Test Results of HD2, a High Field Nb_3Sn Dipole with a 36 mm Bore

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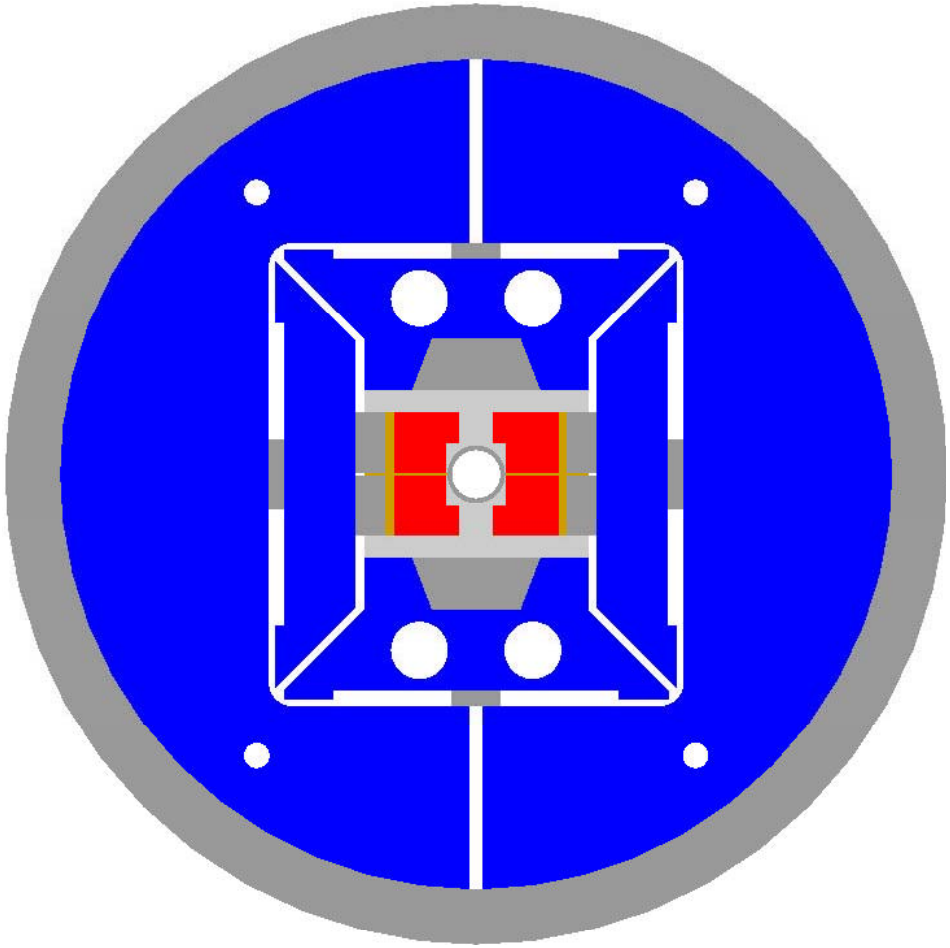
Outline

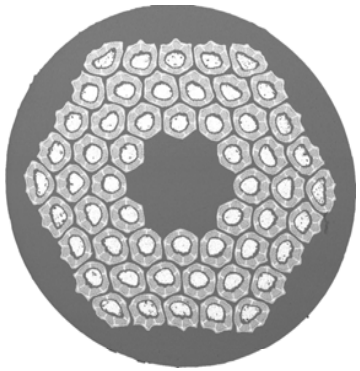
- Introduction
- Conductor and magnet parameters
- Coil design and magnetic analysis
- Support structure and mechanical analysis
- Test results
- Summary and future plans

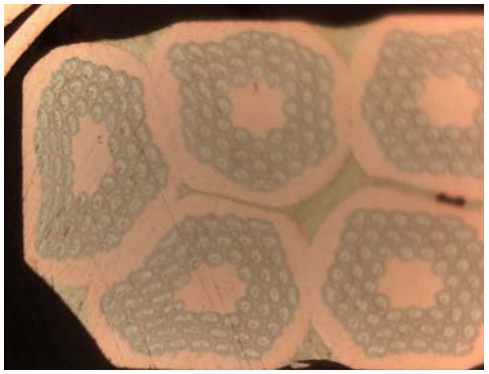
Introduction

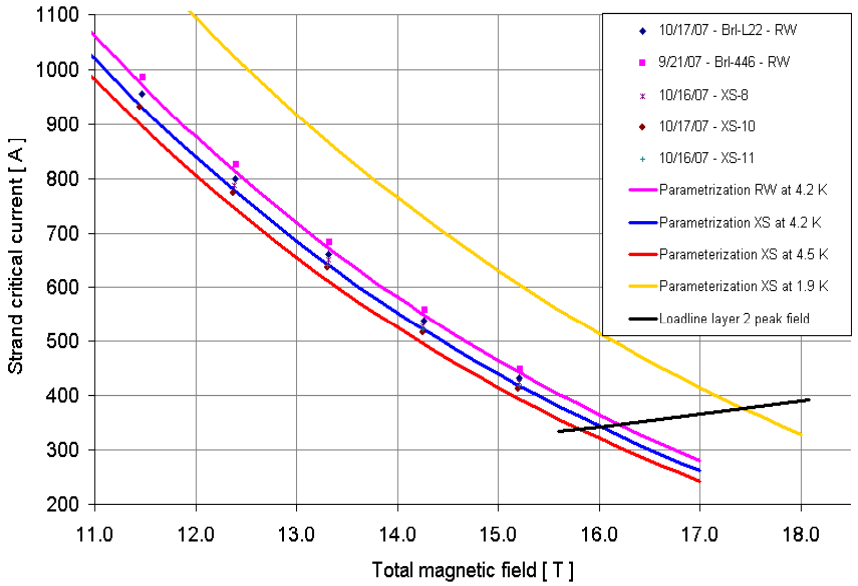
- Application of block-type coils to high-field accelerator magnets
- 15 T in a 36 mm bore
- Flared ends
- Optimized field quality
- 150-180 MPa coil stress



