

D2 status

P.Fabbricatore INFN GENOVA

D2 Status

**P.Fabbricatore
INFN Genova**

- The contract for the construction of the short model
- The present D2 design as starting point of the industrial activities
- Some results of the revised mechanical analysis
- Conductor insulation, Quench Heaters and Coil wedges

MAGIX & INFN participation to HL-LHC

MAGIX

WP1	CORRAL	Design, construction and test of the five prototypes of the corrector magnets for the HL interaction regions of HiLUMI
WP2	PADS	2D & 3D engineering design of the D2 magnets
WP3	SCOW-2G	Development of HTS coil for application to detectors and accelerators
WP4	SAFFO	Low-loss SC development for application to AC magnets

MAGIX is a INFN-funded research project, (1.3 M€ in 2014-2017) with goal to develop superconducting technologies for application to future accelerator magnets . It includes four WP's, two of which are relevant to HL-LHC

CERN-INFN Collaboration Agreement

CERN endorses MAGIX WP1 & WP2 deliverables and milestones, contributing with 527 k€, through the collaboration agreement KE2291/TE/HL-LHC

Done in two copies in the English language on:

Date: 25 GIU. 2014

Istituto Nazionale di Fisica Nucleare (INFN)

Prof. Fernando Ferroni
President



Date: 17 JUL. 2014

The European Organisation for Nuclear Research (CERN)

Prof. Rolf-Dieter Heuer
Director-General



T. Lagrange
Head of Finance, Procurement
and Knowledge Transfer Department

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INFN already involved in FP7-HiLumi
WP2 beam dynamics, LNF
WP3 magnets, MI-LASA
WP6 cold powering, MI-LASA



New agreements (under signature) CERN-INFN for magnet constructions

- For D2 the agreement is finalised to the construction (in industry) of a short model (1.6 m) and a prototype (8 m).
- The short model shall be delivered to CERN at the end of 2017 and tested at CERN in a vertical cryostat.
- The prototype shall be delivered at end of 2019, assembled in a cold mass with the correctors, and tested in a horizontal cryostat.
- The involved INFN section is the Genova section.
- On the basis of this agreement and subsequently to an international tender, INFN has awarded to ASG Superconductors the construction of the short model

Tender and contract to ASG Superconductors

- In the framework of the new agreement CERN-INFN the first step is the procurement of a short model. The main aim of the model (1.6 m long) is to verify the magnetic field cross talk compensation with asymmetric specular coils.
- On 2016 May 31th the request for an offer were asked to the 4 companies qualified by CERN. The tender was of the type «*Best Quality/Price ratio*»
- Two offers were received on 2016 July 15th
- The selecting board (3 persons) met on July 25th for technical evaluation and on July 26th for opening the envelopes with economical offers. A company was selected.
- On Sept. 14th the INFN management approved the tender. ASG Superconductors to be awarded with the contract, which due to formal technicalities (ex. 35 days waiting time) can formally start within November. The expected delivery is 15 months from contract start. However on Oct. 21st we hold the kick-off meeting.

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Present cross section of the D2

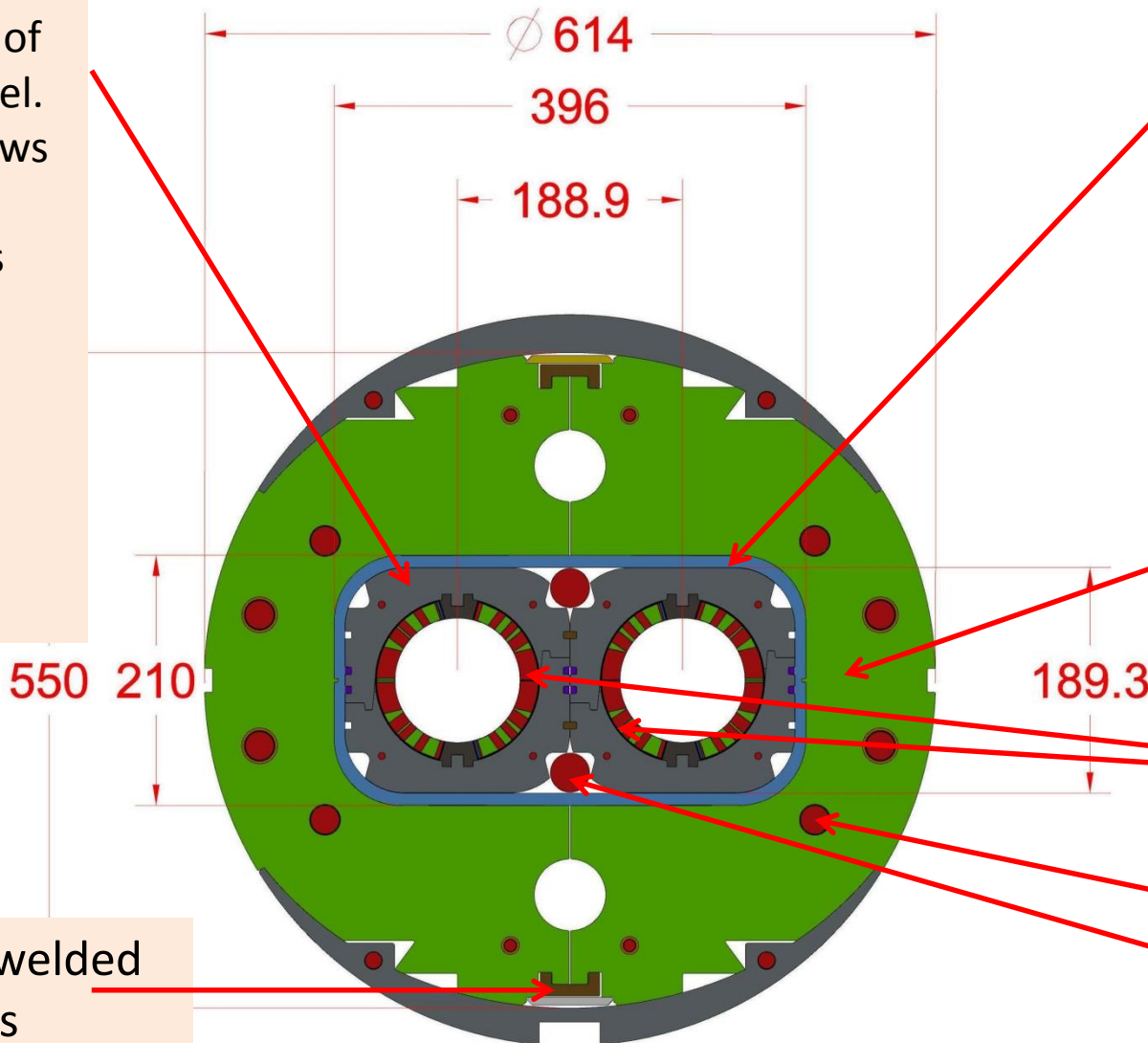
Collars made of austenitic steel. The nose allows future coil modifications without changing the main collar structure

Aluminum alloy sleeve 6061-T6 or 7075-T6 made of short elements 50-100 mm. At room temperature the gap with collared coils is 0.2 mm

