EuroCircol

2nd Review of the EuroCircol WP5

Block coil: mechanics

CEA

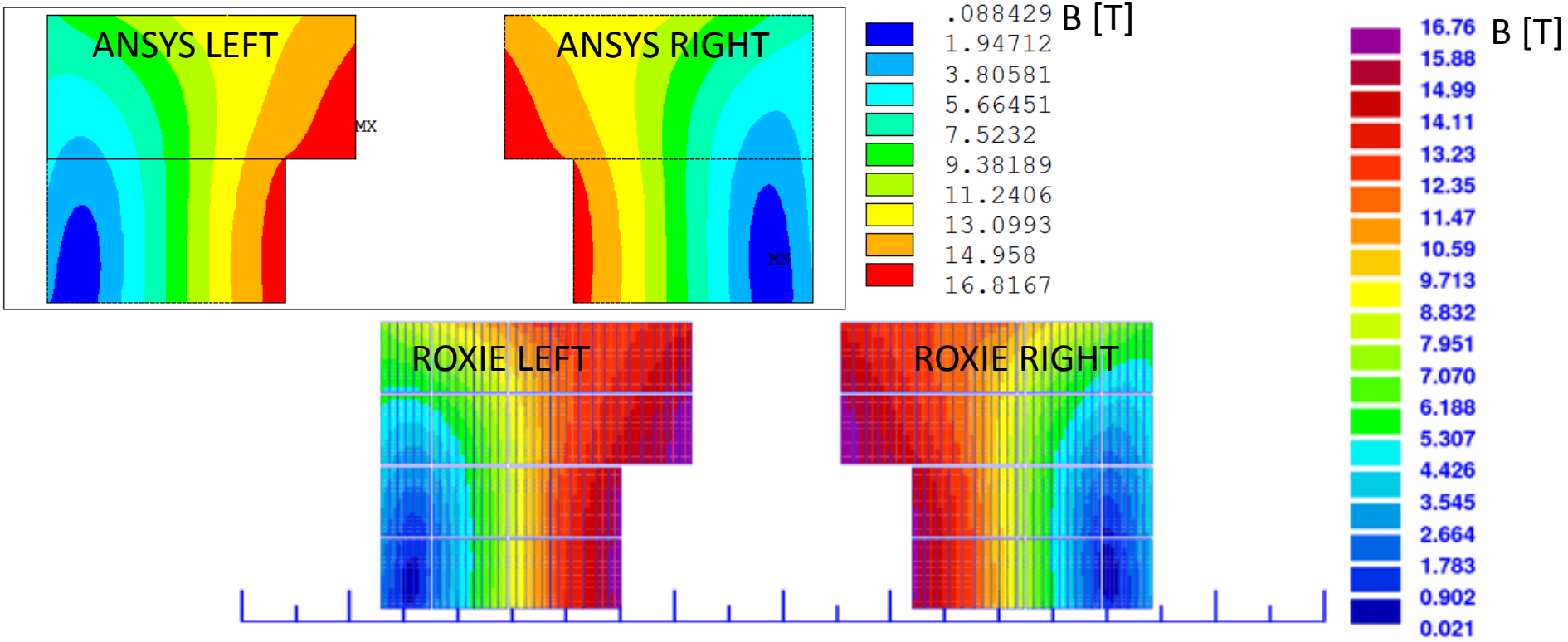
CERN, 9 oct 2017

Mechanical investigation

- Double aperture model 194 mm interbeam
- Investigation up to 16.0 T central field (100% of nominal current)
- Bladder&key structure
- 2D analysis

Magnetism Roxie-Ansys

- Ansys: Coefficient 1.01 on the current: 10 100 A instead of 10 000 A in Roxie



kN/m	Roxie	Roxie	Ansys	Ansys
	Left	Right	Left	Right
Fx	-8269	7636	-8259	7634
Fy	-3535	-2960	-3649	-3071

Material properties (davide 3rd FCC week)

- Coil maximum stress
  - @ 4.2 K: 200 MPa
  - @ 300 K: 150 MPa

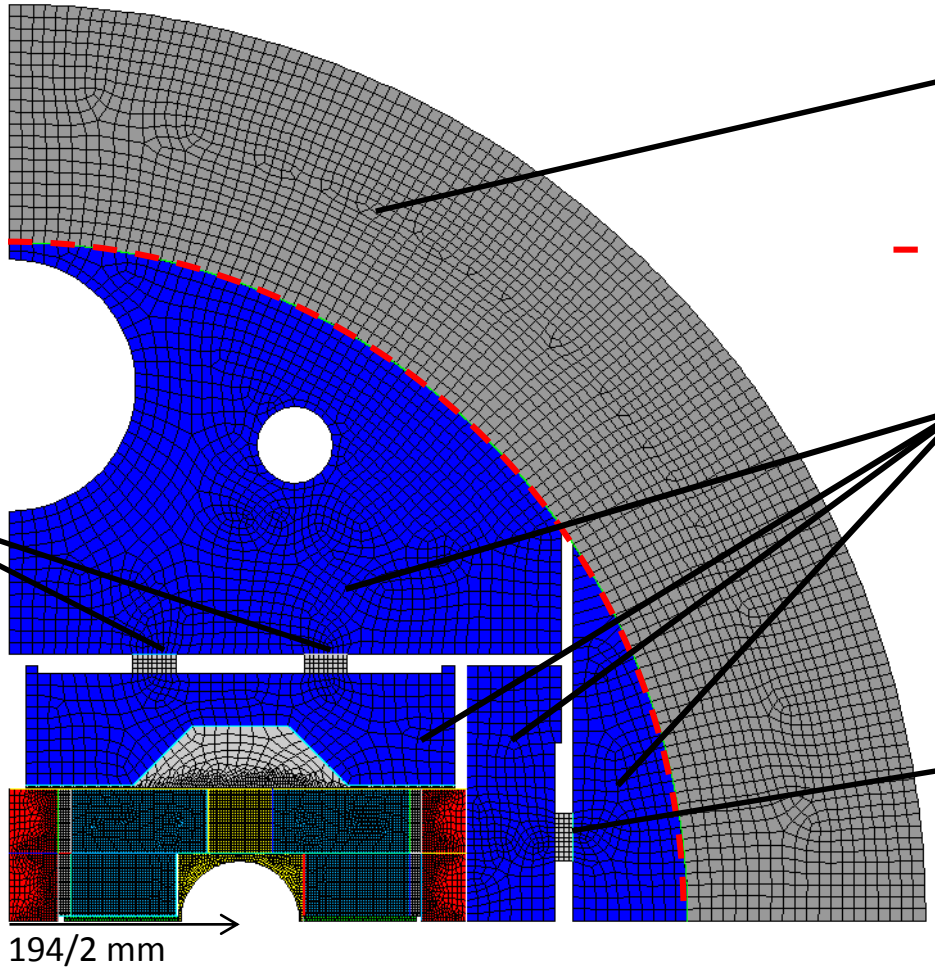
Material	$R_{p\ 0.2}$ [MPa]	
	293 K	4.3 K
Al 7075	480	690
SS 316 LN	350	1050
NITRONIC 40	350	1240
Ferromagnetic iron	~~180~~ 230	720*
Ti 6Al 4V	800	1650

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 = ~~44~~ 25 EY = ~~52~~ 30 GXY = 21	EX = ~~44~~ 27.5 EY = ~~52~~ 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	~~130~~ 115	~~130~~ 126.5	0.3	1.74e-3
Nitronic 40	210	225	0.28	2.6e-3

*Ferromagnetic iron @ 4.2 K stress < ~~200~~ 380 MPa in tension (1st principal stress)

