DE LA RECHERCHE À L'INDUSTRIE

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OVERVIEW OF LTS AND HTS ACTIVITIES AT CEA-PARIS SACLAY

Helene Felice for the Superconducting Magnet Lab at CEA

Special thanks to: M. Durante, P. Fazilleau, C. Lorin, T. Lecrevisse, A. Madur, D. Simon, E. Rochepault

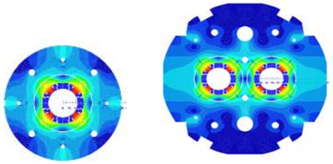
4 MATERIALS

NbTi

Accelerator magnets for LHC

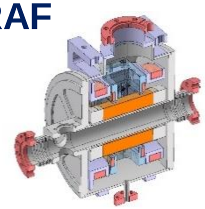
MQ

MQYY

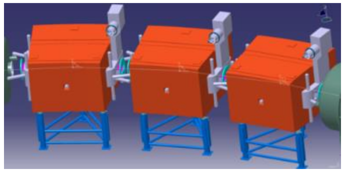


Other Accelerator Magnet

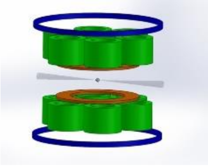
SARAF



SuperFRS



MRI magnet: **ISEULT**

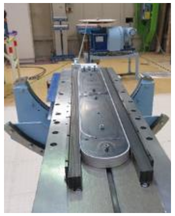


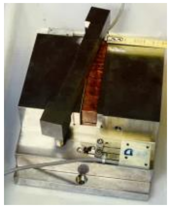
Special magnet
WAVE: neutron diffraction=> condensed matter physics

Nb_3Sn

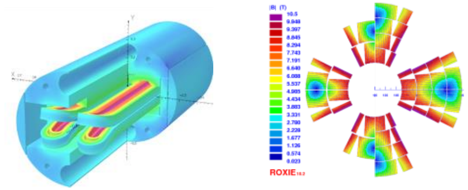
FRESCA 2

Technology development





Dipole and Quad for FCC

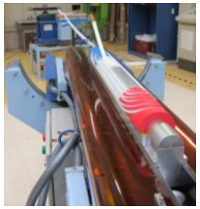


HTS => ReBCO

For accelerator magnets

EUCARD

EUCARD2



For high field magnets

MgB_2

LOTUS: radio isotope production

Conductor characterization

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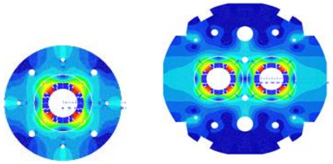

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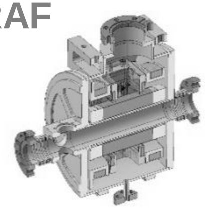
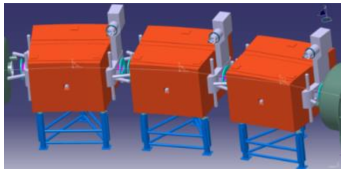


SuperFRS



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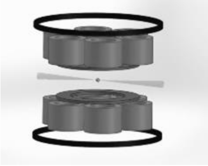

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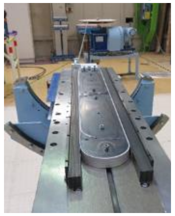
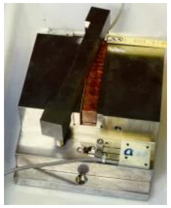
FRESCA 2

Technology development





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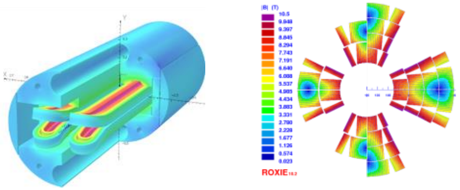

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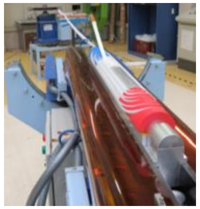
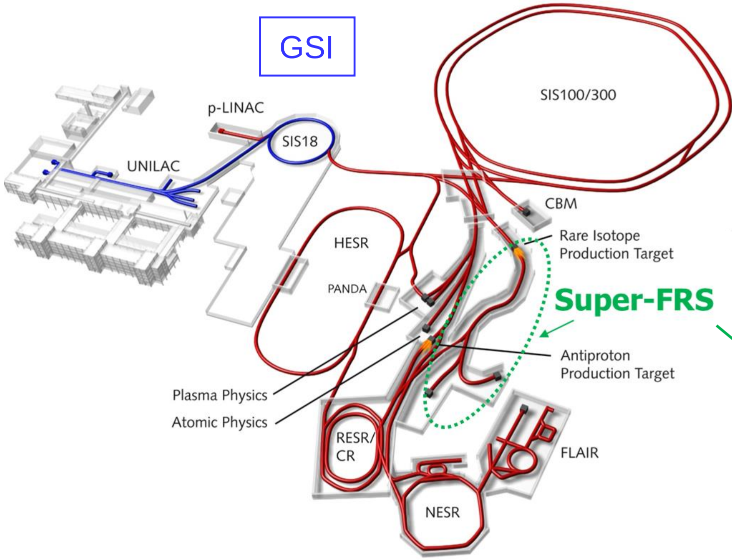


For high field magnets

FAIR, THE SUPER-FRS AND ITS SUPERFERRIC DIPOLES

FAIR: on-going construction

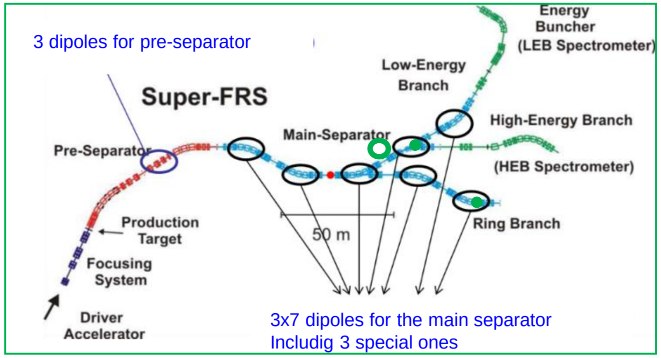
GSI



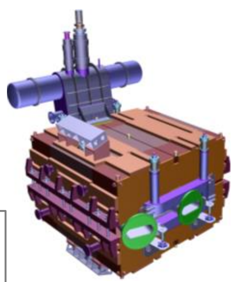
FAIR = Facility for Antiproton and Ion Research in Darmstadt, Germany

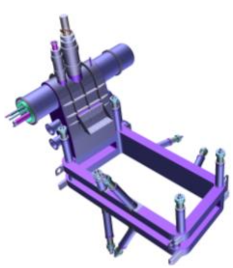
Super-FRS: **Super**conducting- **FR**agment **S**eparator

In kind contribution for design study and production follow-up

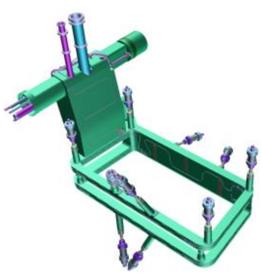


- Superferric magnets~ 15 m^3
- 18 + 3 standard dipoles
- 3 special dipoles

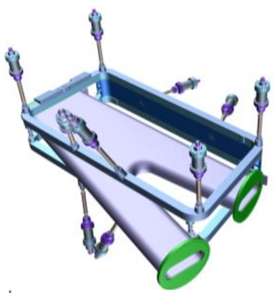




LHe vesel



Thermal shield



Vaccum chamber

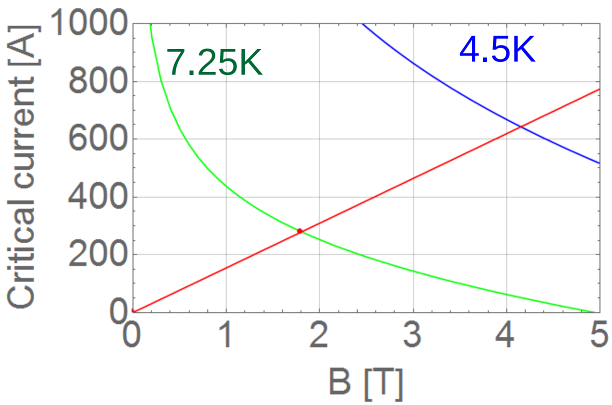
- Technical specification by CEA
- FAIR call for tender
- Contract with Elytt ELYTT ENERGY
- Contract follow-up by CEA
- Tests at CERN

