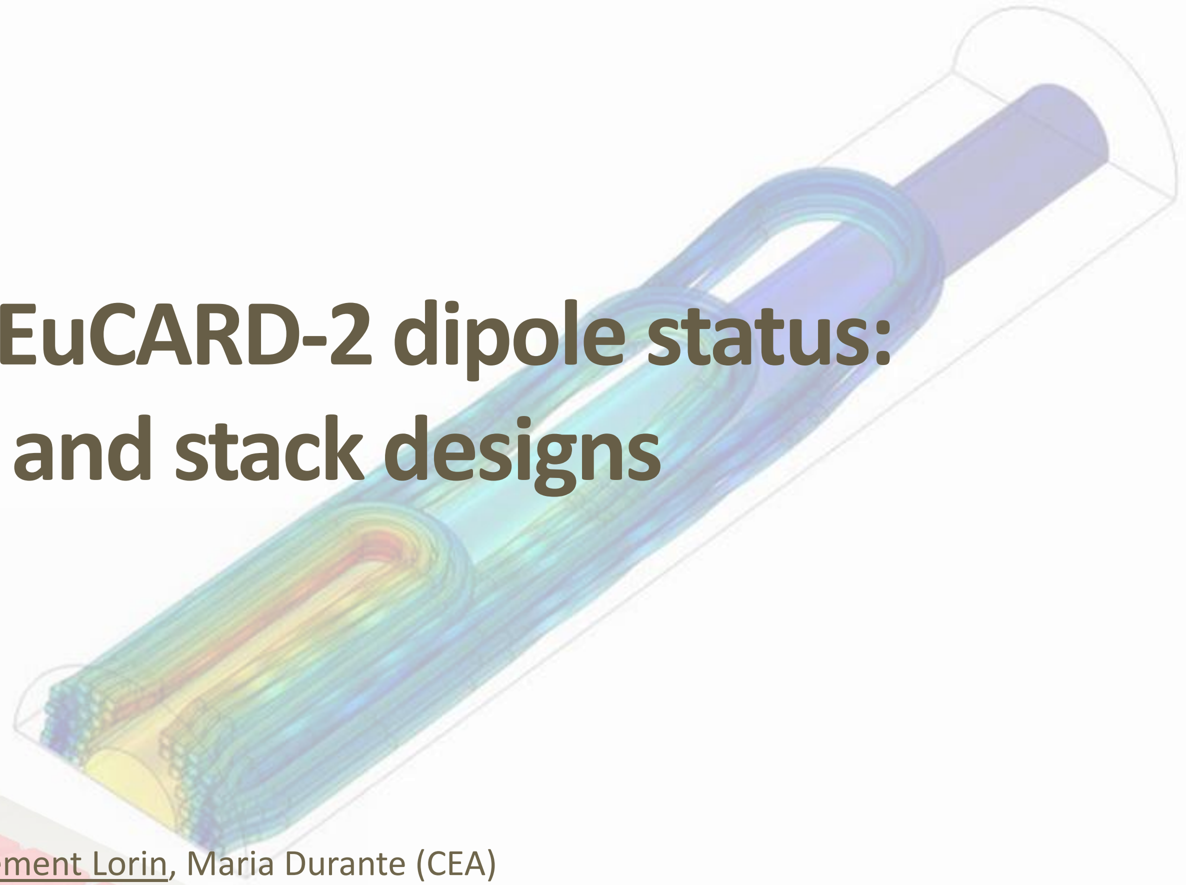
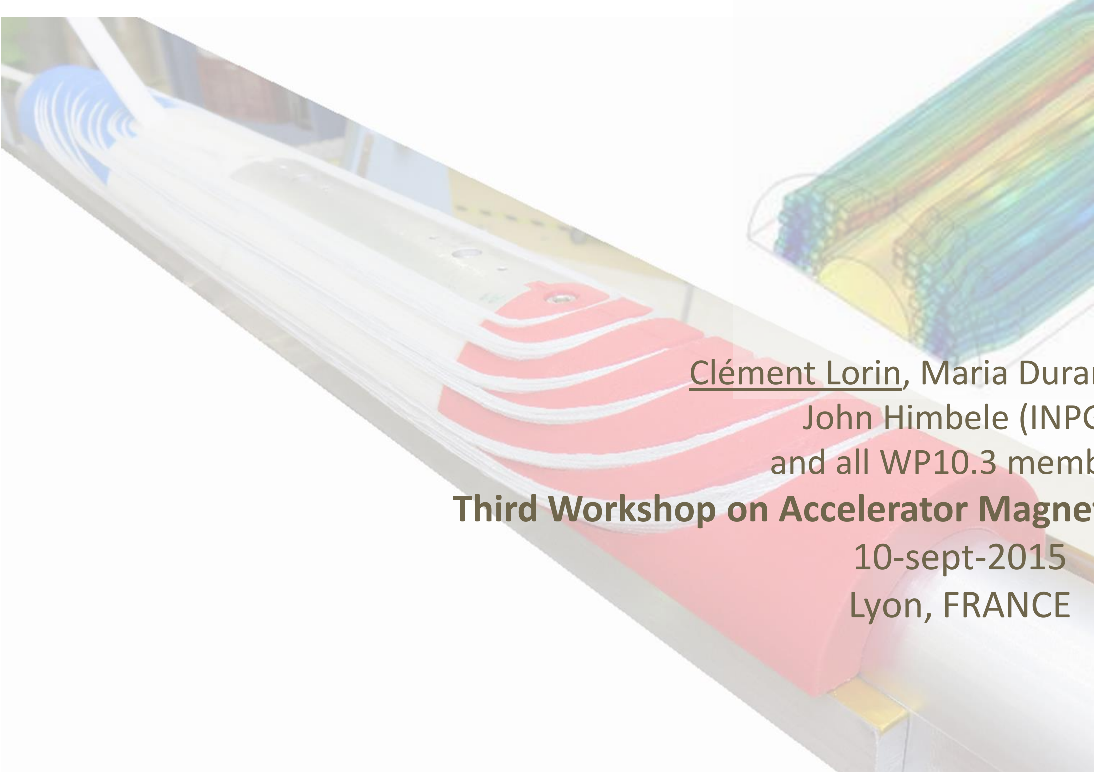


