EuroCircol – The Cosine-theta Configuration:

Electromagnetic Design Ver. 2.1

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EuroCirCol A key to New Physics

INFN Istituto Nazionale di Fisica Nucleare

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
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

88% before

1.0 before

- Magnetic design for a **double aperture** magnet
- Mechanical design for a **single aperture** magnet

Additional costrains (reviewer suggestions):

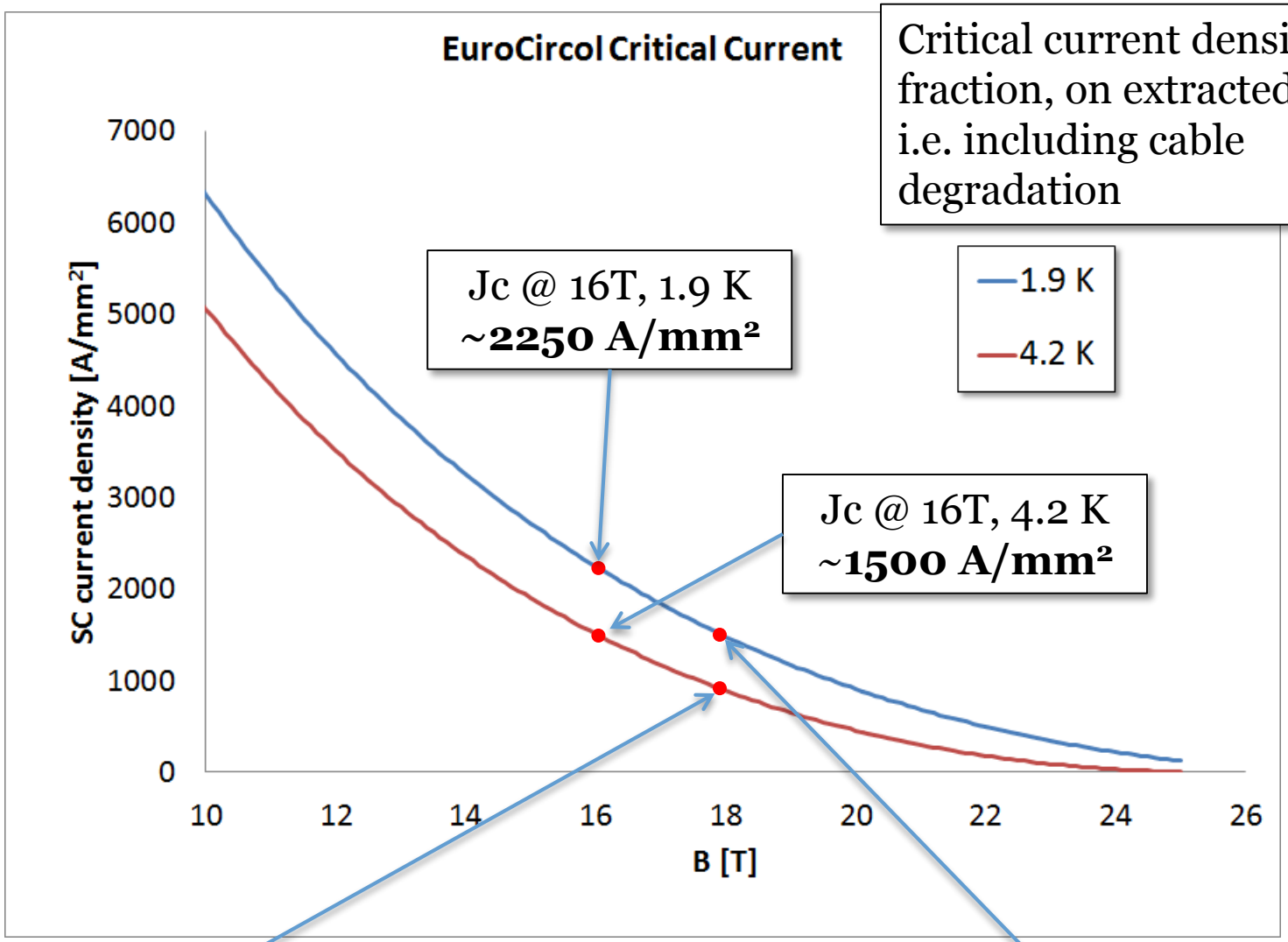
- Maximum strand diameter: 1.2 mm
- Minimum dimensions of wedge between blocks: ~1 mm

Other costrains:

- Number of layers: (even) → 4

This drive to have an optimized value of current of ~10.5 kA and so a number of strands < 40.

