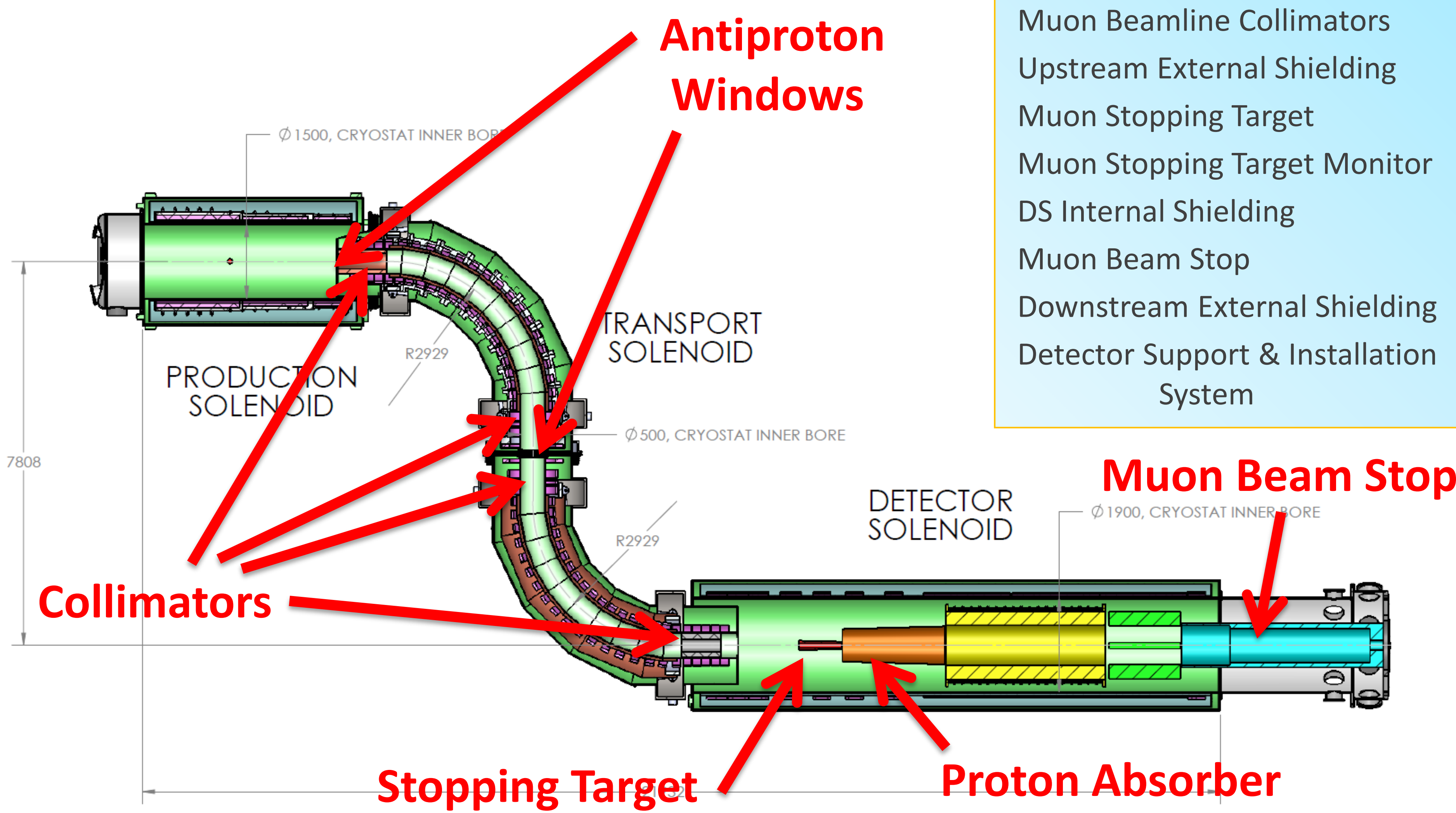
Mu2e WBS 5 Muon Beamline CD-2 Director's Review

George Ginther
Muon Beamline Level 2 Manager
7/8/2014

Muon Beamline Orientation

- Muon Beamline Vacuum System
- Muon Beamline Collimators
- Upstream External Shielding
- Muon Stopping Target
- Muon Stopping Target Monitor
- DS Internal Shielding
- Muon Beam Stop
- Downstream External Shielding
- Detector Support & Installation System



Requirements

- Provide end enclosures for muon beamline vacuum spaces
- Maintain pressure inside the Production Solenoid (PS) + Upstream Transport Solenoid (TSu) warm bore at $\leq 10^{-5}$ torr
  - Primary target lifetime
- Maintain pressure inside the Downstream Transport Solenoid (TSd) + Detector Solenoid (DS) warm bore at $\leq 10^{-4}$ torr
  - Detector performance
- Collimators preferentially charge and momentum select muons from the particle beam spiraling downstream from the PS production target
- Reduce beam related backgrounds
  - Suppress antiproton transmission down the beamline
  - Suppress migration of radioactive molecules from PS+TSu to TSd+DS region

Requirements

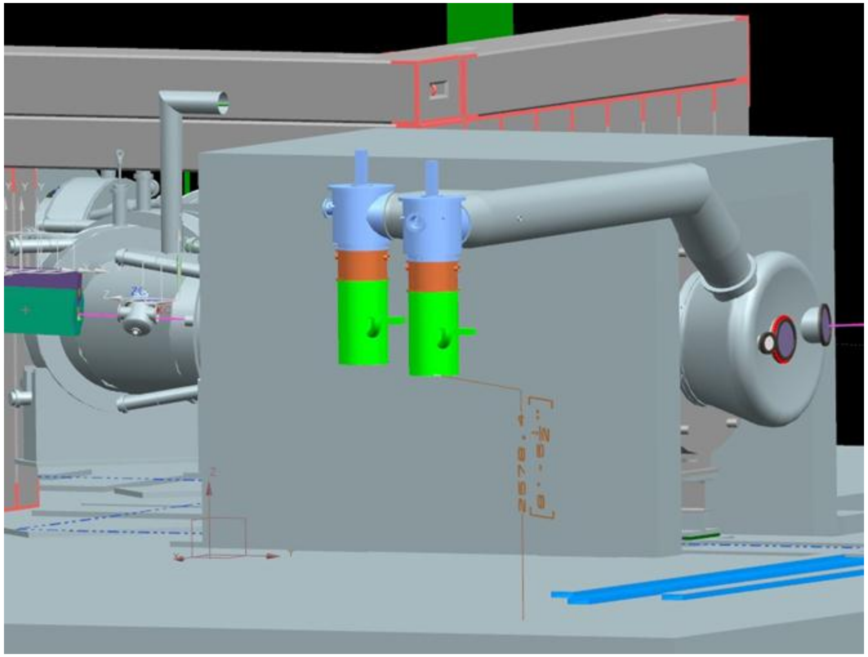
- Reduce TS superconducting coils from the heat load
- Reduce background rates at detectors to facilitate efficient operation and experiment sensitivity
  - Shielding to reduce rates at the Cosmic Ray Veto
  - Shielding to reduce rates at the tracker
- Efficiently capture muons in the stopping target
  - 40% efficiency or higher without compromising the sensitivity of the detectors and maximizing signal-to-background ratio (including energy resolution degradation due to energy straggling in the stopping target)
- Monitor the number of captured muons at the stopping target
- Absorb the beam that passes through the target in the muon beam stop
  - Reduce this potential source the backgrounds in the detectors generated by the secondaries

Requirements

- Provide mechanical infrastructure to facilitate installation, positioning, alignment, and servicing of the detector train
  – Detector train is composed of the following elements
    - Stopping Target and surrounding shielding (Proton Absorbers)
    - Tracker
    - Calorimeter
    - Muon Beam Stop
  – Detector access requires extracting the detector train from the DS bore
  – Provide 500 µm transverse position reproducibility for the tracker and calorimeter
  – Provide 1mm longitudinal position reproducibility for the tracker and calorimeter
- Provide a mechanical base to support the Cosmic Ray Veto

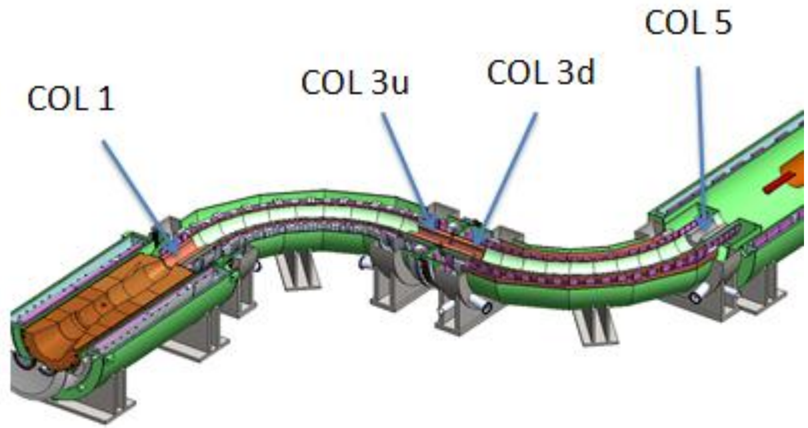
- Requirements documents are available on the Review web page

WBS 5.2 Muon Beamline Vacuum System Design

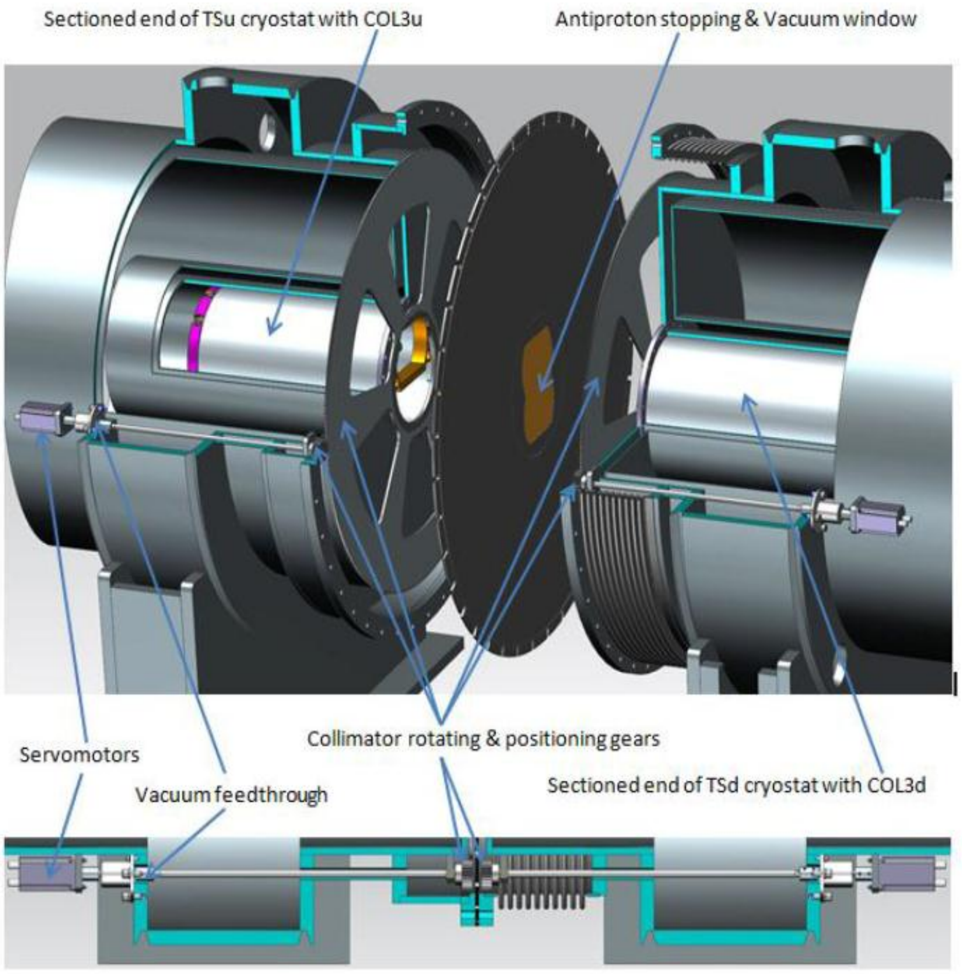


- Major Components
  - Enclosures on PS and DS ends
    - Windows
    - Feedthroughs
  - External Vacuum Components
    - Roughing pumps
    - High vacuum pumps
      - Diffusion pumps
    - Piping
    - Seals, instrumentation, valves
  - Controls, Monitoring and Interlocks
- Radiation levels, magnetic fields, gas loads, and shielding requirements must be considered

