Overview of HiLumi LHC Low-β quadrupoles and FRESCA2

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Acknowledgments
HiLumi LHC Low-β quadrupoles

- **CERN**
  - **TE/MSC/MDT section**
    - *S. Izquierdo Bermudez, P. Ferracin, M. Juchno, L. Lambert, J. Mazet, J. C. Perez, E. Todesco*
  - **TE/MSC/CSD section**
    - *A. Ballarino, B. Bordini, L. Oberli*
  - **TE/MSC/LMF section**
    - *H. Prin*
  - **EN/MME/EDM section**
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  - **BNL**
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Acknowledgments
FRESCA2

- **CERN**
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HiLumi LHC Low-β quadrupoles MQXF Overview

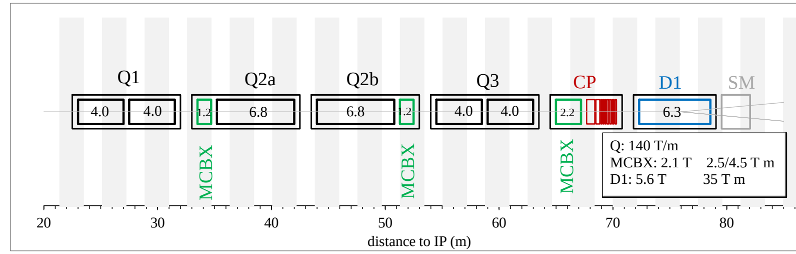
- Target: 140 T/m in 150 mm aperture

- Q1/Q3 (by LARP) 4.0 m long
- Q2 (by CERN), 6.8 m long

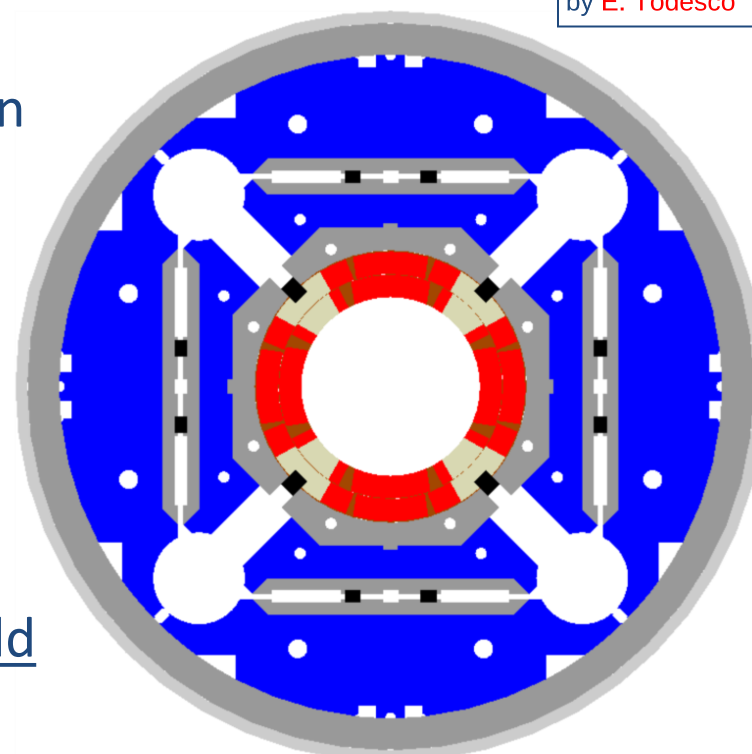
- Baseline: different lengths, same design

- Plan
  - Short model program: **2014-2016**
  - Long model program: **2015-2017**
  - Series production: **2017-2021**

- Accelerator quality Nb_3Sn cos2ϑ coils and magnet in the 12 T operational field level



