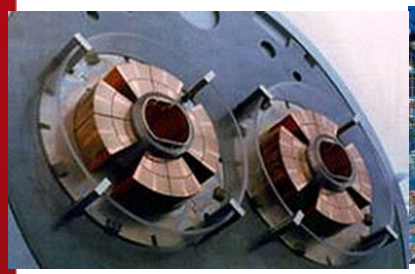
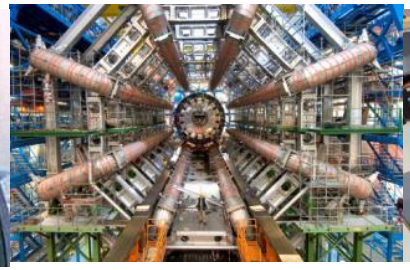
FROM RESEARCH TO INDUSTRY

www.cea.fr

SUPERCONDUCTING MAGNET DEVELOPMENTS AT CEA SACLAY FOR HL-LHC AND OTHER CERN PROGRAMS

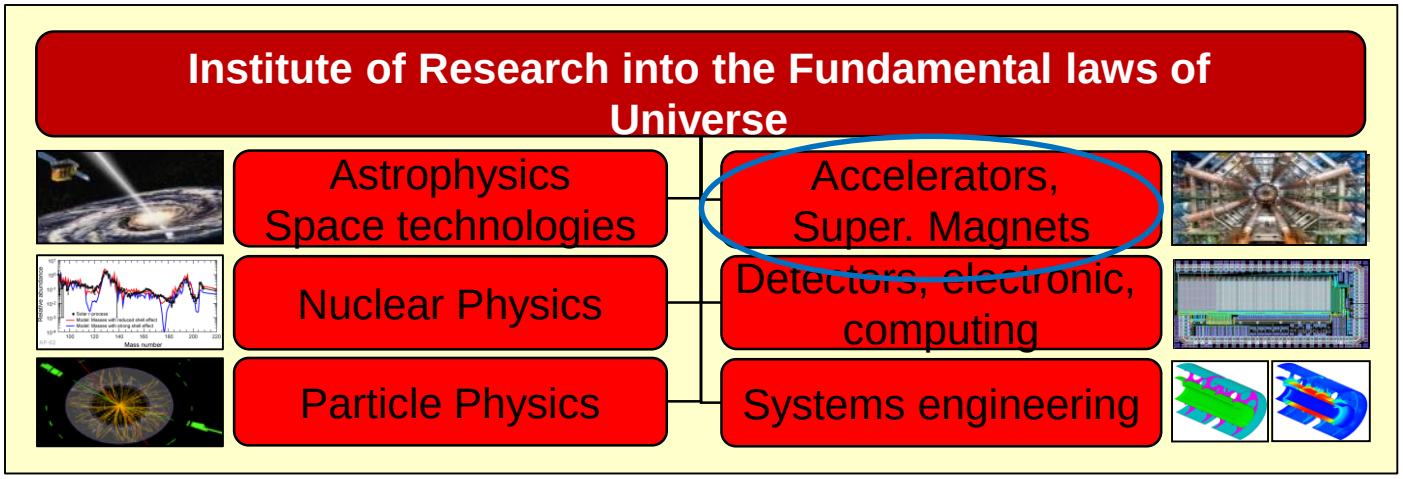




Pierre VEDRINE

DRF/Irfu/SACM

14 NOVEMBER 2016

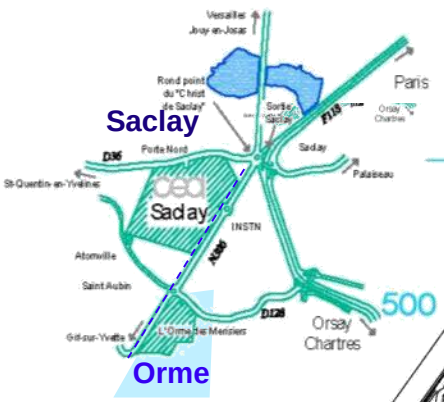
ADVANCED TECHNOLOGIES ACTIVITIES (~160 FTE) FOR ACCELERATORS AND SUPERCONDUCTING MAGNETS

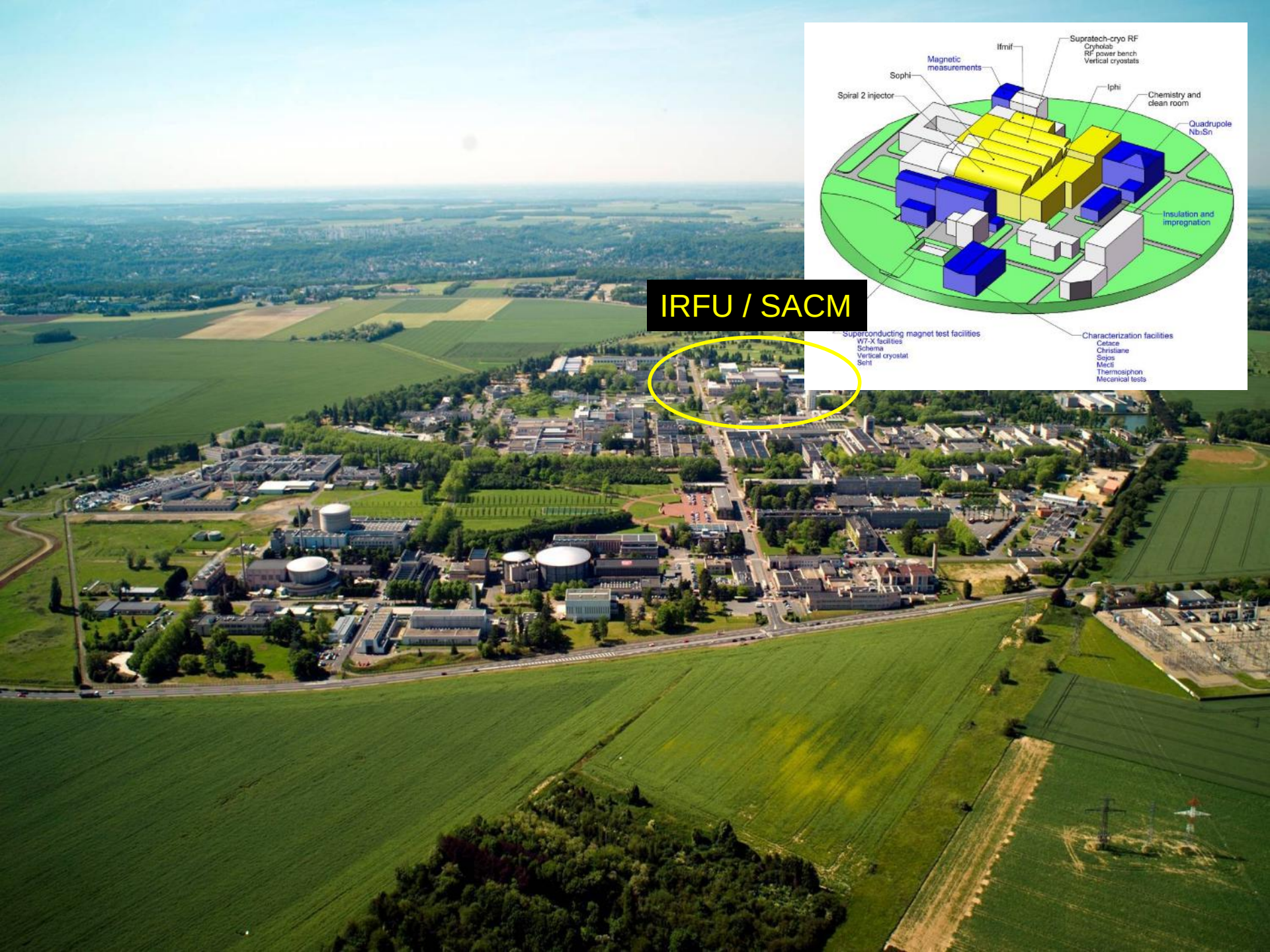


- Irfu/SACM is developing and realizing particle accelerators, cryogenic systems and superconducting magnets for the scientific programs of Irfu and more widely of CEA.
- Iru/SACM develops R&D activities to support theses programs.
- Irfu/SACM is also involved in large scale projects in Europe and Japan
- In November 2016, 80 engineers and 43 technicians, CEA staff, and 36 postdocs belong to the Irfu/SACM division.

