Magnet R&D programmes in Europe

Joint Snowmass-EuCARD/AccNet-HiLumi LHC meeting
'Frontier Capabilities for Hadron Colliders 2013'

21-22 February 2013

Gijs de Rijk
CERN

CERN program on High Field Magnets

HFM program aim: High field magnets technology (dipoles and quads) for LHC upgrades and future accelerators

Priorities:
- Conductor is the heart of the magnet
- Magnet design and tests
- Germinate new projects

First step (2004 – 2012):

- Conductor technology : NED 1.25 mm, Fresca2 1 mm (2010), 11 T 0.7 mm (2011)
- Magnet technology : Short Model Coil (2011)
- Personnel training on existing technologies : test TQ & HQ @ CERN (2009)

Second step (2009 – 2014):

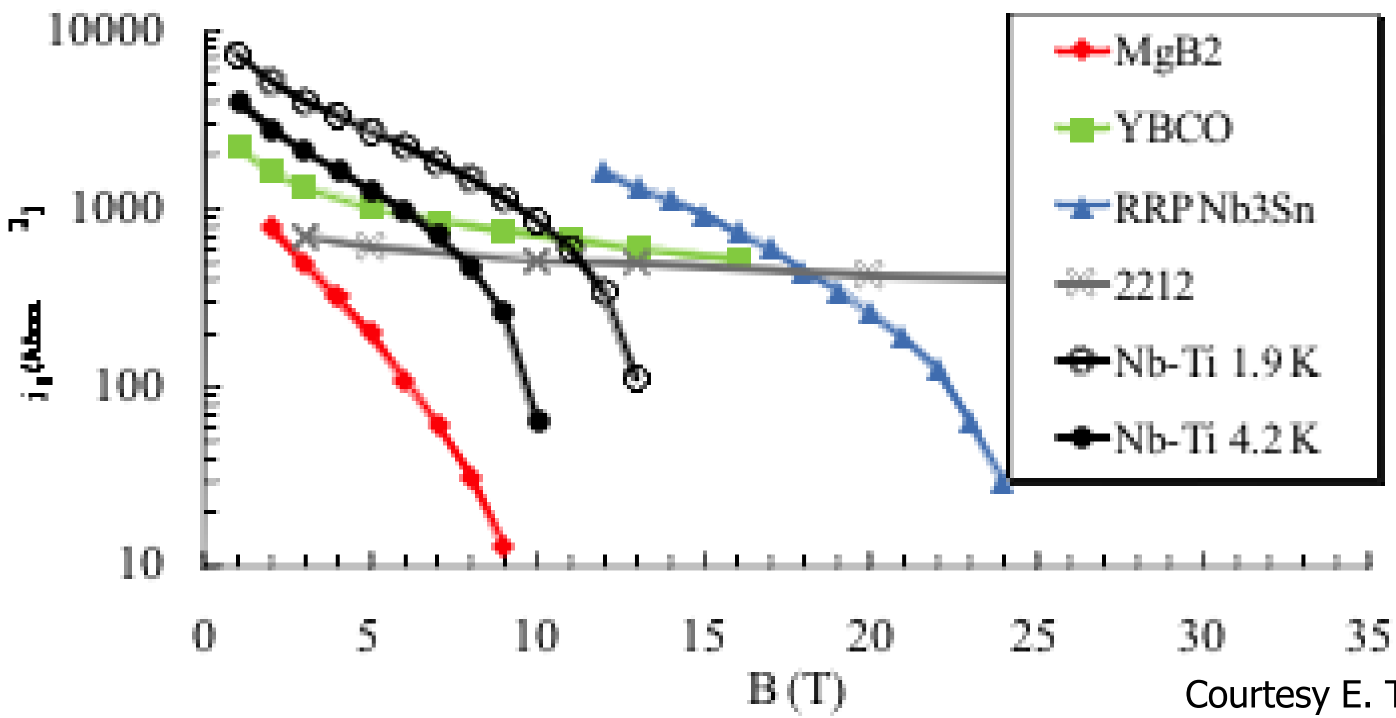
- Magnet models : Fresca2 (2013), IR quad model (2013), 11 T dipole model (2013)
- Conductor test facilities upgrade to 15 T test station (2014-2015)
- Radiation hardness studies for Nb_3Sn and coil insulation (2010-2014)
- Magnet concepts from 15 T to 20 T : EuCARD 6 T insert (2013), EuCARD2 (2016)

Third step (2014 – 2016):

- LHC Dispersion Suppressor dipole prototype (2015)
- LHC Inner triplet quadrupole prototype (2016)

Conductors for HFMs

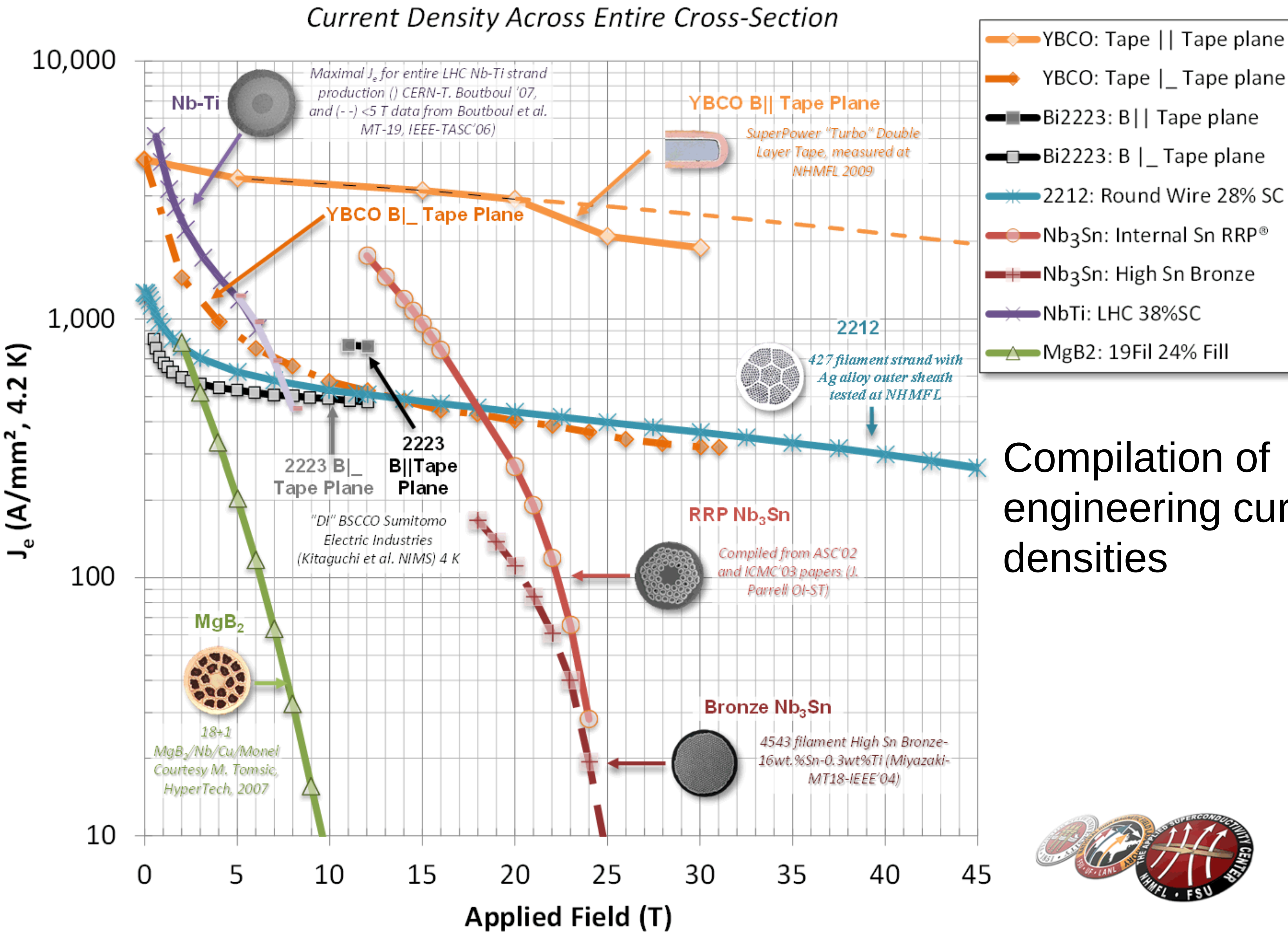
To meet these requirements one has to switch from Nb-Ti to Nb_3Sn conductors



