CARE-HHH Workshop 2008

Scenarios for the LHC upgrade and FAIR

SPS Upgrade

24 November 2008

E. Shaposhnikova (CERN/AB)
for SPSU Study Team

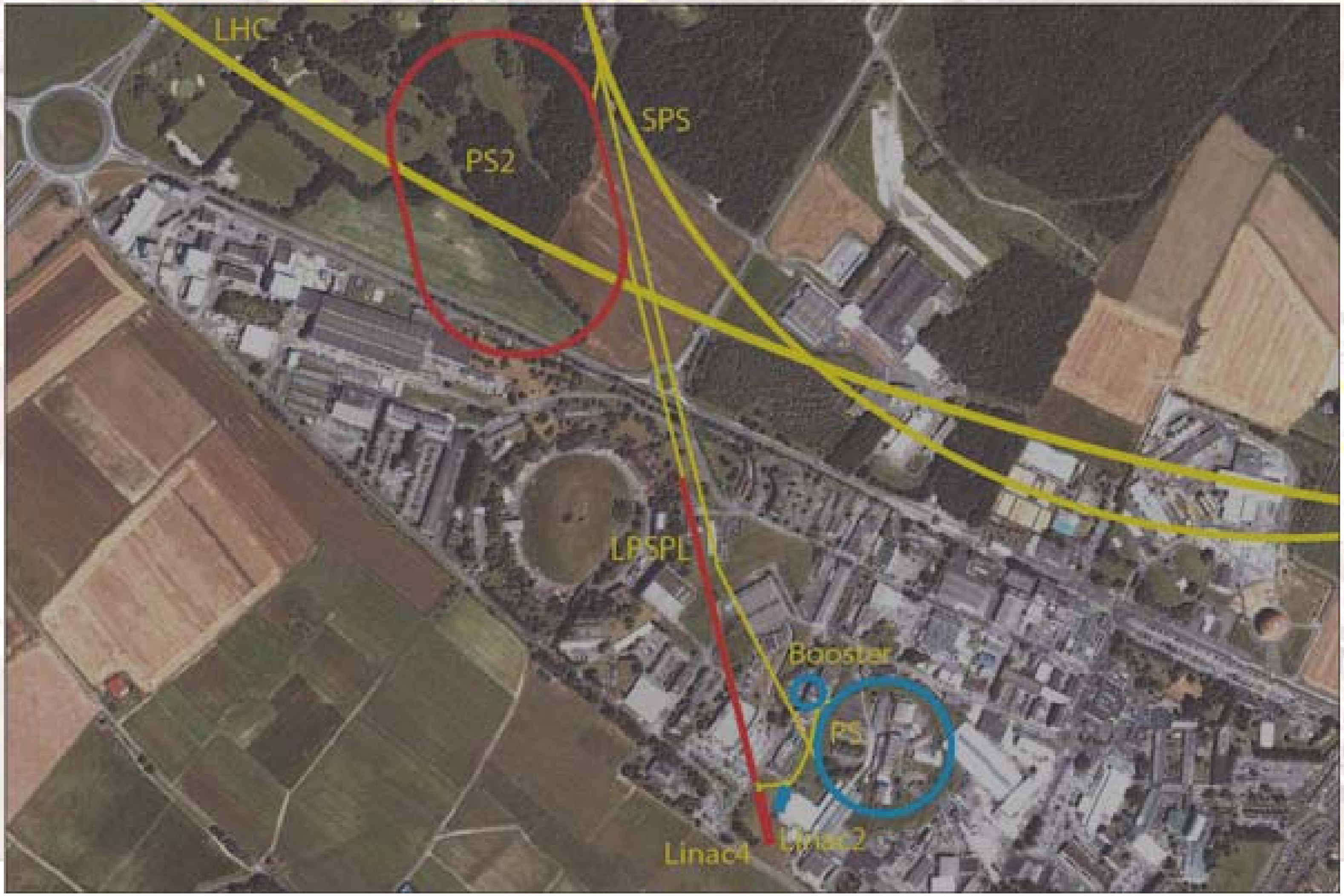
- **Motivation for SPS upgrade**
- **SPSU activities in 2008**
- **SPS limitations and proposed actions**

