EPFL

CS coil preconceptual design and electromagnetic analysis for the 2024 DEMO baseline

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MAG-T.01.01-T031-D001

MAG-T.01.01-T031-D003

SWISS PLASMA CENTER

Outline

LAR-DEMO CS requirements + inputs

SPC’s CS preconceptual design with 316LN jackets

How to increase the premagnetisation flux?

Summary

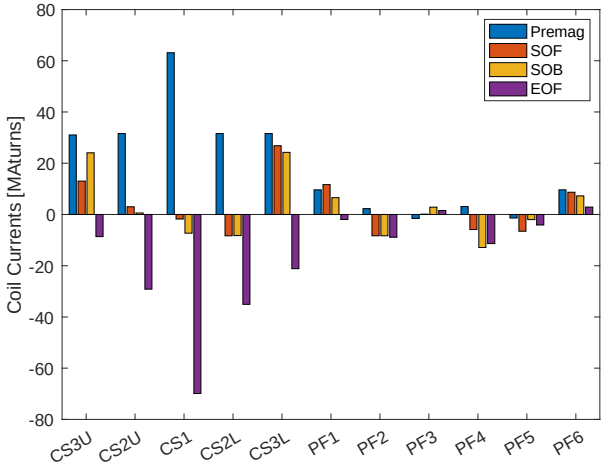
Baseline Requirements & Assumptions

1. 30,000 plasma cycles
2. Premagnetisation flux of 235 Wb
3. Outer radius of ≤2.735 m (including outer precompression structure)

CS design should be independent of PF and TF design choices

SPC also assume:

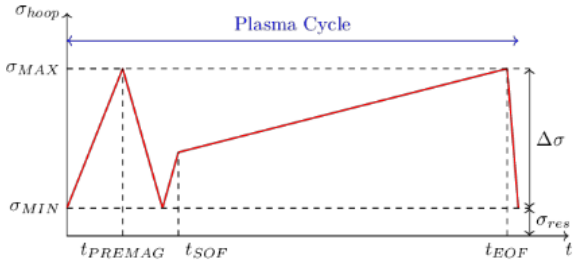
- 115 mm of radial space for the precompression structure
- Maximum steel jacket thickness of 16 mm

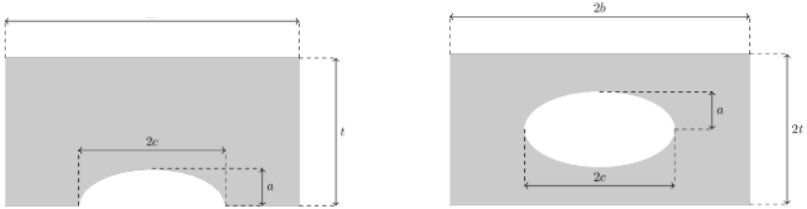


	R $[m]$	Z $[m]$	DR $[m]$	DZ $[m]$
CS3U	2,41	8,48	0,65	3,39
CS2U	2,41	5,08	0,65	3,39
CS1	2,41	0,00	0,65	6,78
CS2L	2,41	-5,09	0,65	3,39
CS3L	2,41	-8,48	0,65	3,39

FCGR Studies: 316LN, JK2LB, N50H/CNHS01

The FCGR studies performed in the previous baseline were repeated





The same safety factors and assumptions were used. **No relaxation**

Steel	Maximum Hoop Stress
316LN	250 MPa
JK2LB	300 MPa
N50H	380 MPa

See presentation on MAG-S.01.04-T021-D001

Uniform J_{eng} Predimensioning

Coil modules are broken down into:

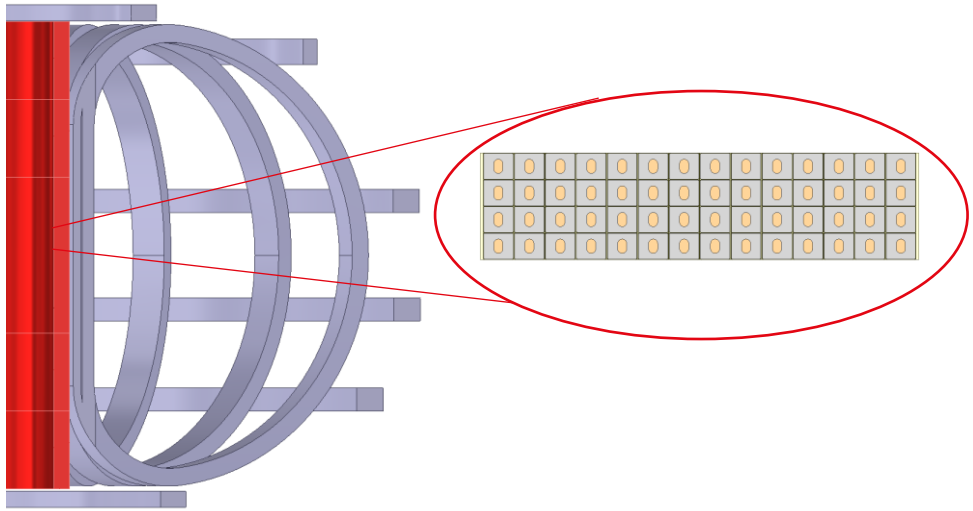
- 14 layers
- 90 turns (CS1), 45 turns (other modules)
  →1260 turns in CS1 (compared to 1560 in previous baseline)

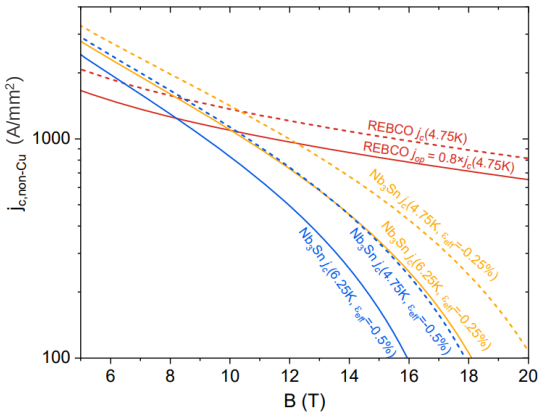
The current in each turn is treated as an infinitesimally thin line current.

The magnetic fields are calculated numerically and the mechanical stresses analytically.

Scaling laws:

- LTS: common reference document
- HTS: previous baseline (Wesche, Sarasola)





