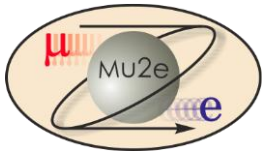
Fermilab

U.S. DEPARTMENT OF ENERGY Office of Science

Mu2e WBS 5.6 Stopping Target Monitor Director's CD-2 Review



James Miller

Level 3 Manager, WBS 5.6

7/8/2014

Requirements

- Determine the number of muons stopped in the stopping target
  - Establishes overall normalization for experiment
  - σ~10% uncertainty over one hour at nominal beam intensity
  - σ~10% uncertainty over the life of the experiment ~3 years at 2×10^7 seconds/year assuming nominal beam intensity
- Method: detect gammas associated with stopped muon interactions in the target atoms.
  - Energies are in general unique to the target material chosen
  - Rates are proportional to the rate of muon capture

Requirements

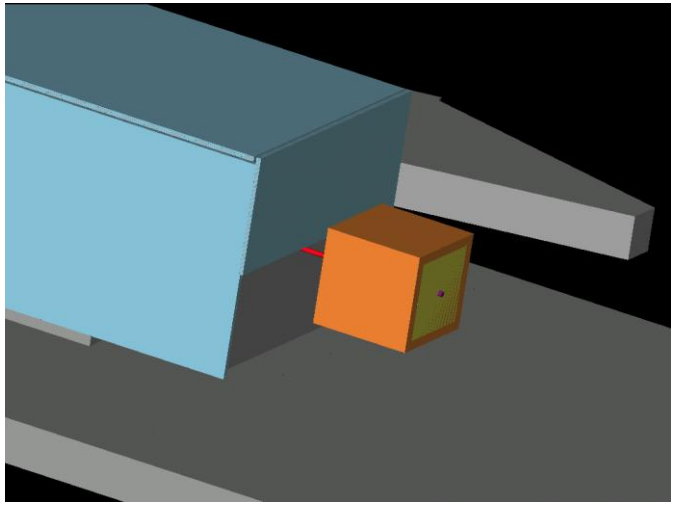
- Summarizing, the requirements for the detector location are:
  - Adequate collimation and shielding so that the detector rate is below the maximum operable detector rate.
  - The materials for the collimators and the windows (if any) need to be such that the muonic X-rays or gamma rays of those materials 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 (due to e.g. windows) 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.

Requirements

- CHOICE OF DETECTOR TYPE
  - Use an intrinsically pure germanium (Ge) detector
    - Good efficiency, excellent resolution (~ 2 keV at 844 keV)
    - However, slow time response and susceptible to radiation damage
      - subject to radiation damage from neutrons,e lectrons and photons; the baseline scheme avoids these problems.
      - Cost-effective approach: Radiation damage can be annealed in a ~2 day cycle
- DETECTOR LOCATION
  - Three requirements determine the best location for the Ge detector to view the muon stopping target:
    - The detector should only view the target, if possible. Hence the first requirement is for good collimation ahead of the detector.
    - Because of the extraordinarily high X-ray, neutron, and gamma rates the detector must be far from the source, along a low attenuation path for photons.
    - The detector must lie beyond the Detector Solenoid (DS) magnetic field where it can be serviced periodically and annealed to repair radiation damage.

Design

- Choose ~ 5 cm ϕ x 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 a vacuum window in DS endcap
    - Easiest access point to view stopping target
  - Gamma (844 keV) rates entering Ge are adequate: ~40 Hz @ $1x10^{10}$ Hz stopping muon rate

