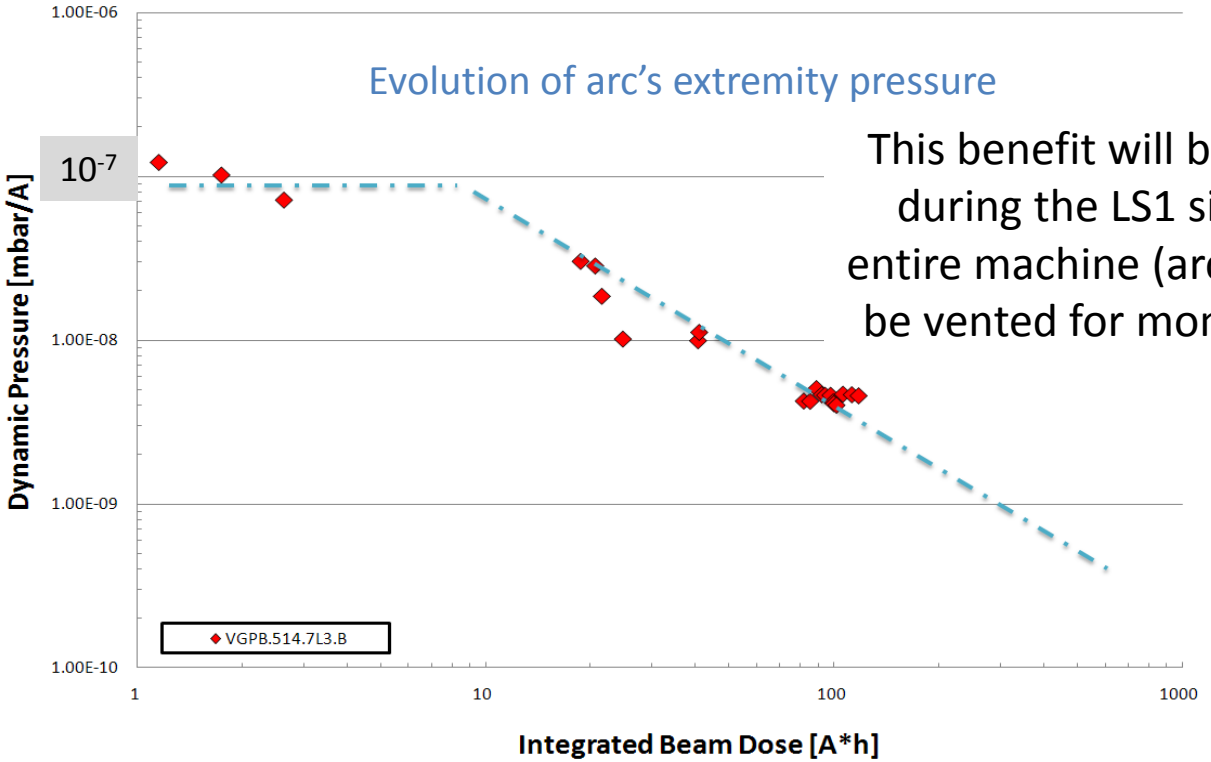
10^{-7}

Evolution of the pressure at TDI levels during fill 2022. Both TDIs drift with time. This drift is also seen on D1R8 by conductance effect

Other vacuum induced effects (4/4)

- Synchrotron Radiation effects
  - With 25 ns beams, more photon flux, from 2.5 10^{16} ph/m/s to 5 10^{16} ph/m/s with nominal current (2804 bunches) BUT same critical energy (5.5 eV)
  - Twice the Pressure increase, still conditioning but it is a log scale !