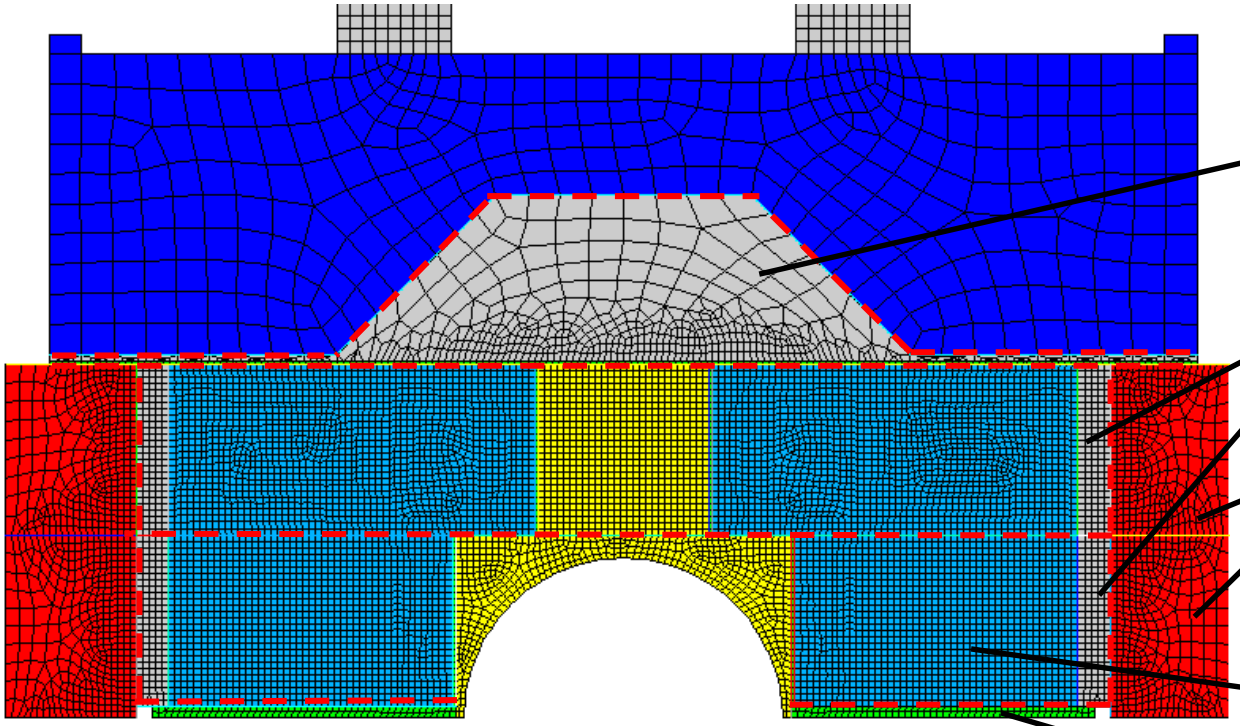
2D model description

- Double aperture: 194 mm interbeam



2D model description

– – – Sliding contact: c.o.f. 0.2 with seperation



Pusher: 316L

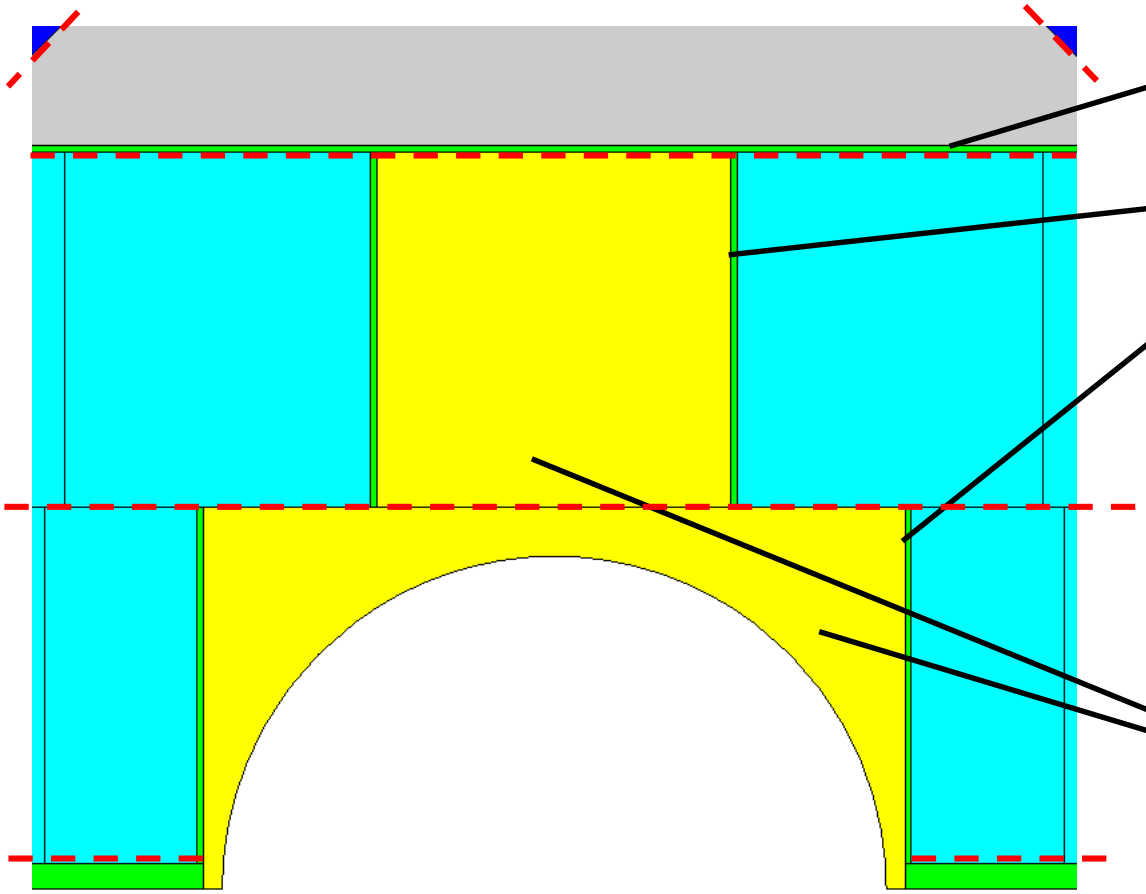
Shoe: 316L

Rail: Al-Bronze (still opened)

