FCC Week 2017
Berlin, 29 May – 2 June 2017

16 T magnet R&D - CDR plan and status

Davide Tommasini

16 T dipoles: an intensive program

Time	Tuesday		Wednesday		Thursday	
08:30-09:00 09:00-09:30 09:30-10:00	Conductor: FCC-CDP (Conductor Development Program)/1 A.Ballarino	08h30: The CERN FCC Conductor Development Program (A. Ballarino) 08h40 FCC Conductor Development at Bruker EAS 09h00 FCC Conduct… evelopment in Japan (T. Ogitsu) 09h20 FCC Conduct… t at KAT-Korea (J.Kim) 09h40 FCC Condu… t in Russia (V. Pantsyrny)	16 T Magnets: EuroCirCol 1 E. Todesco	08h30 : Baseline parameters (D.Tommasini) 08h40 : Electromagnetic design of the block coil option (C.Lorin) 09h00 : Electromagnetic design of the common-coils option (F.Toral) 09h20 : Electromagnetic design of the cosθ option (V.Marinozzi) 09h40 : electromagnetic design of the FCC main quadrupoles (C.Lorin)		
10:00-10:30						
10:30-11:00 11:00-11:30 11:30-12:00	Conductor: FCC-CDP/2 D.Larbalestier	10h30: Nb3Sn … he-art performance (B. Bordini/L.Cooley) 11h00: Maximu… and RRP (P.Lee) 11h20:Developmen… APC (ZrO2) Nb3Sn multifilamentary and ternary conductor for FCC applications (M.Sum…) 11h40:Neutron irra… on (Pfe… Stephan)	16 T Magnets: EuroCirCol 2 S. Zlobin	10h30 : Mechanical design of t… lock co… ion (C.Lorin) 10h50 : Mechanical desig… s option (J.Munilla) 11h10 : Mechanical design o… option (B.Caiffi) 11h30 : Protection of the 16 T Eur… les (T.Salmi)	16T Magnet… S Program P.Vedrine	10h30 : Overview of the US MDP (S.Prestemon) …
12:00-12:30 12:30-13:00 13:00-13:30						
13:30-14:00 14:00-14:30 14:30-15:00	Conductor: FCC-CDP/3 C. Senatore	13h30: R&D on Nb3S… (E. Barzi) 13h50 High Field potentials of MgB2 and Iron based superconductors (M. Putti) 14h20: REBCO and B… field magnets(D.Larbalestier)	16T Magnets : Models & Technology ERMC-RMM-Wound Conductor S.Gourlay	13h30 : Status of ERMC-RMM … 13h50 : Design of ERMC-RMM (E.R… ault) 14h10 : Status of the Wound Co… F.Lackner) 14h40 : A canted cosθ option f… chmann)		
15:00-15:30						
15:30-16:00 16:00-16:30 16:30-17:00	Conductor: Electromechanical characterization E.Barzi	15h30: Effect of transv… ssure on Nb3Sn wires (Carmine Senatore) 15h50: Effect of transverse pressure on Nb3Sn cables (B. Bordini)	Other Magnets T.Ogitsu	15h30 : Magnet families … (A.Chancé) 15h50 : Performance of … margin (E.Todesco) 16h20 : HL-LHC Focusing … ursors to HE-LHC/FCC Magnet Development (G.Apollinari) 16h40 : Status of High Field Magnet Technology for CEPC-SPPC (Q.Xu)	16T Review: Status … talks … ts, Cost … M. Benedikt	15h30 : Cost Model status towards the CDR (D.Schoerling) … ductor … rds the CDR (A.Ballarino) … Questions …

Conductor

Magnets

US MDP

16 T Review

POSTERS

Strategies to reduce the voltage to ground in the FCC main dipole circuits (M.Prioli)
Design Studies of 16 T Nb3Sn Dipole Magnets at Fermilab (A.Zlobin)
Analysis of stresses in a 16-T superconducting dipole during a quench (Z.Junjie)
Test of HTS Demonstrator Dipoles i… T Background Fi… of the SULTAN Facility (X.Sarasola)
Compact common-coil design for a …
Epoxy impregnated Nb3Sn cables (… udio Fi…
Development of metallic substrates for the realization of Fe(Se,Te) superconducting coated conductors (V.Braccini)
An innovative process for the fabrication of Bi-2212 wires to boost their applications in high fields (A.Malagoli)
Internal tin strands designed in RF for application in high field dipoles (A. Ildar)
Development of Distributed Tin processed Nb3Sn wire for FCC (K.Shinya)