by E. Todesco

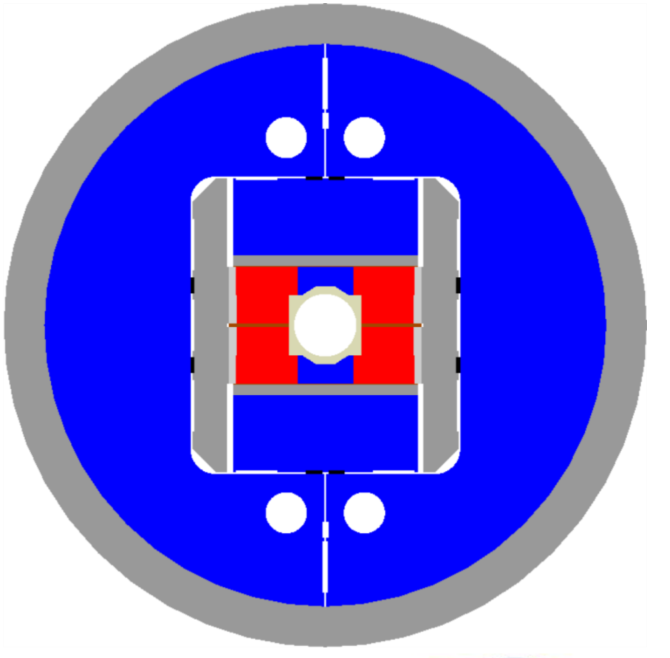


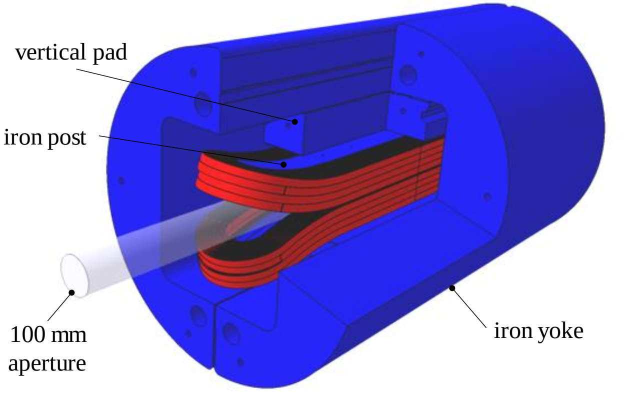
FRESCA2
Overview

- Goals
  - Upgrading the CERN cable test facility FRESCA
    - 88 mm → 100 mm aperture
    - 10 T → 13 T, ultimate 15 T
    - Nb-Ti → Nb_3Sn
  - Provide background field for HTS insert

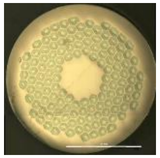
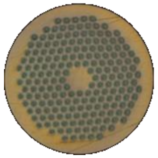
- Plan
  - Coil fabrication: **2014-2015**
  - Magnet tests: **2015-2016**

- Development of block-type coil design towards high field and large forces
  - Following HD2/HD3 experience
  - No accelerator quality



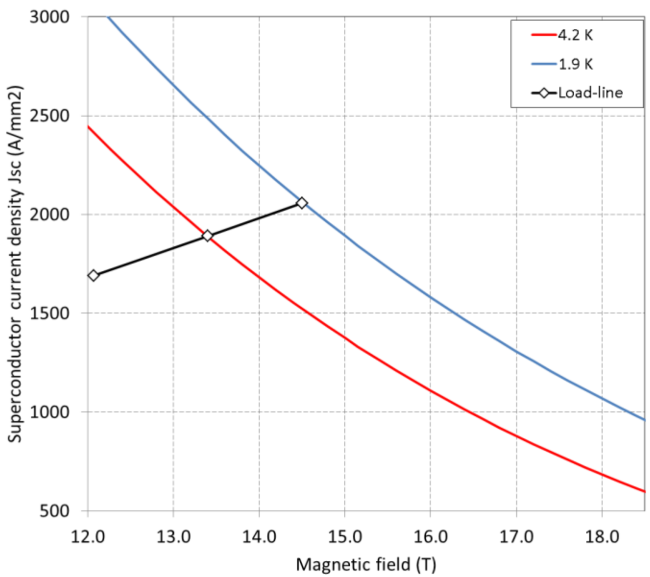


Field levels

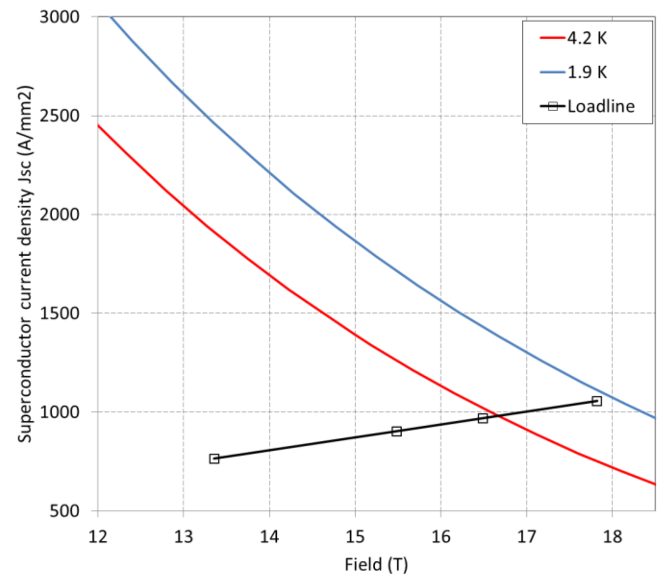



- Jc of virgin strand (4.2 K)
  - 2500 A/mm^2 at 12 T, 1400 A/mm^2 at 15 T

- **MQXF**
  - 0.85 mm strand
  - Operational: 12 T (82% of Iss)
  - Maximum: 14.5 T

