Plans for the upgrade of the PS injector are presented. The baseline scenario consists in a consolidation and upgrade of the existing PS Booster. The PSB upgrade can be broken up in the upgrade of the injection (H- injection from Linac4) and a possible energy upgrade of the machine from 1.4 to 2.0 GeV. As an alternative, a feasibility study for the replacement of the Booster by a Rapid Cycling Synchrotron (RCS) has recently started. Both scenarios are presented along with time lines and resource requests, notably for the first long LHC shutdown.
alternative locations outside the PS ring also being studied
PS Booster Upgrade

- upgrade of the BI line and injection region for 160 MeV H- & intensity increase
- upgrade of the Booster ring and the transfer line to the PS for 2 GeV
2.1 Management
2.1.1 Overall coordination - management activities (EVM, APT, EDMS, planning, resources…)
Klaus Hanke
Deputy: Bettina Mikulec
2.1.2 Safety
Nicolas Gilbert
2.1.3 LARP collaboration
Eric Prebys
2.1.4 Design Office
Ramon Folch
2.1.5 Integration
Yvon Muttoni
2.1.6 Optics Database
2.1.7 Layout Database
2.1.7.1 Equipment data
Sonia Bartolome
2.1.7.2 Layout database model
Pascal Le Roux
2.1.8 Consolidation and Shutdown work
Nicolas Gilbert
2.1.9 LIU-PSBU meetings
Thomas Hermanns
2.1.9.1 2010
Thomas Hermanns
2.1.9.2 2011
Thomas Hermanns
2.2 PSB Beam dynamics
2.2.1 Ring beam dynamics
Christian Carli
2.2.2 Exploitation of Energy Painting
Christian Carli
2.3 Magnets
2.4 RF systems
2.4.1 RF cavities & Power
Mauro Paoluzzi
2.4.2 LLRF
Maria Elena Angoletta
2.4.3 PSB Transverse Damper
Alfred Blas
2.4.4 RF Controls
Andy Butterworth
2.5 Power Convertors
2.5.1 Booster injection
David Nisbet
2.5.2 2 GeV upgrade
Serge Pittet
2.5.3 RCS studies
Serge Pittet
2.6 Beam instrumentation
2.7 Beam Intercepting Devices
2.8 Vacuum System
2.9 LINAC4 to PSB transfer line and PSB injection systems
2.9.1 Beam dynamics studies
Christian Carli
2.9.2 Injection system equipment
Wim Weterings
2.10 PSB Extraction system and PSB-PS transfer line
2.10.1 Beam dynamics studies
Christian Carli
2.10.2 Extraction and transfer line equipment
Jan Borburgh
2.11 Controls
Steen Jensen
2.12 Electrical Systems
Davide Bozzini, Slawomir Olek
2.13 Cooling and Ventilation
Mauro Nonis
2.14 Installation, Transport and handling
2.14.1 Transport and handling equipment
Ingo Rühl
2.14.2 Transport and handling services (incl. feasibility studies)
Caterina Bertone
2.15 Civil Engineering
2.16 Radiation Protection
2.16.1 General RP
Markus Widorski
2.16.2 RP studies
Markus Widorski
2.17 Interlock systems
2.17.1 WIC
Bruno Puccio
2.17.2 BIC
Pierre Dahlen
2.18 Alarms
2.19 Access Systems - Doors
2.20 Survey
2.21 Commissioning and Operation
Bettina Mikulec
2.22 Dismantling
Tobias Dobers
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.

