ECC

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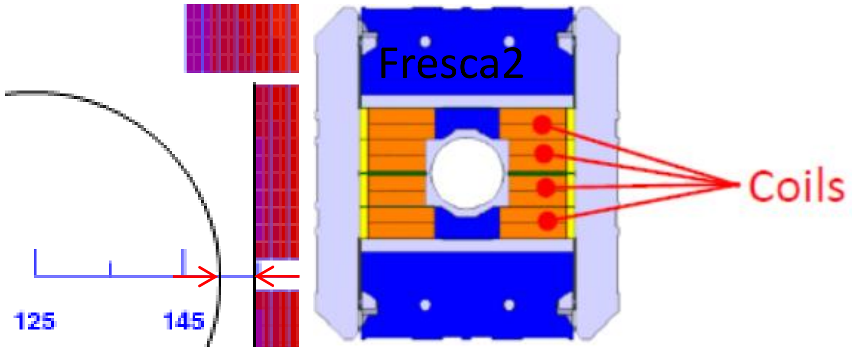
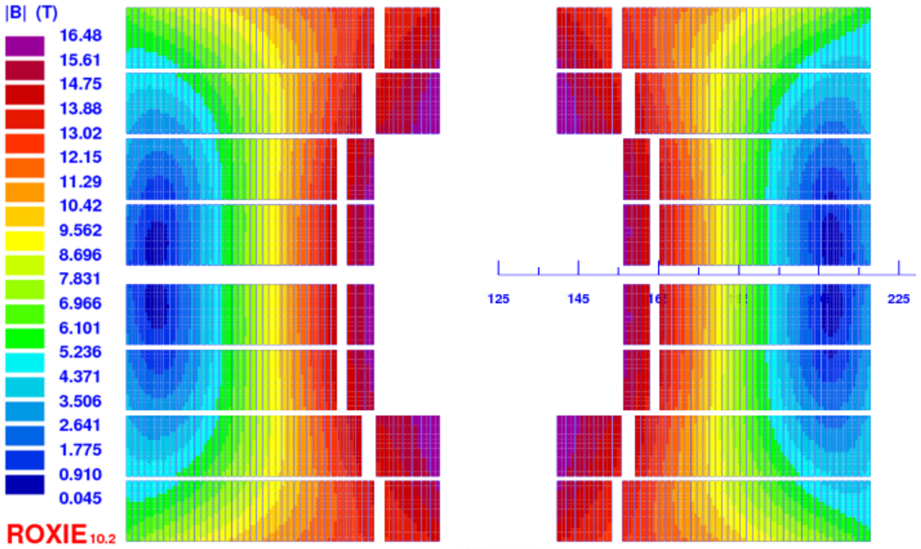
Acknowledgements: Fresca2 team

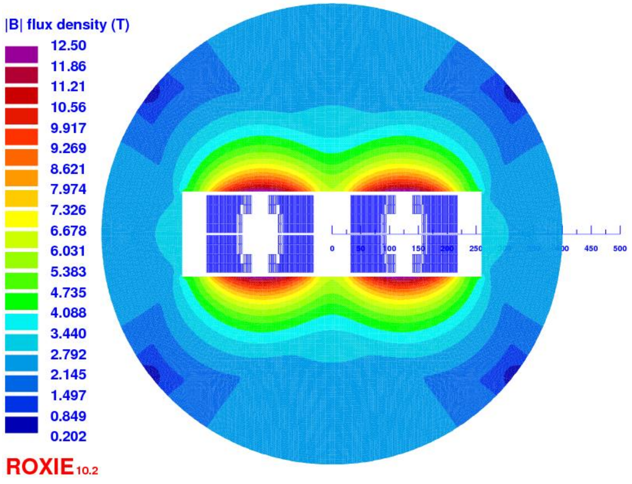
Foundations

- Context:
  - 16 T dipole – **4.5** K – ~10% LL margin – Nb_3Sn – 50 mm aperture
  - No-grading leads to too much conductors: >20,000 tons (4800 dip, 15 m, d = 8.7)
  - Preliminary graded cos-theta designs: ~12,000 tons (not protectable!)
- Grading needed for block (as well!)
  - An efficient grading: extremes strand dimensions (1.1 mm – 0.7 mm)
  - Number of coils (manufacturing): large current, big cable (40 strands)
  - Cables:
    - 1.1 mm, 26 strands, 15 mm, 2 mm (~125 tons per turn)
    - 0.7 mm, 40 strands, 15 mm, 1.25 mm (~75 tons per turn)
- Mechanical support: 6 mm
  - Fresca2 = 8 mm, 15 T @ 1.9 K not optimized



