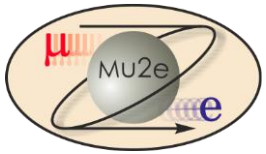
Fermilab

U.S. DEPARTMENT OF ENERGY Office of Science

475.04.04 Mu2e Detector Solenoid

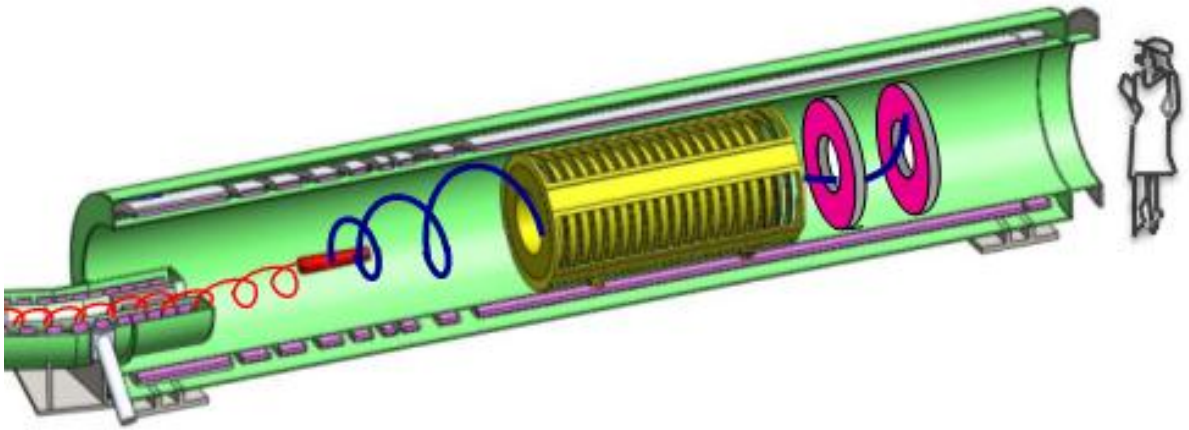


Marc Buehler

L3 for Mu2e Detector Solenoid

July 8-10, 2014

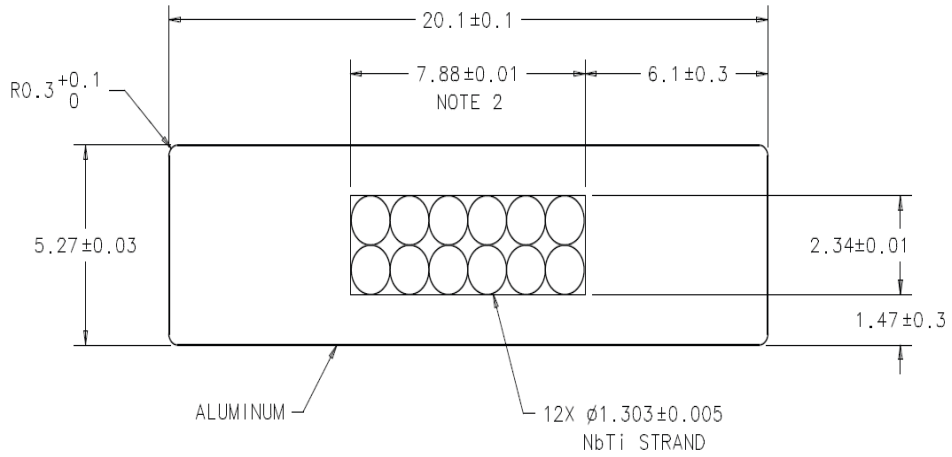
Requirements: Overview

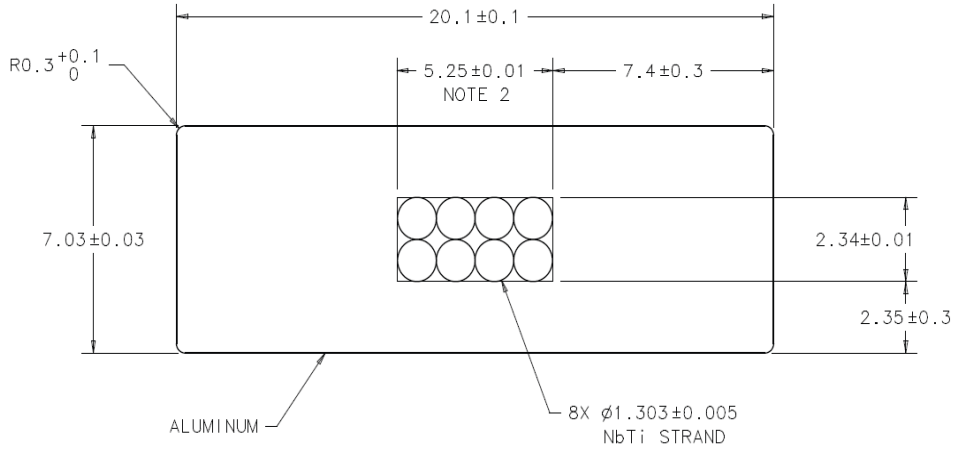


- Provide volume for the Mu2e experiment:
  - 1.8 m aperture, 10 m length
- Provide precision magnetic field:
  - Graded field region (2 T to 1 T) to focus muons on stopping target and deflection of conversion electrons towards spectrometer
  - Uniform field region (1 T) for precision tracking and calorimetry

Design: Cable

DS uses Al-stabilized NbTi Rutherford cable





"Narrow" Conductor ("DS1")

"Wide" Conductor ("DS2",)

