Fermilab

WBS 5 Muon Beamline
Mu2e CD-2 Review

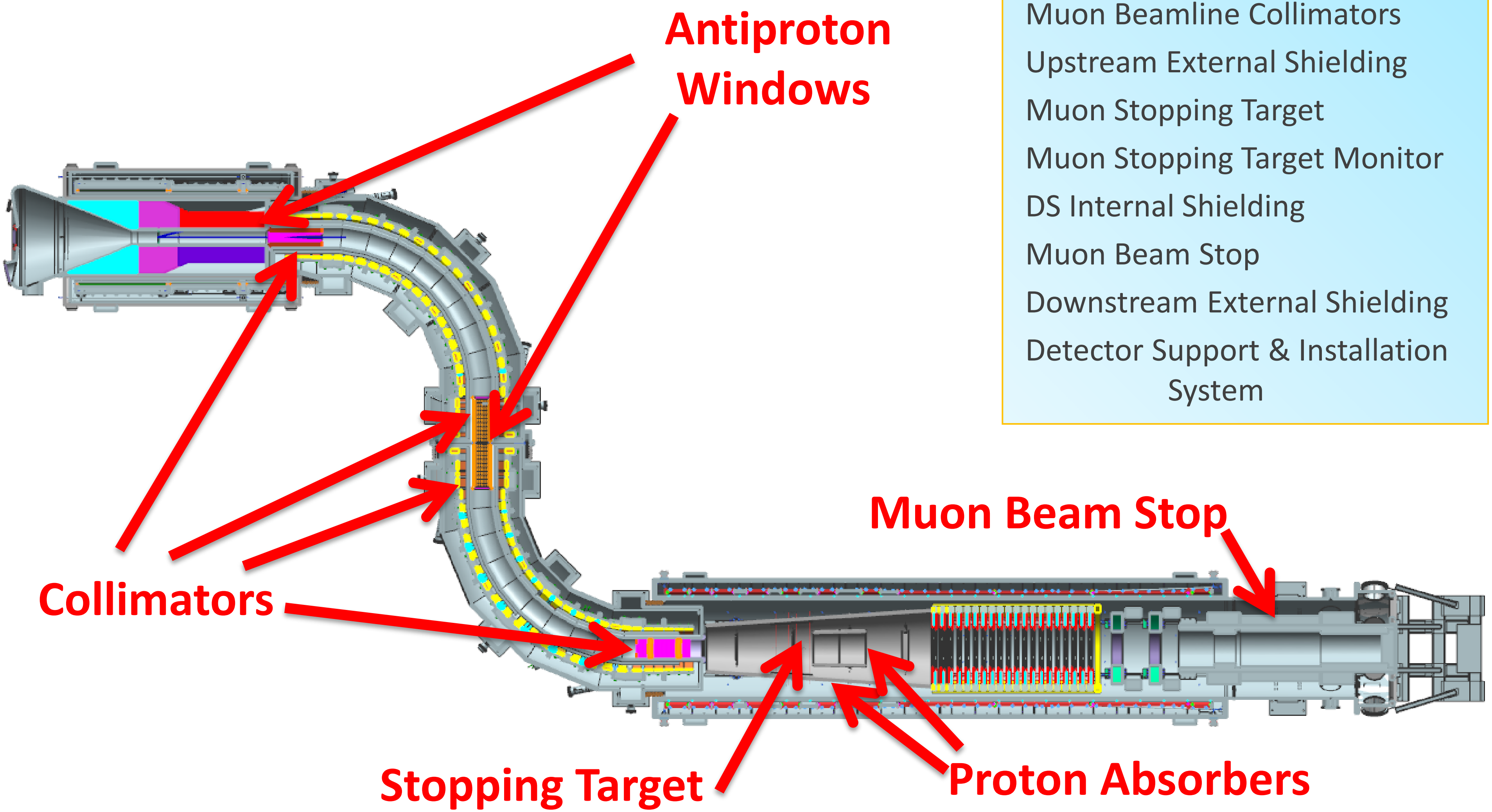
George Ginther
Muon Beamline Level 2 Manager
10/21/2014

L2 Manager’s Previous Experience

- Participated in a Fermilab prompt muon triggered charm search (1979-1985)
- Participated in assembly, operation and commissioning of the Fermilab E706 electromagnetic liquid argon calorimeter (1985-1988)
- Physicist-in-charge for Fermilab fixed target experiment E706 from 1988 through completion
- Physicist-in-charge for the SSC GEM Fermilab test beam program (1993)
  - Planned decommissioning of Meson West Spectrometer in anticipation of re-purposing beamline to serve as a GEM test beam and preliminary planning of the test beam installation and operation
- Level 4 for the DØ Run II Fiber Tracker VLPC cassettes (1997-2001)
  - 100000 channels, 5M$ M&S and team of ~10 people including engineer, techs, post doc and grad students
- Managed the CMS HCAL Motion Table fabrication the H2 beamline at CERN (1997-1999)
- Coordinated commissioning and operation of the DØ fiber tracker and preshower detectors (2001-2003)
- Level 2 co-manager for DØ Run IIb silicon tracker upgrade 2003 through project termination
  - Assisted in converting the successful R&D into the Run IIb Layer 0 project
- DØ Technical Integration Coordinator since 2004
  - Oversight of detector operations and data quality
  - Scheduled and coordinated shutdown activities, installation and commissioning of DØ Run IIb Upgrade project
- Particle Physics Division DØ Experiment Department Head (2007-2012)
  - ~40 department personnel in addition to technical support team
  - Managed department resources and facilities in support of the DØ experiment, the professional growth of the department staff, and other lab priorities as appropriate
- Currently serving as a Guest Scientist in the Technical Division (2012-2015)

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

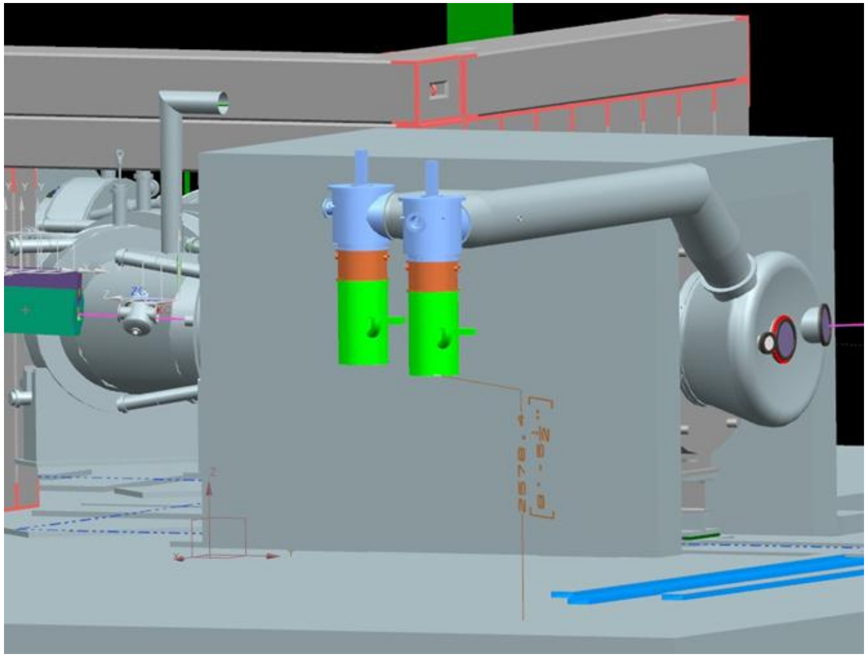
- Reduce heat load on TS superconducting coils
- Reduce background rates at detectors to facilitate efficient operation and experiment sensitivity
  - Shielding to reduce rates at the Cosmic Ray Veto
  - Shielding to reduce rates at the tracker
- Efficiently capture muons in the stopping target
  - 40% 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

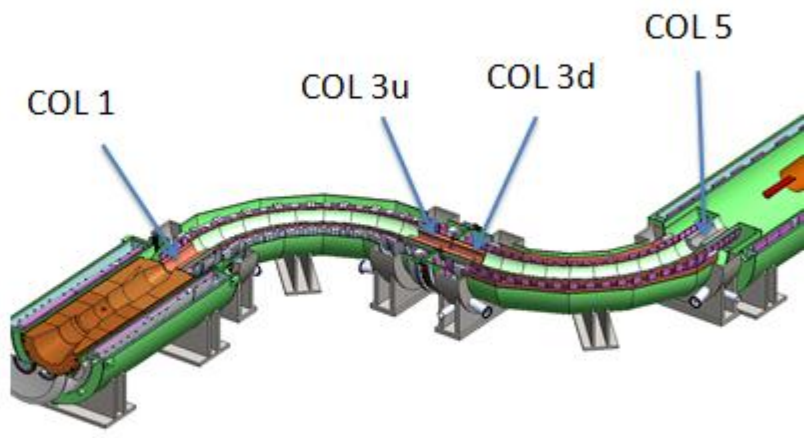
- Requirements documents are available via the Review web page

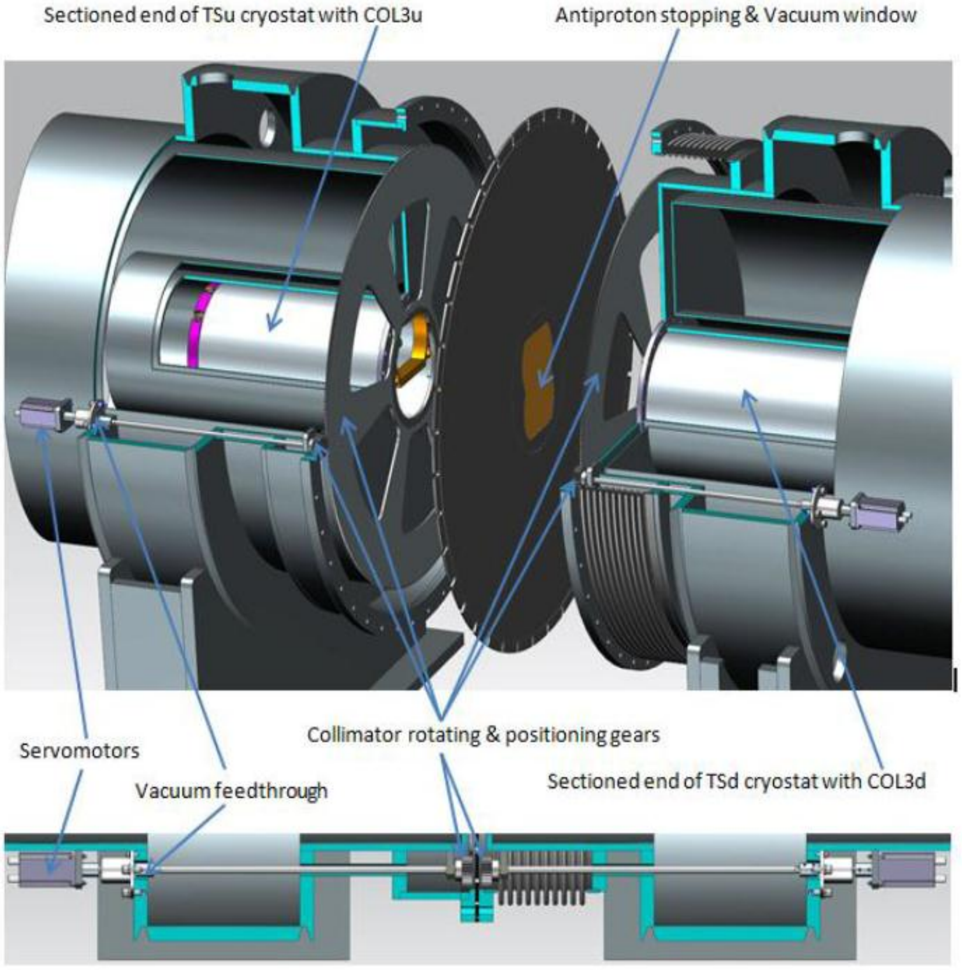
WBS 5.2 Muon Beamline Vacuum System Design