Conductor and magnet parameters



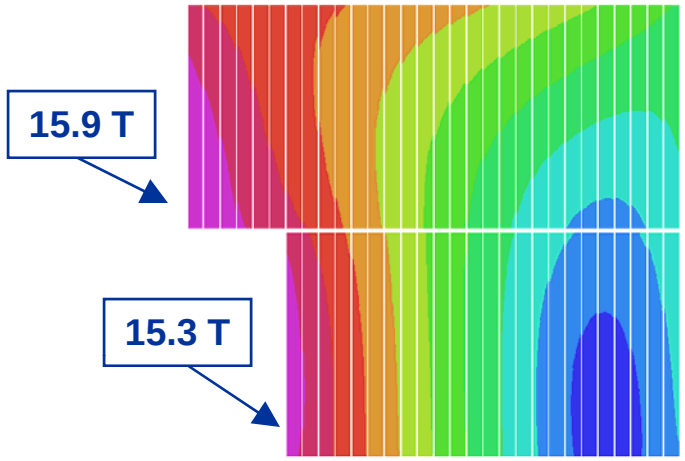


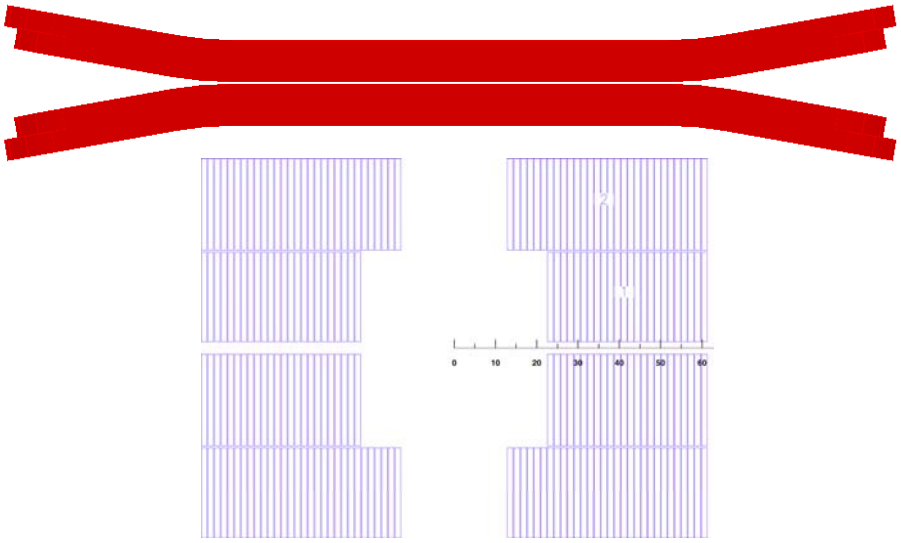


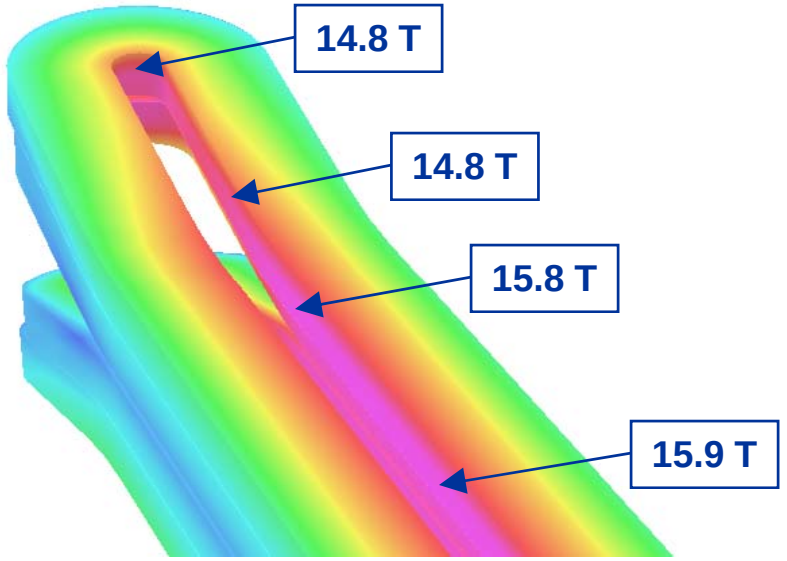
- Conductor (RRP 54/61)
  - Strand diameter: 0.8 mm
  - Non Cu: 51-54 %
- Cable
  - 22.008 x 1.401 mm
  - 51 strands
  - 0.095 mm thick ins.
- Three coils fabricated
- Magnet limits at 4.3 K (coil 1)
  - I_{ss}: 17.4 kA
  - B_{bore}: 15.1 T
  - B_{peak}: 15.9 T
  - Stored energy: 845 kJ/m
- Coil 2 and 3: about 0.6 T more

Magnetic analysis
Peak field

- Straight section
  - Peak field in pole turn of layer 2
- End region
  - 1 T margin in the ends
    - Flared ends
    - Shift between layers
    - Iron optimization

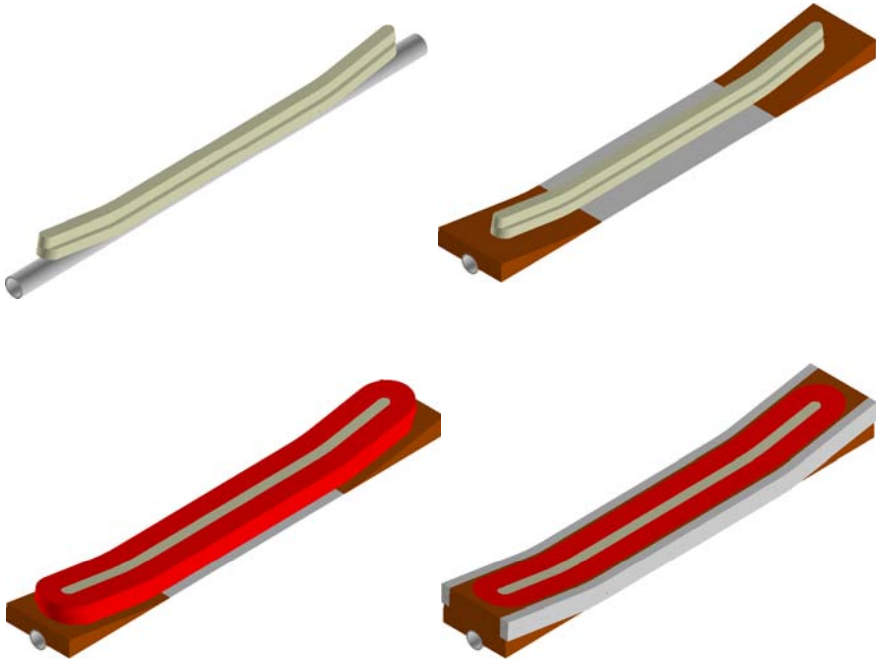


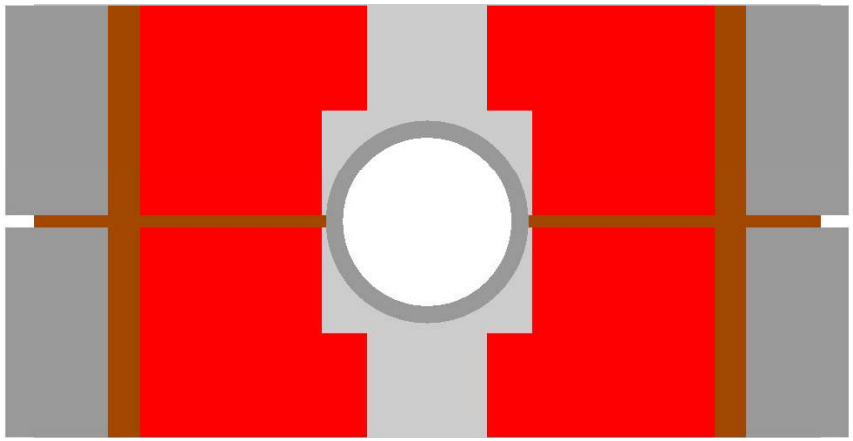




Support structure

- Nitronic 40 bore tube
  - Aperture: 36 mm
  - Thickness: 3.65 mm
- Ti alloy island
  - Two layers
- Stainless steel mid-plane shim
- Bronze wedges
- Bronze end-shoes
- Stainless steel side rails

