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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 (kinetic) beam energy of the CERN PS Booster (PSB, Booster) from presently 1.4 GeV to about 2.0 GeV. The aim of this is to overcome bottlenecks in the LHC injector chain for high-brightness LHC beams. The motivation for this upgrade as well as a preliminary list of possible issues is given in [2]. 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 design 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 within the 1.2 s cycle, 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 margin for operation at higher energies and must be replaced anyway.
- For the beams delivered to the PS we have studied the following scenarios (ISOLDE beams remain at the present 1.0/1.4 GeV in all scenarios):

	Beam Energy to PS		ppm mode for	
Scenario	LHC Beams	non-LHC Beams	PSB Extraction	BTP Line
1	2.0 GeV	2.0 GeV	yes	no
2	2.0 GeV	1.4 GeV	yes	yes
3	2.0 GeV	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.

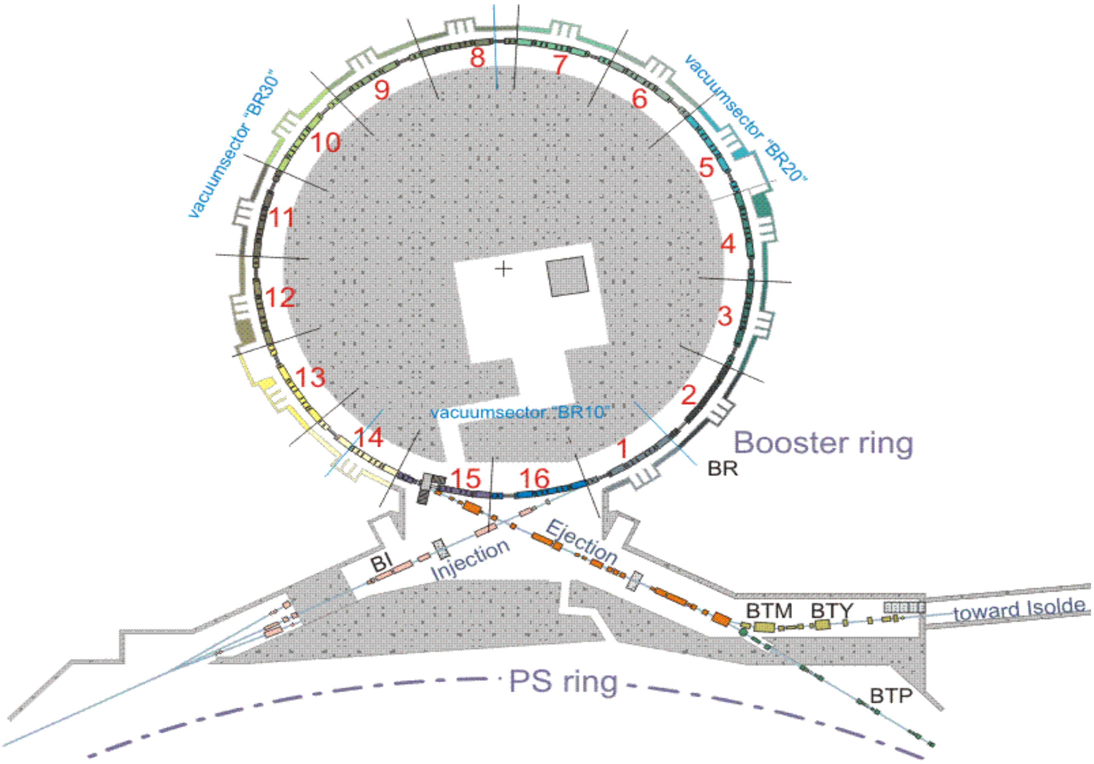


Figure 1: PS Booster and its transfer lines.

2. SUMMARY AND RECOMMENDATIONS

We have confirmed the arguments presented at the 2010 Chamonix workshop [1] and, although the figures are optimistic (theoretical upper limit assuming no beam loss and other imperfections), it is generally accepted that an increased injection energy into the PS will facilitate extraction of the higher intensities produced in the PSB with Linac4 to the PS. However, potential beam dynamics effects in the PS might limit the expected gain and are discussed in section 3 (Beam Dynamics). MDs carried out so far have given encouraging results, and further MD studies are in progress.

We have done a complete 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 solutions, 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 54 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 hardware modifications). This is because at the time of writing this first report 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 27 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 2016 assuming the shut-down periods as defined in [3]. 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.

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 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 reduction 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 sufficient time for 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. 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.

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 at this point in time. 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 then 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 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. The momentum spread at PSB 2 GeV top energy and extraction could be slightly larger than at 1.4 GeV (for constant longitudinal emittance, but it could be even larger for scenarios with larger longitudinal emittance), but this should not pose aperture problems in the PSB or in the transfer line to the PS, because the effect in the horizontal beam size is outdone by the higher energy and lower physical emittance.

In general, the increase of the PSB extraction energy to 2 GeV will allow sending beams to the PS with 1.86 times the present intensity and the same space charge tune shifts at the PS injection (assuming the same normalised transverse emittances and bunch length). If the bunch length remained unchanged at the PS injection and if the only PS limitation were space charge at injection, the upgrade of the PSB extraction energy to 2 GeV (combined with the intensity increase that will be made possible by the injection into the PSB at 160MeV from the Linac4) would trivially translate into the feasibility of almost double intensity beams with respect to those presently produced. However, an h1 bunch (like the LHC25 in double batch transfer) could shorten by a factor 1.33 at 2 GeV for constant longitudinal emittance of 1.3 eVs and constant 8kV up to flat top, which would limit the space charge intensity gain to a factor 1.43 instead of 1.86. It is sensible to assume that this factor will be improved by injecting into the PS beams with a larger longitudinal emittance: for example, with a 50% larger longitudinal emittance (2.0 eVs), possible thanks to the 50% larger bucket area at the PS injection, the bunch shortening factor could be decreased to 1.07, which would result into a potential intensity increase by a factor 1.74. Besides, considering in particular the LHC beams, for the PS to be able to digest an LHC25 beam at 2 GeV with theoretically 1.43 times to twice the present intensity, a few more issues than space charge alone must be looked into in detail:

1. Resistive wall head-tail instabilities at flat bottom, which could become up to 50% faster than presently. This has already been observed with the nominal 25 ns beam. 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:

- Concerning the longitudinal bunch characteristics at the PSB extraction/PS injection, a study with different scenarios for the possible longitudinal beam parameters/RF settings needs to be undertaken in order to assess a realistic figure for the attainable space charge gain factor.
- 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 [4].
- Point 3) is already listed as a subject with high priority among the RF MDs proposed in the 2010.

- We have written and submitted an MD proposal to carry out a detailed study of point 4). The goal of the MD 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 increased.
- 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 1σ normalised, both planes) 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

The most important machine studies to be done at the PSB/PS to investigate on the possibility of producing higher intensity LHC25 beams are:

1. Generate an LHC25 beam up to the highest intensity in the PSB (within the longitudinal specifications requested by the PS and with loosened transverse constraints) and send it to the PS. This has been done (dedicated MD block of Week 22) and the beam injected into the PS with transverse emittances of ~4μm per plane (1σ normalised) was also transferred to the SPS with the nominal longitudinal parameters and slightly blown up transverse emittances (5μm per plane, 1σ normalised). The blow up seems to happen at transition. Results of this long MD have been summarized in the MSWG meeting on 18.06.2010.
2. MD proposals to study the longitudinal coupled bunch instabilities with LHC25 beams in the PS were already submitted by the PS RF team (H. Damerau, S. Hancock)
3. Summary of the new proposal for an MD to 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. Its correlation with electron cloud in the PS should be also pinned down.

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 current configuration of the cooling circuits is not adequate for operation at 2 GeV if there is an increase in RMS current with the new magnetic cycle. The extent of the modifications to the cooling parameters is dependent on the increase; two scenarios are explored, less than 10% and from 10 - 30% increase from the 1.4 GeV operational values. Different scenarios of the magnetic cycle are being explored by other members of the working group.
- A concern over the life span of the magnets at 2 GeV operations has been raised with respect to the forces acting on the coils with the increased field.
- It has been seen through previous testing with faster cycling that the damping resistors placed in parallel with the main units reach unacceptable temperatures. If a faster magnetic cycle is used for 2 GeV operations then these resistors will need to be upgraded. A more detailed study and tests will need to be carried out to confirm the characteristics of new resistors; this will not be considered further as part of this document.
- During previous tests in the machine the reference bending magnet used for the B-train has been found to be one of the weakest links when considering the coil insulation. This magnet was built as the proto-type for the ring magnets. Although no further consideration will be given in the context of this document, all modifications detailed for the ring magnets apply as a minimum modification to this magnet. At most either through consolidation or for purposes of the upgrade the change of the coils may be recommended.
- Bus bars (water cooled cables) – The design for water cooled cables for the PSB was taken from the ISR machine and are over specified for today's operation. Through measurements with today's cooling parameters there will be little risk for operation at 2 GeV even with a 30% increase in RMS current. It is known that there are no identical replacements for these cables; however, if a breakdown occurred which cannot be repaired, solid cables could be used as an immediate repair solution. These cables are not under the responsibility of the magnet group and will not be considered further in this section of this document.
- The main bending magnets weigh 12.7 T, it is understood that the crane capacity in the machine is only 10 T. Further study must be made to understand how the magnets were placed in the machine, and what will need to be done in the future in case the magnets need to be removed.

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 remaining magnets are used at ejection energy and are detailed in the 'Extraction, Transfer, PS Injection' section of this document.

Transfer line magnets

- Initial study shows that the up to 40 % of the transfer line magnets may not be appropriate for 2 GeV operations. This can only be confirmed when a complete study has been made for the optics, and different possibilities for the powering of the magnets.
- The magnet BT.BHZ.10 is currently being consolidated with a planned new spare to be built. The current design for the magnet is not compatible for 2 GeV operations. Studies are being carried out for an interim solution in case of a breakdown of the current magnet until a firm design for 2 GeV operation can be put in place.

Study is still ongoing.

PS Injection Bumpers, Low Energy Correctors and Quadrupole Magnets

- Operation at 2 GeV goes beyond the original specification for two out of the four PS Injection Bumpers. Further study is needed to see if the magnets can be upgraded or will need to be replaced with new units.
- Initial study shows that the Low Energy Correctors both horizontal (50 x Back Leg Winding, BWL on main units) and vertical (20 magnets) may not be adequate for 2 GeV operations. For the horizontal correctors 'real magnets' may be available to replace the BWL. For the vertical correctors further modeling and study is required to see if the magnets can be upgraded. However, new designs may need to be put in place.
- There are two types of Low Energy quadrupole magnets in the PS machine, 40 normal quadrupole magnets and 40 skewed versions. Initial studies by BE/ABP suggest that the function of the normal quadrupole magnets could be replaced by the existing Pole Face Windings (PFW) or Figure of eight winding (F8L) on the PS main units, an MD is planned. For the skewed quadrupole magnets it has been seen that there is adequate margin to allow the use of these magnets at 2 GeV operations.

4.1.1 CRITICAL ISSUES AND PROPOSED CURES

Main unit cooling

Scenario: < 10% increase of RMS current but increased voltage due to faster cycle possible with POPS

An increase of the RMS current by 10% is the limit where no major modifications to the cooling circuits are needed.