- 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

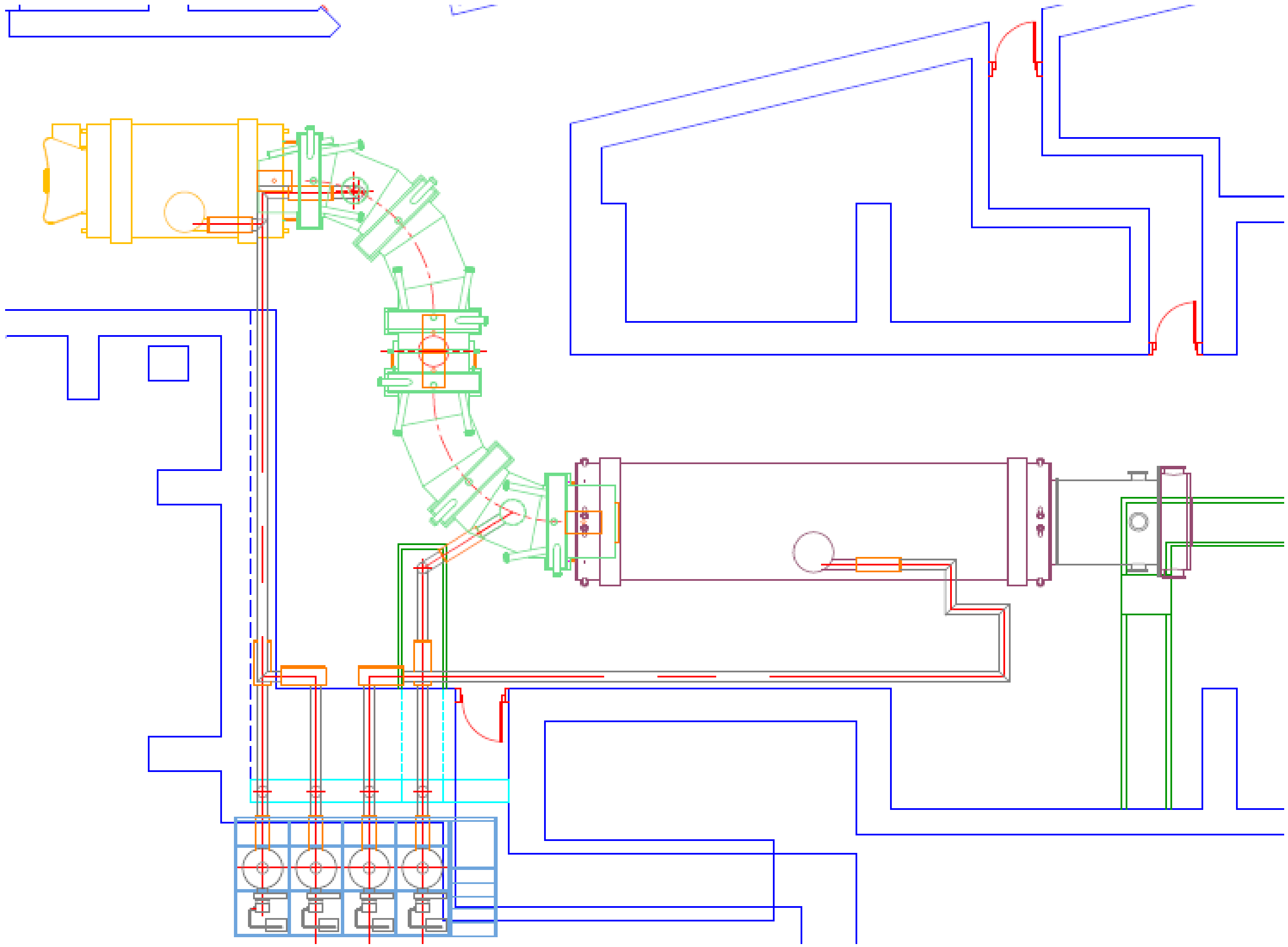
WBS 5.2 Muon Beamline Collimator Design



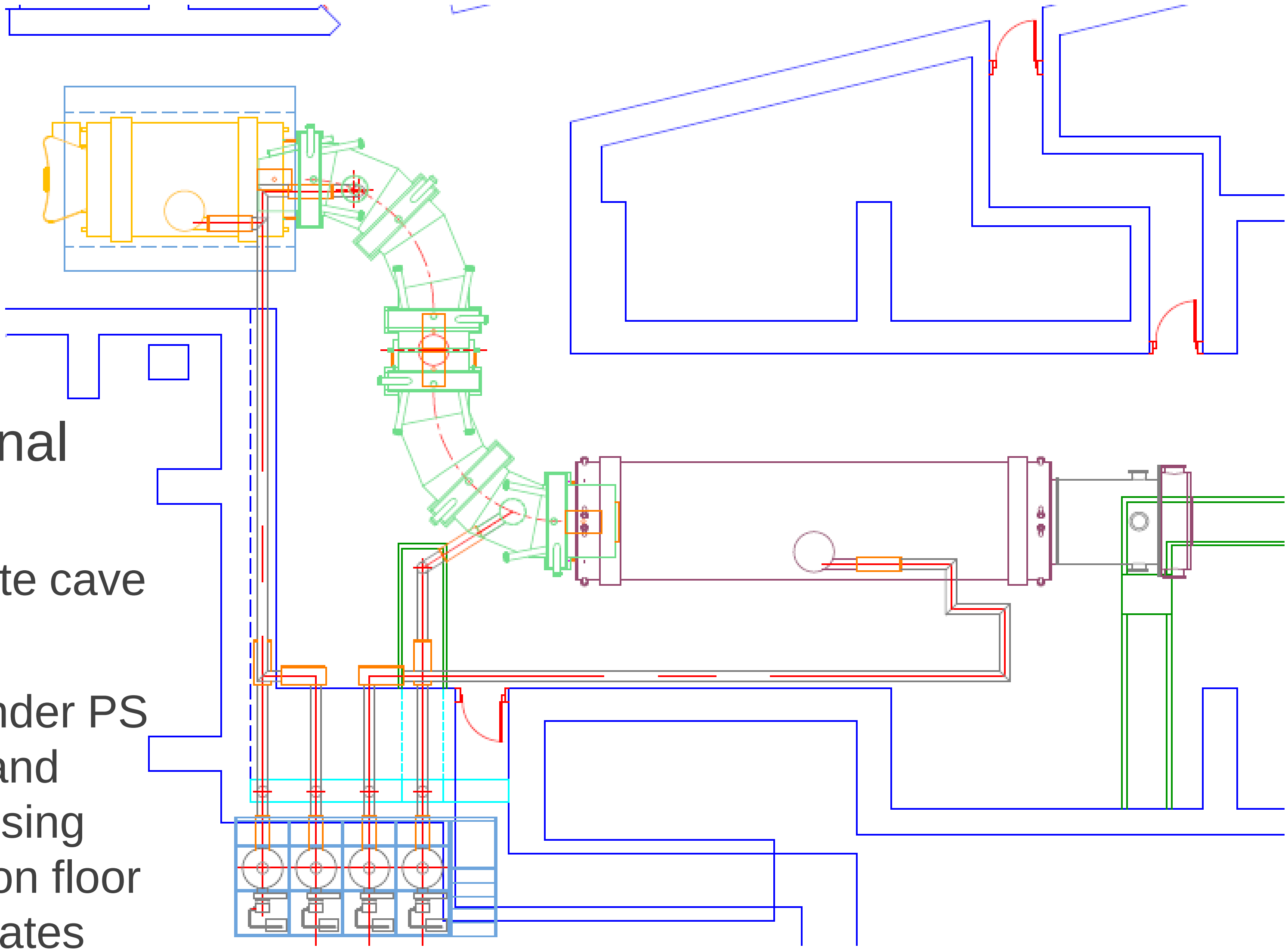


- COL 1, COL3u and COL3d are (primarily) copper
- COL 5 is poly
- COL3u and COL3d can be rotated to select positive charge for calibration purposes
- Antiproton window also isolates upstream from downstream vacuum space

WBS 5.4 and 5.9 External Shielding Design

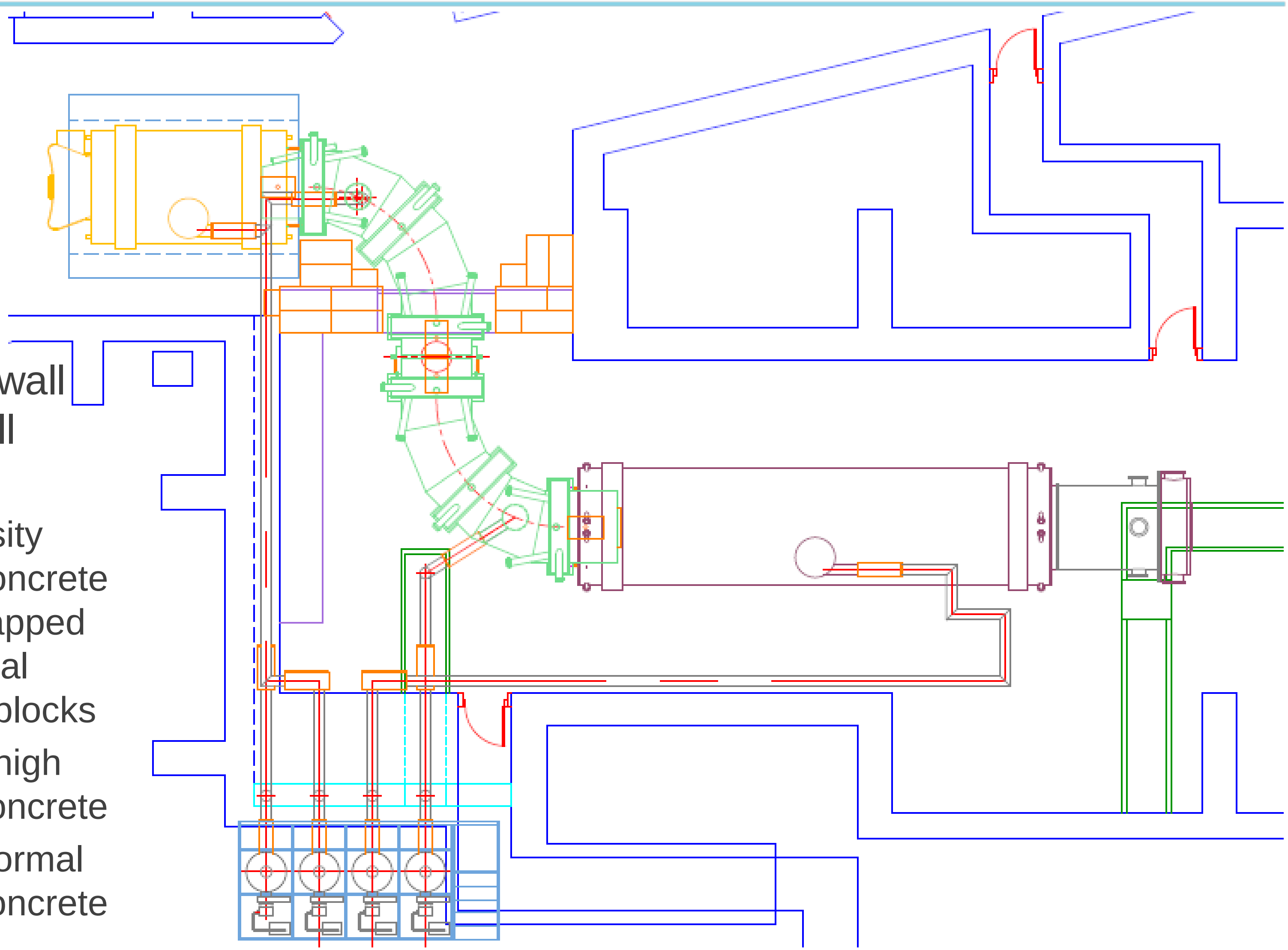


WBS 5.4 and 5.9 External Shielding Design



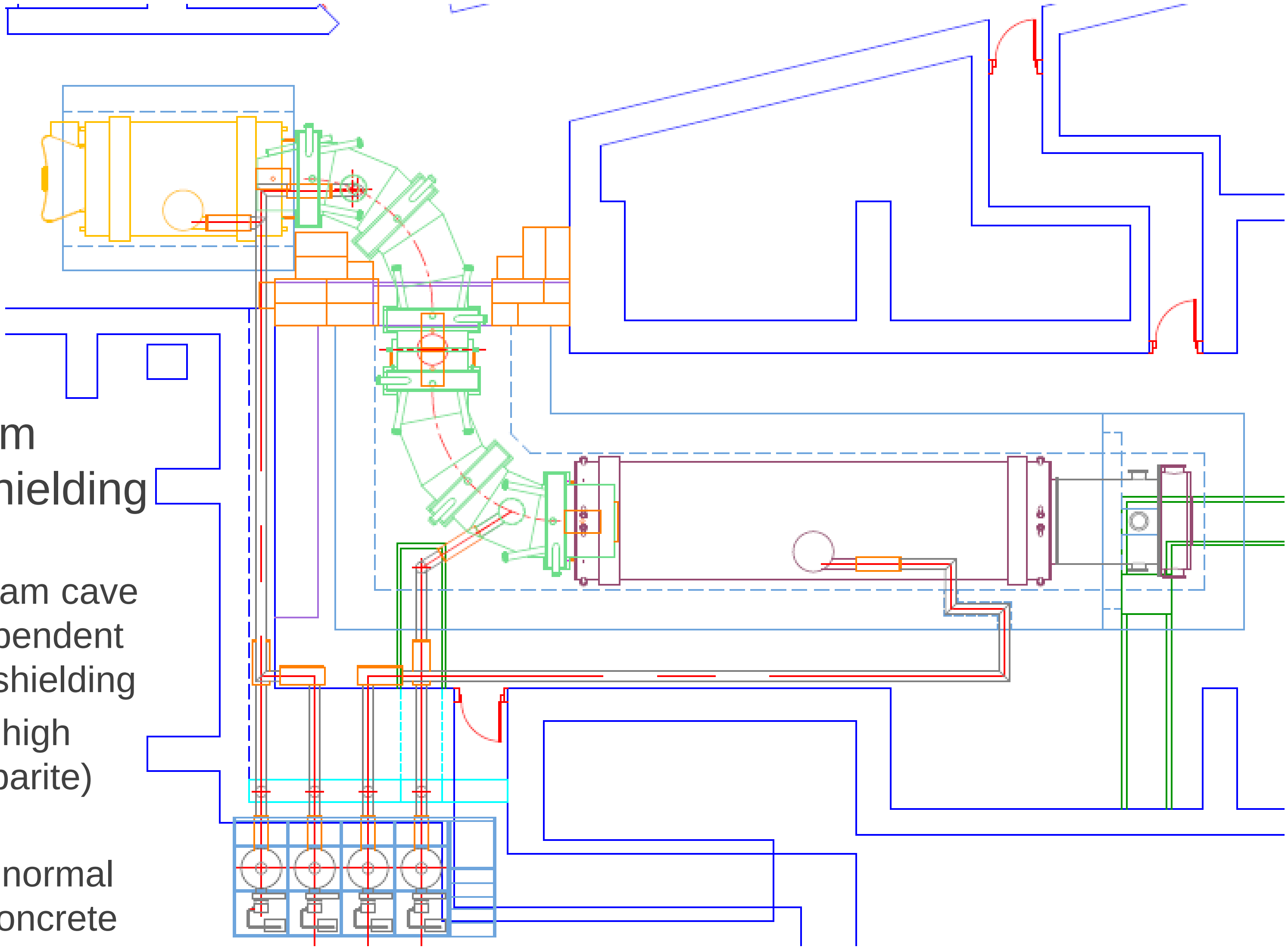
- PS External shielding
  - Concrete cave
  - 90 tons
  - Cast under PS Hatch and move using rollers on floor track plates

WBS 5.4 and 5.9 External Shielding Design



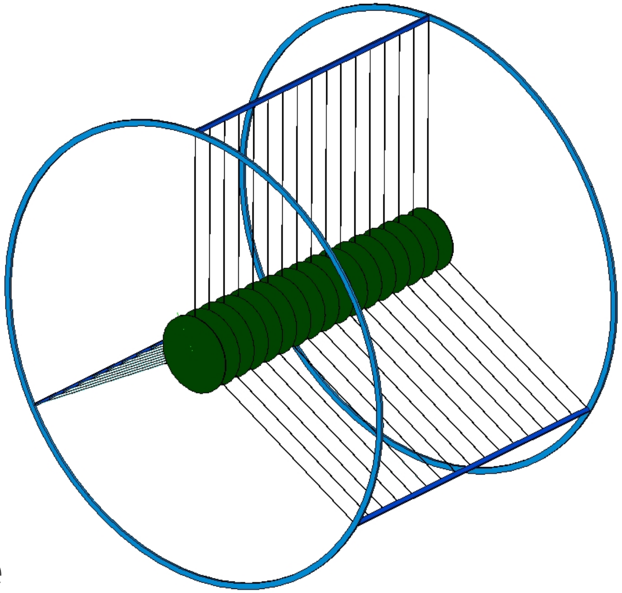
- TS isolation wall and west wall shielding
  - High density (barite) concrete blocks capped with normal concrete blocks
  - 242 tons high density concrete
  - 48 tons normal density concrete

