DE LA RECHERCHE À L'INDUSTRIE

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High-Field Magnets R&D in France Status update

E. Rochepault
With inputs from: CEA Colleagues
CERN colleagues
PSI and EPFL colleagues

2nd FCC-France Workshop / January 20-21 2021

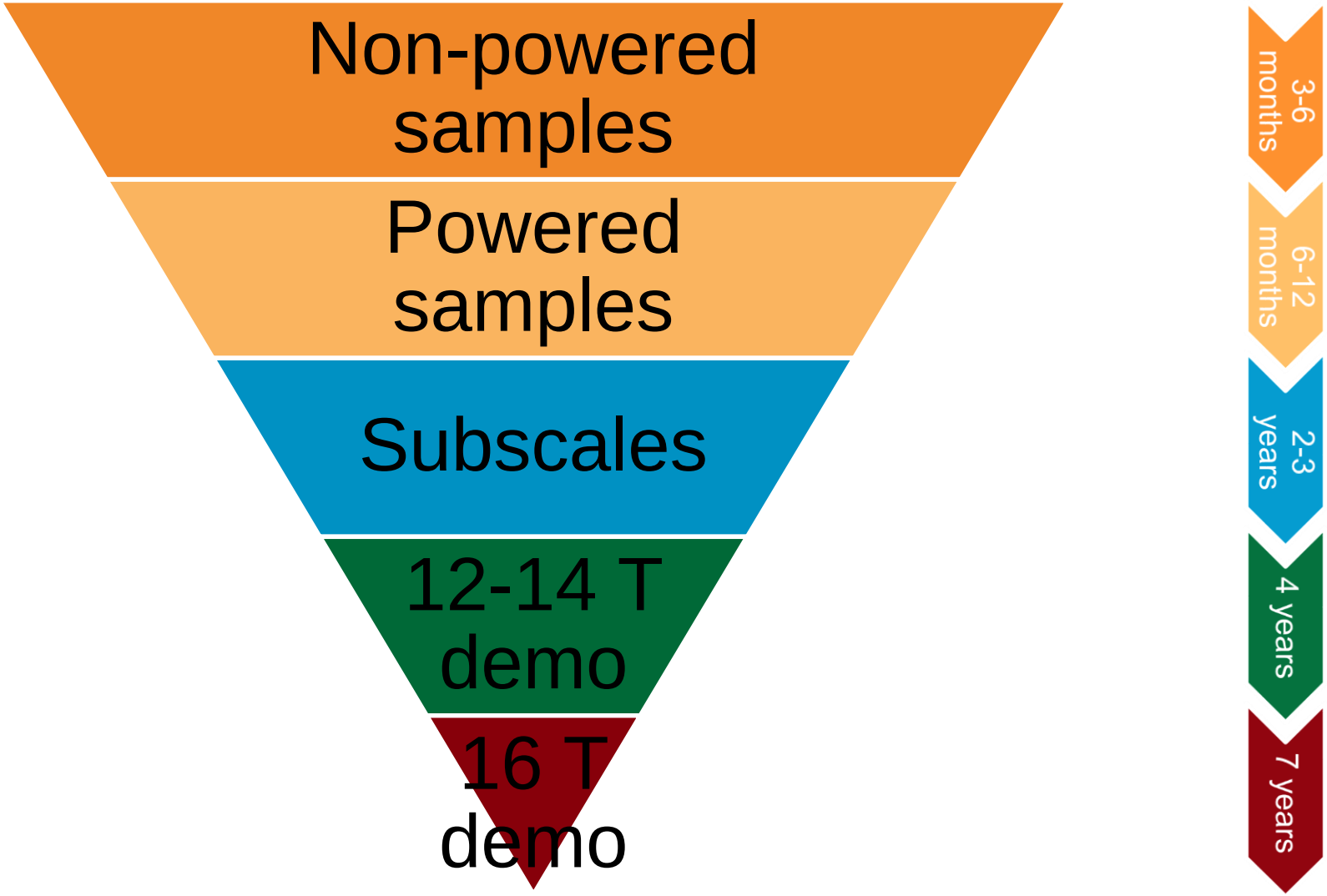
High Field 16T Nb3Sn magnet development

Courtesy T. Lecrevisse – CEA Paris-Saclay

TAKE-AWAY MESSAGES FROM LAST PRESENTATION

- **CEA/CERN strategy for FCC-hh 16T Magnets:**
  - **Quadrupole** conceptual design finalized
  - CEA/CERN **Dipole** Magnet strategy towards 16 T
- **CEA carrying parallel R&D programs:**
  - Winding → **grading**
  - Junctions → **grading**
  - Thermo-mechanics during HT → **Nb_3Sn performances**
  - Electrical insulation → **high voltages**
  - Mechanical structures → **high stresses**
- **CEA involved in many collaborations**

