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

DTT Magnet system & Cryosystem

DTT industry day

Villa Mondragone, Monte Porzio Catone (Rome), Italy – 14/12/2018

G.M. Polli on behalf of the DTT team

Outline

Magnet system:

- Supercondutcing & Copper Strands
- TF coils:
  - Conductors
  - Winding packs
  - Casing structure
  - Intergration
  - Testing
- CS coils:
  - Winding
  - Assembly
- PF coils

Cryosystem:

- Cryoplant
- Current leads
- Current leads boxes
- Feeders & cryodistribution inside cryostat

Magnet system: requirements and overview

Requirements:

- Flexibility for plasma shaping
- 6 T on plasma @ 2.11 m radius
- Ripple < 0.3%
- Pulse length ~ 100 s
- Mature technology for schedule constraint

Overview:

- 18 TF coils in Nb_3Sn
- 6 independent CS coils with conductor grading in Nb_3Sn
- 4 independent PF coils in NbTi
- 2 independent PF coils in Nb_3Sn
- 4 independent in-vessel divertor coils (Cu)
- 2 independent in-vessel coils (Cu) for vertical stabilization

Magnet systems: reference parameters

18 Toroidal Field coils

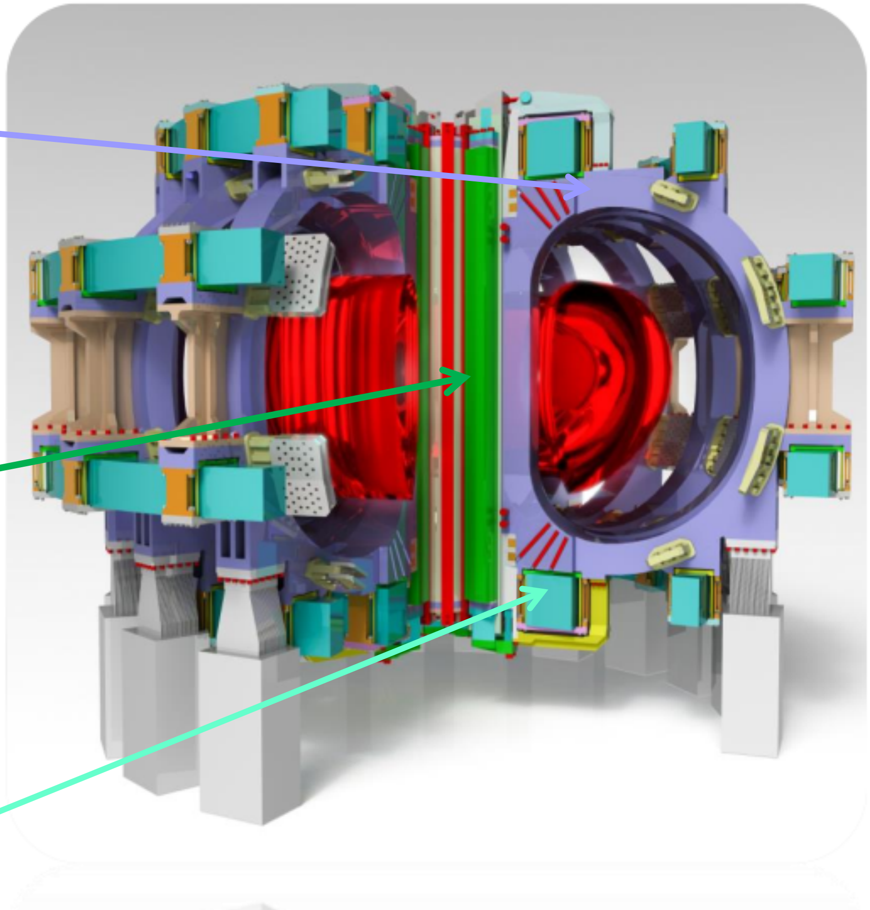
Nb_3Sn Cable-In-Conduit Conductors
6 *Double-Pancakes* (4 regular + 2 side)
B_{max} = 11.7 T
I_{op} = 26.9 kA
ΔT_{margin} > 1.6 K

6 Central Solenoid module coils

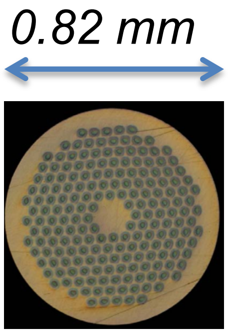
Nb_3Sn Cable-In-Conduit graded Conductors
Layer Wound (3 sections)
B_{max} = 14 T, 12 T, 8.2 T
$I_{op\text{-}max}$ = 28 kA
ΔT_{margin} > 1 K

6 Poloidal Field coils

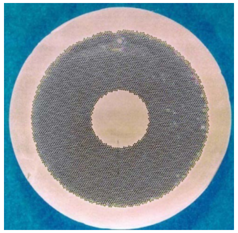
4 NbTi Cable-In-Conduit Conductors
2 Nb_3Sn Cable-In-Conduit Conductors
Double-Pancakes winding
B_{max} = 2.5 – 7.5 T
$I_{op\text{-}max}$ = 11 - 29 kA
ΔT_{margin} > 1.6 K in all coils



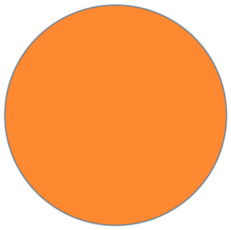
Superconducting & Copper Strands



Nb_3Sn:
Diameter = 0.82 ± 0.005 mm, Cu:non-Cu = 1.00 ± 0.05, Cr coating = 2 ± 1 μm
Hi-Grade operative conditions: Ic (6.2K, 12T, -0.6% applied strain) **≥ 80 A**
Hi-Grade performance at 4.2K: Ic (4.2K, 12T, 0.0% applied strain(*)) **≥ 290 A**
RRR: > 100
46 tons FOR TFC + 13 tons FOR CS + 9 tons FOR PF1/6 (> 13'800 km)



NbTi:
0.82 ± 0.005 mm, Cu:non-Cu = 1.90 ± 0.05, Ni coating = 2 ± 1 μm
Required Performance at 4.2K: Ic (4.2K, 5T) **≥ 500 A**
RRR: > 100
32 tons FOR PF2/3/4/5 (> 6'400 km)