A. Madur
H. Allain
M. Daly

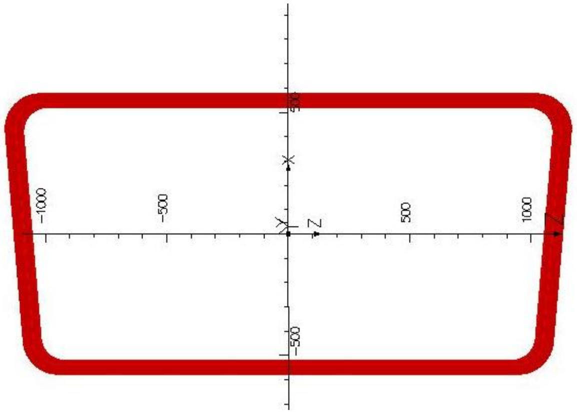
SUPER-FRS SUPERFERRIC DIPOLE PARAMETERS

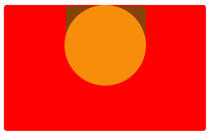
Conductor	value
Material	NbTi
Bare conductor width [mm]	1.97
Bare conductor height [mm]	1.17
Insulation material	PET braid
Insulation thickness [mm]	0.13
Strand diameter [mm]	0.715
Filament diameter [mm]	0.065
Cu/SC ratio	11
RRR	>80
Minimum current at 4T, 4.22K	660

COIL	value
Nb turns	560
Nb layers	28
Nb turns per layer	20
Average turn perimeter [m]	6.576



Margins : 57%; 2.75 K





Superferric dipoles	D3	D2	D3Y
Quantity	18	3	3
Field @ center: $B_z(0,0,0)$ [T]	1.6	1.6	1.6
Field integral: I_z [T.m]	3.40	3.84	3.40
Bending angle: q [°]	9.75	11	9.75

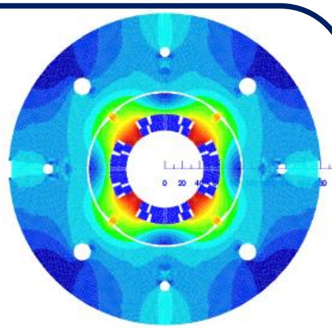
- Mock ups ongoing
- 1st of series expected in 2019
- End of production foreseen in 2021

ELYTT ENERGY

A. Madur
H. Allain
M. Daly

NBTI MAGNETS FOR HL-LHC: MQYY

MQYYM: MQYY short model

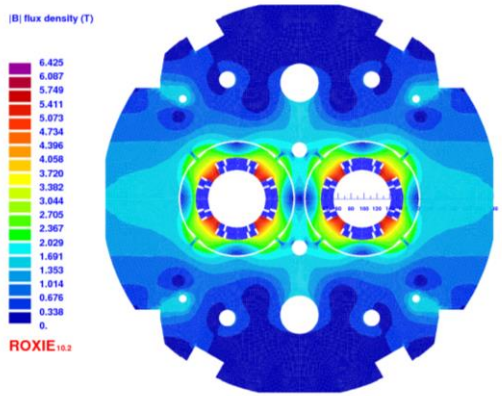


Within CERN-CEA collaboration

Aperture	90 mm
Physical length	1350 mm
Magnetic length at 1.9 K	1204 mm
Outer diameter	360 mm
Bare cable width	8.8 mm
Bare cable thickness	0.77/0.91 mm
Kapton Insulation thickness at nominal	0.080 mm
Short sample current	5980 A
Operating Gradient	120 T/m
Operating current	4550 A
Bpeak at operation	6.42 T

MQYY prototypes (MQYYP) within QUACO

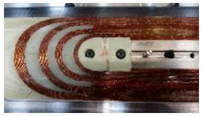
Based on a design study carried out at CEA (M. Segreti)

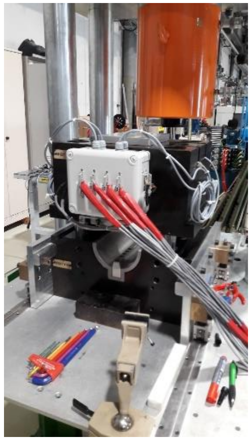


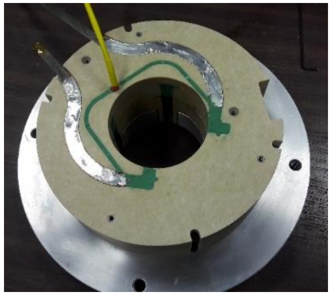
- Selection of 4 companies to design and manufacture MQYY prototypes(competitive process 4/3/2 in conceptual/engineering/manufacturing phase)
- Starting point:
  - CEA magnetic design
  - Mechanical design is NOT provided
- Phase 3: first of a kind manufacturing => ongoing

MQYYM FABRICATION


- Coil fabrication at CEA
- Technical spec by CEA, orders placed by CERN
- Procurement follow-up by CEA
- Assembly at CERN with a CEA/CERN team in Feb/March 2019





- Test in preparation at CEA in a saturated bath 23 mbar 1.9 K
- Magnetic measurements will be performed using a CERN system

H. Felice
D. Simon
S. Perraud
M. Segreti
J.M. Rifflet
JM Gheller
D. Bouziat

CERN team
A. Foussat
JC Perez
M. Guinchard
N. Bourcey
L. Fiscarelli

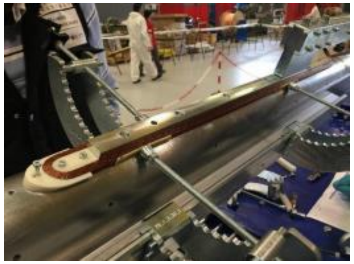
NBTI MAGNETS FOR HL-LHC: MQYY

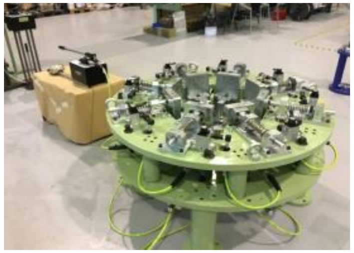
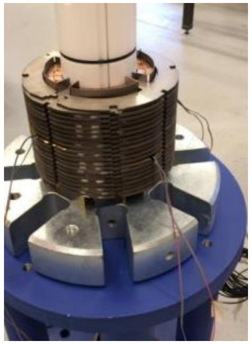
2015	Mi 2018	End of 2020
PHASE 1 Concept. design	**PHASE 2** Engineering design	**PHASE 3** Manufacturing
Company A – ELYTT ENERGY	Company A – ELYTT ENERGY	Company A – ELYTT ENERGY
Company B – tesla MAGNET DIVISION	Company B – SIGMAPHI	Company B – SIGMAPHI
Company C – SIGMAPHI	Company C – Antec	
Company D – Antec	Company D	

