The SSC Collider Beam Halo Scraper System

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1. INTRODUCTION

In the SSC [1] Collider, p-p collisions at the interaction points and the beam-gas scattering around the ring are expected to produce beam halo at a rate of ~ 2×10^7 protons per second. Various instabilities, errors and RF noise can easily raise this number by one order of magnitude or even more. Radiation effects due to beam loss in the lattice elements and the possible protective measures have been analyzed in an earlier report [2] for the following beam halo sources: p-p collisions at the interaction points, beam-gas scattering, accidental beam loss and interaction of the beam with Lambertson magnet.

To protect the superconducting magnets in the collider lattice, and to minimize the background at the High Energy Physics detectors, a very efficient scraper system is essential. Such a system should be capable of intercepting a high rate of halo particles and absorbing most of their energy with no effect to the downstream equipments. Results of preliminary studies of possible scraper system are presented in this report.

2. PHYSICS

For the purpose of our study, the interaction of the beam with the scraper is divided into two categories. In the first, the protons undergo an elastic and/or inelastic scattering at the front or the edge (surface) of the scraper and exit with an energy loss, less than a few percent of the initial 20 TeV. These scattered protons travel with the beam over a long distance downstream, even circulate several turns, before they get lost.

In the second category, the protons undergo deep inelastic scattering producing hadronic and electromagnetic showers. A fraction of the total energy is absorbed by the scraper. The rest leaks primarily downstream posing a threat to the downstream superconducting magnets unless they are protected by collimators and other devices.

The problems of the scattered protons, the energy deposition on the scraper and the downstream energy leak, and possible solutions are discussed below.

3. SCATTERED PROTONS

In order to protect the superconducting magnets from the scattered protons it is necessary 1) to minimize the number of scattered protons and 2) to intercept them with a set of second scraper and collimators downstream of the primary scraper. For a scraper at 6σ, where σ is the r.m.s. beam size, the phase space distribution of the scattered protons after scattering and their x-distribution at the scraper front before scattering were studied with the Monte Carlo simulation code ELSIM [3]. Independent calculations with MARS12 [4] agree within a few percent with the ELSIM predictions.

3.1 minimization

The shorter the nuclear interaction length of the material, larger the probability of having deep inelastic scattering in short distance, and thus fewer number of scattered protons. Except for Platinum, Tungsten has the shortest interaction length (λ=9.6cm). However, consideration of energy deposition in the scraper (see below) suggests that Copper (λ=15.1 cm) is the prefered material for scraping. Since the interaction length of Copper is ~1.5 times that of Tungsten, the length of a Copper scraper would be ~1.5 times that of the desired length for Tungsten.

Interaction of halo particles with the scraper occurs not only at the front surface of the scraper but also at the edge (surface parallel to the beam direction). Therefore, as the length of the scraper increases, the number of edge to edge/back scattering events is expected to rise steadily while the front to back scattering falls off exponentially. Both the expected results are verified by the simulation results, as shown in Fig. 1. The Fig. 1 also indicate that the length of a Copper scraper should be 80 - 110 cm long.

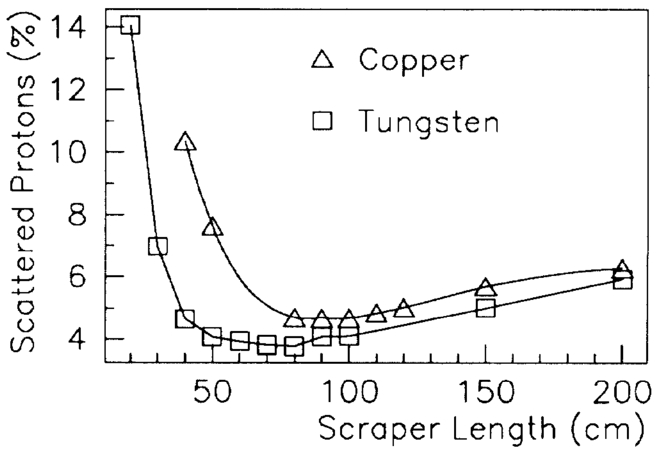

Fig.1 Number of scattered protons as a function of length for Tungsten and Copper scrapers.

