Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Status of Performance Testing of the Mu2e Transport Solenoid Coils

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Magnet Technology Conference

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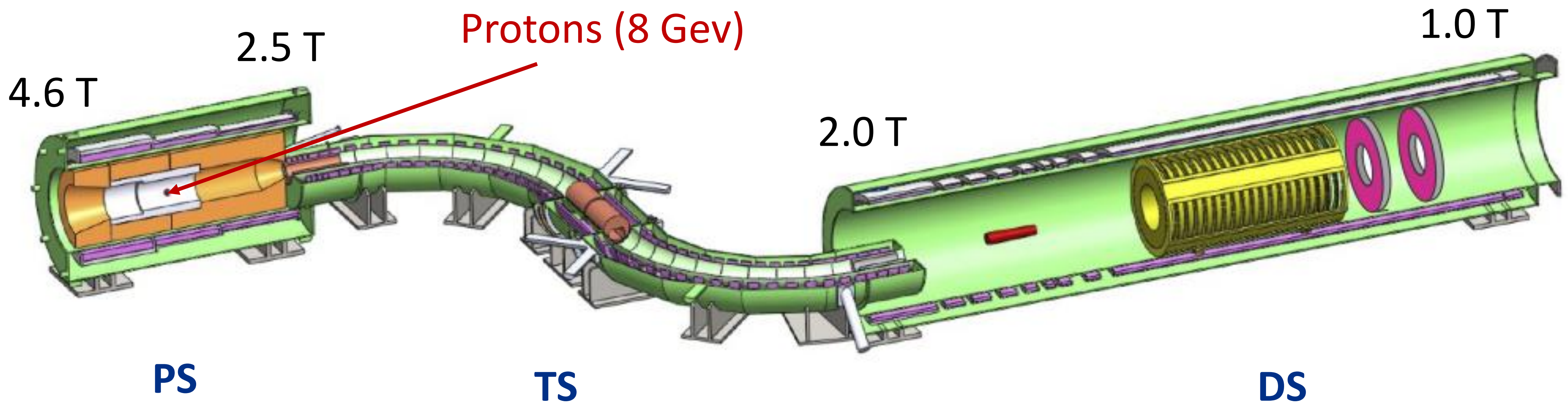
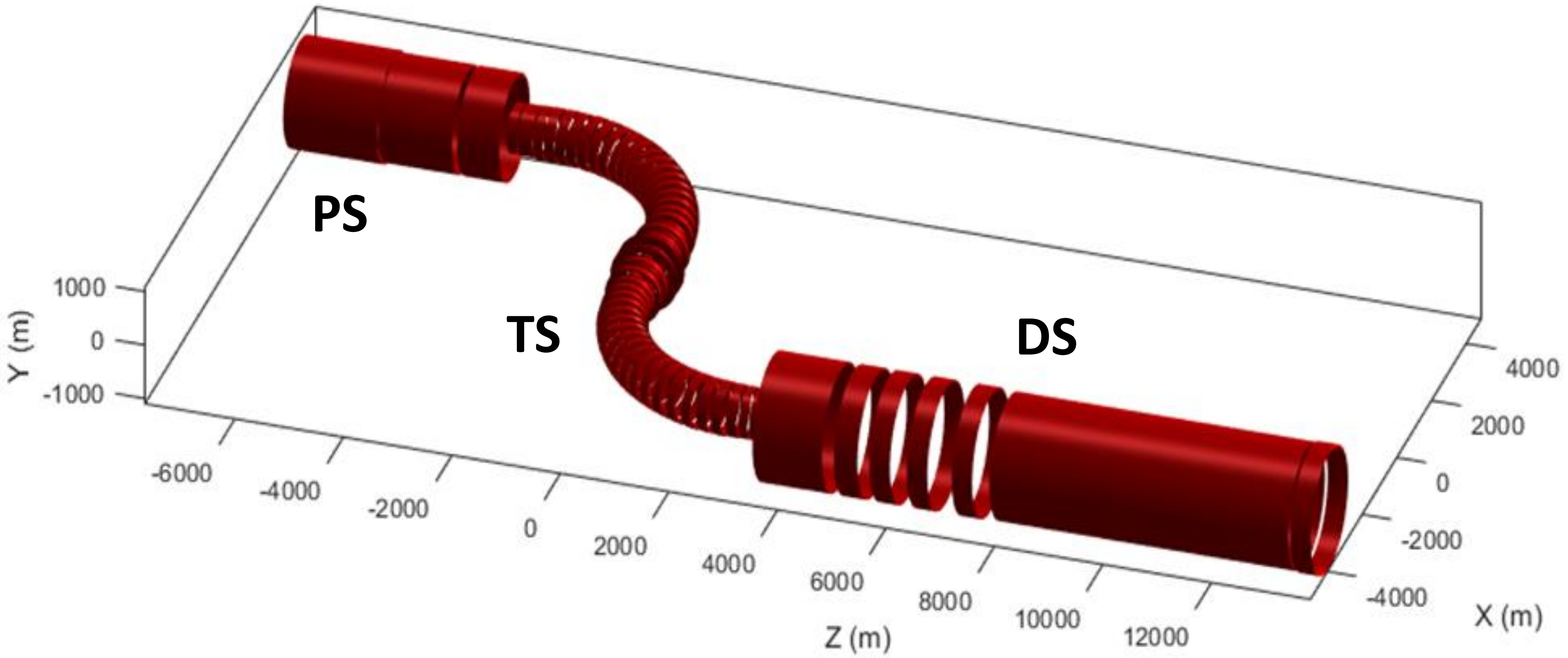
Mu2e Experimental Layout

- Mu2e will search for the neutrino-less conversion of a muon into an electron in the presence of a nucleus, $\mu N \rightarrow eN$
- 10000 improvement over previous experiment
- Could discover the violation of Flavor Symmetry in the charged leptons → physics beyond the Standard Model



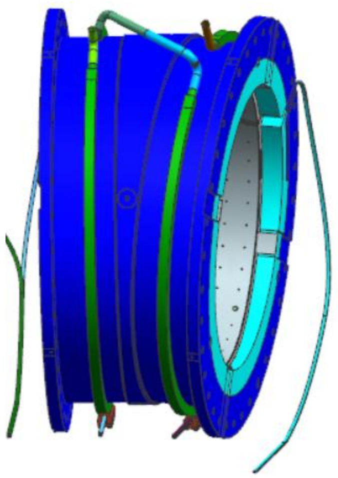
Mu2e Magnet System

- 66 Solenoids, PS(3), TS(52), DS(11)
- PS and DS fabricated and fully assembled in industry
- Sections of the TS cold mass fabricated in industry, testing and assembly at Fermi

