

Development of a Curved Fast Ramped Dipole for FAIR SIS300

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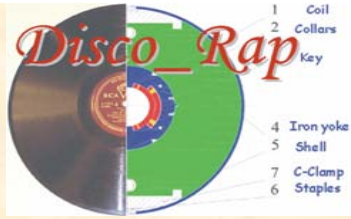
(1)INFN-Genova, Italy

(2)INFN-LASA and Milan University, Physics Department, Italy

(3)INFN-Laboratori di Frascati, Italy

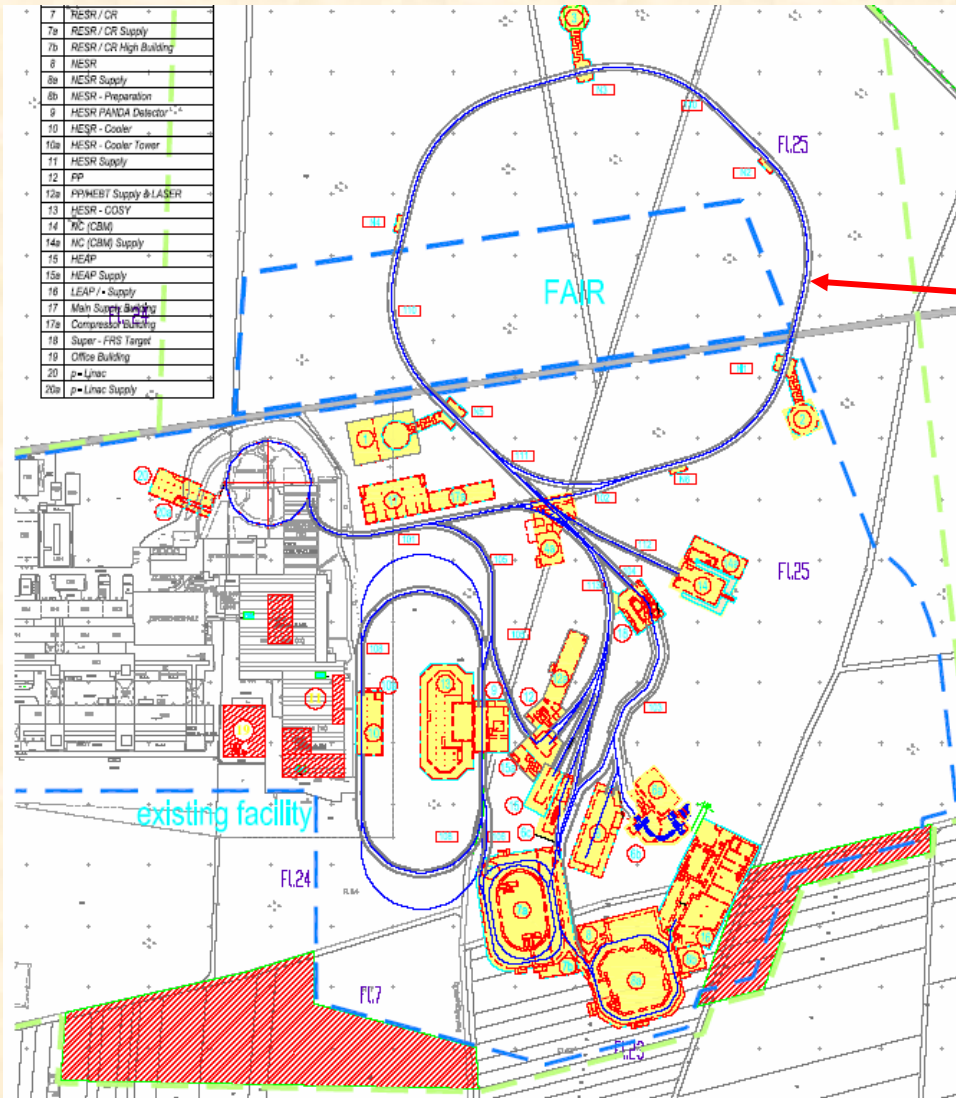
(4)GSI, Germany

(5)ASG-Superconductors (former Ansaldo), Genova, Italy,



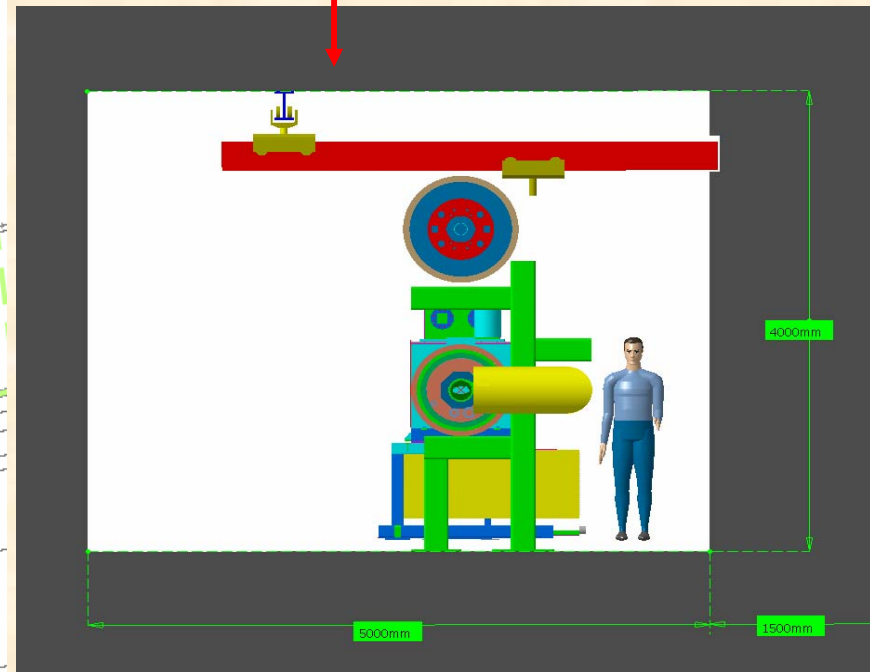
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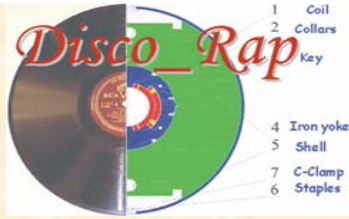
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The facility **FAIR** including the synchrotrons

