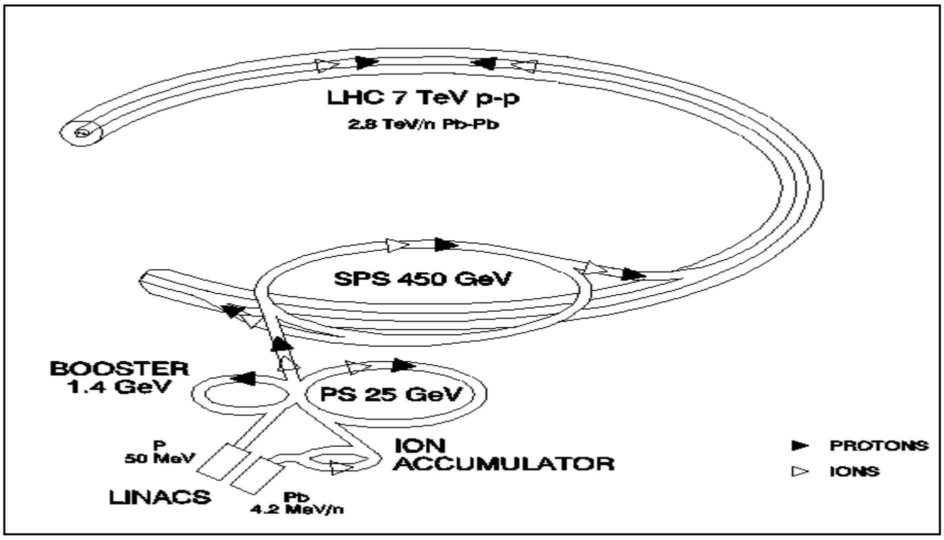
CHAPTER 1

INTRODUCTION AND SUMMARY

CERN's Large Hadron Collider (LHC) [1] will be supplied with protons from the injector chain Linac2 - Proton Synchrotron Booster (PSB) - Proton Synchrotron (PS) - Super Proton Synchrotron (SPS), shown in Fig. 1.1. These accelerators were upgraded to meet the very stringent needs of the LHC: many high intensity proton bunches (2808 per LHC ring) with small transverse and well defined longitudinal emittances.

The main challenges for the PS complex are (i) the unprecedented transverse beam brightness (intensity/emittance), almost twice that which the PS was able to produce in the past and (ii) the production of a bunch train with the LHC spacing of 25 ns before extraction from the PS (25 GeV).

Figure 1.1: The LHC injector complex.



Initially, a scheme requiring new Radio Frequency (RF) harmonics of h = 1, 2 in the PSB and h = 8,16, 84 in the PS, an increase of the PSB energy from 1 to 1.4 GeV and two-batch filling of the PS was proposed [2]. After a partial test of the scheme's main ingredients in 1993 [3], a project to convert the PS complex for LHC operation was started in 1995 and completed in 2000 [4]. Major parts of this project were

- (i) new h = 1 RF systems in the PSB,
- (ii) upgrading the PSB main magnet supply from 1 GeV operation to 1.4 GeV,
- (iii) new magnets, septa, power supplies, kicker pulsers for the PSB-PS beam transfer,
- (iv) new 40 and 80 MHz RF systems in the PS,
- (v) beam profile measurement devices with improved resolution.

About one quarter of the project resources (funds, manpower) was provided by TRIUMF under the Canada-CERN Co-operation Agreement on the LHC.

During first beam tests with the complete scheme in 1999, difficulties for producing the LHC bunch train at PS extraction were encountered. The problem was an instability of the coasting beam after adiabatic debunching just before recapture with the new 40 MHz RF system. As a consequence the final bunch length at extraction was too large (>5 ns) to fit the SPS 200 MHz RF system. A modified scheme [5], avoiding debunching in the PS while changing the number of bunches by multiple bunch splitting operations was proposed. This method is based on using RF harmonics 7, 21, 42 and 84 in the PS and required the installation of an additional 20 MHz RF system in the PS.

An overview of the PS conversion as well as the beam dynamics issues involved are presented in Chap. 2. A comparison of the initial and modified schemes for producing the LHC bunch train in the PS complex is made and the most important side effects of the new scheme are outlined. Recent beam tests indicate that assumptions on beam losses throughout the injector chain have been too optimistic. A beam loss inventory is given and the consequences of increased losses are discussed.

Measures that led to a significant increase of proton beam intensity (to ~180 mA) and brilliance from Linac2 are outlined in Chap. 3.

Increasing the beam energy of the PSB by 40% (momentum by 26%) to 1.4 GeV called for renewal or overhaul of several systems and components, such as the main magnet supply (including transformers and chokes), the PSB-PS 4-level recombination and transfer line magnets and their DC or pulsed power supplies, the pulsed magnetic septa and fast kicker pulsing systems and the water and air cooling system to tackle the increased power dissipation. Chap. 4 deals with the new or upgraded power supply systems, whereas new magnets, septum magnets, kicker pulsers and water cooling are discussed in Chap. 5.

Operating each of the four PSB rings with just one bunch opened up the way for PS two-batch filling. The new $h = 1$ and converted $h = 2$ cavities as well as the digital beam control systems dealing with the new harmonic numbers in the PSB (h = 1, 2) are presented in Chap. 6.

The multiple bunch splitting scheme in the PS, for establishing the LHC bunch train structure, is described in Chap. 7 where all PS beam control modifications are summarised. Chap. 7 also touches on the repercussions of the new RF harmonics in PSB and PS on other operational beams of the complex.

Short (< 4 ns) bunches with 25 ns spacing are produced in the PS by fixed-frequency RF cavities (one at 40 MHz with 300 kV and two at 80 MHz with 300 kV each) which have to withstand the beam loading of much higher intensity beams without perturbing them. The cavities and their driving systems are dealt with in Chap. 8 where the new 13.3 - 20 MHz RF system required for the multiple bunch splitting is also described.

The transverse emittances of the LHC beam have to be maintained at their unusually small size throughout the injector chain. Small amounts of mis-steering and mismatch between the accelerators of the chain, virtually negligible for normal operation, are becoming increasingly important and their effect has to be measurable, calling for high-resolution beam profile monitors. Moreover, various position measurement systems were modified to deal with the new harmonics in the circular machines and to allow bunch-by-bunch observation in TT2. The new or modified diagnostic devices are summarised in Chap. 9 which also deals with work on an injection oscillation damper for the PS.

Finally, Chap. 10 summarises the performance of the PS complex as LHC injector and addresses open issues concerning the ultimate beam.

REFERENCES

[1] P. Lefèvre, T. Petterson (Editors), *The Large Hadron Collider, Conceptual Design,* CERN/AC/95-05(LHC), Geneva, 1995.

[2] F. Blas et al., *Conversion of the PS complex as LHC proton pre-injector*, Proc. PAC '97, p. 973, Vancouver, 1997.

[3] The PS Staff, reported by K. Schindl, *Partial test of the PS complex as LHC proton pre-injector*, Proc. EPAC '94, p. 500, London, 1994.

[4] M. Benedikt (Editor), *The PS Complex as Proton Pre Injector for the LHC – Design and Implementation Report,* CERN 2000-003, Geneva, 2000.

[5] R. Garoby*, Status of the nominal proton beam for LHC in the PS*, Proc. of the Chamonix Workshop on LEP-SPS Performance, pp. 94-98, Chamonix, 1999.