Development Pyramid



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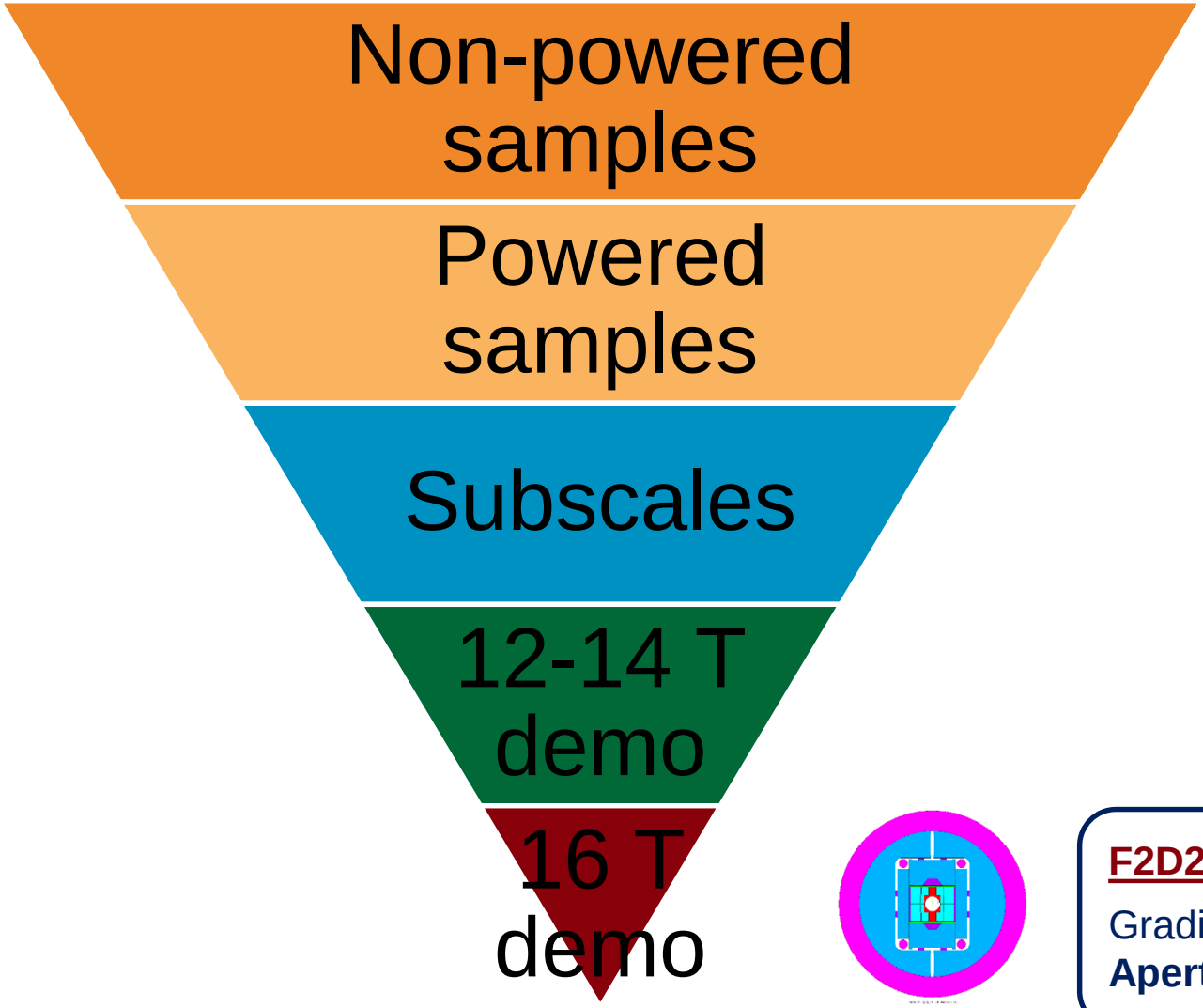

F2D2 Short model

Grading + Flared-ends +
Aperture = 16 T

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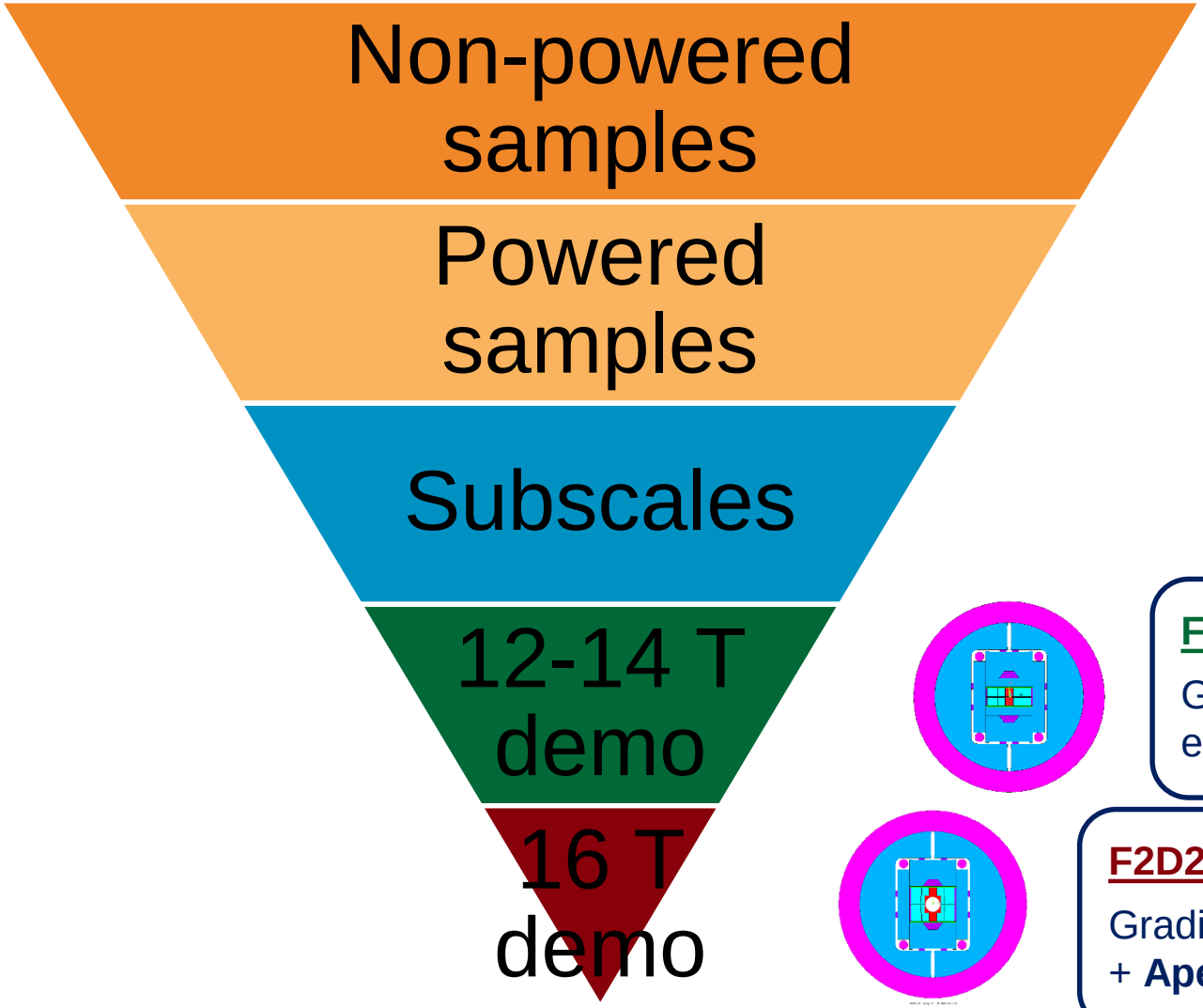

