E-cloud observations at the LHC

G. Arduini – CERN-BE/ABP

with input from: V. Baglin, H. Bartosik, O. Dominguez Sanchez De La Blanca, U. Iriso, J.M. Jimenez, K. Li, H. Maury, E. Métral, F. Roncarolo, G. Rumolo, B. Salvant, F. Zimmermann

Acknowledgements: BI, Cryo, Injection, OP, RF teams

Outline

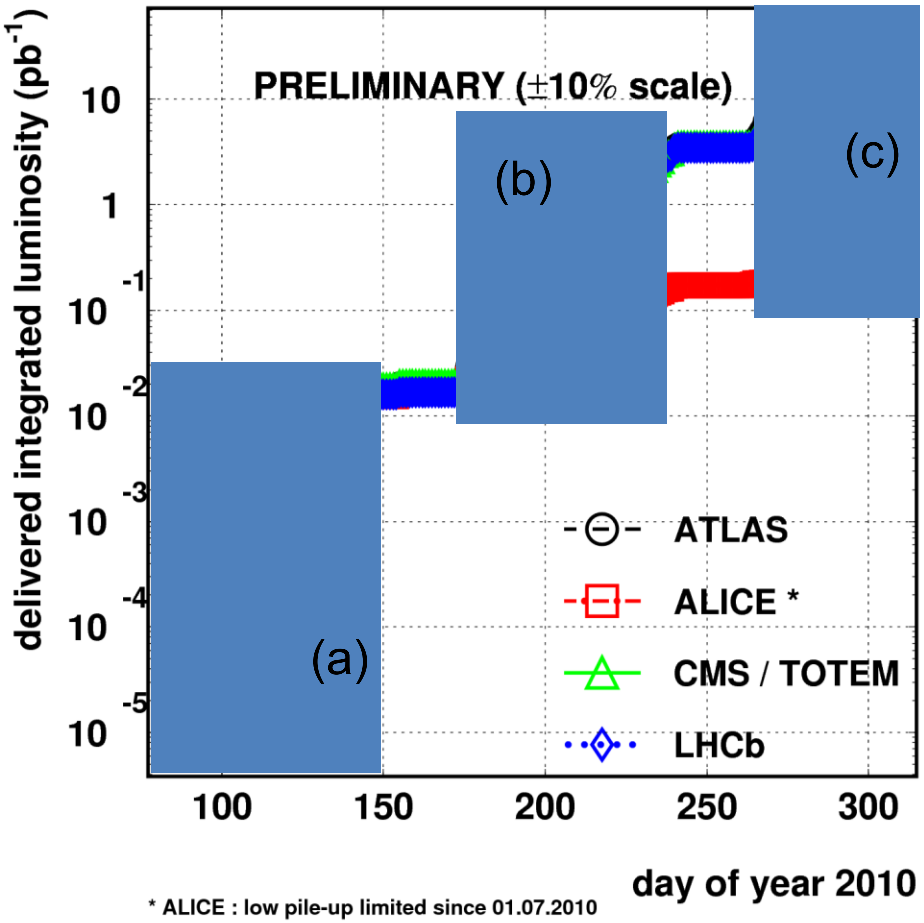
- Overview of 2010 run
- Motivations for 50 and 75 ns runs in 2010
- LHC countermeasures for electron cloud
- Effects on vacuum
- Effects on cryogenics
- Beam stability observations and expectations
- Summary

Overview of 2010 proton run

- 2010 in numbers:
  - Max peak luminosity ~**2 10^{32} s^{-1} cm^{-2}** (p-p run)
  - Integrated luminosity: **48 pb^{-1}** (p-p run)
- Machine parameters achieved at the end of the p-p period

Parameter	2010	Nominal
Energy ($\rightarrow\gamma$)	3.5 TeV	7 TeV
Squeeze (β^*)	3.5 m	0.55 m
Transverse emittance (ε_N)	2-3 μm rad	3.75 μm rad
Protons per bunch (N)	Up to 1.2 10^{11}	1.15 10^{11}
Bunch separation	150 ns	25 ns
Number of bunches (n_b)	368	2808

Overview of 2010 proton run

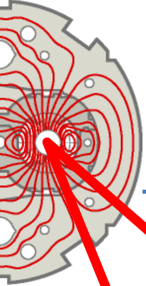


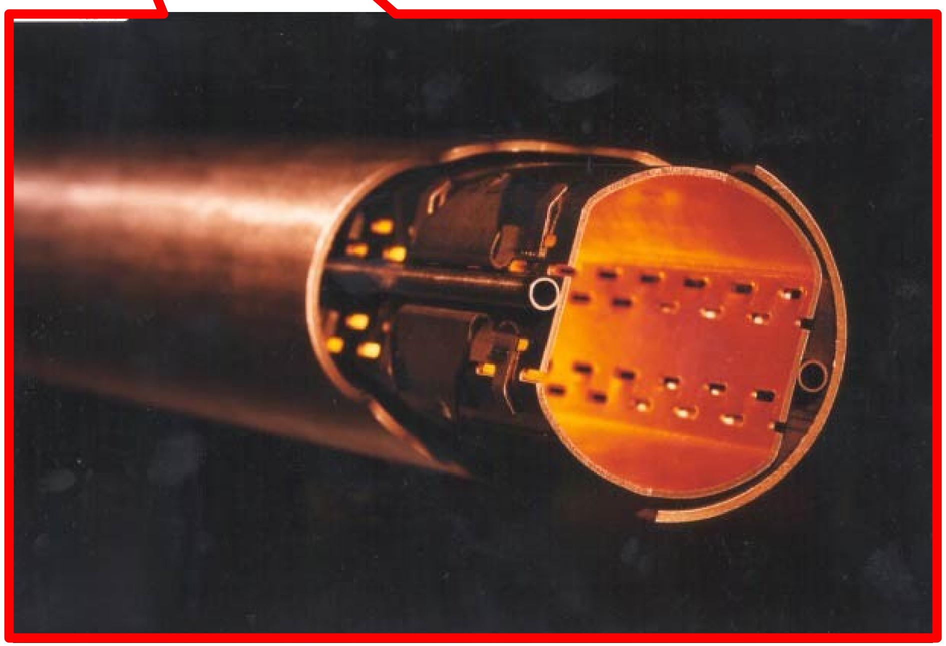
- Three distinct periods:
  - (a) Initial phase with low intensity bunches
  - (b) Then a phase with nominal bunch population but sparsely spaced bunches
  - (c) Finally a last phase with bunch trains and 150 ns separation between bunches. During this operation vacuum pressure rise observed in common regions close to the IPs

Motivations for the 50 and 75 ns MDs

- Early look at potential problems for 2011 operation with 50 and 75 ns beams at the end of the proton run with 150 ns beams:
  - Study of electron cloud effects (vacuum rise, heat load on the cryogenics, instabilities) and benchmark with simulations
  - Preliminary validation of the countermeasures (e.g. scrubbing)
  - .....
  - Study long range beam-beam effects
  - Analyze behaviour of Beam Instrumentation and RF/transverse feedback
  - Exploration of luminosity production (backgrounds, lifetimes, etc.)

LHC countermeasures against e-cloud



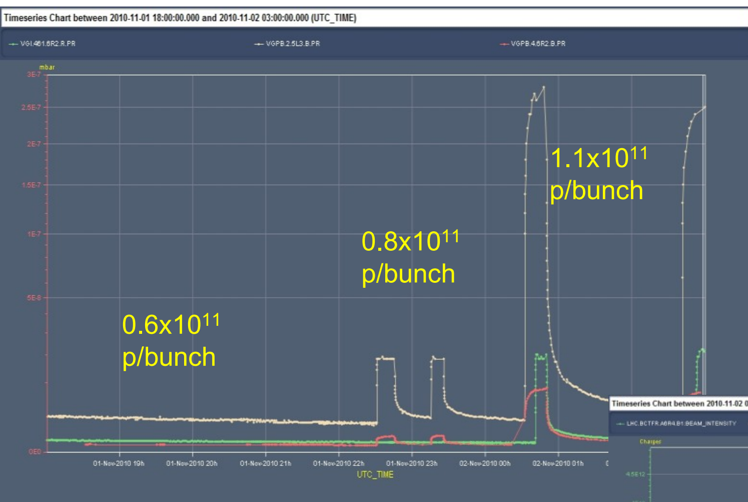


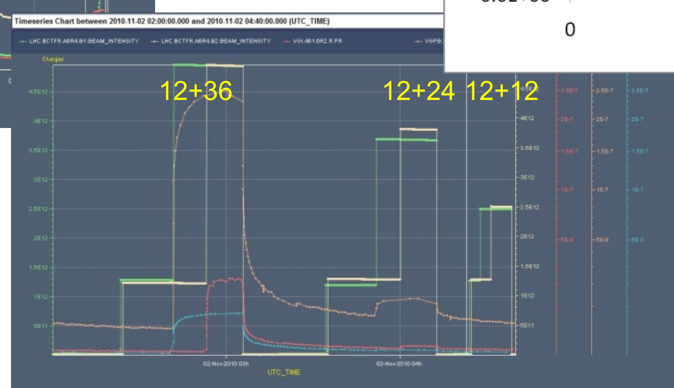
- Warm sections (20% of circumference) coated by TiZrV getter ➔ low SEY. Excepted cold-warm (uncoated and unbaked) and warm-warm transitions (uncoated) – few hundred meters
- Outer wall of beam screen (at 4-20 K, inside 1.9-K cold bore) with sawtooth surface to reduce photon reflectivity to ~2% ➔ photoelectrons emitted only from outer wall & confined by dipole field
- pumping slots in beam screen are shielded to prevent electron impact on cold magnet bore
- rely on surface conditioning (‘scrubbing’) to reduce SEY

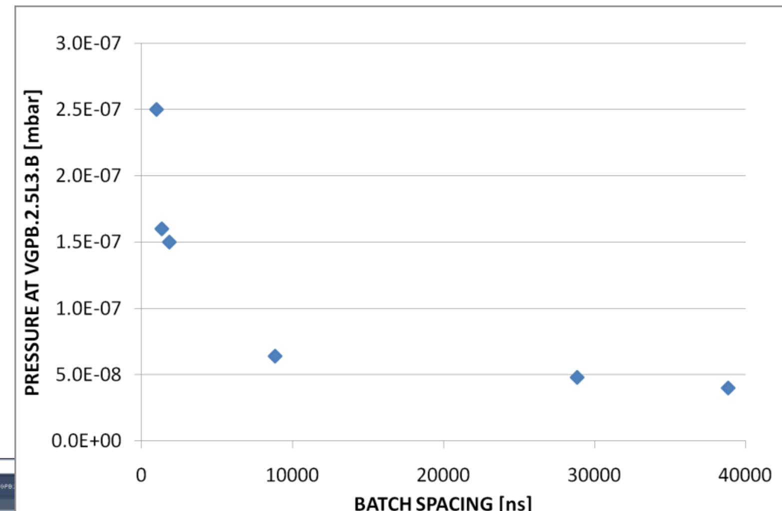
F. Zimmermann – CERN/GSI meeting 30/3/2006

