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PS2 BEAM TRANSFER SYSTEMS: CONCEPTUAL DESIGN CONSIDERATIONS

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Abstract

The replacement of CERN's existing 26 GeV Proton Synchrotron (PS) machine with a separated function synchrotron PS2 has been identified as an important part of the future upgrade of the CERN accelerator complex [1,2]. The PS2 will require the design of a number of beam transfer systems associated with injection, extraction, beam dumping and transfer. The different requirements are briefly presented. A first iteration of the conceptual design aspects of these systems is presented, based on the initial PS2 parameter set [3] and assuming a simple 90-degree phase advance FODO lattice. The required equipment sub-system performance is derived and discussed, and possible limitations are analysed. The impact on the overall design and parameter set is discussed, together with some recommendations for the direction of the continuing studies.

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ABSTRACT

The replacement of CERN's existing 26 GeV Proton Synchrotron (PS) machine with a separated function synchrotron PS2 has been identified as an important part of the future upgrade of the CERN accelerator complex [1,2]. The PS2 will require the design of a number of beam transfer systems associated with injection, extraction, beam dumping and transfer. The different requirements are briefly presented. A first iteration of the conceptual design aspects of these systems is presented, based on the initial PS2 parameter set [3] and assuming a simple 90-degree phase advance FODO lattice. The required equipment sub-system performance is derived and discussed, and possible limitations are analysed. The impact on the overall design and parameter set is discussed, together with some recommendations for the direction of the continuing studies.

INTRODUCTION TO PS2

The existing CERN PS is a combined-function synchrotron with an injection energy of 1.4 GeV and a top energy of 25 GeV. It forms the core of the CERN complex, presently providing proton beams for the SPS Fixed Target (FT) programme including CNGS, the LHC beam for the SPS, physics beams for the East Hall, high intensity proton beams for neutron time-of-flight facility nTOF, antiproton production beams for the Antiproton Decelerator and heavy ion beams for the LHC physics programmes. The PS first accelerated beams to high energy in 1959, and although its performance has outstripped the initial design goals by an incredible margin, aging of PS machine components affecting reliability, and stray radiation from beam losses have in recent years become limiting factors in the performance of the CERN complex [4]. Major renovation programmes have been started to address the most debilitating issues, but the age, design and location of the PS are all factors which cannot be overcome. In addition, the requirements for production of the very high brightness LHC beams and the very high intensity CNGS beams have proved difficult to meet for a variety of reasons associated with the PS fundamental design and technological limitations.

For these reasons the replacement of the existing PS with a modern, reliable, flexible and robust synchrotron has been identified as an important part of the future upgrade programme of the CERN accelerator complex, both to allow efficient and reliable exploitation of the SPS and LHC machines, and to provide extra potential for LHC performance upgrades [5]. Main design goals include low radiological impact, significantly improved performance, flexibility for possible future applications and upgrades, very high reliability and availability and compatibility with staged upgrade programme and with the ongoing LHC exploitation during the construction.

The 'basic' parameters of the machine are the circumference, the injection and extraction energies, the dipole field, the aperture, the transition energy and the lattice type. For a first iteration a separated function machine is assumed, with a circumference of 1260 m (twice that of the existing PS) and an initial parameter set for the preliminary conceptual studies as given in Table 1. It is to be noted that the injection energy is assumed to be 3.5 GeV, but that as low as 1.3 GeV may be required to be able to accept heavy ions from the LEIR machine. The PS2 extraction energy is assumed to be 50 GeV: depending on the eventual choice of normal or superconducting magnet technology (which could affect the energy reach) this could increase to around 75 GeV.

Table 1. Main PS2 design parameters

Injection energy	GeV	3.5
Extraction energy	GeV	50
Circumference	m	1256.6
Injection B.ρ.	T.m.	14.5
Extraction B.ρ.	T.m.	169.9
Maximum beta function	m	35
Revolution period at injection	μs	4.289
Revolution period at extraction	μs	4.192
Beam intensity	p+	1.2×10^{14}
Cycle period	s	2.4

BEAM TRANSFER REQUIREMENTS

In order to meet the beam transport requirements for the different beams and clients, and also to ensure that the limitations on beam losses and activation are respected, it is assumed that the following systems are required:

Injection

- Fast single-turn injection of ions at 1.3 GeV, for LHC beams, and of protons at 3.5 GeV, for LHC beams, PS2 FT beams and SPS FT beams;
- Multi-turn H^- injection of protons at 3.5 GeV, for PS2 FT beams, SPS FT beams and LHC beams.

Extraction

- Fast single-turn extraction of protons and ions at 50 GeV, for LHC beams;
- Slow 3rd integer resonant extraction of protons at 50 GeV, for PS2 FT beams;
- Low-loss 5-turn continuous transfer of protons and ions at 50 GeV for SPS FT beams.

Beam dumps

- A fast single-turn 'emergency' beam dump;
- Beam dump blocks in transfer lines, for setting-up.

Beam transfer lines

- The injection line able to accept 1.3 GeV ion beams and 3.5 GeV proton beams;
- A line to the SPS, for 50 GeV protons and ions;
- Extraction lines to experimental areas, for 50 GeV protons.