QUACO

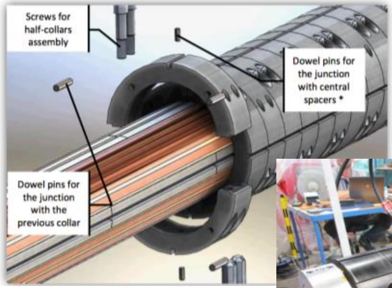
D. Simon
S. Perraud
J.M. Rifflet
E. Rochepault

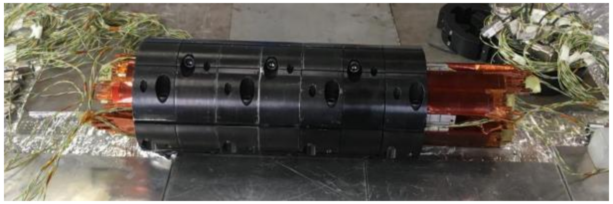
ELYTT ENERGY



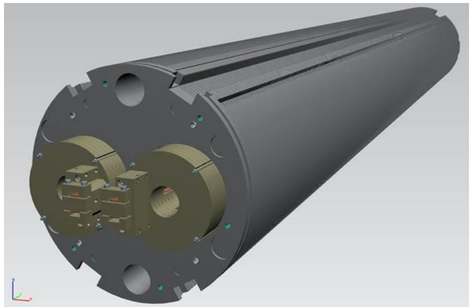



SIGMAPHI ACCELERATOR TECHNOLOGIES




NBTI MAGNETS FOR LHC: MQ SPARES



Conductor	NbTi
Gradient	223 T/m
Current	11.9 kA
Magnetic length at 1.9 K	3.1 m

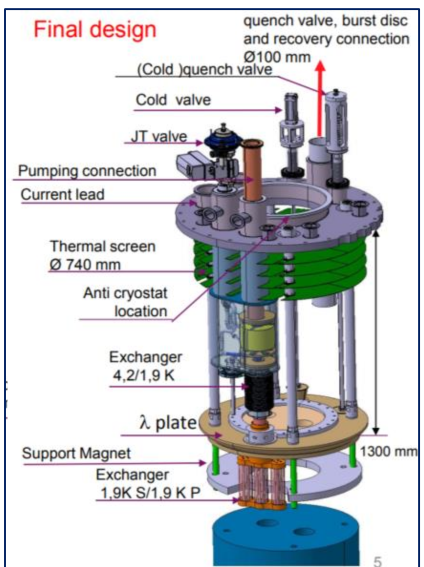
Within CERN-CEA collaboration

- Replenishment of MQ spare magnets stock => 6 magnets
- CEA responsible for:
  - ✓ Rebuild of the manufacturing folder
  - ✓ Preparation of the technical specification
  - Production follow-up at the manufacturer

Call for tender and order placed by CERN

- Contract signed with TESLA in september 2018

Key difficulty:
To make identical magnets more than a decade after the series production
- To resuscitate CAD models
- To update the drawings with present ISO norms



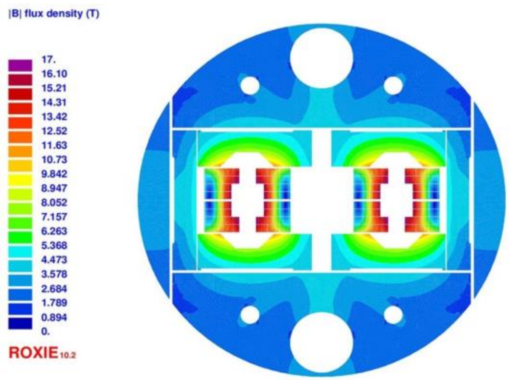
- Test of the 6 MQ spare magnets at CEA Paris Saclay
  - Upgrade of the test facility
    - Lambda plate allowing for 640 mm diameter magnet
    - Up to 5 m long magnet

C. Lorin
J.M. Rifflet
S. Roux
J.M. Gheller
H. Allain

DIPOLE BLOCK DESIGN FOR EUROCIRCOL

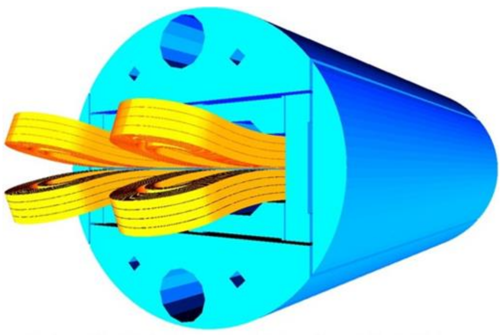
Within the ECC program => CEA Saclay in charge of the double aperture block-type configuration

2D magnetic model

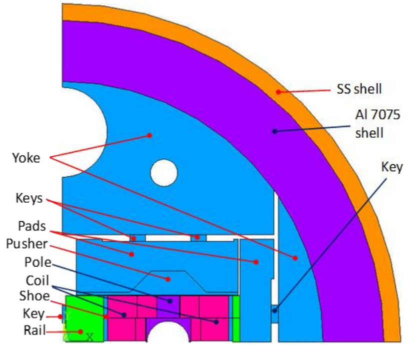


Aperture	50 mm
I_{op}	10176 A
LL margin HF	14.0 %
B_{bore}	16 T
B_{peak} HF	16.7 T
σ_x / σ_{VM}	
RT loading	-147 / 136 MPa
Cool-down	-180 / 165 MPa
Excitation	-185 / 167 MPa

3D magnetic model

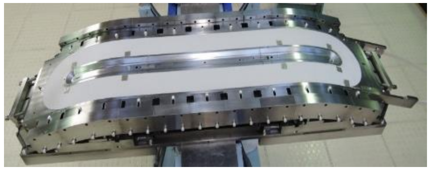


2D mechanical model



- Design Study ECC
- Fabrication experience with FRESCA2

FRESCA2



F. Rondeaux

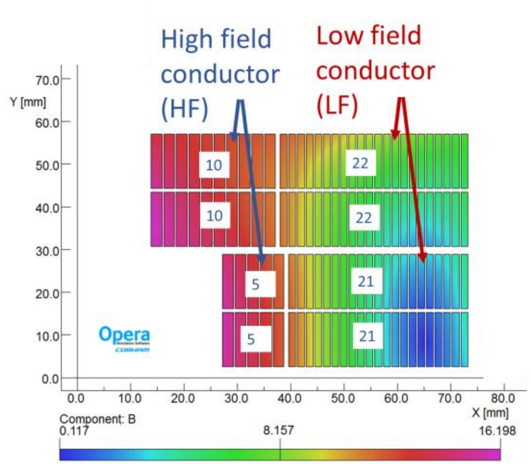
M. Durante
C. Lorin
M. Segreti
C. Pes

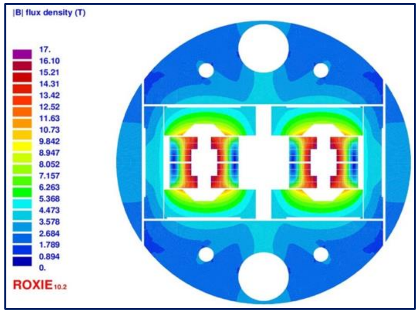
DIPOLE MODEL TOWARD FCC

CERN-CEA collaboration agreement to design and fabricate a single aperture block model at CEA