Vacuum – 50 ns – 450 GeV/c

- Vacuum rise in all uncoated warm-warm and warm-cold transitions (where vacuum pressure measurements exist):
  - pressure rise is observed also in vacuum pipes with single beam (not for 150 ns)
  - threshold of 6-8×10^{10} p/bunch and with trains of 24 bunches
  - Electron-cloud builds up after more than 12 bunches
  - Electron survival time up to 8-9 μs

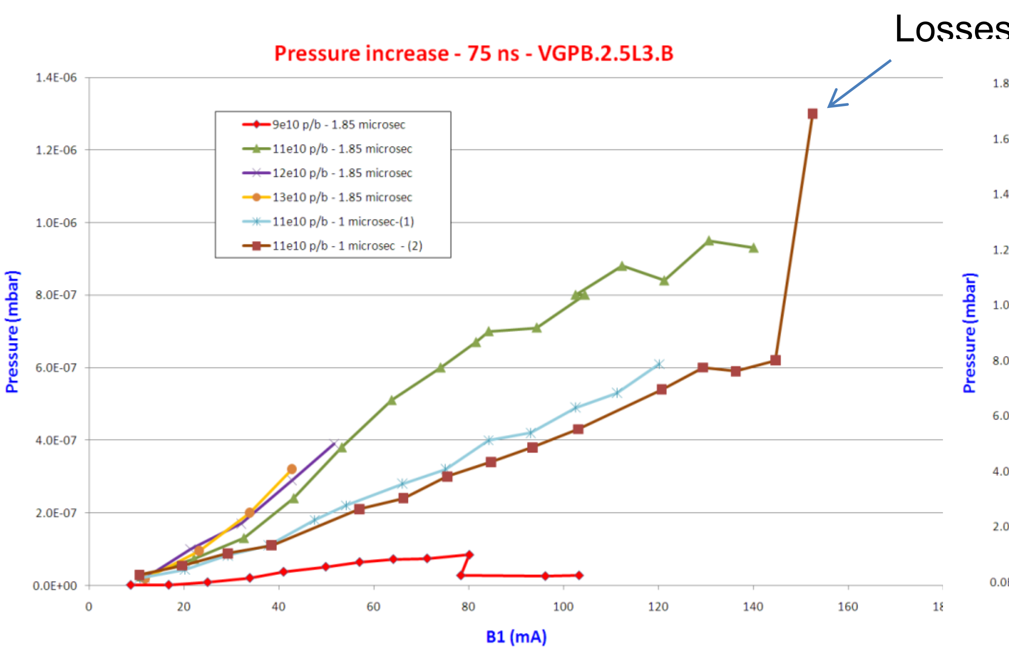


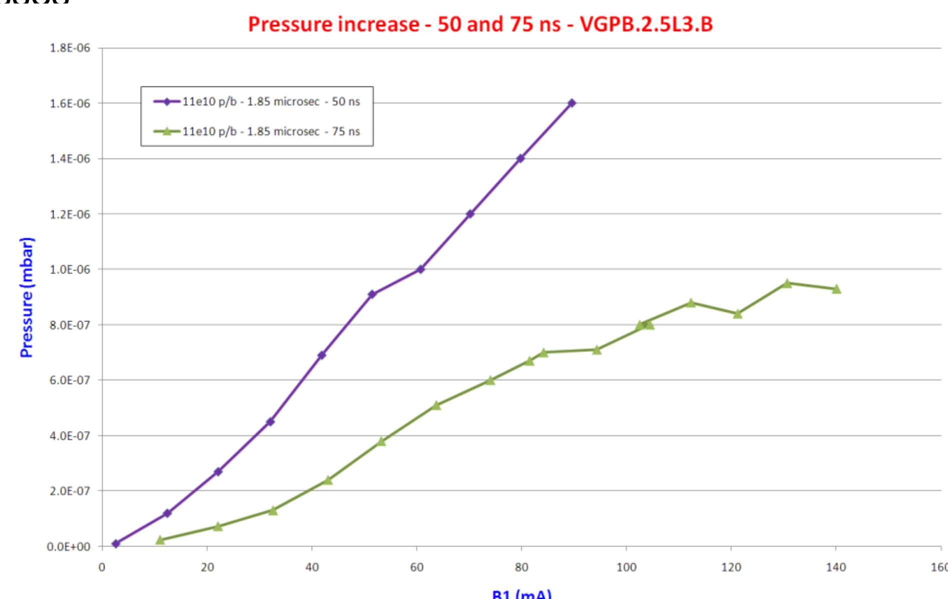




Vacuum – 75 ns – 450 GeV/c

– Vacuum rise in all uncoated warm-warm and warm-cold transitions:
  - pressure rise is observed also in vacuum pipes with single beam (not for 150 ns)
  - Threshold of 9-10×10^{10} p/bunch. Increase by a factor ~3 when going from 1.1 to 1.3 x 10^{11} p/bunch.
  - Saturation after 2-3 trains of 48 bunches each
  - Important pressure rise when we inject a larger number of bunches (incompatible with ramp where we have additional effect of synchrotron light for p>~1.5-2 TeV)



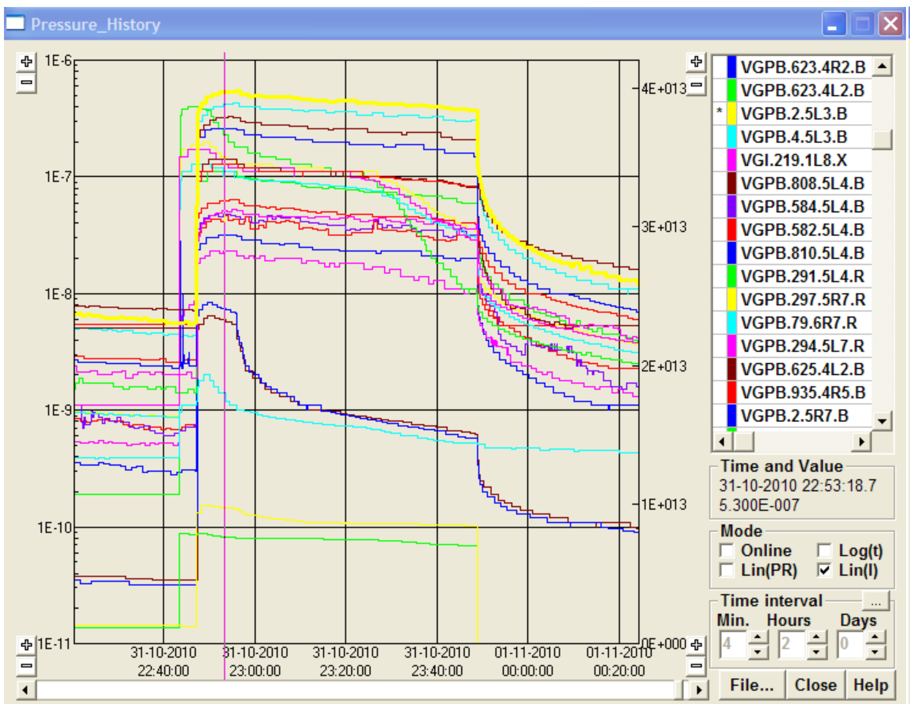


V. Baglin

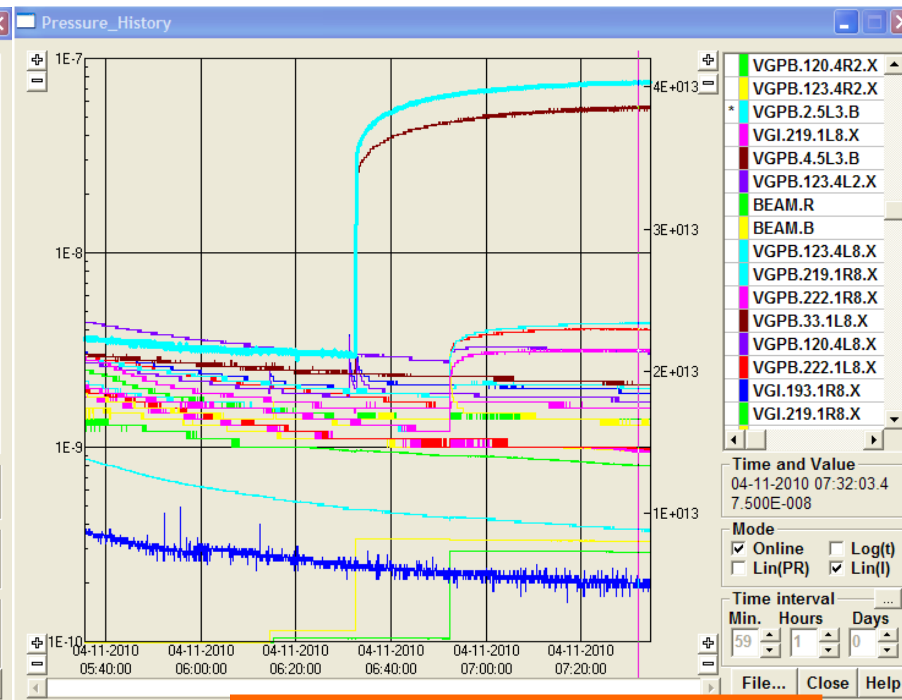
Scrubbing – 50 ns

- Comparison between pressure rise before and after scrubbing run for 12+36 bunches at 450 GeV (reduction by a factor 7 after ~16 hours with pressures larger than 10^{-7} mbar)

