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Feasibility Study

FEASIBILITY STUDY OF AN ENERGY UPGRADE OF THE CERN PS BOOSTER

Abstract

This document summarises a first survey of the CERN PS Booster systems with respect to a possible energy upgrade to about 2 GeV.

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1. INTRODUCTION AND SCOPE OF THE DOCUMENT

As a follow-up of the Chamonix 2010 workshop [1], a study has been requested by the director of accelerators to investigate an increase in beam energy of the CERN PS Booster from presently 1.4 GeV to about 2.0 GeV. A task force has been set up to identify potential show stoppers in the following areas:

1. Beam Dynamics
2. Magnets
3. RF System
4. Beam Intercepting Devices
5. Power Converters
6. Vacuum system
7. Instrumentation
8. Commissioning
9. Extraction, Transfer, PS Injection
10. Controls
11. Electrical Systems
12. Cooling and Ventilation
13. Radioprotection and Safety
14. Transport and Handling
15. Survey

This paper summarises a first survey of all Booster systems with regard to this energy increase.

Although the mandate of this study is purely the energy increase to about 2 GeV, the study needs to be seen in the major context of

1.) The expected intensity increase with the re-commissioning with Linac4.
2.) The consolidation of the machine for operation through the next 25 years.
3.) Possible future operation modes (faster cycling).

It is therefore insufficient to study a sheer energy increase of the Booster beams with their present specifications. The scope of the study must be to study an energy increase with increased beam intensities (from Linac4). Secondly, if a major renovation program of e.g. the main power supply and the RF system is launched, future operation modes as e.g. faster cycling must be anticipated and kept as an option.

All equipment upgrade must therefore be studied with the following constraints:

- The beam intensity the study is based on must be the one expected with Linac4.
- Beams to ISOLDE will remain at the present 1.0/1.4 GeV. All beams to the PS will be executed at 2.0 GeV. In case of a longer ISOLDE stop, it must be possible to

run all cycles in a Booster supercycle at 2 GeV. Therefore all systems must be compatible with running every Booster cycle in a supercycle at 2.0 GeV.

- All systems must be compatible with a 900 ms cycle length, or easily upgradable. In cases where a cycle length of 1.2 s and 900 ms makes a major difference in complexity/cost, both options will be quoted. A cycle time shorter than 900 ms is not considered in the frame of this study.

2. WP 1 BEAM DYNAMICS

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

None at this stage.

2.2 CRITITAL ISSUES AND PROPOSED CURES

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

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

1. Resistive wall head-tail instabilities at flat bottom, which could become up to 50% faster than presently. Linear coupling, octupoles and transverse feedback are potential cures.

2. TMCI at transition crossing. Extrapolating with a simple scaling law from the existing observations on the TOF beam, we expect a factor 2 margin that guarantees the stability of the double intensity LHC25 beam if it crosses transition with the γ-jump scheme.

3. Longitudinal coupled bunch instabilities during the ramp and at flat top. More studies are necessary to determine to what extent they may limit the future performance. A possible solution, which requires anyway a full study, is the installation of a broad band cavity to be used for longitudinal feedback.

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

2.3 FURTHER STUDIES NEEDED

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

- For point 1), a simulation study could be useful to confirm the expected decrease of rise time and assess the efficiency of the possible cures (i.e., how much linear coupling would be needed, how much octupole strength, how much gain/bandwidth of a transverse feedback system)

- To confirm the predicted margin of the instability at point 2), a simulation study for the LHC beam with doubled intensity at transition crossing will be carried out. The study is planned to become the natural closure of the current Ph.D. work on TOF [2].

- Point 3) is already listed as a subject with high priority among the RF MDs proposed in the 2010.

- We have written and plan to submit an MD proposal to carry out a detailed study of point 4). The proposal is found in the appendix. Our goal is to determine the nature and behavior of the transverse instability, as well as its relation to the presence of electron cloud in the machine. In parallel, since we know that the electron cloud actually builds up in the PS with the LHC25 beam for bunch lengths below a certain threshold, it could be very helpful to carry out a simulation study of the beam stability against electron cloud, when the intensity is doubled.

