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Construction Technology for the 10 T HTS Energy Saving Dipole Magnet of the Italian Facility IRIS

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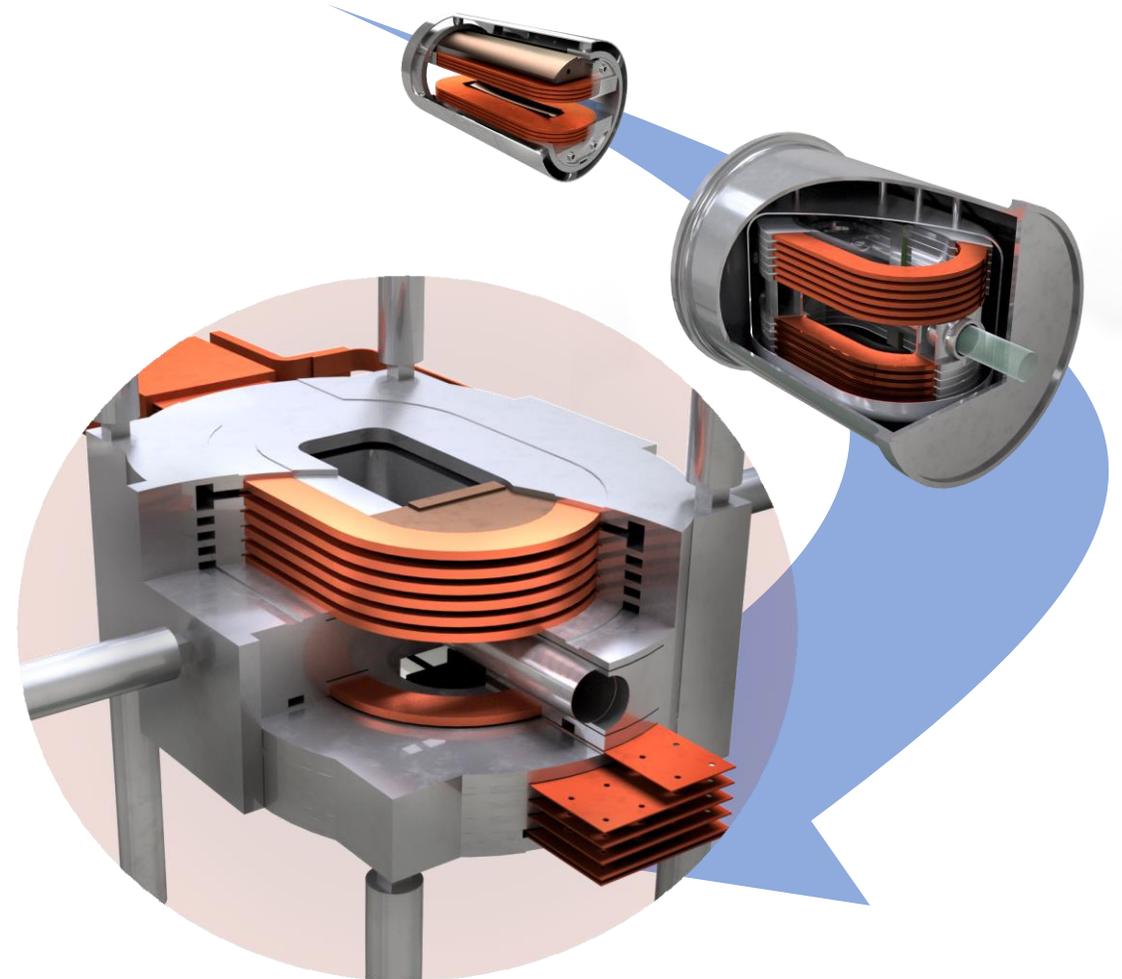
ASG Superconductors





Outline

- IRIS Energy Saving Magnet ESMA
- Design
 - Electromagnetic
 - Mechanical
 - Thermal
 - Protection
- Procurement Status
 - HTS Tape
 - Winding Machine and Components
- Assembly
- Single Prototype Coil Test
- Final Magnet Tests



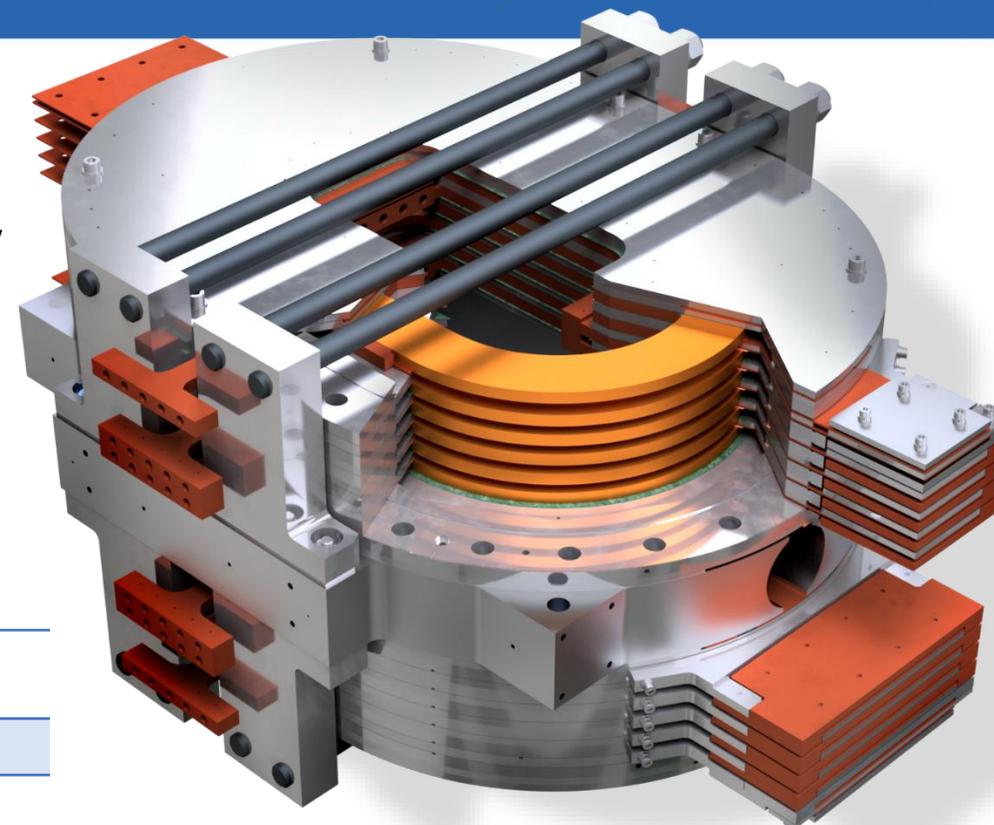
IRIS Energy Saving Magnet (ESMA)

