Evolution of the cos-theta design of the 16 T FCC main dipole

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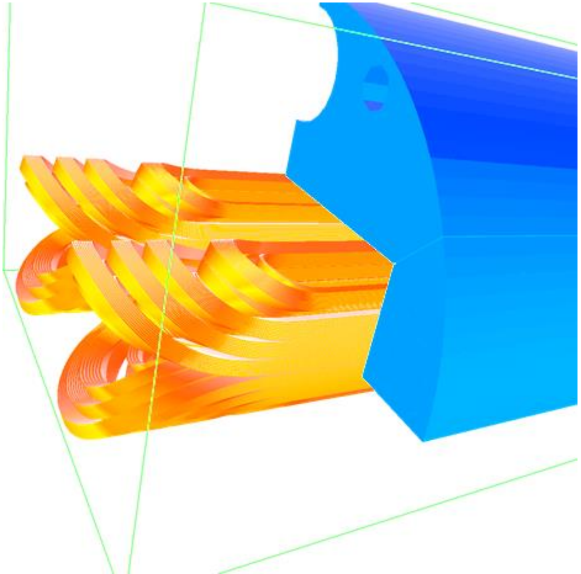
Outline

- Evolution of the electromagnetic design
- Focus on the CDR electromagnetic design
- Evolution of the mechanical design
- Focus on the CDR mechanical design



Evolution of the electromagnetic design

FCCweek2016 → ***FCCweek2017*** → ***FCCweek2018*** → ***CDR***

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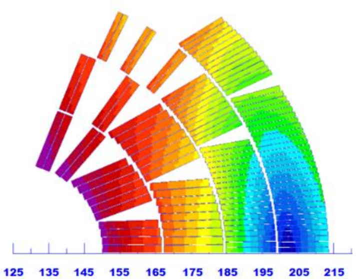
Design parameters

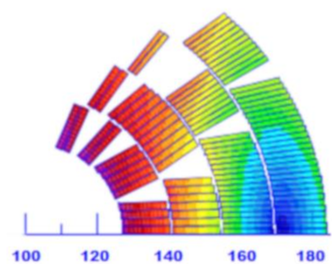
	2016	2017	2018	CDR
bore inner diameter [mm]	50	50	50	50
beam distance [mm]	250	204	204	250
bore nominal field [T]	16	16	16	16
operating temperature [K]	4.2	1.9	1.9	1.9
operation on the load line @ 1.9 K	82%	86%	86%	86%
max. strand number per cable	40	40	40	40
insulation thickness [mm]	0.15	0.15	0.15	0.15
Cu/non Cu	≥1	≥0.85	≥0.85	≥0.85
field harmonics (geom./saturation)	≤3/10 units	≤3/10 units	≤3/10 units	≤3/10 units
yoke outer diameter [mm]	800	750	600	660

Evolution of the electromagnetic design

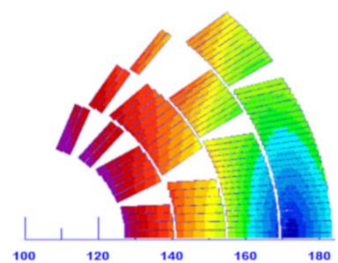
	FCCweek2016		FCCweek2017		FCCweek2018		CDR	
	HF Cable	LF Cable	HF Cable	LF Cable	HF Cable	LF Cable	HF Cable	LF Cable
Strand number	28	38	22	37	22	38	22	38
Strand diameter [mm]	1.1	0.7	1.1	0.7	1.1	0.7	1.1	0.7
Cu/non Cu	1	2.04	0.9	2.2	0.82	2.1	0.82	2.08
Turn number	35	79	32	68	31	68	32	68
Operating current [A]	10275	10275	11060	11060	11390	11390	11441	11441
Operating point on LL (1.9 K)	82%	82%	86%	86%	86%	86%	86%	86%
Peak field [T]	16.25	12.48	16.35	12.60	16.44	12.80	16.39	12.71



