Low-luminosity D2 for FCC

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INFN Sezione di Genova

Introduction

- D2 is one of the dipoles separating and recombining the particle of the two proton beams around the interaction regions (ATLAS and CMS)
- D2 is a twin aperture dipole generating in both apertures a magnetic dipolar field with the same polarity

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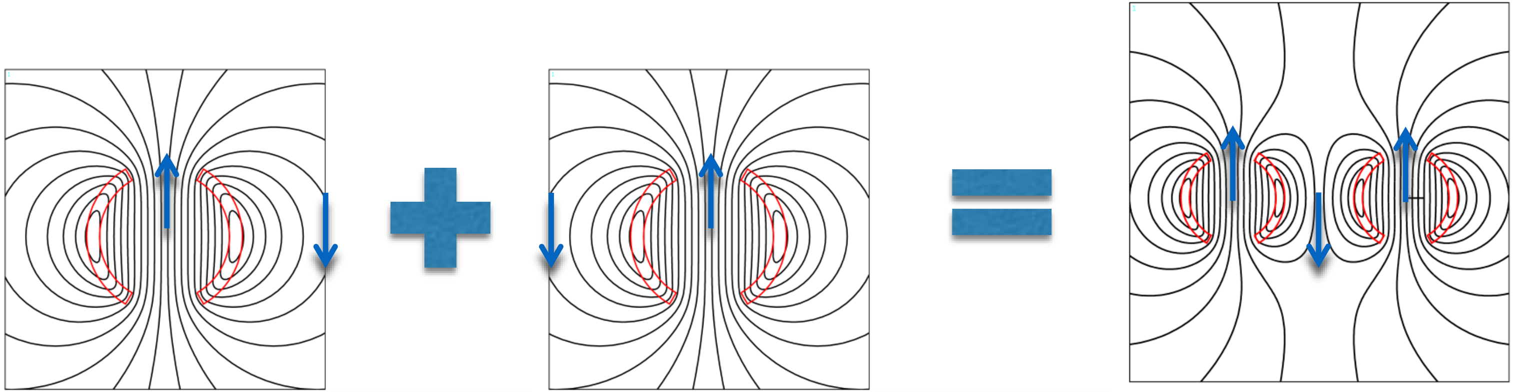
- D2 is a twin aperture dipole generating in both apertures a magnetic dipolar field with the same polarity
- the fringe magnetic field between the two apertures sums up, creating a problem of cross-talk, which is the main issue to be addressed:



EuroCirCol A key to New Physics

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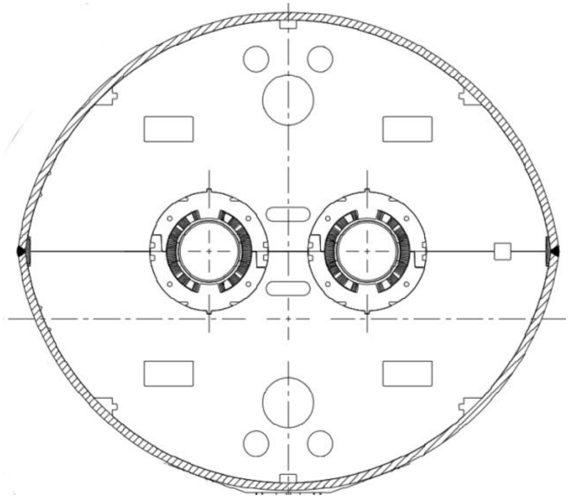
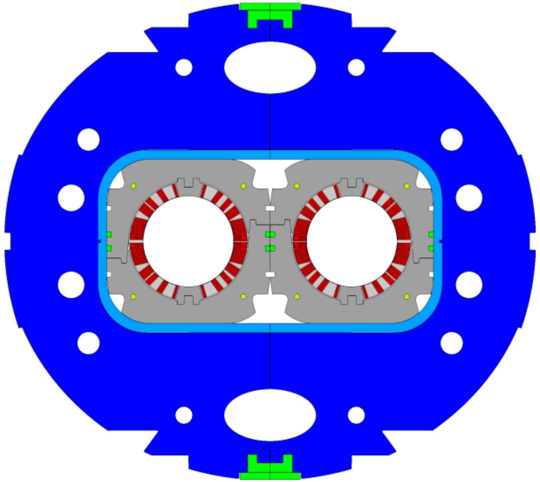
11/04/2018

LHC D2

HL-LHC D2

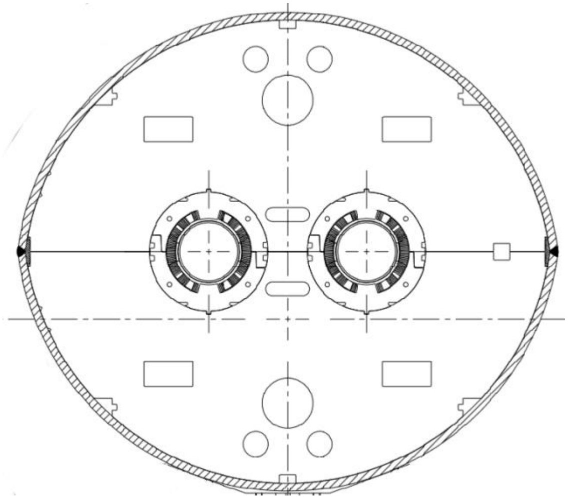


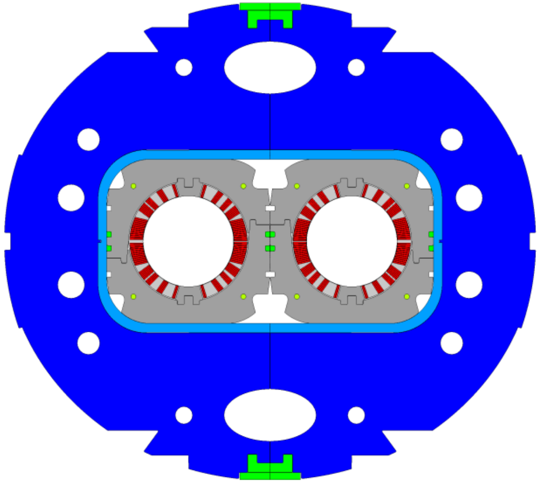


	LHC	HL-LHC
integrated strength (Tm)	35	35
bore field (T)	3.8	4.5
magnetic length (m)	9.45	7.8
aperture (mm)	80	105
inter-beam distance (mm)	188	188
conductor material	NbTi	NbTi