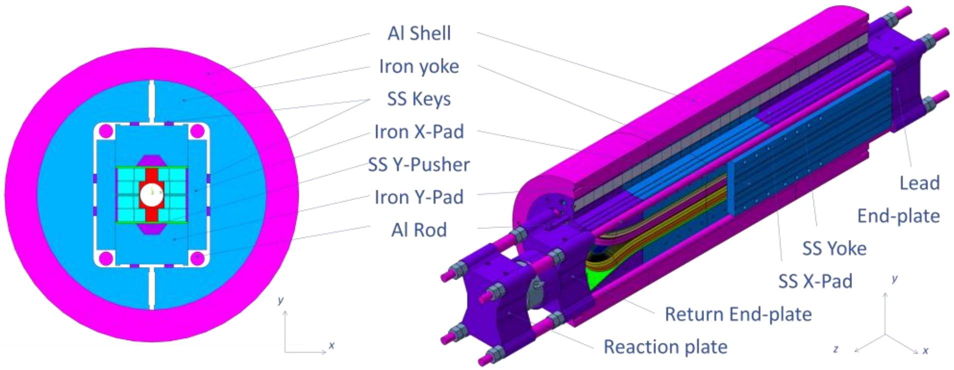
⇒ FCC Flared-ends Dipole Demonstrator: F2D2 => as close as possible to ECC

Conductor parameters	HF	LF
Strand diameter	1.1 mm	0.7 mm
Cu/nonCu ratio	0,8	2
Jc at 4.2 K and 16 T	1200 A/mm2	
Cable number of strands	21	34
Unreacted bare cable width	12.579 mm	
Unreacted bare cable thickness	1.969 mm	1.253 mm
HT cable thickness dim. change	4.6 %	4.5 %
HT cable width dim. change	1.3 %	
Reacted bare cable width	12.74 mm	
Reacted bare cable thickness	2.06 mm	1.31 mm
Insulation thickness at 50 MPa	0.150 mm	



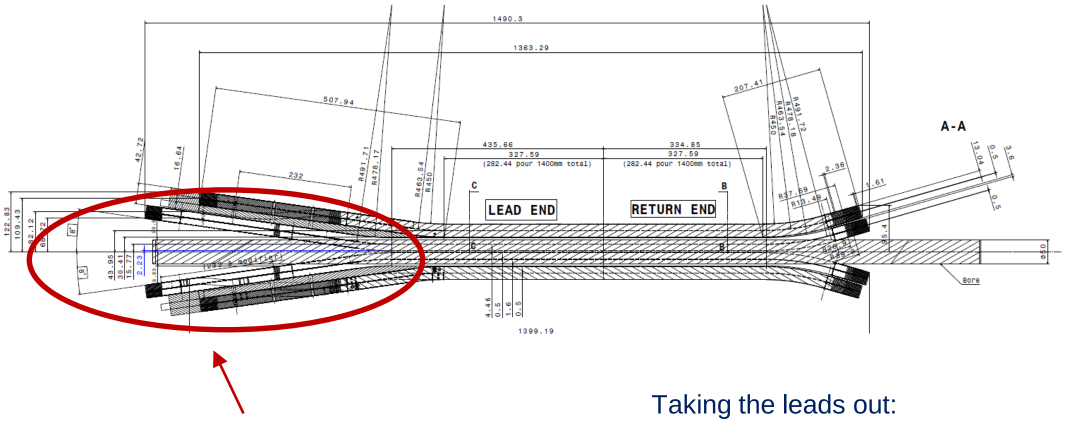


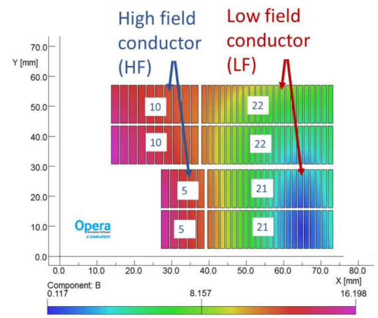
2D magnetic parameters	
I_{op}	10469 A
LL margin HF	14.0 %
LL margin LF	15.4%
B_{bore}	-15.54 T
B_{peak} **HF**	16.20 T
B_{peak} **LF**	11.85 T
b_3 **at nominal**	2.98
b_3 **at injection**	-14.80
b_5	-0.50
b_7	-2.98
b_9	-1.46



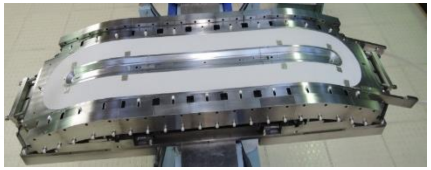
H. Felice
E. Rochepault
V. Calvelli
M. Durante
P. Mallon

DIPOLE MODEL TOWARD FCC





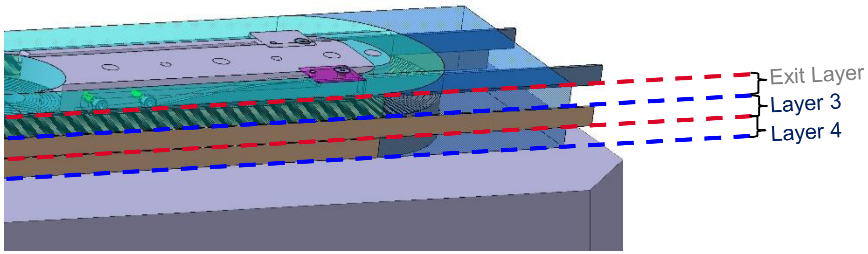
FRESCA2

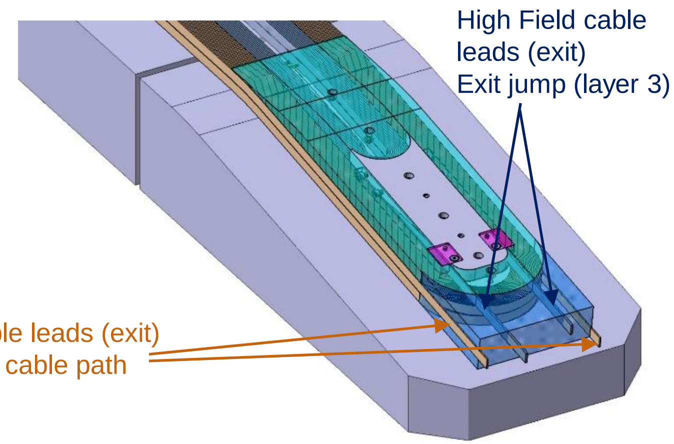


Taking the leads out:

- Btw coil 1-2 and 3-1 for coil 3-4
- Toward the aperture for coil 1-2

- High complexity due to grading
- Baseline scenario: external joints





<u>Key challenge</u>: Coil and tooling engineering design
<u>Objectives</u>: fabricate and assemble F2D2 at CEA

NB_3SN MAGNET TOWARD FCC
FCC MQ (I)

Within CERN-CEA collaboration

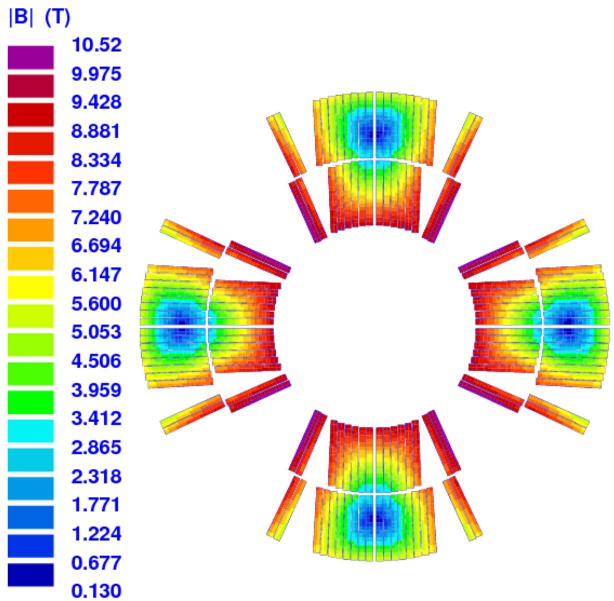
- In CEA tradition => design study of main quadrupole for FCC

- **Design study:**
  - 2 layer versus 4 layer designs ?
  - Margin of the quadrupoles?

