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Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

# CS Winding and Precompression structures

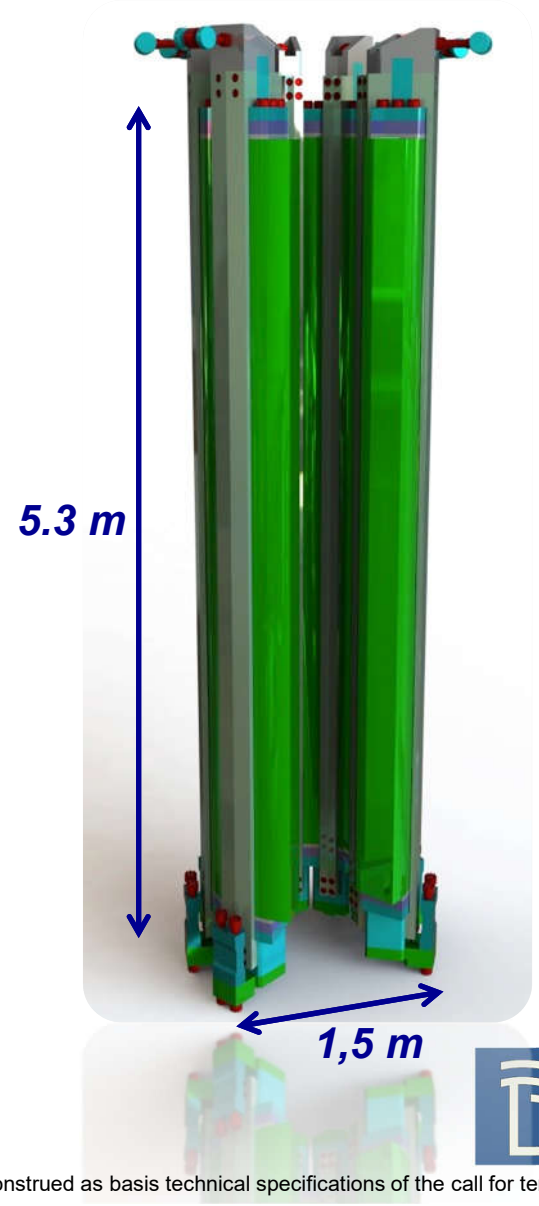
## DTT info-day

*C.R. ENEA Frascati (Rome), Italy – October 2019*

**The DTT team**

# Outline

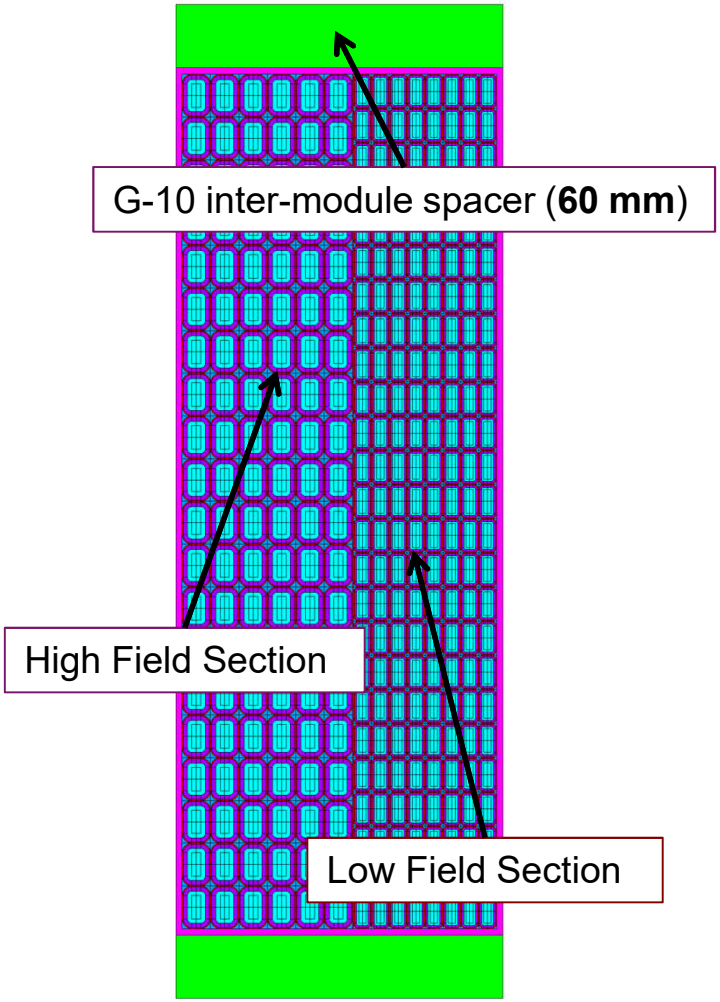
- CS coil description
- CS modules manufacturing approach
- Coil winding
- Pre-compression structures
- Final coil assembly
- Conclusions and recommendations