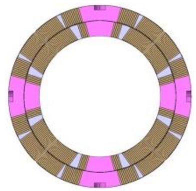


- **FRESCA2**
  - 1 mm strand
  - Operational: 13 T (72% of I_{ss})
  - Maximum: ~18 T

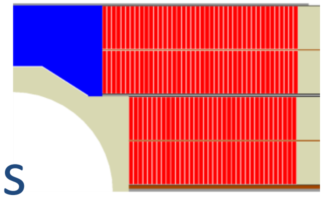


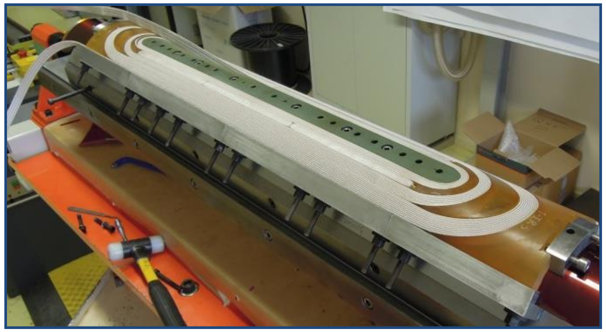
Coil technology

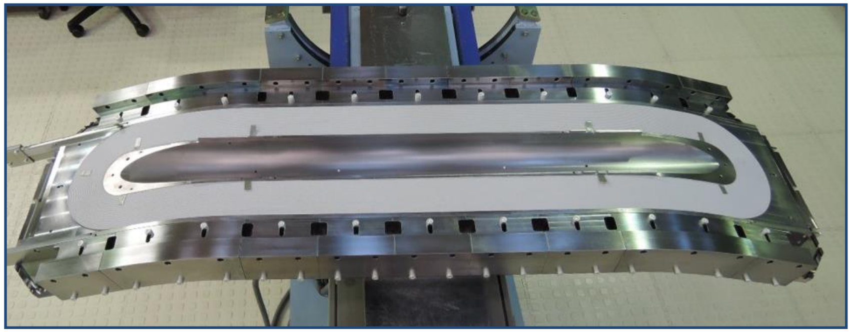
- **MQXF**
  - Cos2ϑ coils
    - 18 mm wide cable
    - Field quality, alignment, cooling, length, ***quench protection (!)***
  - To be fabricated: 200 coils



- **FRESCA2**
  - Block-type Coils
    - 21 mm wide cable
    - 2 double-layers with flared ends
      - No field quality
  - To be fabricated: 8 coils



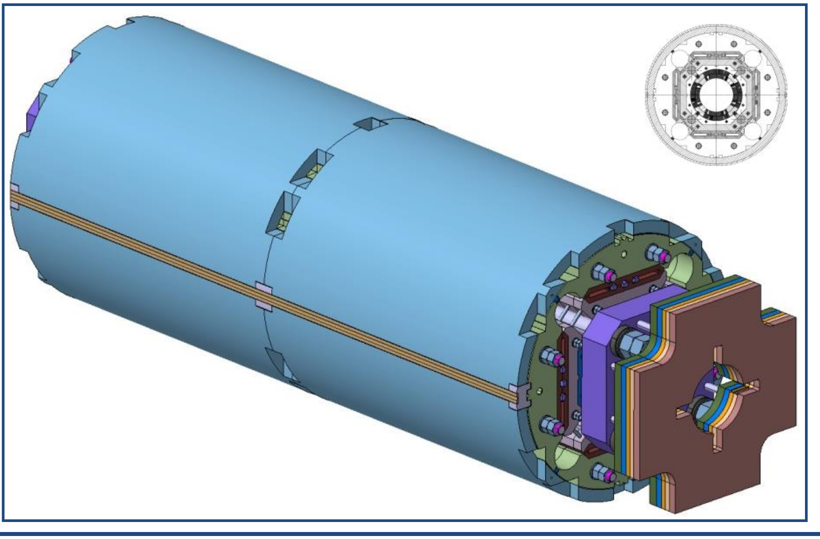


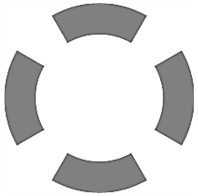


Cu practice coil

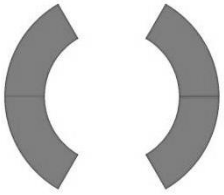
Support structure

- **MQXF**
  - Al shell preloaded with bladders
    - Capability of delivering large force
  - OD 630 mm
  - Challenges
    - Compatibility with accelerator
      - Alignment, cooling , Lhe containment, integration (size)
- **FRESCA2**
  - Same concept, pushed to 15 T
    - 100 mm clear bore
  - OD: 1.030 m
  - 3 pre-load and cool-down with Al dummy coil performed in 2013
    - Increasing pre-load force