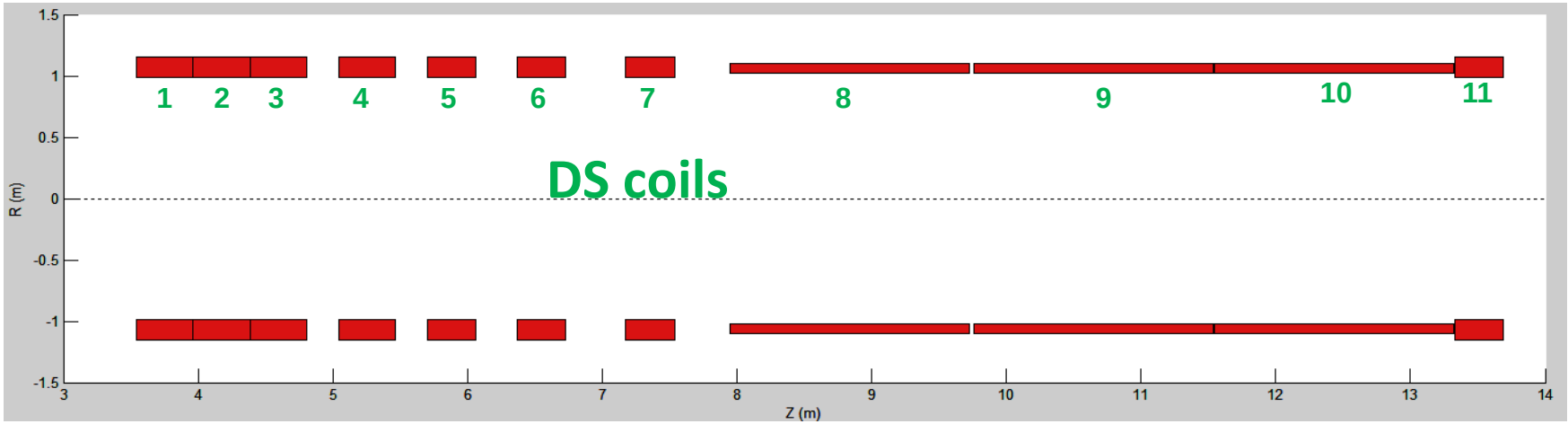
Cable	Number of Units	Unit Length
DS1	9	1100 meters
DS2	4	1750 meters

Furukawa

Hitachi

Order for production quantity of DS cable has been placed

Design: Coils

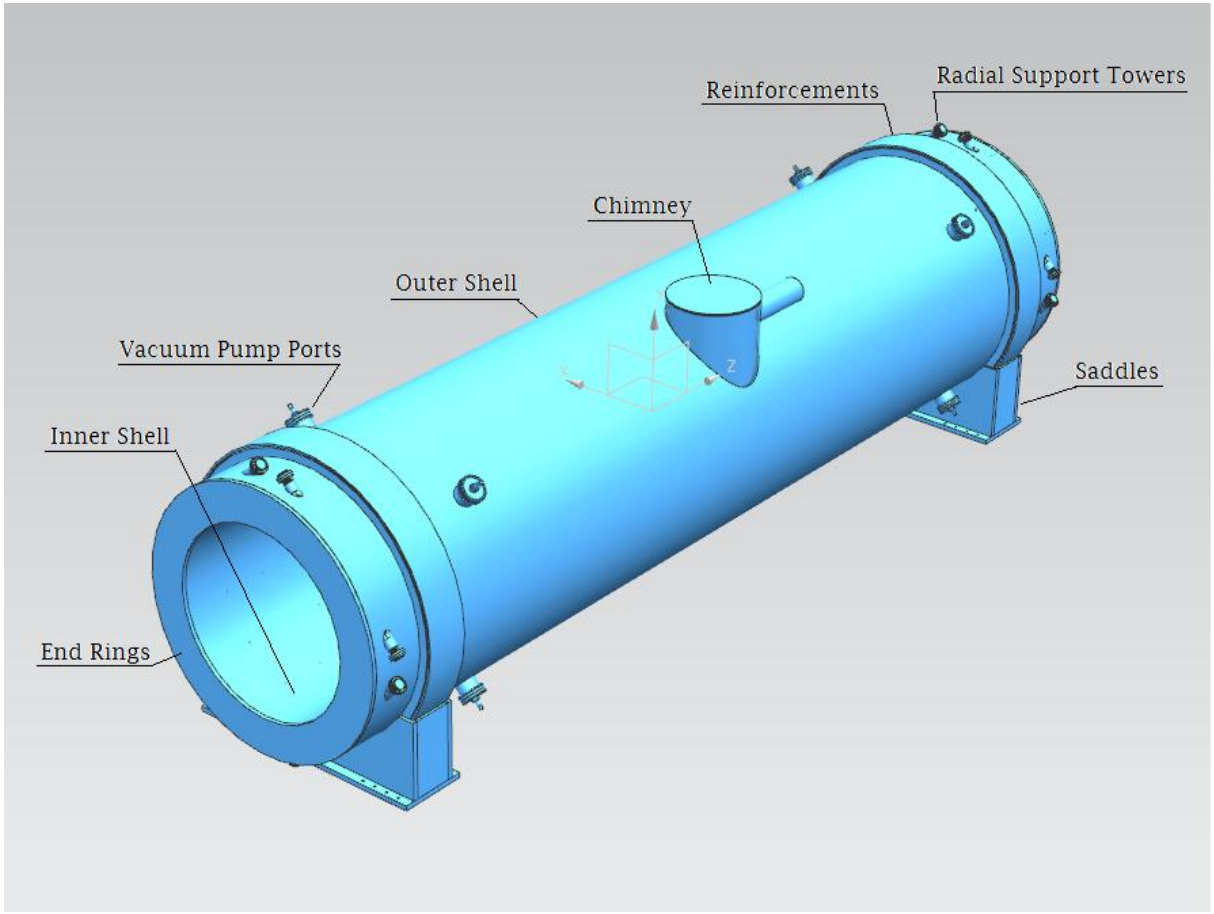


- DS has 11 coils
- Single-layer in tracker/calorimeter region
- Double layer everywhere else