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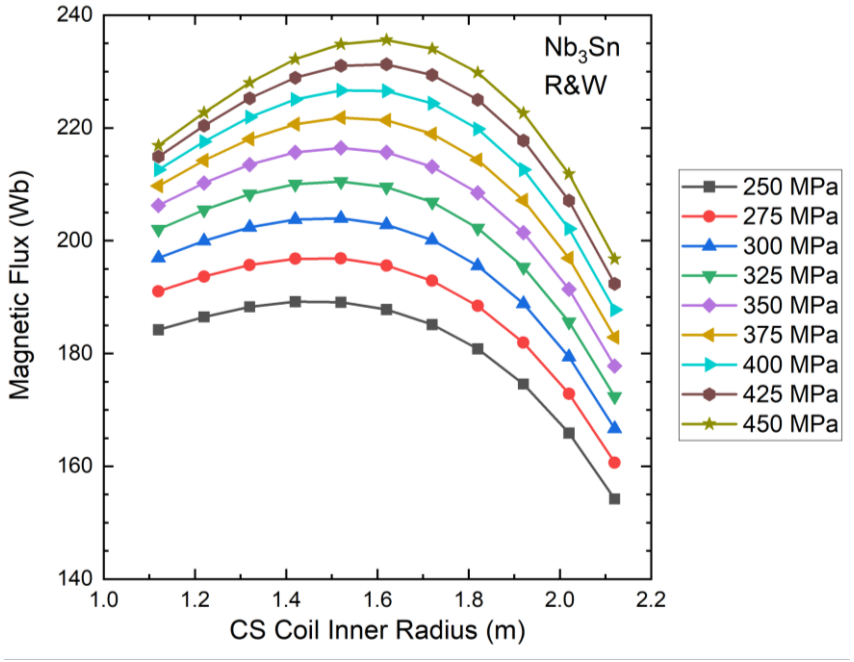
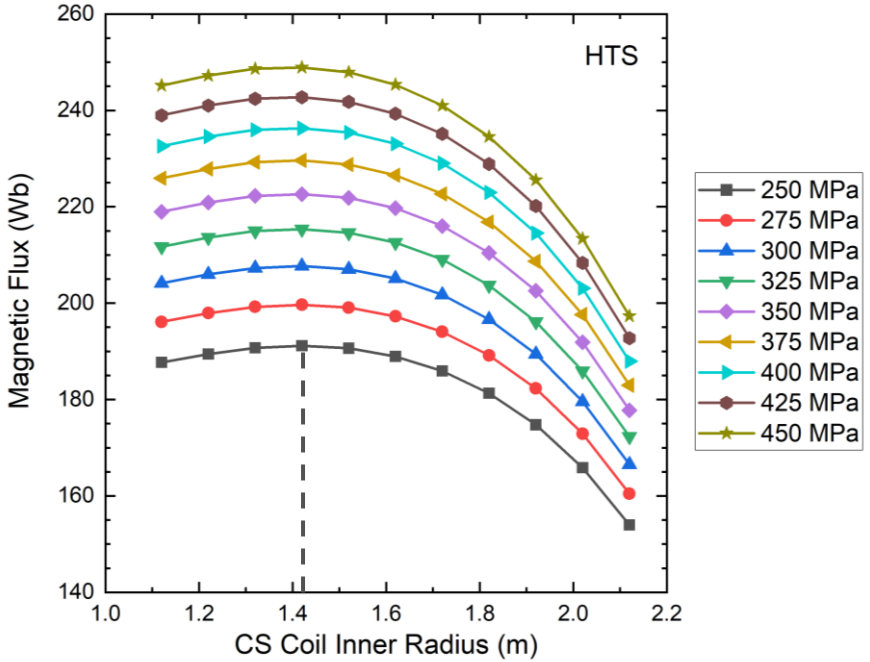
Premagnetisation Flux – UCD Solenoid Studies

UCD solenoids cannot get close to 235 Wb unless the allowable hoop stress is very high

For 316LN (250 MPa), the flux boost from HTS is quite small (<5 Wb)

