Analysis of previous projects

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EuCARD ESAC review for the FRESCA2 dipole
CERN
28-29 March, 2012

Outline

- LBNL D10
- KEK Block Dipole Magnet
- Texas A&M TAMU
- LBNL HD2-HD3 series
- Conclusions

D10 (1983)

- Early years of Nb_3Sn wind-and-react magnets and internal tin superconductor
  - 1.7 mm wire, 11 strands cable (11 x 3 mm)
- 4 double-pancakes wound around s.s. poles and 40 mm aperture tube, and with 10° flared ends

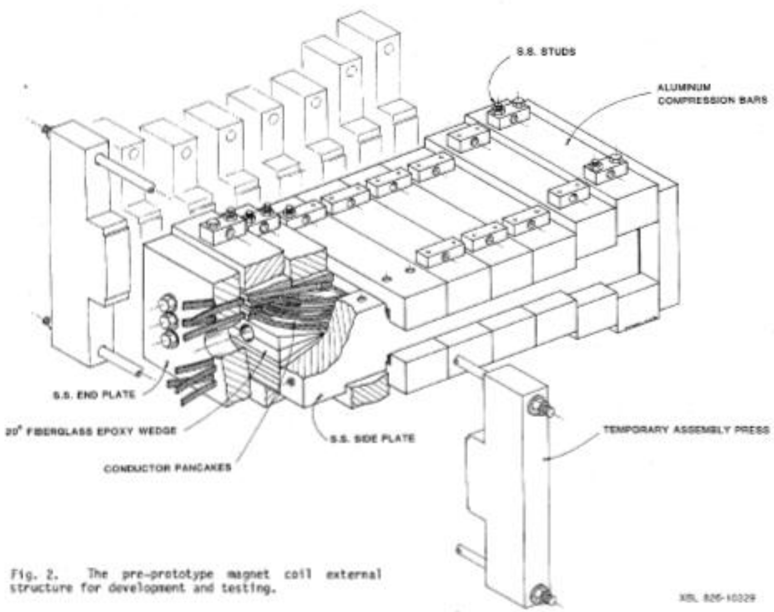
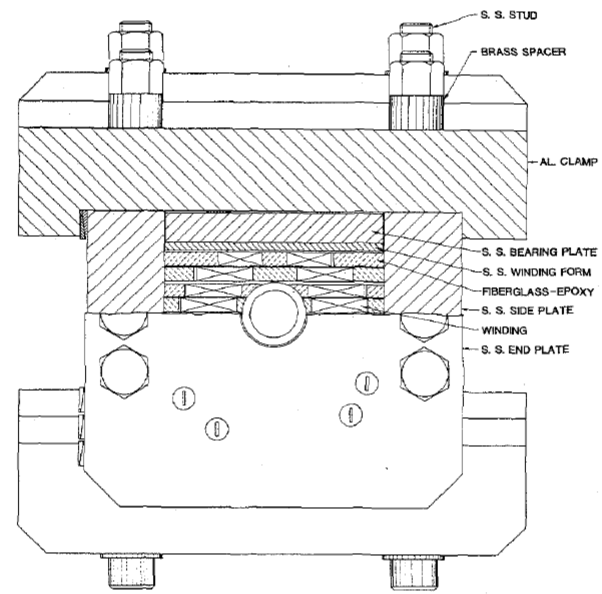
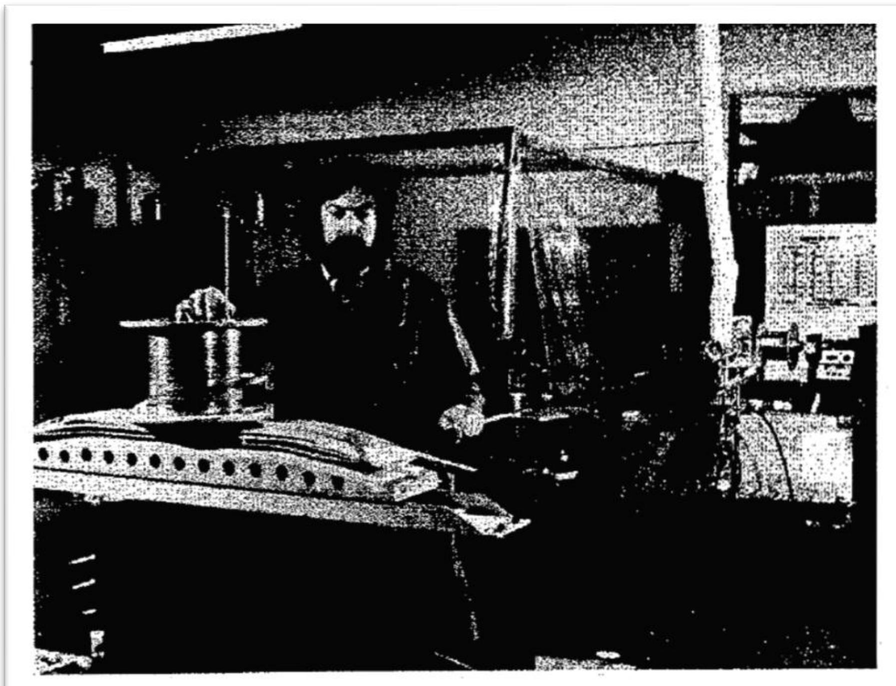


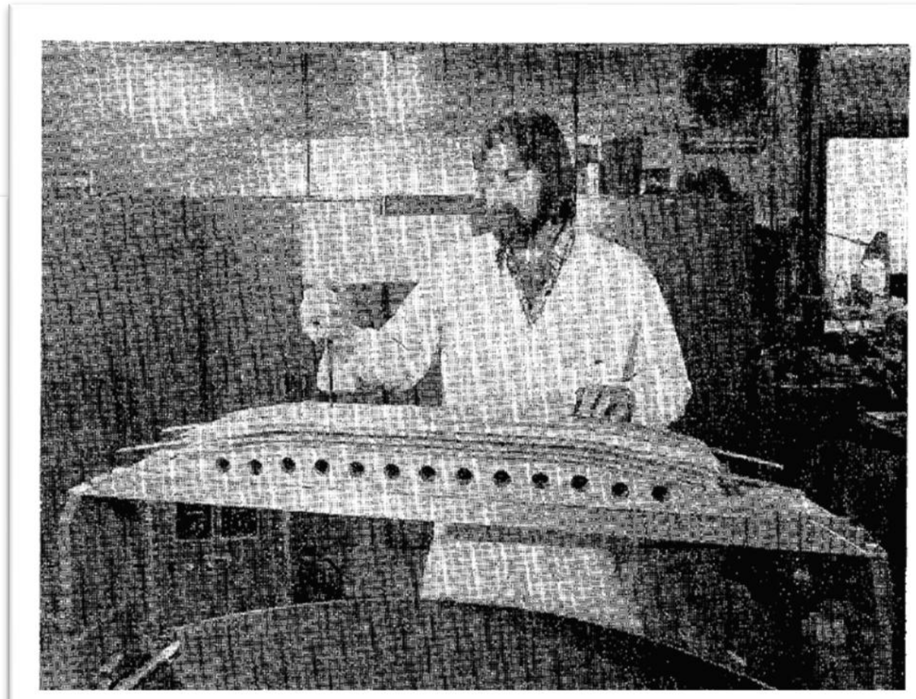
Fig. 2. The pre-prototype magnet coil external structure for development and testing.



D10 (1983)

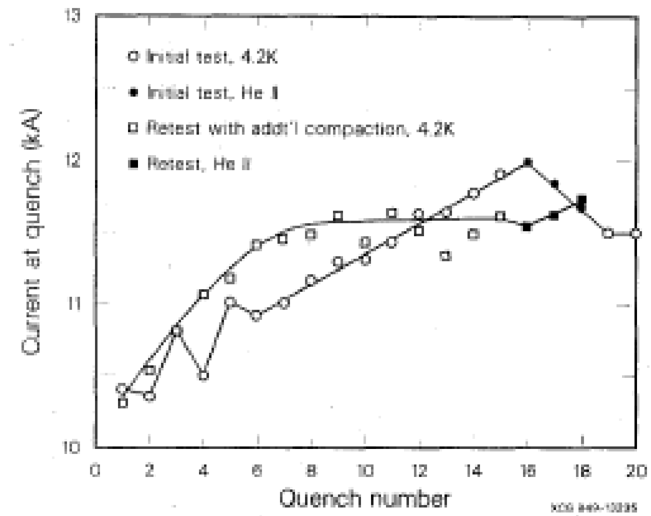
- Coil fabrication
  - (Roy Hannaford!)

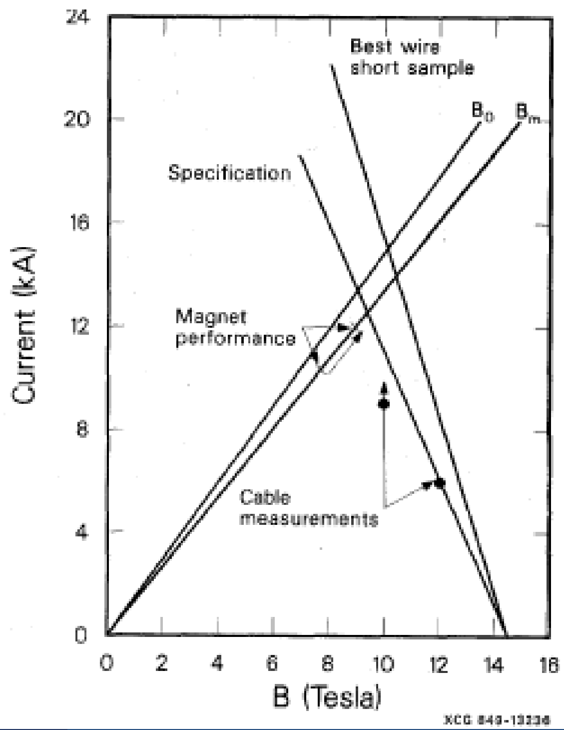




D10 (1983)

- Training from 7 T to 8 T (12 kA)
- Last quench with failure of extraction rack.





