Analysis of Potential Target Materials for the Mu2e Production Target

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Introduction

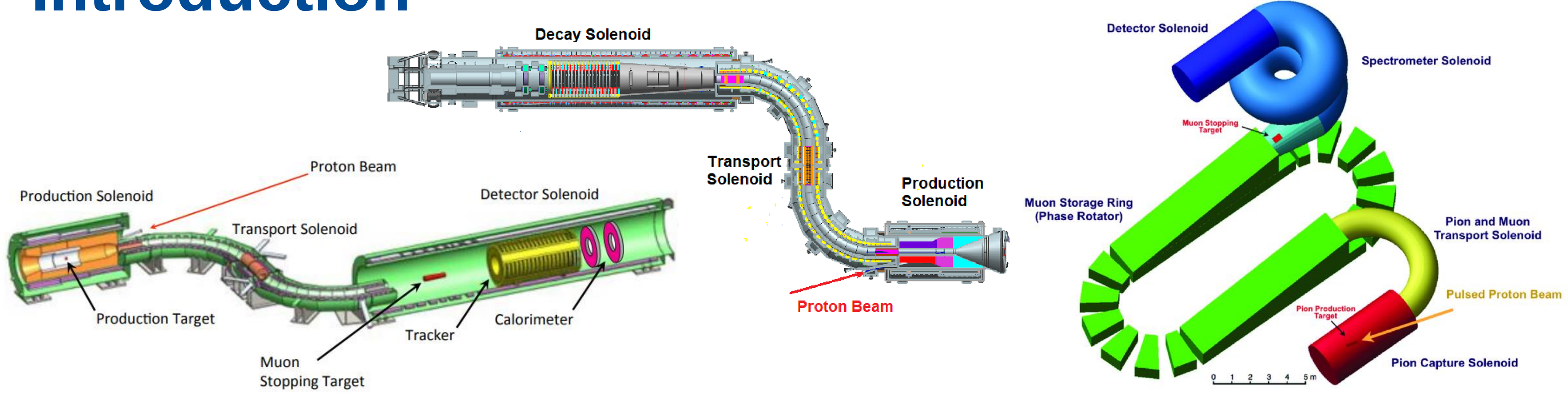

Fig. 1: Current and future projects at Fermilab that require muon production targets. From left to right, Mu2e[1], Mu2e-II[2], and the Advanced Muon Facility[3].

The need for high intensity secondary beams—in particular muon beams—is becoming increasingly evident, necessitating innovation in target design. Ideal muon production targets are temperature stable while producing high muon yields. We have identified radiation length and nuclear interaction length as proxies for these parameters, with longer radiation length decreasing energy deposition in the target and shorter nuclear interaction length increasing muon yield. Thus, the ideal target material will have long radiation length and short nuclear interaction length.