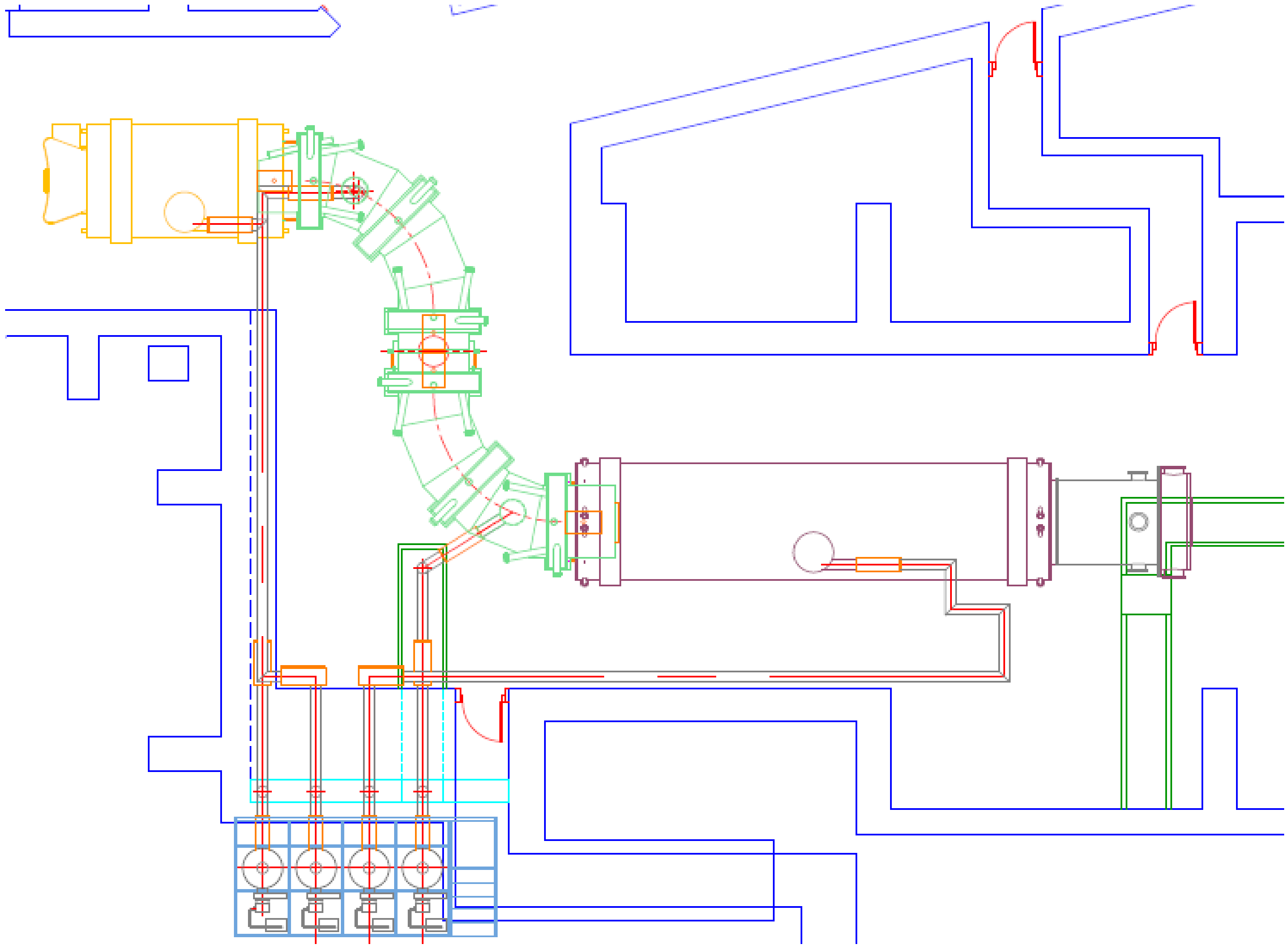
WBS 5.2 Muon Beamline Collimator Design



- COL 1, COL3u and COL 3d are (primarily) copper
- COL 5 is poly
- COL3u and COL3d can be rotated to select positive charge for calibration purposes
- Antiproton window also isolates upstream from downstream vacuum space

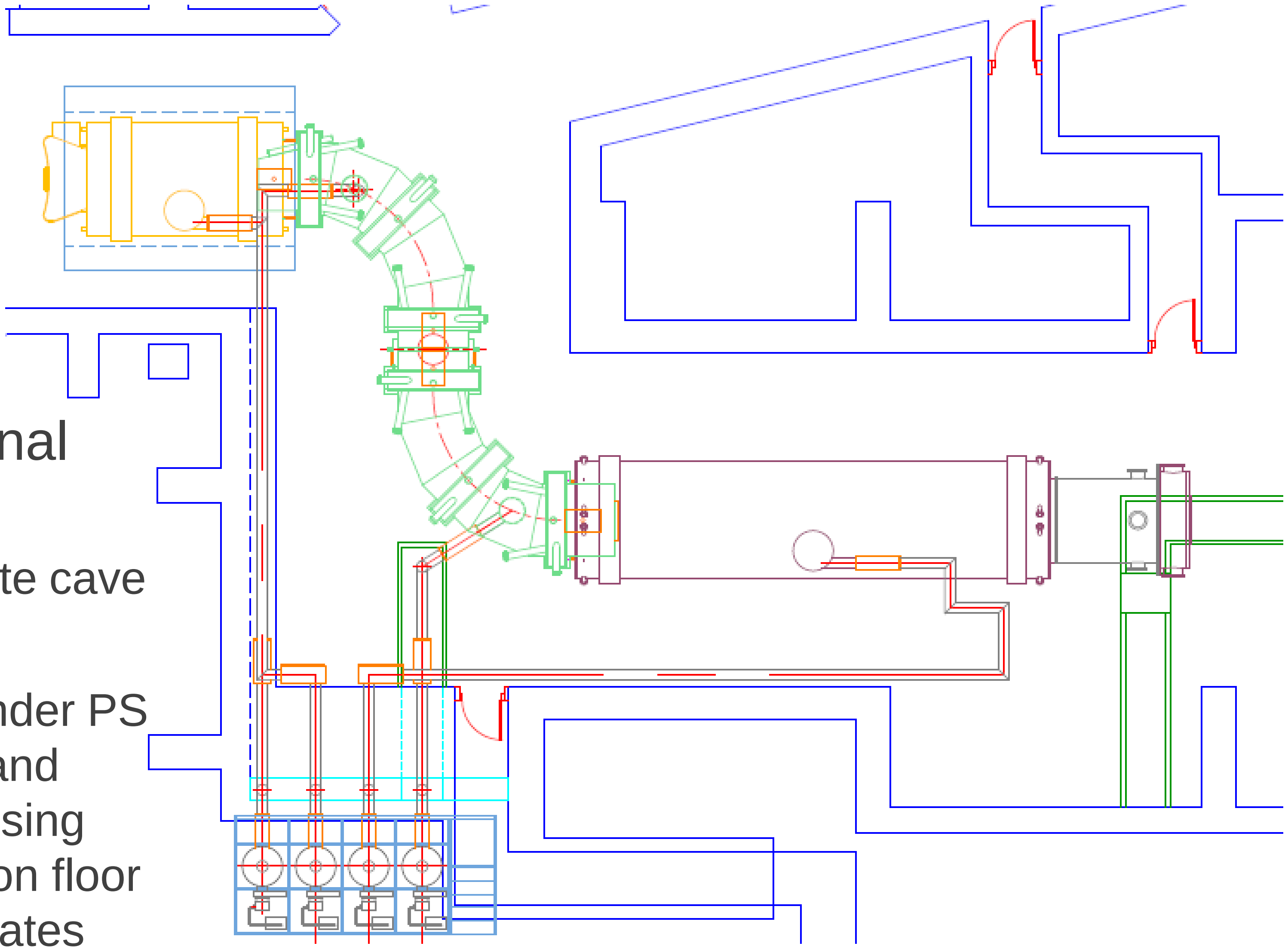


WBS 5.4 and 5.9 External Shielding Design



WBS 5.4 and 5.9 External Shielding Design

- PS External shielding
  - Concrete cave
  - 90 tons
  - Cast under PS Hatch and move using rollers on floor track plates



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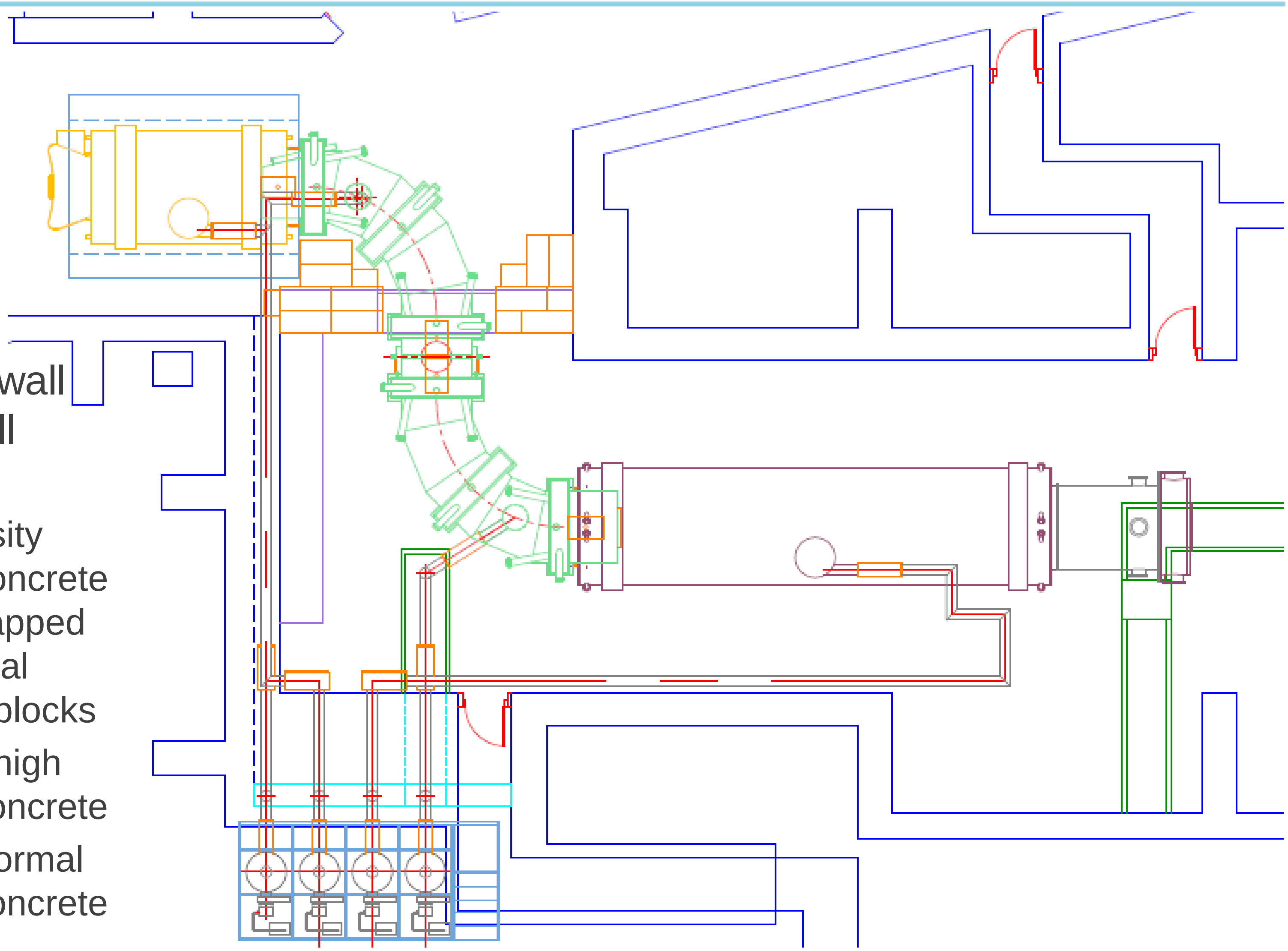
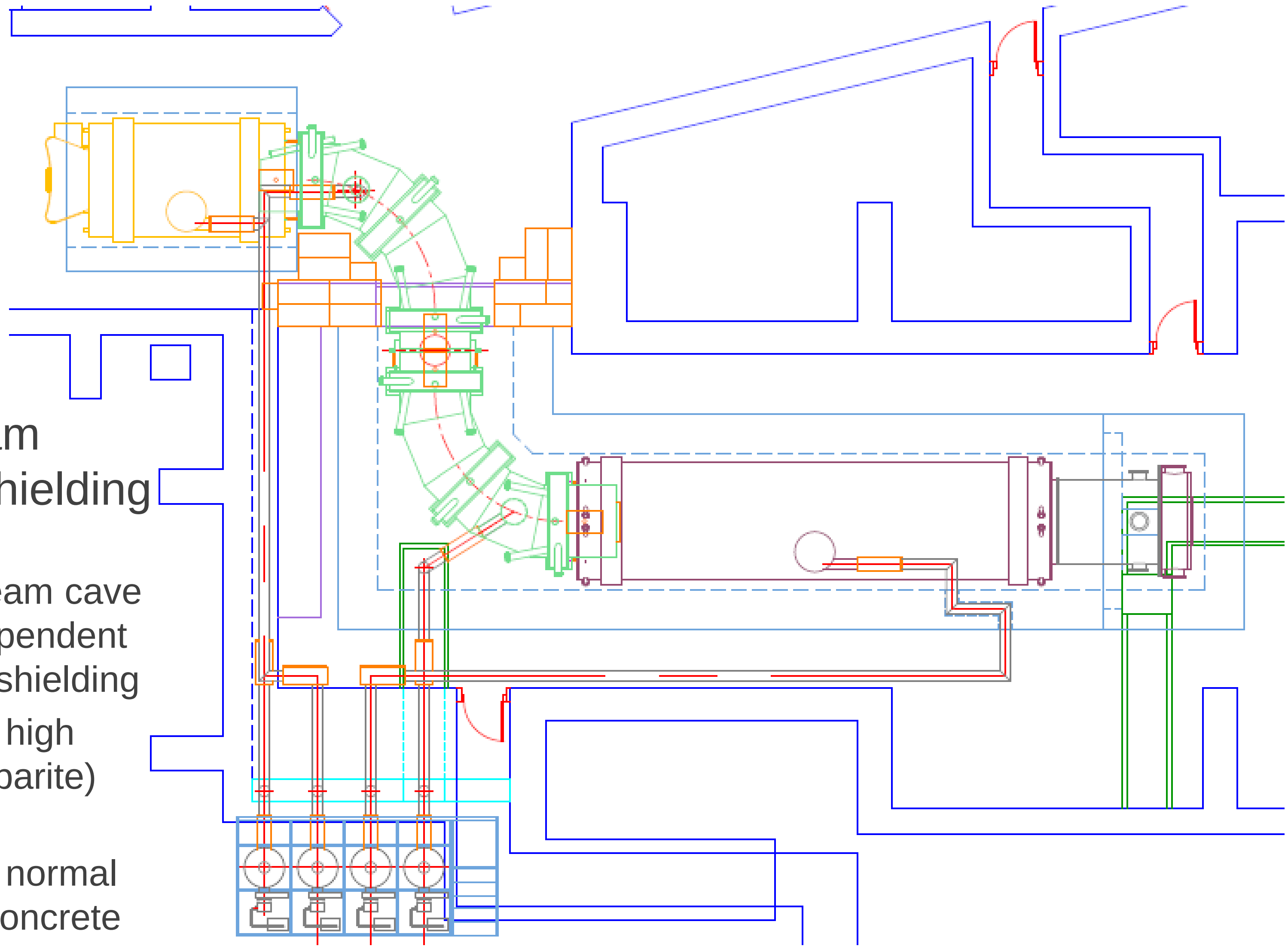