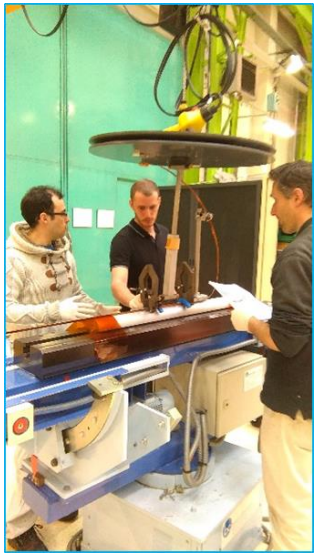
SACM LOCATION

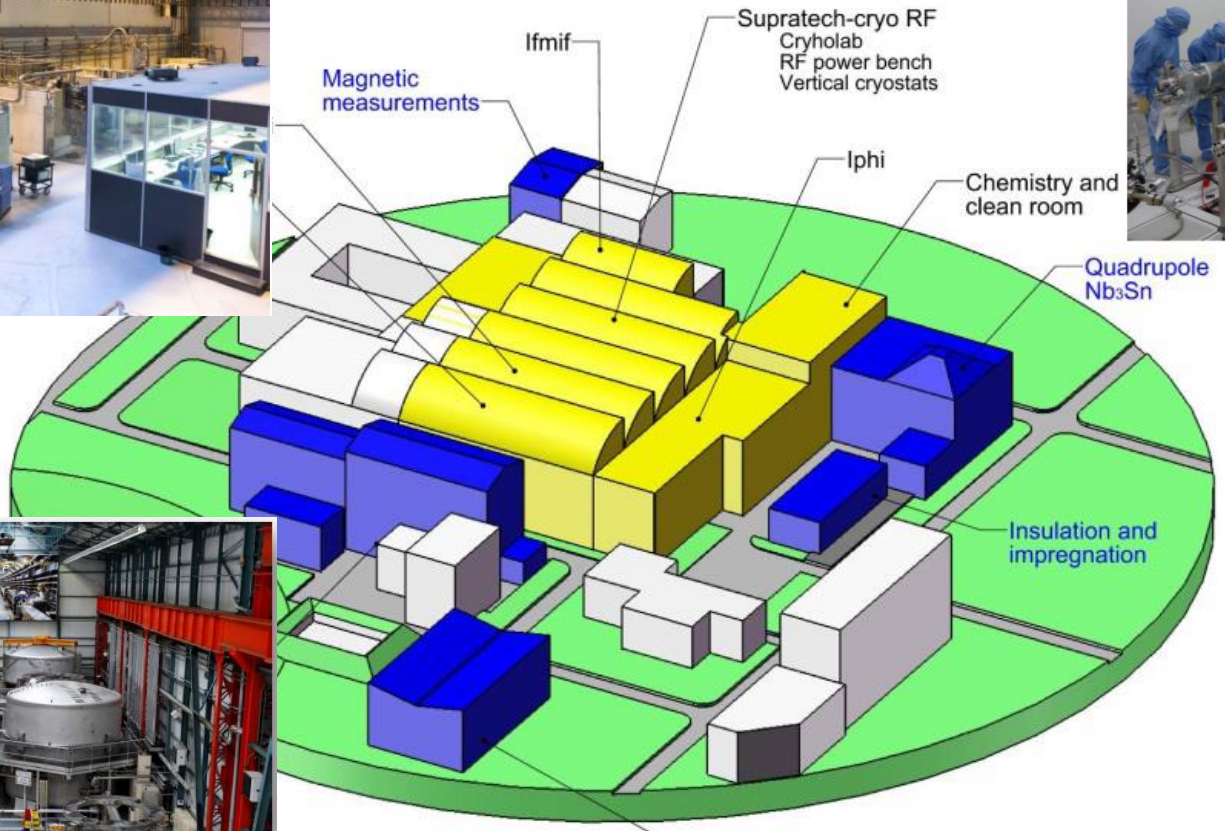
Irfu Saclay&Ormes
50 000 m^2, 130 M€




IRFU / SACM
Ifmif
Supratech-cryo RF
Cryholab
RF power bench
Vertical cryostats
Magnetic measurements
Sophi
Iphi
Spiral 2 injector
Chemistry and clean room
Quadrupole Nb3Sn
Insulation and impregnation
Superconducting magnet test facilities
W7-X facilities
Schema
Vertical cryostat
Sehi
Characterization facilities
Cetace
Christiane
Sejos
Mecti
Thermosiphon
Mecanical tests

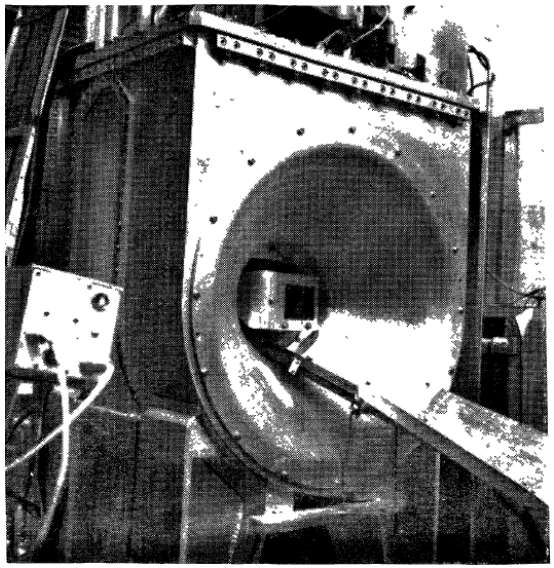
SACM TECHNOLOGICAL INFRASTRUCTURES (25 000 M²)