Iron yoke

Asymmetric specular coils

Longitudinal tie rods

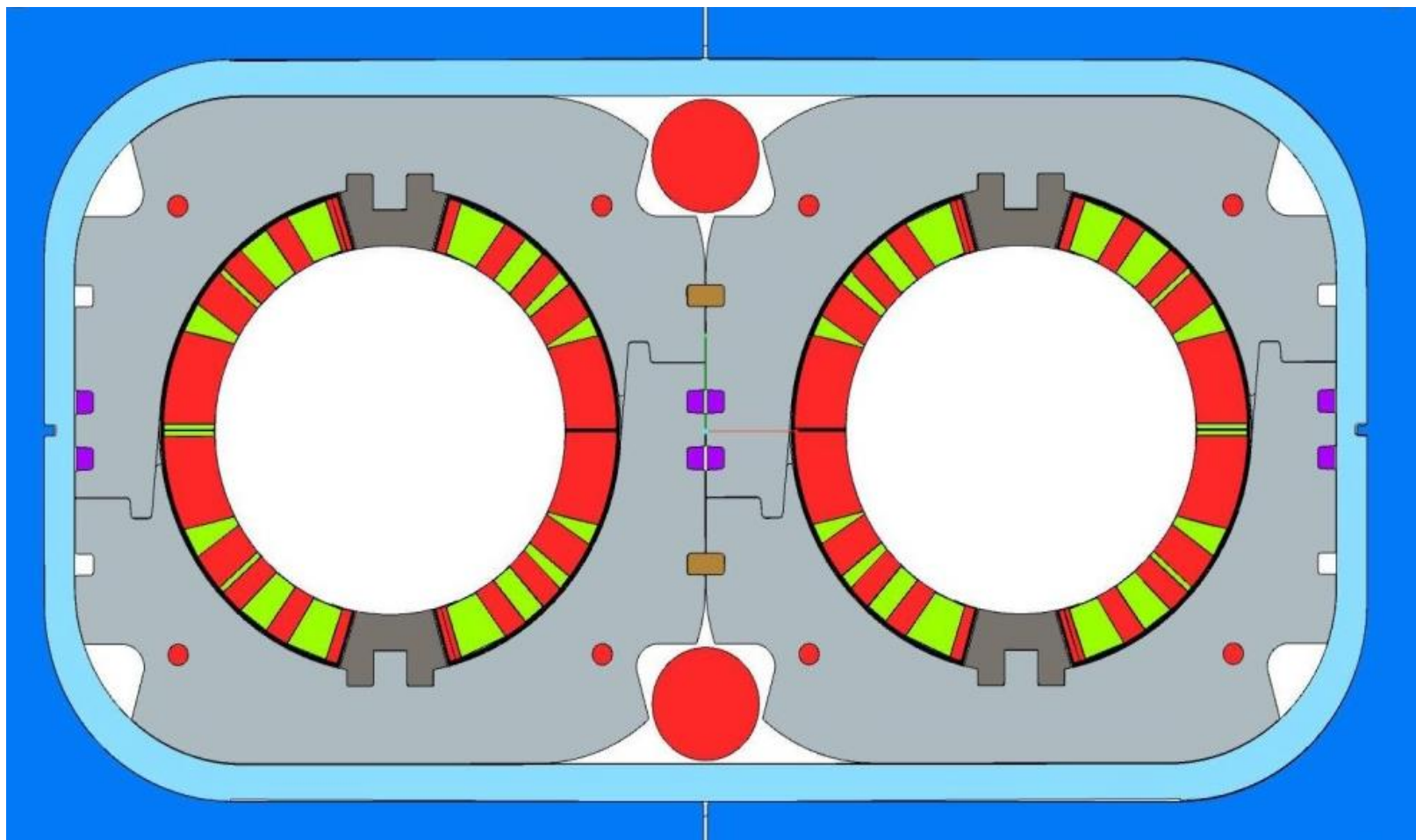


Clamps and welded stiffening bars

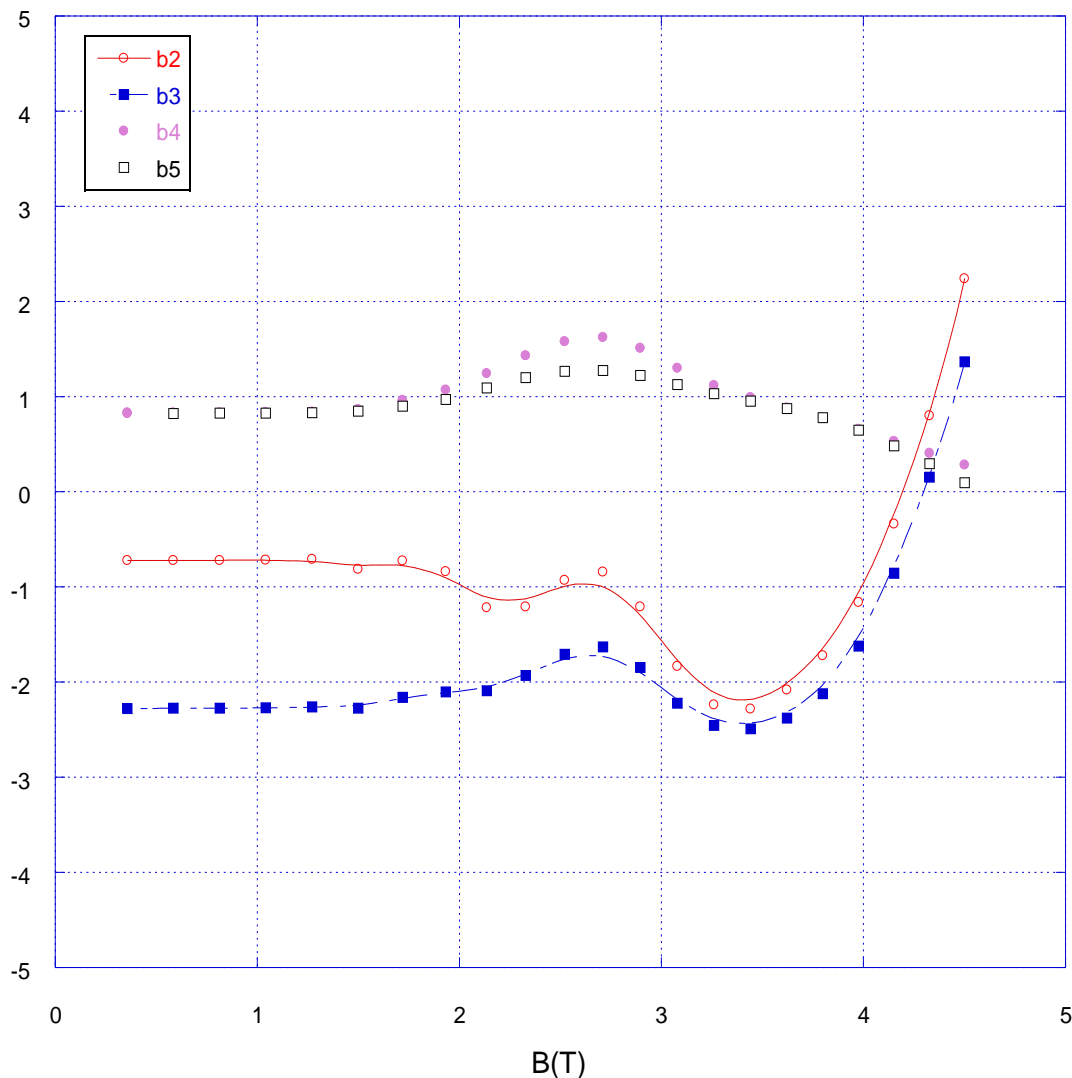
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Detail of the collared coil cross section. The role of the Al sleeves



Field quality and construction phases



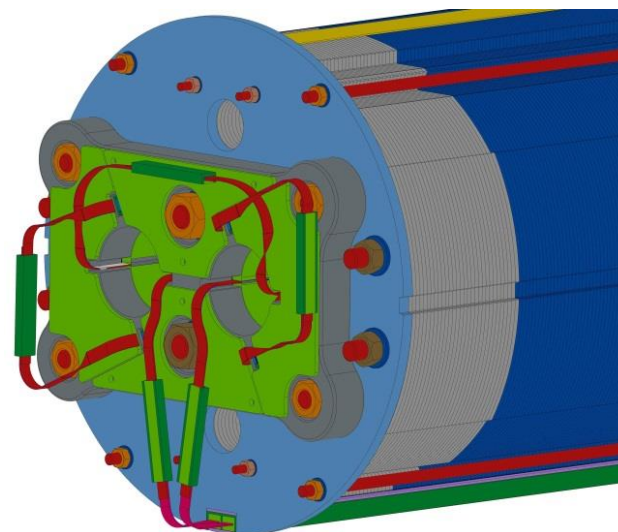
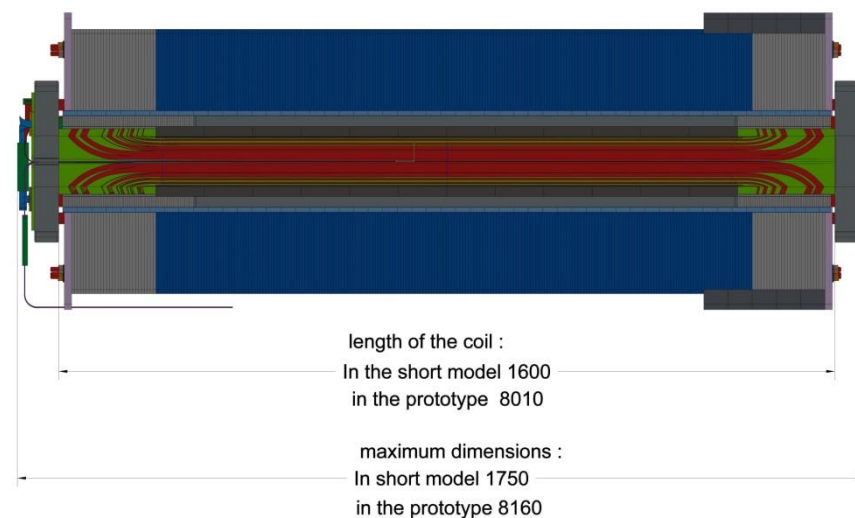
Magnetic measurements at room temperature. The measurement of the room temperature multipoles in three stages:

- (i) collared coil,
- (ii) collared coils in the Al sleeve, and
- (iii) final assembly in the iron yoke.