# Alternative EuCARD-2 dipole status: cos-$\vartheta$ and stack designs



Clément Lorin, Maria Durante (CEA)
John Himbele (INPG)
and all WP10.3 members

**Third Workshop on Accelerator Magnets in HTS (WAMHTS-3)**

10-sept-2015

Lyon, FRANCE

# Framework

- **Field target**: Accelerator-type magnet
  - stand-alone mode + yoke: 5 T
  - insert mode: the more the better
- **Constraints**:
  - Magnet dimension: 40 mm aperture and 99 mm outer diameter

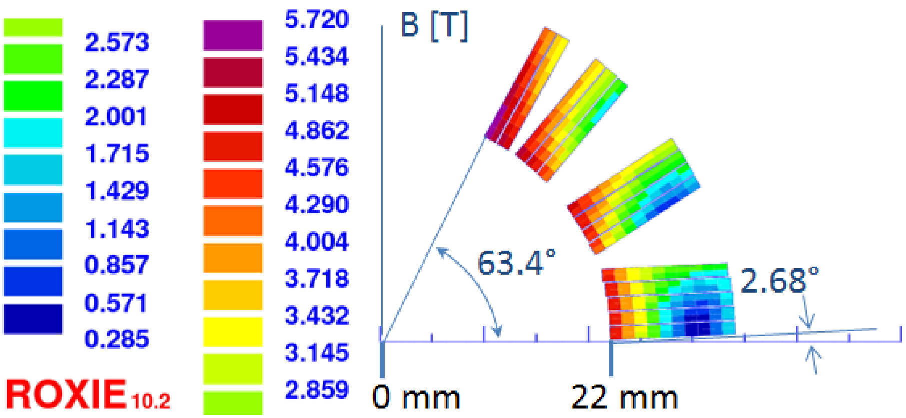
# Contents

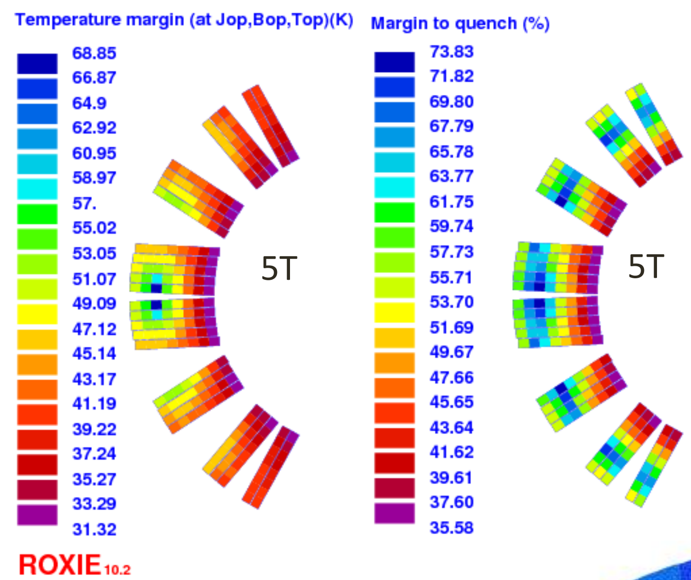
- **Cos-$\vartheta$** design at CEA:
  - 12-mm wide Roebel cable
- **Stack** design at INPG:
  - 4x4 mm$^2$ stack of tapes

# Cos-ϑ : Magnetism

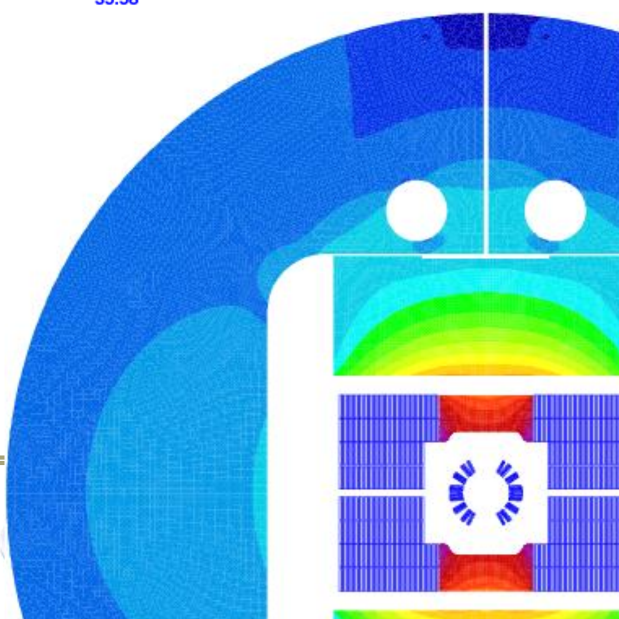
Bruker $J_{e,c\ tape}$ = 1741 $A/mm^2$ (5 T, 4.2 K, ⊥)
= 725 $A/mm^2$ (18 T, 4.2 K, ⊥)

