

DE LA RECHERCHE À L'INDUSTRIE



## FCC week 2018

# Block-coil 16T Design for the FCC



*The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.*



**E. Roche pault, M. Segreti,**  
on behalf of C. Pes, M. Durante, C. Lorin  
With contributions of the EuroCirCol collaboration

10/04/2018

# EVOLUTION OF THE DESIGN

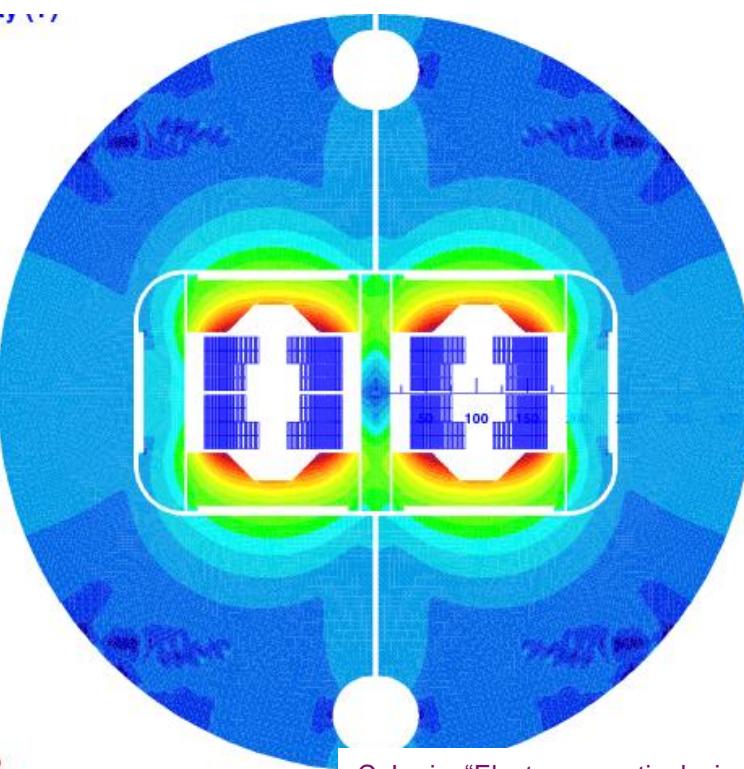
- FCC week 2017:

204 mm interbeam

750 yoke diameter

63 mm Al shell

v1ari204



C. Lorin, "Electromagnetic design of the block coil option", [FCC week 2017](#)

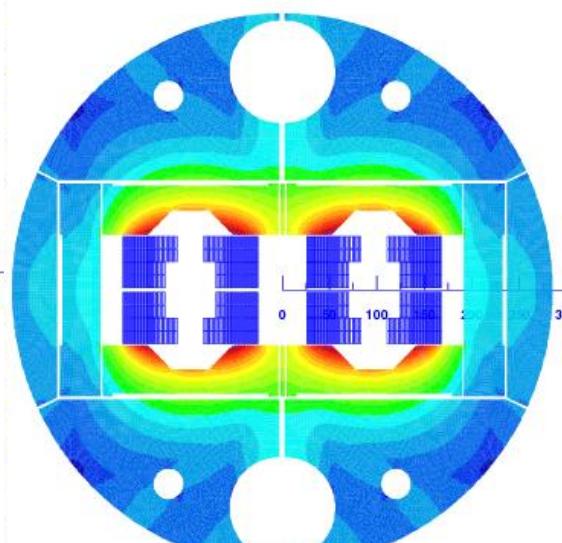
- Review Oct. 2017:

**194 mm interbeam**

**570 mm yoke diameter**

100 mm Al shell

MT2017



C. Lorin, "Block-coil electromagnetic design", [ECC review 2017](#)

- Today:

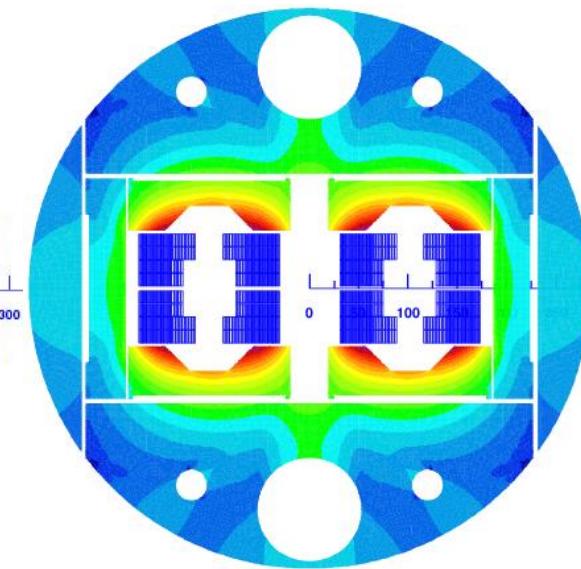
204 mm interbeam

570 yoke diameter

67 mm Al shell +

**20 mm SS shell**

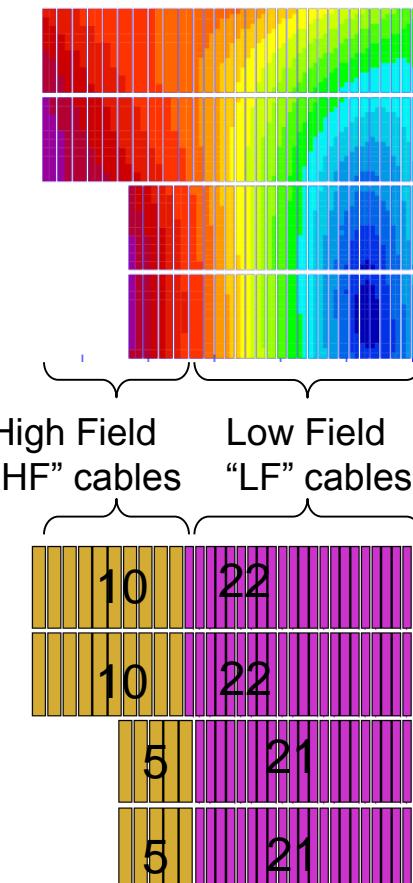
v5ari204



# 2D MAGNETIC DESIGN – MAIN PARAMETERS

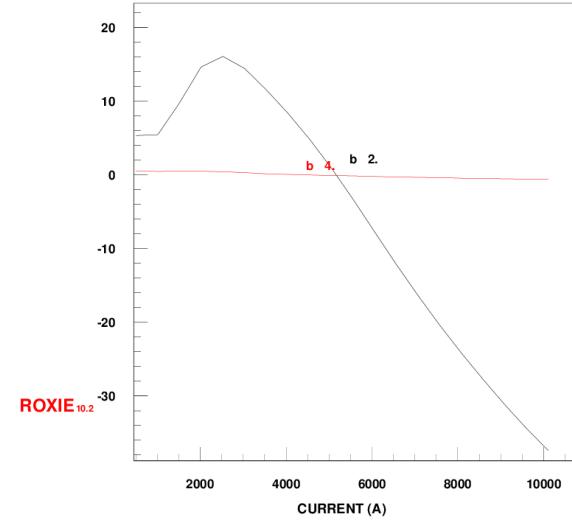
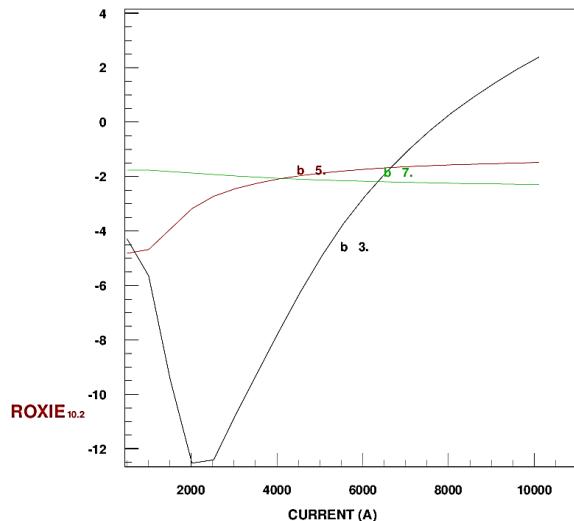
Parameter	Value	Unit
I <sub>nom</sub>	10.123	kA
Nturns	5+10+21+22	-
Bore thickness	1.9 (1.4 + 0.5)	mm
Mid-plane shim	2.28	mm
Conductor area	138	cm <sup>2</sup>
Estimated weight*	7.90	kt
Yoke diameter	570	mm
B <sub>center</sub>	16.00	T
B <sub>peak</sub>	16.75	T
Load-line margin	13.75	%
Diff. inductance	49.1	mH/m

\*Area x 4668 dipoles x 14.1m x 8.7 t/m<sup>3</sup>

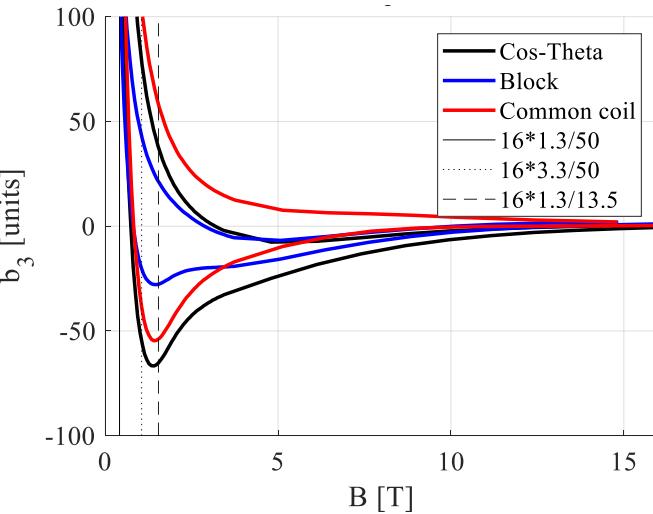


# 2D MAGNETIC DESIGN – HARMONICS

- Without persistent currents (geometric + saturation):