Coil: Nb_3Sn

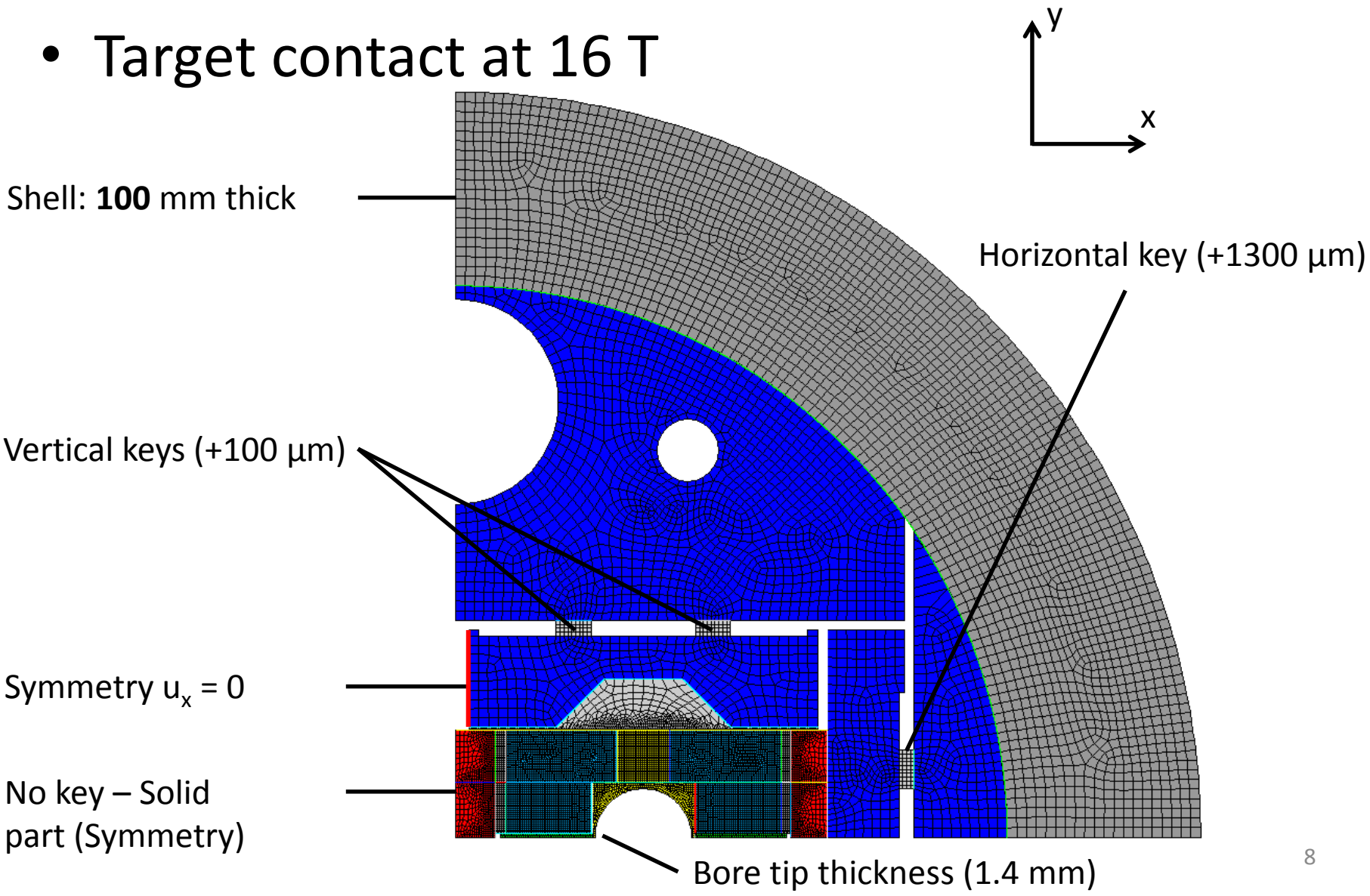
Mid-plane shim: G10

2D model description



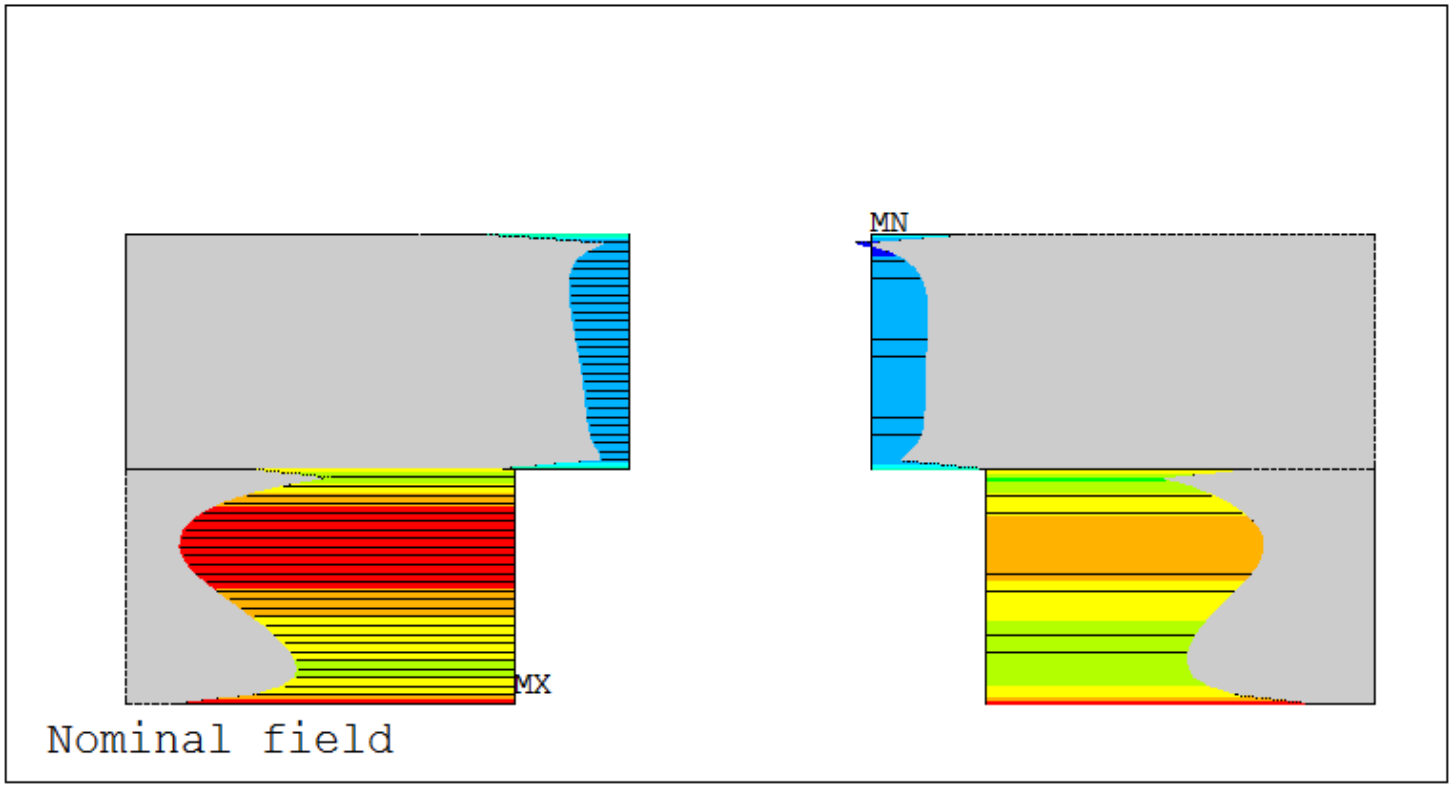
Model features

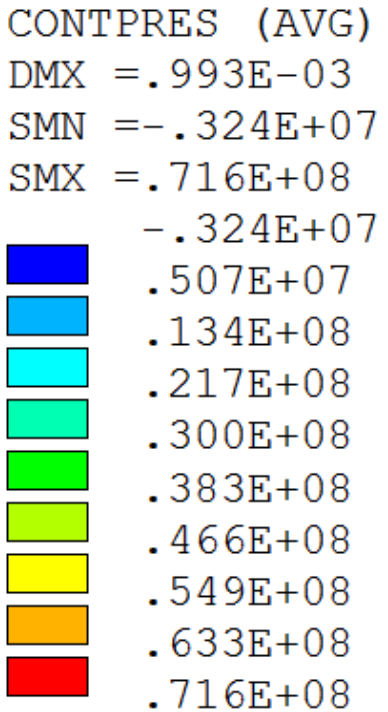
- Target contact at 16 T



Contact at 16 T

- Distribution under nominal operation:
  - Reminder Fx_left = 8.3 MN/m; Fy_left = 3.5 MN/m
  - Contact from -3 MPa (tension) to 72 MPa (compression)

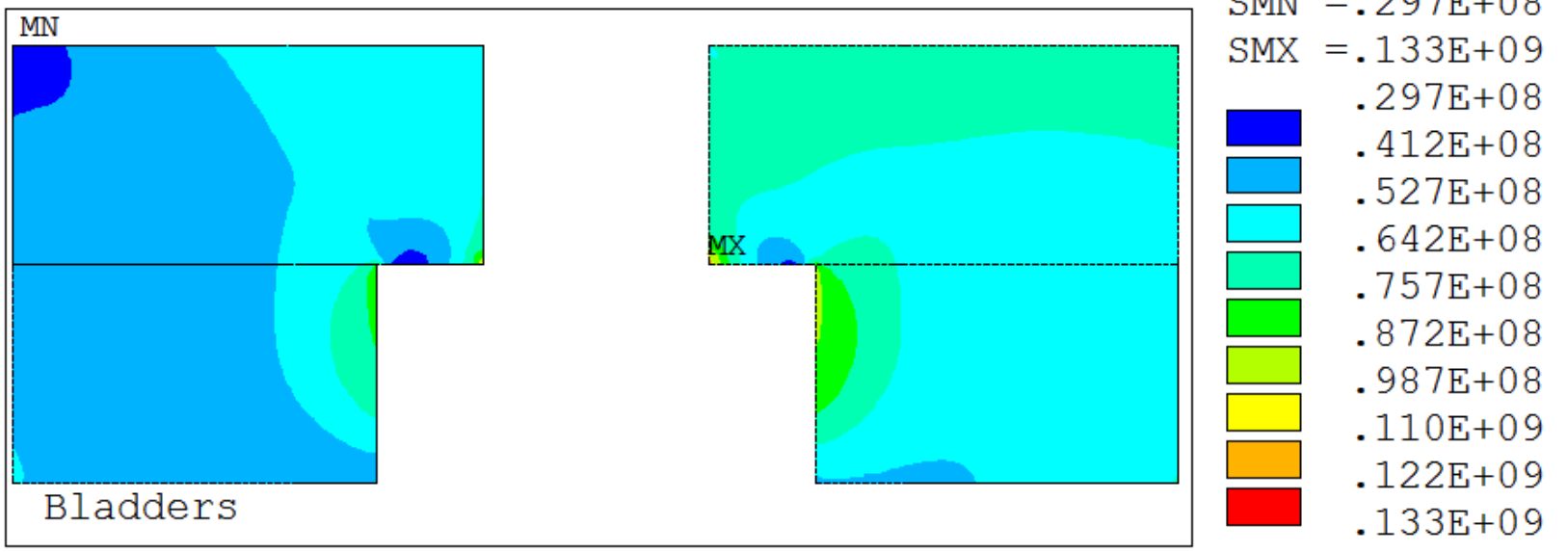




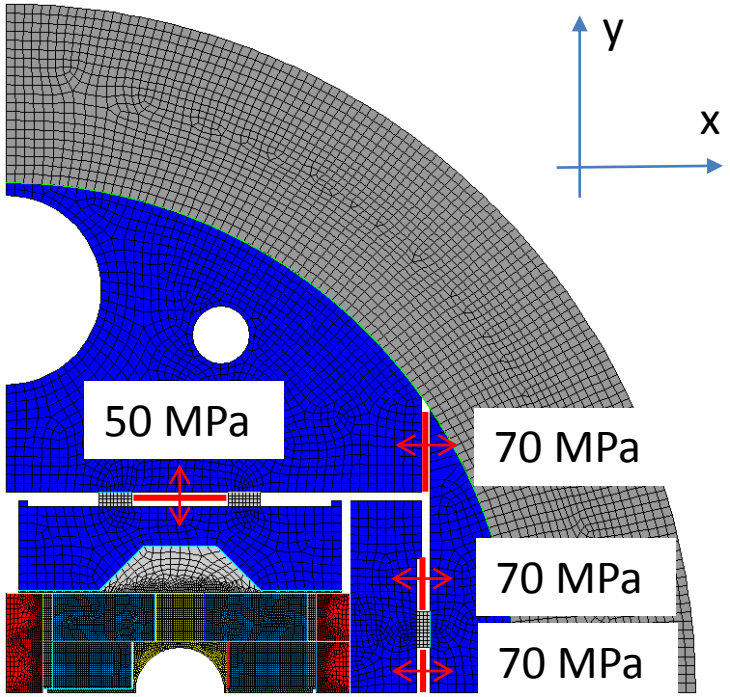
Nb_3Sn coil stress (bladders)

