Status of WP-6 Development

of Nb-Ti Quadrupole Magnet Prototype

Stephan Russenschuck

for the WP-6 team

05.02.2010

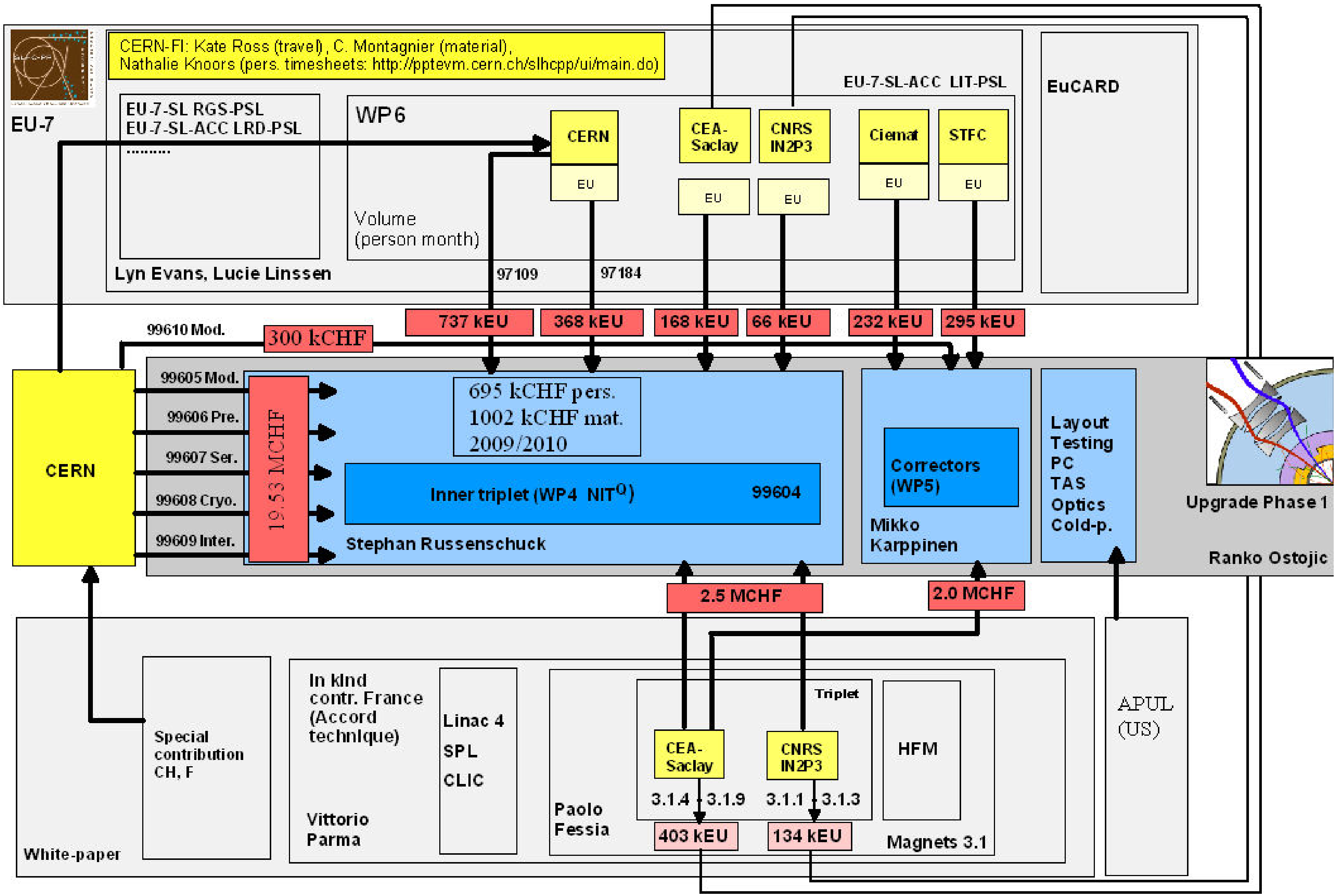
Overview

- Framework: EU-WP6 and White-Paper
  - Deliverables and Milestones

- Design and construction activities/challenges
  - Challenges (Heat load, powering and protection, axial forces, collaring)
  - New features (Porous cable and ground-plane insulation, tuning shims)
  - Integrated design process (quench simulation, end-spacer design)

- Planning issues (How much R&D)

The EU and White-paper Framework



EU-FP7 and Accord-Technique (F)

Year	Q	Deliverables	Milestones	Accord-Technique
2008	4		Component qualification (6.1)	
2009	1		Basic magnetic design (6.2)	
	2	Basic MQXC design (6.1.1)		Cryostat proto. design review
	3		Coldmass design (6.3)	
	4	Model construction (6.2.1)	Cryomagnet design (6.4)	Cryostat proto. production review Cryostat f. corrector package design review Corrector magnet design Cold-bore tube tech. spec.
2010	1			Cryostat f. corrector package production readiness review Quench heater tech. spec. Collars for MQXC tech spec.
	2	Model cold-test and design assesment (6.2.2)		
	3	Corrector package construction (6.3.1)		
	4	Prototype construction (6.3.2)	Corrector package cold-test (6.7) MQXC ELQA (6.6)	Cryostat prototype tooling installation Cryostat component delivery Corrector magnet series production start First quench-heater delivery Collar delivery for MQXC
2011	1	MQXC prototype cold-test (6.3.3)		Cryostat f. corrector package ready
	2	Complete IR design (6.3.4)		
	3			
	4			All corrector magnets delivered

EU-FP7 and Accord-Technique (F)

Year	Q	Deliverables	Milestones	Accord-Technique
2008	4		Component qualification (6.1)	
2009	1-4		Basic magnet design (6.2)	
2010	1	Basic MQXC design (6.1.1)		
	2			Cryostat proto. design review
	3		Coldmass design (6.3)	
	4	Model construction (6.2.1)	Cryomagnet design (6.4)	Cryostat proto. production review Cryostat f. corrector package design review Corrector magnet design Cold-bore tube tech. spec.
2011	1			Cryostat f. corrector package production readiness review Quench heater tech. spec. Collars for MQXC tech spec.
	2	Model cold-test and design assesment (6.2.2)		
	3	Corrector package construction (6.3.1)		
	4	Prototype construction (6.3.2)	Corrector package cold-test (6.7) MQXC ELQA (6.6)	Cryostat prototype tooling installation Cryostat component delivery Corrector magnet series production start First quench-heater delivery Collar delivery for MQXC
2012	1	MQXC prototype cold-test (6.3.3)		Cryostat f. corrector package ready
	2	Complete IR design (6.3.4)		
	3			
	4			All corrector magnets delivered

EU-FP7 and Accord-Technique (F)

Year	Q	Deliverables	Milestones	Accord-Technique
2010	1	Basic MQXC design (6.1.1)		Parameters fixed for all correctors (except for orbit correctors in Q2)
	2	All drawings (magnet, instrumentation and tooling)		
	3	All tooling (winding, curing, collaring, lifting, assembly, coil finishing, yoking) All components Coil measurements	Coldmass design (6.3)	
	4	Model construction (6.2.1)	Cryomagnet design (6.4)	Cryostat f. corrector package design review Corrector magnet design
2011	1	Test in vertical cryostat Integration in horizontal cryostat, test-bench preparation, cycling, field measurements		Cryostat f. corrector package production readiness review Quench heater tech. spec. Collars for MQXC tech spec.
	2	Model cold-test and design assesment (6.2.2)		
	3	Corrector package construction (6.3.1)		
	4	Prototype construction (6.3.2)	Corrector package cold-test (6.7) MQXC ELQA (6.6)	Corrector magnet series production start First quench-heater delivery Collar delivery for MQXC
2012	1	MQXC prototype cold-test (6.3.3)		Cryostat f. corrector package ready
	2	Complete IR design (6.3.4)		
	3			
	4			All corrector magnets delivered

List of Components, Tooling, Assembly Activities, and Tests (MQXC)

Components	Tooling	Assembly	Tests/Studies
Concept design Drawing Specifications Prototype (Series) manufacture	Concept design Drawing Manufacture Installation	Started Finished	
Coil (50%) End-spacers (80%) Ramp and splice box (50%) Copper wedges (100%) Quench heaters (80%) Wiring diagrams (0%) Capacitance gauges (100%) Strain gauges (100%) Spot heaters (0%) Head shims (0%) Collars (Instrumented) (100%) Collar (Non-instrumented) (0%) Collar (Punched) (0%) Collaring shoe (100%) Collaring keys (100%) Ground insulation (50%) Pole turn fishbones (60%) Outer layer fish-bone (60%) Yoke laminations (Wire, punched) (100%) Yoking tie rods and nut assembly (0%) Aperture end plate components (0%) Joint box components (0%) Yoke end plates (0%) Main assembly drawing (20%) Instrumentation feedthrough system Helium vessel End-domes	Coil winding mandrel (20%) Curing mold assembly (50%) Collar pack assembly tooling (0%) Assembly for collar packs on coil (100%) Multipurpose test press (Hydraulics) (100%) Collaring press horizontal (100%) Auxiliary tooling for collaring press (50%) Ground insulation former (0%) Layer jump and splice former (0%) E-mod size press (straight section) (80%) E-mod size press (end section) (0%) Steel dummy coils (straight section) Steel dummy coils (end section) Collapsible mandrel for apert. assemb. (short) Collar rectification table Longitudinal compaction press Lifting tooling Quench heater fabrication tooling Soldered joint tooling	Insulate and cut wedges Cure and measure coil packs Calculate best position of coils Assemble collar packs Assemble 150 mm model Insulate cable Insulate Cu wedges Coil winding Coil curing Coil size measurements Collaring Mechanical measurements Warm magnetic field measurements Mount end flanges Solder electrical joints Yoke assembly Warm magnetic field measurements	Arch curing tests Arch E-modulus test Cold test 150 mm model Quench heater discharge Quench heater high-pot Connection box ELQA 1 After collaring ELQA 2 After joking Warm magnetic field meas. 1 Warm magnetic field meas. 2 Cold test in vertical cryostat: Field quality Quench behavior Cold test in horizontal cryostat Dump Quench heater delay Propagation velocity RRR Field quality Dynamic effects

MQXA (KEK)

5 years

- 1996_asc_Design.pdf
- 1998_asc_Model_test.pdf
- 1998_epac_TUP20G.pdf
- 1999_mt16_00828194.pdf
- 1999_mt16_Mech_tolerance.pdf
- 2000_asc_5Model_comp..pdf
- 2000_asc_00920090.pdf
- 2000_asc_00920094.pdf
- 2001_mt17_01018377.pdf
- 2001_mt17_01018386.pdf
- 2001_mt17_01018733.pdf
- 2001_mt17_Prototype_testing.pdf
- 2002_asc_01211840.pdf

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 7, NO. 2, JUNE 1997

Design Study of a Superconducting Insertion Quadrupole Magnet for the Large Hadron Collider

A. Yamamoto, K. Tsuchiya, N. Higashi, T. Nakamoto T. Ogitsu, N. Ohuchi, T. Shintomi, and A. Terashima
National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki, 305, Japan

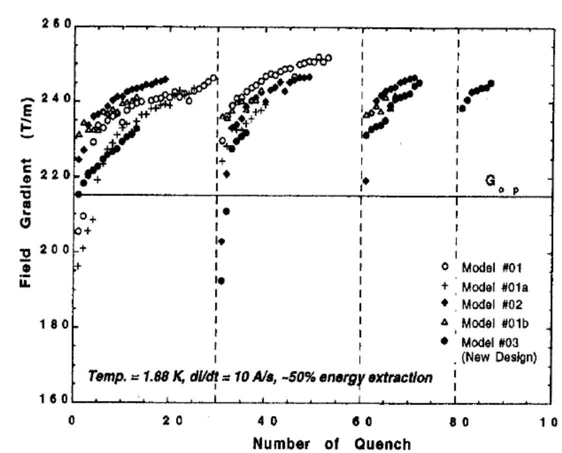
G. Kirby*, R. Ostojic, and T. M. Taylor
European Laboratory for Particle Physics (CERN), 23 Geneve, CH-1211, Switzerland

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 9, NO. 2, JUNE 1999

Quench and Mechanical Behavior of an LHC Low-β Quadrupole Model

T. Nakamoto, K. Tanaka, A. Yamamoto, K. Tsuchiya, E. Burkhardt, N. Higashi,
N. Kimura, T. Ogitsu, N. Ohuchi, K. Sasaki,† T. Shintomi, and A. Terashima,
High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

G. A. Kirby, R. Ostojic, and T. M. Taylor
European Laboratory for Particle Physics (CERN), 1211 Geneva 23, Switzerland



170 IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 12, NO. 1, MARCH 2002

Quench Protection Study of a Prototype for the LHC Low-Beta Quadrupole Magnets

Tatsushi Nakamoto, Earle E. Burkhardt, Toru Ogitsu, Akira Yamamoto, Takakazu Shintomi, and Kiyosumi Tsuchiya

5 Models built (revision of inner layer)

MQXB (Fermilab)

- 1996_asc_00614571.pdf
- 1996_epac_Design.pdf
- 1996_epac_MOP045G.pdf
- 1997_pac_6P001.pdf
- 1997_pac_6P004.pdf
- 1998_asc_00783334.pdf
- 1998_asc_Model_test.pdf
- 1999_mt16_00828186.pdf
- 1999_mt16_00828187.pdf
- 1999_mt16_00828189.pdf
- 1999_pac_THP96.pdf
- 1999_pac_THP103.pdf
- 2000_asc_9Model_performance.pdf
- 2001_mt17_01018352.pdf
- 2001_mt17_01018368.pdf
- 2001_mt17_Prototype_result.pdf
- 2002_asc_01211835.pdf
- 2003_pac_WPAE015.pdf
- 2004_asc_01439830.pdf
- 2004_asc_01439834.pdf
- 2005_mt19_01642881.pdf
- 2005_nim.pdf
- 2006_epac_WEPLS109.pdf

5 years

DESIGN OF A HIGH GRADIENT QUADRUPOLE FOR THE LHC INTERACTION REGIONS

R. Bossert, S.A. Gourlay, T. Heger, Y. Huang, J. Kerby, M.J. Lamm, P.J. Limon, P.O. Mazur, F. Nobrega, J.P. Ozelis, G. Sabbi, J. Strait, A.V. Zlobin
Fermilab, Batavia, Illinois, USA;

S. Caspi, D. Dell'orco, A.D. McInturff, R. M. Scanlan, J.M. Van Oort
Lawrence Berkeley National Laboratory, Berkeley, California, USA;

R.C. Gupta, Brookhaven National Laboratory, Upton, New York, USA

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 9, NO. 2, JUNE 1999

Design, Development and Test of 2m Quadrupole Model Magnets for the LHC Inner Triplet

J. Kerby, A.V. Zlobin, R. Bossert, J. Brandt, J. Carson, D. Chichili, J. Dimarco, S. Feher, M.J. Lamm, P.J. Limon, A. Makarov, F. Nobrega, I. Novitski, D. Orris, J.P. Ozelis, B. Robotham, G. Sabbi, P. Schlabach, J.B. Strait, M. Tartaglia, J.C. Tompkins,
Fermi National Accelerator Laboratory, Batavia, Illinois, USA

S. Caspi, A.D. McInturff, R. Scanlan,
Lawrence Berkeley National Laboratory, Berkeley, California, USA

Field Measurement of a Fermilab-Built Full Scale Prototype Quadrupole Magnet for the LHC Interaction Regions

R. Bossert, R. Carcagno, J. DiMarco, S. Feher, H. Glass, J. Kerby, M. J. Lamm, A. Nobrega, T. Nicol, T. Ogitsu, D. Orris, T. Page, R. Rabehl, G. Sabbi, P. Schlabach, J. Strait, C. Sylvester, M. Tartaglia, J. C. Tompkins, G. Velev, and A. V. Zlobin

TABLE V

Quench current and b_6 as a function of coil curing cycle

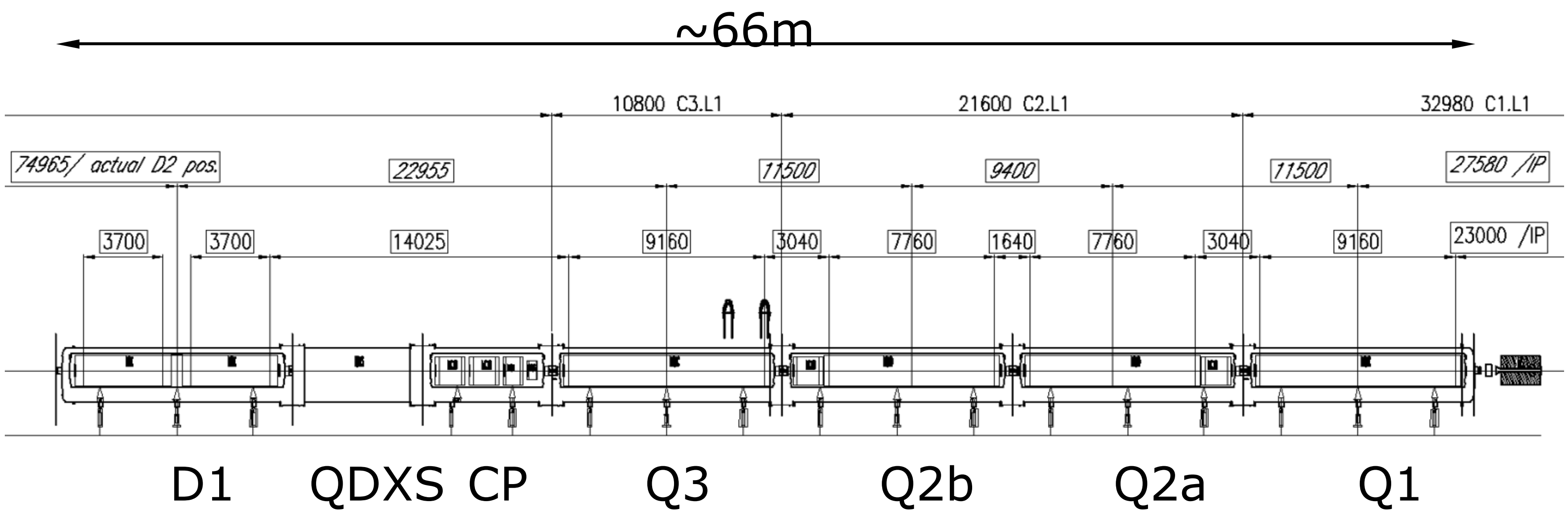
	coil curing cycle		I_c	$\Delta b_6, 6kA$
	temperature	pressure	300 A/s	40 A/s
HGQ01	135°	low	10965	0.02
HGQ02	190°	low	11335	0.21
HGQ03	195°	low	11298	0.16
HGQ05	130°	low	10519	0.12
HGQ06	190°	high	6433	-1.04
HGQ07	190°	high	4487	-0.55
HGQ08	190°	high	3941	-0.72
HGQ09	190/135°	low/high	12946	0.13

9 Models (change of cables)

Can we do Better than 4-5 Years ?

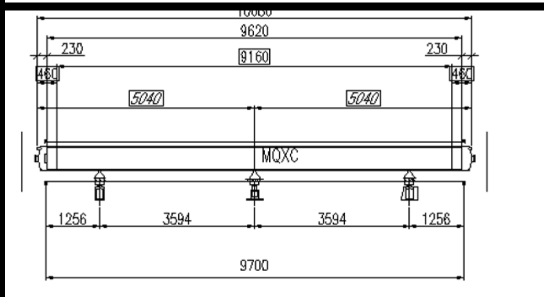
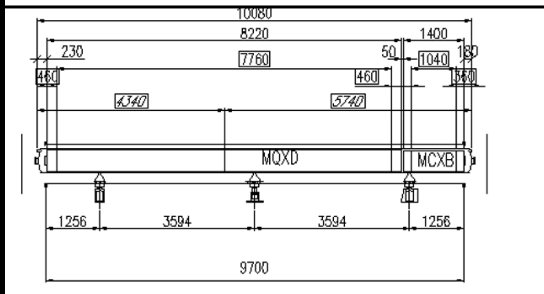
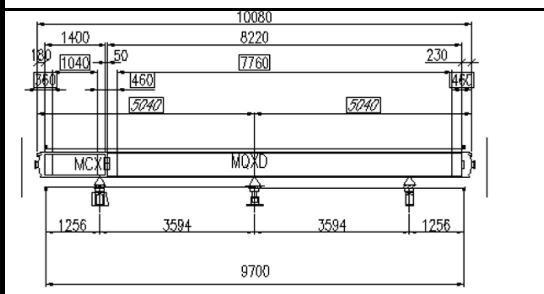
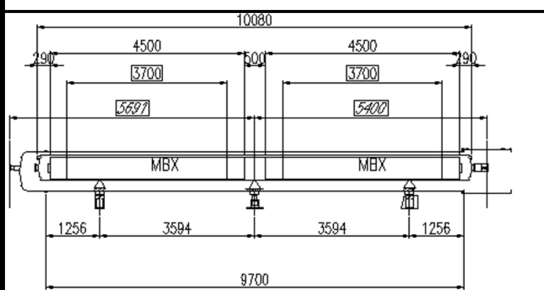
Pro		Contra
More advanced simulation tools	Cable available	Heat load (porous insulation; coil modulus)
Integrated design and manufacture for end-spacers	Large aperture	Busbar design and routing
Faster link between CAD and FE modeling	EU-Industrial suppliers	Horizontal collaring (new press to be procured)
More sophisticated CAD/CAM	EU/White paper	Magnet protection (nested PCs, heaters)
Existing specifications	Technical experience	Axial forces
Cryostat identical to MB	In-house production	EU-Certification of tooling

Layout – General Overview



- One cryostated cold mass per main magnet
- Part of the correctors located in an individual cold mass (CP)
- Distribution feed box removed from the tunnel
- Magnets, cold masses and cryostating performed at CERN (except D1&DFX)
- Maximum standardization with the existing LHC components
- Matching section magnets are left in their current position

Layout – Cryo-assemblies 1/3

	Drawing	Magnets	Cold mass length	Cryostat length	Dist btw supports
Q1=Q3		MQXC (Lmag = 9160mm)	10.080m	9.7m Depending on W bellows	3.594m Identical to the ones in separation dipoles D2, D3, D4
Q2a		MQXD (Lmag = 7760mm) + MCXB (Lmag ≃ 1040mm)			
Q2b		MQXD (Lmag = 7760mm) + MCXB (Lmag ≃ 1040mm)			
D1		MBXC x 2 (Lmag = 3700mm)			

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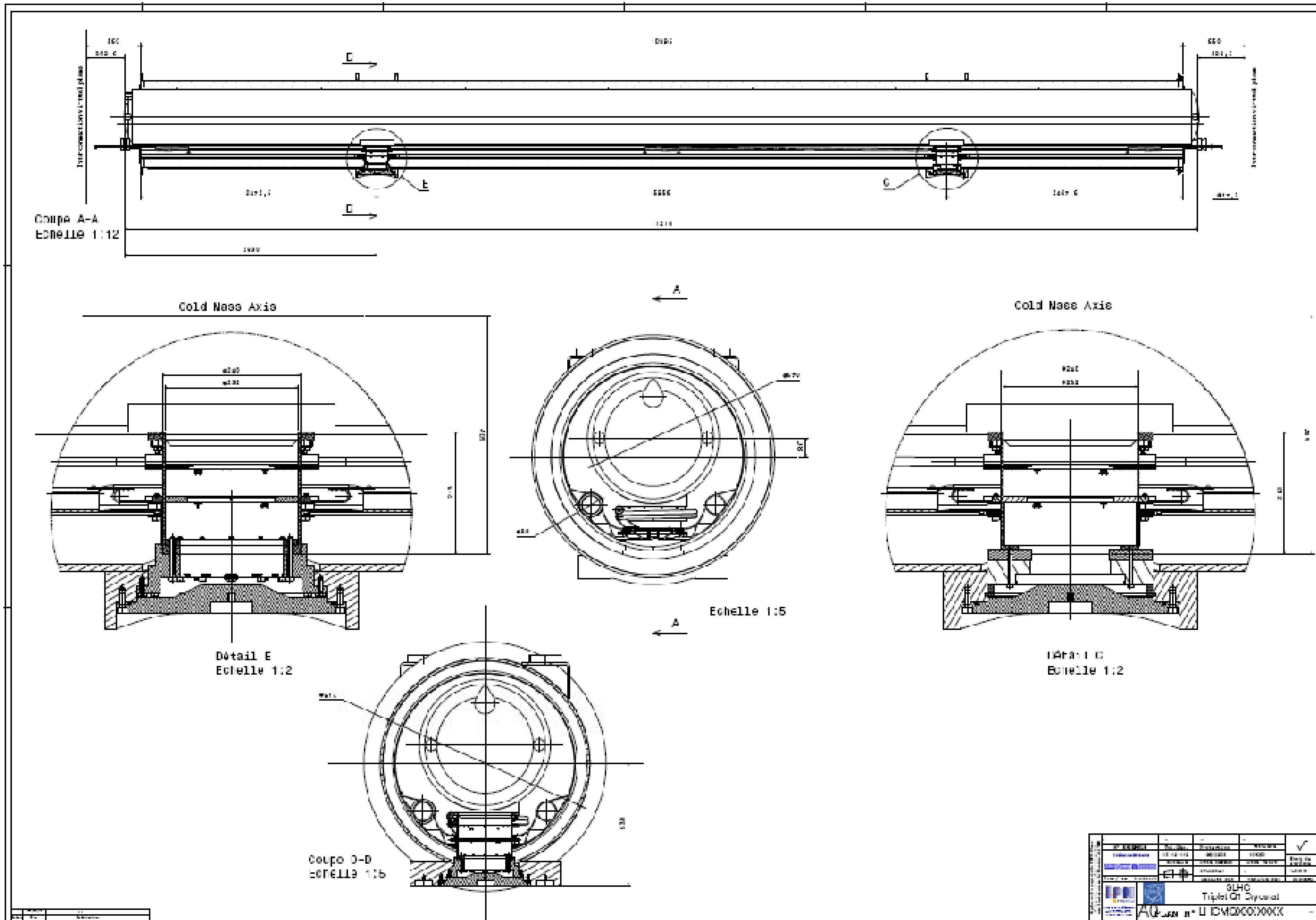
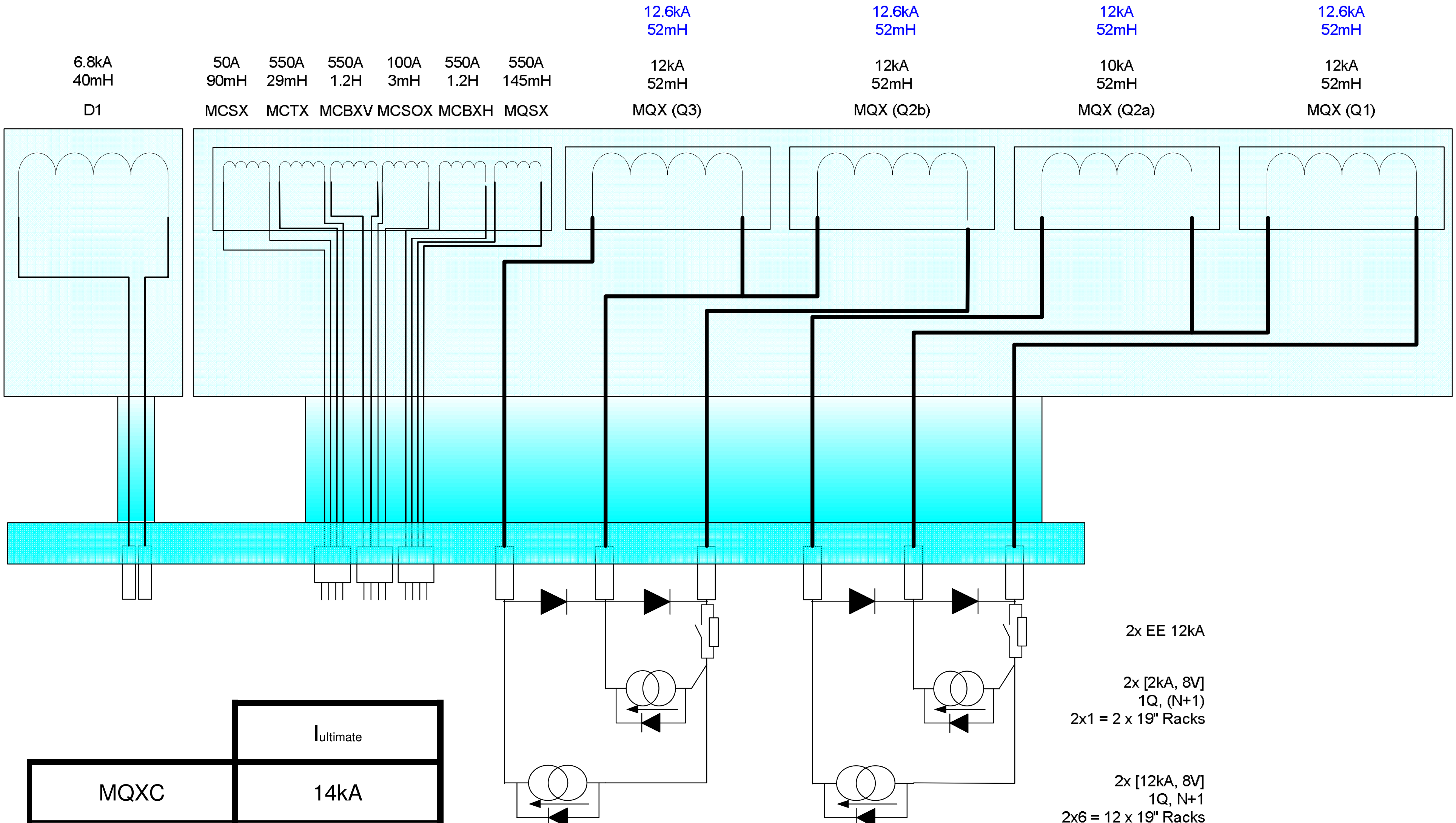
Cryostat Design identical to MB