Courtesy E. Todesco

Engineering current density in practical superconductors

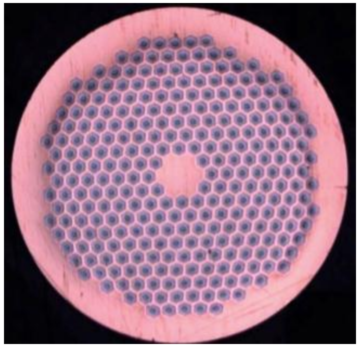
Superconductors



Compilation of engineering current densities

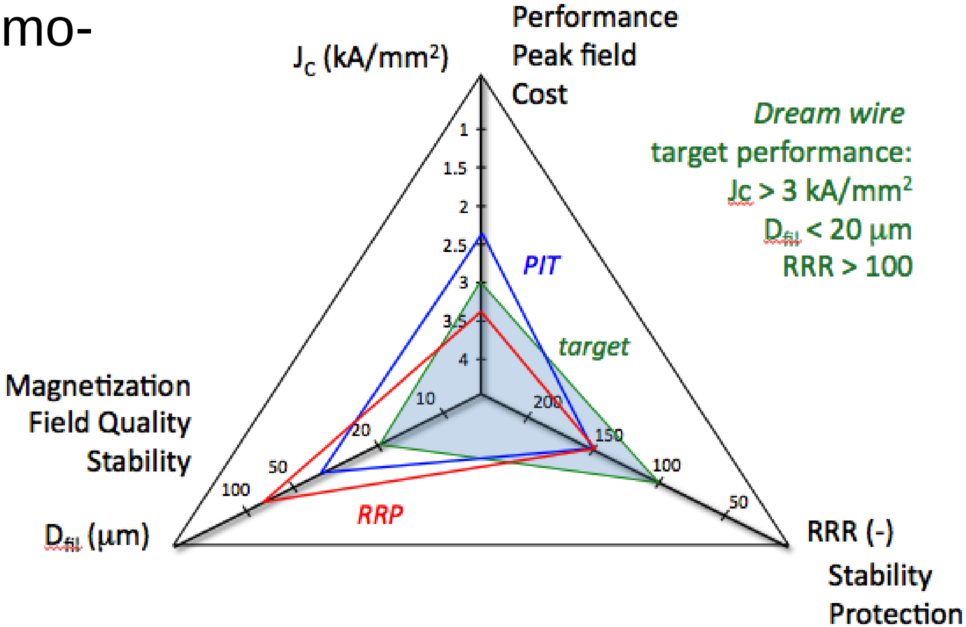
Conductor R&D - NED and post-NED strands

- The NED program (2004-2008/2010) achieved Nb_3Sn 1.25 mm strands with J_C of 1500 A/mm^2 at 15 T and 4.2 K, filament diameter of 50 μm, and RRR regularly in excess of 150
- Nb_3Sn is produced by industry in Eu (PIT) and US (RRP)
- The HFM program has since focussed on issues of cable production and degradation, and thermo-magnetic stability



Bruker-EAS PIT, 288 subelements, $(Nb\text{-}Ta)_3Sn$

A Nb_3Sn dream wire for the LHC

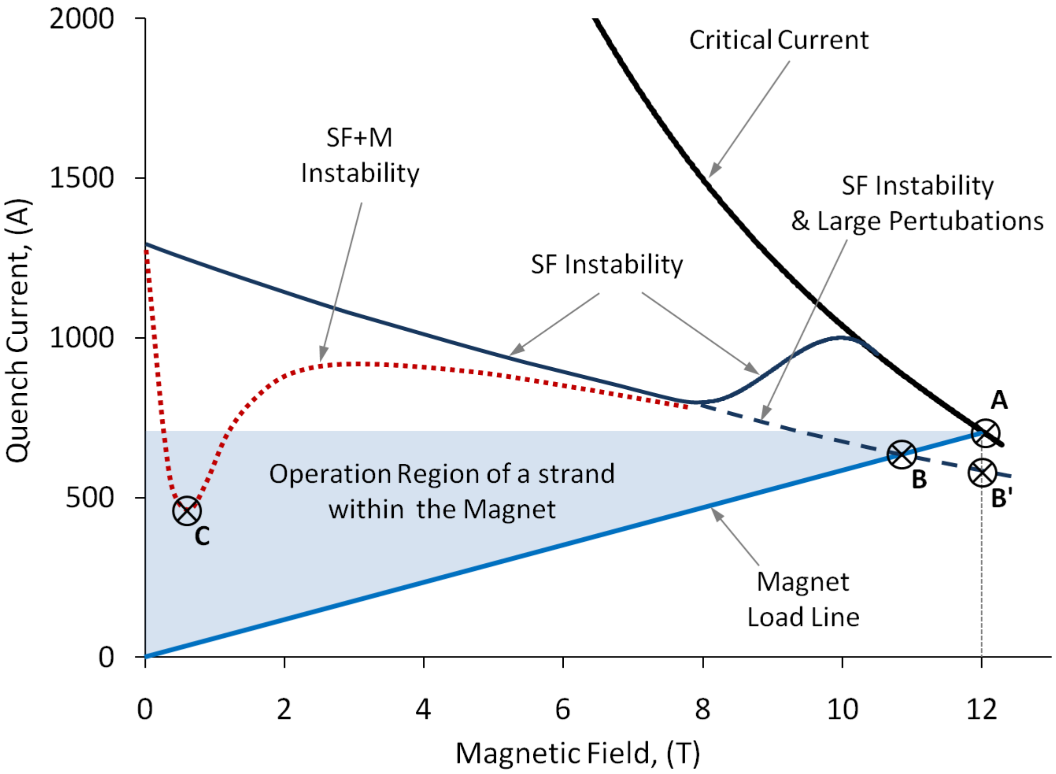


Courtesy L. Bottura, B. Bordini

Conductor R&D: improve Jc and stability

Conductors to be studied in detail:

- Nb_3Sn Critical current as function of field and temperature
- Nb_3Sn stability: magneto-thermal instabilities understanding
- Accompany industry with detailed characterization and metallurgic studies

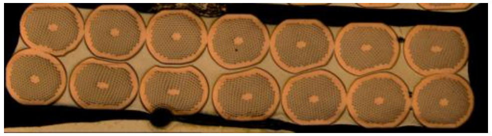


Example:
Magneto-thermal instabilities
In-depth study to understand this effect which was seen in other labs,
Guide strand choice and strand layout development :
-small sub-elements ≤50 μm
-reduce strand diameter: 1mm,
-high RRR: ≥100
-reduce J_c: 1250A/mm^2@15T, 4.2 K

