E-cloud effects for PS2, SPS, LHC

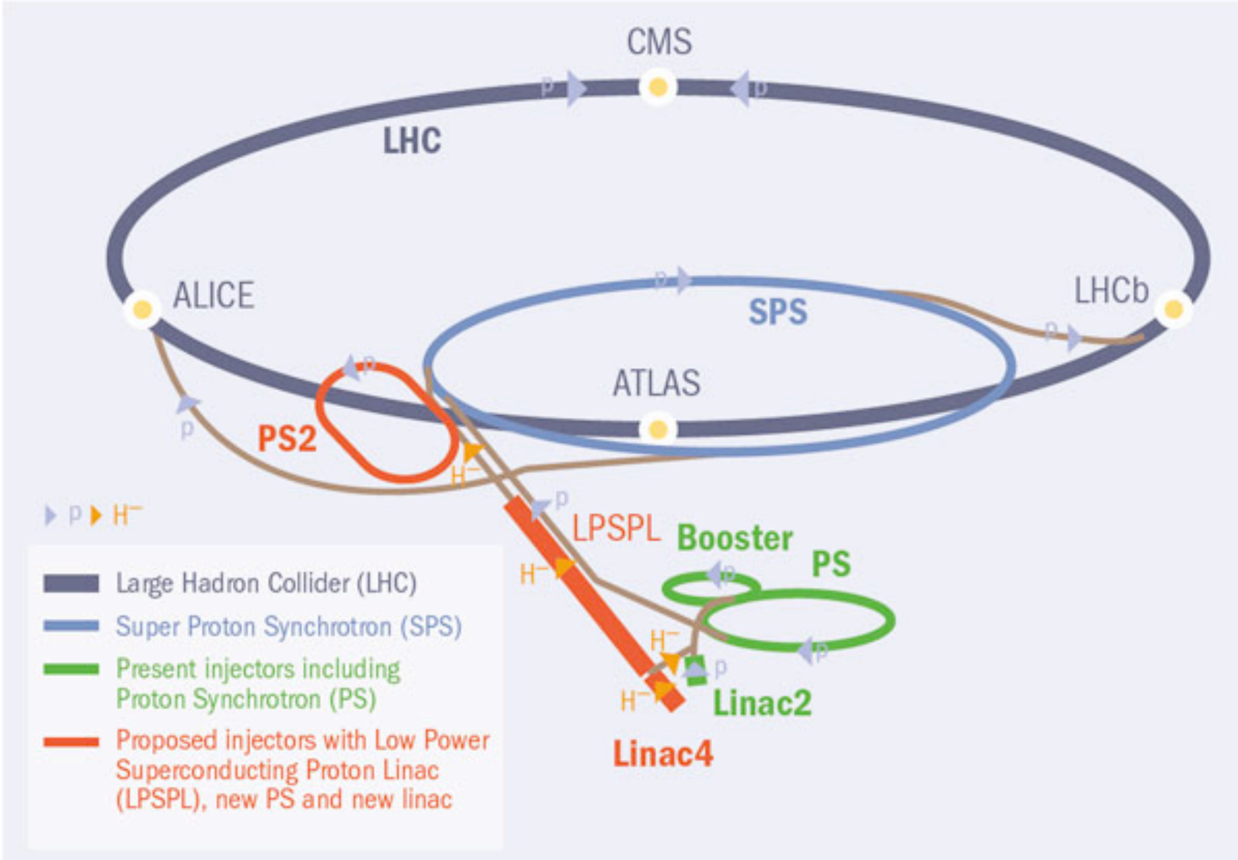
G. Rumolo, in CARE-HHH Workshop 2008
„Scenarios for the LHC upgrade and FAIR“, Geneva, 24-25 Nov 2008
*with SPSU-Working Team + E. Benedetto, J. Byrd, R. Calaga, R. de Maria, J. Fox, G. Franchetti, M. Furman, W. Höfle, G. Papotti, B. Salvant, J. Thompson, R. Tomás....

- Electron cloud issues in connection with injector upgrade scenarios
- Studies for PS2
- SPS upgrade studies:
  - Scaling law of e-cloud instability with beam energy
  - SPS instability measurements 2006-2007
  - 2008: e-cloud in liners and feedback system
- LHC
  - Heat load calculations
  - Slow emittance growth
- Conclusions

CERN future accelerators

New injectors

- Linac4 (2013)
  - → 160 MeV
- LPSPL (2017)
  - → 4 GeV
- PS2 (2017)
  - → 50 GeV



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Reasons for upgrade

- Future LHC upgrade
- Age of accelerators and reliable operation for the next X years
- New experiments at lower energy

Future situation with PS2 + SPS

Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	25 ns	50 ns	FT	25 ns	FT	25 ns	50 ns
bunch intensity $/10^{11}$	4.4	**5.5**	1.6	**1.2**	0.13	1.7	**5.0**
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	7.4	4.6	**12.0**	3.5	**5.3**	5.7	8.4
long. emittance [eVs]	0.6	0.7	0.4	0.6	0.8	<1.0	<1.0
norm. H/V emitt. [μm]	3.5	3.5	15/8	**3.6**	8/5	3.5	3.5

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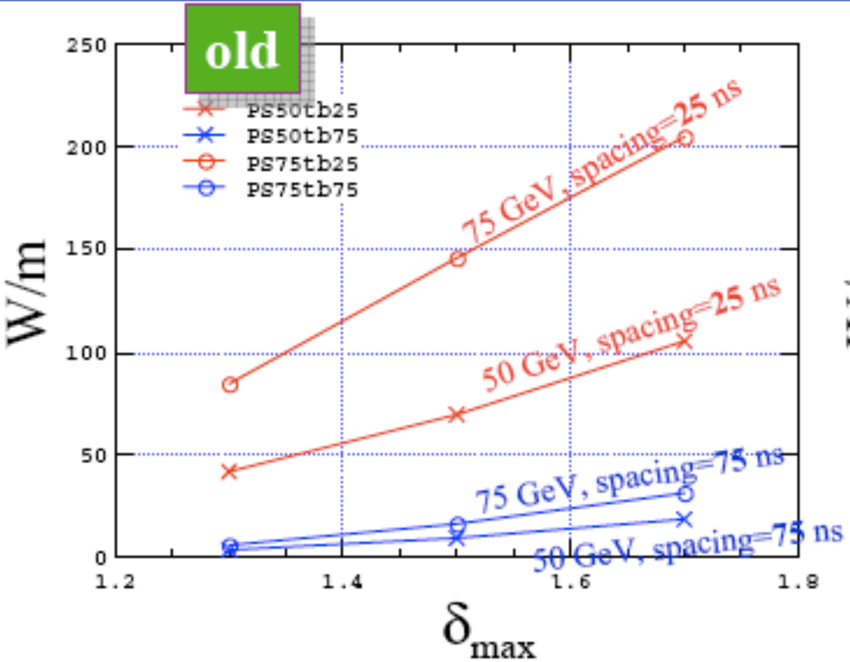
→ **need to upgrade SPS**

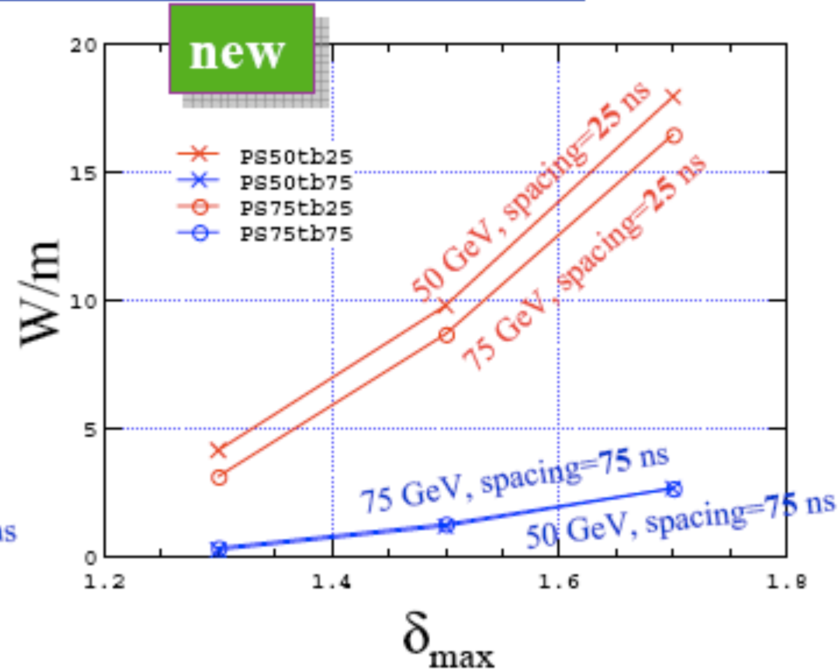
Even if the higher injection energy is expected to improve the performance in many respects, electron cloud mitigation is necessary!

