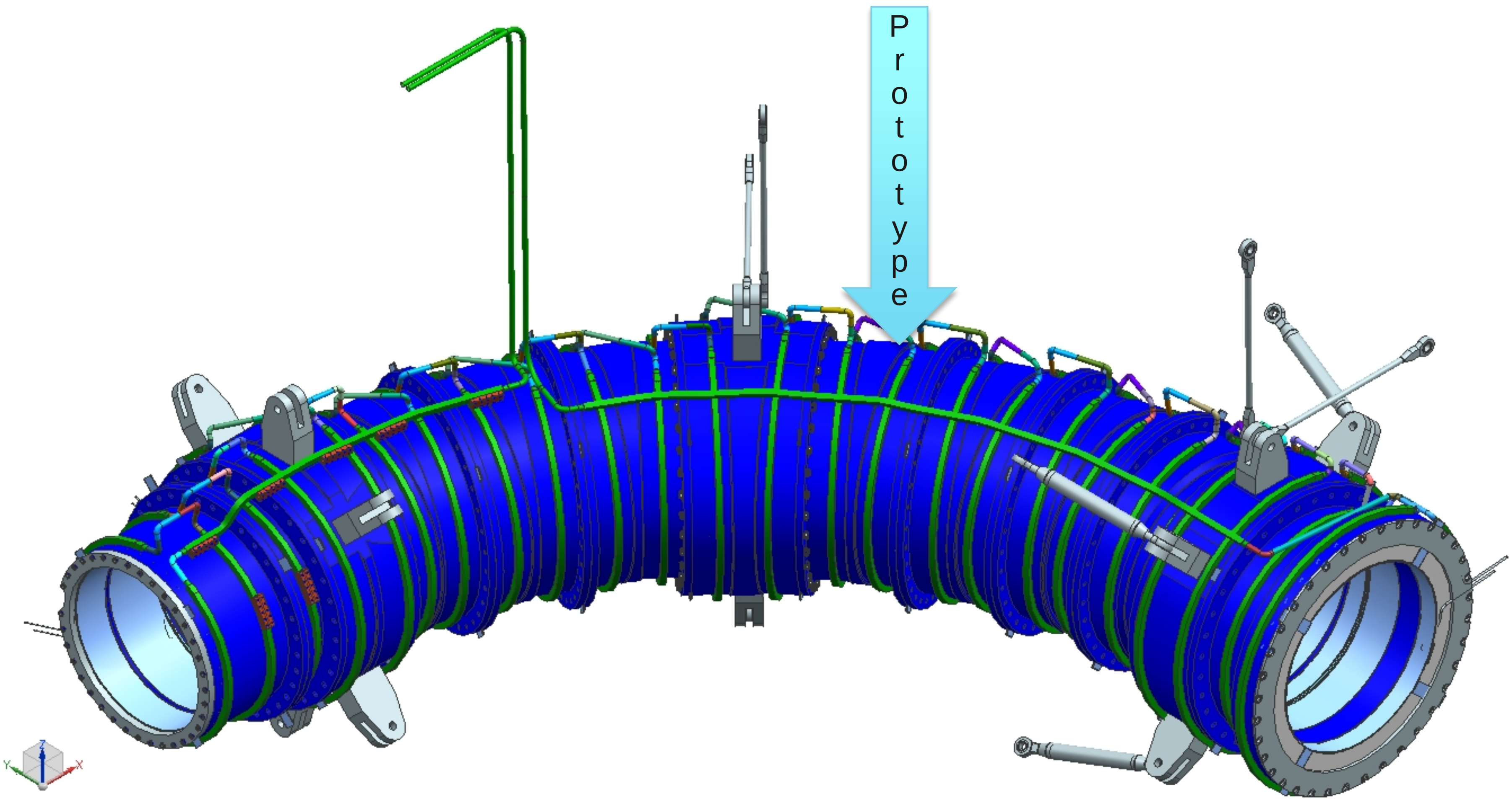
Fermilab

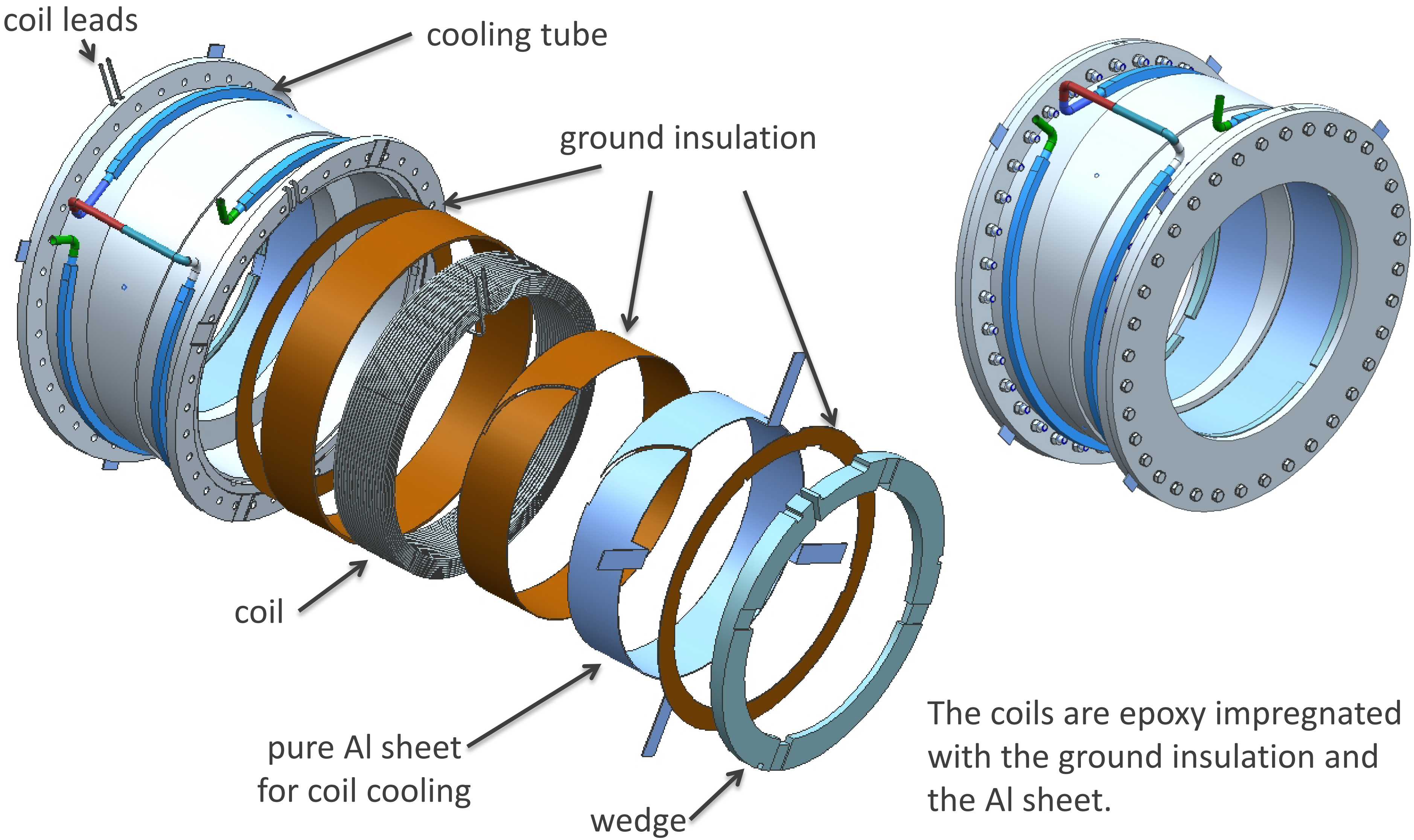
475.04.03.02.01 TS Cold Mass Prototype

Giorgio Ambrosio
L3 deputy for the Transport Solenoid
Oct 21-24, 2014

TS Cold mass assembly



TS Prototype = Coil#14#15 Module + Flanges



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

Goals

Allows validation of:

- Design concept
- Drawings
  - Tolerances, fabrication and integration details
- Coils and Shell Fabrication
  - Achievable tolerances, procedure for He pipe, QC plan
- Integration
  - Procedure, gap ➔ prestress
- Performance

Plan

The TS prototype is fabricated by FNAL-INFN collaboration

- INFN-Genoa group lead by P. Fabbricatore

FNAL is in charge of:

- Prototype conductor procurement and QC
- Complete CAD model
- Coils drawings (envelope)
- Shell fabrication drawings
- Shell fabrication and QC
- Shell instrumentation and Test

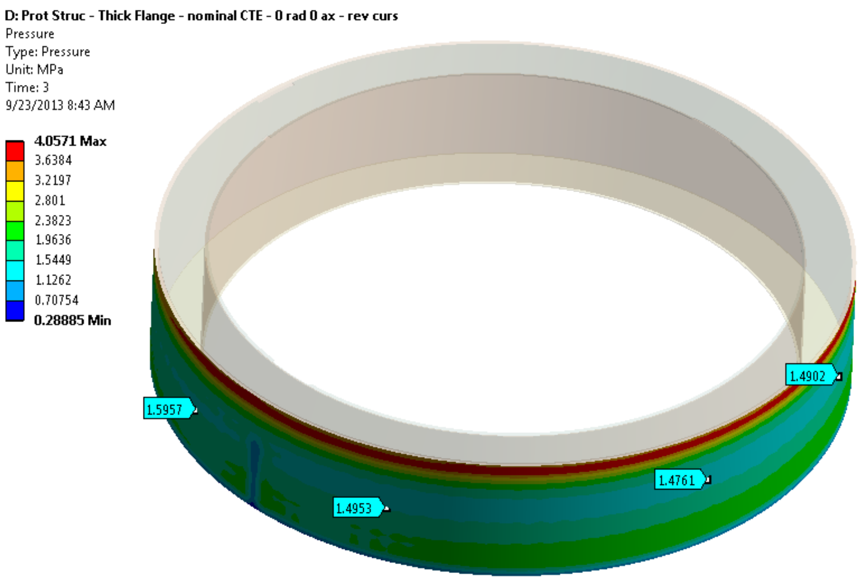
INFN is in charge of:

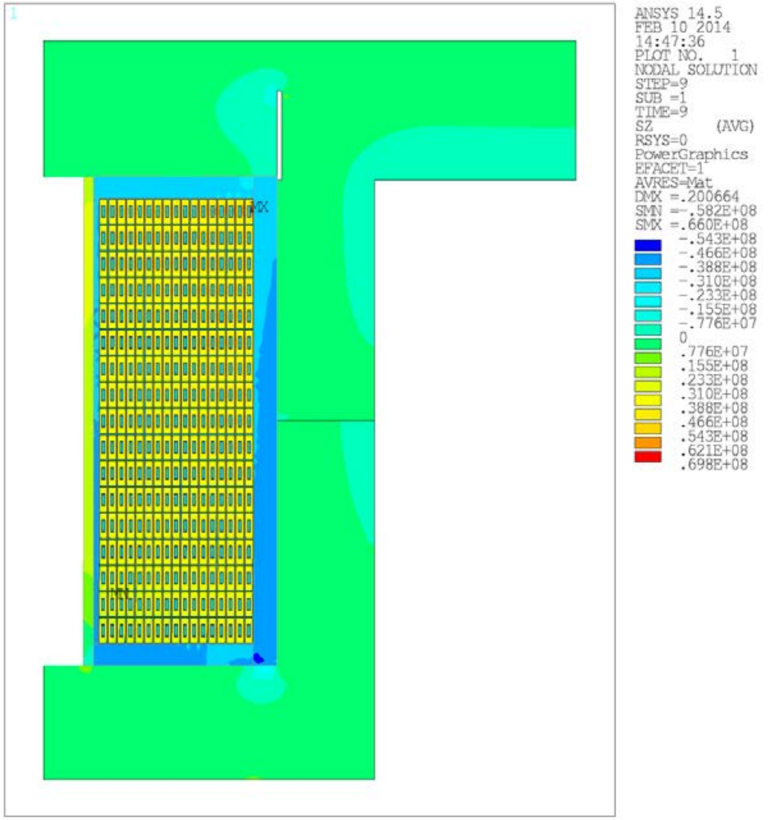
- Coil fabrication and integration (vendor selected by INFN)
- Supervision of work performed by vendor