$$\dot{\Gamma} \propto \frac{E}{\rho} I \propto B I$$

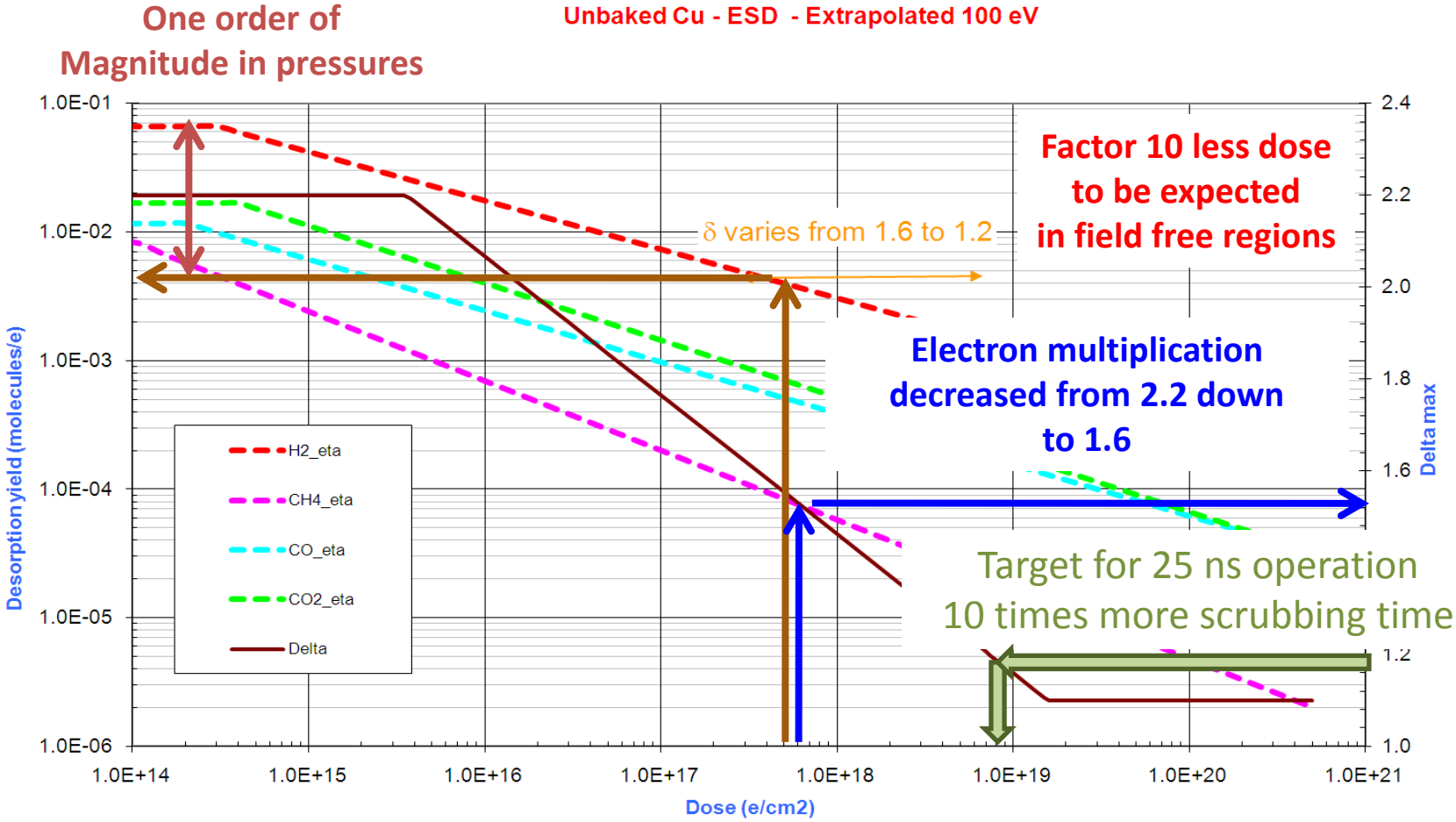


This benefit will be lost during the LS1 since entire machine (arcs) will be vented for months...