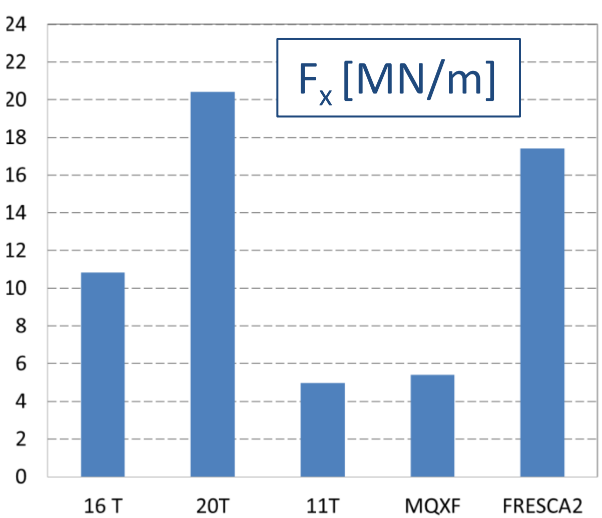


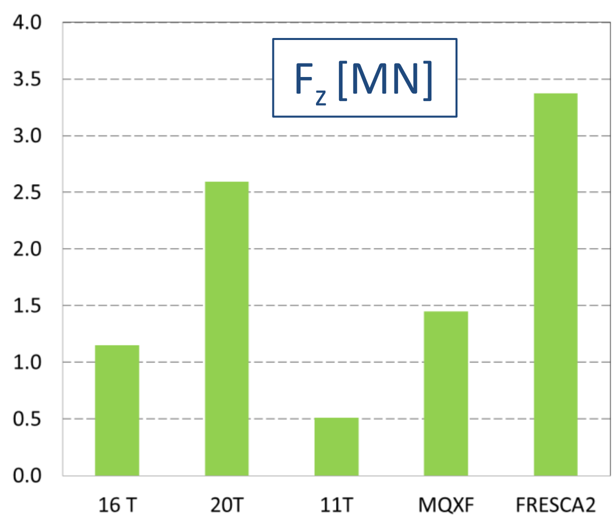


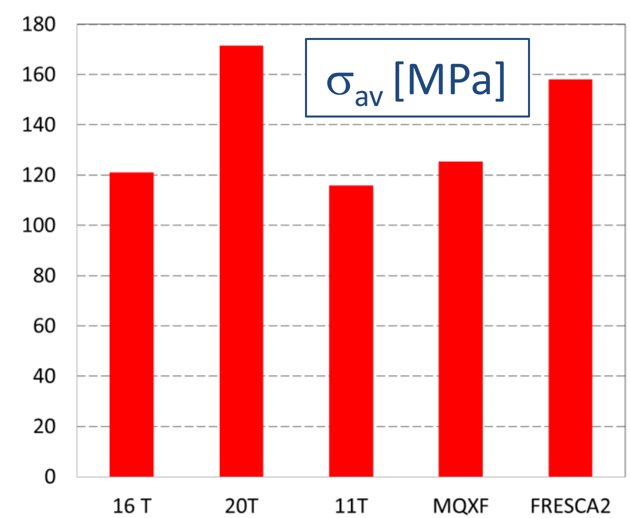
Force/stress levels



- Computations with sector coils
  - F_x on FRESCA2 (15T) similar to 20T magnet (80 mm coil)
  - Large apertures of MQXF and FRESCA2 (15T) -> large F_z
  - σ_{av} of 11T-MQXF not far from 16T magnet (60 mm coil)
- Challenges: peak stresses and overall size