- Magnet performance, looking at best short sample wires, between 75 and 85 % of I_{ss}
- Increase of pre-load in 2nd test

Block dipole magnet (1985)

KEK HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

- 10 T design field with NbTi superconductor
- 60 mm aperture
- 8 double-pancakes 1 m long
- Cable with 27 strands (0.95 mm ∅)
- Wedges/filler of high manganese steel and stainless steel collar
  - Different thermal contraction

- *"Four coils in the median part are bent up or down at their ends with a special hydraulic press to accommodate a beam pipe"*

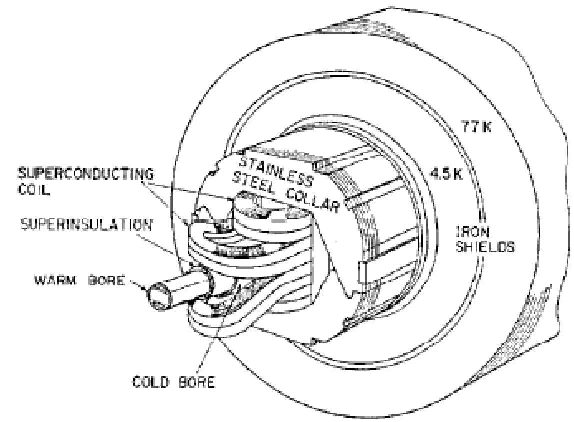
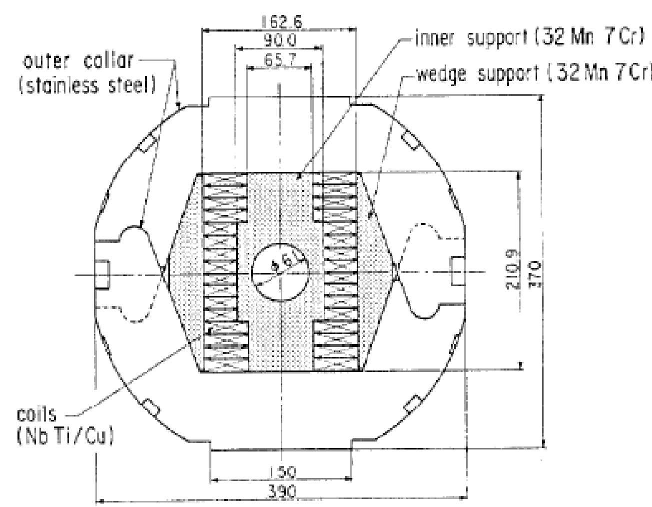


Fig. 1 End structure diagram of the magnet

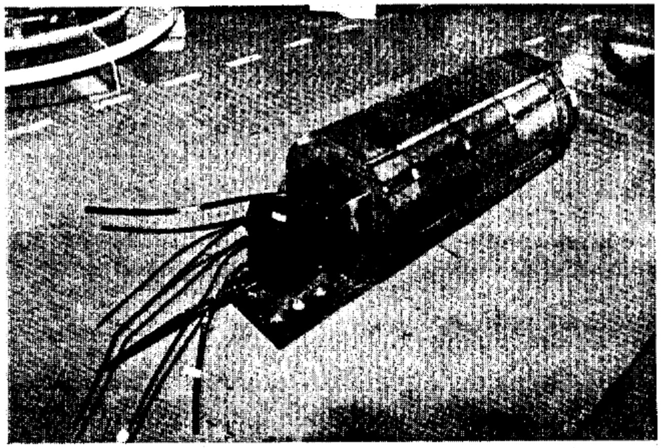


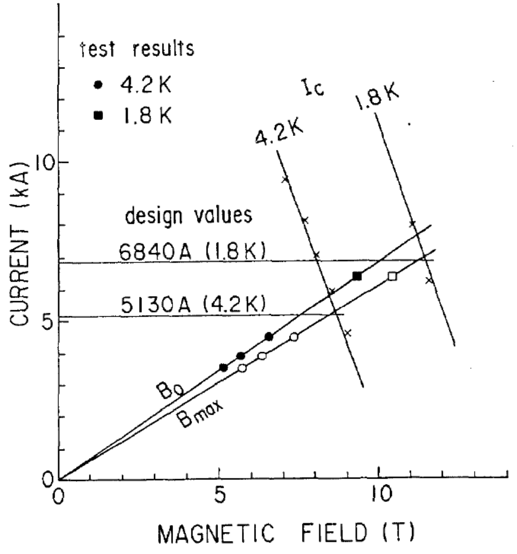
Block dipole magnet (1985)

- The initial quench (4.2 K) occurred at 3450 A corresponding B_0 = 5.2 T
- The third quench took place at 4488 A, corresponding B_0= 6.6 T

- In the first excitation at 1.8 K, the quench happened at 6,340 A, corresponding B = 9.3 T and B =10.4 T

- The maximum current was 93% of the short sample critical current on the magnet load-line.





TAMU block dipole

- "Stress management" system
  - Each coil block is isolated in its own compartment
  - E.m. force exerted on multiple coil blocks does not accumulate
  - A laminar spring is used to preload each block

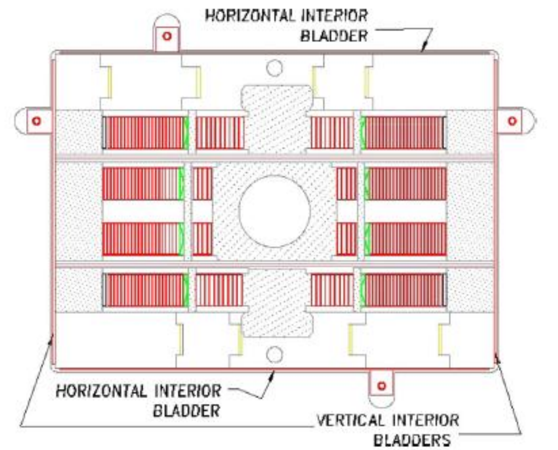
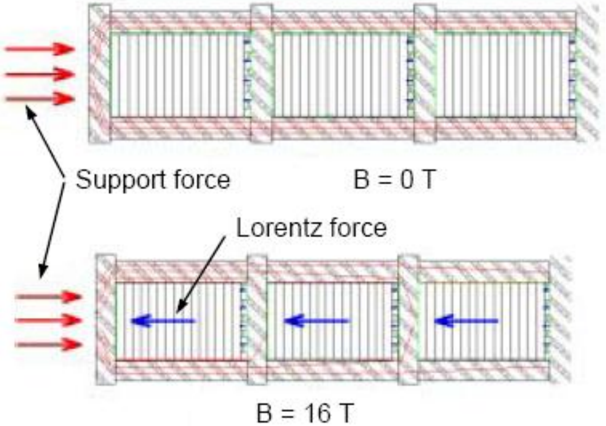
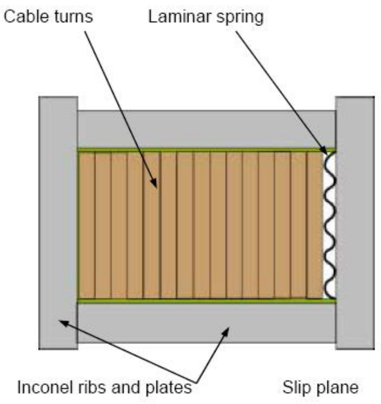
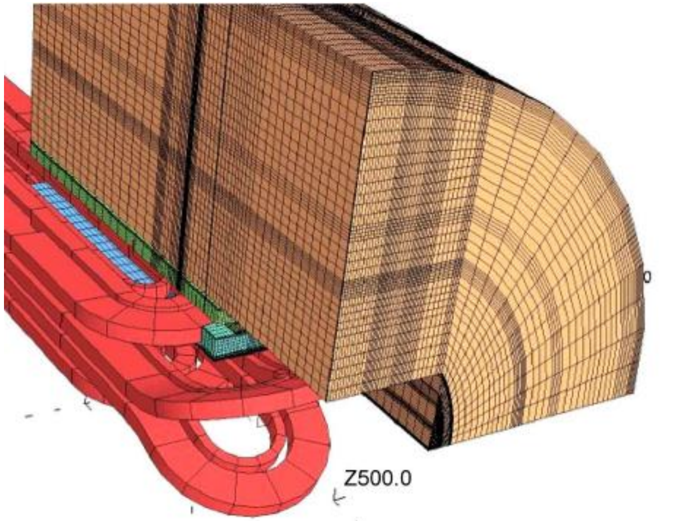


Fig. 2. TAMU5 winding module assembly and interior bladders.

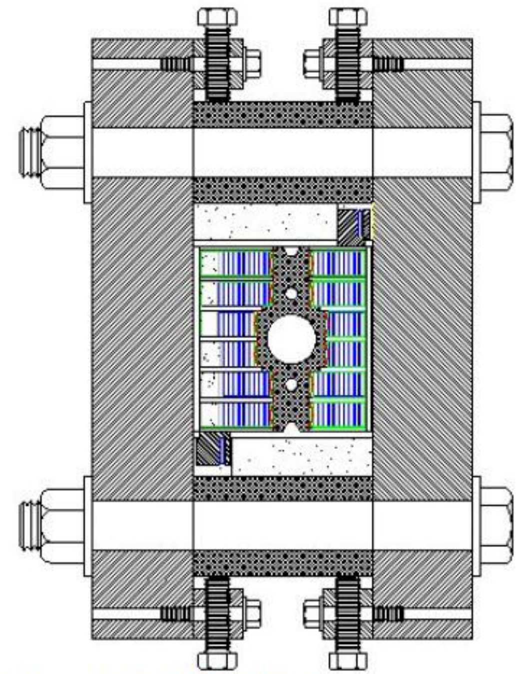






TAMU block dipole

- TAMU1 (2001): NbTi conductor
  - “The dipole attained a reproducible quench current of 8,050 A, ~98% of short-sample limit, on the sixth quench. The dipole field was measured to be 6.6 T at 8 kA”
- TAMU2 (2006): Nb_3Sn coil
  - 6.9 T expected max. conductor peak field
  - Maximum current reached with no training
- TAMU3 (under development)
  - Same as TAMU2 but with high performance Nb_3Sn cond.