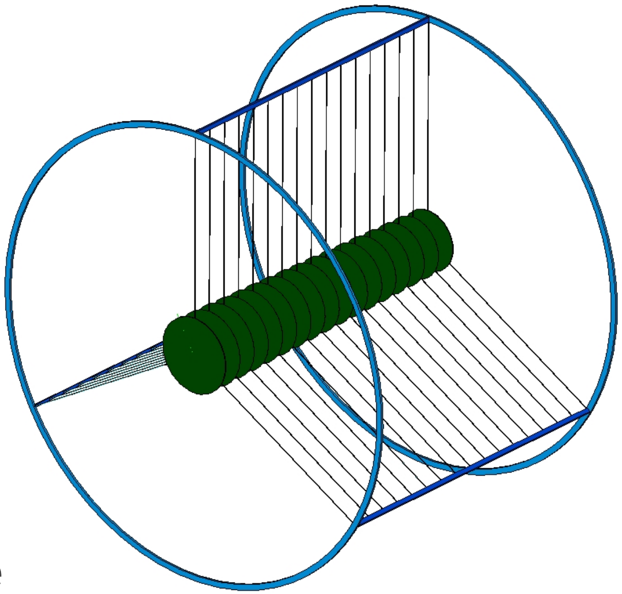
- TS isolation wall and west wall shielding
  - High density (barite) concrete blocks capped with normal concrete blocks
  - 242 tons high density concrete
  - 48 tons normal density concrete

WBS 5.4 and 5.9 External Shielding Design



- Downstream External Shielding
  - T block downstream cave and independent end cap shielding
  - 409 tons high density (barite) concrete
  - 430 tons normal density concrete

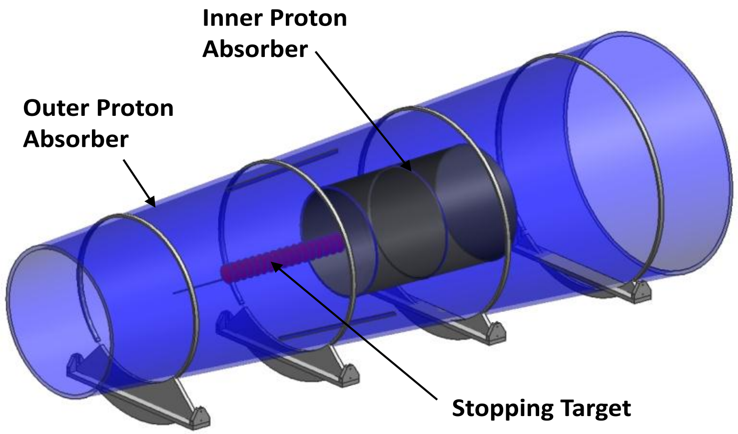
WBS 5.5 and WBS 5.6 Designs

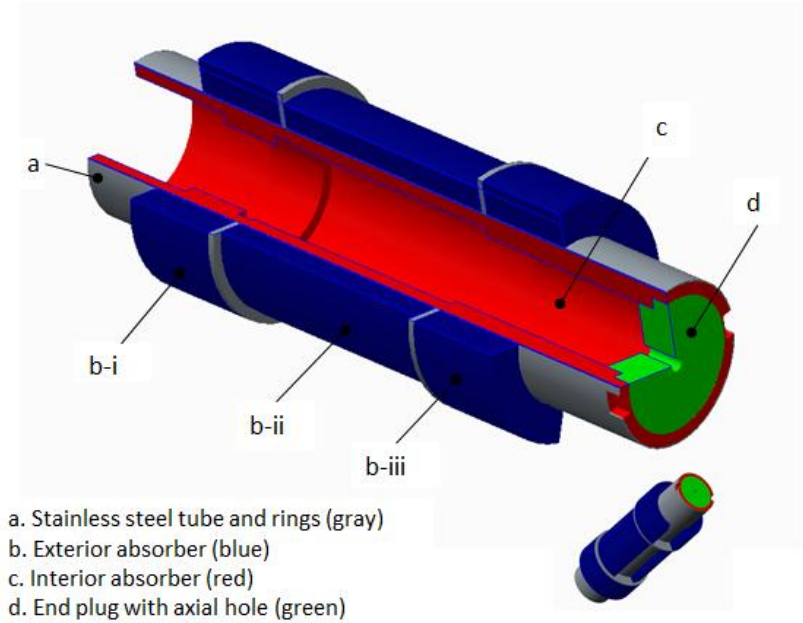


- WBS 5.5 Muon Stopping Target
  - Seventeen 200μm thick aluminum disks
  - Tungsten wire supports
- WBS 5.6 Muon Stopping Target Monitor
  - Stopping Target Monitor is a germanium detector monitoring delayed photons from the de-excitation of ^{27}Mg created by muon capture on aluminum
    - ^{27}Mg decays to excited ^{27}Al with a 9.5 minute half life
      - Detect 844 keV photon from ^{27}Al transition
  - Germanium detector located outside vacuum volume downstream in low mag filed region
  - Sweeping magnet
  - Beam shutter protects detector from beam flash
  - Additional shielding surrounding detector

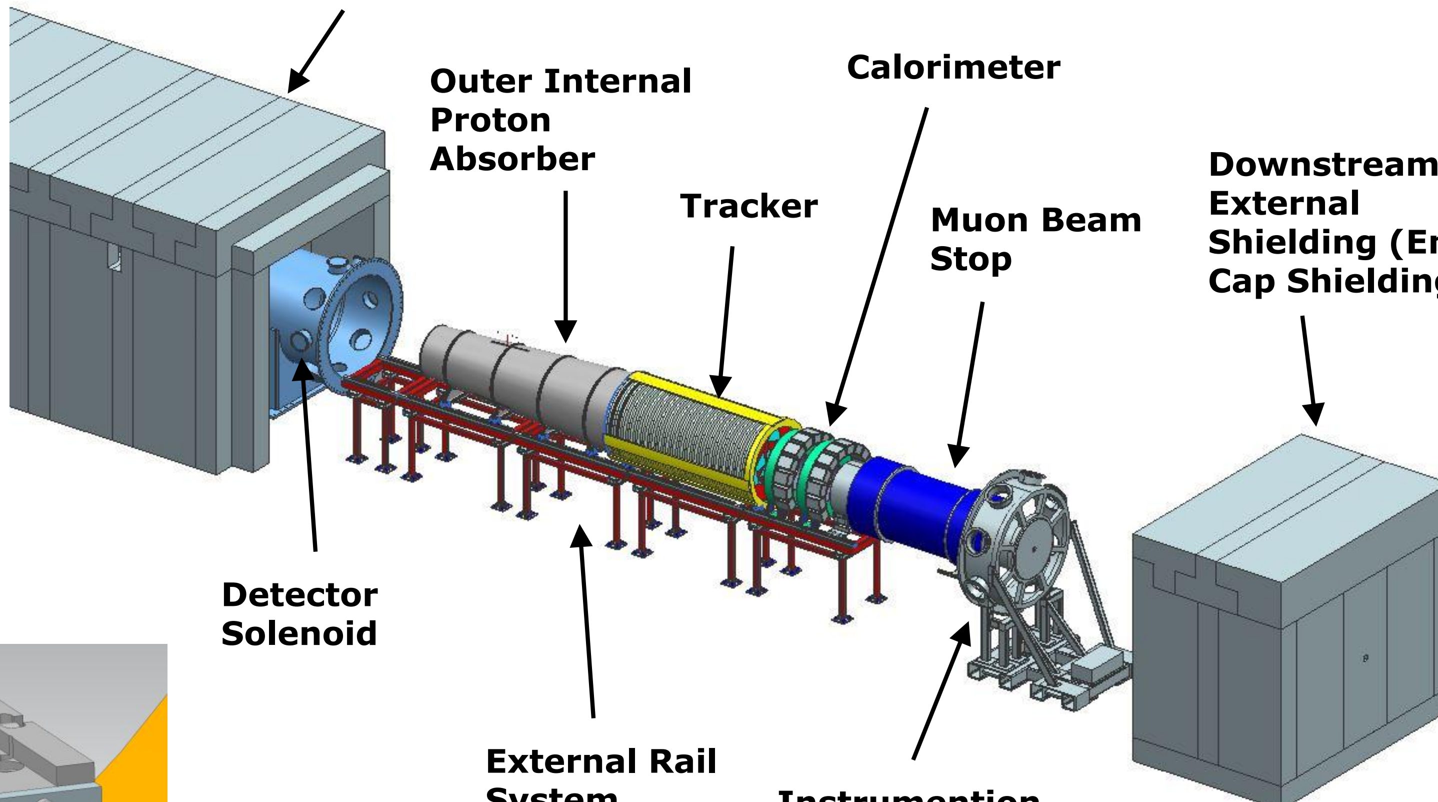
WBS 5.7 and WBS 5.8 Designs

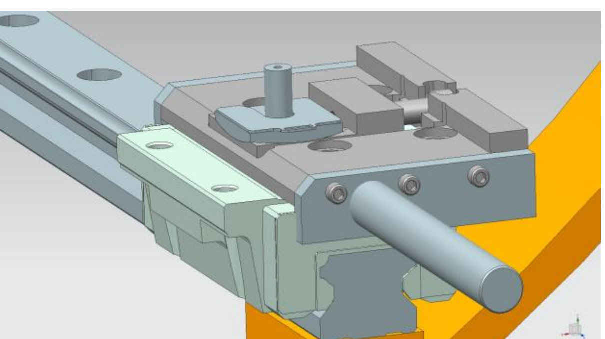
- WBS 5.7 Detector Solenoid Internal Shielding
  - 50 mm thick poly covering the downstream end of the TSd cryostat vacuum jacket
  - Inner Proton Absorber
    - 0.5 mm thick
  - Outer Proton Absorber
    - 20 mm thick borated polyethylene
- WBS 5.8 Muon Beam Stop
  - Stainless steel tube supporting polyethylene both inside and outside
  - Hole in the downstream end for line of sight to the muon stopping target monitor





WBS 5.10 Detector Support & Installation System Design

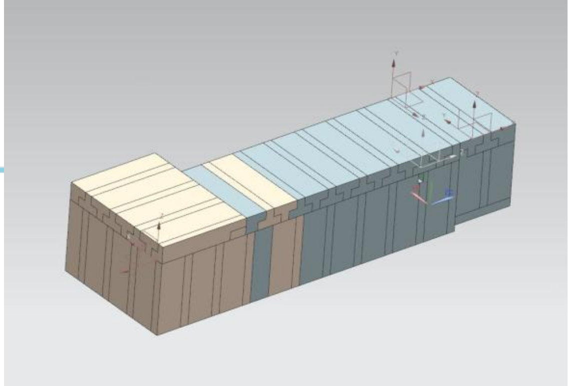




Changes since CD-1

- WBS 5.2 Muon Beamline Vacuum System
  - PS+TSu warm bore maxiumum operating pressure requirement adjusted from 10^{-1} torr to 10^{-5} torr
    - Requirement to support radiatively cooled primary target
    - Modifications which help address this challenge
      - Isolate outside surface of Heat and Radiation Shield reducing surface area inside volume
        - But introduces another volume to be purged or pumped
      - Explored and dropped poly liner inside TSu warm bore
      - Move upstream high vacuum pump closer
      - Increase duct size for upstream high vacuum pump
      - Plan on dry nitrogen backfills during pump and purge cycle
  - Replace several large seals with welds
    - Should improve reliability particularly in areas that will be difficult to service after operations begin due to high radiation levels anticipated
  - Include potential for additional pumping capacity for TSd+DS warm bore if needed
  - Introduce dry purges and modified transitions plans