Grading 1 – (reference)



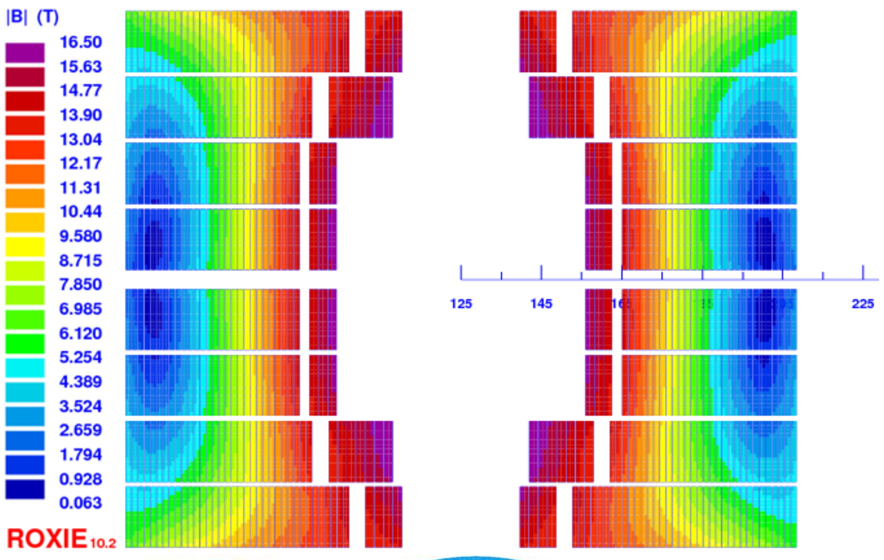


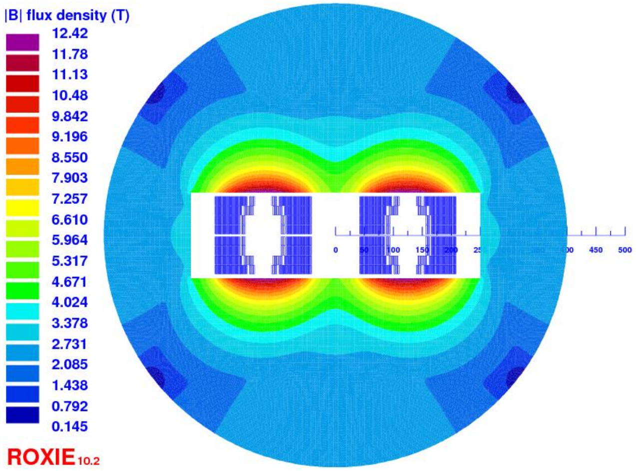
- Splice room = Large cable thickness (>2.3 mm)
- Cu/nonCu = 1.0 both cable
- Protectable (50 ms, hotspot < 300 K)
- 19/146 turns -> 13,600 tons (217 cm²)
- Iop = 8395 A
- Gap closed 15/148 turns -> 13,300 tons (212 cm²)

FCC quad remark [Ezio]:

- 1% less dipole field is 8 outer turns (~quantity of conductors needed for the FCC quad)

Grading 2 – (Cu/nonCu reduction 0.6)

