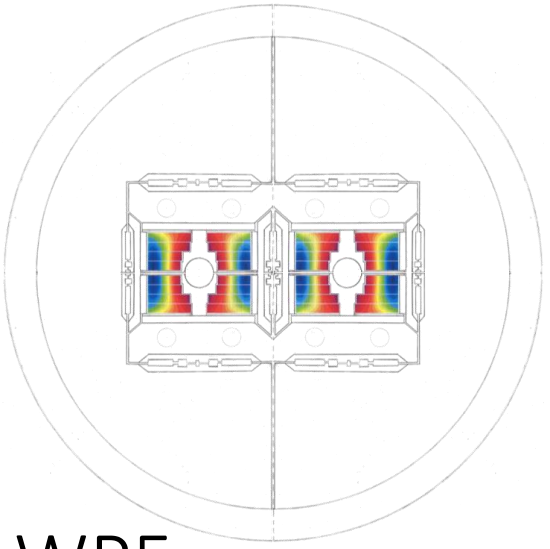


EuroCircol

1st Review of the EuroCircol WP5

Block coil: electromagnetic

Clément Lorin
Maria Durante

CEA

CERN, 11 May 2016

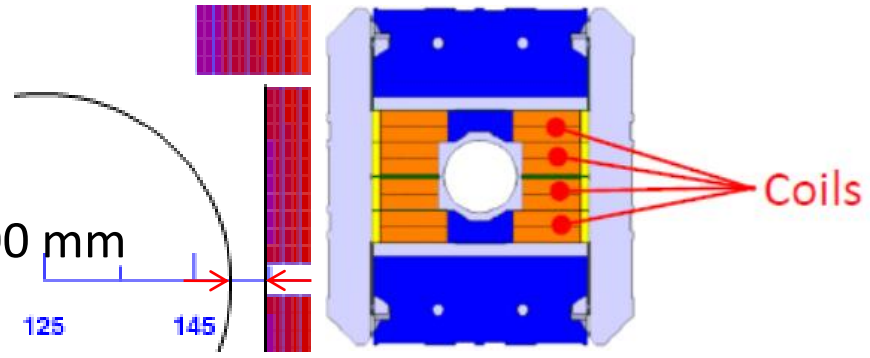
Magnet specifications

- Magnet specifications
  - Double Aperture (DA) configuration
  - harmonics < 3 units @2/3 aperture
  - b3 @ 1 T ~10 units (beam energy at injection)
  - Fringe field < 100 mT
  - Protection @ 105% of nominal current
    - $T_{hotspot}$ < 350 K with a conservative adiabatic model
      - 20 ms (detection+validation) + 20 ms (QH delay)
      - deeper analysis later on [see Tiina Salmi's talk]

- Block design specificity:
  - Wall thickness 6 mm

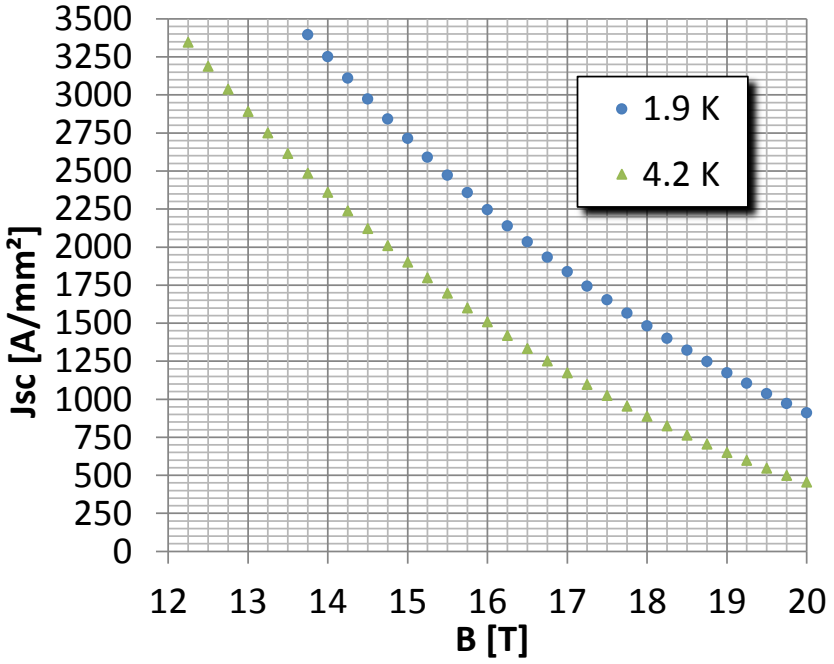
    Fresca2 = 8 mm, 15 T @ 1.9 K, Φ = 100 mm

Fresca2



SC & Cable specifications

- SC current density
  - 1500 A/mm² @ 16 T and 4.2 K
  - 2250 A/mm² @ 16 T and 1.9 K
- 16 T
  - 10% margin @ 4.2K
    leads to ~18% margin @ 1.9 K
- Cable specifications
  - Strand diameter max: 1.1 mm
  - Strand diameter min: 0.7 mm
  - Number of strands max: 40
  - Cu/non-Cu ratio min: 1/1
  - Insulation: 0.15 mm

