Combined Function Optimum Integral Design for B0pF
(Risk reduction)

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Magnet Steering Group Meeting

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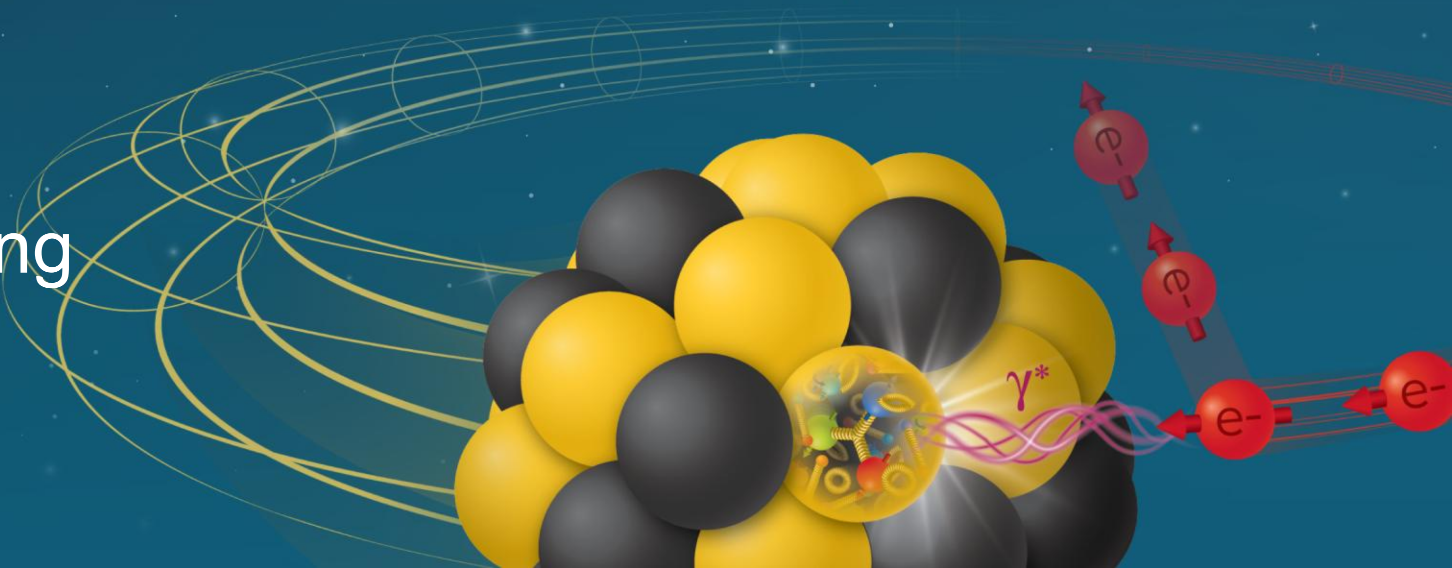
Electron-Ion Collider



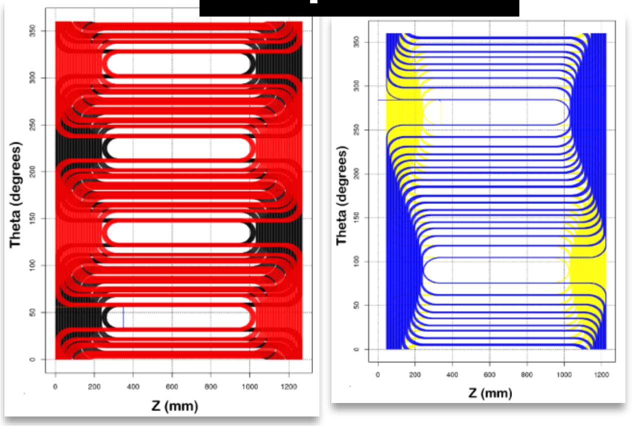
Update on Risk Reduction in B0pF

Two options, both offer significant advantages:

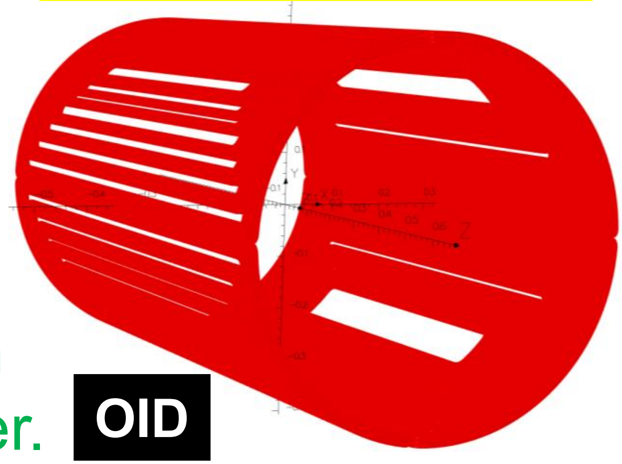
1. Number of layers reduced from 10 to 6 (or 8).
2. Operating Current reduced from 1143 A to 889 A (or 671 A).
3. Load line fraction improved from 70% to 60% (or 50)%.
4. Reduction in Lorentz force density (IXB), better mechanically.
5. Quench heaters are no longer essential (next presentation).
6. Voltage to ground reduced from 950 V to 535 V (or 466 V).

- ➢ Major benefits come from the inherent value of the Optimum Integral Design (OID) in short magnets (small coil length/ diameter ratio), as the loss in field due to ends is minimized.
- ➢ Another advantage comes from making it a combined function.
- ❖ 8 layers offers very large margin; load line fraction is 54% even after replacing the central sc wire in 6-around-1 cable by copper.