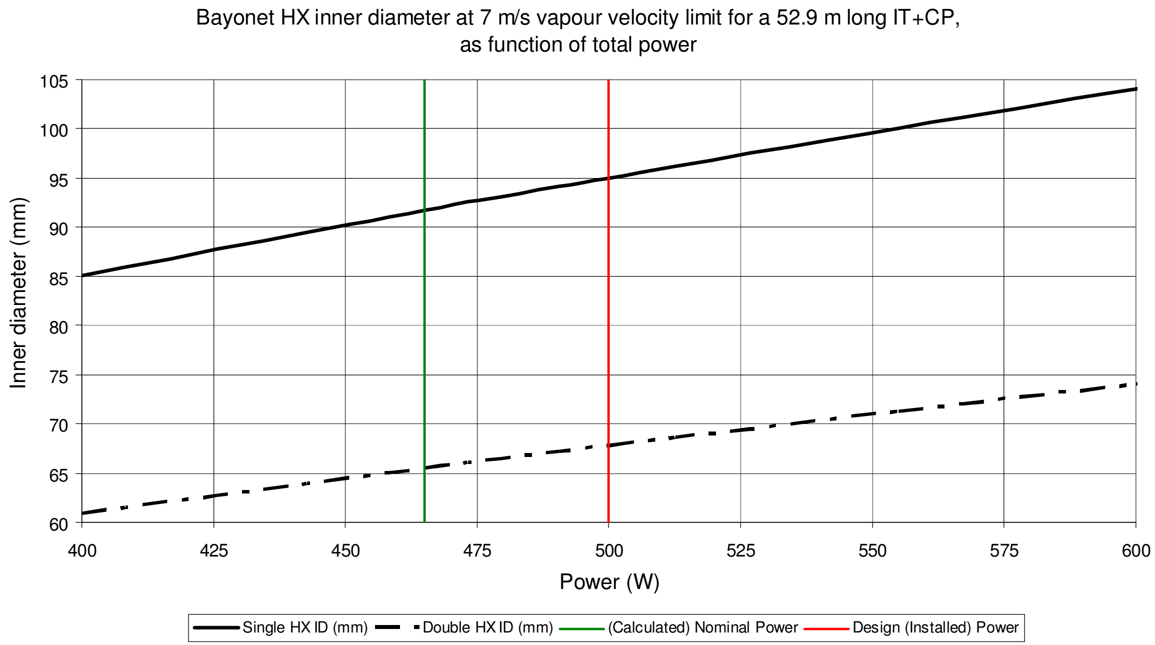


Electrical Powering Scheme



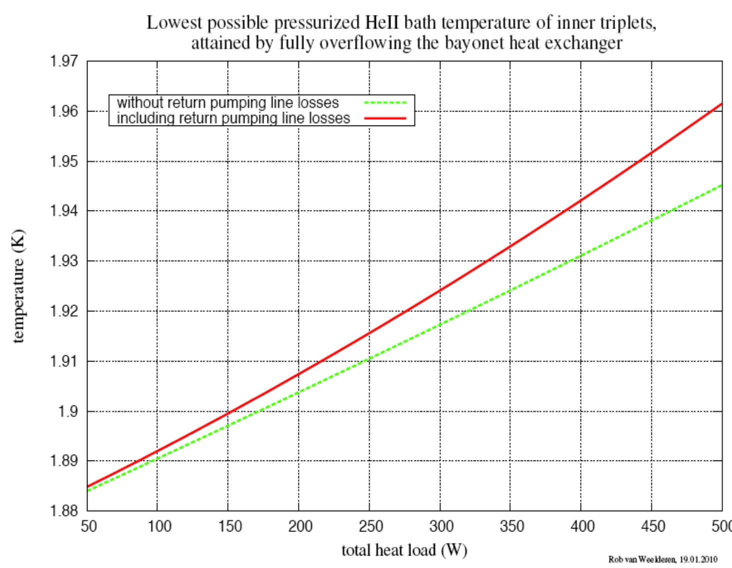
	$I_{ultimate}$
MQXC	14kA
MQXD	12kA
MCXB	3kA
MQXS	3kA

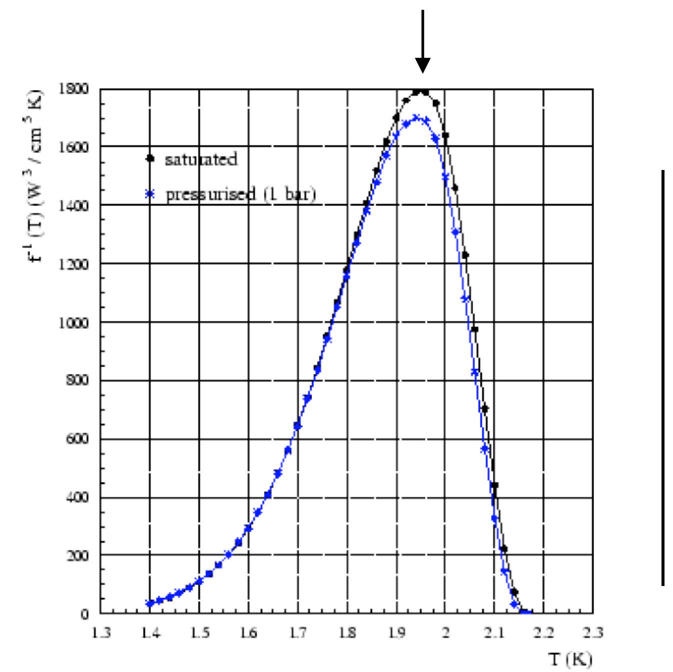
Heat-Load and Cooling Requirements



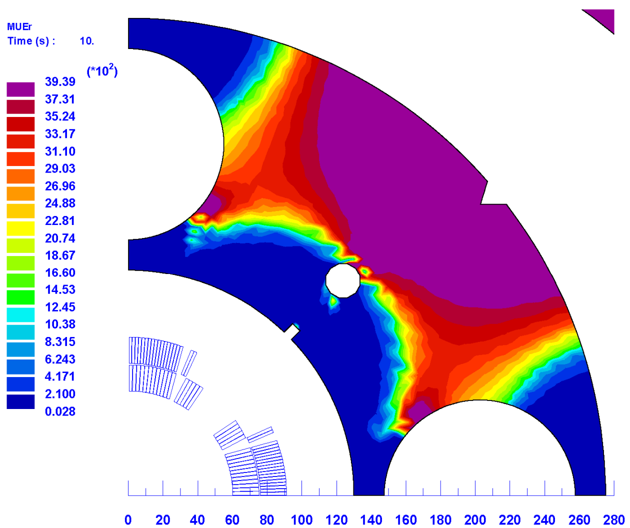
Consequence:
Redesign of magnet cross section

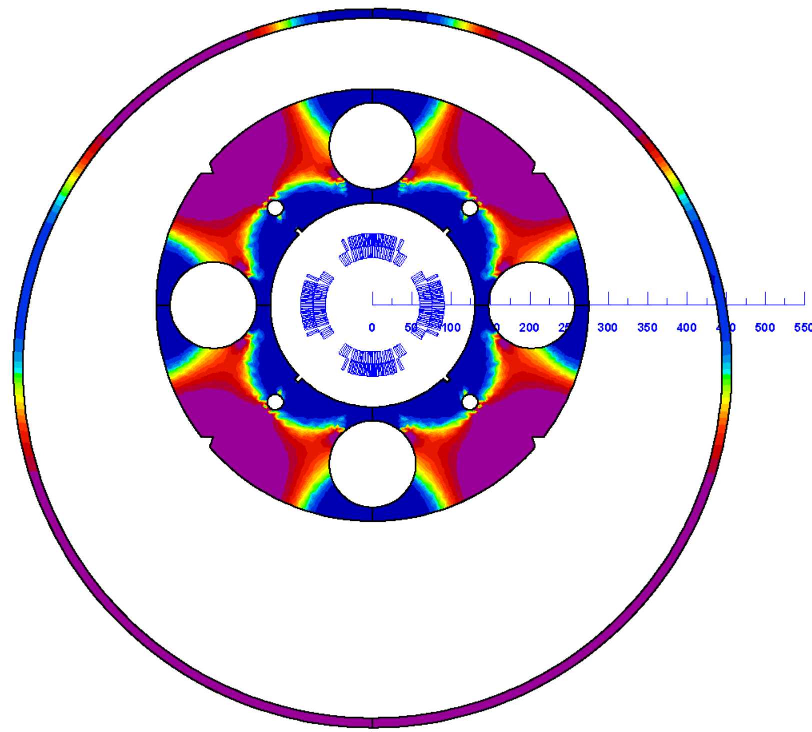
Consequence:
More porous insulation (coil and ground-plane)

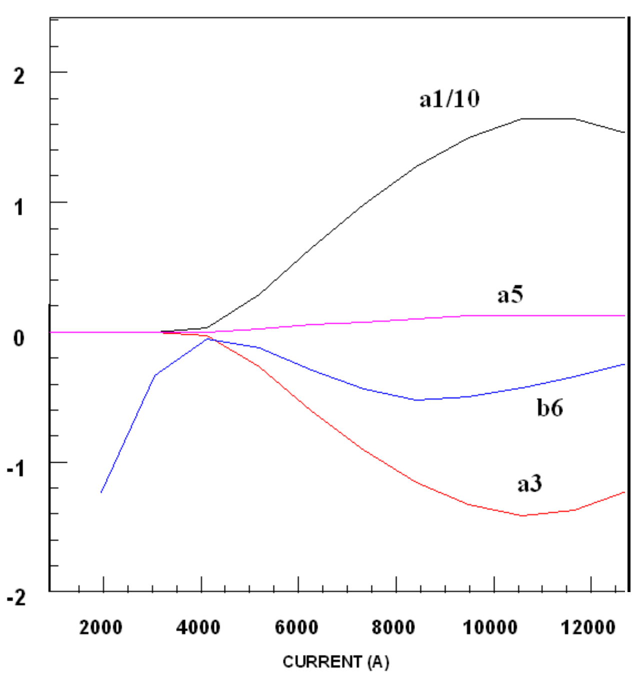




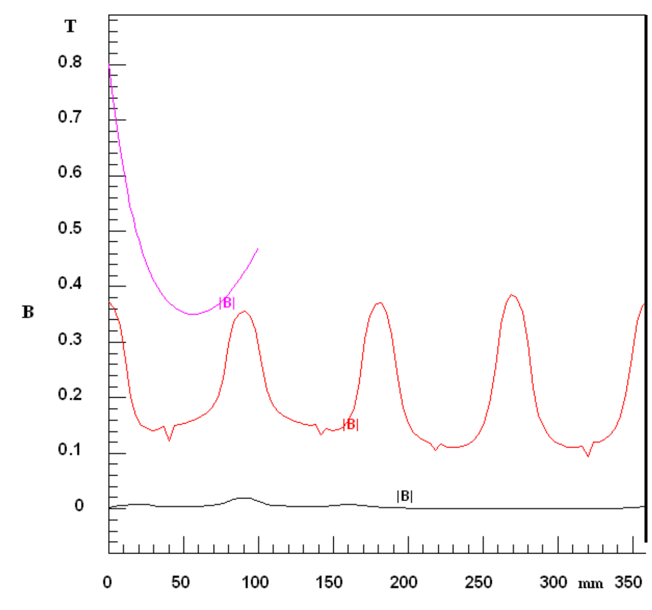
Baseline-Design (105 mm Heat-Exchanger at Mid-Plane)



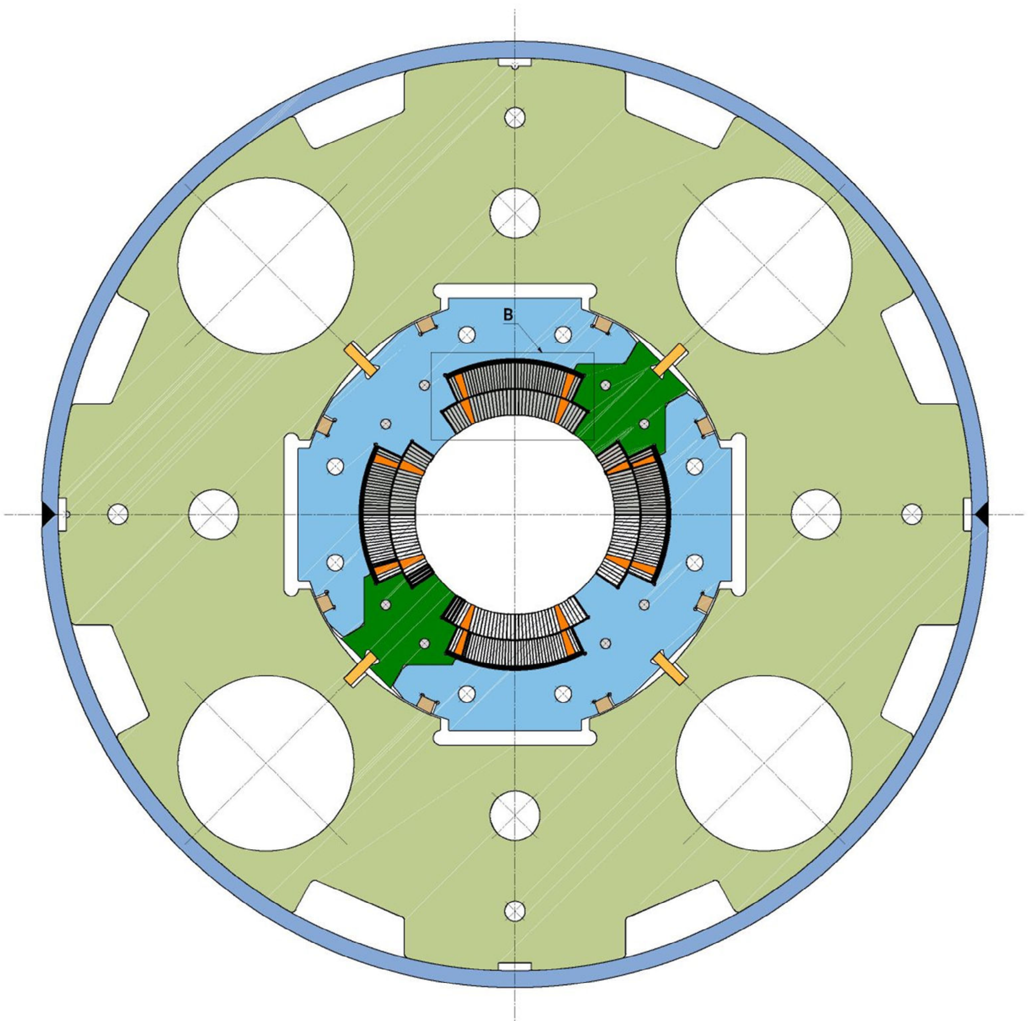




Saturation effects from off-centered cryostat



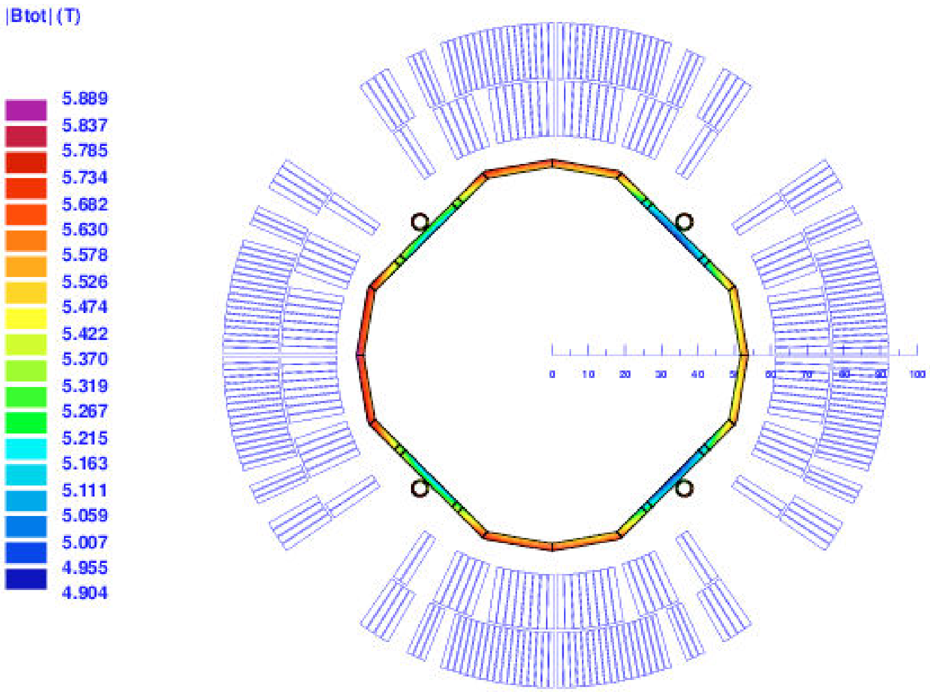
Low-β Quadrupole MQXC



➔	Coil aperture	120 mm
➔	Gradient	127 T/m
➔	Operating temp	1.9 K
➔	Current	13.8 kA
➔	WP on load-line	85%
➔	Inductance	5.2 mH/m
➔	Yoke ID	260 mm
➔	Yoke OD	550 mm
➔	Magnetic length	9160 mm (Q1,Q3) 7760 mm (Q2)

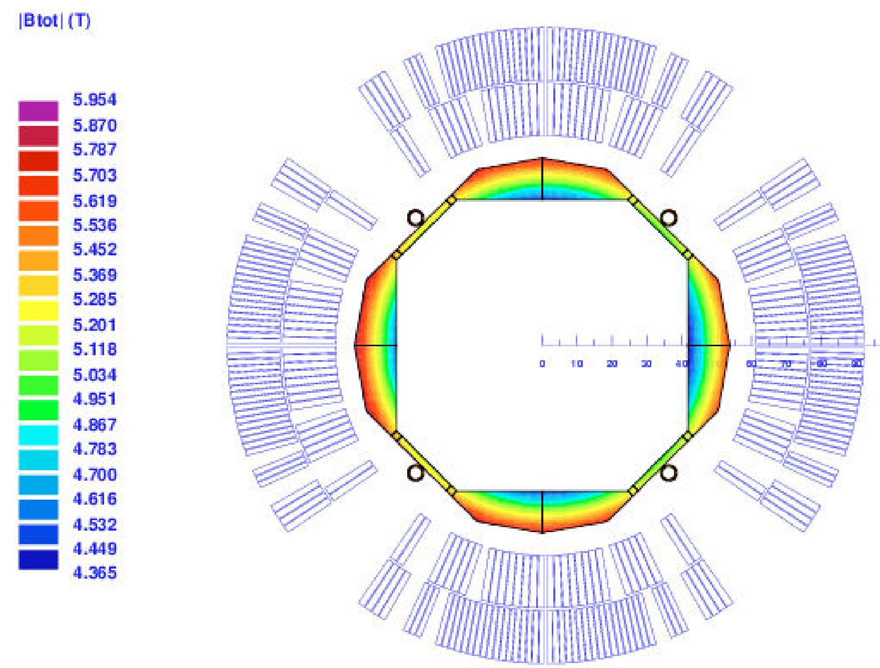
- LHC cables 01 and 02
- Porous cable polyimide insulation
- Yoke OD identical to MB
- Self-supporting collars
- Single piece yoke
- Welded-shell cold mass

Beam Screen Type 1 (Field Quality for Eccentricity of 1 mm)



NORMAL RELATIVE MULTIPOLES (1.D-4):

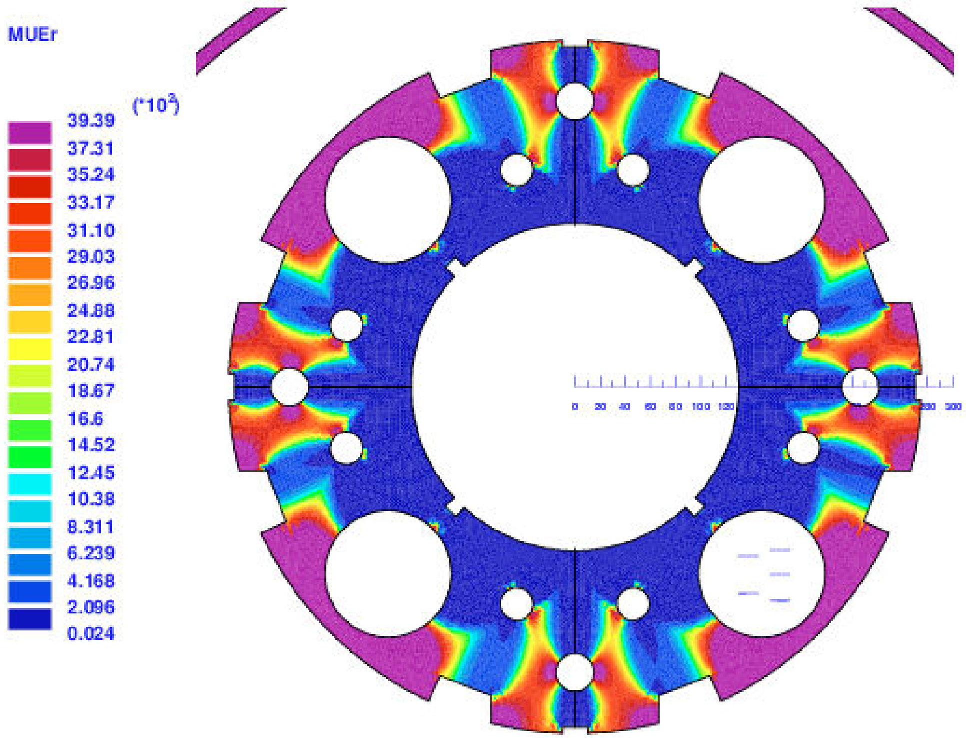
b 1:	0.00316	b 2:	10000.00000	b 3:	-0.00486
b 4:	-0.00338	b 5:	-0.02279	b 6:	-0.19069
b 7:	0.00512	b 8:	0.00497	b 9:	0.02075
b10:	0.09316	b11:	-0.00266	b12:	-0.00394
b13:	-0.01022	b14:	0.11445	b15:	0.00133



NORMAL RELATIVE MULTIPOLES (1.D-4):

b 1:	-0.06983	b 2:	10000.00000	b 3:	0.07682
b 4:	-0.00505	b 5:	-0.04988	b 6:	-0.41232
b 7:	0.01509	b 8:	0.01626	b 9:	0.12523
b10:	0.55097	b11:	-0.01056	b12:	-0.00870
b13:	-0.04982	b14:	-0.01027	b15:	0.00306

Cartridge Solution

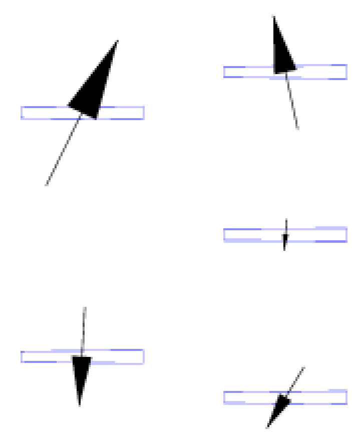


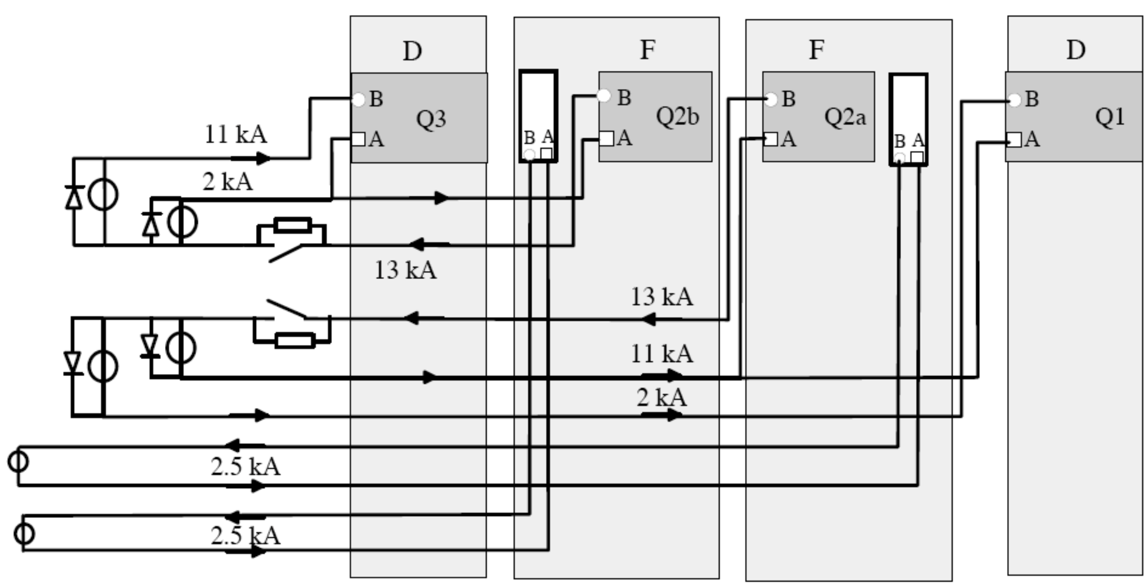
NORMAL RELATIVE MULTIPOLES (1.D-4):

b 1:	3.38036	b 2:	10000.00000	b 3:	0.43334
b 4:	0.63923	b 5:	-0.03264	b 6:	1.34425
b 7:	0.00177	b 8:	0.00644	b 9:	-0.00034
b10:	-0.00065	b11:	0.00001	b12:	0.00002
b13:	0.00000	b14:	0.06372	b15:	0.00000
b16:	0.00000	b17:	0.00000	b18:	0.12829
b19:	0.00000	b20:	0.00000	b	

