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The
PSB Upgrade
Working Group

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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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1. INTRODUCTION AND SCOPE OF THE DOCUMENT

As a follow-up of the Chamonix 2010 workshop [1], a study has been requested by the director of accelerators to investigate an increase in beam energy of the CERN PS Booster (PSB, Booster) from presently 1.4 GeV to about 2.0 GeV. A task force has been put in place with the following mandate:

"The aim of the study is to evaluate the technical feasibility of an increase in beam energy of the CERN PS Booster from presently 1.4 GeV to about 2 GeV as proposed at the Chamonix 2010 workshop.

The study comprises:

- *Confirm the potential gain in terms of intensity and brilliance for LHC-type beams as presented at the Chamonix 2010 workshop.*
- *Confirm the technical feasibility. Identify accelerator components and equipment that need to be upgraded or exchanged. Identify potential showstoppers and point out solutions. Assign the responsible groups/units. Provide first rough time estimates for the various interventions needed.*
- *Provide a first estimate of material and personnel resources needed to complete the upgrade. Draft a project break-down into work packages, in preparation for a project to be launched by the director of accelerators."*

A working group has been set up to evaluate the technical feasibility of such an upgrade covering the following areas:

1. Beam Dynamics (BE/ABP)
2. Magnets (TE/MSC)
3. Magnetic Measurements (TE/MSC)
4. RF System (BE/RF)
5. Beam Intercepting Devices (EN/STI)
6. Power Converters (TE/EPC)
7. Vacuum System (TE/VSC)
8. Instrumentation (BE/BI)
9. Commissioning and Operation (BE/OP)
10. Extraction, Transfer, PS Injection (TE/ABT)
11. Controls (BE/CO)
12. Electrical Systems (EN/EL)
13. Cooling and Ventilation (EN/CV)
14. Radioprotection and Safety (DGS/RP)
15. Transport and Handling (EN/HE)
16. Survey (BE/ABP)

Further to the above listed work units, representatives are involved in the working group for drawing office (EN/MME), consolidation (EN/MEF) and PS operation (BE/OP/PS) as well as an US-LARP representative.

This document summarises the conclusions of the working group reached between March 2010 and June 2010. Technical solutions are proposed along with a preliminary estimate of the required resources and the time lines. The document should serve as a basis for the decision making on a possible future project and it is the first step towards a technical design report to be edited subsequently.

1.1 BOUNDARY CONDITIONS

A few points were clarified at an early stage of the study.

- The study does not comprise other upgrade options as e.g. faster cycling.
- The request was made to put the energy increase into operation rather rapidly, if technically feasible before the commissioning of Linac4 in 2015. This would entail ramping the beams up from the present 50 MeV to 2 GeV, and furthermore that the upgrade would be put in place before completion of the Booster consolidation, notably the one of the RF system. We have preliminarily studied the consequences of running the PSB at 2 GeV with the present 50 MeV Linac2. In the course of the study it was found that the time lines are such that putting in place the energy upgrade before the commissioning of the PSB with Linac4 in 2015 is not feasible, and the option to run the PSB at 2 GeV with the present 50 MeV Linac2 was therefore discarded.
- Any energy upgrade significantly above 1.4 GeV but below 2.0 GeV is not recommended, because the estimated budget would not be reduced. In particular, the main power supply (MPS) as the main cost item of the upgrade project has no essential margin for operation at higher energies and must be replaced anyway.
- For the beams delivered to the PS (see Figure 1 for an overview of the accelerator complex) we have studied the following scenarios (LHC beams to the PS are always executed at 2.0 GeV):

	Beam Energy		ppm mode for	
Scenario	Non-LHC Beams to PS	ISOLDE Beams	PSB Extraction	BTP Line
1	2.0 GeV	1.0/1.4 GeV	yes	no
2	1.4 GeV	1.0/1.4 GeV	yes	yes
3	1.4 GeV	1.0/1.4 GeV	yes	no

(1) All beams to the PS are executed at 2.0 GeV. Beams to ISOLDE will remain at the present 1.0/1.4 GeV. The Booster extraction must work in ppm mode between 1.0 and 2.0 GeV, but the BTP line (presently not ppm) does not need to be upgraded. In case of a major ISOLDE breakdown, it must be possible to direct all Booster cycles to the PS. Therefore all systems must be compatible with running every Booster cycle in a supercycle at 2.0 GeV.

(2) Only LHC-type beams are executed at 2.0 GeV, all other beams remain at the present 1.4 GeV. LHC-type beams and other beams are executed in ppm mode, which requires an upgrade of the BTP line for ppm operation.

(3) Only LHC-type beams are executed at 2.0 GeV, all other beams remain at the present 1.4 GeV. The BTP line is not upgraded. During periods when LHC-type beams are executed (LHC filling as well as setting up and optimisation in the injectors) the supercycle must be composed with a number of zero cycles in order to allow the BTP line magnets to change settings.

The difference between scenarios (1) and (2) is purely a cost issue. In the course of the study it was found that the option to run LHC beams at 2 GeV in ppm mode with 1.4 GeV cycles does not reduce the cost of the energy upgrade, but leads even to a slight increase in cost.

Scenario (3) has been looked into and the loss of beam time for the non-LHC physics program estimated. The details are reported in chapter 11 “Commissioning and Operation”. It was found that no significant savings can be expected, while the loss of beam time for the fixed target users and the loss in operational flexibility would be unacceptable.

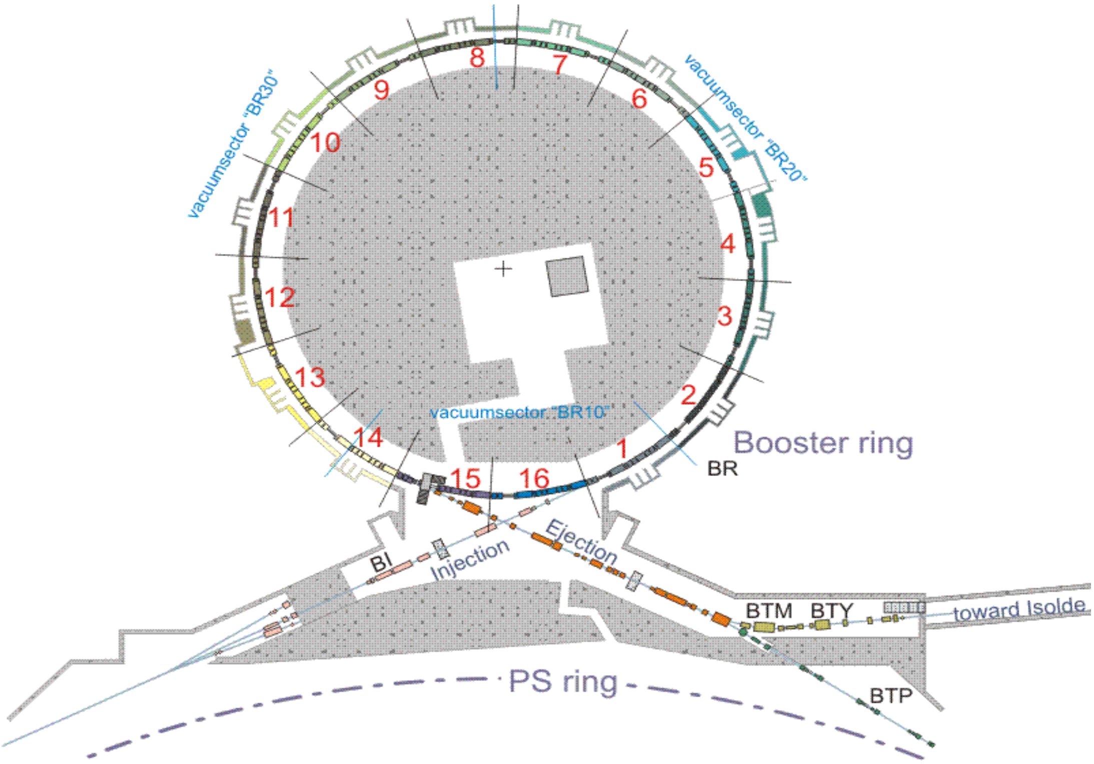

Figure 1: PS Booster and its transfer lines.

2. SUMMARY AND RECOMMENDATIONS

We have done an as complete as possible survey of all Booster equipments and systems with regard to a possible operation at 2.0 GeV beam energy. The first objective of the study was to confirm the feasibility of such an upgrade; this technical feasibility could be confirmed.

We have tried to identify all Booster equipments and systems which need to be either exchanged or upgraded in order to allow operation at 2.0 GeV. A significant number of components were identified. For these items technical solutions for the upgrade are proposed. The details are given in the following sections.

Along with the proposed technical solution, a first estimate of resources (budget and manpower) is given for scenario 1 (baseline) where all beams to the PS are executed at 2.0 GeV. The total costs are assumed to be 41 MCHF (detailed figures are given in the appendix). For some items there is still a substantial uncertainty (e.g. electrical systems, cooling and ventilation, PS injection). This is because at the time of writing this document the study has not been completed in all details.

Additionally we have identified items which were already accounted for in the consolidation program. For these items, we have reduced the estimated cost by 15 MCHF. This amount was already allocated in the consolidation budget to our best knowledge.

We have furthermore made a first estimate of the time lines. The overall conclusion is that the upgrade, if launched as a project with the requested resources (budget and manpower) in 2010, can be completed at the earliest in 2015. This planning is tight and further trimming of the underlying planning of the different work units as well as of the injector shutdown periods may become necessary. It is worth noticing that the re-commissioning of the Booster with Linac4 is likely to coincide with the re-commissioning at 2.0 GeV.

In conclusion, we recommend that all beams going to the PS should be upgraded to 2.0 GeV, while beams to ISOLDE remain at the present 1.4/1.0 GeV.

An energy upgrade to significantly above 1.4 GeV but below 2.0 GeV will not substantially reduce the total budget because the main power supply (MPS) as the main cost item of the upgrade project has no essential margin for operation at higher energies and must be replaced anyway.

In the course of the study we have evaluated various scenarios, notably to run only LHC-type cycles at 2.0 GeV while executing all other cycles at the present 1.4 GeV. It turned out that such a scenario would not lead to a decrease in cost (details in the budget tables). In contrary, the additional requirement to upgrade the BTP transfer line to ppm operation would even lead to a slight increase in cost.

We have also studied a variant of this proposal, i.e. to run 2.0 GeV LHC beams and 1.4 GeV non-LHC beams in the same supercycle but adding zero cycles in order to allow the BTP line to change settings. The loss of protons for non-LHC physics user would be significant, while the reduction in costs would only be at the per-cent level.

Although these conclusions from a pre-study of only a few months duration are somewhat preliminary and not all technical details (and along with it resource and time estimates) are settled to the last detail, we felt it useful to summarise the outcome of the working group in this report. It can serve as a basis for future work and for decision making. After project approval this document will be followed by a technical design report which will detail the design choices and technical solutions.

The following chapters address the various areas in detail with regard to a survey of the equipment/system at 2.0 GeV, identification of critical issues and potential show-stoppers and the technical solutions that are proposed to be put in place.

3. BEAM DYNAMICS

3.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

None at this stage.

3.1.1 CRITICAL ISSUES AND PROPOSED CURES

No critical beam dynamics issue is anticipated in the PSB with the 2 GeV operation.

However, for the PS to be able to digest an LHC25 beam at 2 GeV with doubled intensity, a few issues must be looked into in more detail:

1. Resistive wall head-tail instabilities at flat bottom, which could become up to 50% faster than presently. Linear coupling, octupoles and transverse feedback are potential cures.
2. TMCI at transition crossing. Extrapolating with a simple scaling law from the existing observations on the TOF beam, we expect a factor 2 margin that guarantees the stability of the double intensity LHC25 beam if it crosses transition with the γ-jump scheme.
3. Longitudinal coupled bunch instabilities during the ramp and at flat top. More studies are necessary to determine to what extent they may limit the future performance. A possible solution, which requires anyway a full study, is the installation of a broad band cavity to be used for longitudinal feedback.

4. Electron cloud and transverse instabilities at flat top. If the dependence of the instability onset on the bunch length versus intensity alone is confirmed, a double step bunch rotation can help (as opposed to the present adiabatic shortening followed by a fast compression).