FNAL & INFN: FEM modeling and interference decision

FEM Analysis

- 3D model with average coil properties and actual dimensions (Wands)
- 2D model with measured coil properties and simulation of all assembly steps (Farinon)



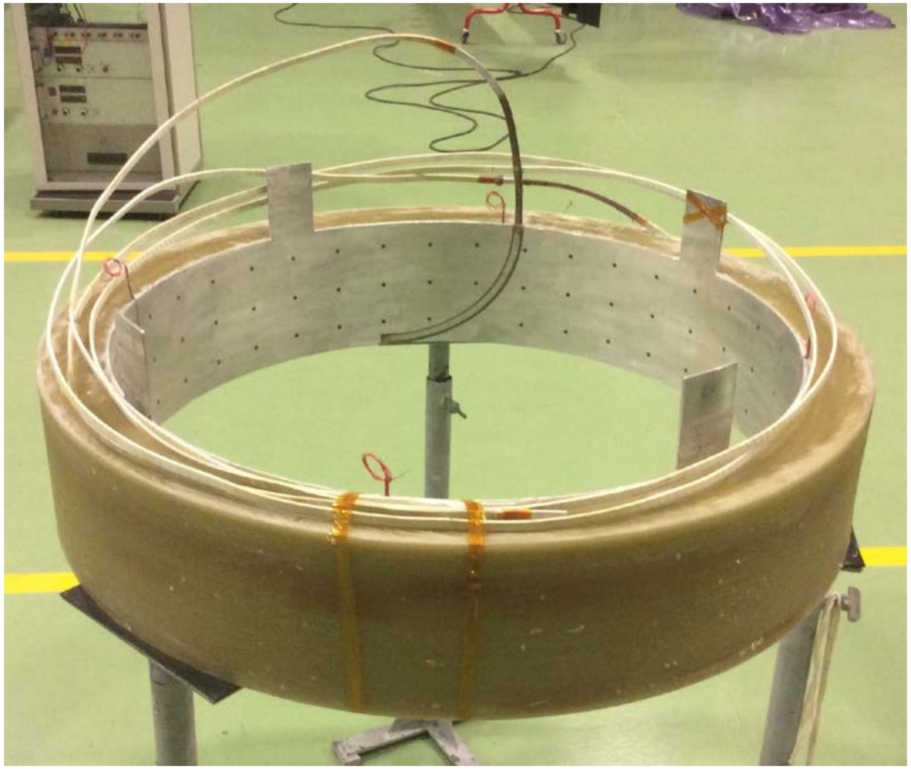


Optimal rad. interference 3D: 100+ um

Optimal rad. interference 2D: 100-300 um

➔ **Nominal rad. interference: 200 +/- 100 um**

Coil Fabrication



Coil #14
17 layers

Coil #15
18 layers

Coil Electrical QC

Both coils passed all tests

- Electrical tests:
  - During winding:
    - V_tot and layer-layer DV with 1 A
    - Coil to ground at 1kV
  - After impregnation:
    - Inductance and resistance
    - Coil to ground at 2 kV
    - Coil to heaters at 1 kV
  - After coil machining:
    - Inductance and resistance
    - Coil to ground at 2 kV
    - Coil to heaters at 1 kV
    - Impulse test at 1 kV

