HQ design and analysis

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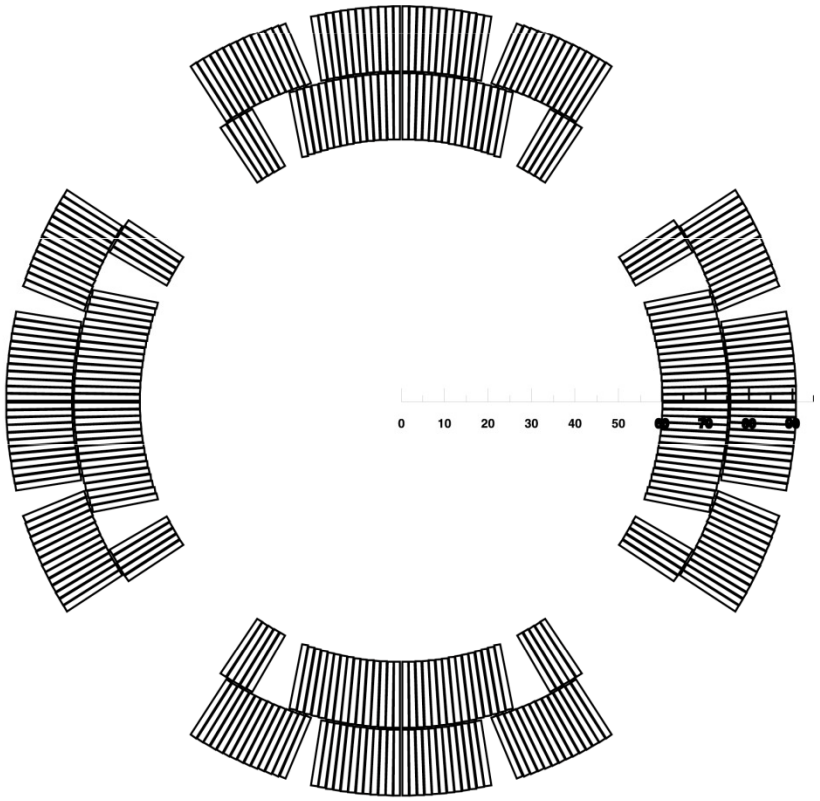
LARP Collaboration Meeting
Napa Valley, CA
April 8-10, 2009

Outline

- Magnet design
- Magnetic analysis
  - Conductor peak field
  - Magnet parameters
  - Field quality and saturation effect
- Mechanical analysis
  - Pre-load conditions
  - Coil and structure stress
- Conclusions

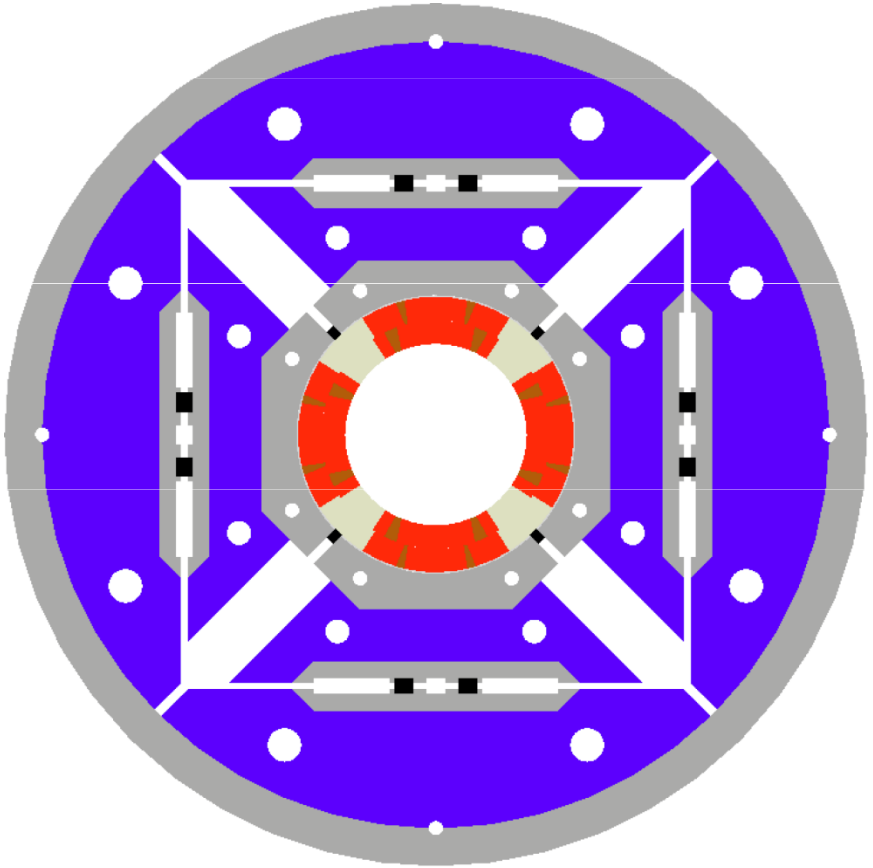
Cable and coil design

- Cable
  - 35 strands
  - Width: 15.150 mm
  - Mid-thickness: 1.437 mm
  - Keystone angle: 0.750
  - Insulation thick.: 0.1 mm
- Coil
  - Aperture: 120 mm
  - 4 blocks
  - 46 turns