- **Stand-alone**:
  - $J_{o,insulated\ cable}$ = 684 $A/mm^2$
  - 5 T with a yoke



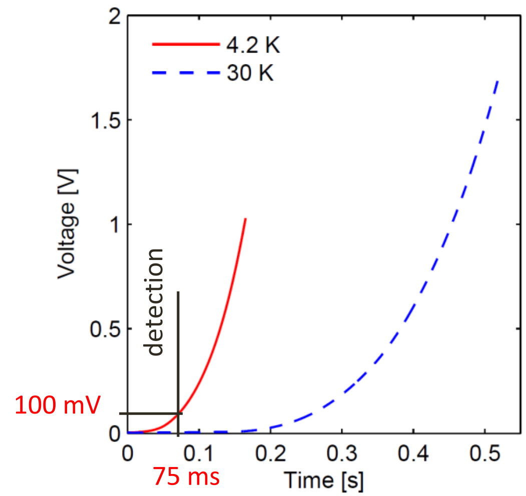



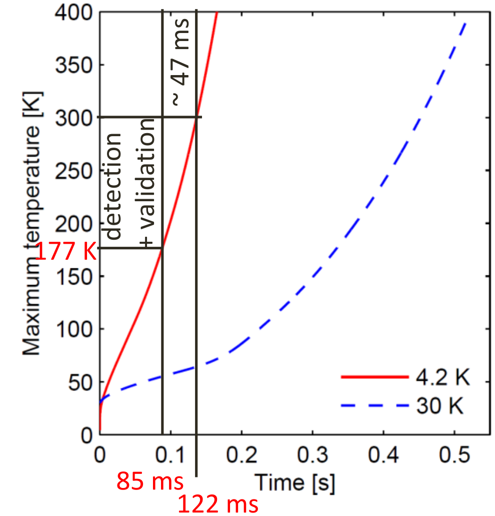

- **Insert**:
  - $J_{o,insulated\ cable}$ = 450 $A/mm^2$ (~20 % loadline margin)
  - 13 T + 2.5 T (max) in Fresca2



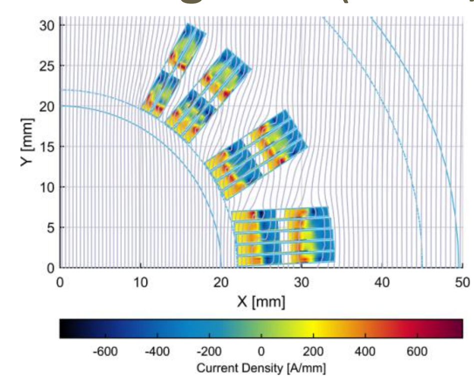
# **Cos-ϑ** : Quench/Magnetization

- Quench analysis carried out by **Erkki Härö** and **Antti Stenvall** (TUT)
  - Standalone: very challenging
  - Insert mode: ok ->
  - see Antti's talk.



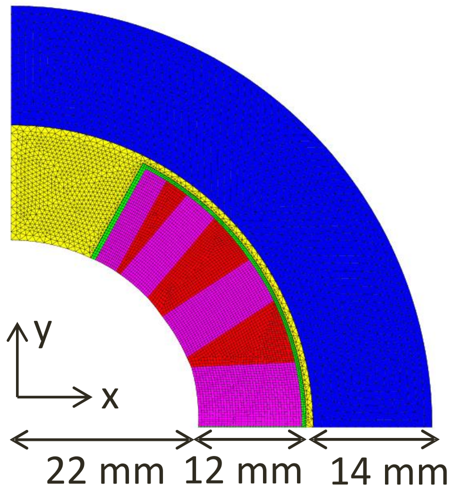

- Magnetization analysis carried out by **Jeroen van Nugteren** (CERN/Twente)
  - *"b3, 60 unit's variation at low field reducing to < 20 units at high field. b5 and b7 we see ~ 10 units variation, then converge to low values at high field."**

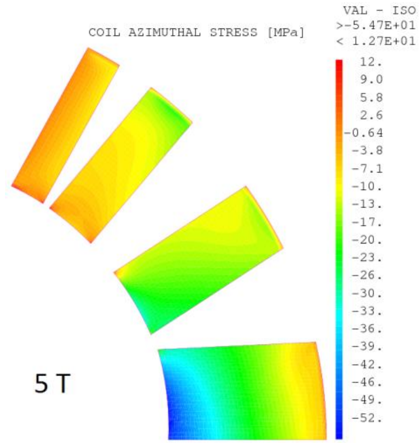


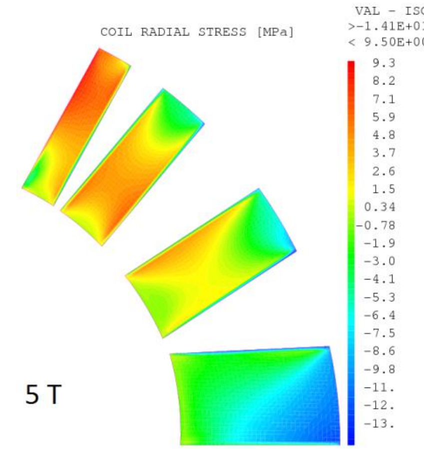

G. Kirby, L. Rossi et al. "Status of the High Current REBCO Roebel Cable Coils for the EuCARD-2 Future Magnets Project" EuCAS 2015, IEEE TAS