Perspectives and limitations

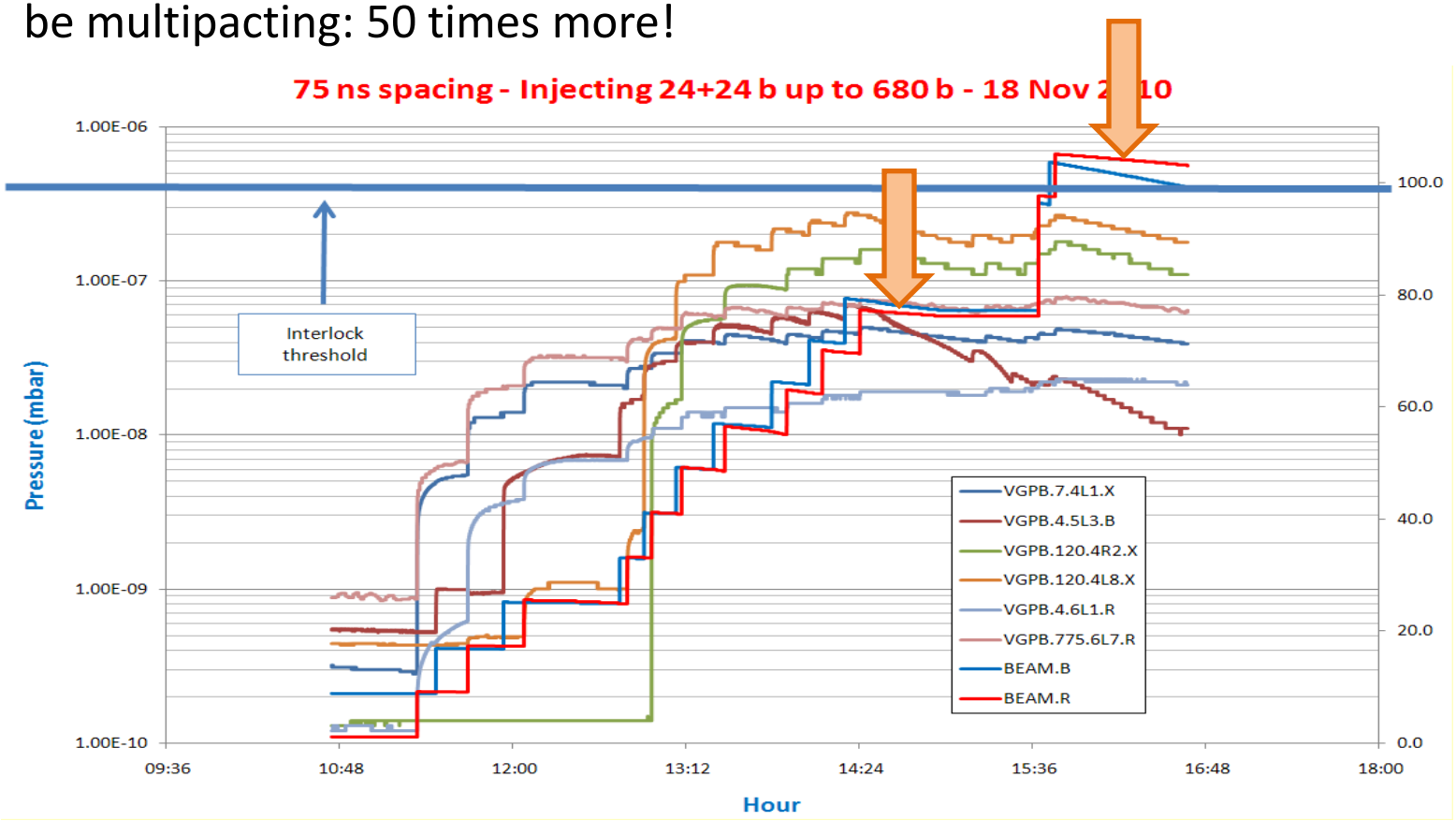
Perspectives and limitations (1/5)