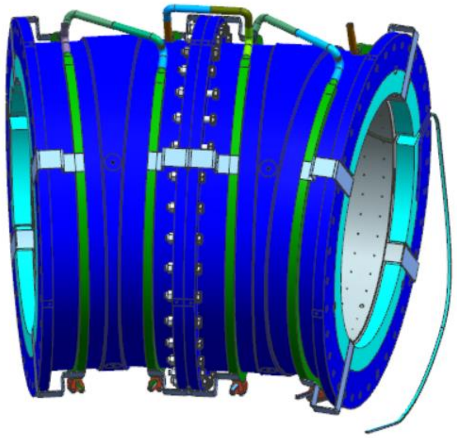


Transport Solenoid

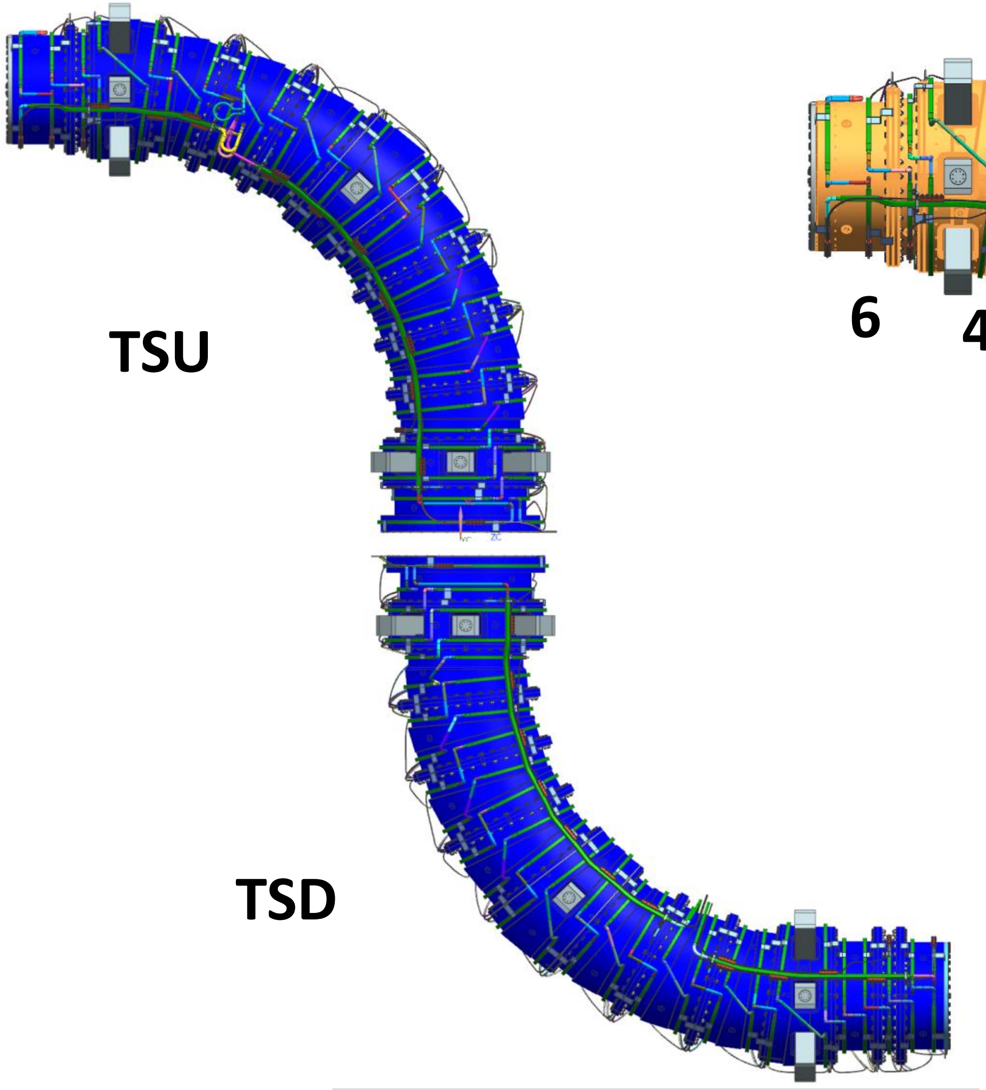
Typically 2 coils per module



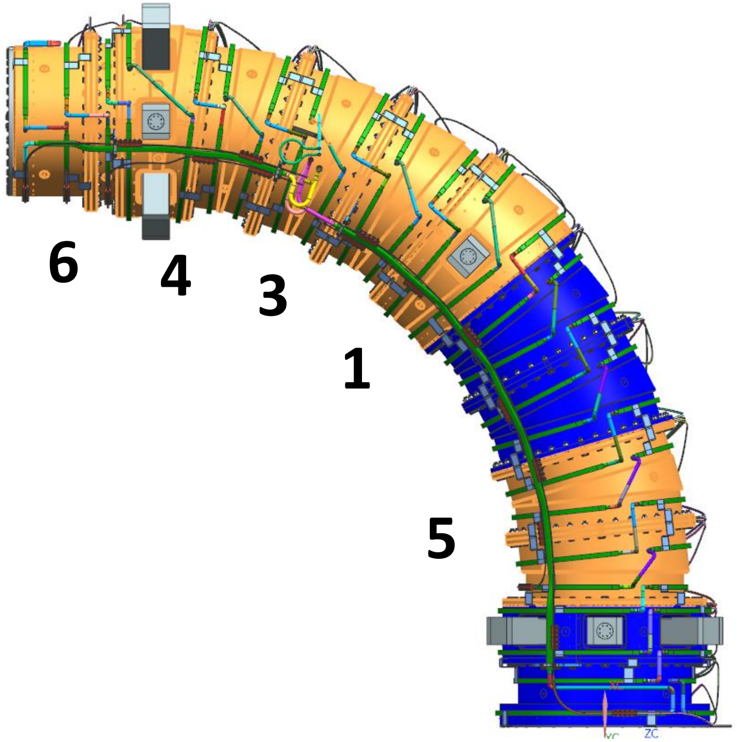
1-3 modules per unit



14 units for the TS



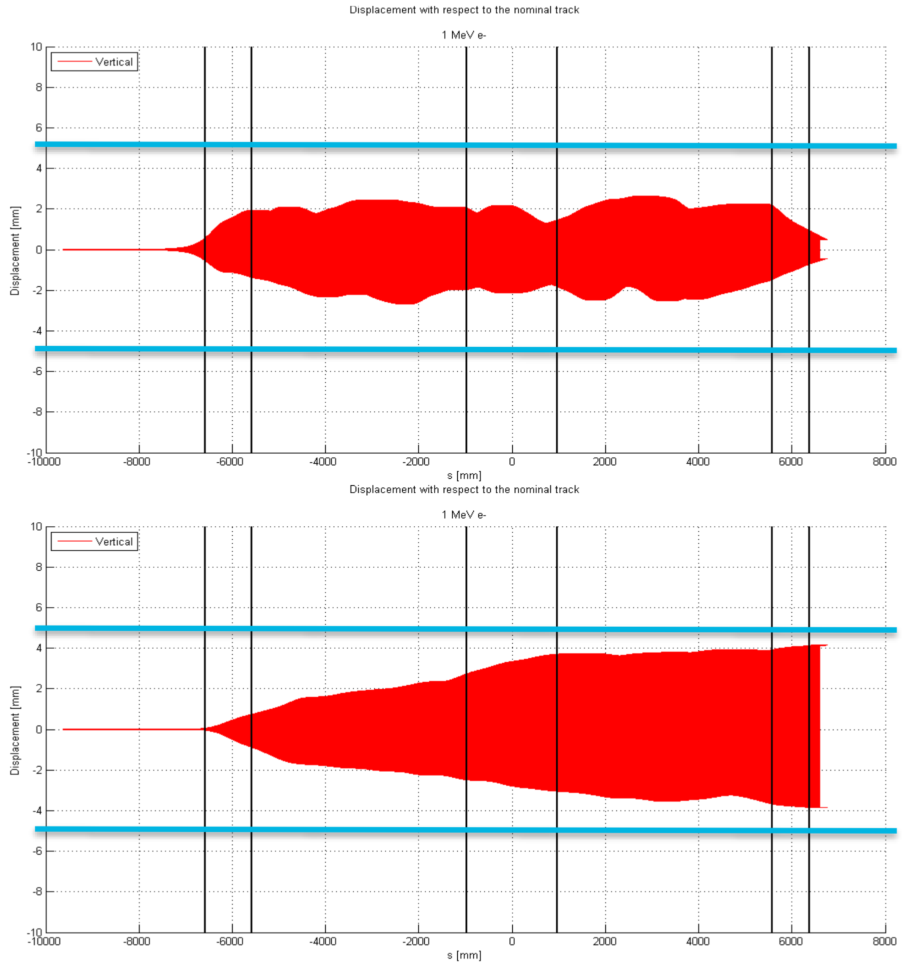
5 TSU units delivered



Requirements and Tolerance

Tolerance studies of the Mu2e solenoid system

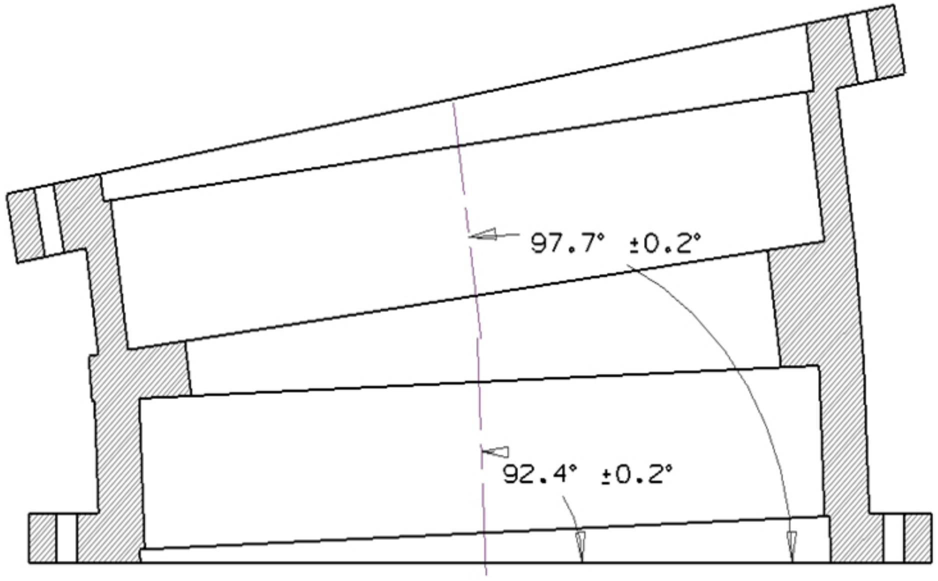
M. L. Lopes, G. Ambrosio, M. Buehler, R. Coleman, D. Evbota, S. Feher
M. Lamm, V. Kashikhin, G. Moretti, T. Page, M. Tartaglia, *Fermilab*,
J. Miller, *Boston University*
J. Popp, *York College CUNY*
R. Ostojic, *CERN*



