Mu2e WBS 5.6 Stopping Target Monitor
DOE CD-2/3b Review

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Stopping Target Monitor Level 3 Manager
10/21/14
Requirements

- Determine the number of muons stopped in the stopping target
  - Establishes overall normalization for experiment
    \[ R_{\mu e} = \frac{\mu^- + {^{27}Al} \rightarrow {^{27}Al} + e^-}{\mu^- + {^{27}Al} \rightarrow \text{capture}} \]
    - $\sigma$~10% uncertainty over one hour at nominal beam intensity
    - $\sigma$~10% uncertainty over the life of the experiment ~3 years at $2 \times 10^7$ seconds/year assuming nominal beam intensity
- Method: detect gammas associated with stopped muon interactions in the target atoms.
  - Energies are unique to the target material chosen
  - Rates are proportional to the rate of muon capture
Design

- Choose ~ 5 cm $\phi \times 5$ cm coaxial intrinsically pure germanium
- Place Ge inside a concrete shield box, a few meters beyond the downstream end of the Detector Solenoid
  - View stopping target through collimators and a vacuum window in DS endcap: easiest access point to view stopping target
  - Gamma (844 keV) rates entering Ge are adequate: ~40 Hz @ $1 \times 10^{10}$ Hz stopping muon rate
Requirements

The requirements for the detector location are:

- Adequate collimation and shielding so that the detector rate is below the maximum operable detector rate, and the detector sees for most part just the target.
- The materials for the collimators and the windows need to be such that the muonic X-rays or gamma rays from those materials do not fall too close in energy to the X-rays or gamma rays of interest.
- The amount of material between the detector and the target must not result in significant absorption of the X-rays or gamma rays of interest from the target.
- The detector system must be able to survive the ‘flash’.
- The detector system should be radiation-resistant, or if the detector suffers radiation damage, there must be a cost-effective means to replace/repair it.
Design

- **CHOICE OF DETECTOR TYPE**
  - Use an intrinsically pure germanium (Ge) detector
    - Good efficiency, excellent resolution (~ 2 keV at 844 keV)
    - Susceptible to radiation damage
      - subject to radiation damage from neutrons, electrons and photons; the new baseline scheme avoids these problems.
      - Cost-effective approach: Radiation damage can be annealed in a ~2 day cycle if necessary
  - High data rates are a significant challenge for commercially available Ge detectors
    - The ‘flash’- a high intensity burst of low energy electrons that strike the target ~100 ns before the muons arrive at the target- can be especially problematic.
      - Commercially available Ge detectors can not recover from the flash quickly enough to detect the muonic xrays
      - Therefore baseline uses a beam shutter to block the flash
Design

- Observe gamma rays from beta decay of nuclei activated by muon capture
  - For Al stopping target, for ~13% of captures,
  - Measure rate of 844 keV gamma from $^{27}$Mg beta decay, 9.5 minute half-life
  - Beam Shutter to protect Ge from radiation damage and high rates from the flash (take advantage of beam structure)
    - Mu2e receives no beam for 12/20 beam batches, over about 0.8 seconds (Mu2e takes 2 out of the remaining 8 in remaining 0.4 seconds of Booster cycle)
    - Beam shutter is open during ‘beam off’ to catch gamma from delayed decays of $^{27}$Mg
    - Beam shutter is closed during ‘beam on’, thereby protecting the detector from high rates and radiation damage.
GEANT4 Model of STM Shielding

- Germanium Detector
- Beam Shutter
- Sweeping Magnet
Improvements since CD-1

• We adopted a new concept since CD-1:
  – detect delayed gammas from $\beta$ decay of $^{27}$Mg ($\tau(1/2)=9.5$ min)

• CD-1 concept was to detect muonic x-rays emitted promptly when the muon stops in the stopping target
  – Extensive GEANT4-based simulations were performed since CD-1 to examine signal and backgrounds at the Ge location
  – Muons stop in target and produce x-rays very soon (~100 ns) after blast of electrons (which create bremsstrahlung photons in the target) associated with the primary proton pulse (the ‘flash’)
  – Commercially available Ge cannot recover from the flash in time to collect the muonic x-ray data
  – Commercially available Ge suffers radiation damage from the flash and neutrons that requires the detector to be annealed on an unacceptably short time scale (less than a day)
Performance

• AlCap experiment at PSI: stop muons in candidate stopping targets for Mu2e and COMET.

