Fermilab

U.S. DEPARTMENT OF ENERGY Office of Science

Mu2e Accelerator Upgrades

Mu2e Independent Cost Review

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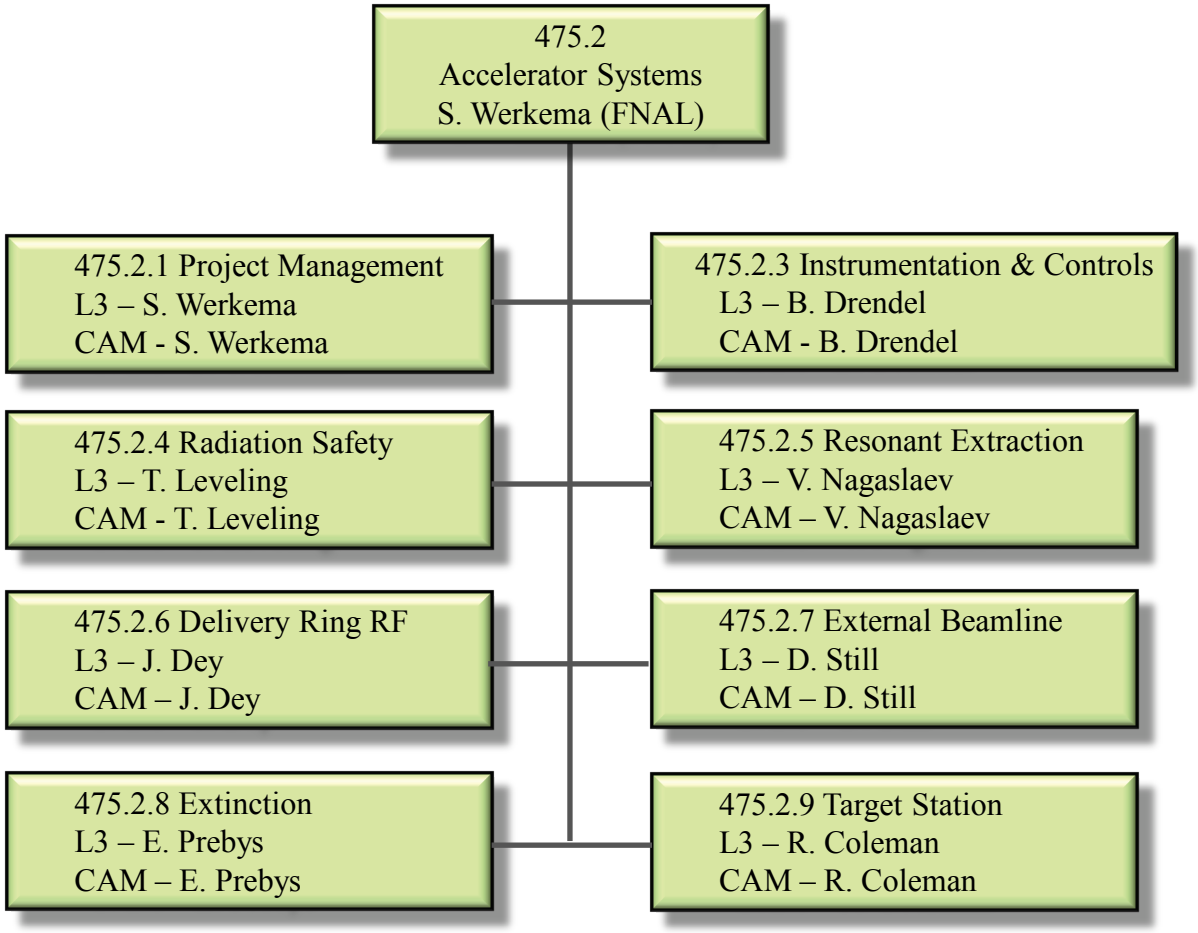
Mu2e Accelerator Upgrades Level 2 Manager

8/26/2014

Organization



Requirements

The Mu2e Accelerator upgrades are driven by 8 requirements documents that are under Configuration Management.

