Fermilab

Mu2e WBS 5.2 Muon Beamline Vacuum DOE CD-2/3b Review

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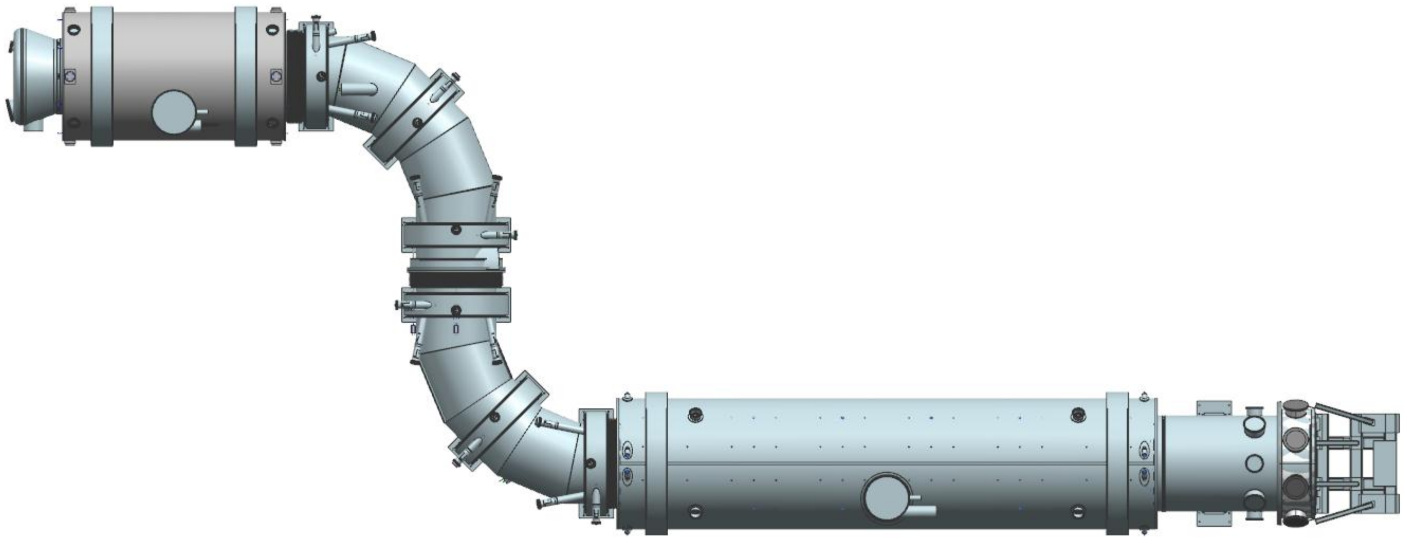
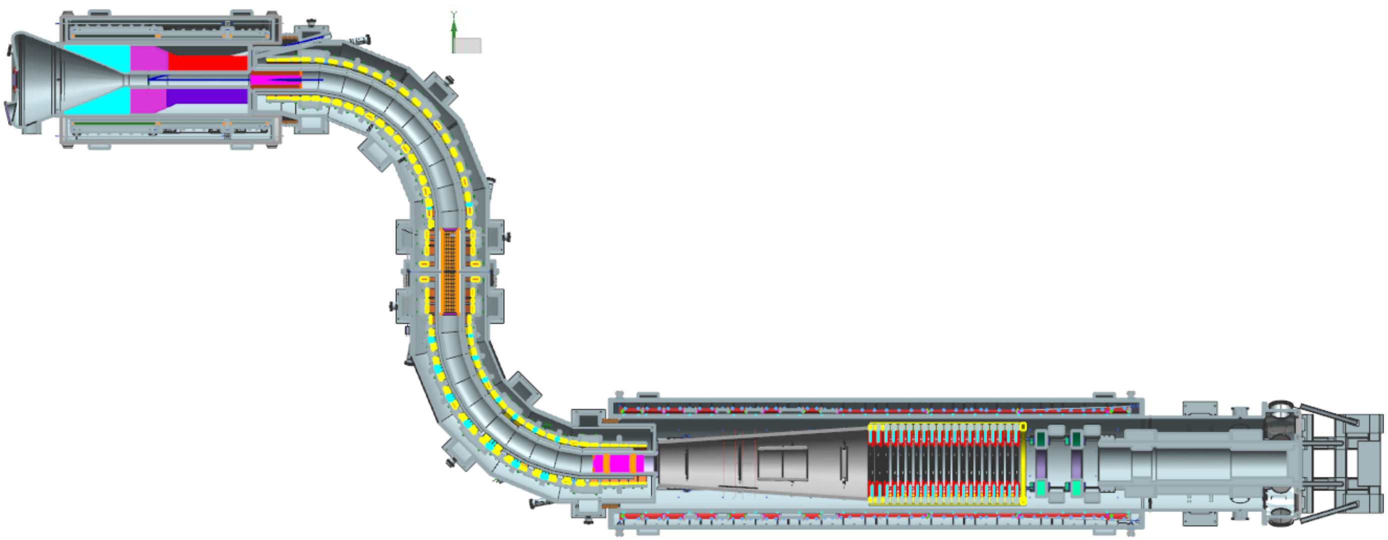
Overview of the Orientation:





Requirements

- Required vacuum level:
  - o PS + TSu; ≤1 x 10^{-5} torr.
  - o DS + TSd; ≤1 x 10^{-4} torr.
- Required vacuum pump down time:
  - o PS + TSu; approximately 100 hours.
  - o DS + TSd; approximately 100 hours.
- Anticipated magnetic field at location of high vacuum pumps:
  - o PS + TSu; approximately 500 Gauss.
  - o DS + TSd; approximately 600 Gauss.
- Anticipated magnetic field for location of backing and roughing vacuum pumps:
  - o PS + TSu; approximately 100 Gauss.
  - o DS + TSd; approximately 100 Gauss.
- Required pre-operational cleanliness for vessels:
  - o PS + TSu; standard high vacuum cleaning and degreasing
  - o DS + TSd; standard high vacuum cleaning and degreasing

Requirements

- Required operational cleanliness:
  - o PS + TSu; minimize, but not eliminate vacuum pump oil back-streaming.
  - o DS + TSd; minimize, but not eliminate vacuum pump oil back-streaming
- Appropriate windows and access ports must be provided as part of the enclosure for the Production Solenoid
- Appropriate window, ports and feedthroughs must be provided as part of the enclosure for the Detector Solenoid
- Vacuum lines (and other services) must be routed to minimize penetrations in the detector shielding
  - o Penetrations to the transport and detector solenoids should if at all possible come through the bottom, and if they cannot be through the bottom, then they should be away from the target region. In no case, should they penetrate the top.

Design

- Designs for the PS end cap, the VPSP and the IFB are largely unchanged from CD-1.
- Changes to the vessels will be made as part of the next design iteration. Specifically:
  - The PS shape will be optimized to use conventional pressure vessel design details.
  - The VPSP will have nozzles changed to better match the pump orientation and maximize conductance.
  - The IFB will be analyzed to evaluate the shape with respect to the vacuum loading to optimize the fabrication cost.