The Innovative Research Infrastructure on Applied Superconductivity (IRIS) is a project funded by the Italian Minister for University and Research (Next Generation EU framework), with leadership assigned to INFN and LASA laboratory serving as its coordinator. IRIS involves the design and construction of an Energy Saving, fully high-temperature superconducting dipole Magnet.

ESMA

- Test operation with *cryogen-free technology*
- Test (non)-insulation technology
- Installed in INFN Genoa facility @ end 2025

Central field B0 (min. accept)	T	10 (8)
Free aperture	mm	Ø70
Good field region uniformity	N/A	3%
Good field region	mm	H50xV30xL350
Operating temperature	K	<20
Critical current margin	N/A	>20%



IRIS WP9 institutes



Engineering Design
and Construction





Electromagnetic Design

Cable:

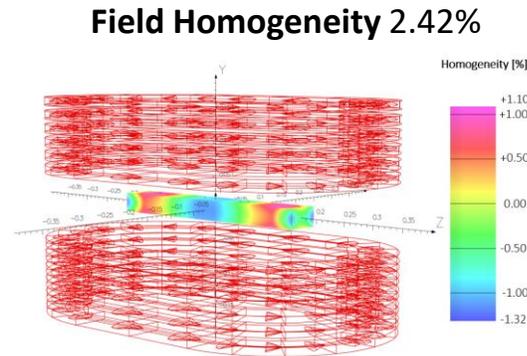
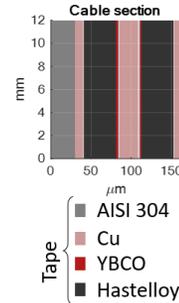
- 2x12-mm-wide YBCO tape + 1 mill (26 μm) **AISI 304** tape (Metal Insulated)
- 1150 A (920 A 8 T), $J_{cable} = 600 \text{ A/mm}^2$

Coil:

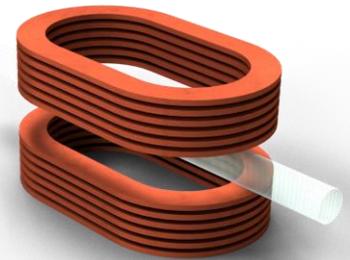
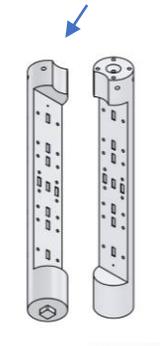
- 350 turns (516 m x 2 YBCO Tape per coil – 12384 m YBCO Tape total)
- Inner R heads 130 mm
- Length straight part 237.3 mm
- REBCO Tape Spool unit length: from 200 m to 400 m. At least 2 splices per coil are foreseen (a dedicated splicing campaign has been successfully performed by ASG to be ready for real winding)

Magnet:

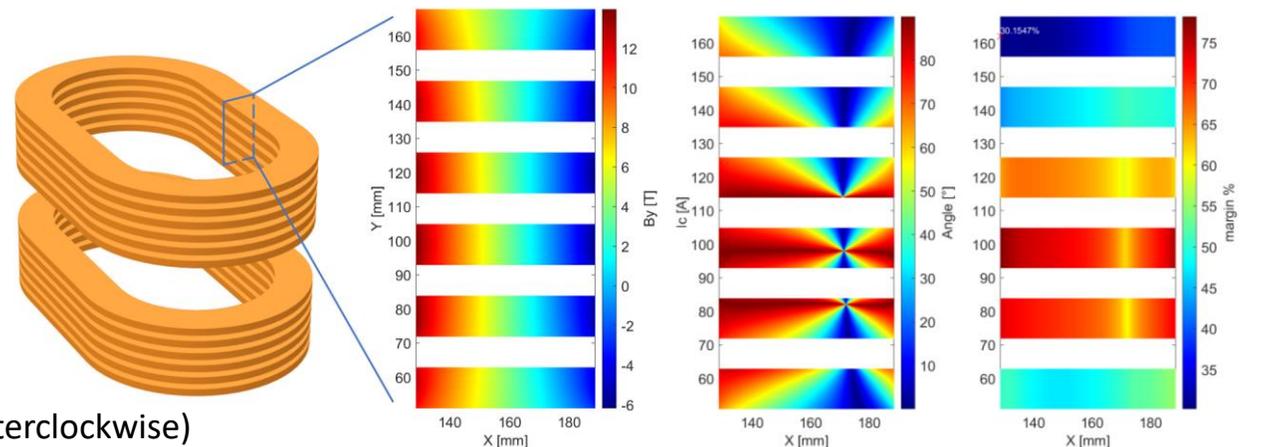
- Modular structure with 12 identical coils (8 clockwise - 4 counterclockwise)



