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

James Miller
Stopping Target Monitor Level 3 Manager

10/21/14

Requirements

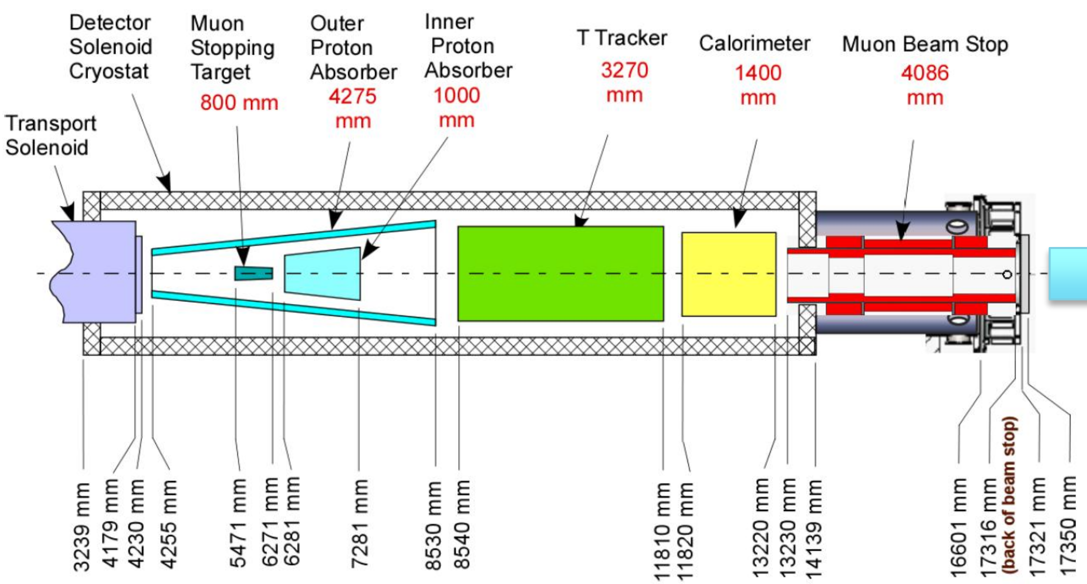
- Determine the number of muons stopped in the stopping target
  - Establishes overall normalization for experiment

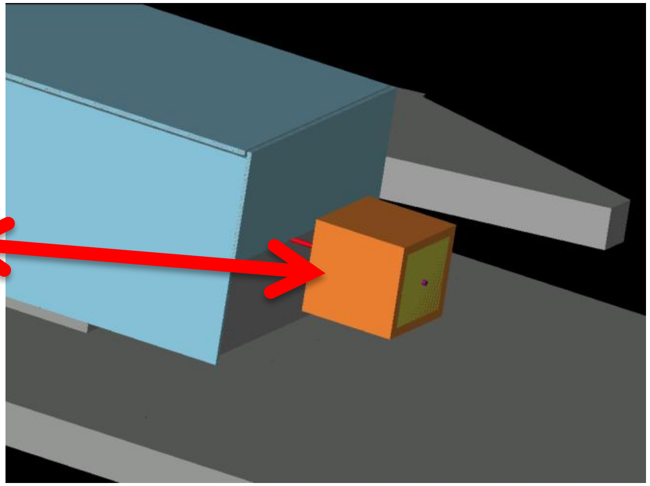
$$R_{\mu e} = \frac{\mu^- + {}^{27}Al \rightarrow {}^{27}Al + e^-}{\mu^- + {}^{27}Al \rightarrow \text{capture}}$$

  - 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 unique to the target material chosen
  - Rates are proportional to the rate of muon capture