Electron cloud studies in the CARE-HHH program (from 2006 on)

- 2006:
  - ⇒ **LUMI'06 (**Valencia)
    - ✓ First results on the dependence of the electron cloud instability threshold on energy (G. R.)
    - ✓ First heat load calculations for the PS2 (M. Furman)
    - ✓ Incoherent effects, potentially dangerous for LHC (G. Arduini, G. Franchetti)
- 2007:
  - ⇒ **ECL2** (CERN)
    - ✓ Mini-workshop specially devoted to enamel electrodes as possible electron cloud suppression technique
    - ✓ Review of the PS2 simulations (M. Venturini on behalf of M. Furman)
  - ⇒ **BEAM07** (CERN)
    - ✓ Results of the experimental verification of the e-cloud instability threshold on energy (G. R.)
    - ✓ More refined models for e-cloud incoherent effects (G. Franchetti)
- 2008:
  - ⇒ **ECM'08** (CERN)
    - ✓ **Novel mitigations techniques** and synergy with the satellite community

PS2 (50 or 75 GeV extraction energy): 2007 vs 2006





- Old: MF talk at LUMI06
  - 21 kicks/bunch, or $\Delta t=(6\text{-}7)\times 10^{-10}$ s
- New: MF paper in LUMI06 proceedings (LBNL-61925)
  - 201-251 kicks/bunch, or $\Delta t=(5.5\text{-}6.7)\times 10^{-11}$ s

M. Furman & M. Venturini

PS2 (50 or 75 GeV extraction energy)

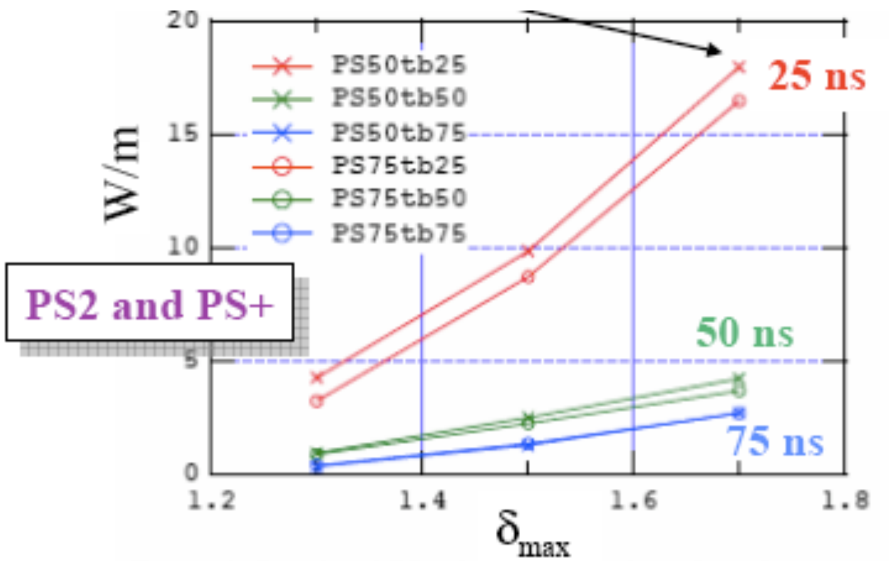


Figure 4: Simulated PS ecloud heat load vs. δ_{max} for cases PS50 and PS75 (PS2 and PS+ in "psplusetcparameters," respectively).

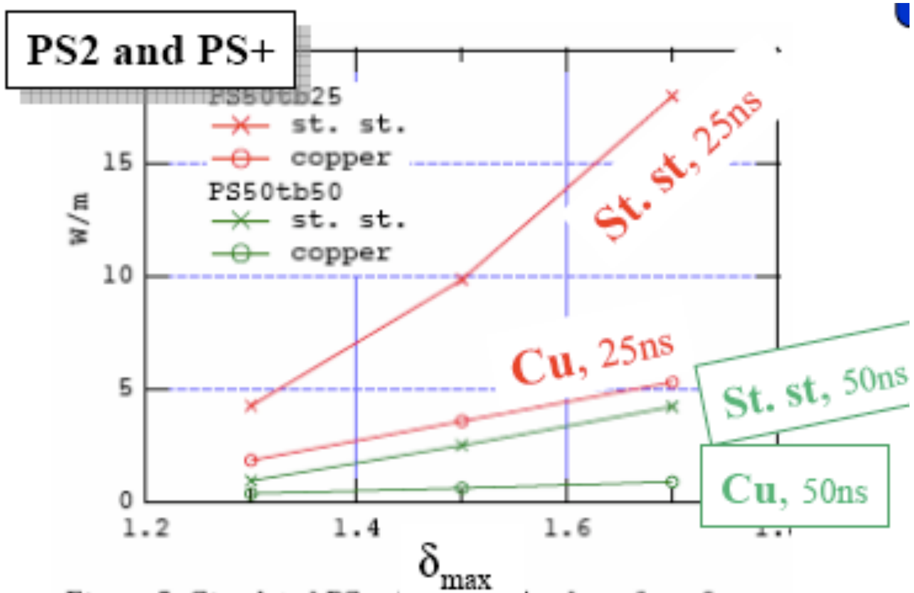


Figure 5: Simulated PS ecloud heat load vs. δ_{max} for case PS50, for copper and stainless steel chamber. The only dif ference in the calculation for the two cases is the secondary emission energy spectrum of the two metals.

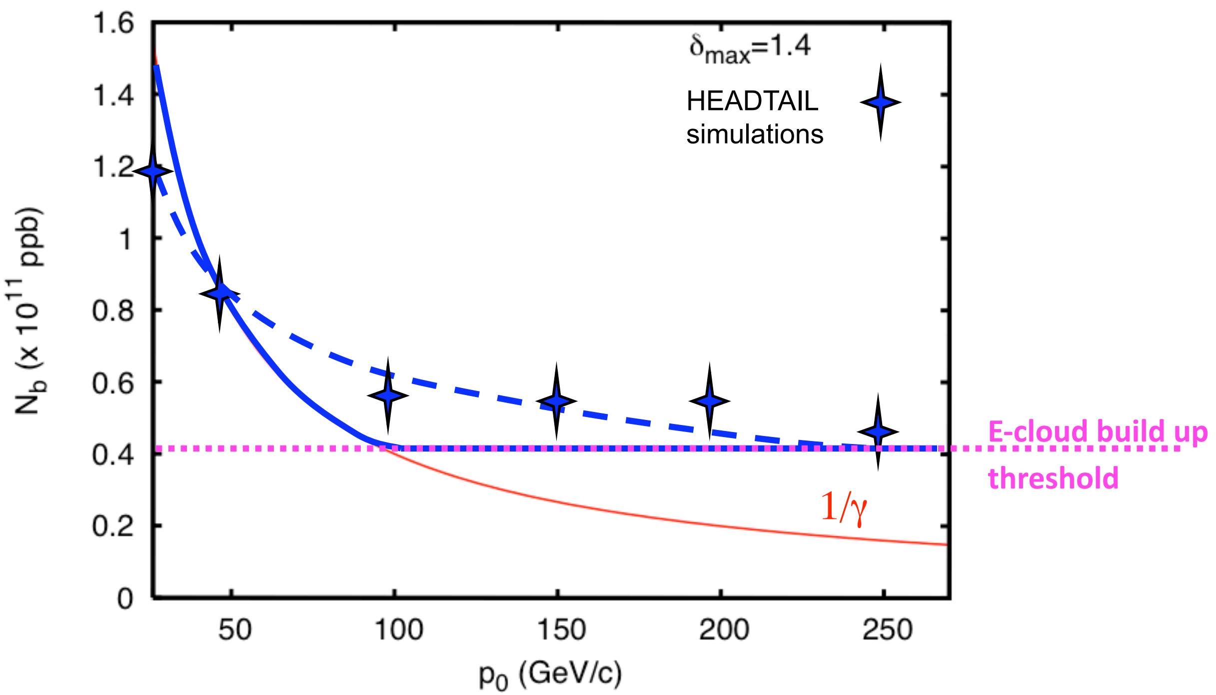
- Copper much more favorable than St.St.
  - Owing to smaller rediffused component in SE energy spectrum
  - Subtle mechanism; explained in detail in Sec. IV-B of http://prst-ab.aps.org/pdf/PRSTAB/v9/i3/e034403

M. Furman & M. Venturini

SPS upgrade: the e-cloud instability ?

- In the framework of the PS2/SPS Upgrade studies, the injection into the SPS with higher energy (50-60 GeV) poses the following question:
  - How does the electron cloud single bunch instability scale with energy, conserving the specifications and assuming unchanged production scheme ?
  - Answer not straightforward because
    - → Higher energy means more rigid, therefore **more stable**, beam
    - → At higher energy the beam gets **transversely smaller**, which enhances the pinch of the electrons as the bunch goes through them
    - → The matched voltage is lower at higher energy, which translates into a **lower synchrotron tune** (destabilizing)
  - Detailed HEADTAIL simulation study was carried out to find out the correct scaling law with energy
  - Experimental verification at the SPS was first attempted in 2006, and then continued throughout all 2007

HEADTAIL prediction using model with self-consistent e-cloud



For δ_{max}=1.4 the instability threshold is found to decrease with γ up to ~100 GeV/c, then it levels off at the value of the build up threshold

→ Conservation of longitudinal emittance, bunch length and normalized transverse emittances.

→ Bunch always matched to the bucket !

