Chamonix 2011
LHC Performance Workshop

Summary of session 9:

"LHC Injectors Upgrade"

(protons only)

1. Performance reach of the injectors in 2011 - *R. Steerenberg*
2. Possibility of a higher PSB to PS transfer energy - *K. Hanke*
3. PS potential performance with a higher injection energy - *S. Gilardoni*
4. Electron Clouds in the SPS: progress in the analysis of cures/mitigations measures and potential schedule of implementation - *J.M. Jimenez*
5. Lessons from SPS studies in 2010 - *E. Shaposhnikova*
6. Alternative / complementary possibilities - *C. Carli*

R. Garoby

9/02/2011

Beam characteristics

Peak Performances !!!

Obtained Characteristics 2010	PSB extraction				PS extraction			SPS extraction			
	[illegible] / ring [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	Nb bunches	Ip / bunch [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	bunches
[illegible]	16	2.5	2	4 + 2	1.3	2.5	72	1.15	3.6	≤ 0.8	1 - 4 x 72
LHC25 High int.	25	3.6/4.6	2	4 + 2	1.7 (1.9)	5	72	1.5	~ 10	~ 0.8	1 – 4 x 72
LHC50 (SB)	16	2.5	1	6	1.3	2.5	36	1.15	2.5	≤ 0.8	1 - 4 x 36
LHC50 High int. (SB)	24	3.5	1	6	1.8	3.5	36	1.5	3.5	≤ 0.8	1 - 4 x 36
LHC75 (SB)	11	1.5	1	6	1.3	1.8	24	1.2	2	≤ 0.8	1 - 4 x 24
LHC150	5	< 1.5	1	6	1.2	< 2	12	1.1	< 2.5 (1.6)	≤ 0.8	1 - 4 x 12

Possible Characteristics 2011	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [$\times 10^{11}$]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.1 5	3.6	0.7	1 - 4 x 72
LHC50 (SB)	24	3.5	1	3 x 2	1.75	3.5	36	1.45	3.5	≤ 0.8	1 - 4 x 36
LHC50 (DB)	8	1.2	2	4 + 2	1.3	1.3	36	1.15 (?)	1.5 (?)	≤ 0.8	1 - 4 x 36
LHC75 (SB)	11	1.5	1	3 x 2	1.3	1.8	24	1.2	2	≤ 0.8	1 - 4 x 24
LHC75 (DB)	5.5	0.9	2	4 + 2	1.3	0.9	24	1.2 (?)	1 (?)	≤ 0.8	1 – 4 x 24
LHC150 (SB)	5	< 1.5	1	3x 2	1.2	< 2	12	1.1	< 2.5 (1.6)	≤ 0.8	1 - 4 x 12

The LHC50 and LHC75 double batch beams were not used in 2010.

- LHC50DB characteristics remain to be confirmed and can perhaps be pushed
- LHC75DB characteristics at extraction of SPS were never obtained, “tentative guess”

Increased PSB to PS transfer energy (1/2)

Outcome of the Task Force nominated after the LHC Workshop in 2010 for studying and costing the increase of the PSB to PS transfer energy above 1.4 GeV.

Task Force members

CERN
CH-1211 Geneva 23
Switzerland

PSB 2.0

The **PSB Upgrade** Working Group

PSB Upgrade Working Group Document No.
1082646-0003

CERN Div./Group or Supplier/Contractor Document No.
BE-OP

EDMS Document No.
1082646 v.3

DATE: 2010-09-23

Feasibility Study

PS BOOSTER ENERGY UPGRADE
FEASIBILITY STUDY
FIRST REPORT

Abstract

This document summarises a survey of the CERN PS Booster systems with regard to a possible energy upgrade to 2 GeV. Technical solutions are proposed along with a preliminary estimate of the required resources and the time lines.

