FEASIBILITY STUDY OF A CERN PS INJECTION AT 2 GEV

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Abstract

In the framework of the planned CERN PS Booster (PSB) energy upgrade, a study was initiated to look into the possibilities and constraints to inject protons into the PS at kinetic energies up to 2 GeV, for LHC type beams and other (high intensity) beams. This paper highlights the identified bottlenecks and potential solutions and addresses the resulting requirements for the hardware in the transfer line and injection region of the PS. In conjunction with the proposed upgrade of the PSB-PS transfer line hardware the optics can be changed for different cycles. Optics solutions optimized for the different requirements of LHC type and other beams are presented.

INTRODUCTION

For the feasibility study for the PS Booster energy upgrade [1], only the injection of the LHC upgraded beams were taken into account. The feasibility to inject high energy beams into the PS was identified in [2]. Essentially, 2 GeV LHC-type beams, with a transverse emittance $\varepsilon_x = \varepsilon_y$ 3 mm mrad (1σ normalised) can be injected with the modifications of the PS injection kicker and septum, including an under vacuum septum-like bumper.

However limitations for the injection of high intensity beams, such as beams for the fixed-target physics of the SPS or nTOF, remained unclear with this injection scheme. The possibilities to inject high intensity (HI) beams at energies greater than 1.4 GeV are investigated to profit from the reduced physical emittance and therefore reduced continuous injection losses.

INJECTION OF HI BEAMS

Requirements

In order to inject HI beams at 2 GeV, the septum and kicker strengths have to be increased by 30 % while keeping the required fall time for the kicker magnets of 68 ns (2-98 %). Increasing the kick strength in straight section (SS) 45 without violating the fall time requirements has shown to be not feasible. Instead, a second kicker system 180 degrees downstream in phase advance is suggested to compensate for the kick leakage, Fig.1.

In view of taking full advantage from Linac4's doubled bunch intensity [1] the study aims at removing aperture bottlenecks in the PSB-PS transfer line (TL), squeeze the beam at injection to reduce present losses at the septum and improve the injection bump to reduce continuous losses in the ring.

Squeezing the HI beam at the injection septum for loss reasons and matching the line optics to the PS for the LHC beam types requires different optics for these cycles and therefore pulse to pulse modulation capability of the PSB-PS transfer line elements.

The transfer line equipment shall be improved by installing a new beam stopper, new pick-ups and five corrector magnets. The currently proposed new optics requires an additional quadrupole and in order to reduce losses at injection, a collimator is foreseen to shave off transverse tails.

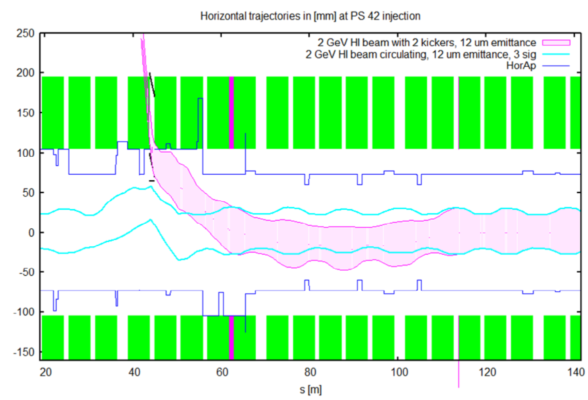

Figure 1: 3 sigma envelopes at 2 GeV for the HI beam at PS injection. The boxes in green show the PS combined function magnets, the blue line the horizontal aperture, the boxes in magenta the kicker elements in SS 45 and SS 53. The transverse emittance ε_x= 12 mm mrad (1σ normalised).

Optics

Figure 2 shows the transfer line optics matched to the PS injection parameters by using a new additional quadrupole. In the vertical plane there remains an unavoidable mismatch of the dispersion function due to the vertical recombination of the four PS booster rings.

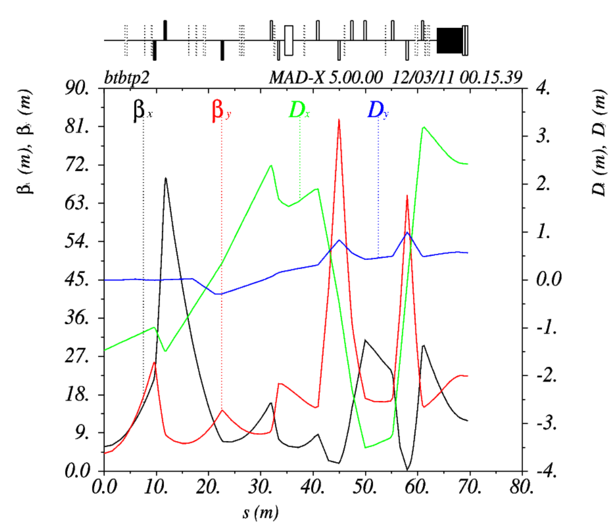

Figure 2: Transfer line optics matched in the horizontal plane to PS injection optics.