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

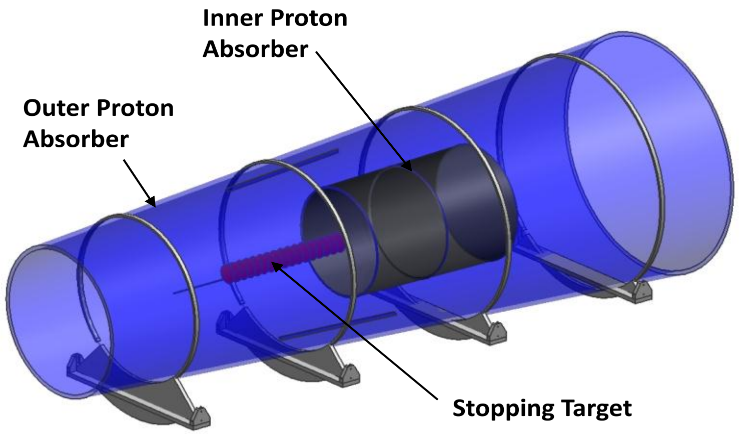
WBS 5.5 and WBS 5.6 Designs

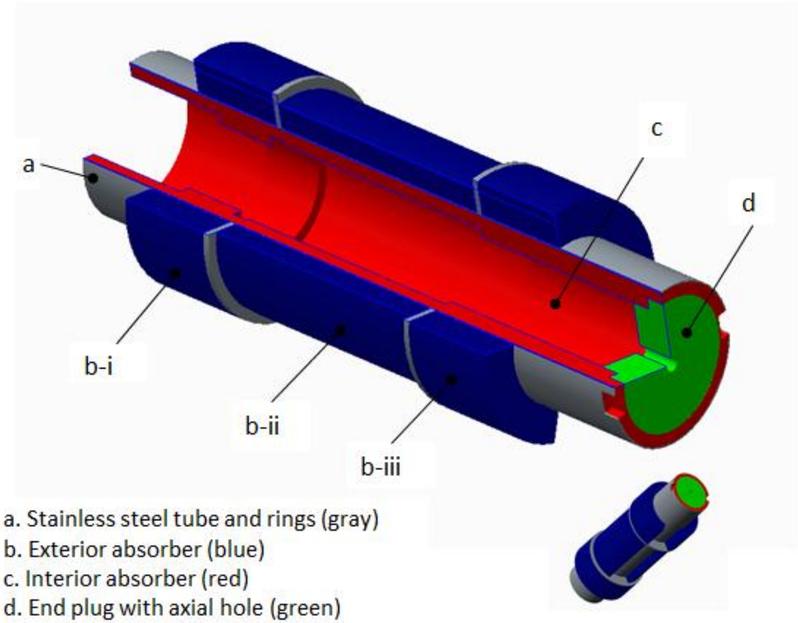


- WBS 5.5 Muon Stopping Target
  - Seventeen 200μm thick aluminum disks
  - Tungsten wire supports
- WBS 5.6 Muon Stopping Target Monitor
  - Stopping Target Monitor is a germanium detector monitoring delayed photons from the de-excitation of ^{27}Mg created by muon capture on aluminum
    - ^{27}Mg 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 magnetic field region
  - Sweeping magnet
  - Beam shutter protects detector from beam flash
  - Additional shielding surrounding detector

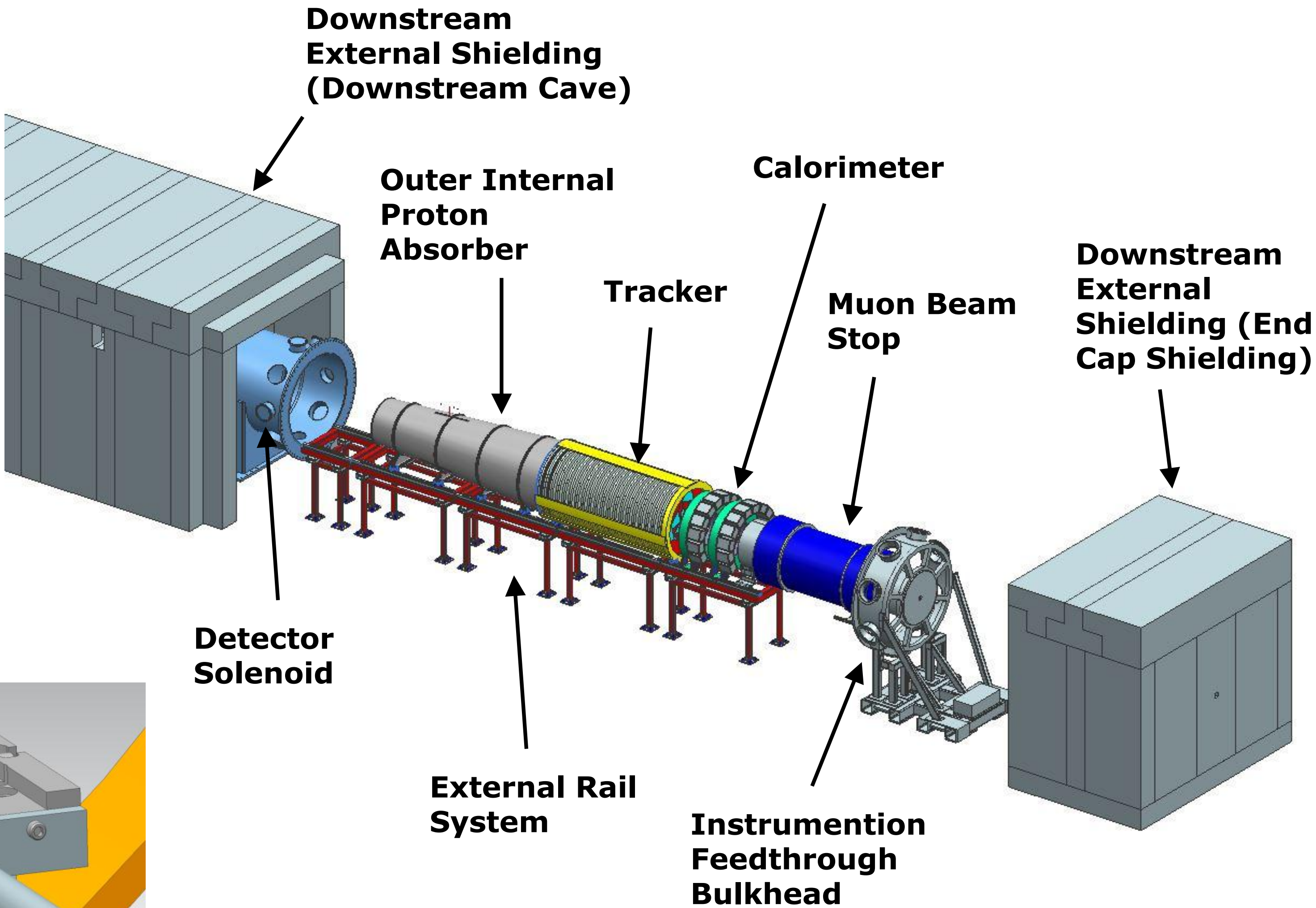
WBS 5.7 and WBS 5.8 Designs

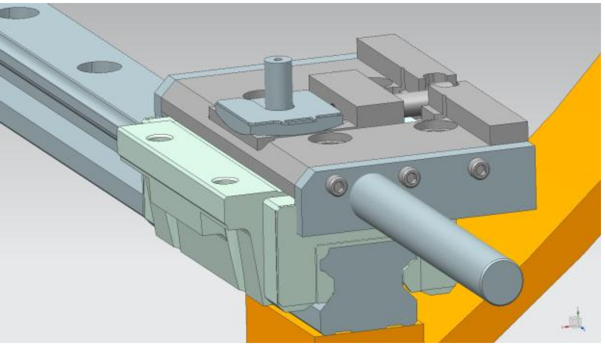
- WBS 5.7 Detector Solenoid Internal Shielding
  - 50 mm thick polyethylene covering the downstream end of the TSd cryostat vacuum jacket
  - Inner Proton Absorber
    - 0.5 mm thick
  - Outer Proton Absorber
    - 20 mm thick borated polyethylene
- WBS 5.8 Muon Beam Stop
  - Stainless steel tube supporting 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

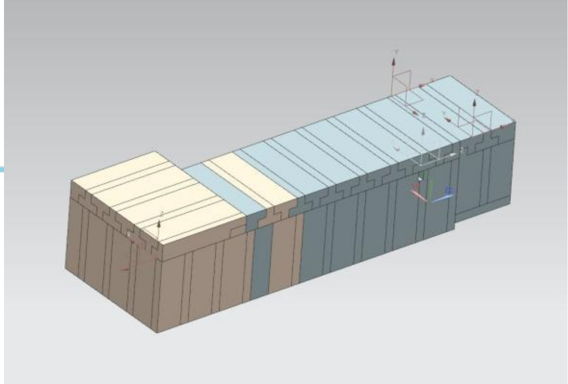




Improvements since CD-1

- New Level 2 manager appointed
- WBS 5.2 Muon Beamline Vacuum System
  - Dave Pushka now serving as the Level 3 manager
  - PS+TSu warm bore maxiumum operating pressure requirement modified 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
        - Introduces another volume to be purged or pumped
      - Explored and dropped poly liner inside TSu warm bore
      - Position upstream high vacuum pump closer to vacuum volume
      - 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

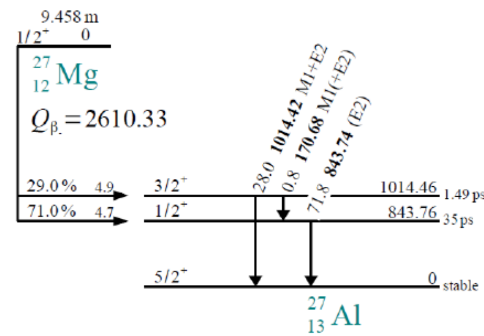
Improvements since CD-1



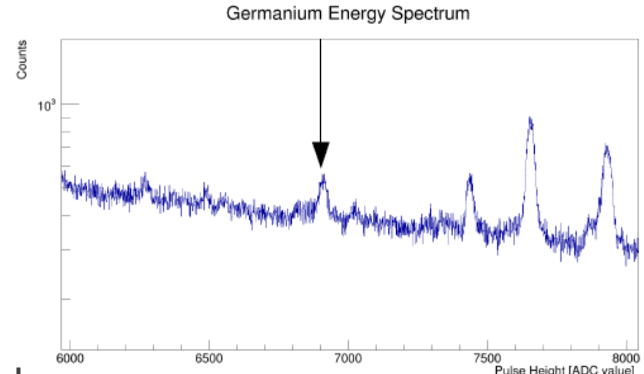
- WBS 5.3 Muon Beamline Collimators
  - Collimator locations shifted slightly
  - Additional optimization of antiproton suppression
    - Introduced an antiproton window in the vicinity of COL1
    - Refined geometry of antiproton window at the TSu/TSd interface
    - Added a lip on the downstream edge of the COL1 graphite liner
  - Now anticipate mag field instrumentation inside the collimators
- WBS 5.4 and 5.9 Upstream and Downstream 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 introduce high density concrete around stopping target
  - Extend cave to surround TSd (entirely high density concrete)
  - Minimize cracks in downstream cave (T-block design)
  - Incorporate penetration to facilitate DS thermosiphon cooling

Improvements since CD-1

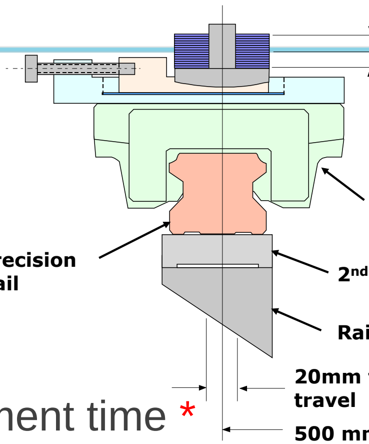
- WBS 5.7 Detector Solenoid Internal Shielding
  - Hank Glass now serving as the Level 3 manager
  - Inner Proton Absorber length reduced
  - Introduce Outer Proton Absorber
    - 0.4 tons additional borated polyethylene
  - Introduce TSdA
- WBS 5.5 Muon Stopping Target
  - Outer Proton Absorber surrounds Muon Stopping Target complicating support
  - Prototyping to refine target support material
- WBS 5.6 Muon Stopping Target Monitor
  - Switch to delay gamma signal
  - Introduce beam shutter
- 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



$^{27}\mathrm{Mg}_{\mathrm{nucl}}\,(844\ \mathrm{keV})$

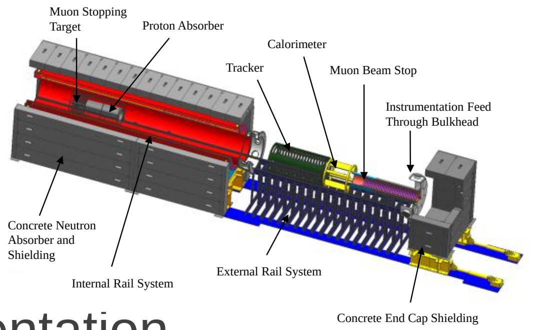


Improvements since CD-1

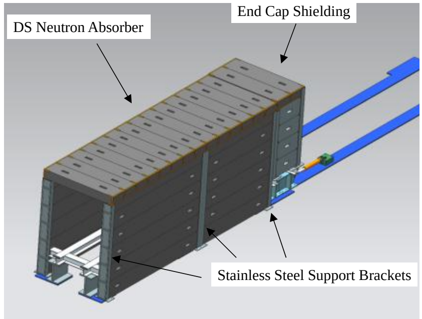


- WBS 5.10 Detector Support and Installation System
  - Develop 2nd tier bars in rail alignment system *
    - Based upon experience with rail system mock-up
  - Refined external rail supports design
    - Fewer individual stands should reduce installation/alignment time *
    - Reduced footprint will 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