Coil #	Coil IR [m]	Coil OR [m]	Coil Length [m]	#ZC [m]	# Layers	#Turns Per Layer	Total #Turns
1	1.0500	1.0915	0.42075	3.7489	2	73	146
2	1.0500	1.0915	0.42075	4.1739	2	73	146
3	1.0500	1.0915	0.42075	4.5989	2	73	146
4	1.0500	1.0915	0.42075	5.2519	2	73	146
5	1.0500	1.0915	0.36325	5.8801	2	63	126
6	1.0500	1.0915	0.36325	6.5701	2	63	126
7	1.0500	1.0915	0.36325	7.3971	2	63	126
8	1.0500	1.0705	1.8310	8.8178	1	244	244
9	1.0500	1.0705	1.8310	10.6528	1	244	244
10	1.0500	1.0705	1.8310	12.4883	1	244	244
11	1.0500	1.0915	0.36325	13.6425	2	63	126

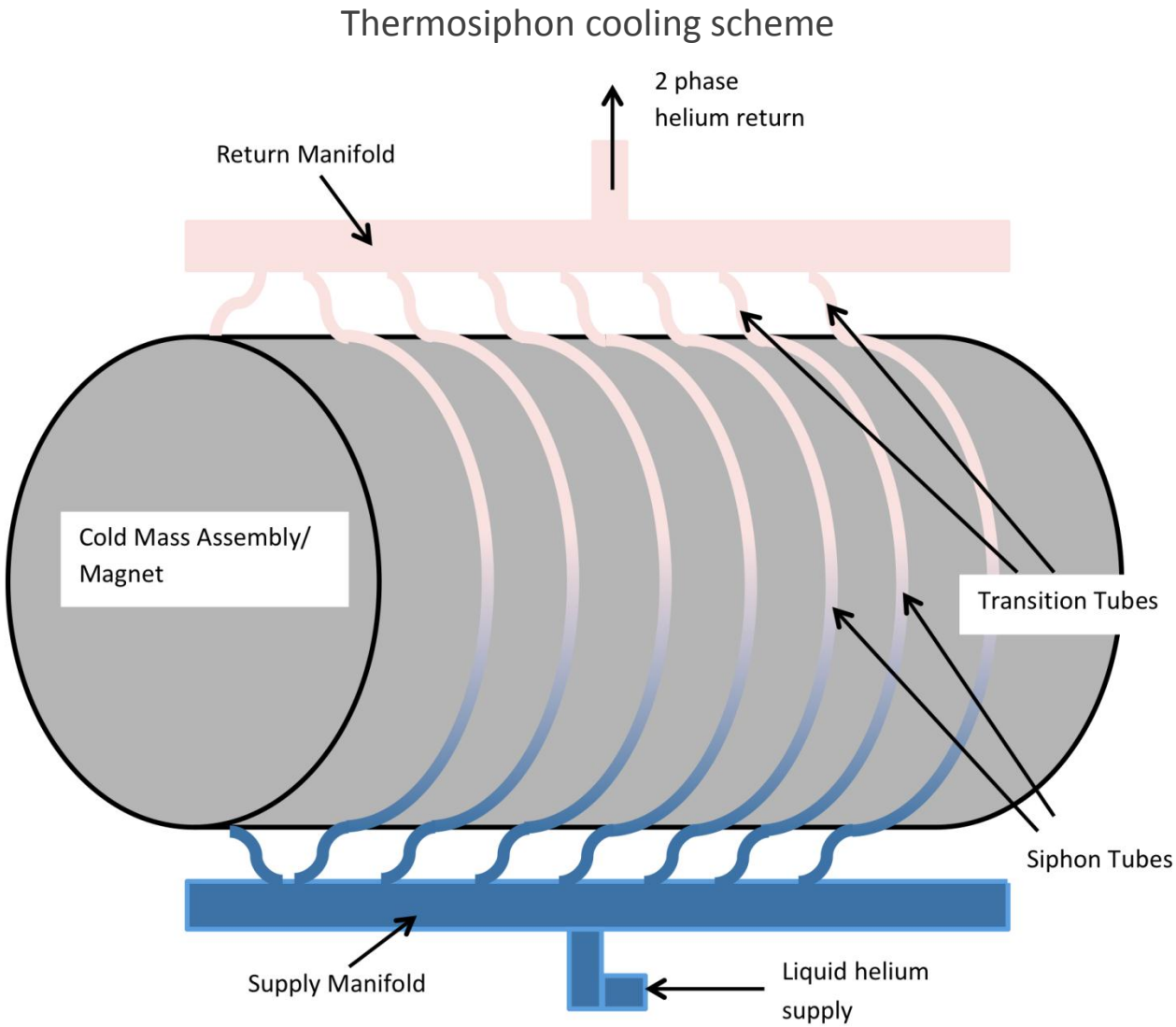
Design: Cryostat

- ~10 m long
- ~2.7 (1.9) m OD (ID)
- Stainless steel
- Openings in outer shell:
  - Chimney for transfer line
  - Vacuum ports
  - Radial support towers
- Bore must accommodate ~10 tons of equipment via rails attached to inner shell



Changes since CD-1

- Decision to use thermosiphon cooling scheme for cold mass assembly
- Magnet length changed