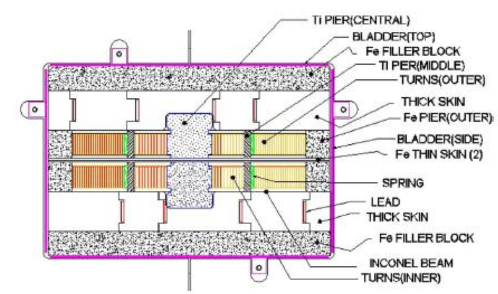
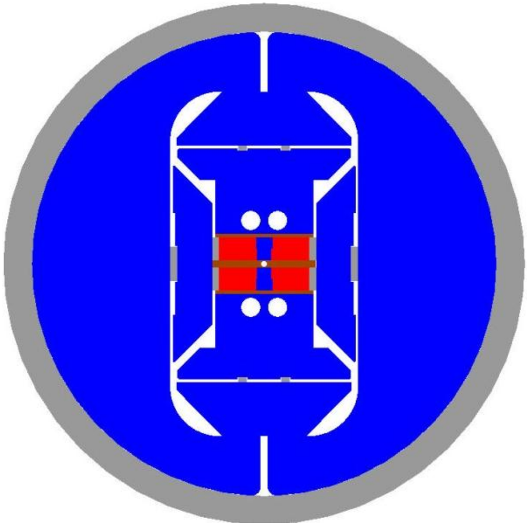
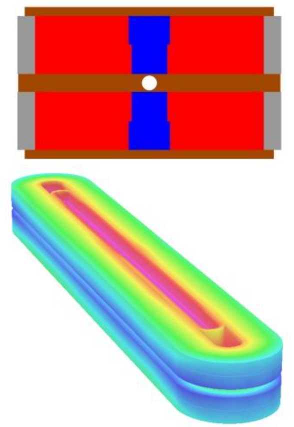


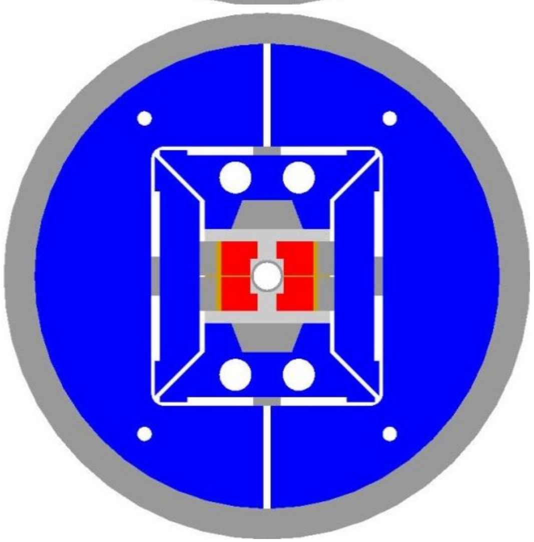
Fig. 1. TAMU3 winding module components and interior bladder locations

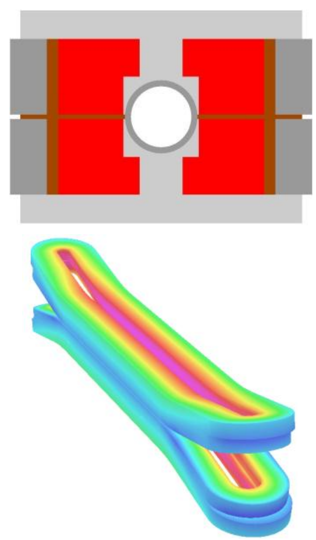
From HD1 to HD2





- HD1 (2003): explore Nb_3Sn limits
  - 16.7 T in a 10 mm bore
  - Coil peak field 16.1 T
  - Flat racetrack coils
  - 150-180 MPa coil stress

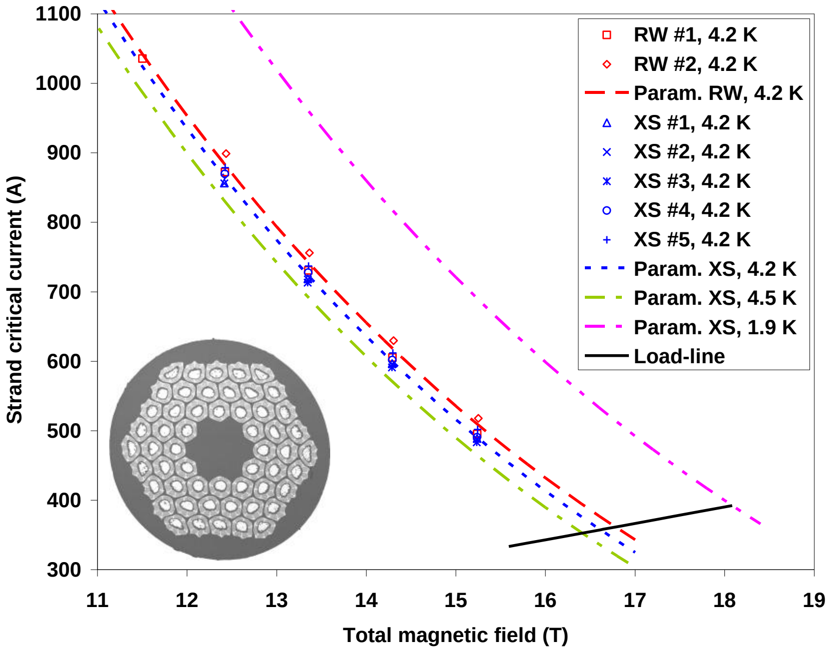




- HD2: apply block-type coils to high-field accelerator magnets
  - 15 T in a 36 mm bore
  - Coil peak field 15.8 T
  - Flared ends & field quality optimization
  - 150-180 MPa coil stress

HD2 conductor and magnet parameters

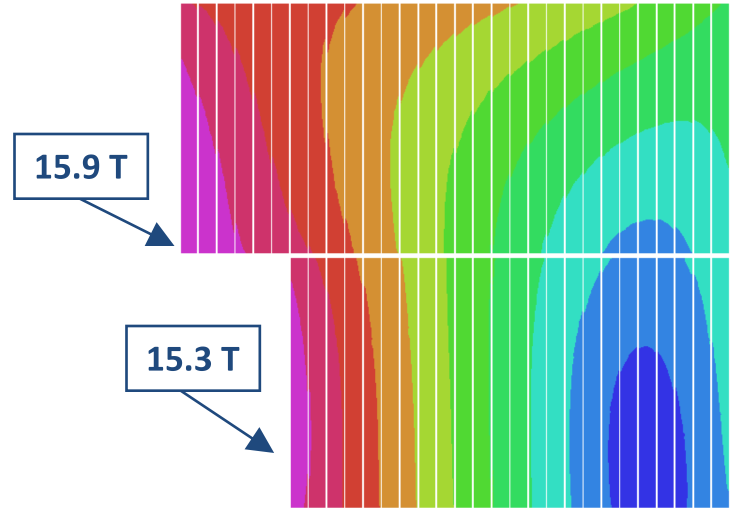
- Conductor: 0.8 mm RRP 54/61
  - Non Cu: 51-54 %
- Cable: 22.008 x 1.401 mm
  - 51 strands
- Cabling degradation: 2% - 4%
- J_c (12T, 4.2 K) > 3000 A/mm^2

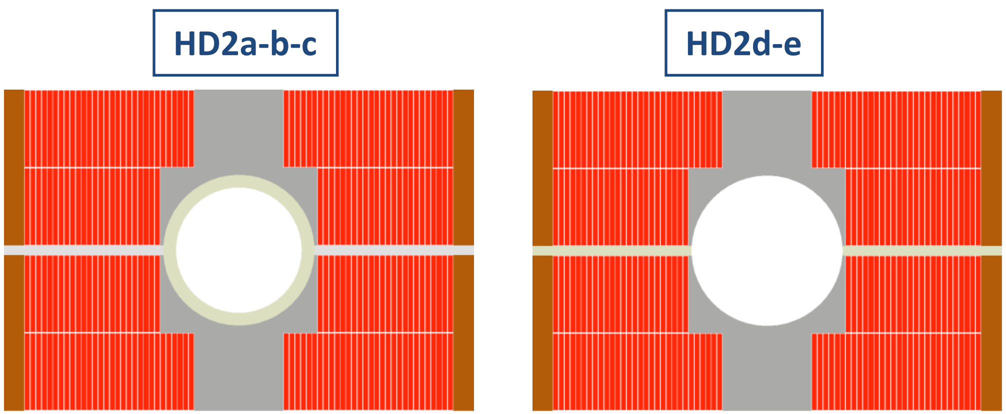


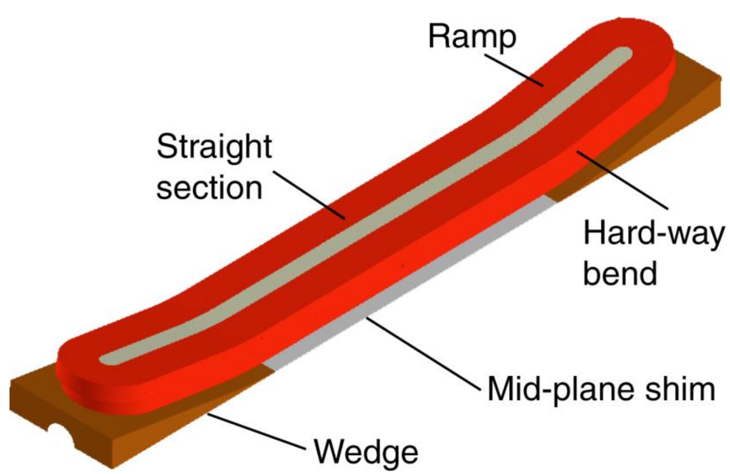
- Three coils fabricated
  - RRR from 16 to 290
- Magnet limits at 4.3 K (coil 1)
  - I: 17.3 kA
  - B_{bore}: 15.0 T
  - B_{peak}: 15.9 T
- Magnet limits at 4.3 K (coil 2-3)
  - B_{bore}: 15.6 T
  - B_{peak}: 16.5 T
- Extrapolation at 1.9 K (coil 2-3)
  - B_{bore}: 17.1 T
  - B_{peak}: 18.1 T