- To allow the maximum flexibility in scanning parameters during the above proposed MDs, the first requirement is to assess the maximum intensity that can be presently produced in the PSB and sent to the PS for both the single and multi-bunch LHC beams. The present constraint on the transverse emittances (2.5 μm) can be relaxed (both because it turned out to be too conservative and secondly because it is better to inject into the PS with larger transverse emittances in order to compensate for the increased intensity and try to stay within the space charge limits at injection)

2.4 INPUT NEEDED FROM OTHER WORK PACKAGES

None at this stage.

3. WP 2 MAGNETS

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

PSB Magnets

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. More detailed measurements are planned.
- The current magnet cooling parameters are not adequate for the increase to 2 GeV operation and must be modified.
- A concern over the life span of the magnets at 2 GeV operation has been raised.

Auxiliary ring magnets

- Study on all auxiliary ring magnets is still to be completed.

Transfer line magnets

- Study on all transfer line magnets is still to be completed.

3.2 CRITITAL ISSUES AND PROPOSED CURES

Main unit cooling - The current magnet cooling parameters for the main units are not adequate for 2 GeV operation. This becomes more critical when considering all cycles could be at 2 GeV. Initial calculations suggest that the pressure and flow must be almost doubled to maintain the same operational temperature of the magnets. Although it may be possible to achieve these new values with an upgrade of the cooling station it would not be advisable to run the magnets at this higher pressure due to the design of the cooling circuits. It has been stated that a trade off between an increase in pressure/flow and a higher operational working temperature could be acceptable; while this is generally true there is a risk that the life span of the magnet could be reduced at the higher temperature. Another required action could 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.

Life span concerns – A concern has been raised over the ability of the bending magnets to withstand the forces of the coils against the restraining plates. Initial calculations show that although there is a substantial increase in force the absolute levels should be acceptable.

3.3 FURTHER STUDIES NEEDED

Main unit cooling – More detailed studies/calculations must be made to determine the correct action to take to achieve the required cooling. Testing and Design/modifications of the spare magnets must be planned.

Life span concerns – Testing of one of the spare main bending magnet is planned to confirm the calculated forces acting on the coil retaining plates. Testing is being planned at the nominal current, upgrade current and up to nearly 2 times the upgrade current to prove the robustness of the assembly.

3.4 INPUT NEEDED FROM OTHER WORK PACKAGES

The magnet cycles need to be determined for both 1.2 s and 900 ms.

It should be noted that calculations to date have only been made with 1.2 s cycles keeping the same time durations for the rise/flat top/fall as the current operation. Studies have NOT yet been made for the 900 ms cycles, here it should also be noted that not only will the RMS current increase again on top of that seen for the 2 GeV upgrade, but the voltage seen by the magnets will also increase with a shorter rise time.

A table is being compiled 'Magnets_PSB_V1.xls' which will need to be completed to determine if the auxiliary and transfer line magnets can operate at 2 GeV. Information such as the magnet parameters, 1.4 GeV operation values (current and cycle), upgrade values (current and cycle) and power supply values will need to be completed by the responsible people.

4. WP 3 RF SYSTEM

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

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

PSB Low Level Beam Control

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

PSB High Level Cavities and Control (by M.Paoluzzi)

C02 and C04 RF system:

No problems expected to cover the new frequency range, digest the additional beam current and supply the increased power.

C16 RF system:

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

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

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

PSB Transverse Feedback System

The increase of energy to 2 GeV has only a marginal impact on the specifications (7% more power), so this demand will be included in the study underway by A.Blas to define the system requirements associated with LINAC 4.

4.2 CRITITAL ISSUES AND PROPOSED CURES

This will depend upon the 2 GeV cycle in the PSB, as a step from 1.2s to 0.9s cycles at 2 GeV would require an investigation into the functioning of the cavities at such a duty cycle.

4.3 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.

Evaluation of RF systems with 0.9s cycle at 2 GeV.

4.4 INPUT NEEDED FROM OTHER WORK PACKAGES

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

5. WP 4 BEAM INTERCEPTING DEVICES

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

Investigation on the existing PSB dump started. No other Beam intercepting device recognized. Future objects (H-/H0, Head and tail dump) will take into account the new operational scenario.

