Electron cloud observation in the LHC

Giovanni Rumolo

IPAC'11, San Sebastian (Spain), 8 September 2011

On behalf of the large team of experimenters and simulators
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BE-ABP-ICE

Related papers:

⇒ *Observations of Electron Cloud Effects with the LHC Vacuum System*, V. Baglin et al. **TUPS018**

⇒ *Electron Cloud Parameterization Studies in the LHC*, O. Domínguez et al., **TUPZ015**

⇒ *Simulation of Electron-cloud Build-Up for the Cold Arcs of the LHC and Comparison with Measured Data*, H. Maury Cuna et al., **TUPZ003**

Synopsis & outline

- Electron cloud was observed in the LHC when reducing the bunch spacing (single bunch nominal parameters)
  - 150ns and 75ns (N_b=1.15 x 10^{11} ppb and $\varepsilon_{x,y}$≈3μm)
  - 50ns (N_b up to 1.35 x 10^{11} ppb and $\varepsilon_{x,y}$ down to 1.5μm)

→ The **electron flux to the wall** $\dot{\Gamma}_e$ and its energy distribution determine

1) $$\Delta P = kT \frac{\int \eta_e(E)\dot{\Gamma}_e(E)dE}{S_{\text{eff}}}$$

2) $$\boxed{\Delta W} = \int \dot{\Gamma}_e(E)EdE$$

$\propto \Delta T$

$\propto \sin\varphi_s$

→ Electrons in the middle of the vacuum chamber can cause **beam instabilities**

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⇒ 2010 observations
  - Pressure rise in common vacuum chamber (150 ns)
  - Pressure rise, heat load, beam instability (75 ns vs. 50 ns)

⇒ 2011 observations
  - Effect of the scrubbing run with 50ns beams
    → Pressure and heat load evolution
    → Beam observables
  - 25 ns beams?

Historical (prior to direct LHC observations!)

- Crash program on electron cloud simulations at CERN since 1997 (F. Ruggiero)
  - Development of ECLOUD simulation code
  - F. Zimmermann, *A Simulation Study of Electron-Cloud Instability and Beam-Induced Multipacting in the LHC*, CERN LHC Project Report 95 (February 1997)

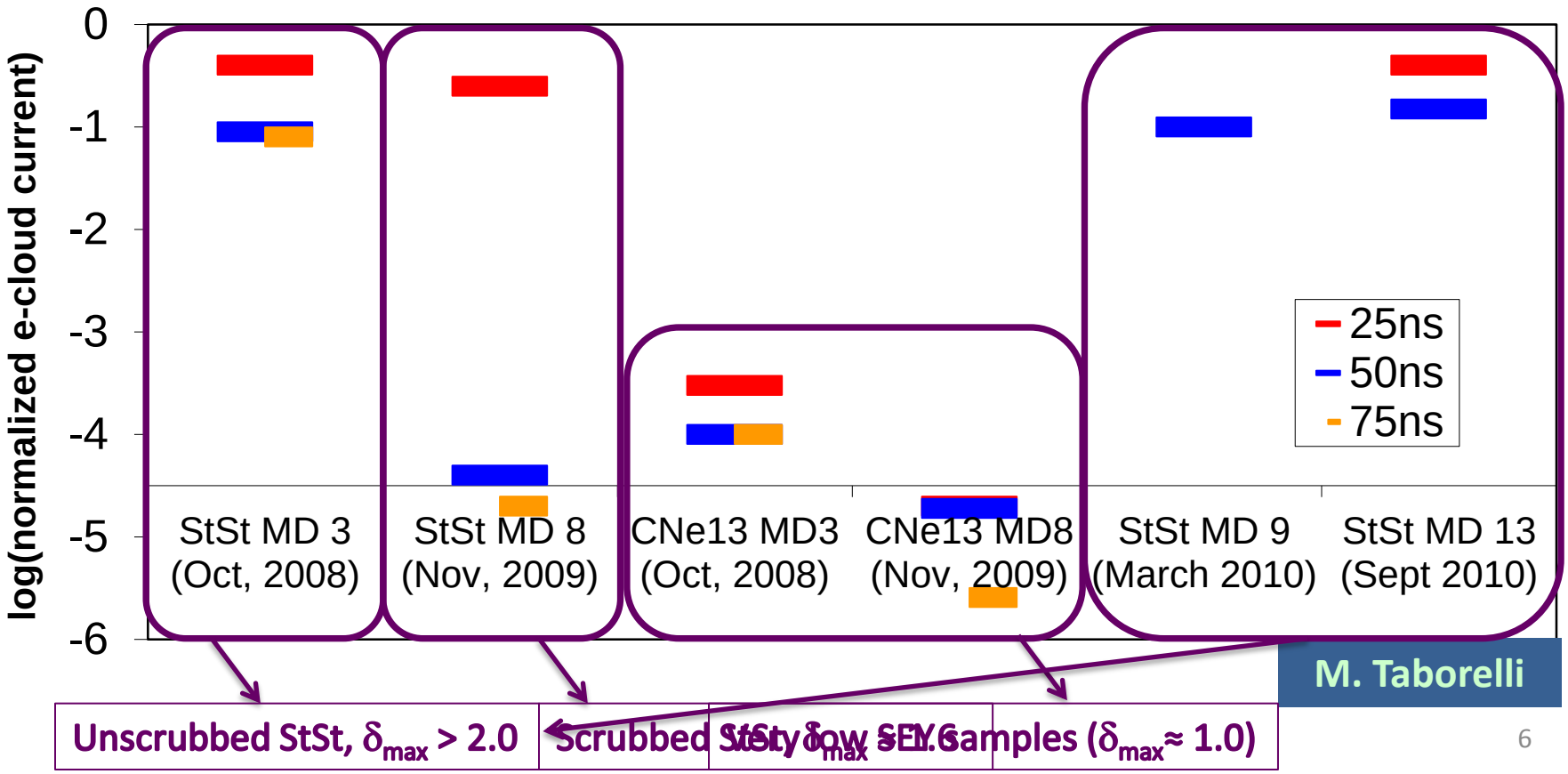
⇒ Chamonix X and XI (CERN-SL-2000-007, CERN-SL-2001-003)
  - F. Zimmermann, *Electron Cloud Simulations for SPS and LHC*
  - G. Rumolo and F. Zimmermann, *Theory and simulation of electron-cloud instabilities*

⇒ ECLOUD'02, ECLOUD'04
  - Overview paper → F. Zimmermann, *Electron-Cloud Effects in the LHC*, Proc. ECLOUD'02, CERN-2002-001

