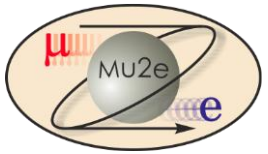
Fermilab

U.S. DEPARTMENT OF ENERGY Office of Science

Mu2e WBS 5.5 Stopping Target Director's CD-2 Review



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Stopping Target Level 3 Manager

7/8/2014

Requirements: Stopping Target

- Target material must be chemically stable and available in the required size, shape, and thickness. Self-supporting is highly desirable.
  - Satisfied by current design with 17 x 0.02 cm x 15 cm ϕ Al disks spaced by 5 cm
- Conversion electron energy must be higher than for other processes in the muon capture process
  - Radiative Muon Capture $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{12}X + \nu_\mu + \gamma$, photon must have an energy below the CE energy $\Rightarrow$ $m({}^{27}_{12}X) > m({}^{27}_{13}\mathrm{Al})$
- Z of stopping target must optimize signal in Measurement Period
  - Major fraction of muonic atoms must remain un-decayed during Measurement Period (MP) between 700 ns and 1700 ns after proton pulse
  - Start of MP is ~700 ns after proton pulse to ensure that pions in beam line have disappeared $\Rightarrow$ lifetime > 700 ns; Al lifetime is 864 ns
  - Conversion electron sensitivity roughly proportional to Z for nucleus for low Z

$\Rightarrow$ Maximize Z (Al is a good compromise between high Z and long muonic atom lifetime)

Requirements: Stopping Target (2)

- The target must be sufficiently thick in the direction of the muon beam to stop a large fraction of the incoming muons.
  - Nominally, we need to stop at least 40% of the transported muons in order to reach the desired signal sensitivity $\Rightarrow$ target should be thick
- The target must present the minimum possible path length to hypothetical conversion electrons that would be within the acceptance of the detector.
  - Energy straggling in the stopping target is a major contributor to the resolution of the electron energy spectrum, and in addtion bremstrahlung in the target leads to a low energy tail. $\Rightarrow$ target should be thin
- The target thickness should also be minimized in order to help control background $\Rightarrow$ target should be thin
  - Bremsstrahlung caused by beam electrons traversing the target
  - delta rays produced in the target by energetic cosmic ray muons, or other cosmic ray interactions, etc.

Requirements: Stopping Target (3)

- The target material must be pure enough to avoid background due to muon DIO in impurity nuclei.
  - This is not stringent for Al because of its high conversion electron energy
  - This is much more of a problem for higher Z nuclei, which have lower conversion electron energies
- The radii of the target (e.g. extent of the target away from the solenoid axis) should be optimized
  - target needs to intercept as much of the muon beam as possible in order to maximize the number of stops $\Rightarrow$ target should extend to large r
  - minimize the number of decay in orbit (DIO) electrons which can reach out to the inside radius of the tracker and produce unnecessarily large hit rates

    $\Rightarrow$ target should not extend to large r
- Position each disk within 2 mm along any dimension
  - Trackback to target provides background suppression, uniform 5 cm spacing will help
  - More predictable simulations (although accurate *knowledge* of positions would suffice)

Requirements: Stopping Target (4)

- Target supports must not cause loss of Conversion Electron sensitivity
  - Supports must not produce backgrounds or noise hits in the detectors during the Measurement Period (700-1700 ns after proton pulse)
    - If muons stop in target supports at radii larger than that of the target, DIO electrons will reach a large enough radius to cause unnecessary hits in the detectors
      $\Rightarrow$ low mass in support materials where the radius (and the muon flux) is large
    - If muonic atoms formed in the supports have a long lifetime, they can present a significant background or noise source during the measurement period

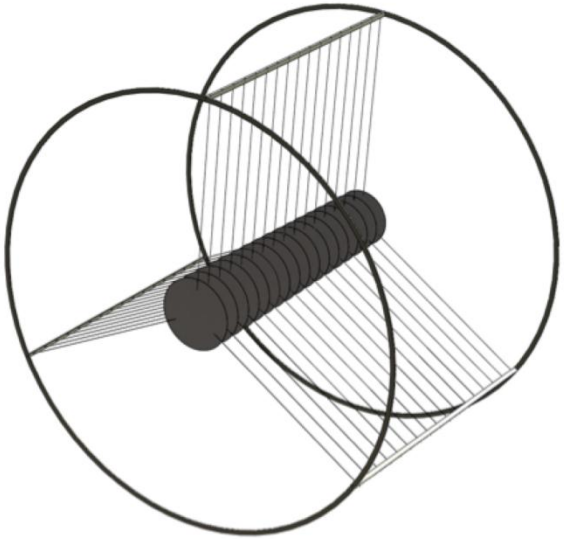
    $\Rightarrow$ supports made of high Z nuclei: short lifetime and lower DIO maximum energy