• Science Driven Requirements	Mu2e-doc-4381
• Proton Beam Requirements	Mu2e-doc-1105
• Beam Extinction Requirements	Mu2e-doc-1175
• Extinction Monitor Requirements	Mu2e-doc-894
• Production Target Requirements	Mu2e-doc-887
• Heat and Radiation Shield (HRS) Requirements	Mu2e-doc-1092
• Proton Absorber Requirements	Mu2e-doc-948
• Protection Collimator Requirements	Mu2e-doc-2897

All of these documents are available on the review web site.

Scope Overview

475.02.08.03 Extinction Monitor

475.02.09 Target Station

475.02.07 External (M4) Beamline

475.02.08.02 Extinction

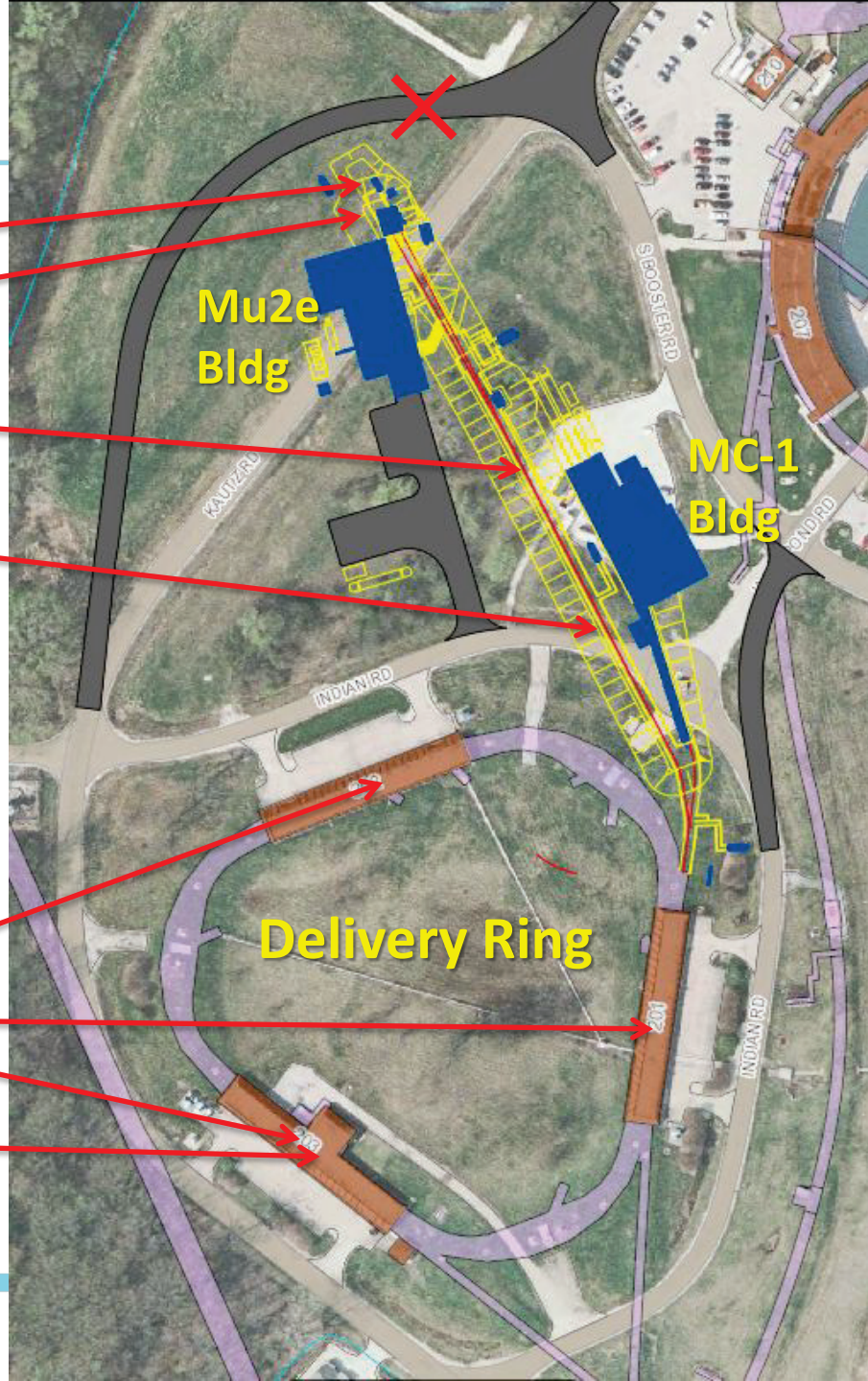
475.02.03 Instrumentation & Controls

475.02.04 Radiation Safety

Everywhere

475.02.05 Resonant Extraction

475.02.06 Delivery Ring RF



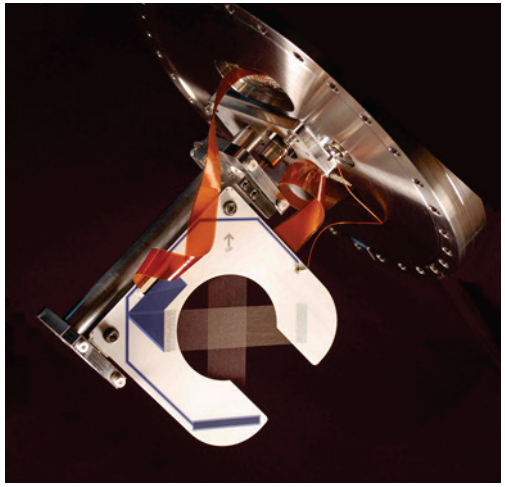
WBS 475.2.3 Instrumentation and Controls

- Design and fabricate the equipment for the accelerator controls and instrumentation upgrades required for beam delivery to Mu2e.

  Estimate to Complete from May 1, 2014:

  - 475.02.03.01 Accelerator Controls ($274k)
  - 475.02.03.02 Delivery Ring Instrumentation ($331k)
  - 475.02.03.03 Extraction beamline Instrumentation($1,299k)
  - Technical Documentation* ($503k)

- Basis of Estimate
  - Vendor quotes for materials
  - Understanding of the costs of implementation of similar technology in other Fermilab beamlines.



Multiwire Beam Profile Monitor

*Technical Documentation includes costs of Technical Design Report preparation, Review preparation, BOE preparation and review, and project management costs for each Level 3

WBS 475.2.4 Radiation Safety

- Design and implement the Radiation Safety upgrades that are required to permit an 8 kW increase in beam power and maintain the level of radiation protection required by the Fermilab Radiological Controls Manual.