Design

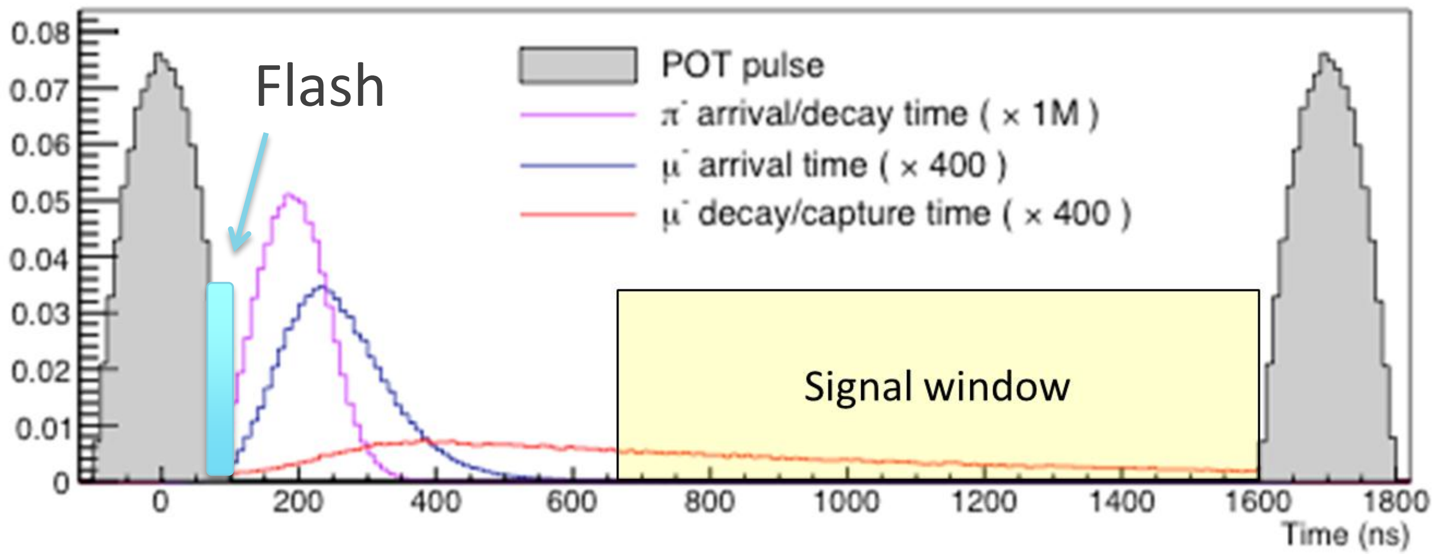
- Choose ~ 5 cm ϕ x 5 cm coaxial intrinsically pure germanium
- Place Ge inside a concrete shield box, a few meters beyond the downstream end of the Detector Solenoid
  - View stopping target through collimators and a vacuum window in DS endcap: easiest access point to view stopping target
  - Gamma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