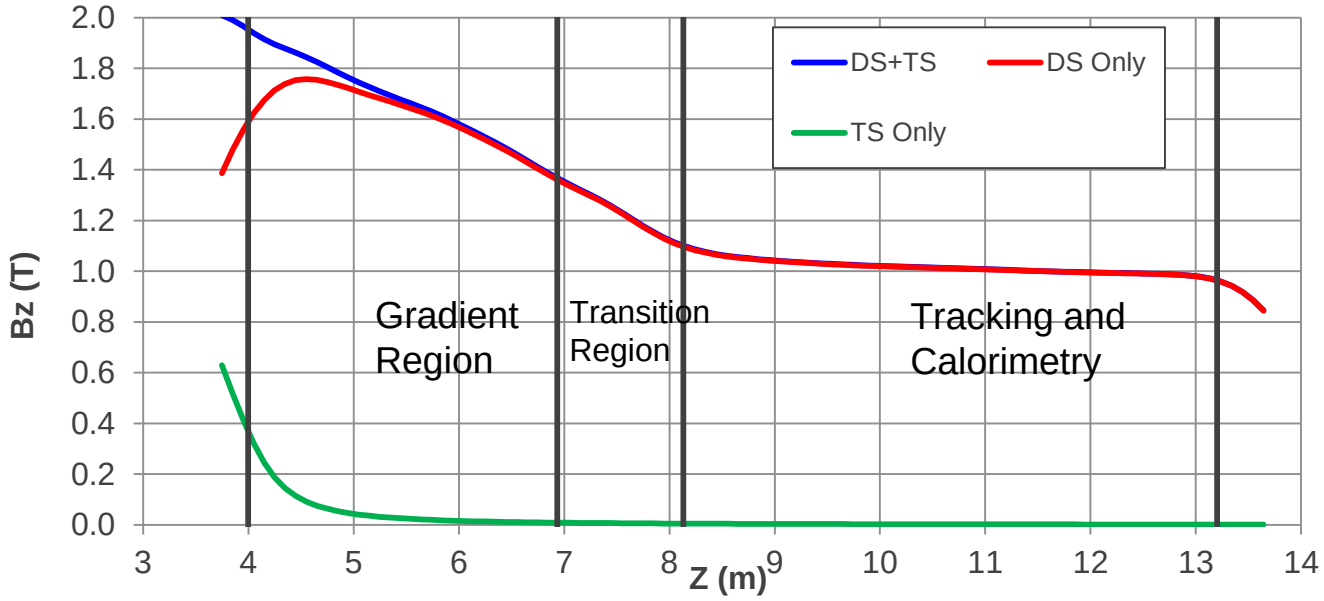


Value Engineering since CD-1

- Overall stable design:
  - Develop RDR, technical drawings and solid model for potential vendors
- Similar design approach for both DS and PS

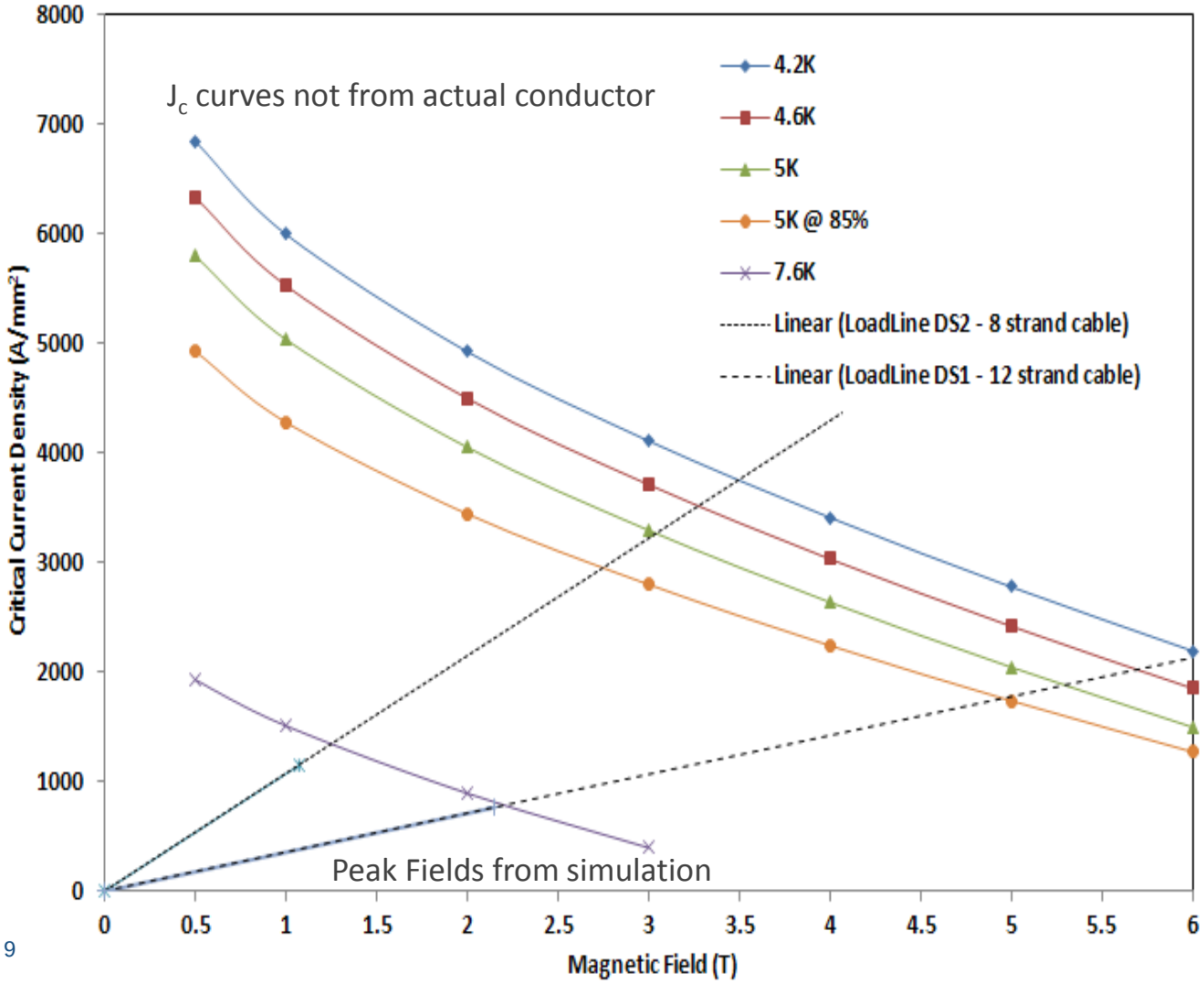
Performance: Magnetic Field

- Field maps with coil displacement errors were generated assuming manufacturing tolerances
- Mu2e Tracking group used these field maps as inputs to their track reconstruction algorithms
- Mu2e Tracking group verified that inputs satisfied physics requirements



