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DECAY RING DESIGN UPDATES FOR nuSTORM *

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Abstract

The nuSTORM FODO decay ring is designed to achieve both a large phase space acceptance of 2 mm and a large momentum acceptance of 3.8±10% GeV/c. The goal is challenging, not only because the high dispersion needed at the Beam Combination Section (BCS) of the ring enlarges the beam size, but also because of the nonlinear beam dynamics. In this paper the preliminary design of the nuSTORM ring is presented, which includes the requirements, the ring parameters, and also the tracking results in the MADX PTC_TRACKING module.

INTRODUCTION

nuSTORM (neutrinos from STORed Muons) uses accelerator facilities including a primary proton beamline, a target station, a pion beamline, and a muon decay ring to generate a precisely known neutrino flux at the detectors to study short-baseline neutrino oscillations and cross sections. The purpose of using the ring is to store a muon beam in a large acceptance while the beam circulates and the muons decay into neutrinos. Proton bunches will be extracted from the Fermilab Main Injector (MI) to the target station to bombard a solid target, which generates a secondary beam including $K\pm$ and $\pi\pm$ over a wide range of energies. Depending on the neutrino flavor needed, a magnetic horn around the target is tuned to focus and collect π+ or π-, which will be transported and injected into the ring through the pion beamline [1]. The pion beamline is defined as the beamline from the downstream end of the horn to the end of the first decay straight. This includes the pion transport beamline, the Beam Combination Section (BCS), and the first decay straight. The muons from pion decay in the pion beamline can be captured in the ring acceptance and circulate in the ring.A schematic drawing of the nuSTORM pion beamline and the proposed layout of the nuSTORM facility at Fermilab is shown in Figure 1.

The BCS and the first decay straight are shared by both the pion beamline and the muon decay ring. The purpose of this design is to implement "stochastic injection", proposed by D. Neuffer [2], and to accommodate both pion and muon beams using the same magnets after the BCS. This design avoids using a separate pion decay channel and a full-aperture fast kicker to inject the muons, which is routinely used in full-scale neutrino factory designs. Although reducing the cost and avoiding some technical difficulties, this scenario needs a very large transverse dispersion function D_x at the BCS for the orbit separation where the pion beamline and the ring join together. The large D_x results in increased beam size, and thus needs to be suppressed quickly in both the upstream

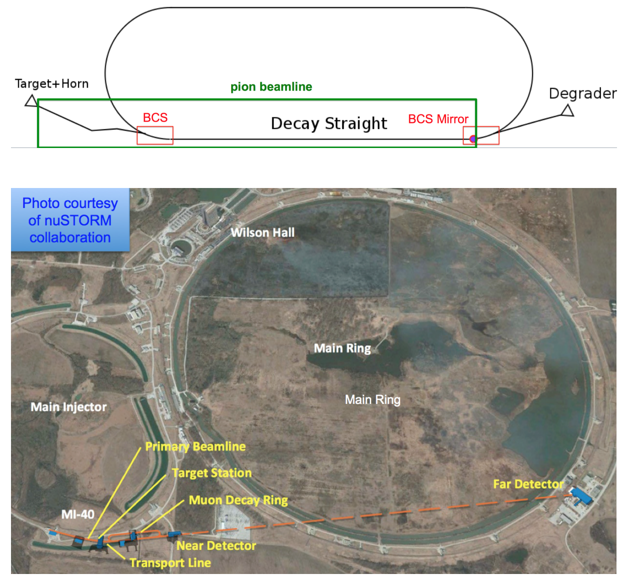

Figure 1: Upper: Schematic drawing of the nuSTORM pion beamline and muon decay ring; Lower: The Fermilab layout of the nuSTORM facility.

and the downstream magnets of the BCS. The higher-order dispersion effects induced at the BCS are destructive for a beam with very large momentum spread. In this paper the effects of adding nonlinear magnetic field are presented.