BASIC ASSUMPTIONS

Layout and lattice

In addition to the basic PS2 design parameters listed above a number of assumptions have been made, in order to allow a first conceptual definition of the various beam transfer systems and quantitative estimates to be made concerning deflection angles, apertures, numbers of extraction elements and installed lengths. The main assumption concerns the lattice, and in particular the long straight sections available for injection and extraction. For simplicity the conceptual systems presented here have been evaluated on the basis of the following assumptions:

- Regular FODO cell structure in the injection and extraction regions;
- Phase advance of ≈90º per cell;
- β-functions in the range 6-33 m;
- 21 m cell length;
- 7 m 'free' drift per half-cell available to accommodate beam transfer elements (which could be increased to about 8.5 m if absolutely required);
- Local dispersion function matched to $|D_x| < 0.5$ m.

Acceptance and aperture requirements

The kicker and septum apertures/elements are kept outside a canonical half-aperture of 50 mm at a β of 33 m, which corresponds to about 300 π.mm.mrad geometric acceptance in the horizontal plane. In the vertical plane the acceptance is assumed to be defined by the main dipole full aperture of 100 mm at a β of 33 m, which again gives a geometrical acceptance of about 300 π.mm.mrad.

Lattice quadrupoles

To provide enough aperture in the injection and extraction regions, it is assumed that the design will use enlarged quadrupoles where needed (denoted QFE and QDE). These are assumed to have 85 mm radius good field regions, compared to 50 mm for the regular quadrupoles. In addition, it is proposed that the extraction trajectories can be via openings in these coils as is the case for the SPS, Fig. 1, with the beam experiencing only linear fields in this case. The field in the horizontal plane in the gap and the coil window of such an SPS magnet is shown in Fig. 2.

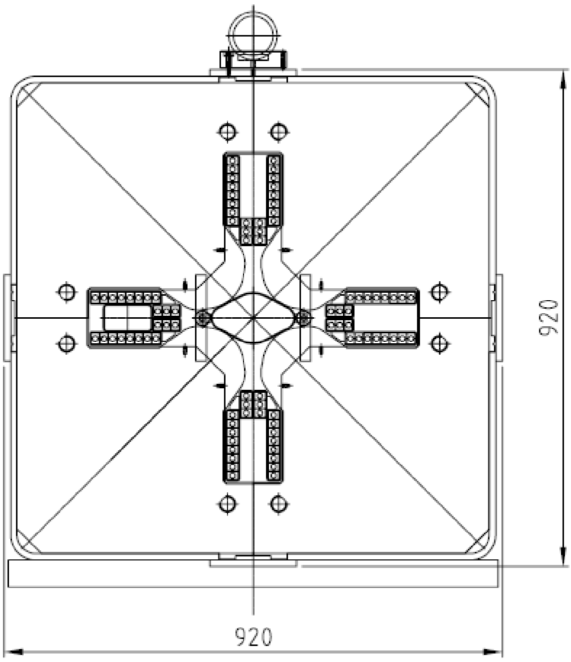

Figure 1. Enlarged SPS quadrupole with coil window passage for injected/extracted beams.

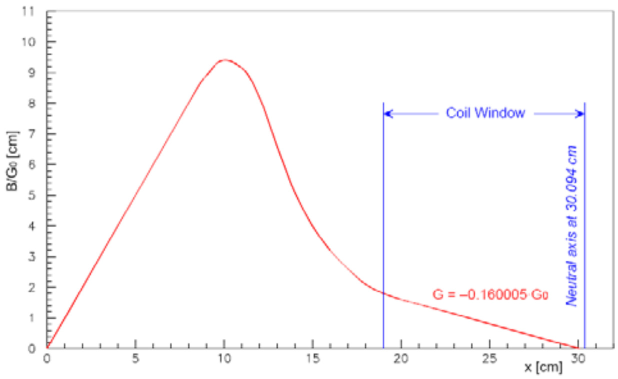

Figure 2. Field profile for enlarged SPS quadrupole, showing linear field in coil window region.

To estimate the injection and extraction angles required, the lattice quadrupole yokes are assumed to be 700×700 mm for standard types, and 900×900 mm for enlarged types. The enlarged types are assumed to be 20 % longer that the regular types.

Beam characteristics

The H/V circulating beam emittances are assumed to be 15 and 8 π.mm.mrad, respectively. From the SPL [6], the H^- beam emittance is assumed to be 1 π.mm.mrad. With an intensity of 1.2×10^{14} p+, the stored beam energy is 1 MJ.

INJECTION SYSTEM CONCEPTS

Fast single-turn p+/ion injection

A classical single-turn type injection system (orbit bump, septum, fast kicker) with variable kick length is needed from the very beginning, when PS2 will operate with the present injectors, and will in any case always be needed for ion operation. The main requirements are:

- The system will have to cover the energy range from 1.3 GeV (proton equivalent for ion injection from LEIR) to 3.5 GeV, i.e. a maximum magnetic rigidity of Bρ = 14.5 Tm;
- For the fast kicker the required pulse length is up to 2.5 μs, with rise and fall time of ≤100 ns;
- The maximum vertical beam size (3σ) at injection will be ±25 mm.

With these requirements a fairly simple injection system can be envisaged, Fig. 3, with a pulsed septum and a fast kicker. At these low energies, and with a 1.3 GeV beam which basically fills the acceptance, there does not seem to be a need for an injection bumper system, although this might be an interesting option to reduce the kick strength needed at higher energy.

The lattice requirements are for 2 half-cells, with one QDE in the centre.