Performance: Operating Margins

Cable critical current density in the field range of interest at reference Temp. (4.2 K), operating temp. (5 K), and 7.6 K to account for margin



- Cable designed to operate at least at 45% of conductor quench current
- 2.5 K temperature margin w.r.t. conductor temperature of 5 K
- Peak field in narrow conductor is 2.15 T
- Peak field in wide conductor is 1.07 T
- Larger margins in all other segments

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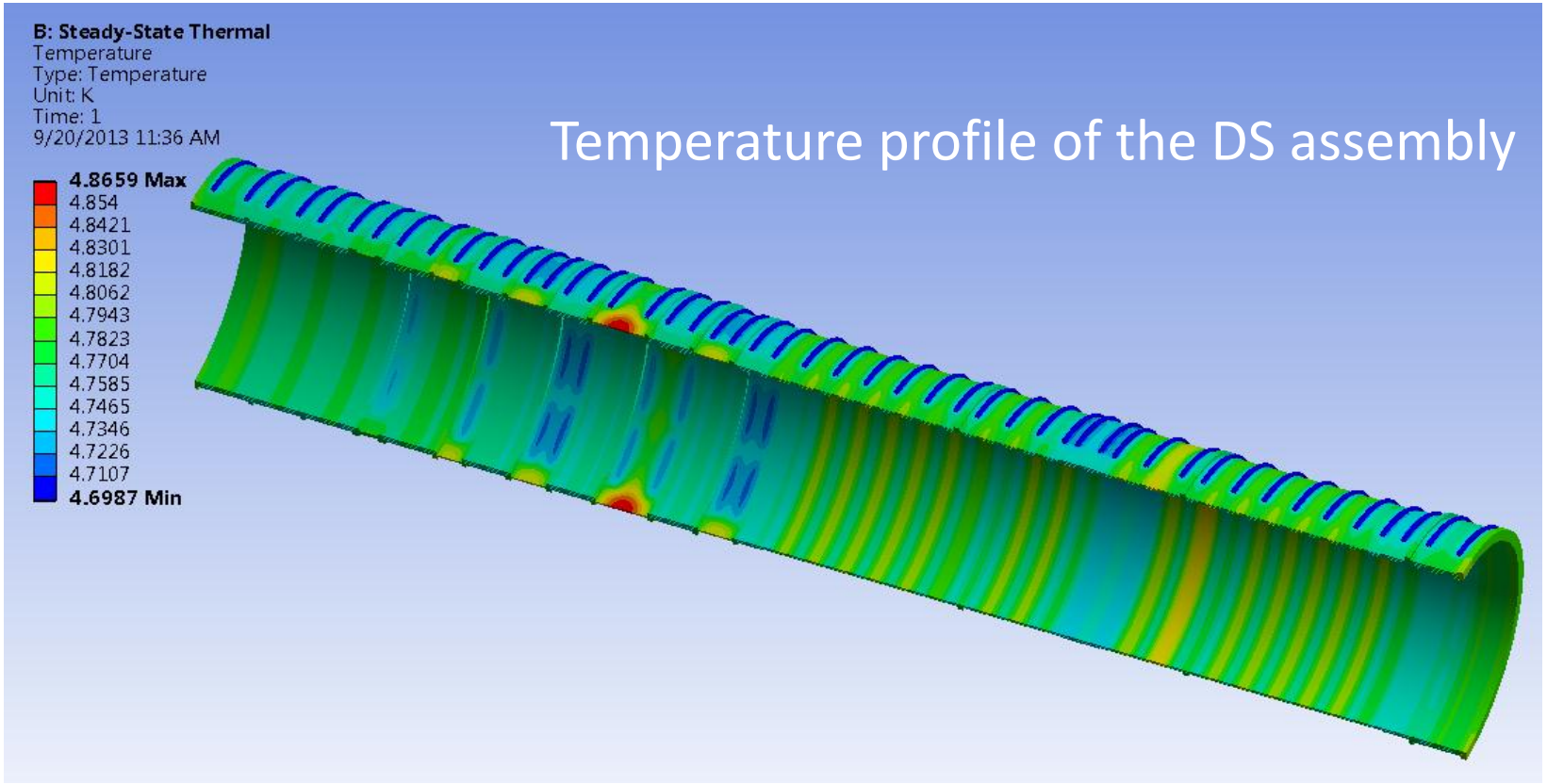
Performance: Thermal Analysis

- Performed extensive modeling, to estimate cooling tube size and locations taking into account insulation material properties (FEA)
- Temperatures do not exceed 5 K



Remaining work before CD-3

- Vendor develops final design and Fermilab approves
- Prepare final design of DS support stand

Quality Assurance

- Site visits to potential vendors before award of contract
- Site visits during fabrication
- Traveler System:
  - Magnet vendor has to call out all fabrication steps, including internal sign-offs and data validating successful completion
- Tests:
  - Tests will be performed during all phases of magnet fabrication to insure that specifications are met
  - Leak, pressure, electrical, … tests are specified
- Magnet vendor is required to implement a Quality Assurance Plan
- Acceptance tests:
  - A detailed sequence of tests before acceptance has been specified
- Model coil:
  - Before building the DS, the magnet vendor has to successfully demonstrate fabrication techniques for tooling, cable insulation, coil winding, impregnation etc.
- Details are outlined in our Procurement Specification document (DocDB 3670)