ΔV = 10 mm

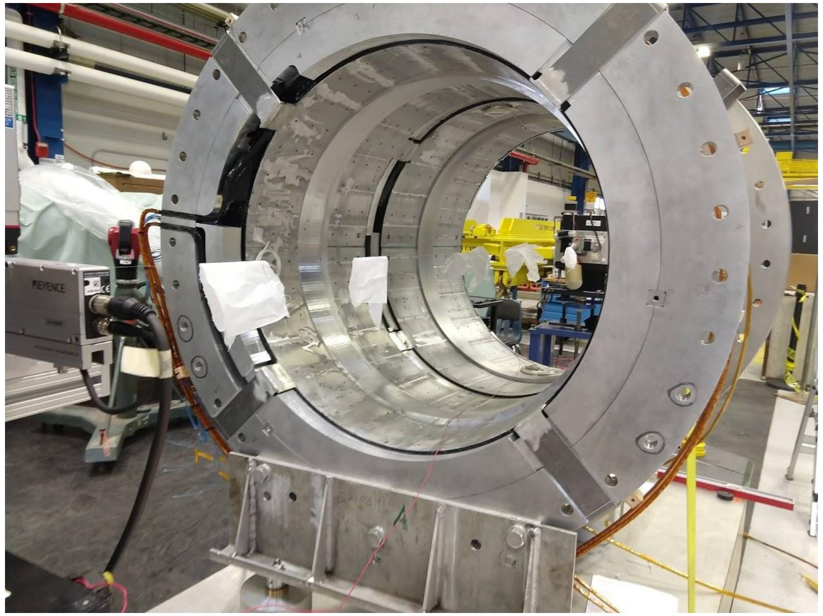
ΔP = 5 mrad

- Mu2e required efficient muon transmission and no trapped particles
- Previous studies helped set the tolerances for fabrication and assembly



Magnetic Axis

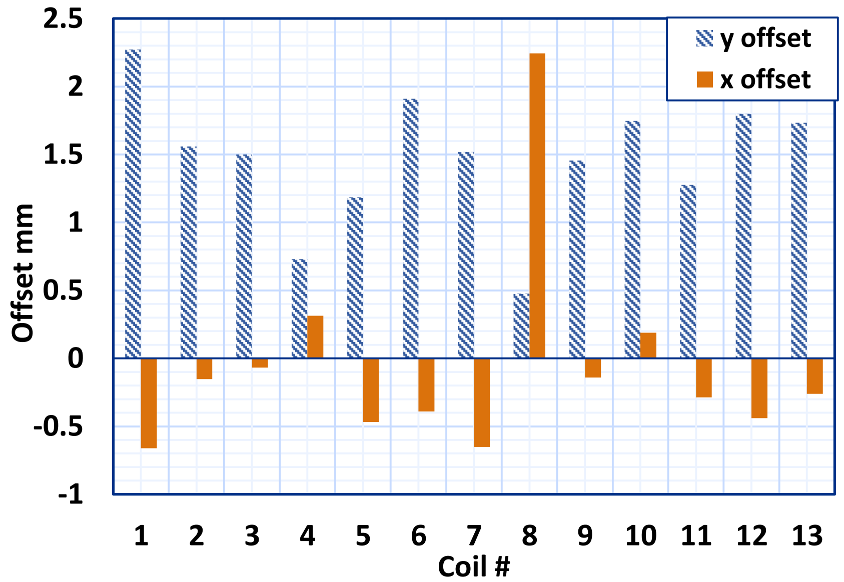
- Vibrating stretched wire measurement made for each coil, with AC current on the magnet to reject earth's magnetic field and remnant magnetization effects
- Sag correction made ~100 μm
- Position measured with respect to fiducials on the shell and wire system, translated to the Mu2e coordinate system



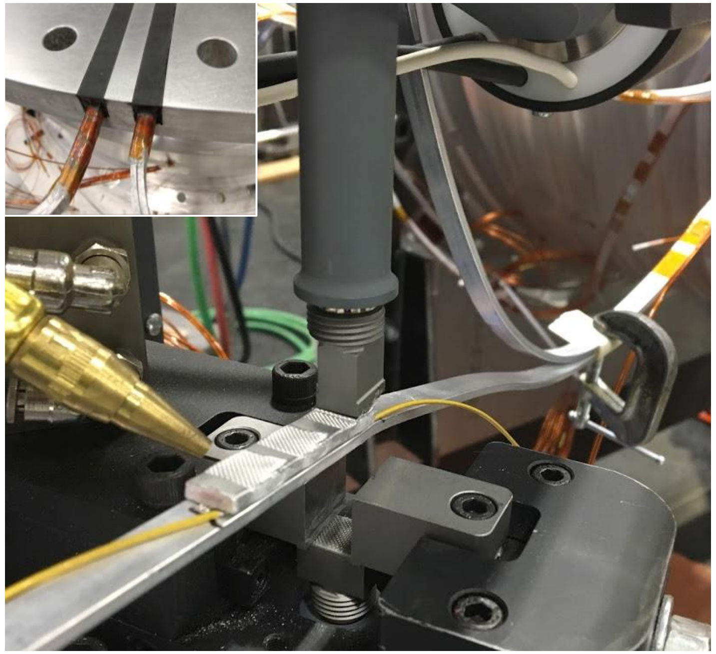
TRANSPORT SOLENOID COIL TO COIL ANGLE MEASUREMENTS

Coils	Requirement (Degree)	Measurement (Degree)	Difference (Degree)
1/2	0 ±0.2	0.174	0.174
2/3	0 ±0.2	0.067	0.067
3/4*	0 ±0.2	0.002	0.002
4/5	5.7 ±0.2	5.538	-0.162
5/6	4.8 ±0.2	4.790	-0.01
6/7	5.3 ±0.2	5.280	-0.02
7/8*	5.5 ±0.2	5.624	0.124
8/9	5.5 ±0.2	5.352	-0.148
9/10	5.5 ±0.2	5.582	0.082
10/11	5.5 ±0.2	5.558	0.058
11/12*	5.5 ±0.2	5.365	-0.135
12/13	5.4 ±0.2	5.465	0.065

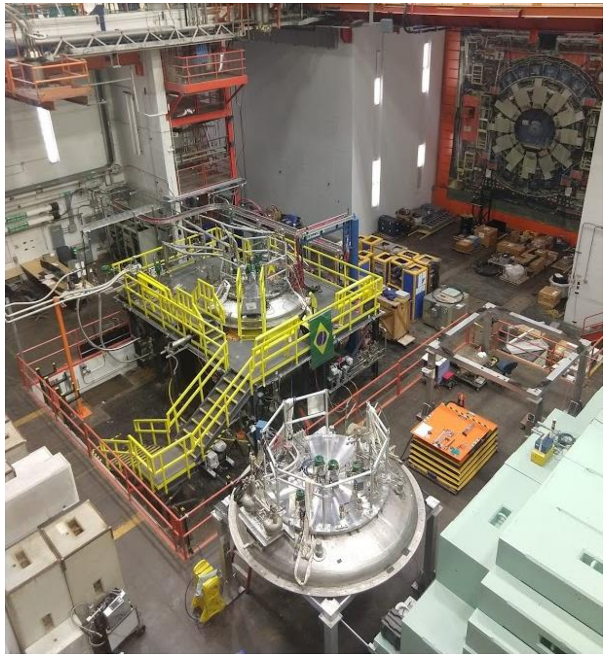
* Marked coils represent boundaries between units; for these coils the angles assume perfect unit-to-unit assembly.



