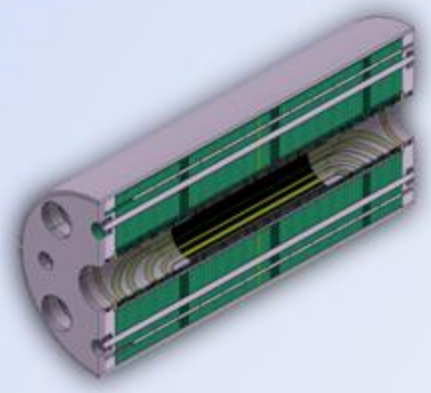
Design, Analysis & Performance of Superconducting Accelerator Magnets



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Technology Department

Superconducting Magnet Design and Technology (MDT)

- Superconducting magnet design and technology: from functional specification to the construction of short prototypes.
- Design study of the LHC upgrade and future projects involving superconducting magnets.
- Superconducting magnet performance analysis and feedback on the design.
- Magnetic model of the LHC, and support to beam commissioning and operation (FiDeL and WISE).
- Superconducting magnet insulation development and CERN-wide support for polymer casting and rapid prototyping.

People

- Nicholas Aquilina (doctoral student)
- Bernhard Auchmann
- Dariusz Bocian (LARP fellow)
- Per Hagen
- Nicolas Bourcey
- Sebastien Clement
- Dominique Cote
- Paolo Fessia (section leader)
- Carlos Fernandes
- Paolo Ferracin
- Remy Gauthier
- Mikko Karppinen
- Glyn Kirby
- Charilaos Kokkinos (fellow)
- Clement Lorin (fellow)
- Jacky Mazet
- Gregory Maury
- Attilio Milanese (fellow)
- Isabella Moser-Roth (doctoral student)
- Juan Carlos Perez
- David Smekens
- Ezio Todesco
- Dimitrios Tsirigkas (fellow)
- Qingjin Xu (project associate)

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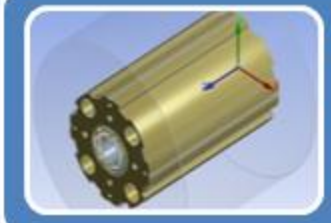
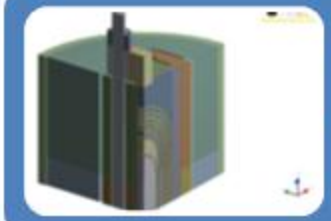
MCXB

- Dipole, Orbit Corrector
- NbTi Cable



MCXB-DL

- Quadrupole, Orbit Corrector
- NbTi Cable



SMC

- Racetrack Configuration, R&D
- Nb3Sn Cable

11T - SMC

- Dipole, Collimator
- Nb3Sn Cable

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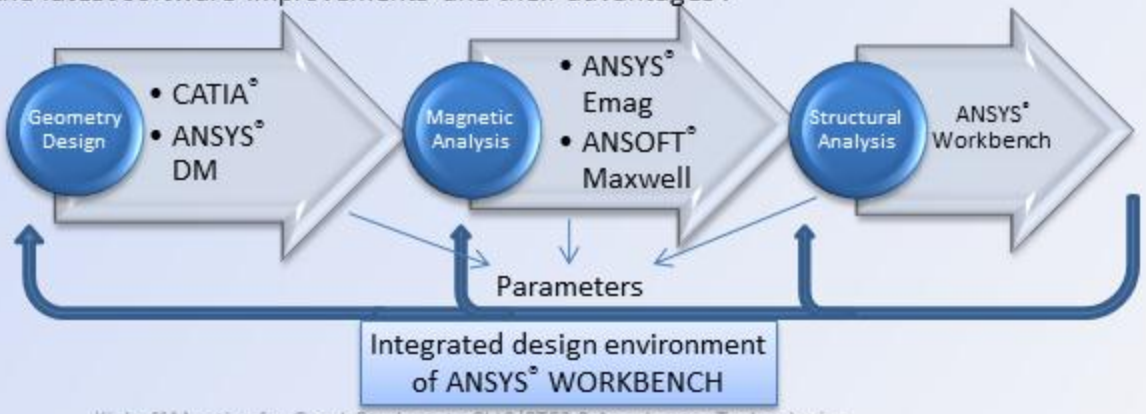
Transition from ANSYS Classic to ANSYS Workbench Why?

- Direct use of *CATIA* files along with their parameters . Bi-directional linkage to *ANSYS Workbench*.
- The geometry used for future analysis is exact as the one used for the assembly. No simplifications due to difficulties in geometry design.
- Fully parametric design that allows any geometry changes to be applied directly .
- More FEA friendly . Any geometry modifications needed for assigning contact regions and for better mesh control can be done anytime through the *Design Modeler* Workbench.
- Ability to control all parameters and the expected results , through the *Design Exploration Table*.
- Great technical model reports .
- The implementation of *ANSOFT MAXWELL* in ANSYS Workbench allows direct transfer of the Lorentz Forces.
- No more use of Input Files .
- Use of the latest Software improvements and their advantages .



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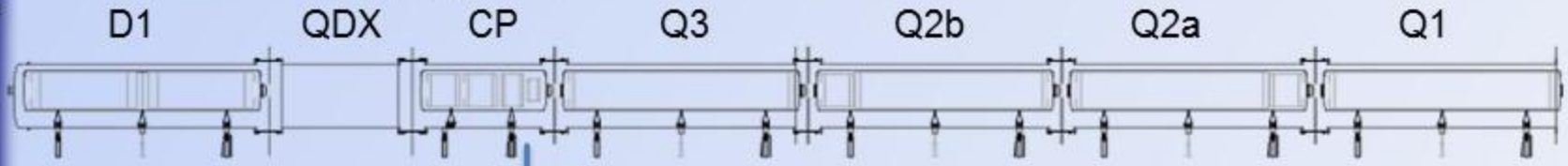
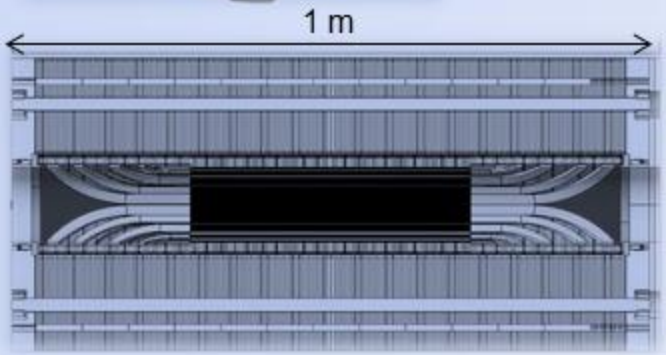
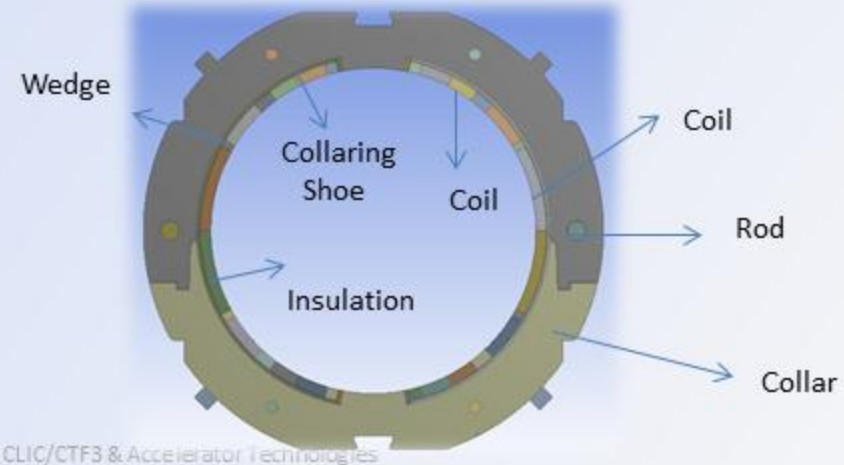
- Horizontal and vertical orbit correctors
- The MCXB orbit correctors are used to correct the misalignment of the MQXC quadrupoles and to adjust the crossing angle and position of the two beams at the IP.



Corrector Package

MCXT	MCXSO MCXO	MCXSS MCXS	MQXS	MCXBV	MCXH
~0.5 m	~0.5 m	~0.5 m	~0.9 m	~1 m	~1 m





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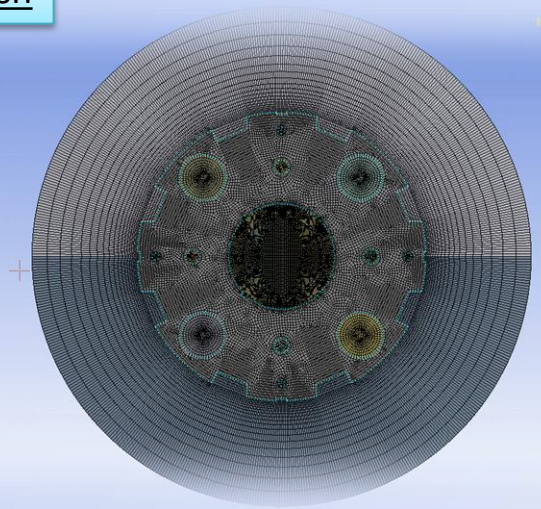
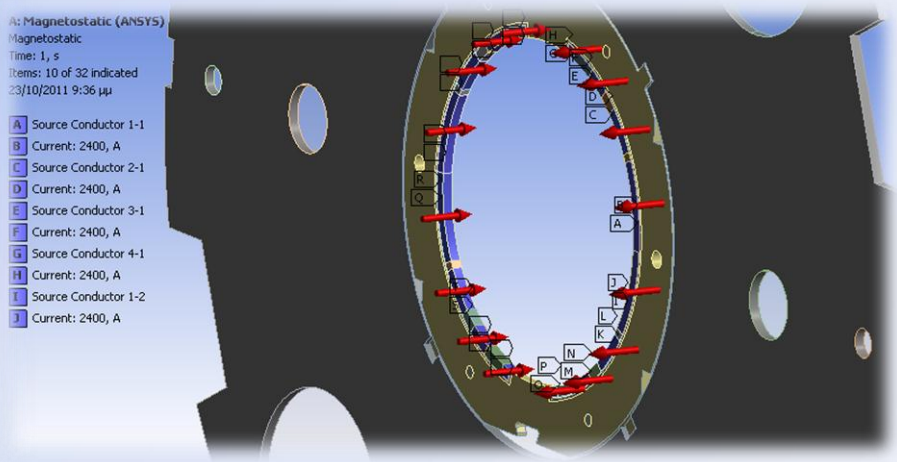
3D Magnetic Analysis