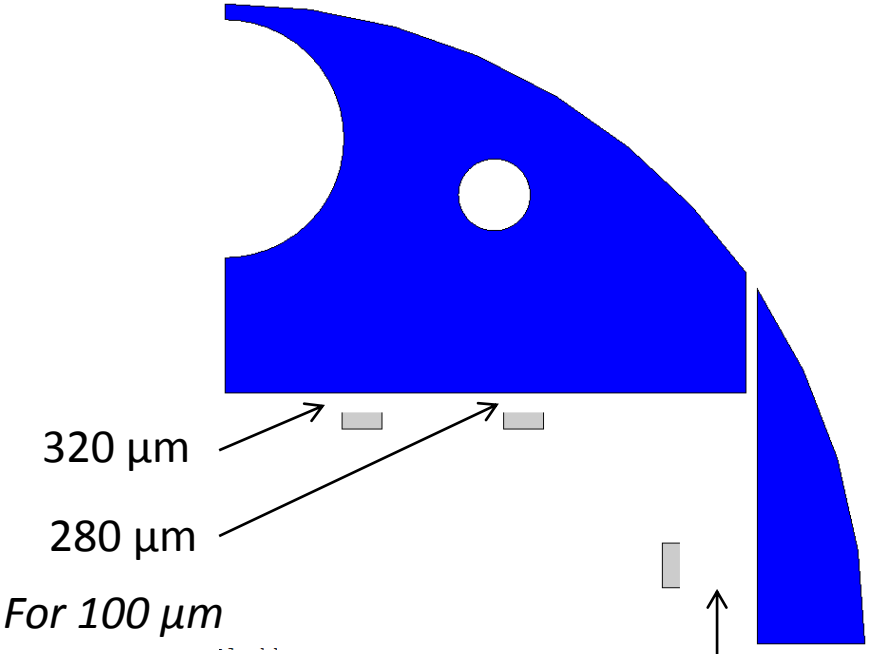
- Von Mises stress (bladders inflated)

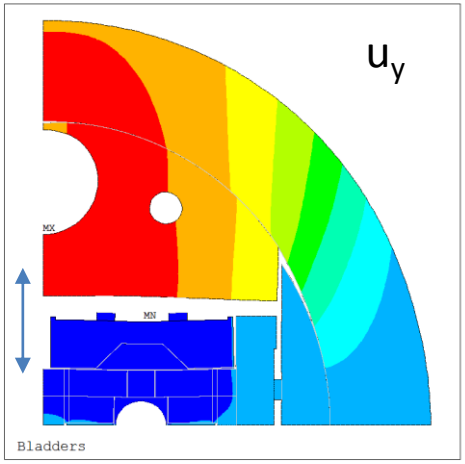
Peak von Mises stress: 133 MPa

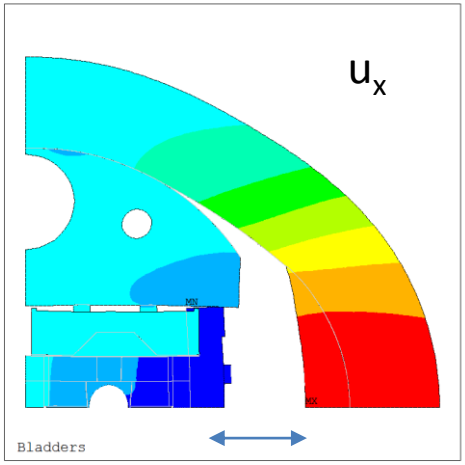


Bladder inflation





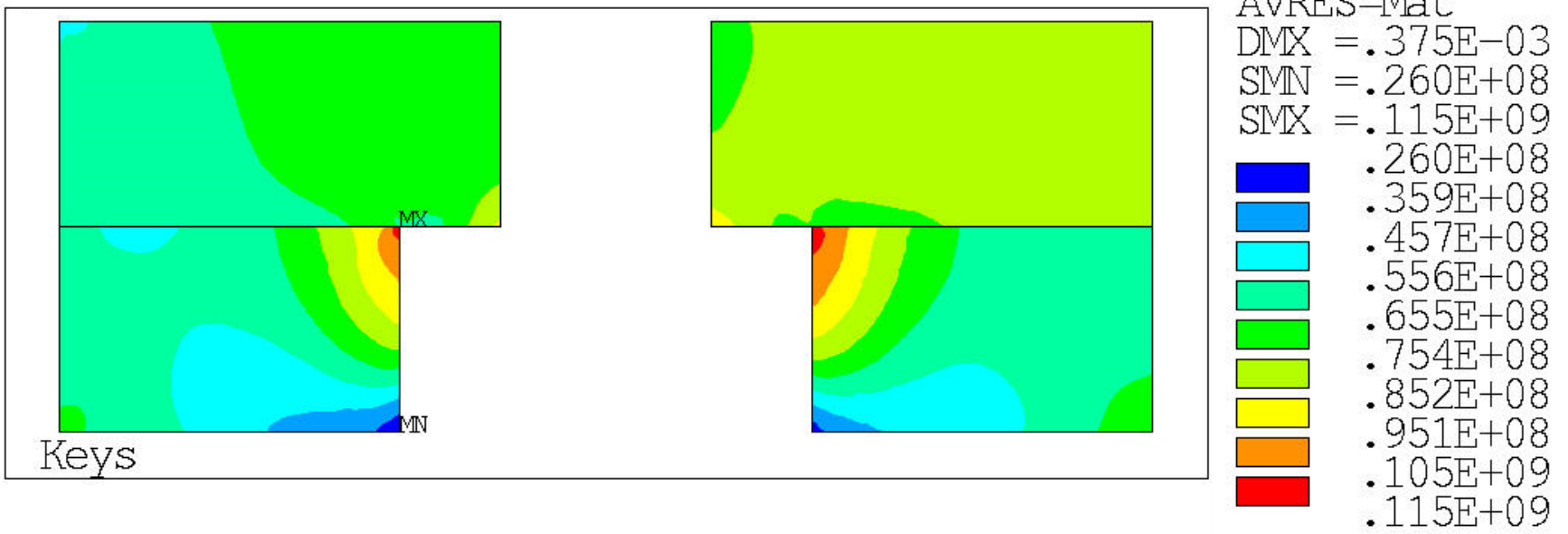




Nb_3Sn coil stress (keys in)

- Von Mises stress (keys in)