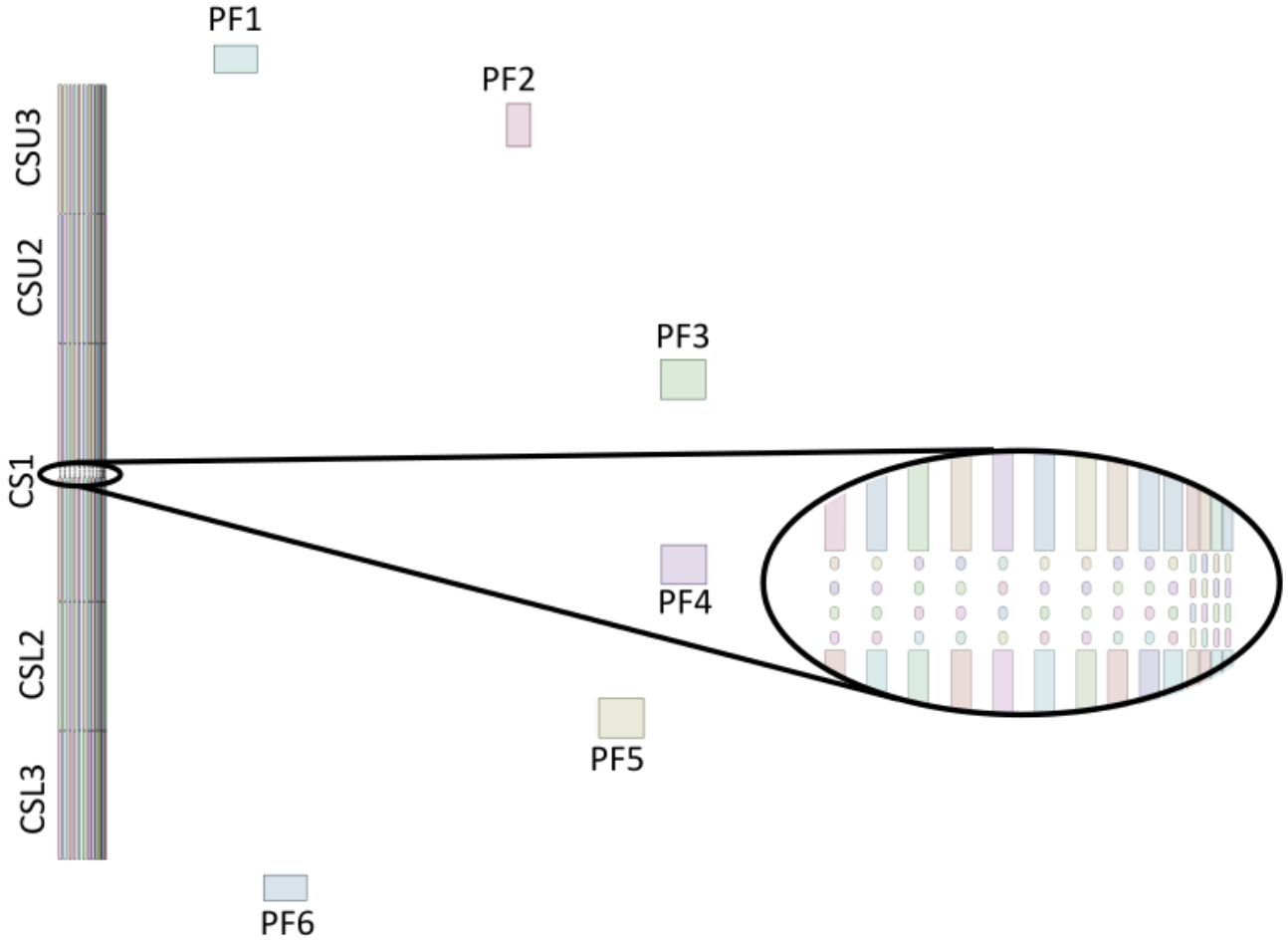




Next Step

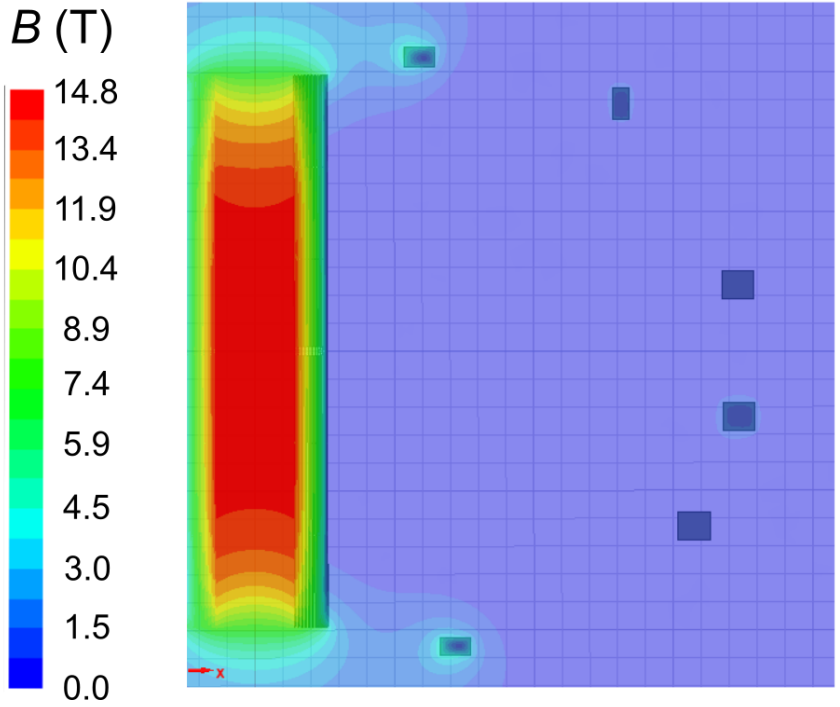
Grading the superconductor and steel

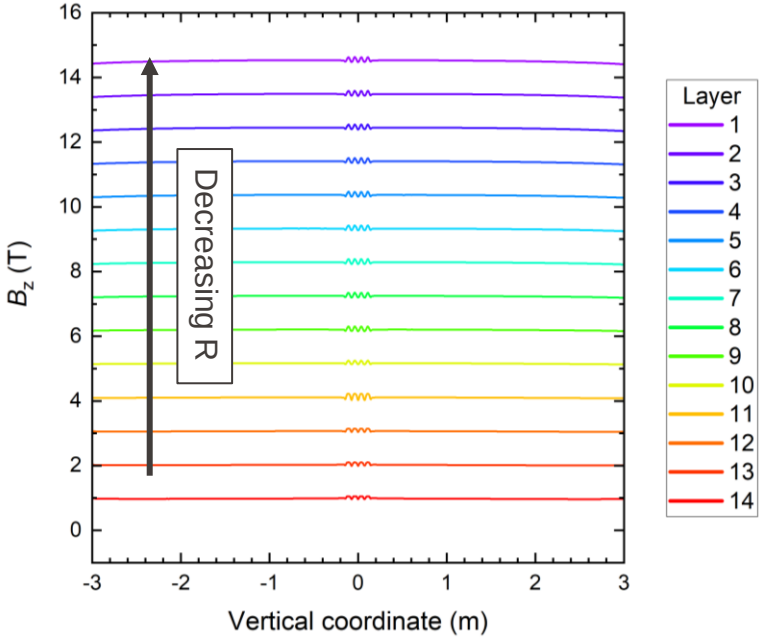
2D Axisymmetric EM + Mech. Simulations



2D Electromagnetic Simulations - Premagnetisation

Flux: 192 Wb



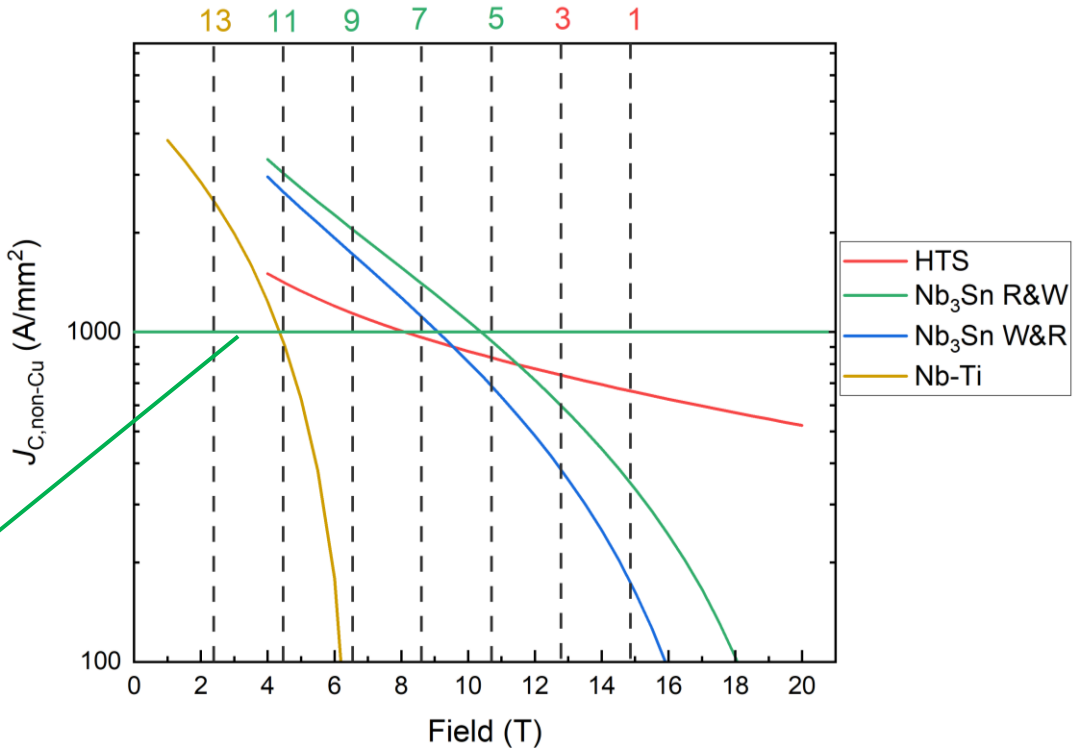


Grading the Superconductor