Serpentine

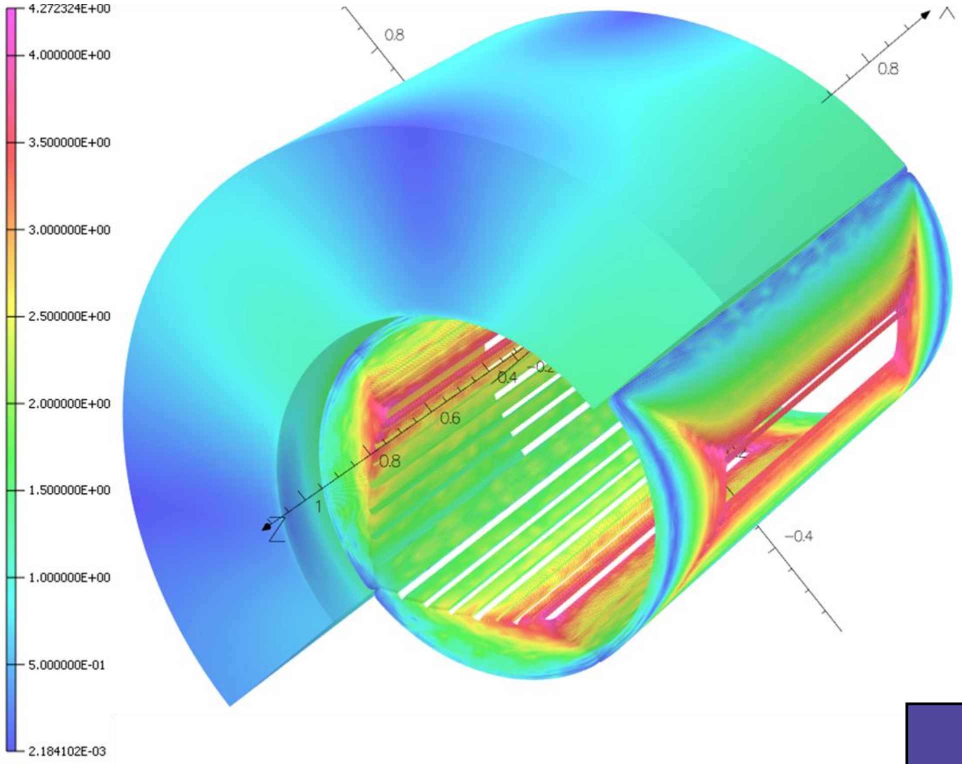


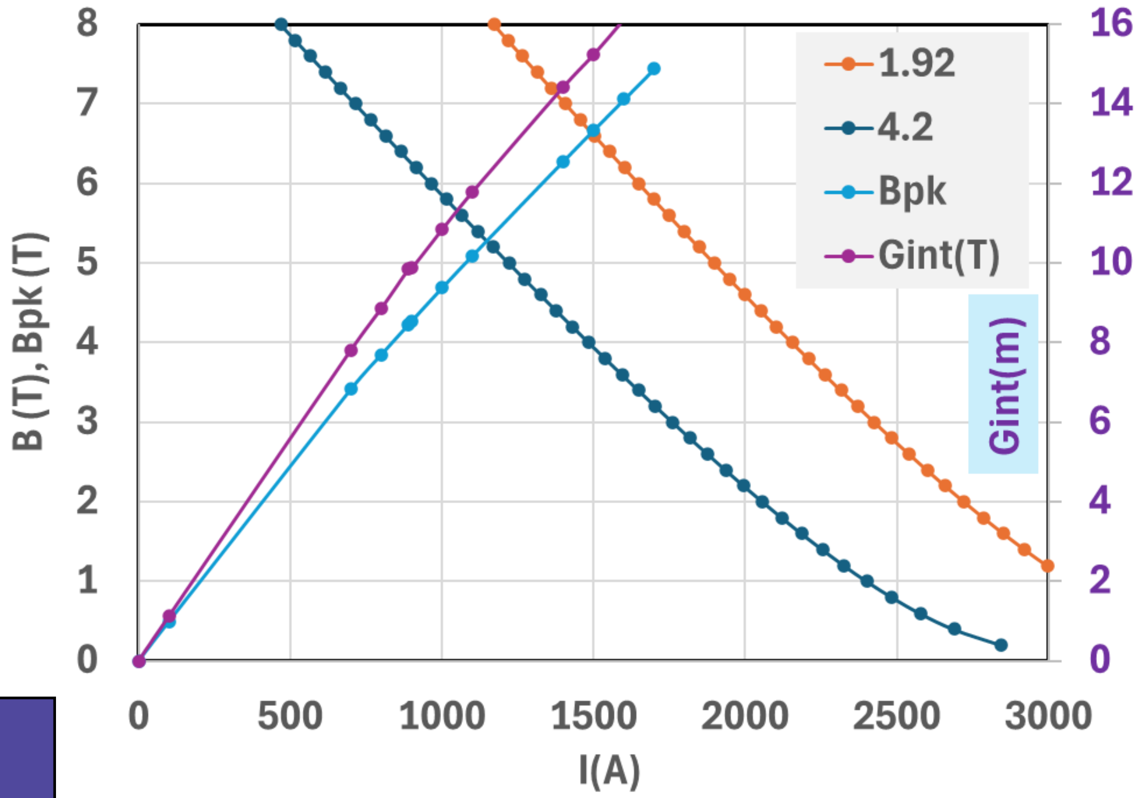
Coil length: 1200 mm
Inner diameter: 656 mm



OID

6-layer Optimum Integral Combined Function Design
(6 around 1 cable, all super – performance at 1.92 K & 4.2 K)





Original Current 1143 A

A GOOD SOLUTION

Design Values		Current (A)
Gint(T)	9.75	889
Bint(h)	1.56	889

	Iss(A)	Margin(%)	LoadLineFraction(%)
All SC @1.92K	1494	68%	60%
All SC @4.2K	1150	29%	77%

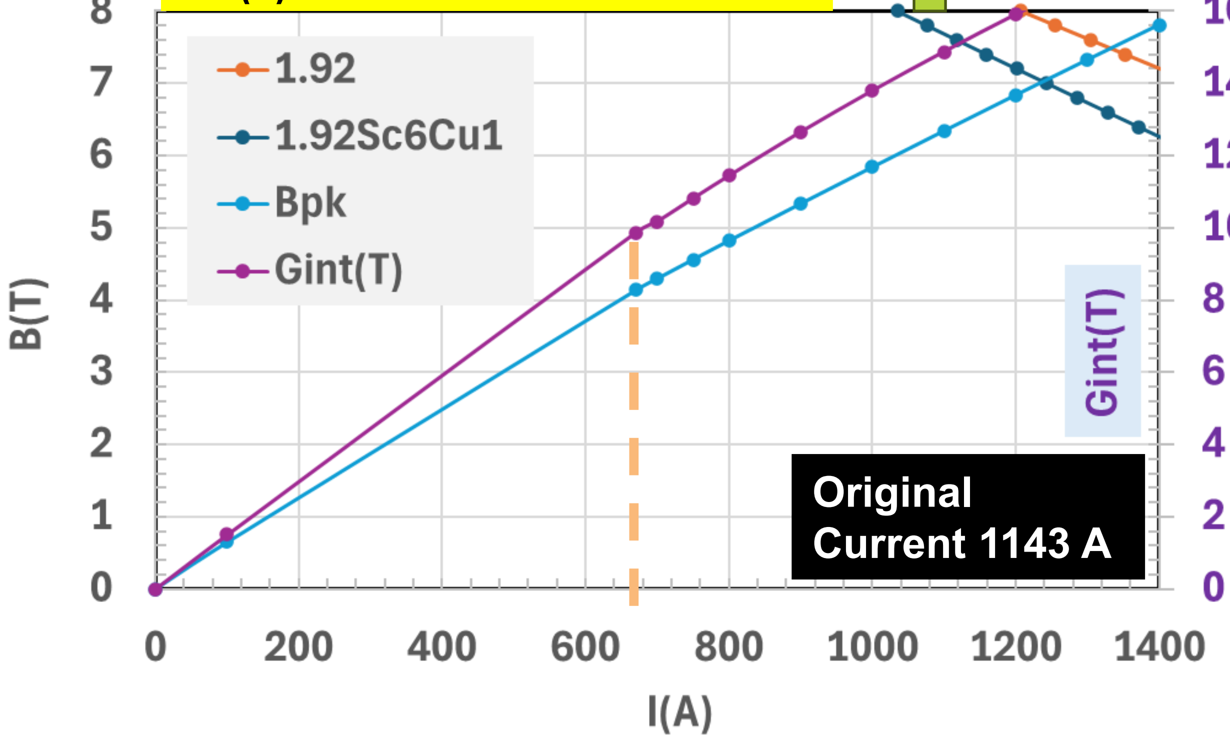
Lower current (78%); and a healthy margin

