U.S. MAGNET DEVELOPMENT PROGRAM

BERKELEY LAB

# US Magnet Development Program

## Design of a shell-based Utility Structure


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# Outline

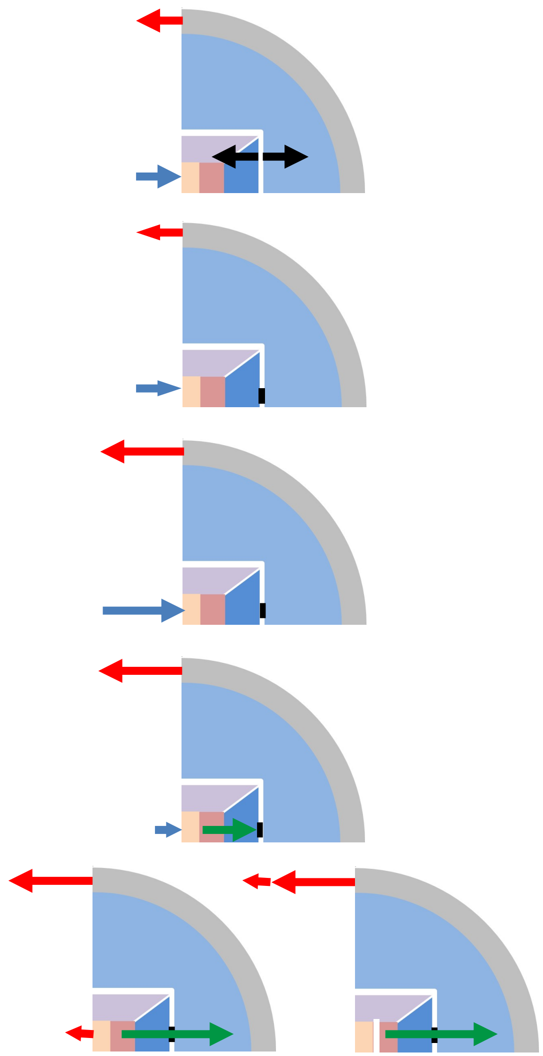
- Goals of the utility structure design effort
- Shell based structure concept
- Present and future coil parameters
- Utility structure cross-section details
- 2D and 3D model results for 15T coil pre-load
- Towards 16 T coil
- Conclusions

# Goals

## Developing a shell-based magnet structure to be used for testing MDP coils

- Provide adequate pre-stress for 17T operation
  - 200MPa peak compressive stress
  - Prevent tensile stress in the pole area (pole-turn separation)
  - Rapid and reproducible magnet assembly/disassembly
  - Compatible with the existing 15 T 4-layer Cos-theta magnet design (FNAL)
- Investigation of design limits and sensitivities
  - Close coil-structure design effort
  - Impact of structure dimensions and features on pre-load capability
  - Coil features and fabrication technology impact on the ability to provide pre-load
  - Effect of fabrication tolerances on mechanical performance

# Bladder and Key pre-load concept in a Shell-based structure



- Bladder operation
  - Pressure acting on the yoke side compensated by reaction force in the shell (tension)
  - Pressure acting on the pad side compensated by the reaction force in the pole (compression)
- Room temperature pre-load
  - Keys replace bladders
  - Reaction forces drop slightly (~10-20%)
- Cool-down
  - Reaction forces increase due to aluminum shell shrinkage
- Magnetic forces (coil pre-loaded)
  - Reaction force in the shell remains almost the same as after cool-down
  - Reaction force in the pole decreases due to magnetic force
- Magnetic forces (coil un-loaded)
  - Magnetic forces higher than pre-load
  - Coil can separate from the pole
  - Reaction force in the pole drops to zero
  - Reaction force in the shell increases due to magnetic forces

