Future Magnets Report from WP10

Philippe Fazilleau (CEA)
Lucio Rossi (CERN)

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WP10 main scopes

1. Develop a **10 kA-class cable** in HTS (High Temperature Superconductor) suitable for accelerator (collider) magnets,
   - Large current to reduce magnet protection issues,
   - Cable properties suitable for accelerator (AC losses, coupling/persistent currents, mechanical behavior…)
   - Uniformity of properties over long lengths
2. Design, Manufacture and test **a first accelerator quality, small prototype, dipole**
   - Bore diameter 40 mm
   - Outside diameter, 99 mm to be inserted in Fresca2
   - Length > 400 mm
   - Field 5 T, good homogeneity (< 10^{-4})

WP10 structure

- Task 10.1: **Coordination & communication**
  (L. Rossi – CERN / P. Fazilleau – CEA Saclay)
- Task 10.2: **Conductors**
  (L. Bottura – CERN / C. Senatore– UniGeneva)
- Task 10.3: **Magnet prototype**
  (M. Durante– CEA Saclay / G. Kirby– CERN)
- Task 10.4: **Tests** (stand-alone configuration)
  (G. Volpini – INFN LASA / M. Bakjo– CERN)

WP10 collaboration

Several institutes:

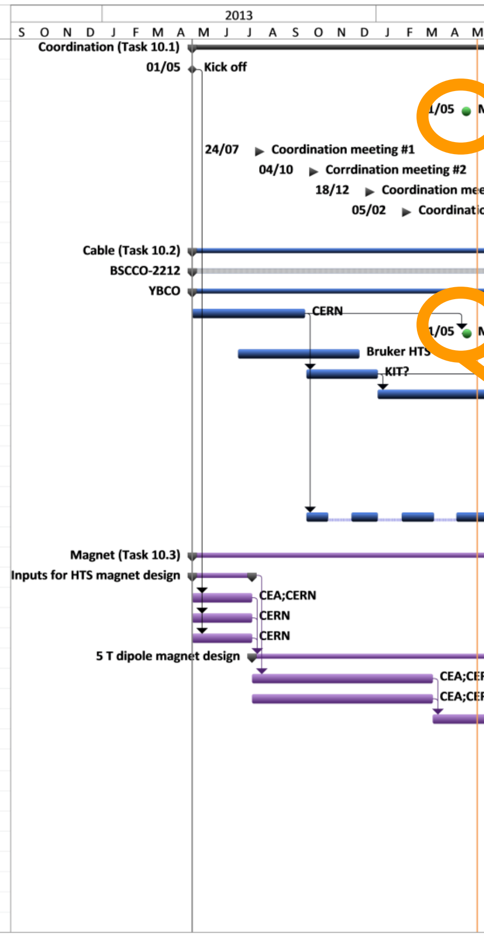
- CERN (L. Rossi, L. Bottura, A. Ballarino, G. Kirby, M. Bajko)
- CEA Saclay (M. Durante, P. Fazilleau),
- INPG (P. Tixador),
- INFN LASA (G. Volpini, M. Sorbi),
- KIT (W. Goldacker, A. Kario),
- University of Geneva (C. Senatore),
- University of Twente (M. Dhallé),
- University of SouthHampton (Y. Yang),
- Tampere University of Technology (Antti Stenvall)
- Danish Technological Institute (N. Zangenberg)

Industrial:

- Bruker EST (A. Usoskin)

Planning

N°	Task Name
1	Coordination (Task 10.1)
2	Kick off
3	D10.3 Parameters for choice of Sc type (CERN)
4	MS62 Organised collaboration with DOE Program Bi 2212 (CERN)
5	MS67 Report on HE-LHC Main Dipole Design (CERN)
6	Coordination meeting #1
7	Corrdination meeting #2
8	Coordination meeting #3
9	Coordination meeting #4
10	Intermediate Review
11	Cable (Task 10.2)
12	BSCCO-2212
27	YBCO
28	Cable design proposal
29	MS63 Cable concept design report (CERN)
30	Delivery of R&D tapes
31	Cable dummy lengths
32	Cable prototypes (Roebel)
33	D10.2 Prototype Cable lengths and report (CERN)
34	FRESCA sample test
35	Delivery of production tapes
36	Production of cable lenghts
37	MS66 First cable length for magnet winding (CERN)
38	Tape characterization
39	Cable characterization
40	Magnet (Task 10.3)
41	IMS01 : Inputs for HTS magnet design
42	HTS magnet parameter list
43	Bi2212 conductor objectives
44	YBCO conductor objectives
45	5 T dipole magnet design
46	magnet design options study
47	Preliminary tests
48	magnet detailed design
49	CAD magnet and tooling design
50	D10.1 : Conceptual study of HTS accelerator magnets (CEA)
51	MS64 : YBCO magnet design report (CEA)
52	IMS02 : HTS magnet(s) detailed design
53	Components and tooling procurement
54	MS68 : Technical and economical comparison YBCO/Bi2212 magnets (CEA)
55	YBCO magnet manufacturing
56	Bi-2212 magnet manufacturing
57	IMS03 : HTS magnet(s) built
58	Tests (Task 10.4)



MS62

"Organized collaboration with DOE Program Bi2212"

