Fermilab

Mu2e WBS 5.5 Stopping Target DOE CD-2/3b Review

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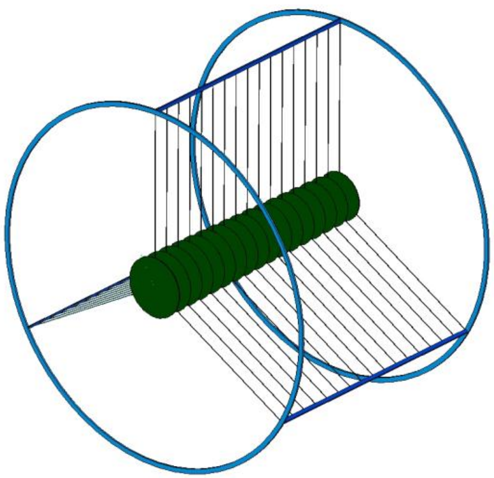
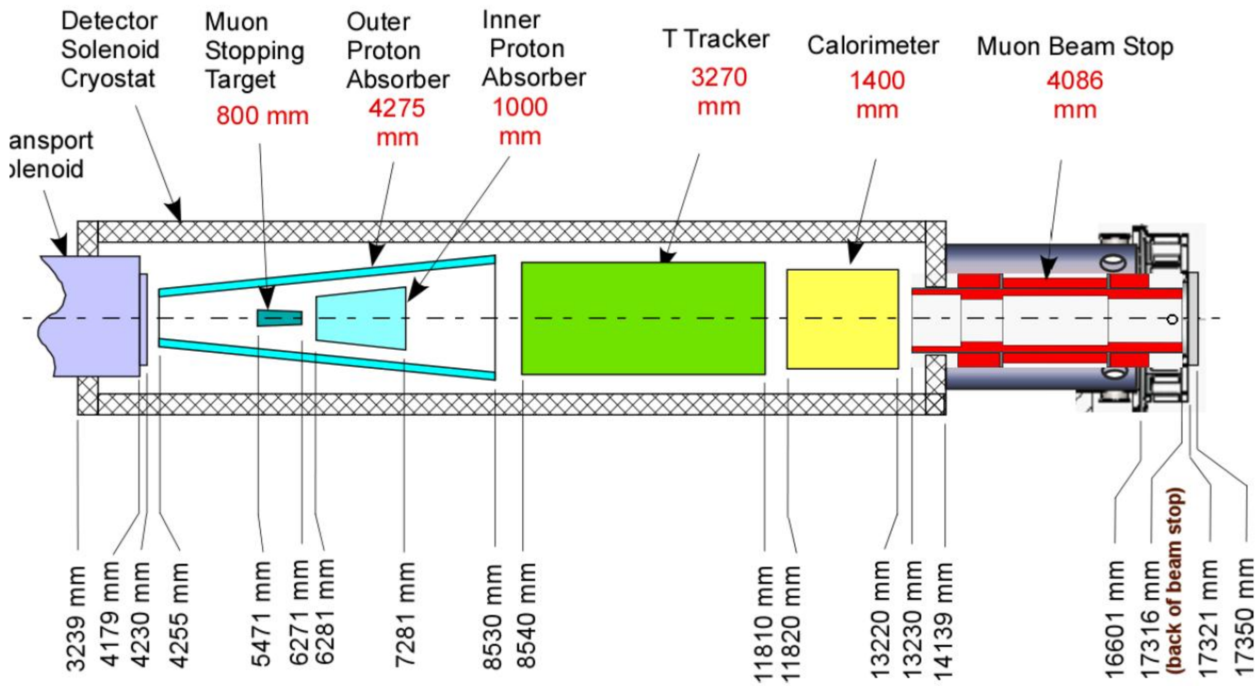
10/21/2014

Design

- Suspension of each foil by three x 3 mil (75 micron) diameter Tungsten wires





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

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 17-13 cm ϕ Al disks spaced by 5 cm, tapered linearly to smaller diameters going downstream

- Conversion electron energy must be higher than the energies of other secondary particles 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

$$\Rightarrow \; m({}^{27}_{12}\mathrm{X}) = m({}^{27}_{13}\mathrm{Al}); \; m({}^{27}_{12}\mathrm{Mg}) = m({}^{27}_{13}\mathrm{Al}) + 2.6\ \mathrm{MeV}$$

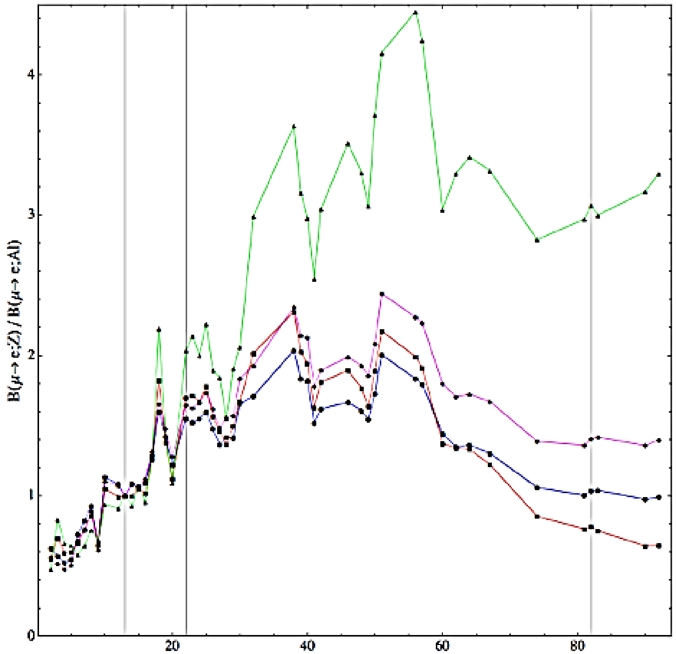
- Z of stopping target must optimize signal in Measurement Period
  - Major fraction of muonic atoms must remain un-decayed during Measurement Period (MP) between 700 ns and 1700 ns after proton pulse