- Persistent currents P.C.:



Operation	Case	b2	b3	b5	b7	b91
Injection (3.3 TeV)	without P. C.	5.2	-3.2	-4.9	-1.7	
	P. C. only	0	-25.5	-2.1	-5.7	-2.5
	with P. C.	<b>5.2</b>	<b>-28.9</b>	<b>-7.0</b>	<b>-7.4</b>	
	Max. target <sup>2</sup>	-	60	-	-	-
Collision	negligible P. C.	<b>-37.48</b>	<b>0.49</b>	<b>-1.96</b>	<b>-2.43</b>	<b>-1.59</b>
	Max. target <sup>2</sup>	50	4	3	3	3

S. Izquierdo Bermudez, "Field Quality Table Update for EuroCirCol 16 T designs", FCC-hh magnet-beam dynamics coordination meeting 03, 2017

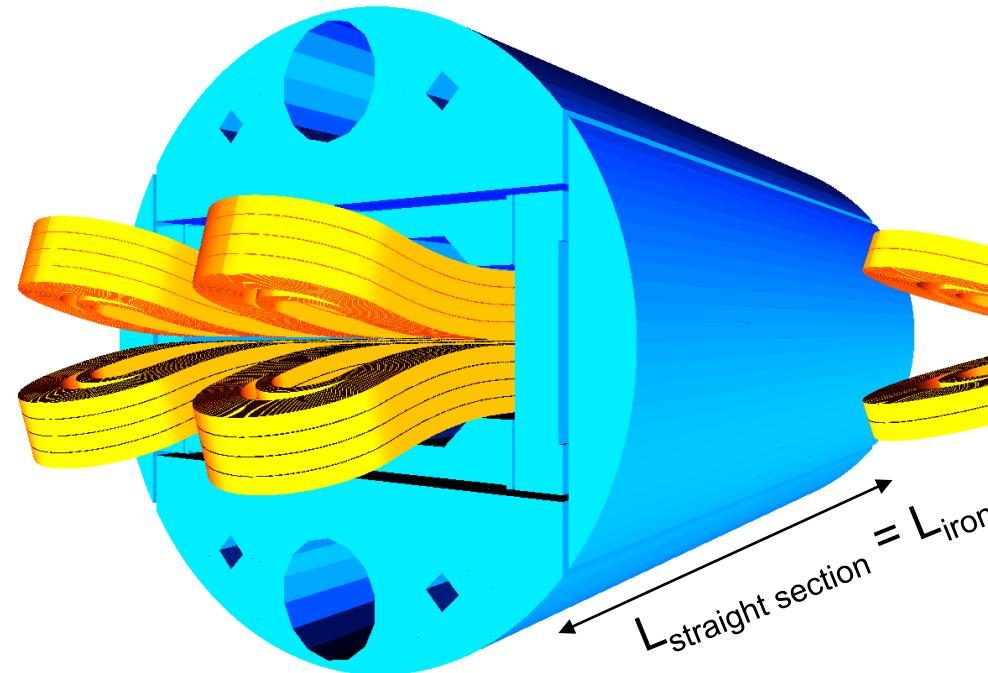
<sup>1</sup>Other harmonics <1 unit

<sup>2</sup>Absolute value

# 3D MAGNETIC DESIGN – 2 OPTIONS

## Compact:

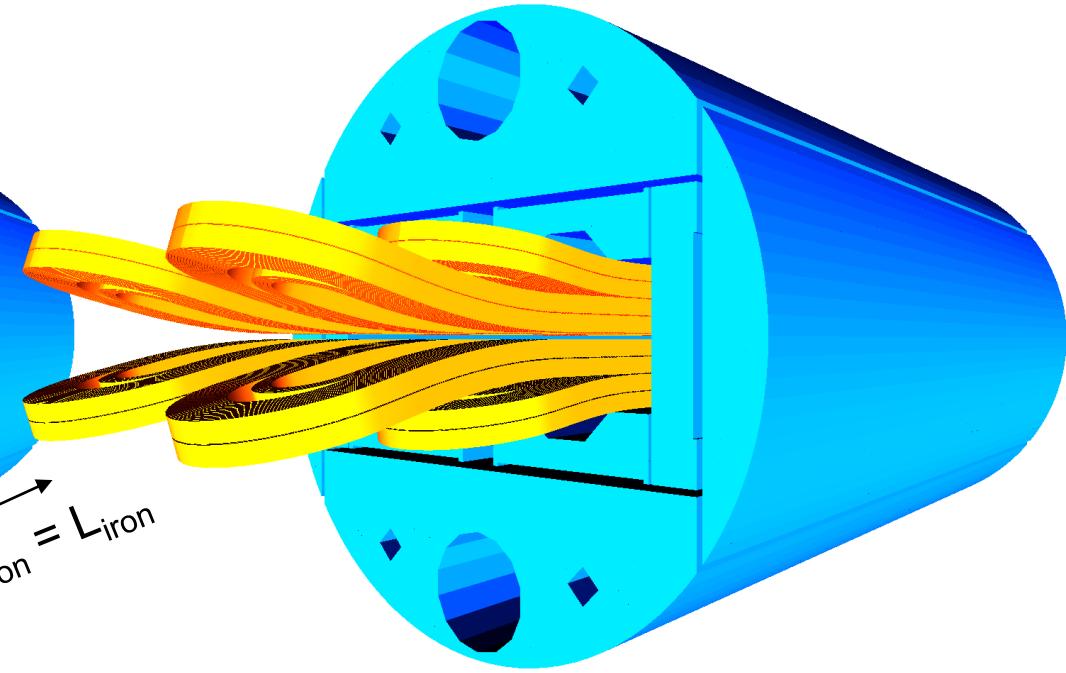
- Coil ends to the shortest
- Room in the spacers for internal joints



- Minimum conductor length
- Are the harmonics still within spec?
- Is the peak field still in the straight section ?

## Long:

- Extension of coil ends
- Compensation of the b3 in the ends

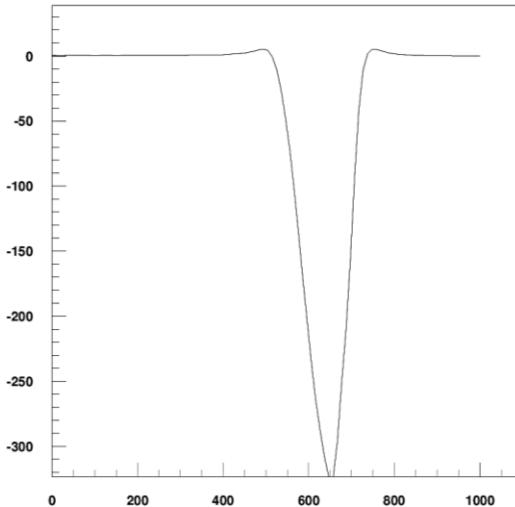


- What impact on the lengths? (conductor, coil ends)
- What impact on the peak field?

# 3D MAGNETIC DESIGN – HARMONICS

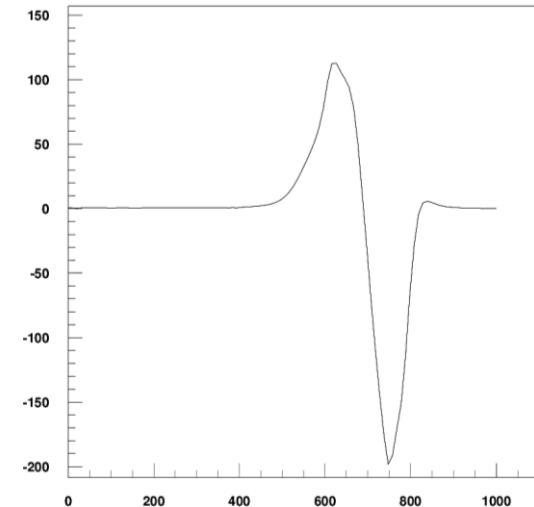
Compact:

b3



Long:

b3



## Design

b2

b3

b5

b7

b9

Design	b2	b3	b5	b7	b9
2D	-37.48	0.49	-1.96	-2.43	-1.59
3D, Compact ends	-39.03	<b>-4.59</b>	-2.37	-2.47	-1.58
3D, Long ends	-39.41	<b>0.08</b>	-2.41	-2.51	-1.58
3D compact + compensation	-38.95	<b>-2.70</b>	-1.90	-2.29	-1.57
2D compensation	-37.40	<b>2.39</b>	-1.48	-2.43	-1.59