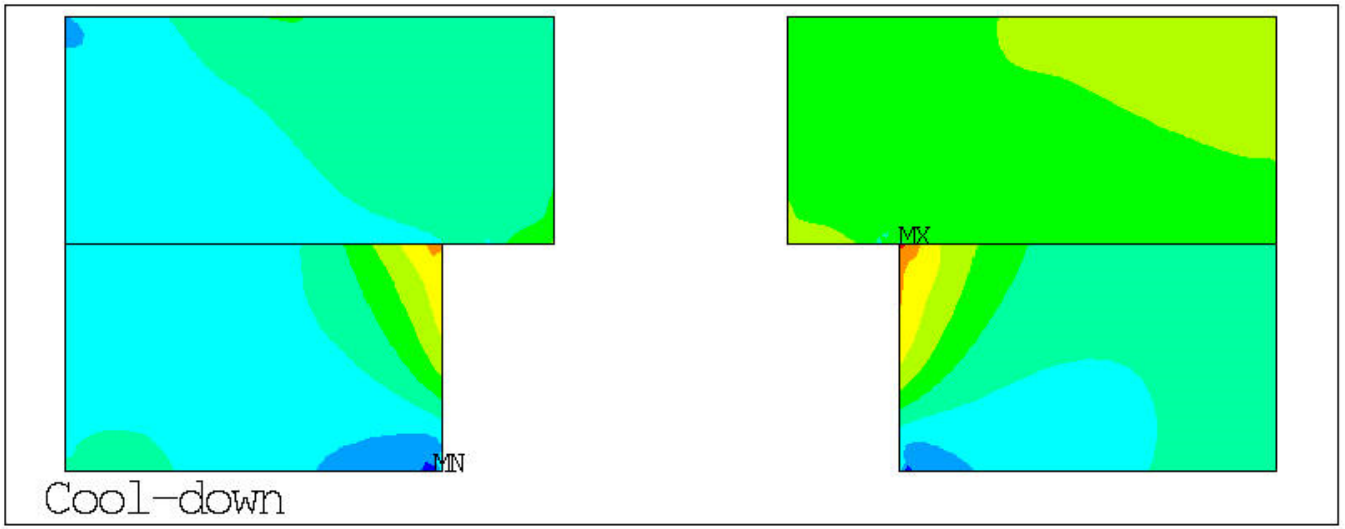
Peak von Mises stress: 115 MPa

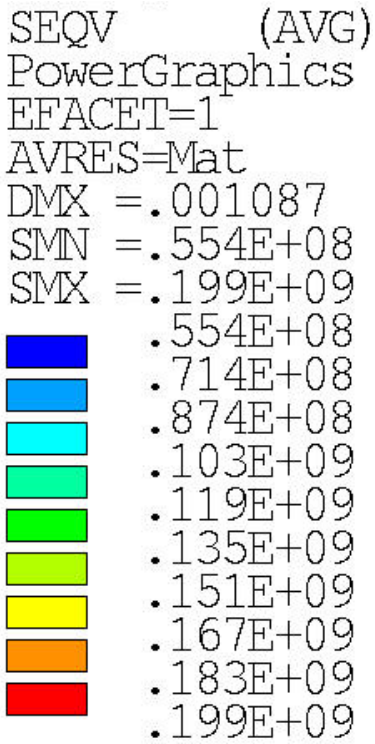


Nb_3Sn coil stress (cool-down)

- Von Mises stress (cool-down)

Peak von Mises stress: 199 MPa

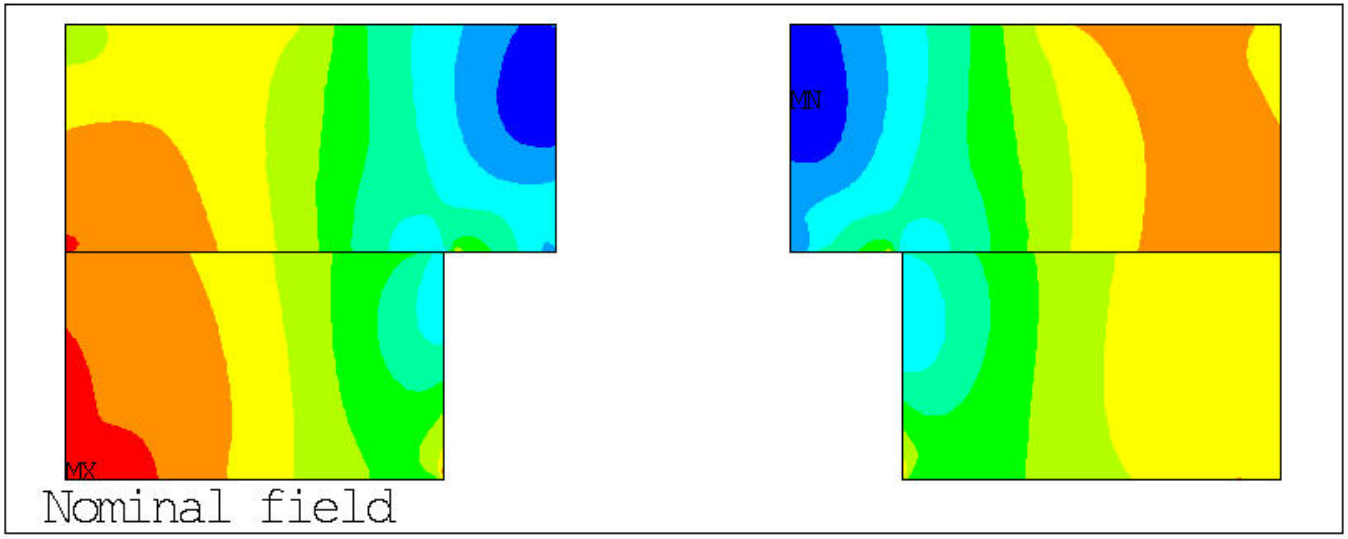


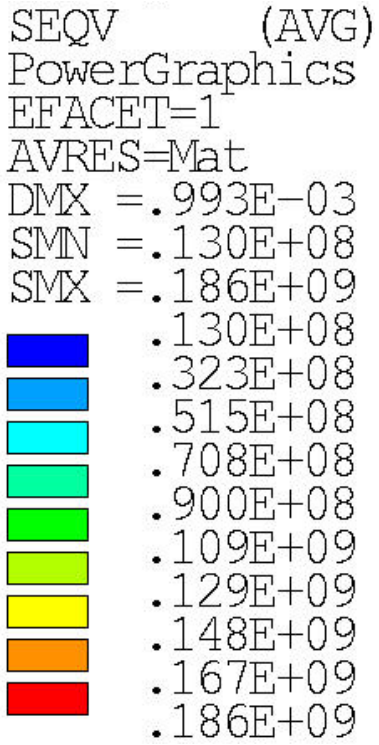


Nb_3Sn coil stress (16 T)

- Von Mises stress (16 T)

Peak von Mises stress: 186 MPa





Summary of peak stresses

- Summary peak stress values:

σ von Mises [MPa]	Left	Right
Bladder	114	133
Key	115	113
Cool-down	188	199
Powering 16 T	186	160

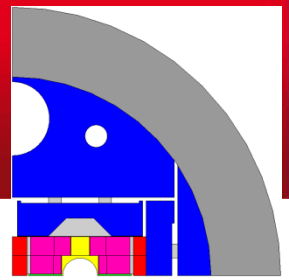
Right: To better balance

σ_x [MPa]	Left	Right
Bladder	-92	-102
Key	-123	-121
Cool-down	-205	-218
Powering 16 T	-205	-180

Right: To better balance

-> To better balance the right part, one can play on the positioning/width/thickness of the vertical/horizontal keys (to be done)

