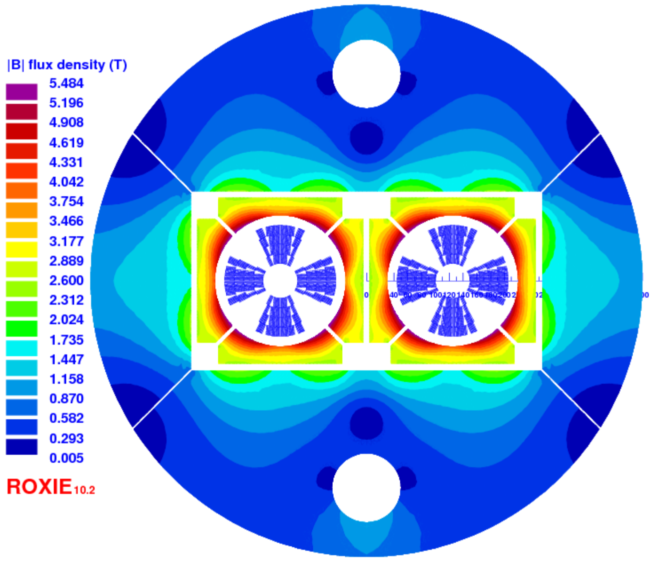
FCC Main Quad

C. Lorin

Inputs from: G. Dilasser, D. Schoerling, T. Salmi, H. Felice, E. Rochepault, M. Segreti

11 april 2018

Philosophy

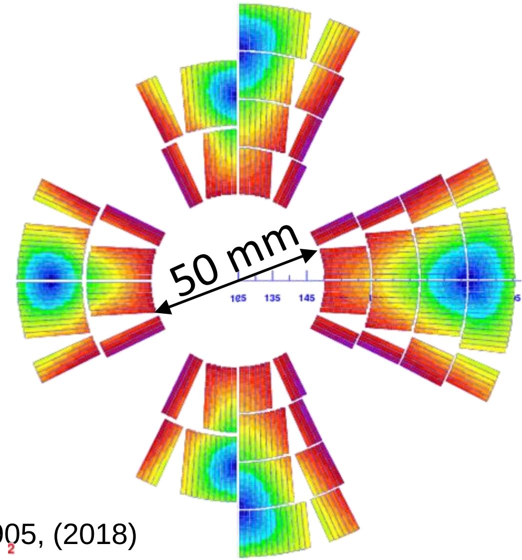


Till last year*

- Reaching the highest gradient to release constraints on the dipole (FODO cell filling)
- 4 *cos2ϑ* layers.
- Loadline margin: 14%
- Conductor : EuroCirCol cables – strands – J_c (2250 A/mm² @ 1.9 K, 16 T)

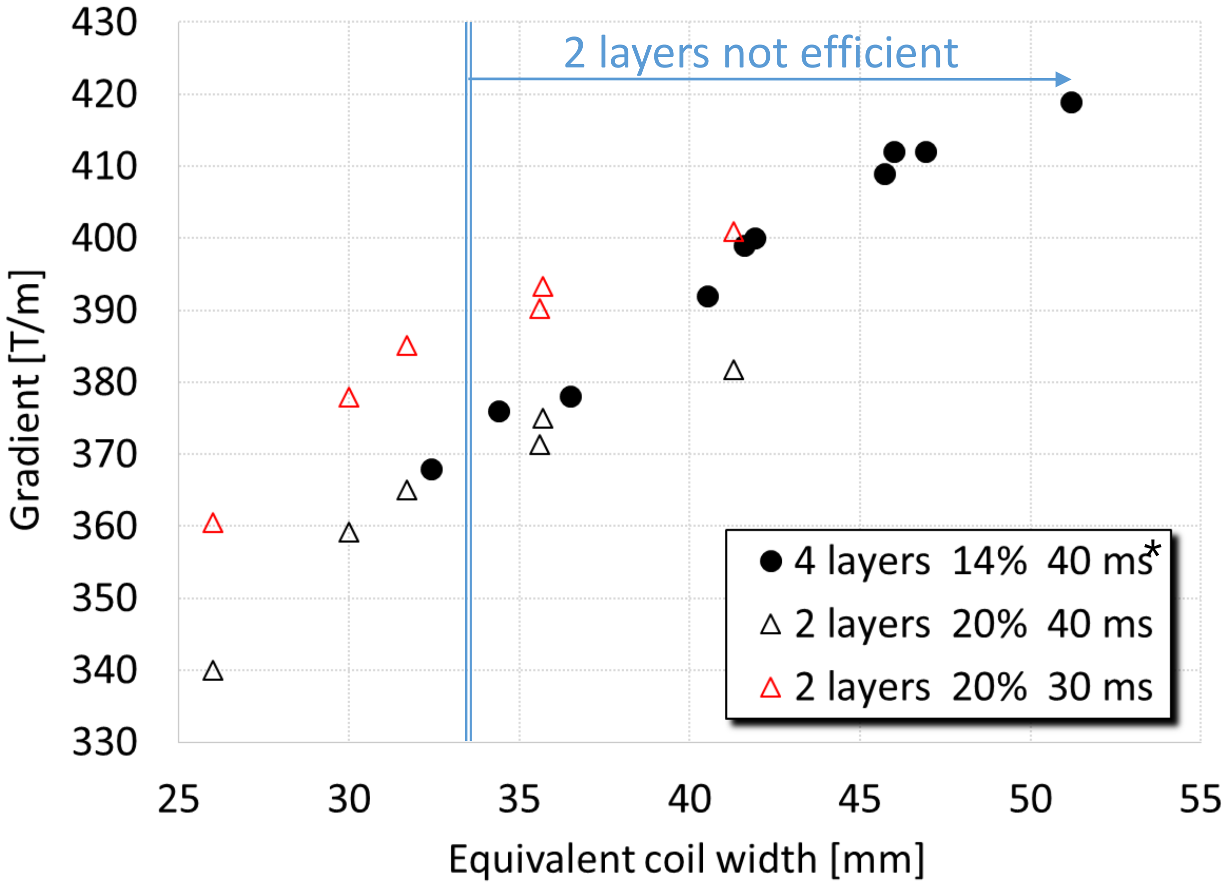
New Philosophy

- Quads in the shadow of the dipoles (manufacture + operation)
  - Assembly complexity: 4 layers -> 2 layers
  - Loadline margin: 14% -> 20%
  - Re-opened cable parameters: up to 60 strands
  - Re-opened strand parameters: Φ = 0.7-0.9 mm
  - Challenge the protection: 40 to 30 ms



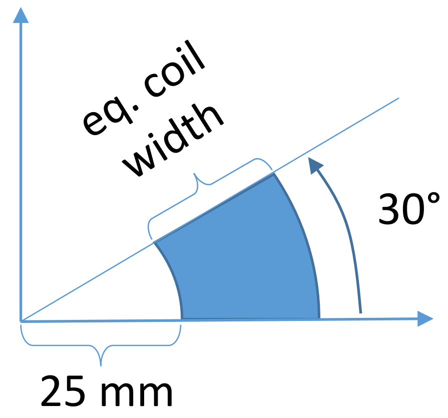
*C. Lorin et al., Design of a Nb_3Sn 400 T/m quadrupole for the Future Circular Collider, IEEE Transaction on Applied Superconductivity, 4004905, (2018)