SKEW RELATIVE MULTIPOLES (1.D-4):

a 1:	-2.75975	a 2:	0.35356	a 3:	0.64007
a 4:	0.21998	a 5:	0.01367	a 6:	-0.00172
a 7:	0.00222	a 8:	0.00133	a 9:	0.00013
a10:	-0.00004	a11:	0.00000	a12:	0.00000
a13:	0.00000	a14:	0.00000	a15:	0.00000
a16:	0.00000	a17:	0.00000	a18:	0.00000
a19:	0.00000	a20:	0.00000	a	





BLOCK	FORCE -X- (N/m)	FORCE -Y- (N/m)
7	-0.1617E+03	-0.2908E+04
8	0.2113E+04	0.4293E+04
9	-0.1105E+04	-0.1804E+04
10	-0.6970E+02	-0.8870E+03
11	-0.7191E+03	0.3349E+04
SUMM:	0.5749E+02	0.2043E+04

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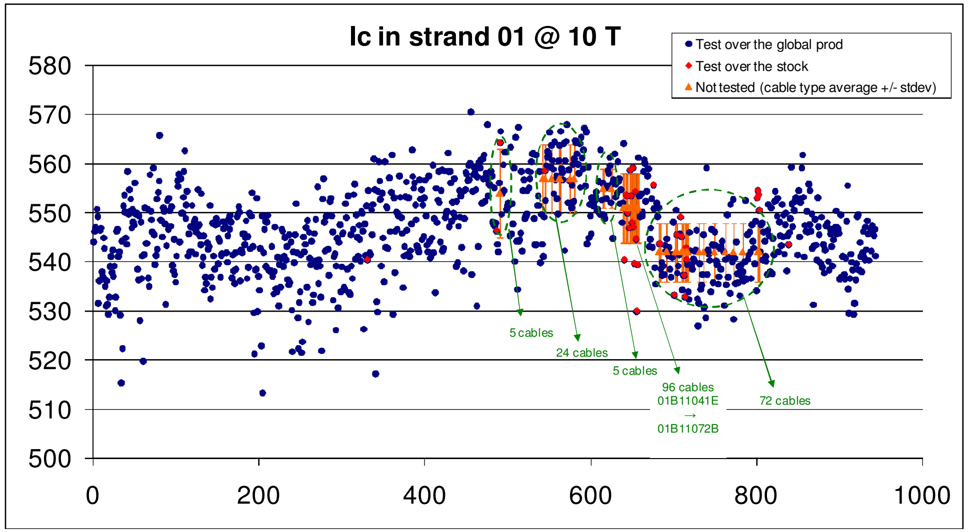
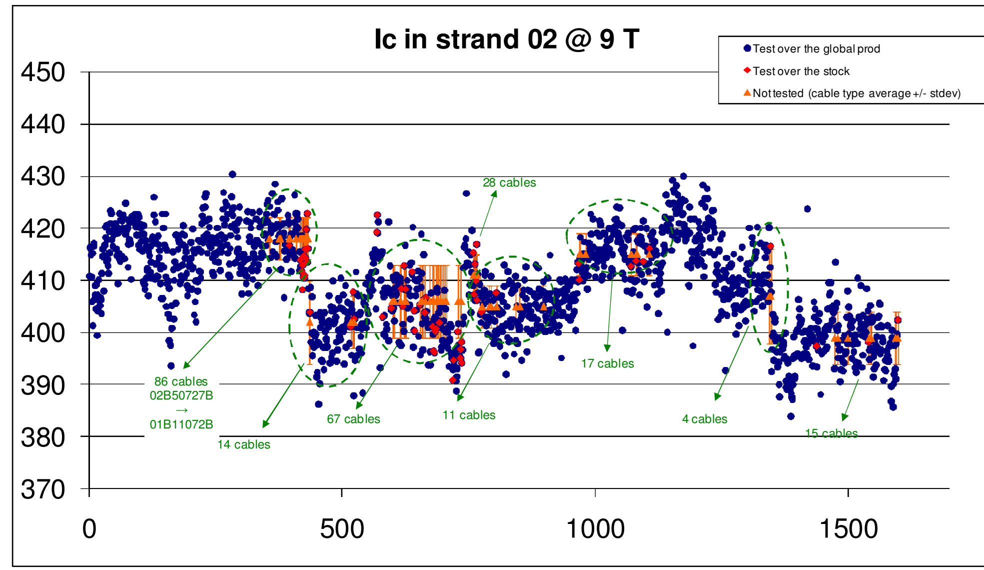
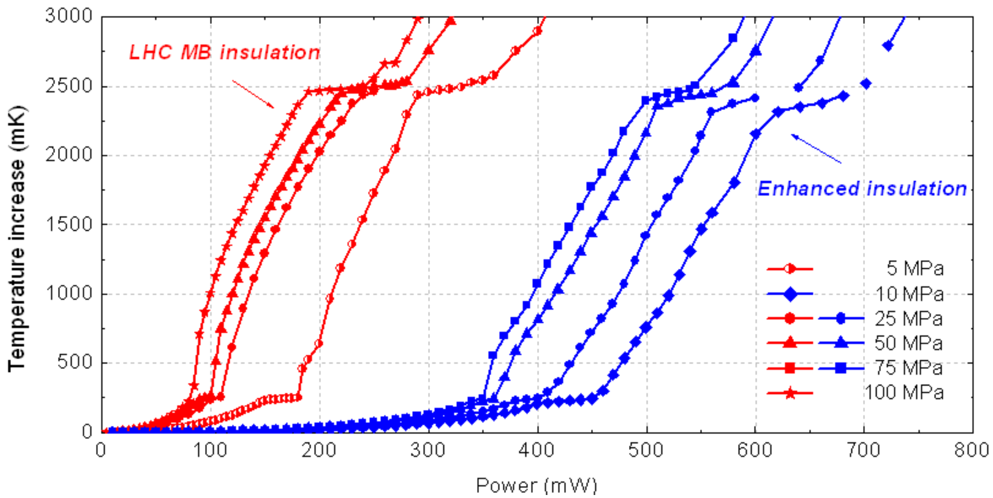
Selection of Cables

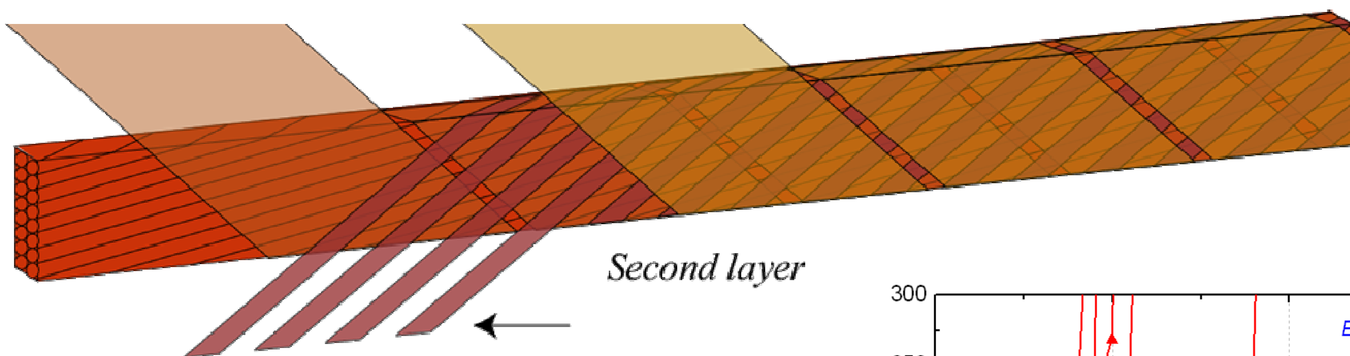


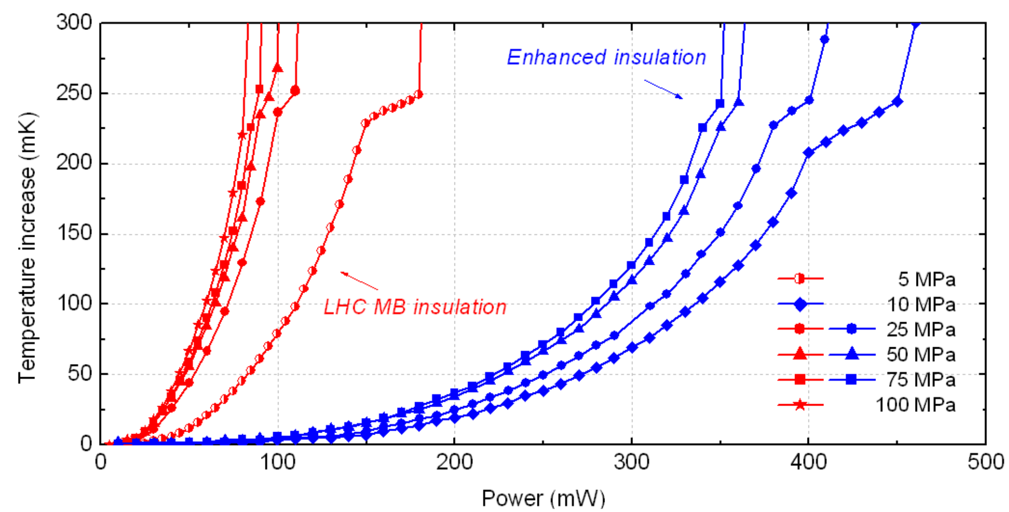


Aperture diameter [mm]	Magnetic length [m]	Inner layer turns	Outer layer turns	Total cable inner layer [m]	Inner layer unit length [m]	Total Outer layer [m]	Outer layer unit length [m]
110	9	15	19	320	448	400	740
120	10.3	18	19	420	448	445	740
130	11.5	18	24	445	448	590	740

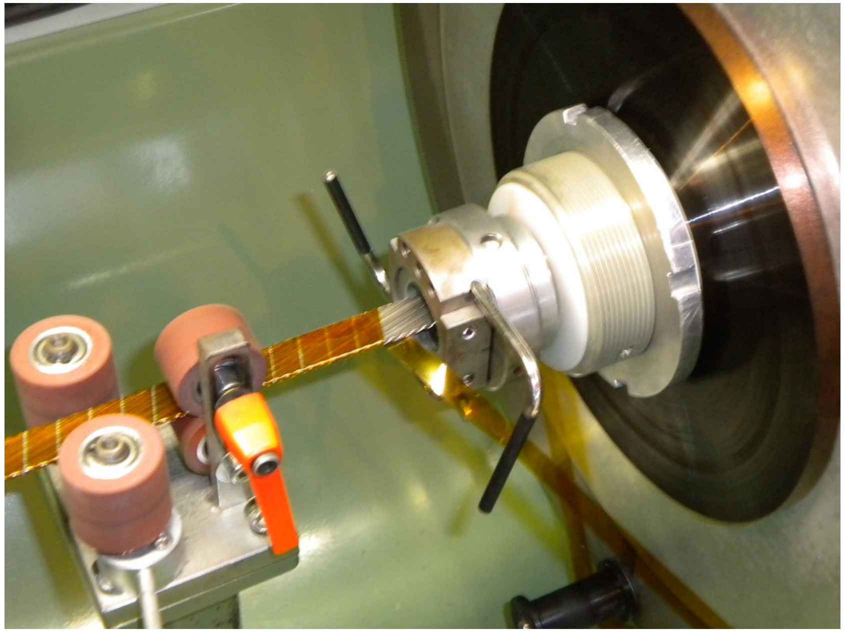
Heat Transfer up to T λ and up to 3 K

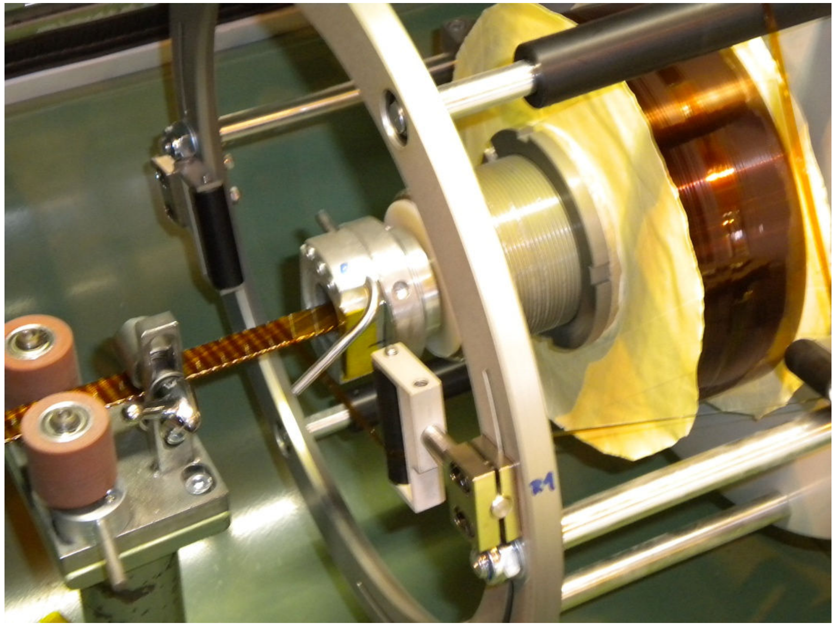


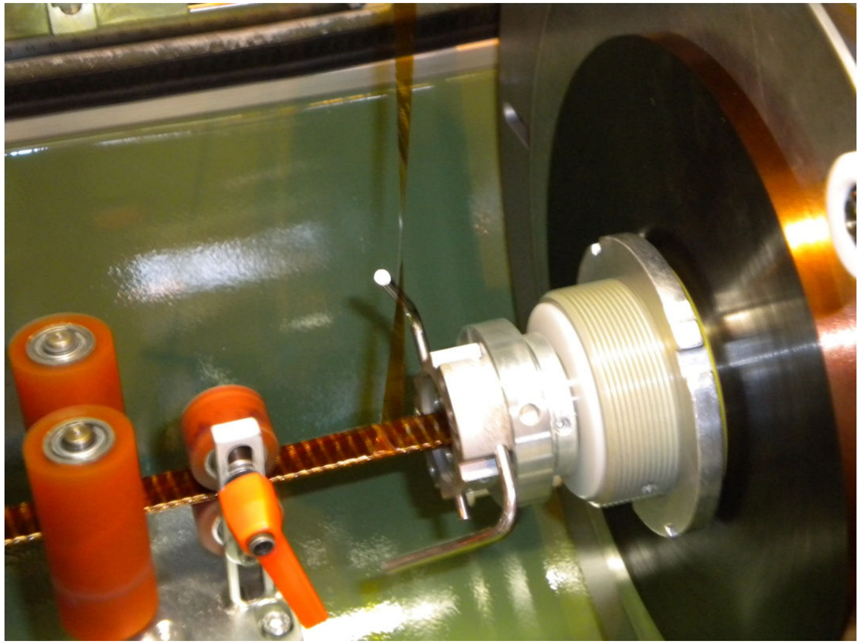


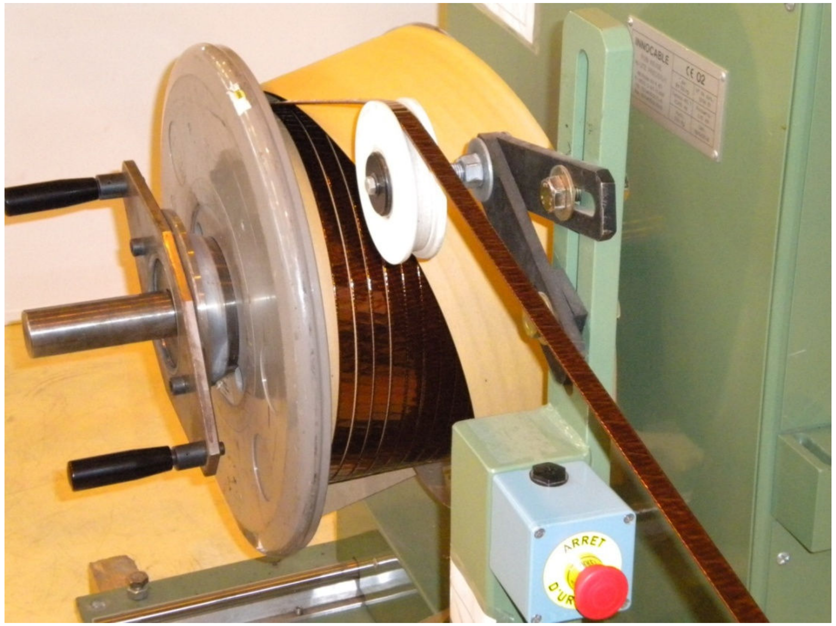


Wrapping Machine fully Commissioned

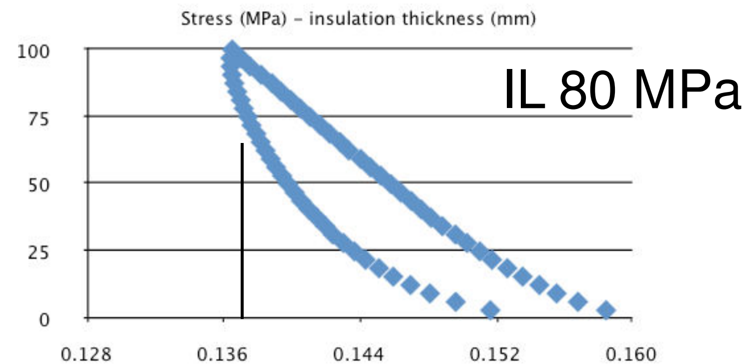


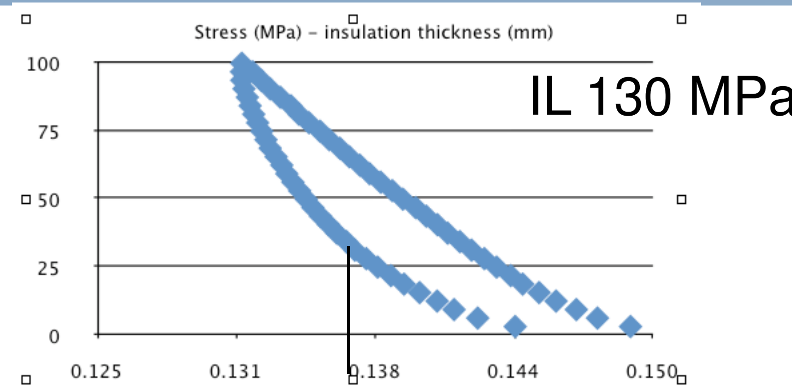




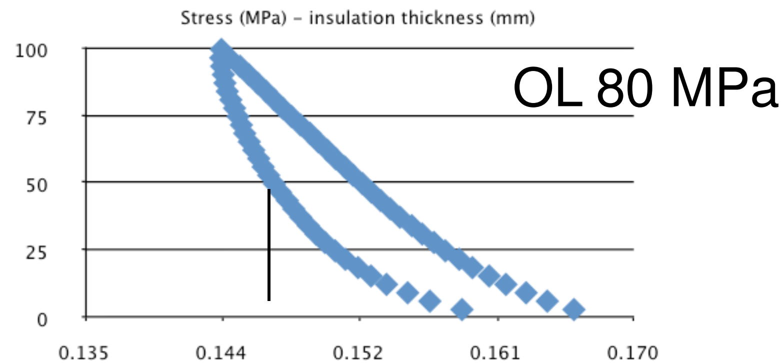


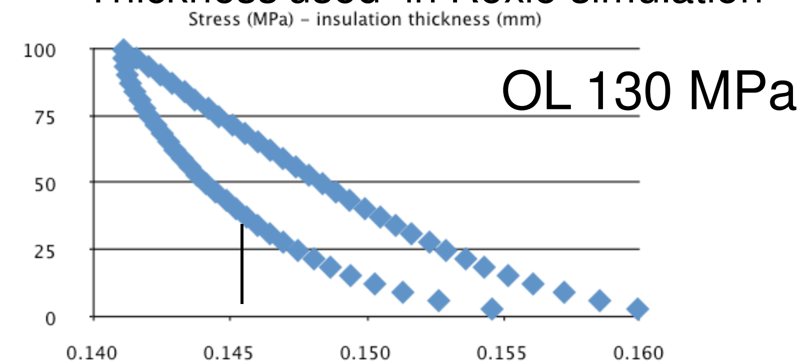
Insulation Thickness

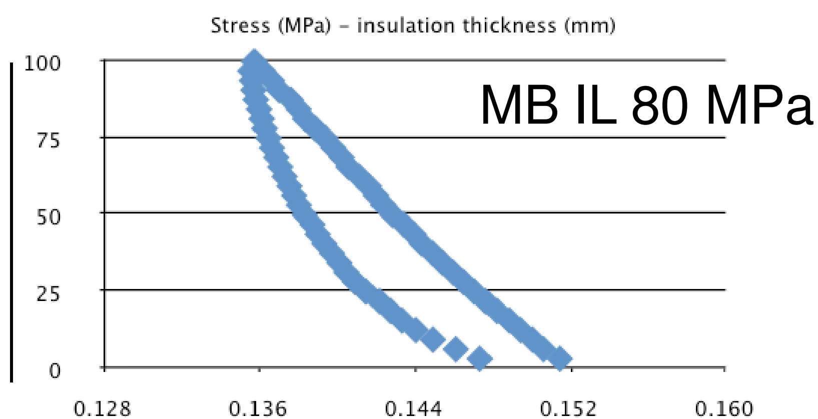


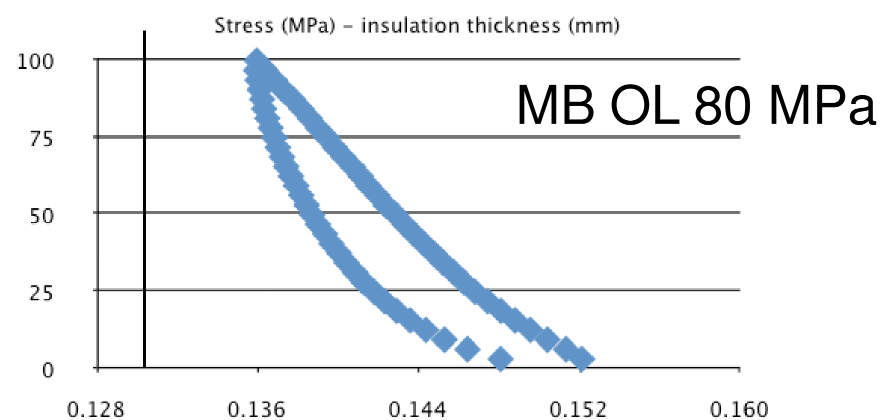


Thickness used in Roxie simulation



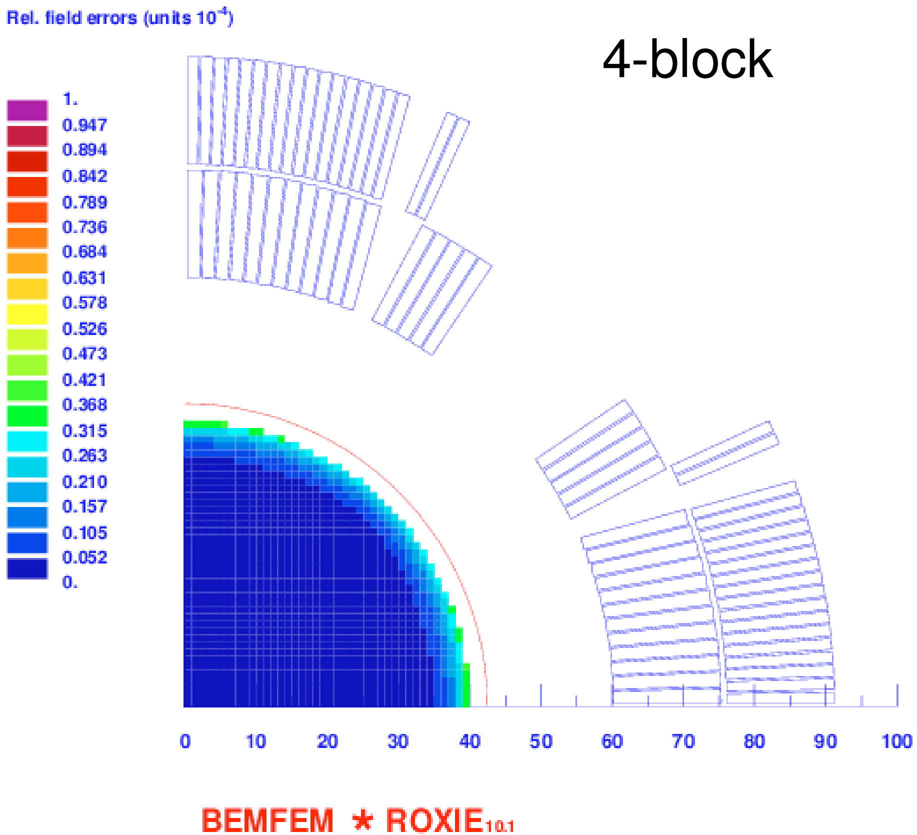


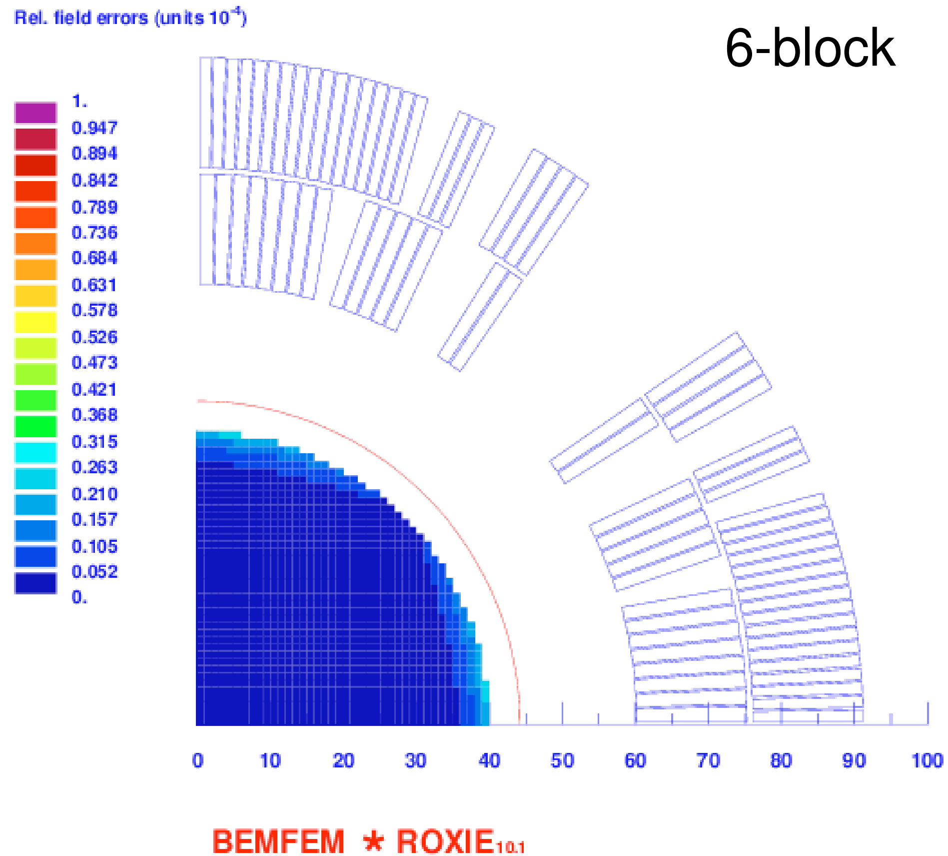




Instrumented collar pack needed for final verification

Coil Layouts





Geometric !