Due to the higher voltage generated by a shorter ramp it would be beneficial to divide the machine into two. For example, with a new POPS-type power supply (see section "Power Converters"), it would become possible to power independently the bending magnets rings 1 & 4 with focusing quadrupoles, and the bending magnets rings 2 & 3 with de-focusing quadrupoles. With this configuration the induced and resistive voltage would be halved and below 1.4 GeV values. This configuration has the added value that the trim power supply on the bending magnets rings 1 & 4 would be no longer needed. The whole machine is currently connected in series.

Scenario: Between 10 and 30% increase of RMS current (30% increase reflects a scale of 1.4 to 2 GeV operation for the current magnet cycle)

The current magnet cooling parameters for the main units are not adequate. Initial calculations suggest that with no modifications, the pressure and flow must be almost doubled to maintain the same operational temperature of the magnets to that seen at 1.4 GeV operations. 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.

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 30 normal 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. The two special injection and extraction bending magnets already have all coils connected in parallel thus the same approach as the 'normal' magnets cannot be taken. For these two magnets an increase of inlet pressure / flow rate or a new coil design would be the minimum solution but new magnets may also have to be considered.

For the main quadrupole magnets, one 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 / semi rigid system. It may be possible to perform this action in the machine without removing the magnets. Alternatively, a similar modification to that of the main bending magnets could be made where cooling circuits would be split into parallel circuits, therefore allowing the pressure drop to remain within reasonable limits with an increased of flow.

For both main bending and quadrupole magnets further study and trials would be needed to determine the most suitable action to take.

Life span concerns

A concern has been raised over the ability of the bending magnets to withstand the increase of force 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. During the first measurements on a spare magnet to confirm calculations, it was seen that the original method for shimming the coils is indeed a concern. Modifications to the method of how the coils are shimmed including increasing the surface area and the material of the shims are being trialled.

4.1.2 FURTHER STUDIES NEEDED

Main unit cooling – When the magnetic cycle has been defined further studies will continue.

Life span concerns – Testing at the nominal current and upgrade current has been completed in b.867 leading to modifications of the coil shimming method as described, while the test at two times the upgrade current can only be completed in SM18 due to the availability of a suitable power supply. In SM18 several thousand cycles will be performed to prove the robustness of the assembly, these tests are ongoing and at the time of writing several hundred cycles have been successfully completed.

Transfer line magnets – detailed models and measurements for each magnet must be completed.

PS Injection Bumpers, Low Energy Correctors and Quadrupoles – detailed models and measurements for each magnet must be completed.

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 (see Magnetic Measurement section of this document).

4.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

The magnet cycles and parameters need to be determined for all magnets in the ring and transfer lines.

4.2 TECHNICAL DESCRIPTION

Main Units

Main normal bending magnet cooling circuits

An increase of the RMS current of up to 10% would only dictate minor modifications of the cooling circuits without the need to remove the magnets from the machine. It has been seen through calculation and measurements that the original flow switches installed on the magnets for 800 MeV operations are not suitably sized for operation at 1.4 or 2 GeV operations when considering the needed flow rate. Due to this miss-sizing of the flow switches there is an unnecessary pressure drop on the circuit. Re-sizing these flow switches or completely eliminating them from the circuit will increase the flow rate on the magnets for the same total pressure drop. This increase in flow will allow for an additional 10% in RMS current with almost no increase in temperature or pressure.

An increase of RMS current above 10% and up to 30% would dictate that each bending magnet has to be removed from the machine for the cooling circuits to be modified. This would involve replacing the series connection between pairs of coils for each aperture with a parallel connection. This modification would allow an increase of flow by 300% for the same pressure drop with a greatly reduced operational temperature; it would therefore be possible to reduce the pressure drop to arrive at a similar temperature rise. The modification to each of the magnets is estimated to take around one week. When considering the dose rate of the magnets and technical difficulty of the modifications it would be necessary to remove the magnets from the machine.

Main ‘special’ bending magnet cooling circuits

An increase of the RMS current above 10 % will dictate either an increase of pressure / flow, or a new coil design as the cooling circuits are already split into parallel circuits. An increase in pressure / flow would dictate a special cooling installation and modifications of the flexible parts of the cooling circuit to a rigid / semi-rigid system. New coils could be envisaged with an increased number of cooling circuits.

Main quadrupole magnet cooling circuits

As for the bending magnets two scenarios are considered. When considering an increase of up to 10% RMS current the solution is as per the ‘normal’ bending magnets. For an increase of between 10 % and 30 % two possibilities are available; the increase of the inlet pressure / flow rate to allow for the same operational temperature; an increase of pressure would dictate that the cooling circuits are modified to a rigid/semi-rigid system (also recommended for consolidation). The alternative solution is to modify the cooling circuits introducing parallel circuits to allow an increase of flow for a similar pressure drop as per the bending magnets, again this solution may dictate that the magnets are removed from the machine.

Main Bending magnet coil shimming

As previously explained the current shimming method for the magnets is a concern for operation a 2 GeV. The force of the coil on the retaining plate will increase from approx. 32 kN to 55 kN. Although the absolute increase is still within the capabilities of the mica resin insulation for the intended contact surface, it has been found through testing that the method of shimming allows contact between the coil and retaining plate by around 10 %, thus substantially increasing the pressure on the insulation. To continue the testing in SM18 at nearly two times the upgrade current modifications are being trialled where the contact surface, method of shimming and material has been modified. When the endurance testing in SM18 has been proved, further studies will be needed to establish if it will be possible to complete the modifications in the machine without removing the magnets.

Main bending magnet saturation – The bending magnets have already entered into saturation for the outer rings at 1.4 GeV operations. This effect is compensated with a 30 A 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 A will be required. Dividing the circuit in two as suggested (see "Power Converters") would remove the need for this supply as the two circuits 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 required modifications to the magnet coil shimming.