31/10: max p @
LSS3 VGPB.5L3.B = 5.5E-7 mbar



04/11: max p @
LSS3 VGPB.2.5L3.B=7.5E-8 mbar

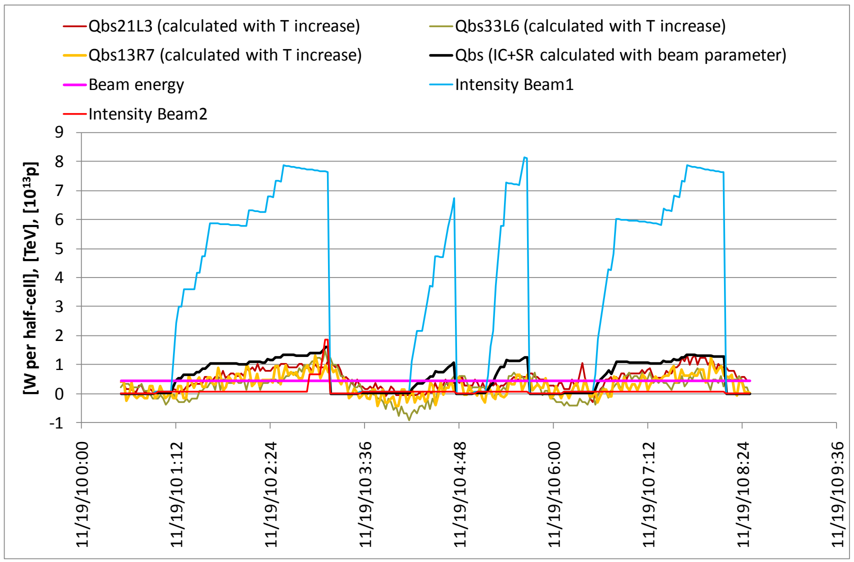


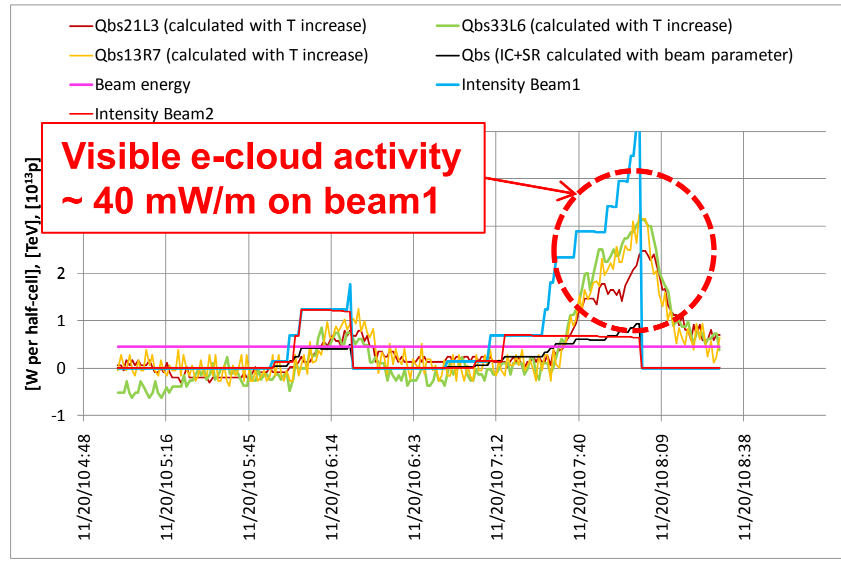
G. Bregliozzi, G. Lanza

Cryogenics: 75 ns vs. 50 ns

75 ns up to 824 bunches (Beam 1). No detectable heat load due to e-cloud ➔ no scrubbing in the arcs

50 ns up to 444 bunches (Beam 1) ➔ heat load due to e-cloud ➔ scrubbing in the arcs



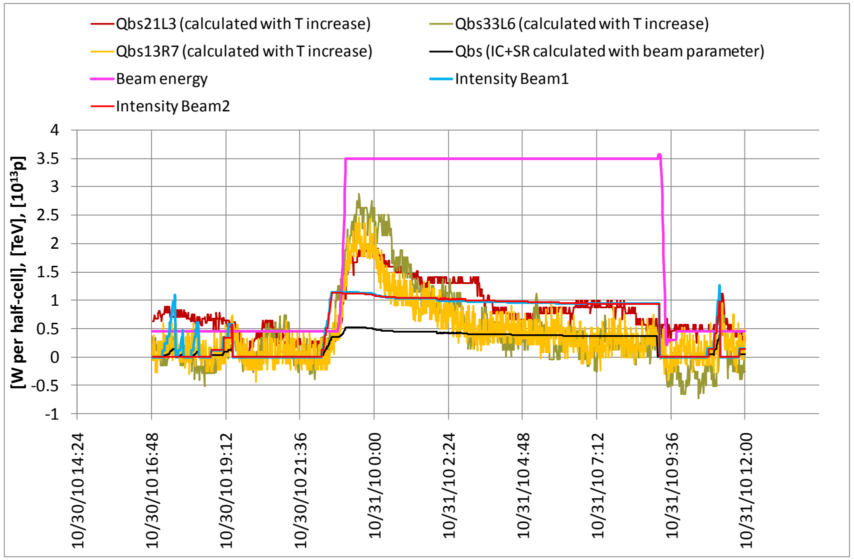


L. Tavian

For both beams significant heat load in the beam-screens of the triplets-cold D1 region (particularly L8)

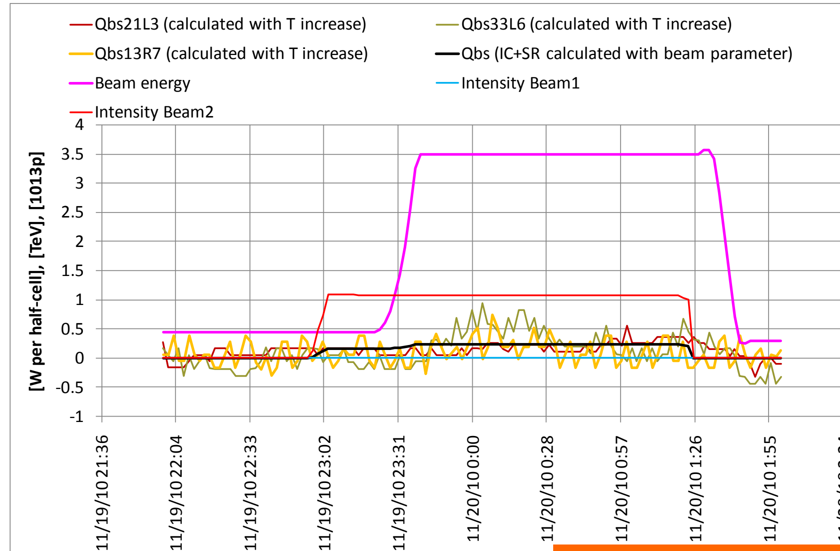
Effect of scrubbing (50 ns)

Before scrubbing (30/10): Heat load ~20 mW/m/beam



After scrubbing (19/11)

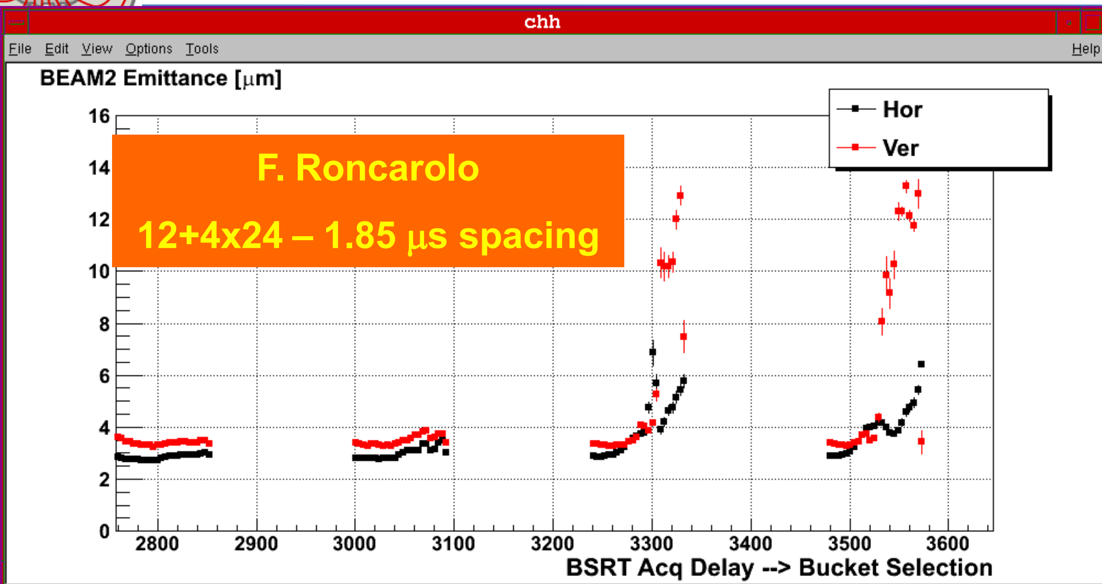
Heat load <10 mW/m/beam. Only B2



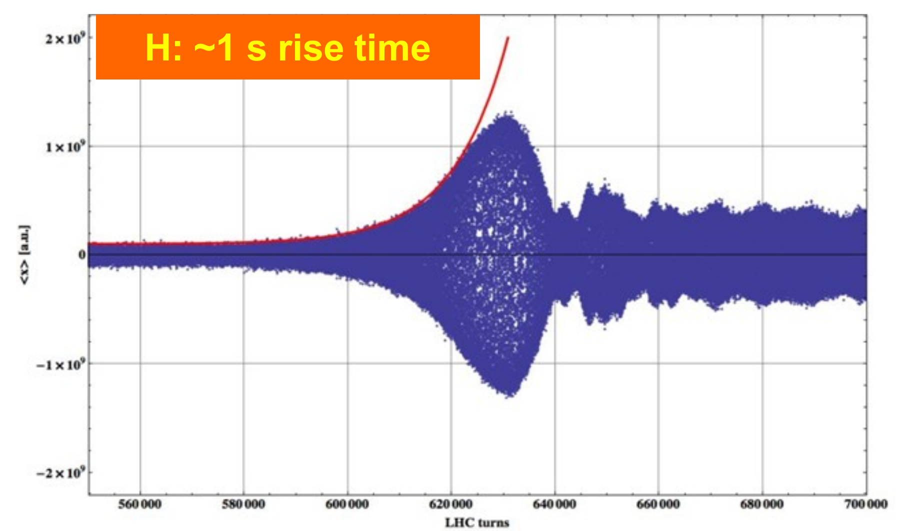
L. Tavian

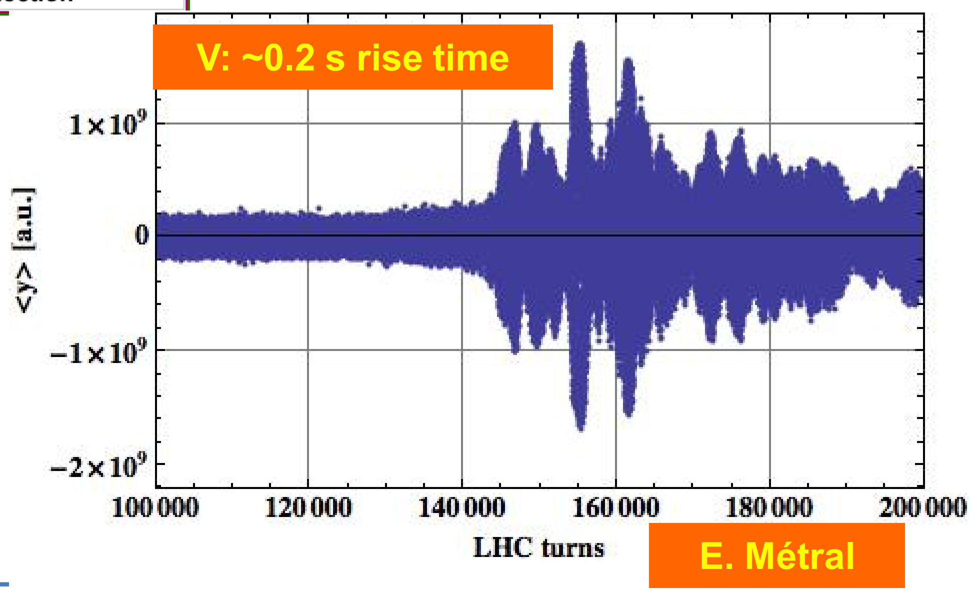
Same filling pattern (9x12 b) and bunch population (~10^{11} p). Scrubbing at 450 GeV effective also for 3.5 TeV in the arcs