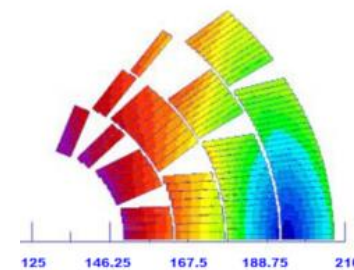
FCCweek2016



FCCweek2017



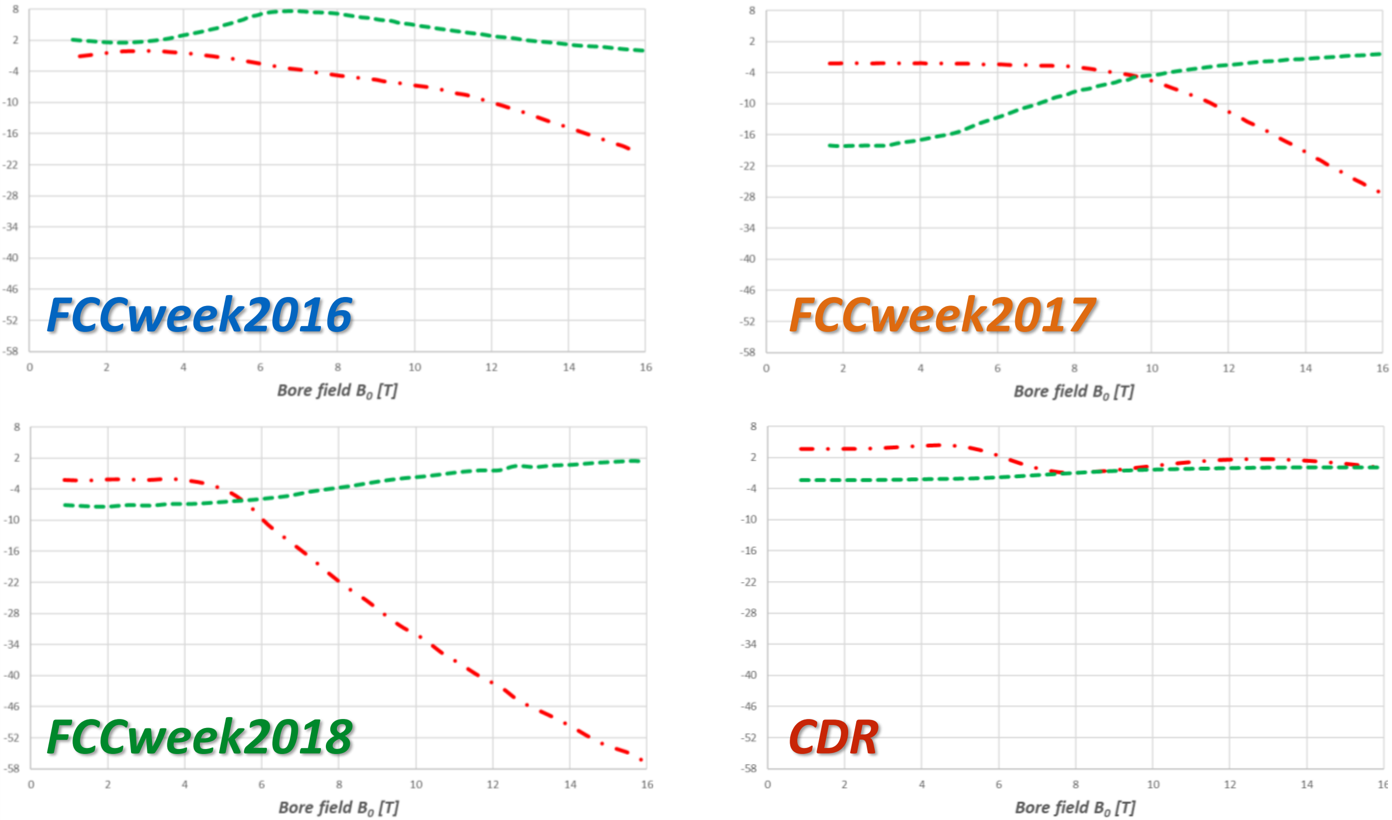
FCCweek2018



CDR

Field quality geometric/saturation

b2 b3