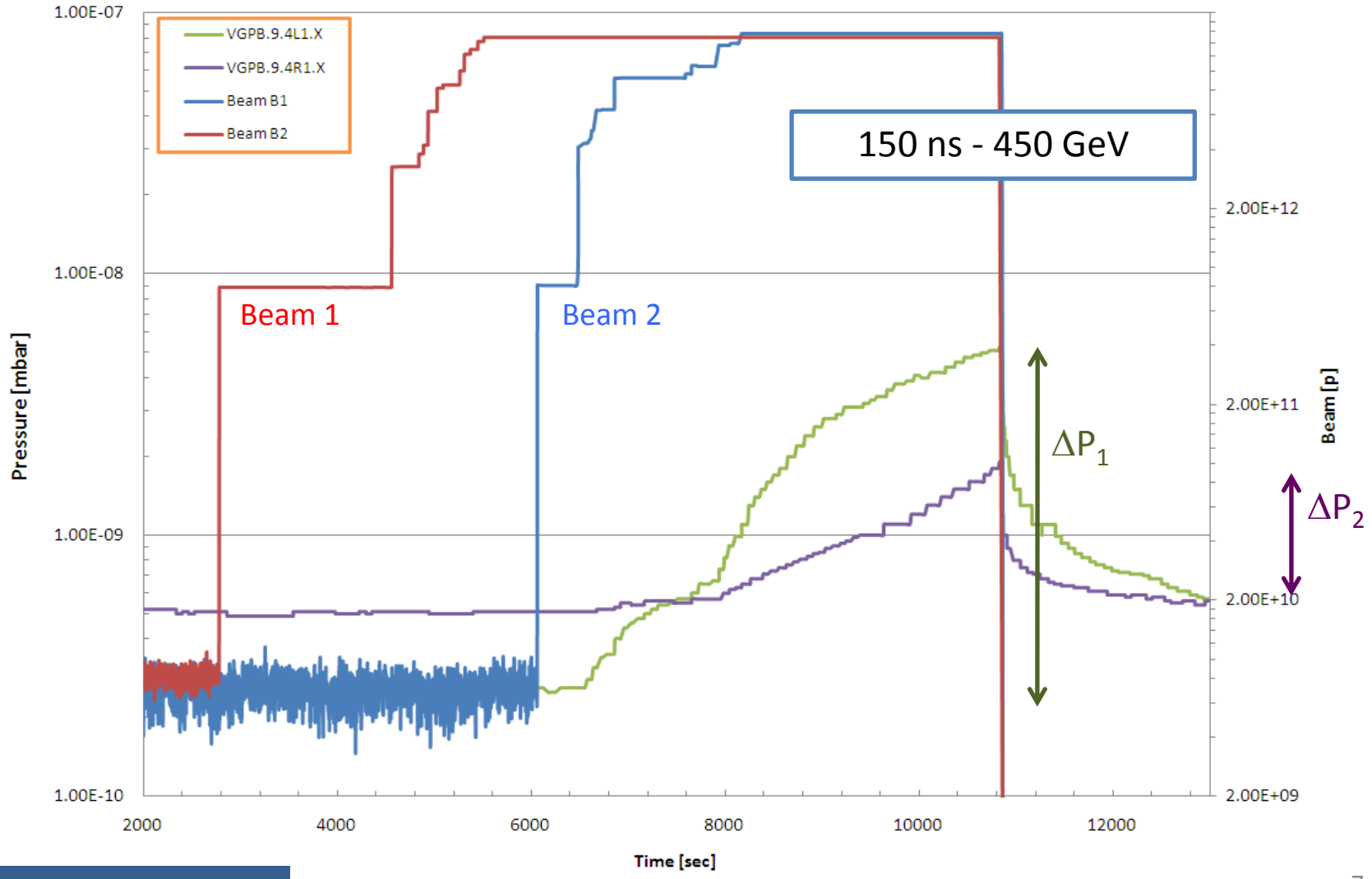
- Experimental observation of electron cloud in the SPS (and even PS) with LHC-type beams since 2000
  - M. Jimenez et al., *SPS vacuum observations and electron scrubbing with LHC beams*, CERN-SL-2001-003
  - G. Arduini, K. Cornelis, et al., *Transverse behaviour of the LHC proton beam in the SPS: an update*, Proc. PAC'01, Chicago (US)

Historical (prior to direct LHC observations!)

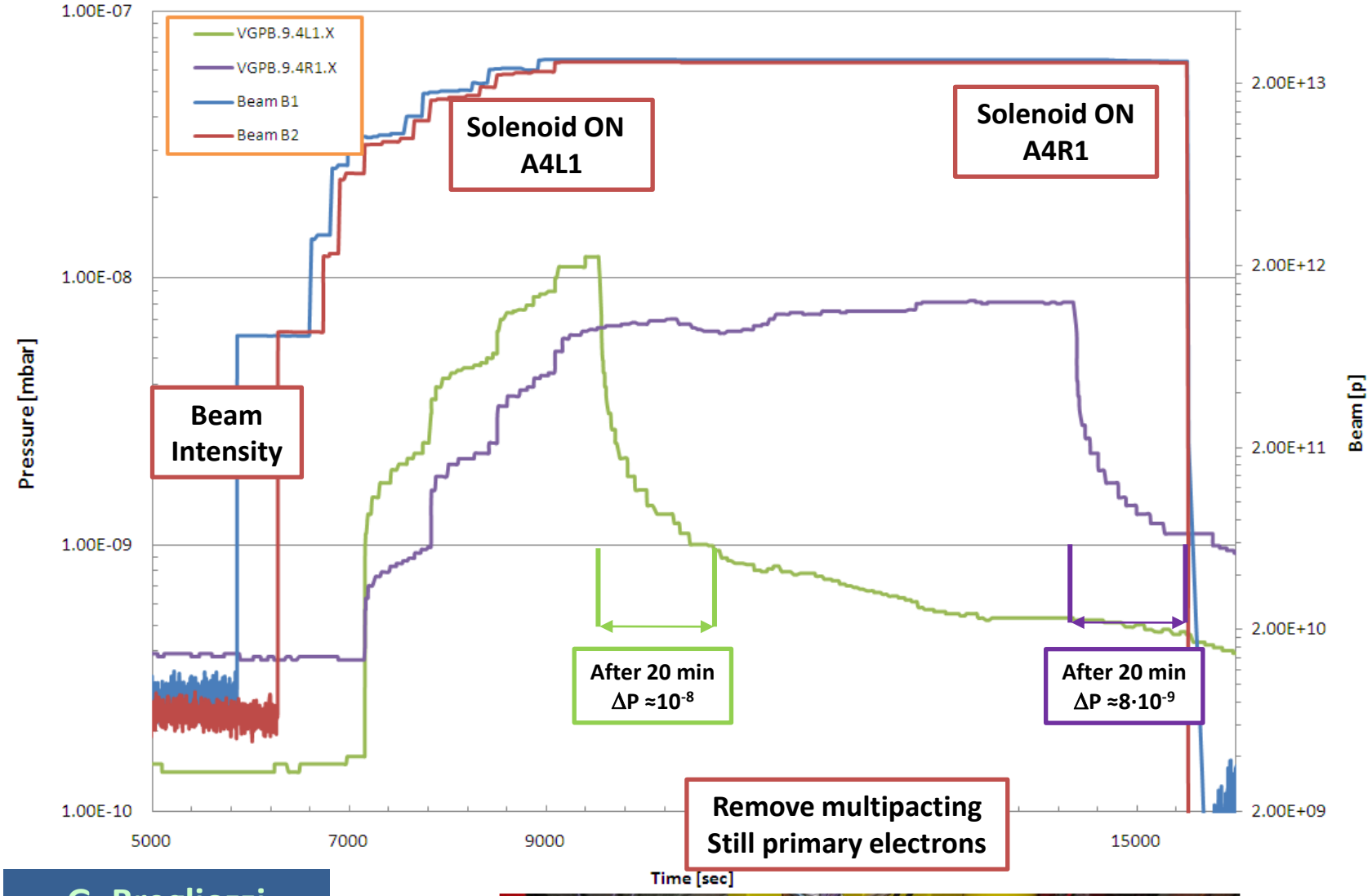
⇒ Also based on previous SPS experience, the electron cloud in the LHC with 75ns and 50ns beams and a still unconditioned machine was no surprise!!



