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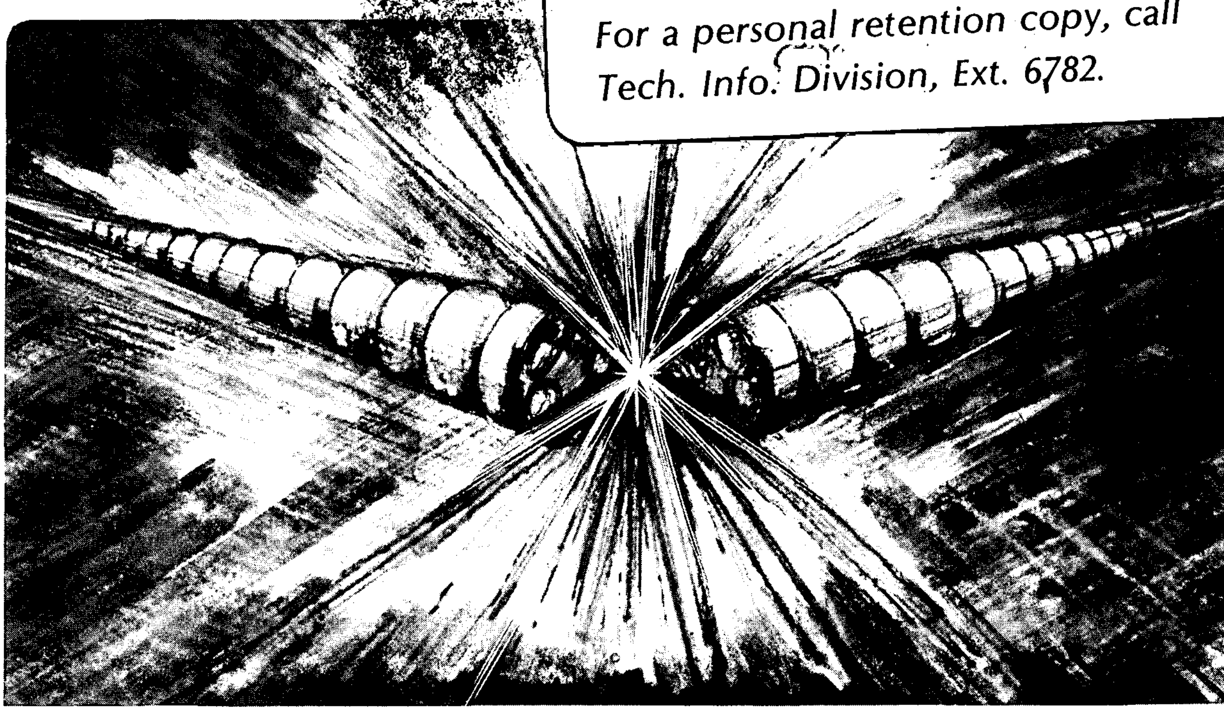

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Introduction

The subject of beam extraction and abortion from a 20 TeV accelerator has been explored by one working group at the 2nd ICFA workshop[1)] in 1979. This study concluded that the design of a fast extraction channel is relatively straightforward, and involves conventional extraction channel elements. Similarly, in a contribution to the present proceedings, Wille[2)] comes to the same conclusion with regard to a 1 TeV injection channel for the SSC. In this paper we demonstrate the feasibility of implementing injection and extraction channels into the 6.5 Tesla sample lattice designed by Garren[3)] using hardware parameters as suggested in refs. 1) and 2). Finally, an attempt is made to estimate the required beam size at the beam dump and its consequences for the transfer line optics are considered.

Lattice

A detailed discussion of the 6.5 Tesla sample lattice is found in Garren's[3)] contribution to these proceedings. Topology and major features are evident from the schematic shown in fig. 1. The lattice with superperiodicity 3 has 6 interaction regions located at the center of the mirror-antisymmetric insertions, which provide sufficiently long open space sections to accomodate injection and extraction elements: Each half-insertion provides two driftspaces of 305 m and 186 m length, respectively, and two 76 m drift spaces located in the dispersion suppressor cell.