We split the CS coil up into 2-layer “sub-coils”

The superconductor for each sub-coil was chosen using the peak field in that sub-coil

For Nb_3Sn, we set an upper limit on the non-Cu J_C of 1000 A/mm^2, based on SULTAN sample tests



Key Coil Design Parameters – 316 LN Design

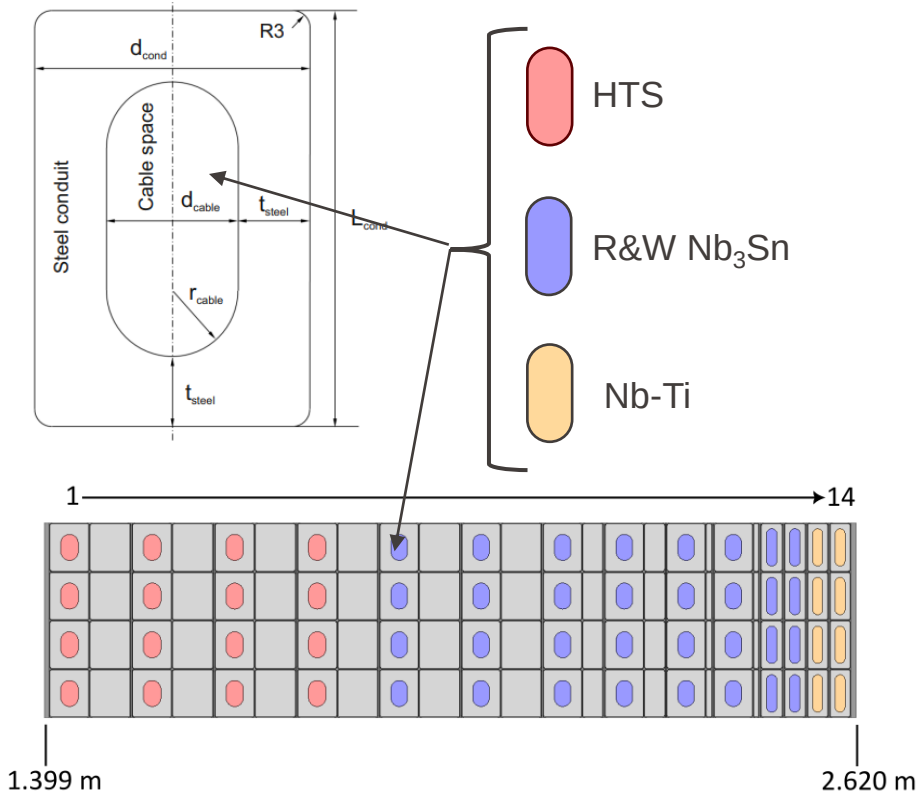
Parameter	Uniform J	SC graded	SC + steel graded
Total current (MAt)	76.27	76.27	76.27
Conductor current (kA)	60.53	60.53	60.53
WP R_i (m)	1.415	1.417	1.399
WP R_o (m)	2.62	2.62	2.62
SC material in sub-coils (RE-123/Nb_3Sn/Nb-Ti)	14/0/0	4/8/2	4/8/2
Peak B field (T)	14.86	14.86	14.83
CS flux during premagnetisation (Wb)	**192.0**	**192.4 (+0.2%)**	**215.0 (+12%)**