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

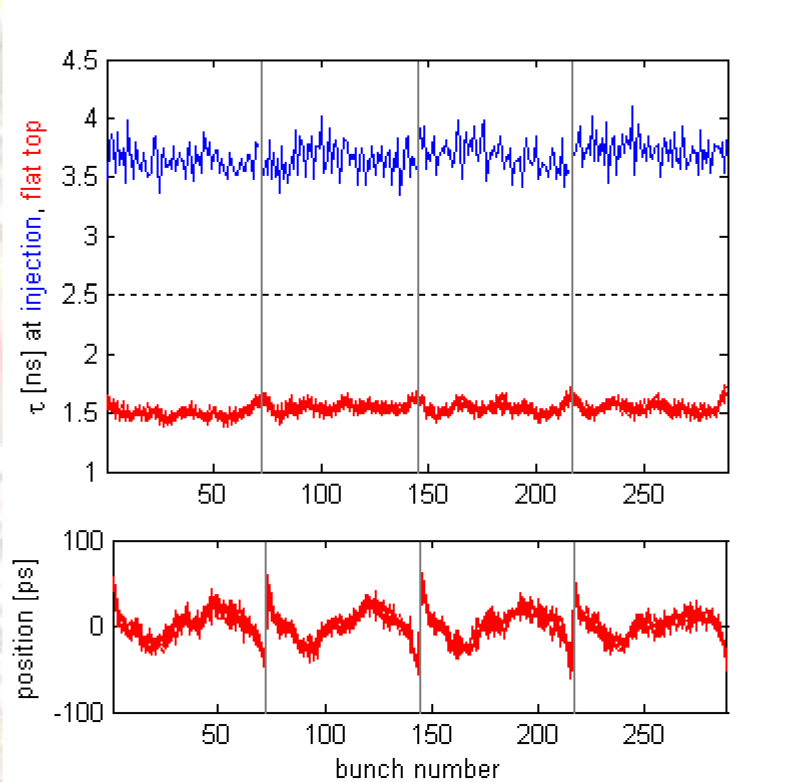
Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	25 ns	50 ns	FT	25 ns	FT	25 ns	50 ns
bunch intensity $/10^{11}$	4.4	**5.5**	1.6	**1.2**	0.13	1.7	**5.0**
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	7.4	4.6	**12.0**	3.5	**5.3**	5.7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

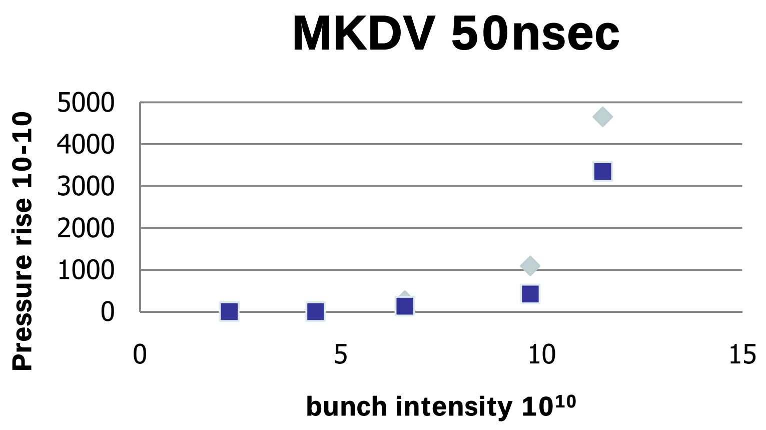
Bunch length and position over 4 LHC batches at injection and flat top

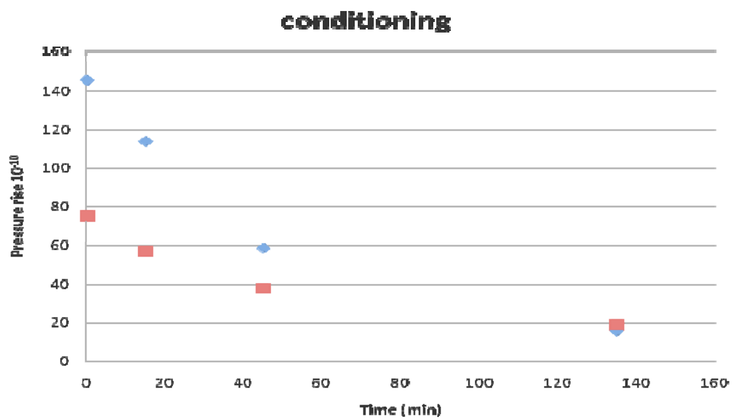


G. Papotti et al., 2008

SPS: today's status of 50 ns spaced LHC beam

- bunch intensity: 1.1 10^{11}
- 4 batches of 36 bunches
- beam loss ~ 5%
- bunch length at 450 GeV/c: 1.3 ns → emit. = 0.4 eVs without controlled blow-up (not needed for stability)
- transverse emit. < nominal
- fast pressure rise in MKDV1 → interlock – intensity limitation
  - intensity threshold
  - RF voltage (bunch length)
  - conditioning, but quickly lost





K. Cornelis

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

+ R. Garoby, M. Jimenez

Main tasks (defined by PAF):

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

2007: 11 (formal) meetings and video conference
2008: 12 (formal) meetings and …

2008 budget: ~350 kCHF

SPSU activities in 2007-2008 (1/2)