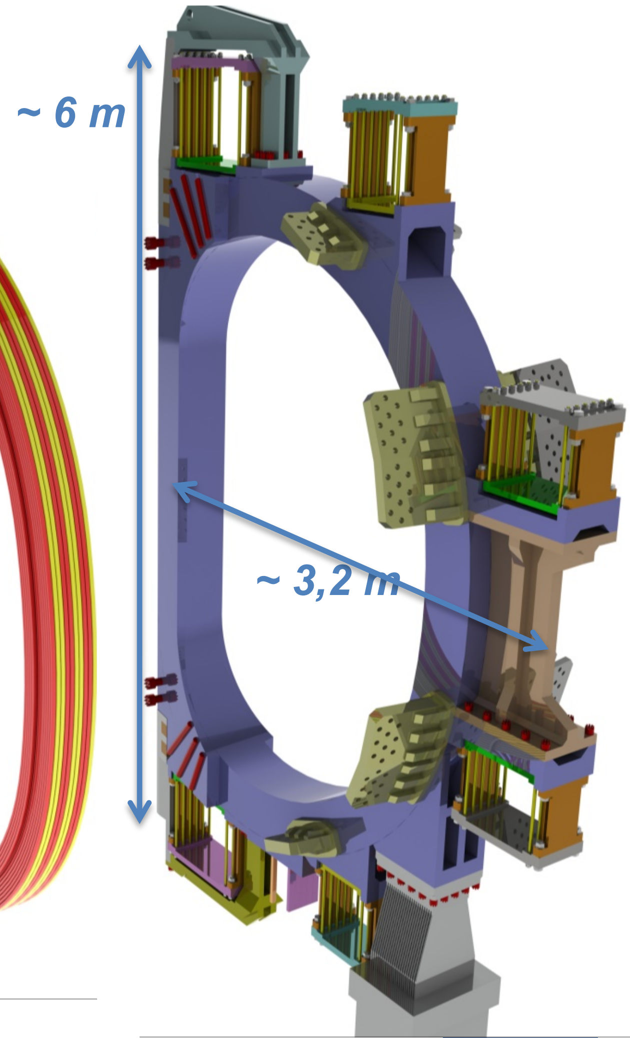
Cu:
0.82 ± 0.005 mm, Cr/Ni coating = 2 ± 1 μm
RRR: > 300
35 tons FOR TFC & CS & PF1/6 + 20 tons FOR PF (> 10'900 km)

TF coils: overview

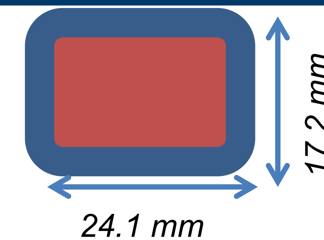
I_{op}: 26.92 kA
B_{max}: 11.7 T
ΔT_{margin} > 1.6 K
20 tons (each TFC)

Procurements:

- Nb_3Sn & Cu (Cr plated) strands
- TFC cabling & jacketing
- TFC WP
- TFC casing
- TFC in-casing integration
- TFC testing in cryogenics
- TFC assembling



TF coils: Conductors



Conductors & Strand manufacturing schedule: 3.5 years from kick-off-meeting, 2 sets of UL every 2.5 months

Main features:

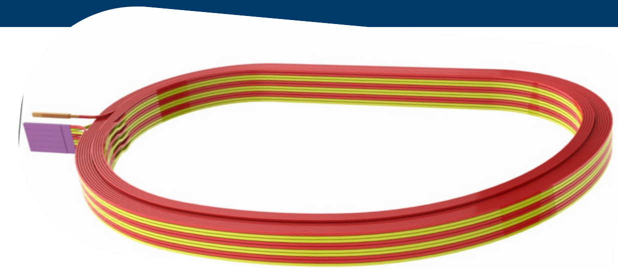
- External dimensions: *24.1 x 17.2 mm*
- Jacket thickness: *1.9 mm*
- Cable: *300 Nb_3Sn and 54 Cu strands*
- 0.82mm ITER-like Nb_3Sn strands *(slightly enhanced)*
- Cable pattern: *3x4x5x5 + 3x3x6 Cu core*
- Unit length (UL): 270 m (regular), 190 m (lateral)
- Total # of ULs: 72 (regular) + 36 (lateral) + 8 spare

Key issues:

- 316 LN jacket (samples and dummies to be provided in advance for winding test)
- 100% welds testing
- He leak testing (pressure, flow)
- Jacketing line ~ 880 m (for CS & PF)

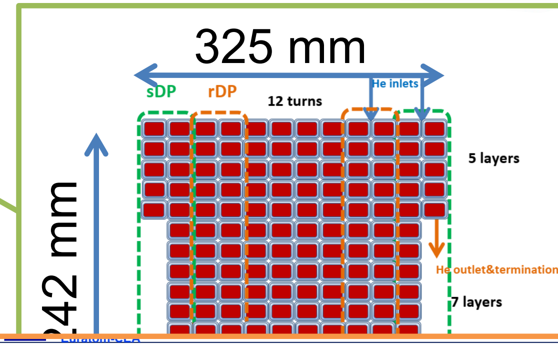
TF coils: Winding Packs (WP)

TF WP manufacturing schedule: 4.25 years from kick-off-meeting, ~1 DP every week



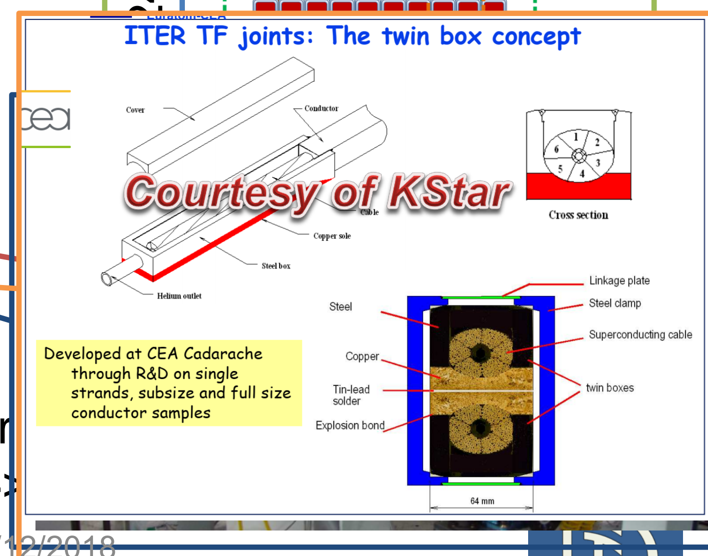
4 rDPs (regular Double-Pancakes)
2 sDPs (side Double Pancakes)

Max. hydraulic length: 135m
turns: 130
~ 5 tons



Key issues:

- Double pancakes (DP) winding is in the critical path (multiple shifts and/or multiple lines expected)
- Heat treatment
- Insulation after heat treatment
- Internal joint (<2nOhm)
- Vacuum pressure impregnation (VPI)
- High shear strenght on insulation
- Tight tolerance on current line (phi < 2 mm) -> laser
- High voltage DC tests in vacuum (Paschen proof) ->