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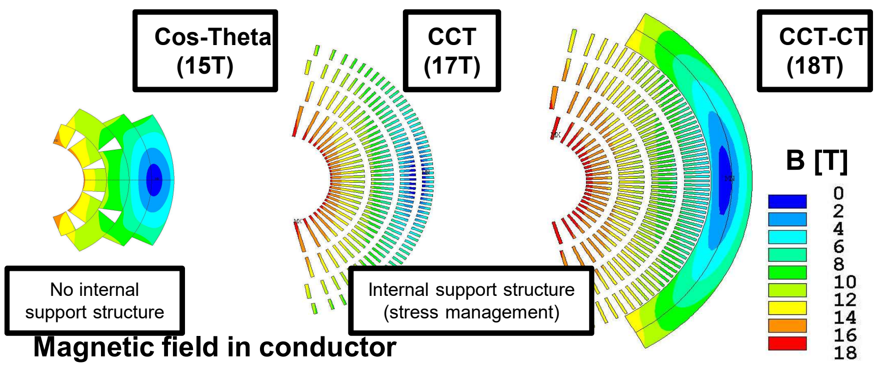
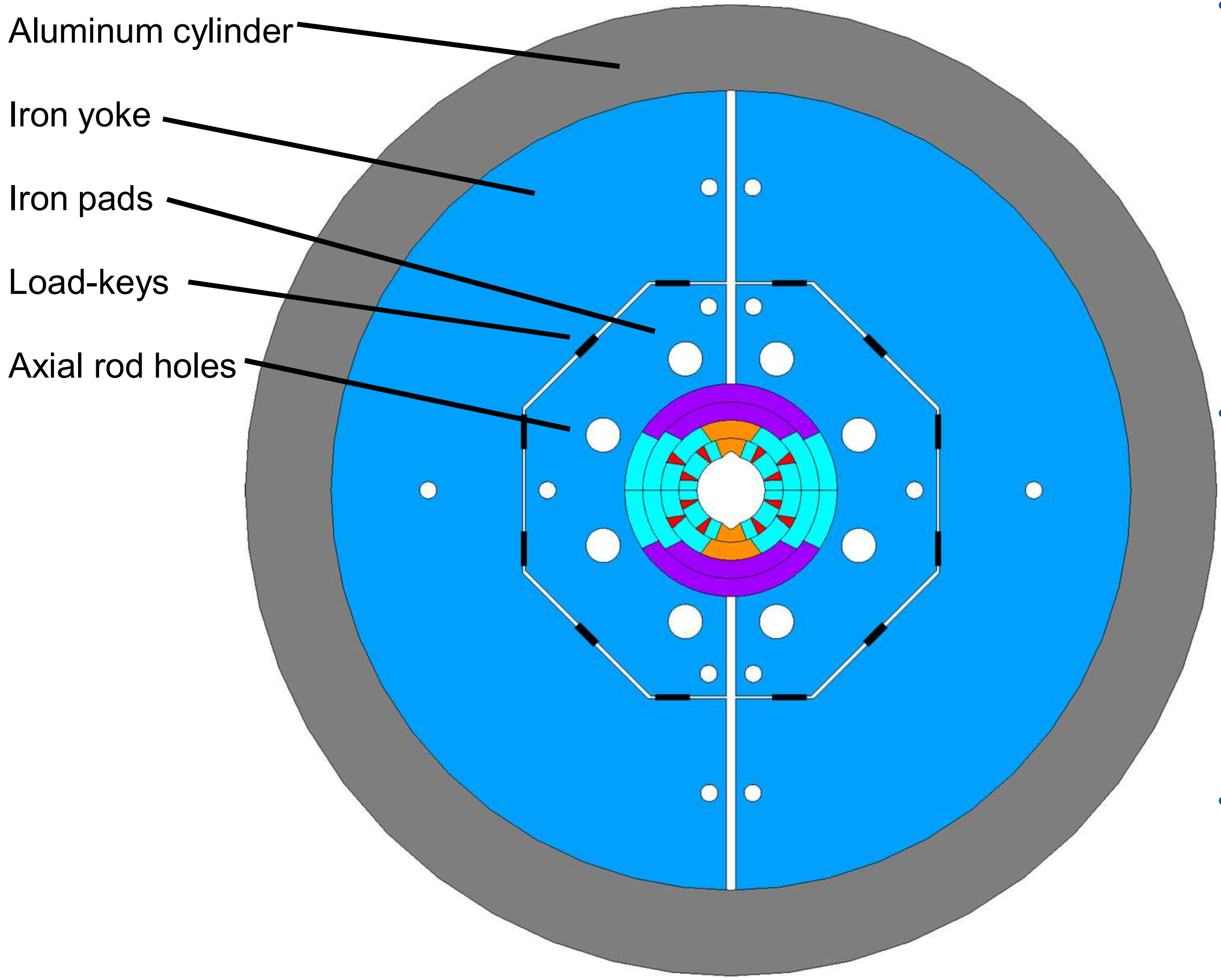
# Coil parameters [preliminary/conceptual/approximate]

| | B [T] | $Fx_{quad}$ [MN/m] | $Fy_{quad}$ [MN/m] | OD [mm] |
|---|---|---|---|---|
| CT | 15<br>15.6 | 6.8<br>7.4 | -3.9<br>-4.5 | 188 |
| CT-SM | 16 | 9.5 | 4.1 | 208 |
| CCT | 17 | 11 | | 194 |
| CCT-CT | 18 | 14 | | 256 |
| HTS/LTS | >16 | ? | ? | < 280 ? |



