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Large Hadron Collider Project

Beam Transfer to and Injection into LHC

A. Hilaire, V. Mertens, E. Weisse

Abstract

Transfer of 450 GeV protons from SPS to LHC will be carried out through two new beam transfer lines with a length of about 2.8-km per line. One beam will use the existing SPS west extraction in LSS6 from where a new line will lead to the LHC injection near intersection 2. A new fast extraction facility in SPS LSS4 is needed for the other beam line which will lead to LHC intersection 8. Economy considerations have led to the decision to use classical magnets of compact design. A lot of components will be recuperated from closed down installations. The injection systems consist of horizontally deflecting Lambertson type septum magnets and vertically deflecting kickers. A careful control of the trajectory and the preservation of the very small emittance during transfer and injection are of key importance. Construction for the transfer lines will start in 1998 to allow first injection tests in 2003. The report describes the layout and optics design and the required performance of the main components.

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Transfer of 450 GeV protons from SPS to LHC will be carried out through two new beam transfer lines with a length of about 2.8-km per line. One beam will use the existing SPS west extraction in LSS6 from where a new line will lead to the LHC injection near intersection 2. A new fast extraction facility in SPS LSS4 is needed for the other beam line which will lead to LHC intersection 8. Economy considerations have led to the decision to use classical magnets of compact design. A lot of components will be recuperated from closed down installations. The injection systems consist of horizontally deflecting Lambertson type septum magnets and vertically deflecting kickers. A careful control of the trajectory and the preservation of the very small emittance during transfer and injection are of key importance. Construction for the transfer lines will start in 1998 to allow first injection tests in 2003. The report describes the layout and optics design and the required performance of the main components.

1 INTRODUCTION

Two new transfer lines, called TI 2 and TI 8, with a combined length of 5.6 km will be built at CERN to transport 450 GeV protons from the SPS to the LHC collider [1] which will be housed in the LEP tunnel.

Using a dedicated SPS cycle of 16.8 s each line will transport 12 trains of 3 * 81 bunches = 2835 bunches of 10^{11} p (last 81 bunches left empty for LHC dump kicker rise time) to fill either of the two LHC rings. Both rings are thus filled in about 7 minutes. Except during machine studies this will only happen once or twice per day.

The main design goals of the transfer lines were to meet the LHC orbit with high precision and reproducibility (including all errors to better than $\pm$ 1.5 σ), to achieve a perfect optical match and to remain sufficiently flexible to accommodate future machine optics.

2 SPS EXTRACTION AND TRANSFER LINES

2.1 Layout

The geometrical layout, the vertical profile and the main geometrical parameters of TI 2 and TI 8 are given in fig. 1. TI 2 re-uses the existing extraction facility in LSS6, branches off from the beam line TT60 and leads to the injection near LHC intersection 2. To stay entirely in the solid rock TI 2 has to pass below an underground river bed, requiring additional vertical deflection. A new fast extraction facility in LSS4 is needed to put beam into TI 8 which leads to LHC intersection 8. The first part of TI 8