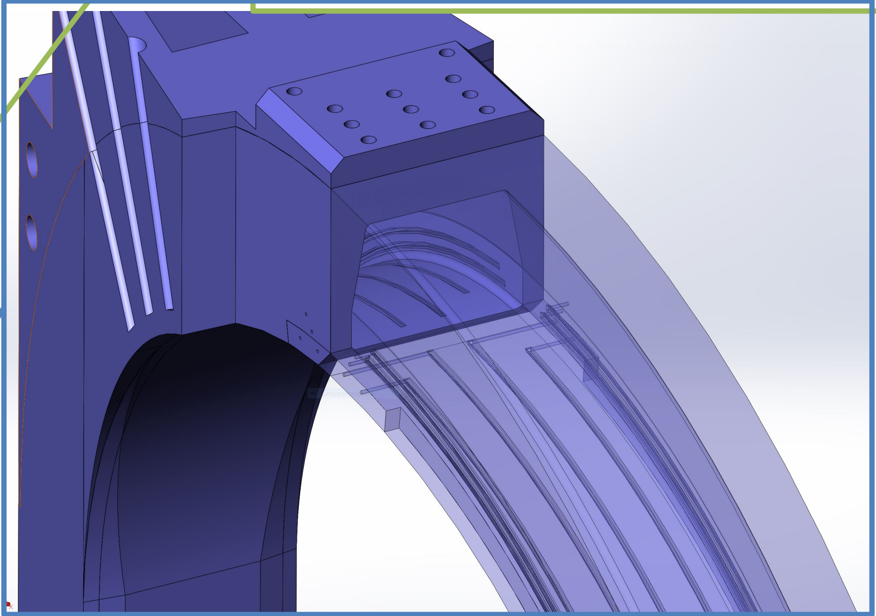
TF coils: casing

TF casing manufacturing schedule: 4 years from kick-off-meeting, 1 casing every ~ 3 months

~ 15 tons
Max thickness: ~ 90 mm
Support structures for PF included
Outer Intercoil structures included

Key issues:

- 316LN
- 100% welds control
- Dimensional controls with laser track
- KSTAR solution envisaged
- Channels for cooling machined inside and sealed



TF coils: integration

TF casing integration schedule: 4.25 years from kick-off-meeting, 6 months per TFC from WP & casing available

Main features:

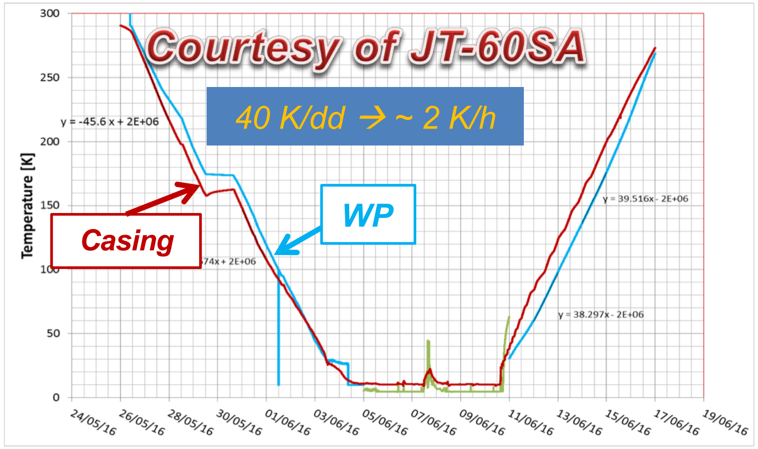
- WP insertion into casing
- Casing welding
- Embedding impregnation
- Mechanical final machining
- He cooling piping insertion
- Final acceptance tests

Key issues:

- High voltage DC tests in vacuum (Paschen proof)
- Electrical breakers
- 316LN
- 100% welds control
- Final machining for tolerance
- Piping insulation
- Electrical terminations

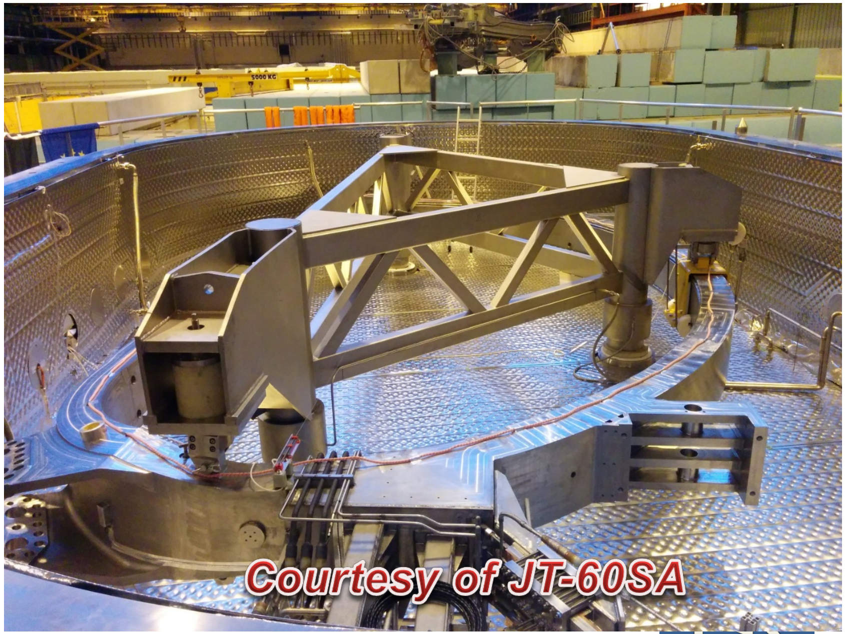
TF coils: testing

TF cryogenic testing schedule: 4 years from kick-off-meeting, ~ 2 month per TFC including coil preparation (2 weeks), cool-down (1 week), testing (1 week), warm-up (1 week), coil release (2 weeks)



Key issues:

- High voltage DC tests in vacuum at Cryogenic
- 4,5 K, 6 bar, nominal current
- Quench test
- Insulation resistance test
- Joint resistance test (< 2 nOhm)



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Cryosystem:

- Cryoplant
- Current leads
- Current leads boxes
- Feeders & cryodistribution inside cryostat