  - Supports must not degrade acceptance or energy resolution of the Conversion Electron $\Rightarrow$ low mass in support materials
  - Supports should not significantly reduce the rate of muons stops in target

    $\Rightarrow$ low mass in support materials
- Solution: use tungsten (Z=74) wire supports within the radius where there are incoming muons
  - W muonic lifetime ~ 80 ns (compare Al 864 ns)
  - Thin tungsten wire readily available and strong

Design

- Suspension by three x 3 mil (75 micron) diameter Tungsten Wire



- Support wires must pass through the outer proton absorber through slots

Changes since CD-1

- In prototype tests, one mil tungsten wire was not sufficiently strong
- Three mil tungsten wire prototype works
  - From simulations: no problems introduced by thicker wire: does not degrade CE energy resolution, causes no significant background, few noise hits in the tracker or collimator

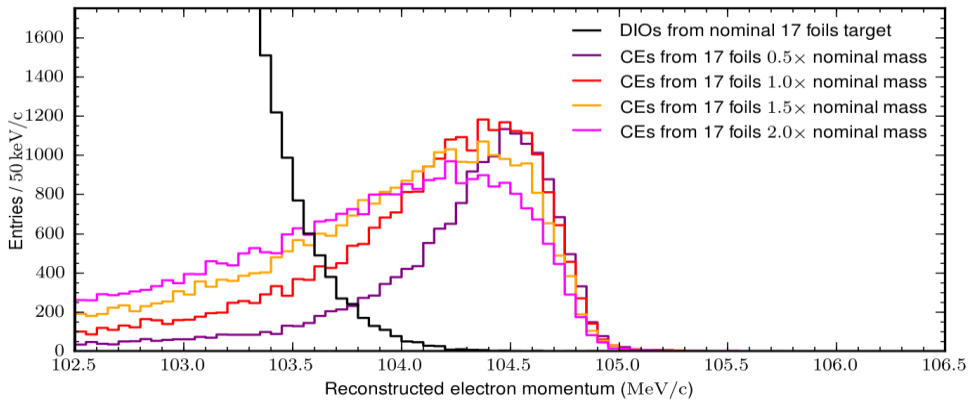
Performance

- Prototype support wires with various tensions, wire connections at ends.
- All but one target foil have held for months
- The one failure is associated with wire cutting through solder end connection- this method of connection will be discarded.
- Wires threaded through metal (Al target or bolts) work well

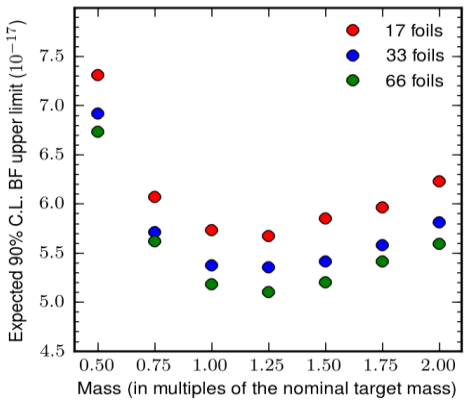
Performance

- Stopping target simulation team has verified the performance
  - Continue optimization of target configuration

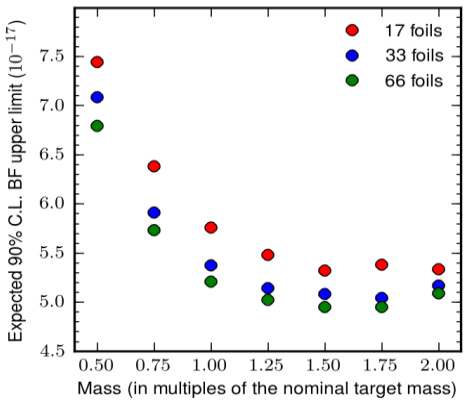
(a) Electron momentum spectra for different 17 foil target configurations



