Thermal vacuum chamber demonstration of a cryocooled, HTS rotor for a 1.4 MW electric machine for electrified aircraft propulsion

4LPo1E-01 [L33]

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Introduction / Motivation

- Enable **reduced energy consumption, emissions, & noise of commercial transport aircraft** via electrified aircraft propulsion
- NASA's High-Efficiency Megawatt Motor (HEMM) sized as generator for NASA's STARC-ABL concept

Performance impact of HEMM

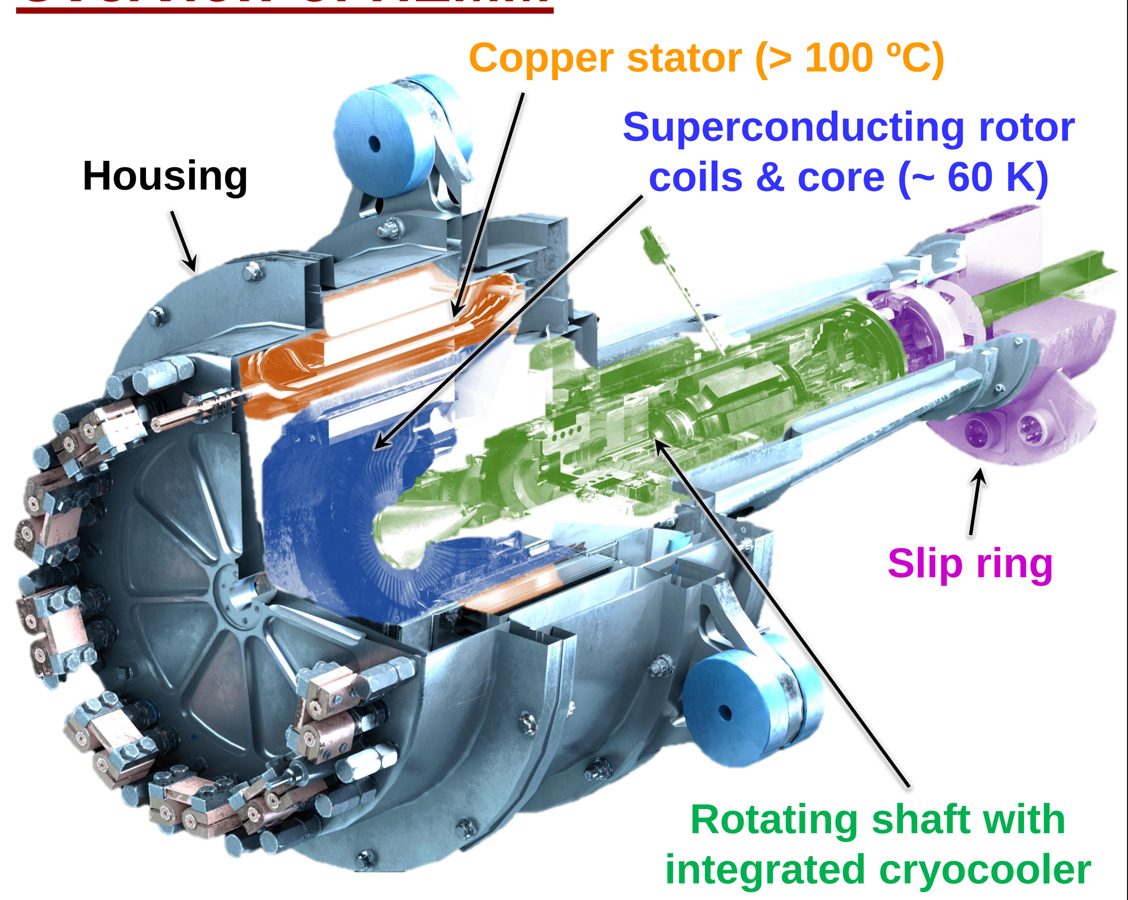
	Fuel burn with HEMM + advanced power electronics	Baseline
Refined assessment [1] (higher fidelity power system & thermal management)	–2.5% to –2.8%	Refined STARC-ABL rev. B2.0

1.Schnulo, S.L. et al., Proc. of EATS, 2020.