Posters

16 T dipoles: Targets for the CDR

by the end of 2018 we shall provide:

- a reference design for the 16 T dipoles, including integration in cryostat;
- a concept for the magnet and circuit protection;
- an estimate of the cost for the series production;

The content of the CDR shall be **CREDIBLE**

Being credible is not obvious …

Many unknowns:

- conductor cost
- achievable conductor performance, no enhancements expected within 2018
- electromechanical performance of conductor and cable not yet fully characterized
- achievable magnet performance (required margin) has a major impact on cost
- no one Nb3Sn magnet operating in a particle accelerator by the time of the CDR

still I believe we can manage, by making best use of the available time and experience

What we will have available to be credible

- 16 T already achieved as maximum field in a no-gap dipole configuration both in US and at CERN
- a comprehensive review of the past experience on Nb_3Sn accelerator magnets*
- some preliminary results of conductor development worldwide
- new information about the electromechanical characterization for the conductor and cable
- the indication that 12 T industrial accelerator magnets are feasible (HILUMI)
- hopefully a good performance of Fresca II (hitting 14 T in a laboratory magnet)
- hopefully the demonstration that 16 T can be achieved with margin, though in a no-gap dipole configuration (test of ERMC in 2018), even with the conductor presently available. Perhaps first test of RMM (50 mm gap).
- ideally a good performance of the US-MDP 14-15 T model (with real physical aperture)

It is useless to say that a good performance of the US-MDP model would certainly contribute to the scientific credibility of a proposal for 16 T for the FCC. No other “accelerator like” model >14 T can be developed and tested within the same timeline (within end 2018).