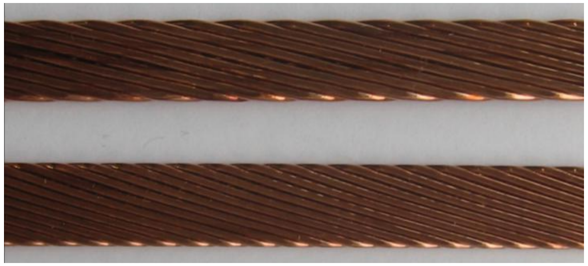
Courtesy of B. Bordini (CERN)

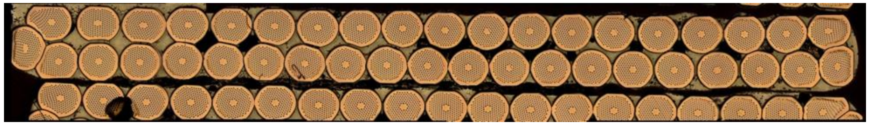
Cables for HFM Program

- Cabling tests were performed on several variants of strands/cable sizes to explore the space of parameters, and among others: dimensions, compaction, twist pitch, cabling angle and cabling force, …
- Cabling degradation was reduced from 45 % (worst case) to *negligible* (within the scatter of measurements of extracted strands)



SMC Dipole cable – 14 strands (1.25 mm) and
18 Strands (1 mm), Width = 10 mm, Twist Pitch = 60 mm
Average I_C degradation 0 … 4 %





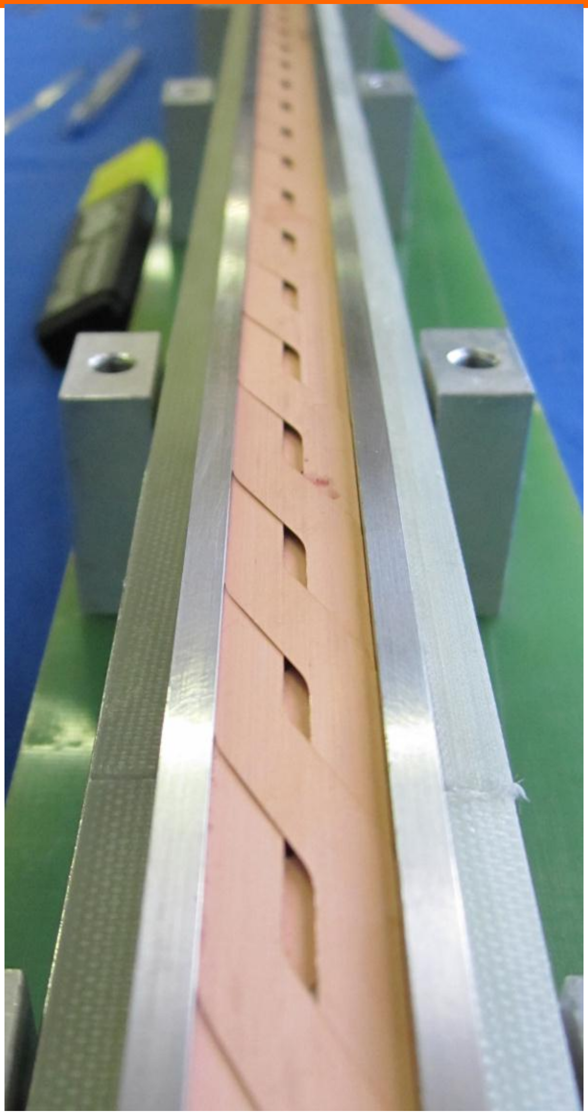
Fresca 2 Dipole cable – 40 Strands (1 mm)
Width = 20.9 mm, Twist Pitch = 120 … 140 mm
Average I_C degradation < 5 %

**Cabling by
L. Oberli and
A. Bonasia (CERN)**

DS Dipole cable – 40 Strands (0.7 mm)
Width = 14.7 … 15.1 mm, Twist Pitch = 100 mm, 0.8° keystone
Average I_C degradation < 3 %

A high current HTS (YBCO) cable

- Roebel cables of punched HTS tapes after an idea of W. Goldacker (KIT)
- Manufacturing by IRL Ltd.
- First test at liquid helium (4.3 K) and in high field (10 T) show a current carrying capacity of **4 to 10 kA**



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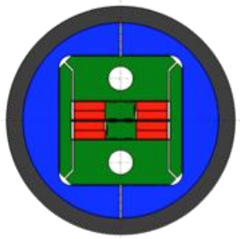
By courtesy of J. Fleiter, Ph. Denis, G. Peiro, A. Ballarino

High Field Magnet R&D

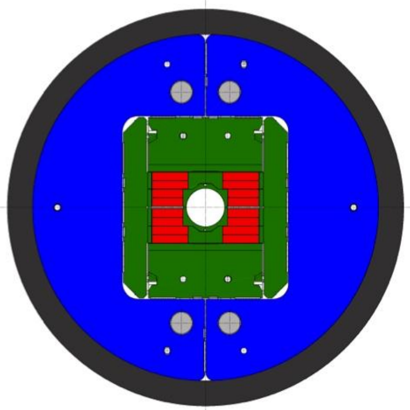
FReSCa2

Short Model Coil

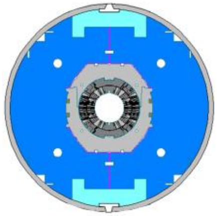
Race-track Model Coil



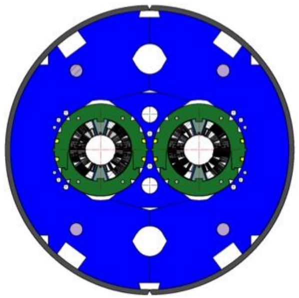
Nb_3Sn Dipole



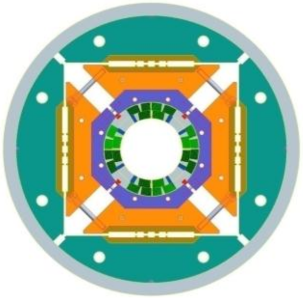
11 T DS 1-in-1 model



11 T DS Nb_3Sn Dipole



HQ/LHQ Nb_3Sn Quadrupole

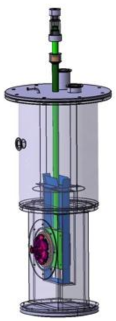


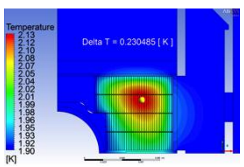
US-LARP program

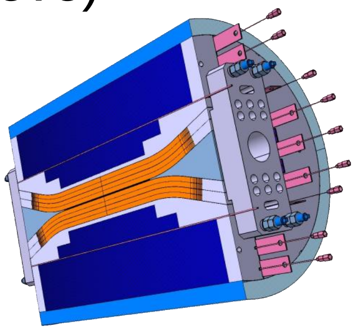
2012 2013 2014 2015 2016 2017 2018 2019 2020