Overview of HEMM

Parameter	Value
Rated continuous power	1.42 MW
Nominal speed	6,800 rpm
Tip speed	107 m/s (Mach 0.31)
Rated torque	2 kNm

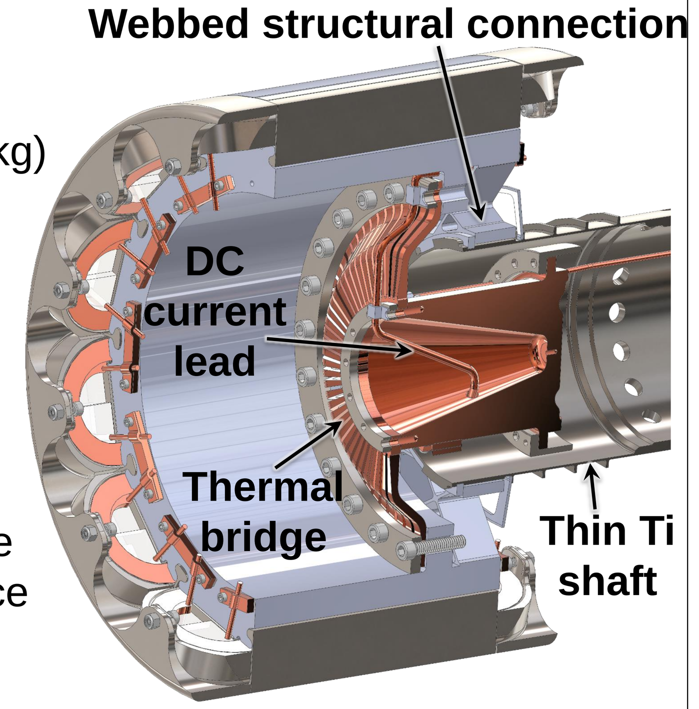
Goal	Value
Electromagnetic specific power	16 kW/kg
Efficiency	> 98%



Overview of HEMM's Superconducting Rotor

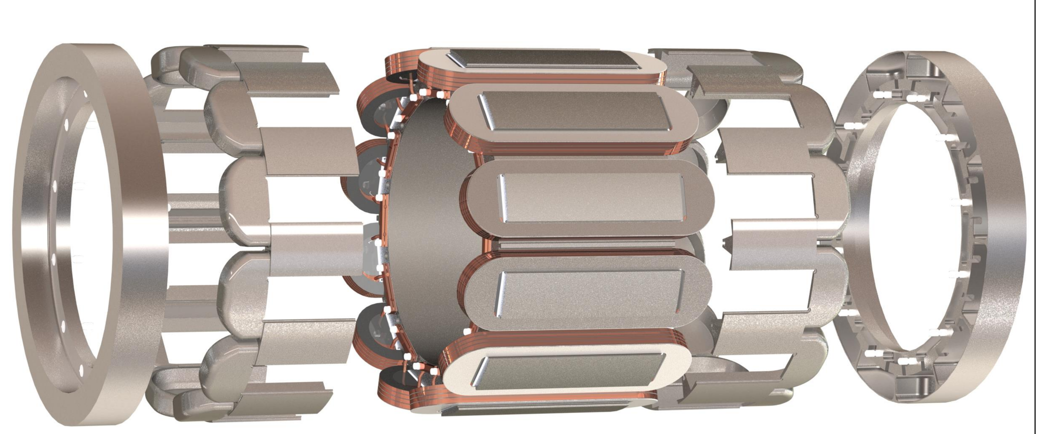
Thermal design

- **Conductively cooled** by cryocooler inside rotor (goal: 50 W at 50 K with 1.8 kW input; approx. 25 kg)
- Reduce windage & convection: < 10^{-3} torr vacuum
- Reduce radiation: PVD gold on rotor components; low emissivity paint on interior of stator
- Reduce heat leak: optimal current lead length
- Improve conductive heat transfer path:
  - Cu thermal bridge for high thermal conductance connection to cryocooler & structural compliance
  - PVD gold ↑ thermal contact conductances



Electromagnetic design

- Solid $Fe_{49.15}Co_{48.75}V_2$ rotor core
- 22.5 mm air gap to stator iron
- Nominally 600 turns per coil