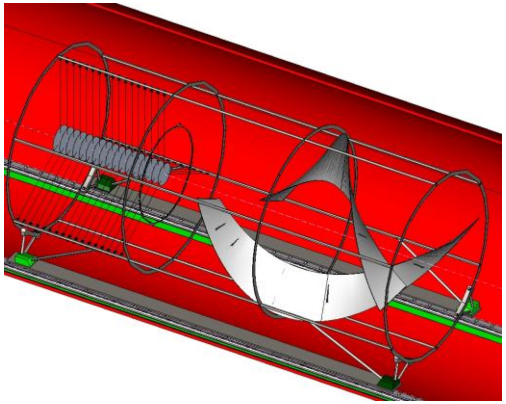


- Diffusion pumps instead of cryo pumps
- Instrumentation/ports to verify COL3u and COL3d orientation
- Shielding related optimizations
  - Investigate less expensive shielding materials
    - Employ high density concrete instead of copper or stainless steel
    - Increase concrete thickness instead 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

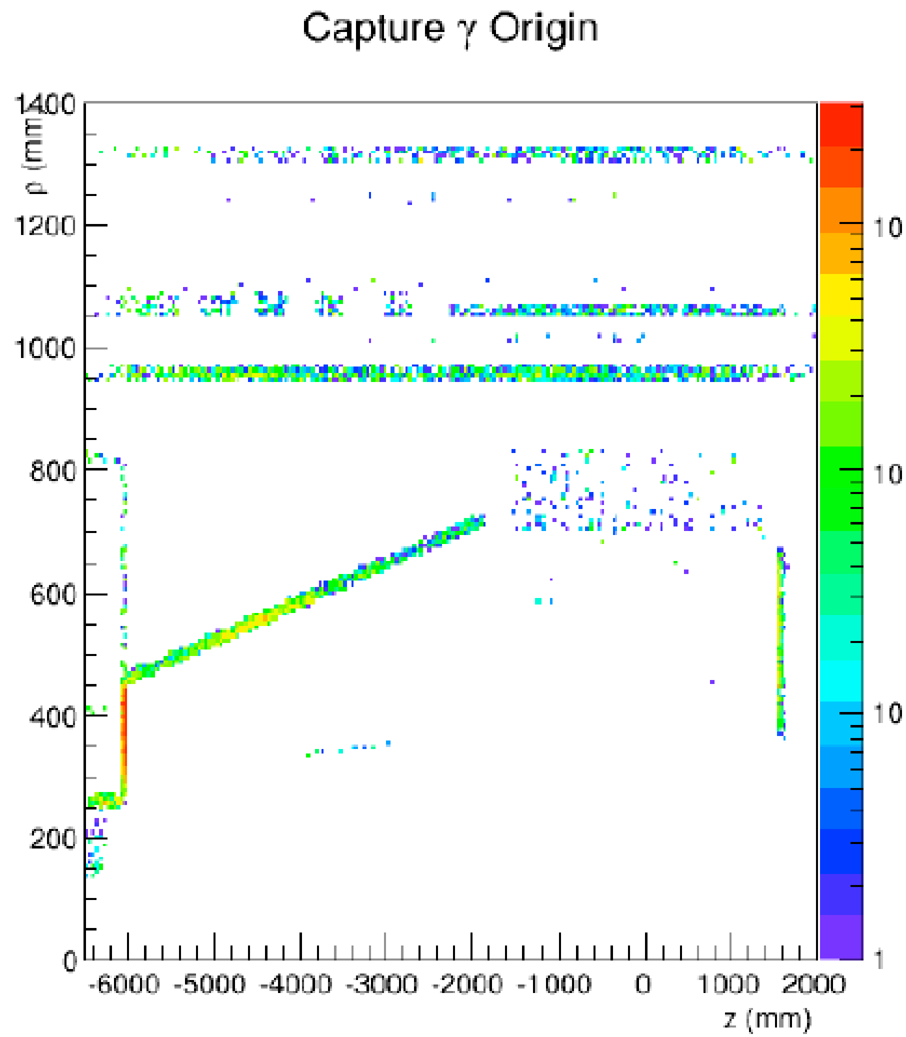
- Explored and eliminated poly liner within TS warm bore
- Confirmed copper as the material of choice for COL3
- Confirmed poly as the material of choice for COL5
- Explored and eliminated inner neutron absorbers (from DS bore)
- Inner proton absorber
  - Frustum selected over blade configuration



- Explored many different shielding configurations and identified one that addresses detector performance requirements

Muon Beamline Vacuum and Shielding Performance

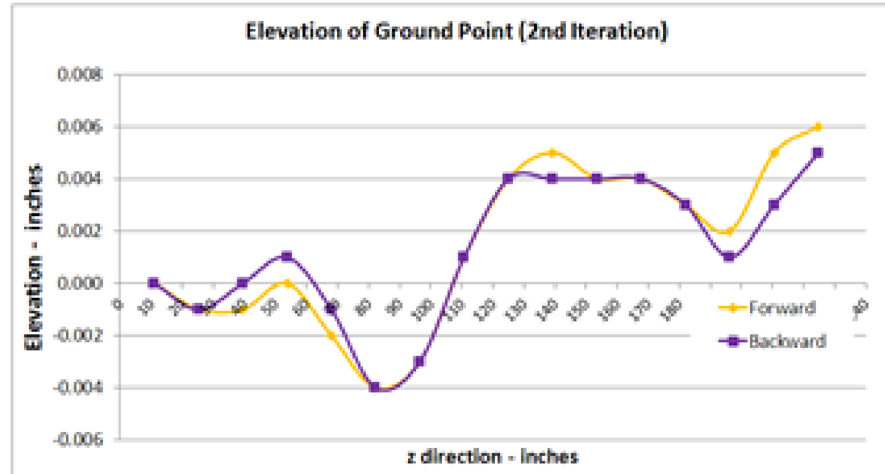
- Many muon beamline deliverables are particularly sensitive to and dependent upon interfaces with most other subsystems
  - Based upon current gas load and pumping configuration, anticipate after 10 hours
    - PS+TSu pressure 5×10^{-5} torr
    - TSd+DS pressure 6×10^{-4} torr
    - Once outgassing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

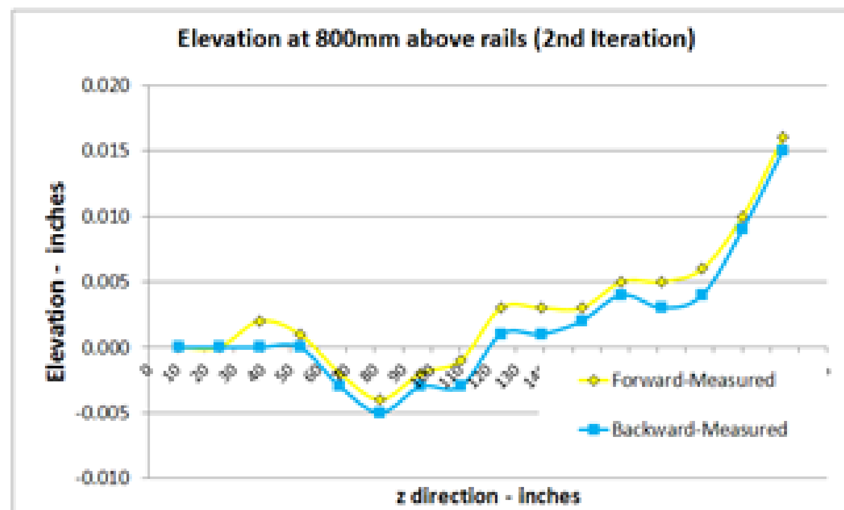


D. Brown Mu2e docdb 3479

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

Integration and Interfaces

- Muon Beamline has external interfaces to Accelerator, Conventional Construction, Solenoids, Tracker, Calorimeter, CRV, and Trigger & DAQ
- The muon beamline level 3 subsystems each have interfaces to other several muon beamline level 3 subsystems
- The external and internal interfaces are identified and described in the WBS dictionary and the Muon Beamline interface document (docdb 1168).
- Identifying and addressing interfaces and integration is central to muon beamline
  - Bi-weekly muon beamline meetings
  - Regular participation in mechanical and electrical integration meetings
  - Regular participation in accelerator target station, solenoid, CRV and calorimeter meetings
  - Highlight key features at Mu2e Tech Board meetings
  - Participated in conventional construction formal value engineering exercise
  - Review of conventional construction plans (and participated in conventional construction meetings)
  - Formal sign-off between owners of all external interfaces will be part of the final design process

Muon Beamline Organization

475.5
Muon Beamline
G. Ginther (FNAL/Rochester)
L2 Manager and CAM

- 475.5.1 MB Project Management
  L3 – G. Ginther
- 475.5.2 MB Vacuum System
  L3 – D. Pushka
- 475.5.3 MB Collimators
  L3 – N. Andreev
- 475.5.4 Upstream External Shielding
  L3 – N. Andreev
- 475.5.5 Stopping Target
  L3 – J. Miller
- 475.5.6 Stopping Target Monitor
  L3 – J. Miller
- 475.5.7 DS Internal Shielding
  L3 – H. Glass
- 475.5.8 Muon Beam Stop
  L3 – R. Bossert
- 475.5.9 Downstream External Shielding
  L3 – R. Bossert
- 475.5.10 Detector Support and Installation System
  L3 – R. Bossert
- 475.5.11 MB Integration
  L3 – G. Ginther

- J. Brandt, G. Gallo, S. Krave, and B. Woods are providing significant additional engineering
- York is contributing to the vacuum system
- Boston University is involved in stopping target and stopping target monitor
- NIU 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)
- Accelerator Physics Center 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 Specialist

Quality Assurance

- Quality Assurance in the muon beamline efforts 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
    - 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

- Risks are being mitigated to the extent possible
- After mitigation, three identified muon beamline related risks remain (at the moderate or higher classification level)
  - All three represent potential threats
    - Muon-138 Detector installation takes longer than anticipated
      - Classified as a high risk due to potential cost impact
    - Muon-146 Rate exceeds muon stopping target monitor capability
      - Classified as a moderate risk
    - Muon-147 Degrader required for calibration
      - Classified as a moderate risk
- One risk has been retired
- Nine risks are being mitigated and the residual risk has been transferred
- Mitigation plans for the identified risks are documented in forms available on docdb, and linked from the Risk Register (docdb 4320)

ES&H

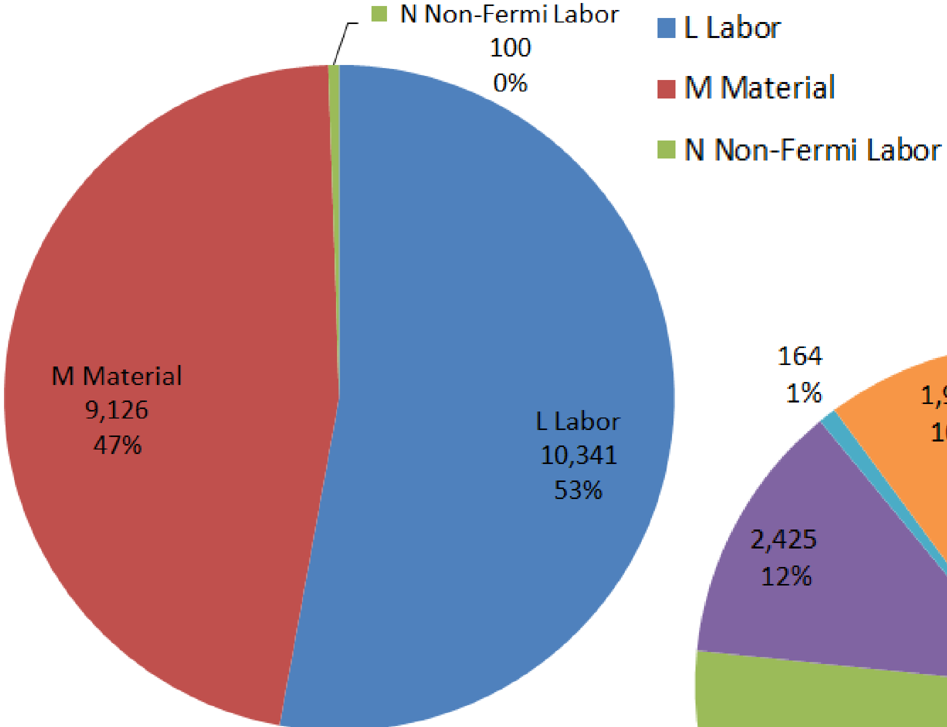
- To perform muon beamline activities safely will require appropriate planning (JHA), attention to ES&H considerations and FESHM and FRCM requirements
  - Vacuum vessels FESHM 5033
  - Thin windows on the vacuum vessel FESHM 5033.1
    - Possibly beryllium (hazardous materials) FESHM 5052.5
  - Inspection 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

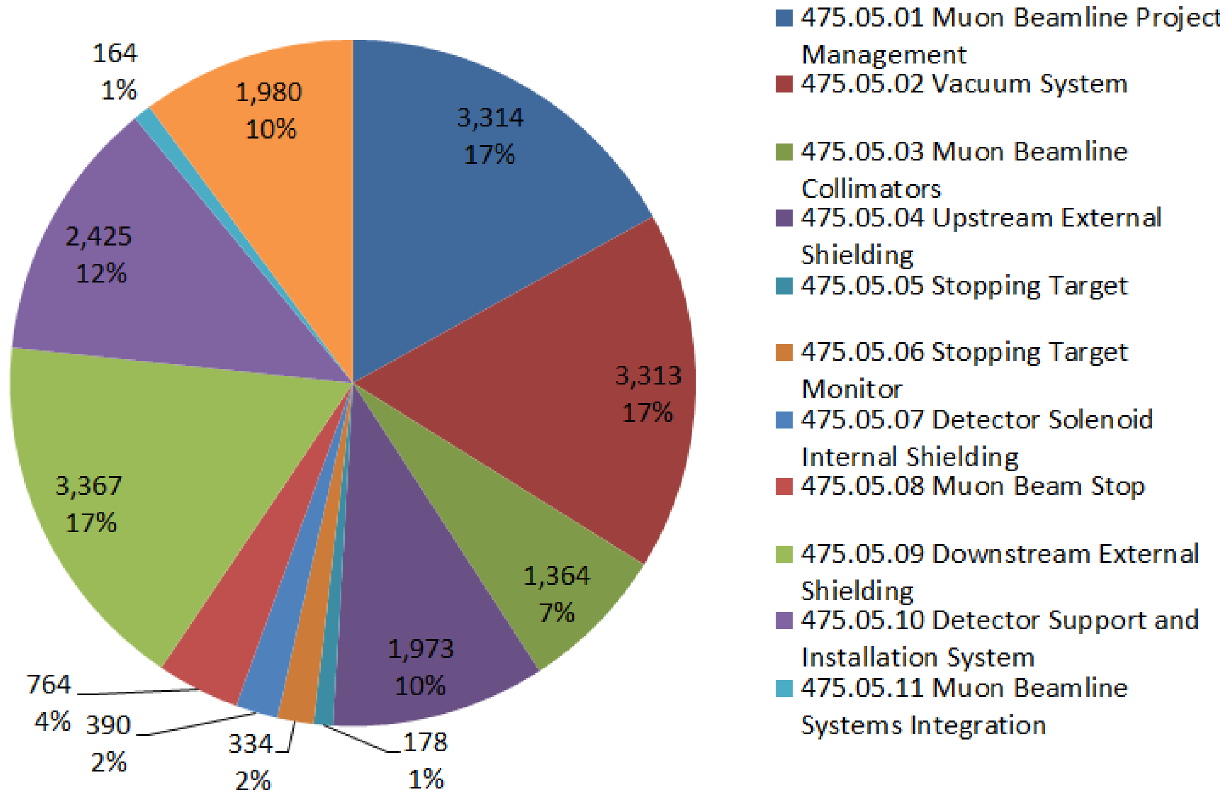
Muon Beamline Cost Table (k$)