  Estimate to Complete from May 1, 2014:
  - 475.02.04.01 AP1 Line to Delivery Ring Total Loss Monitor System ($73k)
  - 475.02.04.02 Delivery Ring Radiation Safety Upgrades ($932k)
  - 475.02.04.03 External Beamline Safety System ($316k)
  - 475.02.04.04 Mu2e Safety Systems ($334k)
  - 475.02.04.05 Technical Documentation ($366k)

Total Loss Monitor Detector

- Basis of Estimate
  - Known costs for fabrication and installation of prototype Total Loss Monitor radiation safety systems in beamlines at Fermilab
  - Shielding estimates based on implementation of similar structures for other projects at Fermilab (NuMI, NOvA).

WBS 475.2.5 Resonant Extraction System

- Design, manufacture, and installation of the systems necessary for the resonant extraction of beam from the Delivery Ring synchrotron.

  Estimate to Complete from May 1, 2014:
  - 475.02.05.01 General Design of Resonant Extraction System ($403k)
  - 475.02.05.02 Electrostatic Septum (Mechanical) ($2,495k)
  - 475.02.05.03 Magnets for the Resonant Extraction System ($914k)
  - 475.02.05.04 Fast Feedback Devices for the Resonant Extraction System ($79k)
  - 475.02.05.05 Fast Feedback Electronics for the Resonant Extraction System ($269k)
  - 475.02.05.06 RF Knockout Kicker for the Resonant Extraction System ($172k)
  - 475.02.05.07 Magnet Power Supplies for the Resonant Extraction System ($543k)
  - 475.02.05.08 Technical Documentation for the Resonant Extraction System ($605k)

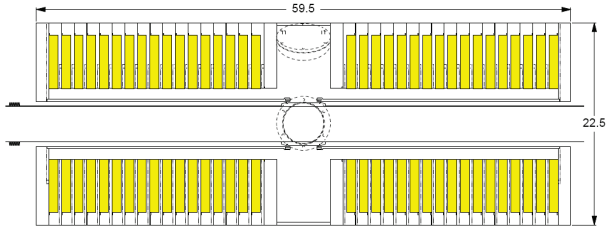
- Basis of Estimate
  - Engineering estimates based on implementation of similar technology in other Fermilab accelerators and beamlines.
  - Magnet fabrication and refurbishment cost estimates based on historical procurement and labor records for fabrication of magnets of same type.

