U.S. MAGNET DEVELOPMENT PROGRAM

BERKELEY LAB

Utility Structure Design

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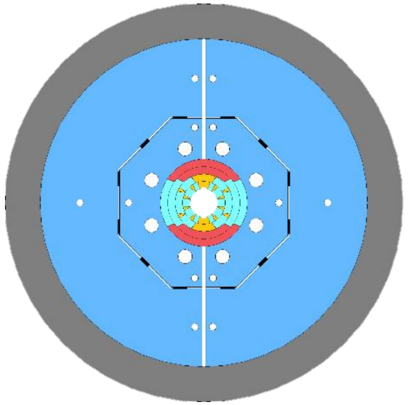
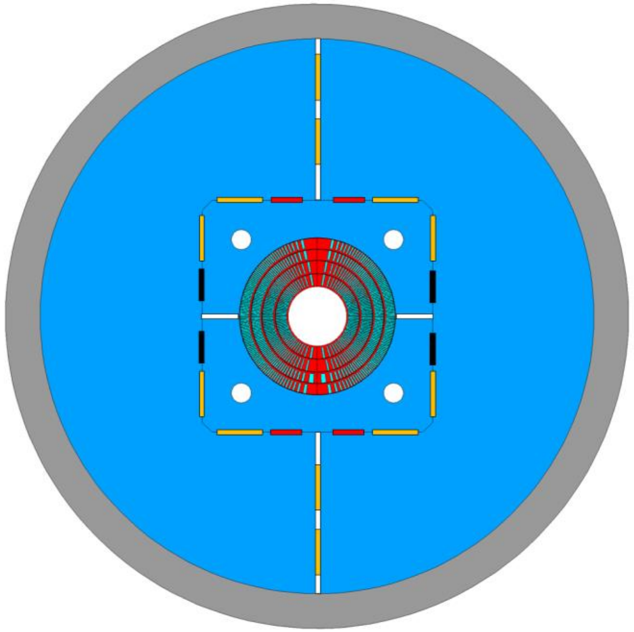
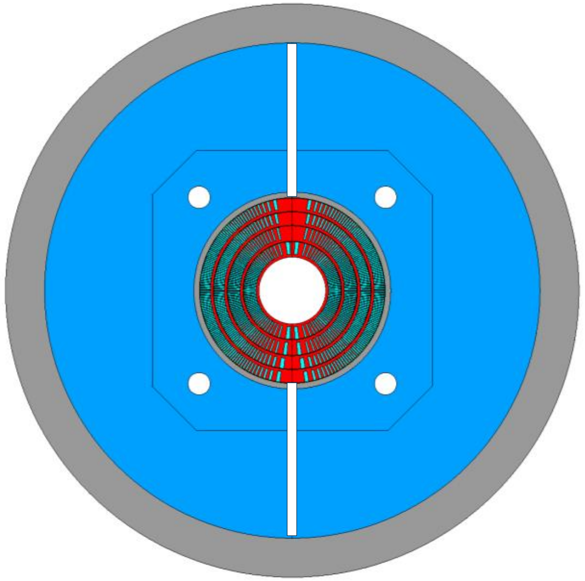
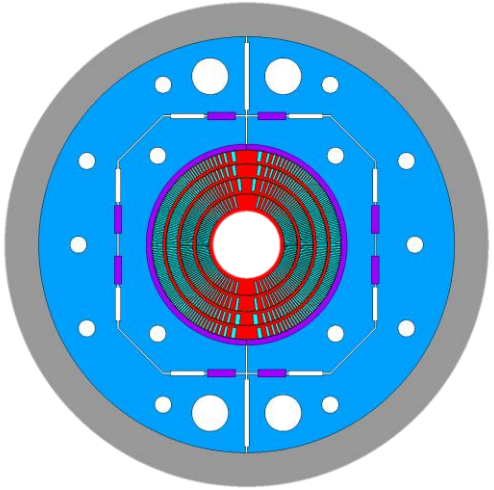
MDP structure design evolution for various goals/constraints







This presentation



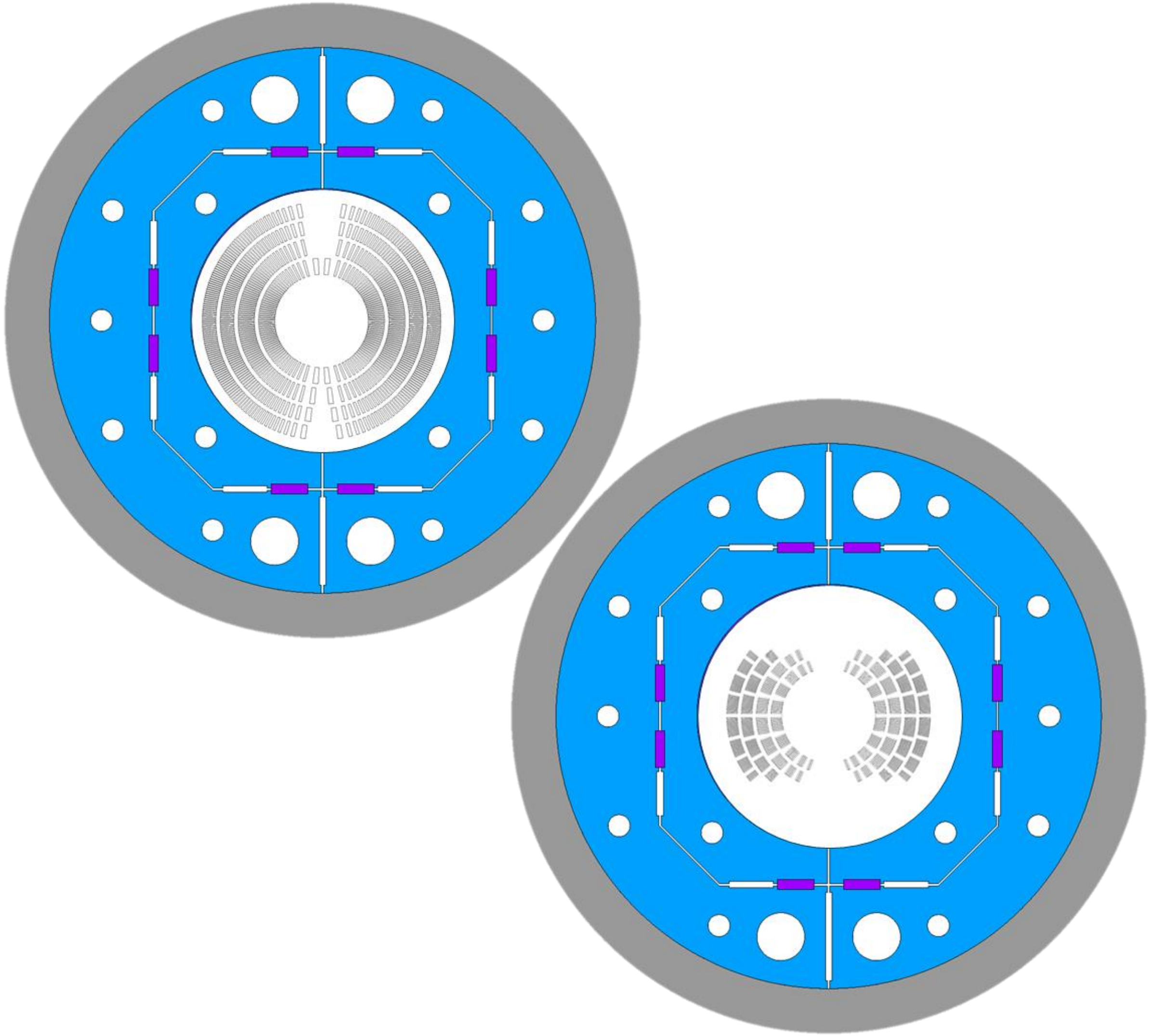
750 mm OD
- CCT5/MDPCT
- Smaller FNAL cryostat (?)
- Octagonal pad due to limited space