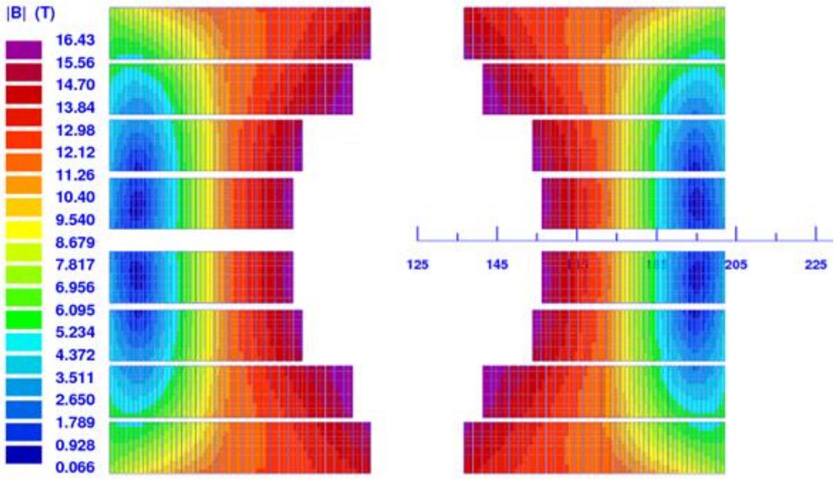


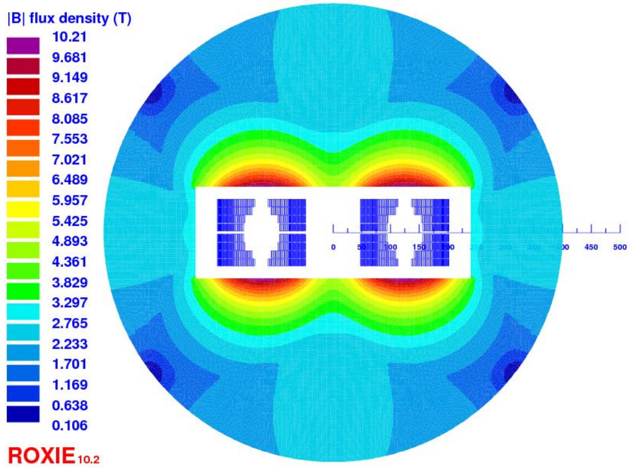


- Splice room = Large cable thickness (>2.3 mm)
- Cu/nonCu = 0.6 inner 1.0 outer
- Protectable (50 ms, hotspot < 300 K)
- 17/122 turns -> 11,500 tons (184 cm^2)
- Iop = 9700 A

Gain ~2000 tons (~3 times the quantity of conductors for the quadrupoles!)

Grading 3 – (Cu/nonCu 0.6 + 48 str. 0.5 mm)