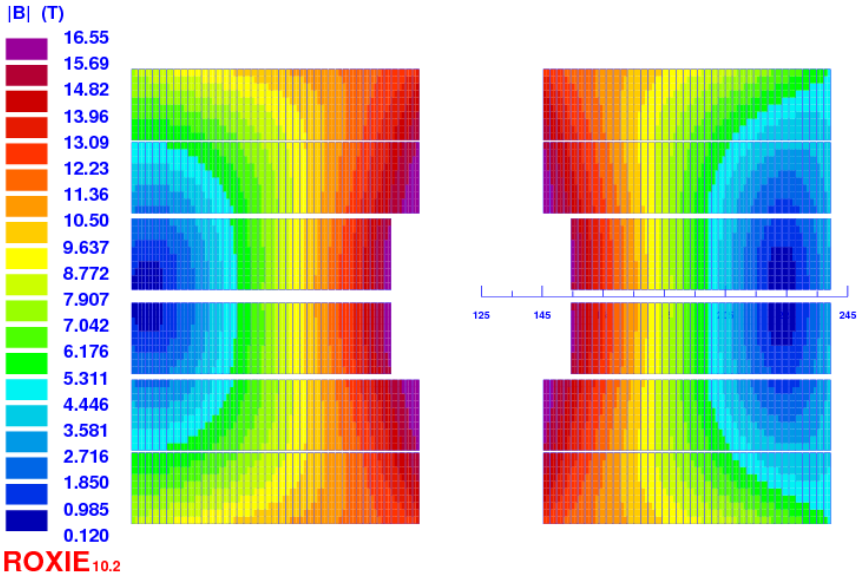


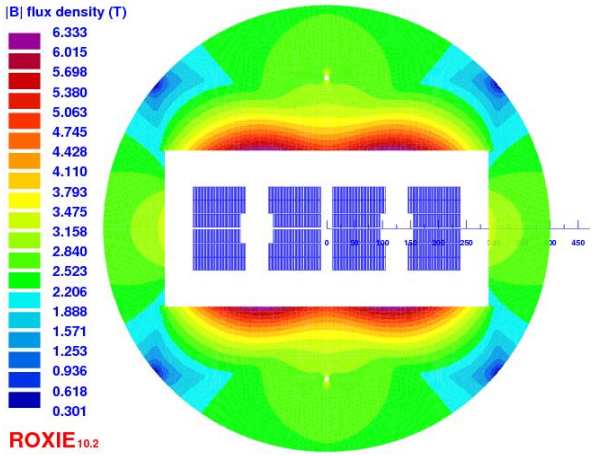
1st design round- no grading

- One type of cable only

Quantity	Unit	Value
W_bare	mm	23.1
T_bare	mm	2.0
Cu/nonCu	.	1.0
N strands	.	40
Φ	mm	1.1

Quantity	Unit	Value
Iop	A	13210
Bpeak	T	16.55
Fx per ½ coil	kN/m	9,520
Ld 2 ap.	mH/m	52.3
Energy 2 ap.	kJ/m	4,738
Strand area 2 ap.	cm²	362

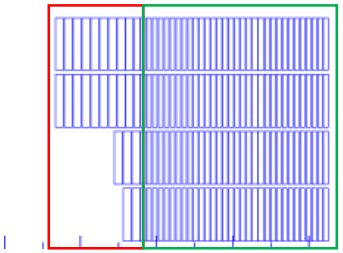


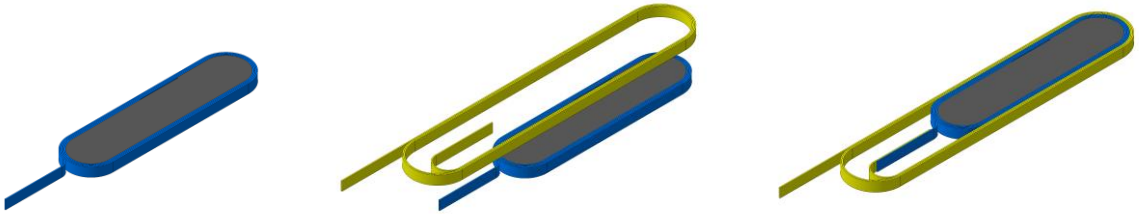


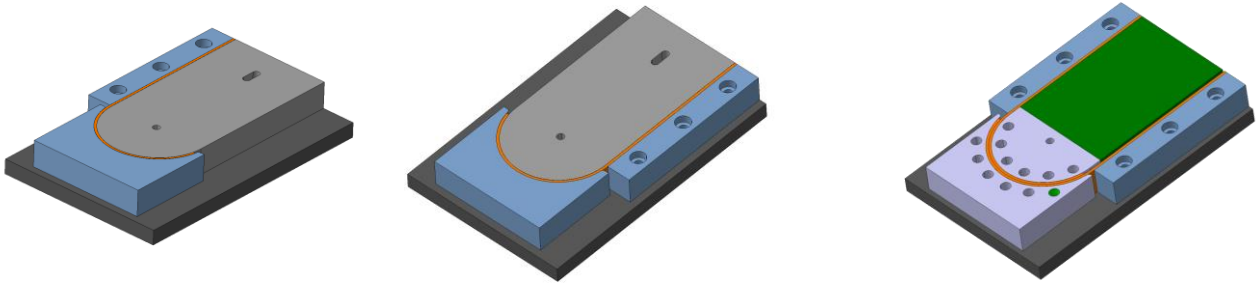
20,000 tons !

2nd design round

- Conductor amount reduction:
  - Two cables: High and Low field regions
  - Internal splice in magnet ends *(ideas!)*
    - Straight





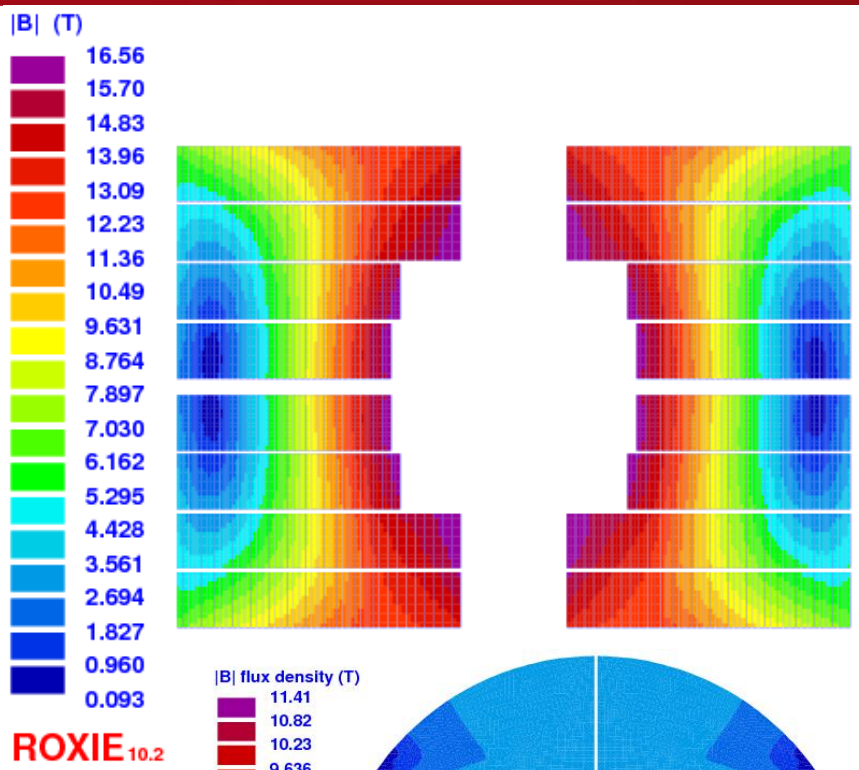


[All images courtesy of Juan Carlos Perez- Susana Izquierdo Bermudez, CERN]