HD2 coil design

- 22.0 x 1.4 mm cable
  - Two layers with Ti pole
- With and without bore tube
  - From 36 mm to 43 mm bore



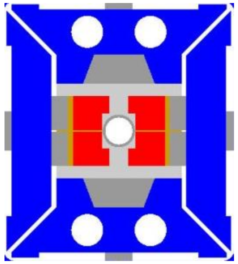


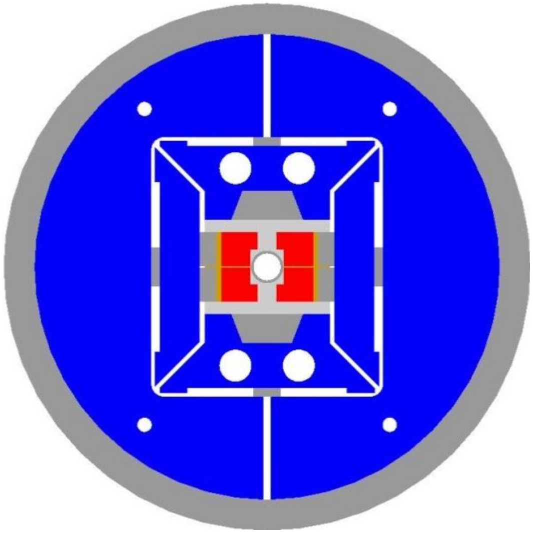


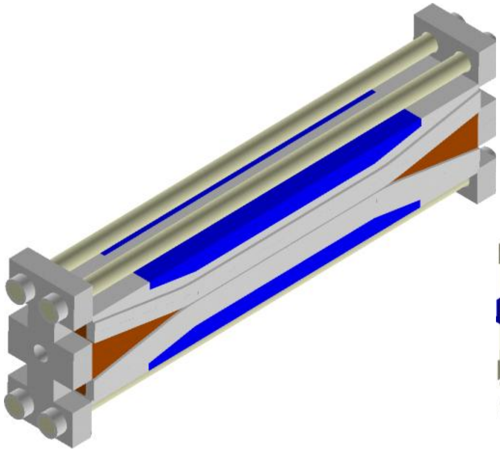
- Flared ends (hard-way bend)
- Peak field in layer 2 pole turn

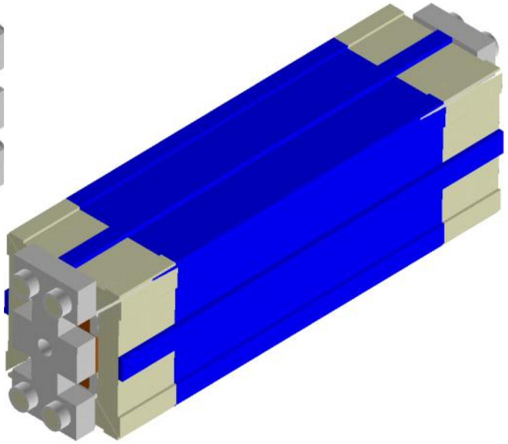
HD2 magnet design and parameters

- Coil-pad in yoke-shell
- Pre-loading with bladders
  - Stress increase at 4.3 K
- Coil end support: 600 kN
- No coil–pole separation
- Magnet limits at 4.3 K
  - I_{ss}: 18.1 kA
  - B_{bore}: 15.6 T
  - B_{peak}: 16.5 T