# Cos-ϑ : Mechanics

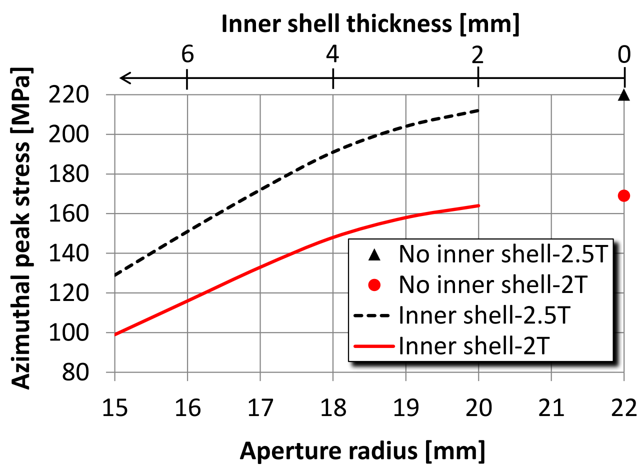
- Roebel transverse stress limit: 170 MPa (tests carried out at Twente University)
- Stand-alone stress (no inner shell)
  - $\sigma_T$ = 55 MPa
  - $\sigma_R$ = 15 MPa

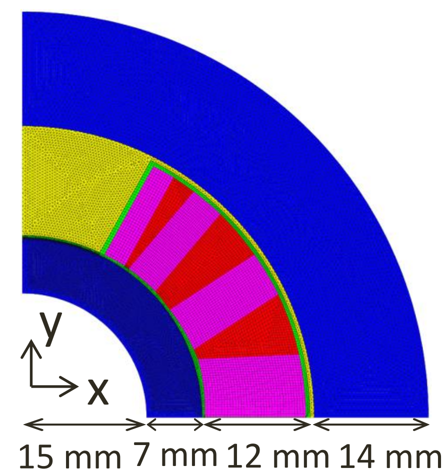


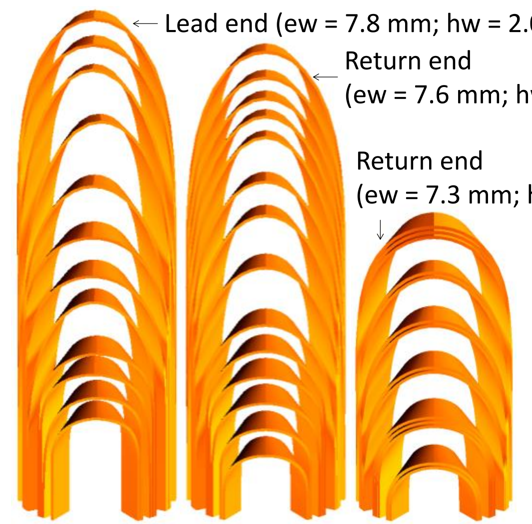




- Insert mode
  - 13 T background field
  - + 2.5 T (no inner shell) $\sigma_T$ = 220 MPa
  - + 2 T (no inner shell) $\sigma_T$ = 170 MPa