3.1.2 FURTHER STUDIES NEEDED

To address all the above points in an exhaustive manner, we can envisage actions on both simulation studies and dedicated MDs:

- For point 1), a simulation study could be useful to confirm the expected decrease of rise time and assess the efficiency of the possible cures (i.e., how much linear coupling would be needed, how much octupole strength, how much gain/bandwidth of a transverse feedback system)
- To confirm the predicted margin of the instability at point 2), a simulation study for the LHC beam with doubled intensity at transition crossing will be carried out. The study is planned to become the natural closure of the current Ph.D. work on TOF [2].
- Point 3) is already listed as a subject with high priority among the RF MDs proposed in the 2010.
- We have written and plan to submit an MD proposal to carry out a detailed study of point 4). The proposal is found in the appendix. Our goal is to determine the nature and behaviour of the transverse instability, as well as its relation to the presence of electron cloud in the machine. In parallel, since we know that the electron cloud actually builds up in the PS with the LHC25 beam for bunch lengths below a certain threshold, it could be very helpful to carry out a simulation study of the beam stability against electron cloud, when the intensity is doubled.
- To allow the maximum flexibility in scanning parameters during the above proposed MDs, the first requirement is to assess the maximum intensity that can be presently produced in the PSB and sent to the PS for both the single and multi-bunch LHC beams. The present constraint on the transverse emittances (2.5 μm) can be relaxed (both because it turned out to be too conservative and secondly because it is better to inject into the PS with larger transverse emittances in order to compensate for the increased intensity and try to stay within the space charge limits at injection)

3.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

None at this stage.

3.2 TECHNICAL DESCRIPTION

MD proposals, see appendix 20.1.

4. MAGNETS

4.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Main Units

- Modeling of the magnets shows that the new field levels seem to be achievable. Initial magnetic measurements confirm the results of the models for the bending magnets. The saturation of the outer rings of the bending magnets will increase from around 1% to 5%. More detailed measurements are planned.
- The extent of the modifications to the cooling parameters is dependent on the RMS current of the magnet cycle. Different scenarios of the magnet cycle are being explored by TE/EPC.
- A concern over the life span of the magnets at 2 GeV operations has been raised.

Auxiliary ring magnets

- The majority of the auxiliary ring magnets is only used at injection energy and will not be affected by the upgrade to 2 GeV. The study for the remaining magnets used at ejection energy is still to be completed.

Transfer line magnets

- Initial study shows that the majority of the transfer line magnets will be ok for 2 GeV operations. This can only be confirmed when a complete study has been made for the optics.
- The magnet BT.BHZ.10 is currently being consolidated with a planned new spare to be built. Consideration is now being made for 2 GeV operation as is has already been stated by TE/EPC that the existing power supply would not be compatible with the existing magnet run at a higher current.

Study is still ongoing.

PS Injection Bumpers, Low Energy Correctors and Quadrupoles

- Further Study is needed

4.1.1 CRITICAL ISSUES AND PROPOSED CURES

Main unit cooling.

Scenario 3121 A RMS (Scale of today's magnet cycle)

The current magnet cooling parameters for the main units are not adequate. Initial calculations suggest that the pressure and flow must be almost doubled to maintain the same operational temperature of the magnets to that seen at 1.4 GeV if there are no modifications made to the cooling circuits. Although it may be possible to achieve these new values with an upgrade of the cooling station it would not be advisable to run the magnets at this higher pressure due to the design of the cooling circuits.

It has been stated that a trade off between an increase in pressure/flow and a higher operational working temperature could be acceptable; while this is generally true there is a risk that the life span of the magnets could be reduced at the higher temperature.

For the main bending magnets the proposed action would be to modify each of the magnets by connecting pairs of coils in parallel instead of than in series. This would keep the water pressure drop with an increased flow within reasonable limits. This action would require that each magnet is removed from the machine to be modified.

For the main quadrupole magnets the proposed action would be to install a new high pressure cooling circuit around the machine. This action would require a change of the flexible cooling circuits to rigid system. It may be possible to perform this action in the machine without removing the magnets. Further study is needed.

Scenario 2369 A RMS (faster pulse possible with POPS)

The increase in RMS current is relatively small compared to the 1.4 GeV cycle and no major modifications would need to be made to the magnet cooling circuits. Due to the higher voltage generated by a shorter ramp it would be beneficial to divide the machine in two and use two MPS as discussed with TE/EPC bringing the voltage seen by the magnets to a similar level to that of the 1.4 GeV operation. It is still to be seen if the magnet field can follow the faster current ramp.

Life span concerns

A concern has been raised over the ability of the bending magnets to withstand the forces of the coils against the retaining plates. Initial calculations show that although there is a substantial increase in force the absolute levels should be acceptable. If however after the calculations have been confirmed with measurements there is still a concern, the amount of shimming material between the coils and plates can be increased to compensate for the increase in force.

4.1.2 FURTHER STUDIES NEEDED

Main unit cooling – This will depend on the magnetic cycle.

Life span concerns – Testing of one of the spare main bending magnet is planned to confirm the calculated forces acting on the coil retaining plates. Testing is being planned at the nominal current, upgrade current and up to nearly two times the upgrade current to prove the robustness of the assembly. Testing at the nominal current and upgrade current will be completed in b.867 while the test at two times the upgrade current can only be completed in SM18 due to the availability of a power supply.

Magnetic measurements – Further magnetic measurements are planned to confirm the field quality of the main units. Measurements will also be made to confirm that the magnets can followed the suggested cycles with respect to the eddy current effects.

4.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

The magnet cycles and parameters need to be determined.

4.2 TECHNICAL DESCRIPTION

Main Units

Main bending magnet cooling circuits – The worst case scenario is that each bending magnet has to be removed from the machine for the cooling circuits to be modified.
For the best case scenario the cost would be greatly reduced as the magnets would not need to be removed from the machine with only minor modification needed.

Main quadrupole magnet cooling circuit – The worst case scenario is that the cooling circuit of each quadrupole magnet is upgraded to a rigid system so that they could operate with a higher supply pressure.
For the best case scenario only minor modifications would be needed to the magnet circuits.
For the quadrupole magnets even with the best case scenario a more robust cooling system would still be recommended as part of a consolidation program somewhere between what is needed for an increase in supply pressure and where we are now.

Main Bending magnet shimming – If it is seen that the main bending magnets would need additional shimming material between the coils and retaining plates it may be possible to complete the work inside the machine.

Main bending magnet saturation – The bending magnets have already entered into saturation for the outer rings at 1.4 GeV operation. This effect is compensated with a 30 amp trim power supply connected to the outer rings. At 2 GeV operation it has been shown through modelling and measurements that the amount of saturation will increase further and if the same approach is taken to compensate for the saturation then a trim supply of around 300 amps will be needed. Dividing the circuit in two as suggested by TE/EPC would remove the need for this supply as the two MPS could be run at different currents, however the total RMS current could be reduced further if the saturation effect could be removed. Modelling of the magnets suggests that the saturation effects could be reduced if not completely eliminated by changing the current solid coil retaining plates to laminated plates. Further study and measurements would need to be completed to confirm this. The work to complete the change of the plates could be made simultaneously to the magnet shimming.

It is envisaged that the work listed above given adequate resources could be completed during the next two long shutdowns. Most modifications can be made independently without requiring the immediate upgrade of related equipment. For example modifications to the main quadrupole magnet cooling circuit could be made without the upgrade of the cooling station.

Auxiliary ring magnets

Worst case some new magnets would be needed which are relatively low cost items.
Study is still to be completed.

Transfer line magnets

Worst case some new magnets or components will be needed again these are relatively low cost items.
It must be said that several magnets have recently been identified which either need spare units or parts for operation at 1.4 GeV. These projects are now waiting for confirmation of the need to run at 2 GeV operations before decisions for procurement are made. For example the power supply for the BT.BHZ.10 switching magnet has already been identified by TE/EPC as being inadequate for 2 GeV operations. It may be possible with a redesign of the magnet to save the existing power supply (as understood a relatively high cost item) for this a detailed study must be made.
Study is still to be completed.

PS Injection Bumpers, Low Energy Correctors and quadrupoles

Study is still to be completed.

5. MAGNETIC MEASUREMENTS

5.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

- The magnetic instrumentation currently available (i.e. straight flux coils) is suitable for the measurement of integral field and eddy current transients in main dipoles and quadrupoles at various current levels.
- The Holec power supply in 867-RH-29 is able to provide 5515 A @ 30 kA/s, or up to 6000 A at a lower ramp rate to a PSB main dipole (the most demanding case).

- First test results indicate saturation levels up to 6% at 6 kA and small eddy current effects up to 30 kA/s (to be confirmed in Week 19)
- If needed, the measurement of field harmonics will require the development of an ad-hoc multi-coil fluxmeter system (straight or curved).

5.1.1 CRITICAL ISSUES AND PROPOSED CURES

No critical issues identified. Two potential problems that may arise:

- Holec power converter: this is an unique piece at CERN in terms of power and stability, and is apparently very difficult to maintain properly. To guarantee reliability, the possibility of alternative solutions (e.g. refurbishing an old converter used for magnet heating tests in bldg. 150) should be explored.
- PSB B-train system: should eddy current effects have an impact on the new magnet cycles, the possibilities for upgrading the current system could be studied (e.g.: putting on-line the existing NMR probes at high field, etc.)

5.1.2 FURTHER STUDIES NEEDED

- Main dipole: completion of integral eddy current tests in two apertures (one outer and one inner) on one spare unit. Field saturation (and possibly harmonic quality) tests in the final configuration (ramp rate, field level, trim supply current). Should the main coils have to be disassembled and replaced, magnetic side-effects should also be measured.
- Mechanical tests at 2x current levels on a spare dipole in SM18 (see 3.1.2): the integral magnetic field shall be measured during these tests to gain more information on saturation and monitor the response of the magnet.
- Main quadrupole: integral saturation and eddy current tests in two apertures on one spare unit.

5.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

- Number and type of new or refurbished magnets to be measured.
- Precise definition of powering cycles (magnets have to be tested in the same conditions in which they will be used)
- Field quality tolerances for the beam: BdL/GdL, harmonics, field direction, quadrupole magnetic axis, settling time at the end of ramp-up.

5.2 TECHNICAL DESCRIPTION

Besides the activities described in 4.1.2, the workload of this WP is entirely dependent on the number of magnets that will have to be measured. With the exception of the fluxmeter mentioned at point 4.1, existing instrumentation and infrastructure is adequate for all foreseeable tests (pending conformation of the specifications of new magnets).

As a general rule, the minimum test program for a new or refurbished magnet could include:

- Loadline (magnetization curve): integral BdL/GdL at ~10 current levels
- Eddy current effects: time lag during the ramp-up and overshoot decay time on the flat-top of the main integral field component
- Field quality: integral quadrupole to decapole components at nominal current

However, the details of the program must be specified in accord with magnet group and beam optics for each kind of magnet.

A preliminary breakdown of the possibility activities is as follows:

- Main Dipoles:

Best case scenario: tests on the spare unit demonstrate that the magnetic performance is consistent with calculations and within specs. No further measurements needed.

Worst-case scenario: all units have to be taken out of the ring and modified. Magnetic testing could be envisaged if the position of the main coils is changed significantly.

- Main Quadrupoles: no modifications other than to the cooling circuit are foreseen and no particular need for magnetic measurement is anticipated (to be confirmed by tests on the spare unit)

- Auxiliary ring magnets:

Best-case scenario: nothing to do

Worst-case scenario: if new magnets are made, a small statistical sample of the production may need to be tested. No special problems are foreseen.

- Transfer line magnets:

Best-case scenario: nothing to do

Worst-case scenario: if new magnets are made, a small statistical sample of the production may need to be tested. No special problems are foreseen.

- PS Injection Bumpers, Low Energy Correctors and quadrupoles:

No information available to date

6. RF SYSTEM

6.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Situation supposing a beam intensity 5E9- 1.65E12 per ring, H=1 or H=2, 8 kV from 160 MeV-2 GeV in a 1.2 s cycle.

- PSB Low Level Beam Control

  If present consolidation program is respected, the required changes can be included for the 2 GeV cycle. Study underway by M.E.Angoletta & A.Blas.

- PSB High Level Cavities and Control

  C02 and C04 RF system:

  Provided the 25 yeas consolidation program is implemented, no problems are expected to cover the new frequency range, digest the additional beam current and supply the increased power.

C16 RF system:

The frequency range cannot be extended to 18 MHz (limited to ~ 16 MHz).

Lowering the blow-up frequency sent to this cavity is the present operational solution, and it will be tested with the new frequency range.

If higher beam current is required the new scenarios must be defined and studied.

- PSB Transverse Feedback System

  The increase of energy to 2 GeV has only a marginal impact on the specifications (7% more power), so this demand will be included in the study underway by A.Blas to define the system requirements associated with Linac4.

6.1.1 CRITICAL ISSUES AND PROPOSED CURES

This will depend upon the 2 GeV cycle in the PSB.

6.1.2 FURTHER STUDIES NEEDED

For LHC beams and intensities beyond the present LHC nominal intensity, the limitations of the RF systems with a cycle to 2 GeV must be evaluated.

6.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

- A 2 GeV cycle definition including acceleration duration, Bdot & extraction flat top length.
- We only have one set of hardware, so any changes to the hardware should take into consideration ALL required cycles from the PSB, so the cycles for all beams need to be defined.