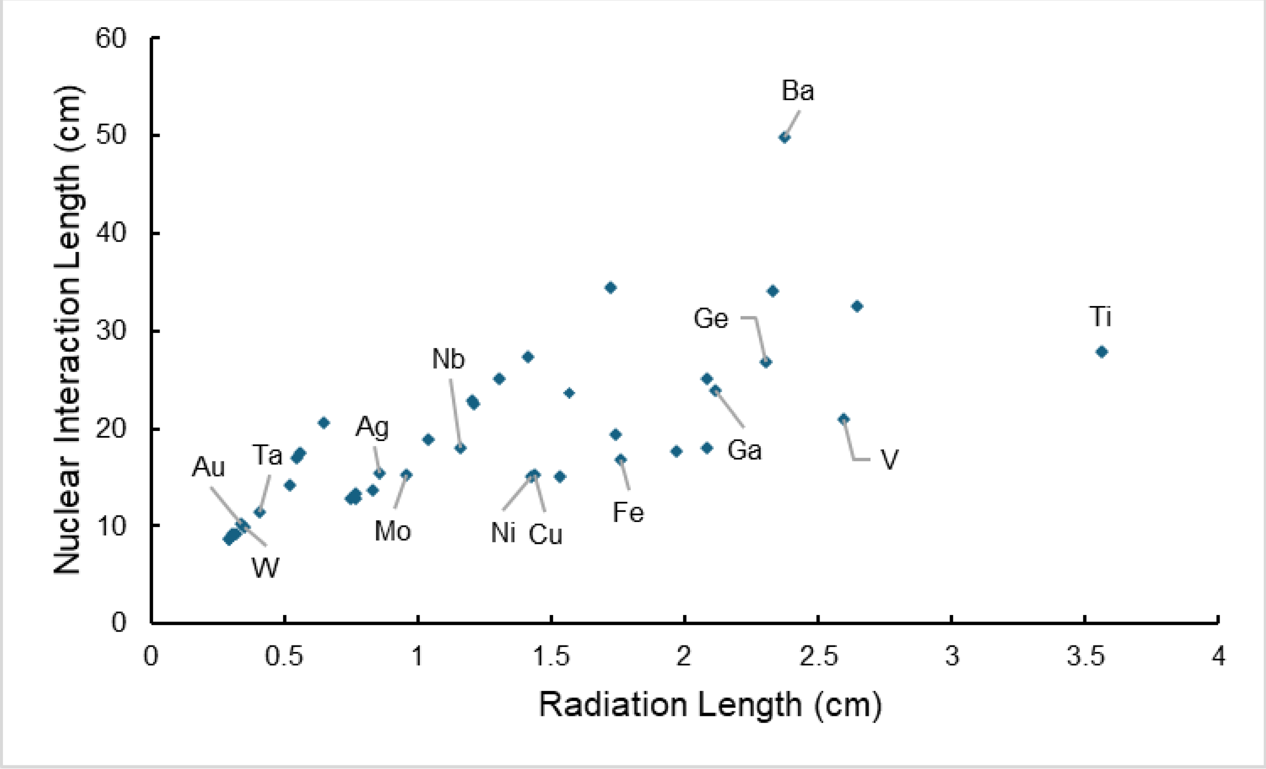

Fig. 2: Nuclear interaction length versus radiation length for various materials. Graphite is not pictured for clarity, but it has a radiation length of 19.32 cm and a nuclear interaction length of 38.83 cm.