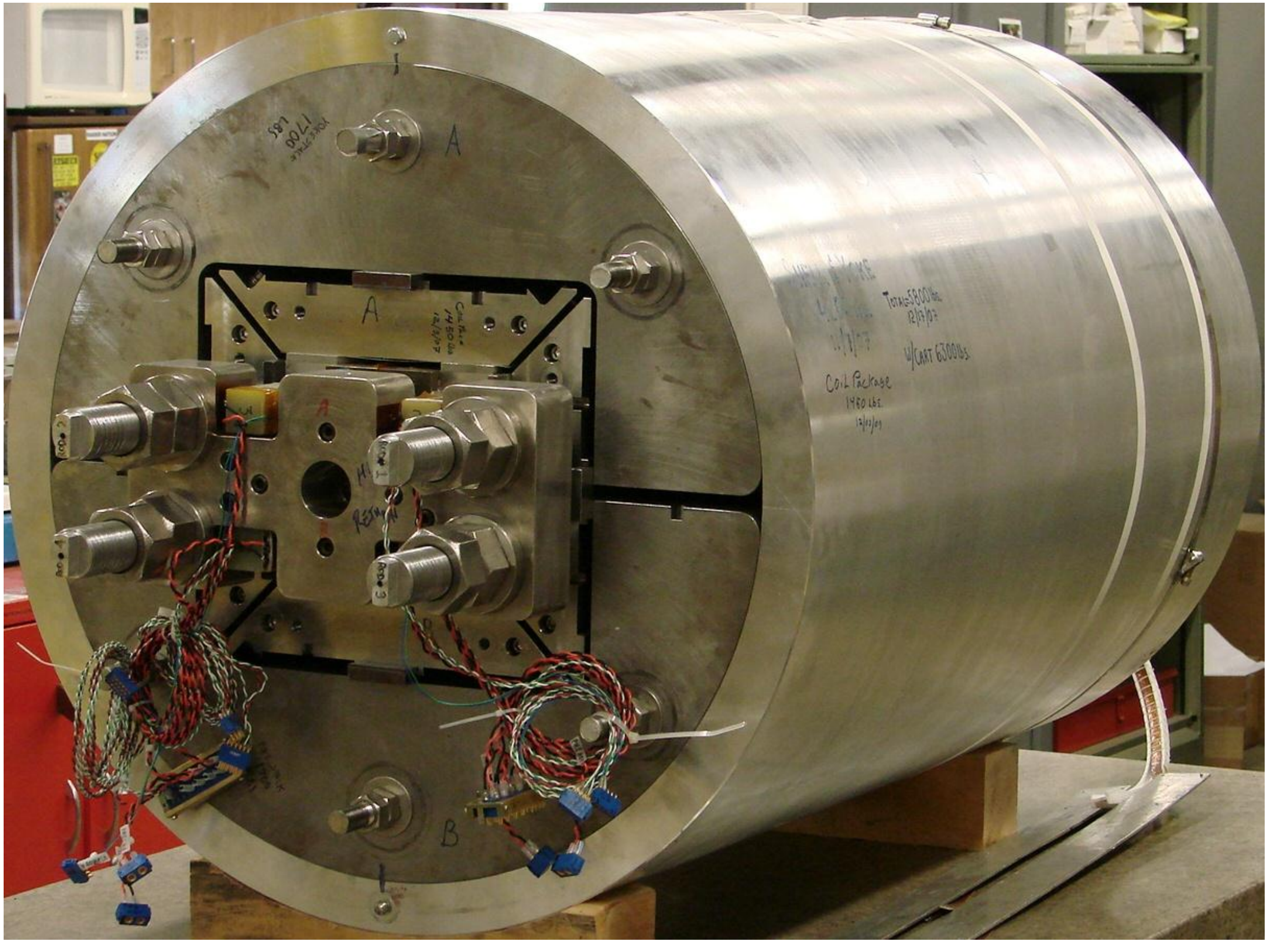






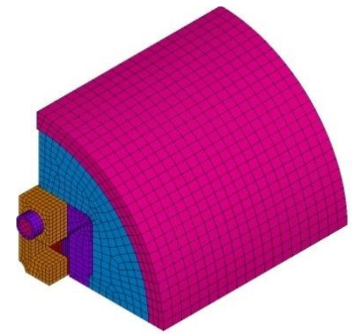


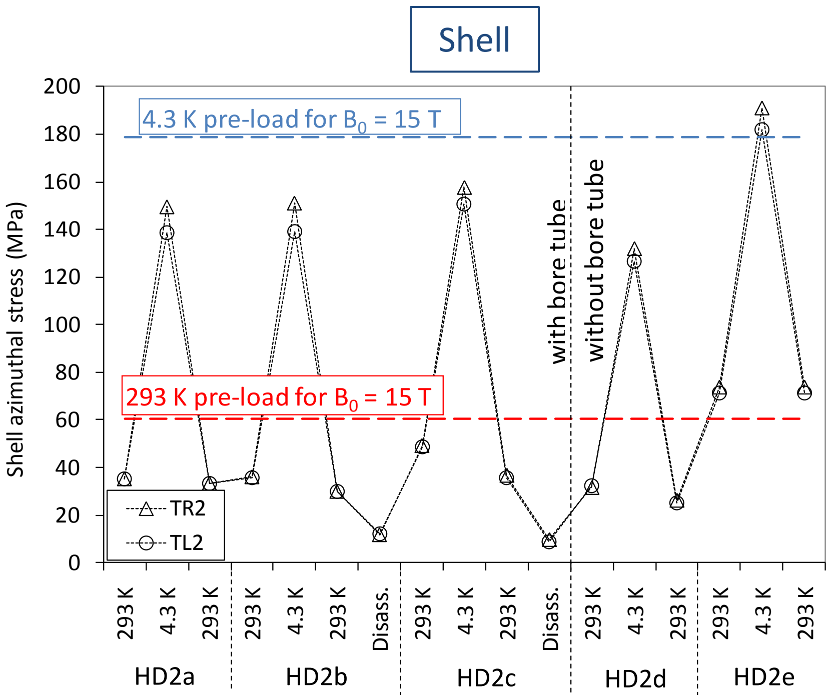
HD2 magnet

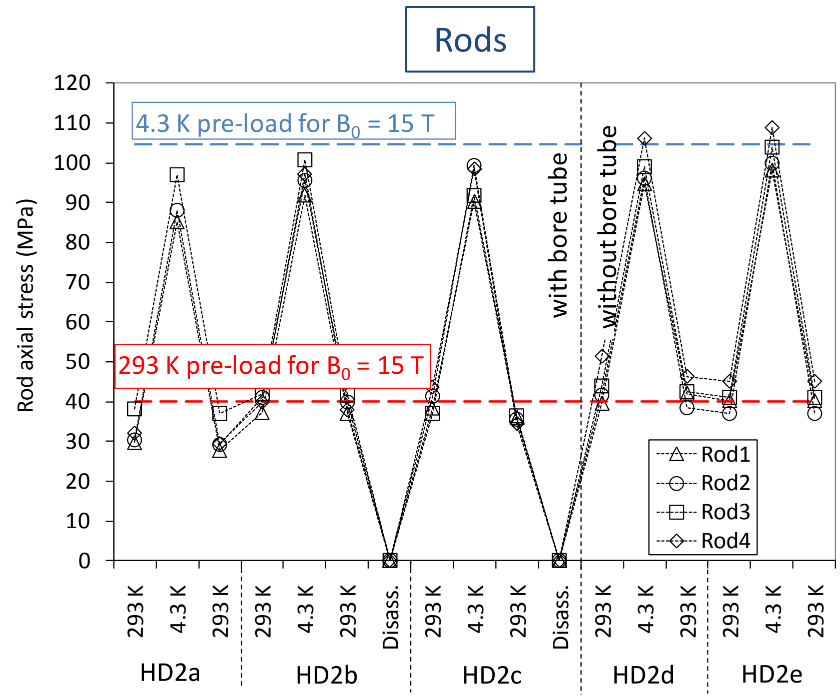


HD2 pre-loading sequence
Shell and axial rods

- Shell
  - 13.5 T pre-load level in HD2a-b-c (*with bore tube*)
  - Reduction and final increase in HD2d-e (*without bore tube*)
- Rod
  - Axial tension ranging from 90 to 100 MPa

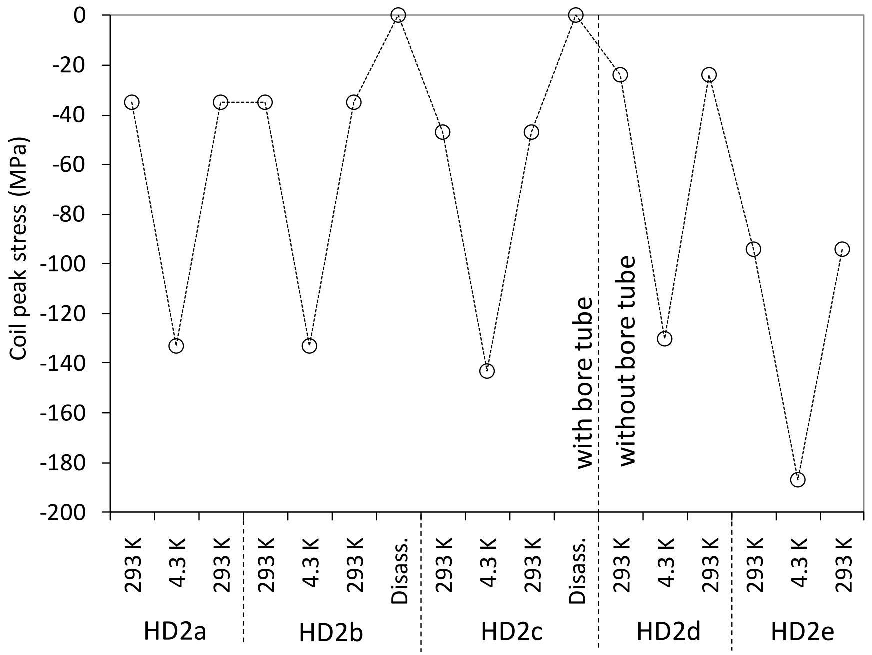


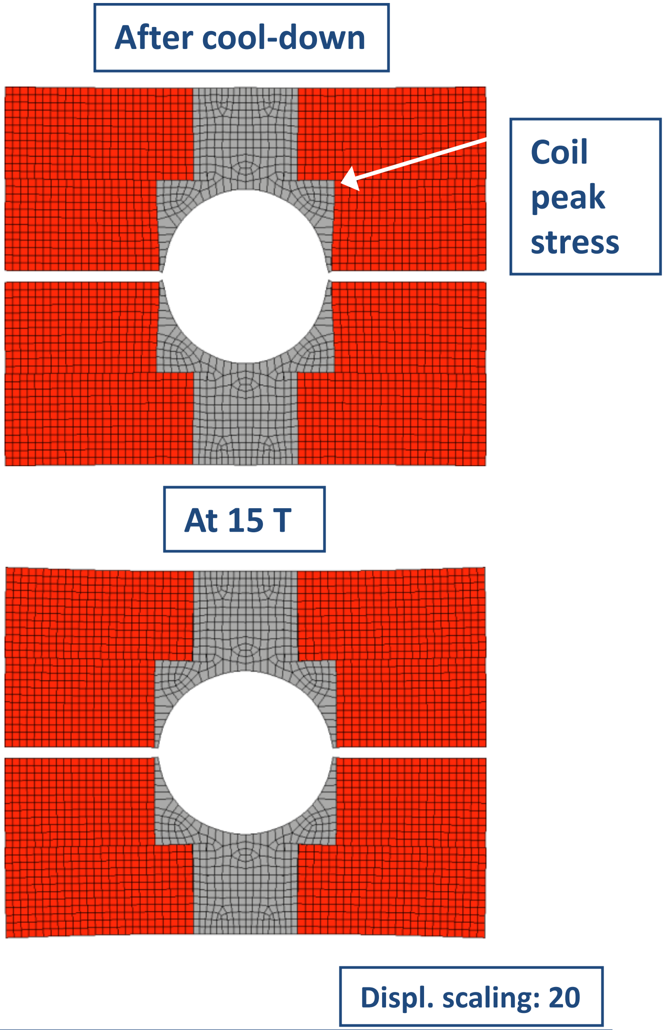




HD2 pre-loading sequence
Coil stress

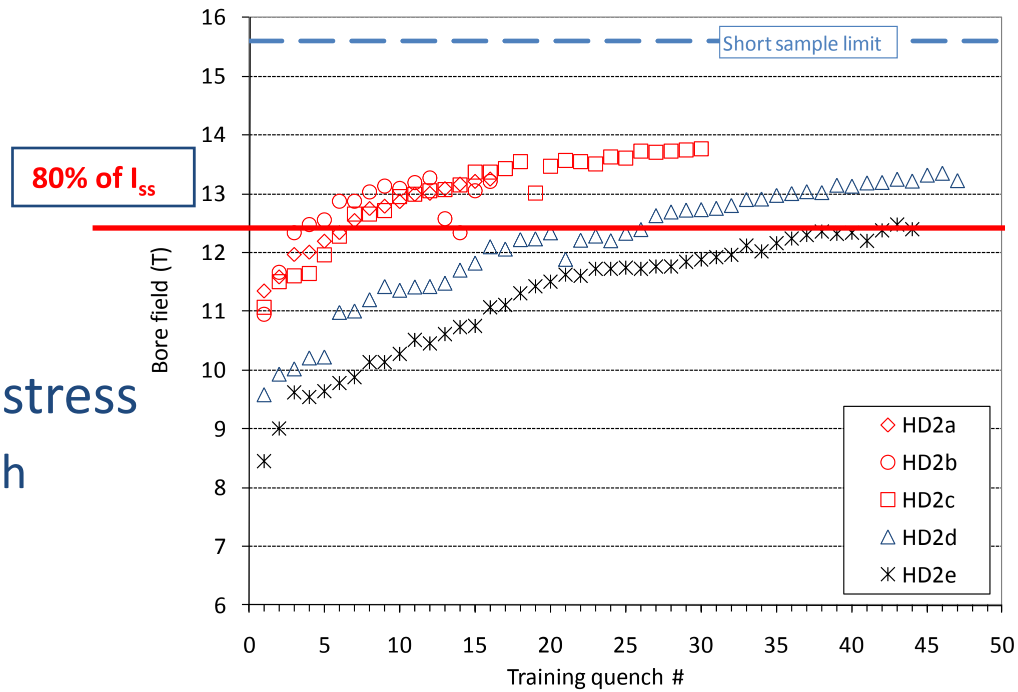
- Peak stress in layer 1 pole turn, close to layer 2
  - Horizontal ("oval") deformation of layer 1 pole
- With and without bore tube
  - Similar stress and displacement (about 90 μm)





