DESIGN OF INJECTION AND EXTRACTION SYSTEMS
FOR THE SPS BY-PASS

K.H. Kissler

Prévessin, 1 June 1981
1. **INTRODUCTION**

An SPS by-pass which would allow high energy protons to collide with electrons in the LEP interaction region P1, has been studied in some detail during the past year\(^1\). Two basic options exist for the operation of such a by-pass:

a) Protons circulate in the by-pass from injection onwards. In this case the by-pass is ramped with the rest of the machine during acceleration.

b) Protons are accelerated in the regular SPS to the required energy and are then switched into a by-pass which is operating in d.c. mode.

As explained in ref. 1), the most favourable solution appears to be a d.c. by-pass branching off in LSS5 and rejoining the SPS in LSS6 with a length equal to that of the part of the SPS which it replaces. The proposed by-pass asks for extraction of high energy protons from LSS5 towards the outside of the accelerator and for their re-injection from the outside into LSS6.

The long straight sections LSS5 and LSS6 are rather crowded regions used for pp experiments and West Area extraction and in the future also for \(e^+\) and \(e^-\) transfer. Clearly it would be desirable to allow all the present and planned operational modes of the SPS to continue unimpeded by the by-pass equipment. The layout of the injection and extraction systems for the by-pass should therefore be chosen to avoid any significant restrictions on:

- injection of electrons and antiprotons in LSS6
- extraction of high energy protons towards the West Area
- extraction of positrons and electrons from LSS5 and LSS6, respectively
- colliding beam physics in LSS5.

It is also important to keep modifications to existing SPS equipment to a minimum and further to choose injection and extraction angles which avoid major civil engineering work in making the junctions between the SPS and the by-pass.
The present note describes a layout of injection and extraction systems fulfilling the above requirements for an operation up to 400 GeV/c.

2. EXTRACTION INTO THE BY-PASS AND RE-INJECTION INTO THE SPS.
PRINCIPLE OF OPERATION AND BASIC LAYOUT

The operation of the d.c. by-pass can shortly be described as follows: Protons are injected into the regular SPS lattice and are accelerated to the required energy (up to some 400 GeV/c). The SPS then goes into coasting mode. A fast pulsed magnet system MKB deflects the beam into a septum magnet MSBE similar to the present extractor magnet MSE, which in turn bends the protons into the by-pass starting in LSS5. Having passed through the by-pass, the protons are re-injected into LSS6 via another septum magnet MSBI and another switch magnet system MKB. Both, extraction and re-injection, are done in the horizontal plane.

The fast switch magnet systems are excited to produce a step function. Their field must rise rapidly, between the passage of two successive proton bunches, and must then stay constant for hours. Such step function kicker systems can indeed be realized with a minimum rise time of less than 300 ns$^1$.

During injection of the protons into the SPS and during acceleration, the septum magnets MSBE and MSBI have a radial position at the limit of the injection aperture. When the SPS has gone into coasting mode, the magnets are moved towards the circulating beam before the MKB's are fired. This procedure makes it possible to maintain the normal aperture of the SPS equipment between the septum magnets and the corresponding MKB (upstream of MSBE in LSS5 and downstream of MSBI in LSS6).

The deflection by MSBE is not sufficiently strong to clear the downstream machine quadrupole. As in the case of the existing extraction systems to the North and West areas the solution is to enlarge this quadrupole and pass the proton beam through a slot between the coils. Similarly, the protons pass between the coils of an enlarged quadrupole in LSS6 before entering the MSBI.
The circulating beam positions at MSBE and MSBI are controlled by systems of horizontal and vertical bumpers.

The installation of MSBE and of MSBI asks for a quasi-empty half period in LSS5 and LSS6 respectively. This condition fixes the lattice positions of the septum magnets, since the only half periods that can be made "free" in LSS5 and in LSS6 are the half periods 5161 to 5171 and 6191 to 6201. The step function kickers MKB must then be placed in the missing magnet positions downstream QF 5141 and upstream QF 6221 if they are to have the correct betatron phase difference with respect to the septa.

The resulting general layouts of the extraction system in LSS5 and of the re-injection system in LSS6 are shown in Figs. 1 and 2 respectively. The first and last parts of the by-pass, the standard SPS equipment, the main components of the proposed positron and electron extraction systems and the e\(^-\) injection kicker are also shown in these figures.

Even though the elements for the by-pass do not significantly restrict present or planned operation, it can be seen from Figs. 1 and 2, that some minor interference with the SPS equipment used for fixed target physics and for pp operation cannot be avoided. The most significant inconveniences are:

- the electrostatic deflectors installed upstream of QD 5171 for luminosity measurements in LSS4 and in LSS5, must be removed from the SPS unless a suitable position near LSS4 can be found for these elements;

- the central detector of the pp experiment in LSS5 must be retracted into its garage during by-pass operation;

- the fast extraction kickers MKE4 to MKE7 downstream of the existing extraction channel in LSS6 must be removed. Only fast retraction of part of the beam is affected by this measure, whereas fast extraction of the full beam and coherent resonant extraction, both needed for narrowband neutrino physics, remain entirely possible. It is also likely that the kickers concerned can be

*Note that injection and extraction of e\(^+\) and e\(^-\) are possible without these inconveniences as will be shown in a forthcoming LEP Note.
installed in suitable positions around LSS2. A coherent oscillation of the protons excited by the upstream kicker in LSS6 would then be suppressed two superperiods further downstream.