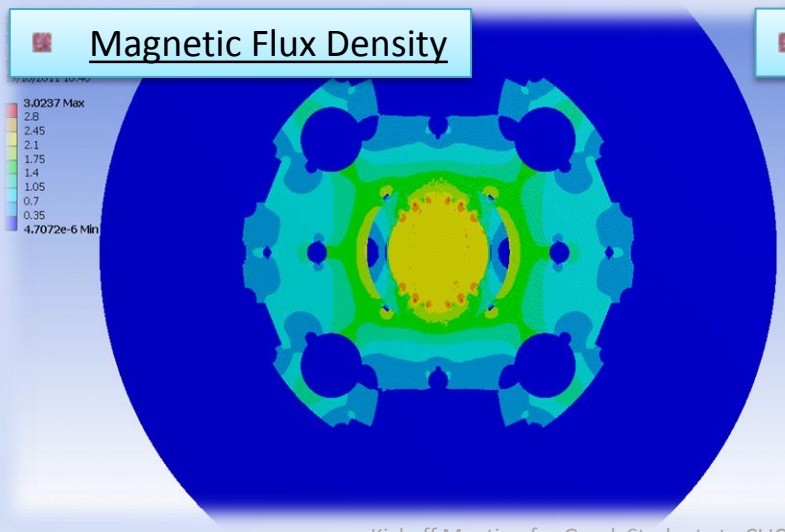
Mesh



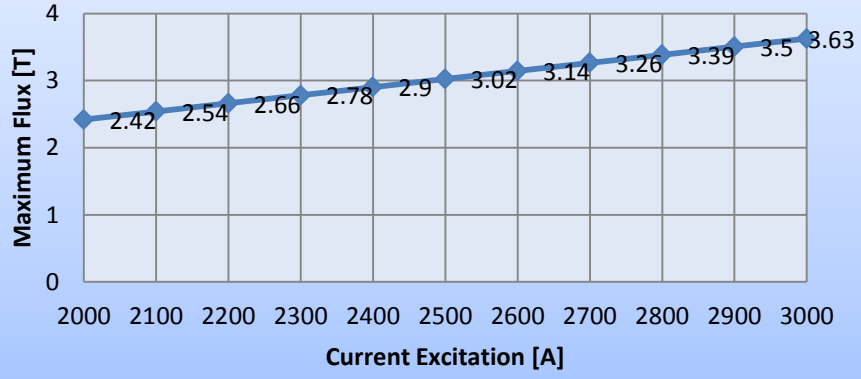
Current Excitation



Magnetic Flux Density



Load Line



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1. MCXB

2. MCXB-DL

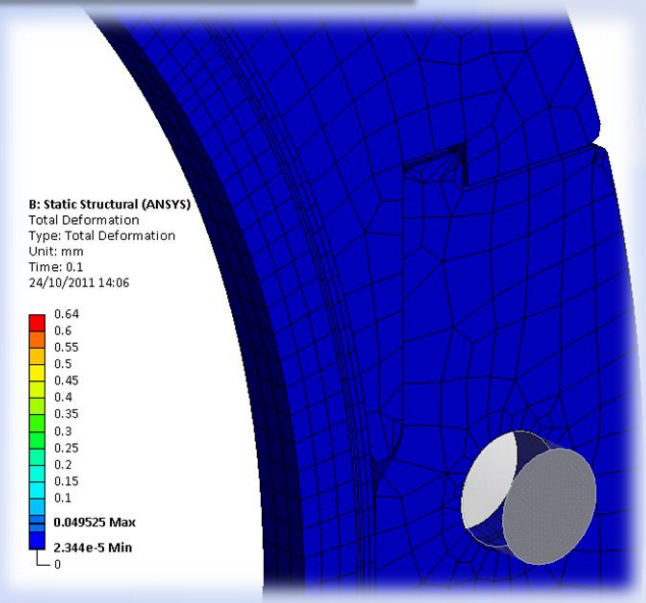
3. SMC

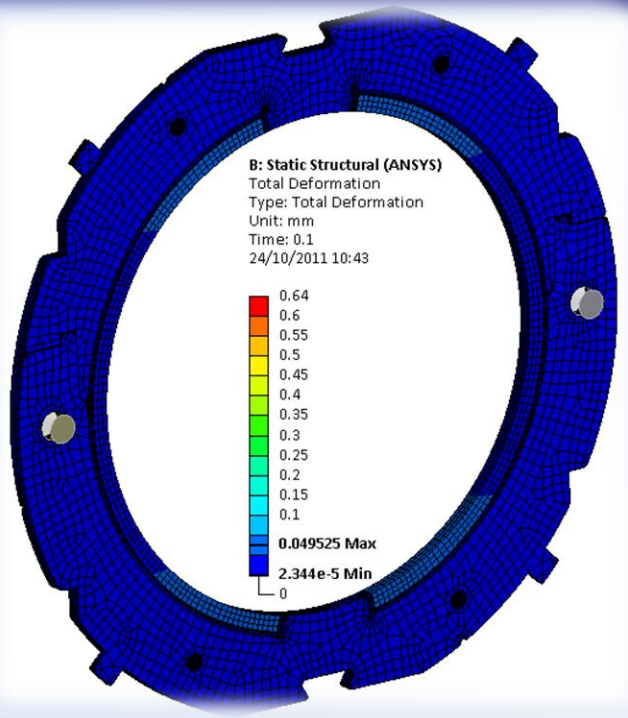
4. 11T Dipole

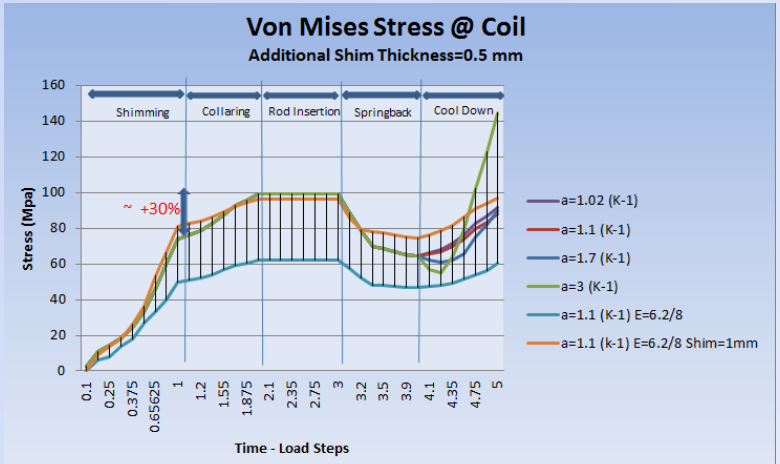
3D Structural Analysis

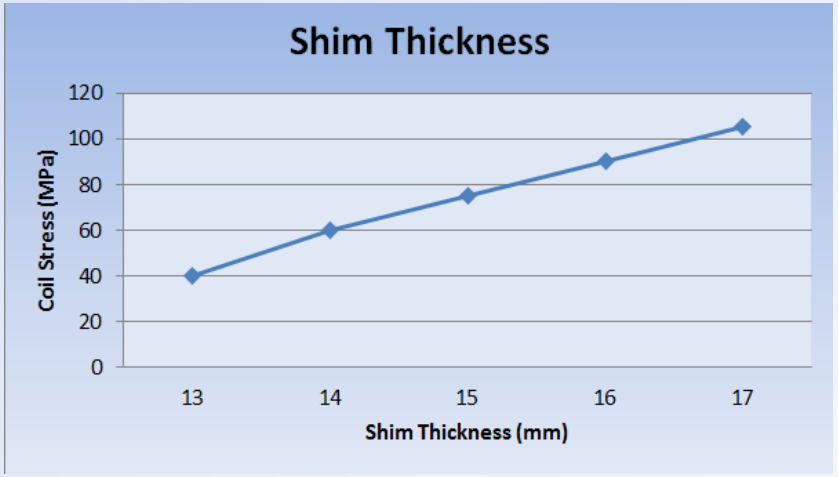
5 Load Steps :

1) Shim Pre-stress
2) Collaring
3) Rod insertion
4) Spring back
5) Cool Down









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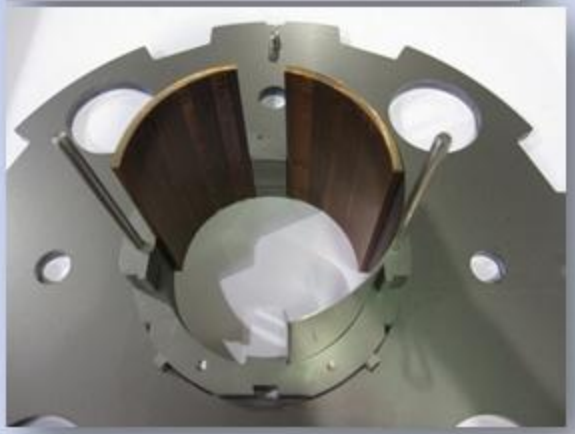
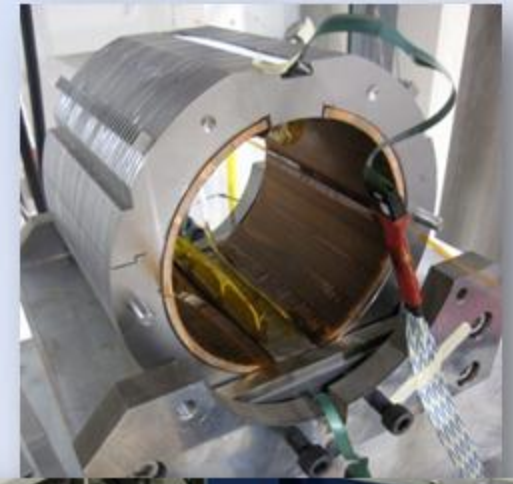
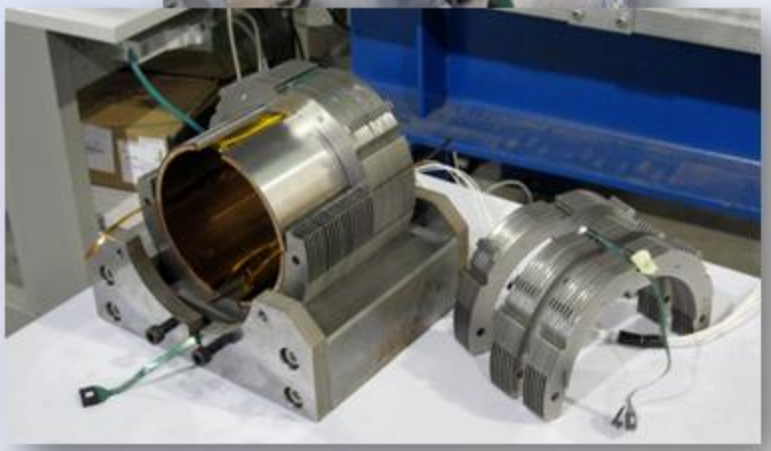
Assembly



MCXB Laminations Trial Assembly





MCXB Short Mechanical Model (150mm) collared with instrumented collars and capacitive gauges.

