SLHC, the high-luminosity upgrade

Public Event

SPS Upgrade

26 February 2009

E. Shaposhnikova (CERN/BE/RF)
for SPSU Study Team

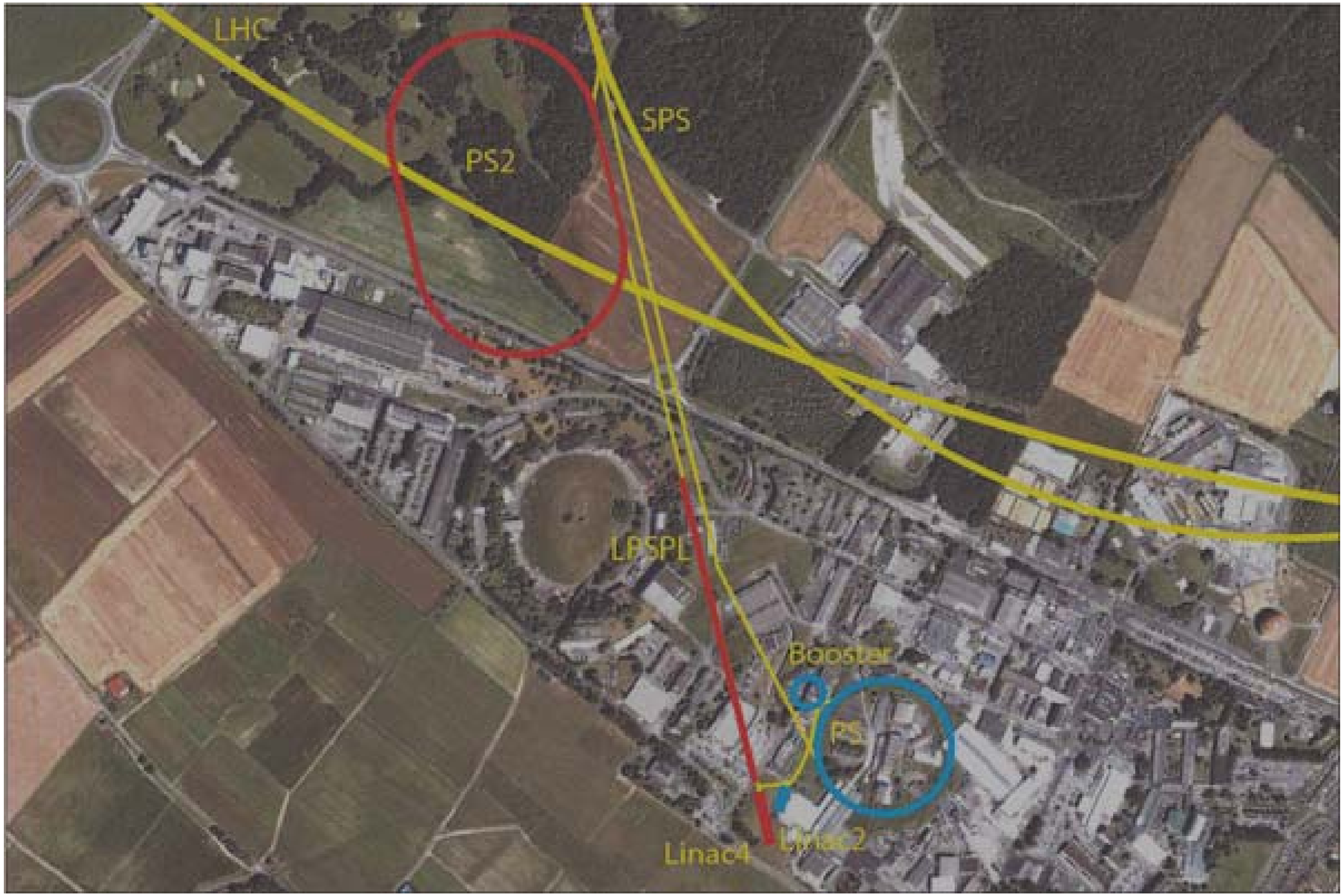
- Motivation for SPS upgrade
- SPSU activities
- SPS limitations and proposed actions

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

LHC injectors: present and future



SPS: present achievements and future needs

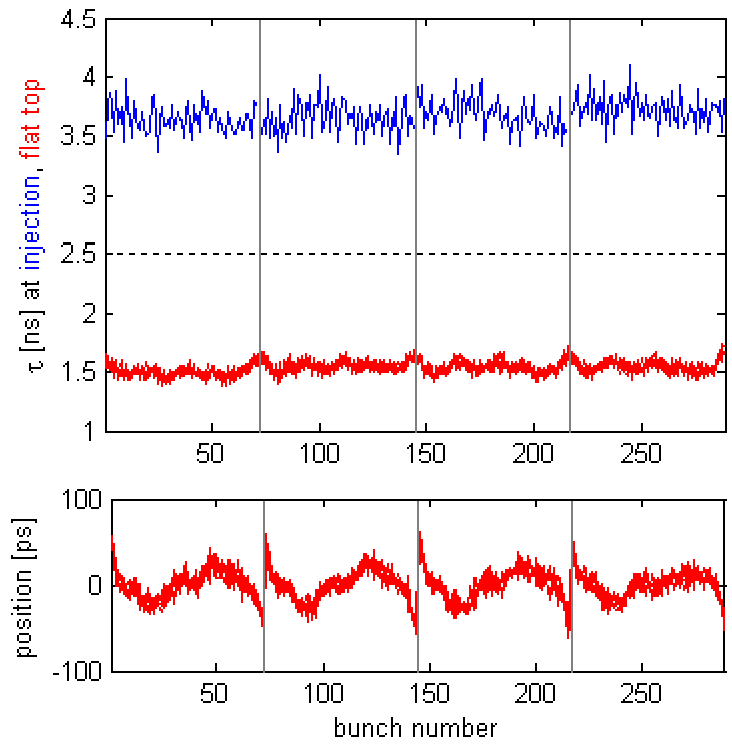
Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	25 ns	50 ns	FT	25 ns	FT	25 ns	50 ns
bunch intensity $/10^{11}$	4.4	**5.5**	1.6	**1.2**	0.13	1.7	**5.0**
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	7.4	4.6	**12.0**	3.5	**5.3**	5.7	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: today's status of nominal LHC beam