LHC D2

HL-LHC D2





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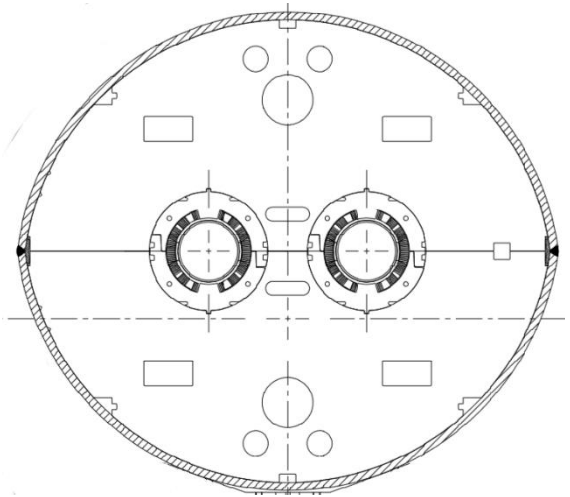
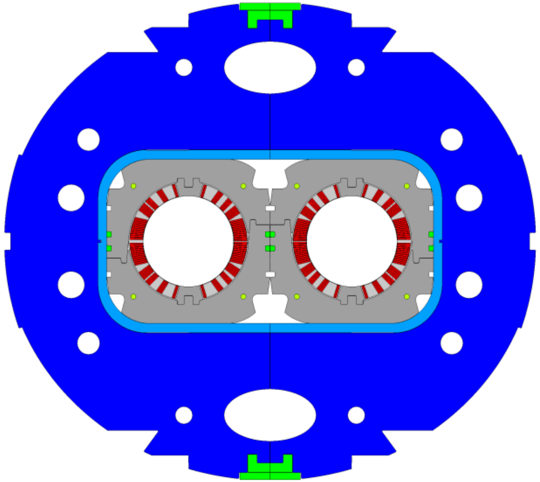
- cross-talk issue addressed by:
  - **LHC:** decoupling the magnetic field in the two apertures through iron yoke
  - **HL-LHC:** a-symmetric winding, elliptical iron yoke, rectangular window

LHC D2

HL-LHC D2



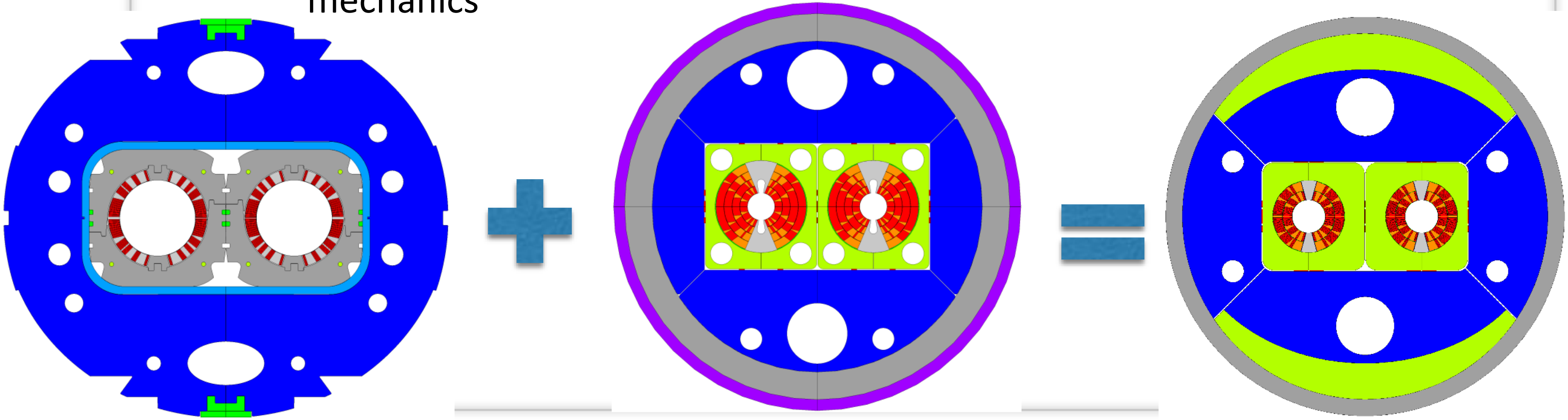


	LHC	HL-LHC	FCC
integrated strength (Tm)	35	35	122
bore field (T)	3.8	4.5	10
magnetic length (m)	9.45	7.8	12.2
aperture (mm)	80	105	60
inter-beam distance (mm)	188	188	204
conductor material	NbTi	NbTi	Nb_3Sn

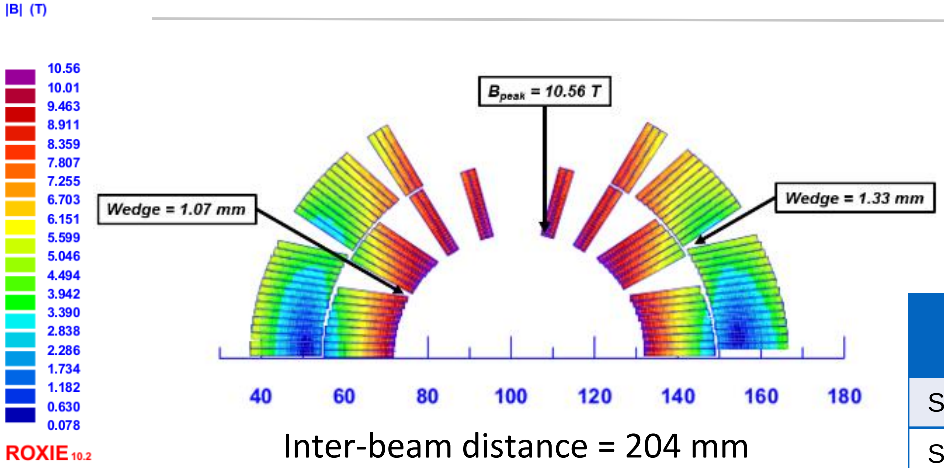
- cross-talk issue addressed by:
  - **LHC:** decoupling the magnetic field in the two apertures through iron yoke
  - **HL-LHC:** a-symmetric winding, elliptical iron yoke, rectangular window

from HL-LHC D2 and FCC 16 T dipole to FCC D2

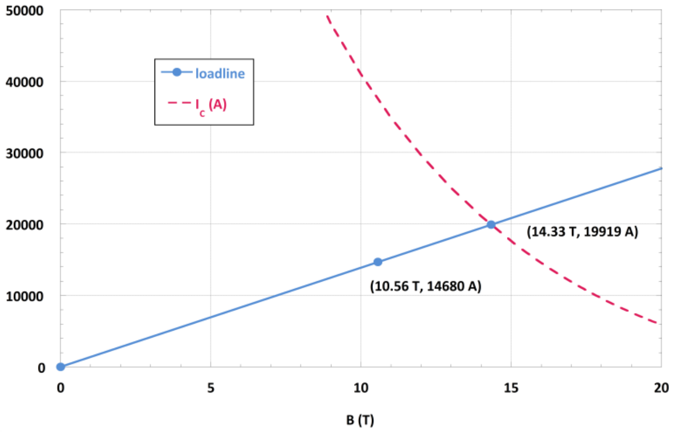
- INFN Genova is presently working on both HL-LHC D2 and FCC 16 T cos-theta dipole design
- the FCC D2 design is a merger of the two designs
  - from HL-LHC D2: a-symmetric winding, elliptical iron yoke, rectangular window
  - from FCC 16 T dipole: cable definition, bladder&key solution for the mechanics