- At collision
- Magnetic length 14 m

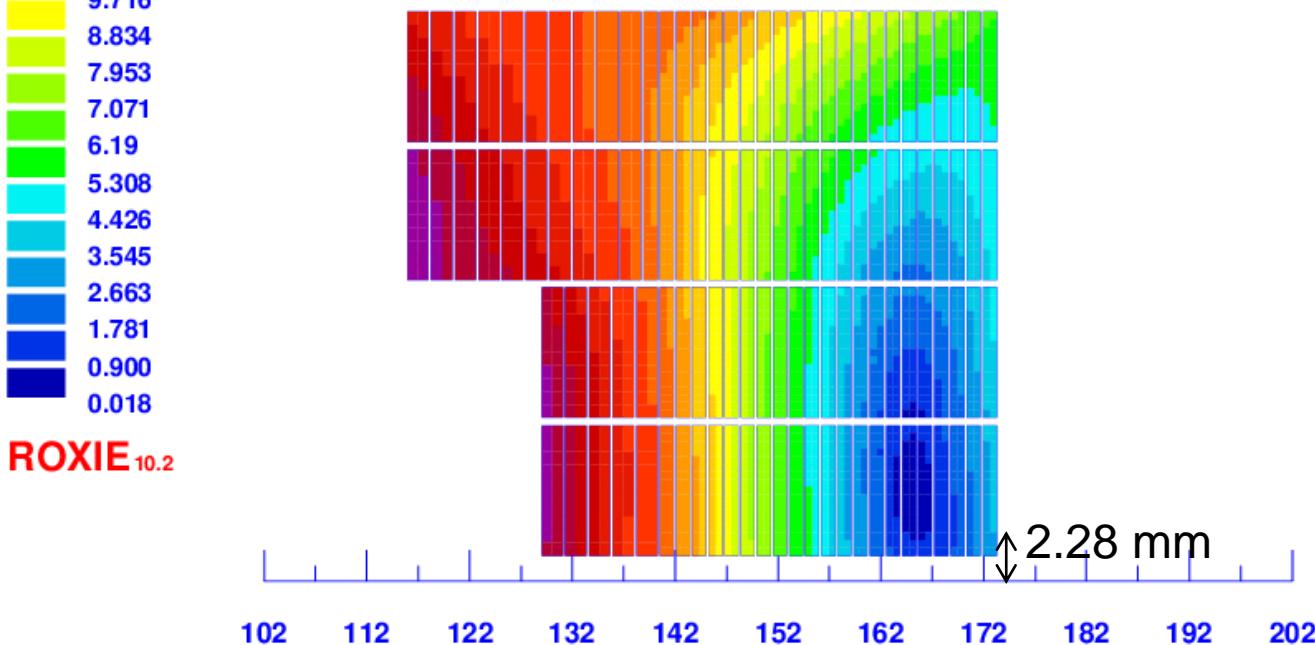
# COMPENSATION OF $b_3$ IN 2D



Midplane shim 2.35 mm → 2.28 mm

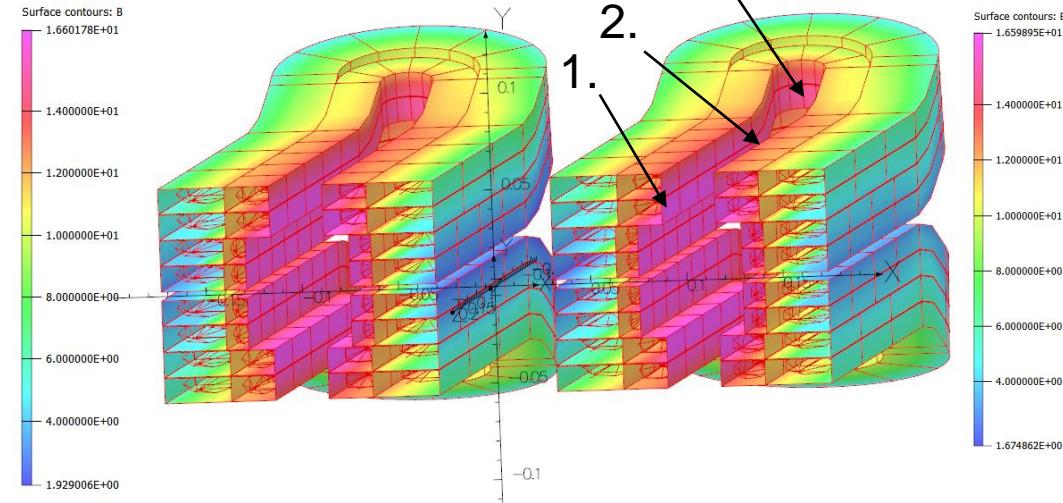
- $b_3$  in the straight section (2d): 0.49 units → **2.39 units**
- $b_3$  integrated -4.59 units → **-2.70 units**
- Slightly lower **other harmonics**
- Slightly higher **margin**

v5ari204

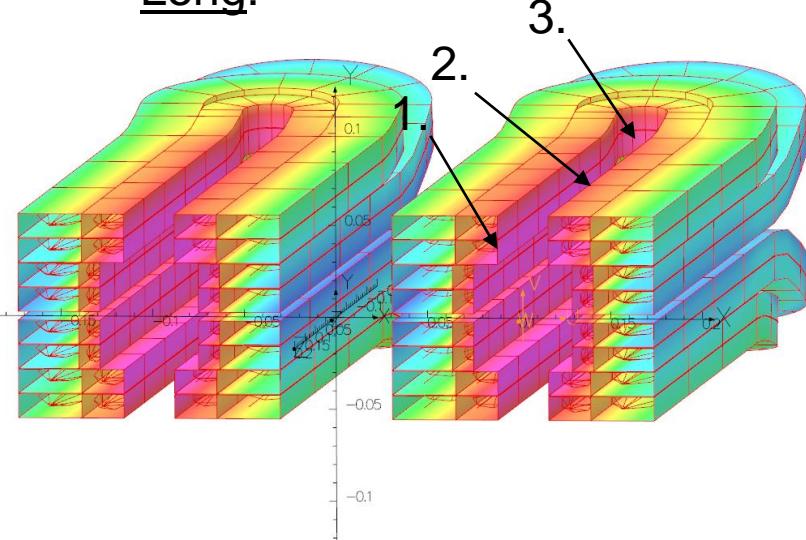


# 3D MAGNETIC DESIGN – PEAK FIELD

Compact:

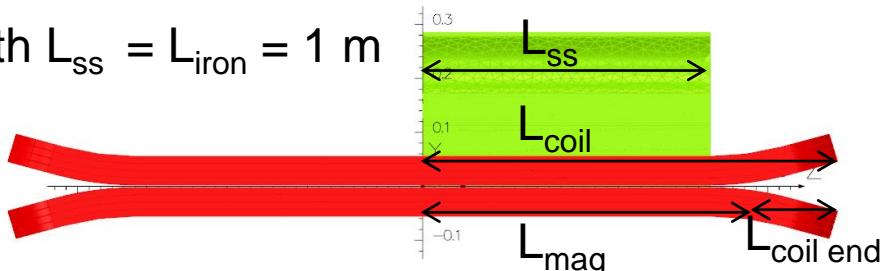


Long:



1. Peak field in the center ( $z = 0$ ) = 16.6 T for both cases
2. at the beginning of the coil ends  $\sim 16$  T
3. Peak field in the pole tip  $\sim 15$  T

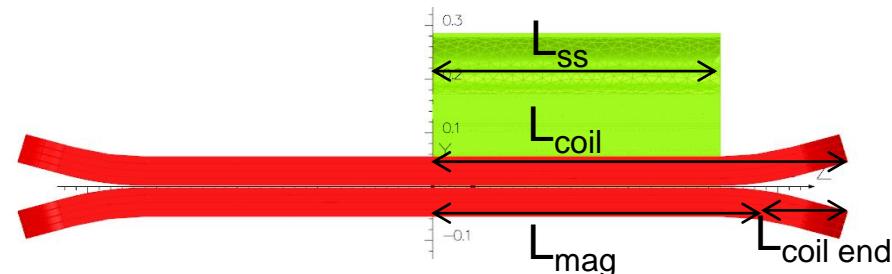
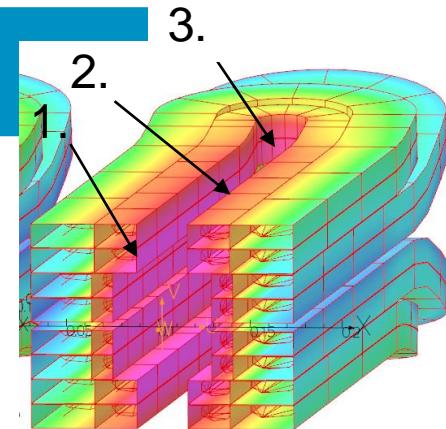
With  $L_{ss} = L_{iron} = 1$  m



- $B_{peak\ center} - B_{peak\ ends} = \Delta B_{peak} > 0.6$  T
- Additional operational margin in the ends