- bunch intensity: 1.15 x10^{11}
- 4 batches of 72 bunches spaced at 25 ns
- bunch length: 1.6 ± 0.1 ns
- bunch position (FT) < 100 ps
- longitudinal emittance:
  0.6 ± 0.1 eVs
- transverse normalised emittances:
  - H-plane 3.0 ± 0.3 µm
  - V-plane: 3.6 ± 0.3 µm
- beam loss ~ 10%

Bunch length and position over 4 LHC batches at injection and flat top



G. Papotti et al., 2008

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, E. Mahner, E. Metral, G. Rumolo, E. Shaposhnikova, M. Taborelli, C. Yin Vallgren, F. Zimmermann + J. Bauche, P. Costa Pinto, G. Vandoni, N. Gilbert + R. Garoby, M. Jimenez + guests (Y. Kadi, M. Barnes, …)

Main tasks

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

~12 (formal) meetings per year + informal discussions and meetings

SPSU activities in 2007-2009 (1/2)

- **SPS beam dump**
  - beam dump - TIDVG
    - improved spare or a new one?
  - beam dump kickers – MKDV, MKDH
    - impedance issues (no transition pieces)
    - heating with 75 ns spaced beam
    - outgassing with 50 ns spaced beam – limitation, MDs in 2008
- **MKE kickers**
  - impedance issues, heating: shielding or a new design?
- **SPS impedance budget**
  - search for missing transverse impedance

SPSU activities in 2007-2009 (2/2)

- **e-cloud**:
  - simulation studies
  - e-cloud mitigation options and their possible implementation
  - experimental set-up in the SPS
  - measurements with beam during scrubbing runs and long MDs (special ‘MD cycle’ in 2007)

SPS: known intensity limitations

- **Single bunch effects:**
  - space charge
  - TMCI (transverse mode coupling instability)

- **Multi-bunch effects:**
  - e-cloud
  - coupled bunch instabilities at injection and high energy
  - beam loss (7-10% for 25 ns bunch spacing and 5% for 50 ns bunch spacing and nominal bunch intensity)
  - beam loading in the 200 MHz and 800 MHz RF systems
  - heating of machine elements (MKE, MKDV kickers, …)
  - vacuum (beam dump and MKDV outgassing), septum sparking

SPSU: possible actions and cures

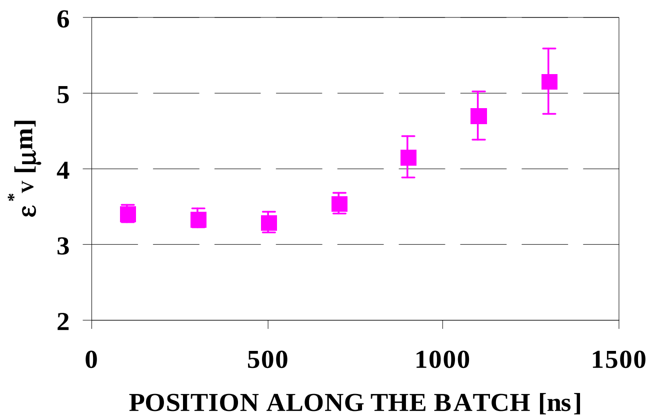
- Higher injection energy: 25 → 50 GeV with PS2
- e-cloud mitigation
- Impedance reduction (after identification!)
- Damping of instabilities:
  - active: upgrade of beam control (transverse and longitudinal feedbacks)
  - "passive": due to increased nonlinearity
    - 800 MHz (4^{th} harmonic) RF system
    - increased longitudinal emittance (more losses at capture in LHC)
- Hardware modifications: injection kickers, RF system, beam dump system, beam diagnostics, radioprotection…
- New hardware: collimation?