Hall Sensor Holder to measure Magnetic Field Homogeneity during Tests



Margin @ 20 K > 20% in the worst spots

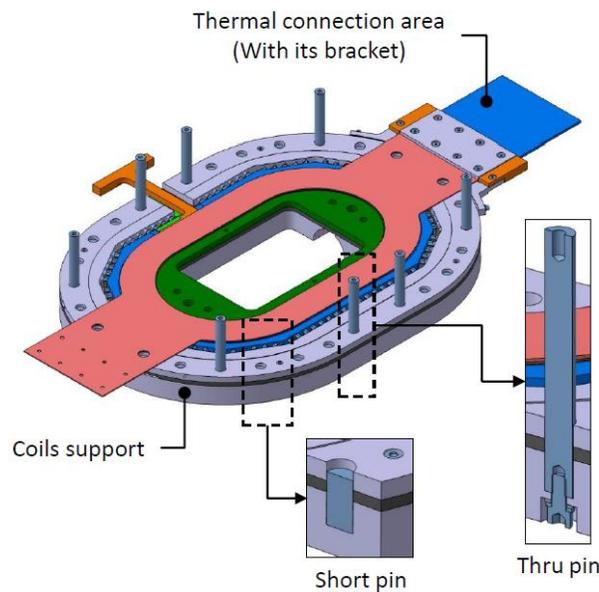
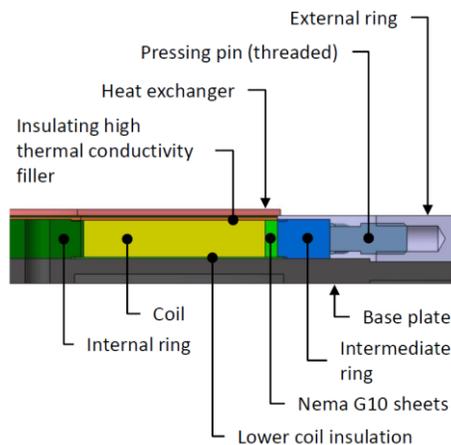
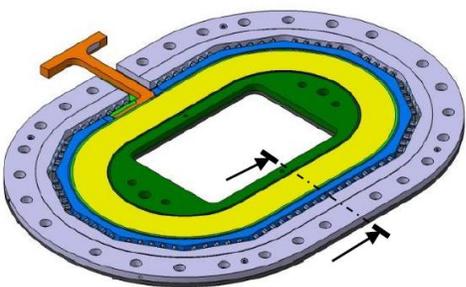




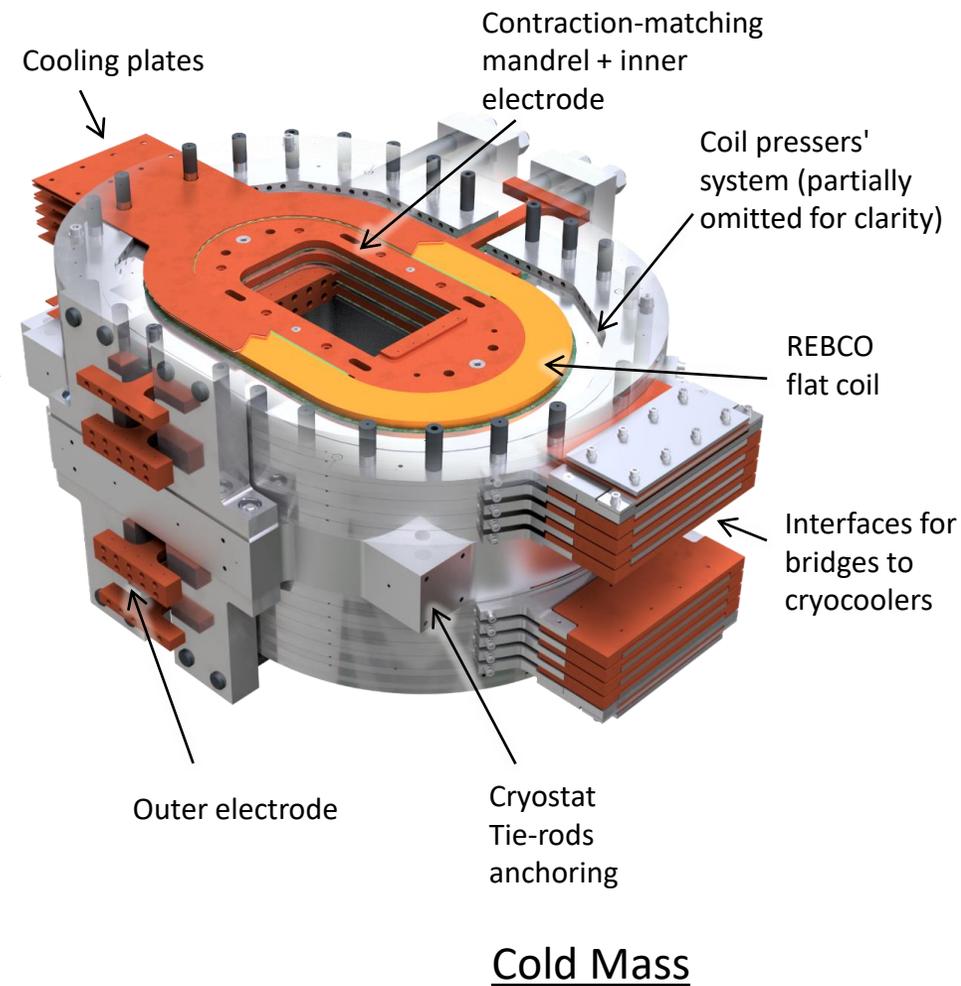
Mechanical Design

- Single-pancake **modular** structure: giving coil precompression, 10-20 MPa
- Modules packed with Thru Locking Pins: not just alignment pins

