Mu2e CD-2 Director's Review
Accelerator Radiation Safety
475.02.04

A. Leveling

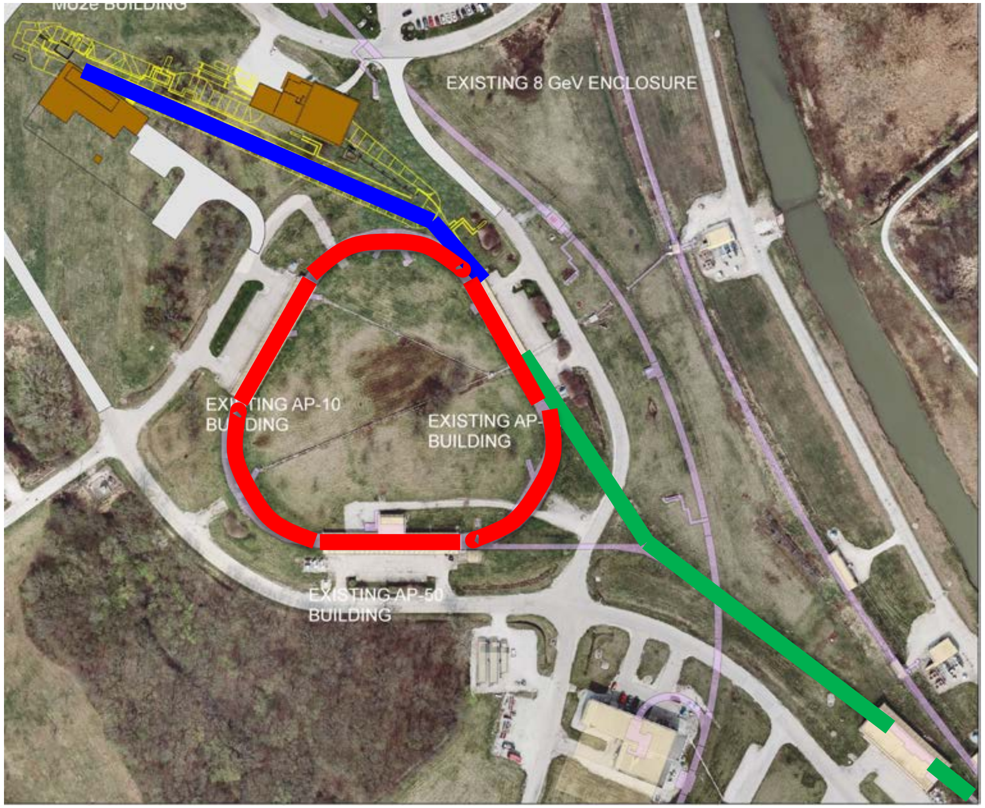
L3 Manager, Accelerator Radiation Safety Improvements

7/8/2014

WBS 475.02.04   Radiation Safety Improvements

Scope includes:

- Beam enclosure interlocks
  - Radiation Safety Systems
  - Electrical Safety Systems
- ODH for the Solenoid Rooms
- Muon Campus Total Loss Monitor systems
  - AP1 line to Delivery Ring
  - Delivery Ring
  - M4 beam line
- In Tunnel shielding
  - Delivery Ring at AP30 extraction
  - Temporary shield wall at the M4/M5 intersection
  - M4 line shield wall at Diagnostic Absorber
- Other
  - Friskers, wallflowers, air monitors



Requirements

- Fermilab Radiological Controls Manual (FRCM)
  - Key requirements:
    - Prompt radiation dose rate outside beam enclosure shields
      - Includes radiation skyshine
    - Residual activation in the beam enclosures
      - Most notable are AP30 extraction and PS Room
    - Entry Controls
      - AP service buildings not accessible during operations
    - Radiological Postings
      - Muon campus beam lines will required Controlled Area posting
    - Air activation
    - Surface water activation
    - Groundwater activation
    - Preliminary shielding assessments
      - Required before going out for construction bids
    - Exemption Request to allow use of interlocked radiation detectors in lieu of passive shielding
- The Radiation Safety Plan has to accomodate 8 kW operation

Design Assumptions

- Antiproton Source Facilities designed for 13 watts, 8 GeV
- Repurposed facilities now to operate at 8 kW, 8 GeV
- Available passive shielding is insufficient to meet requirements of FRCM
- Design basis:
  - the distribution of beam power lost
  - not the beam power delivered
  - this point will be illustrated

- The design must simultaneously meet all requirements for the FRCM, i.e.,
    - accommodate normal beam loss
    - Limit the severity of single-pulse, beam loss within the time-weighted average FRCM dose limits
    - Not require inordinate beam operation interruption to recover from interlocked radiation detector trips
      - Implies a critical level of shielding is required for all areas

Design Assumptions

- Known loss points
  - AP30 extraction region
  - Delivery Ring cleanup abort
  - Extinction Collimators
  - Diagnostic Absorber
  - Mu2e Production Solenoid
  - Mu2e Main Beam Absorber

- Other potential loss points
  - Delivery Ring Injection
  - Delivery Ring Cleanup/Abort line
  - Delivery Ring distributed losses due to beam scattering at extraction region

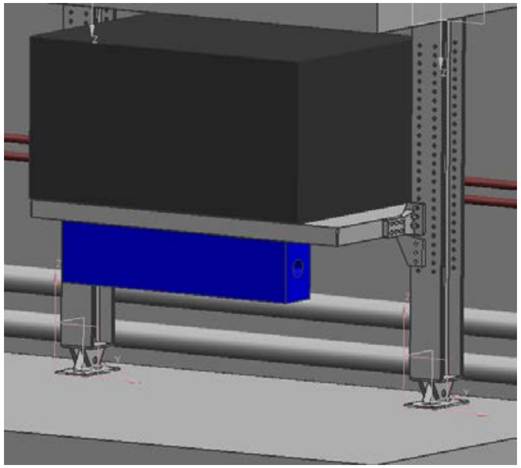
- The design assumes:
  - beam loss at known loss points
  - no significant losses at other potential loss points

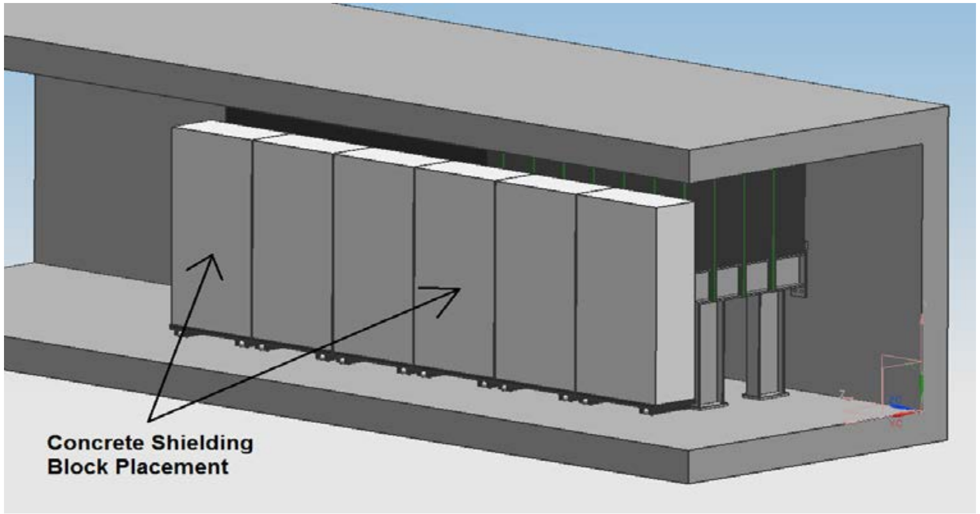
Design Activities

- An in-tunnel shield design has been produced to shield the AP30 extraction region
  - Can be adapted to other locations if found to be required
- A new radiation beam loss detector has been developed and characterized
  - Total Loss Monitor System
    - Provides continuous coverage of beam loss through areas of common shield thickness
    - Conservatively limits total beam loss based upon trip levels established for single point beam loss
    - Serves as active protection in the capacity of a credited safety system
      - Preliminary approval has been given by the ESH&Q Section
    - Prototype electrometer design is developed & deployed
- MARS simulations for TLM detector have been produced to predict response
- MARS simulations have been made to study some shield/TLM design combinations for beam loss conditions

In-tunnel shielding at AP30 extraction region

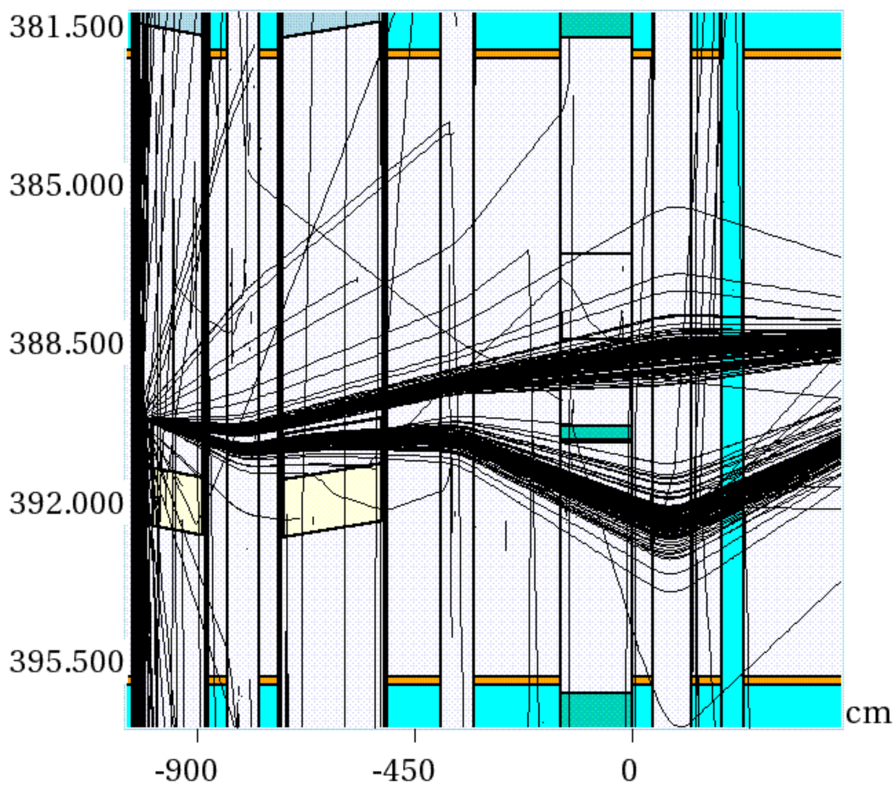
- The design for in-tunnel shielding has been created
  - Modular
  - Requires unobstructed clearance above the loss points
  - Cable trays, especially at AP30, have to be re-routed
    - This is already underway
  - Shield design has been incorporated into the resonant extraction line MARS simulation
  - Aisle shield is included to limit worker radiation exposure (ALARA)

