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Ring Cooler for Muon Collider

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Abstract. The possibilities of a ring cooler stage in a muon collider are explored. A basic design is examined both with analytic calculations and simulation of the evolution of beam phase space.

INTRODUCTION

This report examines the possibility of using a ring accelerator in the cooling stage of a muon collider. The main merit of such a cooler is its lower projected costs. The expense ratio linear/ring coolers scales roughly as the number of turns needed to achieve effective cooling in the ring, which is about 20 in a typical scenario.

Significant 6D cooling of a bunch is possible mainly by compression of its size since angle and energy spreads are dominated by scattering and straggling in the absorber. A system with decreasing β–function can be used for cooling in a linear scheme. For example, [1] describes a linear cooler using Li lenses with increasing gradient along the path.

The ideal solution for a ring cooler would be a system with a transfer matrix $\lambda \times I$ for each turn where λ is the cooling coefficient. In this case, all variables in 6D phase space are independent 2and bunch compression without change of angle and energy spread is possible. The following is an attempt to design a system with the appropriate features and to investigate its potential as a stage in a muon collider. The parameters assumed for the injected beam in the calculations are listed in Table 1. (The second column describes the cooled beam, see below). Definitions of normalized transverse and longitudinal emittances adopted here are:

$$\epsilon_x = \sigma_x \sigma_{p_x}/mc, \qquad \epsilon_z = \sigma_T \sigma_E/mc^2$$

SCHEMATIC OF COOLER

A schematic of the cooler is shown in Fig. 1. It includes two bending sections with wedge absorbers and two straight sections which house RF cavities and the

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TABLE 1. Parameters of the Beam

	Injected beam	Cooled beam
Momentum	225 MeV/c	170-225 MeV/c
σ_x	70 mm	9.9 mm
σ_y	70 mm	16 mm
σ_z	1500 mm	69 mm
$\sigma_{x'}$	0.15 rad	0.11 rad
$\sigma_{y'}$	0.15 rad	0.11 rad
$\sigma_{\Delta p/p}$	7.8%	3.3%
Norm. r.m.s. X-emittance	22 mm-rad	2.0 mm-rad
Norm. r.m.s. Y-emittance	22 mm-rad	3.3 mm-rad
Norm. r.m.s. Z-emittance	225 mm	3.7 mm
6D emittance	$11 \times 10^4 \text{mm}^3$	$24\ \text{mm}^3$

main absorbers assumed here to be lithium hydride (Fig. 2). Each bending section includes magnets with field index 0.5 for focusing and bending the beam in vertical and horizontal planes. A wedge absorber is placed in the center of the section where the dispersion function is large. Skew quadrupoles are used to control dispersion in the straight sections. Betatron phase advances are 360° to get independent variation of coordinates and angles (which is why turns in two planes are used). Each straight section includes three FODO cells with phase advance per cell of 60° for X and 120° for Y in the leading part of the section, and two 90° FODO cells in the trailing part. This gives betatron transfer matrices $M_{x,y} = \pm\sqrt{\lambda} \times I$ per half-

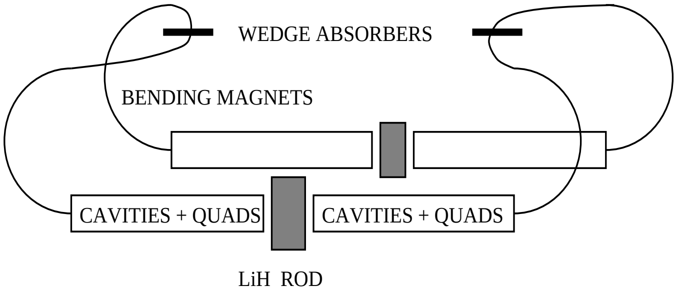

FIGURE 1. Schematic of ring cooler.

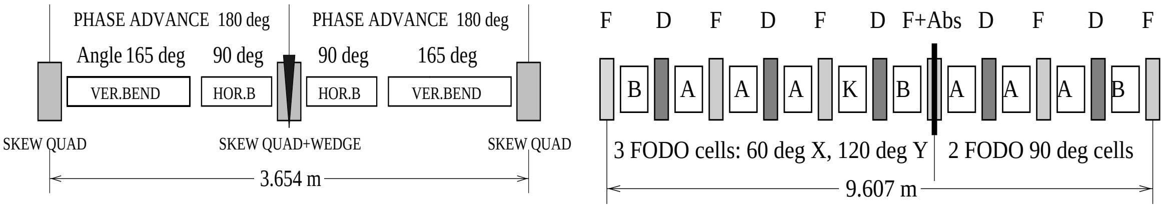

FIGURE 2. Bending and straight sections of ring cooler (F,D-quads,A,B-accelerating cavities and bunchers, K-kicker).

TABLE 2. Parameters of the Cooler

Muon momentum	170 – 225 MeV/c
Circumference	28.4 m
Bending radius	0.411 m
Length of straight sections	9.607 m
Revolution frequency	9.29 MHz
Energy rate in SS (average)	5 MeV/m
Length of main absorber (LiH)	27.6 cm
Angle of the wedge absorber	15.7 deg

turn, and $M_{x,y} = \lambda \times I$ per turn, as desired. Revolution frequency is independent of energy with an appropriate choice of length for the straight section. Bunchers are installed to provide energy-time coupling so as to get a longitudinal transfer matrix $\lambda \times I$. Some parameters of the cooler are listed in Table 2.