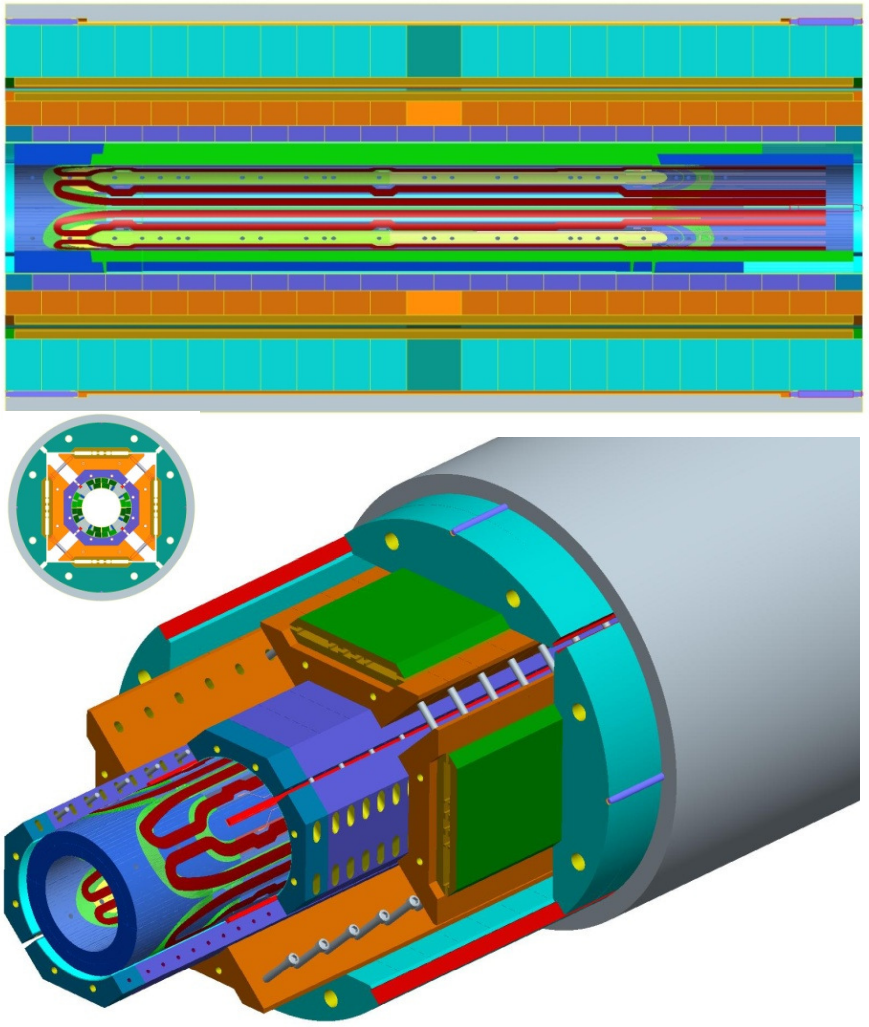
Magnet design
Cross-section

- Aluminum collars
  - 25 mm thick
  - OD = 570 mm
- 4-split iron yoke
- Bolted iron pads
  - Gaps for coil end support and cooling channels
- Iron masters
  - 2 bladders 50 mm wide
  - 2 interference keys
- Bolted aluminum collars for azimuthal alignment
- G10 sheet between coil and collars



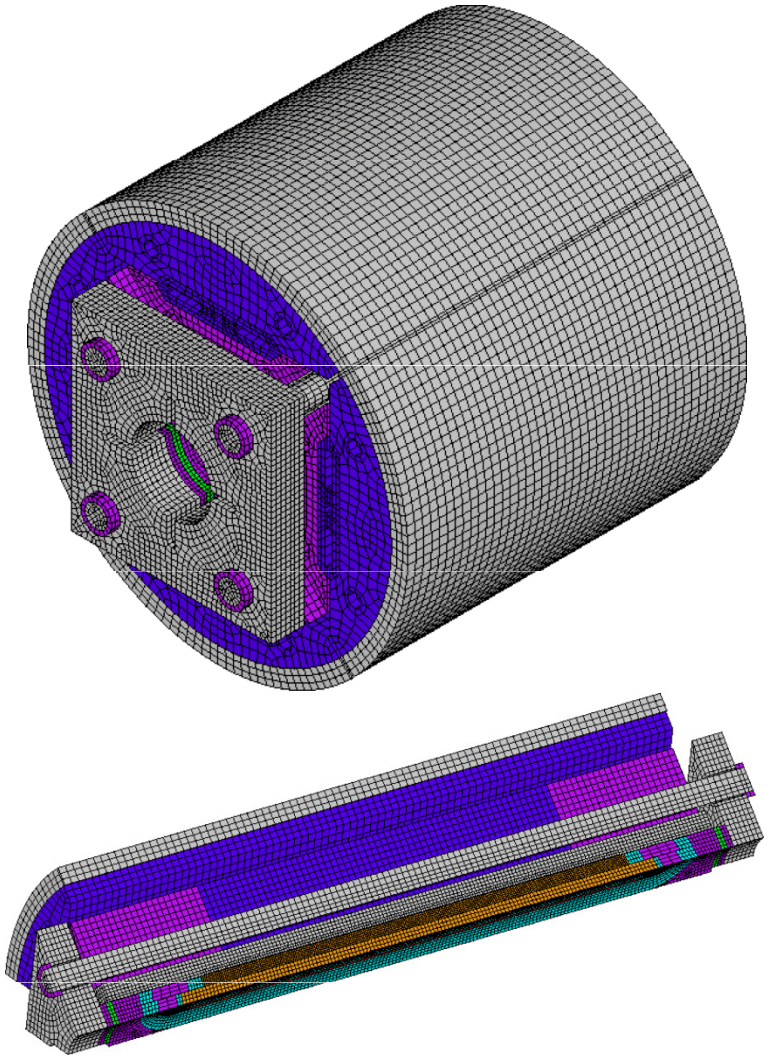
Magnet design
3D components

- Yoke laminations, 50 mm thick with tie rods
- Iron pad laminations, 50 mm thick tie rods
- Collar laminations, 50 mm thick with tie rods
- Iron masters
  - Easy insertion and removal of coil pack (large clearance)
  - Continuous surface
  - Pad-yoke alignment
  - Improved tolerances



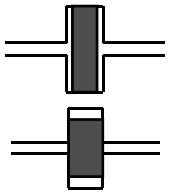
Magnet design
Axial support

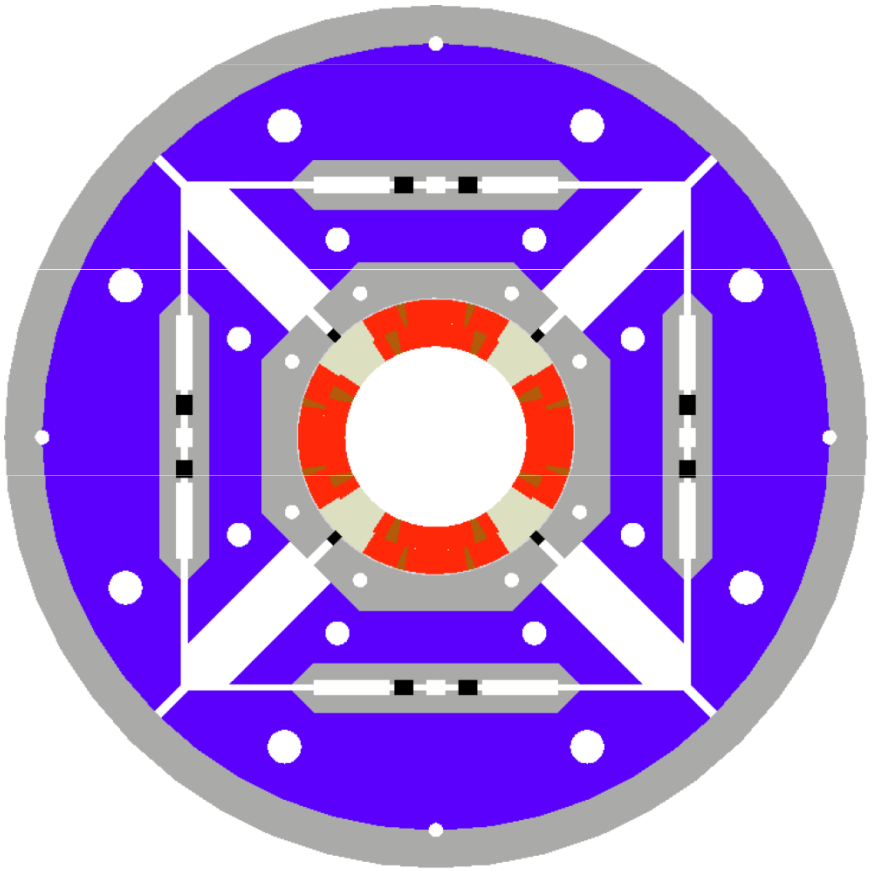
- Stainless steel (Nitronic 40) end plate
  - 50 mm thick
- Aluminum axial rods
  - 34 mm diameter
- Axial pre-load provided by additional plate and piston
  - Piston actuated to spread apart the two end plates
  - Nuts to lock the pre-compression



