SPS Upgrade

CARE-HHH: e-cloud mitigation workshop 2008 - ECM'08

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for SPSU Study Team

- **Motivation for SPS upgrade**
- **SPS limitations and possible cures**
- **e-cloud issues**

Motivation for CERN injector upgrade

- **Future LHC upgrade:**
  - radiation damage of LHC IR Quads (~2016)
  - statistical error reduction saturates after a few years of nominal operation
  - physics motivation for **10 times** higher $\mathcal{L}$
    - 25% more discovery range in particle mass
    - 2 times higher precision

    ►**new beam requirements**
- **Age of the present injectors and need for reliable operation for the next X(?) years**
  - Linac2 1978
  - PSB 1975
  - PS 1959
  - SPS 1976
- **New experiments at low beam energy**

Present LHC upgrade scenarios

F. Zimmermann et al.

Parameter		Nominal	Ultimate	ES & FCC	LPA
bunch intensity	10^{11}	**1.15**	**1.7**	**1.7**	**4.9**
transv. emitt.	µm	3.75	3.75	3.75	3.75
bunch spacing	ns	25	25	**25**	**50**
beta* at IP1&5	m	0.55	0.5	0.08	0.25
crossing angle	µrad	285	315	0 & 673	381
peak lumi $\mathcal{L}$ average $\mathcal{L}$ (turnaround time 10h)	10^{34} $cm^{-2}s^{-1}$	1.0 0.46	2.3 0.91	**15.5** **2.4**	**10.7** **2.5**
event pile-up		19	44	294	403

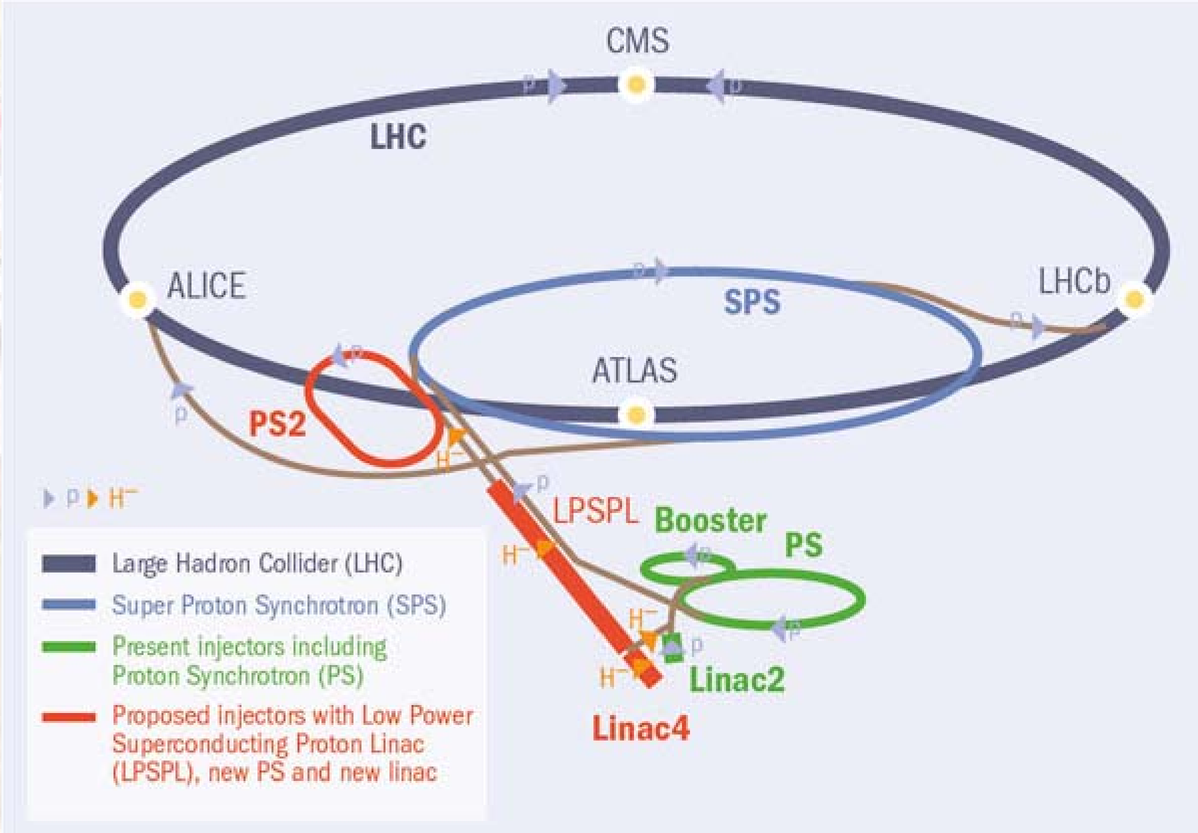
Today's performance of the LHC injector chain (nominal parameters)

