FAST EXTRACTION

B.Goddard

Abstract

Fast extraction is foreseen for the LHC beams and for the fixed-target proton beam for the neutrino beam line to Gran Sasso. Due to the high intensity and energy of the above beams any malfunction of the extraction elements might result in serious damage to the accelerator equipment. The layout of the extractions in LSS4 and LSS6 and the design parameters of the hardware are discussed.

1 INTRODUCTION

Injection into LHC will use fast extracted beams from SPS LSS4 and LSS6. The locations of these areas in relation to the SPS and LHC, and the new lines TI2 and TI8 [1], are shown in figure 1.

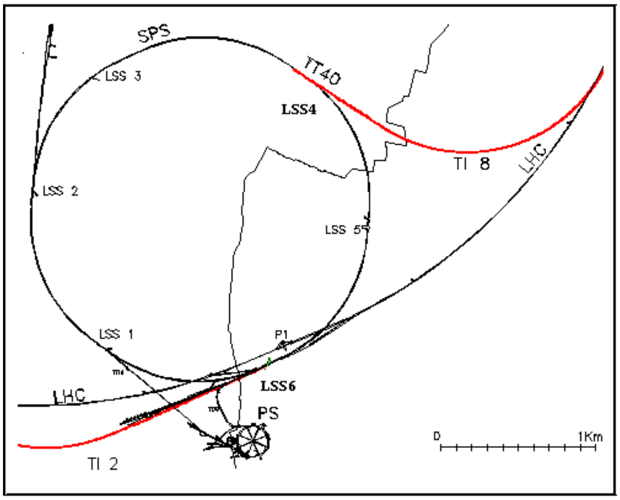

Figure 1. Location of LSS4 and LSS6 extraction channels, with SPS, LHC and TI2 and TI8 lines.

In LSS6 the existing extraction channel will be used to send the LHC beam to TI2. Existing equipment, including the electrostatic septum ZS, will be reused and must be protected from damage.

A completely new extraction channel is required in LSS4, to send the LHC beams to TI8, via TT40. This new system requires the construction and installation of many subsystems, described in the following sections. The design for this extraction [2] now uses a fast pulsed extraction septum located in half-period 418. This extraction channel must be compatible with the beams for the NGS project, and therefore must be able to extract lower momentum, larger emittance fixed target beams, compared to the small emittance high momentum LHC beam.

2 LSS6

The reuse of the existing extraction channel in LSS6 offers many advantages, the most important of which is the economy involved. However, the LSS6 extraction is designed to supply resonantly extracted beams to the West Area, and as such is more complex than is necessary for a simple fast extraction. The fast extraction in LSS6 is shown schematically in figure 2.

During fast extraction the electrostatic septum ZS has to be used at nominal field, which is a potential source of problems for operation. The ZS septum is made up of 5 units each of 3m electrode length, with each anode (septum) element made up of an array of 2080 stretched wires at 1.5mm spacing. These wires are made from a W/Re alloy, and are only 50μm in diameter for the first two ZS, to minimise the losses during resonant extraction. This septum element is fragile, and the consequences of a mis-steered LHC type fast extracted beam impinging directly on these wires are likely to involve serious equipment damage. Hence the main concern in LSS6 is the protection of the ZS septum from damage during extraction. In theory the fast extraction should be a loss-free process, and a certain amount of protection can be obtained from a well conceived interlock system involving the verification of the status of the extraction septa, the bumpers, the kickers, the orbit, etc. In addition the extraction setup can be made such as to minimise the consequences of comment kicker failure modes (missing or erratic kicks) by attempting to place the beam away from the septum wires.

Despite these precautions, however, it will not be possible to *guarantee* that the fast extracted beam will never strike the ZS wires, either through equipment failure, software problems or human error. Given the high cost and radiation constraints associated with the fabrication and replacement of ZS septa, a mechanical dummy septum (absorber) element will almost certainly be necessary to protect the wires. This object will not be simple to make, as it will have to be moved quickly into place before any fast extraction, and removed before resonant extraction. At present there is no space available upstream of the first ZS to locate such an object; thus if an absorber element is found to be necessary, an important redesign of the extraction layout in LSS6 will be required, involving the removal of obsolete lepton equipment to make space for an extension of the ZS girder to six units, and the displacement of the ZS units to make a space upstream.