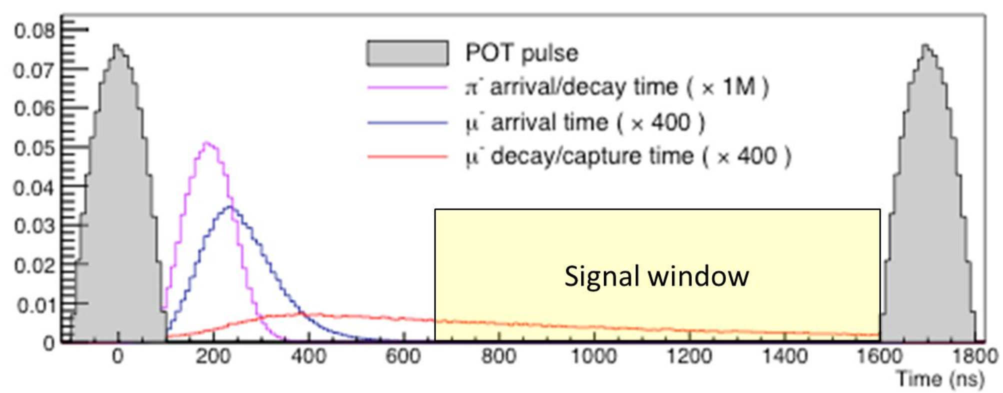
⇒ low Z preferred for longer lifetime

  - Conversion electron sensitivity roughly Proportional to Z for nucleus for low Z

⇒ high Z preferred

Al (lifetime 864 ns) is a good compromise between high Z for sensitivity and low Z for 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 addition bremsstrahlung 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 photon background caused by beam electrons traversing the target
  - Delta rays produced in the target by energetic cosmic ray muons, or other cosmic ray interactions.

Requirements: Stopping Target (3)

- The target material must be pure enough to avoid background due to electrons from muon Decay in Orbit (DIO) in impurity nuclei.
  - This is not stringent for Al because of its high conversion electron energy relative to most other nuclei- this is much more of a problem for higher Z nuclei, which have lower conversion electron energies
- The radial extent 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 incoming 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 (although accurate *knowledge* of positions to 2 mm would also suffice)
  - Traceback of trajectories from the Tracker to the target provides background suppression, uniform 5 cm spacing will assist in this traceback
  - More predictable simulations, e.g. electron energy losses

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 both the radius and the muon flux are 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 (r<25 cm)
  - W muonic lifetime ~ 80 ns (compare Al 864 ns)
  - Thin tungsten wire readily available; it is strong and therefore it can be thin

Improvements since CD-1

- One mil tungsten wire was tested as a prototype, and found to be challenging due to failures at kinks
- Three mil tungsten wire was tested at the prototype, and has performed well
  - 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

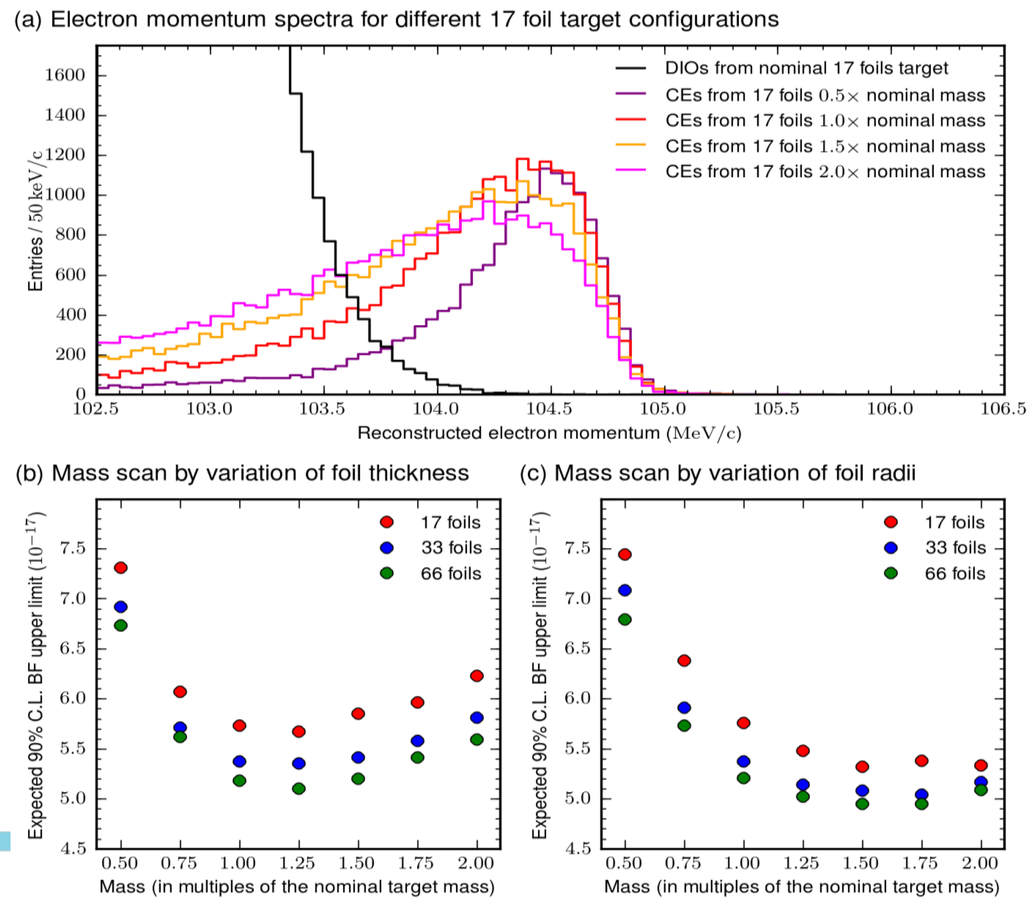
nominal 17 foil target, new offline, w/ proton absober	reference w/o wires	1.5mil wires	3.0mil wires	6.0mil wires	3mm wires (corresponds to several kilograms)
SES (x1E-17)	2.10	2.08	2.15	2.14	2.35
90% CL upper limit (x1E-17) (Feldman-Cousins)	5.72	5.72	5.76	5.72	6.32
#CEs in opt. window (BR 1E-16)	4.76	4.80	4.66	4.67	4.26
#DIOs in opt. window (BR 1E-16)	0.33	0.36	0.28	0.27	0.30
optimized window	103.7-105.8	103.7-105.7	103.7-105.7	103.7-105.8	103.7-105.9