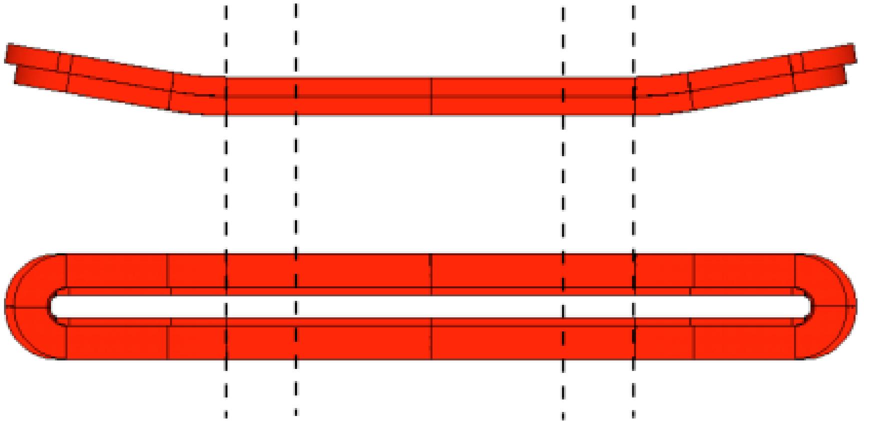
HD2 training quenches (4.3 K)

- HD2a-b-c
  - Bore tube
    - From 11 T (70% of I_{ss}) to 13.8 T (87% of I_{ss})
    - Coil peak field of 14.5 T
- HD2d
  - No bore tube and low pre-stress
    - Decrease of 7-8% in quench current
- HD2e
  - No bore tube and high pre-stress
    - Further decrease of 5-6%

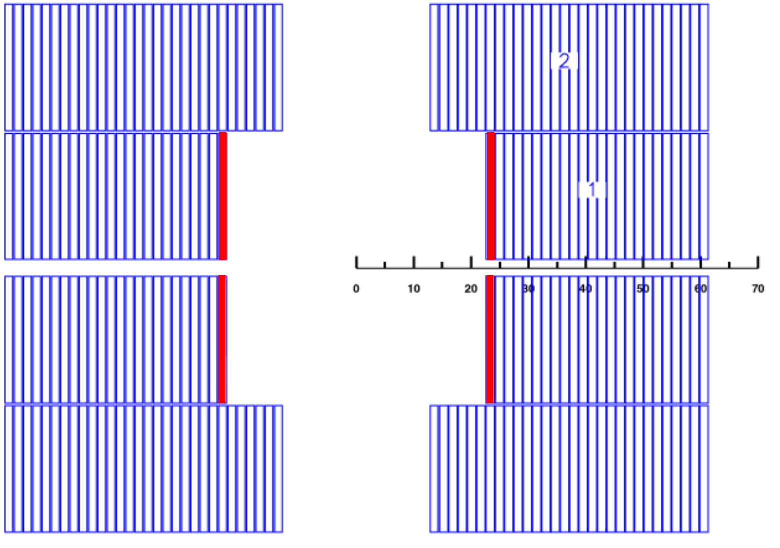


HD2 quench locations

- Layer 1 pole turn
  - 4% in field margin
- End of straight sect.
  - Before the hard-way bend

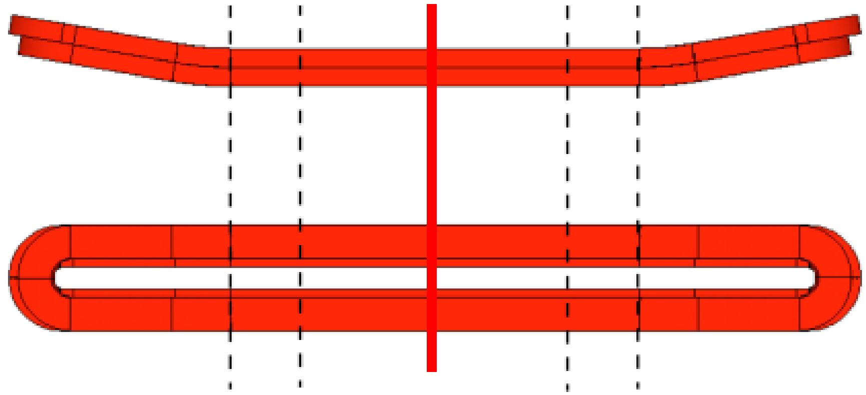


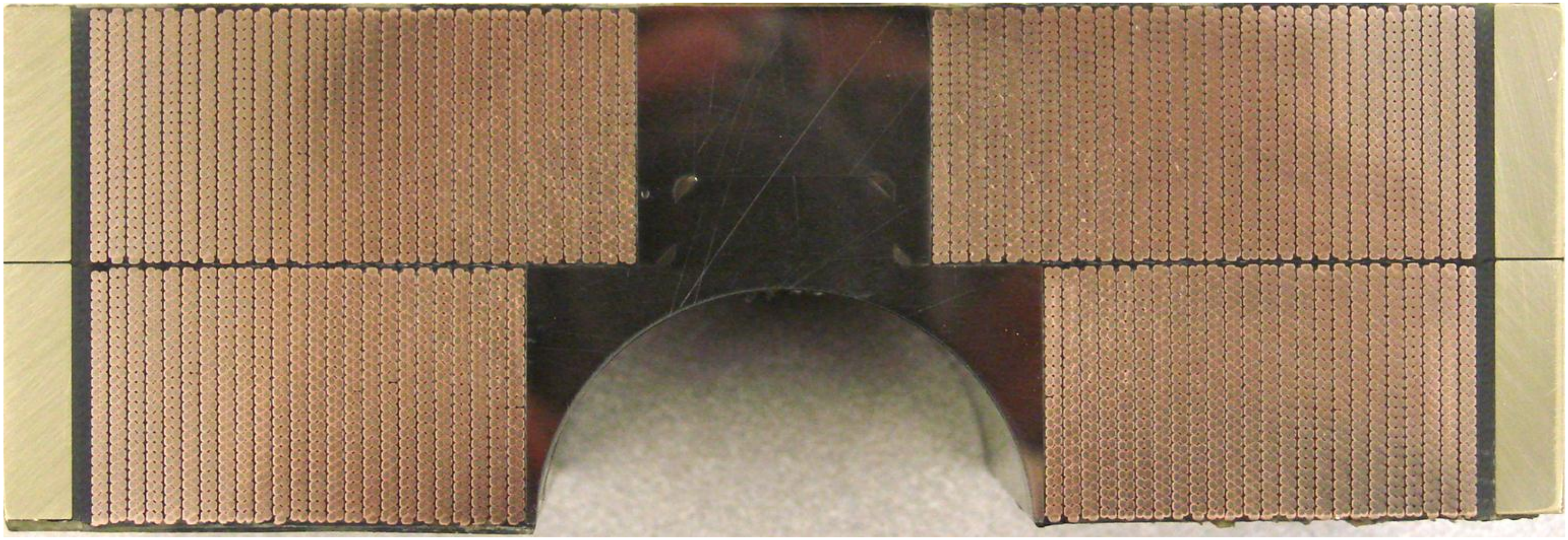
- Evenly distributed
  - Coil #2 and #3
  - Left and right side
  - Lead and return ends.
- None in central part or in end regions



HD2 coil visual inspection

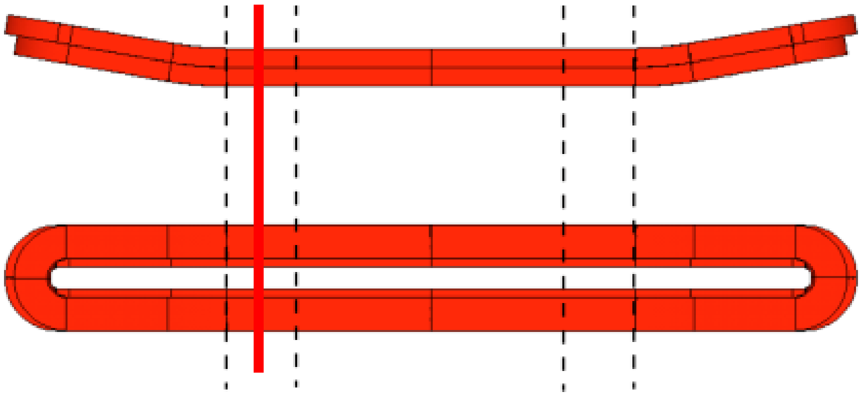
- Cross-section cuts
  - Straight section “center”
    - No quenches recorded
    - Turns aligned with poles