Magnetic design – Cable definition



Inter-beam distance = 204 mm

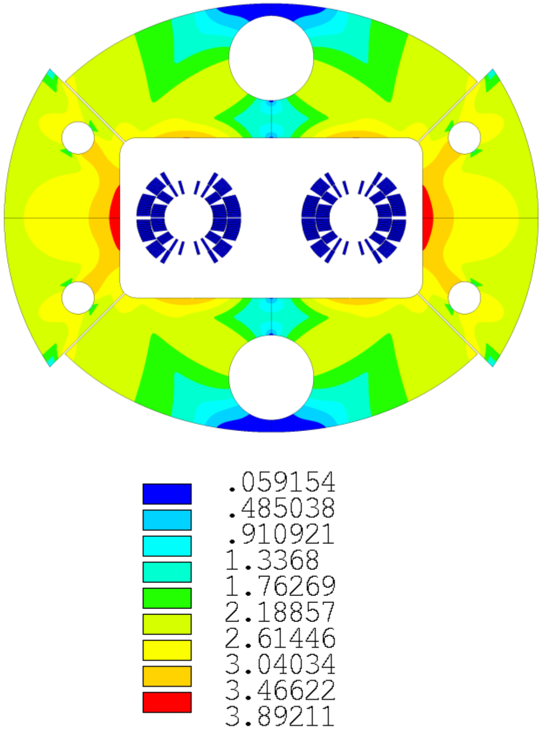


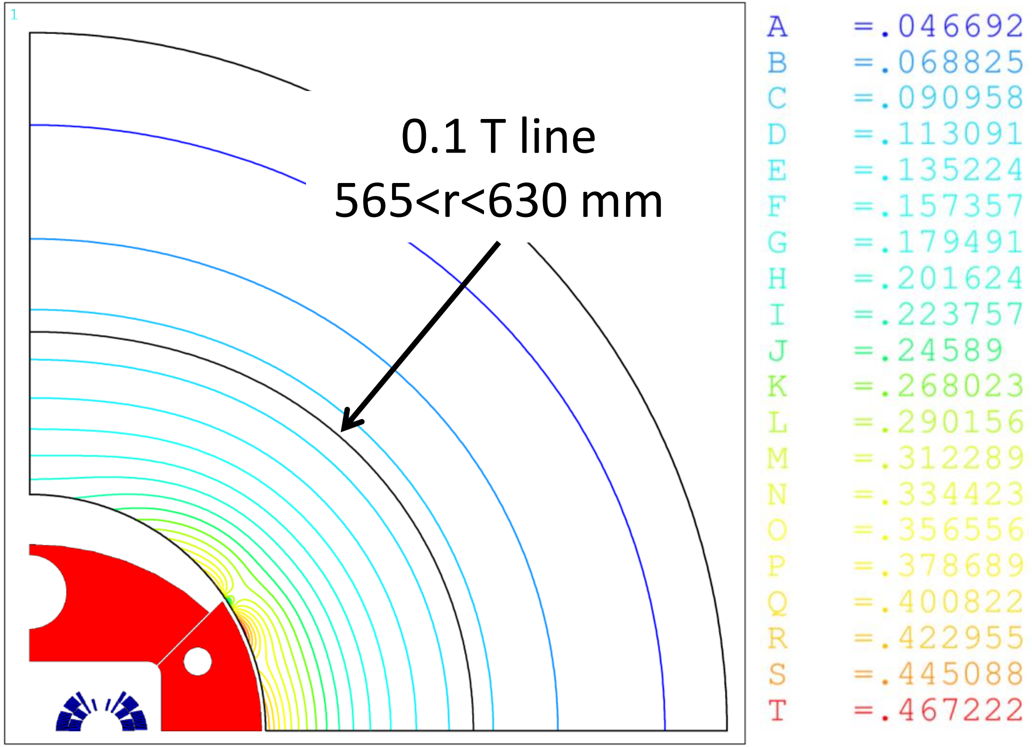
Number of turns:
Layer 1: 19
Layer 2: 28
TOT: 94/ap.

at nominal current:
L = 7.5 mH/m
U= 0.8 MJ/m

	FCC D2	FCC dipole
Strand number	40	38
Strand diameter	0.8 mm	0.7 mm
Bare width	16.8 mm	14 mm
Bare inner thickness	1.376 mm	1.204 mm
Bare outer thickness	1.610 mm	1.326 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.8°	0.5°
Cu/NCu	2.1	2.1
Operating current	14680 A	11390 A
Operating point on LL (@1.9 K)	73.7%	86%

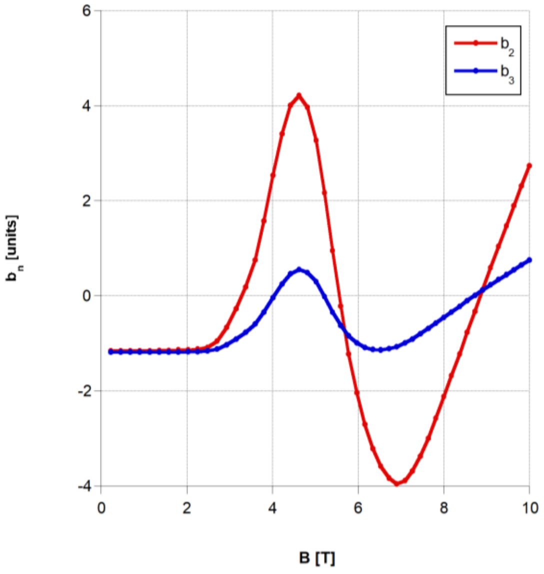
Magnetic design – Iron yoke

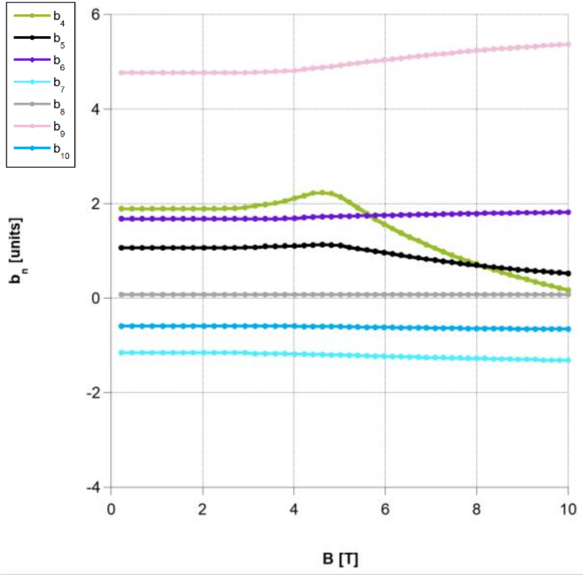




Magnetic design – Field quality

Harmonics at 10 T								
b2	b3	b4	b5	b6	b7	b8	b9	b10
2.73	0.84	0.18	0.51	1.83	-1.31	0.08	5.37	-0.66