1.2 Main design parameters



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

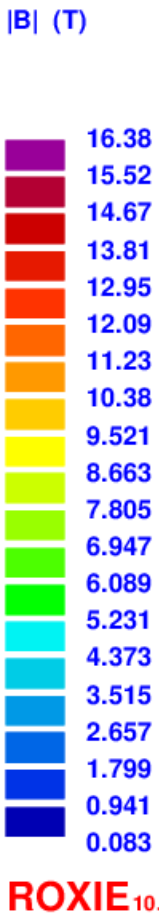
Jc @ 16T, 1.9 K
~2250 A/mm²

Jc @ 16T, 4.2 K
~1500 A/mm²

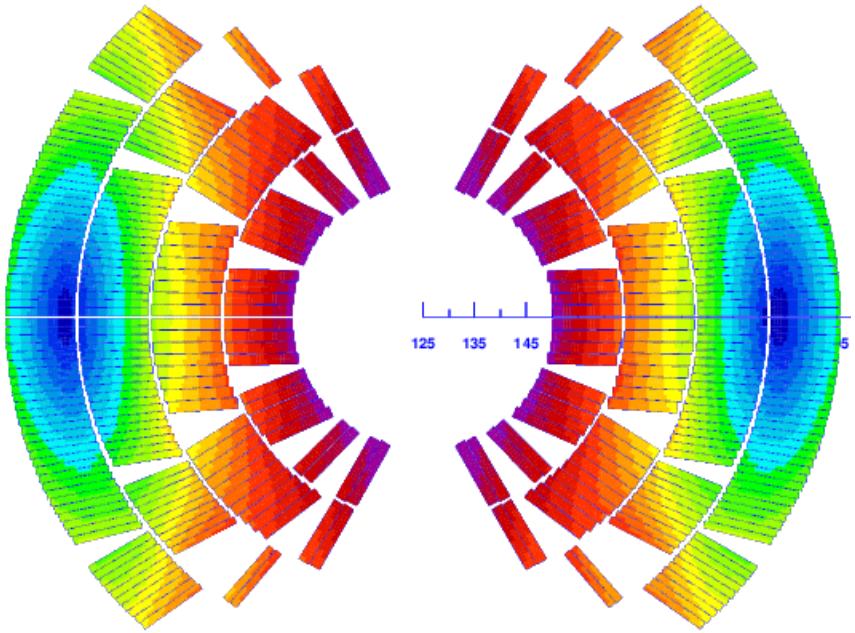
Jc @ 18T, 4.2 K
~890 A/mm²

Jc @ 18T, 1.9 K
~1500 A/mm²

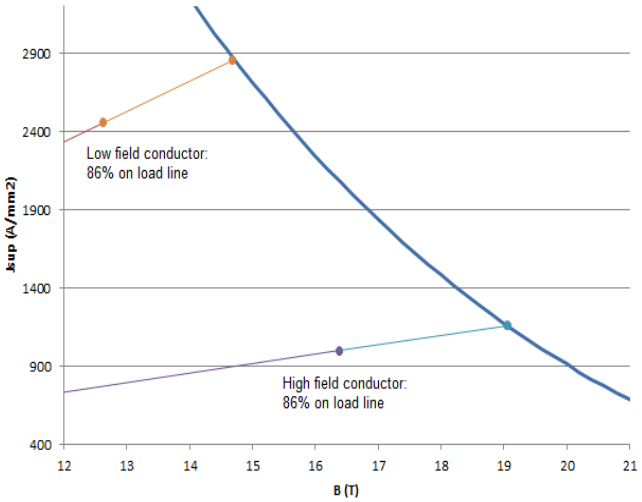
Configuration: **16T-22b-36-optd5f6**



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



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



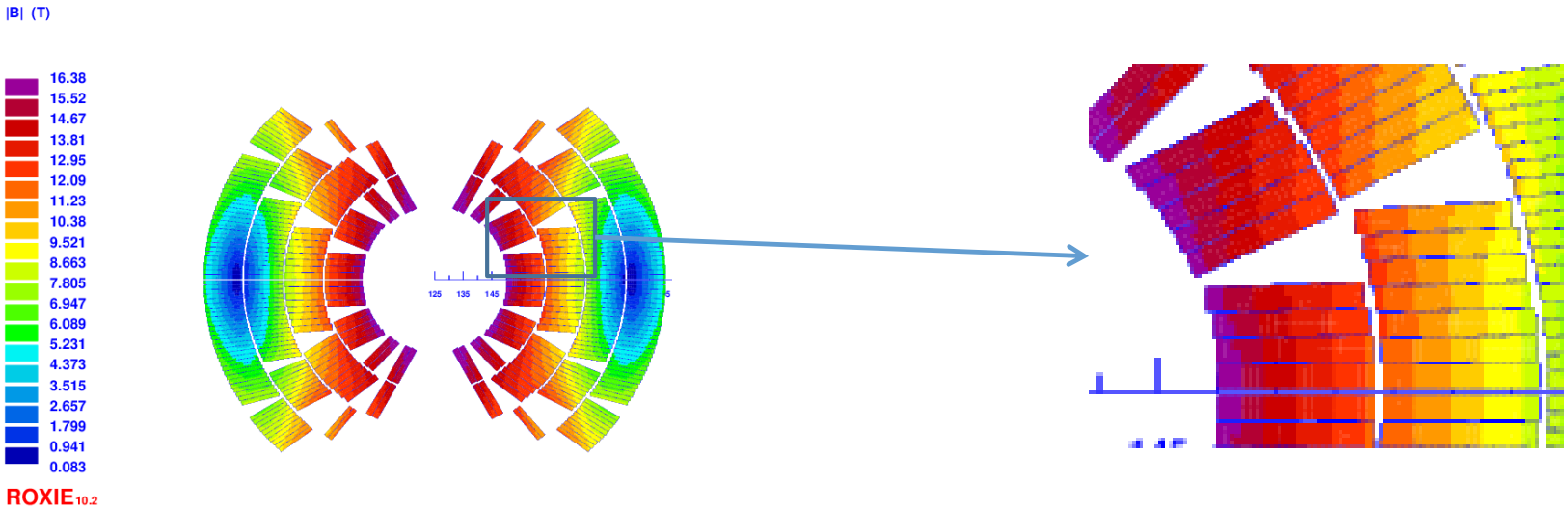
Turn number:

high-field cond.
- Layer 1: 13
- Layer 2: 20

low-field cond.
- Layer 3: 30
- Layer 4: 38

Tot: 202/ap.

2.1 Magnetic design – cross section



	Cable 1 (inner)	Cable 2 (outer)
Strand number	22	36
Strand diameter	1.1 mm	0.712 mm
Bare width	13.2 mm	13.5mm
Bare inner thickness	1.892 mm	1.225 mm
Bare outer thickness	2.072 mm	1.343 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.5°	0.5°
Cu/NCu	0.85	2.15
Operating current	**11180 A**	**11180A**
Copper current density	1165 A/mm²	1143 A/mm²
Operating point on LL (1.9 K)	**86%**	**86%**

