

Critical Current – Strain Dependence, $I_c(\epsilon)$, of Solenoids Wound with Bi-2212 Round Wire

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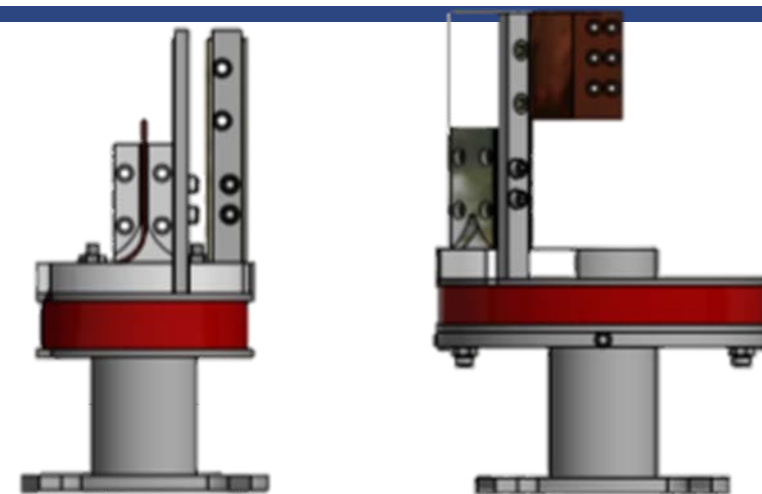
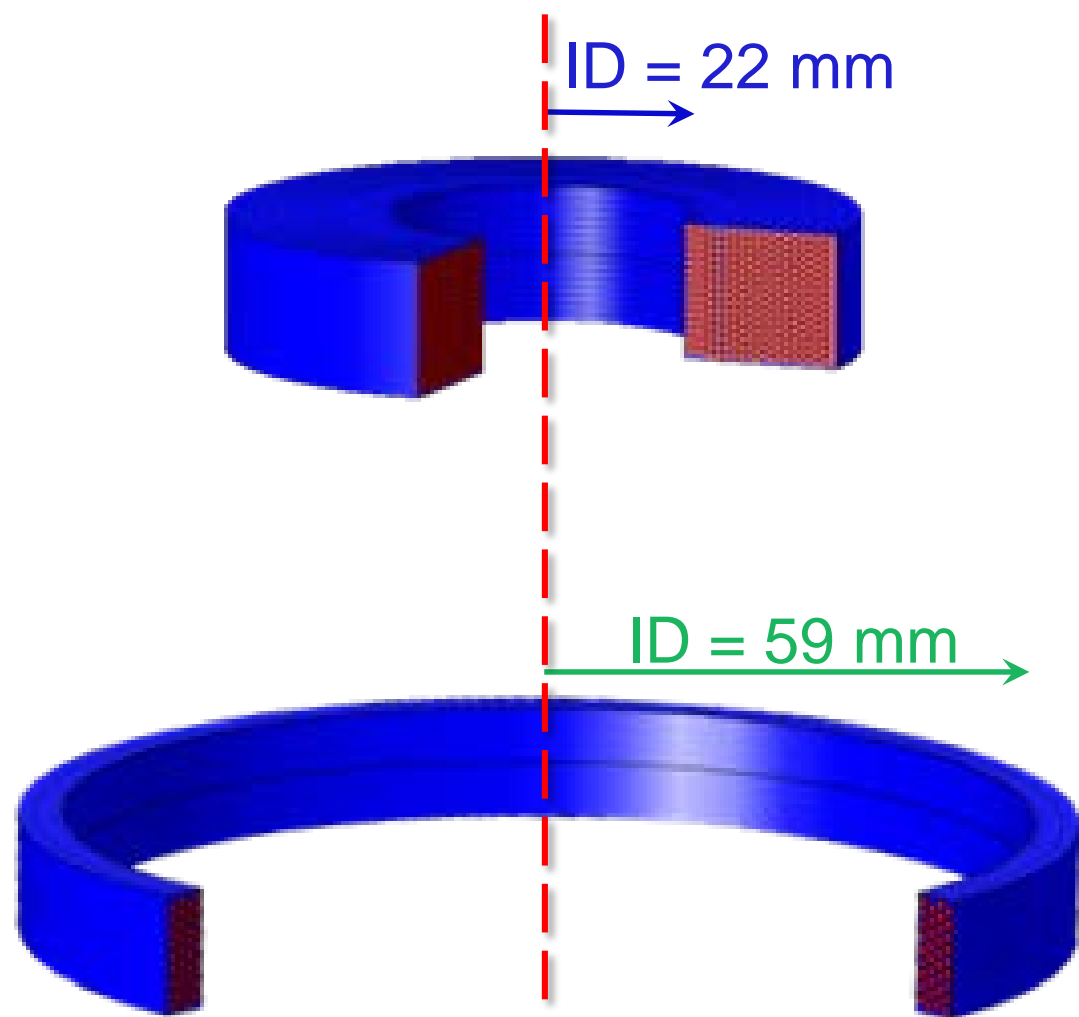
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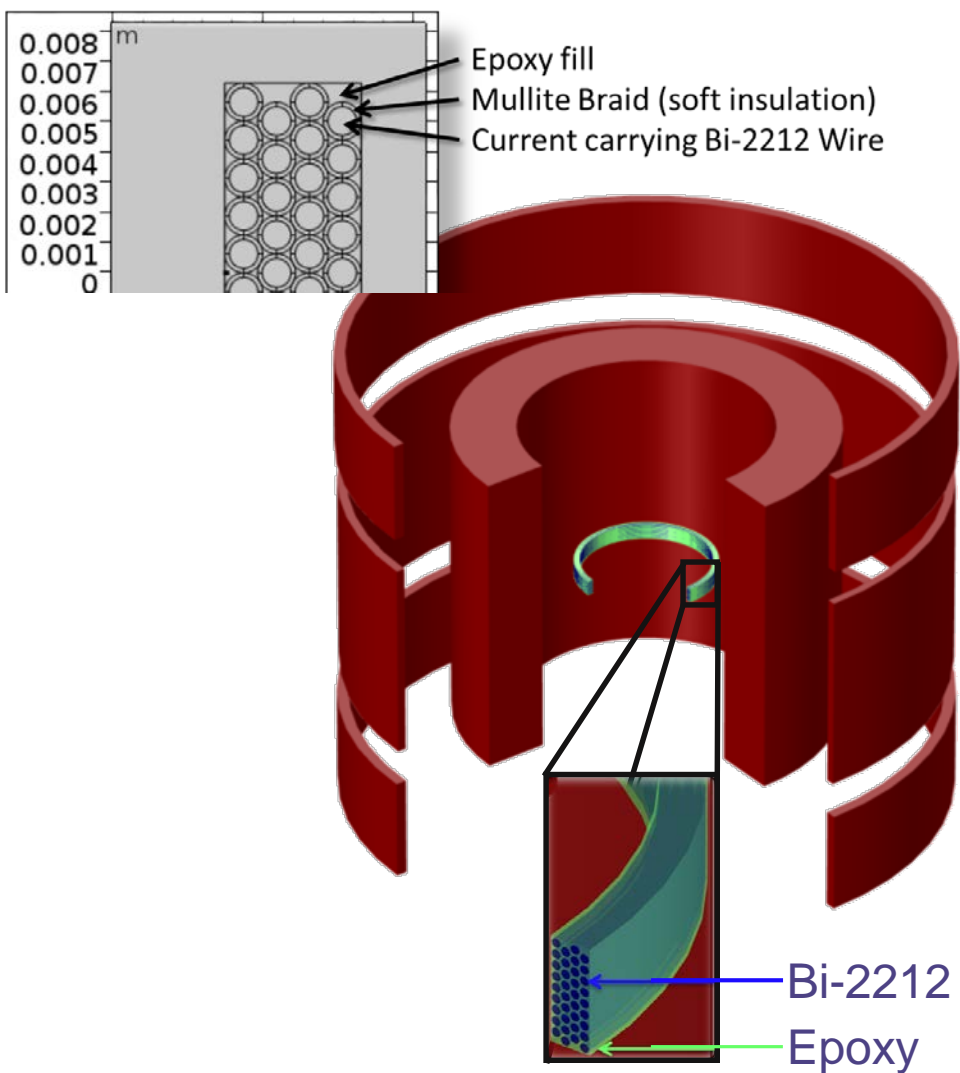
Pup and Ricky Prototype Coils