Experimental verification: MDs in 2007

26 and 37 GeV/c before the scrubbing run

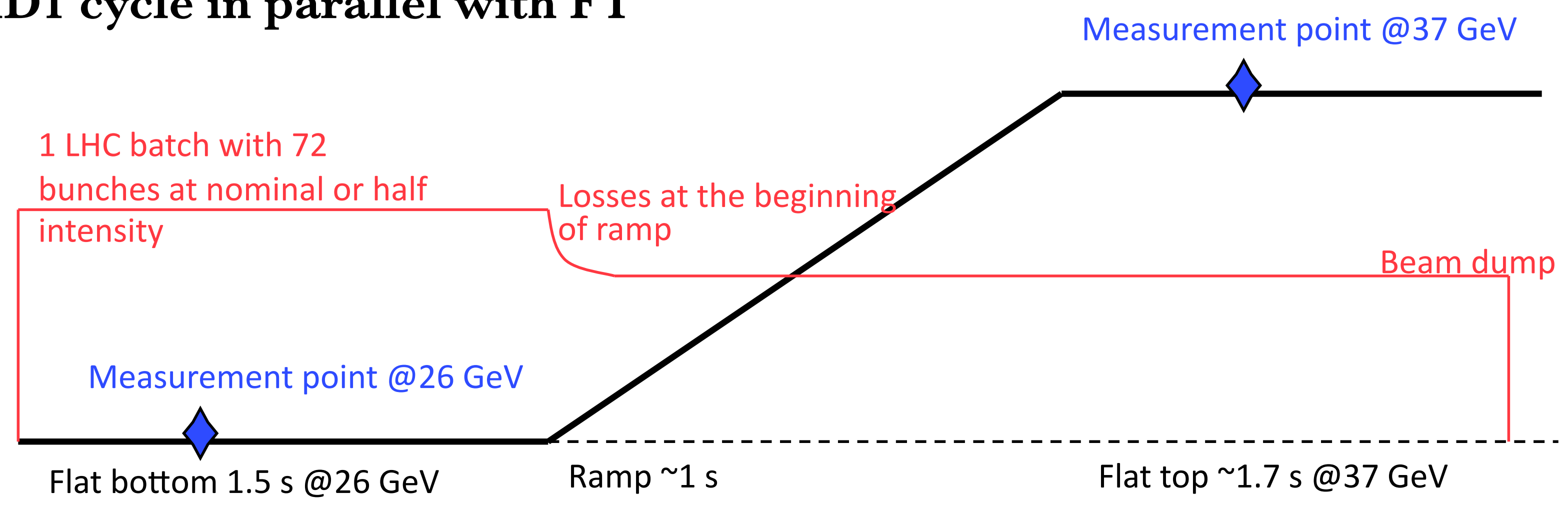
- Vertical chromaticity was lowered at the measurement points, till the beam (1 batch nominal LHC) becomes unstable. Look for *Q′* threshold for instability

  → *Q′=-0.19* at 26 GeV/c (setting value)

  → *Q′=0* at 37 GeV/c (setting value)

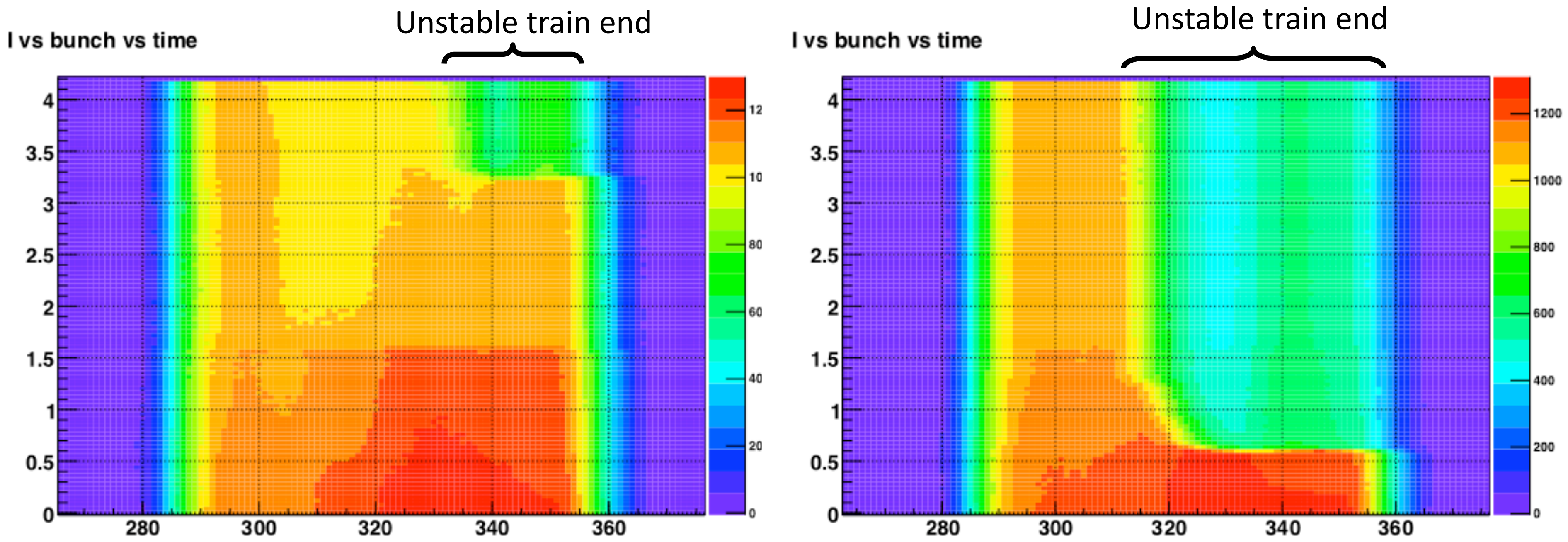
- The damper gain was kept to nominal value all along the cycle