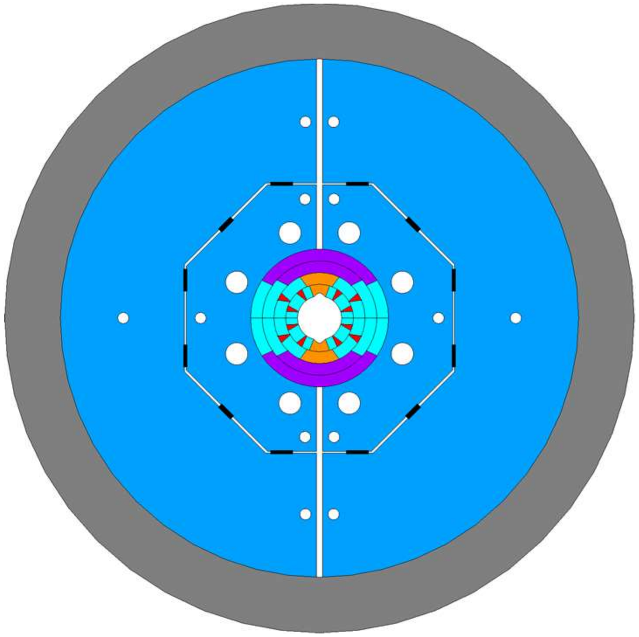
# Structure with octagonal coil-pack



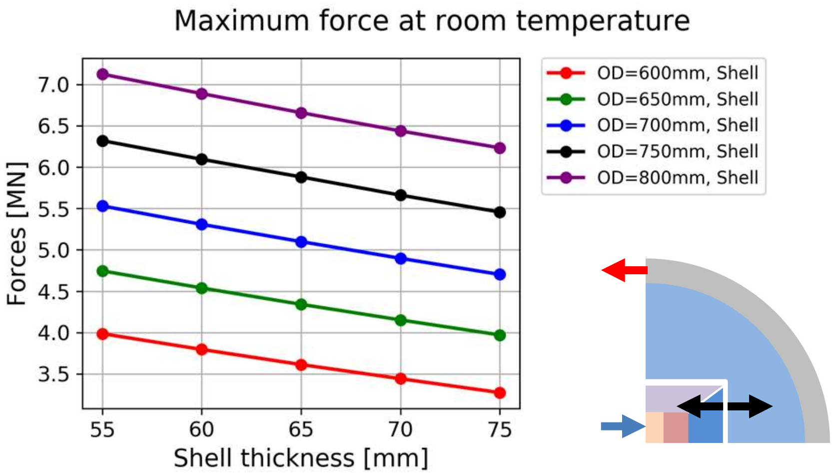

- Structure with octagonal coil-pack
  - Improves yoke stress distribution and rigidity
  - Coil-pack horizontal and vertical size = 320 mm
    - Smaller coil – axial rods in the coil-pack
    - Bigger coils – axial rods in the yoke
- Three load-keys
  - Horizontal
    - Pre-load function
  - Diagonal
    - Stress distribution and rigidity
  - Vertical
    - Alignment
  - Possibility of closing yoke gap
- Bladders
  - Mid-plane (2)
  - Diagonal (8)
  - Yoke (4 or 6)
  - Vertical (2)

# Structure and coil-pack dimensions

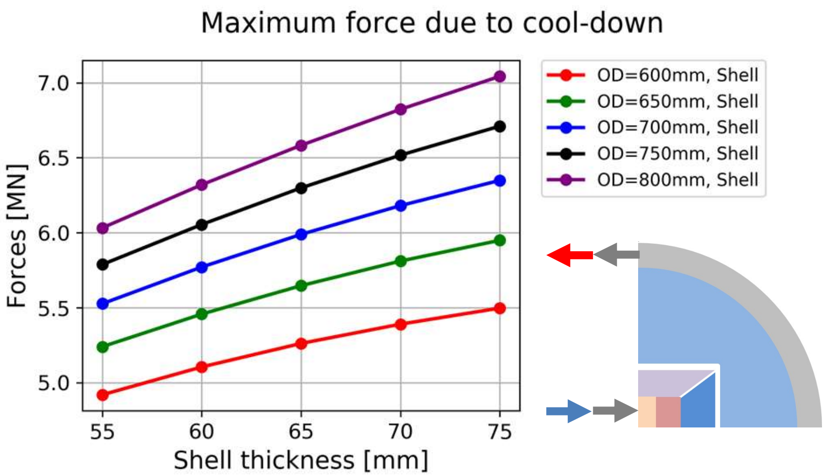
- Currently considered for calculation
  - Coil pack width 320 mm
  - Shell OD 750 mm
  - Shell TH 75 mm
- Current configuration allows pre-tensioning the shell to ~12 MN/m force per magnet quadrant
  - Assuming that yoke remains open
  - Assuming max. 45 MPa bladder pressure
  - Maximum forces defined but the shell OD
- Factors needed to be consider
  - Hybrid HTS/LTS coils (coil pack size)
  - Cryostat (Shell OD)
  - Closed yoke gap (structure rigidity)