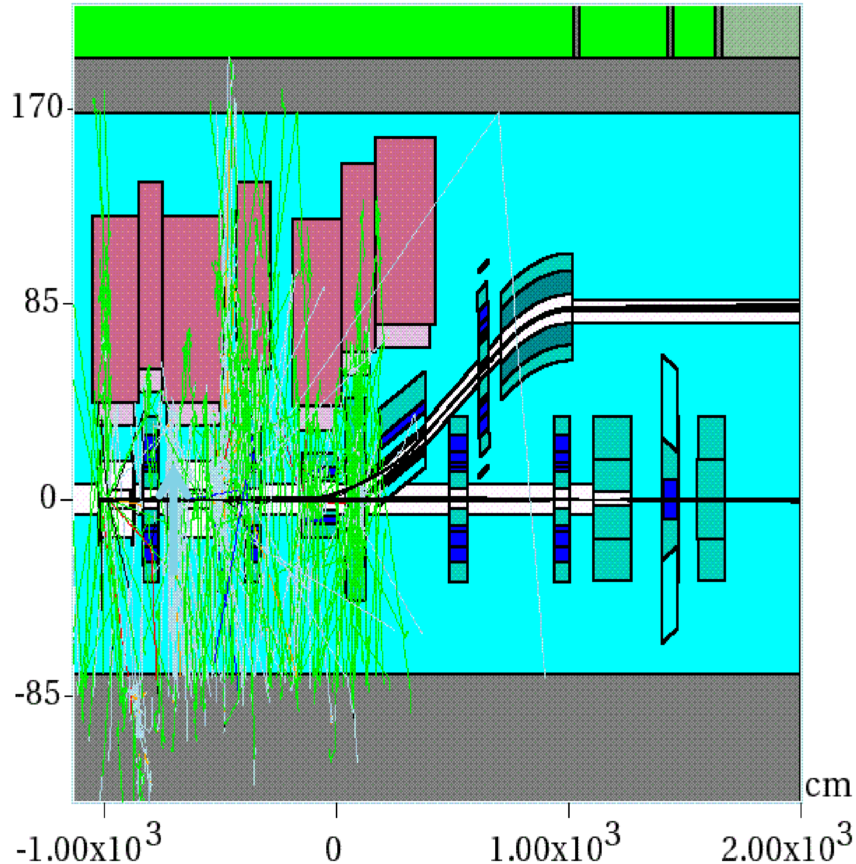




MARS simulation is used to predict beam loss and prompt radiation effective dose with in-tunnel shielding

Inside to outside extraction



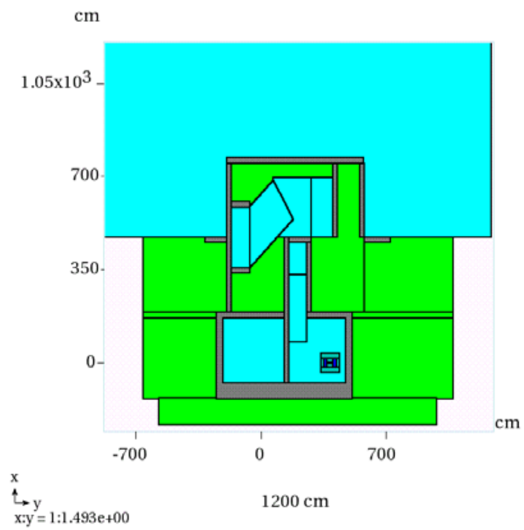


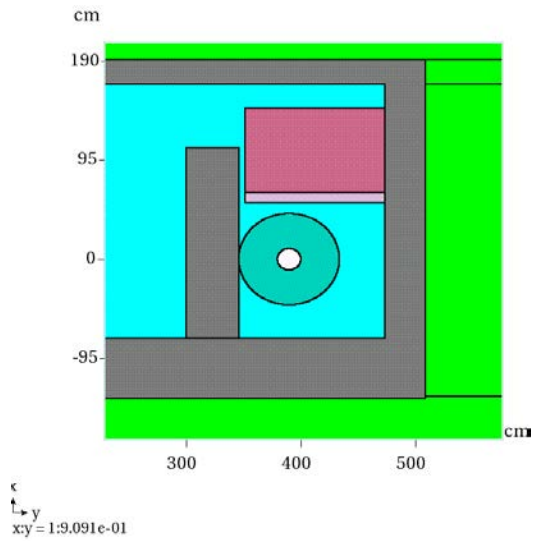
Plan view
Proton beam through the Electrostatic septa, quads, Lambertson, and cmagnet

Elevation view
Full extraction system model with in-tunnel shielding

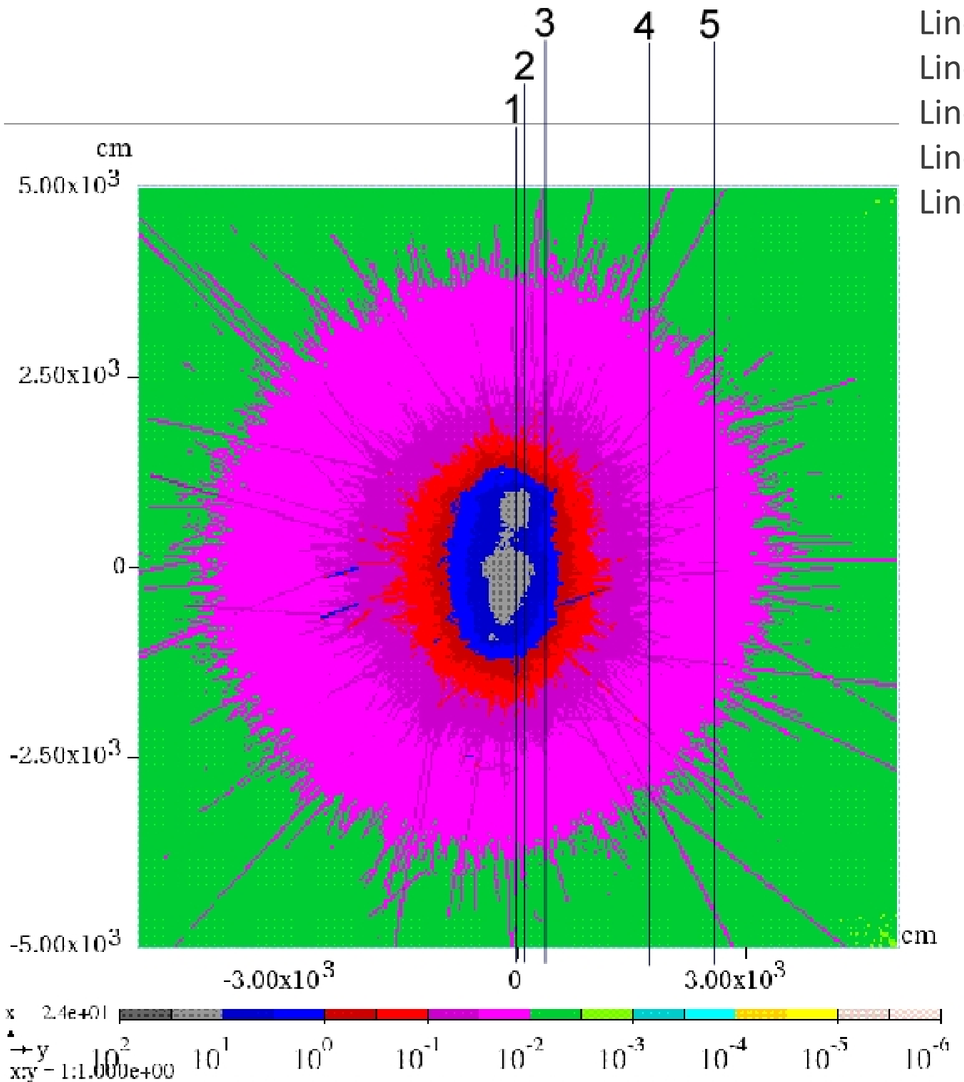
Extraction system model detail

- A detailed model of the aisle shield and the exit stairway near the extraction region is included in the MARS simulation





MARS simulation results for AP30 service building region



Line 1: Delivery Ring centerline
Line 2: Tunnel outer concrete edge
Line 3: Edge of service building
Line 3/4: Parking Lot 0.05 to 2 mrem/hr
Line 5: Edge of Indian Road <0.05 mrem/hr