Comparison with last year study



All designs with a 350 K hotspot (EuroCirCol)

*Todesco et al, Semi-analytical approaches to magnet design, Wamsdo 2013
Rossi L., Todesco E. Electromagnetic design of superconducting quadrupoles, PRSTAB, 2006

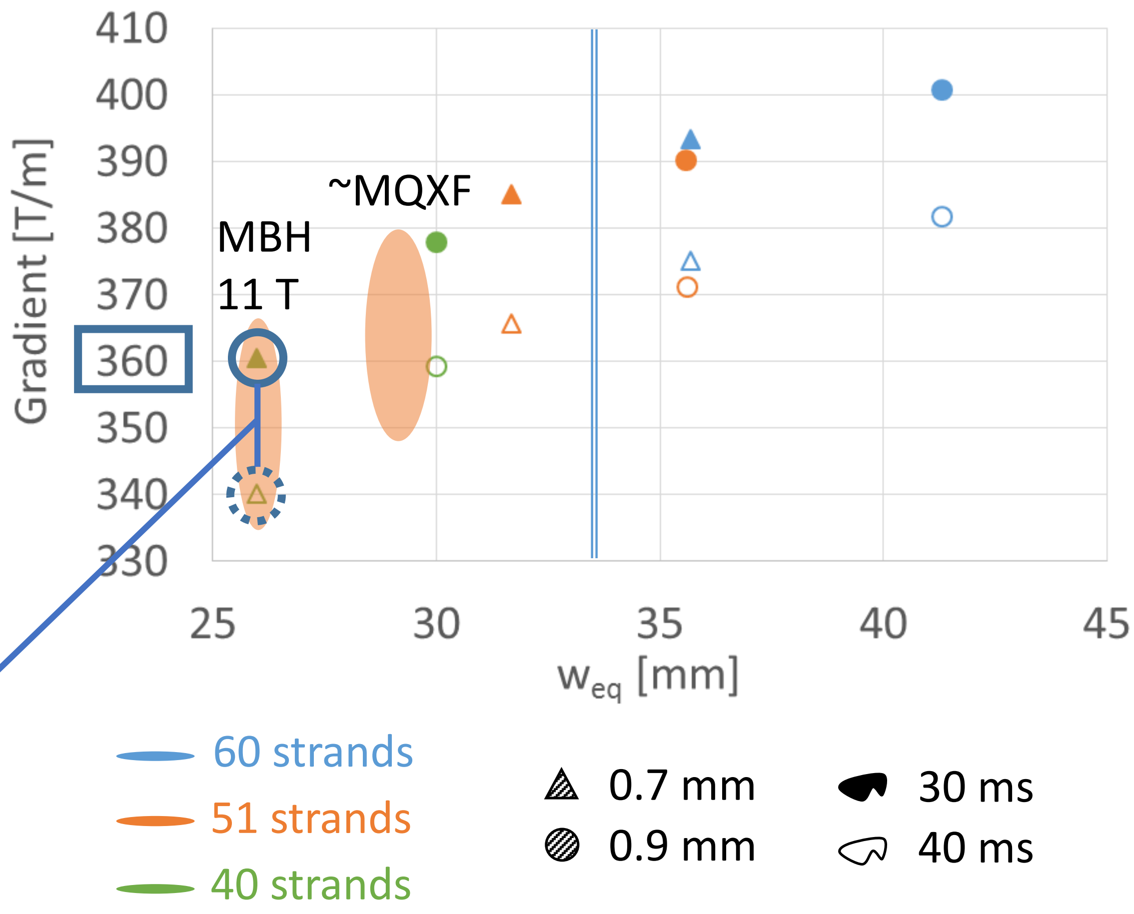


*C. Lorin et al., Design of a Nb_3Sn 400 T/m quadrupole for the Future Circular Collider, IEEE Transaction on Applied Superconductivity, 4004905, (2018)

2D exploration of the parameter space

- Strand diameter: 0.7 mm or 0.9 mm
- Nb of strands: 40-51-60
- Protection delay: 30 ms or 40 ms

Protection: 40 to 30 ms (Hotspot = 350 K)
  - + 20 T/m on the gradient (~5%)
- 2 layers efficiency:
  - Lower than ~51 strands
- Worry about windability (50 mm aperture)
  - Windability test with MBH 11 T cable or MQXF cable would be welcome