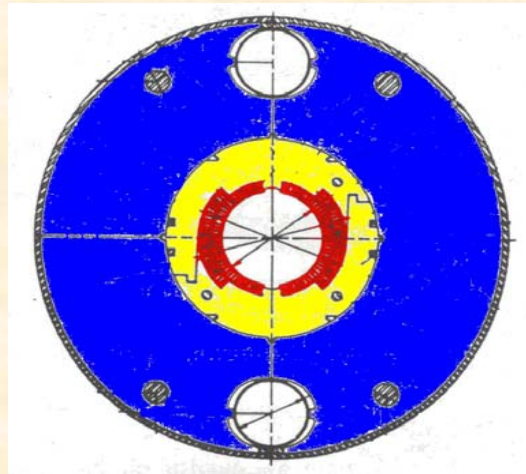
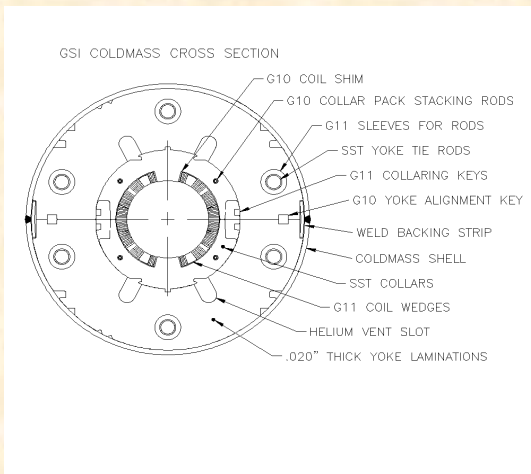
SIS100 and SIS300





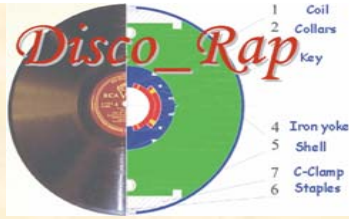
Present characteristics of SIS300 magnets

| | Number of Magnets | Usable Aperture (mm) | Eff. Magnet Length (m) | Max. Field / Max.Gradient | Max. Ramprate |
|-----------------------------|-------------------|---|------------------------|---------------------------|---------------|
| Dipoles (curved, R= 66.7 m) | 48/12 | 86 (circular) (coil inner diameter: 100mm) | 7.757 / 3.879 | 4.5 T | 1 T/s |
| Quadrupoles | 84 | 105 (circular) (coil inner diameter: 120mm) | 1.0 | 45 T/m | 10 T/m/s |



4.5 T dipole; 7.8 m
curved (R= 66.67 m)

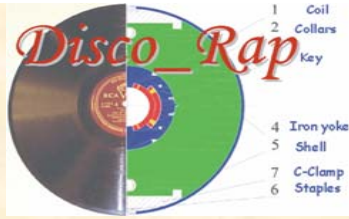
Preliminary studies in 2006
R&D **DISCORAP** started
in 2007 at INFN



Crucial aspects demanding R&D

- 1) **Ac losses 1** → Try to reduce the losses down to a value compatible with an efficient heat extraction, not mechanically weakening the coil → **Material and winding optimization**
- 2) **Ac losses 2** → Try to reduce the losses limiting at the same time the effects on stability and on critical current → **Conductor R&D**
- 3) **Curvature** (114 mm sagitta)/**Cored cable** → **Winding technology**
- 4) **Fatigue** (10^6 cycles) → **Design optimization, Material qualification**

| | Aperture (mm) | B (T) | dB/dt (T/s) | Q (W/m) |
|--------|---------------|-------|-------------|----------|
| LHC | 53 | 8.34 | 0.0075 | 0.18 |
| RHIC | 80 | 3.5 | 0.07 | 0.35 |
| SIS300 | 100 | 4.5 | 1 | 5 |



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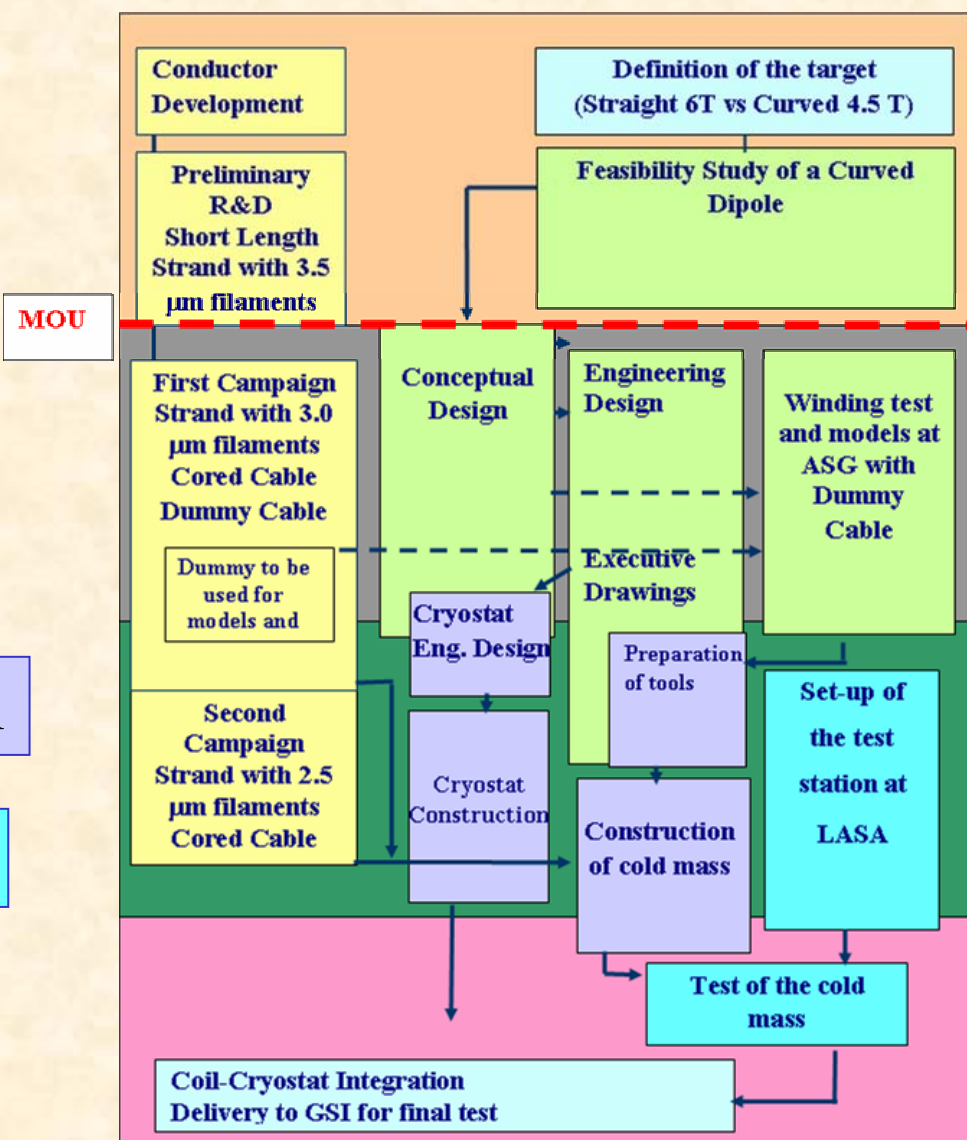