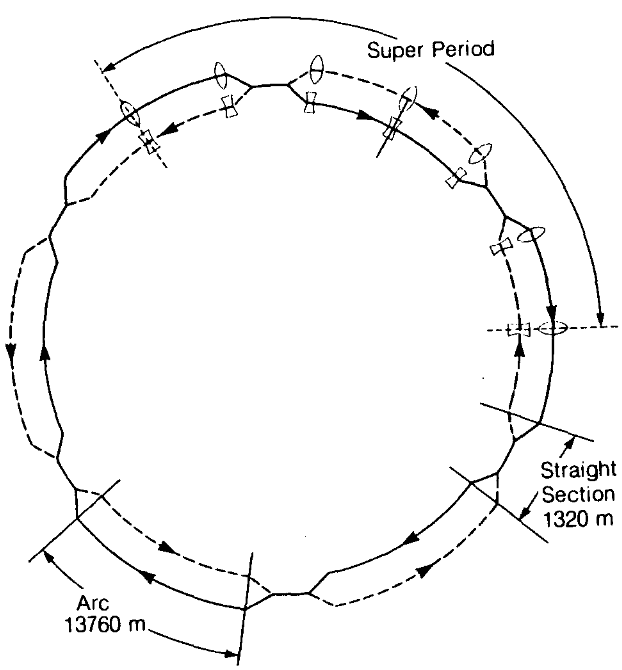

Fig. 1 Schematic of 6.5 Tesla sample lattice as given in ref. 3.

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Injection

In choosing the injection channel elements for the SSC Wille's[2)] parameters have been adopted: Two 10 m long magnetic septa of 1T and 0.2T strength, operated in a dc-mode, are followed by a 15 m long pulsed kicker magnet with a maximum strength of 0.13T. Arranged in a driftspace the overall length of the injection channel amounts to 110 m. The "bunch into bucket" transfer from the 1 TeV injector to the SSC with a bunch separation as short as 15 m requires a kicker rise time better than 50 ns.

Some of the factors to consider in selecting a particular injection scheme are:

i) The injected beam must enter the collider beyond the interaction point in order to protect the experimental equipment in case of a malfunction of the injection elements.

ii) Superconducting magnets in the vicinity of the injection channel have to be replaced by conventional magnets or protected against quenching during a malfunction of the injection elements.

iii) Minimizing the total bending angle and length of the injector-collider transfer line will reduce the cost of the beam transfer system.

iv) Optically identical transfer lines and injection channels for the two collider rings are desirable.

Fig. 2 shows a possible horizontal, symmetric injection scheme, where the injection channels are located in the dispersion suppressor cell at either end of the insertion. In this scenario the two magnetic septa are placed in the first half and the kicker in the second half of this cell. The injected beam passes 1 cm off center through the center quadrupole of this cell. For reasons mentioned above this quadrupole has to be replaced by a conventional magnet. The total bending angle for each transfer line is 90°. Assuming that collider ring dipole magnets of 6.5T strength and 15 m length are used, 51 such magnets are required per transfer line.

The total bending angle can be drastically reduced by reversing the injector field after one collider ring has been filled. This scheme is shown in fig. 3. In this case the injection channel is located in the 186 m long open space of the insertion straight section. With the generous separation of 30 m between injector and collider to avoid interference with detectors the total bending angle per transfer line is 7.1°, requiring only 4 collider ring magnets and reducing the transferline length by a factor of 2 as compared to the conventional scheme above.

An additional advantage of this scenario is that the injection channel does not share any optical elements with the collider ring. The injector, however, requires two injection and extraction systems and a cost estimate is required to determine if such a system is cost efficient.