• Data from Dec. 2013, preliminary spectrum
  – Muons stopped in Al target and registered in germanium detector
  – No timing cuts applied (i.e. Ge is in ‘singles’ mode)
  – Desired gamma ray (844 keV) is clearly visible above background

\[ ^{27}\text{Mg}_{\text{nucl}}(844\,\text{keV}) \]

\[ ^{27}\text{Mg} \]

\[ Q_\beta = 2610.33 \]

– Simulations under way to estimate backgrounds and signal for Mu2e
Remaining work prior to fabrication

- Refine design of collimators
  - Simulation studies to attenuate neutron, electron, photon background fluxes
  - Geometry so that Ge sees mainly the target and little else
- Complete design of shield box
  - Must be able to remove shielding fairly quickly in case detectors inside Detector Solenoid need to be serviced.
- Finish detailed analysis of AlCap germanium data
- Complete design of the supporting infrastructure
- Design beam shutter
Integration and Interfaces

- Stopping target monitor has external interfaces to Conventional Construction, Solenoids, CRV and DAQ
- Internal interfaces to
  - Stopping target
  - Detector solenoid internal shielding
  - Muon beam stop
  - Detector support and installation system
- Integration and interfaces addressed via
  - WBS dictionary and interface documents
  - Muon beamline meetings
  - Mechanical and electrical integration meetings
  - Formal signoff between responsible parties for all external interfaces will be required as part of the final design
Quality Assurance

- Test performance (acceptance, resolution, data rate handling) of germanium detector with radioactive sources
- Check alignment and function of collimators with radioactive sources
- Monitor response of Ge relative to rates in calorimeter, tracker.
Risks

• Moderate risk that the flux of particles may exceed the Ge data rate or radiation resistance capability (Muon-148 Mu2e docdb 3853)
  – Mitigation
    • Refined simulations and test beam studies to verify anticipated rates and performance
    • If necessary:
      – Install thicker beam shutter with a cycle time of 1.3 seconds (same as Main Injector cycle time)
      – Add collimation
      – Add shielding
ES&H

- ODH: The germanium detector will need to be cooled by liquid nitrogen. The Ge will be partially enclosed and proper venting of LN2 will be required, following FESHM 5064.
- Radioactive sources, such as Europium-152, are required for calibration purposes (again, see ANSI N42.14-1999). Proper procedures will be followed according to the FNAL radiation safety requirements.
- Activity level should be monitored before maintenance or repair work is performed.
- The Ge detector will be powered by high voltage (~3000 volts) and care must be taken to properly wire and ground the installation according to standard HV practice.
## Cost Table

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<table>
<thead>
<tr>
<th>Base Cost (AY K$)</th>
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<tbody>
<tr>
<td>M&amp;S</td>
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<tr>
<td>------</td>
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<tr>
<td>475.05 Muon Beamline</td>
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<tr>
<td>475.05.06 Stopping Target Monitor</td>
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<tr>
<td>475.05.06 Stopping Target Monitor</td>
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<tr>
<td>Grand Total</td>
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</table>

Costs are fully burdened in AY k$
Cost Distribution by Resource Type

Base Cost (AY k$)

- **M Material**: 165, 50%
- **L Labor**: 142, 42%
- **N Non-Fermi Labor**: 26, 8%
Quality of Estimate

Base Cost by Estimate Type (AY k$)

- L1 Actual / M1 Existing P.O.: 143 (43%)
- L2 LOE Task / M2 Procurements for LOE/Oversight Work: 17 (5%)
- L4 / M4 Preliminary: 44 (13%)
- L5 / M5 Conceptual: 128 (39%)
- L6 / M6 Pre-Conceptual: 0.3 (0%)

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## Labor Resources

### FTEs by Discipline

<table>
<thead>
<tr>
<th>Discipline</th>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
<th>FY18</th>
<th>FY19</th>
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<tbody>
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Cumulative FTEs:

- FY15: 0.6
- FY16: 0.8
- FY17: 1.0
- FY18: 1.2
- FY19: 1.4
Milestones documented in Mu2e docdb 4301

<table>
<thead>
<tr>
<th>Milestone Code</th>
<th>Description</th>
<th>Date</th>
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<tr>
<td>47505.6.001360</td>
<td>T5 - Stopping Target Monitor 2nd iteration Design Complete</td>
<td>11/9/2015</td>
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<td>47505.6.001425</td>
<td>T5 - Stopping Target Monitor ready for CD-3 Review</td>
<td>11/23/2015</td>
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<td>47505.6.001426</td>
<td>T5 - CD-3 approval for Stopping Target Monitor</td>
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<td>47505.6.001410</td>
<td>T5 - Stopping Target Monitor Ready for fabrication</td>
<td>2/20/2018</td>
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<td>47505.6.001455</td>
<td>T5 - Stopping Target Monitor at FNAL</td>
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<td>T5 - Stopping Target Monitor Infrastructure at FNAL</td>
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<td>T5 - Stopping Target Monitor Test Complete</td>
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<td>47505.6.001480</td>
<td>T5 - Stopping Target Monitor Ready for CD-4</td>
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Summary

- Normalize the number of muon captures by measuring gamma rays from activated nuclei meets the physics requirements.
- Risks have been evaluated, mitigated to the extent possible and are under control.
  - There is a risk that the Ge detector cannot handle radiation levels, and this risk will be mitigated via collimators, shielding, and a thicker beam shutter.
    - For example if the detector must be annealed excessively often because of radiation damage.
- Interfaces are identified and defined.