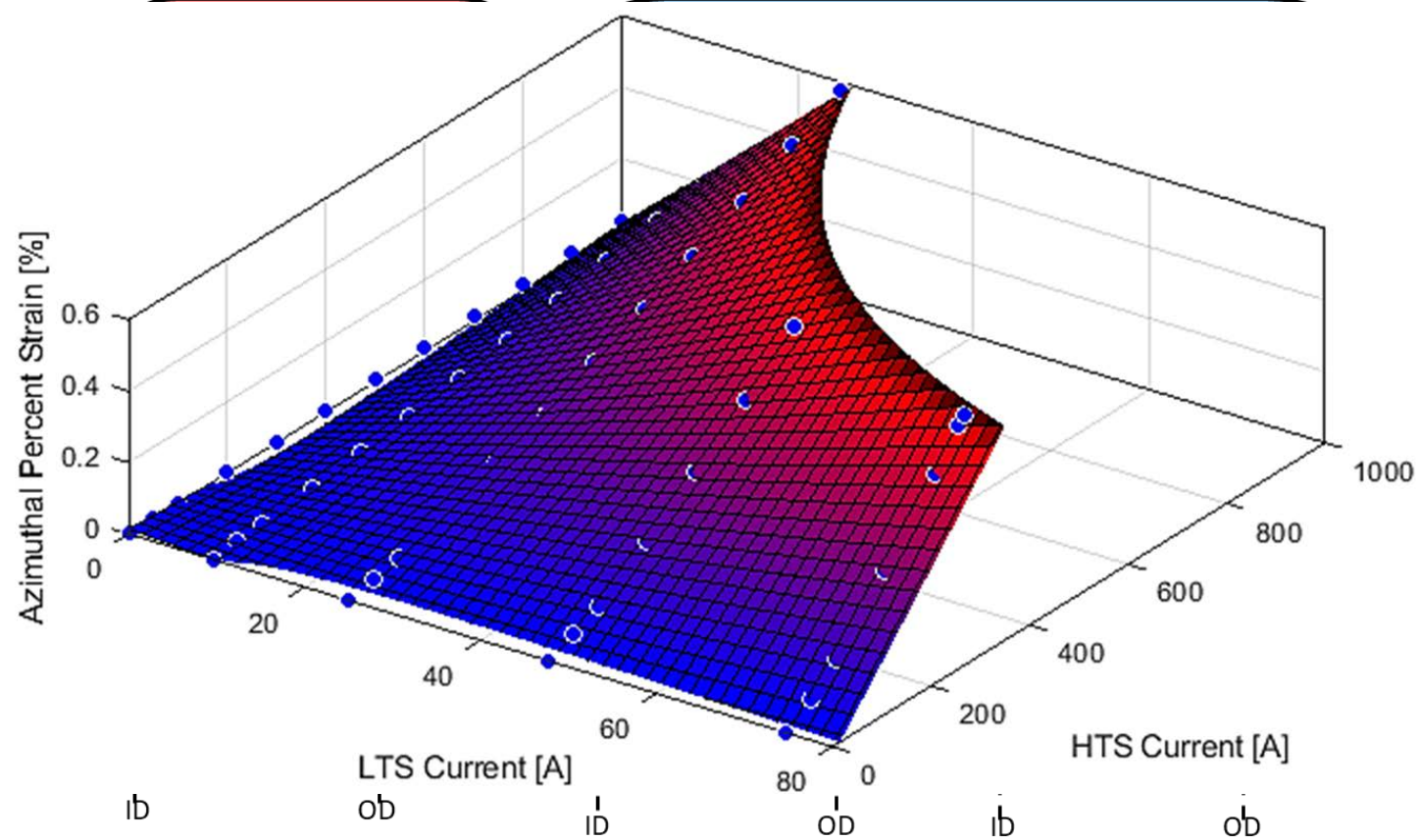
Specifications	Pup	Riky
ID ; OD ; Height [mm]	44.0 ; 83.3 ; ~ 25.0	118.0 ; 127.0 ; 12.5
Turn ; Layer (Total)	~ 20 ; 18 (350)	10 ; 4 (38)
Magnet constant	6.58 mT/A	0.39 mT/A
Conductor length	> 70 m	15 m
Features and Purpose	High field insert coil Hard to make Expensive to test Real Stress \neq BJR	Stress test coil Easy to make Cheap to test Real Stress \approx BJR

(Y. Kim, Mon-Mo-Or2-04)

Finite Element Performance Envelope Predictions



$I_{op} = 275 \text{ A (} 227 \text{ A/mm}^2 \text{) within the 8 T outsert}$

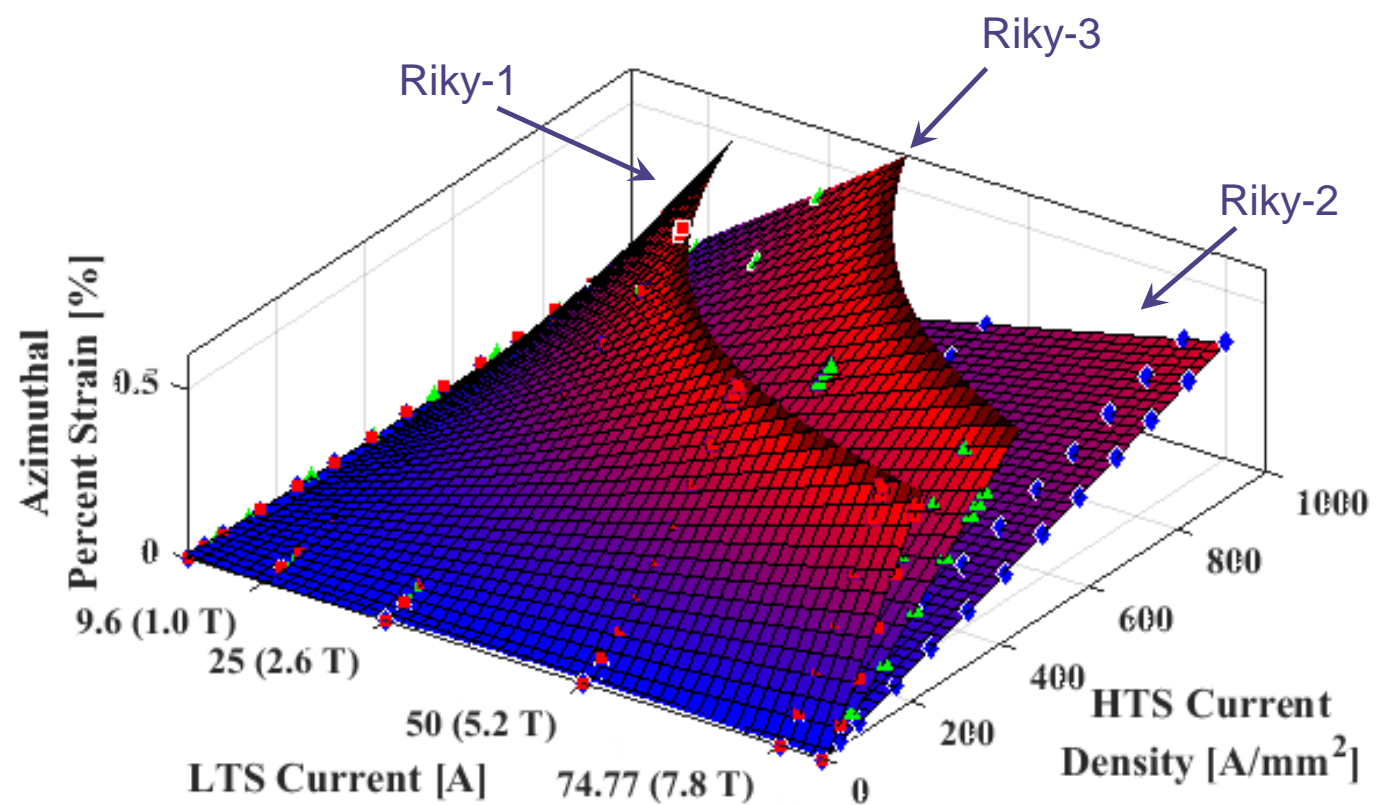
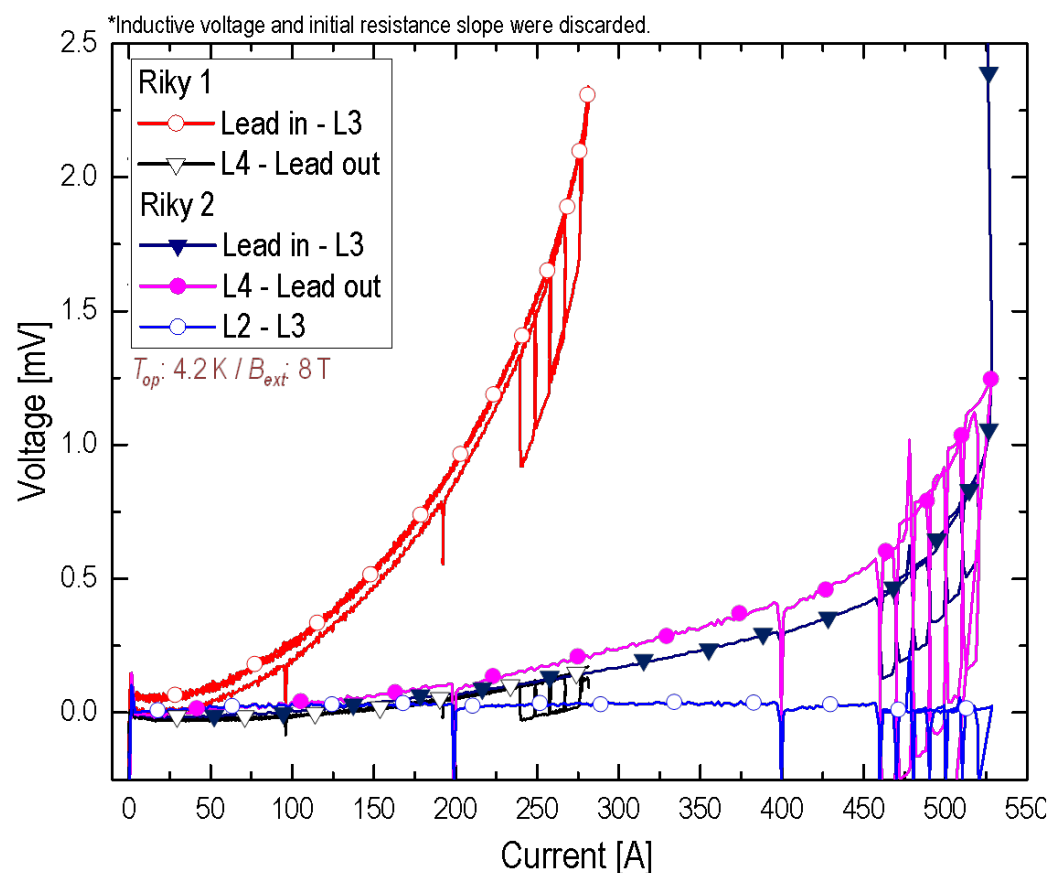