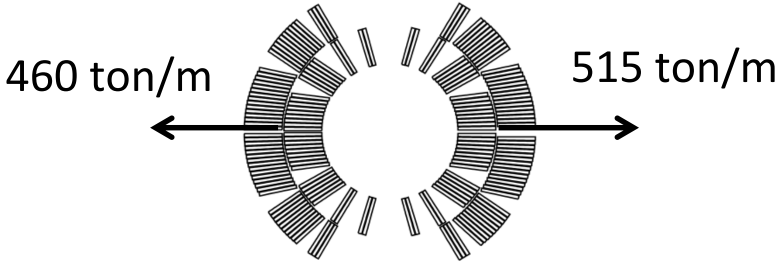




Lorentz forces

Lorentz forces in a twin aperture dipole with bore fields of the same polarity tend to:

- push the coil outward in the radial-horizontal direction



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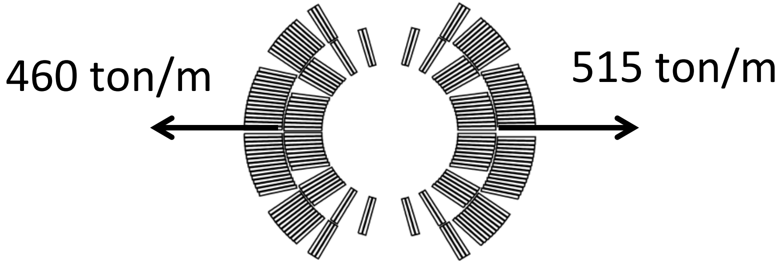
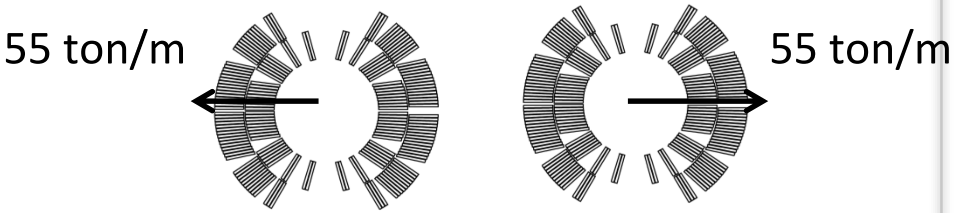


- put apart the two apertures in the horizontal direction



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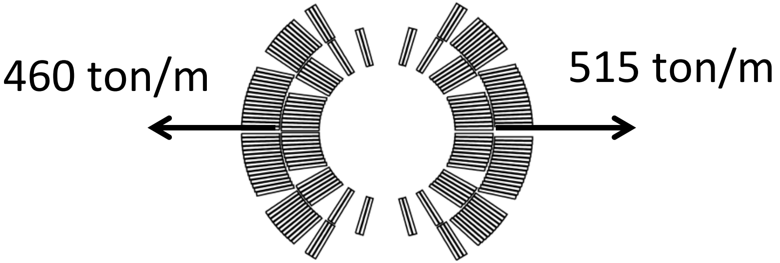

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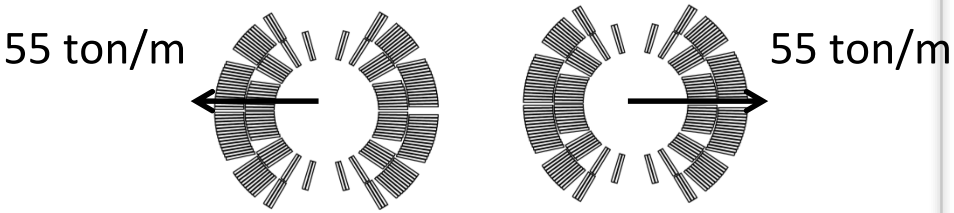
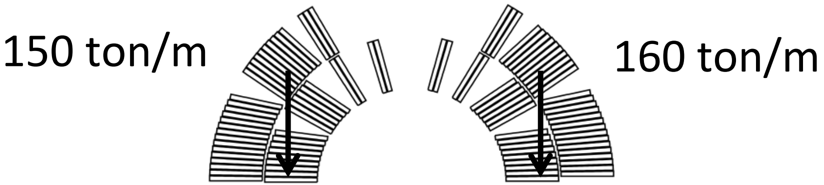


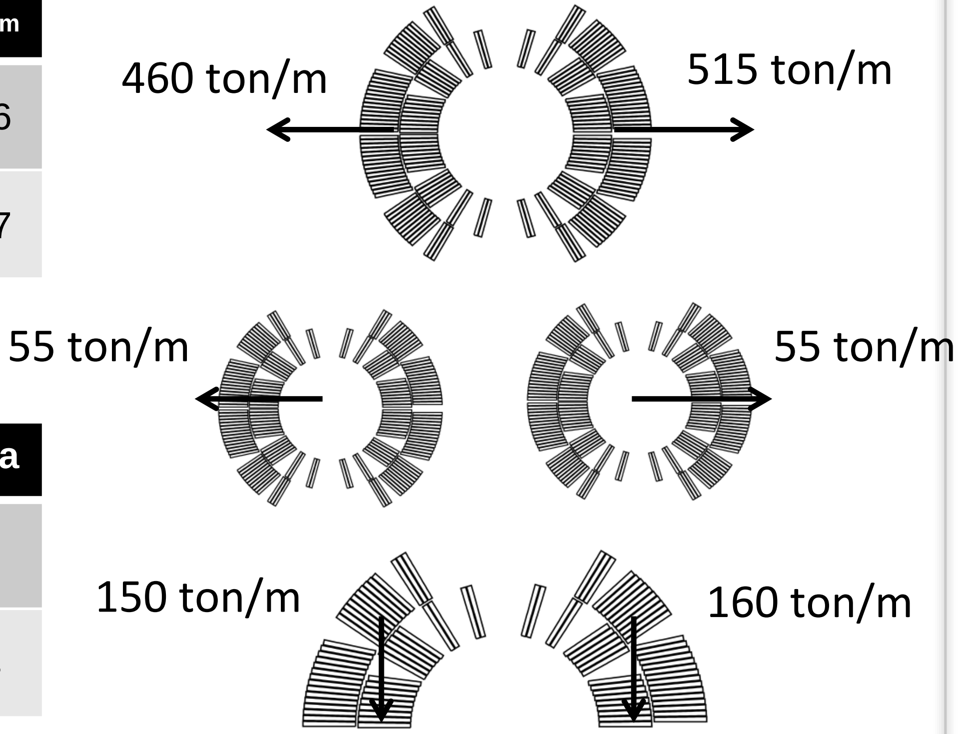
- push the coil toward the mid-plane in the vertical-azimuthal direction