Mechanics are in presentation on MAG-S.01.04-T021-D001

Conductor Dimensions - 316LN

A large amount of steel grading using thick co-wound steel strips (or multiple thin strips) is needed to achieve **215 Wb** of flux

Layer	L_{cond} (mm)	d_{cond} (mm)	d_{cable} (mm)	t_{steel} (mm)	d_{strip} (mm)
1 & 2	71.0	58.2	26.2	16.0	60.0
3 & 4	71.0	58.0	26.0	16.0	60.0
5 & 6	71.0	56.8	24.8	16.0	60.0
7 & 8	71.0	56.8	24.8	16.0	30.0
9 & 10	71.0	56.8	24.8	16.0	8.0
11 & 12	71.0	30.8	15.8	7.5	-
13 & 14	71.0	29.7	14.8	7.5	-

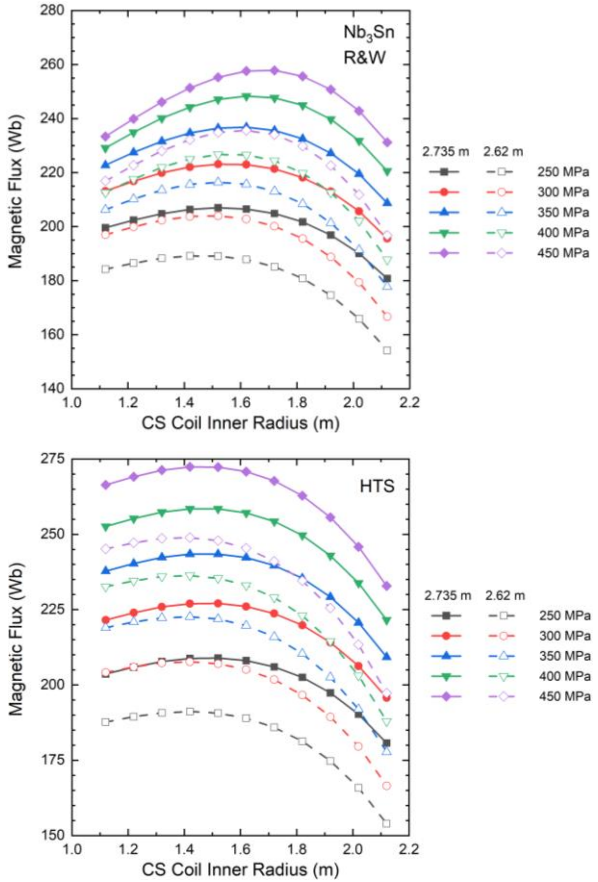


Boosting the Flux

Option 1: Increasing the CS Outer Radius

The UCD solenoid simulations were repeated for an outer radius of 2.735 m

A flux boost of ~20 Wb is possible for 316LN



Option 1: Does it Fit?

