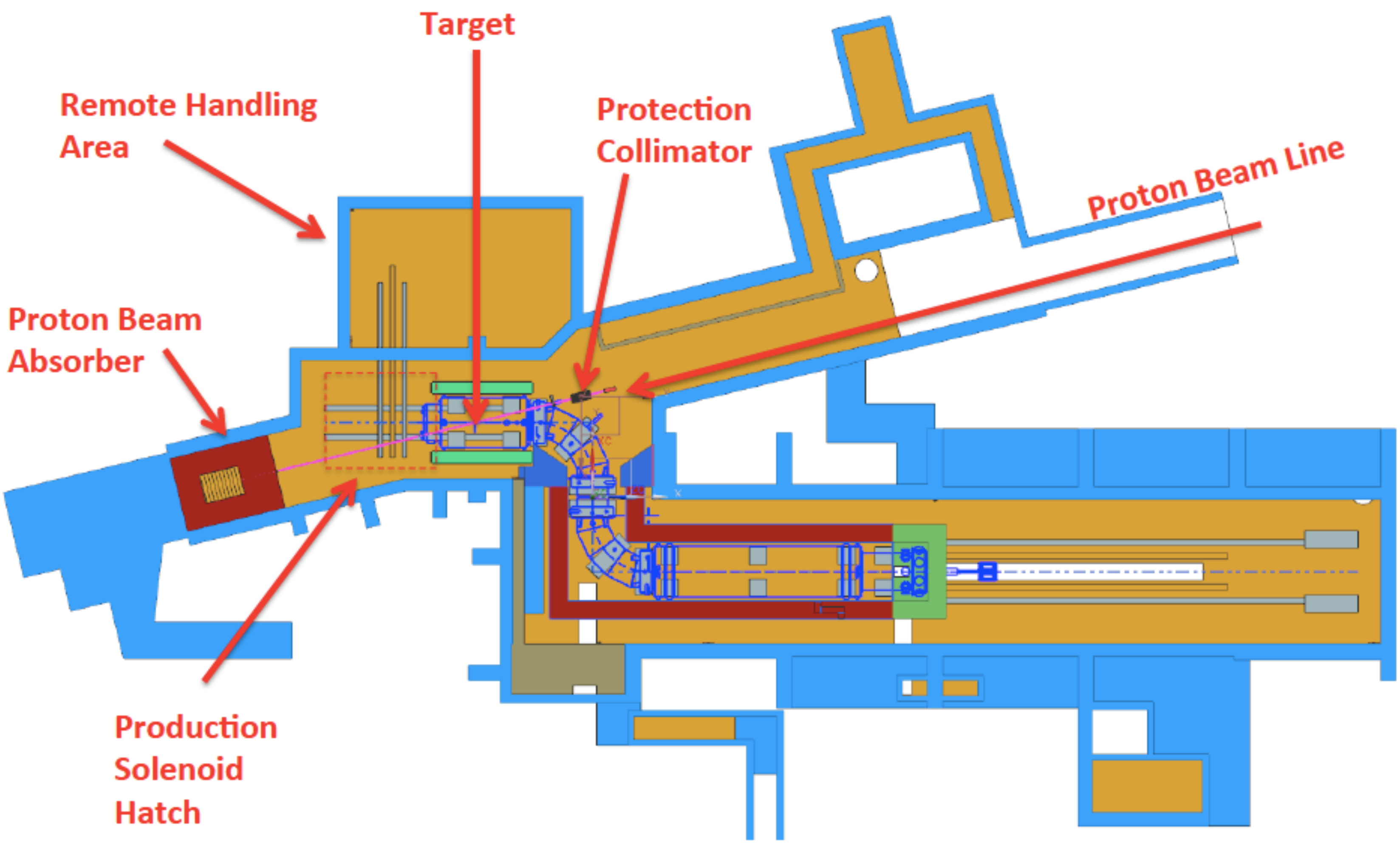
Mu2e CD-2 Review Target Station

Rick Coleman
L3 Manager Target Station
7/9/2014

WBS 475.02.09 Target Station

- The Target Station consists of the proton beam production target, heat and radiation shield (HRS), target remote handling system, proton beam absorber and protection collimator
- The proton beam strikes the target in the Production Solenoid creating secondary particles. Charged pions decay to muons which are collected in the Transport Solenoid. A beam of negative muons is delivered to the Detector Solenoid for use in the experiment.
- Adequate shielding for radiation and experiment backgrounds must be provided. In particular, the target is located in a superconducting solenoid which must be shielded.

Overview of Layout



Requirements

- Mu2e Proton Beam Requirements (DocDB 1105)
  - 3.6 x 10^{20} protons on target over 3 years to obtain sensitivity
  - Repeat period > 864ns (lifetime of muons in aluminum stopping target)
  - 6 x 10^{12} protons/sec at 8 GeV delivered every 1.33 seconds, 0.3 duty factor
  - Transverse Spot Size 0.5 to 1.5 mm (rms), Divergence < 4 mr (rms)
  - For alignment & target scans +/- 1 cm and +/- 0.8 mr
  - Low intensity for commissioning and special calibration runs

- Production Target Requirements (DocDB 887)
  - Maximize number of stopped muons (high Z material, small radius target and minimize target support structure material to reduce pion reabsorption)
  - Target Lifetime > 1 year to minimize interruptions to experiment, since target replacement time ~ 1 month
  - Target-Beam Alignment < 0.5 mm transverse, < 10 mr angle

Requirements

- Mu2e Proton Beam Absorber Requirements (DocDB 948)
  - Designed to absorb the primary proton beam and secondary particles left after the production target for normal beam over for the experiment lifetime(10 yrs) and full beam power for 10 minutes in an accident condition
  - Placed far enough away from target to eliminate back scattered particles from entering muon beam channel and allow access for target remote handling
  - No maintanance or service directly over lifetime
  - Maintain surface and ground water contamination below limits
  - Air Activation from absorber must be below limits after cooled down
  - Minimize residual radiation during access
  - Shielding the extinction monitor must be sufficient

- Protection Collimator Requirements (DocDB 2897)
  - With loss monitor instrumentation provide a means to abort the proton beam if it is mis-steered to provide protection for the solenoid systems
  - Provide an "out" position for target scans

Requirements

Mu2e Production Solenoid (PS) Heat and Radiation Shield (HRS) Requirements (Mu2e-doc-1092- G. Ambroio, R. Coleman, V. Kashikhin, M. Lamm, M. Lopes, N. Mokhov, J. Popp, V. Pronskikh)

- Limit Magnet from Heat Load

  Limit the overall dynamic heat load in the PS magnet to less than 100 W.

  Limit the instantaneous heat load in any coil of the PS to less than 30 μW/gm.

- Prevent radiation damage to PS magnet materials

  Limit dose rate to the superconductor insulation and epoxy to less than 350 kGy/year.

- Geometry

  The heat shield must have sufficient inner aperture to preserve the muon yield

- Maintain electrical conductivity of superconducting cables and normal conducting quench stabilizing matrix

  Limit the DPA † experienced by the component metals of any PS superconducting cable to less than 4 to 6 $\times 10^{-5}$ DPA/year.

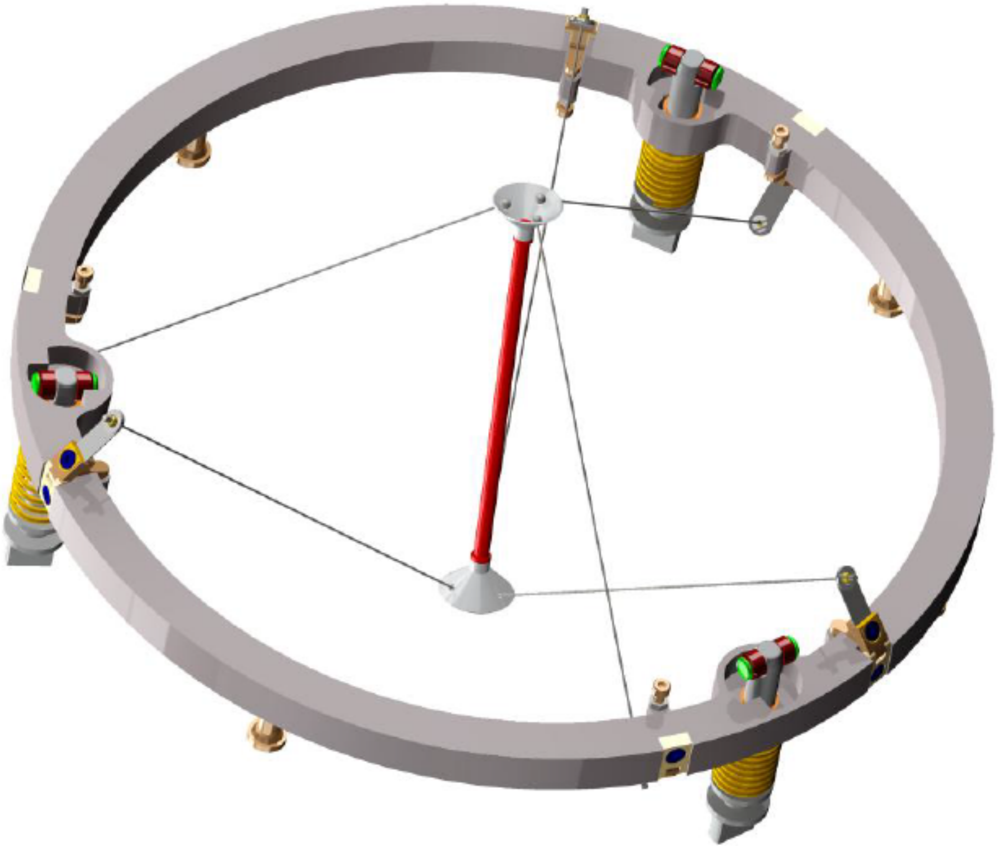
➔ RRR*> 100 , Annual warm-up to anneal

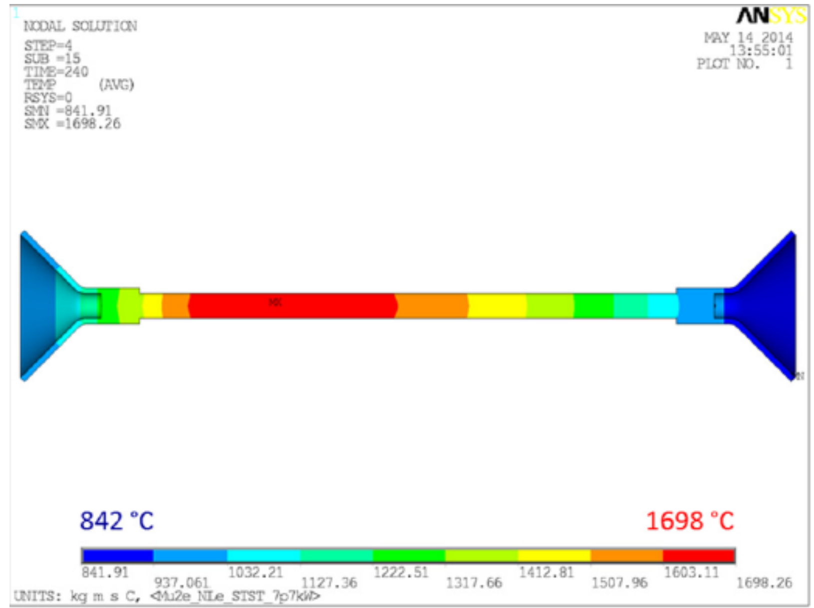
† DPA = Displacements per Atom

$$*RRR = \frac{\rho_{300K}}{\rho_{4.5K}}$$

Target Design

L=16 cm r=3.2 mm Tungsten Rod

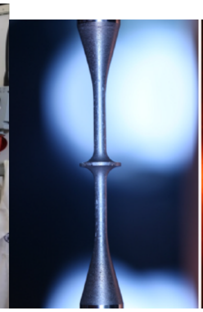


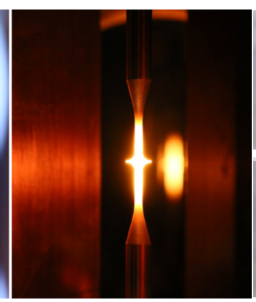


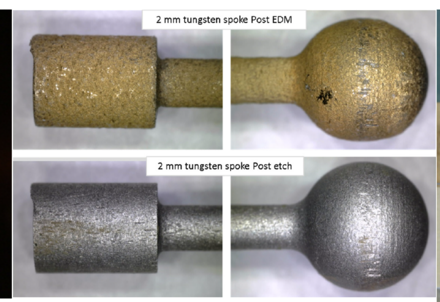
Target Design

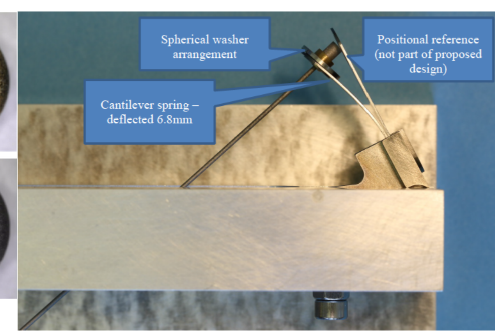
STFC Rutherford Appleton Laboratory
High Power Targets group

- Design, Testing, and Prototype work- Doc db 4305, 76 pages
  - Design shown on previous page
    - spoke tensioner, support ring detailed work
  - Measurements
    - vacuum vessel and equipment setup for testing
    - emissivity measurements at high T (5% verification of literature)
    - lifetime pulsed heating tests (fatigue)-OK for 4 yrs equivalent so far
  - Study of Creep in the Target Support- 6 micron elongation OK
  - Chemical Erosion Study (vacuum quality, oxidation) 1e-3 Torr not good enough
  - Spoke Prototyping (manufacturing, spring tests, adjustments)