	Linac2	PSB (4 rings)	PS	SPS
energy	50 MeV	1.4 GeV	25 GeV	450 GeV
max bunch intensity		**1.5×10^{11}** (x12)	**1.3×10^{11}**	**1.15×10^{11}**
number of bunches		1 per ring	$6 \rightarrow 72$	4 x 72
repetition x N pulses	1.2 s	2 x 1.2 s	4 x 3.6 s	12 x 21.6 s
intensity limitations	vacuum, RF triodes	space charge	space charge, radiation, CBI	e-cloud, CBI, TMCI, losses

CERN future accelerators

New injectors

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



Planning and milestones

- Linac4 project start: 2008; commissioning: 2012
- Beam from modified (2012/2013) PSBooster: May 2013
  → Shorter PS cycle and LHC filling time, ultimate LHC intensity, more beam for low energy physics

- Project proposal for LP-SPL, PS2 and SPSU: June 2011
- Project start: January 2012
- LP-SPL commissioning: mid-2015 – end-2016
- PS2 commissioning: mid-2016 – end-2016
- SPS commissioning: May 2017
- Nominal LHC beam for physics with new SPS injectors: July 2017
- Ultimate beam from SPS: 2018
- High intensity beam for physics: depends on the SPS upgrade
  → More reliable operation, shorter LHC filling time with higher intensity, high proton flux from LPSPL, PS2 and SPS
  → Potential for DLHC with SPS+ (new magnets 50 GeV → 1 TeV)

SPS: present achievements and future needs

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

→ **SPS upgrade is necessary**

SPS → SPSU(pgrade)

http://paf-spsu.web.cern.ch/paf-spsu/

SPSU Study Team (exists since March 2007):

G. Arduini, F. Caspers, S. Calatroni, P. Chiggiato, K. Cornelis, B. Henrist, E. Mahner, E. Metral, G. Rumolo, E. Shaposhnikova, M. Taborelli, C. Yin Vallgren, F. Zimmermann

Ultimate goals:

- Reliably provide the LHC with the beam required for reaching ten times the nominal luminosity
- Optimum use of possibilities offered by the new injectors both for the LHC and other users (FT, CNGS...)

Main tasks:

- Identify limitations in the existing SPS
- Study and propose solutions
- Design report in 2011 with cost and planning for proposed actions

Reports to PAF (chair - R. Garoby) http://paf.web.cern.ch/paf

SPS: known intensity limitations

- **Single bunch effects:**
  - space charge
  - TMC (Transverse Mode Coupling) instability

- **Multi-bunch effects:**
  - e-cloud
  - beam loss
  - vacuum: beam dump outgasing, septum sparking

  - coupled bunch instabilities
  - beam loading in the 200 MHz and 800 MHz RF systems
  - heating of machine elements (e.g. MKE, MKDV kickers)

SPSU: possible actions and cures

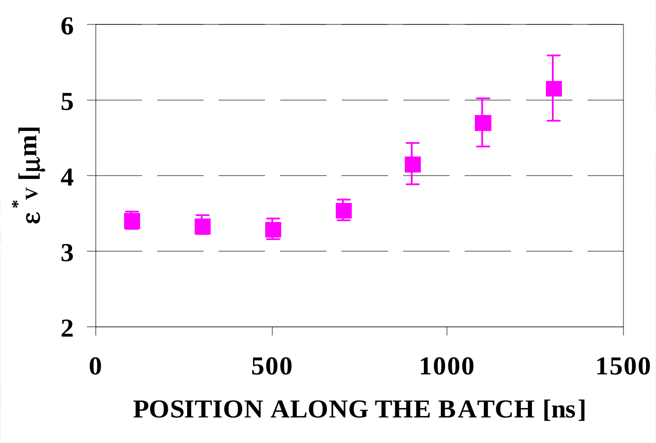
- higher injection energy: 25 → 50 GeV with PS2
- e-cloud mitigation
- impedance reduction (after identification)
- damping of instabilities:
  - active: upgrade of beam control
  - “passive”: due to increased nonlinearity
    - 800 MHz (4^{th} harmonic) RF system
    - increased longitudinal emittance
- hardware modifications: injection kickers, RF system, beam dump system, collimation, beam diagnostics, radioprotection