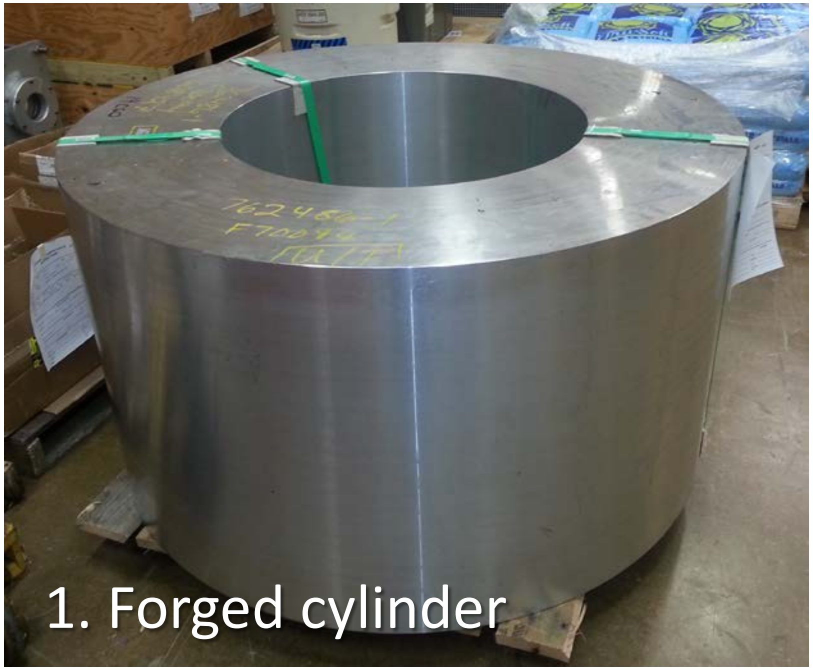
Coil Dimensional QC

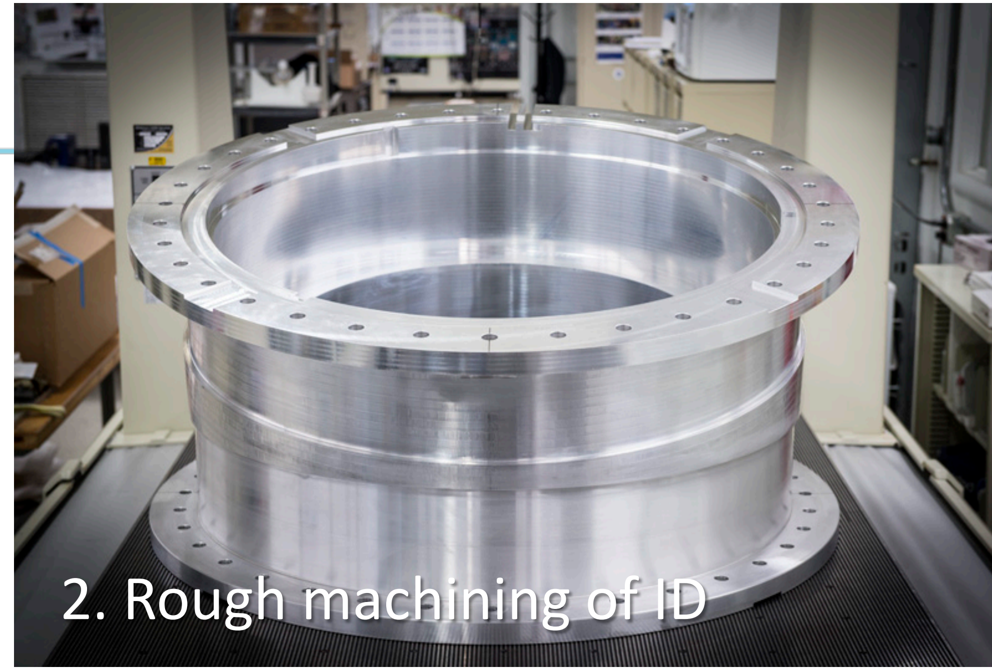
- Dimensional tests:
  – During winding:
    - Min & Max radius at selected layers and positions
  – After impregnation:
    - ID, OD, height, coil sides parallelism
  – After final machining:
    - Inner radius (best fit, max inscribed, min circumscribed) and range
    - Outer radius (best fit, max inscribed, min circumscribed) and range
    - Sides: planarity and parallelism
    - Concentricity, Perpendicularity,
    - Roughness of outer surface.