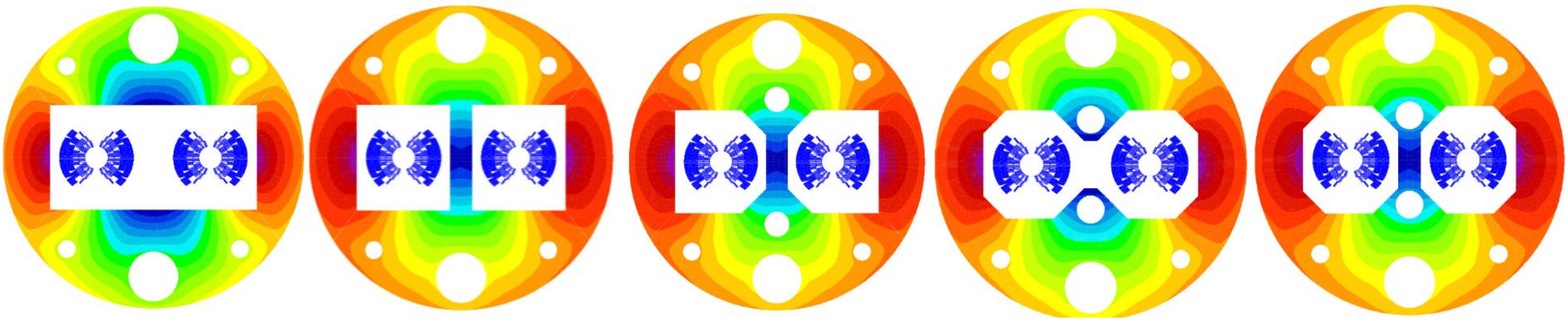
	interbeam	yoke outer diameter
16	250	800
17	204	750
18	204	600
CDR	250	660

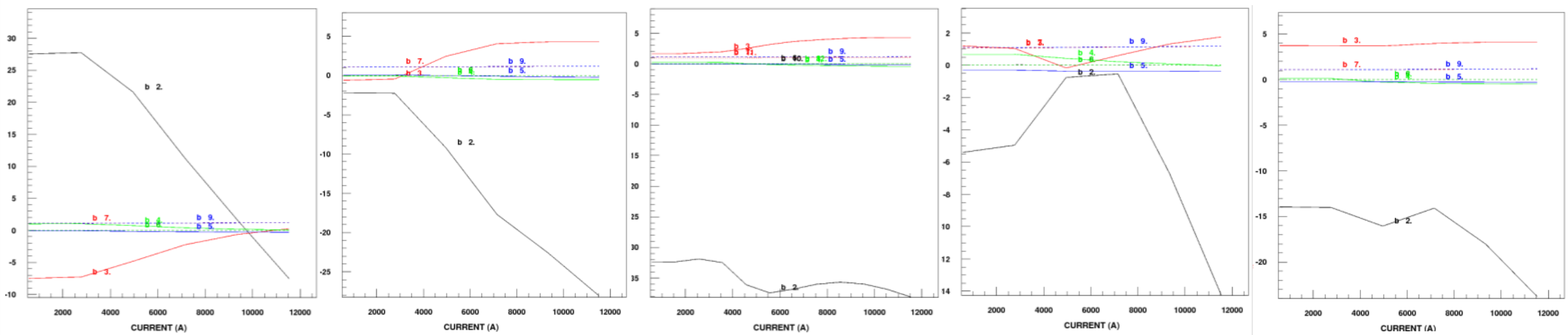
	Δb_2	Δb_3
16	19	2
17	25	18
18	54	8
CDR	4	2