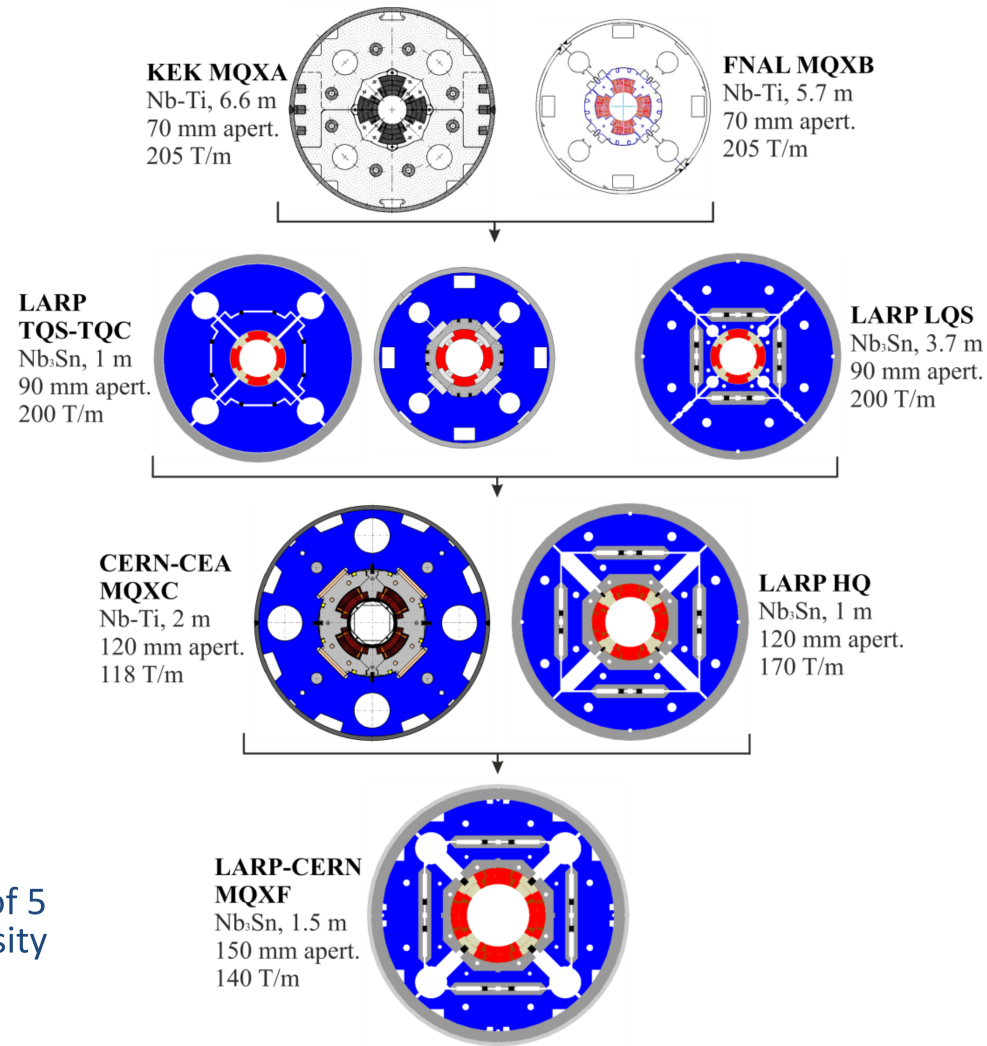
Appendix

Sector coils

		16 T	20T	11T	MQXF	FRESCA2
A/m2	J	385000000	365000000	540000000	498000000	290000000
m	r1	0.02	0.02	0.03	0.075	0.05
m	r2	0.08	0.1	0.0598	0.112626	0.125
m	w	0.06	0.08	0.0298	0.037626	0.075
T or T/m	B1 or G	-16	-20	-11	-140	-15
N/m	Fx tot (half magnet)	10834197	20400788	4956370	5405177	17418028
N	Fz tot aperture	1152598	2592026	510863	1447113	3370570
Mpa	Max stress on mid-plane	-121	-171	-116	-125	-158

LHC low-β quadrupole overview

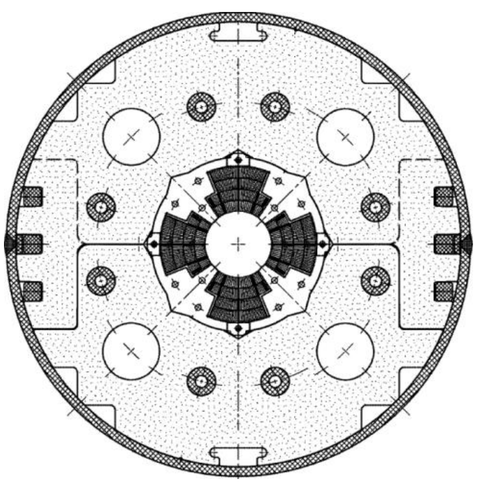
- Present Nb-Ti low-β quadrupole
  - Nominal luminosity
    - $L_0 = 10^{34}$ cm^{-2} s^{-1}
  - Integrated luminosity
    - ~300–500 fb^{-1} by 2021
- 2004, start of LARP Nb_3Sn program
  - Same gradient in larger aperture for ultimate luminosity (2-3 · L_0)
- 2008, two-phase upgrade
  - Phase-I, NbTi for ultimate
  - Phase-II, Nb_3Sn for higher L
- 2012, large aperture Nb_3Sn design
  - Increase the peak luminosity by a factor of 5 and reach 3000 fb^{-1} of integrated luminosity



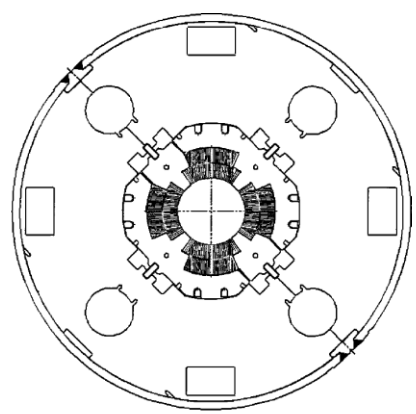
LHC low-β quadrupole support structures

- Cold mass OD from 490/420 in MQXA-B to 630 mm in MQXF
  - More than double the aperture
  - ~4 times the e.m. forces in straight section
  - ~6 times the e.m. forces in the ends

