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Requirements for the Mu2e Production Target
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Change Log

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Requirements for the Mu2e Production Target

The Mu2e experiment will search for charged lepton flavor violation through a search for muon to electron conversion in the field of a nucleus. Mu2e will measure the ratio

$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N)}$$

to $R_{\mu e} < 6 \times 10^{-17}$ @ 90% C.L with a single event sensitivity of about 2×10^{-17}.

Mu2e requires ~ 3.6 x 10^{20} protons directed onto a target; that target is the subject of this document. The interactions of these protons will produce pions, which subsequently decay to muons. The primary beam will consist of 8 GeV KE protons, have approximately 8 kW of beam power, and contain micro pulses of ~10^7 protons delivered every 1.7 μs. The rms diameter of the proton beam at the target will be about 1 mm and in time Gaussian with 100-120 ns rms, non-Gaussian tails resulting in a 200-240 ns base width. The cycle time is 1.33 s and duty factor 0.3. Detailed properties of the beam are described in Ref. 1.

The production target must function in a harsh and complex environment presenting a number of technical challenges, one of which is operation in vacuum. For a radiation cooled [2] target, the vacuum requirement is 10^{-5} torr to reduce oxidation corrosion of target materials [3]. However, the basic requirements for the production target are quite straightforward. The technical details for a target system that satisfies these requirements are considerably more complex.

The production target must be designed to maximize the number of stopped muons at the stopping target. Maximizing the number of stopped muons depends on many factors that must be optimized simultaneously. These include the target material, density, shape, size, position and orientation of the target, as well as the target support structures. Other factors not directly related to the production target also have an impact including the details of the proton beam, the magnetic fields of the solenoids, the clear bore of the Heat and Radiation Shield, the collimators in the Transport Solenoid and the details of the stopping target design. The production target must be optimized under these external design constraints.

The target material must have a high atomic number and density to ensure a high rate of beam-target interactions. The pion production cross section of the target material must be large enough to allow Mu2e to produce the required number of stopped muons. The choice of target material also depends on the geometry and dimensions of the target and choice of cooling system, if any. The target and cooling system must also have chemically low reactivity with any materials it is in contact with. Furthermore, the system must be designed to minimize any pion reabsorption that would have a negative impact on the muon stopping rate in the DS target. Operating in a graded magnetic field induces charged pions to follow spiral trajectories which can return to the target region, possibly suffering reabsorption on some part of the target system.

Given the choice of beam and target size to optimize the stopped muon yield, overall alignment of the target rod with respect to the beam transversely (i.e. x-y where the beam is along z) needs to be less than about 0.5 mm to avoid losing more than a few percent of the muon yield [4]. Muon yield is significantly less sensitive to target position along the muon channel (z), locating the target within +/-1 cm is sufficient.

The alignment strategy to accomplish these requirements is:

- The target/supports/mounting must be quite stable and reproducible during target change relative to the PS. The tolerance on the manufactured target rod dimensions should be: length = +/- 2 mm and radius= +/- 0.1 mm. The target position relative to the PS must be stable to about ±0.25 mm during operation, taking into account distortions due to thermal cycling from ambient conditions when the beam is turned on. The target support structure and remote handling system must allow replacement targets to be placed within about ±0.25 mm of the first.

- The relative alignment of the target with respect to the PS axis is not as critical as the target-beam alignment. The muon yield is very insensitive to transverse [5] or motion along the z axis up to several cm. There is a potential background for ~100 MeV electrons, if the target source is more than 2 cm below the nominal elevation [6]. The relative alignment of the target to the PS axis should be +/- 5 mm transversely and +/- 1 cm along the PS axis.

- The PS axis must be aligned transversely to the proton beam to within: +/- 5 mm in position and +/- 0.2 degrees in angle. The angular requirement is set by the narrow channel available to the proton beam to pass through the transport solenoid entrance beam pipe which is 4.75" inner diameter about 3 m upstream of the target. Given the target z location, this pipe sets an angular acceptance of +/- 1 degree. The muon yield is much less sensitive to the angle [7].

The proton beamline has the ability to adjust the transverse position +/-1 cm and +/- 0.8 degrees at the target. If the alignment moves outside the range allowed by the beamline adjustment then the beam-PS alignment must be corrected.

The impact of pion reabsorption on stopped muons suggests a target that is compact, low-mass, and presents a small geometric profile to the trajectories of pions in the Production Solenoid. The target, its supports, and any associated infrastructure (e.g. cooling) must be included in calculations of stopped muons and pion re-absorption must be included in heating calculations.

The main design problem for the production target is direct heating from the energy deposited by the incident proton beam.The target must have high thermal conductivity to help achieve an acceptably low operating temperature. The production target must be made from a material with a melting point well above the anticipated operating temperature. The target must maintain its mechanical integrity at high temperature. Simulations have shown that a radiation-cooled target is feasible [2]. The production target must be designed with a wide operating margin based on a careful failure risk analysis.

The useful expected operational lifetime for a target, its supports, and cooling must not limit the sensitivity of the experiment. The goal would be a target lifetime of at least one year if possible. However, target failure must be anticipated. The target access area will be a high-radiation environment. Therefore, a replacement system is needed that can change the target or vacuum windows on the access port within a few weeks while minimizing exposure of radiation workers.

References:

1. Mu2e Conceptual Design Report, Mu2e-doc-db-1169
2. Radiation Cooled Target Design Study, Mu2e-doc-db 2406.
3. Rutherford's Presentations on a Radiation-Cooled Production Target, Mu2e-docdb-3197; Oxidation of Tungsten at Ultra High Temperatures, Mu2e-docdb-3610.
4. Stopped Muon Yield Variation with Transverse Beam Motions, Mu2e-docdb-3611.
5. Stopped Muon Yield with Production Target Transverse Offsets, Mu2e-docdb-3609.
6. A Few Simulation Issues, Mu2e-docdb-923, High momentum electrons in S-Shape and C-Shape Transport Solenoids, Mu2e-doc-db-1910.
7. Target/Beam Angle Range Requirement, Mu2e-docdb-3473.