They will be jointly analysed by INFN and by the contractor to validate the final assembly. These measurements need a stainless steel tube to be temporary installed in both apertures.

Main Characteristics of the short model

Parameter	Unit	Value
Bore field	T	4.5
Peak field	T	5.25
Current	kA	12.250
Temperature	K	1.9
Load line margin	(%)	35
Overall current density	A/mm ²	443
Stored energy	MJ	2.18
Differential inductance per meter	mH	27.3
Superconductor		Nb-Ti
Strand diameter	mm	0.825
Cu/No Cu		1.95
RRR		>150
Superconductor current density at 10 T, 1.9 K	A/mm ²	2100
Number of strands per cable		36
Cable bare width	mm	15.1
Cable bare mid thickness	mm	1.480
Keystone angle	degrees	0.90
Insulation thickness per side radial	mm	0.160
Insulation thickness per side azimuthal	mm	0.145



SCOPE OF THE SUPPLY OF THE ASG SUPERCONDUCTOR CONTRACTS

The contracts aims at **constructing a short (1.6 m) model of D2 magnet**. The supply is composed of **the following five deliverables**:

Engineering design of the short model dipole. The engineering design documentation shall consist in a set of executive drawings and engineering reports covering the whole cold mass design issues: geometrical and electrical lay-out, winding procedures, collaring and implementation of the iron yoke. The activity shall be performed on the basis of this specification and the attached documents. As the contract will be awarded, INFN will provide a set of final drawings developed on the basis of the INFN conceptual design. The firm is obliged to follow the INFN magnetic design.

Engineering design of general equipment for the construction. In this category winding machine, curing press, collaring press, Young modulus measurement tools and other minor equipment are included

Extracted from technical specifications

SCOPE OF THE SUPPLY (CONT)

Engineering design of specific equipment for the winding, the thermal curing of the coils and the integration into the iron yoke. In this category winding mandrel, polymerization moulds and yoke integration tool are included.

Construction of the cold mass. This includes activities and part of the materials for 4.1) Winding of the two coils composing the dipole with an insulated cable provided by INFN; 4.2) Curing; 4.3) Collaring; 4.4) Collared coil integration; 4.5) Iron yoke integration, 4.6) Electrical exits preparation and instrumentations, 4.7) Quality control. Some materials will be provided by CERN through INFN as described later.

A complete set of documents at the conclusion of this contract including a complete set of "as built" assembly and detail drawings of all the components associated with this contract, both in hard copies and as electronic files according a format to be agreed

Extracted from technical specifications

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ITEMS AND SERVICES PROVIDED BY INFN/CERN

INFN will provide the following items and services:

- 4.1 Nb-Ti insulated superconducting cables;
- 4.2 Stainless steel collar raw material;
- 4.3 Iron yoke raw material;
- 4.4 Quench heaters.

CERN

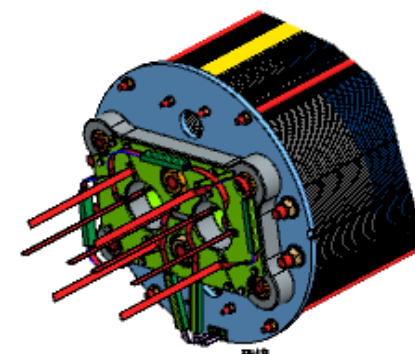
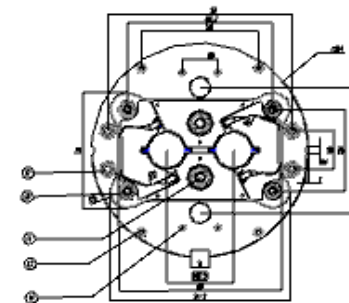
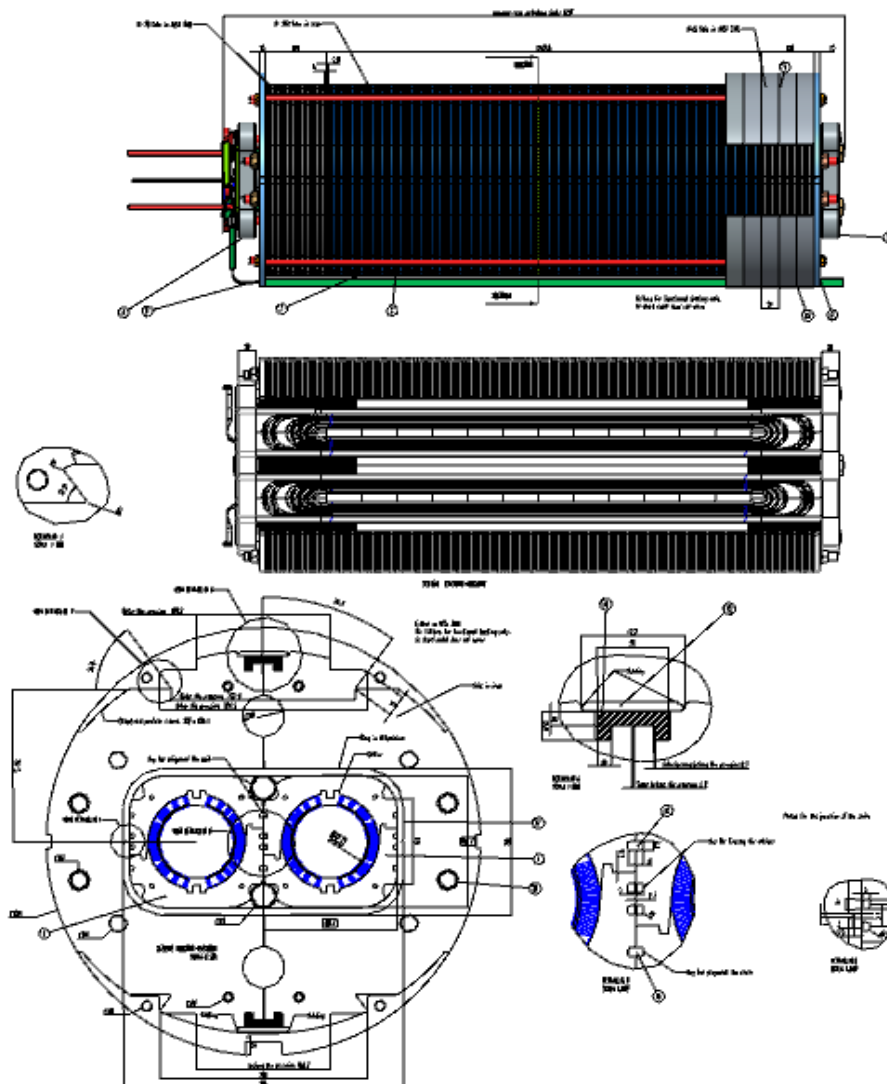
4.5 An engineering design including:

- Electromagnetic design of the cross-section;
- Coil end design;
- Mechanical structure based on separate collars;
- Iron yoke design;
- Lifting interface features;

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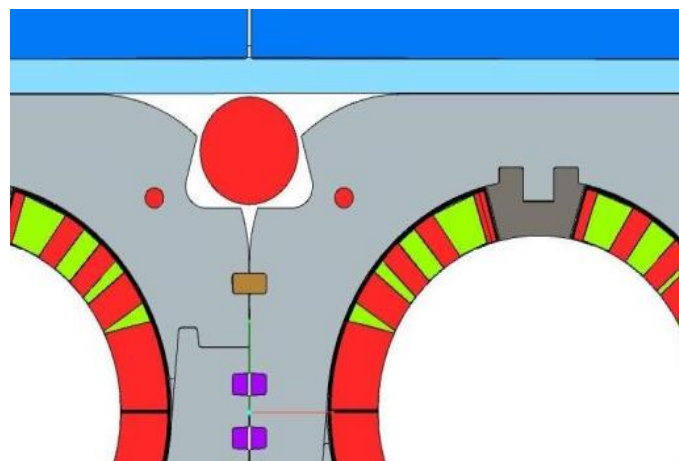
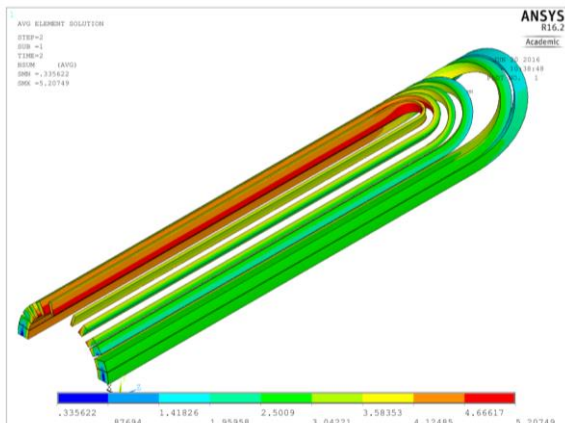