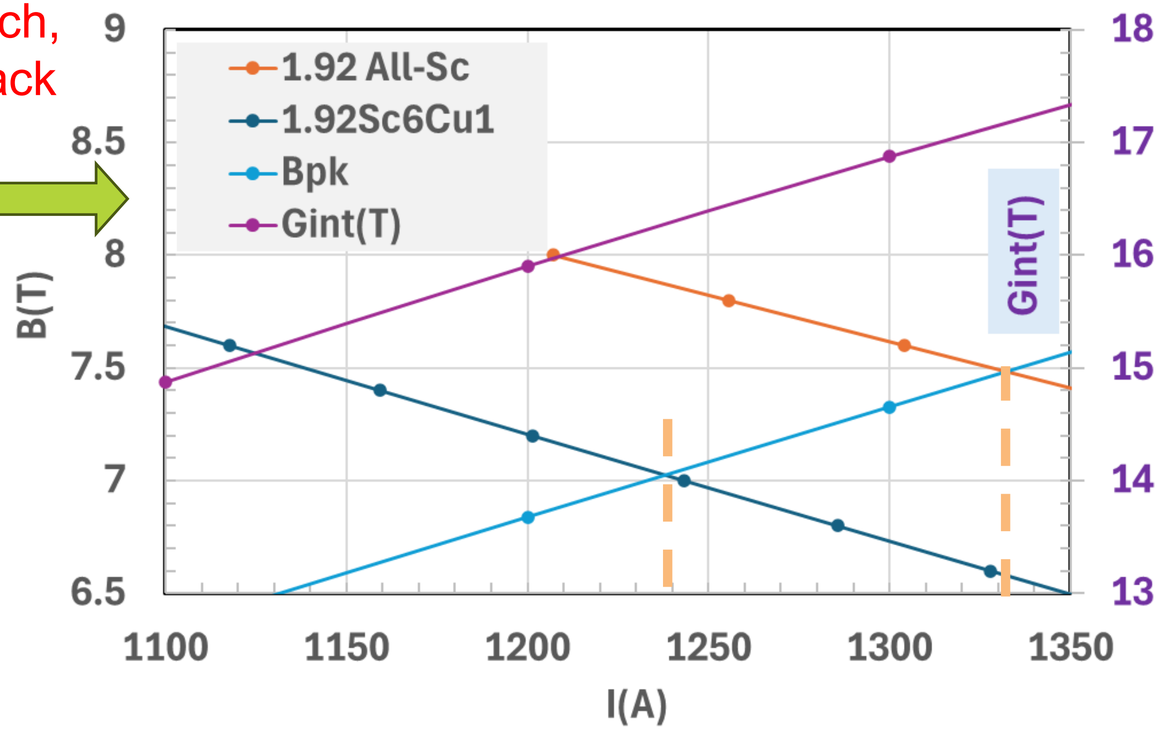
8-layer Optimum Integral Combined Function Option

(Central wire in 6-around-1 cable can be copper, 6 transposed wire are superconductor)

Making central wire Cu increases effective cu/sc ratio at quench, should reduce hot spot temperature, and help from quench back

Design Values		Current (A)
Gint(T)	9.75	671
Bint(h)	1.56	671





	Iss(A)	Margin(%)	LoadLineFraction
All-SC @1.92K	1330	98%	50%
SC6Cu1 @1.92K	1240	85%	54%

✓ **Operates at a much lower current (59%), has healthy margin, & more Cu for quench protection.**

*All super option for 4K operation (see extra slides)

Summary and the Next Step

- Because of a low (~1.8) length/diameter aspect ratio, optimum integral design based on the direct wind technology offers the most efficient design among those known.
- The proposed combined function optimum integral design theoretically retires the risks raised earlier (quench protection, high voltage, quench heaters, lower margin).
- Next presentation will show that both options are quench protectable (despite not including many effects specific to 6-around-1, which will further improve the situation).
- Initial mechanical analysis reflects the expected improvements (a few slides follows).
- B0pF is one of the most challenging magnet in EIC. It is the largest aperture; high field direct wind magnet ever-built & tests the reach of the technology. Early test is prudent.
- We request this design to become baseline now and get ok to wind first two layers; followed by more layers on the top of them to validate the design and technology.
- We request another month or so to carry out more detailed analysis to weigh two options. In any case, it will be a few months before the tube is available for winding coil. We will use this time to fine tune the first (and quick) EM design analyzed so far.