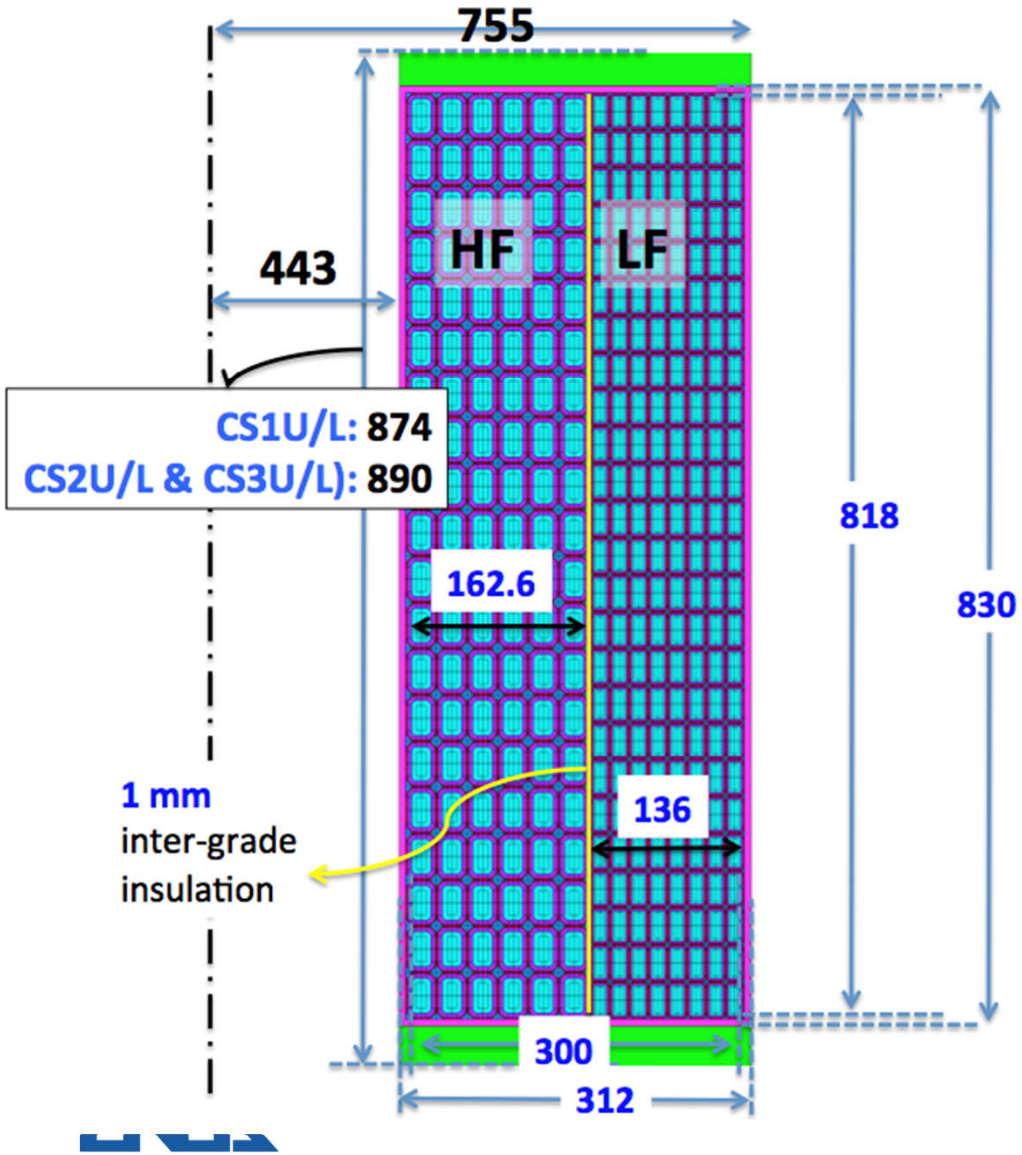
# CS module: main features

To satisfy the DTT CS Design requirements:

| | HF (inner) section | LF (outer) section |
|---|---|---|
| CICC Op. Current | 29.04 kA | |
| Peak field | 13.4 T | 8.5 T |
| # s.c. wires | 648 | 180 |
| # Cu wires | 0 | 204 |
| Steel jacket thickn. | **4.1 mm** | **2.0 mm** |
| Turn insulation | 1.0 mm (glass-fiber + resin) | |
| Ground insulation | 6.0 mm (glass-fiber + resin + Kapton) | |
| Wind & Insulate → React → Impregnate | | |
| $J_{ENG}$ (A/mm$^2$) | 26.2 | 52.2 |
| # layers x turns | 6 x 20 | 8 x 25 |
| Magnetic Fux | **16.2 Wb** | |
| Inner/outer radius | **443 mm / 755 mm** | |
| Max. voltage | 3.5 kV *(terminal to terminal)* | |