1260 mm OD
- CCT6/SMCT/20T
- Existing LD1 shell
- Vertical split yoke, horizontal split pad due to high (fixed) cool-down pre-load

1030 mm OD
- CCT6/SMCT
- Current LBNL pit, new cryostat
- Vertical split yoke/pad thanks to smaller shell

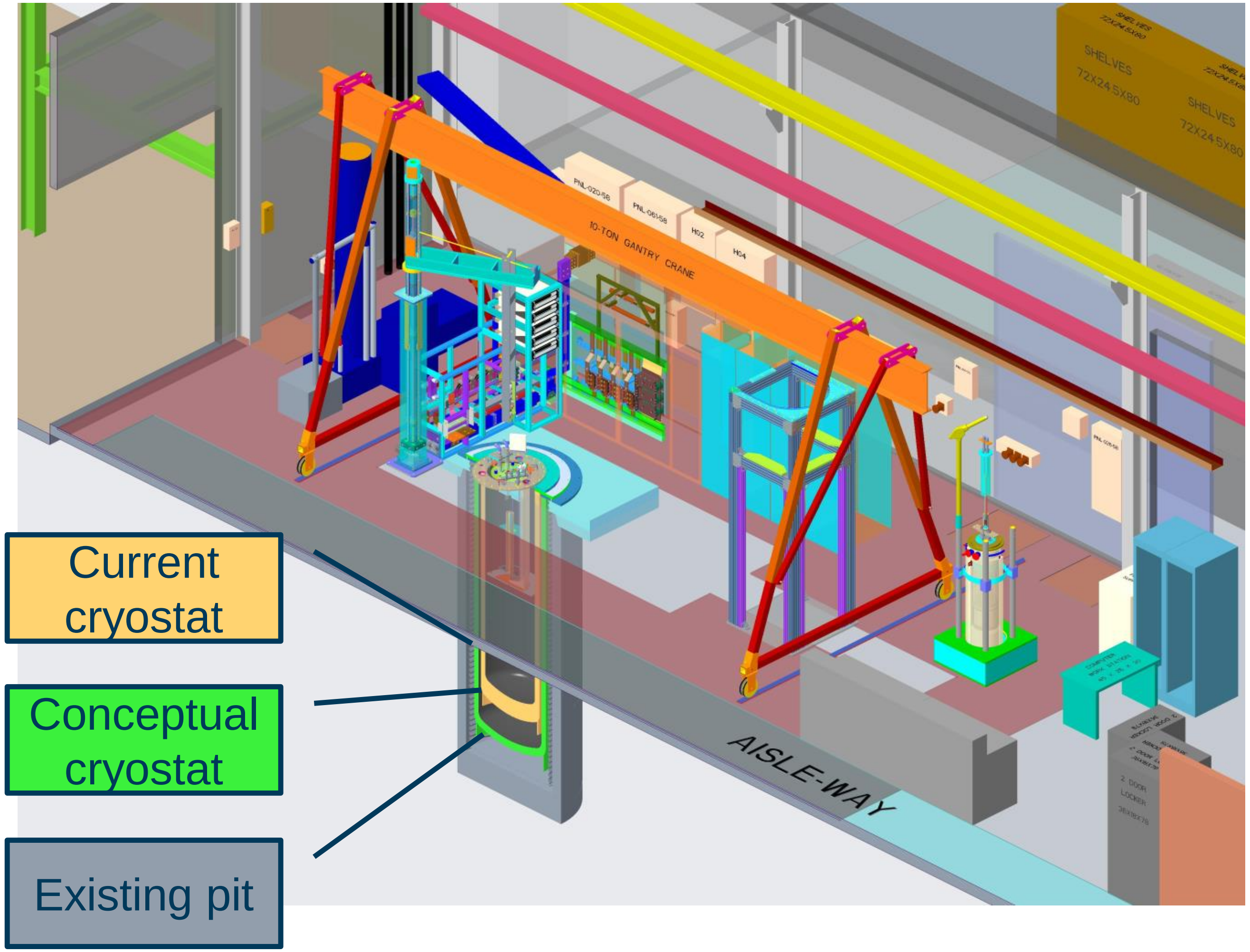
860 mm OD
- CCT6/SMCT
- Current LBNL cryostat
- Optimized spar thickness and new mandrel material