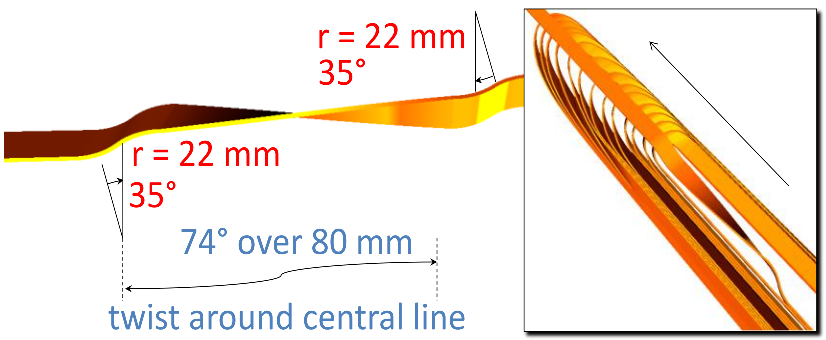



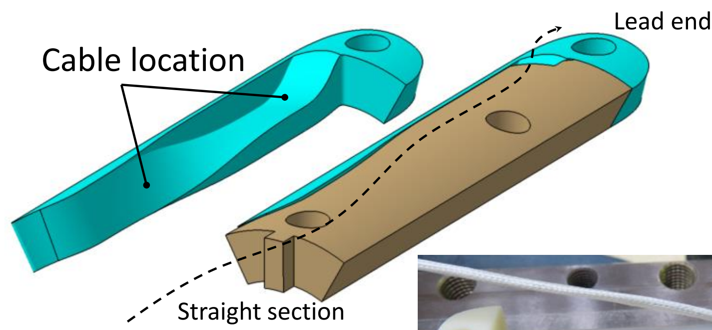
# **Cos-ϑ** : Magnet ends

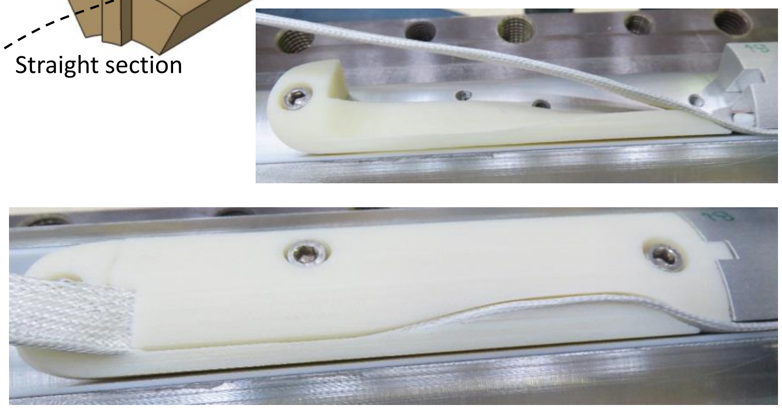



- Two end designs
  - One spacer for each cable turn (ew: 7.6 mm, hw: 2 m)
  - Conventional design (ew: 7.3 mm, hw: 22 cm)

- Innermost turn path outwards the magnets



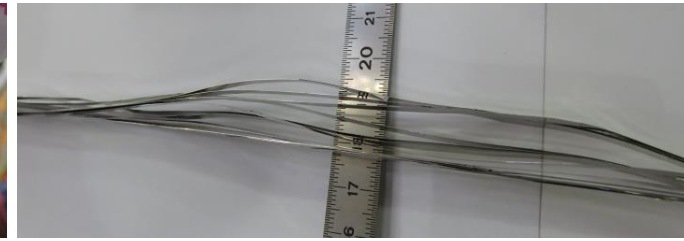



- Twist strain: ε ϵ [-0.16 % ; 0.31%]
- Test at KIT at 77 K coming soon.

# Cos-$\vartheta$ : Winding tests

- Roebel cable
  - Differential path in magnet ends*



  - Longitudinal gap long enough to absorb: winding variation, assembling mis-placement, punching precision…)

- Similar behavior for both ends
  - Keep the conventional way as baseline

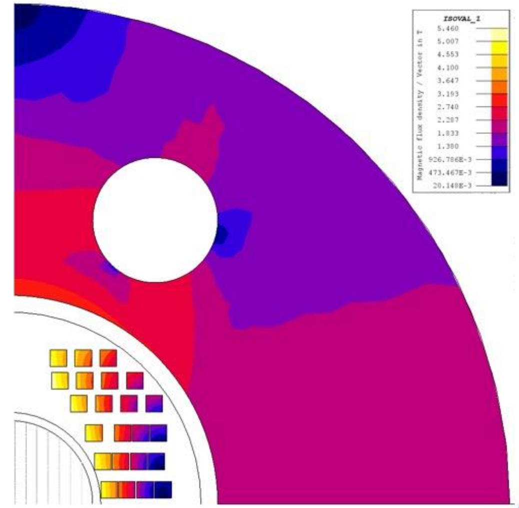
  - Conductor length 20 m per coil

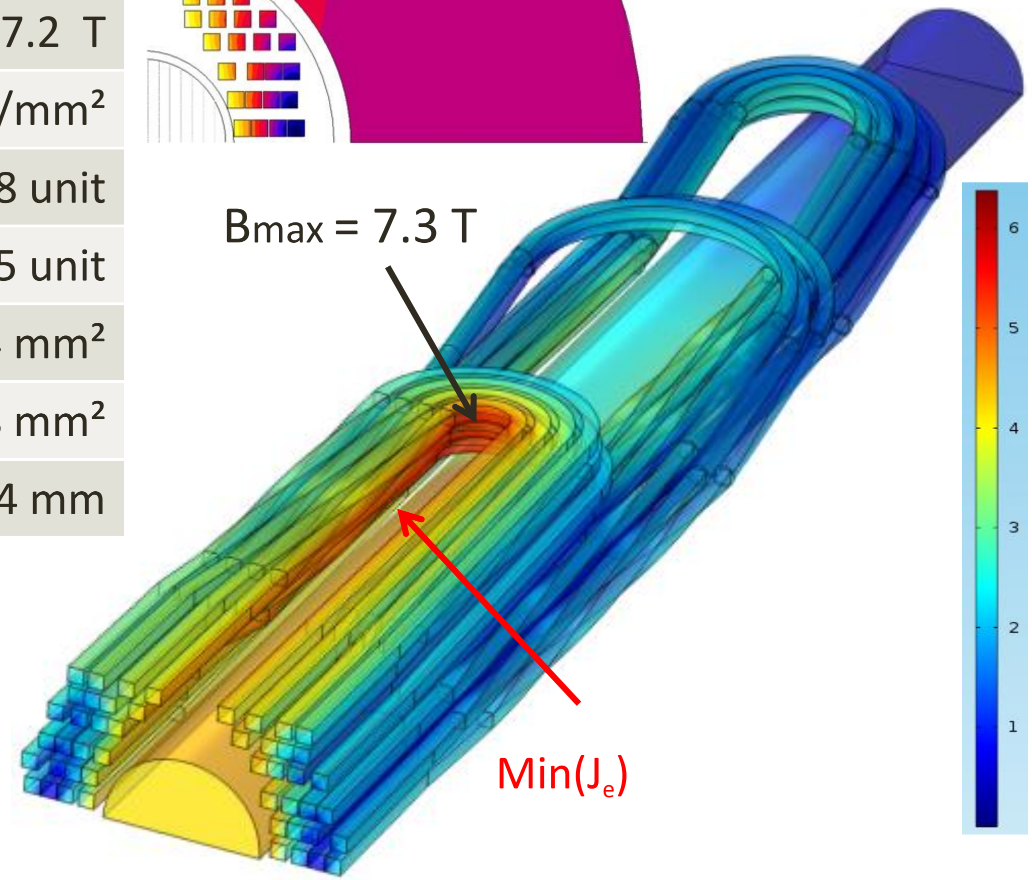
***J. Fleiter et al. "On Roebel Cable Geometry for Accelerator Magnet", EuCAS 2015**