Reinforcing the Riky Coils

Riky-1: No Reinforcement, predicted failure at 275 A (227 A/mm²) within the 8 T outsert

Riky-2: Fully Reinforced, predicted failure well above I_c of Riky-2 conductor

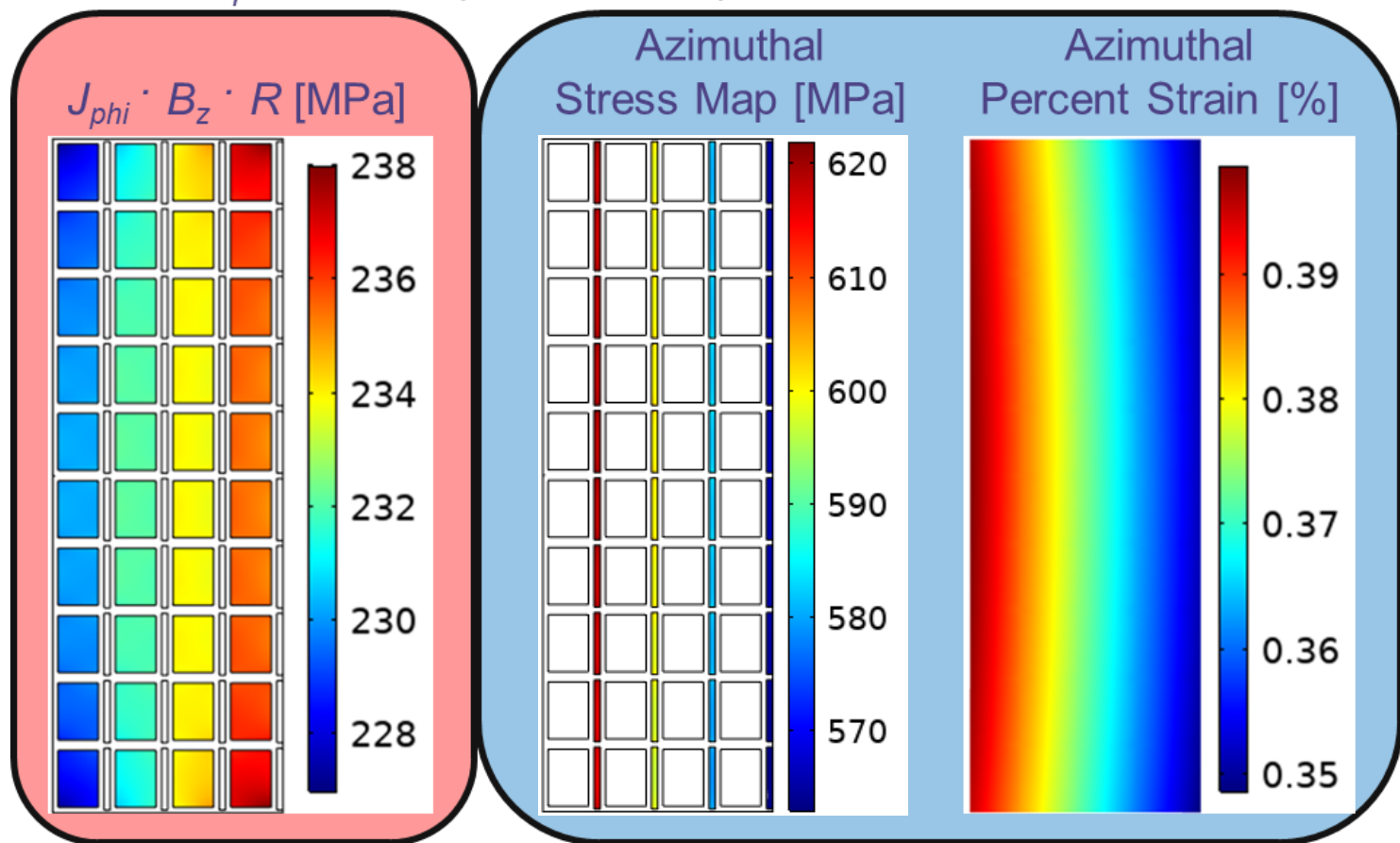
Riky-3: Reinforced with express intent to get to failure at 350 A (489 A/mm²) within the 8 T outsert (*Reached 349 A*)



Metallic Reinforcement for Aspected Wire in a Riky Coil

Riky-8: Aspected conductor, cowound with metallic strip as reinforcement (*Reached 476 A (352 A/mm²)*)