Design

- A remotely located large diffusion pump connected by a large diameter, high vacuum line will evacuate the PS.
- Two directly mounted smaller diffusion pumps will evacuate the DS.
- Roughing pumps will also serve as the backing pumps for the diffusion pumps.
- Roughing systems will be tied together and roughing will be performed slowly to minimize the differential pressure across the anti-proton stopping window at the TSu/TSd interface.
- A first draft of the written interlock description has created.
- A P&ID has been created.

Design

- For the PS, where a remotely located large diffusion pump connected by a large diameter, high vacuum will evacuate the PS:
  - Diffusion pump is located in the remote handling room where the radiation exposure is lessened.
  - Current design has two diffusion pumps, one to use, one as a hot stand-by unit.
  - Pumping capacity limited by the conductance of the high vacuum line between the PS and the diffusion pumps.
    - Operating both pumps will have little affect on increasing the pumping speed.
  - Diffusion pumps are fitted with cold traps to reduce the oil back-streaming into the PS to improve cleanliness.

Design

- For the DS, where two close coupled diffusion pumps mounted on the VPSP will evacuate the DS:
  - Diffusion pumps are located inside the shielding.
  - Current design has two diffusion pumps, both in use.
  - Current design has two ports for additional pumps if required.
  - Pump size limited by the available space between the VPSP and the shielding.
  - Diffusion pumps are fitted with cold traps to reduce the oil back-streaming into the DS to improve cleanliness.
  - Testing occurred in July and August 2014 to verify satisfactory operation of vacuum valves in 100 to 1000 Gauss magnetic fields.
  - Outgassing measurements were made for HDPE and Borated HDPE in August and September 2014. Published values did not exist for Borated Poly and only two published values were found for HDPE.

Improvements since CD-1

- Re-evaluated magnetic field as a design input to the vacuum pumping system.
  - Changed to diffusion pumps.
- Used outgassing rates from published literature for surfaces consistent with anticipated conditions.
- Vacuum requirements in the PS region tightened substantially (a higher quality, lower pressure level) to improve primary target lifetime.
- By-pass lines around the anti-proton stopping window at the TSu/TSd interface eliminated.   By-pass lines wound not protect the anti-proton stopping window in the event of a vacuum window failure in the PS.

Value Engineering since CD-1

- Continuous value engineering exercises have been performed during the course of the design.
  - Experts consulted
  - Vendors contacted
- In developing the P&ID, design decisions have been made to select the most cost effective solutions while meeting the performance requirements.
- Safety criteria (FESHM 5033 – Vacuum Vessels) are explicitly specified for the vessels.

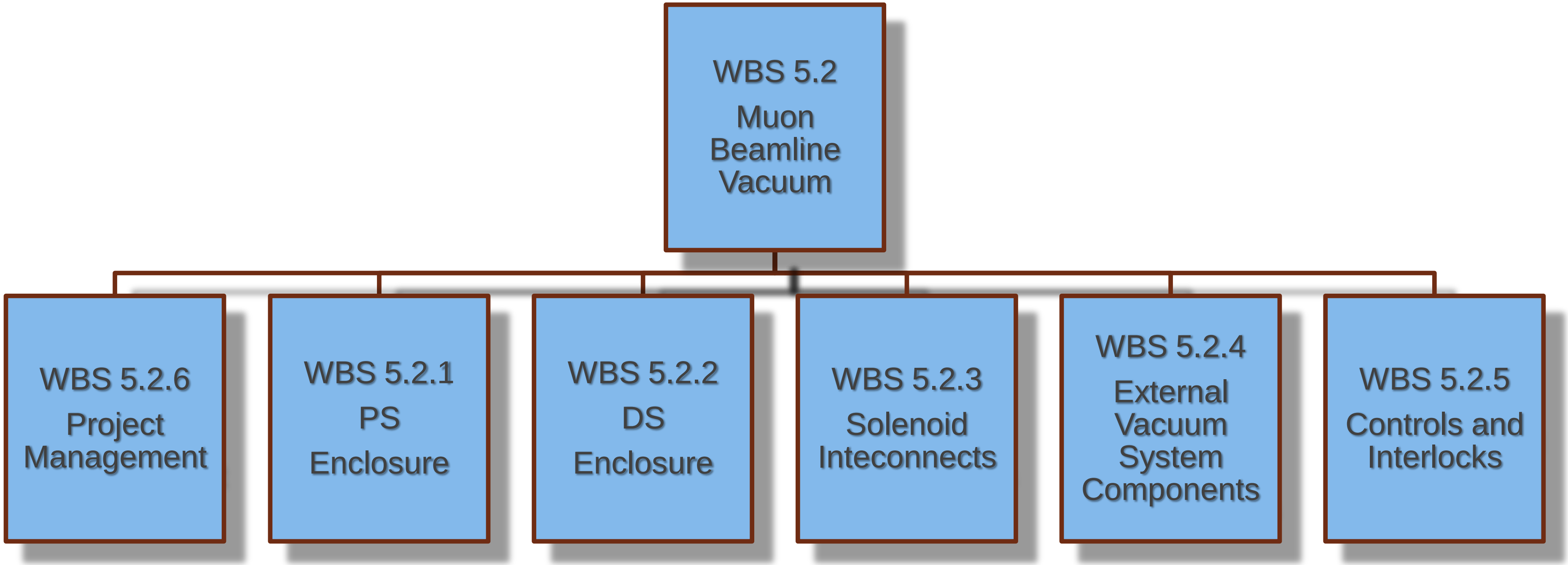
Performance

- Gas loads used as inputs to the pumping system design are:
  - PS + TSu; 0.94 torr-l/sec.
  - DS + TSd; 32 torr-l/sec.
- Pressures achieved at 10 hours of high vacuum pumpings are:
  - PS + TSu; 5×10^{-5} torr
  - DS + TSd; 6×10^{-4} torr
- Pressures achieved at 100 hours of high vacuum pumping meet the performance requirments and are:
  - PS + TSu; 5×10^{-6} torr
  - DS + TSd; 6×10^{-5} torr

Remaining work before fabrication

- Prepare FESHM 5033 vessel calculations for the three vessels and the PS evacuation line which are part of this system:
  - Productions Solenoid End cap (PS)
  - Vacuum Pump Spool Piece (VPSP)
  - Instrumentation Feed Through Bulkhead (IFB)
  - PS high vacuum evacuation line
- Modify designs shown as required to meet safety requirements.
- Prepare FESHM 5033.1 vacuum window calculations for all thin windows not already covered as part of the vessels.
- Generate purchase specification (including drawings) for the PS, VPSP, and IFB.
- Generate design documentations for all portions of the system per chapter 4 of the Engineering Manual and have reviewed per chapter 5.

Organizational Breakdown



Quality Assurance

- Procured vessels and pipe (PS, VPSP, IFB, vacuum lines) will be helium mass spectrometer (HMS) leak tested to verify the specified leak rate is achieved prior to installation.
- HMS leak testing will be repeated after installation.
- Leak checking reduces the risk of the system not initially meeting the performance goals.