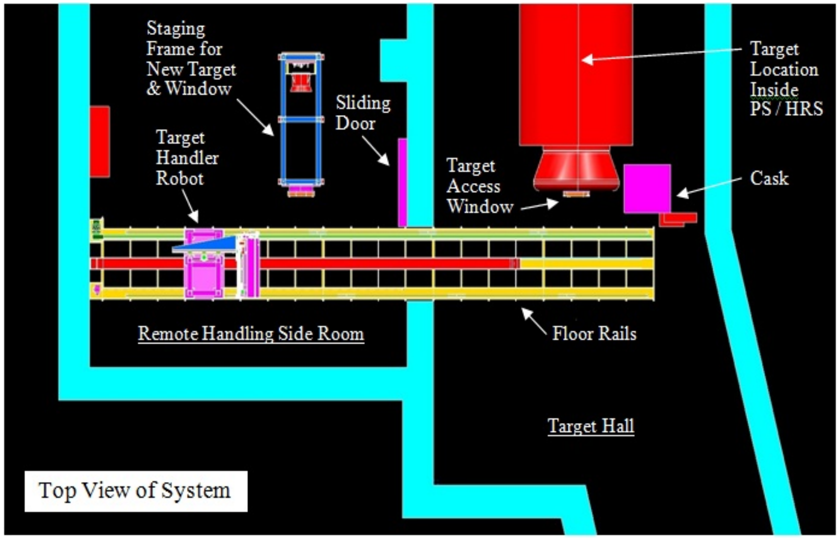


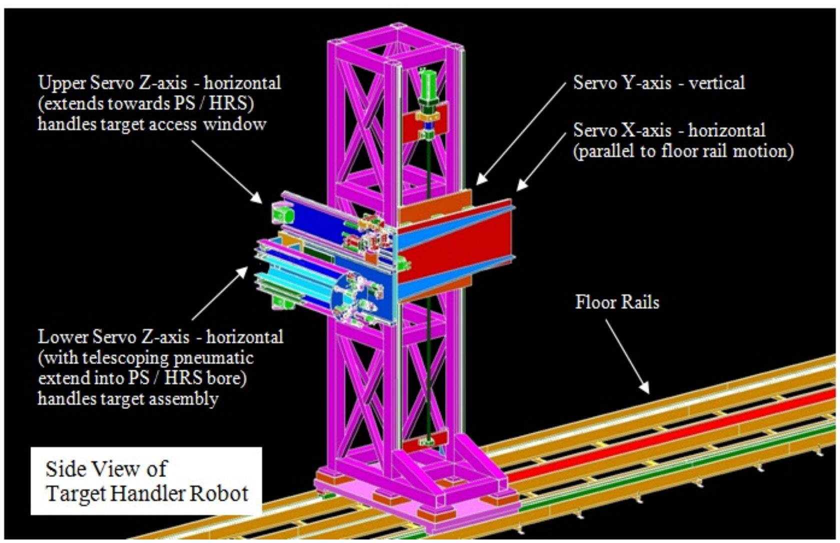




Target Remote Handling Design

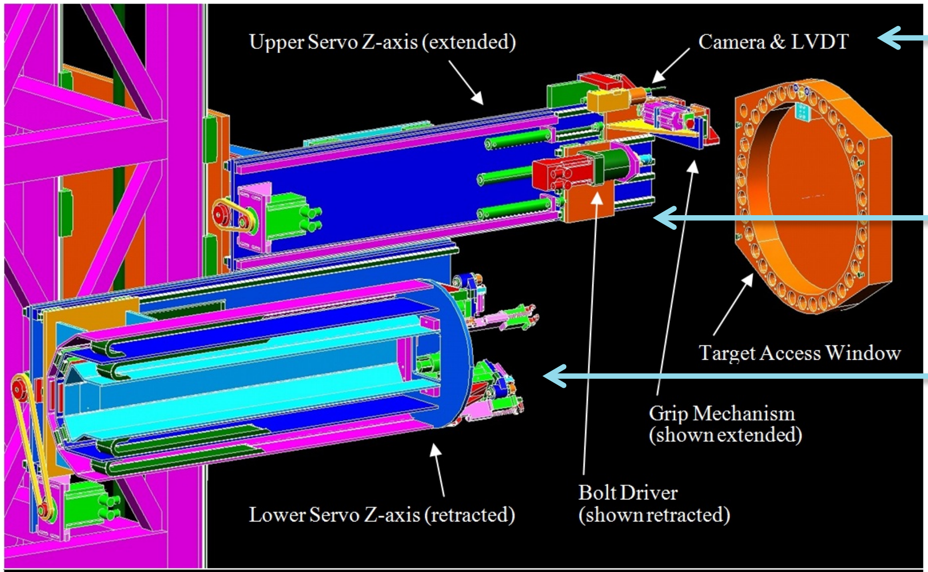
Mike Campbell/ FNAL





- Tasks
  - Enter Hall from RH room
  - Remove access window
  - Place window in cask
  - Detach/remove target
  - Place old target in cask
  - Obtain new target
  - Latch new target into place
  - Obtain new window
  - Bolt window in place
  - Exit Target Hall

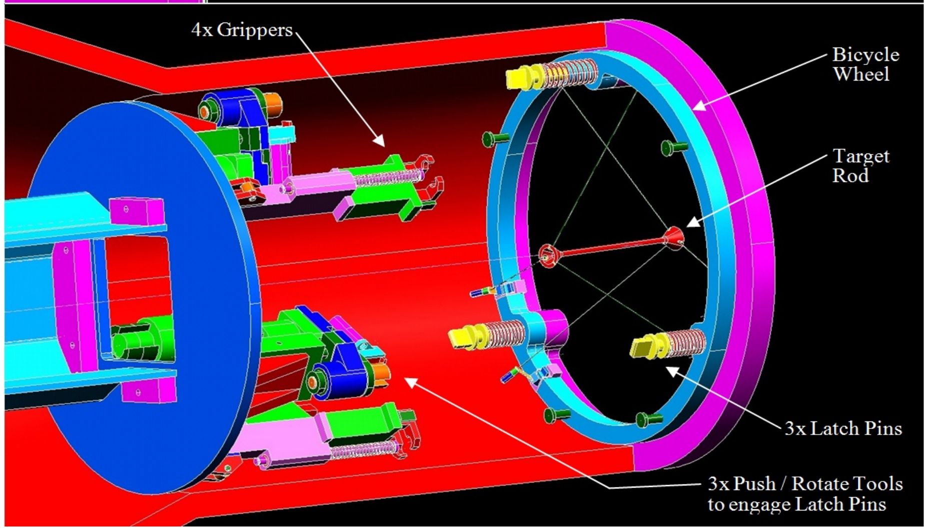
Target Remote Handling Design



Camera with machine vision software

Target Access Window
Upper Servo z-axis

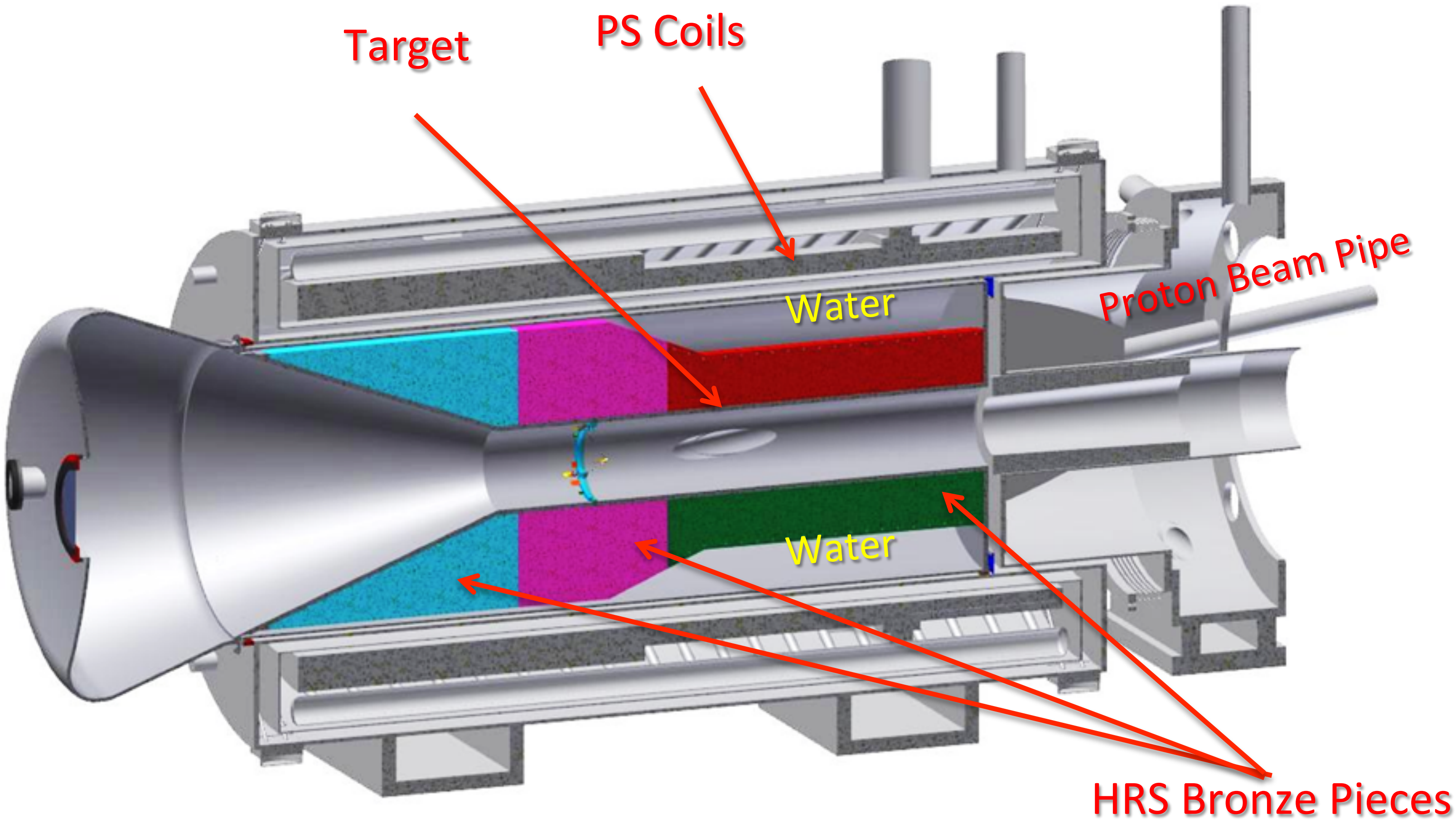
Target Interface Mechanism
Lower Servo z-axis



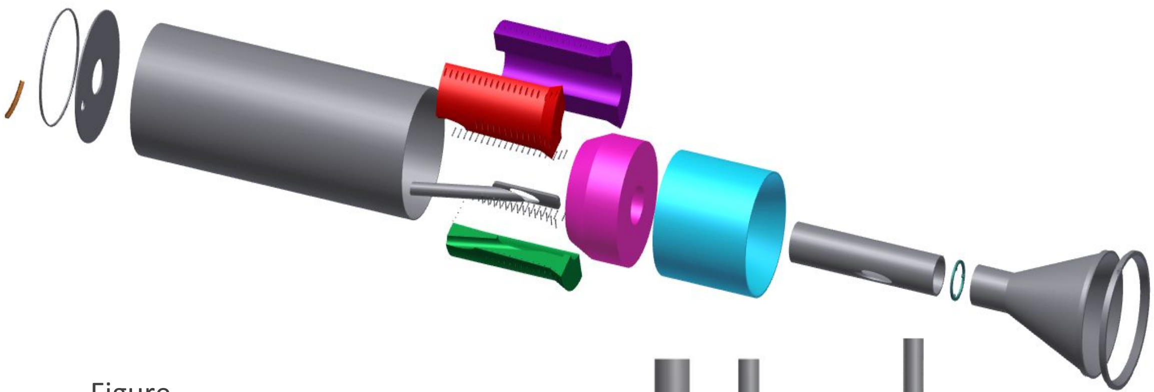
Target Interface Mechanism
Detailed View