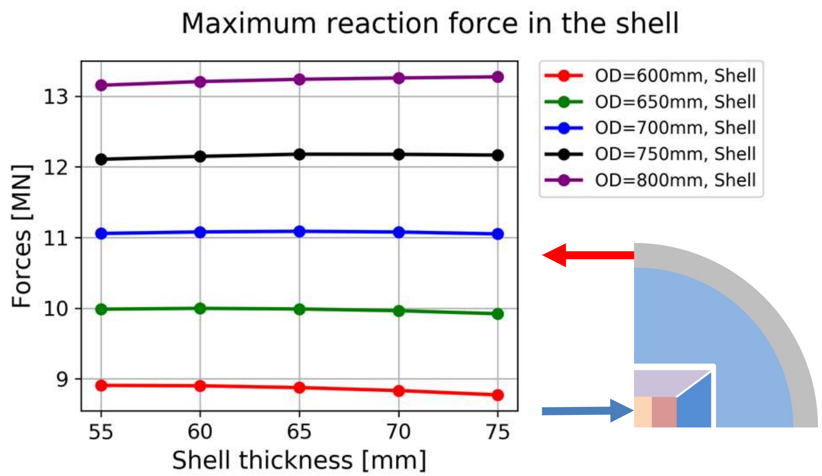


# Maximum reaction forces in the shell

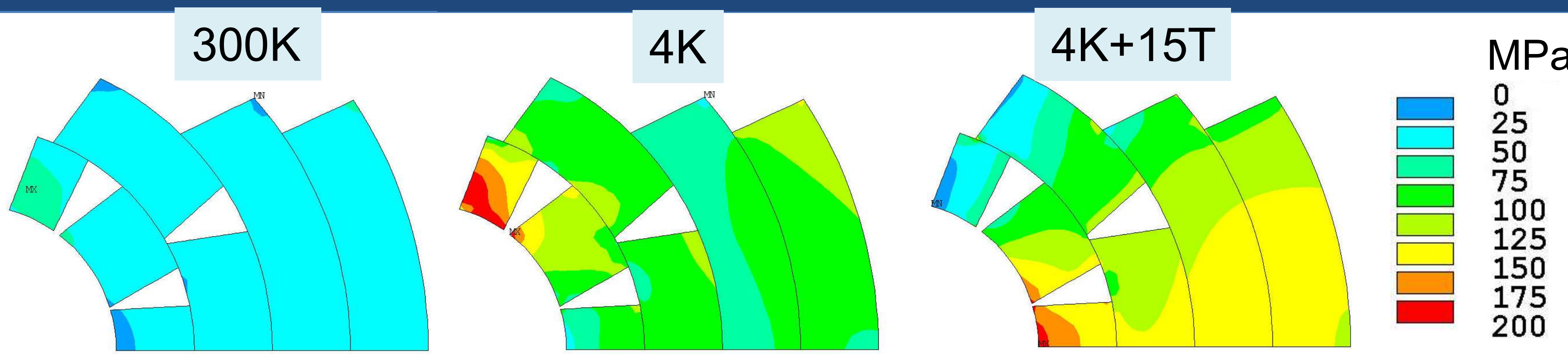



- Maximum force defined by OD
- Thicker shell
  - Less space for bladder
  - Thinner shell can be inserted with fixed bladder pressure
  - Higher force gained during cool-down



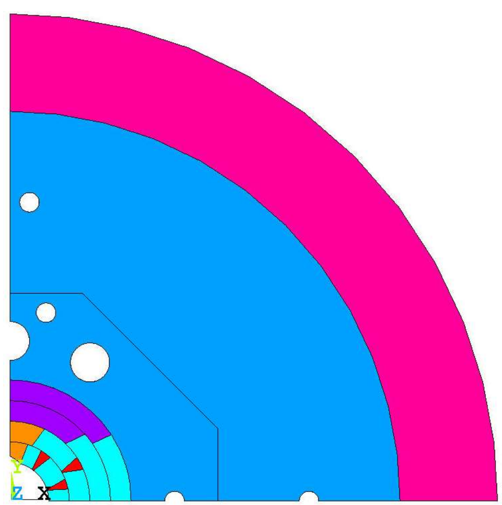



# Utility Structure 2D analysis

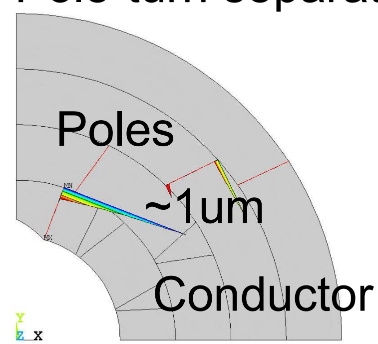



- **15 T Pre-load**
  - **Bladder operation < 80 MPa**
  - **Room temperature < 60 MPa**
  - **Cool-down < 200 MPa**
  - **Magnetic forces < 200 MPa**
- **16 T Pre-load**
  - **Bladder operation ~ 100 MPa**
  - **Room temperature ~ 80 MPa**
  - **Cool-down ~ 220 MPa**
  - **Magnetic forces ~ 220 MPa**

Updated cross-section



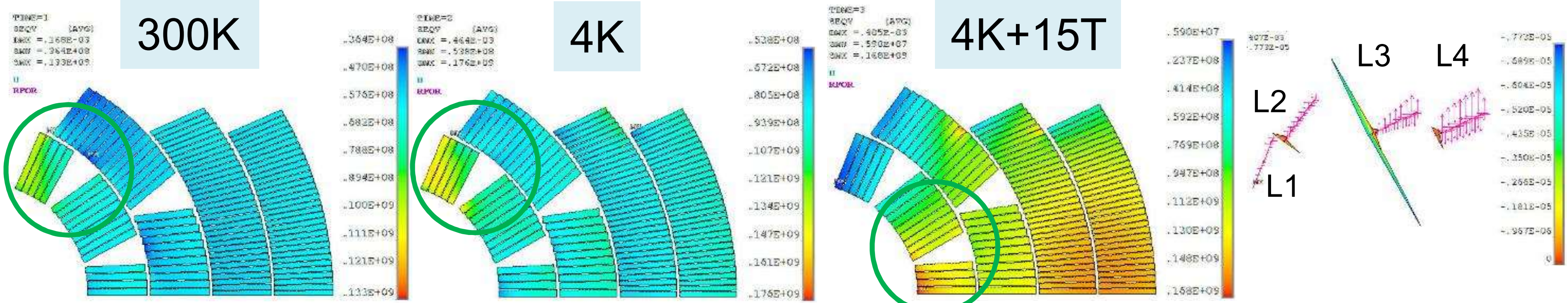
Pole-turn separation




| | 4 K | 300 K |
|---|---|---|
| $E_r$ | 55 GPa | 44 GPa |
| $E_\Theta$ | 44 GPa | 44 GPa |
| $\alpha_r$ | 2.6 x$10^3$ 1/K | |
| αΘ | 3.3 x$10^3$ 1/K | |