Magnet design
Alignment

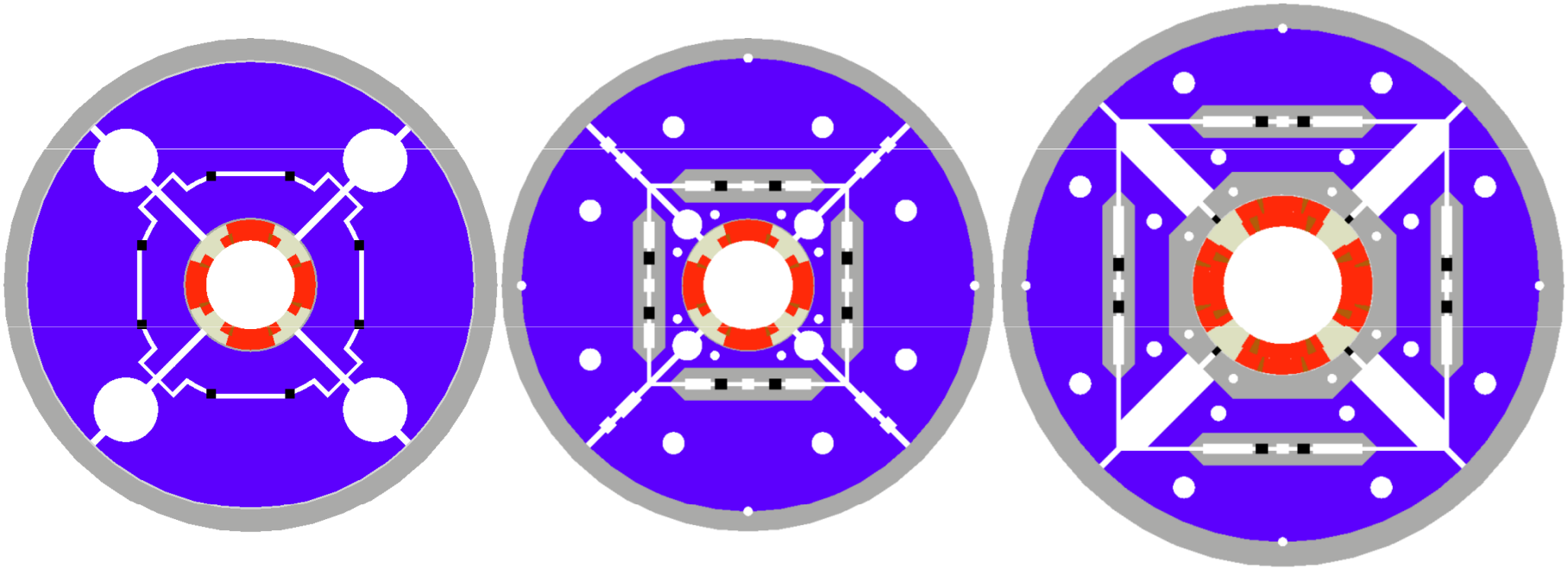
- Pins shell – yoke
- Master keys pad – yoke
  - Trapezoidal shape
  - Interference keys
  - Alignment keys
- Pad – Collar
- Collar – coil
  - Alignment keys
    - Under compression from assembly to excitation





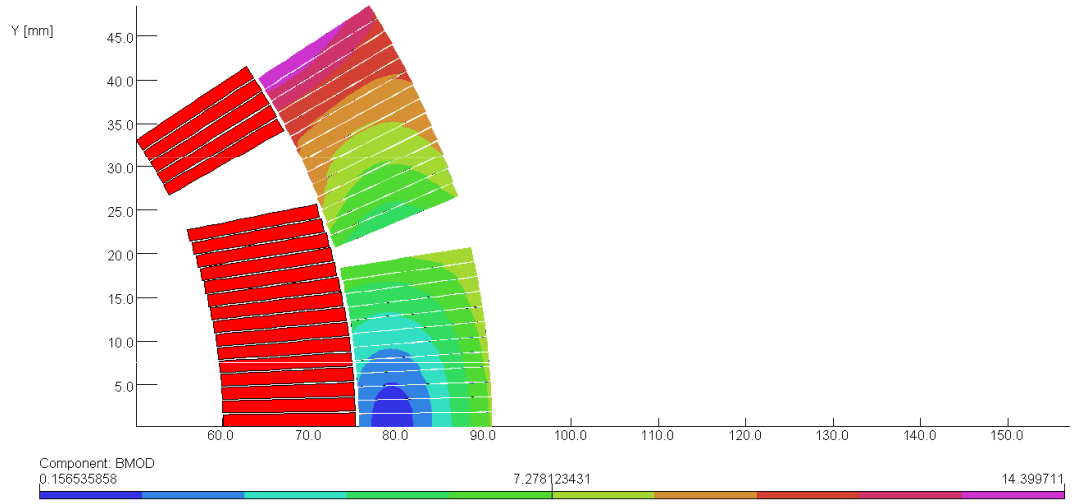
Magnet design
From TQS to HQ

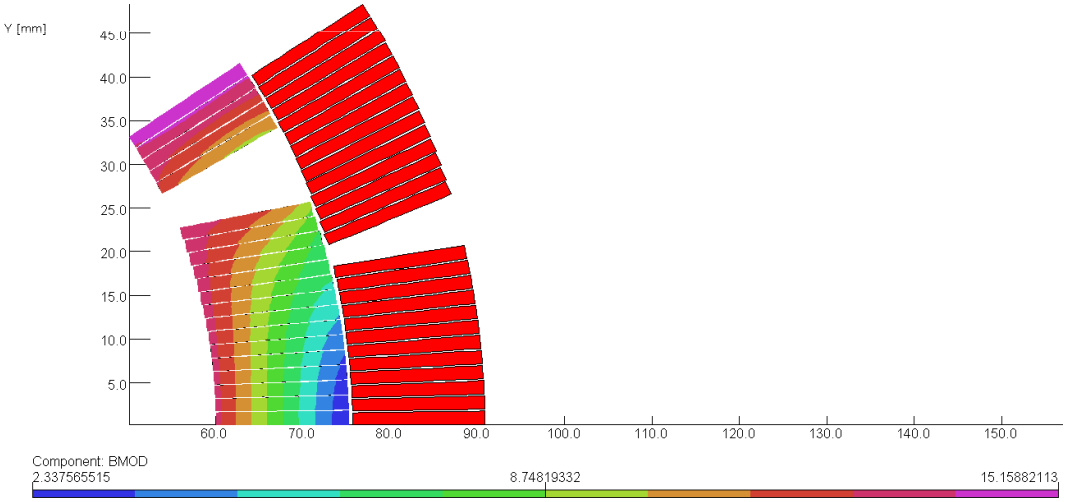
TQS **LQS** **HQ**



2D magnetic analysis
Conductor peak field and magnet parameters

- J_c of 3000 A/mm^2 (4.2 K, 12 T)
- About 0.7 T difference between layer 1 and layer 2