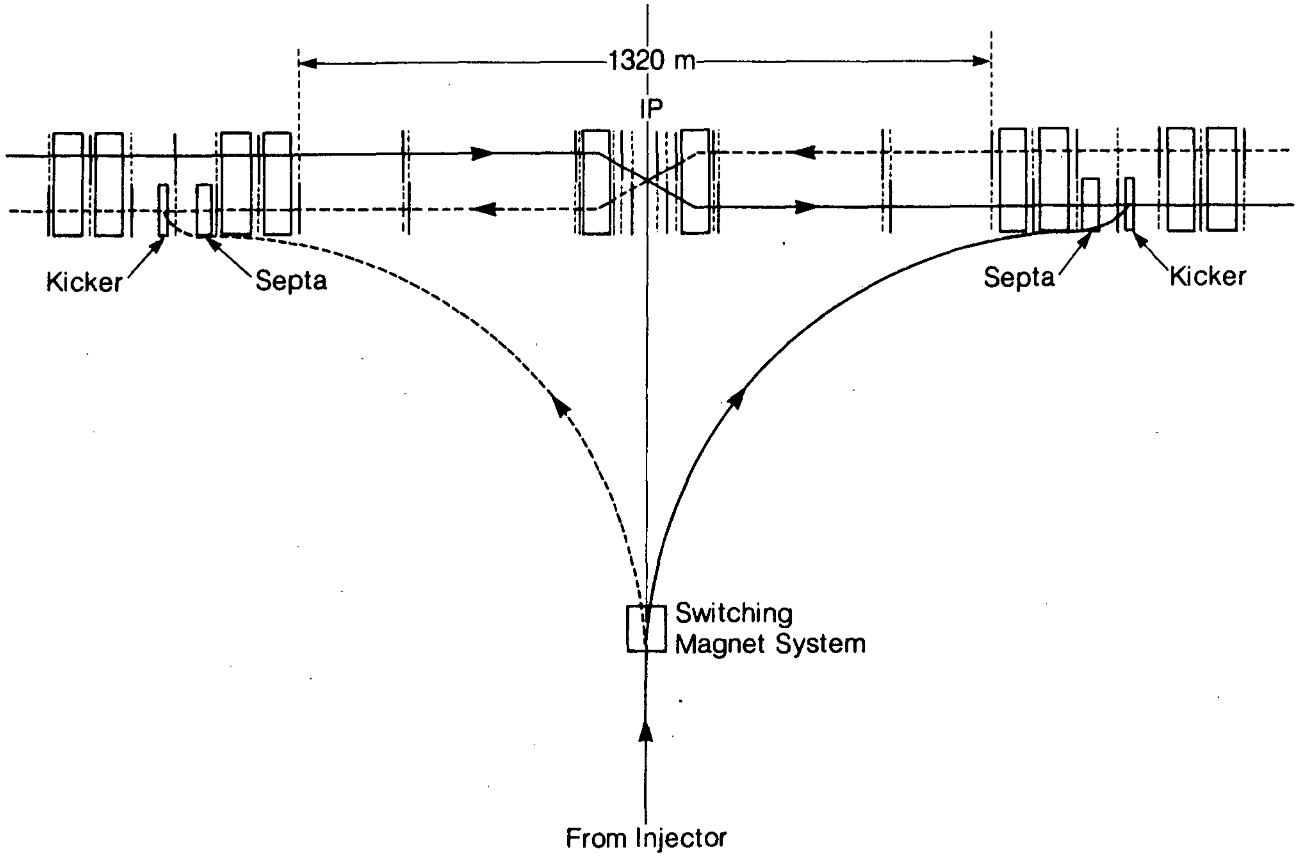

Fig. 2 Injection scheme for 6.5 Tesla sample lattice.