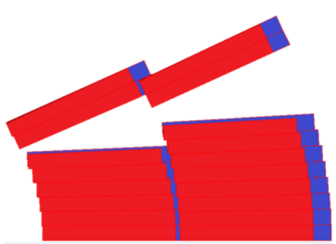
    - Reduce complexity of the quad vs the dipoles => 2 layer quad
    - 20 % margin (instead of 14 % for the dipoles)
    - Nominal gradient of 360 T/m

  - Conductor definition
    - Small aperture => cable windability is a concern

Cable Parameter	FCC quad (v12)
Strand diameter	0.85 mm
Cu/NonCu	1.65
Nb of strands	35
Cable bare width (before/after HT)	15.956/16.120 mm
Cable bare mid-thick.(before/after HT)	1.493/1.538 mm
Cable width expansion	1.0 % (ECC)
Cable thickness expansion	3.0 % (ECC)
Keystone	0.40°
Insulation thickness per side (5 MPa)	0. 150 mm



Cable validation
Winding test with
MQXF cable

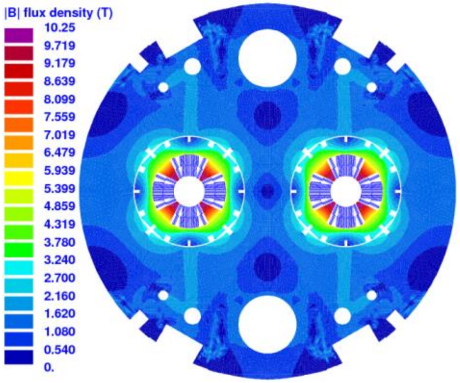


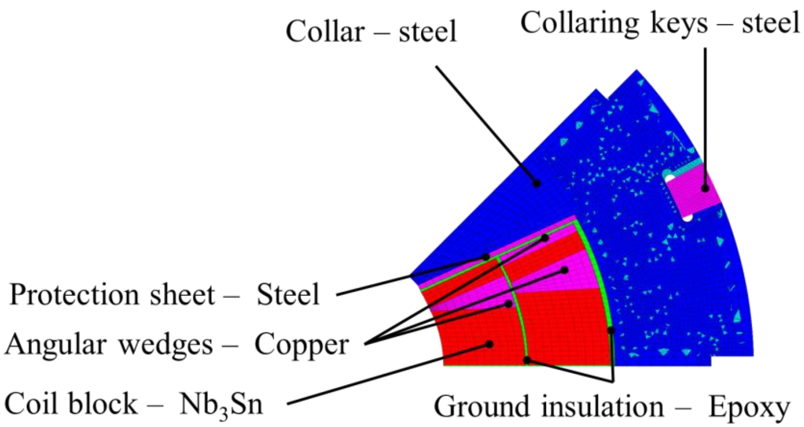
Magnet Parameter	Values
Nominal current	22500 A
Peak field	10.52 T
Gradient	367 T/m
Loadline margin	20.0 %
Temperature margin	4.6 K

NB_3SN MAGNET TOWARD FCC
FCC MQ (II)

MAGNET PARAMETER	Unit	Values
Nominal current	A	22500
Peak field	T	10.52
Gradient	T/m	367
Stored energy (2 apertures)	kJ/m	520
Azimuthal force (per ½ coil)	kN/m	1740
Radial force (per ½ coil)	kN/m	780

Support structure: Self supported collar



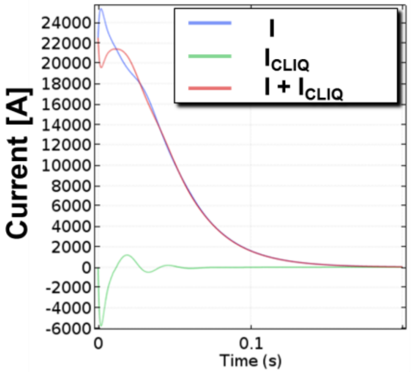


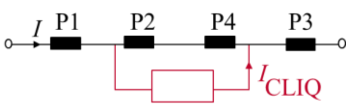
Modeled in Cast3M in 4 steps (in MPa)

	Collaring	Stress relaxation	Cold	Powering
peak average	-101.5 -85.5	-91.4 -76.9	-88.5 -73.2	-111.1 -69.7

Protection
Tiina Salmi TUT

Use of a CLIQ Unit
Hot spot temperature < 350 K (ECC)





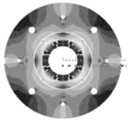
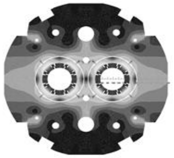
C. Lorin

4 MATERIALS

NbTi

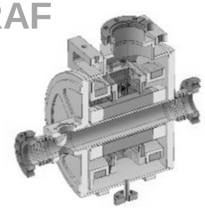
Accelerator magnets for LHC

MQ **MQYY**

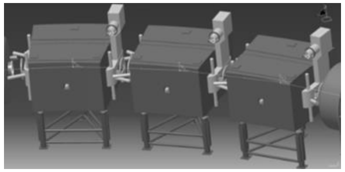




Other Accelerator Magnet

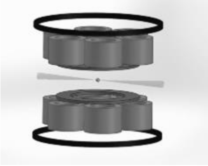
SARAF



SuperFRS



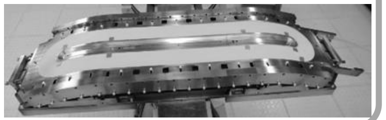
MRI magnet: **ISEULT**



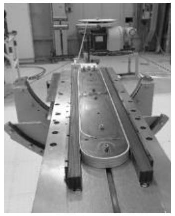
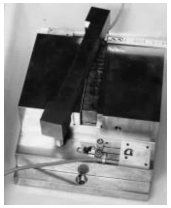
Special magnet
WAVE: neutron diffraction=> condensed matter physics

Nb_3Sn

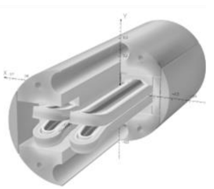
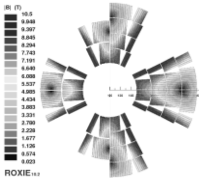
FRESCA 2