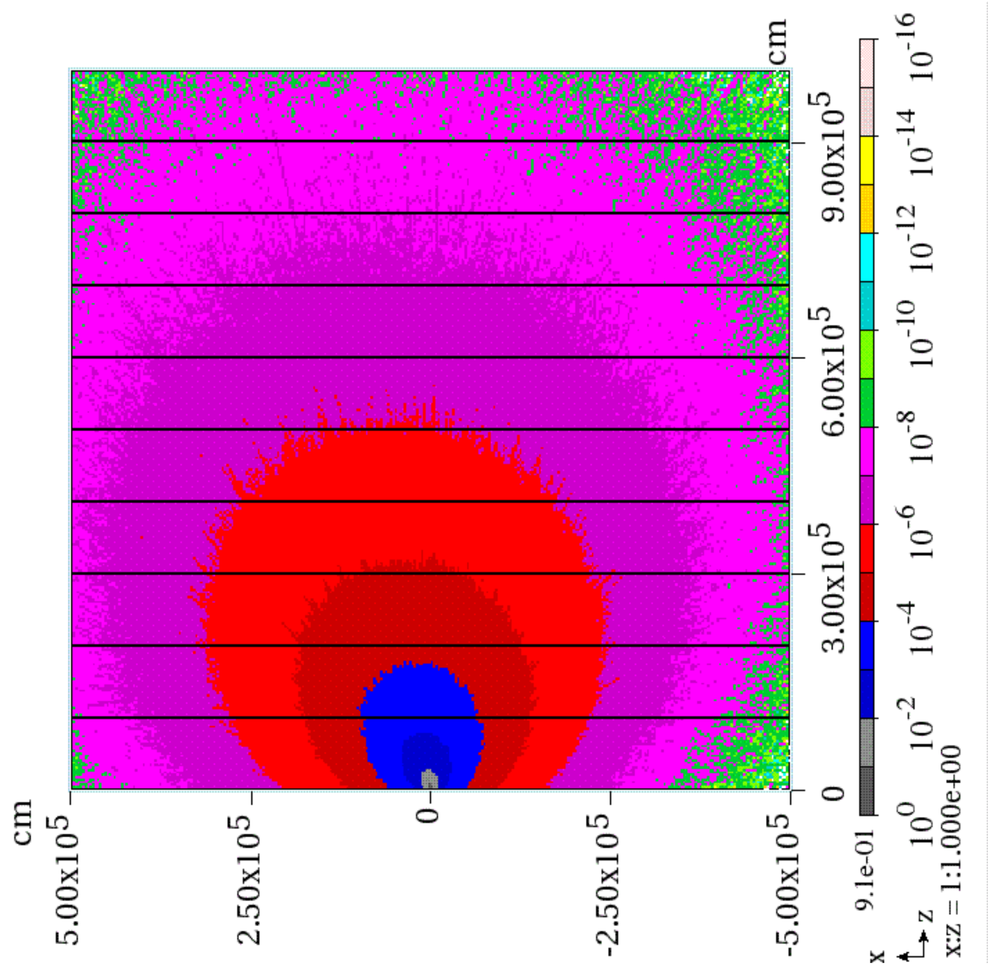
Normal losses at extraction region running at 8 kW

Includes direct and skyshine contributions
Units are mrem/hr

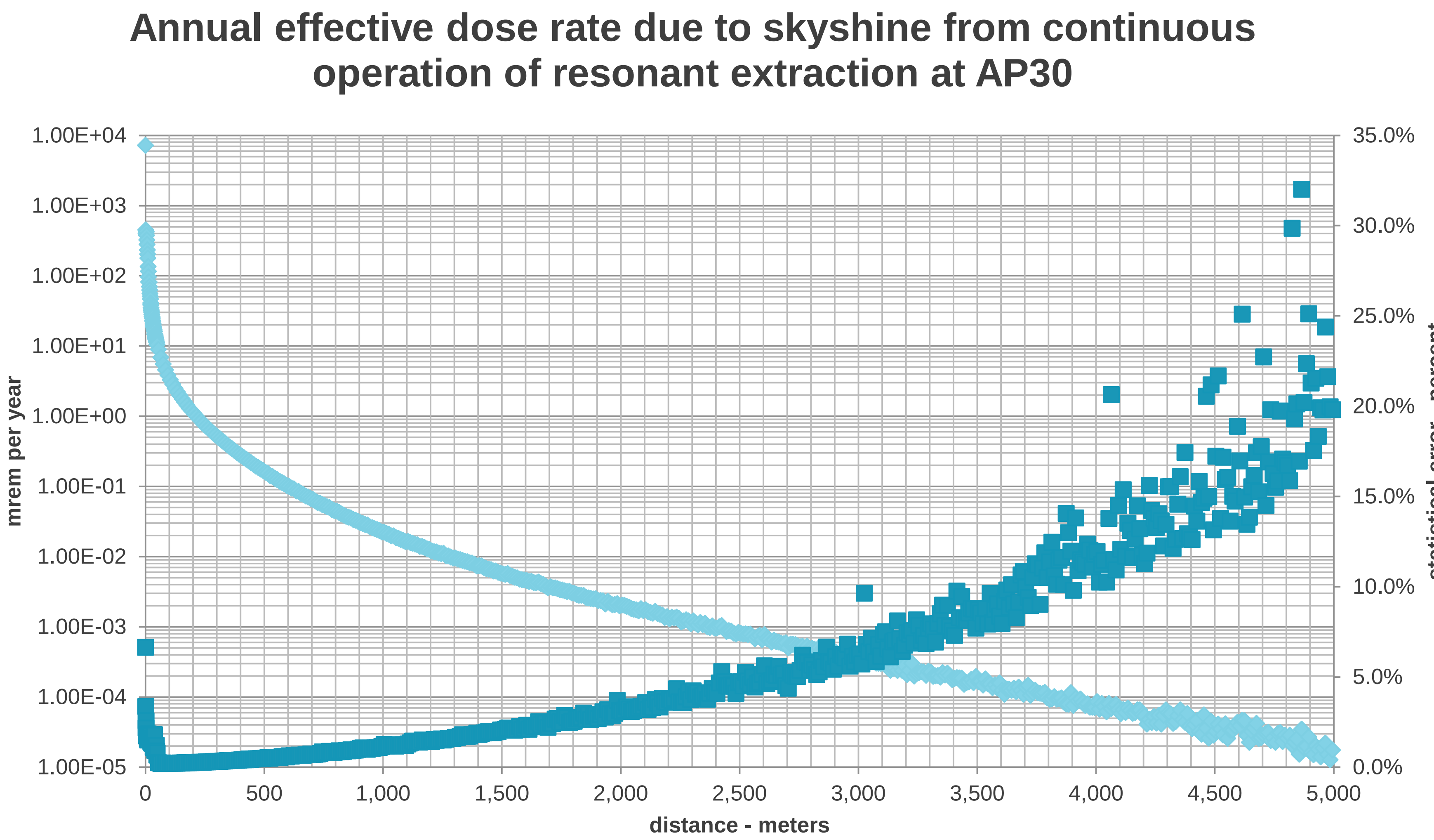
MARS simulation result for radiation skyshine – mrem/hr

Radiation skyshine has been calculated using the model for slow resonant extraction at AP30.

This model has a radius of 5 km and a height of 10 km.