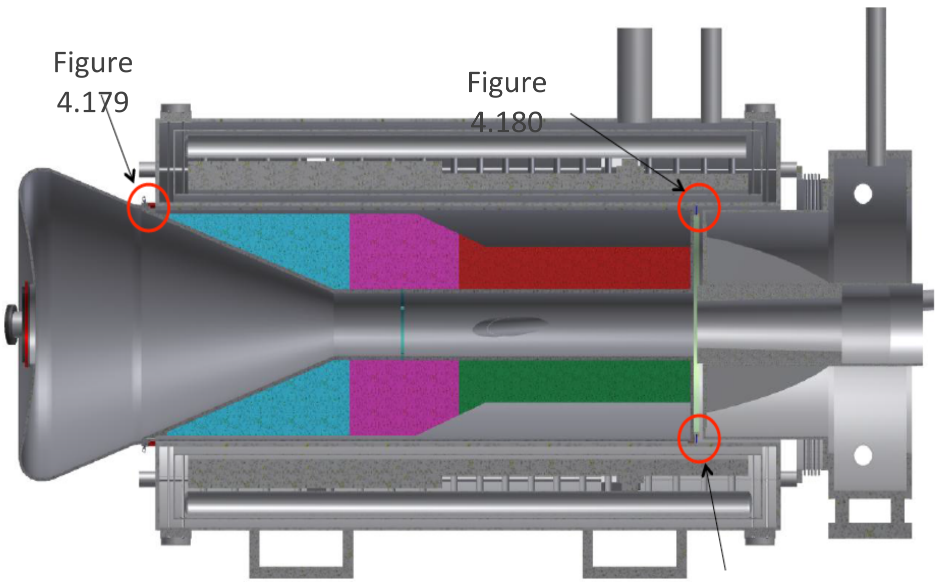
Heat & Radiation Shield Design

Bartoszek Engineering
Larry Bartoszek

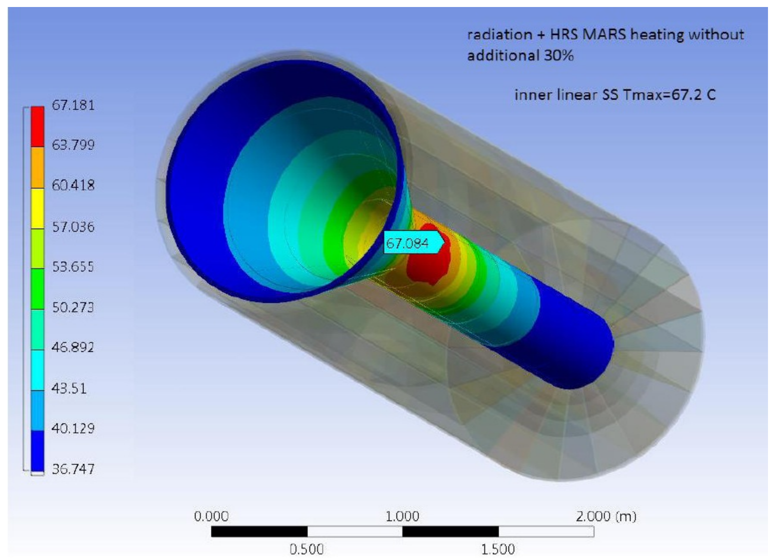


Heat & Radiation Shield Design

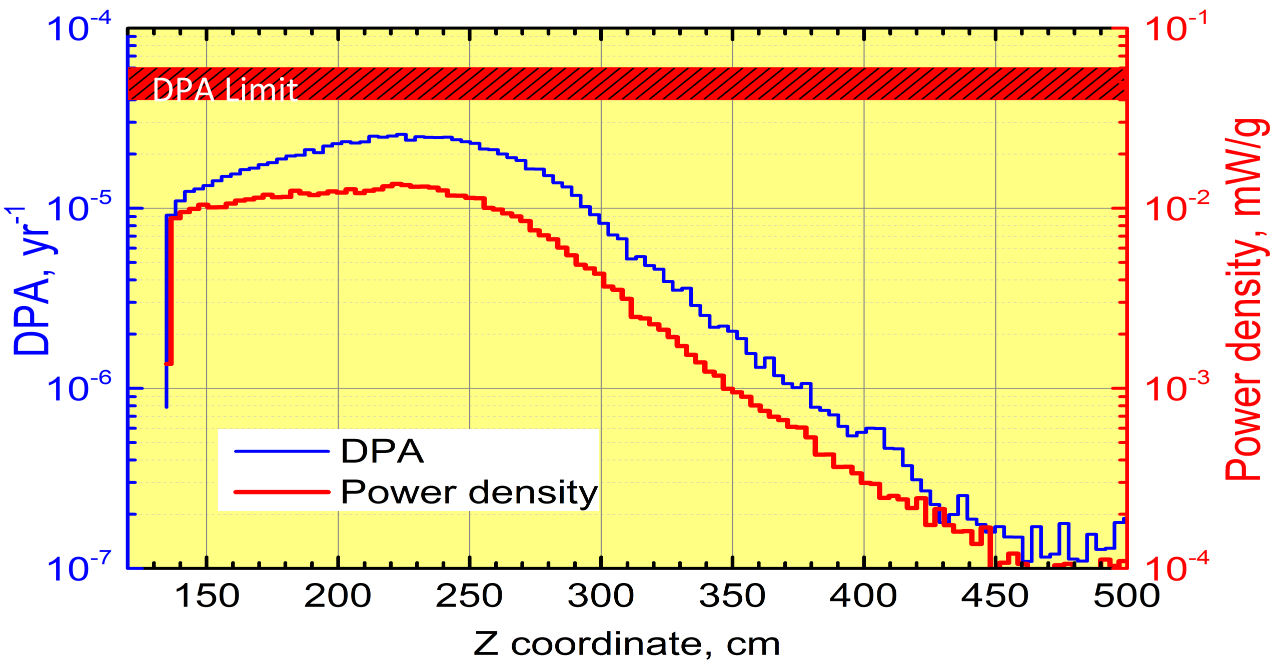




67° C max



Performance- HRS



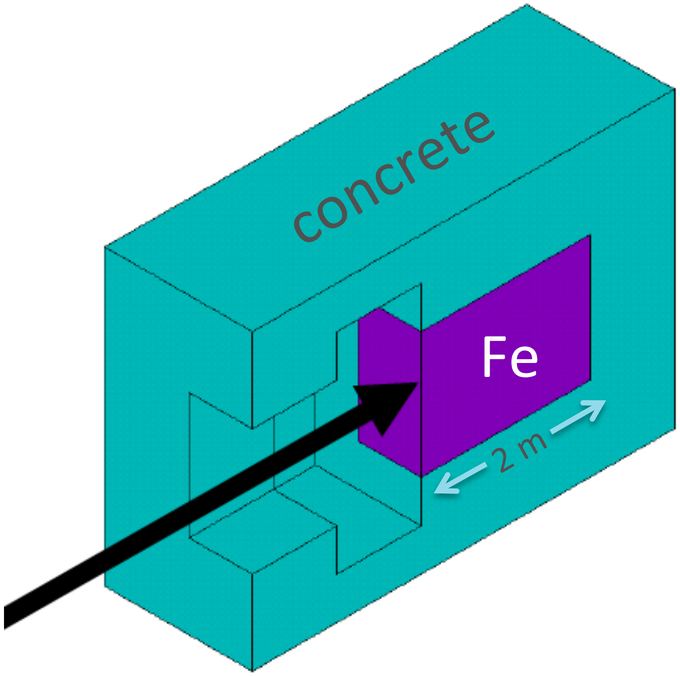
MARS Simulations
Vitaly Pronskikh

	Peak DPA/yr* [10^{-5}]	Peak Power Density [μW/g]	Absorbed Dose [MGy/yr]	**Years Before 7 MGy	Dynamic Heat Load [Watts]
Specification	4 to 6	30	0.35	20	100
Performance	2.4	13	0.26	27	24

Proton Beam Absorber Design

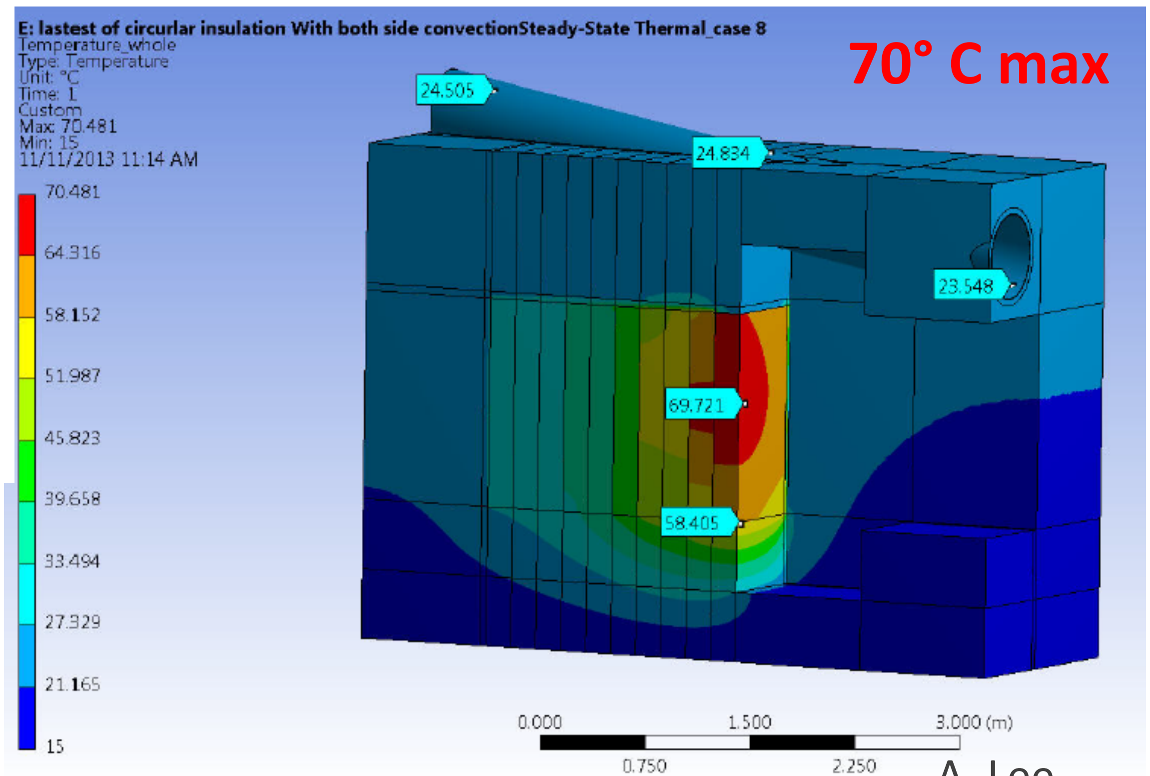
Andy Stefanik

Left Section View



Proton Beam

Fe core 1.5 m x 1.5m x 2 m



A. Lee

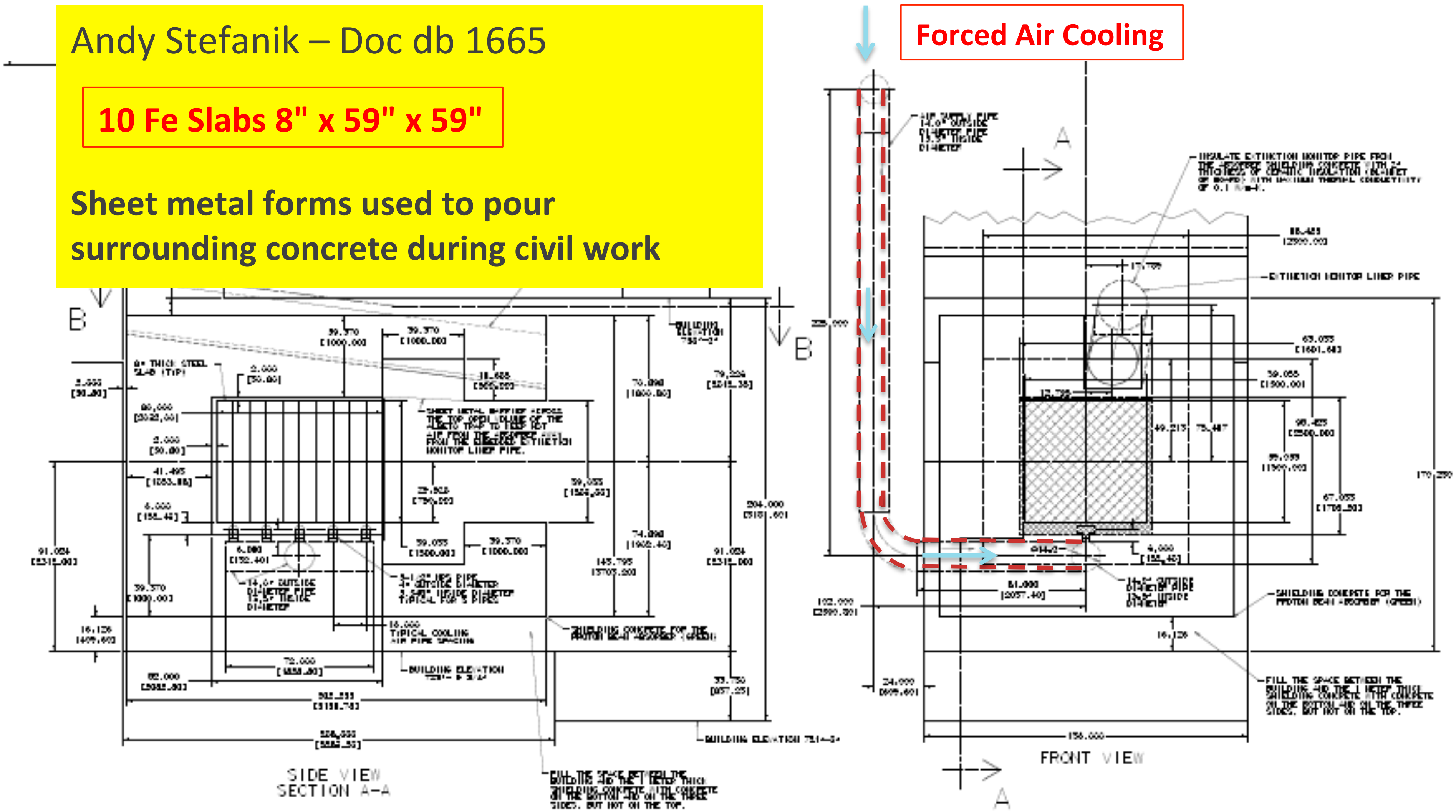
forced air cooliing

Proton Beam Absorber Design

Andy Stefanik – Doc db 1665

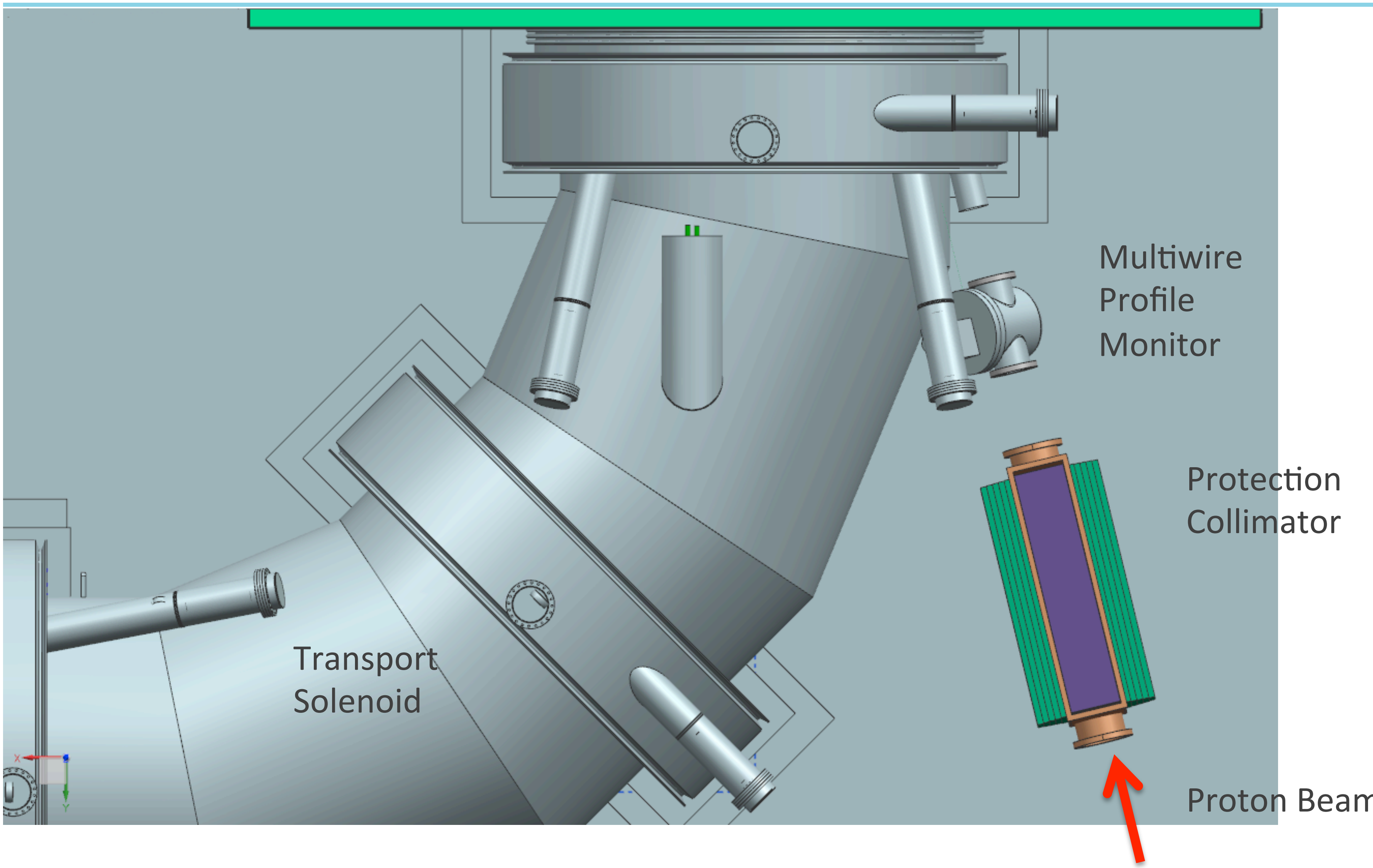
10 Fe Slabs 8" x 59" x 59"