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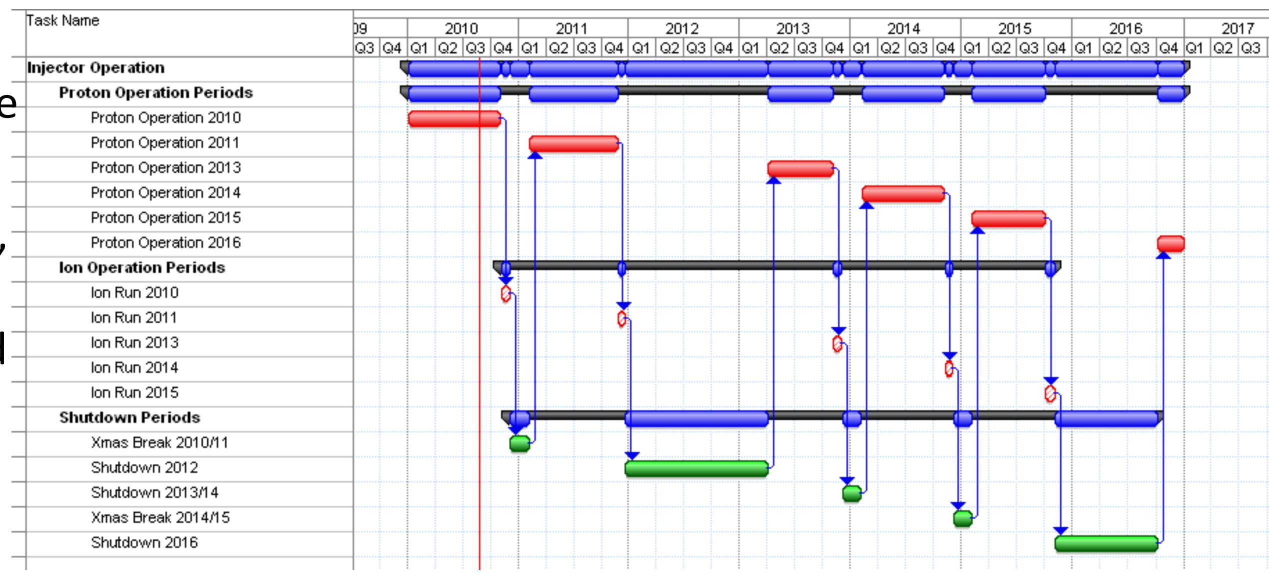
Increased PSB to PS transfer energy (2/2)

- one year of intense work
- different options studied; baseline scenario chosen
- an upgrade of the PSB from 1.4 GeV to 2.0 GeV is technically feasible
- a realistic estimate of budget and time lines has been made; the upgrade can be completed by 2016
- the budget has been entered in the MTP according to our estimate (consol. and upgrade)
- ready for preparing TDR, pending evaluation of alternative scenarios and management decision

Estimated total cost:
~60 MCHF
(Consolidation: 27.320 MCHF
Upgrade: 26.432 MCHF
H- injection: ~ +10 MCHF
2 GeV PS injection: ~ -5 MCHF)



PS performance potential with 2 GeV injection (1/2)

Issues:

- Hardware for injection at 2 GeV: studied by the Task Force on «PSB energy upgrade » ⇒ preliminary solutions found
- Blow-up and instabilities in the transverse phase planes:
  - Dilution after injection oscillations due to mis-steering
  - Laslett tune shift due to space charge (even if < |0.3|)

    → Blow-up of first batch waiting for the second batch injection
  - Head-tail instability at low energy
  - TMCI close to transition
  - e-clouds effects on high energy flat-top
- Blow-up and instabilities in the longitudinal phase plane:
  - Transient beam loading effects especially at low voltage during gymnastics
  - Coupled bunch instabilities due to cavities impedances (reminder: 5 different RF systems in the PS for a total of 22 cavities)

PS performance potential with 2 GeV injection (2/2)