Technology development

Dipole and Quad for FCC

MgB_2

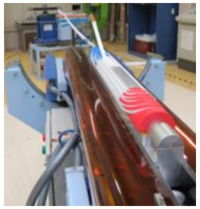
LOTUS: radio isotope production

Conductor characterization

HTS => ReBCO

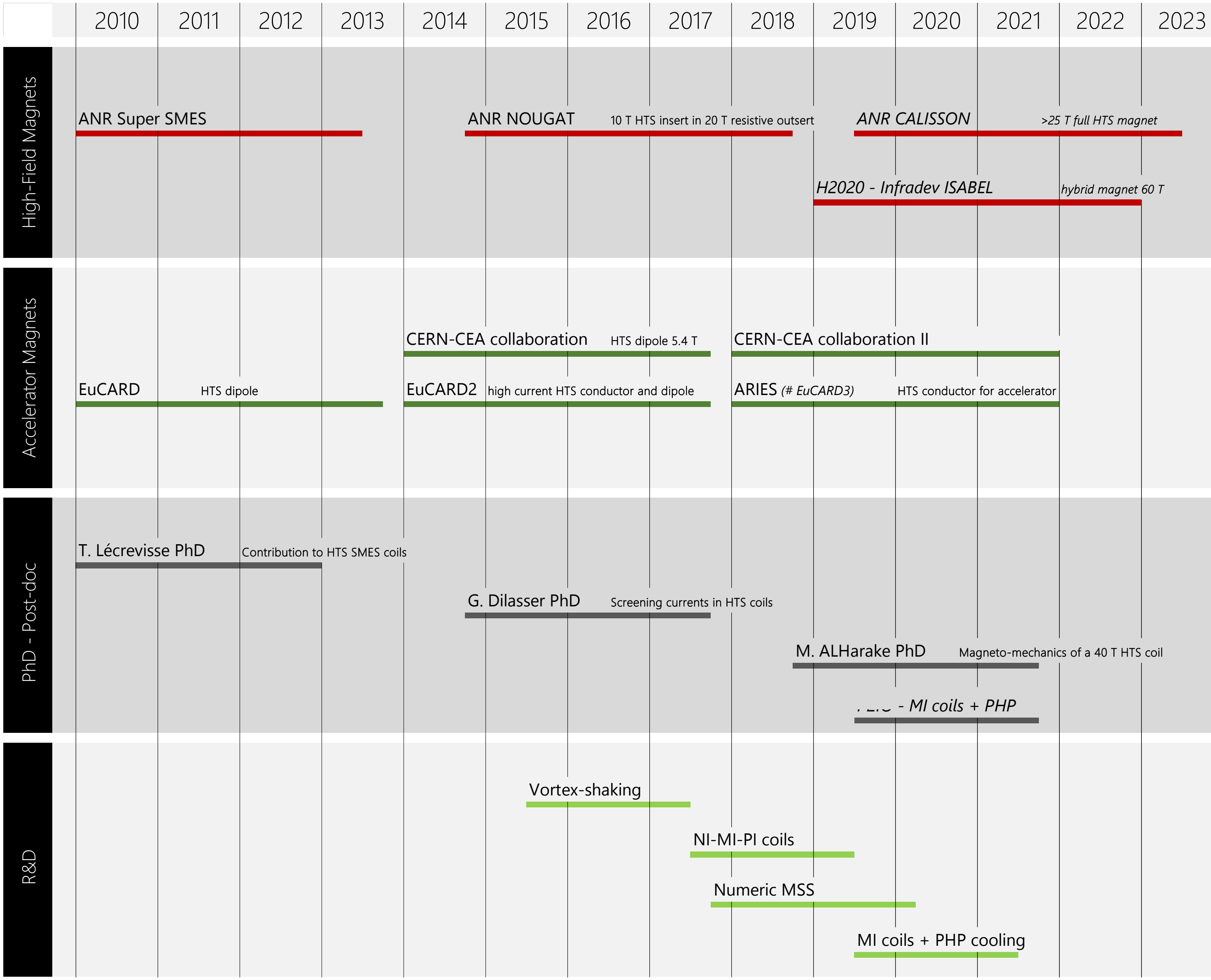
For accelerator magnets
EUCARD

EUCARD2



For high field magnets


HTS ROAD MAP



P. Fazilleau
T. Lecrevisse

M. Durante
T. Lecrevisse
C. Lorin
P. Fazilleau

P. Fazilleau

P. Fazilleau
T. Lecrevisse
G. Dilasser

HTS HIGH FIELD R&D OVERVIEW

P. Fazilleau
T. Lecrevisse
G. Dilasser

Detection/Protection

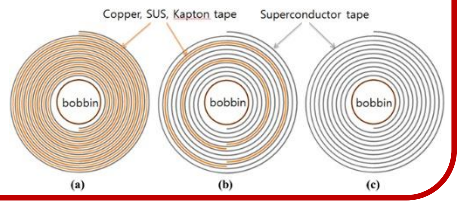
Detection difficult due to very low propagation velocities during a quench.
Protection not easy due to very high energy margin (high Tc)

- *Numeric Magnet Safety System*, more accurate and faster (FPGA)

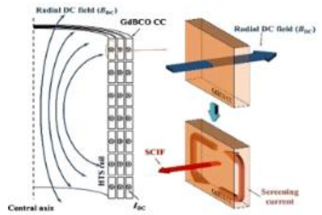
Remove/replace insulation between turns :

- *NOUGAT project*
  # HTS insert HTS with Metal-as-insulation winding

- *Internal R&D "No Insulation-Partial Insulation –Metal-as-Insulation"*
  # study of stability/protection/ time constants of different windings

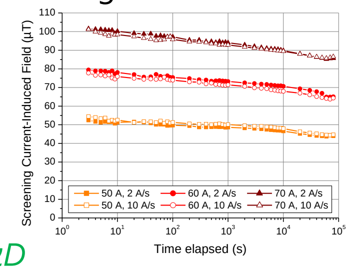


Stability/Homogeneity

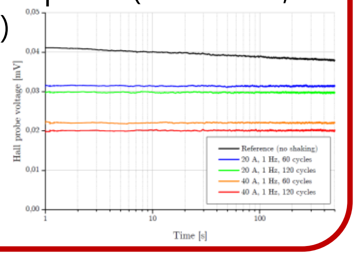


Degradation of stability/homogeneity due to screening currents generation

- *Guillaume Dilasser PhD*
  # Experimental and numerical studies of screening currents in REBCO tapes

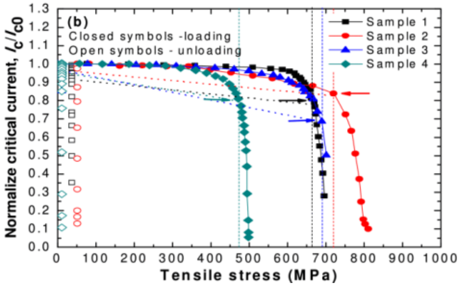


- *Internal R&D*
  # experimental/numerical study of different techniques (overshoot, vortex shaking)



Mechanics

Issue for very high-field magnets (> 30 T)
Ex : JBr > 1000 MPa
J=500 A/mm², B = 40 T, r=5 cm

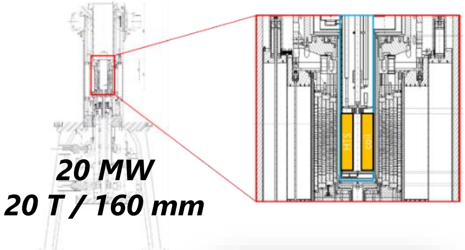


- *MI winding* co-wound tape is a strong mechanical reinforcement
- *M. ALHarake PhD* : mechanical study of non impregnated windings at very high fields

P. De Antoni (DIS)
P. Fazilleau, T. Lecrevisse, G. Dilasser

GOAL: 10 T HTS INSERT IN 20 T RESISTIVE OUTSERT

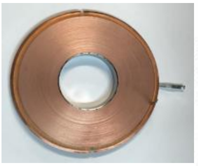
- 4 years project (oct 2014 -2018)
- Fundings from French National Research Agency (lead LNCMI)
- Collaborative project with CNRS Grenoble (LNCMI, Neel institute)

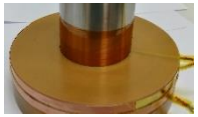


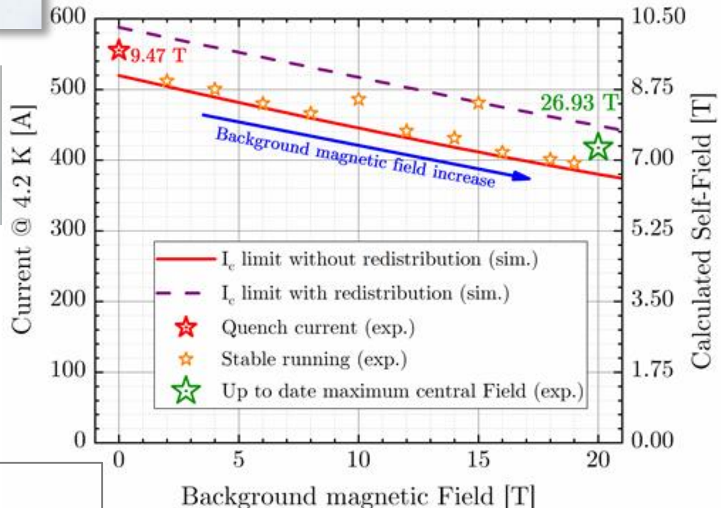
- Double pancakes, 6 mm-w ReBCO
- Metal-as-Insulation winding
- Prototypes (1 SP, 2 DP), codes (current dynamics…)
- 9 DP, ~ 2 kms of conductors