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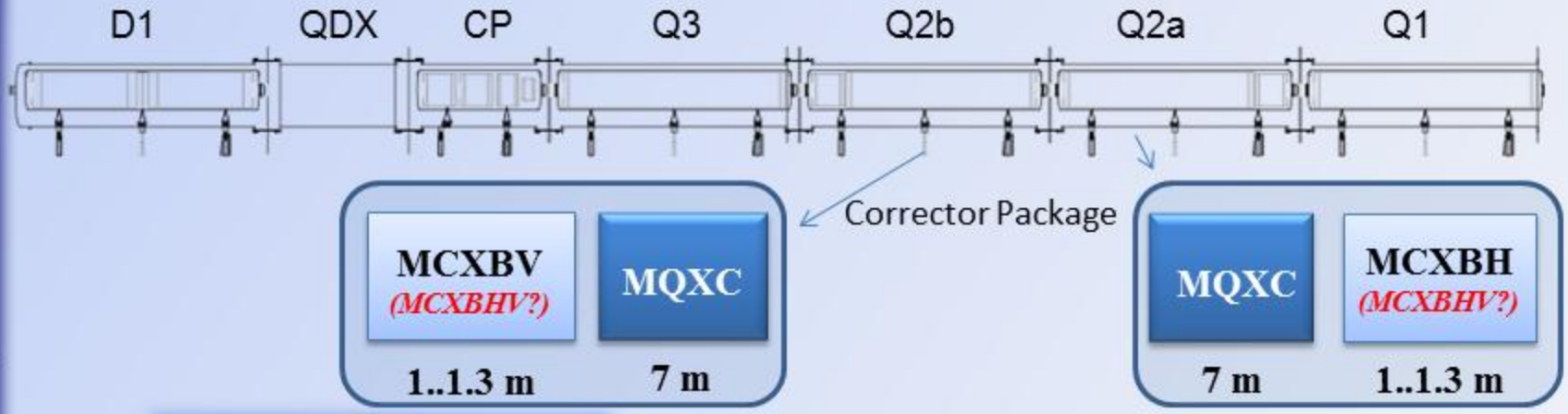
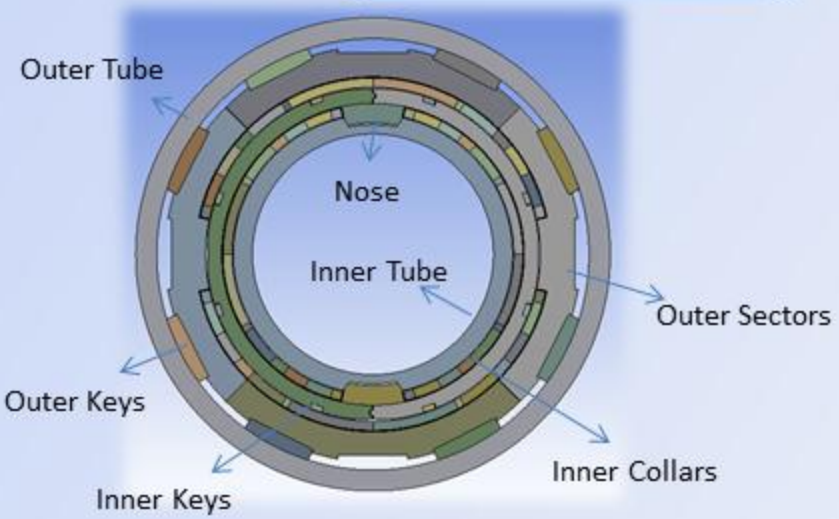
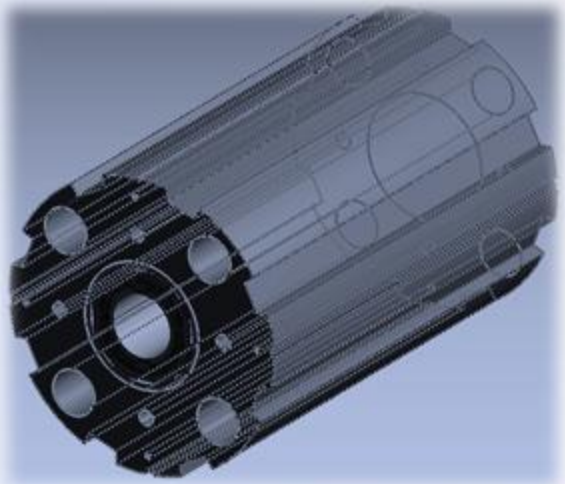
- Horizontal & vertical orbit corrector
- Nested Coils Design
- Biggest Challenge : Torque Capture







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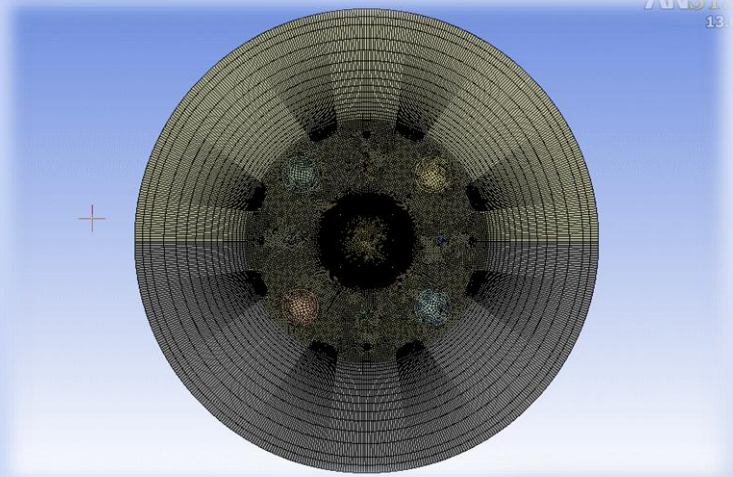
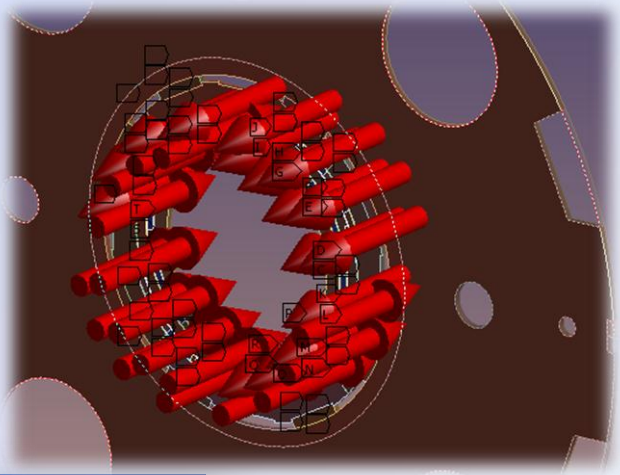
3D Magnetic Analysis

