

SESSION 7 – FUTURE UPGRADE SCENARIOS FOR THE INJECTOR COMPLEX

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Abstract

The programme of session 7 was designed to review the present situation concerning studies for injector upgrades, looking at the benefits, costs and timelines, and to put this in the context of the latest information on what the LHC will actually expect from its injectors in the medium to long term. This review is necessary since the delay in the start-up of the LHC, the impact of the incident in 2008 and a more realistic look at the way the performance of the machine will develop shows that the assumptions under which the original upgrade studies were launched are no longer valid. In this session only the issues concerning the use of the injector chain for LHC were discussed.

LIST OF PRESENTATIONS

The following presentations were made in session 7:

What will SPL/PS2 provide for the LHC?, M. Benedikt

Keeping the present injector complex running with high reliability for 10-20 more years, S. Baird.

Possible improvements to the existing pre-injector complex in the framework of continued consolidation, M. Giovannozzi.

Upgrade possibilities in the SPS, E. Shaposhnikova.

Other scenarios for a partial upgrade of the injector complex, C. Carli.

INTRODUCTION

Figure 1 shows a schematic of the present injector complex together with one possible

scenario for the upgrade of the complex. The first link in the new chain, Linac4, is presently under construction. The LP-SPL and PS2 are the subject of design studies as laid out in the ‘White Paper on New Initiatives’ [1]. The rationale behind this upgrade path of the LHC injector chain is to replace the ageing machines of the present complex whilst providing higher brightness and higher intensity beams in for the LHC. The first stage, Linac4, will be connected to the present PS Booster and will provide the capability of doubling the intensity injected. The LP-SPL and PS2 would then take over the role of pre-injectors and allow this intensity to be injected at a higher energy into the SPS. At the same time as the studies for LP-SPL and PS2 were launched, another study into the upgrade of the SPS was started.

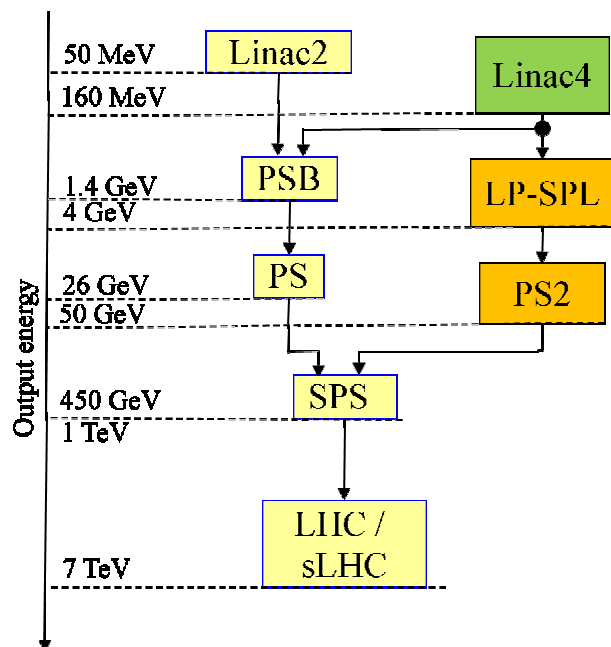


Figure 1: Schematic of the present injector complex (left) and the proposed complete upgrade for sLHC (right).

LP-SPL/PS2

One aim of the LP-SPL and PS2 is to double the beam brightness (with margin) that could be delivered to the SPS and hence the LHC. This increased brightness could either be in the form of a higher intensity, or a reduced transverse emittance. At the same time it is argued that the replacement of the ageing PSB and PS would increase the reliability of the complex. Finally the method used to generate the 25ns beam for LHC could be significantly simplified by direct production using a chopper, rather than production via bunch splitting in the PS, as at present.

The LP-SPL study is for a superconducting linac, approximately 430m long with an exit energy of 4GeV. The beam would then be transported via a transfer line parallel to the present TT10 to the entrance of the PS2.

The PS2 machine has a circumference of 1346m (approximately twice that of the present PS) and would be built at the same level as the SPS, i.e. approximately 50m underground. A new connection to the SPS with an upgraded injection region would be needed to take the 50GeV beam from PS2 and inject it into the SPS.