Risks

- Major risks include:
  - Outgassing rates that exceed the values used to size the vacuum pumping equipment
  - Leak rates that exceed the values used to size the vacuum pumping equipment
  - Building and shielding size limitations that preclude installing larger capacity pumps and evacuation lines
- Mitigation strategies include:
  - Reducing surface areas of items in the vacuum space.
  - Reducing materials in the vacuum space.
  - Waiting a longer time for the outgassing to decay before achieving the required vacuum level.
  - Locating and Repairing leaks.

Risks

- Cost/schedule impacts if these risks are realized:
  - If an external leak is causing the vacuum to remain too high, it will take some time to locate and repair the leak.
  - If an internal leak (perhaps from the tracker) is causing the vacuum to remain too high, it will take some time to locate and repair the leak or add more pumps to compensate for the leak.
  - Leaks consume labor to repair.
- Minor risks include vessels that do not pass the pre-installation helium leak test initially and require repair.
  - Should not affect the overall schedule so long as the vessel procurements are not on the critical path.

ES&H

- FESHM (the Fermilab Environment, Safety and Health Manual) includes chapters which directly apply to the vacuum vessels and vacuum windows used on this system.
- Engineering notes will be necessary to show vessels meet the requirements.
- These engineering notes also provide a quality assurance that the designs will safely hold vacuum and will not collapse.

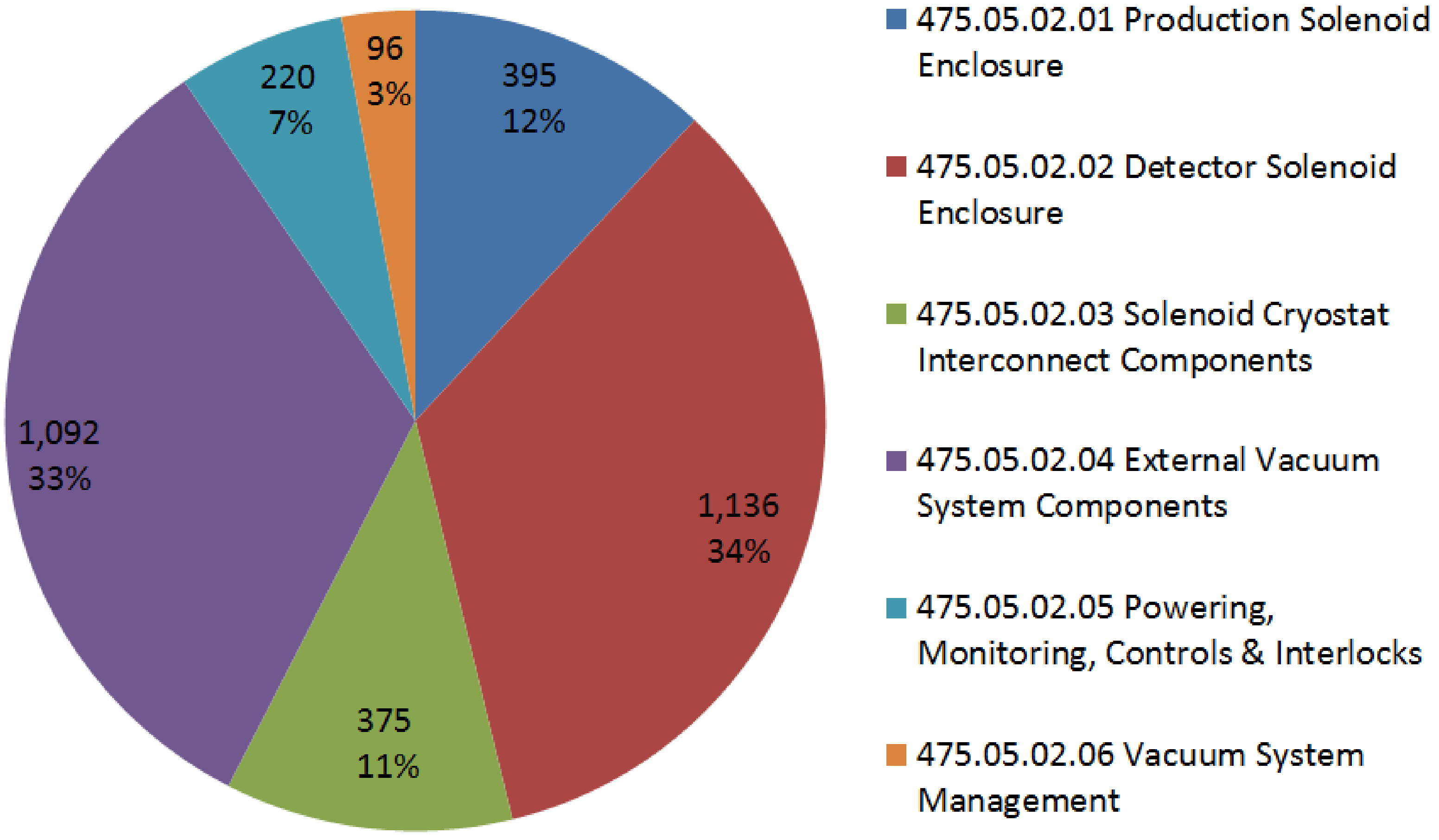
Cost Table

- WBS 5.2 Muon Beamline Vacuum System
  - Costs are fully burdened in AY k$

	Base Cost (AY K$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency (on remaining budget)	Total Cost
475.05 Muon Beamline						
475.05.02 Vacuum System						
475.05.02.01 Production Solenoid Enclosure	214	181	395	168	47%	563
475.05.02.02 Detector Solenoid Enclosure	842	294	1,136	421	39%	1,557
475.05.02.03 Solenoid Cryostat Interconnect Components	118	258	375	120	35%	496
475.05.02.04 External Vacuum System Components	827	264	1,092	369	36%	1,460
475.05.02.05 Powering, Monitoring, Controls & Interlocks	57	162	220	82	52%	302
475.05.02.06 Vacuum System Management		96	96	32	35%	127
Grand Total	2,058	1,255	3,313	1,191	39%	4,505