- *Led by task 1*
- *Slight delay as we changed it to a tripartite agreement (EuCARD, Japan, US)*

MS63

« Cable concept design report »

- *Led by task 2*
- *Report on time, may 2014*

Task 1 progress
Coordination & communication

1. **Meetings**:
   – Regular coordination video-meetings with task leaders/deputies (5 for the first year),
2. **Visit** to industry (BEST)
3. **Video-meetings** with the USA labs (NHMFL, LBNL, FNA, BNL and OST)
4. **Visit** to Japan (Riken, Univ. of Kyoto and KEK)
5. **Visit** to CERN of Fujikura (japanese cable provider)
6. WP10 **website** https://espace.cern.ch/EuCARD2-Future-Magnets/SitePages/Home.aspx
7. Preparation of **MS / Annual report**
8. **Tripartite agreement** – ***Memorandum on Cooperation*** - (MS62) is being signed:
   – EuCARD collaboration + Japan (KEK, Riken, Kyoto univ.) +US (NHMFL, LBNL, FNAL)
   – Intensifies exchange of scientific information and technological innovation,
   – Provide a ground for interchange of scientific and technical personnel
   – Organize a series of Workshop on Accelerator Magnets with HTS Technology (WAM-HTS)

Three Workshop for Accelerator Magnets in HTS planned in the framework of this agreement :

– **High-current HTS cables** (DESY, Hamburg, Germany, 21-23 may 2014
– **Dipole magnet technology** (University of Kyoto, Japan, november 2014)
– **US workshop** (2015, to be planned)

Task 2 progress Conductors

1. **Review of HTS material** performance and issues:
   - state-of-the-art,
   - definition of appropriate performance targets for the R&D work

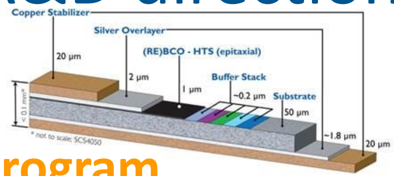
Parameter	Units	Target for SC R&D	Minimum required for magnet design
J_E (4.2 K, 20 T)	(A/mm^2)	600	400
Unit length	(m)	100	50
σ (I_c)	(%)	10	
M (1.5 T, 10 mT/s)	(mT)	300	
Maximum $\sigma_{transverse}$	(MPa)	100	
Range of $\varepsilon_{longitudinal}$	(%)	$\pm$0.3	

675 A/mm^2 @ 15 T
750 A/mm^2 @ 12 T

Task 2 progress
Conductors

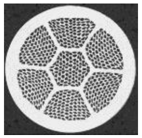
2. **HTS material** R&D directions

YBCO



- **Main focus of the EU program**
- Produced by Bruker EST (beneficiary of EuCARD²)
- Available from others suppliers (Superpower, AMSC, Fujikura, Sunam, SuperOx)
- Anisotropic : Jc (B⊥) # 0,1-0,3 Jc (B//)
- Tape: 4, 12 mm (10 mm) width => dedicated cable needed
- Very robust: hastelloy layer
- React and wind technique

Bi-2212



- Backup option for WP10
- BSC Collaboration supported by DOE (US)
- Isotropic properties
- Round wire -> Rutherford cable
- Very sensitive to mechanical strain
- Wind and React technique
- Reaction # homogeneous 900 ° C under 100 bar with 1 bar of O_2

Task 2 progress
Conductors

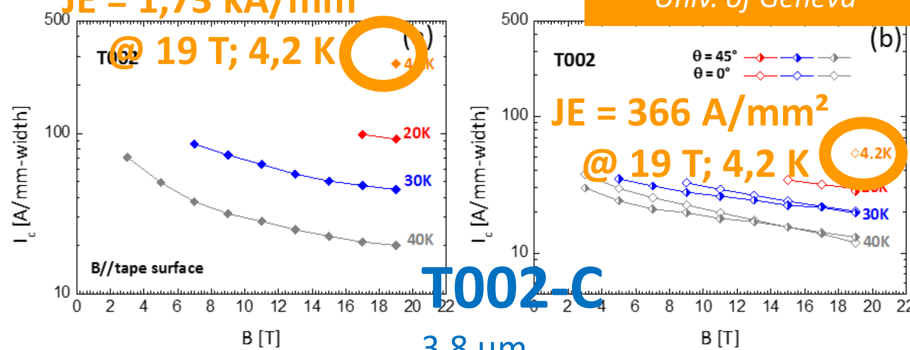
3. Characterization of the critical surface

- dependence of critical current (UniGeneva / INPG)
- Temperature range is between 4.2K and 77 K
- 3 field orientations ⊥(0°), //(90°), skew (45°)
- 2 tapes provided by BEST T002C (150 µm / 3.8 µm) and T003 (130 µm / 1 µm)

Courtesy of C. Senatore
Univ. of Geneva

JE = 1,73 kA/mm² @ 19 T; 4,2 K

JE = 366 A/mm² @ 19 T; 4,2 K



T002-C

3,8 µm
REBCO thickness

T002-C vs T003 has:

- Higher critical current (and JE)