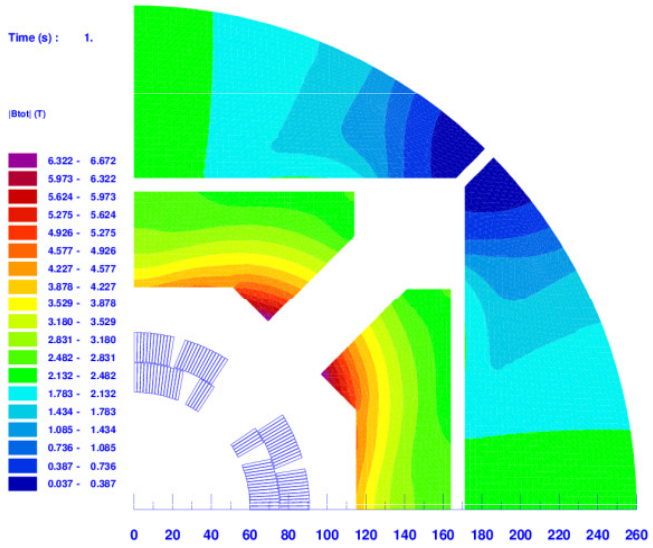


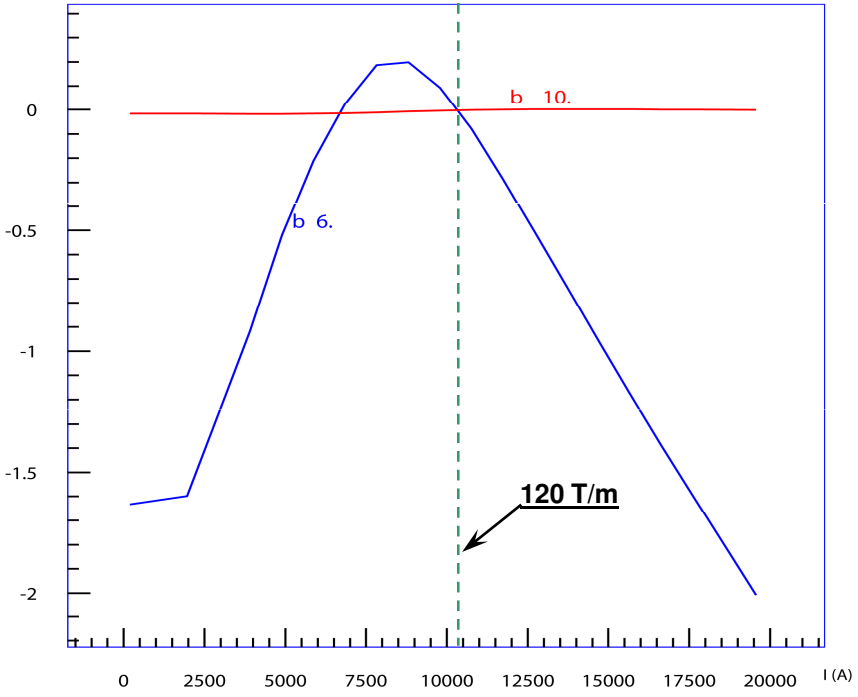


			Layer 1	Layer 2	
Temp.	Current	Grad.	Peak field	Peak field	Stored energy
K	kA	T/m	T	T	kJ/m
4.4	17.73	199	13.90	13.24	1174
1.9	19.45	219	15.17	14.45	1405

2D magnetic analysis
Iron saturation and field quality

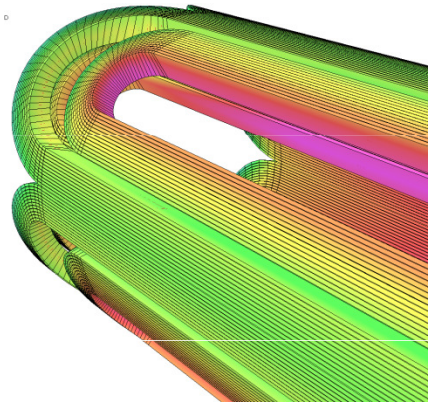
- R_{ref} = 40 mm
- At 120 T/m
  - All allowed harmonics below 0.5 units
- Saturation effect
  - b_6 ± 1 unit from 0 to 20 kA

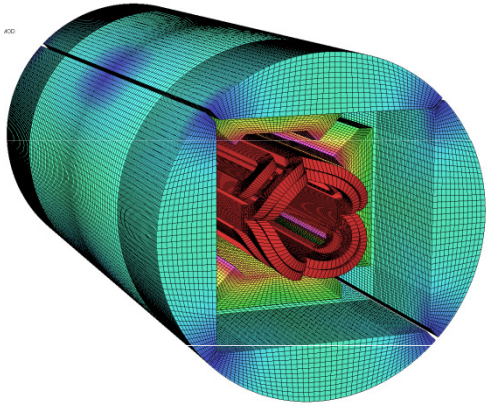




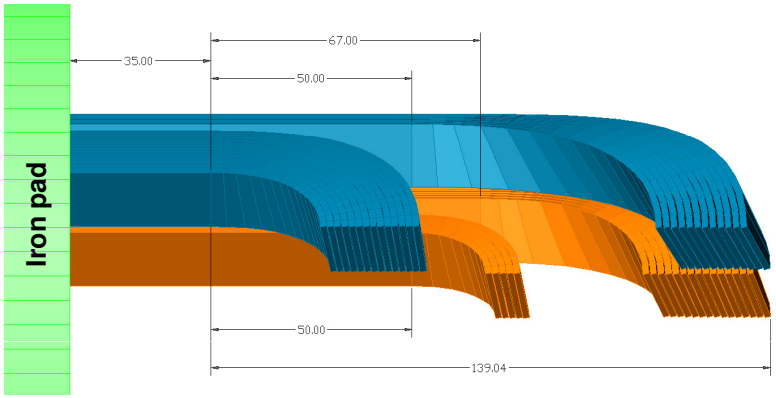
3D magnetic analysis
Conductor peak field

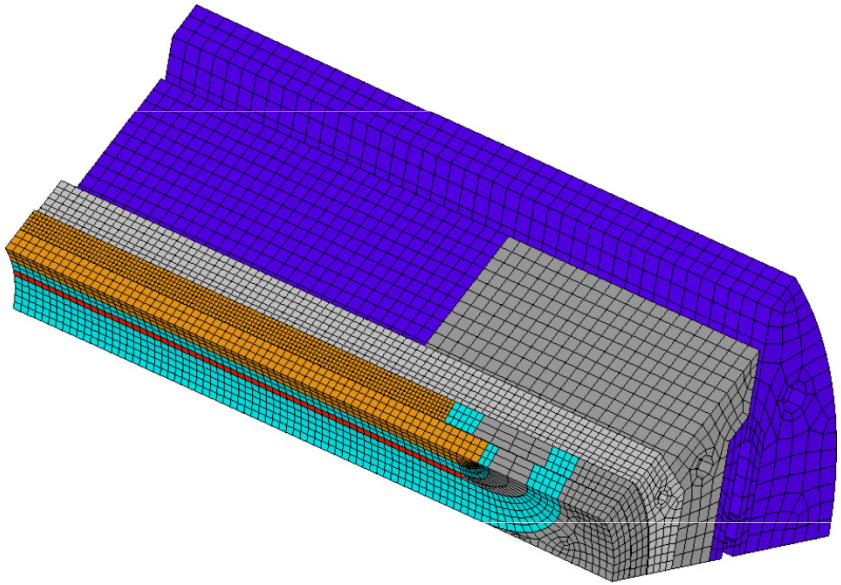
- Peak field in the end located on pole turn, layer 2