NORMAL RELATIVE MULTIPOLES (1.D-4):

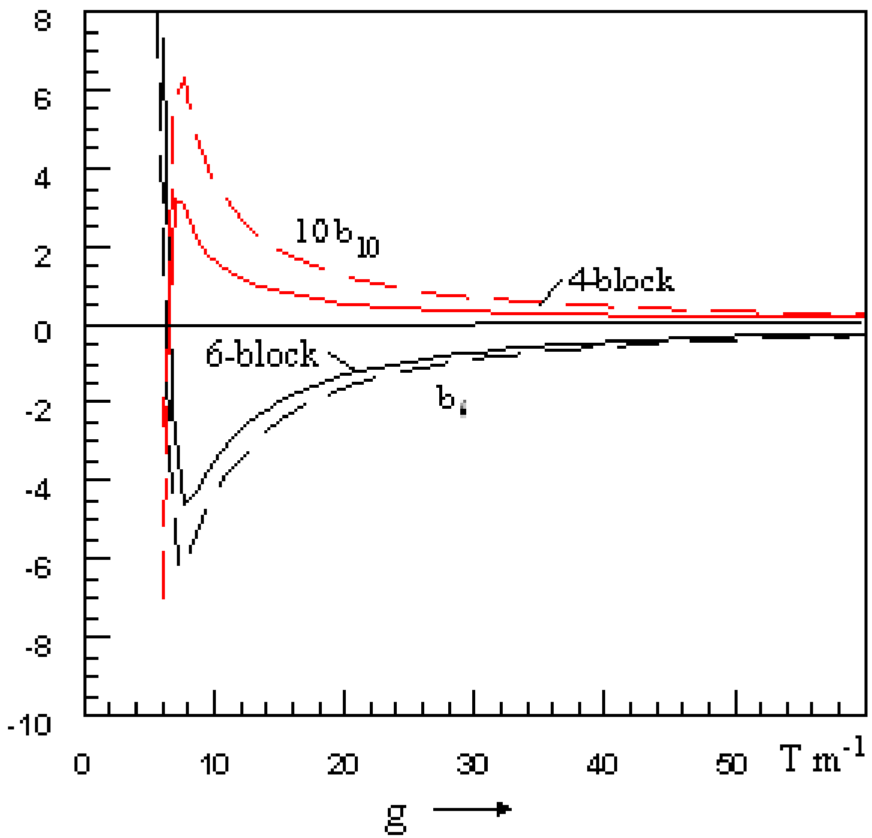
b 1:	0.00000	b 2:	10000.00000	b 3:	0.00000
b 4:	0.00000	b 5:	0.00000	b 6:	-0.00015
b 7:	0.00000	b 8:	0.00000	b 9:	0.00000
b10:	0.00015	b11:	0.00000	b12:	0.00000
b13:	0.00000	b14:	-0.05686	b15:	0.00000

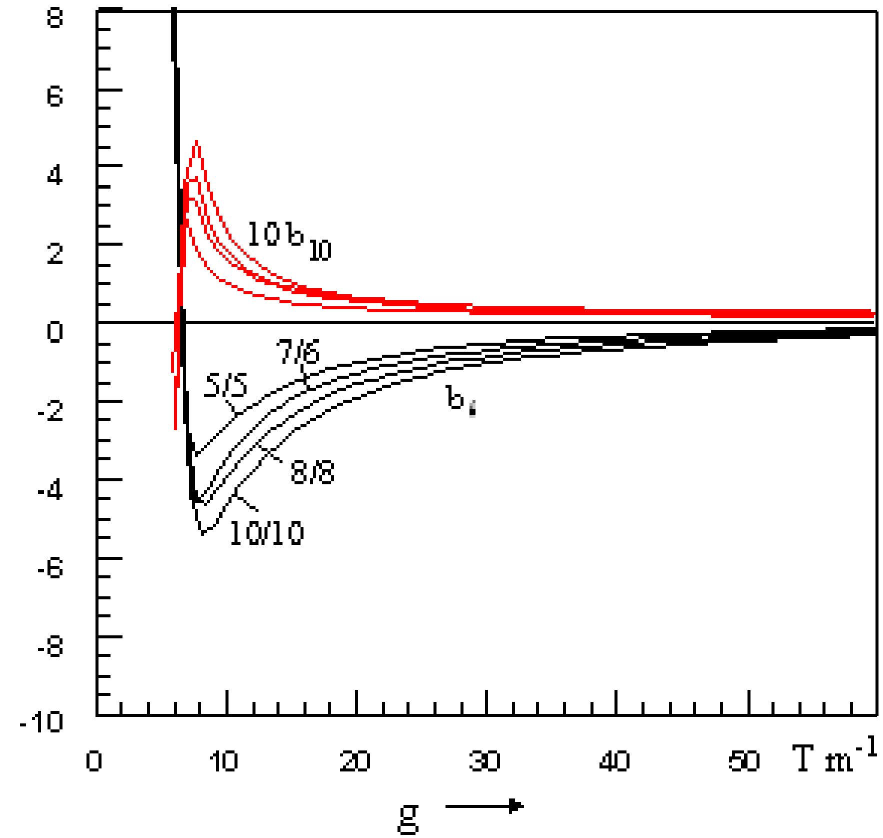
NORMAL RELATIVE MULTIPOLES (1.D-4):

b 1:	0.00000	b 2:	10000.00000	b 3:	0.00000
b 4:	0.00000	b 5:	0.00000	b 6:	-0.00031
b 7:	0.00000	b 8:	0.00000	b 9:	0.00000
b10:	-0.00001	b11:	0.00000	b12:	0.00000
b13:	0.00000	b14:	0.13018	b15:	0.00000

12804 A, 79.6% on load-line NL – calc. 12683 A, 78.45% on load-line

Persistent Current Multipoles





Sensitivity of Multipole Field Errors

Separate powering

	4-block	6-block
Only outer layer: b_6	128.9	0.803
Only outer layer: b_{10}	-4.99	0.202
Only inner layer: b_6	-115.7	-0.905
Only inner layer: b_{10}	4.48	-0.227

Coil size effect

	4-block	6-block
Nominal: b_6	-0.0335	0.
Nominal: b_{10}	0.0005	0.
Inner + 0.34, Outer + 0.34: b_6	-7.75	-6.49
Inner + 0.34, Outer + 0.34 b_{10}	0.699	0.344
Inner + 0.34, Outer - 0.34: b_6	-4.06	-2.46
Inner + 0.34, Outer - 0.34: b_{10}	0.828	0.255

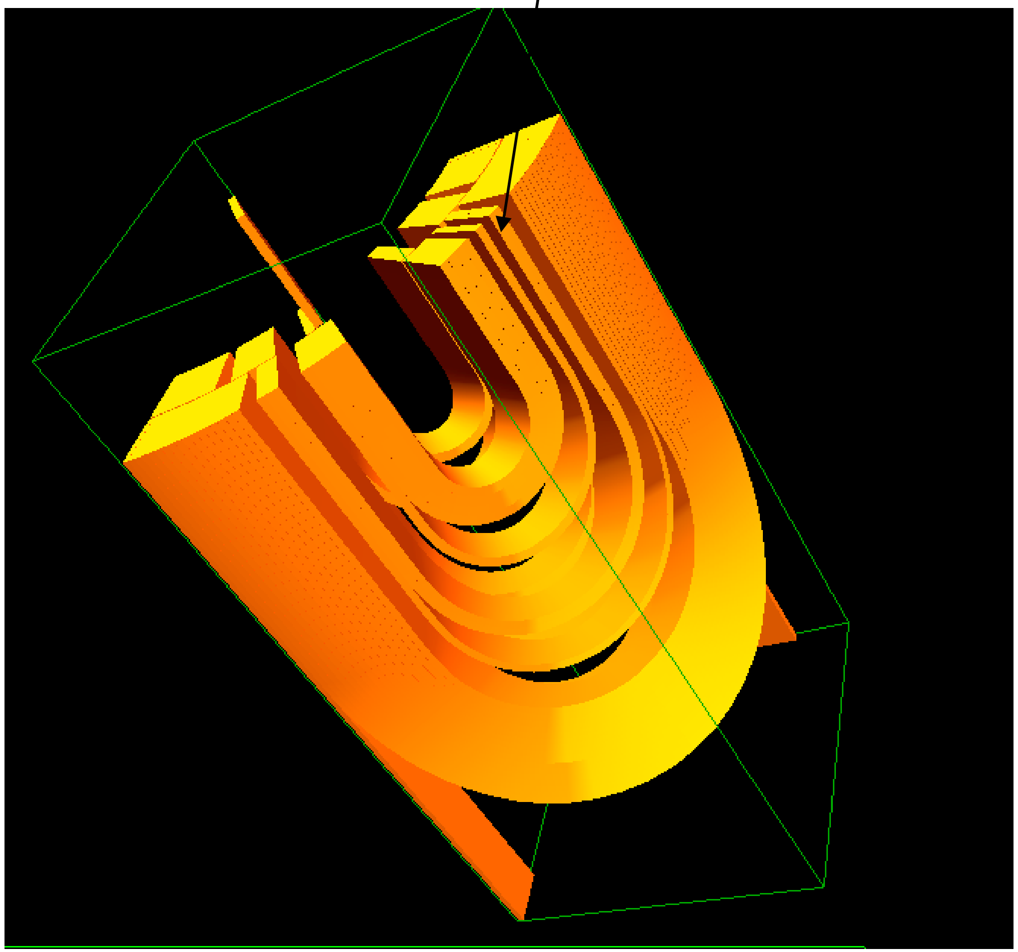
	4-block	6-block
b_1	0.767	0.684
b_3	0.623	0.534
b_4	0.446	0.398
b_5	0.330	0.258
b_6	0.218	0.188
b_7	0.137	0.119
b_8	0.093	0.086
b_9	0.056	0.054
b_{10}	0.034	0.037

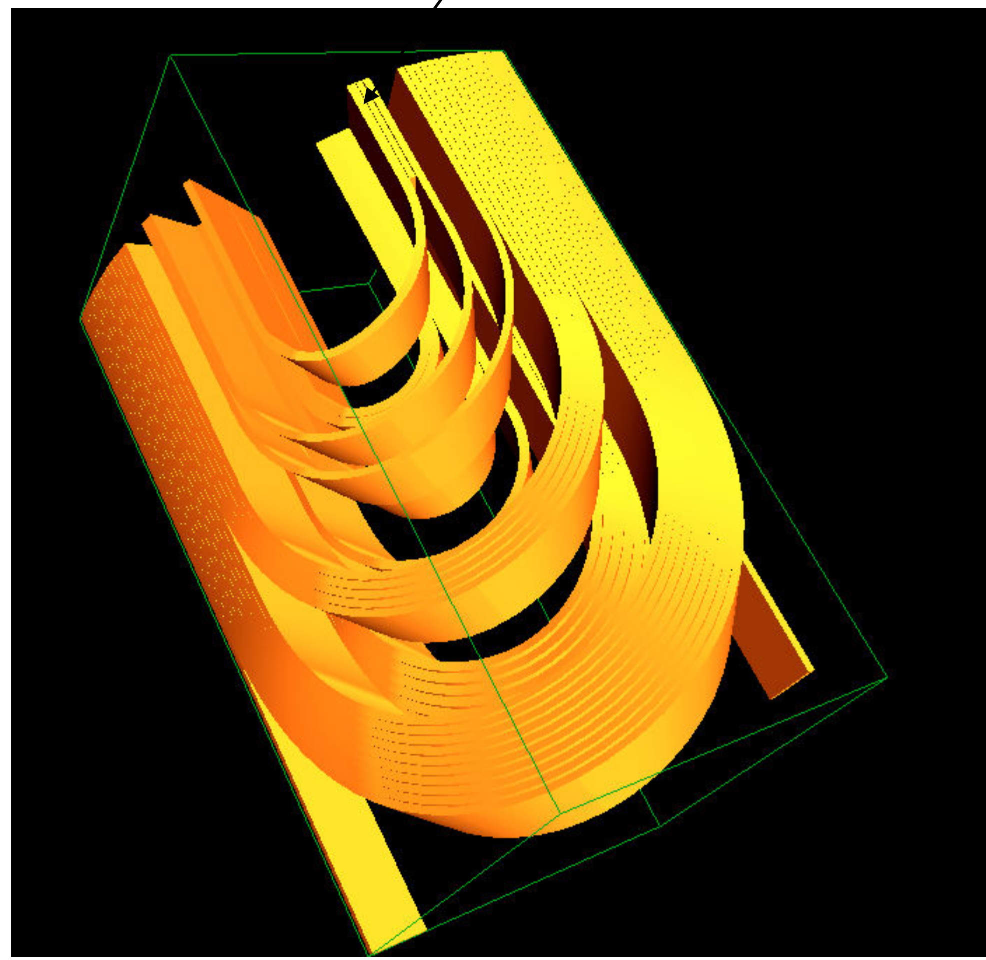
Random errors

Coil Layouts (4-block / 6-block)

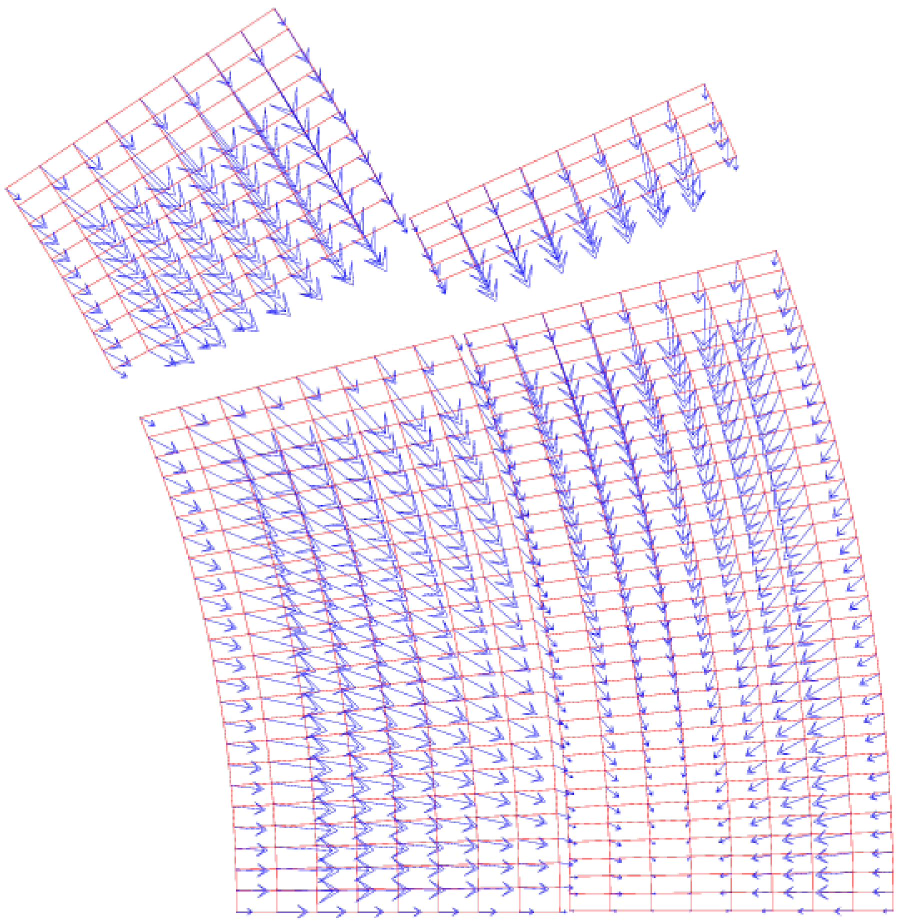
Internal Splice

Special splice collar needed

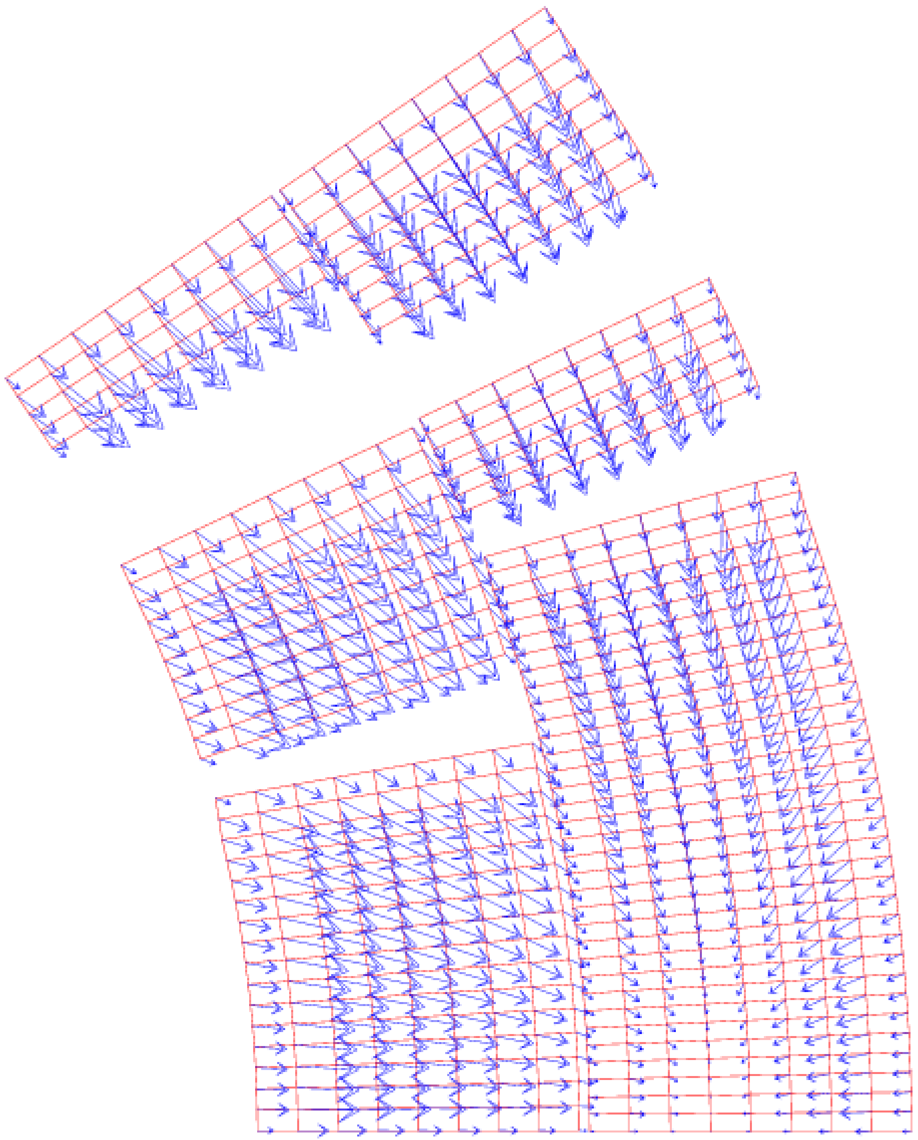




Magnetic Forces

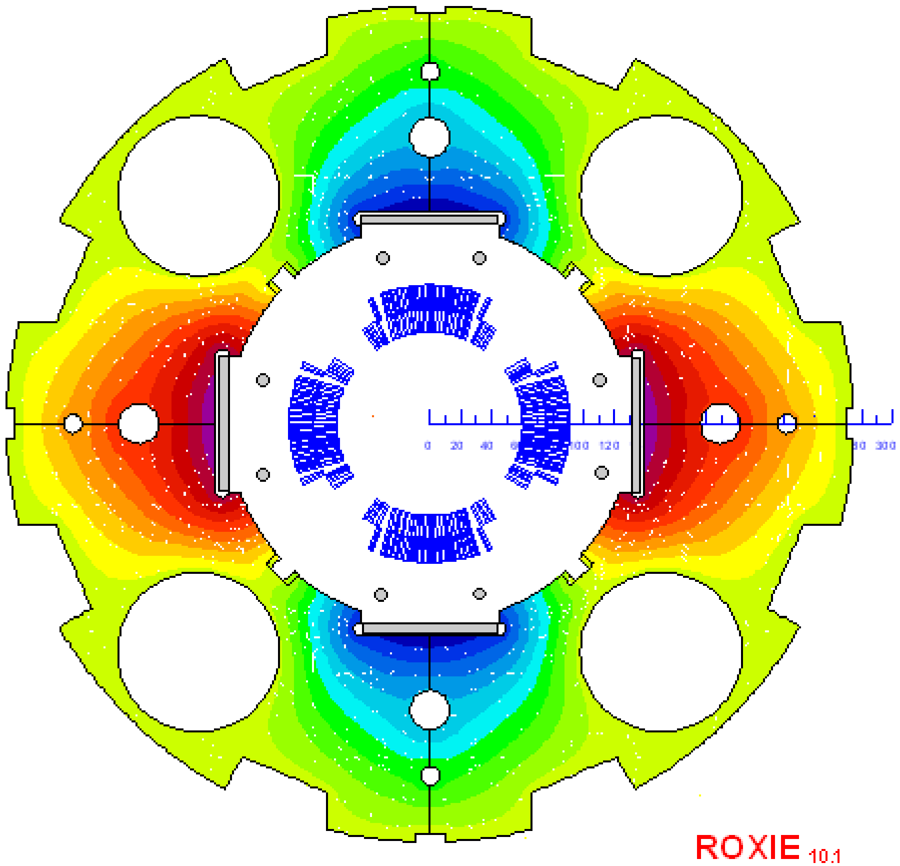


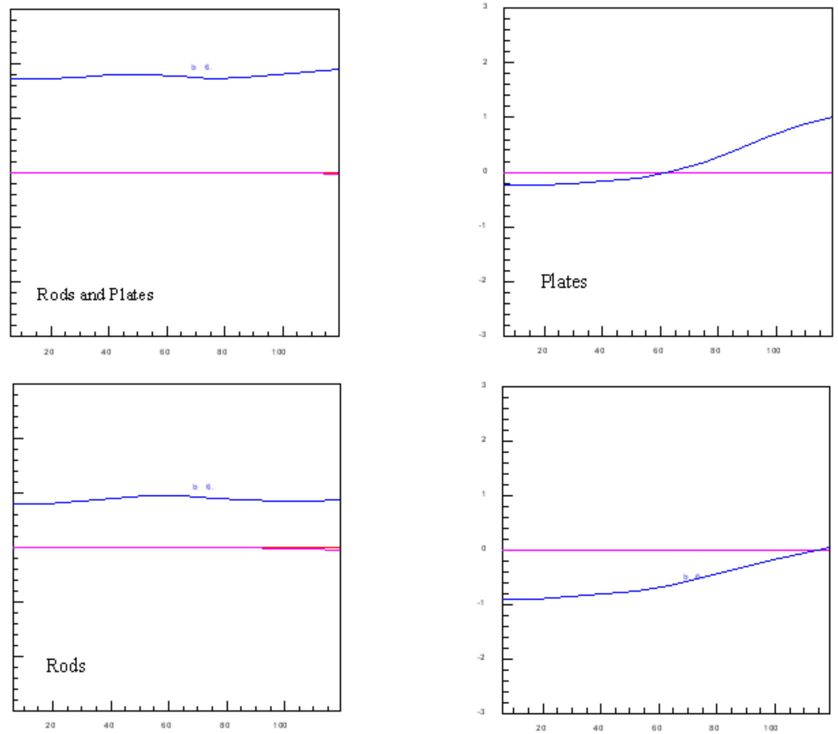
4-block model
(F = 1.6 MN/m)



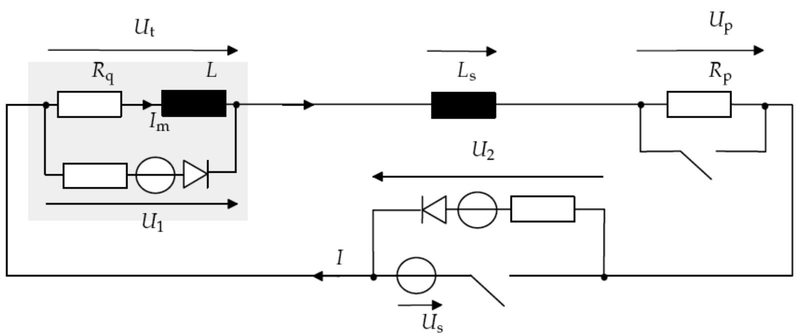
6-block model
(F = 1.8 MN/m)

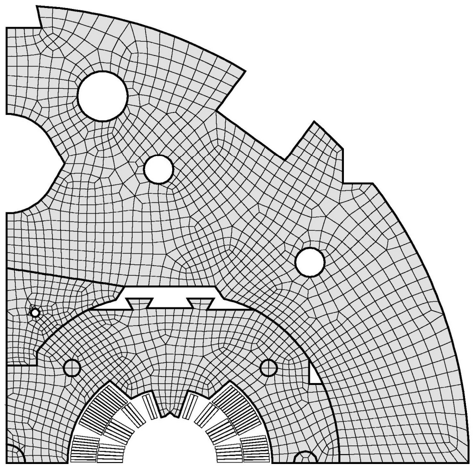
Ferromagnetic Tuning Shims (Rods and Plates)