In addition to the above modifications some other SPS equipment will be displaced or modified without any noticeable bearing on present or planned SPS potentialities.

3. SOME REMARKS ABOUT THE SWITCH MAGNET SYSTEM MKB

As mentioned above two fast pulsed magnet systems MKB are needed, one for the extraction of protons from LSS5 into the by-pass and the other one for their re-injection into the SPS in LSS6. These systems have to meet the following requirements:

Rise time : \( \lesssim 300 \text{ ns} \)

(leaving out one of the 140 proton bunches which are supposed to circulate in the SPS)

Duration of flat top : unlimited

Deflection at 400 GeV/c : \( \sim 0.5 \text{ mrad} \)

(determined by the proton beam diameter, the septum thickness of MSBE and MSBI and the necessary total clearance of \( \sim 10 \text{ mm} \))

Total length : \( \leq 11.2 \text{ m} \)

(determined by the space which can be made available upstream of QF 6221 after having removed MKE6 and MKE7)

A feasibility study of a kicker system fulfilling the above requirements has been made. A complete system MKB consists of number of ferrite kicker modules MKBF for the fast rise and a pair of laminated steel kickers MKBS which, during the relatively slow fall of MKBF, take over the deflection for d.c. operation. These kickers are arranged in such a way that their bending centres coincide. With the available space a rise time of 300 ns seems possible.
4. THE EXTRACTOR MAGNET MSBE AND THE FIRST PART OF THE BY-PASS IN LSS5

As described in chapter 2, the fast switch magnet system MKB deflects the proton beam into a septum magnet MSBE which then bends the beam sufficiently to allow its passage between the coils of the downstream enlarged machine quadrupole. Once the electrostatic deflectors in LSS5 have been removed, the straight section between quadrupoles 5161 and 5171 is practically empty. Therefore, neither the location of MSBE within this straight section nor its length are subjected to any hindering restrictions. A relatively large extraction angle* of 14 mrad can be chosen. This permits easy installation of additional bending magnets adjacent to the low beta quadrupoles QW in half period 5171/5181 and it also helps to guide the proton beam correctly into the proposed by-pass. An extraction angle of 14 mrad still guarantees sufficient clearance between the beam and the vacuum chamber walls during the passage through the coil window of QDA 5171. At this quadrupole the extracted beam has an average distance of some 250 mm from the SPS centre line.

The septum magnets in the existing SPS extraction channels have a gap height of 20 mm. Such a gap height would, in principle, also be adequate to MSBE if the vertical beam position was sufficiently well controlled during the coast. However, although a control by vertical bumpers is foreseen, it seems advisable to work with a somewhat larger gap. Tentatively, a gap height of 30 mm is proposed for MSBE.

In order to establish a preliminary design the following further assumptions were made:

- MSBE is composed of 10 units, each with a magnetic length of about 1.29 m. These units are installed pairwise in vacuum tanks of 3076 mm length which are separated by bellows assemblies. Ion pumps are fitted under each tank. The somewhat odd lengths of the magnet units and vacuum tanks are explained by their standardization with the corresponding components of MSBI in LSS6 where optimum use of the available length must be made (see chapter 5).

*) Angle between the extracted beam and the SPS centre line downstream of QDA 5171
- The laminations composing the yokes of MSBE are identical to those of the SPS extractor magnets MSE except for the gap height.

- Similarly, with 17 mm the copper septum has the same thickness as that of the extractor magnets, allowing d.c. excitation to a field of the order of 1.7 T. This is the field nearly required in MBSI for 400 GeV/c operation. MSBE requires only 1.55 T at this energy.

Computations have shown that the field errors in the useful part of the gap remain within acceptable limits ($\frac{\Delta B}{B}$ within $\pm 1.5 \times 10^{-3}$) at 1.7 T.

Fig. 3 shows details of the proposed layout in half period 5171/5181. After passing through the slot between the coils of QDA 5171, the extracted protons enter a slim radially defocusing quadrupole followed by 4 dipoles, also of slim construction, which bend the beam away from the SPS by an additional 18.5 mrad. The next quadrupole in the by-pass is conveniently placed between QF 5181 and the wall of the SPS tunnel. In the middle of this quadrupole the by-pass has a radial distance of about 953 mm from the SPS centre line.

