Final Status of WP6:

Development of Nb-Ti quadrupole magnet prototype

S. Russenschuck

for the WP6 design and construction team

Background

- ➔ After the re-scheduling and re-scoping of the LHC Upgrade Phases no more "Next Inner Triplet (NIT)" Project.
- ➔ Nevertheless, and in coherence with WP6 proposals, identification of technological challenges in magnet technology. Concentration of efforts to push the limits of Nb-Ti technology (fallback solution).

  - Wide aperture magnets using existing cable
    - Instrumented collar pack
  - Heat transfer
    - New coil insulation
    - Open ground plane insulation
    - Quench heater design
  - Horizontal collaring
    - Self-locking collars
  - Radiation hard insulation and coil components
    - Metallic end-spacers
  - Field quality
    - Tuning shims

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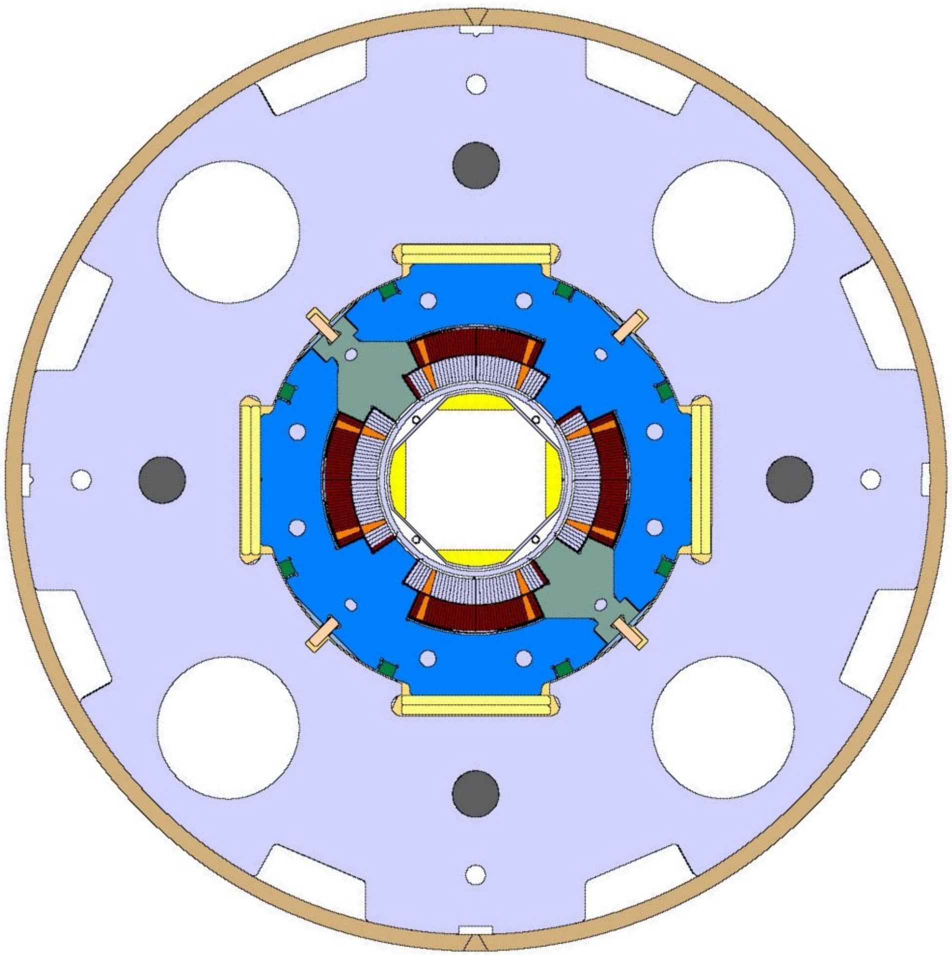
Workpackages and Core-Teams

- WP 6.1: Inner triplet quadrupole magnet (MQXC)
  - M. Durante, P. Manil, J.-M. Rifflet, M. Segretti (CEA) S. Luziuex, P. Fessia, J.C. Perez, M. Karppinen, G. Kirby, S. Russenschuck, T. Sahner (CERN)
- WP 6.2: Instrumented collar pack
  - E. Bielert, G. Kirby, L. Williams (CERN)
- WP 6.3: Construction of corrector magnet package
  - Orbit corrector magnet (MCXB)
    - A. Brummitt, M. Courthold, S. Jones (STFC-RAL) N. Dalexandro, N. Elias , L. Favre, O. Gumenyuk, A. Kuzmin, M. Karppinen, J. Mazet, J-C. Perez, D. Smekens, V. Sytnik, G. Trachez, G. Villiger (CERN)
  - Octupole (MCXO), Sextupole (MCXS)
    - F. Aragón, J. Calero, J. Gama, J.L. Gutiérrez, E. Rodríguez, I. Rodríguez, L. Sánchez, F. Toral (CIEMAT) D. Smekens, M. Karppinen (CERN)
- WP 6.4: Cryomagnet design
  - B. Laune, D. Reynet (IN2P3) V. Parma, J.P. Tock, L. Williams (CERN)

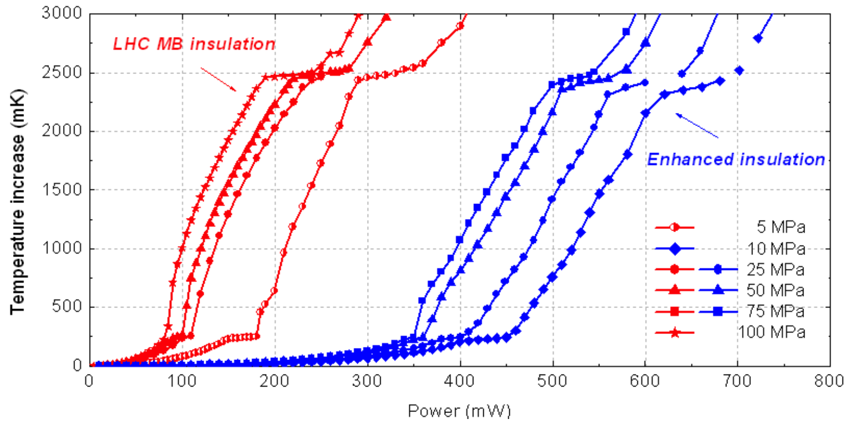
Thanks to all those (not mentioned or forgotten) colleagues
at CERN, CEA, SIEMAT, STFC, IN2P3

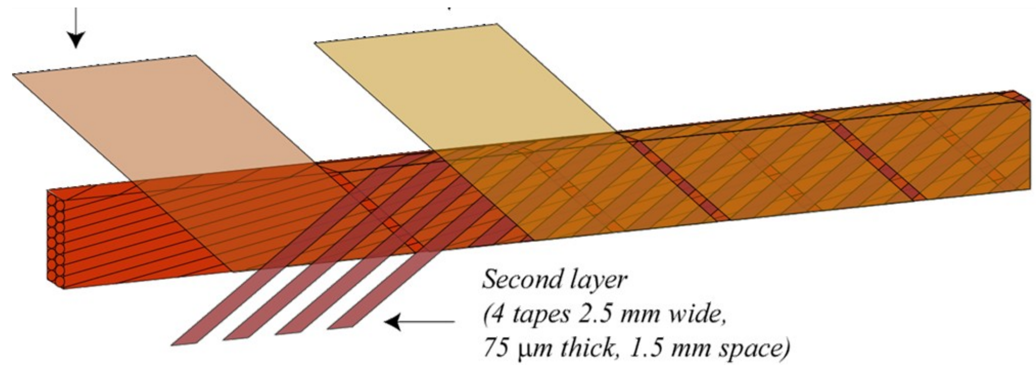
Low-β Quadrupole MQXC

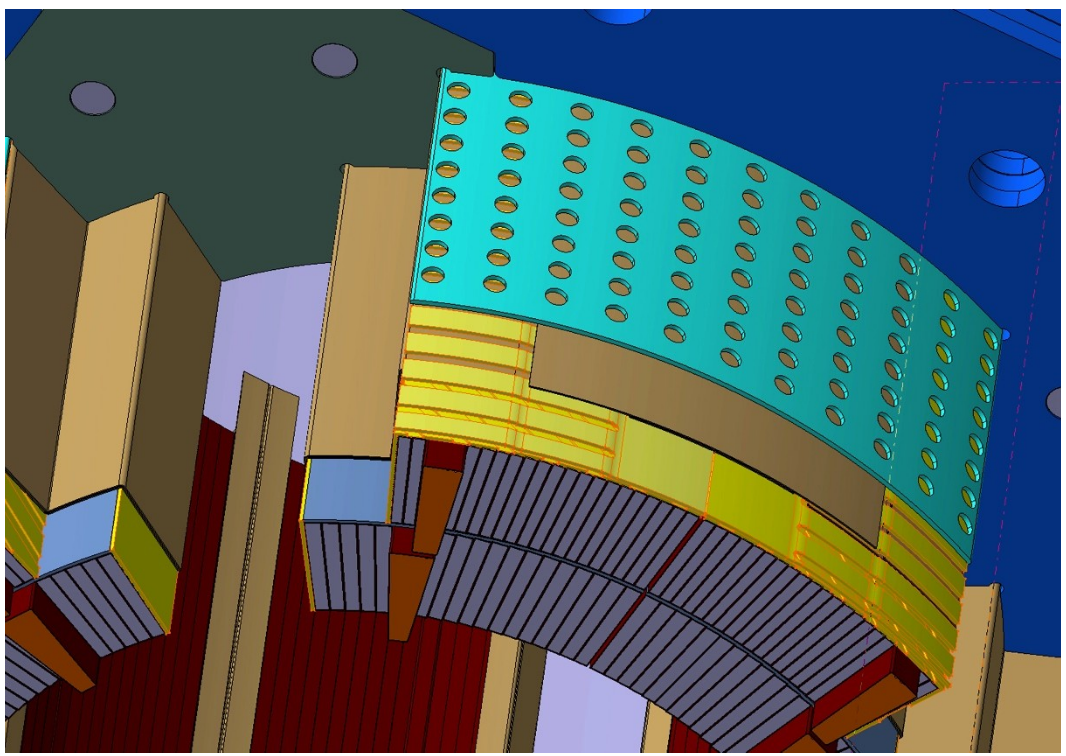
More than 400 engineering design drawings completed in 2010, all material and tooling procured

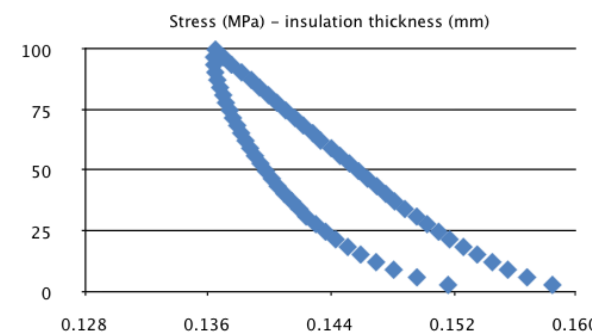


- Operating temp 1.9 K
- Aperture 120 mm
- Field gradient 127 T/m
- Current 13.8 kA
- WP on load-line 85%
- Use of existing Nb-Ti cables
  - LHC cables 01 and 02
- Heat load on inner triplet 500 W (cryogenic installation unchanged)
  - Porous cable polyimide insulation
  - New ground plane insulation scheme
  - New quench heater design
- Yoke OD identical to MB (550 mm)
- Cryostat identical to LHC MB
- Self-supporting collars
  - Horizontal assembly
- Tuning shims