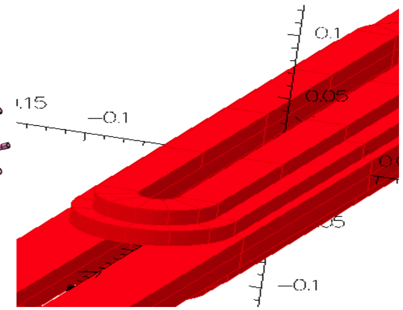
EuCARD WP7 High Field Magnets

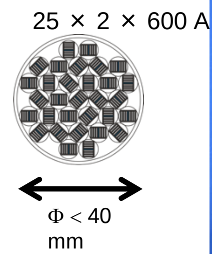
12 partner collaboration : CEA-Saclay, CERN, CNRS-Grenoble, Columbus (Genova), BHTS (Bruker), INFN-LASA (Milano), KIT (Karlsruhe), PWR (Wroclaw), SOTON (Southampton), STFC-Daresbury, TUT (Tampere), UNIGE (Genève)

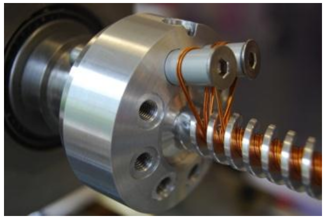












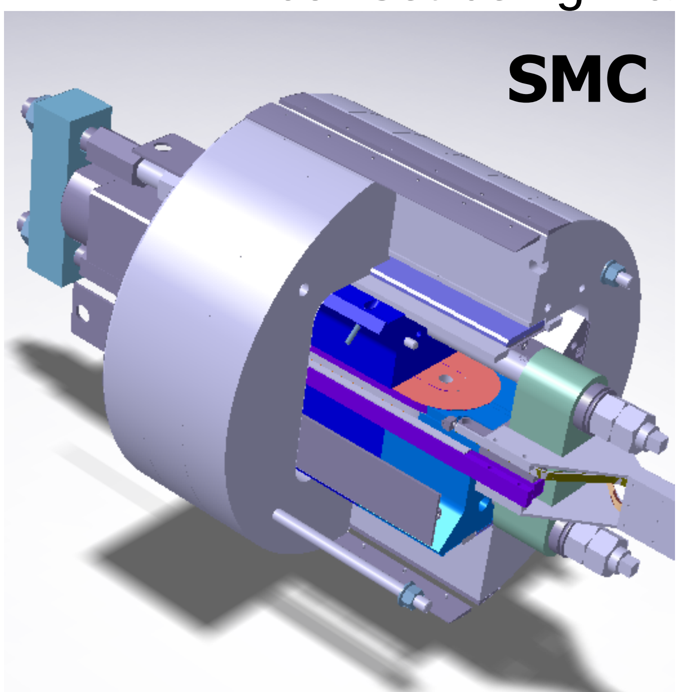
One management and 5 R&D tasks:

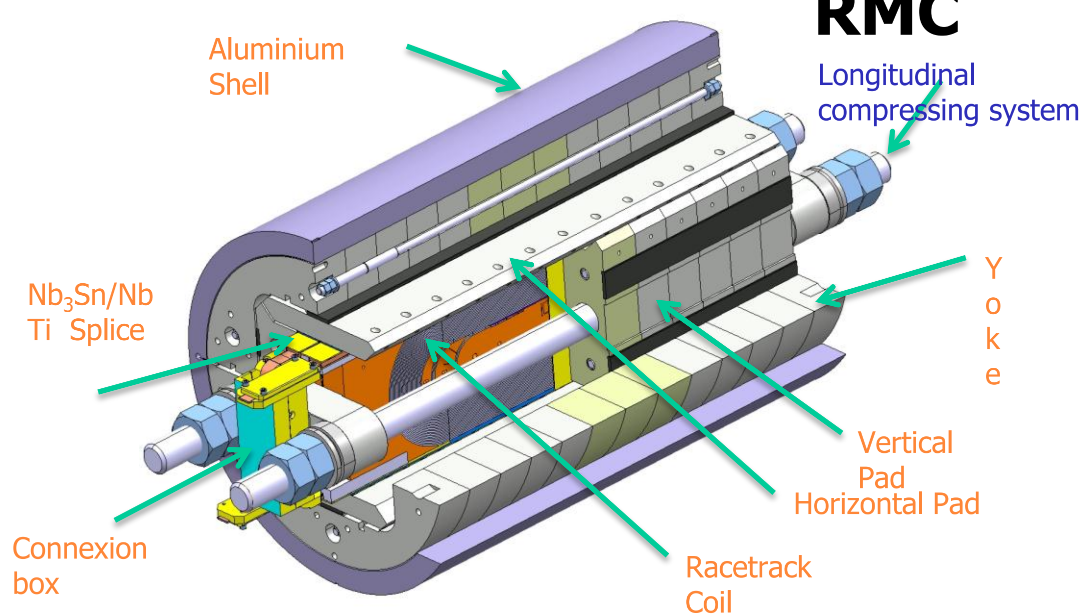
1. Coordination and Communication.
2. Support studies, thermal studies and insulation radiation hardness
3. High field model: 13 T, 100 mm bore (Nb_3Sn)
4. Very high field dipole insert (in HTS, up to ΔB=6 T)
5. High Tc superconducting link (HTS powering links for the LHC)
6. Short period helical superconducting undulator (ILC e^+ source)

Duration: 1-4-2009 – 31-3-2013, Budget:6.4 M€ total, 2.0 M€ EC contr.

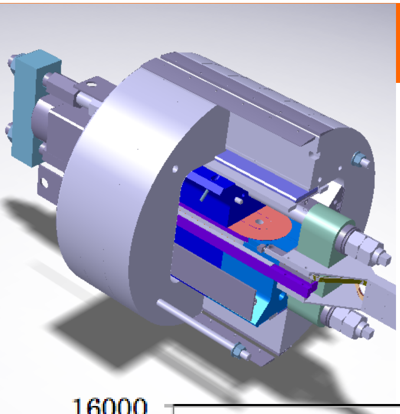
Short Model Coil and Racetrack Model Coil

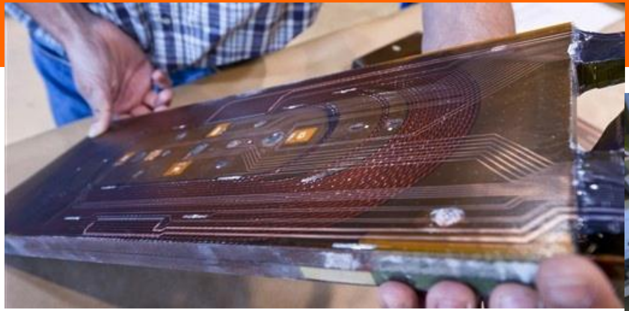
- SMC : test Nb_3Sn conductor and coil technology with a small 10 mm cable
  - 1 coil set tested
  - 2nd coil set reacted: to be tested in spring 2013
- RMC: test the Fresca2 conductor and coil technology with the 21 mm Fresca2 cable
  - 1st coil set being manufactured: to be tested end spring 2013