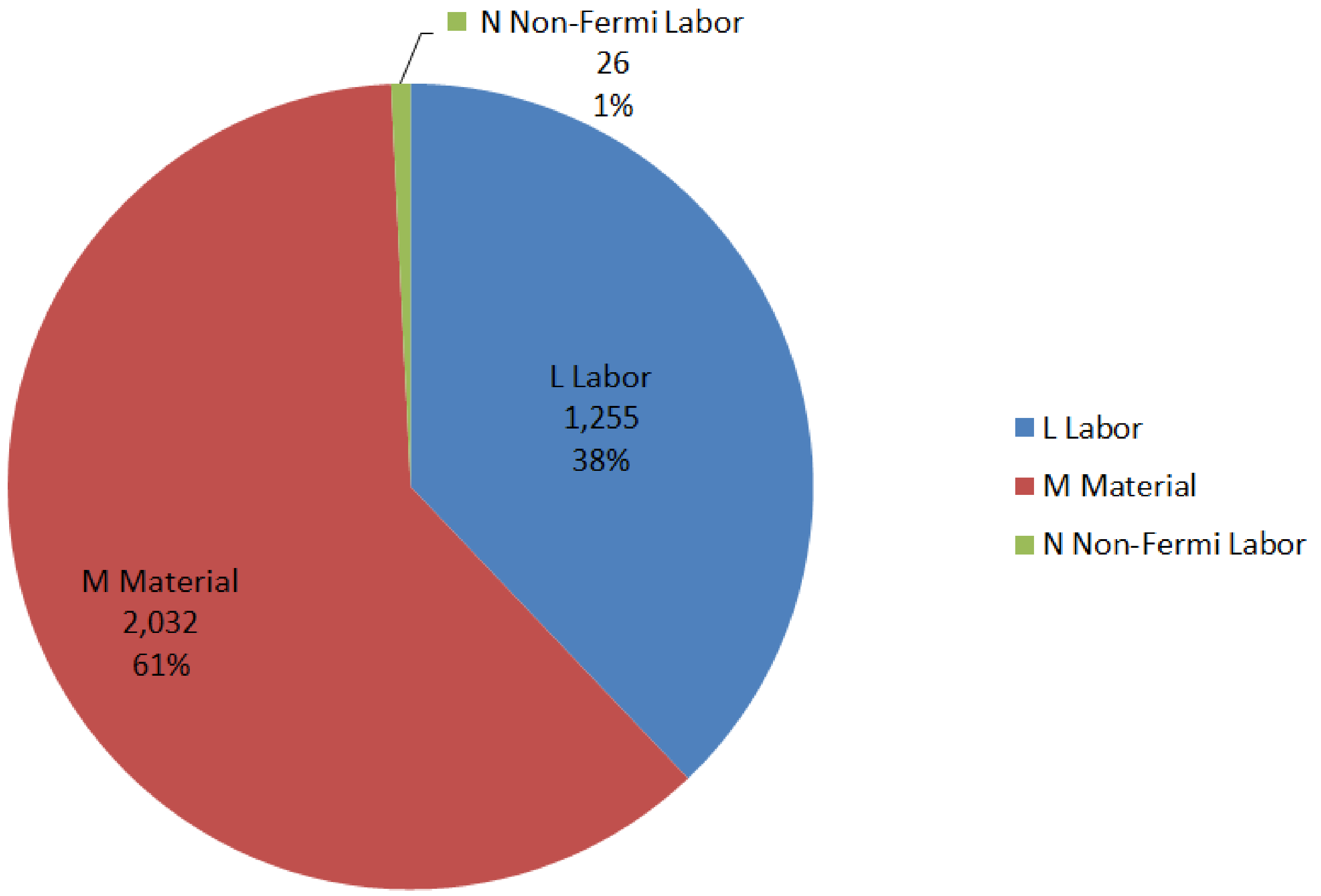
Cost Distribution by L4

- Base Cost by L4 (AY k$)



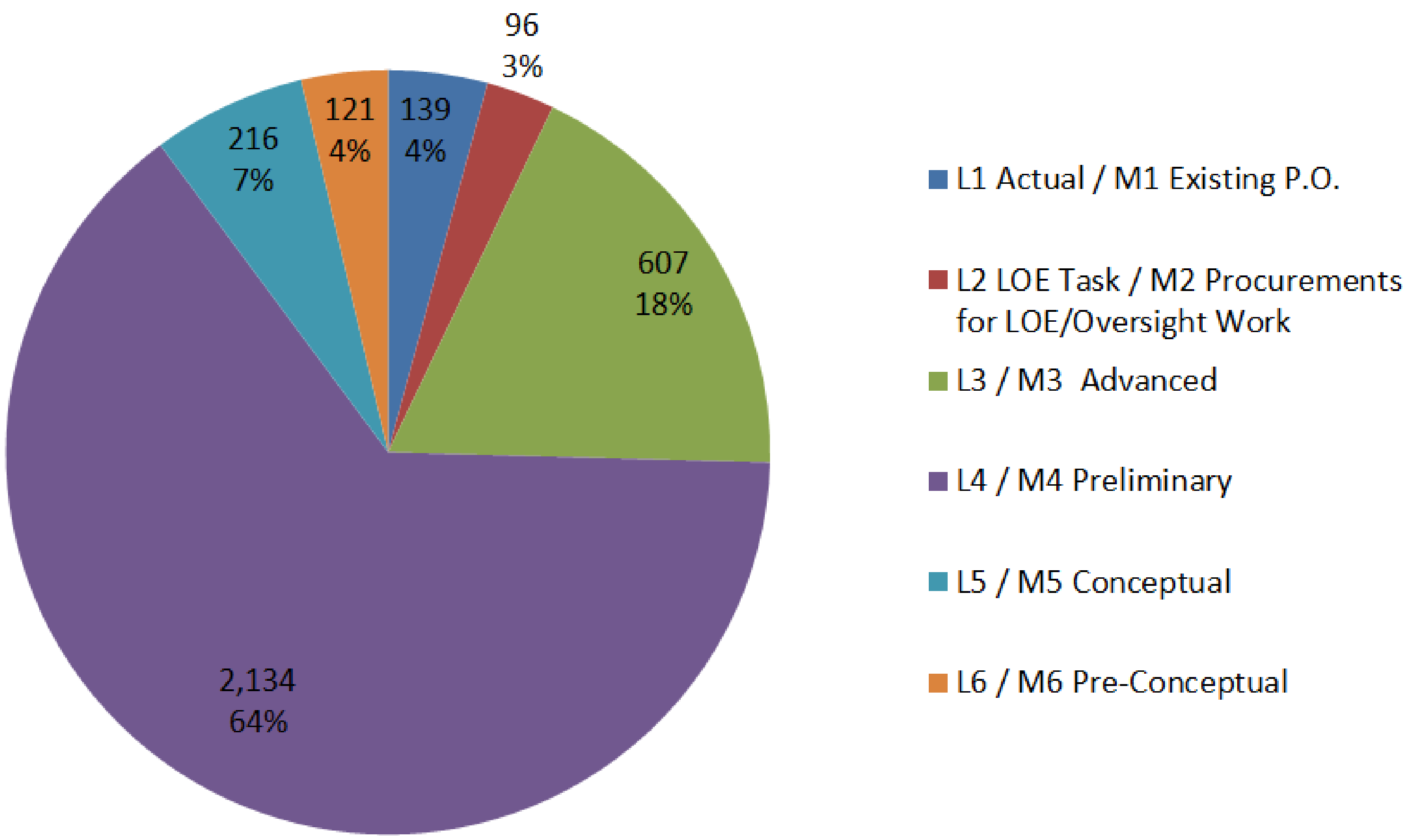
Cost Distribution by Resource Type

- Base Cost (AY k$)



