SIMULATION STUDY OF A MULTI-STAGE RECTILINEAR CHANNEL FOR MUON COOLING

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Introduction

The muon collider has the potential to be a powerful tool for the exploration of frontiers in particle physics. In order to reach the high luminosity, the 6D emittance of the muon beam needs to be reduced by several orders of magnitude. Ionization cooling, which has recently been demonstrated in 4D by the Muon Ionization Cooling Experiment (MICE), is a promising cooling method for the muon beam. In the future, muon production and 6D ionization cooling experiments are planned at the High Intensity Accelerator Facility (HIAF) at the Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS). In this paper, a multi-stage rectilinear 6D ionization cooling channel is developed and the cooling simulation results using G4Beamline are presented, indicating good performance for muon beams with large emittance. This work serves as a good starting point for future research at HIAF.

Methodology

- Formulas of Ionization Cooling

$$\frac{d\epsilon_n}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_T(13.6\text{ MeV})^2}{2E_\mu m_\mu c^2 L_R}$$

Evolution of transverse emittance

→

$$\epsilon_{n,eq} = \frac{\beta_T(13.6\text{ MeV})^2}{2\beta m_\mu c^2 L_R\left|\frac{dE_\mu}{ds}\right|}$$

Transverse equilibrium emittance

→

small β_T(strong focusing)
material with large $L_R\frac{dE}{dx}$

- Optics Design of Rectilinear Cooling Lattice

$$2\beta_T\beta_T'' - \beta_T'^2 + 4\beta_T^2 k^2 - 4(1+L^2) = 0$$

Evolution of transverse beta function

→

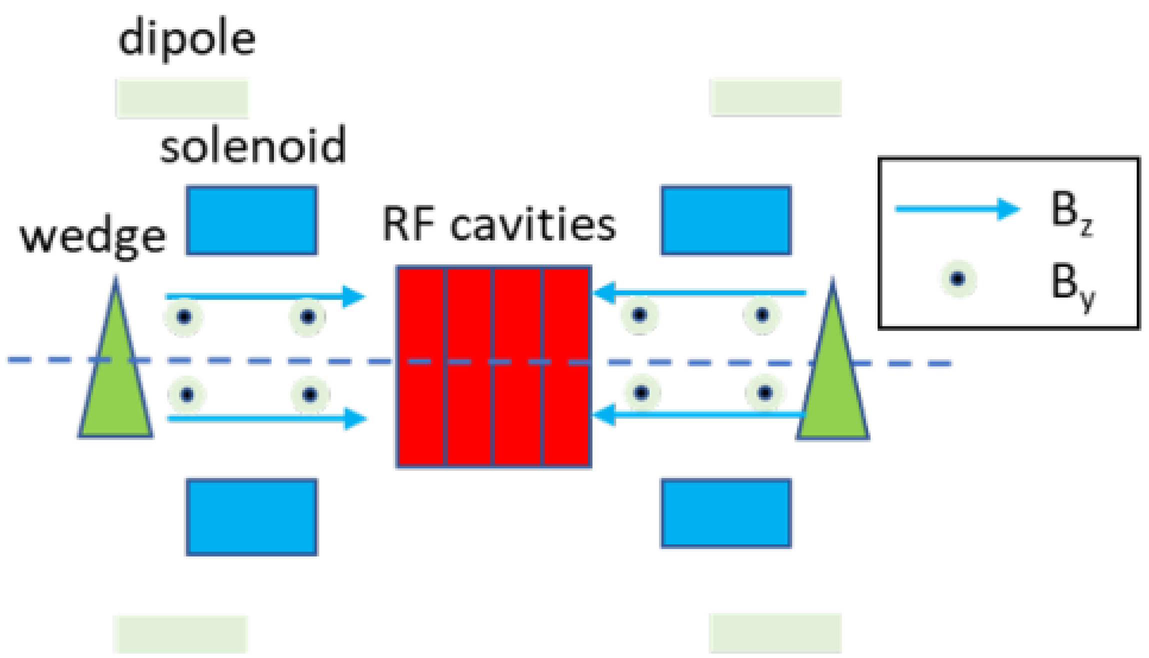
$$\phi = \int\frac{1}{\beta_T}dz \quad D_x = \frac{\delta x}{\delta p}$$