CS coils: overview

I_{op}: 28 kA

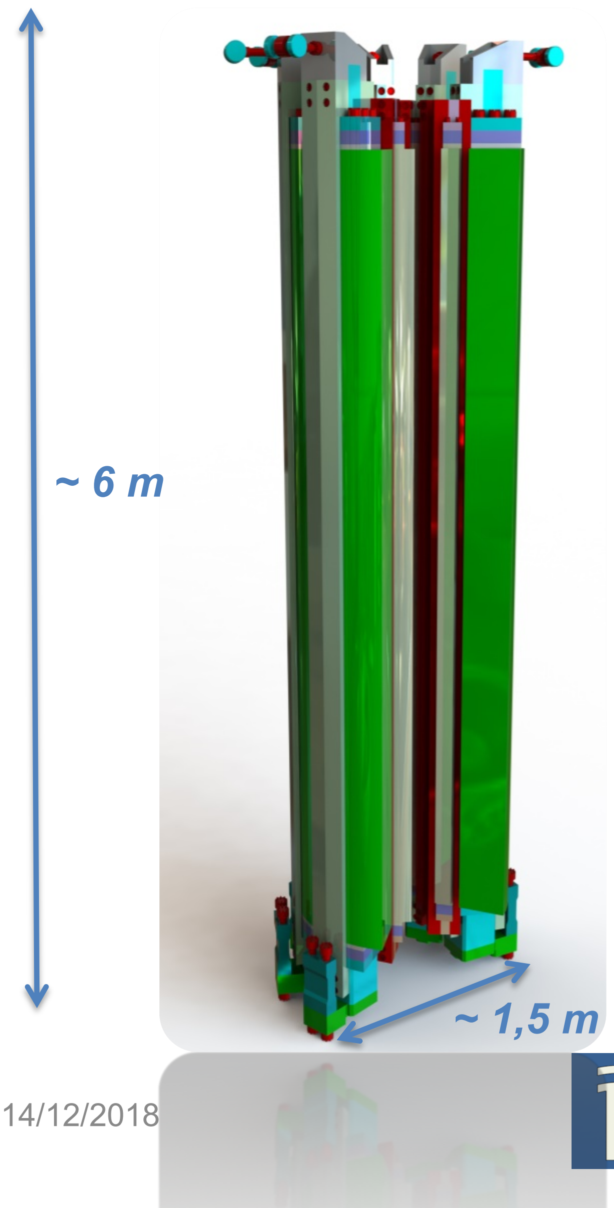
B_{max}: 14.0 T

ΔT_{margin} > 1.1 K

51 tons (whole solenoid)

Procurements:

- Nb_3Sn, Cu (Cr plated) strands
- CS cabling & jacketing
- CS module manufacture
- CS testing in cryogenics
- CS pre-assembling
- CS assembling



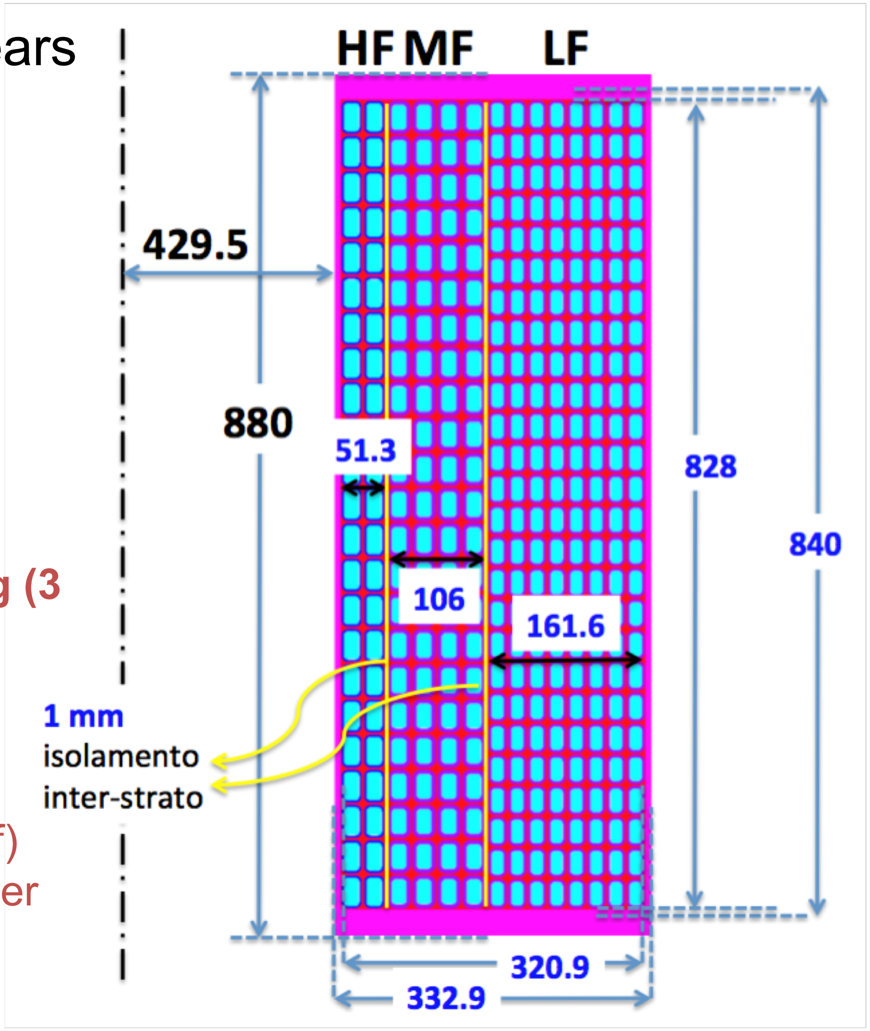
CS coils: CS modules

CS module manufacturing schedule: 3 years from kick-off-meeting, 1 module every 3 months

Coil height	~ 0,9 m
Coil inner diameter	~ 0,8 m
Coil outer diameter	~ 1,5 m
Mass	~ 7 tons

Key issues:

- **Layer wound solution with conductor grading (3 grades)**
- Insulation before heat treatment (only glass)
- Embedded joints bewteen layers
- Vacuum pressure impregnation
- High voltage DC tests in vacuum (Paschen proof)
- Tight tolerance on current line diameter and center axis
- Cycling loading conditions (> 30000 cycles)

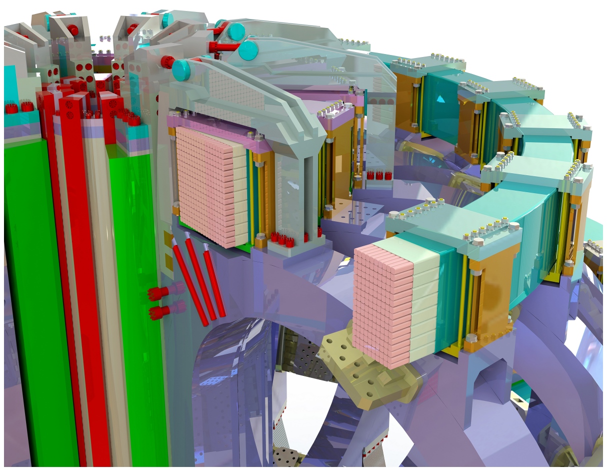


CS coils: CS assembly

CS module assembling schedule: 2.25 years from kick-off-meeting (including pre-assembly)

Key issues:

- Tight tolerance on center axis during pre-assembly
- **Assembly possible only after TF & PF magnet system completed**
- Total mass ~ 51 tons
- Total height > 6 m