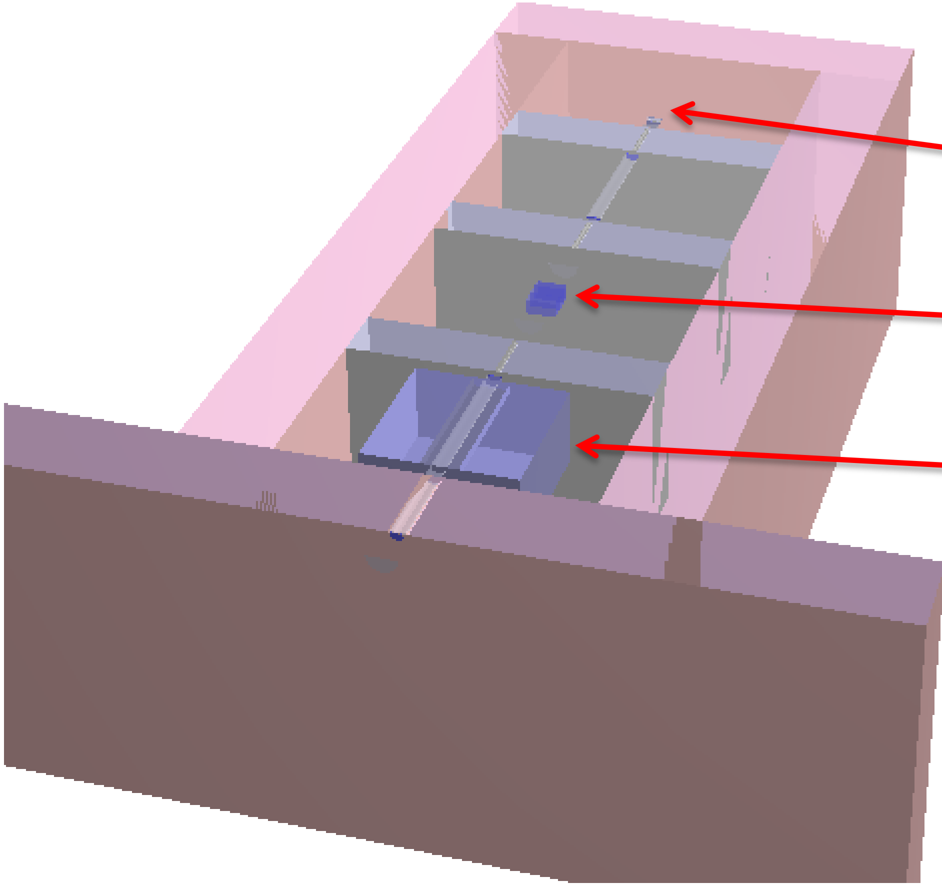
Design

- 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

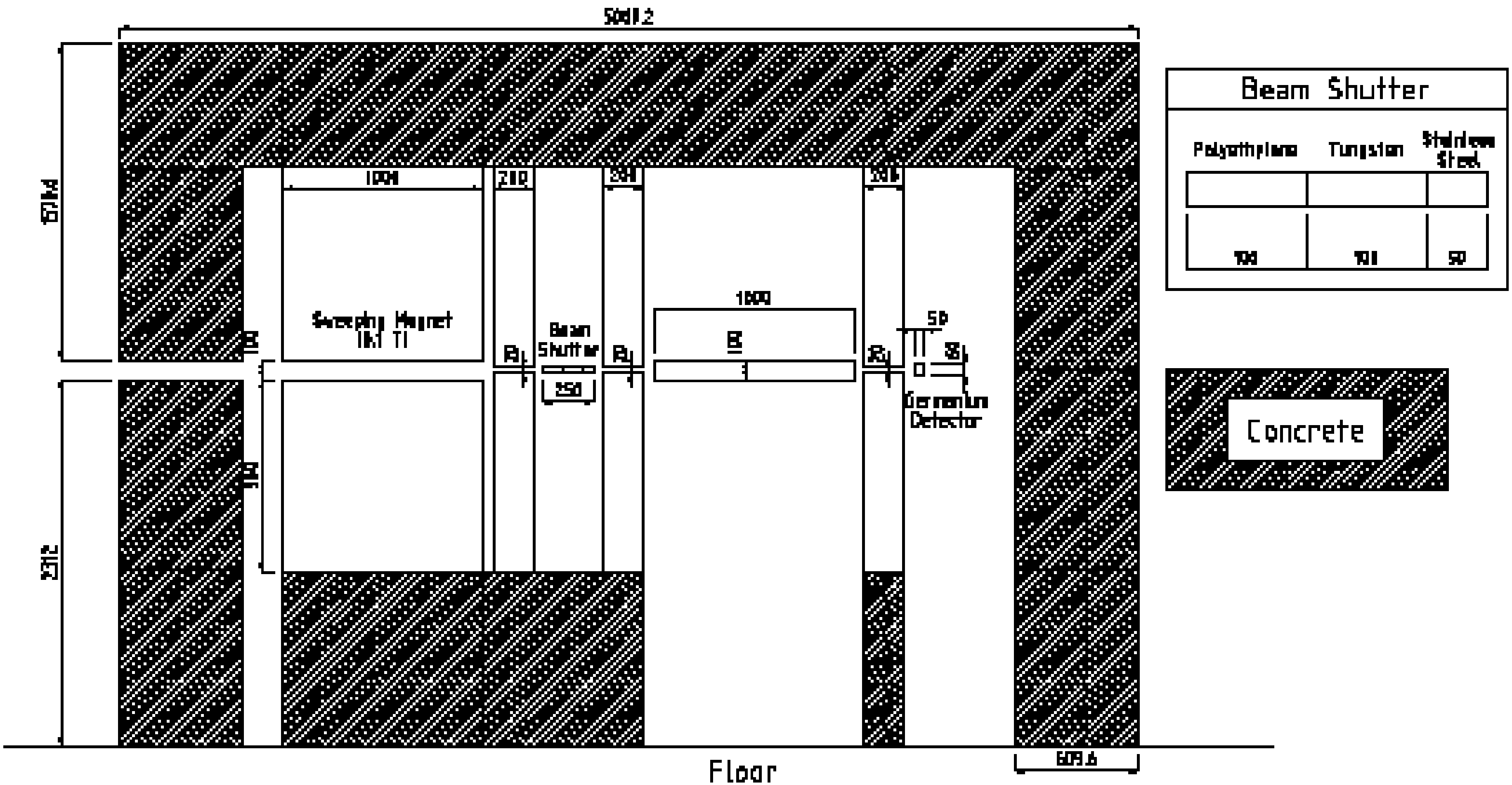
Design

- Observe gamma rays from beta decay of nuclei activated by muon capture
  - For Al stopping target, for ~13% of captures, $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{12}Mg + \nu_\mu$