Quality of Estimate

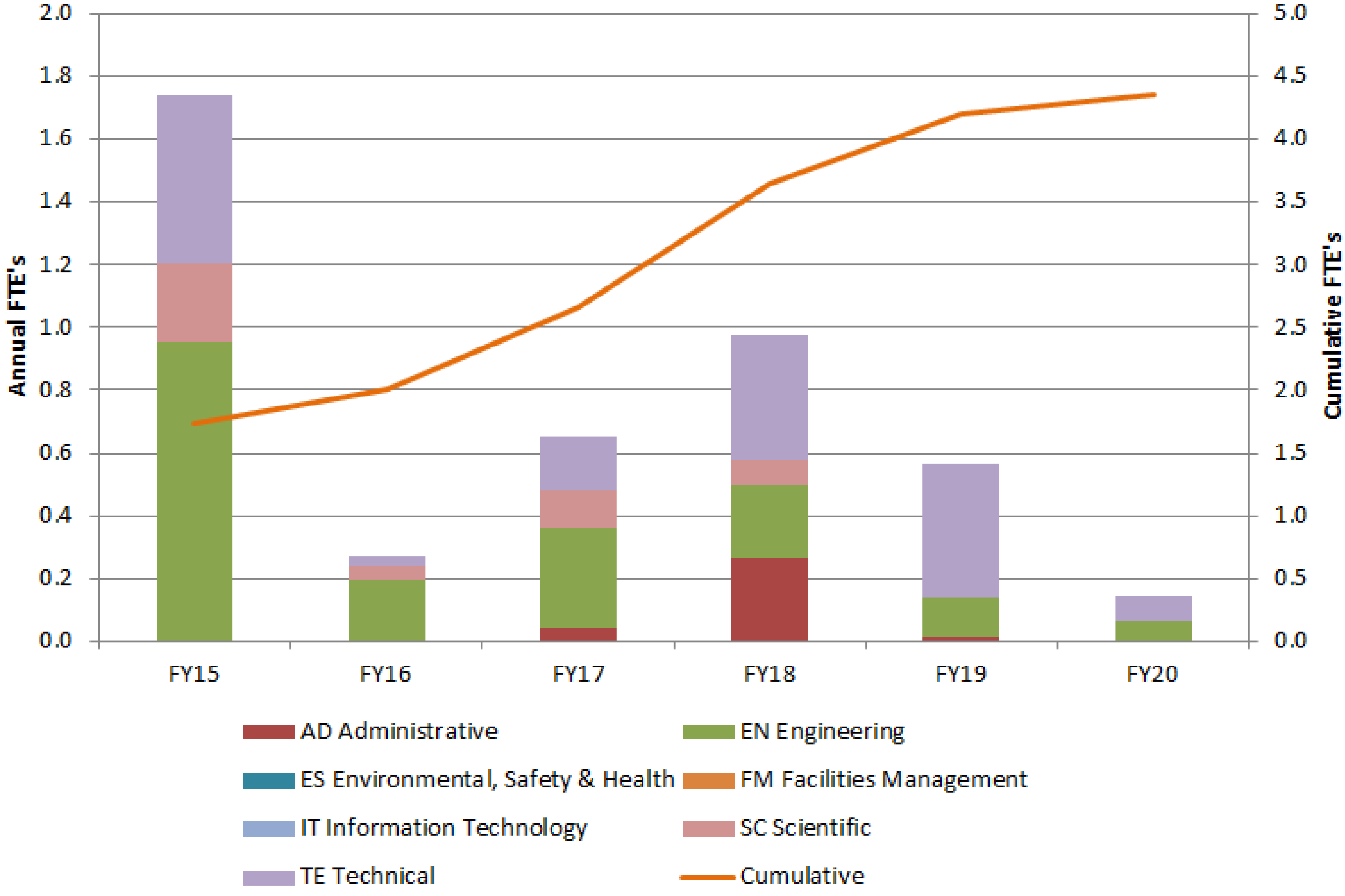
- Base Cost by Estimate Type (AY$k)