Performance

- Prototype support wires with various tensions, wire connections at end
- Wires threaded through metal (Al target or bolts) work well
- Prototype has held for >8 months

Performance

- Stopping target simulation team has verified the performance
  - Continue optimization of target configuration
  - Increase number of foils, reduce foil thickness modestly improves CE signal



Remaining work prior to fabrication

- 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

Integration and Interfaces

- Stopping target has external interface to Solenoids
- Internal interfaces to
  - Muon beamline vacuum system
  - Stopping target monitor
  - Detector solenoid internal shielding
  - Detector support and installation system
- Integration and interfaces addressed via
  - WBS dictionary and interface documents
  - Muon beamline meetings
  - Mechanical and electrical integration meetings

Quality Assurance

- Quality Assurance relies upon the following tools :
  - Fermilab Quality Assurance Manual
  - Fermilab Engineering Manual
  - Mu2e Quality Assurance Program
  - Documented engineering calculations and drawings
    - reviewed, approved and released
  - Verification of physics simulations
  - Prototypes will be tested for many months to verify long-term viability
  - Materials certifications will be required for the key components
  - Components received from vendors will be inspected for conformance to specifications, alloy and purity confirmed
    - Dimensions and positions of each disk will be verified

Risk

- Due to the delicate nature of the target supports, there is a risk that the target might be damaged during transport or installation
  - Design of the surrounding outer proton absorber is being optimized in an effort to mitigate this risk
  - Ongoing studies with the stopping target prototype will also mitigate this risk
  - The risk is classified as low

ES&H

- To perform muon beamline activities safely will require appropriate planning (JHA), attention to ES&H considerations and FESHM and FRCM requirements
  - Accessing confined space FESHM 5063
  - Crane, hoist, and forklift use FESHM 5021
    - Including lifts beyond direct crane coverage
  - Fall Hazards FESHM 5066
  - Magnetic fields FESHM 5062.2
  - Electrical hazards FESHM 5042
  - Radiation hazards FRCM
    - Activation by beam
  - And possibly ODH
    - FESHM 5064