Sheet metal forms used to pour surrounding concrete during civil work

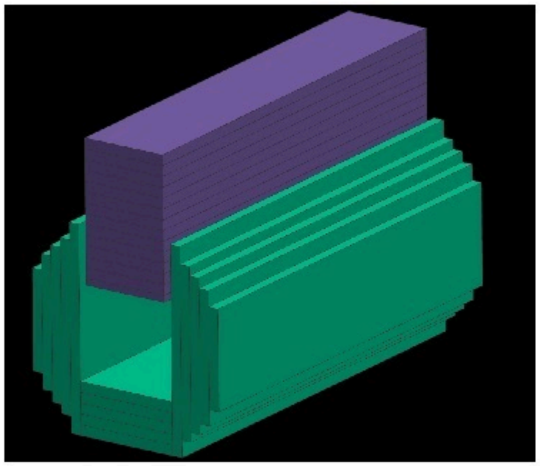


Protection Collimator Design

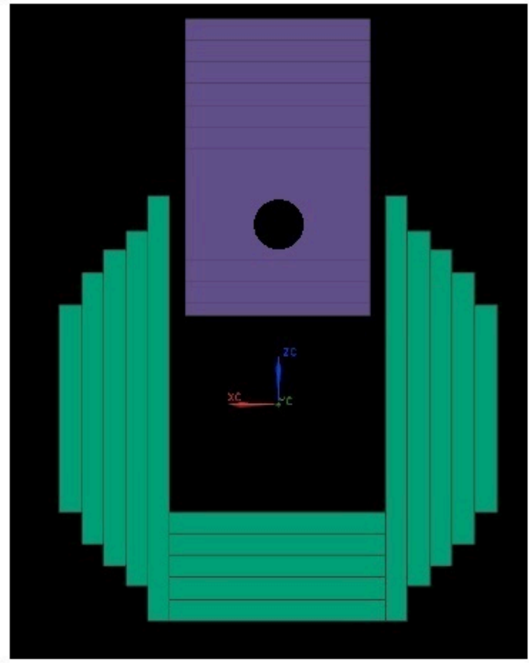
A. Stefanik



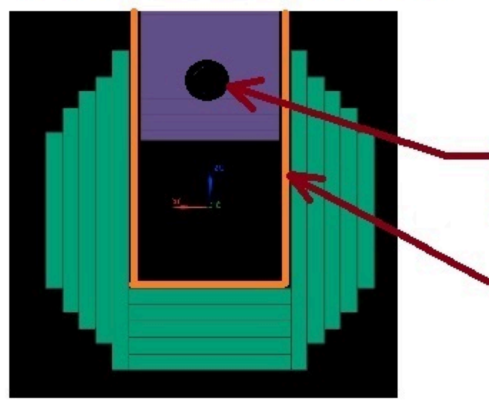
Protection Collimator Design



NEW CORE ISO VIEW. STATIONARY PART OF THE CORE IS GREEN. MOVING PART OF THE CORE IS PURPLE.



NEW CORE CROSS SECTION

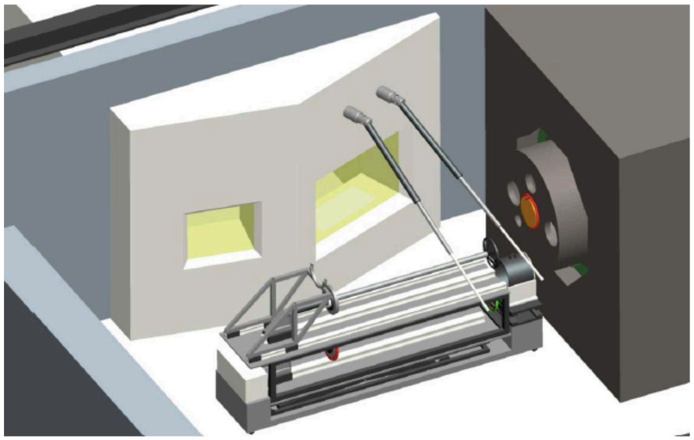


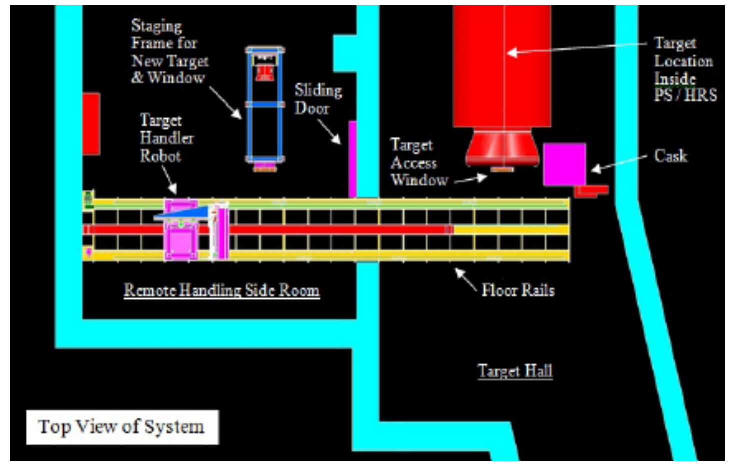
Beam Hole
shown in out position

Vacuum Vessel

Changes since CD-1

- Target Remote Handling   Hot Cell and manipulator arms changed to current "robot" design

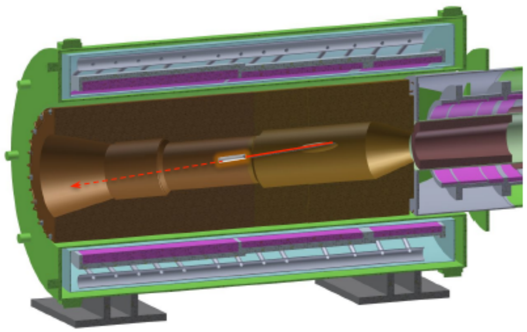


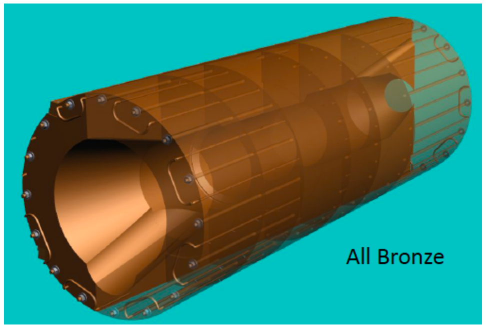


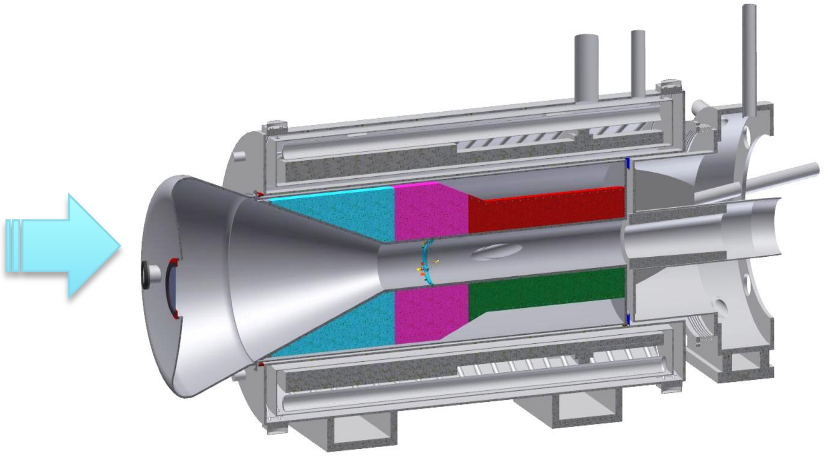
  - Move (Overall project beam power reduced by 3x for economics) -> from water-cooled to radiatively cooled target
  - Above removes the need for a longer plunger tool as shown on left
  - Responsibility of remote handling changed from contractor to FNAL
  - Started from discussions of a moveable hot cell
  - Minimize need for access through main PS hatch with temporary crane into high radiation area
  - Given building layout and large span to reach PS hatch, requires very large crane ($$$)
  - Minimize the need for massive shielding for hot cell/ manipulator arms (40 ton shield not shown in picture on left)

Changes since CD-1

- Heat & Radiation Shield, vacuum liner provides cleaner.







  - Mass of Bronze reduced from 41 tons to 31 tons
  - Water replaces some Bronze, serves as cooling & neutron shielding
  - Shape of Bronze simplified to cone plus cylindrical pipe, original had steps in radius, scalloped region
  - Stainless Steel liner -> Vacuum cleaner, vacuum surface area reduced
  - Concerns about water cooling lines contact in shield eliminated, number of pipe connections reduced

Value Engineering since CD-1

- Both design changes for Remote handling and HRS described on previous slides were motivated by Value Engineering
- Proton Beam Absorber design simplified, cost effective
  - Machined Al plates for core replaced with "boneyard" steel
  - Much of concrete around core poured in place during civil construction rather than using blocks
- Proton Collimator design simplified, cost effective
  - Motion of block inside vacuum changed, greatly reduces vacuum volume
  - Further work with look at larger reduction in mass of steel used

Value Engineering since CD-1- Rutherford Labs

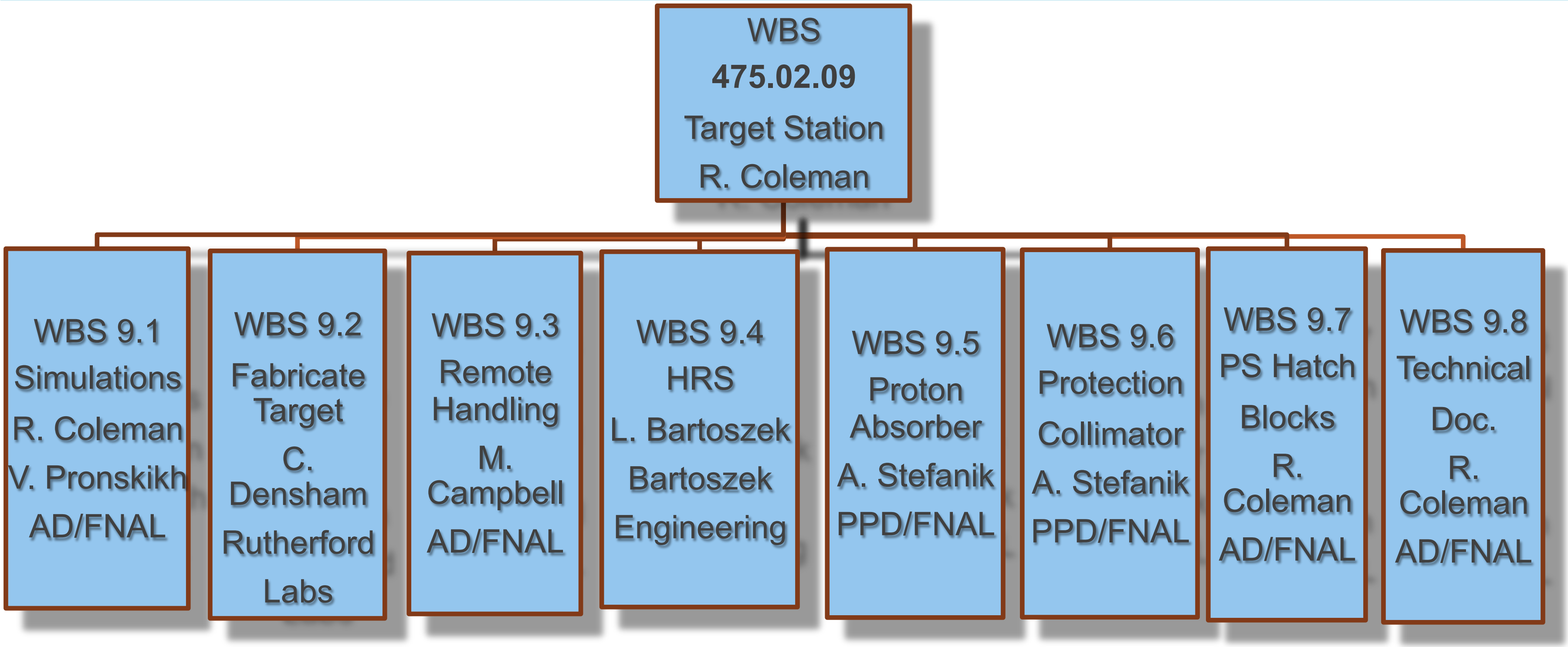
- here is a list of the value of equipment RAL have used, or in some cases purchased specifically with no cost to the project:
-
- 1. Roger's 'little wire' test rig – c.£10k(?) of relevant costs not including pulsed psu
- 2. Vacuum pumps (turbo + scroll), gauges (Pirani + Penning + Controller/Display) - £9435
- 3. Pulsed PSU (components and much of the effort) c.£15k
- 4. DC power supply for emissivity measurements c.£2k
- 5. Induction PSU for future testing of prototype target £20k
- 6. Tensile test facility £300k
- 7. TGA test machine
- 8. Vac furnace for baking out and stress relieving – Run in a large vacuum furnace @ Culham ~ £500/day (Captial cost ~ £50,000 ?)
- 9. Oscilloscope - £2240
- 10. DAQ system
- 11. Optical pyrometer
- 12. Digital pyrometer - £3175
- 13. Optical microscope - £5k
- 14. EDM capital costs (running costs only paid for?) Machine cost ~100k +VAT
- 15. Laser fin cutting (prototyping)
- 16. Advanced metrology facilities (3D co-ordinate measuring machine, profilometry, non-contact measuring machine etc) – A number of high value instruments
- 17. Graphtec datalogger - £2500
- 18. ANSYS multiphysics license - £45k purchase list price plus £8.4k pa support
- 19. Residual Gas Analyser – c.£5k

Remaining work before CD-3

- Complete Proton Beam Absorber and install during early civil construction
- Evaluate the alternate of an overhead remote handling room with crane coverage
  - Civil bids done with and without underground RH room
  - Decide mods to RH (already started) & ground level building and crane requirements
  - Get costs and review plans

- Based on completed target R&D, decide on radiation cooled or He cooled target, modifications to RH, minimal if overhead solution is chosen

Organizational Breakdown



Quality Assurance

- Every part of the target will be thoroughly prototyped and tested off-line. A complete prototype will then be manufactured. All manufacturing and test methods will be thoroughly documented. The actual target supplied for experimental operation will use the same procedures as were developed for the prototype.