FODO RING LATTICE

The Twiss betatron function β for 3.8 GeV/c muons in the production straight FODO cells of the ring are chosen to balance the criteria of maximizing the muon-based neutrino flux, minimizing the number of cells needed for a ~150 m FODO channel, and minimizing the beam size. These purposes conflict with each other to some extent. The dispersion at the BCS is created by using the combination of a dipole and a defocusing quadrupole, at which D_x ~2.2 m. The higher-order dispersion along with D_x creates a separation of 50 cm between the 3.8 GeV/c reference muon and the 5 GeV/c reference pion. This separation distance is confirmed by both PTC tracking in MADX and G4Beamline particle tracking in the magnetic field. The Twiss functions from the production straight FODO cells to the BCS injection point for a 3.8 GeV/c reference muon beam (upper) are displayed in Figure 2.

One way to control the beam size in the arc section of the ring is to have zero dispersion to the extent one can. Under such circumstances, a "double-bend achromat" cell structure was proposed, which has zero dispersion between cells, but non-zero values within each cell. In order to further reduce beam loss, with the understanding that the neutrinos produced in the other straight section will not be utilized,

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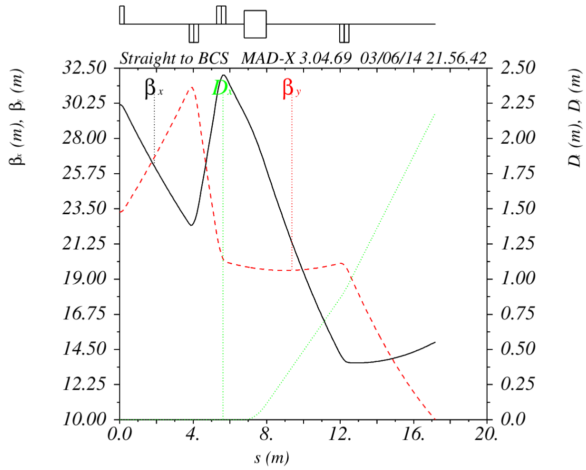

Figure 2: The optics of the 3.8 GeV/c reference muon from the FODO cells to the injection point. The beam moves from the right to the left in the BCS.

the Twiss β values in the return straight section are reduced to smaller values than β in the production straight. This makes the ring asymmetric. The optics of half of the ring are shown in Figure 3.

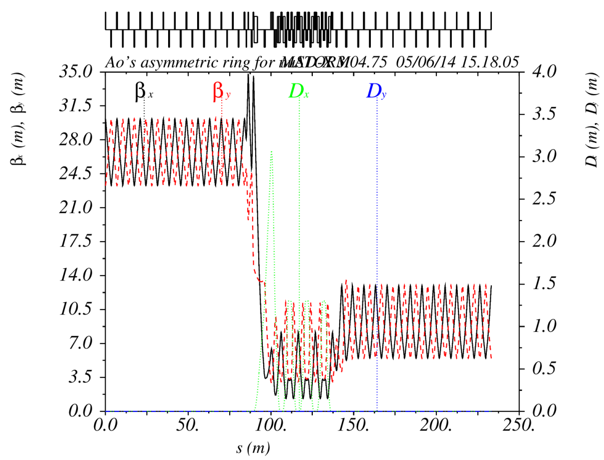

Figure 3: The Twiss of half of the FODO ring, from the middle of the production straight to the middle of the other straight section.

Particle tracking was done with MADX PTC tracking. Starting with a beam that is transversely Gaussian distributed within 2 mm·rad, and momentum uniformly distributed within 3.8±10% GeV/c, the beam loss due to the aperture limit is approximately 14% in a single turn, and 40% in 100 turns, after which the muons have decayed by more than 80%.