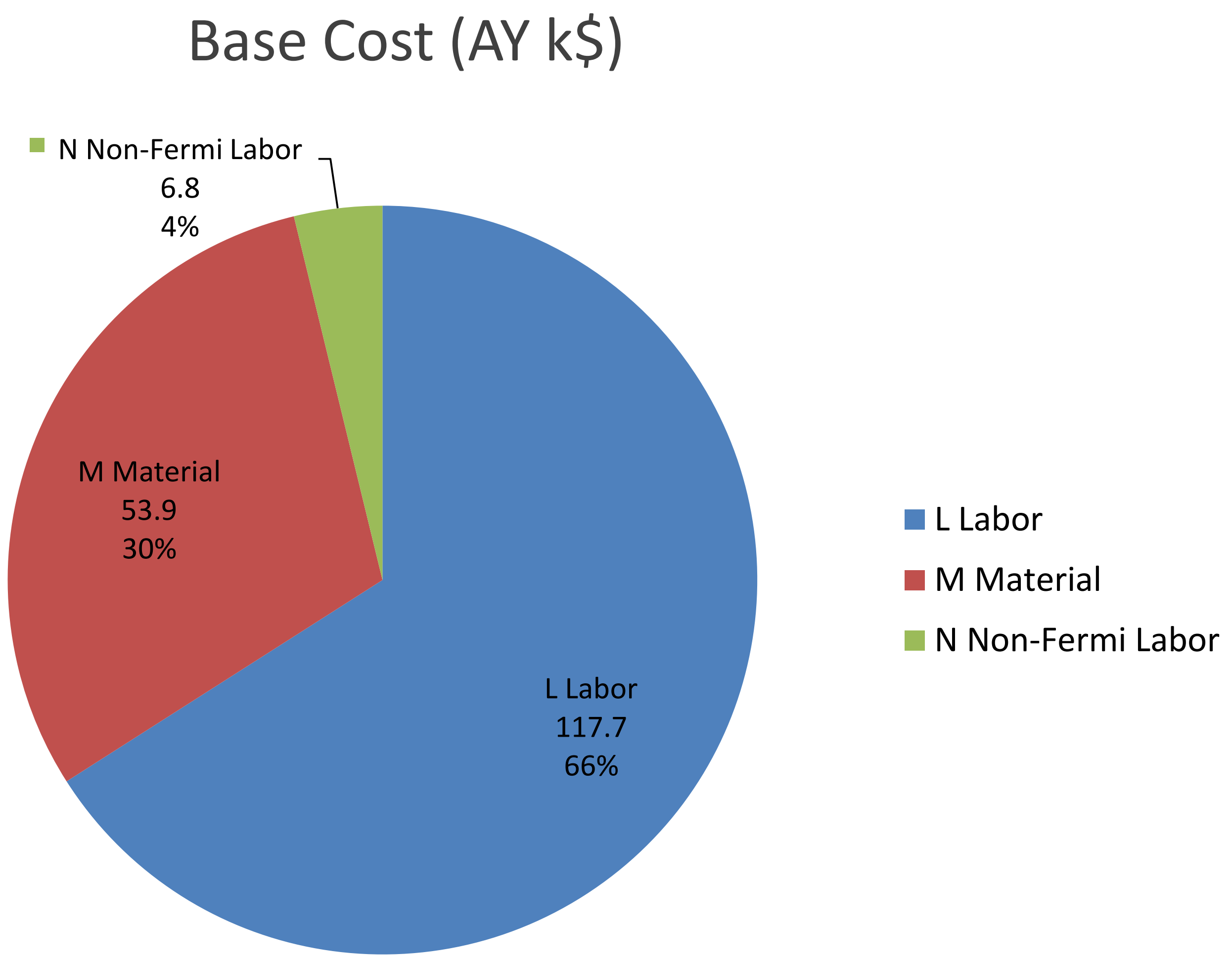
Cost Table

WBS 5.5 Stopping Target

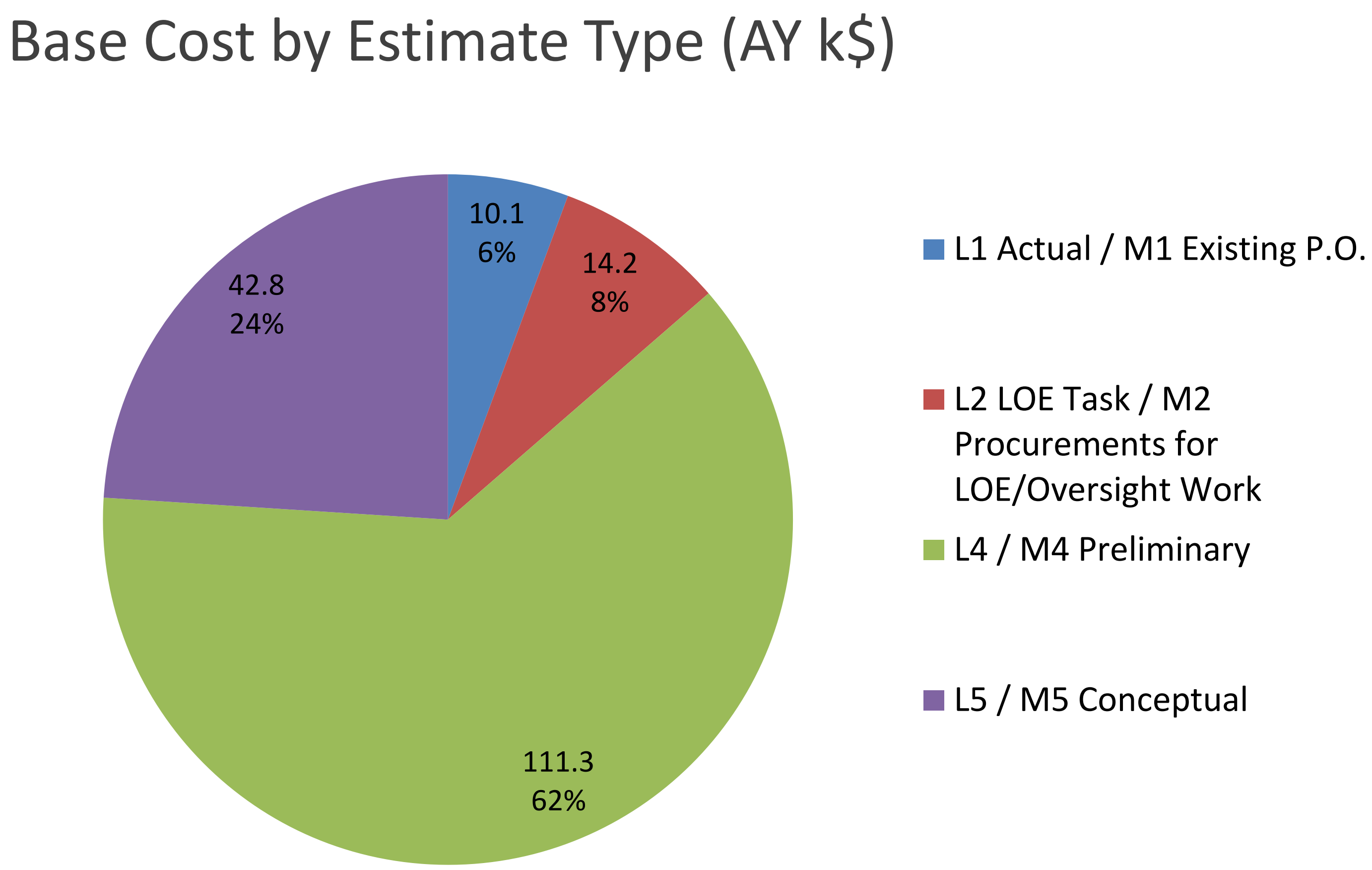
Costs are fully burdened in AY $k

	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	61	118	178	66	39%	245
Grand Total	61	118	178	66	39%	245

