MUON CHARGE SEPARATION BY MIXED STRUCTURE OF DIPOLES AND SOLENOIDS *

Y. P. Song[1†], J.Y.Tang, H. T.Jing, IHEP, Beijing, China
[1]also at NSRL, USTC, Hefei, China

Abstract

A charge separation system comprised by dipoles and solenoids is described which aims to separate positive particles and negative particles apart in secondary beam with a large emittance and huge momentum spread, particularly for mixed-charge muon beams. Nonlinear effect and fringe field effect due to large aperture and large moment range are crucial under this circumstance, which make the charge separation extremely complicated. The design schemes by dipoles and bent solenoids and also simulation results are showed in the paper.

INTRODUCTION

Intense muon beams are important in some neutrino-beamlines or muon sources for muon physics. Positive and negative muons (and also pions) are mixed from a solenoid-based target-capture system. One of them should be removed from the main beamline before sending the remained one to the downstream beamline. Due to the extremely large beam emittance and momentum range, it is the challenge to design the separation system. Here, two schemes, one by mixed dipoles and solenoids, the other by bent solenoids, are proposed. The methods are applied to a muon source – EMuS (Experimental Muon Source) at CSNS (China Spallation Neutron Source). The optics and the tracking results with G4Beamline [1] and TRANSPORT [2] are presented here.

SEPARATION BY MIXED DIPOLES AND SOLENOIDS

The major scientific goals at EMuS are: as R&D effort for future neutrino beams based on muon beams such as Neutrino Factory and MOMENT [3], carrying out neutrino cross-section measurement using pion-decayed neutrinos and muSR applications. For the two first goals, we need to obtain pions or muons of 300±33% MeV/c in momentum range, and 1.6 πmm-rad in the RMS emittance. The charge separation should be performed in a short distance of less than 5 m due to pion's short lifetime (26 ns) and cost saving.

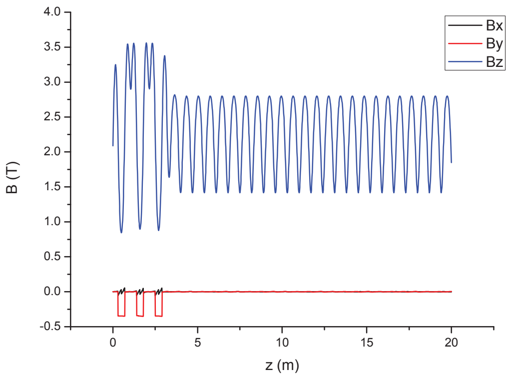

Figure 1: Field map along the reference trajectory.

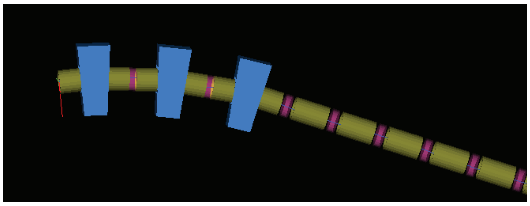

Figure 2: Schematic of charge separation section and decay channel.

EMuS has adopted a design with a long carbon target inside a high-field superconducting solenoid. The secondary beams (including π+/π-, μ+/μ-) are captured and transported to the downstream beamline. A dedicated section in the beamline is designed to select one charge for further transport. A pure double-function dipole-based scheme is found to be too weak in transverse focusing, thus a mixed dipole-solenoid scheme is studied. Charge separation section is composed of three cells, with each cell of one sector dipole and two half-solenoids, see Figure 1 and Figure 2. The downstream decay channel is composed of periodic solenoid cells. As the fringe-field effect is still needed to be included in the G4Beamline code, it is not included in the present result. However, the fringe field effect is included in TRANSPORT calculations. The preliminary study show that this scheme can work in the condition. The simulation results with different momentum ranges and different beam emittances are summarized in Table 1 and Table 2. Also separation results under emittance 1.6mm are showed in Figure 3.

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† songyp@ihep.ac.cn

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Table 1: Transmission Efficiency and Emittance Growth with Different Beam Emittance

πmm rad	Trans	σ_x growth	σ_y growth
1.6	94.2%	12.2%	22.2%
2.5	97.5%	14.1%	26.1%
4.489	96.7%	11.1%	17.2%
6.889	96.4%	12.4%	17.8%

Table 2: Transmission Efficiency and Emittance Growth with Different Momentum Spread, under Emittance 1.6

Δp/p	Trans	σ_x growth	σ_y growth
0	98.8%	0	0
±10%	98.7%	4.0%	4.4%
±20%	98.0%	11.9%	11.4%
±30%	95.8%	10.0%	20.8%