Cold Test Preparation

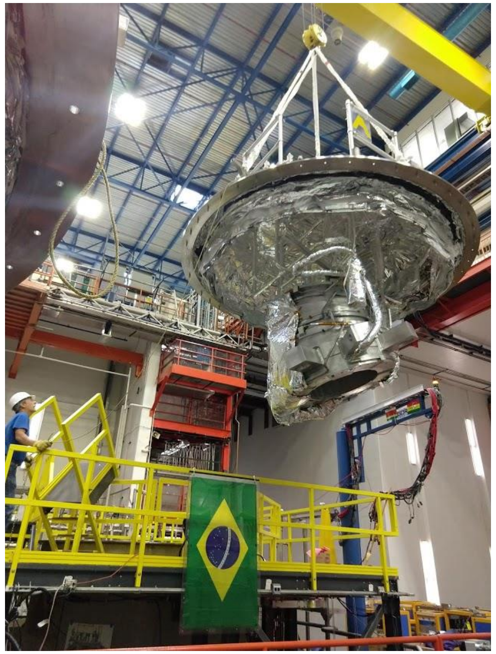


Ultrasonic weld of splices and voltage taps



Dished heads and test cryostat

Cryogenic, electrical, and RTD connections

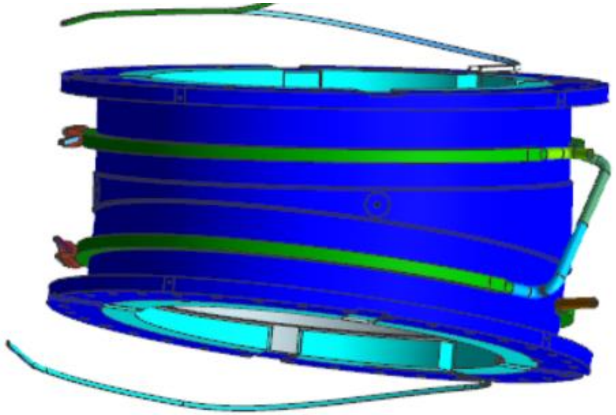


Dished head and unit moved to the cryostat

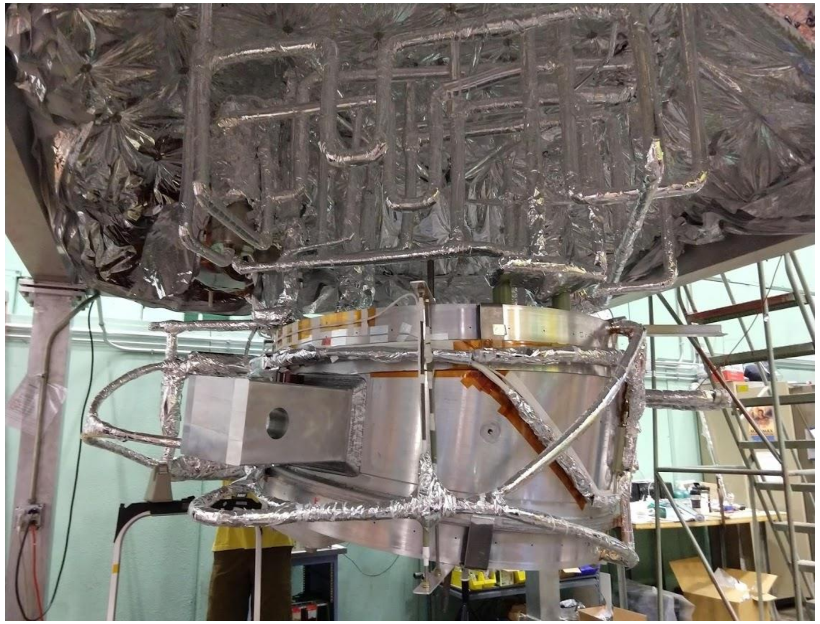
- Max temperature differential between the shell and coil of 23 K to avoid stress on coil from differential thermal contraction
- Each unit takes ~ week to cooldown/ warm-up

Cold Acceptance Tests

- Coils must reach 2100 A, 120% of 1730 A operating current
- No more than 5 quenches allowed per coil
- Any quench in the coil requires a thermal cycle



Unit 1



- Quench ~1800 A
- Reached 2100 A during second powering
- Suspect quench in leads between coils
- After thermal cycle, we found a few temporary lead supports had popped off

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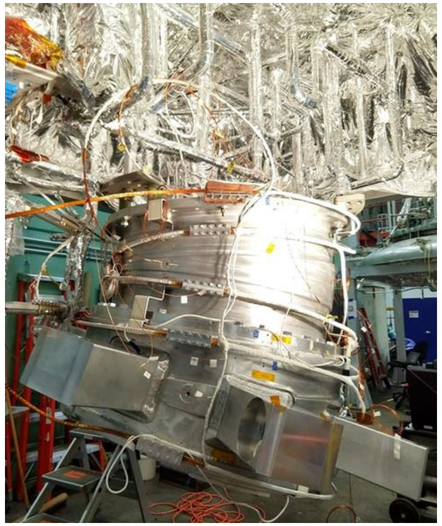
Cold Test Results

Unit 3

- Quenched at ~1500 A, unable to reach 2100 A during first cooldown
- Quench due to motion in leads connecting to the dished head
- Removed from cryostat and added additional lead support
- Reached 2100 A after second cooldown

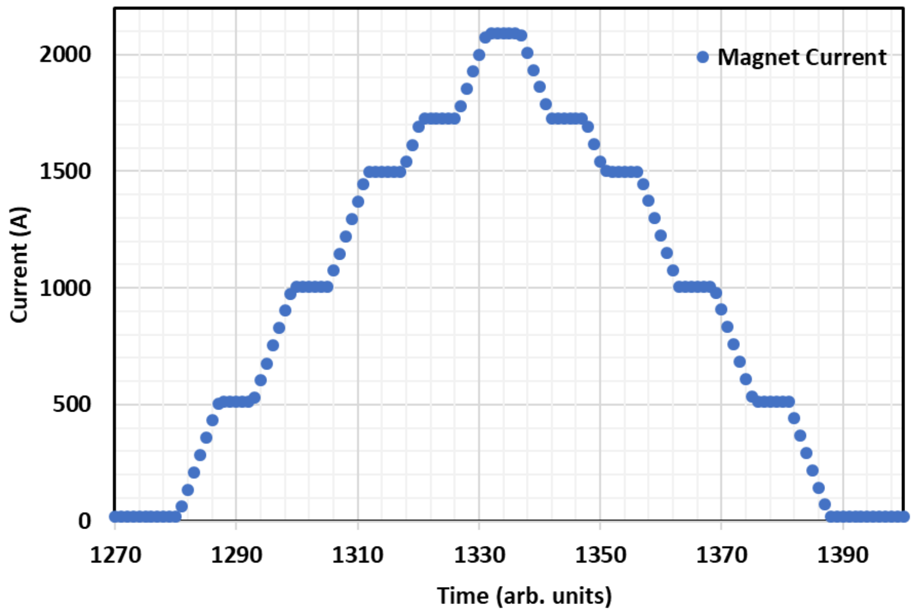
Unit 4



- Quench ~1800 A
- Quench origin was either in coil 7 or in the leads between coil 6 and 7
- Reached 2100 A on second ramp
- Currently undergoing thermal cycle

Splice Measurements

- Splice voltage measurements made at several currents
- Requirement on splice to be less than 2 nΩ
- All splices below the requirement



TS Coil to Coil Splice Measurement	
4/5	0.5 ± 0.1
5/6	0.46 ±0.04
6/7	0.5 ± 0.1
7/8*	
8/9	0.4 ± 0.1
9/10	0.38 ± 0.03
10/11	0.7 ± 0.2
11/12*	
12/13	0.82 ± 0.06