It is envisaged that the work listed above given adequate resources could be completed during the next two long shutdowns. It may be possible to make some of the listed modifications to the main magnets 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

With the currently provided information from the operation group it will not be necessary to replace any of the auxiliary magnets as they are mainly used at low injection energy. Through the study for this working group, it has been found that with the previous upgrades of the PSB, little consideration has been made to the amount of cooling water that these magnets consume. Initial studies show that the magnets are operated at a fraction of their intended design current, while the cooling parameters have been increased with each energy upgrade. When considering the cooling and ventilation section of this document flow restriction valves could be considered.

Study is still to be completed.

Transfer line magnets

From the original specifications it has been found that around 40 % of the transfer line magnets (14 to 18 magnets) from the PSB to the PS will not be able to operate at 2 GeV energy. For many of these magnets it has to be seen if they can be powered in a different manner (D.C. to cycled) without a huge impact to the cost of the connected power convertor. Magnetic measurements will also be required for many of the magnets to confirm their suitability. The quadrupole magnets in the BTP line are of a solid yoke construction and cannot be operated in P.P.M. (Pulse to Pulse Mode operation), if this operation is required a similar laminated magnet built in 1996 to replace the same type of magnet could be copied as a replacement. The coils for these magnets are already being consolidated in the Linac4 LBE line. If the BTP line magnets are replaced money could be saved on the Linac4 magnets for which the project has not yet started.

A special case the BT.BHZ10 switching magnet has already been identified for consolidation with no spare magnets and only one spare coil. This magnet will not be able to operate at 2 GeV. Consideration must be made to design a new magnet with respect to the either existing power convertor (in need of consolidation) or the possibility of changing the layout of the transfer line (possible change of the PS injection).

Study is still to be completed.

PS Injection Bumpers, Low Energy Correctors and Quadrupole Magnets

Two out of the four PS Injection Bumpers will need to be operated above their original nominal current of 4500 A when considering 2 GeV operations with a 10% margin.

The low energy normal quadrupole magnets are being operated at a limiting current of 5 A at 1.4 GeV. A machine development will help evaluating if the “Pole Face Windings” together with the “Figure of Eight Windings” held in the main magnets can be used instead. In this case, the low energy normal quadrupole Magnets will simply be switched off and the two windings will be operated thanks to the five new independent power converters used since 2008. In case of a negative conclusion, a new magnet design will be considered [5].

The low energy skew Quadrupole magnets have a margin of operation which may allow the upgrade without any changes.

The Low Energy Horizontal correctors called “Back Leg Windings” have a limitation on the power supplies already saturating at 10 A with the actual 1.4 GeV beam. A study will be done to evaluate the installation of several available auxiliary magnets to be installed in the straight sections of the PS ring together with dedicated power supplies. In this case, the actual “Back Leg Windings” will be switched off and the operation will be ensured by the magnets. The alternative solution will be to either replace the actual power supplies and/or increase the number of turns of the BLW cables held in the main magnets [6].

The low energy vertical correctors have a 3.5 mT.m integrated field at 10 A corresponding to a temperature increase of 41°C which is already at the maximum allowable limit [7].

Further studies and magnetic measurements must be completed to verify if the limitations are with the magnetic field or cooling capabilities for all magnet type.

5. MAGNETIC MEASUREMENTS

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

- Magnetic measurement of main dipoles and quadrupoles: the instrumentation currently available (i.e. straight flux coils) is suitable for the measurement of relative integral field (BdL) and eddy current transients in main dipoles and quadrupoles at various current levels.
- If needed, the measurement of field harmonics would require the development of an ad-hoc multi-coil fluxmeter system (straight and/or curved).
- Magnetic measurement of auxiliary ring and transfer line magnets: in all likelihood, these magnets can be measured with existing rotating coil equipment, namely various kinds of “moles” developed for the LHC (to be confirmed when the list of magnets to be fabricated or refurbished shall be made available).
- On-line magnetic measurement equipment for the B-train: the whole system, including dynamic NMR field marker, flux coils, ADC-based integrator and output channel bandwidth is currently designed for a nominal current ramp rate of about 10 kA/s in the main dipoles. At present, it is not clear whether the system can operate reliably or even at all at 20 to 30 kA/s.

The results from the first test campaign on a spare main dipole indicate a drop of BdL due to saturation of about 6% at 6 kA. The exponential transient due to eddy currents observed in the outer aperture has a time constant between 50 and 30 ms (decreasing at higher field) and a peak amplitude of about 5% of the flat-top value at 20 kA/s

5.1.1 CRITICAL ISSUES AND PROPOSED CURES

No showstoppers identified. The only two potentially critical issues are the following:

- Measurement of field quality in the main dipoles and quadrupoles: a dedicated instrument has to be developed.
- B-train system: the compatibility of the existing system with the new proposed cycling, including the effects of larger eddy currents etc, has to be assessed in detail. We note that, in the framework of the consolidation of all B-trains in operation at CERN, R&D activities towards a new acquisition system are currently underway. Enhanced specifications linked to the upgrade project can in principle be accommodated in the new system.

On a side note, we recall that the only one power converter (i.e. the Holec converter in 867-RH-29) is currently available at CERN to test a PSB main dipole close to the upgraded operating conditions. Since this unit is rather old and very difficult to repair, alternative solutions to guarantee reliability should be considered (e.g. refurbishing an old converter used for magnet heating tests in bldg. 151).

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 4.1.2): 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 and stability at the end of ramp-up.

5.2 TECHNICAL DESCRIPTION

Besides the activities described in 5.1.2, 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 under point 5.1, 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:

- Load line (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 expected.

• 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 of 5E9-1.4E13 per ring, H=1 or H=2, 8kV peak RF voltage from 160 MeV-2 GeV in a 1.2s cycle.

