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50×50 GeV $\mu^+\mu^-$COLLIDER BEAM COLLIMATION [*]

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Abstract

A summary of different techniques and systems to scrape beam halo in a 50×50 GeV $\mu^+\mu^-$collider is presented. Such systems are installed in a special utility section with optics specifically designed to meet both the requirements of the scraping system and of injection. Results from a realistic Monte Carlo simulation (STRUCT-MARS) show that a system consisting of steel absorbers several meters in length suppresses halo-induced backgrounds in the collider detector by more than three orders of magnitude. The heat load in superconducting magnets near the scraper system can be reduced to tolerable levels by appropriate collimator design and location. This reduction applies to both injection and collider mode of operation. Also discussed is extraction of halo particles using electrostatic deflectors and bent crystals, although neither appears to be effective for a muon collider at this energy.

1 INTRODUCTION

The halo-originated background in a $\mu^+\mu^-$collider detector arises from muons which strike and subsequently interact in the physical apertures of the machine[1, 2]. Muons lost anywhere along the lattice contribute to the source term, because they can penetrate through tens and hundreds meters of lattice components. Only with a dedicated beam cleaning system far from the interaction point (IP) can one mitigate this problem[1, 3]. Three beam halo scraping schemes are investigated here for a 50×50 GeV $\mu^+\mu^-$collider:

- collimation using a solid absorber,
- halo extraction using electrostatic deflectors,
- halo extraction using a bent crystal.

Previously, our studies[1, 3] showed that no absorber—ordinary or magnetized—will suffice for beam cleaning at high energies (2 TeV); in fact the disturbed muons are often lost in the IP vicinity. At 50 GeV, on the other hand, scraping muon halo with a steel absorber is exceptionally effective. The second scheme is attractive because halo muons which spill into the deflector gap are completely extracted from the machine and can be directed into a beam dump. Only those muons interacting with the septum wires appear to be lost on the limiting apertures in the machine. The third scheme with a Si bent crystal is inexpensive and compact, and, therefore, its efficiency is also studied in this paper.

A 50 GeV beam of 4.2×10^{12} muons with a normalized emittance of $90\pi \;\; mm \cdot mrad$ is assumed in the simulations. A utility section of about 100 m long was incorporated into the collider lattice on the side of the ring opposite to the IP[4] (Fig. 1). It consists of two identical cells with phase advance of about π between cells and two matching regions. A large β-function of 100 m in horizontal and vertical planes was designed into the lattice in order to scrape efficiently. A high dispersion is also required to intercept and scrape the tails of the energy distribution. Monte-Carlo simulations of the beam halo collimation are done in three steps. Primary muon interactions with a collimator and electrostatic deflector wires are simulated with the MARS code[5]. Multi-turn muon tracking in the collider lattice with scattering in collimators and bent crystals and the analysis of particle losses on physical apertures are performed using the STRUCT code[6] supplemented with CATCH[7]. Following this, full-scale hadronic and electromagnetic shower simulations in the collider and detector components are tracked in MARS.

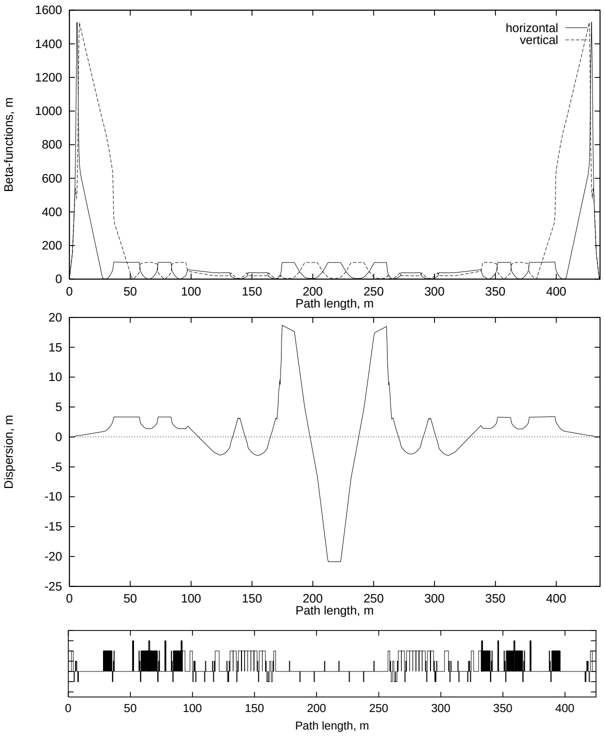

Figure 1: Muon collider β-functions and dispersion.

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2 SOLID ABSORBER

Horizontal collimators are placed in the high-β and high-dispersion region with a π-phase advance between them (Fig. 2). Vertical collimators are installed in a high vertical β region with a $\pi/2$ phase advance downstream of the horizontal ones. On average, 50 GeV muons loose 8% of their energy and receive a significant angular deflection (Fig. 3) after interacting with a 4 m long steel absorber. As a consequence, almost all of the scraped muons are lost in the utility section (where in this scheme conventional magnets can be used) or in the first 50 m downstream (in a superconducting part of lattice, Fig. 4).