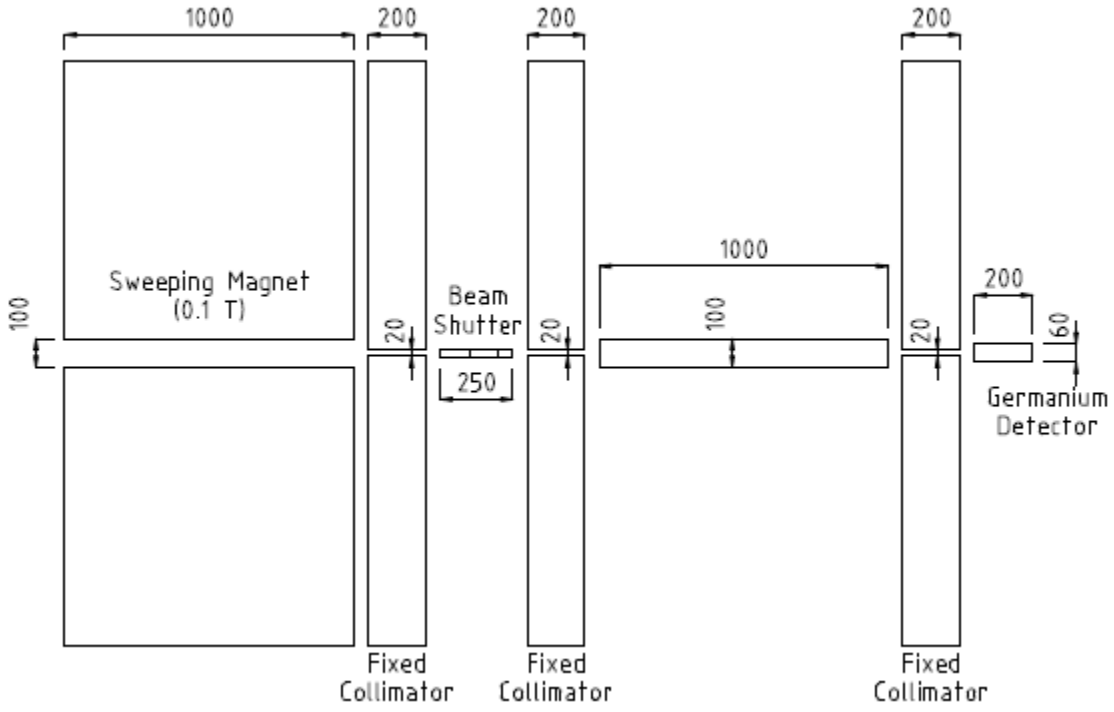


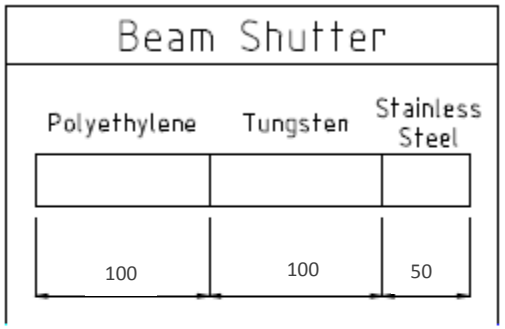
Design

- Observe gamma rays from beta decay of nuclei activated by muon capture
  - For Al stopping target, for 13% of captures, $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{12}Mg + \nu_\mu$
  - 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
    - Mu2e receives no beam for 12/20 beam batches (takes 2 out of the remaining 8)
    - Beam shutter is open during ‘beam off’ to catch gamma from delayed decays of ^{27}Mg
    - Bean shutter is closed during ‘beam on’, thereby protecting the detector or from high rates and radiation damage.

Design

- Collimation





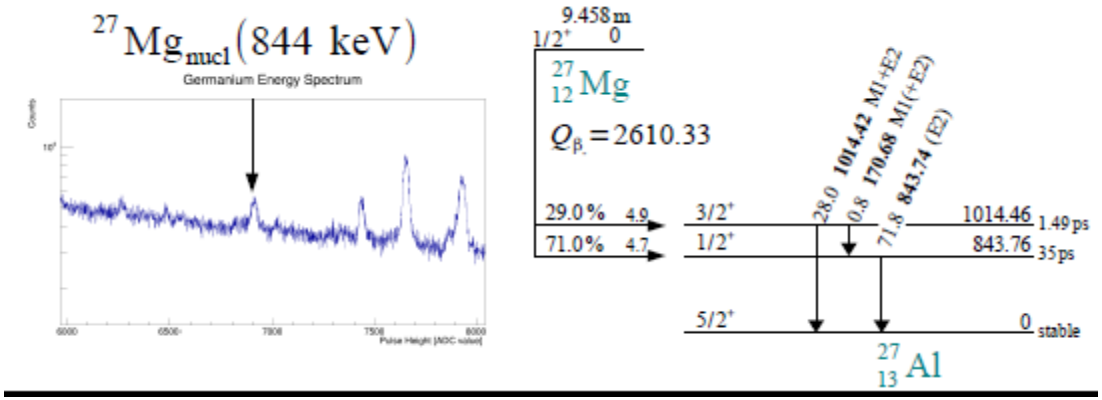
Units are mm

Changes since CD-1

- Reiterating, new CD-2 concept: detect delayed gammas from beta decay of ^{27}Mg (9.5 minute half-life)
- CD-1 concept was to detect muonic xrays 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 xrays 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 xray data
  - Commercially available Ge suffers radiation damage from the falsh and from neutrons that requires the detector to be annealed on an unacceptably short time scale (days)

Performance

- Data from AlCap experiment at PSI, 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



  - Simulations under way to estimate backgrounds and signal for Mu2e layout

Remaining work before CD-3

- Design 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 fairly quickly in case detectors inside Detector Solenoid need to be serviced.
- Finish detailed analysis of AlCap data
- Complete design of the supporting infrastructure
- Design beam shutter

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.