2010 Observations @ LHC



2010 Observations @ LHC

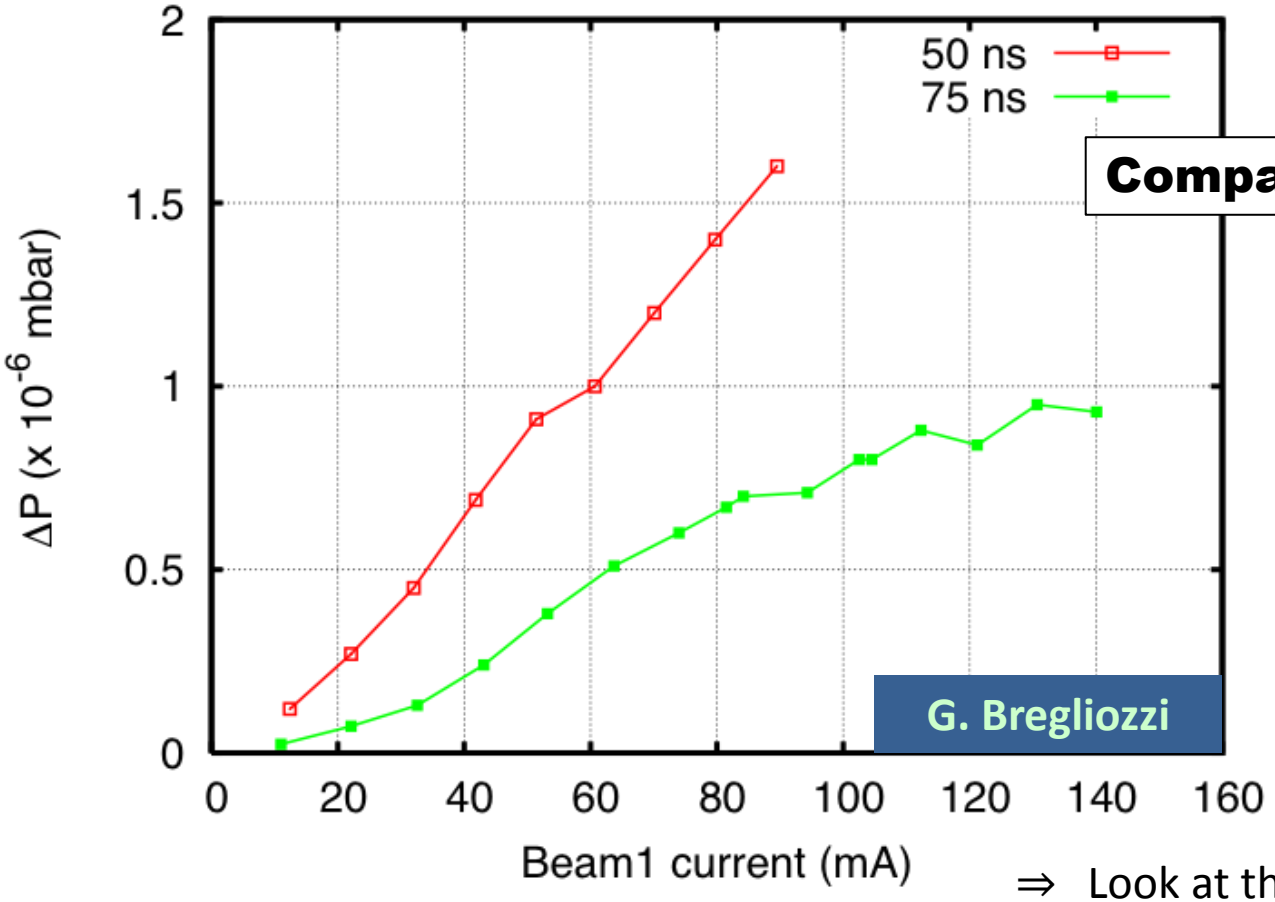


2010 Observations @ LHC

- **50 and 75 ns beams**
  - First attempts to inject 50ns beams in trains longer than 24 bunches led to severe pressure rises and beam instabilities
  - A 3 days “mini-scrubbing run” took place with 50ns beams and then, a Machine Development session with 75ns beams

⇒ Let’s compare observations with the two bunch spacings …

2010 Observations @ LHC



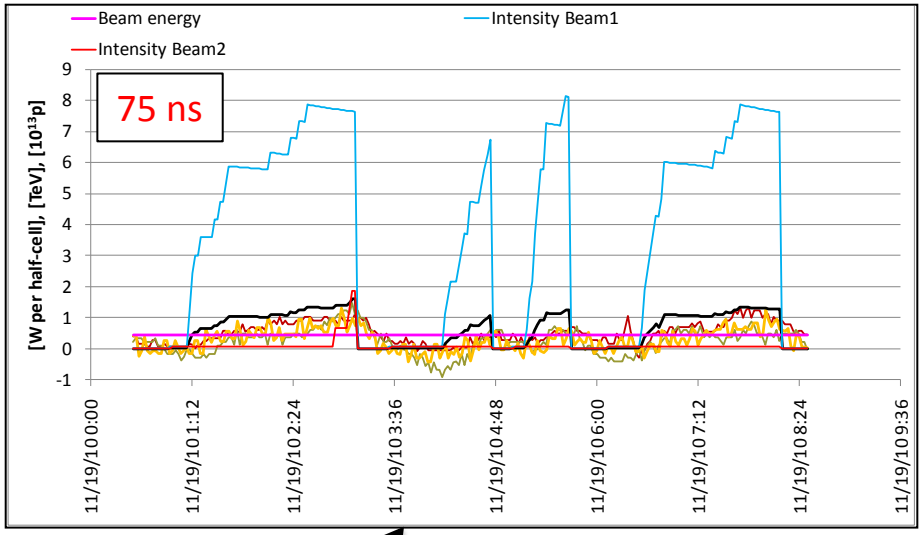
Comparing vacuum

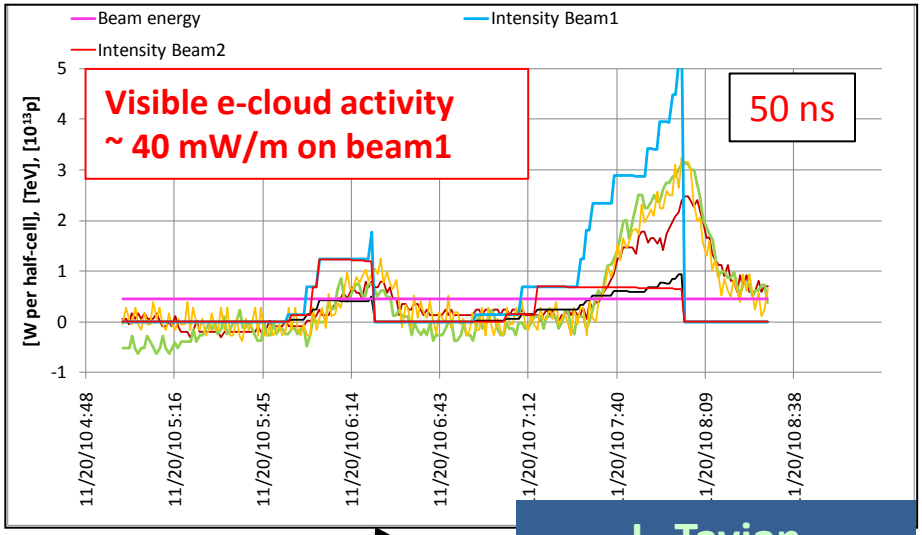
⇒ Look at the pressure gauge that shows the maximum pressure increase