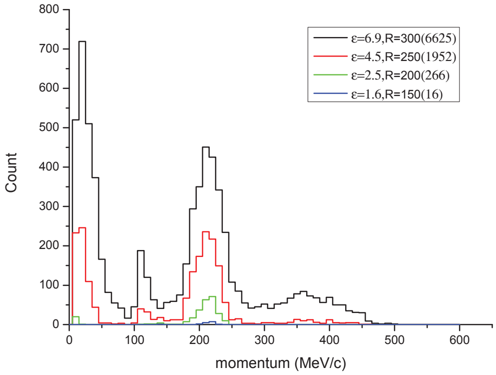

Figure 3: Separation results with different emittances, negative beam with 100000 particles, uniform momentum distribution from 0 to 600 MeV/c. number in bracket is value of residual negative particles.

The separation efficiency will decrease as the growth of beam emittance, we can use larger bending angle or adjust the currents of solenoids to wipe out residual negative particles, but that will harm the transmission efficiency and enlarge the emittance growth, where there is a balance we need to consider. We can find the fact that the escaping particles are associated with momentum, studies show that Larmar wavelength accounts for that.

SEPARATION BY CURVED SOLENOID AND COMPARASIONS

Curved solenoid method for charge separation has been developed for many years [4], some designs [5,6] are based on this method. The movement of charged particle in curved solenoid includes two parts, one is helical movement along beam line, and another is the vertical drift perpendicular to the curved plane, which can be used to do separation. The up helical angle α [5] is proportional to particle's momentumP_z as in Equation (1).

$$\alpha \in \frac{P_z}{\rho B} \qquad (1)$$

We can hardly separate one kind of charged particle from the other one due to the wide momentum spread of secondary beams if we want to keep them simultaneously. An alternate choice is scarifying one kind of particles by adding a By field on curved solenoid, we can eliminate another kind of particles totally. But transmission efficiency and separation efficiency cannot reach the optimum simultaneously, because high transmission efficiency need high Bz filed which is harmful to separation efficiency according to Equation (1). Table 3 and Table 4 can give you a light on that. The centre line field and schedule of the design are showed in Figure 4 and Figure 5.

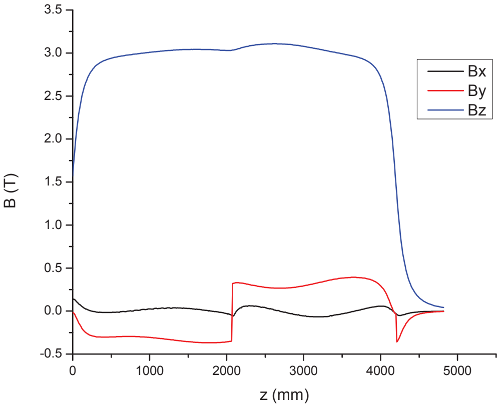

Figure 4: Field map along reference trajectory.

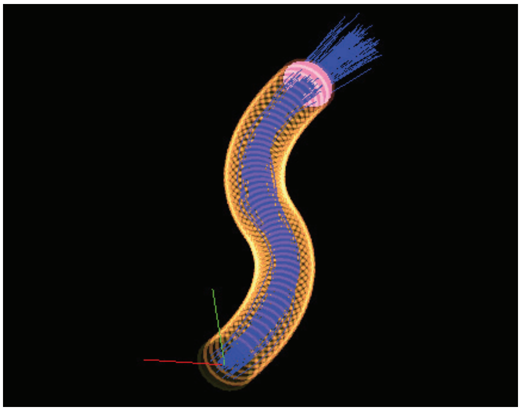

Figure 5: Schematic of curved solenoid.

Table 3: Separation preferred. Under emittance 1.6, ΔP/P=±33%, negative beam with 100000 particles, uniform momentum distribution from 0 to 600 MeV/c.

	Trans	σ_x growth	σ_y growth	Negative particle
dipoles	95.7%	22%	33%	0
curved solenoid	97.2%	21%	38%	0

Table 4: Transmission preferred. Under emittance 1.6, ΔP/P=±33%, negative beam with 100000 particles, uniform momentum distribution from 0 to 600 MeV/c.

	Trans	σ_x growth	σ_y growth	Negative particle
dipoles	94.2%	12.3%	22.6%	16
curved solenoid	93.5%	13.1%	20.8%	13

SUMMARY

Two schemes aiming for charge separation in high-intensity muon beamlines have been studied. The scheme with mixed dipoles and solenoids has shown good performance. Another scheme with bent solenoids is also acceptable. Both schemes can give good transmission efficiency and separation efficiency. Further optimization will be carried in the future.

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