	Base Cost (AY K$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency on (on remaining budget)	Total Cost
475.05 Muon Beamline						
475.05.01 Muon Beamline Project Management	71	3,243	3,314	260	10%	3,573
475.05.02 Vacuum System	2,058	1,255	3,313	1,191	39%	4,505
475.05.03 Muon Beamline Collimators	737	628	1,364	527	44%	1,891
475.05.04 Upstream External Shielding	1,369	604	1,973	808	47%	2,781
475.05.05 Stopping Target	61	118	178	66	39%	245
475.05.06 Stopping Target Monitor	192	142	334	185	56%	518
475.05.07 Detector Solenoid Internal Shielding	188	202	390	119	35%	509
475.05.08 Muon Beam Stop	475	289	764	219	37%	983
475.05.09 Downstream External Shielding	2,539	828	3,367	1,368	45%	4,735
475.05.10 Detector Support and Installation System	1,404	1,021	2,425	644	32%	3,069
475.05.11 Muon Beamline Systems Integration	27	138	164	68	55%	232
475.05.13 Muon Beamline Conceptual Design/R&D	107	1,873	1,980		0%	1,980
475.05.99 Risk Based Contingency				468	-	468
Grand Total	9,226	10,341	19,567	5,922	39%	25,490

Cost Breakdown

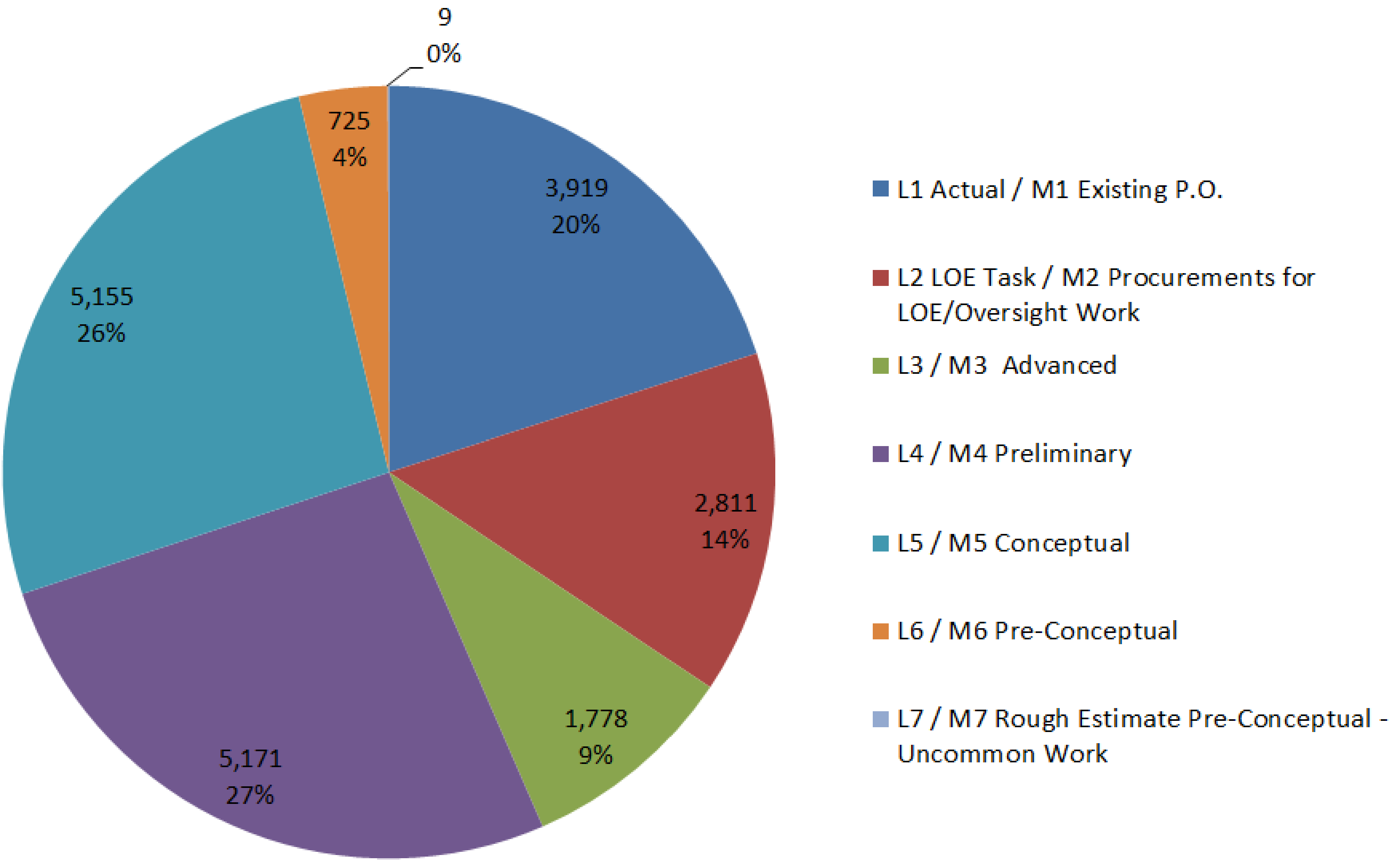
Base Costs in AY k$



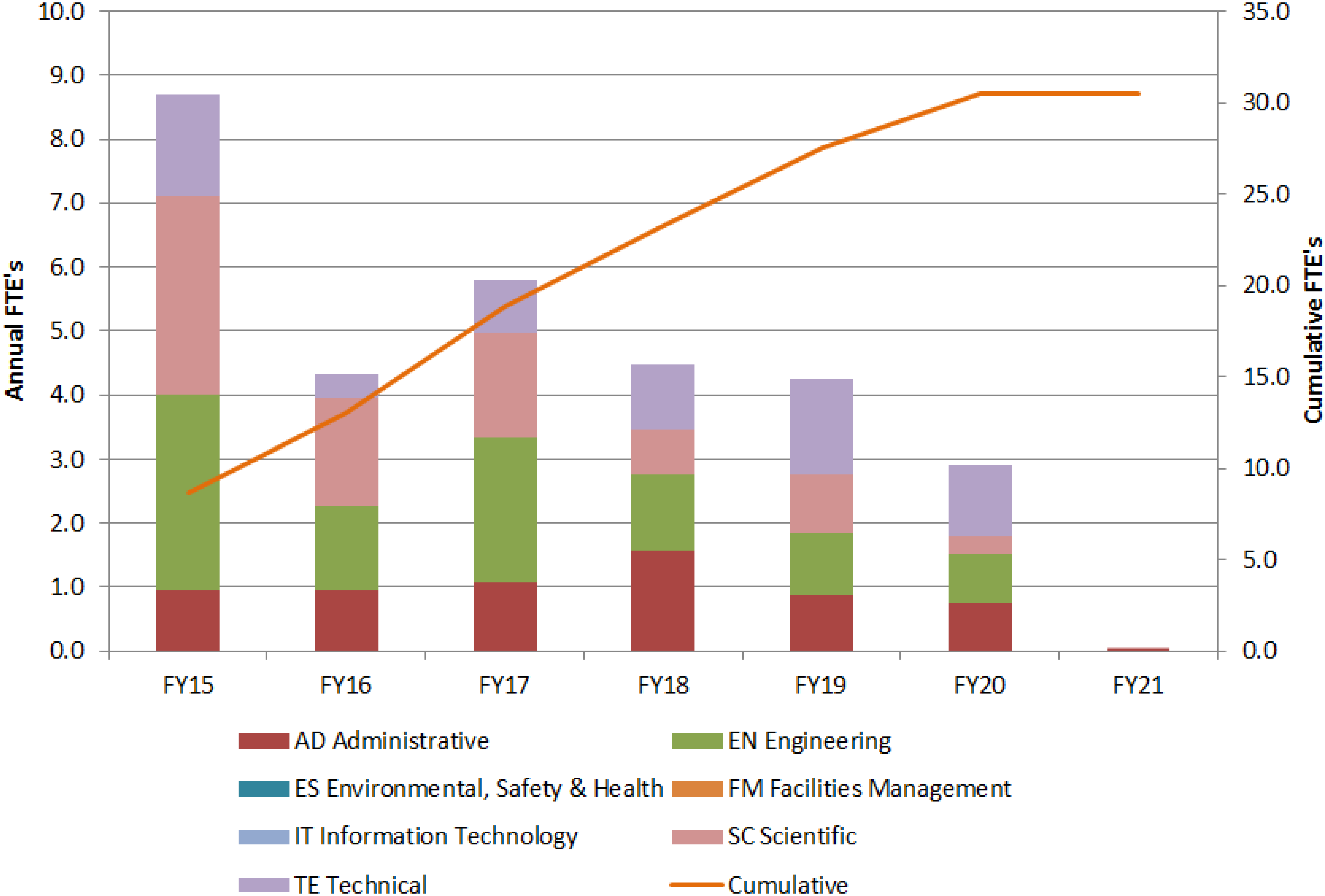


Quality of Estimate

Base Costs in AY k$



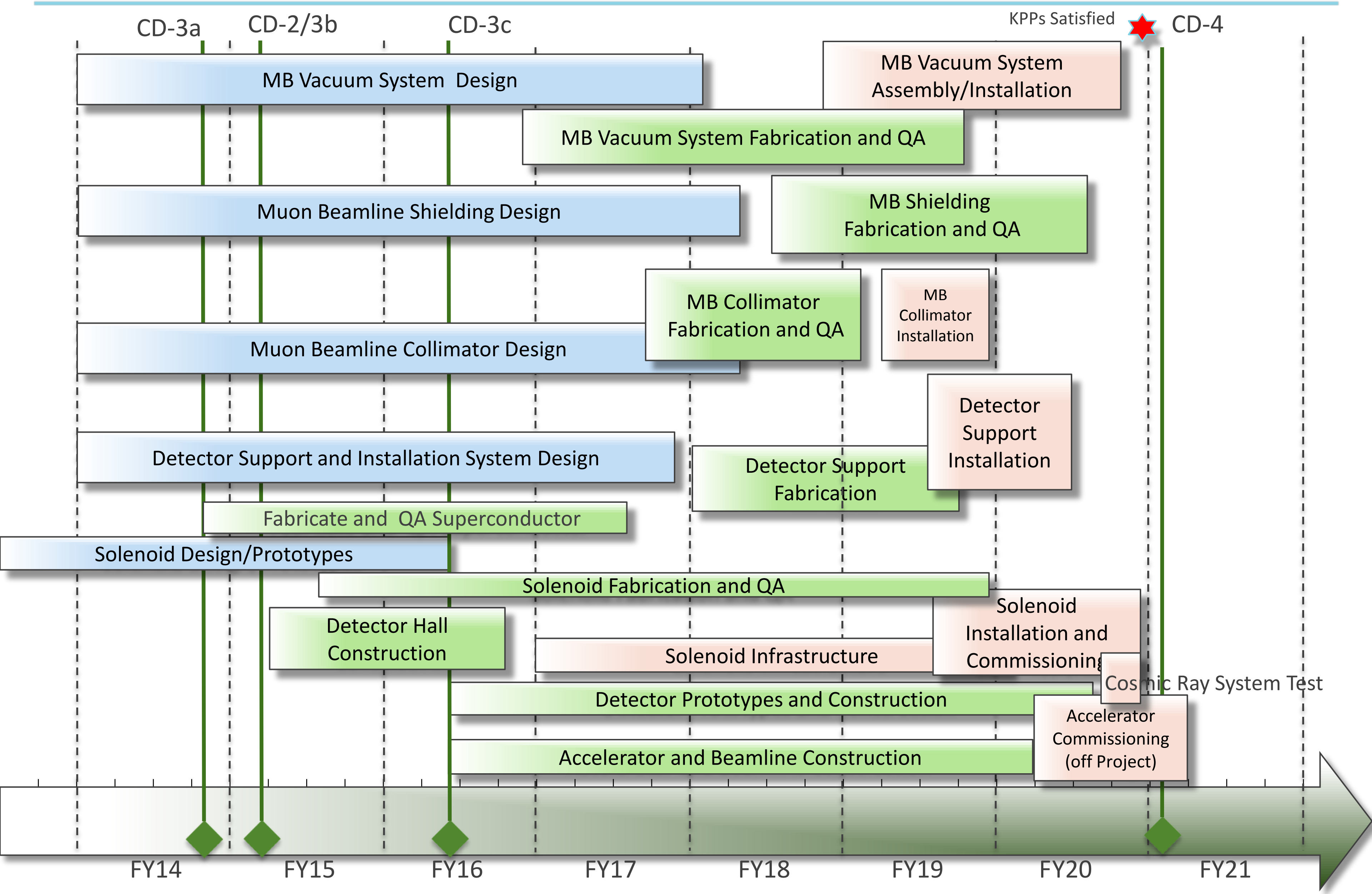
Labor Resources by FY



Major Milestones

• Muon Beamline ready for CD-3c review	15-Dec-2015
• External vacuum components ready for fabrication	9-Dec-2016
• Downstream External Shielding ready for fabrication	17-Nov-2017
• All external vacuum system components at FNAL	15-Sep-2017
• Upstream Shielding ready for fabrication	26-Jan-2018
• DS Internal Shielding ready for fabrication	26-Jan-2018
• Muon Beam Stop and Supports at FNAL	11-Apr-2018
• Stopping Target at FNAL	26-Apr-2018
• Stopping Target Monitor Infrastructure at FNAL	09-Oct-2018
• PS enclosure ready	15-Oct-2018
• COL1 installed	22-Jan-2019
• All DS enclosure components at FNAL	12-Mar-2019
• COL3u and COL3d installed	30-Aug-2019
• COL5 installed	9-Sep-2019
• Detector Train Test Insertion Complete	21-Feb-2020
• Muon Beamline Ready for CD-4	16-Jun-2020