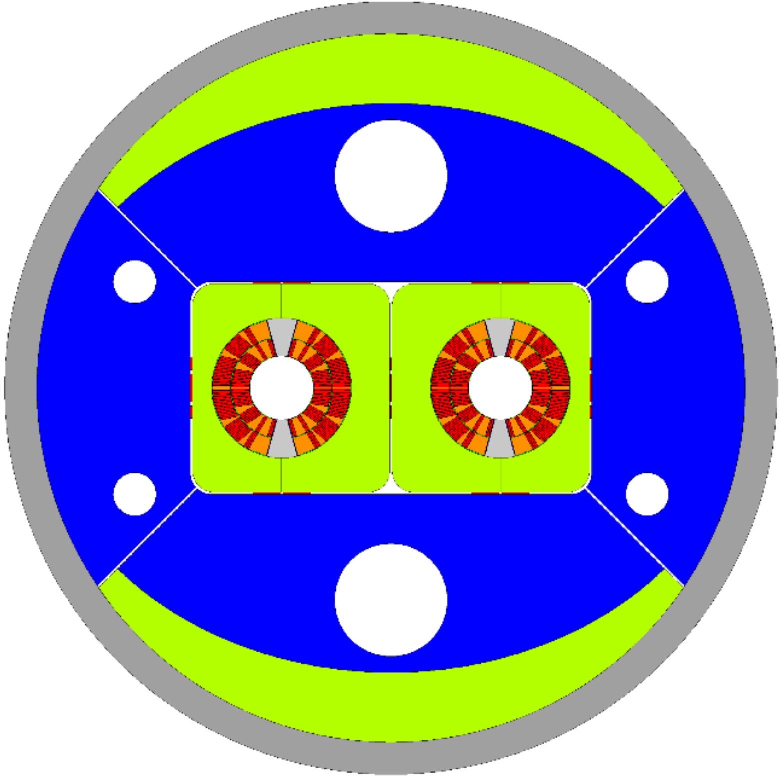
Lorentz forces

f_θ	tons/m	f_θ	tons/m
1st layer left branch	131	1st layer right branch	136
2nd layer left branch	133	2nd layer right branch	147

σ_θ	MPa	σ_θ	MPa
1st layer left branch	75	1st layer right branch	78
2nd layer left branch	76	2nd layer right branch	84

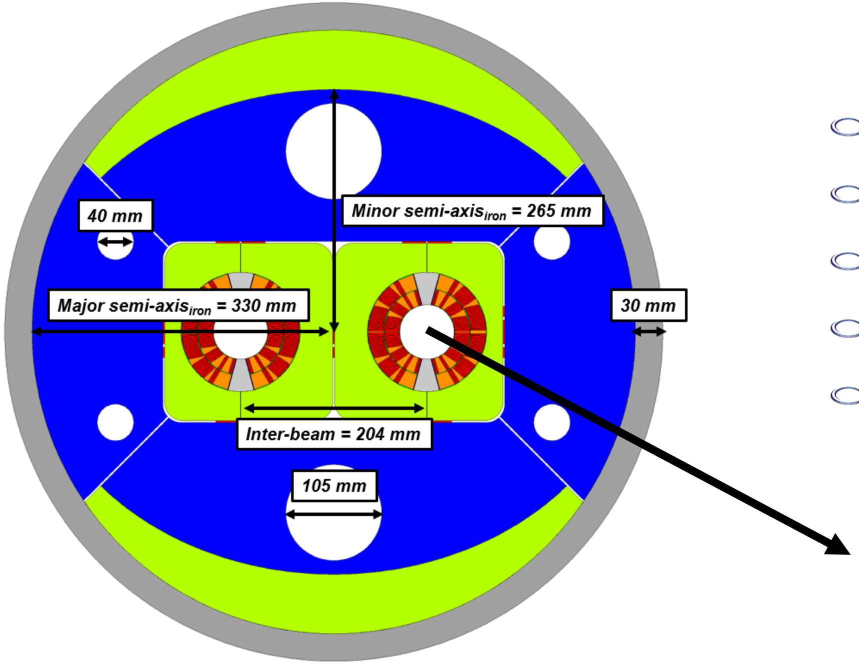


Mechanical structure

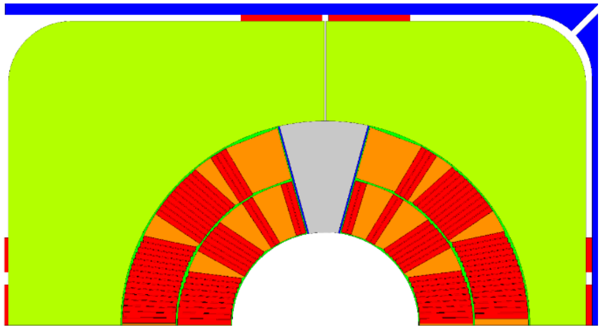


- Bladder and Key technique is proposed:
  - can ensure good pre-stress
  - Allows to decouple x and y directions (iron yoke cut at 45°)
  - pre-stress is given partly during assembly and partly after cool down
  - rectangular steel pad cut vertically
- Collaring is a possible alternative

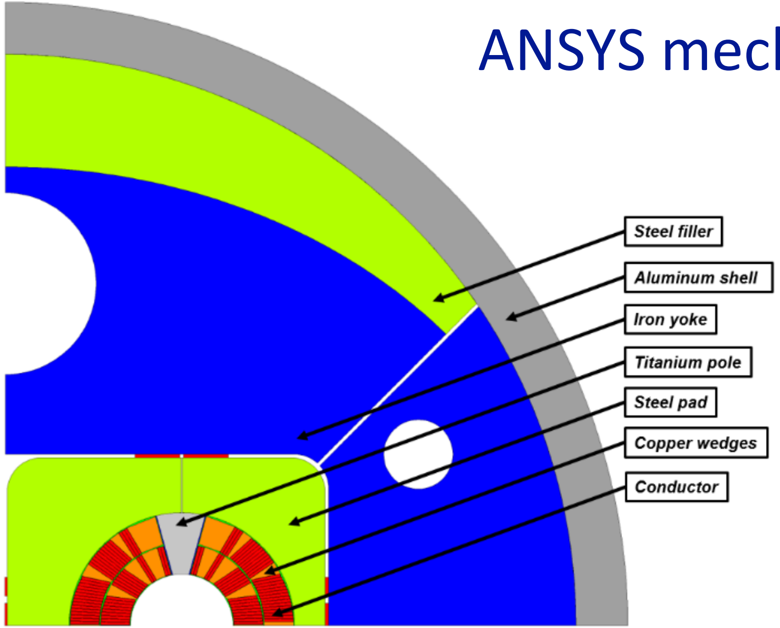
Mechanical structure



- yoke major semi-axis: 330 mm
- yoke minor semi-axis: 265 mm
- Al alloy shell thickness: 30 mm
- magnet outer diameter: 720 mm
- inter-beam distance: 204 mm