Beam stability at 450 GeV/c (50 ns)

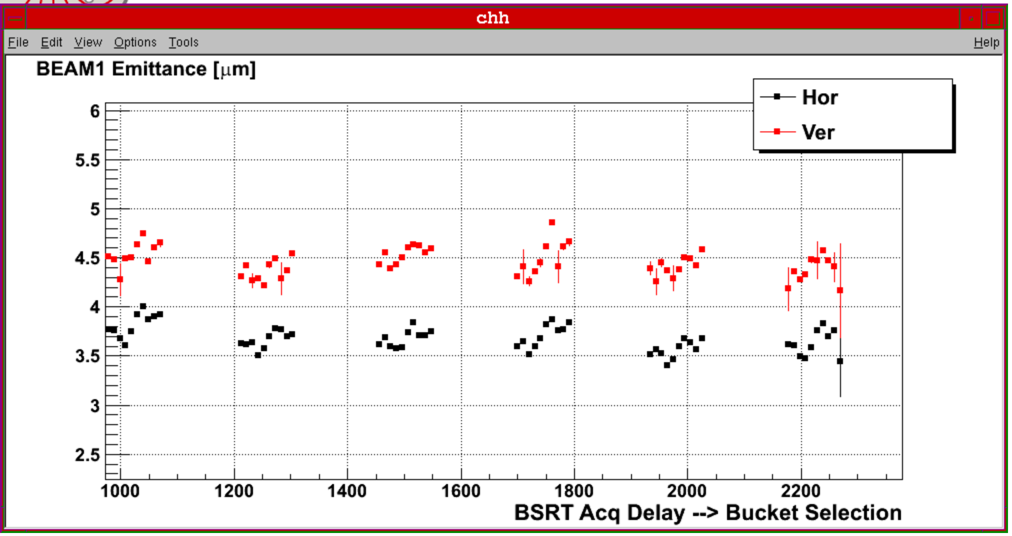


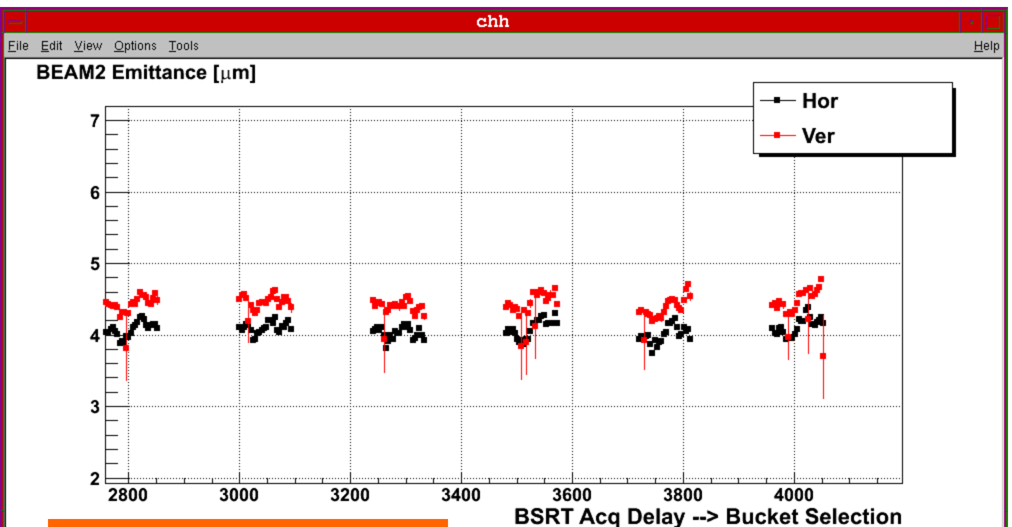
- E-cloud build-up over more trains ➔instabilities, ε blow-up (mostly V)
- Expected behaviour of instability driven by electron cloud in the arcs: coupled bunch instability in H-plane (➔ damper)
- single bunch instability in the V-plane





Beam stability at 450 GeV/c (50 ns)





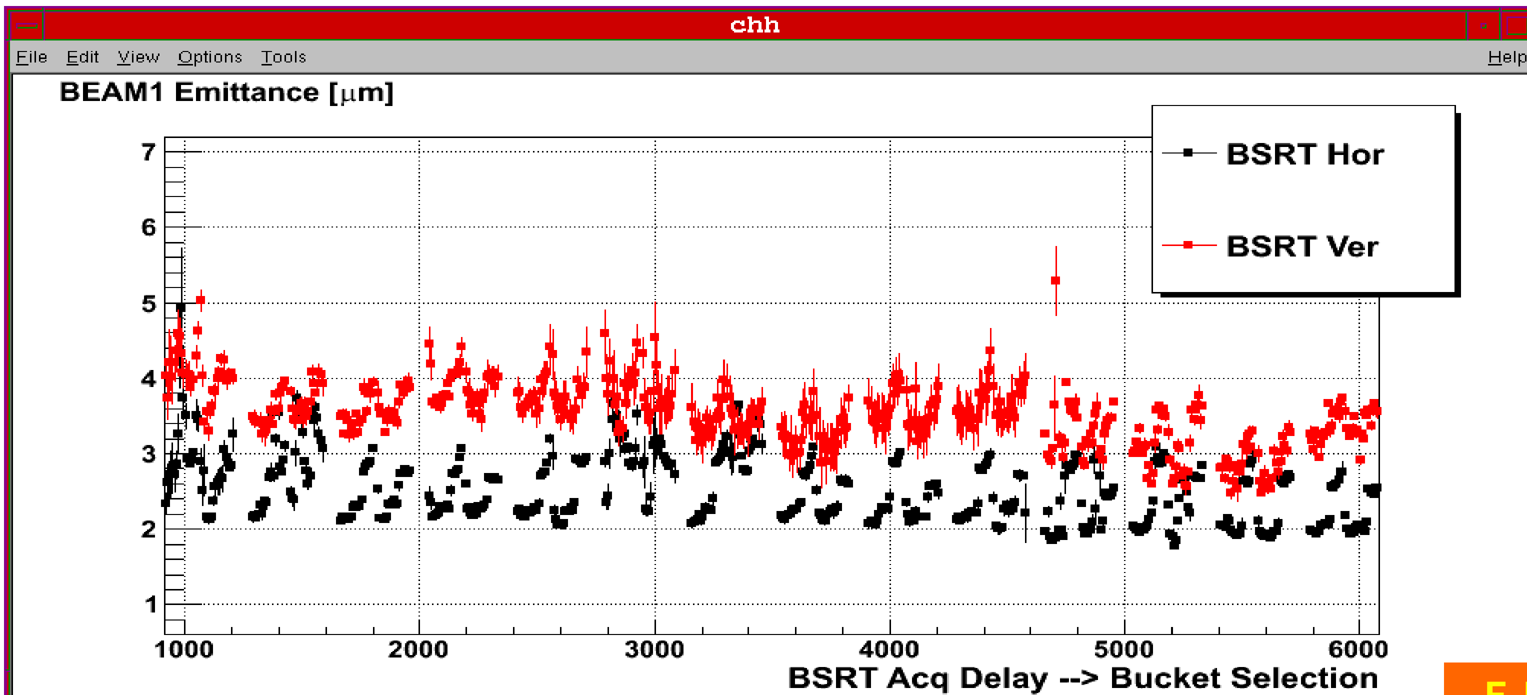
F. Roncarolo

- Single bunch instability can be stabilized by increasing chromaticity to very large values (up to 18 units) and by transverse emittance blow-up in the injectors (~3-3.5 μm @ SPS extr.) although blow-up is still observed.
- Effect of the chromaticity predicted by simulations (E. Benedetto, F. Zimmermann 2006)
- This is the way we have to run for scrubbing but not possible for physics due to the low lifetime and blow-up

Beam stability at 450 GeV/c (75 ns)

High chromaticity allows stabilizing the beam but blow-up (mainly vertical) is still observed ➔ Larger blow-up in the vertical plane compatible with instability and incoherent effects generated by e-cloud close to threshold