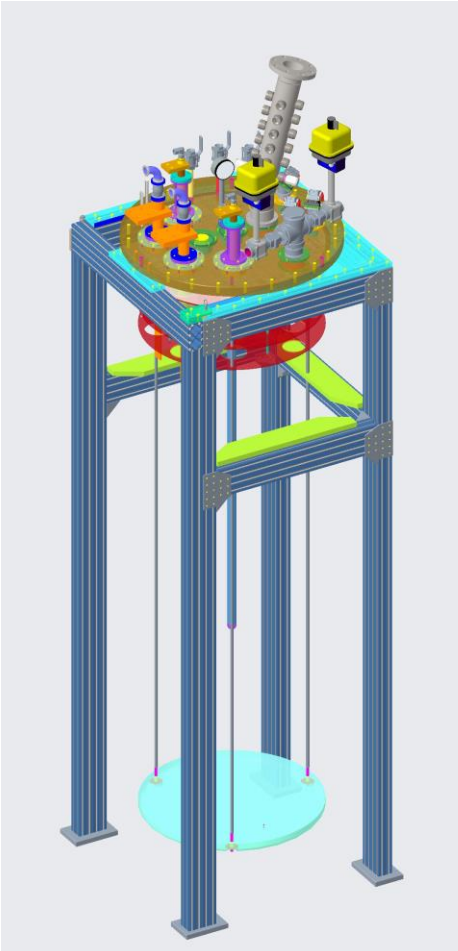
Compatibility with magnets and test facilities



- Magnets
  - CCT6
    - 2 layers with a spacer
    - 4 Layers with protective a (split) cylinder
  - SMCT
    - 2 or 4 layers with a spacer
    - Axial preload?
  - Hybrid configurations
- Facilities
  - LBNL at 4.2K
    - Compatible with current cryostat thanks to 860 mm OD
  - FERMILAB at 1.9K
    - With additional magnetic shielding
      - HFVMTF uses two 1 inch thick cylinders made of AISI 1020