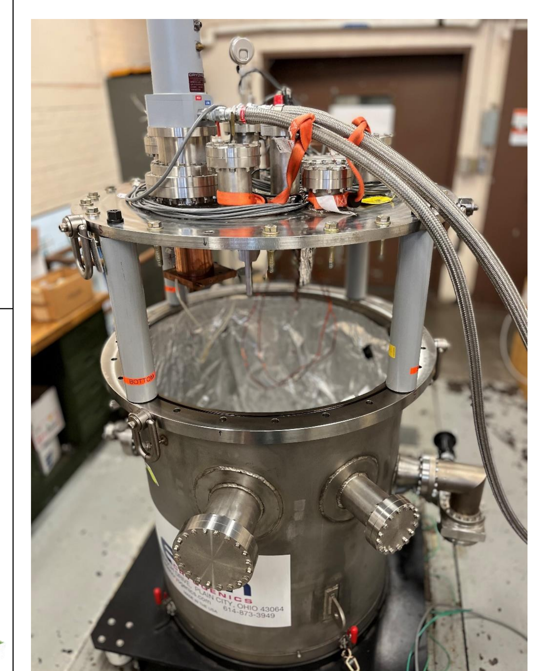


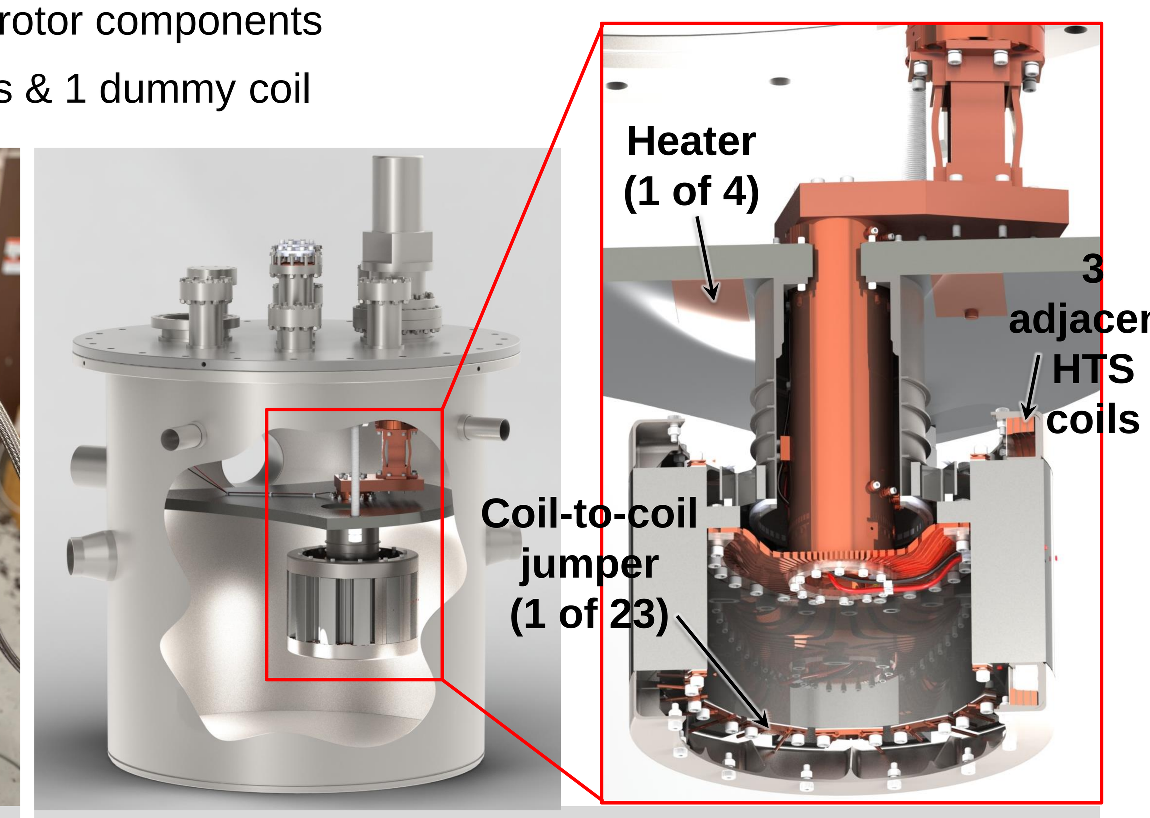
Parameter	Value
Superconductor	2G HTS
HTS temp. limit	62 K
DC operating current	57.2 A