SPS with PS2 and 50 GeV injection

- Sufficient improvement for space charge tune spread up to bunch intensity of 5.5×10^{11}
- Increase in TMC instability threshold by a factor 2.5
- Shorter injection plateau (2.4 s instead of 10.8 s) and acceleration time (10%) – shorter LHC filling time (and turnaround time)
- No transition crossing for all proton beams and probably light ions
- Easier acceleration of heavy ions (lead):
  - smaller tune spread and IBS growth rate,
  - smaller frequency sweep - no need for fixed frequency acceleration
- Smaller physical transverse emittance – less injection losses

SPS limitations: e-cloud

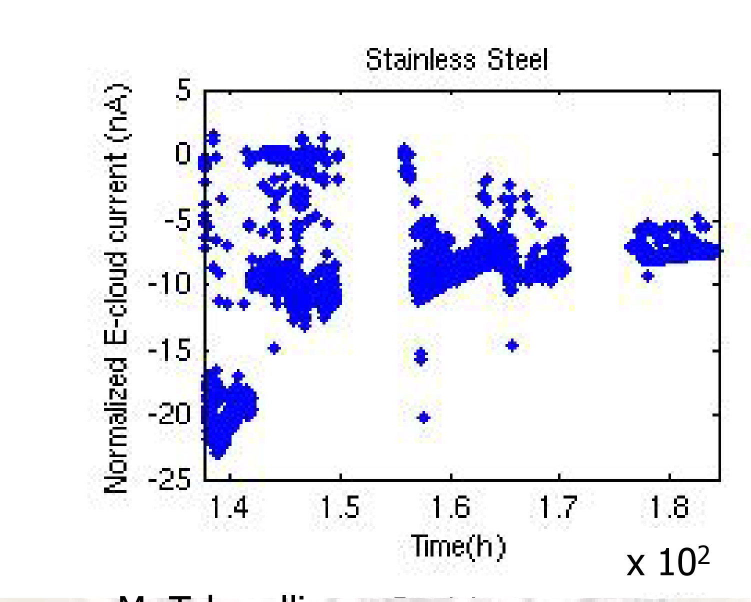
- pressure rise, septum sparking, MKDV - beam dump kickers outgasing (talk M. Barnes)
- beam losses
- transverse emittance blow-up and instabilities:
  - coupled bunch in H-plane



G. Arduini

Today's cures

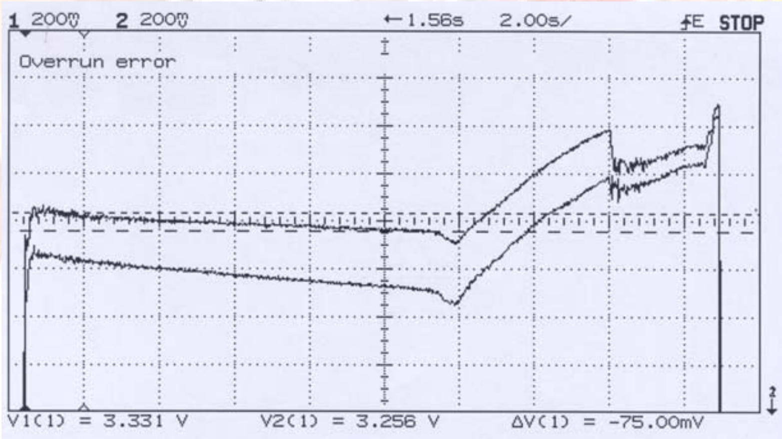
- high chromaticity in V-plane
- transverse damper in H-plane
- scrubbing run (from 2002): SEY decrease 2.5 → 1.5



