475.04.03 Transport Solenoid

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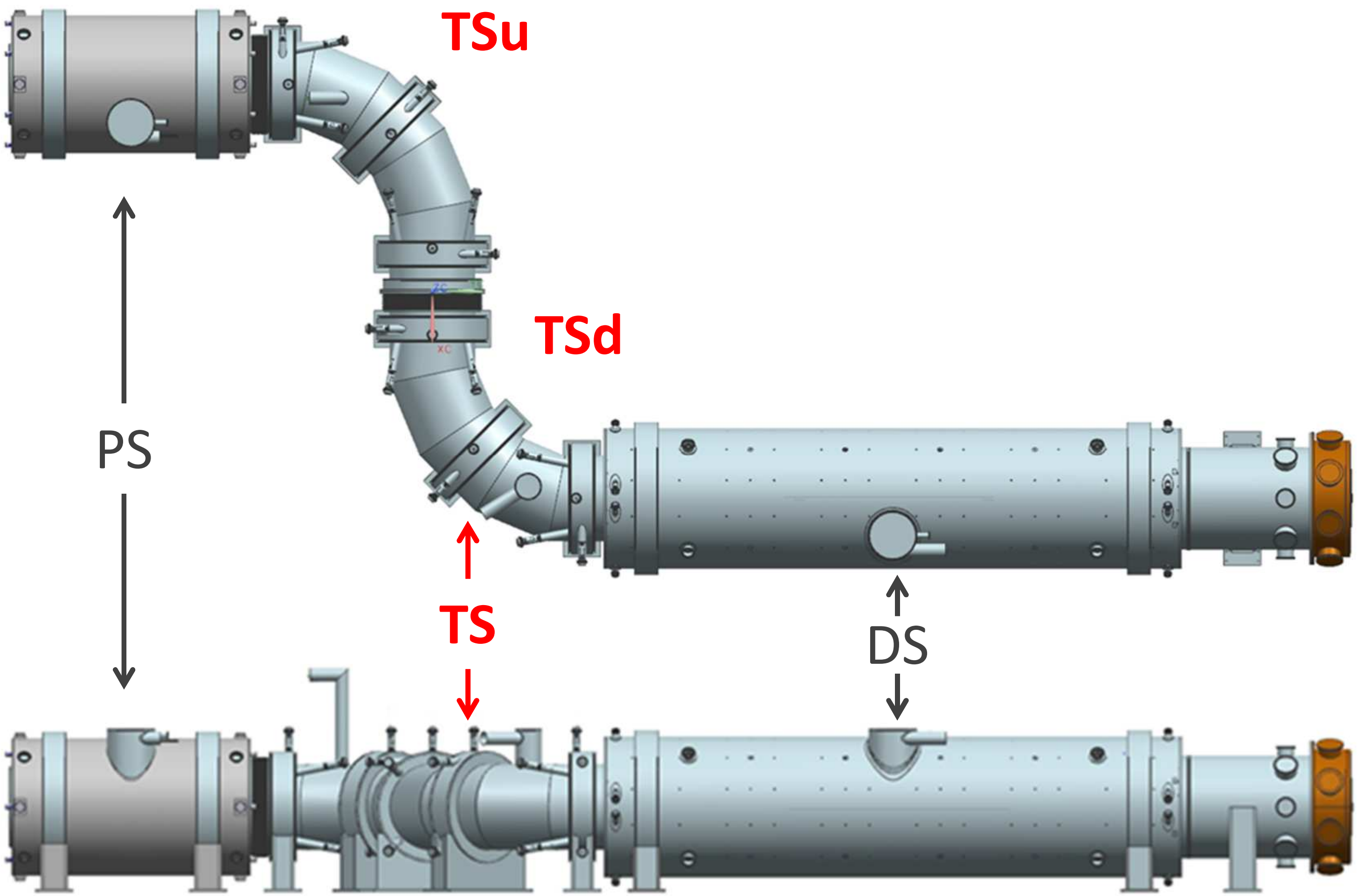
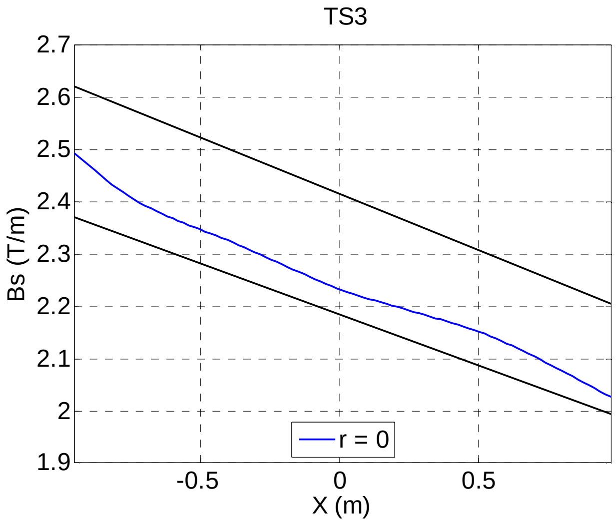
L3 for the Transport Solenoid
7/8/2014

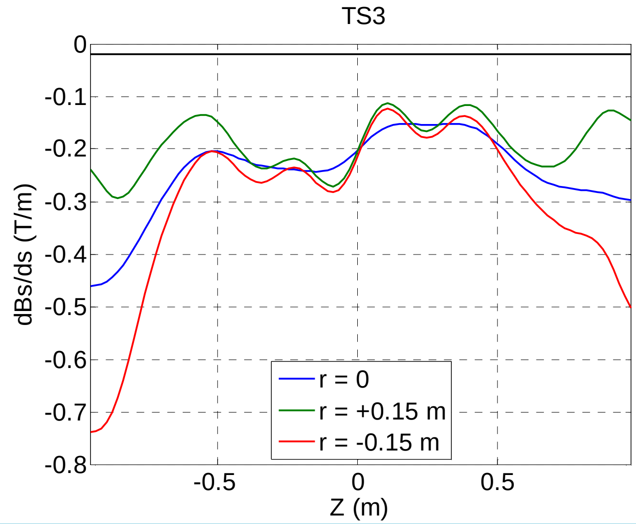
Scope



Requirements - Magnetic requirements

Region	s_{min} (m)	s_{max} (m)	$B_{initial}$ (T) ±5 %	B_{final} (T) ±5%	R_{max} (m)	dB_s/d_s (T/m)	dB_s/d_r (T/m)	Ripple (T)	Where
TS1	-6.58	-5.58	2.50	2.40	0.15	< -0.02	na	na	r=0, r=0.15 m
TS2	-5.58	-0.98	na	na	0.15	na	> 0.275	±0.02	r < 0.15 m
TS3	-0.98	0.98	2.40	2.10	0.15	< -0.02	na	na	r=0, r=0.15 m
TS4	0.98	5.58	na	na	0.15	na	> 0.275	±0.02	r < 0.15 m
TS5	5.58	6.58	2.10	2.00	0.15	< -0.02	na	na	r=0, r=0.15 m