In an MD in 1998 the fast extraction in LSS6 was recommissioned using a fixed target beam of low intensity (around 10^{12} protons per pulse). No major problems were encountered, although the exercise demonstrated that the concept of a loss-free extraction remains somewhat utopic.

3 LSS4

A complete description of the extraction system planned for LSS4 can be found in [2], including a comparison of the use of MSP and MSE magnets. The features of the MSP design are here reviewed.

A conventional fast extraction will be used in LSS4 with horizontal closed orbit bump, fast kicker and magnetic septum. A vertical closed orbit bumper system will also be necessary. If a sequence of several fast extractions is required then the kicker field must descend during a suitable gap in the circulating beam.

The extraction channel in LSS4 will require the installation of kickers, bumpers, enlarged quadrupoles (QFA418 and QDA419), an absorber (dummy septum) and an extraction septum.

The extraction has been designed for two different proton beams, the LHC beam and the fixed target NGS beam. The Pb^{82+} beam for LHC is considered as having the same transverse dimensions as the proton beam [3], and as such is not considered explicitly.

3.1 Absorber or dummy septum

In order to protect the first extraction element from a mis-steered beam, an absorber (dummy septum) will be installed just upstream.

3.2 Beam instrumentation

The LSS4 extraction channel will be equipped with screens on the septum girder at the beginning, middle and end of the septum. Pick-ups will be added on the extracted beam line, and on the two transfer line quadrupoles in the SPS tunnel. For the circulating beam, couplers will be fitted on the quadrupoles in the extraction region.

3.3 Extraction interlocks

The protection of the extraction equipment will depend heavily on a fail-safe interlock (or veto) system. Just prior to extraction an ideal system would verify the bumper currents, the septum current, the charging of the kicker supply, the horizontal and vertical orbit and the beam emittance. If any of these are not within the predefined tolerances then the beam should be dumped. The interlock system remains to be designed.

3.4 Horizontal bumper system

Four horizontal bumper magnets will be installed at locations near QF414, 416, 420 and 422, to allow a closed orbit bump of approximately 80 mm at the entrance of the septum in half-cell 418. The largest bump that could be envisaged in operation is about 60 mm at the entrance to the septum (determined by the 90 mm good field limit in QFA418). There is then about 25% strength remaining for horizontal orbit correction up to about ±20 mm at QF418 and at the entrance to the extraction septum. All power supplies will be 400 A, 700 V as specified in [4].

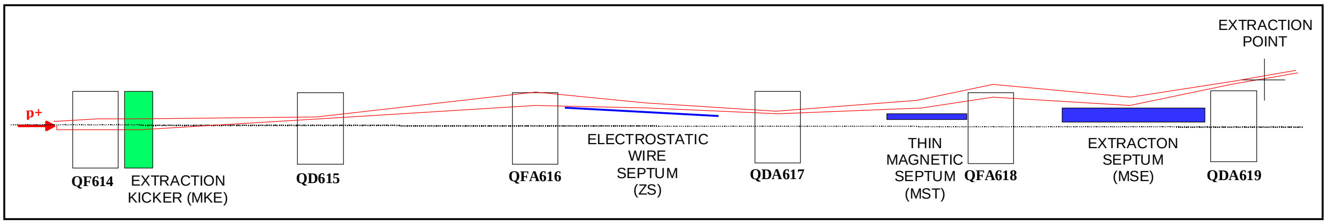

Figure 2. Schematic of fast extraction using existing equipment in LSS6.