- 89% of costs understood at the Preliminary Design level or better

Labor Resources

- FTEs by Discipline



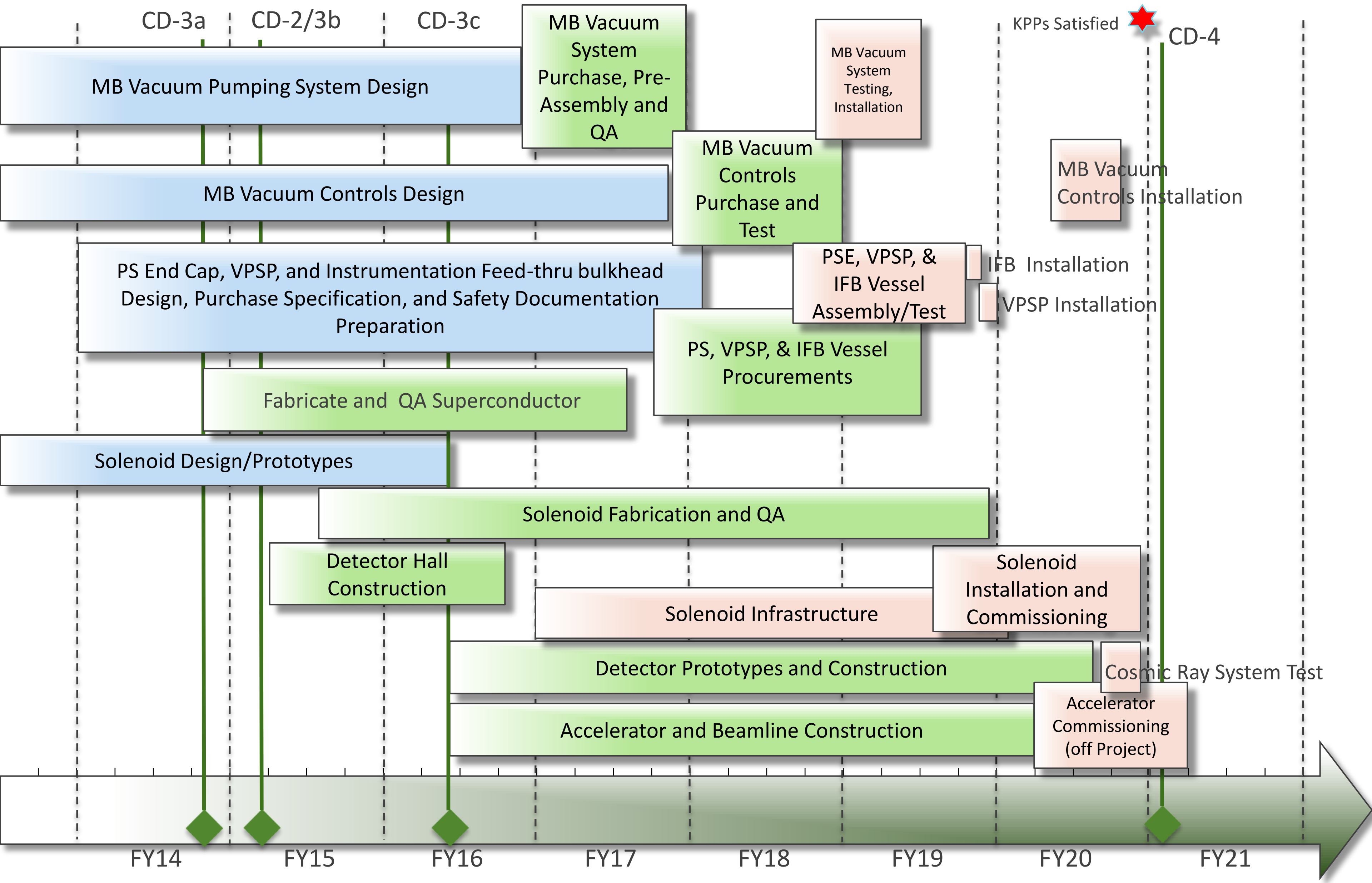
Milestones

47505.2.3.001330	T5 - MB Solenoid Cryostat Interconnects 2nd iteration Complete	11/12/2015
47505.2.5.001290	T5 - MB Vacuum Controls 2nd iteration Complete	12/2/2015
47505.2.000950	T5 - MB Vacuum Systems ready for CD-3 Review	12/15/2015
47505.2.3.001410	T5 - Interconnects Ready for CD-3 Review	12/15/2015
47505.2.4.001380	T5 - External Vacuum Components Ready for CD-3 Review	12/15/2015
47505.2.5.001375	T5 - MB Vacuum Controls Ready for CD-3 Review	12/15/2015
47505.2.000960	T4 - CD-3 approval for MB Vacuum System	2/23/2016
47505.2.4.001350	T5 - MB External Vacuum Components Ready for fabrication	12/9/2016
47505.2.1.001380	T5 - PS Enclosure Ready for fabrication	7/26/2017
47505.2.4.031010	T5 - MB External Vacuum System Components at FNAL	9/15/2017
47505.2.5.001360	T5 - MB Vacuum Controls Ready for fabrication	9/19/2017
47505.2.2.001390	T5 - DS Enclosure Ready for fabrication	10/12/2017
47505.2.000945	T5 - MB Vacuum Systems Ready for Fabrication	10/19/2017
47505.2.3.001380	T5 - MB Solenoid Cryostat Interconnects Ready for fabrication	10/19/2017
47505.2.4.031025	T5 - External Vacuum Components Ready for Installation	2/21/2018
47505.2.1.021017	T5 - PSE Components at Fermilab	5/8/2018
47505.2.5.001405	T5 - MB Vacuum System Controls Components at FNAL	5/29/2018
47505.2.2.010007	T5 - VPSP at Fermilab	6/21/2018
47505.2.5.001475	T5 - MB Vacuum System Controls Ready for Installation	8/15/2018
47505.2.2.011107	T5 - IFB at Fermilab	9/5/2018
47505.2.1.051015	T5 - PSE ready for Installation	10/15/2018
47505.2.1.051030	T5 - PSE Ready for CD-4	11/29/2018
47505.2.3.071000	T5 - Solenoid Cryostat Interconnect Components at FNAL	1/22/2019
47505.2.4.031070	T5 - External Vacuum Components Ready for CD-4	2/25/2019
47505.2.2.091050	T5 - DSE Feedthrough Components at FNAL	3/12/2019
47505.2.2.091060	T5 - All Detector Solenoid Enclosure components at FNAL	3/12/2019
47505.2.3.071030	T5 - Interconnects Ready for CD-4	3/13/2019
47505.2.2.091075	T4 - DSE Components Ready for Installation	7/19/2019
47505.2.2.095005	T5 - VPSP Installation Complete	9/11/2019
47505.2.2.095020	T5 - DSE Ready for CD-4	2/26/2020
47505.2.005000	T5 - MB Vacuum System Ready for CD-4	6/16/2020
47505.2.5.001500	T5 - MB Vacuum System Controls Ready for CD-4	6/16/2020

Integration and Interfaces

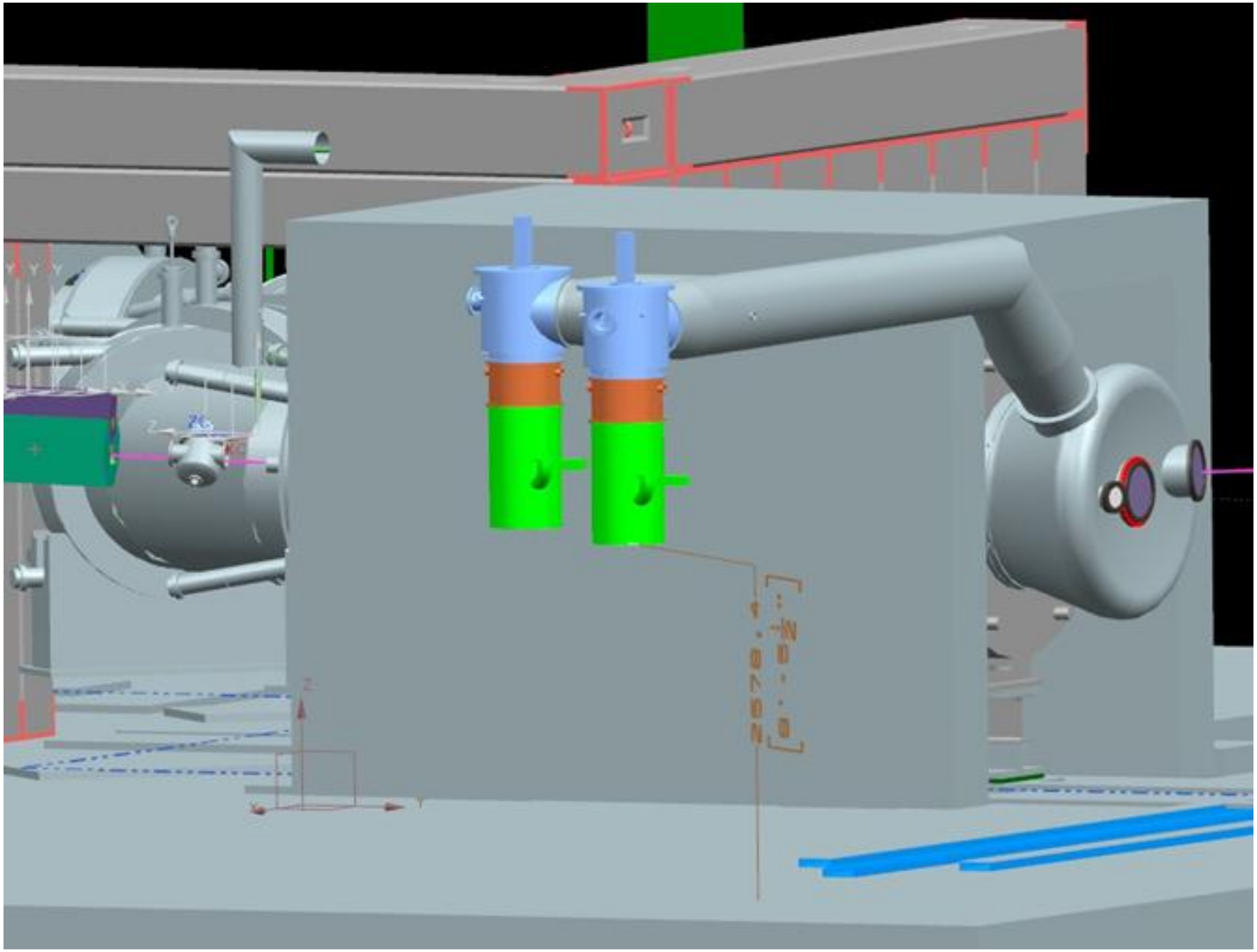
- Vacuum System has external interfaces to Accelerator (gas loads and vacuum requirements), Conventional Construction (space for pumps and routing of services), Solenoids (geometry for connections), Tracker and Calorimeter (gas loads) CRV (penetrations) and DAQ (monitoring)
- Internal interfaces within Muon Beamline include Collimators, Upstream External Shielding, Stopping Target, Stopping Target Monitor, DS Internal Shielding, Muon Beam Stop, Downstream External Shielding and Detector Support and Installation
- Participation in bi-weekly integration meetings
- Formal sign-off between owners of all external interfaces as part of final design requirements.
- Interfaces understood and under control.

