Low Energy Muon Capture and Transport from a Heavy Target

Wesley Winter, Under Advisor Dr. Carol J. Johnstone, Paradise Valley Community College
CCI Summer Intern

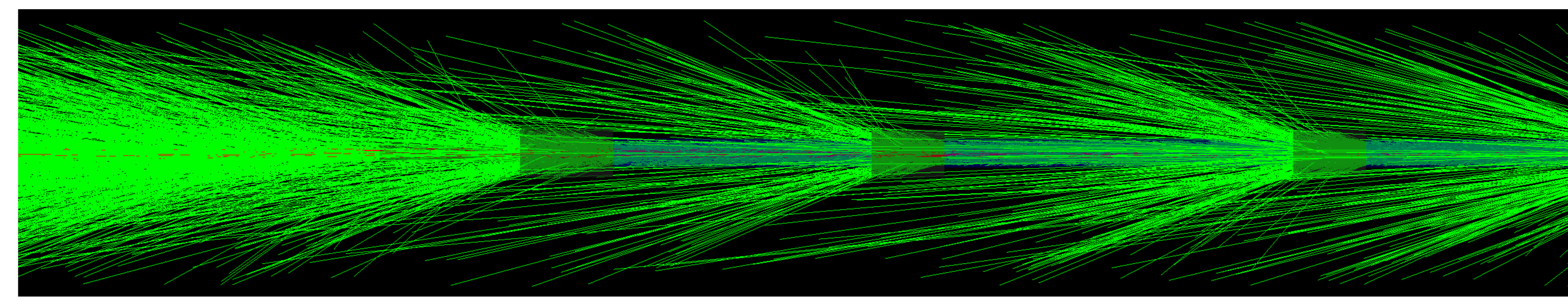
FERMILAB-POSTER-23-246-AD-STUDENT

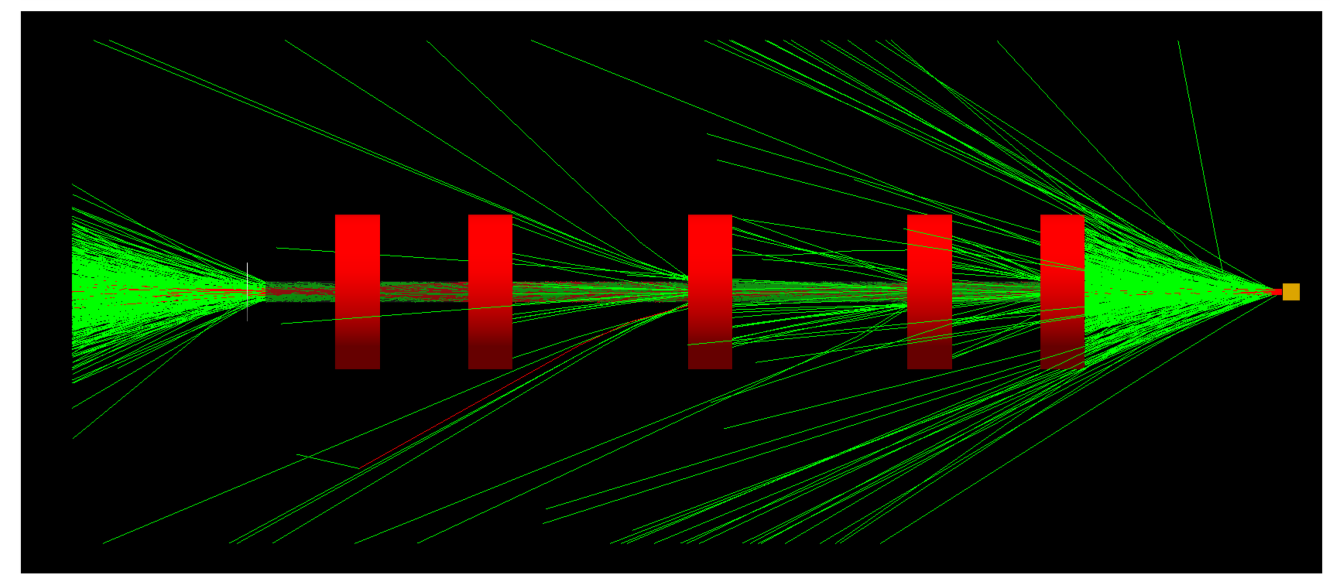
MTA Quadrupole and Lattice Upgrade

The MeV Test Area (MTA) secondary beamline is currently designed to produce and capture a low energy pion beam that then produces a tertiary muon beam via decay along the secondary line. The challenge presented in capturing muons from low-energy decay-in-flight pions, is the large decay angle that results from the low momentum. The current air-core quadrupoles lack the strength to bend/capture muons at large angles. Recently much stronger 400- MeV Linac quadrupoles have become available which are capable of strong focusing and large-angle capture. Initial results from this upgrade and reconfiguration are presented here.