Single Pancake



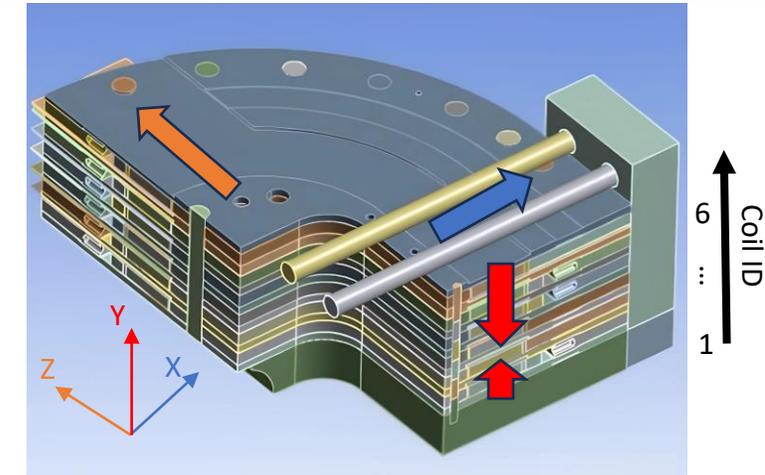
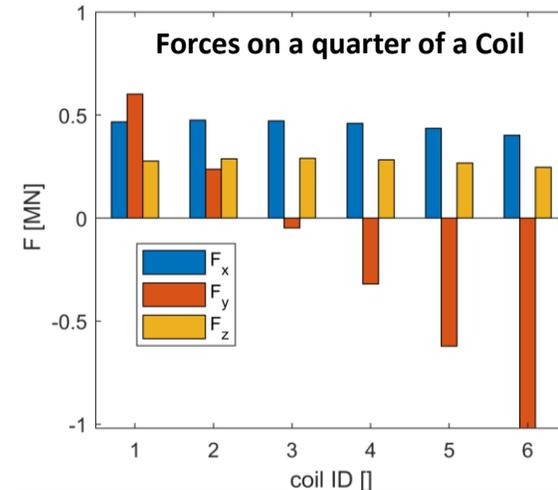
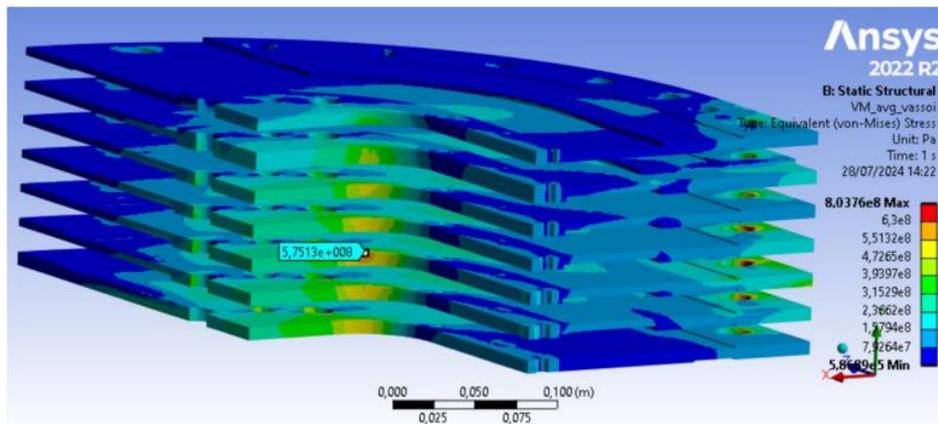
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Mechanical Design

- Most parts by AISI 316 LN, very **high force density**.
- Accepting the possibility of small local plasticization.



Component	Material	SF Undisturbed vs Yield	SF Average vs Ultimate	SF Peak vs Ultimate
Sample Holder Plate	AISI 316L (@77K)	1.6	4.4	1.7
Base Plate	AISI 316LN (@20K)	1.5	2.3	1.4
External Ring	AISI 316LN (@20K)	2.9	4.2	1.9
Intermediate Ring	AISI 316LN (@20K)	4.4	6.5	3.6
Pressinf Pins	AISI 316LN (@20K)	3.2	4.7	3.0
Insulation G10	G10 (@77K)	-	3.7	-
Internal Ring – Curved Heads	AISI 316LN (@RT)	1.8	3.3	2.6
Internal Ring – Stright Part	Ti-6Al-4V (@RT)	5.5	5.9	4.7
Pressors	AISI 316LN (@20K)	1.8	2.6	2.2
Lateral Reinforce	AISI 316L (@77K)	1.9	5.2	2.0
		SF > 1.5	SF > 2.0	SF > 2.0