Cost Distribution by Resource Type

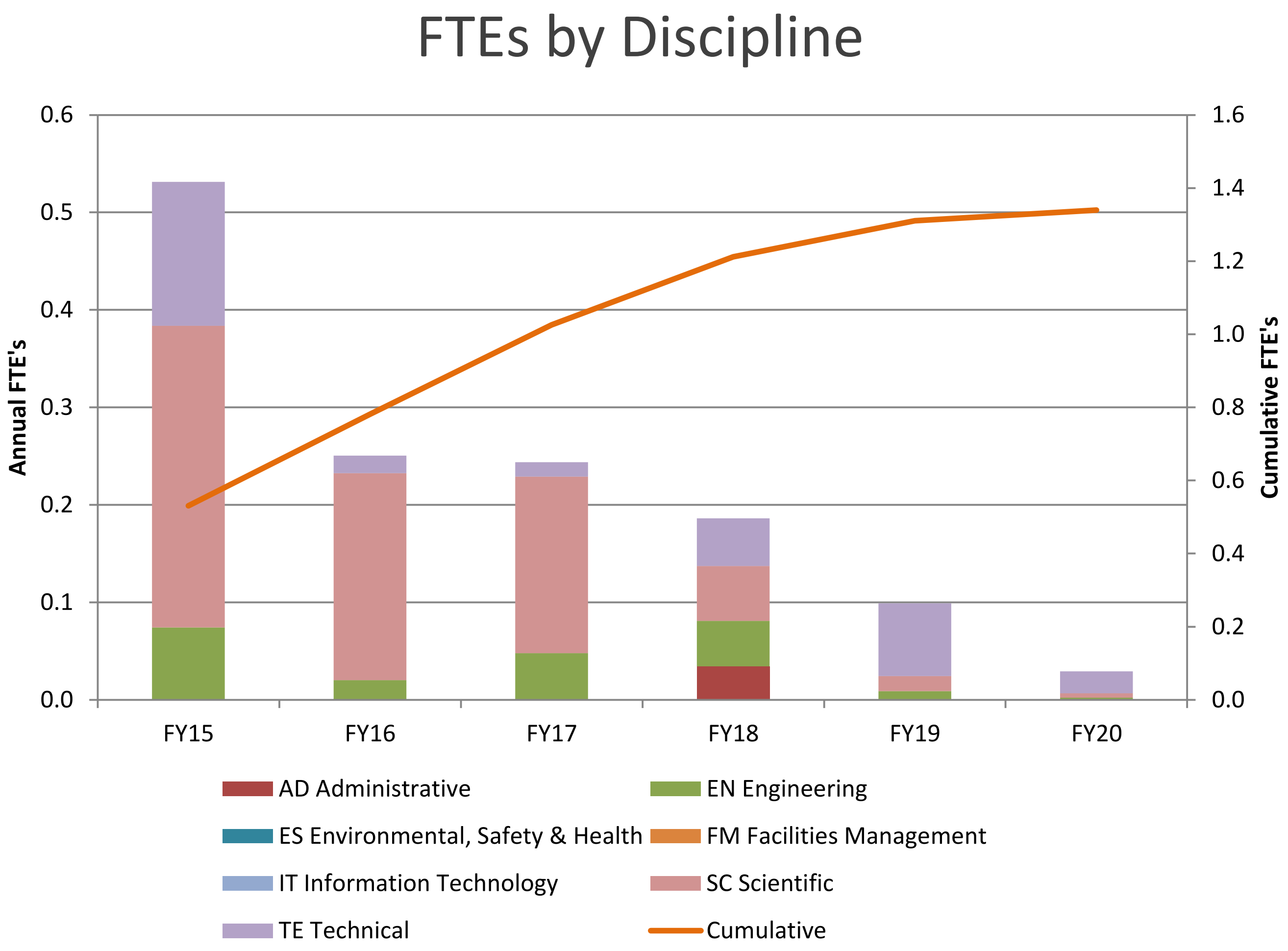


Quality of Estimate

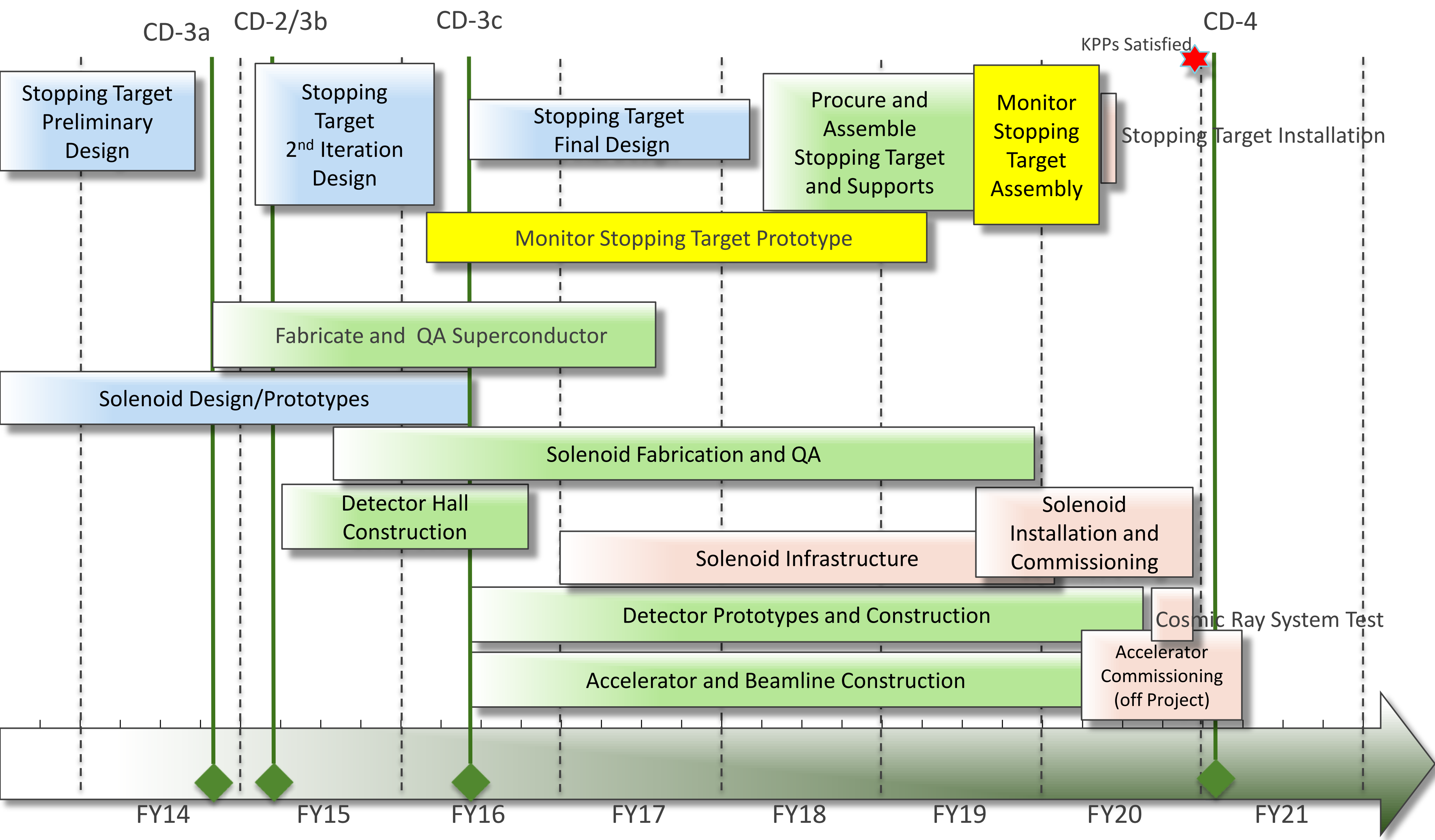


76% of the cost at the preliminary design level or higher

Labor Resources



Schedule



CD-3a
CD-2/3b
CD-3c
CD-4
KPPs Satisfied
Stopping Target Preliminary Design
Stopping Target 2nd Iteration Design
Stopping Target Final Design
Procure and Assemble Stopping Target and Supports
Monitor Stopping Target Assembly
Stopping Target Installation
Monitor Stopping Target Prototype
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 Commissioning (off Project)
Accelerator and Beamline Construction
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Milestones