Multi-turn H^- injection

An H^- charge exchange injection system will be needed if the PSB is replaced with an SPL type machine and not an RCS. This system will consist of an injection septum, similar or identical to that described above, short special dipoles, the stripping foil, and a system of fast orbit bumpers in the PS2 machine for phase-space painting during the injection process (≤100 turns i.e. ≤500 μs). The vertical painting could be replaced by fast steering of the vertical injection trajectory. The stripping efficiency of a foil of about 400 μg/cm^2 density at 3.5 GeV is expected to be about 95 % [7]. For the initial PS2 parameters this gives about 5 kW of unstripped H^0/H^- to be dumped. For beam loss management reasons, it is assumed that this will need an external dump, which imposes the use of secondary stripping foils, an extraction septum and a short transport line. A preliminary configuration is shown in Fig. 4.

The example given here is based on a 3.5 GeV injected beam. For higher energies, or even for this energy, a more detailed analysis may show that a dedicated non-FODO insertion is required – for instance, in the SNS, the H^- injection system at 1.3 GeV takes up one of the four long straights, a total of 32 m in the lattice [8]. This insertion has two quadrupole doublets, two 6 m long short straights and one long 12 m long straight housing the injection chicane.

The issues here for the layout are the maximum dipole field the H^- beam can traverse, to avoid magnetic stripping (SNS: <0.3 T for 1 GeV), together with the maximum allowed beam loss rate.

The lattice requirements are assumed to be 3 half-cells, with one QFE and one QDE in the centre.

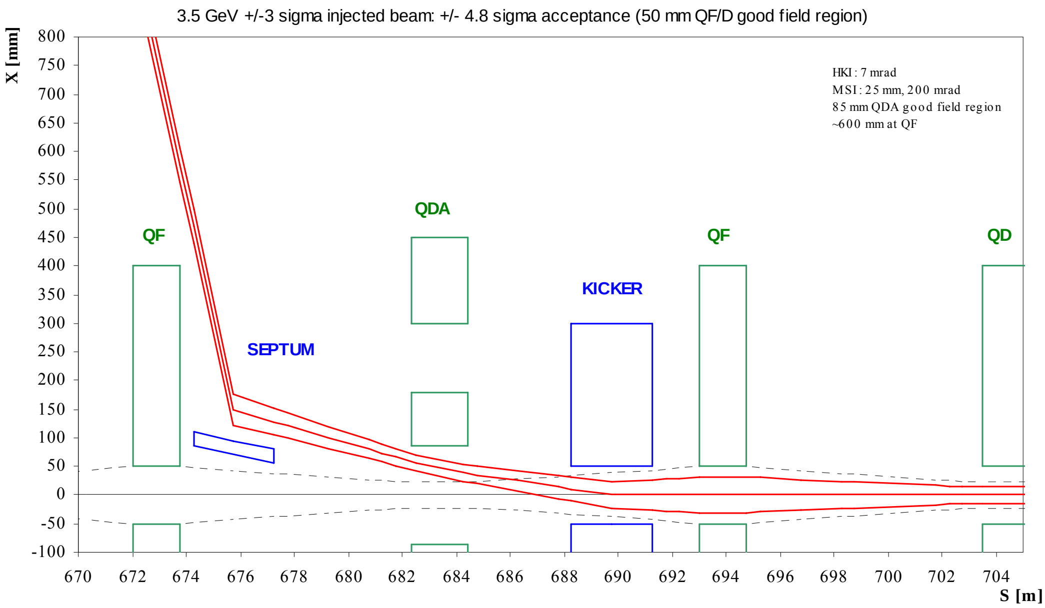

Figure 3. Elements, beam trajectories and envelopes for a fast injection at 3.5 GeV. The limits of the quadrupole good field regions are shown.

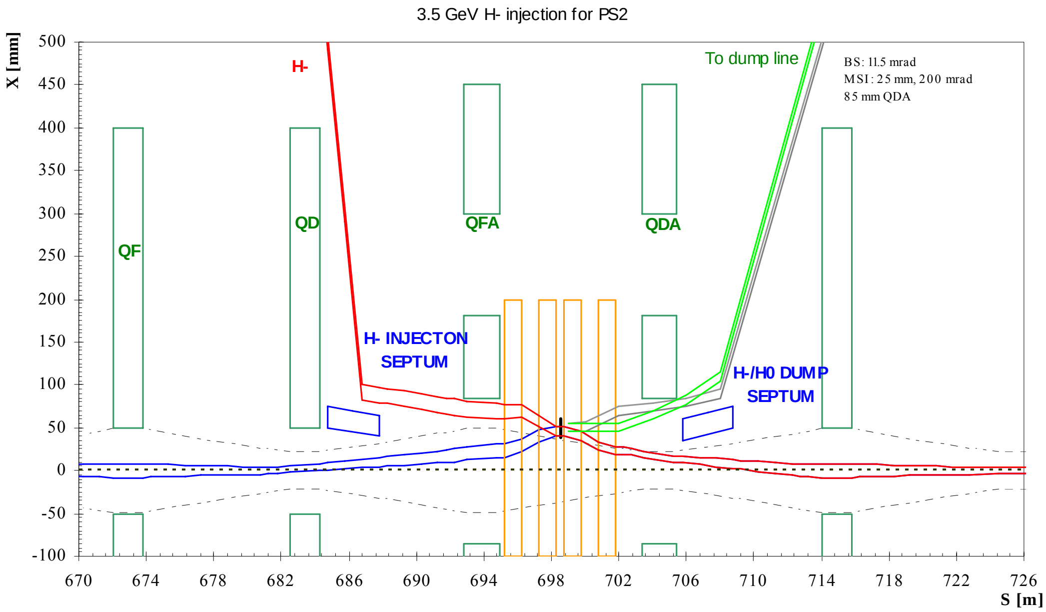

Figure 4. Elements, beam trajectories and envelopes for an H^- injection at 3.5 GeV.