⇒ Pressure rise more severe with 50 ns beams than with 75 ns

2010 Observations @ LHC

Comparing heat loads





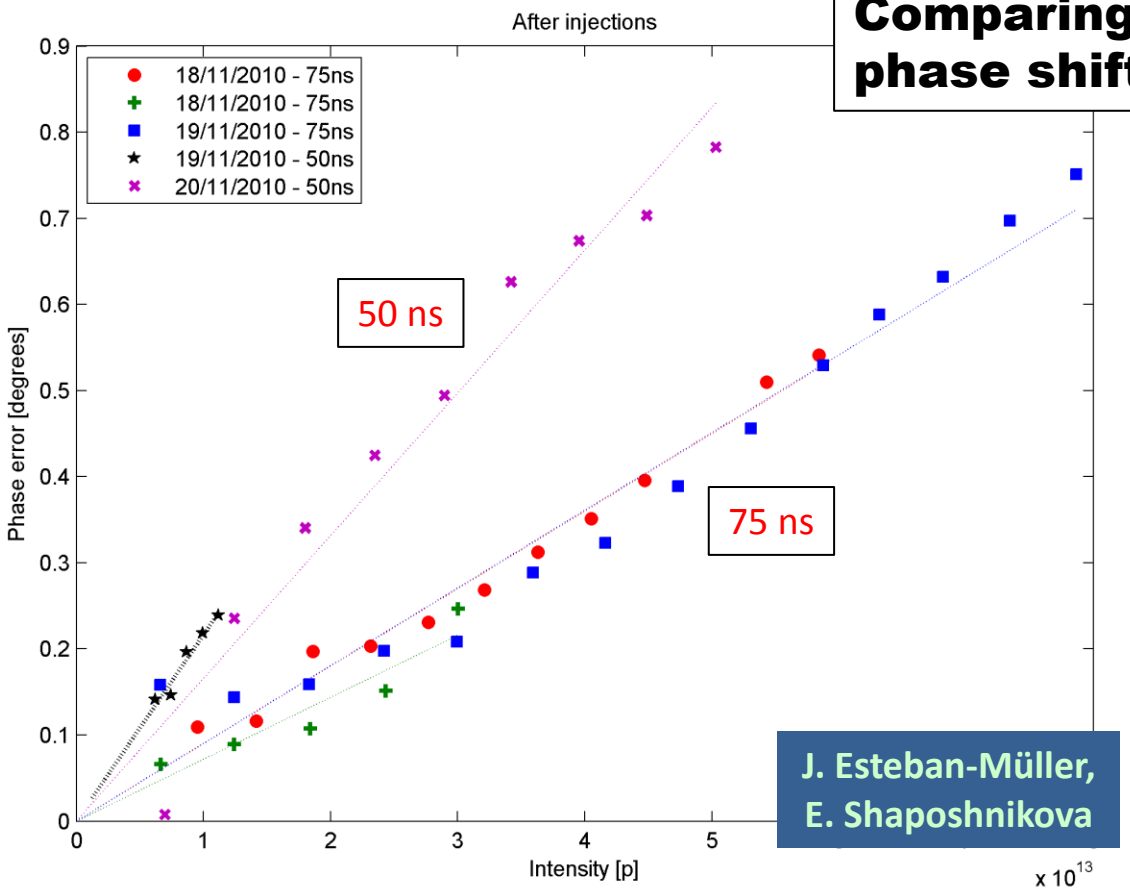
L. Tavian

⇒ Heat load measured at the beam screen hardly detectable from the noise level for the 75 ns beams (up to 824 bunches injected)

⇒ Significant heat load (40mW/m/beam) measured with 50 ns beams (up to 444 bunches injected)

2010 Observations @ LHC

Beam 1
50 ns and 75 ns beams
Voltage 3.5 MV

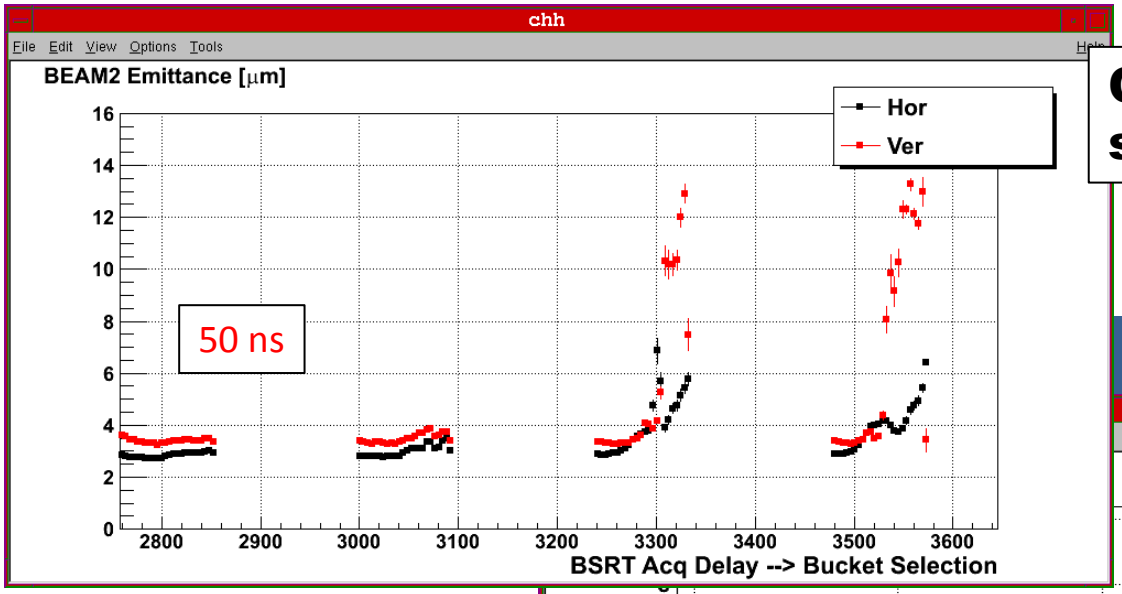


Comparing stable phase shifts

J. Esteban-Müller, E. Shaposhnikova

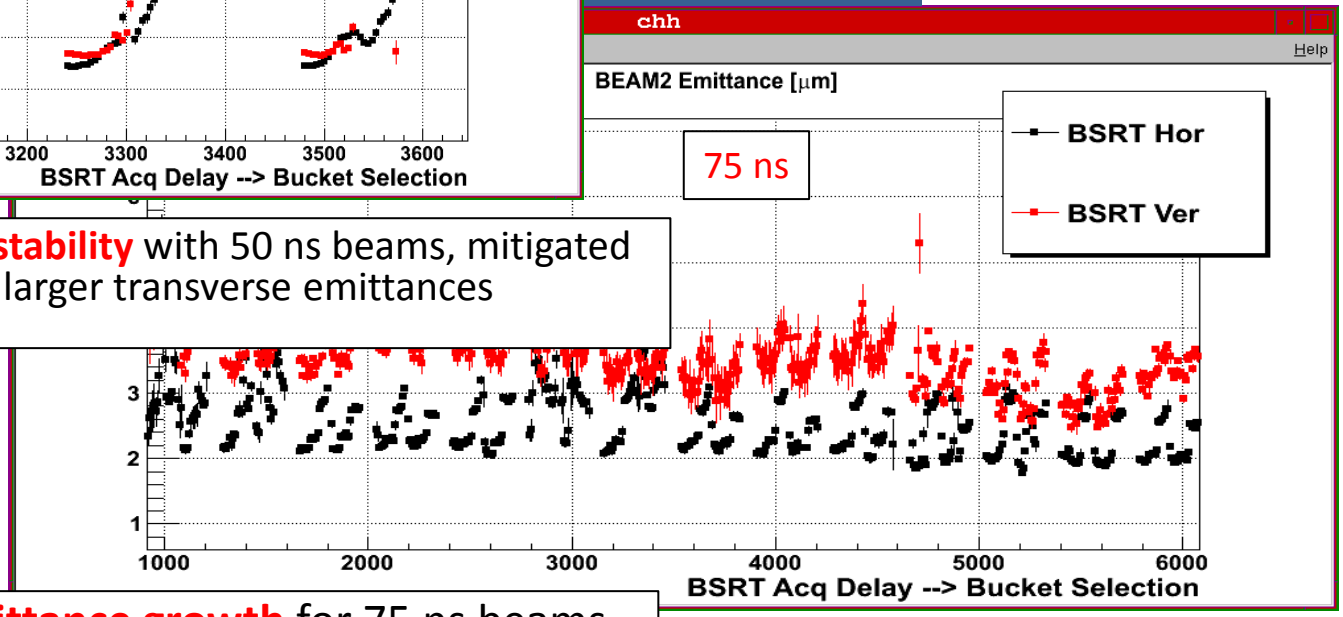
⇒ The **slope $\Delta\phi_s/\Delta N$** with 50 ns beams is about twice the value measured with 75 ns beams

2010 Observations @ LHC



Comparing beam stability

F. Roncarolo



⇒ Typical **electron cloud instability** with 50 ns beams, mitigated by larger chromaticity or larger transverse emittances