# 15 T dipole demonstrator – 2D FEA

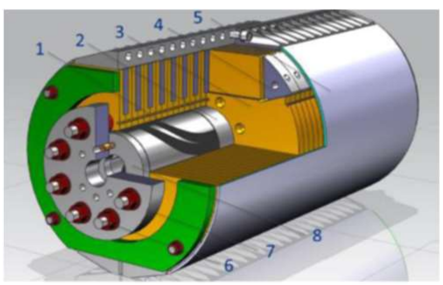
## FNAL analysis

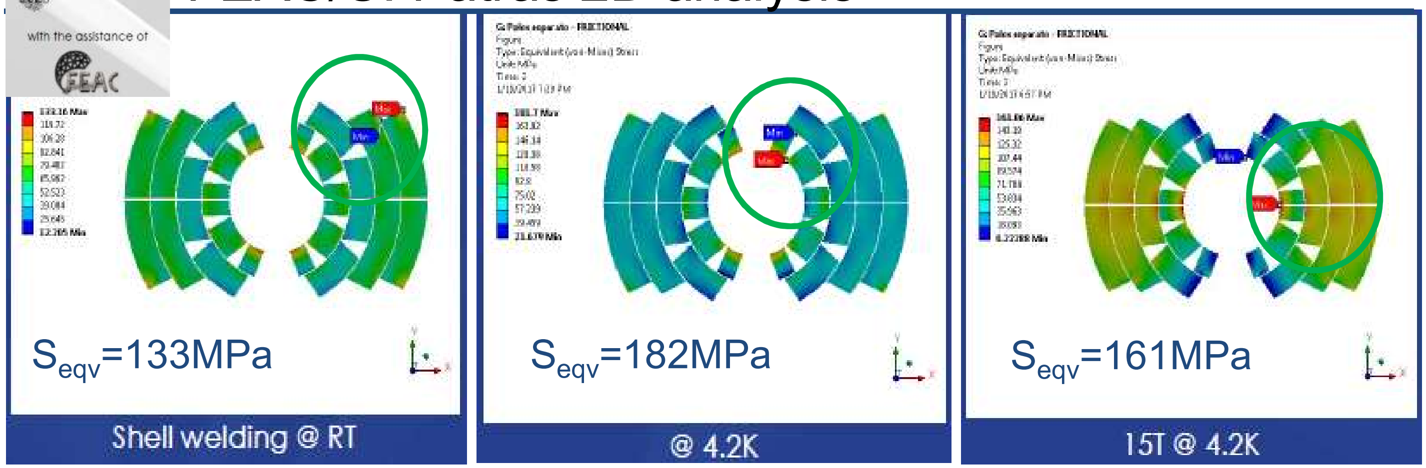



$S_{eqv}$=133 MPa $S_{eqv}$=176 MPa $S_{eqv}$=168 MPa

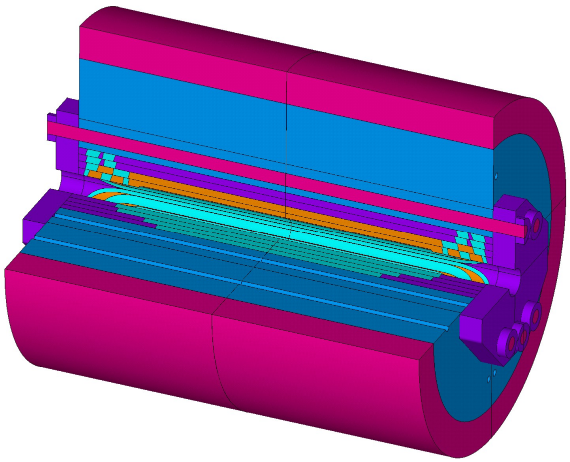
## FEAC/U. Patras 2D analysis

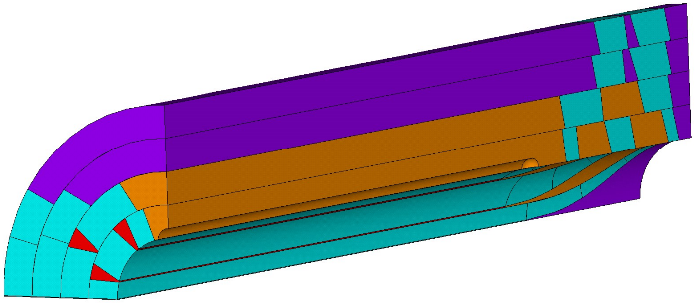
with the assistance of FEAC



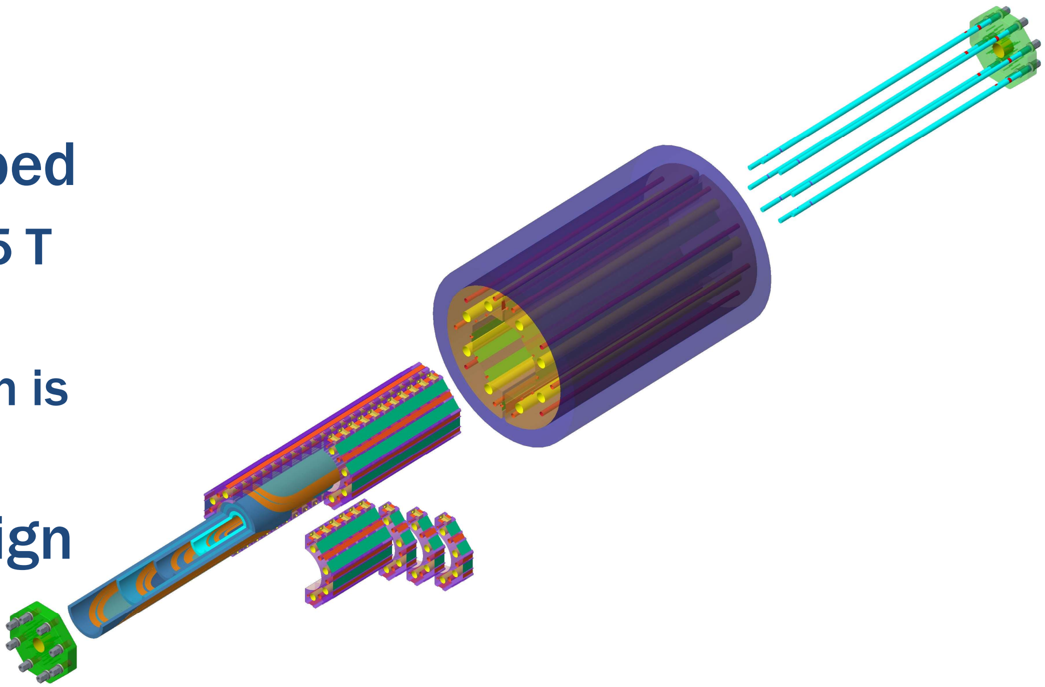


