REDTOP Beam Modeling for Raised Transition Energy and Third Integer Resonance Extraction

Justin Cammarota, Lebanon Valley College – SULI Program

Corrado Gatto and Michael Syphers, Fermi National Accelerator Laboratory and Northern Illinois University

Abstract

To explore physics beyond the Standard Model, the experiment called Rare Eta Decays with a TPC for Optical Photons (REDTOP) is in its proposal stage at Fermi National Accelerator Laboratory to study η decays. The existing delivery ring will destabilize the beam as it is decelerated for REDTOP's use, so modifications to the magnet arrangement have been proposed and must be simulated.This work focused on using MAD-X to model the introduction of new quadrupoles and sextupoles to raise the transition energy and shape the beam for extraction.

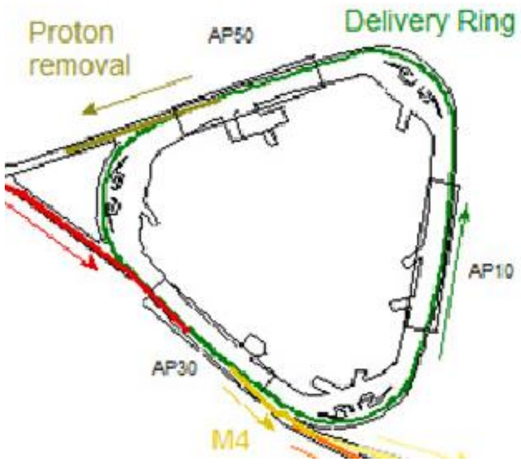

Figure 1: Current Delivery Ring setup for Muon g-2 experiment. REDTOP plans to use the ring to prepare a 1.9 GeV proton beam for extraction to a fixed beryllium target.

Background

REDTOP aims to examine the three main rare decays of an η meson: 3-π, γ $\ell^+ \ell^-$, and $\pi^0 \ell^- \ell^+$, especially the intermediary stages where symmetry violation may occur. The dark photon, theorized to take part in these interactions, is an example of the new physics REDTOP aims to discover. REDTOP is designed to use the existing Muon Campus facilities at Fermilab (see Figure 1), however, some modifications are required.

Modifications Tested

REDTOP's proposal[1] requires the 8 GeV proton beam delivered from the Main Injector be decelerated to 1.9 GeV. However, under the current design of the delivery ring, this would cause the beam to cross its transition energy, destabilizing the beam. To reduce beam loss, an alteration to 18 quadrupoles (3 groups of 6) has been proposed[2]. Once the beam has been decelerated, its stable phase space must be shaped into a triangle, from the normal ellipse, as called for by the third integer resonance extraction, similar to Mu2e's method[3].

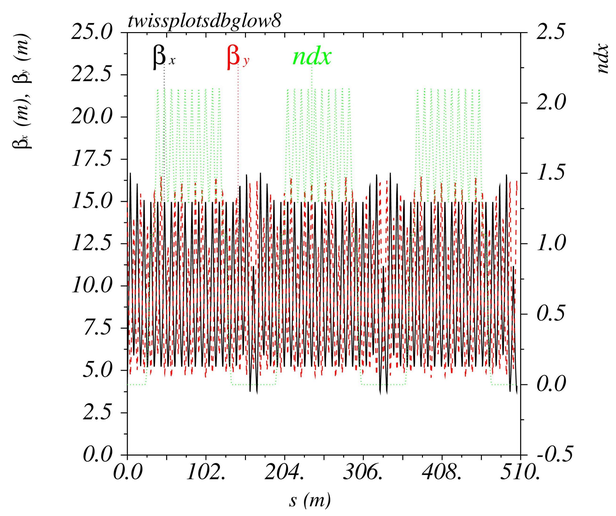

Figure 2: Twiss parameter plot for a transition energy of 7.64, the current value.

Quadrupole Modeling

Using the Twiss module of MAD-X, the Twiss parameters such as β_x, β_y, D_x, α_x, α_y, μ_x, and μ_y were calculated and plotted for each element in the lattice. In Figures 2 and 3, the beta functions and horizontal dispersion is plotted. Transition energy is inverse to the integral of dispersion^2, so it was confirmed the new quadrupoles decrease the transition energy of the delivery ring. While the beta functions look high, the actual beam width is proportional to the square root of β, so the 9 times increase in the beta function is only a 3 times increase in beam size, which does not cause beam loss in this case.