- Preliminary extrapolations with Linac4

Intensity PS ej. (ppb)	Bunch spacing	$\varepsilon_{(x,y)}$ PS ej. (1 σ norm) **no blow-up**	Laslett ΔQ_x	Laslett ΔQ_y	ε_l @ PSB	PSB int. per ring **(assuming 5-10% losses)**	Comment	
$3.0 \cdot 10^{11}$	25 ns (DB)	2.5 μm rad	-0.24	-0.37	< 2 eVs (160 ns)	~ $400 \cdot 10^{10}$	Optimistic from Low εL	Stretched
$1.5 \cdot 10^{11}$	25 ns (SB)	2.5 μm rad	-0.18	-0.28	1.4 eVs (120 ns)		Limited by L4 brightness	
$1.9 \cdot 10^{11}$	25 ns (DB)	2.5 μm rad	-0.14	-0.22	< 2 eVs (160 ns)	~ $240 \cdot 10^{10}$	Pessimistic lower limit	Realistic
$3.0 \cdot 10^{11}$	50 ns (DB)	2.5 μm rad	-0.11	-0.17	< 2 eVs (160 ns)	~ $190 \cdot 10^{10}$	Optimistic from Low εL	Stretched
$1.9 \cdot 10^{11}$	50 ns (DB)	2.5 μm rad	-0.07	-0.11	< 2 eVs (160 ns)	~ $125 \cdot 10^{10}$	Pessimistic lower limit	Realistic
$1.7 \cdot 10^{11}$	25 ns (DB)	1.5 μm rad	-0.3	-0.3	< 2 eVs (160 ns)	~ $220 \cdot 10^{10}$	Minimum $\varepsilon_{(x,y)}$	
$2 \cdot 10^{11}$	25 ns (DB)	1.8 μm rad	-0.3	-0.3	< 2 eVs (160 ns)	~ $250 \cdot 10^{10}$	Minimum $\varepsilon_{(x,y)}$	
$2.7 \cdot 10^{11}$	50 ns (DB)	1.1 μm rad	-0.3	-0.3	< 2 eVs (160 ns)	~ $170 \cdot 10^{10}$	Minimum $\varepsilon_{(x,y)}$	Stretched

- Need further studies and MDs to improve these estimates:
  - Longitudinal phase plane: impact of beam loading and possible cures,
  - Transverse phase planes: blow-up rate with high space charge, e-clouds effects
  - Radio protection (especially if other users attempt to profit from a higher PS intensity)
  - Specifications of feedbacks and analysis of feasibility

SPS performance potential (1/2)

Main lessons/results from 2010

- Nominal 25 ns beam in good shape: low beam losses (5%) even with low ξ_v = 0.1
- Ultimate (injected) beam - needs studies
  - 25 ns: large losses and emittances, instabilities
  - 50 ns: 15% losses, 1.5×10^{11}/bunch at 450 GeV/c in 4 batches
- TMCI threshold is at ultimate intensity (low ξ). Ultimate single bunch accelerated to 450 GeV/c with low loss and ξ_v, but with some emittance blow-up. More problems for small injected emittances.
- New low γ_t optics: promising results for beam stability and brightness
- Limitations for dedicated LHC filling/MD: MKE, MKP, MKDH3 heating/outgassing
- MDs issues: transverse emittance measurements, time allocation, data analysis

SPS performance potential (2/2)

Conclusions - Q&A

- **Intensity per bunch and emittance as a function of the distance between bunches today and after upgrade?**

  - now one can hope to reach single-bunch performance with 50&75 ns beams (~3 μm emittances at ultimate intensity); probably less (2.5 μm ?) with low γ_t (RF voltage limit to be seen); > 4 μm for 25 ns (ultimate beam)

  - after upgrades (200 MHz RF upgrade, e-cloud mitigation/cure, transverse impedance reduction, upgraded transverse feedback, etc.) one can hope to be at the space charge limit (~2.5 μm with ultimate intensity for 50&25 ns beams)

- **What should be done for delivering smaller transverse emittances at ultimate current?**

  - more MDs with PS beams of very small transverse emittances

  - need for improved beam instrumentation (trans. emittance measurement)

  - low γ_t optics ?

e-clouds in the SPS (1/2)

Operating the SPS with:

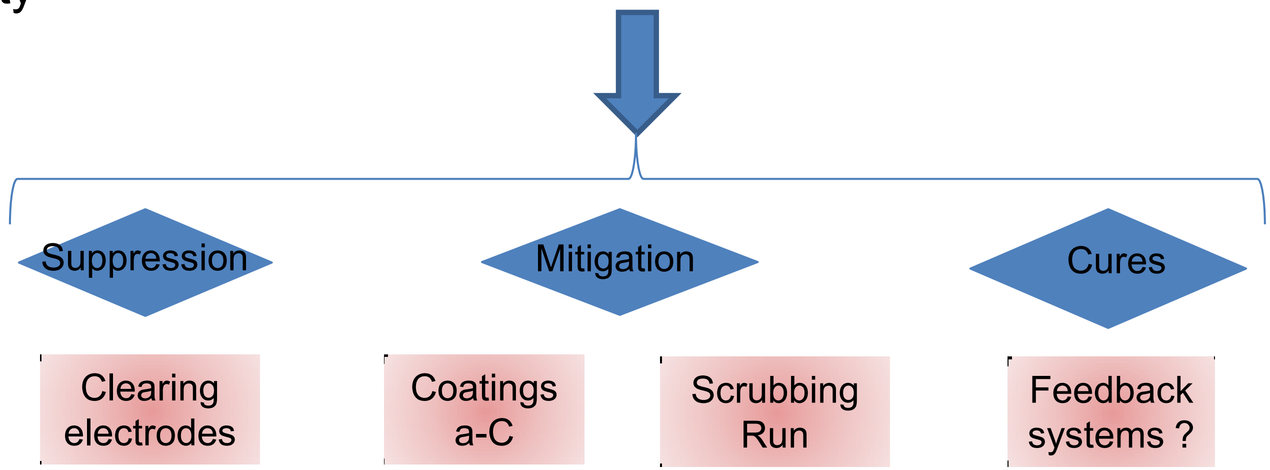
High bunch intensity, up to 2.5 10^{11} p/bunch

and/or

Small emittances (LHC requirements)

is impossible at **short bunch spacing** because of electron clouds generating:

- *pressure rise*: beam gas scattering, dose rates to tunnel and components
- *beam instabilities*: transverse emittance blow-up and single bunch vertical instability



Milestones for decision process and implementation are proposed:

- Strategy : October 2012 (for installation of pilot sector during LSD1)
- Full installation: LSD2

e-clouds in the SPS (2/2)