SPS with PS2 and 50 GeV injection

- Sufficient improvement for space charge tune spread up to bunch intensity of 5.5 $\times 10^{11}$
- 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

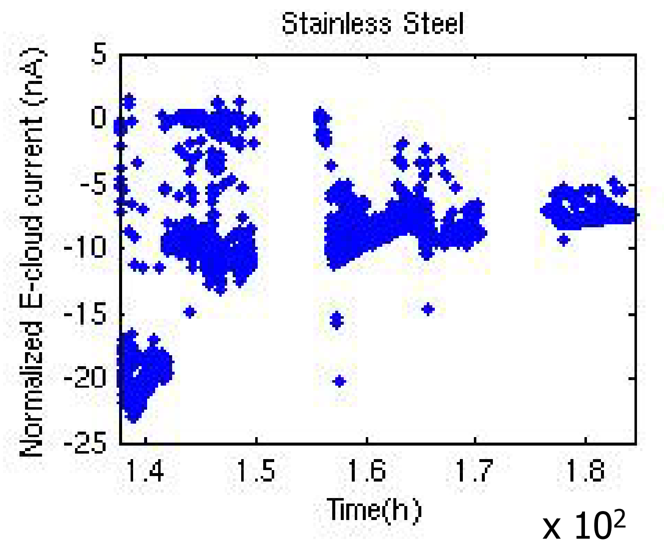
- pressure rise, septum sparking, beam dump, MKDV outgassing
- beam losses on flat bottom
- transverse emittance blow-up and instabilities:
  - coupled bunch in H-plane
  - single bunch in V-plane



G. Arduini

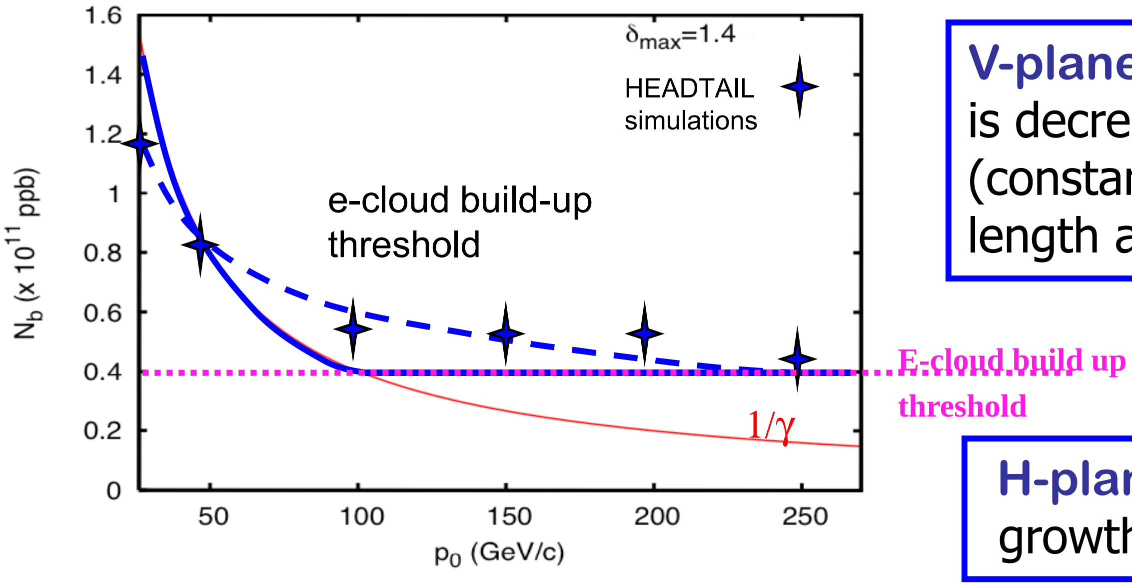
Today's cures

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



M. Taborelli

SPS limitations: e-cloud Scaling with beam energy



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

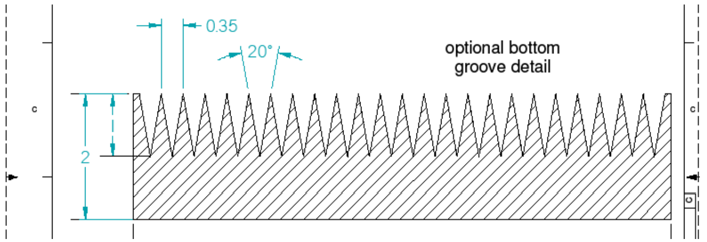
H-plane: e-cloud instability growth time ~γ

Experimental studies of the scaling law in the SPS:

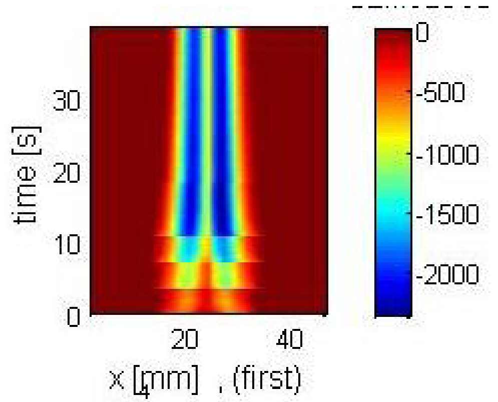
- 2006: measurements at different points during ramp with reduced chromaticity and damper gain – difficulties in interpretation
- 2007: special cycle with flat portion at 55 GeV/c, dependence on transverse size was confirmed (G. Rumolo et al. PRL, 100, 2008)

e-cloud mitigation

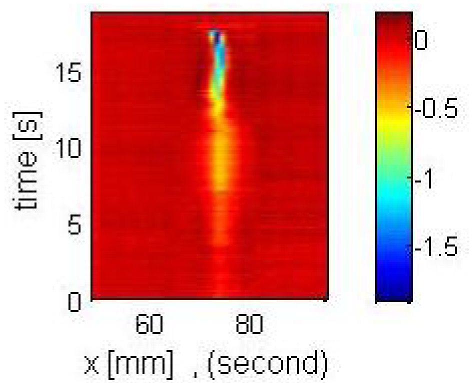
- surface treatment: in-situ, no aperture reduction, no re-activation (S. Calatroni, P. Chiggiato, M. Taborelli, C. Yin Vallgren…)
  - carbon based composites, SEY<1 obtained, - ageing problem (with venting)
  - rough surfaces – 2 layers
  - electromagnetic roughness (F. Caspers)
- clearing electrodes (F. Caspers et al.)
- active damping system in V-plane (W. Hofle + LARP)
- grooves - 35% reduction was measured in lab (for Al) (M. Pivi – SLAC, M. Taborelli)