Bunch population = 1.2×10^{11} p - batch spacing 1.005 μs



F. Roncarolo

Instability thresholds

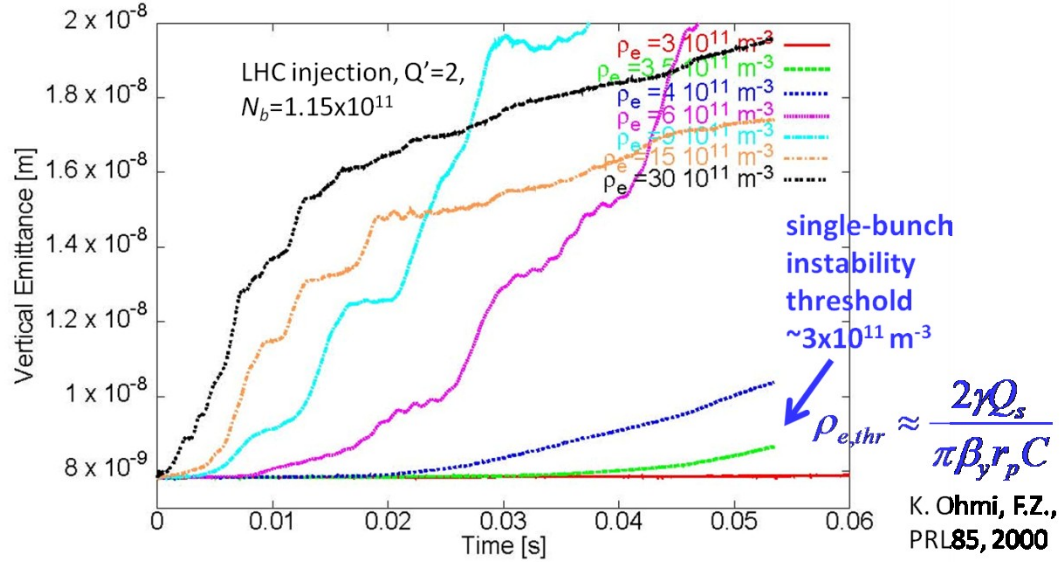


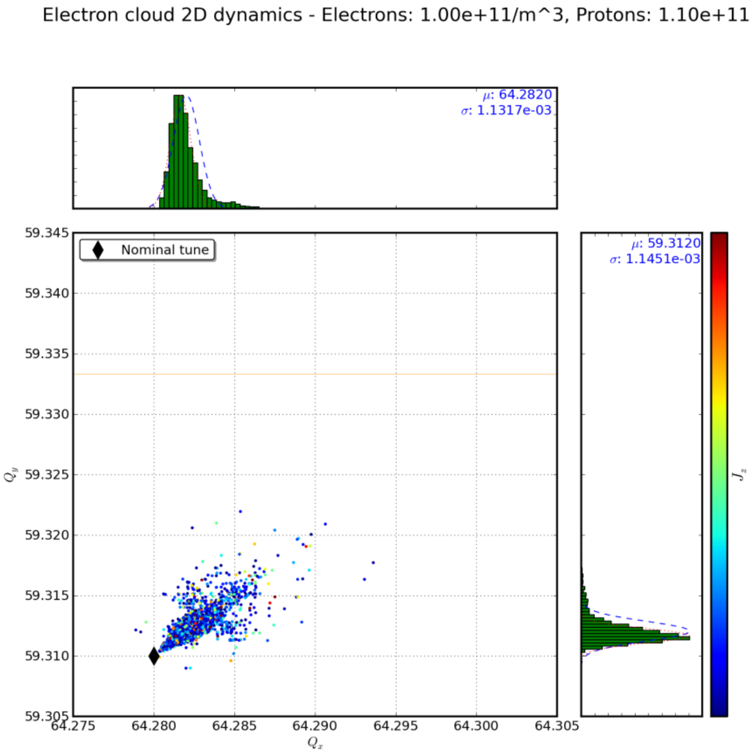
Figure 7.8. Vertical emittance as a function of time for different values of electron cloud density, and $Q' = 2$ (for LHC at injection).

enedetto, F. Zimmermann (2006)

- No single bunch e-cloud instability expected at 450 GeV/c (worst case) and 3.5-4 TeV/c if electron density <10^{11} e^-/m^3 at the beam position.
- Once the threshold electron density is reached the beam is unstable

Incoherent effects

450 GeV/c (for 30% of LHC field free and 70% of LHC dipole field)



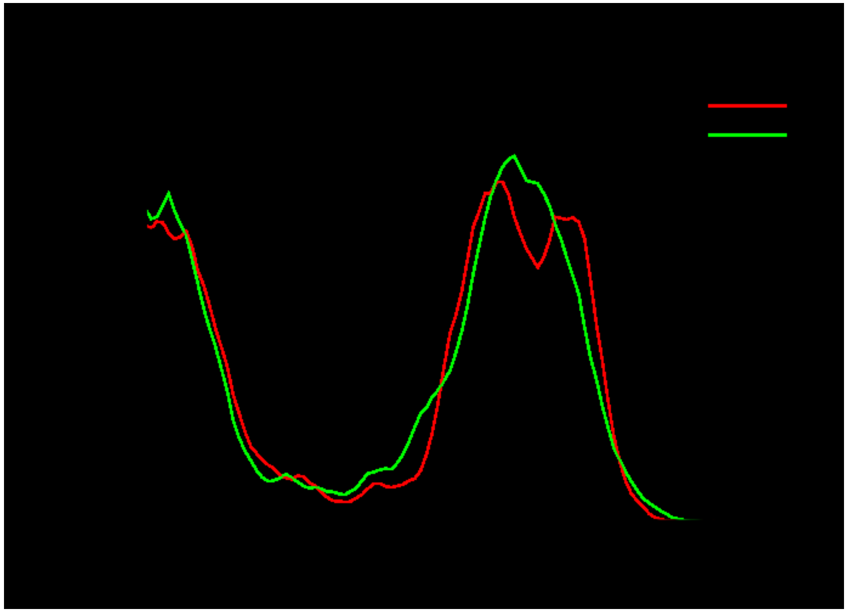
- Tune spread due to electron cloud pinching can reach 0.01 for 10^{11} e^-/m^3 at 450 GeV/c (worst case) at the beam position
- At 75 ns (>600 bunches) the heat load measured in the arcs was ~10 mW/m (close to resolution limit) ➔ AVERAGE e^- density of 6 x 10^{10} e^-/m^3 assuming an average e- energy of 100 eV and ~800 bunches
- 75 ns beam is at the limit of single bunch stability/incoherent effects even for low cryo activity in the arcs

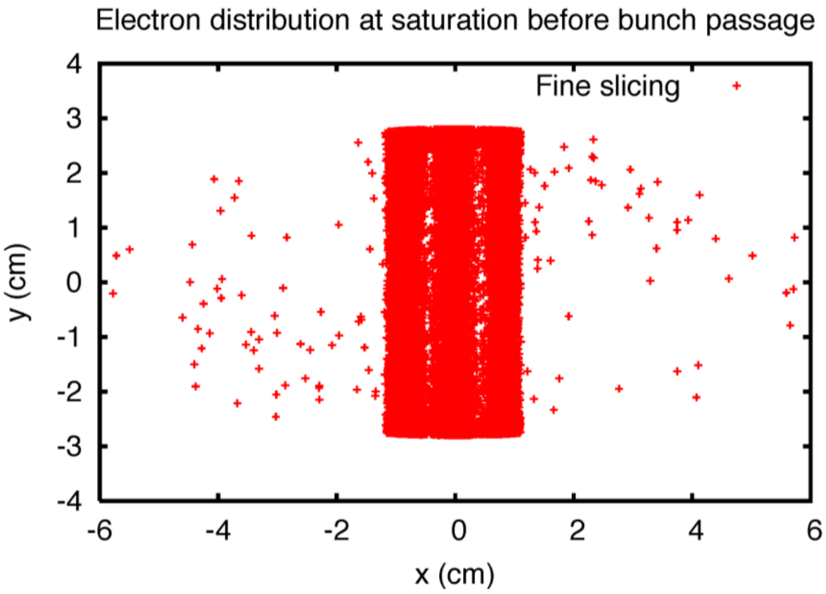
K. Li, G. Rumolo

Summary

- Reduced vacuum activity with 75 ns spacing as compared to 50 ns but important pressure rise observed for large number of bunches also for 75 ns ➔ need scrubbing to ramp and collide more than ~200-300 bunches with 75 ns spacing with no significant pressure rise
- Low heat load (close to detection limit) due to e-cloud in the beam screens for 75 ns beam (➔ *slow or no scrubbing in the arcs with 75 ns beam* ➔ *need scrubbing with 50 ns beam*)
- Typical signature of ECI observed with 50 ns. For 75 ns beam blow-up is visible correlated to coherent and incoherent effects close to ECI threshold leading to low lifetime and losses ➔ scrubbing
- Comparison of 50ns vacuum and heat load during the ramp and at 3.5 TeV before and after scrubbing at 450 GeV shows clear improvement in the straight sections and arcs
- Scrubbing with 50 ns beam is required for operation with 75 ns (and possibly 50 ns) beams ➔ planned for the first half of April

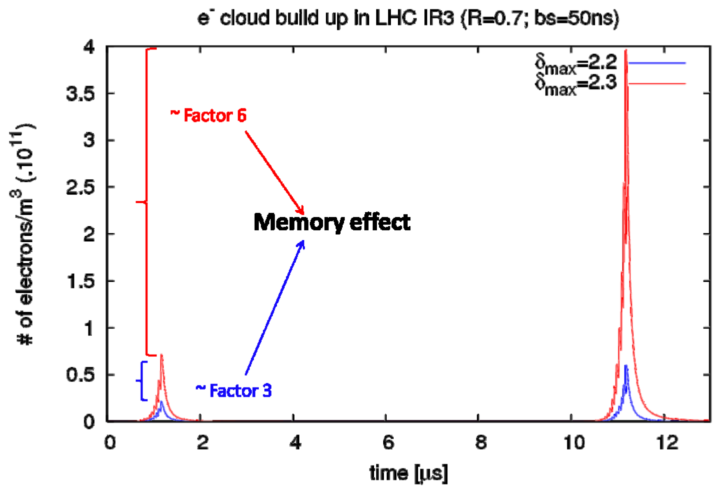
Spare slides

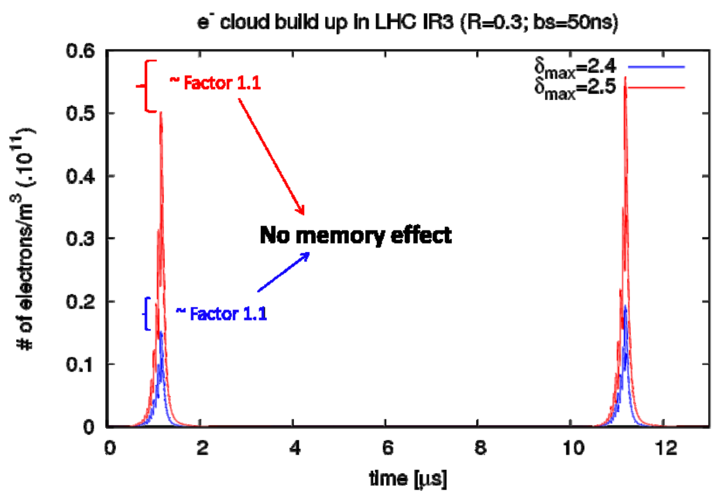


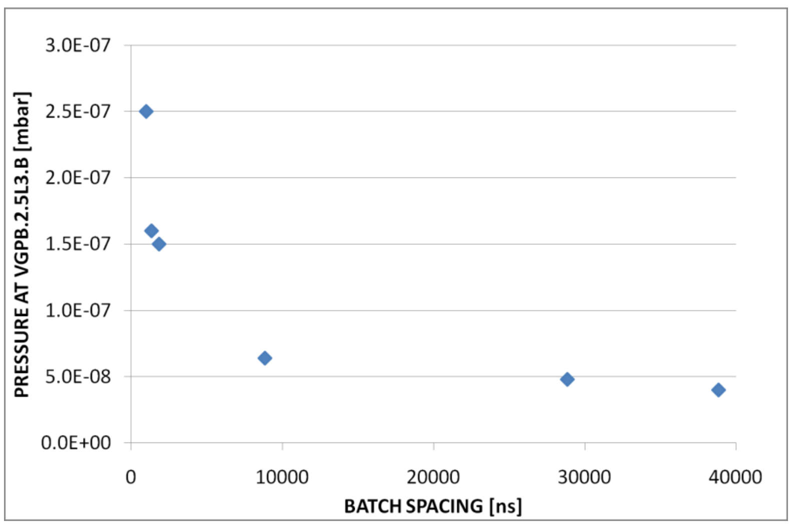

Electron distribution at saturation before bunch passage
Fine slicing
y (cm)
x (cm)
4
3
2
1
0
-1
-2
-3
-4
-6
-4
-2
0
2
4
6

Simulations (e-cloud build-up)

- Preliminary simulation results indicate that the observations with 50 ns beam for the pressure rises in the uncoated field free regions are consistent with SEY>2.2-2.5 and r~0.5 assuming ε_{max} of 230 eV and initial pressure of 10^{-9} mbar.