FD Sub-scale

Grading + Flared-ends **= 12-14 T**

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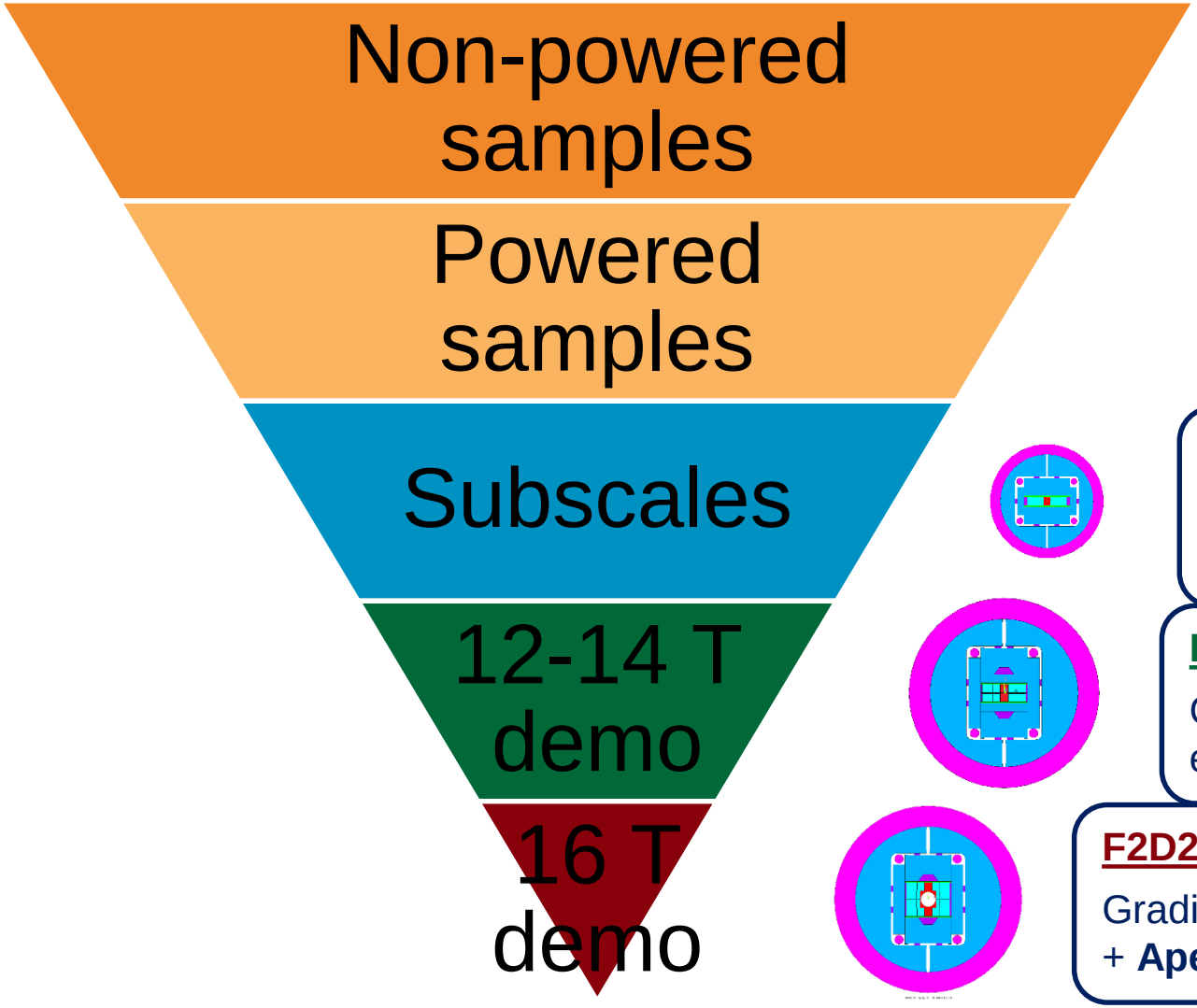

R2D2 Demonstrator

Grading **= 12 T**

FD Sub-scale

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DEVELOPMENT PYRAMID

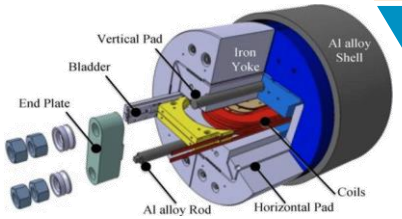
Non-powered samples

Powered samples

Subscales

12-14 T demo

16 T demo



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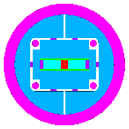
State of the art coil fabrication **= 12 T**



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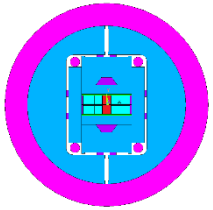

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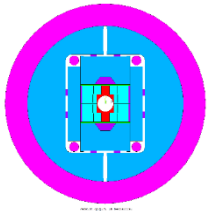

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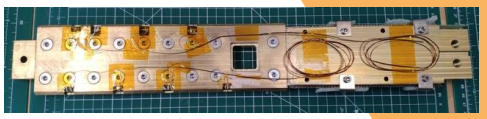
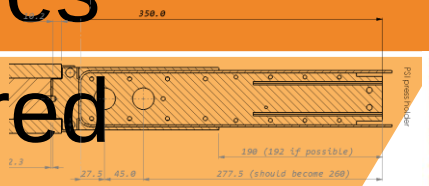
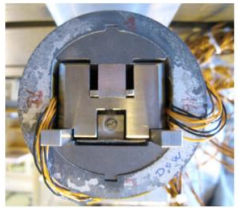
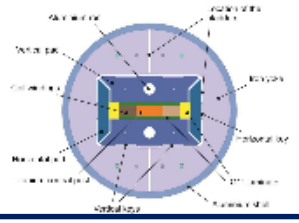
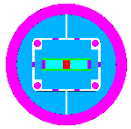
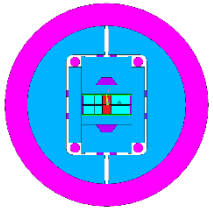