Stainless steel

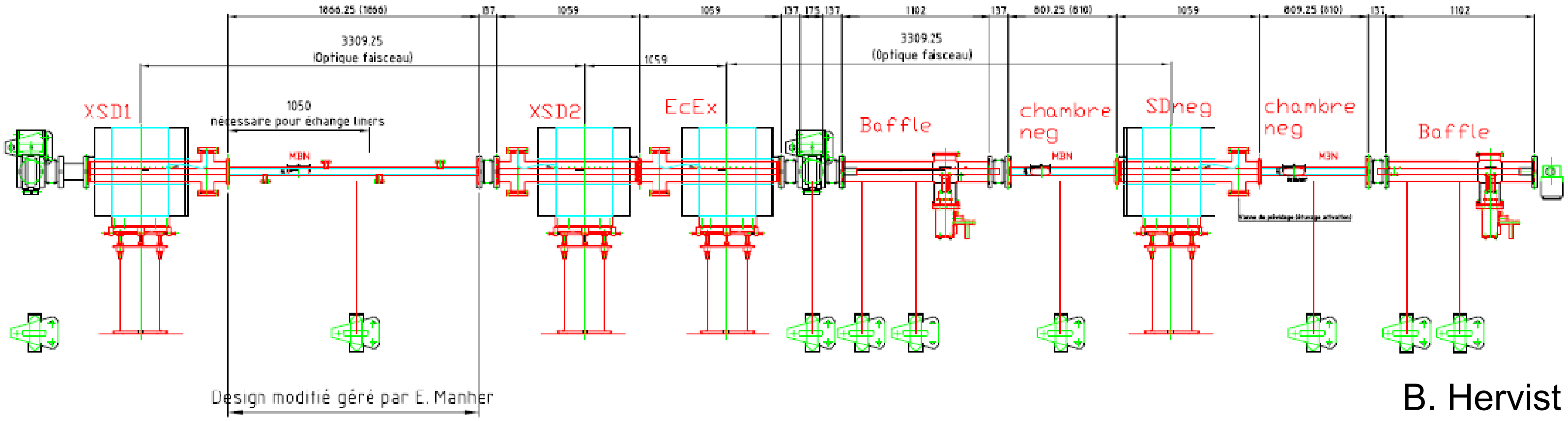


a-Carbon C-8



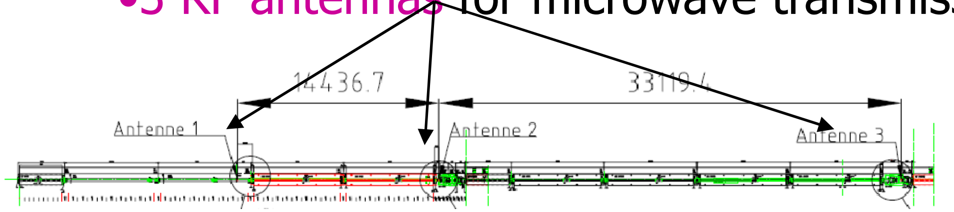
M. Taborelli

SPS experimental set-up for e-cloud studies in 2008



B. Hervist

- 3 strip-line monitors: stainless-steel, a-C coating, NEG → 4 in 2009!
- clearing (enamel) electrodes with button PUs
- C - magnet with exchangeable samples → 2 magnets in 2009
- 3 RF antennas for microwave transmission measurements (at 2.8 GHz)