Focus on the CDR electromagnetic design

symmetric → *asymmetric*

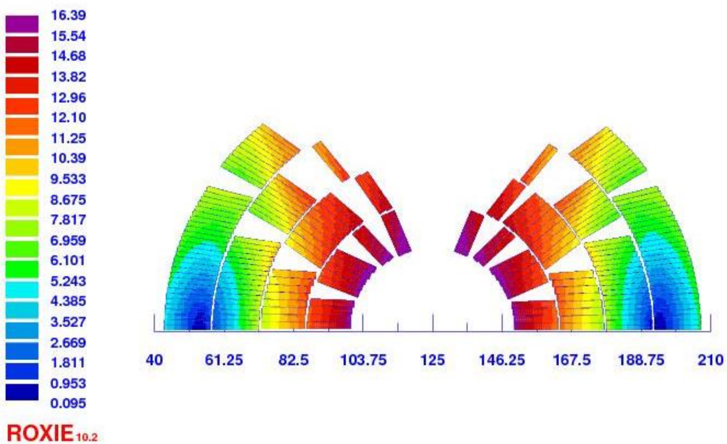
Symmetric configurations

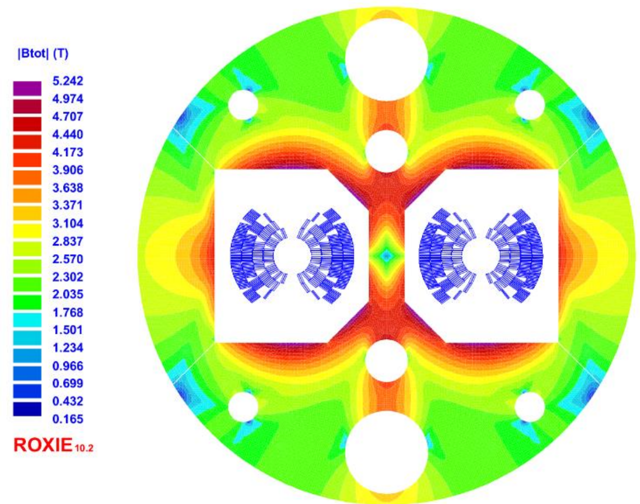


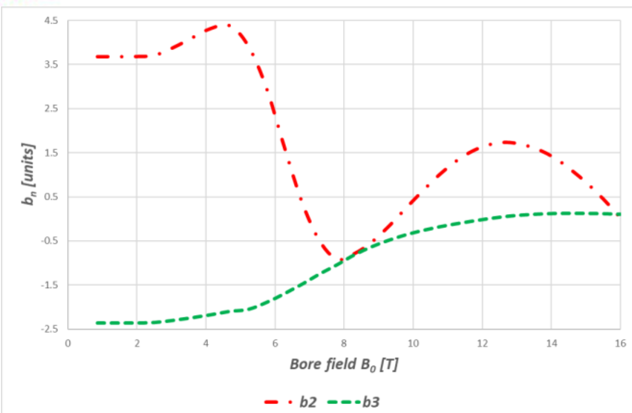


- no way to fulfill requirements on b_2:
  $b_2 < 20$ units at injection, $b_2 < 3$ units at collision