Muon Production

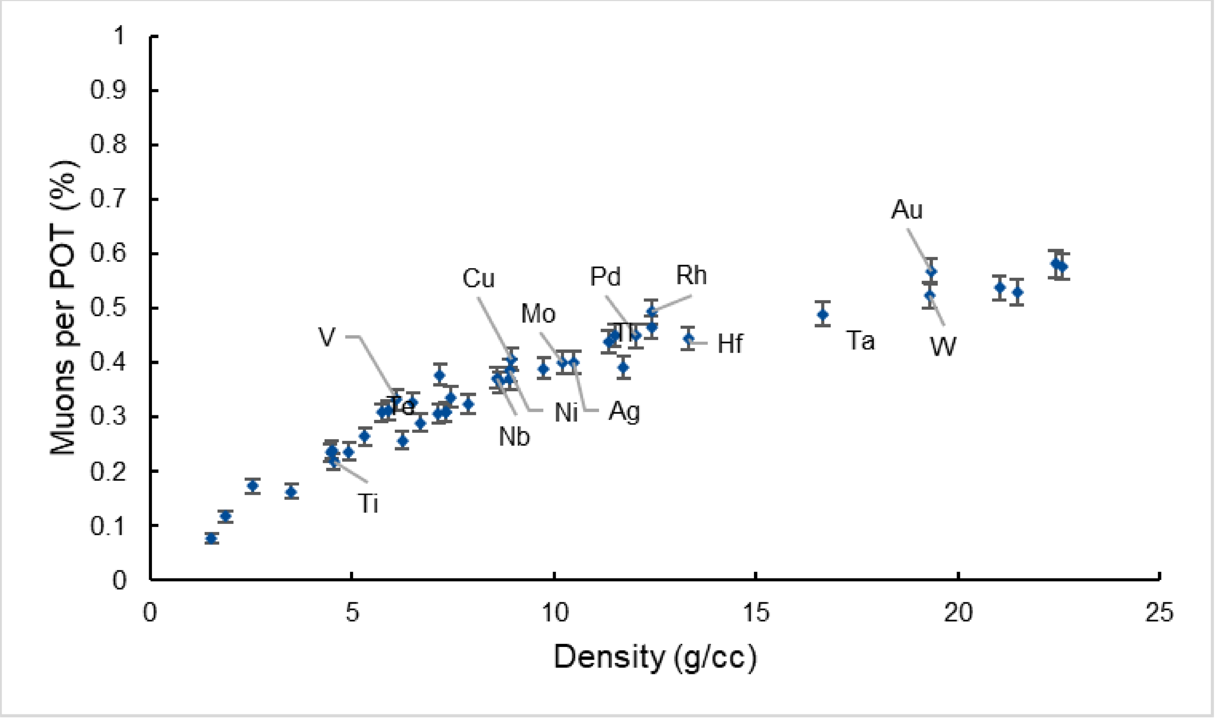

Fig. 3: Percentage of muons per proton on target versus density for various materials from a G4Beamline simulation of a cylindrical target with radius 3.15 mm and length 160 mm.

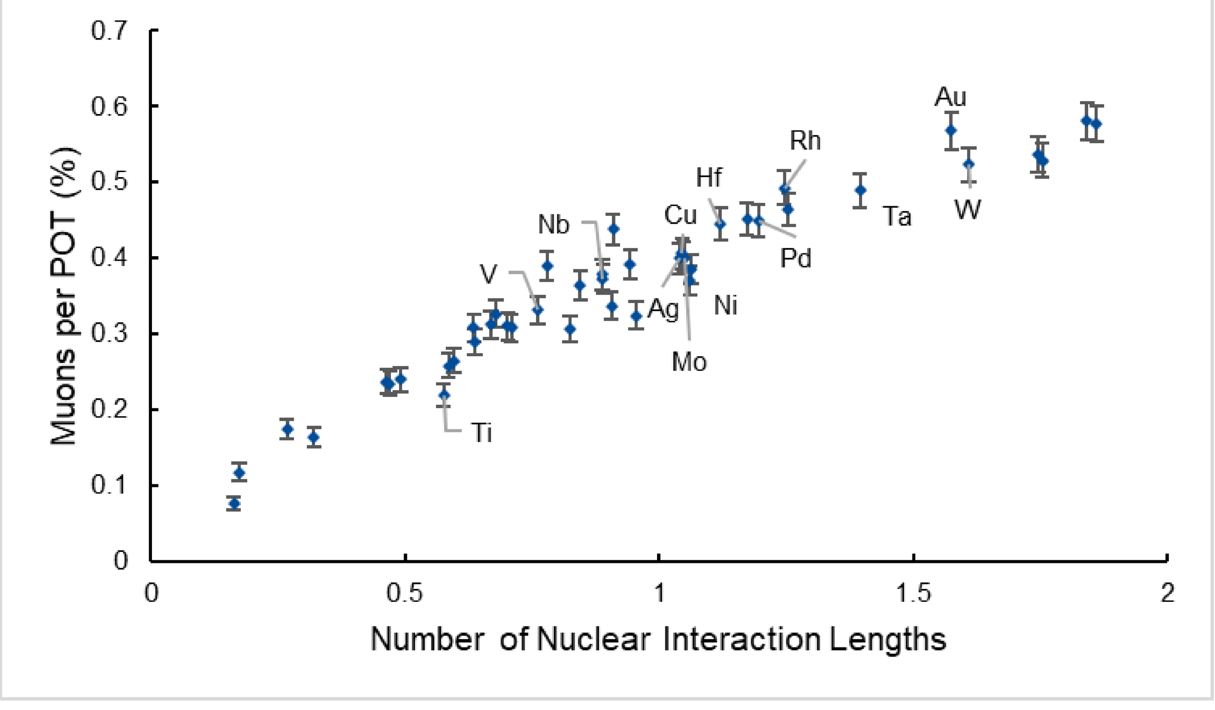

Fig. 4: Percentage of muons per proton on target versus number of nuclear interaction lengths for various materials from a G4Beamline simulation of a cylindrical target with radius 3.15 mm and length 160 mm.