- **SPS beam dump**
  - beam dump - TIDVG (Y. Kadi)
    - improved spare or a new one?
  - beam dump kickers – MKDV, MKDH (M. Barnes)
    - impedance issues (no transition pieces)
    - heating with 75 ns spaced beam
    - outgassing with 50 ns spaced beam – limitation, studies during two SPS MDs
- **MKE kickers**
  - impedance issues, heating (M. Barnes): shielding or a new design?
- **SPS impedance budget**

SPSU activities in 2007-2008 (2/2)

- **E-cloud** (talks by G. Rumolo, J.M. Jimenez, P. Chiggiato in Session 7):
  - 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, W 28 and W 41 in 2008)

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 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

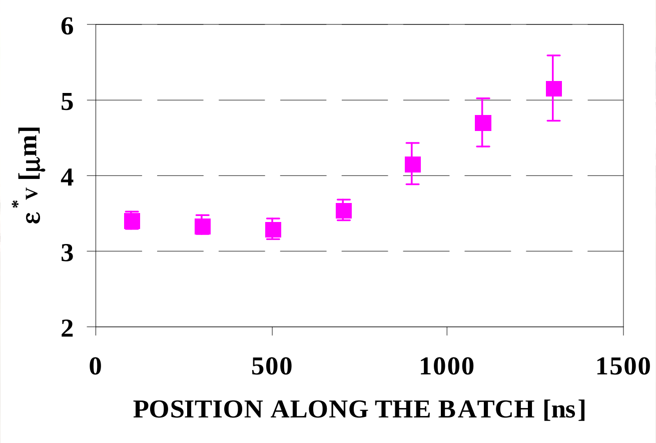
- Higher injection energy: 25 → 50 GeV with PS2
  (SPS injection kickers are considered as a part of PS2 studies)
- E-cloud mitigation
- Impedance reduction (after identification) – with help from SPS impedance informal meetings (organised by E. Metral)
- Damping of instabilities:
  - active: upgrade of beam control (transverse and longitudinal feedbacks) – foreseen by White Paper
  - "passive": due to increased nonlinearity
    - 800 MHz (4th 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 $\times 10^{11}$
- 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

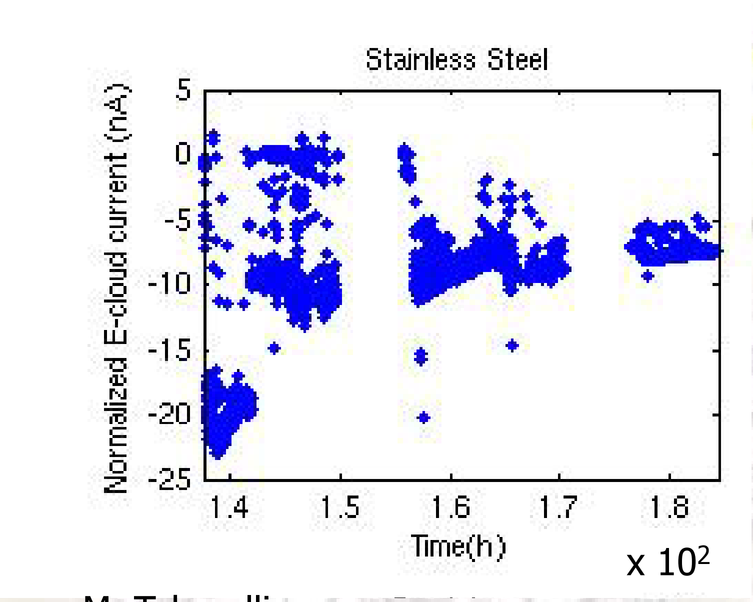
- pressure rise, septum sparking, beam dump, MKDV outgassing
- beam losses
- transverse emittance blow-up and instabilities:
  - coupled bunch in H-plane
  - single bunch in V-plane