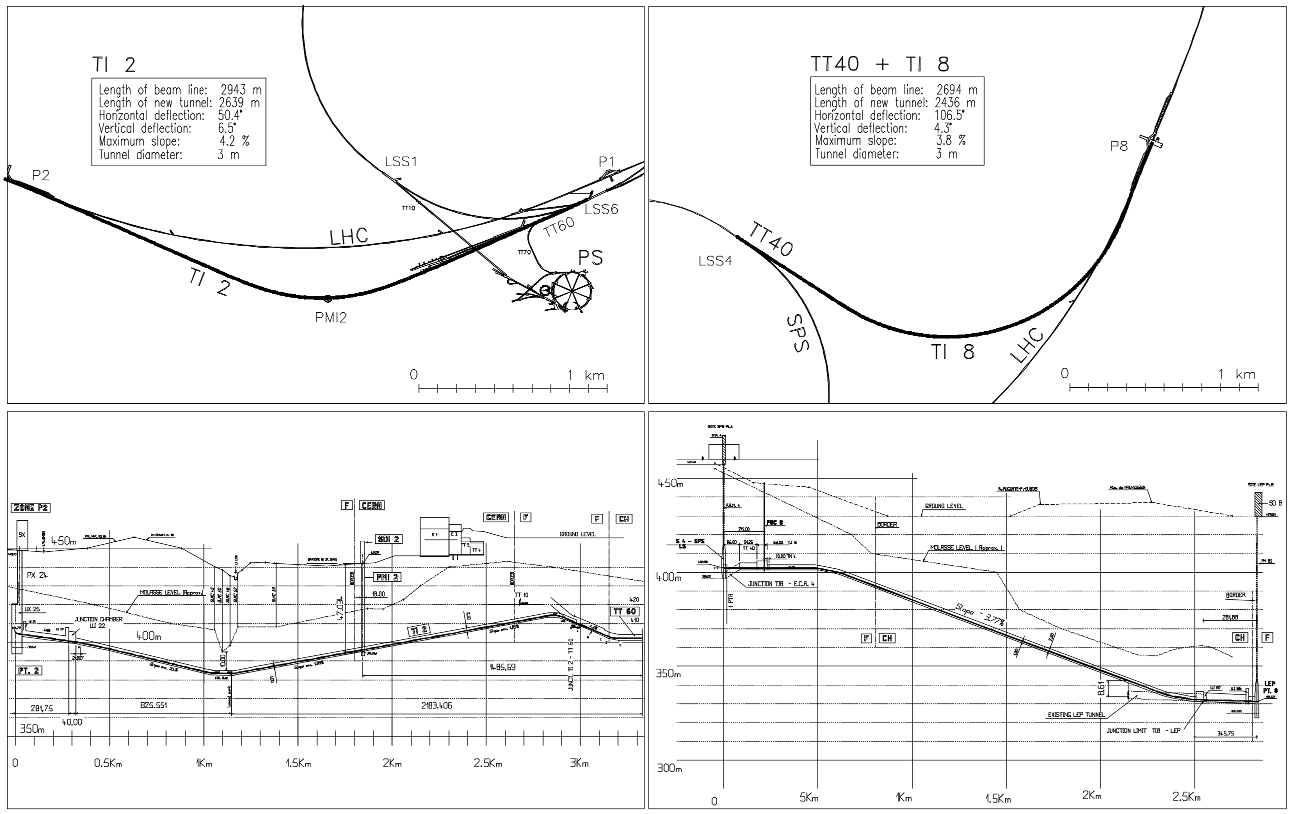

Figure 1: Geometrical layouts with main parameters (top) and vertical profiles (bottom) (TI 2 left, TI 8 right)

(in common with a possible future neutrino production line) is called TT40. The chosen layout leaves the LHC high-luminosity insertion 1 unaffected and permits to use room-temperature magnets which has been found to be overall considerably more economic than superconducting magnets, both from the constructional and operational point of view, given that TI 2 and TI 8 will only be operated during short periods.

2.2 Optics

Both lines use a FODO lattice with about 90°-phase advance per cell and a half-cell length of 30.3 m with four dipoles per half-cell, similar to the SPS. Fig. 2 shows the sequence of elements with betatron and dispersion functions for both lines. The main optical parameters and requirements are summarised in table 1.

The main horizontal arc in TI 2 has been designed as achromat. Space reasons dictated a different solution for TI 8.

Beam optics calculations to second order show negligible effects, which do not require higher-order corrections.

2.3 Magnets

To build up TI 2 and TI 8 it needs over 700 magnets of which 170 dipoles, quadrupoles and correctors will be recuperated from then closed down installations. The 348 dipoles forming the main horizontal bends and 178 main quadrupoles are being built by the Budker Institute for Nuclear Physics at Novosibirsk in the framework of the Russian participation in the LHC. The primary design criterion for the dipoles was the re-use of the main high-current LEP power supplies, resulting in the following dipole characteristics: 6.3 m length, 25 mm gap height, and a field of 1.81 T at a nominal current of 5340 A. The quadrupoles are 1.4 m long, have a gradient of 53.5 T/m at a nominal current of 530 A and an inscribed diameter of 32 mm.