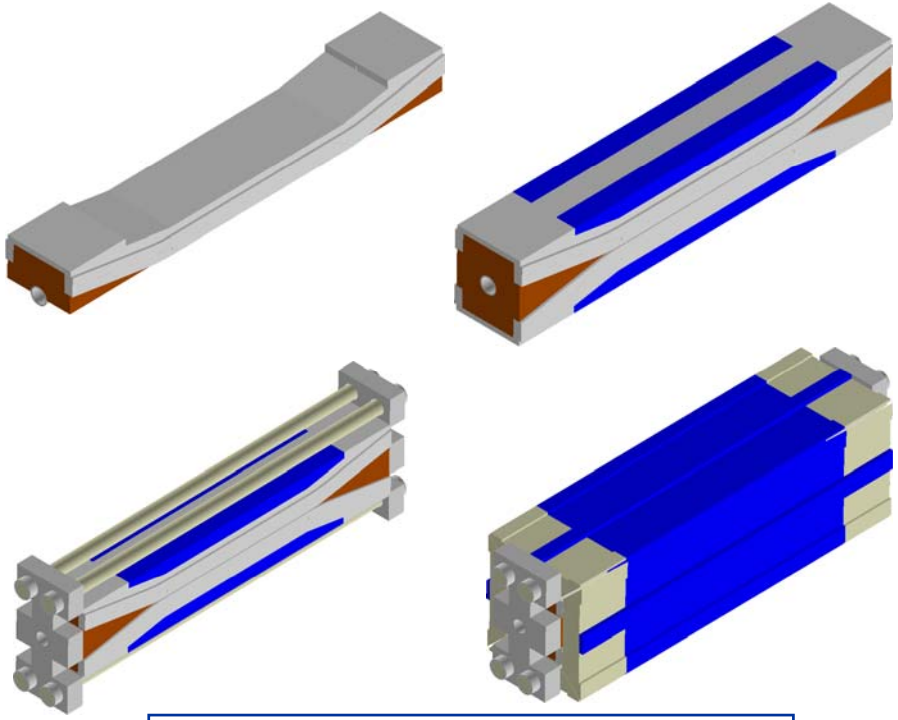


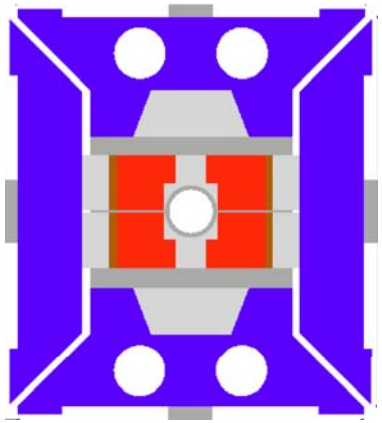


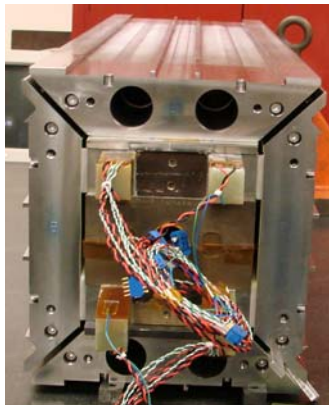
Inner and outer layer pole

Support structure

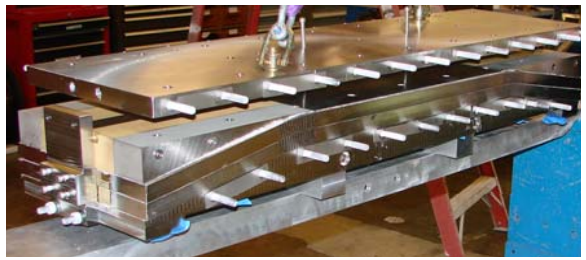
- Stainless steel filler
  - Winding base
- Iron and stainless steel pushers
  - Field quality
- Iron pads
  - Stainless steel in the ends
- Holes for aluminum rods
  - Plate to support ends

