STATUS OF THE MANX MUON COOLING EXPERIMENT*

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Abstract

A demonstration experiment of six-dimensional (6D) phase space muon beam cooling is a key milestone on the roadmap toward to a real muon collider. In order to achieve this goal, we have designed the Muon collider And Neutrino factory eXperiment (MANX) channel, which consists of the Helical Cooling Channel (HCC). We discuss the status of the simulation study of the MANX in this document.

CONCEPTUAL DESIGN OF MANX

We have considered a 6D phase space cooling demonstration experiment, which we call MANX [1]. The main goals of this experiment are to prove the helical cooling theory and to demonstrate the feasibility of the HCC. The crucial advantage of the MANX experiment is that the output signal from the MANX channel is very robust. Consequently, a high-precision experiment is not required in order to demonstrate clearly the effectiveness of the beam cooling.

The current MANX channel design is shown in Figure 1. It consists of three sections; an upstream matching section, a helical cooling section, and a downstream matching section. The helical cooling section is made of the superconducting helical solenoid (HS) coil. By adjusting current distribution in each HS coil, we can generate the desired helical dipole, helical quadrupole, and solenoid components [2]. The matching section is designed to connect between the beam phase space in the straight section and the helical beam phase space. From the recent design study, the optimum matching field can be generated by the HS coil [2]. In this study, the whole MANX field is generated in the analytical field expression for simplicity.

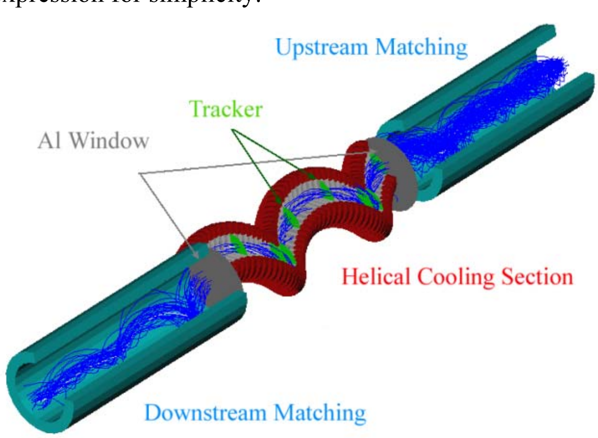

Figure 1: Whole layout of the MANX.

It is better to use a low Z (atomic number) material as a cooling absorber to reduce the heating effect caused by the stochastic process (multiple scattering and energy straggling). Liquid helium (LHe) is used as the cooling absorber in the current design since it is widely used and easy to handle without any serious safety considerations. LHe can also work as a coolant of superconducting coils.

BEST COOLING SCHEME

Figure 2 shows the field amplitude on the reference orbit in the whole MANX channel in the best cooling scheme for a muon collider. The field amplitude in the helical cooling section is ramped down along with the beam path length since the average beam momentum is degraded by the ionization energy loss with LHe. The design parameter is listed in Table 1.

Table 1: Design Parameters in Cooling Section

Initial mean momentum Final meam momentum	**p**	300 MeV/c 170 MeV/c
Helical pitch	**κ**	1
Helical period	**λ**	1.6 m
Helical ref. orbit radius	***a***	0.255 m
Initial solenoid strength Final solenoid strength	**Bz**	-3.8 T -1.7 T
Initial helical dipole strength Final helical dipole strength	**b**	1.2 T 0.8 T
Initial helical quad. Strength Final helical quad. Strength	**b’**	-0.9 T/m -0.5 T/m

In the matching section, the amplitude of helical dipole field component is adiabatically ramped up. The transverse momentum is induced in this section and the beam position is moved from the coaxial center. A detailed discussion has been done in Ref. [3].

Figure 3 shows the 6D emittance evolution in the MANX with best cooling scheme. We can observe the 6D cooling factor of 2.

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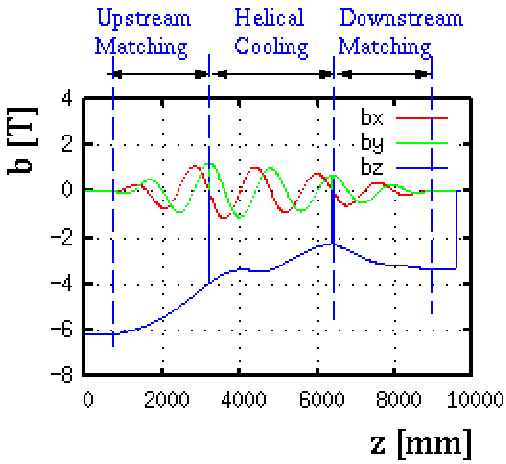