# Development of the 3D model

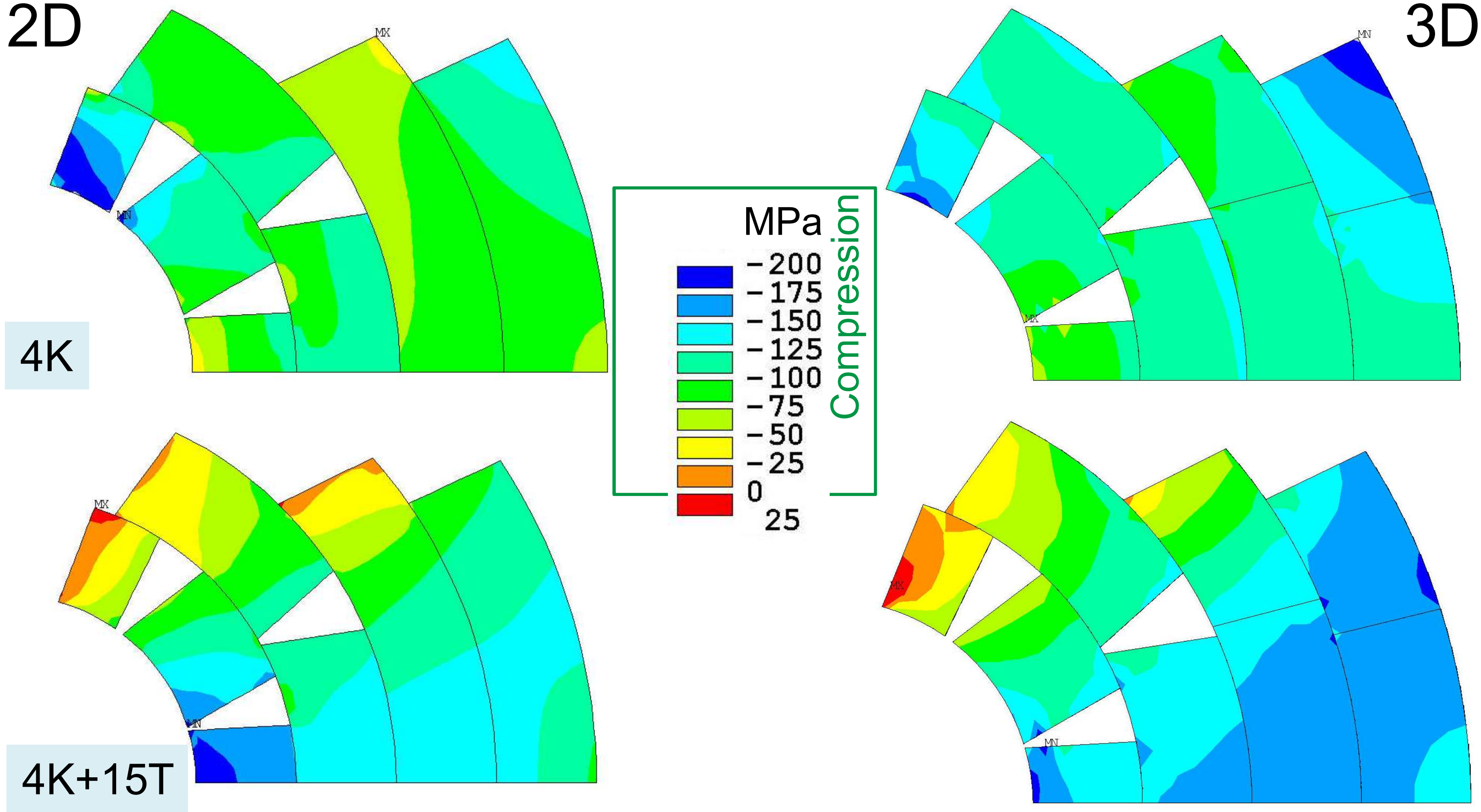




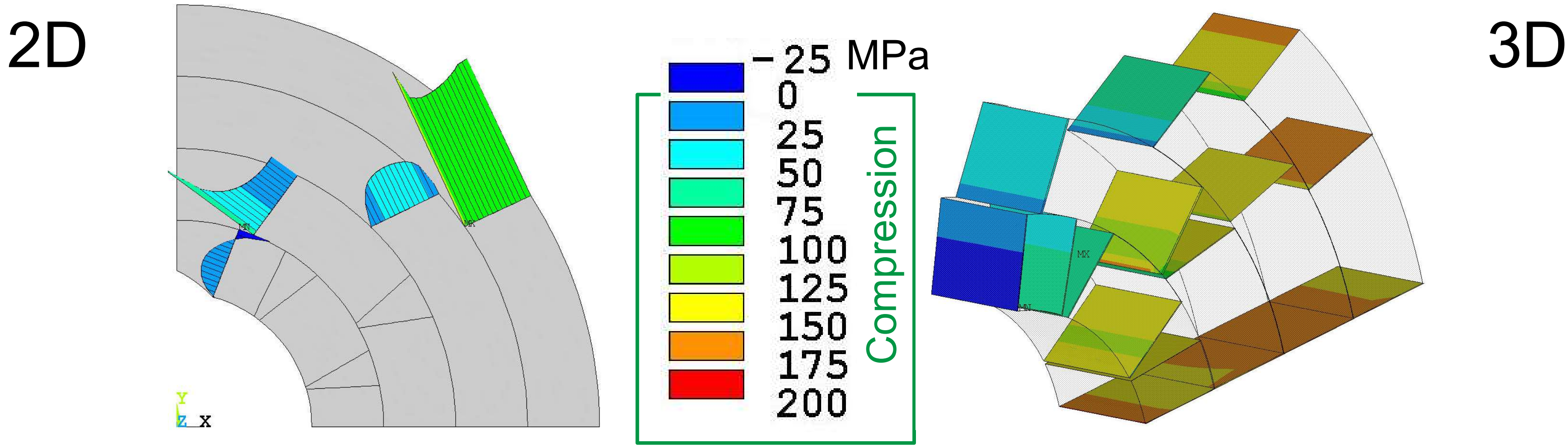
- 3D ANSYS model developed
  - Initial simulations using 15 T Cos-Theta coils
  - Validation and optimization is ongoing
- Work on engineering design was initiated



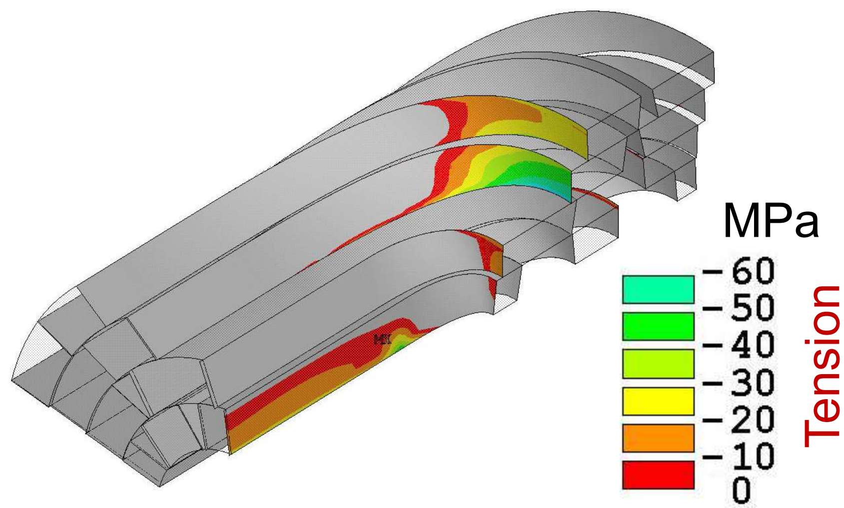