Conductor

Studies,
Design
and
Models

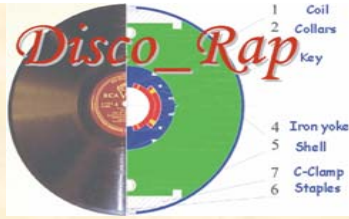
Construction

Tests



The INFN R&D program for curved SIS300 dipole

Final goal:
3.8 m long
4.5 T
curved dipole
in its
horizontal
cryostat



Conductor R&D

more details in talk 1E06 – G.Volpini
(see also poster 1N11 by G.P. Willering et al for studies on Ra)

TABLE I. WIRE MAIN CHARACTERISTICS.

| | | | |
|---------------------------------|----------------------------|-----|-------------------------------|
| Diameter after coating | 0.825 ± 0.003 | | mm |
| Filament twist pitch | 5 +0.5 -0 | | mm |
| Effective Filament Diameter | 1 st generation | 3.5 | μm |
| | 2 nd generation | 2.5 | μm |
| Interfilament matrix material | Cu-0.5 wt% Mn | | |
| Filament twist direction | right handed (clockwise) | | |
| I_c @ 5 T, 4.22 K | > 541 | | A |
| n-index @ 5 T, 4.22 K | > 30 | | |
| Stabilization matrix | Pure Cu | | |
| ρ_t at 4.22 K | $0.4 + 0.09 B$ [T] | | $\text{n}\Omega\cdot\text{m}$ |
| Cu+CuMn:NbTi ratio (α) | > 1.5 ± 0.1 | | |
| Surface coating material | Staybrite (Sn-5 wt% Ag) | | |

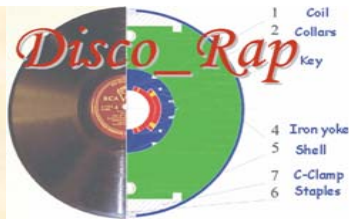
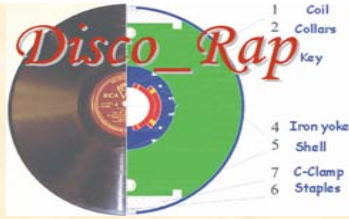


TABLE II. CABLE MAIN CHARACTERISTICS.

| Geometrical | | |
|-------------------------------|--------------------------------------|----|
| Strand Number | 36 | |
| Width | 15.10 +0 -0.020 | mm |
| Thickness, thin edge | 1.362 ± 0.006 | mm |
| Thickness, thick edge | 1.598 ± 0.006 | mm |
| Mid-thickness at 50 MPa | 1.480 ± 0.006 | mm |
| Edge radius | ≥ 0.30 | mm |
| Core material | AISI 316 L stainless steel, annealed | |
| Core width | 13 | mm |
| Core thickness | 25 | μm |
| Transposition pitch | 100 ± 5 | mm |
| Cable transposition direction | left-handed screw thread | |
| Electrical | | |
| I _c @ 5 T, 4.22 K | >18,540 | A |
| Stabilization matrix RRR | >70 | |

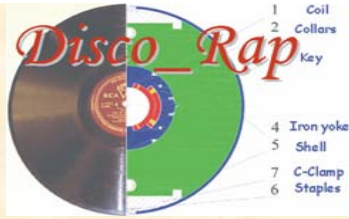


Towards the construction of a curved dipole

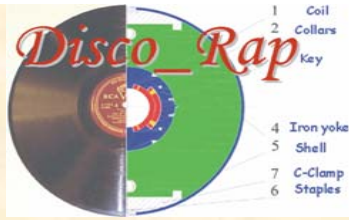
Our starting assumption was that **the coil should be wound curved** because:

- 1) This solution allows defining without uncertainty the geometrical dimensions of a curved stress-free coil;
- 2) Once cured, the coil can be handled in a simple and safe way for the following manufacturing operations (collaring, insertion in the iron yoke, ...).

Very important to develop in a short time curved poles using existing tools, if possible, and dummy cable



The choice of a curved winding naturally oriented, on the design side, to a **single layer coil mechanically supported only by the collars**. These important choices are based on the reason that the **mechanical coupling between two curved layers or between a curved collared coil and a curved yoke appeared to be critical operations**, which could be afforded only once the simplest curved layout (single collared layer) had been deeply investigated.