*Boundary between units. Splices will be made during assembly

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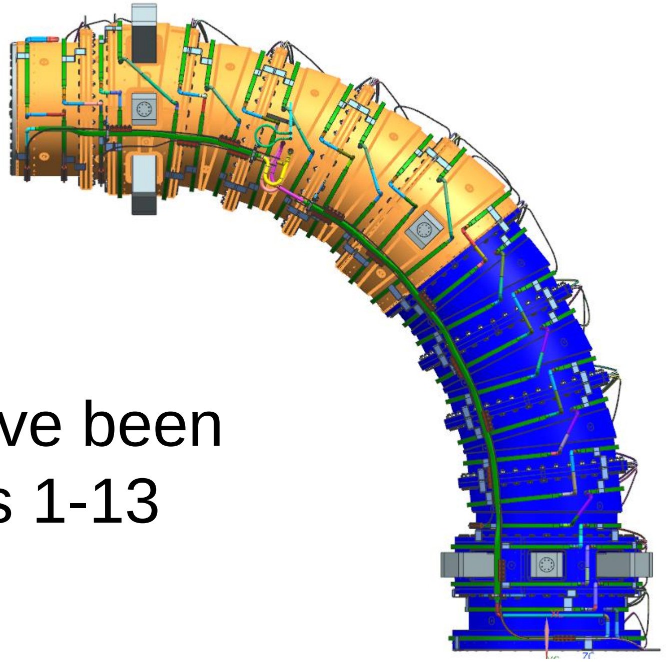
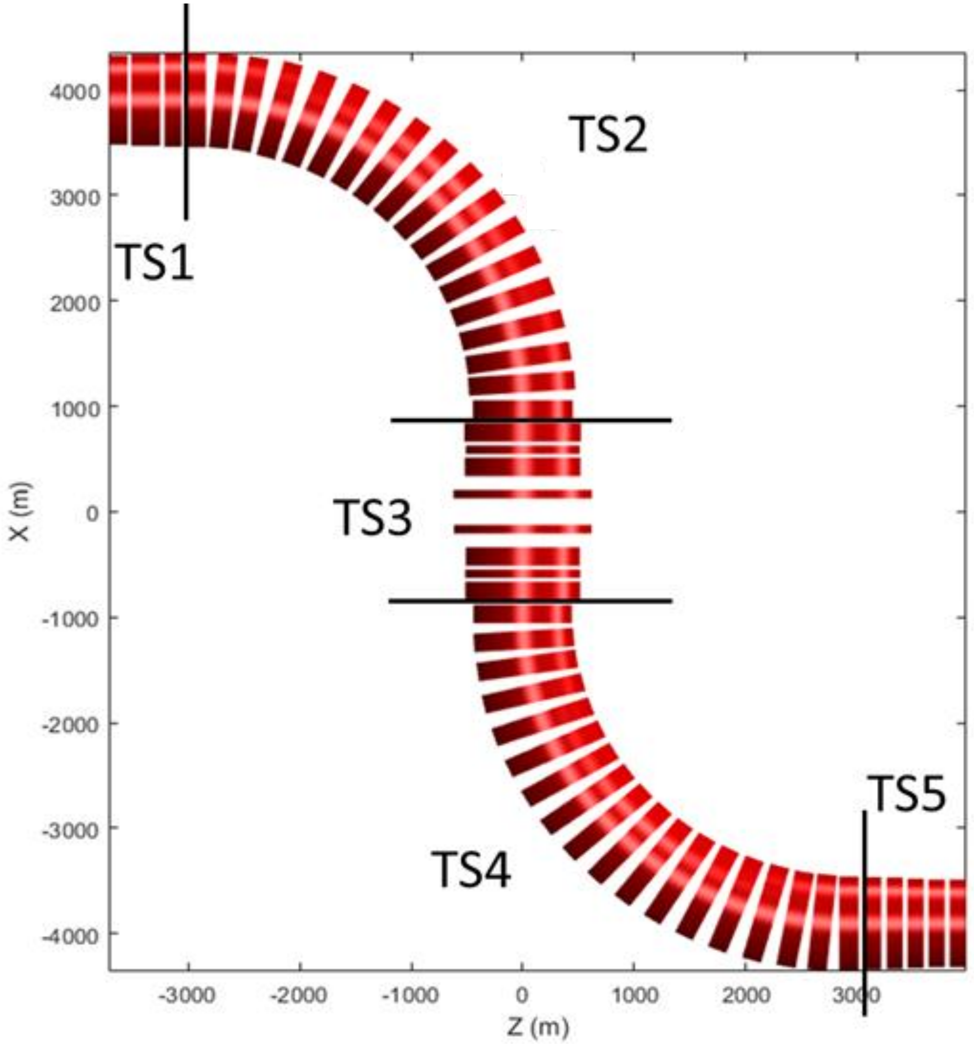
Transport Solenoid

Transport Solenoid Magnetic Requirements

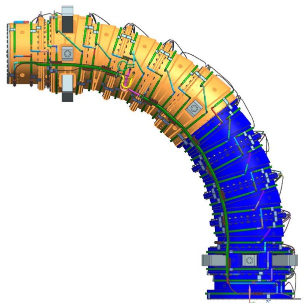
Region	B Initial/Final ±5% (T)	dBs/ds (T/m)	dBs/dr (T/m)	Ripple (T)	Location* (m)
TS1	2.50/2.40	< -0.02	NA	NA	r=0, r=0.15
TS2	NA	NA	> 0.275	±0.02	r < 0.15
TS3	2.40/2.10	< -0.02	NA	NA	r=0, r=0.15
TS4	NA	NA	> 0.275	±0.02	r < 0.15
TS5	2.10/2.0	< -0.02	NA	NA	r=0, r=0.15



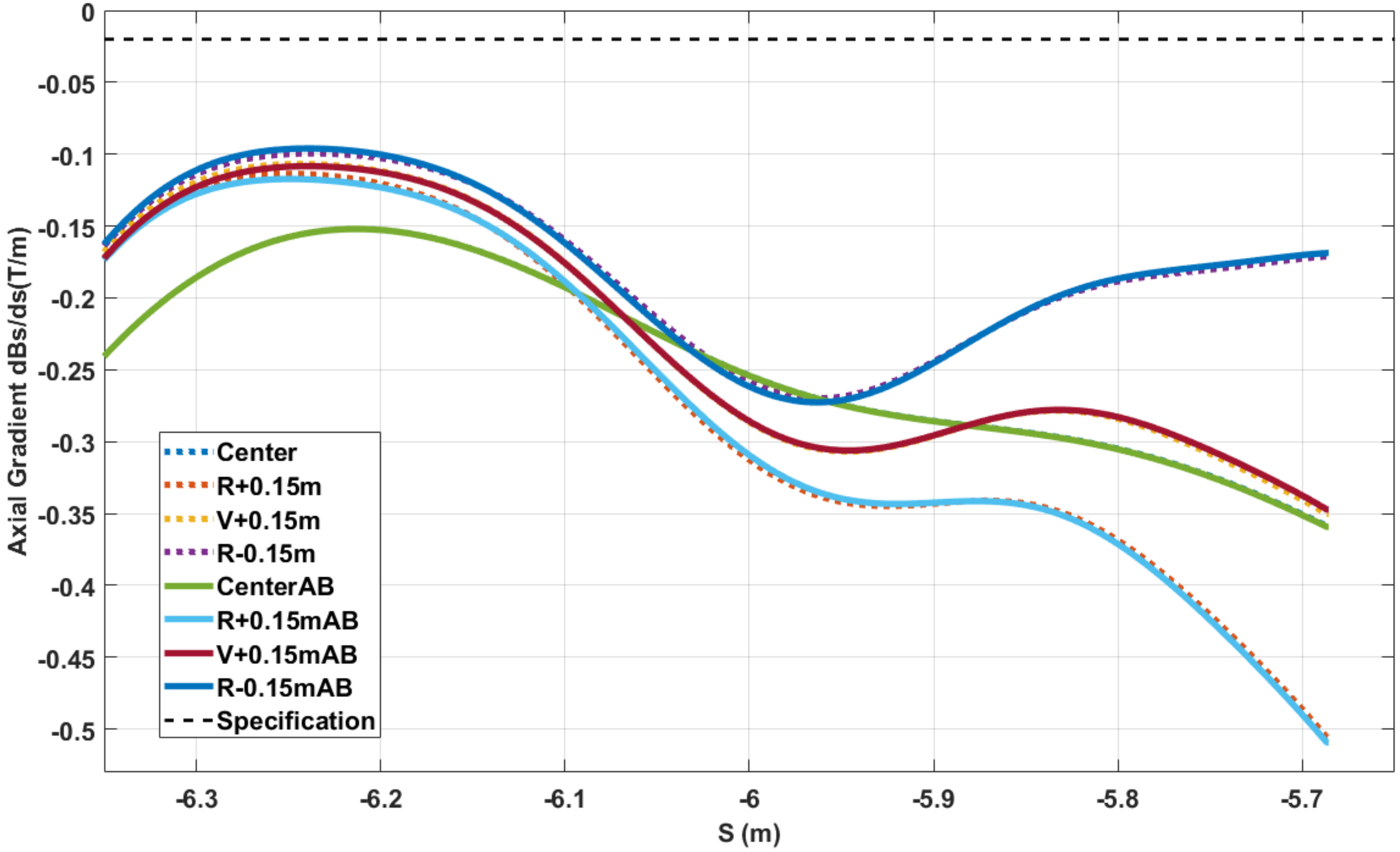
Stretched wire measurements have been completed on coils 1-13



As-built TS1

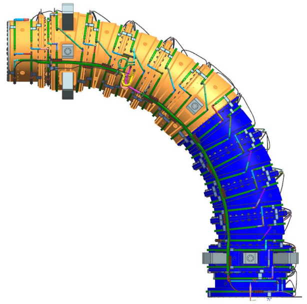


- Stretched wire results used to update magnetic model and ensure magnetic requirements are met
- Nominal model with as-built values for coils 1-13