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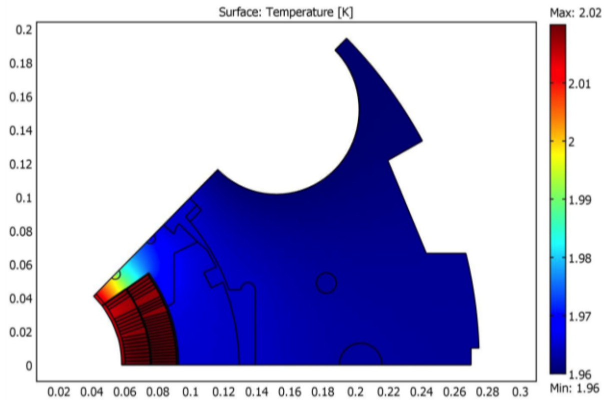
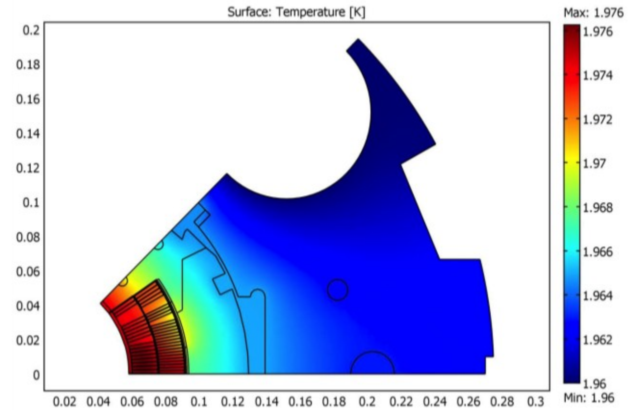
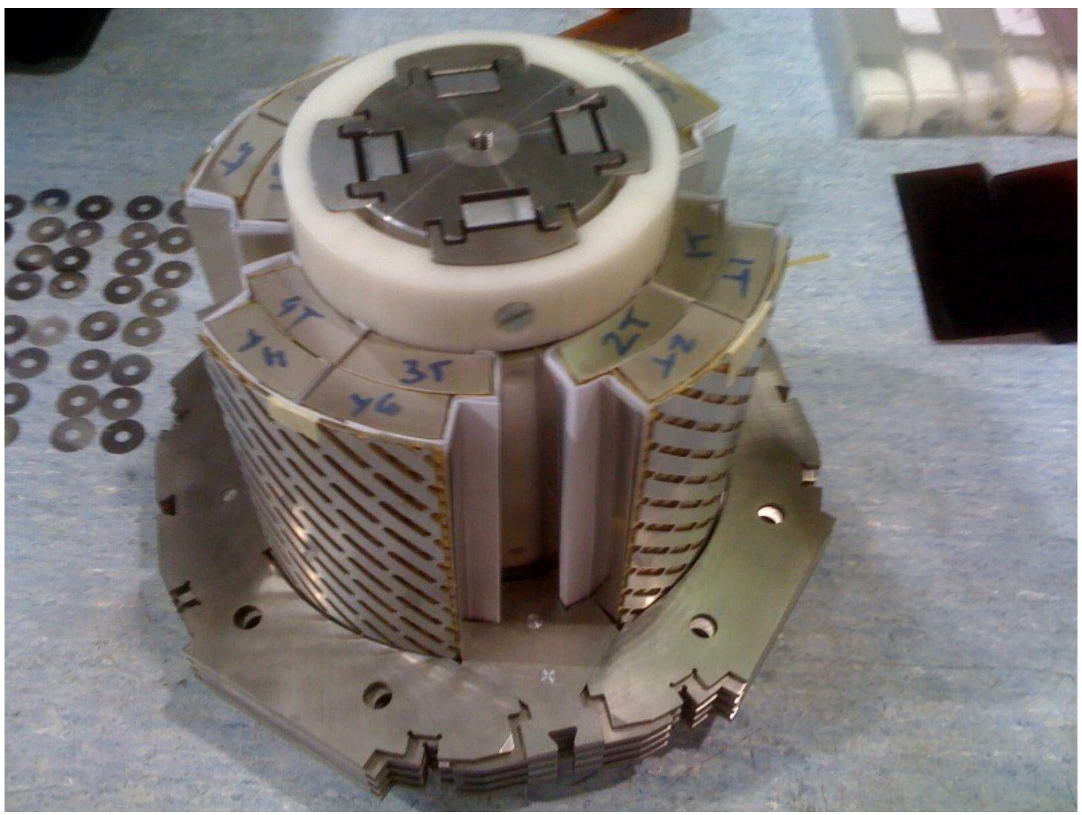
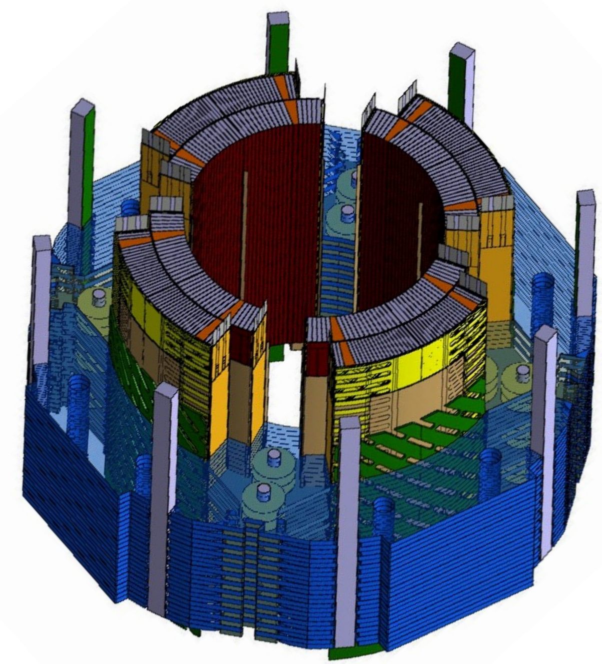
Extraction of the Steady-State Heat Load (Short Model Test)

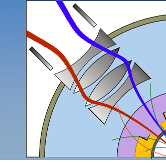




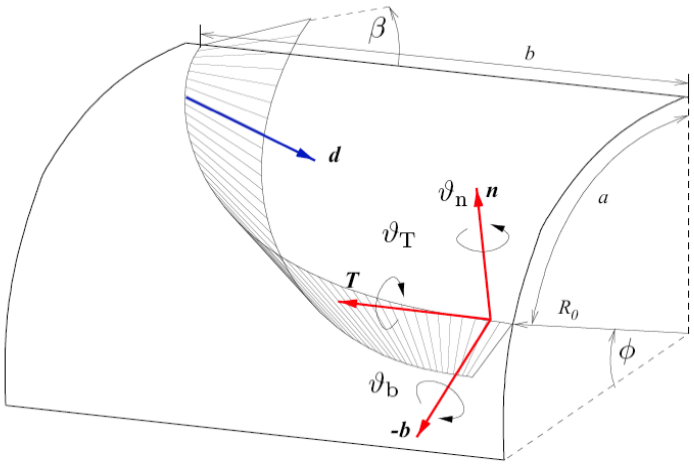


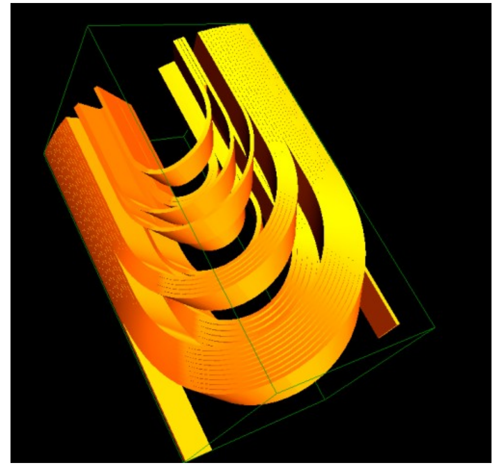


Endspacer Design and Manufacture

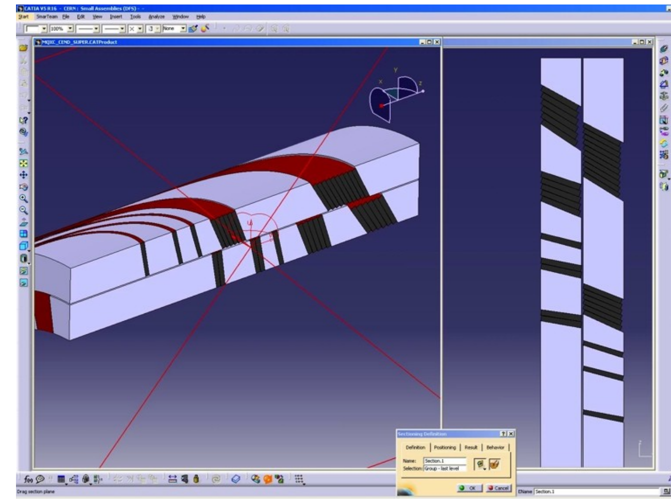


Differential Geometry Model

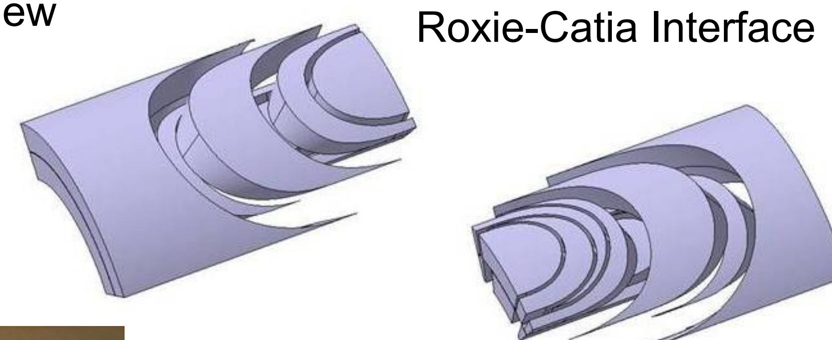




Virtual Reality Preview

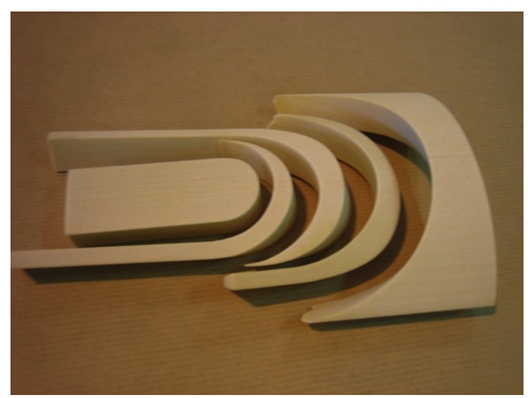


Roxie-Catia Interface

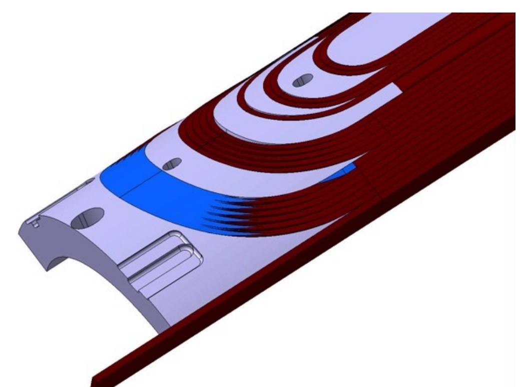


CNC-Machining

Rapid Prototyping



Reinforced with cyanide-ester

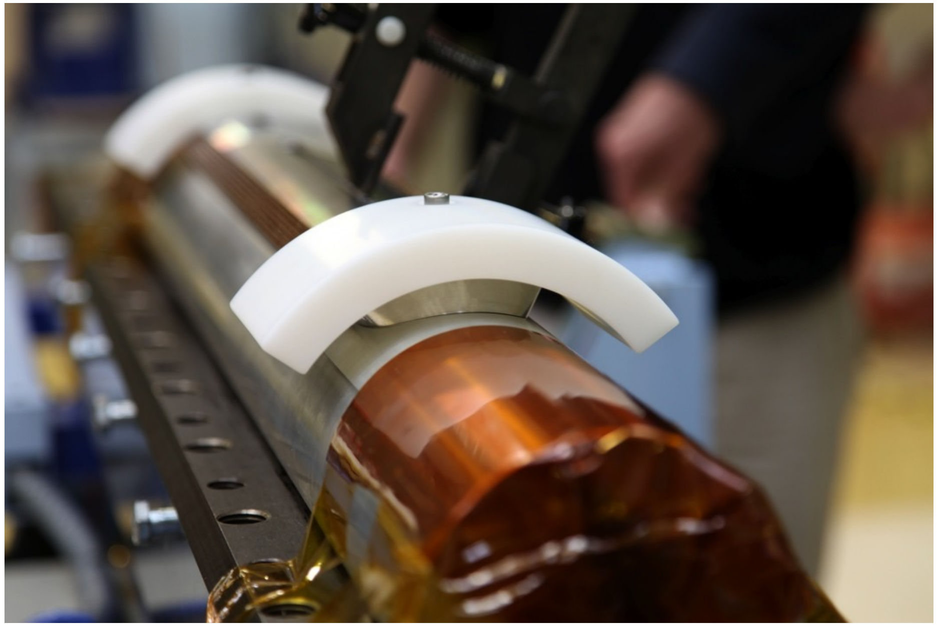


Coil-Winding Trials (CEA and CERN)

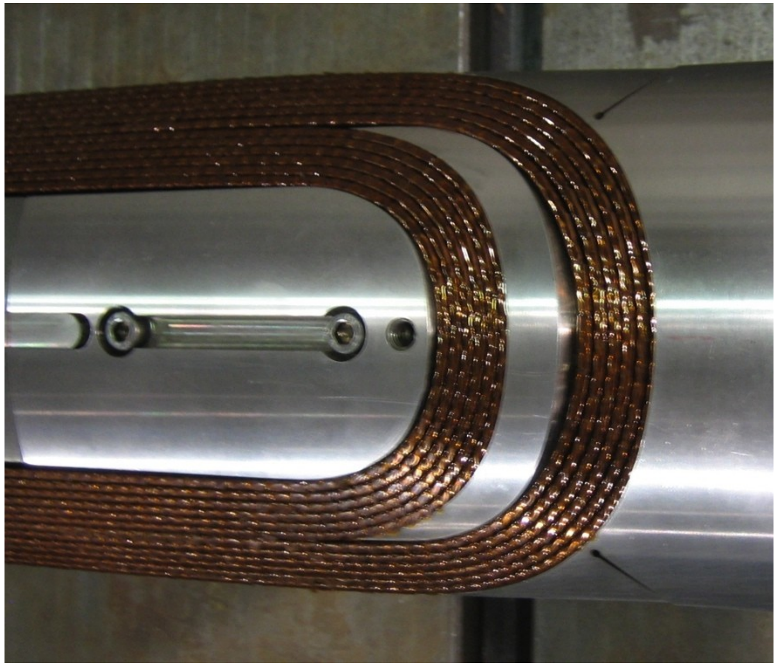
Modification of equipment for exerting the winding tension

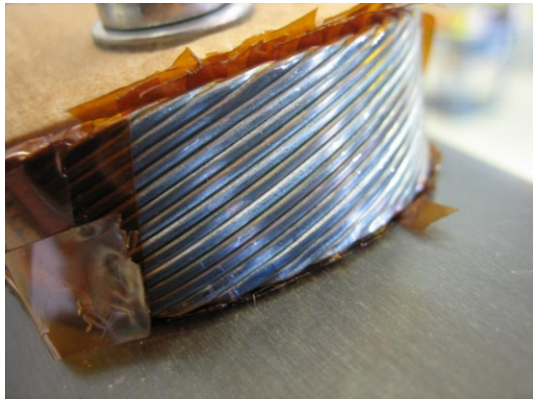
Modification of curing mold (insulation, shimming)