# 3D MAGNETIC DESIGN – SUMMARY

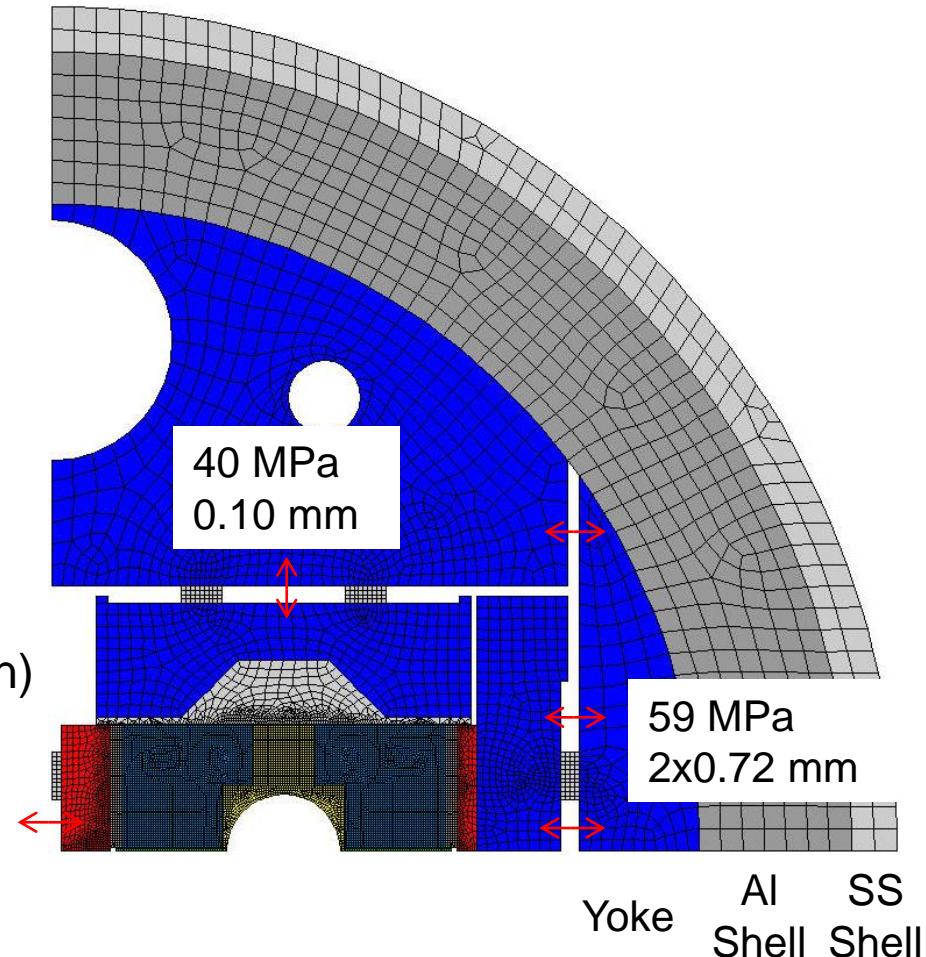
Parameter	Compact	Compact compensated	Long	Unit	
b3 integrated	-4.59	-2.70	0.08	units	
B <sub>peak1</sub> , z=0	16.6	16.6	16.6	T	
B <sub>peak2</sub> , bend	15.9	15.9	16.0	T	
B <sub>peak3</sub> , tip	15.0	15.0	15.2	T	
L <sub>straight section</sub>	500	500	500	mm (half length)	
L <sub>iron</sub>	500	500	500	mm (half length)	
L <sub>coil</sub>	722	722	813	mm (half length)	
L <sub>mag</sub>	642	642	678	mm (half length)	
L <sub>coil end</sub> = L <sub>coil</sub> - L <sub>mag</sub>	80	80	135	mm (per end)	



## Nominal:

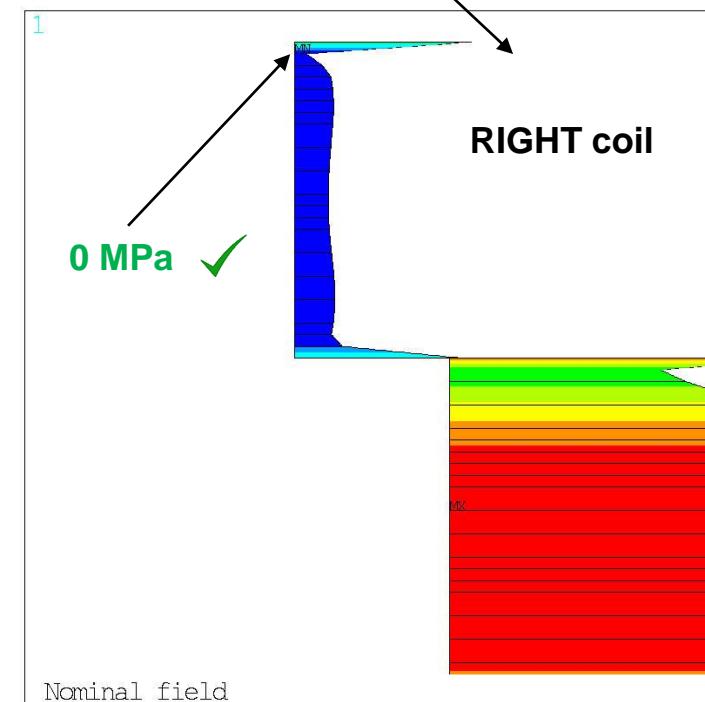
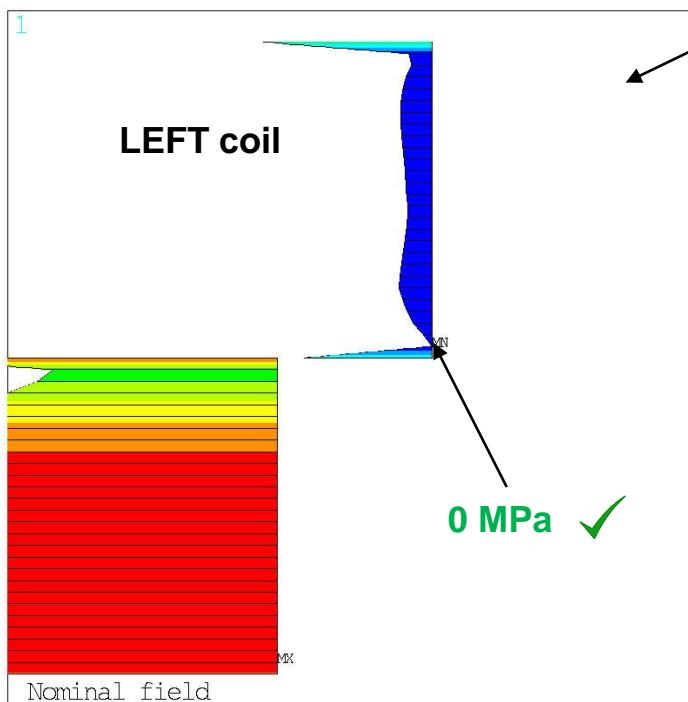
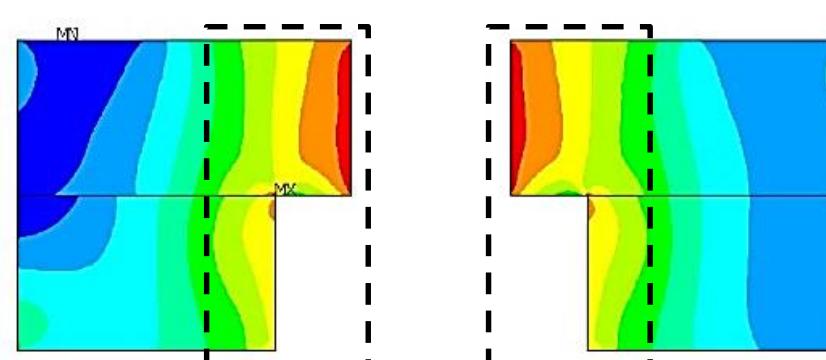
- Short ends
- Low harmonics
- Margin ( $\Delta B_{\text{peak}} > 0.6 \text{ T}$ )

- Geometry:
  - Interbeam distance = 204 mm
  - Outer yoke  $\varnothing$  = 570 mm
  - 67 mm Al shell + 20 mm SS shell
- ECC Coil properties (293K/4.2K):
  - $E_x = 25 \text{ GPa} / 27.5 \text{ GPa}$
  - $E_y = 30 \text{ GPa} / 33 \text{ GPa}$
- Pre-load:
  1. Bladders without SS shell
  2. 2 Horizontal + 2 Vertical keys
  3. Imposed displacement on SS shell bottom = -0.2 mm (260 MPa tension)
- Contacts:
  - Bonded: inside the coils, with the poles
  - Separation allowed with 0.2 friction: between the coils, with the structure



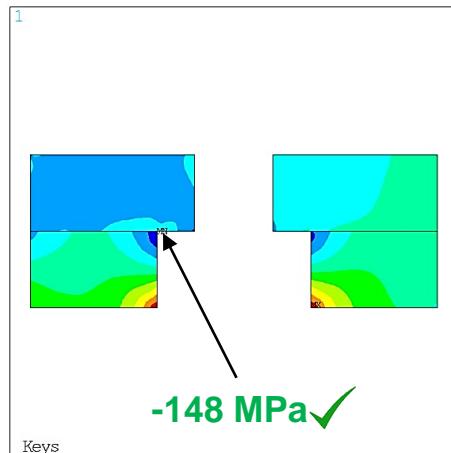
# 2D MECHANICAL DESIGN – COIL-POLE CONTACT