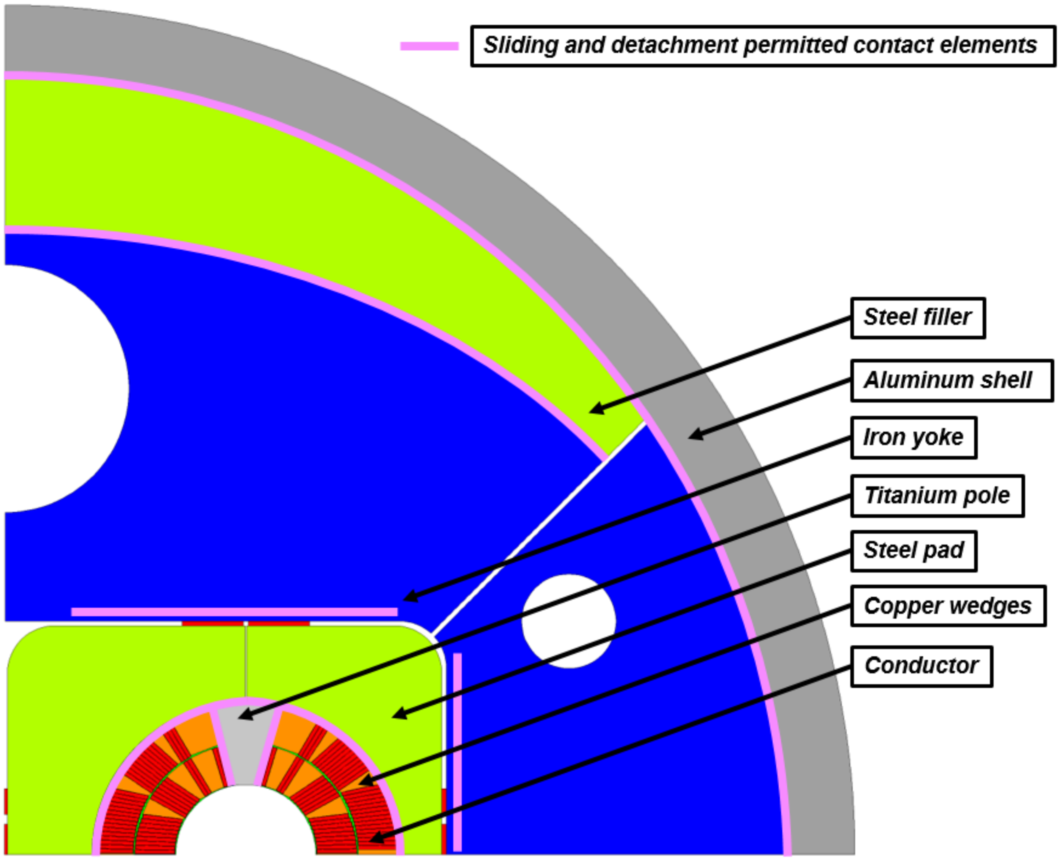
ANSYS mechanical model



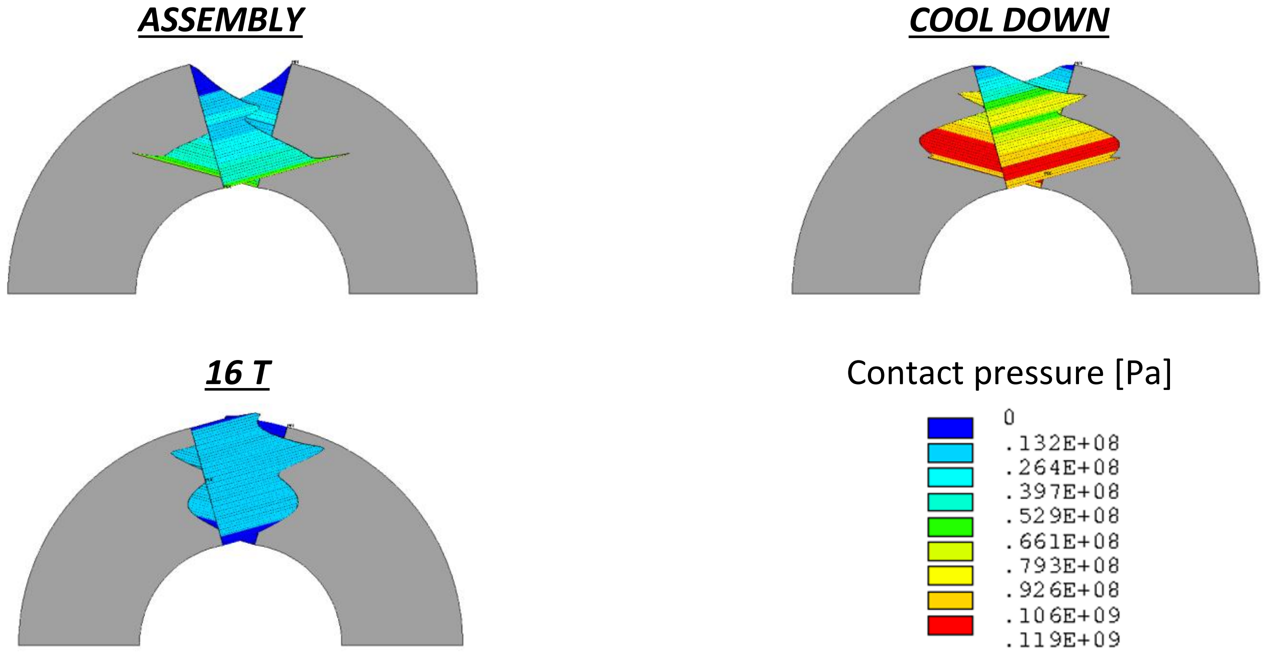
- **Step 1**: assembly (key insertion)
- **Step 2**: cooling down
- **Step 3**: energization to 16 T (application of Lorentz forces to the conductor elements)

MATERIAL	Stress limit [MPa] RT	Stress limit [MPa] 1.9 K	E [GPa] RT	E [GPa] 1.9 K	α [mm/m] RT → 1.9 K
Austenitic steel (316LN)	350	1050	193	210	2.8
Al 7075	480	690	70	79	4.2
Coil	150	200			
Radial dir.			30	33	3.1
Azimuthal dir.			25	27.5	3.4
Ferromagnetic iron	230	720	213	224	2.0
Ti6Al4V	800	1650	115	126	1.7
Glidcop/Discup (wedges)	270	>300	100	110	3.37