M. Taborelli

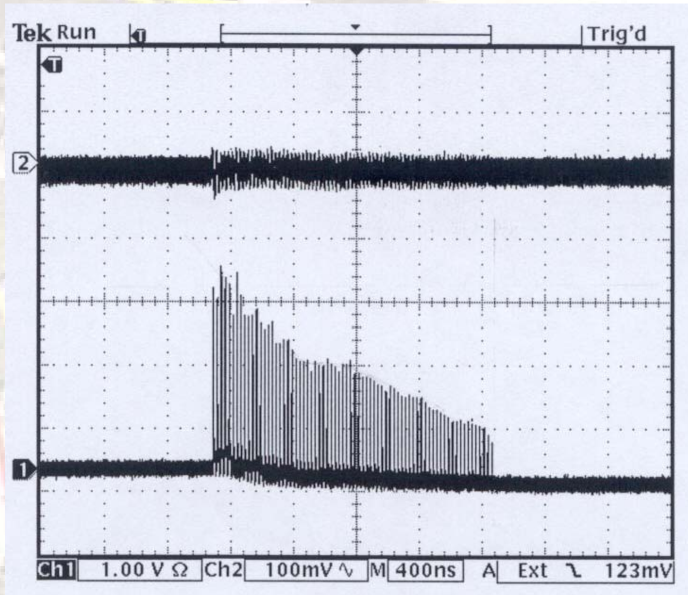
SPS limitations: beam losses

- Bunch peak amplitude in the head and tail of batch



Possible loss mechanism connected with e-cloud (G. Franchetti et al.)

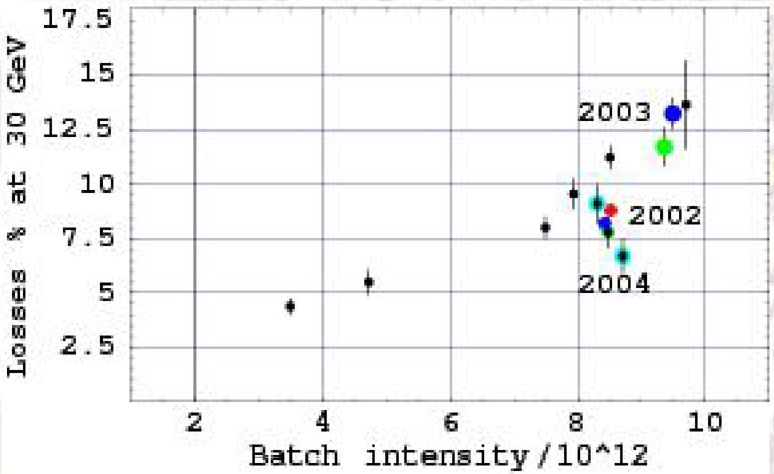
- LHC batch after 30 min of coast at 26 GeV/c



T. Bohl et al.

SPS limitations: beam losses

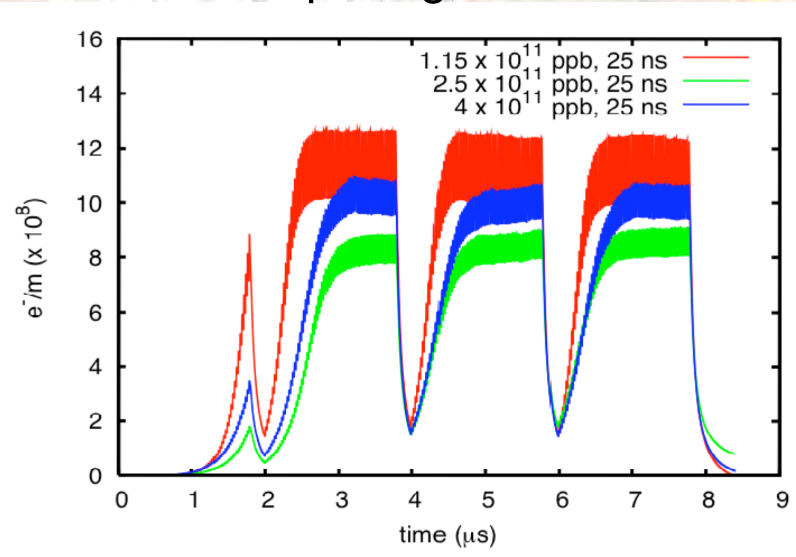
LHC beam (25 ns bunch spacing): relative capture loss for different batch intensities