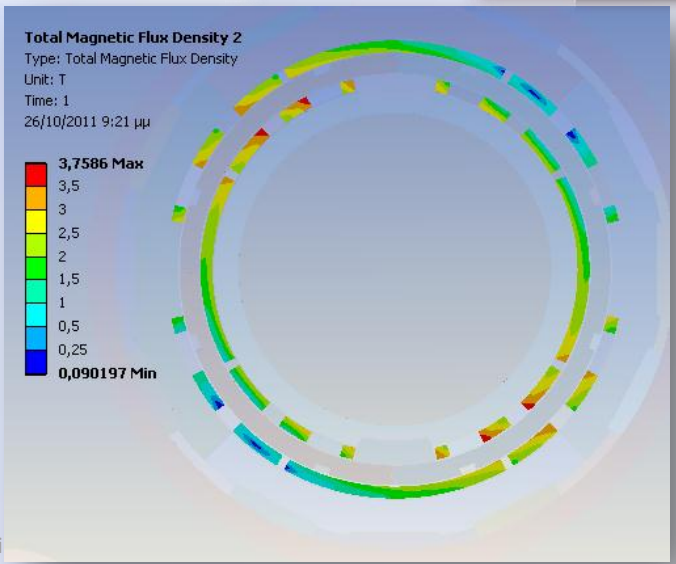
- Mesh



- Current Excitation



- Magnetic Flux Density



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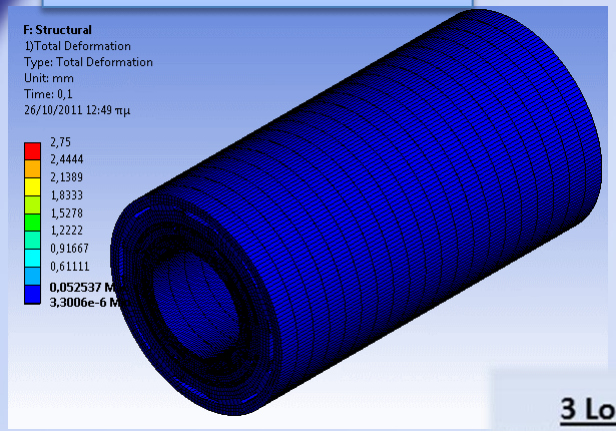
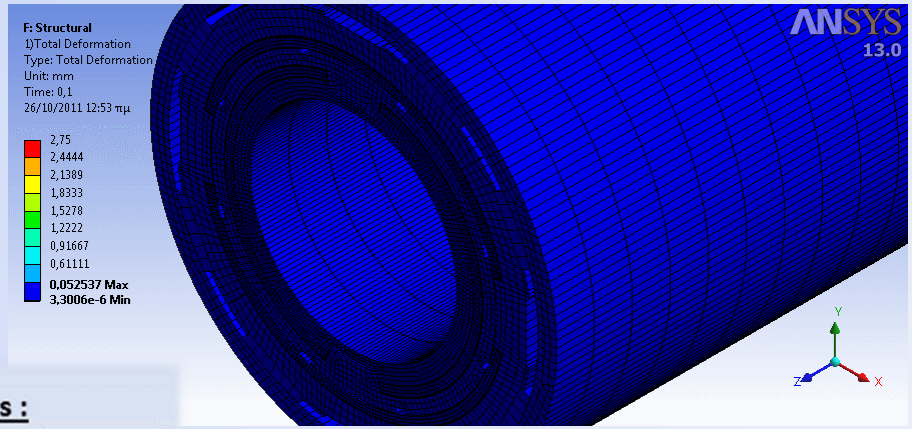
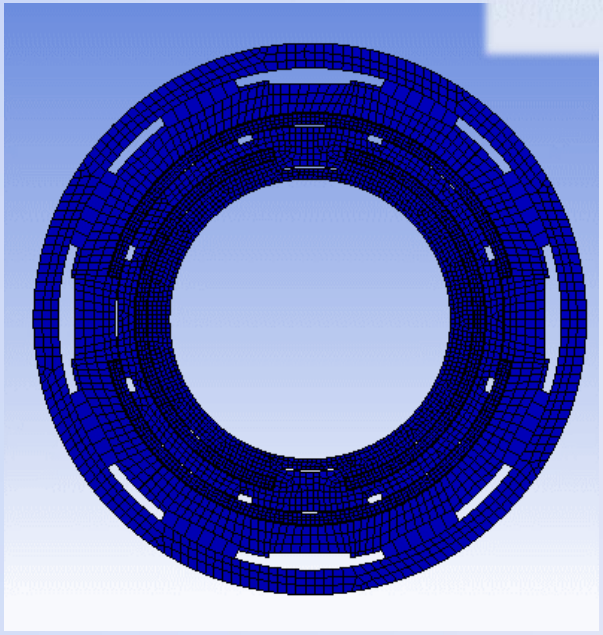
3D Structural Analysis

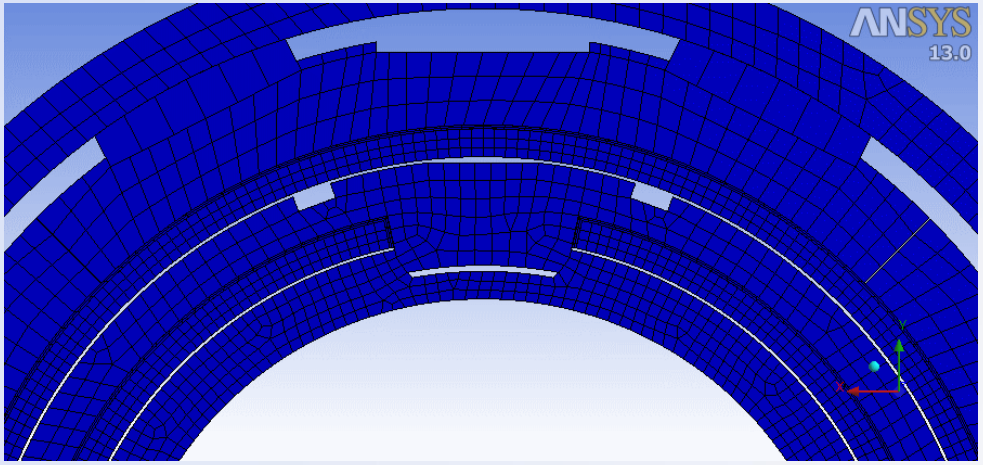




3 Load Steps :

1) Shim Pre-stress
2) Cool Down
3) Powered





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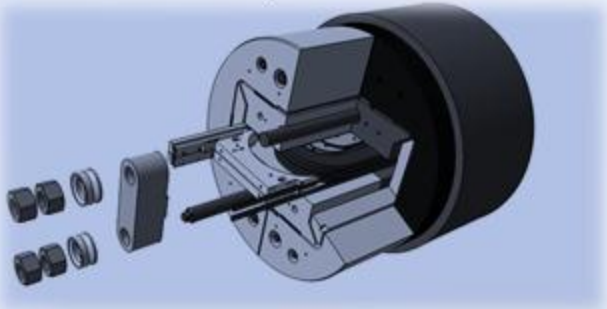
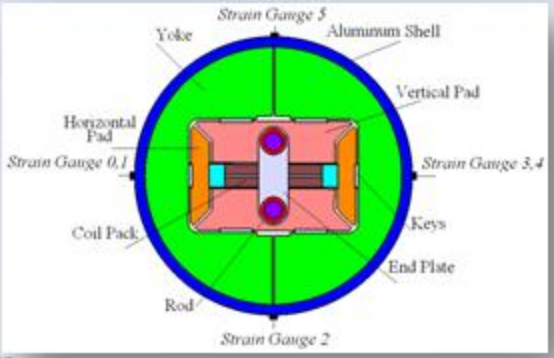
- The SMC (Short Model Coil) project aims at testing superconducting coils in racetrack configuration
- European collaboration between CEA (FR), CERN and STFC (UK), with the technical support from LBNL (US)

- Test bench for short racetrack coils wound with Nb_3Sn cable
- An essential step in the validation of procedures for the construction of superconducting magnets with high performance conductor
- Study of the magnetic properties degradation, by applying different level of pre-stress

Structure

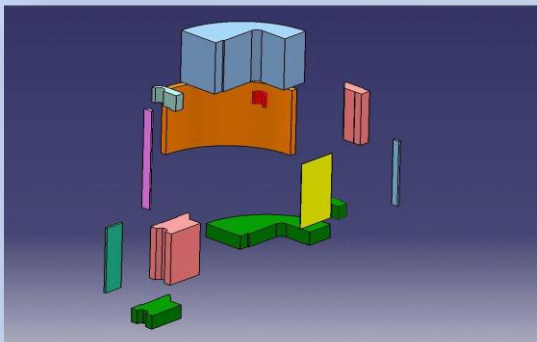


- The structure has to allow variable lateral and longitudinal pre-stress on the coil, to allow testing different cable and insulation types and to be versatile and easy-to-assemble
- Shell-based structure using bladders and keys
- The lateral pre-stress is applied by pressurized bladders, whereas two aluminum rods provide the axial pre-stress

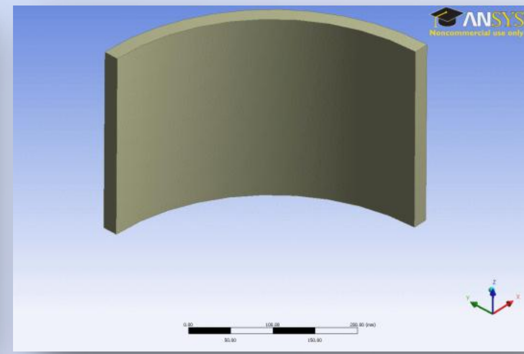


CATIA → ANSYS Design Modeler → ANSYS Mechanical

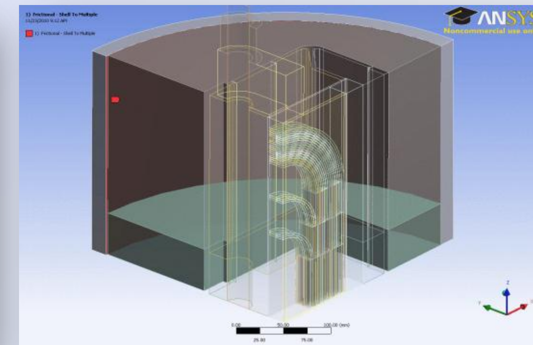
Assembly Design



Geometry Design



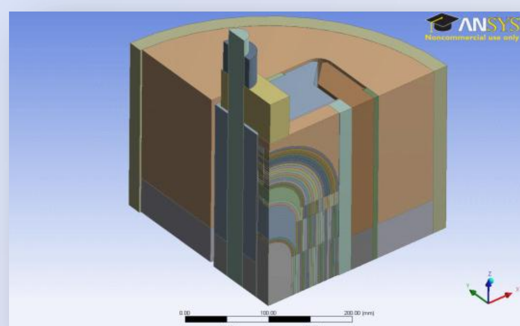
Contact Regions



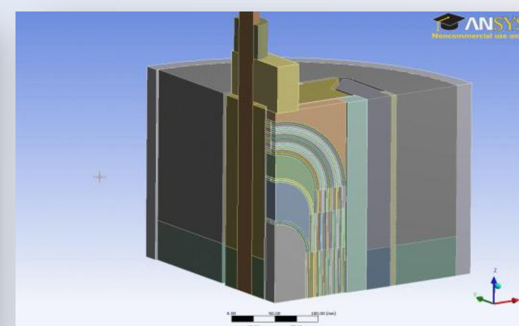
ANSYS DM

- Import CATIA File
- Parametric Coil Block Design
- Boolean/Body Operations
- Draft Projections / Element
- Sizing / Mesh Definition
- Meshing Process
- Mesh Topology
- Analysis Settings Definition

Parametric Coil Block



Meshing Process



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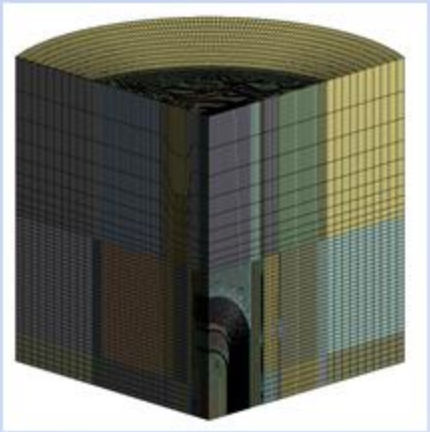
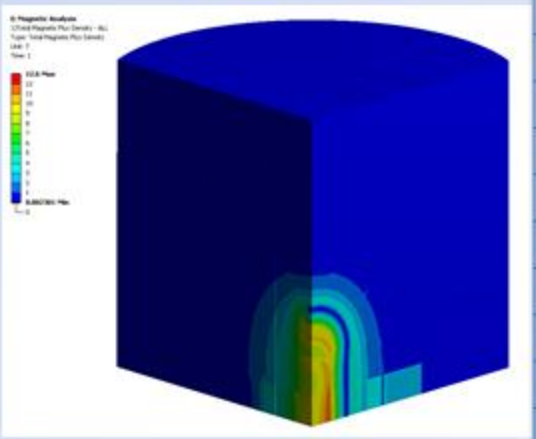
3D Magnetic Analysis