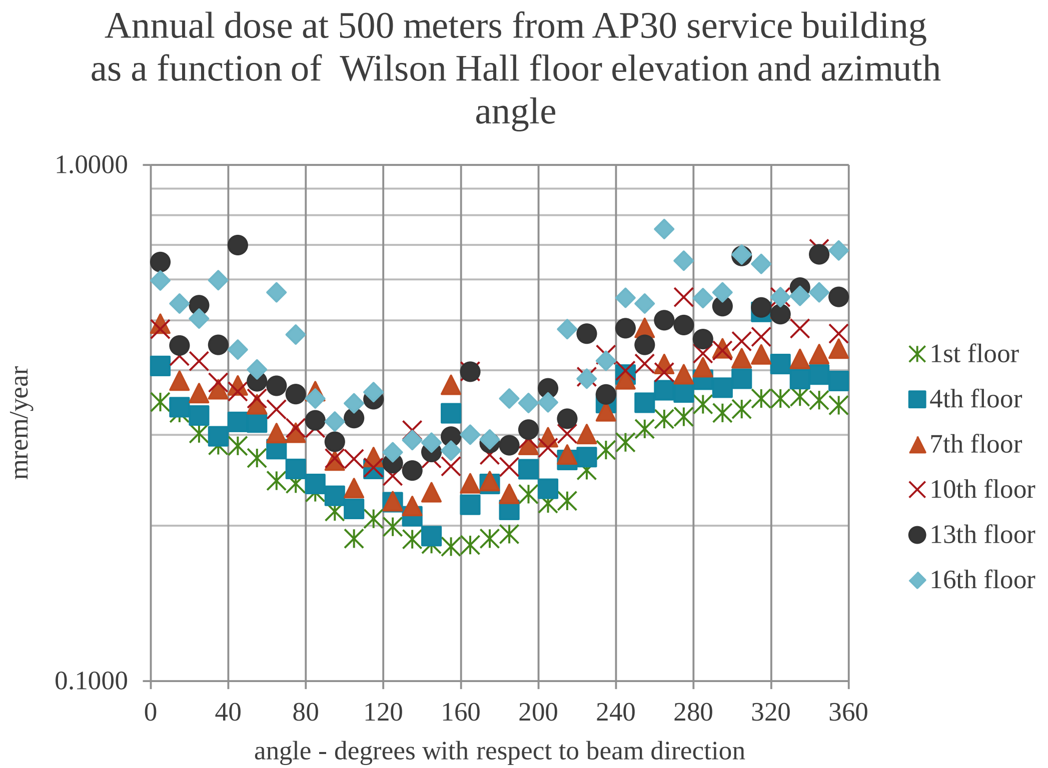


MARS simulation result for radiation skyshine

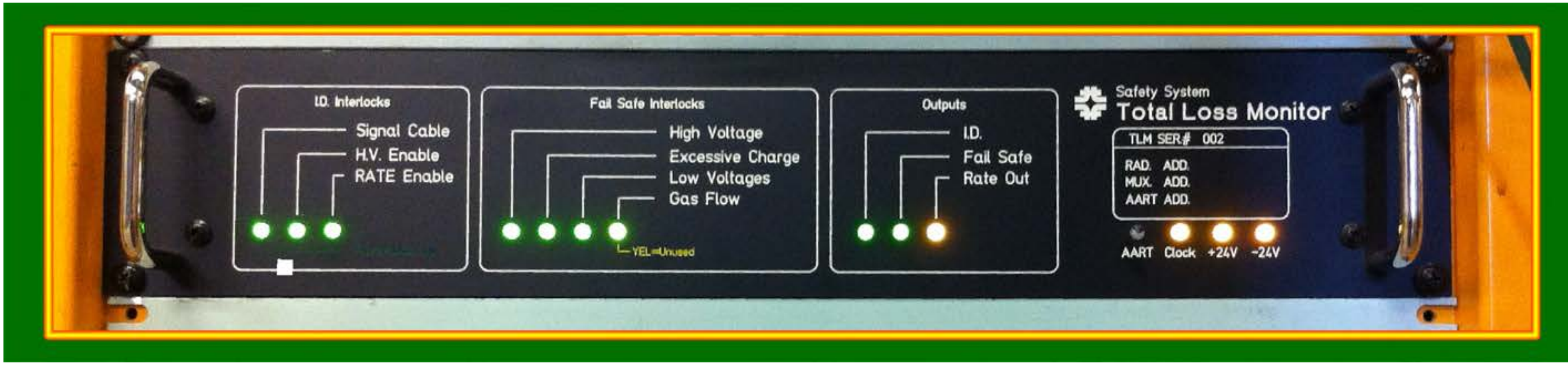


MARS simulation result for radiation skyshine

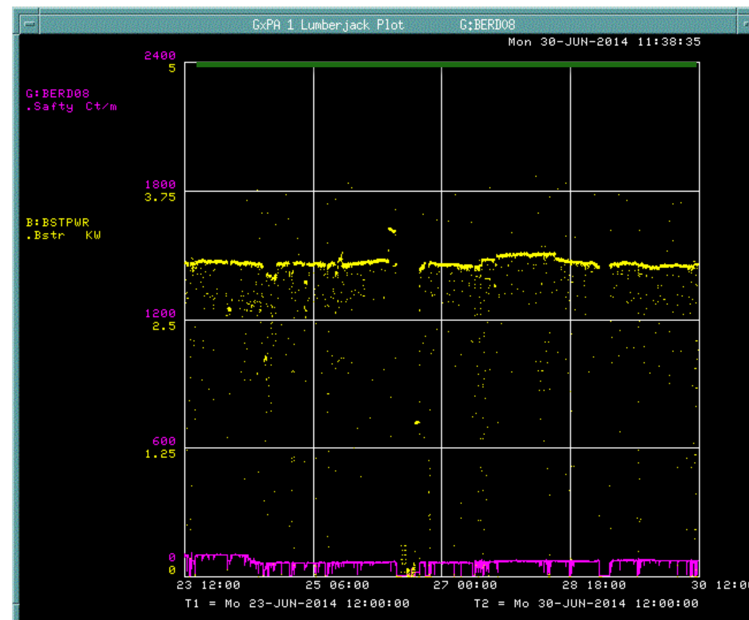
- In addition, the annual effective dose rate at Wilson Hall as a function of floor has been calculated based on the extraction system model. Radiation dose rates are acceptable



Prototype TLM at Booster – covers P10-12

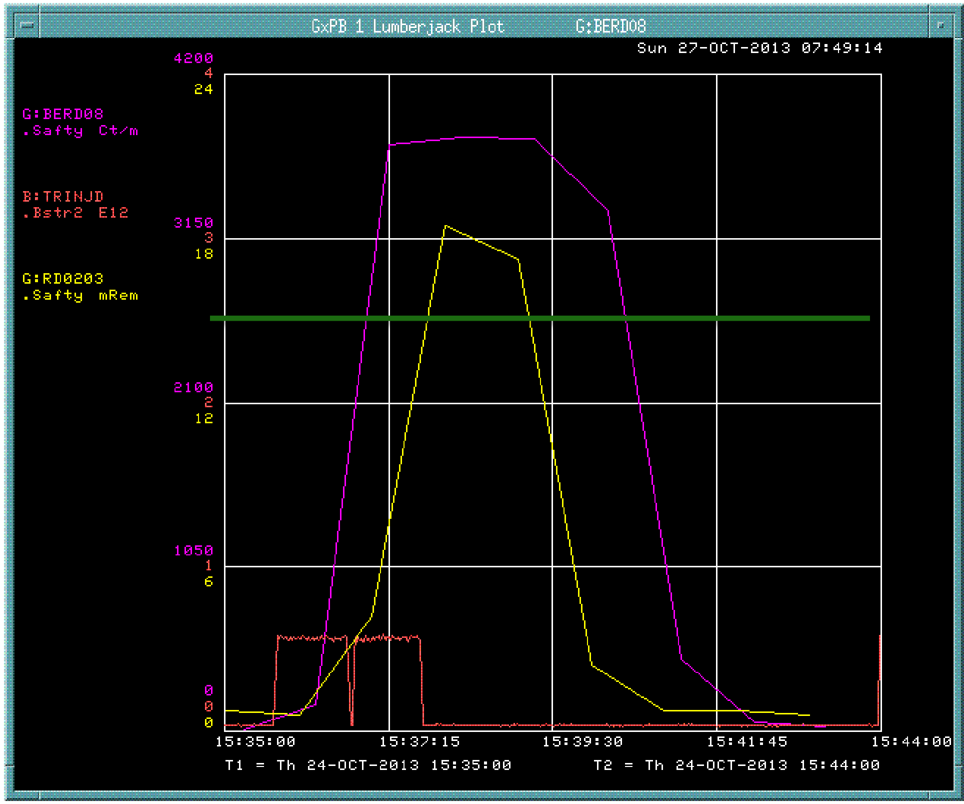


- TLM electrometer chassis deployed at Booster
- TLM response (magenta) and Booster Power (yellow) – nominal operation
- Full scale (green line) would be the Booster trip level



Booster 6 to 8 GeV beam loss study and TLM response

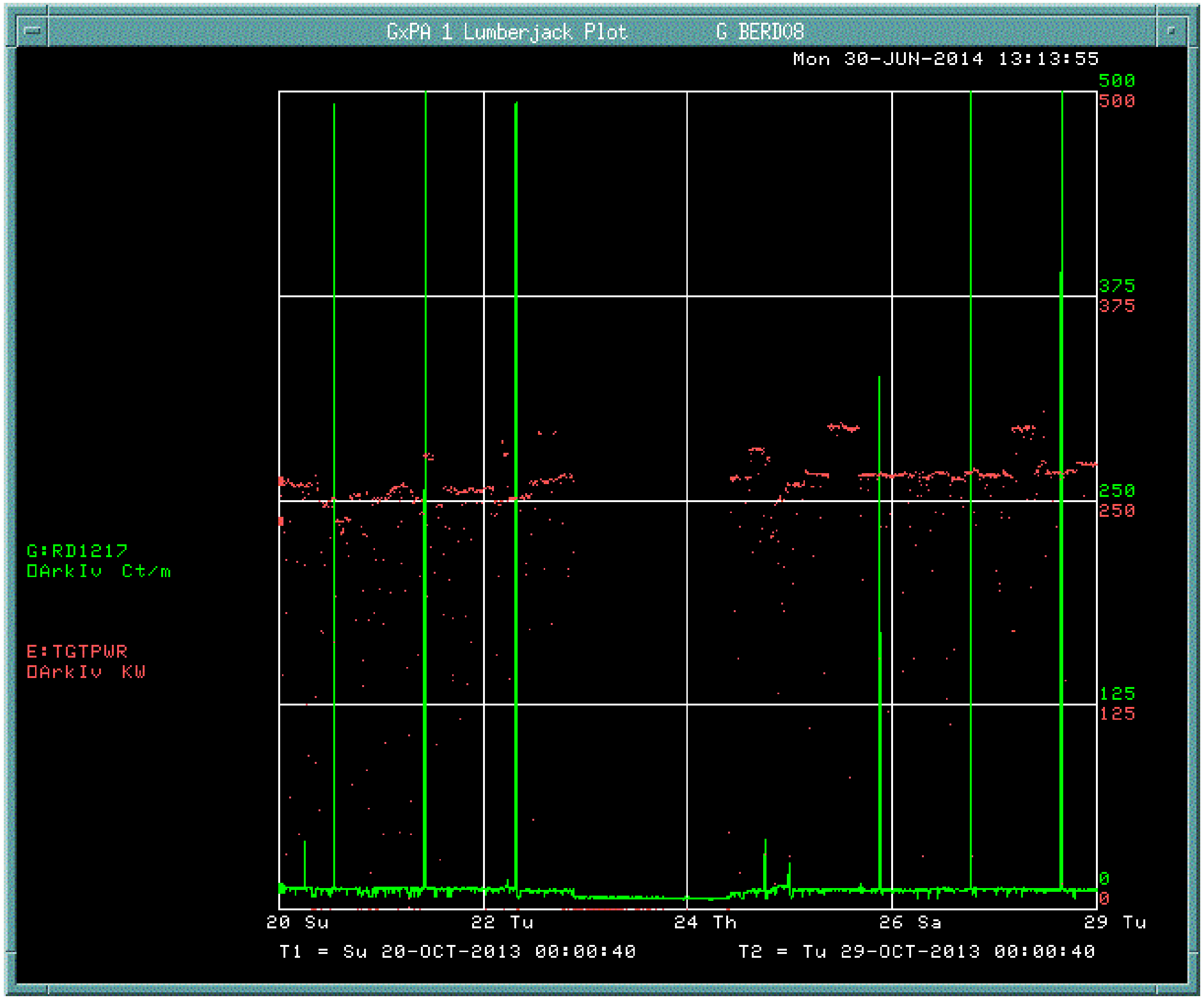
- Booster accident condition, ramping radial position late in the acceleration cycle
  - 6 to 8 GeV
    - TLM response (magenta)
    - Booster beam intensity (red)
    - chipmunk response (yellow)
    - TLM trip level (green)