Parameter	Value
# poles (coils)	12
Coil configuration	No-insulation quadruple pancake

Cryo-Vac Chamber Experimental Setup

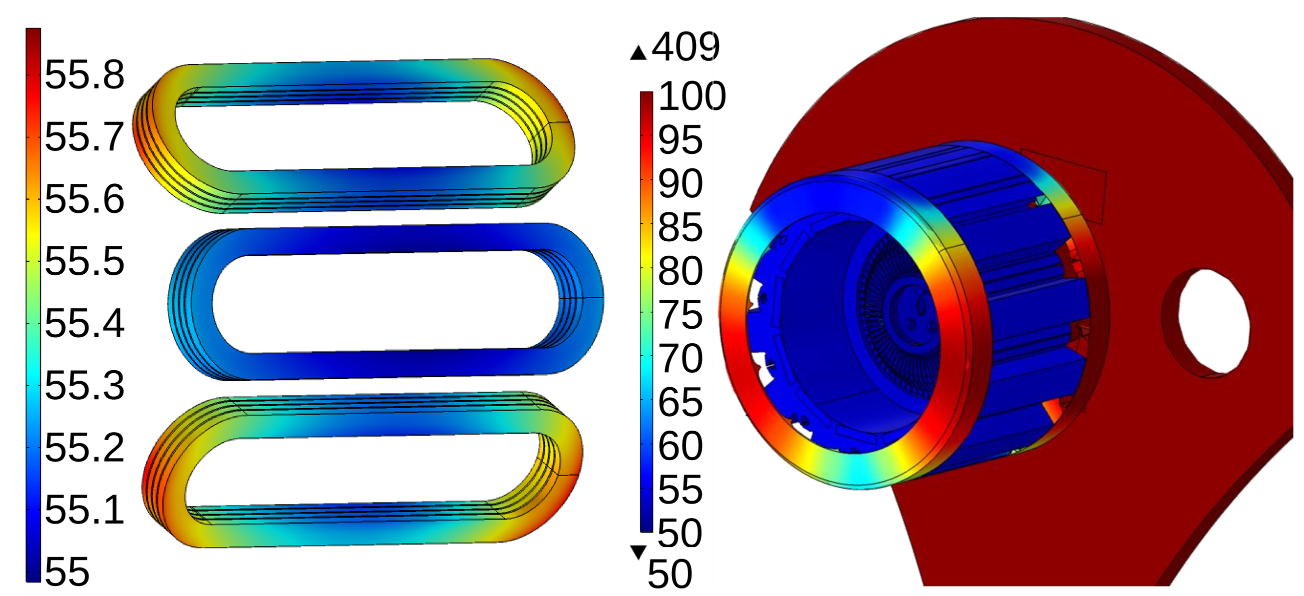
- 10^{-6} to 10^{-3} torr vacuum
- Heaters at torque tube mount to mimic temperature of cryocooler's heat rejector
- Conduction from rig's cryocooler sufficient to maintain cold tip interface at ≤ 50 K
- 16 negative temperature coefficient RTDs, 9 thermocouples
- Full-scale, gold-plated rotor components
- 3 superconducting coils & 1 dummy coil