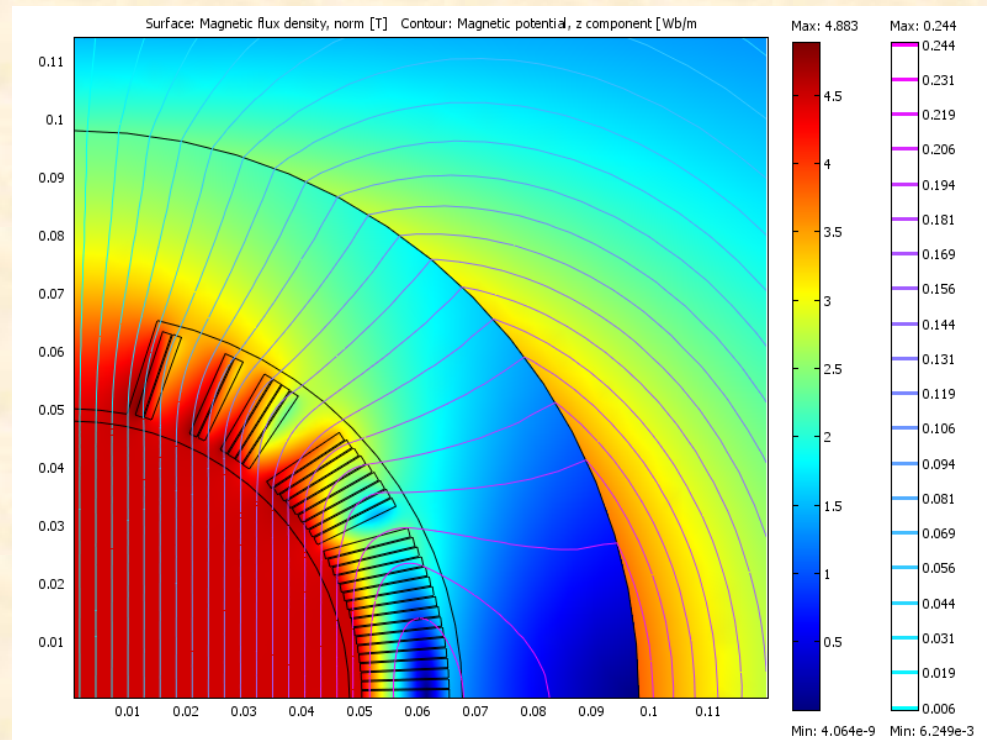


Reference Design: 5-blocks selected configuration

(more details in talk 2A03 – M.Sorbi)

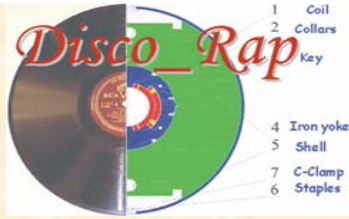
| | |
|---|---------------|
| Block number | 5 |
| Turn number: | 17-9-4-2-2 |
| Current | 8924 A |
| B_{peak} (with self-field) | 4.90 T |
| B _{peak} / B ₀ | 1.09 |
| Temperature margin | 0.99 K |
| Coil inner radius | 50 mm |
| Yoke inner radius | 98 mm |

$$(\mu_r \text{ yoke} = \infty)$$

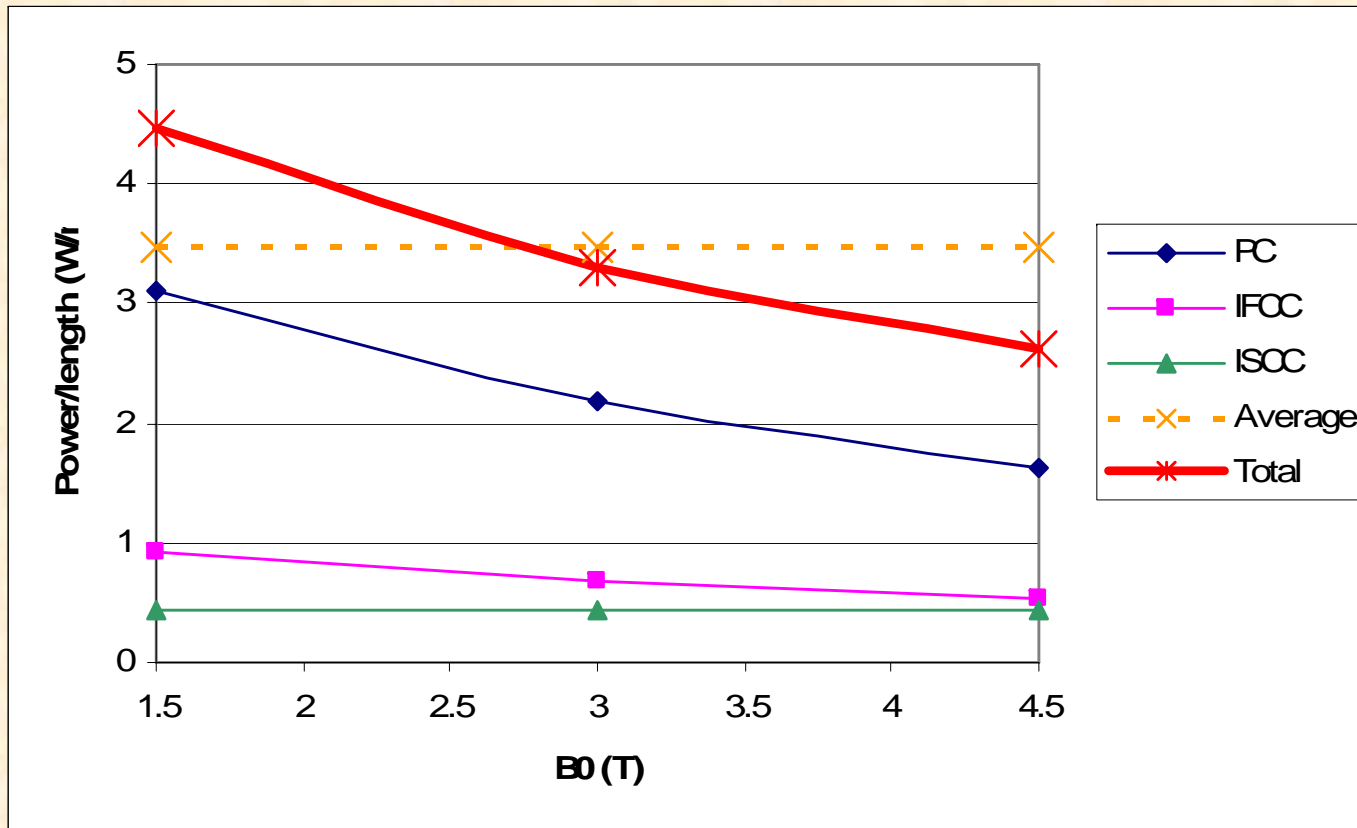


Geometrical harmonics (units E-4) at ref. radius R=35 mm

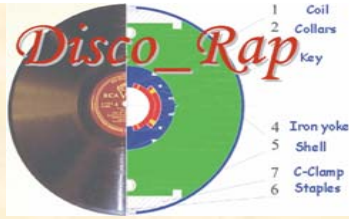
| b3 | b5 | b7 | b9 | b11 | b13 |
|-----------|-----------|-----------|-----------|------------|------------|
| 0.10 | 0.10 | 0.40 | 0.48 | 0.95 | -1.11 |