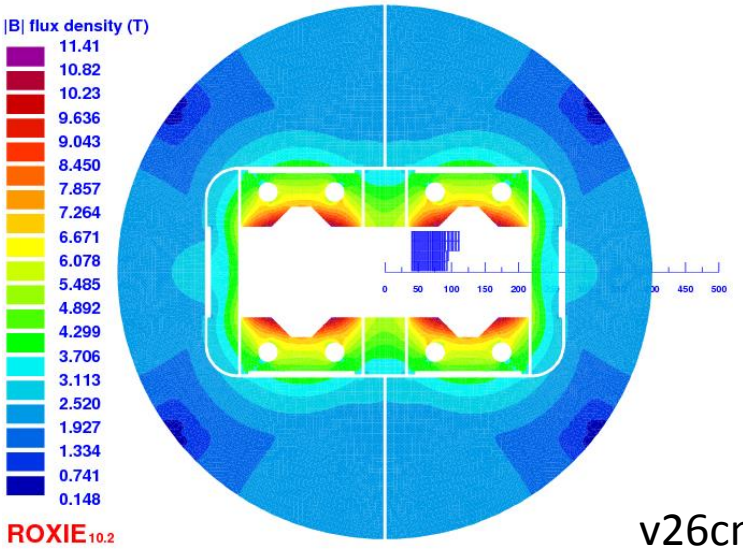
2nd design round - grading

- Two cables

Cable parameter	value	unit
strand diameter	1.1 – 0.7	mm
nb of strands	24 – 37	N/A
width	13.85 – 13.85	mm
average thickness	2.0 – 1.25	mm
insulation	0.15	mm
Cu/nonCu	1.0– 1.0	N/A
I_{nom}	8470	A
B_{peak}	16.56	T
LL margin (4.2 K)	9.3	%
T margin (4.2 K)	1.65	K
Inductance diff. (2 ap)	88.19	mH/m
Stored energy (2 ap)	3340	kJ/m
Conductor area (2 ap)	**190***	cm²
Nb of turns	153 = 2+3+9+9 +32+32+33+33	-
Yoke OD	800	mm
Fx (per ½-coil)	8817	kN/m
Fy (per ½-coil)	-3703	kN/m
Hotspot	310	K
Wall thickness	6	mm



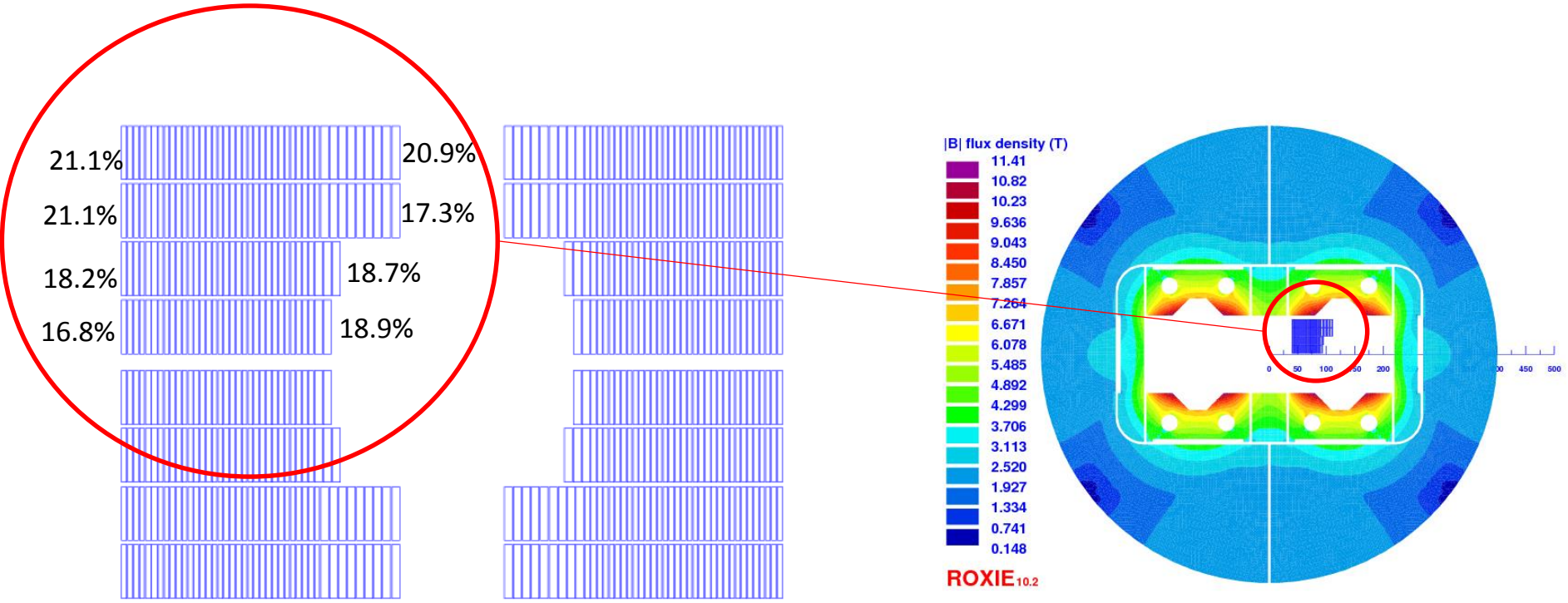
*11150 tons



v26cmag

Loadline Margin @ 1.9 K

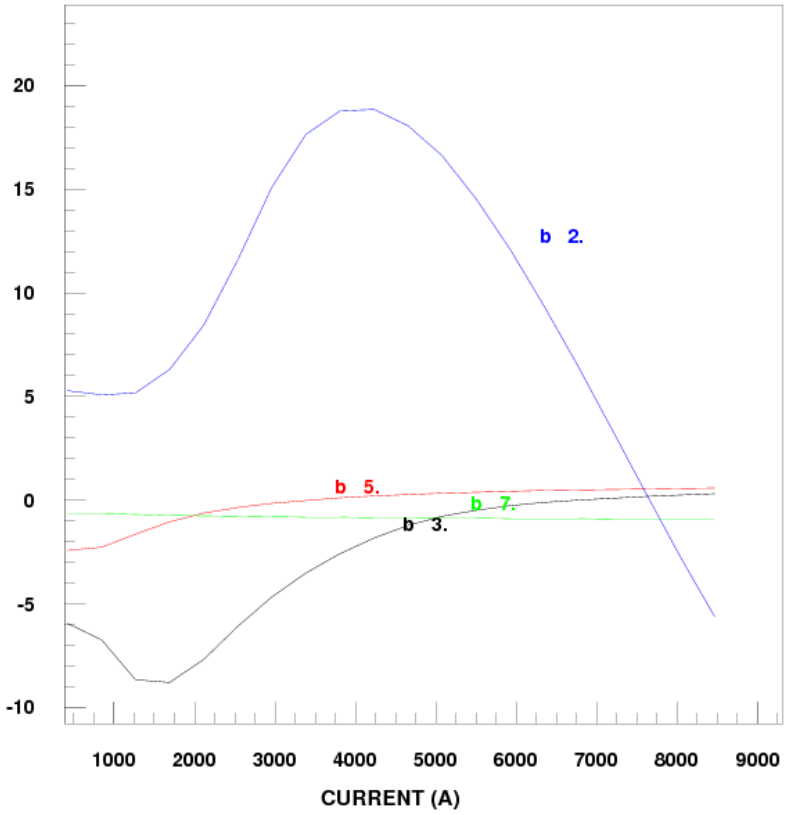
Recent modification of the operating temperature down to 1.9 K for the FCC design study