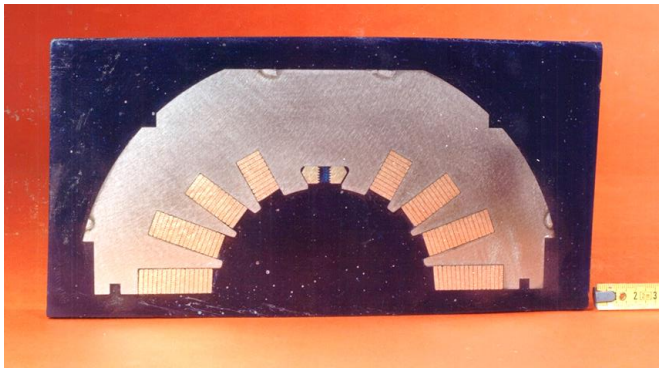


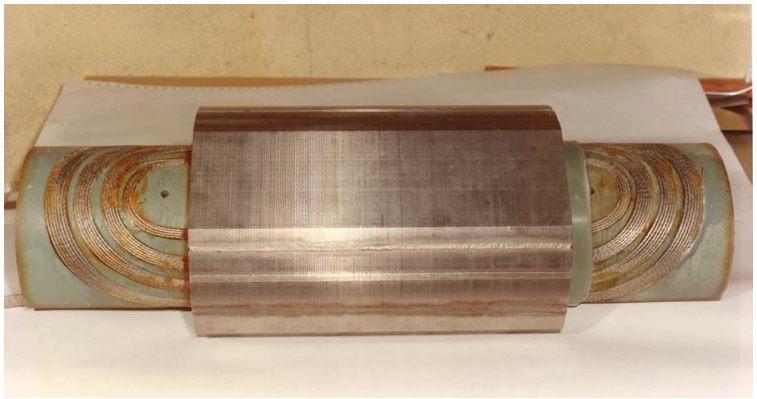
ACADEMIC AND INDUSTRIAL PARTNERS

LONG HISTORY OF SUPERCONDUCTING MAGNET DEVELOPMENTS AT SACLAY



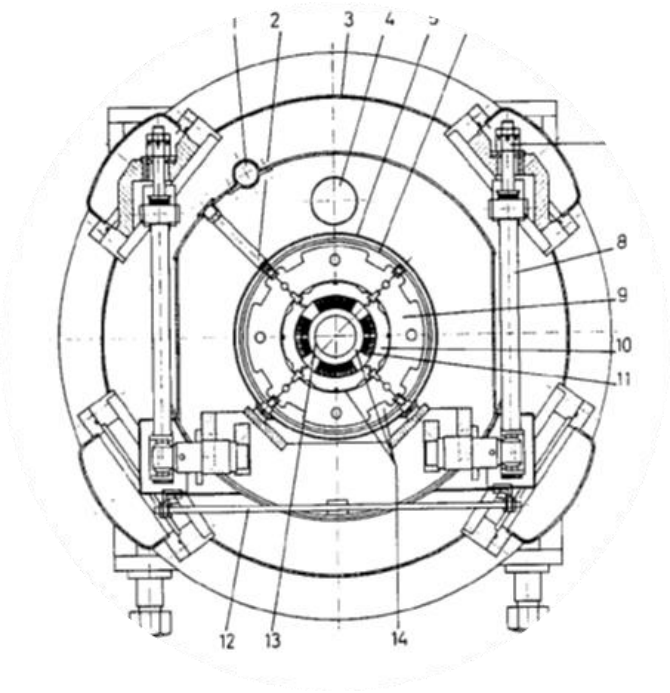
Helmotz-type magnet HERA experiment on CERN PS 5T, 400 mm aperture (1967)





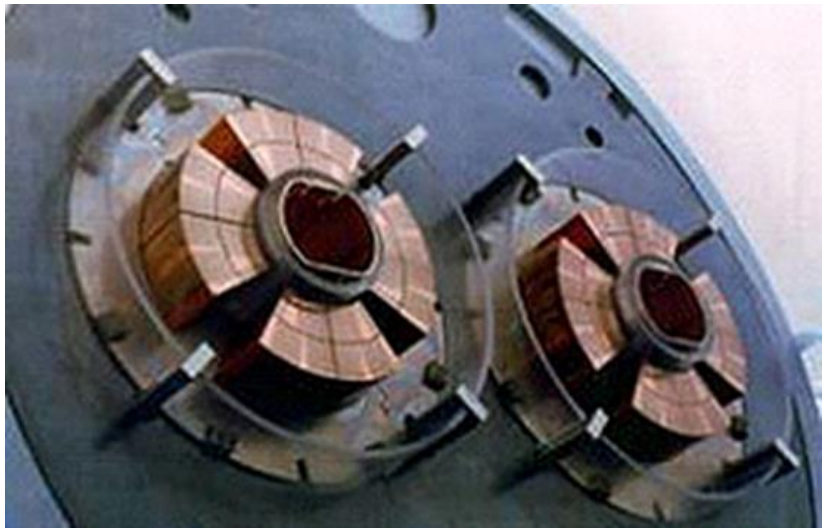
Block-type dipole prototype 5T, 100 mm aperture (1983)

LONG HISTORY OF SUPERCONDUCTING MAGNET DEVELOPEMENTS AT SACLAY



HERA quadrupole magnets protyping and series production follow-up
92 T/m, 75 mm aperture (1986)

SSC HEB Quadrupole Magnet prototyping
182 T/m 50 mm aperture (1993)



LHC quadrupole magnet prototyping and series production follow-up
223 T/m, 56 mm aperture (1989- 2006)

ALEPH Solenoid Detector Magnet

	ALEPH
Accelerator	LEP
Laboratory	CERN
Designed by	Saclay
Manufactured by	Saclay
Inner Bore (m)	4.96
Outer Bore (m)	5.98
Winding Length (m)	6.35
Overall length (m)	7
Conductor (mm2)	35 x 3.6
Stabiliser	Al
Cold Mass (t)	25
Conductor mass (tons)	8
Current (A)	5000
Design field (T)	1.5
Stored energy (MJ)	137
Cooling method	Thermo siphon
Radiation length (X0)	2
Year of completion	1987

LHC DETECTOR MAGNETS…THE GIANTS !