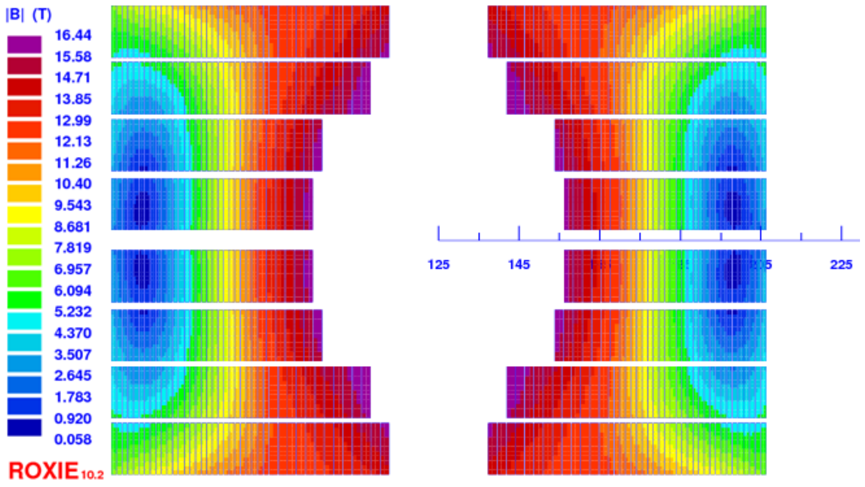


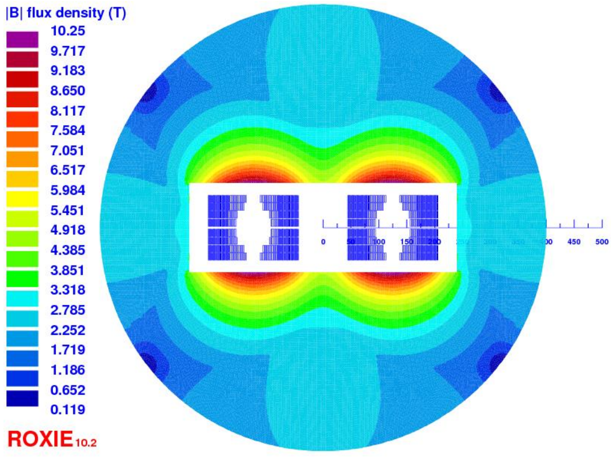


- No splice room
- Cable
  - 1.1 mm, 22 strands, 12.7 mm, 2 mm
  - 0.5 mm, 48 strands, 12.7 mm, 0.9 mm
- Cu/nonCu = 0.6 inner 1.4 outer
- 15 + 10 ms, hotspot ~ 350 K
- 45/98 turns -> 9,300 tons (149 cm²)
- Iop = 8840 A
- About the same quantity of conductor as GL Sabbi, same time to react*

*Design study of a 16 T block-dipole for FCC» to be published in IEEE TAS

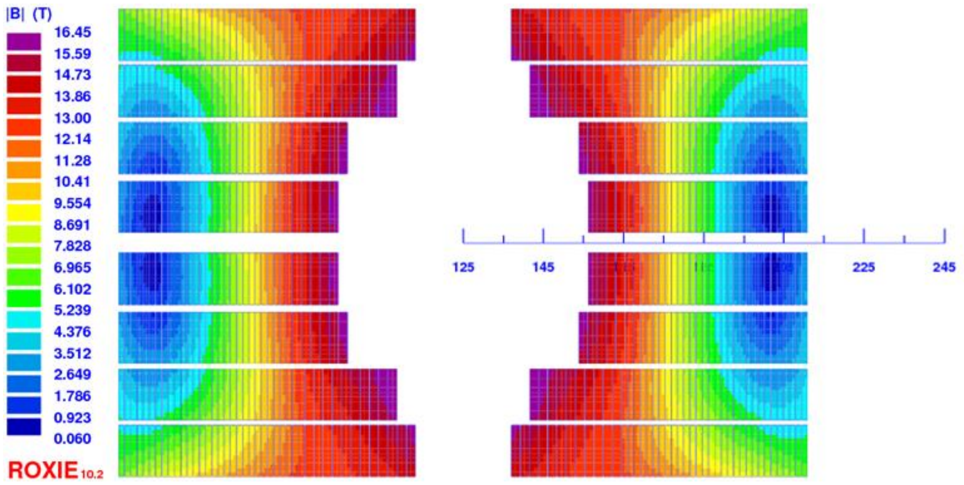
Grading 4 – (Cu/nonCu 0.6 + 40 str. 0.6 mm)