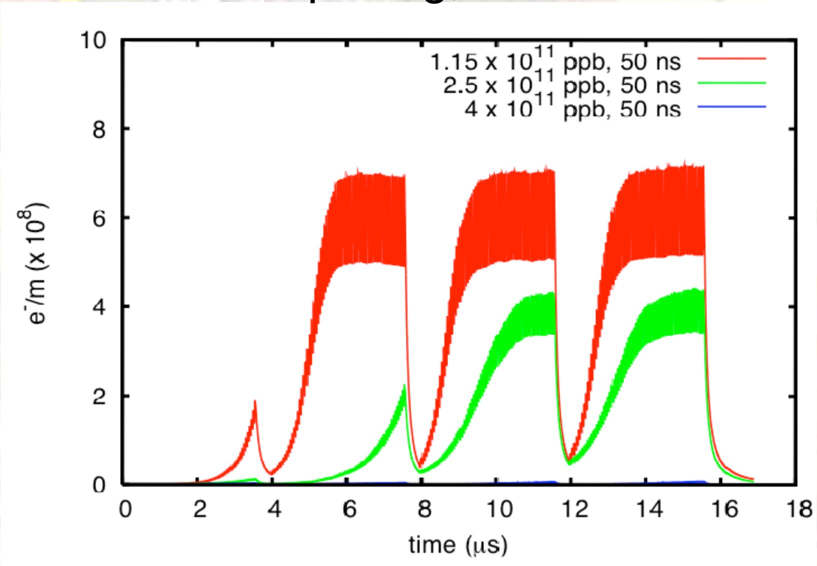
- Strong dependence on batch intensity, much less on total (number of batches)
- Reduction of losses in 2004 with new working point and RF gymnastics (2 MV → 3 MV)
- Increase of losses in 2008 (typically ~10-15 %)
- Much smaller relative losses for 75 ns and 50 ns bunch spacing for the same bunch intensity: (5-7 % in 2008)

SPS limitations: e-cloud
Scaling with bunch spacing and intensity

25 ns spacing, SEY=1.4



50 ns spacing, SEY=1.6

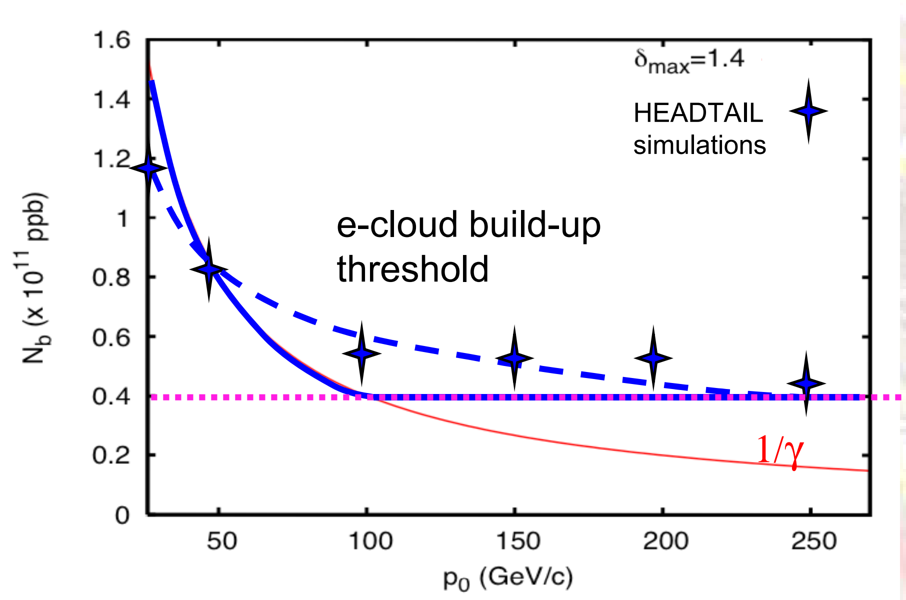


e-cloud build-up - results from ECLOUD simulations (G. Rumolo et al.):

→ non-monotonic dependence on bunch intensity for fixed spacing and SEY

→ for **50 ns spacing** a higher intensity is always better

SPS limitations: e-cloud Scaling with beam energy



V-plane: instability threshold is decreasing with energy γ (constant emittances, bunch length and matched voltage)