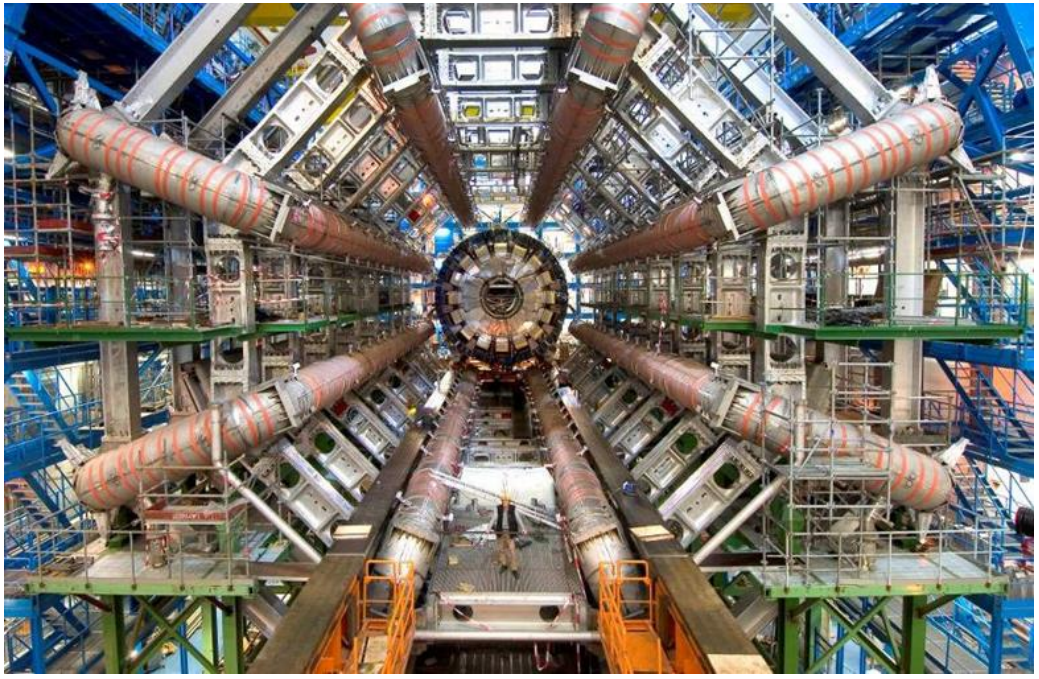
CMS

Largest Solenoid – 4T, 2.7 GJ, 7m dia, 12m long

ATLAS TOROIDS

Largest field volume – 8200 m3 self contained field (no yoke) open structure

1.55 GJ, 20 m dia, 25 m long



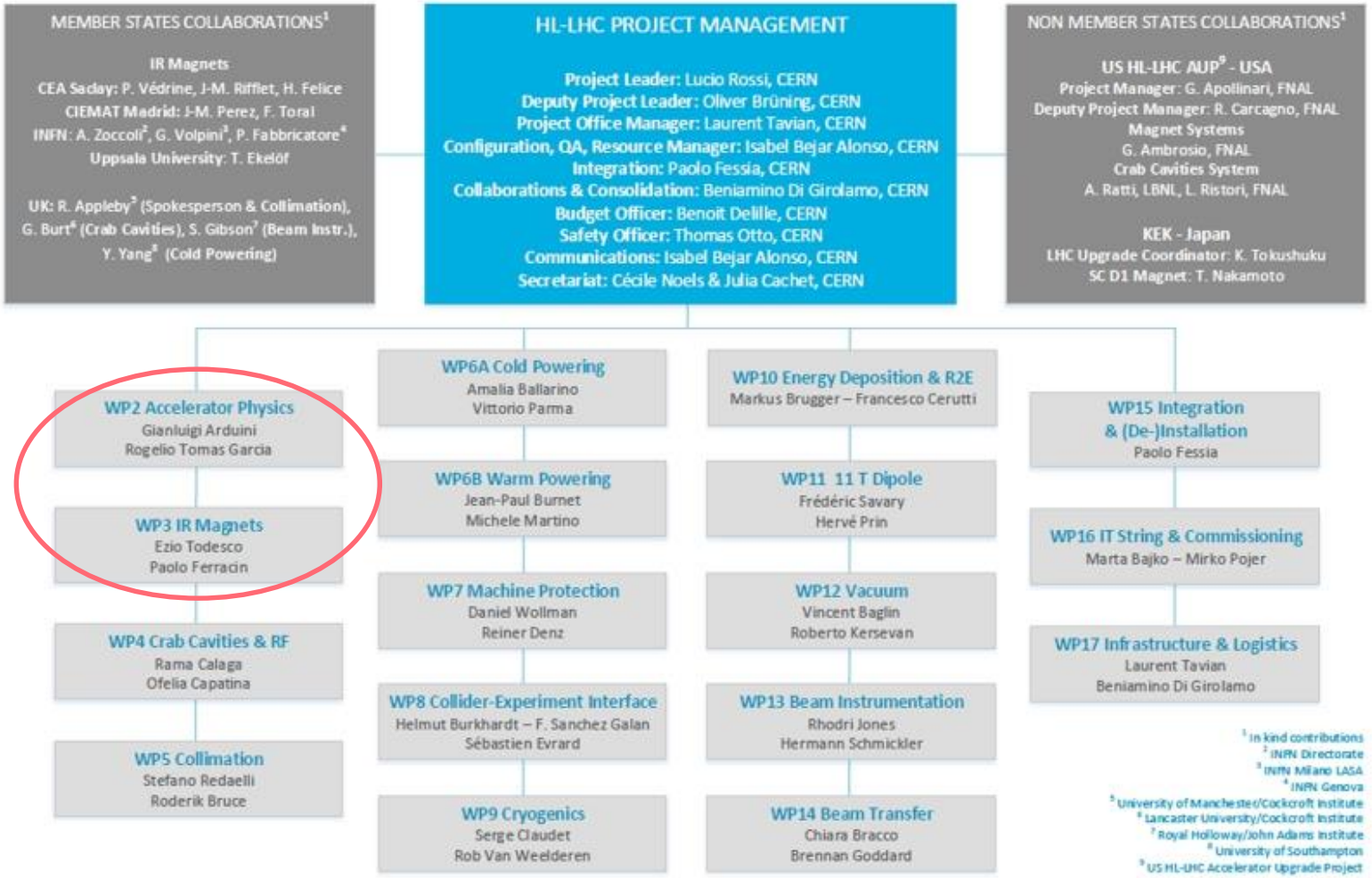
Engineering design and manufacturing follow-up

LONG HISTORY OF COLLABORATION WITH CERN

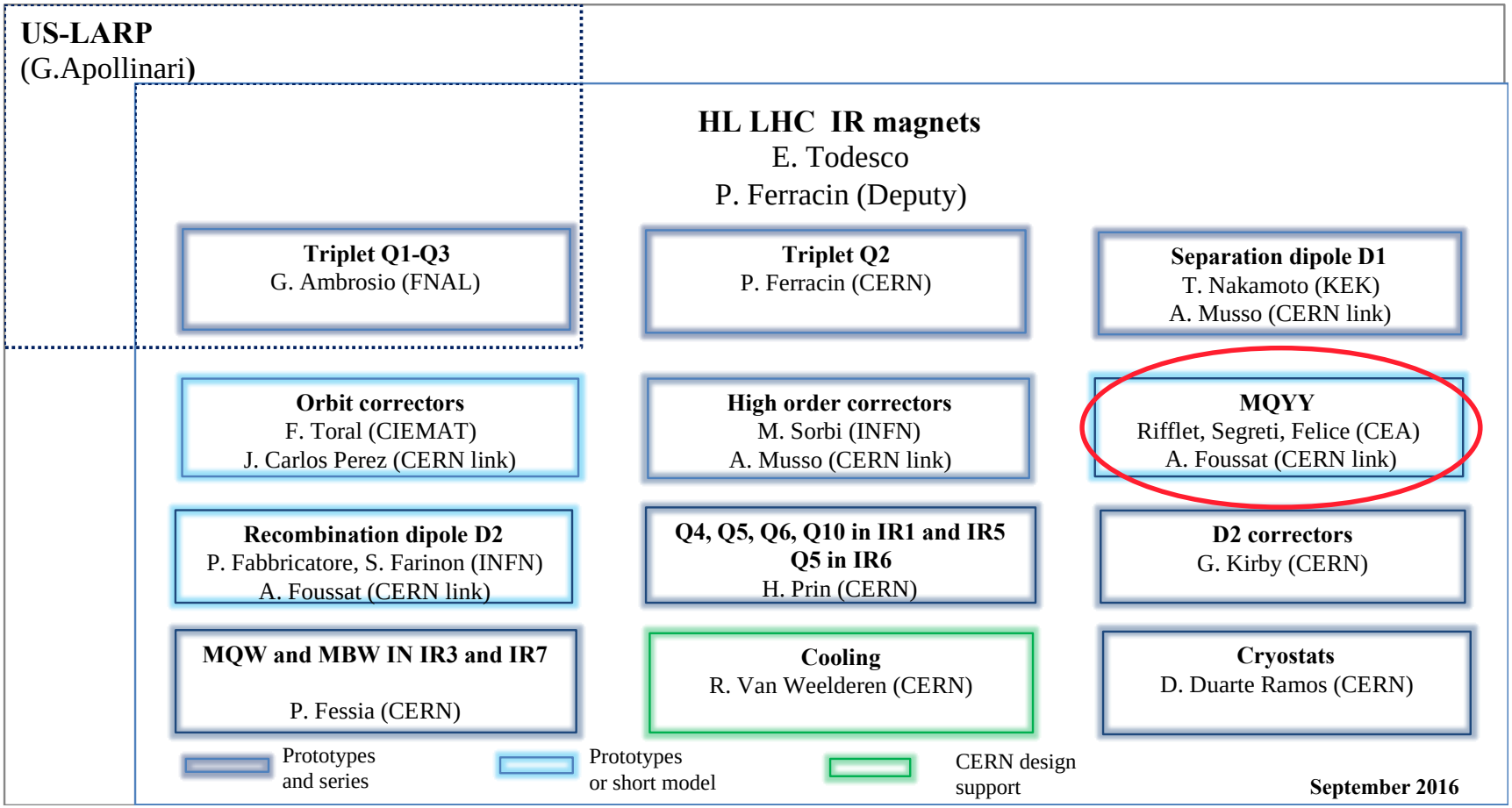
- Long history of collaboration with CERN on superconducting magnets for accelerators :
  - 1989 - 2006 : Design, prototyping and follow-up in the industry of the manufacturing of 400 LHC main quadrupole cold masses (Collaboration Agreement and Specific French Contribution to LHC) NbTi
  - 2004 - 2006 : NED (CARE,FP6) Nb_3Sn, R&D cryo
  - 2008 - 2011 : SLHC-PP (FP7) NbTi
  - 2009 - 2013 : EuCARD HFM (FP7) Nb_3Sn, HTS
  - 2009 - 2014 : New Specific French Contribution to CERN NbTi, Nb_3Sn, R&D cryo
  - 2011 - 2015 : HiLumi LHC Design Study (FP7) NbTi
  - 2013 - 2017 : EuCARD2 (FP7) HTS
  - 2014 - 2016 : Collaboration agreement CEA-CERN NbTi, Nb_3Sn, HTS
  - 2015 - 2019 : EuroCirCol (H2020) Nb_3Sn
  - 2016 - 2020 : HL-LHC Quaco (H2020) NbTi
  - 2017 – 2021 : New collaboration agreement in preparation