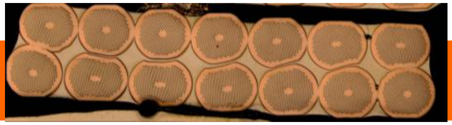


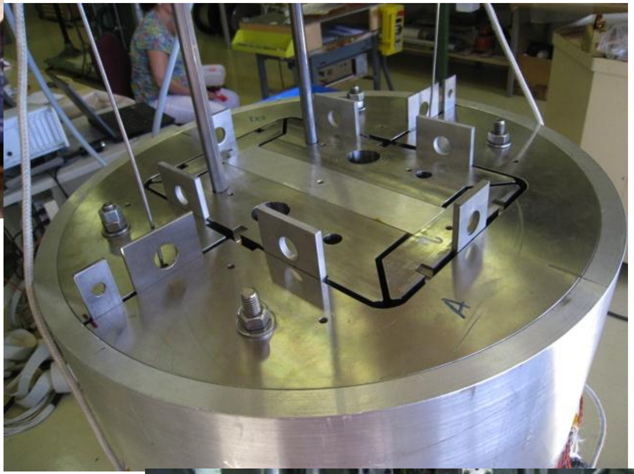


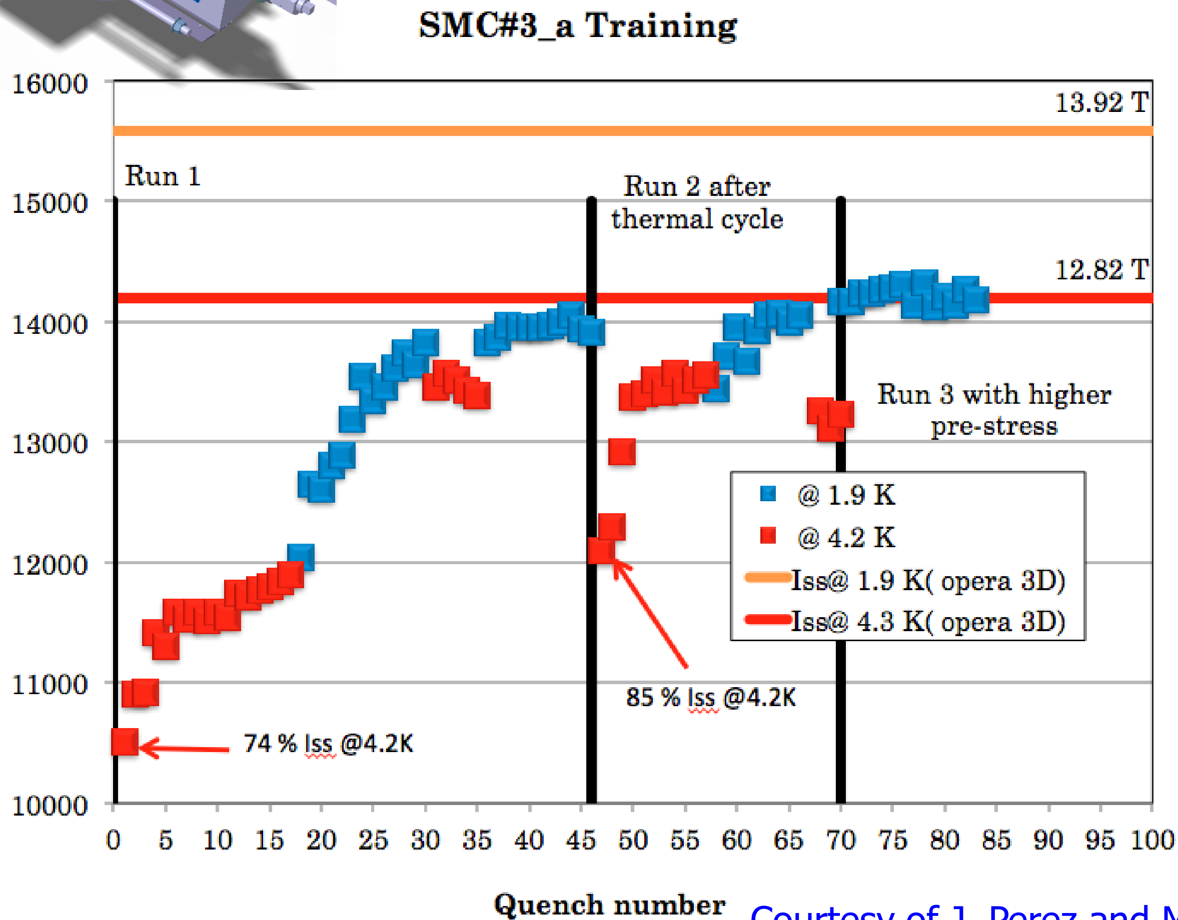
SMC, tested in 2011: 12.5 T on the coil











Courtesy of J. Perez and M. Bajko

EuCARD High field model (Fresca2)

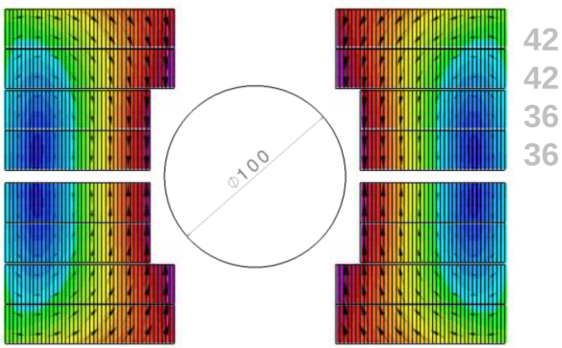
Challenging construction with several new concepts:

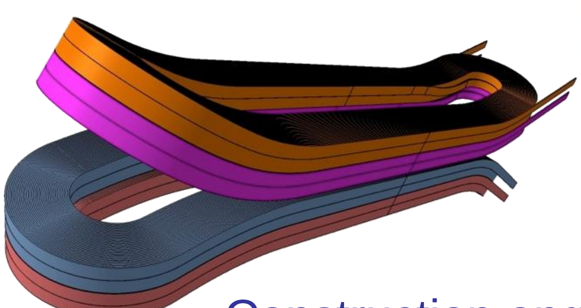
- Block coil geometry with flared ends
- Shell-bladder and key structure

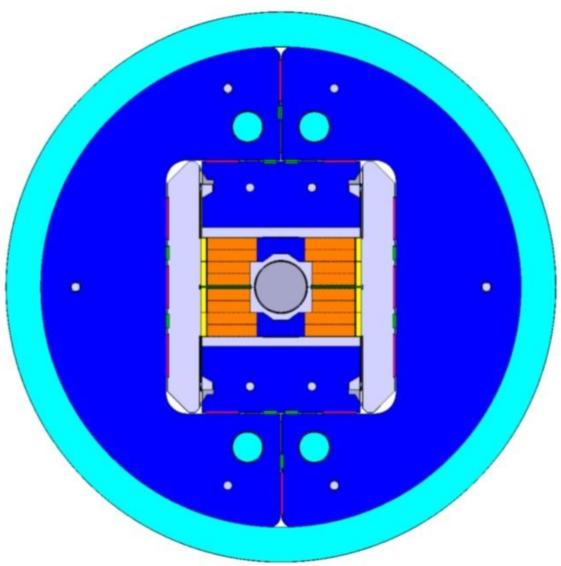
(inspired by the HD2 of LBNL)

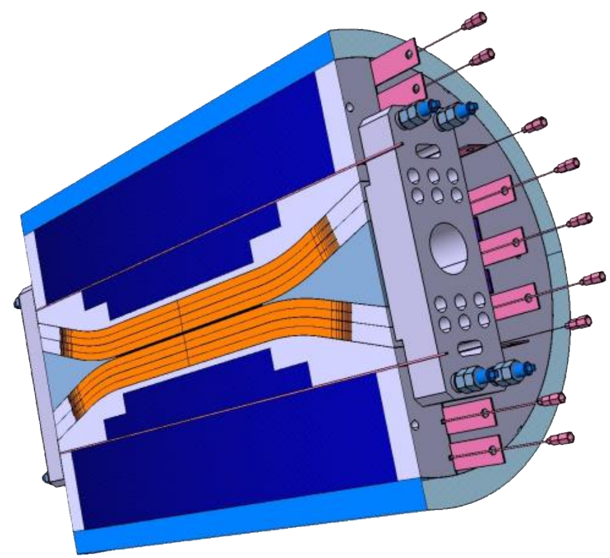
- 156 turns per pole
- Iron post
- B_{center} = 13.0 T
- I_{13T} = 10.7 kA
- B_{peak} = 13.2 T
- E_{mag} = 3.6 MJ/m
- L = 47mH/m