PROLIMINARY
Not valid for the manufacture

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The mechanical analysis was completely revised due to a modification of the longitudinal pre-stressing system

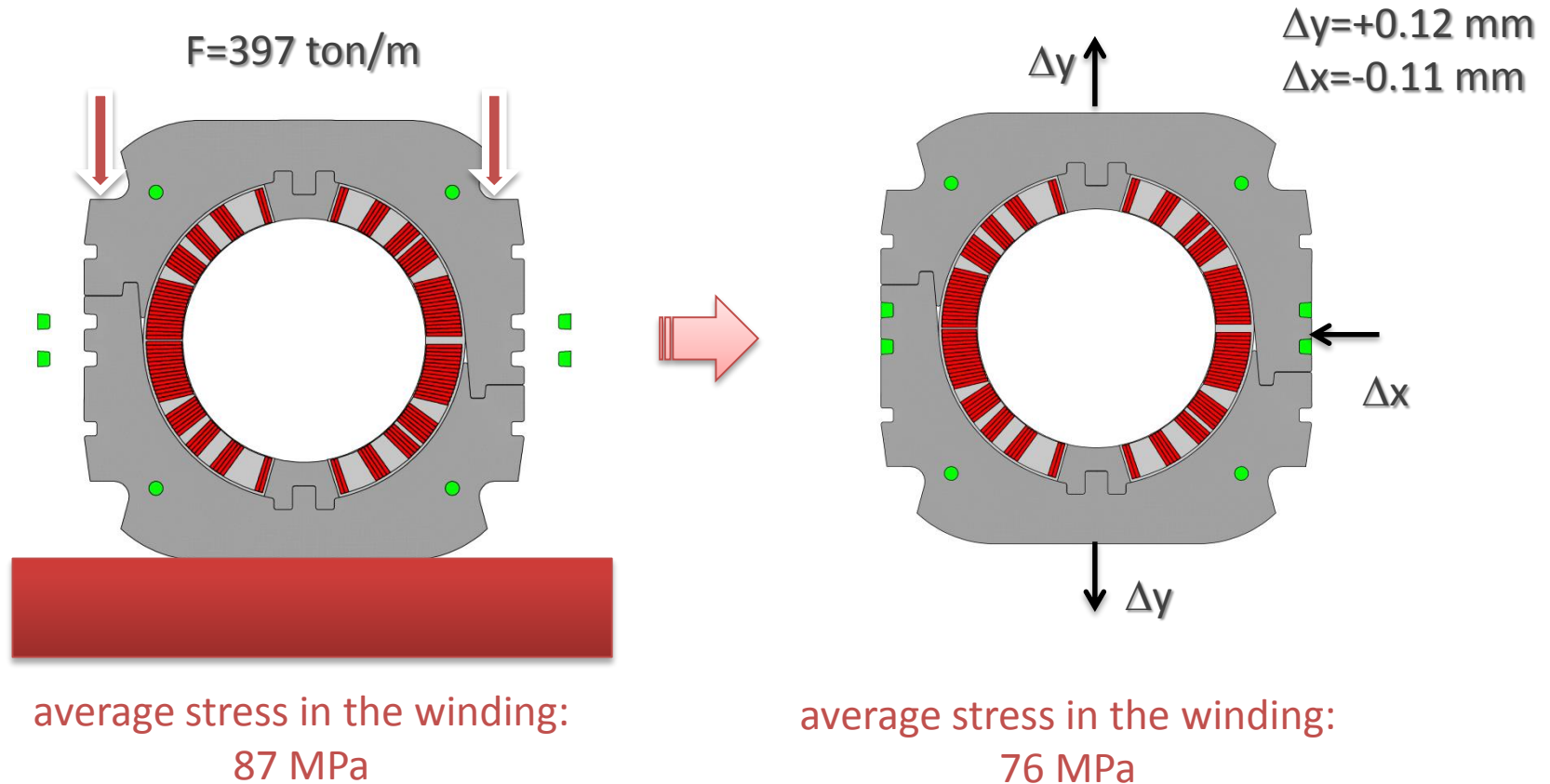
- The total axial magnetic force sums-up to 264 kN (calculated with both ANSYS and Roxie).



- This force is held by the prestressed magnet (coils + collars) and by longitudinal tie-rods. **Recently the tie rods diameter was increased and we have now six ss tie rods (two 30 mm diameter and four 25 mm).** Collars were modified.
- The total longitudinal displacement due to magnetic force for the 8 m long magnet is about 0.15 mm (each side). The revised 3D mechanical analysis is still under way

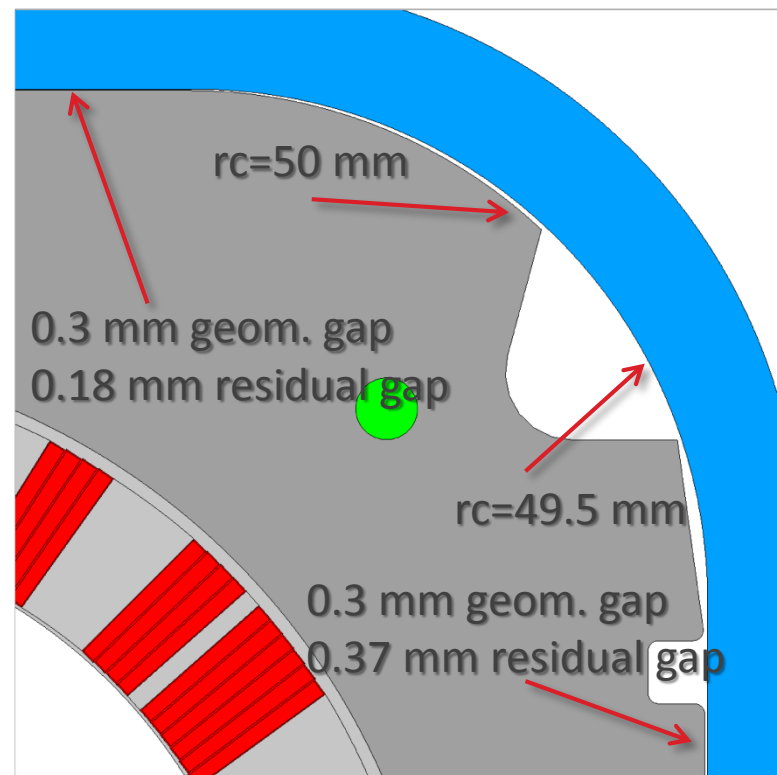
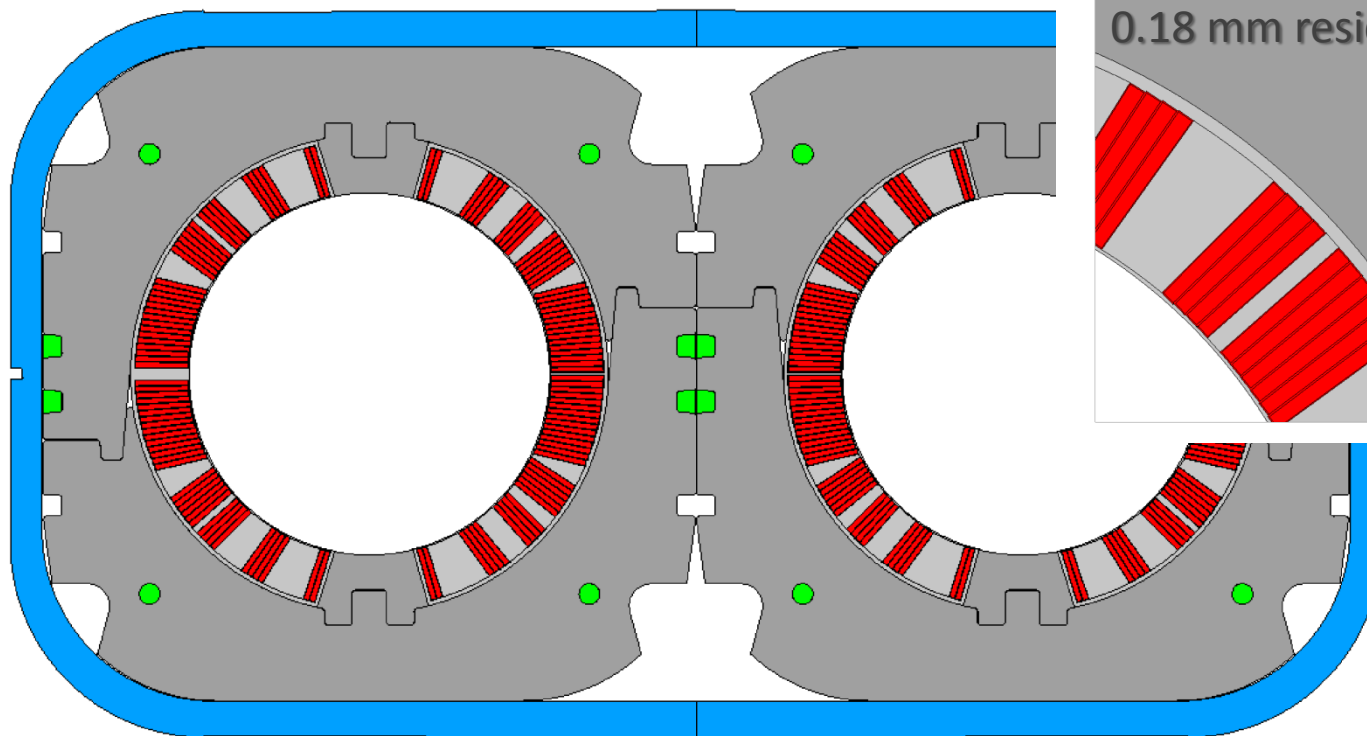
COLLARING