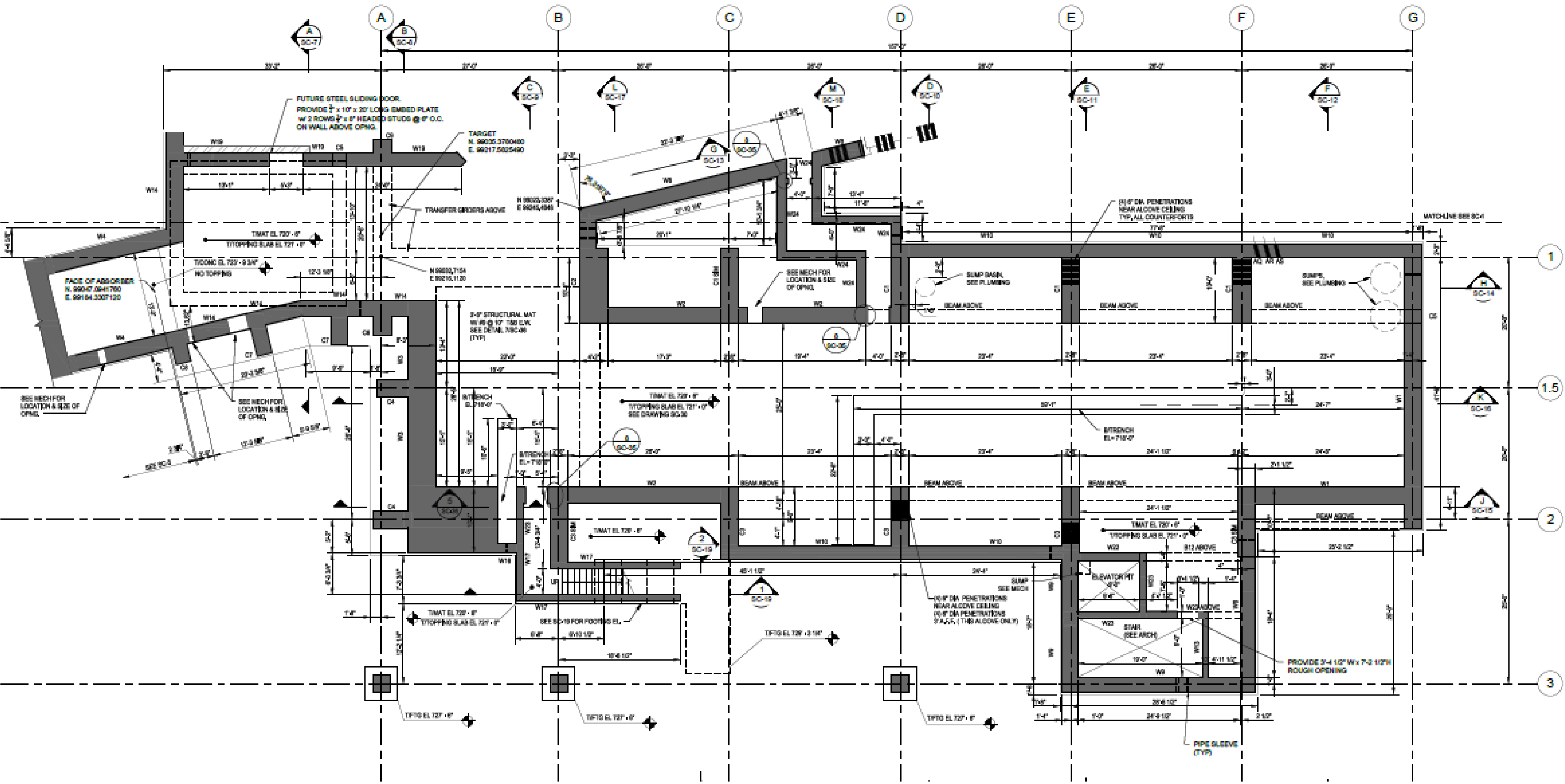
Schedule

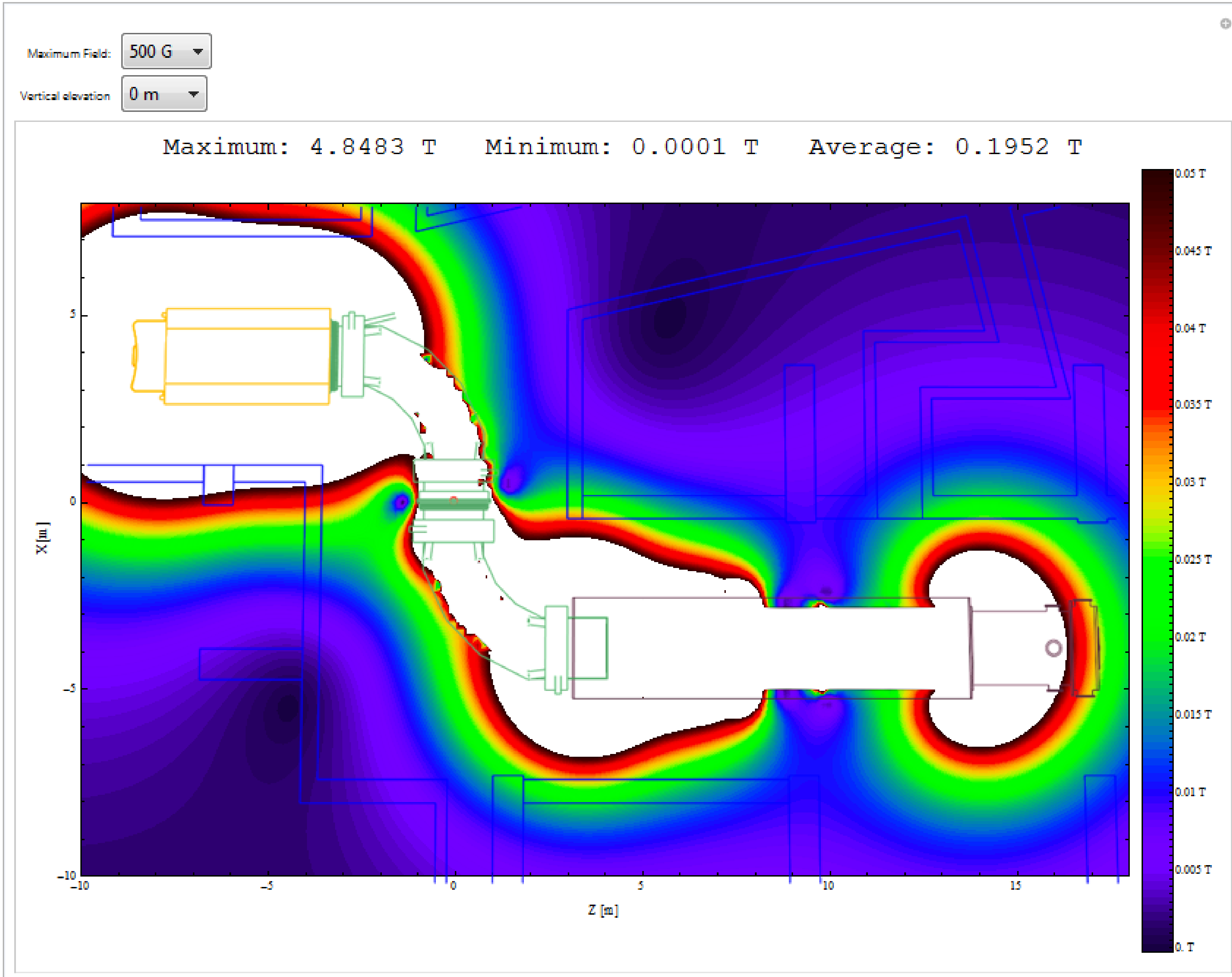

CD-3a
CD-2/3b
CD-3c
KPPs Satisfied
CD-4
MB Vacuum Pumping System Design
MB Vacuum System Purchase, Pre-Assembly and QA
MB Vacuum System Testing, Installation
MB Vacuum Controls Design
MB Vacuum Controls Purchase and Test
MB Vacuum Controls Installation
PS End Cap, VPSP, and Instrumentation Feed-thru bulkhead Design, Purchase Specification, and Safety Documentation Preparation
PSE, VPSP, & IFB Vessel Assembly/Test
IFB Installation
VPSP Installation
PS, VPSP, & IFB Vessel Procurements
Fabricate and QA Superconductor
Solenoid Design/Prototypes