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Fig. 2 shows the initial x-distribution, at the scraper front, of the halo-particles which scattered out. It is clear that the surface smoothness of the scraper must be within 0.8 μm, in order to avoid the peak that occurs in this distribution and to minimize the production of scattered protons from an irregular surface. Considering the fact that only the first μm of the scraper surface contribute to the scattered protons, spreading the beam halo over the front surface as described in the next section will also reduce the number of scattered protons.

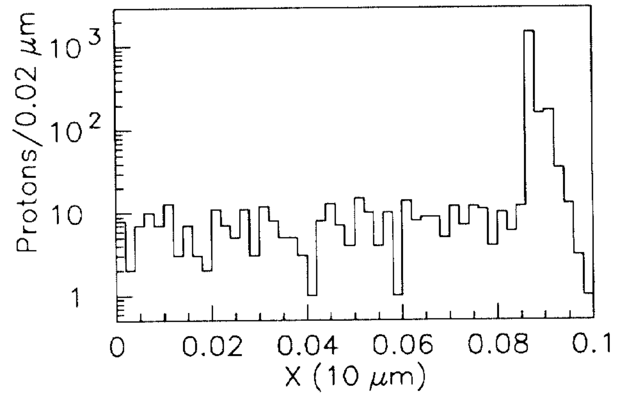

Fig.2 The initial x-distribution, at the scraper front, of the halo particles which scattered out.

3.2 Intercepting

If all of the beam-halo particles scatter out with the same momentum and angular deflection, the scattered protons would be expected to have peak amplitude at a phase advance of $180^o - \varepsilon$, where ε is a function of the angular deflection. But in reality, the beam halo has a certain phase space distribution and the momentum and scattering angle of the proton is also statistical in nature; therefore ε is not unique to all scattered particles. Thus it is necessary to track the scattered particles through the lattice to determine the position of the second scraper where it will be most efficient to intercept them.

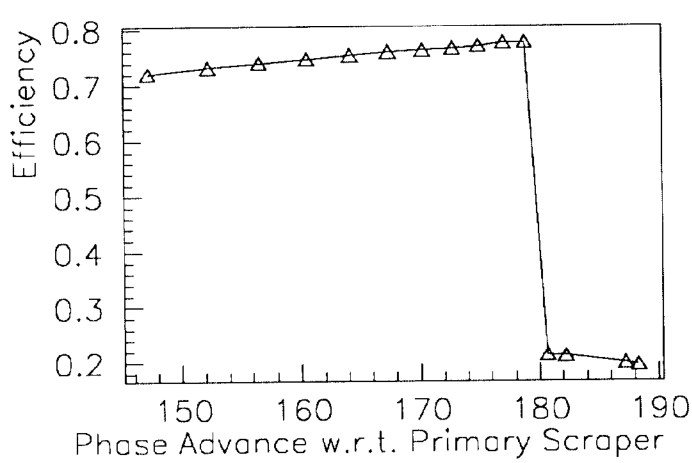

Fig.3 Efficiency of the second scraper as a function of the phase advance with respect to the primary scraper.

In the tracking study, the scattered protons were launched from the back of the scraper. Their phase space distribution was as determined by the scattering simulation. The scraper was located upstream of the appropriate dog leg system in the west utility straight section. Monitors were placed along the beam line to register the phase space distribution for later analysis. Large number of the scattered protons were lost before they reach the cold section. Thus the efficiency of the second scraper was determined for those survived in the warm section. It was assumed that the second scraper is also positioned at 6σ, where σ is the r.m.s. beam size at the monitor location. However, in practice its position must be optimized according to beam loss monitors readings. The result of the analysis is shown in Fig. 3. The most efficient and safe phase advance for the second scraper is 177^o.