# Utility Structure
# Azimuthal coil stress (2D vs 3D)



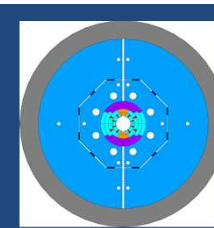
# Coil to pole/spacer contact

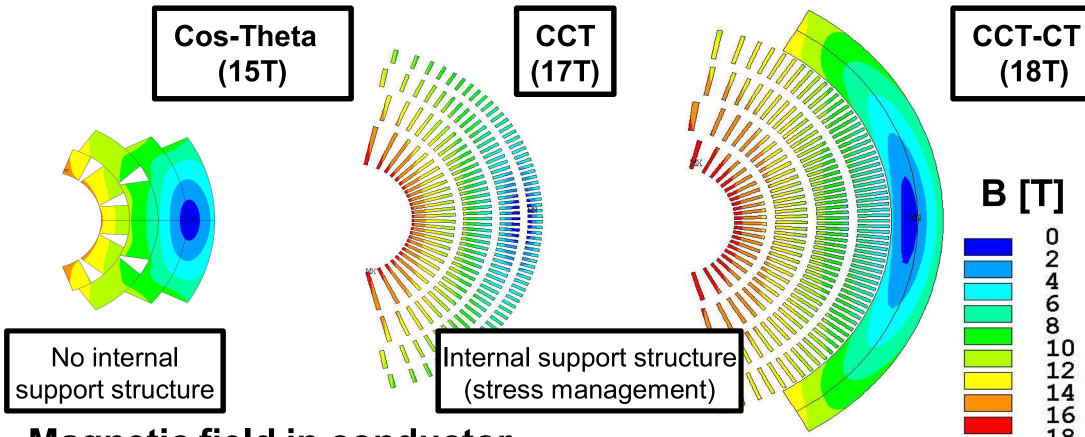



- **Optimization of the pre-load level**
  - **Orthotropic coil properties**
- **Axial pre-load and tension in the coil-ends under investigation**
  - **Copper wedge to spacer interface**
  - **Layer 3-4 to pole contact**