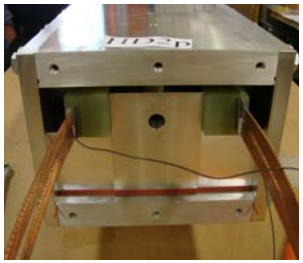






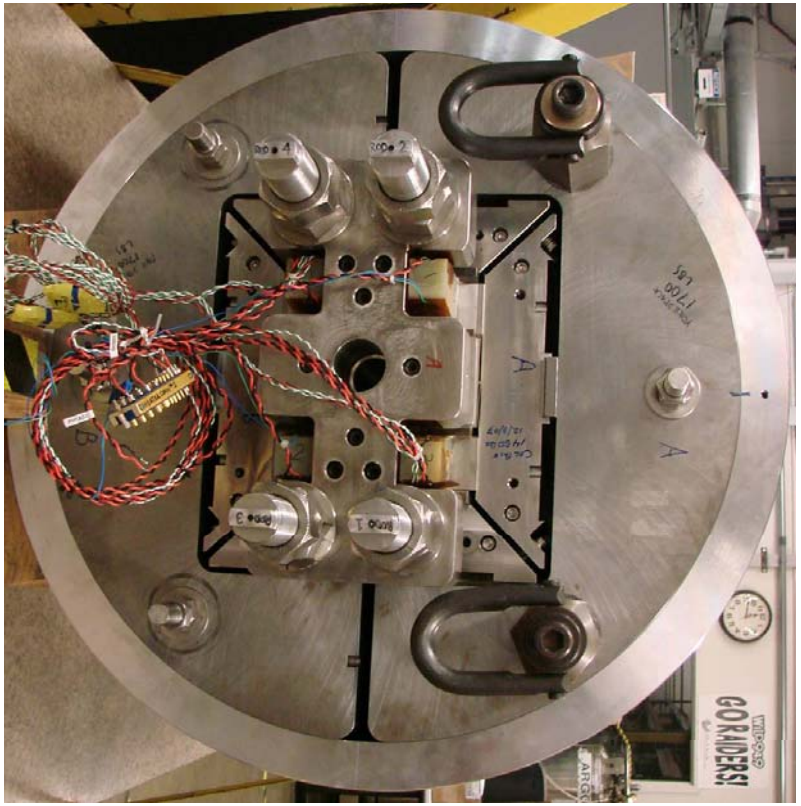
Reaction and impregnation fixture

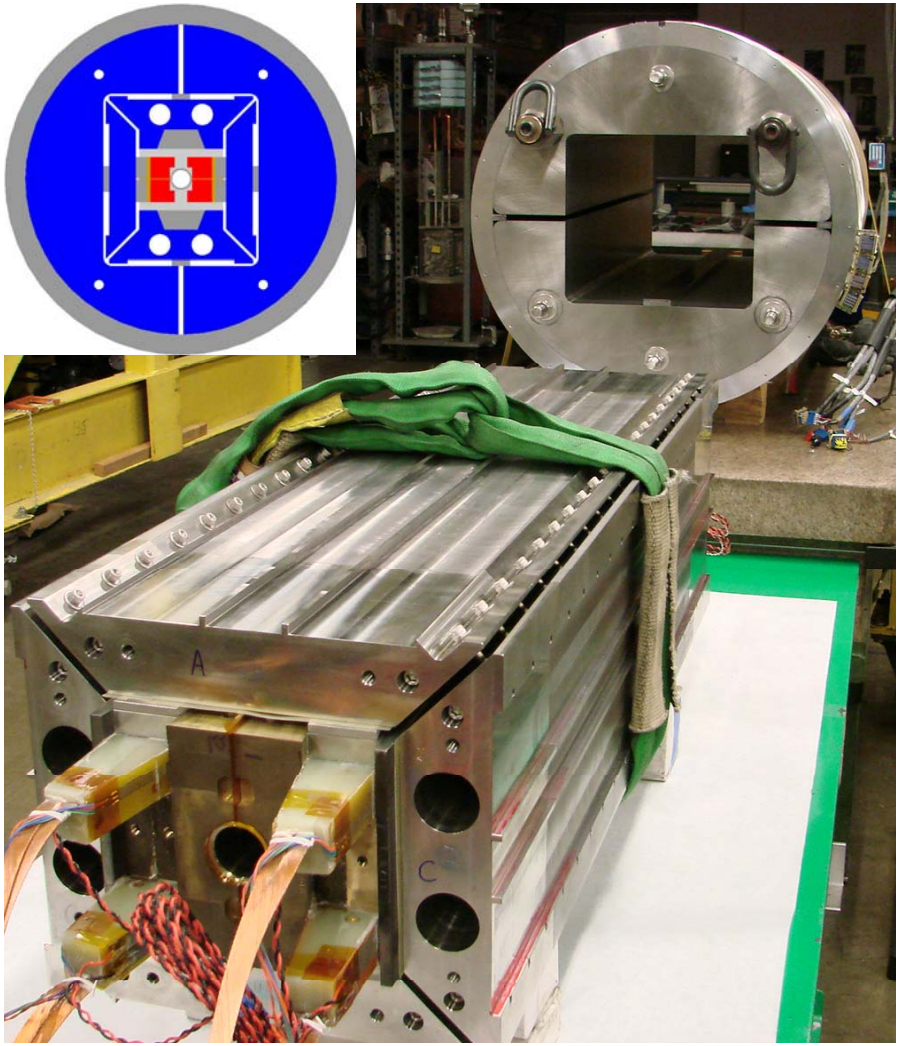




Support structure

- Coil-pad inserted in yoke-shell
- Pre-loading with bladders
- 40 mm thick Al shell

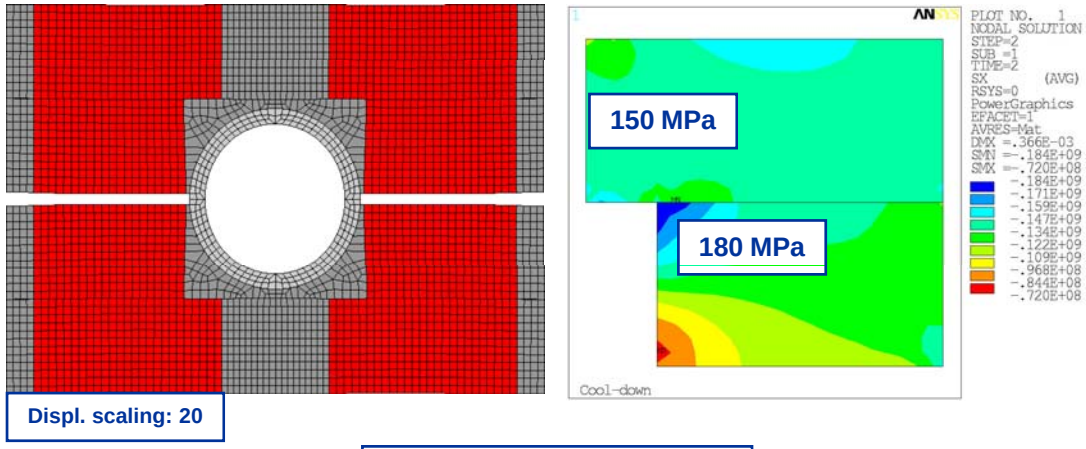




Mechanical analysis
Straight section

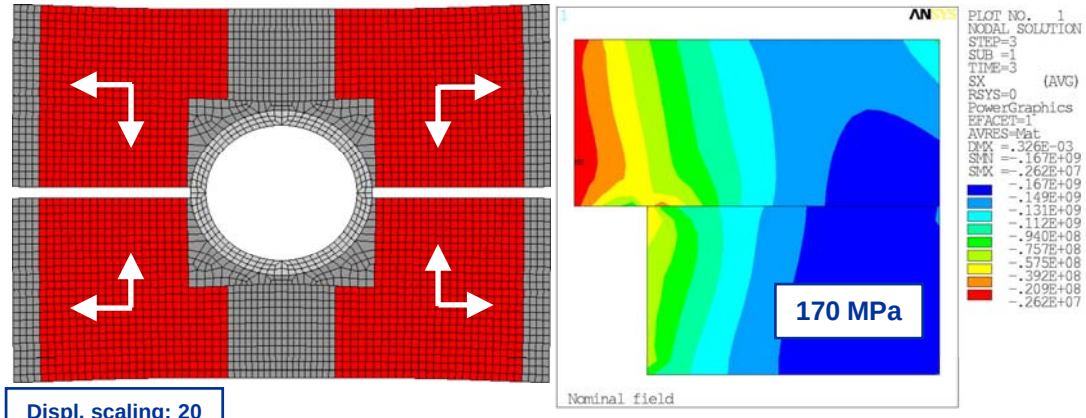
- E.m. forces mainly in the horizontal direction
  - Coil blocks pushed outwards
- Pre-stress to avoid coil – pole separation
- Pre-load at 4.5 K
  - Bore deformed horizontally
  - Max. coil stress of 180 MPa
- At 15 T
  - Peak stress in the low field region