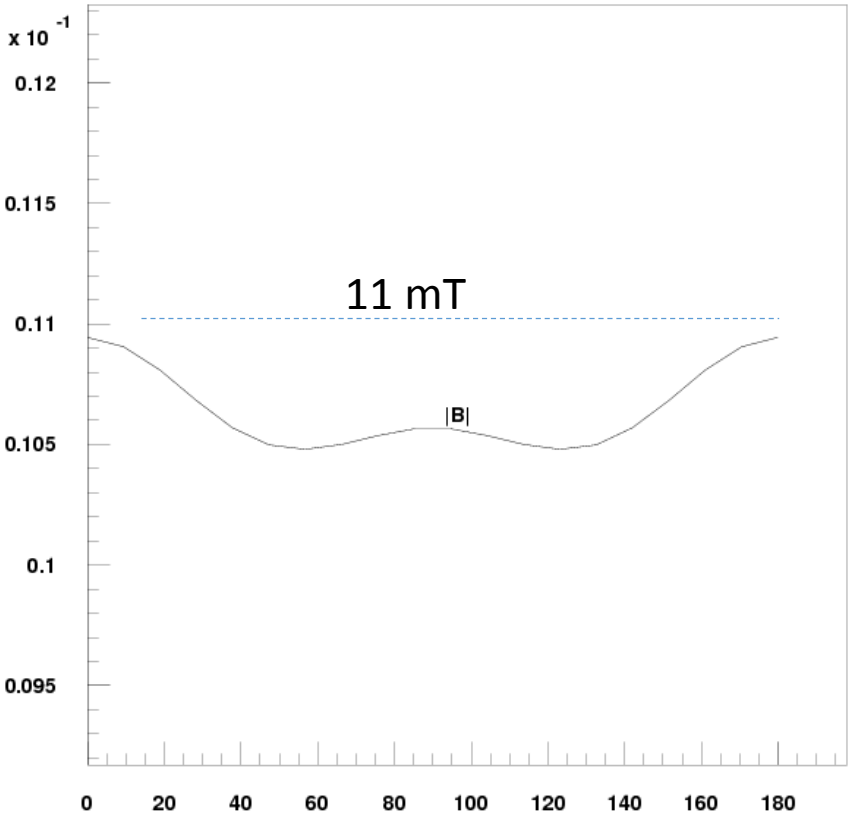
Harmonic – Fringe field

- Harmonic content

1 T to 16 T



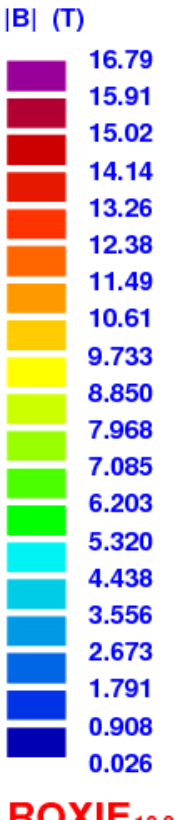
- Fringe field r = 1 m



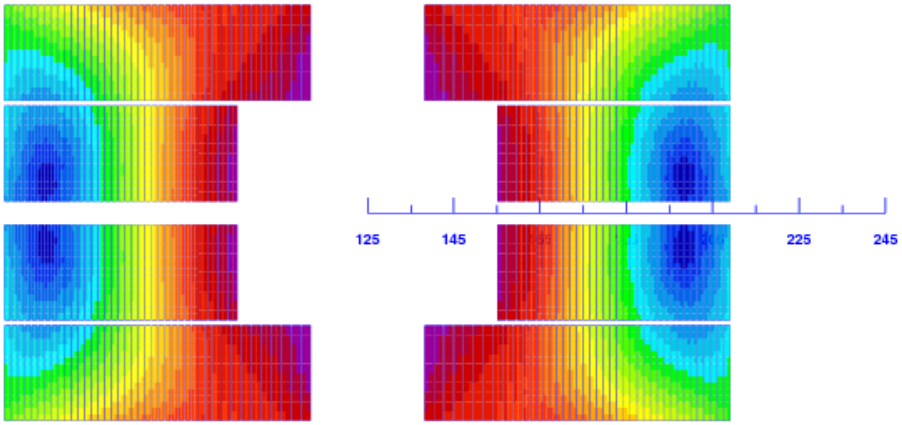
New design - higher Iop

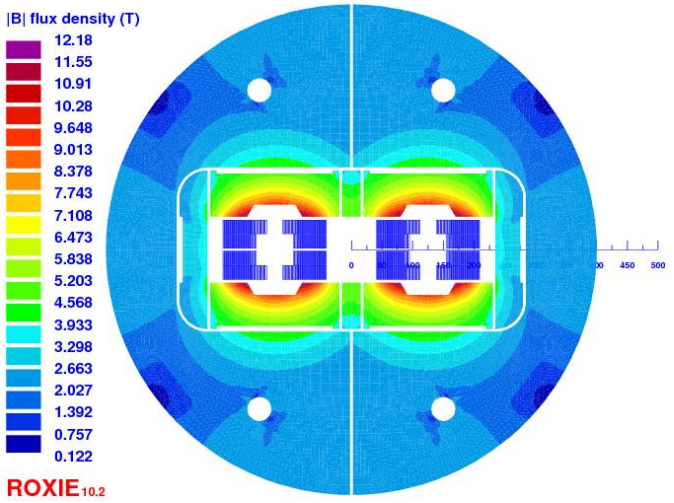
Cable parameter	value	unit
strand diameter	1.1 – 0.7	mm
nb of strands	38 – 60	N/A
width	22 – 22	mm
average thickness	2.0 – 1.25	mm
insulation	0.15	mm
Cu/nonCu	0.8– 1.5	N/A
B_{nom}	16	T
I_{nom}	15600	A
Margin loadline	15.7	%
Margin temp.	3.7	K
B_{peak}	16.79	T
Inductance diff. (2 ap)	23	mH/m
Stored energy (2 ap)	3090	kJ/m
Nb turns	74 =4+10+29+31	N/A
Conductor area (2 ap)	**152***	cm²
Yoke OD	800	mm
Fx (per ½-coil)	7780	kN/m
Fy (per ½-coil)	-3550	kN/m
Validation time	20	ms
Heater delay	20	ms
Hotspot	323	K
Wall thickness	5	mm