B0PF OID 8 Layer
2D Half Coil Analysis

Chris Runyan, Mechanical Engineer

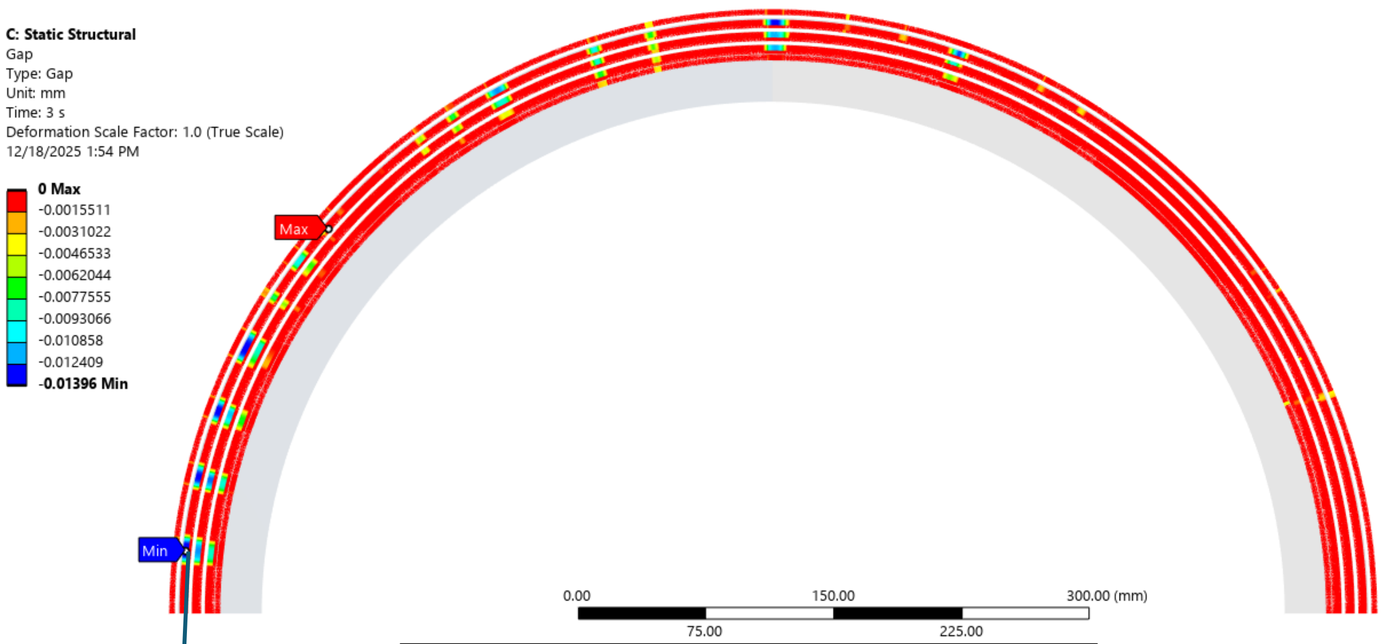
12/19/25

Electron-Ion Collider

Results Gap between all roving interfaces [mm]