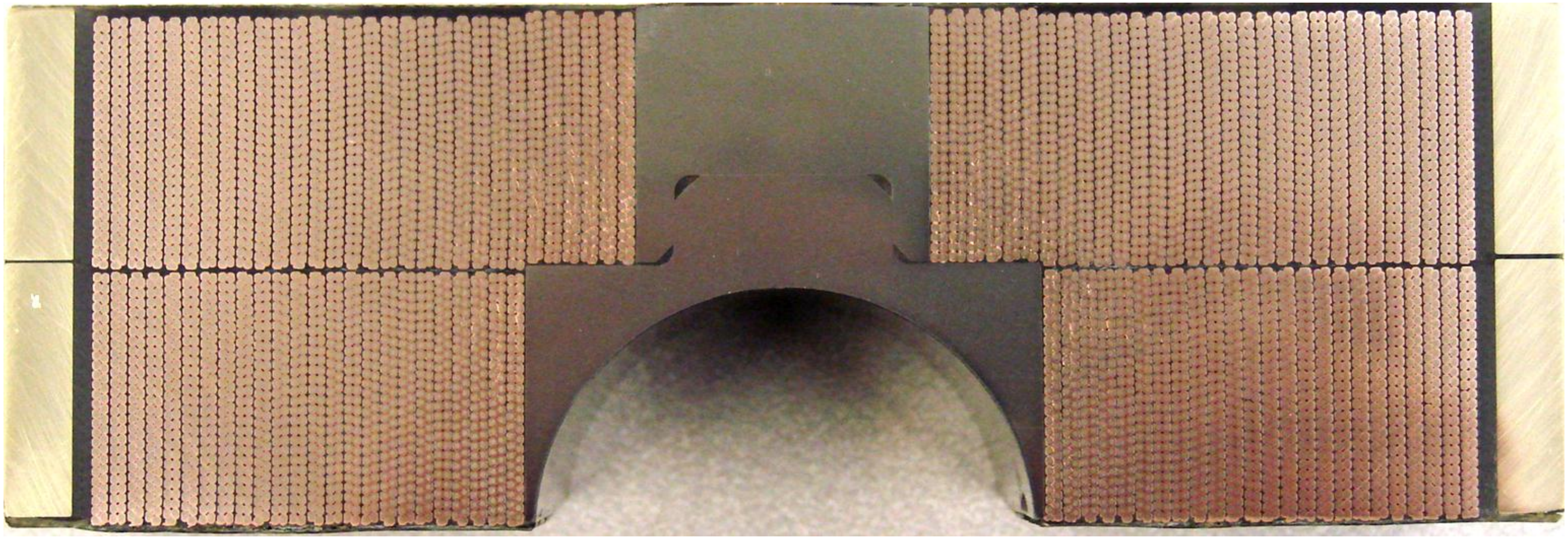




HD2 coil visual inspection

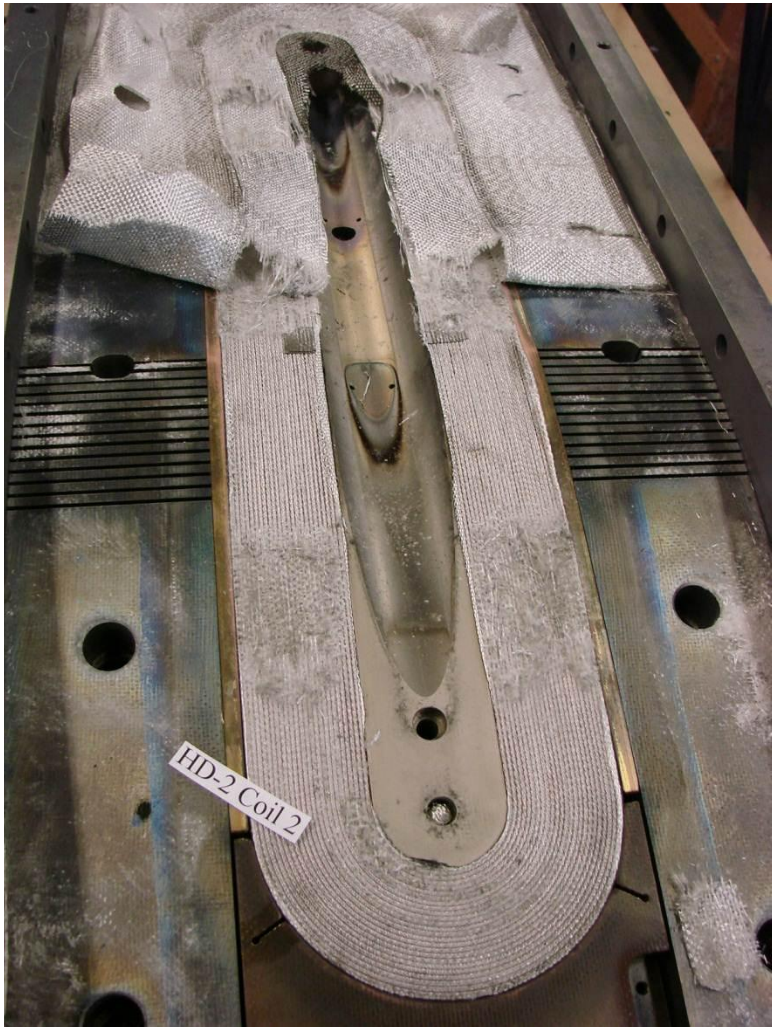
- Cross-section cuts
  - Straight section "end"
    - Quenching area
    - Vertical shift of layer 2





HD2 coil after reaction

- Fiberglass sheet between coil and tooling
  - High pressure points caused damage in fiberglass sheet
- Visual observation of insulation status: way to identify motions, pressure, strain during reaction

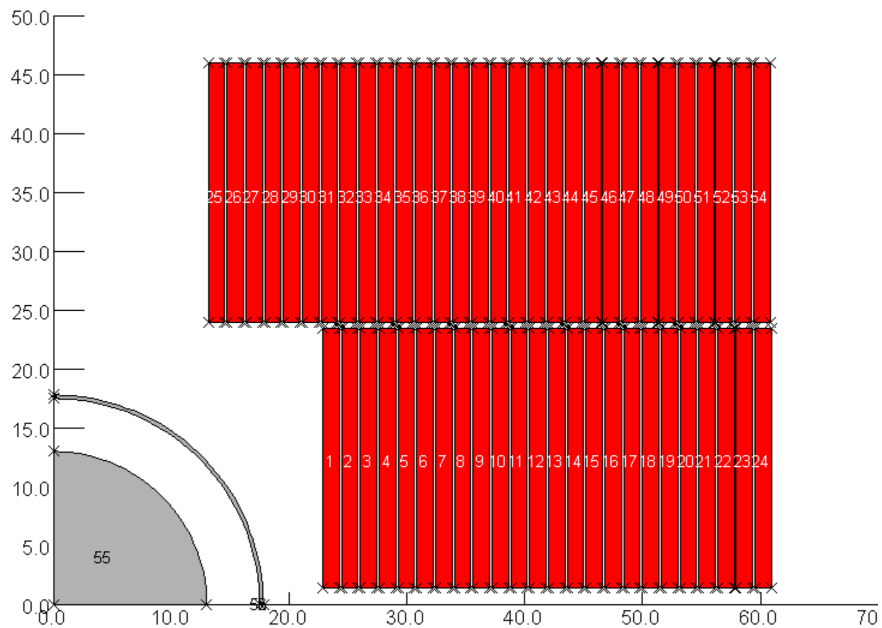


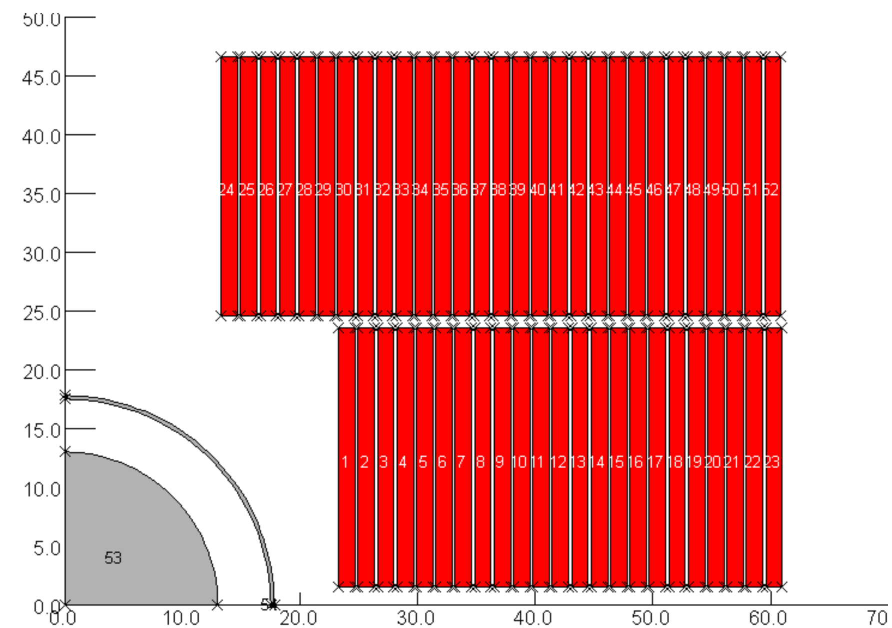
HD2 coil after impregnation

Coil cross-section
HD2 vs. HD3 (v5)

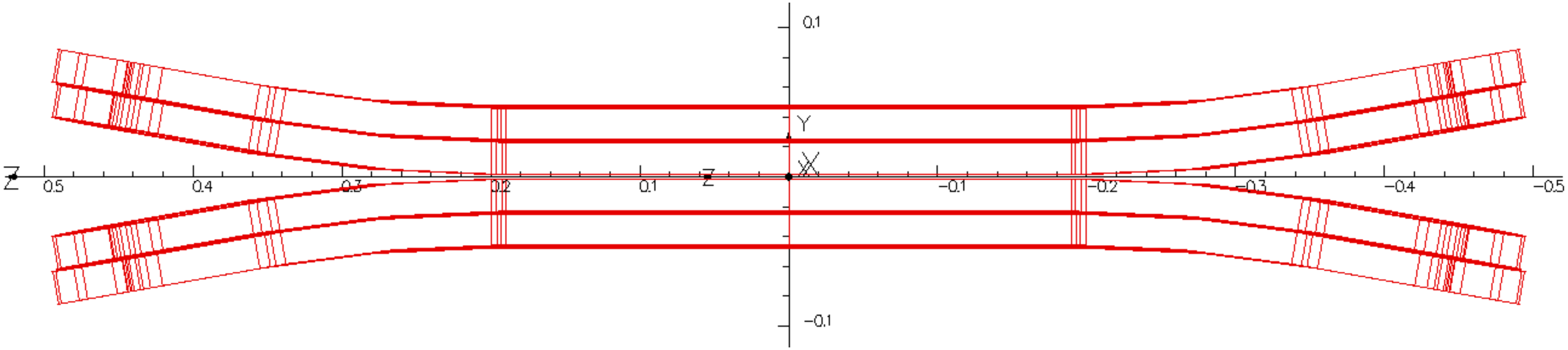
- Bare cable: 21.999 x 1.406 mm
- Insulation: 0.095 mm
- Ins cable: 22.189 x 1.596 mm
- Layer gap between ins. cables
  - 0.285 mm (11 mils)
- Layer 1: 24 turns
- Layer 2: 30 turns