As seen from Fig. 3, the by-pass equipment is fully compatible with the existing SPS installation in half period 5171/5181. To permit the extension of the by-pass beyond position 5181, the central detector of the $\bar{p}p$ experiment in LSS5 must be retracted into its garage during ep runs as has already been mentioned. The extracted protons traverse another quadrupole near the upstream end of QD 5191 before they enter the by-pass tunnel through a hole in the corner of the 6 m wide extension of the experimental hall ECX 5 (for details see reference 1).

5. RE-INJECTION OF THE HIGH ENERGY PROTONS IN LSS6

The proton by-pass re-enters the SPS tunnel at the junction between its normal and its enlarged section upstream of the electrostatic septum ZS in LSS6. After having traversed a radially focusing quadrupole near QFA 6161, the protons run through a vacuum tube installed behind the electrostatic septum (seen from the passage).
No by-pass magnets are foreseen in this region, since those adjacent to the electrostatic septum would suffer considerable radiation damage and easy access must be guaranteed to the high voltage feedthroughs and to the components of the high voltage circuit of the septum. Interventions on this equipment must remain unrestrained, mainly because of the high level of remanent radioactivity near the ZS.

Fig. 4 shows the layout of the by-pass and of the SPS equipment in half period 6171/6181. Only minor modifications to existing accelerator components are required. Most of these modifications are already needed for $e^-$ extraction as will be described in a forthcoming LEP Note.

The two standard MBB magnets installed in the by-pass reduce the radial angle between the incoming proton beam and the SPS centre line from 29 mrad to the injection angle of 12.1 mrad.

From Fig. 5 it is clear that modifications to the existing extractor magnet MSE are unavoidable. Special vacuum tanks must be manufactured for this magnet and the coil connections which are on the rear side (see from the passage) must be modified.

Downstream of the MSE there is space for a slim quadrupole with main characteristics as indicated in Fig. 5.

It is obvious that the installation in half period 6181/6191 requires an injection angle (angle between by-pass and SPS centre line at the upstream end of QDA 6191) which has at least the proposed value of 12.1 mrad. To achieve this angle at 400 GeV/c, maximum use has to be made of the space that can be made available for MSBI in the region between QDA 6191 and QF 6201. Fig. 6 shows how the SPS and TT60 equipment must be arranged in this region to permit the operation of a proton by-pass. Installation of a sufficiently strong injection septum magnet MSBI is just feasible. This magnet is assumed to be composed of 8 units, identical to those of MSBE and run at a nominal field of about 1.65 T. The units are housed in 4 vacuum tanks, traversed by all beams that have to be handled in LSS6:
- p and e^- beams coming down TT60 to be injected in LSS6
- beams circulating in the SPS
- proton beams extracted towards the West Area
- the by-pass beam.

The installation of the MSBI vacuum tanks is as compact as practicable, the tanks only being separated by 150 mm long bellows.

For completeness, Fig. 6 also shows a possible position of the e^- extraction kicker.

The proton beam coming from the by-pass is deflected by MSBI in such a way that it passes through the downstream machine quadrupole QF 6201 at a nominal radial distance of 42.5 mm from the SPS centre line, that is at 20 mm distance from the edge of the good field region. Finally, the protons are bent onto the SPS closed orbit by the fast switch magnet system MKB upstream of QF 6221.

6. CONCLUSIONS

It has been shown that extraction of high energy protons from LSS5 into the proposed d.c. by-pass and their re-injection into LSS6 are feasible without significantly affecting present or planned SPS modes of operation. Layouts have been worked out in sufficient detail to understand the main hardware requirements and to outline practical solutions. Initial coordinates for the by-pass in LSS5 as well as in LSS6 were defined to provide a firm basis for its design.

7. ACKNOWLEDGEMENTS

Many discussions with G. Schröder about the feasibility of step function kicker systems and with E. Weisse about the overall layout were of considerable help. J. Dupin has done calculations on MSBE and MSBI showing that these magnets can run in d.c. mode up to 1.7 T with an acceptable quality of the magnetic field.
8. REFERENCES

1) E. Weisse, "Layout and geometry of the SPS proton by-pass" - CERN/SPS/ABT/81-1 and LEP Note 299.

2) G. H. Schröder, "A fast pulsed magnet system with short rise time and unlimited flat top duration for the SPS by-pass" - CERN/SPS/ABT/81-3 and LEP Note.

3) J. Dupin, Private communication.
FIG. 1 - SPS + PROTON BY-PASS
Schematic layout around LSS5
FIG. 2 - SPS + PROTON BY-PASS
Schematic layout around LSS6
FIG. 3 - SPS + PROTON BY-PASS
Schematic layout of half period 5171 to 5181
Fig. 4 — SPS + Proton BV-FAS

Schematic layout of half period

MDHA + BP4A
Special VE5W
MST
VEBX
VEBX
MST
VEBX
Special TPST

Bellows ass.

SPS

Centre of SPS ring

Space needed for vertical extraction of e-

By-pass coordinates:

Z = 0.94 m
X1 = 1.27 m
X2 = 5.97 mm

By-pass coordinates:
FIG. 6 - SPS + PROTON BY-PASS
Schematic layout of half period 6191 to 6201