High Luminosity LHC Participants

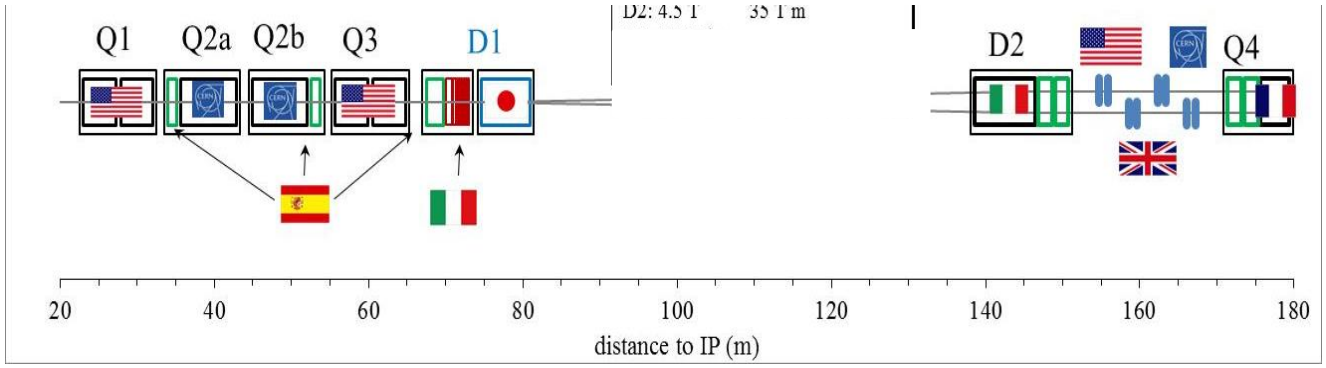
High Luminosity LHC Project

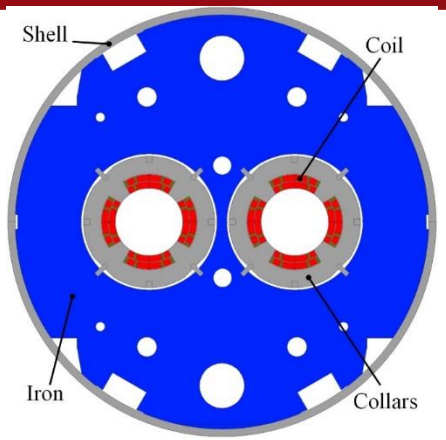


MQYY DEVELOPMENT IN WP3



LHC UPGRADE IN LUMINOSITY
QUADRUPOLE Q4 (HI-LUMI)





- Quadrupole cos2θ double layer
- Aperture = 90 mm, Integrated gradient = 440 T, Magnetic length = 3.67 m,
- Nominal gradient = 120 T/m
- Temperature = 1.9 K, Nominal current = 4590 A
- Stored energy = 0.81 MJ

Initial HL-LHC baseline was to use MQYY, a new double aperture quadrupole with 90 mm aperture.

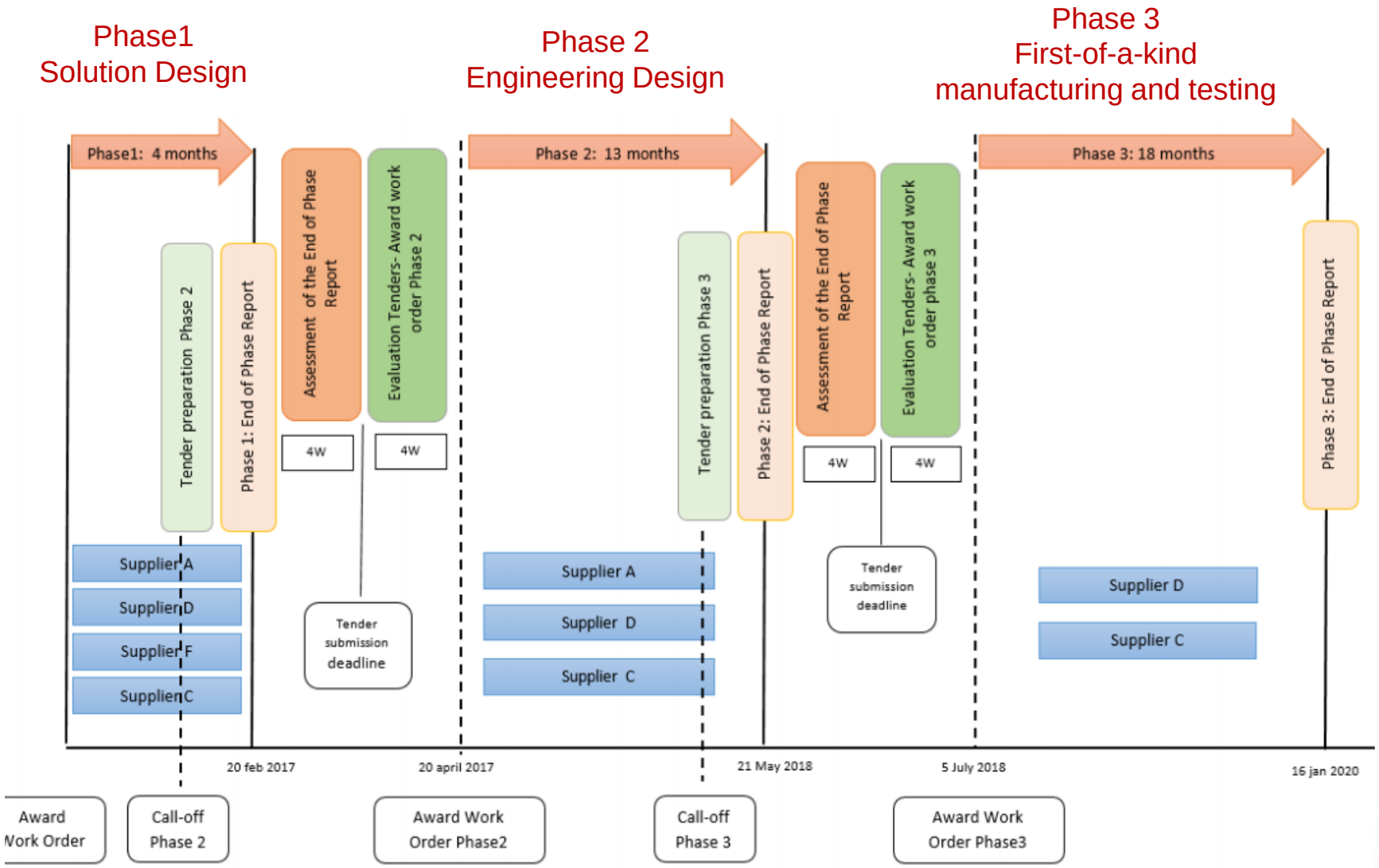
- **2011**: development starts with a CEA- CERN initiative (J.M. Rifflet et M. Segreti)
- **March 2014:** collaboration agreement between CERN and CEA including activities on MQYY (WP2 of the agreement)
- **September 2015**: Formal decision to change the cable with a reduced size and current.
- **June 2016:**
  - Decision to keep MQY to reduce cost
  - Decision to continue with the development of MQYY short model and prototype
  - Updated CEA-CERN collaboration content: Single aperture model MQYYM developed by CEA and CERN
- Parallel development: two prototypes developed in the QUACO initiative

TOWARDS THE PROTOTYPE: QUACO

- In 2015 a program to build two prototypes in the industry using EU funds has been launched (M. Losasso, I. Bejar Alonso)
  - QUACO is a PreCommercial Procurement (PCP)

- Principle:
  - R&D project in industry lead by a consortium of EU labs: CEA, CIEMAT, NCBJ and CERN
  - Industries are in competition in 3 phases. At each end of phase, a company is eliminated.
  - In Spring 2020 two companies will have produced two prototypes (one per company)
  - The magnetic design and protection are given, mechanical structure and tooling have to be proposed by the company

QUACO OVERVIEW



MQYY
MAGNETIC AND MECHANICAL DESIGN OPTIMIZATION

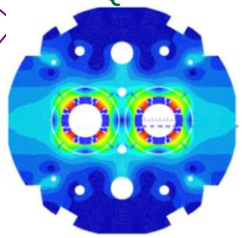
09/2015

SHORT MODEL MQYYM

Magnetic reoptimization 2D of the double aperture with MQM cable

COMPLETED

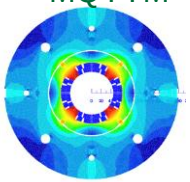
MQYY



Magnetic and mechanical Design

- Fine tuning of the magnetic design (2D + 3D) in ROXIE
- Self standing collar structure in Castem