Mechanical analysis – contact surfaces



Contact pressure

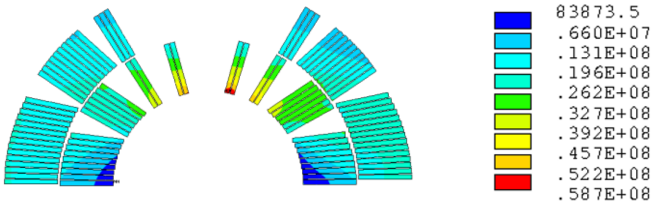


- Contact pressure increases after cool down (Aluminum shell shrinking)
- P_{cont} > 2 MPa for 1st layer after energization at 16 T

Von Mises stress in conductors

ASSEMBLY

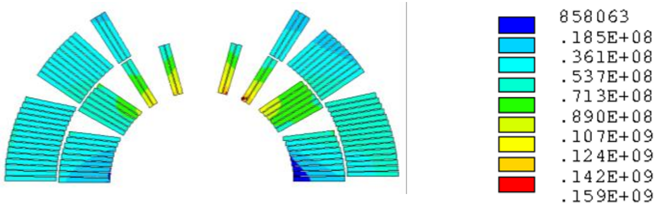
VM stress [Pa]



$б_{VM,max}$ = 58.7 MPa

COOL DOWN

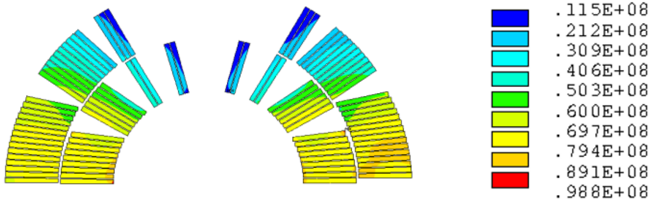
VM stress [Pa]



$б_{VM,max}$ = 159 MPa

16 T

VM stress [Pa]



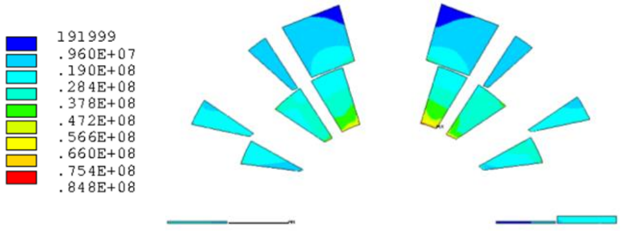
$б_{VM,max}$ = 98.8 MPa

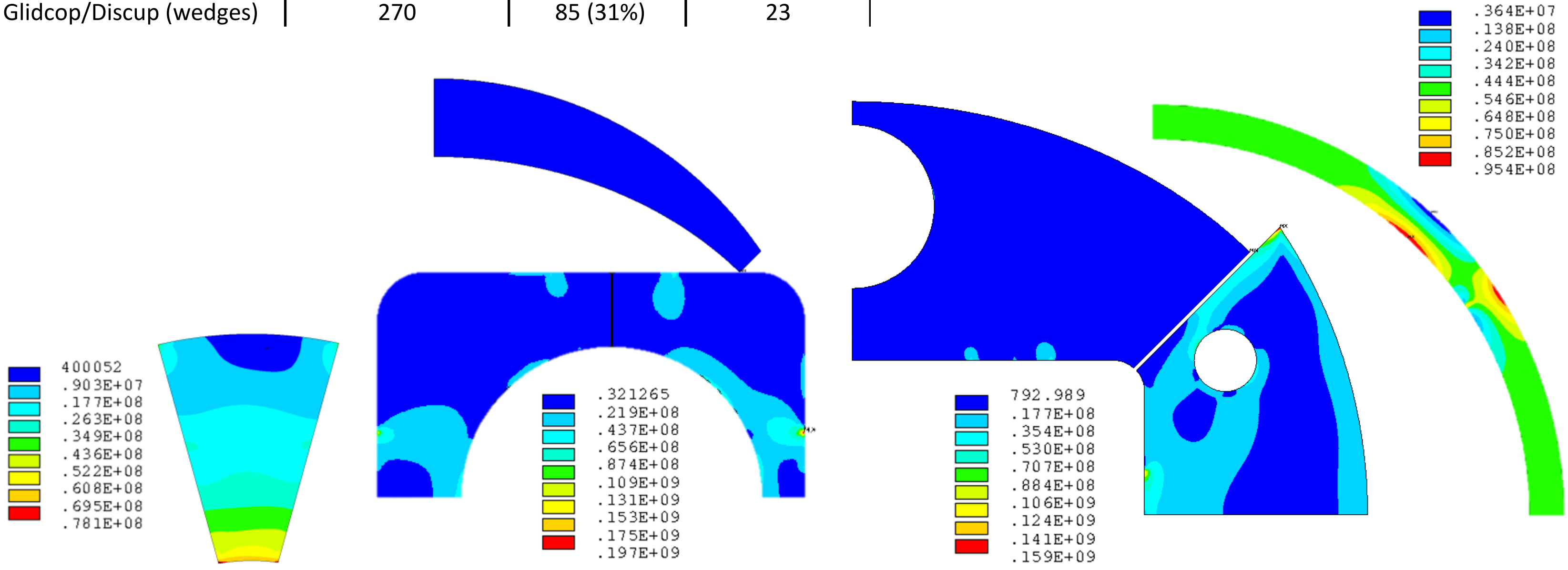
- VM stress far below current degradation limit set for FCC dipole (150 MPa @ RT, 200 MPa @ 1.9K)
- After energization, a VM stress below 30 MPa is expected in the peak field region

Von Mises stress in mechanical structures

ASSEMBLY

MATERIAL	Stress limit [MPa] RT	$б_{VM,max}$ [MPa] RT	<$б_{VM}$> [MPa]
Austenitic steel (316LN)	350	197 (56%)	9
Al7075	480	95 (20%)	50
Ferromagnetic iron	230	159 (69%)	11
Ti6Al4V	800	78 (10%)	22
Glidcop/Discup (wedges)	270	85 (31%)	23