• double checked the arguments presented at the 2010 Chamonix workshop - confirm that an increase in beam energy will facilitate injection of high-brilliance and high intensity beams into the PS
• survey of all PSB equipment and systems with regard to an energy increase - did not find any showstopper
• identified PSB equipment and systems that need to be modified or exchanged in order to operate at 2 GeV beam energy
• propose technical solutions for these items, along with a cost estimate and schedule
• identified items, which were already accounted for in the consolidation program - disentangled these items from the budget estimate for the energy upgrade
• we propose a project schedule, which is in line with the long-term LHC planning

• injection at 2GeV lowers space charge effect by a factor \( (\beta \gamma^2)_{\text{2GeV}} / (\beta \gamma^2)_{\text{1.4GeV}} \approx 1.63 \)
  → can inject beams ~65% more intense keeping the same space charge tune spread as now

• if we assume to conserve the longitudinal emittance (e.g., 1.3 eVs, LHC beam h=1), the bunch at 2GeV will be 33% shorter at the exit of the PSB, which would in principle limit the above gain to less than 40%; however, the PS bucket acceptance at injection also increases by 50%, which allows for injection of larger longitudinal emittances, recovering the desired gain (50% larger longitudinal emittance required)

• larger transverse emittances acceptable at the PS injection, if the final transverse emittances to the LHC are the same? Unlikely, as the previously PSB specified transverse emittances have meanwhile become the “nominal” LHC emittances!
  → at least 65% intensity increase (within constant emittance) expected

\[
\Delta Q_x = \frac{R_p N_b}{(2\pi)^{3/2} \gamma^3 \beta^2 \sigma_z} \int \beta_x(s) ds \frac{\sigma_x(s)}{\sigma_x(s) + \sigma_y(s)} \\
\Delta Q_y = \frac{R_p N_b}{(2\pi)^{3/2} \gamma^3 \beta^2 \sigma_y} \int \sqrt{\beta_y(s)} ds \frac{1}{\sigma_x(s) + \sigma_y(s)}
\]

\[
\begin{align*}
\sigma_x(s) &= \sqrt{\epsilon_x \beta_x(s) + D_x(s) \left( \frac{\delta p}{p_0} \right)^2} \\
\sigma_y(s) &= \sqrt{\epsilon_y \beta_y(s)}
\end{align*}
\]

\[
\epsilon_{x,y} = \frac{\epsilon_{x,y}}{\beta \gamma}
\]
### LHC Beams from the PSB with L4 and 2 GeV [B. Mikulec]

<table>
<thead>
<tr>
<th>User</th>
<th>Description</th>
<th>Harmonic at extr.</th>
<th>PSB rings used</th>
<th>Intensity per ring</th>
<th>rms emittance at extr. [mm mrad]</th>
<th>Bunch length at extraction [ns]</th>
<th>Extr. energy [GeV]</th>
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<tbody>
<tr>
<td>LHC25A/B</td>
<td>25 ns LHC beam (double batch PS transfer)</td>
<td>1</td>
<td>1-4 and 3+4 (2 extractions)</td>
<td>2.43E12 (ultimate) and smaller</td>
<td>hor.: ≤2.5 vert.: ≤2.5</td>
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<td>3.25E12 (nominal) and smaller by factor 20</td>
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<td>80-85</td>
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</table>

Emittance values as specified today – can be reduced with Linac4

---

B. Mikulec / Commissioning
maximum intensity fixed to 1.4E13 p/ring (5.6E13 total) due to magnet cooling and RF limitations in principle Linac4 could deliver up to 1.6E14 ppp with 65 mA current and 400 μs pulse no user known to us for such intensities
2 GeV Booster: Schedule
2 GeV Booster: Schedule

**LS1:**
- beam dump/beam stopper
- PSB injection
- transport/handling facilities

**LS2:**
- magnet upgrade
- MPS installation and commissioning
- upgrade kicker/septa transfer line
- upgrade electrical system
- upgrade cooling/ventilation
2 GeV Booster: Budget

<table>
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</table>

33588 = 54776,5 (total) – 20348,5 (cons.) – 840 (already paid by L4)

**consolidation:** items that are required for the 2 GeV to work (e.g. Booster RF, dump, …)

**Linac4 injection:** transferred from Linac4 project to LIU-PSB, added to budget, partly paid
\(\rightarrow\) entered into MTP
since Chamonix 2011:

- RCS option to replace the Booster
- would make both consolidation and upgrade obsolete
- work on 2 GeV Booster suspended
- RCS feasibility study and rough cost estimate launched (conclusions by summer 2011)
- if found competitive, more detailed study