Testing facility in B58 not compatible with LD1 shell

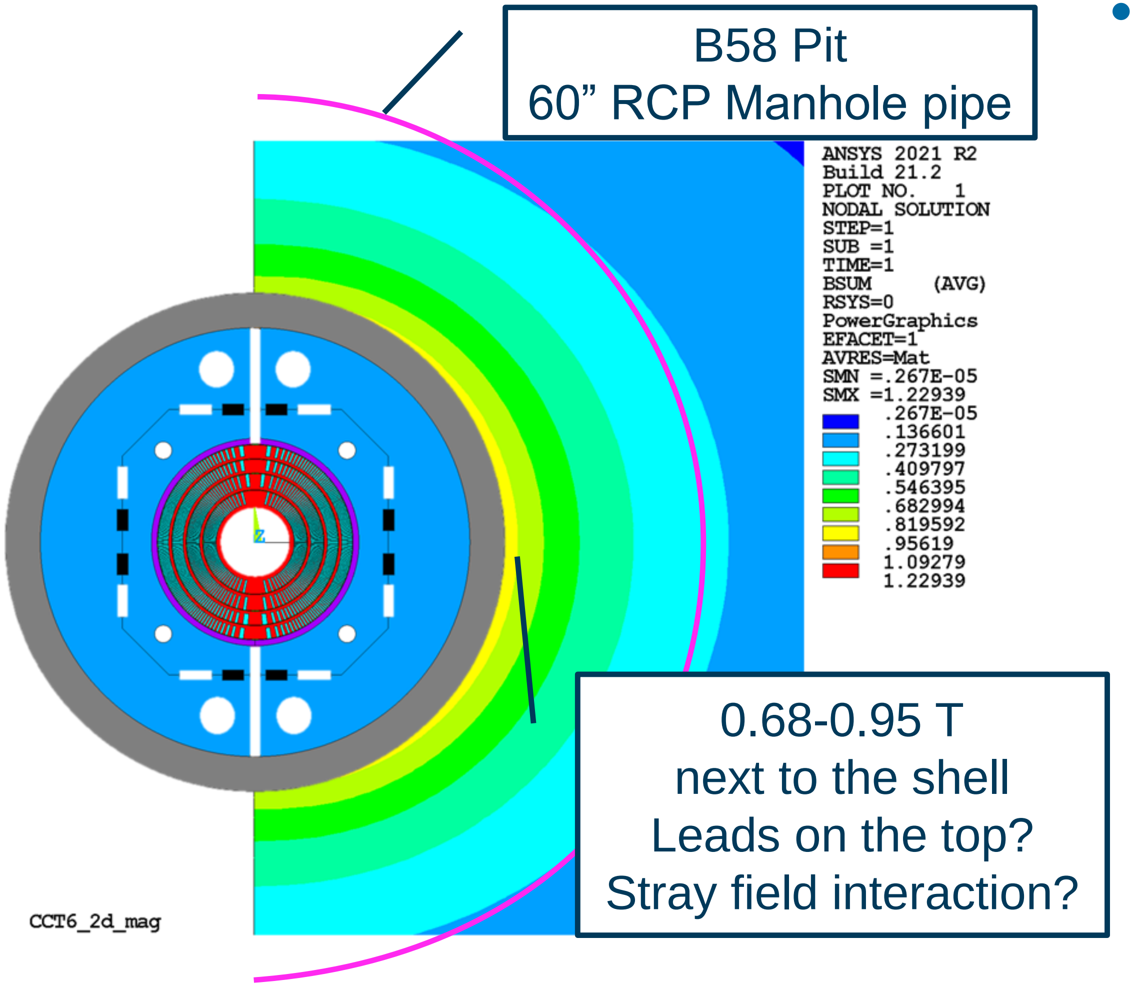




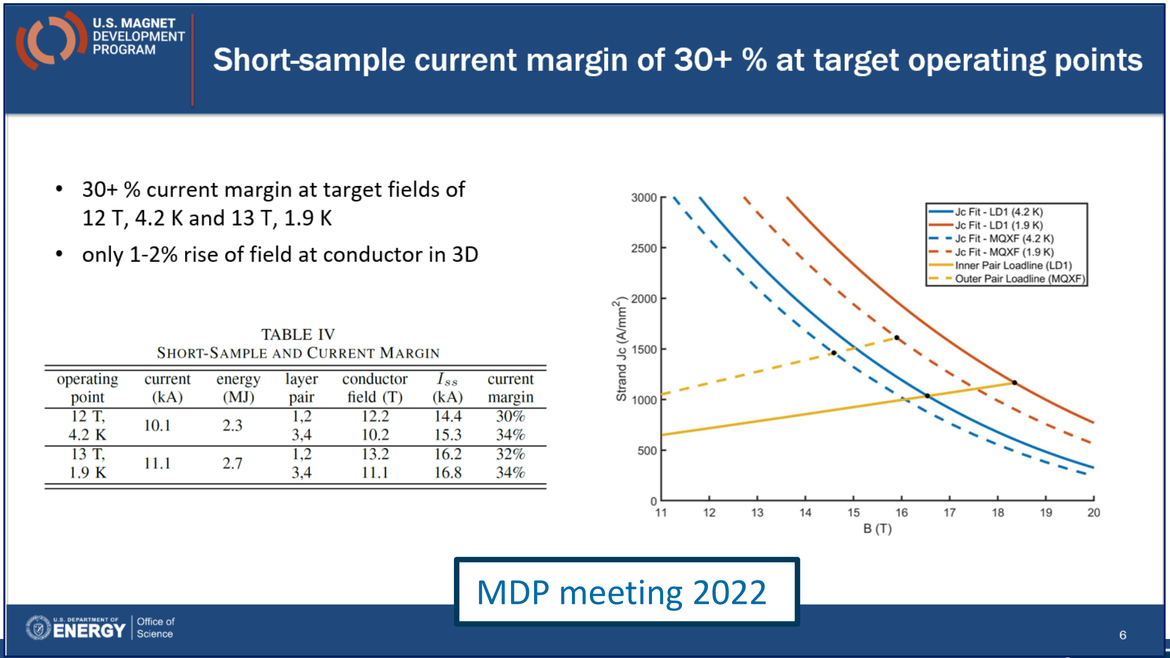
Current facility

- Crane
  - ~10t or 20k lbs
  - Can be used up to 80% without riggers
  - Clearance below the crane 13ft 6in (4.115m)
- The pit
  - ID 53.7” (~1364 mm)
  - DEPTH 162.5” (4127.5 mm)
- The cryostat
  - OD 42“ (1066.8 mm)
  - ID 36” (914.4 mm)
  - DEPTH 138” (3505.2 mm)
  - Radial thickness 3”
- Max. magnet dimensions
  - OD 34” (860 mm)
  - Radial separation 1”

Impact of reduced yoke OD



- Mechanical analysis at 13.2 T
  - Current for 1260 mm OD structure
    - 11.8 kA
  - Current for 860 mm OD structure
    - 12.58 kA
  - About 6.6% increase due to reduced iron OD
    - Impact on current margins (1-2 %? TBD)



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Short-sample current margin of 30+ % at target operating points

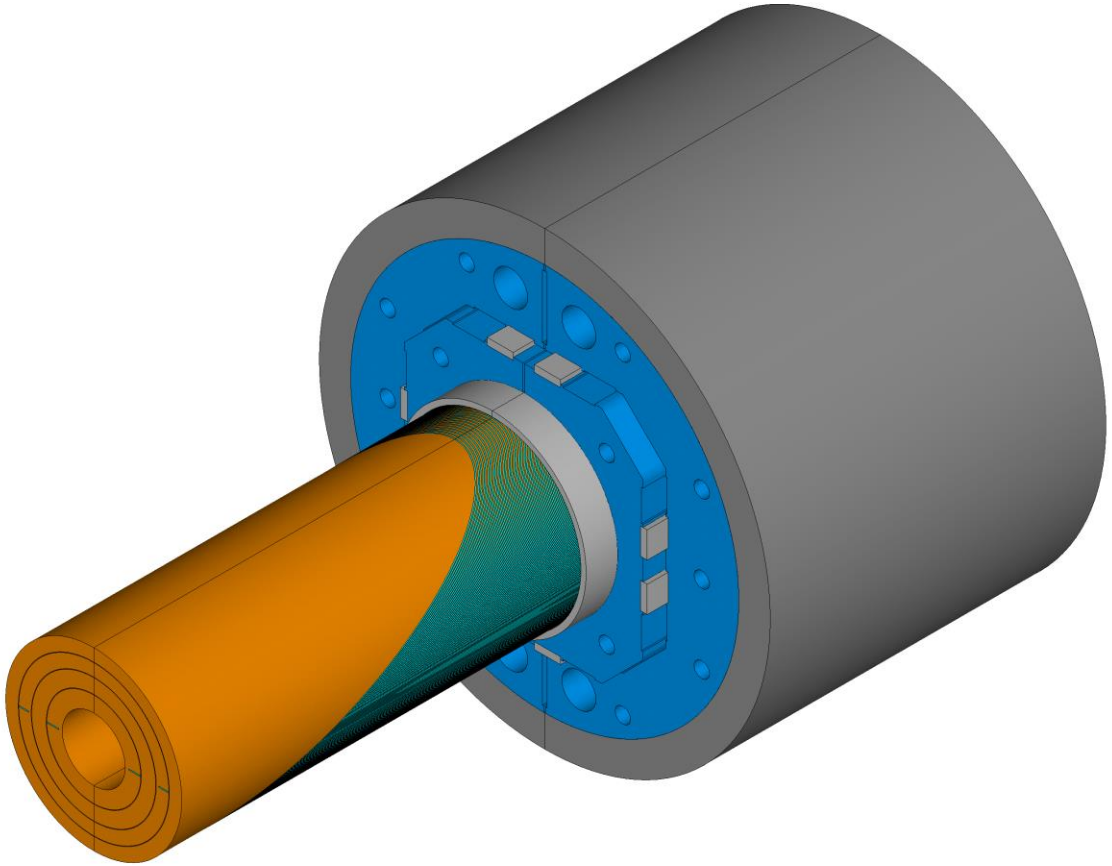
- 30+ % current margin at target fields of 12 T, 4.2 K and 13 T, 1.9 K
- only 1-2% rise of field at conductor in 3D