- Pre-load: interference tuned
- Operation at 16 T: contact pressure >0

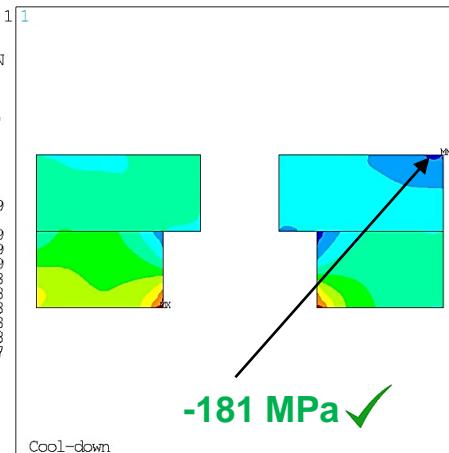


# 2D MECHANICAL DESIGN – COIL PEAK STRESS

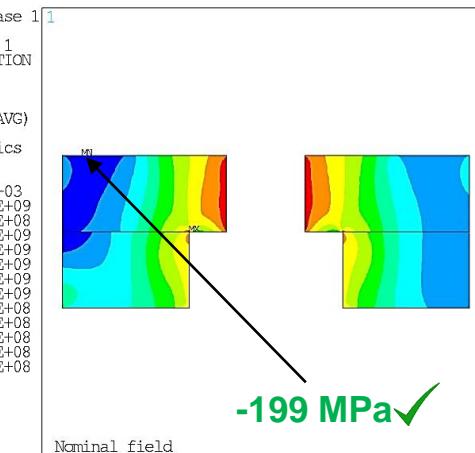
## Room-temperature pre-load



## Cool-down to 1.9K



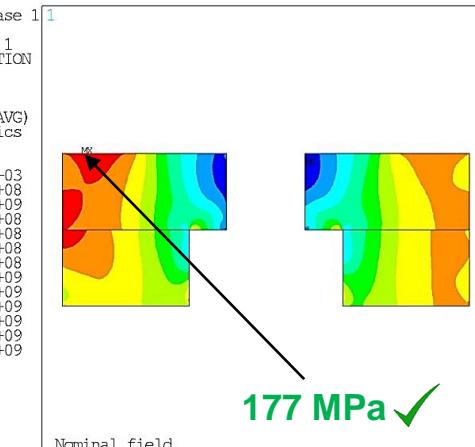
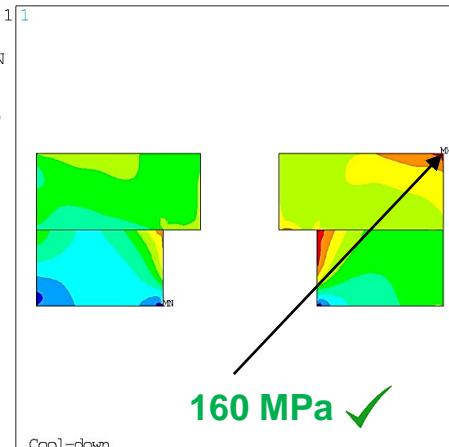
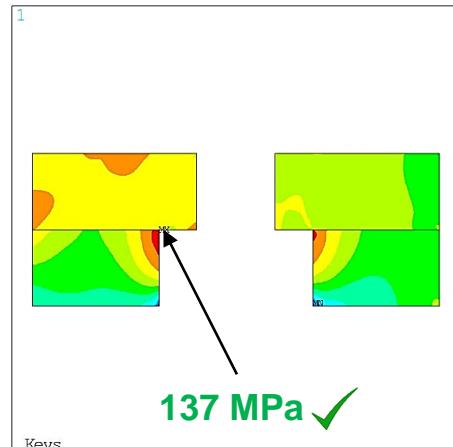
## Operation at 16 T



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SX (AVG)  
RSYS=0  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .657E-03  
SMN = -.199E+09  
SMX = .122E+08  
-.199E+09  
-.152E+09  
-.129E+09  
-.105E+08  
-.819E+08  
-.584E+08  
-.348E+08  
-.113E+08  
.122E+08

 $\sigma_x$  $\sigma_{\text{Von Mises}}$ 

Criteria: &lt;150 MPa

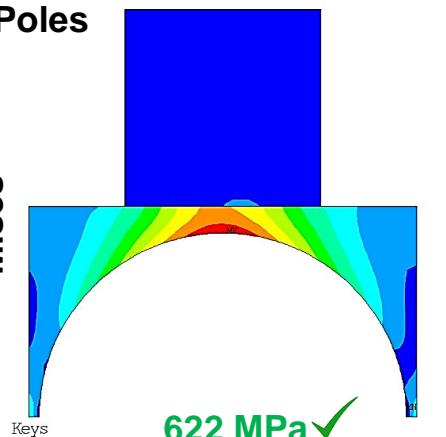


ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .657E-03  
SMN = .510E+09  
SMX = .177E+09  
.510E+07  
.242E+08  
.434E+08  
.625E+08  
.816E+08  
.101E+09  
.120E+09  
.139E+09  
.158E+09  
.177E+09

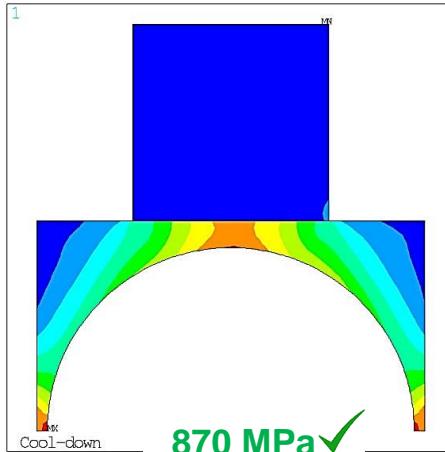
# 2D MECHANICAL DESIGN – STRUCTURE

## Room-temperature pre-load

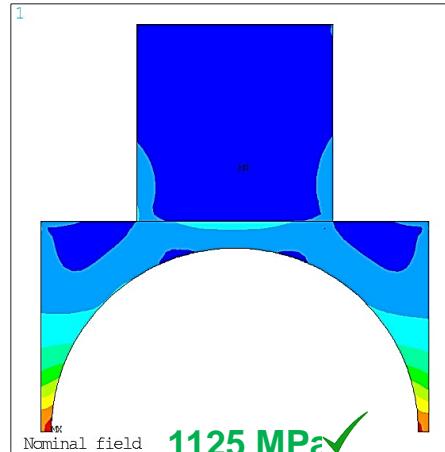
### Ti Poles



## Cool-down to 1.9K



## Operation at 16 T



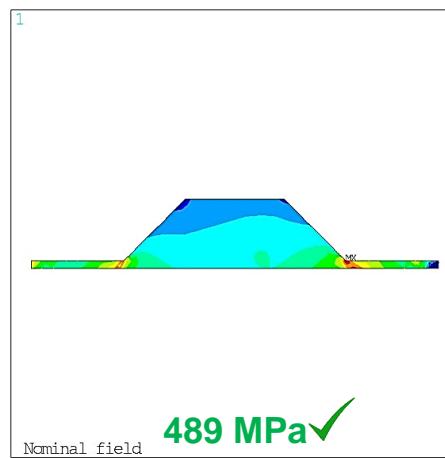
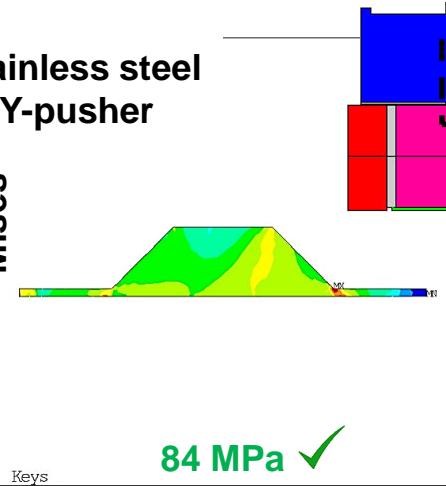
### Criteria:

<800 MPa

### Stainless steel

#### Y-pusher

### $\sigma$ Von Mises

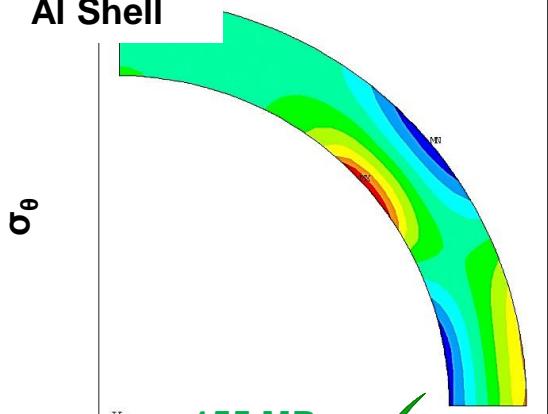


Criteria: <350 MPa

# 2D MECHANICAL DESIGN – STRUCTURE

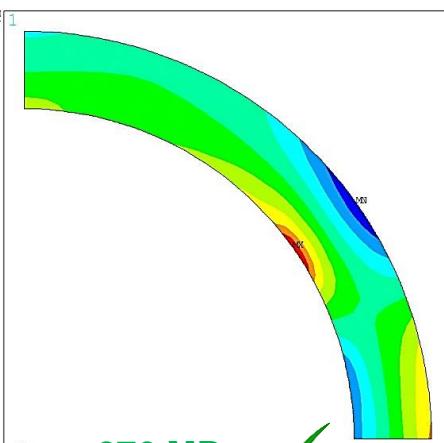
## Room-temperature pre-load

### Al Shell



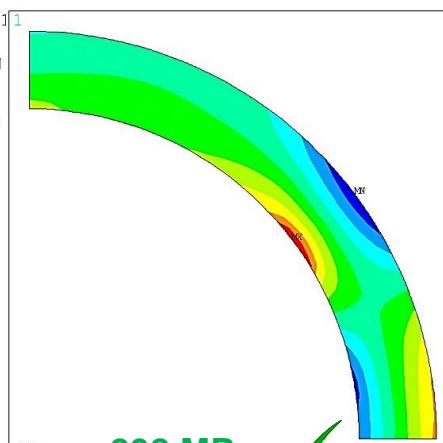
ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .832E-03  
SMN = -.353E+08  
SMX = .155E+09  
-.353E+08  
-.142E+08  
.699E-07  
.282E+08  
.493E+08  
.705E+08  
.917E+08  
.113E+09  
.134E+09  
.155E+09

## Cool-down to 1.9K



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001082  
SMN = .527E+08  
SMX = .276E+09  
.527E+08  
.775E+08  
.102E+09  
.127E+09  
.152E+09  
.177E+09  
.201E+09  
.226E+09  
.251E+09  
.276E+09

## Operation at 16 T



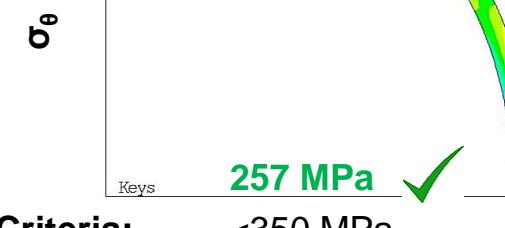
ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001155  
SMN = .384E+08  
SMX = .298E+09  
.384E+08  
.673E+08  
.961E+08  
.125E+09  
.154E+09  
.183E+09  
.212E+09  
.240E+09  
.269E+09  
.298E+09

