EuroCircol – The Cosine-theta Configuration:

Electromagnetic Design

Vittorio Marinozzi
on behalf of INFN team:

Giovanni Bellomo, Barbara Caiffi, Pasquale Fabbricatore,
Stefania Farinon, Massimo Sorbi, Giovanni Volpini

UNIVERSITÀ DEGLI STUDI DI MILANO

EuroCirCol
A key to New Physics

INFN
Istituto Nazionale di Fisica Nucleare

FCC hh ee he

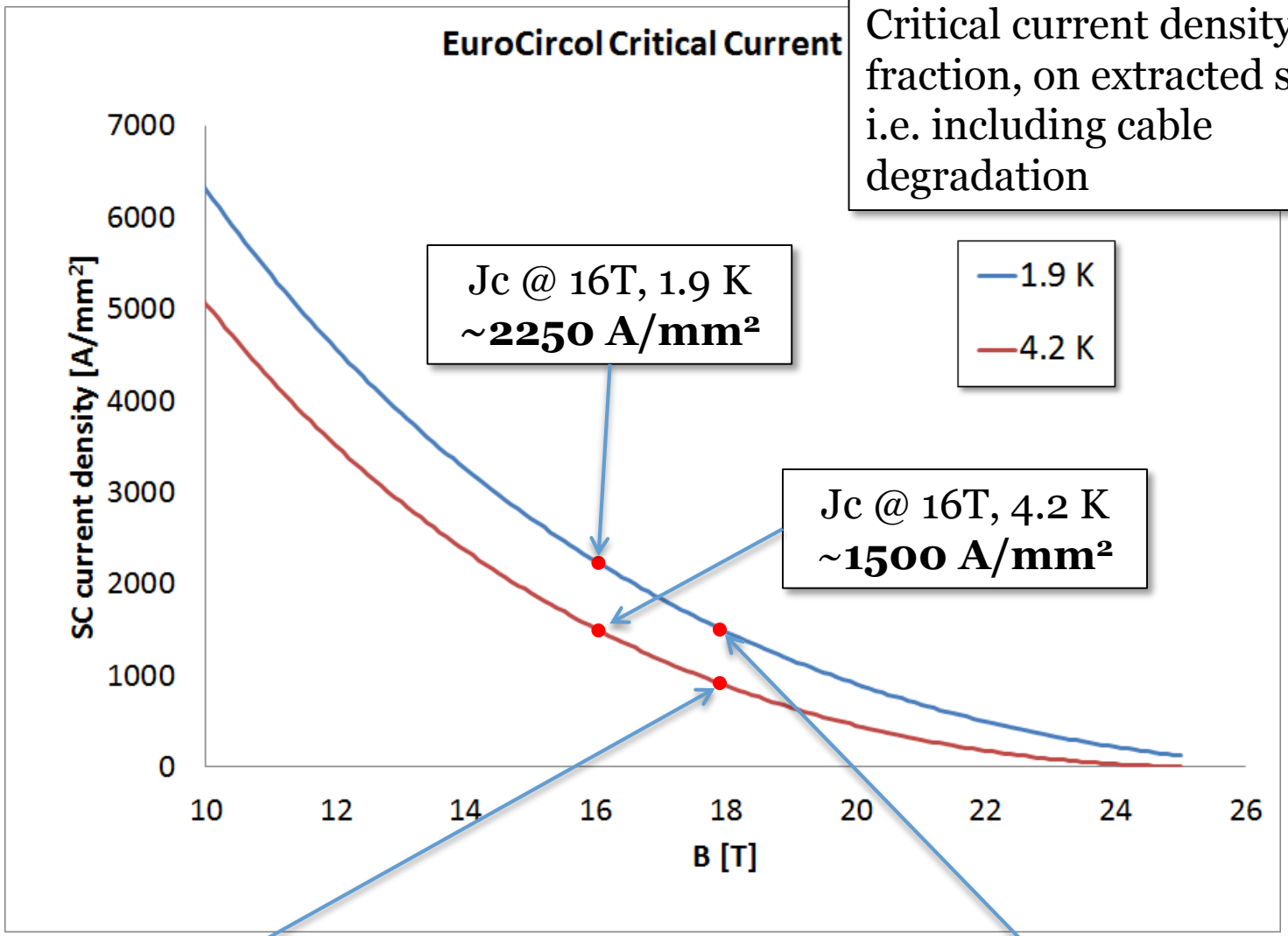
Outline:

1. Main design parameters
2. Magnetic design
3. Protection

1.1 Main design parameters

Constraints for the magnet design	
Bore inner diameter	50 mm
Beam distance	250 mm
Bore nominal field	16 T
Operating temperature	1.9 K
Oper. point on the load line (with "self field")	≤86 %
Strand number per cable	≤60
Maximum strand diameter	1.2 mm
Cable insulation thickness	0.15 mm
Cu/NCu	≥0.8
Field harmonics (geometric/saturation)	≤3/10 units
Peak temperature (105 % of operating current)	≤350 K
Yoke outer radius	400 mm
Maximum voltage to ground	~1 kV
Minimum wedge thickness	~1 mm

1.2 Main design parameters



Critical current density in S.C. fraction, on extracted strands, i.e. including cable degradation

Jc @ 16T, 1.9 K
~2250 A/mm²

Jc @ 16T, 4.2 K
~1500 A/mm²

Jc @ 18T, 4.2 K
~890 A/mm²

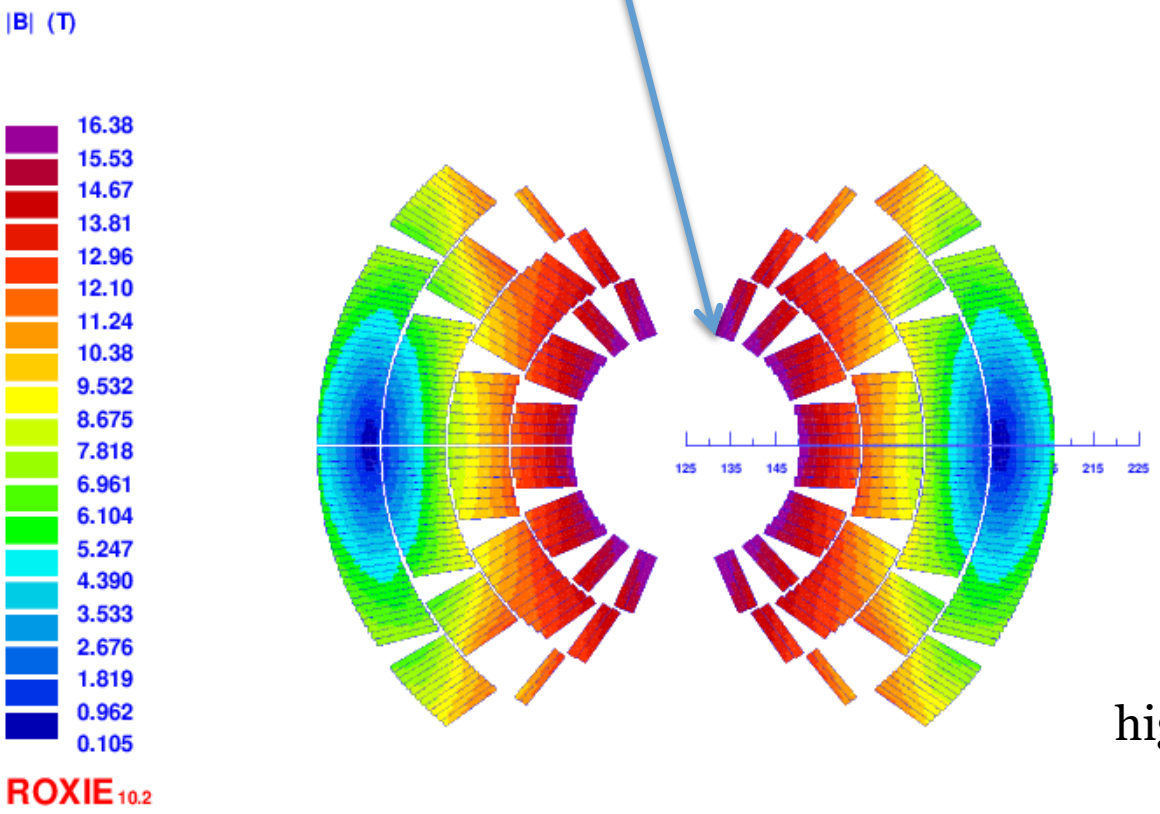
Jc @ 18T, 1.9 K
~1500 A/mm²

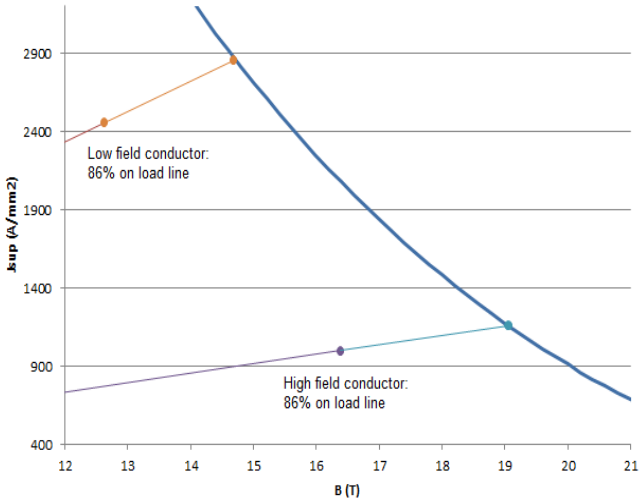
2.1 Magnetic design - cross section

Configuration: **16T-22b-37-optd6f6**

B peak
16.38 T (with strand "self-field")

Main characteristics:
- 2 double-pancakes
- 2 conductor size
- Splitting of pole blocks to decrease peak-field





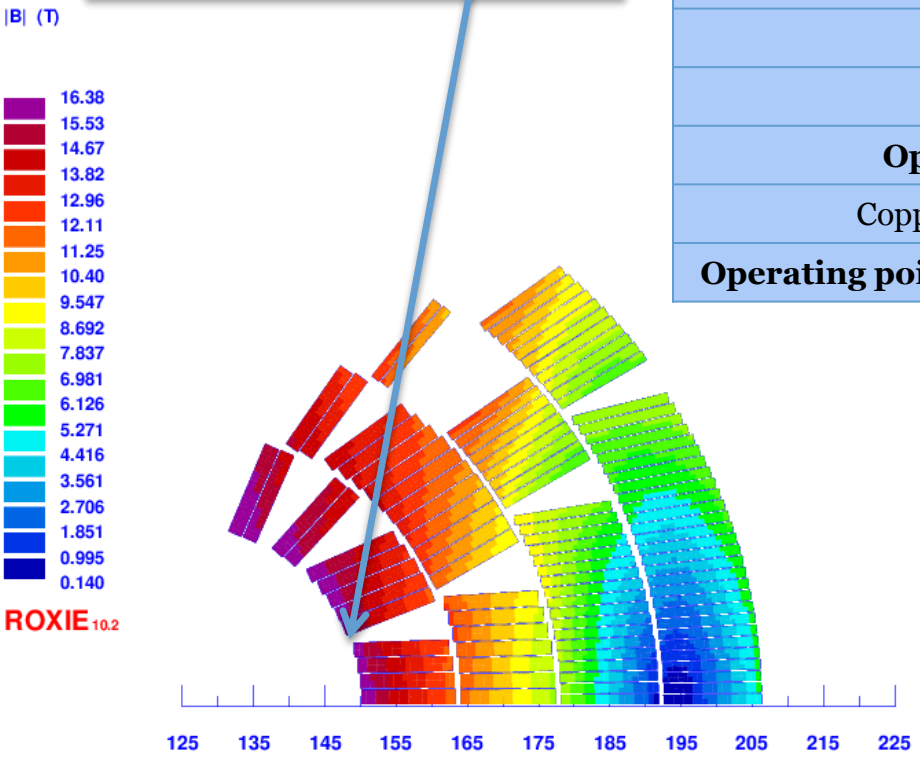
high-field cond.
low-field cond.

Turn number:
Layer 1: 13
Layer 2: 20
Layer 3: 29
Layer 4: 39
Tot: 202/ap.