6.2 TECHNICAL DESCRIPTION

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7. BEAM INTERCEPTING DEVICES

7.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The investigation on the existing PSB dump has started. The BTPSTP10 beam stopper also has to be checked for 2 GeV operation. Future objects (H-/H0, Head and tail dump) will take into account the new operational scenario.

7.1.1 CRITICAL ISSUES AND PROPOSED CURES

No showstopper identified.

No spare PSB dump available, new design needed and the production of 2 units has to be launched.

Longer design for the Beam stopper might be necessary. The actual positions would be insufficient to install a larger stopper?

7.1.2 FURTHER STUDIES NEEDED

FLUKA and ANSYS studies. In case of larger dimensions the objects need a new integration study.

7.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Parameter table and description of different beams, worst case scenario.

7.2 TECHNICAL DESCRIPTION

Dump:

Option 1: The results confirm the survival of the dump for the upgrade in Intensity and Energy. We built a new spare based on the existing design (with improved cooling)

Option 2: A new design is needed, two new units have to be produced and integration has to be looked at.

Beam stopper:

Option 1: Keep the vacuum tank and modify only the absorber material (unlikely)

Option 2: Adapt a ‘TBSE’ type design. Two units to be produced.

Option 3: A completely new design with the fabrication of two units

For option 2 and 3 the available space will be insufficient. Shifting of the stopper or civil engineering will be needed.

8. POWER CONVERTERS

8.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Current settings at 2 GeV are assumed to be 1.33 times higher than what is used now at 1.4 GeV plus a 10% margin. No changes in optic have been considered. The cycle period is 1.2s.

Booster Injection:

- Booster Injection will be upgraded for Linac 4 connection. No changes needed related the Booster 2GeV upgrade.

Booster Ring:

- The existing supply can not provide the additional RMS current. An increase of peak power, using traditional thyristor technology, would have a significant negative effect on power quality of the Meyrin network 18 kV, which would be inadmissible. The solution will probably be a design similar to the new POPS for the PS, using DC capacitors to store the energy for the pulsating load (civil engineering work required). Inner dipoles and quadrupoles trims will also have to be replaced.
- Dipoles correctors and multipoles converters are mainly used at low energy and have enough margins. They will be consolidated during the shutdown 2011-2012.
- The Qstrips are only used at injection. Any upgrade would be part of the linac 4 project and not of the Booster energy upgrade.
- BDLs are used at ejection but have enough margins.
- The DBS are dedicated to destructive beam measurement and will probably not be used at 2GeV.
- The shavers are only used at injection. Any upgrade would be part of the linac 4 project and not of the Booster energy upgrade.

Booster Ejection:

- BE.SMH 2GeV setting is still within the converter rated current if one considers a 7.5% margin only. The capacitor bank size will have to be adapted to provide the additional energy.

- Even approaching their rated limits, BE DHZ and DVT converters will not need to be upgraded for 2GeV operation.

BT, BTP and BTM transfer:
- BT.SMV20, BT1.SMV10 and BT4.SMV10 settings are still within the converter rated current. The capacitor bank size will have to be adapted to provide the additional energy.
- BT.DVT 30, 40 and 60 will have to be replaced.
- All bendings supplies are already approaching their limits and will have to be replaced for 2GeV operation.
- Quadrupoles supplies on the BT line can handle the additional current at 2GeV, but will have to be replaced in order to allow PPM operation between 1GeV Isolde and 2 GeV PS cycles.

PS Injection and Ring:
- PI.BSM40, PI.BSM42, PI.BSM43 and PI.BSM44 have enough margin to provide the additional current.
- A longer magnet will probably be used for PI.SMH42, keeping the present rating. The capacitor bank size will anyway needed to be adapted to provide the additional energy and a new capacitor charger has to be foreseen.
- PR.DVT, DHZ, QFN, QDN, QSK (150 Power converter in total) will probably have to be upgraded. Today operation of those converters is mainly limited by magnet thermal considerations.

8.1.1 CRITICAL ISSUES AND PROPOSED CURES

Many power converters are not able to deliver the additional current requested for 2GeV operation or not able to guarantee PPM operation between 1GeV Isolde and 2GeV PS. A few converters can be upgraded (capacitor discharge type) but most of the under-rated converters will have to be replaced.

8.1.2 FURTHER STUDIES NEEDED

- Current and voltage ratings exact specification.
- Civil engineering work estimation.

8.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

RF and magnets acceleration limitation for the Ring MPS

8.2 TECHNICAL DESCRIPTION

If the definitive ratings are not available end 2010, this would delay the commissioning period.

The following power converters upgrade or replacement will be needed.
Not included: control cables and hardware, DC cables, AC cables and switchboard.

Booster Ejection, BT, BTP and BTM transfer:
- 5 Capacitor bank adaptations.
- 4 Mididiscap.
- 2 (+1spare) new 700A/700V bending supplies.
- 1 new 400A/300V bending supply.
- 9 (+1spare) new 400A/150V bending supplies.

PS Injection and Ring:

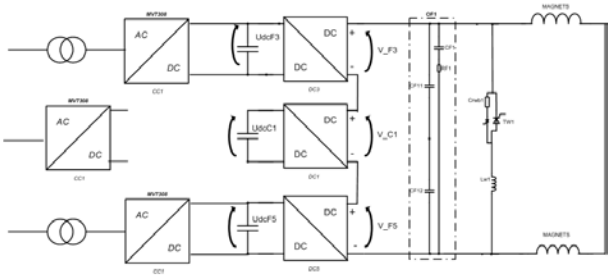
- 2 New PI.SMH42.
- 160 New 20A/50V power supplies for PR.DVTs, DHZs, QFNs, QDNs and QSKs.

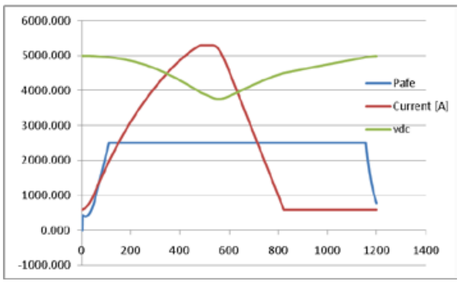
Ring MPS:

The existing MPS can run faster but cannot provide more peak current. In addition the output voltage available at 2 GeV would only be 3.6 kV and the magnetic cycle cannot be implemented within a 1.2 s cycle.

The basic principle of a POPS-like topology is to manage the energy transfer between the magnets and a huge capacitor bank installed near the power converter. Only the power needed to compensate the losses is driven from the 18 kV network, considerably reducing its stress. This would allow more flexibility on the MPS cycle without disturbing other users on the Meyrin site.

- Keeping the existing configuration, the following hardware would be needed:

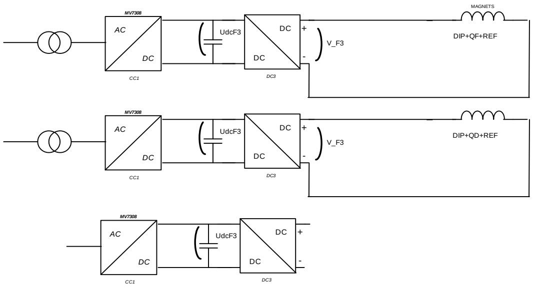


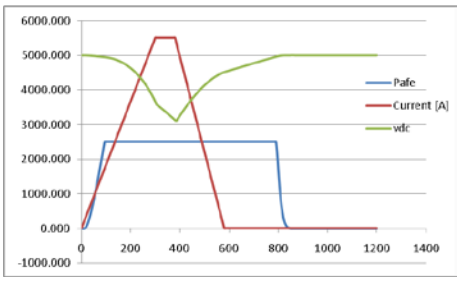


  - 1 new 6000A/4000V main supply.
  - 1 (+1spare) new 300A/2000V dipole trim.
  - 2 (+1spare) new 400A/700V quadrupoles trims.

Limiting factor is the maximum voltage to ground of the magnet (2 kV). For this reason we must apply a maximum of 4 kV to the magnets. What we can do is therefore to realise the cycle proposed above.

- The magnet chain can be divided in two, allowing an increase of the nominal voltage and a faster acceleration. The RMS current could then be reduced to a value close to 1.4 GeV operation, provided that RF and magnets can follow the proposed acceleration. The hardware would then be:





  - 2 new 6000 A/3000 V main supplies.
  - 2 (+1spare) new 400 A/700 V quadrupoles trims.

The minimal voltage on the capacitor is slightly low with this solution and the capacitor banks size may have to be increased, depending on the cycle which will finally be used.

9. VACUUM SYSTEM

9.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The vacuum system of the Booster is divided into three sectors (BR10, BR20, and BR30). Pumping is provided by fixed turbo molecular pumping groups, sputter ion pumps and sublimation pumps which are mounted, together with the Penning/Pirani gauges, on so called manifolds. CERN standard vacuum equipment is used and no special precautions or machine specific spares are needed for 2 GeV operation.

Different beam pipe shapes and vacuum chamber materials were used for the Booster construction: elliptical 0.4 mm thick corrugated chambers (Inconel X750) for the bending magnets, diamond shaped 1.5 mm thick chambers (316LN st.st.) for the quadrupoles, and circular 1.5 mm thick chambers (316LN st.st.) for the long straight sections. The only specific vacuum items used in the Booster are the anodized clamps for the flanges, which are equipped with RF bypasses to minimize the total impedance of the rings.

9.1.1 CRITICAL ISSUES AND PROPOSED CURES

If main machine components, e.g. the magnet system, need to be removed from the Booster ring, a dismantling of the vacuum system would be required. This might lead to surprises and consequences that cannot be judged at the moment. It is therefore recommended to minimize the amount of equipment to be removed from the Booster.

Dynamic vacuum problems are strongly related to beam dynamics issues. Pressure rises, either induced by increased beam loss or electron cloud, are not expected for a 2 GeV Booster operation. On the other hand, electron cloud induced pressure rises might become more significant in the PS.

9.1.2 FURTHER STUDIES NEEDED

No specific study is needed for the Booster vacuum system, but electron cloud studies are needed for the PS. Two dedicated electron cloud experiments are presently installed in straight sections (ss) 98 and 84 of the PS. The vacuum chamber of ss 84 is coated with amorphous carbon and equipped with button-type pickups and a clearing electrode to investigate electron cloud mitigation in the PS, experiments will start in 2010.

9.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Input is required from the Beam Dynamics Work Package, especially for the PS.

9.2 TECHNICAL DESCRIPTION

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10. INSTRUMENTATION

10.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Summary of investigations of present equipment/system with respect to 2 GeV operation

1. Pick-Ups

2. Fast current transformers
3. DC current transformers
4. BBQ tune measurement
5. SEM Grids
6. BLMs
7. FWS

10.2 CRITICAL ISSUES AND PROPOSED CURES

No critical issue has been identified so far.

10.2.1 FURTHER STUDIES NEEDED

Upgrades are needed for the following instruments:

- Pick-Ups: The electronic chain upgrade is included in the consolidation scheme.
- BT.SMV10/20: Depending on the change of septum length, the stack of pick-ups BT. UES10 might have to move.
- DC current transformers:
  - for high ß : Modification of the normaliser modules. Not an issue
  - for high Np : two options
    1. dismount and modify the calibration and feedback windings
    2. new head electronics for increasing the calibration and feedback current.
- BLM: an upgrade is included in the consolidation scheme.
- BT.MTV10i+s, BT.MTV20: three new tanks housing the screens are needed due to the change of length of the vertical septa in the recombination line

10.2.2 INPUT NEEDED FROM OTHER WORK PACKAGES

New length of BT.SMV10 and of BT.SMV20

10.3 TECHNICAL DESCRIPTION

Ring pick-ups:

Replace the Booster orbit measurement system by a trajectory measurement system similar to the one of the PS.

The idea is to have the hardware operational by the time LINAC4 goes on-line.

Ejection pick-ups in the recombination line:

The set of 10 inductive pick-ups, which is to replace the capacitive one, is going to be produced and tested this year. Their integration in the transfer line is also included in the package; BT. UES10 might have to move.

A three-week stop is needed for replacing the present set by the new one: this depends on the next shutdown length (2011 or 2012)

The full upgrade of the electronic chain will be completed in 2012.

The budget is already committed.

DC current transformers:

With operation in the Linac4 era (large number of particles):

The preferred option would be the modification of the head electronics for increasing the calibration and feedback current: 3man.month.

BLMs:

The target is to have at the end of 2012 a basic version of the new system.

Consecutive updates of the firmware during 2013 will bring additional features and better measurements.

MTVs:

BT.MTV10 : There are in fact two screens housed in the BT.SMV10 tank.