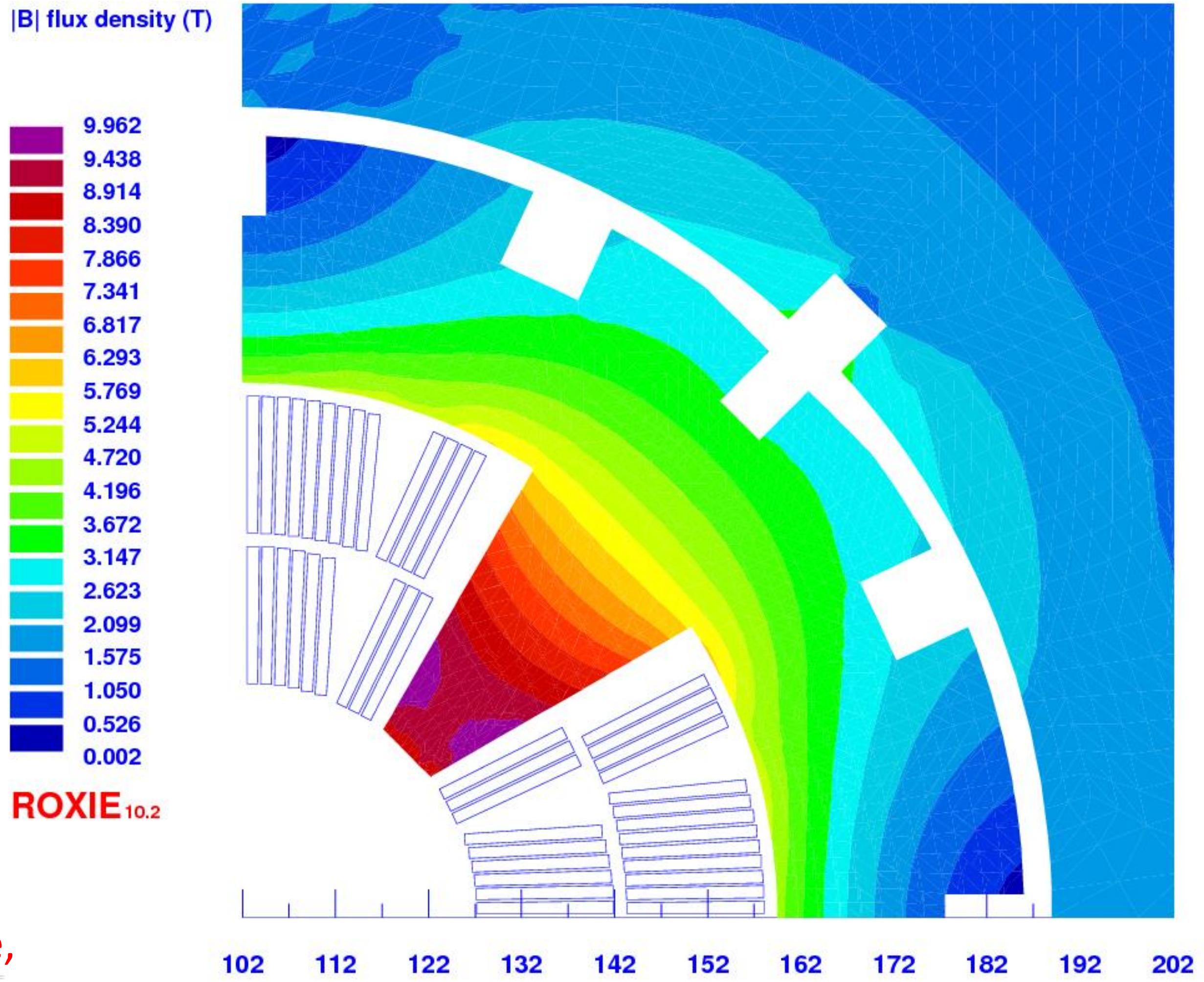


Design selected for this study:
Most simple design in-line with the optics baseline of 360 T/m

2D electromagnetic design - cable

Cable

Strand diameter	(mm)	0.7
Nb of strands	(-)	40
Bare cable width	(mm)	14.75
bare mid-thickness	(mm)	1.262
Bare thin edge	(mm)	1.181
Bare thick edge	(mm)	1.343
keystone angle	(°)	~0.6
Copper/nonCopper	(-)	1.8



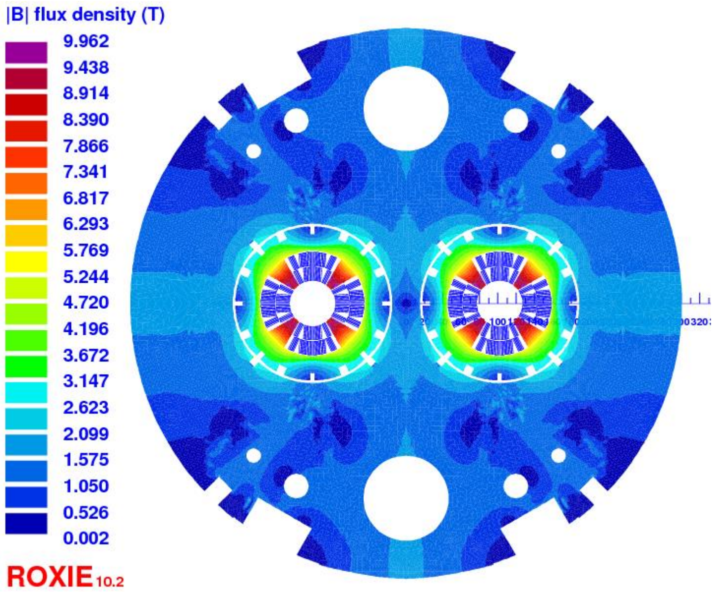
→ To be properly realigned on 11 T MBH HiLumi Dipole,
And/ or use 11 T MBH cable experience

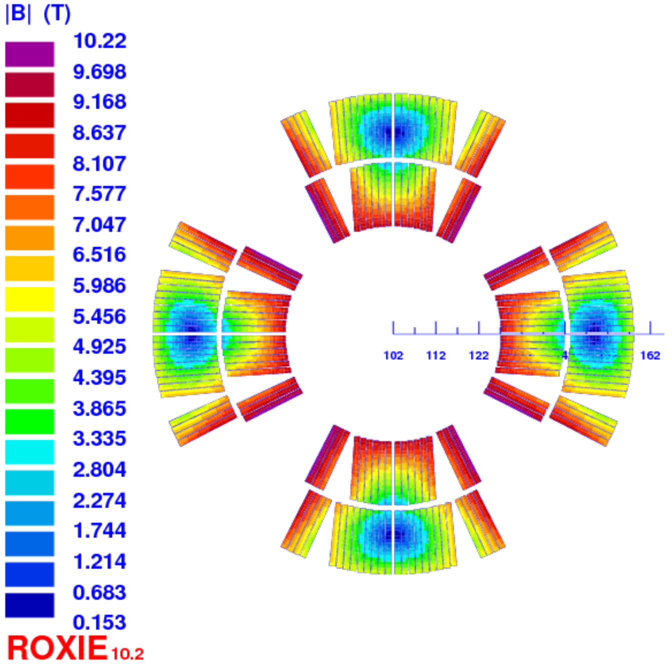
2D electromagnetic design - magnet

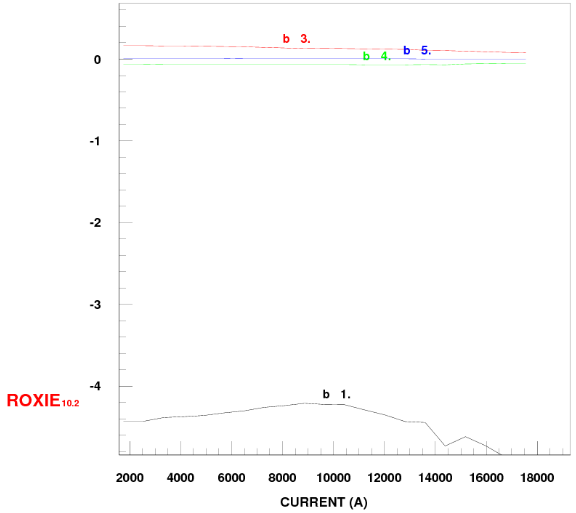
Quantity	2layers_V4_collarMQ	Unit
gradient	**353**	T/m
I_{nom}	**17550**	A
B_{peak}	10.22	T
LL margin (1.9 K)	20.0	%
Inductance diff. (2 ap)	3.02	mH/m
Stored energy (2 ap)	466.5	kJ/m
Nb of turns	22 = 6 + 3 + 9 + 4	-
F_/_ & F // (per ½-coil)	1.63* & 0.60	MN/m
FX & FY (per ½-coil)	-1.03 & -1.48	MN/m
Hotspot	350 (***30 ms***)	K
Midplane shim	0.3	mm
length	7.35**	m
Iron yoke OD (match dipole yoke OD)	600	mm
Interbeam	204	mm