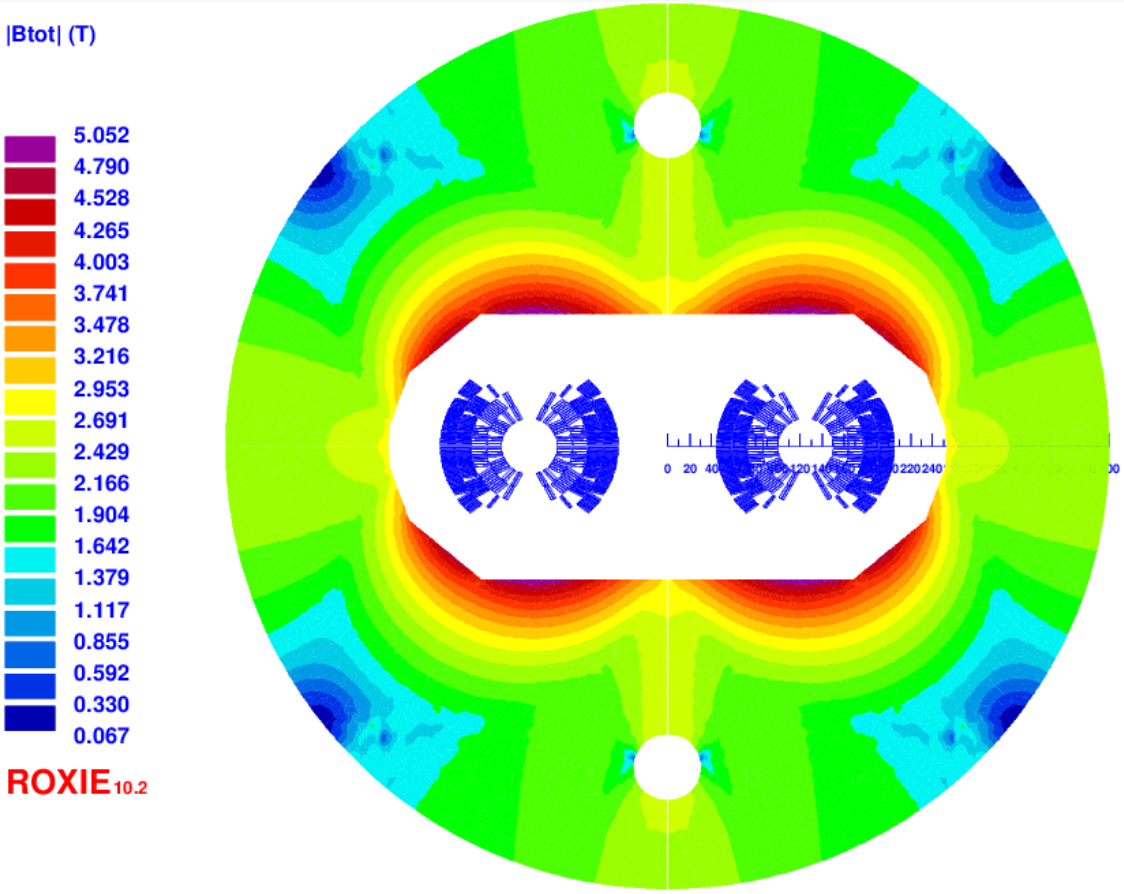
Wedge minimum thikness: **0.80 mm**

In LHC: 0.70 mm
In D11: 0.98 mm

→ including the ”self-field”

2.2 Magnetic design – iron yoke

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



Collar +
Bladder & key

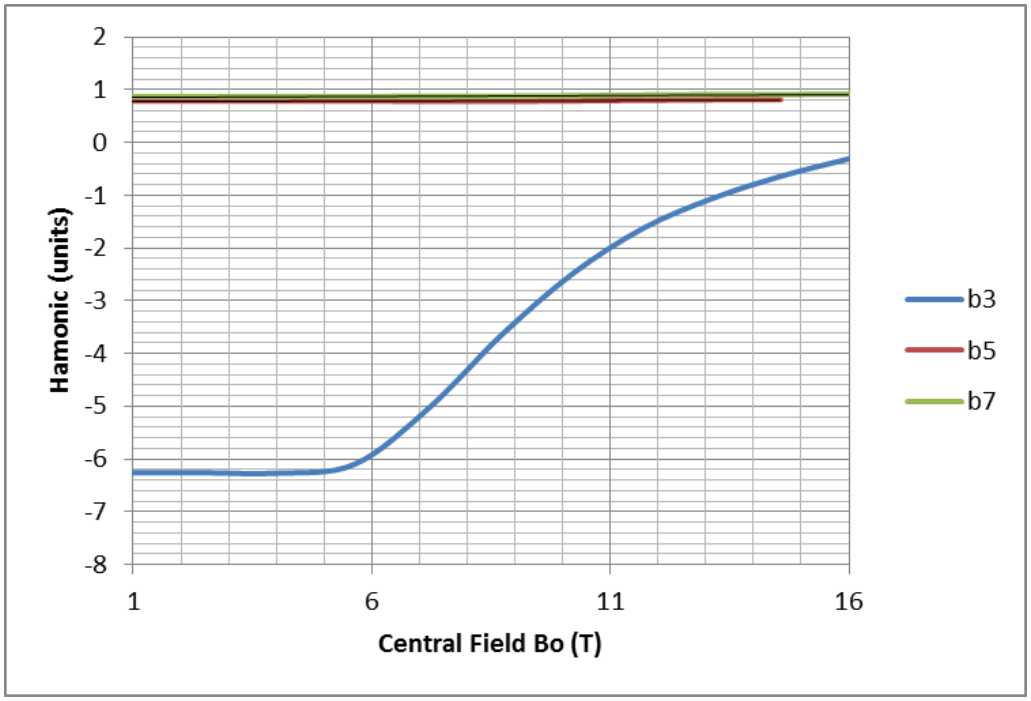
Inductance@I_{op} (1 ap)	Stored energy (1 ap)
19.9 mH/m	1.3 MJ/m