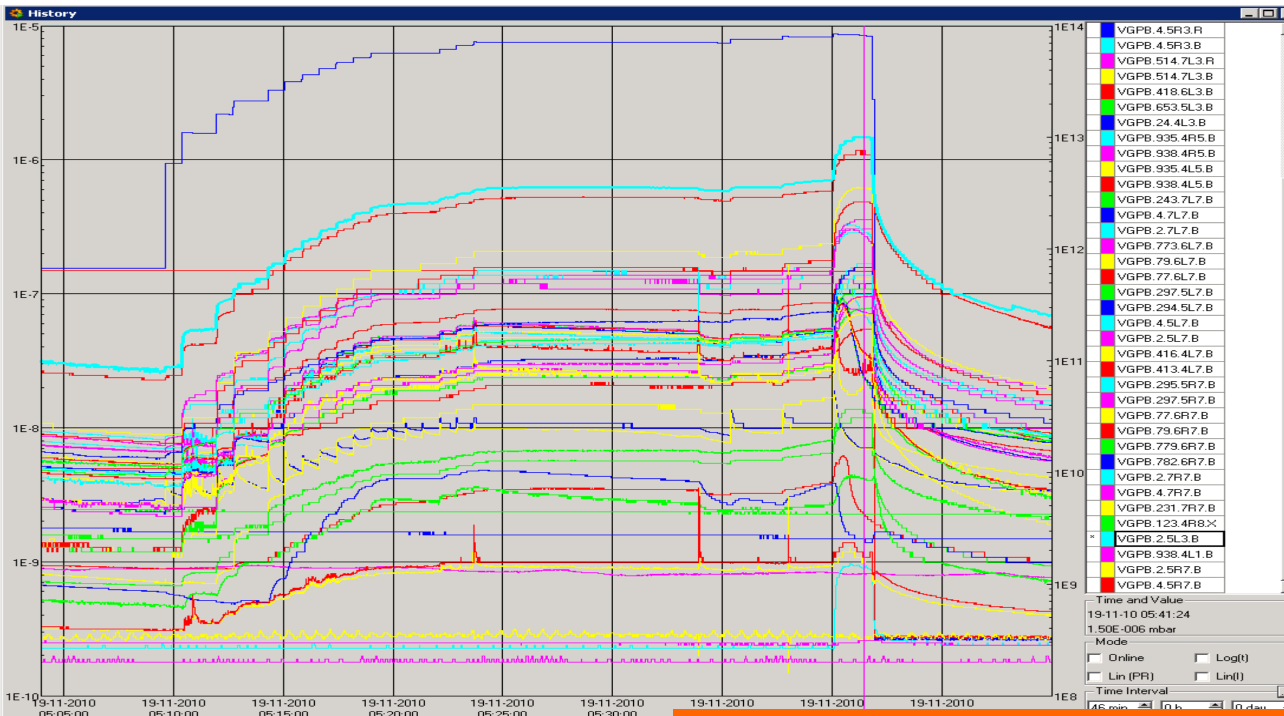




O. Dominguez, G. Rumolo, F. Zimmermann

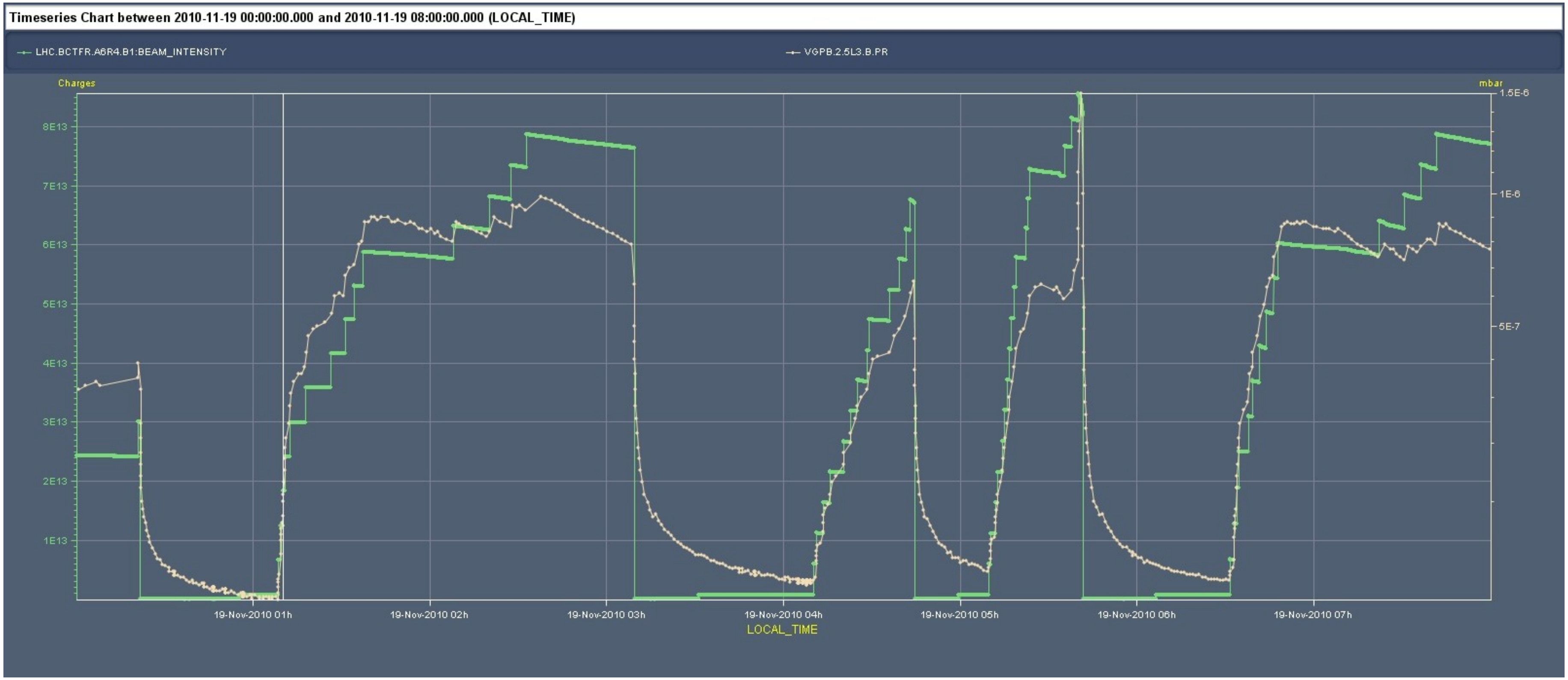
75 ns – 824 bunches

- 75 ns is certainly better than 50 ns but scrubbing will be required in order to ramp with 936 bunches also taken into account that the nominal scheme assumes trains of up to 96 bunches (here maximum train length is 48 bunches)



V. Baglin, G. Bregliozzi, G. Lanza

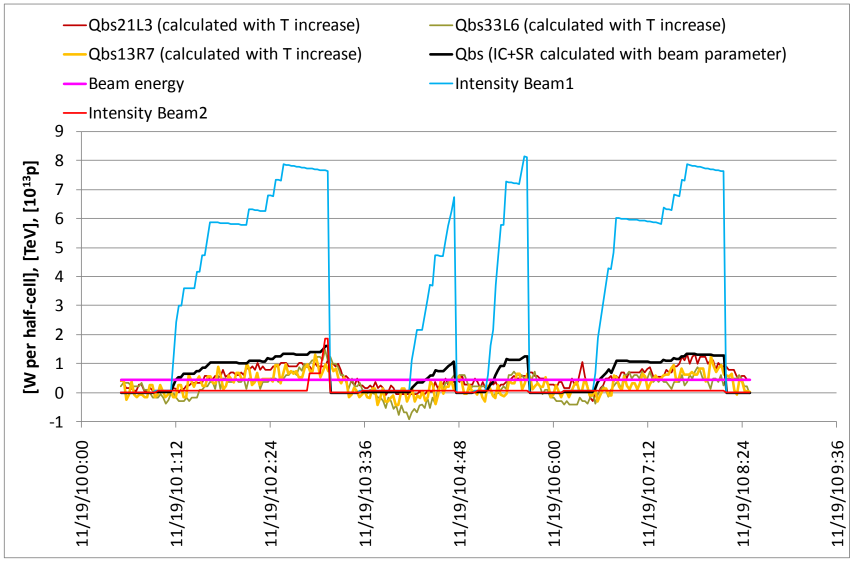
75 ns beam and vacuum at 450 GeV

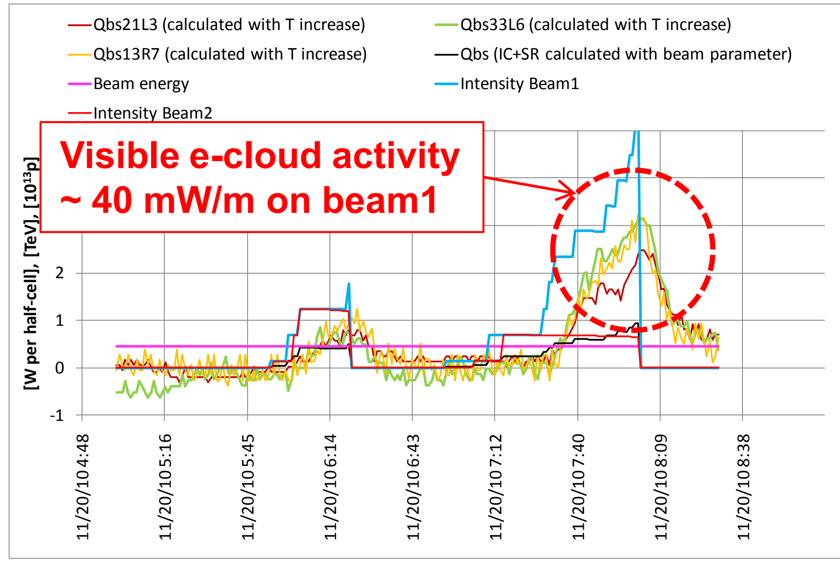


Cryogenics: 75 ns vs. 50 ns

75 ns up to 824 bunches (Beam 1). ~10 mW/m heat load (close to detection limit) ➔ AVERAGE density ~6x10^{10} e-/m^3