- Target Station sub-systems will be designed and built in accordance with the requirements of the Fermilab Engineering Manual. The design of these systems is monitored by in-progress design review during weekly meetings of the Target Station Group. The in-progress review is followed by a final project review. The design is documented in the requirements and specification documents, CAD model, and drawings. As-built dimensions will be checked against the fabrication drawings. Operation is verified as part of the fabrication process and again after installation.

Risks

- **Poor quality vacuum reduces target lifetime due to chemical processes**
  - Erosion of the tungsten rod, supports and spoke material is expected due to oxidation and water vapor-induced corrosion from impurities in the vacuum. It is difficult to predict the erosion rate by these processes at the expected achievable vacuum level of 1×10^{-5} Torr due to uncertainties in the vacuum impurity constituents, uncertainties in the operating temperature as described above, and discrepancies and extrapolations in the data from different sources in the literature.
  - Mitigation Strategy is the extensive RAL studies, measuring the effect, testing protective coatings, and exploring He cooling as an alternative.
  - Impact is very large to remote handling in current RH scheme. However, we have a common remote handling solution for both radiative or He cooled

- **Remote Handling needs redesign and cost increase if we abandon radiatively cooled target (in baseline remote handling scheme)**
  - Mitigation Strategy is the extensive RAL studies, measuring the effect, testing
  - Explore our option of above ground remote handling room with crane and a common remote handling solution for either radiative or He cooled target.

ES&H

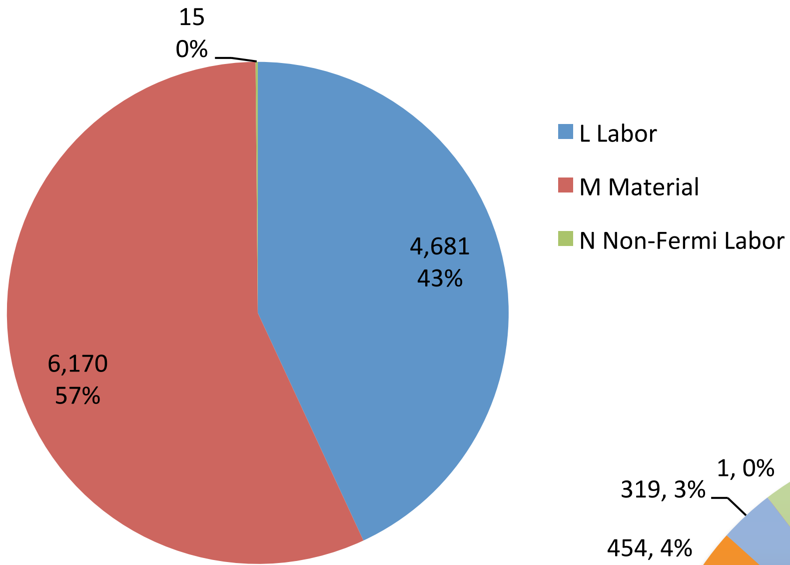
- Mu2e Hazard Analysis Document doc-db 675 covers a complete list of topics

- Radiation Safety is particularly important for the Target Station, including:
  - Prompt Dose
  - Residual Dose
  - Air Activation
  - Ground Water Activation

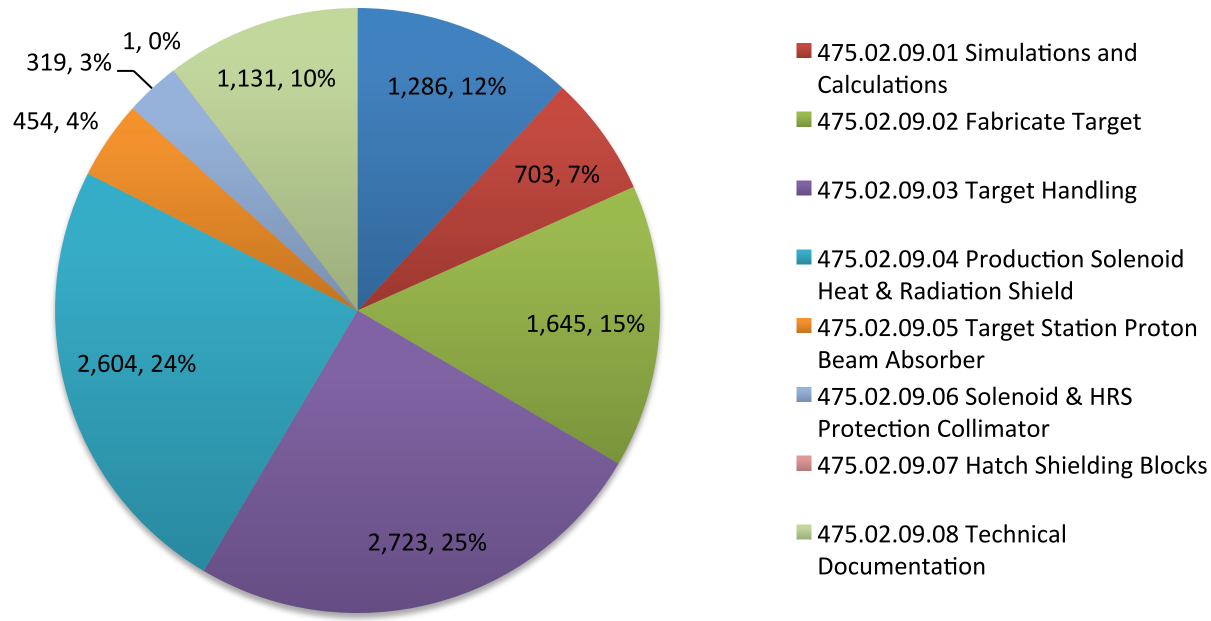
Cost Table

	Base Cost (AY $)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.02 Accelerator						
475.02.09 Target Station						
475.02.09 Target Station Actuals	302	983	1,286			1,286
475.02.09.01 Simulations and Calculations	64	638	703	175	25%	878
475.02.09.02 Fabricate Target	1,645		1,645	504	31%	2,149
475.02.09.03 Target Handling	1,533	1,191	2,723	857	31%	3,580
475.02.09.04 Production Solenoid Heat & Radiation Shield	2,411	194	2,604	899	35%	3,503
475.02.09.05 Target Station Proton Beam Absorber	106	349	454	106	25%	561
475.02.09.06 Solenoid & HRS Protection Collimator	124	195	319	125	39%	443
475.02.09.07 Hatch Shielding Blocks		1	1		25%	1
475.02.09.08 Technical Documentation		1,131	1,131	253	24%	1,384
Grand Total	6,185	4,681	10,866	2,919	31%	13,785