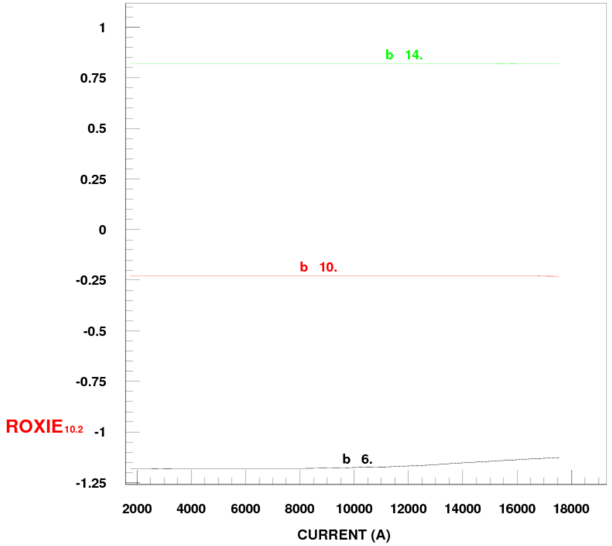
*0.71 + 0.92 MN/m per layer

**+15 cm wrt to current baseline to stick to the integrated gradient



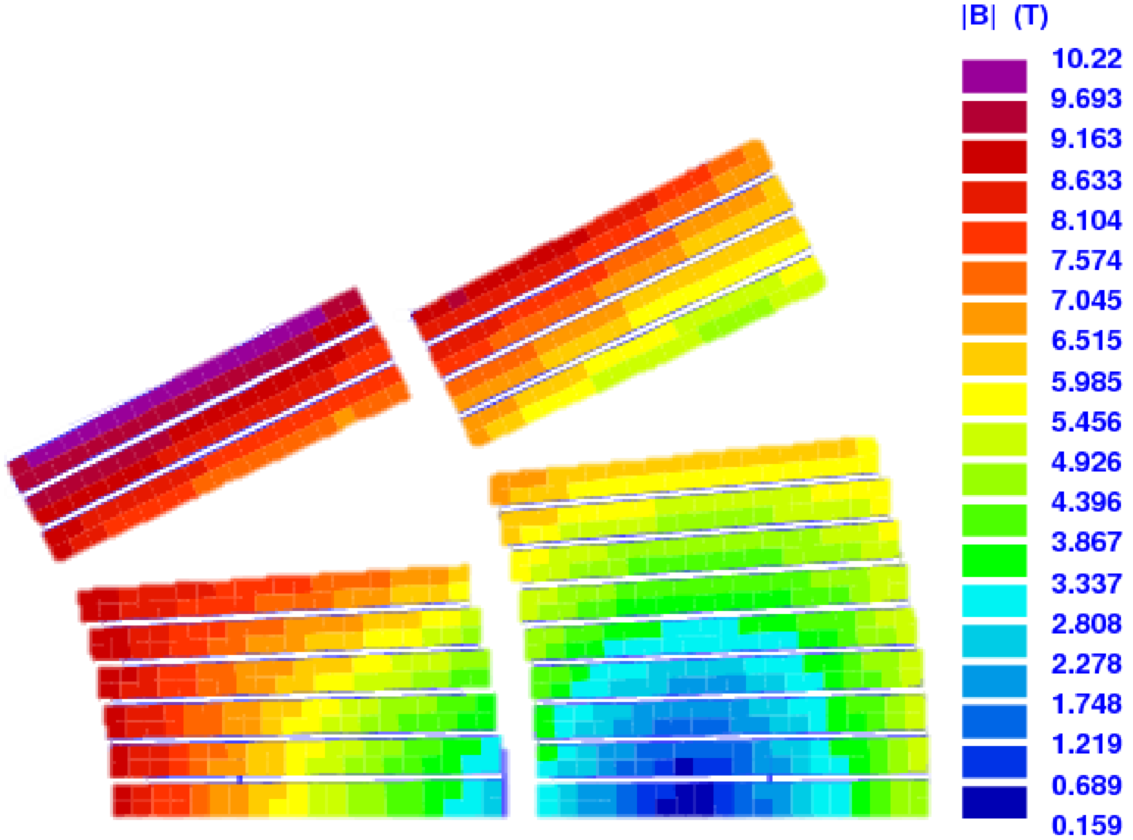


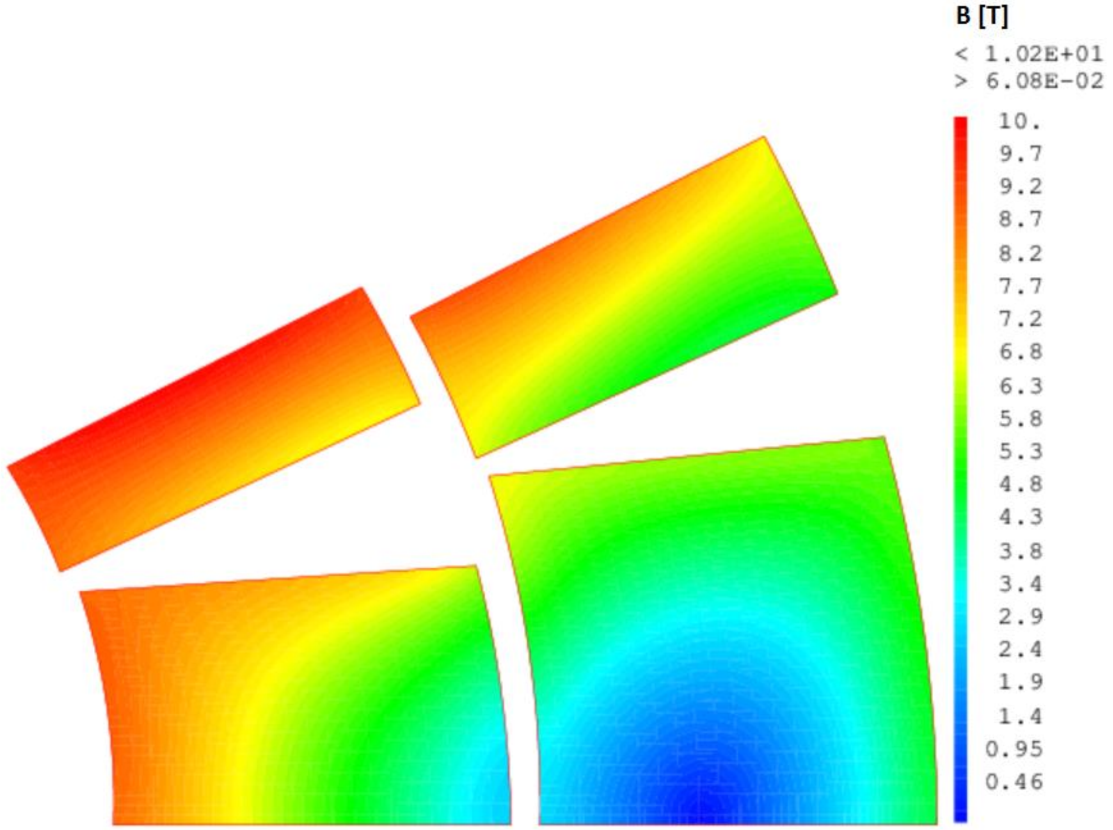




Collar structure investigation (1/3)