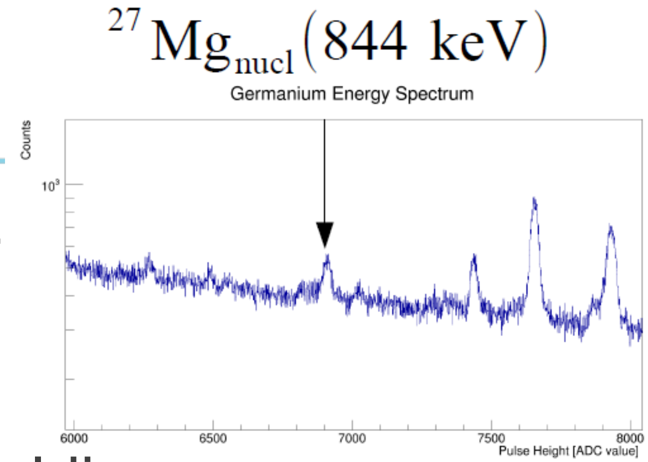
Changes since CD-1

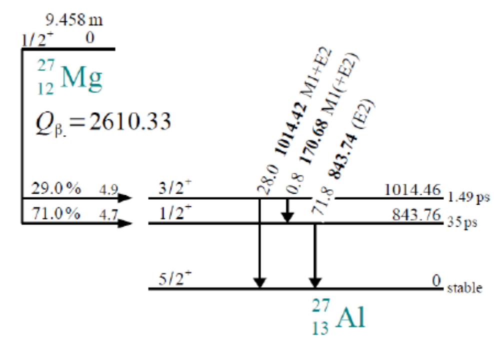


- WBS 5.3 Muon Beamline Collimators
  - Collimator locations shifted slightly
  - Additional optimization of antiproton suppression
    - Introduced an antiproton window in the vicinity of COL1
    - Refined geometry of antiproton window at the TSu/TSd interface
    - Added a lip on the downstream edge of the COL1 graphite liner
  - Now anticipate mag field instrumentation inside the collimators
- WBS 5.4 and 5.9 External Shielding
  - Introduce PS external shielding (90 tons)
  - Make TS isolation more robust
    - 240 tons of hand stacked blocks now 249 tons barite blocks and 48 tons concrete blocks
  - Increase shielding around DS from 18 inches thick to 36 inches thick
    - And include high density concrete around stopping target
  - Extend cave to surround TSd (entirely high density concrete)
  - Minimize cracks in downstream cave (T-block design)

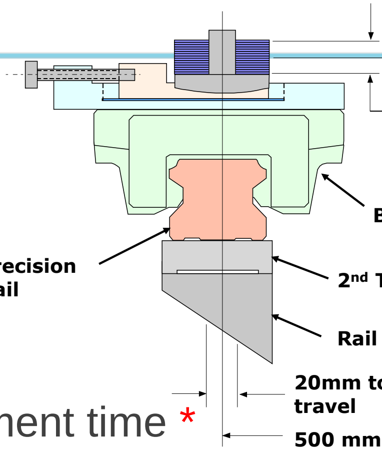
Changes since CD-1

- WBS 5.6 Muon Stopping Target Monitor
  - Change to delay gamma signal
  - Introduce beam shutter
- WBS 5.7 Detector Solenoid Internal Shielding
  - Inner Proton Absorber length reduced
  - Introduce Outer Proton Absorber
    - 0.4 tons additional borated polyethylene
- WBS 5.5 Muon Stopping Target
  - Outer Proton Absorber surrounds Muon Stopping Target complicating support
- WBS 5.8 Muon Beam Stop
  - Optimizing design to enhance performance
  - Support of downstream end transferred from rails to enclosure
    - Reduces number of individual external stands required in detector support and installation system



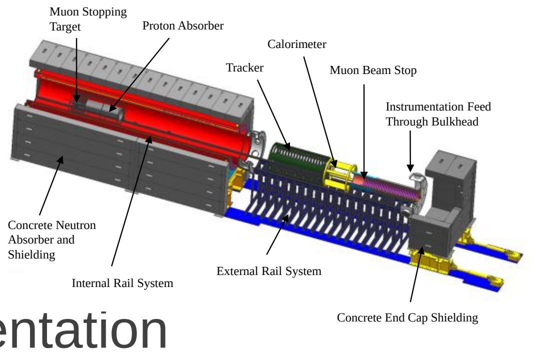


Changes since CD-1

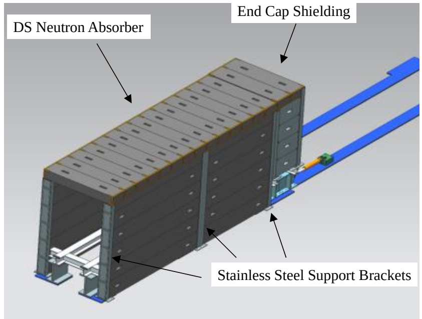


- WBS 5.10 Detector Support and Installation System
  - Develop 2nd tier bars in rail alignment system *
    - Based upon experience with rail system mock-up
  - Refined external rail supports design
    - Fewer individual stands should reduce installation/alignment time *
    - Reduced footprint will allow better access to detector train but requires additional floor track plates *
  - Preliminary design of detector support adjustment mechanism
  - Include bore heaters and associated instrumentation to reduce temperature variation inside warm bore
  - Revisit tolerance specifications for positioning of detector elements to optimize cost/performance *
- WBS 5.11 Muon Beamline Integration
  - Substantial development of installation sequence
  - Introduce hydrostatic levels *
- Note * that several of these items might also be considered as examples of value engineering

Value Engineering since CD-1



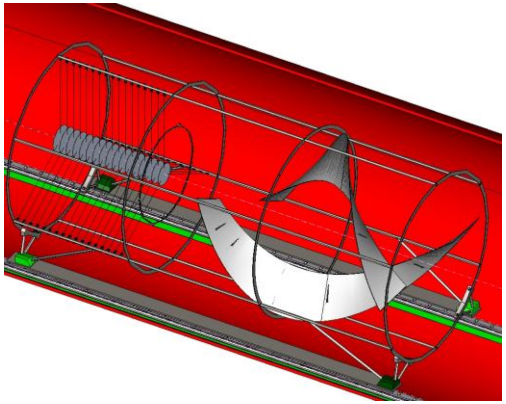
- Diffusion pumps instead of cryo pumps
- Instrumentation/ports to verify COL3u and COL3d orientation
- Shielding related optimizations
  - Investigate less expensive shielding materials
    - Employ high density concrete instead of copper or stainless steel
    - Increase concrete thickness instead of higher density concrete
  - Eliminate stainless steel frame from DS cave
  - Plan to cast PS external shielding
  - Plan for multiple use of same hydraulic system



- Influence civil construction plans
  - Optimize installation crane coverage, hatch size and locations to streamline shielding installation process (where possible)
  - Floor track plates and trenches
  - Plan for staging area for shielding
  - Increase floor space to facilitate equipment staging
  - Routing of services in the building

Downselects

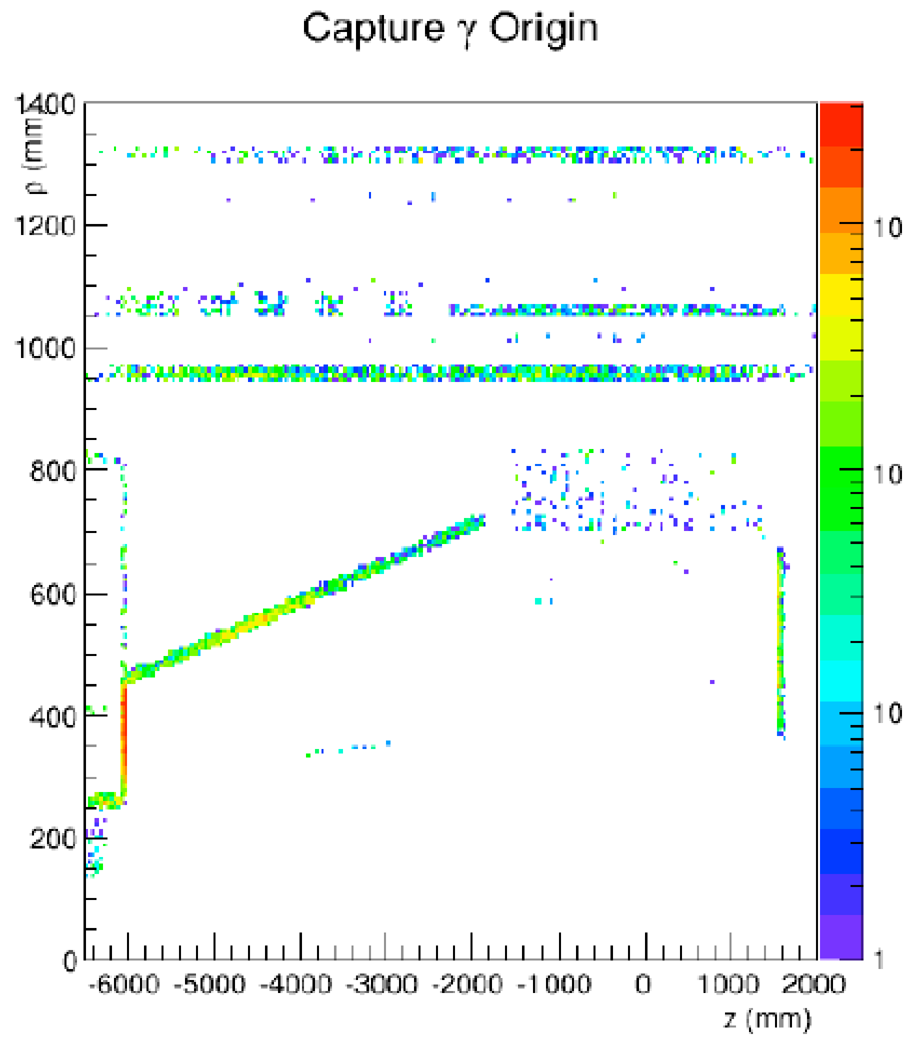
- Explored and eliminated poly liner within TS warm bore
- Comfirmed copper as the material of choice for COL3
- Confirmed poly as the material of choice for COL5
- Explored and eliminated inner neutron absorbers (from DS bore)
- Inner proton absorber
  - Frustum selected over blade configuration



- Explored many different shielding configurations and arrived at a one that addresses detector performance requirements

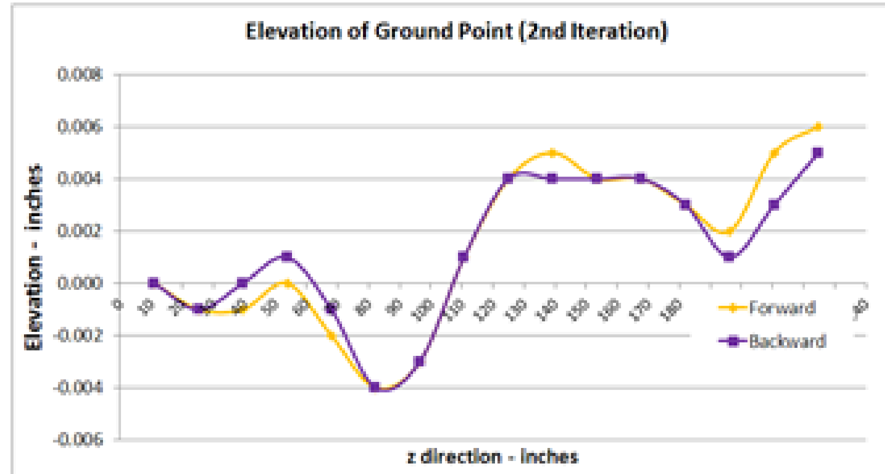
Muon Beamline Vacuum and Shielding Performance