G. Arduini

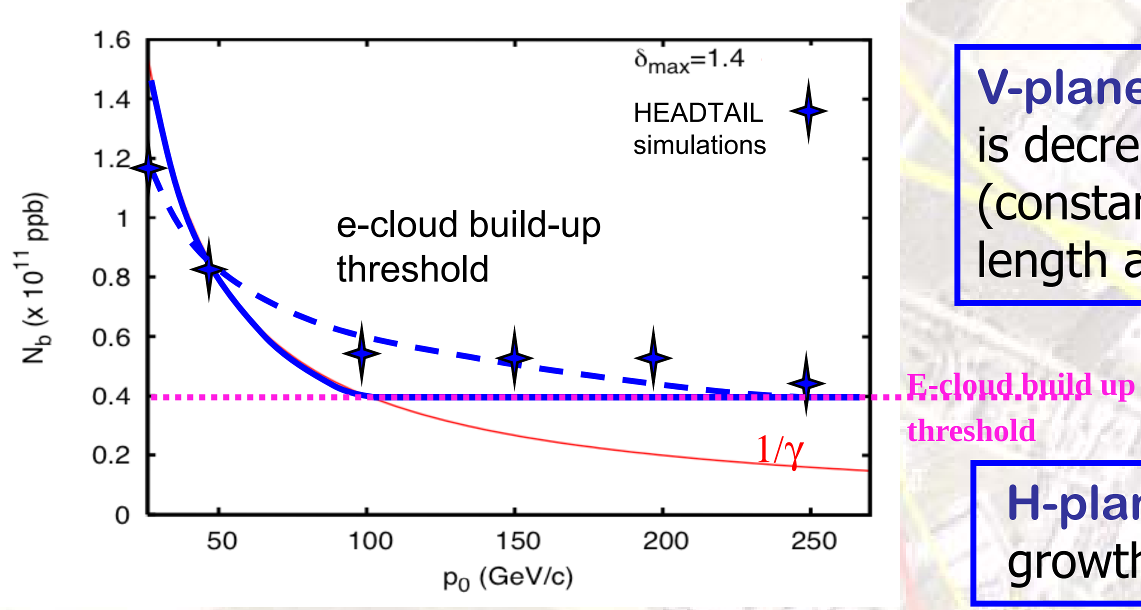
Today's cures

- 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)

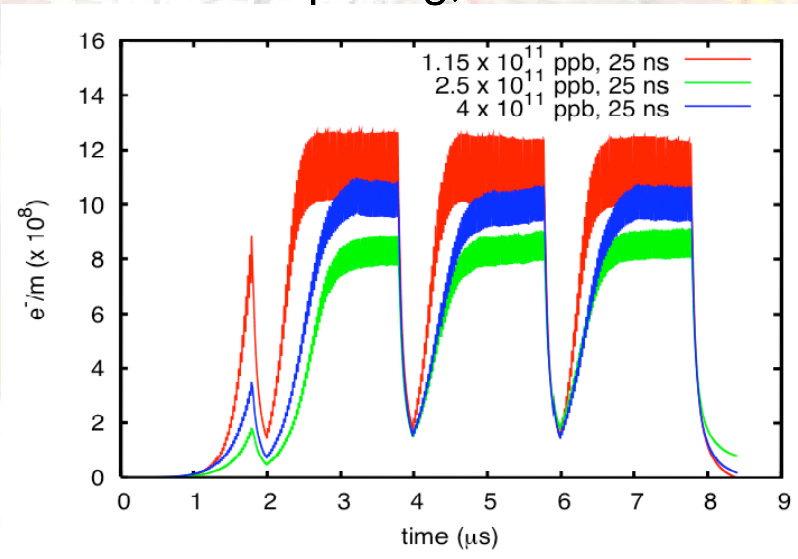
H-plane: e-cloud instability growth time ~γ

Experimental studies of the scaling law in the SPS:

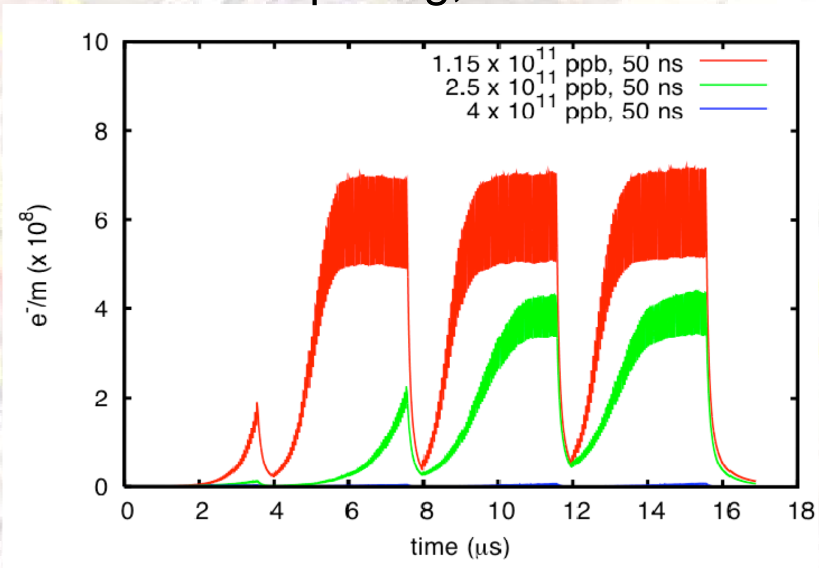
- 2006: measurements at different points during ramp with reduced chromaticity and damper gain – difficulties in interpretation
- 2007: special cycle with flat portion at 55 GeV/c, dependence on transverse size was confirmed (G. Rumolo et al. PRL, 100, 2008)