5.2 CRITITAL ISSUES AND PROPOSED CURES

No spare PSB dump available, new design needed and production of 2 units

5.3 FURTHER STUDIES NEEDED

FLUKA and ANSYS studies.

5.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Parameter table and description of different beams, worst case (energy, intensity, dimensions) on dump, accident scenario?

6. WP 5 POWER CONVERTERS

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

Power converters capability to provide an additional current and to keep PPM operation for all users.

6.2 CRITITAL ISSUES AND PROPOSED CURES

Ring MPS:

The existing supply can not provide the additional RMS current.

An increase of peak power, using traditional thyristor technology, would have a significant negative effect on power quality of the Meyrin network 18 kV, which would be inadmissible.

The solution will probably be a design similar to the new POPS for the PS, using DC capacitors to store the energy for the pulsating load (civil engineering work required).

6.3 FURTHER STUDIES NEEDED

Current and voltage ratings specification.

Civil engineering work estimation.

6.4 INPUT NEEDED FROM OTHER WORK PACKAGES

For the ring, the current profile at 2GeV for each user.

For the transfer lines the current for each user (1GeV and 1.4GeV Isolde, PS 2GeV)

7. WP 6 VACUUM SYSTEM

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

xxx.

7.2 CRITITAL ISSUES AND PROPOSED CURES

xxx

7.3 FURTHER STUDIES NEEDED

Xxx

7.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Xxx

8. WP 7 INSTRUMENTATION

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

- Pick-Ups
- Fast current transformers
- DC current transformers
- BBQ tune measurement
- SEM Grids
- BLMs
- FWS

8.2 CRITITAL ISSUES AND PROPOSED CURES

No critical issue identified so far.

8.3 FURTHER STUDIES NEEDED

Only upgrades are needed for the following instruments :

- Pick-Ups : The electronic chain upgrade is included in the consolidation scheme.
- DC current transformers :
- for high ß : Modification of the normalizer modules. Not an issue
- for high Np : two options
- 1/ dismount and modify the calibration and feedback windings
- 2/ new head electronics for increasing the calibration and feedback current.

- BLM : an upgrade is included in the consolidation scheme.

8.4 INPUT NEEDED FROM OTHER WORK PACKAGES

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9. WP 8 COMMISSIONING

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

PSB beam parameters with Linac4 intensity and energy of 2 GeV at extraction. An overview of the different beams is given in the appendix.

<u>Injection energy:</u> 160 MeV (revolution frequency ~1 MHz; synchrotron frequency* ~1.68 kHz*)

* at 8 kV, h=1 and 0 synchr. phase; multiply with sqrt(2) for h=2

<u>Extraction energies:</u>

1 or 1.4 GeV (revolution frequency ~1.67 or ~1.75 MHz; synchrotron frequency ~645 or 446 Hz)

2 GeV (revolution frequency ~1.81 MHz; synchrotron frequency ~256 Hz)

Nominal cycling: 1.2 s (0.83 Hz)

BUT: should not create bottle-neck for faster cycling of 900 ms (1.11 Hz)

9.2 CRITITAL ISSUES AND PROPOSED CURES

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9.3 FURTHER STUDIES NEEDED

Preparation of a magnetic cycle; 2 scenarios have to be prepared

1.) Injection on flat bottom and slow adiabatic capture (1st commissioning step)

2.) Injection on a ramp (to minimise space charge effects)

dB/dt of ~1.21 T/s currently assumed

Max. dB/dt with current MPS: 2.65 T/s

Min. flat top for synchronisation: ~25 ms

9.4 INPUT NEEDED FROM OTHER WORK PACKAGES

-

10. WP 9 EXTRACTION, TRANSFER, PS INJECTION

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

BE.BSW: magnet and generator OK up 2.2 GeV;

BE.KFA : not enough margin on magnet (but OK up to 1.7 GeV); design new magnets and vacuum vessel;

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

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

BT.KFA10: magnet and generator OK up to 2 GeV;

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

BT.KFA20: magnet 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 additionally required length;

PI.KFA45: magnet and generator no margin (1.4 GeV) only if used in short circuit mode 2 GeV is attainable, but with increased rise and fall times. Perhaps alternative injection scheme may provide additional margin;

10.2 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 subsequently their construction.

