International Journal of Modern Physics A

A MUON COOLING RING WITH LITHIUM LENSES

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We discuss particle tracking simulations in a storage ring with Lithium lens inserts designed for the transverse phase space cooling of muons by the ionization cooling. In a hard-edged magnetic element model, we demonstrate the equilibrium normalized transverse emittance of 0.3 mm*rad which is necessary for a Higgs Factory, a low energy mu+mu- Collider. For the 6 dimensional phase space cooling of muons, a method of using bent Lithium lenses were discussed.

1. Overview

For the final cooling of the muons in a Higgs Factory, a lower energy version of a $\mu^+\mu^-$ collider, the normalized transverse emittance must be around 0.3 mm $\cdot$ rad in the muon phase space cooling ring. The ionization cooling is one of the most promising method to reduce the 6 dimensional phase space of muon beam, where both transverse and longitudinal momenta are reduced due to the energy loss in absorbers, and only longitudinal components of the muon momenta are restored through the accelerating fields of RF cavities. The multiple Coulomb scattering contributes to heat the transverse phase space. And the dE/dx straggling through absorbers contributes to heat the longitudinal phase space. Wedge absorbers in dispersive region in bending cells, or a gas-filled cooling ring perform the emittance exchange between the longitudinal emittance and the horizontal emittance. [1]

Lithium lens is an active focusing element with energy absorber function as well. With β at 1 cm with high current density Lithium lenses, the equilibrium normalized transverse emittance can be at around 0.3 mm $\cdot$ rad, which is necessary for a Higgs Factory, a lower energy $\mu^+\mu^-$ collider. [2] Bent Lithium lenses provide a possible method to achieve the emittance exchange in the extremely small beta in the lithium lenses. This method is similar to the method of using a gas filled muon cooling rings for the 6 dimensional muon phase space cooling.

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2. Muon cooling in a Cooling Ring with Lithium lenses

In the muon cooling ring with Lithium lenses, Lithium lenses with the β function as low as 1.0 cm is placed in a straight section with matching solenoid magnets. Figure 1 shows a schematic view of a muon cooling ring with a Lithium lens(left) and the β vs. z and D vs. z in a half Ring(right). This ring model was designed by using SYNCH code. [3]

Fig. 1. A schematic diagram of a muon cooling ring with Lithium lenses in straight sections(left), and β vs. z and D vs. z in a half Ring(right).

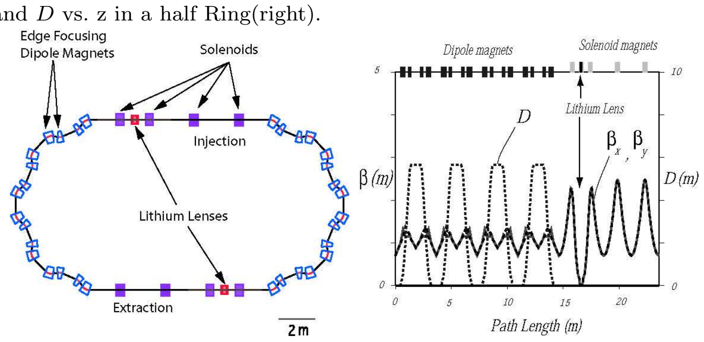


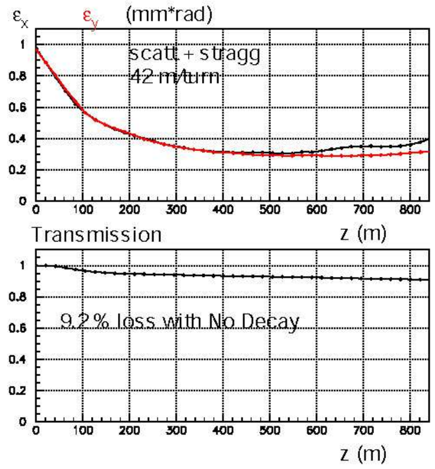
Figure 2 shows the development of the normalized transverse emittance as a function of z through 20 turns of the muon cooling ring(top) and the muon transmission as a function of z without muon decay in consideration(bottom). In this simulation, the loss of muon p_z due to the dE/dx energy loss through the Lithium lens is recovered through a thin RF cavity by adding average p_z kick. The equilibrium normalized transverse emittance is around 0.3 mm $\cdot$ rad. A tracking simulation code, ICOOL, was used in this simulation.[4]