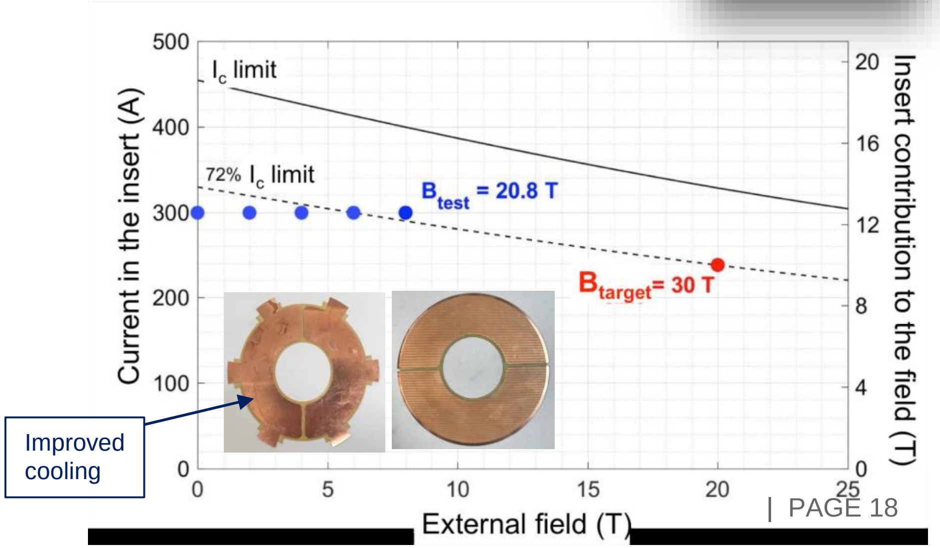
NOUGAT insert tests (9DP)
First phase (2018)
12.8 T *+ 8 T res*
Second phase (2019)
*@**10 T**+20 T res VM # 500 MPa*

2 DP proto tests
6.93 T *+ 20 T res*
VonMises> 800 MPa
Validation of fabrication, assembly and testing techniques and mechanics





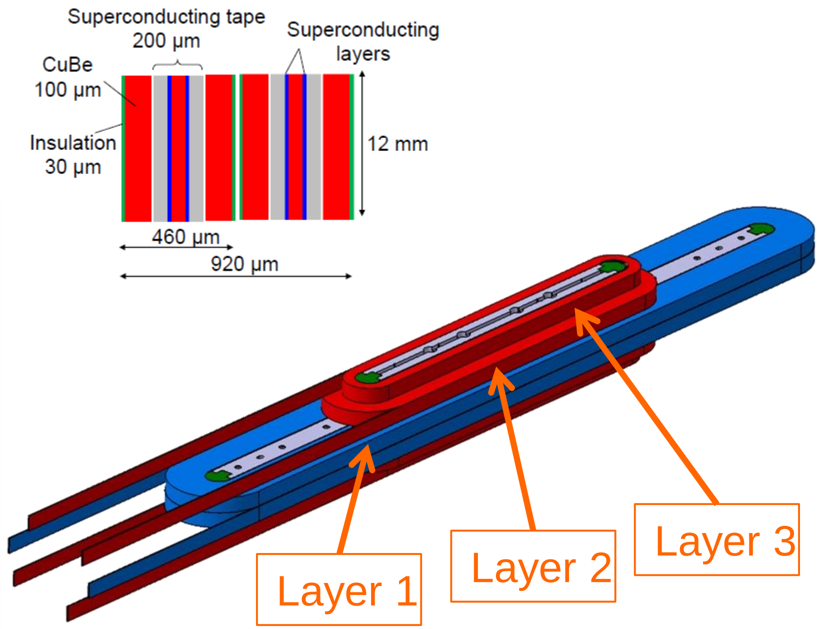


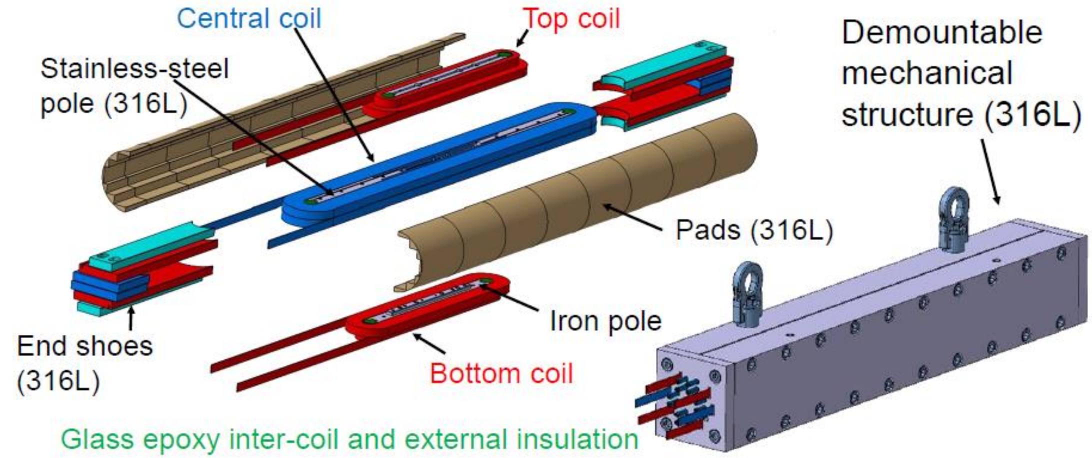


P. Fazilleau
T. Lecrevisse

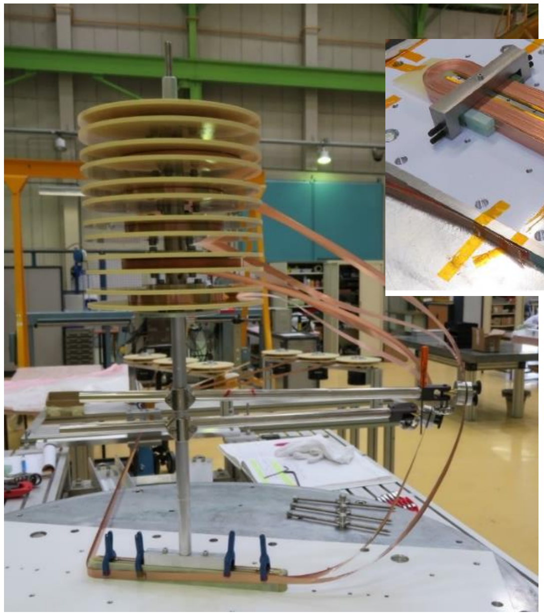
TOWARD HTS ACCELERATOR MAGNETS: EUCARD

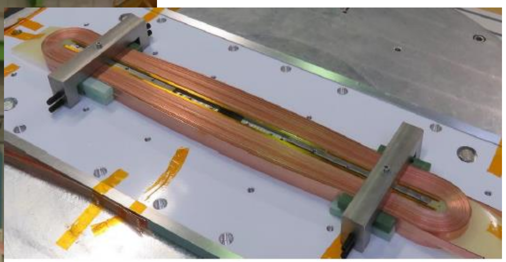
6 co-wound tapes: 2 SC + 4 CuBe





PARAMETER	Built Magnet	Unit
# of turns central coil layer 1	30	turns
# of turns external coils layer 2	24	turns
# of turns external coils layer 3	10	turns
Engineering current density	235	A/mm^2