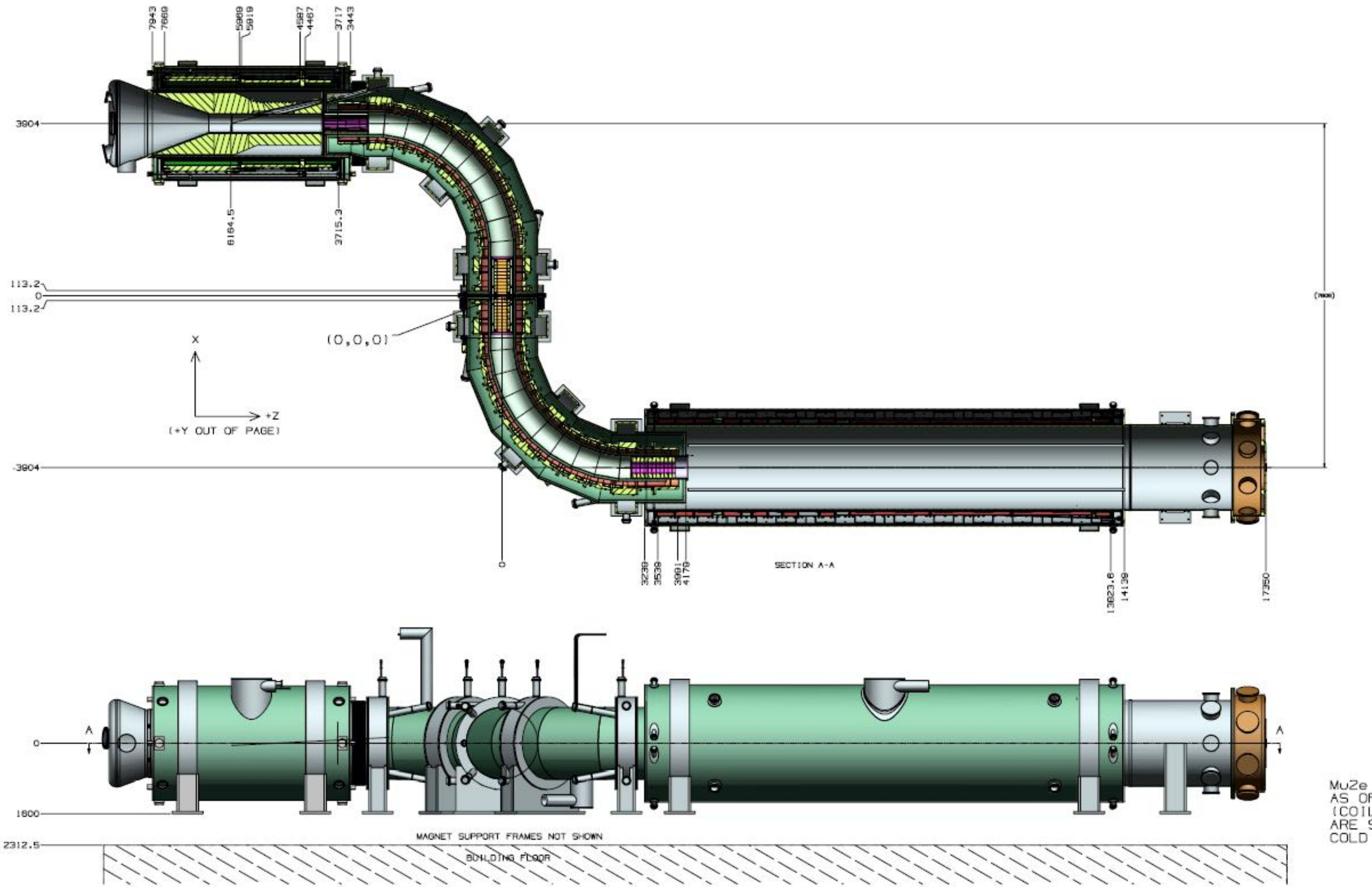
Schedule



CD-3a
CD-2/3b
CD-3c
KPPs Satisfied
CD-4
MB Vacuum System Design
MB Vacuum System Assembly/Installation
MB Vacuum System Fabrication and QA
Muon Beamline Shielding Design
MB Shielding Fabrication and QA
MB Collimator Fabrication and QA
MB Collimator Installation
Muon Beamline Collimator Design
Detector Support Installation
Detector Support and Installation System Design
Detector Support Fabrication
Fabricate and QA Superconductor
Solenoid Design/Prototypes
Solenoid Fabrication and QA
Solenoid Installation and Commissioning
Detector Hall Construction
Solenoid Infrastructure
Cosmic Ray System Test
Detector Prototypes and Construction
Accelerator Commissioning (off Project)
Accelerator and Beamline Construction
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
- Cost estimate are complete
  - 70% of the costs understood at the preliminary design level or better
- Interfaces are identified
- Risks are understood and being mitigated to the extent possible
- 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
- Muon Beamline is prepared for CD-2



7943
7669
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5919
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4487
3717
3443
3804
6164.5
3715.3
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113.2
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X
+Z
(+Y OUT OF PAGE)
-3804
0
3238
3538
3981
4178
SECTION A-A
13823.6
14138
17350
A
A
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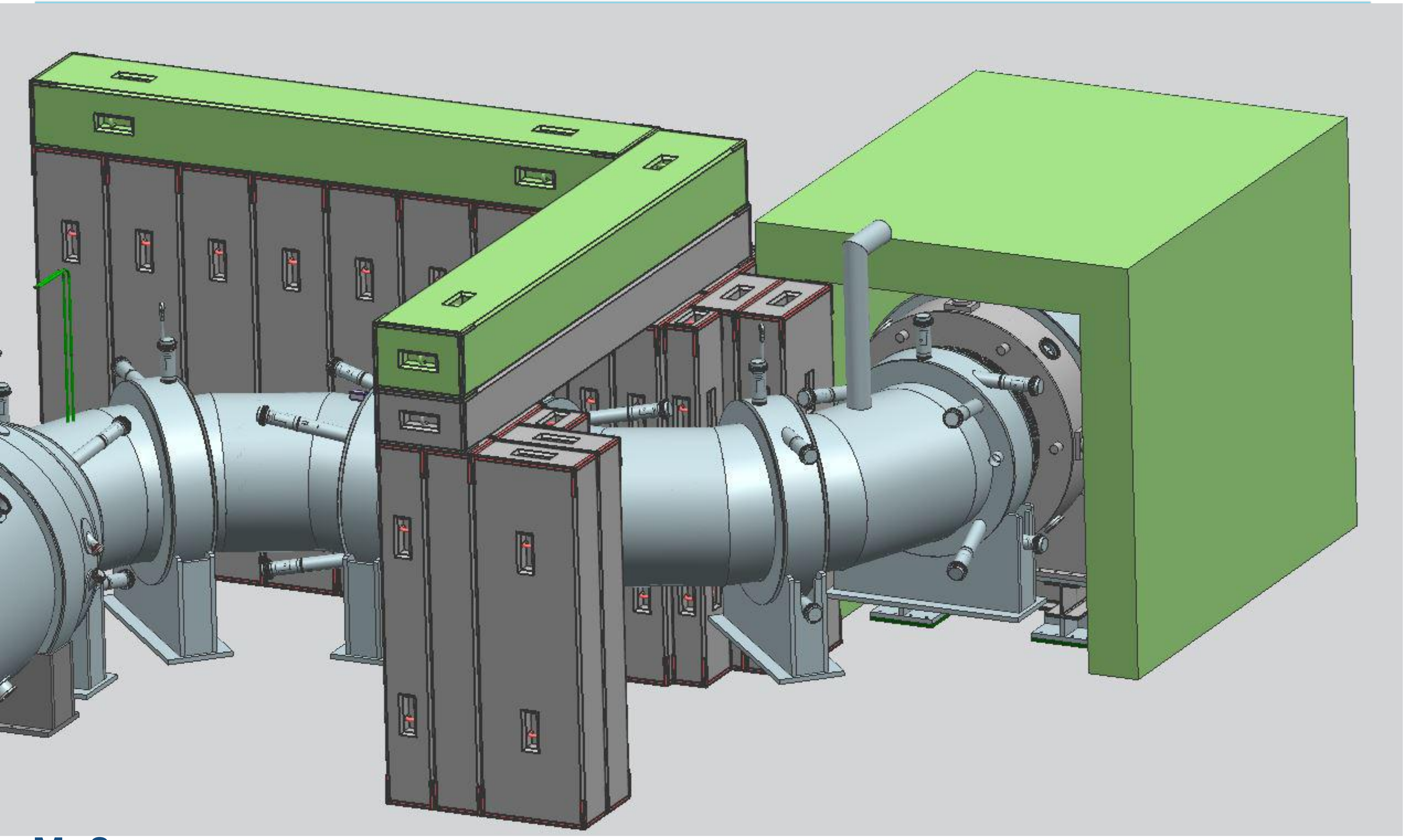
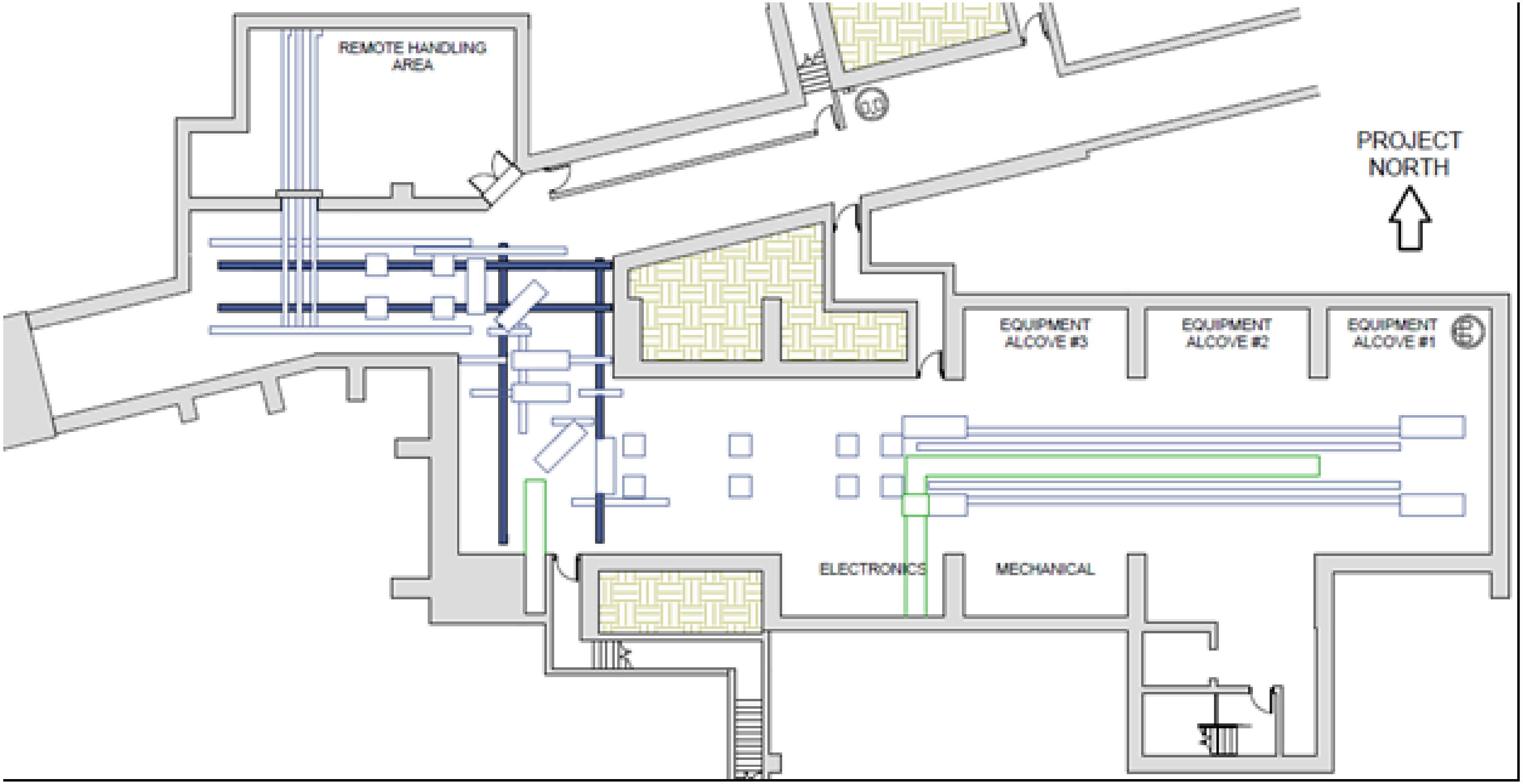
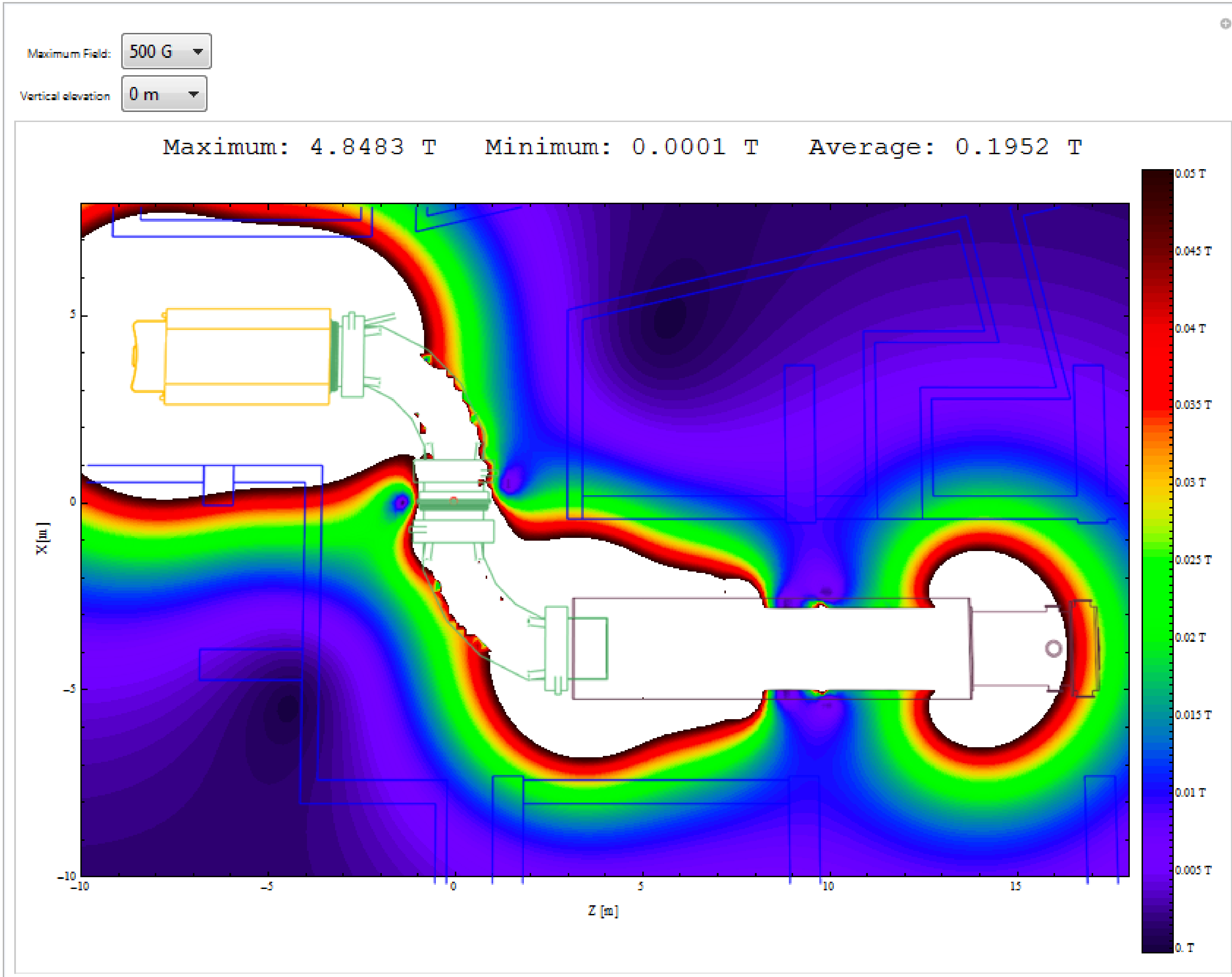
1600
2312.5
MAGNET SUPPORT FRAMES NOT SHOWN
BUILDING FLOOR