50 ns up to 444 bunches (Beam 1) ➔ heat load due to e-cloud: ~ 40 mW/m ➔ AVERAGE density ~5x10^{11} e-/m^3

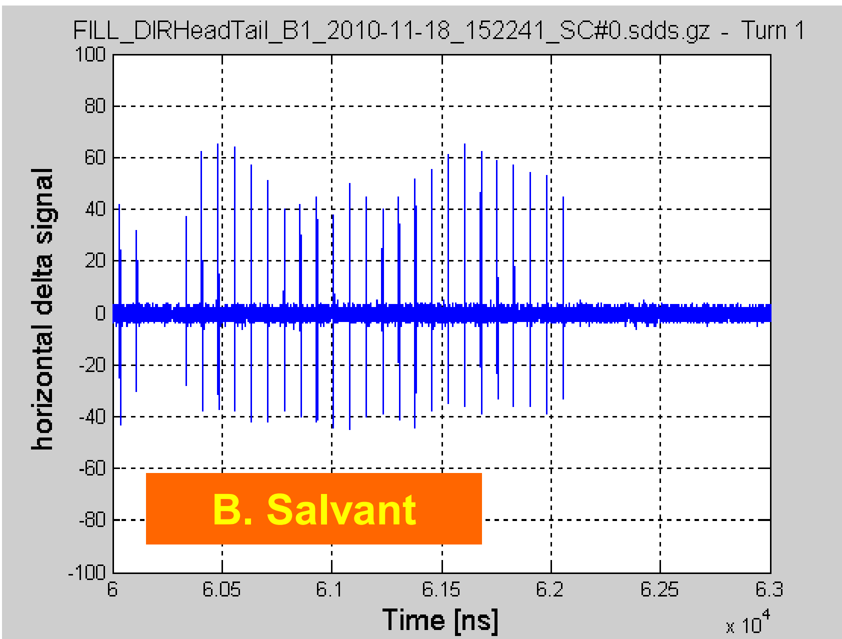




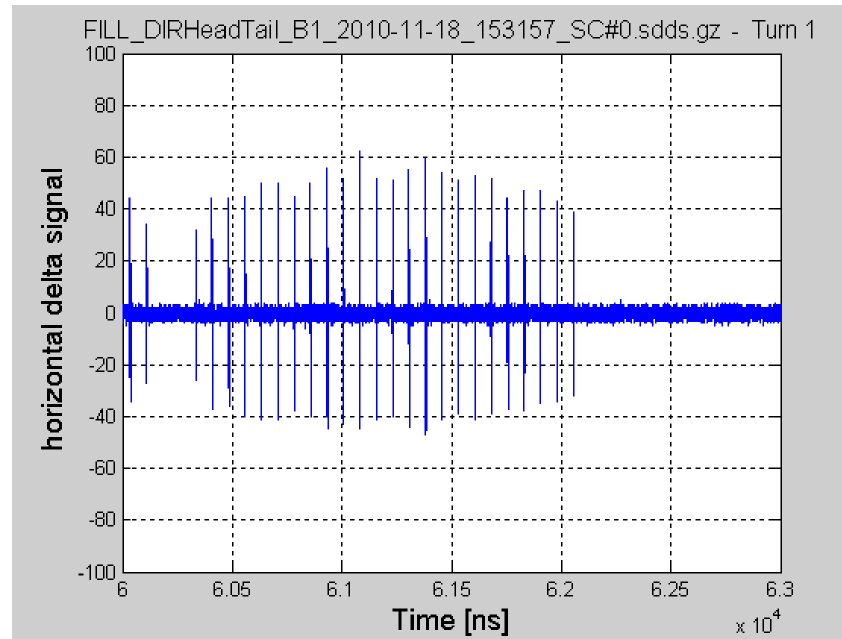
L. Tavian

Beam stability at 450 GeV/c (75 ns)

$Q'_{H,V}=14$



$Q'_{H,V}=24$



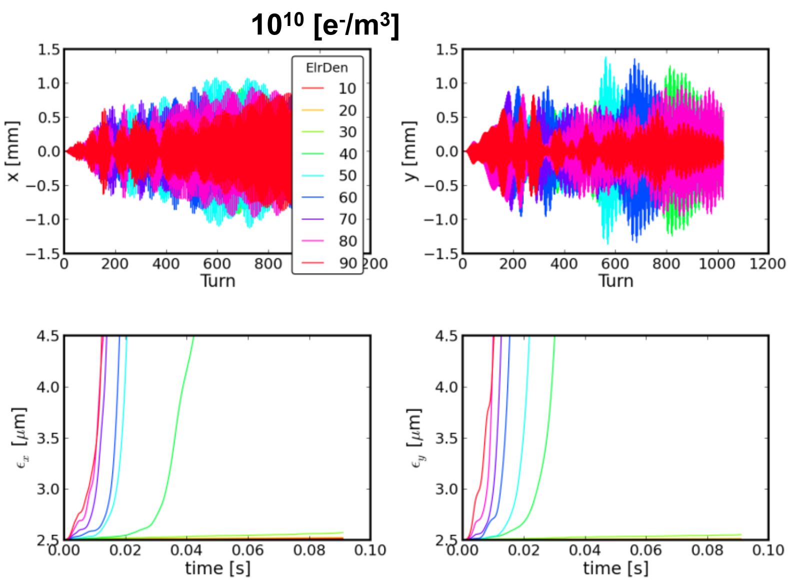
Observed oscillation (coupled-bunch mode) could be related to sources other than e-cloud as not only the tail of the batch is oscillating ➔ to disentangle need to test operation with low chromaticity in the H-plane.

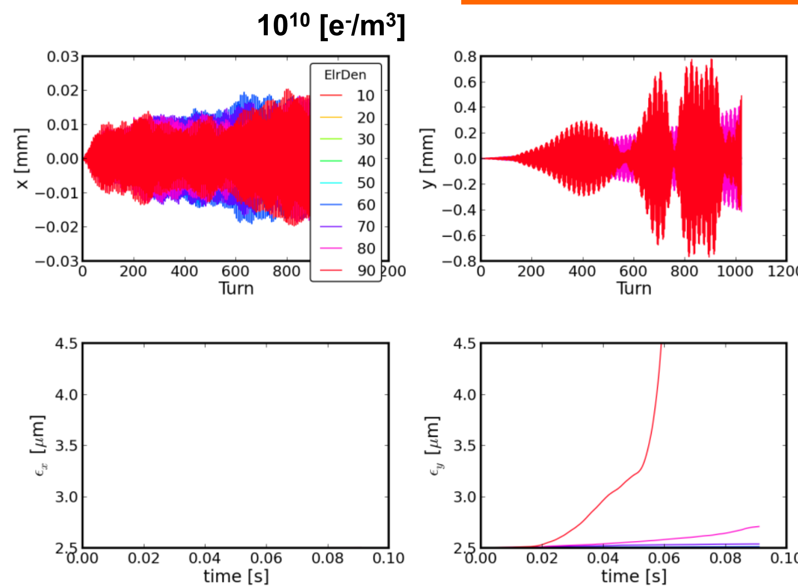
Instability thresholds

450 GeV/c field free

450 GeV/c dipole

K. Li, G. Rumolo PRELIMINARY



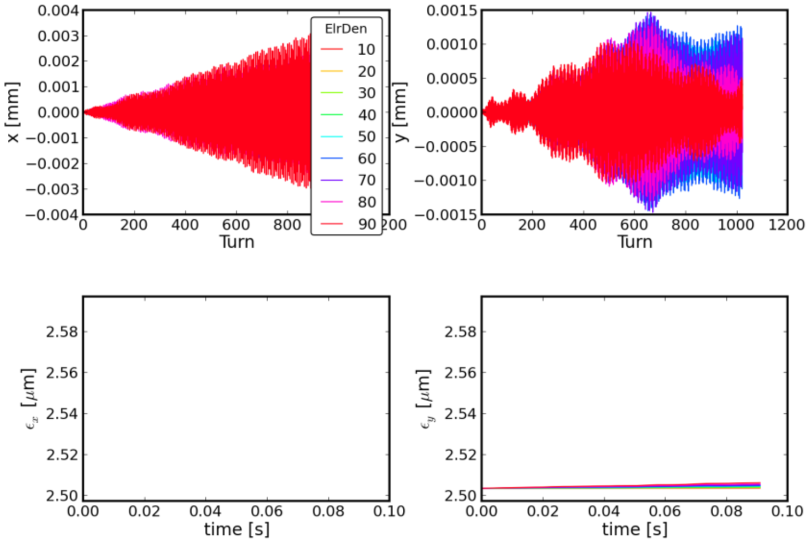


- No single bunch e-cloud instability expected at 450 GeV/c (worst case) and 3.5-4 TeV/c if electron density <10^{11} e^-/m^3 at the beam position.
- Once the threshold electron density is reached the beam is unstable
- If dominated by:
  - e-cloud in field free regions ➔ single bunch instability (SBI) in both planes,
  - e-cloud in dipole field regions ➔ SBI in V-plane only

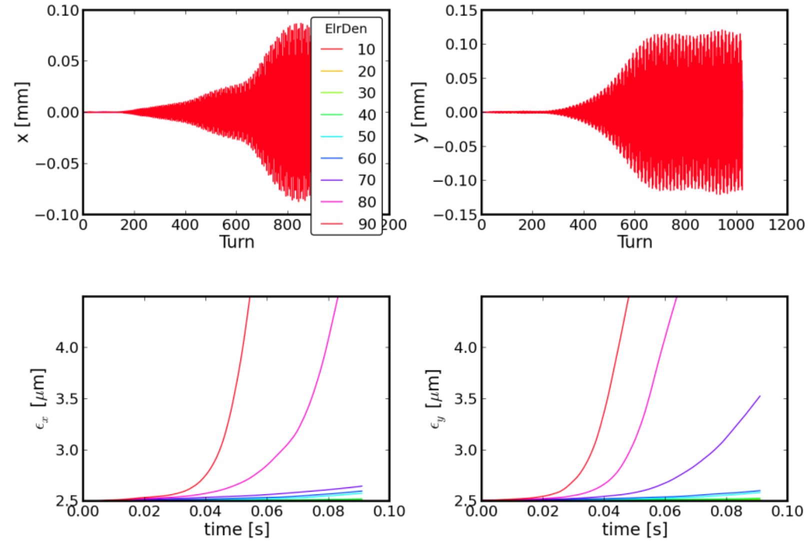
Ongoing simulations work

- If dominated by
  - e-cloud in field free regions ➔ single bunch instability (SBI) in both planes,
  - e-cloud in dipole field regions ➔ SBI in V-plane only