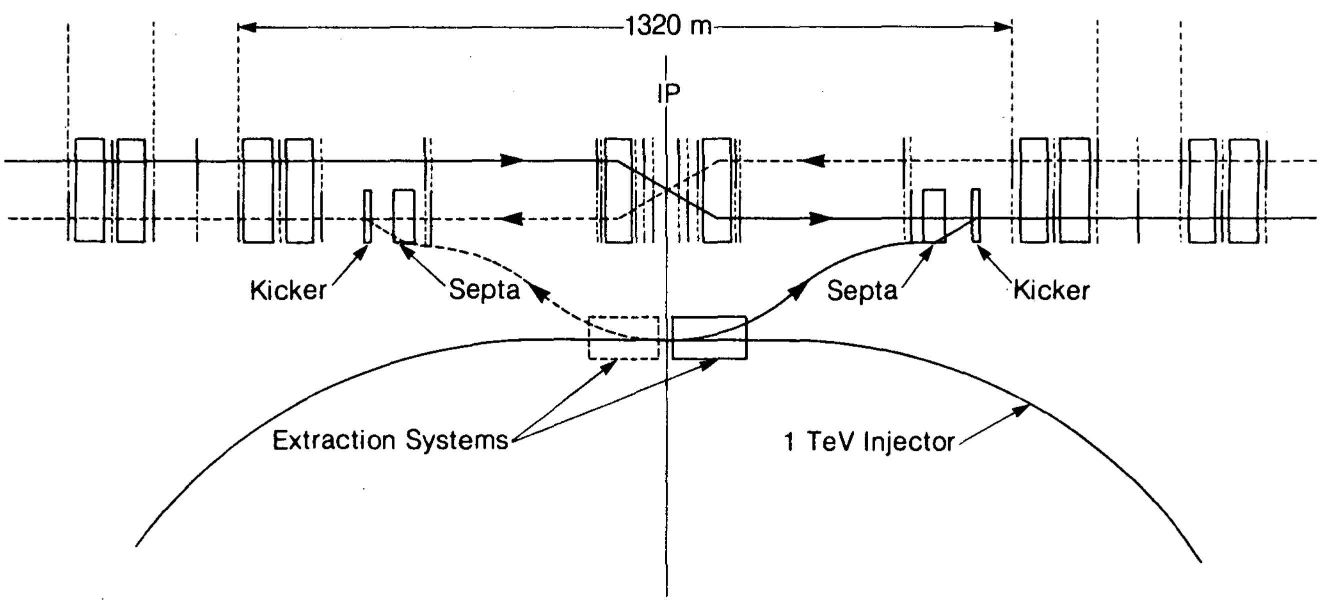

Fig. 3 Alternative injection for 6.5 Tesla sample lattice requiring injector field reversal.

Fast Extraction

With regard to a fast, single turn extraction system the ICFA workshop[1] arrived at the following conclusions:

Besides the questionable reliability of an electrostatic system in an abort system for a 20 TeV beam of 10^{15} ppp, there are thermal problems arising when such a beam is swept across a thin electrostatic septum by a fast kicker. For a 0.1 mm thick electrostatic septum and a kicker rise time of 3μs the protective absorber (in Beryllium) would intercept 4×10^{10} particles, causing a temperature rise of ~ 2000°C.

To avoid this problem a gap can be put in the circulating beam, long enough to ramp a fast kicker. For a kicker rise time of 3 μs, e.g., the required gap length is ~ 1 km. The extraction channel for single turn extraction thus consists of a fast kicker magnet, that deflects the beam, clearing a thin magnetic septum, that is followed by a thick magnetic septum as shown in fig. 4.

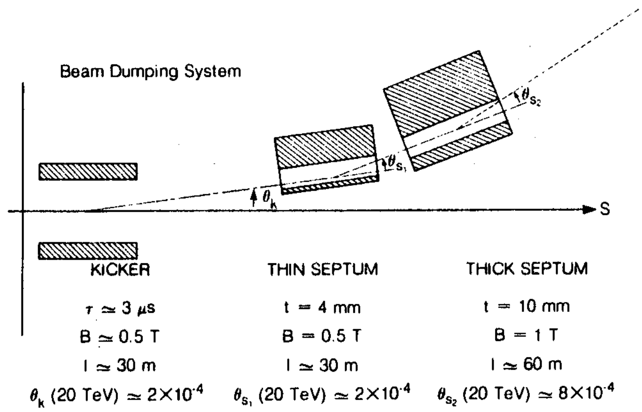

Fig. 4 Extraction schematic for a SSC beam dumping system. Parameters listed are taken from ref. 1.

The entire extraction channel, including the pulsed kicker H. V. supply, tracks the ring at all times. A fast logic, receiving inputs from beam loss monitors, power supply controls, interlocks, etc., generates the abort trigger. Operational experience gained from the Tevatron[4),5)] beam abort system will be very important for the design of the SSC beam extraction system.

The time it takes the beam gap to arrive at the kicker will add a further delay beyond the signal transmission and processing time. In case of the Tevatron the abort takes place at most within three revolutions (~ 60 μs) from the time of a detected beam loss or power supply failure, and this has been found to be adequate.[4)] For the SSC, however, the total delay time is an order of magnitude larger: The signal transmission and processing time is of the order of 150 μs; the time it takes for the beam gap to arrive as the kicker can be as large as 300 μs. Further studies are needed to evaluate if this is still acceptable. The gap related delay can be reduced either by increasing the number of gaps in the beam or by having two "parallel" abort systems on opposite sides of the ring. This might be desirable also to give some redundancy and improved reliability.

In case of an emergency beam abort one has to assume that the various beam parameters have been degraded by some machine component failure. The actual beam size, e.g., might be substantially larger than the nominal size of the circulating beam. To keep beam scraping to a minimum and to prevent quenching of nearby superconducting magnets, it is advisable to use generous apertures in the extraction channel and have it point away from superconducting ring elements. Overall reliability is improved by not pushing the kicker to its limits. Careful selection of the location of kicker and septum with regard to β-functions and a phase advance close to π/2 allow to minimize the required kicker strength for a given beam displacement at the septum.