Figures 3 and 4 show the according beam envelopes in the horizontal and vertical plane, respectively.

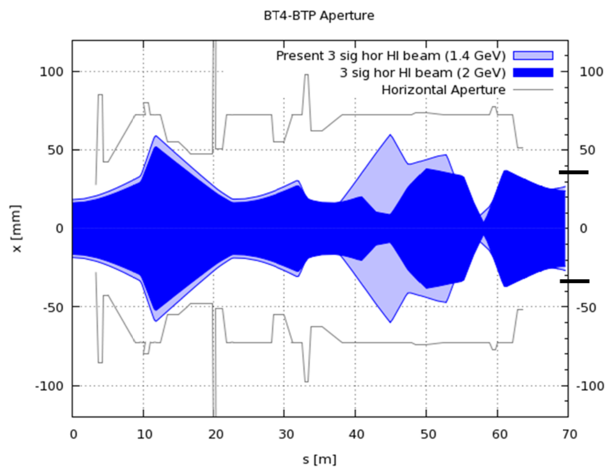

Figure 3: Horizontal 3 sigma beam envelopes for dp/p of $1.3{\cdot}10^{-3}$. The black bars on the right indicate the septum acceptance. The transverse emittance ε_x= 12 mm mrad (1σ normalised).

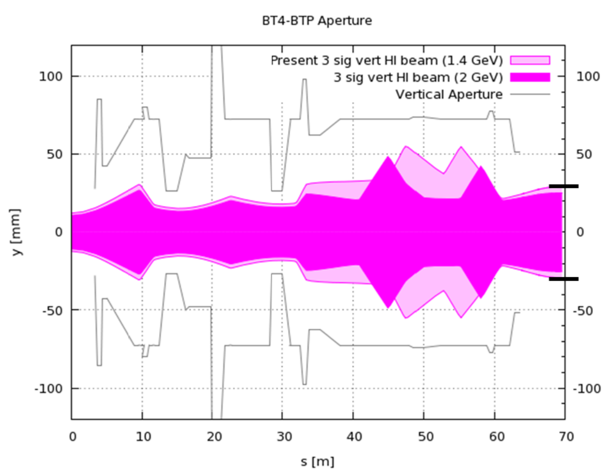

Figure 4: Vertical 3 sigma beam envelopes for dp/p of $1.3{\cdot}10^{-3}$. The black bars on the right indicate the septum acceptance. The transverse emittance ε_x= 9 mm mrad (1σ normalised).

The flexibility of the TL optics has been studied for the horizontal plane. By decreasing the beta function from 11 m to 5 m and the dispersion from 2.42 m to 1.8 m the beam size can be squeezed by 30 % while keeping the respective angles matched.

In case the PS injection optics is not adapted, the betatron mismatch would result in an emittance blow-up of 11 % while the dispersion mismatch remains negligible with an emittance blow-up of 1 ‰. Even if the emittance blow-up might be acceptable in case of HI beams, it should be noted that the beam size will increase in the ring and give rise to increased continuous losses at the injection bump maxima. Therefore it is of importance to adapt the PS injection optics accordingly.

Injection Losses and Space Charge

It is possible to reduce the β in the horizontal plane with the γ jump triplet (γ jump is described in [5]) around the injection region only, but at the cost of an increase of β in the vertical plane. However, no further reduction can be achieved using the doublets (upstream as well as downstream) of the region as well.

To reduce the β in the injection region the addition of dedicated insertions needs further study.

The injection of HI beams above 1.4 GeV is desirable for space charge induced losses. Studies show that 1.7 GeV looks most promising for HI beams (in terms of available aperture, i.e. loss reduction, for the circulating beam). The optimum is not firm, and 2 GeV is not excluded.

POTENTIAL SCENARIOS

Only LHC Beams at 2 GeV

Due to less restrictive requirements on the kicker fall time for LHC beams, the short-circuit mode of KFA 45 can provide the 30 % increase in kick strength. The HI beams could be injected with the present optics and injection bump at 1.4 GeV.

This scenario requires a new septum in SS 42 including an under-vacuum bumper in the same vacuum tank and an operational damper system to compensate for the 0.1 µm emittance growth due to the short-circuit mode of the kicker.

All Beams at (up to) 2 GeV

LHC and HI beams will be injected via the existing kicker in SS 45 in terminated mode and an additional kicker in SS 53 to compensate for the missing kick. Different optics in the transfer line and at injection should optimise the emittance conservation for LHC and loss levels for HI beams.