2.4 Trajectory correction

Following an in-depth study [2] a correction scheme is proposed in which two out of every four adjacent cells in each plane are equipped with correctors. Full correction is performed at the beginning and the end of each line. This way TI 2 will use 55 (TI 8: 43) correctors and 55 (TI 8: 46) beam position monitors to stay within the tolerable excursion limit of 4.5 mm.

2.5 Powering

All required power supplies will be recuperated from LEP, except for the correctors. Cabling of the circuits will be done from both sides of each line to minimise cabling costs. The existing powering structures of SPS and LEP can be used with only little modifications.

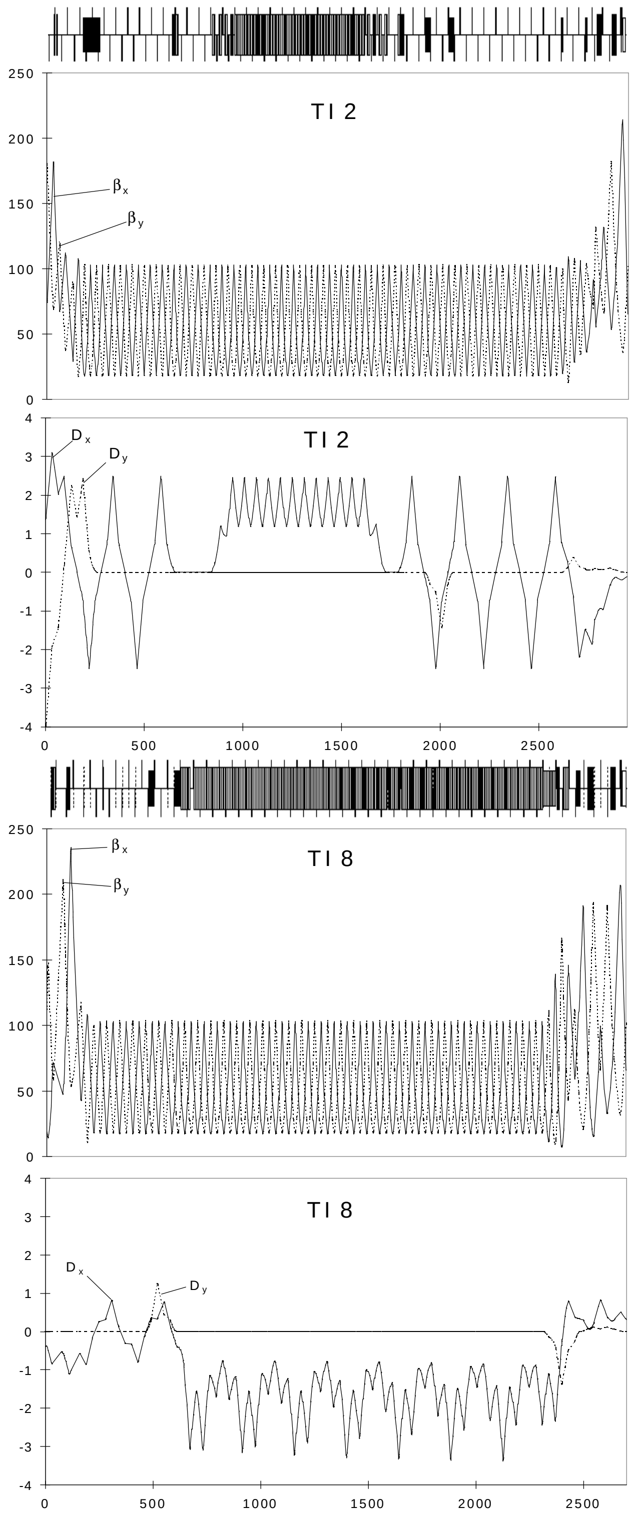

Figure 2: Sequence of elements, betatron and dispersion functions (all values in m) for TI 2 and TI 8

(TI 8 data include TT40 part)