* Being *Edited by D.Schoerling and A.Zlobin*

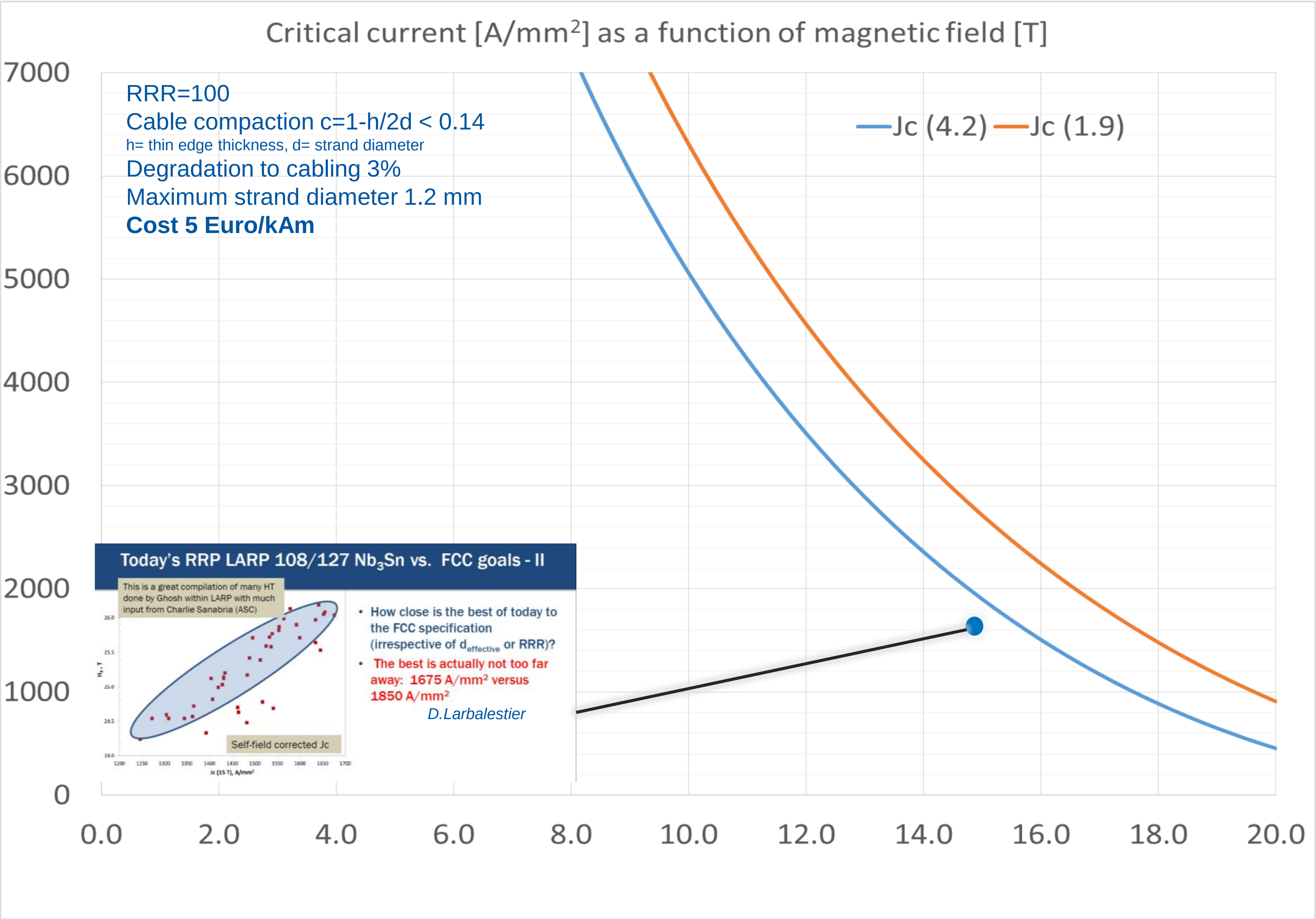
Overview

- FCC 16 T Magnets Technologies (until 2023) ***Tuesday/Wednesday***
  - conductor development & procurement (about 1 ton/year)
  - winding characterization
  - R&D magnets : ERMC/RMM, start winding in 2017
  - model magnets at CERN, CEA, CIEMAT, INFN, PSI, start winding in 2019

- EuroCirCol WP5 (until 2019) ***Wednesday***
  - 7 institutes
  - feed the FCC CDR with baseline design and cost model of 16 T magnets

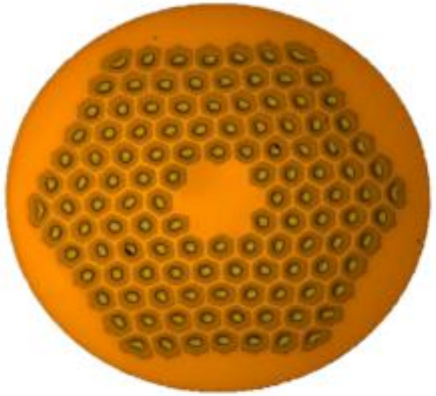
- US Magnet Development Program ***Thursday***
  - initially focused to a 14-15 T cosine-theta demonstrator (2017-2018);
  - also exploring a canted cosine-theta option, in a first step possibly as an insert to the outer layers of the 14-15 T demonstrator above;
  - a slotted cosine-theta option in combination with the optimized inner layers of the 14-15 T demonstrator (see poster "Design Studies of 16 T Nb_3Sn dipole at Fermilab" on Tuesday May 30).

Conductor *(Tuesday)*

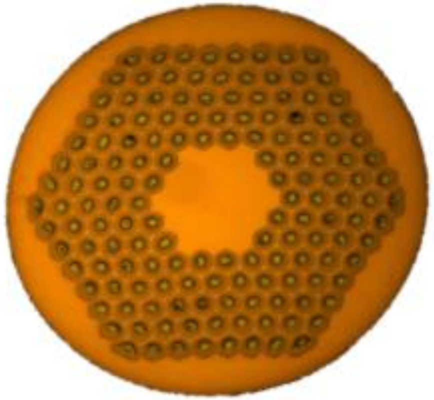


Conductor for initial ERMC-RMM coils (2017-2018)