After cool-down



Displ. scaling: 20

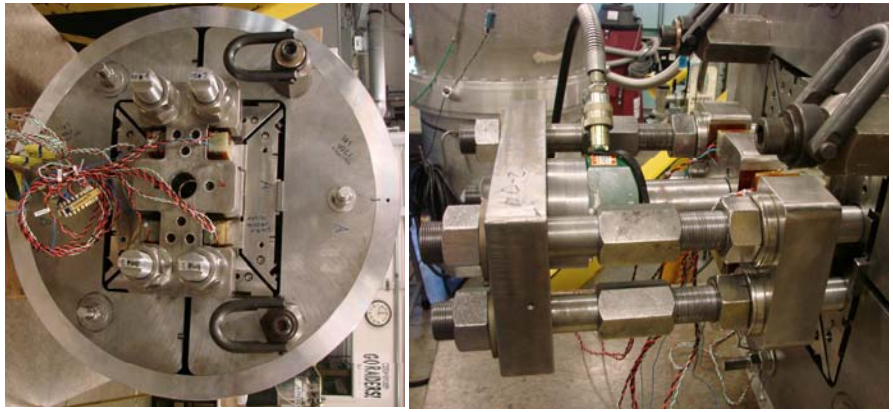
At 15 T

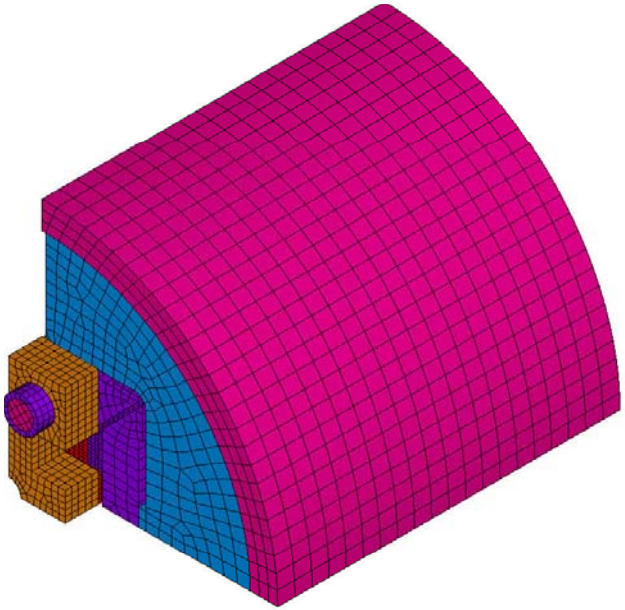


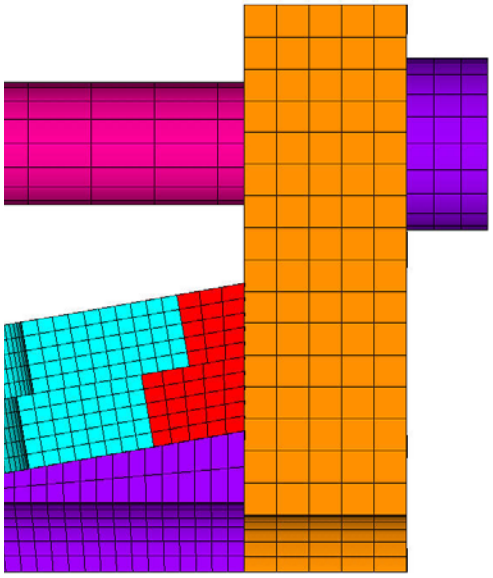
Displ. scaling: 20

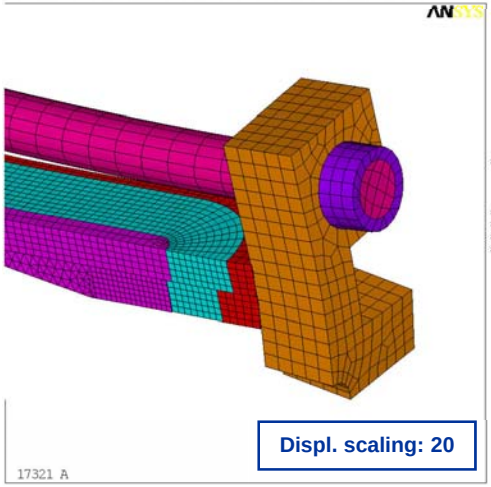
Mechanical analysis
End region

- Axial force at 15 T: 780 kN
- Full axial support at 4.5 K
  - No coil – pole separation in the ends
- Axial force shared between end-shoes and wedge (bullets)