4 TeV/c dipole

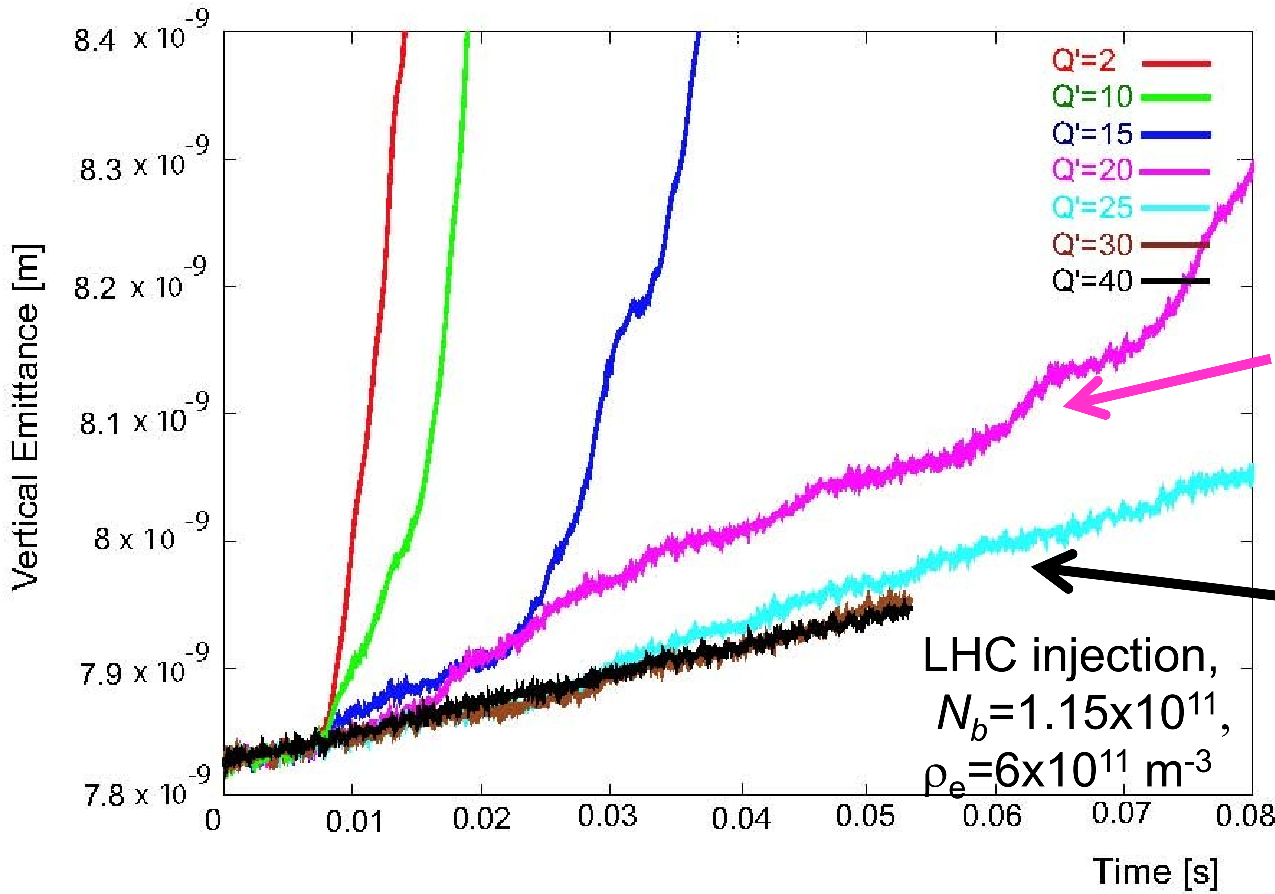


4 TeV/c field free



K. Li, G. Rumolo

PRELIMINARY



at ρ_e=6x10^{11}m^{-3} instability suppressed for Q'>15

similar to LHC

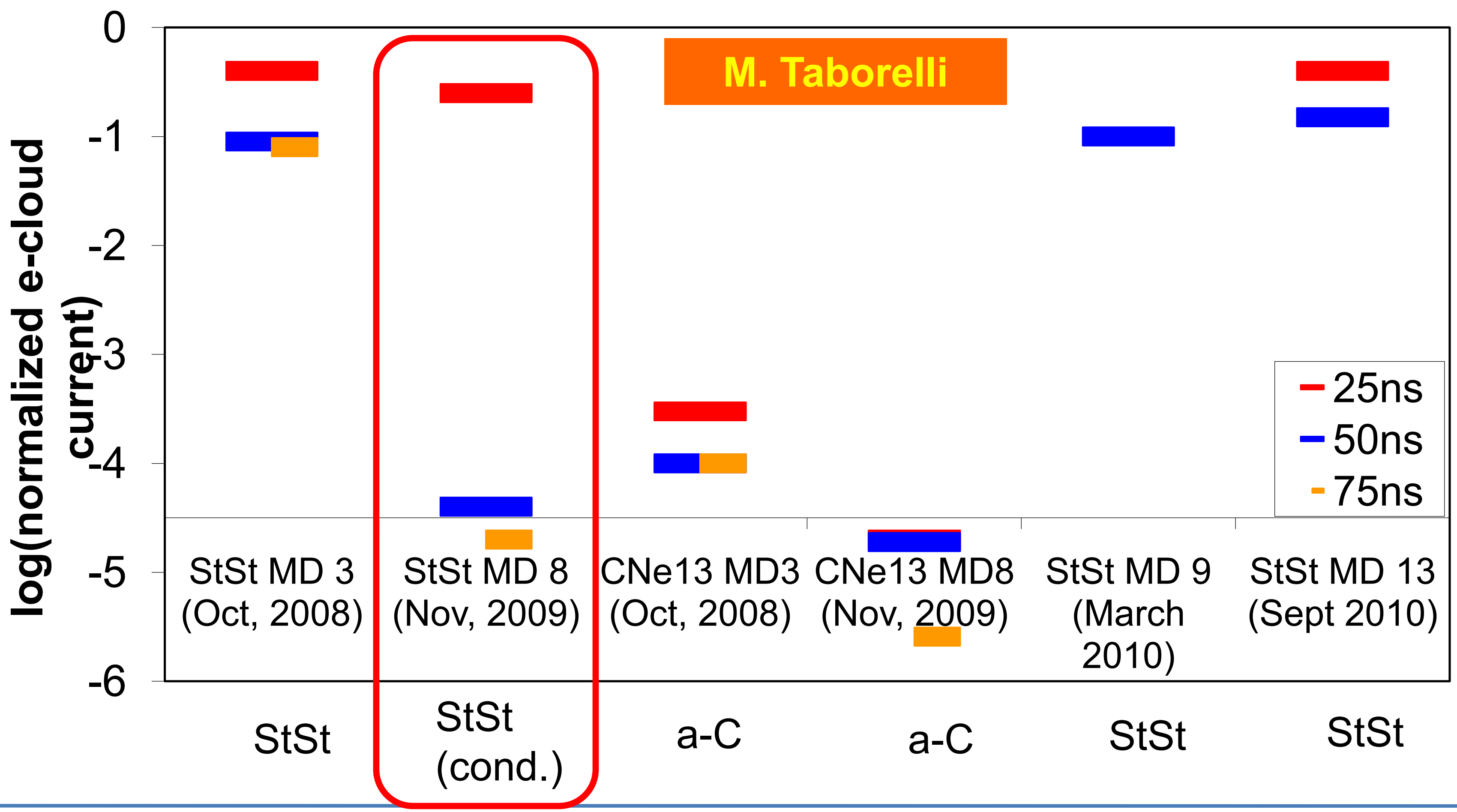
slow emittance growth below threshold

Figure 7.11. Vertical emittance growth for different chromaticities, for LHC at injection, $\rho_e = 6 \times 10^{11}$ m^{-3}

E. Benedetto, Ph.D. Thesis, Politecnico di Torino, 2006

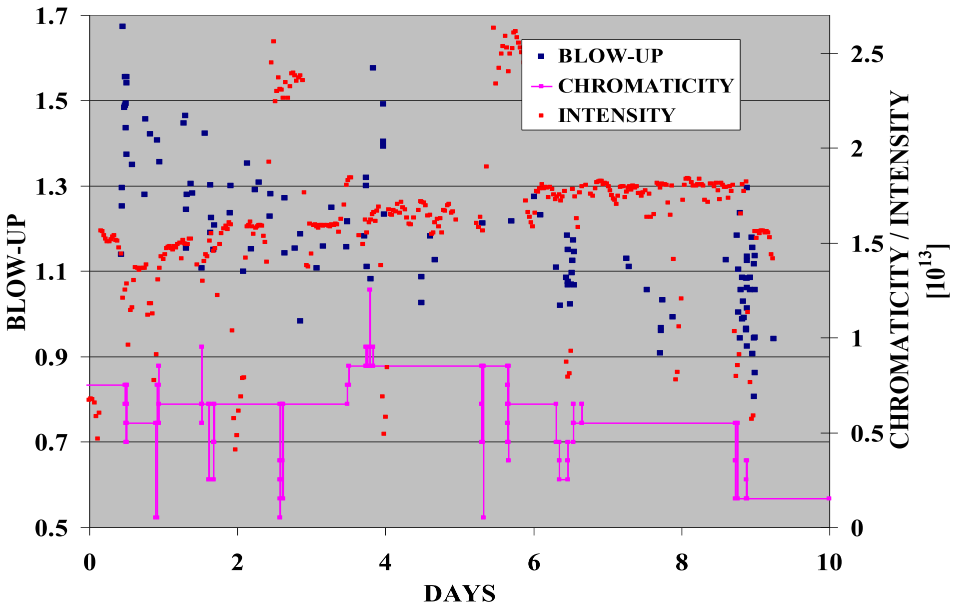
Scrubbing experience (SPS)

- Scrubbing with tightest bunch spacing allows operation below multipacting for the larger bunch spacings



Why scrubbing? (SPS experience)

Scrubbing 2002



Reduction of the V-emittance blow-up along a 15 s injection plateau BUT still blow-up at injection for the beam that is used for scrubbing