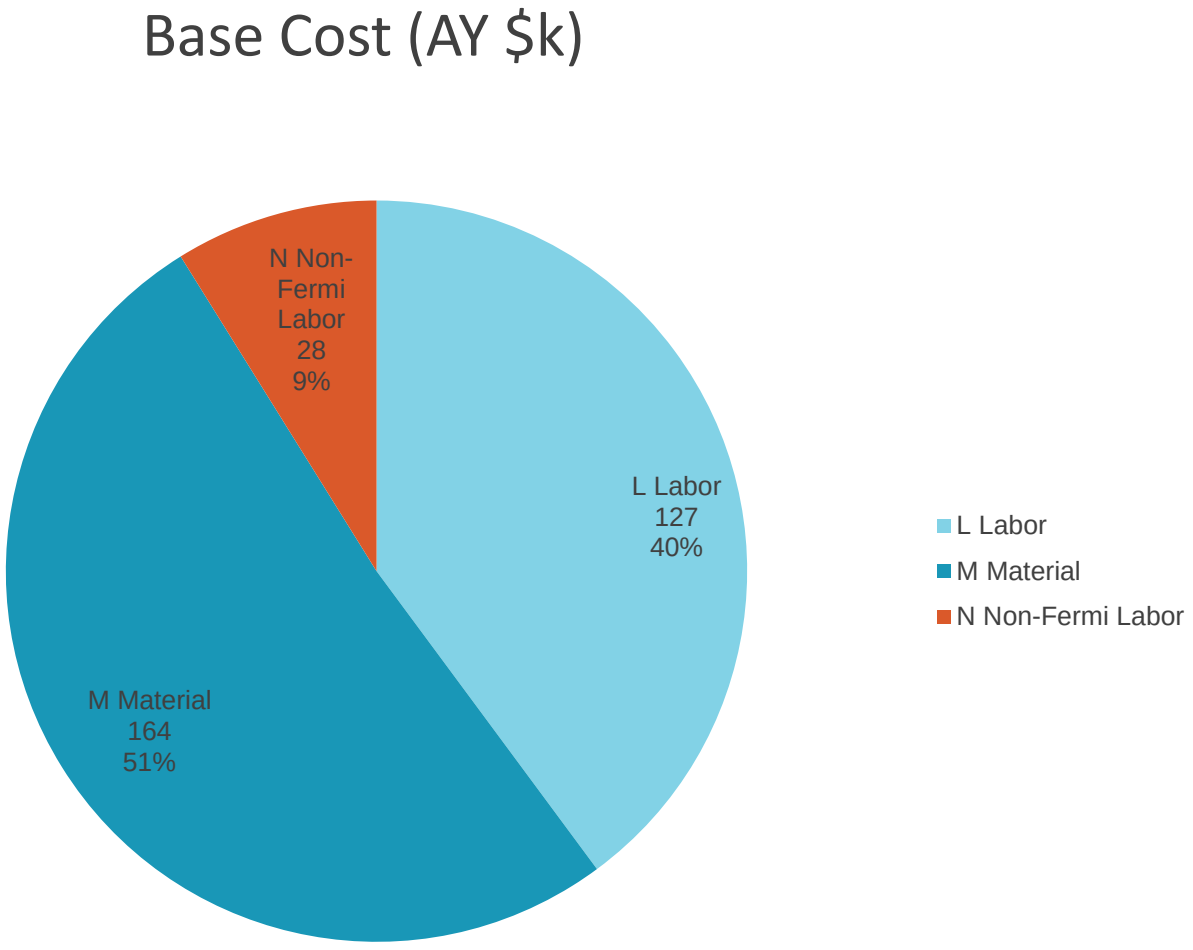
Risks

- The flux of particles may exceed the Ge data rate or radiation resistance capability
  - Mitigation
    - Design and install a beam shutter with a cycle time of 1.3 seconds
    - Add collimation
    - Add shielding