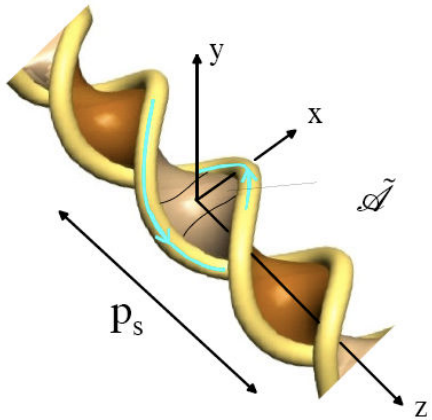


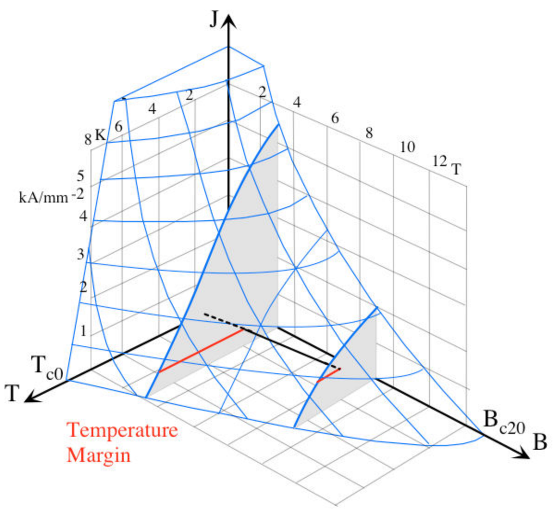


Quench Simulation (Multi-physics, Multi-scale)

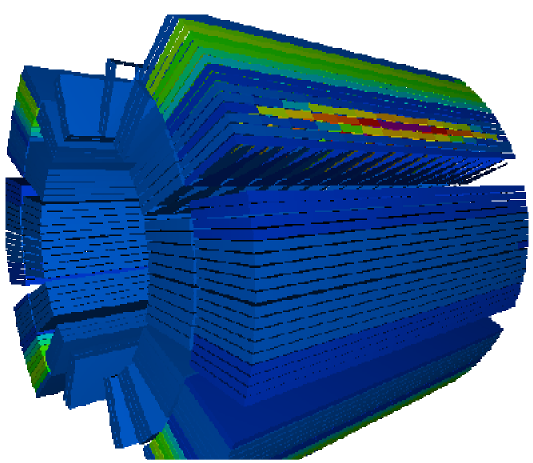


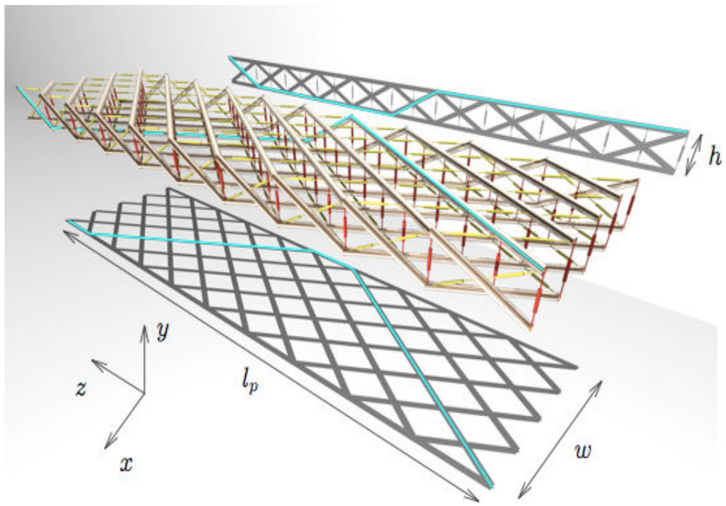


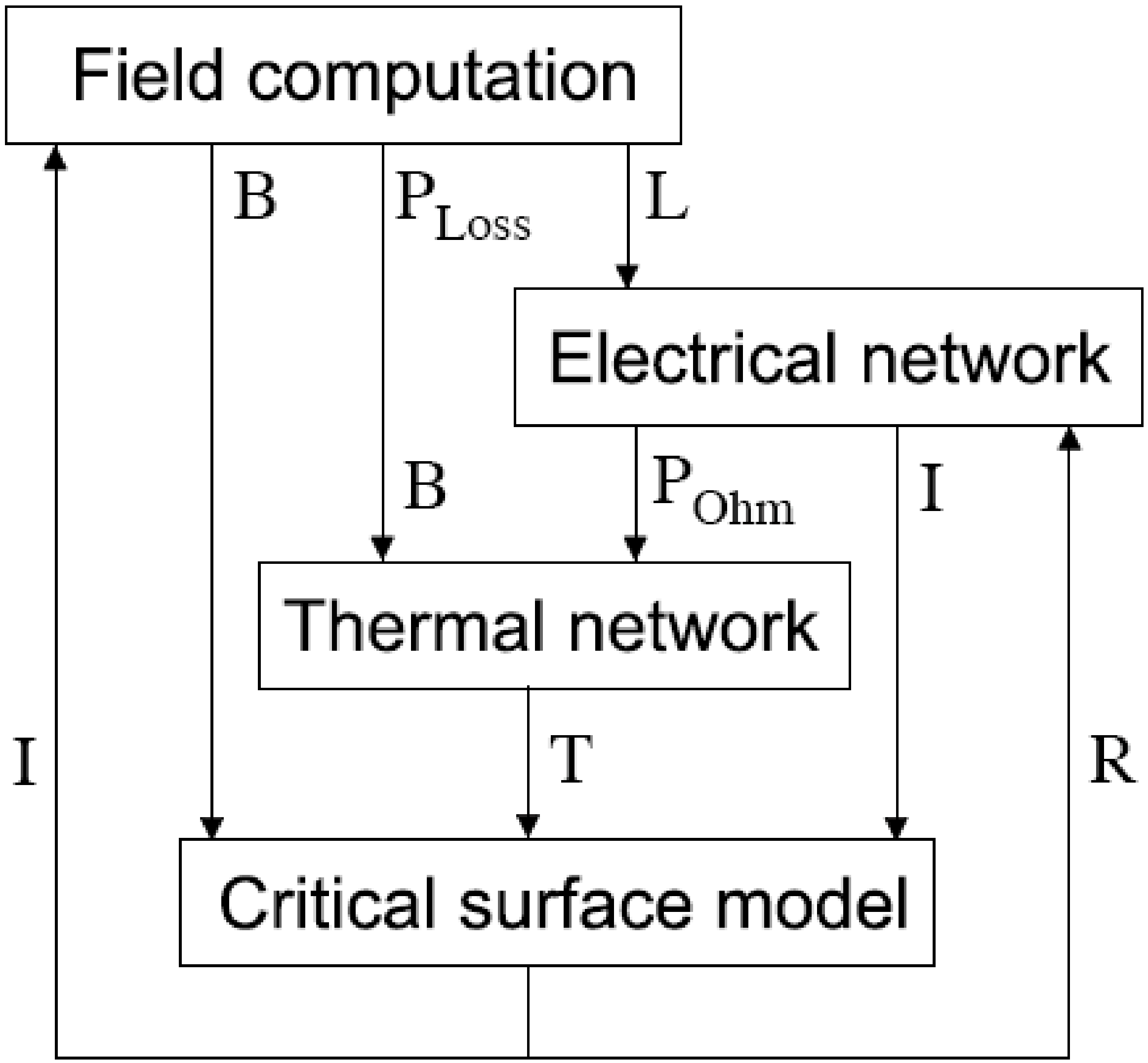




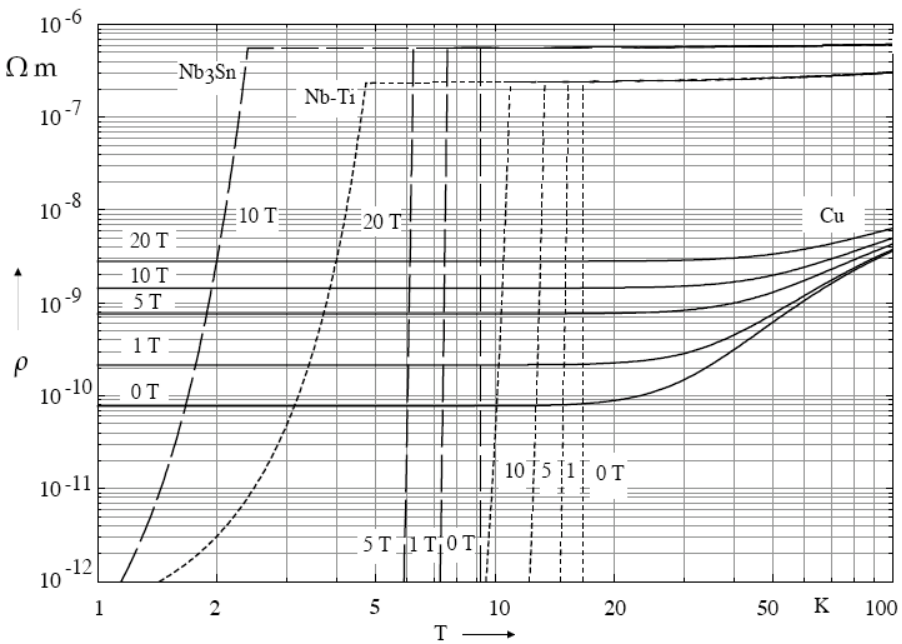
Quench Simulation in ROXIE





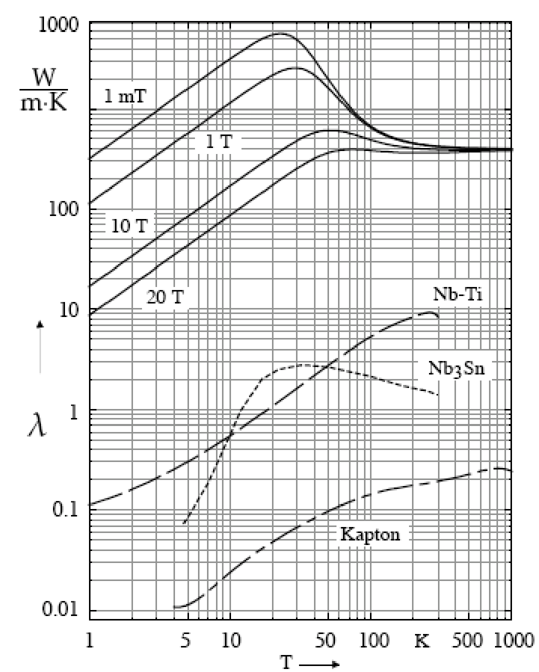

Field computation
B
P Loss
L
Electrical network
B
P Ohm
I
Thermal network
I
T
R
Critical surface model

Material Parameters

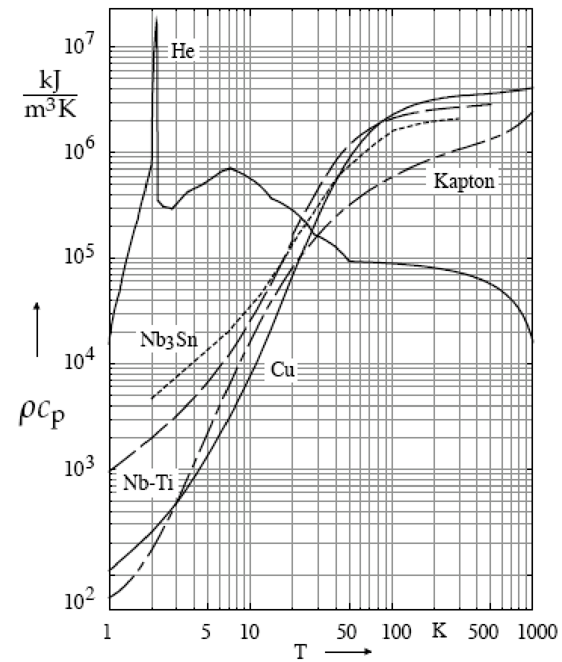


Electrical resistivity

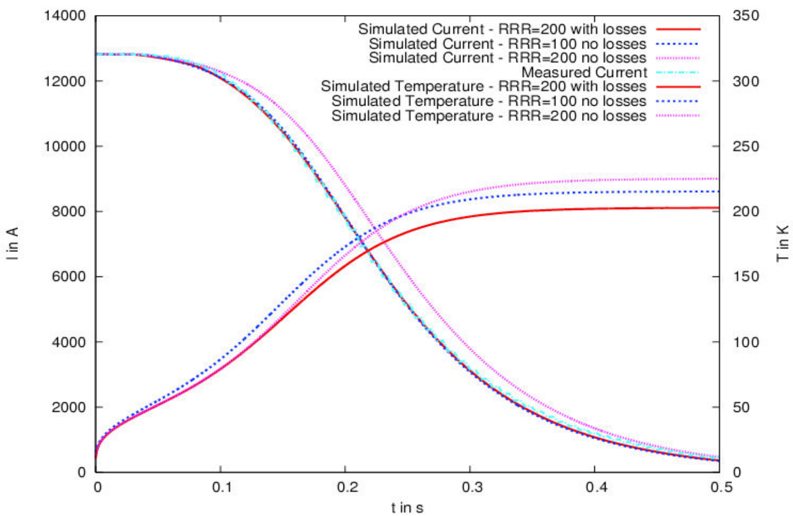
Volumetric heat capacity

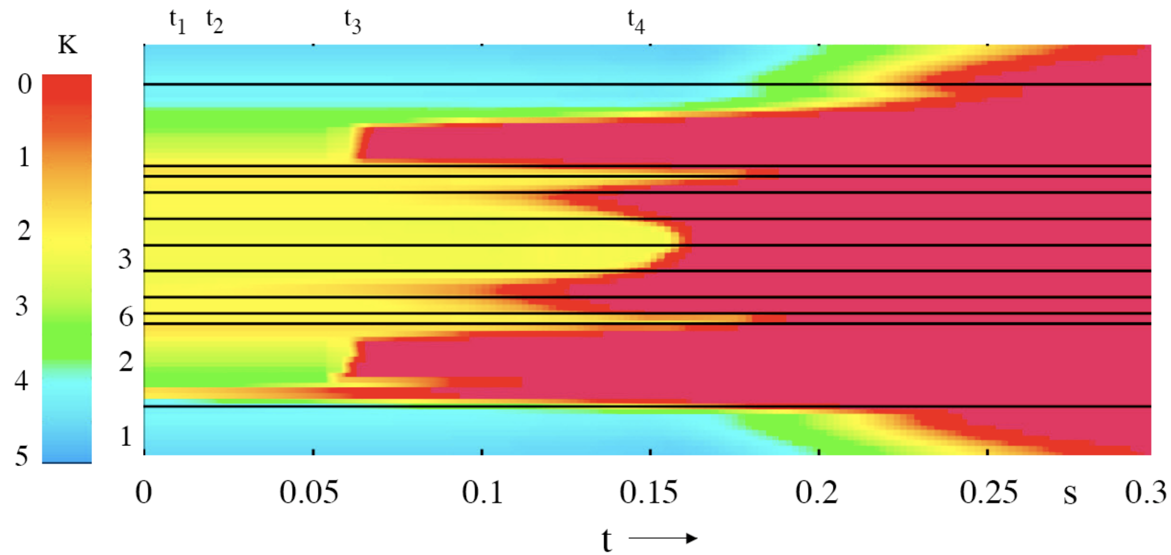


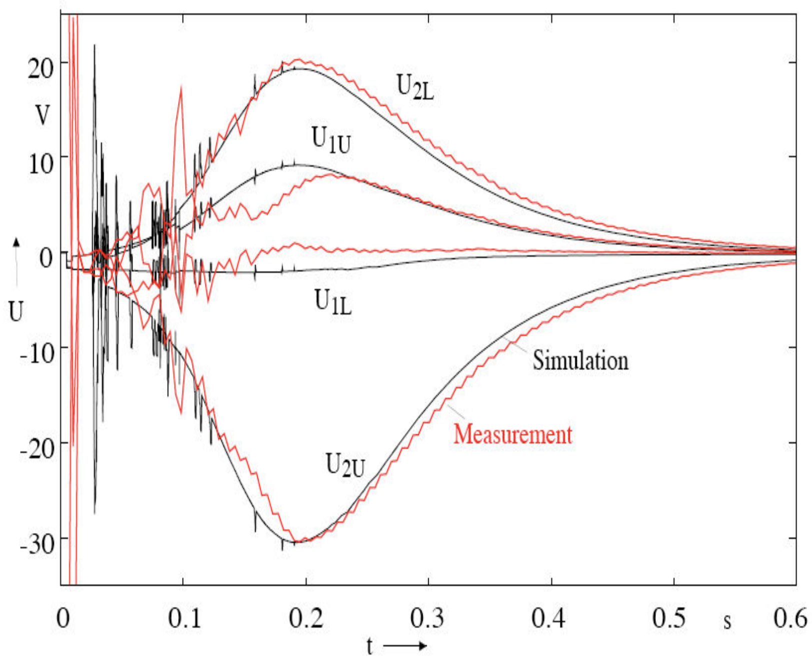
Thermal conductivity

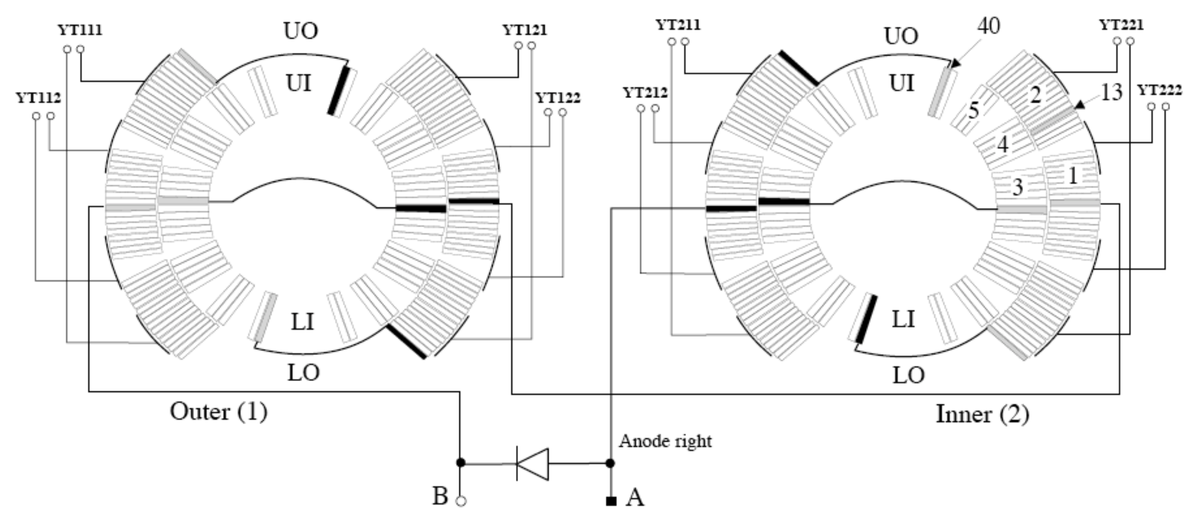


Quench Simulation (LHC MB)

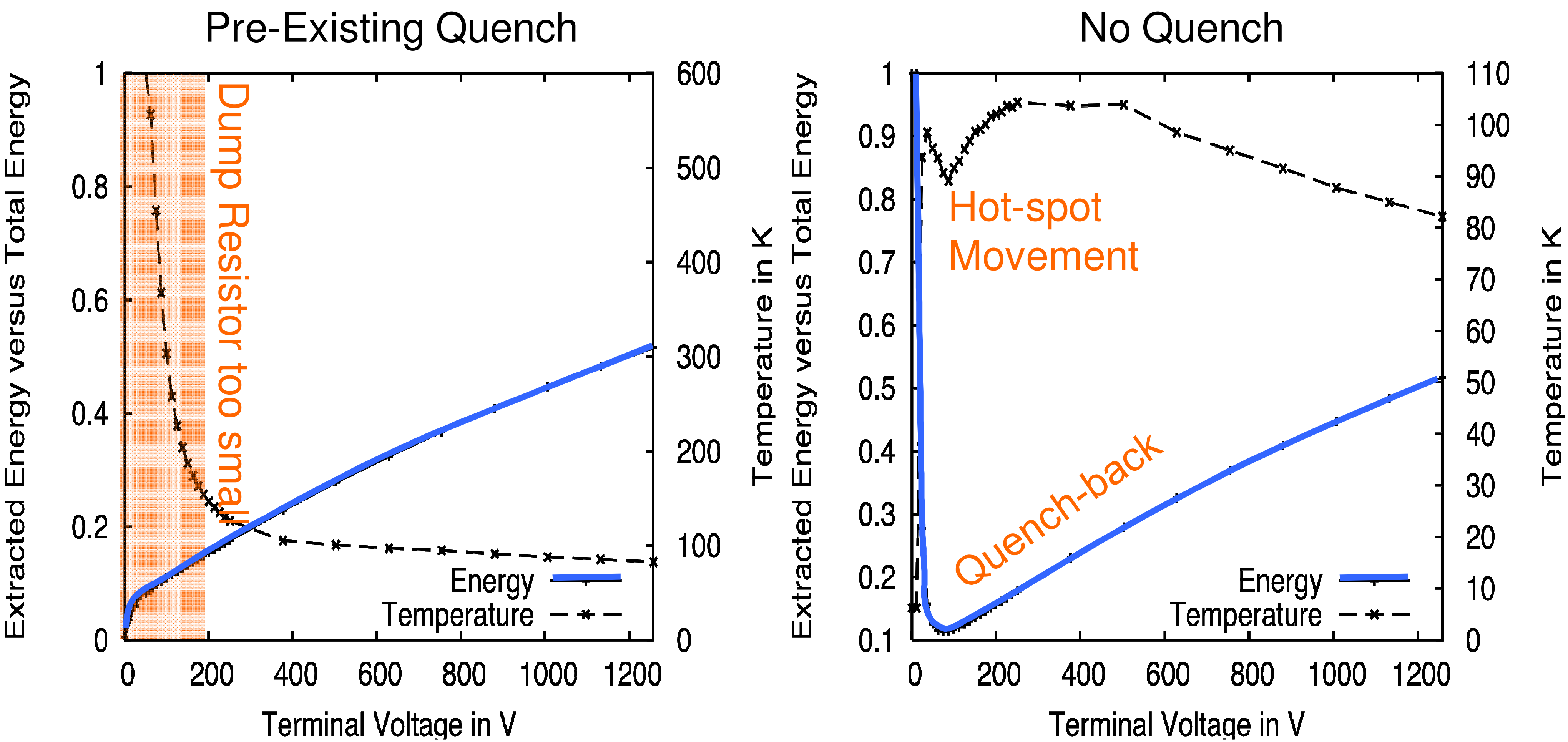




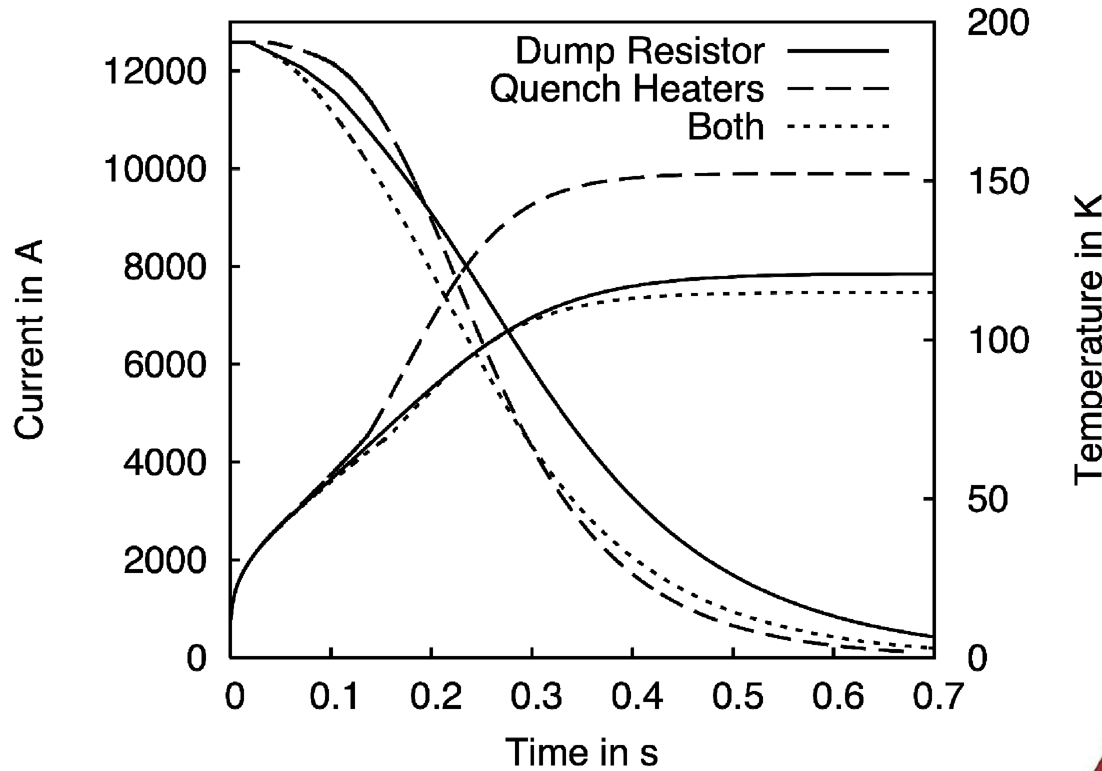


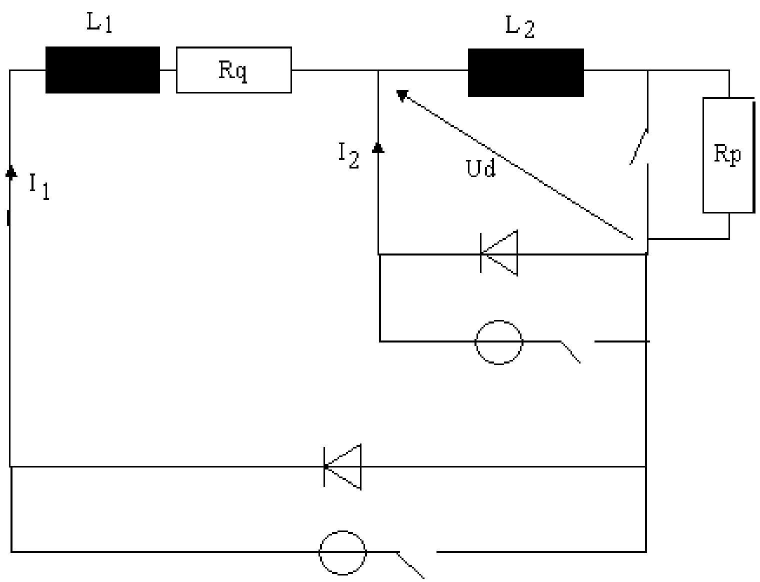


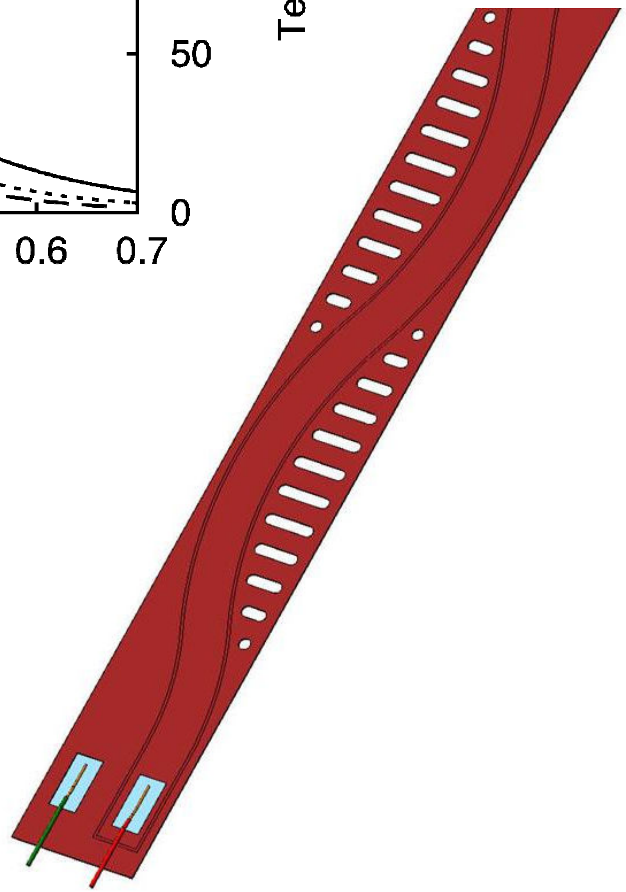
Energy Extraction Study



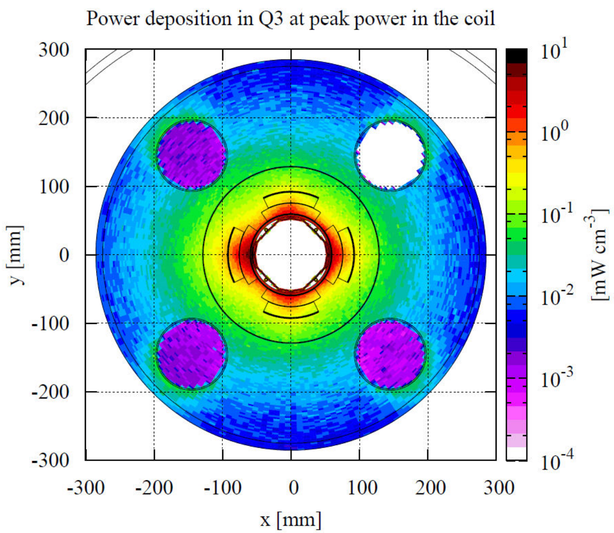
Magnet Protection Study (Dump Resistor and Heaters)