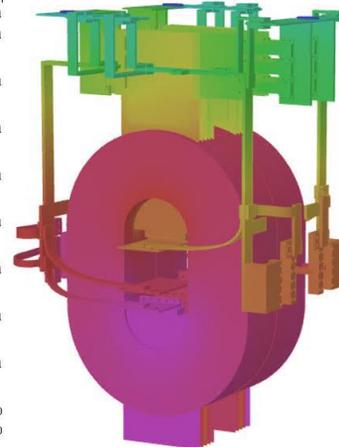
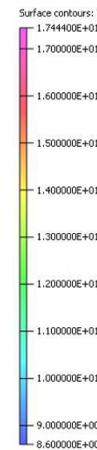
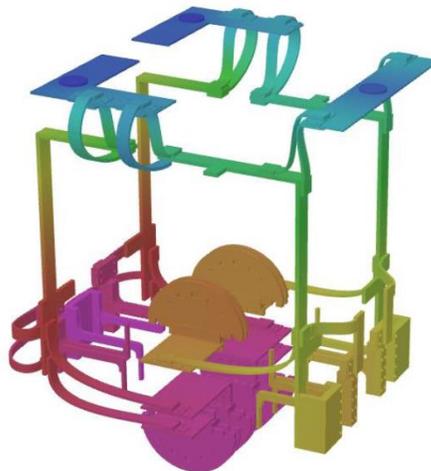
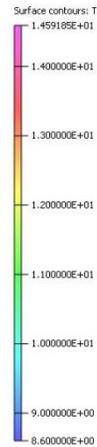
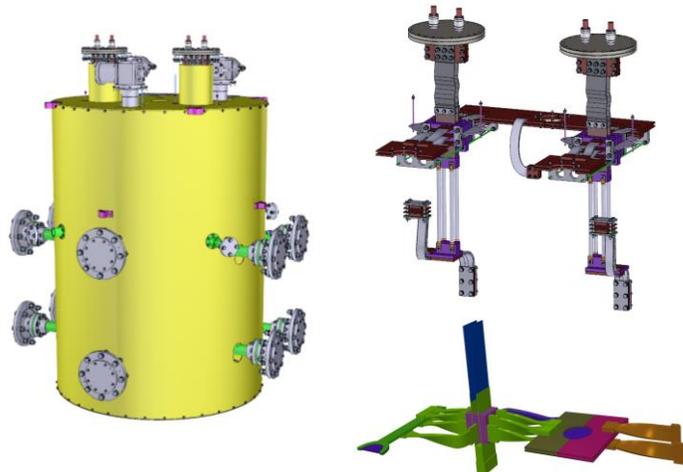
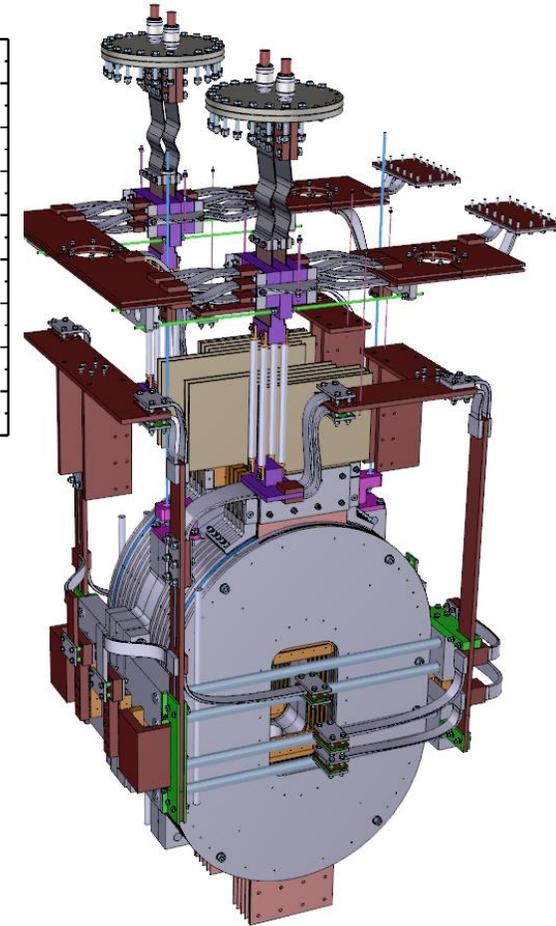
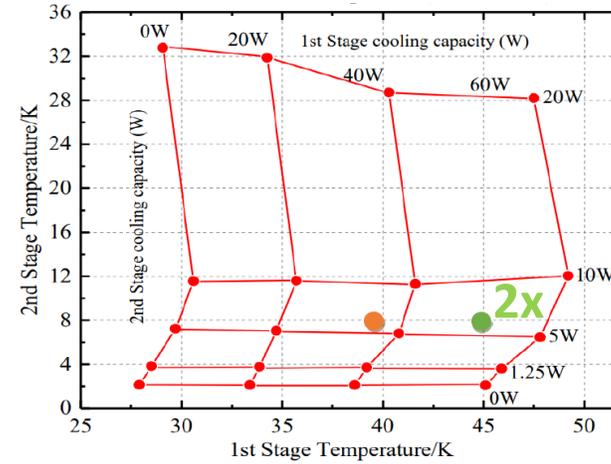
Thermal Design

3x Cryocooler FS to cool Copper shield and Current Leads (<65 K)

- Shield 20 W
- Current Leads 115.4 W
- Cryo1 @ 38.6 K 37 W
- Cryo2 @ 44.8 K 49.5 W (2x)
- T max Current Lead – 56 K
- T max Shield – 58 K

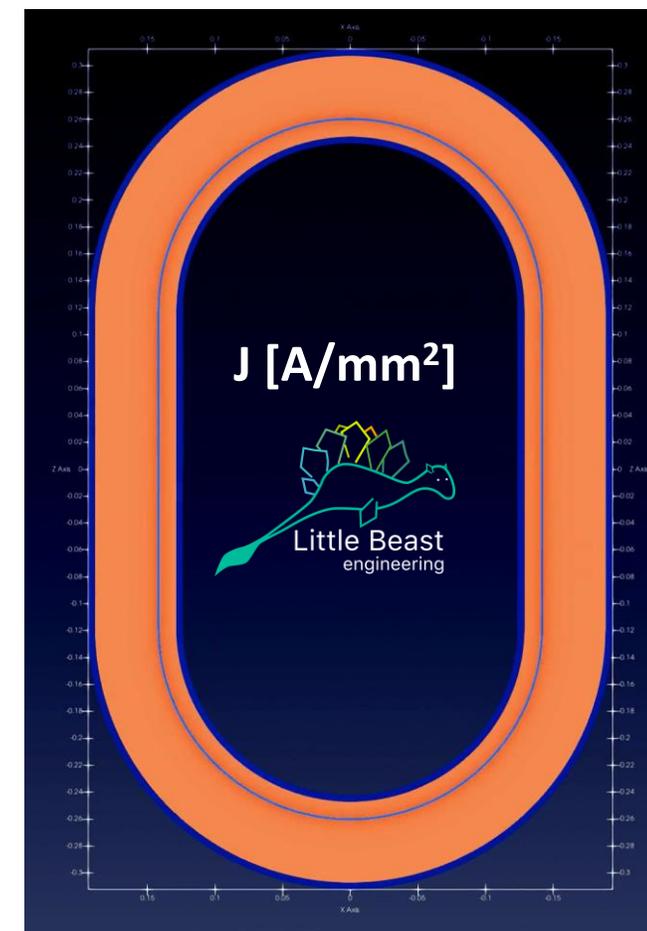
3x Cryocooler SS to cool Cold Mass (<20 K)

- Ramp up 20 W
- Steady State 4.7 W
- Cryo1 @ 8.8 K 6 W
- Cryo2 @ 8.6 K 7 W (2x)
- T max Coil Ramp Up 17.5 K
- T max Coil Steady State 11.4 K



Protection: ESMA first steps

- Very dangerous to assume full **self-protection** (3.6 MJ to discharge uniformly into coil, but some parts have + 40 K margin).
→ Conduction cooling + Not enough hotspot bypass = **bad**
- **Metal-Insulation** means current bypass at hotspot.
→ less demanding detection: “standard” **detection & discharge**.
- Original Stress Test Scenario: artificial heater at weakest point, with 5 J – 35 J to quench.
- Could not get rid of *current shock-wave* (2000 A/mm^2) at sudden discharge (switch opening) → high risk of conductor damage = **bad**
- Must **shift the paradigm** with a more pragmatcal eye on magnet operation (and not quench it artificially)