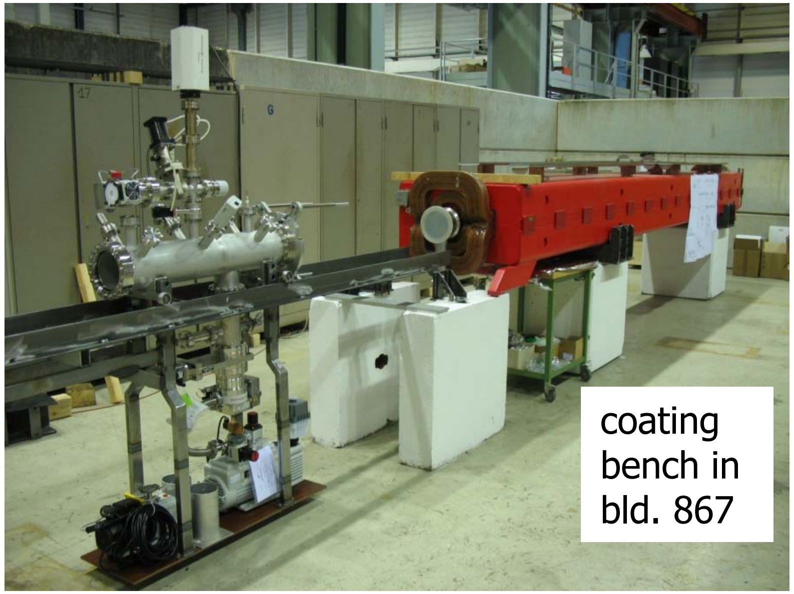


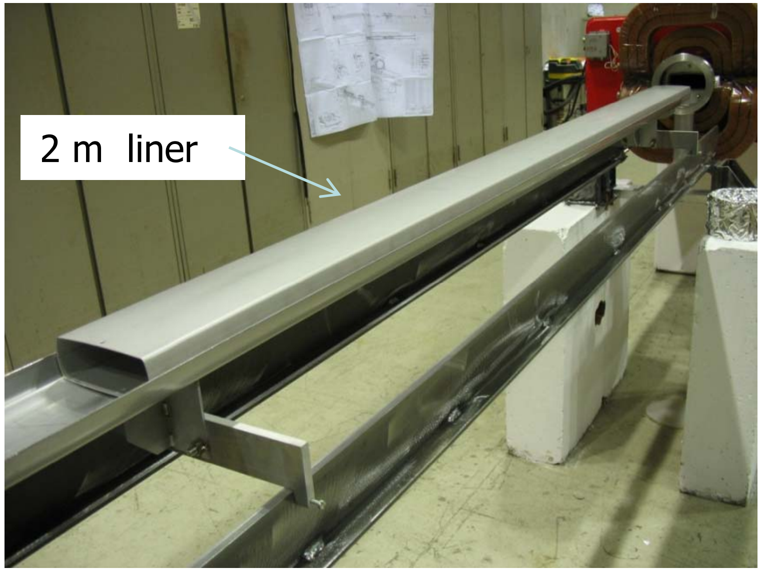
6 RF antennas in 2009 around coated and uncoated magnets

Possible vacuum chamber modification for e-cloud mitigation

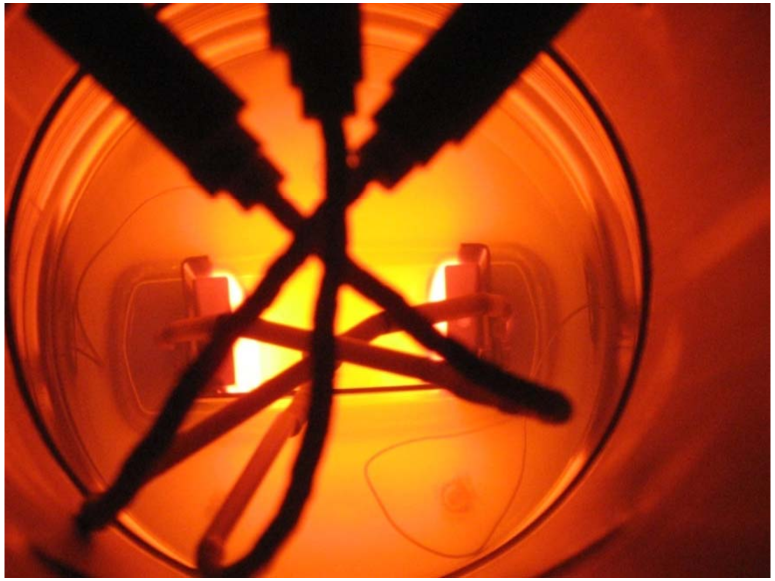
Implementation in the SPS tunnel
(J. Bauche, D. Tommasini, P. Costa Pinto, S. Calatroni et al.)

- Experience due to installation of RF shields (1999-2001) and ongoing refurbishing of the cooling circuits of dipoles (2007-2009)
- Infrastructure: ECX5 cavern – ø20 m
- 750 dipoles can be coated in 120 days → 2-3 shutdowns (48 h/magnet, 6/day, 2 Dumont machines and 2 coating benches)
- Plans for 2009: 3 MBB spare magnets coated and installed in SPS test area with microwave and vacuum diagnostics

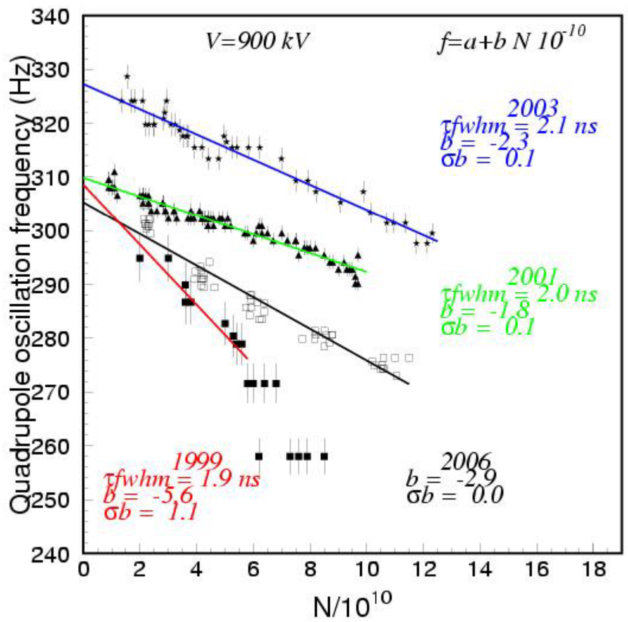




- Special coating system (1mx6) using dipole magnetic field designed (P. Costa Pinto et al.)
- After initial tests on liner, the first SPS MBB magnet was successfully coated with amorphous Carbon this week - due to efforts of many people from different departments and groups!
- 2 MBB till the end of the next week