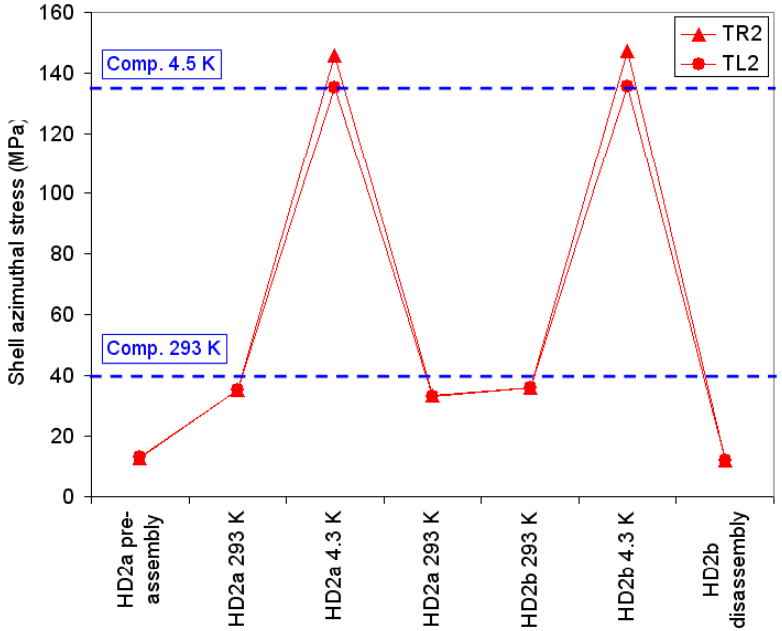




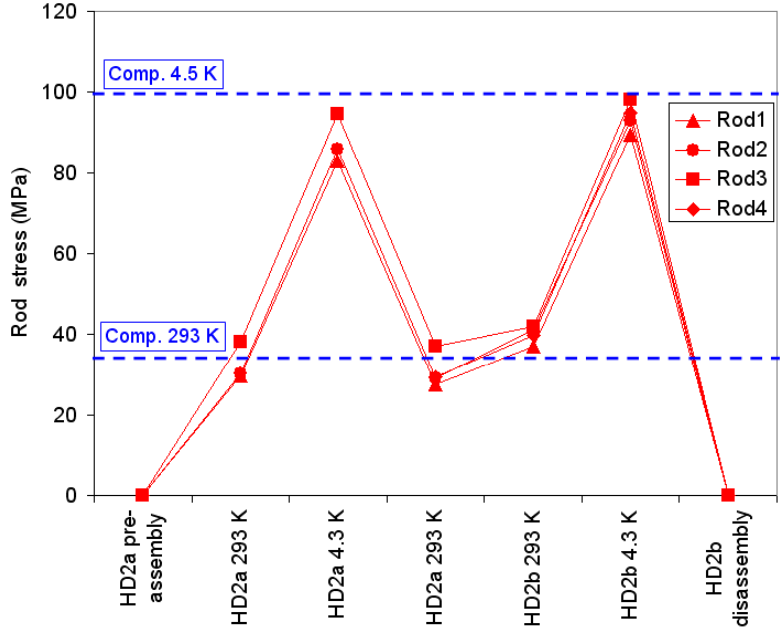
Test overview
Shell and rod stress

- HD2a (coil 1 and coil 2)
  - Shell to 140 MPa and rods to 90 MPa
- HD2b (same coils)
  - Thermal cycle with minor rod tension adjustment

Shell stress

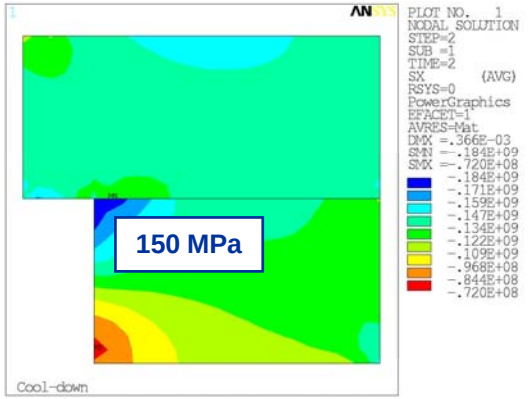


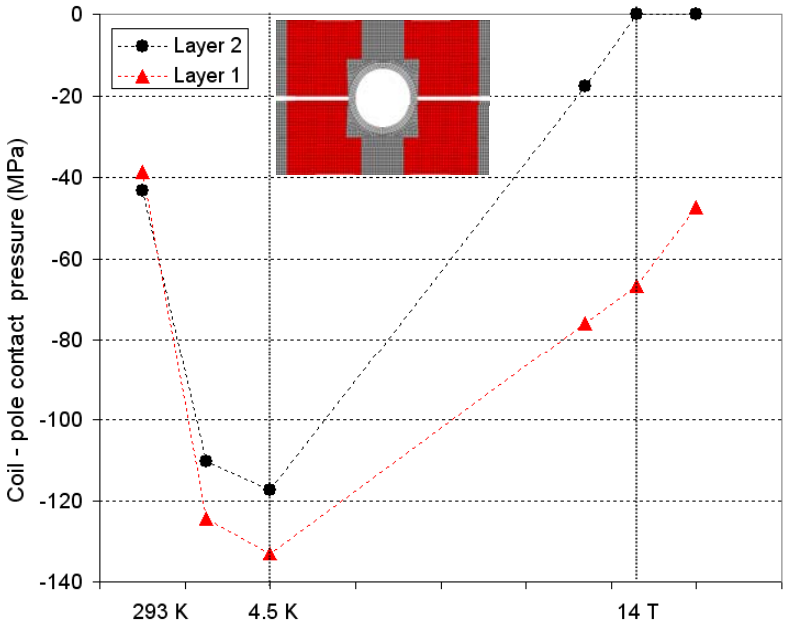
Rod stress

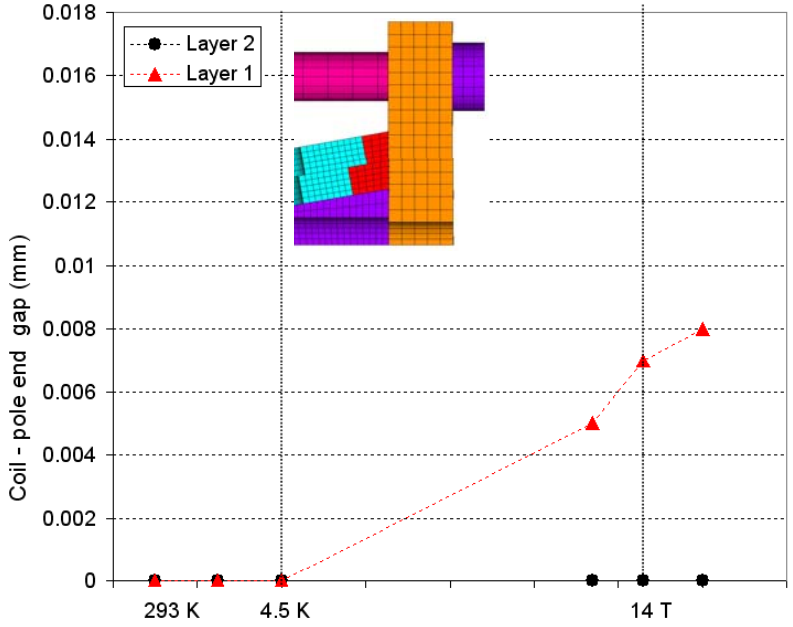


Test overview
Coil - pole contact pressure

- Coil pre-stress to 14 T
  - Coil – pole in contact
- Peak stress ~ 150 MPa
  - Conservative start