MQYYM



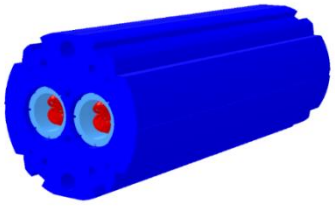
COMPLETED

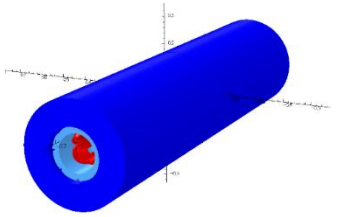
05/2016

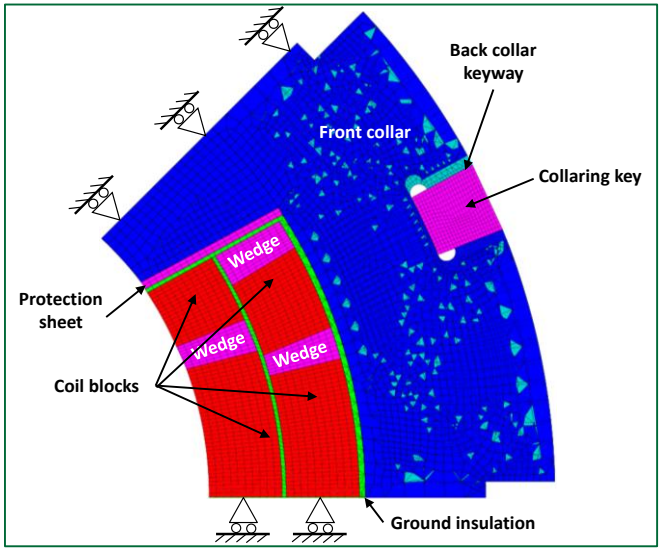
- Comparison Roxie/Opera Castem/Ansys

ONGOING

10/2016







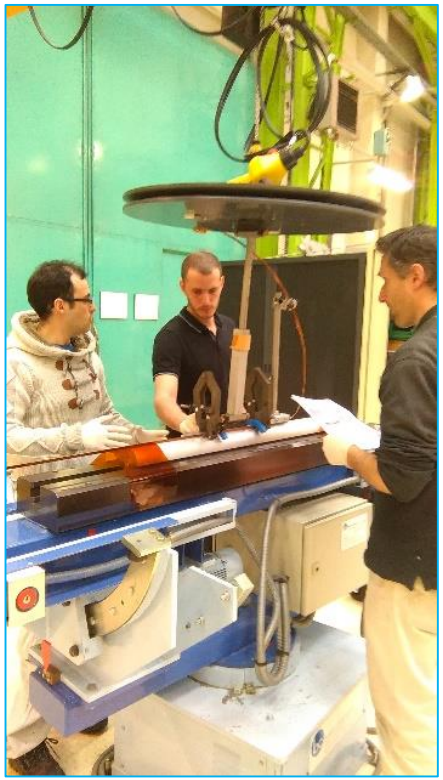
Aperture	90 mm
Nominal Gradient	120 T/m
MQYY Magn. length at 1,9 K (MQYYM)	3,7 m (1,2 m)
MQYY Nominal Current (MQYYM)	**4590 A (4550)**
Peak field	6,4 T
Margin on the loadline	23 %
Differential inductance	2 x 37,5 mH
Cable type	MQM
MQYYM / MQYY outer diameter	360 / 614 mm

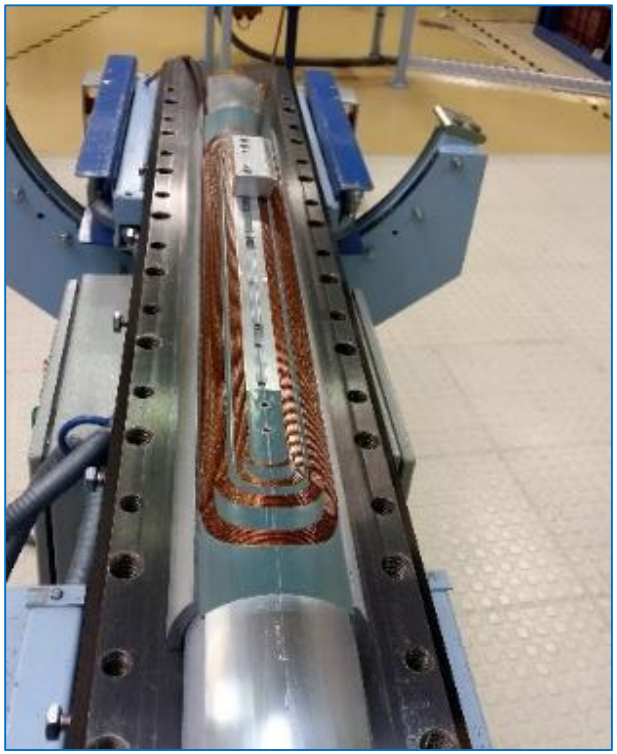
MQYYM
WINDING TESTS

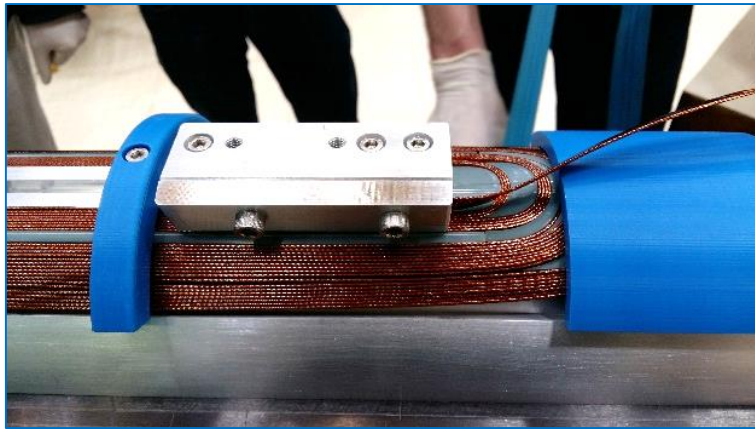
2 mock-ups manufactured:

- Mock-up # 1: ABSPlus 3 printed layer 1 parts (fab at CEA)
  - Winding only
- Mock-up # 2: Blue-stone epoxy layer 1 and 2 (fab at CERN)
  - Winding L1 and L2 and curing L1

- ***Test of MQYYM in the vertical cryostat at CEA-Saclay***







Courtesy H. Felice

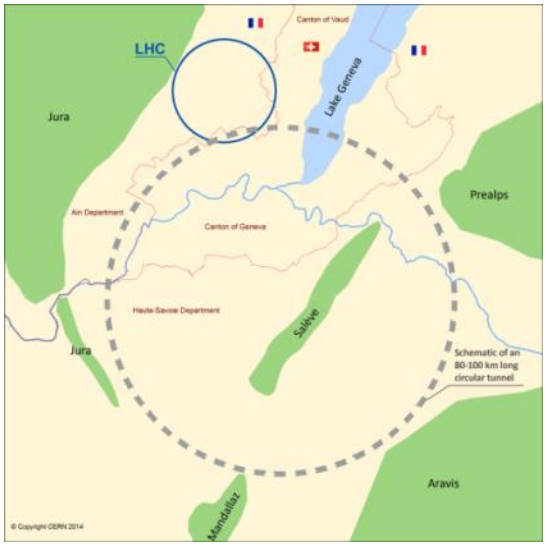
UPGRADE IN ENERGY – FUTURE CIRCULAR COLLIDER

Future Circular Collider: 100 TeV

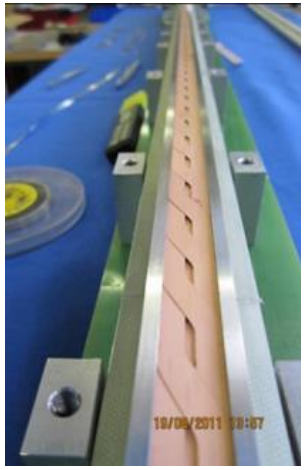
16 T in 100 km ← Nb3Sn

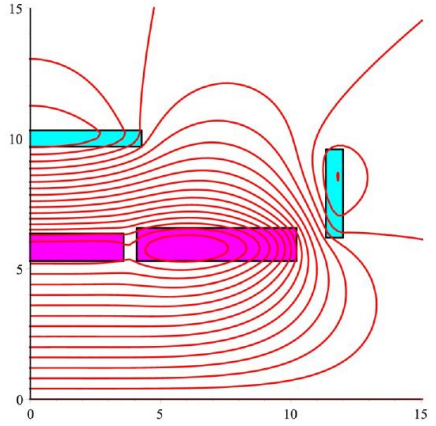
20 T in 80 km ← Nb3Sn + HTS

FCC



- **FRESCA2** : Nb3Sn 13 T dipole;
- **EuCARD** : design and manufacturing of a 6 T HTS dipole;
- **EuCARD2** : Design and manufacturing of a 5 T HTS dipole, 40 mm aperture, to demonstrate the feasability of accelerator field quality
- **FCC & H2020 Design Study EurCirCol**: Complete the EuCARD and EuCARD2 activities to design a 16 T Nb3Sn dipole magnet for FCC.
- **FCC Detector magnet** design.