- a pressure is applied to align the holes, the keys are inserted, the pressure is released



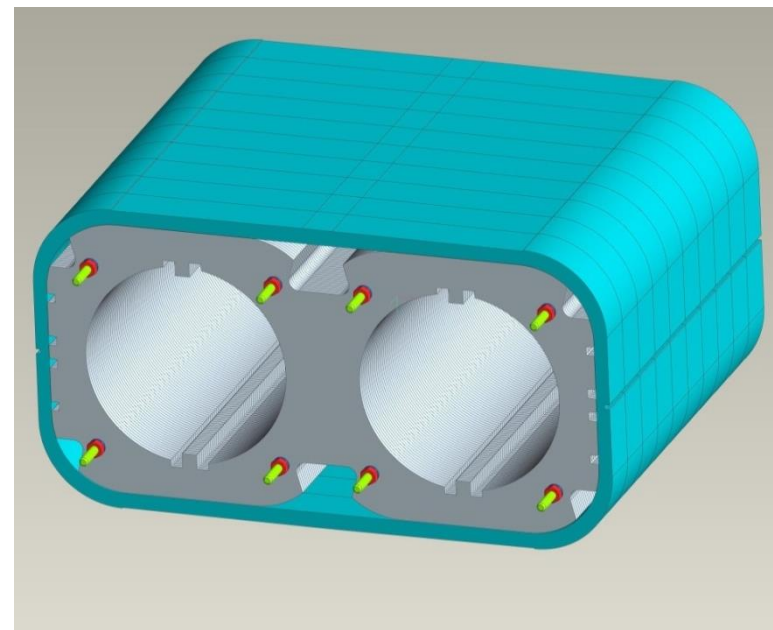
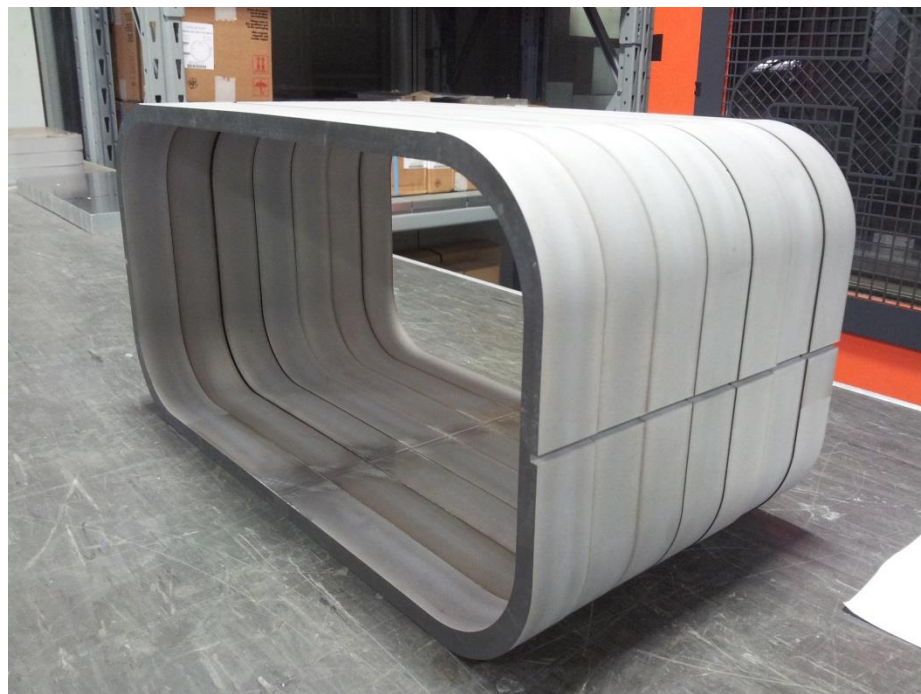
Al alloy sleeve insertion

- no stress results from this operation because of the continuous 0.3 mm gap between collars and sleeves

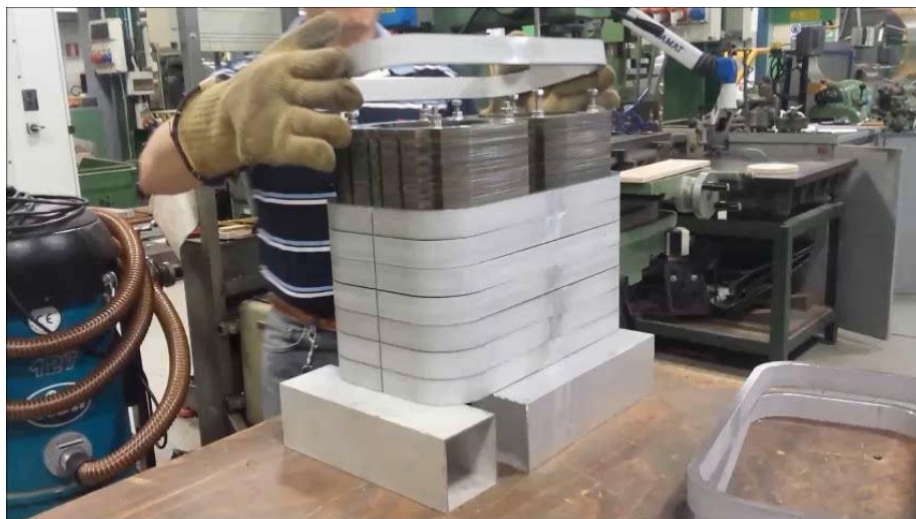


Mock-up

The mock-up construction was finalised to better understand the integration of collared coils into the Al sleeves with 0.2 mm gap any side, is finished.



Integration of collars into the sleeves (0.2 mm any side)