Cost and Timeline

The overall cost of the LP-SPL/PS2 upgrade has been estimated to be around 900MCHF and require approximately 1500MY in manpower. In addition an upgrade of the SPS would be needed in order to benefit from the increased brightness of the beams. A rough estimate of 65MCHF for material cost was given for this.

An advantage of the LP-SPL/PS2 upgrade would be that the construction and commissioning could be achieved independently of the operation of the existing machines. Two significant shutdowns would still be required; one to connect SPL to Linac4 and the other for the connection of PS2 to the SPS.

It should be noted that this upgrade would be problematic for ions. This has been studied; the solution would be to upgrade the energy of the present LEIR machine and make a direct transfer into PS2 via the present TT10 line.

Special, large tuning range cavities would then be needed in the PS2 to capture and accelerate ions as well as the protons.

The timeline for the LP-SPL and PS2 projects has been estimated. Given an approval in mid-2012 the connection to the SPS and start of operation of the complex could be envisaged in 2020. This aggressive schedule is based on a significant investment before the approval for preparatory work on an impact study and civil engineering drawings. If this preparatory work is not done in advance, the start date could slip to 2022.

CONSOLIDATION OF THE EXISTING INJECTOR COMPLEX

Even if LP-SPL and PS2 are built, the existing machines will have to continue to run for around 15 years. This would allow an overlap in case of slippage in the construction schedule of the new machines. On the other hand, if PS2 and LP-SPL were not built, these same machines would have to run for 25+ years, the presumed lifetime of the LHC. In consolidation terms there is little difference between these timescales; both indicate a long term commitment to consolidation. Additional resources must therefore be set aside to allow this to happen.

A consolidation programme already exists for the injectors covering the mid-term; this must be supplemented by the longer-term consolidation issues raised during the session. A preliminary look at the consolidation needs over the next 20 years indicates an approximate cost of 15MCHF/year, although this covers much more than the LHC injector chain itself.

The next step in this process is to incorporate all long-term requests into the present consolidation plan. Here, a clear separation between the injector chain and the experimental facilities of the injector complex must be established and a risk analysis be made to set priorities correctly.

LIFTING THE LIMITATIONS IN THE PRESENT INJECTOR CHAIN

The present state of studies shows that the SPS is the limiting machine in the injector chain; yet

it is the only machine that would remain if the LP-SPL and PS2 are built. The present limitation on the intensity in the SPS is around 1.2×10^{11} protons per bunch (ppb), far below the ‘ultimate’ intensity that could be required by the LHC before a major upgrade of that machine. On the other hand the PS and the PSB have achieved the necessary 1.7×10^{11} ppb. A significant upgrade of the SPS is therefore required under either hypothesis.

SPS Upgrades

At present there are three areas in the SPS that limit the intensity significantly. For each case the SPS upgrade studies working group has identified possible mitigating measures and upgrades [2]. These three areas are:

- **Electron cloud instabilities.** This is a multi-bunch effect due to the build-up of secondary electrons in the vacuum chamber. It is strongly related to the bunch spacing and the intensity per bunch. Feedbacks could be used to limit the impact on the beam, but the optimum solution would be to avoid the electron cloud build-up by coating the vacuum chamber of the whole machine. Investigations so far have indicated that an amorphous carbon coating of the chambers appears to be best suitable.
- **Transverse mode-coupling instabilities.** This is mainly a single-bunch intensity effect and is driven by impedances in the machine. During the preparation of the SPS as LHC injector a campaign of impedance reduction was launched – principally the shielding of the vacuum pumping ports to combat longitudinal microwave instabilities. Since then additional impedance sources have been added to the machine, notably additional kickers for the extraction to the LHC. As well as perturbing the beam these impedances can heat the kicker cores and lead to outgassing. Since their initial installation one kicker has been removed and 3 have been fitted with impedance reducing stripes; 5 kickers remain to be treated.
- **The 200MHz RF power limitations.** It has been seen that with the present arrangement

of the RF cavities the amount of power available for the beam will eventually limit the intensity. A better arrangement of the travelling wave cavities (TWC) into a larger number of shorter structures would allow this power limitation to be lifted. It is a peculiarity of the TWC system that more, shorter structures would also lead to a reduction in the impedance.