2.3 Magnetic design – field quality

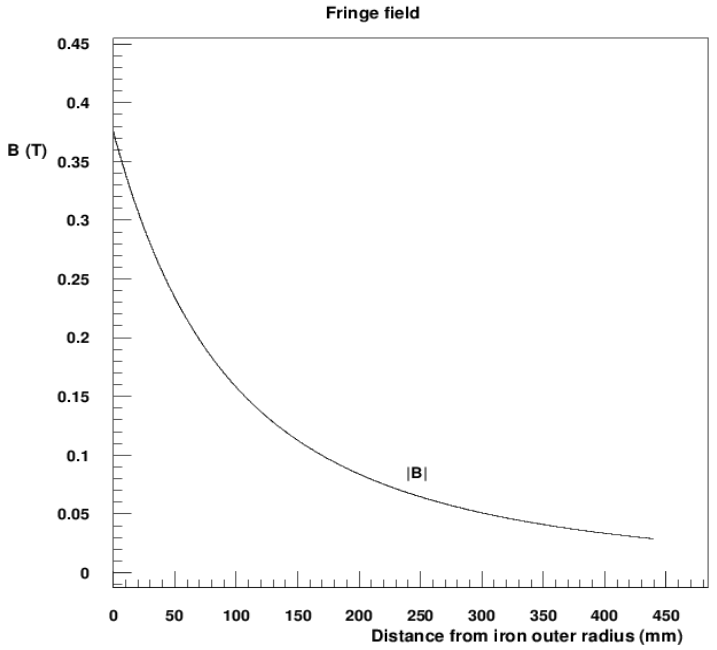
NORMAL RELATIVE MULTIPOLES @ 16 T:

b 1: 10000	b 2: 10.83	**b 3: -0.31**
b 4: -0.25	**b 5: 0.82**	b 6: -0.01
b 7: 0.92	b 8: -0.00	**b 9: 0.80**
b10: 0.00	**b11: 1.09**	b12: 0.00
b13: -0.15	b14: 0.00	**b15: 0.01**

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



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



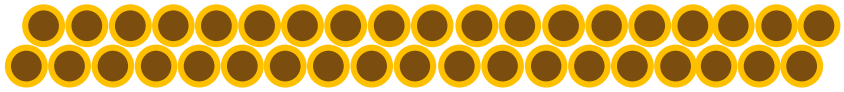
2.4 Magnetic design – strand area

Conductor 1:

- 22 strands
- ∅ = 1.1 mm
- **Cu/NCu = 0.85**
- J_{cu} = 1143 A/mm²
- Strand Area = 27.6 cm²/apert.
- Weight (FCC) = 3.14 ktons

Conductor 2

- 36 strands
- ∅ = 0.712 mm
- **Cu/NCu = 2.15**
- J_{cu} = 1165 A/mm²
- Strand Area= 39.0 cm²/apert.
- Weight (FCC) = 4.44 ktons



COND. AREA (double ap.): = 133.2 cm²

FCC-hh dipoles:

- **COND. MASS: = 7.59 ktons**

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

2.5 Magnetic design – strand area

➢ Option to <u>reduce cost</u>

Conductor 2

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

- ∅ = 0.712 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)

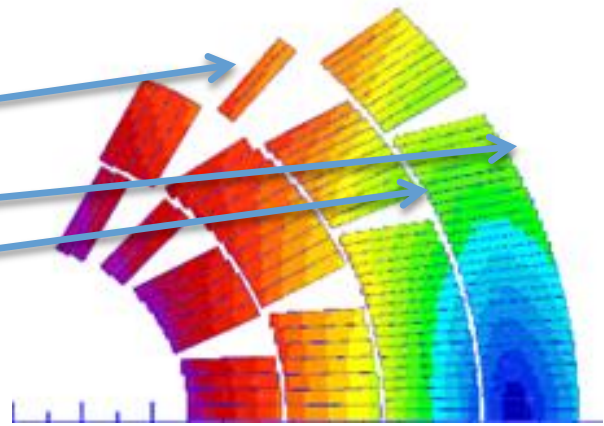
<u>TOTAL SC STRANDS: =</u> 7.59 → **<u>5.98 ktons (-21%)</u>**

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: **344 K**
  - Maximum voltage to ground: **0.77 kV**
  - Layer-to-layer max voltage: **0.91 kV**
  - Turn-to-turn max voltage: **86 V**



More details in the Tiina Salmi EuroCirCol presentations