  - 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 (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



Shielding Design

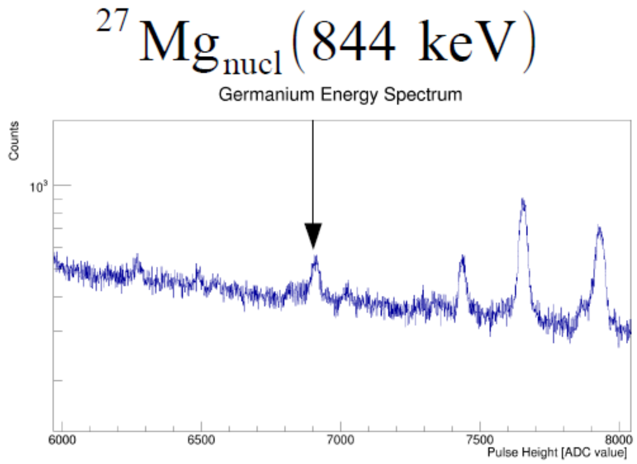


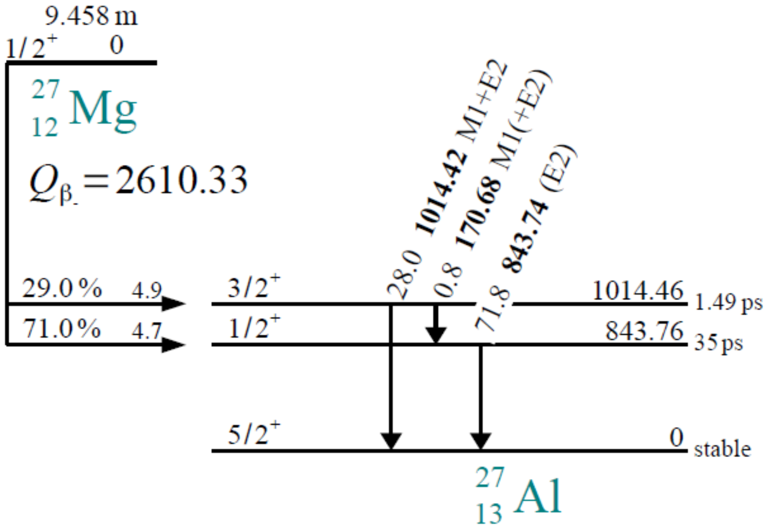
Improvements since CD-1

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





  - 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.