# CS module: geometry




DTT CS Coil_Layered_v50

**HF:**
6 x 20 = 120 turns

**LF:**
8 x 25 = 200 turns

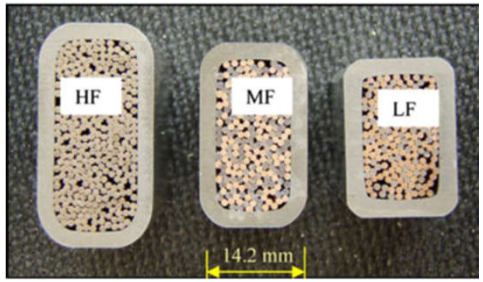
**I_op:** 29.04 kA

**HF CICC (insulated):**
40.9 x 27.1 mm²
Jack. Thickness: 4.1 mm
Turn insulation: 1 mm

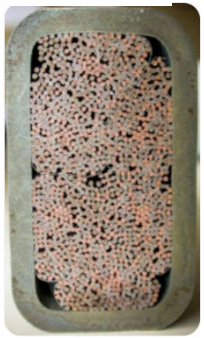
**LF CICC (insulated):**
32.7 x 17.0 mm²
Jack. Thickness: 2.0 mm
Turn insulation: 1 mm

**Similar CICC concepts**

**NHMFL**




**EU-Alt TF**



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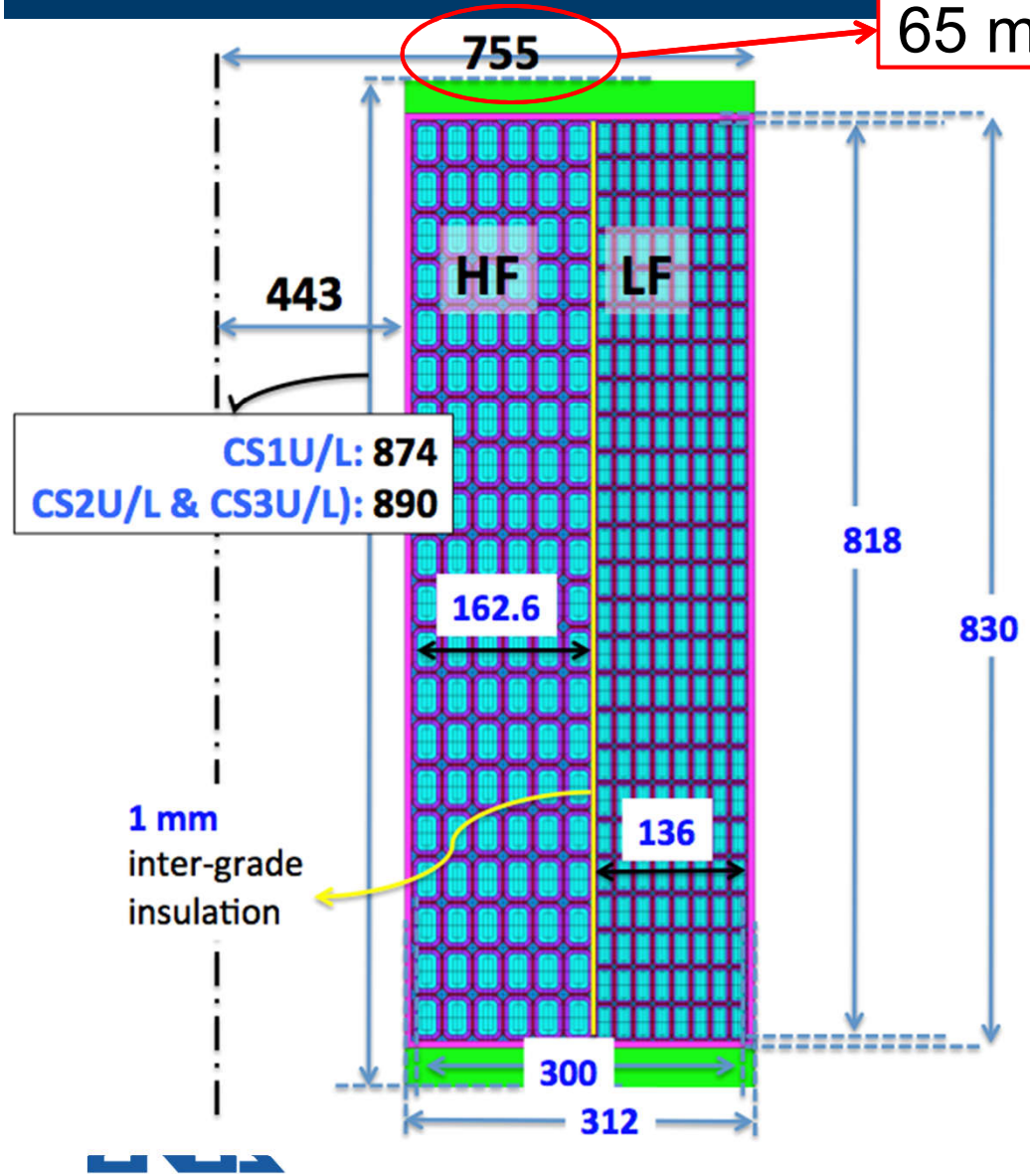