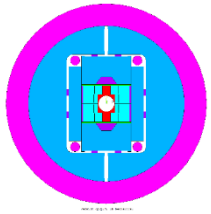












SMC Racetrack

State of the art coil fabrication **= 12 T**

R2D2 Demonstrator

Grading **= 12 T**

FD Sub-scale

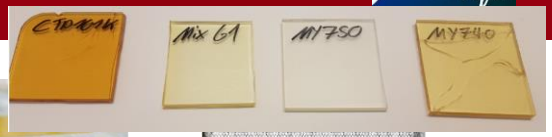
Grading + Flared-ends **= 12-14 T**

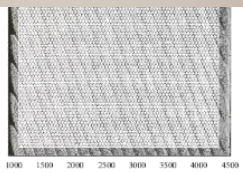
F2D2 Short model

Grading + Flared-ends + **Aperture = 16 T**

Development Pyramid


Non-powered samples





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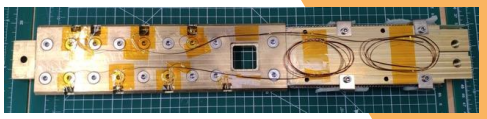
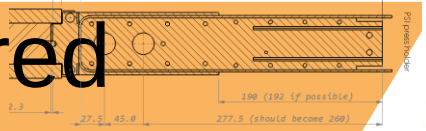
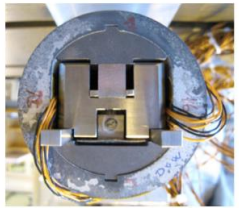
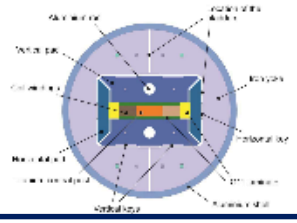






Subscales



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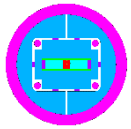
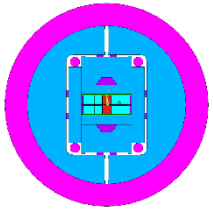


R2D2 Demonstrator

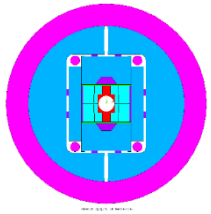
Grading **= 12 T**



FD Sub-scale

Grading + Flared-ends **= 12-14 T**

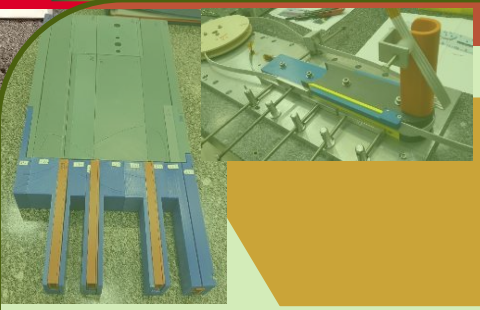
16 T demo

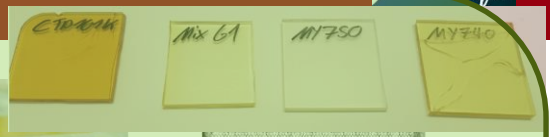


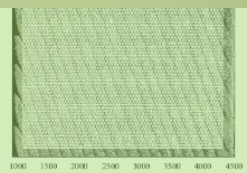
F2D2 Short model

Grading + Flared-ends + **Aperture = 16 T**

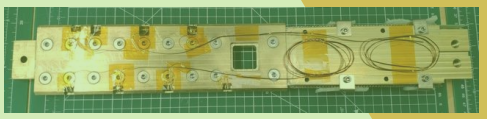
Development Pyramid

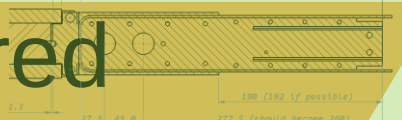






Non-powered samples





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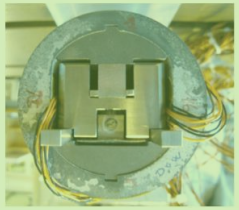
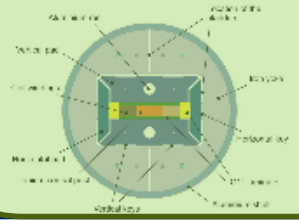
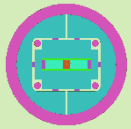




Subscales



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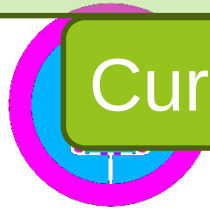
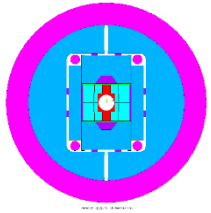


Current Agreement

ends **= 12-14 T**

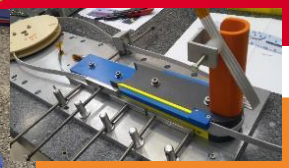
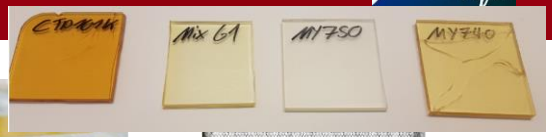
16 T demo

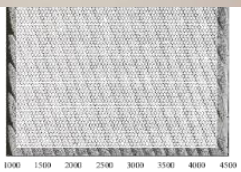


F2D2 Short model

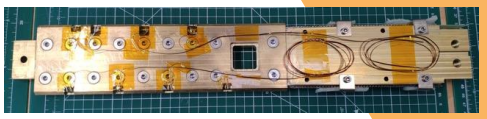
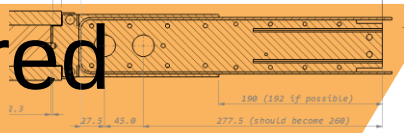
Grading + Flared-ends + **Aperture = 16 T**

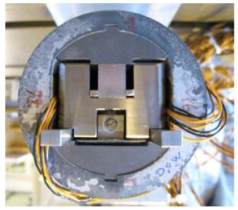
Development Pyramid



Non-powered samples

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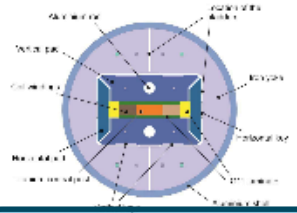
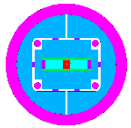