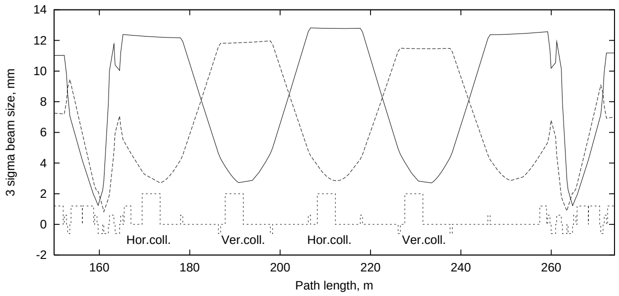

Figure 2: A 3σ horizontal (solid) and vertical (dashed line) beam envelopes in the scraping region with an absorber.

The power density distribution in the SC coils is strongly nonuniform azimuthally, peaking—contrary to the decay-induced process—on the inner side of the magnet aperture relative to the ring center. As shown in[1], the heat load to the SC can be reduced to an acceptable level with a tungsten liner. Assuming 1% of the beam is scraped, about 4×10^6 muons are lost at the IP over the first few turns after injection. Later—during collisions—muons hit the absorber with a very small impact parameter ($\sim$ μm) undergoing smaller orbit distortions than at the beginning of the store. Assuming 5% of the beam is scraped over the duration of the store, 6×10^7 muons in total are lost at the IP.

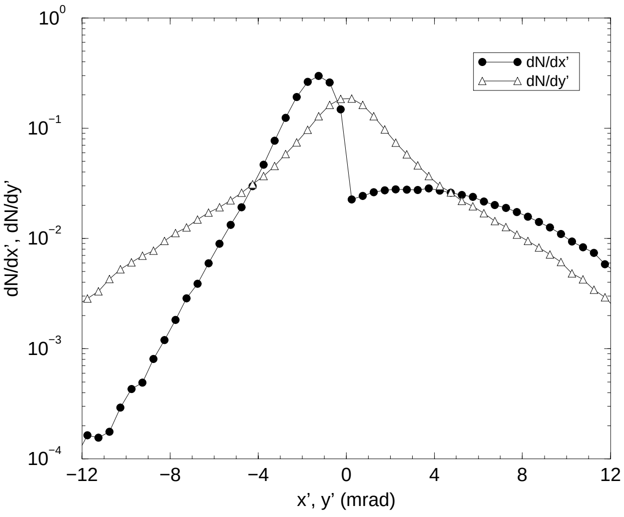

Figure 3: Muon angular distribution after a 4-m steel half-absorber (x>0) at 50 GeV.

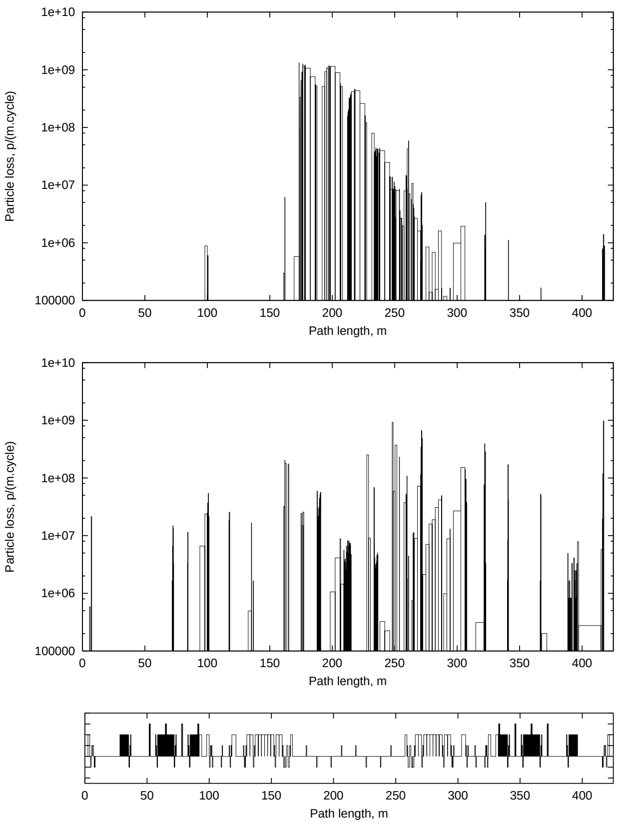

Figure 4: Beam loss at injection with scraping using a 4 m steel absorber (top) and with halo extraction (bottom).