Table 1. Parameters of a muon cooling ring

muon momentum	250 MeV/c
Circumference	42.1 m
straight section length	5.9 m ($\times$ 2)
Structure of half cell	2 dipoles with edges
number of bending cells	8
bend cell length	3.6 m
length of Lithium lens	34.5 cm ($\times$ 2)
lowest β in Lithium lens	1.0 cm
energy loss	35 MeV/turn
dipole bend angles	44.2, -21.7 degree
dipole edge angles	30/-3, -11/-11 degree
dipole magnetic field	6.5, -3.2 tesla
Cell tunes bend cell	0.72/0.70
Cell tunes straight cell	4.0

Table 1 lists parameters of the muon cooling ring with two Lithium lenses in

Fig. 2. Normalized transverse emittance as a function of z through 10 turns of the ring.



straight channels.

In this simulation, the longitudinal phase space grows as the muon beam go through the cooling ring due to the energy straggling through Lithium lenses. In order to achieve the 6 dimensional muon phase space cooling, an emittance exchange scheme can be used by using bent Lithium lenses. Muons with larger P_z lose more energy through bent Lithium lenses and the Δx is affected by the change of the P_z, which generates the emittance exchange in the muon cooling ring.

Fig. 3. A schematic diagram of a bent Lithium lens ring model withRF kicker gaps

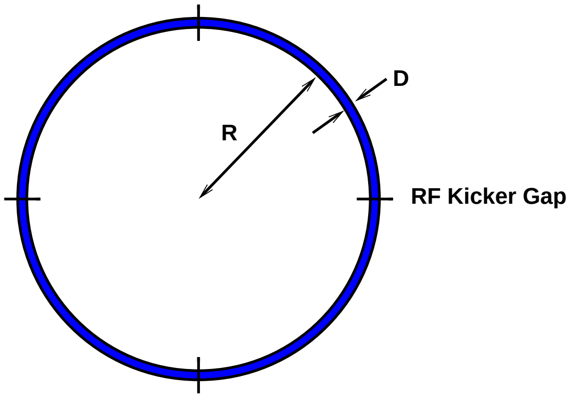


Figure 3 shows the simplest model of the muon cooling ring with bent Lithium lenses. Muons are kicked longitudinally through the RF gaps to compensate the average loss of P_z through Lithium lenses. Typical radius R is around 0.5 m, and the diameter of the Lithium lenses are around 2 cm. Work is in progress in simulationg the muon phase space cooling in this simple ring model.

3. Conclusion

We designed a muon cooling ring with 35 cm long Lithium lenses in straight channels with β at 1 cm. Bending cells have zero-gradient dipole magnets with edge focusing. Study is in progress to obtain the 6 dimensional muon cooling by using bent Lithium lenses in a cooling ring.

Acknowledgments

The authors wish to thank R. B. Palmer, R. Fernow, A Sessler, M. Zisman, D. Neuffer, and V. Balbekov, for useful discussions, and their help and encouragement.

References

1. H. G. Kirk, D. B. Cline, Y. Fukui, A. A. Garren, *Progress Toward A Muon Ring Cooler*, SNOWMASS-2001-M101, Jun 2001. 5pp., Prepared for APS / DPF / DPB Summer Study on the Future of Particle Physics (Snowmass 2001), Snowmass, Colorado, 30 Jun - 21 Jul 2001.
2. C. M. Ankenbrandt, et., al., the NuMu Collaboration, *Status of Neutrino Factory and Muon Collider Reasearch and Developmemt and Future Plans*, Phys. rev. ST Accel. Beams 2 (1999) 081001
3. A. A. Garren, A. S. Kenney, E. D. Courant, A. D. Russel, and M. J. Syphers. *SYNCH - A Compueter System for Synchrotron Design and Orbit Analysis, User's Guide*, SSCL-MAN-0030, 1993
4. R. Fernow, *A Simulation Code for Ionization Cooling of Muon Beams*, Part. Accel. Conf., Edts., A. Luccio and W. MacKay, Proc. 1999, p. 3020.