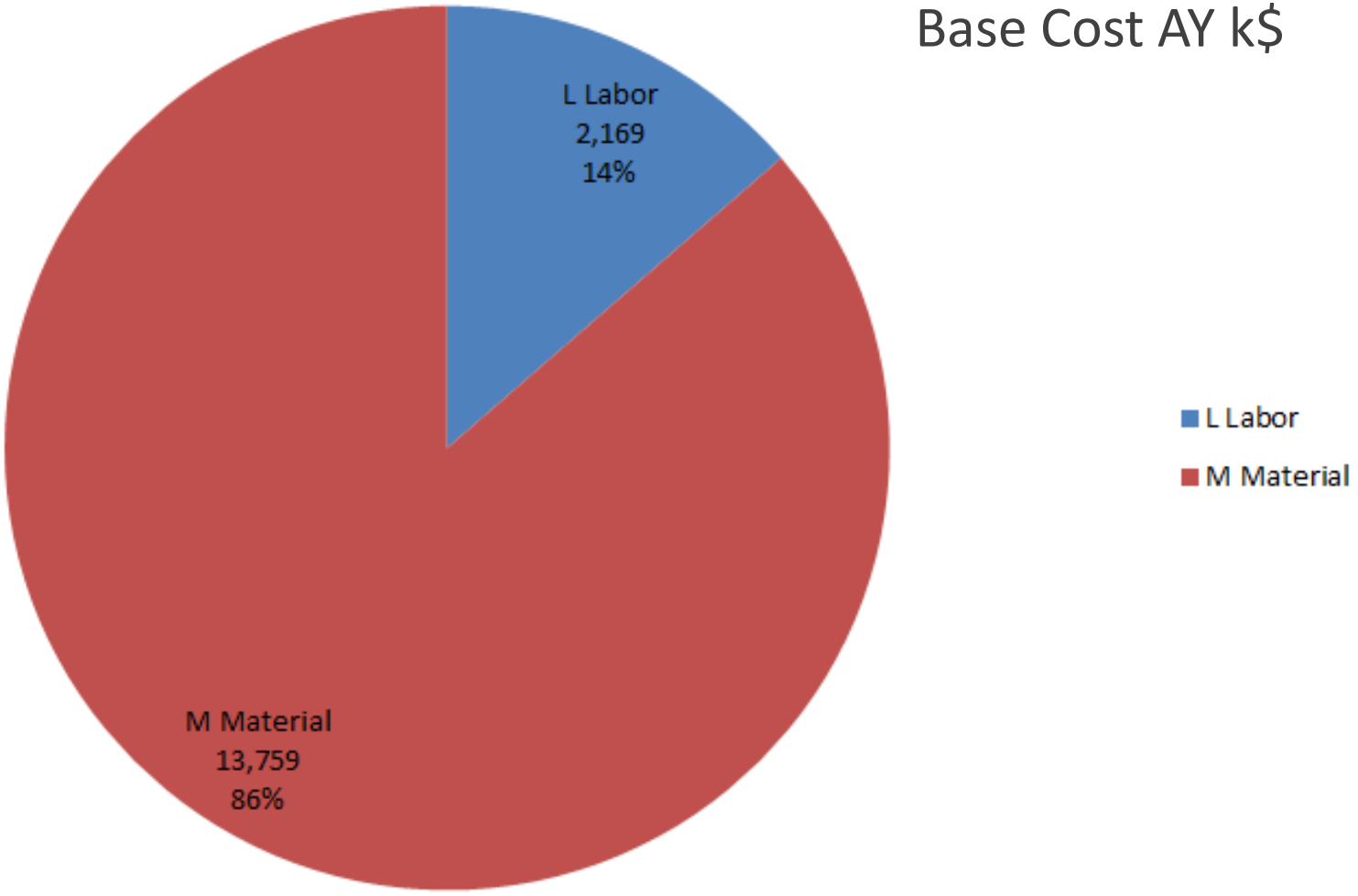
Risks

- Risk: Critical path delayed due to DS schedule delay
- Mitigation:
  - Risk register
  - Quality assurance strategy outlined on previous slide