EXTRACTION SYSTEM CONCEPTS

The extraction elements have all been placed in a single straight section, which enables the possibility to re-use many of the elements for the different extraction types, in particular the horizontal kickers HK and the magnetic septa MS.

Fast single turn extraction

A classical fast extraction system (orbit bump, septum, fast kicker) with variable kick length is needed as principal extraction system. (The system should be combined with an island (or CT) extraction system allowing for four- or five-turn extraction towards the SPS.) The system has to be designed for variable extraction energies up to 50 GeV, i.e. a maximum magnetic rigidity of Bρ = 170 Tm. The fast extraction uses a closed orbit bump to move close to the septum, then one of the two HK systems to extract the beam, Fig. 5. The HK2 system is assumed also to be used for extraction of last turn in the CT process.

The systems needed are:

- Fast extraction kicker system providing ~1.6 mrad;
- Thin, medium and thick extraction septum magnets (pulsed), providing ~40 mrad;
- Horizontal orbit bumpers, providing ~1.2 mrad;
- For the fast kicker the required pulse length is 4.2 µs, at a rise time of ≤150 ns;
- For CT extraction fast bumpers, the pulse length requirements are 21 µs (first step, five turns) and 4.2 µs (second step, one turn) with rise times of ≤150 ns;
- Maximum vertical beam size (3σ) at extraction (injection) will be ±7 (±25) mm.

3rd integer resonant (slow) extraction

A slow extraction system for physics from the PS2 is also needed. This system will require multipole magnets, an orbit bump, electrostatic and magnetic septa. The system should allow for extraction spills of around one second. The system also has to be designed for variable extraction energies up to 50 GeV, i.e. a maximum magnetic rigidity of Bρ = 170 Tm.

The extraction is assumed to be based on a classical 1/3 integer scheme, using an electrostatic and several DC magnetic septa, Fig. 6. The jumps across the ES on the separatrix are assumed to be in the range 10 – 15 mm, allowing an ES gap of 17 – 20 mm. The small opening at the downstream MS mean that a series of 3 MS magnets with increasing coil thickness and strength are needed to give a sufficient extraction angle of about 40 mrad, to reach the coil window gap at the downstream QD.

Systems needed are:

- Thin electrostatic septum, providing ~1.2 mrad;
- Thin, medium and extraction septum magnets (‘DC’), providing ~40 mrad;
- Horizontal orbit bumpers, providing ~1.2 mrad;
- Special sextupole magnets in the lattice at suitable phases;
- Some passive shielding of elements downstream of the ES.

The ES is located about 270º in phase upstream of the MS, to allow space for the kicker elements in the intervening half-cells.

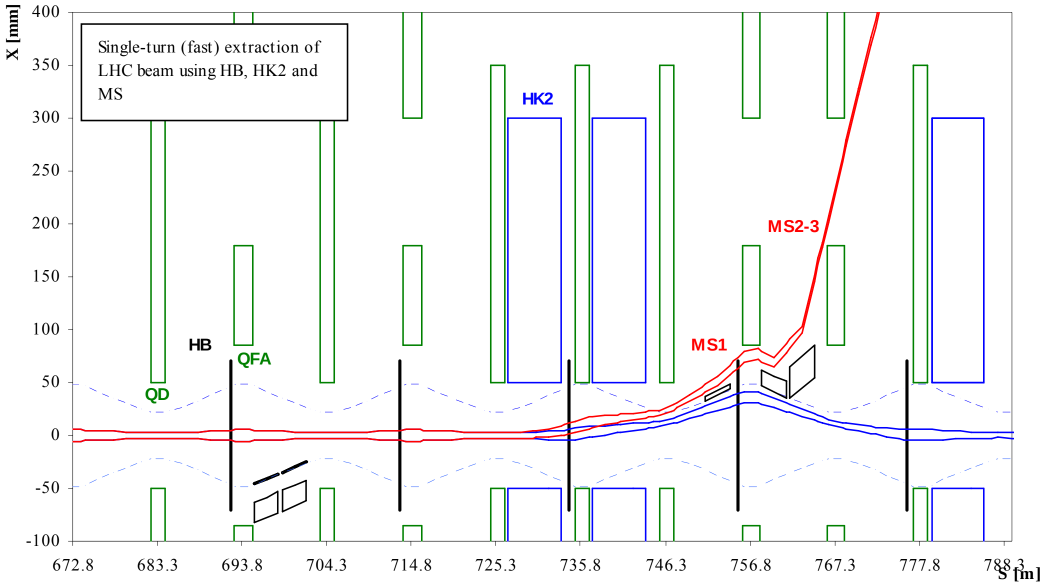

Figure 5. Elements, beam trajectories and envelopes for a fast extraction at 3.5 GeV.