SPS limitations: impedance



Quadrupole oscillation frequency as a function of bunch intensity

$\text{Im}\ Z_{eff} \sim \text{slope}$

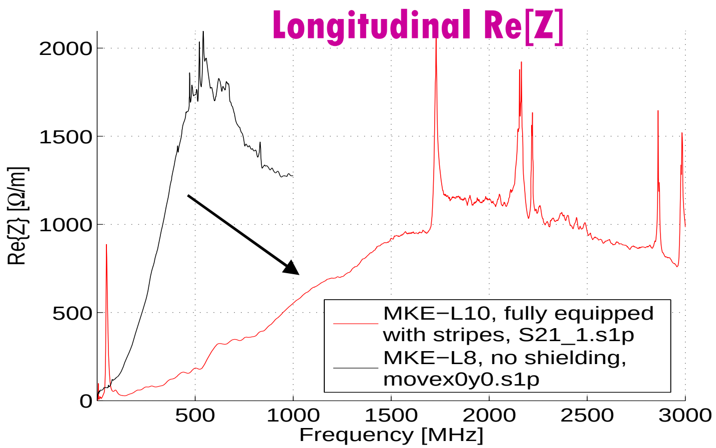
Similar measurements in V-plane

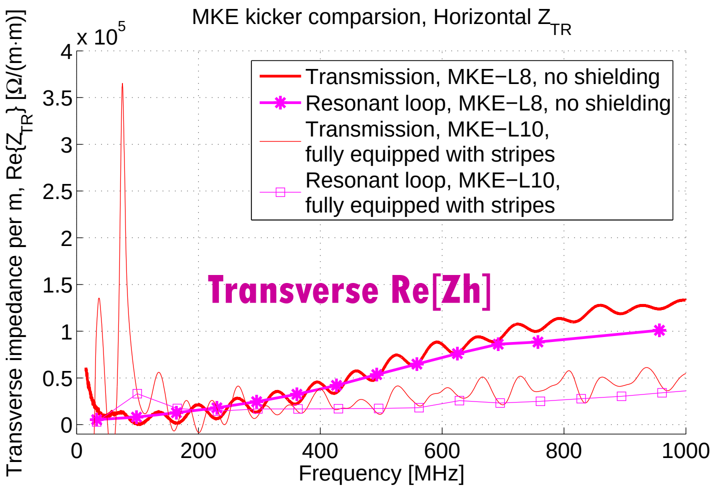
(H. Burkhardt et al.)

- 1999-2001: SPS impedance reduction in preparation for nominal LHC beam → no microwave instability
- 2003-2006: impedance increase, mainly due to re-installation of 8 MKE (extraction kickers for LHC)
- Only 50% of SPS transverse impedance budget is known

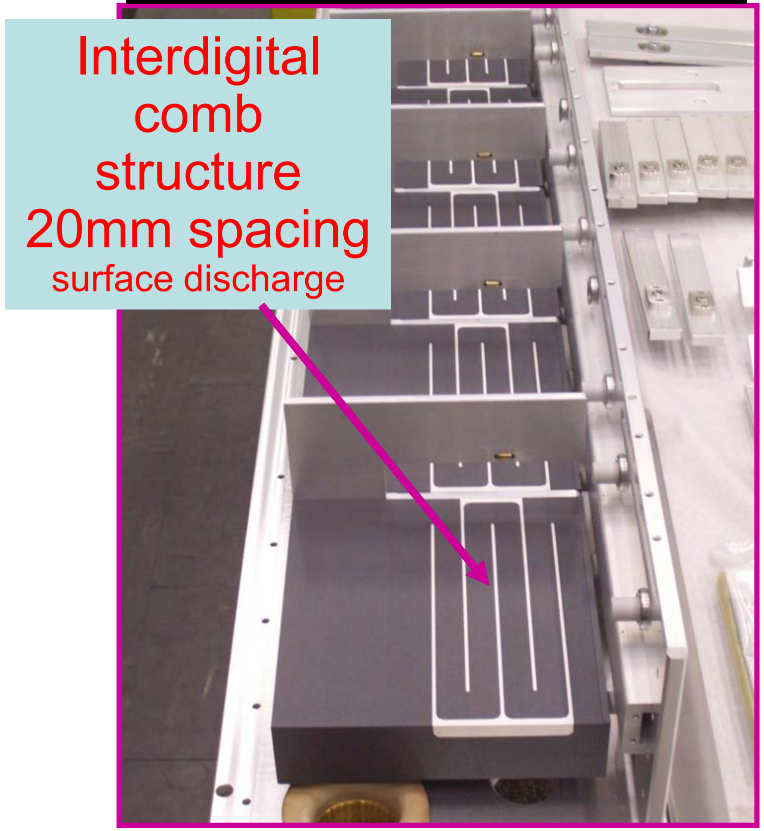
  → search for the rest
- Shielding of the known impedance sources (MKE, MKDV...)
- Active damping of the 800 MHz impedance (FB and FF)