55 A/mm.width vs 27 A/mm.width @ 4.2 K 19 T,

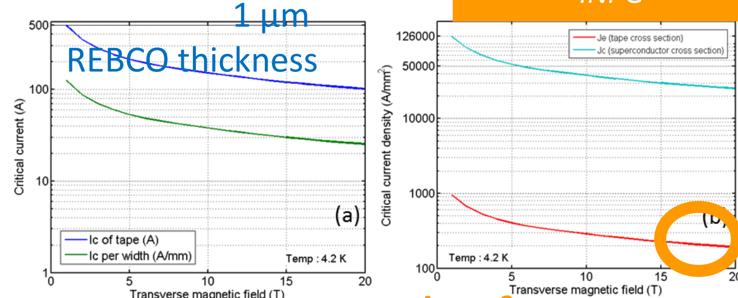
- Lower layer Jc

15 kA/mm² vs 25 kA/mm² @ 4.2K 19 T

T003

1 µm
REBCO thickness

Courtesy of P. Tixador
INPG



JE = 207 A/mm² @ 19 T; 4,2 K

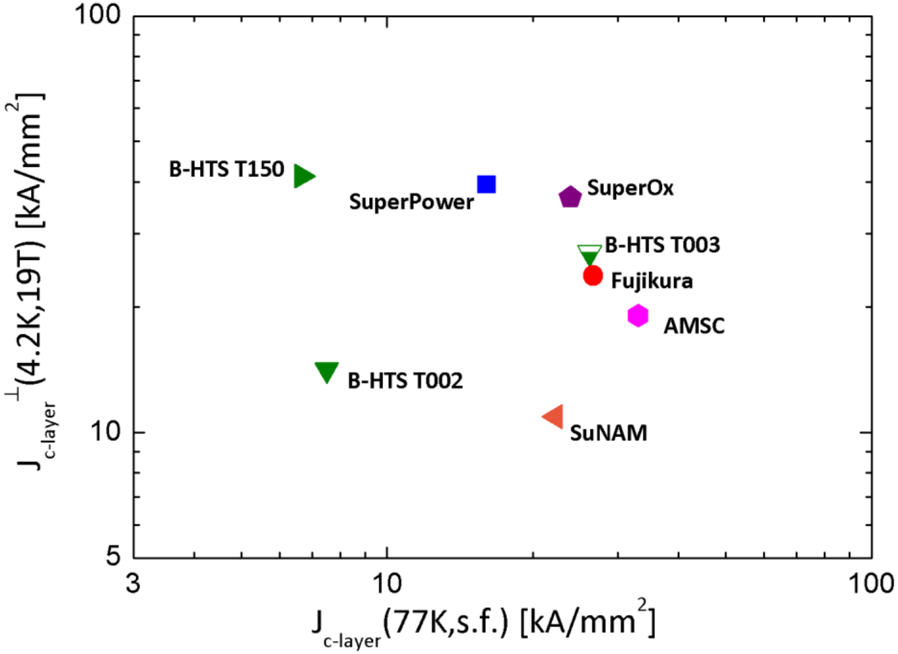
Task 2 progress
Conductors

3. Characterization of the critical surface

Comparison of the **layer critical current density** for the first two samples (T002 T003) of REBCO tapes provided by Bruker-HTS (UniGeneva)

- Jc (77 K, sf) vs Jc(4,2K, 19T)
- Very good electrical performances
- efforts to improve the tape performance by the introduction of artificial pinning centres