1. In a first step, a new separated vacuum vessel will be built and placed dowstream the septum. It will replace the radioactive H-shaped beam pipe for the pumping temporarily. Meanwhile, the screens don't move.

2. The next step is to move the two screens from the septum tank to their dedicated vacuum vessel. This frees two ports for the septum tank for the vacuum pumps.

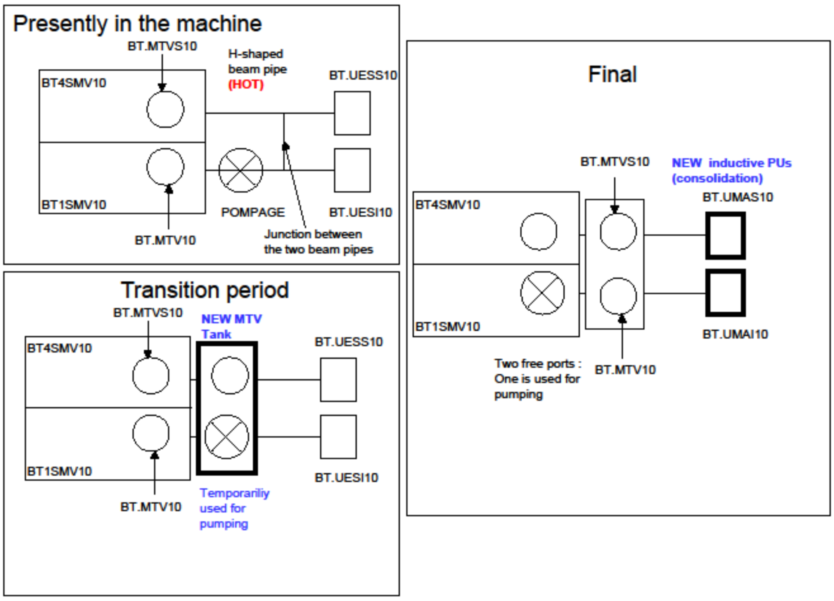

Figure 2 BT.MTV20 is housed in the BT.SMV20 tank. A new separate vacuum vessel for the screen will be built and placed downstream the septum.

11. COMMISSIONING AND OPERATION

11.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

There is no specific system assigned to this work package. The work package will be defined by the equipment/system changes of the other work packages.

In the meanwhile, the work package has to provide input for other working groups. For this purpose, an overview of the different beams with their respective beam parameters, as supposed to be provided by the PSB, is given in the appendix, assuming Linac4 injection and 2 GeV extraction energy.

With Linac4 it will be possible to trade off intensity increase (at maximum a factor 2) against transverse emittance decrease. Therefore the values given in the two tables of the appendix are to be understood as a best estimate. In principle, the maximum intensity provided by Linac4 could be as high as 2.5E13 ppp per ring at the design intensity of the Linac4 source, and new beams or even more challenging beam parameters might be requested by the users at a later stage.

A summary of potential PSB beam parameters for different beams with Linac4 injection and energy of 2 GeV at extraction for beams transferred to the PS is given in the appendix.

Additional parameters:

- Injection energy: 160 MeV (revolution frequency ~1 MHz; synchrotron frequency[1] ~1.68 kHz)
- Extraction energies:
    - 1 or 1.4 GeV for beams to ISOLDE (revolution frequency ~1.67 or ~1.75 MHz; synchrotron frequency ~645 or 446 Hz)
    - 2 GeV for beams to the PS (revolution frequency ~1.81 MHz; synchrotron frequency ~256 Hz)
- Nominal cycling: 1.2 s (0.83 Hz)

11.1.1 CRITICAL ISSUES AND PROPOSED CURES

Critical points can only be identified once the upgrade scenario will be frozen and the time attributed for the commissioning will be known.

11.1.2 FURTHER STUDIES NEEDED

The magnetic cycle studies (see 10.2.1) should be refined to include transverse space charge effects (tune spread) and to evaluate transverse losses at the start of acceleration. In addition, the simulation of the case of a second harmonic contribution to the basic first harmonic will lead to more realistic values of the maximum PSB acceptance.

11.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Operational limitations of a potential new MPS and RF system have to be taken into account, which has already been done for the design of the new magnetic cycle. The magnetic cycle would need to be modified in case these parameters change.

The commissioning steps and time lines for the PSB 2 GeV upgrade have to be planned in detail and require input from each single work package.

11.2 TECHNICAL DESCRIPTION

The upgrade proposals of the other work packages have to be elaborated in the commissioning planning, and are therefore not yet included in this document.

To provide input for other work packages, a comprehensive list of beams including projected beam parameters with Linac4 as PSB injector has been compiled (see appendix).

Magnetic cycles have been calculated based on different assumptions (see 10.2.1).

In parallel, a scenario proposed by TE/EPC, where only LHC beams would be accelerated to 2 GeV and idle cycles inserted at appropriate locations in the supercycle to limit the MPS rms current, has been evaluated (see 10.2.2).

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[1] at 8 kV, h1 and 0 synchronous phase; multiply with sqrt(2) for h2

11.2.1 PSB MAGNETIC CYCLES

Different magnetic cycles for a 1.2 s PSB cycle, accelerating beams from 160 MeV to 2 GeV, have been simulated for varying beam intensities. In these simulations, the model for a new MPS (V_{max}=+/-5 kV, $Vdot_{max}$=1 kV/ms [S. Pittet]) as well as the main bending magnet parameters (L=0.18 H, R=0.5 Ω [A. Newborough]) have been included.

The maximum cavity voltage has been fixed at the current value of 8 kV, because an increase of this limit would require exchanging the cavity and increase its size leading to a major additional investment. Also the current limit of 3 A (minus some margin) was fixed to avoid having to change the amplifiers. It has been assumed to fill the RF bucket up to 80% at injection.

A Bdot of 1.2 T/s for an injection on a ramp has been applied.

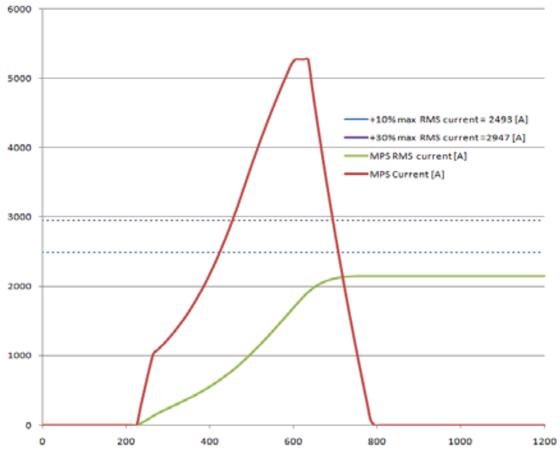
The following simplifications have been made in the calculations:

- Assume pure h1 capture and acceleration and a sinusoidal bunch line density. This represents a pessimistic constraint as the space charge effects will decrease and the effective acceptance increase with h1+h2 acceleration.
- Neglect inductive and resistive wall effect. The PSB impedance is anyway low and the inductive counteracts the longitudinal space charge effect. The beam pipe diameter has been approximated by a circle.
- Transverse space charge effects have not yet been estimated.

Five different scenarios have been studied for the moment and will be described below. A more detailed note with all the results is under preparation and will be published soon.

11.2.1.1 MAGNETIC CYCLE FOR LHC BEAMS

The max. beam current per ring for LHC beams corresponds to **3.25E12 p** (see appendix). With a bucket area defined by the max. cavity voltage of 8 kV minus the reduction due to space charge, a 80% bucket filling yields a longitudinal emittance of 0.99 eVs. A magnetic cycle that fulfils all above-mentioned limitations is shown below. The duration of the acceleration is 340 ms with a flat top of 15 ms (presently: 490/40 ms).



The red line represents the MPS current [A] and the green line the rms current [A]. The blue dashed line limits the rms current to the actual value+10%, whereas the violet dashed line corresponds to the actual value+30%. Exceeding the actual MPS rms current up to +10%, means that only minor modifications to the cooling circuit of the main magnets would be required, but the second limit would necessitate major modifications and the removal of the magnets to the surface. In addition, for the second case, the Meyrin compensator could not cope with the increase.

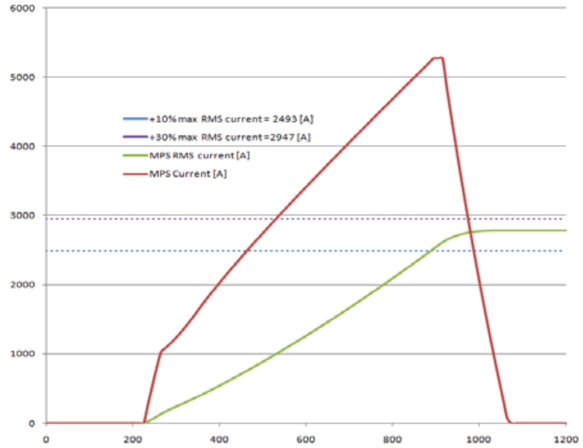
It can be concluded that even for the most intense LHC beams the actual MPS rms current limit would not be exceeded, and the high-level power RF setup would be sufficient (<1A required when 3 A are available).

11.2.1.2 FASTEST MAGNETIC CYCLE FOR THEORETICAL INTENSITY LIMIT WITH THE PRESENT RF POWER SETUP

This scenario covers the max. intensity of **2.5E13 p** per ring that could theoretically be injected with Linac4 if the source would operate at its max. design value. In this case, due to space charge, the longitudinal acceptance would suffer a reduction of 33%. Even with the fastest possible (considering the rf current limitation) cycle and only 5 ms of flat top, the rms current would exceed the 30% limit and could only stay within this limit if the injection would be brought forward.

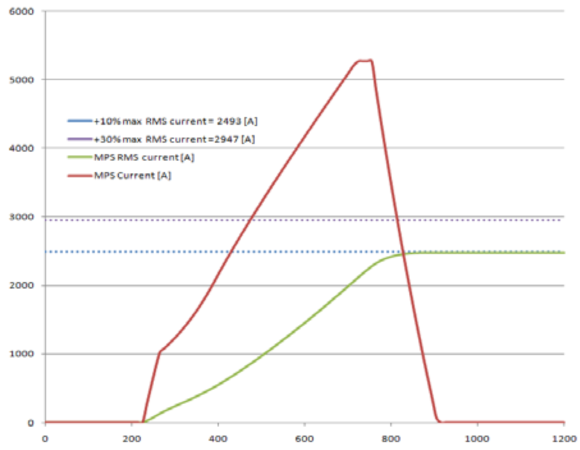
11.2.1.3 FASTEST MAGNETIC CYCLE FOR 2E13 PROTONS WITH THE PRESENT RF POWER SETUP

To stay within the actual MPS current limit+30%, the corresponding beam intensity has been estimated. As a result, **2E13 p** can be accelerated with the present RF setup, but the cycle with beam in the PSB would have to be extended from the actual 530 to 645 ms (15 ms flat top) and the magnet cooling circuit upgraded to accommodate a 20% rms current increase (+modifications of the Meyrin electrical network).



11.2.1.4 BEAM INTENSITY LIMIT COMPATIBLE WITH MINOR COOLING CIRCUIT MODIFICATIONS AND THE EXISTING RF POWER SETUP

This scenario concerns the question of the beam intensity limit that could still be accelerated to 2 GeV, but would stay within the present high-level rf system limits and below a 10% increased MPS rms current (below the dashed blue line). This intensity limit turns out to be **1.4E13 p** per ring, which would mean that all beams with the presently assumed beam parameters (see appendix) could be produced with the 2 GeV magnetic cycle shown below. Also the duration of the acceleration cycle would fit within the current PSB injection and ejection window with a flat top of 15 ms reserved for synchronisation.



11.2.1.5 MAGNETIC CYCLE WITH UPGRADED H1 RF AMPLIFIERS

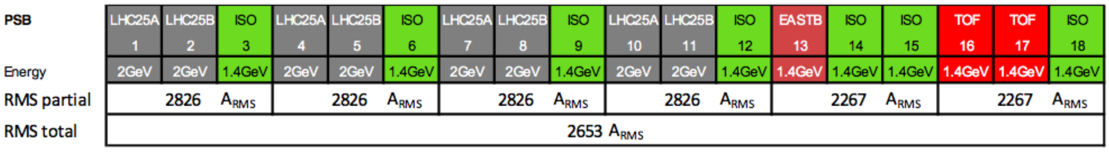
This last study assumes a beam intensity of **2.5E13 p** per ring, but relaxes the constraint on the h1 peak cavity current. Allowing for a 10% increase of the MPS rms current, this scenario would lead to a required h1 peak cavity current of **4.8 A + margin** (compared to the presently available 3 A).