In order to study the nonlinear effects of the lattice, higher order dispersion functions are corrected with added sextupole fields. The effect of the correction is shown in Figure 4, where the phase space coordinates of off-momentum particles with different initial action were plotted. The betatron oscillation amplitudes, especially for the far off-momentum particles, show that after the correction the closed orbit is better centered than in the lattice with uncorrected dispersion functions. The correction reduces the single-turn loss to 10%. However, the sextupole field setup

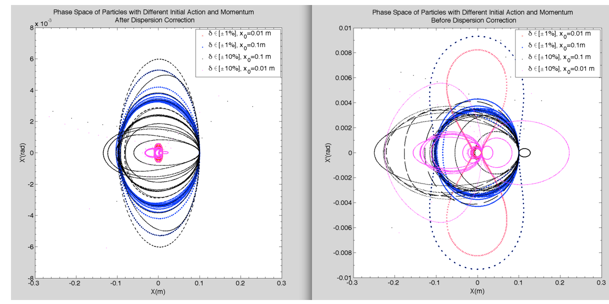

Figure 4: The tracking of off-momentum particles with different initial action in the nonlinear dispersion corrected lattice (left) and uncorrected one (right).

above does not perform chromaticity correction at the same time. The natural chromaticity is roughly -10 for both x and y directions. The multi-turn tracking does not show an obvious improvement in the total acceptance from the correction. Work on other possible correction scenarios is on-going. The summary of the FODO ring parameters is shown in Table 1.

Table 1: FODO Ring Parameters

Parameter name (unit)	**Value**
Circumference (m)	466.44
Production straight (m)	180
Total tune (H,V)	9.72, 7.88
Chromaticity (H,V)	-12.39, -9.24
Transition Gamma	28.51
Maximum Dipole Field (T)	4.14
Maximum magnet aperture radius (m)	0.3

RFFAG RING LATTICE

The summary of RFFAG lattice parameters is shown in Table 2. The most recent multi-particle tracking in the beamline shows a phase space acceptance of as large as 1 mm·rad, and a momentum acceptance of as large as 3.8±16% GeV/c. The injection scheme of the FFAG lattice is under design. A new Python-based code, pyZgoubi, is being developed to perform the MC tracking of muons in the FFAG ring [3]. The layout of the lattice is shown in Figure 5.

SUMMARY

A preliminary design of the nuSTORM muon decay ring has been obtained. The nonlinear corrections show a high possibility of achieving a better dynamic aperture than the current 60%. A Racetrack FFAG decay ring lattice is under design, which has a 3.8±16% GeV/c and a 1 mm·rad momentum and phase space acceptance according to the

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Table 2: FFAG Ring Parameters

Parameter name (unit)	**Value**
Circumference (m)	500
Production straight (m)	175
Total tune (H,V)	7.07, 4.15
Chromaticity (H,V)	0,0
Maximum Dipole Field (T)	3.3
Maximum magnet aperture radius (m)	0.6

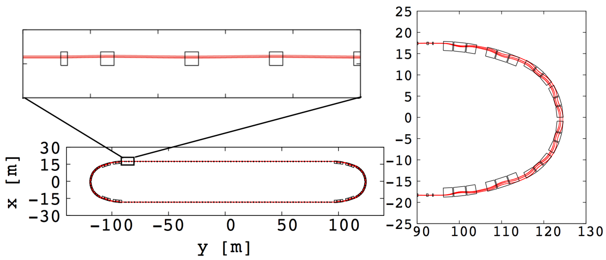

Figure 5: The layout of the RFFAG lattice.

recent studies. The two options will be compared once the optimization of the FODO ring and the injection design of the RFFAG ring are complete.

REFERENCES

[1] A. Liu et al. “nuSTORM horn optimization study", Proc. of IPAC’14, TUPRI005.

[2] D. Neuffer, “Design Considerations for a Muon Storage Ring." Proc. Neutrino Mass Miniconference, Telemark, WI, Oct (1980): 199.

[3] J.B. Lagrange et al. “RFFAG Decay Ring for nuSTORM", Proc of IPAC’14, TUPRO073.