ICE-Box test rig



Experimental setup

Thermal Response of Cryo-Vac Chamber Experiment



Predicted temperature distribution (K) of experiment

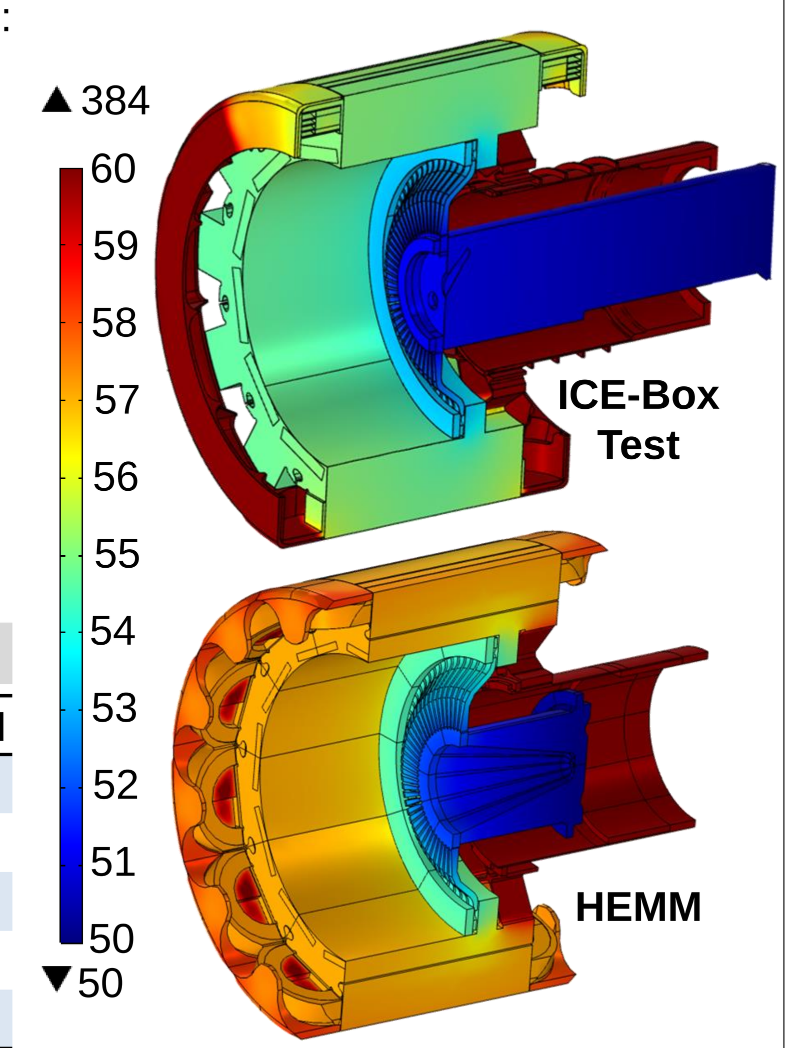
- In ICE-Box test, coils colder & less total heat
- Since ICE-Box test includes only 3 of 12 coils:
  - End turn hoops hotter
  - Larger temperature gradient in coils & between coils
- Heat load within capabilities of facility

Superconductor temperatures (K)

	ICE-Box Test	HEMM
Maximum	55.9	57.4
Average	55.3	57.2

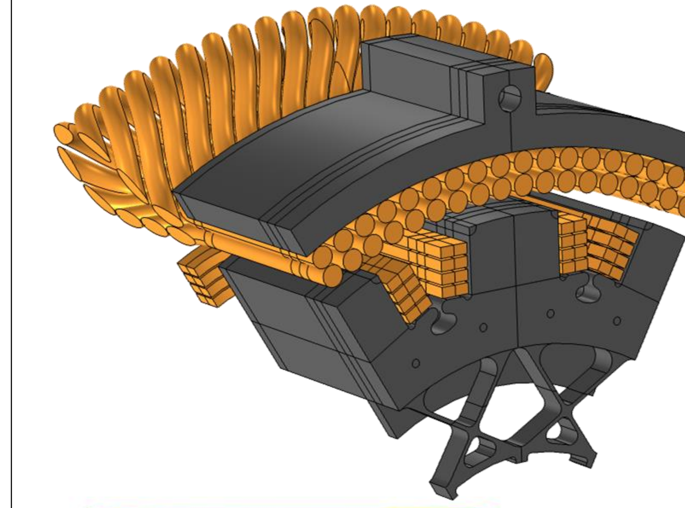
Rotor heat sources (W) at 50 K cold tip

	ICE-Box Test	HEMM
Shaft conduction	9.2	11.4
Current lead conduction	4.4	4.4
Windage & convection	0.0	5.0
Radiation	7.2	4.2
I^2R losses	3.3	3.3
Total cryocooler heat load	**24.1**	**28.2**