11.2.2 ONLY LHC CYCLES AT 2 GEV AND IDLE CYCLES

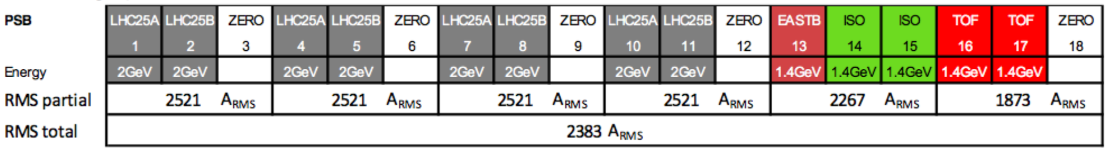
In parallel to the evaluation of different magnetic cycles, a study has been initiated by TE/EPC with the aim to find another solution to keep the MPS rms current below a 10% increase compared to the present limit. This proposal is based on the constraint to limit the PSB energy upgrade to LHC beams only and accelerating all the other beams to 1.4 GeV.

To examine this proposal in detail, the supercycle composition (as it is proposed at the moment) has to be studied.

As an example, the currently foreseen LHC filling supercycle (top image below) would exceed the 10% rms current increase limit, and therefore idle cycles (ZERO cycles) would have to replace ISOLDE cycles that are following LHC 2 GeV cycles (bottom image below).



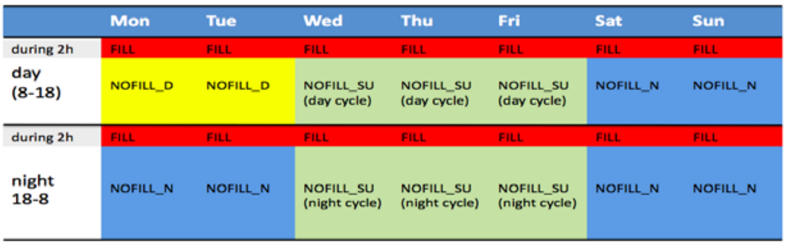
PSB	LHC25A 1	LHC25B 2	ISO 3	LHC25A 4	LHC25B 5	ISO 6	LHC25A 7	LHC25B 8	ISO 9	LHC25A 10	LHC25B 11	ISO 12	EASTB 13	ISO 14	ISO 15	TOF 16	TOF 17	ISO 18
Energy	2GeV	2GeV	1.4GeV	2GeV	2GeV	1.4GeV	2GeV	2GeV	1.4GeV	2GeV	2GeV	1.4GeV	1.4GeV	1.4GeV	1.4GeV	1.4GeV	1.4GeV	1.4GeV
RMS partial	2826 A_{RMS}			2826 A_{RMS}			2826 A_{RMS}			2826 A_{RMS}			2267 A_{RMS}			2267 A_{RMS}		
RMS total	2653 A_{RMS}																	



PSB	LHC25A 1	LHC25B 2	ZERO 3	LHC25A 4	LHC25B 5	ZERO 6	LHC25A 7	LHC25B 8	ZERO 9	LHC25A 10	LHC25B 11	ZERO 12	EASTB 13	ISO 14	ISO 15	TOF 16	TOF 17	ZERO 18
Energy	2GeV	2GeV		2GeV	2GeV		2GeV	2GeV		2GeV	2GeV		1.4GeV	1.4GeV	1.4GeV	1.4GeV	1.4GeV	
RMS partial	2521 A_{RMS}			2521 A_{RMS}			2521 A_{RMS}			2521 A_{RMS}			2267 A_{RMS}			1873 A_{RMS}		
RMS total	2383 A_{RMS}																	

In addition, cycle 18 would also need to be a ZERO cycle if one wants to avoid modifications to the BTP-line quadrupole power converters, which could currently not cope with a ppm change of the settings due to the different optics for the transfer of 1.4 and 2 GeV beams to the PS.

Besides the LHC filling supercycle (FILL; assumed to be present during ~4h each day), the same evaluation has been performed for the day- and night-(weekend-)time supercycles (NOFILL_D/NOFILL_N). Moreover, a new supercycle (NOFILL_SU) has been added to allow for control and setup of LHC cycles in the PS complex following a request of BE/OP. The assumption on the daily use of these supercycles is schematically shown below, understanding the LHC filling cycles (in red) as being floating during the day.



	Mon	Tue	Wed	Thu	Fri	Sat	Sun
during 2h	FILL	FILL	FILL	FILL	FILL	FILL	FILL
day (8-18)	NOFILL_D	NOFILL_D	NOFILL_SU (day cycle)	NOFILL_SU (day cycle)	NOFILL_SU (day cycle)	NOFILL_N	NOFILL_N
during 2h	FILL	FILL	FILL	FILL	FILL	FILL	FILL
night 18-8	NOFILL_N	NOFILL_N	NOFILL_SU (night cycle)	NOFILL_SU (night cycle)	NOFILL_SU (night cycle)	NOFILL_N	NOFILL_N

As summary, the average weekly proton loss for physics amounts to the total loss value given in the table below.

	FILL	NOFILL_D	NOFILL_SU	**TOTAL LOSS**
ISOLDE	11.90%	1.36%	9.22%	23.18%
EASTB	-	-	10.88%	10.88%

A detailed report on this study has been published under EDMS [3].

12. EXTRACTION, TRANSFER, PS INJECTION

12.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

BE.BSW: magnets and generators OK up 2.2 GeV;

BE.KFA14L1: not enough margin on magnets (OK up to 1.7 GeV, ferrite saturation above); design new magnets and vacuum vessel. Generators OK up to 2 GeV;

BE.SMH: magnet succesfully tested at current equivalent to 2 GeVoperation; cooling and interconnects to be reinforced;

BT.SMV10: not enough margin on magnet (OK up to 1.75 GeV); longer magnet to be designed;

BT.KFA10: magnets and generators OK up to 2 GeV; it is advisable to replace the ferrites by more performant ones to run at 2 GeV or higher;

BT.SMV20: not enough margin on magnet (but OK up to 1.9 GeV); longer magnet to be designed;

BT.KFA20: magnets and generator OK up to 2 GeV;

PI.SMH42: not enough margin on magnet (1.4 GeV max.). Needs new PS injection scheme to accomodate the additionally required length for the septum magnet;

PI.KFA45: magnets OK but no margin on generator (1.4 GeV is the limit if magnets are terminated)If magnets are used in short-circuit mode, 2 GeV is attainable, but with increased rise and fall times as well as increased ripple on the flattop.

12.1.1 CRITITAL ISSUES AND PROPOSED CURES

Up to 1.7 GeV all PSB septa and kickers are OK. For 2 GeV operation the PSB extraction kicker and recombination septa need a full redesign and new construction. To provide space for the longer Beam Transfer septa (while retaining the complex vacuum vessels) it is proposed to move the beam screens to the adjacent vacuum chambers.

For PS injection no margin exists on the present either on the septum or on the present kicker system. A new injection scheme is needed to provide the additional space for a longer septum, as well as allow the use of the injection kicker in short circuit mode with the associated degradation of rise, fall time and ripple at the flattop.

Two options are being explored: injection in PS straight section 42 (present PS injection location, standard PS short straight section), or displace the injection region to straight section 41 (PS standard long straight section, in which little equipment is installed at present).

12.1.1.1 OPTION 1: INJECTION IN SD42

The simplest solution is to inject into SD42 as at present, which requires a longer injection septum, and a ~14 mrad bumper integrated into the septum tank. The KFA45 kicker can be operated in short-circuit mode for LHC beam if the blow-up due to the increased ripple is acceptable – if not, a new supplementary kicker can be built in SD53, with about -1 mrad. The details of the aperture limits for the circulating and injected beam still have to be checked for the solution with a supplementary kicker in SD53.

If the integration of the bumper and septum in SD42 is not possible, the next best solution looks like building a shorter under vacuum bumper septum in 42, and then adding a bumper in SD41, to approach the present injected angle. The bumper in SD42 would need to provide about 7 mrad, and the details of the aperture limits for the circulating and injected beam have to be checked (the orbit increases by about 10 mm in main magnet 41, and the trajectory of the injected beam is about 3 mm further out, in main magnet 42).

12.1.1.2 OPTION 2: INJECTION IN SD41

If injection in SD42 is not found to be technically possible, then injecting into SD41 has been looked at. There is plenty of space for the septum and an adjacent bumper, and the kicker strength required is lower, as the phase advance and beta are favourable. However, the beta functions are large at the septum location and the consequent larger beam size will not fit easily into the aperture. Possibly a temporary perturbation of the injection optics would allow the beam sizes to be reduced enough to make such a scheme possible, or replacement of existing chambers with enlarged ones. The present KFA45 could stay where it is, but a total of 5 bumpers would be needed, together with a longer septum.

12.1.2 FURTHER STUDIES NEEDED

To provide space for the longer beam transfer septa, it is envisaged to displace the beam observation equipment downstream. For the MTV screens in the BT.SMV10 and BT.SMV20 vacuum vessels, a short integration study should be able to point out the most economical approach to re-install the existing screens. At first sight, a redesign and new construction of the vacuum chambers immediately downstream of BT.SMV10 could possibly provide the required flanges for the mechanisms and viewport necessary, within any further impact on the septa vacuum vessels. Alternatively, the vacuum vessels (covers) could be stretched, which in case of BT1.SMV10, will lead to necessary modifications of the support structure of the septa. To relocate the screen of the BT.SMV20 the vacuum vessel cover could be stretched and the adjacent vacuum chamber downstream of the septum would have to be adapted.

A new PS injection scheme needs to be developed, to provide space for a longer septum magnet as well as to cope injection kicker system parameters with the kicker in short-circuit mode.

The limitations and performance of a bumper in the same straight section as the injection septum in SD42 are still to be finalized. This should determine if the injection region should be moved.

The impact of the flattop ripple on the LHC beam emittance, due to running the injection kicker in short-circuit mode is to be verified. This should be subject of a future MD, and could determine the need for supplementary kicker (in SD53?).

12.1.3 INPUT NEEDED FROM AND PROVIDED TO OTHER WORK PACKAGES

Extracted beam parameters for all users.

The beam observation screens on the vacuum vessels for the Booster transfer line septa need to be moved to the adjacent vacuum chambers to provide space for the new septa magnets.

The impact on the conventional magnets in the BT and BTP line and PS depends strongly on the injection scheme which will be implemented and still needs to be determined.

To obtain the required increased magnetic strength of the PSB extraction septa, the current of the septa will have to be increased (power supply under the responsibility of EPC). The magnets are not expected to saturate and no electric parameter changes are expected from the required mechanical reinforcement that will be implemented.

To obtain the increased magnetic strength for the BT septa, the magnets will be stretched by approximately 24% (with the associated increased in inductance and resistance of these) and the remaining 6% will have to be obtained by increasing the current of the devices. The power supplies of these septa will have to be upgraded accordingly (under responsibility of EPC).

12.2 TECHNICAL DESCRIPTION

12.2.1 BOOSTER EXTRACTION BUMPERS BE.BSW14L4, 15L1, 15L4.

The magnet current at 1.4 GeV is 525 A (data from 2009 run). At 2.17 GeV, 724 A would be required. The magnets are of booster type 5 (Imax = 765 A) and type 6 (Imax = 845 A) and can be used. The generator voltage will be ~ 460 V which is achievable. Conclusion: no problem with the present system.

12.2.2 BOOSTER EXTRACTION KICKER BE.KFA14L1

The kicker consists of 4 delay line magnets (= 25 Ω) pulsed in parallel for each booster ring. Their generator consists of a gas filled Pulse Forming Line (rated 60 kV) discharged by a 60 kV thyratron.

The maximum PFL voltage required at 1.4 GeV is 42.5 kV (data from 2009 run for ring 2).

The thyratron life time which is more than ten years in the present working conditions is expected to decrease with the new ones. In order to keep 10 % margin, the PFN voltage should be kept below 55 kV. The corresponding beam energy is close to 2 GeV. A few nanoseconds (~1 to 5) rise time are expected to be lost as a consequence of the voltage increase.

Induction in the air gap: $B_{air} = \mu_0 \times I / h$ where I is the magnet current and h the gap height.

$$B_{air} = 4 \times \pi \times 10^{-7} \times 2351 / 0.07 = 0.0422 \text{ T}$$

Induction in the ferrite: $B_f = B_{air} \times S_{air}/S_f$ where S is the cross sectional area.

For the air gap, we have $S_{air} = w_{air} \times lcell$ where wair is the gap width and lcell the magnet cell length.

For the ferrite, we have $S_f = w_f \times l_f$.

This gives: $B_f = 0.0422 \times 0.1175 \times 0.032 / 0.026 \times 0.026 = 0.2347$ T.

In the end cells, the induction in the ferrite is 50 % higher (0.3520 T) and is 17.3 % above the maximum acceptable figure of 0.3 T corresponding to the start of saturation (for 8C11 and CMD5005 grades). The maximum magnet current corresponding to 0.3 T is 2000 A (VPFL = 50 kV), which corresponds to a beam energy of only 1.75 GeV.