## Criteria:

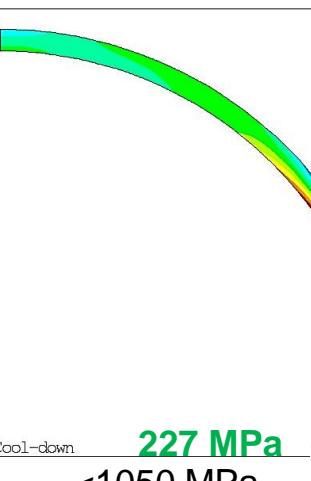
155 MPa ✓  
<480 MPa

### Stainless steel shell

$\sigma_\theta$



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .823E-03  
SMN = .118E+09  
SMX = .257E+09  
.118E+09  
.133E+09  
.149E+09  
.164E+09  
.180E+09  
.195E+09  
.211E+09  
.226E+09  
.242E+09  
.257E+09



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001144  
SMN = .875E+08  
SMX = .227E+09  
.875E+08  
.103E+09  
.119E+09  
.134E+09  
.149E+09  
.165E+09  
.180E+09  
.196E+09  
.211E+09  
.227E+09

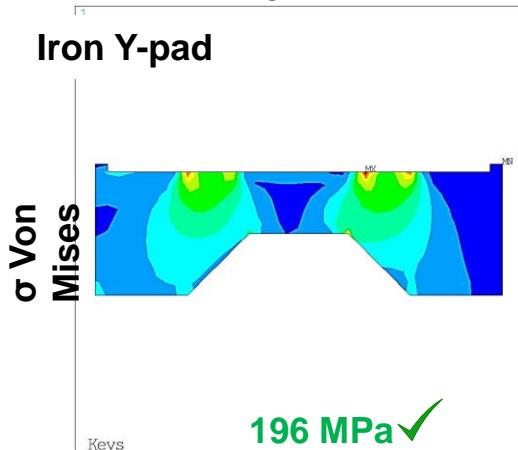


ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001216  
SMN = .796E+08  
SMX = .248E+09  
.796E+08  
.983E+08  
.117E+09  
.136E+09  
.155E+09  
.173E+09  
.192E+09  
.211E+09  
.230E+09  
.248E+09

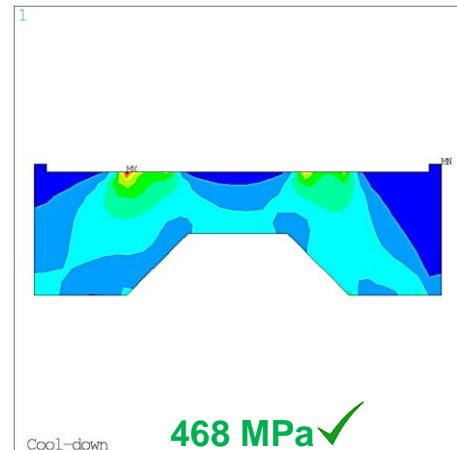
# 2D MECHANICAL DESIGN – STRUCTURE

## Room-temperature pre-load

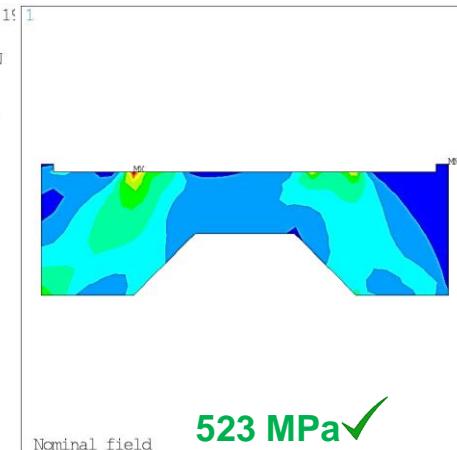
Iron Y-pad



## Cool-down to 1.9K

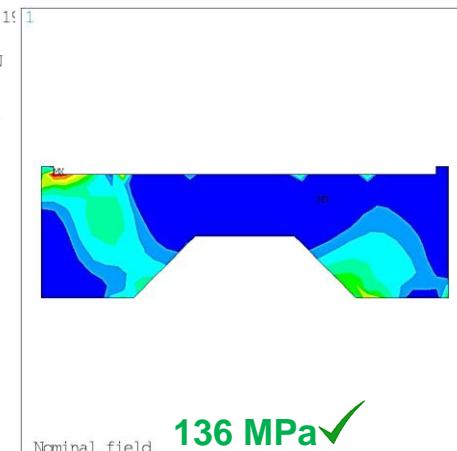
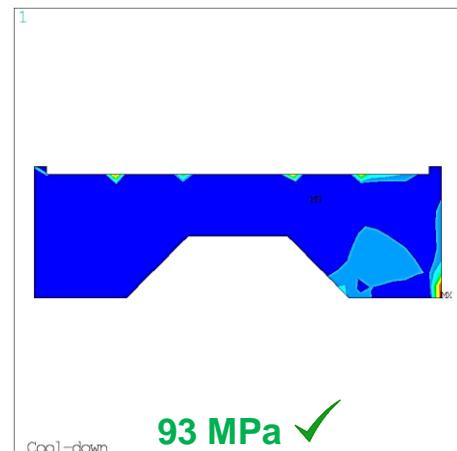
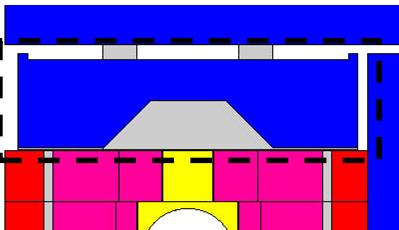


## Operation at 16 T



Criteria:  $<230 \text{ MPa}$        $<720 \text{ MPa}$        $<720 \text{ MPa}$

Sigma I:  
pure tension



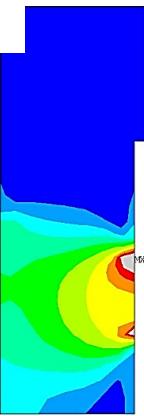
$<380 \text{ MPa}$

$<380 \text{ MPa}$

# 2D MECHANICAL DESIGN – STRUCTURE

## Room-temperature pre-load

Iron X-pad



$\sigma$  Von  
Mises

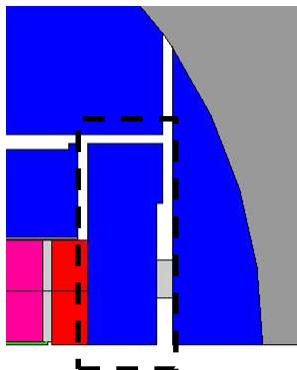
303 MPa

locally

Criteria:

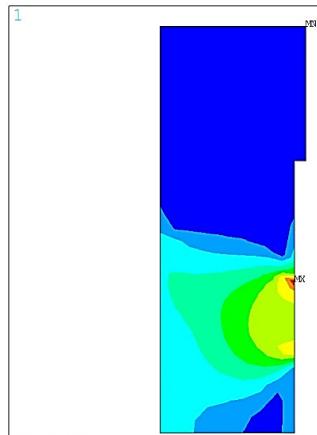
<230 MPa

Sigma I:  
pure tension



```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.149E-03
SMN =-1617.06
SMX =-.303E+09
0
.256E+08
.511E+08
.767E+08
.102E+09
.128E+09
.153E+09
.179E+09
.204E+09
.230E+09
```

## Cool-down to 1.9K

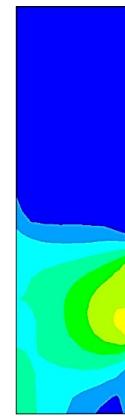


Cool-down

461 MPa

```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =1
TIME=2
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.596E-03
SMN =3603.87
SMX =.461E+09
3603.87
.535E+08
.102E+09
.154E+09
.205E+09
.256E+09
.307E+09
.358E+09
.410E+09
.461E+09
```

## Operation at 16 T



Nominal field

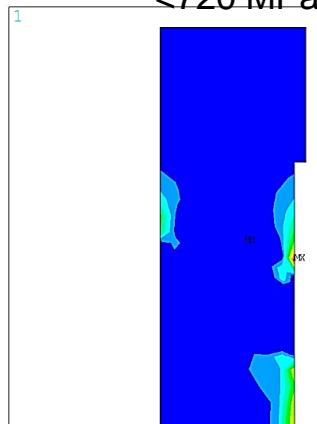
482 MPa

```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =1
TIME=3
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.479E-03
SMN =5650.68
SMX =.482E+09
5650.68
.535E+08
.102E+09
.154E+09
.205E+09
.256E+09
.307E+09
.358E+09
.410E+09
.482E+09
```

Criteria:

<230 MPa

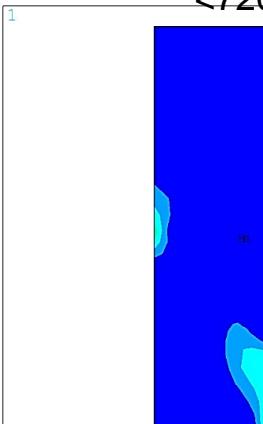
<720 MPa



Cool-down

<380 MPa

```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =1
TIME=2
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.596E-03
SMN =.145E+09
SMX =.188E+09
0
.161E+08
.321E+08
.628E+08
.125E+09
.253E+09
.506E+09
.101E+09
.202E+09
.404E+09
.808E+09
```