- Emag forces: Roxie vs Cast3m (CEA-made code)



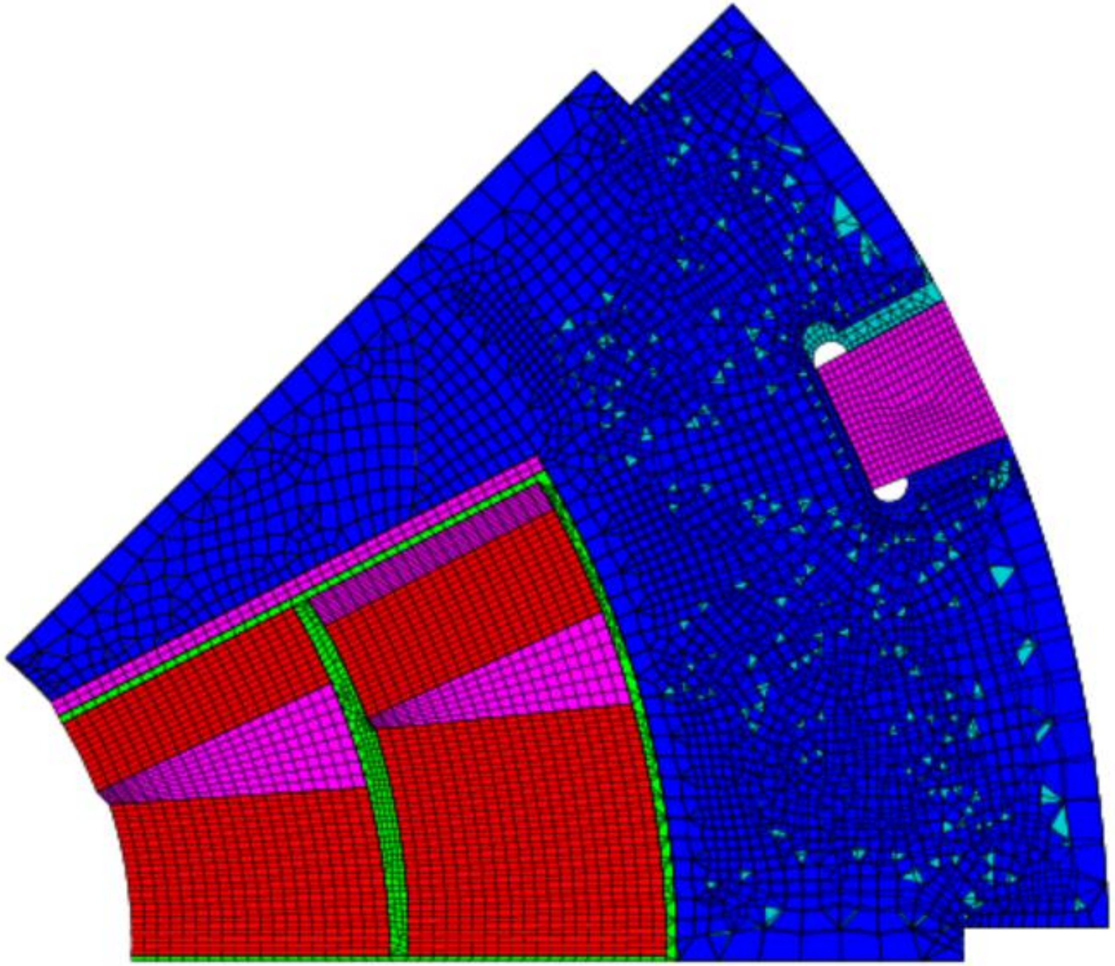


Fx = 1.03 MN/m
Fy = 1.48 MN/m
Roxie

Fx = 1.06 MN/m
Fy = 1.46 MN/m
$I_{cast3m} = 1.01\ I_{roxie}$ to better match the forces

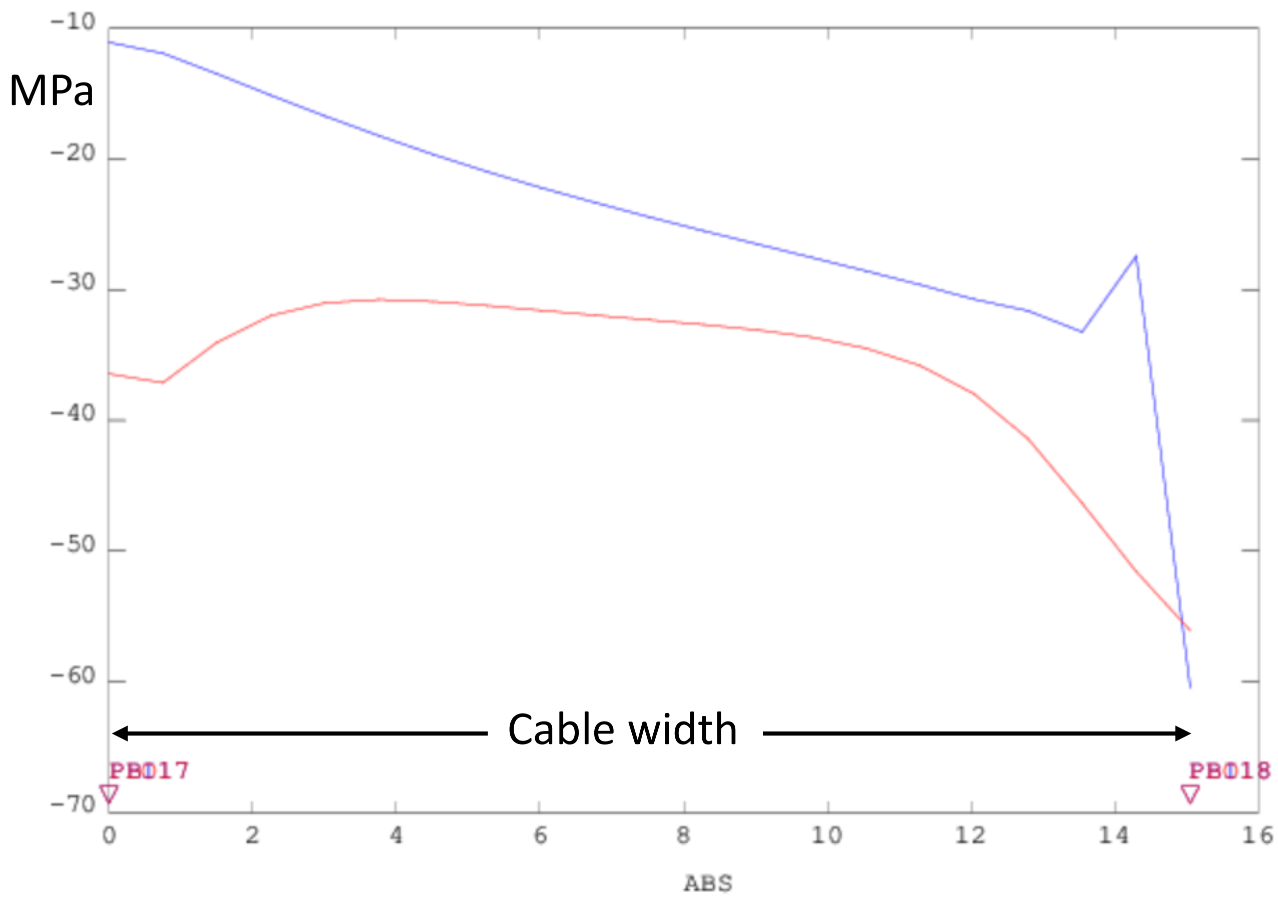
Collar structure investigation (2/3)