MD1 cycle in parallel with FT



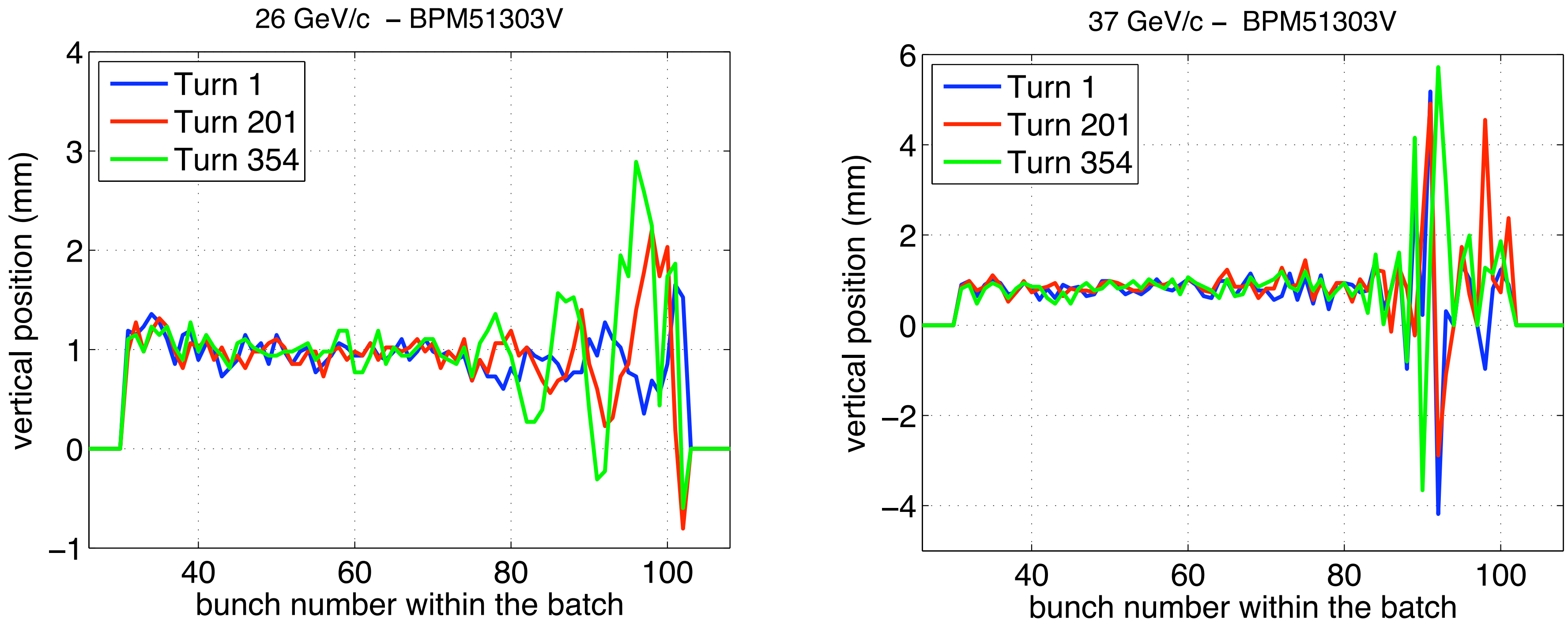
Experimental verification: MDs in 2007

Example of instability @ 26 and 37 GeV/c



Experimental verification: MDs in 2007

Example of instability @ 26 and 37 GeV/c



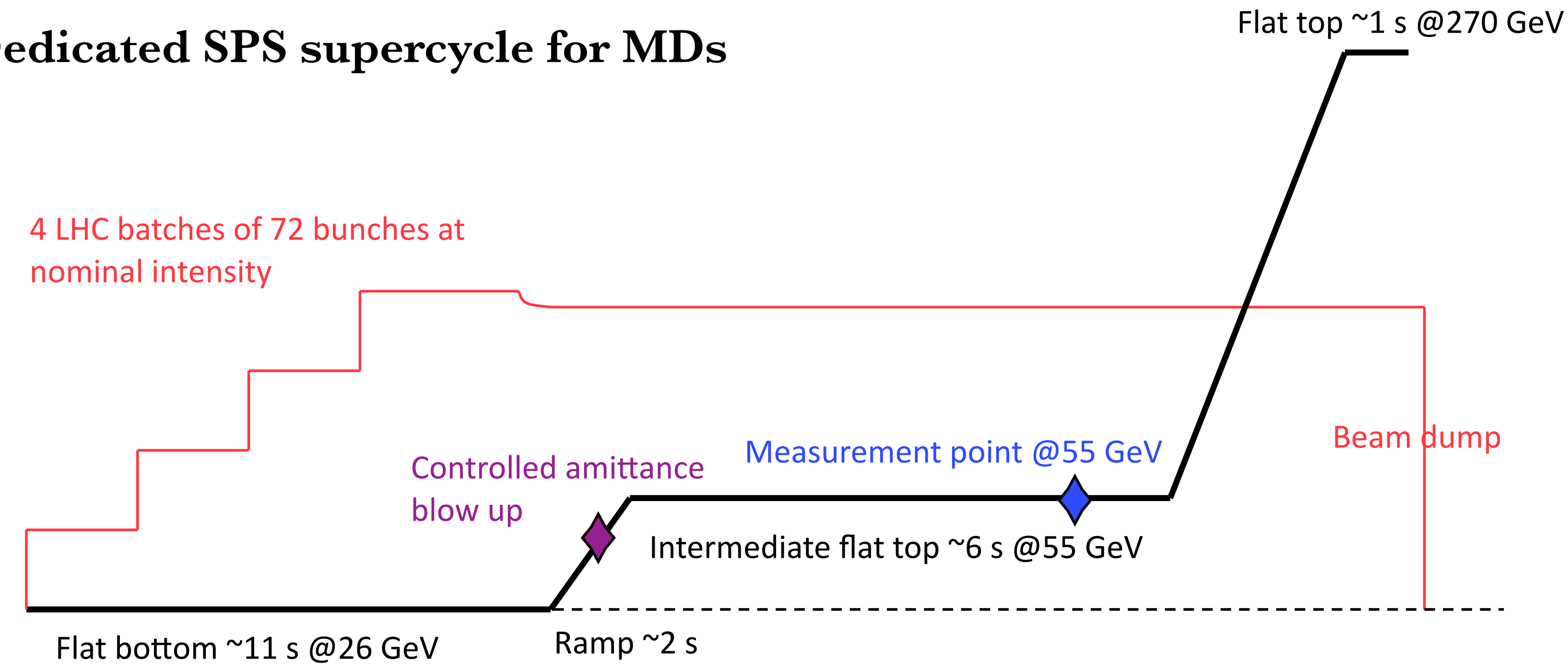
- At 26 GeV/c the dominant instability seemed to be a low mode number coupled bunch instability
- At 37 GeV/c the instability seems single bunch and affects the very last bunches of the train

Experimental verification: MDs in 2007

Study on the 55 GeV/c plateau

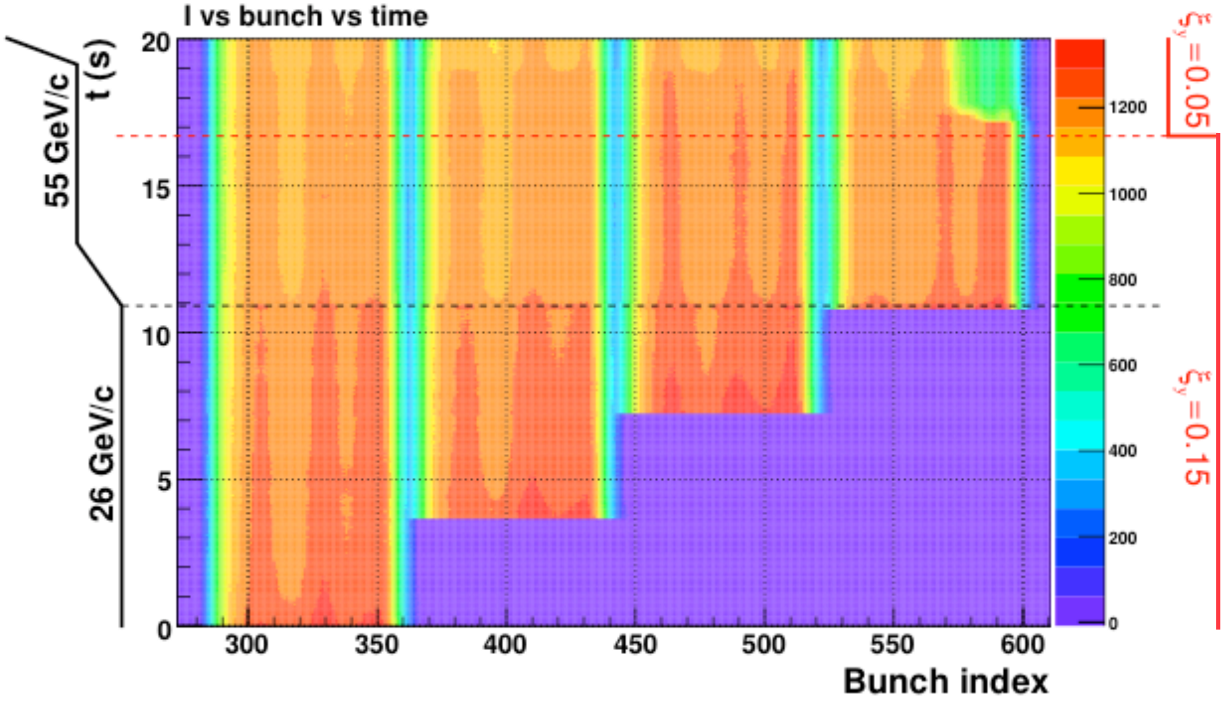
- Vertical chromaticity was lowered at the measurement point, till the beam becomes unstable. Try to stabilize by increasing the transverse emittance (excitation made with the damper).

Dedicated SPS supercycle for MDs



Experimental verification: MDs in 2007

Study on the 55 GeV/c plateau

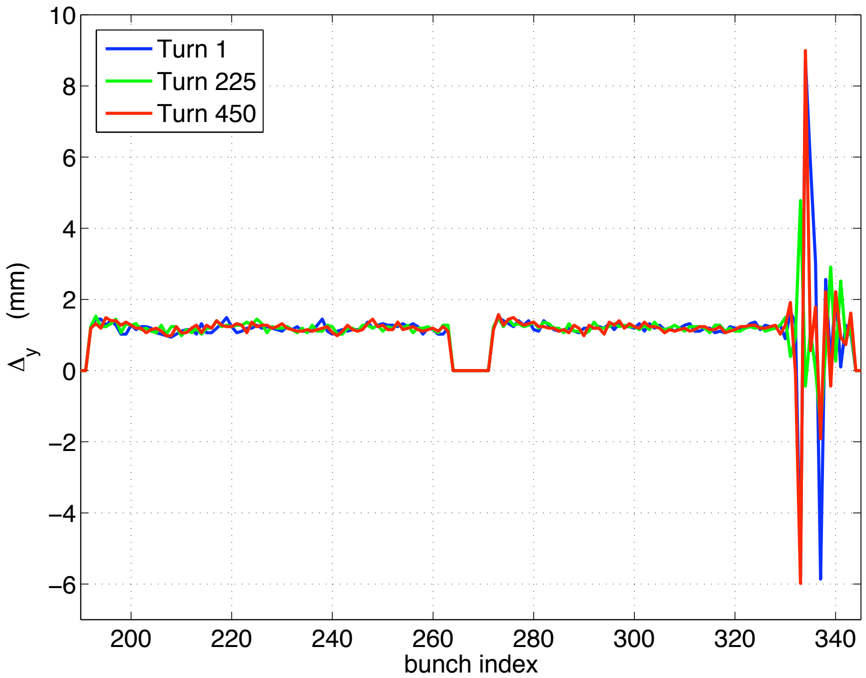


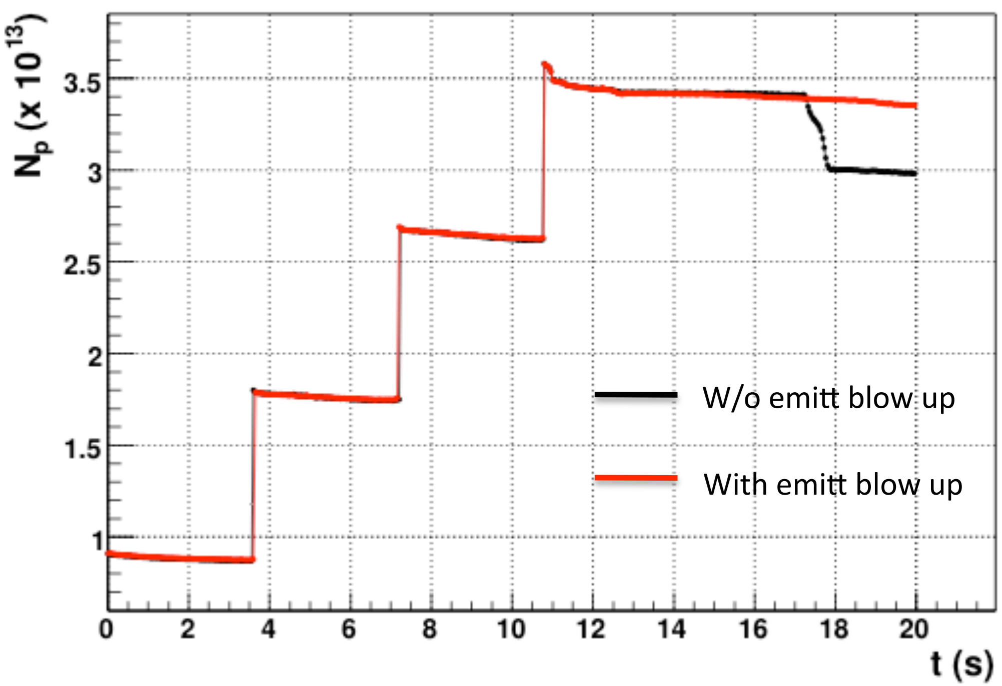
Without emittance blow up:

⇒ An instability caused beam loss at the tail of the fourth batch, when vertical chromaticity was lowered to 0.05 toward the end of the intermediate plateau at 55 GeV/c

Experimental verification: MDs in 2007

Study on the 55 GeV/c plateau





- The unstable coherent motion appears at the end of the 4th bunch train
- The instability is suppressed by blowing up the transverse emittance!