Pole



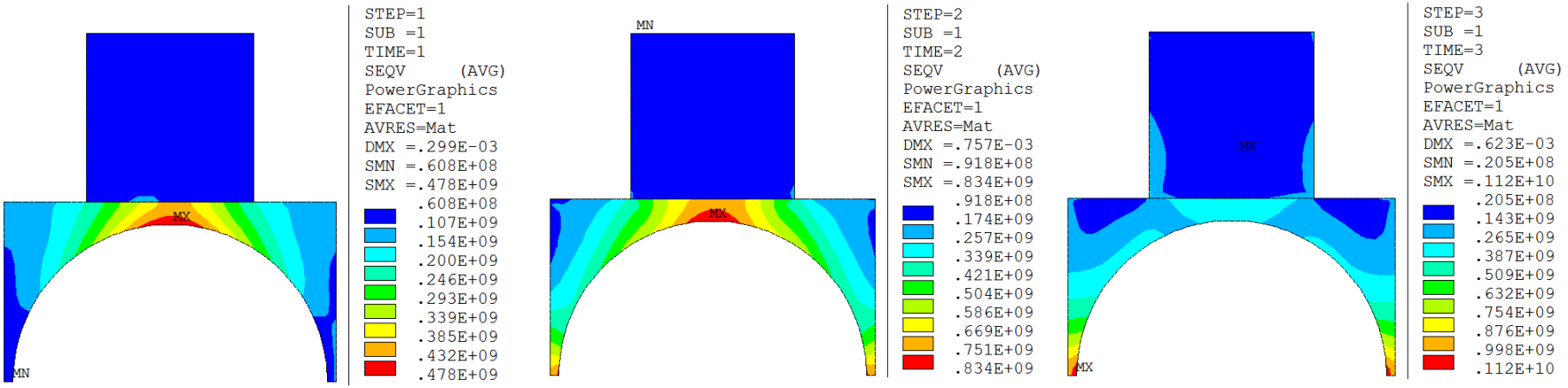
- Pole: von Mises stress

	293 K	4.3 K
Ti 6Al 4V	800	1650

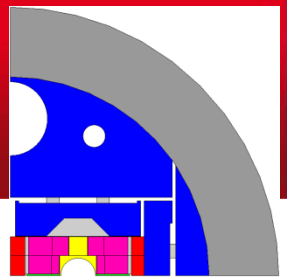
Keys in
478 MPa ✓

Cold
834 MPa ✓

16 T
1120 MPa ✓



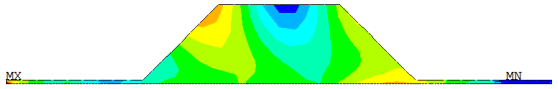
Pusher

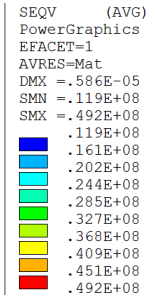


- Pusher: von Mises stress

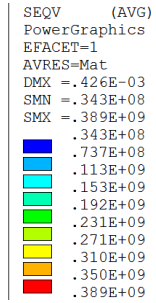
	293 K	4.3 K
SS 316 LN	350	1050

Keys in
50 MPa

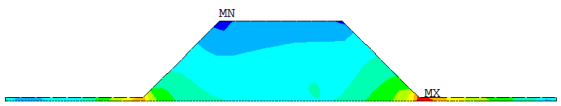


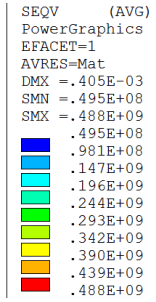


Cold
389 MPa



16 T
488 MPa

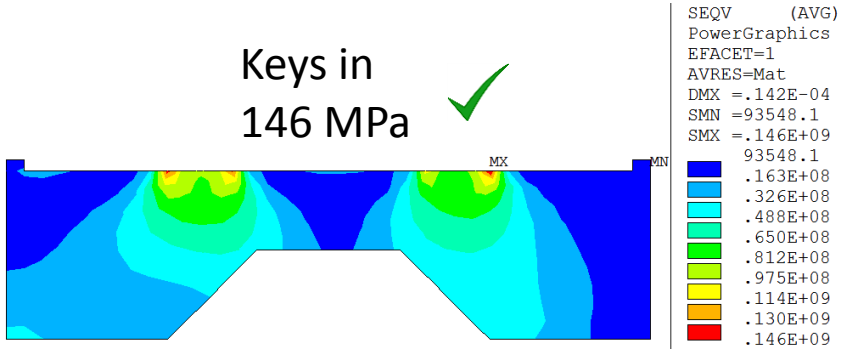




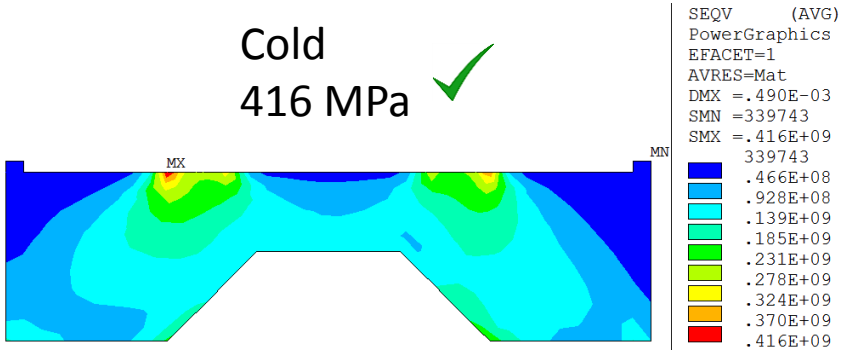
Vertical pad

- von Mises

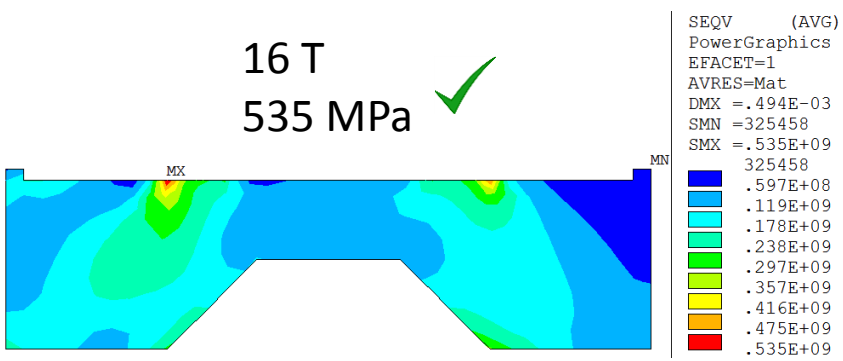
Keys in
146 MPa



Cold
416 MPa



16 T
535 MPa

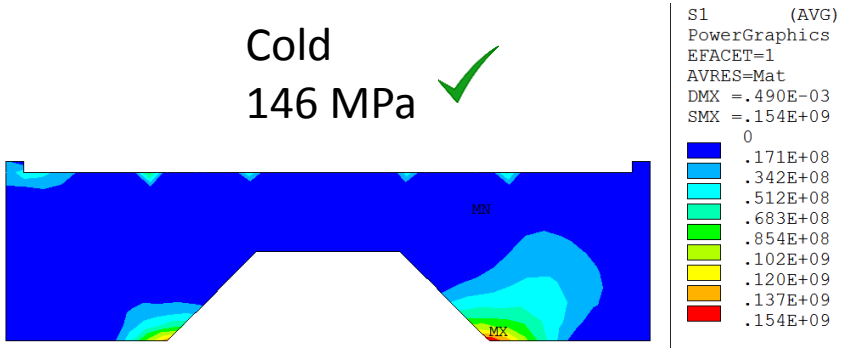


	293 K	4.3 K
Ferromagnetic iron	230	720*

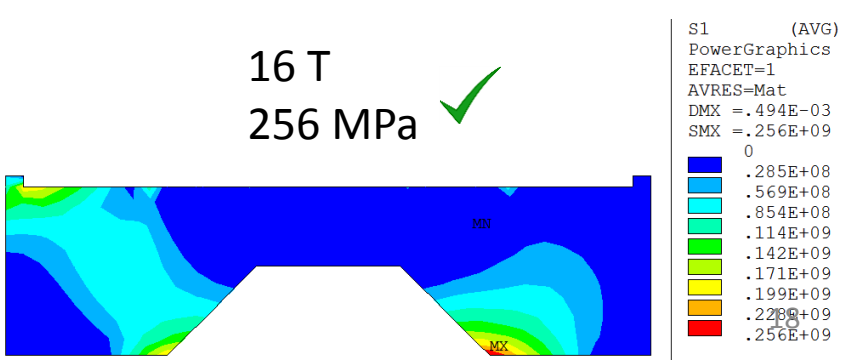
*σ_I < 380 MPa

- σ_I

Cold
146 MPa



16 T
256 MPa

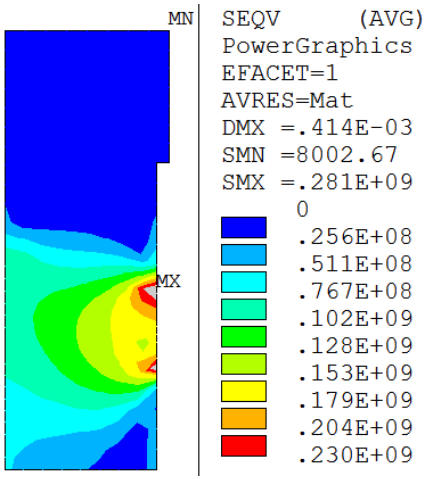


Horizontal pad

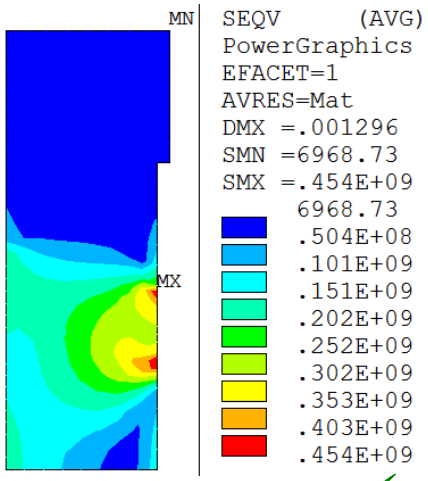
	293 K	4.3 K
Ferromagnetic iron	230	720*