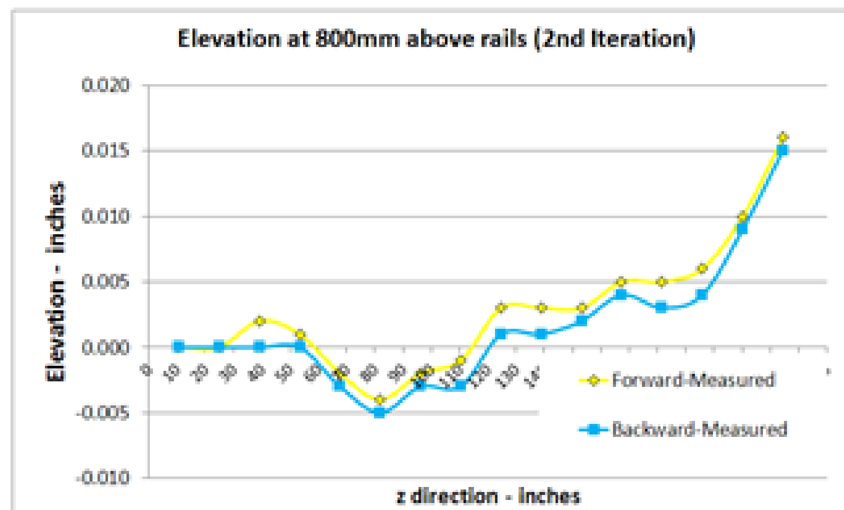
- Many muon beamline deliverables are particularly sensitive to and dependent upon interfaces with most other subsystems
  - Based upon current gas load and pumping configuration, anticipate after 10 hours
    - PS+TSu pressure 5x10^{-5} torr
    - TSd+DS pressure 6x10^{-4} torr
    - Once outgassing becomes negligible the pressures satisfy the requirements
  - See the CRV presentation in particular for a summary of the current performance of the external shielding



D. Brown Mu2e docdb 3479

Detector Support and Installation System Performance

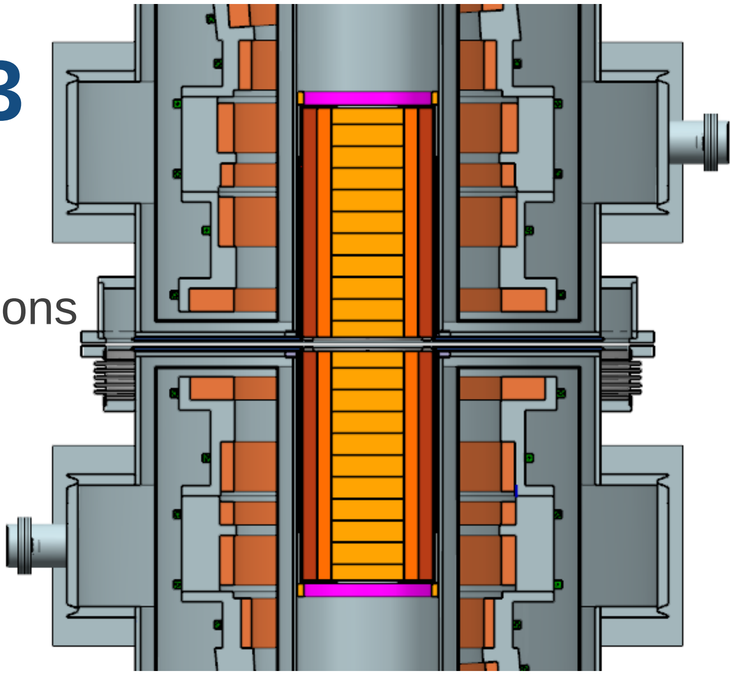




- Studies at rail system mockup indicate that position measurements are reproducible to within $\pm 25\mu m$ at seven meters from the laser tracker as measured via the laser tracker
- Reproducibility degrades as a function of distance from the laser tracker.
- The laser tracker device uncertainty is expected to be $\pm 50\mu m$ at 10 meters.

R. Bossert Mu2e docdb 3037

Remaining work before CD-3



- WBS 5.2 Muon Beamline Vacuum System
  - Verify gas loads to finalize pumping configurations
  - Complete window specifications/designs
  - Finalize enclosure designs
    - Verify feedthroughs
- WBS 5.3 Collimators
  - Finalize material choices
  - Design COL1 antiproton window
  - Finalize COL3u/COL3d interface region
  - Complete integration of mag field instrumentation
- WBS 5.4 and 5.9 External Shielding
  - Continue shielding value engineering effort
  - Optimize design of shielding for reliefs
- WBS 5.5 Muon Stopping Target
  - Complete target design optimizations
  - Complete prototype studies

Remaining work before CD-3

- WBS 5.6 Muon Stopping Target Monitor
  - Complete simulations studies of stopping target monitor performance (and shielding) as well as test beam studies
  - Complete infrastructure design
- WBS 5.7 DS Internal Shielding
  - Complete simulations studies/optimization of Proton Absorber performance
  - Prototype Inner Proton Absorber
  - Optimize fabrication technique for Outer Proton Absorber
- WBS 5.8 Muon Beam Stop
  - Complete simulations studies/optimization of MBS
  - Prototype Muon Beam Stop support
- WBS 5.10 Detector Support and Installation System
  - Complete testing of installation system at mockup
  - Complete FEA of deflections
  - Complete weld studies
  - Refine cable/services management plans

Organizational Breakdown Structure

- **5 Muon Beamline** — G. Ginther, Fermilab/Rochester
  - 5.1 MB Project Management — G. Ginther, Fermilab/Rochester
  - 5.2 MB Vacuum System — D. Pushka, Fermilab
  - 5.3 MB Collimators — N. Andreev, Fermilab
  - 5.4 Upstream External Shielding — N. Andreev, Fermilab
  - 5.5 Muon Stopping Target — J. Miller, BU
  - 5.6 Muon Stopping Target Monitor — J. Miller, BU
  - 5. 7 Detector Solenoid Internal Shielding — H. Glass, Fermilab
  - 5.8 Muon Beam Stop — R. Bossert, Fermilab
  - 5.9 Downstream External Shielding — R. Bossert, Fermilab
  - 5.10 Detector Support & Installation System — R. Bossert, Fermilab
  - 5.11 Muon Beamline Integration — G. Ginther, Fermilab/Rochester

- J. Brandt, G. Gallo and S. Krave are providing significant additional engineering
- York is contributing to the vacuum system
- Boston University is involved in stopping target and stopping target monitor
- NIU heavily involved in the Muon Beam Stop and Detector Support and Installation System
  - D. Hedin and physics students , N. Pohlman and engineering students (currently L. Martin and U. Okafor)
- APC contributing to MARS simulation effort
- Mu2e collaboration continues to make crucial contributions to development primarily through simulations studies
  - Neutron task force
  - Caltech, Fermilab, LBNL, NIU, Rice, UC Irvine, Virginia, York
- H. Brown Muon Beamline Project Controls

Quality Assurance

- Quality Assurance in the muon beamline efforts will rely about 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
    - Comparisons between MARS and GEANT4
  - Prototypes and mockups as appropriate
  - Documentation of procedures
  - Delivered materials will be inspected for conformance to the specifications

Muon Beamline Project Risks

- Technical risk MUON-146 in Mu2e docdb 4320
  - Rate exceeds muon stopping target monitor capability
    - Primary mitigations rely upon ongoing simulation efforts and test beam activities
- Schedule risk MUON-138 in Mu2e docdb 4320
  - Detector installation takes longer than anticipated
    - Primary mitigation is to continue refining the installation plan to account for new information and additional insights
    - Plan for parallel installation activities where and as resources permit
      - For example, take measurements for 2nd tier rails prior to delivery of DS to the Mu2e hall
- Scope risk MUON-147 in Mu2e docdb 4320
  - Degrader required for calibration
    - Could also impact design of internal shielding

Muon Beamline Transferred Risks

- Additional risks are being mitigated, but will only be realized after project completion, and must consequently be transferred
- Technical (and in schedule…)
  - Significantly larger gas loads in DS warm bore than anticipated
  - Vacuum leak
  - Inadequate pumping speed to maintain required vacuum in PS
  - PS vacuum window failure
  - Detector components move after installation
  - Damage to surrounding elements during shielding installation
  - Shielding installation impacts beamline alignment
  - Background rates in Cosmic Ray Veto higher than anticipated

ES&H

- To perform muon beamline activities safely will require appropriate planning (JHA), attention to ES&H considerations and FESHM and FRCM requirements
  - Vacuum vessels FESHM 5033
  - Thin windows on the vacuum vessel FESHM 5033.1
    - Possibly beryllium (hazardous materials) FESHM 5052.5
  - Inspection and testing of relief systems FESHM 5031.4
  - Liquid nitrogen FESHM 5030 series
  - Accessing confined space FESHM 5063
  - Possible use of lead (hazardous materials)
    - FESHM 5052.3
    - Beam shutter and other shielding
  - 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
  - Fire hazards
  - Hydraulic and perhaps pneumatic systems (and potential stored energy)
  - Radiation hazards FRCM
    - Stopping target monitor calibration source
    - Activation by beam
  - Hazardous waste
  - Cable Trays
    - FESHM 5043
  - And possibly ODH
    - FESHM 5064

Muon Beamline Cost Table (k$)

	M&S	Labor	Base Cost	Estimate Uncertainty	% Contingency on ETC	Total
475.05.01 Muon Beamline Project Management	71	3,289	3,360	194	7%	3,554
475.05.02 Vacuum System	2,041	1,264	3,305	1,174	37%	4,480
475.05.03 Collimators	725	830	1,555	515	42%	2,070
475.05.04 Upstream External Shielding	1,452	421	1,873	889	47%	2,762
475.05.05 Stopping Target	54	121	175	63	38%	238
475.05.06 Stopping Target Monitor	192	127	319	182	57%	501
475.05.07 Detector Solenoid Internal Shielding	181	211	392	119	34%	511
475.05.08 Muon Beam Stop	433	300	734	206	36%	940
475.05.09 Downstream External Shielding	2,478	826	3,304	1,339	45%	4,642
475.05.10 Detector Support Structure	1,304	1,041	2,344	620	31%	2,965
475.05.11 Systems Integration, Test & Analysis	27	348	375	193	54%	568
475.05.13 Muon Beamline Conceptual Design/R&D	107	1,873	1,980	0	0%	1,980
Risk Based Contingency				499		499
Total	9,065	10,650	19,715	5,993	38%	25,708

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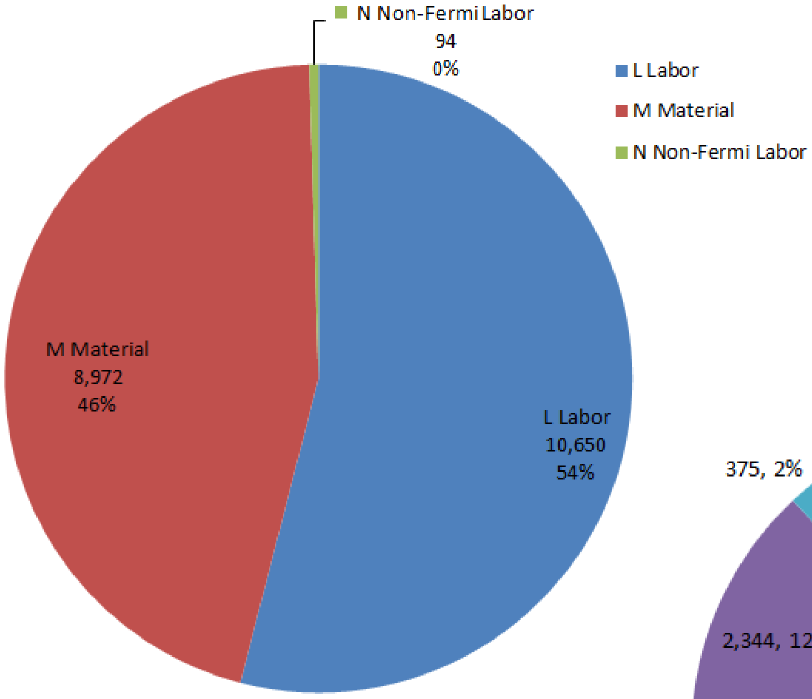
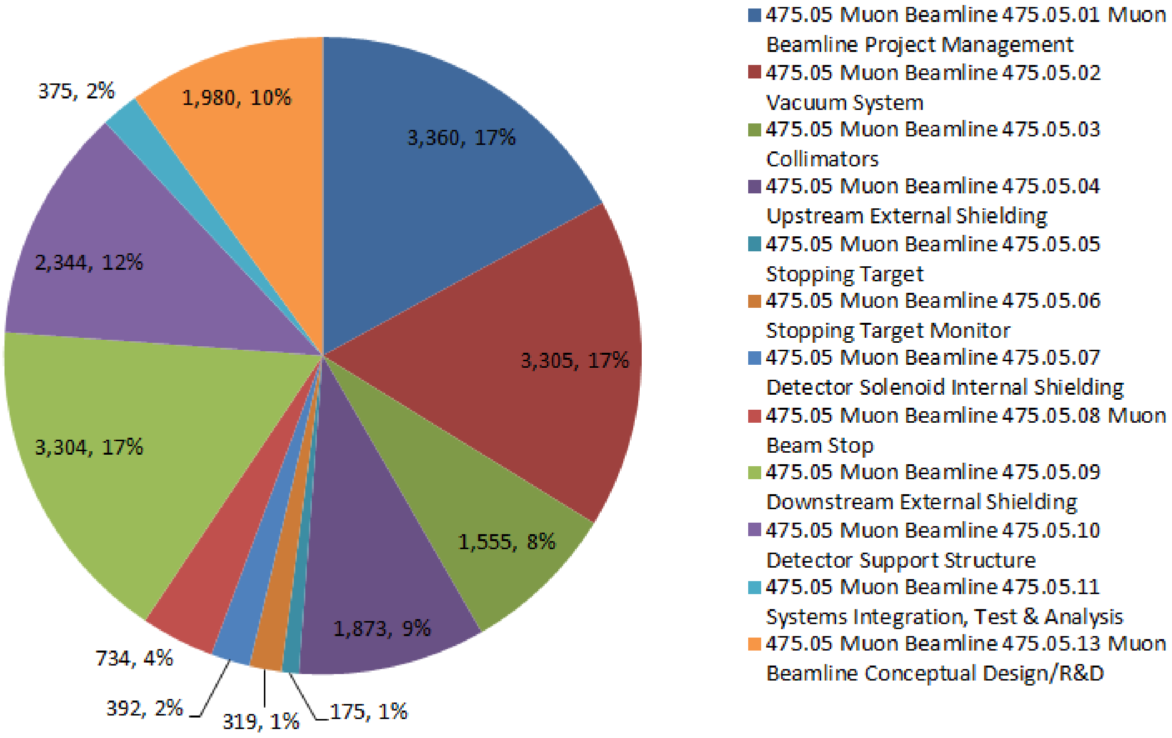
Cost Breakdown