- PSB Low Level Beam Control

  If present consolidation program is respected, the required changes can be included for the 2 GeV cycle. Study is underway by M.E.Angoletta & A.Blas.
- PSB High Level Cavities and Control

  <u>C02 and C04 RF system:</u>
  Provided the 25 years consolidation program is implemented, no problems are expected to cover the new frequency range, digest the additional beam current and supply the increased power.
  <u>C16 RF system:</u>
- The frequency range is limited to ~16 MHz but no problems are expected from this limitation.

- 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

Assuming the cycle with minor cooling modifications on the bending magnets and the existing RF High Level setup (with consolidation) is the cycle adopted, the RF High Level will cope with the estimated maximum of 1.4E13 protons per ring. If this cycle is changed for faster cycling or higher intensity, significant modifications of the High Level systems could be required.

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 should be defined which includes acceleration, Bdot & extraction flat top length.
- Since the PSB LL RF system is a single set of hardware, any changes in the hardware must take into consideration all required cycles from the PSB, so the cycles for all beams need to be defined.

6.2 TECHNICAL DESCRIPTION

All covered within the consolidation project.

The cost estimate given in the appendix of this document assumes that all work required for the energy upgrade will be covered by the 25 years consolidation program. It must be stressed that it is a necessary condition for the energy upgrade to work that the RF consolidation program is done in its completeness and within the time frame of this project.

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. It is to be confirmed whether the present position would be sufficient 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 (Linac4) 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 optics have been considered. The cycle period is 1.2 s.

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

Booster Ring:
- The existing main power supply cannot 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.
- Dipole correctors and multipoles converters are mainly used at low energy and have enough margin. They will be consolidated during the shutdown 2011-2012.
- The Qstrips are only used at injection. Any upgrade would be part of the Linac4 project and not of the Booster energy upgrade.
- BDLs are used at ejection but have enough margin.
- The DBS are dedicated to destructive beam measurement and will probably not be used at 2 GeV.
- The shavers are only used at injection. Any upgrade would be part of the Linac4 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 2 GeV 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 2 GeV operation.
- Quadrupoles supplies on the BT line can handle the additional current at 2 GeV, but will have to be replaced in order to allow ppm operation between 1 GeV 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 2 GeV operation or not able to guarantee ppm operation between 1 GeV Isolde and 2 GeV 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 700 A/700 V bending supplies.
- 1 new 400 A/300 V bending supply.
- 9 (+1spare) new 400 A/150 V bending supplies.

PS Injection and Ring:

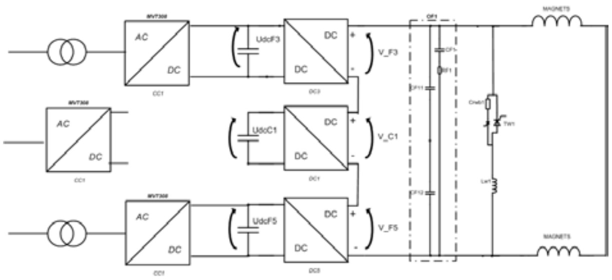
- 2 New PI.SMH42.
- 160 New 20A/50 V power supplies for PR.DVTs, DHZs, QFNs, QDNs and QSKs.

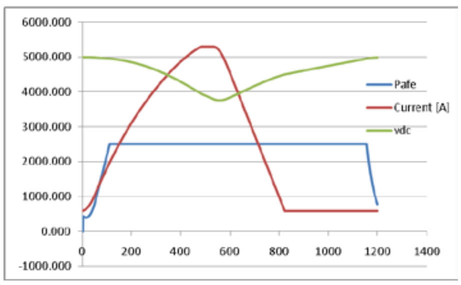
Ring MPS:

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 electrical 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:

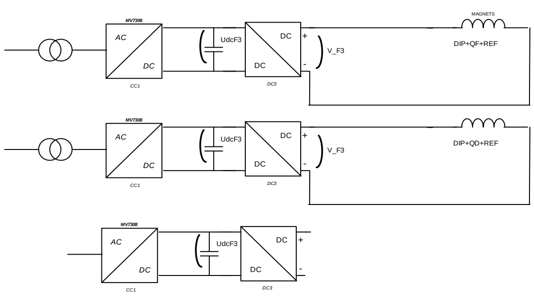


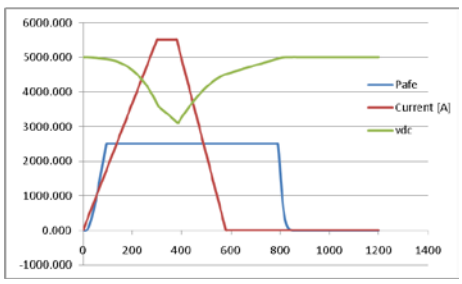


  - 1 new 6000 A/4000 V main supply.
  - 1 (+1spare) new 300 A/2000 V dipole trim.
  - 2 (+1spare) new 400 A/700 V quadrupoles trims.

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 program.
- DC current transformers:
  - for high β : 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 program.
- BT.MTV10i+s, BT.MTV20: two 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

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10.3 TECHNICAL DESCRIPTION

Ring pick-ups
Replace the Booster orbit measurement system by a trajectory measurement system similar to that 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 ones, is going to be produced and tested this year. Their integration in the transfer line is also included in the package.
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 (3 man.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. During this intervention the screens are not moved.

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.