65 mm clearance wrt TF

DTT CS Coil_Layered_v50

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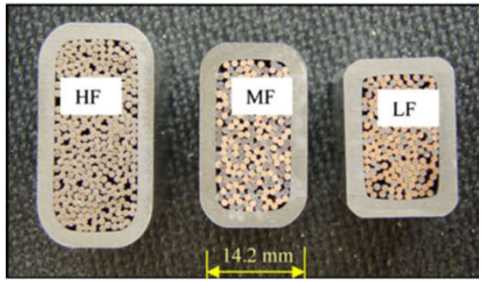


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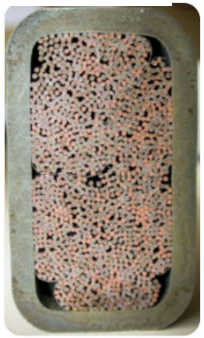
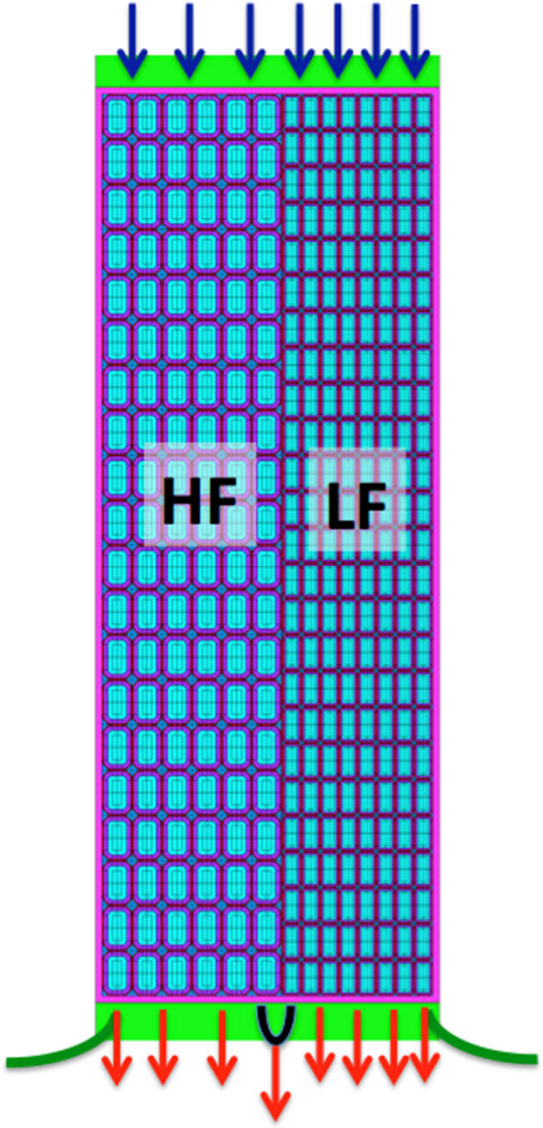