Optimized asymmetric configuration

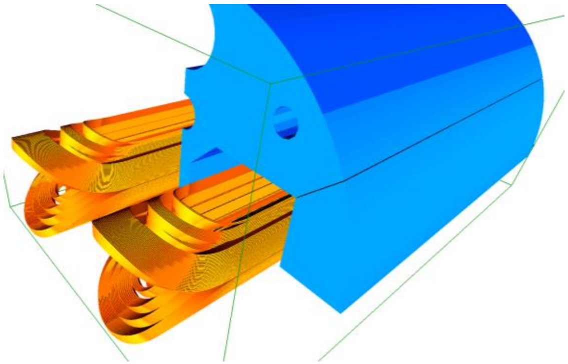


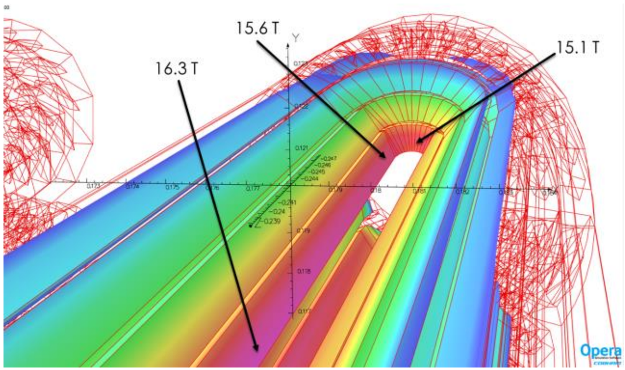


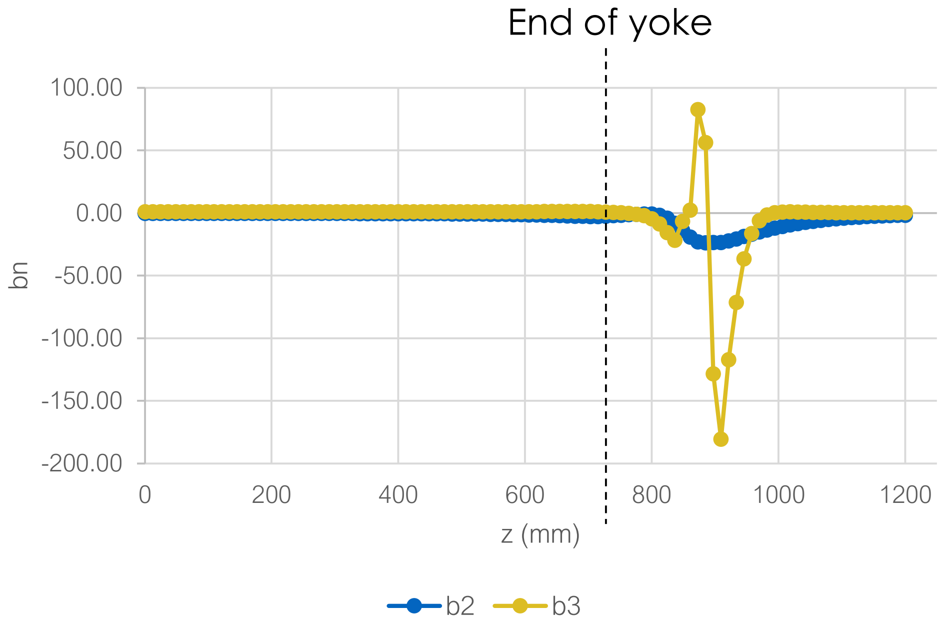


Field quality at operating current								
B	b2	b3	b4	b5	b6	b7	b8	b9
16 T	0.03	0.1	0.1	0.2	0.4	0.2	0.4	0.6