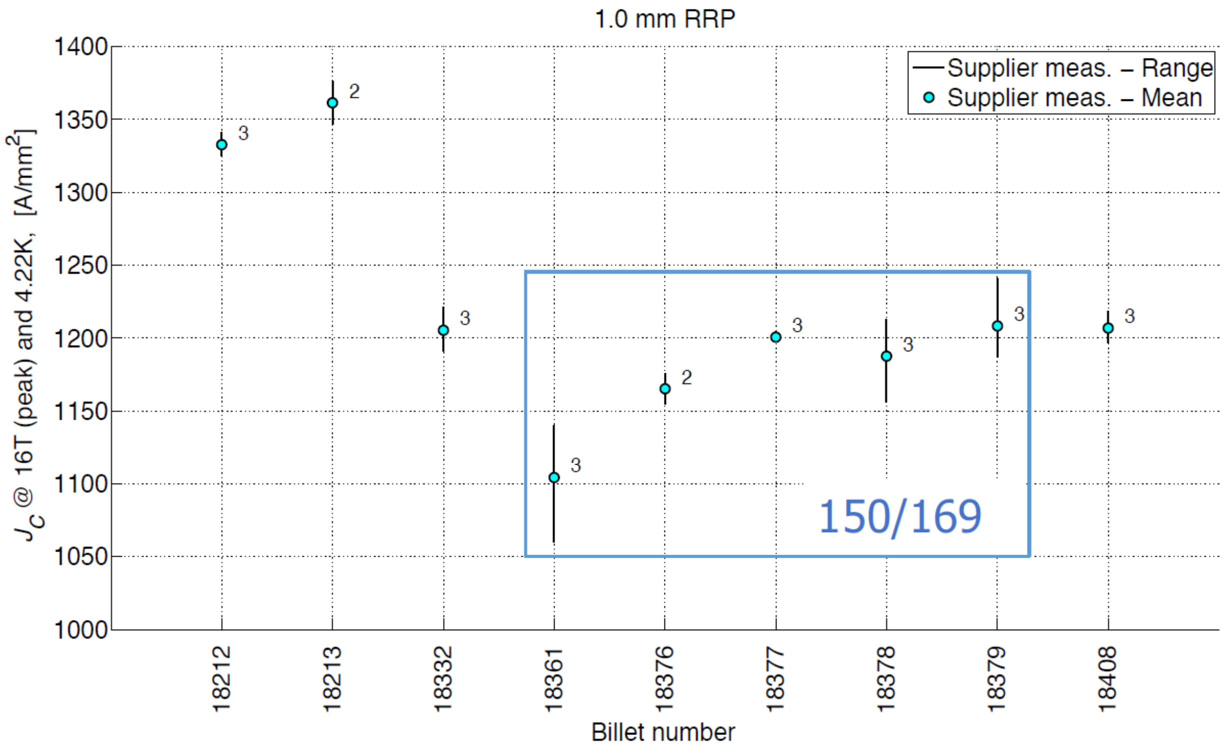
53 km of 1.0 mm, RRP wire delivered in 2016 (from OST)



4 billets 120/127
sub element size 64 μm
Cu/nonCu 1.05-1.10:1



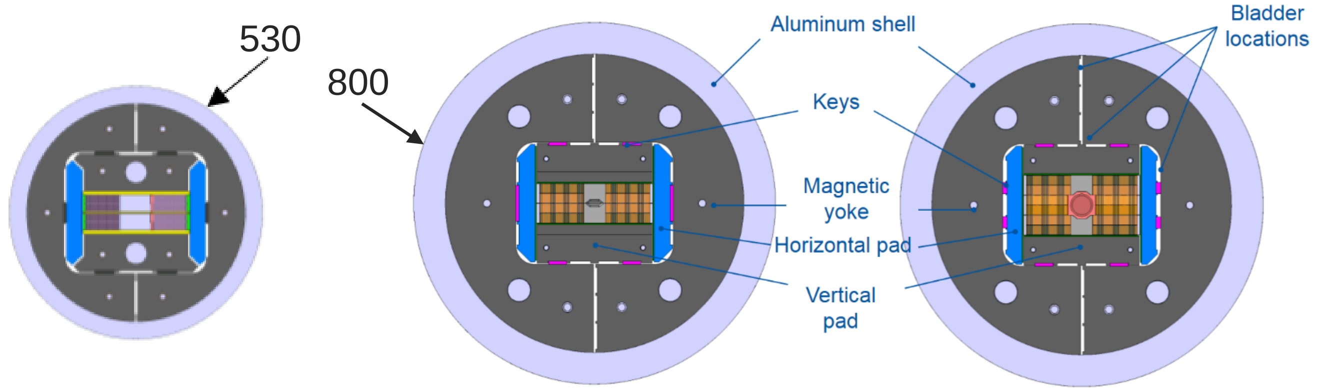
5 billets 150/169
sub element size 55 μm
Cu/nonCu 1.05-1.10:1