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

25 ns spacing, SEY=1.4



50 ns spacing, SEY=1.6



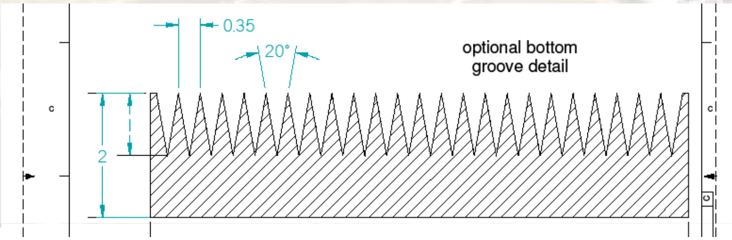
e-cloud build-up - results from ECLOUD simulations (G. Rumolo et al.):

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

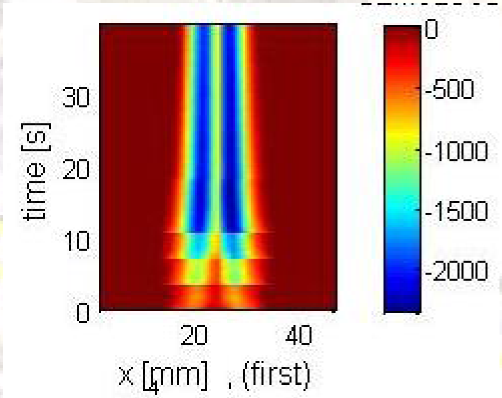
→ For **50 ns spacing** a higher intensity is always better

e-cloud mitigation

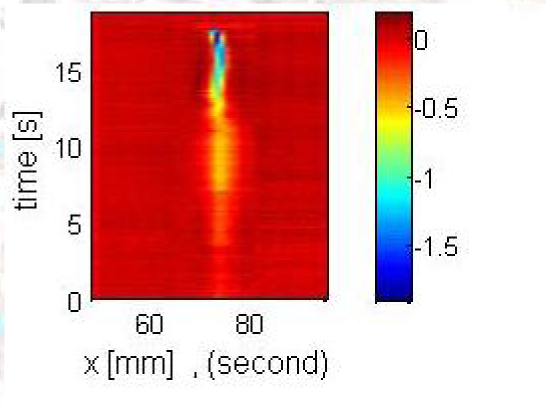
- surface treatment: in-situ, no aperture reduction, no re-activation (S. Calatroni, P. Chiggiato, M. Taborelli, C. Yin Vallgren…)
  - carbon based composites, SEY<1 obtained, - ageing problem (with venting)
  - rough surfaces – 2 layers
- cleaning (enamel) electrodes (F. Caspers)
- active damping system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