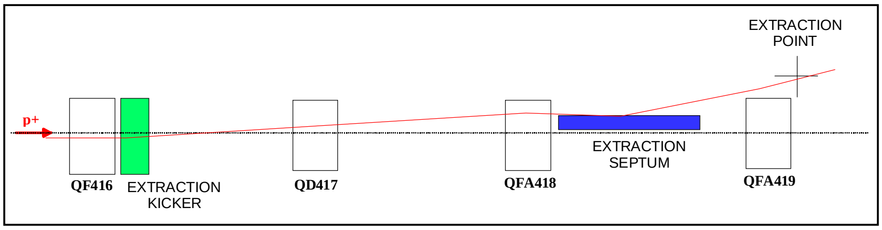

Figure 3. Schematic of fast extraction using new equipment to be installed in LSS4

3.5 Kickers

The flat top ripple of the extraction kicker systems will be decreased to ±0.5 %, from the present value of ±1 %. In addition the rise and fall time of the kicker must be reduced from 1.2 µs to 0.95 µs, in order to allow the fast extraction of a fixed-target beam in several 'chops'. These changes involve reducing the number of cells per kicker module from 7 to 6. The associated reduction in the kicker strength mean that a total of five kicker modules will be required, with a maximum kick strength per module of 0.11 mrad at 450 GeV/c.

3.6 Main ring magnets

The main machine quadrupoles QF418 and QD419 with good field regions extending to 70 mm must be replaced. QFA418 must have an enlarged aperture (90 mm good field region) to accommodate large beam excursions, and QDA419 will be an enlarged quadrupole with a coil window through which the extracted beam passes. The field in this window is quadrupolar, with a gradient of -0.16 of the main gap and an axis displaced by 0.3009 m [5].

3.7 Radiation protection

Some modifications are necessary to improve the radiation shielding between ECX4 and ECA4 [6]. The existing access chicane must be modified to increase the safety factor in the case of beam loss in the extraction. A shielding wall must also be added on the platform in ECX4 alongside the extraction septum.

3.8 Septum magnets

The magnetic septum must deflect the beam by about 12 mrad, and must also give the required 265 mm offset and 10 mrad exit angle at the extraction point. The present design uses a novel pulsed septum that takes advantage of the short (maximum 10.5 µs) flat top required for the fast extraction. A cross-section of the prototype magnet design is shown in figure 4.

The MSP system will have a 200 µs long sinusoidal pulse with a superimposed 3rd harmonic, to give the required flat-top precision of about ±0.02 % over 10.5 µs, enabling extraction of half a full SPS turn if required. The MSP septum will use a yoke of tape wound silicon steel of 50 or 25 µm thickness, profiting from development of similar tape wound steel magnets for the LHC beam dumping system. The septum proper is a passive electro-magnetic eddy current screen of about 5 mm thickness, not connected to the excitation current loop. The advantages of this septum magnet are increased horizontal aperture (12 mm gained compared to the MSE), negligible power dissipation and heat generation (avoiding the need for high-pressure water-cooling), short duration stray field, separation of the vacuum for circulating and extracted beam, reduced complexity and cost and ease of maintenance. The main design parameters of the MSP magnet are shown in table 1.