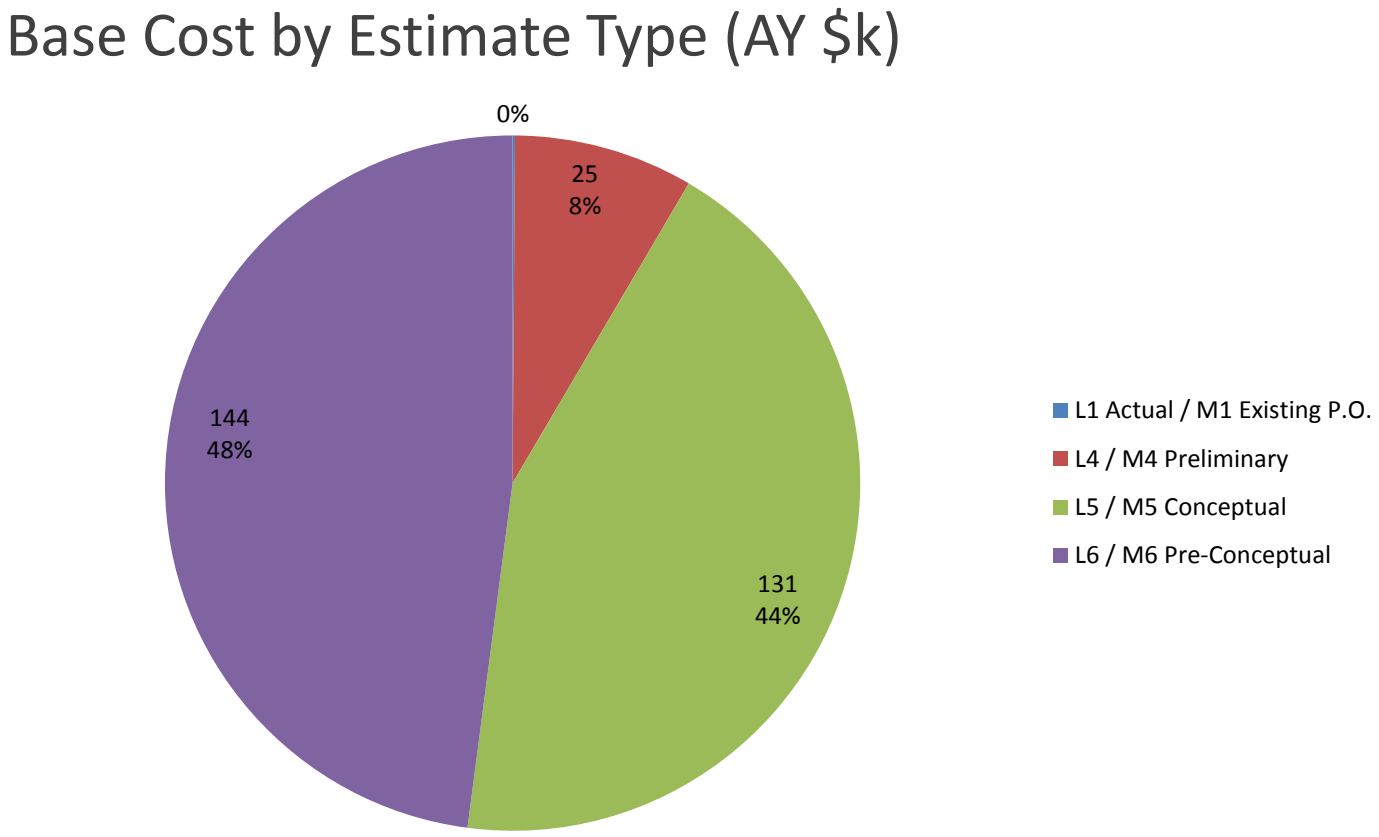
ES&H

- The germanium detector will need to be cooled by liquid nitrogen contained in a ~40 l dewar. The Ge will be enclosed and proper venting will be required.
- 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.