$I_{op} = 476 \text{ A (352 A/mm}^2\text{)}$ within the 8 T outsert



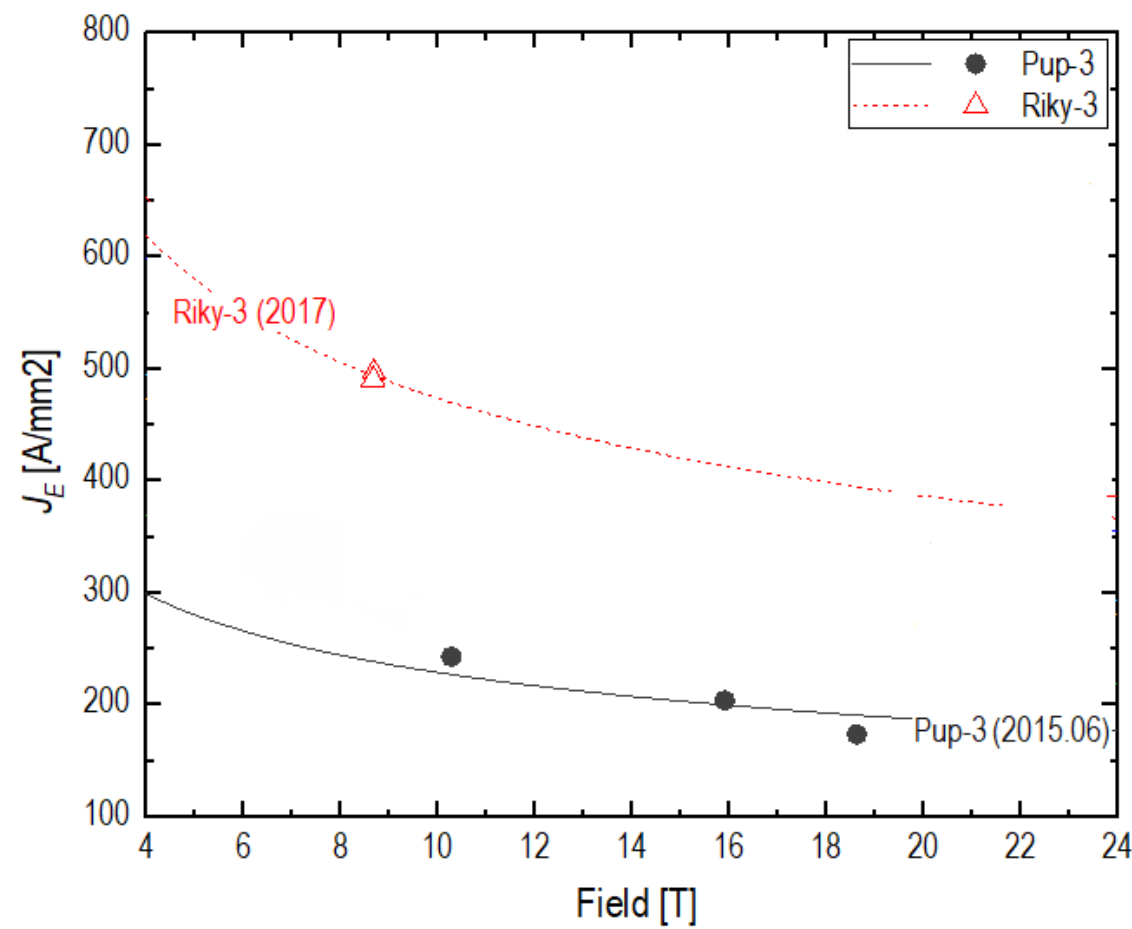
Metallic strip requires oxidization first



Reinforcing the Pup Coils: Progress, Lessons Learned, and Opportunities Still Available

	Pup-3	Pup-5	Pup-6	Pup-7
Test Date	Jun 2015	Feb 2018	Feb 2019	Jun 2019
Wire Diameter [mm]	Φ 1.3	Φ 1.0	Φ 1.0	Φ 1.0
PMM#	PMM131203-2	PMM140606	PMM160909-b	PMM180410-1
Powder	Lot 82	Lot 82	Lot 87	LXB-116
Architecture	121 x 18	55 x 18	121 x 18	85 x 18
ID ; OD ; Height [mm]	44.6 ; 91.6 ; 20.3	44.6 ; 86.6 ; 22.8	44.5 ; 86.2 ; 25.5	44.6 ; 84 ; 25.2
Total Turns	270	370	333	334
Max. I_{op} (B_{ext})	230 A (17 T)	215 A (8 T)	245 A (14 T)	345.8 A (14 T)
Max J_E	190 A/mm ² (18.0 T)	299 A/mm ² (9.5 T)	342 A/mm ² (15.5 T)	440.3 A/mm² (16.3 T)
Max. B_{JR} stress	140 MPa	99.2 MPa	199 MPa	278 MPa
Max. Stress	69 MPa	65.7 MPa	74.8 MPa	102.0 MPa
Max. Strain	0.22 %	0.26 %	0.26 %	0.39 %

(Y. Kim, Mon-Mo-Or2-04)



Pup-5

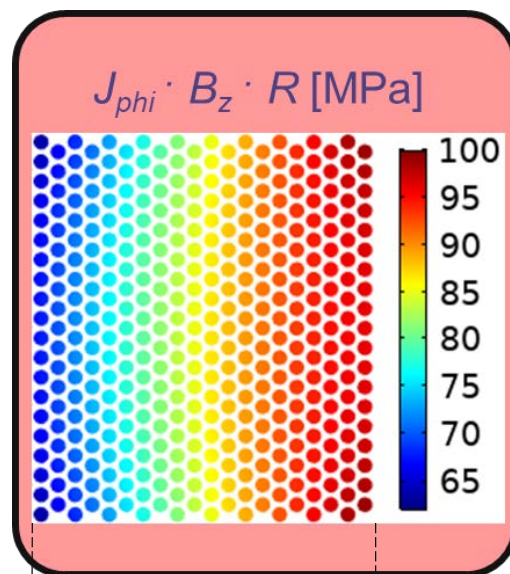


Wound with minimal reinforcement

Pigtail I_c (short sample) indicates decent OPHT

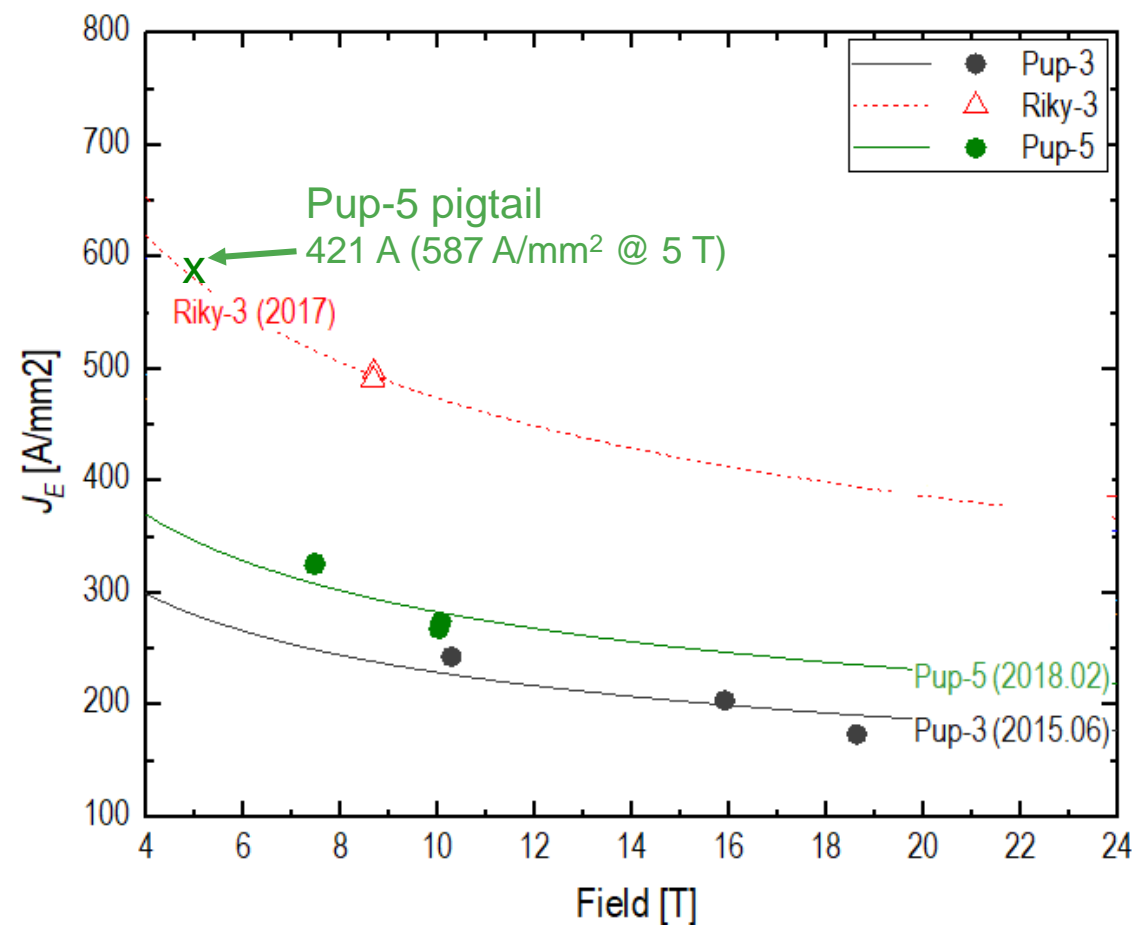
After experimental test, though, even $J \cdot B \cdot R$ too low to be concerned with strain limit.