# CS module: inlet / outlet configuration




DTT CS Coil_Layered_v50
**Layout 1**

Joint 1: HF-LF

Internal termination

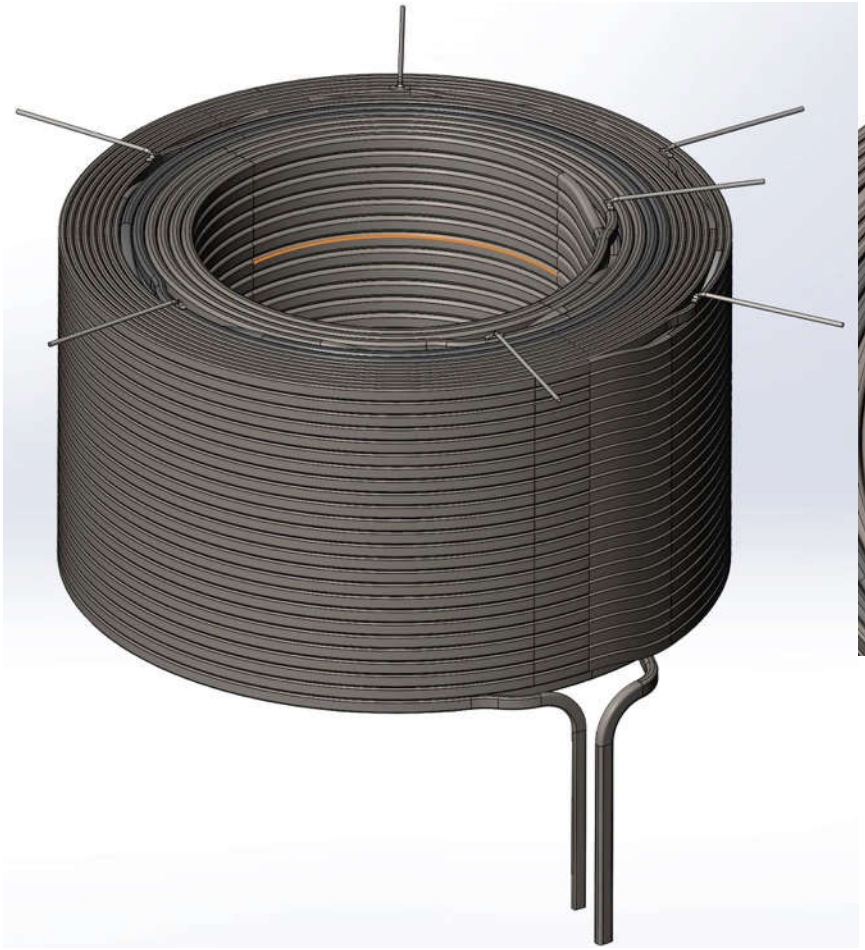
External termination

He outlet

He inlet

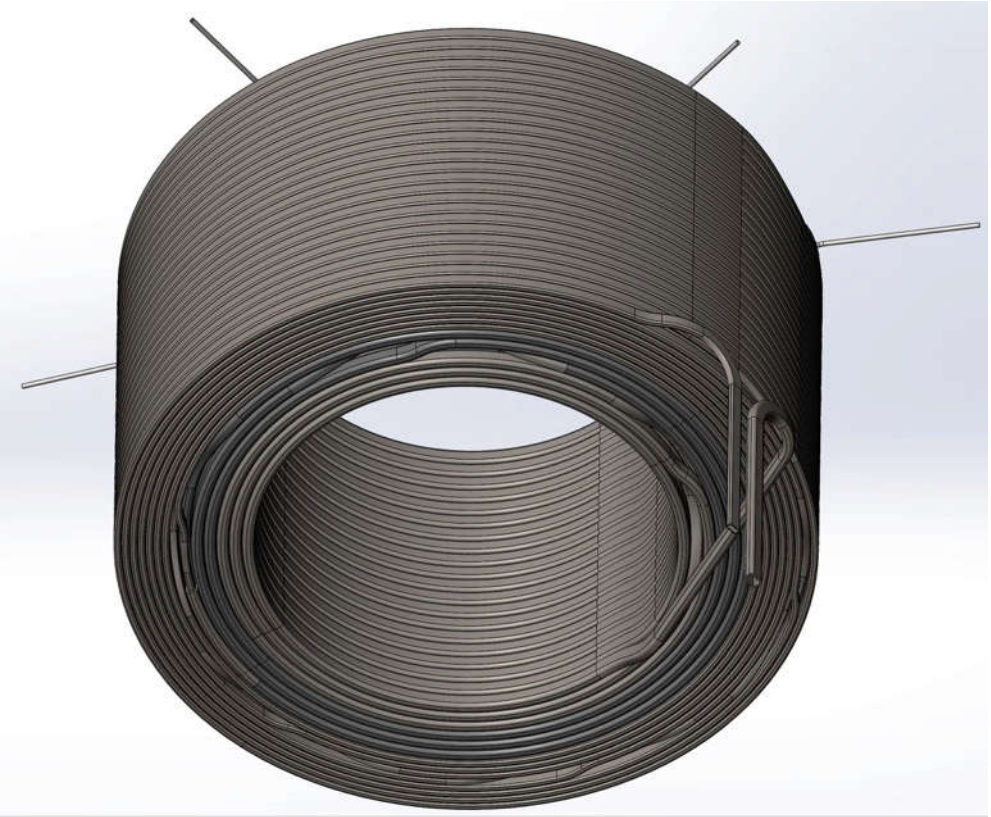
*2 terminations*
*2 intermediate joints*
*7 He inlets*
*8 He outlets*