This scenario requires a newly built septum including the bumper in SS 42 but also an additional kicker in SS 53. With these systems in place but injecting below 2 GeV, there could be a significant continuous loss improvement due to a reduction of the injection bump height. Reducing the continuous losses happens at the expense of higher losses at the injection septum because of the bigger beam size. Injecting at 1.7 GeV is a favourable trade-off not taking into account space charge effects.

HARDWARE

Modifications to the Transfer Line

The part of the transfer line downstream of this switching magnet will have to be modified to use pulsed magnets. Besides at different energies, this allows different optics as a function of the beam user.

In the transfer line between the PS Booster and the PS a switching magnet (BHZ 10) is installed to allow the PS Booster beam also to be sent to a measurement line or to

ISOLDE. From a layout point of view, it is not feasible to modify the transfer line as to send the beam to the measurement line (dump) if the BHZ 10 is not powered. This implies that the BHZ 10 will always have to be powered to avoid the beam being sent onto the vacuum chamber wall. Therefore its current will have to be monitored and interlocked to the beam, the vacuum chamber made sufficiently robust to withstand 2 shots of maximum deliverable intensity beams and a fast beam loss monitor to be installed near the magnet to detect potential failure.

Injection Bumpers

To minimise the continuous losses during injection of the circulating beam onto the septum blade, a faster fall time of the injection bumpers would be advantageous. It is being investigated if it is possible to pulse twice as fast as today (800 μs instead of 1.6 ms half sine). Of the 5 bumpers used for the injection bump, 4 will be out of vacuum magnets around a thin walled corrugated vacuum chamber. Calculations have shown that for a dB/dt of 688 T/s (0.55 T/800 μs) the field delay inside the vacuum chamber would be around 67 μs and the maximum field distortion 46 mT. The fifth bumper is a single turn magnet; the challenge is to obtain the required tracking precision between the power convertors of the different bumpers (under vacuum single turn vs. outside vacuum multi turn).

Injection Septum

A new injection septum will be built to deliver 55 mrad at 2.0 GeV, with a magnetic length of 0.8 m and a gap field of 0.64 T. The septum vacuum tank will also provide space for a new septum bumper. The septum position is remotely adjustable in the horizontal plane and the bumper septum is designed such that the aperture for the circulating beam will not be reduced for any septum position. More details of this arrangement can be found in [2].

Kicker KFA45 and Additional Kicker KFA53

The KFA45 kicker consists of four delay line magnets operating in terminated mode in normal operation. However, each terminating resistor can be short-circuited by a thyratron allowing the magnet current to almost double with a slight degradation of the kick transition times and uniformity (see Table 1).

Table 1: KFA45 Kick Transition Times

	Terminated	Short-circuited
Rise time (2-98)%	42 ns	78 ns
Rise time (1-99)%	46 ns	82 ns
Fall time (98-2)%	68 ns	87 ns
Fall time (99-1)%	96 ns	92 ns

The foreseen KFA53 will operate in conjunction with KFA45 (in terminated mode) to provide an additional deflection angle of 1.2 mrad. Four very short delay line magnets will fill a 730 mm long vacuum tank, leaving 320 mm free in the straight section to install a bumper. The magnet impedance will be 30 Ω and magnets, supplied in pairs, will operate in short-circuit mode to minimise cost and complexity. Ceramic coated 3 mm thick shielding plates will be inserted in the magnet aperture for beam impedance reduction. The cell number and length will be optimised to minimise the kick flat-top and post-pulse ripple. Two high voltage generators will supply the two magnet pairs. The generators will use a usual layout consisting of a Pulse Forming Line made of RG220 like cables, a main switch and hollow anode dump switch thyratrons. The use of saturating inductors as in KFA 45 is envisaged to obtain similar kick transition times. The kicker preliminary data are given in Table 2.

Table 2: KFA53 Preliminary Data for 2 GeV Protons

	nominal	maximum
Deflection angle [mrad]	1.2	1.5
∫B.dl [m.Tm]	11.5	13.9
PFL voltage [kV]	23.8	29.7
Magnet current [A]	793	991
No of magnets	4	
Magnet impedance [Ω]	30	
Magnet gap (w×h) [mm^2]	140 × 59	
Magnet length [mm]	158	

CONCLUSIONS

LHC and HI beams will be injected up to 2 GeV via the existing kicker in SS45 in terminated mode and an additional kicker in SS53 to compensate for the missing kick. Different optics in the transfer line and at injection should optimise the emittance conservation for LHC and loss levels for HI beams.

Higher injection energies for HI beams reduce their physical emittance and therefore will reduce continuous injection losses. Injecting at the reduced energy of 1.7 GeV is considered as a possible option.

Alternatively to the injection from the PS Booster at 2 GeV, injection from an RCS has been under study. The optics as defined for injection from the PSB could be suitable, but the injection hardware and the transfer line would all need to be adapted to 10 Hz operation.

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