COOLING

Cooling is examined both with analytic calculations using transfer matrices—correct up to second moments of the distributions—and Monte Carlo simulations with SIMUCOOL [2]. For now, simulations are limited to what happens to the muons during material traversal. Elsewhere they employ the same transfer matrices as in the analytic approach.

Table 1 gives bunch parameters after cooling. Evolution of r.m.s. sizes and invariant emittances of a cooled bunch as a function of turn–number are presented on Fig. 3 (smooth lines are analytic results, dots – Monte Carlo simulation). The curve labeled N in Fig. 3c shows beam loss during cooling. Approximately 25% of muons are lost because of aperture restriction and almost the same amount by

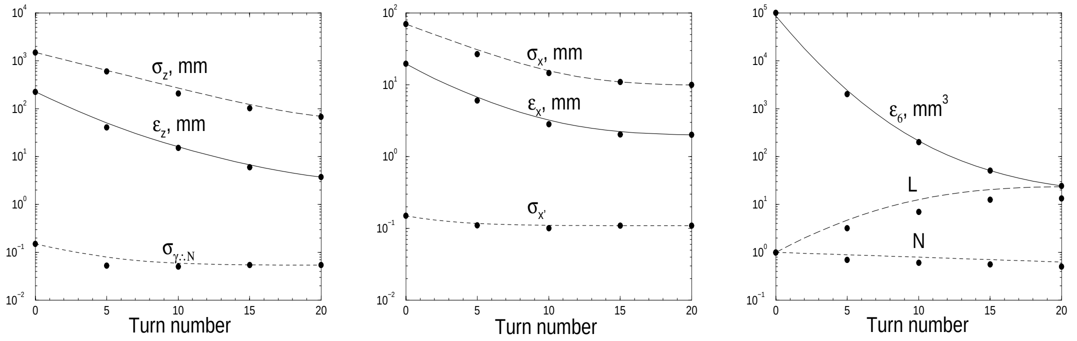

FIGURE 3. Cooling of the bunch: a–longitudinal, b–transverse, c–6D emittance, intensity (N), 'luminosity' (L).

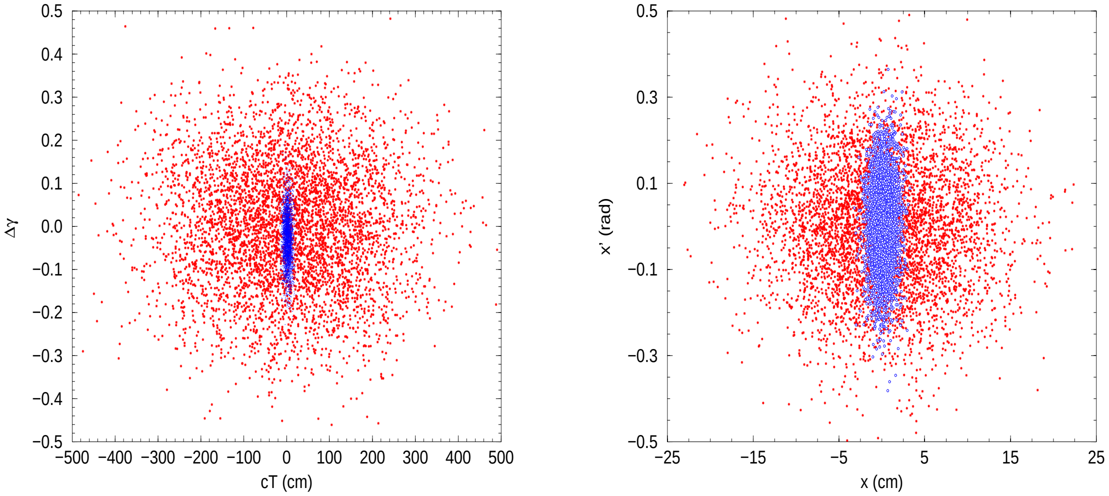

FIGURE 4. Phase space of the bunch before and after cooling: a–longitudinal, b–transverse.

decay (aperture restrictions are not taken into account in the analytic calculations). Luminosity of the collider with optimal β-function depends on beam parameters as $L \propto N^2/\sqrt{\epsilon_6}$. It reaches a maximum after 20 turns which is thus optimal for this cooler. Fig. 4a-b represent initial and final distributions of muons in longitudinal and transverse phase planes (final distributions are the dark central regions).

CONCLUSION

A ring cooler appears capable of satisfactory cooling a muon beam both in transverse and longitudinal directions. The achievable emittance suggests its use as a precooler in a muon collider complex especially for effective bunch shortening which is necessary in any scenario. Full tracking through magnets and cavities will be needed to investigate suppression of both chromatic and nonlinear effects and to study dynamic aperture.

REFERENCES

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2. Van Ginneken, A., *Nucl. Inst. Meth.* **A362**, p. 213 (1995).