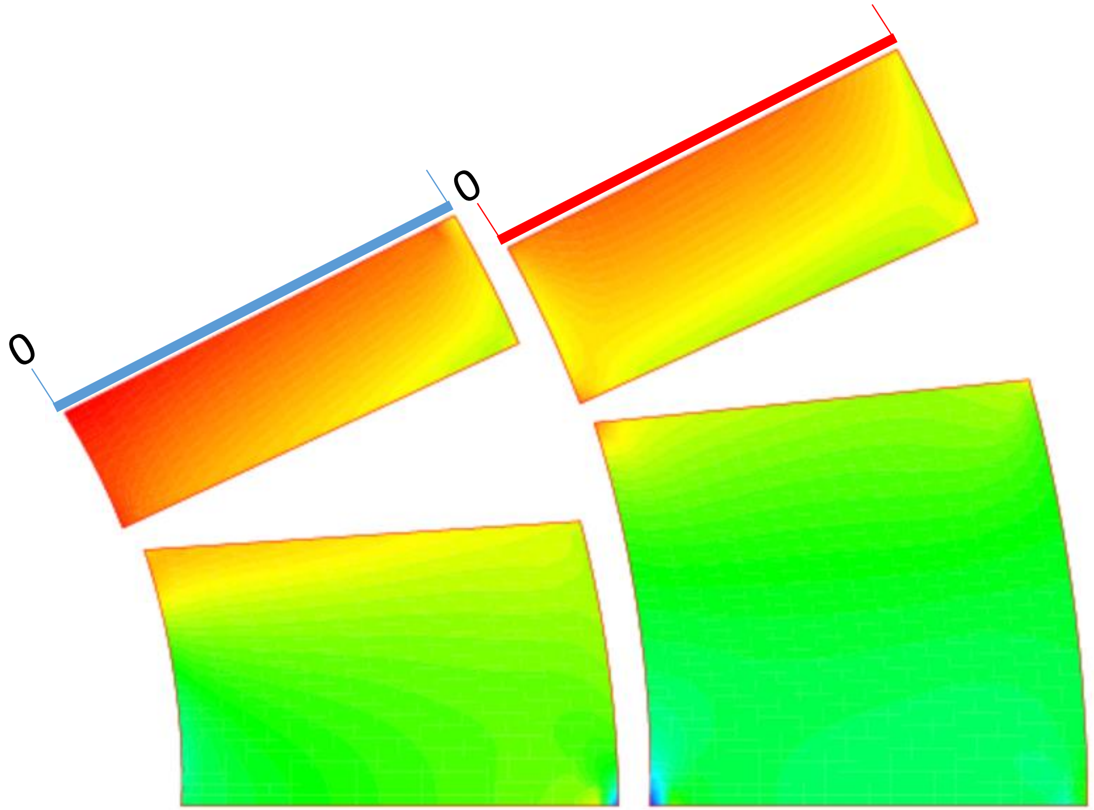
- Contact description:
  - Both layer glued
  - Sliding no friction elsewhere
- Nb_3Sn Coil properties
  - Ecoil = 30 GPa (+10% at cold), isotropic
  - Thermal shrinkage: 3.2E-3



Collar structure investigation (3/3)

- Target: contact at nominal of 10 to 15 MPa

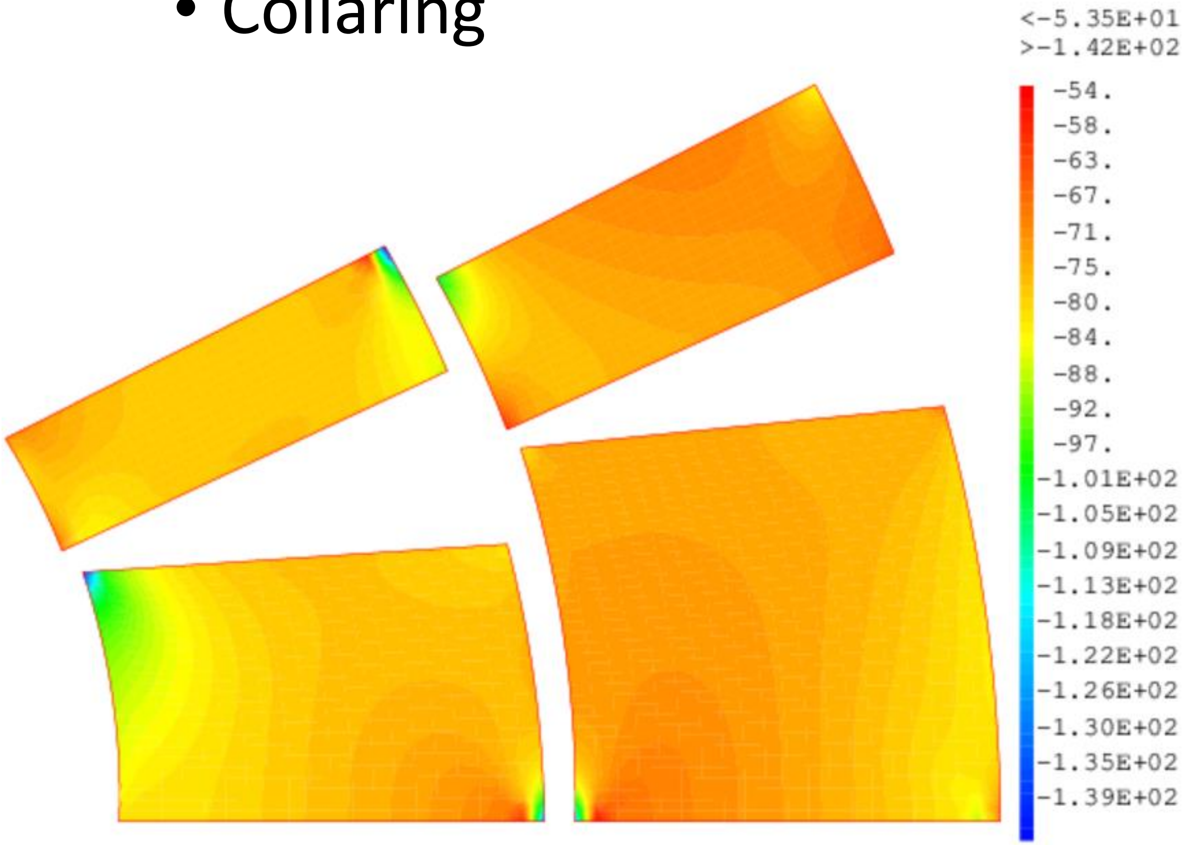




Average contact pressure at nominal: 30 MPa
Lowest contact pressure spot: 11 MPa

Collar structure investigation (4/3)