Stainless steel

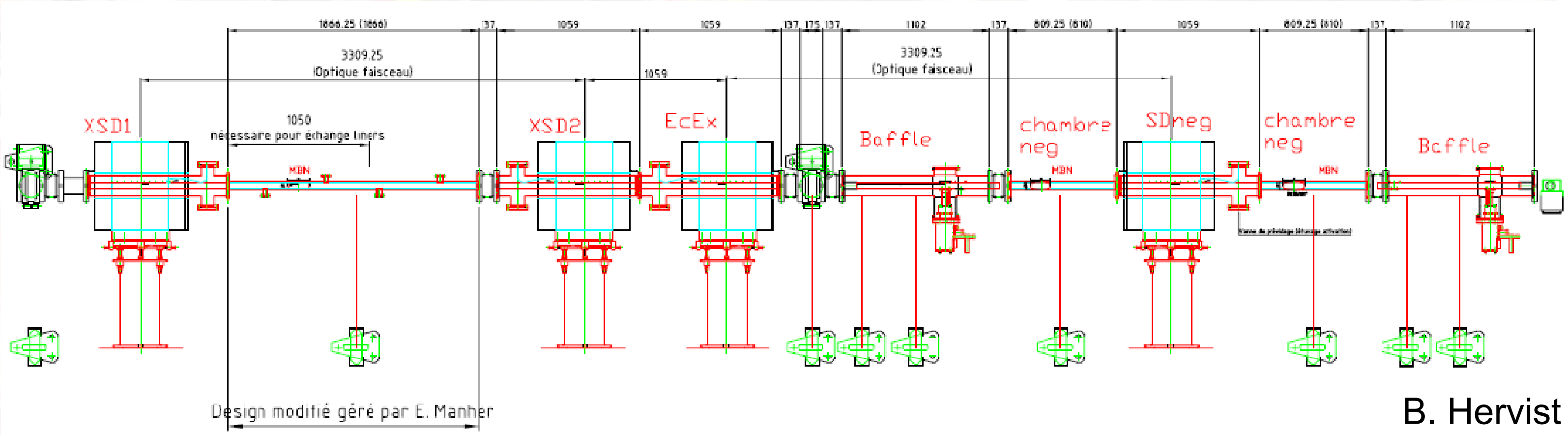


Carbon C-8



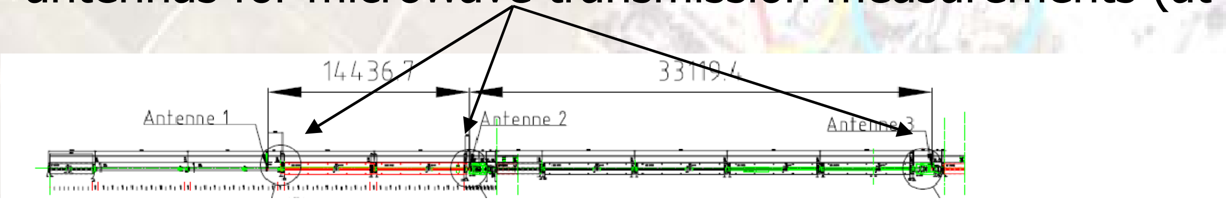
M. Taborelli

Experimental set-up in the SPS in 2008



B. Hervist

- 3 strip-line monitors XSD: St-St for reference, new coating, NEG
- cleaning (enamel) electrodes with button PUs
- C - magnet with exchangeable samples
- 3 RF antennas for microwave transmission measurements (at 2.8 GHz)



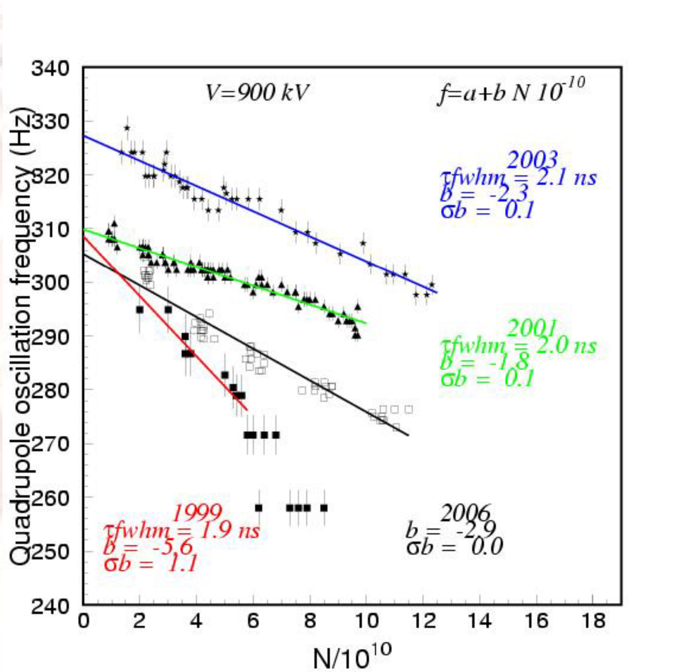
Possible vacuum chamber modification for e-cloud mitigation

Implementation in the SPS tunnel

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

- 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 shutdowns (48 h/chamber, 6/day) with 2 Dumont machines and 2 coating benches
- Plans for 2009: 3 MBB spare magnets coated and installed in SPS test area with mw and vacuum diagnostics

SPS limitations: impedance



Quadrupole oscillation frequency as a function of bunch intensity

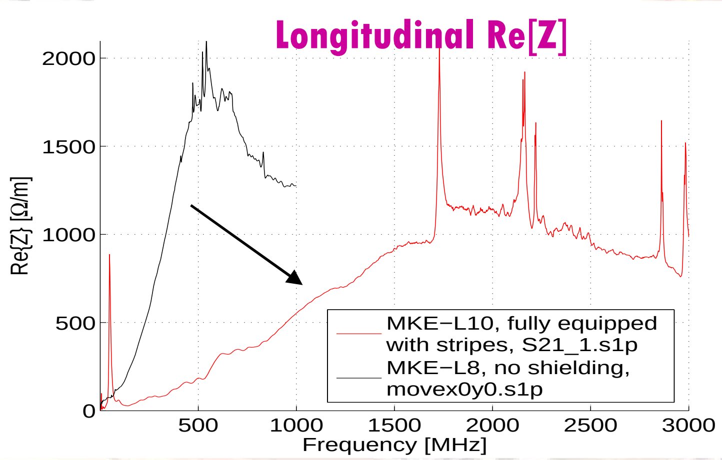
Im Z_{eff} ~ slope

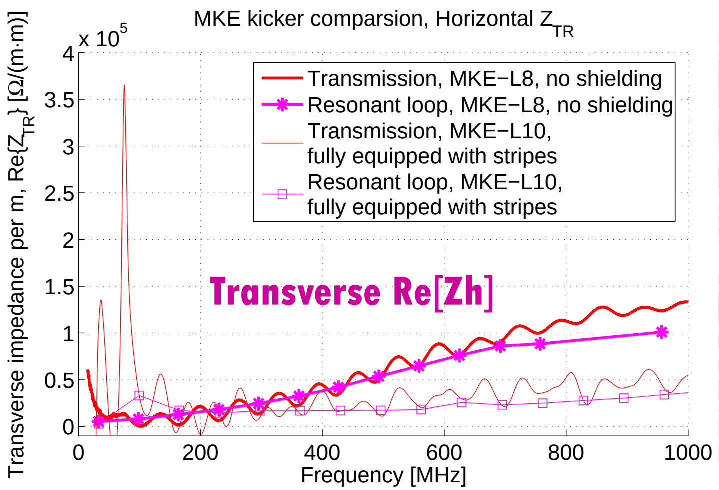
Similar measurements in V-plane

(H. Burkhardt et al.)