- Diameter Aperture = 100 mm
- L coils = 1.5 m
- L straight section = 700 mm
- L yoke = 1.6 m
- Diameter magnet = 1.03 m







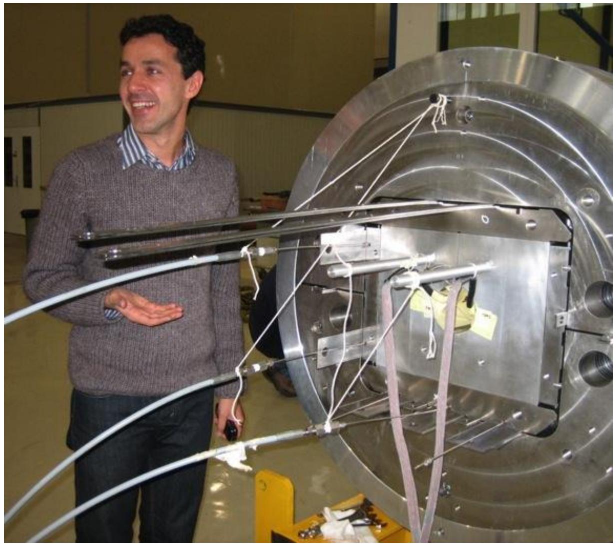


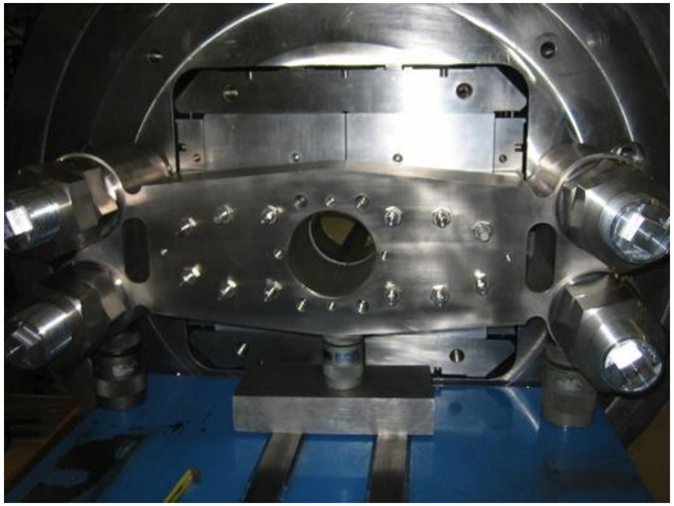
Courtesy Attilio Milanese, Pierre Manil

Construction ongoing, first coil june 2013, test mid 2014

Fresca2 structure, mounting with dummy Al coil blocks

- **Mounting Last week,**
- **LN2 test end of March to study mechanical behaviour**