TABLE IV
SHORT-SAMPLE AND CURRENT MARGIN

operating point	current (kA)	energy (MJ)	layer pair	conductor field (T)	I_{ss} (kA)	current margin
12 T, 4.2 K	10.1	2.3	1,2	12.2	14.4	30%
			3,4	10.2	15.3	34%
13 T, 1.9 K	11.1	2.7	1,2	13.2	16.2	32%
			3,4	11.1	16.8	34%

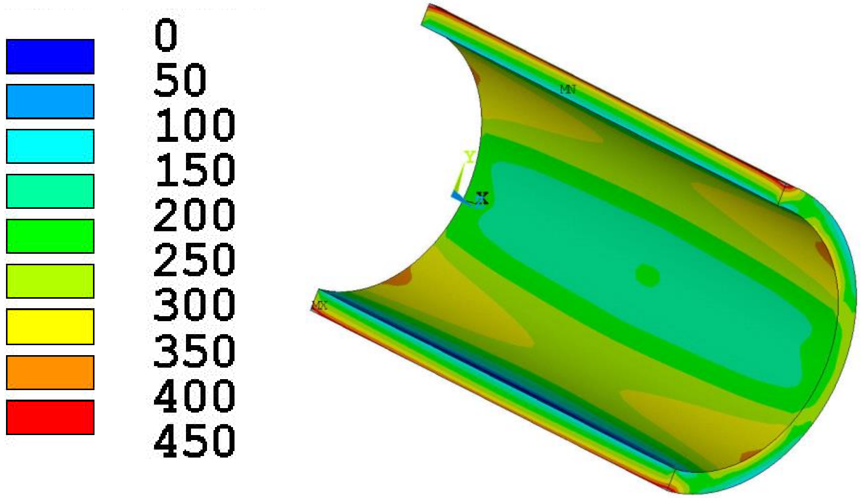
MDP meeting 2022

Mechanical analysis using 3D model



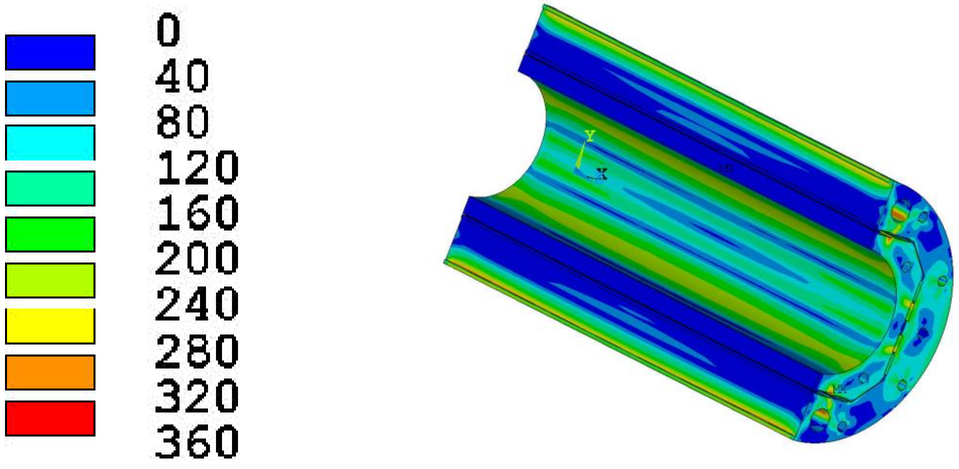
- Geometry
  - Detailed model with slots and holes
  - Detailed geometry of the mandrel and conductor
  - The need of axial pre-load is under investigation
- High number of elements
  - YZ symmetry to reduce element number
  - Coarse mesh
  - Impact of element size studied in 2D
  - Refined mesh calculation still considered
- Results dominated by overlapping solid parts of the mandrel layers
  - Displacement much smaller than in 2D simulation
  - Horizontal key interference reduced from 600 um in 2D model to 50 um in 3D model

Shell and yoke (Stress after cool-down)



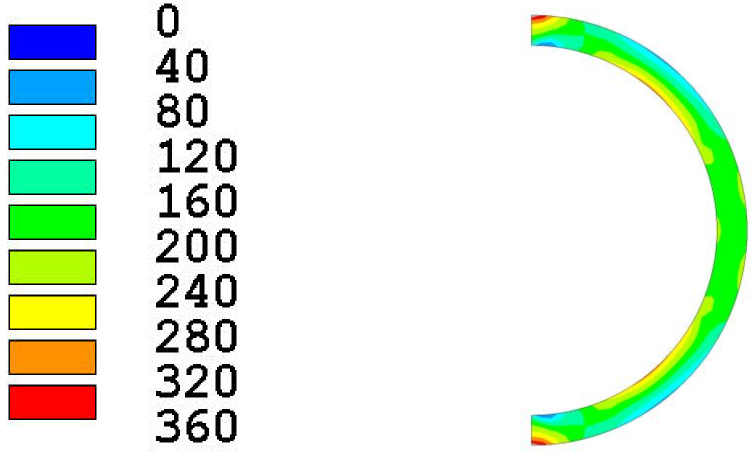
[MPa]

Shell ends < 492 MPa

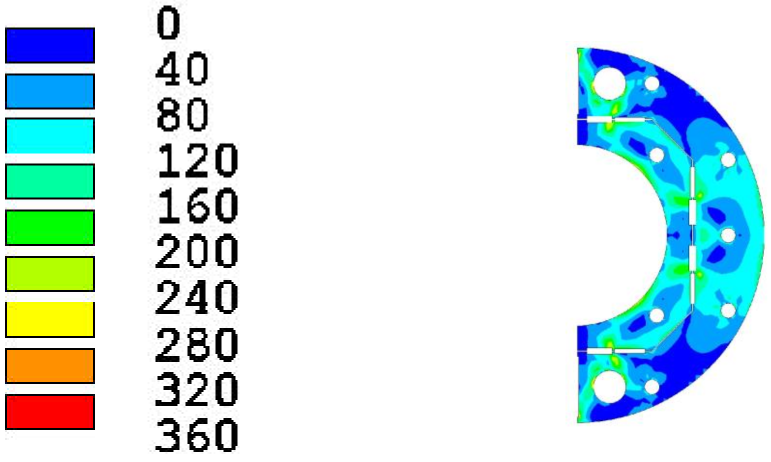


[MPa]