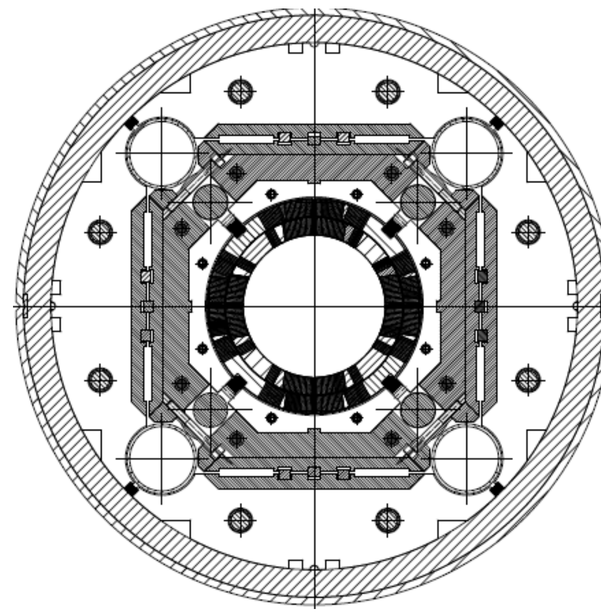
MQXA



MQXB



MQXF

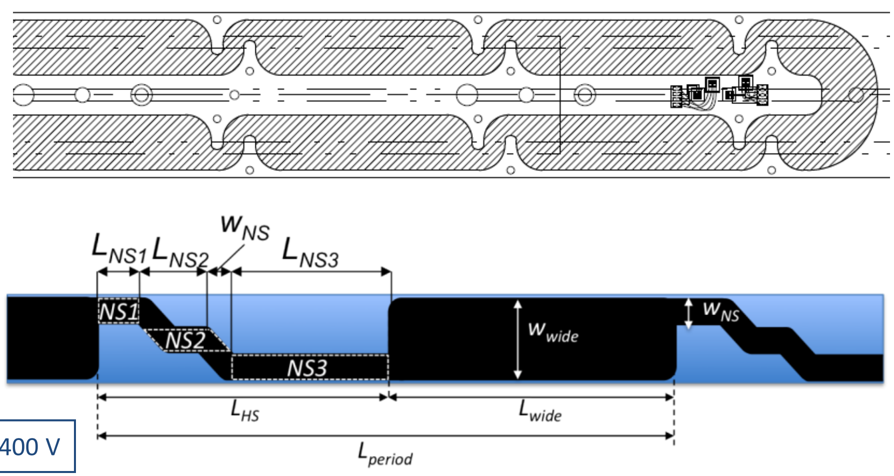


In scale

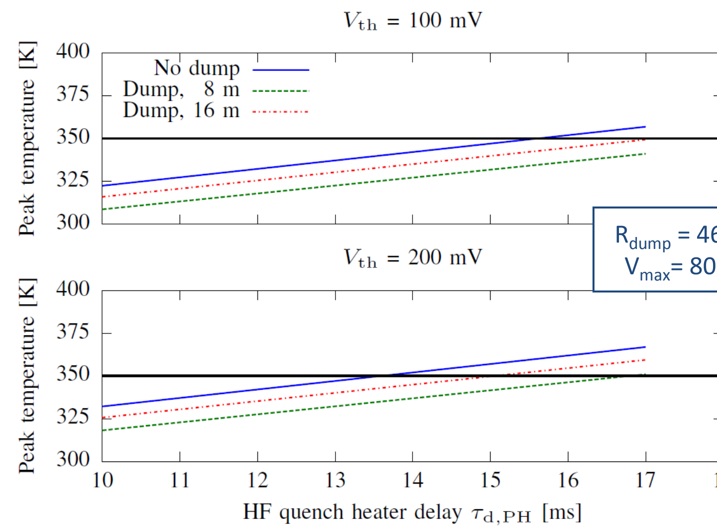
Quench protection

(*G. Manfreda, V. Marinozzi, M. Marchevsky, T. Salmi, M. Sorbi, E. Todesco*)

- Trace Heating stations in outer layer only with 50 µm polyimide ins.
  - Heater delay of about 17 ms
- Before, 10 ms of validation and, after, 20 ms of outer-to-inner delay
- From simulations, hot spot T of 350 K (34 MIITS)
- Working group to define mitigation strategies
  - Modelling of material properties (bronze) and quench-back + *dI/dt* effects
  - Redundancy and CLIQ system
  - Inner layer quench heater (50% open for cooling)