Conclusion: Operation at 2 GeV requires a new ejection kicker tank. The actual tank should also be upgraded to serve as a spare which does not exist for the moment. There won’t be any margin.

12.2.3 BOOSTER EXTRACTION SEPTUM BESMH

The present extraction septa use laminated steel magnet cores. The present magnetic field is around 0.35 T at the peak current 7.2 kA. This design provides sufficient margin to increase the current to obtain the required field for operation with 2 GeV beams. A magnet block was successfully tested up to 11 kA, and the magnet behaviour was still relatively linear. However, the magnets for ring 1 and 2, as well as for 3 and 4 are put electrically and hydraulically in series und? with connections inside the vacuum vessel. The hydraulic circuit will have to be modified so that the magnets can be cooled in parallel to cope with the additional heat dissipation due to the higher currents. The electrical series connections will need to be reinforced to withstand the higher mechanical loads. These are considered minor modifications and could be carried out on the operational spare magnet and after this one has been installed, the magnet removed from the ring could be modified. The exchange of the BESMH for its upgraded version can be planned in any shutdown which allows 4 weeks of access to the Booster extraction area.

12.2.4 BOOSTER TRANSFER SEPTA BT1SMV10, BT4.SMV10

Each of these septa are used (2010) at slightly below their design current of 27.3 kA. To maintain their estimated lifetime at present values, taking into account the high number of pulses annually, it is necessary to lengthen the magnets. The present vacuum vessels could provide space for a 1300 mm magnet (presently 1060 mm) if the installed beam observation screen would be moved to the adjacent vacuum chamber. This would yield a magnet with a magnetic length of approx. 1236 mm, which would need 28.6 kA. It is expected that the life time of these magnets (presently around 5 years) would only be slightly reduced. A new adjacent vacuum chamber would have to be designed and manufactured, to allow the installation of the present beam screens as well as the pumping group already installed in that area. Due to the increase yoke length, the vacuum would degrade up to 25% if the pumping speed would be kept constant.

12.2.5 BOOSTER TRANSFER KICKERS BT1.KFA10, BT4.KFA10.

Each kicker consists of 2 delay line magnets ($Z_0 = 12.5\ \Omega$) pulsed in parallel. Each generator consists of a gas filled Pulse Forming Line discharged by a 60 kV thyratron. The pulse generators have the same limitations as the BE.KFA ones. In order to keep 10 % margin, the PFN voltage should be kept below 55 kV. The corresponding beam energy is close to 2 GeV. A few nanoseconds (say 1 to 5) rise time are expected to be lost as a consequence of the voltage increase.

The maximum PFL voltage required at 1.4 GeV is 42.5 kV (data from 2009 run).

At 2.17 GeV, the voltage required will be 59 kV corresponding to a current of 4702 A in each magnet. The thyratron life time which is more than ten years in the present working conditions is expected to decrease with the new ones.

Induction in the air gap: $B_{air} = 4 \times \pi \times 10^{-7} \times 4702 / 0.11 = 0.0537$ T.

Induction in the ferrite: $B^f = 0.0537 \times 0.053 \times 0.032 / 0.026 \times 0.026 = 0.135$ T.

In the end cells, we have 0.2020 T which is on the limit for the present 4L1 ferrite grade.

Therefore, it is recommended to replace the present 4L1 ferrite by 8C11 or CMD5005 to guarantee the kick maximum value because the µ of 4L1 is about half of 8C11.

This move would also improve vacuum performances because present ferrite cores are glued with epoxy resin. The construction of a spare tank may also be envisaged.

Conclusion: Operation at 2 GeV is possible but a change of ferrite grade is recommended. The construction of a spare tank could also be foreseen. There won’t be any margin.

12.2.6 BOOSTER TRANSFER SEPTUM BT. SMV20

This septum is used at slightly above its design current of 27.2 kA (2010 25.5 kA). To maintain their estimated lifetime at present values, taking into account the high number of pulses annually, it is necessary to lengthen the magnet as well. The present vacuum vessel could provide space for a 1300 mm magnet (presently 1060 mm) if the installed beam observation screen would be moved to the adjacent vacuum chamber. This would yield a magnet with a magnetic length of approx. 1236 mm, which would need 26.4 kA. It is expected that the life time of these magnets (presently around 10 years) would only be slightly reduced. A new adjacent vacuum chamber could be designed and manufactured, to allow the installation of the present beam screens or an extended septum vacuum vessel cover which would provide a flange for the beam observation system in a similar way as in the present system. Due to the increase yoke length, the vacuum would degrade up to 25% if the pumping speed would be kept constant.

12.2.7 BOOSTER TRANSFER KICKERS BT.KFA20.

The kicker consists of 2 delay line magnets ($Z_0 = 12.5\ \Omega$) pulsed in parallel. The magnets are identical to the BTi.KFA10 ones but the pulse generator configuration is not. In order to gain a few nanosecond rise time, the magnets are part of the PFL and are then charged to the full PFL voltage. The actual thyratron is rated 40 kV but can be replaced by a 60 kV one. A few nanoseconds (say 1 to 5) rise time are expected to be lost as a consequence of the voltage increase. The maximum PFL voltage required at 1.4 GeV is 28 kV (data from 2009 run). The magnet voltage hold-off is limited to 37 kV. This corresponds to a beam energy of 2.04 GeV.

The possibility of modifying the pulse generator to work in the same conditions as the BT.KFA10 ones exists. The kick rise time (2-98) % will then increase from 87 ns to 100 ns. It will be the same as the BTi.KFA10 rise time. The ferrite grade is 8C11 or CMD5005 and a spare tank exists.

Conclusion: the BT.KFA20 can be used without modifications up to 2 GeV. There won’t be any margin.

12.2.8 PS INJECTION SEPTUM PI.SMH42

Still under study.

12.2.9 PS INJECTION KICKER PI.KFA45

Each of the four KFA45 magnet modules can be used in terminated or short-circuit mode.

The generators consist of a gas filled Pulse Forming Line discharged by a 100 kV thyratron. Another thyratron is used to short-circuit the magnet terminator when the short-circuit mode is requested. When used is short-circuit mode, the kick is increased by 82 % at full PFL voltage (80 kV). The drawbacks are:

-increase of flattop ripple from ± 2 % to ± 3 %

-increase of post pulse ripple from ± 1.25 % to ± 1.5 %

-increase of rise time (2-98)% from 42 to 68 ns

-increase of fall time (98-2)% from 68 to 87 ns

If the short-circuit mode is not suitable, an additional kicker is required.

The main concerns are:

-unavailability of high voltage gas filled cables used for the PFL and transmission. At present, no potential manufacturer has been identified and it is unlikely we find one.

-no space available in the present 365 building

So, an additional kicker should have a rather small deflection angle to permit the use of standard available cables.Conclusion: if the system can't be used in short-circuit mode, development of new generators with PFL or Pulse Forming Network is required. The solution with PFL is highly desirable for complexity reduction and optimized performance but it depends on the availability of critical components in industry.

12.2.10 ADDITIONAL PS INJECTION KICKER (KFA 53?)

Still under study.

13. CONTROLS

13.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Technical specifications of the Controls equipments have been verified in order to guarantee an adequate response of each component, due to the increase of energy in PSB up to 2GeV. Eventually, only two components were identified as possible showstoppers: Function generators (GFAS) and Synthetic B-Train.

- GFAS: When defining a magnetic cycle, a function generator (module GFAS) is used in order to provide the function reference for the main power supply. This module GFAS in able to provide a transition from 0 to the maximum value in 35ms with a frequency of sampling of 200KHz. This fact brings the first potential showstopper as limit the maximum variation of the magnetic field reference.

- Synthetic B-Train: Precise information in real time of the magnetic field, as a function of time, is important for beam control as well as for many measurement applications. For the time being the most severe demand in PSB is 0.3 Gauss precision and 0.1 Gauss resolution. The information about the magnetic field is synthetically generated (Synthetic B-Train) following a magnet model with some feedback from real acquisition of the magnetic field. This Synthetic B-Train has a resolution of 0.1 Gauss with a frequency of 400Khz. This shows the second potential showstopper in the context of Controls. The maximum rate for increasing or decreasing the Synthetic B-train cannot exceed 40Gauss/ms.

13.1.1 CRITICAL ISSUES AND PROPOSED CURES

Regarding the module GFAS no problems are expected as the response of that module is fairly fast, although checking will be done as soon as the information of the 2GeV cycle is received.

Feedback from equipment groups is required in order to verify if the current design of the Synthetic B-Train is still valid (maximum 40KGauss/s). In case the actual hardware is not able to give the expected response a new set of hardware is ready to be put in place.

13.1.2 FURTHER STUDIES NEEDED

Depending on the request of the equipment groups (new installations, modification of existing installation, hardware or software) further studies should take place.

13.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Input is required in order to validate the Controls systems:

- Could the new magnetic field be generated with the current configuration of the Synthetic B-Train: frequency of 400KHz with a resolution of 0.1 Gauss?
- From each WP is required a description of the Controls system needed for their new installations, in order to evaluate work and manpower.

13.2 TECHNICAL DESCRIPTION

If the requirements for the Synthetic B-train excees the current limits the hardware in charge of such generation will have to be changed, there is already a substitute for this generator. Also due to the high frequency of this train all cables and repeaters will have to be replaced.

From the different workpackages the following requirements have been identified:

- WP Power Converters: 2 Gateways with WorldFip control (MPS and BHP room)
- WP RF: Most of the Controls modifications are covered by consolidation project.
- WP OP: Installations of new Oasis systems. It will be required the specification of the number of signals and also the sampling frequency needed for each of them. A roughly estimation of 100 new signals is taken for the time being.
- WP Extraction, Transfer, PSInjection: Final requirements for Controls are not completely defined. If a new PS injector kicker is needed a new front-end installation will be required.
- WP Vacuum: No need of modifications in the Controls systems.
- WP Instrumentation: No need of modifications in the Controls systems.
- WP Magnets: No need of modifications in the Controls systems.

14. ELECTRICAL SYSTEMS

14.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The booster network is fed from ME*9 substation, in an antenna configuration.

Attention has to be drawn on all the ongoing projects on the Meyrin site (Linac4 , 513, POPS), affecting the total consumption on EHT102/1E and MP5.

The future electrical distribution (LV&HV) of the Booster complex will very much depend on the future power request of Booster end users (mainly TE and EN/CV).

The actual power consumption is fluctuating around 10 MVA.

A 25% increase of the power is conceivable.

Before going any further with the detailed studies, EN/EL need a proper estimation of the power needed, including all Booster end users.

14.1.1 CRITICAL ISSUES AND PROPOSED CURES

No more power is available on the transformer dedicated to the general services.

Since the 18 kV cubicles are of an old type, any extension of the existing HV switchboard is not possible with the existing cubicle type. EN/EL will have to replace all the cubicles of this ME*25 substation, in case of a need for new HV feeders.

The 18 kV power cables feeding the booster are 40 years old. The status of these cables shall be verified and might require some consolidation/exchange.

14.1.2 FURTHER STUDIES NEEDED

Studies concerning the future distribution network are mandatory. This study will be done for the booster (HV&LV) distribution and its integration in the current Meyrin electrical distribution.

14.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

In order to start these studies, a balance sheet concerning the needed power is necessary, including all users of the Booster.

14.2 TECHNICAL DESCRIPTION

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15. COOLING AND VENTILATION

15.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

This is ongoing; before any answer we need a confirmation on requests (cooling powers, flow rates, pressures etc.) both for water cooling and for air conditioning.

15.1.1 CRITICAL ISSUES AND PROPOSED CURES

For the time being the most critical issue will be the length of shutdown to comply with the work to be performed. This includes commissioning time for CV installations and all tests on users' equipment can be done only after the completion of our intervention.

Basic assumption is that the necessary resources (material and manpower) shall be provided according to the planning requests.

15.1.2 FURTHER STUDIES NEEDED

Full definition of new cooling and ventilation installations.

15.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Cooling powers, flowrates, max pressure, acceptable pressure drops and temperature range for water cooled systems (chilled water, raw water, demineralised water).

Same for compressed air needs.

Safety file, RP constraints, heat dissipations in air etc. for HVAC systems and fire extinction needs.

15.2 TECHNICAL DESCRIPTION

According to first input received, the increase of working pressure and of cooling power will require the complete replacement of the cooling station and of distribution piping that is not sized for an increase of flow rate nor of pressure. Once more detailed will be provided, a decision on whether the same number of circuits will be kept or additional circuits (at different working conditions) and consequent space shall be needed.

16. RADIOLOGICAL PROTECTION

16.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Prompt radiation levels and activation of accelerator components related to injection into the PSB are expected to rise by a factor of 2 because of the proton beam intensity increase enabled by Linac 4.