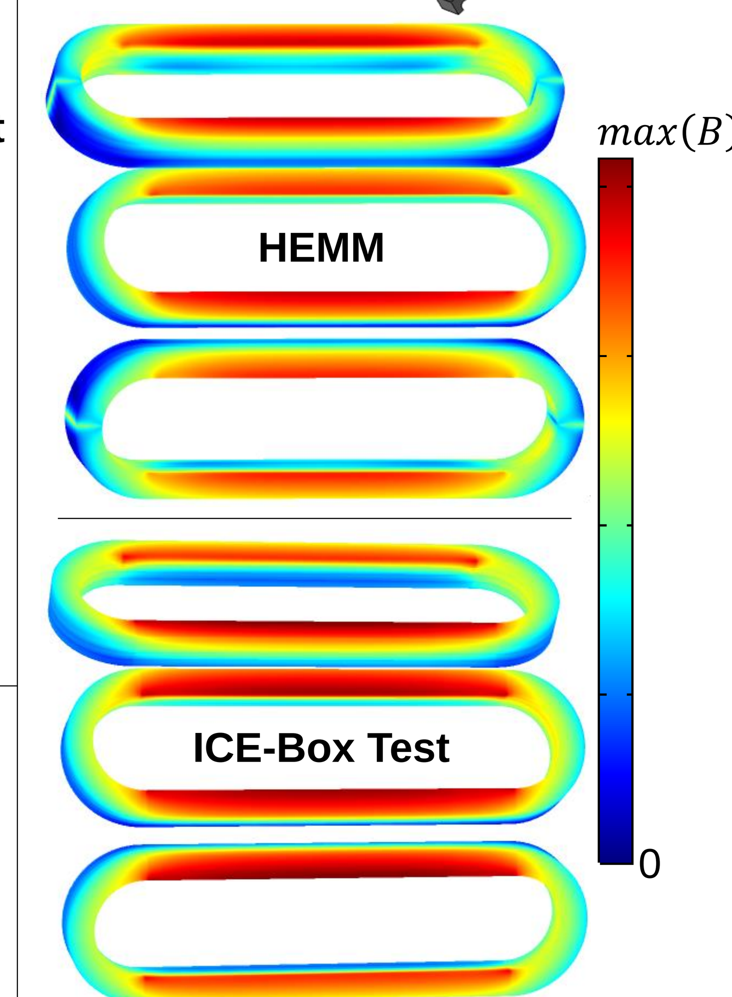


Temperature distribution (K) of HEMM & ICE-Box test

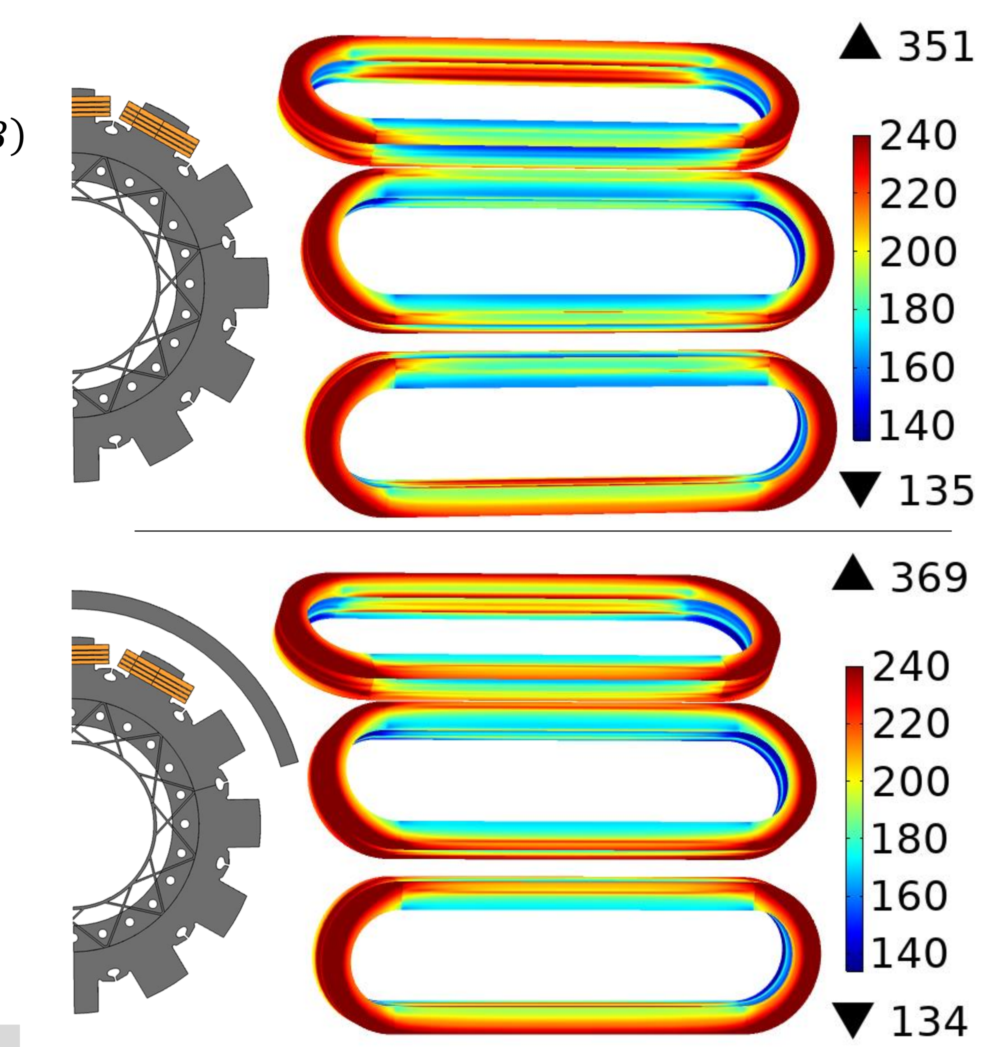
3D Electromagnetic Response of Cryo-Vac Chamber Experiment