Cost Breakdown

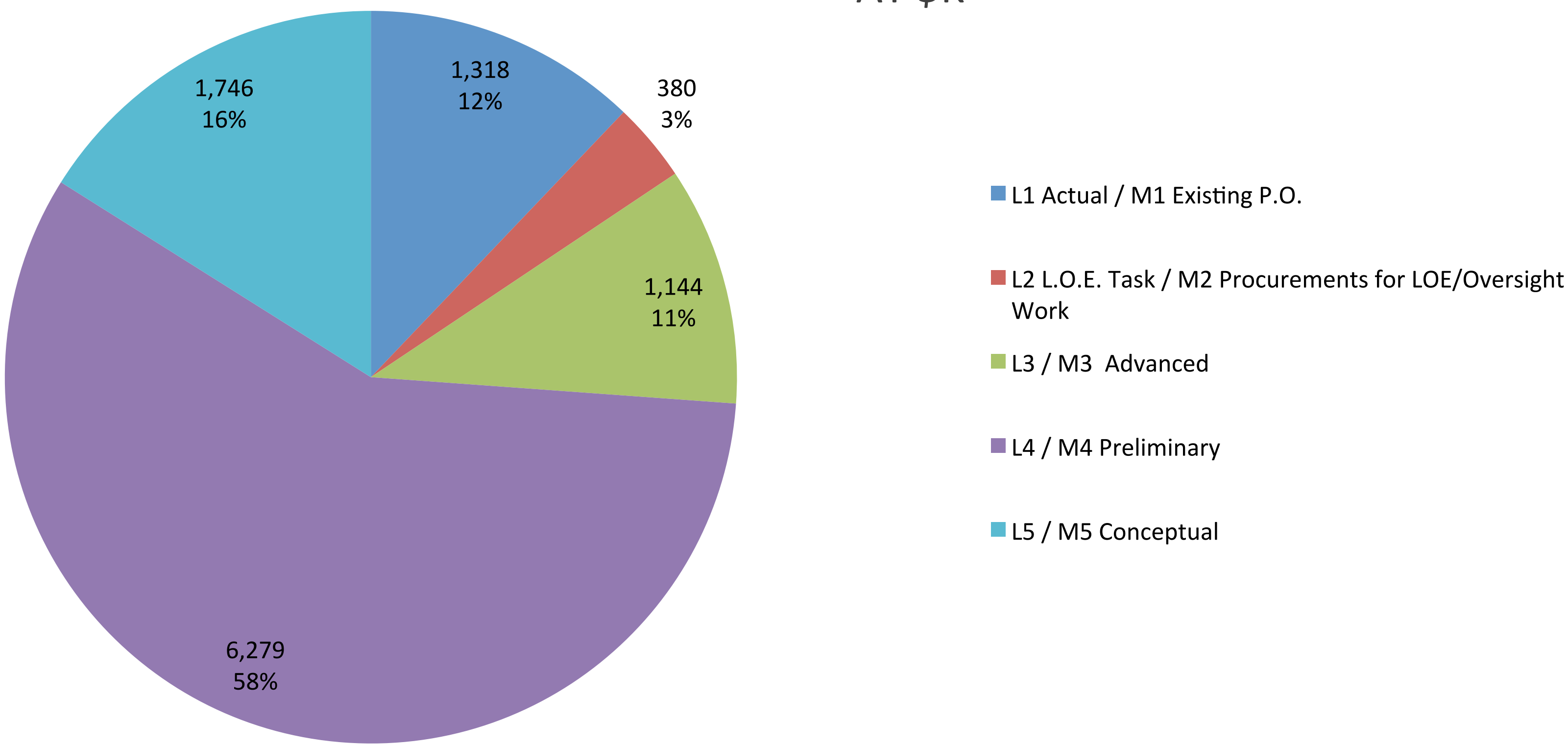


475.02.09 Target Station
WBS Level 4
Base Cost in AY $K

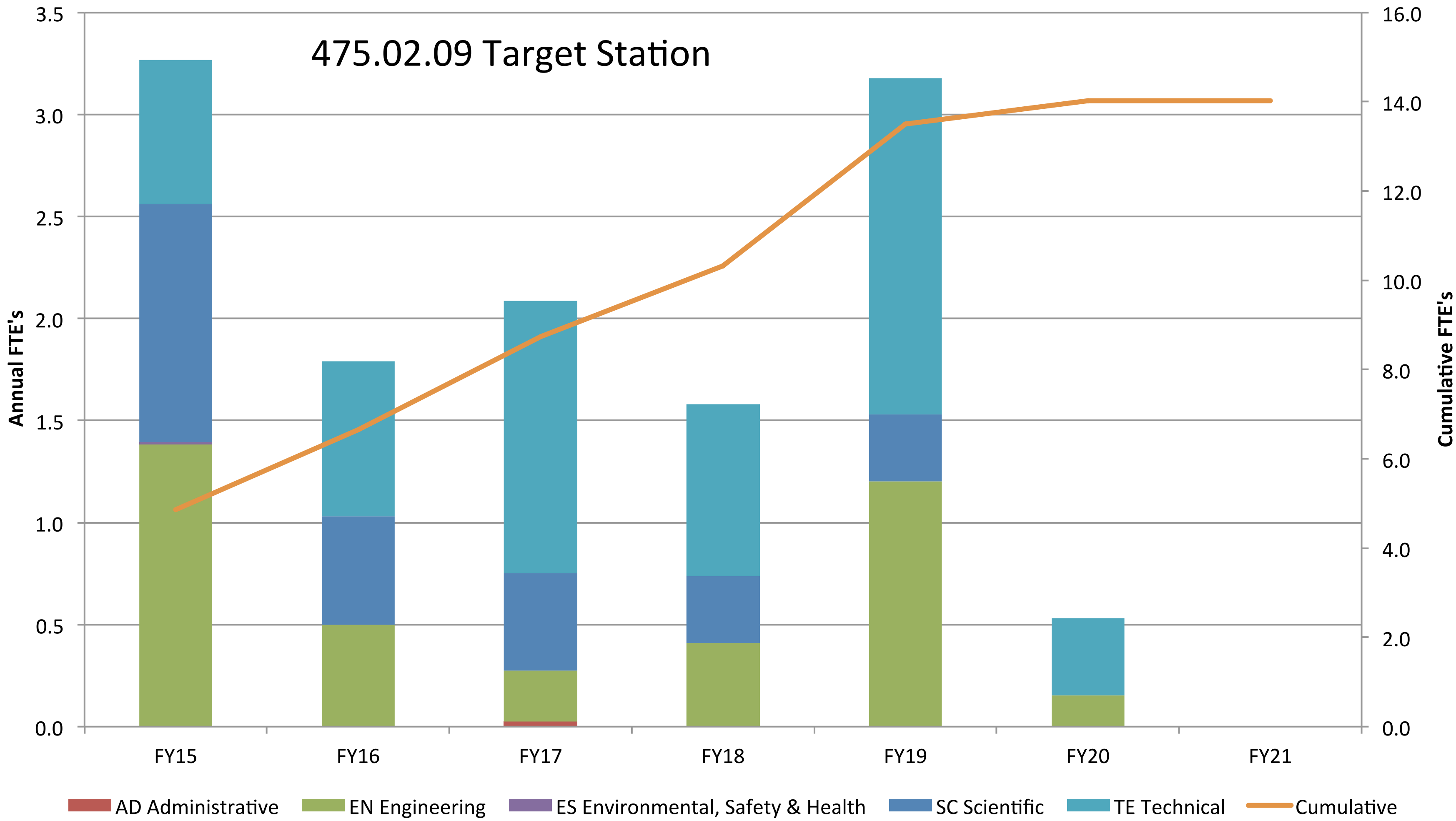


Quality of Estimate

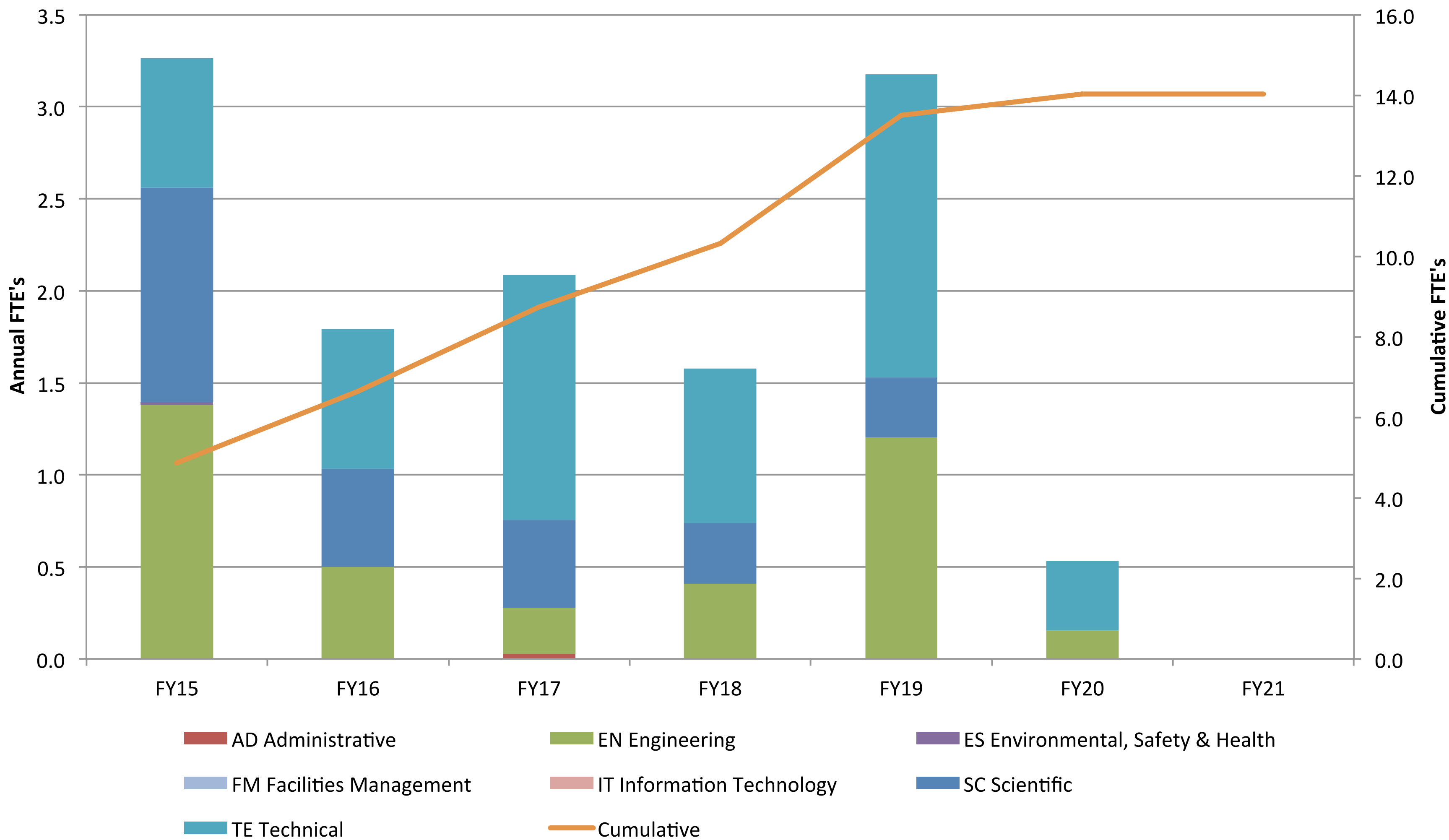
475.02.09 Target Station
AY $K



Labor Resources by FY



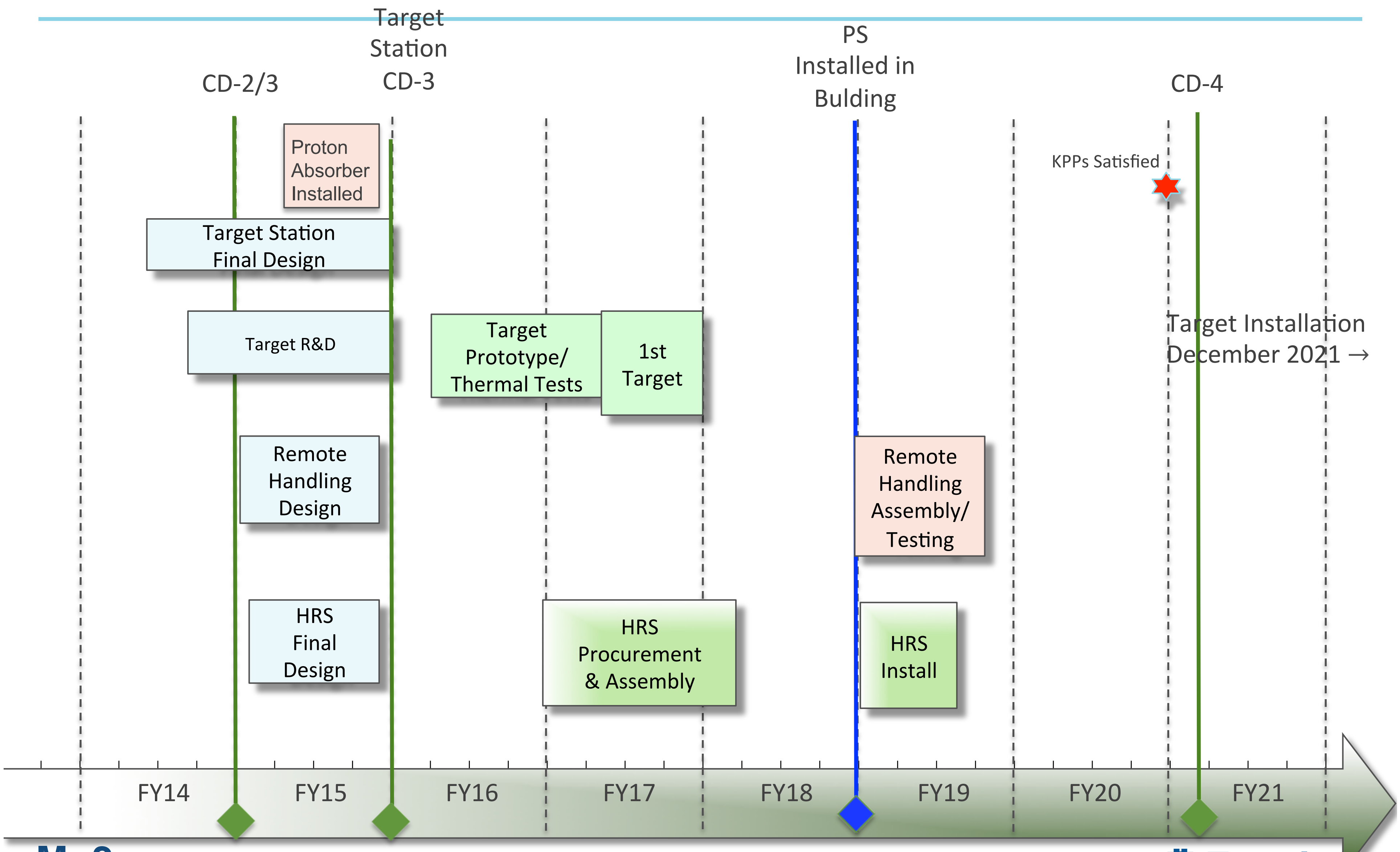
FTE's by Discipline



Major Milestones

Activity ID	Milestone Name	Milestone Date
47502.09.001010	Target Station Preliminary Design Complete	May 1, 2014
47502.09.05.001040	MARS Energy deposition for accident case	June 2, 2014
47502.09.06.001140	Protection collimator design complete	November 5, 2014
47502.09.001020	Mu2e Target Station- Proton Beam Absorber Installation and Close-out Complete	February 13, 2015
47502.09.03.001150	Target Handling Final Design Complete	July 9, 2015
47502.09.001030	Target Station Final Design Complete	September 15, 2015
47502.09.001040	DOE CD-3 Accelerator Target Station/HRS Mini Review Approval	
47502.09.04.001160	Advanced procurement plan for HRS Complete	October 4, 2016
47502.09.04.001190	Readiness review for HRS complete	October 26, 2016
47502.09.04.001230	Vendor for HRS selected	January 5, 2017
47502.09.04.001260	PO issued for HRS	February 27, 2017
47502.09.001050	Mu2e Heat & Radiation Shield Installation Complete	November 19, 2018
47502.09.001060	Mu2e Production Target Station Systems Installation and Close-out Complete	September 24, 2019
47502.09.001070	Target Station Complete	October 28, 2019

Schedule



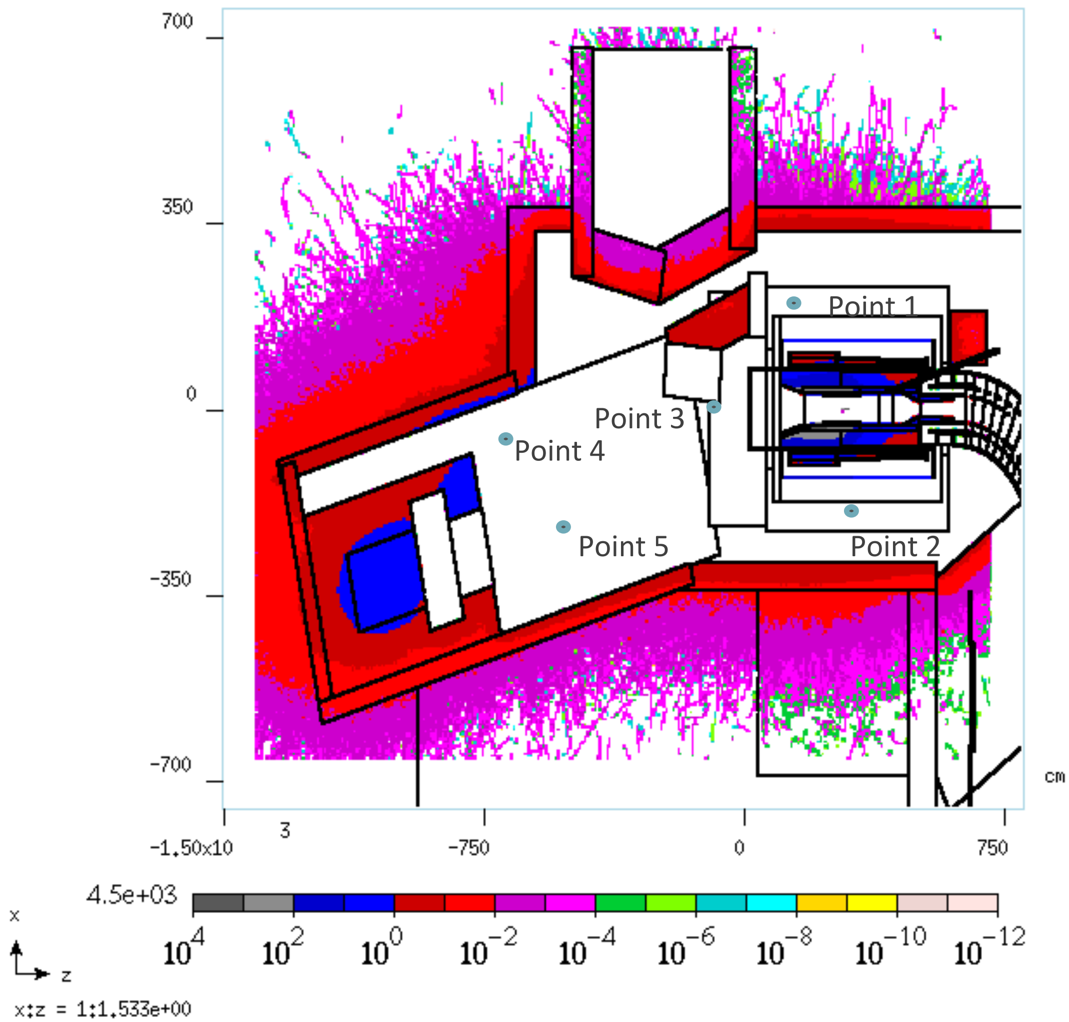
CD-2/3
Target Station CD-3
PS Installed in Bulding
CD-4
Proton Absorber Installed
Target Station Final Design
Target R&D
Target Prototype/ Thermal Tests
1st Target
KPPs Satisfied
Target Installation December 2021 →
Remote Handling Design
Remote Handling Assembly/ Testing
HRS Final Design
HRS Procurement & Assembly
HRS Install
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- The Target Station Design is well integrated with the Solenoids, Muon Beam line, Civil Construction, and Radiation Safety
- A preliminary design is complete
- A review and choice is needed on the remote handling scheme- surface building vs underground soon
- R & D is well underway to decide on target choice- radiative or convection cooled
- We are ready to baseline our schedule