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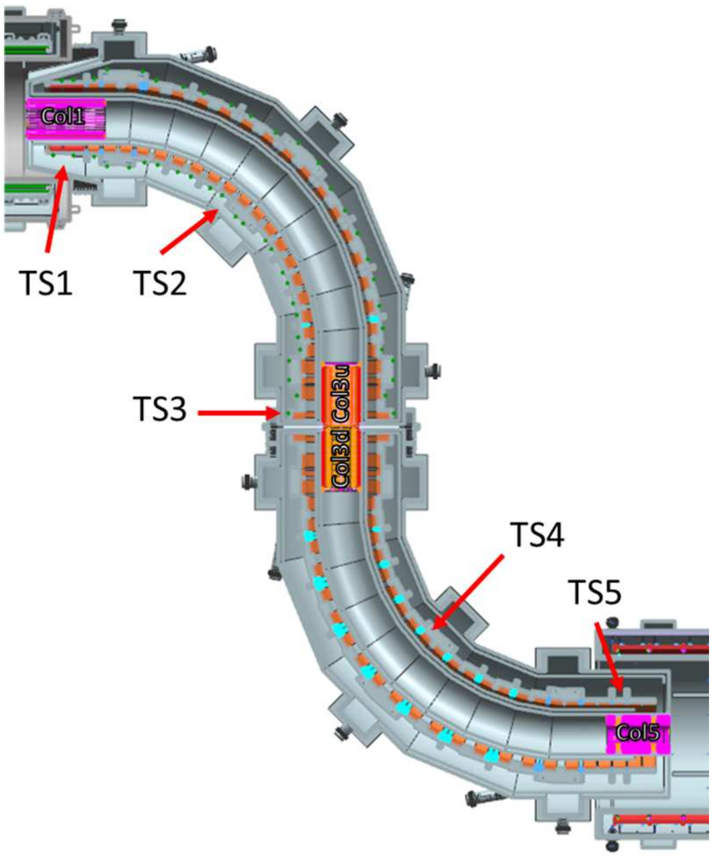
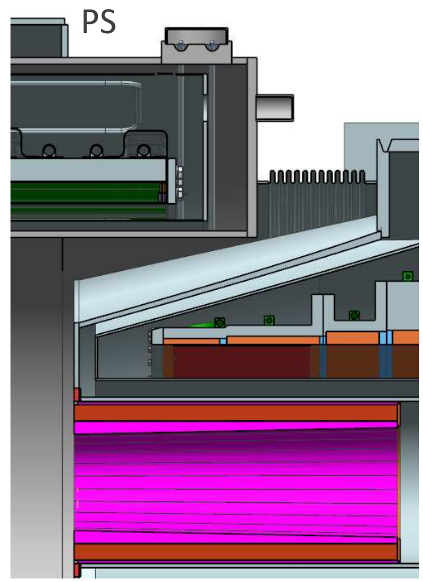
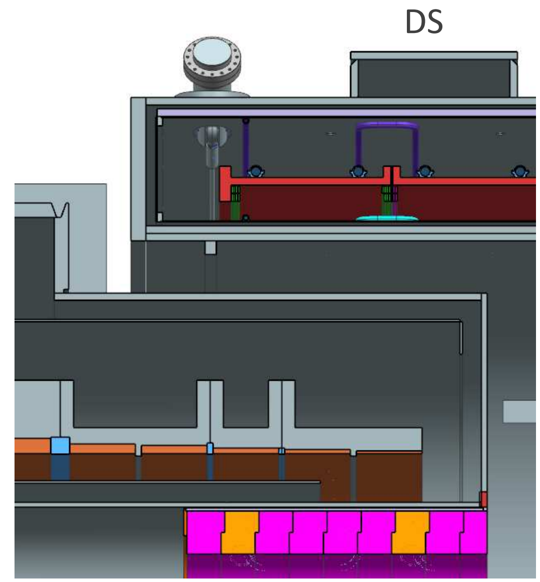
Requirements - Mechanical requirements



There are four collimator elements. COL3u and COL3d are located in TS3 and they are used to filter particles based on electric charge and momentum.



Due to space constraints, the primary proton beam pipe must be routed through the TS cryostat.
When the TS is at full power, there is a net axial force of around 130 Tons pulling the TS and PS together.



There is a physical overlap of around 940 mm between the DS and TS cryostats.
When the TS is at full power, there is a net axial force of around 100 Tons pulling the TS and the DS together.

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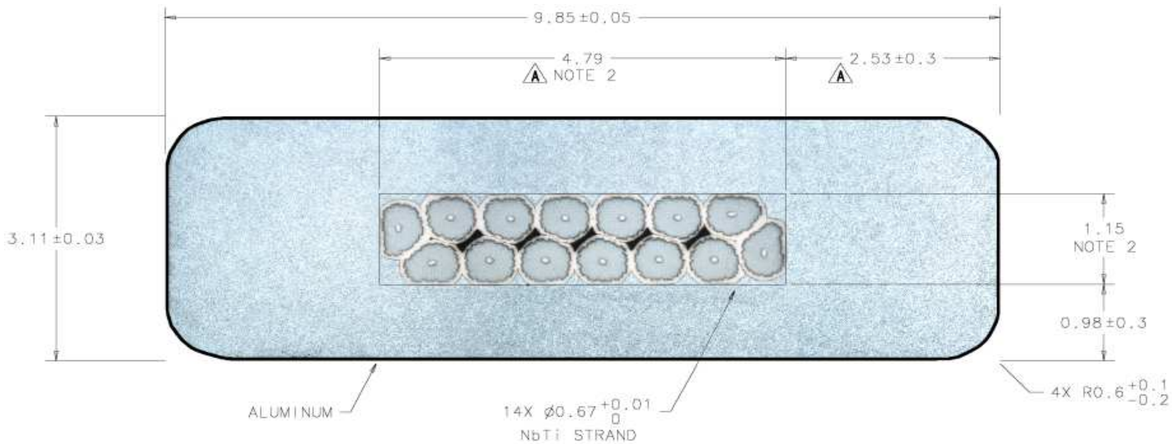
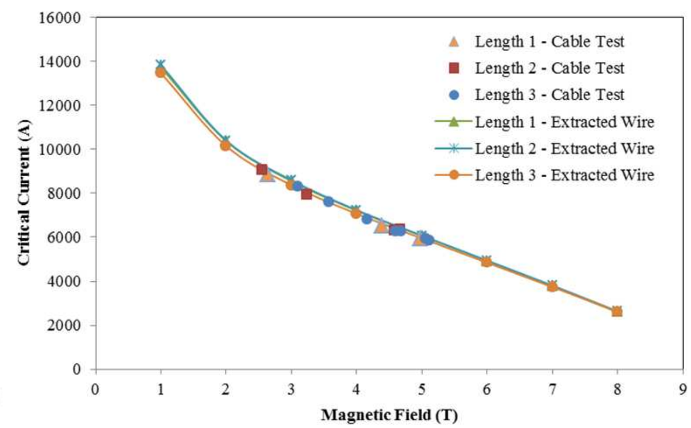
Design - Conductor