In order to arrive at a reasonable estimate for the size of the aborted beam one might consider a system of detectors placed around the ring, whose function would be to trigger a beam abort, whenever beam is detected outside a "safe area," e.g., the "good field" region or a fraction thereof. If W_{sr} is the maximum half width of the "safe region" and β_{sr} the β-function at the corresponding location, the aborted beam half width W_s at the septum is

$$W_s = \left(\beta_s/\beta_{sr}\right)^{1/2} W_{sr} \quad , \tag{1}$$

where β_s is the β-function at the septum location. A more conservative estimate results from the assumption that the size of the aborted beam is determined by the kicker aperture, i.e., if a_k is the kicker aperture and β_k the β-function at the kicker location, the half width of the aborted beam W_s is given by

$$W_s = \left(\beta_s/\beta_{sk}\right)^{1/2} \cdot a_k \quad . \tag{2}$$

Thus for a septum of thickness t, which is flush with the beam pipe aperture of radius a, the displacement δ at the septum has to satisfy the condition

$$\delta \geqslant \delta_{min} = a + t + W_s \quad . \tag{3}$$

As a demonstration of the compatibility of these concepts with a realistic lattice, an extraction channel matching Garren's[3)] 6.5 Tesla sample lattice has been designed. In the 305 m long, open straight section of the insertion the β-functions, β_x and β_y, exhibit an appropriate behaviour for the extraction channel (fig. 5). Choosing a horizontal extraction system, as suggested by the scheme in fig. 6, relaxes somewhat the conditions imposed on the extraction elements. However, horizontal extraction is not essential, for exchanging the focussing structure of the two collider rings results in an interchange of the xand y coordinates and the vertical extraction scheme becomes identical with the horizontal one described here. Also, the current septa indicated in fig. 6 might as well be replaced by Lambertson septa.

The chosen parameters of the extraction elements for this scheme are summarized in Table 1. Nominal beam half width at 1 TeV, divergence and displacement at 20 TeV of an extracted beam along the extraction channel are listed in Table 2. Points of particular interest are the beam displacements at the entrance to the two septa. The values of 24 mm and 35 mm, respectively, satisfy the condition of eq. (3) with an aperture of 15 mm for both criteria (eq. (1) and eq. (2)) by assuming either a "safe region" halfwidth W_{sr} of 6 mm or a kicker aperture a_k of 15 mm.

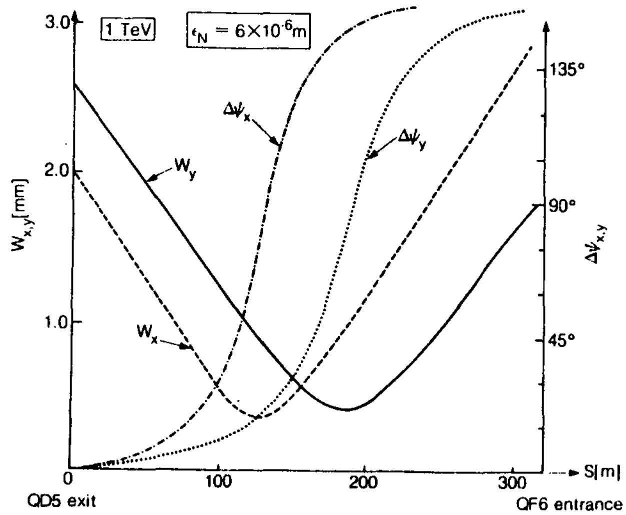

Fig. 5 Beam half widths ($\sqrt{6}\ \sigma$) at 1 TeV and phase advance in long straight section of 6.5 Tesla sample lattice.

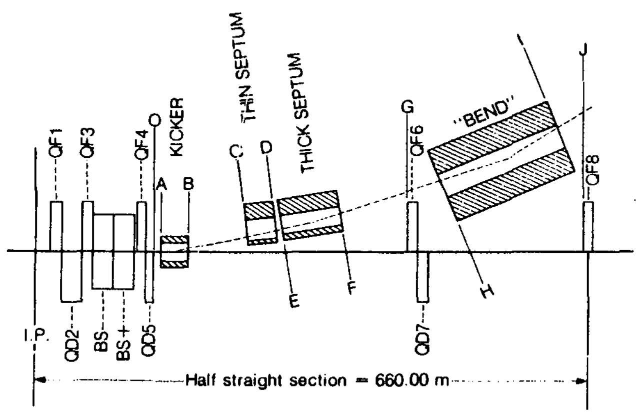

Fig. 6 Fast extraction channel layout for 6.5 Tesla sample lattice.