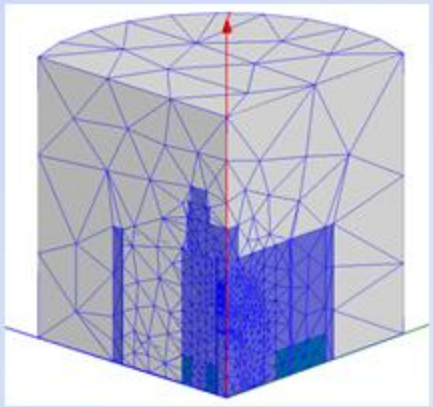
Mesh

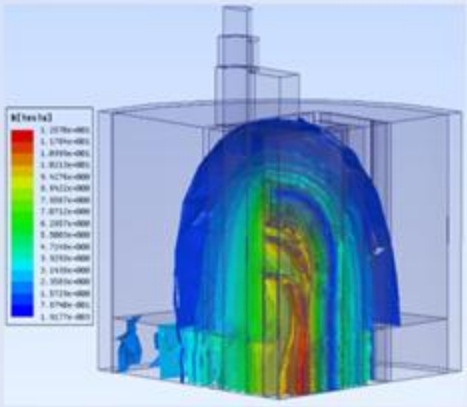


Magnetic Flux Density

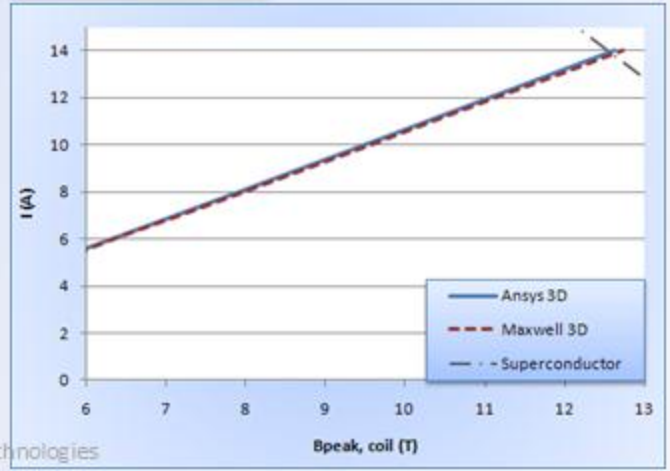


Parameter	Symbol	Unit	Value
Strand diameter	$Ø_{str}$	mm	1.25
Bare cable width	w_{cbl}	mm	9.7
Bare cable thickness	t_{cbl}	mm	2.2
Number of strands	N_{str}	/	14
Number of turns	N_{tot}	/	21
Number of turns in the inner block	N_1	/	2
Number of turns in the mid- block	N_2	/	2
Straight section length	L	mm	150
Axial length of the inner spacer	L_1	mm	30
Axial length of the outer spacer	L_2	mm	10
Pole half-width	r_{int}	mm	40
Interlayer insulation thickness	t_{int}	mm	0.2
Mid-plane insulation thickness	t_{mid}	mm	2.5





Load Line



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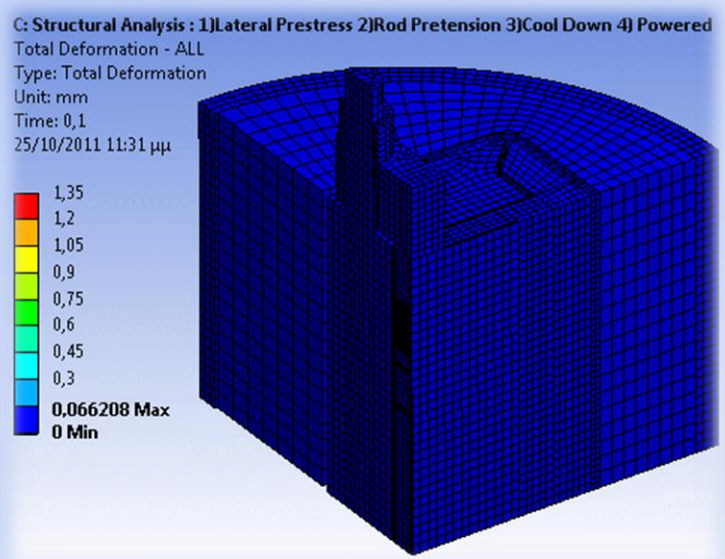
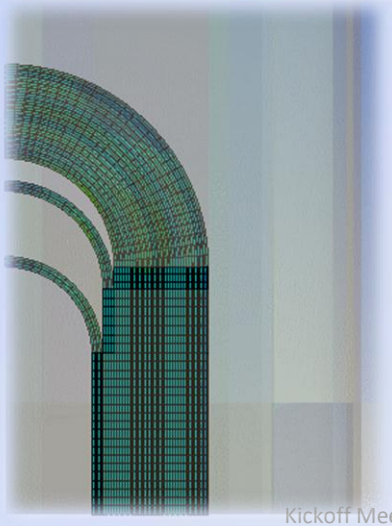
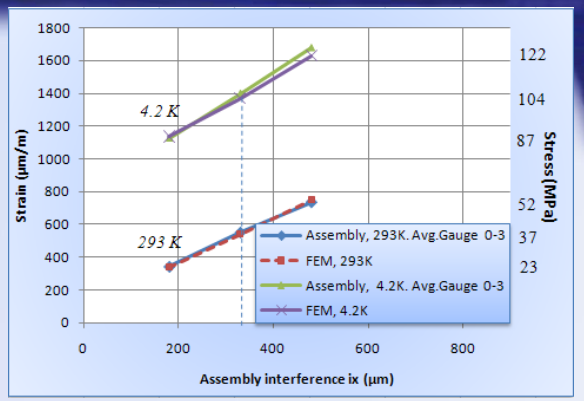
3D Structural Analysis

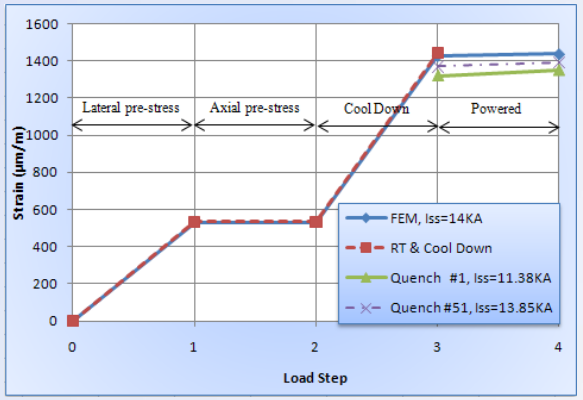


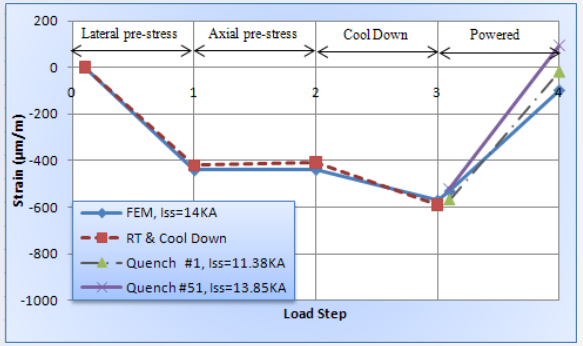


4 Load Steps :

1) Lateral Pre-stress
2) Axial Pre-stress
3) Cool Down
4) Powered @ 12.6 T







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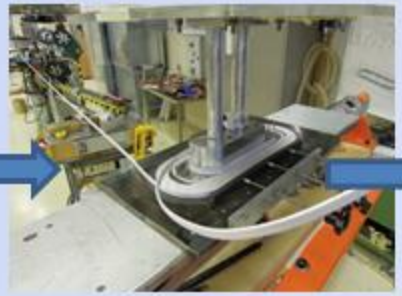
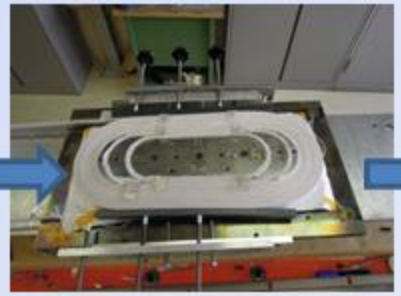
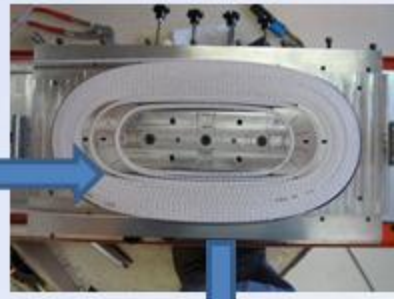
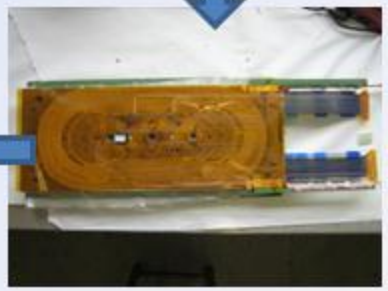
Manufacturing - Assembly