- Operation with 25 ns beams: 10 times more electron dose required



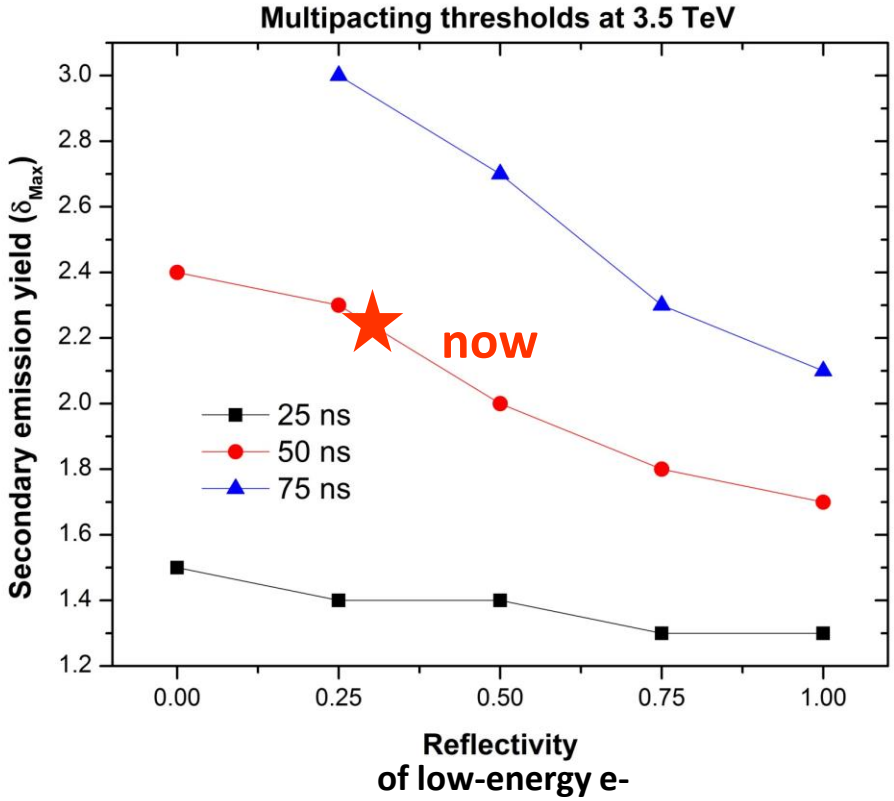
Perspectives and limitations (2/5)

- Operation with 25 ns beams: more multipacting length expected
  - Arcs and standalone magnets with 1 circulating beam per beam pipe will be multipacting: 50 times more!



Perspectives and limitations (3/5)

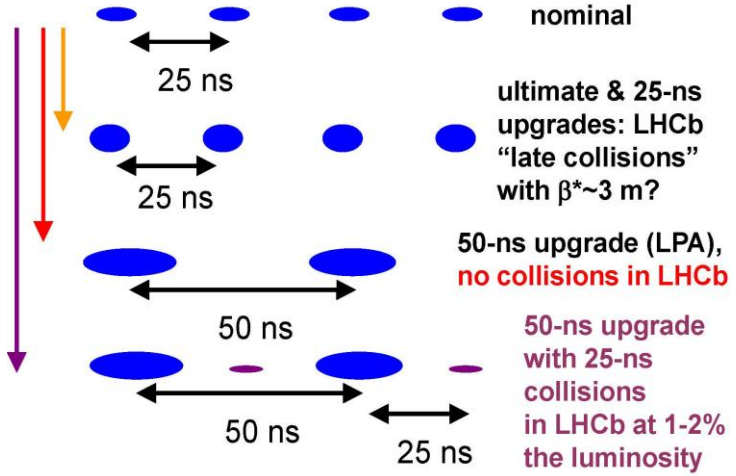
- Operation with 25 ns beams: Dependence with reflection of low energy electrons
  - 25 ns beam are less depending than 50 ns
  - Reflected electrons could become an issue