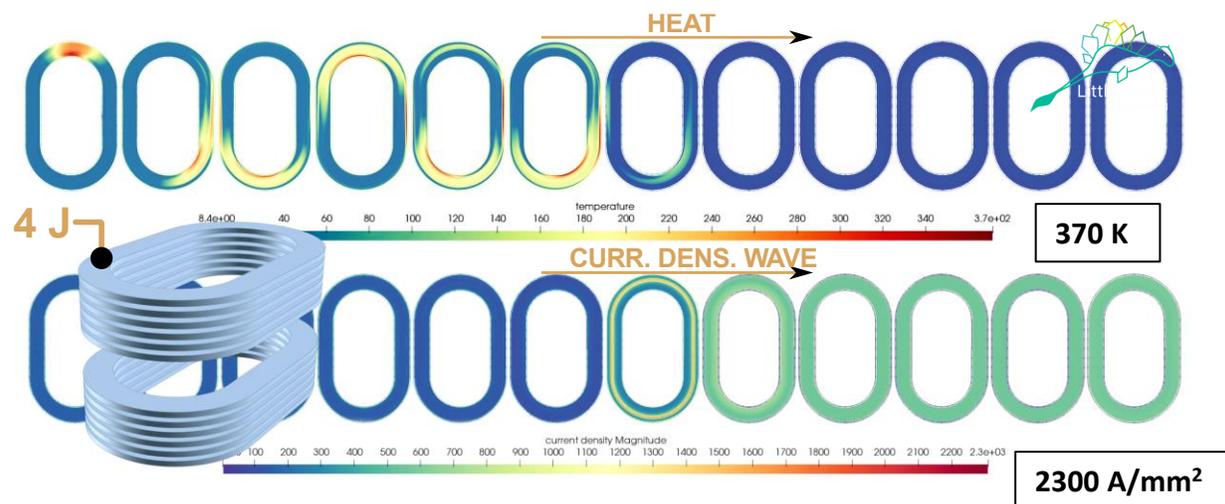
Protection and Operation

Quench and Discharge

- HTS quench causes: **over-heating** (by AC losses or Cooling failure) or **magnet defects**.
- Magnet Fast Ramp Down = Shock Wave
- We are currently looking for the optimal Ramp Down Discharge to generate the less stressful Shock Wave possible
- **Mitigation plan:** operational limits given by on-board diagnostics (online losses estimation through ASG proprietary control system)
→ Prevent quench at all
- Controlled Discharge with diodes (for BSCCO CL protection too) only if needed.

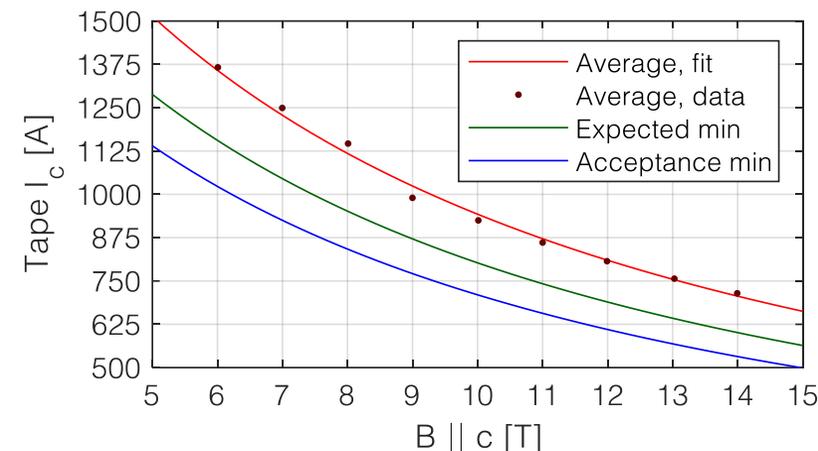
Ramp Up in Operation

- The magnet is expected to have R_c around a few $100 \mu\Omega\text{cm}^2$
- Target in charging is not time, but power. Aim $P < 20 \text{ W}$, adjusting ramp-rate (expected 4 hours charging from 0 T to 10 T)



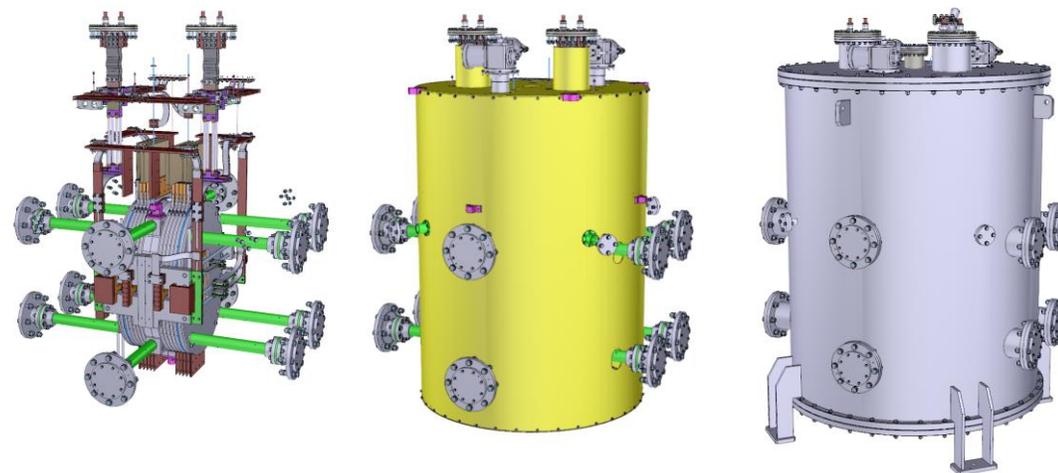
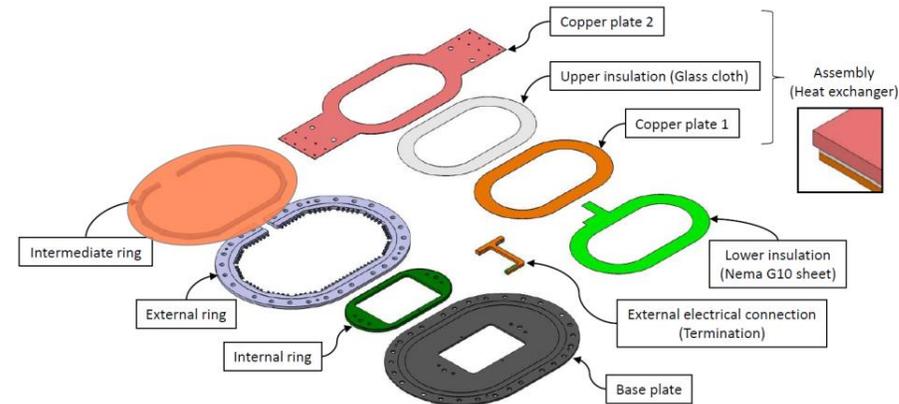
Procurement: HTS Tape