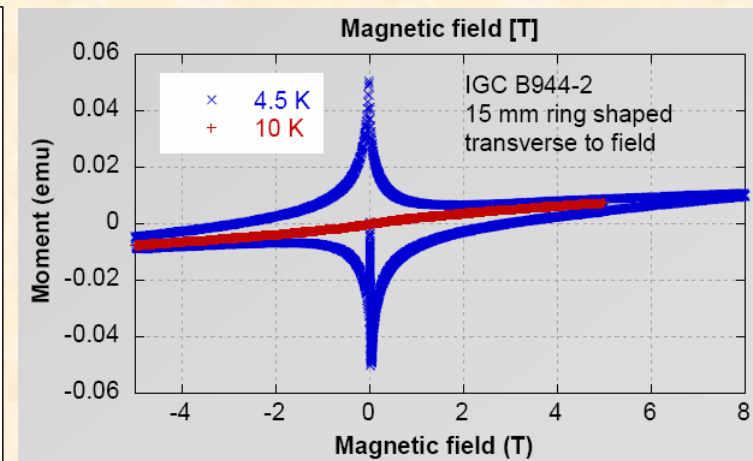
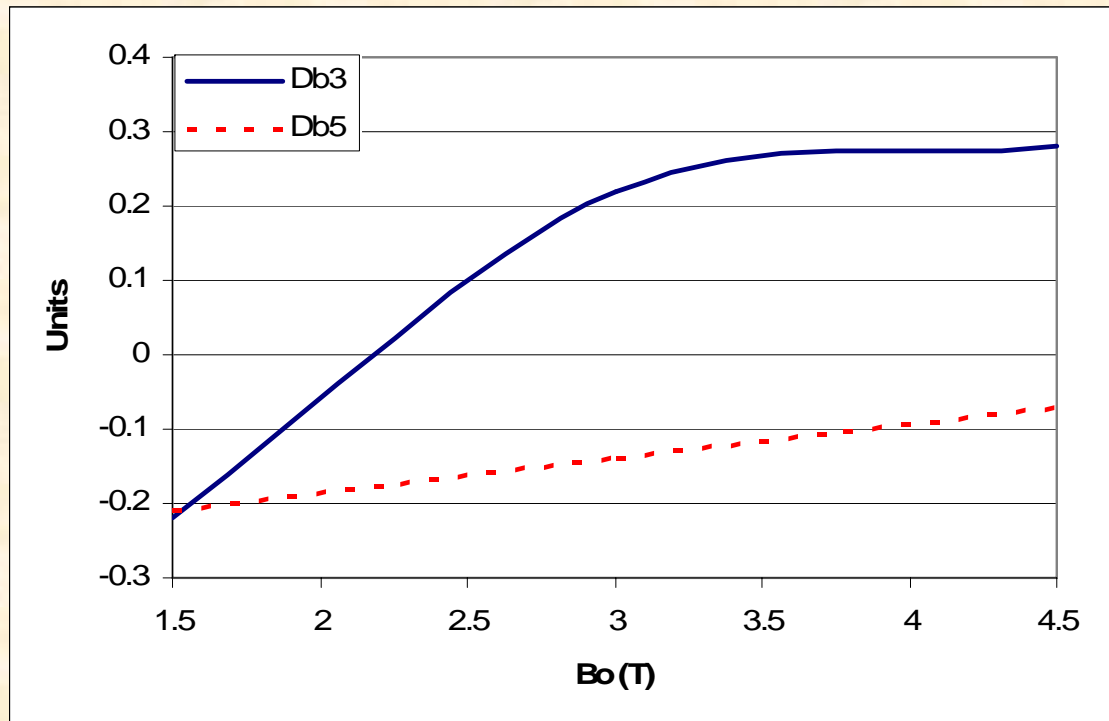
AC losses (more details in talk 2A03 – M.Sorbi)



- Average losses calculations are between 3.5 – 3.7 W/m

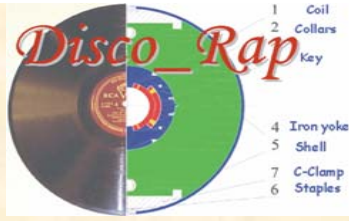


Field quality when ramping the magnet

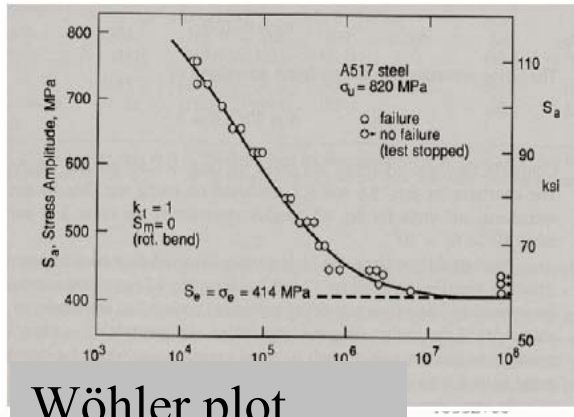


Total variation of sextupole and decapole field harmonics during the ramp up ($dB/dt=1$ T/s), due to persistent currents, eddy currents in conductor and paramagnetism of copper-manganese matrix

Unexpectedly we observed paramagnetic effects in CuMn stabilised wires (Short sample in transverse field measured in VSM). The effect helps in improving the field quality in the operating field range