WBS 475.2.6 Delivery Ring RF System

- Design and fabricate a 2.4 MHz RF system that synchronously captures beam from the Recycler Ring and holds it in a stationary RF bucket during resonant extraction.

  Estimate to Complete from May 1, 2014:

  - 475.02.06.01 Low Level RF System ($1,139k)
  - 475.02.06.02 Delivery Ring RF Studies and Tuning ($214k)
  - 475.02.06.03 Delivery Ring RF Cooling System ($346k)
  - 475.02.06.04 Delivery Ring 2.4 MHz RF ($755k)
  - 475.02.06.05 Technical Documentation ($145k)



Cross-section of 2.5 MHz RF Cavity

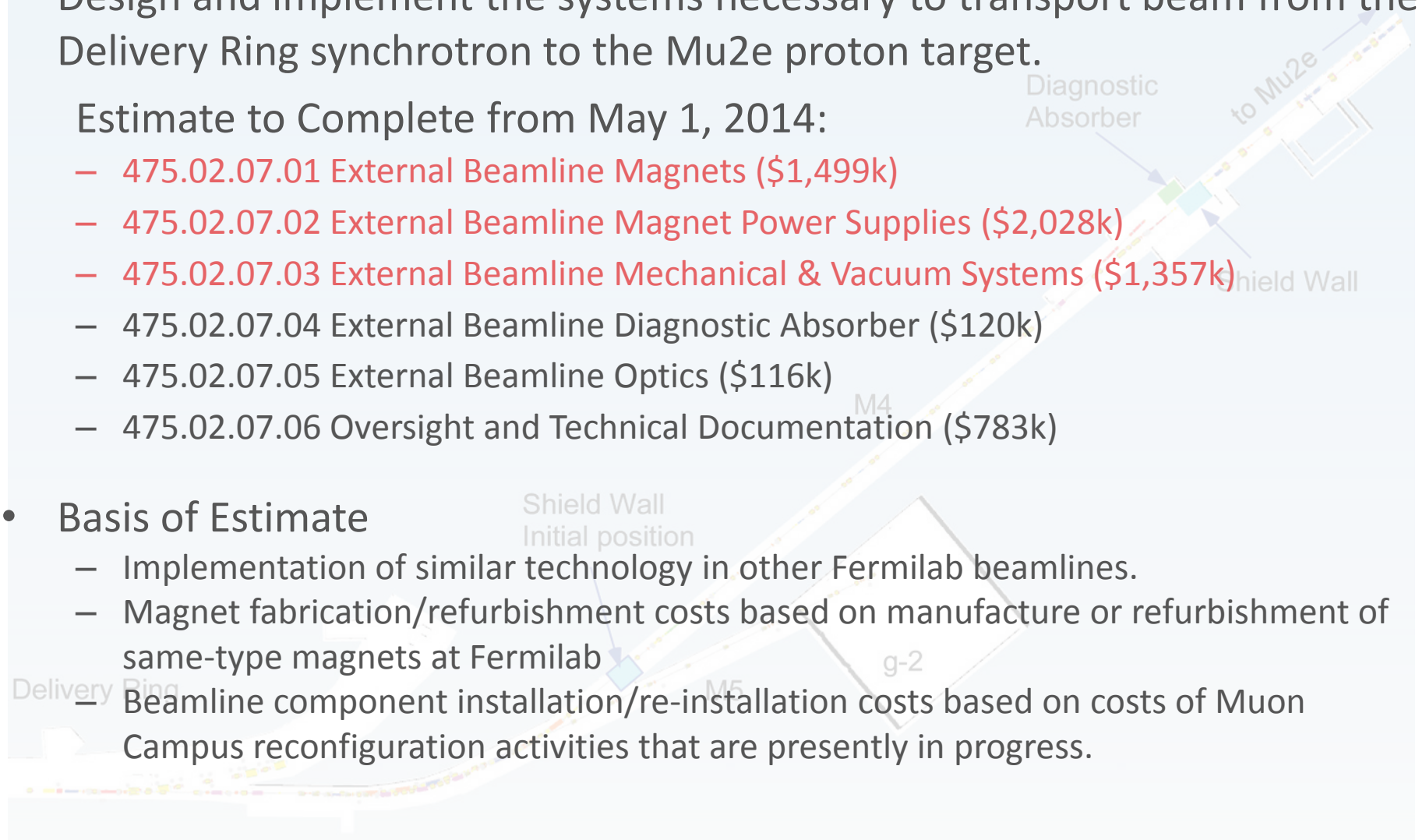
- Basis of Estimate
  - Engineering estimates based on implementation of similar technology in other Fermilab accelerators.
  - Low Level electronics cost estimates based on vendor quotes and recent experience with similar systems at Fermilab.
  - 8 kW solid state driver amplifier cost estimate based on vendor budgetary quotes