Table 1

EXTRACTION CHANNEL PARAMETER LIST

KICKER: (laminated iron)
B_{max} = 0.5T
L_{tot} = 33 m
L_{eff} = 28.5 m
# of modules = 10
τ_{rise} = 3.14 μs
ℓ_{module} = 2.85 m
Θ_k(20TeV) = 0.2136 x 10^{-3}

THIN SEPTUM:
B_{max} = 0.5 T
L_{tot} = 35 m
L_{eff} = 27.5 m
# of modules = 5
ℓ_{module} = 5.5 m
Θ_{S_1}(20TeV) = 0.2061 x 10^{-3}

THICK SEPTUM:
B_{max} = 1.0 T
L_{tot} = 70 m
L_{eff} = 55 m
# of modules = 10
ℓ_{module} = 5.5 m
Θ_{S_2}(20TeV) = 0.8244 x 10^{-3}

Table 2

BEAM HALF WIDTH ($\sqrt{6}\ \sigma$) AT 1 TEV, DIVERGENCE AND DISPLACEMNT AT 20 TEV OF EXTRACTED BEAM

S [m]	Location		Beam-Half Width [mm]	Beam Displacement [mm]	Divergence [mrad]
0	QD5 exit	"O"	2.0421	--	--
0.5	Kicker entr.	"A"	2.0344	--	--
33.5	Kicker exit	"B"	1.5298	3.5725	0.2136
130	S_1 entr.	"C"	0.3601	24.185	0.2136
165	S_1 exit	"D"	0.6720	35.422	0.4197
166	S_1 entr.	"E"	0.6852	35.842	0.4197
236	S_2 exit	"F"	1.7145	94.695	1.2441
305	QF6 ent.	"G"	2.7774	180.54	1.2441
334	"BEND" entr.	"H"	1.623	216.62	1.2441
512	"BEND" exit	"I"	1.1580	1825.0	16.827
516	QF8 entr.	"J"	1.2160	1892.3	16.827

Transfer Line and Beam Dump

More information needs to be gathered and more studies to be done in order to understand the beam dump requirements for a 20 TeV collider. The following paragraphs are an attempt to get a feeling for these requirements by extrapolating available simulation calculations[6] to 20 TeV and by scaling Tevatron beam dump information.[5]

The present Tevatron beam dump consists of a 4.8 m long graphite block with a cross section of 6" by 12", surrounded by a 3" thick aluminum jacket, and shielded by 5' - 7' of iron, followed by a concrete jacket covered by 17' of earth. At 1 TeV 95% of the beam at the dump entrance is contained within an area of ~ 15 mm^2, and the intensity limit for cracking to occur in the graphite, based on nuclear production Monte Carlo and electromagnetic shower calculations, is 6 x 10^{13} ppp.[5] Scaling from these figures to 20 TeV and 10^{15} ppp, by applying a 3/4 power dependence of the specific hadronic deposition density on the incident proton energy, gives a minimum beam size of ~ 23 cm^2. However, based on an extrapolation of Mokhov's[6] simulation calculations from 5 TeV to 20 TeV and 10^{15} ppp, the required minimum beam size is an order of magnitude larger or ~ 220 cm^2. This amounts to a blow up factor of ~ 10^4 as compared to the circulating beam size. This could be accomplished by defocusing elements in the transfer line. However, such an approach would result in an undesirable length of the transfer line. Since the beam pulse is of the order of 300 μs, it would be practical to combine the defocusing action in one plane with beam sweeping in the other plane. This can be accomplished by a few moderately fast ramped magnets, spreading out the beam in time by scanning it over a large area of the beam dump. It is evident that much more work has to be done to understand the SSC beam dump requirements and their consequences for the dump transfer line.

Acknowledgements

I would like to thank Al Garren, Michael Harrison, Thornton Murphy, and William Wenzel, for providing essential information and for helpful discussions.

References

1) "Possibilities and Limitations of Accelerators and Detectors", Proc. of 2nd ICFA Workshop 1979, p. 167.

2) Klaus Wille, contributed paper to present proceedings.

3) Al Garren, contributed paper to present proceedings.

4) Michael Harrison, "The Tevatron Abort System", Fermilab Internal Report UPC-153 (1981) and private communication.

5) Thornton Murphy, private communication.

6) N.V. Mokhov, "Energy Deposition in Targets and Beam Dumps at 0.1 - 5 TeV Proton Energy", Fermilab Internal Report FN 328 (1980).