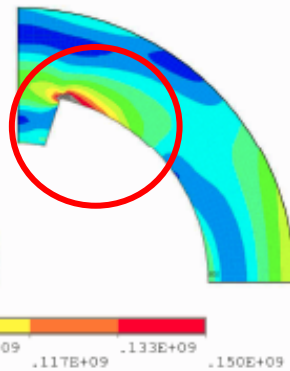


Von Mises stresses

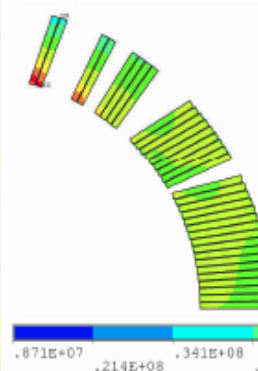


Wöhler plot

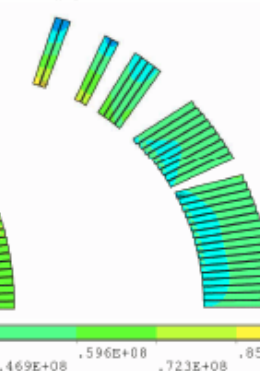
energization



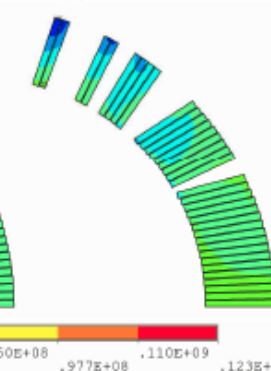
collaring
 $\sigma_{ave} = 73 \text{ MPa}$



cool-down
 $\sigma_{ave} = 50 \text{ MPa}$



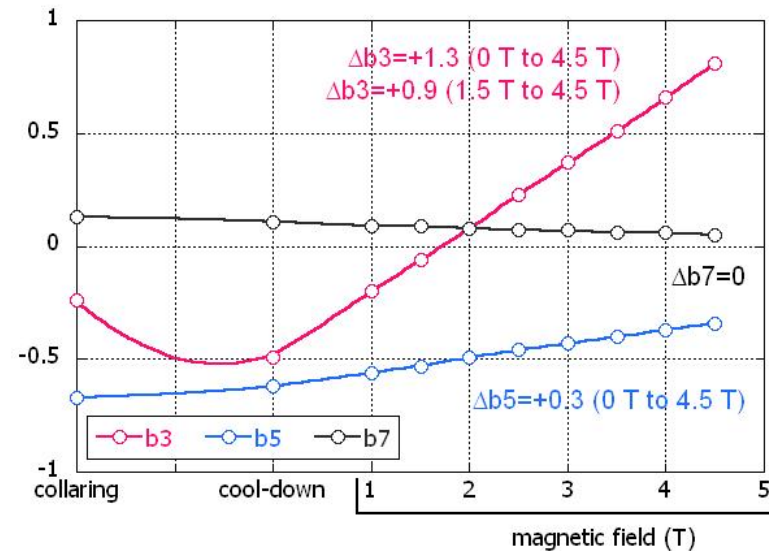
energization
 $\sigma_{ave} = 51.5 \text{ MPa}$

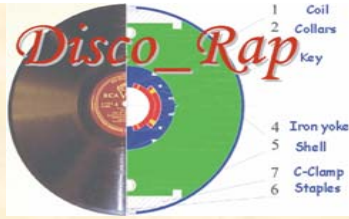


Material properties

| | Young modulus (GPa) | Thermal contraction (4.2 K to 295 K) |
|----------------------------|---------------------|--------------------------------------|
| Nitronic40 | 192 | $2.4 \cdot 10^{-3}$ |
| Insulated conductor | 7.5 | $5.63 \cdot 10^{-3}$ |
| Wedges (G11) | 25.5 | $2.47 \cdot 10^{-3}$ |
| Kapton (ground insulation) | 2.5 | $9 \cdot 10^{-3}$ |