4. ENERGY DEPOSITION IN THE SCRAPER

The choice of the scraper material is primarily determined by its ability to absorb a high rate energy deposition in a limited volume without cracking or melting. Even though the cracking limit in terms of temperature difference for Tungsten is twice that for Copper, in terms of energy, Copper can absorb much higher energy as its specific heat is three times that for Tungsten. Copper is also prefered because of its high thermal conductivity.

As discussed in the previous section, the larger the transverse displacement of the halo particles at the upstream face of the scraper, greater is the efficiency of the scraper system. It also lowers the maximal energy deposition across the scraper, and allows higher rate for scraping. The most convenient way to achieve beam spread at the scraper front is to place the primary scraper at a location where the beta-function is the largest. In the SSC lattice, the largest beta value occurs near the interaction region. For obvious reason the scraper cannot be placed here. The next largest beta occurs in the west utility straight section; the dispersion in this region is zero and therefore suitable for scraping large amplitude particles. The off-momentum particle scraping is expected to be done in the east utility straight section by introducing a high dispersion region.

Even for the large beta (450 m) the r.m.s. beam size is only ~0.145mm. Thus it becomes necessary to explore other means of spreading the transverse distribution of the halo particles. The beam halo particles meant for scraping can be made to displace further away from the central orbit with the help of a very thin scattering target installed at the front face of the scraper. For a 1mm thick Tungsten target extending 100μm from the scraper, scattering simulation and tracking studies indicate that a halo particle would hit the scraper surface on the average after 3.5 turns. The x-distribution of the beam halo particles at the scraper front with and without the target is shown in Fig. 4. The distribution shown for the bent crystal is only a very preliminary result.

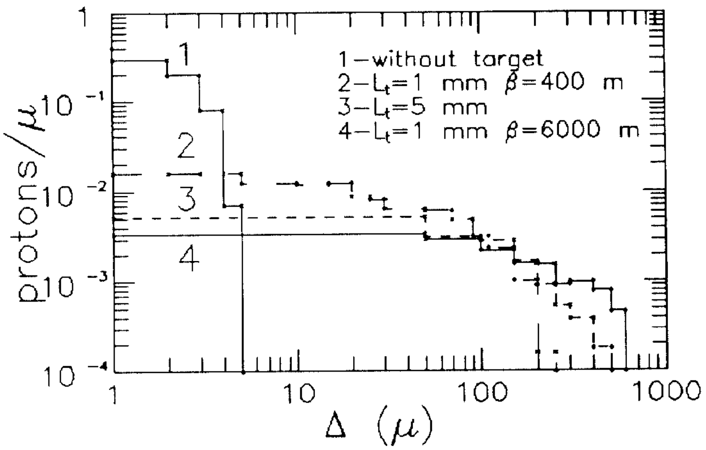

Fig.4. x-distribution of the beam halo particles at the scraper front with and without the scattering target as calculated with MARS12.

Presence of a scattering target and the resulting spread in the transverse distribution of protons on the scraper face has four positive consequences as verified by the full-scale Monte Carlo calculations of hadronic and electromagnetic cascades with the new version of the MARS system [4] MARS12 code:

1. There is reduction of the maximal energy deposition in the scraper (factor of 2.5 for copper scraper with a 1 mm thick Tungsten target) as shown in Fig. 5.