MDs in 2008

E-cloud measurements in the liners

C. Yin Vallgren et al. ECM'08

1. Stainless Steel
2. NEG coating
3. Carbon coating

- All the tests were done in the magnets at a field of 1.2 kGauss.
- The beam energy in the scrubbing run was 26 GeV and in the other MD runs 450 GeV

- SPS Scrubbing run: 10 June - 12 June, 2008
- Injector MD with LHC beam: 8 July, 2008
- Injector MD: 12 August, 2008

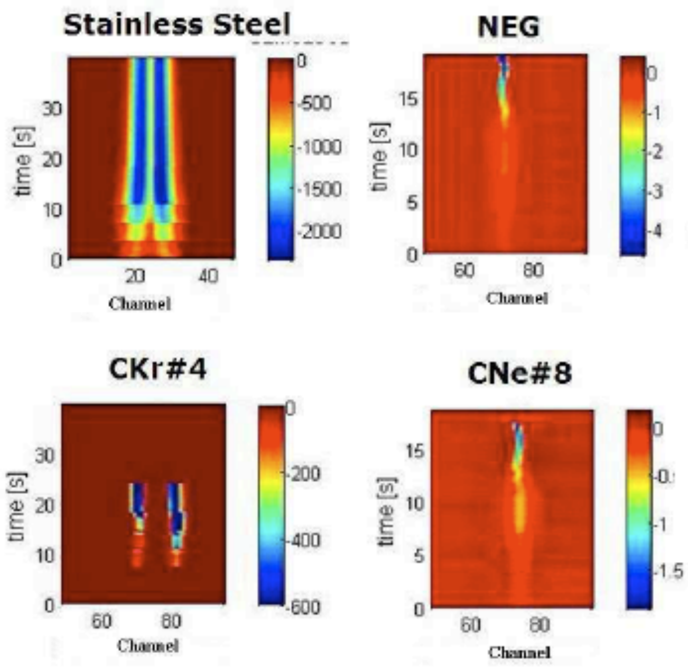
(these three) → 25ns spacing, variable number of batches

- Injector MD: 6 October - 8 October, 2008 → 25, 50 and 75ns spacing

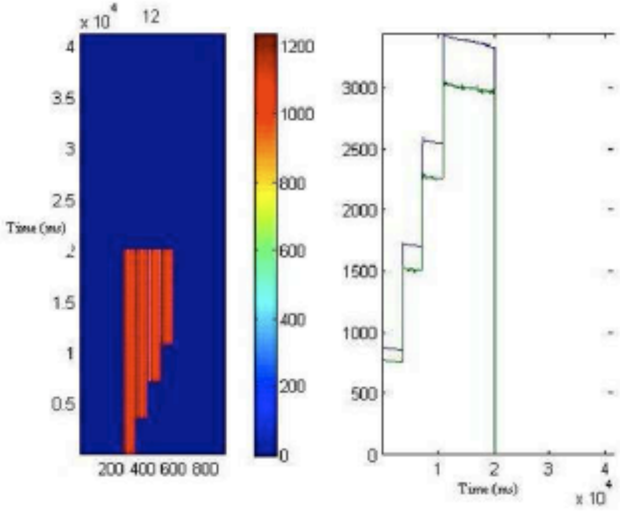
MDs in 2008

E-cloud measurements in the liners

SEMCloud Monitors:



FBCT Monitor:



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1. SPS Scrubbing run: Carbon with Krypton as discharge gas (CKr4)
2. Injector MD with LHC beam: Carbon with Neon as discharge gas (CNe8)
3. Injector MD: Aged Carbon with Neon as discharge gas - 2 weeks venting in air before inserting (CNe13)
4. Injector MD: CNe13 - 2 months in SPS vacuum

See talk by P. Chiggiato for details

MDs in 2008

E-cloud measurements in the liners

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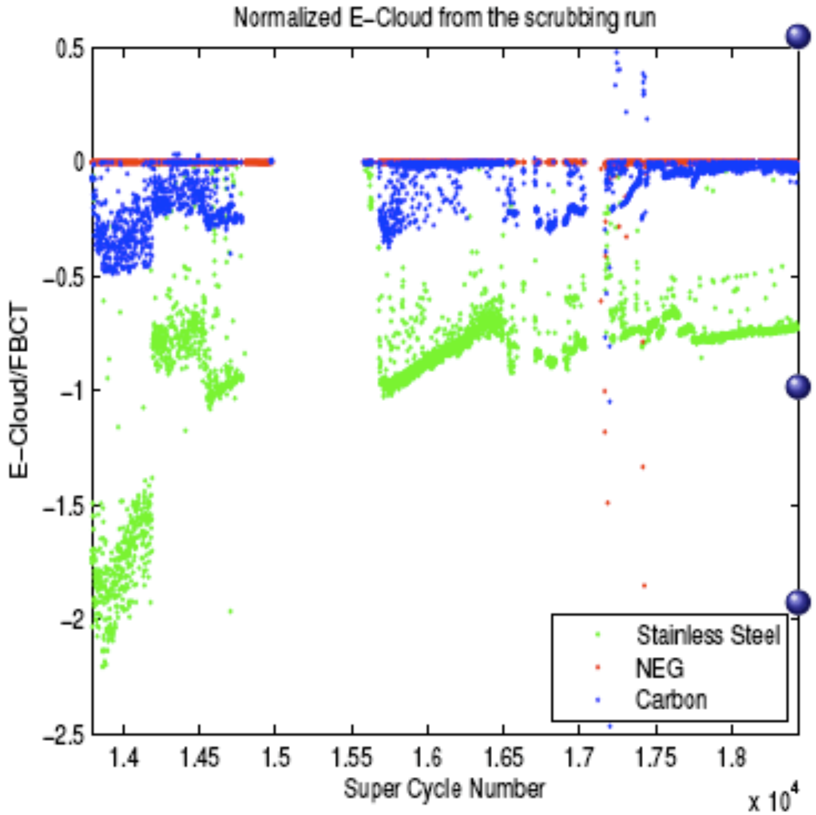
Normalized EC:



Conclusions:

- Stainless Steel (δ_{max} = 2.25) - E-Cloud in Stainless Steel has been reduced by nearly a factor of 2.
- NEG (δ_{max} = 1.1) - E-Cloud in NEG showed no activity.
- Carbon (CKr4) δ_{max} = 1.33. - E-Cloud in Carbon was found to change by nearly a factor of 5.

MDs in 2008

E-cloud measurements in the liners

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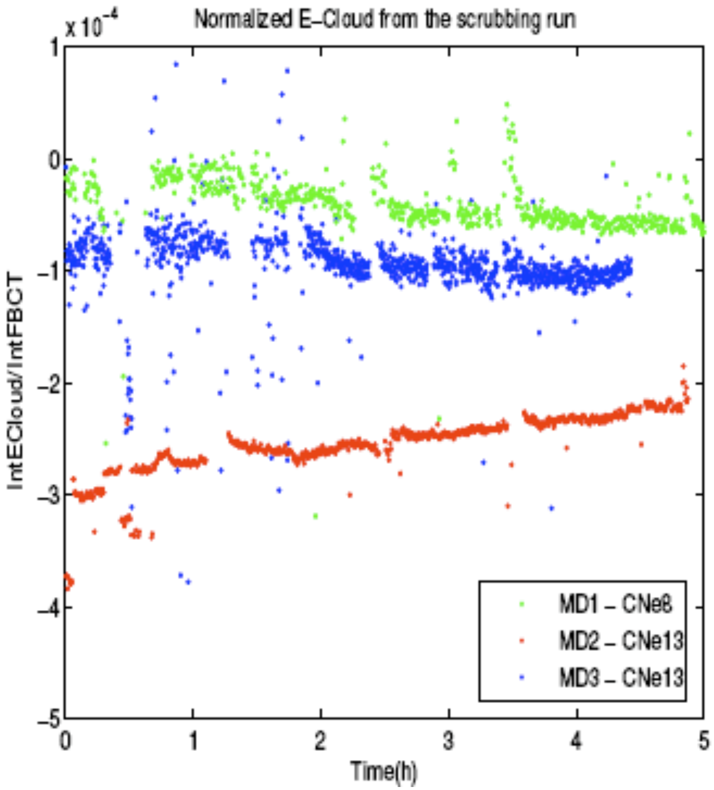
Normalized EC: EC has a magnitude of 10^{-4}.