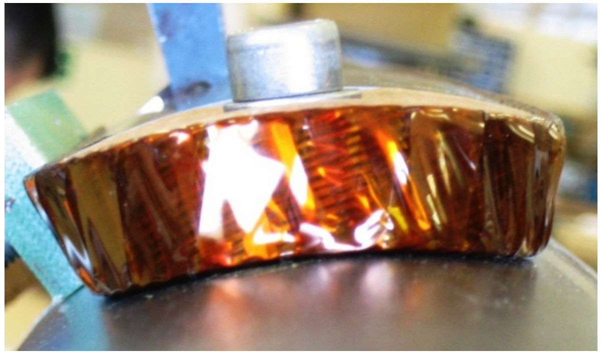
Modification of end-spacer shapes

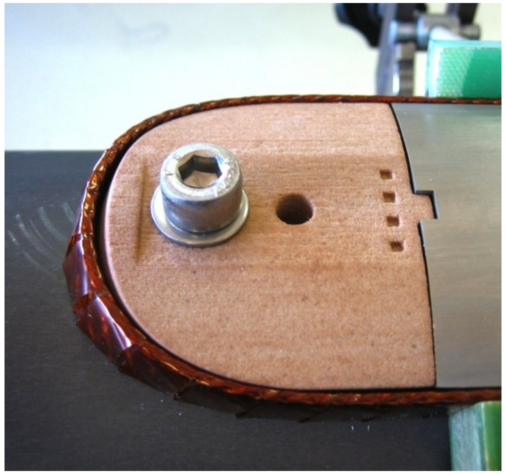


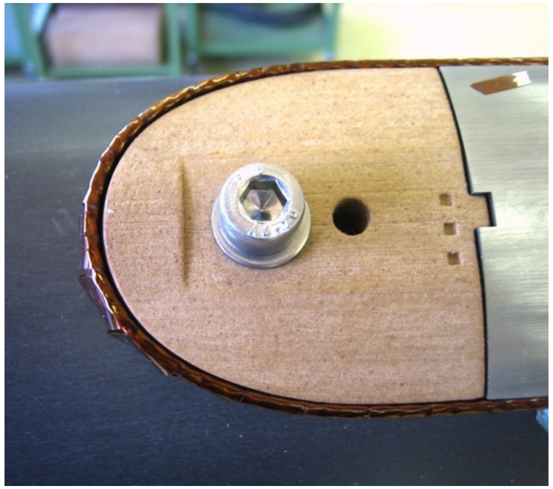
Results of Coil-Winding Trials (Saclay and CERN)

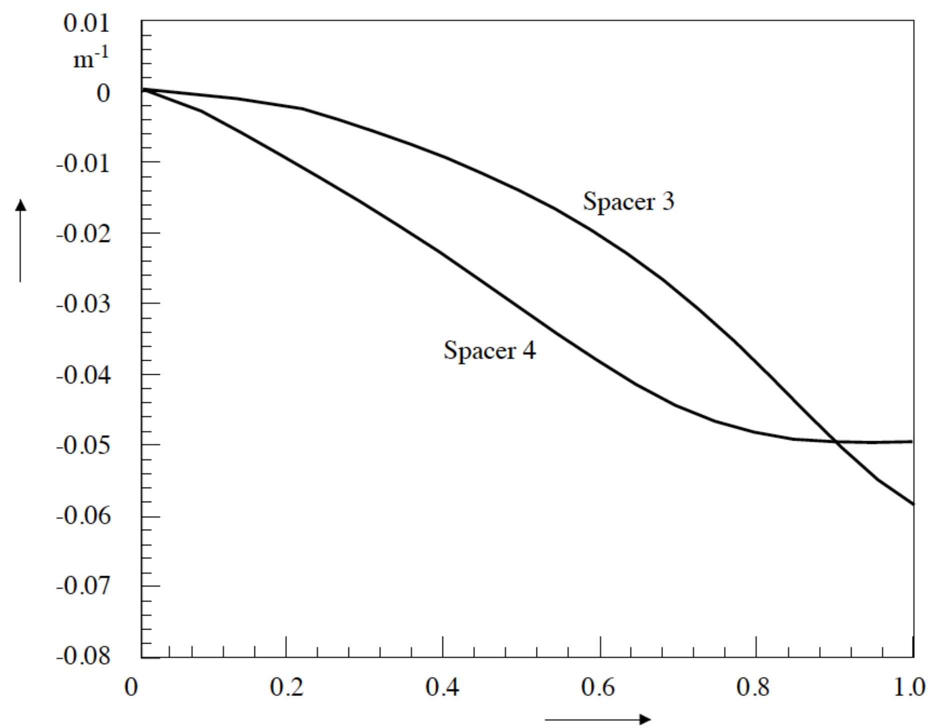




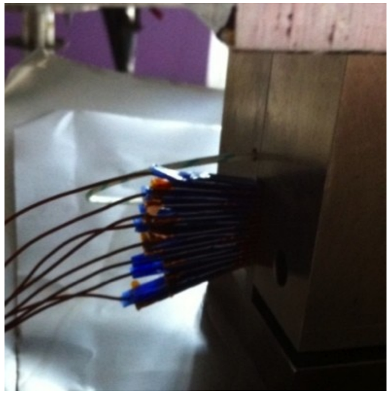


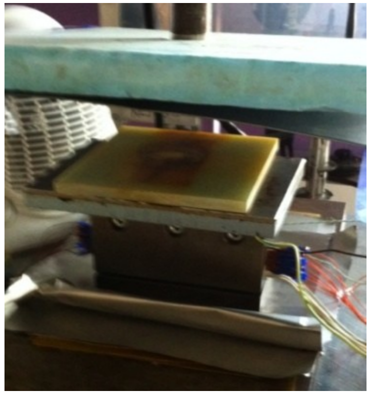


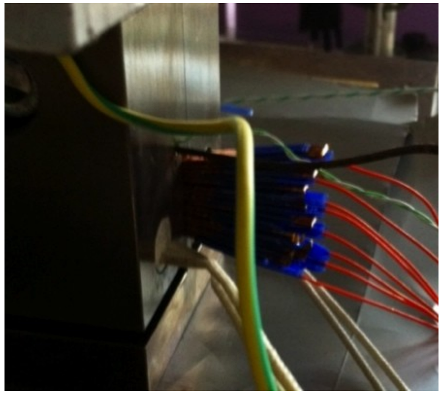




- R&D on coated, metallic end-spacers
  - Laser Sintering of Spacers, in 316LN & Ti Grade 5
  - 5 axis machining 316LN spacers
  - Parylene coating (vacuum deposition)
- Characterization of porous all-polyimide insulation for the 18 strand Rutherford cable
  - e-modulus, dielectric, creep properties

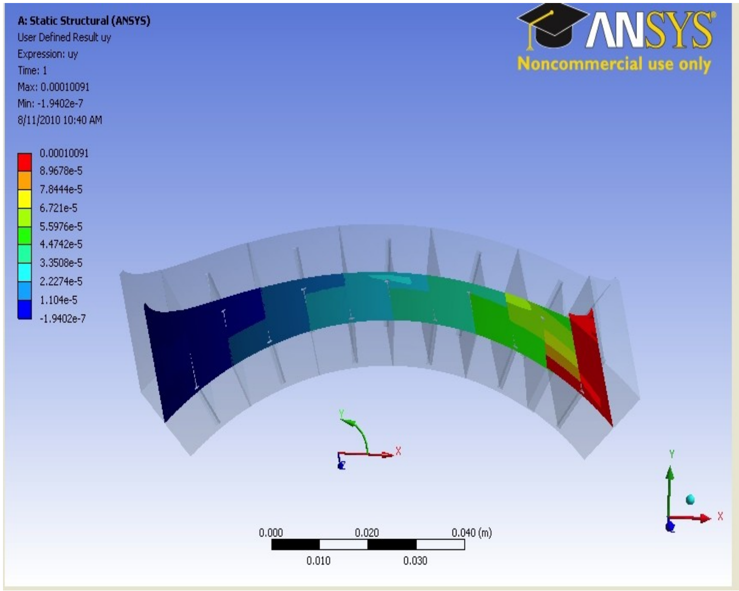




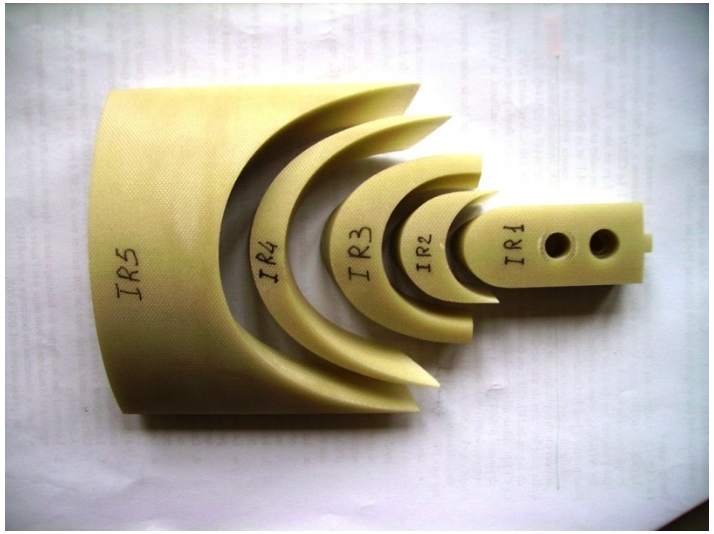


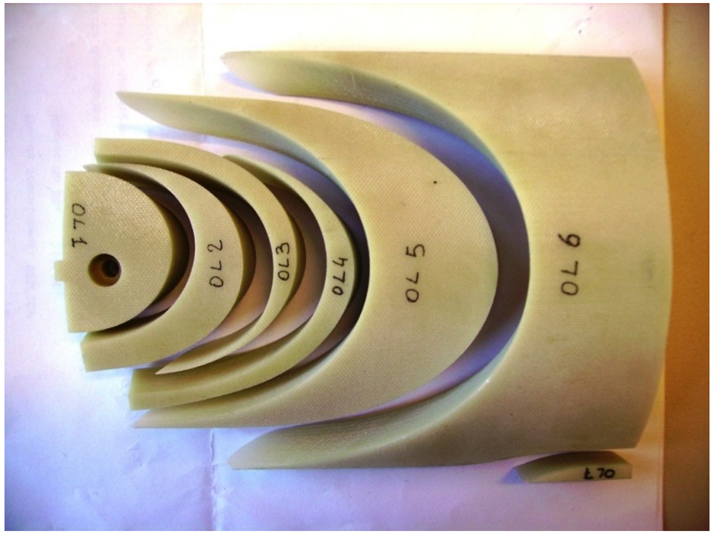
Stacks of insulated cables (all Polyimide). Curing Stage.

Coil-End Spacers (Prototyping and Series Production)



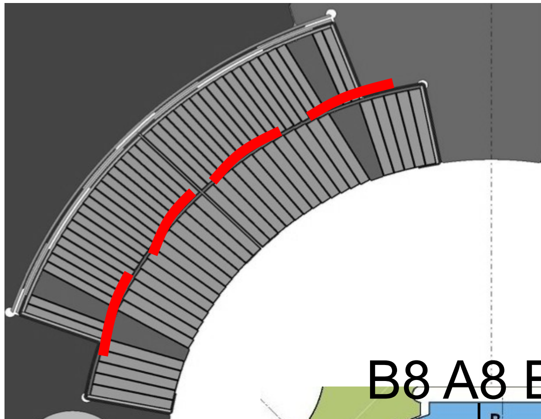
Parylene coating at RAL,5 to 10 μm for 1 kV

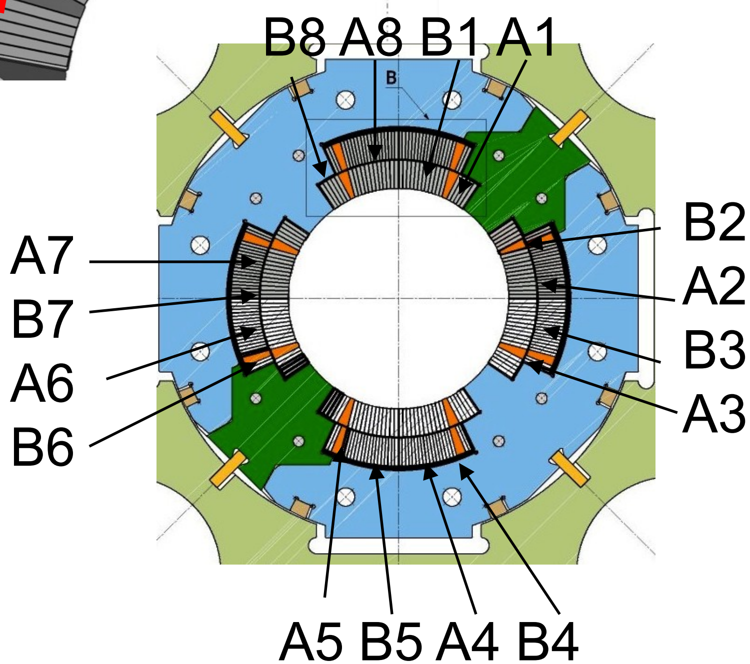




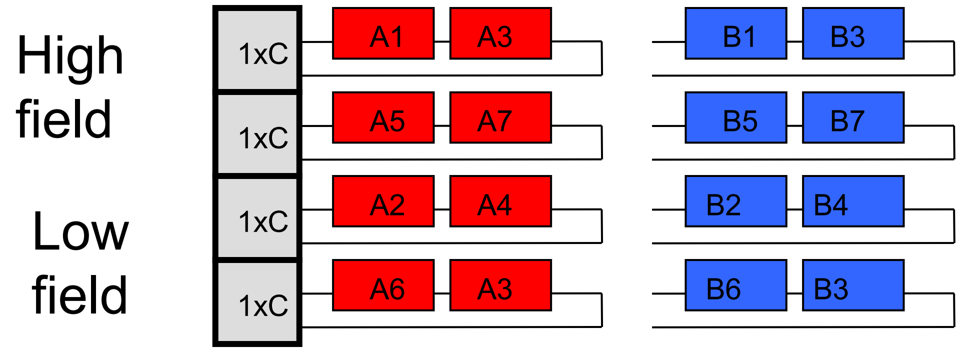
Production sets completed, very high dimensional accuracy