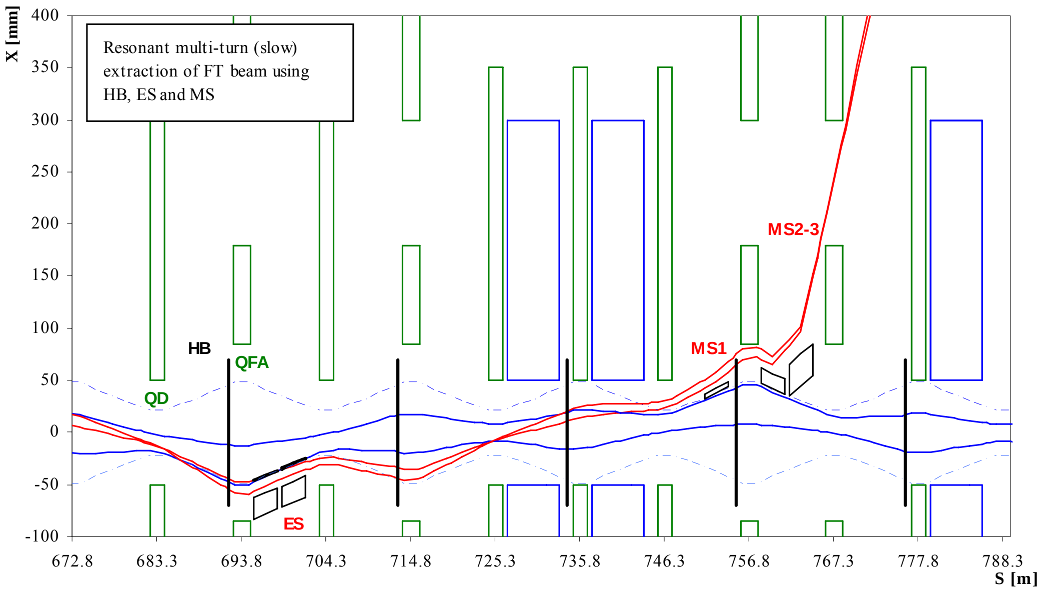

Figure 6. Elements, beam trajectories and envelopes for a 3rd integer resonant (slow) extraction at 3.5 GeV.

Low-loss 5 turn continuous transfer (MTE)

A continuous transfer extraction is considered, based on non-linear fields to allow beam to be captured in stable islands to produce a physical separation at the entrance of the extraction septum, as proposed for the CERN PS [9]. Extraction then takes place at a quarter-integer tune. Systems needed are:

- Fast bumper kicker systems (5 turns – 21 μs) rise time of 150 ns, 1.6 mrad;
- Fast extraction kicker system (1 turn – 4.2 μs) rise time of 150 ns, 1.6 mrad;
- Thin, medium and thick septum magnets, ~40 mrad;
- Special multipole magnets.

In the scheme outlined, there are two series of HK kicker/bumper magnets. The first is installed 90 degrees up and downstream of the MS, Fig. 7, and provides a closed bump over the first 4 turns of the extraction, during which the beam in the islands are extracted. The second system is then pulsed; this is for one turn only, and can extract the beam remaining in the central island. This would allow to fill the SPS with a single extraction from the PS2.

Issues could include horizontal compensation of the slightly different 5th turn extraction trajectory by a smaller HK unit in the transfer line, which could be located at the correct phase, and pulsed together with HK2.

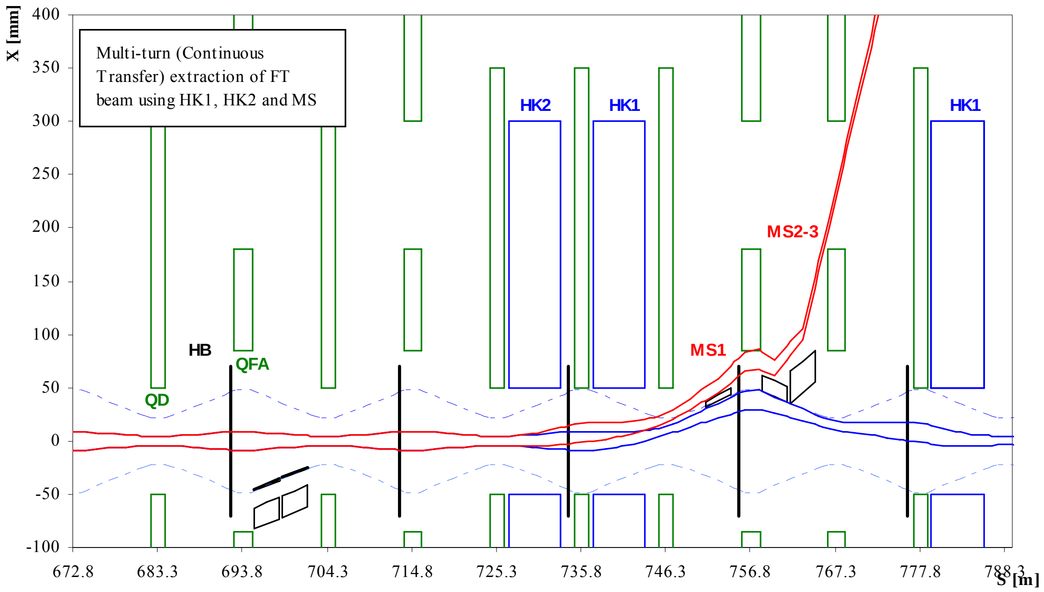

Figure 7. Elements, beam trajectories and envelopes for a 5-turn low loss island CT (MTE) extraction at 3.5 GeV.