Nominal field

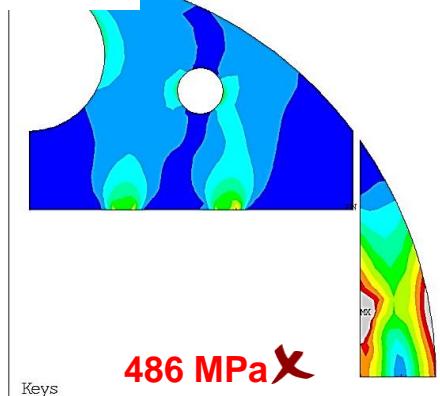
<380 MPa

```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =1
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.479E-03
SMN =.188E+09
SMX =.188E+09
0
.209E+08
.419E+08
.628E+08
.838E+08
.126E+09
.168E+09
.188E+09
```

# 2D MECHANICAL DESIGN – STRUCTURE

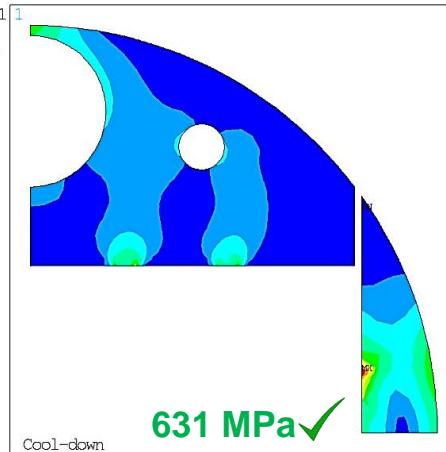
## Room-temperature pre-load

Iron Y-pad



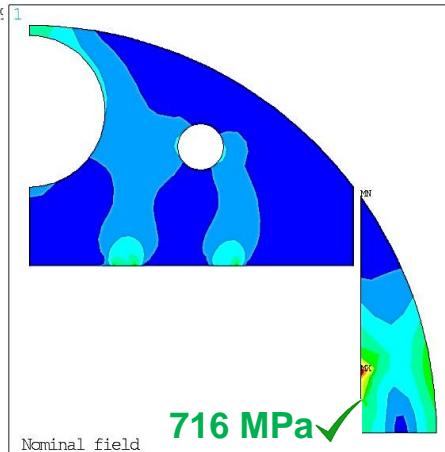
ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .842E-03  
SMN = 173720  
SMX = .486E+09  
0  
.256E+08  
.511E+08  
.767E+08  
.102E+09  
.128E+09  
.153E+09  
.179E+09  
.204E+09  
.230E+09

## Cool-down to 1.9K



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .745E-03  
SMN = 85411.8  
SMX = .631E+09  
85411.8  
.702E+08  
.140E+09  
.210E+09  
.280E+09  
.350E+09  
.421E+09  
.491E+09  
.561E+09  
.631E+09

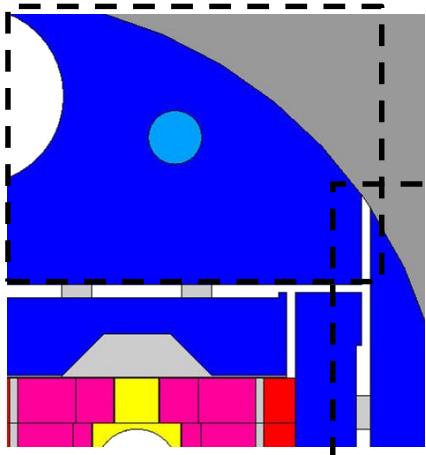
## Operation at 16 T



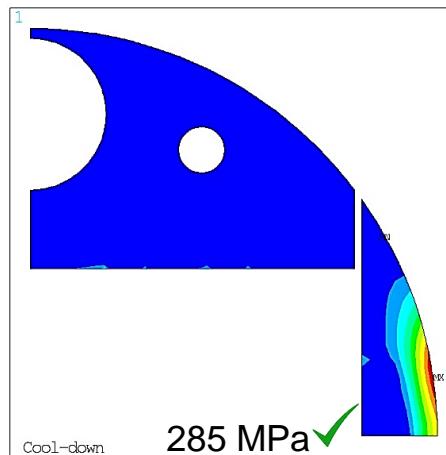
ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .817E-03  
SMN = 246328  
SMX = .716E+09  
246328  
.798E+08  
.159E+09  
.239E+09  
.319E+09  
.398E+09  
.478E+09  
.557E+09  
.637E+09  
.716E+09

Criteria:

<230 MPa

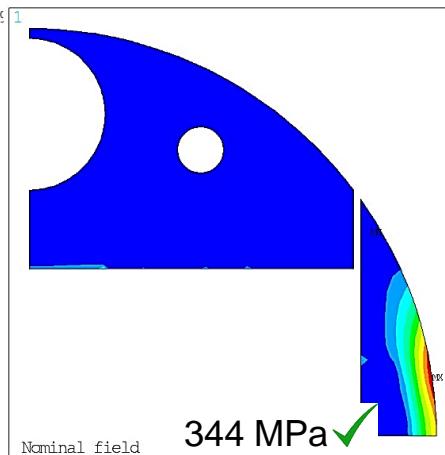


<720 MPa



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .745E-03  
SMX = .285E+09  
0  
.317E+08  
.633E+08  
.950E+08  
.127E+09  
.158E+09  
.190E+09  
.222E+09  
.253E+09  
.285E+09

<720 MPa



ANSYS Release 19.0  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .817E-03  
SMX = .344E+09  
0  
.382E+08  
.765E+08  
.115E+09  
.153E+09  
.191E+09  
.229E+09  
.268E+09  
.306E+09  
.344E+09

<380 MPa

# CONCLUSION

- 2d magnetic design:
  - **16 T at 14 %** of LL margin at 1.9 K
  - At collision: **b3 and higher orders < 3 units** (absolute value)  
**b2 ~ -40 units**
  - At injection: **b3 ~ -30 units**  
→ **block-coil more favorable** than other designs  
b5 and higher orders < 10 units
- 3d magnetic design:
  - **Compact ends**
  - **Similar values for integrated harmonics**
  - **Additional margin in coil ends** ( $\Delta B_{peak} > 0.6 \text{ T}$ )
- 2d mechanical design:
  - **Coil stress < criteria**
  - **Iron X-Pad + Yoke: locally > criterion at warm**
  - **Other components: stress < criteria**

## Short-term future (2018-2019)

- Coil end design to be validated by a 3D mechanical study
  - Compact ends favorable for:
    - Limited number of parts
    - Easier pre-load because of aligned blocks
    - EM Forces more balanced between the blocks
- Protection:
  - To be updated by protection team

→ should stay below the limits (minor modifications wrt previous designs)

## Mid-term future (~2022)

- F2D2: a block-coil short model dipole toward FCC

→ See presentation « The CEA 16T model for the FCC », E. Rocheapault

DE LA RECHERCHE À L'INDUSTRIE



BACKUP SLIDES

# CONDUCTOR PARAMETERS

PARAMETER	Values		Unit
Strand diameter	1.1	0.7	mm
Number of strands	21	34	adim
Unreacted width	12.47	12.47	mm
Unreacted thickness	1.94	1.23	mm
Reacted width	12.6	12.6	mm
Reacted thickness	2.00	1.27	mm
Copper/non-Copper ratio	0.8	2.0	adim
Insulation thickness	0.15	0.15	mm
Bare cable compaction	11.8	12.0	%
Packing factor	85.4	88.2	%
Transposition pitch	93	93	mm

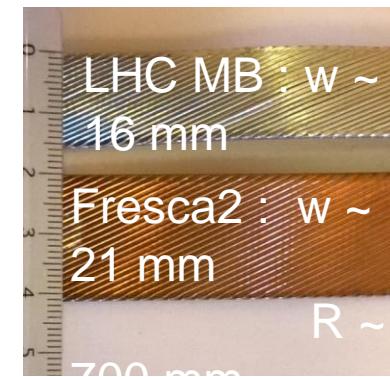
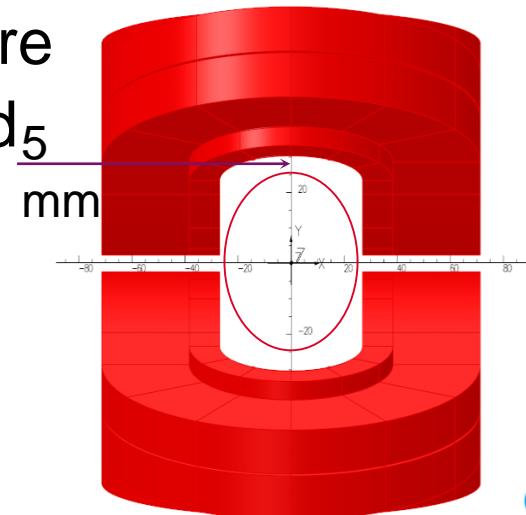
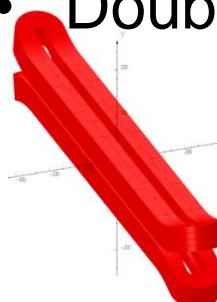
C. Lorin,  
Oct 17 review