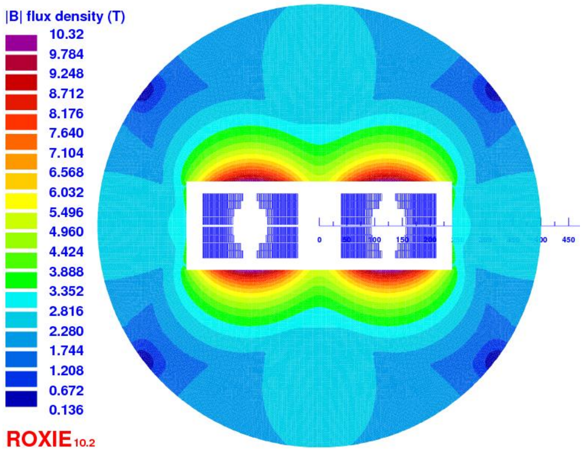




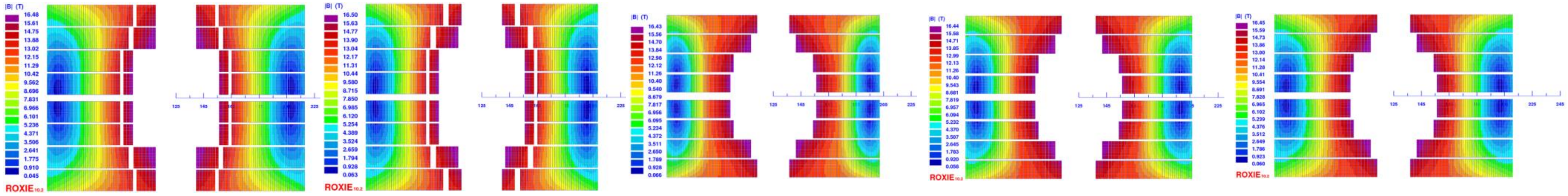
- No splice room
- Cable
    - 1.1 mm, 22 strands, 12.7 mm, 2 mm
    - 0.6 mm, 40 strands, 12.7 mm, 1.1 mm
- Cu/nonCu = 0.6 inner 1.5 outer
- 20 + 20 ms, hotspot ~ 300 K
- 37/108 turns -> 9,999 tons (159 cm²)
- Iop = 8760 A

Grading 5 – (Cu/nonCu 0.6 + 34 str. 0.7 mm)





- No splice room
- Cable
    - 1.1 mm, 22 strands, 12.7 mm, 2 mm
    - 0.7 mm, 40 strands, 12.7 mm, 1.25 mm
- Cu/nonCu = 0.6 inner 1.5 outer
- 20 + 30 ms, hotspot < 300 K
- 33/116 turns -> 11,000 tons (177 cm²)
- Iop = 8620 A

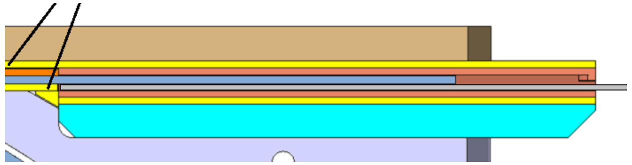


Magnet ID	1	2	3	4	5
Cables [mm]	26x1.1 ; 40x0.7	26x1.1 ; 40x0.7	22x1.1 ; 48x0.5	22x1.1 ; 40x0.6	22x1.1 ; 34x0.7
Cu/nonCu [-]	1 ; 1	0.6 ; 1	0.6 ; 1.4	0.6 ; 1.5	0.6 ; 1.5
Turns [-]	19 ; 146	17 ; 122	45 ; 98	37 ; 108	33 ; 116
Iop [A]	8395	9700	8840	8760	8620
Time [ms]	20+30	20+30	15+10	20+20	20+30
HotSpot [K]	< 300	< 300	~350	~300	< 300
Weight [tons]	13,600	11,500	9,300	9,999	11,000
Area 2 ap. [cm^2]	217	184	149	159	177

-Is a ‘perfect’ cable the better solution for a ‘perfect’ magnet?
-Why do we operate at 4.5 K instead of 4.2 K?
-Where do we make the splices? And how?

From FRESCA2

- No specific feedback about grading from FRESCA2
  - Ungraded coils
  - No Grading options from the beginning
- Feedback on use of 40 strands, 1 mm in diameter :
  - no special issues for winding (R min 45 mm)
  - to be confirmed by coil/magnet test…
- Feedback on coil and tools design:
  - Preliminary winding tests with special tools to study/define head configuration (length, angle, …), layer jump -- >
  - Cable behavior studies relative to heat treatment : to be done as soon as possible with final cable, bare and insulated
- FRESCA2 splices: 2 mm thick copper box (U + wedge)



Splice requirements

- Min splice length = cable twist pitch
- Need space on each side of cables pair for:
  - Copper stabilizer
    - U shape + wedge
  - Insulation
- Need supports to:
  - Guide the cables to splice position
  - Block the cables ends during winding (and reaction?)
  - Support replaced after reaction by copper stabilizer, insulation and soldering tools