- Total of 15 km procurement from **FFJ** and delivered (spring 2024).
- Acceptance criterion 500 A @ 15 T perp. and UL > 200 m. As promised, mostly **outperforming**, batches > 680 A for > 95%.
- Visual inspection at LASA of the full supply: **local non-conformities detected** (geometrical defects).
- Very good responsiveness from **FFJ**:
 - some 100 m lengths “for free” to further test non-conformity effects on Tape performances.
 - **Full NC replacement**: shipped and received.



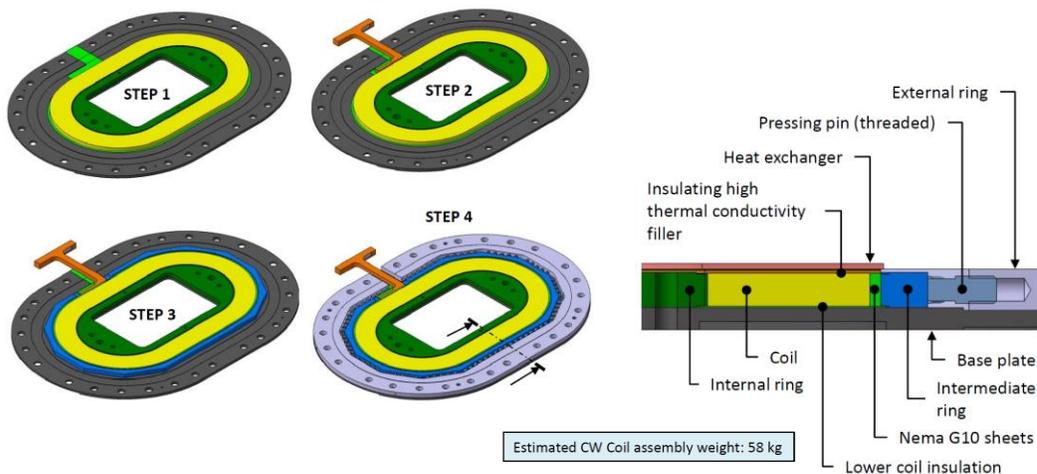
Procurement: Winding Machine, Cryocoolers, and ESMA components

- **Multi Tape Winding Machine:** installed in ASG (winding tests under way)
- **Cryocoolers:** stocked in ASG
- **Mechanical and Electrical Coils' components:** procured – ASG in June (SS 316LN procurement delay)
- **Electrical and Thermal Magnet connections:** procured – ASG in June
- **Shield:** procured – ASG in June
- **Cryostat:** procured – ASG in June

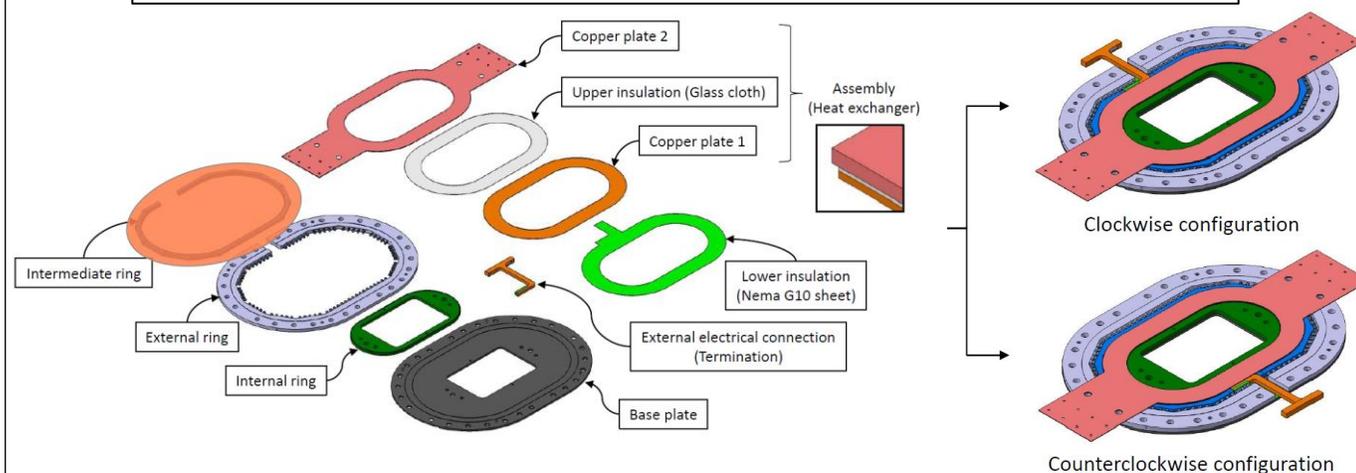


Assembly - Coils

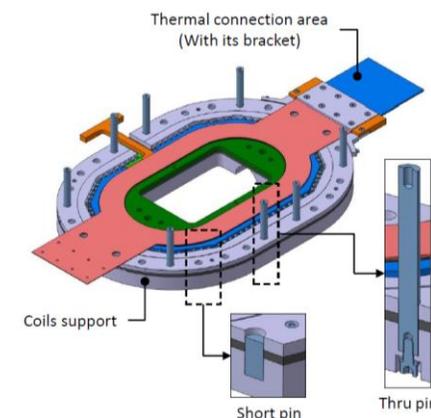
- STEP 1:** Wind on Internal Ring installed on Base Plate
- STEP 2:** Install on the Copper Ts (current leads)
- STEP 3:** Install Intermediate Ring around the Coil
- STEP 4:** Compress the Coil with External Ring and Pressing Pins