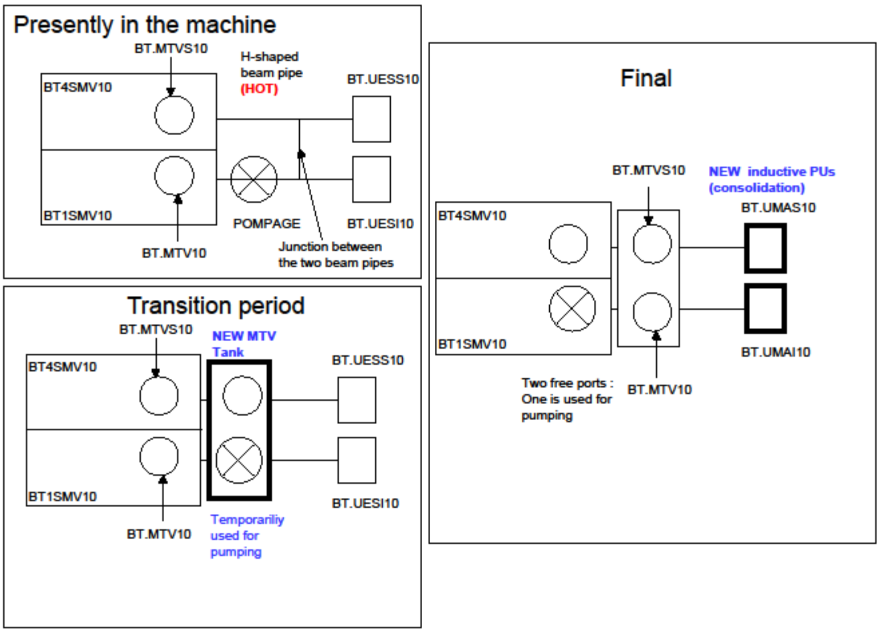

Figure 2: BT.MTV20 is housed in the BT.SMV20 tank. A new separated vacuum vessel for the screen will be built and placed downstream of the septum.

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 11.2.1) 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 – as not yet fixed – not 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 11.2.1).

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 11.2.2).

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, "Power Converters"]) as well as the main bending magnet parameters (L=0.18 H, R=0.5 Ω [A.Newborough, "Magnets"]) 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)

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

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 quantified. The tune spread resulting from incoherent space charge will lead to a certain percentage of losses mainly at injection. With Linac2, these losses amount almost up to 30% for the most intense beams, but this number will be significantly lower with Linac4.

Six 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 maximum beam current per ring for LHC beams corresponds to **3.25E12 p** (see appendix). With a bucket area defined by the maximum cavity voltage of 8 kV minus the reduction due to space charge, an 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).

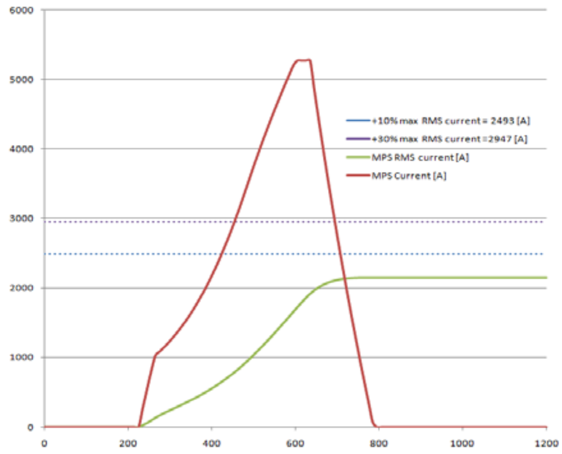

Figure 3: Proposed magnetic cycle for LHC beams at 2 GeV with a max. intensity of 3.25E12 p per ring. RF limitations are respected, and the MPS rms current would not exceed present values.

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 (plus modifications of the Meyrin electrical network).

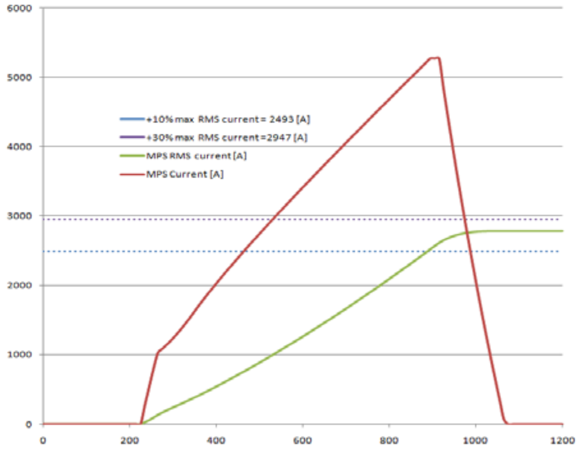

Figure 4: Fastest magnetic cycle for 2E13 p per ring with the present rf power setup. The MPS rms current would increase by 20%, and the cycle length would have to be extended by 115 ms.

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.

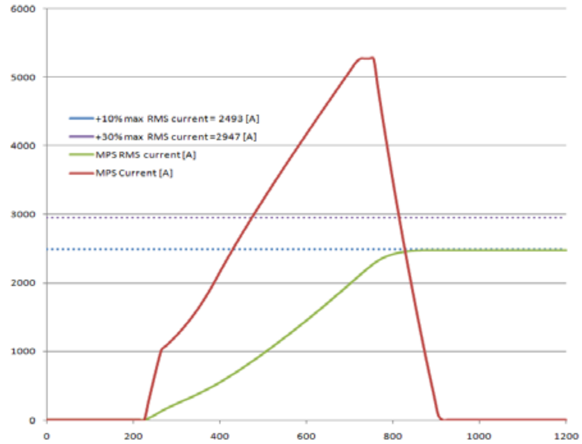

Figure 5: Magnetic cycle with the present rf power setup and PSB accelerating cycle length, not exceeding the 10% MPS rms current increase. The corresponding intensity limit would be 1.4E13 p per ring.

11.2.1.5 BEAM INTENSITY LIMIT WITHOUT MODIFICATIONS AND WITH THE EXISTING RF POWER SETUP

If one would like to avoid even minor modifications to the main magnet cooling system and respect the existing RF power limits, the maximum beam intensity per ring reduces to from 1.4E13 p to **1.05E13 p**, which corresponds approximately to the maximum ring intensity currently available with Linac2 for the ISOLDE beams.