Inverting positions of ES and HK1 and 2 would allow to use the ES in the CT process – which might open the possibility of a combined CT/slow extraction, with a thin ES for low losses during the few turn extraction, to overcome the HK strength limitation.

Overall lattice implications

In the studied version with all extraction systems in one straight, a total of 9 half-cells are required, in addition to some short bumper magnets slightly further out in the lattice. If the slow extraction is made in a separate system in another straight, the total space is still 9 half-cells, with 6 needed for the joint fast/CT extractions and 3 for the slow.

BEAM DUMP SYSTEM CONCEPTS

Emergency dump

A beam dump system will be required to safely dispose of the 1.0 MJ of beam energy. Either an internal dump, or an external dump could be envisaged. An external dump resembles the fast extraction channel described above, with the difference that the aperture must be large enough to accept the beam at injection energy. This imposes difficult constraints for the extraction septa, including much larger gaps and energy tracking of the beam. An internal dump is easier to implement and more compact, but potentially poses more problems in operation due to intense local activation. A horizontal or vertical system could be envisaged – the latter is shown in Fig. 8. At these low beam energies the beam dump is not expected to pose any technological problems; however, the issues of elements with high activation in the ring need to be considered, in addition to the problems which might arise from the necessary proximity to the beam dump kicker magnets.

For equipment specification it is assumed that similar parameters and designs to the extraction system kickers (and eventually septa) can be used, and so these are not treated in detail. Possible economies in space and cost could be envisaged e.g. by having a bipolar extraction kicker which has a separate supply for the beam dump.

For the lattice, 2 or 3 half-cells are required for an internal or external beam dump, respectively.

Transfer line dumps

A series of dumps will be required for the transfer lines, to enable setting up of the injection and extraction systems and of the lines themselves, and for personnel protection reasons when accessing downstream accelerator zones. These objects will be movable and dimensioned according to the beam energy, power and intensity which will be needed; detailed studies are needed and space needs to be foreseen in the layouts, but no specific technical concerns are expected.

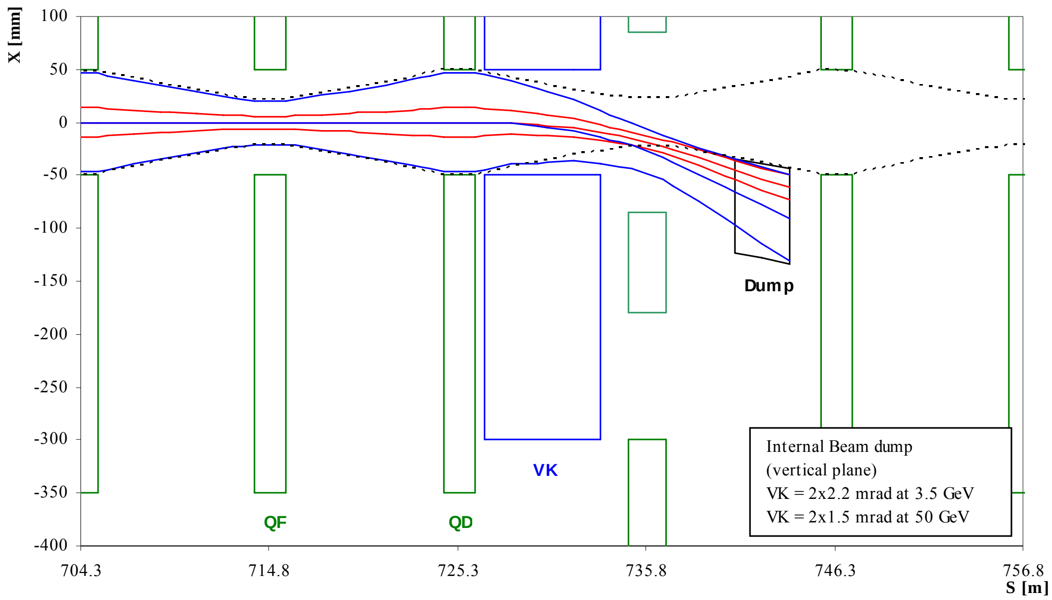

Figure 8. Elements, beam trajectories and envelopes for an internal beam dump (vertical plane) at 3.5 and 50 GeV.

SUMMARY OF EQUIPMENT REQUIREMENTS AND PARAMETERS

Injection kicker

- Request about 100 ns rise/fall time;
- Need about 7 mrad deflection (120 mm offset with average β of 25 m and sinΦ of 0.7), determined by the QDE good field region, the beam size and the septum width;
- 16.6 Ω system operating at maximum of 65 kV to give ~100 ns rise time and 0.101 Tm, in 5.4 m installed length.

Table 2. Injection kicker parameters.

Injection kicker HKI		3.5 GeV
Angle	mrad	7.0
Required B.dl	T.m	0.101
Magnetic length	m	4.1
Installed length	m	5.4
System Impedance	Ohm	16.6
Rise/fall time	ns	100.0
Pulse length	µs	4.5
Aperture height (with screen)	mm	90.0
Aperture width (with screen)	mm	120.0
Maximum voltage	kV	58.7
Peak current	kA	1.77
Peak field	T	0.025

Injection septum

- Need about 200 mrad (2 m lever arm, 400 mm deflection to miss adjacent quad);
- Septum width about 22 mm;
- With the aperture available this can be a 3 m long out-of-vacuum magnet, with 16 turn coil and slowly pulsed.

Table 3. Injection septum parameters.