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Installation and Commissioning
Solenoid Infrastructure
Detector Prototypes and Construction
Cosmic Ray System Test
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- Cost estimates for the vacuum system are complete.
- 89% of the costs are understood at the preliminary design level or higher.
- Risks are understood and mitigated to the extent possible.
- Interfaces are identified and resource needs are understood.
- The muon beamline vacuum system is ready for CD-2







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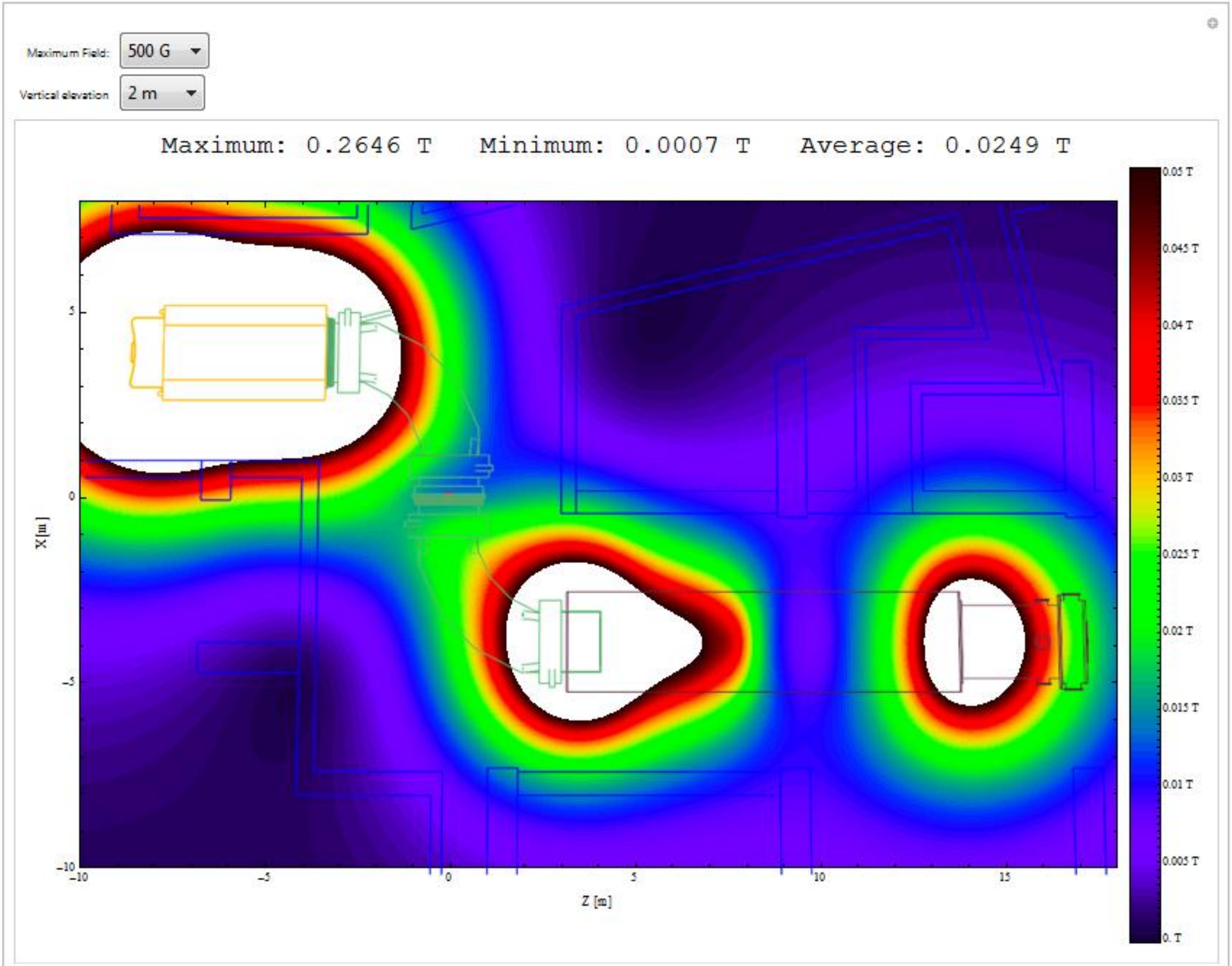
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