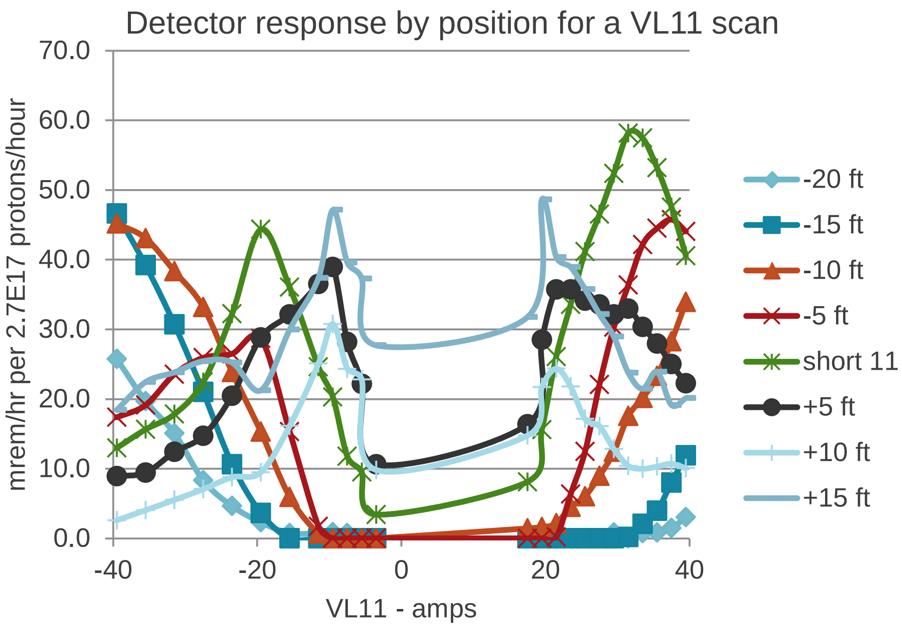
- The TLM trip would occur in seconds rather than in minutes as would occur with the existing protection scheme
- NOTE!!! – Booster operation would not be curtailed by unnecessary safety system trips but is turned off promptly in the event of severe accident condition

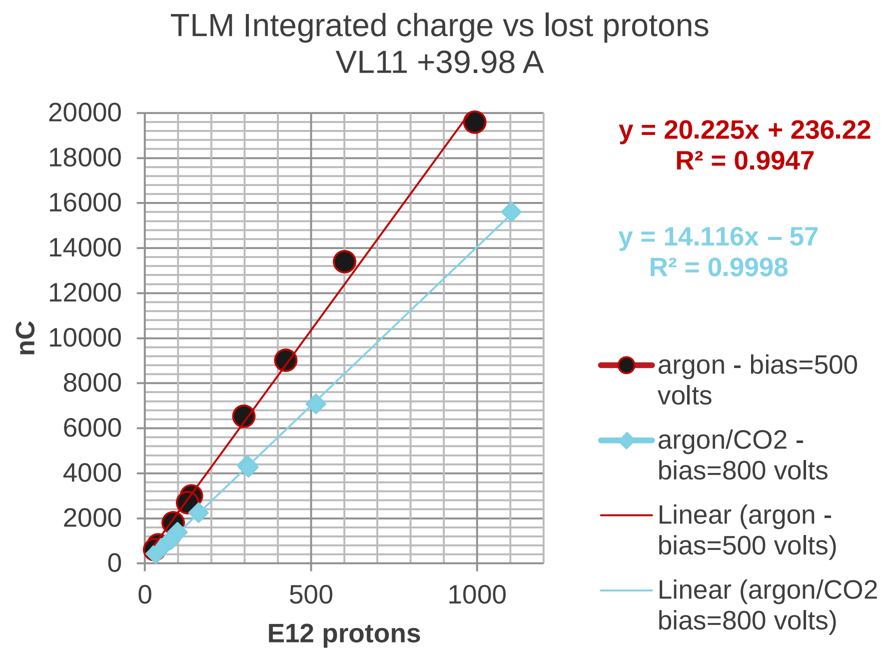
Beam power/beam loss illustration & TLM Response

- 800 foot TLM installed (green trace) at NuMI
- 250 kW beam transmission (red trace) & minimal losses
- Losses are quite insignificant except when wire chambers are inserted for tuning



Booster 400 MeV beam loss study and TLM response



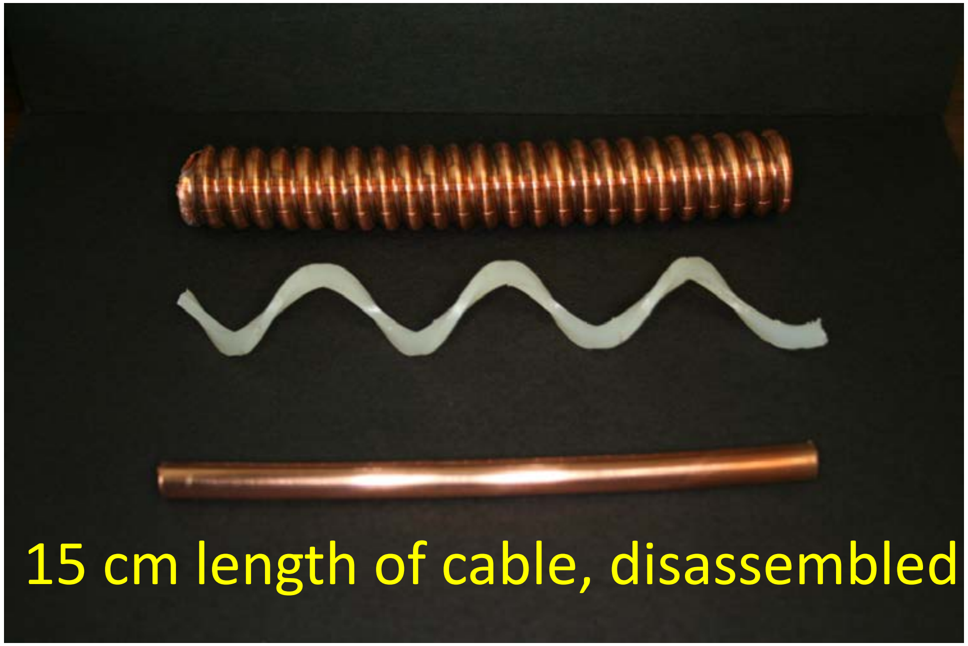


Response for 8 chipmunks spaced 5' apart for various trim magnet currents

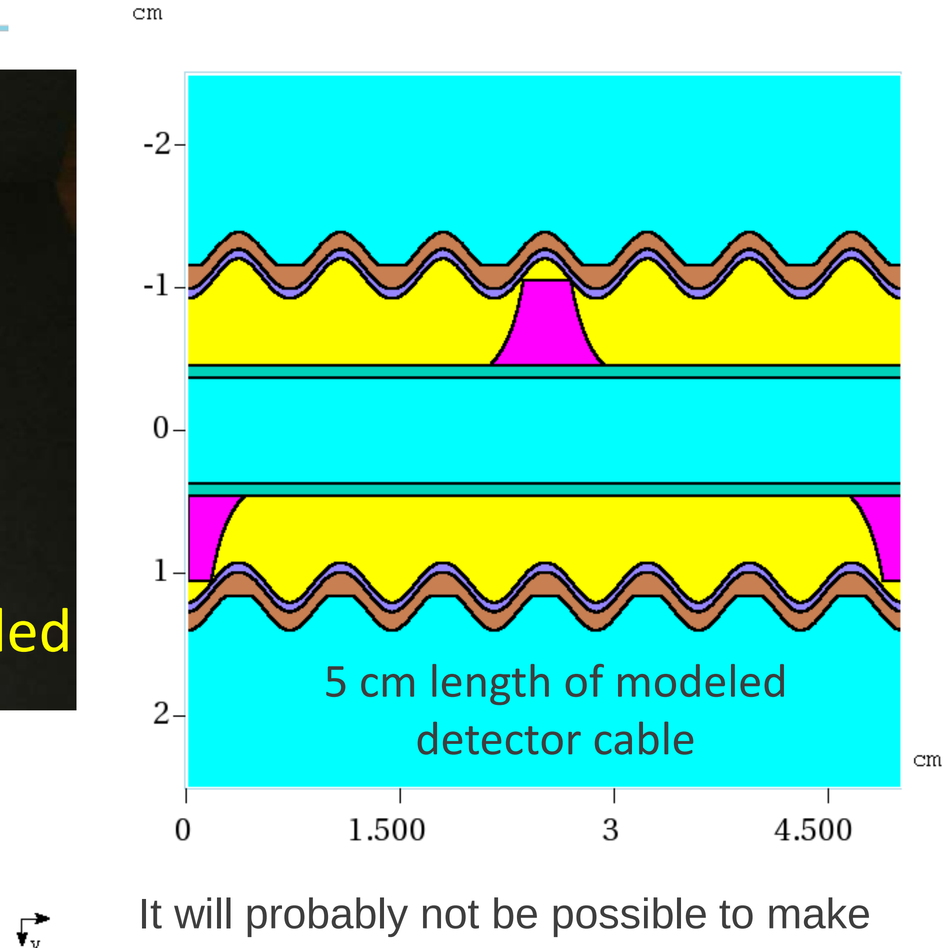
TLM response is demonstrated to be linear over several decades of intensity