PF coils: overview

I_{opmax}: 28.6 kA

B_{max}: 5.9 T

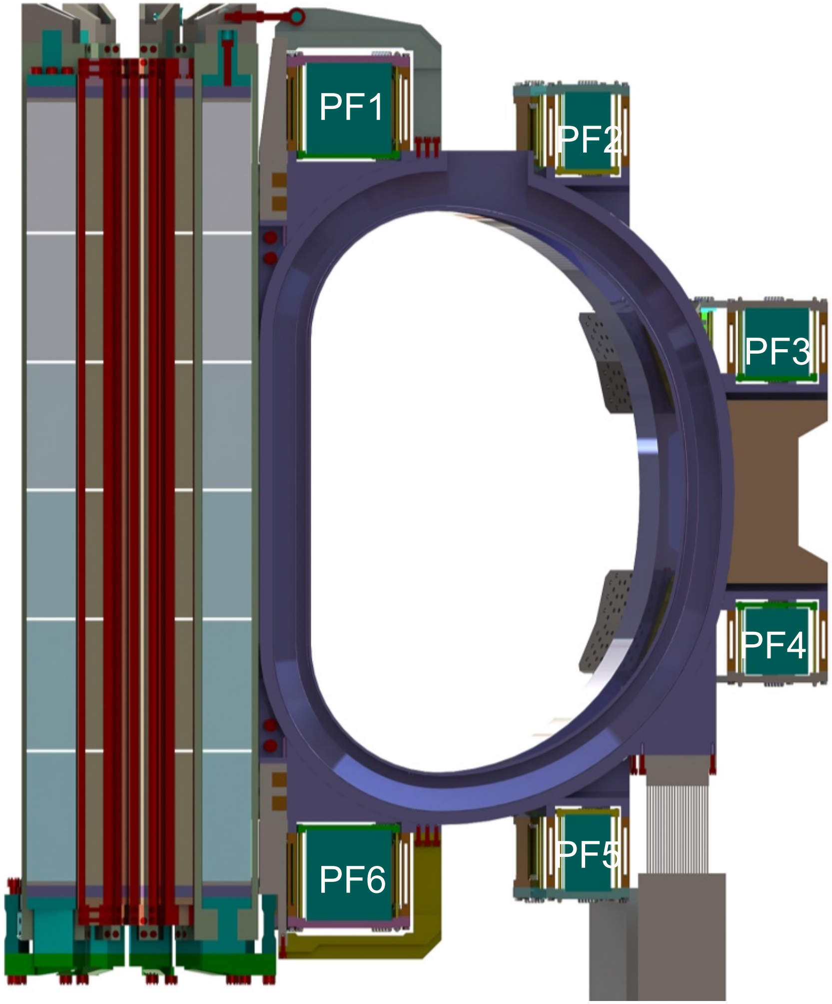
ΔT_{margin} > 1.6 K

PF1/2/5/6 ~ 20 tons each

PF3/4 ~ 33 tons each

Procurements:

- Nb_3Sn, NbTi, Cu (Ni plated) strands
- PF cabling & jacketing
- PF Winding
- PF testing in cryogenics (only PF1/6)
- PF pre-assembling
- PF assembling



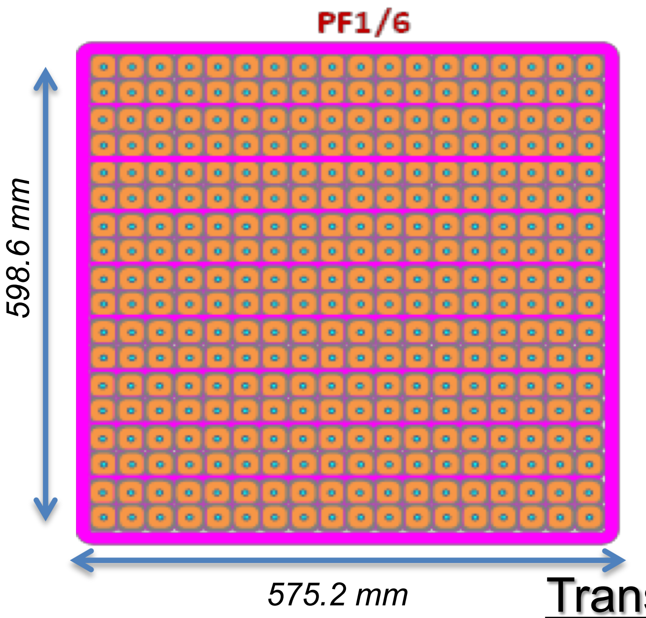
PF coils: PF winding

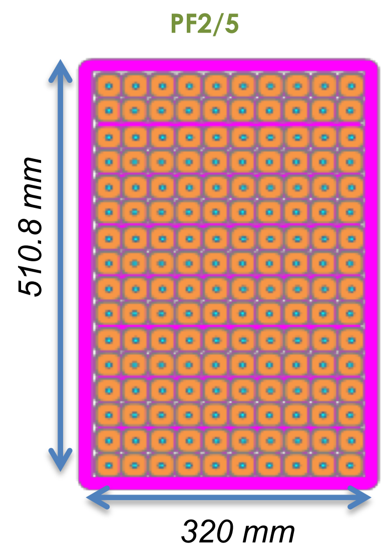
PF winding manufacturing schedule: 4.25 years from kick-off-meeting

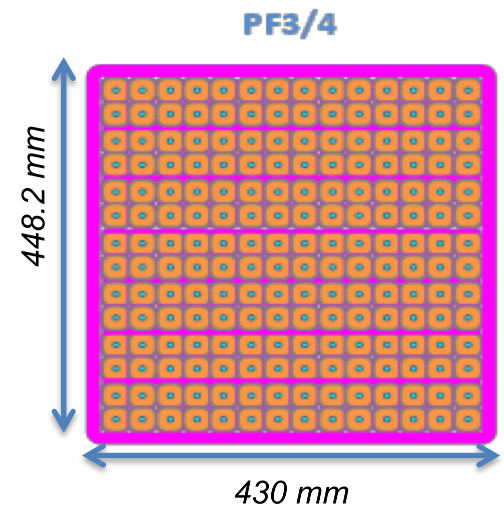
PF1/PF6:
- Coil height ~ 590 mm
- Inner diameter ~ 2,3 m
- Outer diameter ~ 3.4 m
- Mass ~ 20 tons
- Double pancakes 9

PF2/PF5:
- Coil height ~ 500 mm
- Inner diameter ~ 6 m
- Outer diameter ~ 6,6 m
- Mass ~ 20 tons
- Double pancakes 8

PF3/PF4:
- Coil height ~ 590 mm
- Inner diameter ~ 8,2 m
- Outer diameter ~ 9 m
- Mass ~ 33 tons
- Double pancakes 7







<u>Transportation might be an issue</u>

Outline

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Cryosystem:

- Cryoplant
- Current leads
- Current leads boxes
- Feeders & cryodistribution inside cryostat

Cryogenic system: requirements and overview

Requirements:

The Cryogenic System of the DTT has to provide adequate cooling during 100 s plasma pulses with full nuclear heating, repeated every 3600 s to:

- 18 TF coils + 6 current leads + Feeders;
- 6 CS module coils + 12 current leads + Feeders;
- 6 PF coils + 12 current leads + Feeders;
- Thermal shields (TS);
- Cryo-lines:
- Cryogenic pumps (under evaluation) ➡ 3.7 K

Overview:

- **Cryoplant ~ 10 kW cooling power @ 4.2 K**
- HTS Current leads (cooled @ 50K)
- Cryodistribution inside cryostat