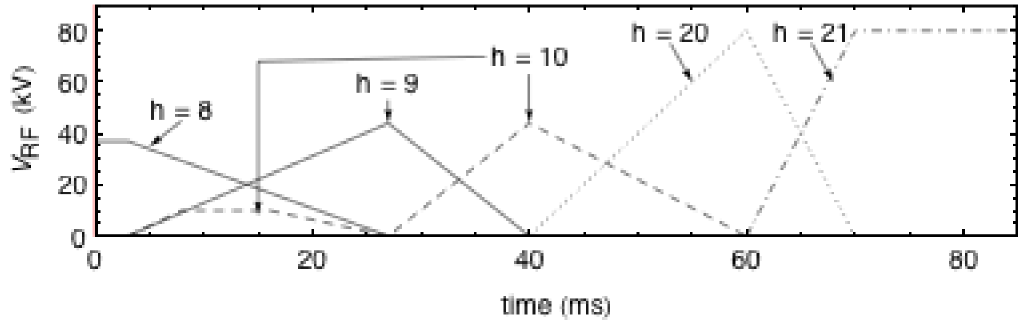
Pending questions

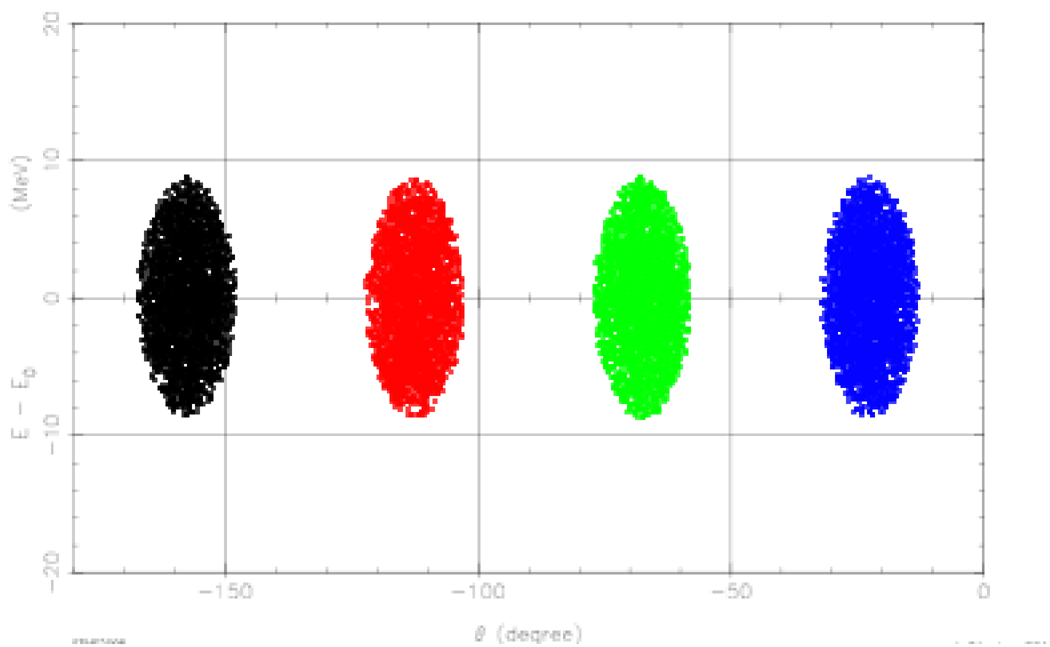
- Suppression: Clearing electrodes
  - Aperture, impedance, technical solution, full-scale feasibility, lifetime, quads, LSS, cabling, powering, etc.
- Mitigations
  - a-C coatings
    - Lifetime, stability with venting, outgassing rates, in-situ coating, LSS.
  - Scrubbing runs
    - Feasibility and margin, MD time.
- (Potential) Cure
  - Wide band feedback systems
    - High speed digitization and digital treatment
- Simulations
  - e-cloud budget, stability expected, emittance growth, impedance from electrodes, effectiveness of wide band feedback, etc.
  - *If we rely on beam scrubbing in the LHC why not in the SPS?*

Alternative scenarios (1/2)

Batch compression schemes using all PSB rings

- Scheme yield
  - Brightnes
  - Reasonal
- Scheme yield
  - Brightnes situation
  - Complex compress
- Any compres PSB energy u
- Tests can pro transfer from delivering be SPS before th significant MD time and efforts from the PS LLRF team).





Alternative scenarios (2/2)

Tentative parameters for an RCS replacing t... PSB

Energy range	160 MeV to 2 GeV
Circumference	(200/7) π m ≈ 89.76 m...
Repetition rate	~10 Hz
RF voltage	60 ...
Harmonics	
Frequency rang...	
Beam ...	...ned by
L...	...periods, ...ht with one cell
Tur...	..., < 5
Relat...	~4
Bendi... ...factor	56 %
Maximu... ...gnetic field	1.16 T

Benefits:

- Competitive cost wrt PSB consolidation and upgrade (?)
- Reliability (new hardware / modern design)
- Commissioning decoupled from physics operation
- Limited risk: Linac2 + PSB can remain available for a few years as back-up solutions.

Conclusions

- **Beam specifications at LHC injection are essential to guide the choices in the injectors => need for close collaboration between HL-LHC and LIU projects.**
- **Experience with beam in the LHC in 2011-2012 will help refine the potential of low transverse emittances.**
- **New batch compression schemes in the PS can immediately help test the generation of beyond ultimate 25 ns bunch trains in the PS and, if successful, provide the possibility to explore the SPS potential.**
- **Increasing the energy of the PSB is the primary solution for substantially upgrading the brightness that the PS can deliver.**
- **A small size RCS replacing the PSB is an especially interesting alternative option.**
- **The SPS remains the limiting accelerator in the injector chain. The well-identified improvements shall be implemented as soon as possible to allow studying the other limitations.**
- **The possibility to connect Linac4 to the PSB during the first long shutdown is worth being investigated.**