Courtesy of C. Senatore
Univ. of Geneva

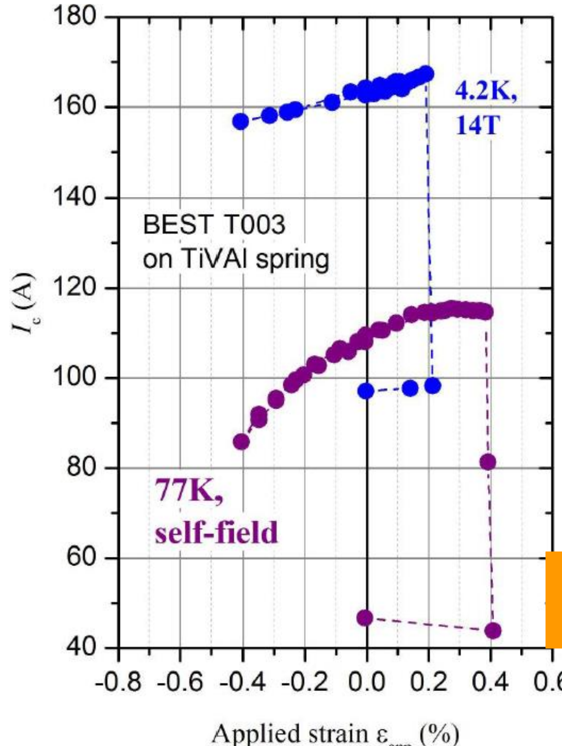


Task 2 progress
Conductors

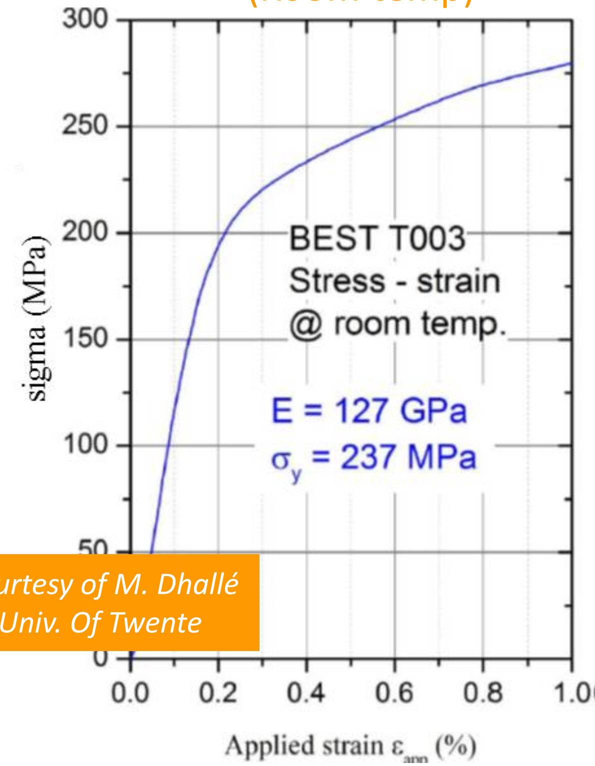
4. Tolerance to **longitudinal strain and transverse**

- **Anomalous** temperature dependence
- **Irreversible degradation** of Ic when strain exceeds 0,2% at 4,2 K
- Occurs above 0,4% at 77 K
- Under investigation

Ic vs axial strain
(4,2 K/14 T - 77K/sf)



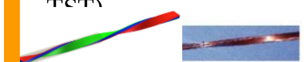
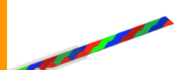
Stress vs axial strain
(Room temp)



Courtesy of M. Dhallé
Univ. Of Twente

Task 2 progress
Conductors

5. Review of YBCO cable configurations

Cable concept	I_{op} (kA)	J_E (A/mm^2)	J_E^{max} (A/mm^2)	$\sigma_{transverse}$ (MPa)	$\varepsilon_{longitudinal}$ (%)	Comments
Tape stacks	5		≈ 600	As for tape		Not transposed
Twisted stacked-tape (TSTC) 	**3 (4.2 K, 12 T)** **4 (4.2 K, 19.7 T)** 8…100 (4.2 K, 16 T)	273 (4.2 K, 16 T)	300…400			Partially transposed; 140 mm bending radius: 3.6% degradation; Sensitive to transverse e.m. loads
Helically twisted stacked-tape (HTST)	 10…20	**100 (4.2 K, 12 T)**	≈ 100	< 30 (1)		Partially transposed; Sensitive to transverse e.m. loads
Cable on Round Core (CORC) 	**5**	**114 (4.2 K, 19 T)**	≈ 150		**+0.8 %**	Transposed; 40 mm bending radius: 2.5% degradation; Core deforms under e.m. load and folds tapes; joint resistance 40..200 nΩ;
Roebel 	**3…10**	**400 (4.2 K, 10 T)**	≈ 500	**> 45** (5)		Transposed e.m. loads are concentrated at cross contac surfaces

Roebel cable

- ✓ Taken as baseline (high JE, high compaction, fully transposed)
- ✓ Old type of cabling (electrical machinery) revisited,
- ✓ Based on punched tapes,
- ✓ Produced by KIT partner of task 2 and New Research Industry –NZ

Task 2 progress
Conductors

6. Definition of baseline cables to be used for magnet design

YBCO from tape . . . to . . . . Roebel cable

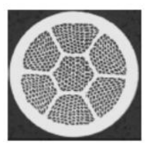
Tape width	(mm)	12
Tape thickness	(mm)	0.1 … 0.15
Critical current (15 T, 4.2 K)	(A)	800
SC layer	(µm)	1…2
Cu layer	(µm)	30…50

Number of tapes	(-)	15
Cable width	(mm)	12
Cable thickness	(mm)	1.2
Transposition pitch	(mm)	226
Critical current (15 T, 4.2 K)	(kA)	5

cos θ design

Number of tapes	(-)	8	15
Cable width	(mm)	10	10
Cable thickness	(mm)	0.6	1.2
Transposition pitch	(mm)	126	226
Critical current (15 T, 4.2 K)	(kA)	2.2	4.2

Bi2212 from strand . . . to . . . Rutherford cable



Strand diameter	(mm)	0.8
Critical current (15 T, 4.2 K)	(A)	340
Stabilizer:SC ratio	(-)	1.85

Number of strands	(-)	22
Cable width	(mm)	9.5
Cable average thickness	(mm)	1.45
Cable thin edge thickness	(mm)	1.39
Cable thick edge thickness	(mm)	1.52
Keystone angle	(degrees)	0.6
Transposition pitch	(mm)	65
Critical current (15 T, 4.2 K)	(kA)	6.7

Task 2 progress
Conductors

7. **Dummy Roebel cables** production

Winding, impregnation, insulation tests:

- CERN: 2*2,4 m stainless steel dummy cable 300 mm twist pitch, 15 tapes,

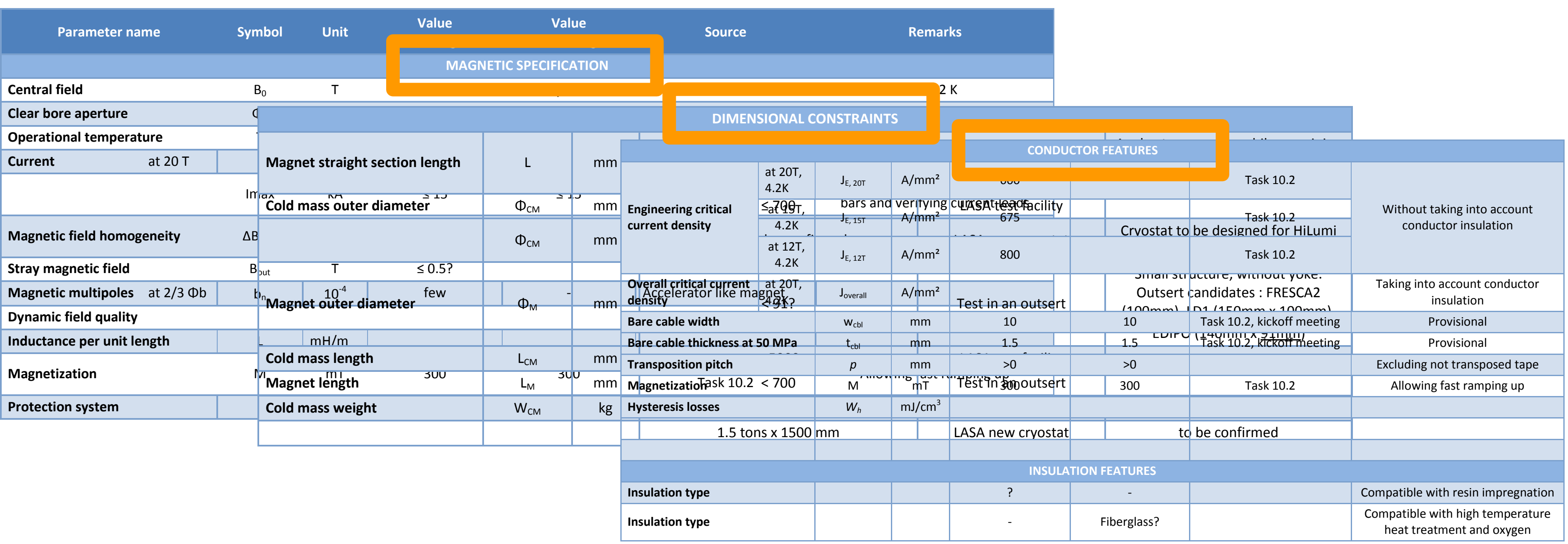
- CERN: 2*2,4 m copper plated stainless steel dummy cable 300 mm twist pitch, 15 tapes,

- KIT: 3 m long, 12 mm wide, 226 mm twist pitch, 15 tapes, 1 cu + 1 SS

Task 3 progress magnet prototype

1. Specification of target performances for the HTS dipole magnet

- Driven by task 3, conjointly with task 2 (conductor) and task 4 (tests)
- The result of the work is a **parameter list** taken as a frame for all the studies

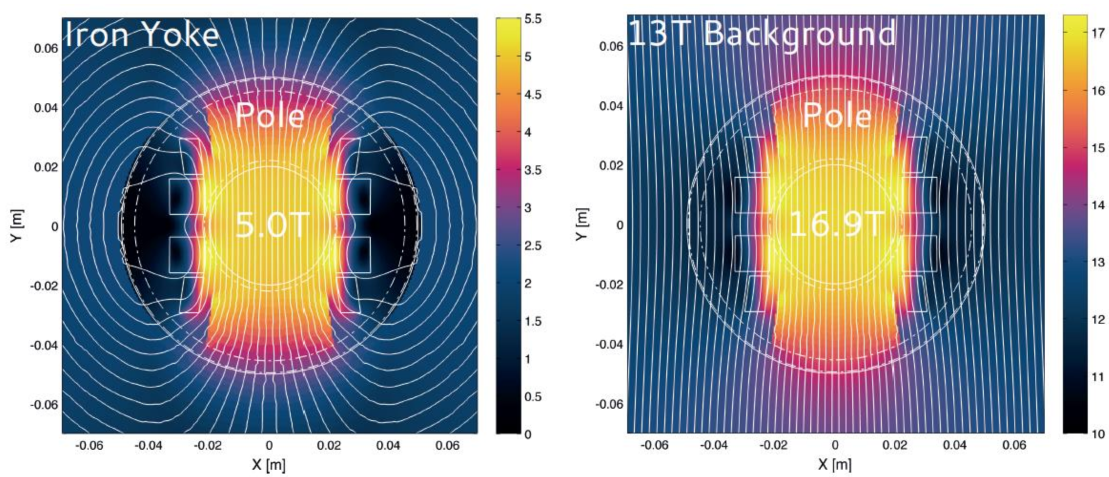


Task 3 progress
magnet prototype

2. Magnetic **design** studies

- « ***Aligned Block*** » design for YBCO Roebel conductor (CERN)
- New type of coil layout
- Optimisation of the angular dependence of the critical surface of the REBCO conductor (anisotropic)
- Tapes oriented in the direction of the field lines, such that the critical current of the cable can be maximized