Prestress + Thermal + Excitation

Red indicates contact

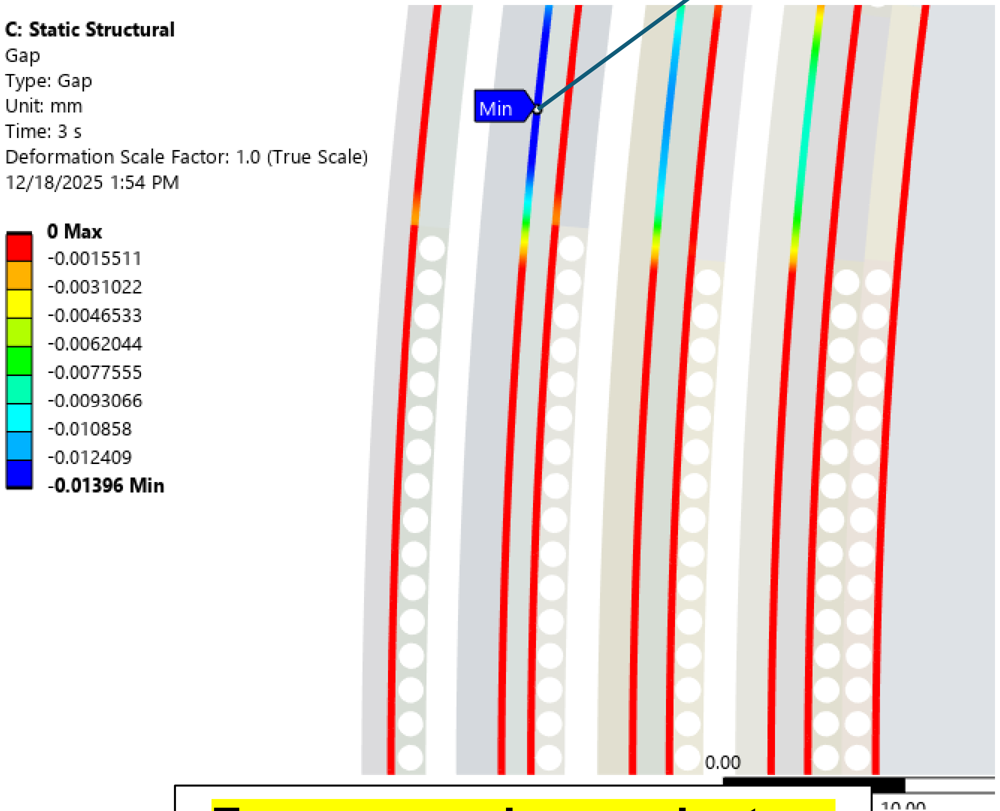


Fiberglass only

Zero gap under conductors

Acceptable

Fiberglass only

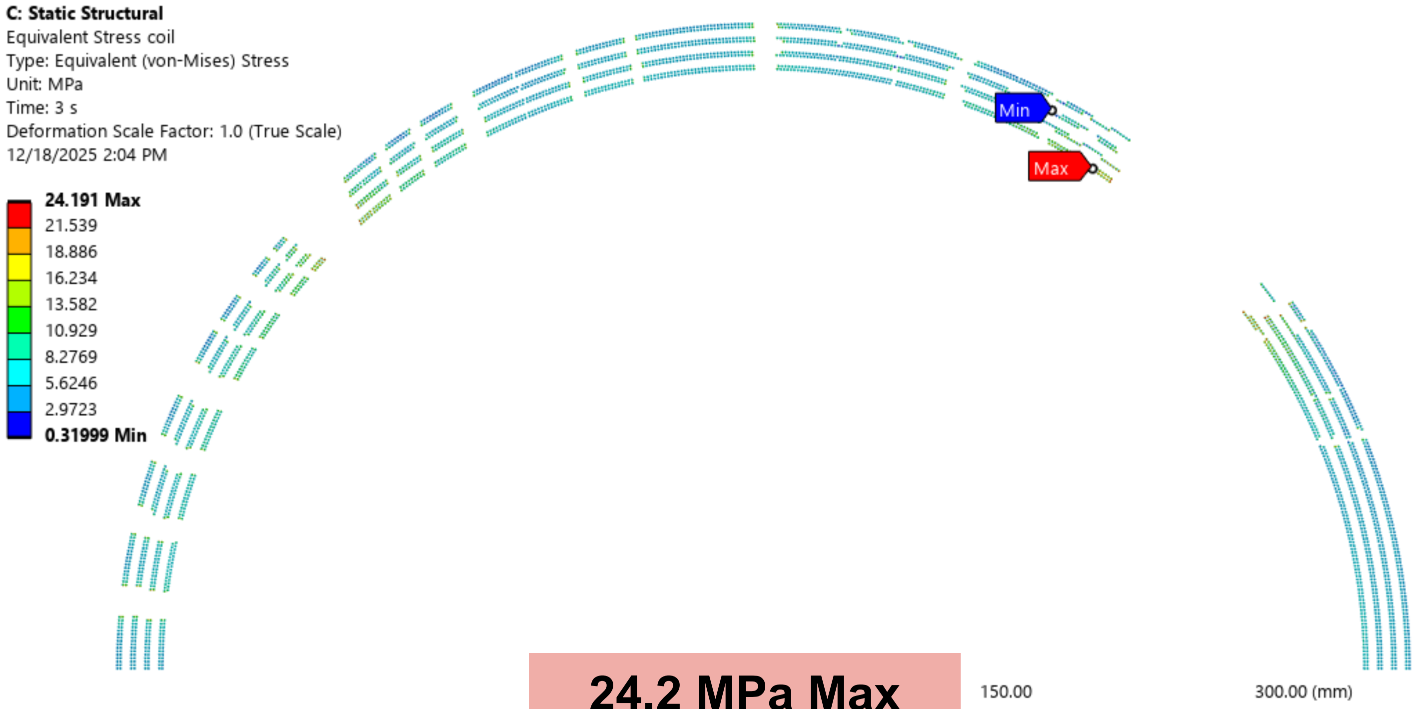


Zero gap under conductors

Acceptable

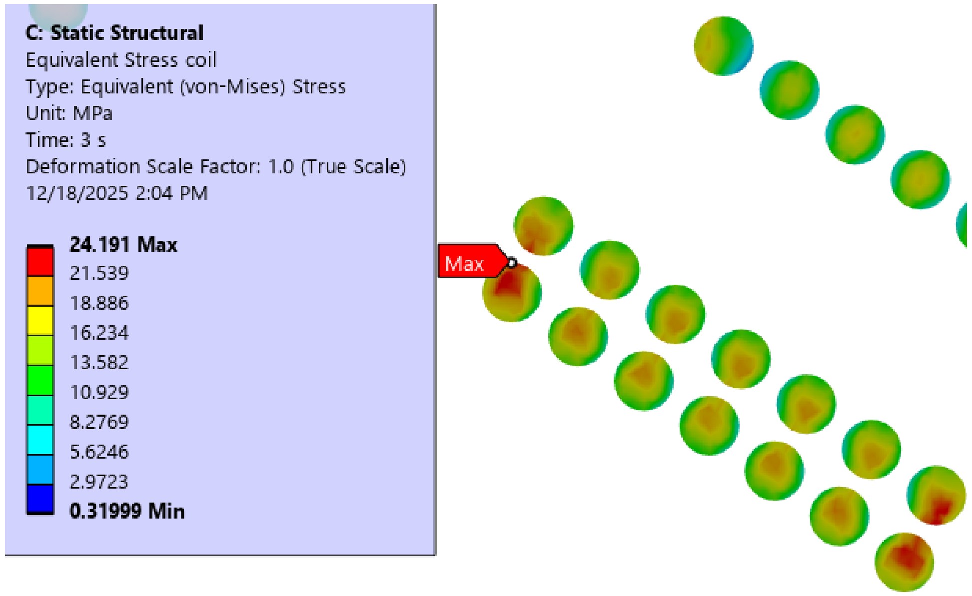
Results Von Mises stress in coils [MPa]