J. Fleiter: Rutherford cable design approach and experience at CERN ([here](#))

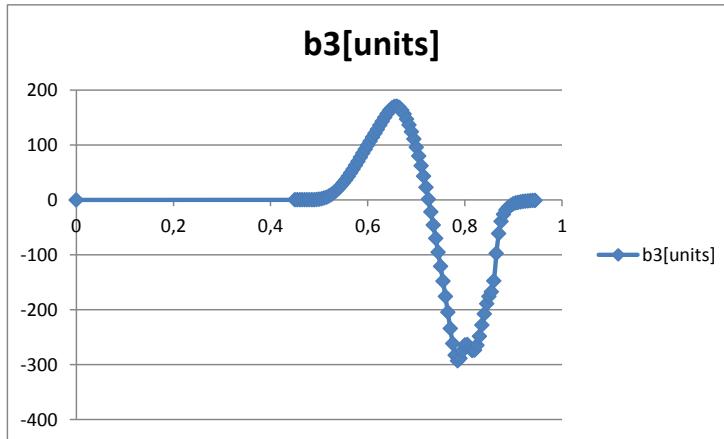
Parameter	Unit	11 T RRP for LS2	11 T PIT for LS2	MQXF (PIT and RRP)	FRESCA2	ERMC	SMC
Number of strands	(-)	40	40	40	40	40	18
Strands diameter	mm	0.70	0.70	0.85	1.0	1.0	1.0
Cable bare width	mm	14.70	14.70	18.15	20.9	20.9	10
Cable bare thickness	mm	1.250	1.250	1.525	1.82	1.82	1.81
<b>Keystone angle</b>	°	<b>0.79</b>	<b>0.50</b>	<b>0.40</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>Thin edge compaction*</b>	%	<b>17.95</b>	<b>15.3</b>	<b>14.02</b>	<b>9.0</b>	<b>9.0</b>	<b>9.5</b>
Thick edge compaction*	%	3.48	6.13	6.57			
Transposition pitch	mm	100	100	109	120	120	63
SS Core width (thickness)	mm		12 (0.0025)		NO	14 (0.0025)	NO

# 3D magnetic design

- Assumptions:
  - Return ends – 1000 mm straight section
  - Hardway bend :  $R_{min} = 450$  mm in upper layer ( $w = 12.6$  mm)
    - Strain 13.8 mm/m (HD2: 30.6 mm/m HD3: 12.4 mm/m Fresca2: 15.3 mm/m)
  - Coil-to-aperture y-dire
  - Double pancake end<sub>5</sub>



# 3D HARMONICS



$$Ib_n = \frac{\int B_n(z) dz}{\int B_1(z) dz} = \frac{\int B_n(z) dz}{L_{mag} \cdot B_{ref}} = \frac{\int b_n(z) dz}{L_{mag}}$$

$$Ib_{n,short} = \frac{\int_{short} b_n(z) dz}{L_{mag,short}}$$

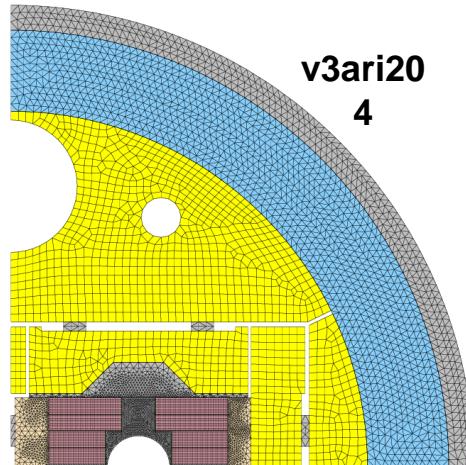
$$Ib_n = \frac{\int_{short} b_n(z) dz + b_n(0) \cdot (L_{mag} - L_{mag,short})}{L_{mag}}$$

$$Ib_n = \frac{Ib_{n,short} \cdot L_{mag,short} + b_n(0) \cdot (L_{mag} - L_{mag,short})}{L_{mag}}$$

Ex: -10 units on a short length

$$Ib_3 = [ -10 \text{ units} \times 0.68 \times 2 - 0.8 \text{ units} \times (14.069 - 0.68 \times 2) ] / 14.069 \\ = \mathbf{-1.69 \text{ units}}$$

# 2D MECHANICAL DESIGNS



Interbeam distance = 204 mm

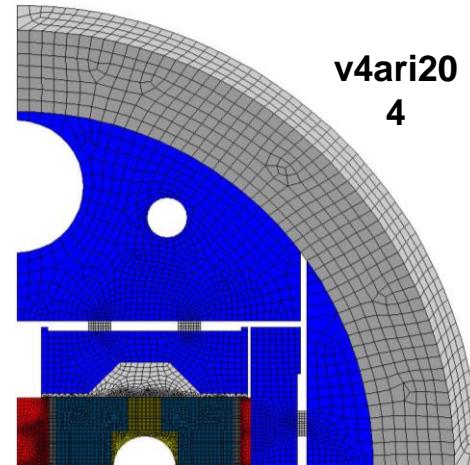
$\varnothing_{ext}$  iron yoke = 570 mm

Total  $\varnothing_{ext}$  = 740 mm

65 + 20 mm thick shells

→ 2 x 0.67 mm ←

	$\sigma_x$ max	$\sigma$ Von Mises max
Keys + SS shell	-170	149
Cool-down	-205	188
Energization 16 T	-188	178



Interbeam distance = 204 mm

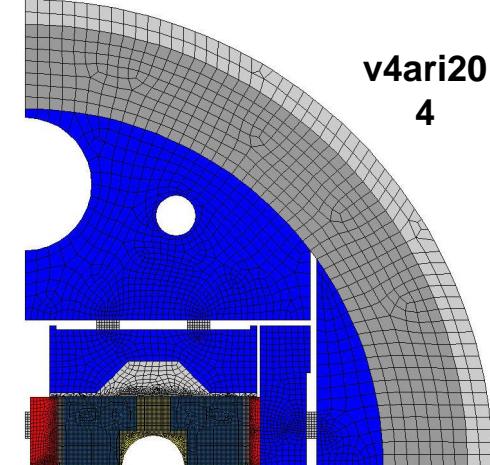
$\varnothing_{ext}$  iron yoke = 570 mm

Total  $\varnothing_{ext}$  = 740 mm

65 + 20 mm thick shells

1.51mm ←

	$\sigma_x$ max	$\sigma$ Von Mises max
Keys + SS shell	-135	123
Cool-down	-184	170
Energization 16 T	-214	186



Interbeam distance = 204 mm

$\varnothing_{ext}$  iron yoke = 570 mm

Total  $\varnothing_{ext}$  = 744 mm

67 + 20 mm thick shells

→ 2 x 0.72 mm ←

	$\sigma_x$ max	$\sigma$ Von Mises max
Keys + SS shell	-148	137
Cool-down	-181	160
Energization 16 T	-199	177

# Material properties

(Davide 3<sup>rd</sup> FCC week)

## Coil maximum stress

- @ 4.2 K: 200 MPa
- @ 300 K: 150 MPa

Material	$R_{p\ 0.2}$ [MPa]	
	293 K	4.3 K
Al 7075	480	690
SS 316 LN	350	1050
NITRONIC 40	350	1240
Ferromagnetic iron	230	720*
Ti 6Al 4V	800	1650

Material	E [GPa]		pr	$(L_{4.3K} - L_{293K}) / L_{293K}$
	293 K	4.3 K	293K/4.3K	293 K -> 4.3K
Coil	EX = 25 EY = 30 GXY = 21	EX = 27.5 EY = 33 GXY = 21	0.3	X = 3.36e-3 Y = 3.08e-3
StSt	193	210	0.28	2.84e-3
Iron	213	224	0.28	1.97e-3
Aluminum	70	79	0.34	4.2e-3
Titanium	115	126.5	0.3	1.74e-3
Nitronic 40	210	225	0.28	2.6e-3

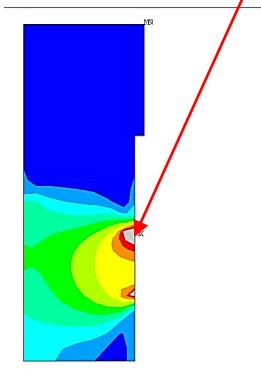
\*Ferromagnetic iron @ 4.2 K stress < 380 MPa in tension (1st principal stress)

# 2D MECHANICAL DESIGN – STRUCTURE

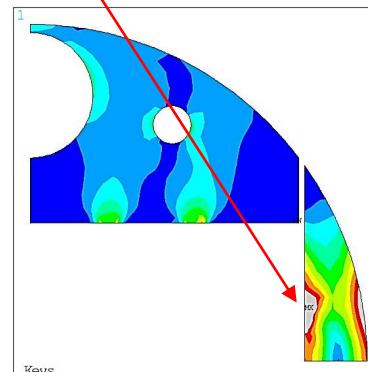
Von Mises [MPa]

Component	Material	Pre-load	1.9 K	16 T	Crit. 293K	Crit 1.9 K
Poles	Ti6Al4V	622	870	1125	800	1650
Y-Pusher	Stainless steel	84	369	489	350	1050
Y-Pad	Iron	196	468	423	230	720
X-Pad	Iron	303	461	482	230	720
Yokes	Iron	486	631	716	230	720
Al shell	Al	155	275	289	480	690
SS shell	Stainless steel	260	230	250	350	1050

Within spec  
At spec or  
localized  
Outside spec



```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQ=1 (AVG)
PostGraphics
EFACTET=1
AVRES=Mat
DMX =.149E-03
SMX =1617.06
SMR =.303E+09
0
.256E+08
.511E+08
.767E+08
.102E+09
.128E+09
.153E+09
.179E+09
.204E+09
.230E+09
```



```
ANSYS Release 15
Build 19.0
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQ=1 (AVG)
PostGraphics
EFACTET=1
AVRES=Mat
DMX =.842E-03
SMX =173720
SMR =.486E+09
0
.256E+08
.511E+08
.767E+08
.102E+09
.128E+09
.153E+09
.179E+09
.204E+09
.230E+09
```