WBS 475.2.7 External Beamline

- Design and implement the systems necessary to transport beam from the Delivery Ring synchrotron to the Mu2e proton target.

  Estimate to Complete from May 1, 2014:
  - 475.02.07.01 External Beamline Magnets ($1,499k)
  - 475.02.07.02 External Beamline Magnet Power Supplies ($2,028k)
  - 475.02.07.03 External Beamline Mechanical & Vacuum Systems ($1,357k)
  - 475.02.07.04 External Beamline Diagnostic Absorber ($120k)
  - 475.02.07.05 External Beamline Optics ($116k)
  - 475.02.07.06 Oversight and Technical Documentation ($783k)

- Basis of Estimate
  - Implementation of similar technology in other Fermilab beamlines.
  - Magnet fabrication/refurbishment costs based on manufacture or refurbishment of same-type magnets at Fermilab
  - Beamline component installation/re-installation costs based on costs of Muon Campus reconfiguration activities that are presently in progress.

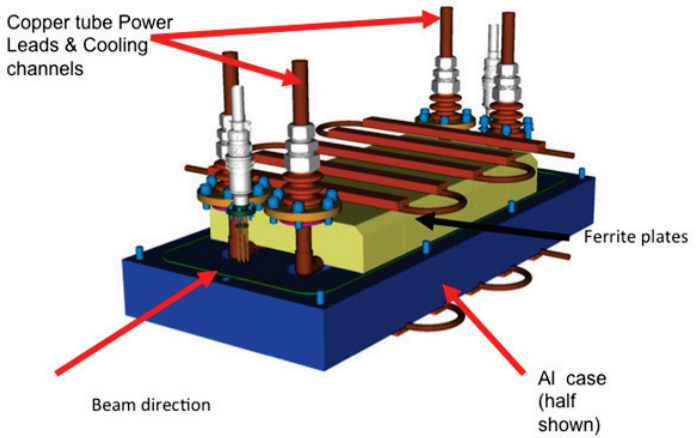


WBS 475.2.8 Extinction Systems

- Design and fabricate the systems necessary for the extinction of out-of-time particles en route to the Mu2e proton target as well as the systems for monitoring the level of extinction achieved.

  Estimate to Complete from May 1, 2014:

  - 475.02.08.01 Internal Extinction System ($0k)
  - 475.02.08.02 External Extinction System ($1,558k)
  - 475.02.08.03 Extinction Monitoring ($1,155k)
  - 475.02.08.04 Technical Documentation ($461k)



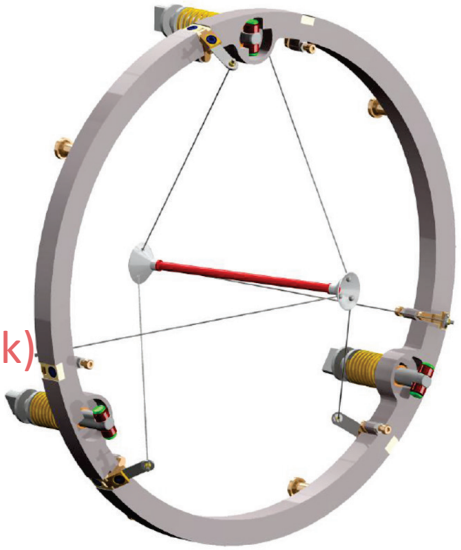
Extinction AC Dipole Magnet

- Basis of Estimate
  - AC dipole cost estimate based experience with a prototype magnet built at Fermilab
  - AC dipole power supply cost estimate based on engineering experience with similar technology and vendor quotes.
  - Extinction monitor M&S cost estimate based on catalog costs of off-the-shelf components