Yoke < 433 MPa

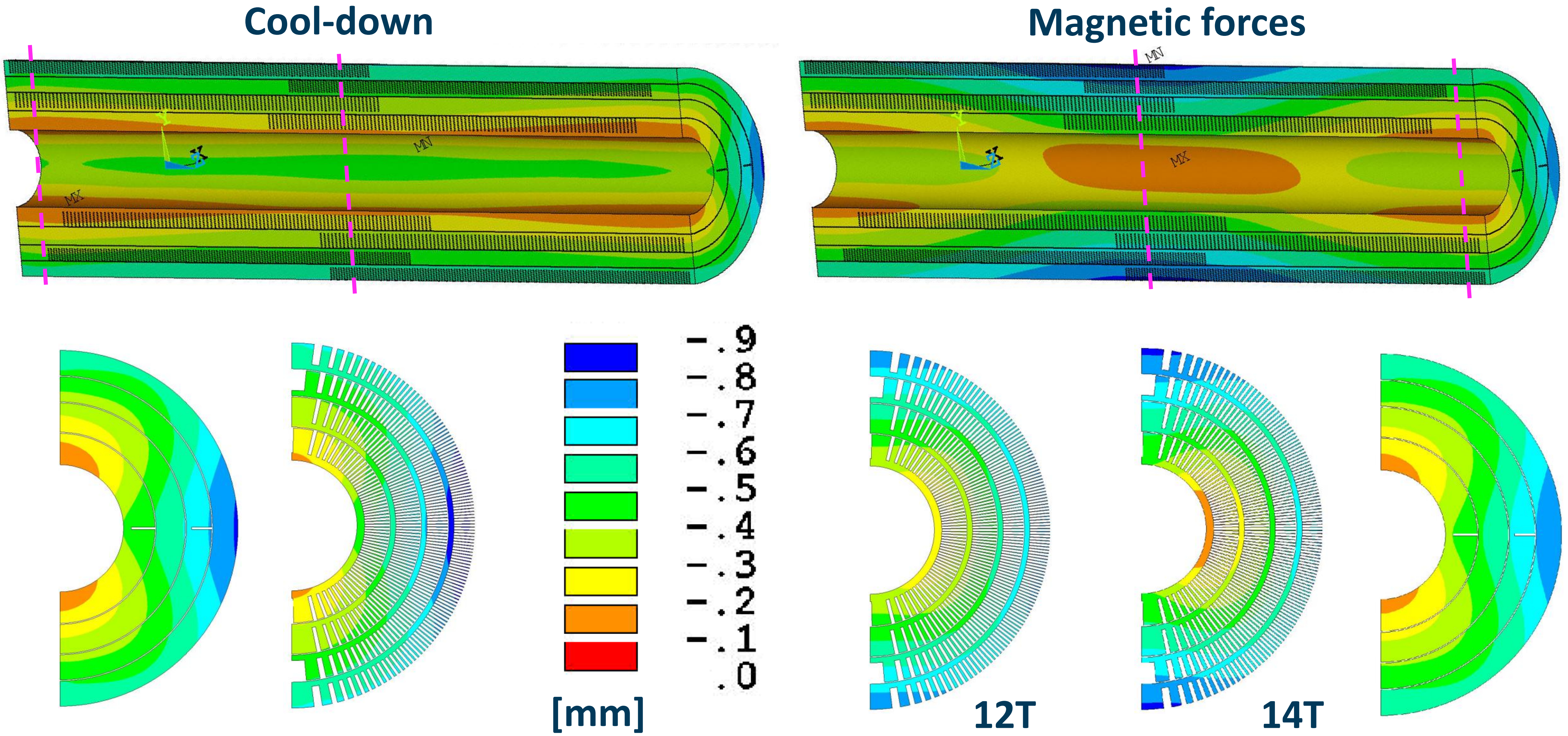


[MPa] Shell central section < 360 MPa

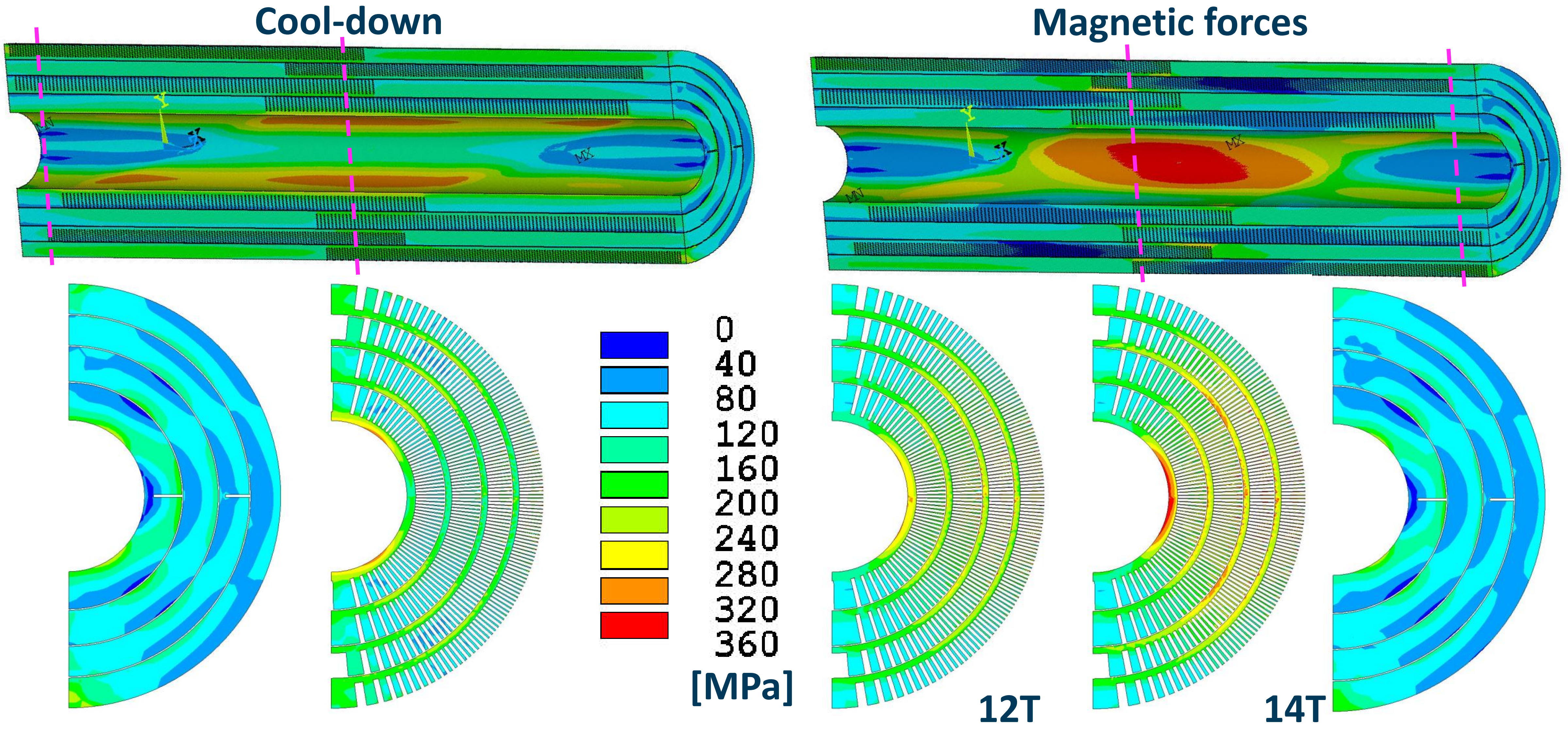


[MPa] Yoke central section < 280 MPa

Mandrel displacement



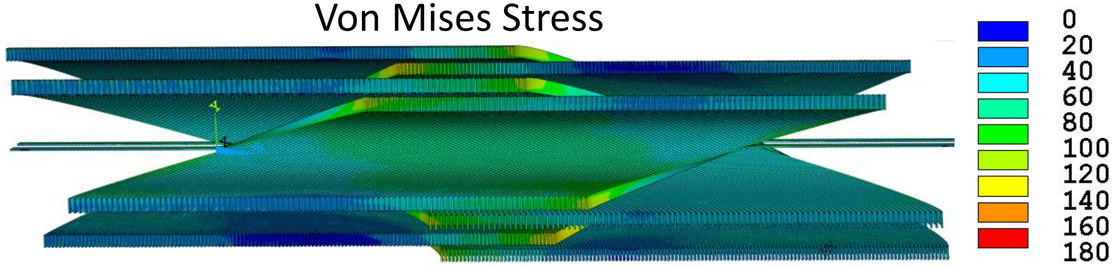