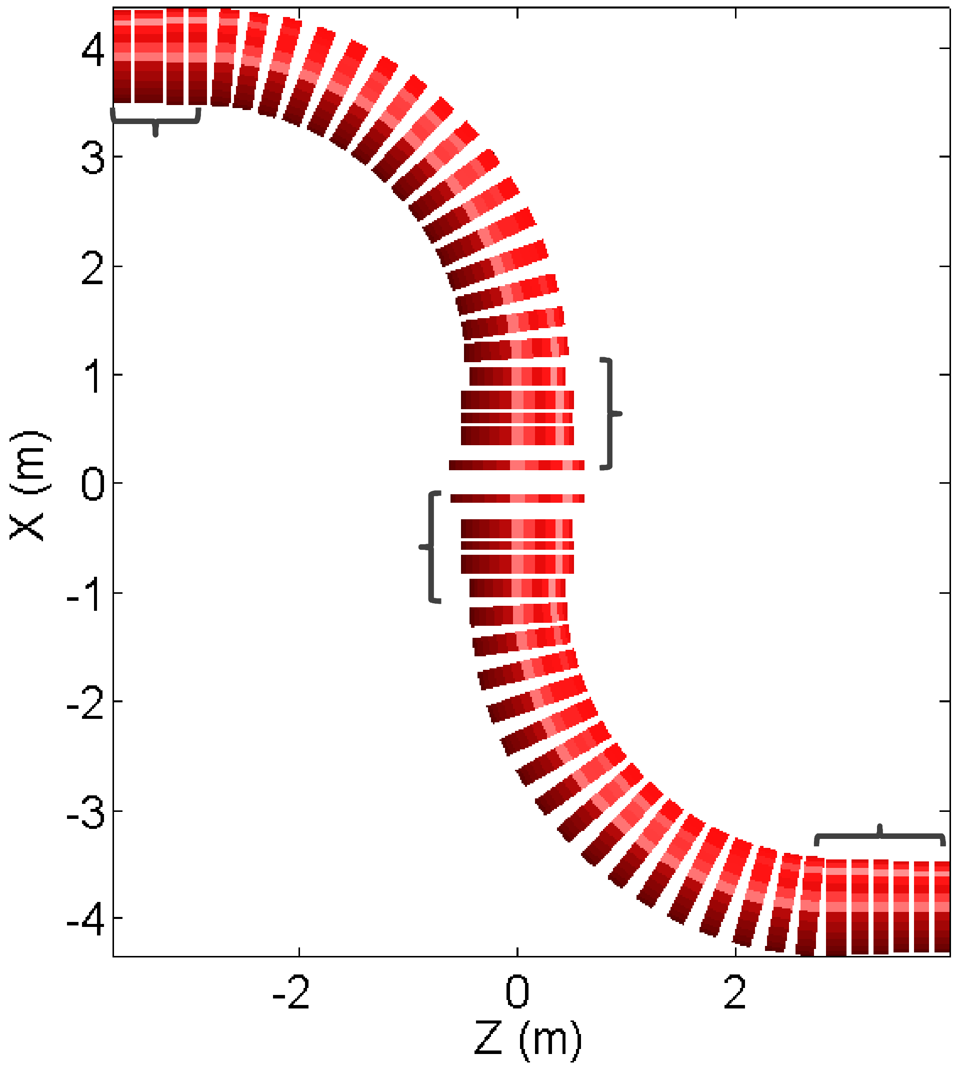




Conductor Parameter	Unit	Design Value	Measured Value
Cable critical current at 5T, 4.2K	A	5900	5950-6300
Number of strands		14	
Strand diameter	mm	0.67	within tolerances
Strand copper/SC ratio		1 ± 0.05	0.97-1.02
Initial RRR of Cu matrix		150	100-104
Filament size	µm	< 30	25.5-25.7
Strand twist pitch	mm	15 ± 2	15.8-15.9
Rutherford cable width	mm	4.79 ± 0.01	within tolerances
Rutherford cable thickness	mm	1.15 ± 0.006	within tolerances
Al-stabilized cable width (bare) at room temperature	mm	9.85 ± 0.05	within tolerances
Al-stabilized cable thickness (bare) at room temperature	mm	3.11 ± 0.03	within tolerances
Initial RRR of Aluminum stabilizer		> 800	925-1160
Aluminum 0.2% yield strength at 300 K	MPa	> 30	45-56
Aluminum 0.2% yield strength at 4.2 K	MPa	> 40	74-84
Shear strength between Aluminum and NbTi strands	MPa	> 20	35-46

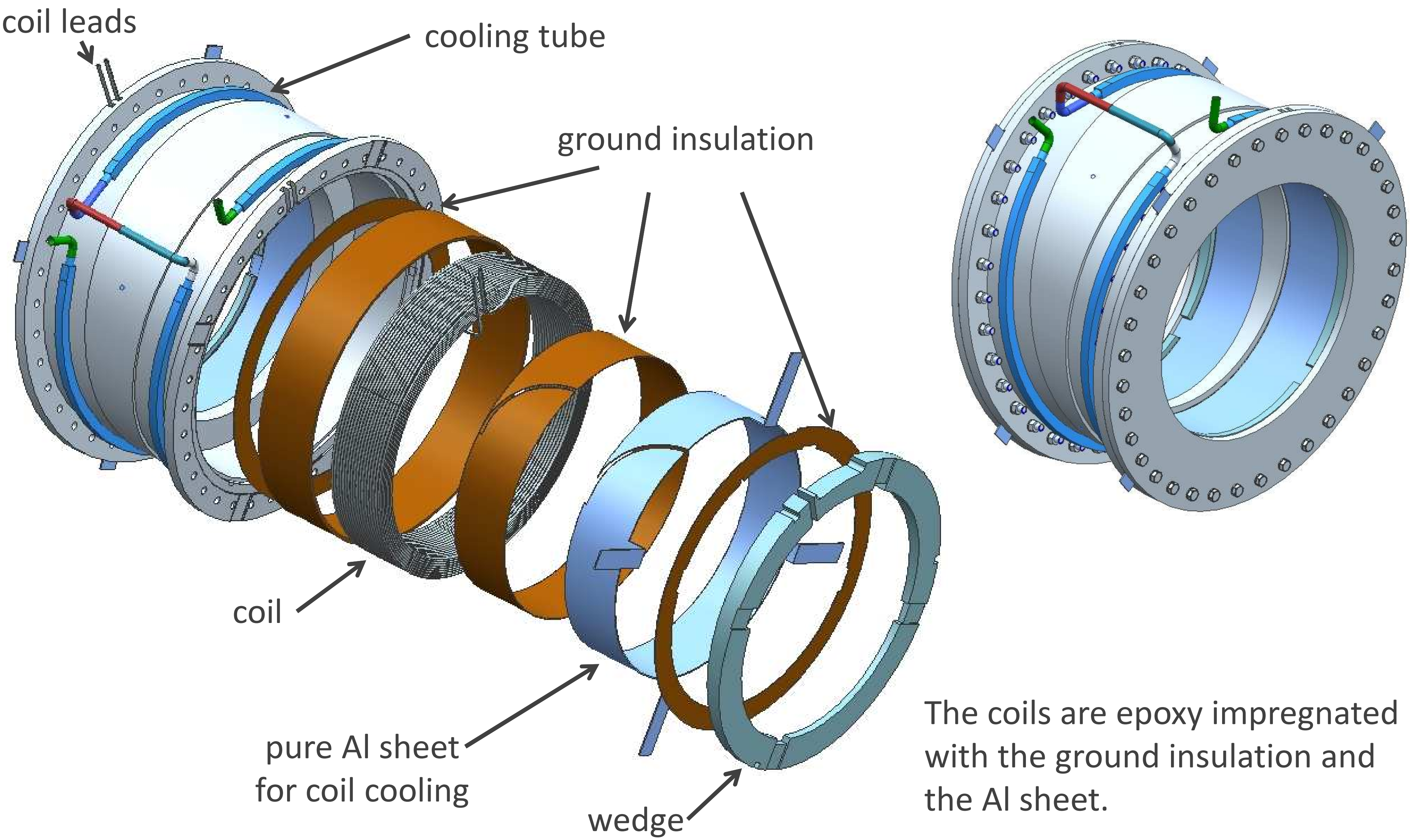
I_{op} = 1730 A
J_{eng} ~ 50 A/mm^2
I_{op}/I_c ~= 58% (at 5.1 K, 3.4 T)
Temp margin = 1.5 K