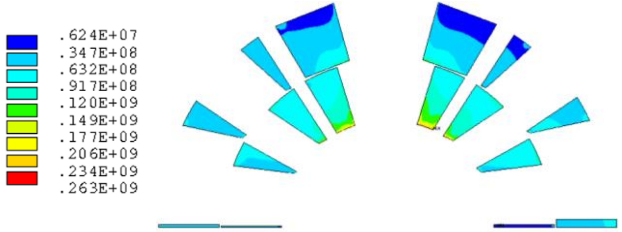


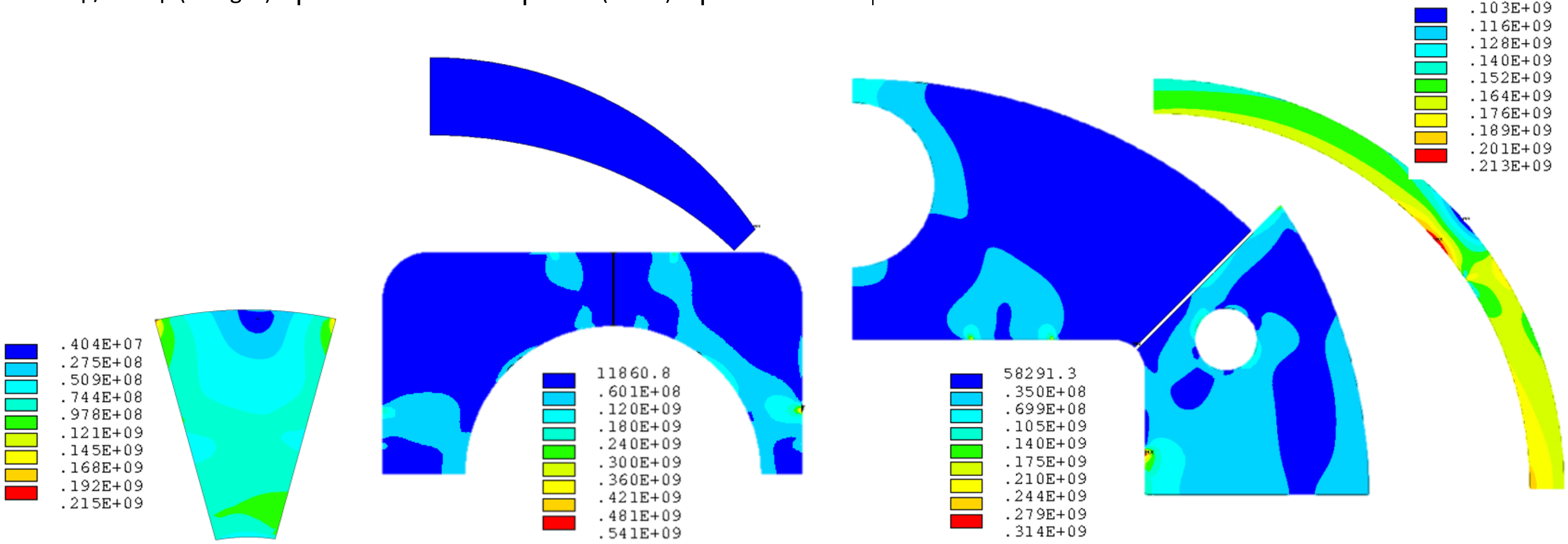


Von Mises stress in mechanical structures

COOL DOWN

MATERIAL	Stress limit [MPa] 1.9 K	$б_{VM,max}$ [MPa] 1.9 K	$<б_{VM}>$ [MPa]
Austenitic steel (316LN)	1050	541 (52%)	28
Al7075	690	215 (31%)	164
Ferromagnetic iron	720	314 (44%)	31
Ti6Al4V	1650	213 (13%)	74
Glidcop/Discup (wedges)	>300	263 (<88%)	64

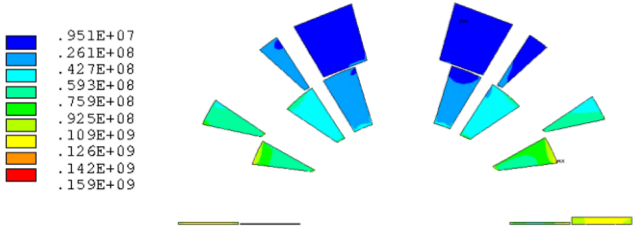


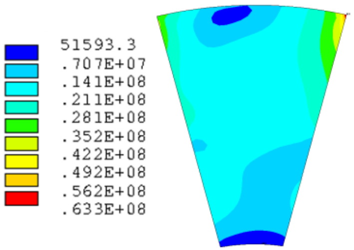


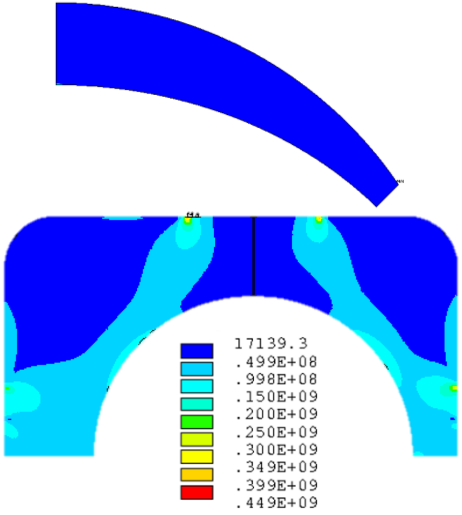
Von Mises stress in mechanical structures

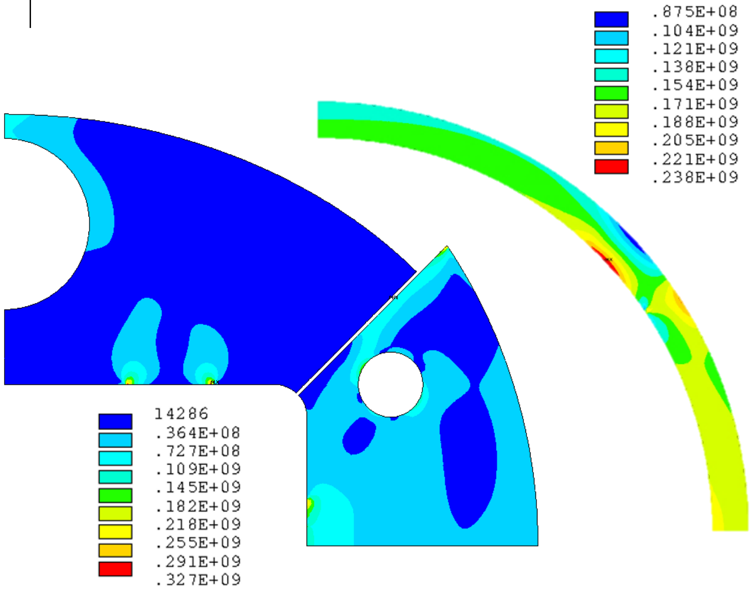
ENERGIZATION

MATERIAL	Stress limit [MPa] 1.9 K	$б_{VM,max}$ [MPa] 1.9 K	$<б_{VM}>$ [MPa]
Austenitic steel (316LN)	1050	449 (43%)	31
Al7075	690	238 (34%)	167
Ferromagnetic iron	720	327 (45%)	32
Ti6Al4V	1650	63 (4%)	17
Glidcop/Discup (wedges)	>300	159 (<53%)	39









Conclusions

- We proposed an electromagnetic and mechanical design of D2 recombination/separation dipole for FCC
- we exploited to the fullest our knowledge of both HL-LHC D2 and FCC 16 T dipole designs
- the proposed design fulfills all the design requirements with no particular criticality
- other solutions are possible (e.g. collaring) but the one we proposed seems to be the most appealing

THANKS FOR THE ATTENTION

INFN Sezione di Genova