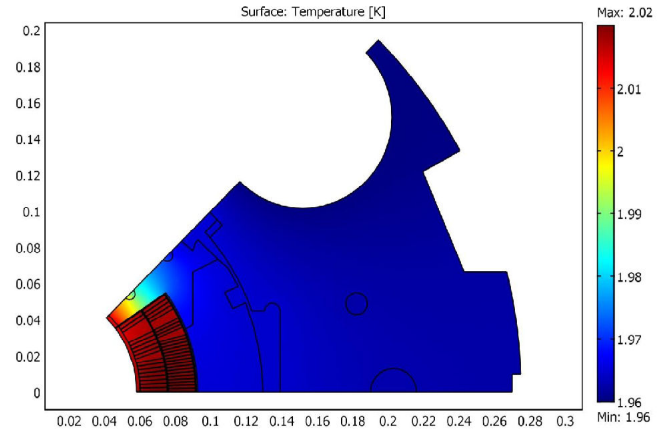


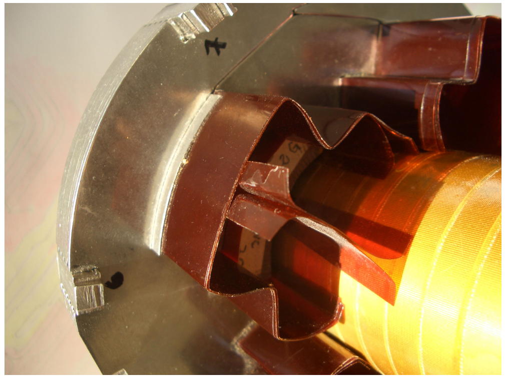




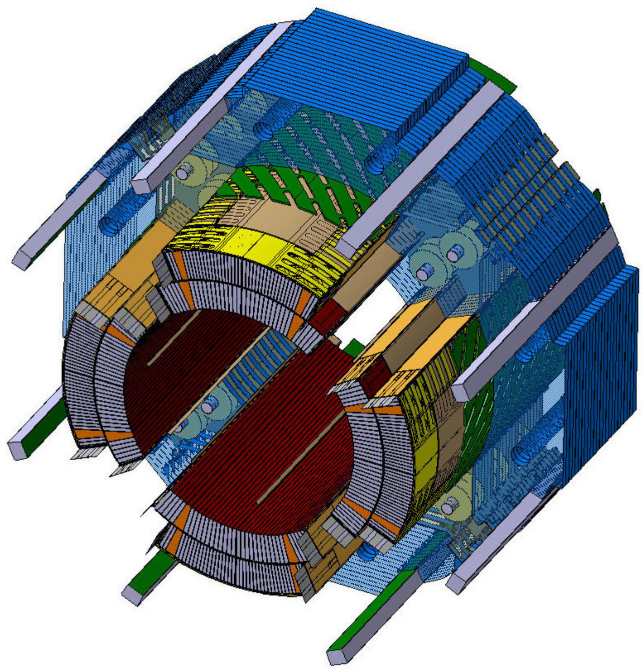
Extraction of the Steady-State Heat-Load 1 (Porous Ground-Plane Insulation)

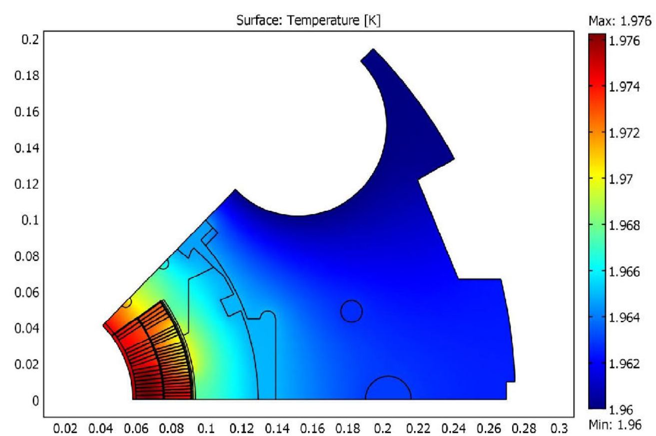


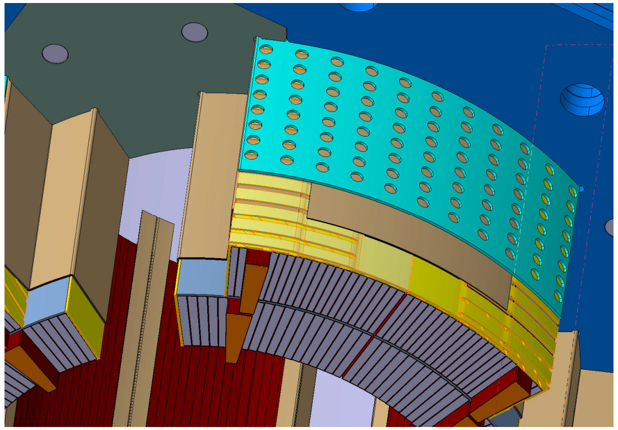




Conventional ground insulation

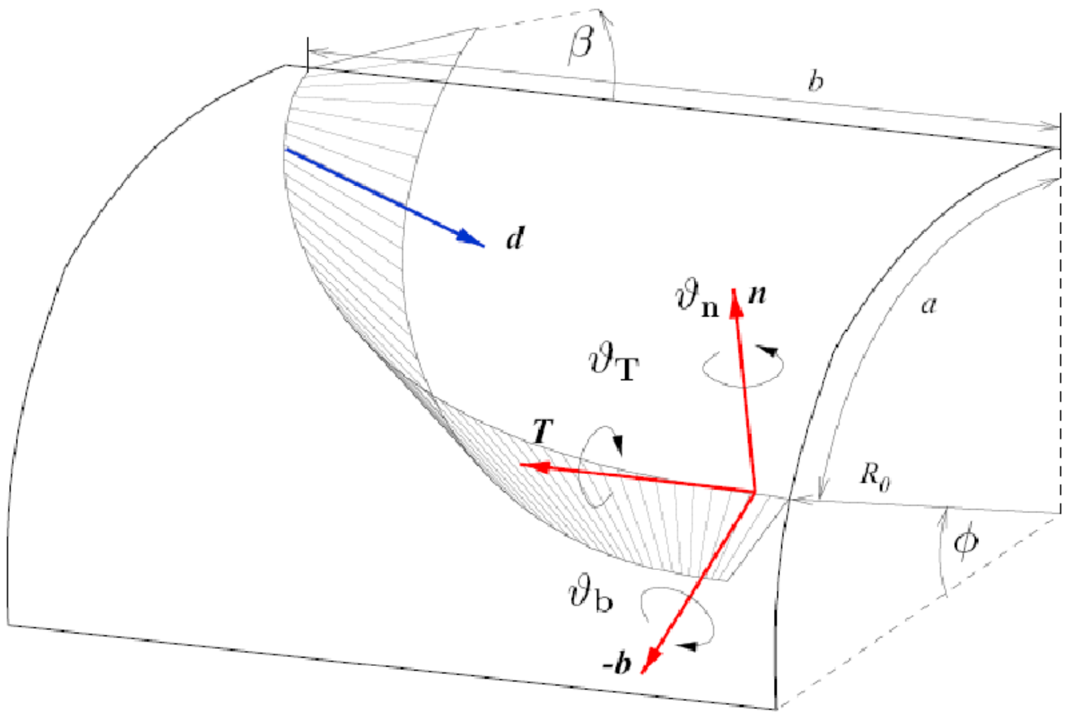






Open KCS ground insulation

Envelope of Planes



$$\tau = \mathbf{b} \cdot \mathbf{n}' = \vartheta_{\mathbf{T}}{}'$$
$$\kappa_{\mathrm{g}} = \mathbf{T} \cdot \mathbf{b}' = \vartheta_{\mathbf{n}}{}'$$
$$\kappa_{\mathrm{n}} = \mathbf{n} \cdot \mathbf{T}' = \vartheta_{\mathbf{b}}{}'$$

$$\begin{pmatrix} \mathbf{T}' \\ \mathbf{n}' \\ \mathbf{b}' \end{pmatrix} = \begin{pmatrix} 0 & \kappa_{\mathrm{n}} & -\kappa_{\mathrm{g}} \\ -\kappa_{\mathrm{n}} & 0 & \tau \\ \kappa_{\mathrm{g}} & -\tau & 0 \end{pmatrix} \begin{pmatrix} \mathbf{T} \\ \mathbf{n} \\ \mathbf{b} \end{pmatrix}$$

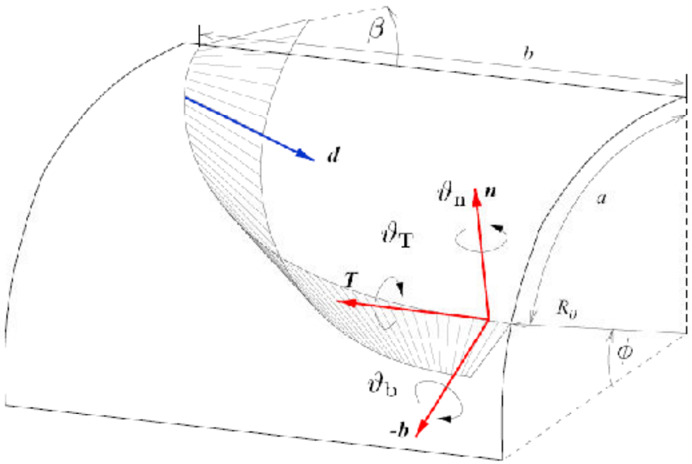
Freney Frame for strips

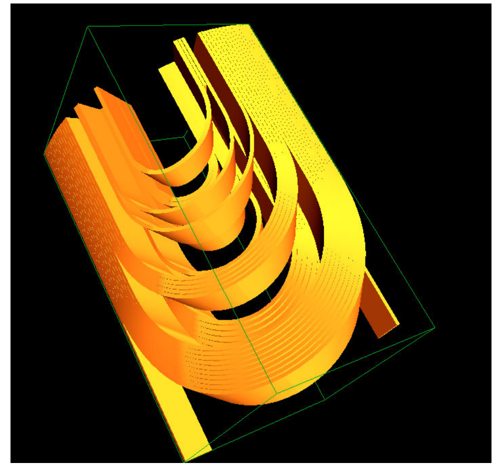
$$\begin{pmatrix} \mathbf{T}' \\ \mathbf{N}' \\ \mathbf{B}' \end{pmatrix} = \begin{pmatrix} 0 & \kappa & 0 \\ -\kappa & 0 & \tau \\ 0 & -\tau & 0 \end{pmatrix} \begin{pmatrix} \mathbf{T} \\ \mathbf{N} \\ \mathbf{B} \end{pmatrix}$$

Freney Frame for space curves

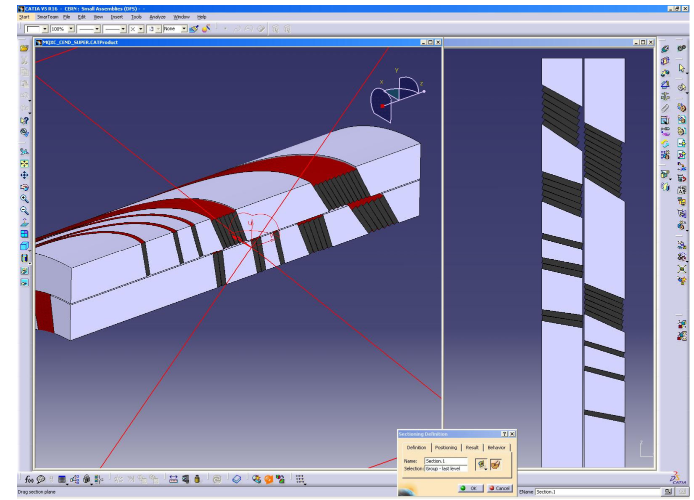
Endspacer Design and Manufacture

Differential Geometry Model

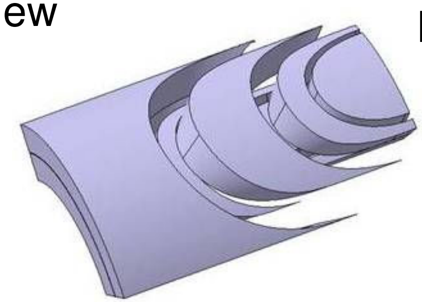


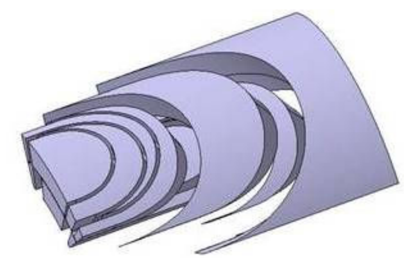


Virtual Reality Preview



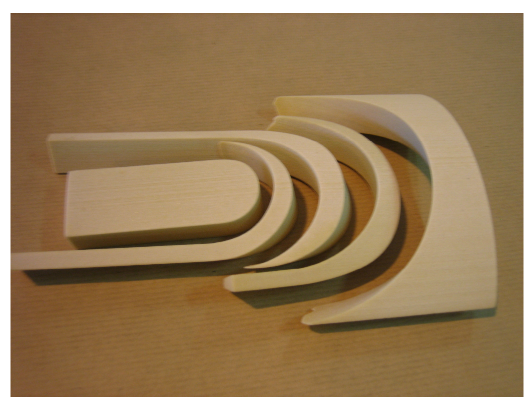
Roxie-Catia Interface

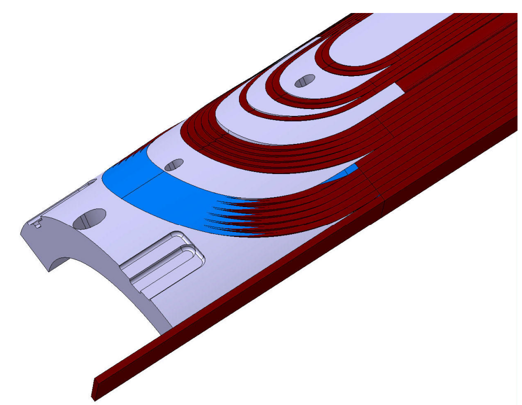




CNC-Machining

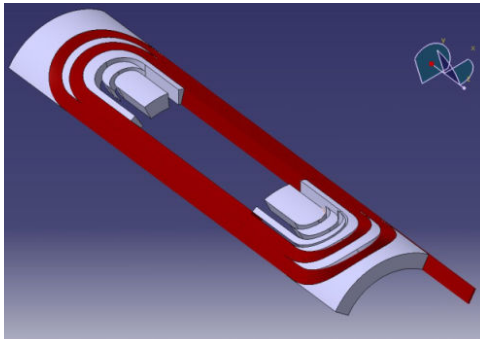
Rapid Prototyping



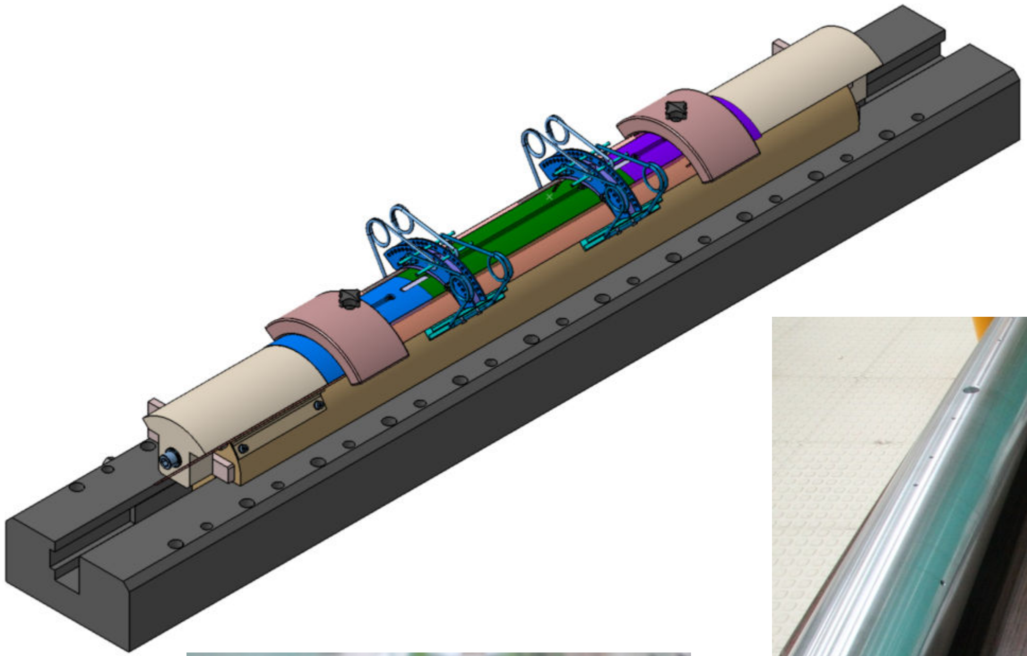


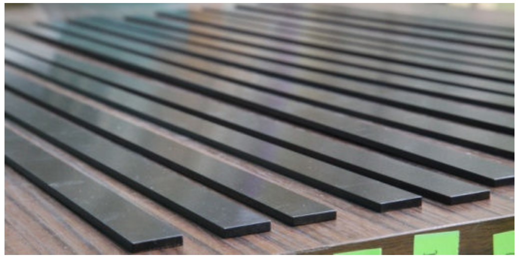
Actual status – Winding and curing trial

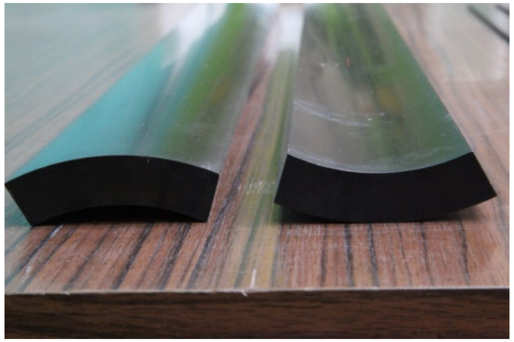
Trial design has been fixed beginning November 2009



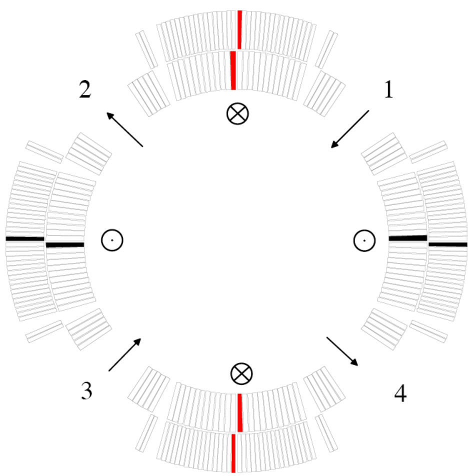
Winding tooling has been designed and procured