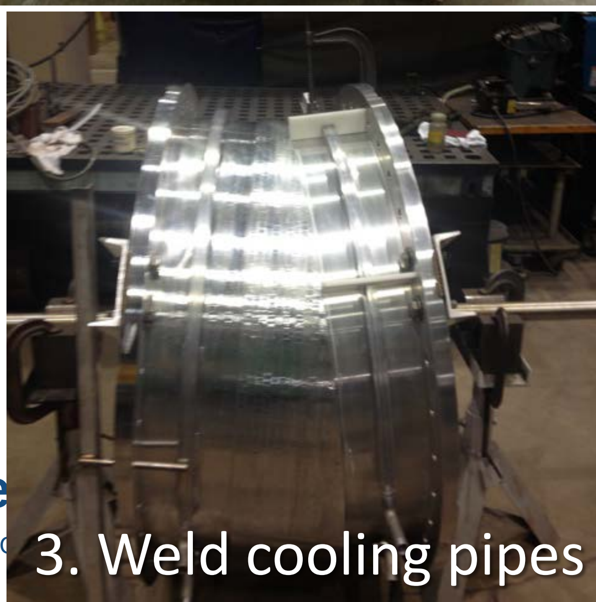
Radius (mm)	Nominal	Tol.	Meas.	Δ_max*	RMS	Temp.
Coil #14	475.0	+/-0.1	475.00	-0.10/+0.08	0.05	21.8 °C
Coil #15	479.0	+/-0.1	479.05	-0.11/+0.08	0.05	22.3 °C