SPS limitations: impedance
MKE kicker shielding





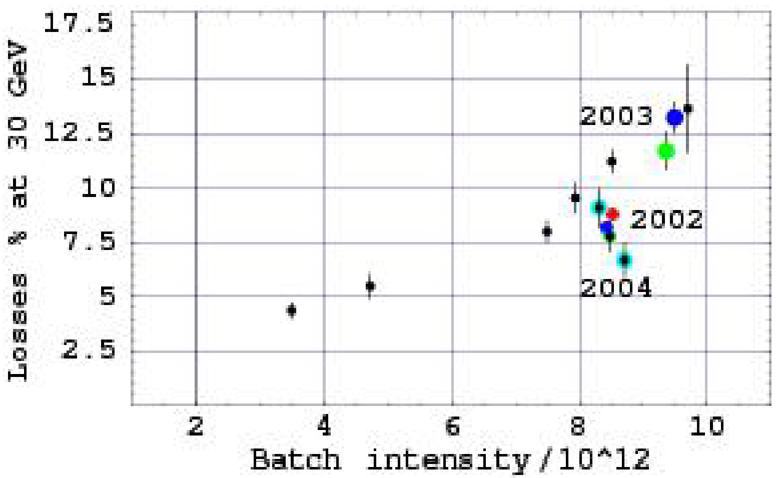
Printed strips in MKE-L10



F. Caspers, T. Kroyer,
M. Barnes , E. Gaxiola

SPS limitations: beam losses

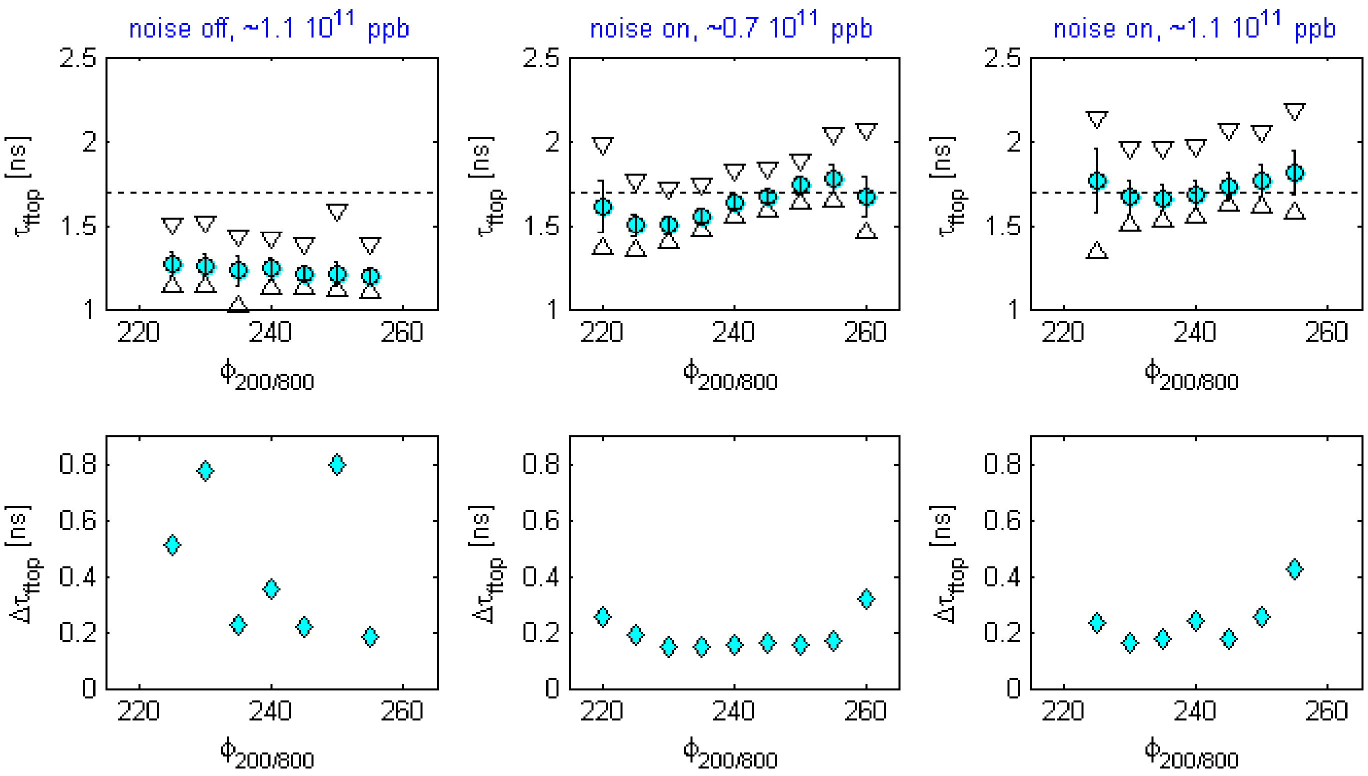
LHC beam (25 ns bunch spacing): relative capture loss for different batch intensities



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

➢ To have the same absolute losses relative losses should be reduced for higher intensities!