Design – Magnet System



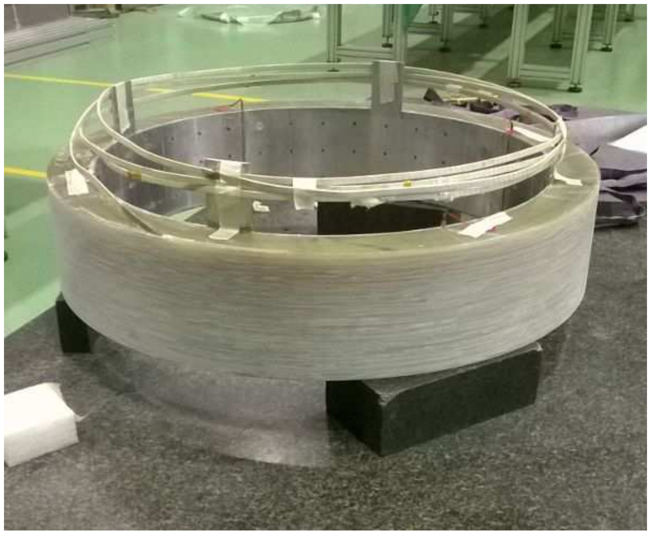
- TS is formed by 52 SC solenoid coils.
- Most coils have the same aperture. TS3 coils have the aperture slightly bigger to help with the large gap between cryostats.
- Each cryostat is powered by a different 2kA power supply (nominal current 1730 A)
- Each magnet has a pair of two 200 A trim power supplies (TPS).
- The TPS allows field matching with the adjacent magnets and gives an extra knob to control backgrounds.
- The coils that form the curve sections had their angles adjusted to center the particle distribution with respect to the axis of the solenoids.

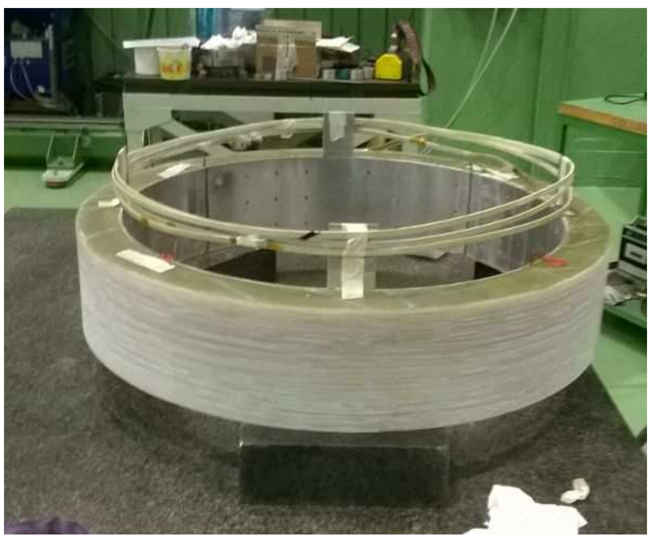
Design – Coil Module

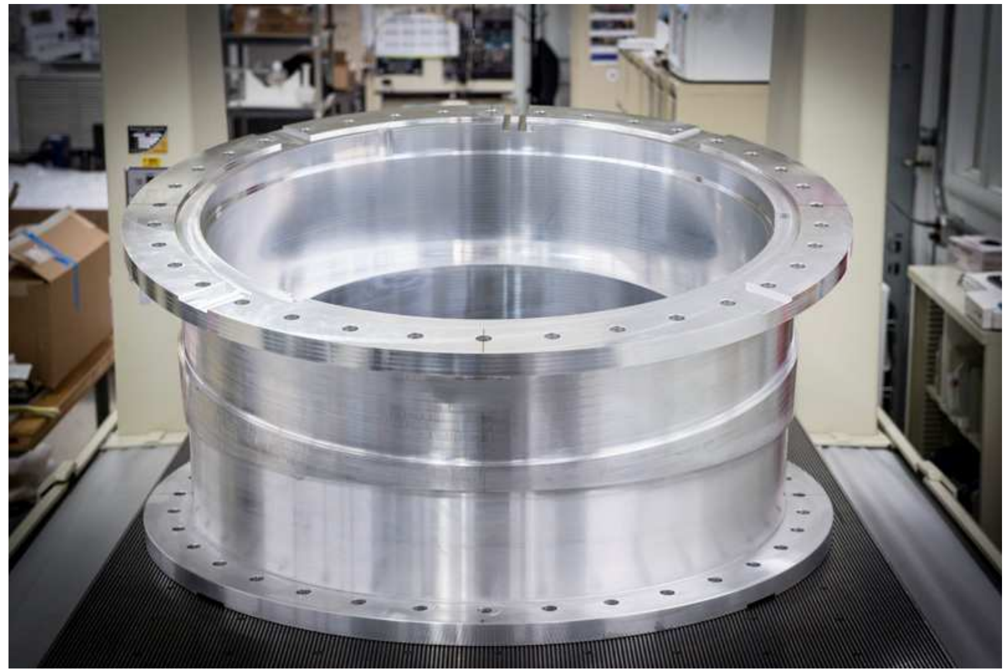


The coils are epoxy impregnated with the ground insulation and the Al sheet.