(b) Mass scan by variation of foil thickness



(c) Mass scan by variation of foil radii



Performance

- 99.99% Pure Al disks readily acquired
- Prototype support for 6 disks has been shown to hold for several months
- One wire supported with solder cut through solder

Wires threaded through metal supports work well

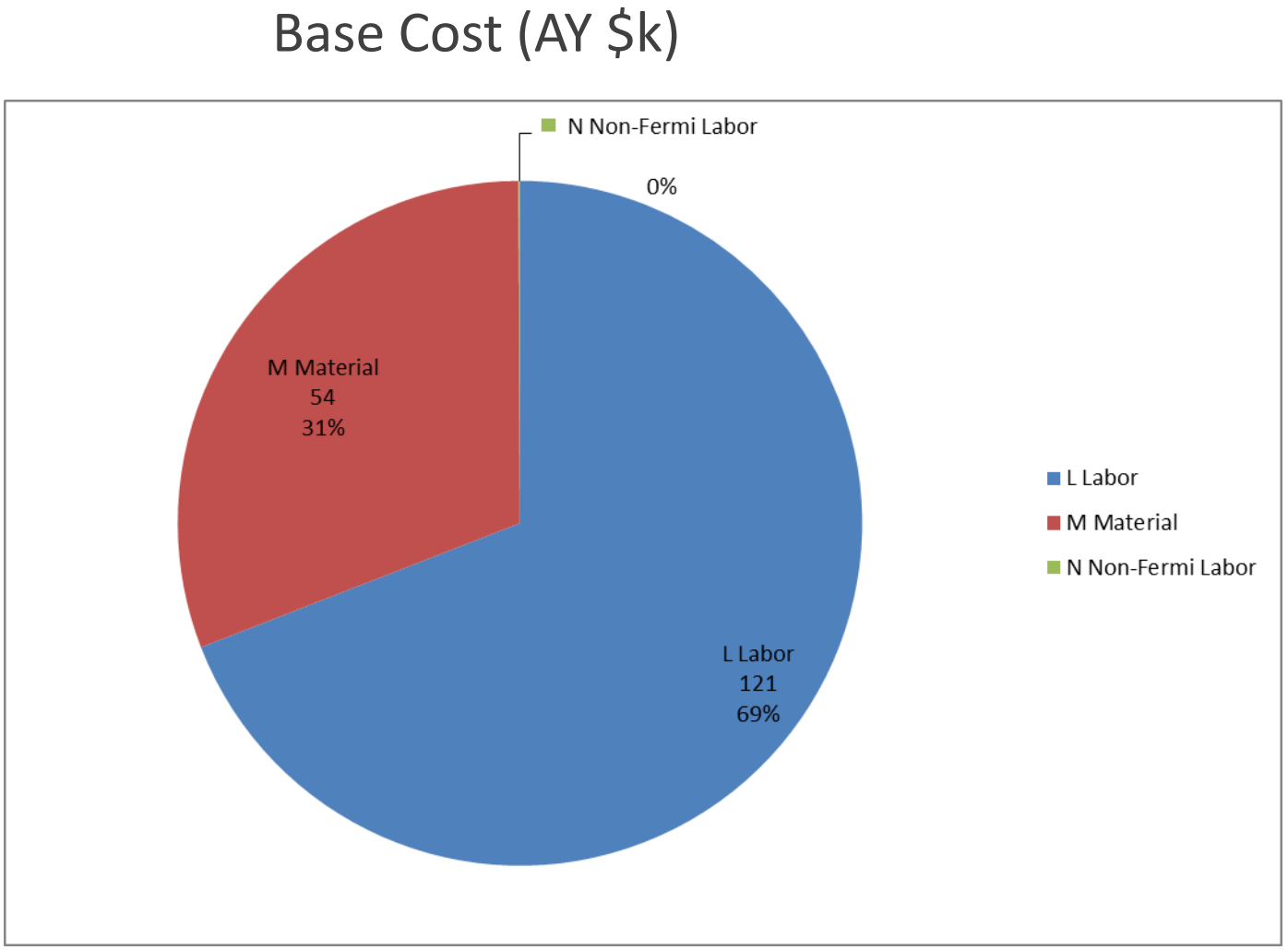
Remaining work before CD-3

- Likely need additional mechanical angled wire support to damp horizontal oscillations in vacuum
- Design frame that fits in with the surrounding proton absorber
- Complete prototype studies
- Complete target design optimizations