Courtesy of J. Van Nugteren
CERN



Task 3 progress magnet prototype

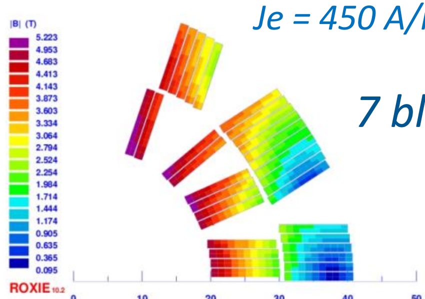
2. Magnetic **design** studies

- « ***cos θ*** » design for YBCO Roebel or Bi2212 keystoned Rutherford (CEA)
- Room for mechanical support needs smaller cables: 10 mm YBCO & 9,5 mm Bi2212
- JE consistent with the target performances # 450 A/mm²

Roxie code 2D model

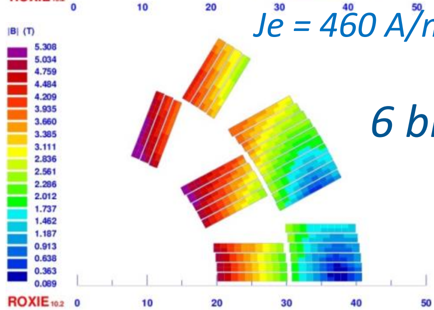
Je = 450 A/mm²

7 blocks



Je = 460 A/mm²

6 blocks

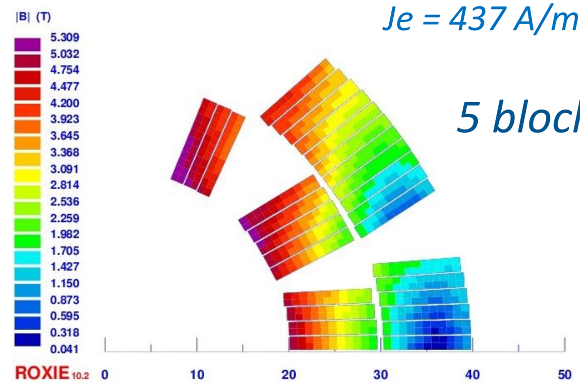


YBCO design with yoke

Courtesy of C. Lorin CEA Saclay

Je = 437 A/mm²

5 blocks



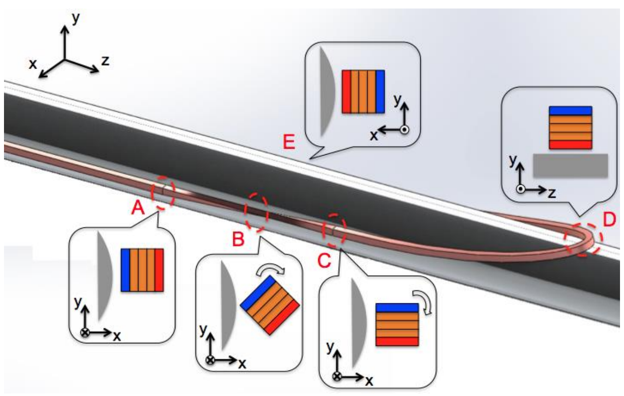
Bi2212 design with yoke

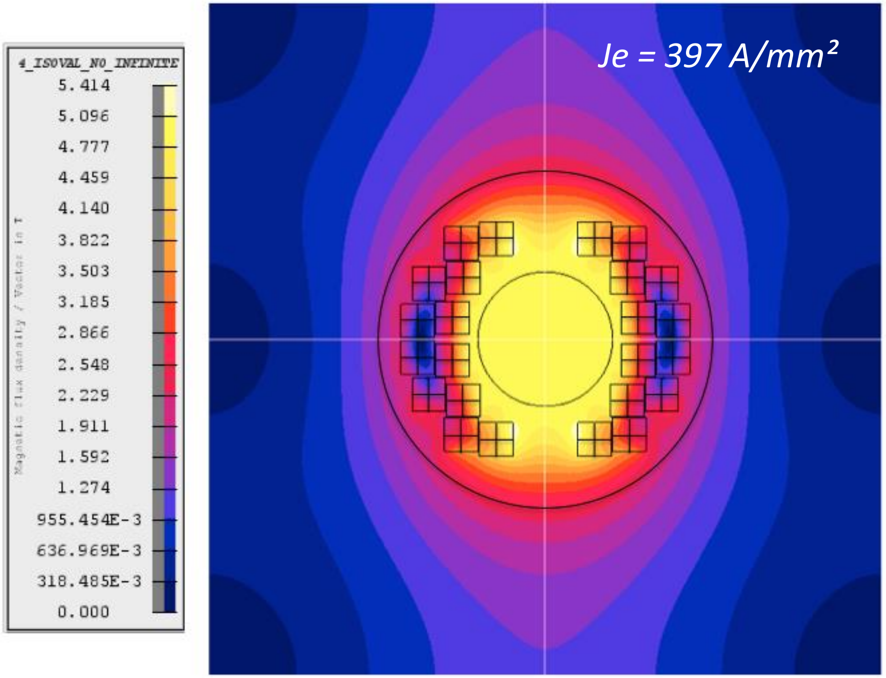
Task 3 progress
magnet prototype

2. Magnetic **design** studies

- « ***stack*** » design for YBCO tapes(INPG)
- 96 block-coils 5*5 mm²
- Transposition of the cables in the ends (study on-going)
- JE # 400 A/mm²