# CS module: winding configuration



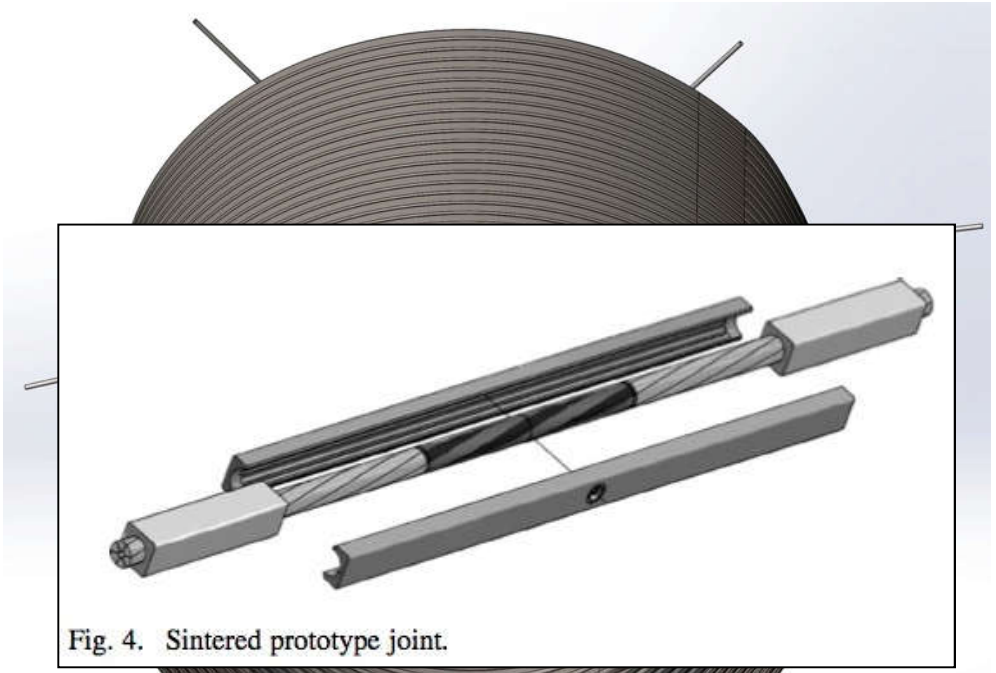
# CS module: HF to LF joint

- Two terminations and one inter-layer joint per module.
- Inter-layer joint: **preferably** manufactured on the external part of the coil, BUT 65 mm clearance wrt TF.



# CS module: HF to LF joint

- Two terminations and one inter-layer joint per module.
- Inter-layer joint: **preferably** manufactured on the external part of the coil, BUT 65 mm clearance wrt TF.
- Another possibility would be to use “internal” joint, manufactured in-line during winding, thus embedded within the winding pack (*EDIPO / NAFASSY / ITER CS – like*).




# CS module: manufacturing approach

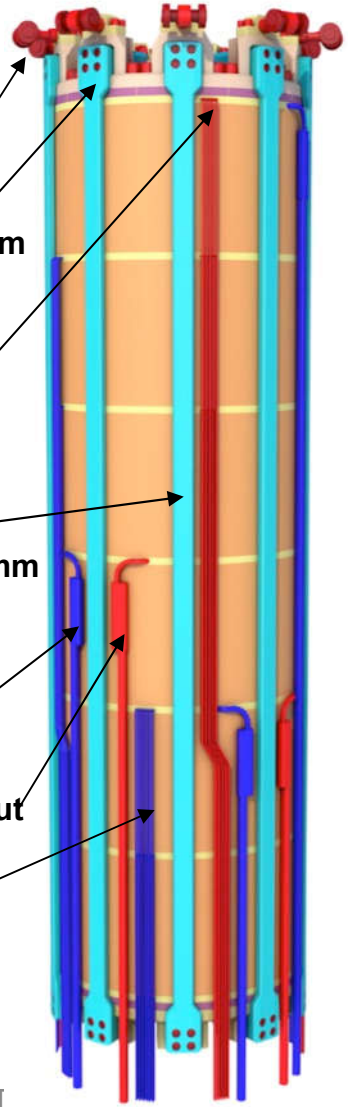
Wind & Insulate → React → Impregnate manufacturing approach