47505.5.001280	T5 - First Iteration Stopping Target Preliminary Design Complete	5/30/2014
47505.5.001363	T5 - Stopping Target 2nd iteration Design Complete	11/10/2015
47505.5.001452	T5 - Stopping Target ready for CD-3 Review	12/11/2015
47505.5.001455	T5 - CD-3 approval (Stopping Target)	2/23/2016
47505.5.001435	T5 - Stopping Target Ready for fabrication	12/13/2017
47505.5.001464	T4 - Stopping Target at FNAL	4/26/2018
47505.5.001621	T5 - Stopping Target Frame at Fermilab	6/26/2018
47505.5.001675	T5 - Stopping Target Assembled	4/2/2019
47505.5.001676	T4 - Stopping Target Assembled	6/3/2019
47505.5.001677	T3 - Stopping Target Assembled	7/3/2019
47505.5.001678	T2 - Stopping Target Assembled	10/3/2019
47505.5.001720	T5 - Stopping Target Installed	2/18/2020
47505.5.001800	T5 - Stopping Target Ready for CD-4	2/18/2020
47505.5.001679	T1 - Stopping Target Assembled	4/2/2020

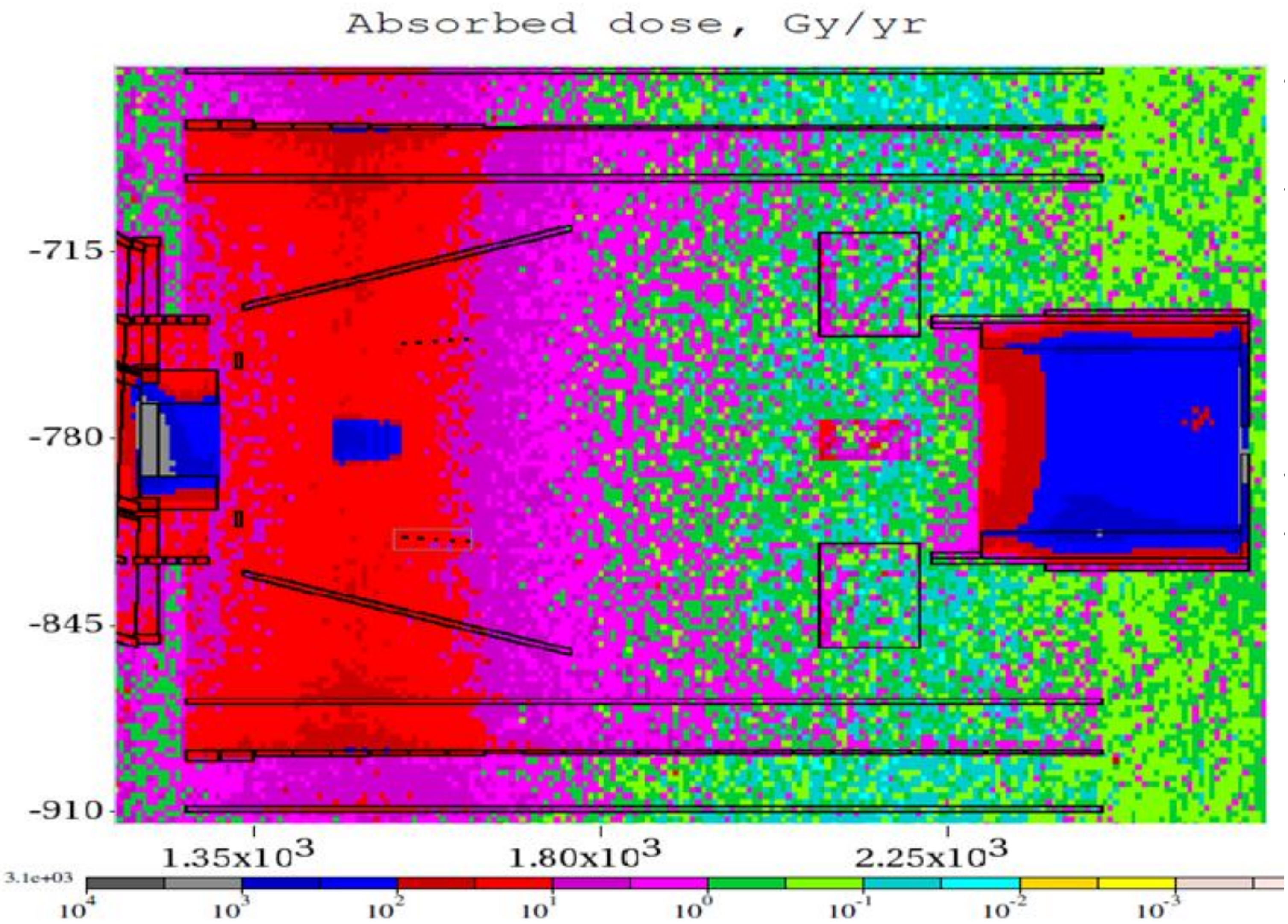
Summary

- Simulations demonstrate that the current design satisfies the requirements
- Prototypes are proof of principle for tungsten wire support of target disks
- Cost estimates for the stopping target are complete
  - 76% of the costs understood at the Preliminary Design level or higher
  - Risks have been evaluated, and mitigation is in progress
- Interfaces are identified and defined
- Resources are understood
- Stopping Target is ready for CD-2

Target Temperature

- Beam power in target is 31 µW (per MARS simulation study documented in Mu2e docdb 3593)
  - Target temperature is estimated at 40^0 C