Prototype

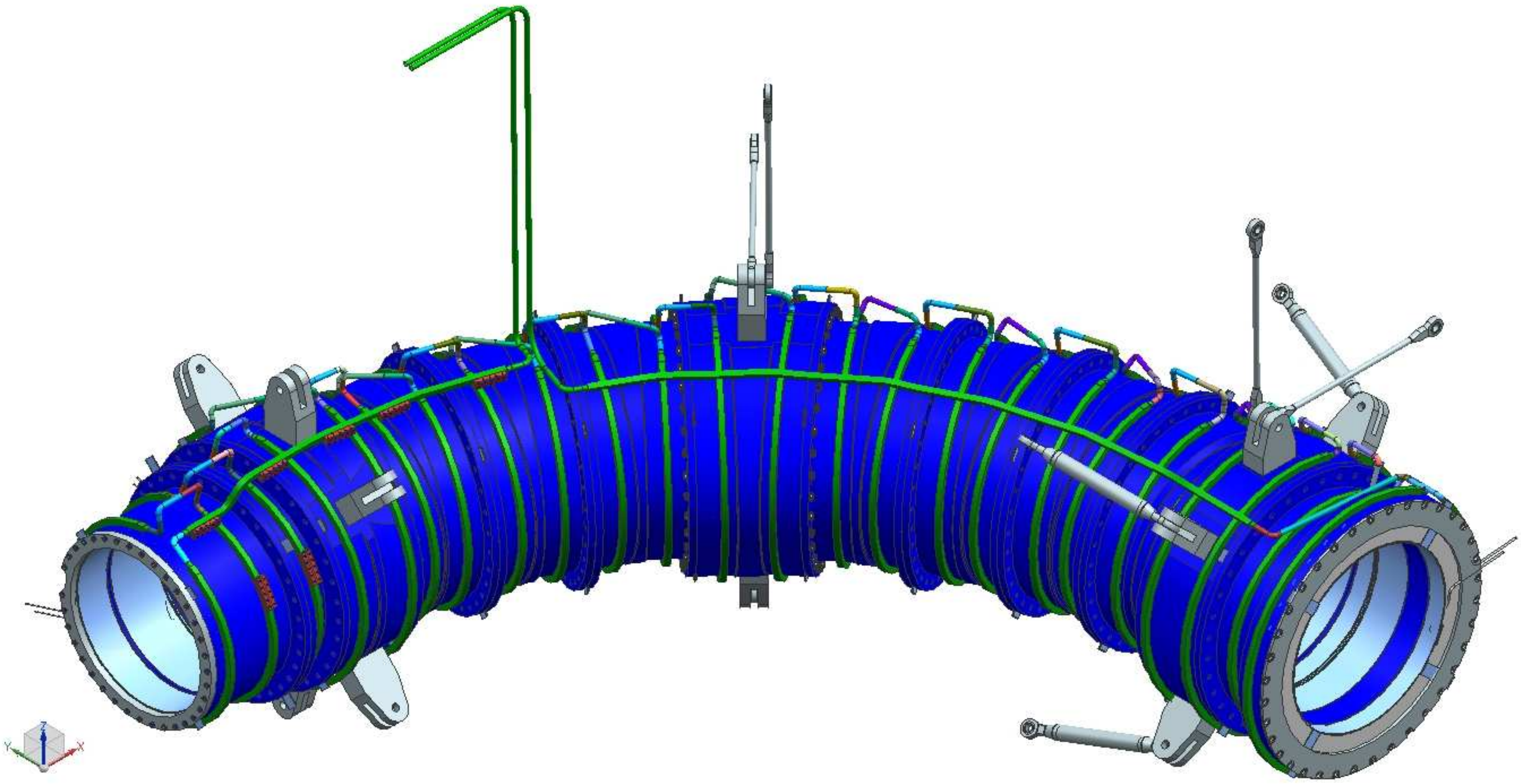




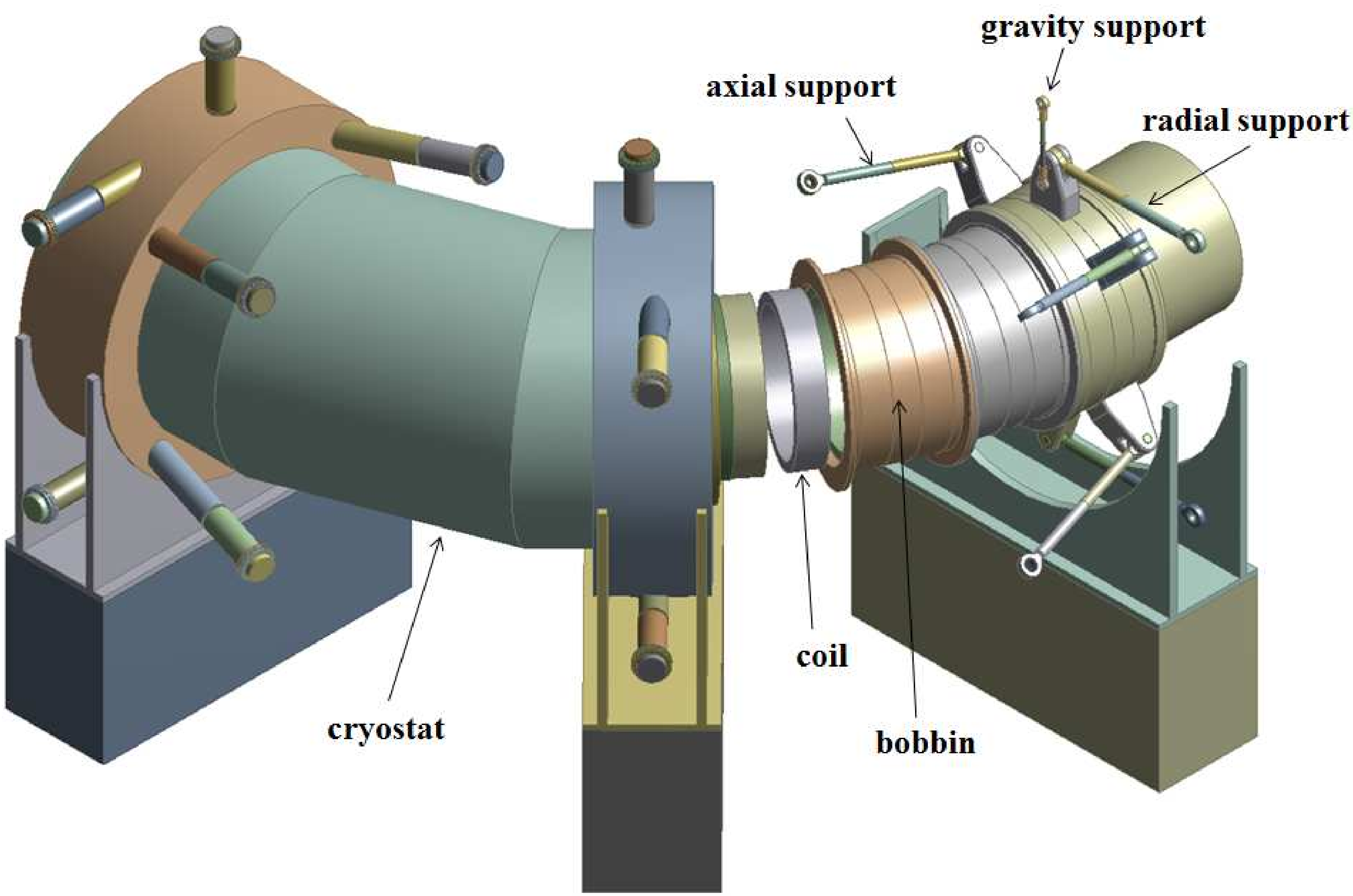


- Integration in September
- Delivery in early October
- Cold test in December

Design – Cold mass assembly



Design – Cryostat assembly



Changes since CD-1

- Changes on the TSu nose that connects to PS due to the proton beam pipe.
- Change of the position of the Chimneys to accommodate the shield around the TS magnets.
- We remove the vertical supports located in the bottom of the magnet due to interference with the support feet.
- Trim power supplies included in TS

Value Engineering since CD-1

- TSu and TSd cryostat geometry nearly identical resulting in common parts, tooling, and assembly.
- TSu and TSd support feet positions identical resulting in common parts, tooling, support frames, and lifting fixtures.
- TSu and TSd axial and radial supports identical resulting in common parts, tooling, and assembly.
- Eliminated lower vertical supports resulting in lower cost, easier assembly, and easier cold mass alignment.