Figure 2: Magnetic field of reference particle in MANX

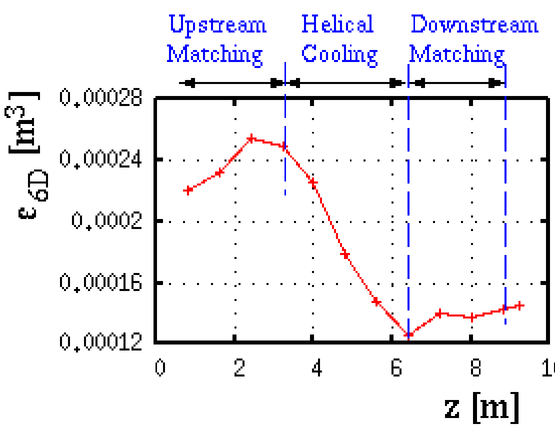


Figure 3: 6D emittance evolution in the best cooling scheme

OPTIONAL COOLING

We tested another cooling scheme in the helical cooling section in simulation; that is longitudinal only cooling. This feature is uniquely happened in the HCC. Therefore, it can be shown the verification of the helical cooling theory. This scheme can be realized with the dispersion factor [4], $\hat{D} = 2\left(1+\kappa^2\right)/\kappa^2$, where κ is the helical pitch which is the ratio between transverse and longitudinal momenta (pφ/pz).

Figure 3 shows the transverse, longitudinal, and 6D emittance evolutions with two different sets of cooling schemes. One set (red and blue lines) shows the longitudinal only cooling scheme (LOCS) and other one (green and magenta lines) shows the best cooling scheme (BCS) as discussed in previous session, respectively. One can find that the transverse emittance cooling efficiency in the BCS is ~30 % larger than that in the LOCS. On the other hand, the longitudinal emittance cooling efficiency in the LOCS is 50 % bigger than that in the BCS. It is worth to note that the 6D emittance evolutions in both schemes are identical. It means that the 6D cooling efficiency is determined by the total amount of energy loss.

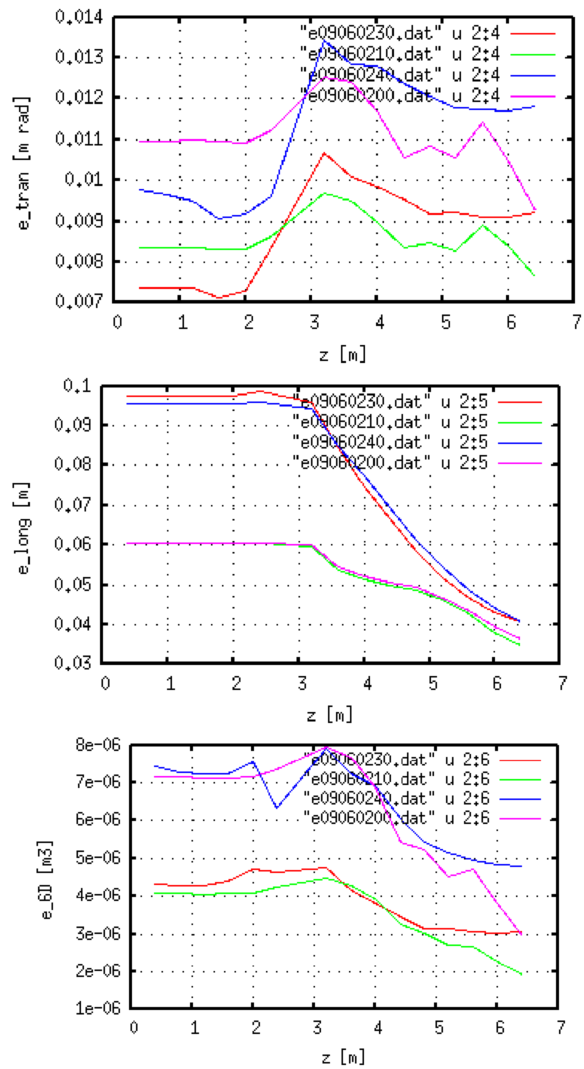


Figure 3: Transverse (top), longitudinal (middle), and 6D (bottom) emittance evolutions in the best cooling (red and blue lines) and the longitudinal only cooling (magenta and green lines) schemes.

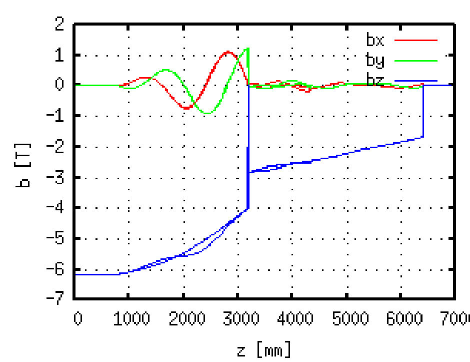


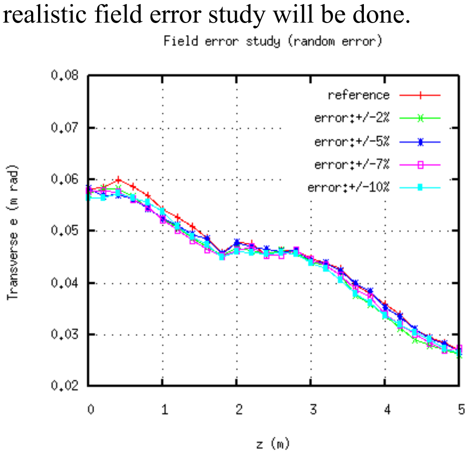
Figure 4: Field amplitude in the longitudinal only cooling decrement channel with the upstream matching magnet. The field is immediately turned off at z = 3200 mm. It is not realistic.