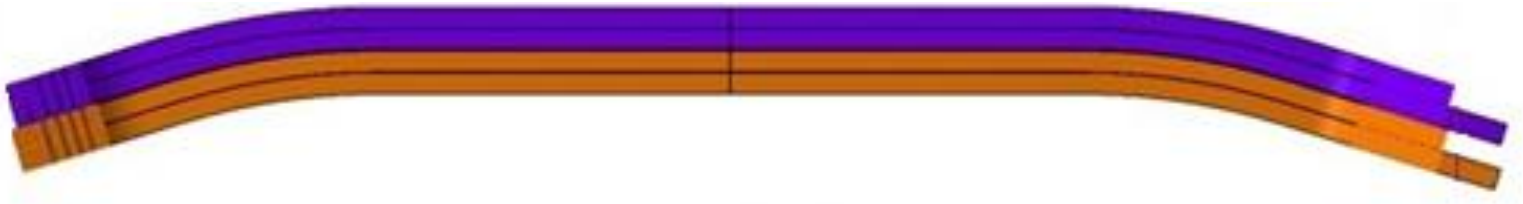
Splice options

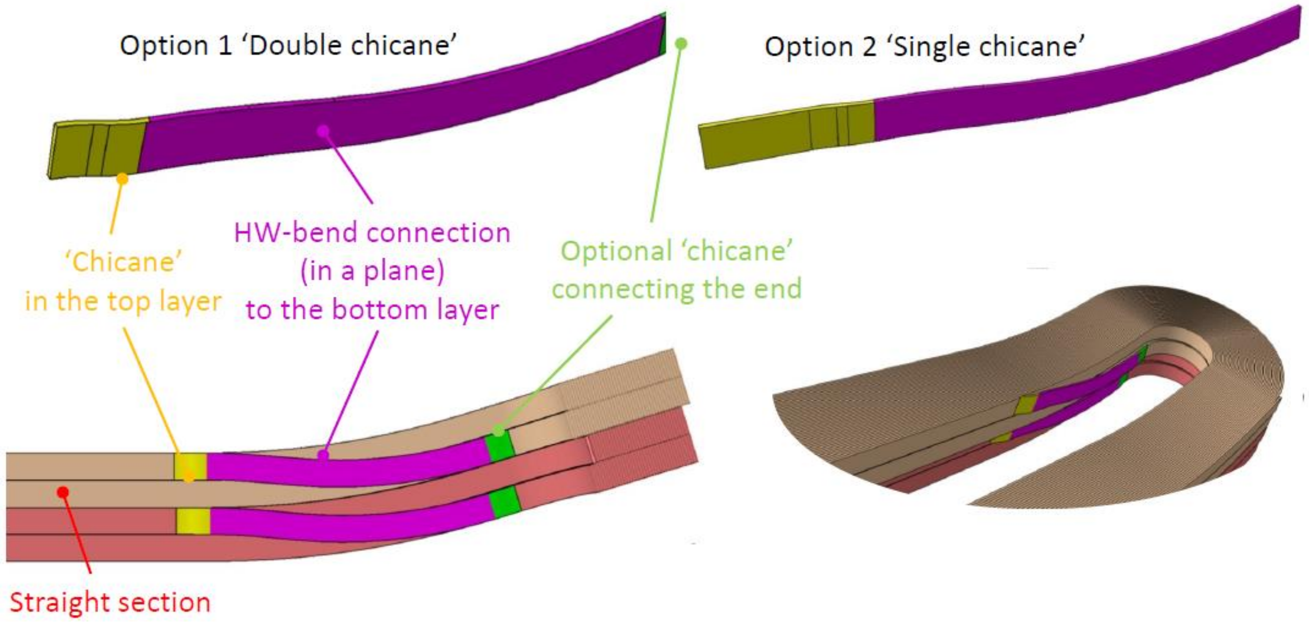
- In the straight section
  - Gap between the two conductors blocks (4 x cable thickness?)
  - Gap between layers