STEP 5: Complete the Coil with extra layers (Copper and G10) Clockwise and Counterclockwise Config



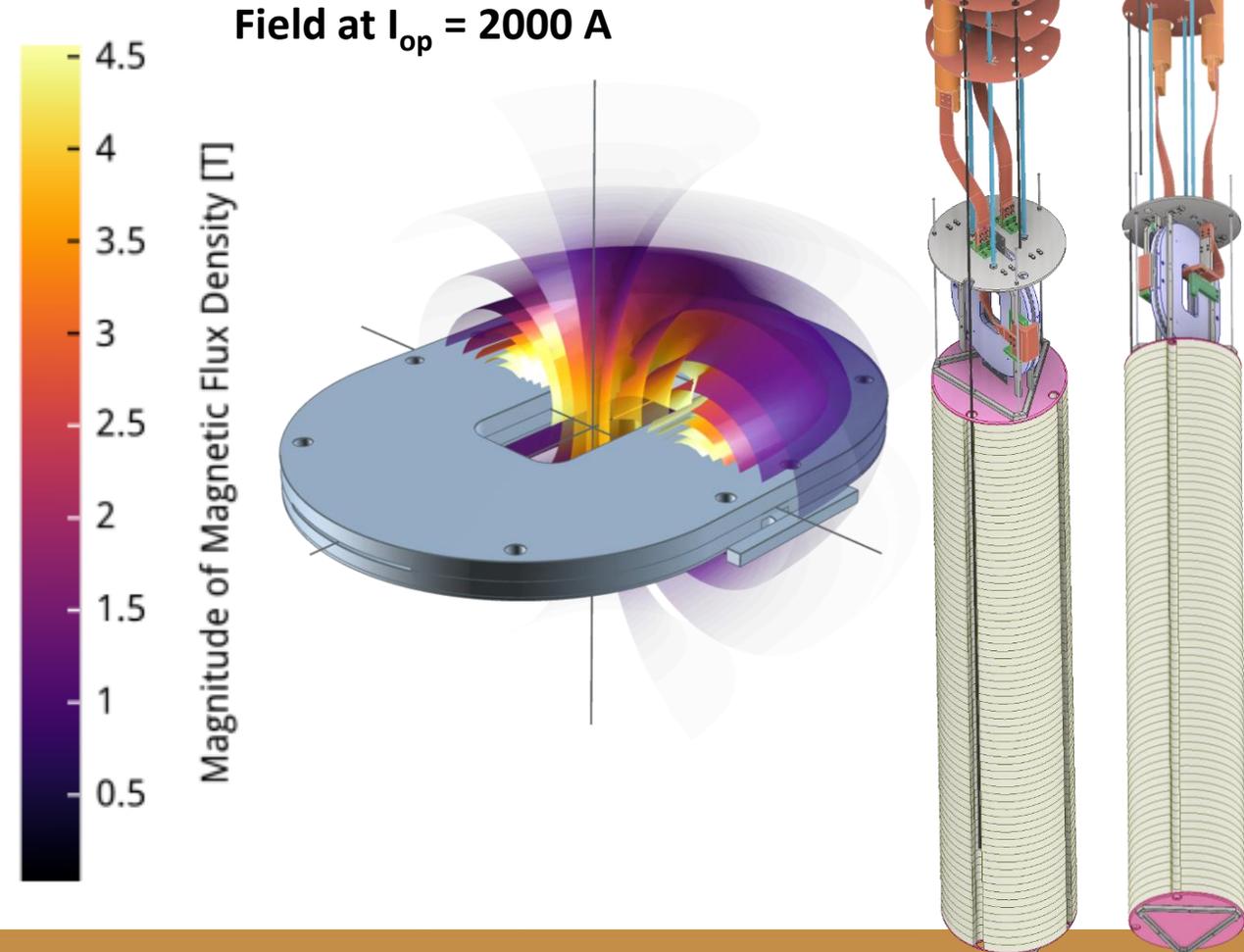
STEP 6: Install Short Pins and Thru Pins to prepare the single Coil for Cold Mass Assembly





Single ESMA Coil Test

- Additional experiments to characterize the magnet
→ **prototype coil-module**
- Cryogen-free system tests @ ASG
- LHe mechanical and magnetic tests @ LASA
 - Coil 2000 A @ 4.2 K \equiv of ESMA 1150 A @ 20 K
 - The main purpose is to qualify the Coil's Mechanic
- Test @ LASA Foreseen for May 2025





Final Tests

September 2025 Factory Acceptance Test @ ASG Genova

- Cool Down 1
 - Ramp Up 1 to 3 T (0.1 A/s)
 - Field Homogeneity Measurement
 - Ramp Up 1 to **8 T** (0.1 A/s)
 - Field Homogeneity Measurement
 - Ramp Down 1
 - Ramp Up 2
 - Ramp Down 2
- Warm Up 1
- Cool Down 2
 - Ramp Up 3
 - Ramp Down 3
- Warm Up 2

December 2025 Site Acceptance Test @ INFN Genova

- Cool Down 3
 - Ramp Up 4 to 3 T
 - Field Homogeneity Measurement
 - Ramp Up 4 to **8 T**
 - Field Homogeneity Measurement
 - Ramp Down 4
- Warm Up 3

February 2026 Full Scale Test @ INFN Genova

- Cool Down 4
 - Ramp Up 5 to 8 T
 - Ramp Up 5 to **10 T**
 - Ramp Down 5
- Warm Up 4





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The End