*σ_I < 380 MPa

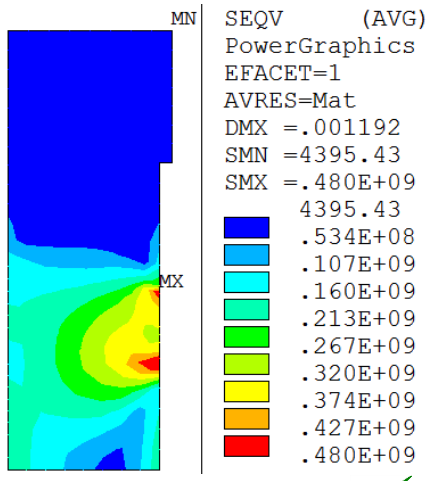
- Von Mises



Keys in: 281 MPa ✗

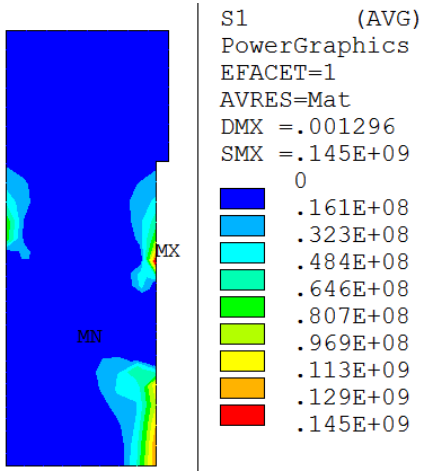


Cold: 454 MPa ✓

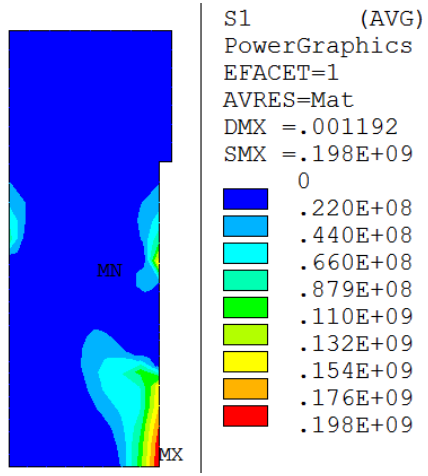


16 T: 480 MPa ✓

- σ_I



Cold: 145 MPa ✓



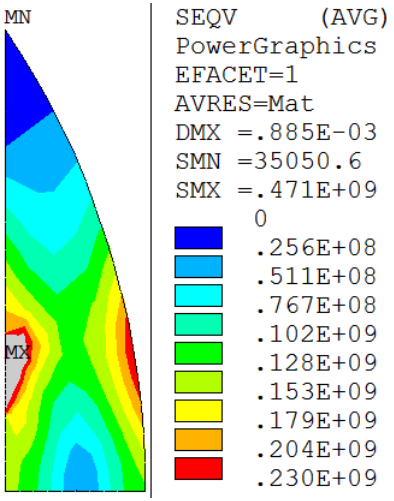
16 T: 198 MPa ✓

Lateral Yoke

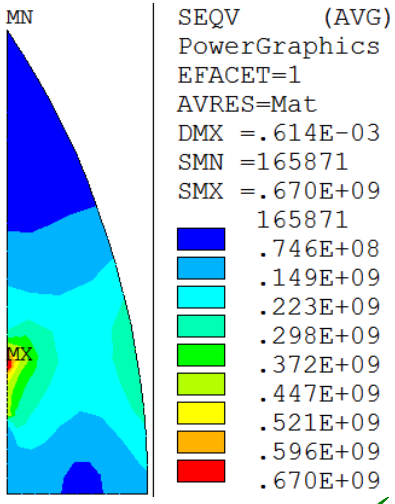
	293 K	4.3 K
Ferromagnetic iron	230	720*