The conventional wisdom has been that high Z, high density materials like tungsten are necessary for high secondary yields. However, there are diminishing returns on muon yield with increasing density, with the additional drawback that higher density results in greater energy deposition. We have found that number of nuclear interaction lengths is a better proxy for muon yield, indicating that it might be possible to increase muon yield via target design for a lower density material with longer radiation length.

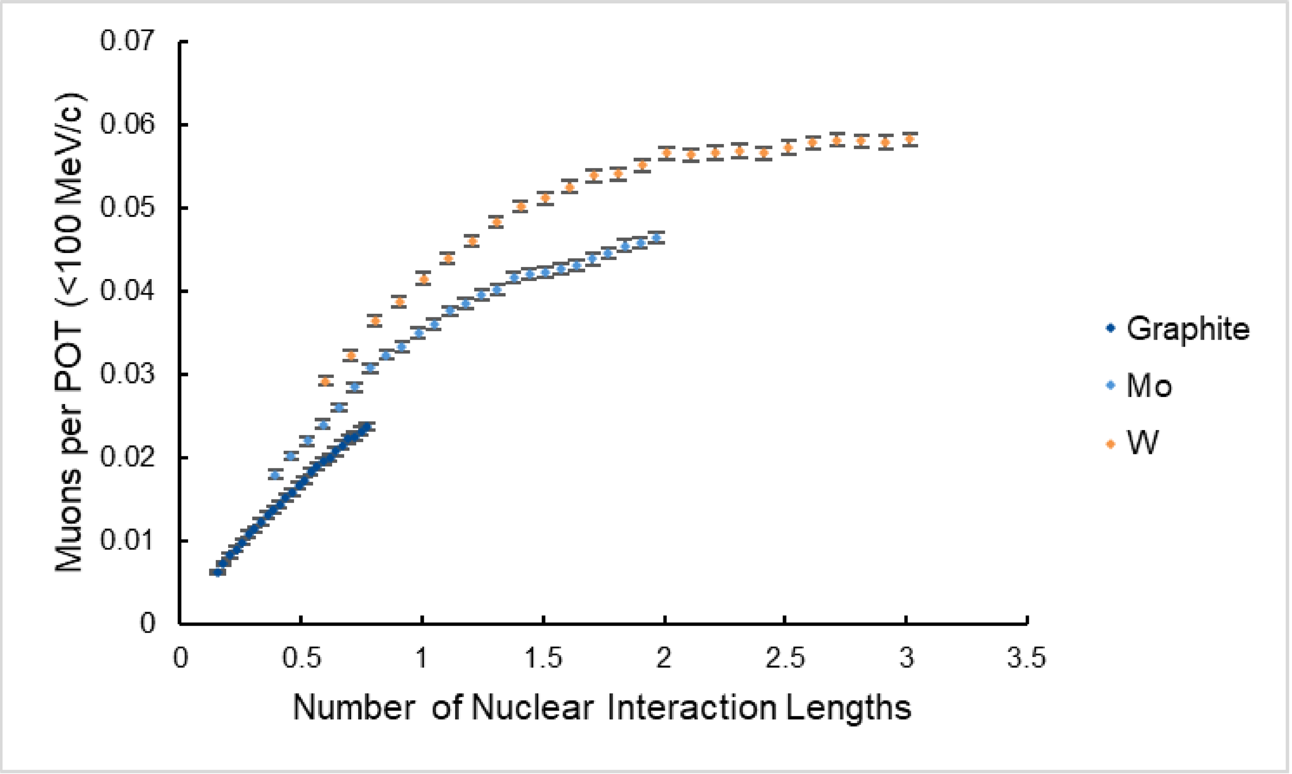

Fig. 5: Low momentum muons per proton on target versus number of nuclear interaction lengths from a G4Beamline simulation of cylindrical targets with various dimensions. Only muons with a momentum below 100 MeV/c were considered because they are within the acceptance of the transport solenoid.