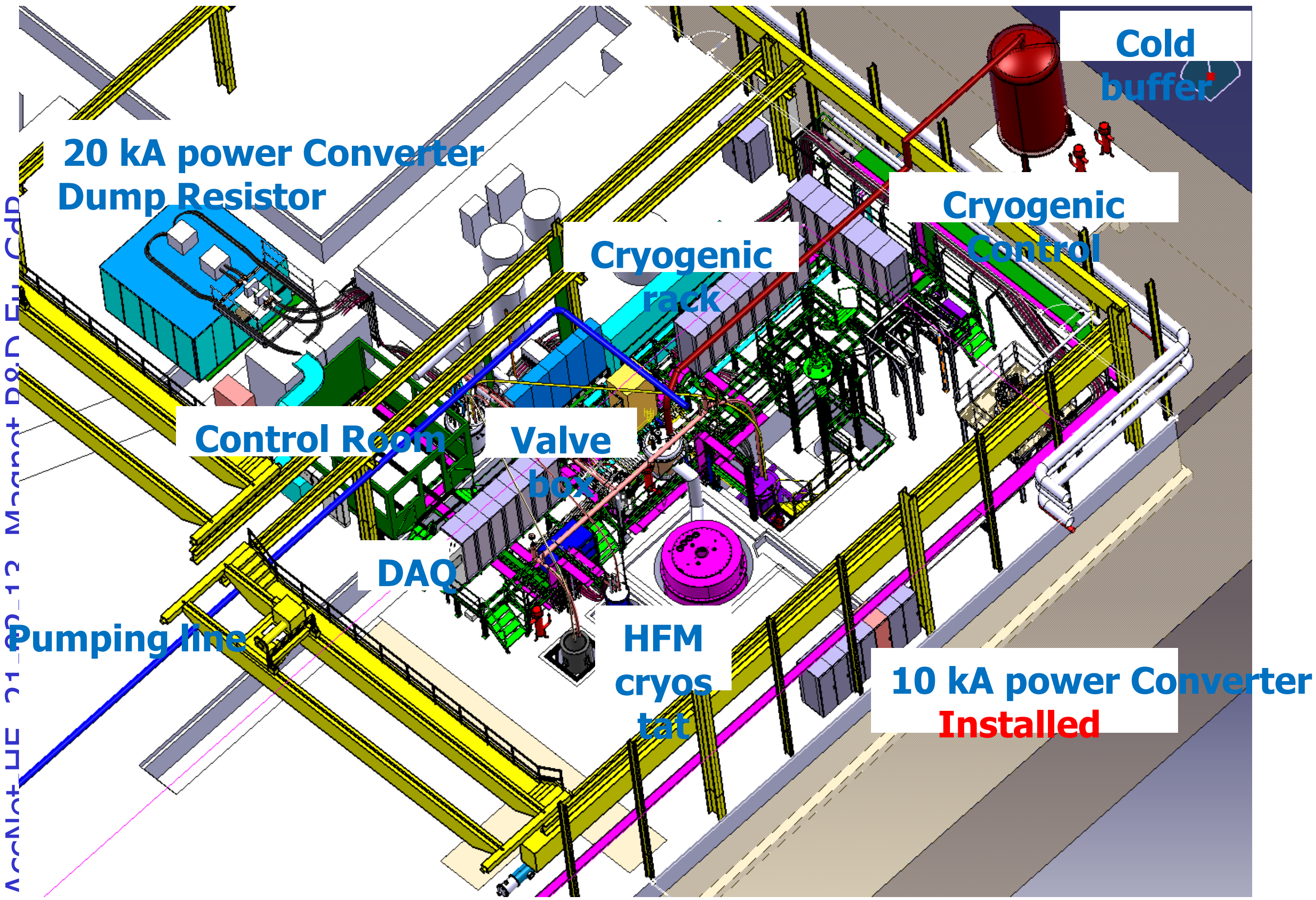


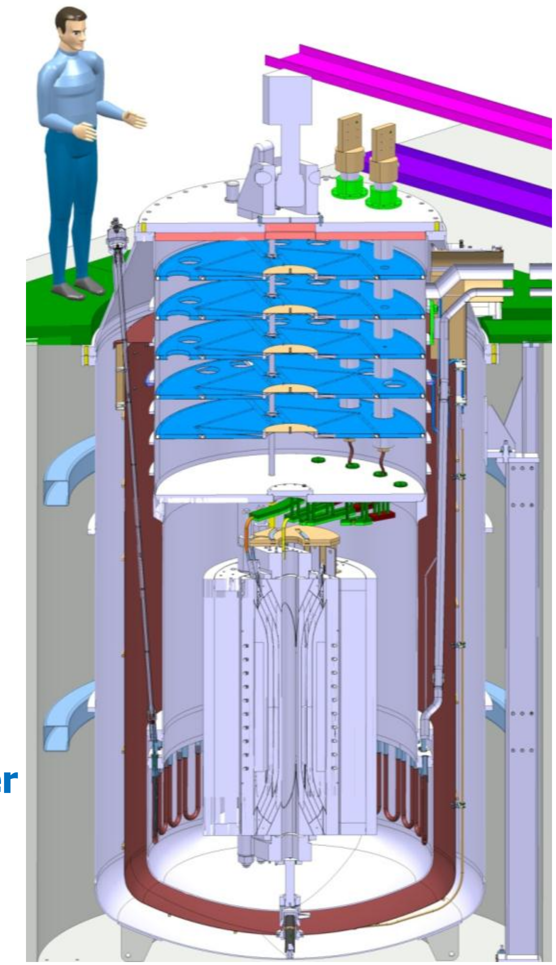
Big tooling: furnace and impregnation tank

HFM test station

- HFM test station being constructed in SM18
- Test of the Fresca2 magnet
- Insert test in Fresca2 and later other large HFM

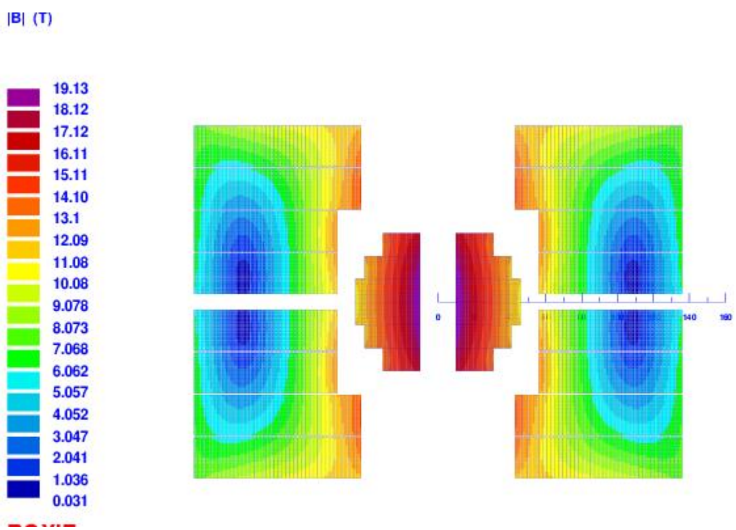
To become operational in summer 2014





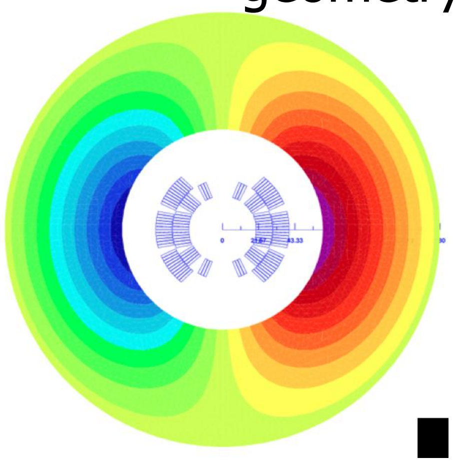
HTS inserts

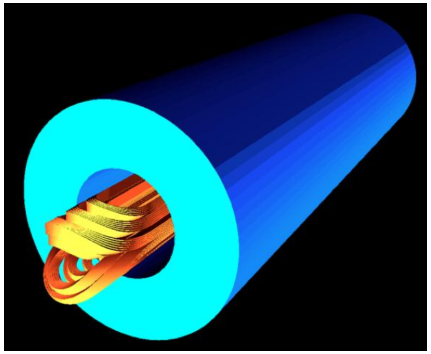
- EuCARD
  - 6 T insert built with YBCO tapes
  - Current density of 250 A/mm^2
  - Race-track, 20 mm aperture (no bore) self-supported for test in FReSCa-2



- EuCARD2 (start mid 2013)
  - 5 T, 40 mm bore, accelerator quality HTS magnet
  - *10 kA-class* HTS cable at 20 T

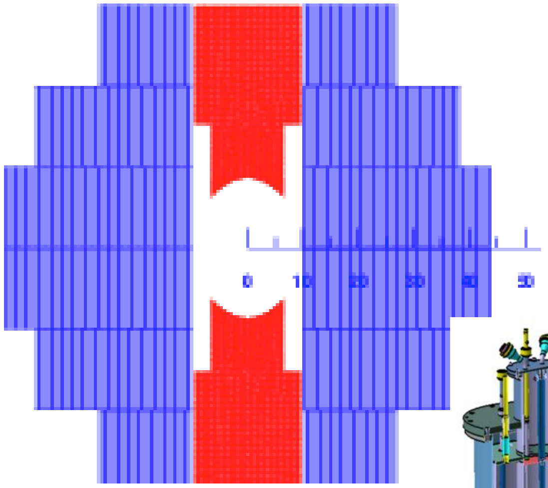
5 T cos-θ magnet design based on flat cable geometry



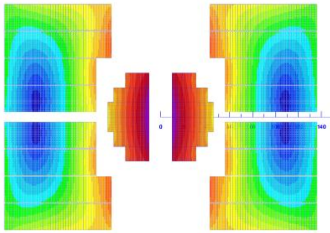


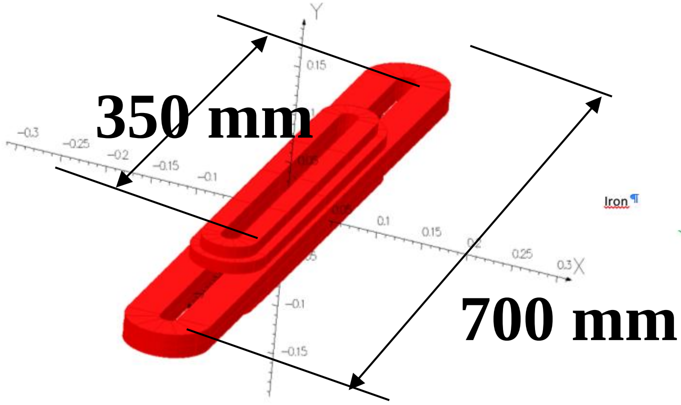
By courtesy of B. Auchmann

EuCARD, 6 T insert (2009-2013)

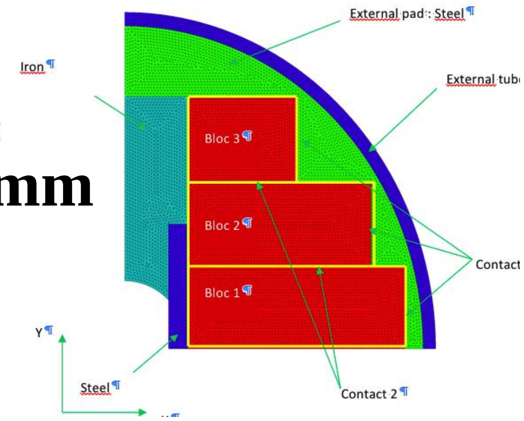


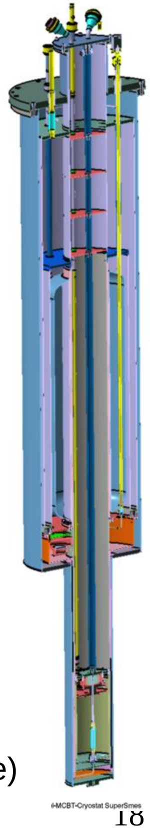
- Conductor: YBCO 12 mm tape, back to back soldered, and 2 in parallel, transposed between the poles
- Number of turns 73 + 61 + 36 = 170 (of 4 tapes)
- Aperture h = 20 mm , w = 15 mm "chopped cylinder" inside racetrack
- Force detainment with welded clamp + shrinking rings
- L total = 700 mm
- L straight part = 274 mm
- I = 2800 A