*8880 tons



[lower voltage-temperature gradient : see Tiina Salmi's talk]



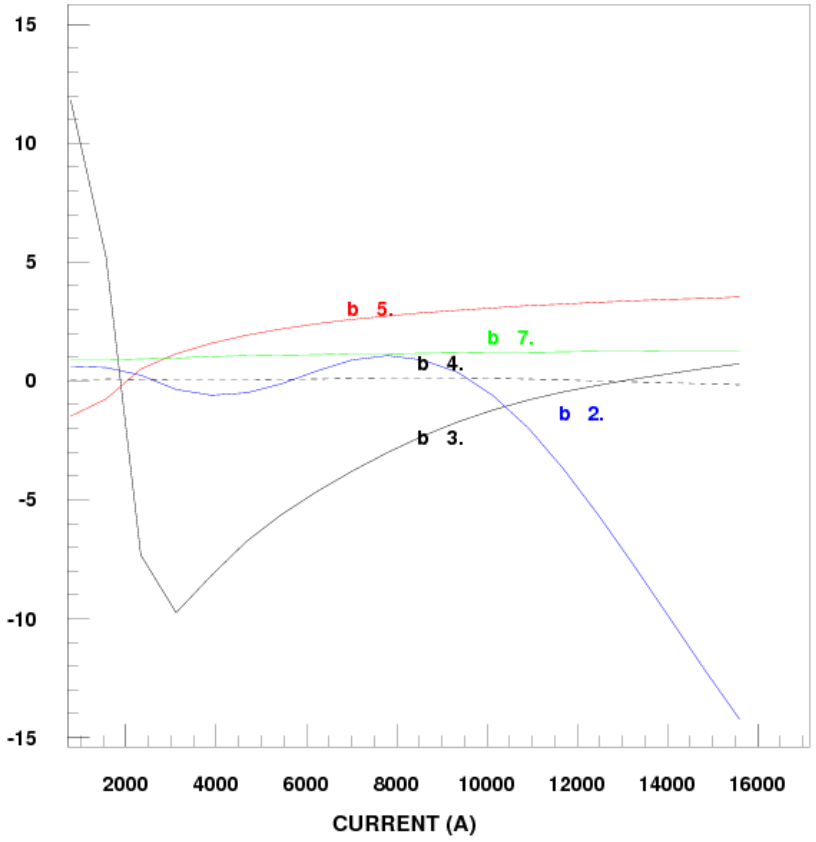


v101

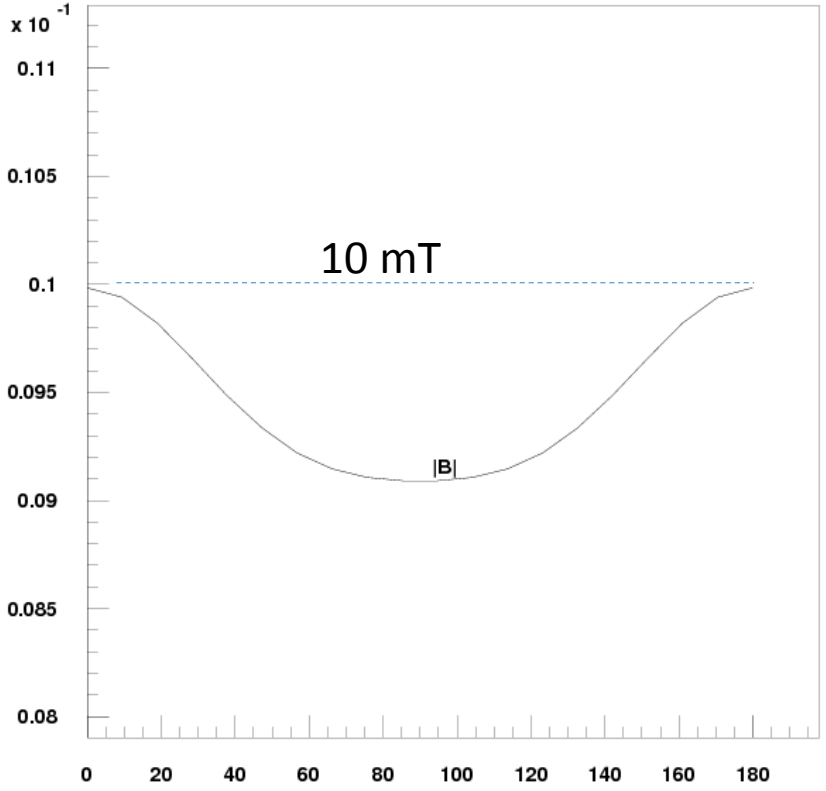
Harmonic – Fringe field

- Harmonic content

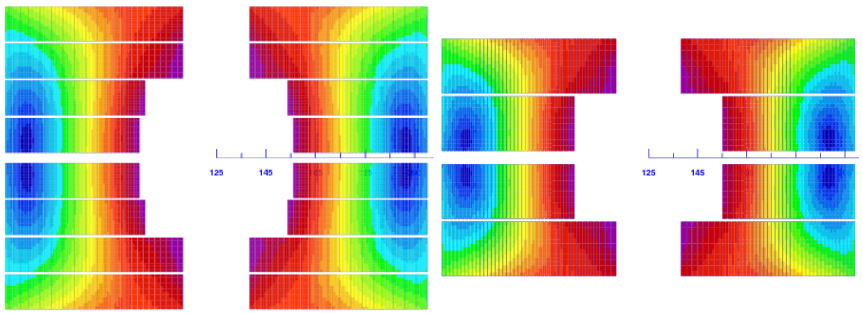
1 T to 16 T



- Fringe field r = 1 m



Summary – 16 T block dipole



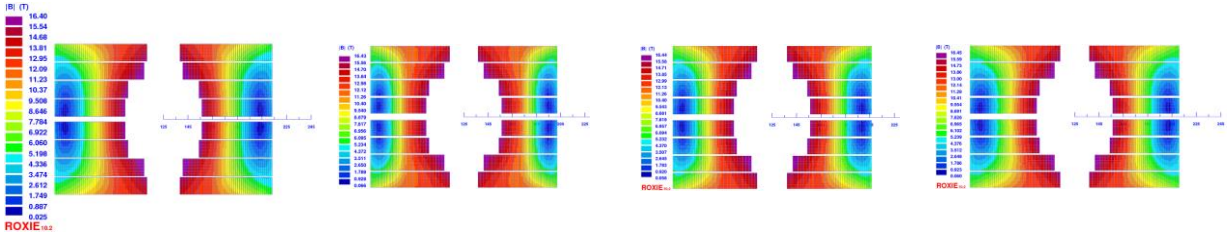
Magnet ID	v26cmag – 4 blocks	V101 – 2 blocks
Cables [mm]	24x1.1 ; 37x0.7	38x1.1 ; 60x0.7
Cu/nonCu [-]	1 ; 1	0.8 ; 1.5
Turns [-]	23 ; 130	14 ; 60
Iop [A]	8300	15600
Time [ms]	20 + 20	20 + 20
HotSpot [K]	310	323
Weight [tons]	11150	8870
Area 2 ap. [cm²]	190	149

- Grading needed to divide by 2 the amount of conductor (no investigation of Nb-Ti grading so far)
  - Internal splices