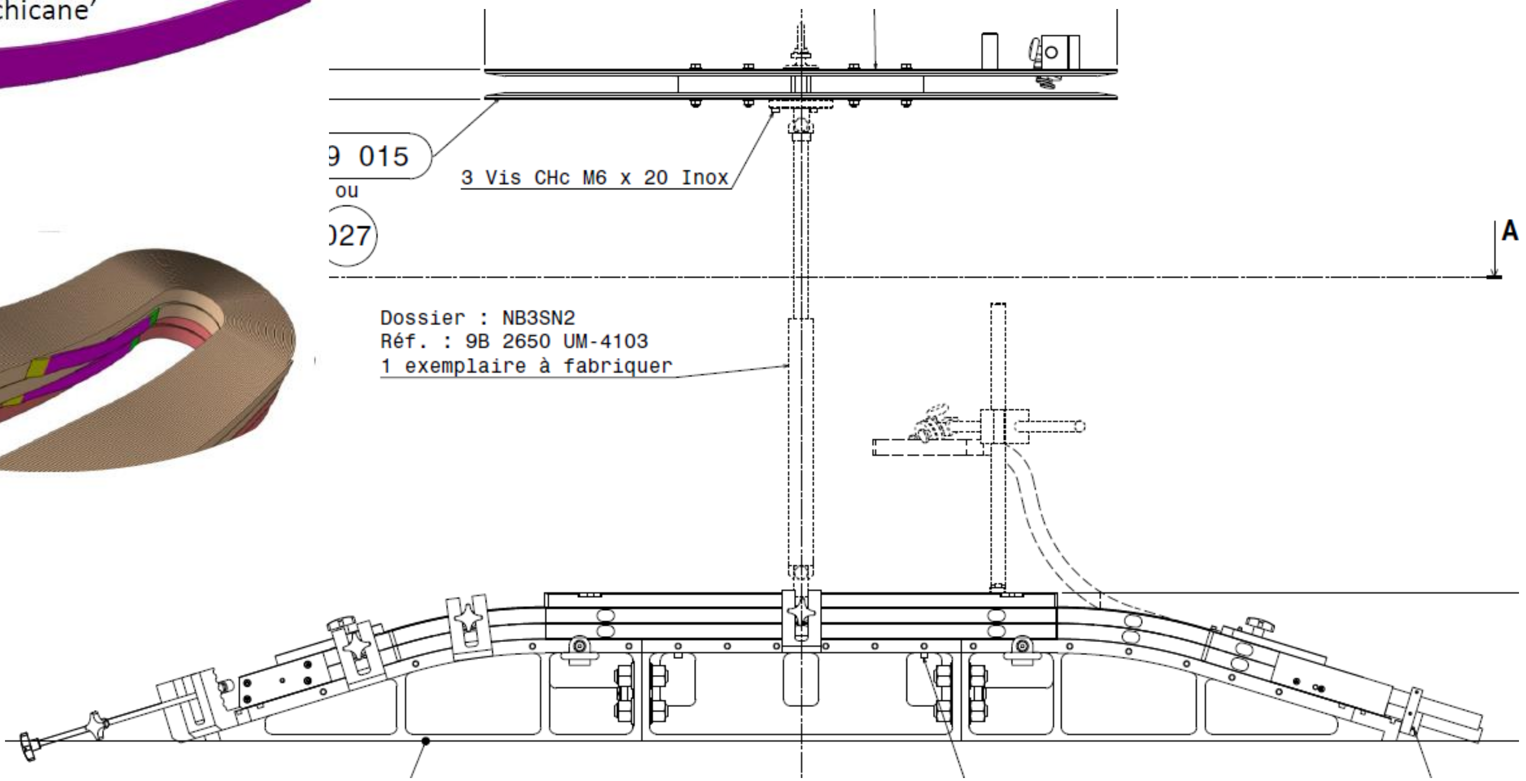
- In the heads
  - Experience on bended splices ?
  - Small radius → short length → need for longer (flared) heads → bigger outer diameter

- External splices/connections

Extra – Fresca2







Extra – D20

DESIGN OF THE Nb_3Sn DIPOLE D20

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Table 1. D20 Cable Parameters