2.2 Magnetic design - Conductor

Wedge minimum thickness: **0.80 mm**

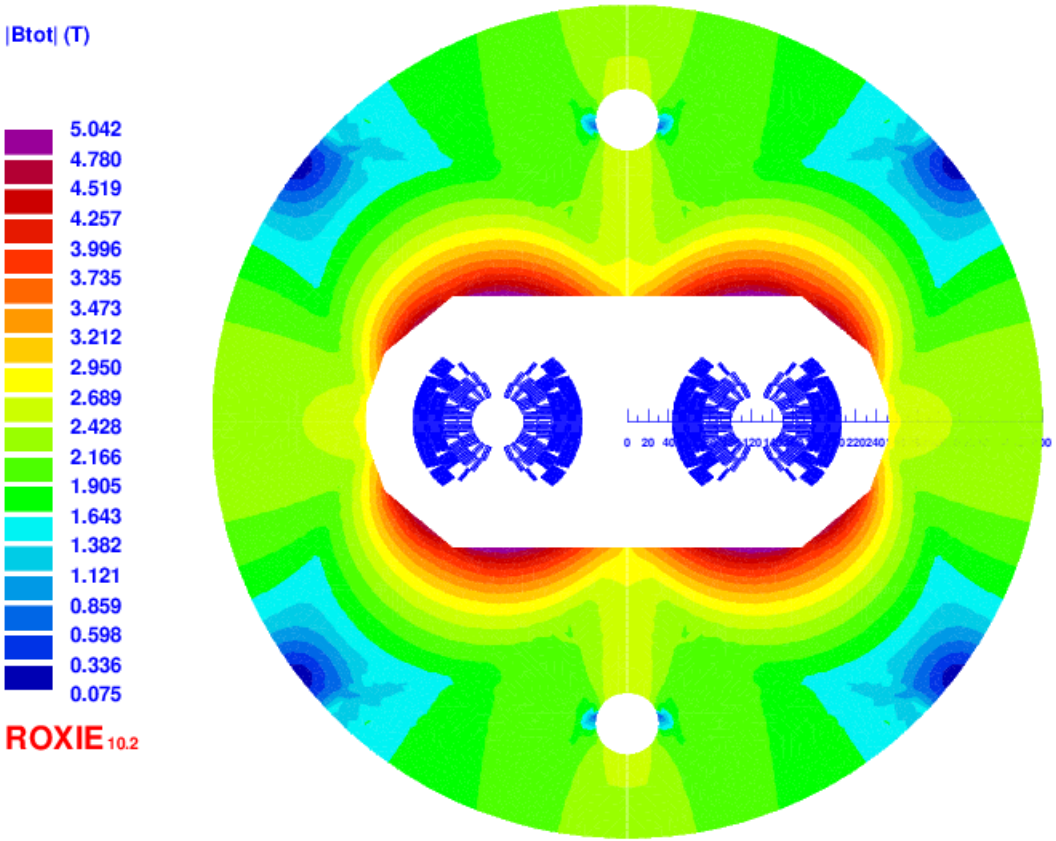
In LHC: 0.70 mm
In D11: 0.98 mm



	Cable 1 (inner)	Cable 2 (outer)
Strand number	22	37
Strand diameter	1.1 mm	0.7 mm
Bare width	13.2 mm	13.65mm
Bare inner thickness	1.892 mm	1.204 mm
Bare outer thickness	2.072 mm	1.3231 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.5°	0.5°
Cu/NCu	0.85	2.1
Operating current	**11230 A**	**11230A**
Copper current density	1169 A/mm²	1165 A/mm²
Operating point on LL (1.9 K)	**86%**	**86%**