In order to achieve the longitudinal only cooling scheme, the helical dipole field component must be zero in the helical cooling section as shown in Figure 4. This magnet structure may be realized by superimpose the field configuration from the other HS coils as discussed in Ref. [5].

The helical magnet structure has another unique feature: It can realize the isochronous condition. It appears when the dispersion function is fulfilled $\hat{D} = \left(1+\kappa^2\right)/\gamma^2\kappa^2$, where γ is the normalized energy by the muon mass. This study is in progress [6].

FIELD QUALITY TEST

Figure 5 shows the transverse and longitudinal emittance evolutions in the helical cooling magnet with a random field error. The various rms of random field error is tested with ±2 %, ±5 %, ±7 %, and ±10 %. These fractions are randomly multiplied to three field components, bx, by, and bz. As a result, the random field error does not strongly affect on the cooling efficiency. The real field error is caused by the misplacement and disorientation of conductor and drift of the current. The realistic field error study will be done.



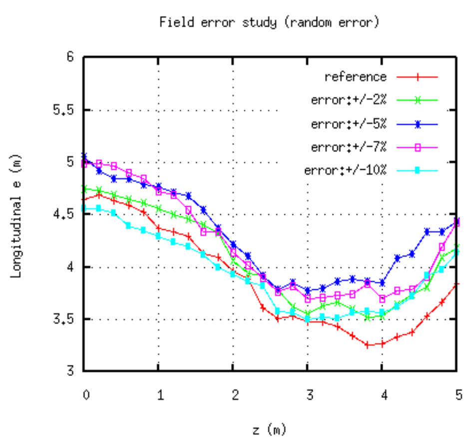


Figure 5: Transverse (top) and longitudinal (bottom) emittance evolutions in the cooling magnet with various field errors

DESIGN OF DETECTOR SYSTEM

The main spectrometers are located upstream and downstream of the MANX channel to measure the initial and final beam phase space. We expect that the MICE type spectrometer can be applied for the MANX experiment [7]. In addition, the fast signal time of flight (TOF) counter is needed for the precise longitudinal phase space measurement. We have collaborated with the University of Chicago group to develop the 2 ps TOF counter.

By putting several tracker planes in the helical cooling section, we can significantly suppress the systematic error caused by the particle loss. Those trackers can be used as the spectrometer if the quality of the field map is sufficiently good. The particle tracking and reconstruction are essential for this purpose. The source of ambiguity is caused by the multiple scattering and energy straggling in the interaction with the absorber. The Kalman filter can deal with this stochastic process as a noise [8]. The tracker detector in the cryostat will be made of a scintillation fiber (SciFi) detector. The feasibility study of SciFi tracker in the cryogenic temperature is in progress.

It will not be critical to determine the particle id in this experiment to remove as a background signal since background particles, like protons and pions, can be absorbed in LHe absorber. But an electron generated from a muon decay after the helical cooling section cannot be separated. The electromagnetic calorimeter which is located at the end of MANX channel can identify a signal of the electron from real signal. The quantitative study of the spectrometer design is on going.

CONCLUSIONS

We have designed the MANX channel to demonstrate the 6D helical cooling concept by comparing experimental result with the simulation results. We discussed two possible cooling options; the best cooling and the longitudinal only cooling schemes. Those tests can be clear evidence that the helical cooling theory is valid.

The output signal from the spectrometer must be sufficiently precise to compare with the simulation result. We have started the design study of the spectrometer system. The design of the fast TOF counter is being optimized for a precision measurement of the longitudinal phase space.

REFERENCES

[1] Letter of Intent "MANX, A 6D MUON BEAM COOLING EXPERIMENT", www.muonsinc.com/tiki-download_file.php?fileId=230
[2] V. S. Kashikhin et al, EPAC'08, WEPD013
[3] K. Yonehara et al, PAC'07, THPMN110
[4] Y. Derbenev and R. P. Johnson, PRSTAB 8, 041002 (2005)
[5] S. Kahn et al, EPAC'08, MOPP090
[6] C. Yoshikawa et al, EPAC'08, WEPP123
[7] T. Hart et al, EPAC'08, TUPC088
[8] A. Cervera-Villanueva et al, NIM A 486, 639 (2002)