11.2.1.6 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 of finding 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	LHC25B	ISO	LHC25A	LHC25B	ISO	LHC25A	LHC25B	ISO	LHC25A	LHC25B	ISO	EASTB	ISO	ISO	TOF	TOF	ISO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	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}																	

Figure 6: Planned LHC filling supercycle (top) and modified LHC filling supercycle (bottom) for LHC beams only at 2 GeV to limit the MPS rms current current increase to 10%.

In addition, cycle 18 would also need to be a ZERO cycle if one wants to avoid modifications to two BT-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 (BT.QNO10 and BT.QNO50), and to avoid replacement of BTP-line quadrupole power converters. It is anyway still very questionable if an operational scenario could be found to allow ppm operation of the BTP line with the currently installed magnets.

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

Figure 7: Schematic overview of the weekly organisation of supercycles.

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%

Figure 8: Overview of the potential proton loss for physics users due to the special supercycle organisation to limit the MPS rms current for LHC beams only at 2 GeV.

A detailed report on this study has been published under EDMS [8].

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 GeV operation; 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 performing 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 accommodate 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 flat top.

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 recombination 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, the option of injecting into SD41 has been looked into. There is sufficient 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 horizontal beta function is large at the septum location and the consequent larger beam size will not fit easily into the horizontal 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 (e.g. 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 present tank should also be upgraded to serve as a spare which does not exist for the moment. There will be no margin.

12.2.3 BOOSTER EXTRACTION SEPTUM BE.SMH

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 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 BT1.SMV10, 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 Ω) 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 is no margin.

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.

12.2.6 BOOSTER TRANSFER KICKERS BT.KFA20.

The kicker consists of 2 delay line magnets (Z_0 = 12.5 Ω) 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 (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 is no margin.

12.2.7 PS INJECTION SEPTUM PI.SMH42

Still under study.

12.2.8 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

Therefore, an additional kicker should have a rather small deflection angle to permit the use of standard available cables. Conclusion: if the system cannot 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.

12.2.9 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 2 GeV. 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 35 ms with a frequency of 200 kHz. This fact brings the first potential showstopper as limits 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 G precision and 0.1 G 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 G with a frequency of 400 kHz. This shows the second potential showstopper in the context of controls. The maximum rate for increasing or decreasing the synthetic B-train cannot exceed 40 G/ms.

13.1.1 CRITICAL ISSUES AND PROPOSED CURES

Regarding the module GFAS no problems are expected with the proposed magnetic field.

Although the magnetic field proposed for 2 GeV fits into the limits of the current synthetic B-Train system, higher frequencies might be required making the current approach invalid. There is an ongoing project to homogenize the measurement and generation of B-Trains for all the accelerators at CERN. In this context the new system for the Booster will be addressed.

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

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

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. To be defined if further requirements are required.
- WP OP: Installations of new Oasis systems are required although still to be defined 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, PS Injection: 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 control systems.
- WP Instrumentation: No need of modifications in the control systems.
- WP Magnets: For the time being only one measurement of the B-Train in Booster is done; three more measurements might be needed to provide a complete control of the system. In any case all the requirements for the measurement and generation of the B-Train in PSB will be addressed during future discussions in the context of the consolidation plan for B-Trains.
- WP Beam Intercepting devices: 2 Gateways equipped with timing cards.

14. ELECTRICAL SYSTEMS

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

The Booster network is fed from the 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 shutdowns 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; at present no specific ventilation requirements seem to be necessary, the work on the ventilation system shall therefore consist in the refurbishment of the existing plant.

15.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Cooling powers, flow rates, max pressure, acceptable pressure drops and temperature range for water cooled systems (chilled water, raw water, demineralised water); same for compressed air and ventilation 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 details 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 Linac4.

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, and improvement of the shielding is required independently of the energy upgrade. The improved shielding should be designed such that it is sufficient to cope with high-intensity beams injected into the PS at 2 GeV.

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.

Provisional collective personal dose for modification work, based on ambient dose rate surveys and on schedules from TE/MSC, TE/ABT, TE/VSC, BE/RF and EN/CV, must be prepared during the planning stage of the upgrade interventions.

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.

TE/MSC, TE/ABT, TE/VSC, BE/RF and EN/CV: schedules of upgrade work for preparing collective personal dose estimates.

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

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

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[5] Mesures magnétiques des quadripoles d’injection, EDMS 371500.

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20. APPENDIX

20.1 BEAMS TO BE DELIVERED BY THE PSB (AFTER 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 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 emit-tance at extr. [mm mrad]	bunch length at extr. [ns]	extr. energy [GeV]
CNGS	2	1-4	0.6-8E12 + ~45% in-crease to reach target limit	hor.: ~10 vert.: ~8 ~12/7 with MTE	180	2
SFTPRO	2	1-4	<6E12 – would an in-crease 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

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

20.2 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.

20.2.1 DETAILED BUDGET BREAK-DOWN BEAM DYNAMICS

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

Remark: A budget of 50 kCHF has been tentatively allocated.

20.2.2 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	0		
	FSU	15	15	0		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	0		
	FSU	25	25	0		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	0.5	
reference magnet (if increased rms current)	material	320	320	0		
	FSU	5	5	0		2 mw
	associates					
	staff				0.2	
reference magnet (comparable rms current)	material	320	320	0		
	FSU	5	5	0		2 mw
	associates					
	staff				0.2	
auxiliary ring	material	0	0	0		

magnets	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 mag-nets re-placement	material	1000	1000	0		
	FSU	120	120	0		48 mw
	associates	130	130	0	2	
	staff	0	0	0	1.5	

Remark: 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.