For PS injection no margin exists. A new injection scheme will be 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 flat top.

10.3 FURTHER STUDIES NEEDED

A new PS injection scheme needs to be developed.

10.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Extracted beam parameters for all users.

11. WP 10 CONTROLS

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

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

E upgrade to 2 GeV: No critical issues

900 cycling rate scenario:

- No show stopper nor critical problems
- Successful test in 2006 of 900 ms operation on Linac2, Linac3, PSB-ISOLDE complex: nominal PSB beam performance reached with 900 ms
- Some adaptations and validations required as conditions changed wrt 2006

11.2 CRITITAL ISSUES AND PROPOSED CURES

No critical issues at 1st sight

11.3 FURTHER STUDIES NEEDED

Reminder: All machine cycles become multiples of 900 ms: Lin2, PSB, CPS, SPS, Lin3-LEIR, ADE

Adaptations & validations

– CBCM: OK some adaptations. + validation that TGM event distribution is capable of coping with total charge

During 2006 tests SPS, LEIR and LHC were not yet handled by CBCM

– Central timing generation: OK small adaptations
– Distributed timing: OK redefinition of all timings
– Applications : OK minor adaptations if BP is hard coded
– CMW & Network (higher refresh rate of applications): ? scalability to be carefully tested.

– CPU of FE machines: ? unknown impact. To be tested.

11.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Definition of input from other workpackages to complete your studies

none a priori

12. WP 11 ELECTRICAL SYSTEMS

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

xxx.

12.2 CRITITAL ISSUES AND PROPOSED CURES

xxx

12.3 FURTHER STUDIES NEEDED

Xxx

12.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Xxx

13. WP 12 COOLING AND VENTILATION

13.1 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.

13.2 CRITITAL ISSUES AND PROPOSED CURES

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

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

13.3 FURTHER STUDIES NEEDED

Full definition of new cooling and ventilation installations.

13.4 INPUT NEEDED FROM OTHER WORK PACKAGES

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

Same for compressed air needs.

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

14. WP 13 RP AND SAFETY

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

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

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

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

14.2 CRITITAL ISSUES AND PROPOSED CURES

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

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

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

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

14.3 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.

14.4 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.

15. WP 14 TRANSPORT AND HANDLING

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

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

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

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

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

15.2 CRITITAL ISSUES AND PROPOSED CURES

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

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

15.3 FURTHER STUDIES NEEDED

Feedback from the equipment responsibles.

15.4 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).

16. WP 15 SURVEY

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

xxx.

16.2 CRITITAL ISSUES AND PROPOSED CURES

xxx

16.3 FURTHER STUDIES NEEDED

Xxx

16.4 INPUT NEEDED FROM OTHER WORK PACKAGES

Xxx

17. SUMMARY

18. REFERENCES

[1] LHC Performance Workshop Chamonix 2010, http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=67839

[2] S.Aumon, PhD thesis, in preparation.

[3] xx

[4] xx

19. APPENDIX

19.1 MD PROPOSAL

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

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

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

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

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

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

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

Table 1: Overview of LHC-type beams to be delivered by the PSB with Lianc4 and after energy upgrade.

user	harm. 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		2
LHCPROBE	1	3	0.005-0.023E12	hor.: ≤2.5 vert.: ≤2.5		2
LHCINDIV	1	1-4	0.023-0.135E12	hor.: ≤2.5 vert.: ≤2.5		2

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

user	harm. at extr.	PSB rings used	intensity per ring	rms emittance at extr. [mm mrad]	bunch length at extr. [ns]	extr. energy [GeV]
CNGS	2	1-4	0.6-8E12 + ~45% increase to reach target limit	hor.: ~10 vert.: ~8 ~15/7 with MTE	180	2
SFTPRO	2	1-4	<6E12 – would an increase be desirable?	hor.: ~6-8 vert.: ~5-6 ~15/7 with MTE	180	2
AD	1	1-4	4E12 (currently)	hor.: ~8 vert.: ~6	190	2
TOF	1	1-4	<9E12 (currently)	hor.: ~20 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	230	1 or 1.4
STAGISO	1	2-4	<3.5E12	hor.: <8 vert.: <4	230	1 or 1.4