Coil end – side opposite to connections





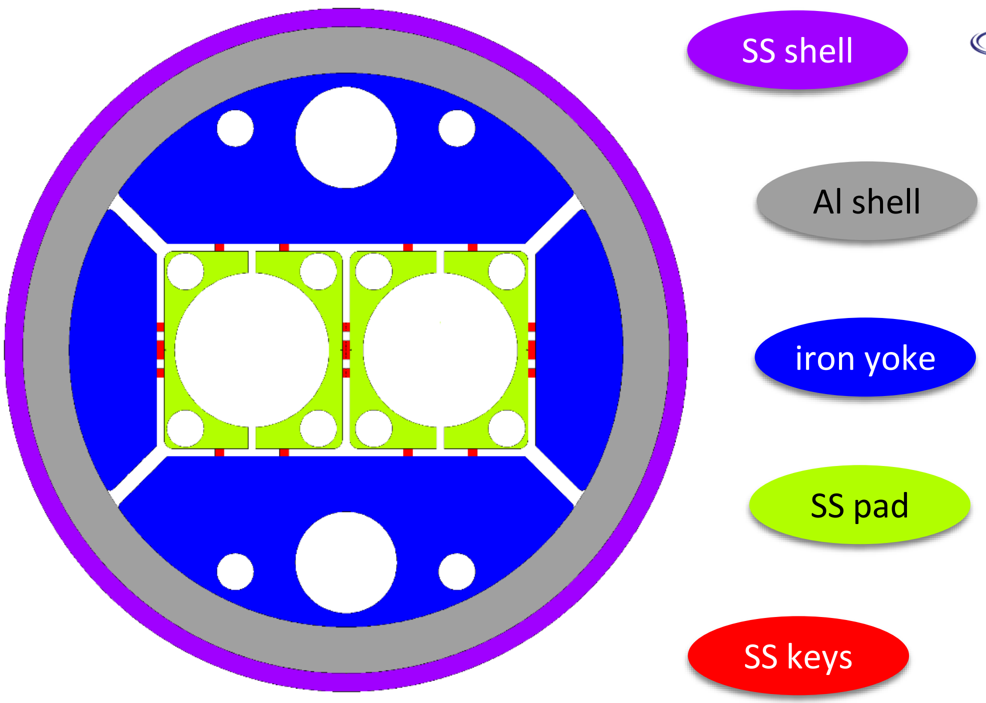


Integrated field quality at operating current (L_{mag}=14.3 m)								
B	b2	b3	b4	b5	b6	b7	b8	b9
16 T	-0.5	-0.2	0.3	0.2	0.4	0.2	0.4	0.6

Evolution of the mechanical design

FCCweek2016 → ***FCCweek2017*** → ***FCCweek2018*** → ***CDR***

Mechanics concept



- the mechanical structure is based on the bladder&key concept:
  - the room temperature pre-load is provided by assembling the keys with interference using bladders
  - the rest from Al shell cool-down
  - SS shell can be present or not

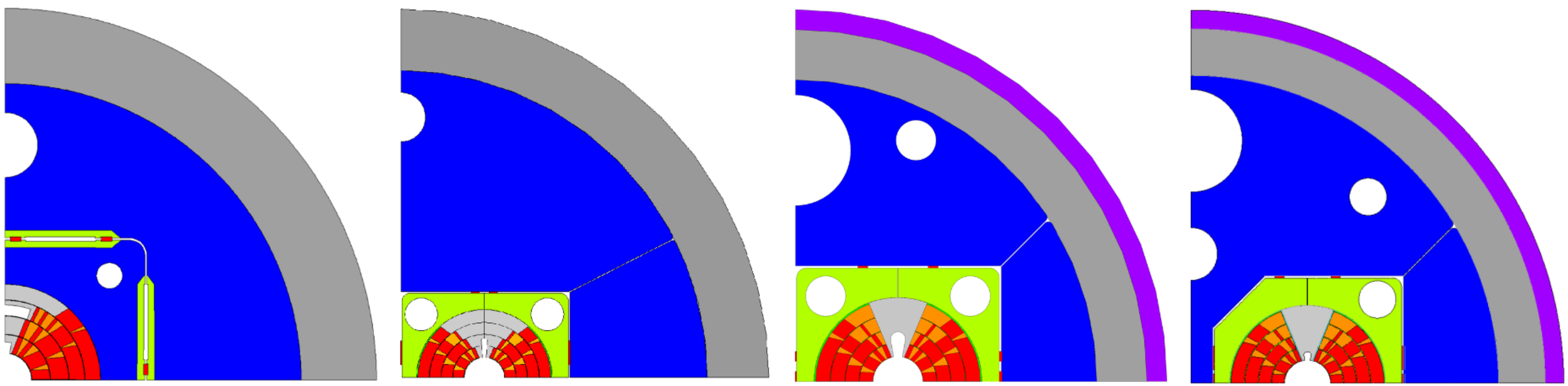
Mechanical parameters and constraints

- Coil in compression up to nominal field
- Stress in conductor
  - Room temperature (RT), < **150 MPa**
  - Cryo temperature (1.9 K), < **200 MPa**
- Stress in mechanical structure below yield strenght (see Tab.)