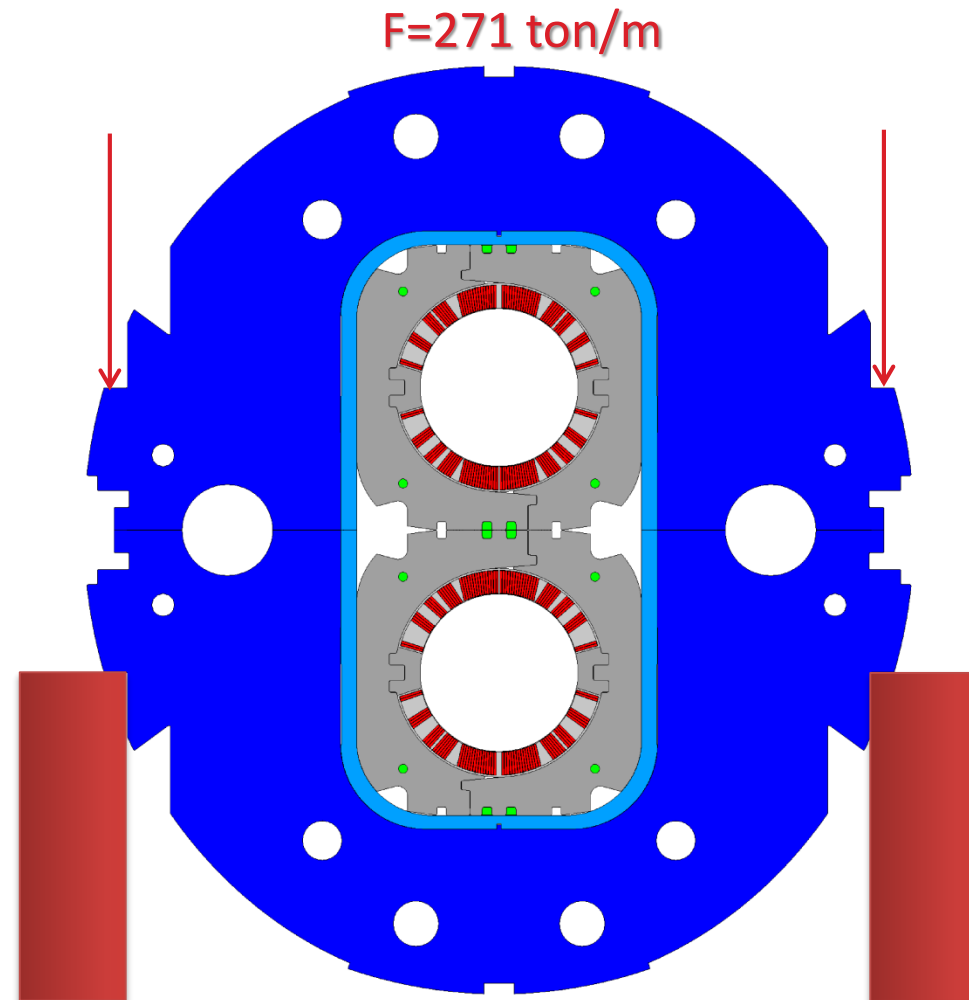
Vertical - Al sleeves warmed up 120 C



Horizontal- Sleeves at room temperature

Iron yoke assembly

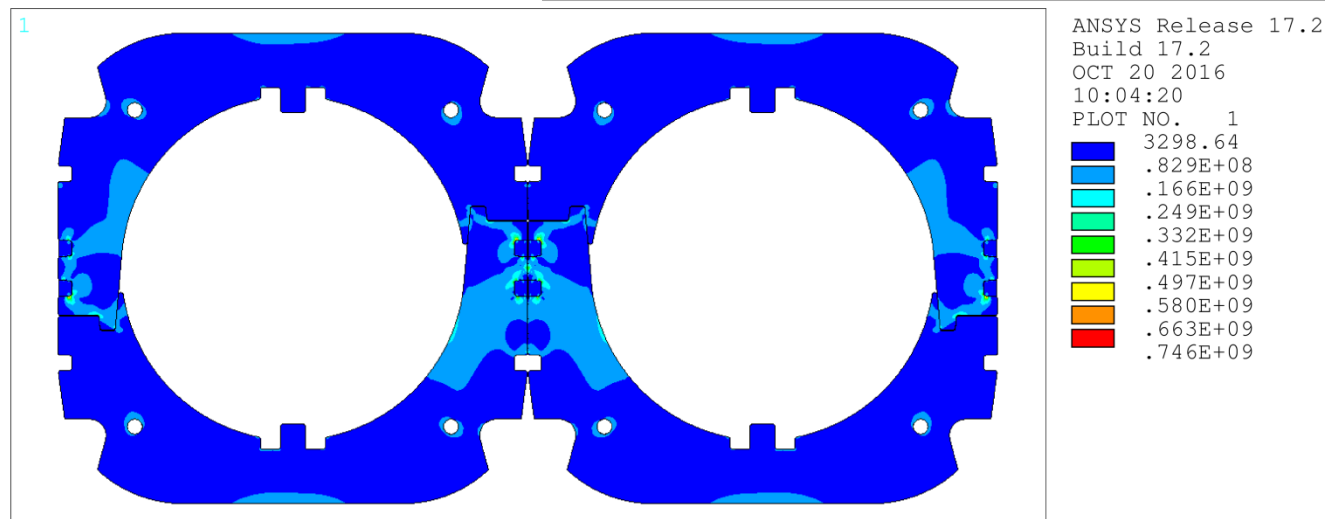
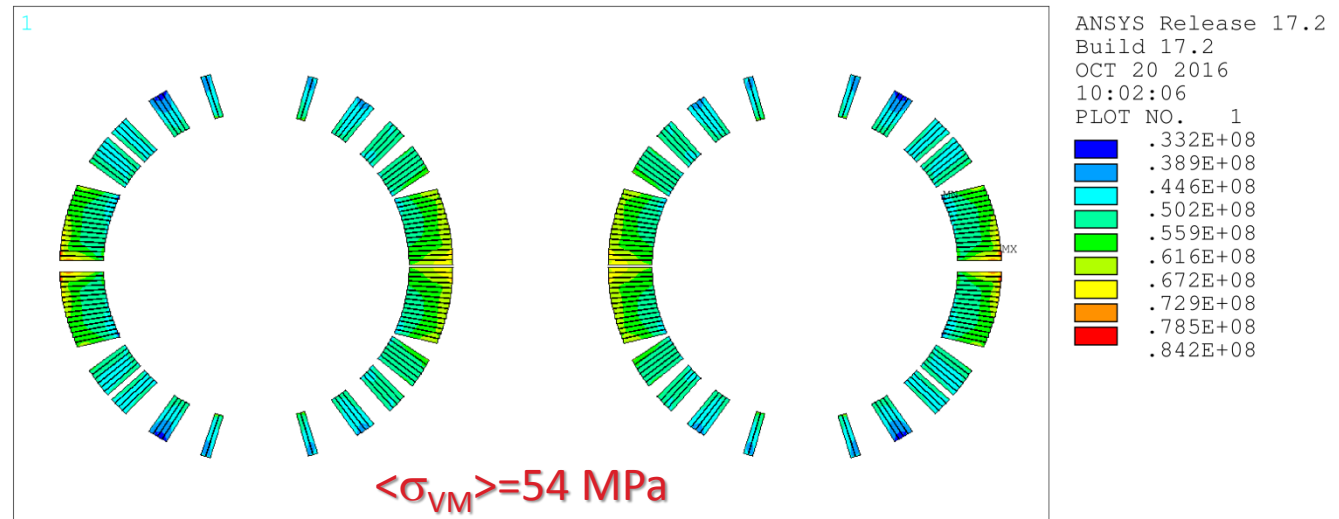
- 0.6 mm per side for a total of 1.2 mm gap between the two halves of the yoke
- the assembly is done under pressure with no effect on the collared coil



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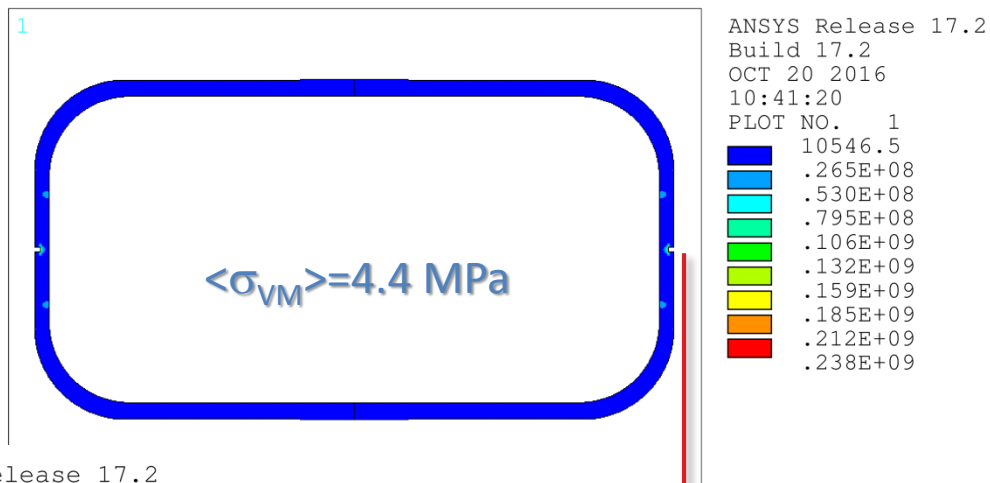
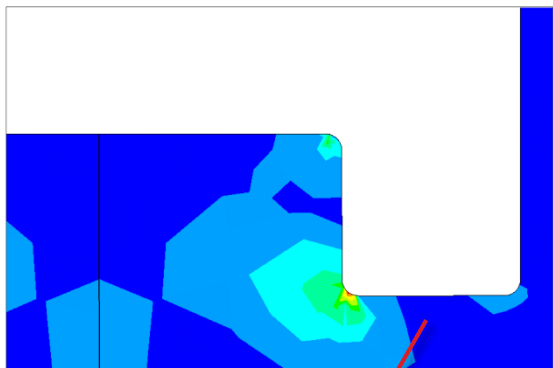
Stress in winding and collars after cool-down