The marriage of these data sets is the basis for establishing trip levels

TLM detector cable



MARS model of detector cable components has been produced; MARS simulations have been compared with experimental data



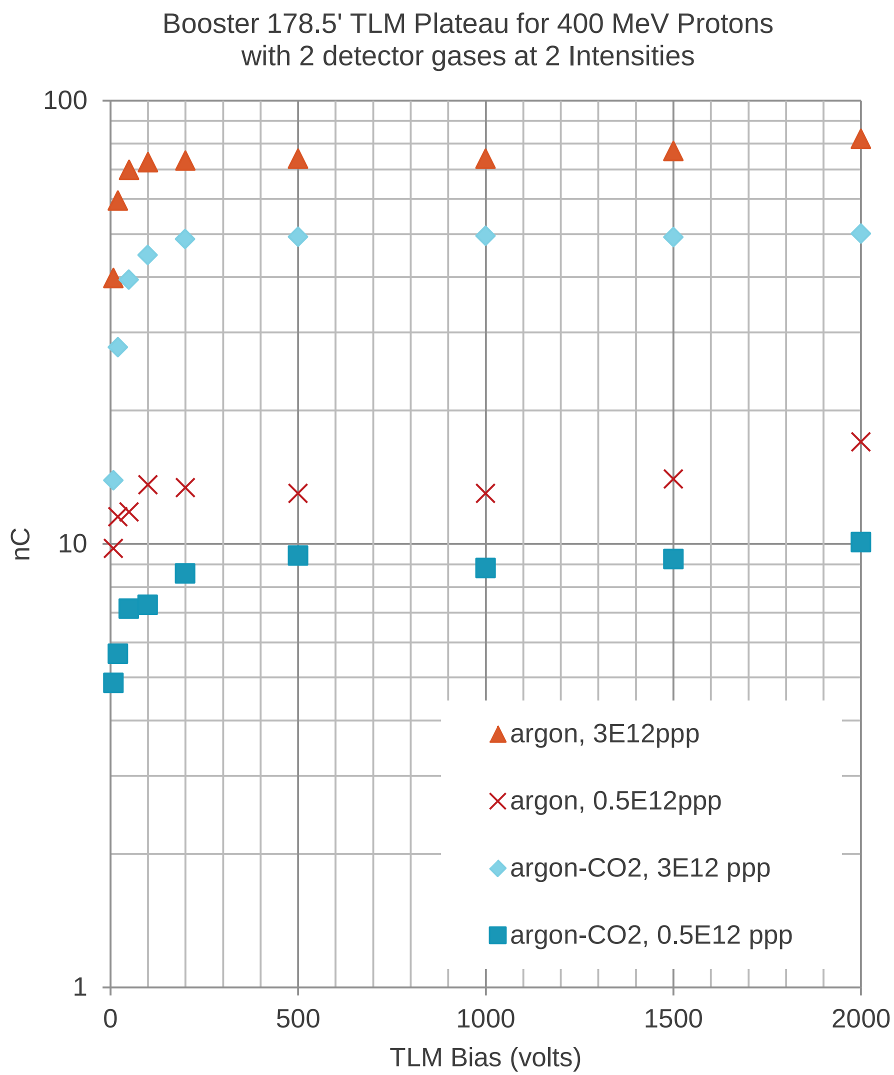
It will probably not be possible to make measurements for every TLM detector installation; consequently, it is important to have a method to predict TLM response

Changes since CD-1

- Developed detailed MARS models for
  - Slow resonant extraction system
  - In-tunnel shielding
  - Skyshine
  - TLM detector cable
- Developed a remote method to monitor TLM detector gas flow at 10 cc/minute with commercially available detector
- Added scope - external beam line shielding walls
  - M4/M5
  - M4 line DS of diagnostic absorber
- Developed TLM electrometer & heartbeat

Value Engineering since CD-1

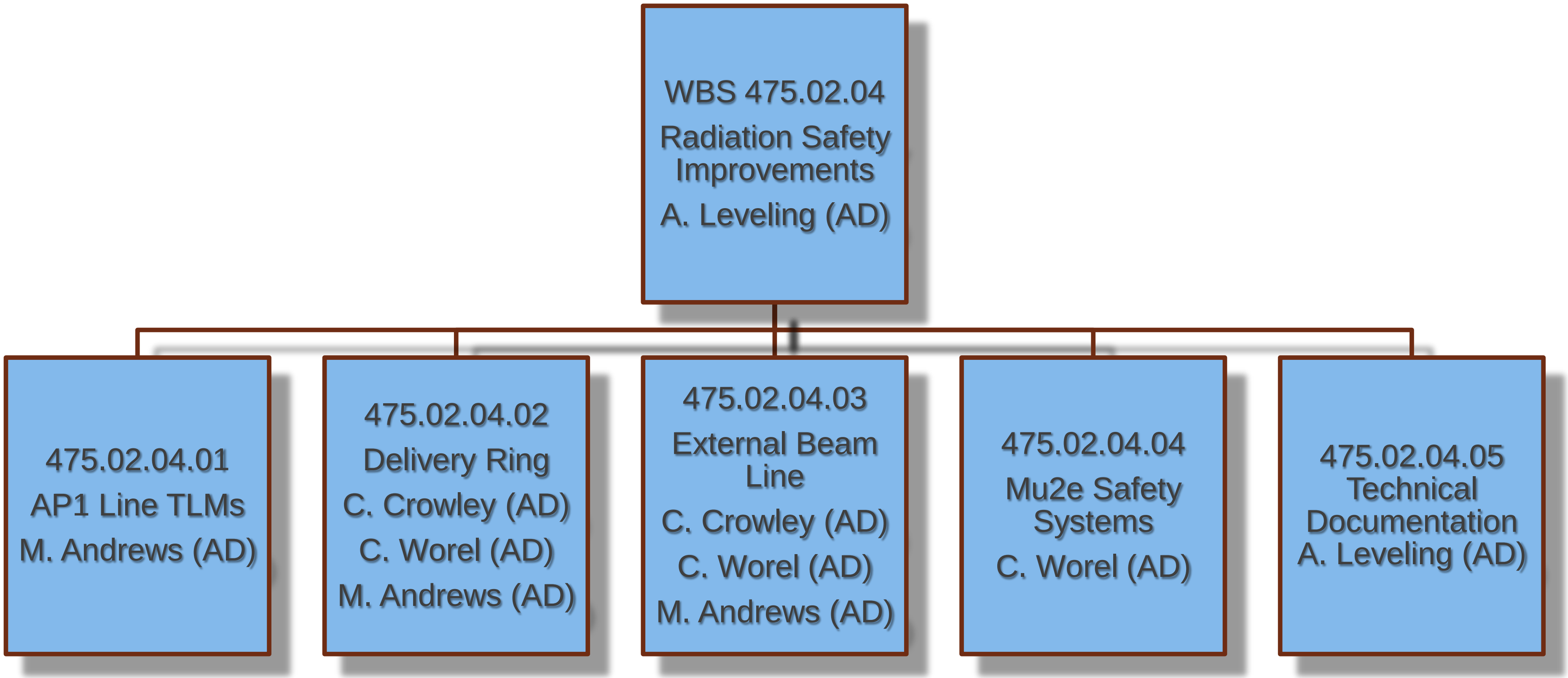
- Changed TLM detector gas from argon to argon/CO_2
  - Lower sensitivity
  - flatter response
  - Lower detector gas cost
  - Increases the dynamic range of the TLM system



TLM review status

- TLM testing continues following preliminary approval
  - Entire Booster will be outfitted with detector systems
  - 1/8 of the Booster will have a parallel redundant TLM system
  - Existing credited safety system inputs (chipmunks) will run in parallel with the new TLM system
  - A testing period of 1 year has been suggested
  - Upon completion of the test period and associated documentation, we will seek final approval from ESH&Q Section
  - Additional MARS simulations, measurements, and inter-comparisons are planned
    - MI-52
    - MI-30
    - NuMI
    - ASTA

Organizational Breakdown



Quality Assurance

- ***In-tunnel shielding***
- AD mechanical engineer created structural design
- Design is documented in an engineering note
- Design is subject to two reviews:
  - Facility Engineering Services Section reviewed the design for compatibility with tunnel enclosure structures
  - AD Mechanical Review committee
- Installation oversight is by AD Mechanical Support Department engineers
-
- ***Radiation and Electrical Safety Systems***
- Proven design in use for decades at the Laboratory
- The RSS and ESS designs are subject to review and approval by the ESH&Q Section
- RSS and ESS undergo thorough testing every 6 months

Quality Assurance

- ***TLM system design***
- System design is subject to review and approval by the ESH&Q section.
- TLM system installation is under the purview of the AD ES&H Department Interlocks Group.
- Initial testing of the detector and electrometer installation is by AD ES&H Department Interlocks Group
- The TLM system will be subject to periodic calibration and testing by AD ES&H Department Interlocks Group
- Specific applications of TLM systems are subject to review by the Laboratory's Shielding Review Committee (SRC) in conjunction with the shielding review process
- Final approval is by the ESH&Q Section Head

Risks – Radiation Safety Improvements

Risk ID	Risk Form	Risk	Impact	Probability	Action
ACCEL-020[1]	3333	TLMs cannot be used to limit the intensity and duration of beam loss	Technical, Schedule	L	Retired
ACCEL-017[2]	3332	Radiation levels outside of the mu2e facility are too high	Schedule	L	Transferred to operations
ACCEL-152[3]	3838	Need to install additional Delivery Ring tunnel shielding (list B)	Technical	M	Transferred to operations
ACCEL-150[3]	3839	Need to install additional DR tunnel shielding (list C)	Cost	L	Transferred to operations

NOTES:

1. Preliminary Approval has been received for TLMs.
2. Improved MARS simulation with extraction device details indicate losses will be low enough. We will need to tune up machines to reduce losses to acceptable levels and believe this will be possible.
3. Based upon observation of losses at other machines, we believe it is possible to run with very low losses, e.g., NuMI, Booster. We will need to tune up machines to reduce losses to acceptable levels and believe this will be possible.