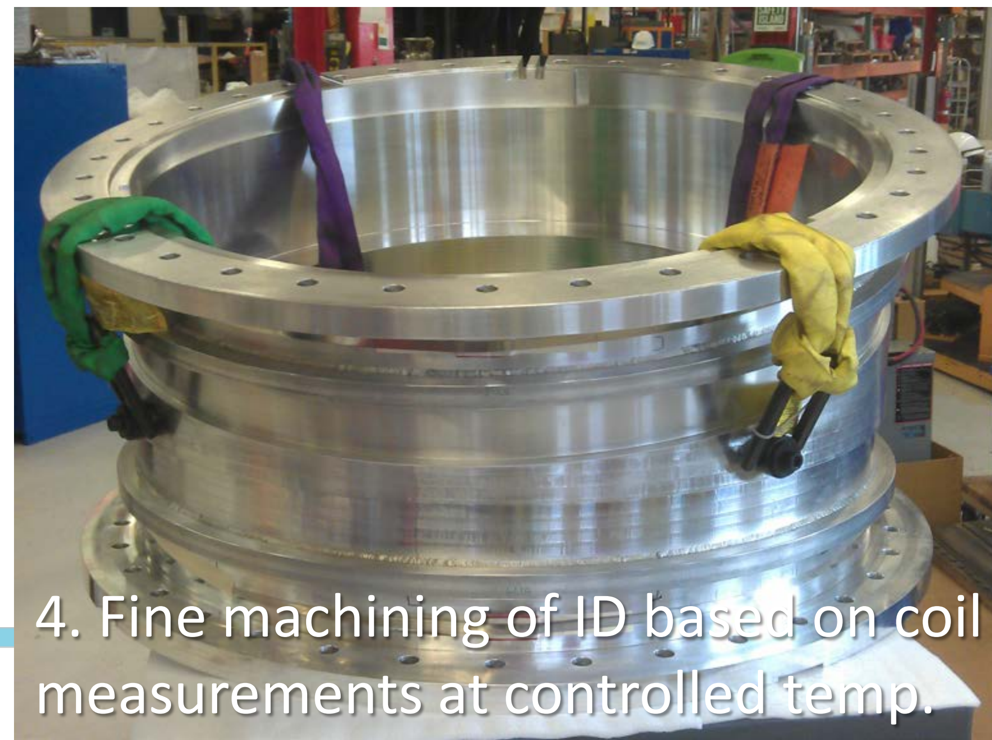
*With respect to measured Outer Radius

Shell Fabrication


1. Forged cylinder


2. Rough machining of ID


3. Weld cooling pipes


4. Fine machining of ID based on coil measurements at controlled temp.

Shell QC

- Cooling pipes ASME test:
  - Hydrostatic Pressure Test at 83 Psig for 10 min

- Dimensional tests:
  - The shell looks very good
  - All major dimensions are within tolerance
    - Seen the impact on the flange flatness of welding the pipes
  - Coil housing surfaces are acceptable
    - Tolerance were very tight requiring temperature adjustment

Radius (mm)	Nominal	Tol.*	Meas. Max In	Meas. LS	Temp.
Coil #14 house	474.78	+/-0.025	474.78	474.83	20 °C
Coil #15 house	478.83	+/-0.025	478.81	478.86	20 °C

*+/-50 um on diameter

Integration

- Plan for shrink-fit integration:
  1. Warm up shell
  2. Insert coil A
  3. Lock coil A in place
  4. Insert coil B
  5. Lock coil B in place
  6. Let shell cold down
  7. Put stycast to fill gap between coil-side and wedge
  8. Install wedge and side flange
  9. Repeat steps 7 and 8 on the other side

Hard copy of integration tooling is available (proprietary)

Integration

Prototype Integration
Oct 20-24

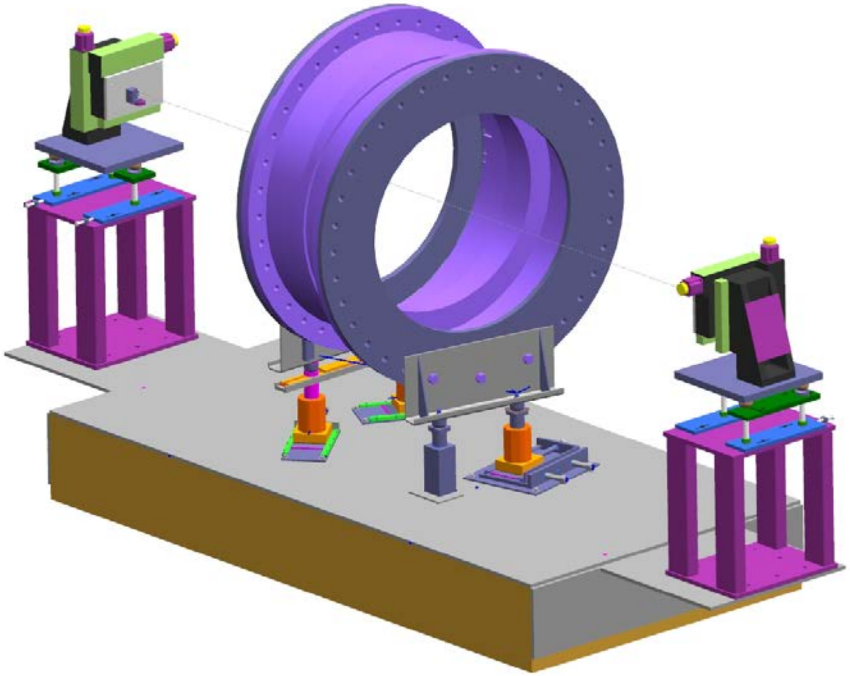
Integration QC & Acceptance Tests - I

- Electrical:
  - Coil to Ground
  - Heater to Coil
  - Inductance & Resistance of each coil
  - Impulse test