Subscales

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Grading **= 12 T**

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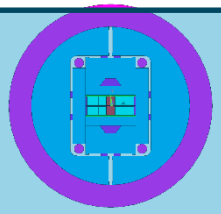
State of the art coil fabrication **= 12 T**

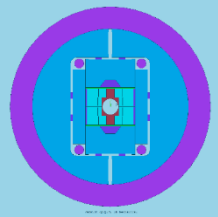
12-14 T demo



FD Sub-scale

Grading + Flared-ends **= 12-14 T**

16 T demo



F2D2 Short model

Grading + Flared-ends + **Aperture = 16 T**

Future Agreement

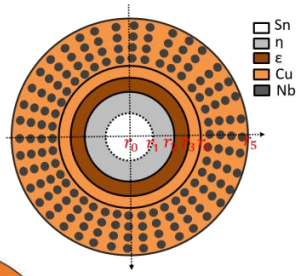
Sub-elements

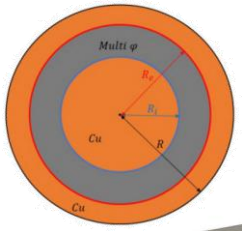
Strands

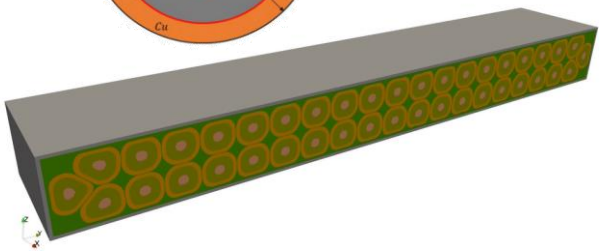
Cables

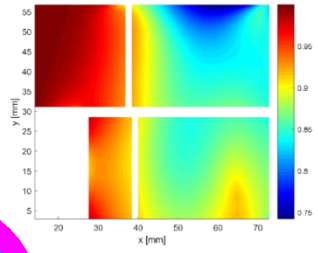
Coils

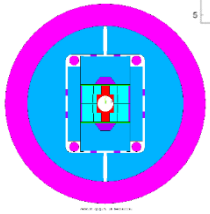
Magnets











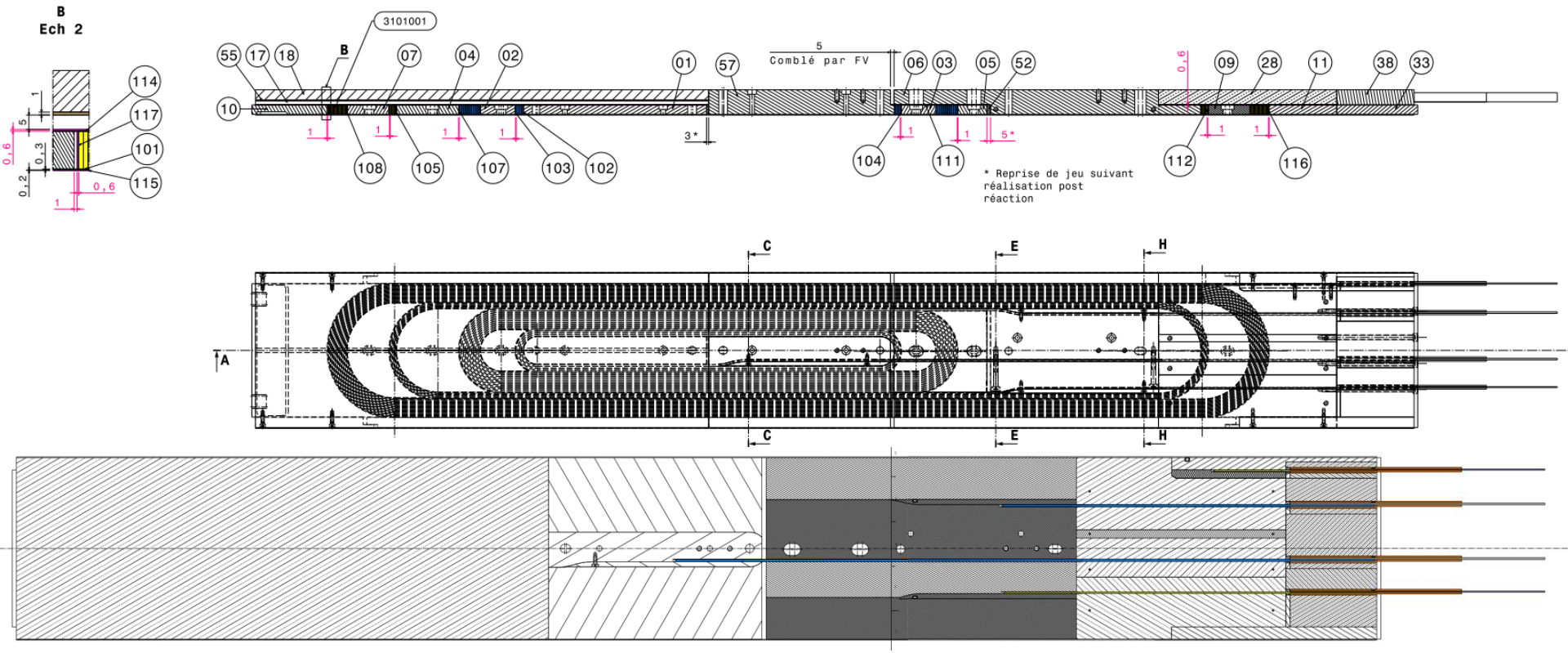
- Detailed CAD design ongoing (drawings for production)

→ Coil components + winding/heat treatment for end Nov.

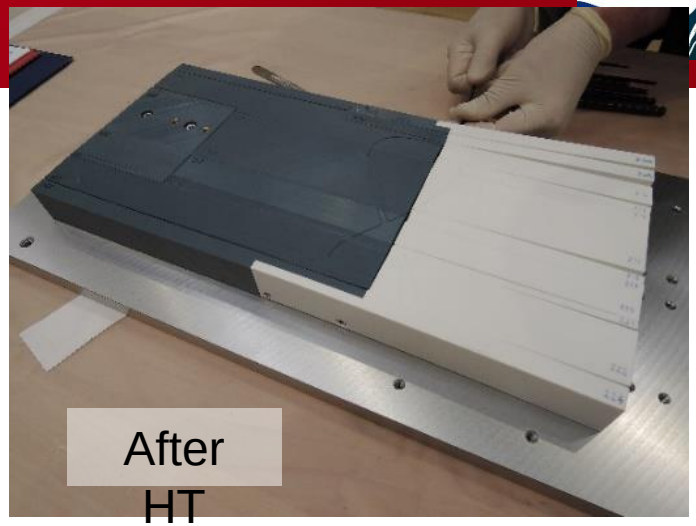
→ Splice tooling + structure for end Dec.