Transposition of a stack

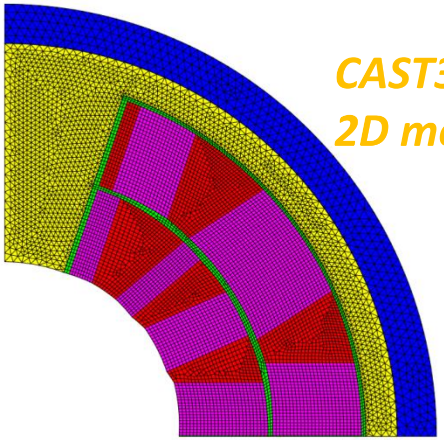




Task 3 progress magnet prototype

3. **Mechanical** studies

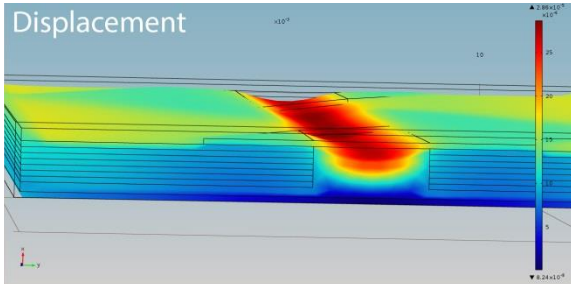
- « ***cos θ*** » magnet study (CEA)

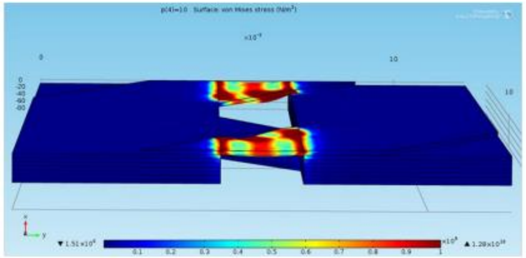


CAST3M FEM code
2D model

Courtesy of C. Lorin
CEA Saclay

- Roebel mechanical behavior (CERN)





Pressure on top surface Not impregnated

ANSYS FEM code
3D model

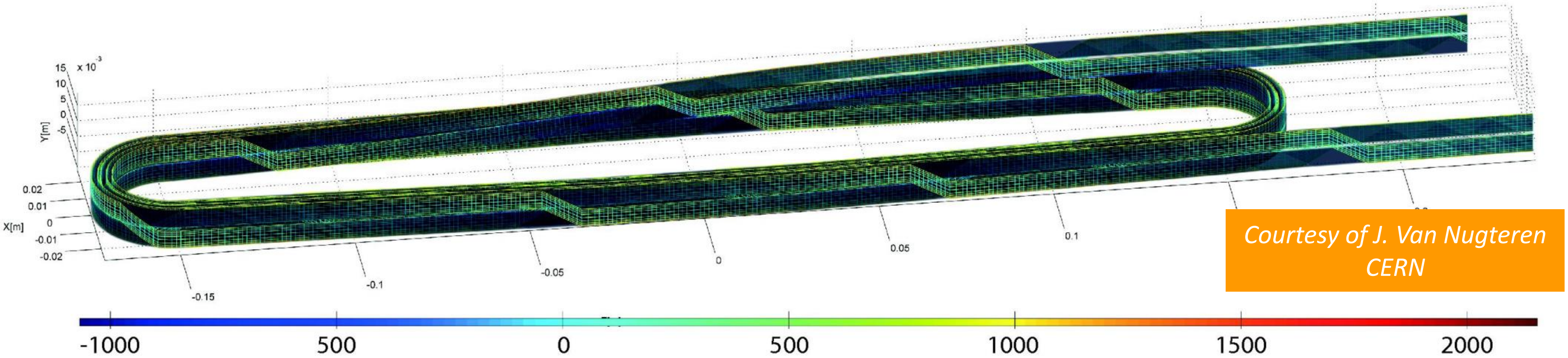
Courtesy of G. Kirby
CERN

EuCARD^2

Task 3 progress
magnet prototype

4. **Transient** cable model (CERN)

- YBCO tapes are like very wide mono filaments: current distribution needs to be known precisely in a Roebel cable
- Large field errors due to the position of the current being poorly defined
- Electrical model of the cable incorporating the dynamic nature of the current position in the tape has been coded



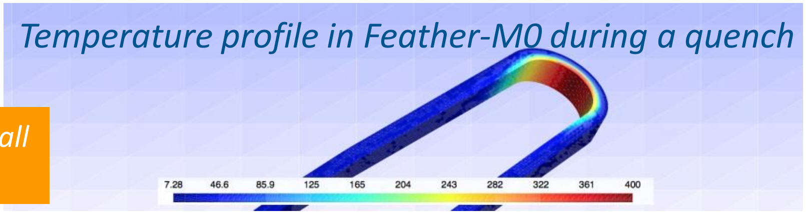
Courtesy of J. Van Nugteren CERN

Task 3 progress magnet prototype

5. **Protection** and **detection**

- **Quench model** being developped (started in EuCARD) (TUT); prediction of voltage and temperature development and current sharing between the copper stabilizer and the superconducting YBCO layer.