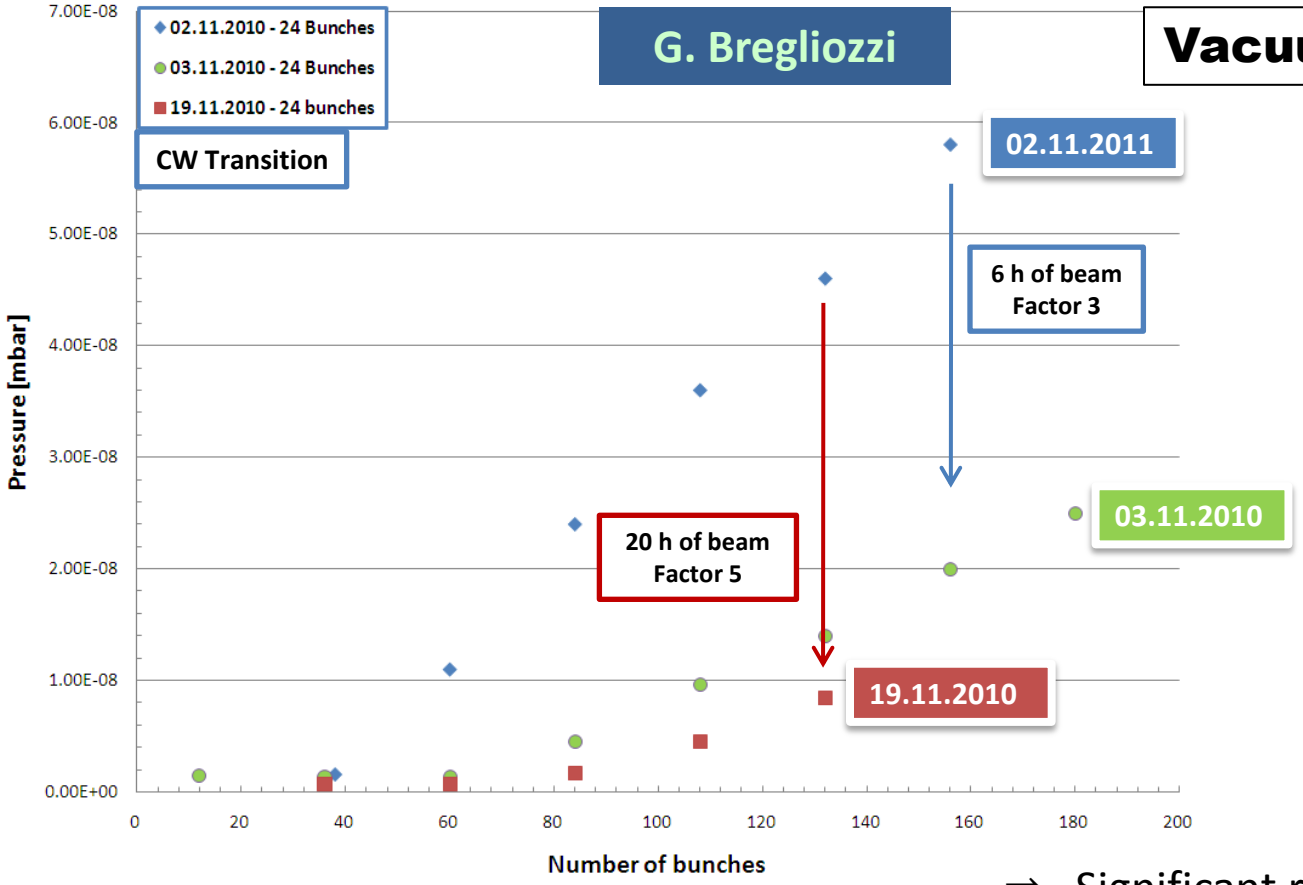
⇒ Some **emittance growth** for 75 ns beams

2010 Observations @ LHC

- **Scrubbing with 50 and 75 ns beams**
  - 3 effective days with 50 ns beam + 2.5 effective days with 75 ns beam and comparative measurements with 50 ns beam
  - Visible improvement of electron cloud related effects

⇒ For example …

2010 Observations @ LHC

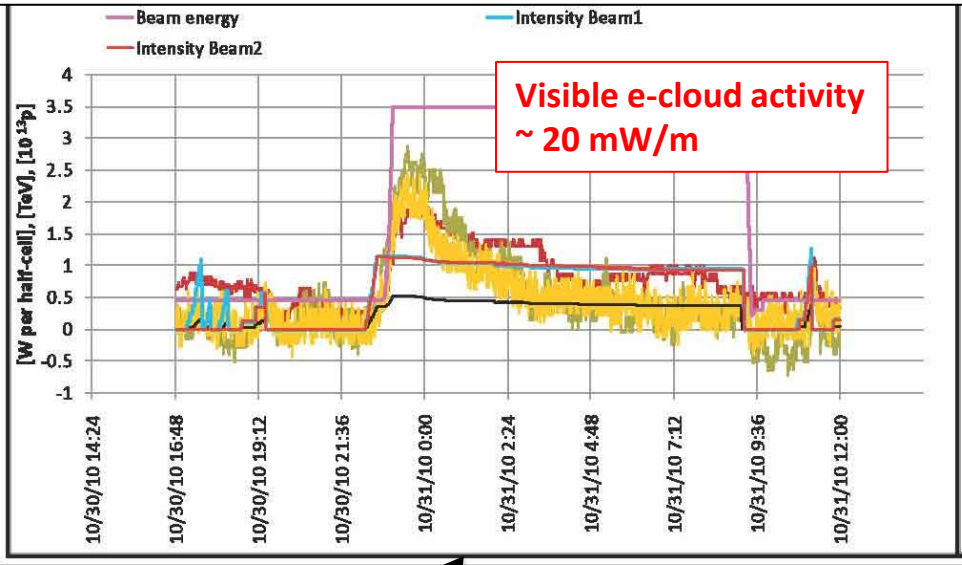


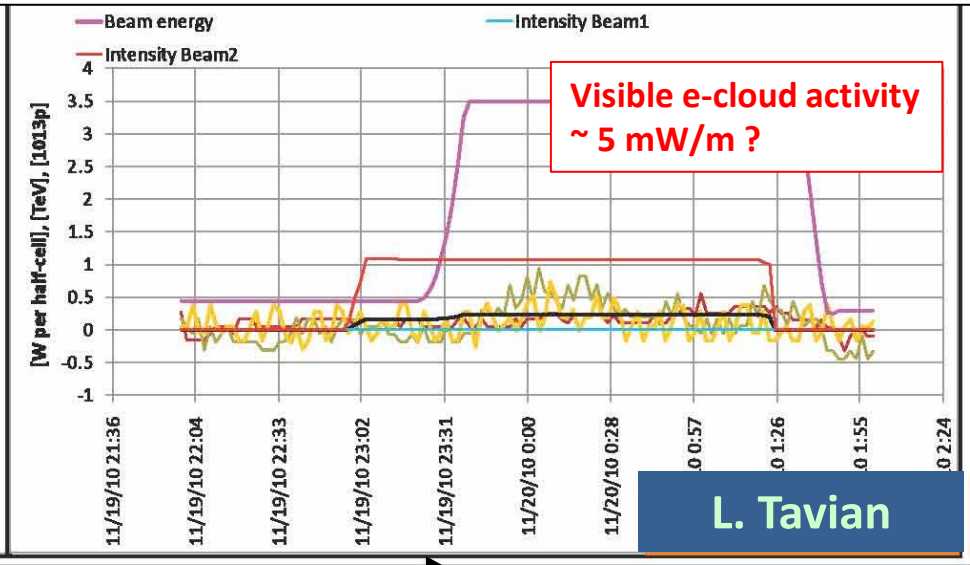
⇒ Significant reduction of dynamic pressure

⇒ Due not only to SEY scrubbing, but also to η_e conditioning!

2010 Observations @ LHC

Heat load improved!





⇒ Heat load measured at the beam screen when ramping to 3.5 TeV one batch of 36 bunches at 50 ns spacing (**prior to scrubbing**)