Coupled bunch instabilities



Bunch length
(av., max-min)

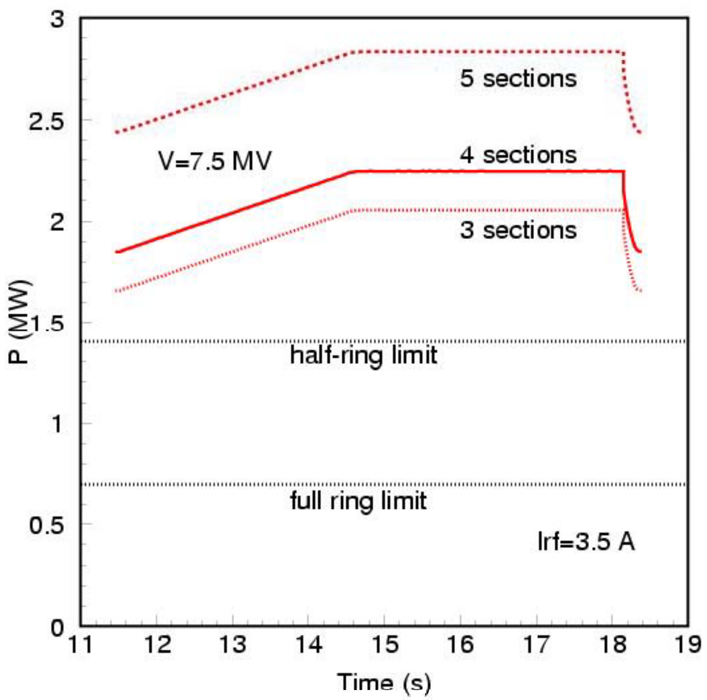
Beam stability

G. Papotti et al.

- **Cures:** 800 MHz RF system in bunch-shortening mode and controlled emittance blow-up → 0.6 eVs (0.9 eVs for upgrade intensities)

RF systems upgrade

200 MHz RF power
(max LHC upgrade intensity)



- Coupled-bunch (long.) instability threshold ~1/5 nominal intensity
- Larger emittance needed for higher intensities (ε~√N)

- The 200 MHz RF system limits:
  - Voltage 7.5 MV
  - Power 0.7 MW for full ring
- (3.3-4.5) MW/cavity (200 MHz) for max PS2 intensity

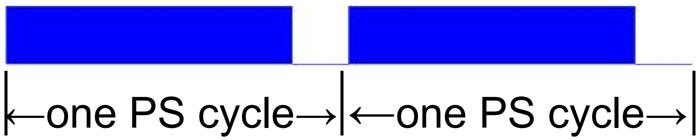
→ The 200 MHz and 800 MHz power plant should be increased

→ R&D for re-design of couplers and coaxial lines

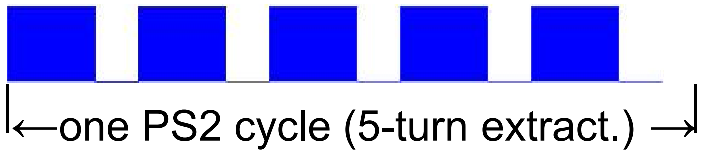
→ Cavity length (200 MHz) could be optimised (5 → 3 sections)

SPS upgrade: potential for other (fixed target, CNGS) beams

with PS



with PS2



Main intensity limitations:

- beam losses (transition crossing, no bunch-to-bucket transfer)
- beam control
- RF voltage and power

Flux: 0.6 (1.0)x10^{20} pot/year for intensity of 6x10^{13} and 6 s cycle

Potential proton flux with maximum PS2 intensity for

- 200 days of operation,
- 80% beam availability,
- 45 (85)% beam sharing

6.0 s cycle: 1.0 (2.0)x10^{20} pot/year
→ RF power upgrade

4.8 s cycle: 1.3 (2.5)x10^{20} pot/year
→ + new RF (voltage)

M. Meddahi, E.S., 2007

Planning and milestones

(before 19 September 2008)

- Project proposal for LP-SPL, PS2 and SPSU: 2011
- Project start: 2012
- LPSPL and PS2 commissioning: 2015 – 2016

- SPS commissioning: 2017
- Nominal LHC beam for physics with new SPS injectors: 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 SPS to CNGS-type users
  → Potential for DLHC with SPS+ (new magnets 50 GeV → 1 TeV)

Summary

- The upgraded CERN injectors should produce high intensity beam with high reliability both for LHC and other users
- All machines in the LHC chain will be replaced by new ones except the SPS, which will profit from a higher injection energy
- The SPS upgrade is a key element for the LHC to benefit fully from new upstream machines
- Some measures proposed for the SPS upgrade would help for the operation with nominal and ultimate LHC beams and can be implemented earlier (e-cloud mitigation, impedance reduction)

Acknowledgments and references

- **PAF (Proton Accelerators for Future) WG:** http://paf.web.cern.ch/paf/
  R. Garoby, M. Benedikt, O. Bruning, M. Meddahi, R. Ostojic, W. Scandale, E. S., F. Zimmermann
- **SPS Upgrade WG:**
  http://paf-spsu.web.cern.ch/paf-spsu/
  Members: G. Arduini, F. Caspers, S. Calatroni, P. Chiggiato, K. Cornelis, B. Henrist, E. Mahner, E. Metral, G. Rumolo, E. S., M. Taborelli, C. Yin Vallgren, F. Zimmermann + many others

RF: T. Bohl, E. Ciapala, T. Linnecar, G. Papotti, J. Tuckmantel