Furthermore, radiation levels and activation at terminal energy of 2 GeV in the PSB and in the PS injection will rise by a factor of 1.3 with respect to 1.4 GeV .

These two effects combined, plus an allowance for non-linear effects which scale more than proportional to beam intensity may lead to radiation level increases by a factor between 2.5 and 3

16.1.1 CRITICAL ISSUES AND PROPOSED CURES

The increased radiation levels coming with the energy- and intensity upgrade are a concern for beam insertions and aperture limitations which are active at terminal energy – foremost the extraction kicker or septa, the transfer line, and the injection septum into the PS.

Radiation levels on the crossing point of Route Goward are already exceeding the limits for areas accessible to public, this situation may become aggravated. Shielding of the road passage will become mandatory.

In the RAMSES 2 light project, a radioactive release monitor will be fitted to the PSB ventilation extraction for the first time. Releases rise proportionally to other radiation effects with intensity- and energy increases. The impact on the total release figure of the Meyrin site, including ISOLDE, n-TOF, TT10 is as yet unknown. If action levels/ optimisation thresholds could be regularly exceeded, modifications to the ventilation system will become necessary.

Independent of the energy rise, radiation effects related to the injection into PSB from Linac4 must be studied. In particular, the injection dumps must be designed such that residual radiation can be shielded during shutdowns.

16.1.2 FURTHER STUDIES NEEDED

Relation of measured or estimated beam loss (BE/ABP, BE/OP) to activation levels (DGS-RP).

Assessment of estimated and measured radioactive releases with the environmental impact model.

16.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

From BE/ABP: best estimates of beam loss figures for more intense, more energetic beams in PSB, incorporating non-linear effects.

From EN/CV: ventilation flows required to remove extra heat from energy increase, planned lay-out of future ventilation system.

16.2 TECHNICAL DESCRIPTION

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17. TRANSPORT AND HANDLING

17.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The major transport and handling equipment listed below is despite its age in reasonable condition for the present intervention scenarios.

CH-066/067	SMISO 10t trailers; 1970; bldg.361
PR-0138	MUNCK 20t crane; 1970; bldg 361
AS-045	GEBAUER 2t lift;1970, bldg 361
PR-134/135/136/137	MUNCK 10t cranes;1970; bldg.360

The consolidation (replacement) of the lift is the most urgent and will take about six weeks and could be done at the next long shutdown. It may be required that the new lift will be ‘interlocked’ to avoid the use during machine operation.

There will be most likely a need for new auxiliary handling equipment such as hoists, slings, spreader beams etc.

17.1.1 CRITICAL ISSUES AND PROPOSED CURES

There are no critical issues identified from our part so far as long as the Booster machine components keep their present characteristics in terms of dimensions, weight, lifting points, sensitivity regarding vibrations, shocks etc.

If higher capacity handling equipment is required then it must be checked for example if the building 360 structure will allow the installation of cranes with capacities higher than 10t.

17.1.2 FURTHER STUDIES NEEDED

Feedback from the equipment responsibles.

17.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Integration: All modifications must be cross-checked with required transport zones

Radiation: Increased radiation values may require optimized (i.e. remote controlled) transport and handling equipment and/or additional shielding (which then becomes again an integration problem).

17.2 TECHNICAL DESCRIPTION

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18. SURVEY

18.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

All equipment and methods needed for the existing magnet of PSB and Transfer Lines are ready and no changes needed for 2 GeV operation.

Consolidation for the existing lines is programmed for the next shut-downs and was scheduled with the machine responsible.

18.1.1 CRITICAL ISSUES AND PROPOSED CURES

If the main dipoles have to be taken out: risk to lose the stability of the geometry; we need to take out all 1st magnets, realign them, and in a second step take out the other 16 (2nd magnets of a sector).

18.1.2 FURTHER STUDIES NEEDED

Investigate about the geometry transfer between the PS Hall and the PSB to smooth the BI line.

In the case that the main dipoles have to be taken out: careful studies of impact on the overall geometry of the Booster Ring needed.

18.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

As soon as the design study starts for any new element to be aligned, we would like to be involved for alignment target and support design.

This information should come from WP 2, 4, 7, and 9.

18.2 TECHNICAL DESCRIPTION

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19. REFERENCES

[1] LHC Performance Workshop Chamonix 2010, http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=67839
[2] S.Aumon, PhD thesis, in preparation.
[3] B. Mikulec, Estimation of Loss for Physics with Idle Cycles during Filling of the LHC with 2 GeV LHC Cycles from the PSB, https://edms.cern.ch/document/1079117/1.

20. APPENDIX

20.1 MD PROPOSALS

Proposed MD for the study of the transverse instability at flat top in the PS

The idea is to reproduce the transverse instability observed in the PS in 2001, 2004 and 2006 at 26 GeV/c, and study in detail its dependence on bunch intensity and length. The goal is to determine the source and the behaviour of this instability and extrapolate from all the observations and studies whether it can act as a serious bottleneck to get the LHC25 beam through the injector chain, once its intensity is potentially doubled.

We need to use an LHC25 beam (with intensity up to the highest that can be produced in the PSB) with bunches which we adiabatically shorten at flat top to values around 10ns, till the beam becomes unstable (with corrected chromaticities). We could try to determine the threshold bunch length (i.e. the one below which the beam is unstable) as a function of the injected intensity. Is the instability only horizontal or does it appear also in the vertical plane? Measurements (in both planes) with the wall current monitor WCM00 used by Sandra for the study of the TMCI at transition crossing could be useful to see the intra-bunch motion while the instability grows.

If possible, the measurements should be done both with the LHC25 user (multi-bunch, by eventually varying the number of bunches up to 72) and with the LHCINDIV (single bunch), in order to pin down whether this is a multi-bunch or single bunch effect (including in the “multi-bunch” also a possible single bunch electron cloud instability).

Parallel electron cloud measurements can be taken with Edgar’s set up in order to find out whether there is a direct correlation between the appearance of the electron cloud, which is known to be present in the PS when the bunches of the LHC25 become short enough, and the observed instability.

The transverse pick-up signals and the screen in TT2 could be used to cross check the electron cloud build up and beam quality also in the transverse line.

20.2 BEAMS TO BE DELIVERED BY THE PSB (AFTER UPGRADE)

Table 1: Overview of LHC-type beams to be delivered by the PSB with Linac4 and after energy upgrade.

user	harmonic number at extr.	PSB rings used	intensity per ring	rms emittance at extr. [mm mrad]	bunch length at extr. [ns]	extr. energy [GeV]
LHC25A/B	1	1-4 and 3+4 (2 extractions)	2.43E12 (ultimate) and smaller	hor.: ≤2.5 vert.: ≤2.5	180	2
LHC25	2+1	2-4	3.25E12 (nominal) and smaller by factor 20	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC50	2+1	2-4	for ultimate expect also 2.43E12 (2 bunches/ring)	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC75	2+1	2-4	variable, but smaller than 25 and 50 ns	hor.: ≤2.5 vert.: ≤2.5	140	2
LHCPILOT	1	3	0.005E12	hor.: 2.5 vert.: 2.5	85	2
LHCPROBE	1	3	0.005-0.023E12	hor.: ≤2.5 vert.: ≤2.5	70	2
LHCINDIV	1	1-4	0.023-0.135E12	hor.: ≤2.5 vert.: ≤2.5	80-85	2

Table 2: Overview of fixed-target physics beams to be delivered by the PSB with Linac4 and after energy upgrade.

user	harmonic number	PSB rings used	intensity per ring	rms emittance at extr. [mm	bunch length at extr.	extr. energy

	at extr.			mrad]	[ns]	[GeV]
CNGS	2	1-4	0.6-8E12 + ~45% increase to reach target limit	hor.: ~10 vert.: ~8 ~12/7 with MTE	180	2
SFTPRO	2	1-4	<6E12 – would an increase be desirable?	hor.: ~6-8 vert.: ~5-6 ~12/7 with MTE	180	2
AD	1	1-4	4E12 (currently)	hor.: ~8 vert.: ~6	190	2
TOF	1	1-4	<9E12 (currently)	hor.: ~10 vert.: ~10	230	2
EASTA/B/C	1	3 (+2)	~0.1-0.45E12	hor.: ~3 vert.: ~1	150	2
NORMGPS NORMHRS	1	1-4	up to 10E12 (currently – increase with HIE-ISOLDE?)	hor.: ≤15 vert.: ≤9	250	1 or 1.4
STAGISO	1	2-4	<3.5E12	hor.: <8 vert.: <4	230	1 or 1.4

20.3 COST AND MANPOWER ESTIMATE

In the following sections, the cost estimate is summarised and the detailed budget break down per work unit is given. The cost for manpower is included in the cost estimate wherever additional manpower (fellows, associates) is requested. Existing CERN staff is not accounted for in terms of cost, but the required manpower is indicated.

20.3.1 DETAILED BUDGET BREAK-DOWN BEAM DYNAMICS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
general budget		50	50	0		

Remarks:

A budget of 50 kCHF has been tentatively allocated.

20.3.2 DETAILED BUDGET BREAK-DOWN MAGNETS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		

main bends cooling (if increased rms current)	material	280	280	0		
	FSU	160	160	0		64 mw
	associates	20	20	0	0.3	
	staff	0	0	0	0.5	
main bends cooling (comparable rms current, baseline)	material	40	40	-40		
	FSU	15	15	-15		6 mw
	associates	0	0	0		
	staff	0	0	0	0.1	
main quads cooling (if increased rms current)	material	80	80	0		
	FSU	25	25	0		10 mw
	associates	0	0	0		
	staff	0	0	0	0.2	
main quads cooling (comparable rms current, baseline)	material	80	80	-80		
	FSU	25	25	-25		10 mw
	associates	0	0			
	staff	0	0		0.2	
main bends shimming and saturation	material	210	210	0		
	FSU	45	45	0		18 mw
	associates	45	45	0	0.7	
	staff	0	0	0	0.7	
auxiliary ring magnets	material	0	0	0		
	FSU	0	0	0		
	associates	0	0	0		
	staff	0	0	0		
transfer line magnets replacement	material	1220	1370	-210		
	FSU	60	60	0		24 mw
	associates	130	130	0	2	
	staff	0	0	0	1.5	
PS injection and low-energy magnets replacement	material	1000	1000	0		
	FSU	120	120	0		48 mw
	associates	130	130	0	2	
	staff	0	0	0	1.5	

Remarks:

Transfer line magnets replacement: 210 kCHF is already agreed for consolidation - project now on hold. This scenario is assuming all magnets in question will need to be replaced with new units. More detailed study will need to be completed with project approval.

PS injection magnets replacement: Still rough estimate - more detailed study is needed.

20.3.3 DETAILED BUDGET BREAK-DOWN RF SYSTEM

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		

C04 amplifiers	design	200	200	-200	rf engineer	8 m
					rf technician	2 m
					mechanical design office	9 m
					electronics design office	9 m
	prototyping, production and testing	1100	1100	-1100	rf engineer	8 m
					rf technician	10 m
					mech. FSU	9 m
					electr. FSU	9 m
	installation and commissioning	200	200	-200	rf engineer	3 m
					rf technician	7 m
					mech. FSU	6 m
					electr. FSU	6 m
	HV power supplies procurement	400	400	-400	TE/EPC	
	amplifier interlocks	100	100	-100	BE/RF	
	amlipier controls				BE/CO	
LL RF		75	75	-75		

Remarks:

If the planned RF consolidation is completed before the energy upgrade is put in place, then all necessary modifications are covered by this and there is no additional cost.