- Current > 15 kA:
  - Cu/nonCu < 1 and Nb strands > 40
- Hotspots around 300-320 K
- Harmonic content ok (1 T to 16 T)
- Unreacted cable dimension

SPARES

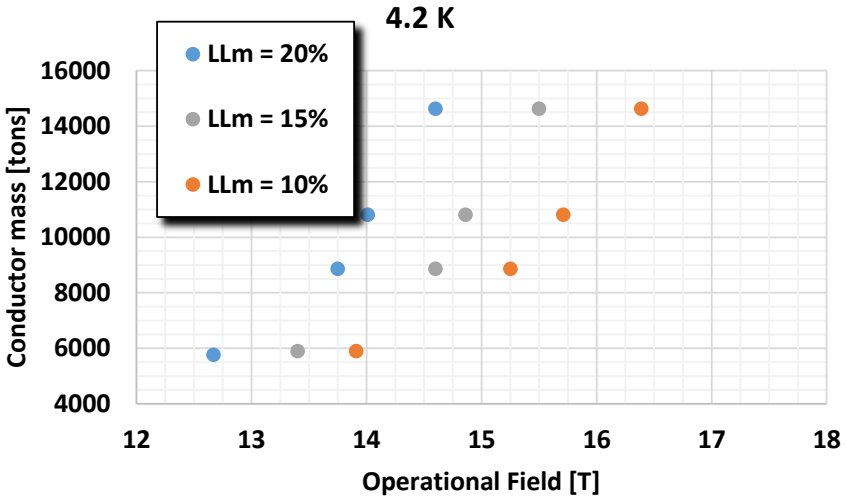
(WP5 meetings)

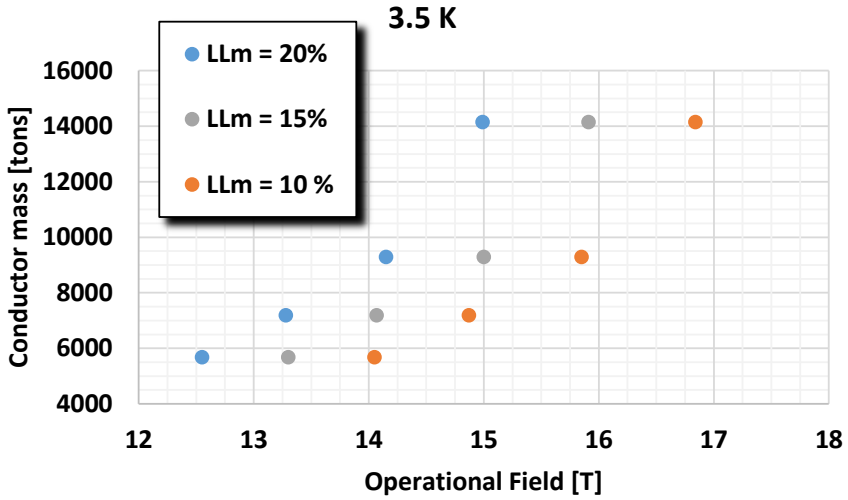
Moving away from actual baseline

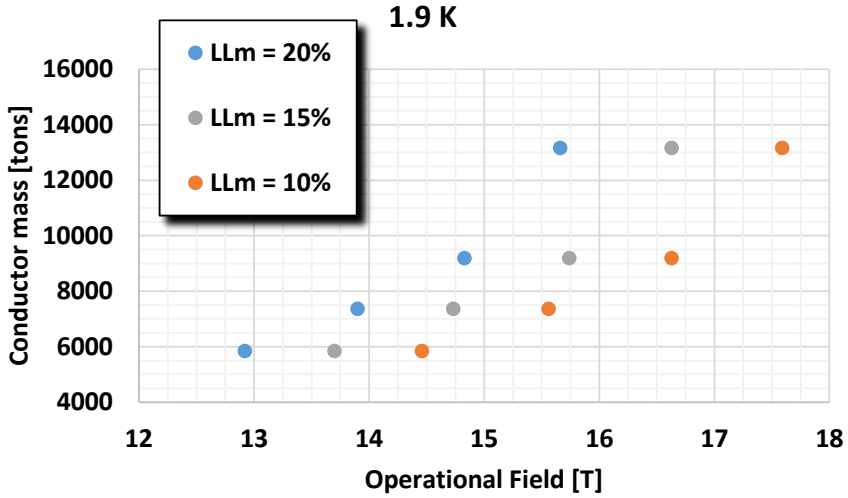


Magnet ID	26cmag - grading	Grading 3 – dec 15	Grading 4 – dec 15	Grading 5 – dec 15
Cables [mm]	24x1.1 ; 37x0.7	22x1.1 ; 48x0.5	22x1.1 ; 40x0.6	22x1.1 ; 34x0.7
Cu/nonCu [-]	1 ; 1.05	0.6 ; 1.4	0.6 ; 1.5	0.6 ; 1.5
Turns [-]	23 ; 130	45 ; 98	37 ; 108	33 ; 116
Iop [A]	8300	8840	8760	8620
Time [ms]	20 + 20	15+10	20+20	20+30
HotSpot [K]	310	~350	~300	< 300
Weight [tons]	11150	8750	9350	10400
Area 2 ap. [cm^2]	190	149	159	177