Quality Assurance

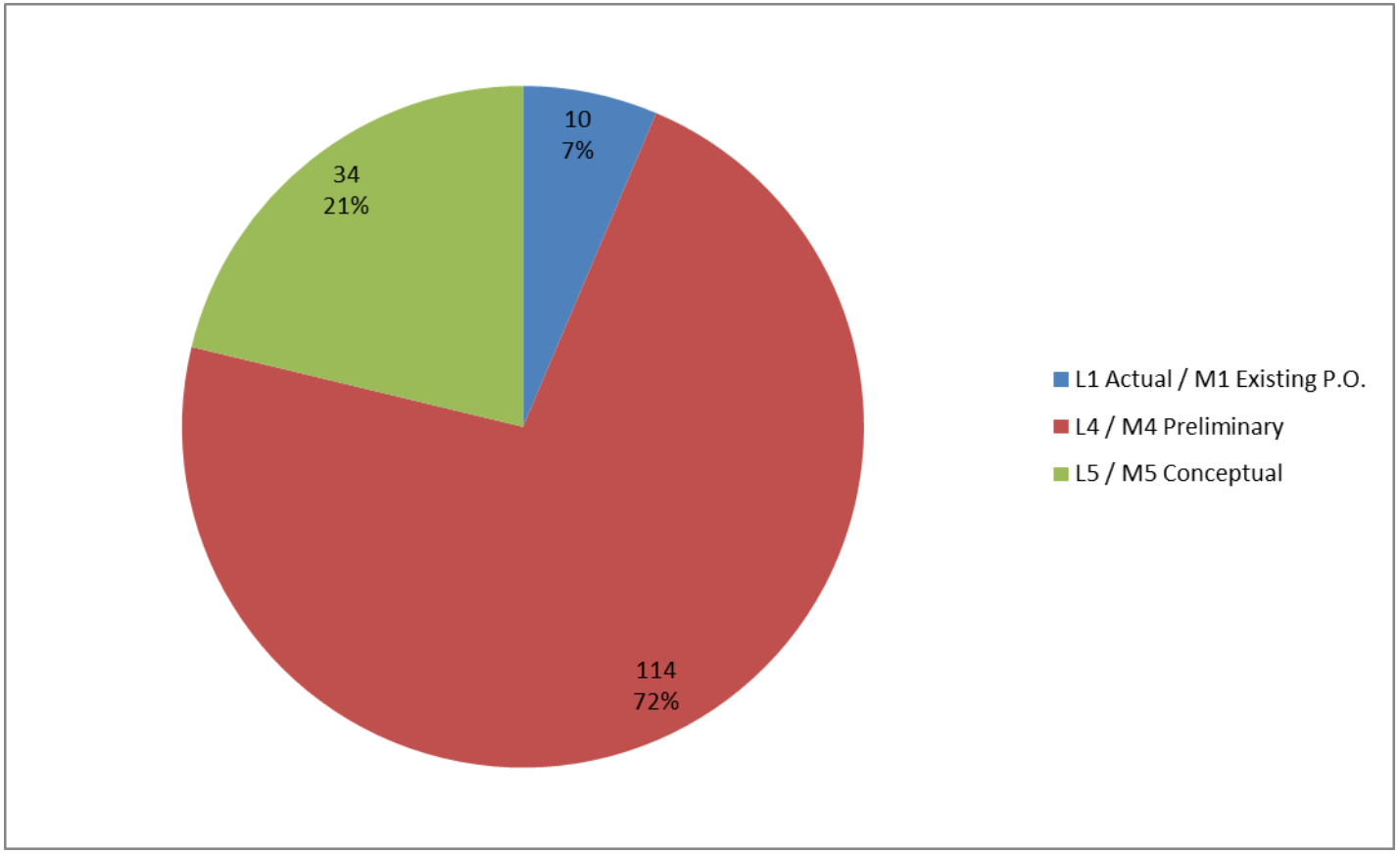
- Prototype supports will be tested for many months to check for long-term viability
- Check thickness and uniformity of each disk