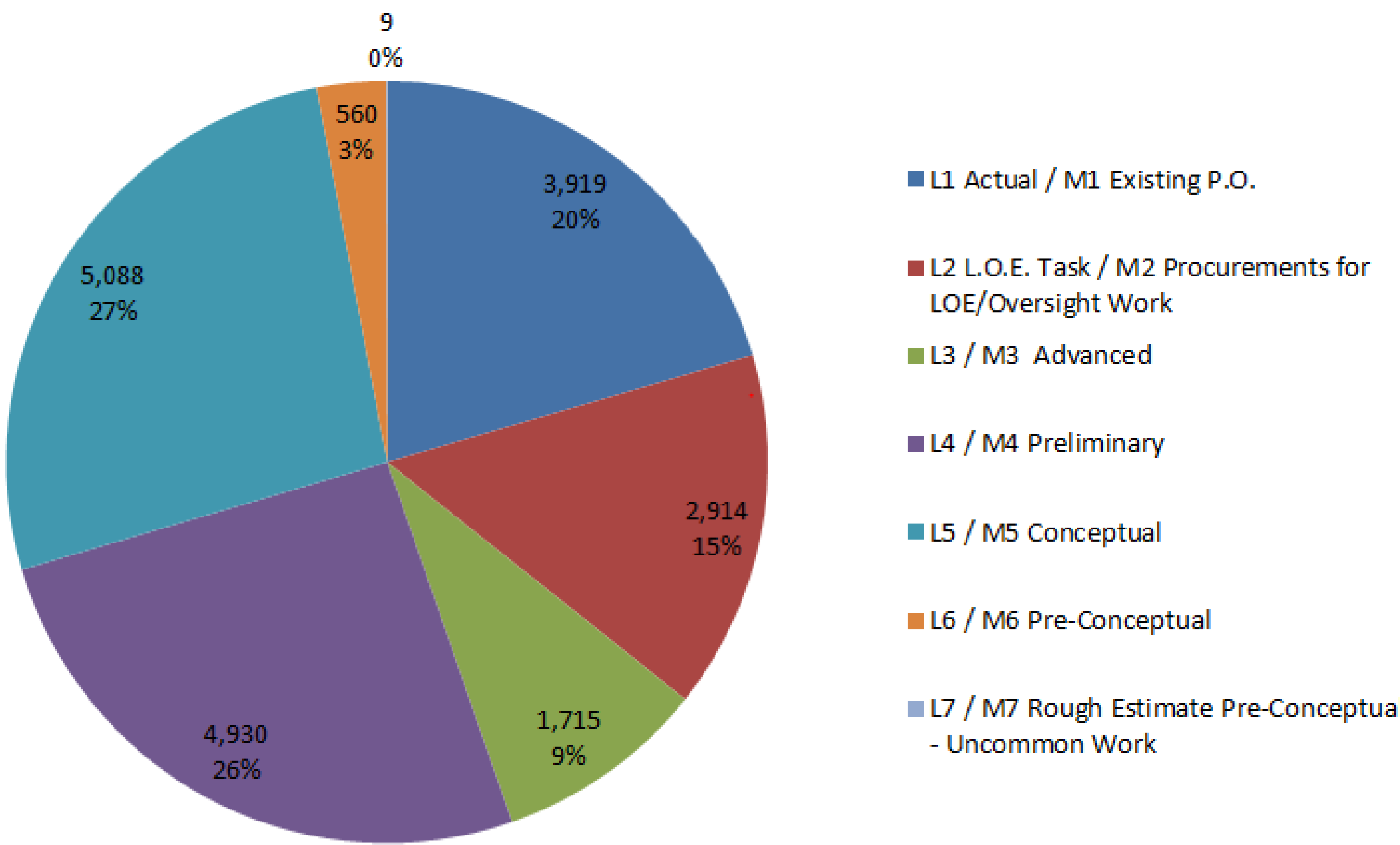
Base Costs in AYk$



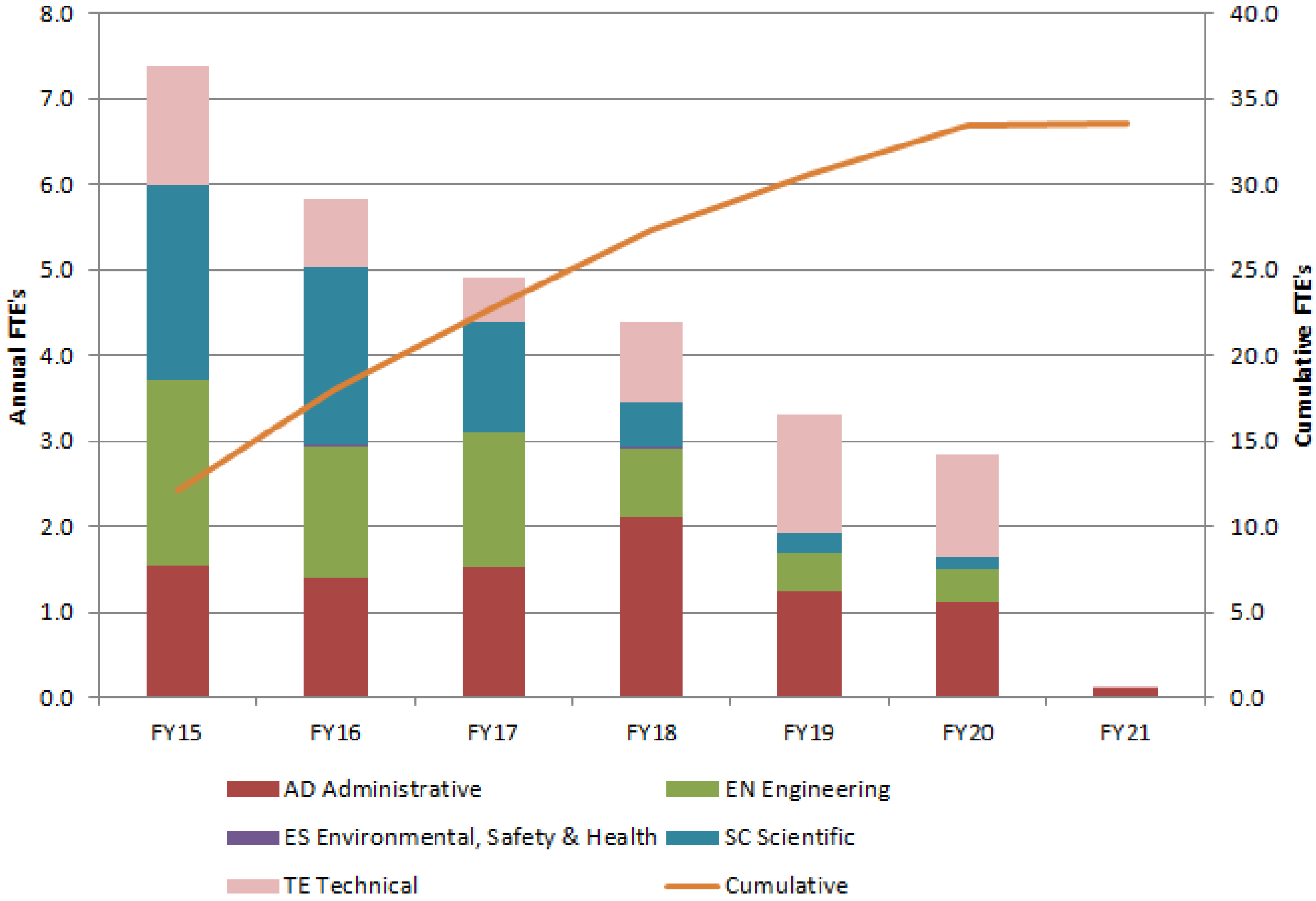


Quality of Estimate

Base Costs in AYk$



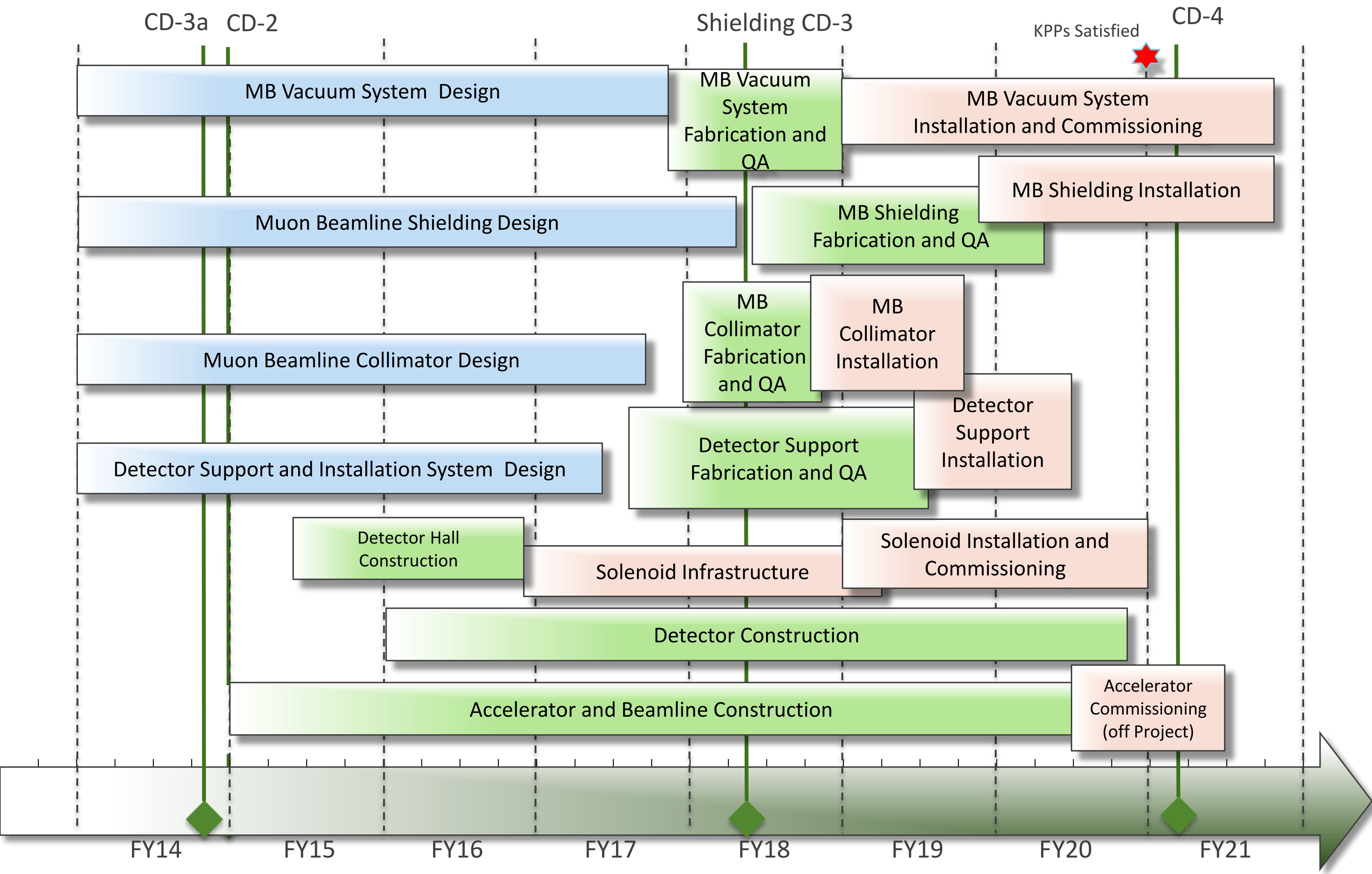
Labor Resources by FY



Major Milestones

• PS enclosure ready	18-Dec-2018
• All DS enclosure components at FNAL	04-Sep-2018
• All external vacuum system components at FNAL	10-May-2018
• COL1 installed	8-Aug-2018
• COL3u and COL3d installed and tested	31-Jul-2019
• COL5 installed	2-Aug-2019
• Upstream Shielding ready for CD-4	18-Nov-2019
• Stopping Target at FNAL	6-Dec-2018
• Stopping Target Monitor Infrastructure at FNAL	13-Sep-2018
• DS Internal Shielding ready for CD-4	17-Oct-2019
• Muon Beam Stop and Supports at FNAL	31-Jan-2019
• Downstream External Shielding at FNAL	3-Feb-2020
• Detector Train Test Insertion Complete	7-Feb-2020