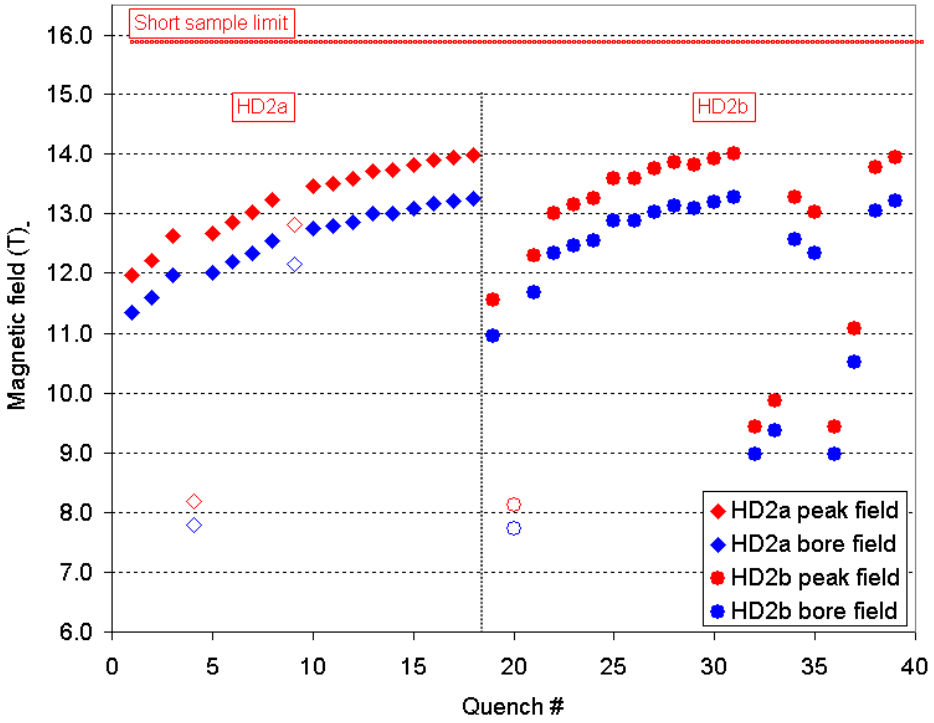




Test results
Quench performance

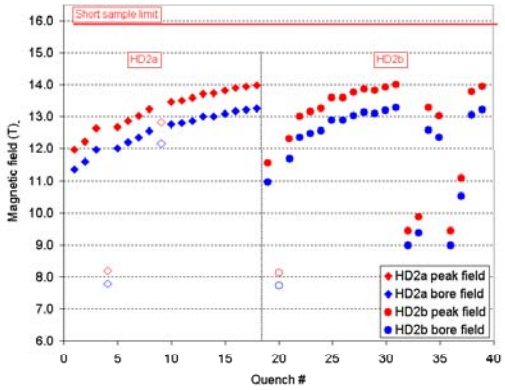
- HD2a
  - First quench
    - B_{peak} = 12.0 T (73% I_{ss})
    - B_{bore} = 11.4 T
  - Highest quench (#18)
    - B_{peak} = 14.0 T (87% I_{ss})
    - B_{bore} = 13.3 T
- HD2b
  - First quench
    - B_{peak} = 11.5 T (71% I_{ss})
    - B_{bore} = 11.0 T
  - Highest quench (#31)
    - Same as HD2a

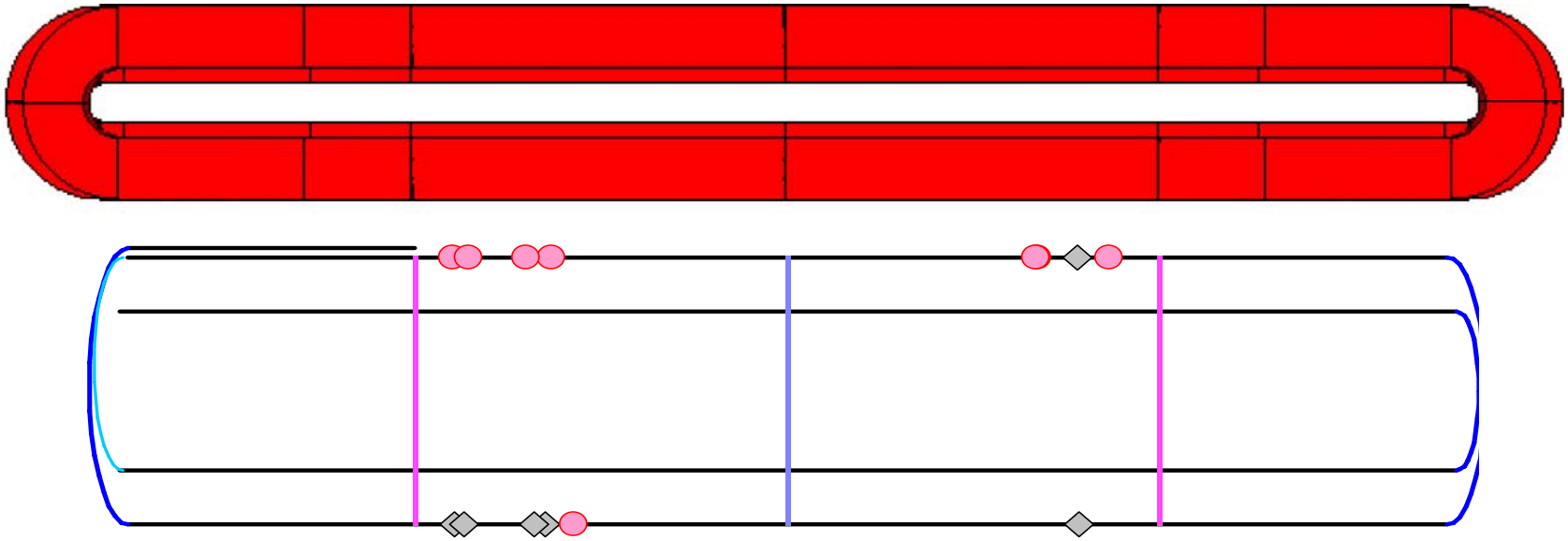
- Quench #31 with higher MIITs (extr. failure) and new location
  - Followed by more ramp rate sensitivity and flux-jumps



Test results
Quench locations (HD2a)

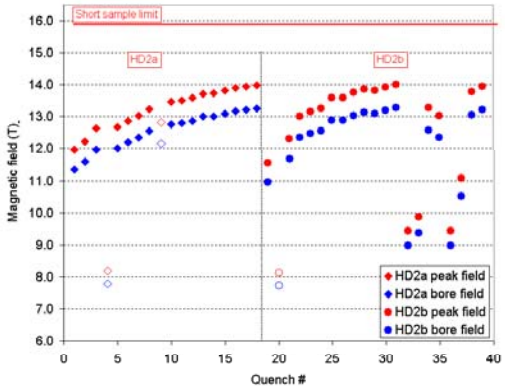
- Out of 14 training quenches, 12 are located
  - 6 quenches in coil 1 and 6 quenches in coil 2
  - Pole turn L1 (0.6 T less than pole turn L2)
  - Towards the end of the straight section