V_{max}= 400 V



R_{dump} = 46 mΩ
V_{max}= 800 V

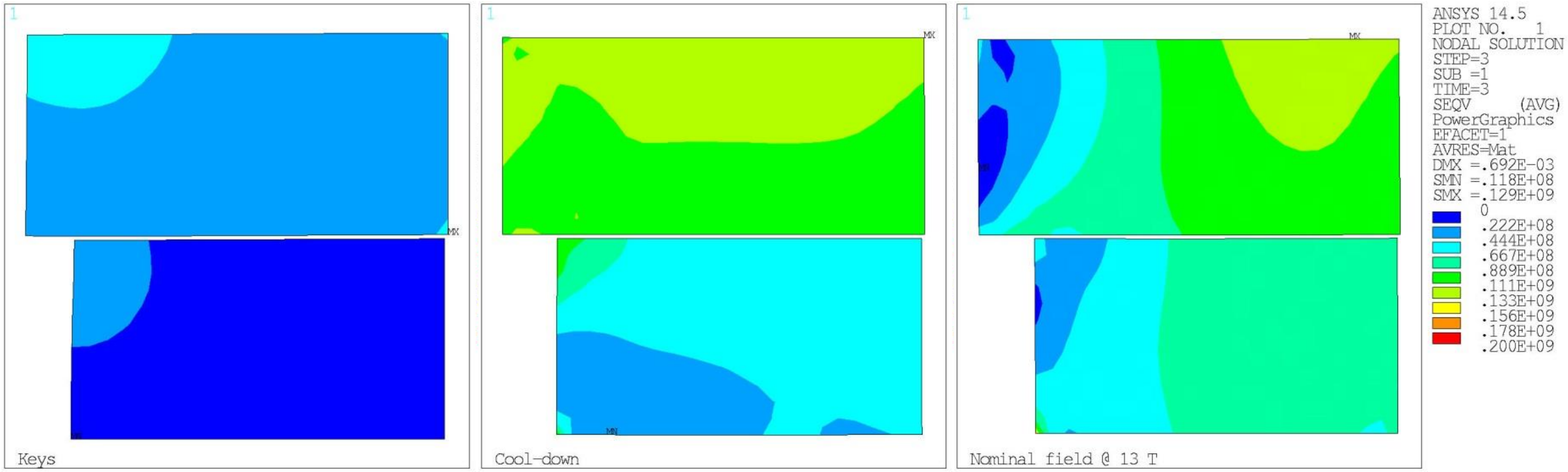
Lengths

- Short coils (CERN + LARP)
  - 19 + 13 = 32 coil
  - 4.8 km cable
  - 208 km strand
- Long model + series
  - (15+45)+(18+90) coils = 60+108 coils = 168 total coils
  - 43 + 46 km cable = 90 km cable
  - 1800 + 1950 km strand = 3750 km strand

	Short model	Q1/Q3 (half unit)	Q2
Magnetic length [m]	1.2	4.0	6.8
"Good" field quality [m]	0.5	3.3	6.1
Coil physical length [m]	1.5	4.3	7.1
Cable unit length per coil [m]	150	430	710
Strand per coil [km]	6.5	18	30