$I_{op} = 215 \text{ A}$ (299 A/mm^2)
within the 8 T outsert



ID

OD



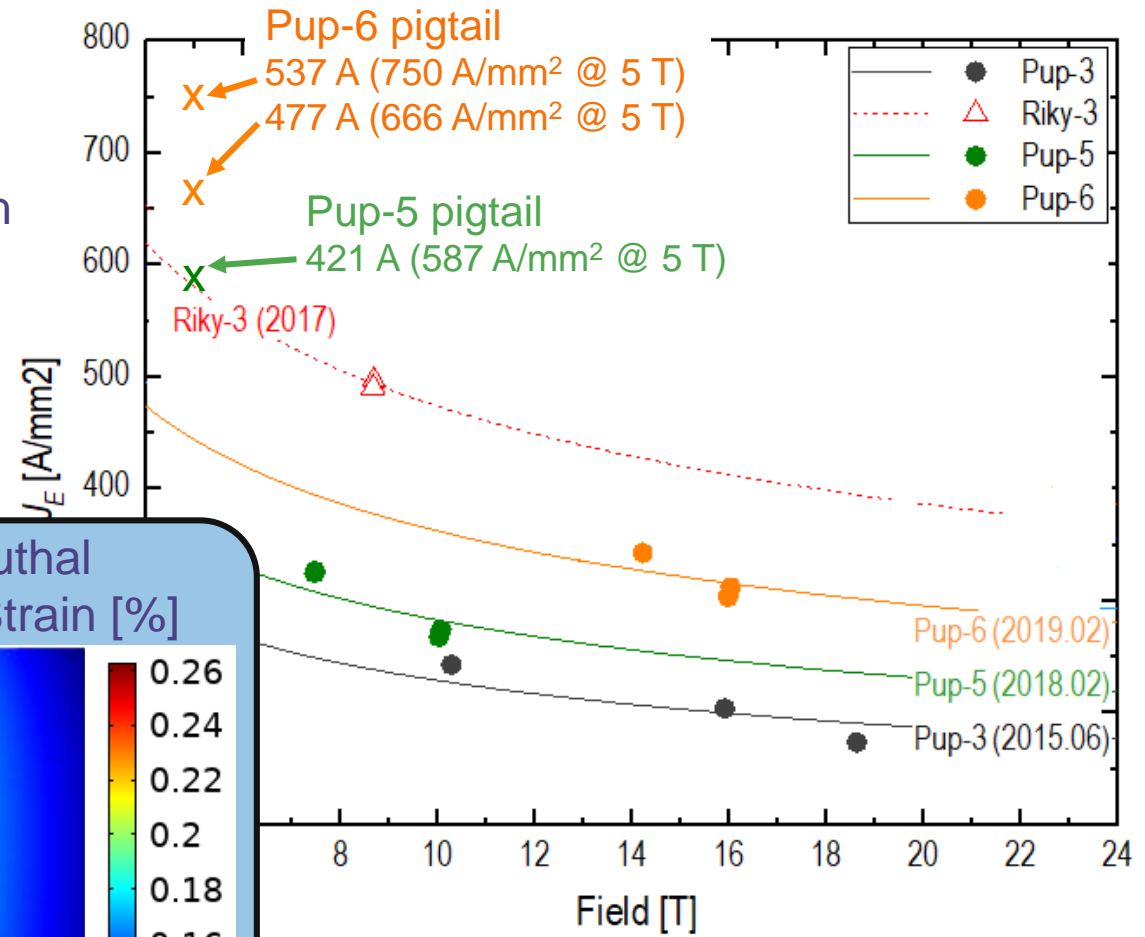
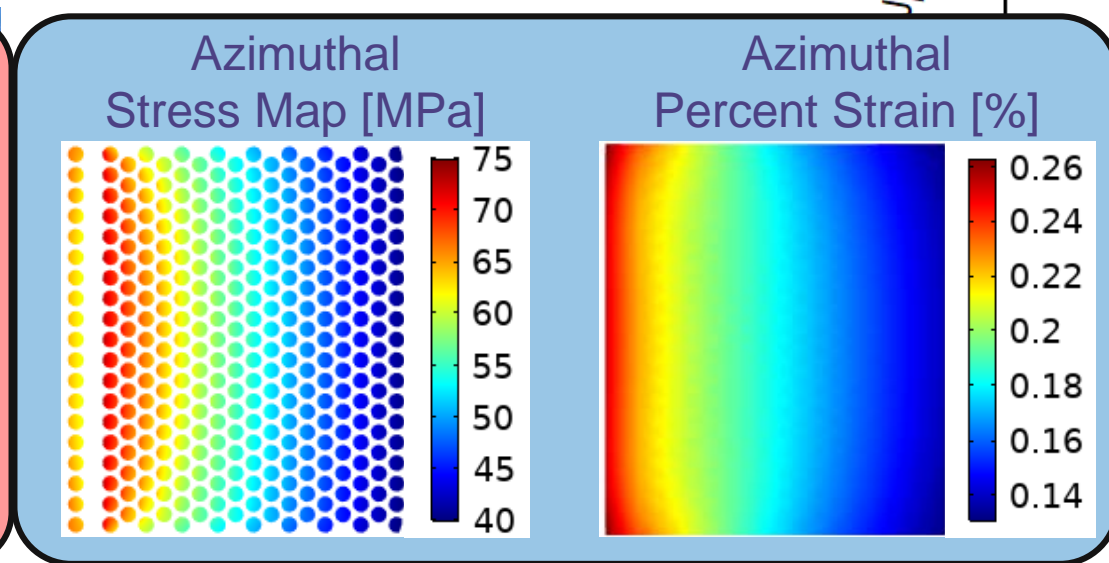
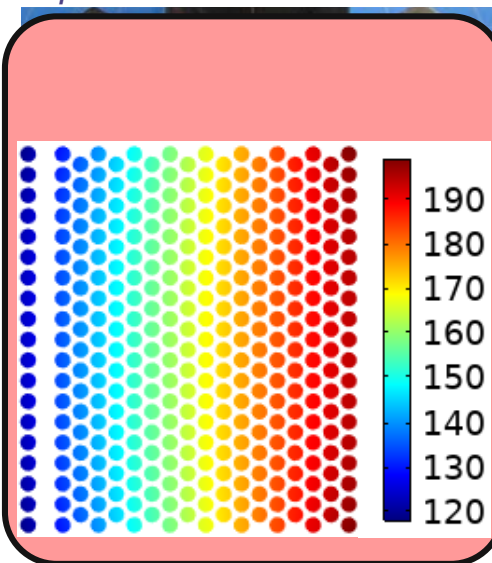
Pup-6 High Field Performance



Significantly reinforced

Pigtail I_c (short sample) indicates better OPHT than Pup-5 – but high field performance still low?