WBS 5.4 Upstream External Shielding



Floor track plate layout

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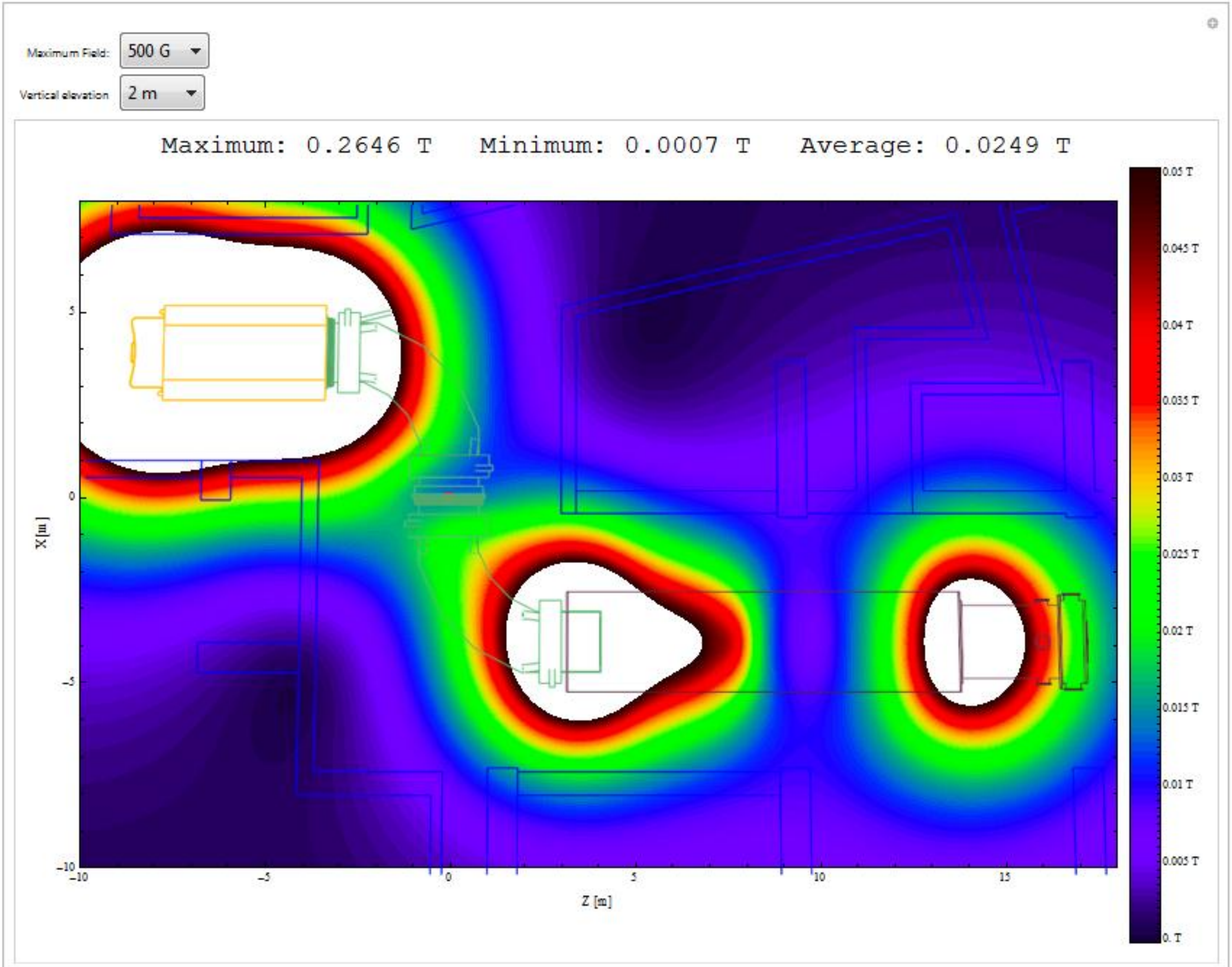
500 G
Vertical elevation
0 m
Maximum: 4.8483 T Minimum: 0.0001 T Average: 0.1952 T
X [m]
Z [m]
0.05 T
0.045 T
0.04 T
0.035 T
0.03 T
0.025 T
0.02 T
0.015 T
0.01 T
0.005 T
0. T



Maximum Field: 500 G
Vertical elevation 2 m
Maximum: 0.2646 T Minimum: 0.0007 T Average: 0.0249 T
X [m]
Z [m]
0.05 T
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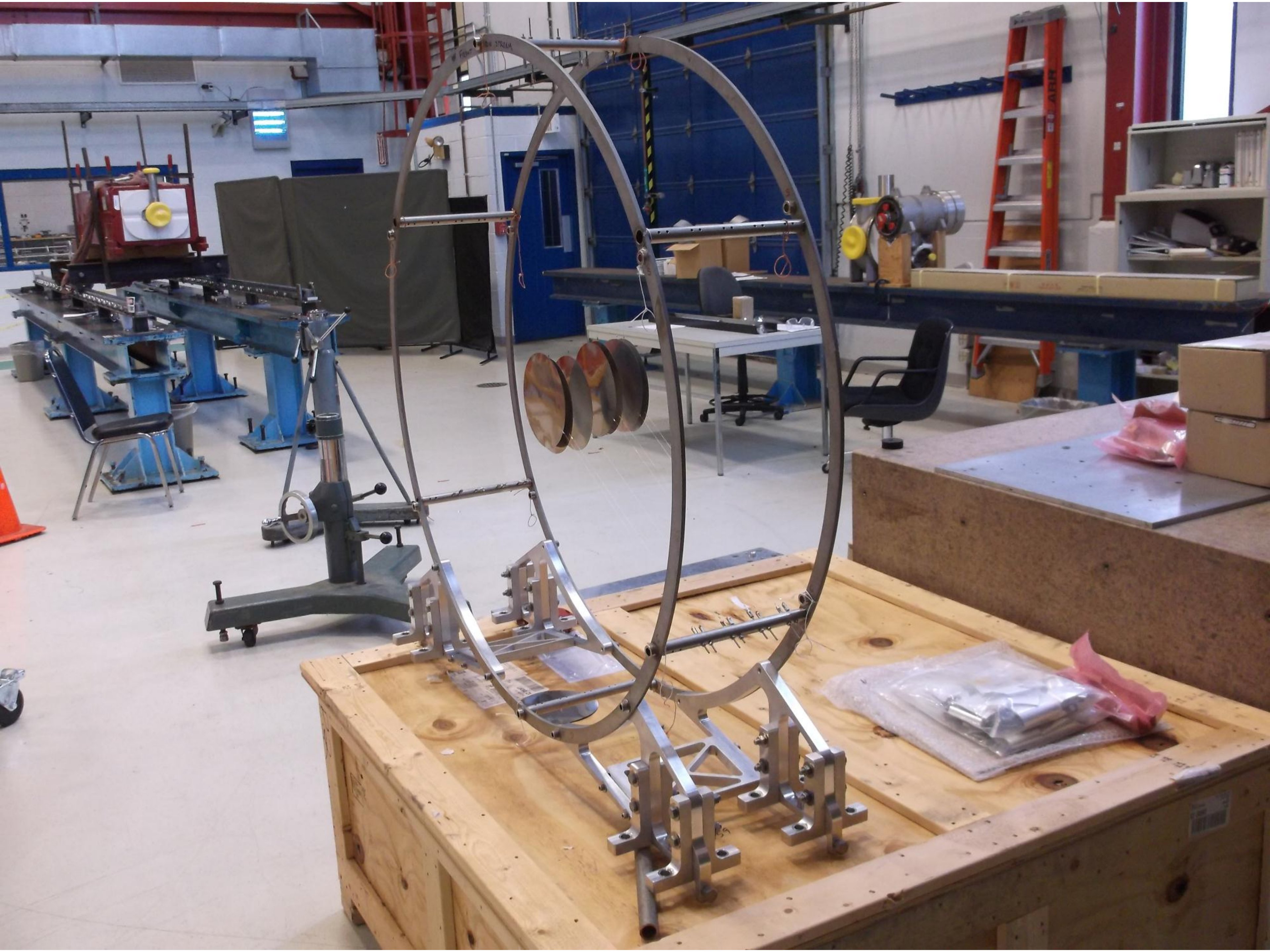
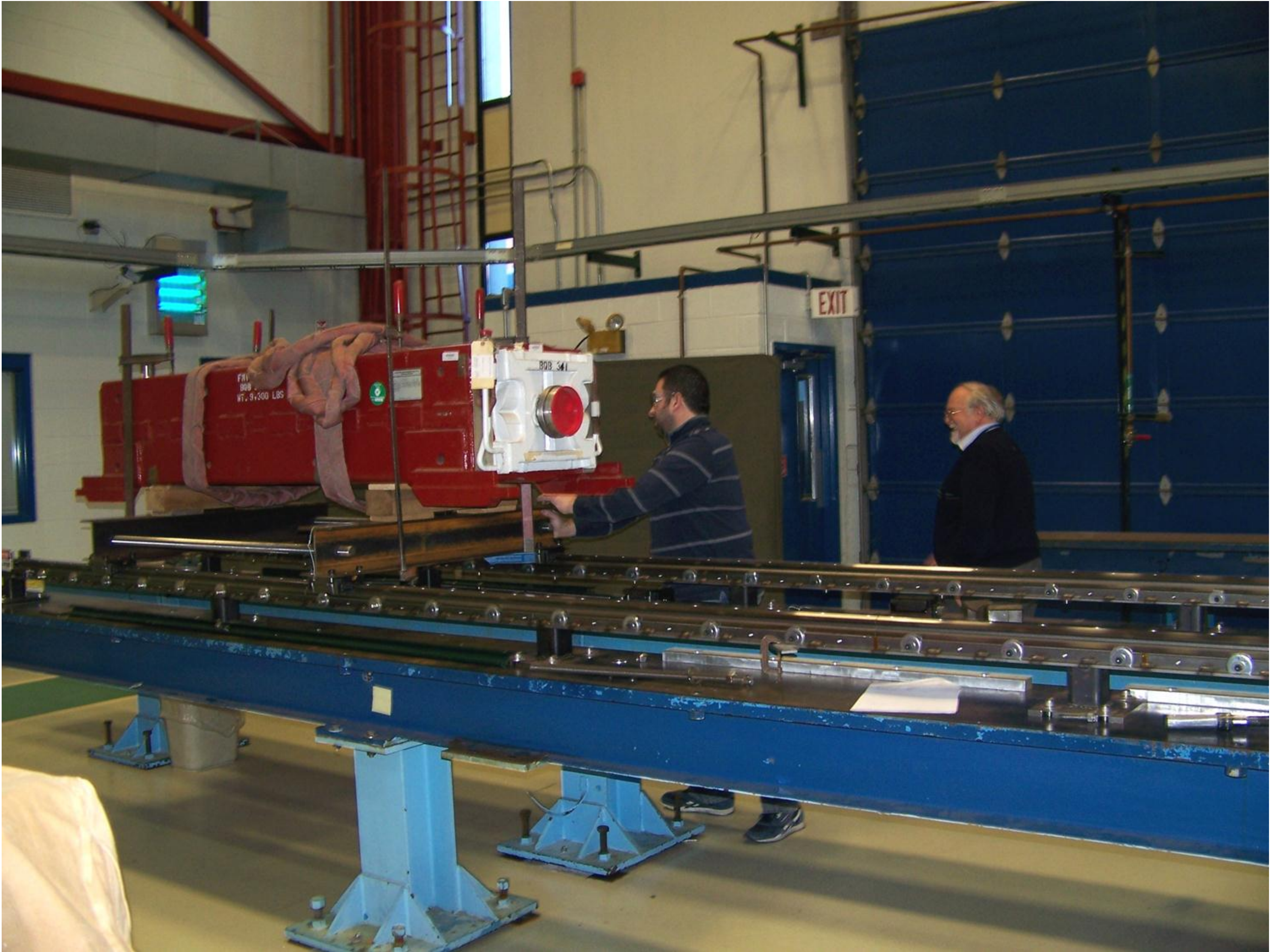
0.04 T
0.035 T
0.03 T
0.025 T
0.02 T
0.015 T
0.01 T
0.005 T
0. T