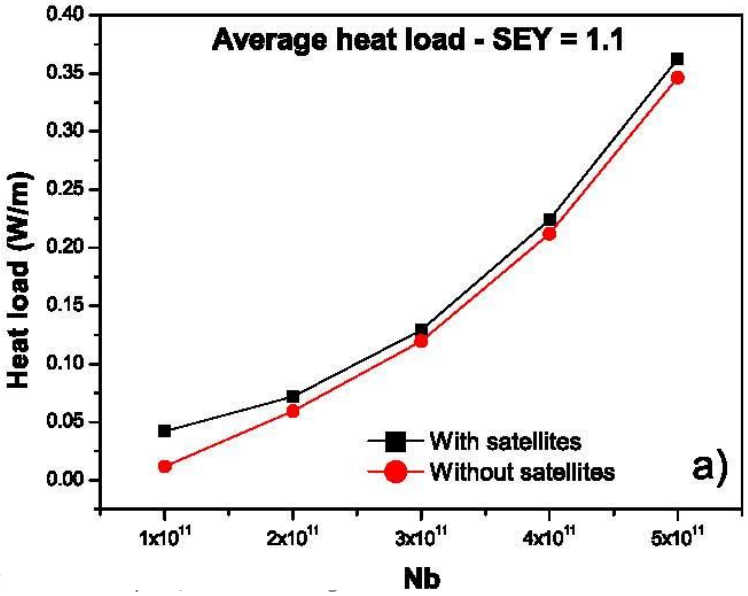


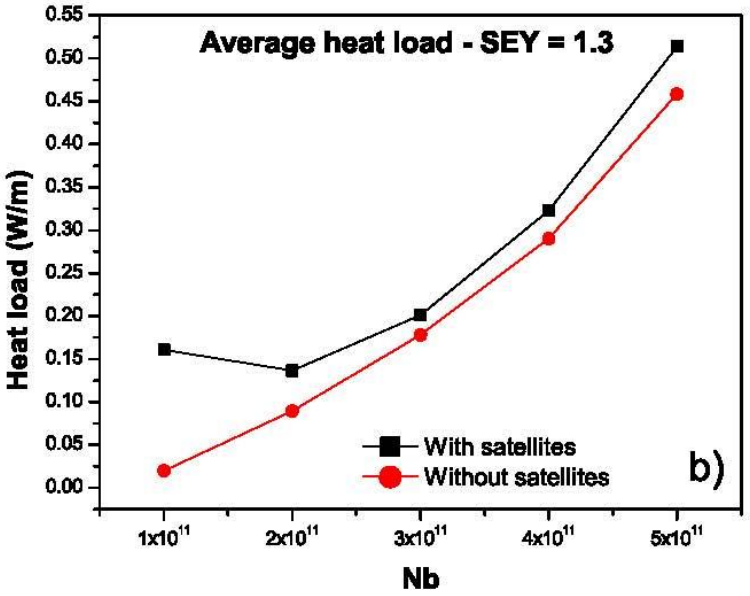
H. Maury

Perspectives and limitations (4/5)

- Operation with 25 ns beams: Effect of LHCb satellite bunches
  - Electron cloud induced heat load fits the cooling power for 50 ns beams







H. Maury
L. Tavian

Perspectives and limitations (5/5)

- Summary (Operation with 25 ns beams)
  - 2-3 weeks of scrubbing will be required to go from δ=1.6 down to 1.2
  - ☞ 10 times more dose (~150 hours of beams)
  - Multipacting length will be 50 times longer (entire ring)
  - Reflectivity of low energy electrons will impact the filling scheme
  - 50 ns beams with interleaved LHCb satellite bunches should not be an issue

Closing remarks

Closing remarks (1/2)

- Confirmations
  - Scrubbing runs baseline was confirmed as an efficient way to decrease the electron cloud
    - Less than 1 hour needed in the arcs and the straight sections with one circulating beams at 50 ns bunch spacing
    - 15 hours in beampipe with two circulating beams
  - NEG coatings provide, as predicted, both a distributed pumping and an electron cloud mitigation (no build-up observed)
  - Solenoids help to avoid electron cloud build-up upstream and downstream the experimental areas (background issues)
  - Background and beam lifetime fully compatible with operation in Physics (1 order of magnitude margin with present beam parameters)