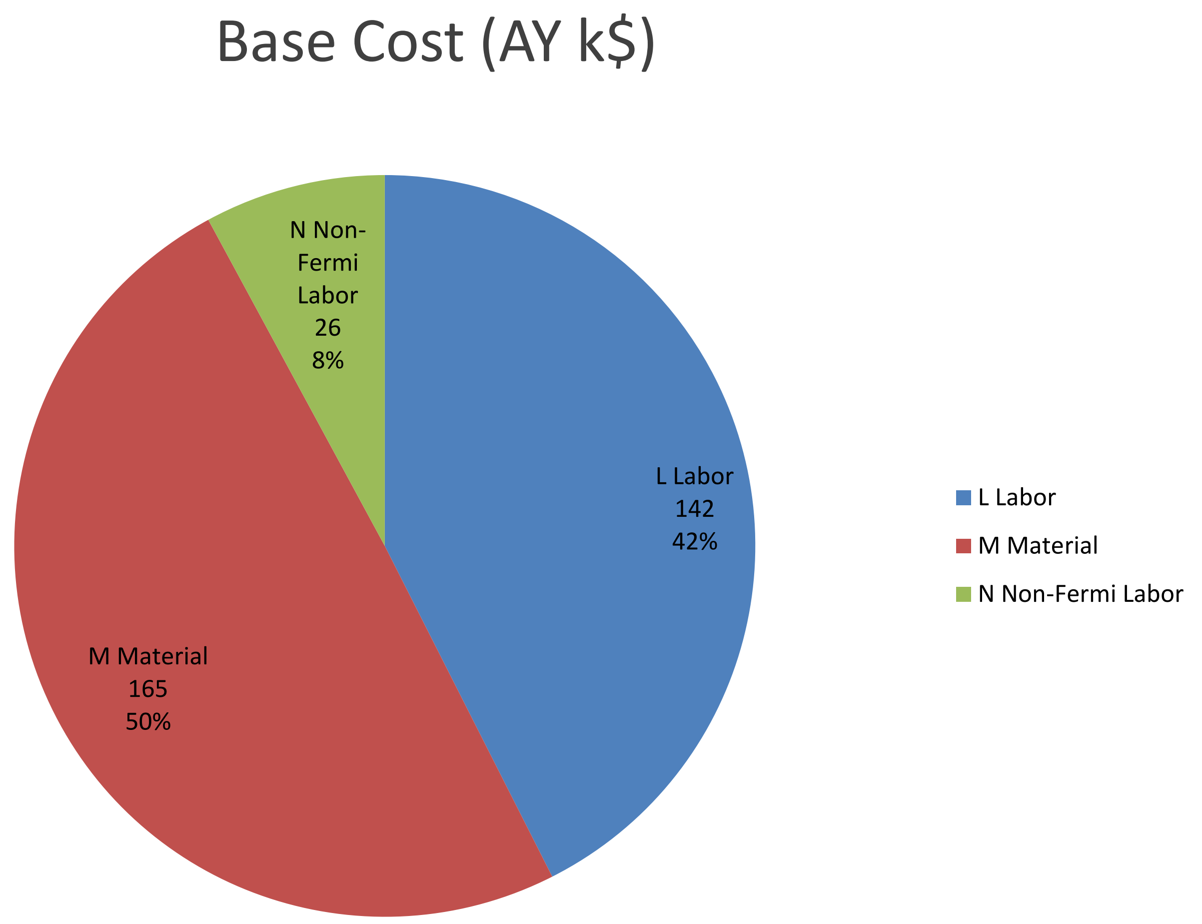
Cost Table

WBS 5.6 Stopping Target Monitor

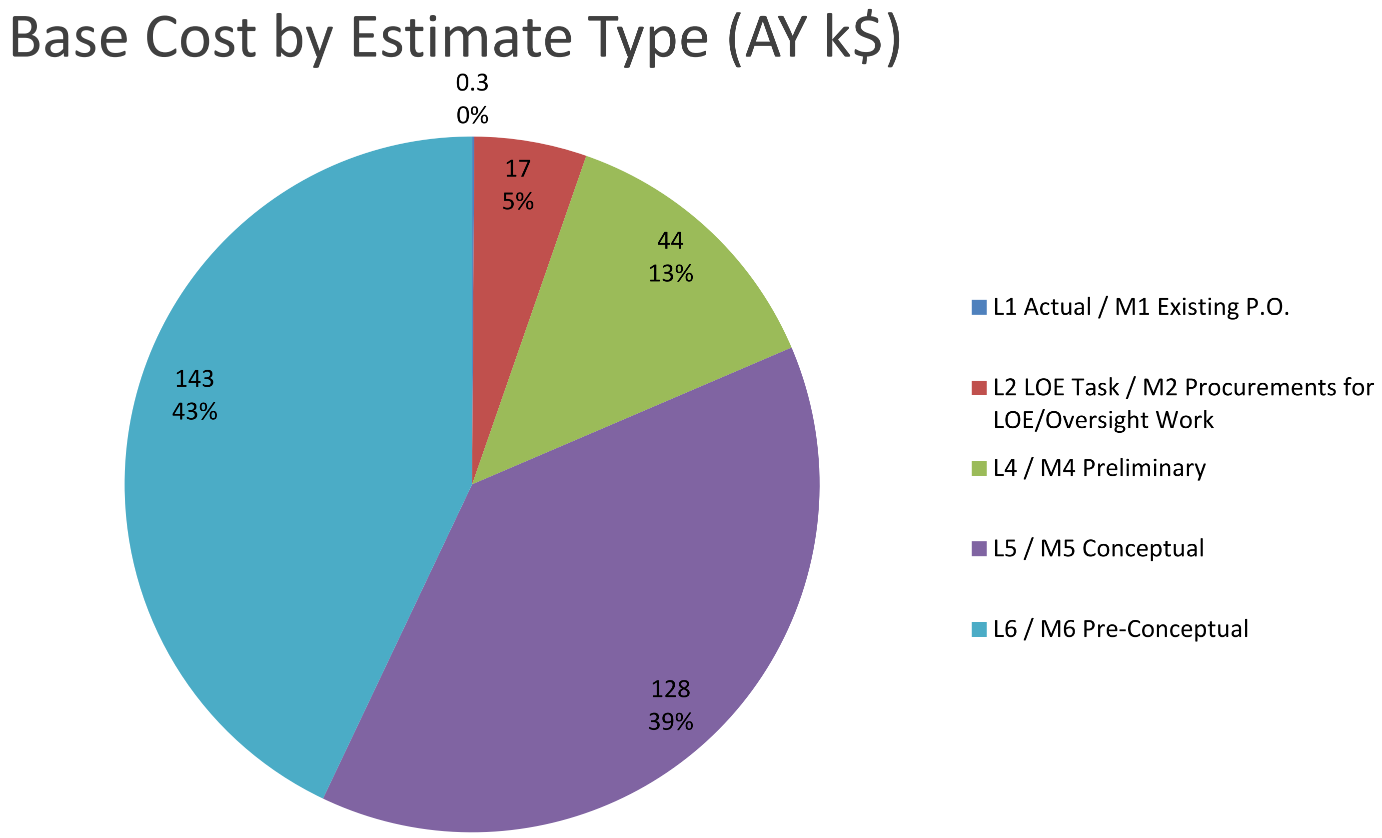
Costs are fully burdened in AY k$

	Base Cost (AY K$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency (on remaining budget)	Total Cost
475.05 Muon Beamline						
475.05.06 Stopping Target Monitor						
475.05.06 Stopping Target Monitor	192	142	334	185	56%	518
Grand Total	192	142	334	185	56%	518