Prestress + Thermal + Excitation



24.2 MPa Max

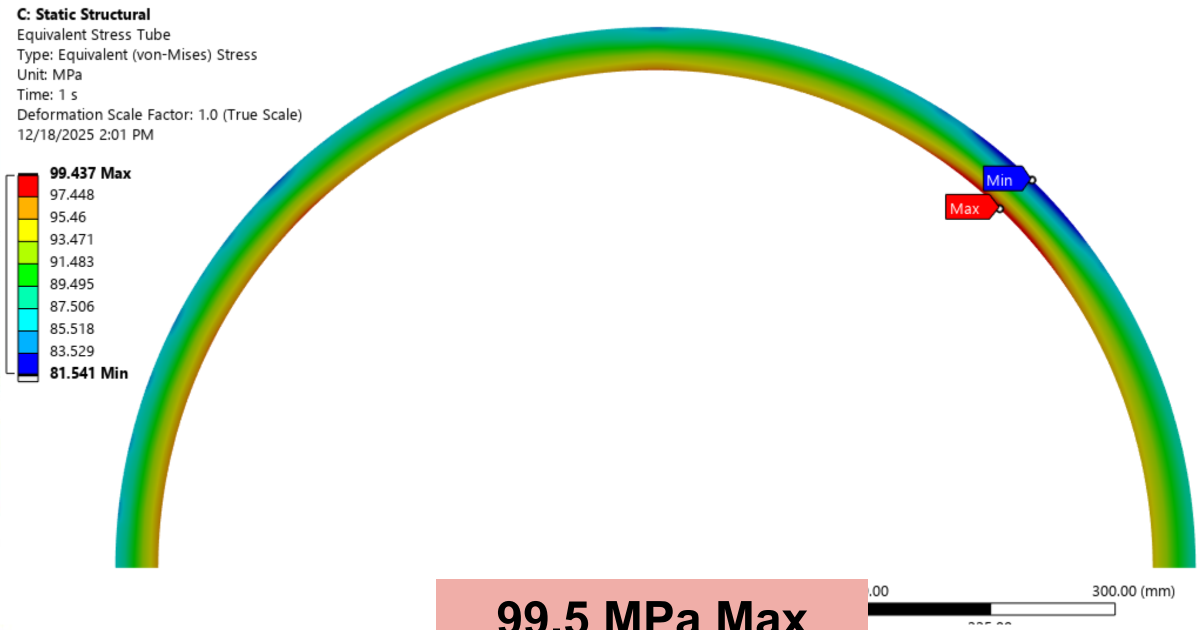
Acceptable



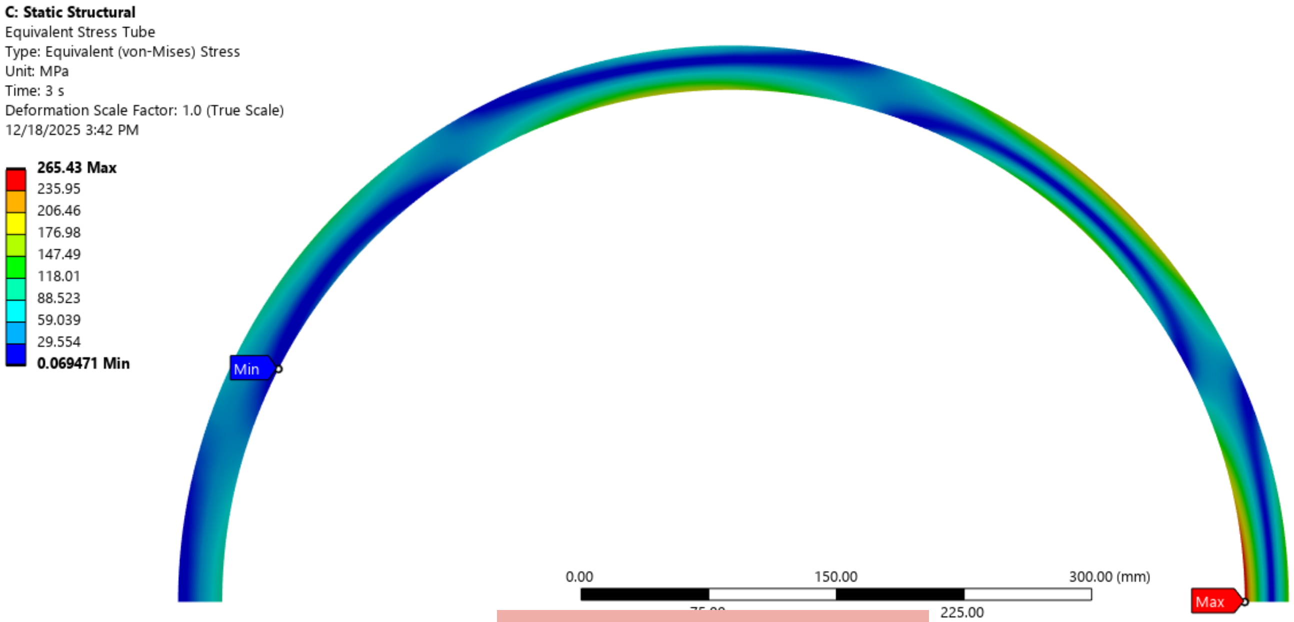
NbTi conductor can withstand up to 150 MPa

Results Von Mises stress of support tube [MPa]

After roving tension, at room temperature	Prestress + Thermal Cooldown + Excitation



99.5 MPa Max
Limit: 206.8 MPa
Acceptable



265.4 MPa Max
Limit: 482.6 MPa
Acceptable

Note: 316/316L Support Tube material has a min yield strength of **206.8 MPa** at room temp and **482.6 MPa** at cryogenic temperatures

Results Table

Measurement	Serpentine design 33 mm thk support tube	OID 26 mm thk support tube	Limit	Units
Maximum/Min Radial Strain of Coil At Excitation	.04/-0.17	.02/-0.08	-	%
Maximum Radial Gap Between Layers Below Conductors at Excitation Step	0	0	0	mm
Max. Von Mises Stress on Support Tube after roving installed at Room Temperature	146.0	99.5	206.8	MPa
Max. Von Mises Stress on Support Tube at Excitation Step	275.3	265.4	482.6	MPa
Max. Von Mises Stress on Coil (All Layers) at Excitation Step while cold	69.9	24.2	150.0	MPa
Max. Normal Radial Stress in Coil (All Layers) at Excitation Step while cold (compression)	51.4	24.4	150.0	MPa
Max. Normal Azimuthal Stress in Coil (All Layers) at Excitation Step while cold (compression)	80.7	16.7	150.0	MPa
Max. Frictional Stress on Coil at Excitation Step while cold	20.9	12.8	20.0	MPa

Room for improvement: given theoretical new buildup and fewer roving layers there is room to increase support tube thickness to approx. 31 mm.

Serpentine analysis: Stycast not modeled and run at higher current/more roving, resulting in higher stresses in coil

Thank You

Extra slides

Six superconductor around one copper in 6-around-1 cable (instead of all super)

- Starting design with a big margin which allows a part to be traded for quench protection (e.g., higher cu/sc – too late).
- However, making the center wire copper (instead of super) is expected to help. This will improve the quench back.
- It should also increase effective cu/sc ratio (from 1.75 to 2.21), after the quench. This would reduce the hot spot temperature, beside the central wire effectively becoming a heater.
- The ramp rate reduction in I_c also will also gets eliminated.
- The penalty will be a reduction in the critical current of the cable which will be now 6/7 of what it was for all super wires. The margin, however, is still very healthy.

➢ However, before making a choice, more analysis should be carried out, apart from any other consideration.