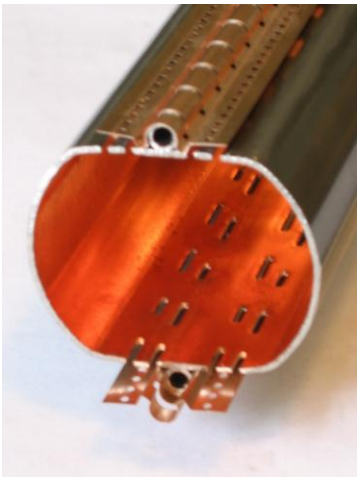
Closing remarks (2/2)

- Concerns
  - Vacuum system very sensitive to beam losses which induce fast pressure spikes. Cannot be filtered ⇨ machine protection
  - Non-NEG coated beam components like beam instrumentation and RF equipments are increasing the electron cloud and gas load
  - Cold vacuum strongly dependant on temperature variations between 12 and 30 K ⇨ More demanding for the cryogenic system
    - ❖ New procedure are successfully applied
- Pending issues
  - Operation with 25 ns beams will be challenging
    - ❖ Beam instabilities, longer scrubbing runs (×10 more than with 50 ns), heat load issues all around the ring (and not only in the inner triplet as observed today)
    - ❖ Needs to keep constant electron flux, still realistic if all arcs are multipacting? (single bunch instabilities)

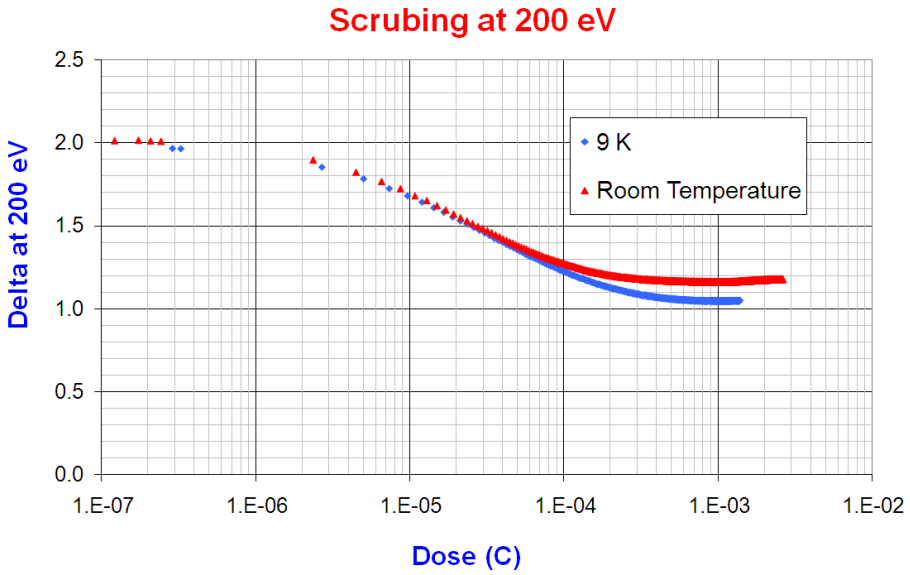
Reserve (slides)

Introduction (5/)

- Specificities of beampipes at cryogenic temperatures



- Unbaked vacuum system by design
- Beam screen's hole provide pumping speed by the cold bore
- Primary and recycling desorption yields : $\eta'_{monolayer} >> \eta$
- Beam screen's surface coverage should stay below a monolayer : minimize the accumulation of gas on the BS (results from electron cloud and synchrotron radiation)
- Scrubbing rate at cryogenic temperature of a **bare surface** is similar to RT