D20	Inner Cable	Outer Cable
Strand No.	37	47
Strand diameter (mm)	0.75	0.48
Cable width (mm)	14.1	11.52
Keystone Angle (°)	1.11	0.87
Mid-thickness (mm)	1.60	1.11
Cu/Sc ratio	0.4	1.15
A_{sc}/turn (mm^2)	11.676	3.956
A_{cu}/turn (mm^2)	4.670	4.549

Extra – HD2

TABLE I
CONDUCTOR PARAMETERS FOR HD2 AND HD1*

Parameter	Unit	HD2	HD1
Strand diameter	mm	0.8	0.8
Average Ic (16 T, 4.2K)	A	322	322
Cu/Sc ratio		0.94	0.94
No. strands		48	36
Cable height	mm	21.0	15.75
Cable thickness	mm	1.36	1.36
Insulation thickness (h/v)	μm	93/130	93/130
No. turns/quadrant		61	69

(*) HD1: measured values; HD2: design values.

MAGNETIC FIELD MEASUREMENTS OF HD2, A HIGH FIELD Nb_3Sn DIPOLE MAGNET*

X. Wang†, S. Caspi, D. W. Cheng, H. Felice, P. Ferracin, R. R. Hafalia, J. M. Joseph, A. F. Lietzke, J. Lizarazo, A. D. McInturff, G. L. Sabbi, LBNL, Berkeley, CA 94720, USA
K. Sasaki, KEK, Tsukuba, Ibaraki 305-0801, Japan

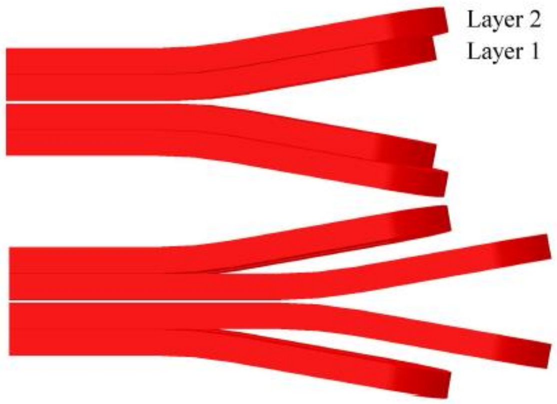

Figure 4: Coil design of HD2 (top) and configuration optimized to reduce integrated harmonics in the ends (bottom).

Design of HD2: a 15 Tesla Nb_3Sn Dipole with a 35 mm Bore

G. Sabbi, S.E. Bartlett, S. Caspi, D.R. Dietderich, P. Ferracin, S.A. Gourlay, A.R. Hafalia, C.R. Hannaford, A.F. Lietzke, S. Mattafirri, A.D. McInturff, R. Scanlan

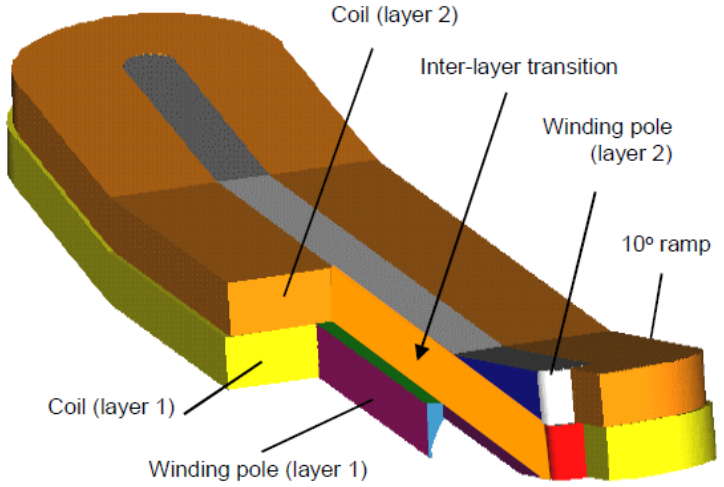

Fig. 5. HD2 coil end design features.