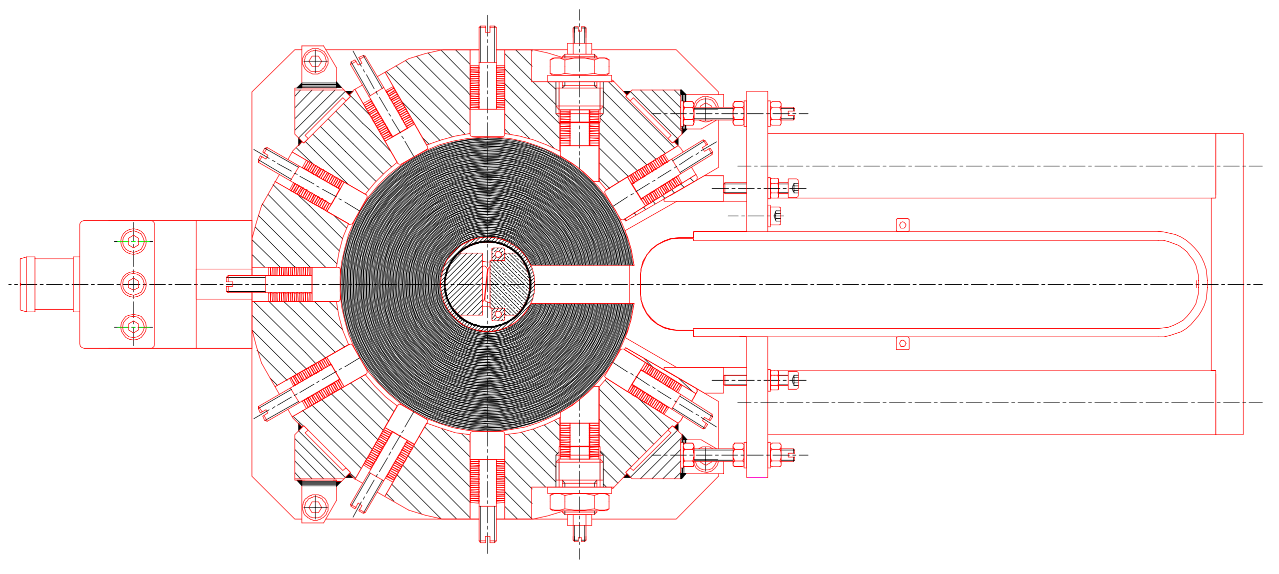

Figure 4. Section through prototype MSP septum. The vertical gap height for the extracted beam is 20 mm. The core is made from tape-wound 25µm thick Si steel.

Table 1. MSP magnet design parameters.

	unit	value
Septum thickness	mm	5
Gap height	mm	20
Maximum field	T	0.95
Kick at 450 GeV/c	mrad	2.090
Magnetic length	m	3.300
∫B.dl max	Tm	3.140
Peak current	A	18,000
∫B.dl / I	Tm/A	$1.74\ 10^{-4}$
Total resistance	mΩ	194
Total inductance	μH	10
Peak voltage	V	3,350
Minimum rise/fall time	ms	0.1
Magnet spacing (centre)	mm	4,100

3.9 TT 40 magnets

In the first section of TT 40 contained within the SPS tunnel several new magnets will be installed. (Full details of the transfer line TI8 can be found in [1].)

3.10 Vertical bumper magnets

Vertical bumpers will be installed at locations near QD415, 417, 421 and 423, to allow a vertical orbit correction of ±15 mm at QD419. A vertical correction of ±8 mm is possible at the septum entrance in half-cell 418. All power supplies are 80 A, 200 V [4].

5 LAYOUT

The drawback of the MSP magnet is the low peak field of 0.95T, which means that a 19 m magnetic length is required to give the necessary deflection. The chosen layout has the absorber and the first MSP unit upstream of QFA418. The absorber then protects the MSP1, which being an active element produces an extra opening at MSP2, reducing the alignment tolerances required and increasing the overall protection level.

6 TRAJECTORIES

Using the above layout and parameters, the trajectories were calculated using MAD [7], and the optimum extraction angle and position were obtained. The constraints imposed were a flat orbit outside the extraction bump, and a maximum particle excursion in QFA418 that should not exceeding 89 mm. A slight refinement of the above can be made by decreasing the strength of the first pair of MSP magnets compared to MSP3-6. This is possible since the magnets will be powered in pairs, using three separate generators. In this case the extra degree of freedom available means that the target co-ordinates of 10 mrad and 265 mm can be obtained exactly, by adjusting the strengths of the MSP1-2 and MSP3-6 magnets. Whether this will be implemented in the final version remains to be decided, as it does imply a higher operating field for MSP3-6. The trajectories obtained for the injected, bumped and extracted beams are plotted in figures 6-8.