Backup Slides

Residual Dose PS Hall-

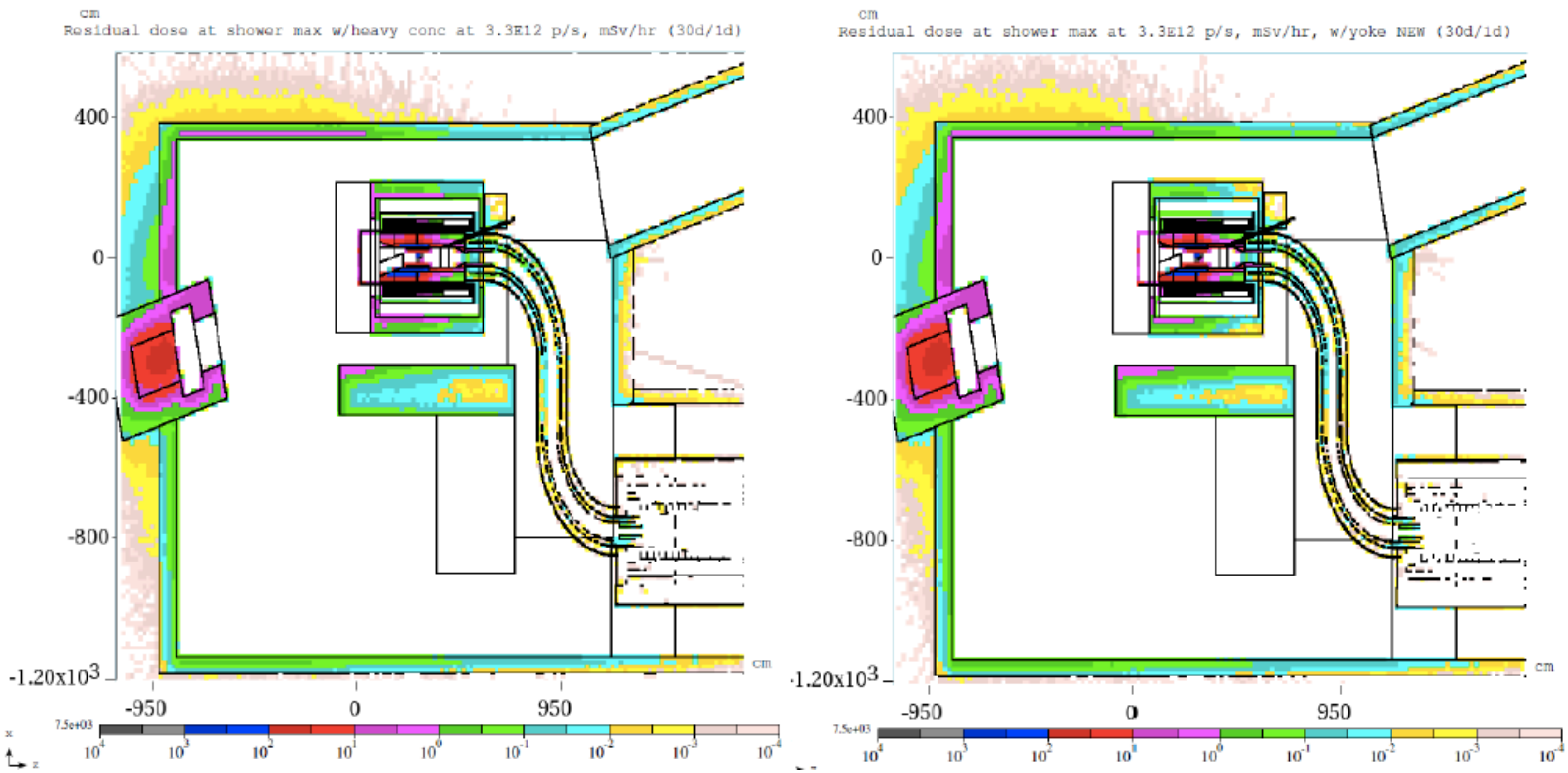


N. Duff, doc db 2717

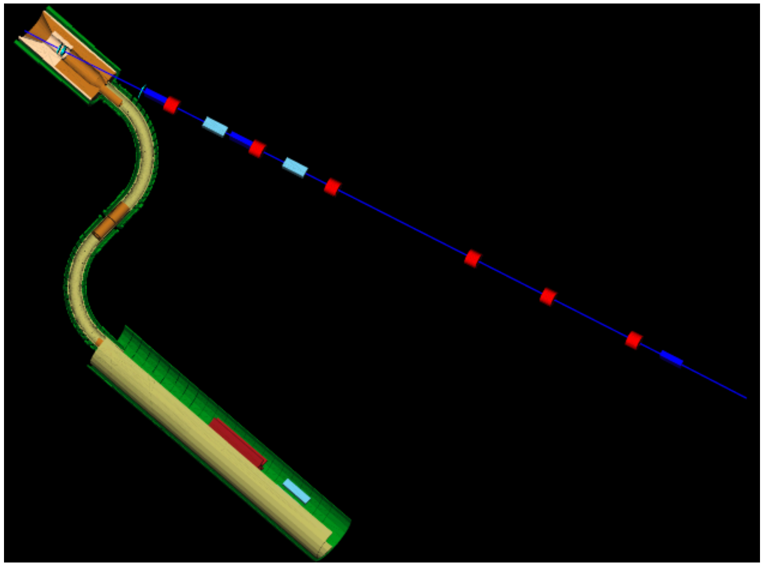
30 Days Irr, 1 Day Cool	(mrem/hr)
Point 1	596
Point 2	1087
Point 3	32816
Point 4	2269
Point 5	2473
30 Days Irr, 7 Day Cool	
Point 1	55
Point 2	101
Point 3	3035
Point 4	210
Point 5	229
365 Days Irr, 1 Day Cool	
Point 1	692
Point 2	1261
Point 3	38066
Point 4	2631
Point 5	2868
365 Days Irr, 7 Day Cool	
Point 1	147
Point 2	269
Point 3	8105
Point 4	560
Point 5	611

Target Hall Radiation Levels

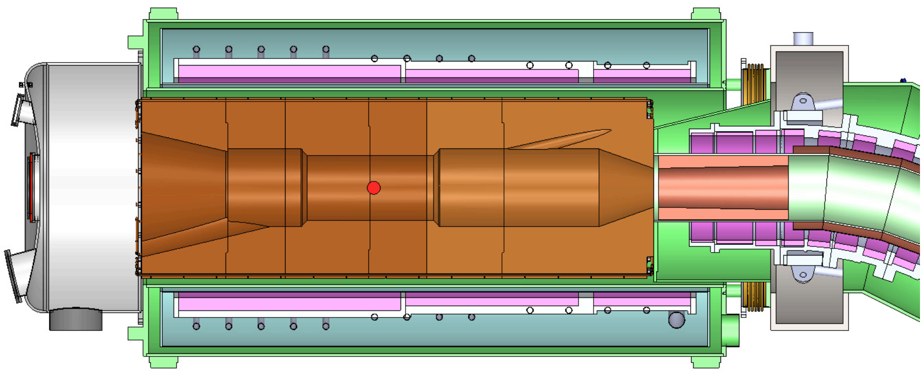
Residual dose w/concrete and w/ iron, mSv/hr

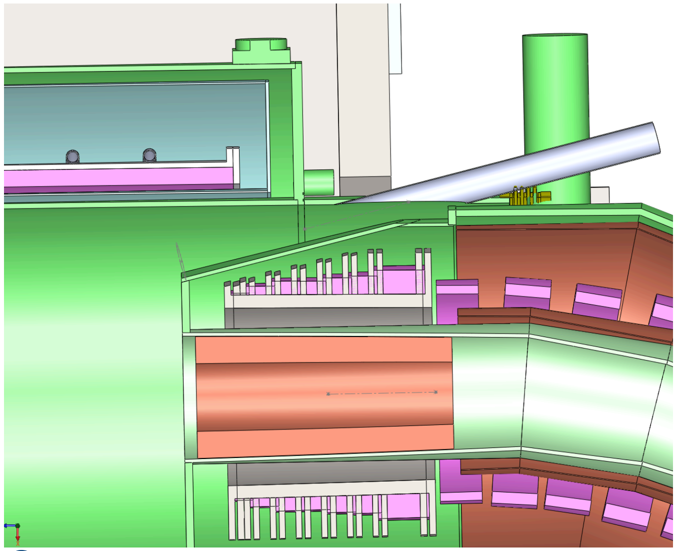


Proton Beam Through Solenoids



T. Page

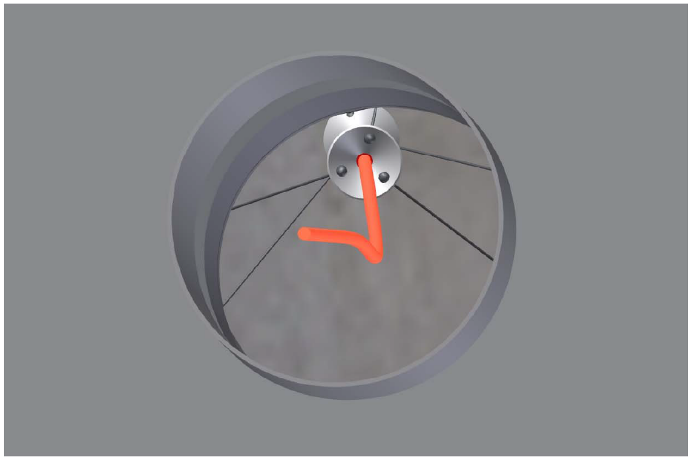




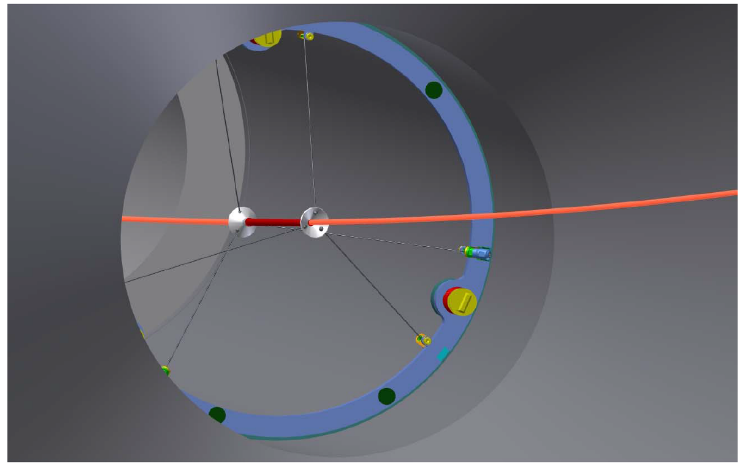
Peter K and I agreed on trajectory Jan 2013

Proton Trajectory in Engineering Model

This view looks proton downstream through the holes in the TS and HRS

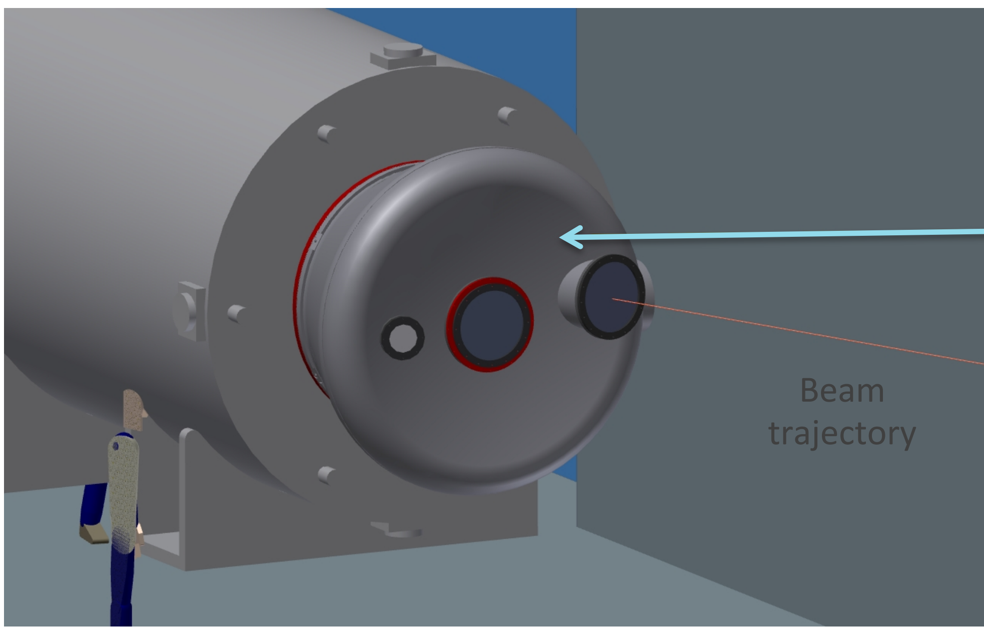


This view shows the proton beam exiting the target



L. Bartoszek
Check of Trajectory

Other checks by:
A. Stefanik
T. Page
J. Brandt



PS endcap

Target Alignment/Tolerances Summary

Target dimension tolerances

- Target Length = 16 cm ±2 mm
- Target Radius = 3 mm ±0.1 mm

Alignment of target with respect to PS/HRS

- Replacement target positioning repeatability: ±0.25 mm
- Transverse placement w/resp. to PS axis: ±5 mm
- Longitudinal placement along PS axis: ±10 mm

Alignment of target with respect to the proton beam:

- Transverse beam positioning requirement: ±0.5 mm
- Horizontal and vertical angle alignment: ±0.2°

Alignment Details

The alignment strategy to accomplish these requirements is:

- The target/supports/mounting must be quite stable and reproducible during target change relative to the PS. The tolerance on the manufactured target rod dimensions should be: length = +/- 2 mm and radius= +/- 0.1 mm. The target position relative to the PS must be stable to about ±0.25 mm during operation, taking into account distortions due to thermal cycling from ambient conditions when the beam is turned on. The target support structure and remote handling system must allow replacement targets to be placed within about ±0.25 mm of the first.

- The relative alignment of the target with respect to the PS axis is not as critical as the target-beam alignment. The muon yield is very insensitive to transverse [5] or motion along the z axis up to several cm. There is a potential background for ~100 MeV electrons, if the target source is more than 2 cm below the nominal elevation [6]. The relative alignment of the target to the PS axis should be +/- 5 mm transversely and +/- 1 cm along the PS axis.

- The PS axis must be aligned transversely to the proton beam to within: +/- 5 mm in position and +/- 0.2 degrees in angle. The angular requirement is set by the narrow channel available to the proton beam to pass through the transport solenoid entrance beam pipe which is 4.75" inner diameter about 3 m upstream of the target. Given the target z location, this pipe sets an angular acceptance of +/- 1 degree. The muon yield is much less sensitive to the angle [7].

The proton beamline has the ability to adjust the transverse position +/-1 cm and +/- 0.8 degrees at the target. If the alignment moves outside the range allowed by the beamline adjustment then the beam-PS alignment must be corrected.