- Stainless steel pad over ends
  - About 1% lower peak field in the end with respect to straight section

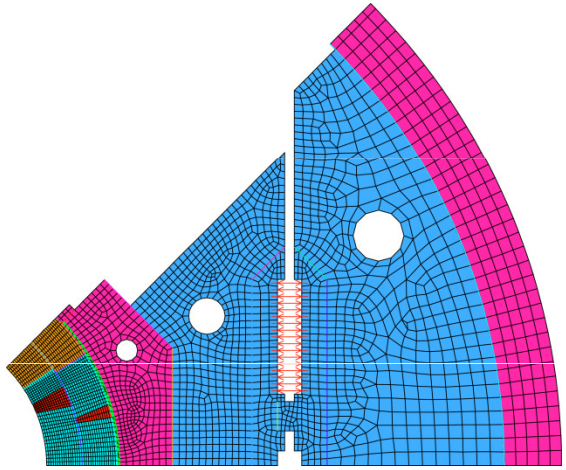




2D mechanical analysis
Parameters and model

- Computational steps
  - Bladder pressurization
  - Key insertion
  - Cool-down
  - Excitation

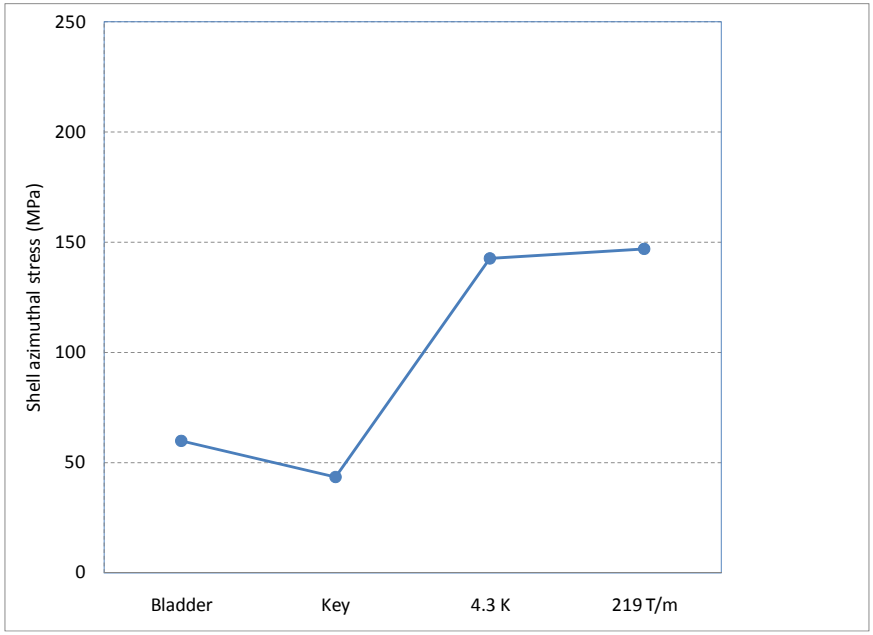
- Impregnated coil surfaces: bonded
- All other surfaces: 0.2 friction factor
- Contact pressure (or tension <20 MPa) between pole and coil
- Two gradient considered
  - 219 T/m: limit conditions
  - 180 T/m: coil peak stress <150 MPa



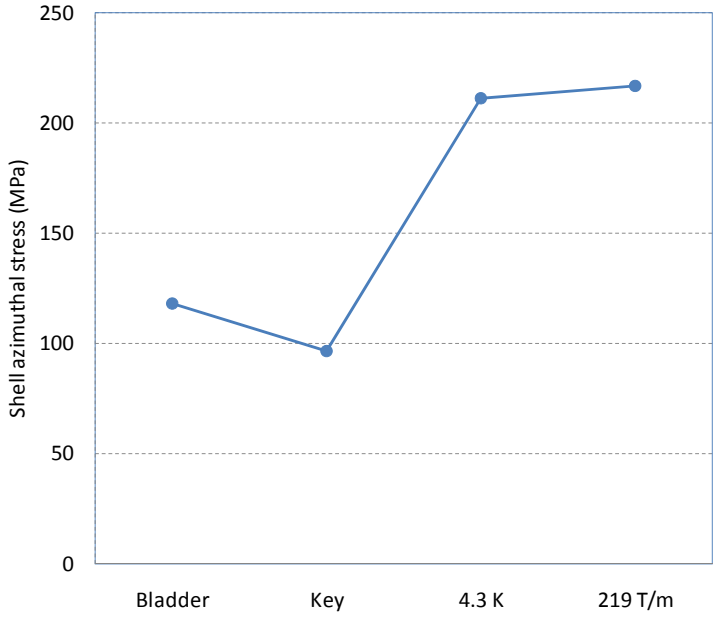
	Grad	T/m	180	219
Layer 1	Fx	N/mm	+2187	+3234
	Fy	N/mm	-1243	-1853
	Fr	N/mm	+1620	+2389
	Ft	N/mm	-1753	-2609
Layer 2	Fx	N/mm	+76	+18
	Fy	N/mm	-2103	-3131
	Fr	N/mm	-724	-1171
	Ft	N/mm	-2097	-3100

2D mechanical analysis
Bladder pressure and shell tension

- Pre-loading for 180 T/m
  - Bladder pressure: 23 MPa
  - Key interference: 0.3 mm
  - Shell tension:

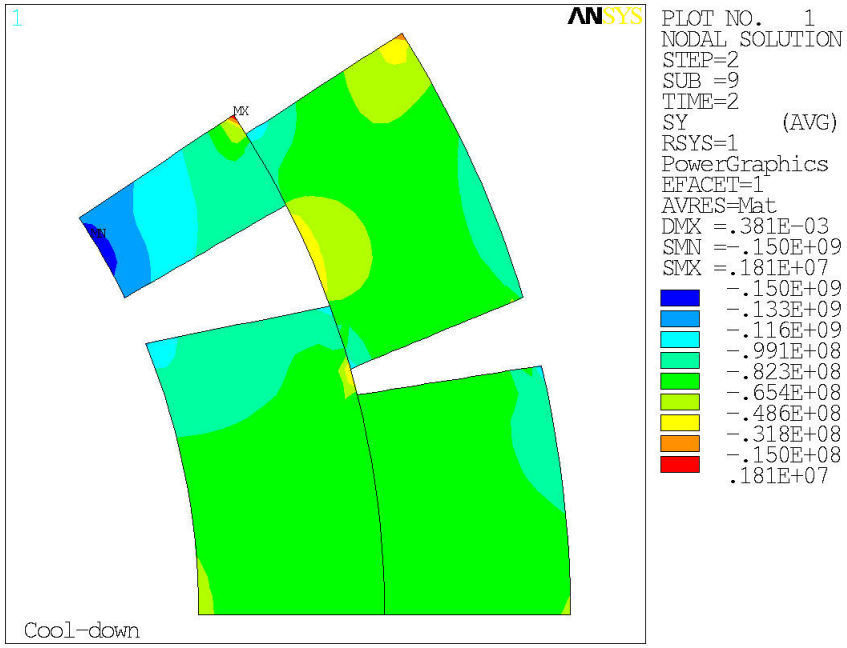


- Pre-loading for 219 T/m
  - Bladder pressure: 46 MPa
  - Key interference: 0.6 mm
  - Shell tension:

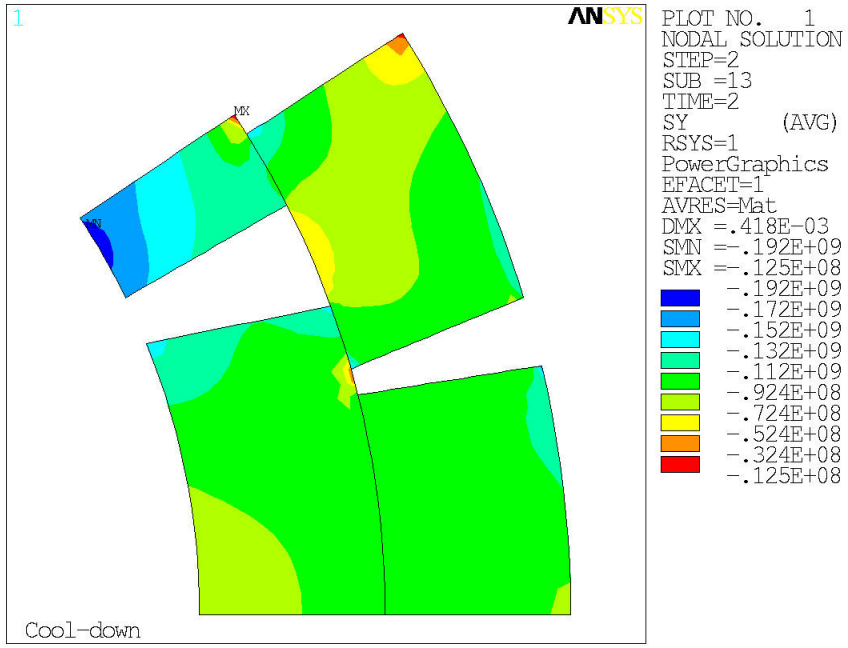


2D mechanical analysis
Coil peak stress after cool-down

- Pre-loading for 180 T/m
  - Coil peak stress: 150 MPa
    - Pole area, inner radius, layer 1

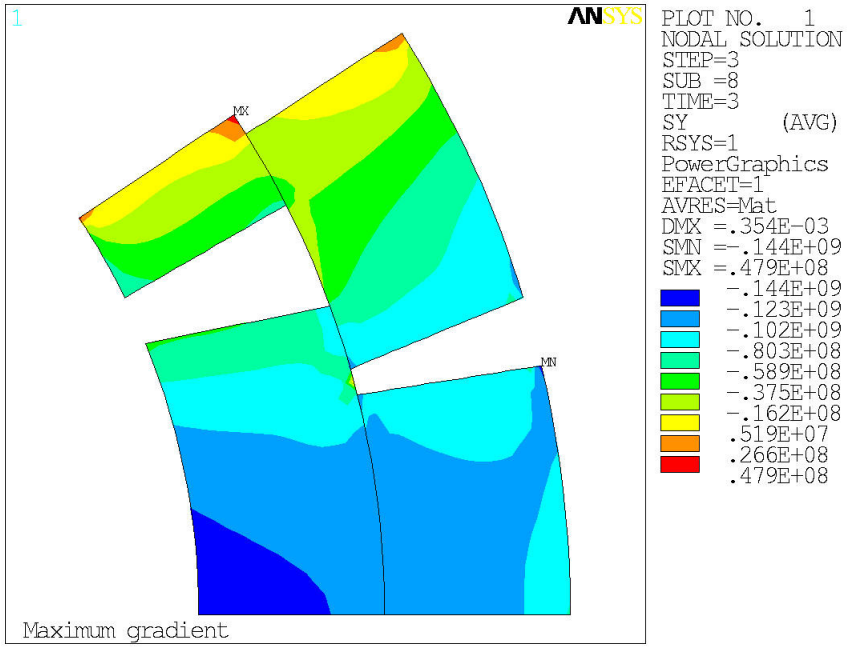


- Pre-loading for 219 T/m
  - Coil peak stress: 192 MPa
    - Pole area, inner radius, layer 1

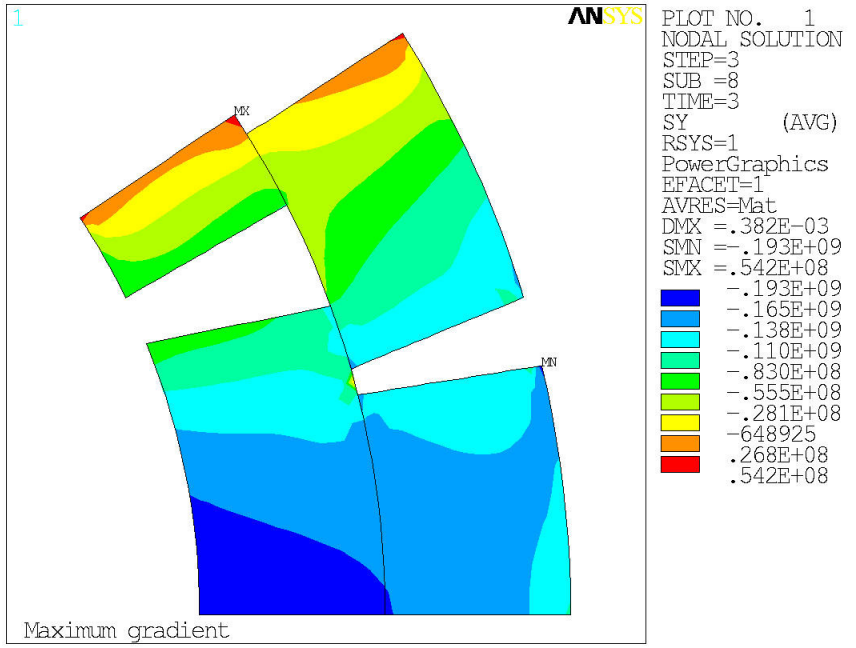


2D mechanical analysis
Coil peak stress with e.m. forces

- Pre-loading for 180 T/m
  - Coil peak stress: 144 MPa
    - Mid-plane, inner radius, layer 1

