LONGITUDINAL BUNCH ROTATION SCHEME IN A MUON COOLING RING

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Abstract

We present an idea of achieving better longitudinal phase space cooling in a muon cooling ring with the RF cavity configuration which generate short bunch length and large energy spread at the energy absorbers in a low momentum muon cooling ring. In this scheme, the heating terms in the longitudinal phase space, the slope of the dE/dx as a function of muon momentum and the dE/dx straggling through absorbers, are relatively small compared to the energy spread of the muon beam in the absorber.

INTRODUCTION

The Muon Ring Cooler, a muon cooling ring with conventional (non-solenoidal) magnet elements, has demonstrated emittance exchange from the longitudinal phase space to the horizontal transverse phase space by using a wedge absorbers in dispersive region.[1] The source of the 6 dimensional phase space cooling is the ionization cooling, where muons lose magnitude of momentum by the ionization energy loss through absorbers, and then only p_z is recovered by the RF cavities, which gives the net effect of the transverse phase space cooling. The transverse heating factor is the multiple Coulomb scattering through absorbers, which effect can be minimized by placing absorbers where the β is small, and hence the beam angles, dx/dz or dy/dz are relatively large compared to the scattering angle. The longitudinal heating factors are, the dE/dx straggling through an absorber, and the non-zero slope of dE/dx as a function of muon momentum. In the same way as in the transverse phase space, those heating terms in the longitudinal phase space can be relatively small compared to the energy spread of the muon beam in the absorber in this scheme.

Table 1 lists a comparison of an electron damping ring and a muon cooling ring on elements of damping, excitation, and the partition numbers in the transverse phase space and in the longitudinal phase space.

CONTROLLING THE LONGITUDINAL PHASE SPACE PARAMETERS

In the transverse phase space, the (transverse) strong focusing FODO lattice system [2] allows us to have a large Δx' (transverse angle) and a small Δx (transverse beam size) at the absorbers where the effect of the multiple scattering (transverse phase space heating) on the Δx' is minimized, due to the large Δx' there. The magnetic elements used here is the focusing/defocusing quadrupole magnets.

Table 1: Comparison of an electron damping ring and the Muon Cooling ring

	e **Damping Ring**		
phase space	x	y	z
Damping	x' synch.rad. $+$RF	y' synch.rad. $+$RF	synch.rad. $\Delta E \propto E^4$
Excitation	x-x' orbit change		quantum fluct. $\propto E^{3.5}$
Partition #	$(1-\mathcal{D})$	1	$2+\mathcal{D}$

	μ **Cooling Ring with Wedge Absobers**		
phase space	x	y	z
Damping	x' Ion.Cooling	y' Ion.Cooling	$\Delta E \propto$ E in Wedge
Excitation	x-x' orbit change mult.scat.	mult.scat.	$\frac{dE}{dx}$ struggling $\propto E^2$
Partition #	2-d	2	d

In the exactly the same way as the transverse phase space, we can think about setting a FODO lattice structure with a *Longitudinal Strong Focusing* which is based solely on the longitudinal phase space.

Figure 1 shows schematics of the transverse and longitudinal strong focusing. UFP(Unstable Fixed Point) and SFP(Stable Fixed Point) in the $\Delta p/p$ - ϕ(RF phase) phase space are used to expand or contract the bunch length of muon beam in a longitudinal strong focusing lattice. The length of the longitudinal strong focusing lattice is allowed to be different from the length of the transverse strong focusing lattice.

In order to realize the longitudinal strong focusing lattice, one or multiple of the following conditions need to be met:
1) muon momentum is low enough or the RF gradient is large enough in order to generate $\Delta c\Delta t$ in going from an absorber to another absorber,
2) the magnitude of the energy straggling in the dE/dx energy loss through an absorber is smaller than the total energy spread of the muon bunch at the absorber location.

SUMMARY

The longitudinal strong focusing lattice can be used to minimize the normalized equilibrium longitudinal phase space of the muon beam, combined with the use of a wedge absorber in a dispersive region in a muon cooling ring. The longitudinal heating factors, the dE/dx straggling through

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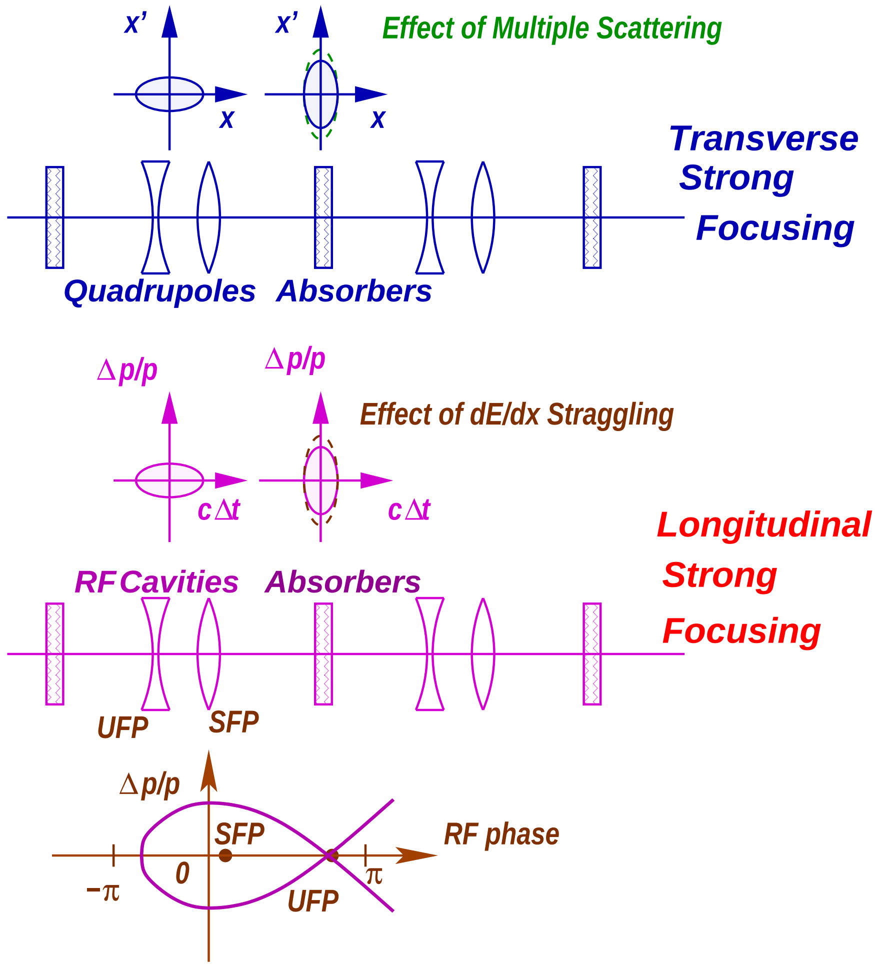

Figure 1: Schematic diagrams of the transverse and longitudinal strong focusing lattices

an absorber, and the non-zero slope of dE/dx as a function of muon momentum, can be made relatively small compared to the energy spread of the muon beam in the absorber in this scheme. This scheme corresponds the scheme of the transverse cooling through the ionization cooling where the low β is required to achieve the low transverse normalized equilibrium emittance.

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] E. D. Courant and H. S. Snyder, *Theory of Alternating-Gradient Synchrotron*, Annals of Physics, 3, 1-48 (1958)