Conclusions:

1. MD1 - Carbon (CNe8)
   - E-Cloud in Carbon showed no activity.
   - $\delta_{max} = 0.92$.
2. MD2 - Carbon (CNe13)
   - Aged in air for 2 weeks before inserting.
   - Initial $\delta_{max} = 1.0$. Aged $\delta_{max} = 1.14$.
3. MD3 - Carbon (CNe13)
   - stayed in SPS vacuum for 2 months.

MDs in 2008

Feedback system for the e-cloud instability

In the framework of the SPSU-WT and LARP collaboration, in 2008 an effort to study the feasibility of feedback system for electron cloud-type instabilities has started

→ Through simulations. Simple models of feedback systems have been implemented in existing simulation codes to investigate on the gain and band-width requirements of such system

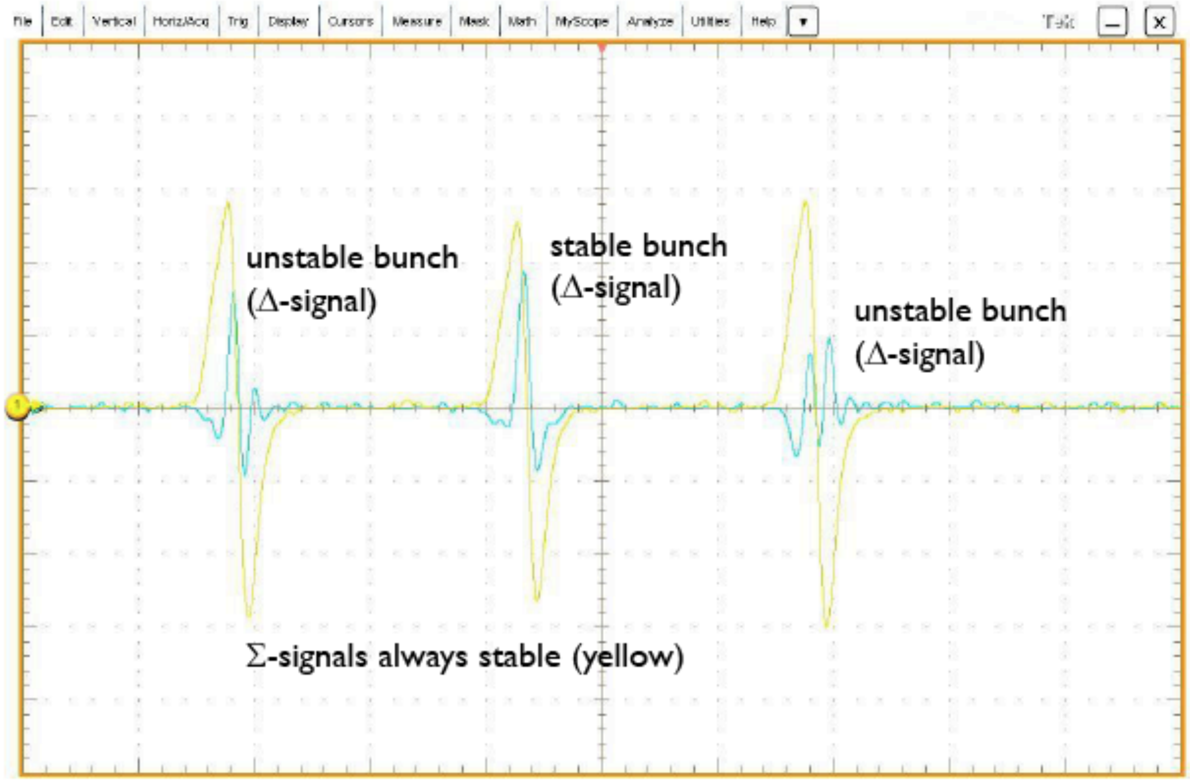
- ✓ HEADTAIL (J. Byrd, W. Hofle, G. R., J. Thompson)
- ✓ WARP-POSINST (M. Furman, M. Venturini)

→ Measurements have been carried out at the SPS in order to have a head-tail characterization of the evolution of the elecron cloud instability to have an idea of the type of signals that should be damped (G. Arduini, R. de Maria, J. Fox, W. Hofle, G. R., J. Thompson)

- ✓ Use an exponential pick-up installed in the SPS for wide-band data acquisition
- ✓ June 2008 (end of the scrubbing run): electron cloud instability measured in the the SPS at 26 GeV/c on the last bunches of the 5th injected batch
- ✓ August 2008 (dedicated block within a long MD): elctron cloud instability excited at the end of the 4th batch by lowering chromaticity.

FEEDBACK SYSTEM: SPS MEASUREMENTS

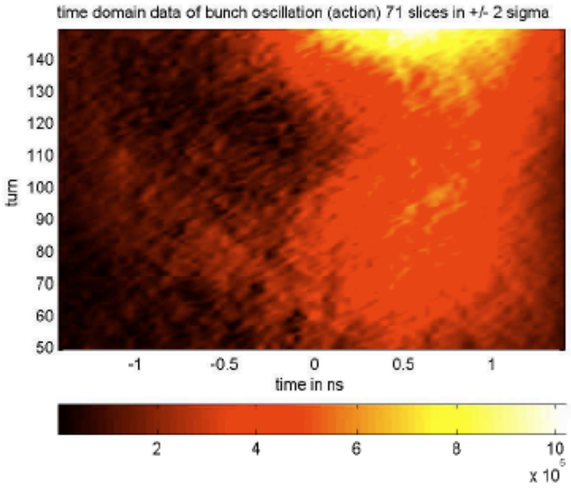
5x72 bunches injected; 25 ns bunch spacing; machine well scrubbed with four batches
shown are the last three bunches of the 5th batch, vertical pick-up, shortly after injection
evidence of single bunch multi-100 MHz transverse instability,



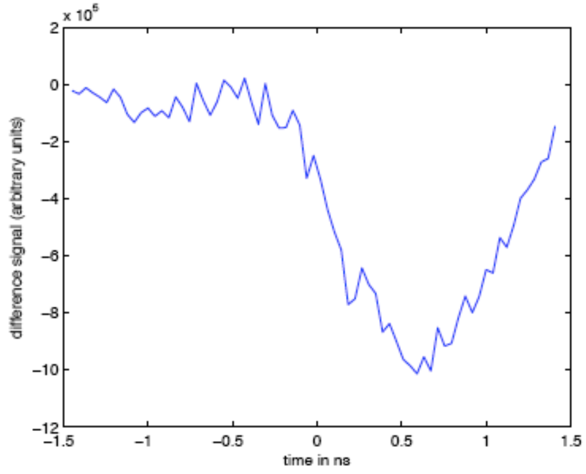
Instability at injection of 5th batch, analysis ongoing 10 ns/div

W. Höfle, R. de Maria, et al. ECM'08

FEEDBACK SYSTEM: HEADTAIL SIMULATIONS



(a)



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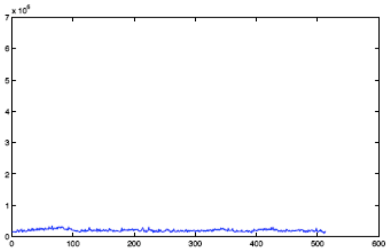

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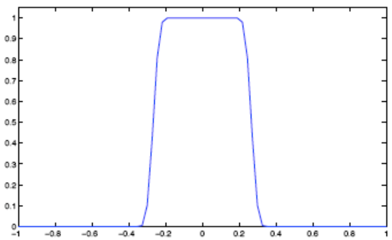

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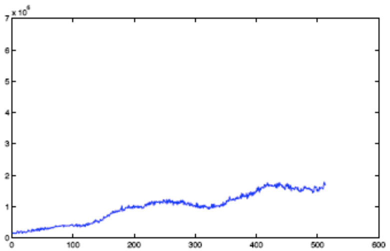
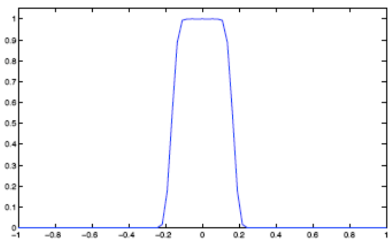