MATERIAL	Stress limit [MPa] RT	Stress limit [MPa] 1.9 K	E [GPa] RT	E [GPa] 1.9 K	ν	α RT→1.9K
Coil	150	200			0.3	
Radial dir			30	33		$3.1\ 10^{-3}$
Azimuthal dir			25	27.5		$3.4\ 10^{-3}$
Austenitic steel (316LN)	350	1050	193	210	0.28	$2.8\ 10^{-3}$
Al7075	480	690	70	79	0.3	$4.2\ 10^{-3}$
Ferromagnetic iron	230	720*	213	224	0.28	$2.0\ 10^{-3}$
Ti6Al4V	800	1650	115	126	0.3	$1.7\ 10^{-3}$

Evolution of the mechanical design

FCCweek2016 *single aperture* | ***FCCweek2017*** | ***FCCweek2018*** | ***CDR***



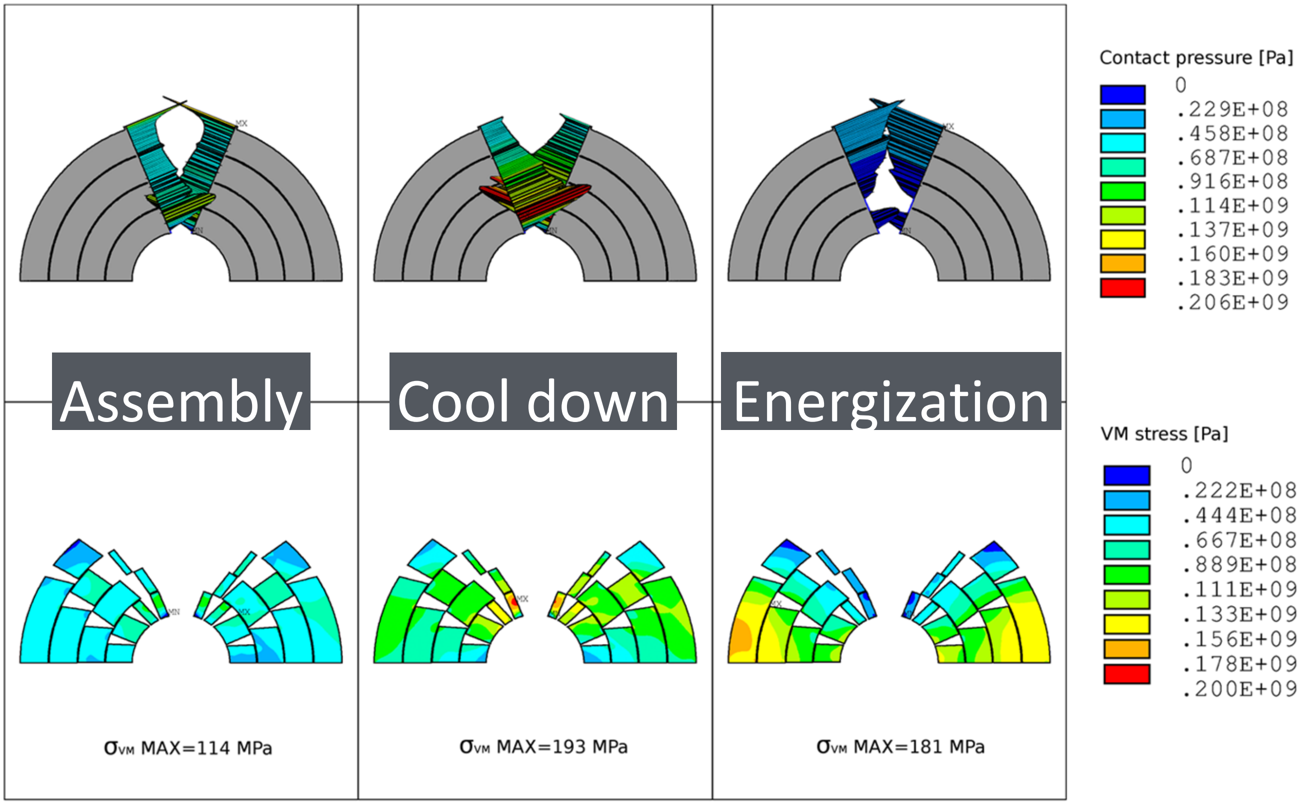
	2016	2017	2018	CDR
yoke outer diameter [mm]	550	750	600	660
Al shell thickness [mm]	50	75	50	50
SS shell thickness [mm]	0	0	20	20
cold mass outer diameter [mm]	650	900	740	800