Remote Handling Alternative Scheme: Surface Building with Crane

Kurt Krempetz, Tony Leveling 1st suggested this alternative;; Mike Campbell reworked the remote handling in detail in Doc db # 4146, text from that document is below:

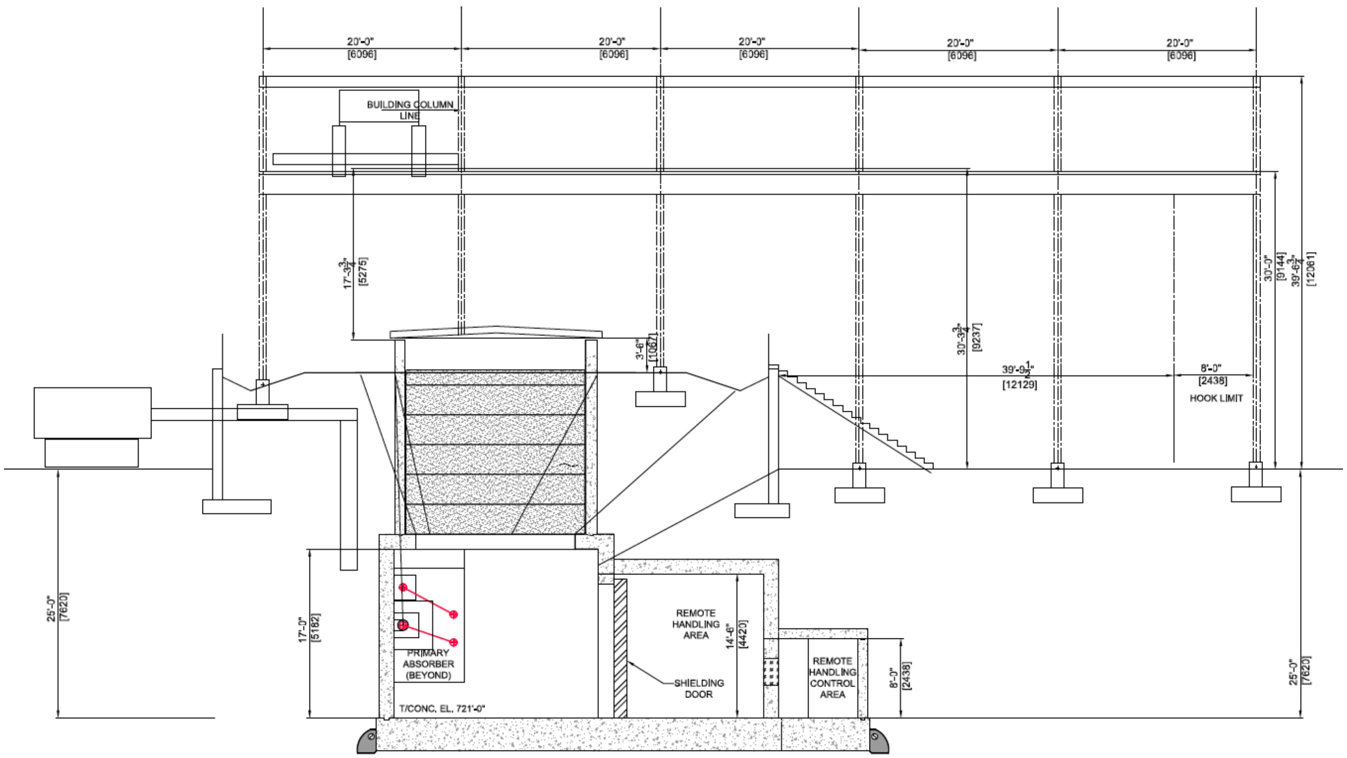
1. Rather than a robot with all required functionality built into a single machine . . . The overhead concept could utilize the built-in crane to lower down a series of three simpler modules to accomplish the RH task.
2. no machine vision, no sliding door, no cask fit issues, 4 servos reduced to 1 stepper, doesn't need to be dismantled / re-installed each time, simplicity of task separation
3. The overhead concept also facilitates modular approach to the target itself :
   A) We continue to assume an RC target for now.
   B) We could move forward with the 3 RH modules needed for the RC target.
   C) We have a design in mind for possible CC target and its' RH.
   D) The CC target and RC target would mount <u>interchangeably</u> within the HRS.
   E) If we do end up later switching to CC, then impact to the project is minimized: 1 of the 3 RH modules is re-usable, and the building /HRS/PS all work for both.
4. For the Accelerator / Remote Handling subsystem : should achieve a significant cost reduction (no SS sliding door, no SS for cask, 3 simple modules = less $ than robot). Should also be a large reduction in risk $ associated with switching to a CC target. However: we still need to determine the bottom line $ impact to whole project.

Remote Handling Alternative Scheme: Surface Building with Crane

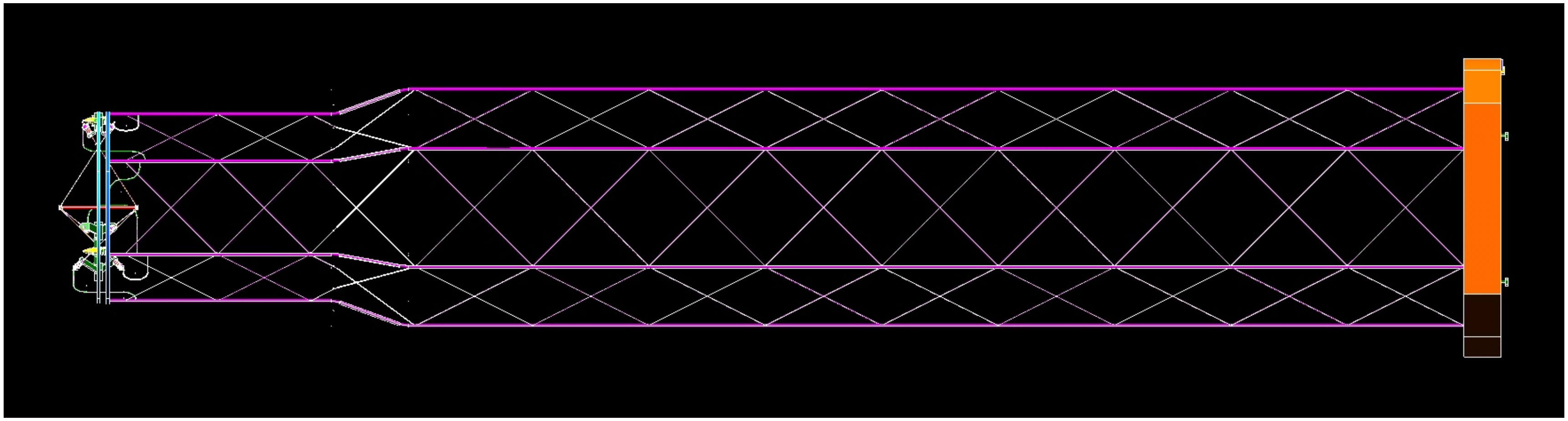
- The remote handling equipment is simpler, and cheaper- perhaps up to one million dollars
- Equipment can be lowered onto precision alignment positions
- The crane allows much greater flexibility in solving unforeseen problems
- Above ground buildings are cheaper, so there is savings in the civil to move the remote handling room upstairs
- But more lense adding a crane
- Cost comparison needed- Current Building being bid two ways, with and without underground remote handling room

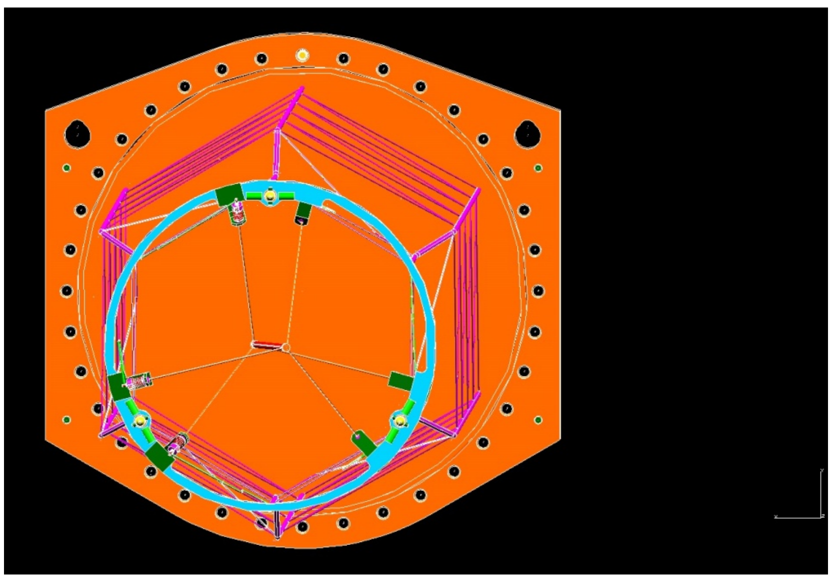
Remote Handling Alternative Scheme: Surface Building with Crane

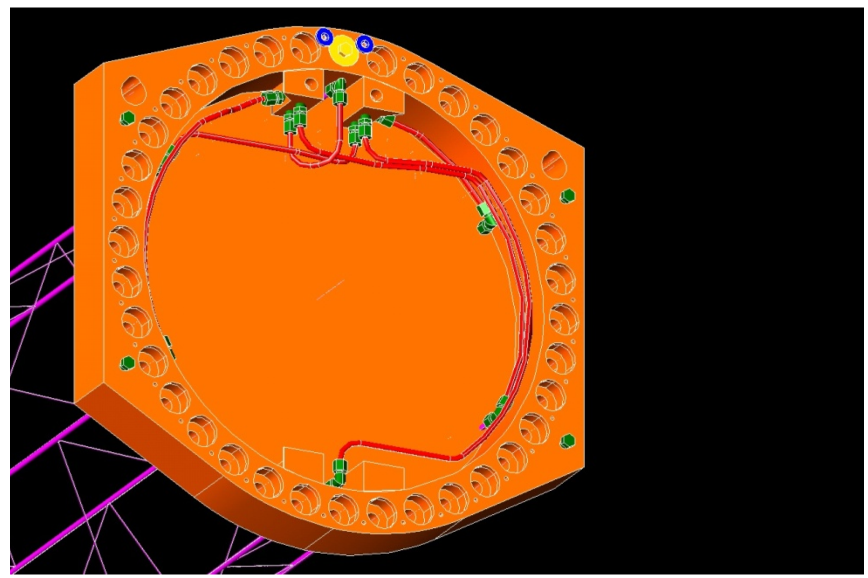
- Surface Building to replace underground remote handling room
- To break even or slightly reduce overall cost, for the surface building & crane:
  - Minimize size to perhaps 25' x 60', Spartan utilities
  - Modest crane (~20 tons)



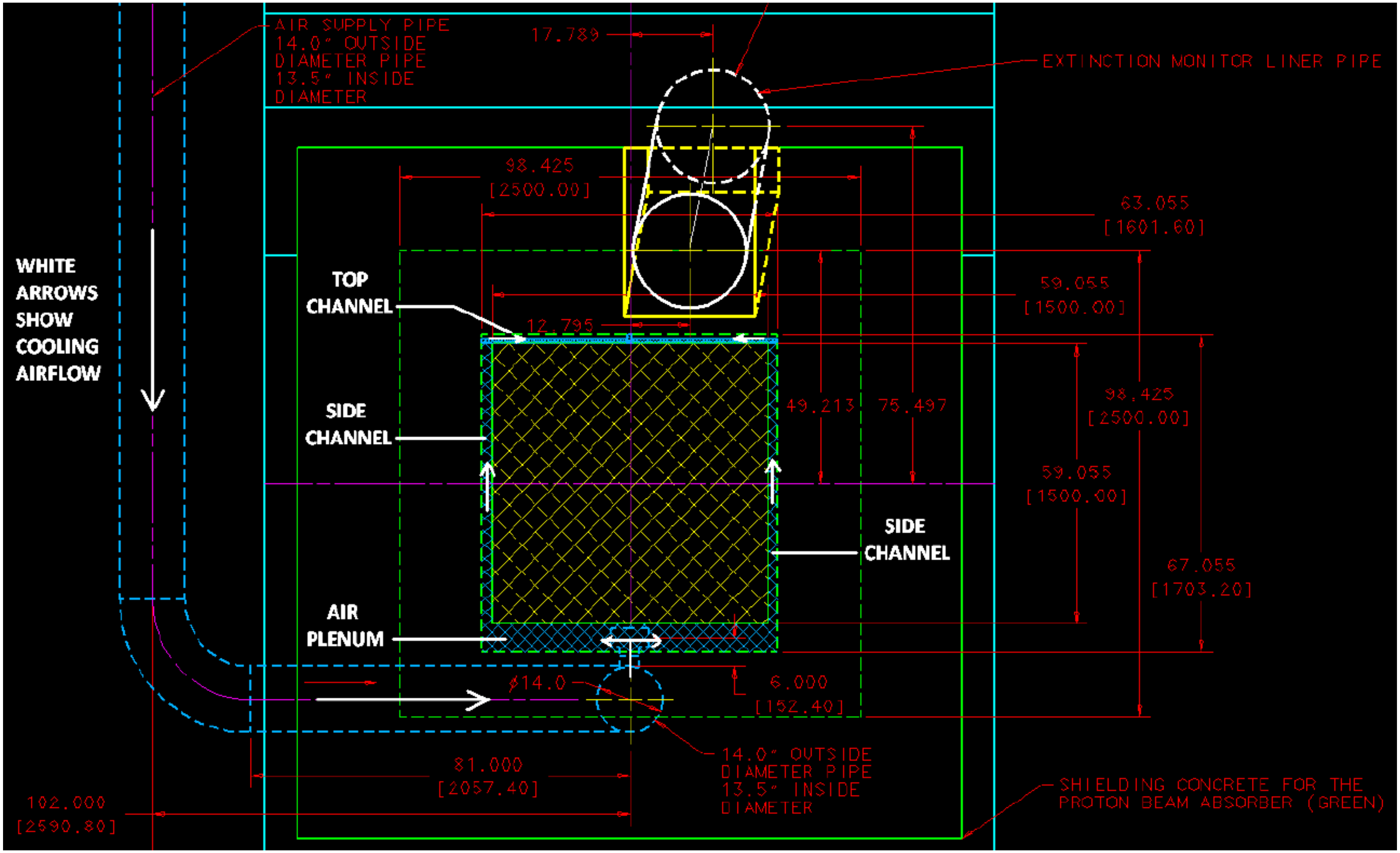
Remote Handling Alternative Scheme: Surface Building with Crane
Convection Cooled Target Support compatible with Remote Handling







Proton Beam Absorber Design



Cost Breakdown by FY