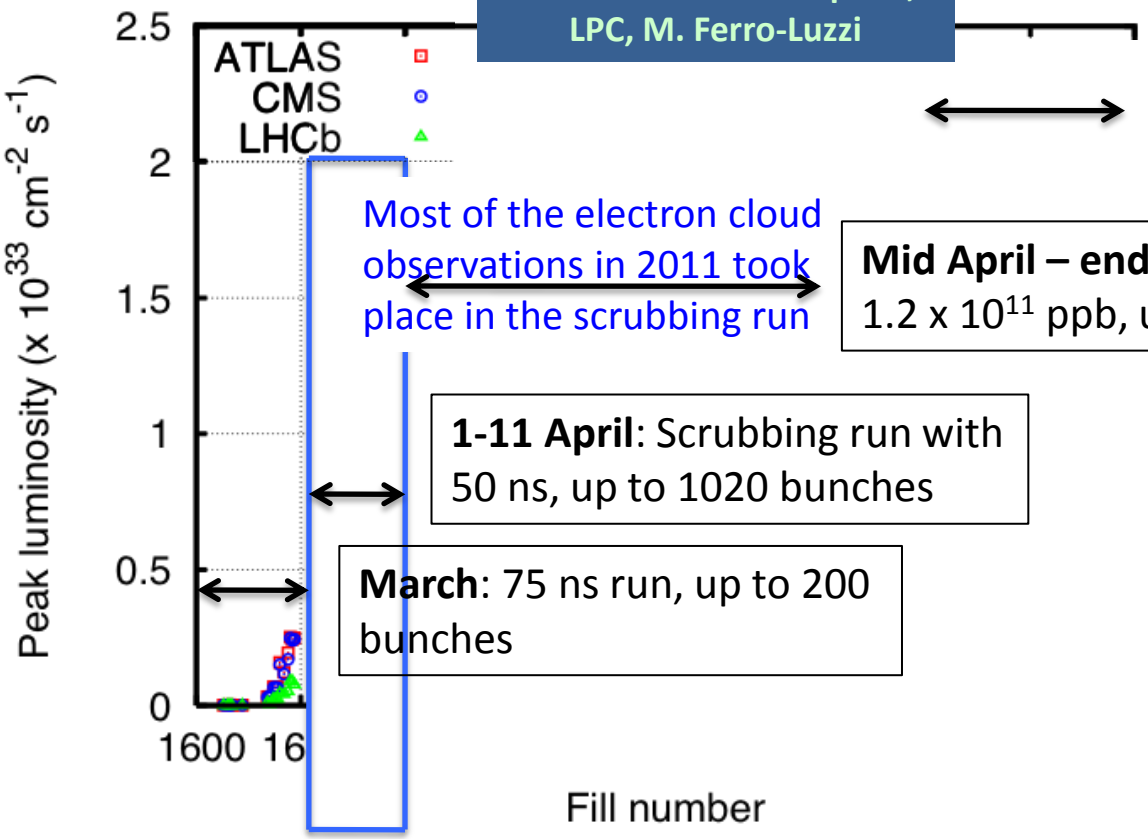
⇒ Heat load measured at the beam screen when ramping to 3.5 TeV one batch of 36 bunches at 50 ns spacing (**after scrubbing**)

2010 Observations @ LHC

- **Partial summary 2010**
  - Lower vacuum activity with 75 ns spacing as compared with 50 ns, but important pressure rise observed for large number of bunches also for 75 ns
  - Heat load in the arcs measured with 50 ns beams, but not with 75 ns beams
  - Typical signature of Electron Cloud Instability observed with 50 ns. For 75 ns beam, emittance blow-up is visible correlated to incoherent effects leading to low lifetime and losses

⇒ Visible improvement of electron cloud related effects achieved with limited time running with 50 and 75 ns beams (mini-scrubbing). Maybe enough to start 75 ns operation, but additional scrubbing necessary for 50 ns !!

2011 Observations @ LHC



Data from LHC Lumi plots, LPC, M. Ferro-Luzzi

Mid July – now: 50 ns run, $\varepsilon_{x,y} \approx 1.5$ μm, up to 1.35×10^{11} ppb, up to 1380 bunches

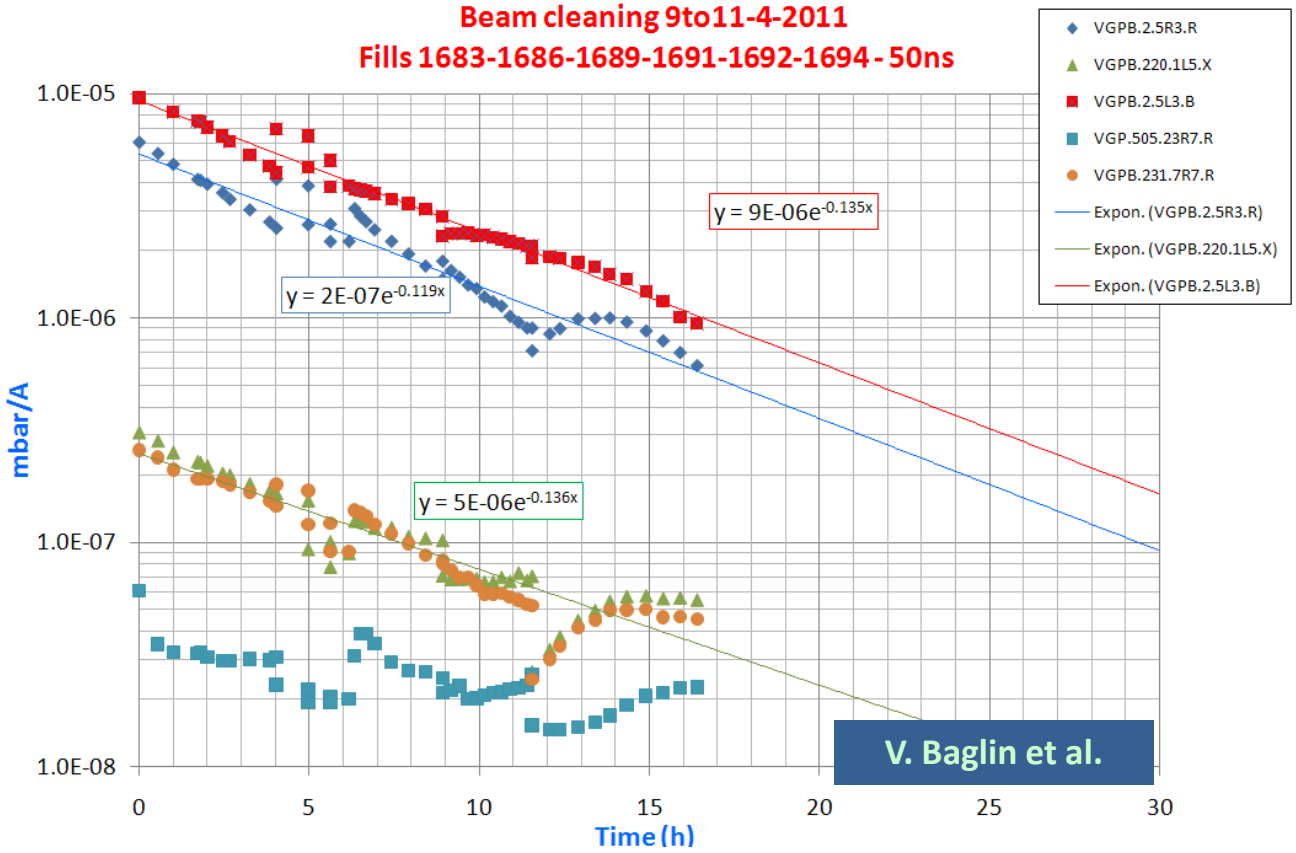
Most of the electron cloud observations in 2011 took place in the scrubbing run

Mid April – end June: 50 ns run, $\varepsilon_{x,y} \approx 2.5$ μm, 1.2×10^{11} ppb, up to 1380 bunches

1-11 April: Scrubbing run with 50 ns, up to 1020 bunches

March: 75 ns run, up to 200 bunches

2011 Observations @ LHC: scrubbing

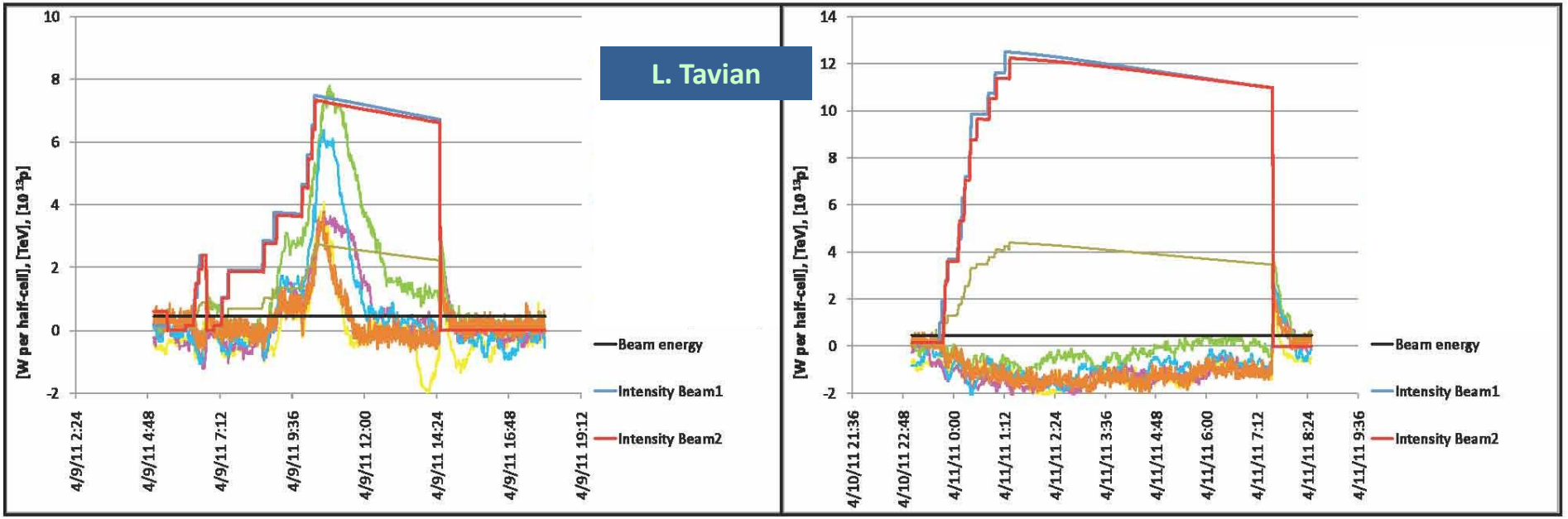


⇒ The pressure around the machine gained one order of magnitude in about 17 hours