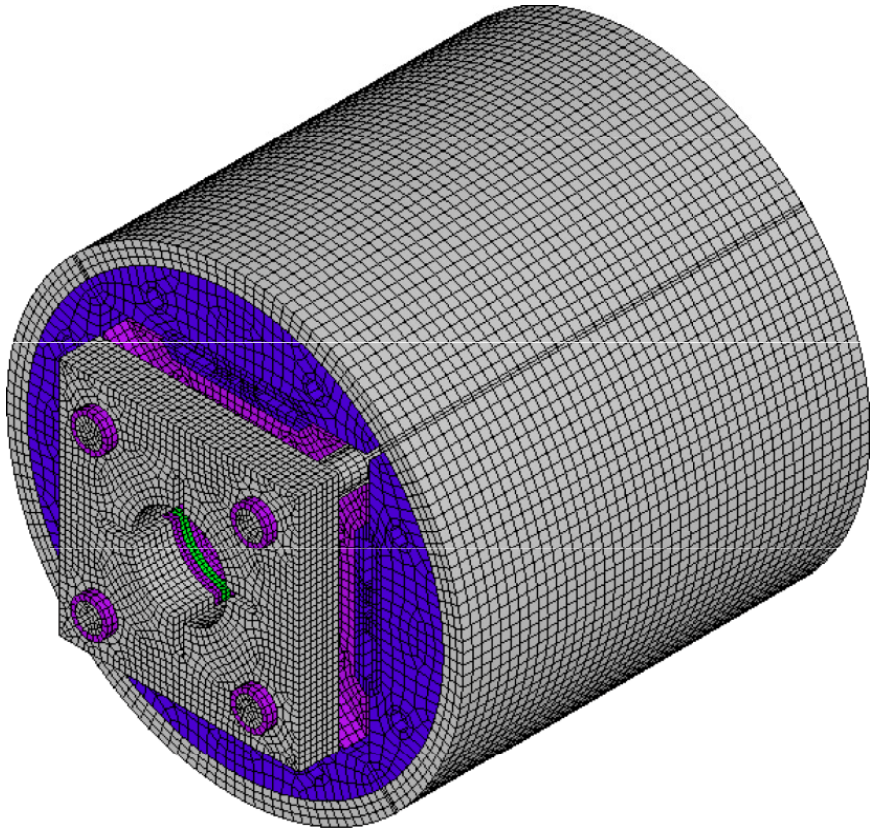


- Pre-loading for 219 T/m
  - Coil peak stress: 193 MPa
    - Mid-plane, inner radius, layer 1

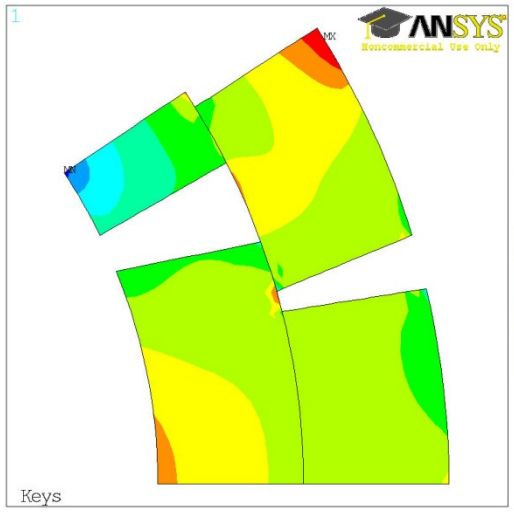


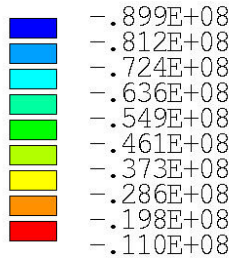
3D mechanical analysis
Parameters and model

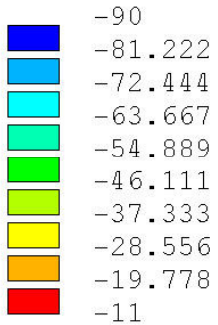
- Computational steps
  - Bladder pressurization
  - Key insertion
  - Cool-down
  - Excitation
- Impregnated coil surfaces: bonded
- All other surfaces: 0.2 friction factor
- Contact pressure between pole and coil