Our simulations corroborate that it is possible to increase muon yields for a particular target material by increasing target length. Therefore, the muon yields for a lower density material like molybdenum could come close to yields for a higher density material like tungsten with appropriate target scaling.

Energy Deposition

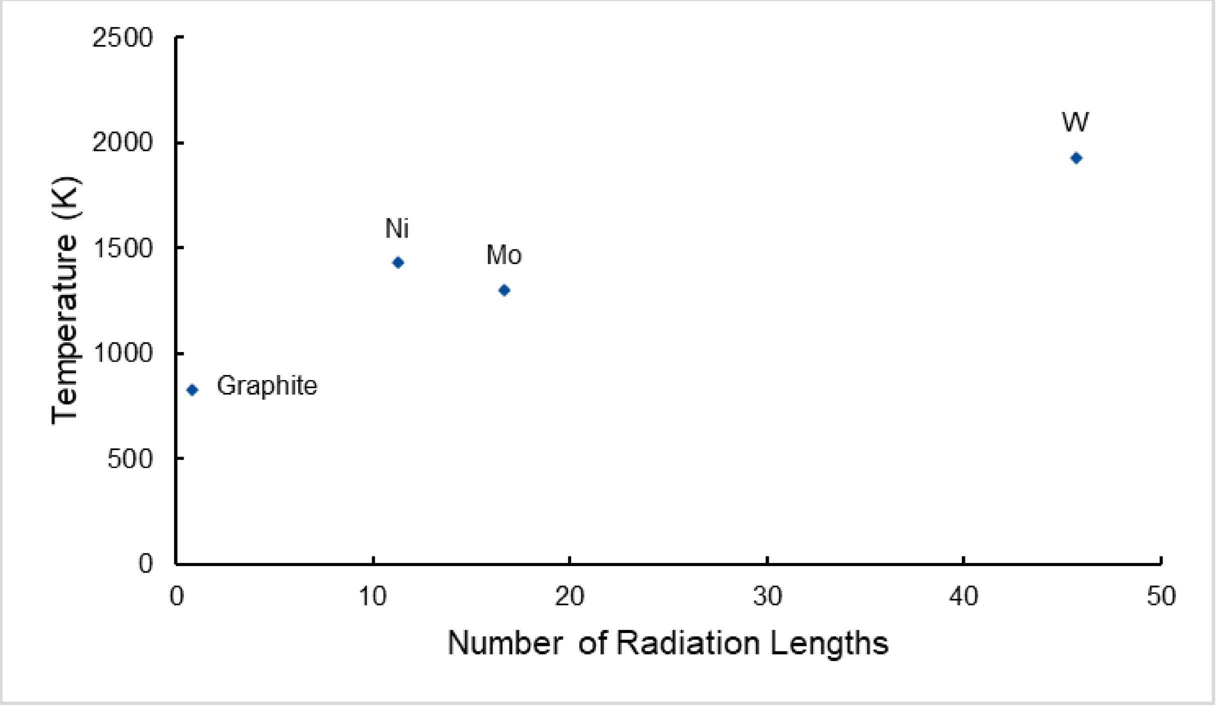

Fig. 6: Temperature versus number of radiation lengths for various target materials. Temperatures were estimated using energy depositions from a FLUKA simulation of a cylindrical target with radius 3.15 mm and length 160 mm.

As predicted, we estimate higher temperatures for targets with fewer radiation lengths. Temperature stability is an important consideration for target lifetime, so a lower density material with a longer radiation length could be a more ideal target material despite lower muon yields (which could be mitigated to some extent by increasing target length).

Conclusions

Although conventional wisdom in targetry has touted high Z, high density target materials as the ideal, we have found that optimizing target materials (and target design) for more nuclear interaction lengths and fewer radiation lengths will help maximize target lifetime in addition to secondary yields.

Acknowledgements

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[1] Bartoszek et al., 2015, "Mu2e Technical Design Report."
[2] Byrum et al., 2022, "Mu2e-II: Muon to electron conversion with PIP-II."
[3] Aoki et al., 2022, "A New Charged Lepton Flavor Violation Program at Fermilab."

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