20.3.4 DETAILED BUDGET BREAK-DOWN BEAM INTERCEPTING DEVICES

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
PSB dump	FLUKA studies	400	400	-400	fellow	3 m
					engineer	1 m

	conceptual design				fellow	3 m
					engineer	2 m
	design				design office	5 m
					technician	3 m
					engineer	2 m
	manufacturing				technician	6 m
					engineer	1 m
					FSU	2 m
	installation				technician	2 w
beam stopper BTP.STP10		300	300	-300		
	FLUKA studies				fellow	3 m
					engineer	1 m
	check present design				fellow	2 m
					engineer	2 m
	design new beam stopper				design office	5 m
					technician	3 m
					engineer	2 m
	manufacture new beam stopper				technician	5 m
					engineer	1 m
					FSU	6 w
	installation				technician	2 w

20.3.5 DETAILED BUDGET BREAK-DOWN POWER CONVERTERS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
MPS	design and specification	1000	1000	0	engineer	9 m
	market survey				engineer	1 m

	call for tender				engineer	2 m
	manufacturing	10000	10000	-900	engineer	24 m
					technician	32 m
	civil engineering	2000	2000	0	engineer	12 m
	installation and commissioning	2000	2000	0	engineer	24
					technician	64
Meyrin TCR maintenance				-2000		
MPS trims	design and specification	100	100	-100	engineer	6 m
					technician	12 m
	manufacturing	400	400	-400	technician	9 m
	installation and commissioning	200	200	-150	technician	9 m
capacitor discharge upgrade	design and specification	10	10	0	engineer	6 m
	component supplies	150	150	0		
	installation and commissioning	40	40	0	technician	6 m
capacitor discharge new	design and specification	60	60	0	engineer	10 m
	market survey				engineer	1 m
	call for tender				engineer	1 m
	component supplies	250	250	0		
	manufacturing	100	100	0	technician	12 m
	commissioning	40	40	0	technician	6 m
transfer line bendings new	design and specification	320	340	320	engineer	30 m
					technician	30 m
	market survey				engineer	2 m
	call for tender				engineer	4 m
	manufacturing	2240	2240	-1400	technician	48 m
	installation and commissioning	640	670	-530	technician	16 m
PS ring CBE	design and specification	100	100	-100	engineer	10 m
					technician	6 m
	market survey				engineer	1 m
	call for tender				engineer	1 m
	manufacturing	1000	1000	-600		
	installation and commissioning	200	200	-130	technician	6 m

Remarks:

xxx

20.3.6 DETAILED BUDGET BREAK-DOWN VACUUM SYSTEM

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
general budget		100	100	0		

Remarks:

A lump sum of 100 kCHF has been tentatively allocated as no detailed estimate is available at this time.

20.3.7 DETAILED BUDGET BREAK-DOWN INSTRUMENTATION

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
DCCT head amplifier	conceptual study	10	10	-10	1 (specify)	3 m
	prototype and tests					
	production					
DCCT normaliser module	modifictation	2	2	0		
BT.MTV10i+s, BT.MTV20	mechanical study	50	50	0	2 (specify)	2 w
	tank production	5	5	0		1 m
	mounting				1 (specify)	1 m
	installation				2 (specify)	1 w

20.3.8 DETAILED BUDGET BREAK-DOWN COMMISSIONING AND OPERATION

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
general budget		50	50	0	2 engineers	8 months
					2 technicians	8 months

Remarks:

A budget of 50 kCHF has been tentatively allocated.

20.3.9 DETAILED BUDGET BREAK-DOWN EXTRACTION, TRANSFER, PS INJECTION

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
KFA14	new KFA14	1067	1067	0	2.3 my	33 m

	spare	357	357	-150	2 my	12 m
KFA10	ferrite replacement	135	135	0	1.7 my	20 m
	full spare	635	635	-400	1.6 my	12 m
BT.SMV10 and SMV20 modification	septa modification	563	563	0	0.8 my	30 m
	one spare per septum	281	281	0	0.4 my	30 m
BE.SMH modification		60	60	0	0.3 my	6 m
PS injection septum	PS injection septum plus spare	487	487	0	1.5 my	30 m
	additional spare	244	244	0	0.8 my	30 m
PS septum bumper		84	84	0	0.4 my	12 m
additional PS injection kicker	kicker	1150	1150	0	2 my	36 m
	spare	700	700	0	1.7 my	12 m

Remarks:

Some items covered by consolidation.

Spares included.

PS injection details under study.

20.3.10 DETAILED BUDGET BREAK-DOWN CONTROLS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
synthetic Btrain	material	20	20	0		
	installation	5	5	0	FSU	2 w

infrastructure for EPC	2 gateway, WorldFip control	9	9	0	FSU	2 w
infrastructure for magnets						
infrastructure for rf						
infrastructure for beam intercepting devices						
infrastructure for vacuum		0	0	0		
infrastructure for instrumentation		0	0	0		
infrastructure for OP	OASIS	100	100	0		8 w
infrastructure for extraction, transfer, PS injection						

Remarks:

The various equipment groups are in the process of defining their controls needs.

20.3.11 DETAILED BUDGET BREAK-DOWN ELECTRICAL SYSTEMS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
dismantling		50	50	0	1 (specify)	6 m
upgrade high voltage	HV switchboard	450	450	0		

	HV protection	150	150	0		
	HV/BT cabling	100	100	0		
upgrade low voltage	LV switchboard	450	450	0	1 (specify)	12 m
	transformer	150	150	0		
	HV/BT cabling	200	200	0		

20.3.12 DETAILED BUDGET BREAK-DOWN COOLING AND VENTILATION

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
cooling	design	2000	2000	-1000	0.3 FTE engineer	6 m
					0.3 FTE draftsman	

	tendering				0.2 FTE engineer	6 m
	details and procurement				0.3 FTE engineer	2 m
					0.5 FTE draftsman	
	installation				0.3 FTE engineer	7 m
					0.5 FTE draftsman	
					0.6 FTE work supervision	
	commissioning				0.3 FTE engineer	2 w
					0.6 FTE work supervision	
ventilation	design	3500	3500	-3500	0.4 FTE engineer	6 m
					0.5 FTE draftsman	
	tendering				0.2 FTE engineer	6 m
	details and procurement				0.3 FTE engineer	2 m
					0.5 FTE draftsman	
	installation				0.3 FTE engineer	7 m
					0.5 FTE draftsman	
					0.6 FTE work supervision	
	commissioning				0.3 FTE engineer	2 w
					0.6 FTE work supervision	

20.3.13 DETAILED BUDGET BREAK-DOWN RADIOLOGICAL PROTECTION

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
study of radiation effects	activation, stray radiation	0	0	0		3 m
dose plan-	before up-	0	0	0		

ning and optimisation	grade work in PSB tunnel and TLs					

Remarks:

No cost expected.

20.3.14 DETAILED BUDGET BREAK-DOWN TRANSPORT AND HANDLING

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
lift AS045		200	200	-200	0.2 (specify)	6 w
transfer tables CH066 and CH067		50	50	-50	0.2 (specify)	1 w
cranes PR134, 135, 136, 137 (10t)		120	120	-120	0.2 (specify)	2 w per crane
crane PR 138 (20t)		30	30	-30	0.1 (specify)	2 w
transport and handling studies		30	30	0	0.1 (specify)	
transport and handling services		100	100	0	0.2 (specify)	
auxiliary handling equipment		50	50	0		
contingency		100	100	0		

20.3.15 DETAILED BUDGET BREAK-DOWN SURVEY

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
general budget		50	50	0		

Remarks:

A budget of 50 kCHF has been tentatively allocated.

20.3.16 COST AND MANPOWER ESTIMATE SUMMARY

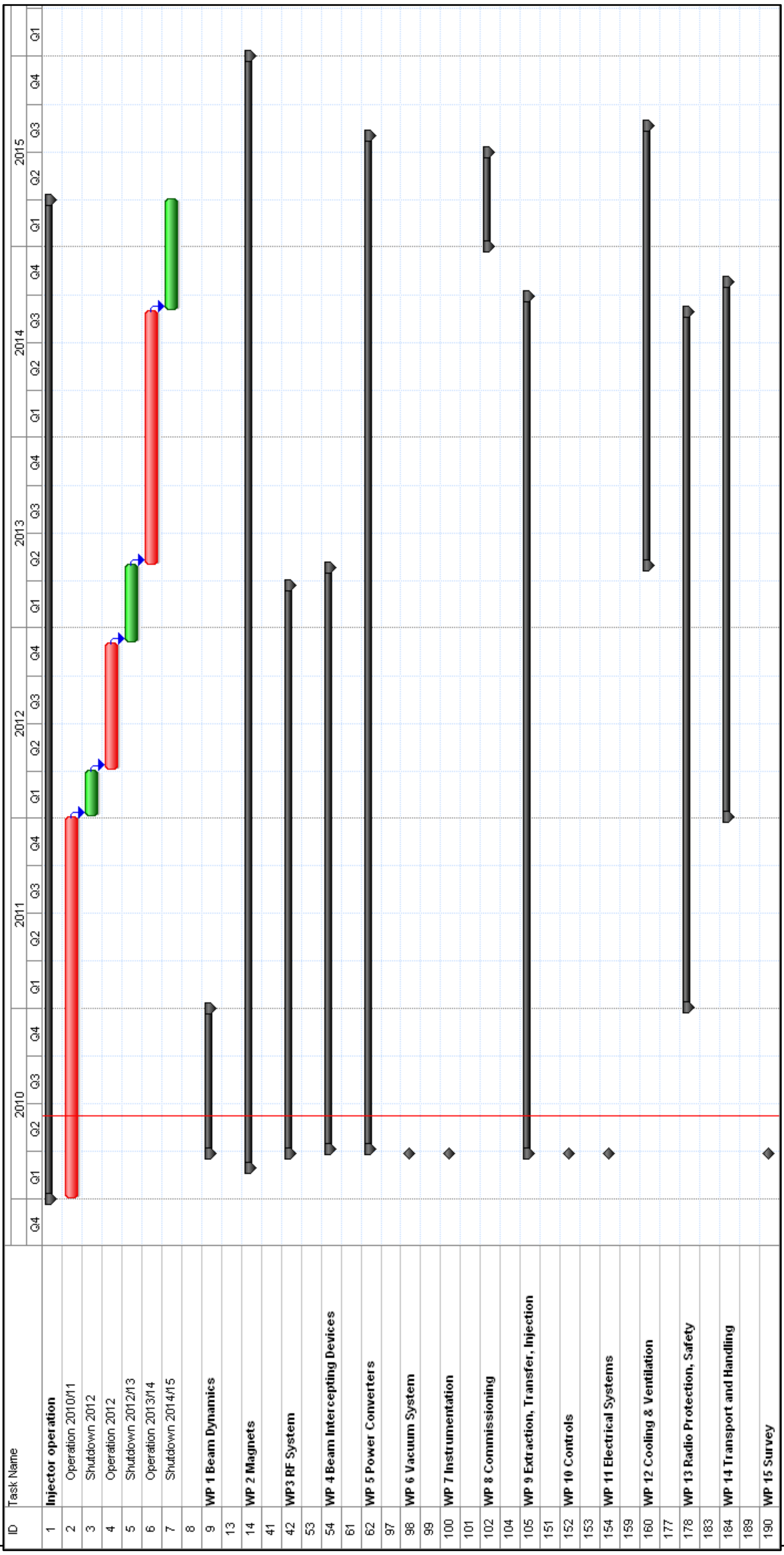
all units kCHF	rms current comparable to present (baseline)		rms current increased wrt present	
	all beams at 2 GeV	LHC beams	all beams at 2 GeV	LHC beams at 2 GeV

	(baseline)	at 2 GeV	(baseline)	only
Beam Dynamics	**50**	50	50	50
Magnets	**3120**	3270	3525	3675
RF	**2075**	2075	2075	2075
Beam Intercepting Devices	**700**	700	700	700
Power Converters	**20850**	21100	20850	21100
Vacuum system	**100**	100	100	100
Beam Instrumentation	**67**	67	67	67
Commissioning and Operation	**50**	50	50	50
Extraction, Transfer, PS Injection	**5763**	5763	5763	5763
Controls	**134**	134	134	134
Electrical Systems	**1550**	1550	1550	1550
Cooling and Ventilation	**5500**	5500	5500	5500
Radiological Protection	**0**	0	0	0
Transport and Handling	**680**	680	680	680
Survey	**50**	50	50	50
Total	**40689**	**41089**	**41094**	**41494**
covered by consolidation	15235		13000	
after correction for consolidation	**25454**	25854	28094	28494

20.4 TIME LINES

Below we give the preliminary project planning in a summary graph. Behind this summary there is a detailed break-down for each work unit. The planning is assuming a project start in 2010, and assumes the injector shutdowns given in the first line of the figure (green bars).

According to this planning the earliest possible date to commission the Booster with 2 GeV is in 2015. As presently some work units overrun the assumed 2014/15 shutdown, the planning must be tightened but most probably also the duration of the 2014/15 shutdown must be revisited.


ID
Task Name
1 Injector operation
2 Operation 2010/11
3 Shutdown 2012
4 Operation 2012
5 Shutdown 2012/13
6 Operation 2013/14
7 Shutdown 2014/15
8
9 WP 1 Beam Dynamics
13
14 WP 2 Magnets
41
42 WP3 RF System
53
54 WP 4 Beam Intercepting Devices
61
62 WP 5 Power Converters
97
98 WP 6 Vacuum System
99
100 WP 7 Instrumentation
101
102 WP 8 Commissioning
104
105 WP 9 Extraction, Transfer, Injection
151
152 WP 10 Controls
153
154 WP 11 Electrical Systems
159
160 WP 12 Cooling & Ventilation
177
178 WP 13 Radio Protection, Safety
183
184 WP 14 Transport and Handling
189
190 WP 15 Survey
2010
2011
2012
2013
2014
2015
Q4
Q1
Q2
Q3
Q4