Schedule

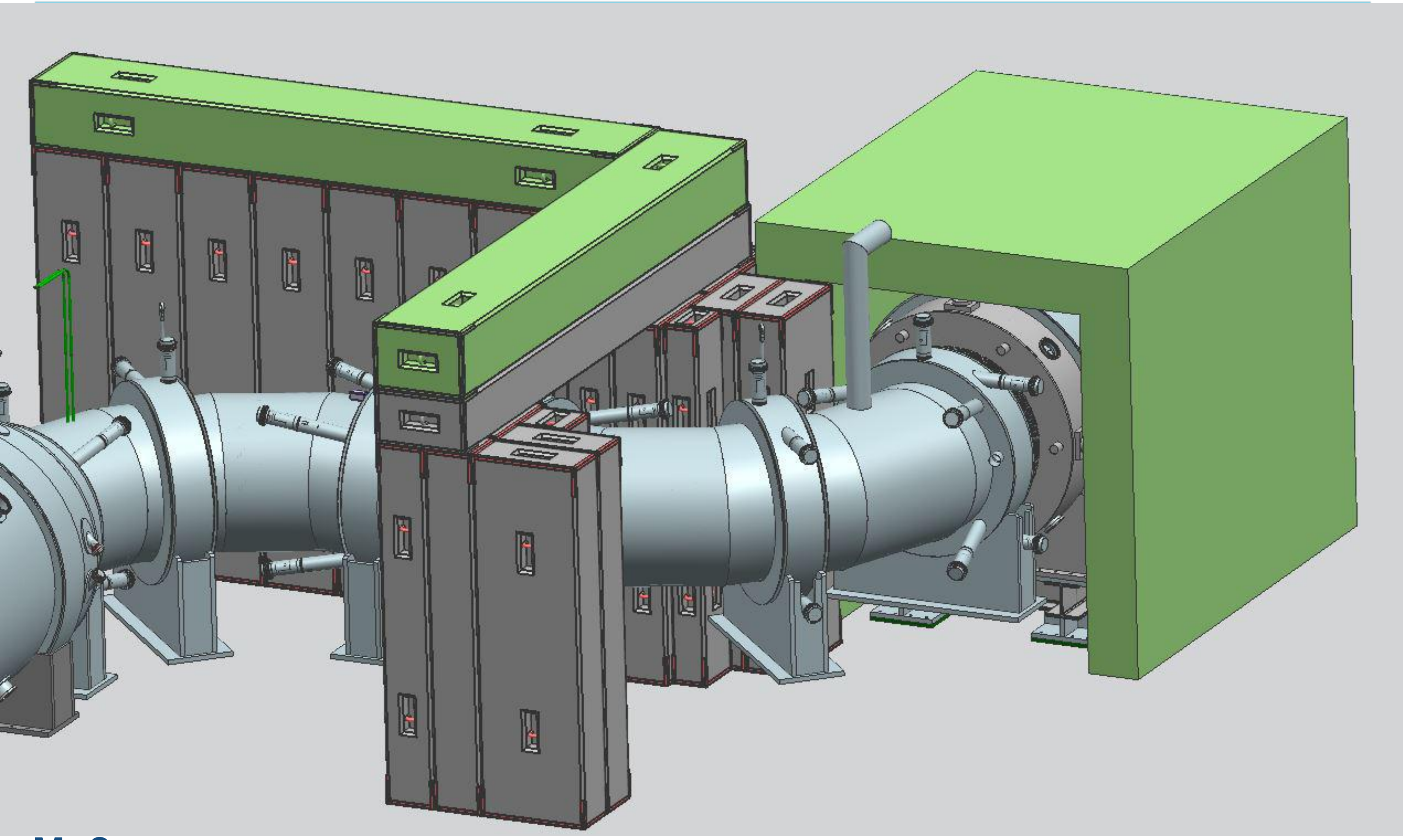

CD-3a
CD-2
Shielding CD-3
KPPs Satisfied
CD-4
MB Vacuum System Design
MB Vacuum System Fabrication and QA
MB Vacuum System Installation and Commissioning
Muon Beamline Shielding Design
MB Shielding Fabrication and QA
MB Shielding Installation
Muon Beamline Collimator Design
MB Collimator Fabrication and QA
MB Collimator Installation
Detector Support and Installation System Design
Detector Support Fabrication and QA
Detector Support Installation
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Detector Construction
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

WBS 5 Muon Beamline Summary

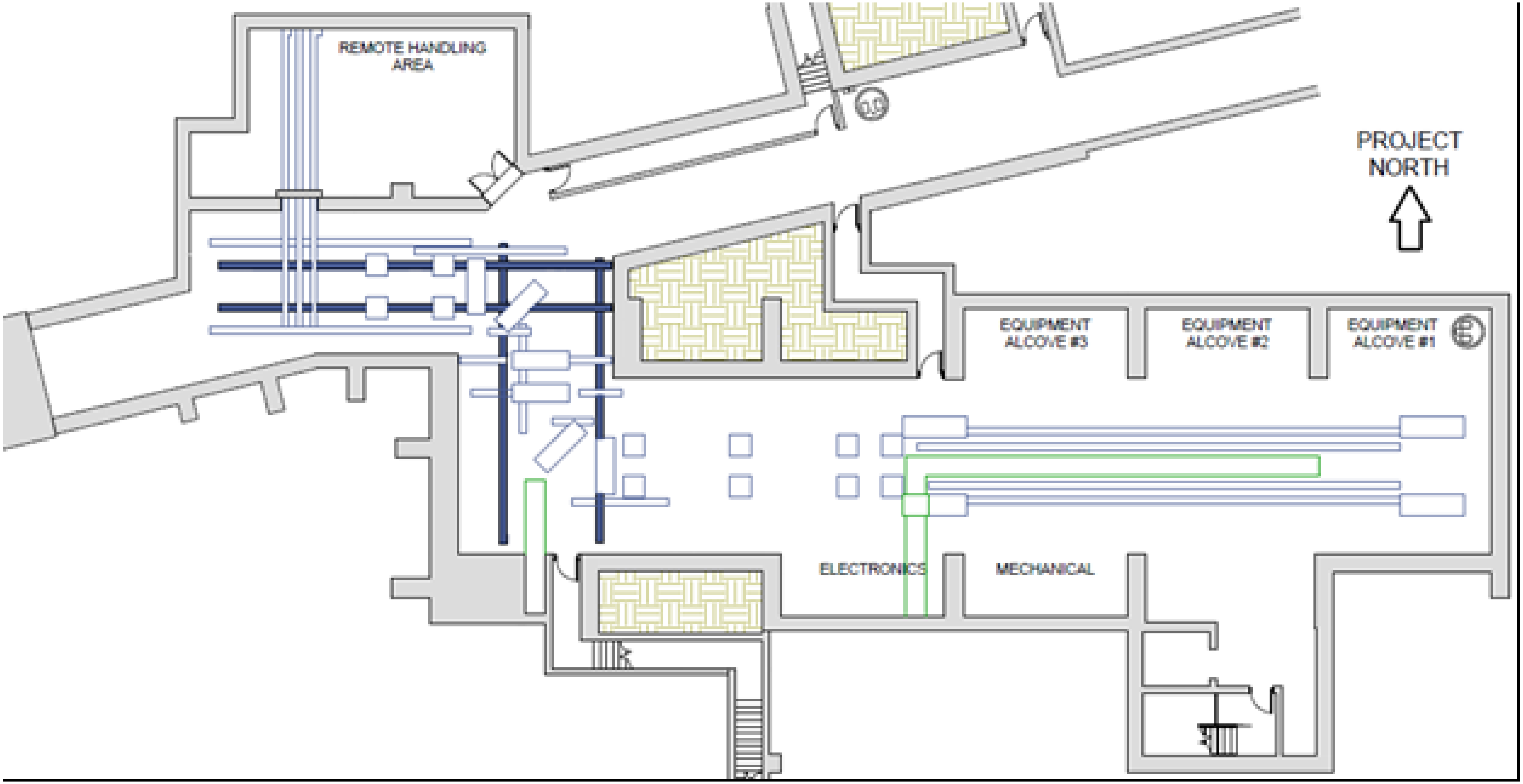
- WBS 5 Muon Beamline has a diverse set of responsibilities aimed at supporting efficient and reliable detector operation
  - Muon beamline deliverables are particularly sensitive to and dependent upon interfaces with all other subsystems
- Have made substantial progress since CD-1
  - Many designs have been significantly refined/optimized
  - Preliminary designs meet the requirements
- Finalizing many of the designs will be dependent upon ongoing physics simulations (and in a few cases prototyping)
  - The collaboration continues to make vital contributions to this effort

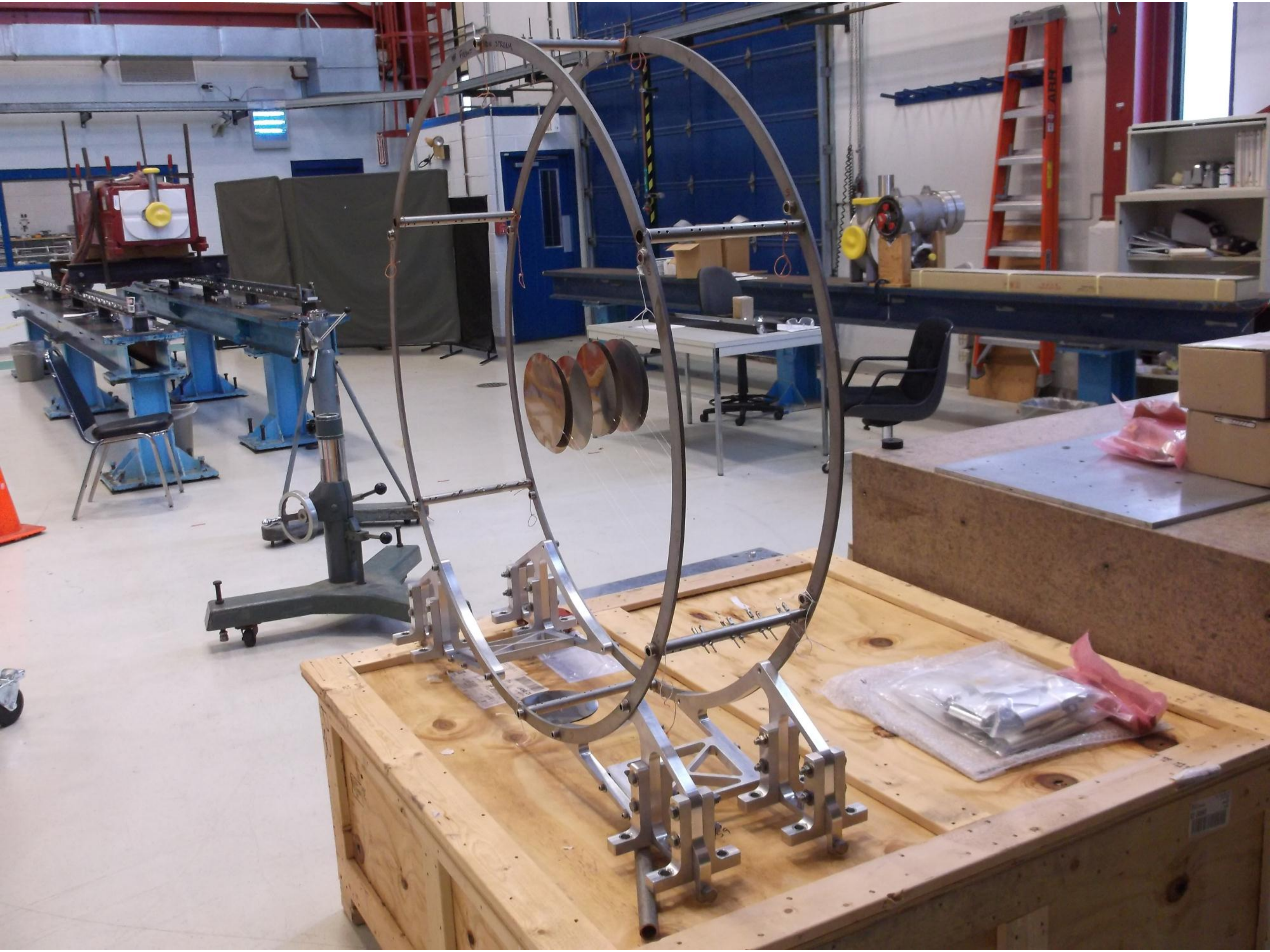
- Anticipate that many major WBS 5 procurements will be scheduled towards the end of the project