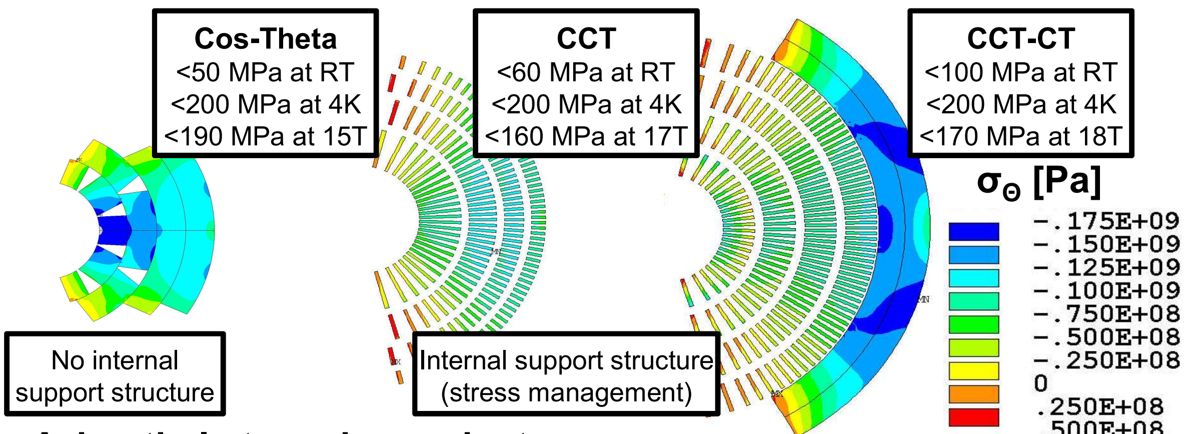


# Utility Structure
# With different coil types



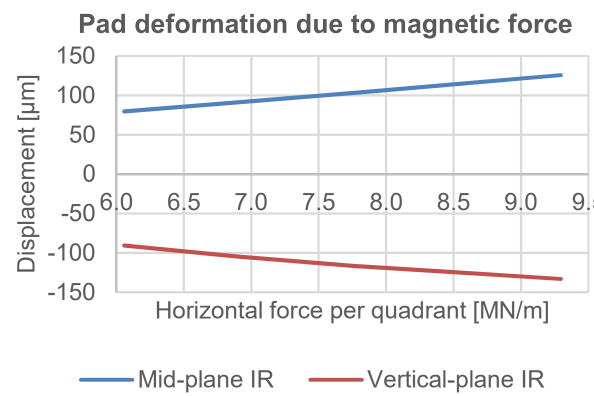



**Magnetic field in conductor**



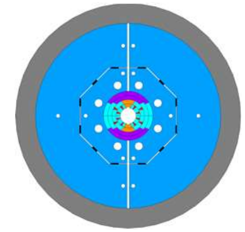
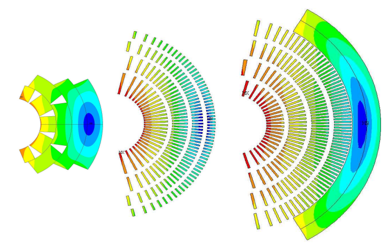
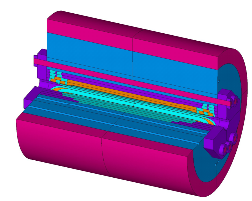
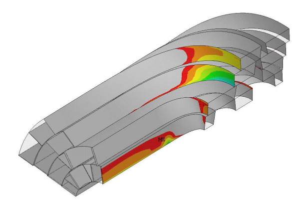
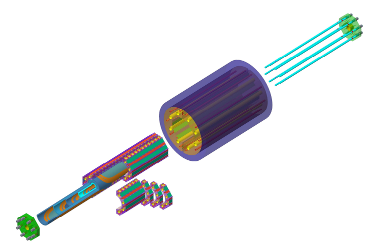

**Azimuthal stress in conductor**

- Same structure was applied
- Shell OD 750mm
- Shell TH 75mm
- Same iron yoke
- Only pads were changed
- Pre-load adjusted only by load-key shims
- Possibility to close the yoke gap at cold (rigidity)
  - Closed collars ?



# Conclusions and Future Work

- Concept of the utility structure has been developed and analyzed
  - Reusable yoke-shell assembly with a coil-dedicated pads
  - Tentative dimensions established but further optimization is needed
  - 15 T Cos-theta coil and CCT coil analyzed with utility structure pre-load
  - Work on 16T coil pre-load analysis initiated (CT/SM, CCT/CT, LTS/HTS hybrids)
  - Structure rigidity with closed yokes needs further investigation (closed collars)
- 3D model of the utility structure developed
  - 15 T Cos-theta coil model implemented
  - Validation and optimization is ongoing
  - Axial pre-load system implemented
- Engineering design work initiated
  - CAD model of the full structure
  - Assembly procedure
  - Short mechanical mock-up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# Thank You!

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