FRESCA2 DIPOLE

Objectives : Nb3Sn technological developments for the LHC upgrade.

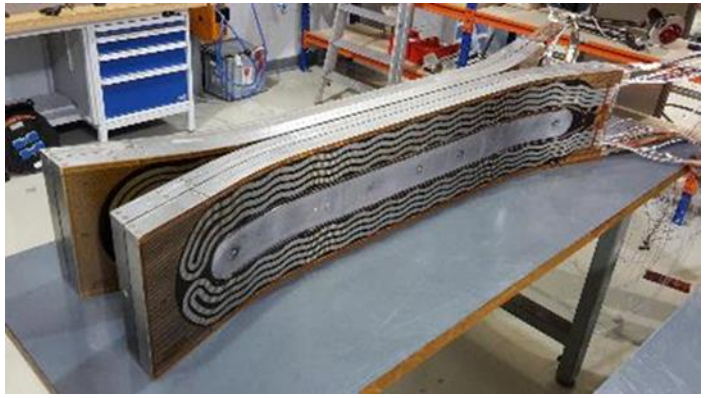
Magnet will be used for the upgrade of cable test faclity at CERN (FRESCA2).

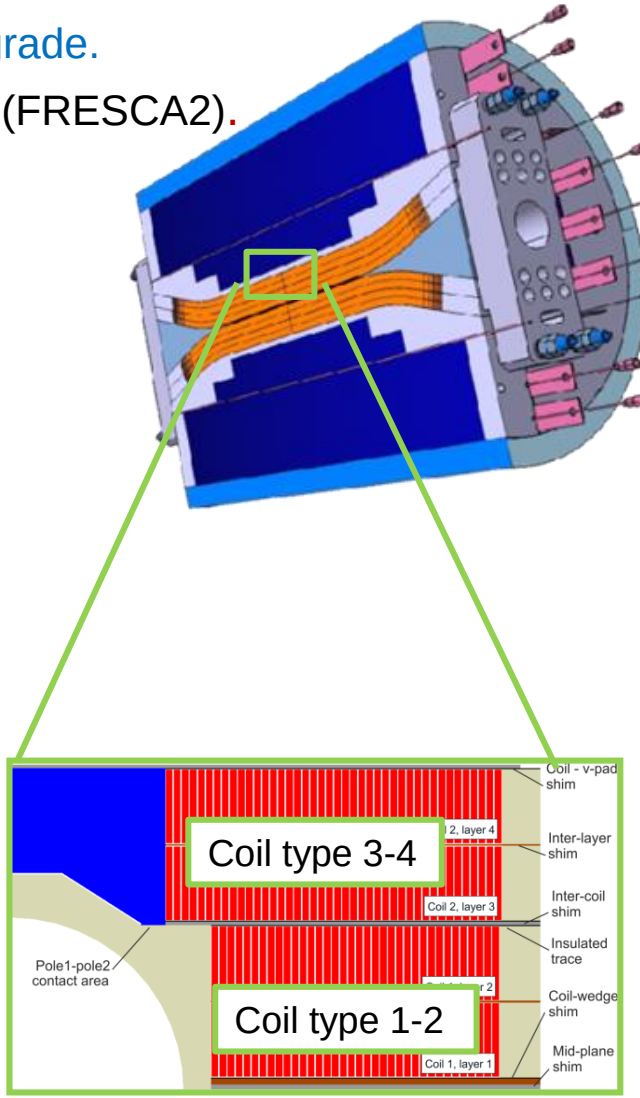
Block type dipole

13 T at 4.2 K, 15 T at 1.9 K
100 mm aperture

4 coils have been wound at Saclay
and impregnated at CERN

Cold test at CERN - December 2016

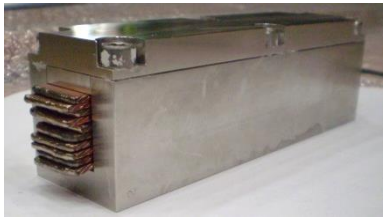




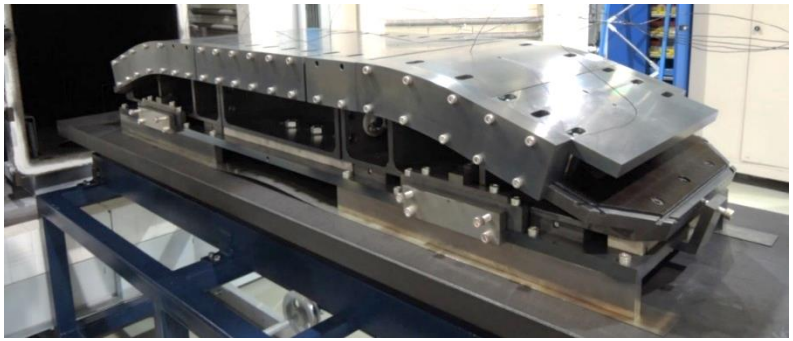
R&D ON HIGH FIELD MAGNETS

- R&D on Nb_3Sn :
  - Nb_3Sn cable behavior studies during heat treatments.

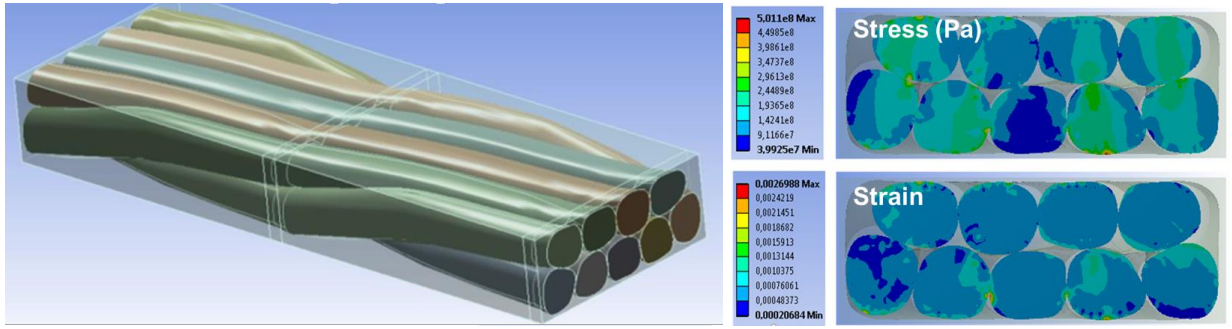
Reaction molds for dimensional changes studies and stress control in Nb_3Sn coils



Reaction mold for Nb_3sn cable thickness variation studies

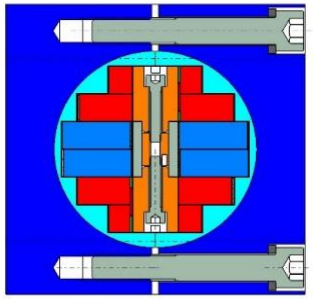


  - Nb_3Sn cable mechanical behavior modeling.