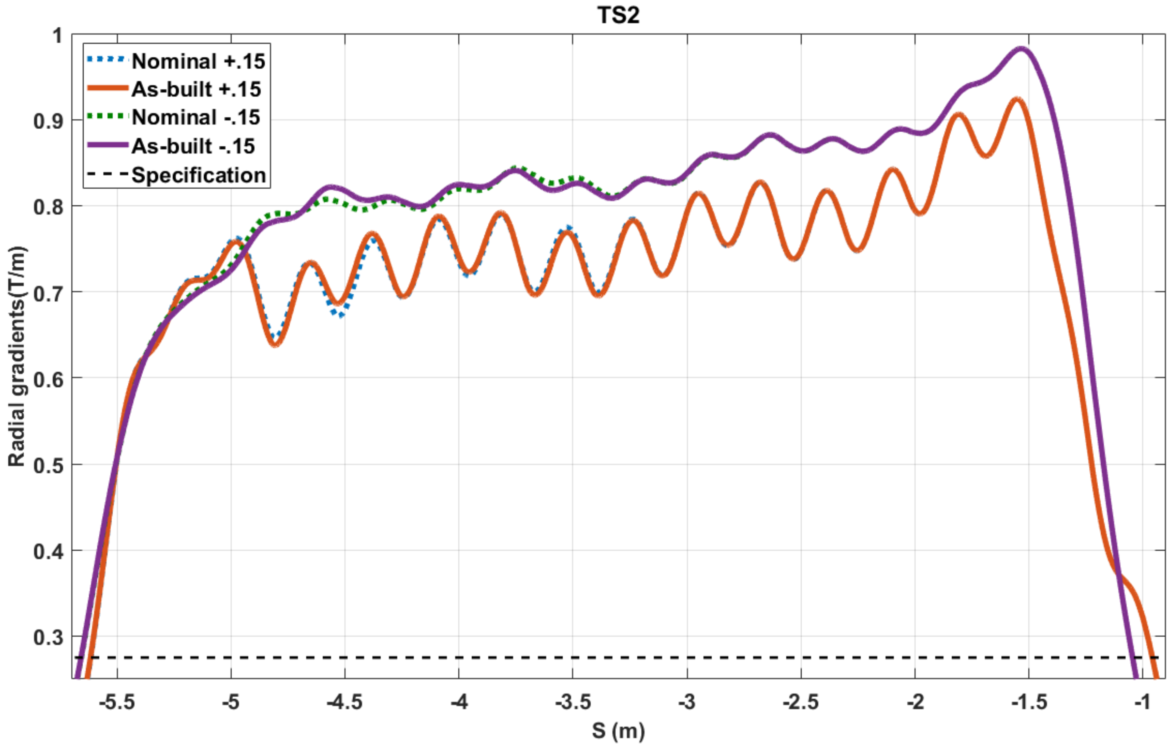


Axial Gradient dBs/ds <-0.02 T/m

As-built TS2

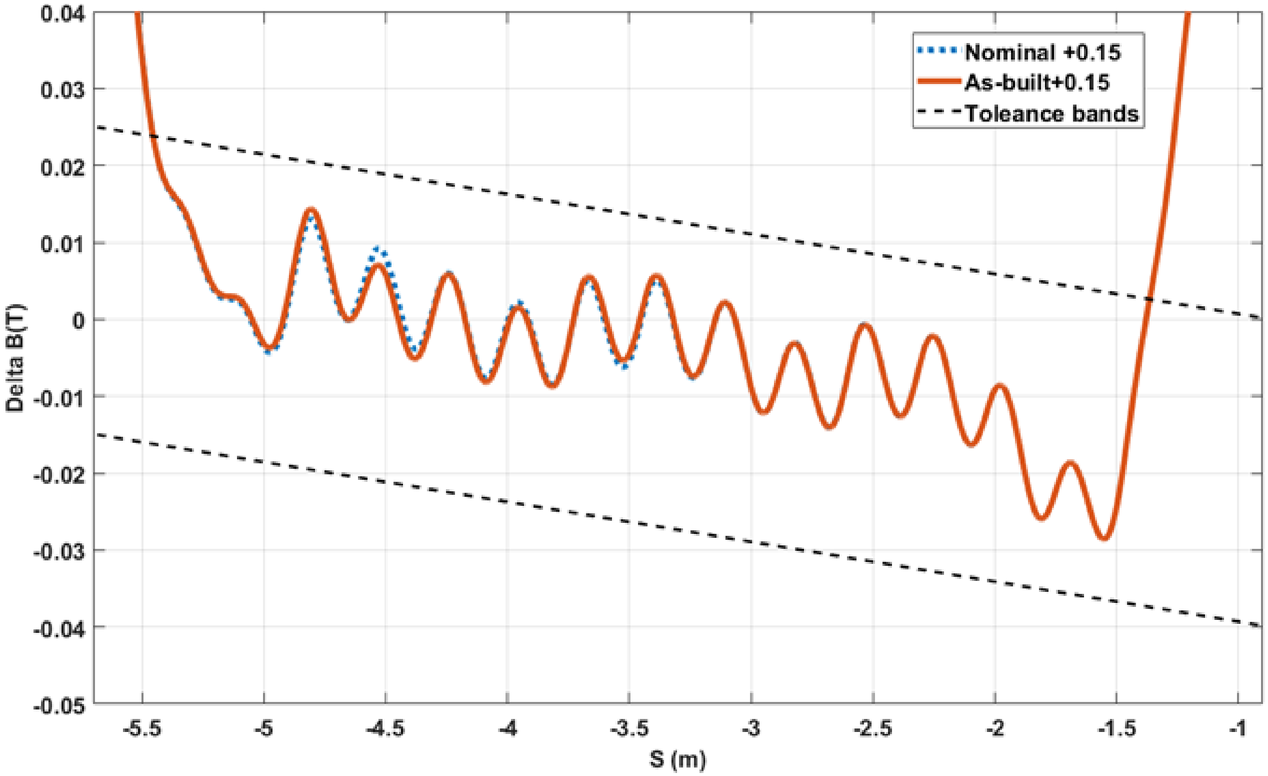


As-built values for coils 1-13

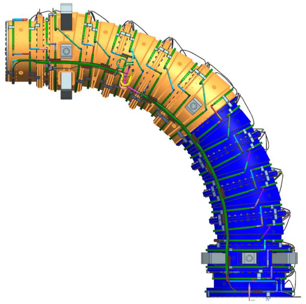


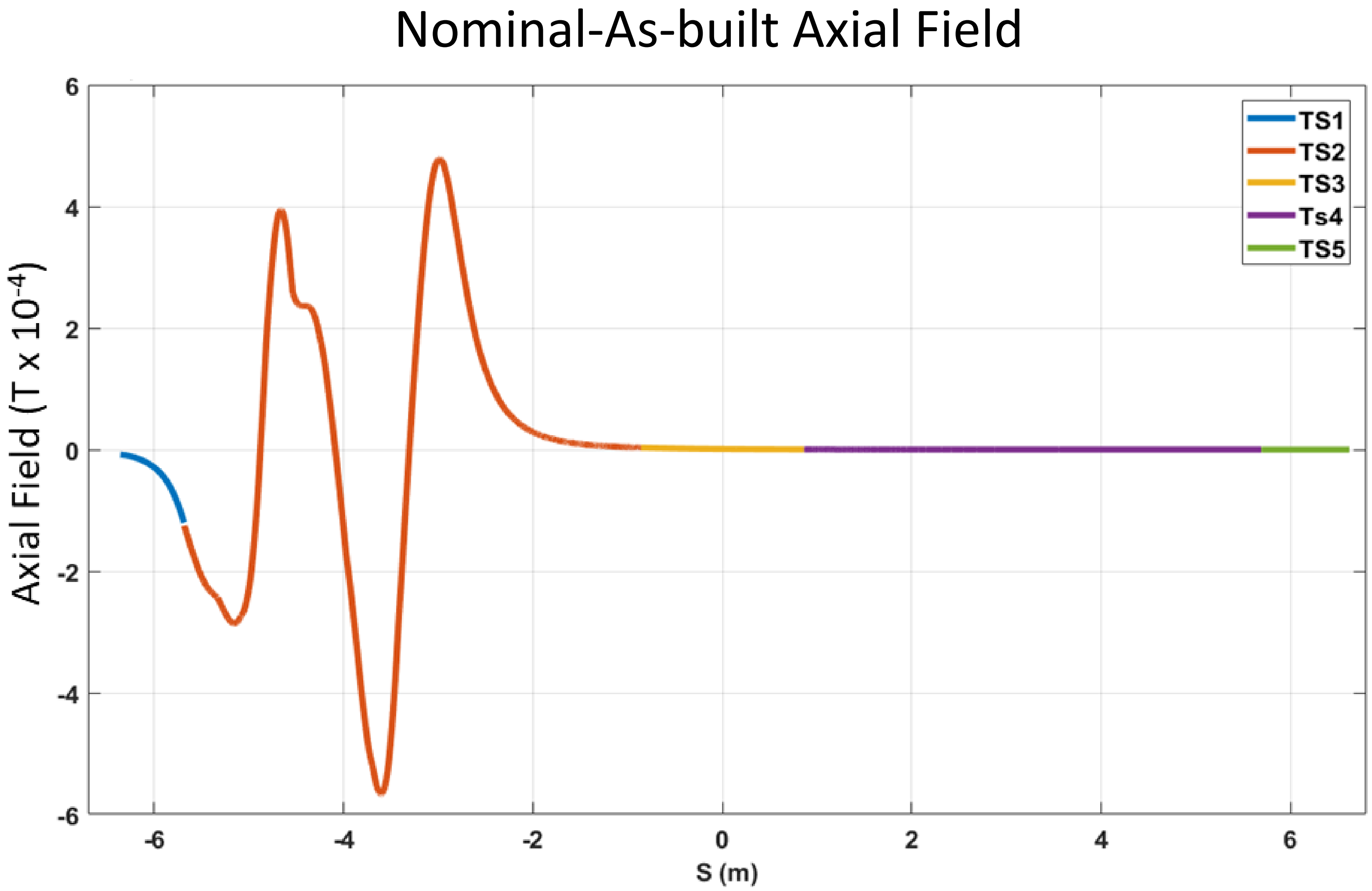
Radial Gradient dBs/dr > 0.275 T/m

Ripple ± 0.02 T out to 0.15 m



As-Built Axial Field

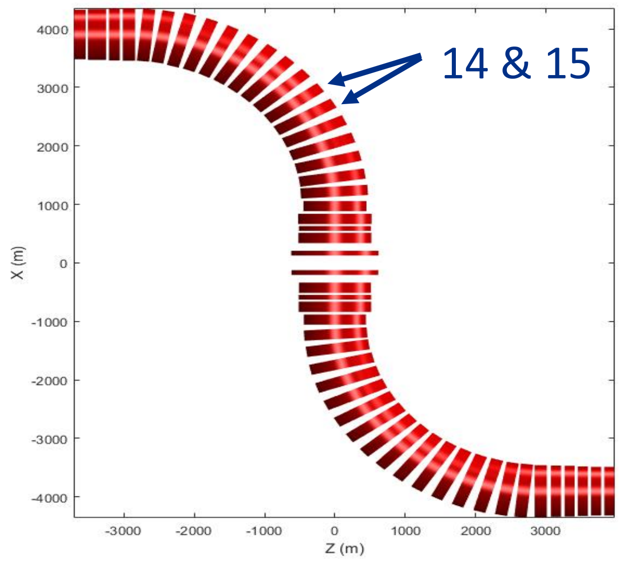


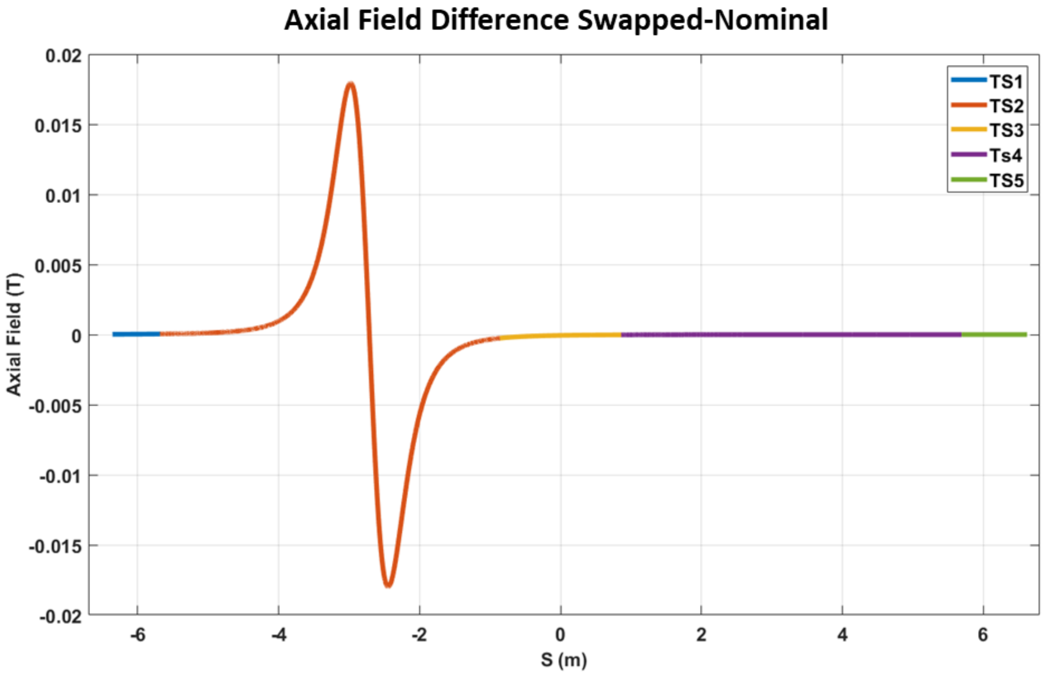