Cost Distribution by Resource Type

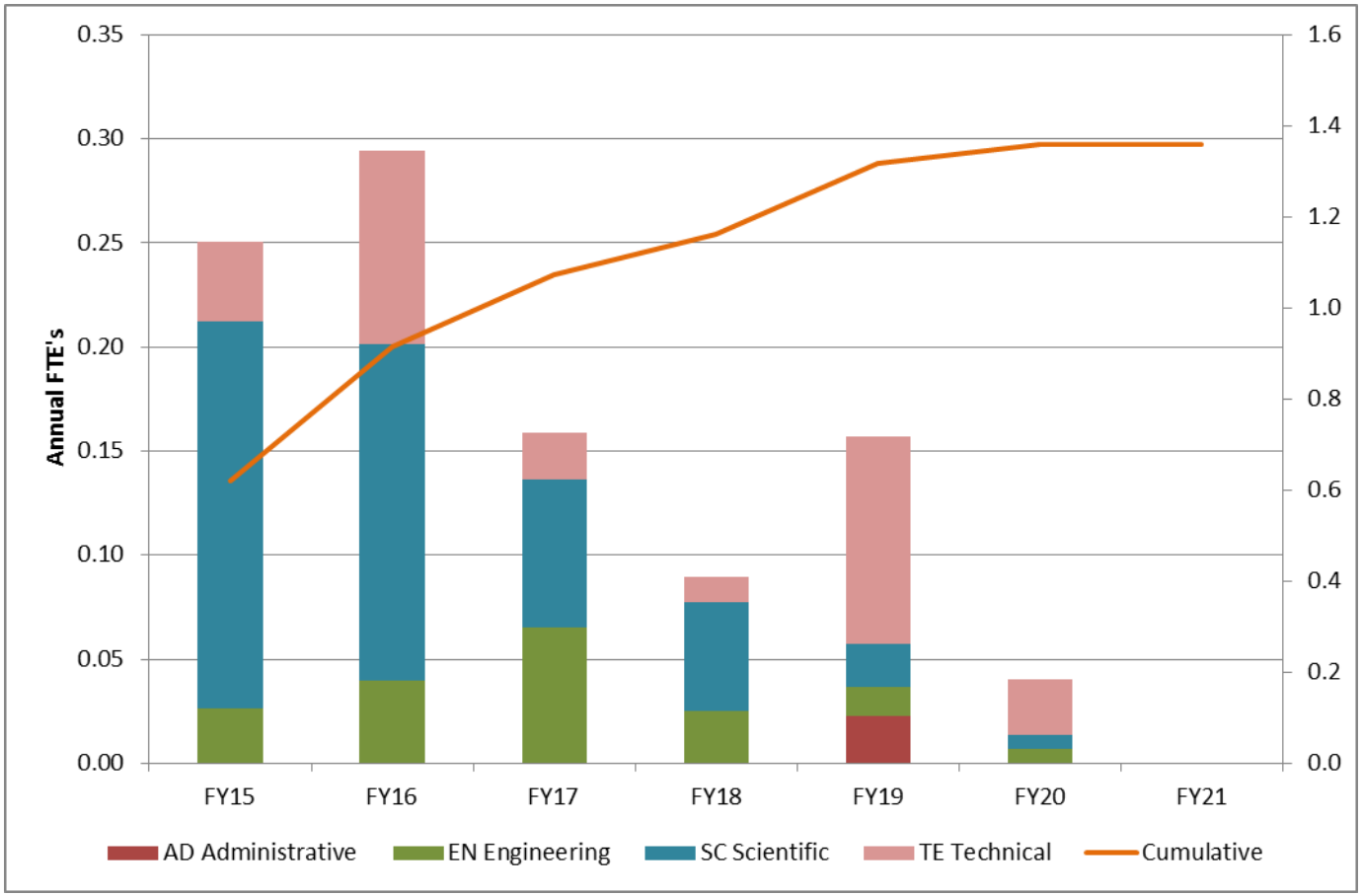


Quality of Estimate

Base Cost by Estimate Type (AY$k)



Labor Resources



Cost Table

WBS 5.5 Stopping Target

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						
475.05.05 Stopping Target						
475.05.05 Stopping Target	54	121	175	63	38%	238
Grand Total	54	121	175	63	38%	238

Major Milestones

- L5- Stopping target preliminary design complete 30 May 14
- L5 - Muon Beamline External Shielding ready for CD 3a Review 23-jan-18
- L5 - CD-3a approval (Stopping Target) 06-Mar-18
- L4 - Stopping Target at FNAL 05-Dec-18
- L4- Stopping Target Ready for CD-4 10-Feb-20

Summary

- Prototypes are proof of principle for tungsten wire supports of target disks
- Simulations demonstrate that the current concept meets physics requirements