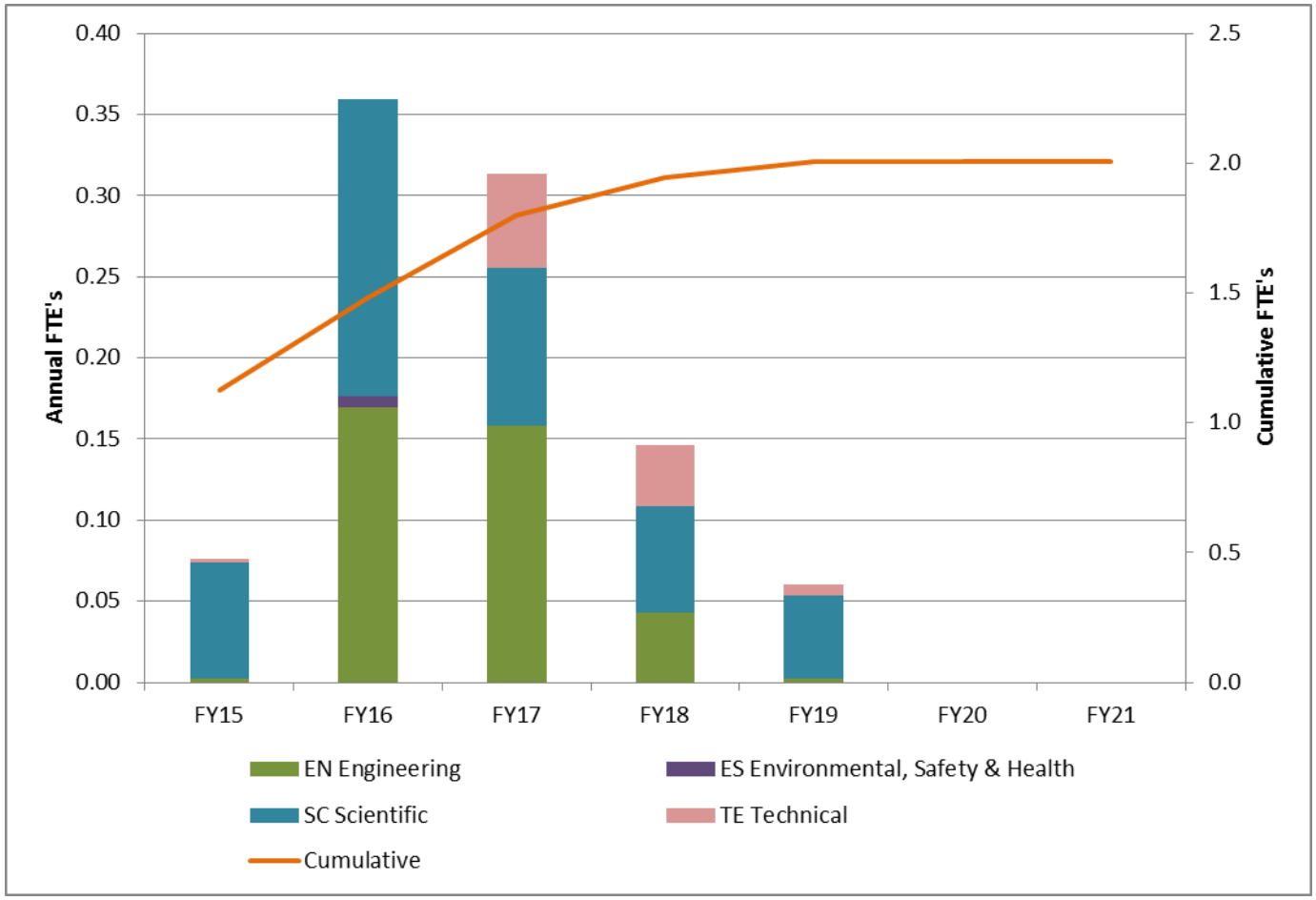
Cost Distribution by Resource Type



Quality of Estimate



Labor Resources



Cost Table

WBS 5.6 Stopping Target Monitor

Costs are fully burdened in AY $k

	Base Cost (AY $k)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.05 Muon Beamline						
475.05.06 Stopping Target Monitor						
475.05.06 Stopping Target Monitor	192	127	319	182	57%	501
Grand Total	192	127	319	182	57%	501

Major Milestones

- L4- Stopping Target Monitor ready for CD-3a Mini Review 12-Jan-18
- L4- CD 3a approval for Stopping Target Monitor 29-Jan-18
- L4 - Stopping Target Monitor at FNAL 16-Aug-18
- L4 - Stopping Target Monitor Infrastructure at FNAL 14-Sep-18
- L4 - Stopping Target Monitor On Project Tasks Complete 13-Nov-18

Summary

- The plan (new since CD-1) to normalize the number of stopped muons by measuring gamma rays from activated nuclei meets the physics requirements.
- There is a risk that the Ge detector cannot handle radiation levels, and this risk will be mitigated via collimators, shielding, and a beam shutter
  - For example if the detector must be annealed excessively often because of radiation damage.