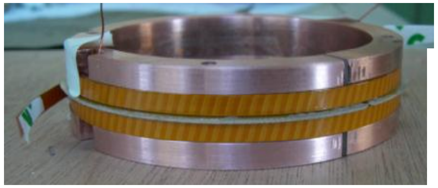


3D geometry





- Detailed insert design finished
- test solenoid pancakes made and being tested
- Quench: dump in 20 ms
- Construction summer 2013



Courtesy:
J-M Rey (CEA),
P. Tixador (CNRS & Grenoble)
A. Ballarino (CERN)

Radiation resistance

The radiation resistance of the Nb_3Sn magnets (and HTS) has to be fully proven

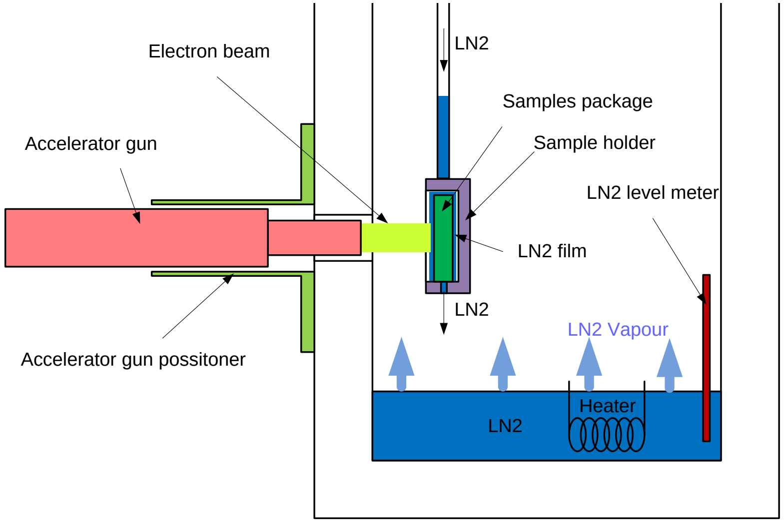
Effects of radiation on the superconductor, the stabiliser (Cu, Al) and the insulator

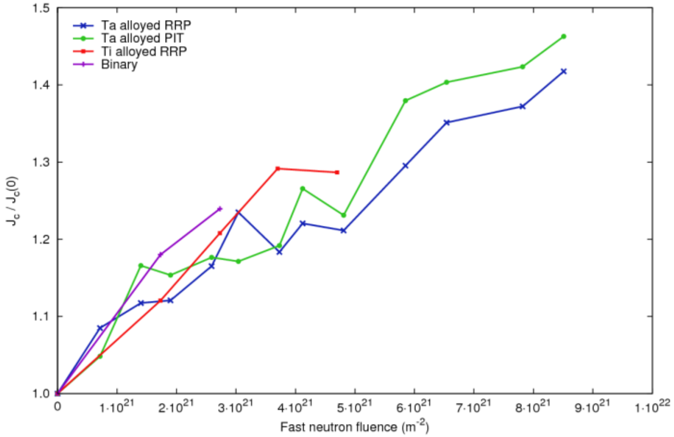
- CERN started in 2010 a program to test radiation effects on the Nb_3Sn conductor
  - Radiation tests on Nb_3Sn conductor carried out at ATI (Vienna) and Kurchatov (Russia)
  -
- In the EUCARD program there is a task to select radiation hard insulator material material (impregnation) for the Nb_3Sn coils
  - Radiation tests on Nb_3Sn insulation carried out in at Swierk (Poland) (irradiation starting this month)

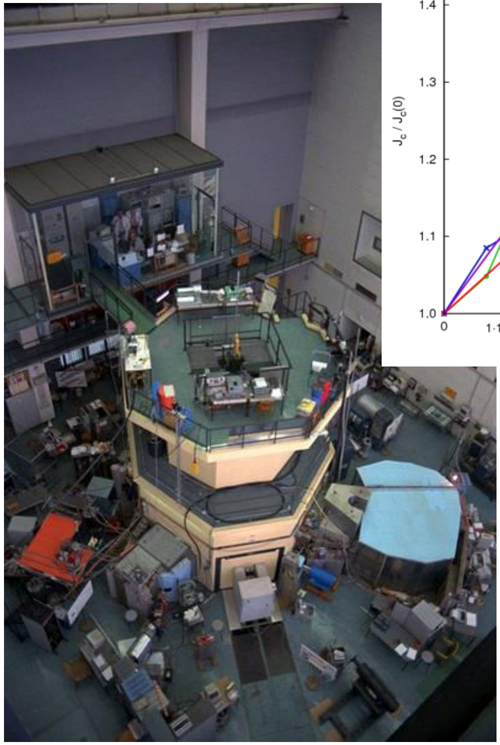
Radiation resistance: irradiation tests

Measurement of Jc of various HEP-grade Nb_3Sn strand in the TRIGA reactor at the Atominsitut of the Technical University in Vienna

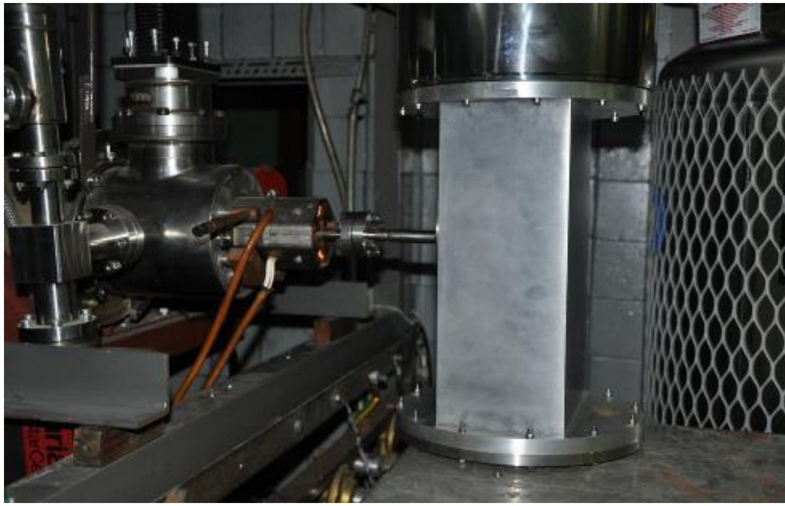
Insulator electron irradiation at Swierk







Courtesy H. Weber (ATI)



Courtesy M. Chorowski (PWR)

Conclusions

- Since 2004 in 2 consecutive EU projects (CARE-NED, EuCARD-HFM)and one new starting on in 2013 (EuCARD2) the technologies for high field magnets are being developed.
  - CARE-NED developed the Nb_3Sn conductor
  - EuCARD-HFM is developing (=building) a 13 T - 15 T dipole
  - EuCARD2 will develop HTS accelerator magnets
- In several labs in Europe (CERN, CEA, etc) and US (LBNL) development programs have started for magnets up to 20 T

www.cern.ch