$I_{op} = 245 \text{ A}$ (342 A/mm^2) within the 14 T outsert

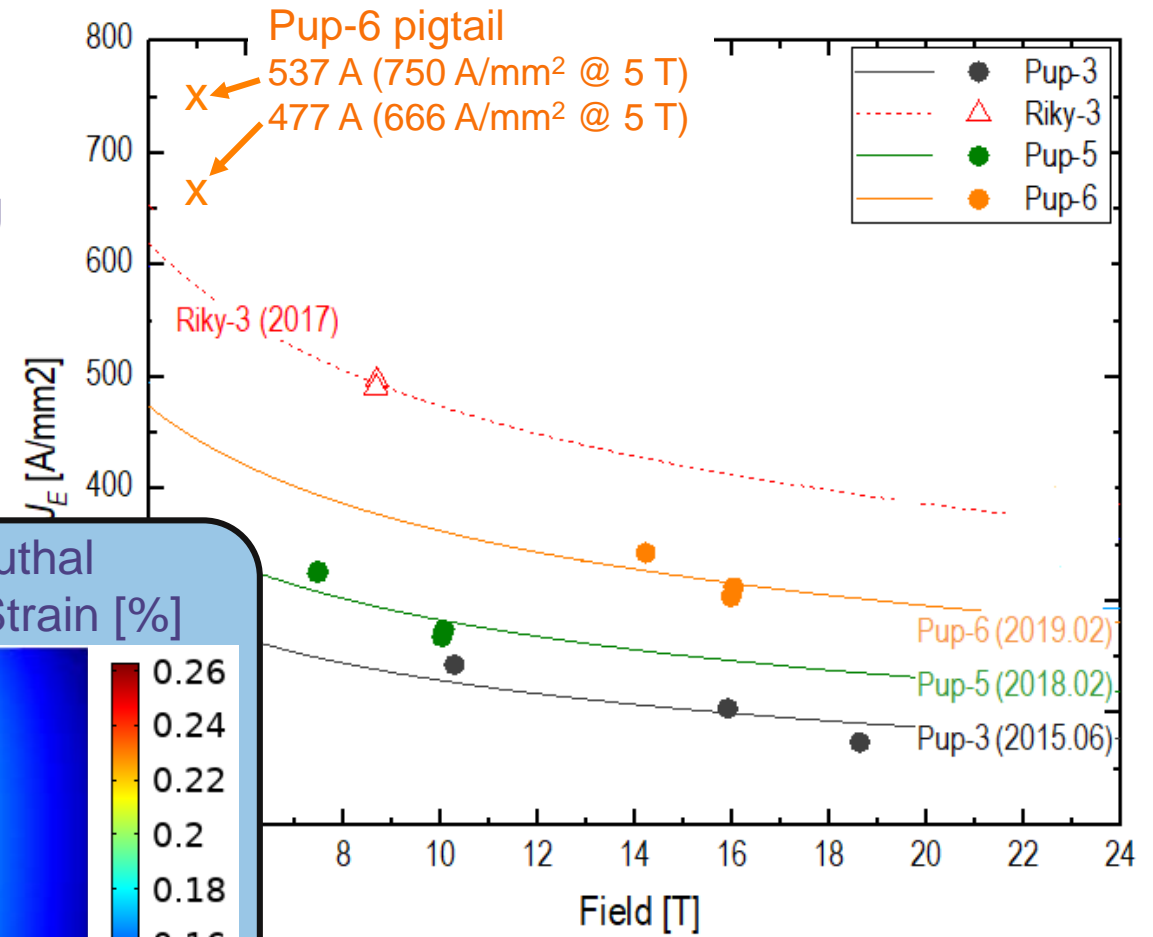


Pup-6 High Field Performance

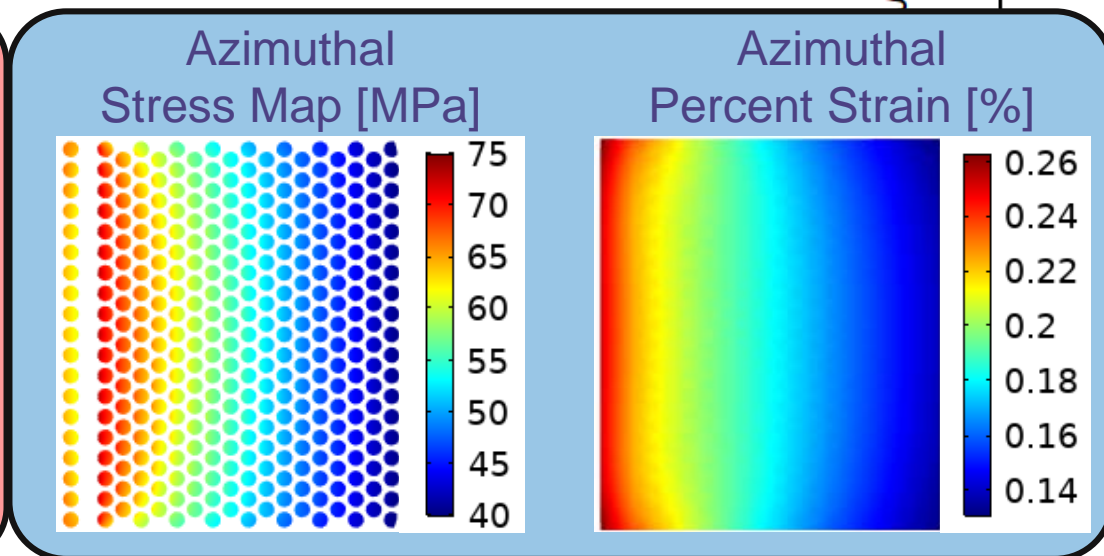
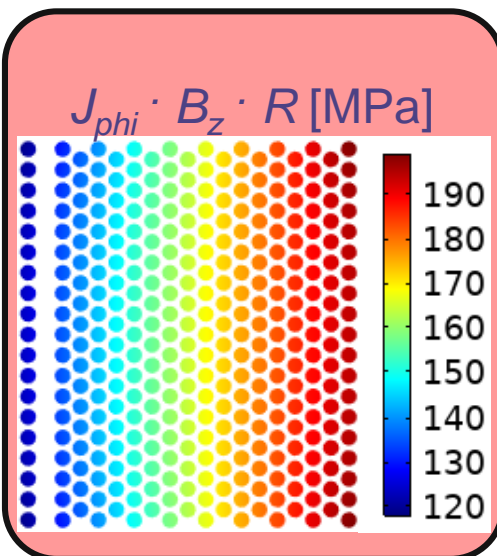


Mid tap included for CLIQ testing

Effectively provides a section (near layer 11) without the winding pack reinforcement, i.e. subject to JBR Lorentz stress.



$I_{op} = 245 \text{ A}$ (342 A/mm²) within the 14 T outsert



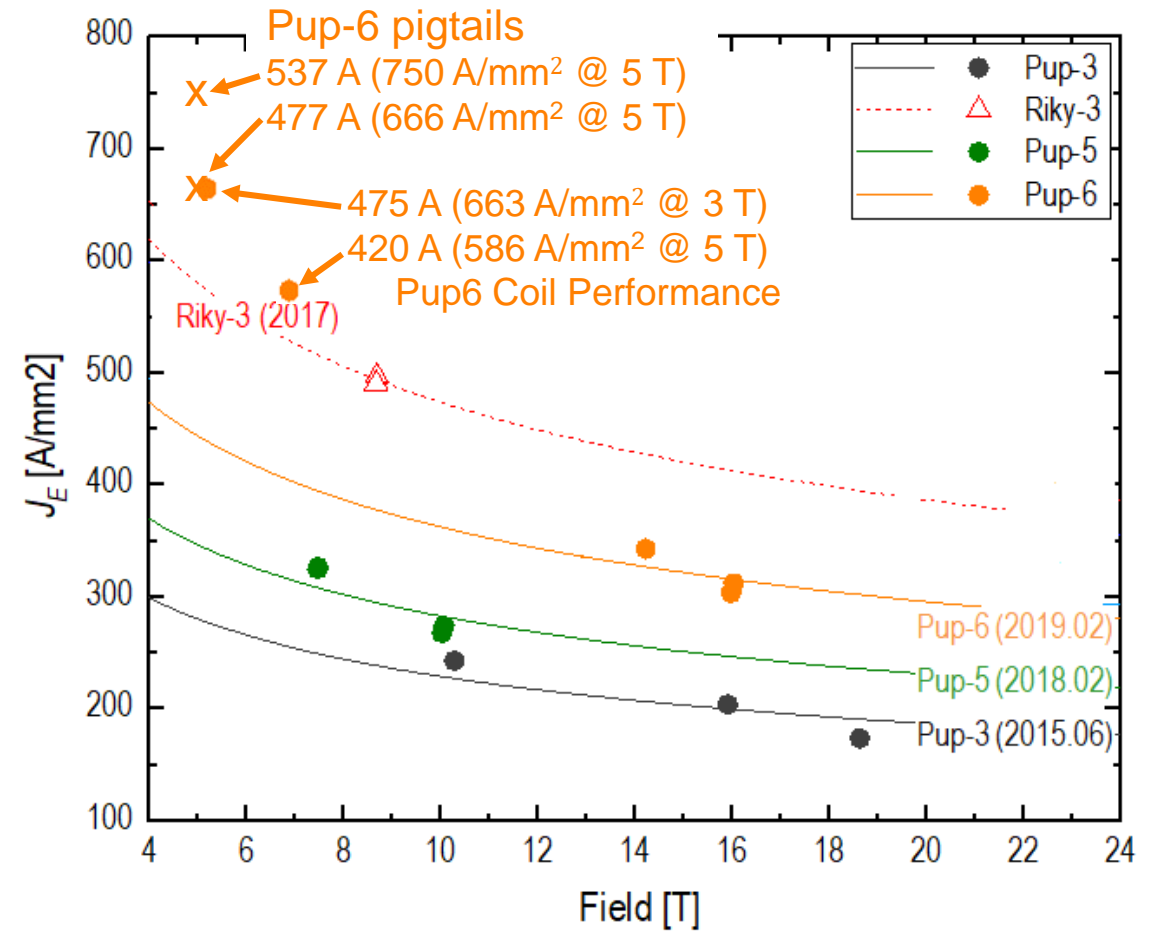
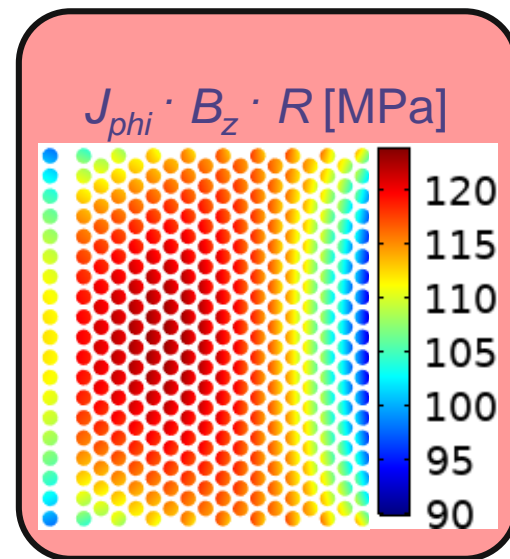
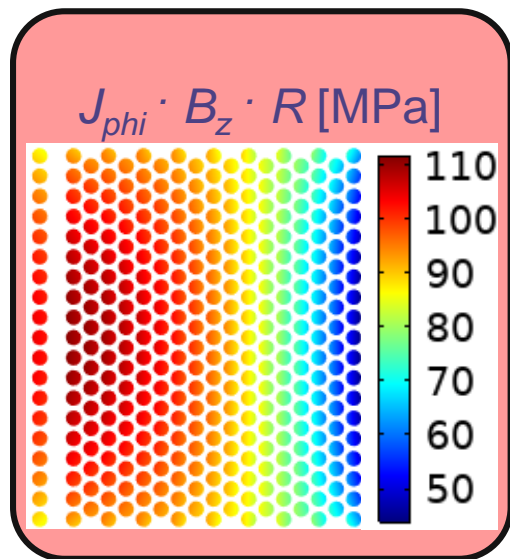
Pup-6 Lower Field Performance