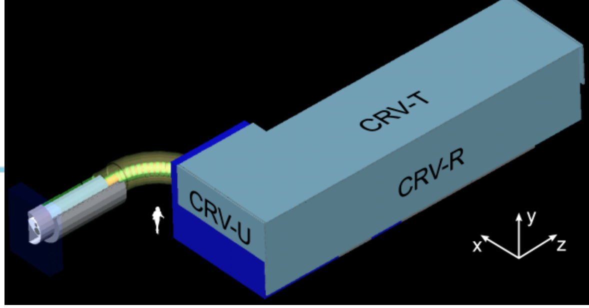

ARM


EXIT
2013/03/07

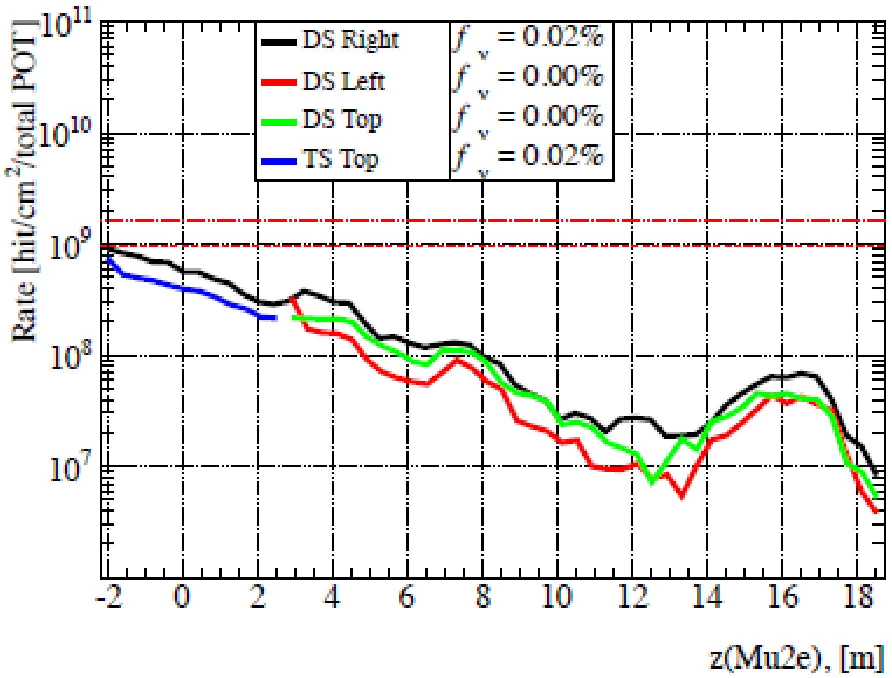

EXIT
DANGER
PINCH POINT

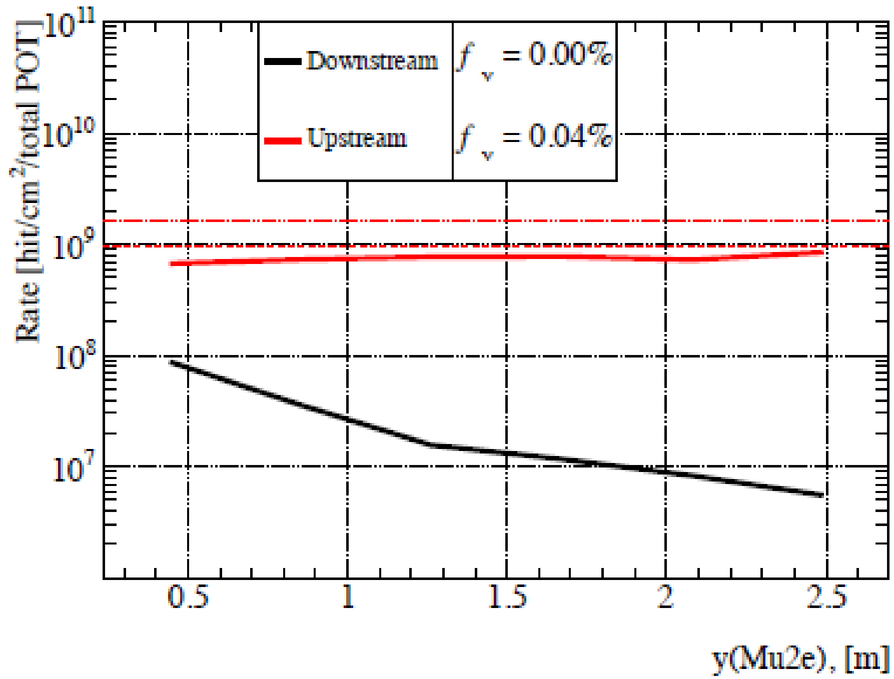

EXIT
WT. 9,300 LBS
BQB 341

Accidental CRV rates

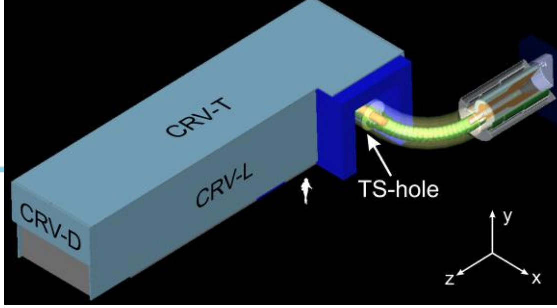


- Accidental hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.
- CRV deadtime requirement is ≤ 10%

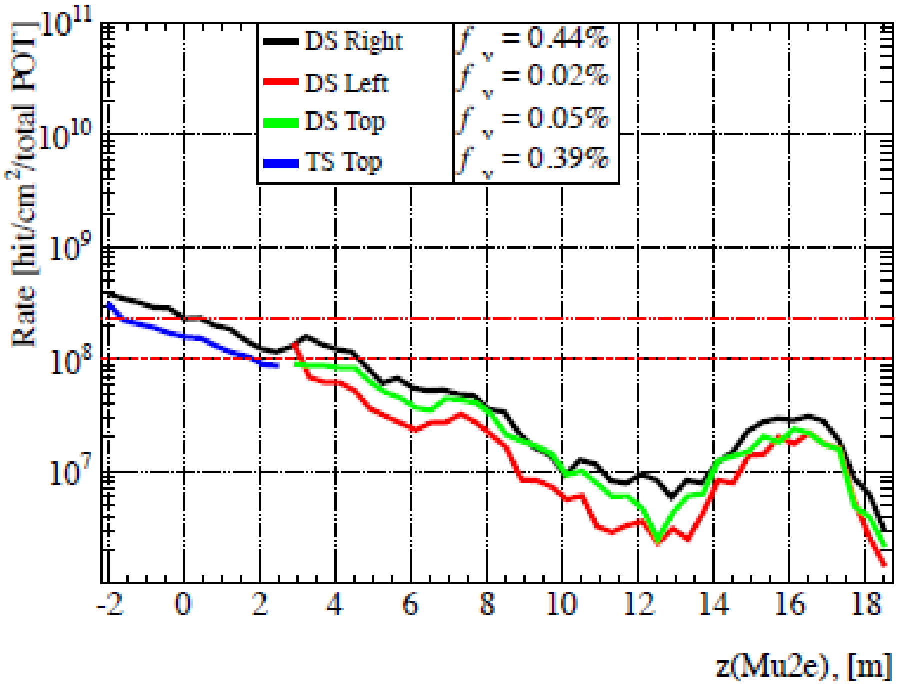


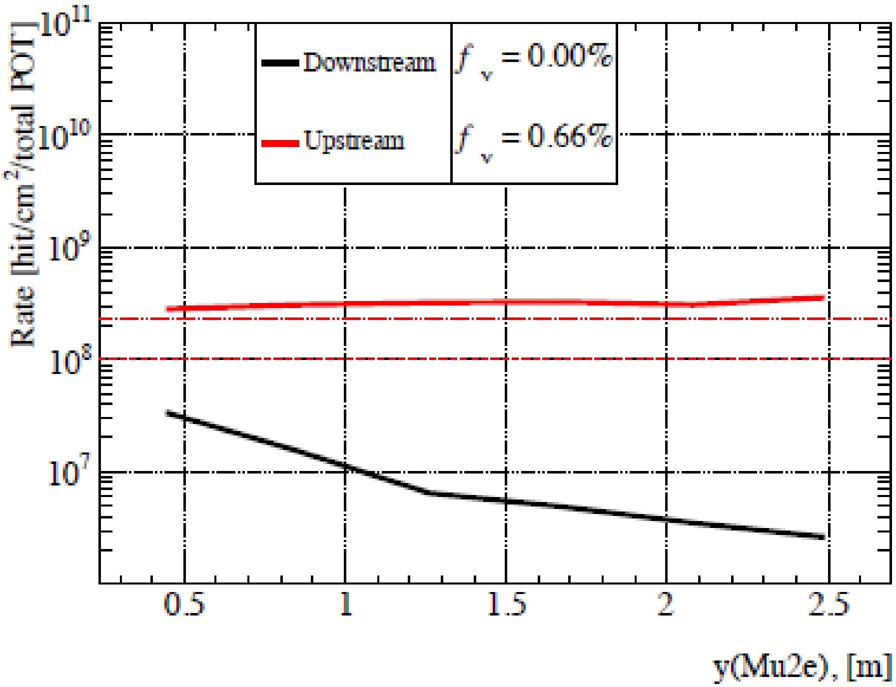


Semi-correlated CRV rates

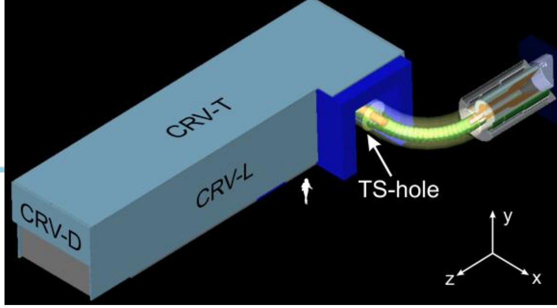


- Semi-correlated hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.
- CRV deadtime requirement is ≤ 10%

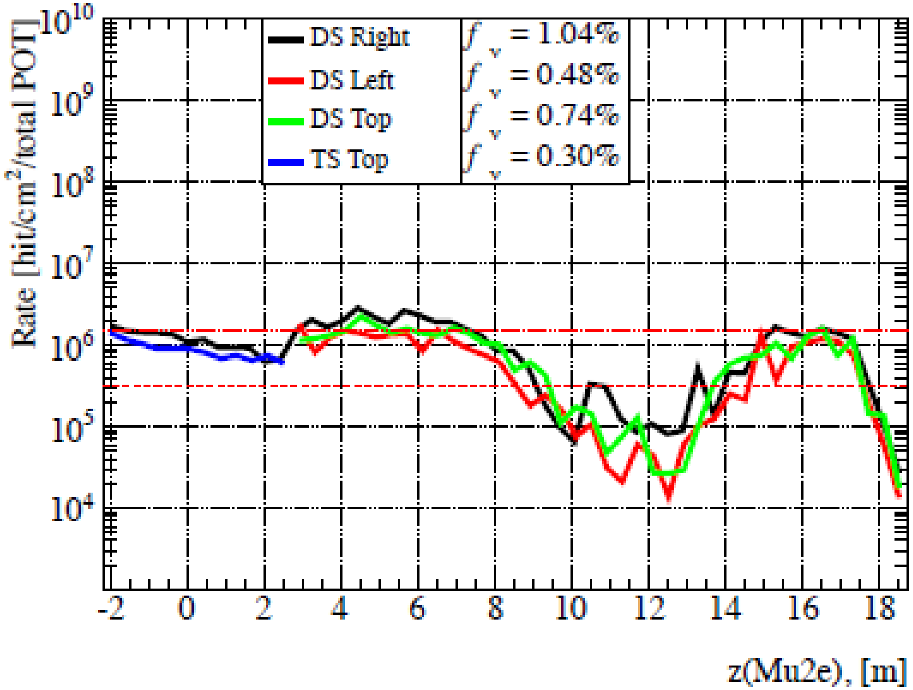


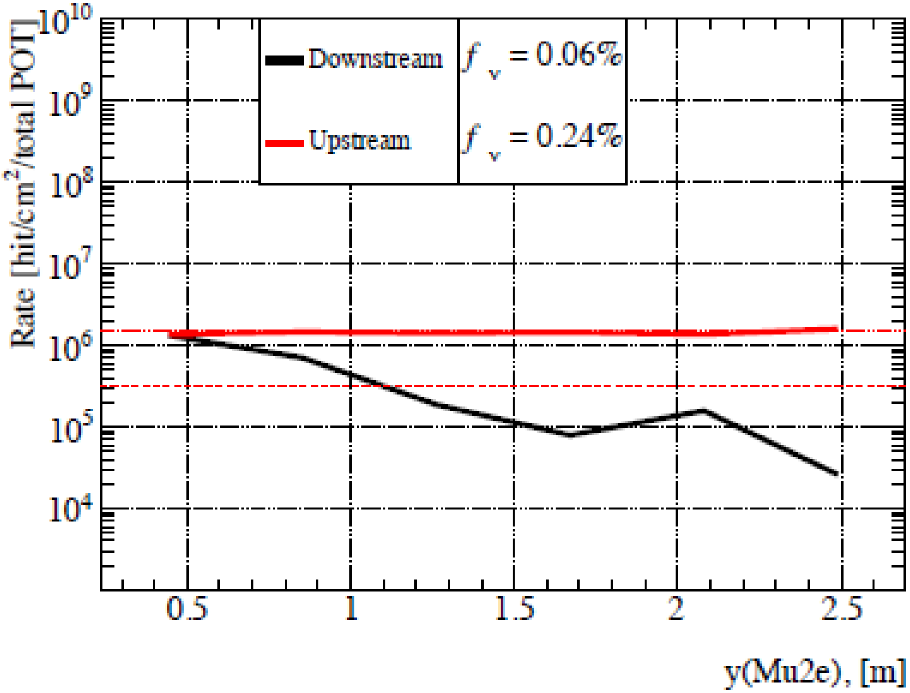


Correlated CRV rates



- 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.
- CRV deadtime requirement is ≤ 10%





Labor and Material per FY in AYk$