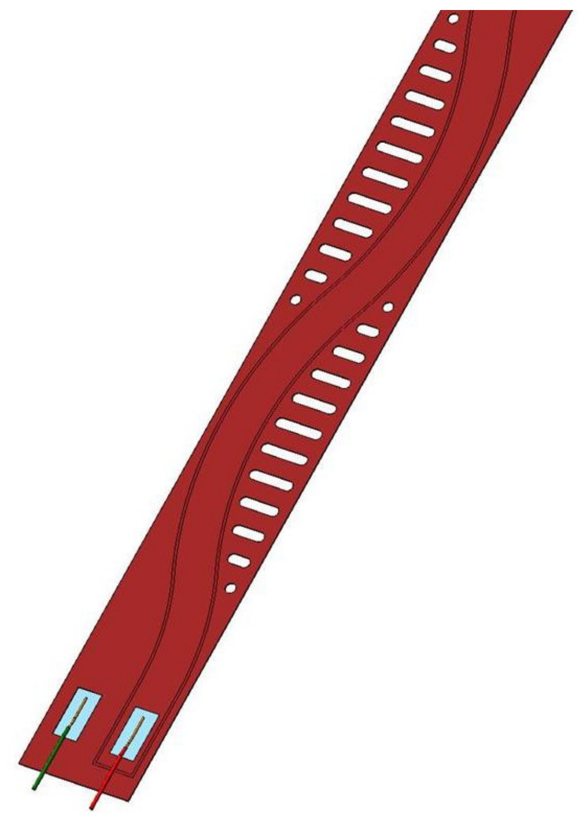
Quench-Heater Circuits (Aim: Porosity, Symmetry, Redundancy)