RCS task force set up to reinforce the Booster Upgrade WG
investigate general parameters (parameters, lattice, size, apertures, location)
look only at potential cost drivers: magnets, power, civil engineering.
**Energy range** | 160 MeV to 2 GeV
---|---
**Circumference** | \((200/7) \pi \text{ m} \approx 89.76 \text{ m}\)  
*assume shortest option*
**Repetition rate** | \(~10 \text{ Hz}\)
**RF voltage** | 60 kV  
*\(h = 3\) to fill 18 out of 21 PS buckets  
\(h = 2\) to fill 12 out of 14 PS buckets*
**Harmonics** | \(h = 2\) or 3
**Frequency range** | 3.48 MHz (\(h = 2\) at injection) to 9.5 MHz (\(h = 3\) at ejection)
**Beam parameters for LHC**  
*(for lower emittances scale down intensity accordingly)* |  
Intensity: up to \(12 \times 2.7 \times 10^{11}\) protons/cycle  
Transv. emittance: \(\varepsilon_{\text{rms}}^* \approx 2.5 \mu m\)  
Long. emittance: \(\varepsilon_{\text{l}} < 12 \times 0.27 \text{ eVs}\) (determined by acceptance for most cases)
**Lattice** | FODO with 15 cells and 3 periods,  
4 cells in arc, straight with one cell
**Tunes** | \(4 < Q_{H,V} < 5\)
**Relativistic gamma at transition** | \(~4\)
**Bending magnet filling factor** | 56 %
**Maximum magnetic field** | 1.16 T
RCS: Beams & Parameters

**LHC beams:**
2.7E11 protons/LHC bunch (estimate for 2 GeV Booster with L4, M.Giovannozzi Chx. 2010)
→ have to deliver intensity for 12 LHC bunches per cycle → 12 x 2.7E11 ppp

**high intensity beams:**
assume maximum 1E13 ppp
to be iterated with the high-intensity users ISOLDE, CNGS, ...

**machine parameters:**
starting point Chamonix 2011 table, lattice and magnetic cycle have been iterated since (C. Carli)
lattice → beam size → aperture → magnet model → main power supply

should allow to get a rough estimate for feasibility and cost drivers; no details.
must not forget modifications to Linac4 in order to run at 10 Hz
RCS: Location inside PS (Chamonix Suggestion)

- RCS inside PS ring, 1 m above PS level
- PS injection from outside
- beam lines cross twice the PS
- relatively short transfer lines

A. Kosmicki, L.A. Lopez-Hernandez
RCS: Location inside PS

- beam Lines cross twice the PS
- stray fields expected to be an issue
- passing under the PS would have to be very deep, estimated minimum 10 m (involving pits ~25 m below ground level)

A. Kosmicki, L.A. Lopez-Hernandez
RCS: Location Parking Bldg 513

- RCS under parking bldg 513, at L4 level
- PS injection from outside
- beam lines do not cross the PS
- relatively long transfer lines
- RP issues probably OK

A. Kosmicki, L.A. Lopez-Hernandez
RCS: Suggested Location closer to L4 (Roundabout Scenario)

- RCS right downstream of L4 at L4 level
- PS injection from outside
- beam lines do not cross the PS
- re-use L4-PSB transfer line, must re-assess from an RP point of view, but looks feasible

B.Goddard, A.Kosmicki
RCS: Comparison of all Locations
Summary

**Booster Energy Upgrade** well advanced
- transformed from a task force into a project
- Linac4 injection has been added (from L4 project), PS injection has been transferred (to LIU-PS project)
- presented at Chamonix 2011, ready to go
- budget entered in MTP
- since Chamonix 2011 on hold, apart from the H- injection where work continues (in particular in view of a possible connection during LS1)

**RCS option** being looked into
- looking only into key issues, parameter space, civil engineering, magnets, power, RP
- Booster Upgrade Working Group reinforced
- feasibility and rough (!) cost estimate by early summer