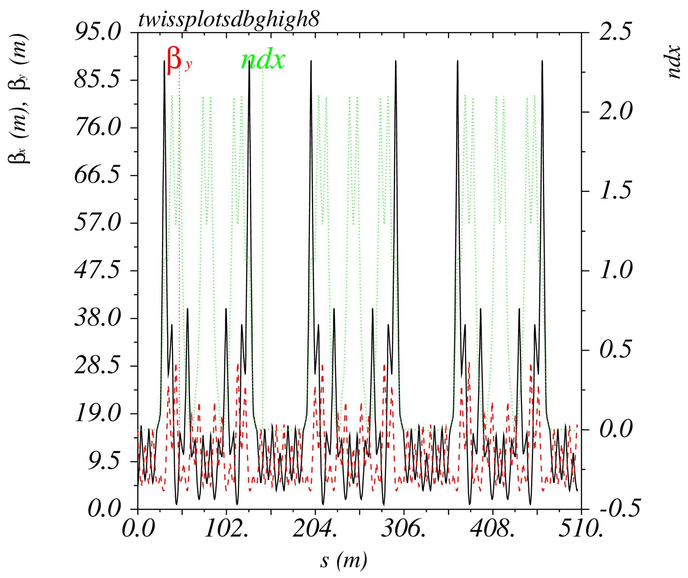

Figure 3: Twiss parameter plot for a transition energy of 10.0286, the value after the addition of the quadrupoles.

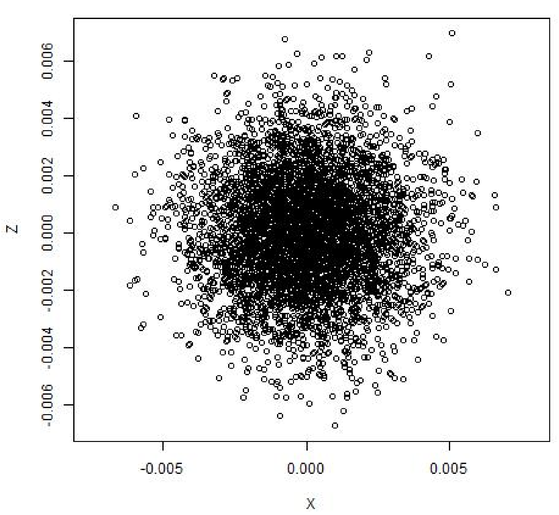

Figure 4: Initial distribution of 5000 particles for a 1.9 GeV beam in normalized coordinates.

Sextupole Modeling

In order to direct a continuous beam of particles to the target hall, REDTOP proposes using a third integer resonance extraction method. This means the beam shape will essentially be a triangle, with each particle returning to near its original position every third turn. Then, sextupole magnets will be powered to limit the phase space of the beam, forcing any particles outside that space to cross a septum and be redirected to the target hall. A Gaussian distribution of 5000 particles was run through 100 turns of the delivery ring, and plots were made of the phase space and individual particle positions at the septum for each turn, where Z = αX + βX', a rescaling for ease of viewing.

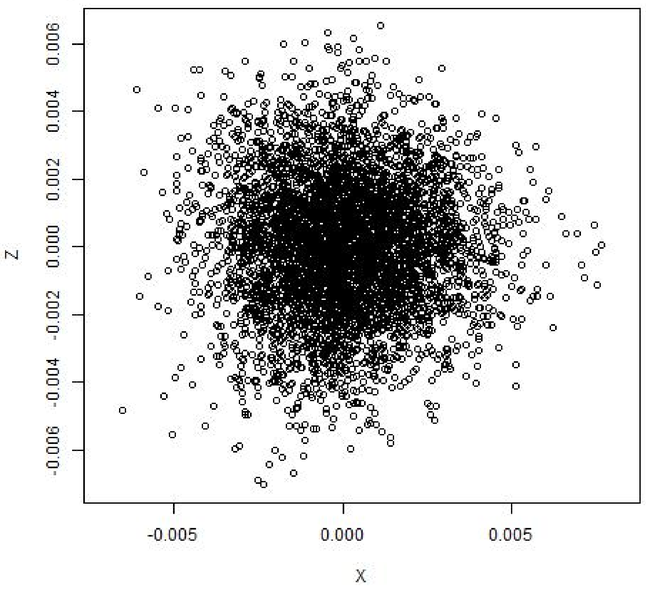

Figure 5: Distribution for the same beam as in Figure 4, but after 100 turns in the modified delivery ring.

Future Work

While this work proved the addition of quadrupoles to raise the transition energy and the sextupoles to change the beam shape are theoretically feasible, REDTOP's proposed setup cannot be confirmed possible until the full deceleration and extraction process is modeled.

References

[1]Y. Alexahin, et al. "Rare Eta Decays with a TPC for Optical Photons Expression of Interest," The REDTOP Collaboration.

[2]J. A. Johnstone, et al. "Delivery Ring Lattice Modifications for Transitionless Deceleration," Fermilab, 2016.

[3]V. Nagalsev, et al. "Third Integer Resonance Slow Extraction Scheme for a Mu→e Experiment at Fermilab," 2012.

Acknowledgments

This work would not have been possible without the support and expertise from John Johnstone at Fermi National Accelerator Laboratory, Andrew Fiedler at Northern Illinois University, and the rest of the IARC community. This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internship (SULI) Program.