ES&H

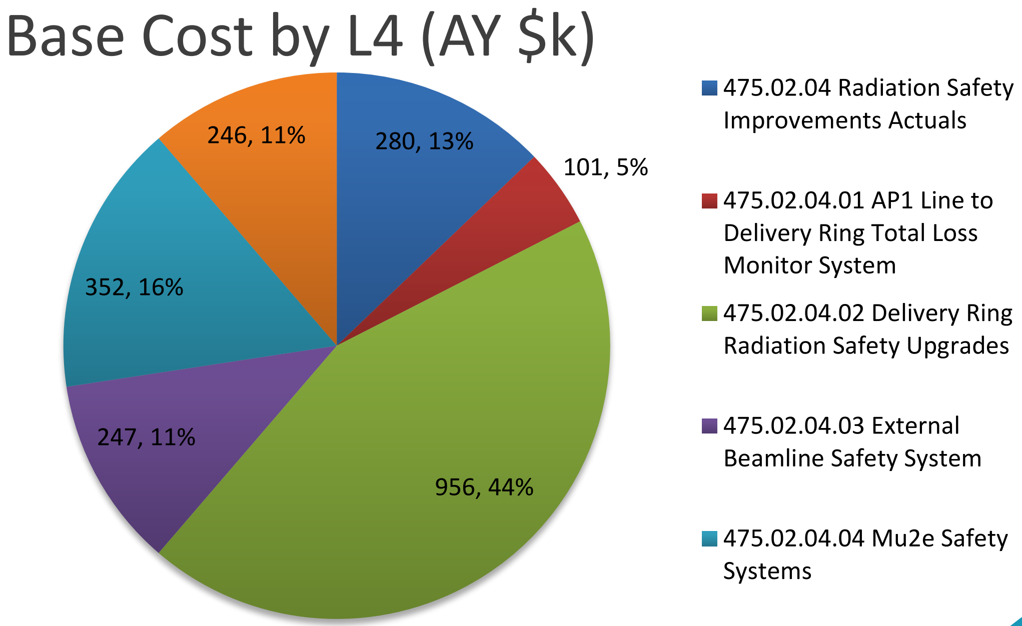
- Air activation
  - No unusual issues
- Surface water activation
  - No unusual issues
- Groundwater activation
  - No unusual issues
- Residual radiation
  - ALARA planning
    - Extraction Region Maintenance
    - Target change out

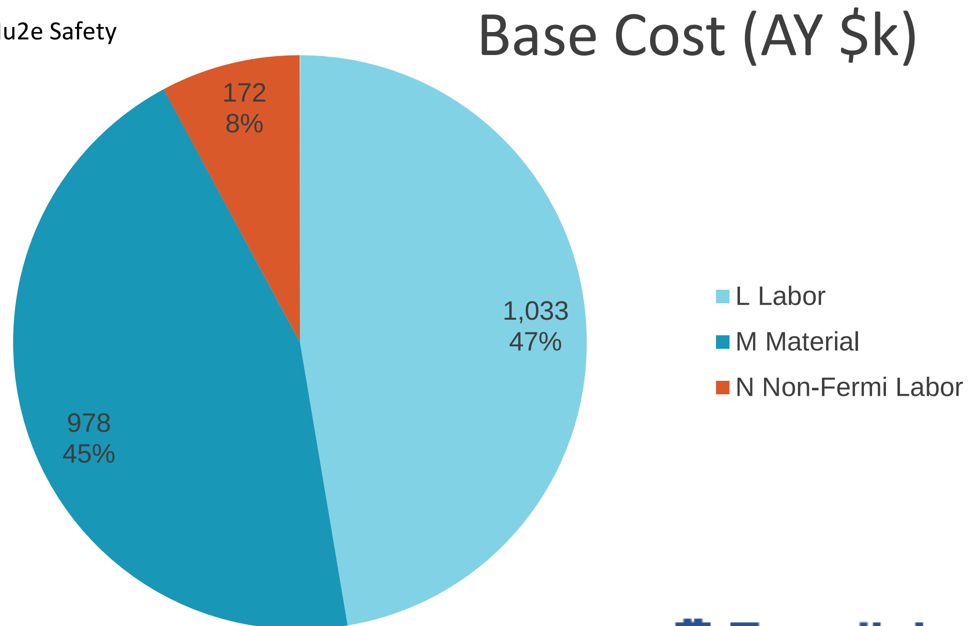
Cost Table

WBS 2.4 Accelerator Radiation Safety Improvements Costs are fully burdened in AY $k

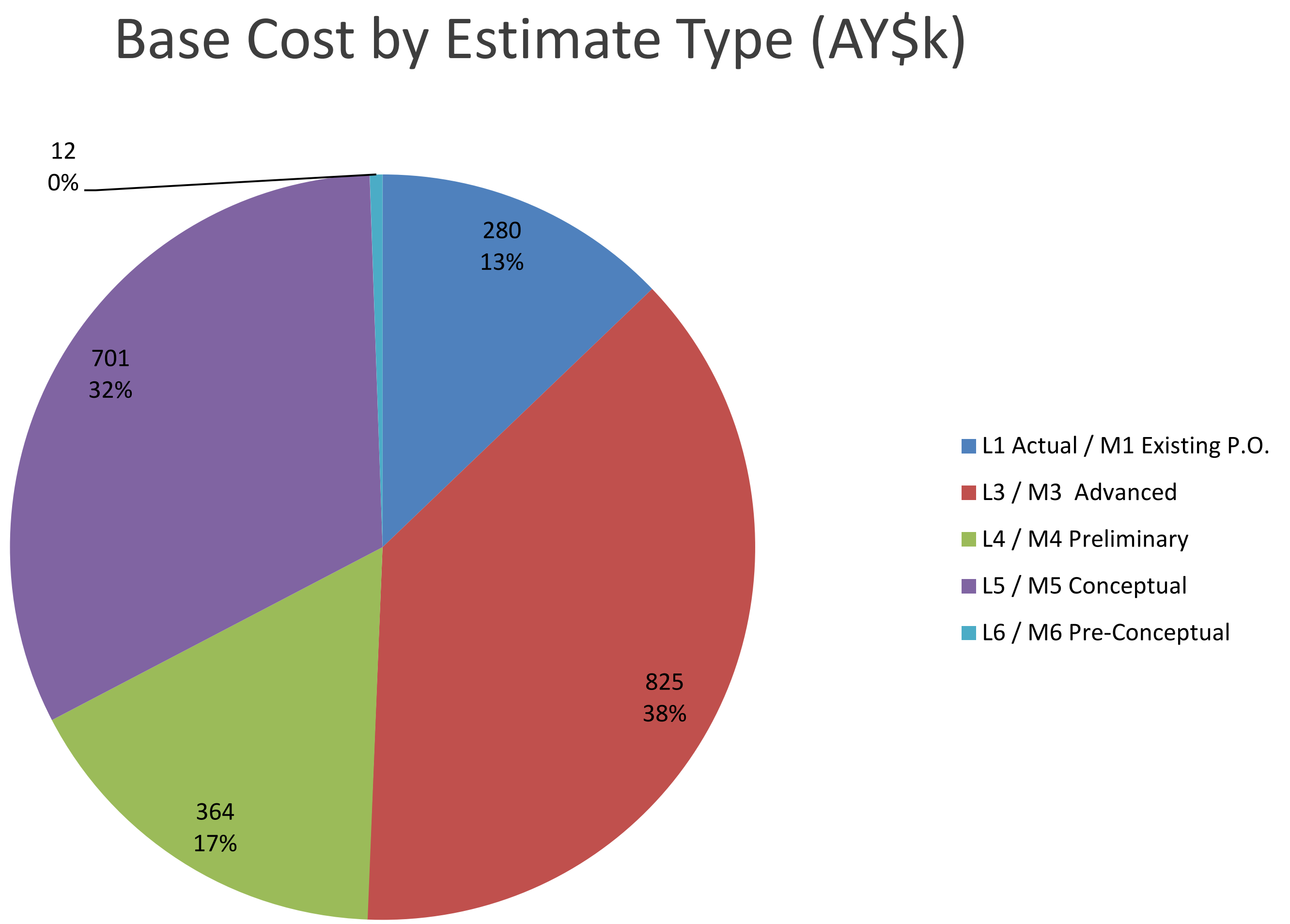
	M&S	Labor	BAC	Estimate Uncertainty	% contingency on ETC	Total
475.02.04 Actuals		280	280			280
475.02.04.01 AP1 Line to Delivery Ring Total Loss Monitor System	20	81	101	34	33%	135
475.02.04.02 Delivery Ring Radiation Safety Upgrades	537	419	956	362	38%	1,318
475.02.04.03 External Beamline Safety System	77	170	247	88	36%	334
475.02.04.04 Mu2e Safety Systems	129	223	352	74	21%	426
475.02.04.05 Technical Documentation		246	246	51	22%	297
Grand Total	764	1,418	2,182	608	32%	2,790