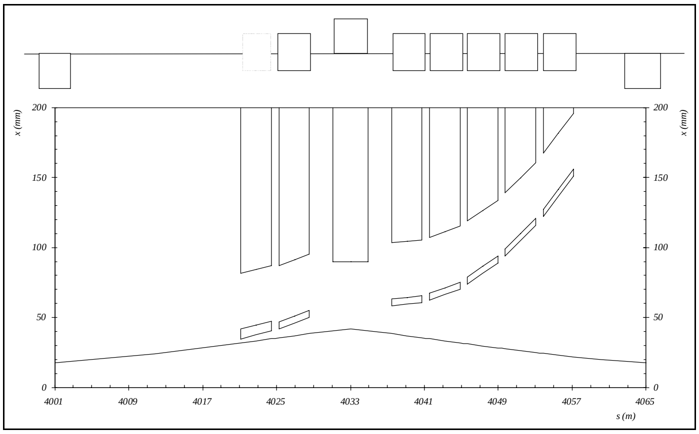

Figure 6. ±5σ envelope of injected NGS beam (p=350 GeV/c, ε_n=10mm.mrad) for MSP extraction.

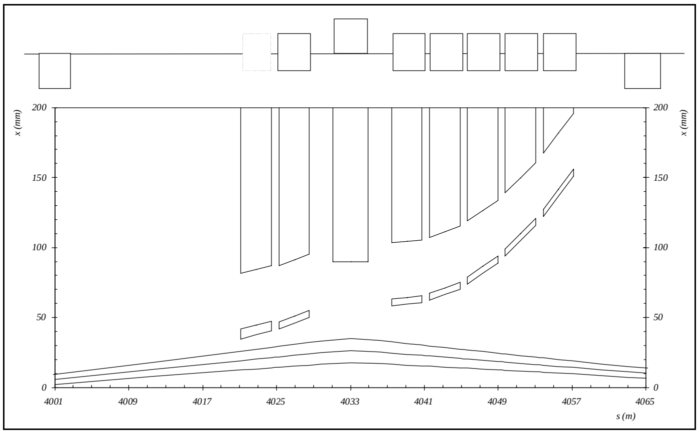

Figure 7. ±5σ envelope of bumped circulating NGS beam (p=350 GeV/c, ε_n=10mm.mrad) for MSP extraction.

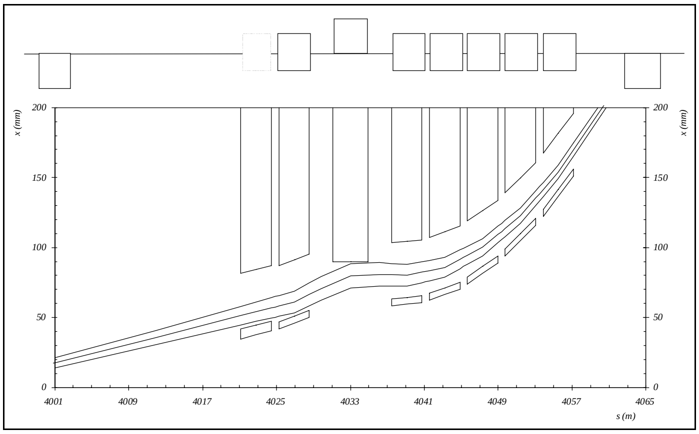

Figure 8. ±5σ envelope of extracted NGS beam (p=350 GeV/c, ε_n=10mm.mrad) for MSP extraction.

7 CONCLUSIONS

In LSS6 the main issue is the protection of ZS septum, which is susceptible to damage from a mis-steered LHC type beam. Work on a physical absorber and an interlock systems are now starting. As a consequence of this, major layout changes in half-cell 616 may be necessary, but will only possible after 2000 due to LEP compatibility.

In LSS4 the design on the new extraction channel has advanced to the stage where the machine layout is know, with the MSP magnet chosen as the best solution for the extraction septum. The stability of the EXC4 platform will be studied in 1999 during operation, the 1m MSP prototype will be tested in 1999, an absorber element and interlock system remain to be designed and built, and the other hardware systems will be ready for installation end 2001. Finally, this LHC extraction channel is also compatible with the NGS project.

8 ACKNOWLEDGEMENT

Many CERN colleagues have contributed to this work and are gratefully acknowledged, including the SLI team in general and M.Gyr, J.Montes, J.Ramillon, B.Riffaud, G.Schröder, E.Weisse, W.Weterings in particular.

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