Final as-built field will be determined after cold mass assembly

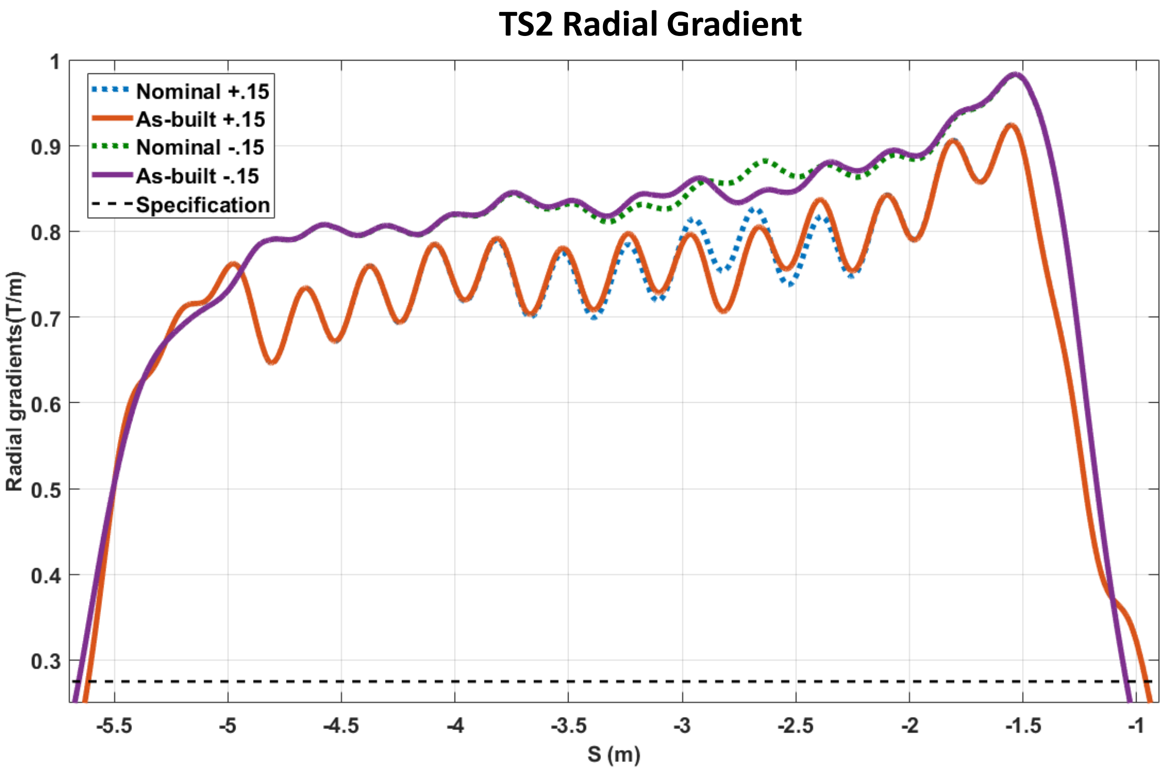
Swapped Coils 14 & 15

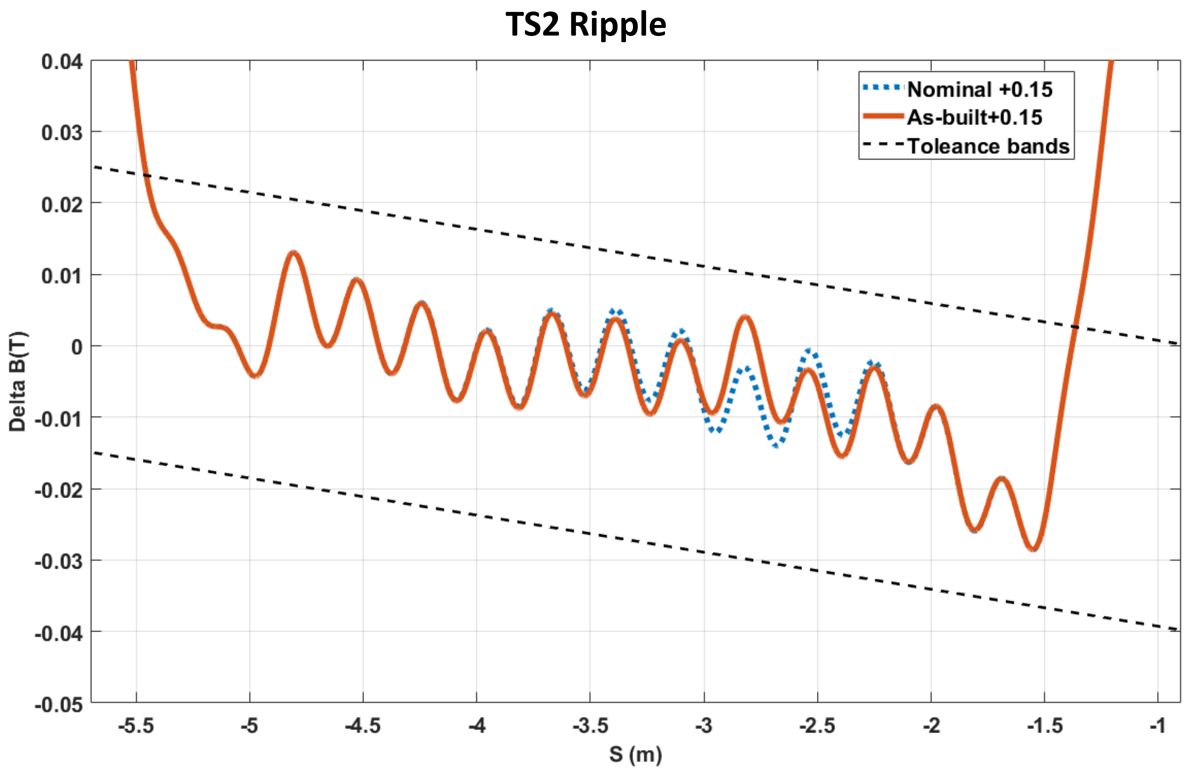
- Due to a fabrication error, we are looking into the feasibility of swapping coils 14 and 15
- The coil lengths and inner diameter are the same, so the coil center position and angles remain at nominal
- Coil 15 has one additional layer of conductor, this increases the axial field at 14 and decreases at 15