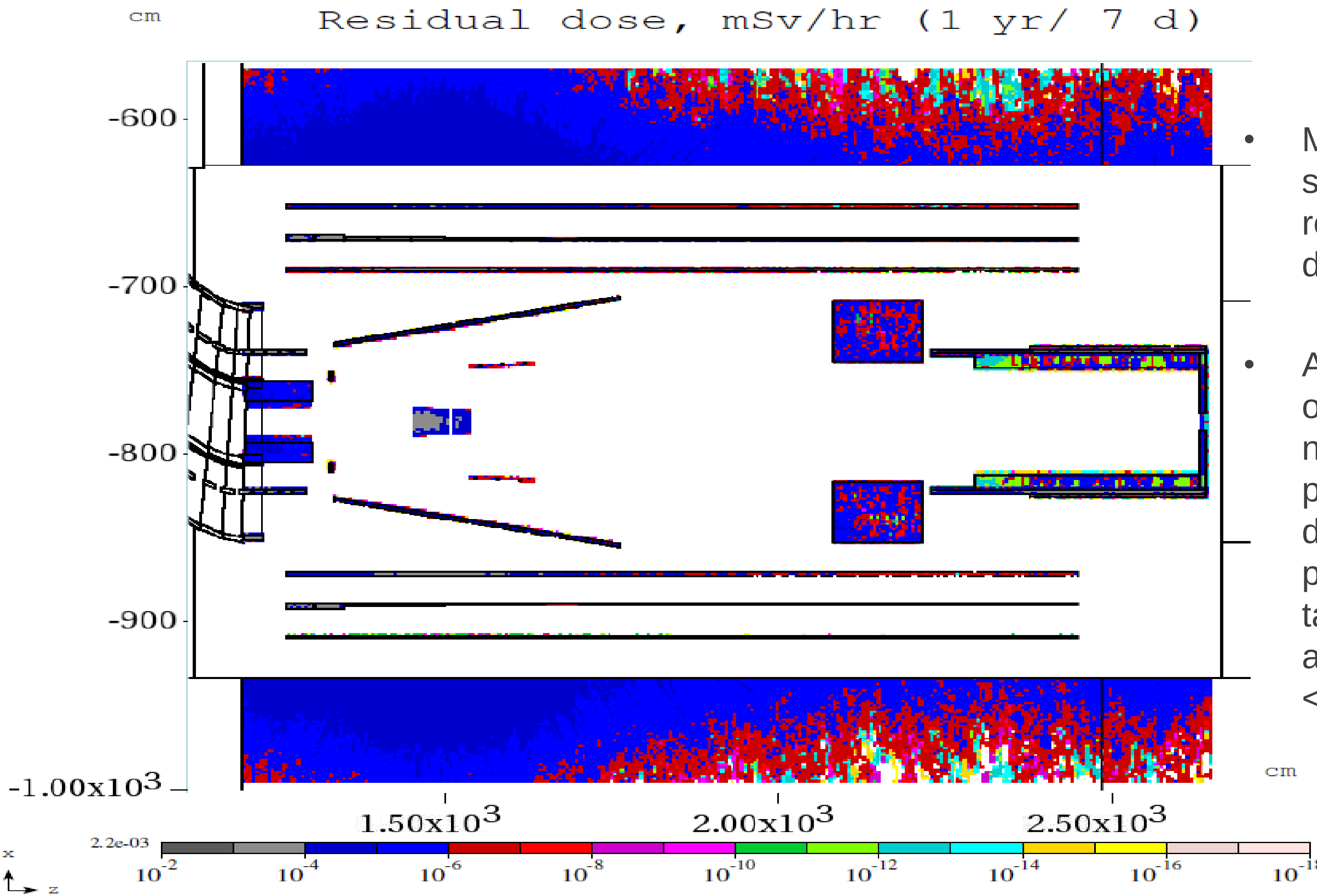
Absorbed Dose in DS region (Gray/year)