Injection Septum MSI		3.5 GeV
Angle	mrad	200
Required B.dl	T.m	2.89
Magnetic length	m	3.0
Installed length	m	3.5
Gap height	mm	80.0
Current	kA	3.8
Septum width	mm	22.0
Peak field	T	0.96

Thick magnetic septum (extraction magnet)

- Need about 25 mrad (5 m lever arm, 125 mm additional deflection needed to extract the beam out through a suitable quadrupole coil window);
- Septum width about 30 mm;
- Can probably make this outside vacuum with several turns (assumed 12);
- Limit is 1.5 T in gap (saturation);
- Space required at 75 GeV goes to about 4.7 m (from 3.5 m at 50 GeV).

Table 4. Thick extraction septum parameters.

Extraction septum MS3		50 GeV
Angle	mrad	25
Required B.dl	T.m	4.25
Magnetic length	m	3.0
Installed length	m	3.5
Gap height	mm	30.0
Current	kA	4.1
Septum width	mm	5.0
Peak field	T	1.42

Intermediate magnetic septum

- Need about 13 mrad (2 m lever arm, 25 mm additional opening at MS3);
- Septum width about 15 mm;
- Technological limit is ~40 A/mm^2 current density in septum coil (0.9 T);
- Space required at 75 GeV goes to about 4.2 m (from 3.5 in 50 GeV version).

Table 5. Intermediate extraction septum parameters.

Intermediate septum MS2		50 GeV
Angle	mrad	13
Required B.dl	T.m	2.21
Magnetic length	m	3.0
Installed length	m	3.5
Gap height	mm	15.0
Current	kA	21.7
Septum width	mm	15.0
Peak field	T	0.74

Thin magnetic septum

- Need about 2.5 mrad (4 m lever arm, 10 mm additional opening at MS2);
- Septum width about 5 mm;
- Limit is ~40 A/mm^2 current density in septum coil (0.18 T);
- Space required at 75 GeV goes to about 4.2 m (from 3.5 in 50 GeV version).

Table 6. Thin extraction septum parameters.

Thin septum MS1		50 GeV
Angle	mrad	2.5
Required B.dl	T.m	0.42
Magnetic length	m	3.0
Installed length	m	3.5
Gap height	mm	
Current	kA	
Septum width	mm	31.4
Peak field	T	0.14

Electrostatic septum

- Need about 1.2 mrad to give 12 mm opening at MS1 (assuming 15 m average β and sinΦ ~0.7);
- Septum width assumed to be 0.1 mm;
- Technological limit is field in gap (maximum of about 10 MV/m);
- Space required at 75 GeV goes to about 9.5 m (from 7.0 m in 50 GeV version).

Table 7. Electrostatic extraction septum parameters.

Electrostatic septum ES		50 GeV
Angle	mrad	1.2
Required E.dl	MV	60
Electrical length	m	6.0
Installed length	m	7.0
Gap width	mm	20.0
Electric field	kV/cm	100.0

Extraction and bump kickers

- Need about 1.6 mrad to give 16 mm opening at MS1 (assuming 15 m average β and sinΦ ~0.7);
- Rise time assumed to be 150 ns – determined basically by inductance of the magnet $L = \mu_o$ w.l/g;
- Characteristic system impedance assumed to be 10 Ω;
- Design for a maximum of 65 kV switch voltage;
- Space required at 75 GeV goes to about 9.5 m (from 7.0 m in 50 GeV version).

Table 8. Extraction and bump kicker magnet parameters.

Extraction/bump kicker HK		50 GeV
Angle	mrad	1.6
Required B.dl	T.m	0.27
Magnetic length	m	6.0
Installed length	m	7.1
System Impedance	Ohm	10.0
Rise/fall time	ns	150.0
Pulse length	μs	24.5
Aperture height (with screen)	mm	90.0
Aperture width (with screen)	mm	120.0
Maximum voltage	kV	67.4
Peak current	kA	3.37
Peak field	T	0.047

Slow extraction bumper magnets

- Need about 1.6 mrad to give 25 mm bump at ES/MS1 (assuming 15 m average β and sinΦ ~0.7);
- Classical many-turn short dipoles – assume 0.3 m magnetic length;
- Some enlarged H^- aperture versions will be needed;
- Technological limit is 1.5 T field in gap (saturation);
- Space required at 75 GeV stays at about 0.4 m.

Table 9. Slow extraction bumper magnet parameters.

Extraction bumper HB		50 GeV
Angle	mrad	1.6
Required B.dl	T.m	0.27
Magnetic length	m	0.3
Installed length	m	0.4
Gap height	mm	100.0
Peak field	T	0.906

TRANSFER LINE SYSTEMS

The detailed requirements of the transfer lines will clearly depend on the choice of experimental area, orientation and injection/extraction types. Assuming that part of the existing TT2/TT10 line could be used to transfer for 3.5 (1.3) GeV beams into PS2, one issue is the acceptance of this line, designed for higher energy. Another important question which affects the positioning of the PS2 machine is the length of 50 GeV transfer line needed for matching into the SPS – the PS2 optics with beta-functions of about 35 m needs matching into the SPS with beta-functions of about 110 m – in addition it is probable that this line will accommodate a final stripping foil for converting the partially stripped Pb ions to Pb^{82+}. In this case a low-beta insertion will be needed to minimise transverse emittance blow-up.