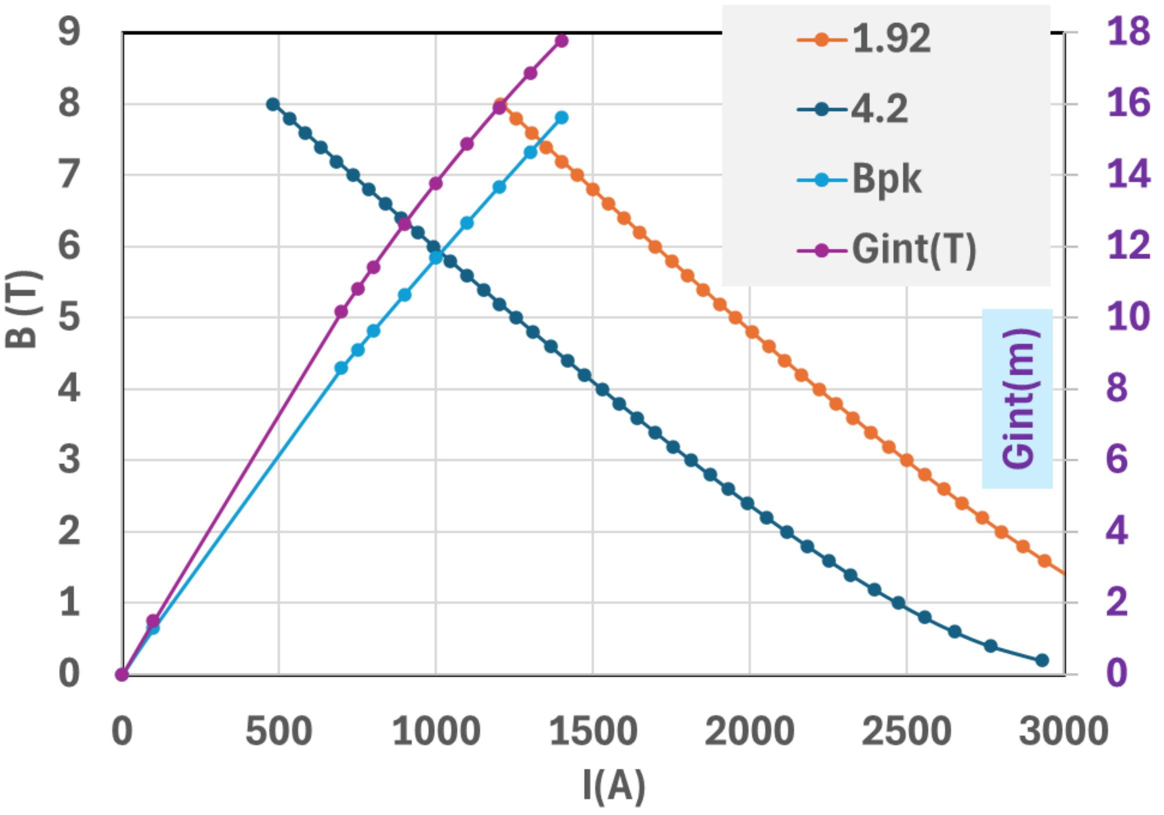
Effective Copper to Superconductor ratio in 6-around-1 copper

Cu/Sc from Brucker		
Original	Cu/Sc	1.75
Cu wires	1	
SC Wires	6	
Wire dia	0.473	mm
Wire area	0.176	mm^2
Super in wire	0.064	mm^2
Cu in Wire	0.112	mm^2
Cable Area	1.230	mm^2
Cu in Cable	0.847	mm^2
Super in cable	0.383	mm^2
Effective	Cu/Sc	2.21
Iquench@4.2K	1077	Amp
Jcu@Qnch	1272	A/mm^2
Iquench@1,92K	1520	Amp
Jcu@Qnch	1795	A/mm^2
Idesign	889	Amp
Jcu@design	1050	A/mm^2

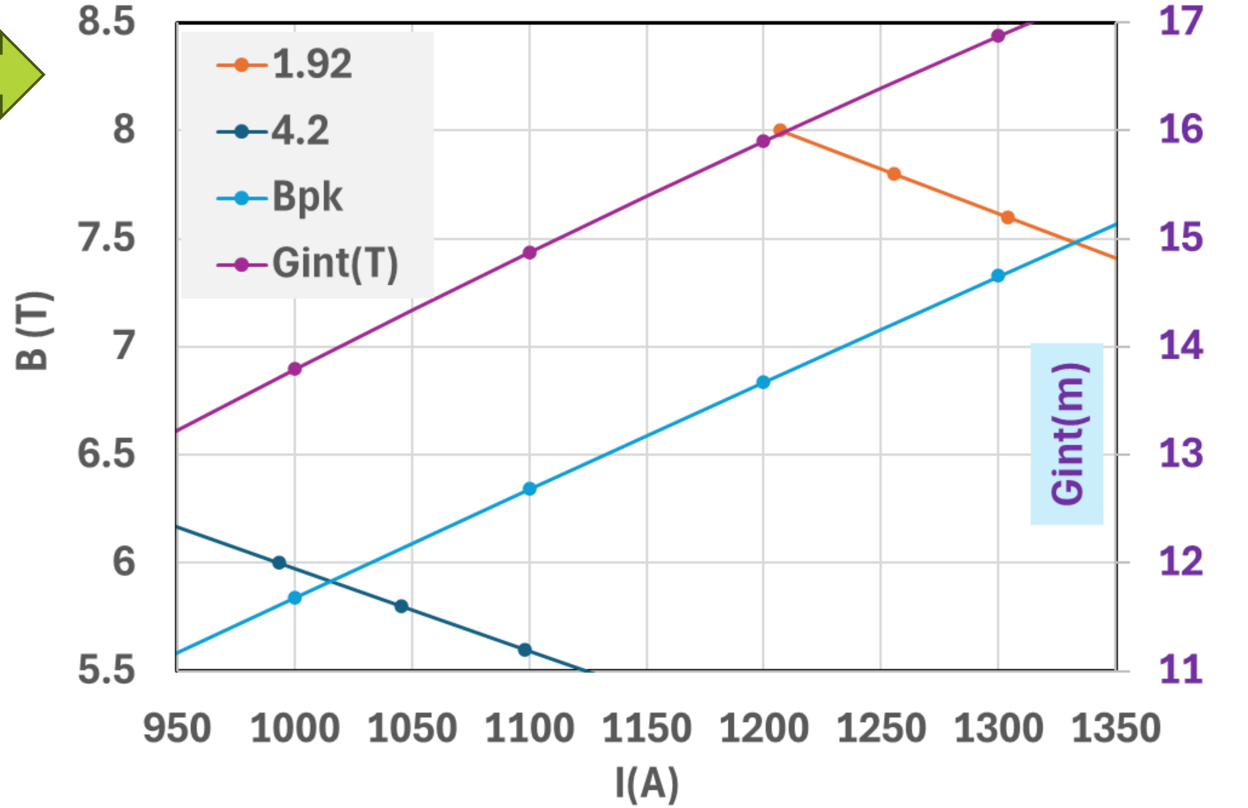
8-layer Optimum Integral Combined Function Option

(All wire in 6-around-1 cable superconductor, 4 K operation possible)