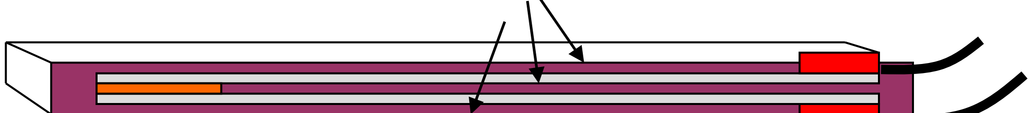


66A 52K@0.01sec Tmax 105 K

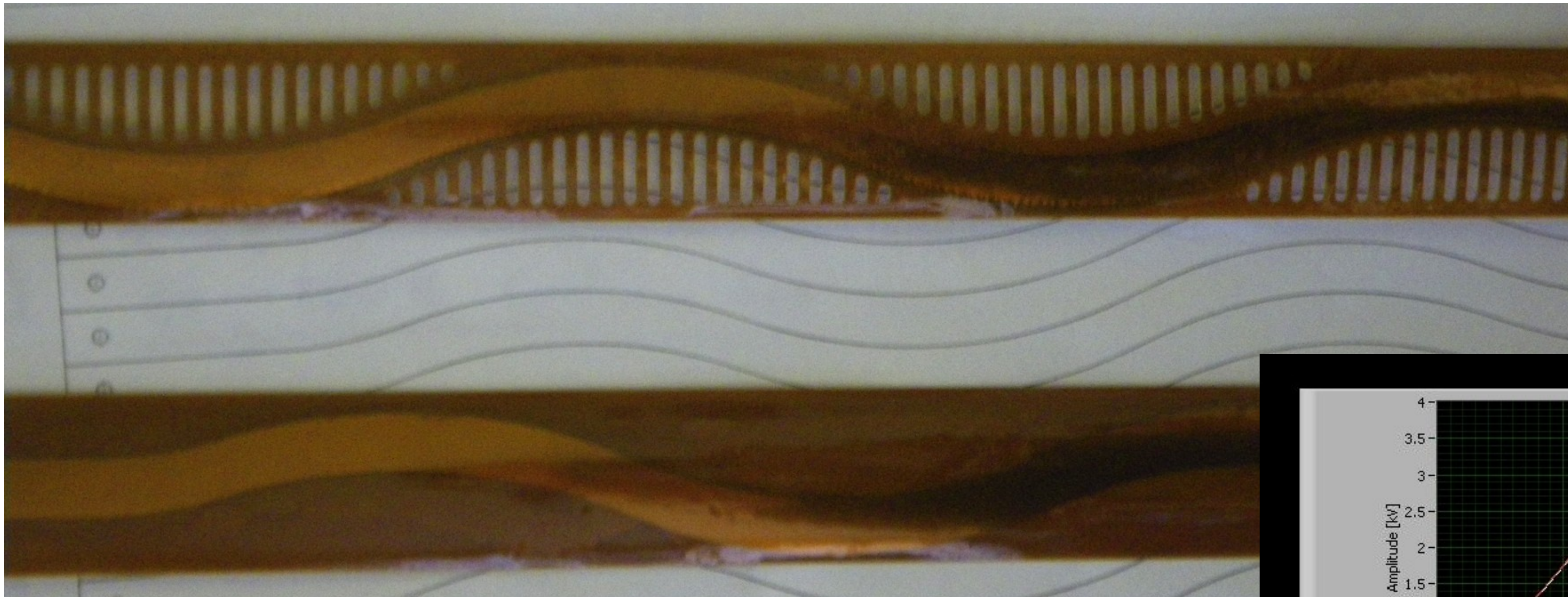


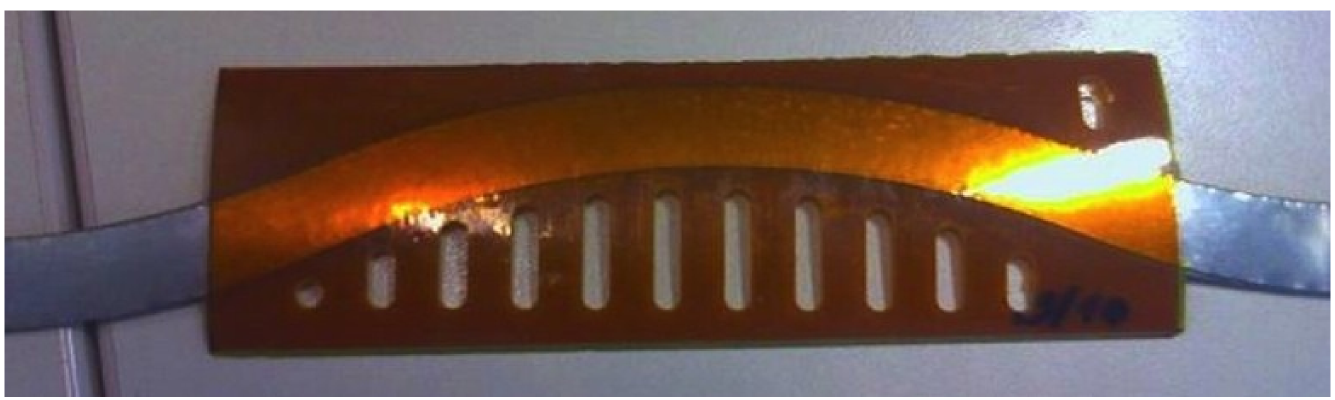


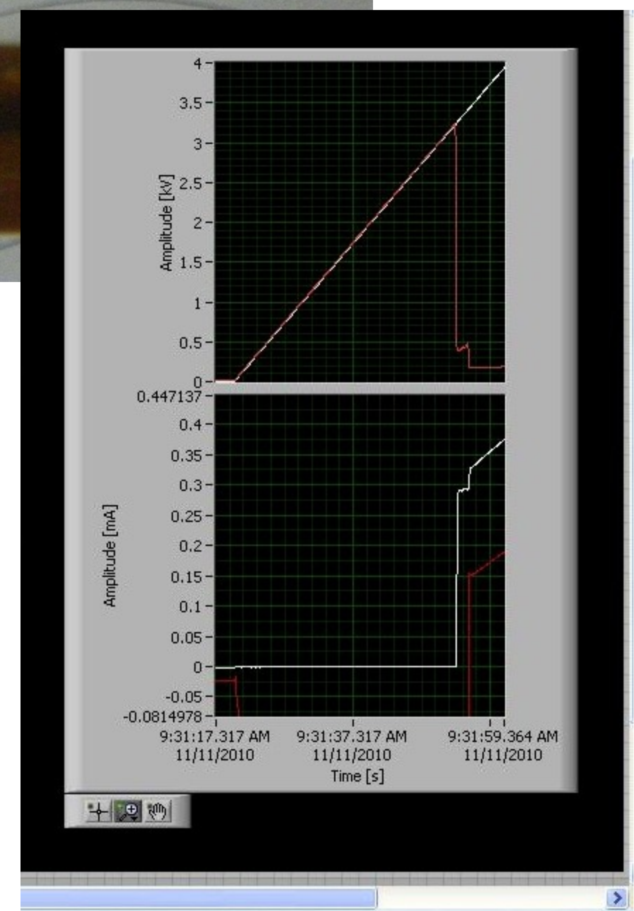
Kapton 0.075 mm



In-House Production of Quench Heaters

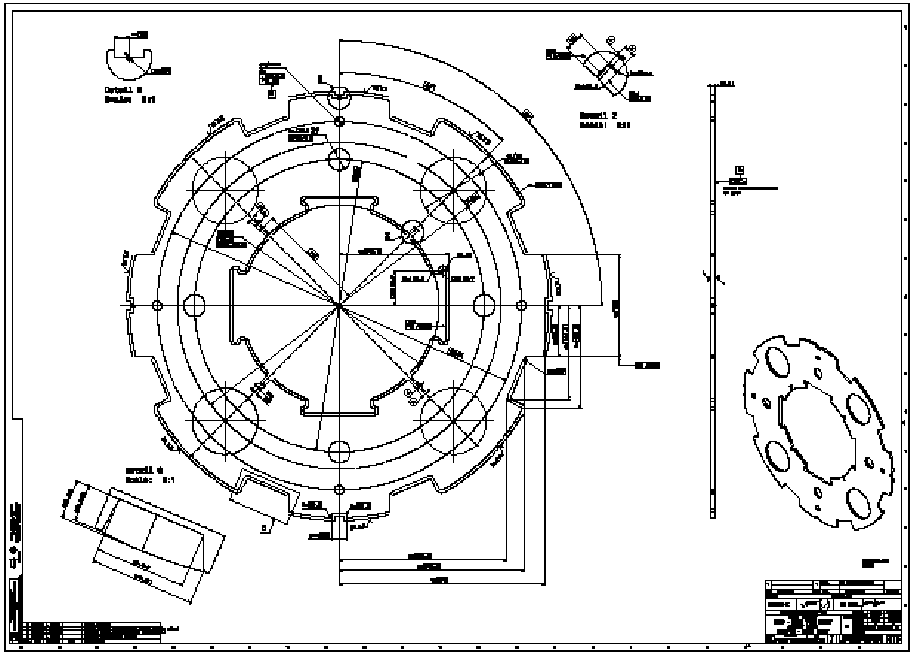






3 kV breakdown voltage

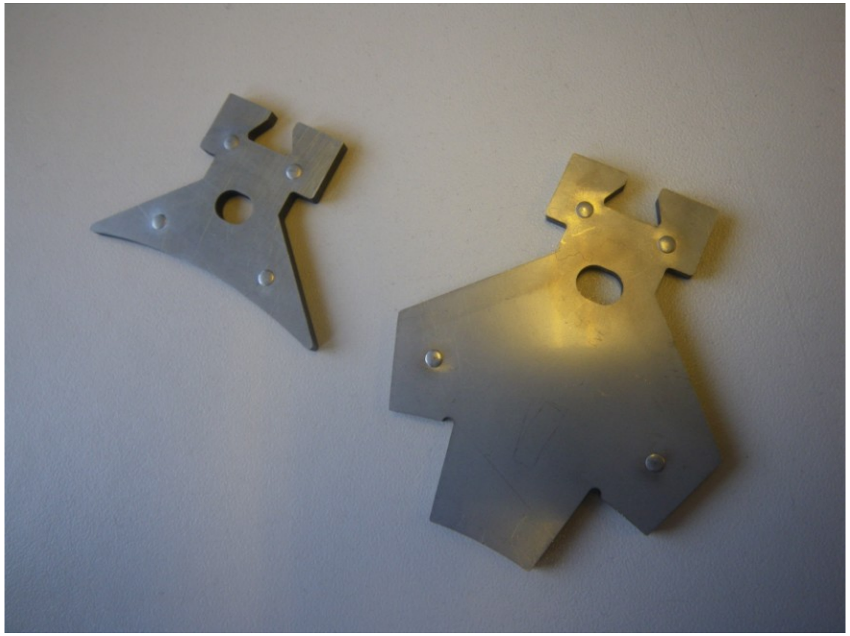
Production of Yoke Laminations

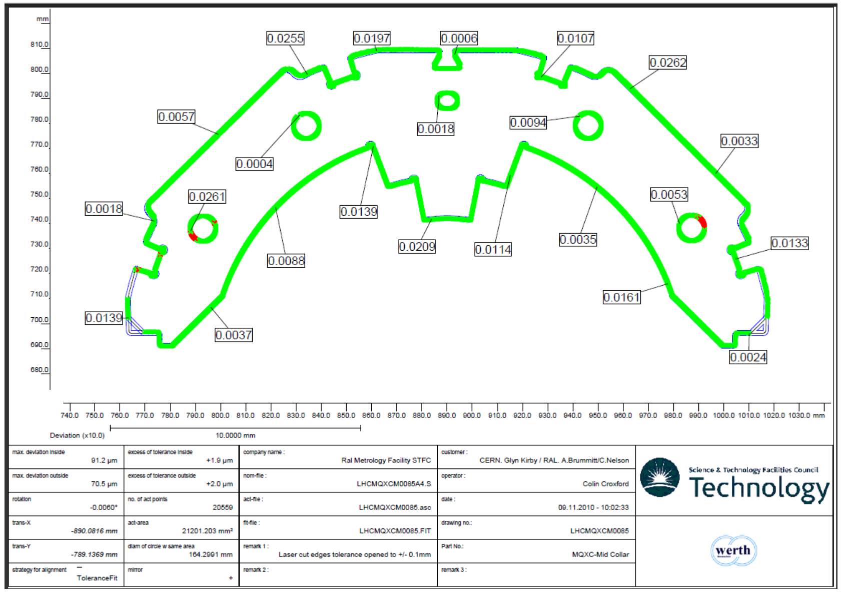


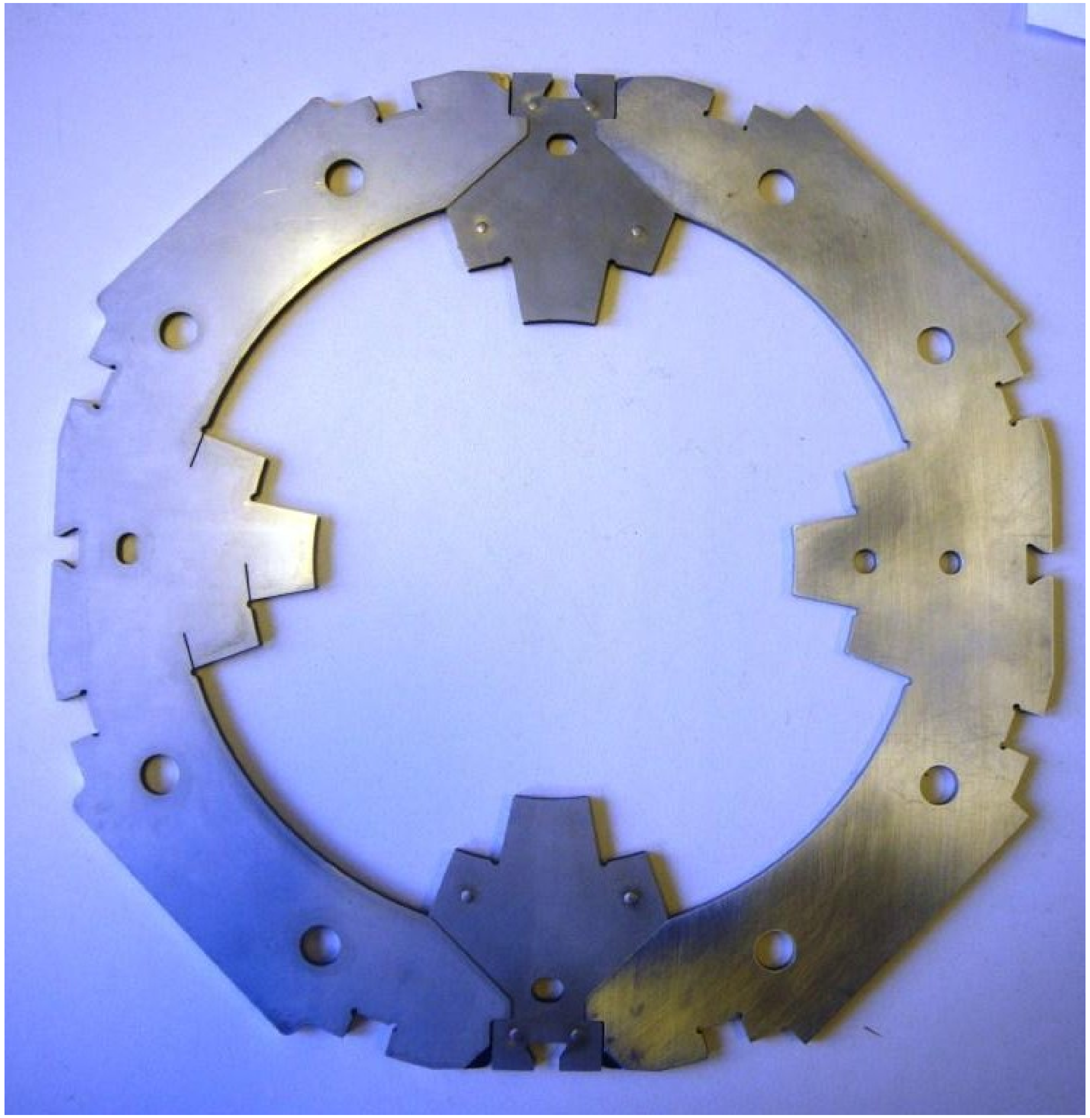
Tolerances

- 0.1 mm achieved with laser cutting
- 0.02 mm with wire cutting

Collar Production





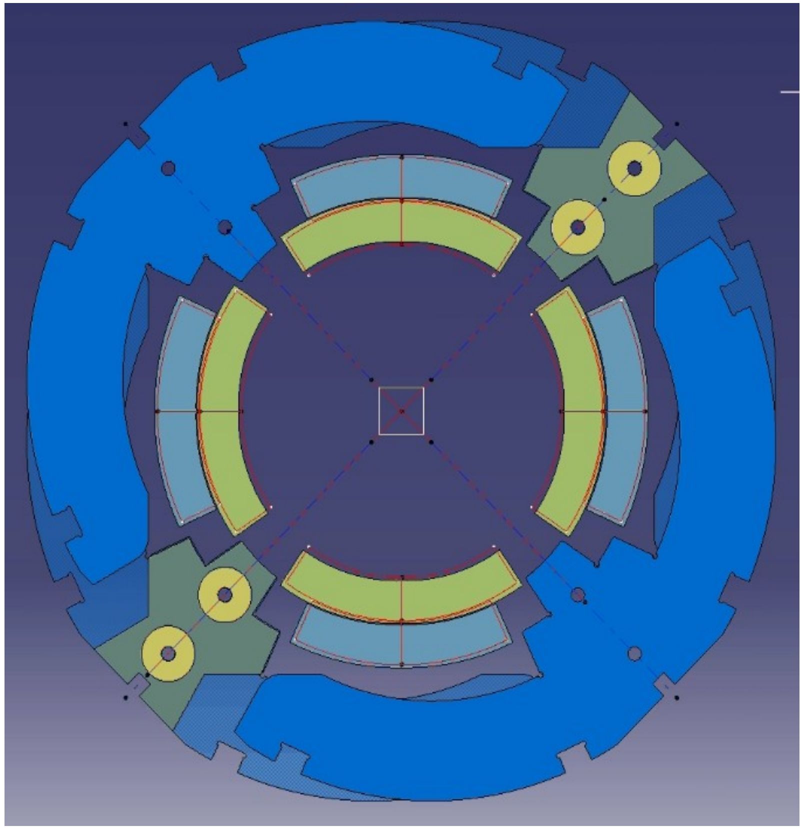


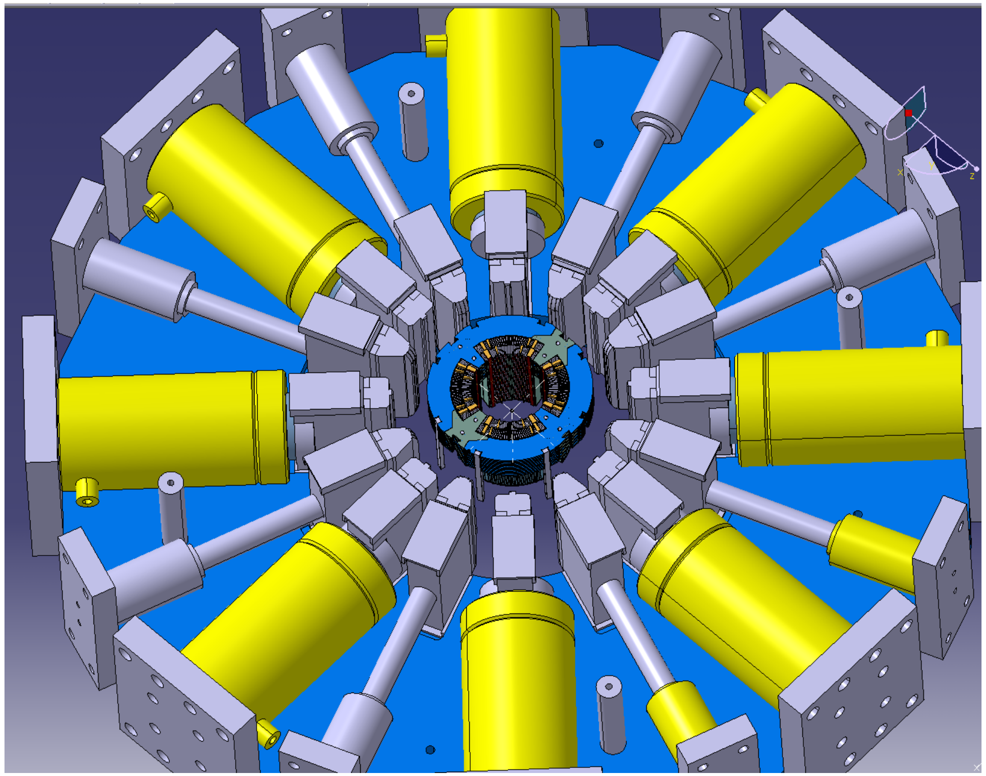
840 main collars

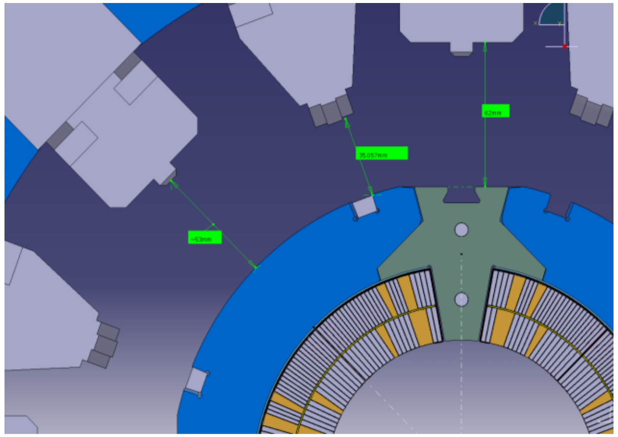
475 end collars per magnet

Horizontal Collaring

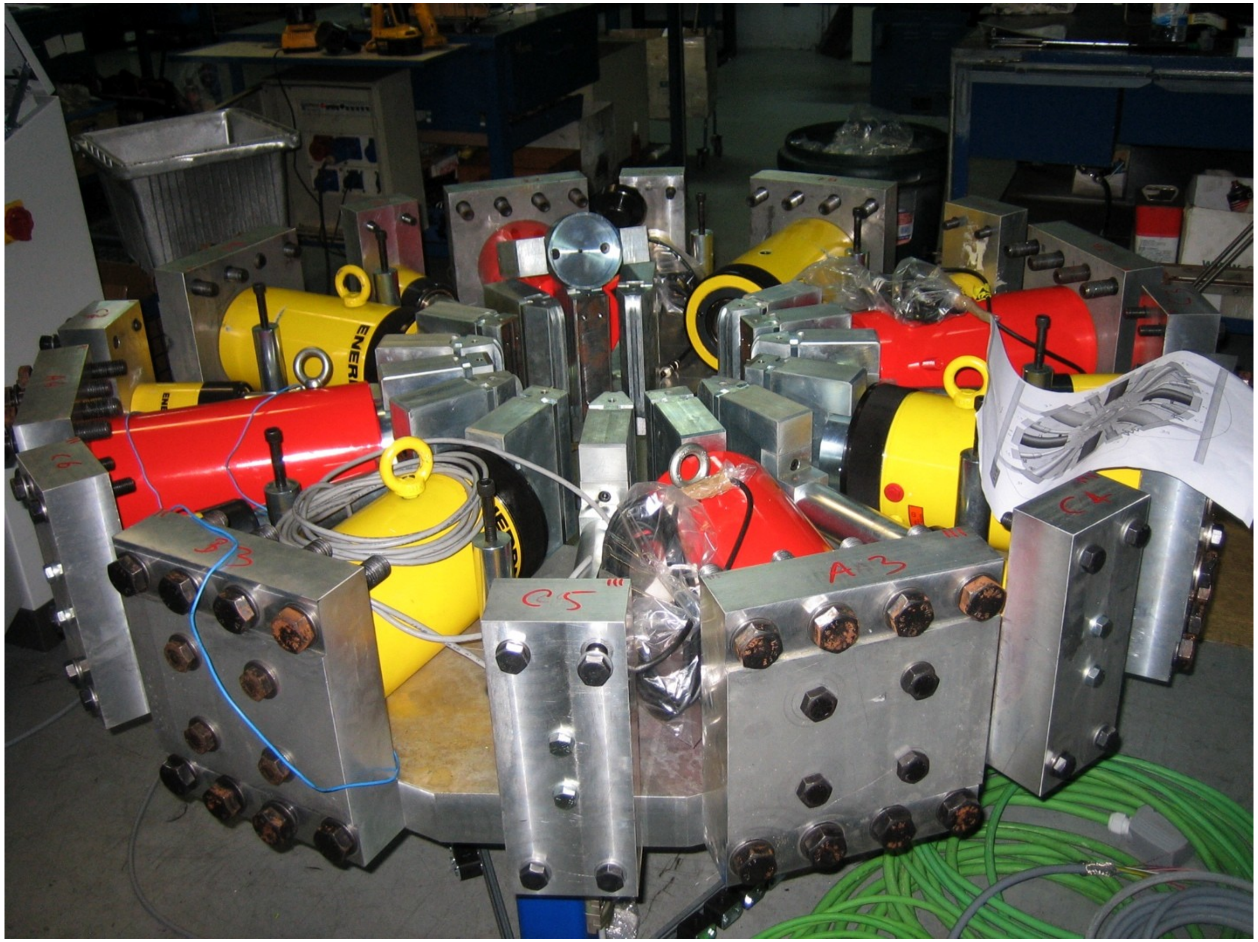
Keeping four-fold symmetry of the quadrupole