# **Stack:** Magnetism

- 23 turns/coil

| Parameter | | Value |
|---|---|---|
| Centrer field B0 | | 5 - 17.2 T |
| Current density $J_{op}$ | | 535 - 650 A/mm² |
| Field quality | $B_3$ | 0.8 unit |
| | $B_5$ | 0.5 unit |
| Block-coil size | | 4 x 4 mm² |
| Conductor area/half coil | | 368 mm² |
| Inner - external tube | | 2 - 4 mm |

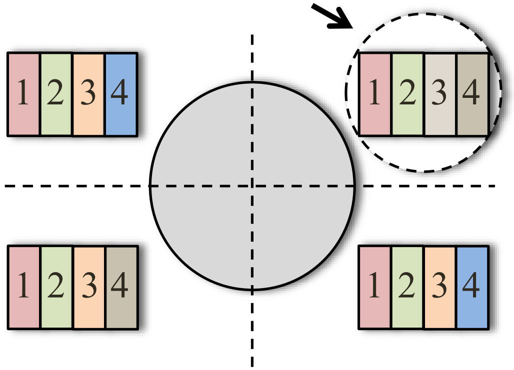




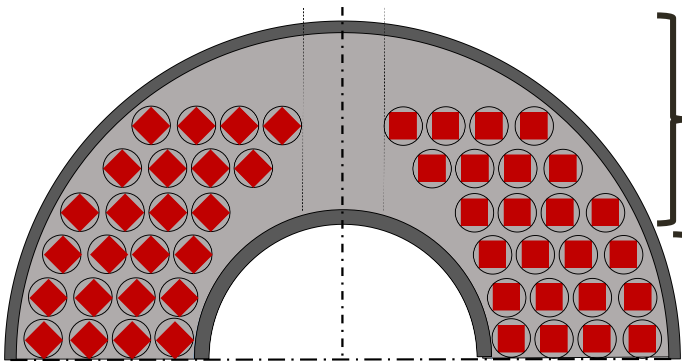

CEA Saclay · CERN · Grenoble INP · INFN Istituto Nazionale di Fisica Nucleare · TTY · Danish Technological Institute · EuCARD² · Future Magnets