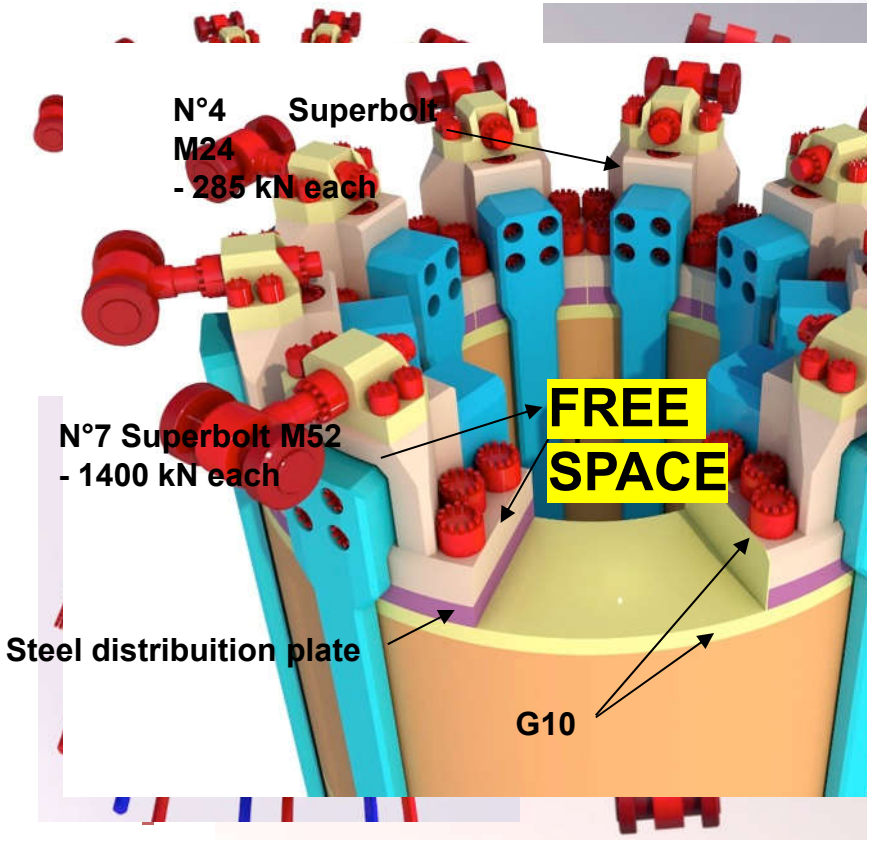
- Insulation to be applied during coil winding, before the $Nb_3Sn$ reaction heat treatment:

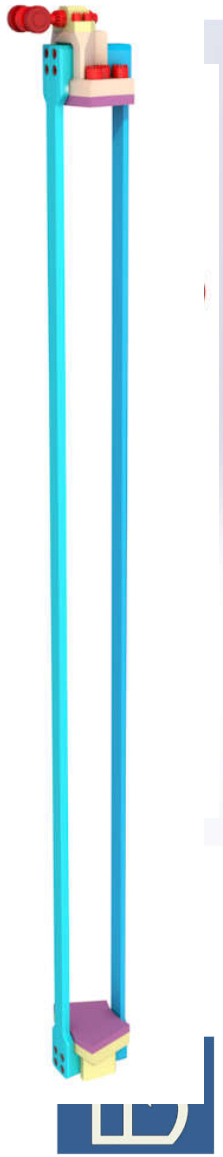
  → turn insulation will not rely on Kapton: but according to computations, it is not necessary for the expected voltage levels (*3.5 kV peak terminal-to-terminal Voltage at plasma breakdown*);

  → the most appropriate choice of insulation material (glass / resin type) and manufacturing process, is under study, to minimize the risks.