EuCARD HTS INSERT

- HTS dipole insert for FRESCA2 dipole background magnet aiming at a fiel increase of about 6 T.
- Started in the framework of EuCARD European program HFM WP7.4
- New collaboration agreement CEA/CERN 2 steps :
  - Step 1 : test in stand alone mode at Saclay
  - Step 2 : test inside Fresca 2 dipole magnet at CERN

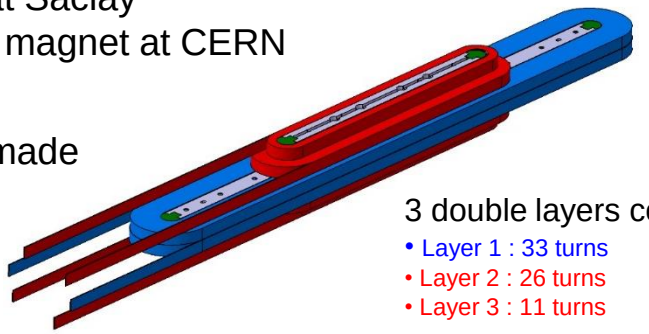


Step 1

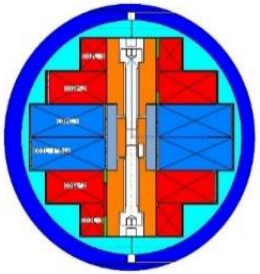
✓ Winding
- ✓ 2 coils type 2-3 (external coil) already made
- ✓ 2 coils type 1-2 ongoing

✓ Test in standalone configuration for T4 2016

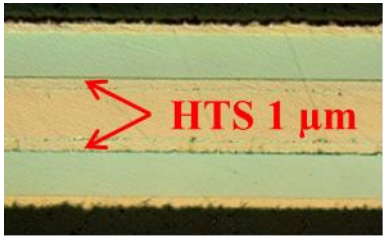
✓ Test in FRESCA 2 in 2017



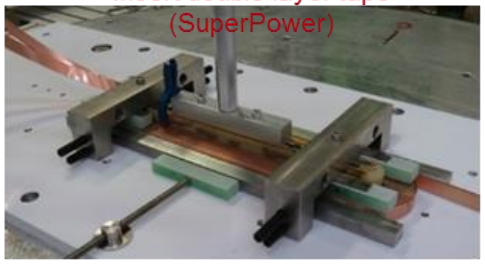
3 double layers coils
- Layer 1 : 33 turns
- Layer 2 : 26 turns
- Layer 3 : 11 turns

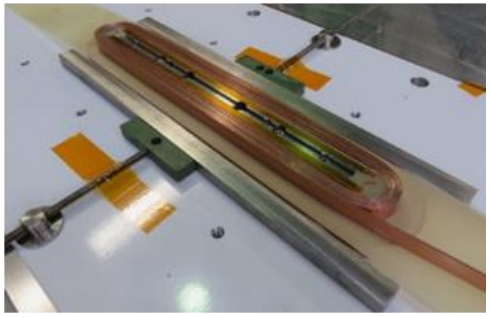


Step 2



Insert double layer tape
(SuperPower)



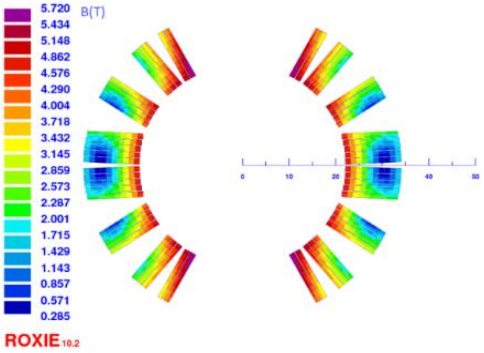


EuCARD² HTS DIPOLE

- FP7 EuCARD2 WP10
  Collaboration with CERN, INPG, INFN, TUT, DTI

- Design, manufacturing and test of HTS cos theta accelerator dipole (YBCO)

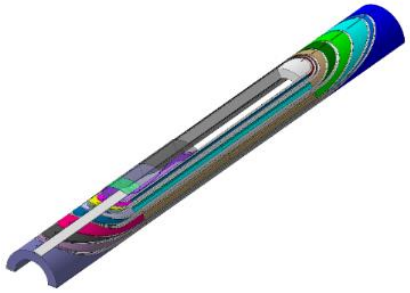
Câble Roebel YBCO (General Cable Superconductors, New Zealand)



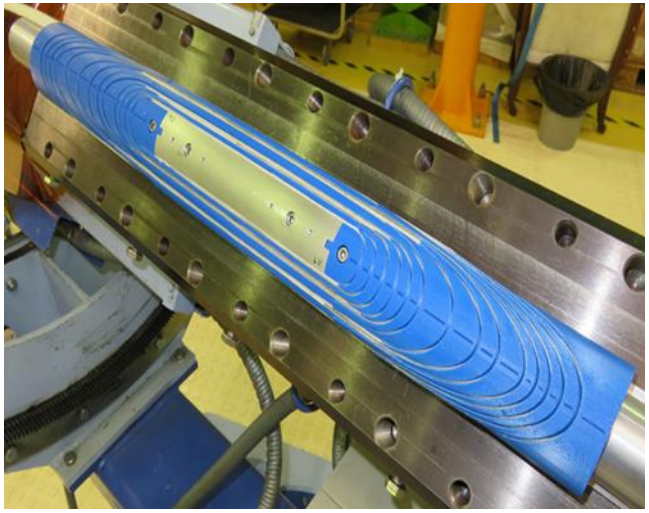
Costheta Design (CEA)

- 5 T, 40 mm aperture, 4.2 K, accelerator field quality

Design A – câble ép. 1.2 mm
13 tapes 0.14 mm
Bruker, partner EuCARD2



Design B – câble ép. 1.0 mm
15 tapes 0.1 mm
SuperOX, Sunam, ou Fujikura

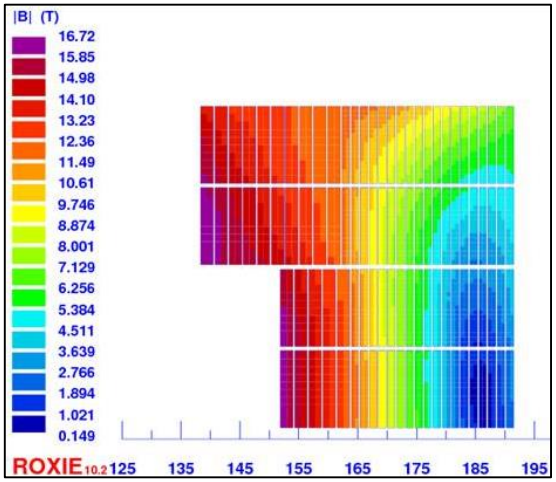


Winding test with Roebel cable (May 2015)

- Test at INFN LASA in 2017

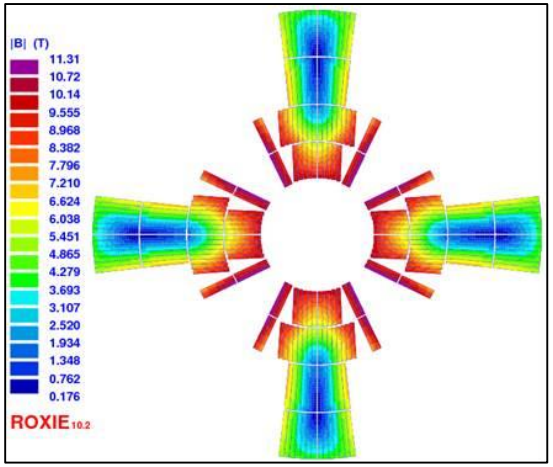
FCC Nb_3Sn MAGNETS

- Nb_3Sn Block type Dipole Model (16 T, ϕ=50 mm, L= 1.5 m) (studied in EuroCirCol) :
  - Manufacturing of 3 impregnated poles at Saclay.
  - Assembly at Saclay
  - Cold tests at CERN.



Courtesy M. Durante, C. Lorin

- Nb3Sn Quadrupole Design Study
  - 2D and 3D mechanical and magnetic analysis.
  - Engineering design.



Courtesy C. Lorin

CONCLUSION

CEA has a long history of collaboration with CERN in superconducting magnet activities (more than 50 years)

CEA Saclay is developing the MQYY quadrupole magnet for HL-LHC

CEA Saclay is participating to the EuroCirCol project on 16 T block-type dipole design.

New agreement are being finalized with CERN for FCC Nb3Sn dipole prototyping and HTS dipole insert development.