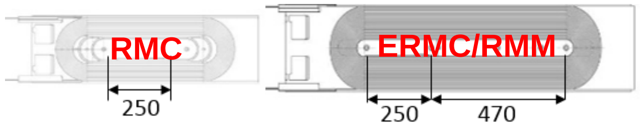
RRR > 120 with exception of billet 18213 (RRR 90-100)

R&D Magnets : ERMC/RMM *(Wednesday)*

Two model types: ERMC and RMM, non-graded and graded versions



- a real straight section

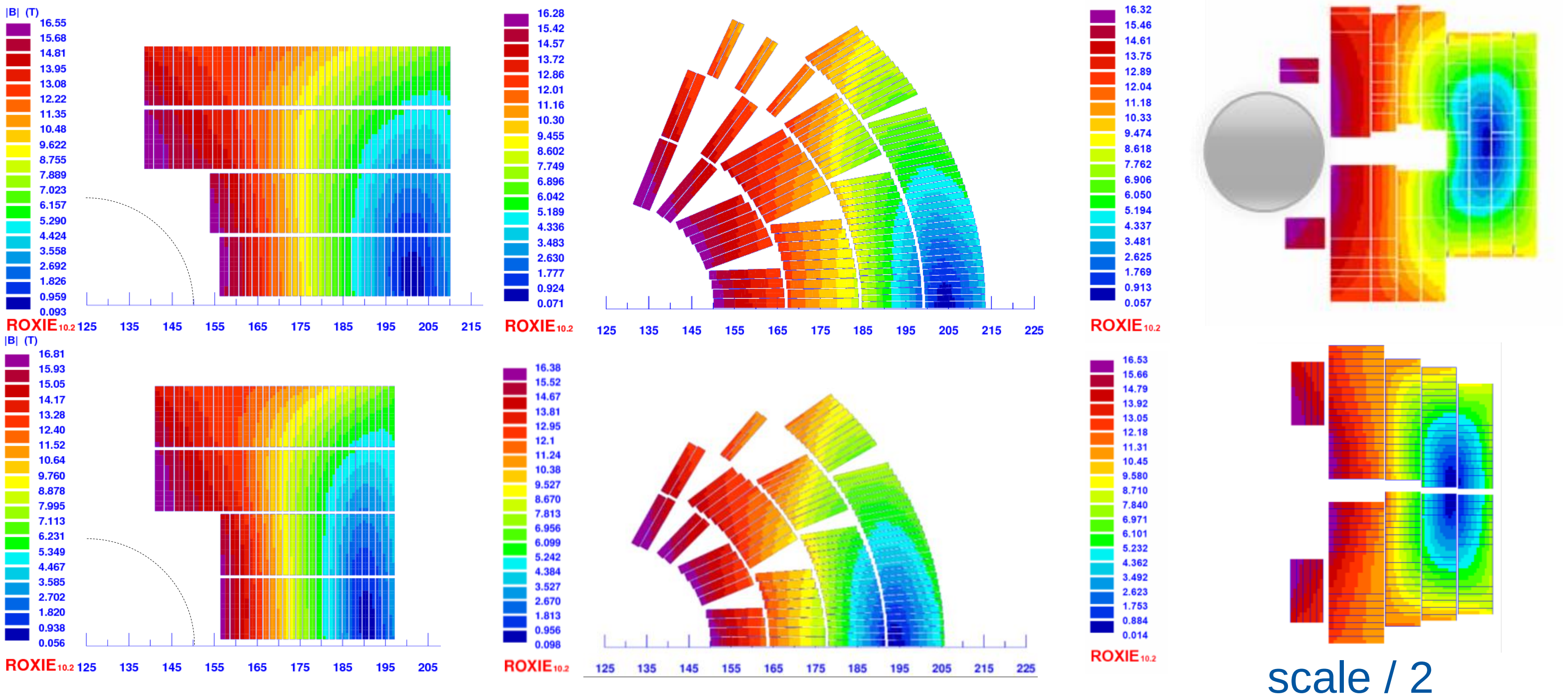


- a structure for fields up to 18-19 T, key & bladders for ease of multiple assembly
- ERMC coils compatible with use in the RMM
- RMM equipped with harmonic field probes