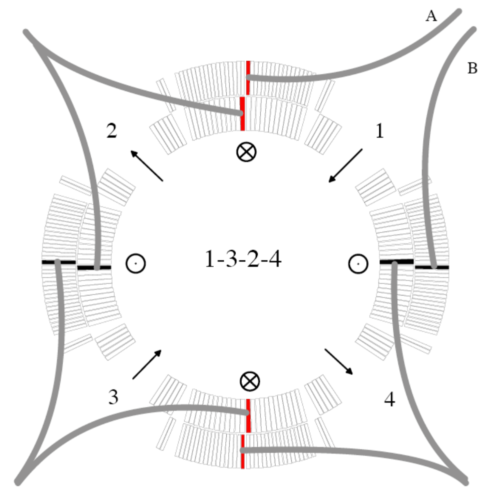


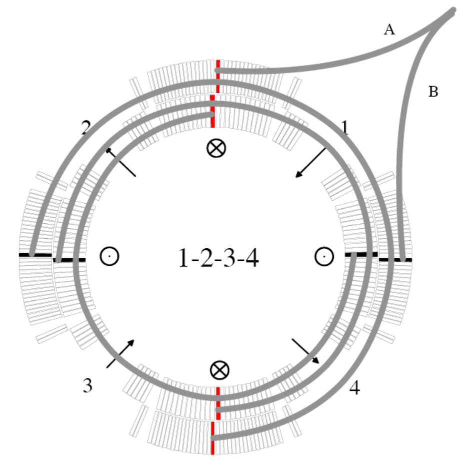


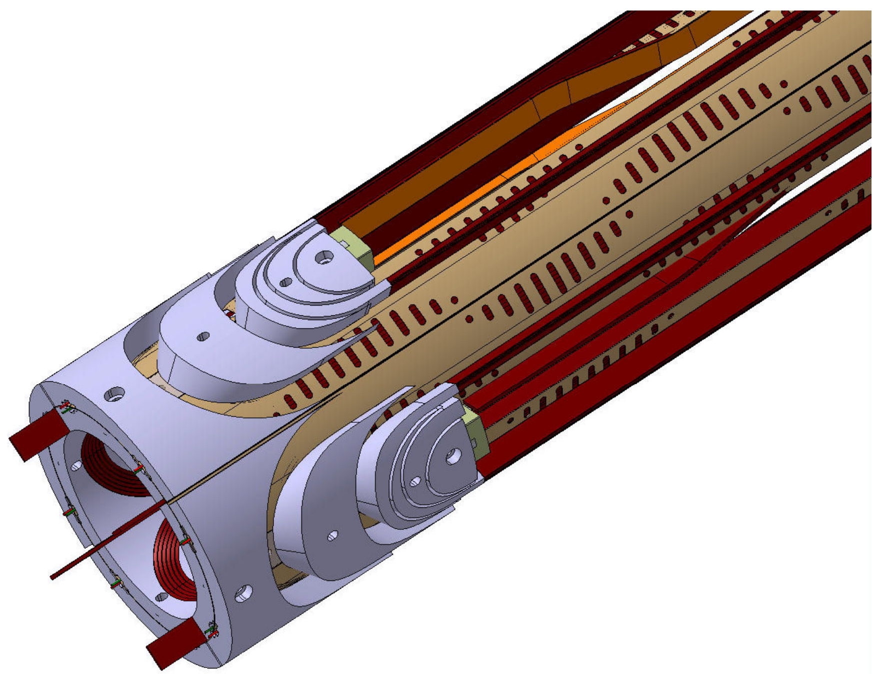


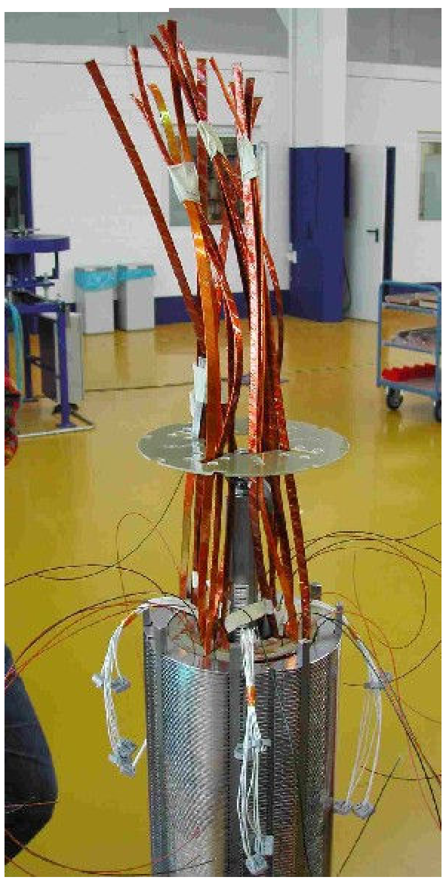
Electrical Connection Scheme



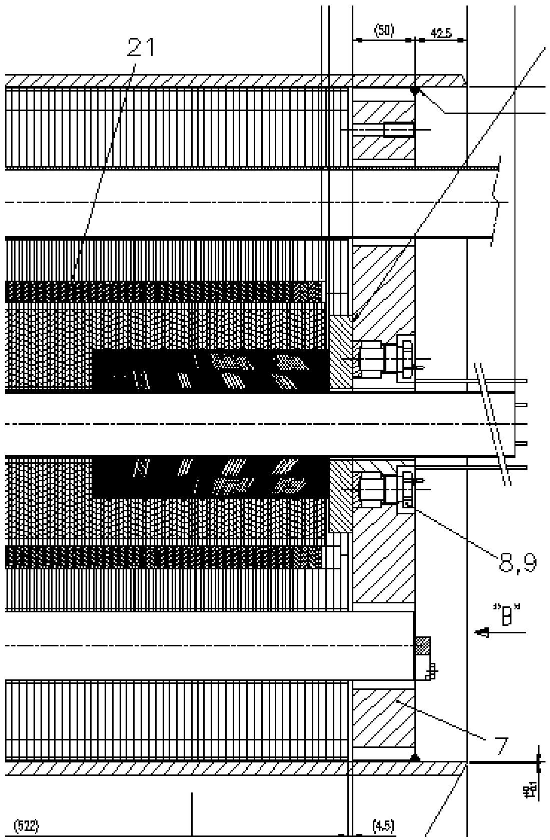


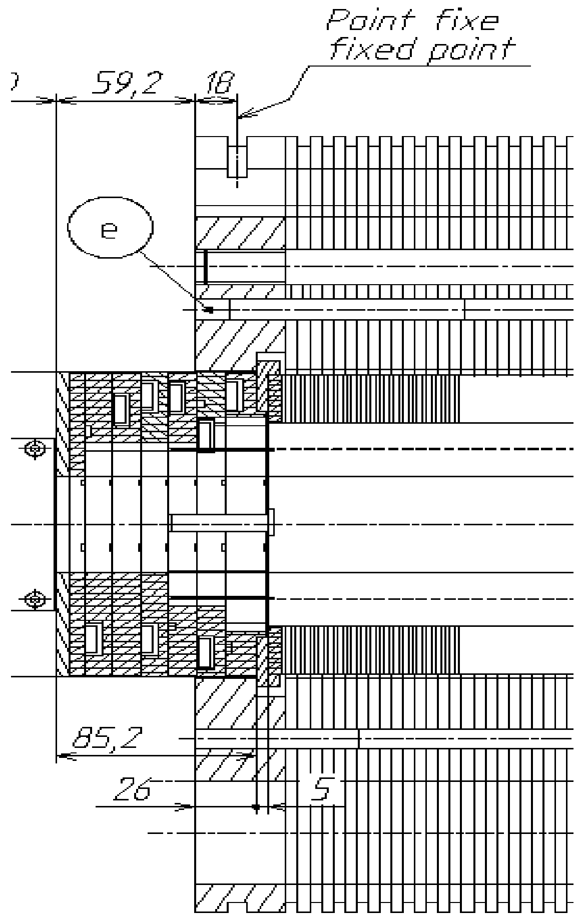


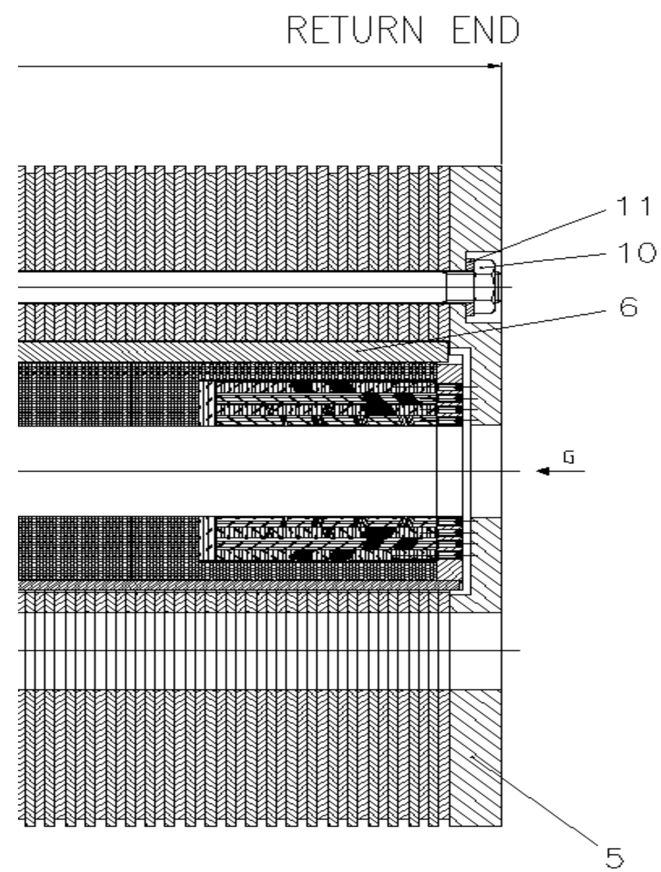




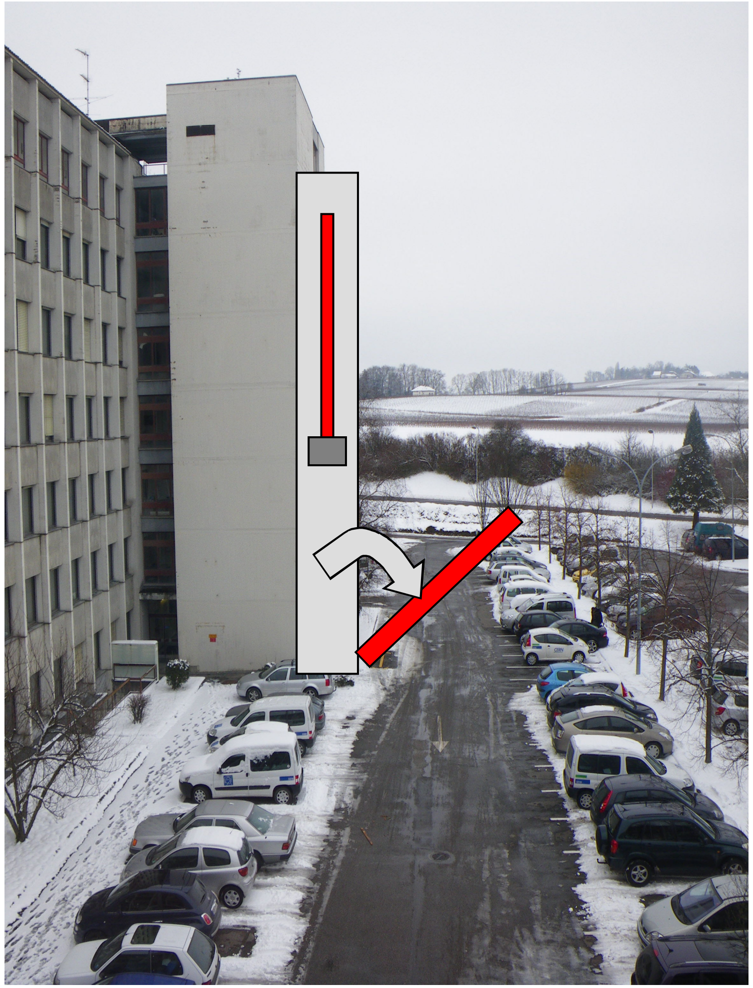
MB, MQ, MQM


21
(50)
42.5
8,9
"B"
7
(522)
(4.5)


Point fixe
fixed point
59,2
18
e
85,2
26
5

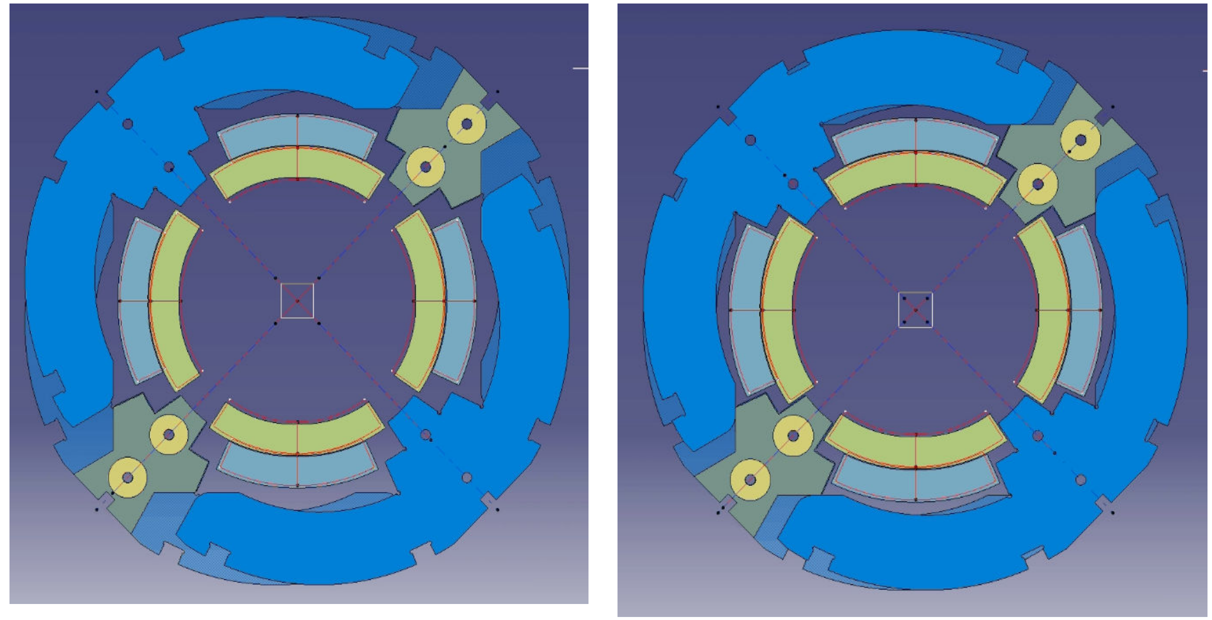

RETURN END
11
10
6
G
5

Vertical Collaring (Hardly Possible for 10-m-long Magnets)

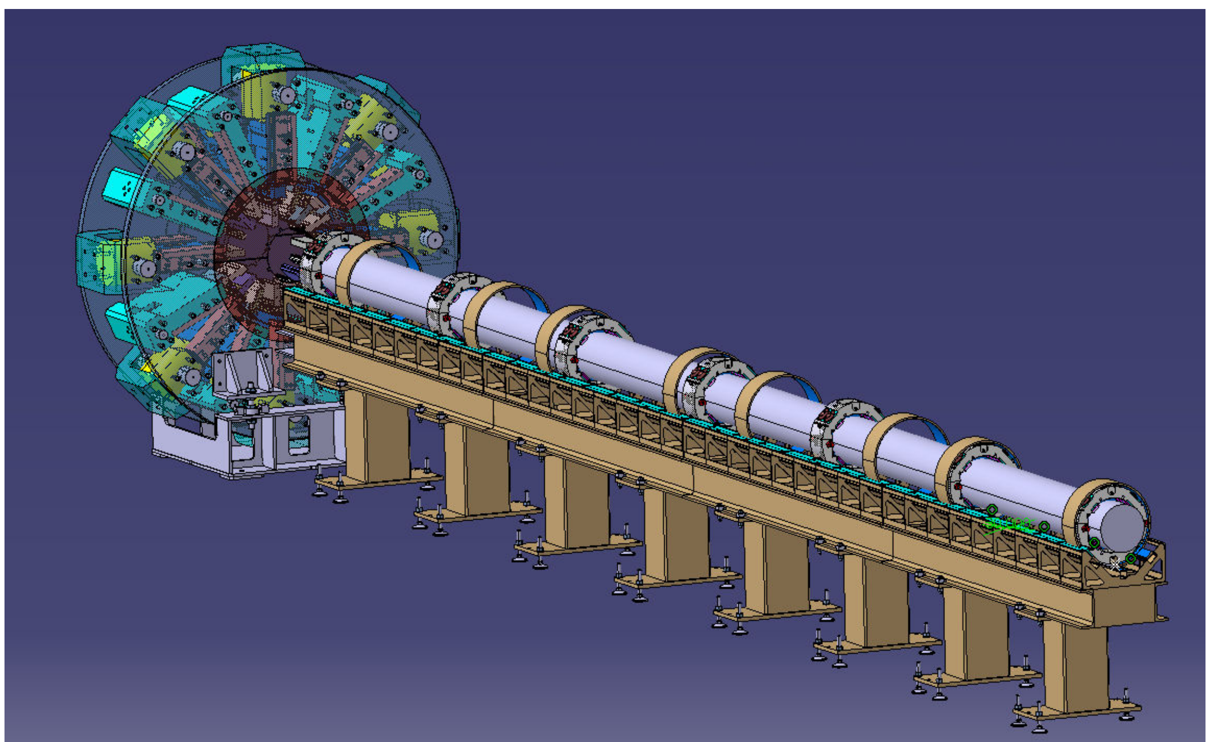


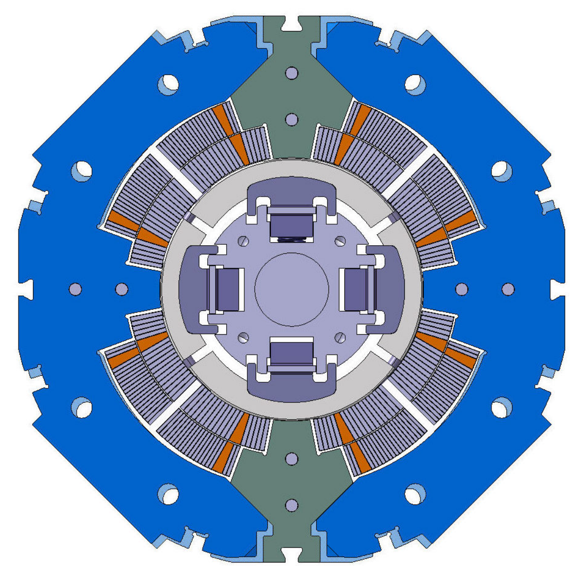
Horizontal Collaring

Self-locking collars



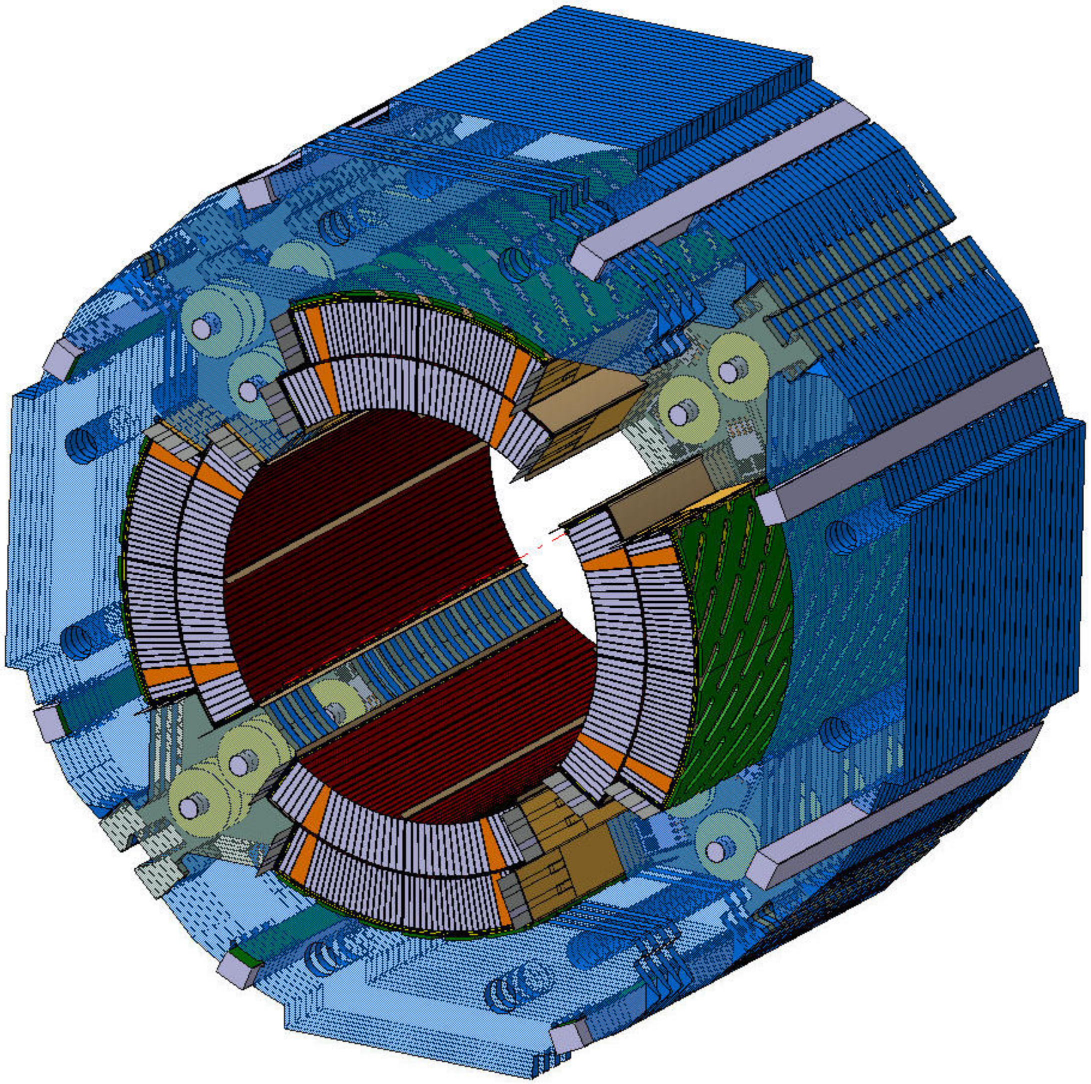
Collaring Press





Assembly mandrel

Intermediate Milestone (The Short Model)



Large Magnet Facility (Building 180)

Cable insulation

Ex-Ansaldo winding machine

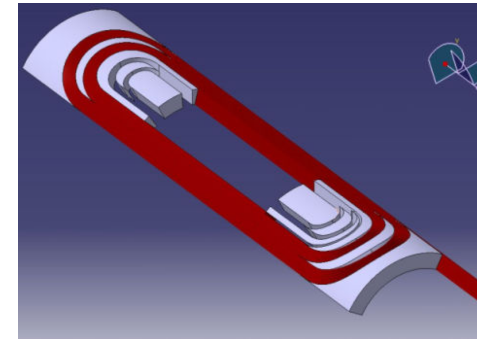
Alignment tables

Welding press area

Ex-Jeumont winding machine

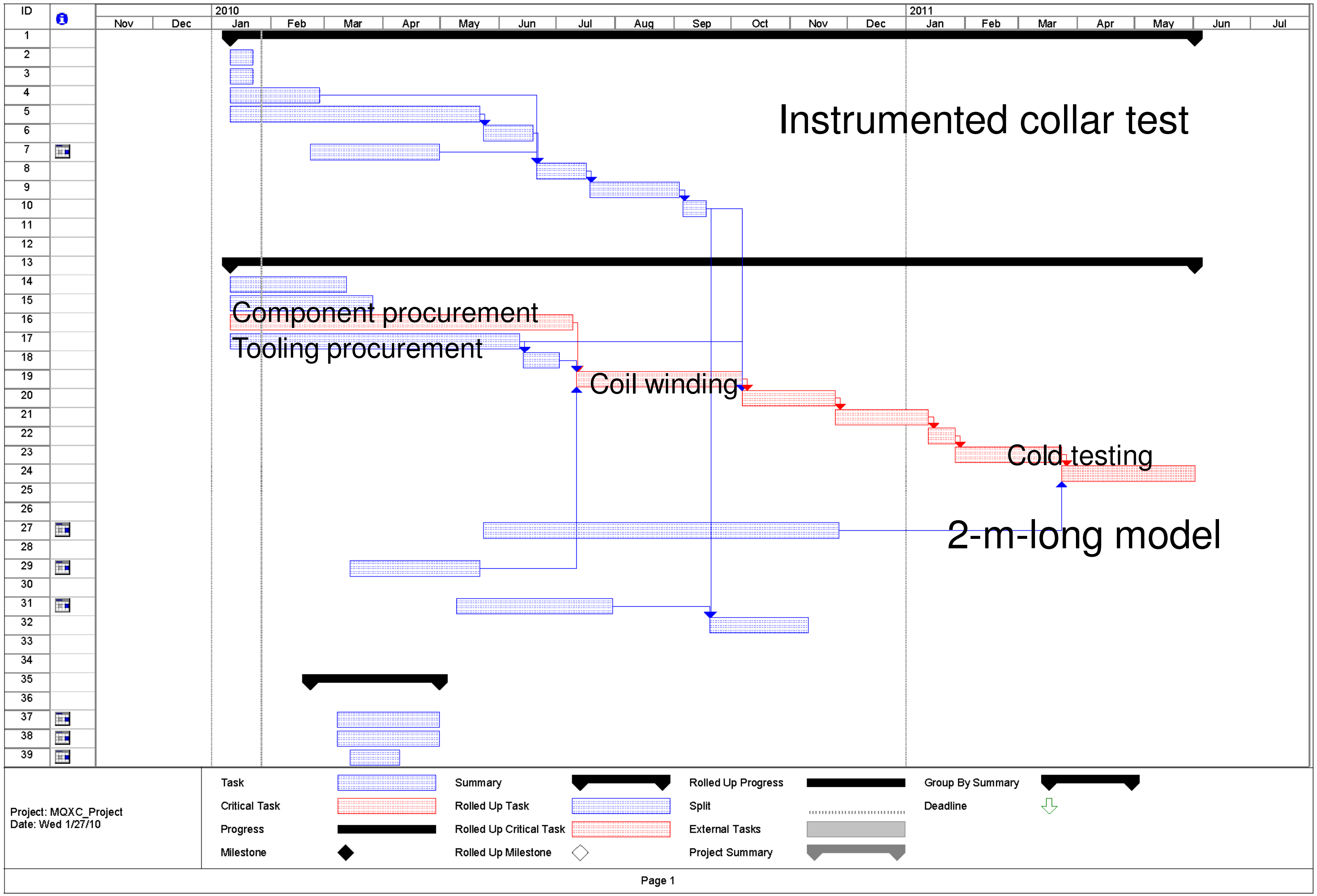
Actual status – Winding and curing trial

Winding machine is operative at CEA Saclay

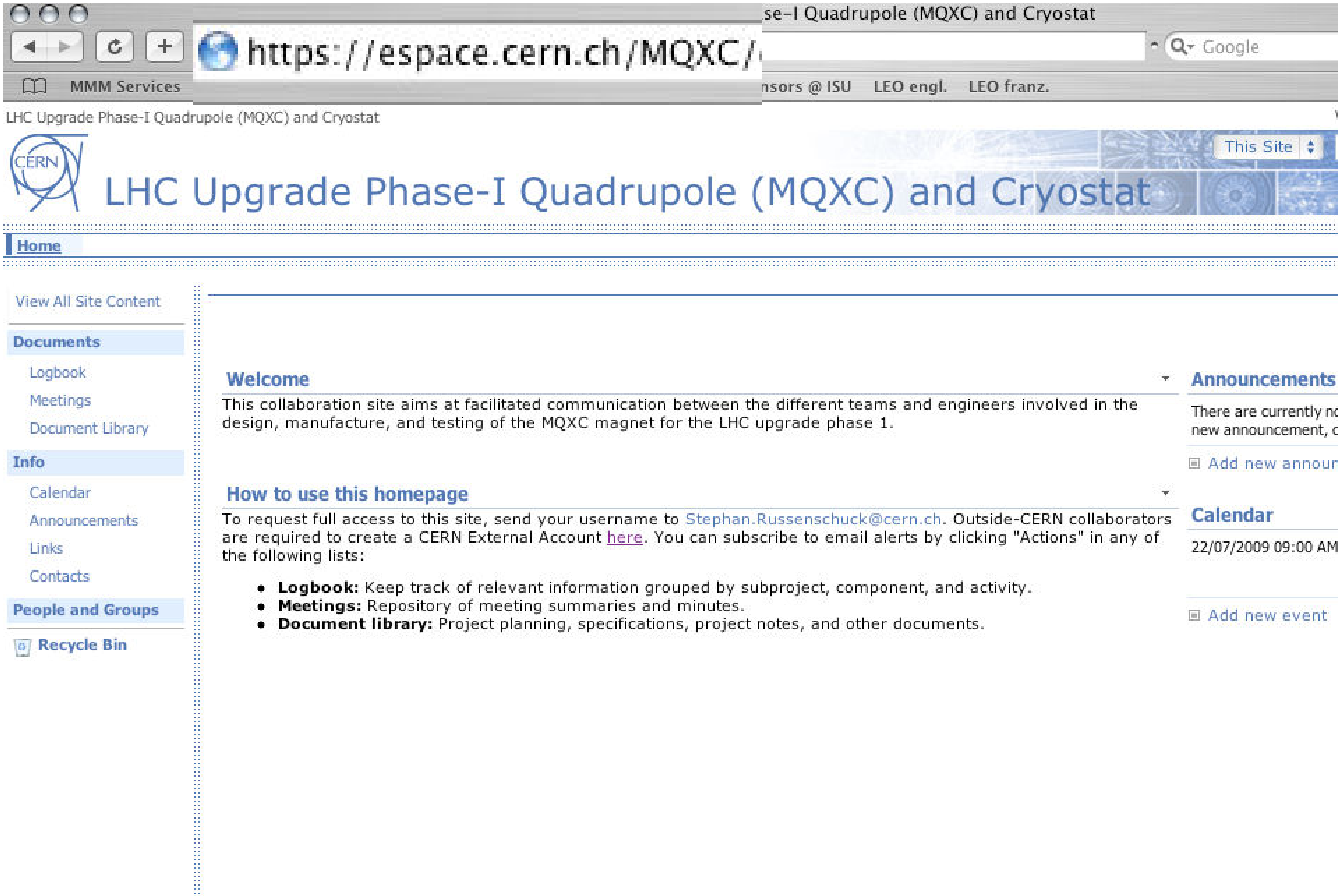


Curing press is under installation and repair → mid March 2010

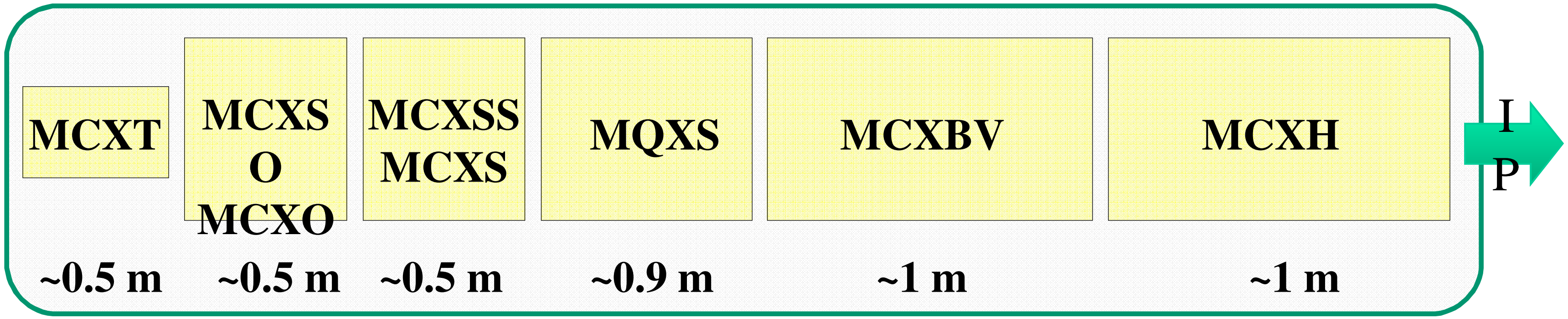
Planning MQXC Model Magnet



Collaboration Website

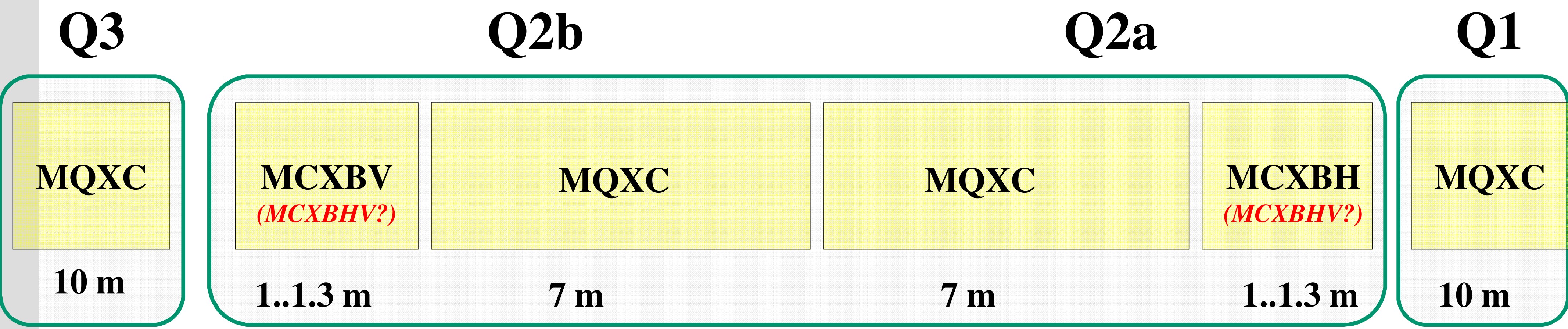


Corrector Package (CP)