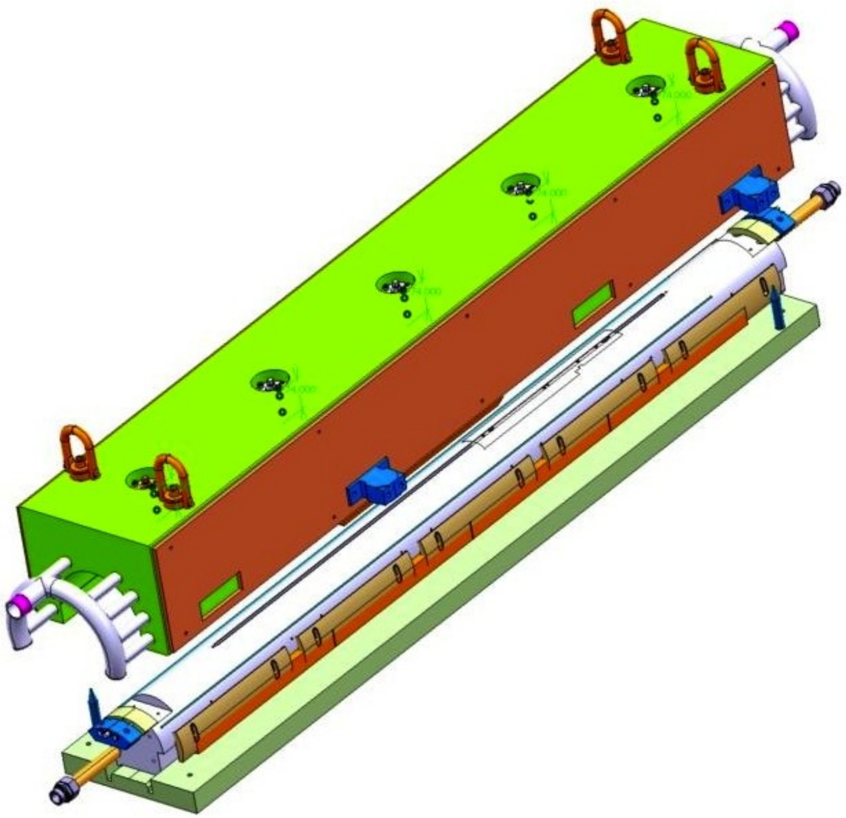




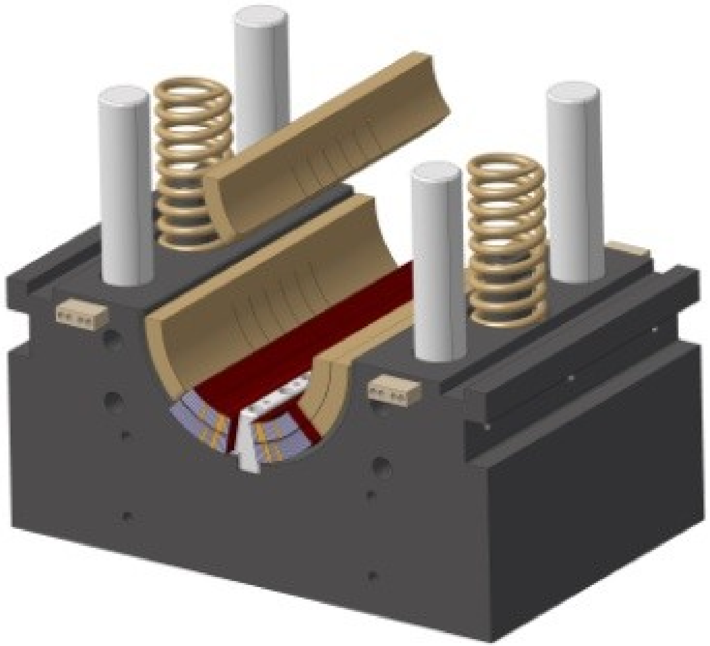
Press-Commissioning

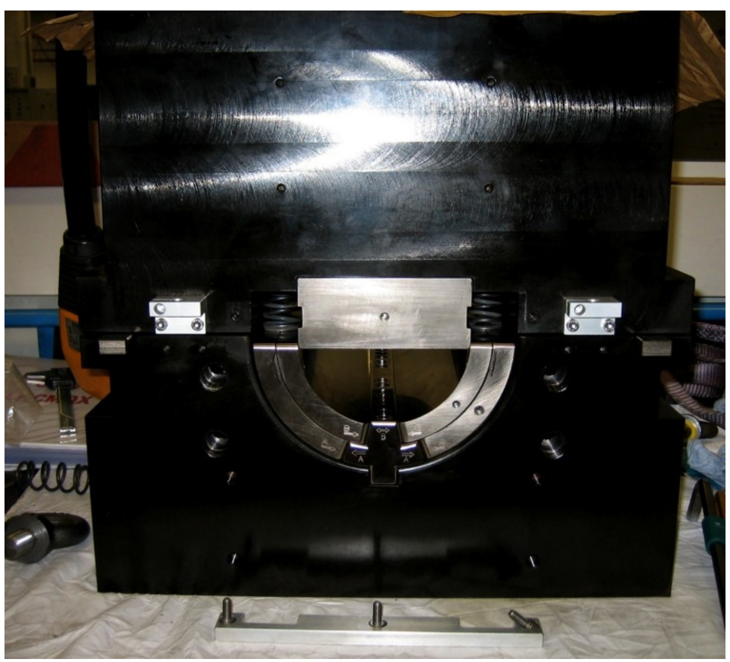


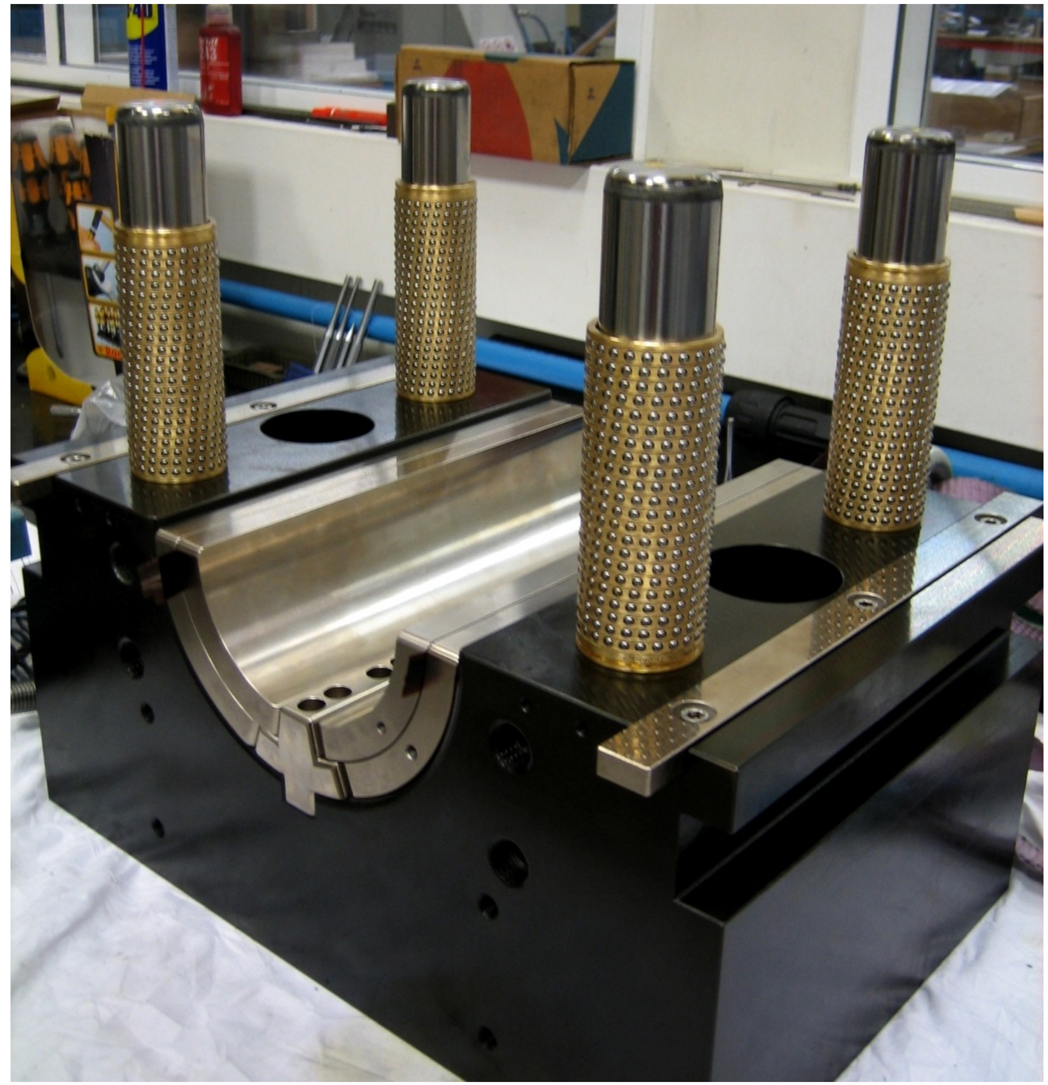
Winding Mandrel and Curing Mold (Design and Production)



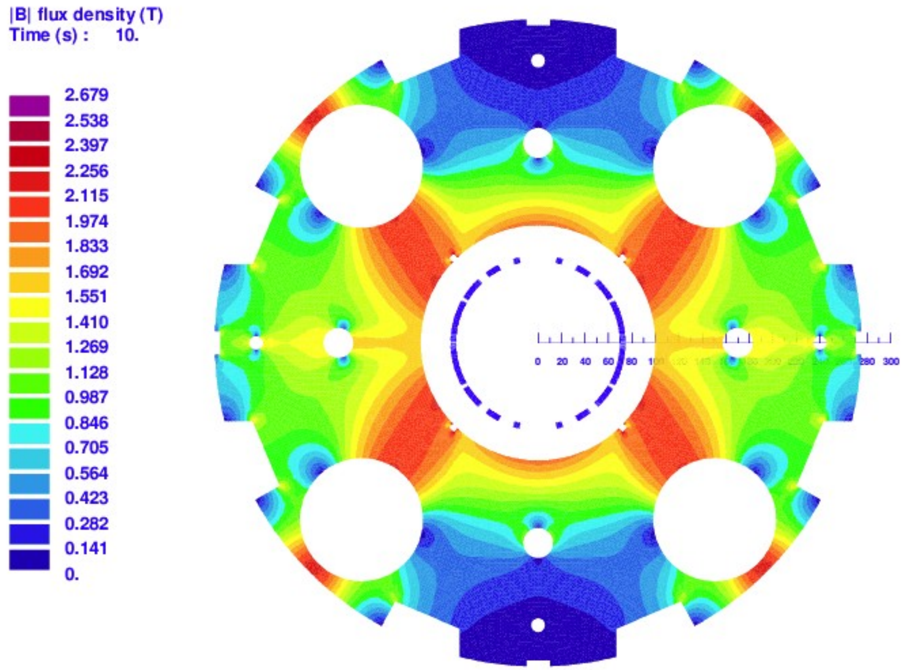
E-Modulus Testing Device



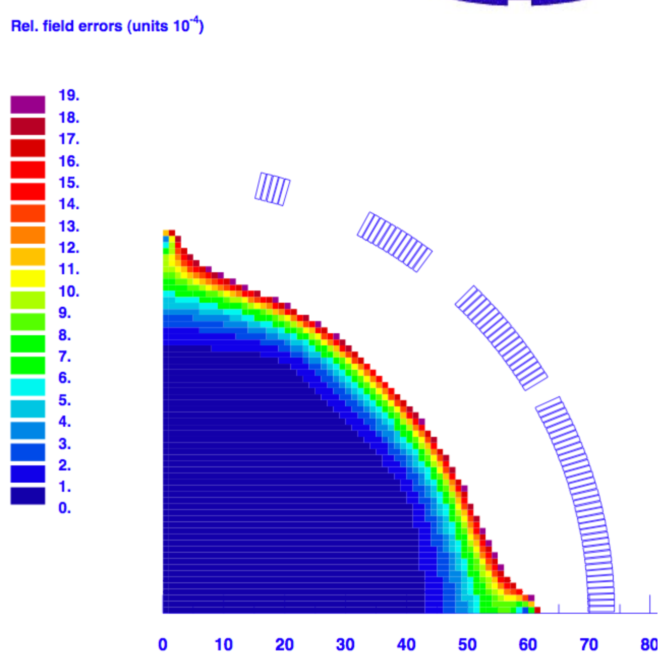


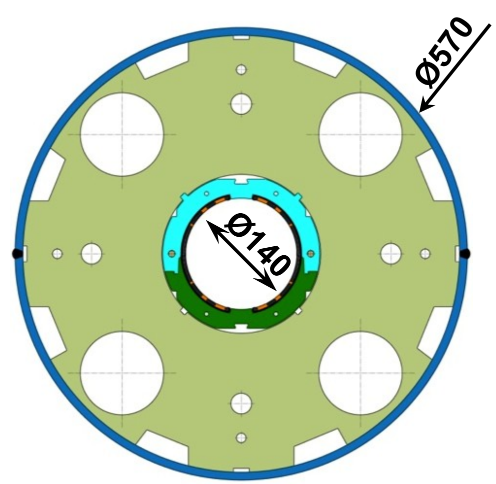


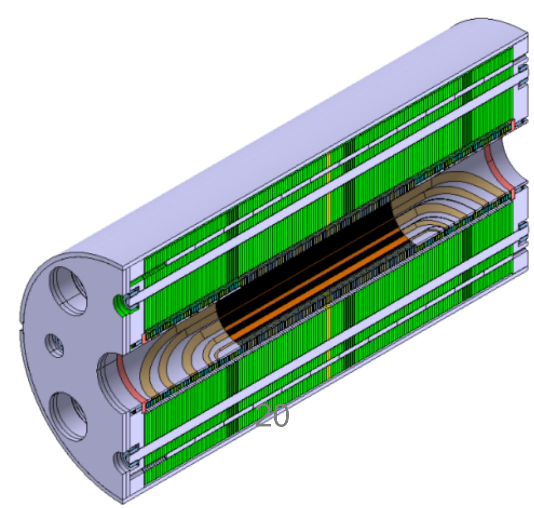
MCXB Single-Layer Design



	Unit	
Integrated field	Tm	1.5
Nominal field	T	2.3
Mag. length	m	0.65
Nominal current	A	2400
Stored energy	kJ	28
Self inductance	mH	10
Working point		50%
Cable width/mid-height	mm	4.37 / 0.845
Total length	m	~1
Aperture	mm	Ø140
Total mass	kg	~2000