Cryogenic system: cryoplant system architecture

6 storage vessels (one for quench recovery)

- ∅ 4 m × 21 m, 250 m^3, 70 tons
- RT, total He content 3,6 tons

8 screw compressors (housed in 4 skids) operating in parallel, oil and gas coolers, dryer

- 4,5 m × 2 m × 2,5 m, 10 tons
- Electrical parameters (2,4 MW)
- Hydraulic properties (RT, 680 g/s, 1,6 MPa)

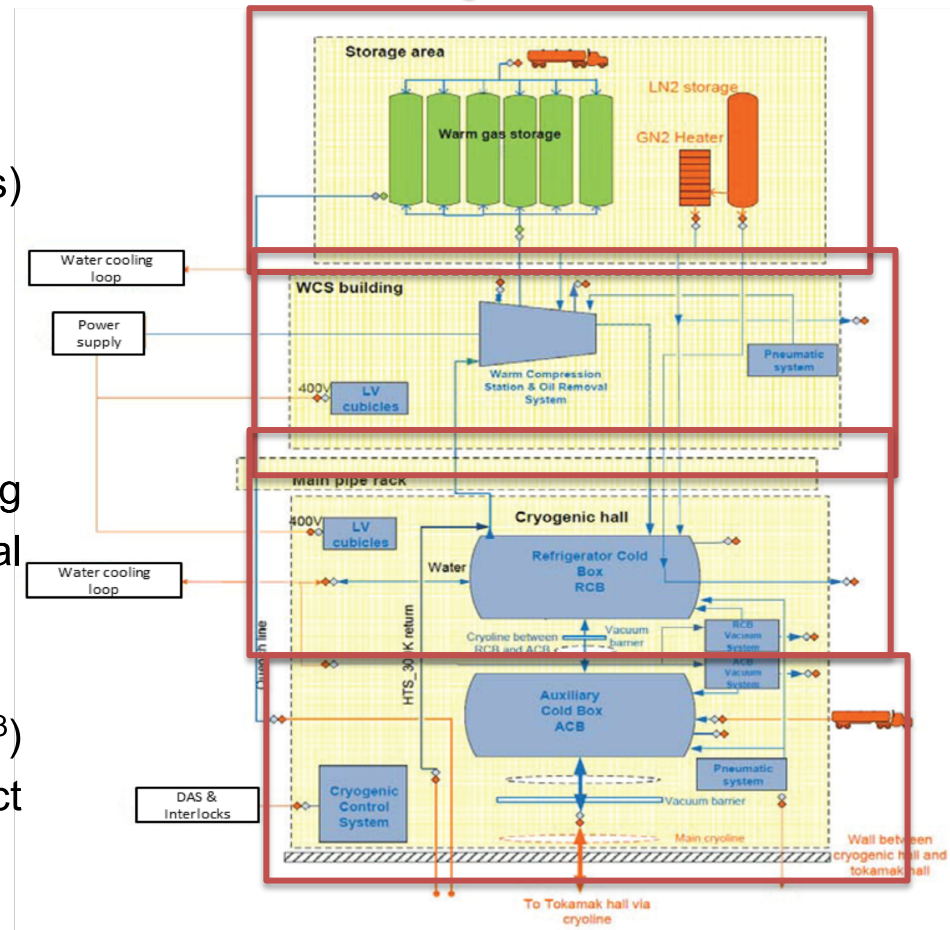
Refrigeration Cold Box – with LN_2 pre-cooling stage, 3 turbo-expanders, heat exchangers, dual 80 K and single 20 K adsorbers

- ∅ 3,2 m × 12 m, 65 tons

Auxiliary Cold Box – with baths at 4,3 K (7m^3) and 3,6 K (1 m^3), 2 cold circulators for 2 distinct loops, 1 cold compressor, and heat exchangers

- ∅ 3,2 m × 11 m, 50 tons

Courtesy of JT-60SA



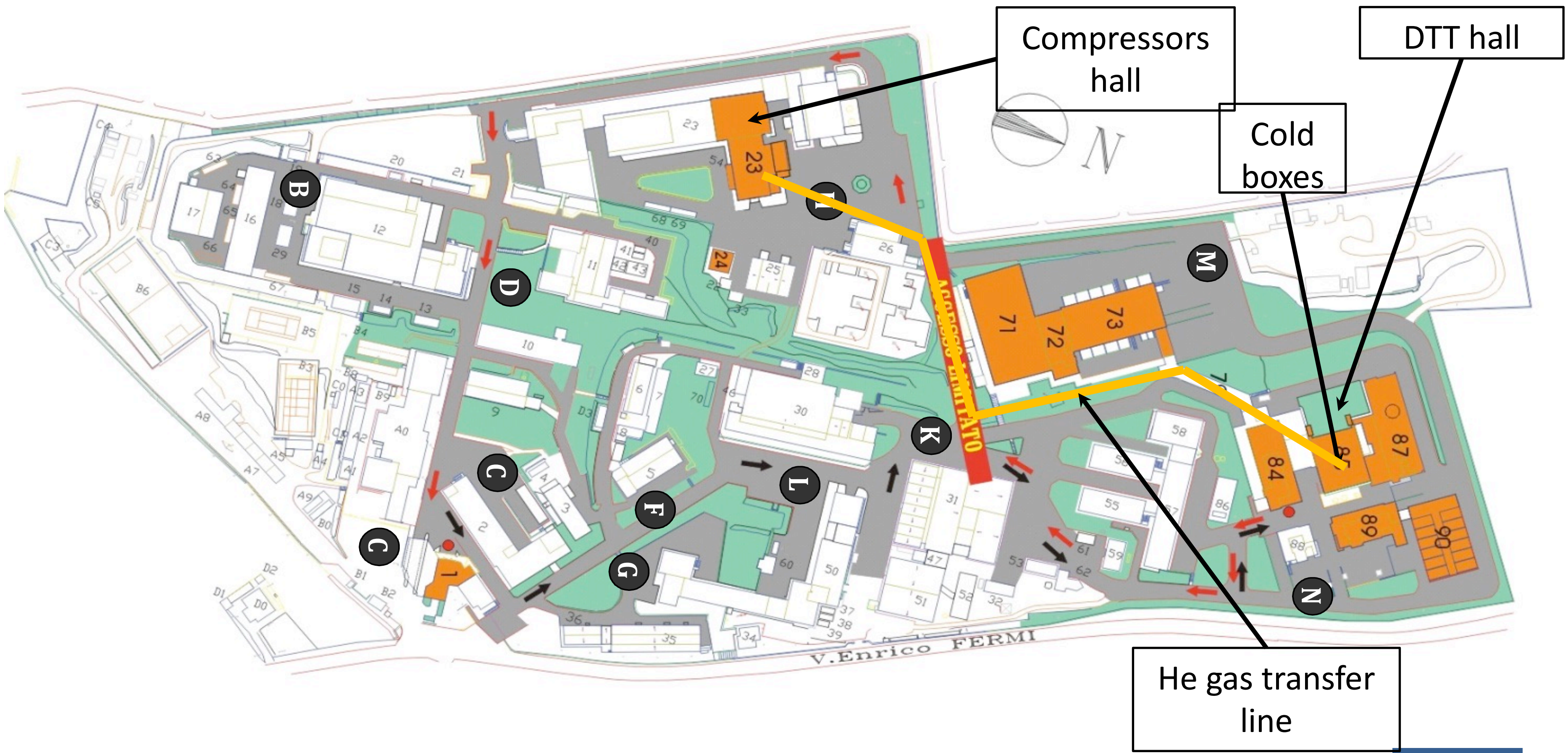
Cryogenic system: cryoplant requirements