Current Air Core Quad Lattice at the MTA Secondary Beamline

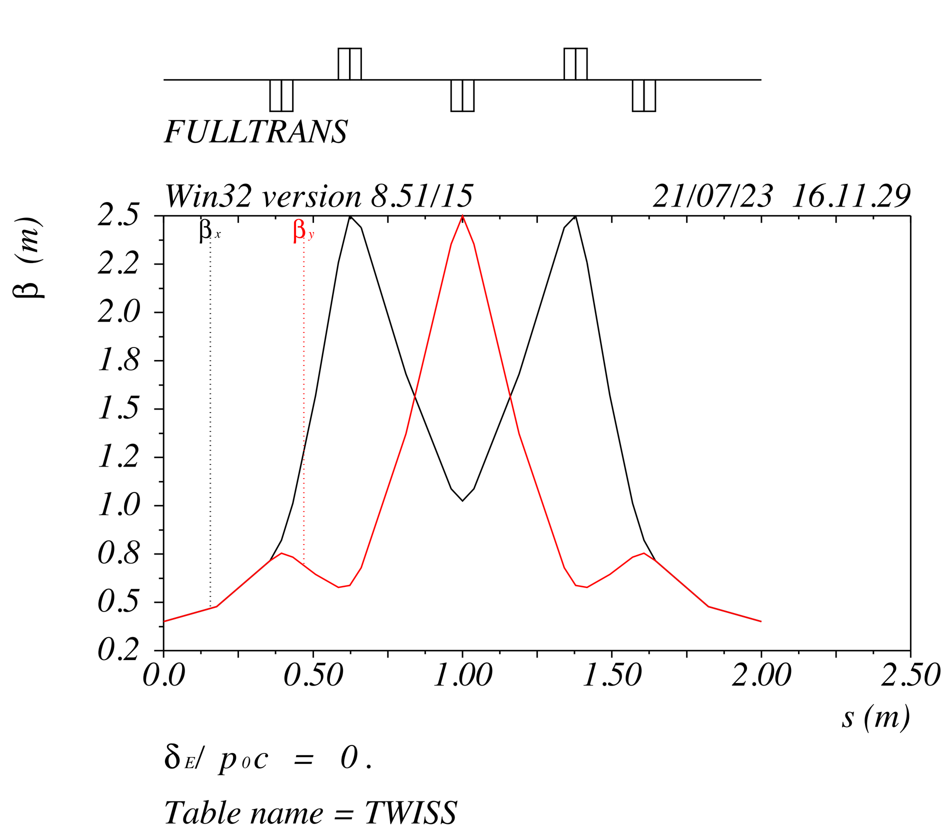
Iron Core Quads available for an upgrade





Old beamline configuration (above) from a prior study and new beamline configuration (left) from current R&D displaying particle tracking from G4beamline. (Tang 2023)