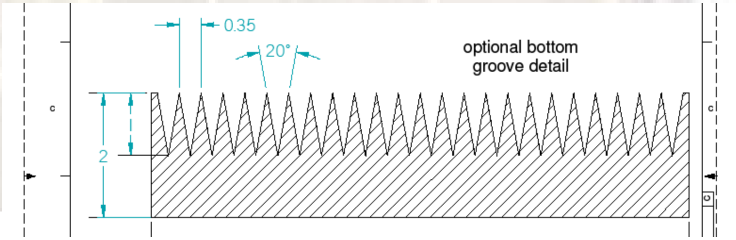
H-plane: e-cloud instability growth time ~γ (G. Arduini)

Experimental studies of the scaling law in the SPS:

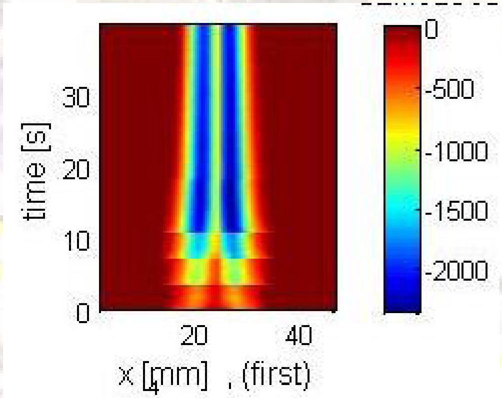
- 2006: measurements at different points during ramp with reduced chromaticity and damper gain – difficulties in interpretation
- 2007: special cycle with flat portion at 55 GeV/c, dependence on transverse size was confirmed (G. Rumolo et al. PRL, 100, 2008)

SPSU: e-cloud mitigation

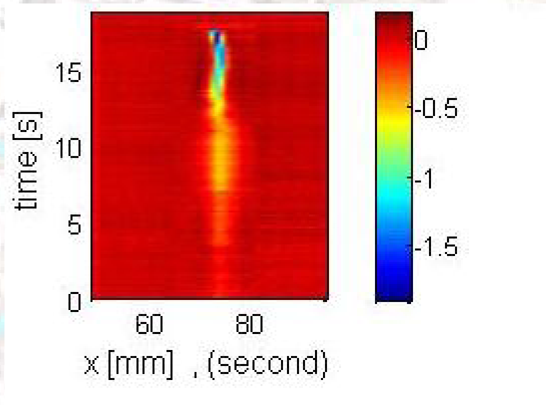
- surface coating requirements: in-situ, no aperture reduction, no re-activation:
  - carbon based composites: SEY<1 obtained, studies of ageing
    (M. Taborelli, C. Yin Vallgren)
  - rough surfaces (e.g. gold and cooper black) - vacuum issues
- cleaning electrodes (F. Caspers, E. Mahner)
- active damping system in V-plane (W. Hofle, J. Fox, R. De Maria, G. Rumolo)
- grooves (M. Pivi et al. - SLAC collaboration)