⇒ By end June, when the LHC was operating with 1380 bunches per beam, an additional decrease by one order of magnitude has been obtained.

⇒ Slight “return” of pressure rises with low emittances and higher bunch currents

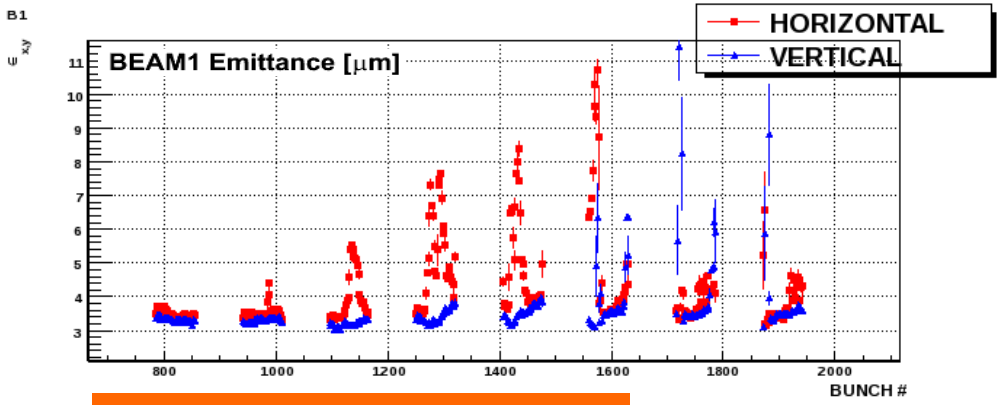
2011 Observations @ LHC: scrubbing



⇒ Heat load on the beam screen was observed at the beginning of the scrubbing run with only 200 bunches per beam in LHC, and was still visible up to half way through it

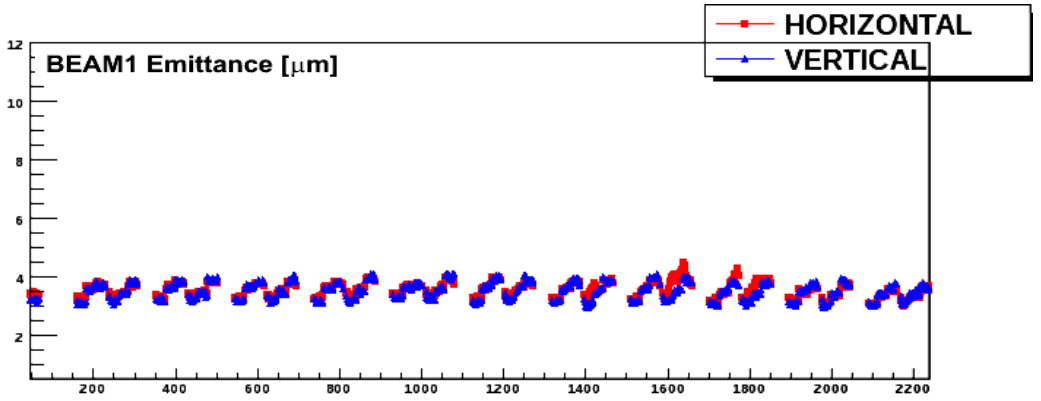
⇒ By the end of the scrubbing run, no heat load could be measured with 1020 bunches per beam inside the LHC!

2011 Observations @ LHC: scrubbing



G. Arduini

Day 1 – 300 bunches

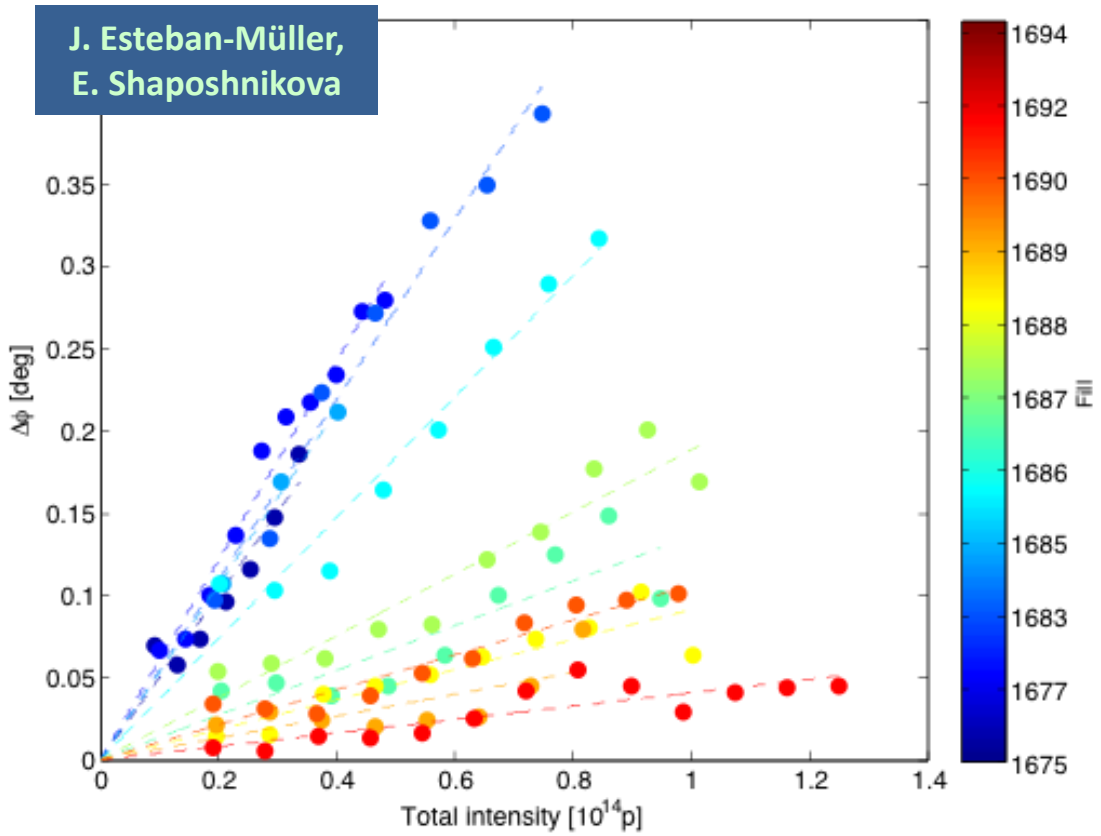


Day 3 – 800 bunches

⇒ Instabilities and emittance growth observed during the first part of the scrubbing run