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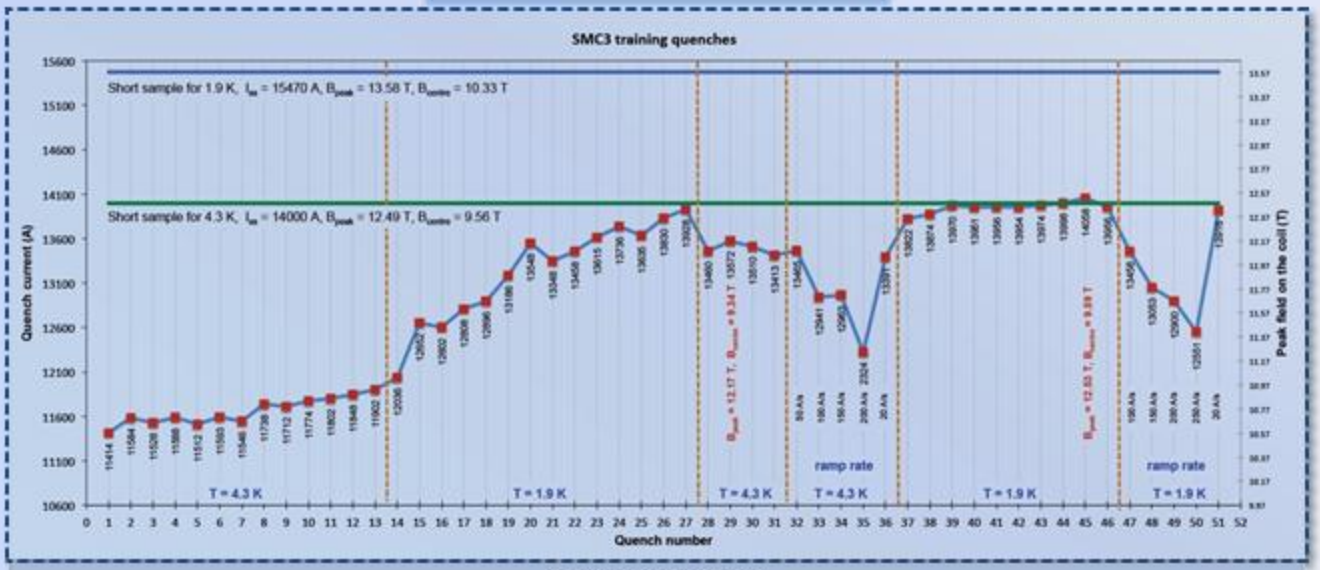
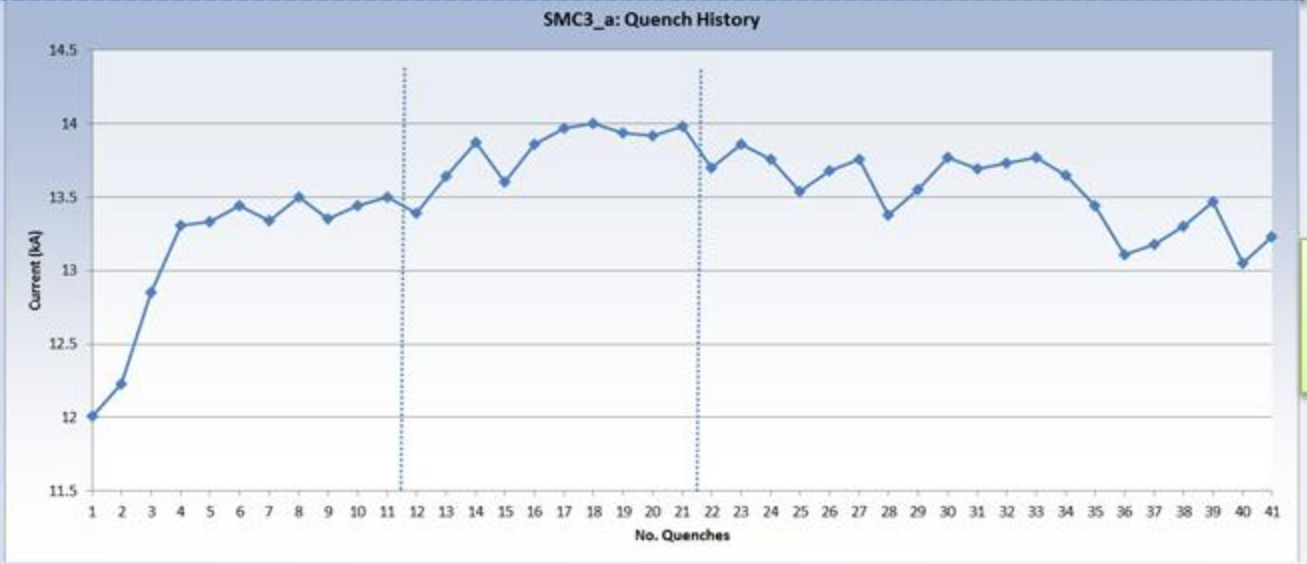
Quench History