2.3 Magnetic design – iron yoke

Possible lay-out of iron yoke for the positioning of collar in double aperture



Collar +
Bladder & key

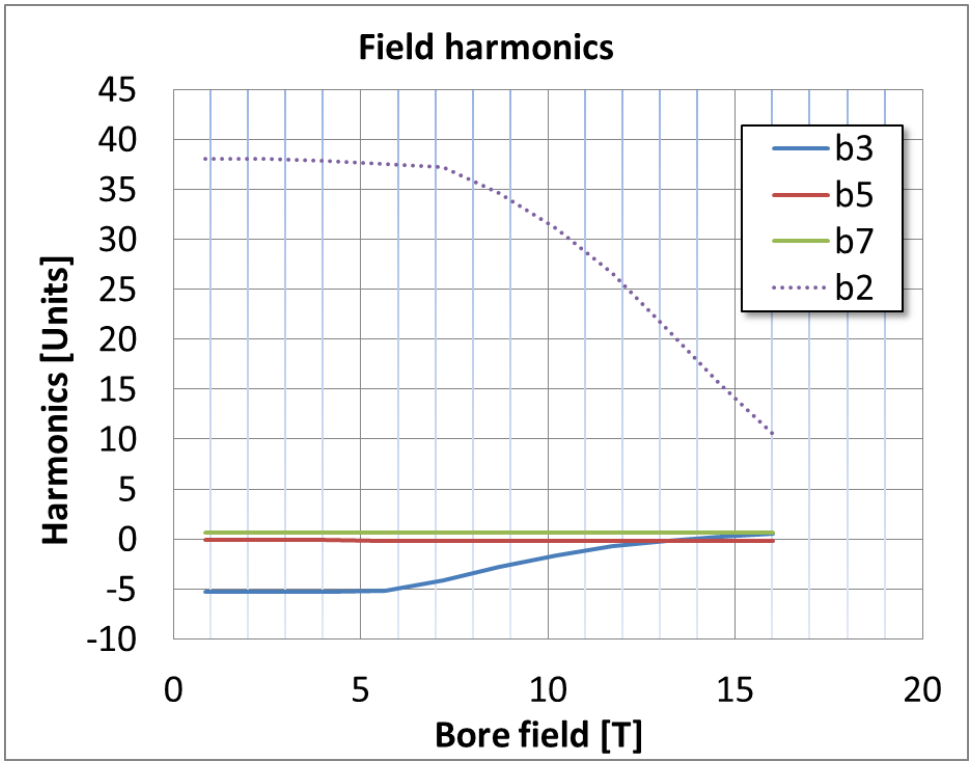
Inductance@I_{op} (1 ap)	Stored energy (1 ap)
19.7 mH/m	1.3 MJ/m

2.4 Magnetic design – field quality

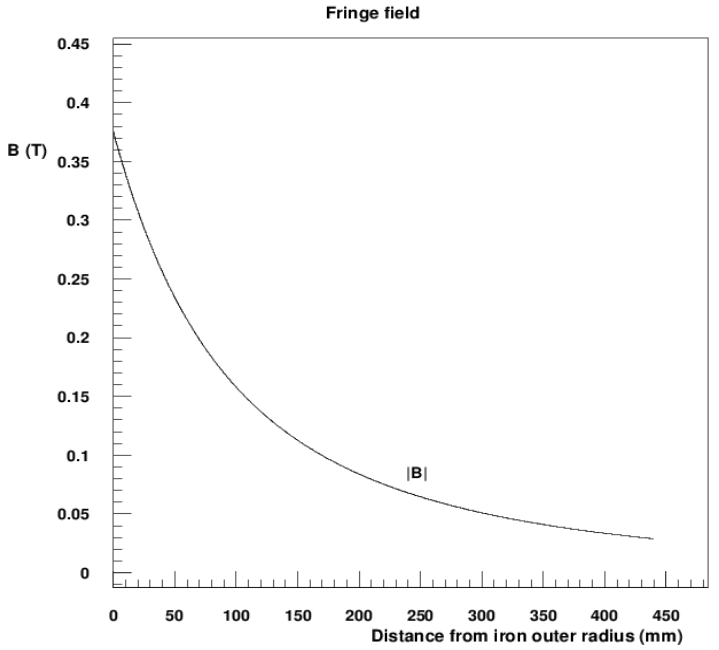
NORMAL RELATIVE MULTIPOLES @ 16 T:

b 1: 10000	b 2: 10.56	**b 3: -0.53**
b 4: -0.25	**b 5: -0.16**	b 6: -0.01
b 7: 0.63	b 8: -0.00	**b 9: 0.98**
b10: 0.00	**b11: 1.01**	b12: 0.00
b13: -0.17	b14: 0.00	**b15: 0.02**

- b2 optimization <u>not performed</u>
- Persistent currents **not** considered



<u>Fringing field < 0.1 T at 200 mm from yoke</u>



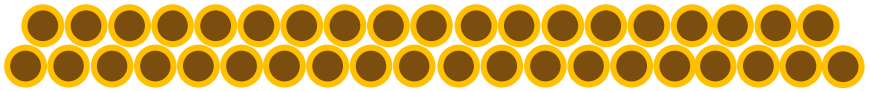
2.5 Magnetic design – strand area

Conductor 1:

- 22 strands
- ∅ = 1.1 mm
- **Cu/NCu = 0.85**
- J_{cu} = 1169 A/mm²
- Strand Area = 27.6 cm²/apert.
- Weight (FCC) = 3.14 ktons

Conductor 2

- 36 strands
- ∅ = 0.712 mm
- **Cu/NCu = 2.10**
- J_{cu} = 1165 A/mm²
- Strand Area= 38.7 cm²/apert.
- Weight (FCC) = 4.41 ktons



COND. AREA (double ap.): = 132.6 cm²

FCC-hh dipoles:

- **COND. MASS: = 7.55 ktons**

Data for FCC-hh collider	
Number of dipole units	4578
Dipole lenght	14.3 m
Conductor density	8.7 kg/dm³

2.6 Magnetic design – strand area

➢ **Option to <u>reduce cost</u>**

Conductor 2

24 (**SC**)+13 (**Cu**) strands

- ∅ = 0.7 mm
- **Cu/NCu in S.C. strand= 1.0**
- J_{cu} = 1165 A/mm²
- Strand Area (SC)= 24.9 cm²/apert.
- Strand Area (Pure Cu) = 14.1 cm²/apert.
- SC strand weight (FCC) = 2.84 ktons
- Pure Cu strand weight (FCC) = 1.61 ktons
- Pure Cu cost << SC cost

➢ Stability as in cable 1 (Cu/NCu = 1)

➢ Current diffusion time in the Cu strands to be evaluated and **compared with discharge time**

- Zero order evaluation seems **ok** (few ms)

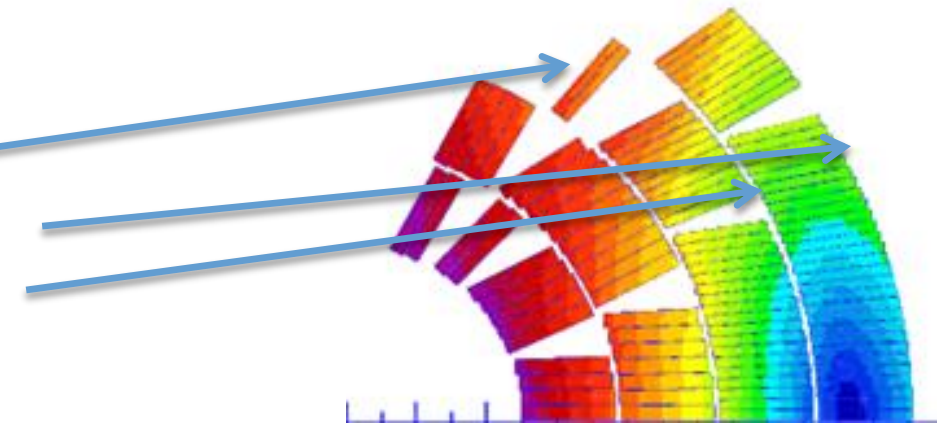
<u>TOTAL SC STRANDS: =</u> 7.55 → **<u>6.00 ktons (-20%)</u>**

3.1 Protection

Simulations from **Coodi** (Tiina Salmi)

- Main assumptions:
  - **No** energy extraction
  - Quench induced in the whole magnet **40 ms** after initial quench start
  - Inductance dependence on the current
  - Material properties from **NIST**

- Results (**105 %** of I_{op}):
  - Hot spot temperature: **340 K**
  - Maximum voltage to ground: **800 V**
  - Layer-to-layer max voltage: **970 V**
  - Turn-to-turn max voltage: **90 V**



More details in the Tiina Salmi talk

Conclusions:

- The magnetic design fully accomplishes the EuroCirCol requirements
- The magnet produce 16 T magnetic field at 86% of the load-line (including self field)
- The pole conductors of the layer 1 and 2 have been misaligned
- Field quality is good: geometric harmonics within 1 unit, saturation of b3 within 5 units.
- 7.55 ktons of conductor, which could be optimized to 6

Work in progress and perspectives:

- Iron yoke to be upgraded to the optimized version of the mechanical structure (see talk on the mechanics), not worrying
- Increase keystoning (thin edge of low field cond.)?
- Optimization of b2 to be performed
- Study feasibility of conductor with pure Cu strands
- Start e.m. 3D study?