- Prestress:
  - Strain gauge readings (after vs. before integration)
  - Shell OD CMM measurements (after vs. before integration)

Integration QC & Acceptance Tests - II

- Dimensional tests:
  - CMM to evaluate impact of integration on all interfaces
- Cooling pipes and joints:
  - ASME pressure test
- Warm Magnetic Measurements:
  - Stretched wire measurements
    - Each coil separately



Cold Tests

- Cold electrical check out
  - Hi-pot tests (coil-ground; heaters-coil)

- Cooling tests:
  - Temperature profile vs. cooling rate

- Cold powering:
  - Up to nominal current
  - Up to 120% nominal current (same Ic margin as in operation)
  - Reverse polarity: up to 60% nominal current (Max axial force vs. flange)

- Warm up: measure RRR

~~Goals~~ Summary

~~Allows validation of~~ The prototype has validated:

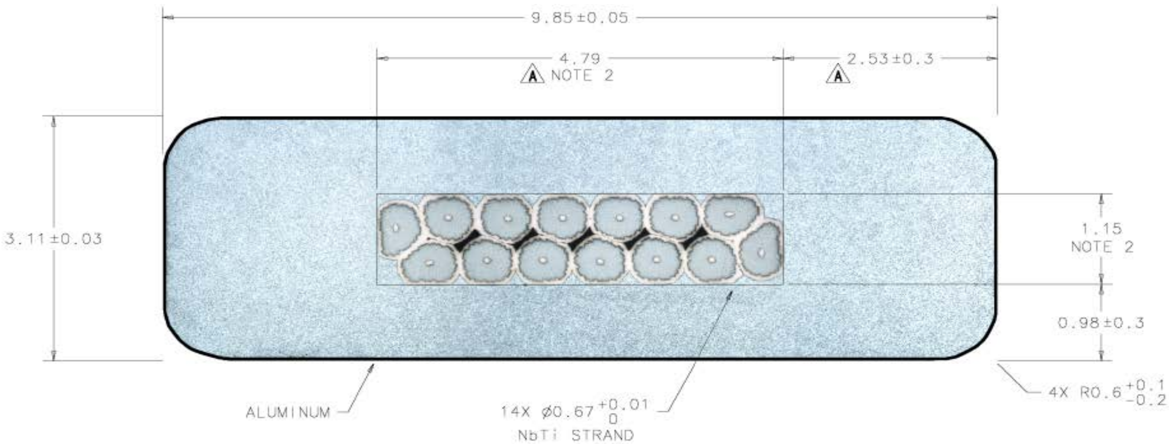
- Design concept ✔
- Drawings ✔
  - Tolerances, fabrication and integration details
- Coils and Shell Fabrication ✔
  - Achievable tolerances, procedure for He pipe, QC plan
- Integration ✔
  - Procedure, gap → prestress
- Performance To be demonstrated in Feb./Mar. 2015

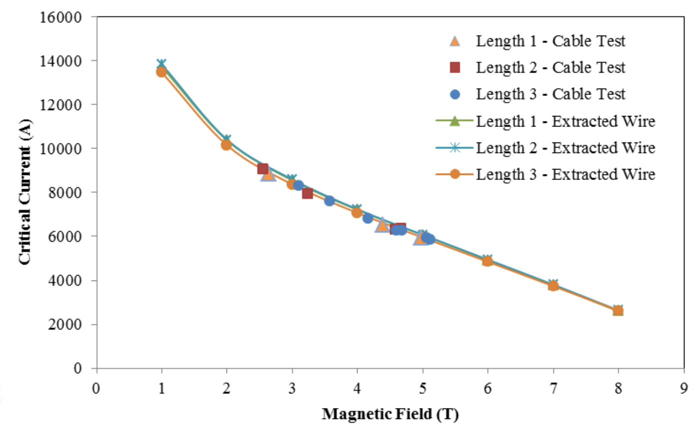
→ **Drawings for tender in progress**

→ **Contract to be placed after Prototype test**

Back-up Slides

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