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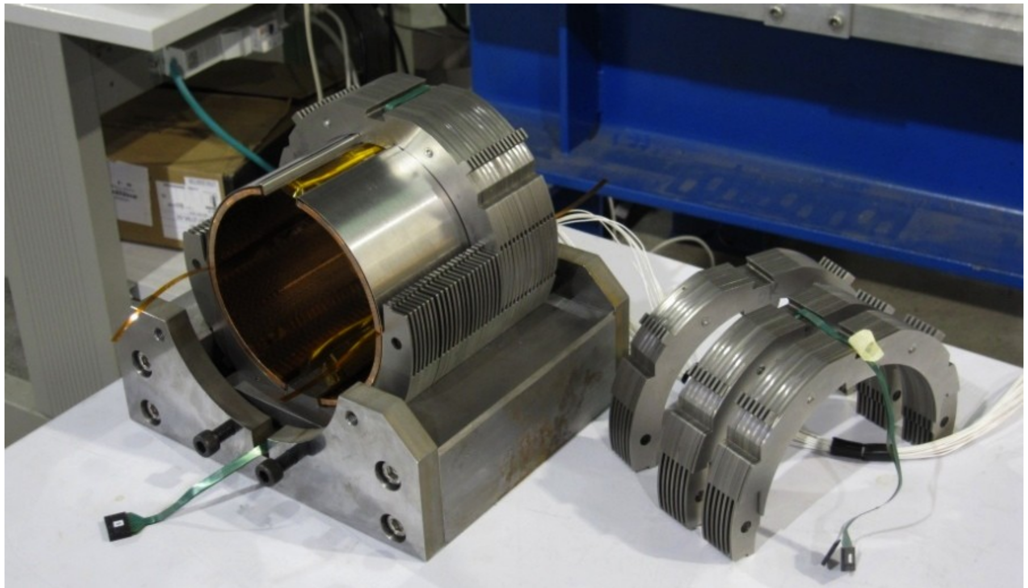
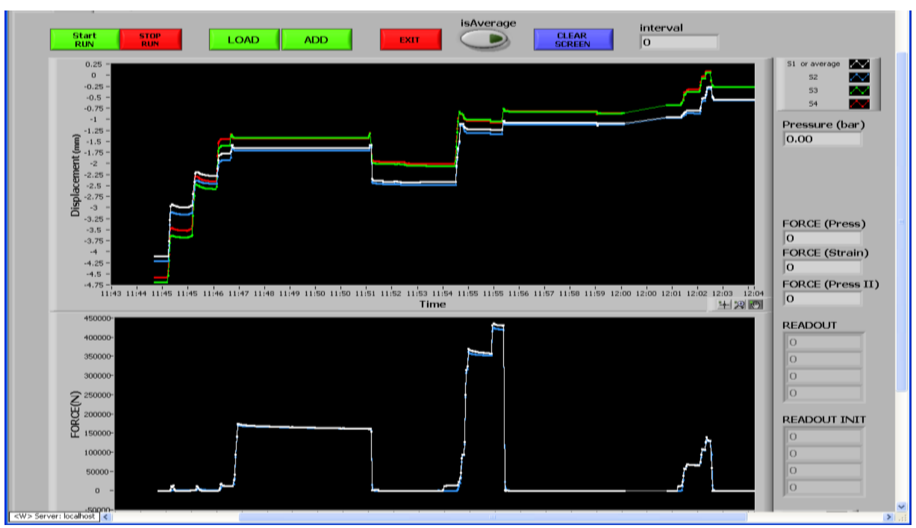
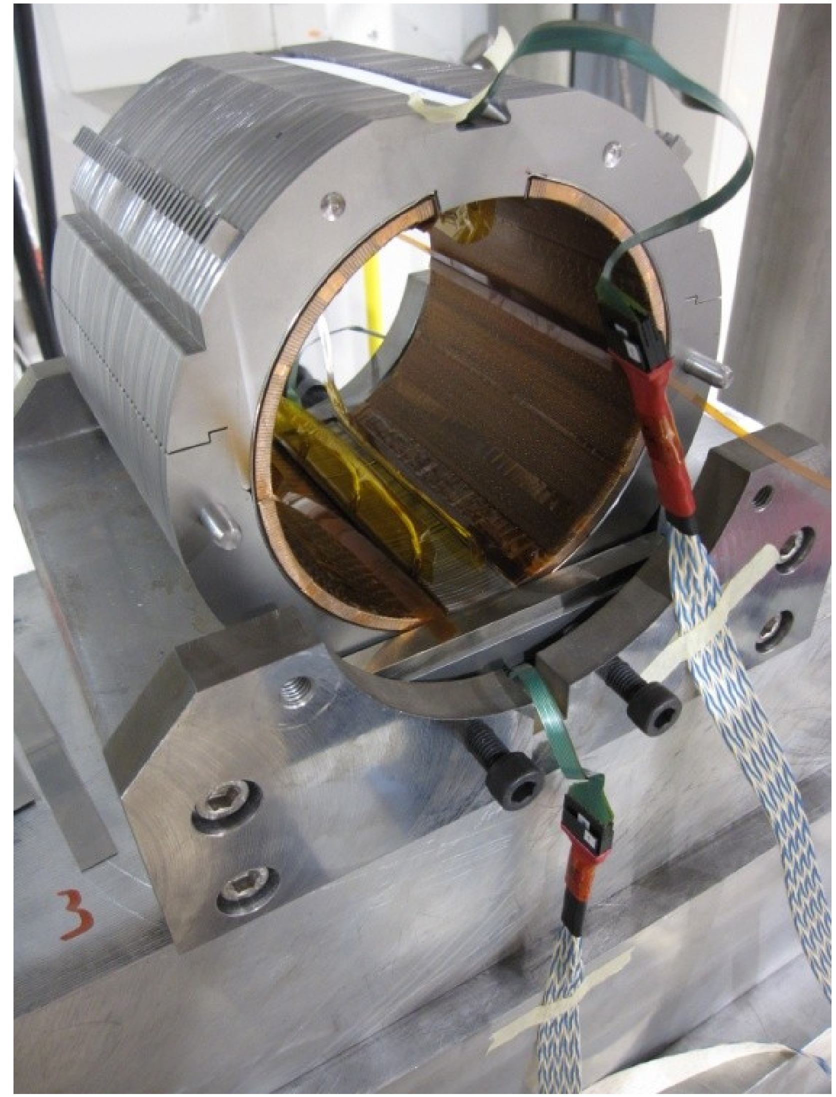
MCXB Short Mech. Model - Collaring





Data acquisition from the collaring press. Vertical displacement = f(collaring force)



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

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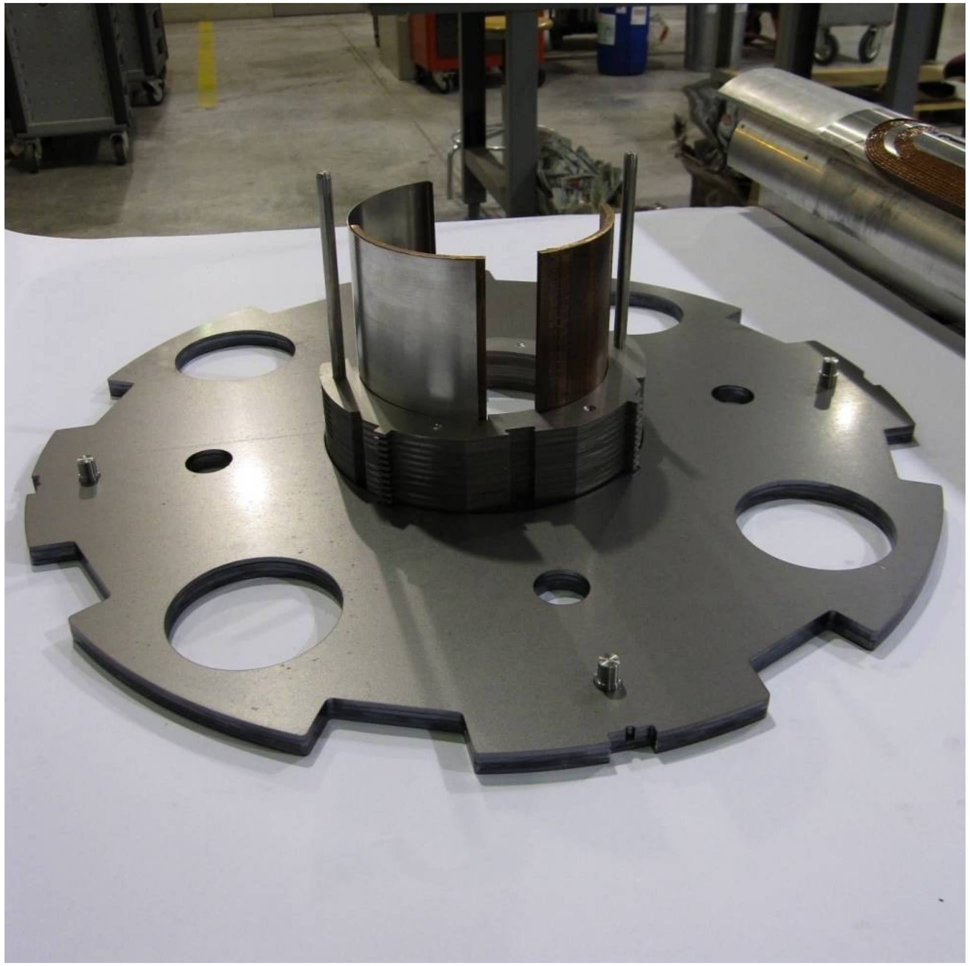
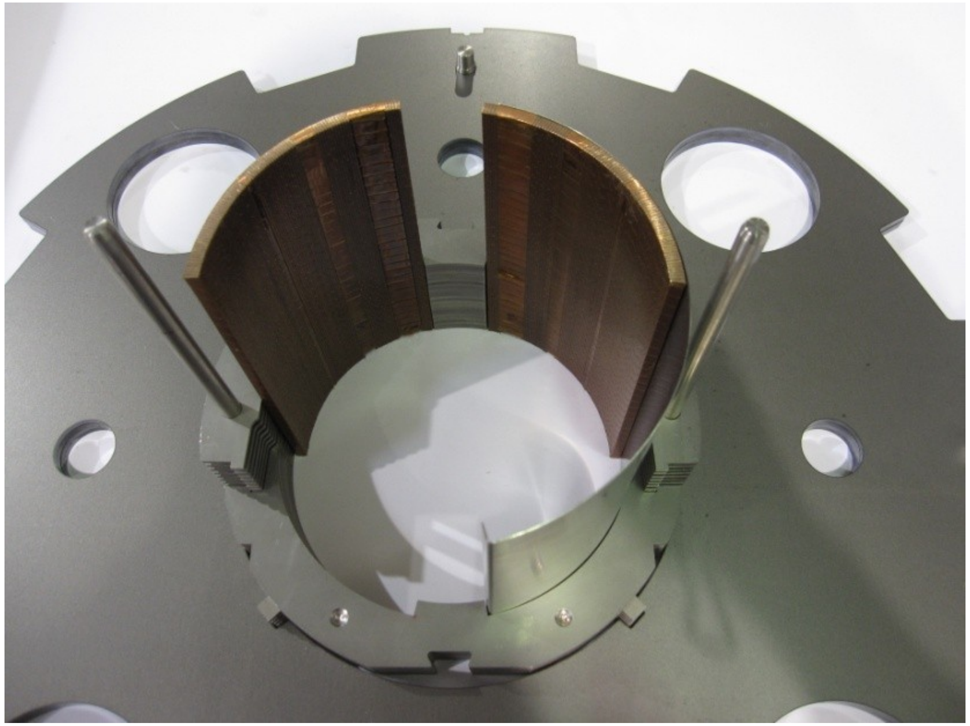
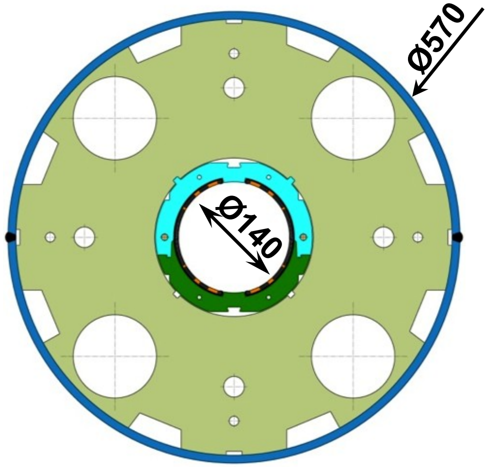
MCXB Laminations Trial Assembly







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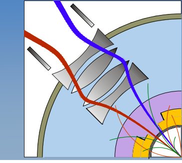
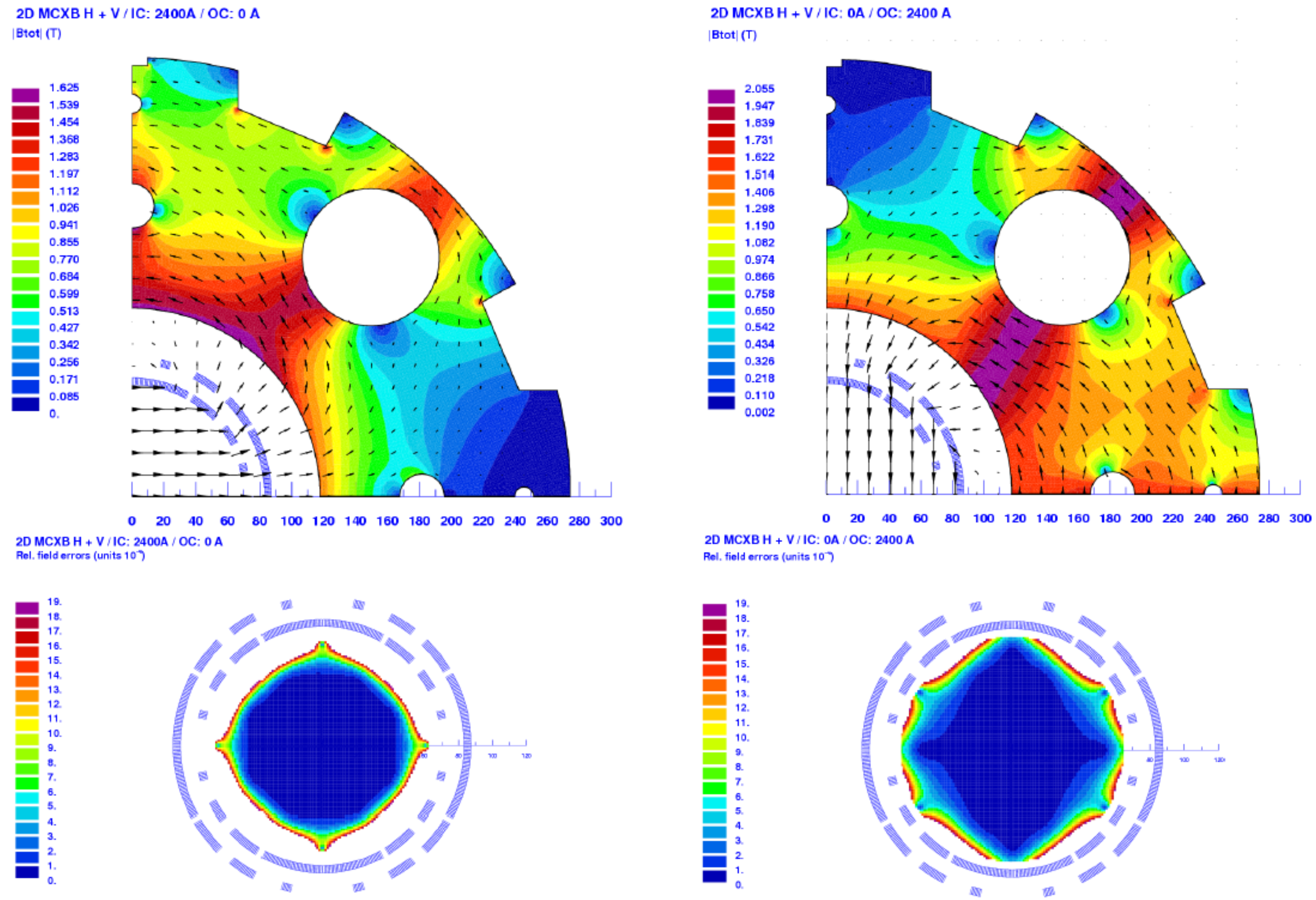
Combined H/V-Dipole (NbTi) - Variants