→ Impregnation tooling for beginning of 2022

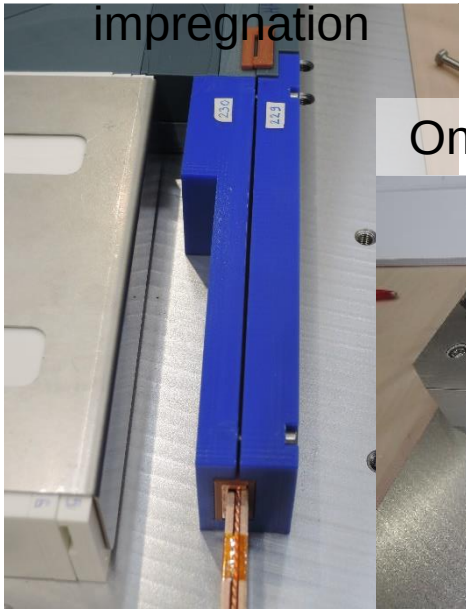
→ Other minor tooling (handling, assembly…) for spring 2022



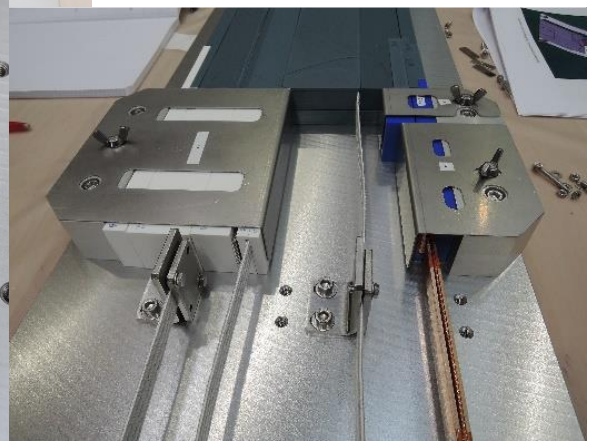
- Test of process for the assembly of external splice
- 3D printed parts + SCM-11T cable
- **No show-stopper identified**
- **Feedback for the detailed design**