Cost Breakdown – Radiation Safety Improvements

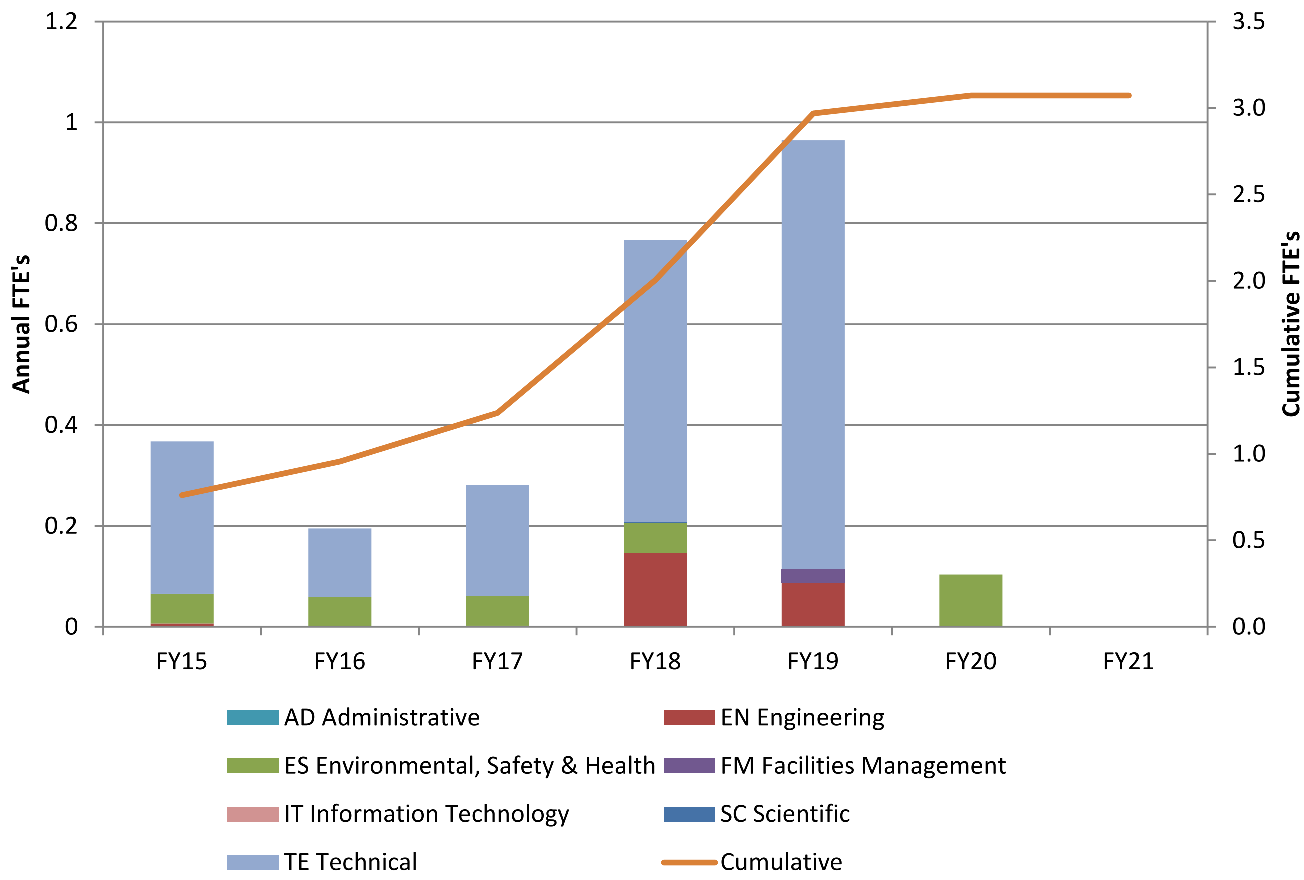




Quality of Estimate



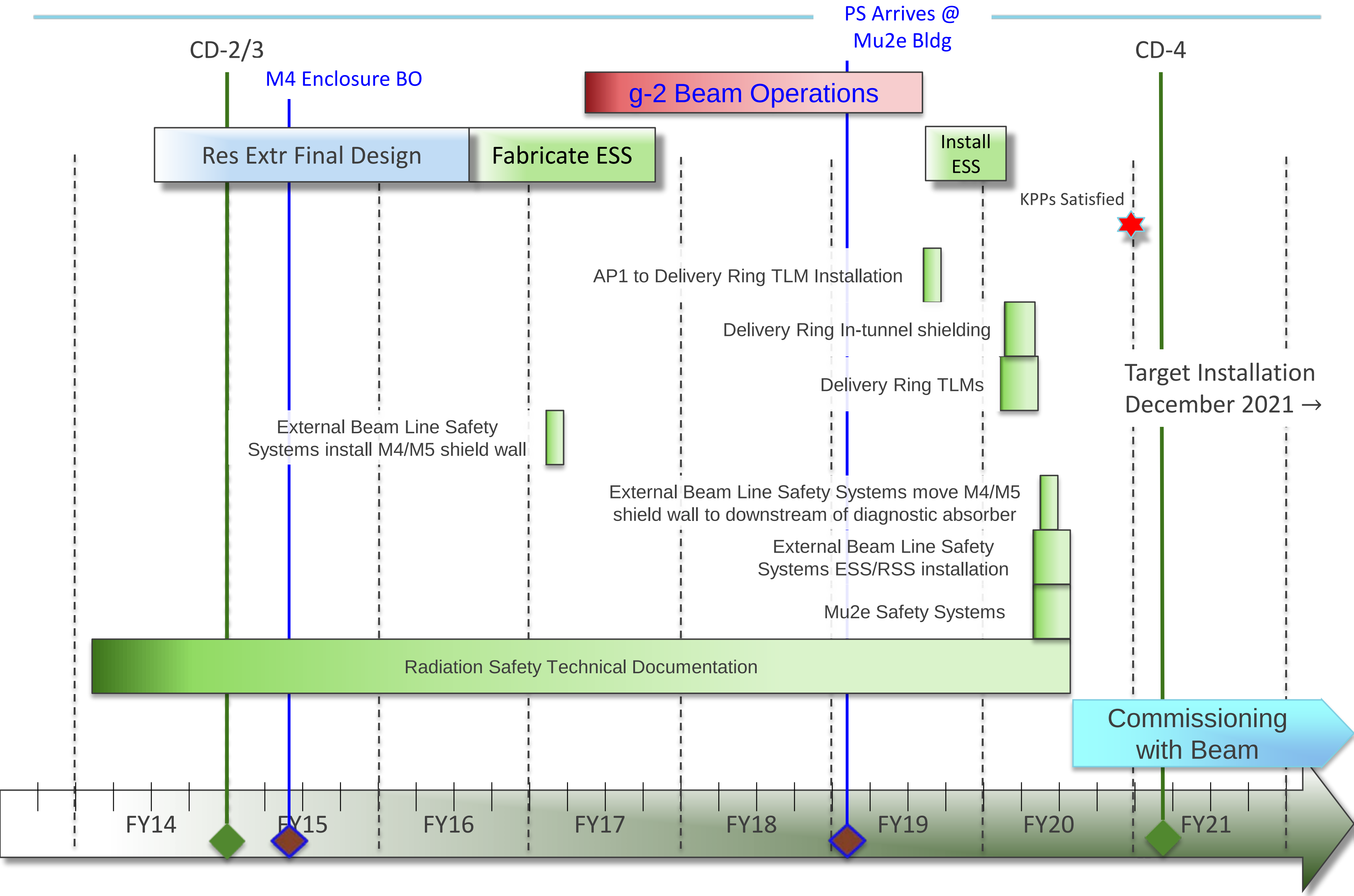
FTEs by Discipline



Major Milestones

475.02	47502.04.001050	Mu2e Radiation Safety System Conceptual Design Complete	Conceptual Design for the Mu2e Radiation Safety System is complete.	A. Leveling	L5	June 28, 2012
475.02	47502.04.001060	Mu2e Radiation Safety System Preliminary Engineering Design Complete	Completion of Accelerator Radiation Safety System Preliminary Design	A. Leveling	L5	May 1, 2014
475.02	47502.04.001070	Mu2e Radiation Safety System Final Engineering Design Complete	Completion of Accelerator Radiation Safety System Final Design	A. Leveling	L5	May 1, 2014
475.02	47502.04.001080	Radiation Safety Improvements Complete	Fabrication and installation complete for all of the deliverables specified for the Mu2e Radiation Safety System.	A. Leveling	L5	March 17, 2020
475.02	47502.04.02.1.001004	Resolution of revisions to beam line geometry at M4 line at extraction from delivery ring	Ready to commence re-calculation of extraction losses using an inward Delivery Ring extraction geometry rather than an outward extraction geometry.	A. Leveling	L6	**May 1, 2014**
475.02	47502.04.03.3.001030	9/20/13 Muon Department decision to leave in place temporary shielding downstream of diagnostic absorber	Decision milestone to make diagnostic absorber shield wall permanent.	A. Leveling	L6	**September 20, 2013**
475.02	47502.04.03.3.001050	Wall at CDF Dismantled	Ready to transfer CDF shielding materials to the M4 enclosure for assembly of temporary shield wall downstream of the M4-M5 split.	A. Leveling	L6	**May 1, 2014**
475.02	47502.04.1080	Radiation Safety ready for beam to the diagnostic absorber	The radiation safety system is ready to run 6W 8 GeV proton beam to diagnostic absorber.	A. Leveling	L5	September 1, 2015

Schedule



PS Arrives @ Mu2e Bldg
CD-2/3
CD-4
M4 Enclosure BO
g-2 Beam Operations
Res Extr Final Design
Fabricate ESS
Install ESS
KPPs Satisfied
AP1 to Delivery Ring TLM Installation
Delivery Ring In-tunnel shielding
Delivery Ring TLMs
Target Installation December 2021 →
External Beam Line Safety Systems install M4/M5 shield wall
External Beam Line Safety Systems move M4/M5 shield wall to downstream of diagnostic absorber
External Beam Line Safety Systems ESS/RSS installation
Mu2e Safety Systems
Radiation Safety Technical Documentation
Commissioning with Beam
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- A final design for Radiation Safety Improvements is complete
- The final design anticipates final approval of the TLM system in 4th quarter of CY15

Extra Slides

Labor/Material Breakdown