Focus on the CDR mechanical design

more details FCC CDR Volume 3

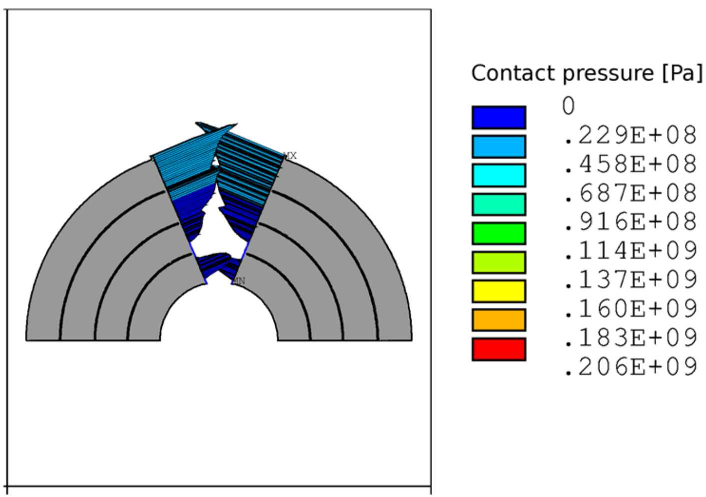
http://cds.cern.ch/record/2651300/files/CERN-ACC-2018-0058.pdf?version=6

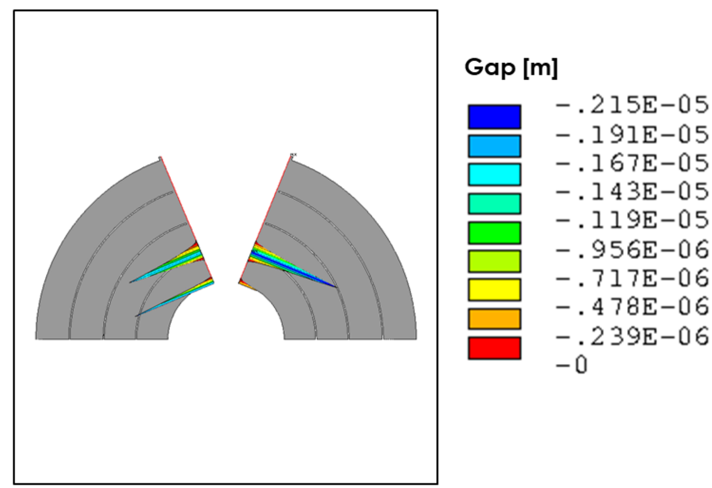
Contact pressure & VM stress on conductors



Contact pressure at 16 T

- **At energization**, the contact pressure between the coil and the pole is guaranteed apart from a small region between the first and the second layer, where a **2 µm gap** is open.





Conclusions

- I showed some of the steps which took us to the final CDR configuration for the **16 T FCC main dipole**
- the main characteristics of this design are:
  - interbeam distance of **250 mm**
  - outer yoke diameter of **660 mm**, to get a total cold mass outer diameter **800 mm** (agreed with the CERN team designing the cryostat)
  - field quality fully under control thanks to an **asymmetric coil configuration** and an **iron insert** in hourglass shape
  - 16 T bore field achieved keeping the working point on the load line below the limit of **86%** as required
  - **3D coil ends** design satisfying field quality and peak field constraints
  - mechanics satisfying required limits and constraints

Short model

- See R.Valente presentation tomorrow at 16:00

FALCON DIPOLE

Thanks for your attention