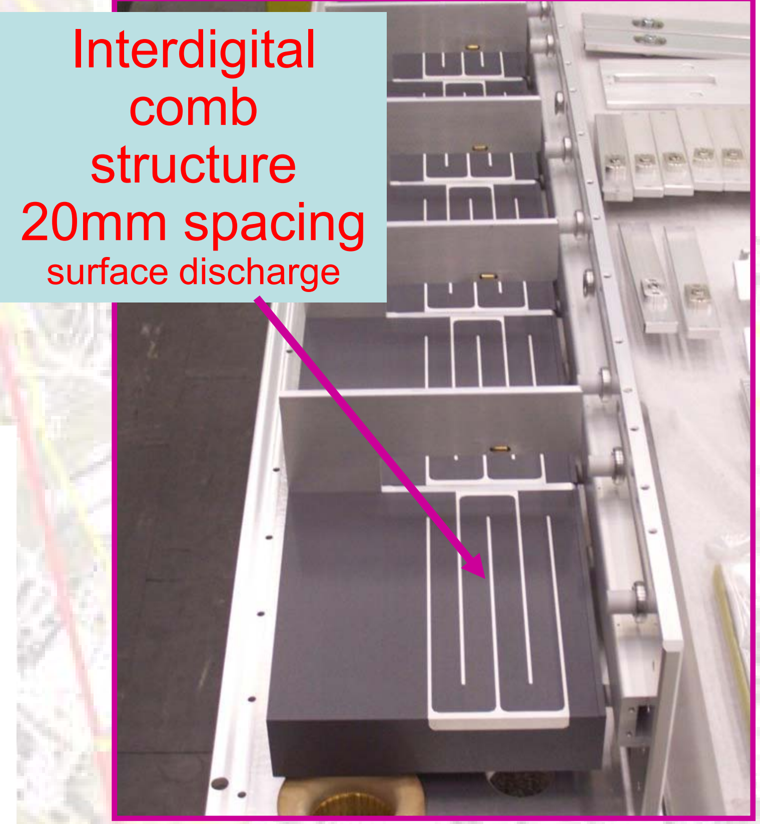
- 1999-2001: SPS impedance reduction in preparation for nominal LHC beam → no microwave instability
- 2003-2006: impedance increase, mainly due to re-installation of 8 MKE – extraction kickers for LHC
- Only 50% of SPS transverse impedance budget is known
  → search for the rest
- Shielding of the known impedance sources (MKE, MKDV...)
- Active damping of the 800 MHz impedance (FB and FF)