WBS 475.2.9 Target Station

- Design, fabricate, and install the systems necessary for the proton target station, including the target, production solenoid (PS) heat and radiation shield (HRS), protection collimator, target handling, and the target beam absorber.

  Estimate to Complete from May 1, 2014:
  - 475.02.09.01 Simulations and Calculations ($1,397k)
  - 475.02.09.02 Fabricate Target ($1,949k)
  - 475.02.09.03 Target Handling ($2,585k)
  - 475.02.09.04 Production Solenoid Heat & Radiation Shield ($2,778k)
  - 475.02.09.05 Target Station Proton Beam Absorber ($331k)
  - 475.02.09.06 Solenoid & HRS Protection Collimator ($327k)
  - 475.02.09.07 Hatch Shielding Blocks ($0k)
  - 475.02.09.08 Technical Documentation ($1,185k)



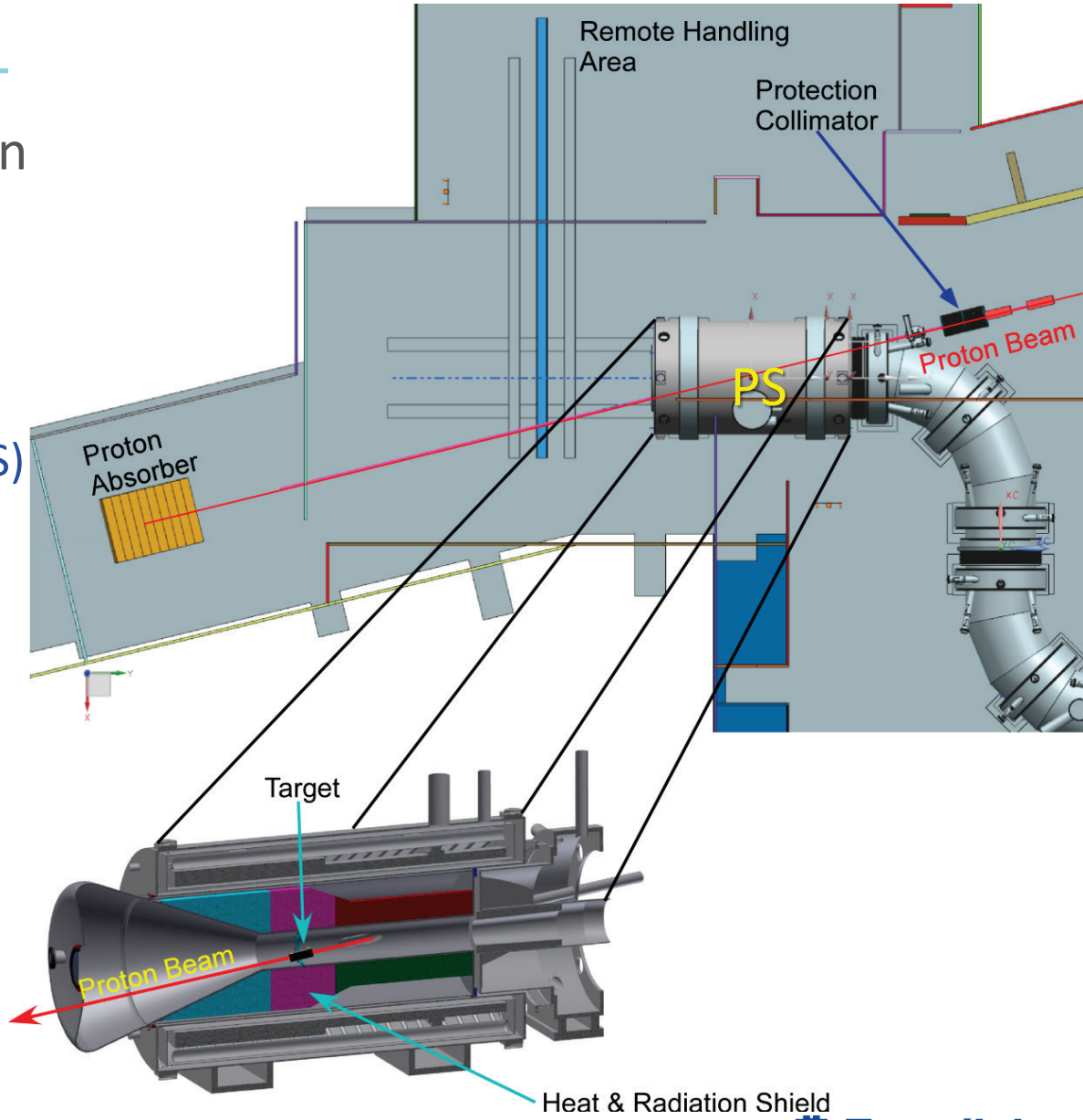
Mu2e Proton Target

- Basis of Estimate
  - Engineering estimates based on implementation of similar technology in other Fermilab beamlines, vendor quotes, and engineering experience.

Target Station Layout

There are five target station components:

- Target
- Target Remote Handling
- Heat & Radiation Shield (HRS)
- Proton Beam Absorber
- Protection Collimator



Risks

- ACCEL- 015: Injection damper required for Delivery Ring
  - Orbit control may not adequately control beam trajectory and lead to excessive emittance dilution.
  - Risk Impact: $185k – cost to design and implement an injection damper in the Delivery Ring
  - Probability: Low
  - Mitigation: Injection studies during commissioning of Muon Campus beam prior to g-2 running