3 HALO EXTRACTION

In this scheme, a horizontal scraping section consists of an electrostatic deflector $ES(h)$ positioned at 3σ off-axis to clean the μ^+ and μ^- beams simultaneously, and two Lambertson magnets $LAMB(h)$ positioned symmetrically at approximately a phase advance of π away from $ES(h)$ (Fig. 5). Such a scheme extracts muons with Δp of both signs. Vertical halo extraction is done by a separate electrostatic deflector $ES(v)$ and a septum-magnet $SM(v)$ for each beam. The beam halo is separated from the circulating beam at the entrance to $LAMB(h)$ and $SM(v)$ (Fig. 6) which allows magnetic septa to be placed between the beams. Large amplitude and halo muons scatter from the ES wires are extracted by $LAMB(h)$.

In this scheme, about 86% of beam halo is extracted from the collider. Muons interacting with the ES wires, loose on average 0.2% of their energy and are mostly lost in the first 50 m downstream of the utility section (Fig. 4). Unfortunately, a significant fraction of them reaches the low-β region upstream of IP and are lost there at the rate significantly higher than in the first scheme. With 1% of the beam scraped at injection and 5% over the store, one obtains 3.5×10^8 and 5×10^9 muons, respectively, lost in the IP region. It has been shown in[1, 3] that in the high-energy 2×2 TeV $\mu^+\mu^-$collider, this extraction-based scraping has a very high efficiency.

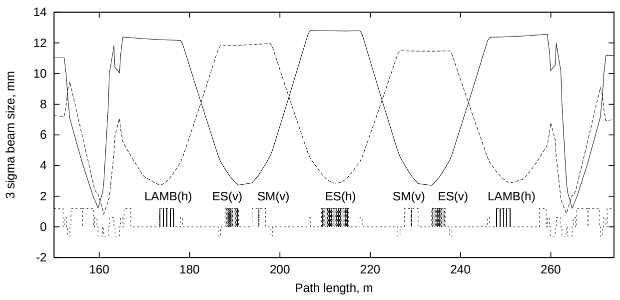

Figure 5: A 3σ horizontal (solid line) and vertical (dashed line) beam envelope for the halo extraction section.

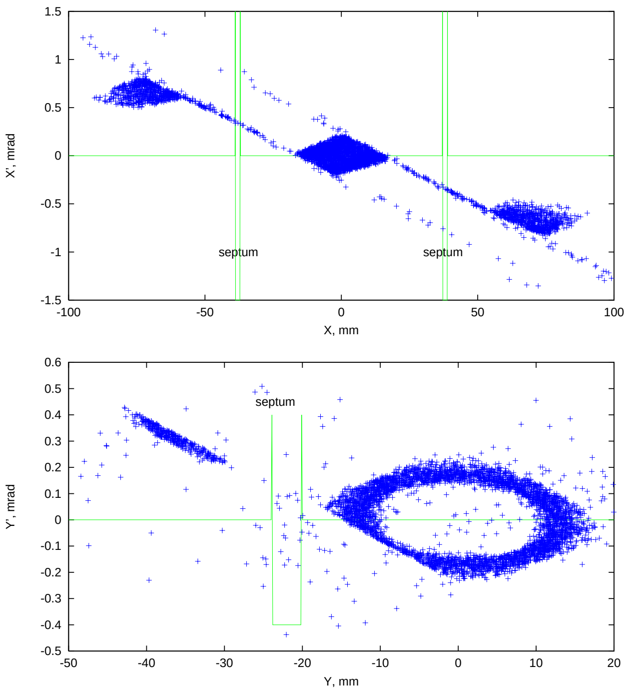

Figure 6: Halo phase space at the entrance to $LAMB(h)$ (top) and $SM(v)$ (bottom).

4 BENT CRYSTAL EXTRACTION

The Si crystal length needed to bend a 50 GeV muon beam by 3 mrad is equal to 5 mm. The natural divergence of the beam in the high-β regions is ±0.15 mrad and the critical angle in a Si bent crystal is $\pm 20\mu$rad. Therefore one can expect an extraction efficiency of only 13%, which is unacceptably low. In addition a narrow angular acceptance requires the bent crystal to be aligned to $\pm 5\mu$rad with respect to the beam. Simulations performed show that only a few percent of the beam halo is extracted from the collider at 50 GeV. The rest is scattered by the crystal as by an amorphous target, and is lost at collider apertures. The calculated background in the detector is tremendously larger compared to the first two schemes.

5 CONCLUSIONS

The studies of halo scraping performed for a 50×50 GeV $\mu^+\mu^-$collider show that a simple and compact absorber-based beam cleaning system provides excellent suppression of the beam loss rate and backgrounds in the collider detector vicinity. That is about hundred times better than with a system based on the halo extraction. In addition, the heat load to the superconducting magnets downstream of the non-superconducting scraping section is higher for the halo extraction scheme compared to the absorber-based system. In any case, a tungsten liner (or other methods) is needed there to protect a group of the superconducting magnets. The use of a bent crystal for halo extraction at the given muon beam parameters was found to be very inefficient.

6 REFERENCES

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