*σ_I < 380 MPa

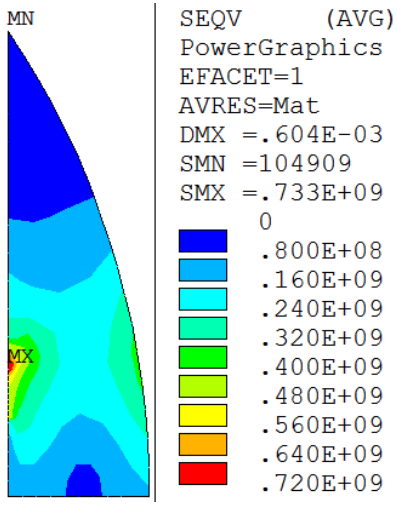
- Von Mises



Keys in: 471 MPa ✗

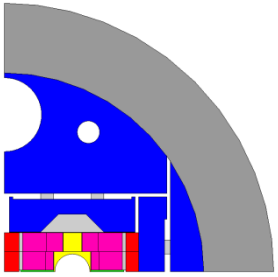


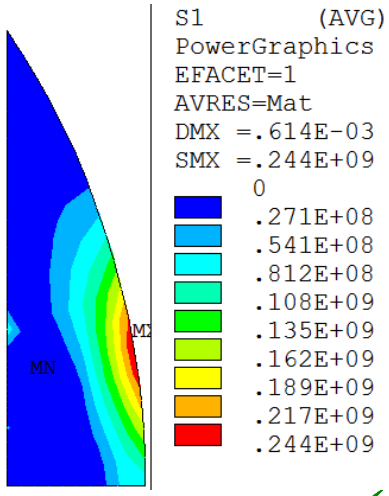
Cold: 670 MPa ✓



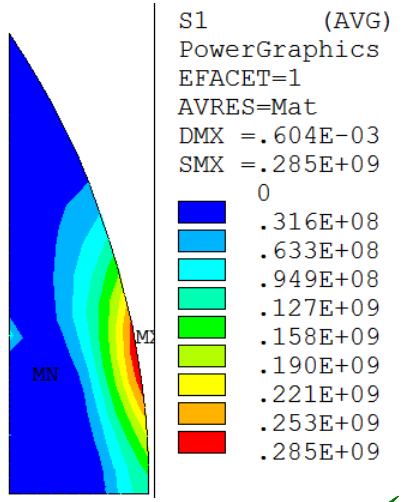
16 T: 733 MPa ✗

- σ_I



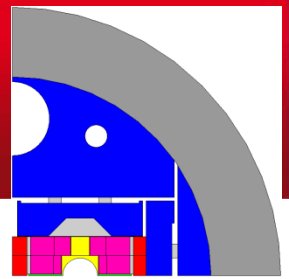


Cold: 244 MPa ✓



16 T: 285 MPa ✓

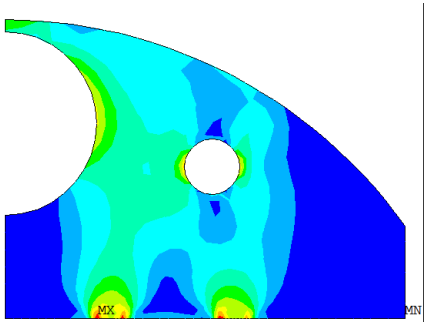
Upper Yoke



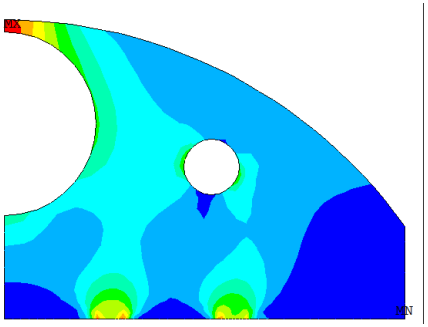
- Von Mises

	293 K	4.3 K
Ferromagnetic iron	230	720*

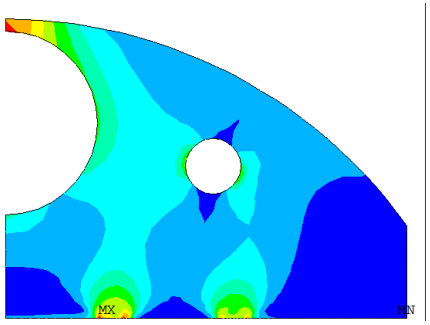
*σ_I < 380 MPa



Keys in
131 MPa

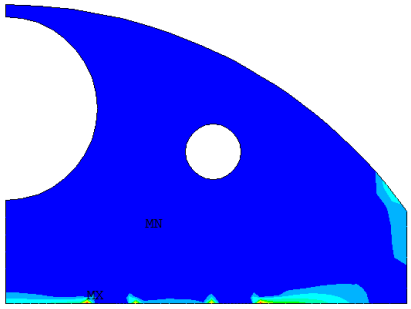


Cold
378 MPa

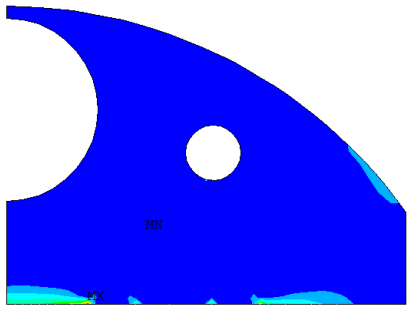


16 T
385 MPa

- σ_I

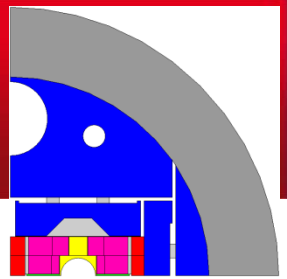


Cold
72 MPa

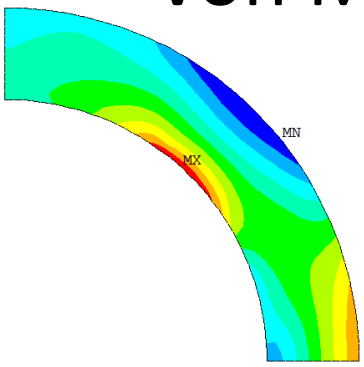


16 T
113 MPa

Shell

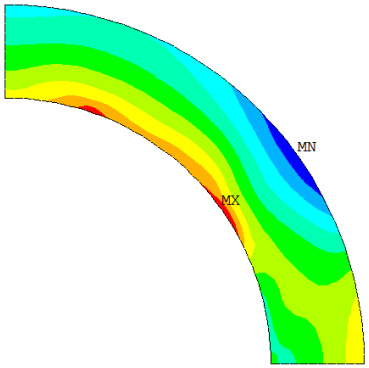


- Von Mises



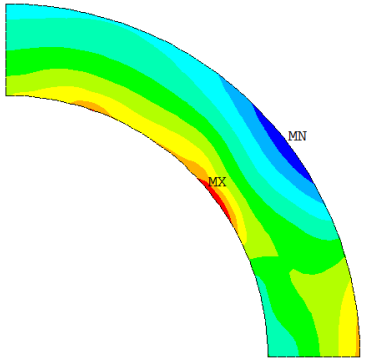
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.880E-03
SMN =123569
SMX =.151E+09
123569
.168E+08
.336E+08
.503E+08
.670E+08
.837E+08
.100E+09
.117E+09
.134E+09
.151E+09

Keys in
151 MPa ✓



SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001229
SMN =.601E+08
SMX =.244E+09
.601E+08
.805E+08
.101E+09
.121E+09
.142E+09
.162E+09
.183E+09
.203E+09
.224E+09
.244E+09

Cold
244 MPa ✓



SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001291
SMN =.495E+08
SMX =.265E+09
.495E+08
.734E+08
.973E+08
.121E+09
.145E+09
.169E+09
.193E+09
.217E+09
.241E+09
.265E+09

16 T
385 MPa ✓

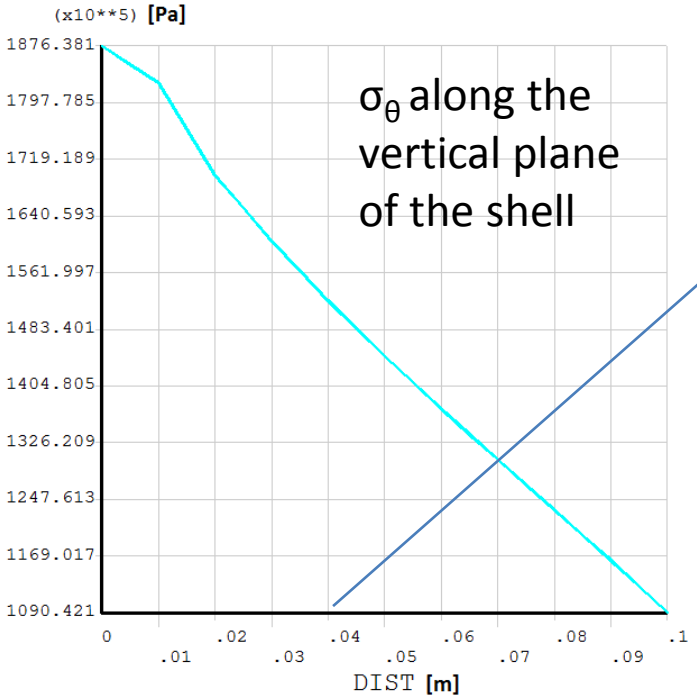
	293 K	4.3 K
Al 7075	480	690

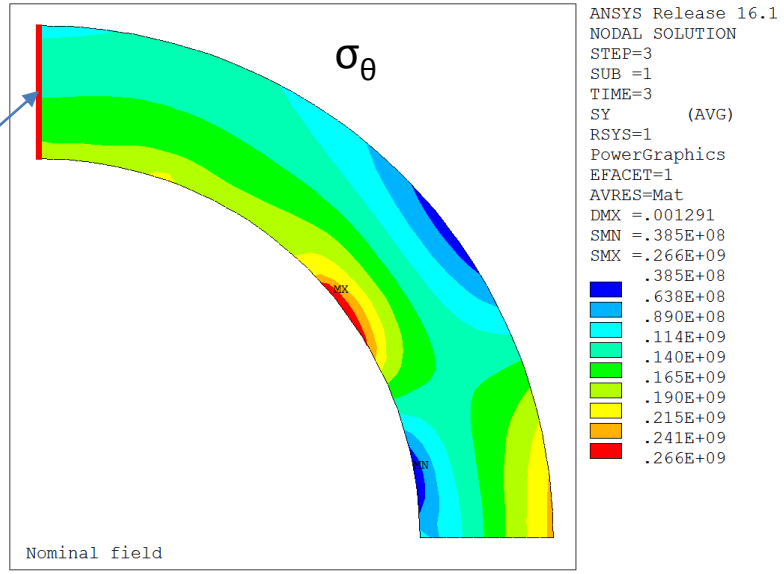
Conclusion

- Investigation of double aperture mechanical design with **194 mm** interbeam disctance
- Investigation **@ 16 T**
- Peak stress in **Nb_3Sn coil at the limit**
- Peak stress in the horizontal **iron** components **above the limit at warm** (key contact with lateral yoke and horizontal pad)
- **Bladder** pressure of **70 MPa** in operation

EXTRA: Force in the shell

- Fx left (+8.25 MN/m) & Fx right (-7.63 MN/m)
  - > 15.88 MN/m
- Average azimuthal force in the shell
  - > 14.65 MN/m





EXTRA: Block magnet comparison

	Bore	Pole tip	displacement [µm]		Δdisp [µm]	Strain [µm/m]		Δε [µm/m]	Δε/Δdisp	Material properties	
Magnet	field [T]	thickness [mm]	cold	powering	pow-cold	cold	powering	pow-cold	[µε/µm]	Nb3Sn	Ti-6Al-4V
ECC block v20ar	16.8	1.75	-198	-49	149	-5887	-1580	4307	29	ECC (E~25;30;27.5;33 GPa)	116 GPa / 126.5 GPa
ECC block v19ar	16.8	1.75	-169	-57	112	-5231	-1598	3633	32	LARP (E~44 GPa,52 GPa)	130 GPa / 130 GPa
ECC block v18ar	16.8	1.9	-162	-50	112	-4558	-1019	3539	32	LARP (E~44 GPa,52 GPa)	130 GPa / 130 GPa
ECC block v17ar	16.8	2	-167	-55	112	-4436	-955	3481	31	LARP (E~44 GPa,52 GPa)	130 GPa / 130 GPa
ECC block v16ar	16.8	6.3	-179	-72	107	-4878	-1272	3606	34	LARP (E~44 GPa,52 GPa)	130 GPa / 130 GPa
Fresca2	13	5	-304	-140	164	-5048	-2480	2568	16	LBNL (E~44 GPa,44 GPa)	100 GPa / 120 GPa
Fresca2	13	6.5	-306	-142	164	-5051	-2481	2570	16	LBNL (E~44 GPa,44 GPa)	100 GPa / 120 GPa
Fresca2	13	8	-307	-141	166	-5058	-2472	2586	16	LBNL (E~44 GPa,44 GPa)	100 GPa / 120 GPa
Fresca2	15	8	-409	-190	219	-7187	-3778	3409	16	LBNL (E~44 GPa,44 GPa)	100 GPa / 120 GPa
Fresca2	13	16	-232	-101	132	-3931	-1042	2889	22	LBNL (E~44 GPa,44 GPa)	100 GPa / 120 GPa
RMM_graded_v21_d	16	1	-174	-56	118	-4617	-1071	3546	30	LBNL (E~44 GPa,44 GPa)	110 GPa / 120 GPa
RMM_graded_v21_c	16	2	-173	-55	118	-4666	-1056	3610	31	LBNL (E~44 GPa,44 GPa)	110 GPa / 120 GPa
RMM_graded_v21_b	16	4	-171	-55	116	-4757	-1115	3643	32	LBNL (E~44 GPa,44 GPa)	110 GPa / 120 GPa
RMM_graded_v21_a	16	6	-168	-58	111	-4832	-1245	3587	32	LBNL (E~44 GPa,44 GPa)	110 GPa / 120 GPa
HD3	14	1.65	-134	-51	83	-3690	-667	3023	36	LARP (E~44 GPa,52 GPa)	110 GPa / 120 GPa

ECC displacement and strain **impacted** by material properties not by bore tip thickness

RMM_graded and **ECC** similar behavior with similar properties

Fresca2 biggest displacement – **HD3** smallest displacement…

Thanks to:
HD3: Helene Felice (CEA)
RMM_graded: Susana Izquierdo-Bermudez (CERN)
Fresca2: Etienne Rochepault (CERN)