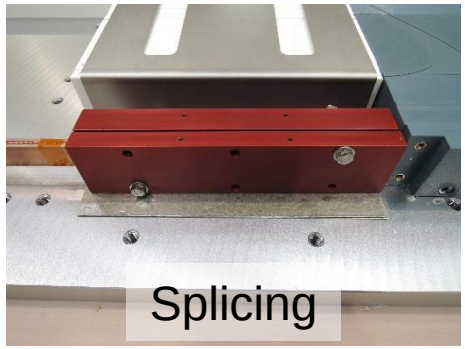


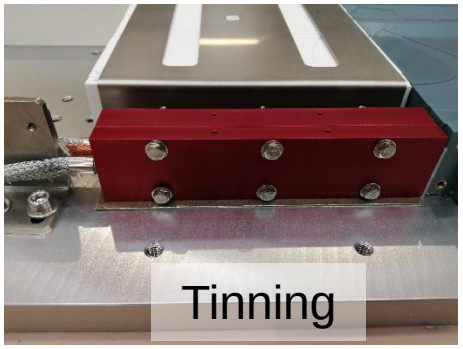
Before impregnation

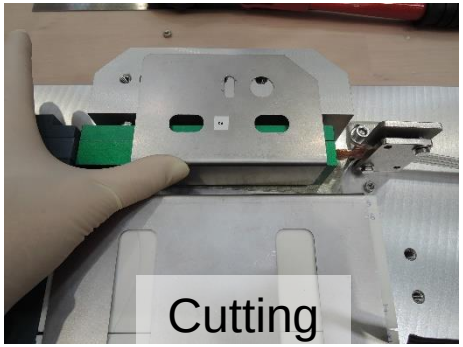


One splice after another

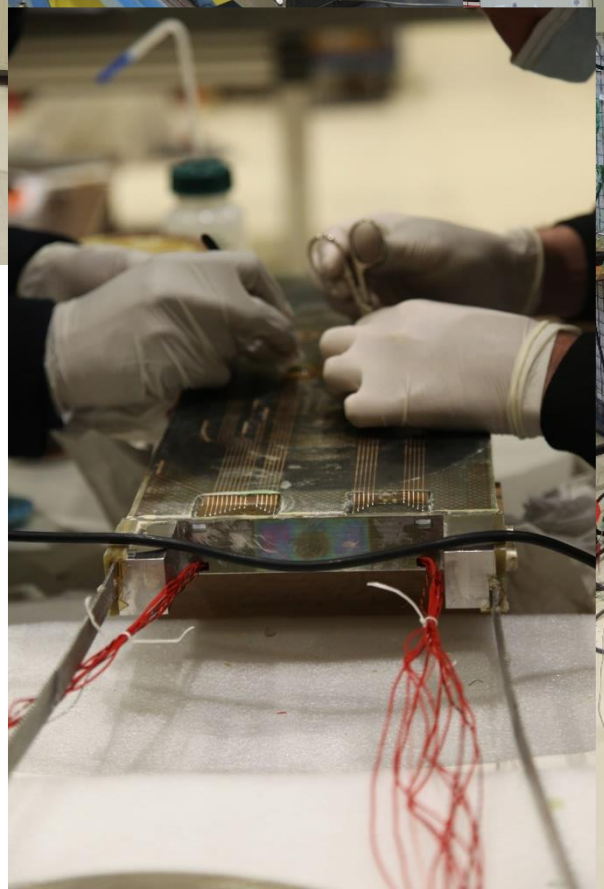


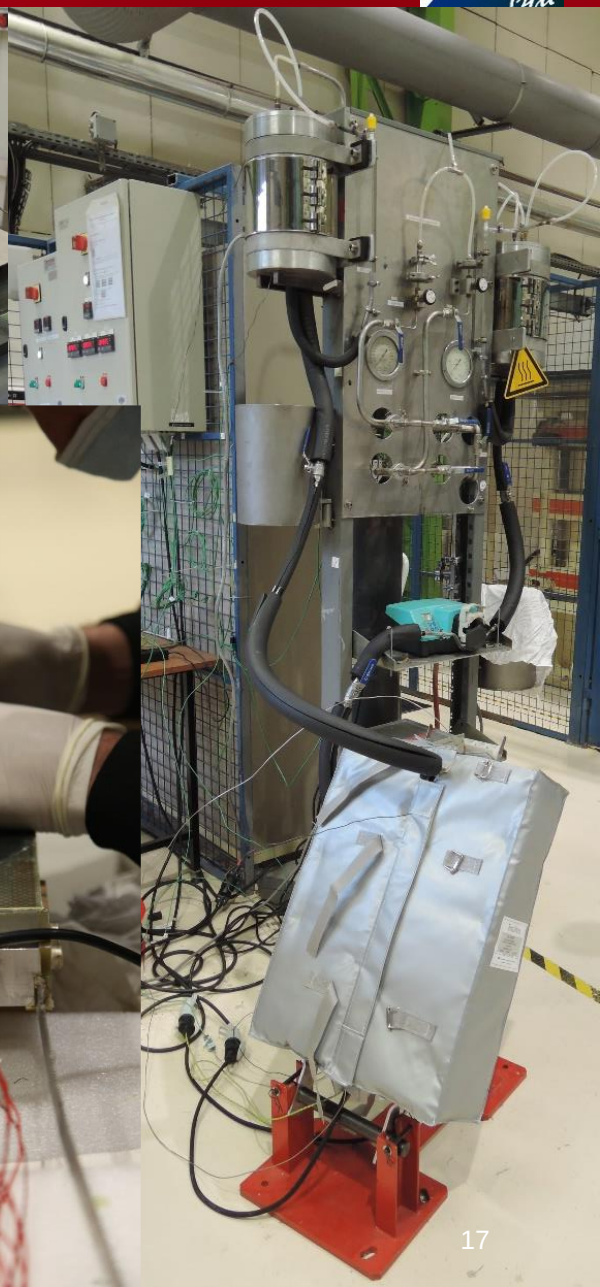






1st Nb_3Sn coil entirely manufactured at Saclay since 10 years!



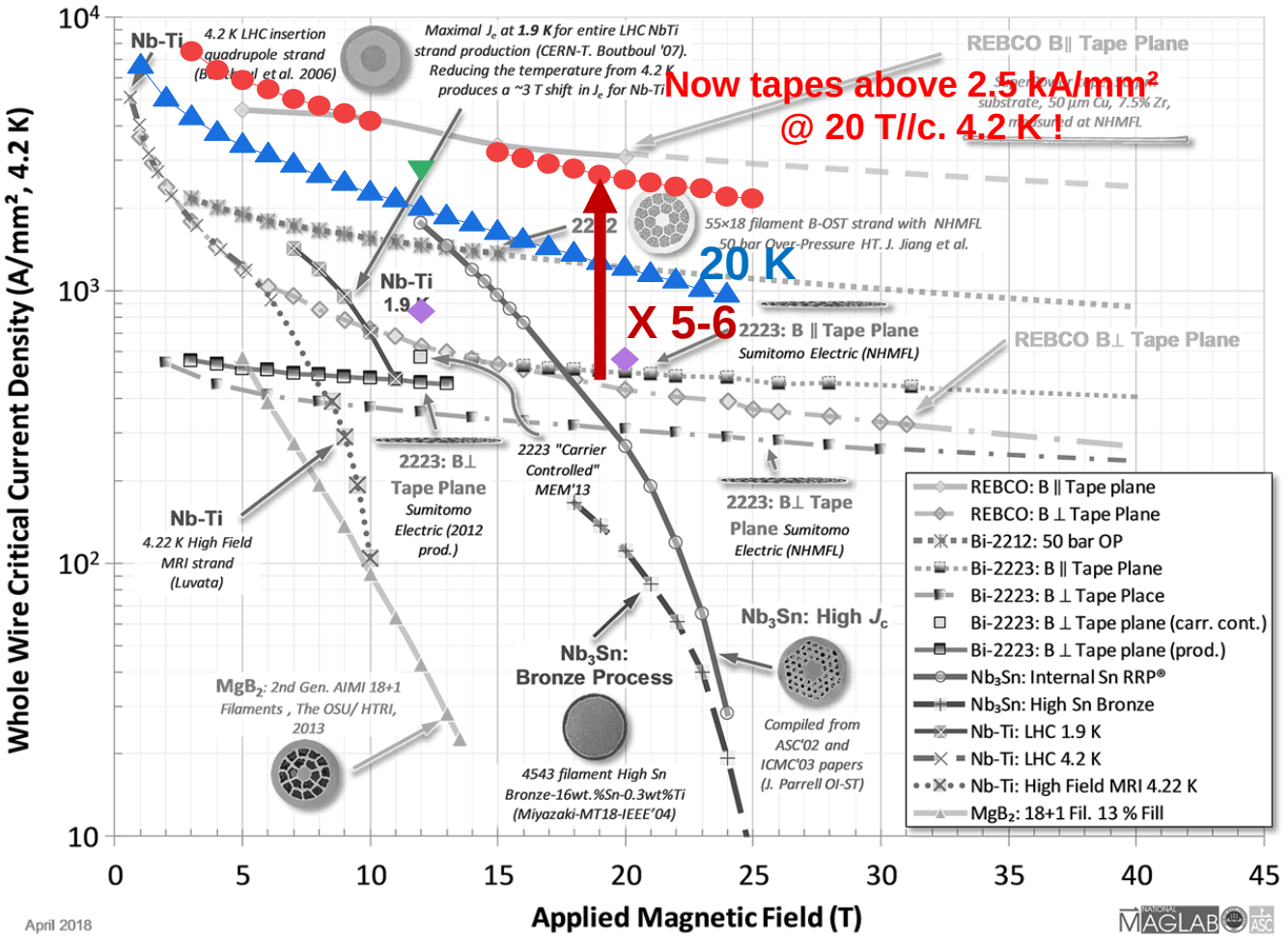


High Field 20T HTS magnet development

Courtesy T. Lecrevisse – CEA Paris-Saclay

REBCO Conductor performance update

- SuperOx 4.2 K B//c [1]
- SuperOx 20 K B//c [1]
- SuperPower 4.2 K B//c [2]
- SuperPower 4.2 K CORC [2]