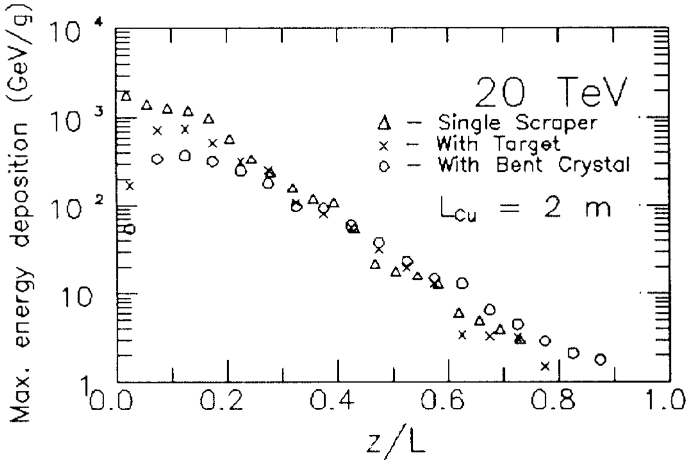

Fig.5 Longitudinal distribution of maximal energy deposition density (GeV/g per 1 proton per pulse) in a 2 m Copper scraper.

2. There is an increase of the total energy absorbed in the scraper. Without the target, 20% of the 20 TeV is absorbed in 2 m long copper scraper whereas 50 % is absorbed with the target (Fig. 6).

3. There is a significant decrease of the number of scattered protons and hence the reduction of irradiation of the downstream elements and long-range beam loss as shown in Table 1.

4. The stringent requirement on the scraper surface finish and on the scraper alignment is relaxed.

Table 1.

	No. of protons per 1 incidence	
	Elastics	Δp/p < 0.3
Without target	4.46E-2	2.52E-2
With target	2.40E-3	1.75E-3

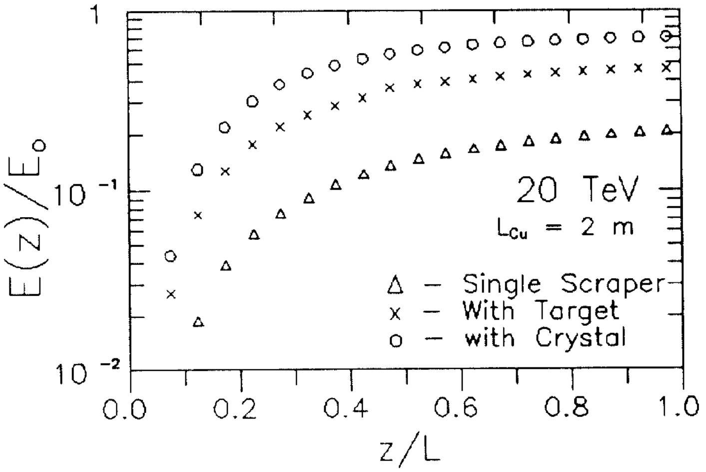

Fig.6 Cumulative distribution of absorbed energy in a 2 m Copper Scraper.

It is evident that the scraping will be much more efficient with the thin target than without. The energy deposition on the scraper peaks around three interaction length of the material and then falls gradually (Fig. 5). It is conceivable to have a scraper with its surface extending towards the beam say 100μm for every interaction length, up to four or five interaction length from the front surface. This would lower the peak energy deposition and distribute energy somewhat more uniformly along the scraper length and thus further improve the efficiency. Such a system is currently under investigation.

Radiation damage to the scraper and target materials is a serious problem. For example, the maximal radiation dose in the cascade maximum in Copper, for just 1% of the total intensity of the 20 TeV beam, is

$$D = 750 \text{ GeV/g} * 1.6\text{E-}5 * 1.\text{E}12 = 1.2\text{E}10 \text{ rad/pulse}.$$

Thus, a rotating target-scraper system with adjustable axis of rotation (aligned to the central orbit) must be considered.

The design of collimators and their positions are currently under investigation.

References

[1] SSC Design Report SSCL-SR-1056, SSCLab, July 1990.

[2] I.S. Baishev, A.I. Drozhdin, N.V. Mokhov, Beam Loss and Radiation Effects in the SSC Lattice Elements, SSCL-306, SSCLab (1990).

[3] A. Van Ginneken, Elastic Scattering in Thick Targets and Edge Scattering, Physical Review D, 37, 3292 (1988)

[4] N.V. Mokhov. The MARS10 Code System, FN-509, Fermilab (1989).