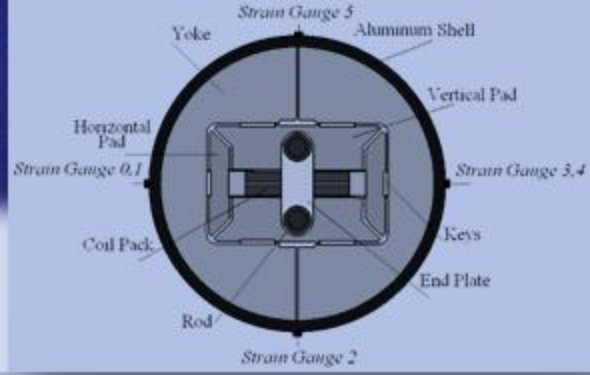


July 2011



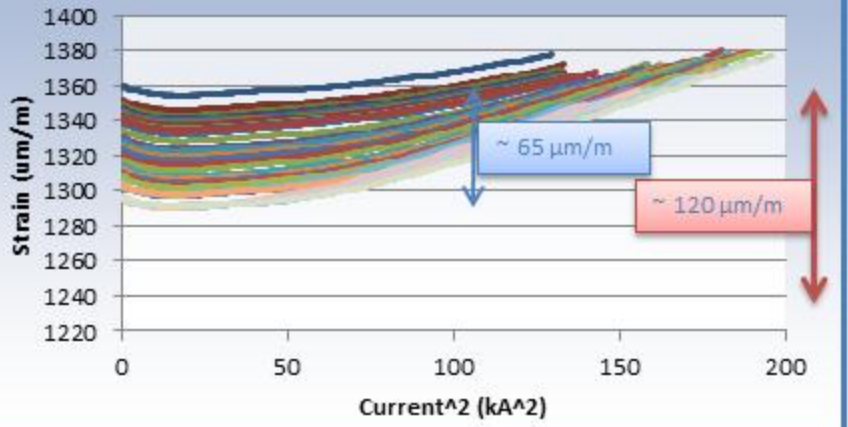
September 2011

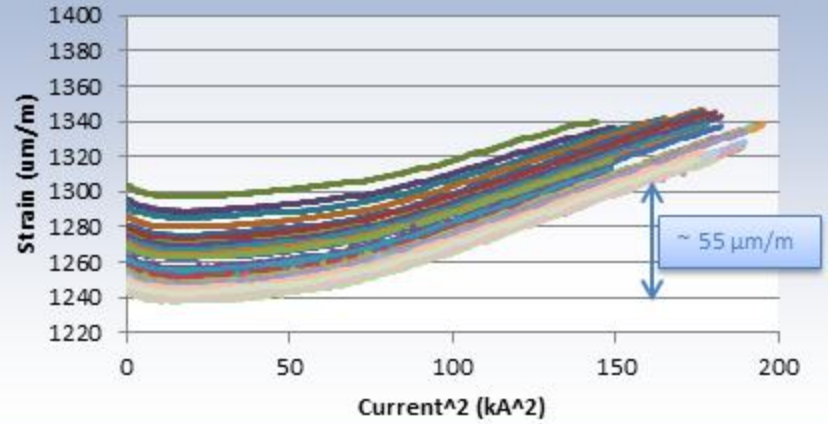
Mechanical Measurements

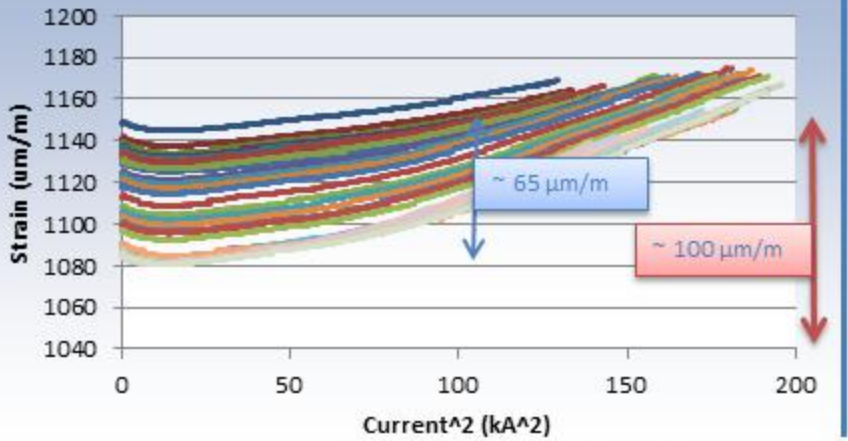


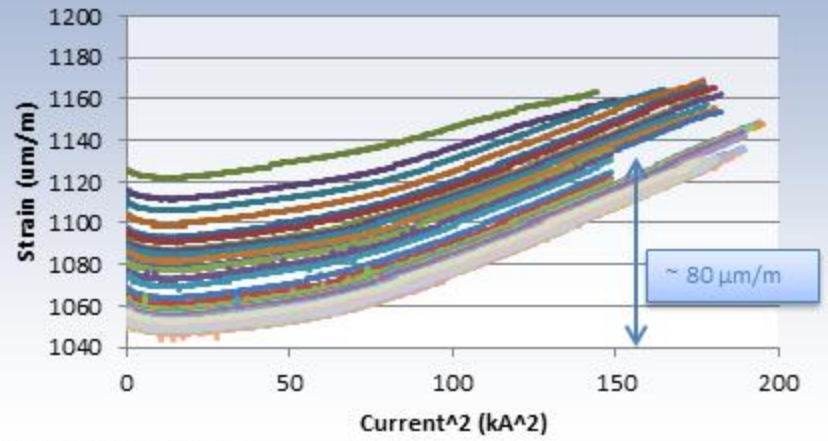
Training

Re-training









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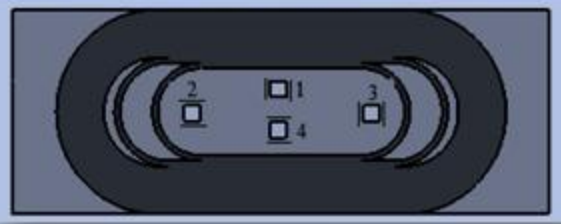
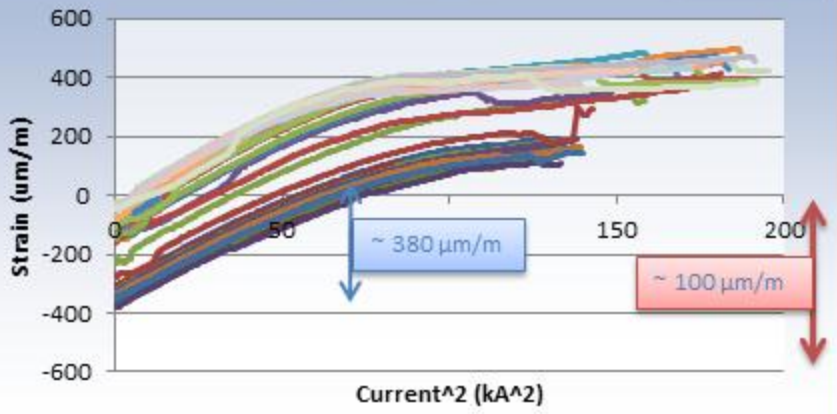
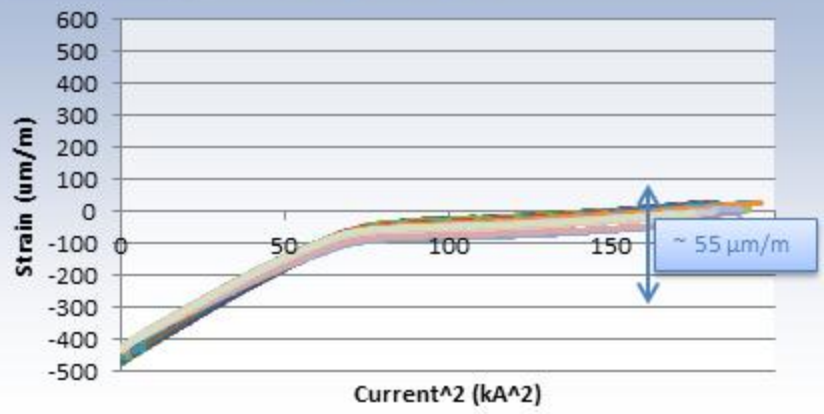
Mechanical Measurements

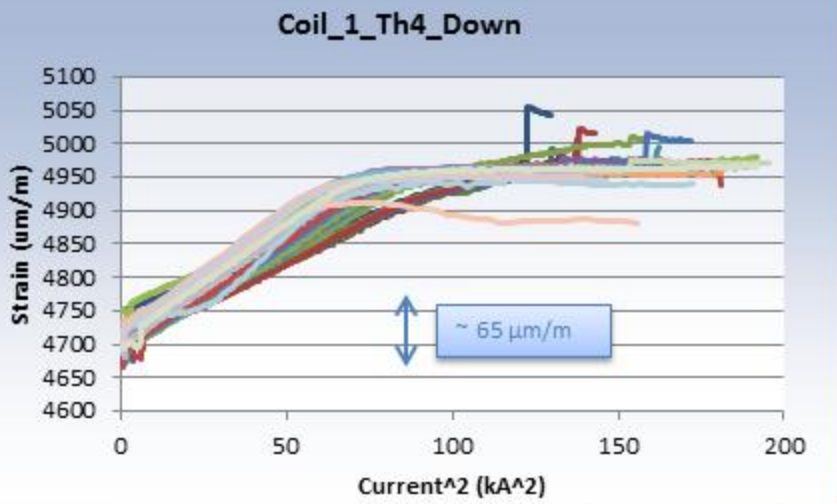


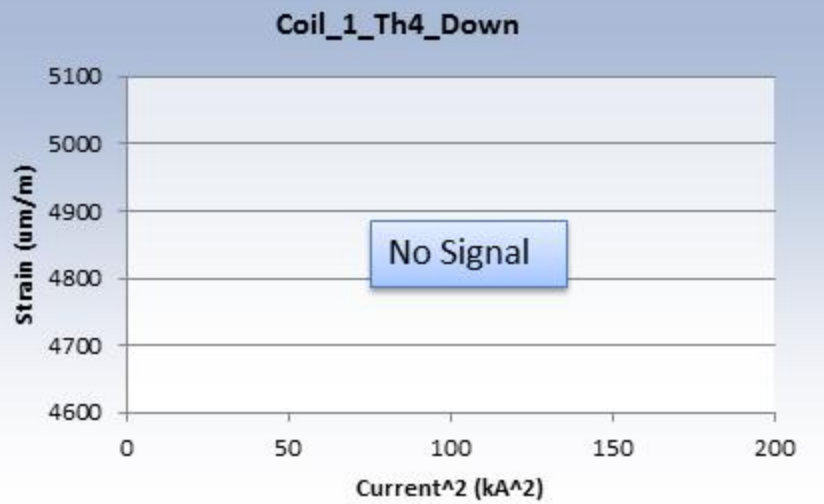
Training



Re-training







Design, Analysis & Performance of Superconducting Accelerator Magnets

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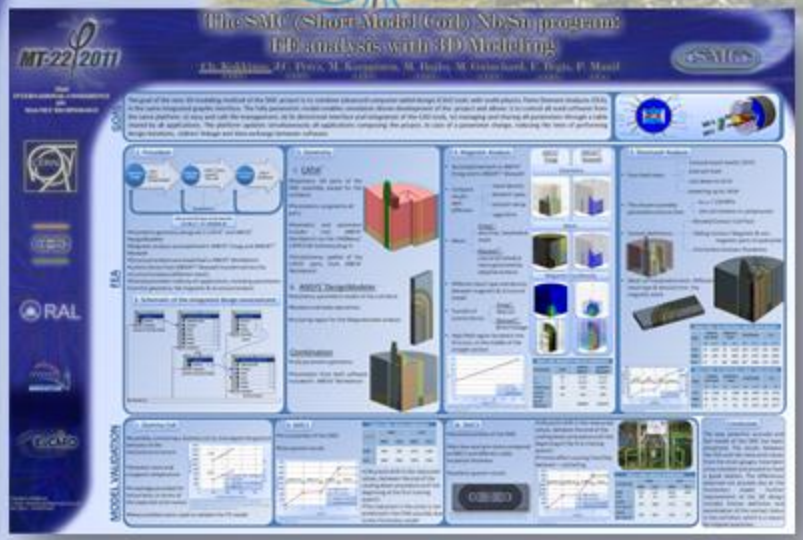
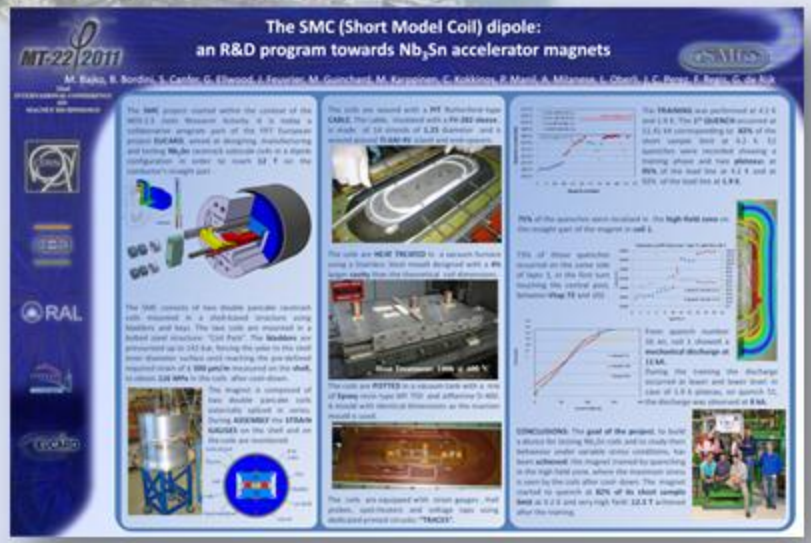
1. MCXB

2. MCXB-DL

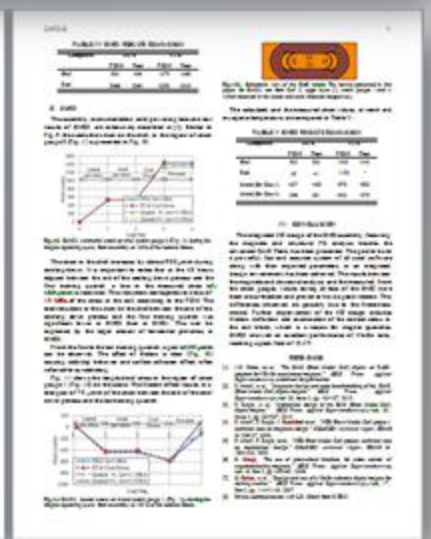
3. SMC

4. TFT Dipole






The SMC (Short Model Coil) Nb_3Sn program:
FE analysis with 3D Modeling



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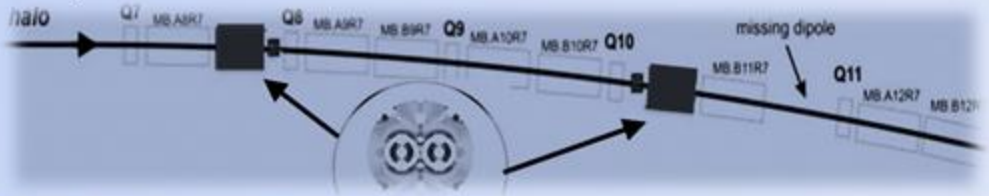
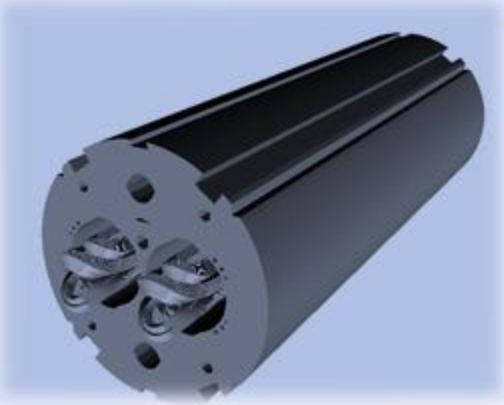
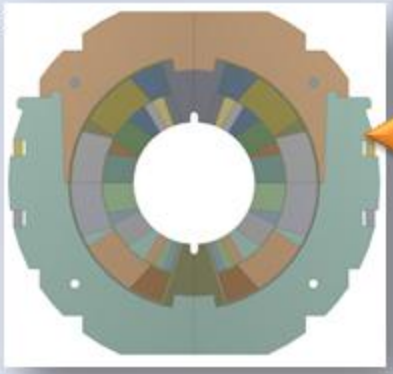
- LHC collimation upgrade foresees two additional collimators installed in the dispersion suppressor regions of points 2, 3 and 7.