Courtesy of A. Stenvall TUT



- **Extensive Data AcQuisition system** (DAQ) has been purchased and delivered to CERN (10 kHz/220 channels); it will be connected to different kind of sensors (Hall probes, voltages taps, pick-up coils, acoustic?, optics?)

Task 3 progress magnet prototype

6. Various **tests on Roebel** cable (CERN)

- **Bare cable pressure tests;** they show impregnation is essential.

SS Roebel cable after compression up to 150 MPa

- **Winding tests;** some stress concentration may appear, under investigation.
- **Cable harway bend tests;** the first tests show the minimal radius is 2 m.

SS Roebel cable bend test

- **Insulation tests;**

Glass sleeve

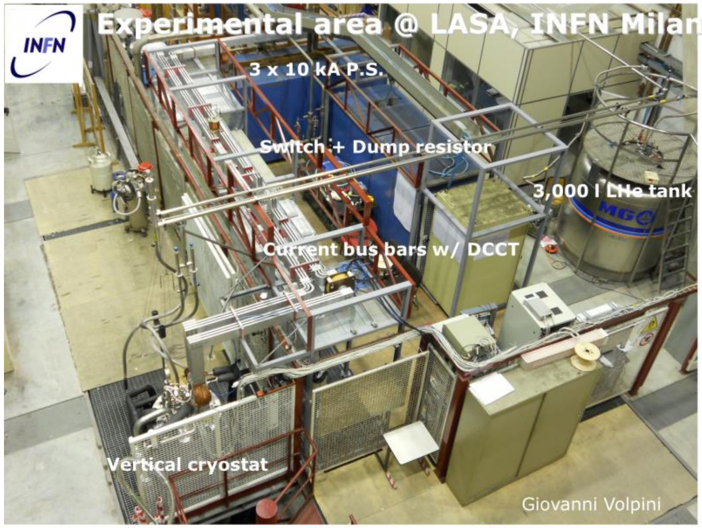
Kapton

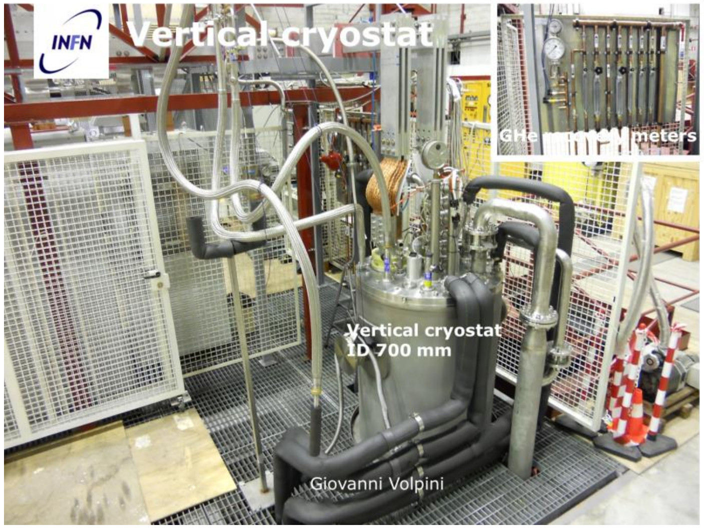
- **Impregnation tests;** a number of issues (chemical attack, temperature limit, thermal contraction stresses) needs to be addressed.

SS Roebel impregnated with CTD 101 resin

Task 4 progress
Tests

1. A **cryostat** is being specified for **internal projects at INFN**; could profitably be used for the HTS magnet test.
2. Selection of the **current leads** has started: ***resistive*** (several suppliers in the 10 kA class) or ***HTS*** (custom-made products) CL.
3. **Safety analysis**: maximum pressure under different scenarios, involving both malfunctions of the magnet and/or of the test station





Plan for the coming year

Task 1

- Preparation of Workshops,
- Regular coordination meeting,
- Following and preparation of MS/DLs and annual report

Task 2

- Study and need of transposition and stabilizer
- Winding properties of the HTS cable,
- Manufacturing process for long length,
- **D10.2 "Prototype Cable lengths and report" May 2015,** *This is the first unit length of 10 kA class HTS cable, usable for characterization and short winding tests.*

Task 3

- Complete mechanical design. Study the maximum attainable stress level for each configuration.
- Compare the different designs.
- Realisation of the first prototypes,
- **D10.1 "Conceptual study of HTS accelerator magnets" November 2014,** *The report will contain all key elements of the novel magnet design, considering electromagnetics, mechanical, thermal, stability and protection aspects.*
- **MS64 "YBCO magnet design report" November 2014.**

Task 4

- MS65 "Test Station Kick-Off " July 2015.

Conclusions

- All tasks are **at work** and **in the planning**.
- **Technical challenges** exist but are being adressed.
- For each task the **work to do** has been clearly **specified.**