Conductor amount vs field







Mass vs B, T, LL margin

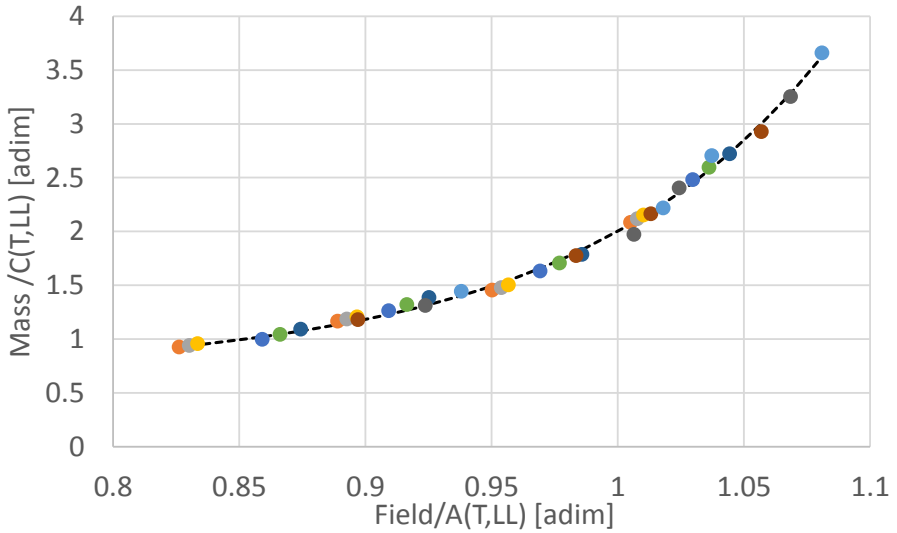
$$M = C(T, LL)\frac{b}{A(T, LL)}\left[1 + \left(\frac{b}{A(T, LL)}\right)^{11}\right]$$

with $$C(T, LL) = 6653 - 37.06T^2 - \frac{LL}{100}(1876 + 4.34T^{5.25})$$

$$A(T, LL) = 19.82 - 0.064T^{2.5} - \frac{LL}{5}$$

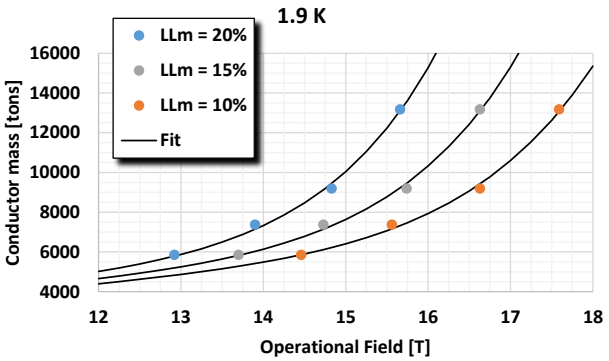
M : mass of conductor in tons ranging from 5500 to 15000
T : temperature in kelvins ranging from 1.9 to 4.2
LL : loadline margin in % ranging from 10 to 20
b : operational field in teslas ranging from 12 to 18
/!\ The fit must be used carefully
if any of the variables is out of its range of variation
C(T,LL) in tons
A(T,LL) in teslas

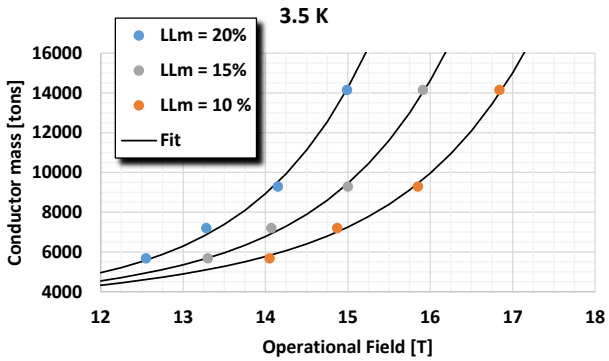
The expression fits the data within +/- 5%