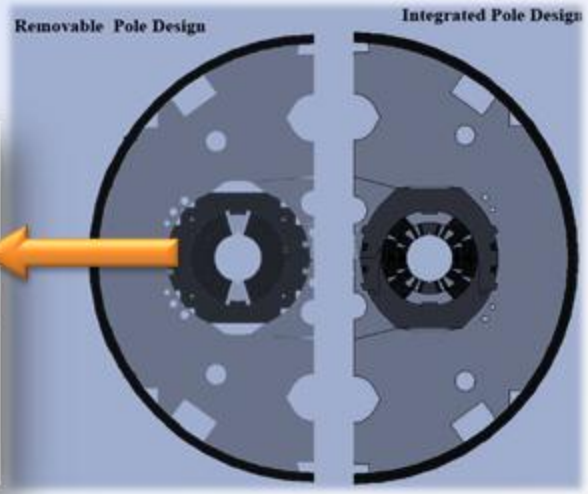


- An 11T Dipole is considered to obtain the necessary longitudinal space for the collimators
- Replacement of the 8.33 T LHC main dipoles
- Development program to demonstrate the feasibility of **Nb3Sn** technology for this purpose
- CERN & FNAL collaboration
- The goal of the second phase is the design and construction of a series of 2-m-long twin-aperture demonstrator magnets with a nominal field of 11 T at 11.85 kA current



Cable Parameters		
Cu/Non-Cu	1.1	
No of strands	40	
Cable thickness	1.307	mm
Cable width	14.847	mm
Cable area	19.405	mm²
Insulation Thickness	0.1	mm

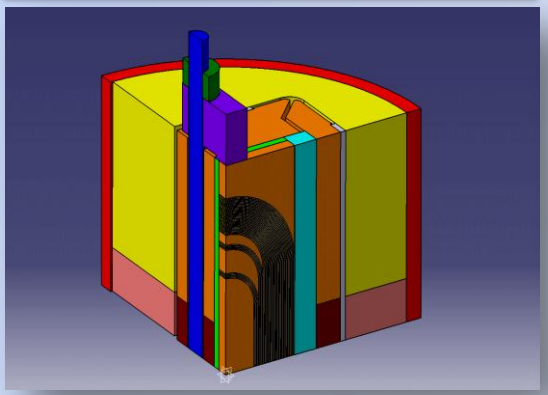




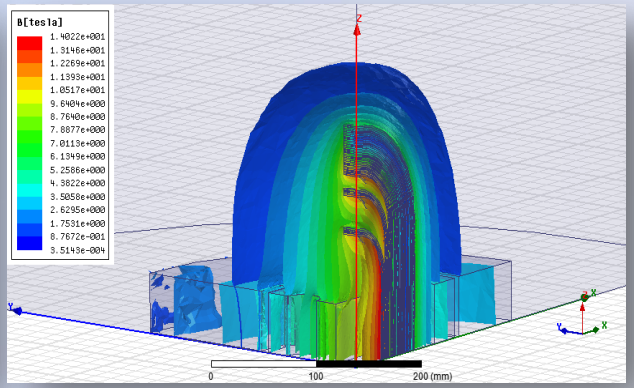
Design, Analysis & Performance of Superconducting Accelerator Magnets

- Development program to demonstrate the feasibility of Nb3Sn technology for this purpose.
- SMC assembly with 11T cable to understand the behavior of Nb3Sn under different level of prestress

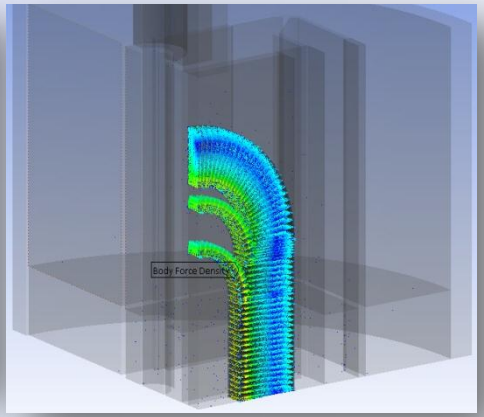
Fully parametric geometry

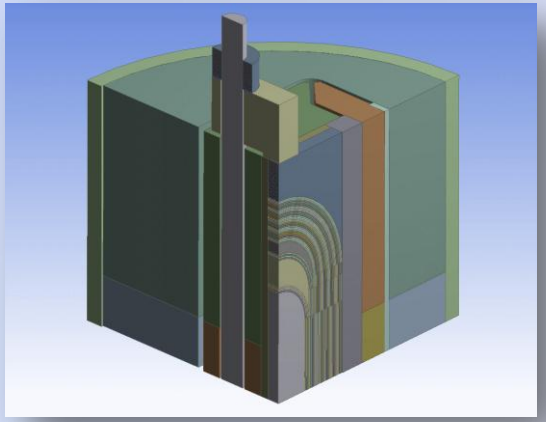


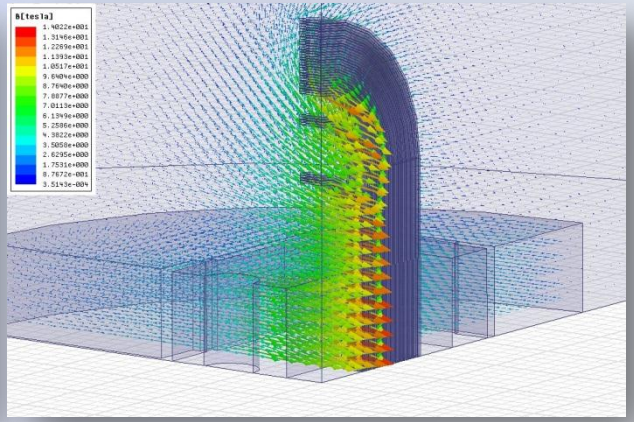
3D Magnetic Model

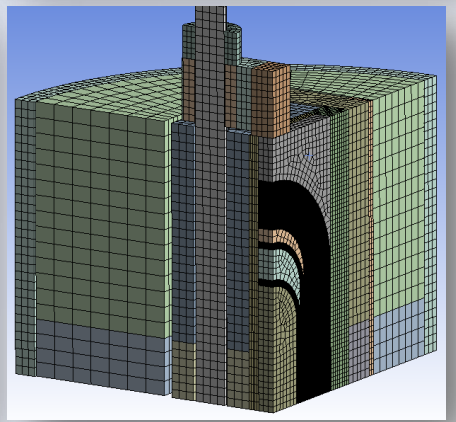


3D Structural Model









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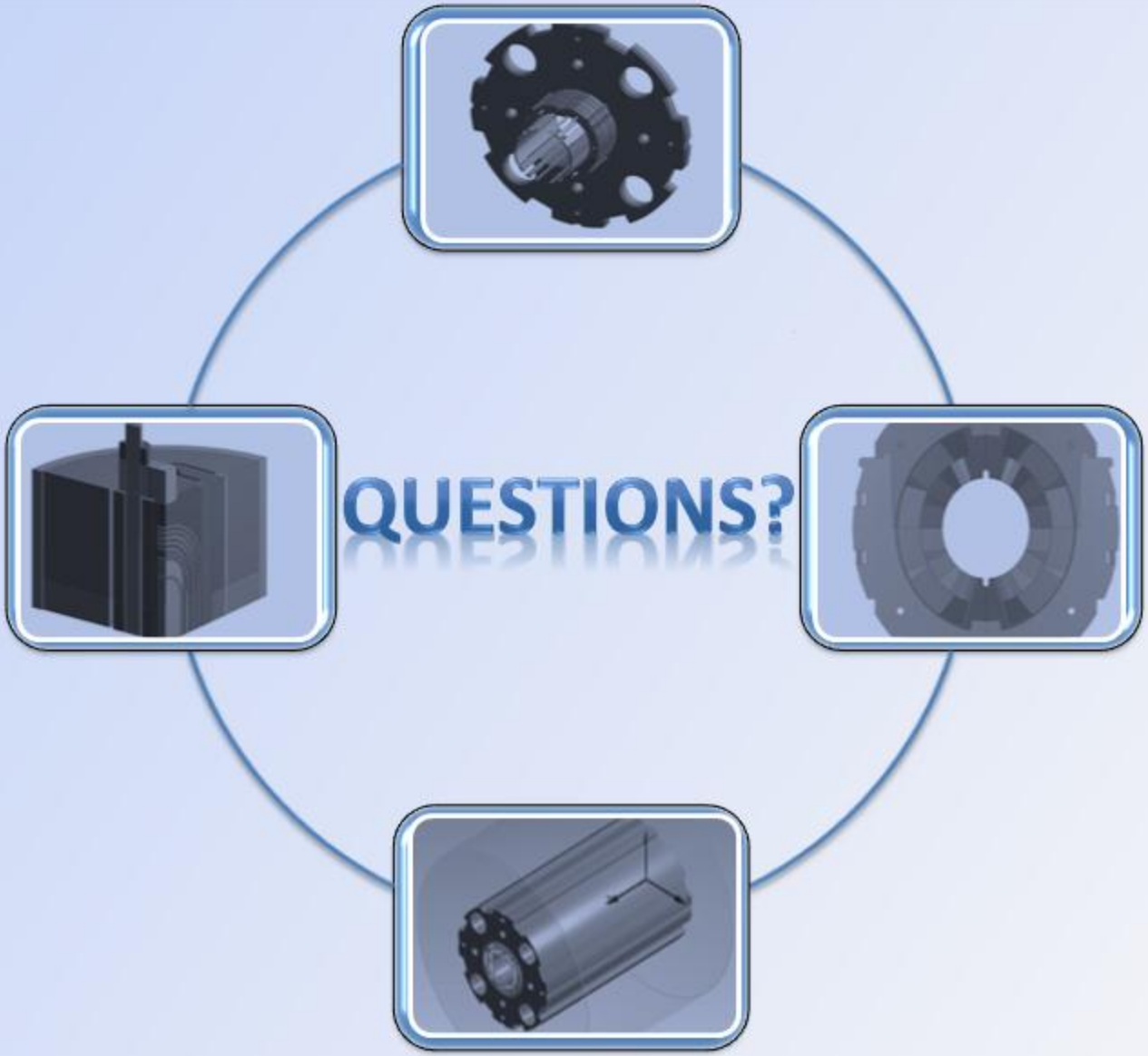

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THANK YOU
FOR YOUR ATTENTION