# **Stack:** Transposition

- Stack of tapes ≠ Roebel or Rutheford
  - Partially transposed

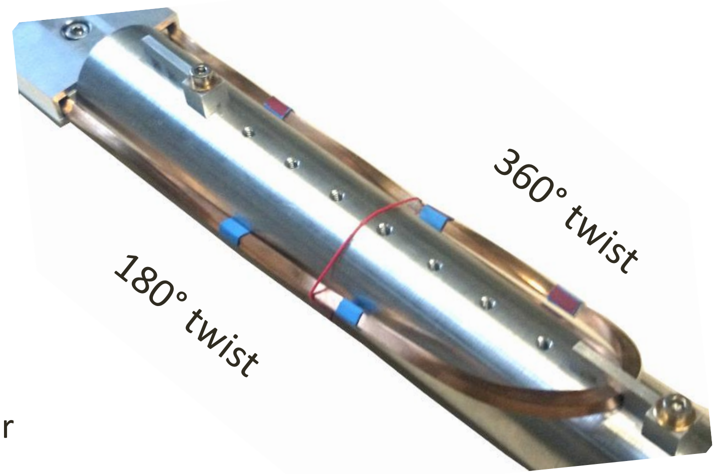



- Transposition in magnet ends



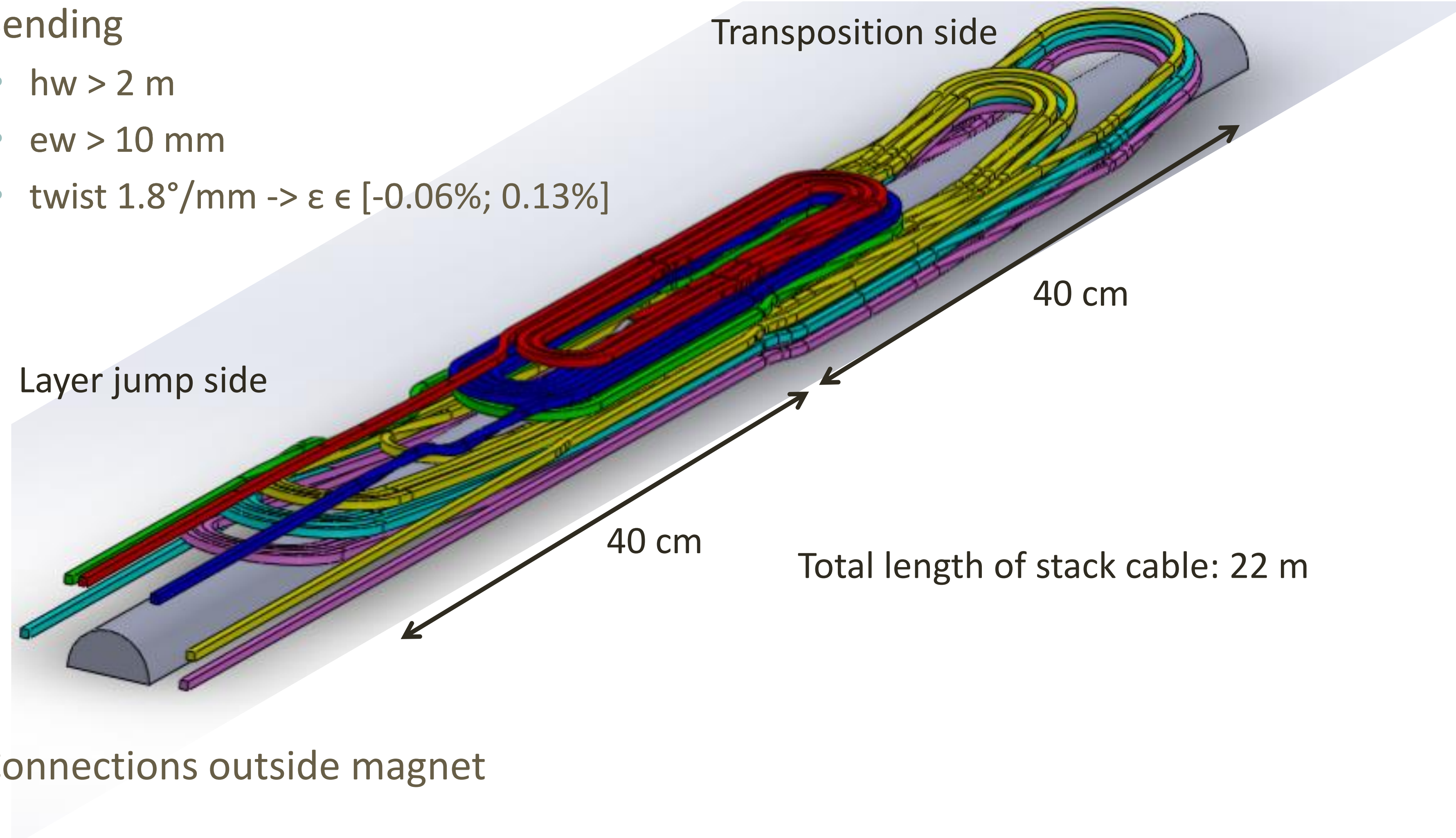
Above the clear bore
180° twist one side
⇨ 0° on the other

Below the clear bore
180° twist one side
⇨ 360° twist on the other



# **Stack:** Magnet ends

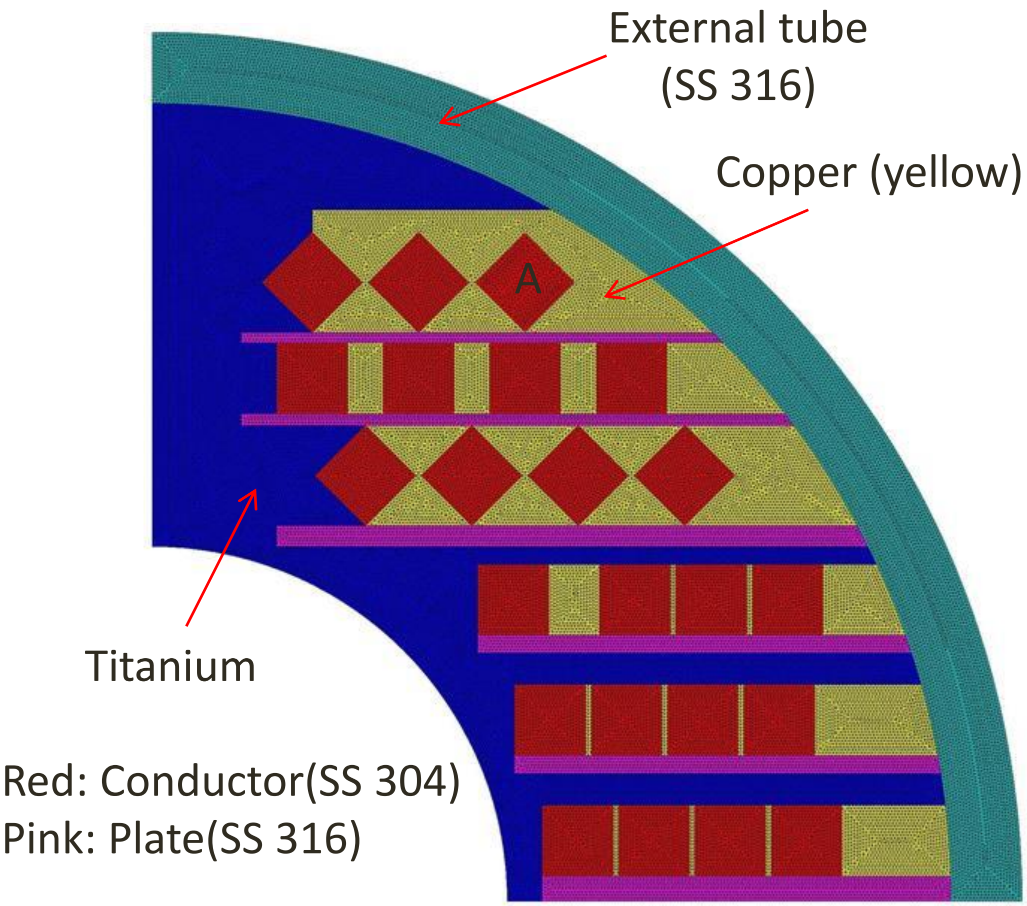
- Bending
  - hw > 2 m
  - ew > 10 mm
  - twist 1.8°/mm -> ε ϵ [-0.06%; 0.13%]