b3 variations



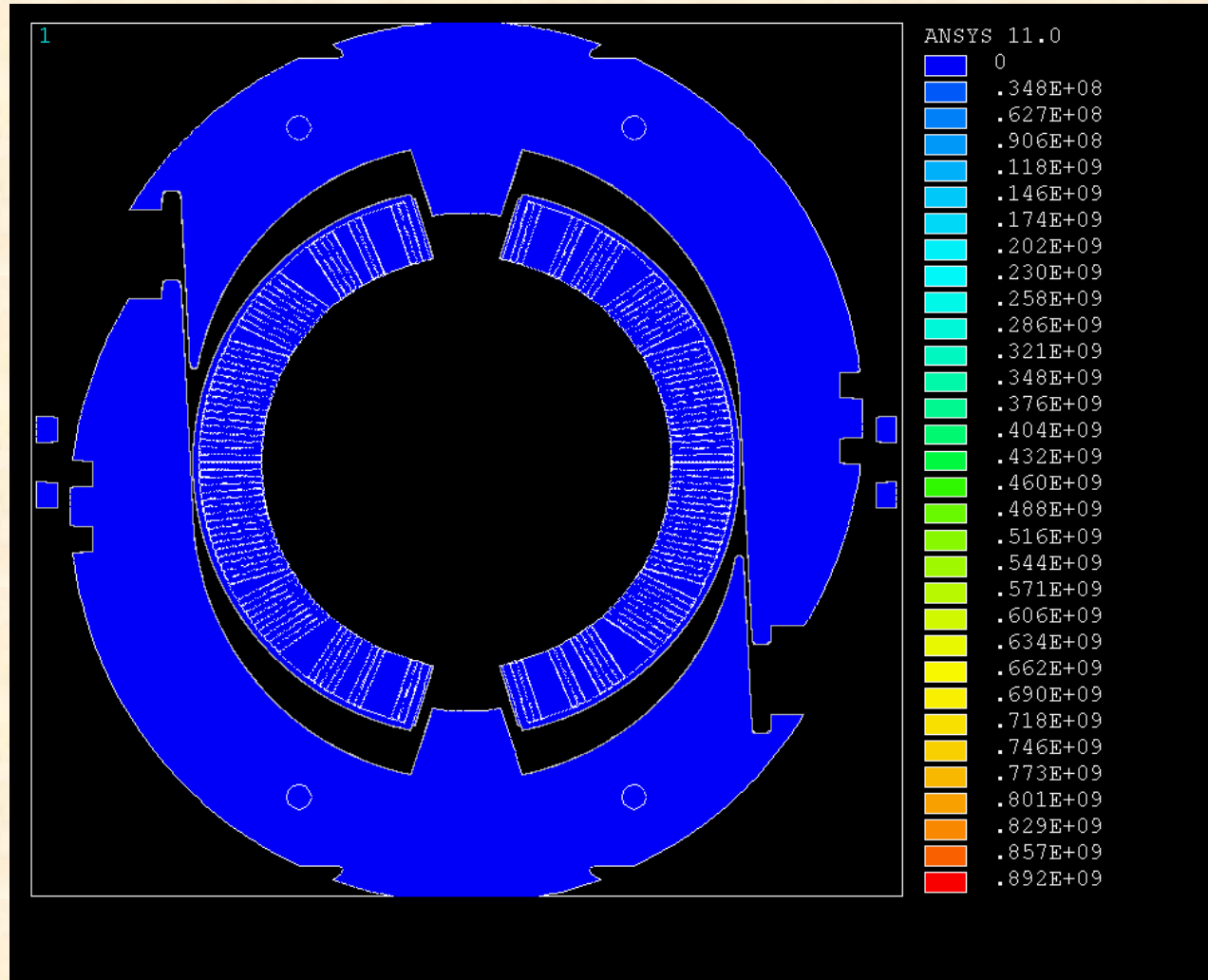


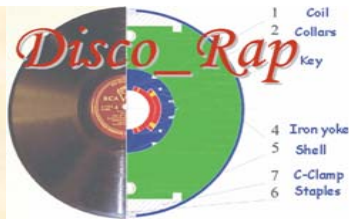
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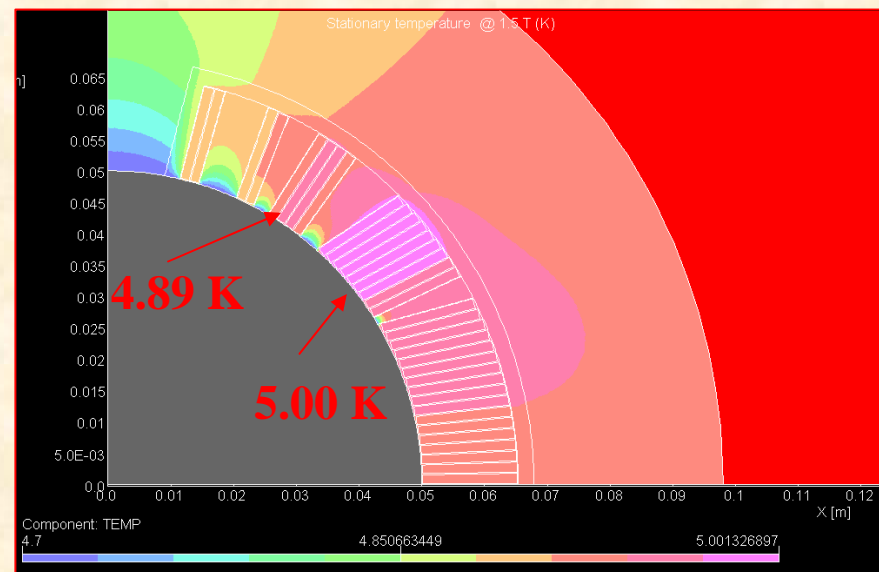
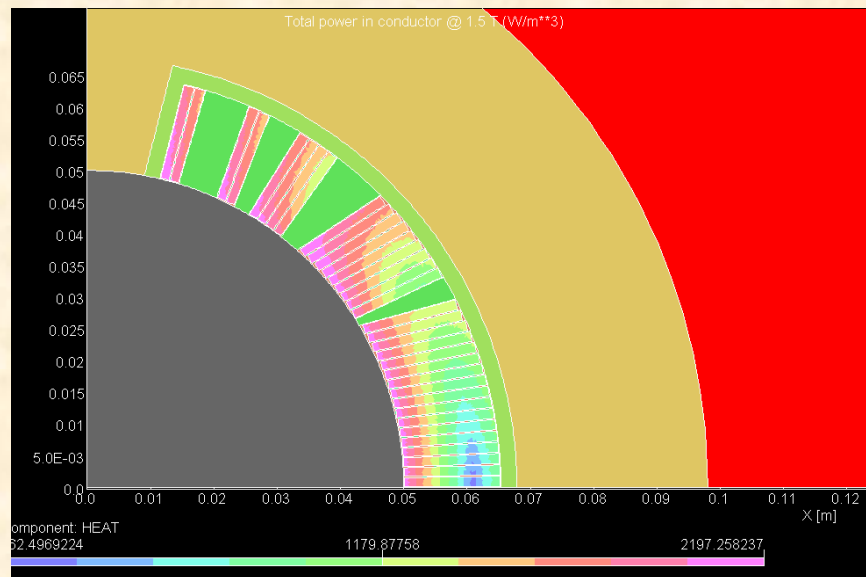
More sophisticated mechanical analysis is going on as the mechanical design is more and more refined

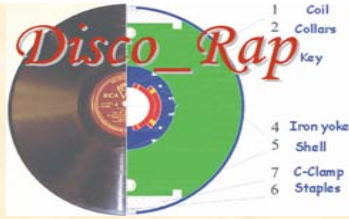




Power distribution in conductor
@ $B_0=1.5\text{ T}$; $dB/dt=1\text{ T/s}$
[Peak power 2200 W/m^3]

Steady state case:
Temperature distribution in
same conditions. Cooling of
the inner surface ($T=4.7\text{ K}$)

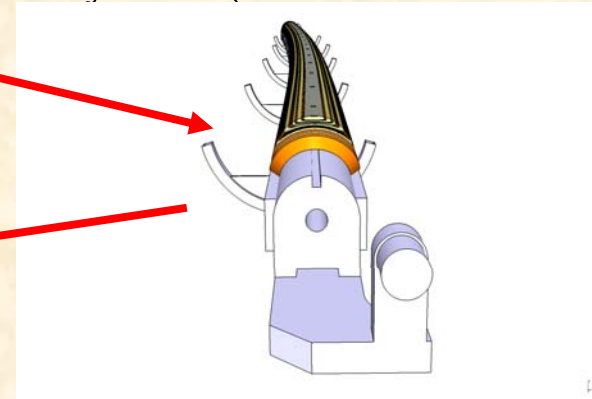




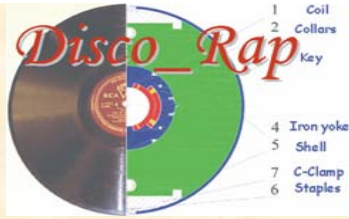
Manufacturing activities

At ASG-Superconductors activities are going on to set-up a winding line for curved magnet. The winding frame is the same used in LHC (thank to CERN).