WBS 5.4 Upstream External Shielding



Floor track plate layout

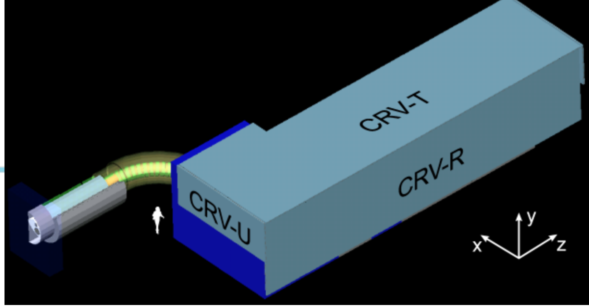




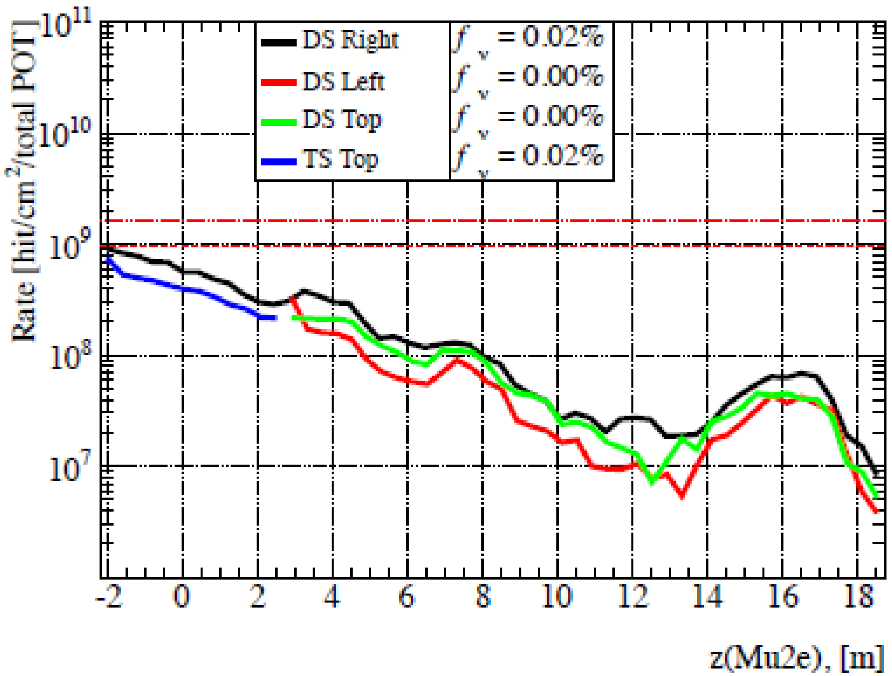

EXIT
2013/03/07

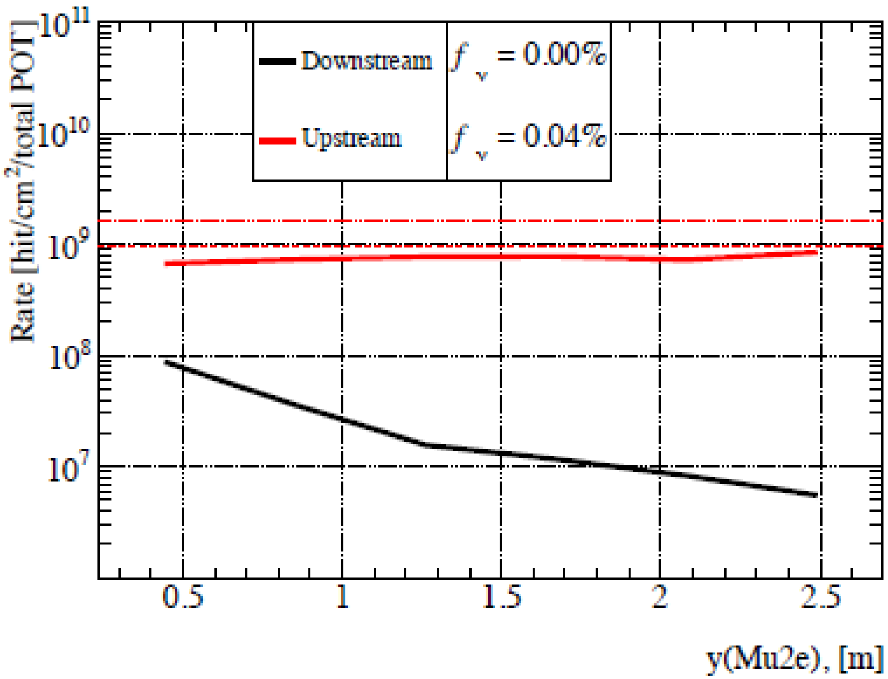

EXIT
DANGER
PINCH POINT
DELL

Accidental CRV rates

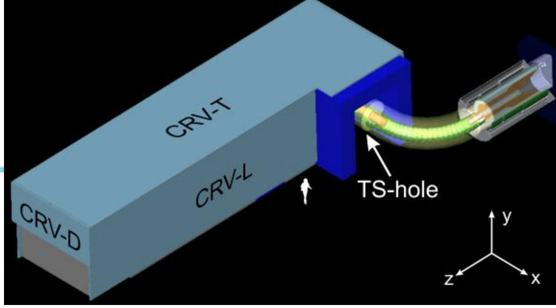


- Accidental hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.

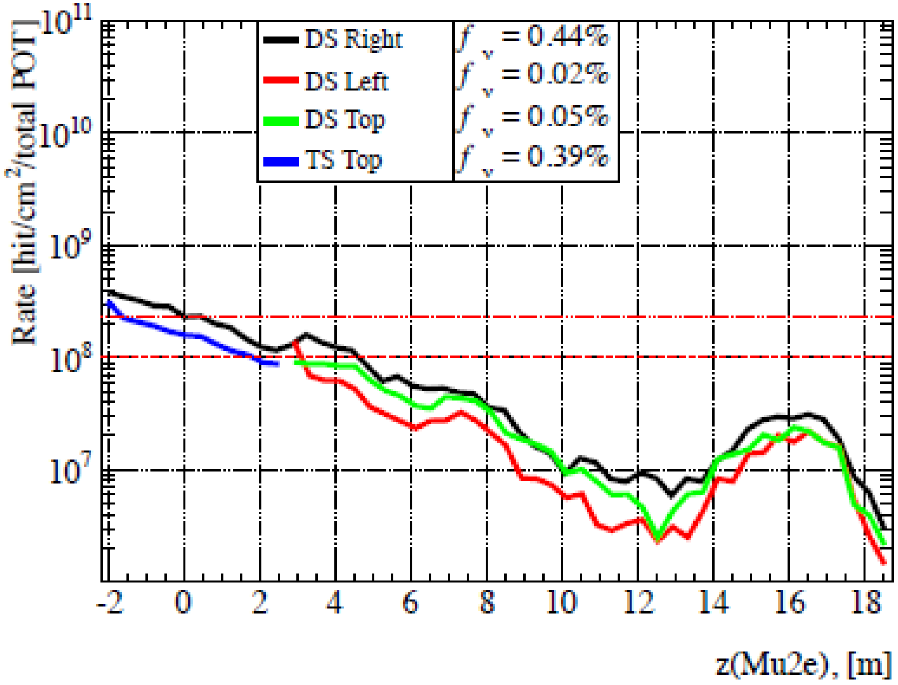


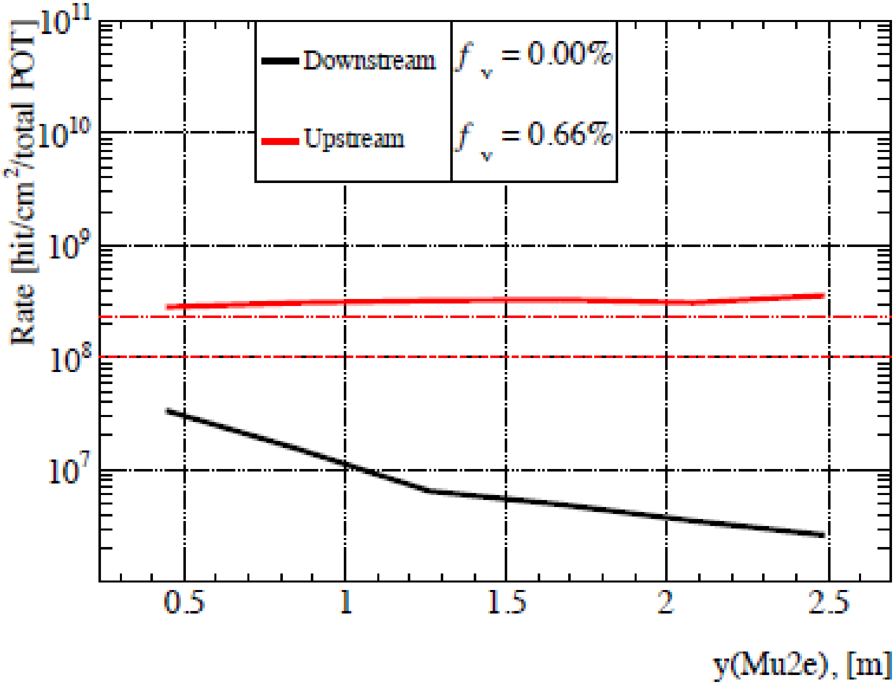


Semi-correlated CRV rates



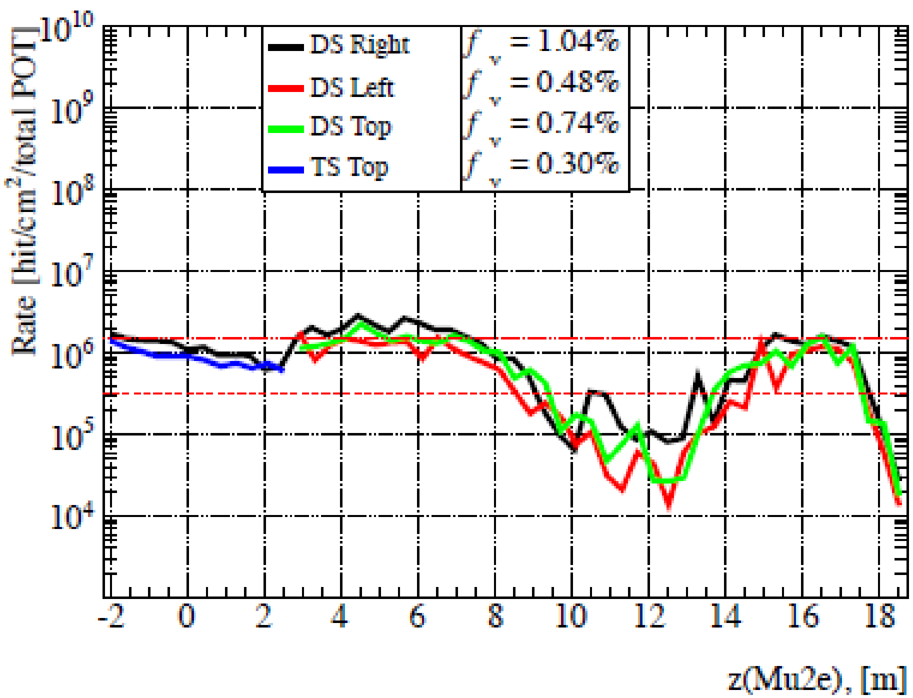
- Semi-correlated hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.

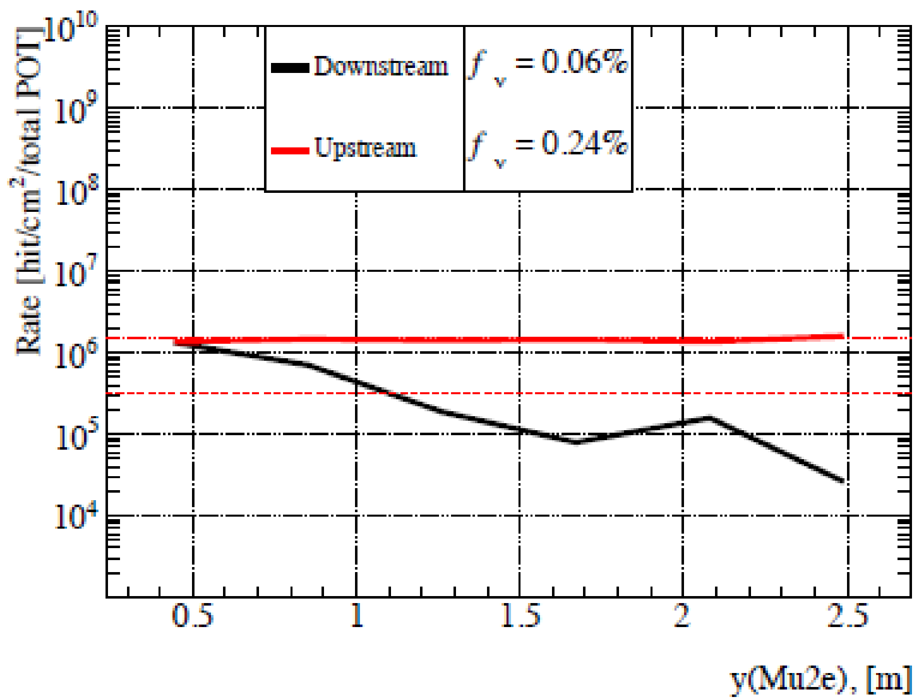




Correlated CRV rates

- Correlated hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.





Labor and Material per FY in AYk$