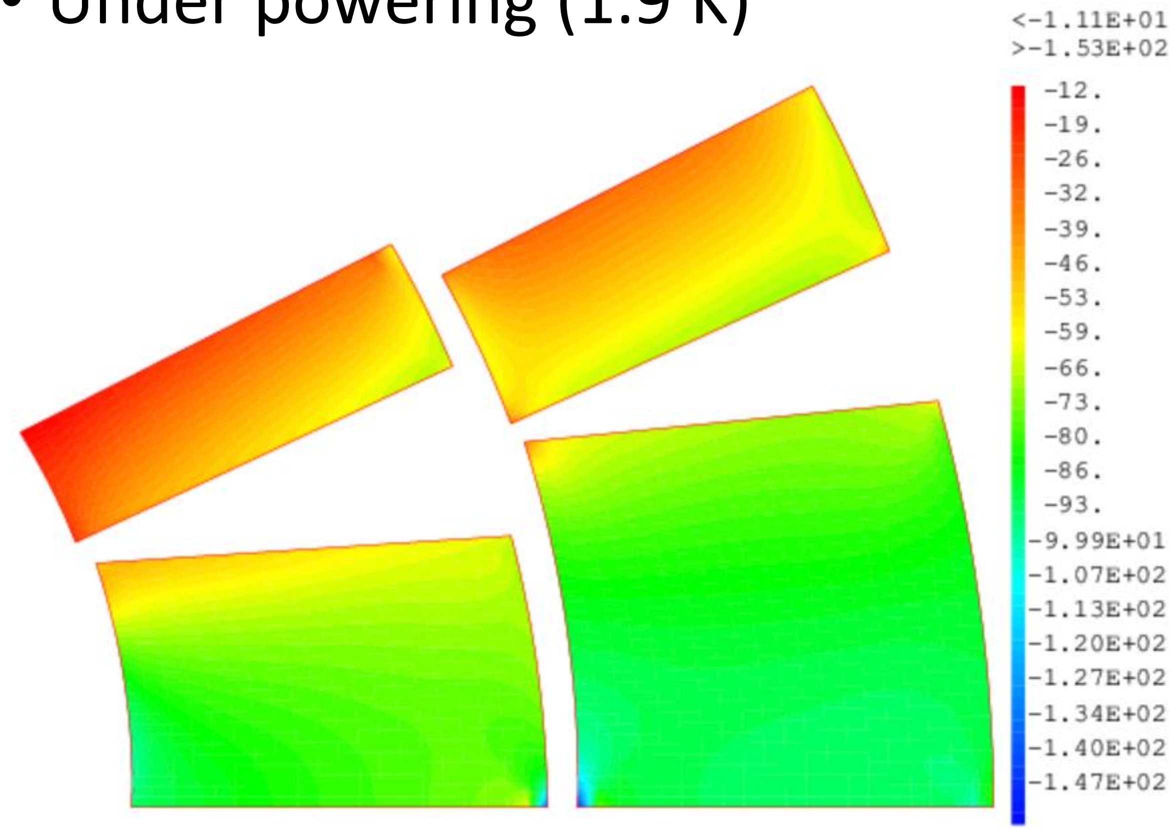
- Collaring



Average azimutal stress: 73 MPa

Peak azimuthal stress: 142 MPa < 150 MPa

- Under powering (1.9 K)



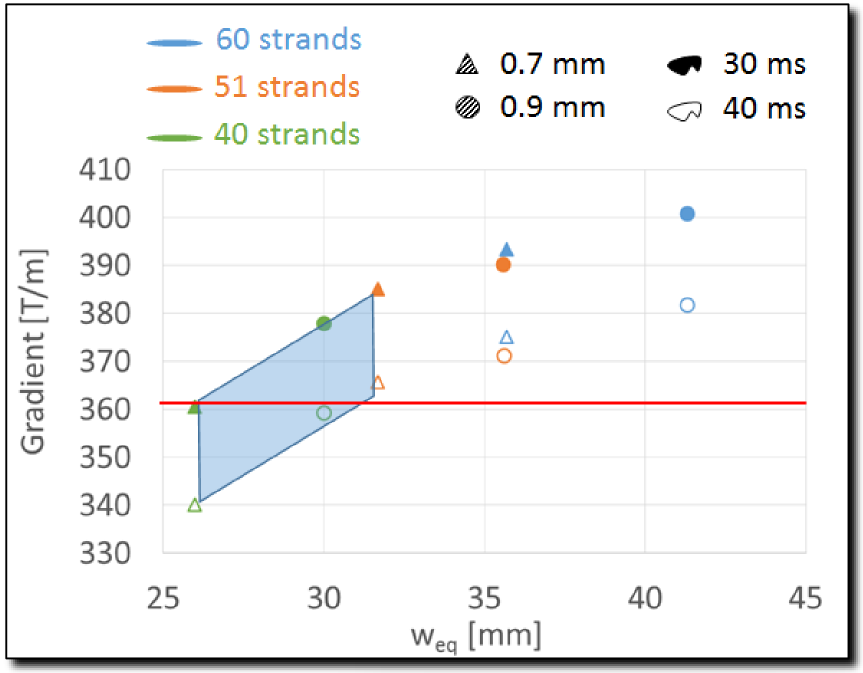
Average azimutal stress: 58 MPa

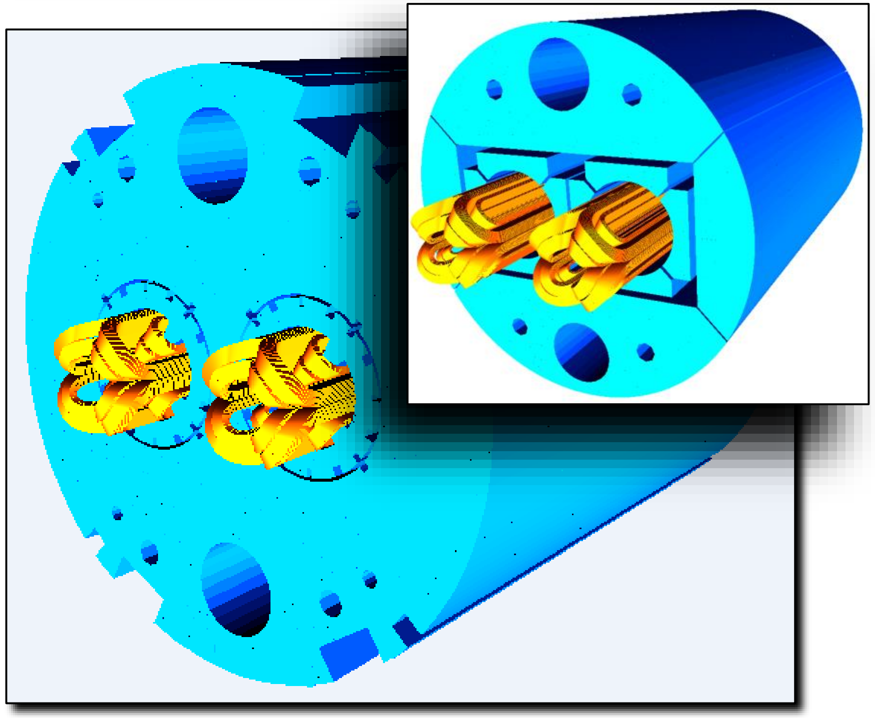
Peak azimuthal stress: 153 MPa < 200 MPa