The mandrel support is completely new (under construction).



LHC tool also used for curing the curved coil

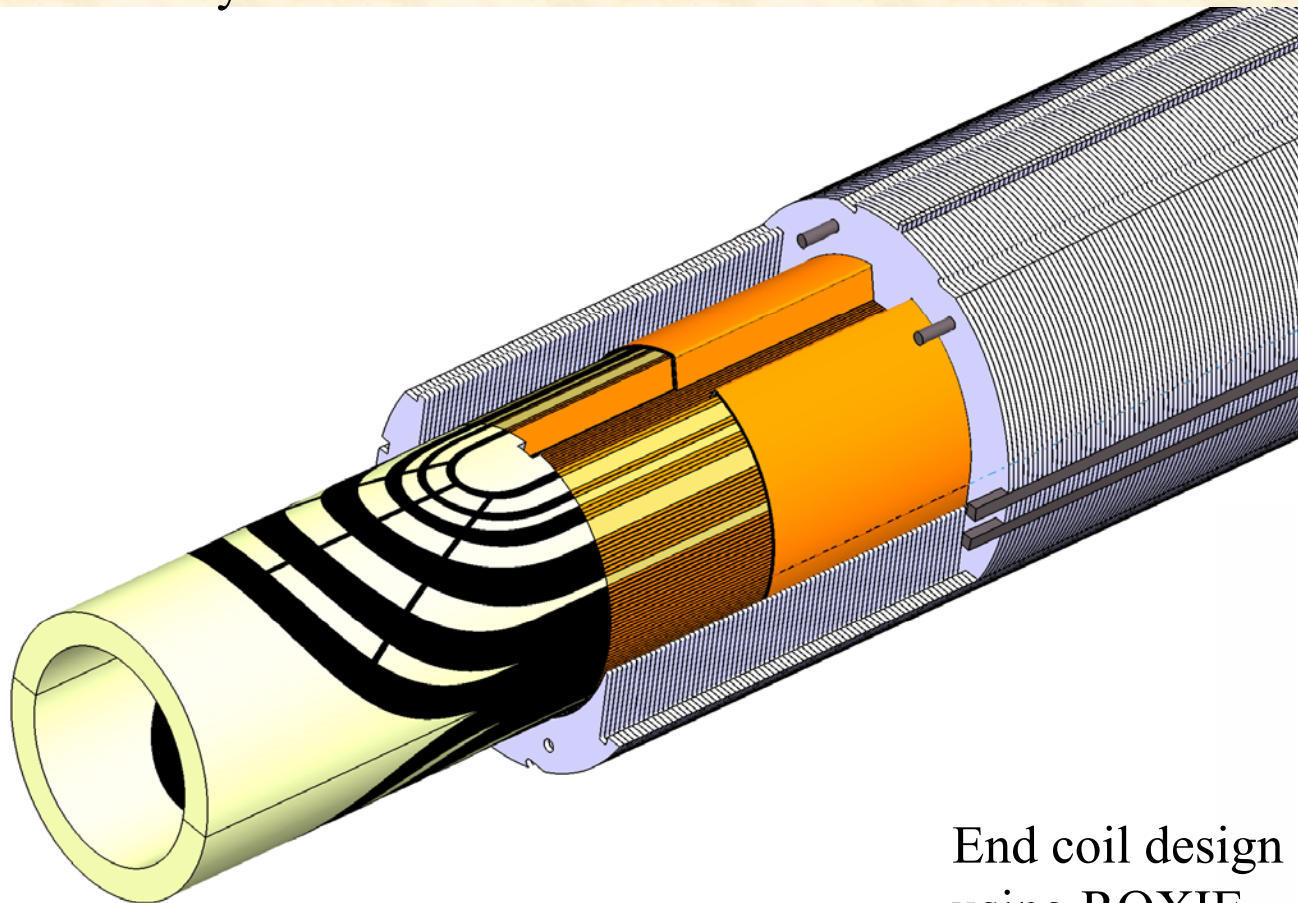


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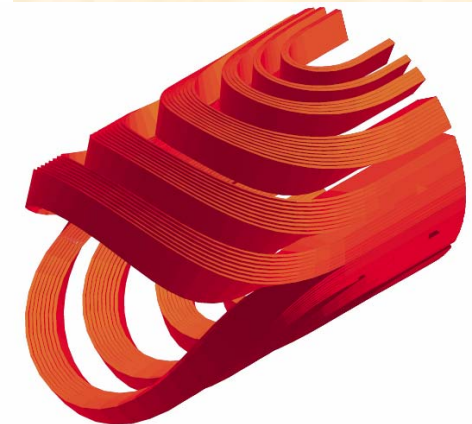
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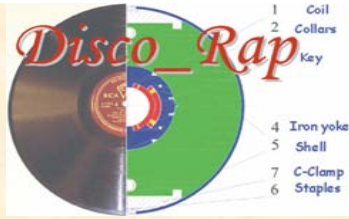


Only after the successful construction of single pole the project will continue, at manufacture level, for finishing the cold mass, of which the complete design is under way



End coil design
using ROXIE

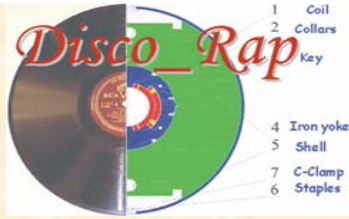




CONCLUSIONS (1)

Design activities coupled with conductor and model coil developments are under way for developing a curved fast cycled superconducting dipole suitable for operations of the SIS300 synchrotron at FAIR.

The main target is the construction within 2009 of a prototype magnet (cold mass fully integrated in a horizontal cryostat), which will be tested at GSI.



CONCLUSIONS (2)

An important intermediate milestone is the industrial assessment of the winding technology for a curve cos-theta dipole, through the construction of cured curved poles by February 2008. The need of using non non-conventional tools (to be completely developed) makes critical the achievements of this goal.

Other crucial aspects of the R&D are related to the development of a low loss conductor, generating during ramps about 3.5 W/m, and to the demonstration that the heat dissipated in the winding can be efficiently removed through the cooling of the dipole inner surface.