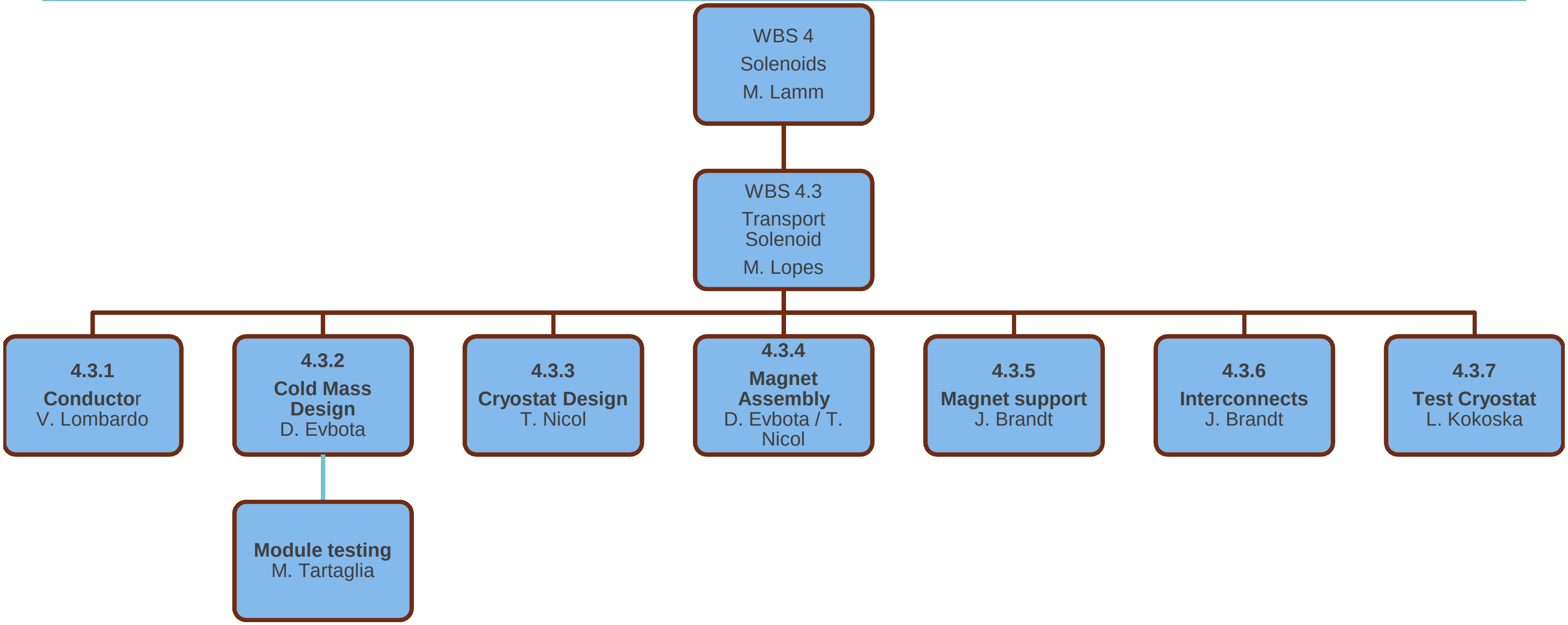
Downselects

- Forced flow was selected as the cooling scheme for TS (as opposed to thermo-syphoning).
- TS1 coils will be housed into a 2+1 coil modules (instead of a single 3-coils module)
- Coils modules will be fabricated in industry. Magnet assembly (cold mass and cryostat) will be done in-house.

Remaining work before CD-3

- Finalize the design of all the coil modules
- Finalize the design of the cryostat
  - Thermal shield
  - Support rods

Organizational Breakdown



Quality Assurance

- Hold points in fabrication at major milestones
- Traveler system
- Regularly scheduled meetings to discuss fabrication status/issues
- Acceptance tests upon delivery at Fermilab
- Vendor must provide Preliminary QAP as part of bid package
- Monthly EVMS-style reporting

Risks

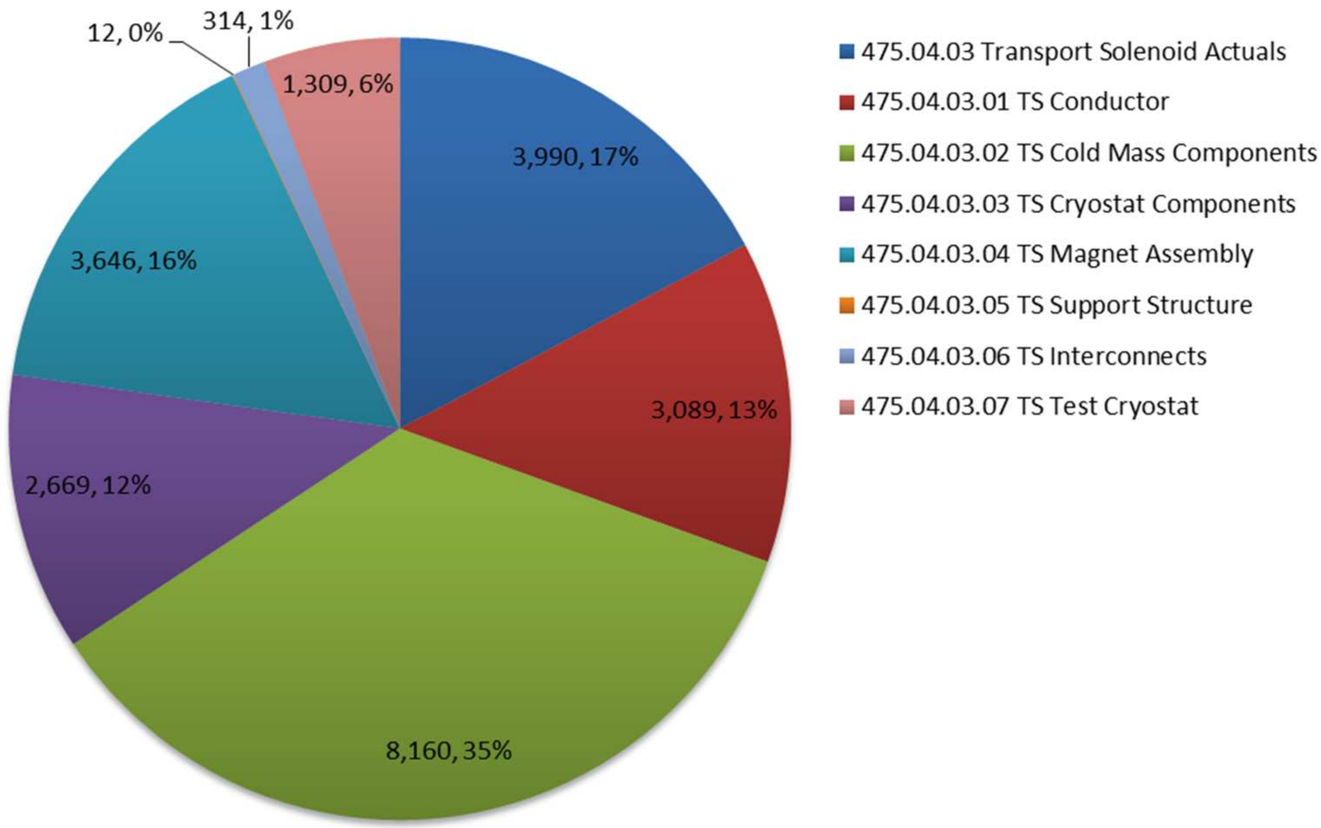
- SOL-066: Critical path delayed due to long solenoid schedule delay.
  - The solenoids are on the critical path, so any delay to their schedule almost certainly delays the overall project schedule.
  - o Close monitoring of the vendor and QC built into the schedule

- SOL-070:Interface problems with the solenoids.
  - The assembled solenoids must function as an integrated magnetic system. The solenoids will all be built by different vendors. Poorly specified interface requirements could lead to mechanical interface problems or to the wrong field configurations in the interface regions
  - o Close oversight and careful documentation of all the interfaces.