- ➢ demonstrate that the field level can be achieved with margin and limited/no training
- ➢ measure and characterize field quality static and dynamic with different conductors
- ➢ management of transitions (layer jump, ends …)
- ➢ study/optimize coil manufacture (including interface conditions coil/pole, coil-coil …)
- ➢ explore different loading configurations/strategies (transversal & longitudinal)
- ➢ splice studies in real magnet configuration

EuroCirCol WP5 : Design Options *(Wednesday)*

A specific feature of this program is that different design options are being considered with the same specification and analysis tools so that they can be compared relatively to each other.



scale / 2

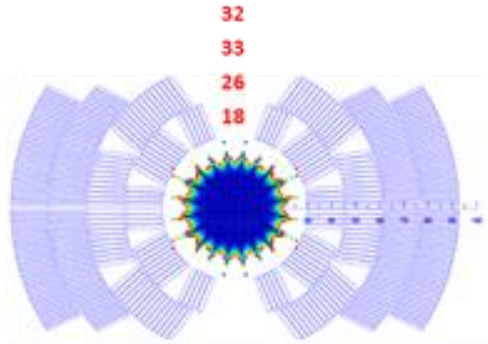
CEA INFN CIEMAT

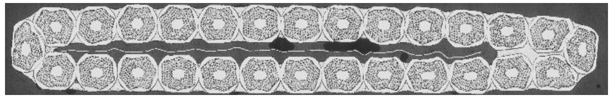
… to which we also add a canted cosine theta design (PSI) thanks to a Swiss contribution to the FCC

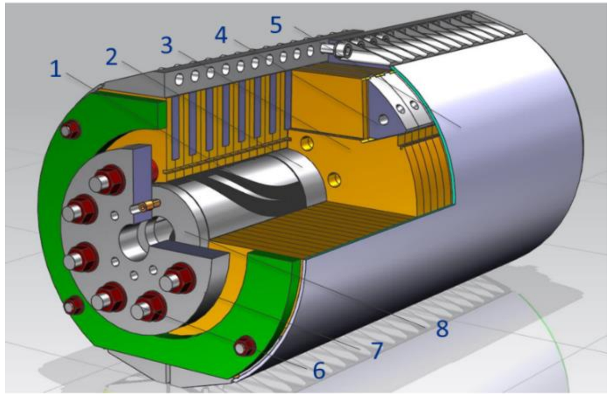
The reference parameter space has been finalized considering recommendations from the 1st WP5 EuroCirCol Review (11-13 May 2016, http://indico.cern.ch/event/516049)

US-MDP Cosinetheta Model *(Thursday)*

- Coil:
  - 60-mm aperture
  - 4-layer graded coil
  - W_{sc} = 68 kg/m/aperture
- Cable:
  - L1-L2: 28 strands, 1 mm RRP150/169
  - L3-L4: 40 strands, 0.7 mm RRP108/127
  - Insulation: E-glass tape
- Mechanical structure:
  - 2-mm StSt coil-yoke spacer
  - Vertically split iron laminations
  - Aluminum I-clamps
  - 12-mm thick StSt skin
  - thick end plates and StSt rods
  - Cold mass OD<610 mm
- Fabrication status:
  - In progress
- Planned magnet test: February-March 2018







EuroCirCol WP5 : Cost Model *(Thursday)*

The development of a cost model has accompanied the project since its beginning, in particular for strategic choices of the parameter space (magnet margin, operating temperature, physical aperture …).

The conductor represents about 50% of the entire magnet cost.

Target conductor cost is:
5 EUR/kA.m at 16 T and 4.2 K (3.5 EUR/kA.m at 16 T and 1.9 K)
corresponding to 450 EUR/kg for a Cu/Non-Cu ratio of 1/1 and target performance of
J_c= 1500 A/mm^2 at 16 T and 4.2 K (J_c= 2300 A/mm^2 at 16 T and 1.9 K)