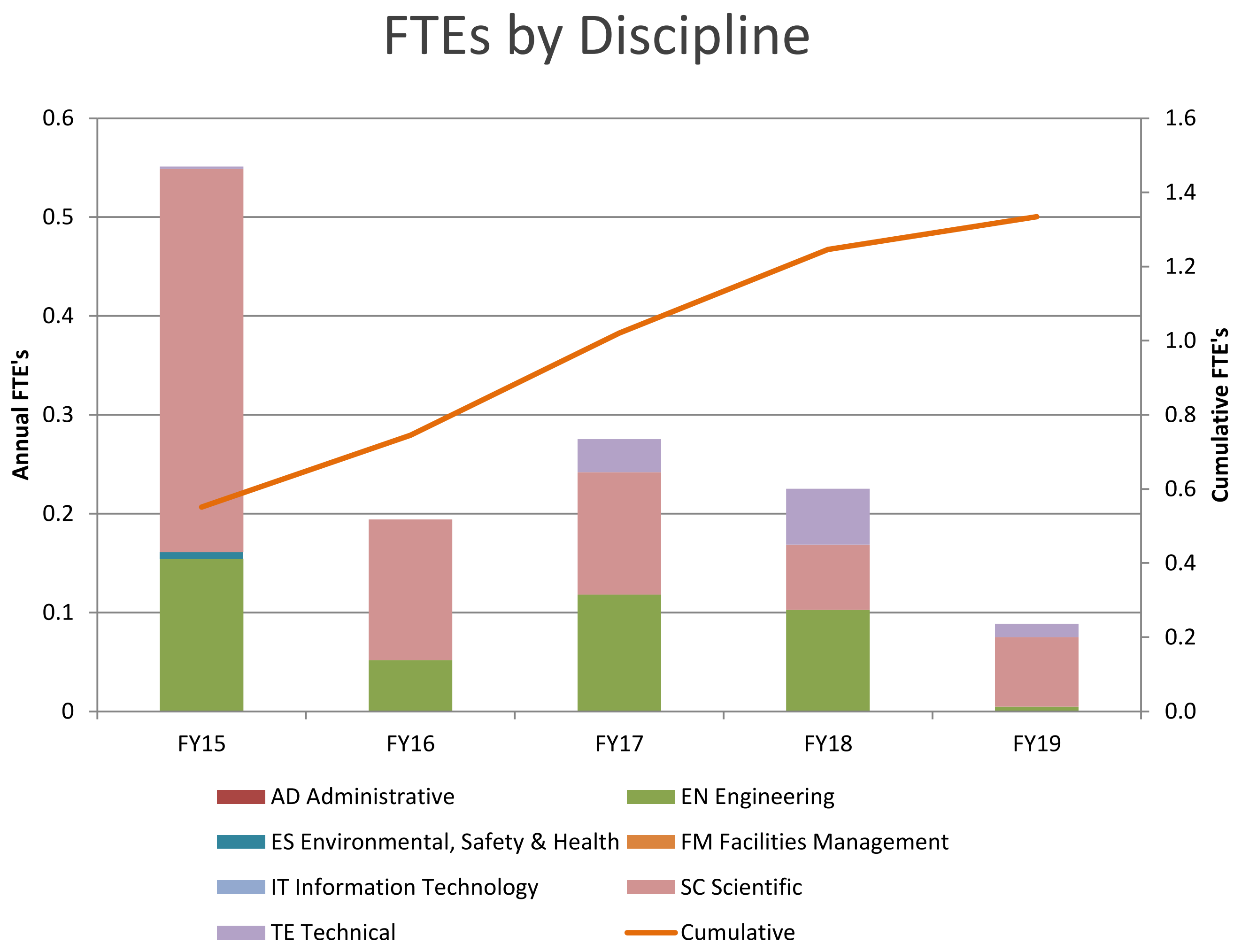
Cost Distribution by Resource Type



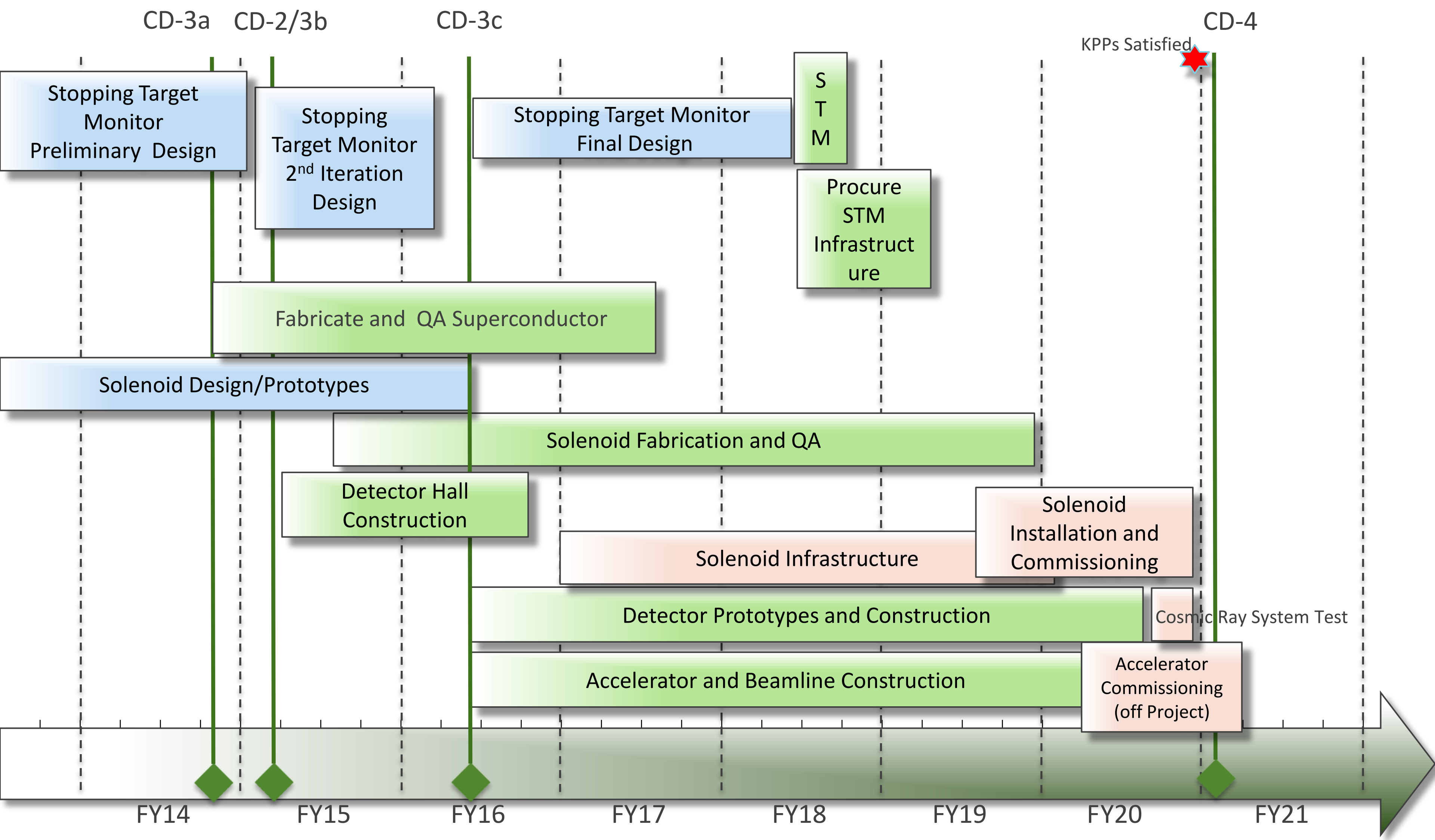
Quality of Estimate



Labor Resources



Schedule



CD-3a
CD-2/3b
CD-3c
CD-4
KPPs Satisfied
Stopping Target Monitor Preliminary Design
Stopping Target Monitor 2nd Iteration Design
Stopping Target Monitor Final Design
S T M
Procure STM Infrastructure
Fabricate and QA Superconductor
Solenoid Design/Prototypes
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Installation and Commissioning
Solenoid Infrastructure
Detector Prototypes and Construction
Cosmic Ray System Test
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Milestones

47505.6.001360	T5 - Stopping Target Monitor 2nd iteration Design Complete	11/9/2015
47505.6.001425	T5 - Stopping Target Monitor ready for CD-3 Review	11/23/2015
47505.6.001426	T5 - CD-3 approval for Stopping Target Monitor	2/24/2016
47505.6.001410	T5 - Stopping Target Monitor Ready for fabrication	2/20/2018
47505.6.001455	T5 - Stopping Target Monitor at FNAL	7/16/2018
47505.6.001465	T5 - Stopping Target Monitor Infrastructure at FNAL	10/9/2018
47505.6.001475	T5 - Stopping Target Monitor Test Complete	12/26/2018
47505.6.001480	T5 - Stopping Target Monitor Ready for CD-4	12/26/2018

- Milestones documented in Mu2e docdb 4301

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