- I_c predicted based on:
  - $I_c(T, |B|, \angle B)$ interpolation function
  - Predicted temperature distribution
  - $I_c(77\ K, s.f.)$ of each pancake
- I_c changes between -68 to 54 A when stator iron added, but limiting value nearly identical

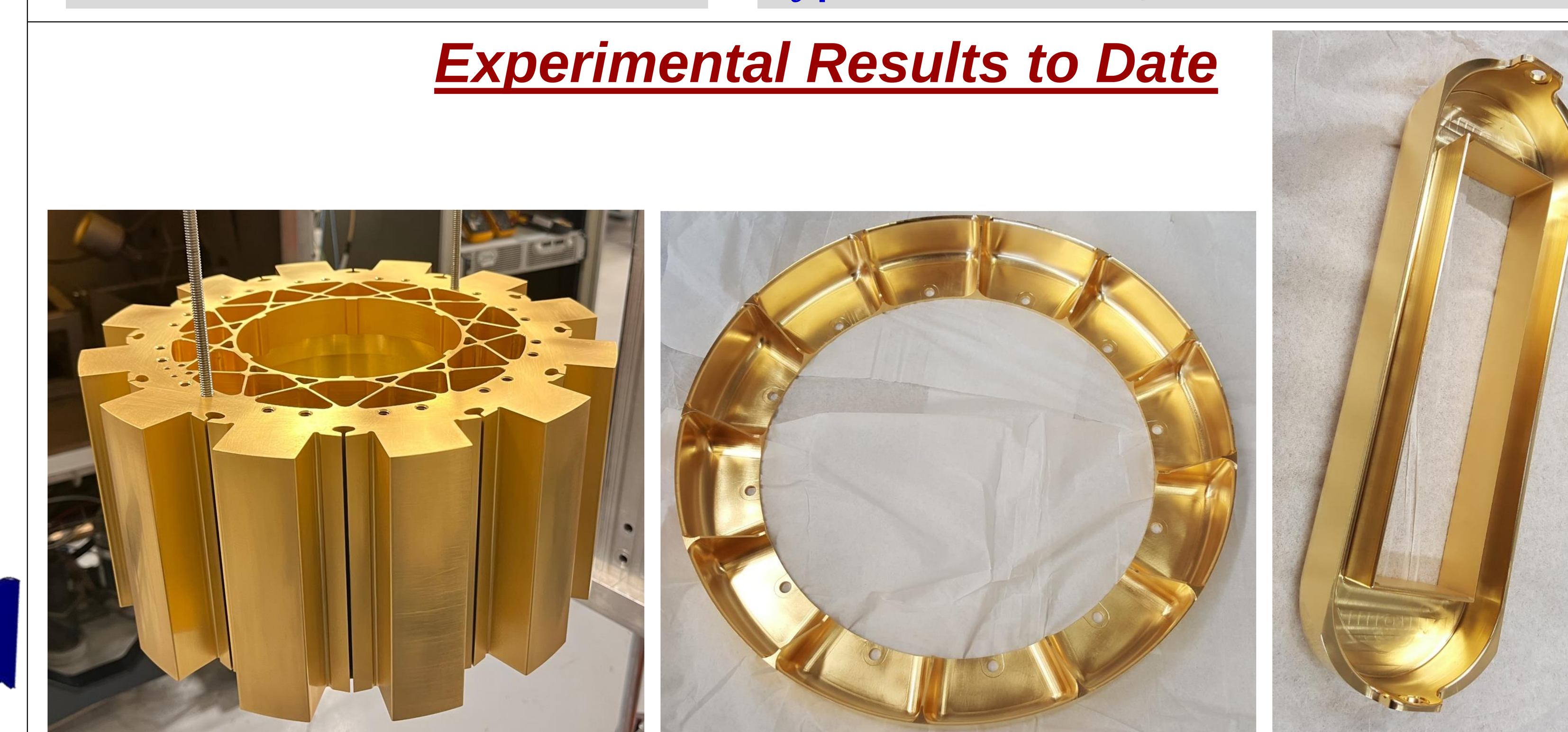