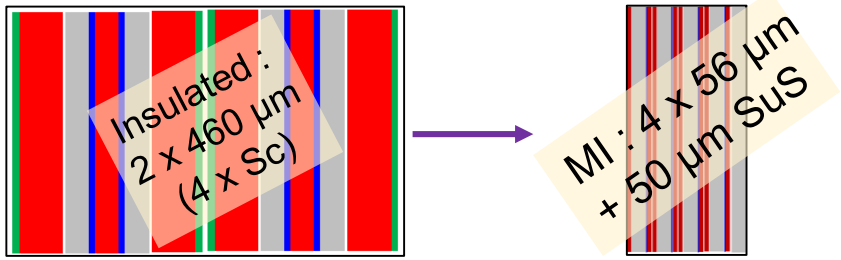
https://nationalmaglab.org/images/magnet_development/asc/plots/Je_vs_B-041118_1024x743_PAL.png

[1] Molodyk. A. et al 2021 Scientific Reports vol. 11. 2084

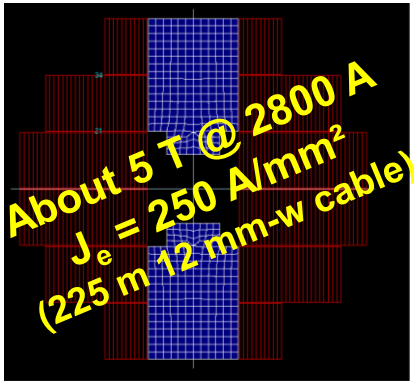
[2] J D Weiss *et al* 2020 *Supercond. Sci. Technol.* **33** 044001

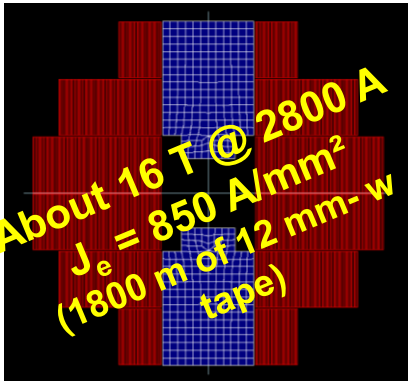
Development proposal

- Same dimension as Eucard 1 standalone magnet
- Preliminary design
- Update of the tape performance to Molodyk. A. et al 2021 Scientific Reports vol. 11. 2084



Only an idea and some **quick numbers**





@ **4.2 K** : **3600 A (j_e of 1095 A/mm²)**
→ **20.1 T** (%LL : 60)
SS limit : 6000 A (j_e of 1825 A/mm²)
→ 33.0 T

@ **20 K** : **2900 A (j_e of 882 A/mm²)**
→ **16.4 T** (%LL :58.6)
SS limit : 4950 A (j_e of 1505 A/mm²)
→ 27.4 T

Advantages of this approach :

- "Lower" risks/cost and "short time" developments
- Change of central coil : aperture
- Adapt the winding to the studies (R_c. I_c…)

20 K working might lower exploitation cost (savings has to be evaluated) or simplify the cryogenics

Global Approach in 5 phases

Phase 1 : preliminary work	• **low cost + medium risks** • **Development of concepts and technologies**
Phase 2 : Subscale model w/o aperture	• **medium cost + high risks** • **8 T+** Subscale model
Phase 3 : Subscale magnet w/o aperture	• **high cost + low risk** • **16+ T** demonstrator
Phase 4 : Subscale model with aperture + tests	• **medium cost + high risk** • **central coil with aperture**
Phase 5 : Subscale magnet with aperture + tests	• **low risk + high cost** • 16 T+ demonstrator

Global Approach in 5 phases

First collaboration : phase 1 to 3 : 5 years

Second collaboration : phase 4 and 5 : 3 more years

Phase		Milestone (M) or Deliverable (D)	Year 1	2	3	4	5	6	7	8
1 : Preliminary Work	M1	Critical parts identification & development plan								
	M2	Quench Mock-up design and conductor choice								
	M3	Test station setup ready								
	M4	Quench mockup ready for tests								
	D1	Test report on quench mockup								
2 : Subscale model w/o aperture	M5	Subscale full design								
	M6	Winding and assembly procedure validated								
	M7	Subscale model ready for tests								
	D2	Subscale model tests analysis report								
3 : Subscale magnet w/o aperture	M8	Magnet w/o aperture full scale design								
	M9	Dummy winding and assembly done								
	M10	Subscale magnet w/o aperture ready for tests								
	D3	Subscale magnet w/o aperture test and analysis report								
4: Subscale model with aperture + tests	M11	Design update for magnet with aperture								
	M12	Central coil with aperture tehnology choice								
	M13	Subscale dummy central coil fabrication								
	M14	subscale model with aperture ready for tests								
	D4	Subscale model with aperture tests report								
5: full scale with aperture + tests	M15	Design update for full scale magnet with aperture								
	M16	subscale dummy central coil fabrication								
	M17	Subscale magnet with aperture ready for tests								
	D5	Subscale magnet with aperture tests report								

CONCLUSIONS

- **CEA/CERN strategy for FCC-hh 16T Magnets:**
  - **Quadrupole** conceptual design finalized
  - CEA/CERN **Dipole** Magnet strategy
    - Small Coil fabrication ongoing
    - 12 T R2D2 Demonstrator: detailed design ongoing
    - 16 T F2D2 Demonstrator: conceptual design proposed
- **CEA carrying parallel R&D programs:**
  - Winding → **grading**
  - Junctions → **grading**
  - Thermo-mechanics during HT → **Nb_3Sn performances**
  - Electrical insulation → **high voltages**
  - Mechanical structures → **high stresses**
- **CEA involved in many collaborations, for instance:**
  - **European institutes** : CERN, EPFL-SPC, PSI, ETHZ…
  - **French universities** : LMT-ENS Paris-Saclay