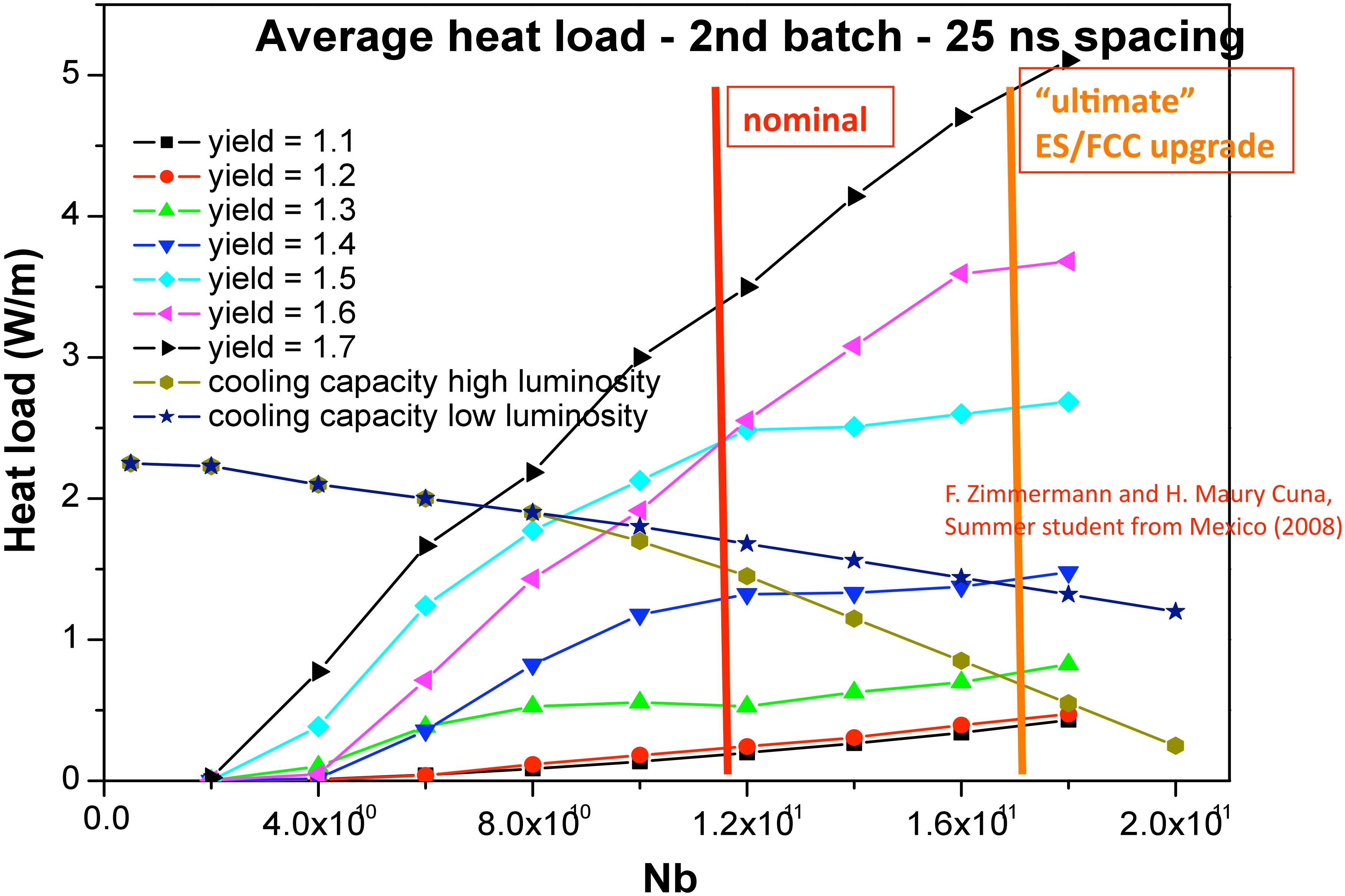


$$\Delta y'_{i,j} = g \left[\frac{y_{i,j}}{\beta_y \tan(2\pi q_y)} - \frac{y_{i-1,j}}{\beta_y \sin(2\pi q_y)} \right]$$

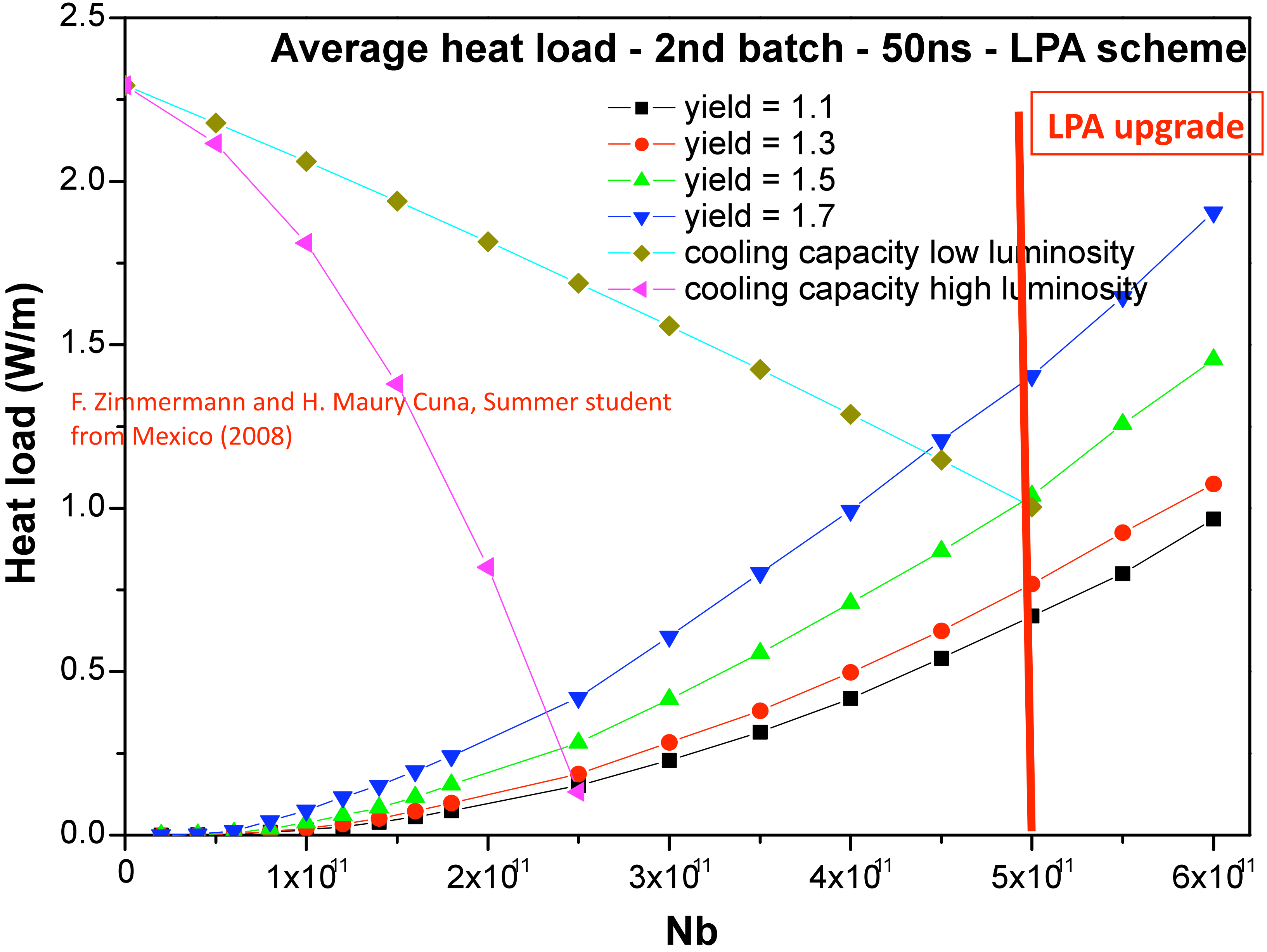
Minimum Gains for Various Bandwidths		
Bandwidth	Gain Factor	Normalized Gain
12.6 GHz	6	0.096
500 MHz	10	0.16
400 MHz	20	0.32
300 MHz	40	0.64