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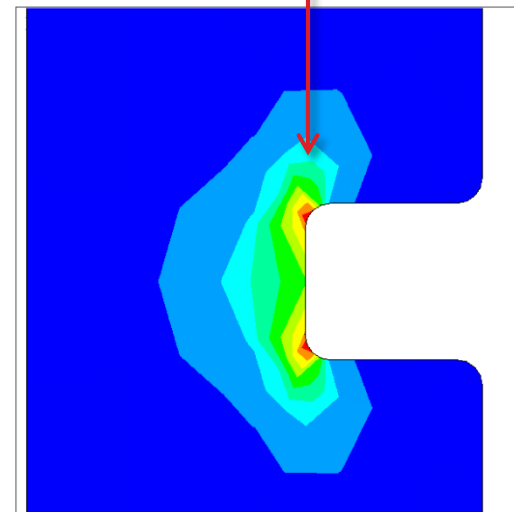
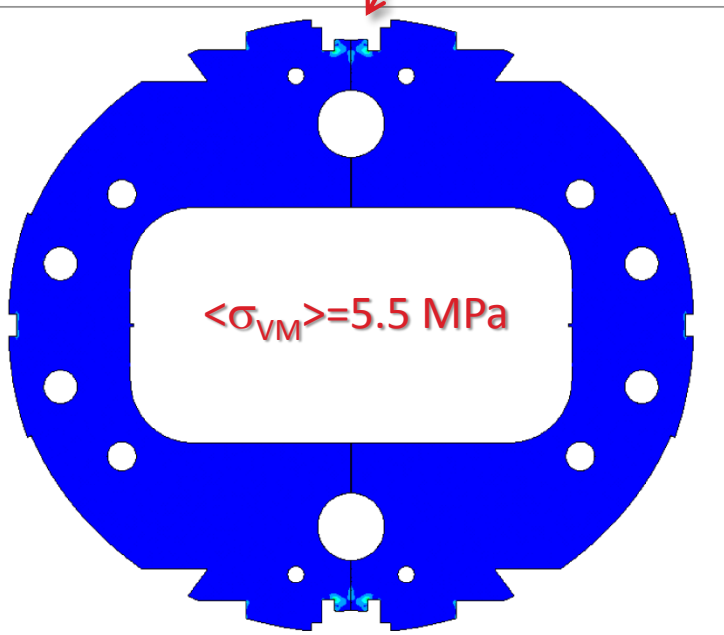
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Stress in iron yoke and Al alloy sleeve after cool-down



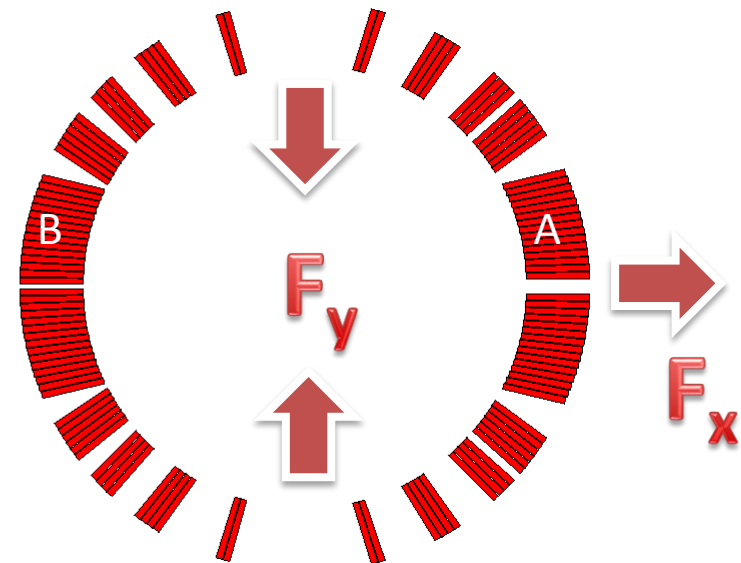
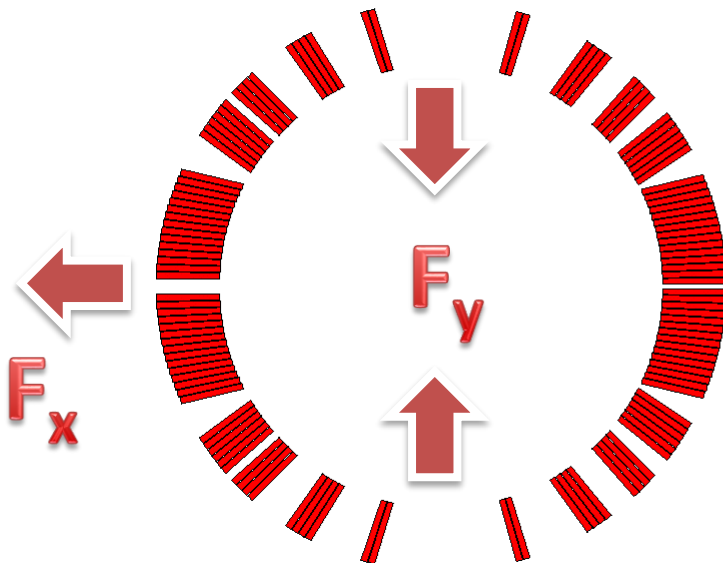
ANSYS Release 17.2
Build 17.2
OCT 20 2016
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.257E+08
.515E+08
.772E+08
.103E+09
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Lorentz forces at 4.5 T

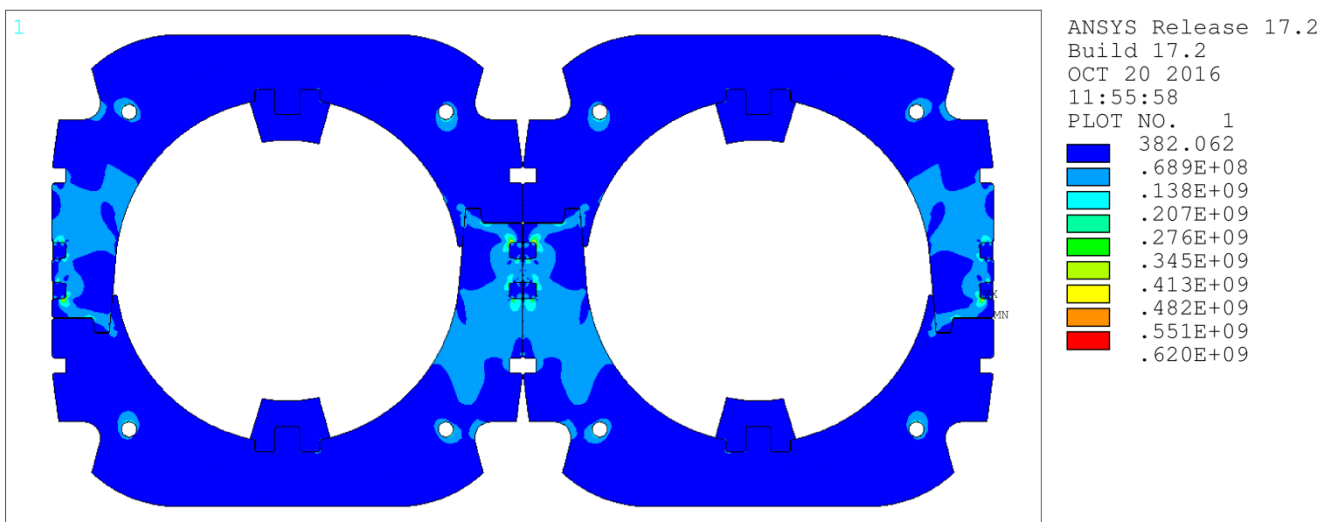
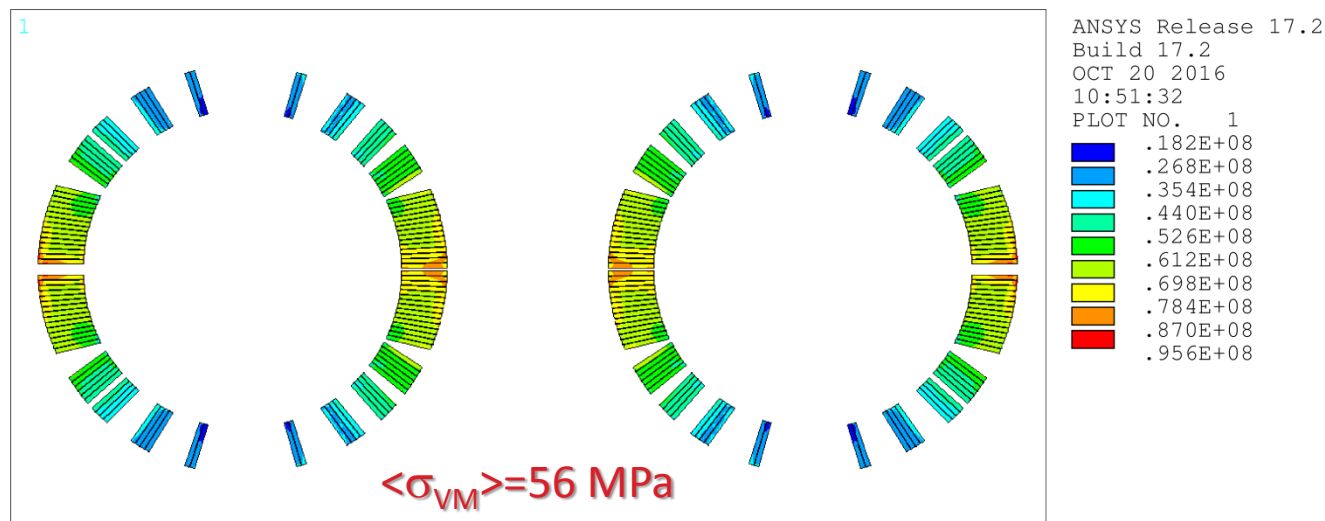
- $F_x = 196 \text{ kN/m}$ and corresponds to the unbalance between the left and right part of each coil ($F_{xA} = +1351 \text{ kN/m}$ and $F_{xB} = -1155 \text{ kN/m}$)
- $F_y = -845 \text{ kN/m}$ ($F_{yA} = -433 \text{ kN/m}$ and $F_{yB} = -412 \text{ kN/m}$)