MARS simulation results per docdb 3593

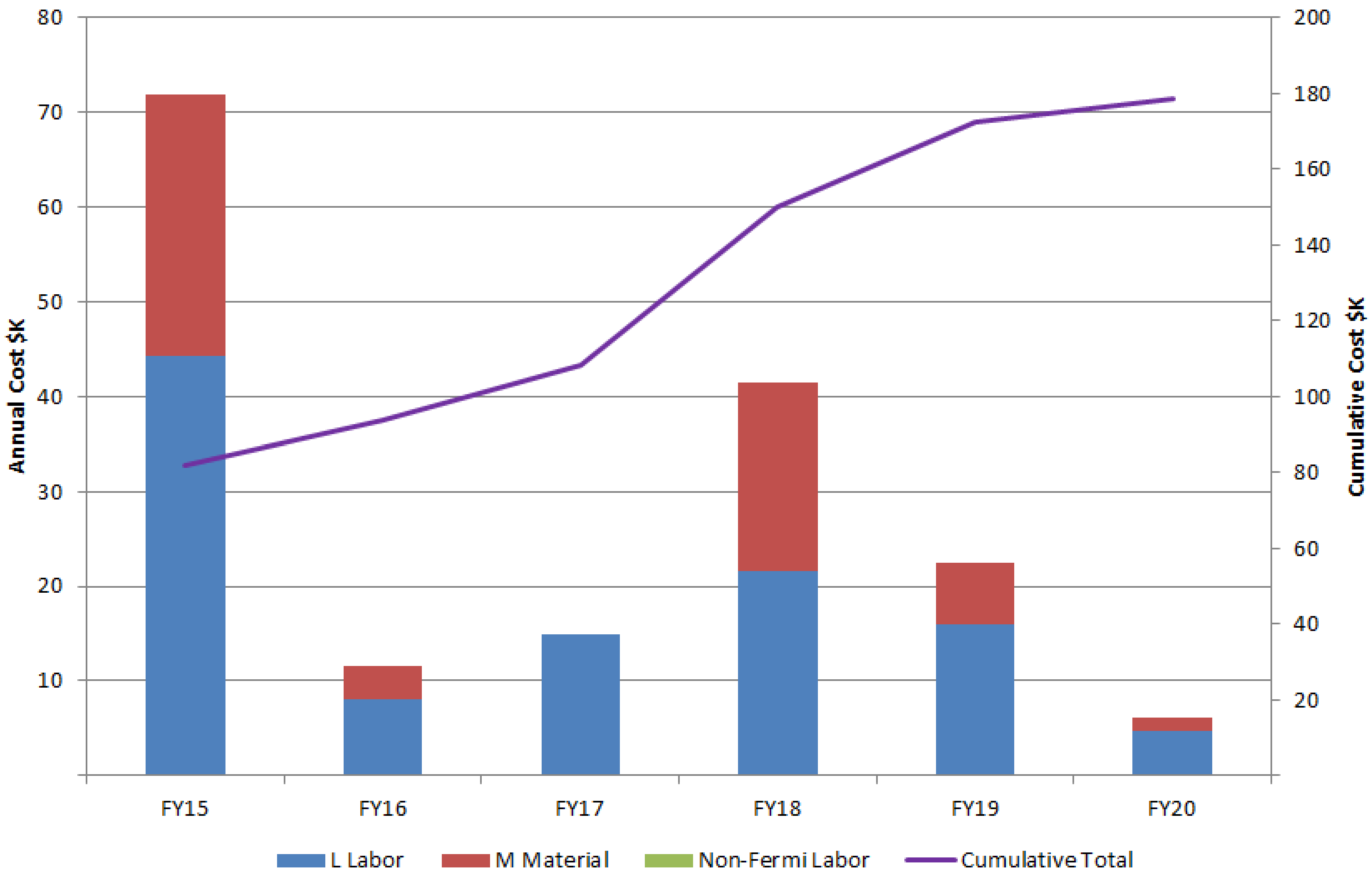
~ kGray per year at the stopping target

Residual Dose in DS Region (mSv/hour)

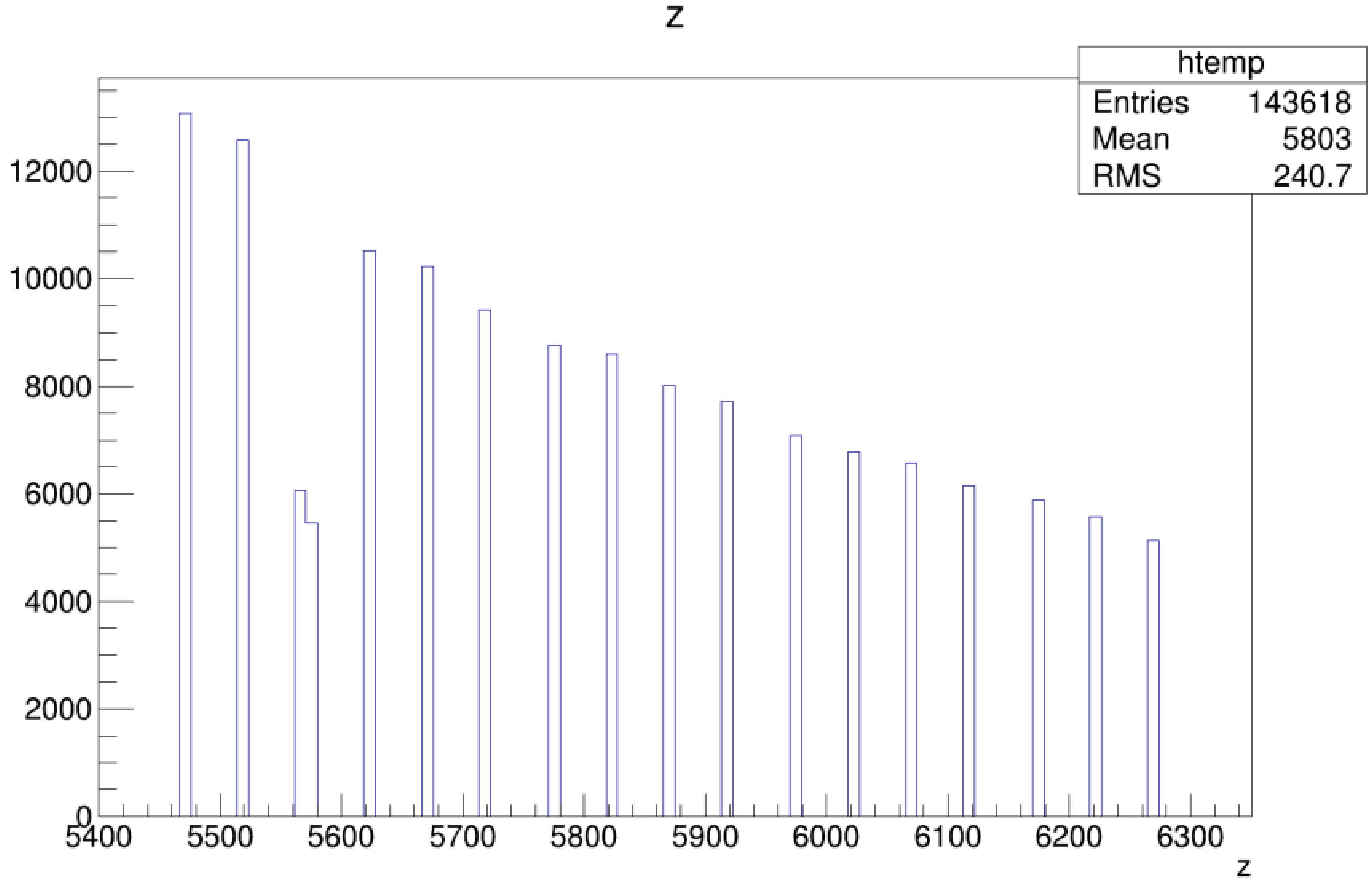


- MARS simulation results per docdb 3593
- After 1 year of operation at nominal beam power and 7 day cooldown period, stopping target should be at <0.3mrem/hour

Labor and Material per FY in AY k$



Z distribution of stopped muons in target



Radial distribution of muon stops