MAD-X and G4beamline Initial Design

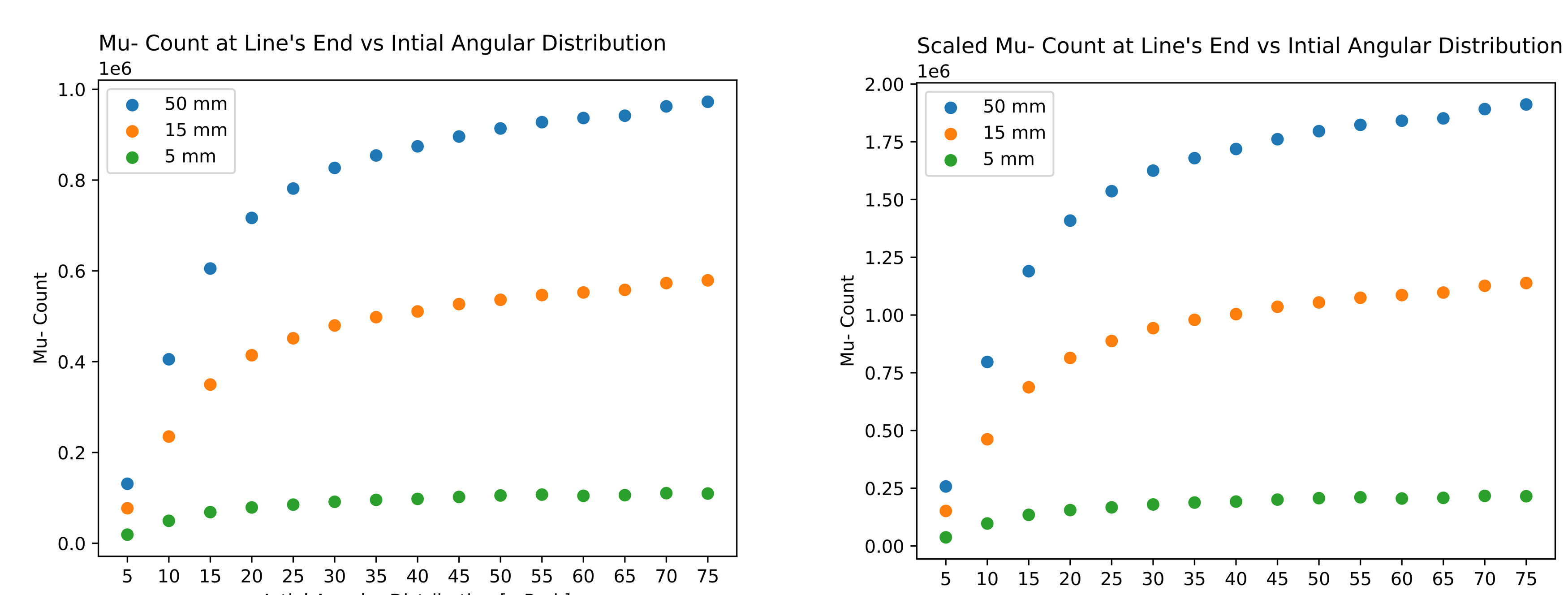


Our current design includes a solenoid that matches into a long half FODO cell, with each focusing element comprised of a group of 3 air core quads to match, 4 in the center of the cell, and 3 to reverse into a circular, parallel beam at the exit of the beamline. that from an effective cell. Our new line is comprised of single quad elements, in a short, strong focusing design. The lattice envelope functions have been modeled for a strong focusing reverse gradient structure. Parameters for a triplet FODO cell are initiated with a low beta of 0.4 m. ~±5 mm target spot size. For a beam spot size of ~±5 mm, the emittance of the initial ellipse is then ~60 mm-mr (geometric, 95%), which is well within the 38 mm diameter bore of the Linac quads. The phase advance of this structure is 151.2° in the x envelope and 178.92° in the y envelope. This current line reaches a maximum of 5 [m], and the studied lattice as currently designed is a little over 2 [m] including a matching final and initial drift. The next step is to implement the remaining two quads to extend our line to the desired 5 [m], because in 5 [m] at 100 MeV/c momentum, 59.163 % of the pions decay. In 2 [m] only 30.096 % of the pions to decay into muons. However, even with that challenge our improved angle acceptance has been increased by almost a factor of 5 in both planes and a factor of 25 overall.

Initial Data Analysis

Currently our predictive model's state our new lattice can:

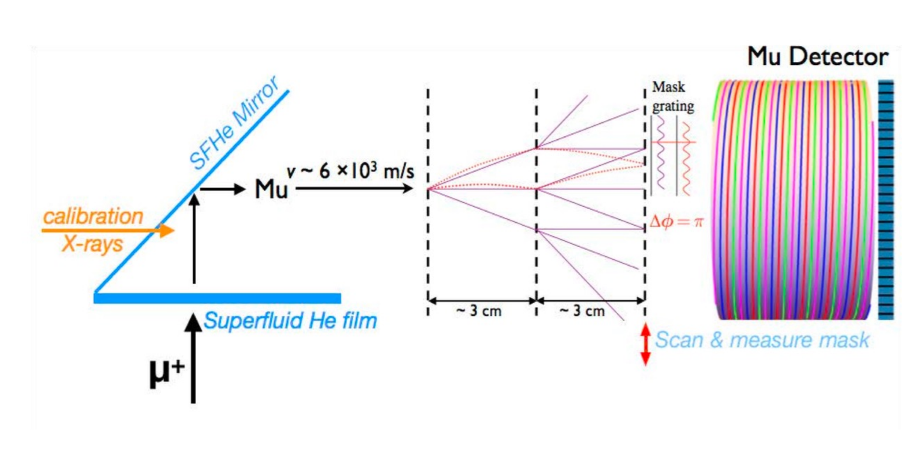
- Increased focusing and angular capture capability by factor x5 per plane
- Triplet quad focusing "telescope" at the end of the beamline potentially reduces muon capture area x100 thus increasing muon flux by this factor
- Factor of x500, or more, in muon flux without increasing primary intensity



Negative muon count vs uniform pion distribution angle at the beginning of the beamline from the target studies. Left plot is the 2m length results and right plot renormalizes the decay muon population by the ratio of the decays in 5m vs 2m.

Future Work

With an upgraded beamline component and lattice design implemented, we will be able to support the intensity requirements of low energy muon experiments such as the NK lab's muon catalyzed fusion experiment, muonium, lepton charge violation, and muon spin resonance experiments. An even lower energy mu⁺ beamline tune is being studied to support experiments on Antimatter Gravity with Muonium, (an exotic pseudo hydrogen molecule).



"Three-grating muonium-gravity interferometer, shown schematically in elevation view, with gravitational deflection and phase shift Δφ exaggerated for clarity." (Antognini et al. 2018).

Special thanks to my mentors Dr. Carol Johnstone and Dr. Casey Durandet, and to my colleagues Erica Garcia Badaracco, Jasmine Tang, and Shiza Ahmed.

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

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 Community College Internships Program (CCI)