Mandrel – Von Mises stress

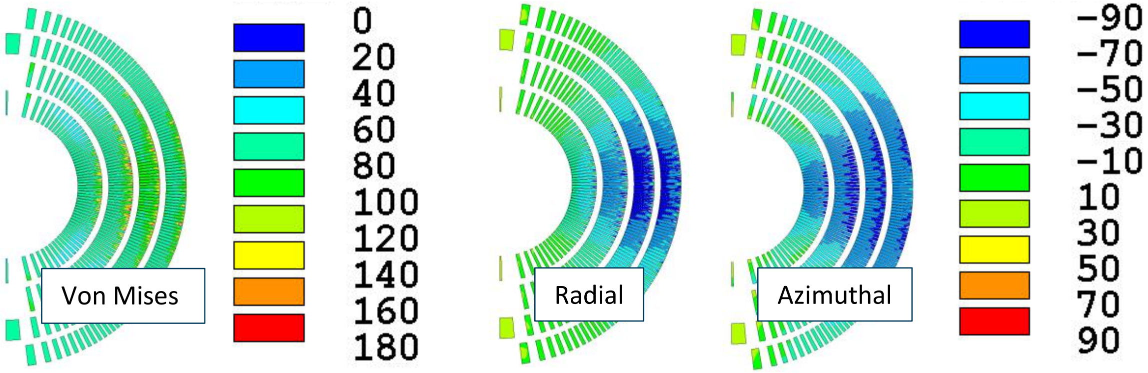


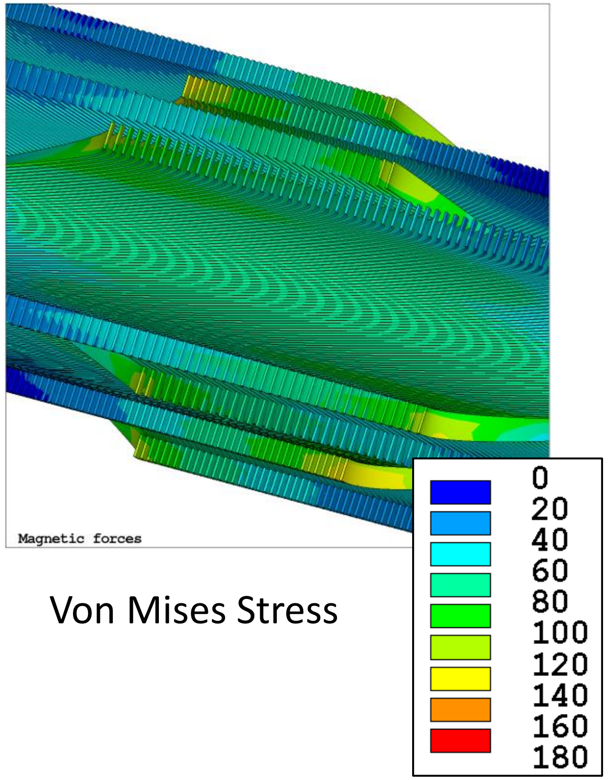
Coil stress – Magnetic forces

Analysis with isotropic cable properties
Next step – analysis with orthotropic analysis