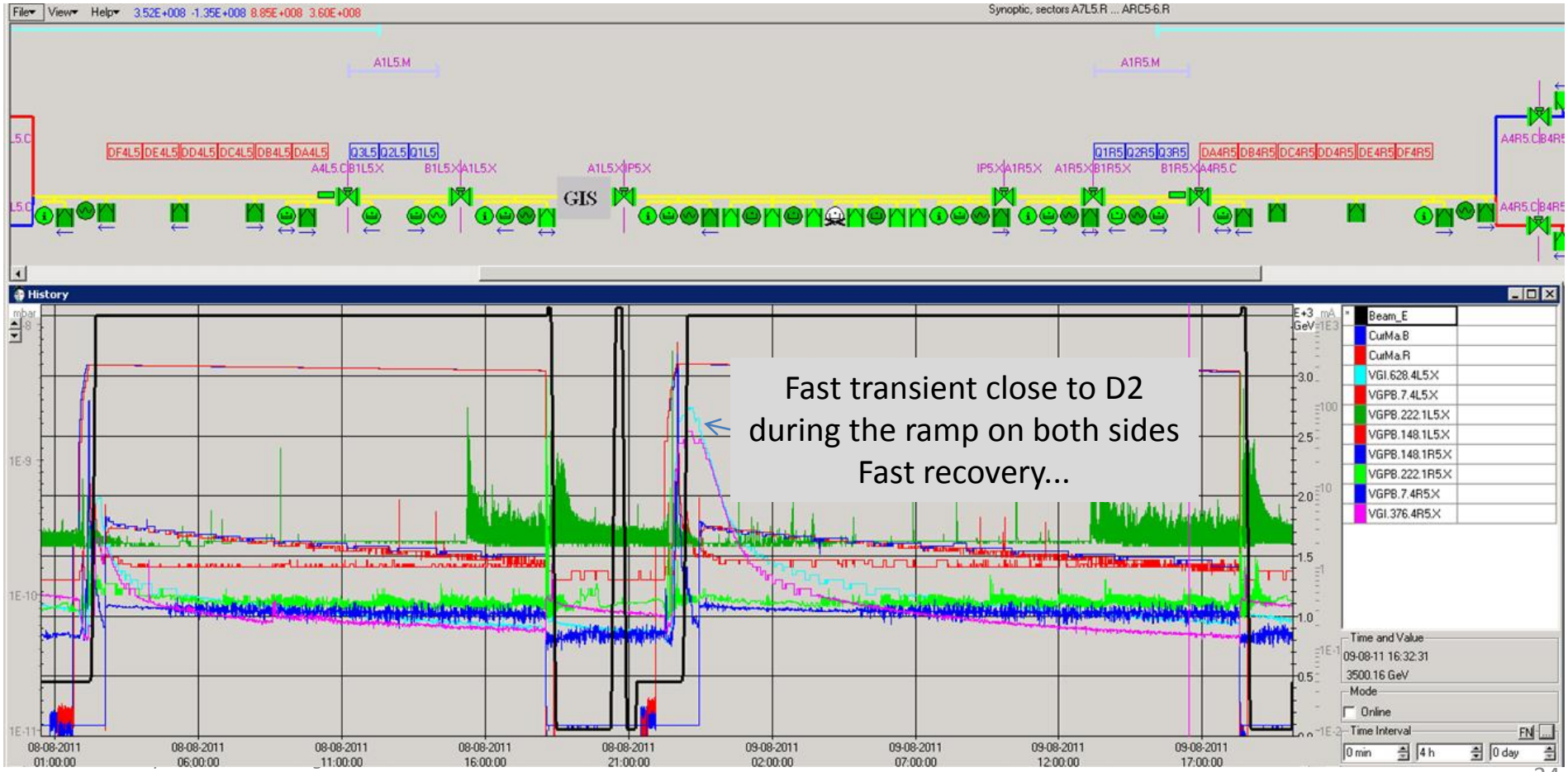


$$P_{cryo} = \frac{\eta_{Electrons}\,\dot{\Gamma}_{Electrons,}}{c}$$

Electron cloud by José Miguel