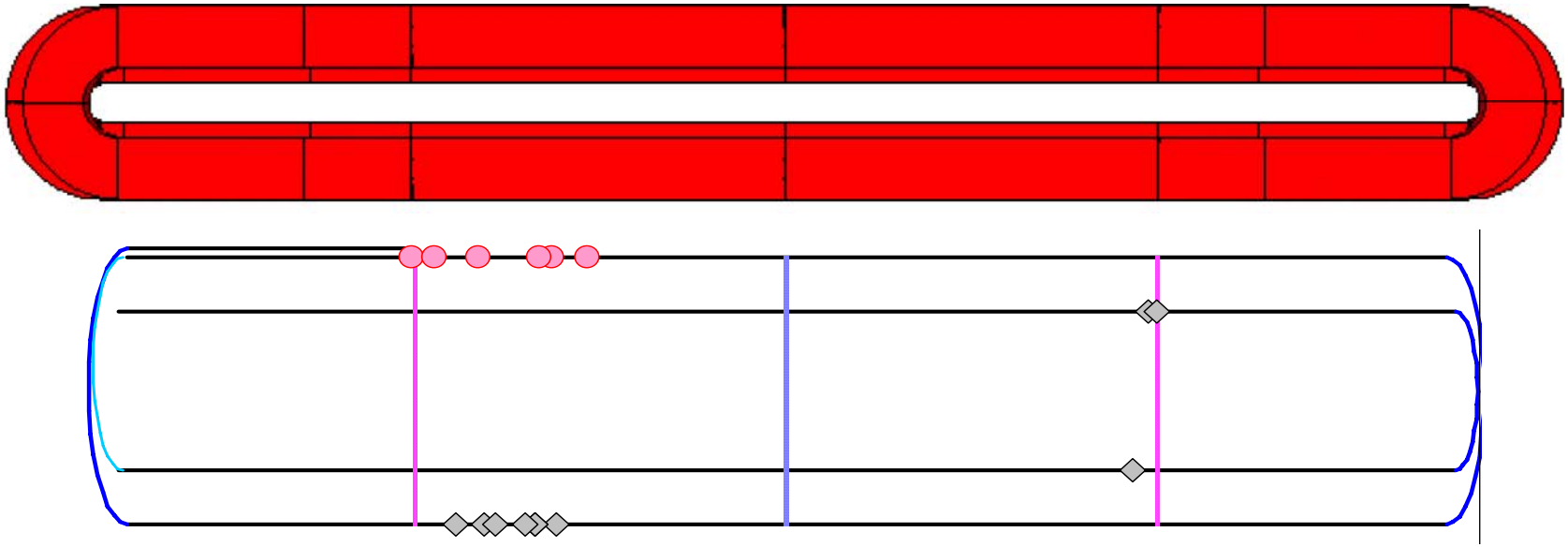




Test results
Quench locations (HD2b)

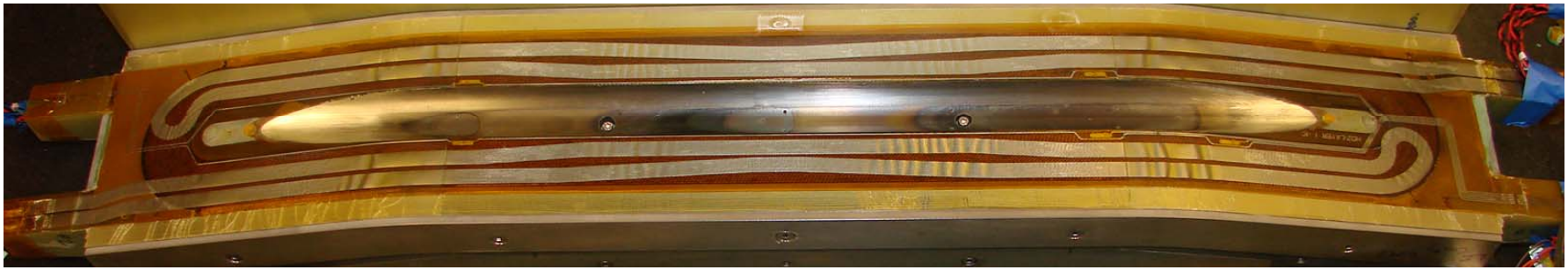
- Before quench #31
  - 4 quenches in coil 1 and 6 quenches in coil 2
  - All in pole turn L1
- After quench #31
  - All quenches in coil 1
  - 3 quenches in L2 pole turn (high current)





Post-test visual inspection

- No epoxy discoloration observed on layer 1 or layer 2

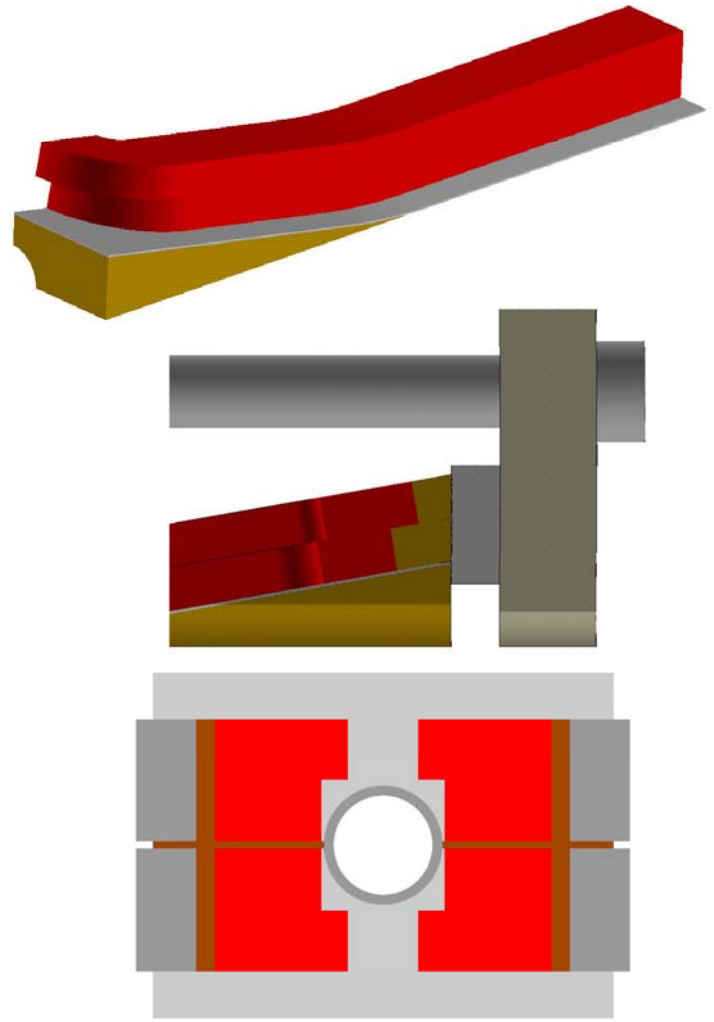


Summary

- HD2 was assembled, pre-loaded and tested at 4.3 K
- Strain gauge measurements of shell and axial rods were consistent with expectations
  - Pre-load for 14 T and coils stresses < 150 MPa
- Magnet reached
  - Bore field of 13.3 T
  - Peak field of 14.0 T
  - 87% of I_{ss}
- Quenches were located in the end of the straight section
- Mechanically limited
  - Both coils participated to the training (coil 2 with higher margin)
- Degradation observed in coil 1 during HD2b

Next steps

- June-July
  - Replace coil 1 with coil 3
  - Modify mid-plane shim
  - Pressure sensitive film test
  - Increase vertical pre-load
  - Improve transfer of axial force to the wedge and end-shoes
- August-September
  - Increase horizontal pre-load (15 T)
  - Field quality measurements
- October-November
  - Reduce or remove bore thickness (from 36 mm to 43 mm bore)
- 2009
  - Planning 1.9 K test at CERN



Appendix

HD2 winding and reaction