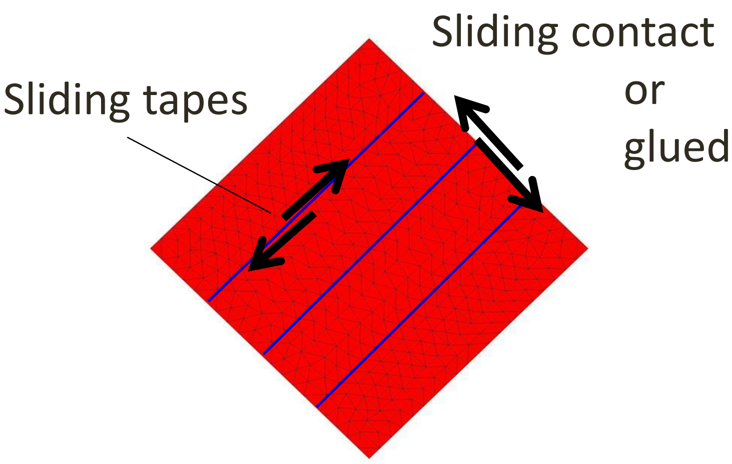

- Connections outside magnet

# **Stack:** Mechanics

- Mechanical analysis carried out by **Chhon Pes** and **Philippe Fazilleau** (CEA)

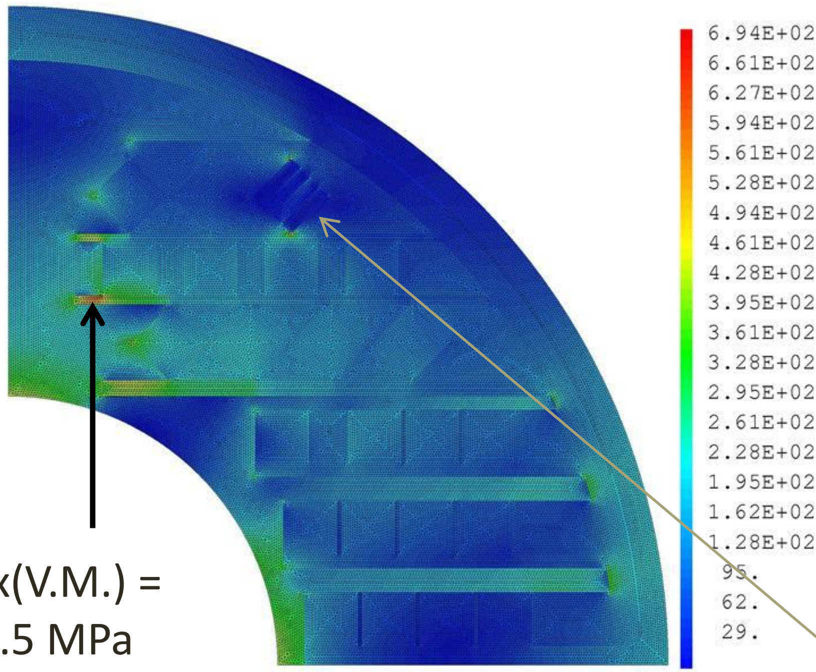



A. Shear stress analysis of 4 stack tapes
   - Sliding contact between tapes
   - Sliding contact or glued on its perimeter and copper



# **Stack:** Mechanics

- Total von Mises stress distribution
  - Max deflection ~ 100 µm



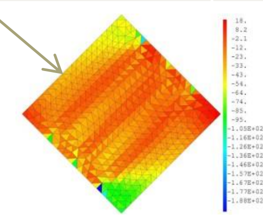

Max(V.M.) = 699.5 MPa

Max Von Mises stresses (MPa) in different parts of structure

| Component | Cooldown | Magnetic forces | Total |
|---|---|---|---|
| Conductor | 342.5 | 295 | 511.7 |
| CuBe | 293.6 | 351.2 | 585.5 |
| Plate – SS316 | 444 | 376.3 | 699.5 |
| Titanium | 325.8 | 431 | 460.75 |
| External tube | 311.9 | 168.6 | 429.15 |

Max Von Mises allowable stresses (MPa) in different parts of structure

| Material | Yield stress(MPa) | Allowable stress(MPa) |
|---|---|---|
| SS 304 | 890 | 593 |
| SS 316 | 980 | 653 |
| CuBe | 1077 | 718 |
| Titanium | 1200 | 800 |



- Shear stress in conductor
  - 49 MPa with sliding, 188 MPa no sliding

# Conclusion

- **Cos-$\vartheta$** design
  - 5 T standalone, an extra 2 T possible as insert
  - Inner shell reinforcement
  - End design (conventional way)
  - Path outwards the magnet (to be tested at KIT)
  - Protection to be deeply investigated
  - Tooling development (drawing office working on it)

- **Stack** design
  - > 5 T in standalone, an extra 4.2 T possible as insert
  - End design with transposition
  - Mechanical fine tuning to be done
  - Winding test coming soon