Temperature level (K)	Heat source	Average Power (W)		Equivalent power @ 4,2 K (W)	
		Normal operation (POS+DWE)	Baking mode (BAK)	Normal operation (POS+DWE)	Baking mode (BAK)
80	TS, CP baffles, cryo-distribution	45.000	135.000(*)	~2.400	~7.100
50	HTS-CL & feeders (TF+CS+PF)(*)	33	0	~3	0
4,5	TF, CS, PF (WP, casing, distribution)	3.000	3.200	3.000	3.200
3,7	Cryo-pump panels(*)	84	0	84	0
(*) *Data from JT60-SA*	**Total equivalent power @ 4.2 K (W)**			**5.484**	**10.305**

- During the baking, the estimated equivalent cooling power @ 4.2 K exceeds 10 kW.
- Moreover, during Plasma Operation State (POS), the DTT cryogenic system shall have to cope with large pulsed heat loads, perhaps twice the average power in normal operation.
- The maximum required cooling power at full performance is estimated in the range of ~10 to 11 kW @ 4.2 K.

Cryogenic system: cryoplant layout in DTT site

Cryoplant procurement schedule: 4.75 years from kick-off-meeting



Cryogenic system: HTS current leads

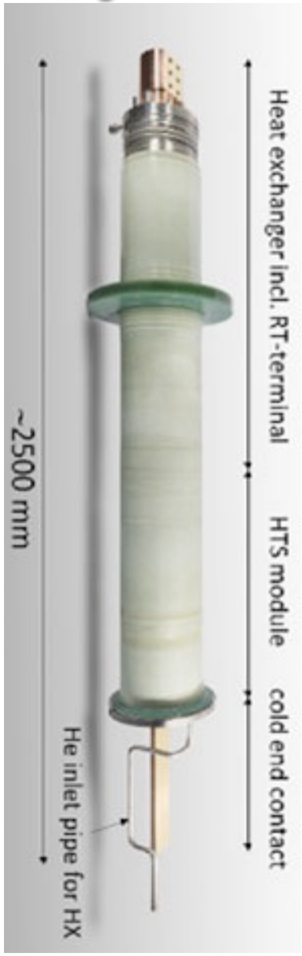
HTS current leads procurement schedule: 3.75 years from kick-off-meeting

TF CL:
- 6 HTS CL (due to quench protection circuit)
- ~ 30 kA
- Stationary working conditions

CS CL:
- 12 HTS CL (one pair per module)
- ~ 30 kA
- Pulsed working conditions

PF CL:
- 12 HTS CL (one pair per module)
- ~ 30 kA
- Pulsed working conditions

Courtesy of JT-60SA

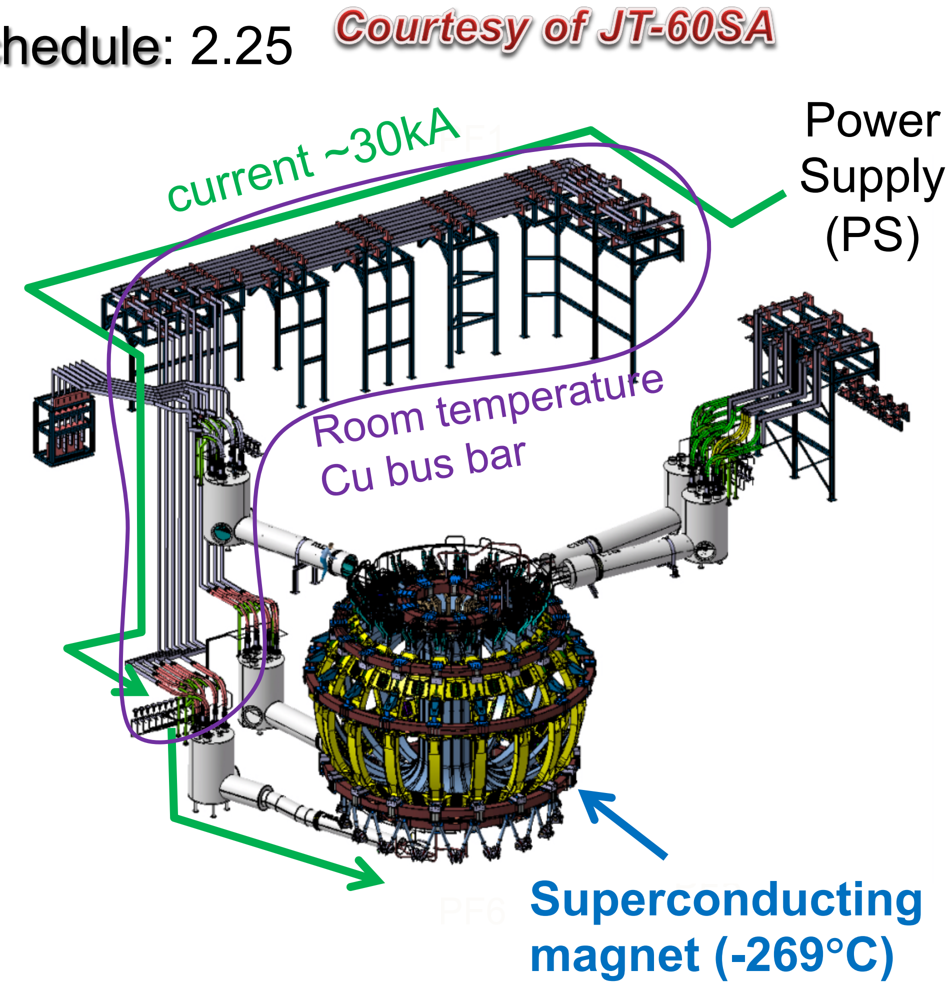


Cryogenic system: current leads boxes

Current leads boxes procurement schedule: 2.25 years from kick-off-meeting

Each current lead box will host 4/6 HTS current leads:

- TF coils will be fed from the bottom
- 3 modules of CS + PF6/PF5/PF4 from the bottom
- 3 modules of CS + PF1/PF2/PF3 from the top