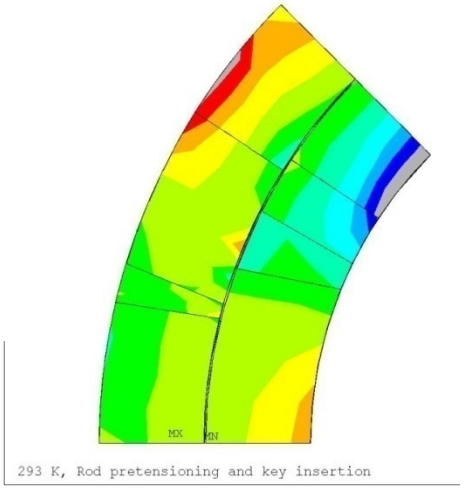


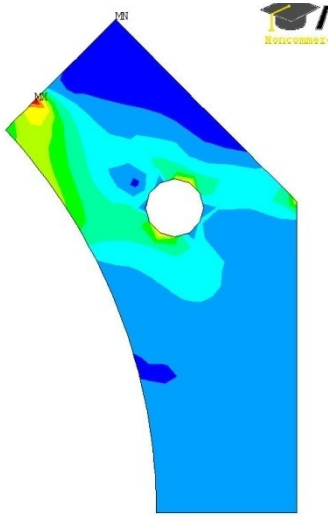
Comparison 2D-3D models

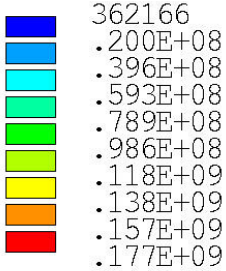


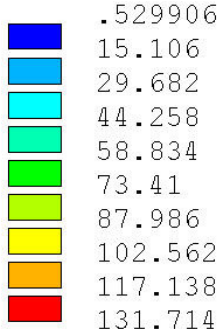


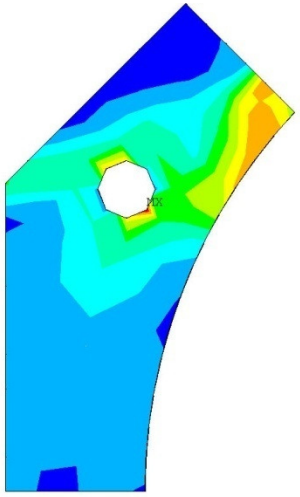






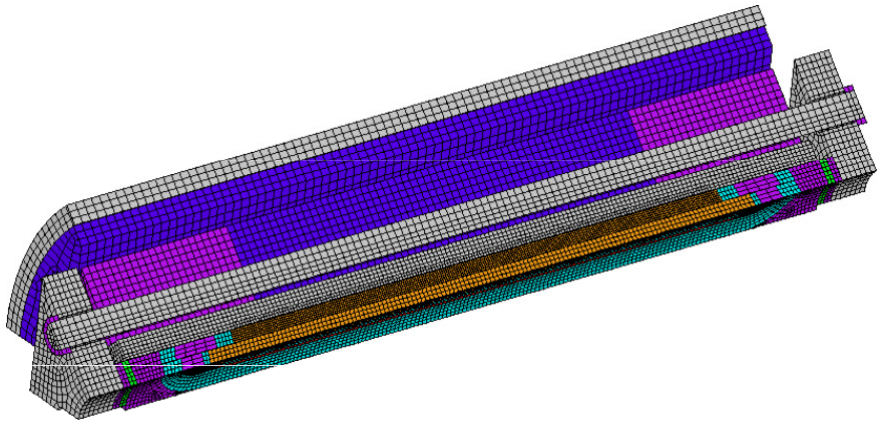


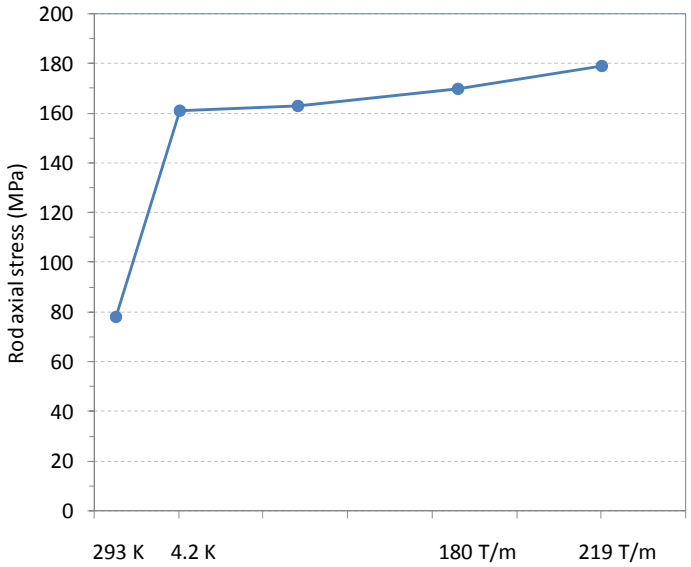


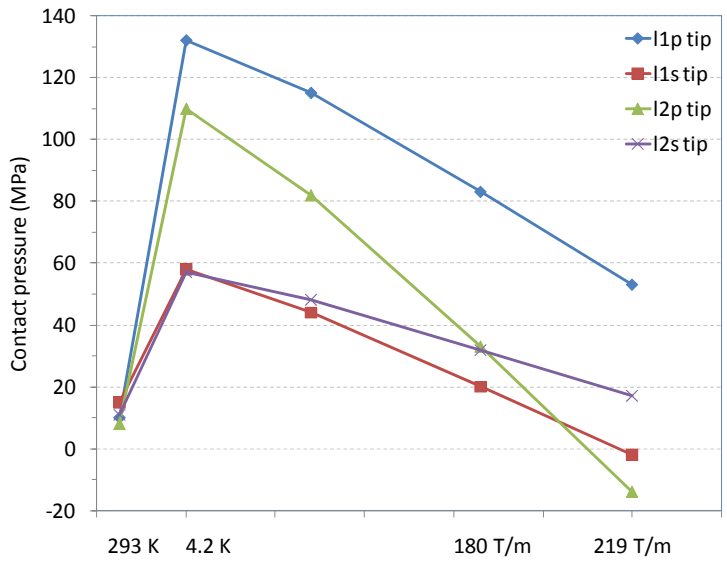


3D mechanical analysis
Aluminum rod tension and coil-pole

- Pre-loading for 219 T/m
  - E.m. force: 1372 kN
  - 620 kN applied at 4.2 K
  - <20 MPa tension at 219 T/m

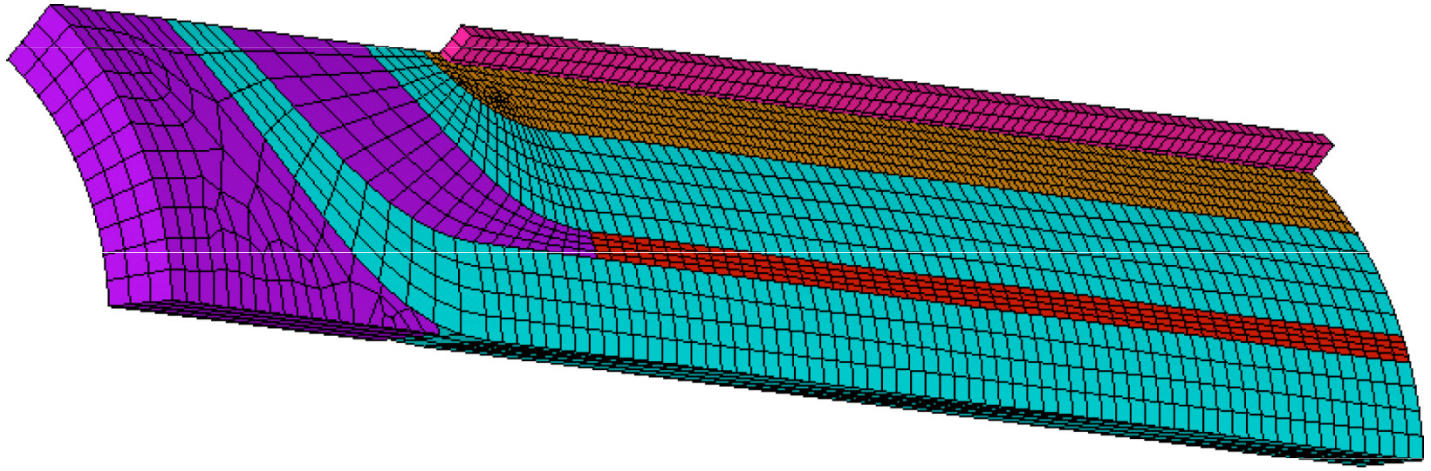


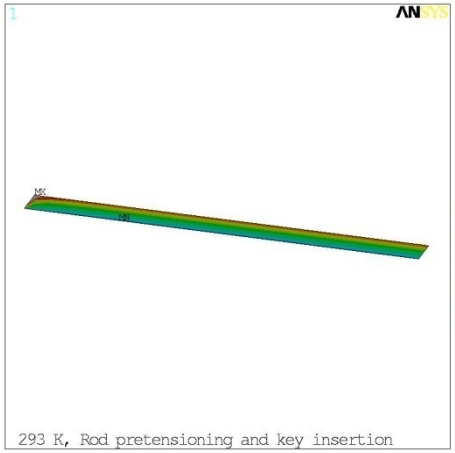


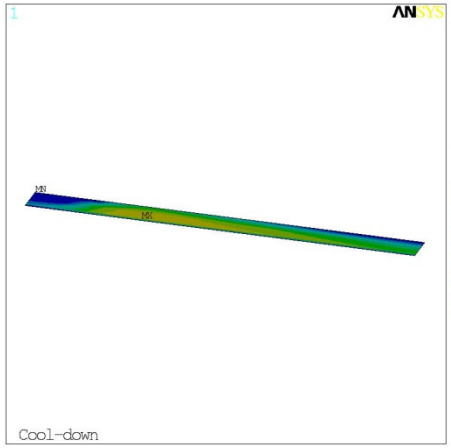


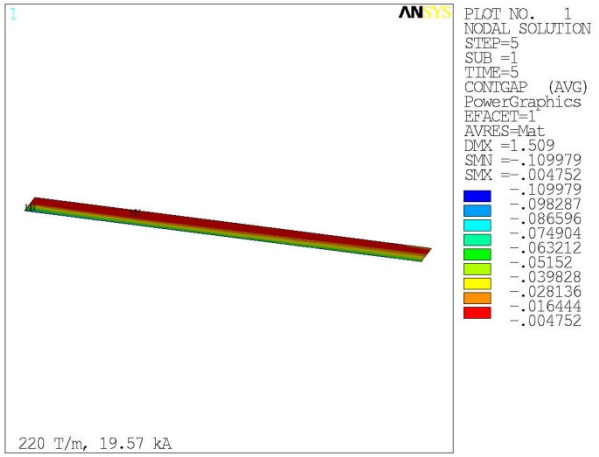
3D mechanical analysis
Alignment key collar-coil

- Contact between collar and alignment key









Conclusions

- HQ is a field quality quadrupole with a 120 mm bore and an expected maximum gradient
  - 199 T/m at 4.4 K and 219 T/m at 1.9 K
- The shell based structure is based on the experience from TQS and LQS
  - Maintains the coil in contact with the pole in the straight section and in the end region up to short sample
  - Provides alignment to coil and structural components
- The coil peak stress can be maintained below 150 MPa with a pre-load for 180 T/m