SPS limitations: impedance
MKE kicker shielding



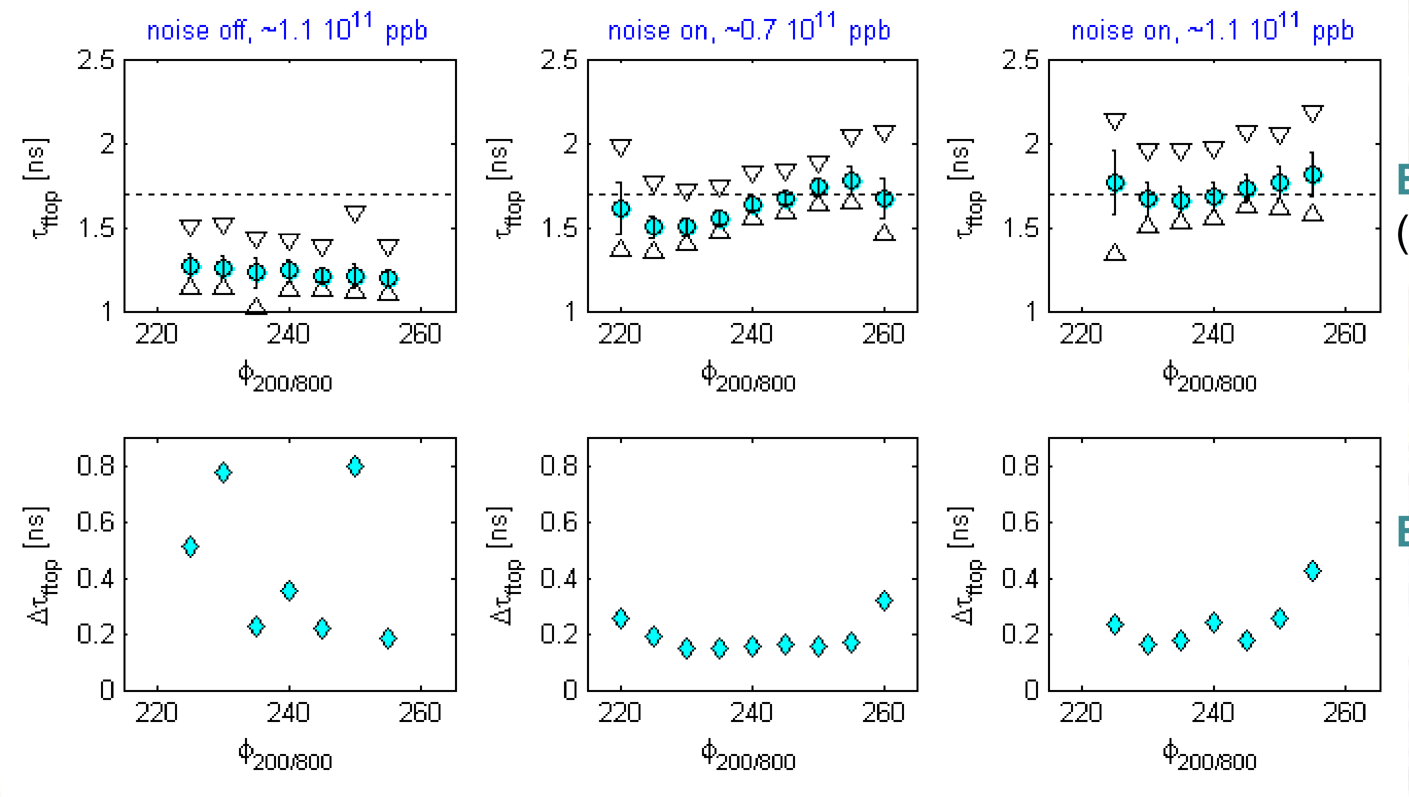


Printed strips in MKE-L10



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

SPS: coupled bunch instabilities



Bunch length
(av., max-min)

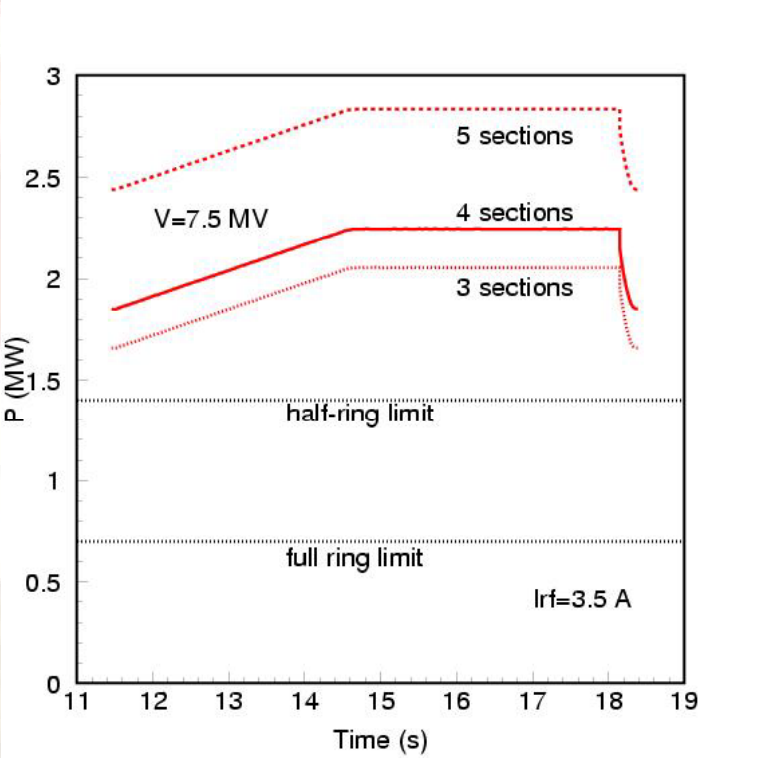
Beam stability

G. Papotti et al.

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

SPS: RF system upgrade

RF power for LHC upgrade intensity



- Threshold of coupled-bunch instabilities is decreasing during cycle with minimum on flat top
- 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 per cavity at 200 MHz for max PS2 intensity

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

→ 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

|←one PS cycle→|←one PS cycle→|

with PS2

|←one PS2 cycle (5-turn extract.) →|

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

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

- **Proton Accelerators for Future (PAF):**
  http://paf.web.cern.ch/paf/
  Members: R. Garoby, M. Benedikt, O. Bruning, M. Meddahi, R. Ostojic, W. Scandale, E. S., M. Vretenar, F. Zimmermann
- **SPS Upgrade:**
  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

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