Tackling these three areas should allow the LHC bunch intensity to reach, or even exceed the ‘ultimate’ value of 1.7×10^{11} . This will be necessary before the fundamental limits of the SPS machine can be explored.

One fundamental limitation in a circular machine is the space-charge tune shift at injection. The exact value is different for each machine but it should normally be a least -0.2 (for PS Booster and PS it is -0.3). If the space-charge tune-shift limit is reached, the only solution would be to increase the injection energy of the machine. For the SPS, this was part of the argument for the LP-SPL/PS2 upgrade. However, with the ‘ultimate’ intensity LHC bunches in the SPS the value of the tune-shift is -0.07. Experiments with lower energy single bunches in the SPS have demonstrated that a space-charge tune shift of -0.2 is possible.

PS Booster Energy Upgrade

Linac4 will raise the intensity limit in the PS Booster by approximately a factor 2. This is achieved by increasing the booster injection energy from 50MeV to 160MeV, giving a factor 2 increase in $\beta\gamma^2$.

A similar limitation exists in the PS machine at injection. Presently the injection energy of the PS is 1.4GeV. This was chosen during the preparation of the PS complex for LHC as the energy that would allow the production of the ‘ultimate’ beam. Raising the injection energy of the PS (by increasing the extraction energy of the PS Booster) would allow this limit to be increased further.

The PS Booster was originally designed as an 800MeV machine. It was later upgraded to 1GeV, then a second upgrade to 1.4GeV was made in preparation for the LHC. A

preliminary study shows that there is further room for increase and extraction at 2GeV appears feasible. This would increase the intensity limit in the PS to $>2.7 \times 10^{11}$ ppb in a 25ns LHC beam.

Clearly, other limitations and instabilities may arise in the PS once the intensity is increased; these can be studied and solutions proposed once the very high intensity beam is available.

Other Partial Upgrades of the Injector Complex

Instead of increasing the energy of the PS Booster other solutions could be found by replacing completely this machine. A variety of machines could be envisaged to provide the bridge between Linac4 and the PS. A short study has been done to look at these possibilities. Parameters for an RCS, an FFAG, or a super-booster were investigated. In each case an extension to Linac4 would be required to reach 500-1000MeV for injection. An extraction energy of around 2.5GeV would provide the possibility of generating beams having a brightness equivalent to that proposed for LP-SPL/PS2. Some of the options look interesting, but the cost of construction would be relatively high compared with the cost of upgrading the present PS Booster (although considerably cheaper than LP-SPL/PS2). In addition the performance gain would not be very high and it is presently not clear that it would be needed for the LHC.

CONCLUSIONS

The present injector complex will have to be capable of providing high intensity, high quality beams reliably to the LHC for many years. A consolidation plan to allow this, combined with upgrades to relieve the bottlenecks in the present injector chain, will be needed.

At present the lowest known limits on the LHC beam are in the SPS. Several upgrades have

been proposed to lift these limits. A technical study must be launched with the aim of making proposals for actual upgrade projects in the near future. At the same time the main limitation in the pre-injector complex could be removed if an upgrade of the energy of the PS Booster to 2GeV can be achieved. A separate study on this possibility should also be launched. These two upgrades of the present complex should be achievable over the next 5-6 years. At this point the injectors should be capable of delivering intensities to LHC in excess of 1.7×10^{11} ppb; how much in excess will depend on what is discovered once the present limitations in the SPS are removed.

The alternative upgrade scenario – to replace the present PS Booster and PS with new machines is rather expensive. The resources required for this construction would be in direct competition with those needed for the consolidation and upgrade of the present complex, which needs to be carried out anyway. The beam brightness that would be possible with such an upgrade seems to be far in excess of what the LHC will actually ever require (see session 9), provided the SPS will be able to deliver it to the LHC. If the maximum 25ns bunch intensity in the LHC is limited to around 2.3×10^{11} ppb, then the present injector chain should be capable of delivering it after some upgrades.

The beam parameters associated with the upgrade of the LHC towards sLHC need to be determined; this should drive the choices made for the injector chain.

REFERENCES

- [1] 'The Scientific Activities of CERN and Budget Estimates for the Years 2008-2011', CERN SPC, May 2007.
- [2] SPS Upgrade Studies Working Group, <https://paf-spsu.web.cern.ch/paf-spsu/default.htm>