Testing this coil at 3 T and 5 T further supports the argument that the mid tap was the root cause of Pup-6's less than desired performance.

$I_{op} = 475 \text{ A}$ (663 A/mm^2)
in a 3 T background

$I_{op} = 420 \text{ A}$ (586 A/mm^2)
in a 5 T background

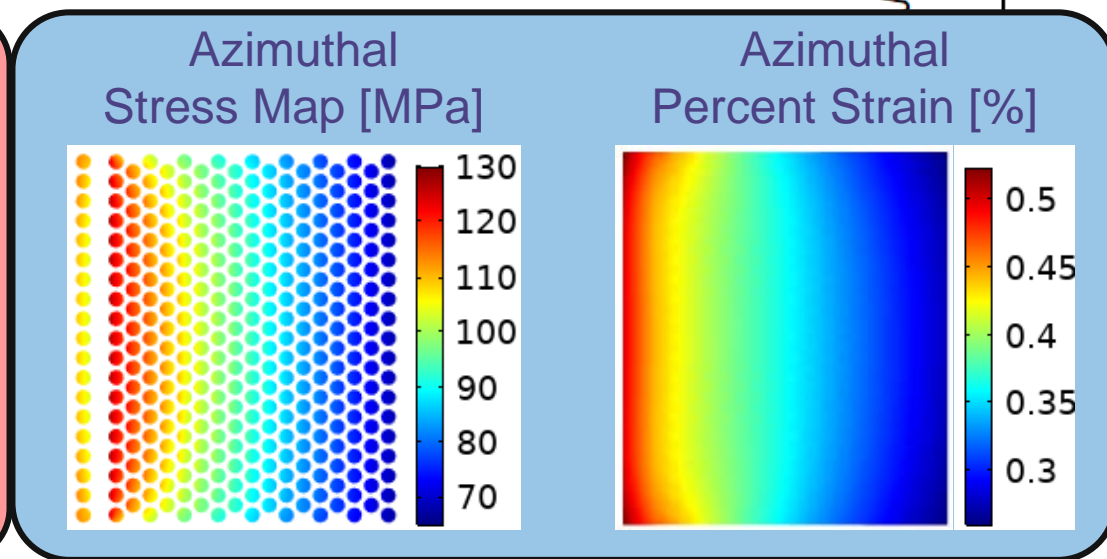
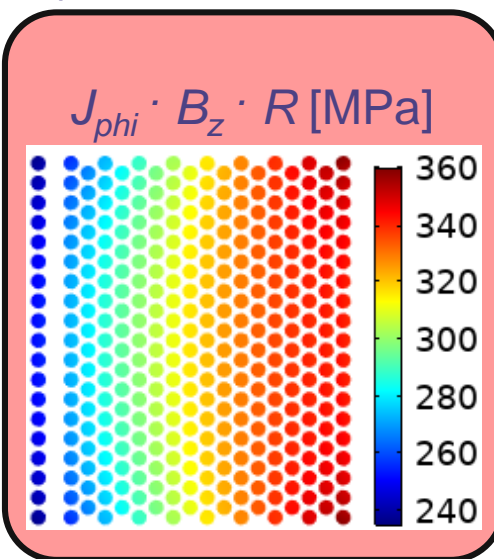
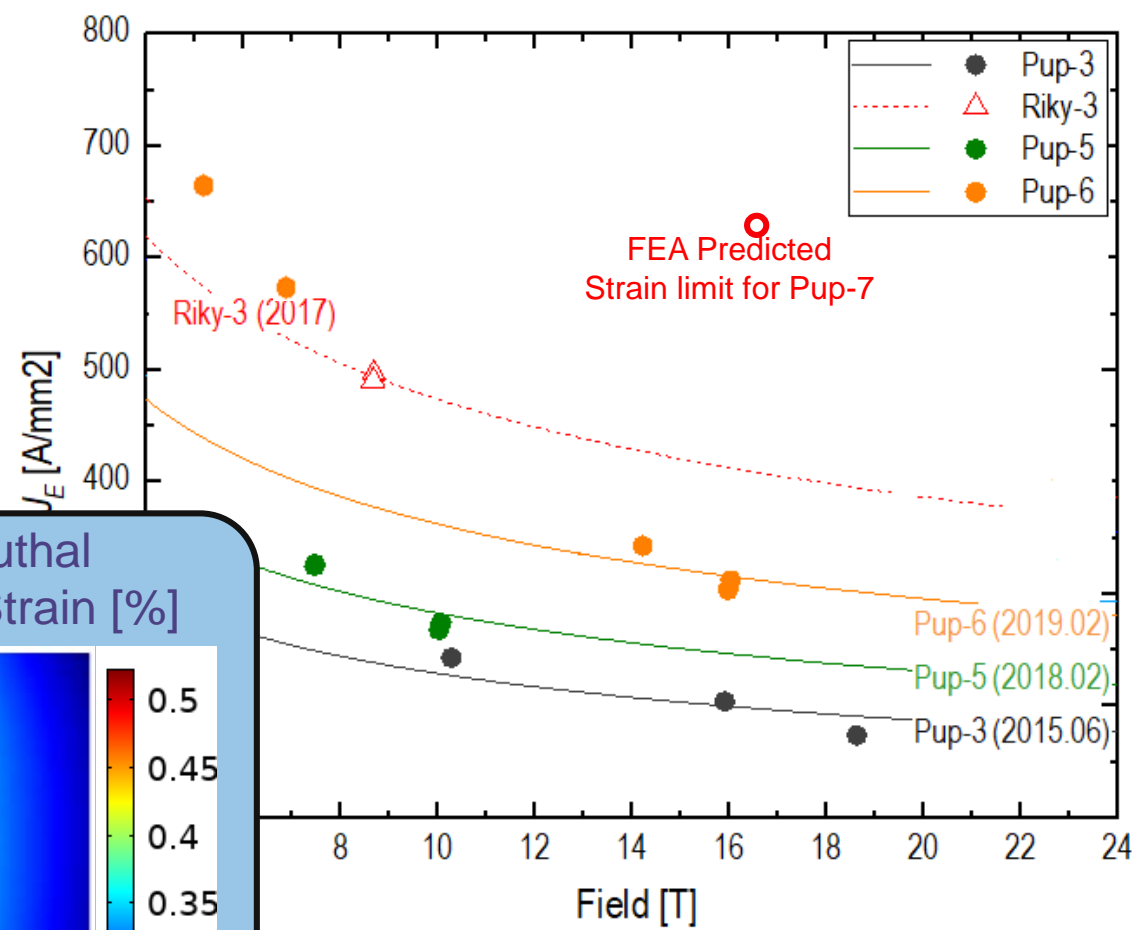


Pup-7 Predicted Strain-limited Performance



Pup-7 was to be run in a 14 T outsert. The coil was well reinforced and did not include a mid tap. The strain-limited performance limit is indicated on the right.