- ACCEL-020: Cannot use TLMs (Total Loss Monitors) to control beam losses
  - TLMs not approved for use in a Fermilab radiation safety system
  - Risk Impact: $2,000k – Cost to fabricate approved monitoring system (chipmunks)
  - Probability: Very Low
  - Mitigation: TLMs have preliminary approval. TLMs are being installed in existing beamlines to be used alongside existing radiation safety systems. It is very likely that TLM use will be routine by the time they are needed for Mu2e.

Risks (Continued)

- ACCEL-033: Inability to stage magnets from the Accumulator enclosure during g-2 operation
  - Insufficient resources or funding to move external beamline magnets into the beamline enclosure prior to g-2 beam operations
  - Risk Impact: $400k – alternative transport costs (cranes, access hatches)
  - Probability: Risk has been realized
- ACCEL-038: Radiated Production Target will not survive design beam power
  - Calculations and prototyping demonstrate that radiative cooling will not be adequate for the production target.
  - Risk Impact: $175k – cost for forced cooled target R&D and testing
  - Probability: Low
  - Mitigation: Target prototype materials testing, oxidation resistant coatings, better PS vacuum
- ACCEL- 151: Redesign the Remote Handling System for forced target cooling
  - Radiatively cooled target does not work in Mu2e environment, so cooling is required.
  - Risk Impact: $3,300k – Remote handling R&D and differential fabrication cost
  - Probability: Low
  - Mitigation: Target materials R&D at Rutherford Appleton Labs (see ACCEL-038)