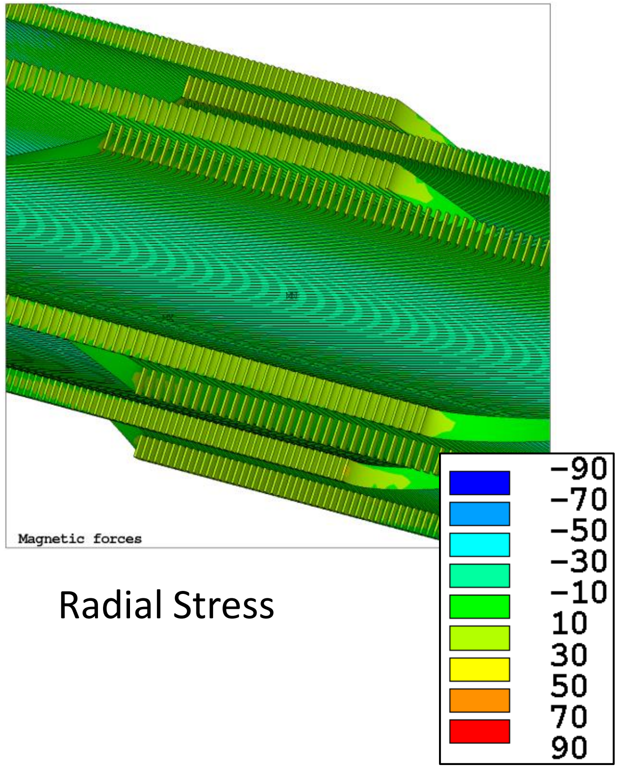
Von Mises Stress



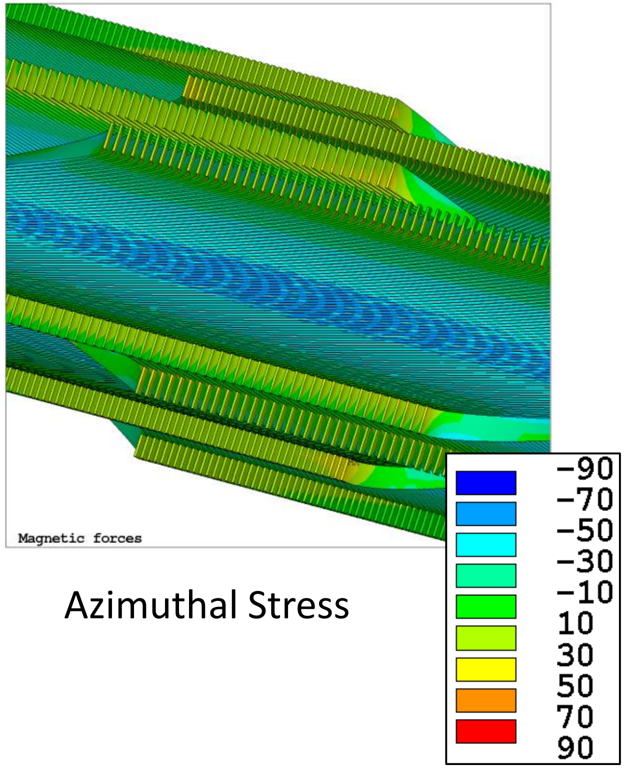




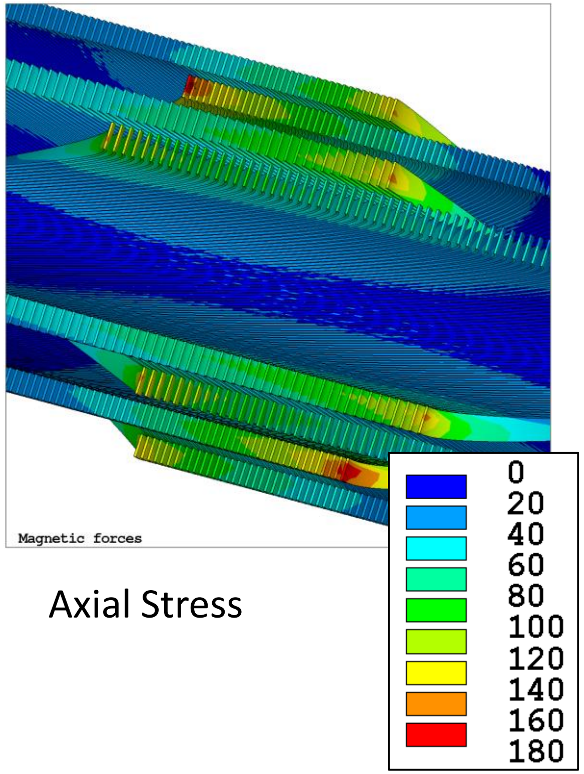
Von Mises Stress



Radial Stress



Azimuthal Stress



Axial Stress

Conclusions

- With key parameters of the CCT6 magnet and the Utility Structure fixed, we are ready to proceed with the engineering design
- Structure preload parameters are selected towards 14 T CCT6 standalone and 12T CCT6 with HTS insert (hybrid analysis is ongoing)
- The Utility Structure ID remains compatible with the 4-layer SMCT dimension but the mechanical analysis should be performed before the engineering design is completed
- Results of the 3D mechanical analysis of the CCT6 magnet are dominated by the 3D effect (overlapping solid mandrel and conductor winding regions)
  - Deformation of the mandrel and the stress in the coil are smaller than in 2D analysis. Analysis with orthotropic material properties will be perform to closely investigate pole-region conductor stress.
  - Stiffer mandrel extremities causes an increase of the shell stress to ~490MPa (detailed analysis will be perform wit the help from G. Valone and AUP experience)
- Axial support system is being implemented in the 3D analysis and its effectiveness will be investigated before the engineering design starts