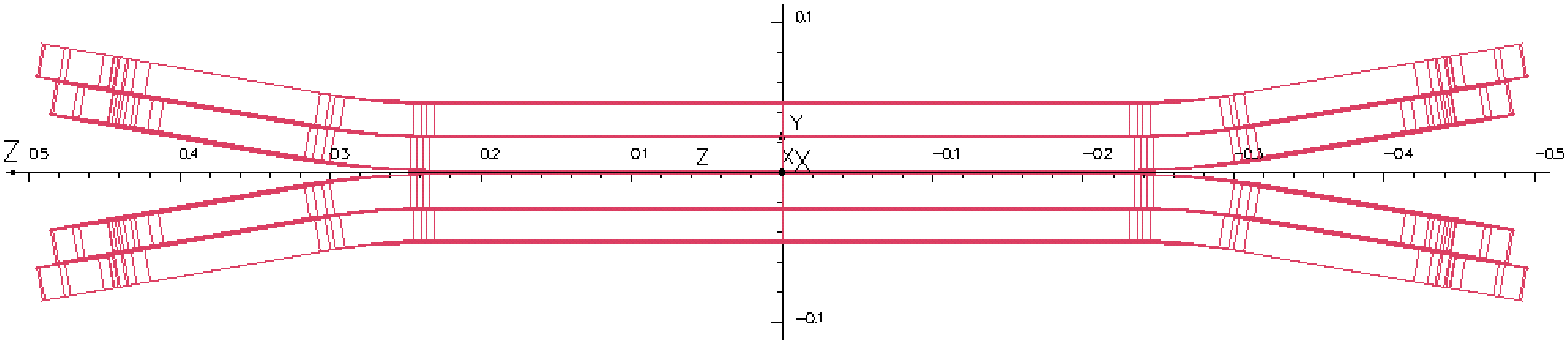
- Bare cable: 22.027 x 1.401 mm
- Insulation: 0.125/0.086 mm
- Ins. cable: 22.199 x 1.651 mm
- Gap between layers
  - 0.92 mm (36 mils)
- Layer 1: 23 turns
- Layer 2: 29 turns





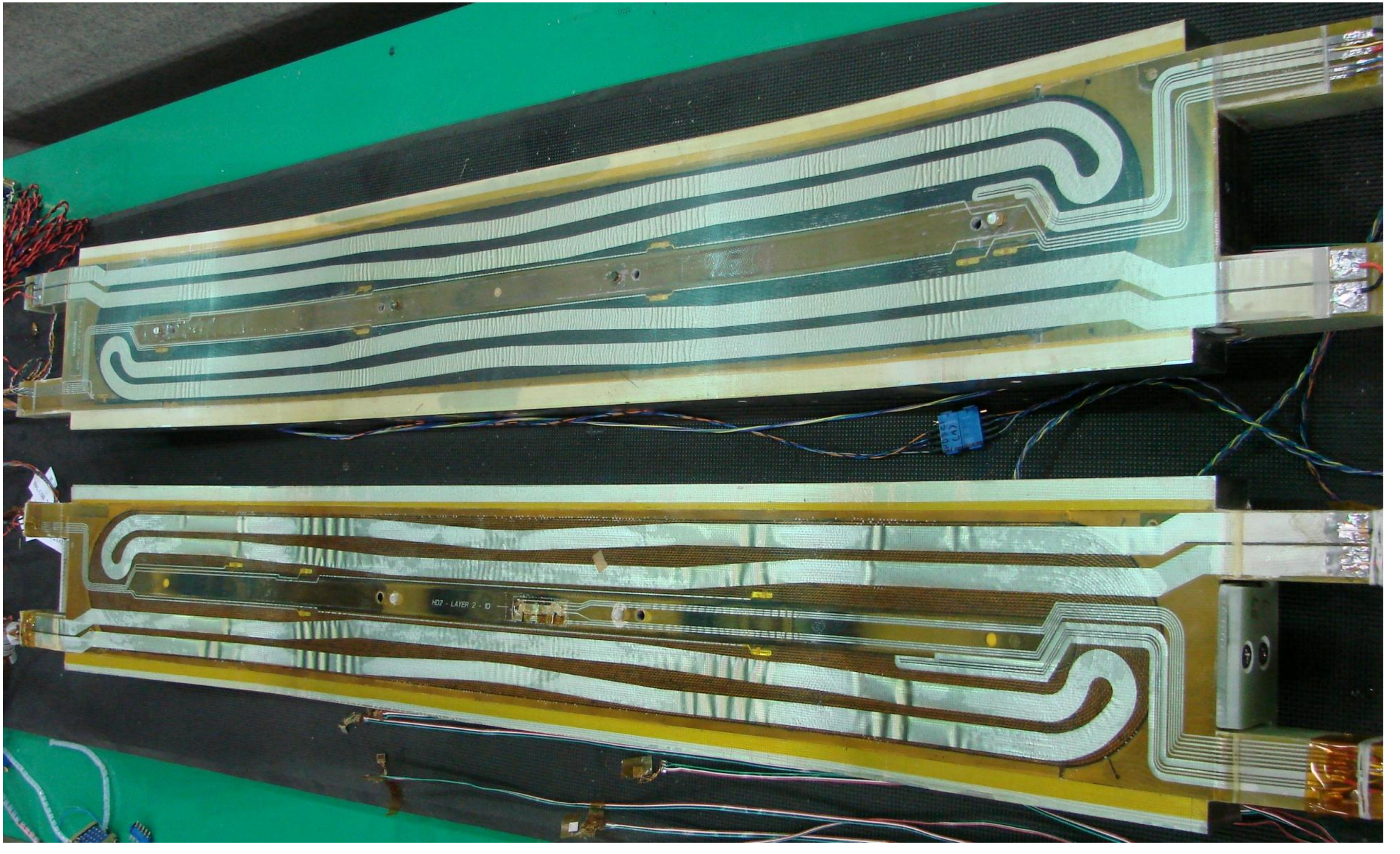
HD3 vs. HD2



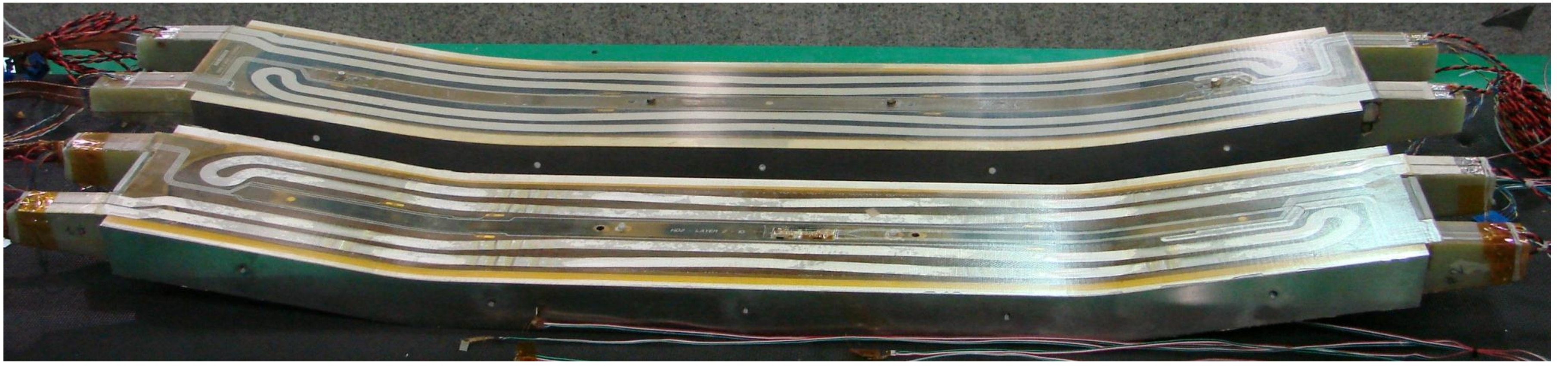


- Hard-way bending radius increased from 350 to 870 mm
- Straight section reduced from 480 to 390 mm

HD2 vs. HD3



Status of HD3 development



- Two coils fabricated with no pole axial gap
- Test executed in fall 2011 but interrupted due to short in the leads (external to coils)
- Coils repaired and test to be repeated in spring 2012
- Additional coils with pole gaps under fabrication

Conclusions

- Three block dipole with flared ends fabricated and tested
  - LBNL D10 (Nb_3Sn)
  - KEK Block dipole (NbTi)
  - LBNL HD2-HD3 (Nb_3Sn)
- All magnet passed the 80% of I_{ss} level
  - FRESCA2 13 T operational conditions
- Quench locations and long training observed in HD2 under investigation in HD3
  - Possible feed-backs to FRESCA2
- FRESCA2 “bladder-and-key” structure
  - HD2 experience on assembly and loading procedures

Appendix

HD3 insulation scheme

- Coil to island
  - 14 mils glass tape
- Interlayer shim
  - 10 mils of ceramic
- Coil to shim
  - 13 mils of ceramic
- Coil-boat
  - 17 mils of glass/G10 + 3 mils of **trace**
- Coil to rail/shoes
  - Coil1:
    - 41 (L1), 27 (L2) mils of ceramic
  - Coil 2
    - 58 (L1), 44 (L2) mils of ceramic