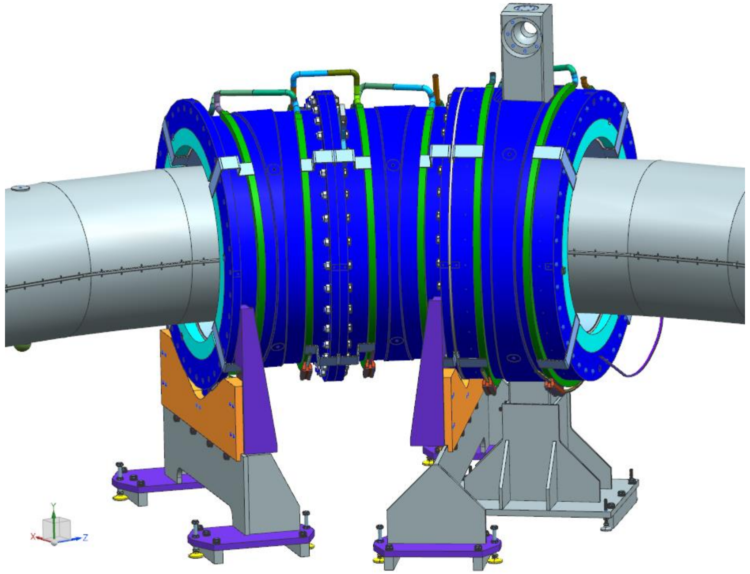
Swapped Coil

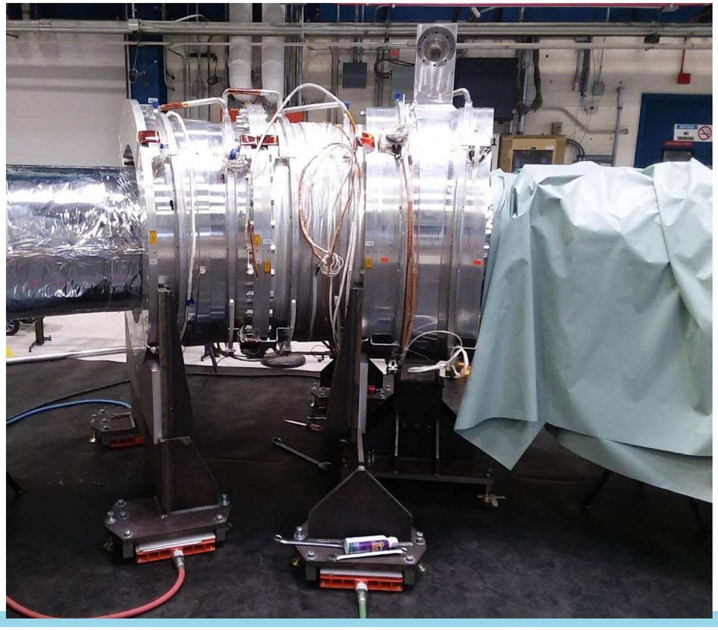


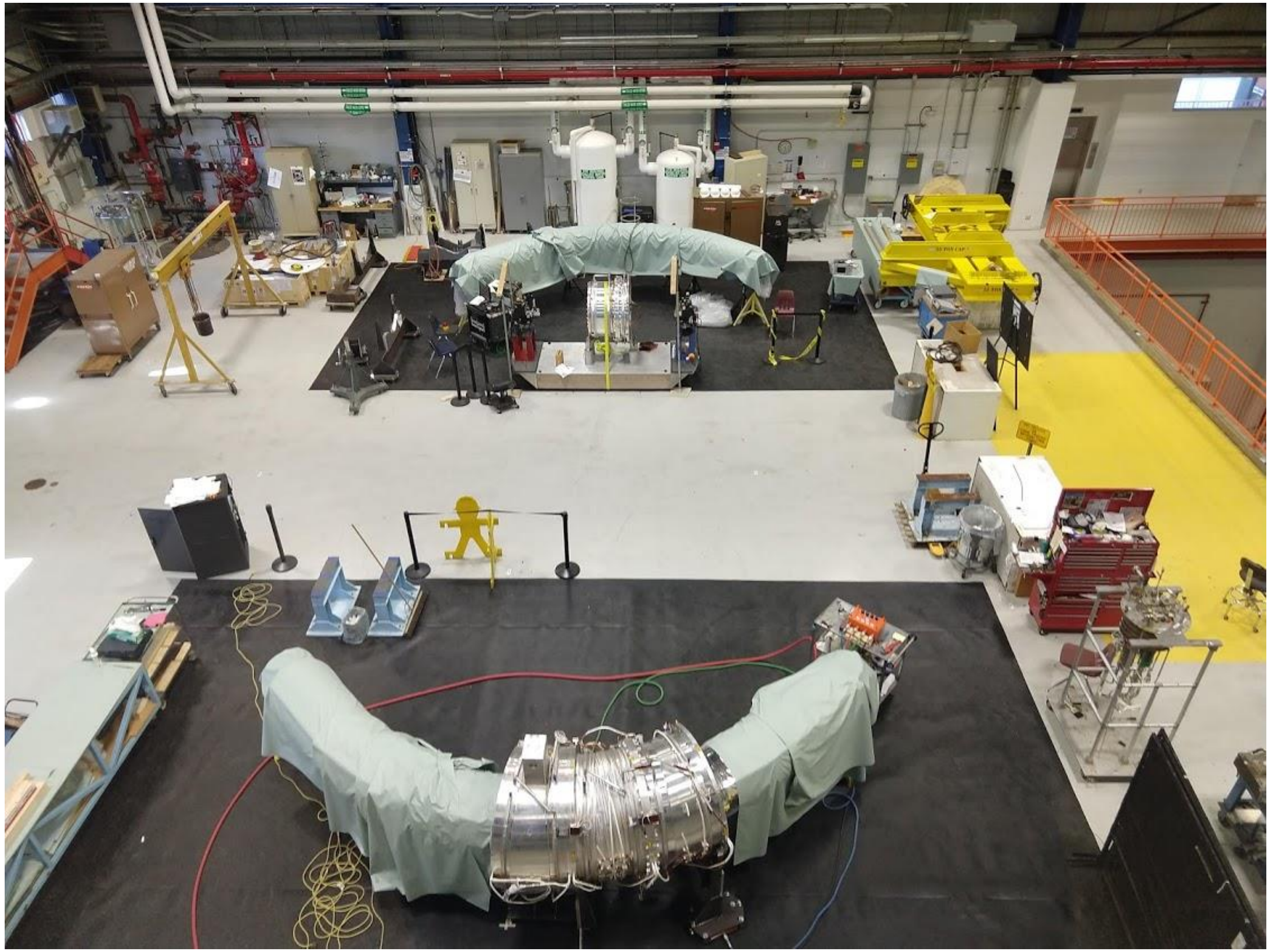


- In addition to checking the magnetic requirements, the field map was given to the collaboration for particle tracking studies
- In the process of checking other mechanical and electrical implications

Cold Mass Assembly







Summary

- Transport Solenoid in production
  - Unit on the stretched wire stand, one in cold test preparation, one cold and ready for second powering
- 5 of 14 units delivered, 3 cold tested, 2 in final assembly
- All cold tested units reached 2100 A
- All as-built values for the first 13 coils meet the magnetic requirements
- All splice measurements below the required 2 nΩ
- Swapping coils 14 and 15 looks feasible from a magnetic and particle tracking standpoint