Stainless steel

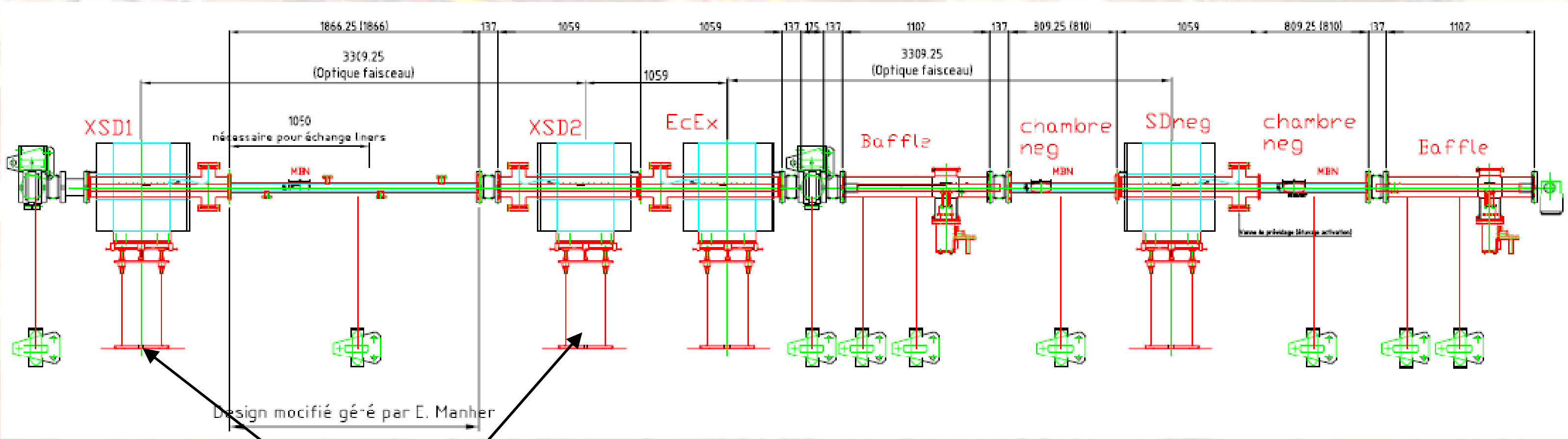


Carbon C-8



M. Taborelli

Experimental set-up in the SPS in 2008 (1/2)

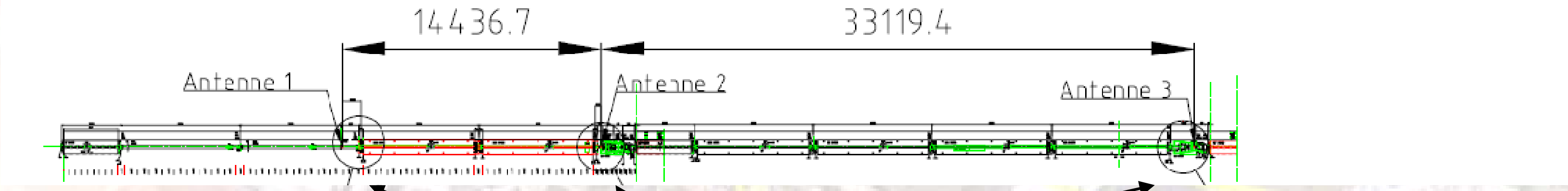


B. Hervist

- strip-line monitors XSD
  - (1) stainless steel for reference,
  - (2) new coating (a-Carbon, …)
  - (3) NEG (also good reference for low SEY)
- cleaning (enamel) electrodes with button PUs
- repeller (Macek type) detector

Experimental set-up in the SPS in 2008 (2/2)

- Microwave diagnostics for e-cloud (F. Caspers, T. Kroyer, E. Mahner et al.)



B. Hervist

3 RF antennas for microwave transmission (at 2.8 GHz)

→ Planned to use in 2009 in the SPS for measurements of e-cloud in group of coated and untreated magnets

- Dedicated vacuum chamber inside a dipole magnet for sample exchange under vacuum followed by measurements in the lab (SEY of StSt after scrubbing,…)

Possible vacuum chamber modification

S. Sgobba

Implementation in the SPS tunnel

(J. Bauche, D. Tommasini, P. Chiggiato, S. Calatroni, …)

•Infrastructure partially exists due to ongoing refurbishing of the cooling circuits of dipoles (ECX5 cavern)

•750 vacuum chambers inside dipoles can be treated in 2 years (during shutdown) → 6 per day with 2 existing Dumont machines and 2 coating benches

•LHC cold bore cleaning machine is also available if cleaning required

Summary

- In the present scenario all machines in the LHC injector chain will be replaced by new ones except the SPS, which will have a higher injection energy
- The SPS upgrade is a key element for the LHC to benefit fully from new upstream machines
- E-cloud is one of the main SPS limitations even for the present performance and it will not be improved at higher injection energy
- Experimental studies of e-cloud instability are essential for simulations, code benchmarking and feedback
- At the moment surface treatment seems to be the most promising solution, but other options should be pursued as well

Some open questions (application to the SPS)

- **Coating:**
  - can we study on time scale of one year the ageing during 10-20 years?
  - impedance measurement of rough multilayer surfaces
- **Simulations:**
  - can we rely on non-linear intensity dependence of e-cloud build-up?
- **Cleaning electrodes:**
  - fixing in-situ (needs very high temperatures 600-800 deg)
  - impedance
- **E-cloud feedback:**
  - can it cure emittance blow-up and beam losses due to e-cloud?
  - does one still need surface treatment?
- **Grooves:**
  - manufacturing, installation and aperture reduction for reasonable size/effect
  - impedance
- **Origin of beam losses on the flat bottom**