ES&H

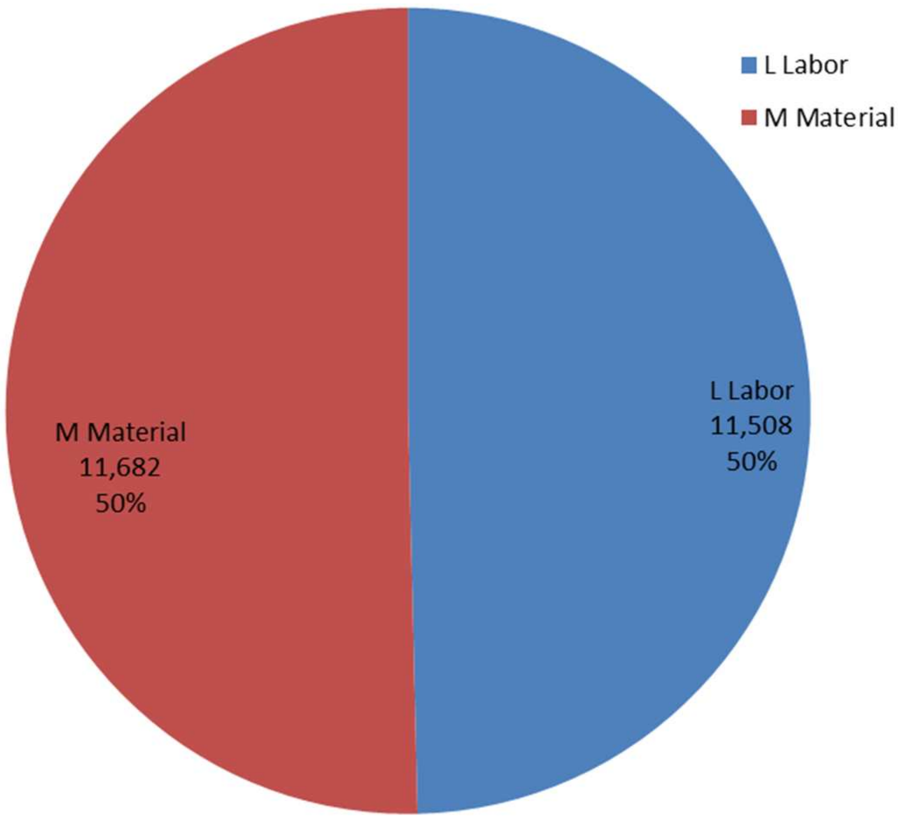
- Common to large superconducting magnet systems
  - Cryogenic fluids
  - Large stored energy (13 MJ)
  - High currents (up to 2 kA)
  - Large voltages during quench (up to 600 V)
  - ODH
  - Mechanical forces (up to 130 Tons of axial force)
  - Stray magnetic fields
  - Use of chemicals (Sodium hydroxide)
  - Radiation