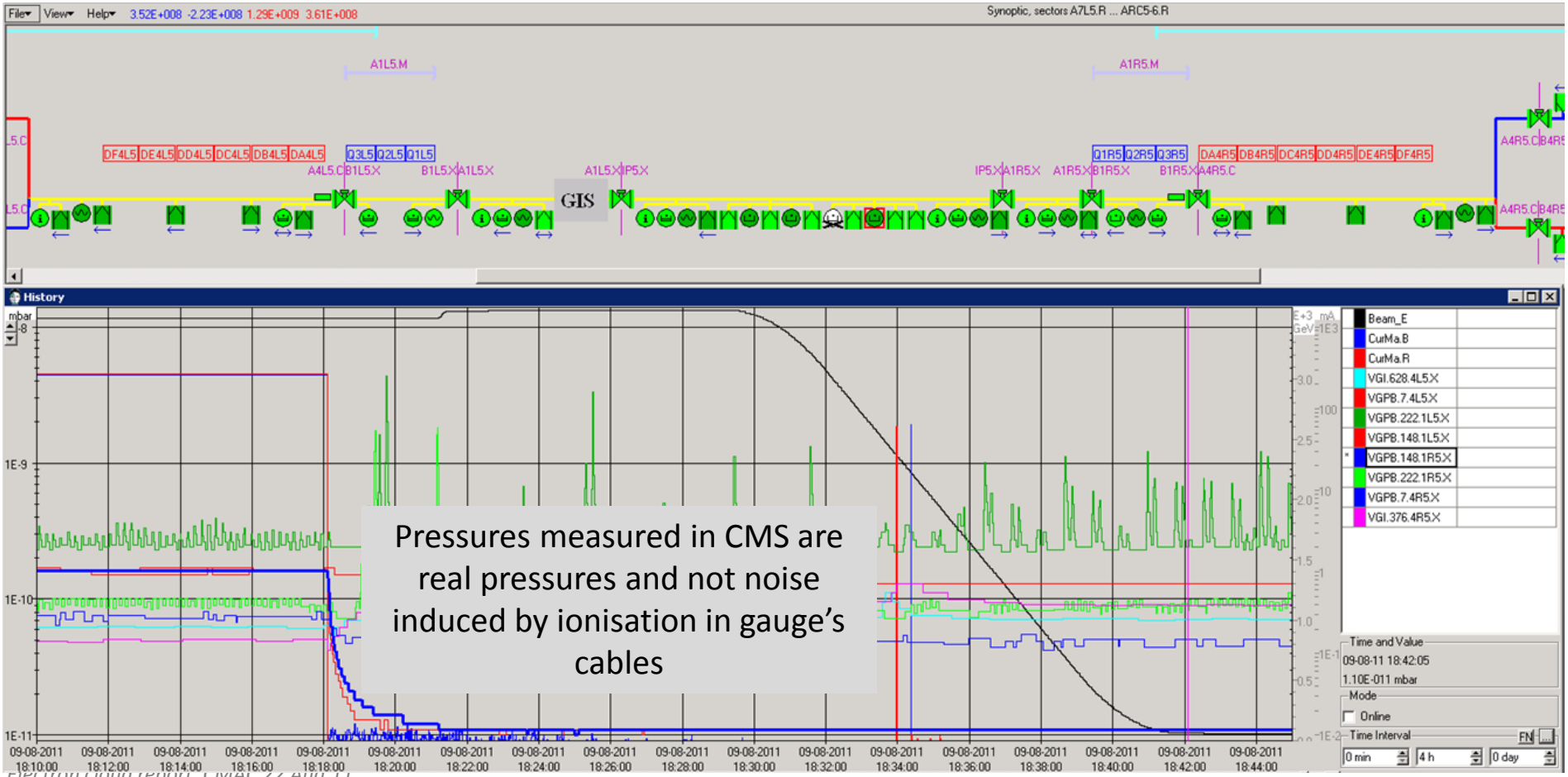
50 ns Beams in Physics (3/7)

- CMS (1/)



50 ns Beams in Physics (4/7)

- CMS (2/)



50 ns Beams in Physics (6/7)

- LHCb