Model Variant #1
Single layer coils
Porous polyimide insulation
status: winding trials

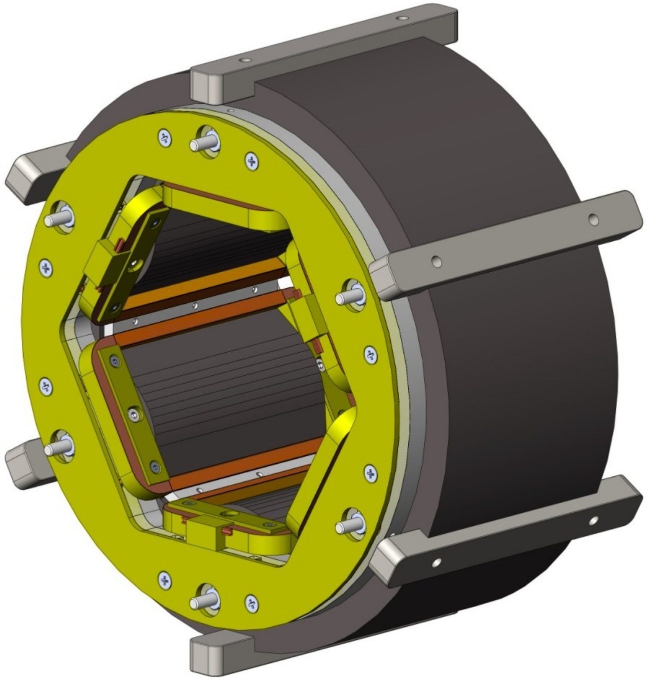
Model Variant #2
Potted coils, same cable
Glass insulation
status: insul. cable characterization

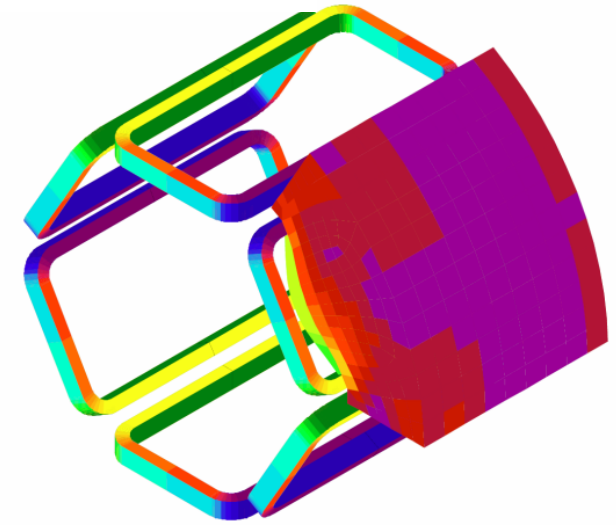
Model Variant #3
Nested H/V-dipole
Status: Mechanical Concept & FEA in progress



Sextupole Design (SIEMAT)

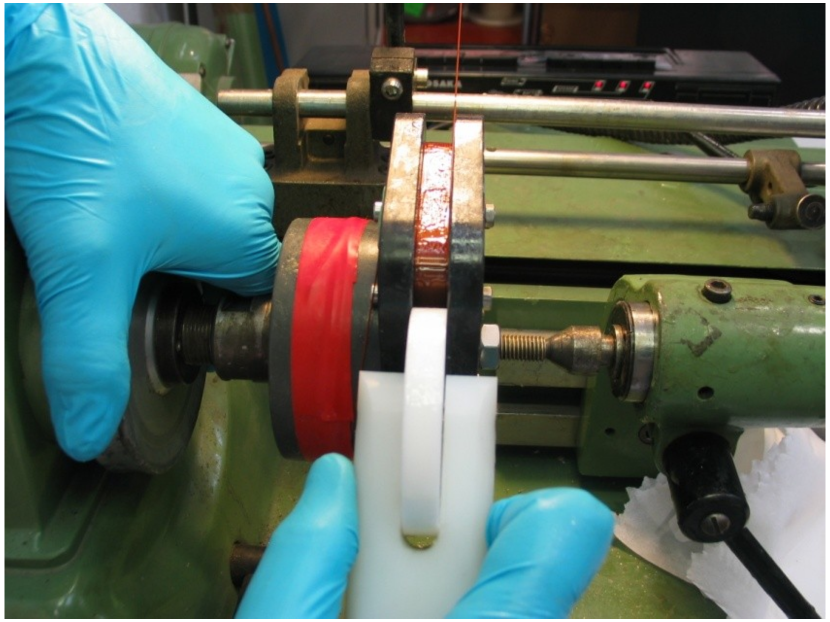
- Wet impregnated coils
- Standard Araldite resin
- Laminated ARMCO iron yoke
- Alignment by stainless steel keys
- Good radiation resistance: wires are concentrated in iron slots and placed further than the aperture.

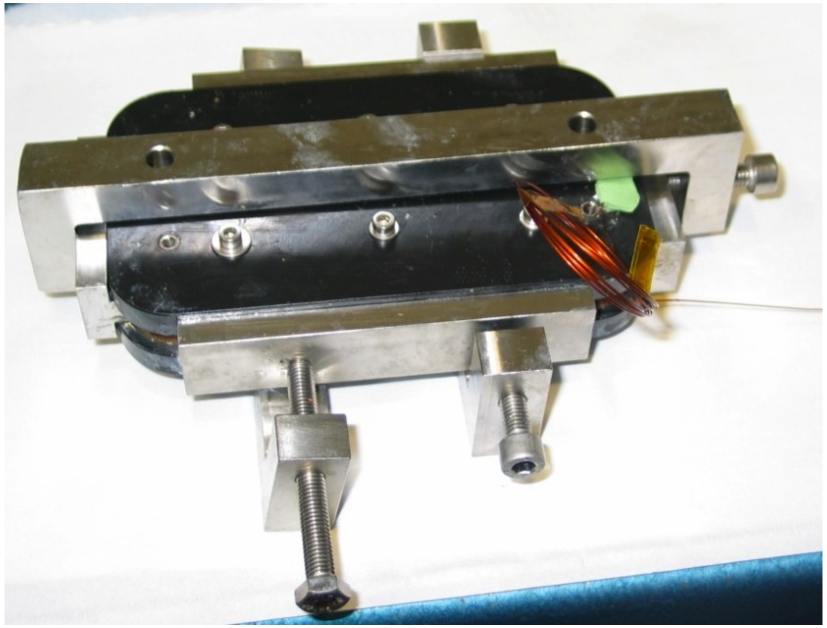


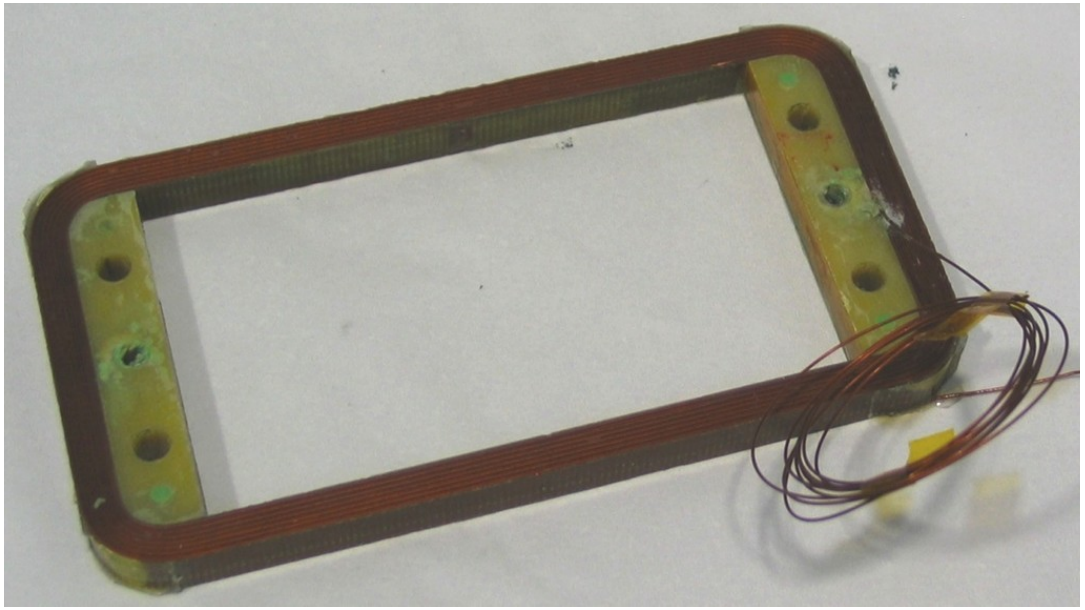


BEMFEM * ROXIE 10.1

Sextupole Fabrication



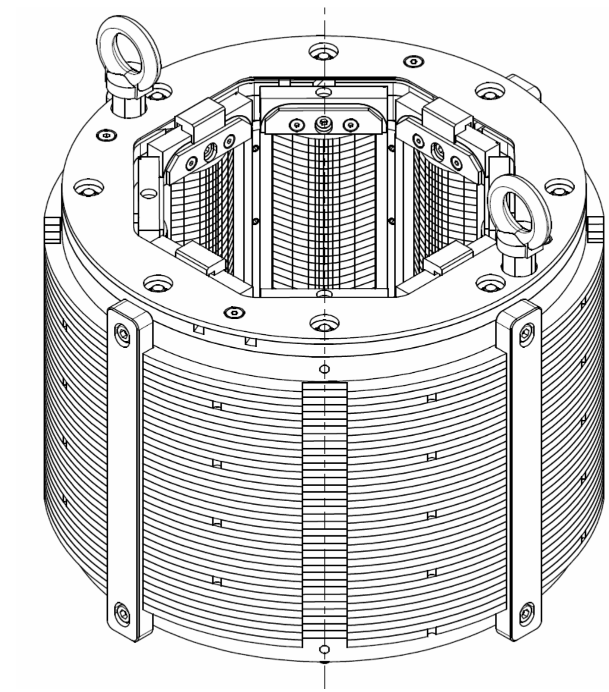


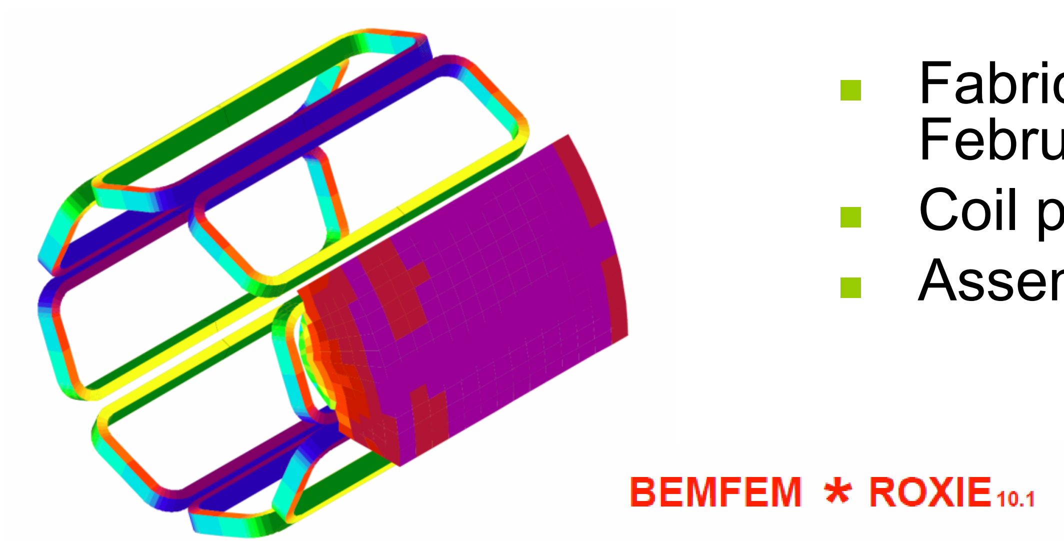


- Assembly: February 2011
- Training test: March 2011

Octupole Design

- Vacuum impregnated coils
- Laminated ARMCO iron yoke
- Alignment by stainless steel keys
- Hard radiation resistance:
  - Polyimide insulated NbTi wire
  - CTD 422B cianate ester resin
  - Stainless steel coil spacers





- Fabrication of impregnation mould: February 2011
- Coil production: March-April 2011
- Assembly: May 2011

Conclusion

- After 3 years of R&D
  - All engineering design drawings are produced
  - Integration studies are completed
  - All heavy tooling has been procured and is being commissioned
  - All components for magnet production have been procured
  - Production and assembly of the magnet(s) has started

- However, reporting will be done at the last possible moment (15th of April) to include all manufactured “hardware”.