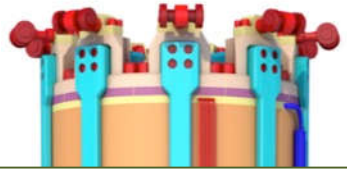
# CS Coil structures & assembly



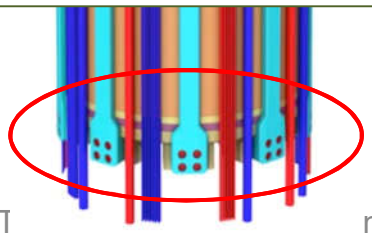
# CS Coil supports



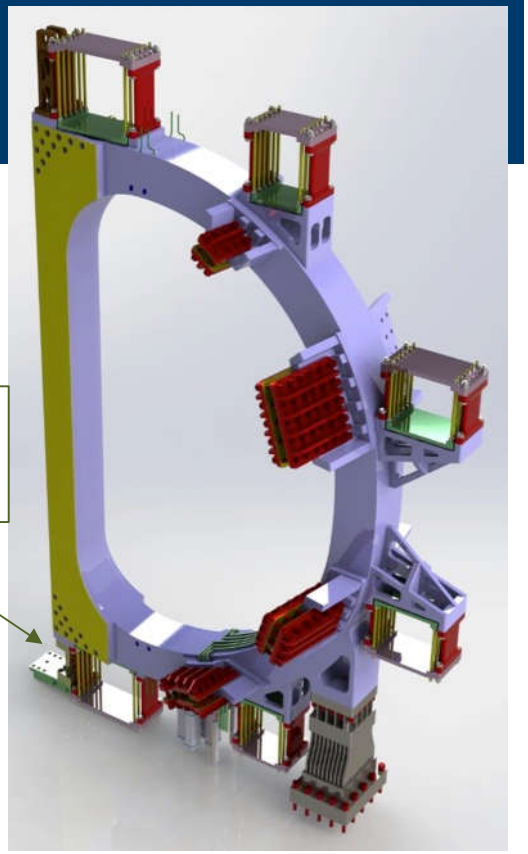
**(on 9 out of the 18 TF coils)**

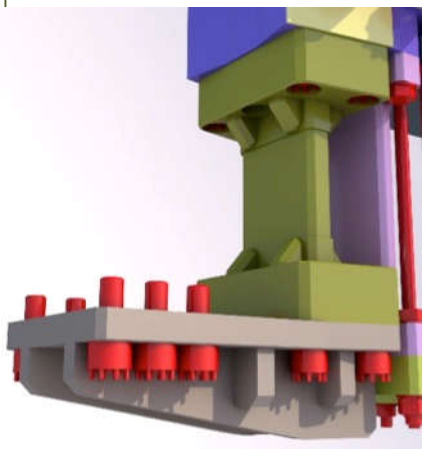
- **Aligns the CS module stack to the machine centerline**
- **Resists net lateral load (plasma kink)**
- **Supports the vertical forces (CS weigth 70 Tons, 25 MN Neg triangularity at SOF)**

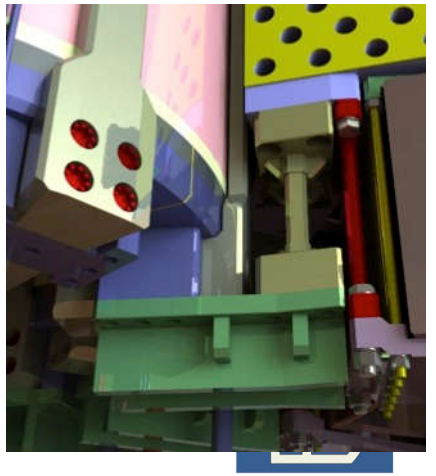
**The system is based on a cantilever connected (X6 M36 superbolts 610 KN each, 33MN tot ) to a vertical plate designed to support the vertical forces, block the toroidal movement but leaving the radial displacement "free".**



**CS gravity support**







# CICC lengths supplied by ENEA

## Dummy Spools

- 1 x complete HF dummy unit length:
  - Copper cable – 400 m;
  - Single layer wound on a > 3 m spool.
- 1 x complete LF dummy unit length:
  - Copper cable – 860 m;
  - Single layer wound on a > 3 m spool.

Cu / s.c. dummies for complete process qualification

- Other Cu dummy lengths for process qualification?
- Superconducting dummy lengths for process qualification?

# CICC lengths supplied by ENEA

## Regular Spools

- 7 x complete HF regular unit lengths:
  - Superconducting cable – 400 m;
  - Single layer wound on a > 3 m spool.
- 7 x complete LF regular unit lengths:
  - Superconducting cable – 860 m;
  - Single layer wound on a > 3 m spool.

6 CS + 1 spare modules

# Module preparation

## Operations to complete (1 module)

1. HF grade turn insulation & winding;
2. LF grade turn insulation & winding
3. He inlets welding;
4. Internal and terminal joint preparation;
5. Heat-treatment at 650°C;
6. Ground insulation application;
7. G10 inter-module grooved spacers insertion
8. VPI and curing;
9. Acceptance tests.

# Coil assembly

After single modules shipped back and forth to/from ENEA for cold tests:

## Operations to complete (6 modules)

1. Module stacking;
2. Pre-compression structures application;
3. Piping welding;
4. Support structures preparation;
5. Acceptance tests;
6. Transport structure preparation;
7. Shipping to ENEA Frascati.

# Conclusions & Recommendations

- Detailed engineering design still under finalization;
- 1 spare module and 1 assembled CS coil made of 6 stacked coils and its pre-compression structures, shall be eventually shipped to ENEA in Frascati.

# QUESTIONS?



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