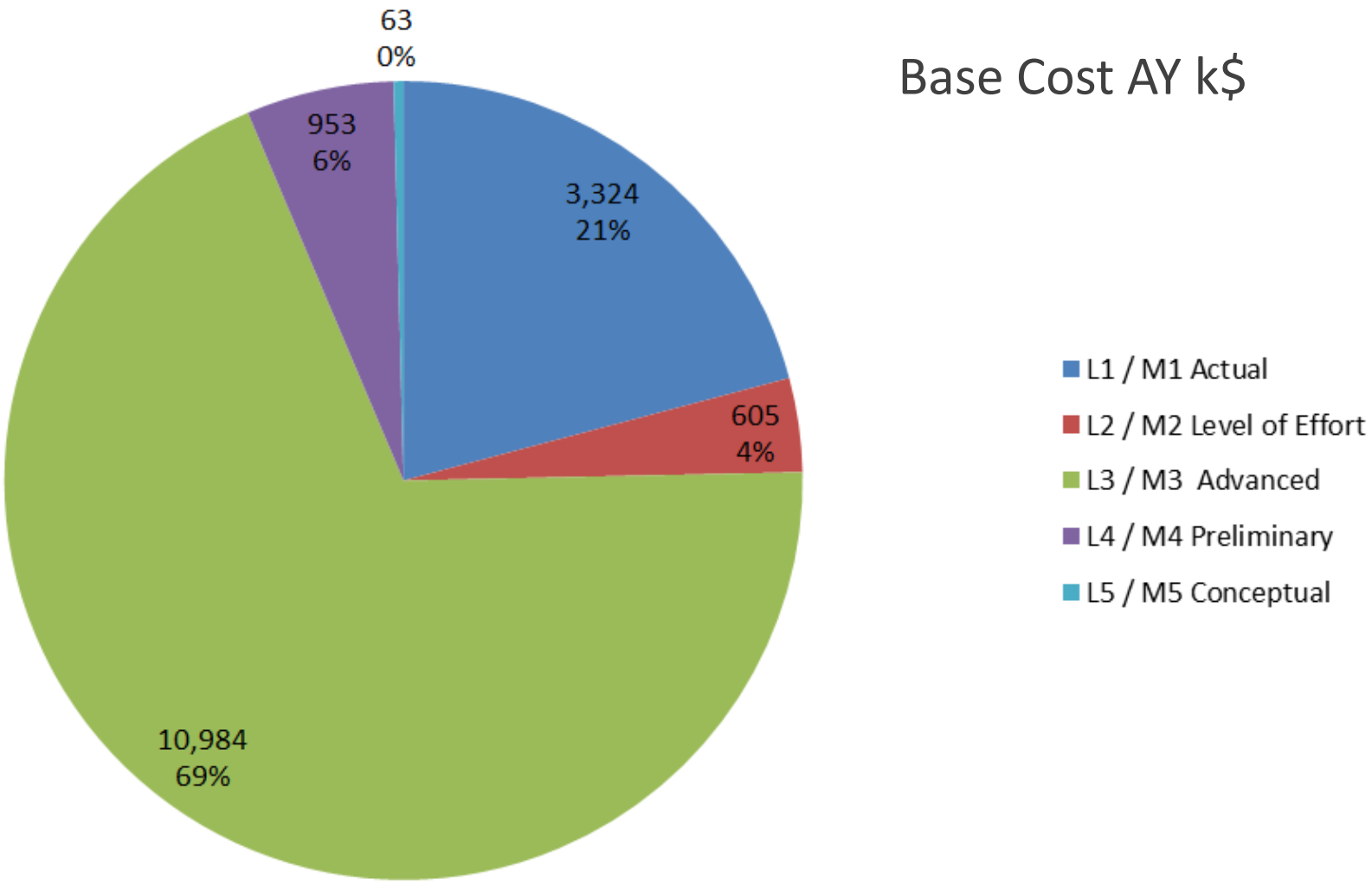
ES&H

- Common to large superconducting magnet systems
  - Cryogenic fluids
  - Large stored energy (26 MJ)
  - High currents (up to 6 kA)
  - Large voltages to ground during quench (up to 500 V)
  - ODH (release of liquid helium during accident, LN2 for 80 K shields)
  - Mechanical forces (large axial force between adjacent magnets, magnet is very heavy)
  - Large volume vacuum systems (beam line + insulating)
  - Stray magnetic fields (no return yoke)