Cost Distribution



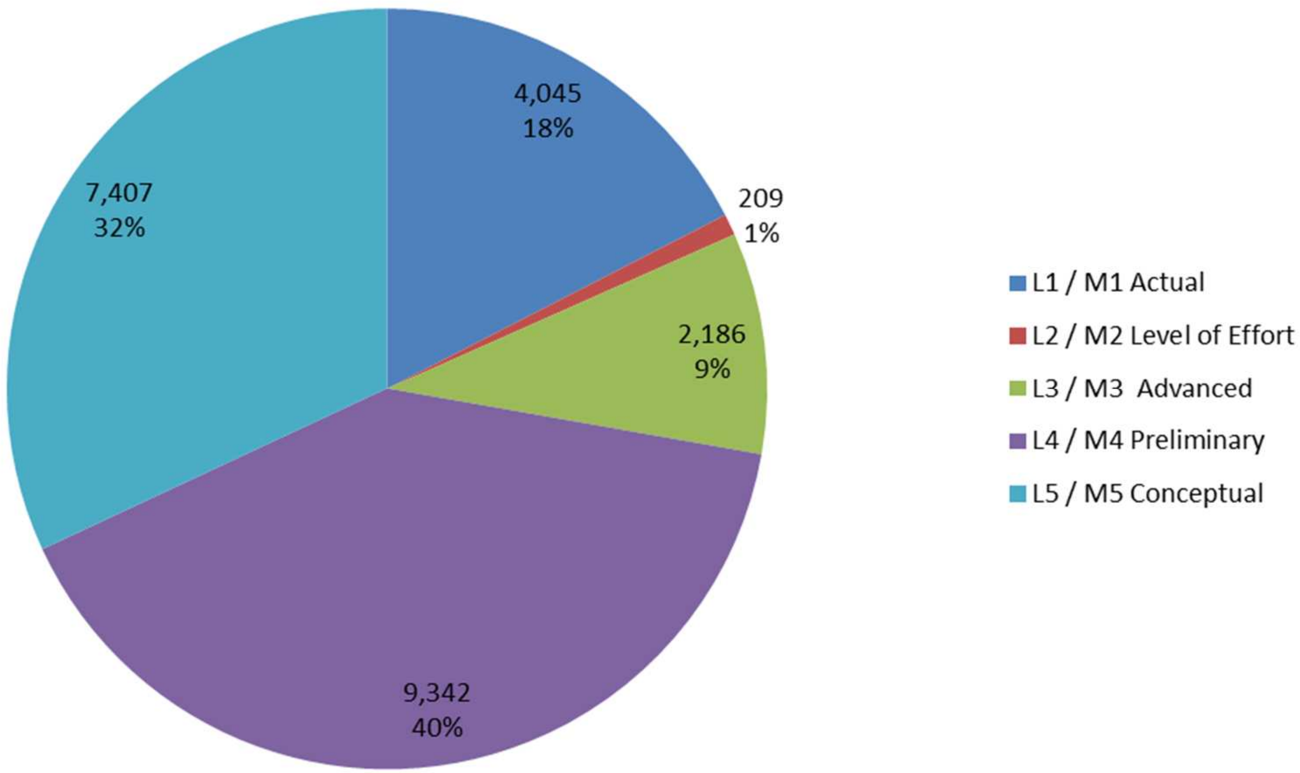
AY k$

Cost Distribution by Resource Type



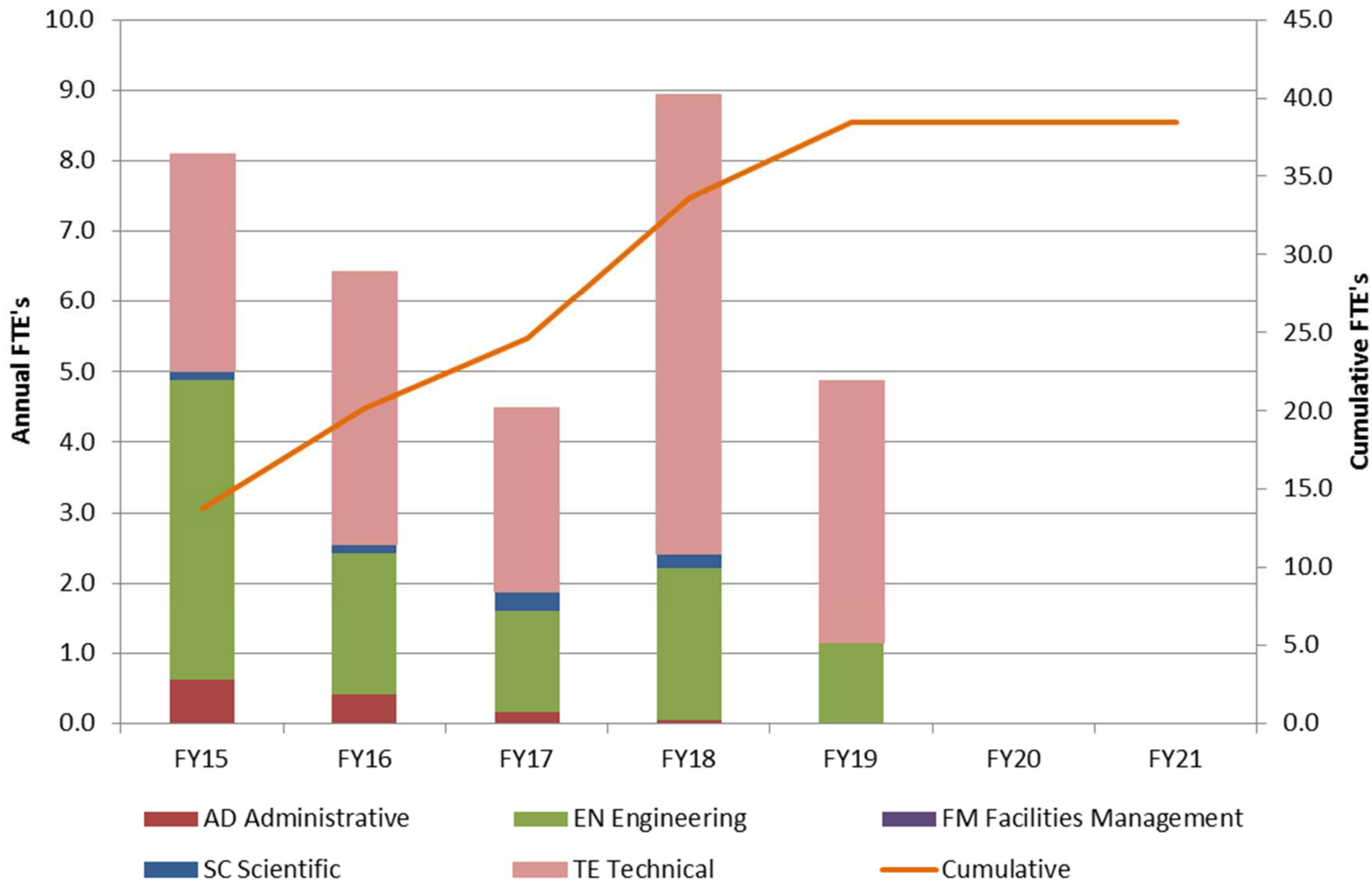
AY k$

Quality of Estimate



AY k$

Labor Resources



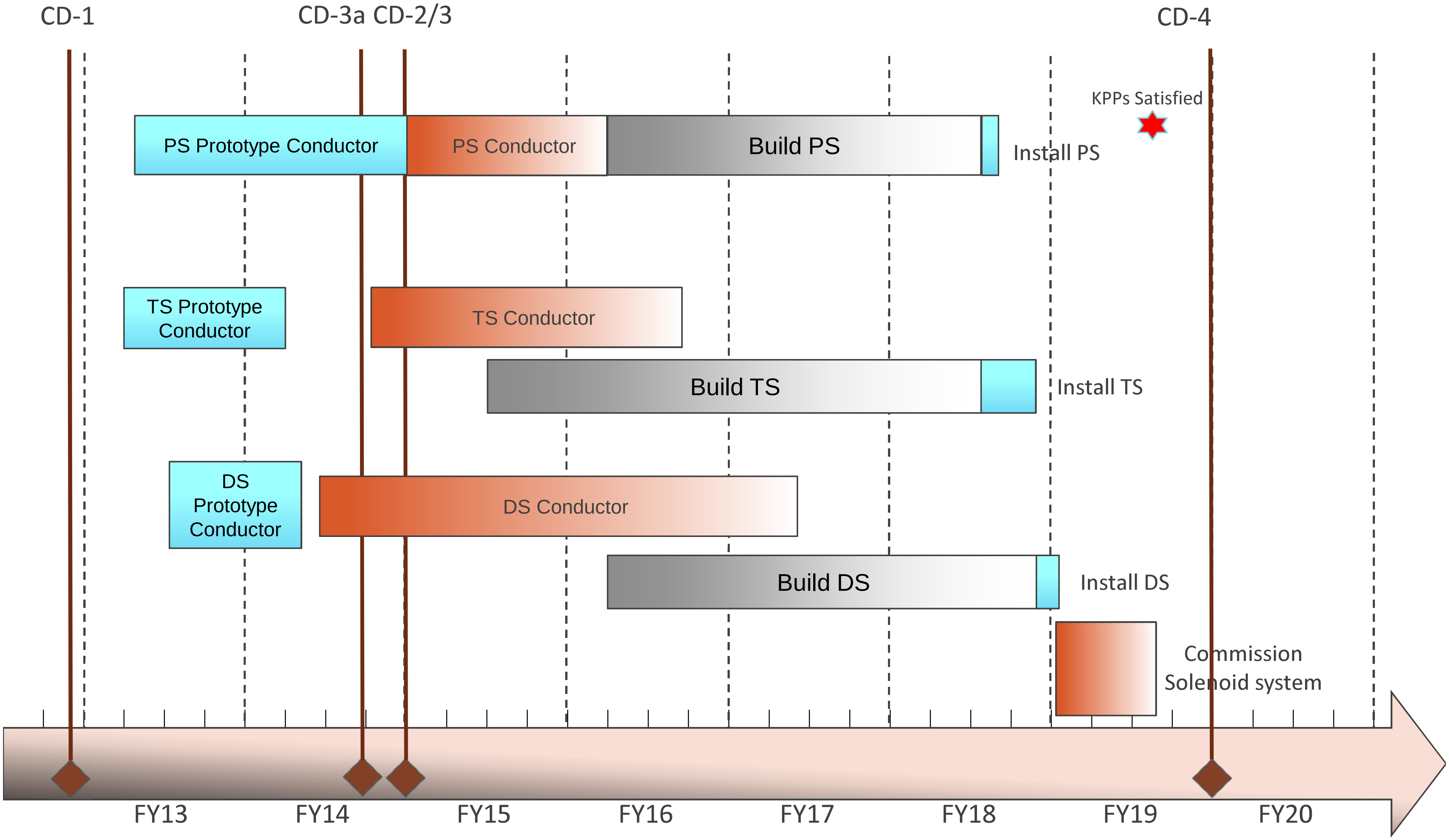
Cost Table

	Base Cost (AY k$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.04 Solenoids						
475.04.03 Transport Solenoids						
475.04.03 Transport Solenoid Actuals	500	3,490	3,990			3,990
475.04.03.01 TS Conductor	2,438	651	3,089	552	18%	3,641
475.04.03.02 TS Cold Mass Components	6,154	2,006	8,160	3,880	48%	12,041
475.04.03.03 TS Cryostat Components	1,628	1,041	2,669	1,218	46%	3,887
475.04.03.04 TS Magnet Assembly	228	3,418	3,646	1,459	40%	5,105
475.04.03.05 TS Support Structure		12	12	5	40%	16
475.04.03.06 TS Interconnects	160	154	314	139	45%	453
475.04.03.07 TS Test Cryostat	573	736	1,309	735	62%	2,044
Grand Total	11,682	11,508	23,189	7,987	42%	31,177

Major Milestones

- PO issued for TS production conductor
- Vendor for module fabrication select
- PO issued for module fabrication
- TSu Modules Completed
- TSd Modules Completed
- Finished testing all TSu modules
- Finished testing all TSd modules
- TSu magnet ready for installation
- TSd magnet ready for installation

Schedule


CD-1
CD-3a CD-2/3
CD-4
KPPs Satisfied
PS Prototype Conductor
PS Conductor
Build PS
Install PS
TS Prototype Conductor
TS Conductor
Build TS
Install TS
DS Prototype Conductor
DS Conductor
Build DS
Install DS
Commission Solenoid system
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20

Summary

- The TS conductor performed really well and the PO is about to be placed.
- The solenoid magnetic design meets the requirements for the experiments and tolerances are well understood.
- Mechanical designs are very advanced and they are based on the experience we are having with the prototype.
- Cost and Schedule understood.
- We are on track to place orders for TS coil modules.
- We believe we are ready for CD2 project baseline