Cryogenic system: feeders inside cryostat

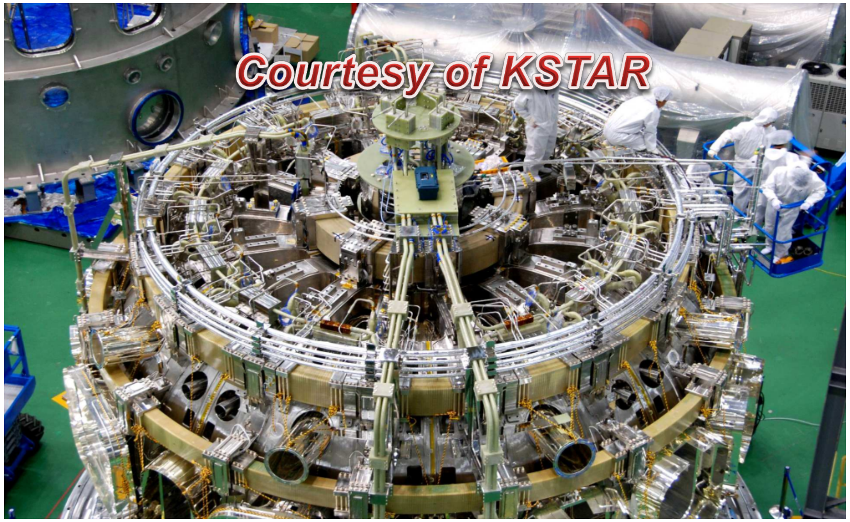
Feeders & cryo-distribution procurement schedule: 1.75 years from kick-off-meeting

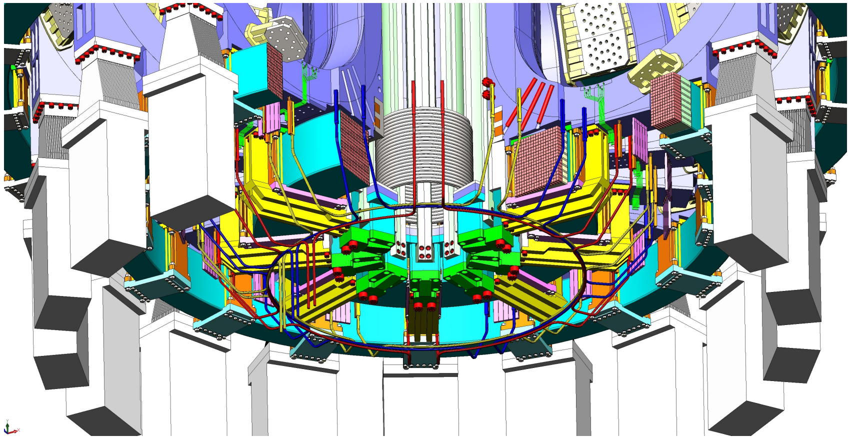
The distribution of coolant will be possible after the magnet system has been completely assembled.

Vacuum vessel (VV) thermal shield will be assembled during VV assembly.

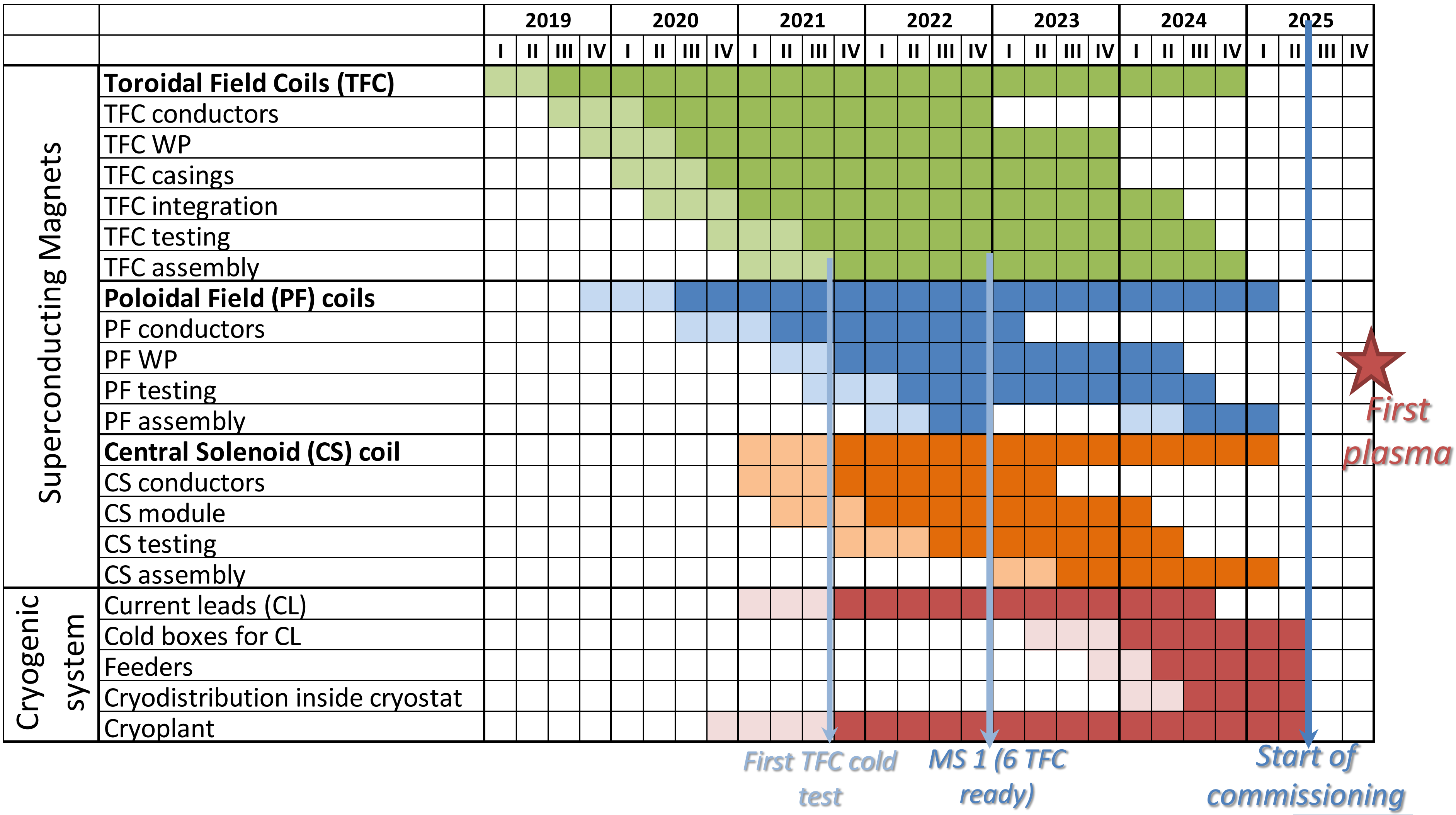
Cryostat thermal shield will be assembled before cryostat closure.

Design activity is still on-going.





Magnet system & Cryosystem: Overall schedule



QUESTIONS?

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