J. Thompson et al., CERN Report, to be published

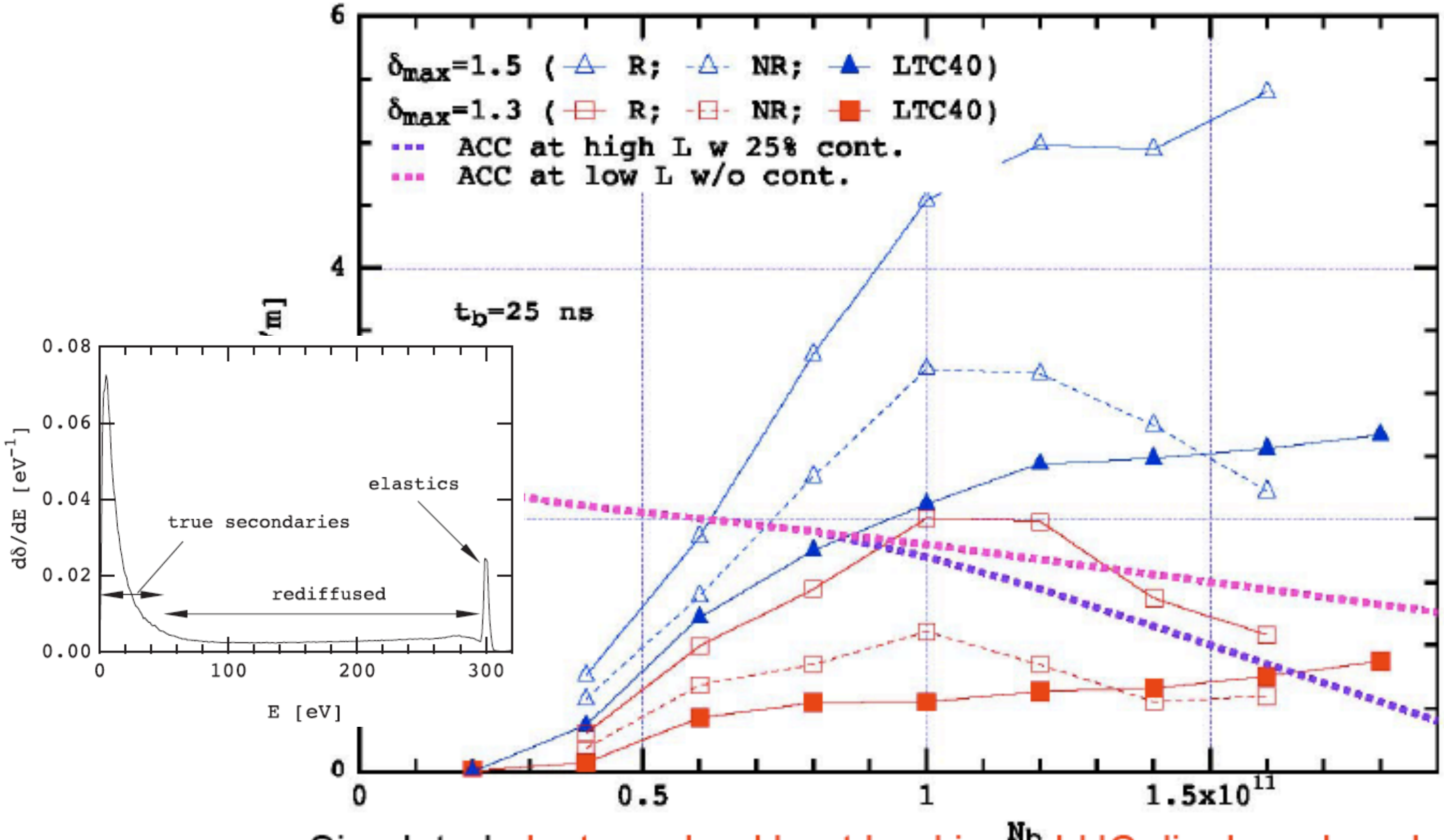
Simulations for LHC: Heat Load



Simulations for LHC: Heat Load



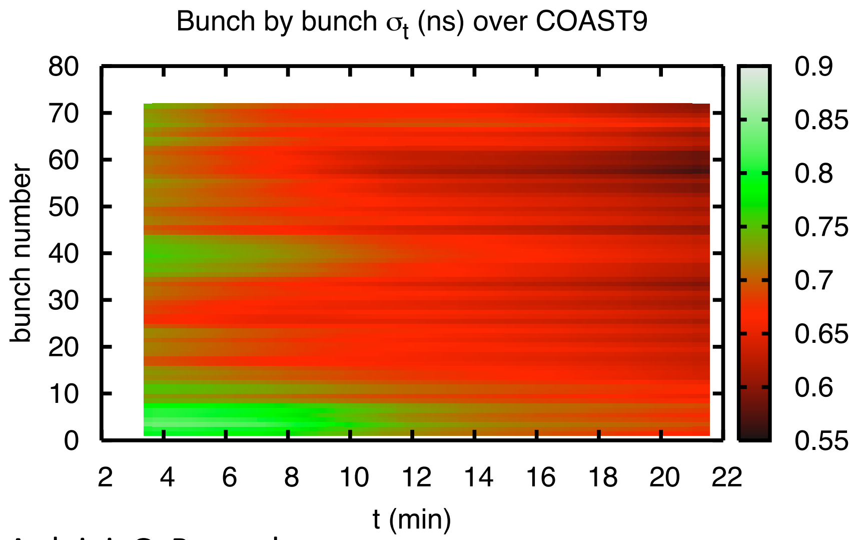
Simulations for LHC: Heat Load

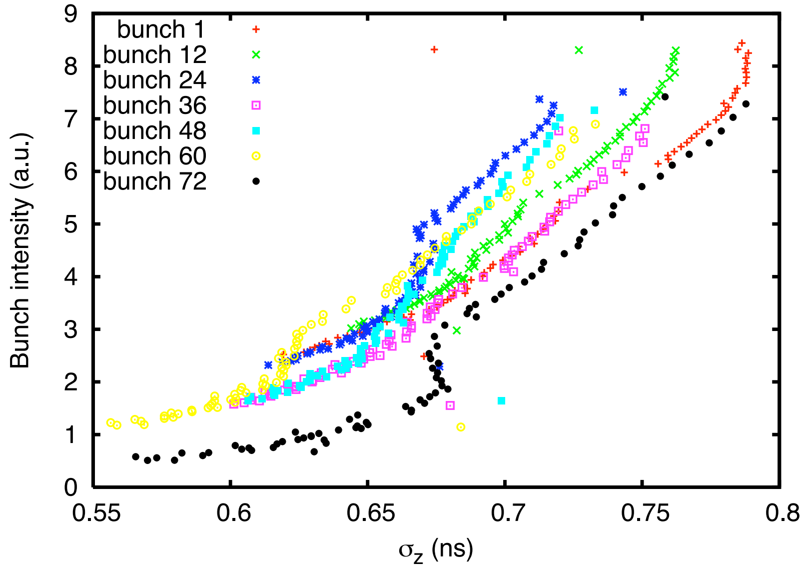


same secondary emission yield model gives about same result for different codes

Simulated electron-cloud heat load in an LHC dipole vs bunch population for two different value of δ_{max}. R: **POSINST code with full SEY model**, NR: **POSINST code with no-rediffused model**, LTC40 : result from **ECLOUD code without re-diffused electrons**. The available cooling capacity (ACC) under two different assumptions is also indicated [M. Furman, V. Chaplin, **PRST-AB 9:034403, 2006]**

Emittance growth observations in the SPS





G. Arduini, G. R., et al.

- Bunch shortening along the batch during a coast
  - ✓ Trains of LHC beams stored over several minutes in the SPS show that bunches at end of the train tend to lose more and to become shorter
  - ✓ There is an effect of chromaticity
- Effect anticipated by HEADTAIL simulations
- Is it an incoherent effect due to electron cloud ?
  - ✓ Lifetime of bunches in the end of the train strongly affected, intolerable effect for LHC stores.

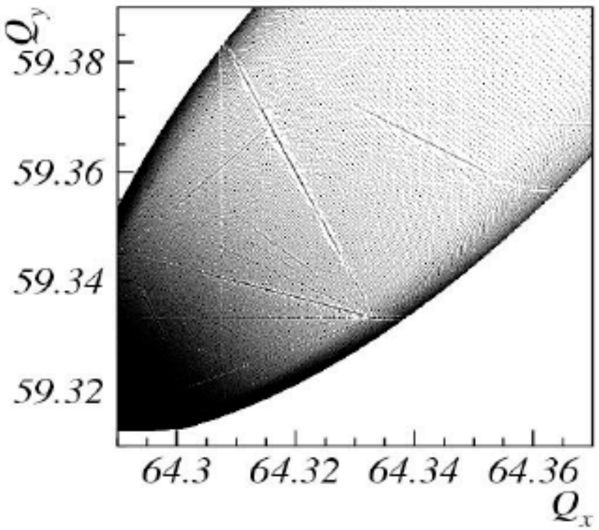
Emittance growth: simulations for LHC

Approximated lattice: constant focusing between EC kick

1 EC kick per dipole -> 1152 kicks

Tunes: Q_x = 64.28 Q_y = 59.31, Q_s = 1/168

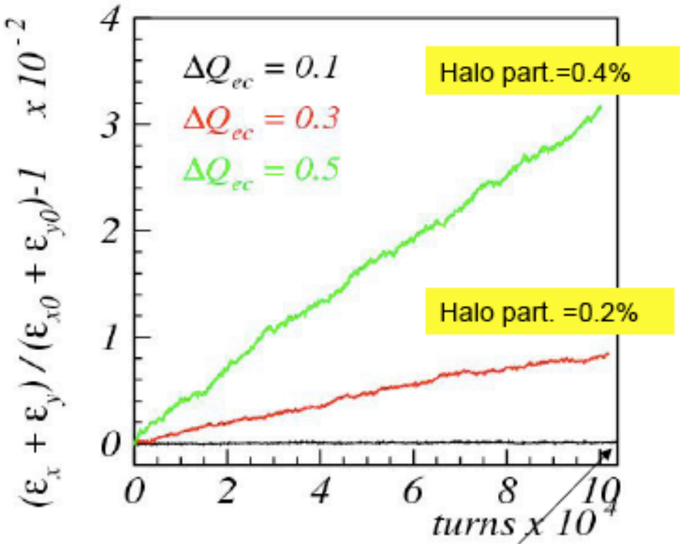
Q_x = 64.28 Q_y = 59.31
ΔQ_{ec} = 0.18



Assumptions:

1 all EC kicks are equally strong
2 no lattice change of beta is included
3 no fluctuations of EC included
4 no adjustment of EC rings as function of total integrated detuning

Slow emittance growth



emttance growth of 0.04 %

G. Franchetti, ECM'08

Summary

- Electron cloud studies for CERN complex upgrade project

→ PS2 could suffer from a heat load in the order of tens of W/m for 25 ns spacing (not very sensitive to the energy)

→ The performances of the SPS are presently limited by electron cloud instability

✓ Both simulations and experimental studies show that it will not become better by increasing the injection energy

✓ Electron cloud mitigation/suppression studies are underway to find techniques to overcome this limitation

- Surface treatment, coating (see talk by P. Chiggiato)
- Feedback system against the instability
- Other (clearing electrodes, magnetized surface layers, etc.)

- LHC

→ Heat load estimations are dependent on the secondary emission process modeling (by a factor as high as 2).

→ Slow emittance growth (observed over SPS coasts) potentially endangers beam quality preservation of beams in an LHC store.