FRESCA2 (2D) 13T → 15T

13T
coil seqv



15T
coil seqv

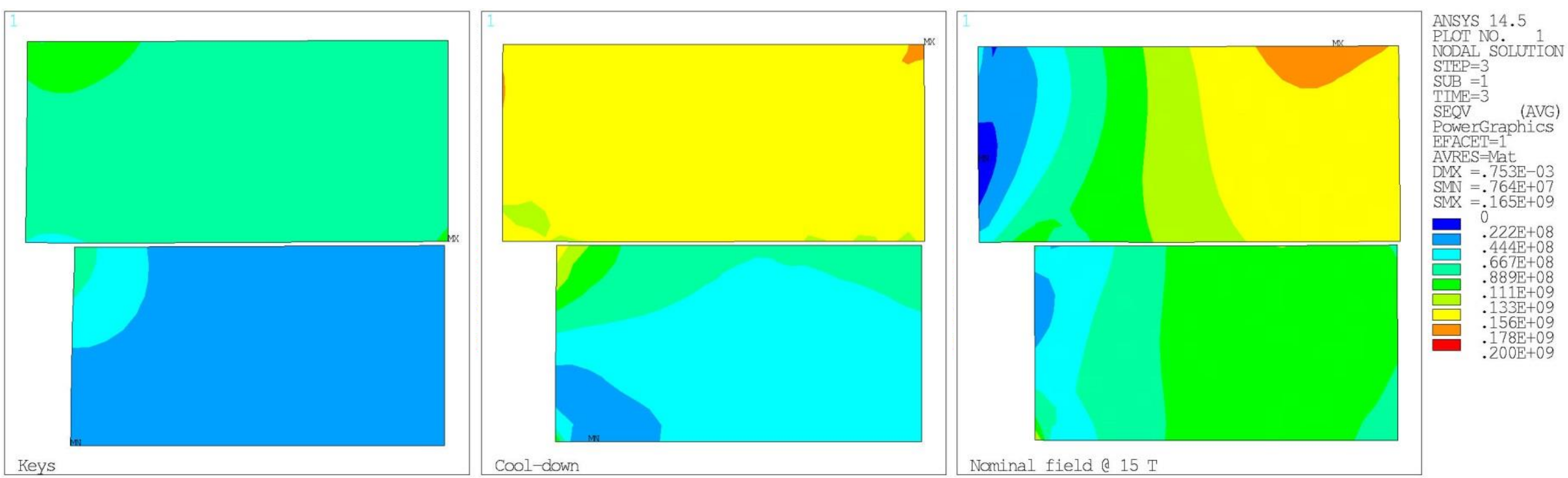


TABLE III
MAXIMUM AZIMUTHAL COIL PRE-STRESS IN POLE AND MID-PLANE REGIONS

Collar/coil design	Position in coil	Azimuthal Coil Stress, MPa				
		Under press	Collared coil	Cold mass	Cool down	B=12T min/max
Removable poles	Inner pole	-126	-92	-143	-115	-27/-5
	Outer pole	-87	-52	-65	-61	-37/-5
	Inner midplane	-115	-55	-65	-58	-134
	Outer midplane	-91	-66	-95	-94	-127
Integrated poles	Inner pole	-69	-54	-108	-124	-7/0
	Outer pole	-97	-65	-70	-50	-14/0
	Inner midplane	-148	-102	-71	-67	-136
	Outer midplane	-79	-55	-78	-66	-116

better stress distribution between inner and outer layers after cooling-down.

The required coil pre-stress in the twin-aperture demonstrator dipole is created in several steps. The initial pre-loading is obtained by ~0.100 mm mid-plane and 0.025 mm radial shims during the collaring of the coils. The maximum achievable pre-stress in the pole region is limited at this stage by the maximum coil stress near the mid-plane. During the cold mass assembly

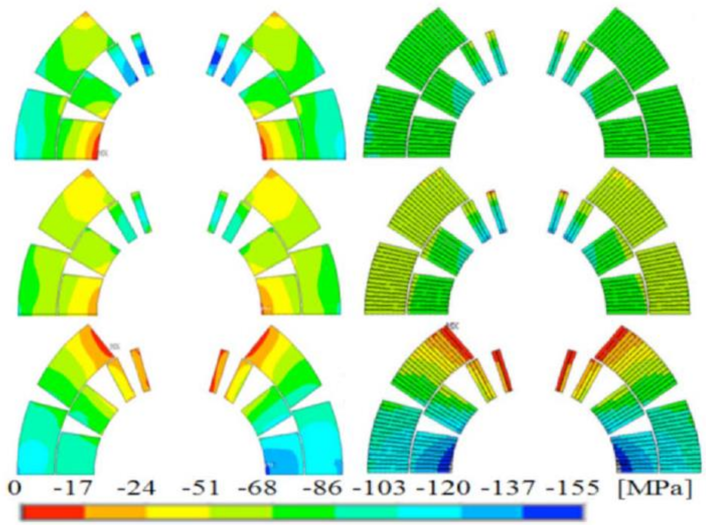


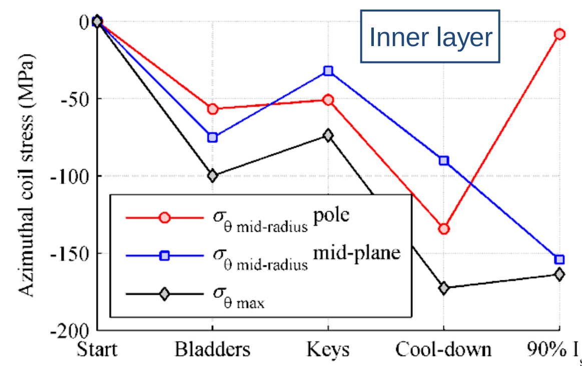
Fig. 7. Azimuthal stress distribution in the coils after the cold mass assembly at room temperature (top), after cool-down (middle) and at 12 T (bottom) for removable pole (left) and integrated pole (right) designs.

system with outer-layer heaters must rely on highly efficient protection heaters. Experimental studies and optimization of the protection heaters are a key part of the demonstrator magnet test program.

Mechanical analysis

(by M. Juchno)

- Optimization of dimensions and locations of new features
- ≥2 MPa of contact pressure at up to 155 T/m (~90% of I_{ss})



- Peak coil stress: -160/-175 MPa
- Coil displ. from start to nominal grad.
  - Radial/azimuth.: -0.3/-0.04 mm
  - Effect on field quality: 0.75 units of b_6