Table 1: Main optical parameters and requirements

Main Optical Parameters and Requirements			
Item	**TI 2**	**TI 8**	**Unit**
Optics			
$\beta_{x,max}$	214.2	235.6	m
$\beta_{y,max}$	182.2	211.2	m
$\beta_{x,max,lattice}$	102.9	103.1	m
$\beta_{y,max,lattice}$	102.9	103.6	m
$D_{x,max}$	3.10	3.38	m
$D_{y,max}$	3.98	1.38	m
$\mu_{x,total}$	11.3	10.8	2π
$\mu_{y,total}$	11.4	10.4	2π
Half cell length	30.3	30.3	m
Number of half cells	95	85	
Acceptance			
Norm'd nominal emittance (β^2/σ)	3.5	3.5	µm
Assumed beam size	±4	±4	σ
Nominal momentum spread	±0.12	±0.12	%
Injection precision			
Deposition precision on LHC c.o. including:	±1.5	±1.5	σ
SPS c.o. errors at extraction			
Power supply ripple / drifts			
Injection kicker ripple / drifts			

2.6 Safety devices

For personnel protection and to be able to carry out tests of the SPS extraction and the entire lines before injecting beam into LHC both lines will be equipped with an adequate number of beam dumps and stoppers.

3 LHC INJECTION

A schematic view of the injection region is given in fig. 3. The beam to be injected passes through 5 horizontally deflecting steel septum magnets (MSI) with a total deflection of 12 mrad and a vertically deflecting kicker (MKI) with a kick strength of 0.85 mrad [3, 4, 5].

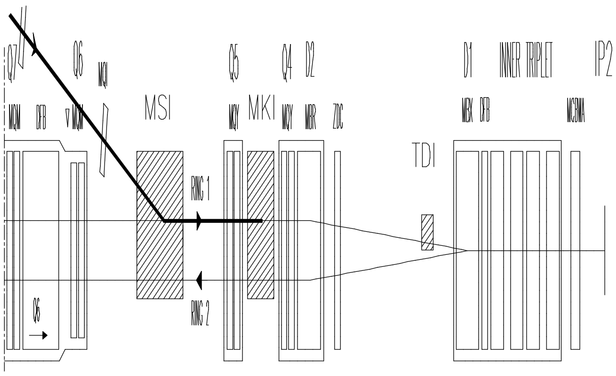

Figure 3: Schematic horizontal view of LHC injection (TI 2)

A beam stopper/diluter (TDI) will be placed downstream of the MKI to protect the parts of the LHC downstream of the injection against quenches or damage due to miskicked bunches. It will also be used during injection setting up and adjustment with pilot bunches.

A cross section of the last of the 5 MSI magnets (operating at 0.76 T) is given in fig. 4 which shows the injected beam in the gap (gap height 25 mm) together with the two circulating LHC beams above. The MSI magnets are being built by the Institute for High Energy Physics at Protvino, again as part of the Russian contribution to LHC.

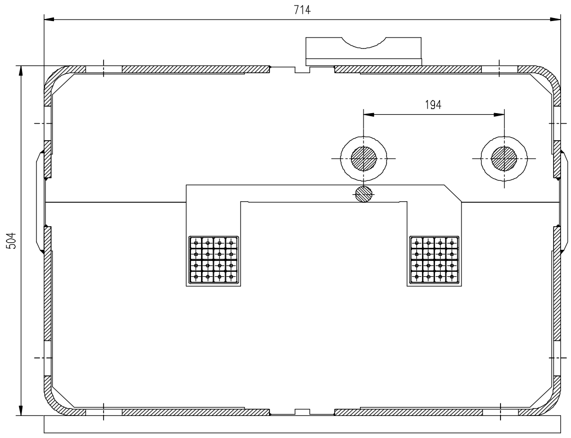

Figure 4: Cross section of steel septum magnet

4 STATUS AND PLANNING

All key elements have been designed. Elements to be recuperated have been identified. Construction is underway for the main dipoles and quadrupoles. Work on the new tunnels is about to start. A first injection test using TI 8 is foreseen in fall 2003. Commissioning of TI 2 is planned for mid 2005.

ACKNOWLEDGEMENTS

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