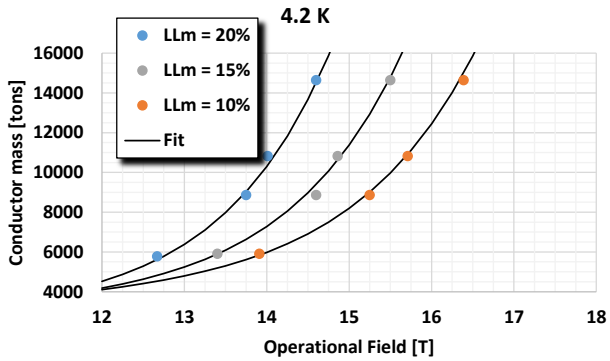


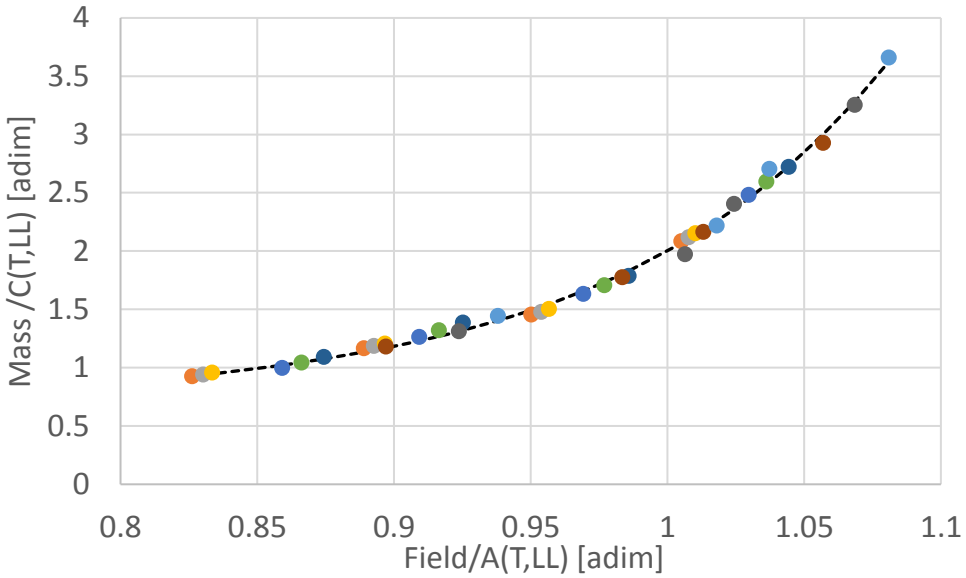
Mass vs B, T, LL margin

- The expression fits the data within +/- 5%

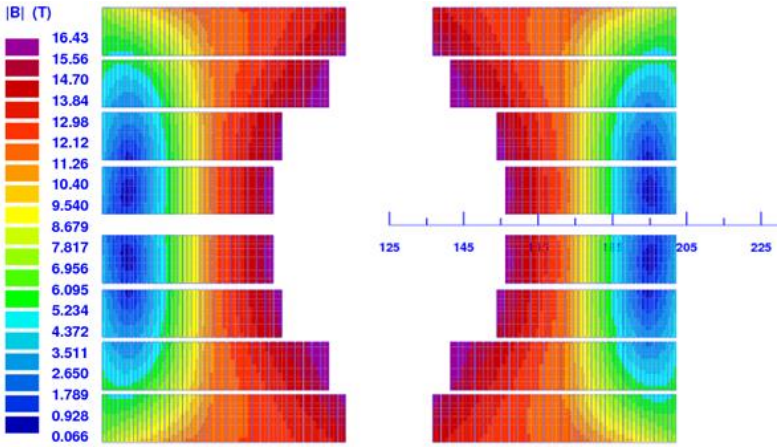


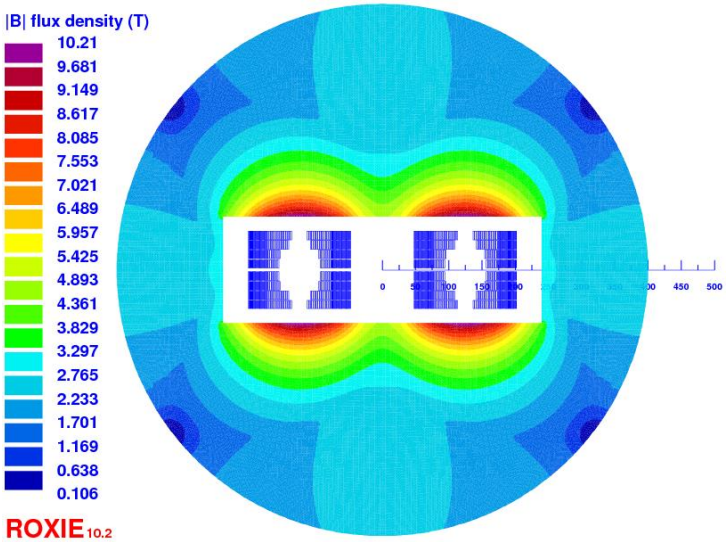






Grading 3 – December 2015 – 4.5 K (Cu/nonCu 0.6 + 48 str. 0.5 mm)

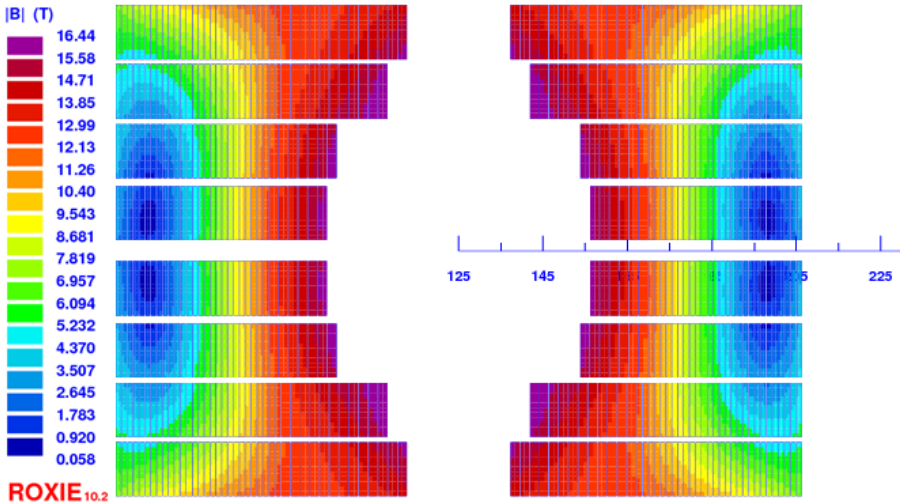


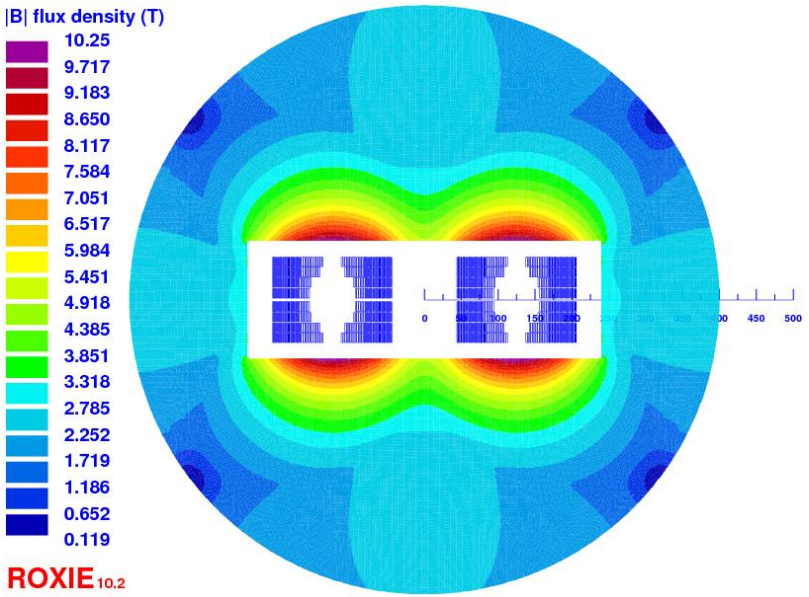


- No splice room
- Cable
  - 1.1 mm, 22 strands, 12.7 mm, 2 mm
  - 0.5 mm, 48 strands, 12.7 mm, 0.9 mm
- Cu/nonCu = 0.6 inner 1.4 outer
- 15 + 10 ms, hotspot ~ 350 K
- 45/98 turns -> 8750 tons (149 cm²)
- Iop = 8840 A
- About the same quantity of conductor as GL Sabbi, same time to react*

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

Grading 4 – December 2015 – 4.5 K (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 -> 9,320 tons (159 cm²)
- Iop = 8760 A