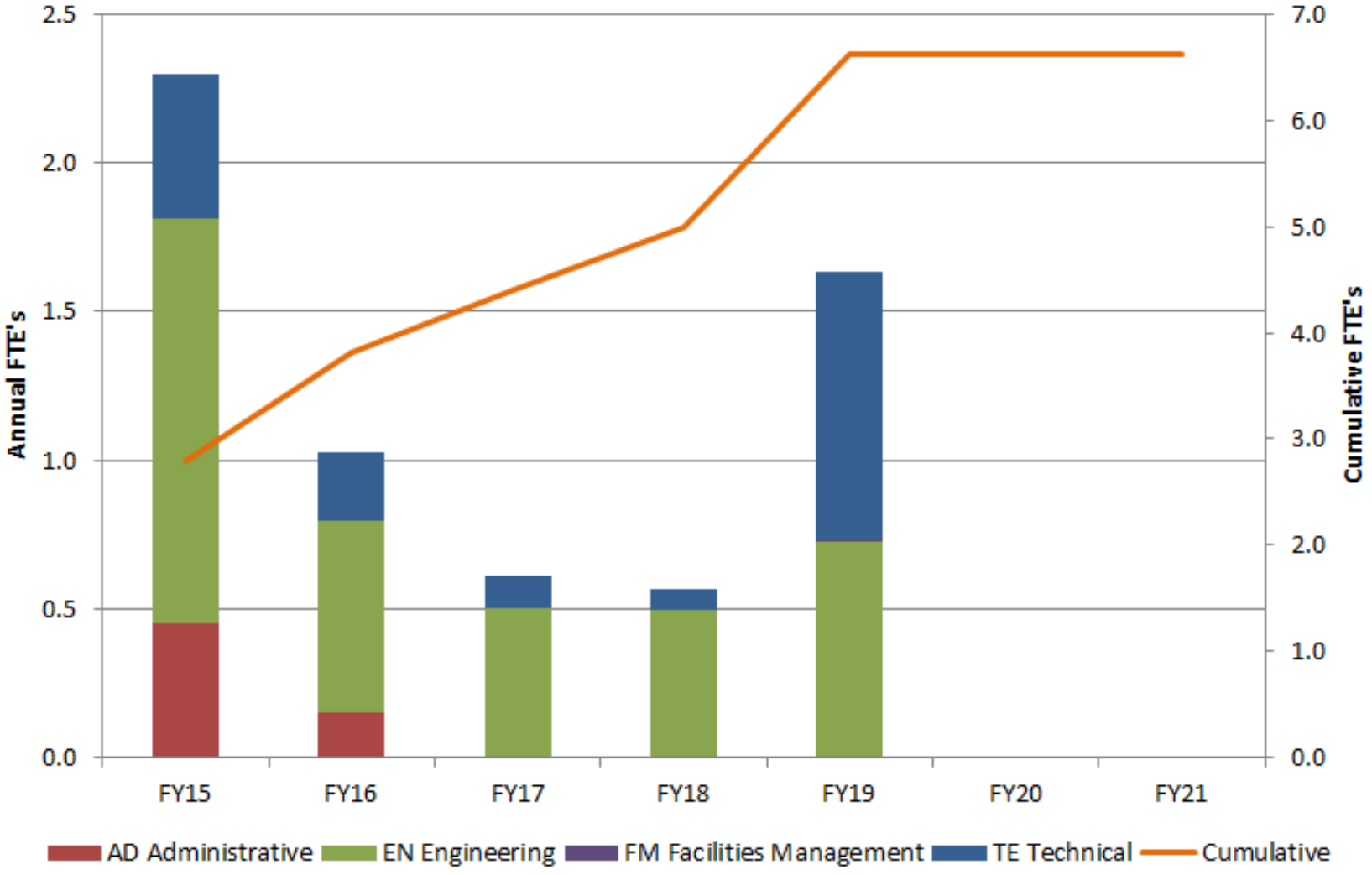
Cost Breakdown Labor vs Material



Quality of Estimate



Labor Resources by FY



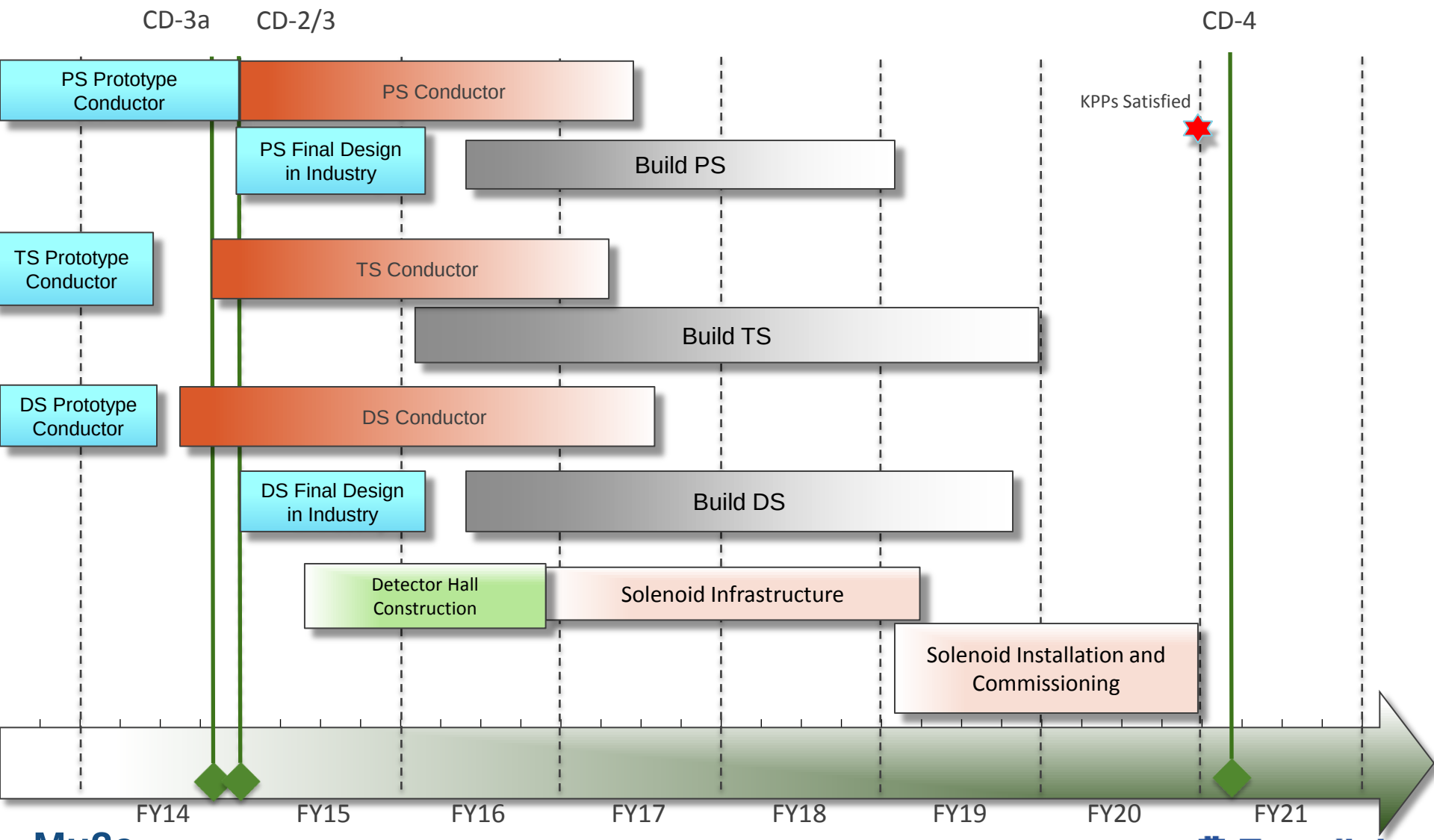
Cost Table

	Base Cost (AY k$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.04.04 Detector Solenoid	13,759	2,169	15,929	2,620	17%	18,549
Grand Total	13,759	2,169	15,929	2,620	17%	18,549

Major Vendor Milestones

- Start of final design contract
- Review and approval of final design
- Award of magnet fabrication phase of the contract
- Delivery of superconductor
- Manufacturing of Model Coil
- Acceptance of Model Coil
- Start manufacturing of DS
- First coil production review
- Cold mass production review
- Cryostat production review
- Tests at vendor site
- Shipping of DS to Fermilab
- Tests at Fermilab
- Final acceptance by Fermilab

Schedule


CD-3a
CD-2/3
CD-4
PS Prototype Conductor
PS Conductor
PS Final Design in Industry
Build PS
KPPs Satisfied
TS Prototype Conductor
TS Conductor
Build TS
DS Prototype Conductor
DS Conductor
DS Final Design in Industry
Build DS
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- A detailed set of requirements and specifications for the DS, including RDR, TDR, drawings, and solid model have been developed
- A vendor for the DS has been identified and the initial contract to develop the final design will be issued shortly
  - Cost and schedule for DS incorporates information provided by vendor
- Order for production quantity of DS cable has been placed
- DS is ready to move into the final design phase