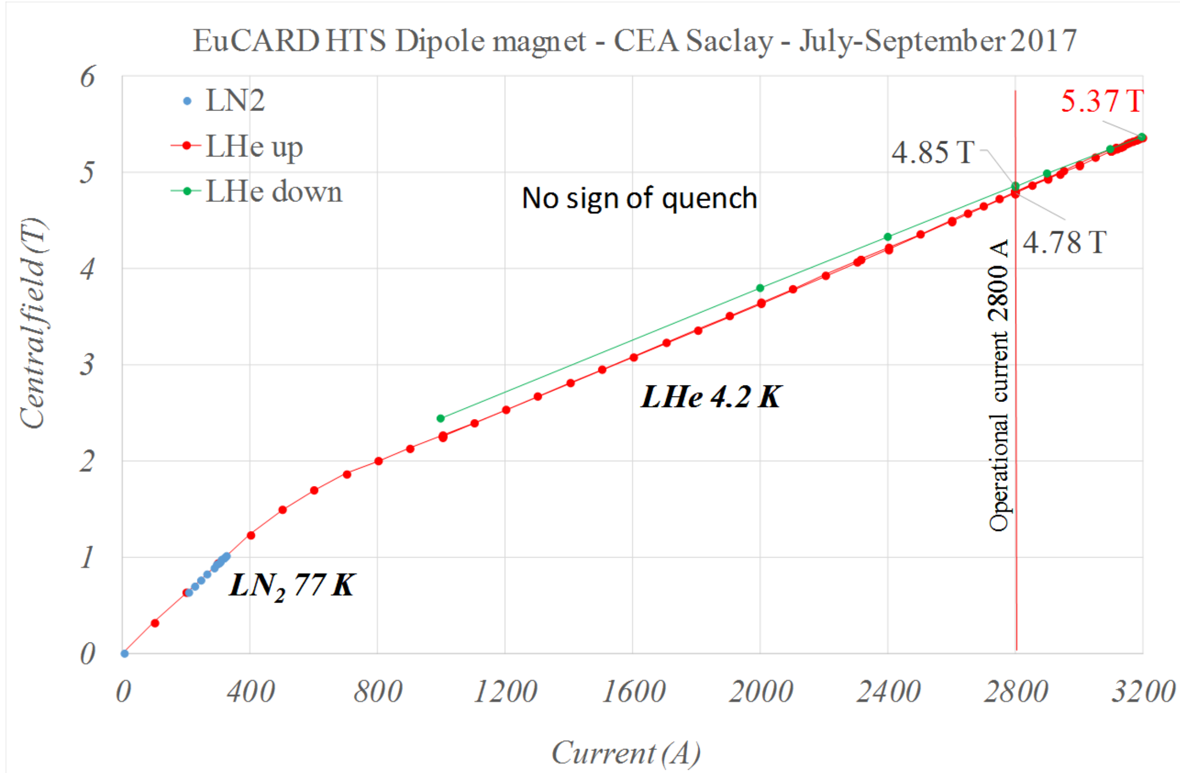




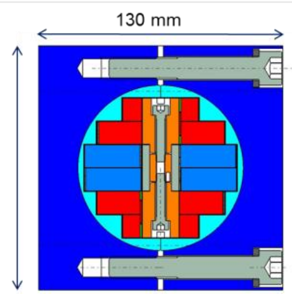
M. Durante
F. Borgnolutti

TOWARD HTS ACCELERATOR MAGNETS: EUCARD

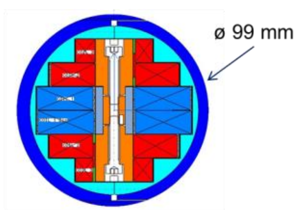
Nominal current	A	2800
Central field wo / w SCIF (screening current induced field)	T	5.4 / 4.7
Temperature	K	4.2
Stocked energy	kJ	12.5
Inductance	mH	3.2
Temperature margin	K	29
Load line margin	%	47



- Tested at CEA Paris Saclay and reached 5.4 T
- Next step: insertion of EUCARD in FRESCA2
  - Preparation is ongoing



Phase 1



Phase 2

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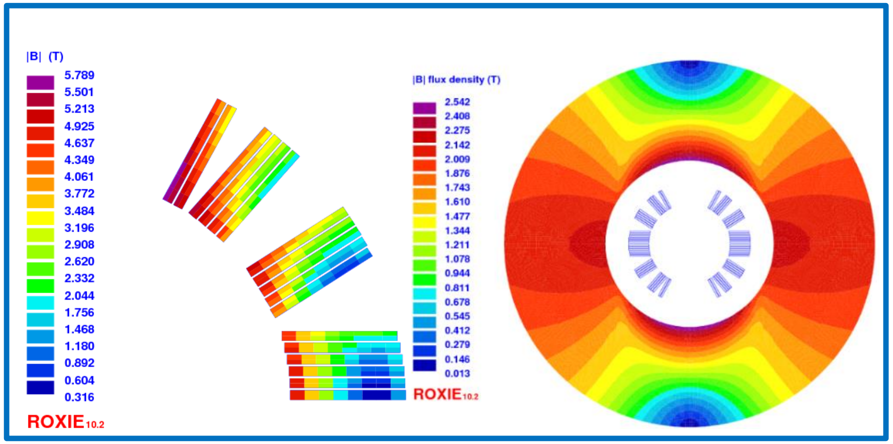
F. Borgnolutti
P. Fazilleau
T. Lecrevisse

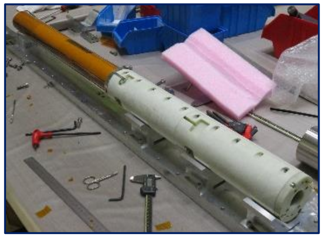
TOWARD HTS ACCELERATOR MAGNETS: EUCARD2 COSΘ

	Unit	Cosθ	In FRESCA 2
Iop	kA	10.06	7.1
Bop	T	5	**2.6** + 13
Ic	kA	15.2	7.9
LL margin	(%)	34	10
T margin	K	30	8
Bore radius	mm	24	16



- Roebel cable 12 x 1.0 mm^2 , 15 tapes, 300 mm twist pitch
- 2x125µm insulation, fiberglass
- **17 turns**

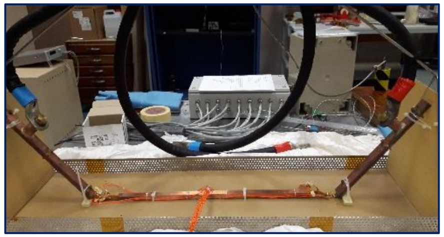
Dummy coil with SS Roeble cable



Practice assembly

Practice yoke stacking

Practice SC splice



- Magnet assembly by Summer 2019
- Standalone test in INFN LASA Sept 2019
- Test in FRESCA2 under discussion

M. Durante
C. Lorin

IN SUMMARY

- A wide range of fields
- A wide range of magnet sizes

- Strong implication with industry

- Fabrication capability from NbTi to Nb_3Sn and REBCO in house

- **Key objectives in near and mid term future**
  - Complete and test : EUCARD2, MQYYM, EUCARD+FRESCA2
  - Complete and test MQ and MQYYP
  - Complete Super-FRS dipoles with Elytt
  - Develop technological options for FCC dipole model
  - Proceed with HTS development:
    - Internal R&D
    - ongoing preparation of collaboration agreement on HTS between CEA and CERN