Magnetic response $|B|$ of coils in HEMM & ICE-Box test

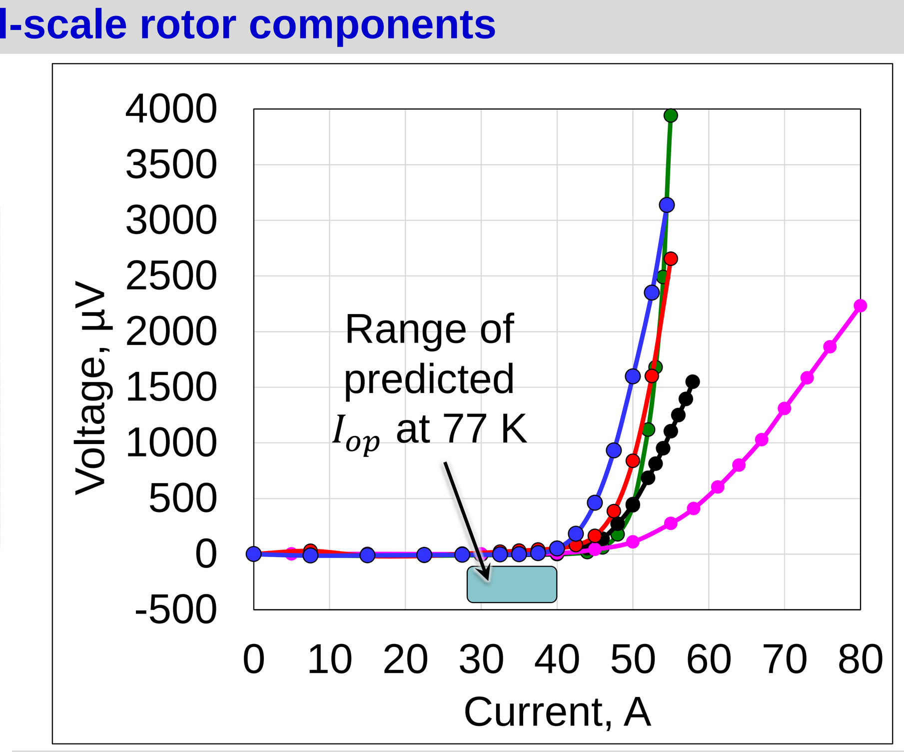


I_c prediction of test, with/without stator iron

Experimental Results to Date


Gold-plated, full-scale rotor components


Full-scale Cu thermal bridge (piece 1 of 3)



Baseline testing of pancake coils in LN2