Phase advance and dispersion

→

Start the cooling simulation by choosing the suitable RF and wedge parameters

- Layout of the Cooling Cell



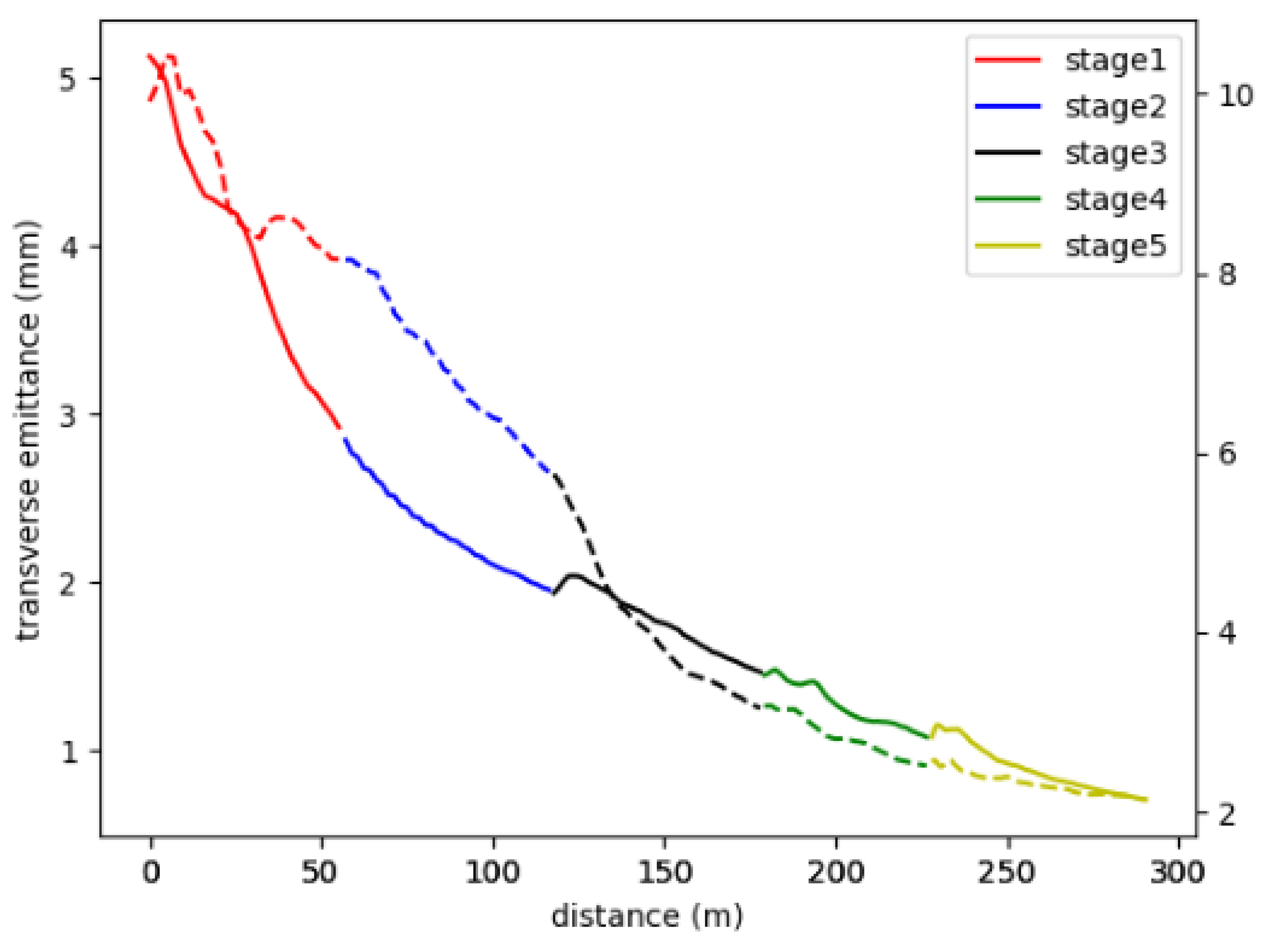
The whole cooling channel consists of 5 stages and each stage includes repeated cells. The cell length will gradually reduce for stronger focusing at the wedge absorber in order to achieve smaller emittance. Fringe field of dipole magnets is considered as well and for now a simple quadratic function is used to describe the fringe. The absorber material in all stages is liquid hydrogen and 100 μm Be safety window is used.

Results

- Parameters of Cooling Cells in Each Stage

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Cell length (m)	2.3	1.8	1.4	1.1	0.8
$B_{z,max}$ (T)	3.1	4.1	4.8	6.2	8.8
β_T (cm)	35	30	20	15	10
B_y (T)	0.3	0.375	0.425	0.45	0.35
Dispersion (cm)	5	5	4.5	2.5	1.8
On-axis wedge length (cm)	37	32	24	20	12
Wedge apex angle	110°	120°	115°	110°	120°
RF frequency (MHz)	325	325	325	325	650
RF #	6	6	6	4	4
RF length (cm)	22	17.7	12	14.6	11.6
RF gradient (MV/m)	22	21.4	24.3	22.9	21.1
RF phase	27.7°	29.8°	27.9°	32°	28.3°

- Emittance Evolution



	ϵ_T(mm)	ϵ_L(mm)	ϵ_{6D}(mm^3)	T(%)
Initial	5.13	9.91	260	
Stage 1	2.92	8.16	71.6	87.1
Stage 2	1.96	5.78	22.6	91.2
Stage 3	1.47	3.16	7.12	88
Stage 4	1.08	2.52	3.11	92.2
Stage 5	0.71	2.14	1.14	89.2

In the future, we will extend the cooling channel to more stages and check the limit of the cooling emittance. Meanwhile, we will explore the collective effects (e.g., space charge, short-range wakefield) in muon cooling.