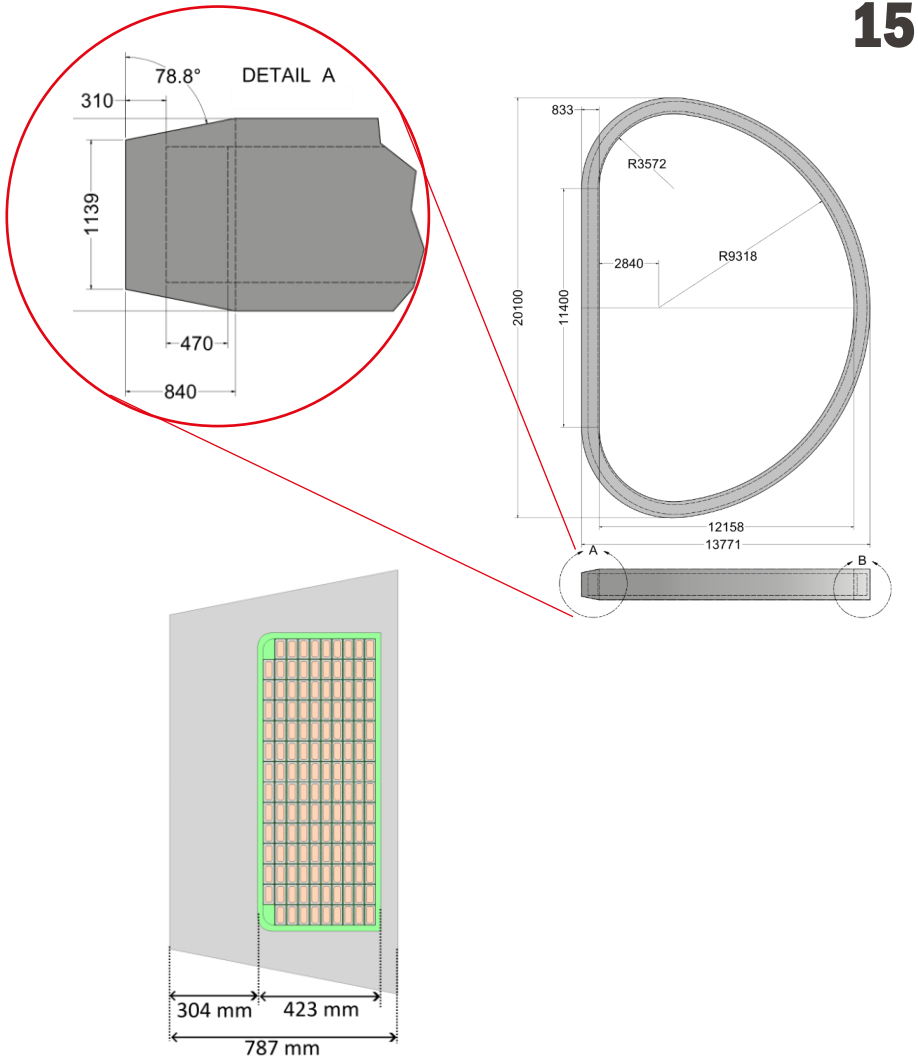
R_o= 2.62 m → R_o = 2.735 m is enough to unlock 20 Wb more flux.

215 Wb → 235 Wb ✓

Could a combination of reductions in:

- TF coil space envelope (SPC's coil is 53 mm thinner than the baseline)
- Outer tie plate thickness (increase toroidal space allocation)
- The CS/TF radial clearance

get us the 115 mm? Perhaps a topic for the future.



Option 2: Allowing Higher Hoop Stresses

Parameter	UCD		SC graded		SC + steel graded	
	JK2LB	N50H	JK2LB	N50H	JK2LB	N50H
Total current (MAt)	82.87	92.15	82.87	92.15	82.87	92.15
Conductor current (kA)	**65.77**	**73.13**	**65.77**	**73.13**	**65.77**	**73.13**
WP R_i (m)	1.415	1.415	1.418	1.418	1.418	1.422
SC material in subcoils (RE-123/Nb_3Sn/Nb-Ti)	14/0/0	14/0/0	4/8/2	6/6/2	4/8/2	6/6/2
Peak B field (T)	**16.11**	**17.95**	**16.11**	**17.86**	**16.06**	**17.82**
Layer 1 Average Hoop Stress (MPa)	**286.5**	**344.1**	**287.2**	**361.4**	**299.0**	**378.0**
CS magnetic flux (Wb)	**207.9**	**230.4**	**208.5 (+0.3%)**	**231.2 (+0.3%)**	**235.3 (+13.1%)**	**258.4 (+12.2%)**

The overall conductor dimensions in each layer are similar to the 316LN design. The main differences are the conductor currents and peak fields.

Summary

We have designed a hybrid HTS-LTS CS coil for LAR-DEMO, with graded superconductor and 316 LN steel, including thick co-wound steel strips:

- 14 layers and 90 turns (CS1) or 45 turns (other modules)
- Outer radius: 2.62 m
- Magnetic flux during premagnetisation: 215 Wb
- Peak field: ~15 T – benefit from HTS is quite small

2 possible options have been identified to reach 235 Wb during premagnetisation:

- Increase the CS outer radius (gives a 20 Wb flux boost)
- Choose a more fatigue resistant steel (JK2LB or N50H)