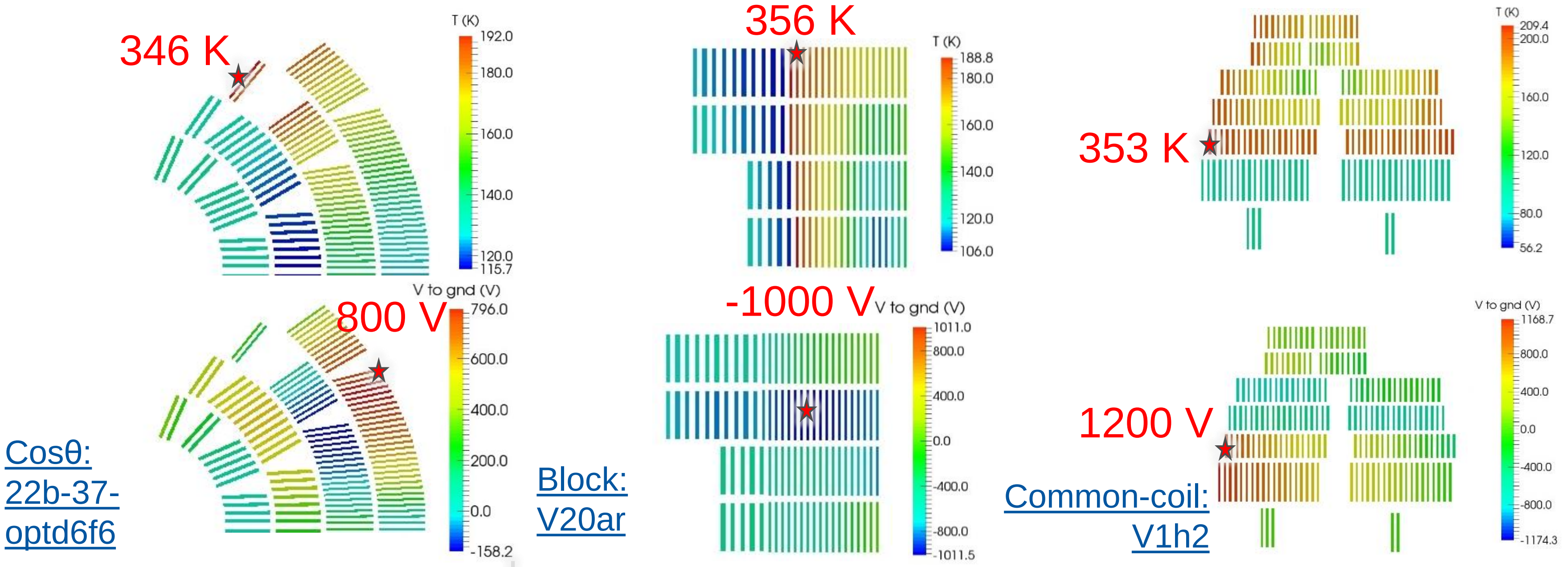
The identification of the other cost drivers and both an analytical and extrapolated cost model are on good track.

EuroCirCol WP5 : Magnet & Circuit Protection

- Quench protection was integrated into the magnet design since an early stage
- In the accelerator the dipole must absorb its stored energy after a quench
- **A 40 ms time margin[1] to 350 K was set as a design criterion**
  - Assume 20 ms for detection + 20 ms for the protection system to effectively quench the entire coil → Hotspot temperature must be **< 350 K**
- A limit for single **magnet voltage after a quench set to 1.2 kV**

Talk T. Salmi, poster M. Prioli, poster J. Zhao

Temperatures and voltages with 40 ms protection delay



[1] E. Todesco, Proc. WAMSDO 2013

In summary

The EuroCirCol WP5 will provide most of the material for the 16T FCC CDR

The credibility of this material will be supported by the information coming from past experience and by results of on-going experimental activity worldwide.

Thank you for your attention

Salient common assumptions

1.	Magnet length	14.3 m	
2.	Free physical aperture	50 mm	
3.	Field amplitude	16 T	
5.	Margin on the load-line @ 1.9K	14 %	
6.	Total time delay	40 ms	
7.	Critical current density @ 1.9 K, 16T (total)	2300 A/mm^2	
8.	Conductor fit (Jc/B)	Bernardo's fit	
9.	Degradation due to cabling	3%	
10.	Minimum Cu/nonCu	0.8	also check 0.9-1.0
11.	Maximum strand diameter	1.2 mm	also check 1.1 mm
12.	Maximum (any) stress on conductor	200 MPa	
13.	Maximum hot spot temperature (@ 105% I_{nom})	350 K	
14.	Maximum number of strands in a cable	40	check up to 60
15.	Maximum voltage to ground (magnet contribution)	1.2 kV	set as tentative value
16.	Maximum TOTAL voltage to ground	2.5 kV	
17.	Conductor cost (performance based)	5 Euro/kAm	