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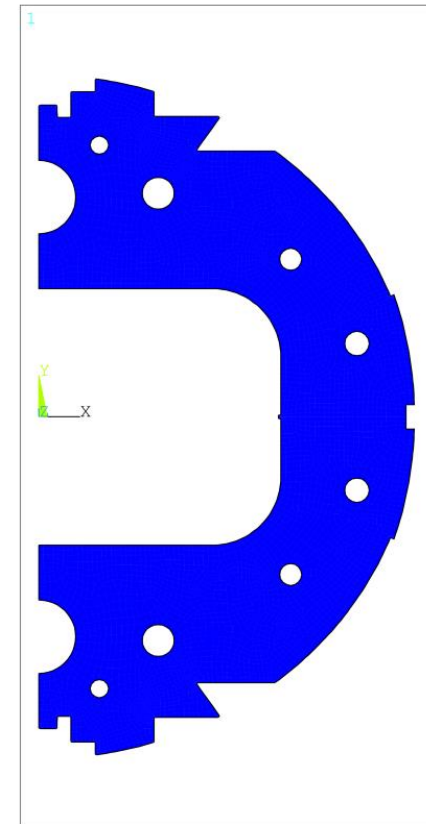
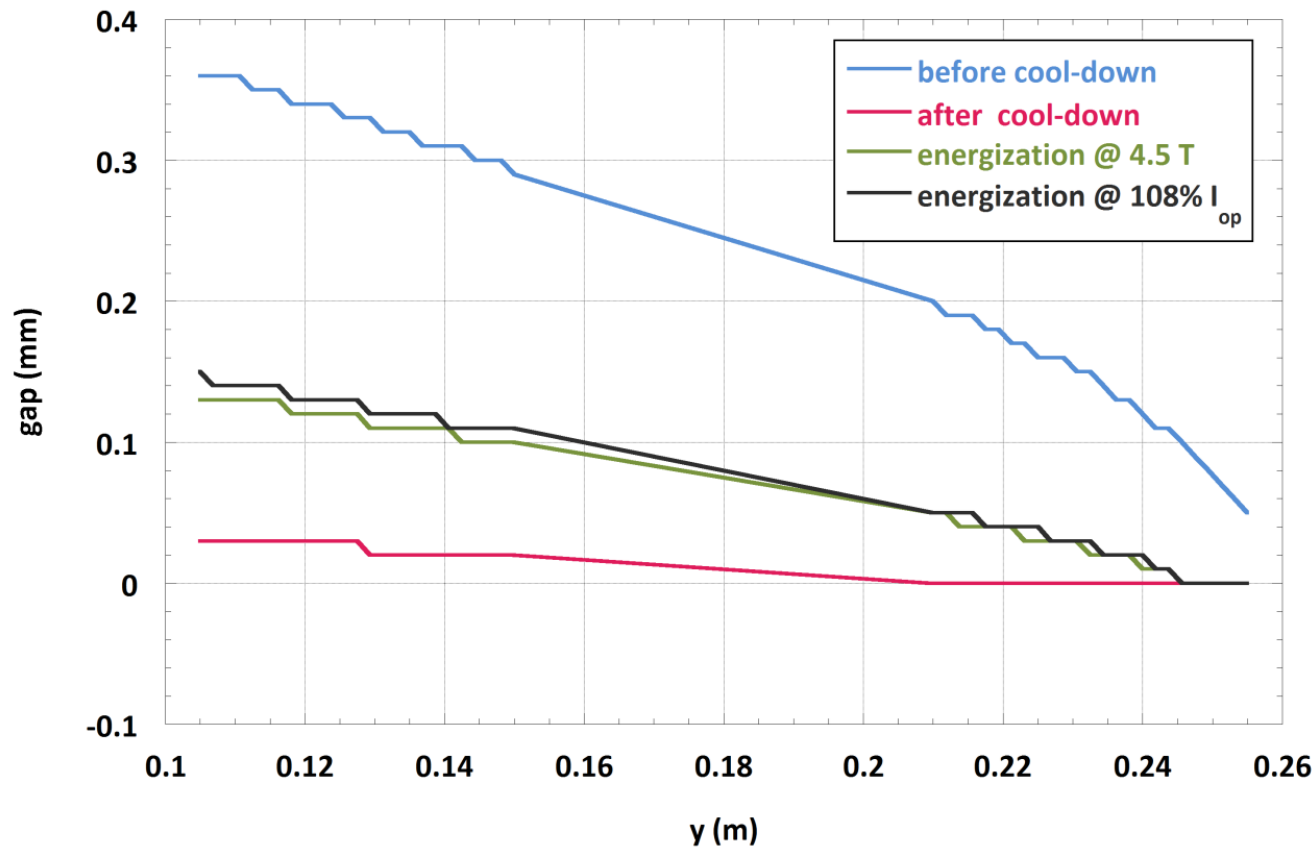
Stress in winding and collars after energization at 4.5 T



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Gap between the iron yoke halves



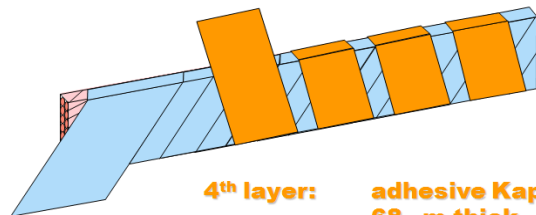
The effect of the outer shell not evaluated yet (the short model has no shell)

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The present D2 insulation scheme based on SIS300 experience was questioned

1st 3 layers: Kapton HN
25 μ m thick
11 mm wide
wound 2/3 overlapped



4th layer: adhesive Kapton HN
68 μ m thick
9 mm wide
wound with 2 mm gap

The resulting thickness after curing is:
98 μ m azimuthal – 125 μ m radial

Rised issues :

- 1) The 25 μ m tape is critical;
- 2) The overlapping 2/3 is critical

Actions and results :

- 1) **Check the use of 25 μ m tape in other LHC magnets (and in accelerator magnets \neq SIS300).**

Result: Many LHC magnets involves 25 μ m tape but never 2/3 overlapped .

- 2) **Possible solutions**

2.1) Replacing the 25 μ m tape with a 37.5 μ m tape and involving 2 layers half overlapped we have the same result of 3 layers of 25 μ m tape 2/3 overlapped. The 68 μ m layer with adhesive being unchanged. – No need to re-design the magnet

2.2) Involving the insulation of LHC MQ (one layer with 37.5 μ m tape ; one layer with 50 μ m layer and a layer cross wrapped 65 μ m thick with adhesive) for a total azimuthal thickness after curing of 110 μ m . Preliminary result: The coil lay-out can remain the same, spacers are modified; acceptable field quality but a disturbing -3.4 unit of b₁₁. → Modified coil design.

2.3) Involving the insulation of LHC MD (The insulation azimuthal thickness is 130 μ m). The coil lay out will change (four configurations under study) . Preliminary result: Far to be satisfactory yet.

QUENCH HEATERS AND COIL WEDGES

Quench Heaters. The quench simulation with Roxie were done considering the QH involved in LHC. Nevertheless this QH is not optimized for the present D2 coil lay-out. INFN and ASG Superconductors will design a new QH.

Coil wedges. The design has been performed considering the coil wedges made of insulated copper. Nevertheless the use of a composite (type G11) seems adequate as well with the advantage to have already in hand a deep knowledge of the coil mechanical properties based on SIS300 experience. CERN/INFN should check possible issues related to the use of G11. If not INFN will perform again the mechanical analysis with this material (same geometry)

CONCLUSIONS

- The contract for short model construction is very close to start at ASG Superconductors
- Kick-off meeting already held. Next meeting before Christmas. ASG Superconductors is supposed to present a detailed schedule
- INFN has ready the reference drawings supported by FEA analysis
- Some doubts to be solved soon about coil insulation, quench heaters and coilwedges