$I_{op} = 450 \text{ A}$ (628 A/mm^2) within the 14 T outsert

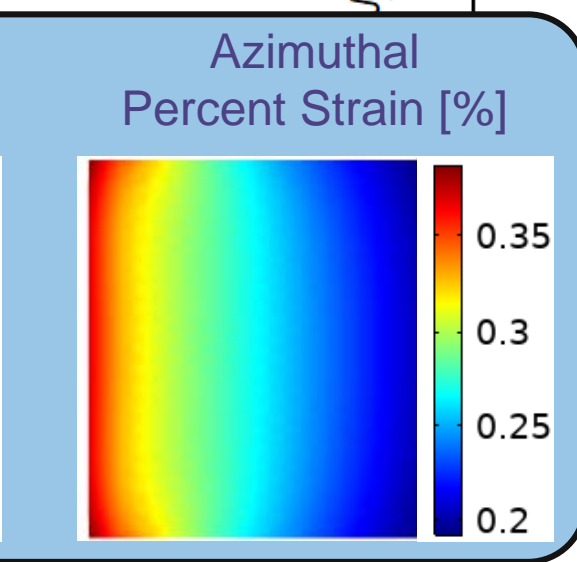
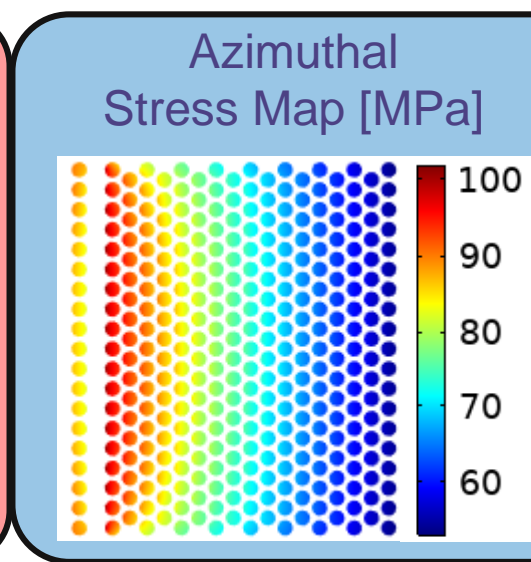
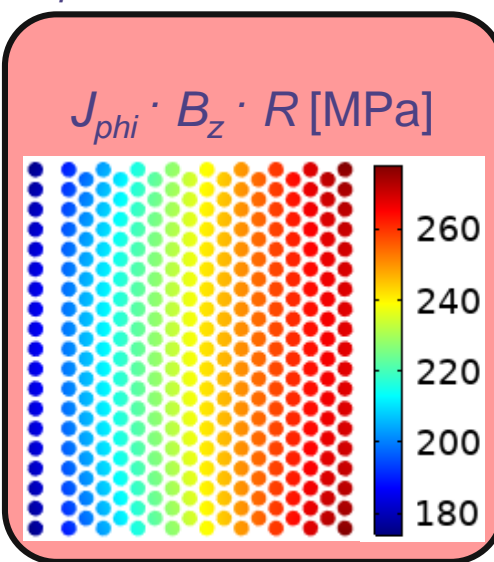
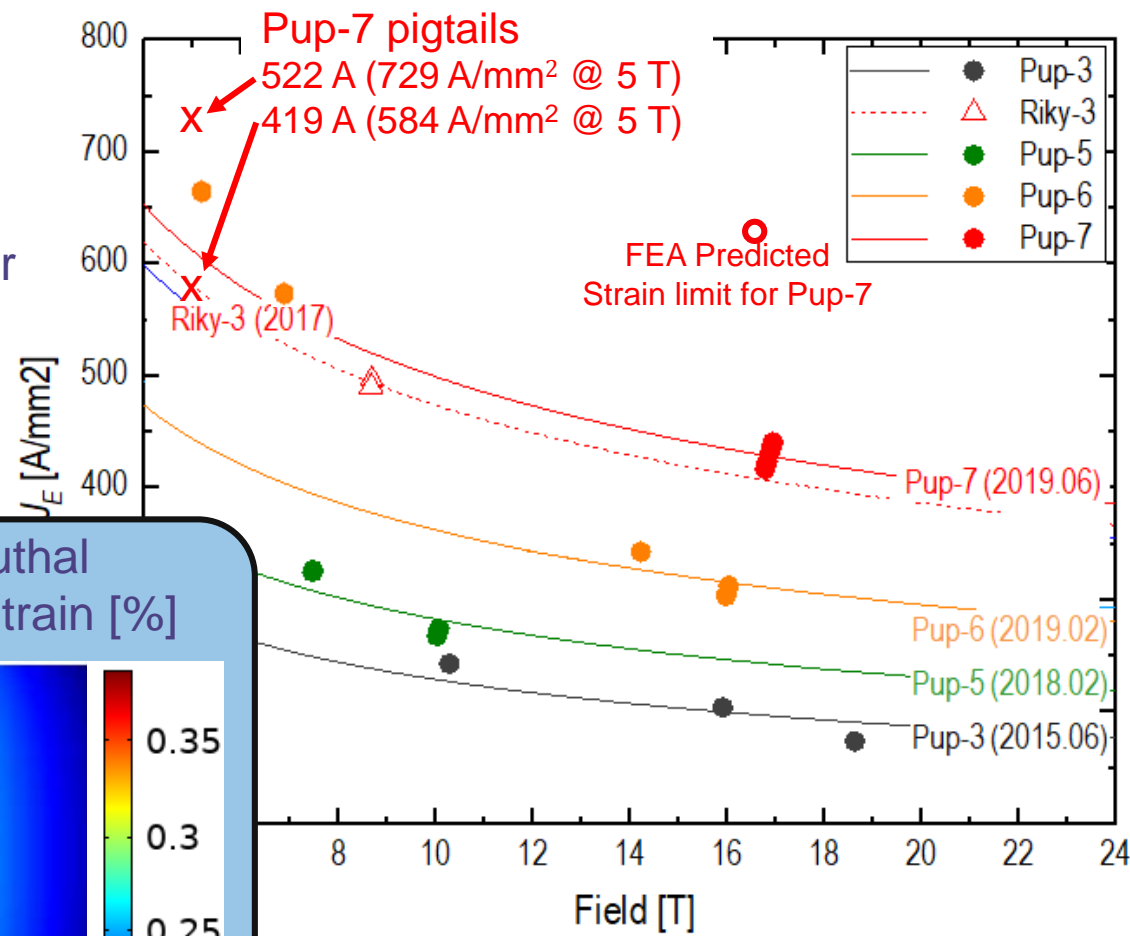


Pup-7 I_c -Limited Actual Performance



Takeaways:
 Better coil manufacturing, design,
 and processing yields pigtails
 which indicate coil performance
 Opportunity still exists to get higher
 I_c and reach target strain-limits!

$I_{op} = 346 \text{ A}$ (483 A/mm^2) within the 14 T outsert



Final Thoughts

Predictive/analysis FEM is working very well to understand our Bi-2212 coil development

The Overpressure Heat Treatment is yielding consistent results, albeit with an opportunity to improve heat treatments for large coil to achieve short-sample I_c values

All other manufacturing steps have been improved, such that coil pigtails provide a good benchmark to overall coil performance

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