⇒ No significant sign left at the end of the scrubbing

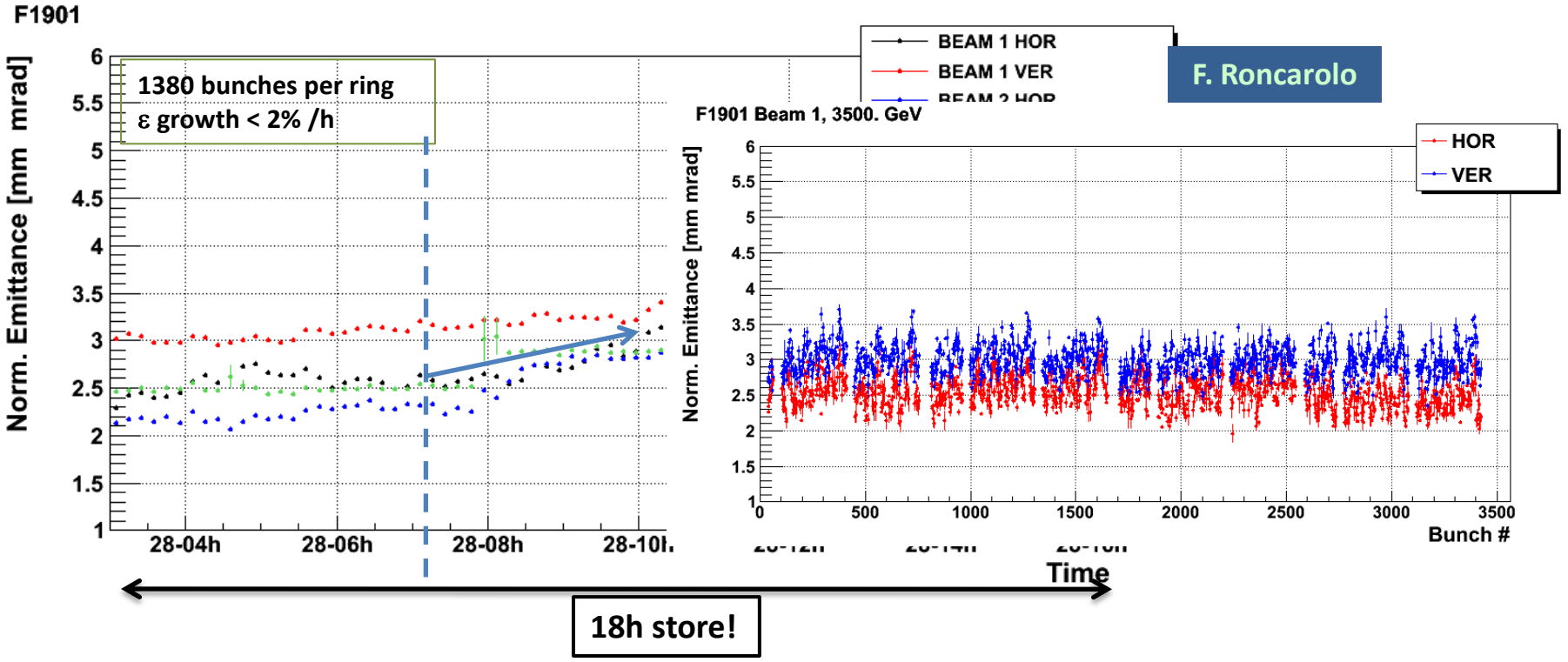
2011 Observations @ LHC: scrubbing



⇒ The slope of the phase shift with intensity has gradually decreased over the period of the scrubbing run (50 ns beams)

⇒ The slope $\Delta\phi_s/\Delta N$ has lost one order of magnitude thanks to scrubbing!

2011 Observations @ LHC: post-scrubbing

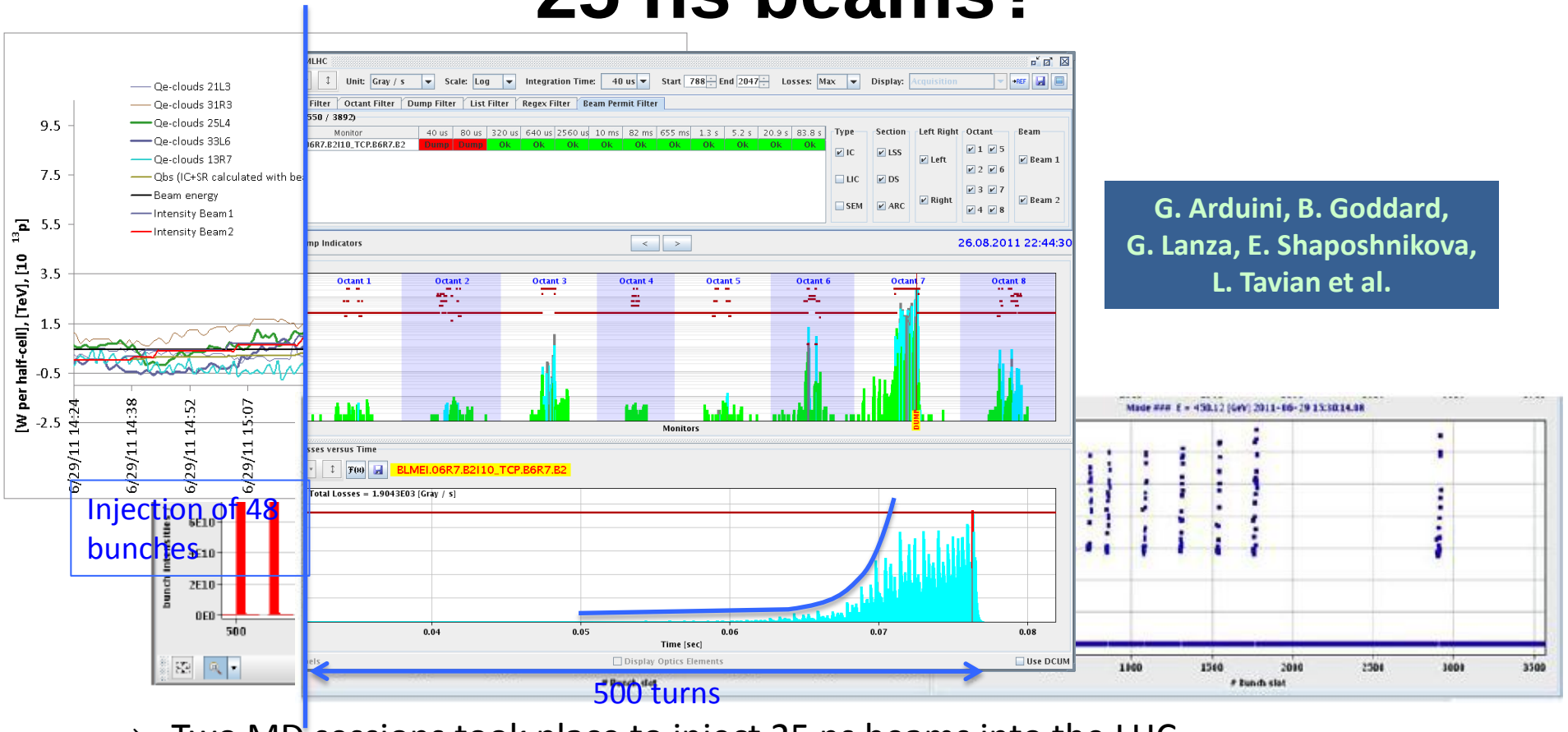


⇒ **Scrubbing successful!!** → number of bunches in LHC gradually increased up to the maximum (1380 per beam)

⇒ SEY inferred by models & observations has decreased from 1.9-2.0 to 1.7

⇒ Pressure & heat load well behaved, little emittance growth and no pattern that can be related to electron cloud

2011 Observations @ LHC: 25 ns beams?



G. Arduini, B. Goddard, G. Lanza, E. Shaposhnikova, L. Tavian et al.

⇒ Two MD sessions took place to inject 25 ns beams into the LHC

⇒ Already injecting trains of only 24 bunches, a few signs are observed (heat load, pressure rise, emittance growth)

⇒ Recrudescence with longer trains? How much additional scrubbing needed??

Summary & Conclusions

- **Electron cloud @ LHC in 2010 – 2011**
  - Several electron cloud indicators were observed at the LHC in the 2010 – 2011 runs
    - Pressure rise around the machine, especially pronounced in the common vacuum chambers
    - Heat load in the arcs measured with 50 ns and 25 ns beams
    - Electron Cloud Instability observed with 50 ns beams and incoherent effects for 75 ns beam
    - Bunch spacing dependent synchronous phase shift to compensate for energy loss due to the beam-cloud interaction

  ⇒ Visible mitigation of electron cloud could be achieved thanks to machine scrubbing → smooth operation with 50 ns beams now possible

  ⇒ 25 ns beams for future operation?