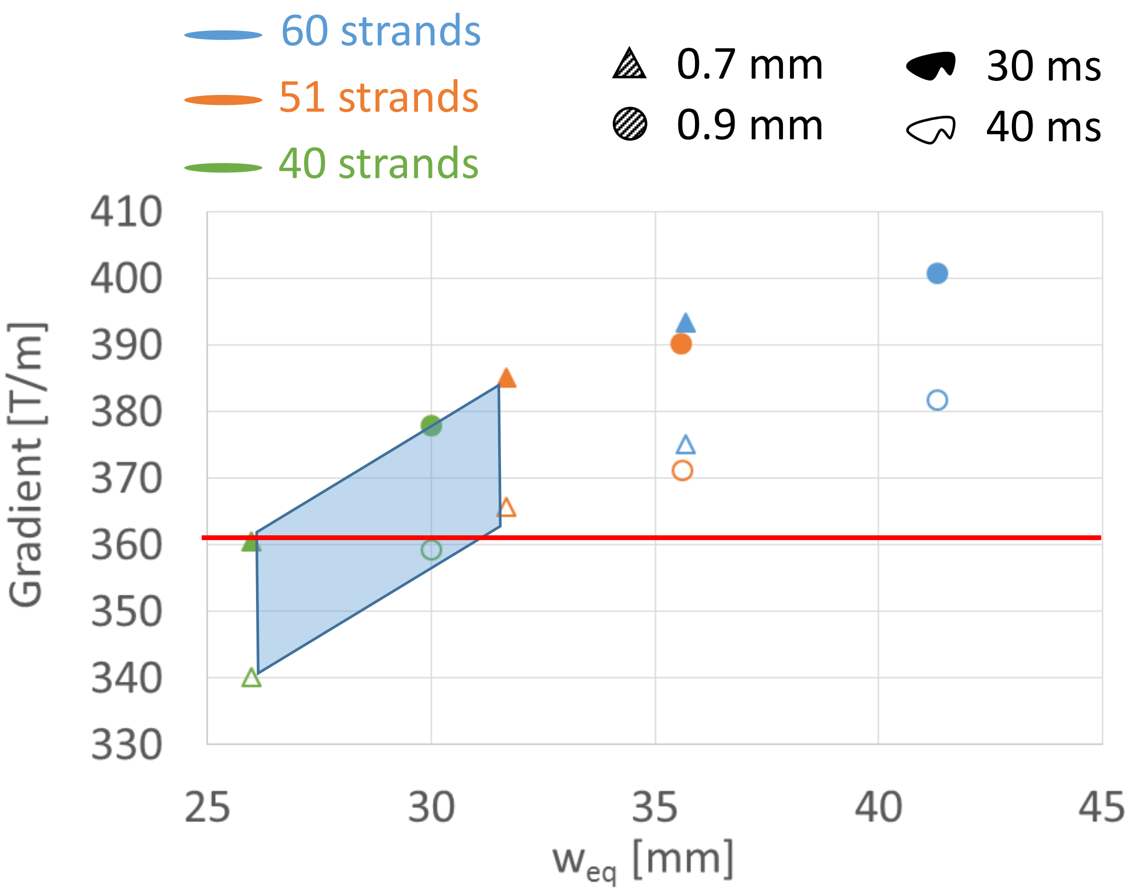
Conclusion

- I would suggest to stay in the blue area, but:
  - CLIQ simulations needed to propely assess the hotspot
  - Windability trials to avoid 'too' big cable temptation
  - Try to keep the forces as low as possible to use the collar technology (creep to be estimated)
- 3D design under development towards windability trials + peak field optimization
- No time for a *slide for fun* today

Thank you.







Daniel Schoerling talk

Magnet type	Number	Max. Strength	Length	SC material	LHC nominal strength (56 mm aperture)	LHC nominal strength scaled to 50 mm aperture
Main Dipole (MB)	4668	16 T	14.1 m	Nb_3Sn	8.33 T	8.33 T
Main Quadrupole (MQ)	744	360 T/m	7.2 m	Nb_3Sn	223 T/m	250 T/m
Trim Quadrupole (MQT)	120	220 T/m	0.5 m	Nb-Ti	123 T/m	140 T/m
Skew Quadrupole (MQS)	96	220 T/m	0.5 m	Nb-Ti	123 T/m	140 T/m
Main Sextupole (MS)	696	7000 T/m^2	1.2 m	Nb-Ti	4430 T/m^2	5560 T/m^2
Main Octupole (MO)	480	200,000 T/m^3	0.5 m	Nb-Ti	63,000 T/m^3	90,000 T/m^3
Sextupole Corrector (MCS)	9336	3000 T/m^2	0.11 m	Nb-Ti	1630 T/m^2	2050 T/m^2
Dipole Corrector (MCB)	792	4 T	1.2 m	Nb-Ti	3 T	3 T
DIS Trim Quadrupole (MQTL)	48	220 T/m	2.0 m	Nb-Ti	129 T/m	145 T/m
DIS Quadrupole (MQDA)	48	360 T/m	9.7 m	Nb_3Sn	129 T/m	145 T/m

List of FCC quad parameters

Inputs for the FCC quad optimization are ticked in the open column with associated values/limits/comments.
Some design inputs have already been fixed based on past experience and philosophy approach for the FCC quad.

Optimization input	Open	Fixed	Values/limits/comments
Conductor material		x	Nb_3Sn
Layers		x	2
No grading		x	no grading
Loadline margin		x	20%
Protection time	x		40 ms , 30 ms
Strand diameter	x		< 0.9 mm ($R_{bending}$ ≈ 4-5 mm – test with MQXF (0.85 mm x 40), 11T, (0.7 mm x 40) Fresca2 (1.0 mm x 40) cables to feel the feasibility)
Cable size	x		up to 60 strands (US cabling machine)
Cable compaction	x		thin edge = 14-18 % ; thick edge = 3-7%
Current	x		no limit
integrated gradient		x	2275 T
Copper/NonCopper	x		> 0.9
$T_{hotspot}$ adiabatic		x	350 K
peak voltage in magnet		x	1.2 kV
J_c		x	FCC fit (2250 A/mm² @1.9 K 16 T) -> 0% cabling deg.
T_{op}		x	1.9 K
aperture diameter		x	50 mm
interbeam (at cold)		x	204 mm
OD st-st shell		x	790 mm