20.2.3 DETAILED BUDGET BREAK-DOWN MAGNETIC MEASUREMENTS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
main MB/MQ R&D 2+1 spares	material cost	40	40	0		
	FSU	10	10	0	16 mw	8 w
main MB/MQ series test (2 kCHF/unit, 0 units)	material cost					
	FSU	0	0	0	0	0
reference MB instru-mentation	material cost	30	30	0		
B-train system	FSU	1	1	0	8 mw	8 w
aux./TL magnets series test (2 kCHF/unit, 15 units)	material cost					
	FSU	30	30	0	15 mw	15 w

20.2.4 DETAILED BUDGET BREAK-DOWN RF SYSTEM

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
high level RF						
	C04	7000	7000	-7000		
	C02	2400	2400	-2400		
	C16	2400	2400	-2400		
low level RF	C02, C04, C16	500	500	-500		
transverse damper		780	780	-780		
LL RF for transv. damper		240	240	-240		
replace all RF cables		1000	1000	-1000		

Remarks: It is a necessary condition for the energy upgrade to work that the RF consolidation program is done in its completeness and within the time frame of this project. In that case all necessary modifications are covered by consolidation and there is no additional cost for this project.

20.2.5 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 stop-per 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				technician	5 m

	new beam stopper				engineer	1 m
					FSU	6 w
	installation				technician	2 w

20.2.6 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 engineer-ing	2000	2000	0	engineer	12 m
	installation and commis-sioning	2000	2000	0	engineer	24 m
					technician	64 m
Meyrin TCR maintenance				-2000		
MPS trims	design and specification	100	100	-100	engineer	12 m
					technician	6 m
	manufacturing	400	400	-400	technician	9 m
	installation and commis-sioning	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 commis-sioning	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	20 m
	market survey				engineer	2 m
	call for tender				engineer	4 m
	manufacturing	2240	2440	-1400	technician	48 m
	installation and commis-sioning	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

20.2.7 DETAILED BUDGET BREAK-DOWN VACUUM SYSTEM

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
new BTP line		100	100	0		

Remark: Linac4 - Booster transfer/injection line: covered by Linac4 Project; Booster modifications: not known yet, needs input from other groups, but consolidation is foreseen.

20.2.8 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	3 m
	prototype and tests					
	production					
DCCT normaliser module	modifictation	2	2	0		
BT.MTV10i+s, BT.MTV20	mechanical study	50	50	0	2	2 w
	tank production	5	5	0		1 m
	mounting				1	1 m
	installation				2	1 w

20.2.9 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

Remark: A budget of 50 kCHF has been tentatively allocated.

20.2.10 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 re-placement	135	135	0	1.7 my	20 m
	full spare	635	635	-400	1.6 my	12 m
BT.SMV10 and SMV20 modification	septa modi-fication	563	563	0	0.8 my	30 m
	one spare per septum	281	281	0	0.4 my	
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	
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

Remark: PS injection details under study.

20.2.11 DETAILED BUDGET BREAK-DOWN CONTROLS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
infrastructure for EPC	2 gateway, WorldFip control	9	9	0	FSU	2 w
infrastructure for magnets						
infrastructure for rf						
infrastructure for beam intercepting devices	2 gateway, timing	7	7	0	FSU	2 w
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						

Remark: Infrastructure for extraction, transfer, PS injection needs further study.

20.2.12 DETAILED BUDGET BREAK-DOWN ELECTRICAL SYSTEMS

item	subitem	budget [kCHF]			manpower	duration
		all beams	LHC beams only	consolidation		
dismantling		50	50	0		
upgrade high voltage	HV switchboard	450	450	0	1	6 m
	HV protection	150	150	0		
	HV cable	150	150	0		
	HV/BT cabling	100	100	0		
upgrade low voltage	LV switchboard	450	450	0	1	12 m
	transformer	150	150	0		
	HV/BT cabling	200	200	0		

20.2.13 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	

20.2.14 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 planning and optimisation	before upgrade work in PSB tunnel and TLs	0	0	0		

Remark: No cost expected.

20.2.15 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	6 w
transfer tables CH066 and CH067		50	50	-50	0.2	1 w
cranes PR134, 135, 136, 137 (10t)		120	120	-120	0.2	2 w per crane
crane PR 138 (20t)		30	30	-30	0.1	2 w
transport and handling studies		30	30	0	0.1	
transport and handling services		100	100	0	0.2	
auxiliary handling equipment		50	50	0		
contingency		100	100	0		

20.2.16 DETAILED BUDGET BREAK-DOWN SURVEY

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

Remark: A budget of 50 kCHF has been tentatively allocated.

20.2.17 BUDGET ESTIMATE SUMMARY

	all units kCHF		
	all beams at 2 GeV (baseline)	only LHC beams at 2 GeV	from con-solidation budget
Beam Dynamics	50	50	0
Magnets	3445	3595	-210
Magnetic Measurements	111	111	0
RF	14320	14320	-14320
Beam Intercepting Devices	700	700	-700
Power Converters	20850	21100	-6630
Vacuum system	100	100	0
Beam Instrumentation	67	67	-10
Commissioning and Operation	50	50	0
Extraction, Transfer, PS Injection	5763	5763	-550
Controls	116	116	0
Electrical Systems	1700	1700	0
Cooling and Ventilation	5500	5500	-4500
Radiological Protection	0	0	0
Transport and Handling	680	680	-400
Survey	50	50	0
Total	**53502**	**53902**	**27320**
covered by consolidation	27320		
after correction for consolidation	**26182**	**26582**	

Remark: In case the rms current would be increased w.r.t. the baseline scenario, the budget for WU Magnests increases by 405 kCHF for both scenarios (all beams and LHC beams only). The consolidation contribution would remain unchanged.

20.3 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 lines of the figure (green bars).