Design Values		Current (A)
Gint(T)	9.75	671
Bint(h)	1.56	671



All seven wires in 6-around-1 superconducting

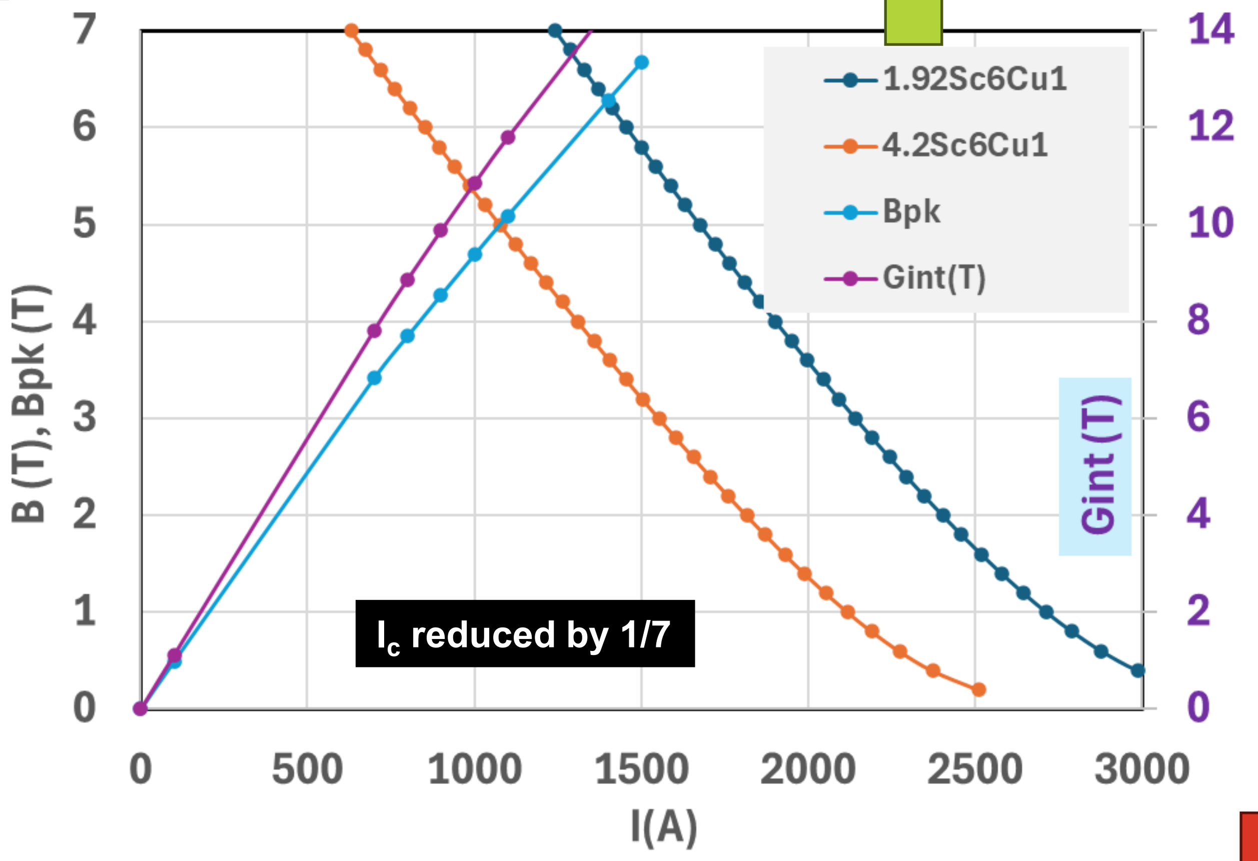


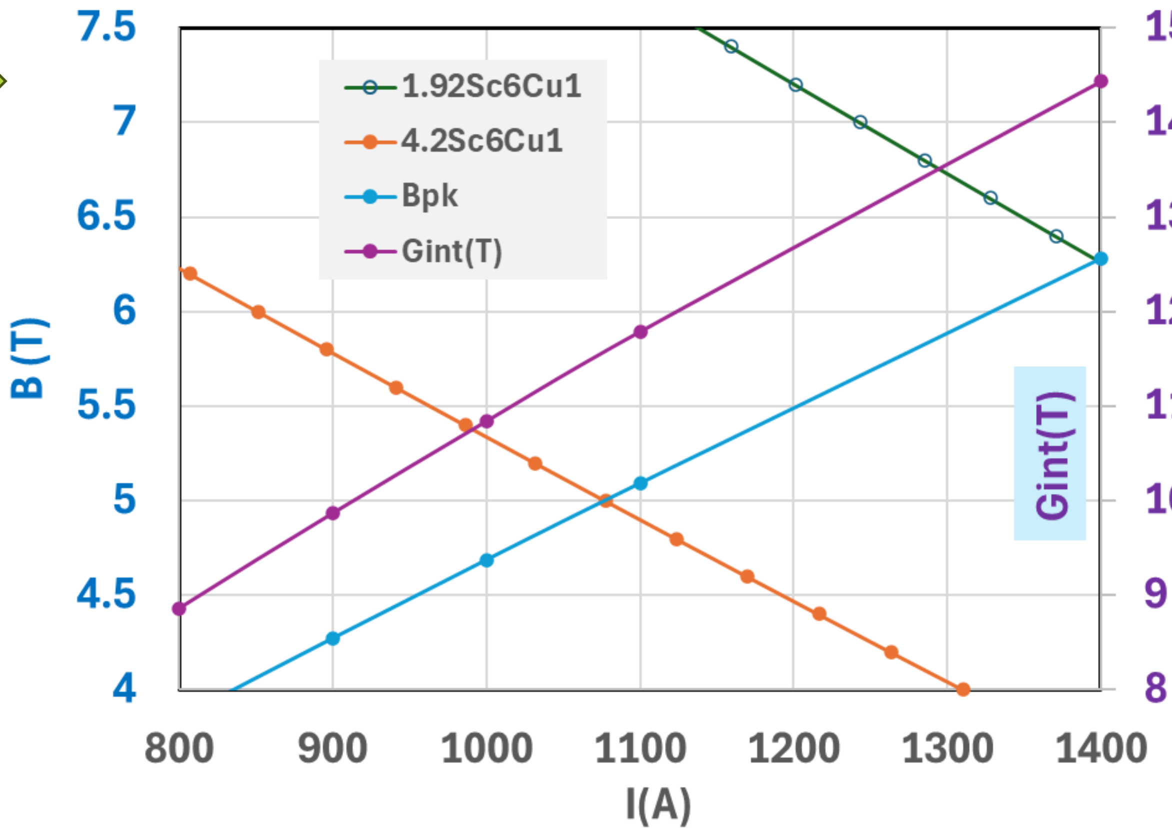
	Iss(A)	Margin(%)	LoadLineFraction
All SC @1.92K	1330	98%	50%
All SC @4.2K	1020	52%	66%

➢ A possible cost saving 4 K option (can be further optimized a little more)

6-layer Optimum Integral Combined Function Design
(six twisted supercondcting wires around one copper wire)

Design Values		Current (A)
Gint(T)	9.75	889
Bint(h)	1.56	889





	Iss(A)	Margin(%)	Load line fraction
SC6Cu1 @1.92K	1400	57%	64%
SC6Cu1 @4.2K	1077	21%	83%

Sill an acceptable margin at 1.92K