OVERALL SPACE AND LAYOUT IMPLICATIONS

The total space required in the lattice for the beam transfer systems depends on the injection and extraction energy of the machine, the number of injection and extraction lines plus the layout with regard to beamline orientation. The basic requirements detailed above amount to about 14 half-cells – however, this number can change depending on which systems are combined where, since in general the septa and kicker are advantageously located near QF elements. In the example shown in Fig. 4, a total of 13 half-cells are required for the two injection systems and the extraction system without slow extraction, with several unused half-cells scattered through the straight. Overall, it seems a reasonable assumption that about 14-18 half-cells will be needed, which is of the order of 150 m of straight section.

DISCUSSION OF SCALING TO 75 GEV

Extraction and bump kickers

The space required for the HK at 75 GeV goes to about 9.5 m (from 7.0 m). This could be a problem with the initial parameters, as the length required for the kicker module will not fit in a single half-cell – this system is already close to the limit for the 50 GeV version. Here the requirements on the very fast rise time (150 ns) mean that the system has to have a relatively high characteristic impendence or be split into a larger number of short magnets, increasing the complexity and cost. This reduces the strength (current) of the magnet for a given applied voltage. Possible improvements could be obtained by:

- Reducing the characteristic impedance to 8.3 or 7.1 Ω would mean 7.2 m magnetic or 5.4 m magnetic (but rise would increase to 190 or 250 ns, Table 10);
- Reducing the vertical gap AND horizontal gap proportionately, since this keeps the inductance of the system and hence the rise time for a given current, while increasing the field. Note that just reducing the vertical gap does not work, as this increases the magnet inductance & hence rise time;
- Reducing the required subsystem deflection by extracting first across an ES during the CT extraction and using both the bump and extraction kicker systems for the fast extraction.

Table 10. Scaling of kicker strength, magnetic length and rise time with characteristic impedance.

50 Ω cables	Impedance Ω	rise time ns	current kA	Field mT	Length m [50 GeV]	Length m [75 GeV]
1	50.0	30	0.6	9	30.0	45.0
2	25.0	60	1.3	18	15.0	22.5
3	16.7	90	1.9	27	10.0	15.0
4	12.5	120	2.6	36	7.5	11.3
5	10.0	150	3.2	45	6.0	9.0
6	8.3	180	3.9	54	5.0	7.5
7	7.1	210	4.5	63	4.3	6.4
8	6.3	240	5.2	72	3.8	5.6
9	5.6	270	5.8	81	3.3	5.0
10	5.0	300	6.5	90	3.0	4.5
11	4.5	330	7.1	99	2.7	4.1
12	4.2	360	7.8	108	2.5	3.8

Magnetic extraction septa

- Thick extraction magnet version: space required at 75 GeV goes to about 4.7 m (from 3.5 m);
- Intermediate version: space required at 75 GeV goes to about 4.2 m (from 3.5m);
- Thin version: space required at 75 GeV goes to about 4.2 m (from 3.5 m).

Electrostatic septum

- Space required at 75 GeV goes to about 9.5 m (from 7.0 m in 50 GeV version). This is above the limit for one half-cell, and could pose a problem, since it will not be possible to distribute this element in two half-cells.

Slow extraction bumper magnets

- Space required at 75 GeV stays at about 0.4 m.

CONCLUSION AND FUTURE WORK

A first study has been made of some aspects of the beam transfer concepts for the PS2 accelerator. This has given some idea of the implications of the chosen parameters for the equipment, and of the possible problems and limitations which may be encountered. Particularly challenging aspects appear to be the H^-

injection at 3.5 GeV, the very fast rise times requested for the fast/CT extraction kickers, especially if a 75 GeV extraction energy is required, and the length of electrostatic septum needed for the slow extraction, again if 75 GeV extracted is needed.

Topics of future studies concerning these beam transfer aspects are of course numerous and depend strongly on the evolution of the overall machine studies – however, areas identified which will be pursued meaningfully in the short-term are the issues surrounding the H^- injection, the effect of different lattices (e.g. requirements with a FODO structure with 60º, 75º per half-cell), possible improvements in the extraction concepts to relax the kicker strength limits, a more detailed investigation of the requirements for the low-loss CT extraction and slow extractions (including multipole magnet types, strengths and phases), possible bipolar kicker system for an internal beam dump, and the length of transfer line needed to match to the SPS. Moreover, some of these affect directly the machine layout, location and main parameters such as straight section requirements, and hence are an integral part of the overall design effort, even at an early stage.

There are also several possible directions of R&D which could help overcome some of the limitations identified above. A detailed breakdown of the possibilities and the potential gains is beyond the scope of this note: a preliminary list of topics and sub-topics is given below:

- Impedance and shielding;
  - Ceramic chamber coatings, surface treatments, geometries, effect on rise times;
  - Ferrite surface treatments, stripes;
- Switch technology: fast solid state high current devices;
- High Voltage technology: flashover under vacuum (magnets, connectors, ceramic chambers);
- Magnetic materials;
  - High saturation ferrites;
  - High Currie-temperature vacuum-compatible ferrites;
  - Ultra-thin laminations, tape-wound cores;
  - Nano-crystalline materials;
- Coil technology: in-vacuum insulation.

Clearly, the requirements are sometime contradictory (for example fast rise times and increased kicker strength) and the potential solutions invariably involve compromises, which furthermore have to take into account various design considerations such as bakeout, vacuum quality, etc. These complications and inter-dependencies mean that that the research and development efforts must be made in parallel and in a coordinated way, and towards well-defined goals.

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