	Current	Integrated strength (field)	Aperture
MCXB (B_1/A_1)	**+/- 2.4 kA**	**1.5 Tm**	**140 mm**
MQXS (A_2)	**+/- 2.4 kA**	**0.65 Tm @40 mm**	**140 mm**
MCXT (B_6)	+/- 120A	*0.075 Tm @ 40 mm*	*140 mm*
MCXO (B_4)	+/- 120A	*0.035 Tm @ 40 mm*	*140 mm*
MCXSO (A_4)	+/- 120A	*0.035 Tm @ 40 mm*	*140 mm*
MCXSS (A_3)	+/- 120A	*0.055 Tm @ 40 mm*	*140 mm*
MCXS (B_3)	+/- 120A	*0.055 Tm @ 40 mm*	*140 mm*

Correctors in Q2

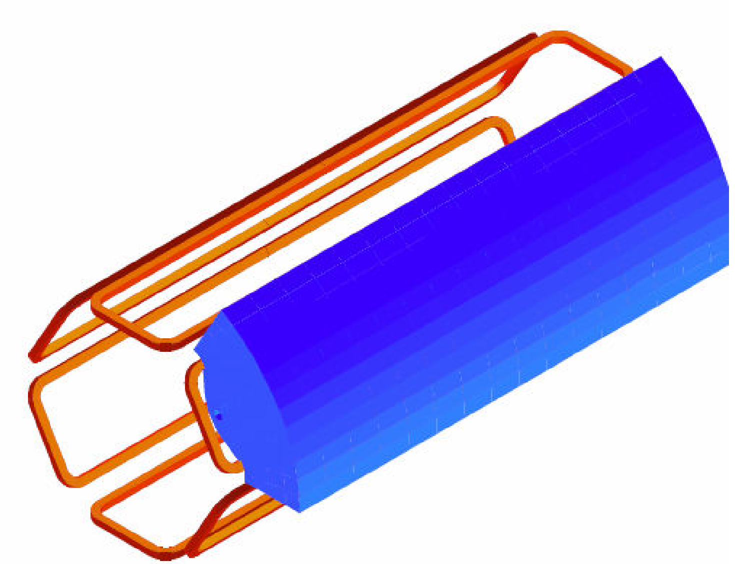


- Base-line (HV and VH) orbit corrector scheme allows controlling the orbit to a level 3 times larger that then BPM resolution.
- To reach the same level as the effective BPM resolution :
  - Provide 1.5 Tm (1.8 Tm) in H&V-plane in BOTH locations.
  - Feasibility study underway on combined H/V-corrector that meets the reliability requirements (Report by Mid-2010 + Model work..)
- An extra H/V pair means:
  - Magnet R&D, material R&D, design, component & tooling procurement
  - Additional powering and protections circuits

REF: S. Fartoukh, R. Tomas, J. Miles: "Specification of the Closed Orbit Corrector magnets for the NEW Inner Triplets", sLHC Project Report 030

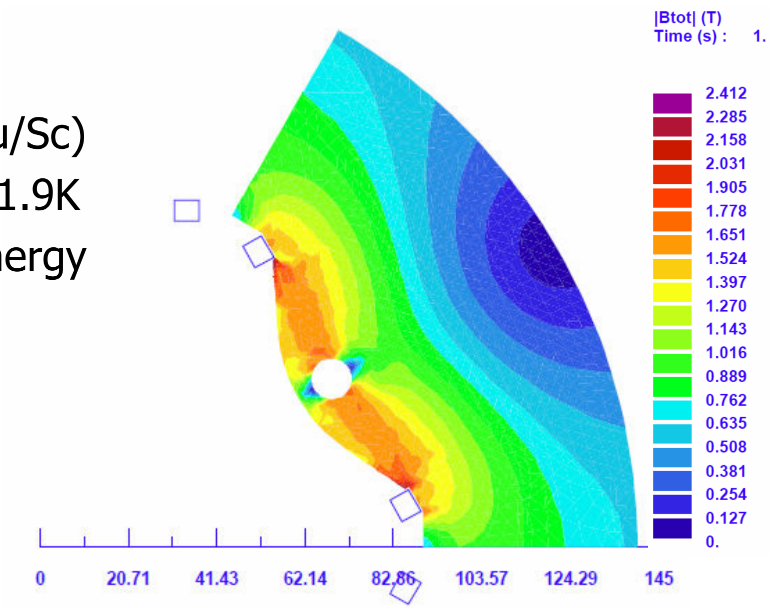
- Original specifications

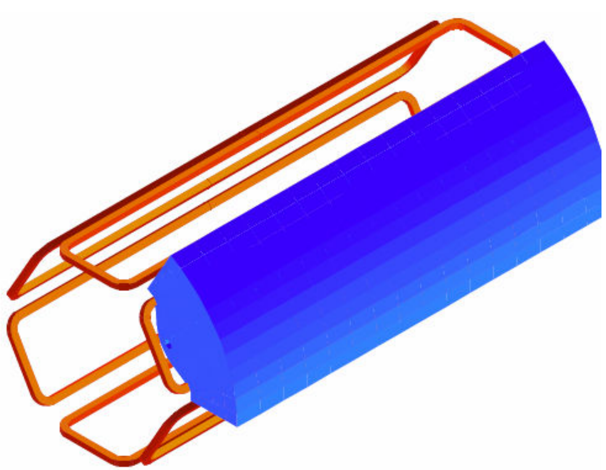
Magnitude	Value	Units
Pole tip radius	70	mm
Reference radius	40	mm
Integrated strength	0.138	Tm
Max. overall length	0.5	m
Current	100 or 600	A

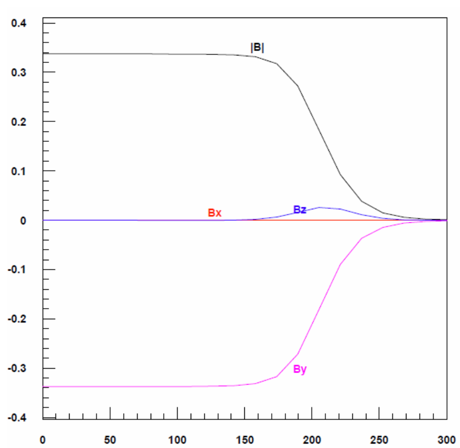


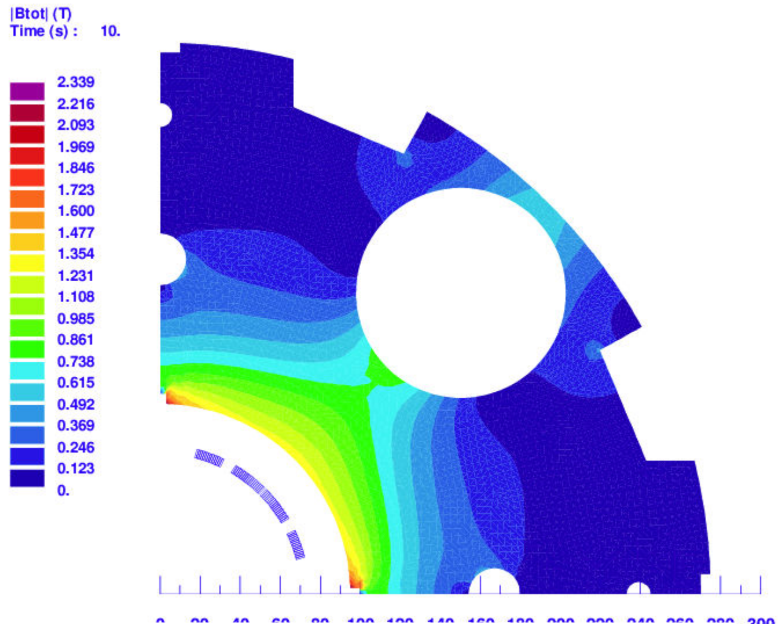
51

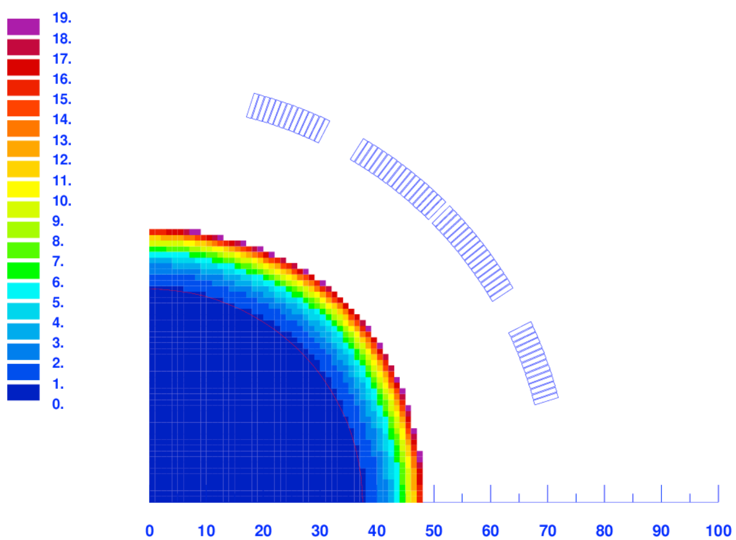
- Calculation results
  - **600 Amps**, 32 turns, 19200 A-turn.
  - 5.84x5 mm coil, 0.73x1.25mm NbTi wire (1.6 Cu/Sc)
  - 210.7 T/m², 0.337 T @ 40 mm. WP=54.3 % @ 1.9K
  - Inductance: **0.028 H/m, 5.15 KJ/m** stored energy
  - Non-linearity in the load line: **0.2 %**
  - 2D field quality (10^{-4} units):
    - b9: -0.0075
    - b15: -0.066
    - b21: -0.003
  - Integrated strength: **0.1387 Tm**
  - Effective length: **0.41 m**
  - Peak field (3D): **2.19 T**
  - Iron length: **392 mm**
  - Iron weight: **126 kg**
  - 3D field quality (10^{-4} units):
    - b9: 0.172
    - b15: -0.059
    - b21: -0.001



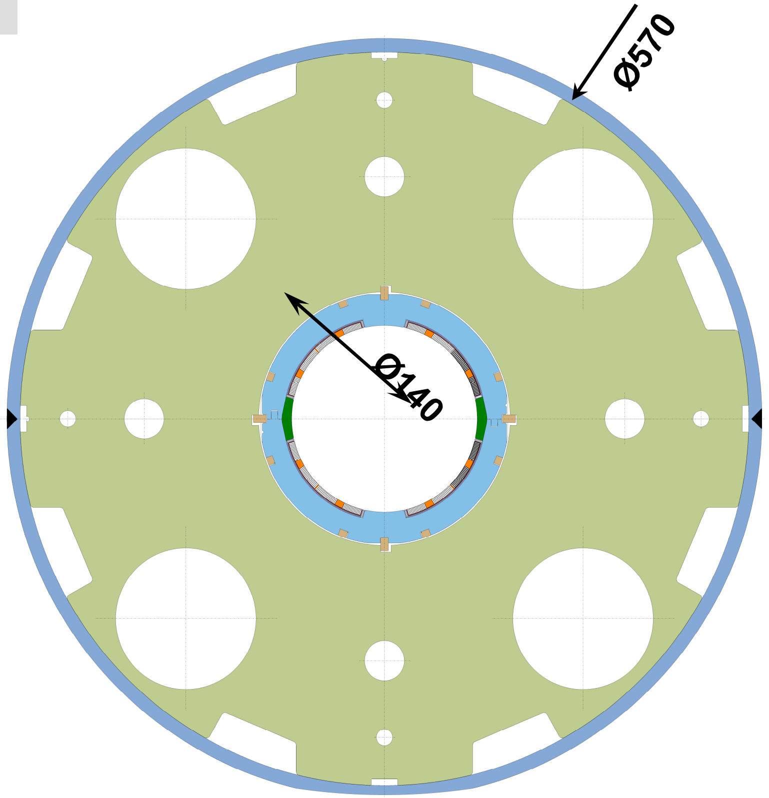


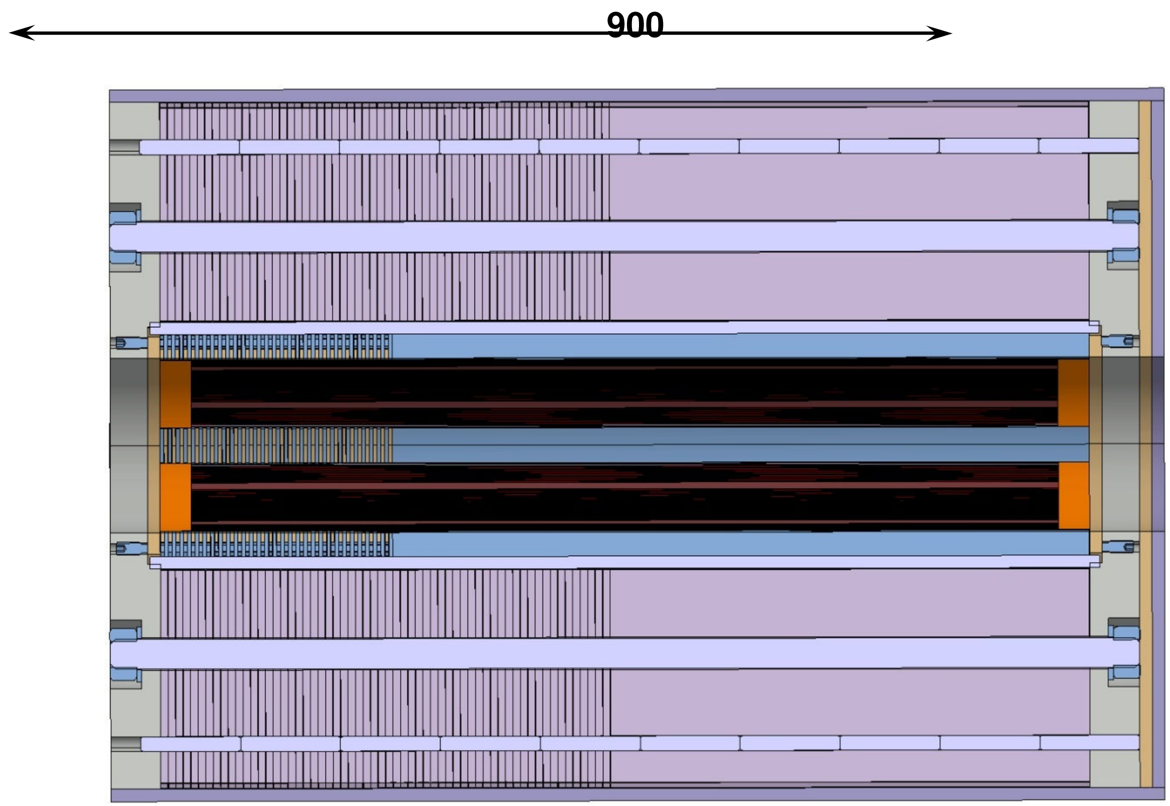




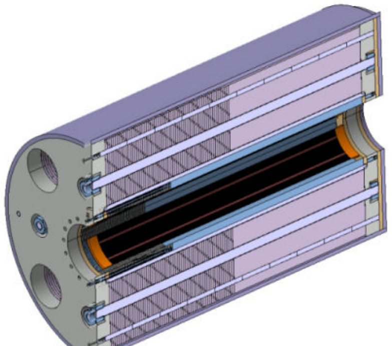


	Unit	
Nominal gradient	T/m	21
Mag. length	m	0.64
Nominal current	A	2400
Stored energy	kJ	8.8
Self inductance	mH	3.0
Working point		44 %
Cable width/mid-height	mm	4.37 / 0.845
Cu/Sc		1.2
Total length	m	~0.9
Aperture	mm	ø140
Total mass	kg	~500





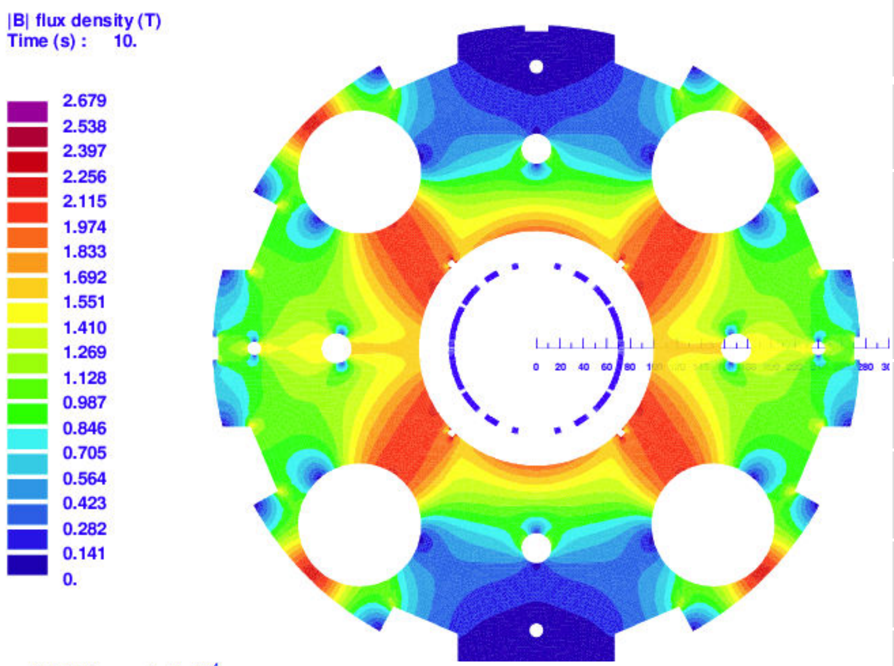
- New 4.37 mm cable & Polyimide insulation
- Single layer coils
- Self-supporting collars
- Single piece yoke

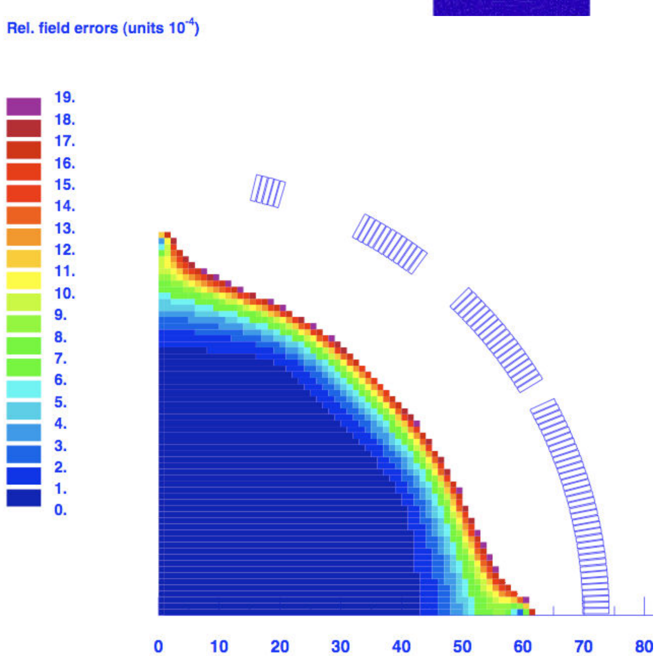


Courtesy of G. Villiger

Field strength	**0.65 Tm**
Gradient	**25.5 T/m**
Operating temp	**1.9 K**
Current	**2.4 kA**
Inductance	**3.3 mH**

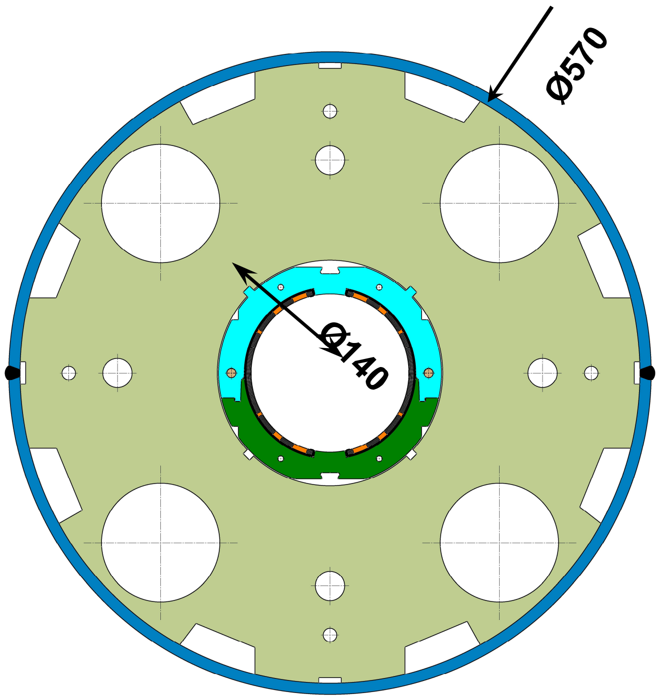
MCXB Single-Layer Design

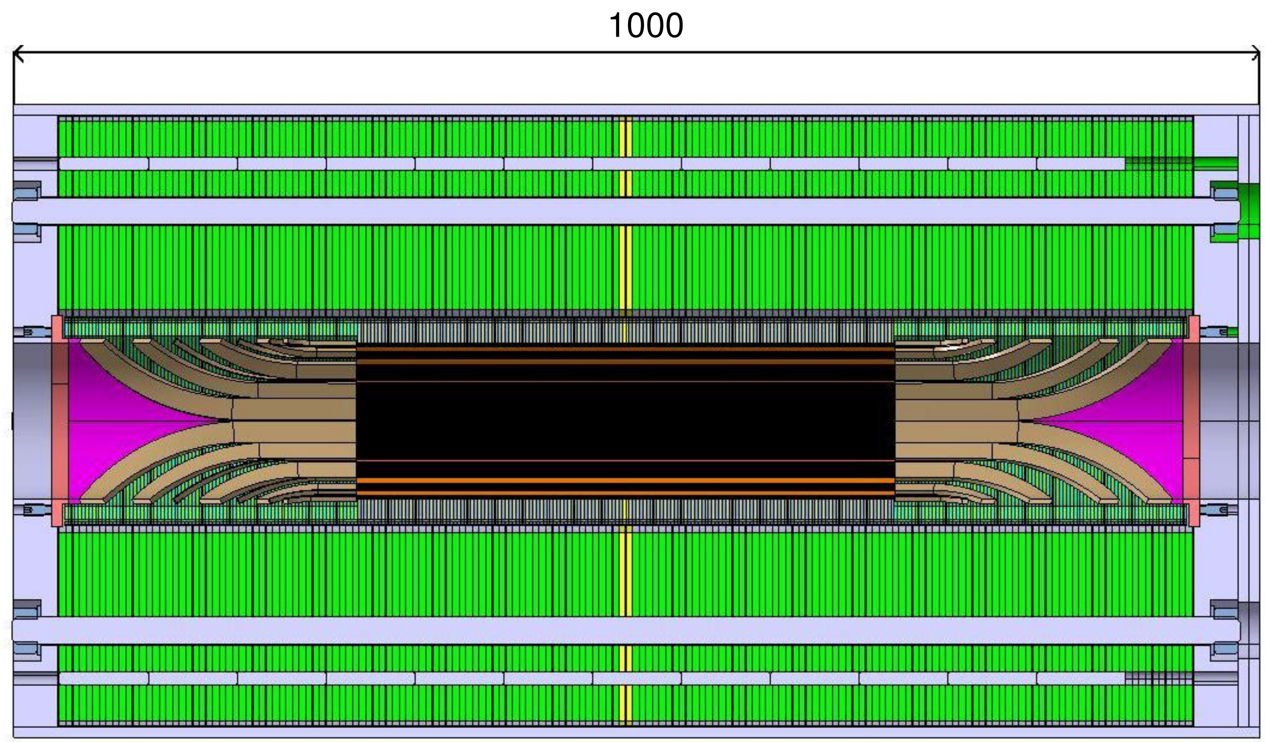




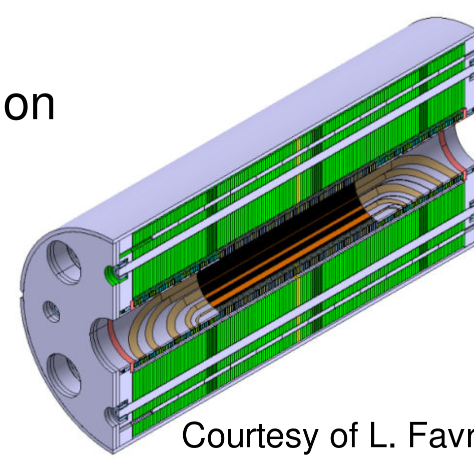
	Unit	
Integrated field	Tm	1.5
Nominal field	T	2.3
Mag. length	m	0.65
Nominal current	A	2400
Stored energy	kJ	28
Self inductance	mH	10
Working point		50%
Cable width/mid-height	mm	4.37 / 0.845
Total length	m	~1
Aperture	mm	Ø140
Total mass	kg	~2000

MCXB 4-Block Design





New 4.37 mm cable & Polyimide insulation
Self-supporting collars
Single piece yoke


Courtesy of L. Favre

Field strength	**1.5 Tm**
Operating temp	**1.9 K**
Current	**2.4 kA**
Inductance	**10 mH**

18-Strand Cable

Strand parameters		
Cu:Sc	1.75	
Strand diameter	0.48	mm
Metal section	0.181	mm^2
No of filaments	2300	
Filament diam.	6.0	µm
I(5T,4.2K)	203*	A
jc	3085*	A/mm^2

*) extracted strand March -09

Cable Parameters		
No of strands	18	
Metal area	3.257	mm^2
Cable thickness	0.845	mm
Cable width	4.370	mm
Cable area	3.692	mm^2
Metal fraction	0.882	
Key-stone angle	0.67	degrees
Inner Thickness	0.819	mm
Outer Thickness	0.870	mm

Polyimide Insulation: 2 x 25µm + 55 µm
Trial cabling length (~100 m) done!
Insulation trials & characterization in progress..

Milestones… (MCXB & MQXS)

→ Parameter list	Oct-09..Jan-10
→ Magnetic and mechanical design	Nov-09
→ Fabrication drawings	May-10
→ Trial coils	Jul-10
→ Mechanical model	May-10 & Jul -10
→ Model magnets completed	Dec-10
→ Technical specifications	Mar-11
→ Industrial contracts	Jul-11
→ Pre-series magnets	Jul-12
→ Series production	Sep-12 .. Dec-13