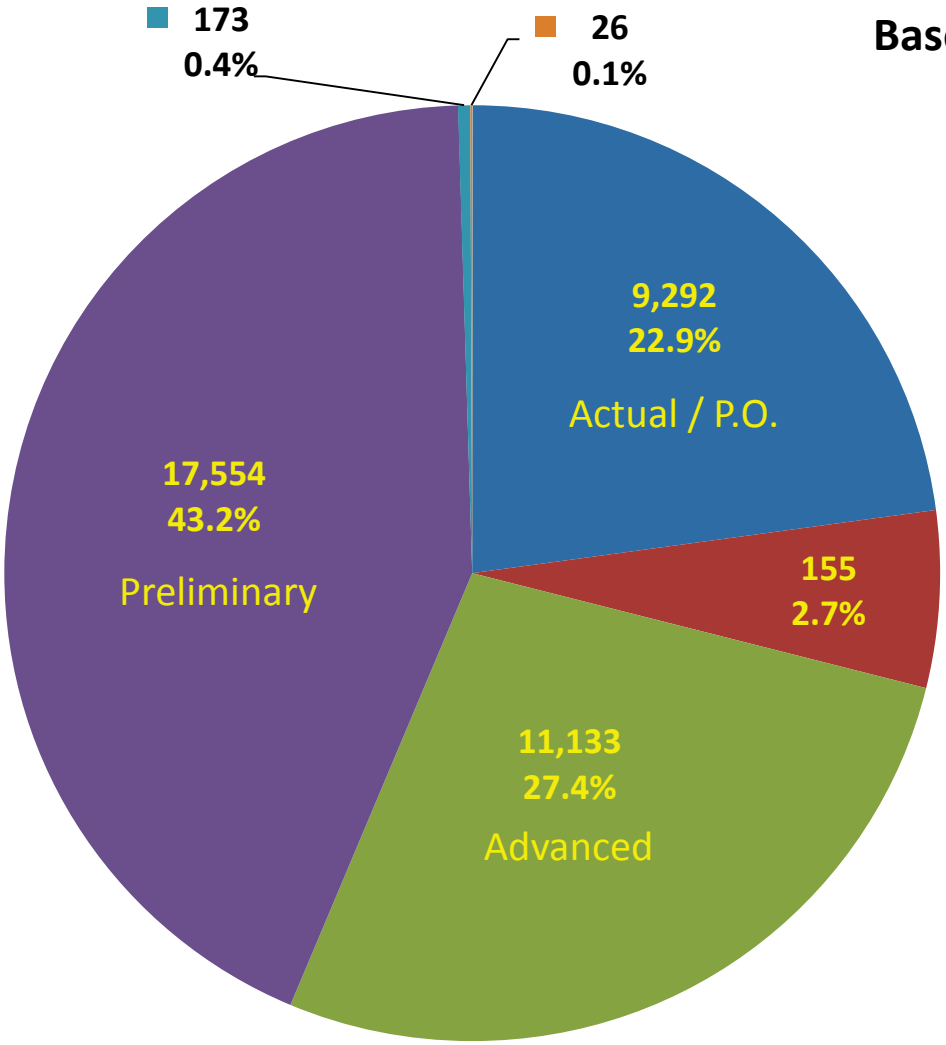
Cost

475.02 Accelerator

Costs are fully burdened in AY $k

	M & S	Labor	Base Cost	Estimate Uncertainty	% Contingency on ETC	Total
475.02.01 Accelerator Project Management	74	3,395	3,469	344	14%	3,813
475.02.03 Instrumentation and Controls	775	1,633	2,407	527	26%	2,934
475.02.04 Radiation Safety Improvements	992	1,029	2,021	489	28%	2,510
475.02.05 Resonant Extraction System	1,628	3,853	5,480	1,626	34%	7,107
475.02.06 Delivery Ring RF System	775	1,825	2,600	541	23%	3,141
475.02.07 External Beamline	2,839	3,064	5,903	1,478	28%	7,381
475.02.08 Extinction Systems	1,473	1,707	3,179	780	30%	3,959
475.02.09 Target Station	5,922	4,629	10,551	2,768	30%	13,319
475.02.10 Accelerator Conceptual Design/R&D	660	4,386	5,045			5,045
475.02.99 Risk Based Contingency				982		982
Total	**15,136**	**25,521**	**40,657**	**9,534**	**31%**	**50,192**

Quality of Estimate



Base Cost by Estimate Type (AY $k)

- L1 Actual / M1 Existing P.O.
- L2 LOE/M2 Procurements for LOE&Oversight Work
- L3/M3 Advanced
- L4/M4 Preliminary
- L5/M5 Conceptual
- L6/M6 Pre-Conceptual

99.5 % of Cost Estimates are at the Preliminary Design Level or Better

Summary

- Estimates for Accelerator Upgrades are complete
  - 99.5% of cost understood at the Preliminary Design level or higher
- Estimates include lessons learned from recently completed NOvA accelerator upgrades
- Risks understood, mitigated where possible. Cost set aside as contingency to cover residual risks.
- Estimates are traceable
  - Comprehensive set of BOEs and backup information developed