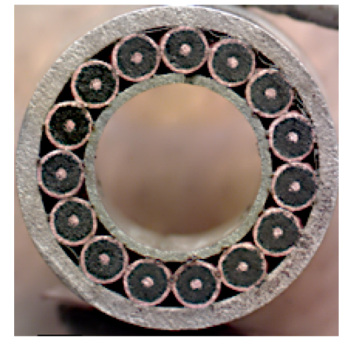
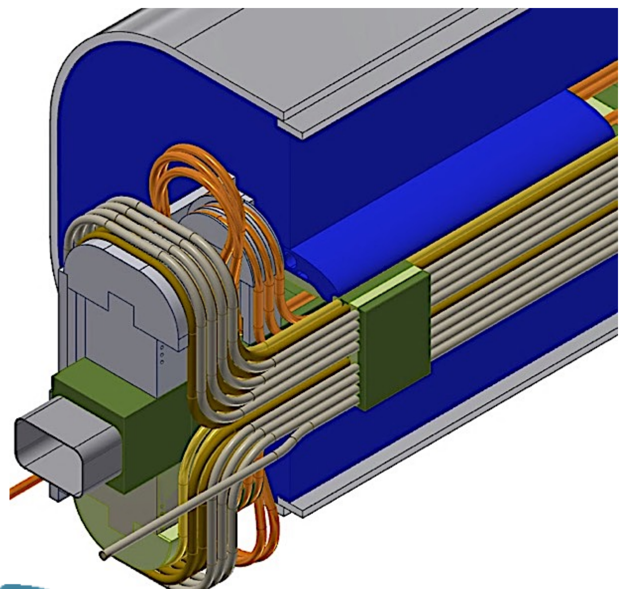
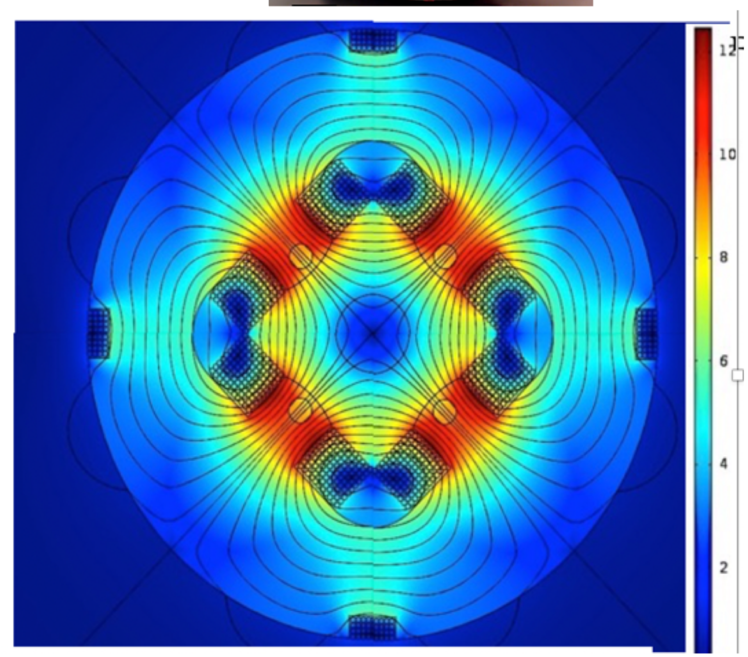
High-Performance CIC Magnets for EIC: Recent Developments

Peter McIntyre

Texas A&M University







Hyper Tech Research, Inc.

Accelerator Technology Corporation

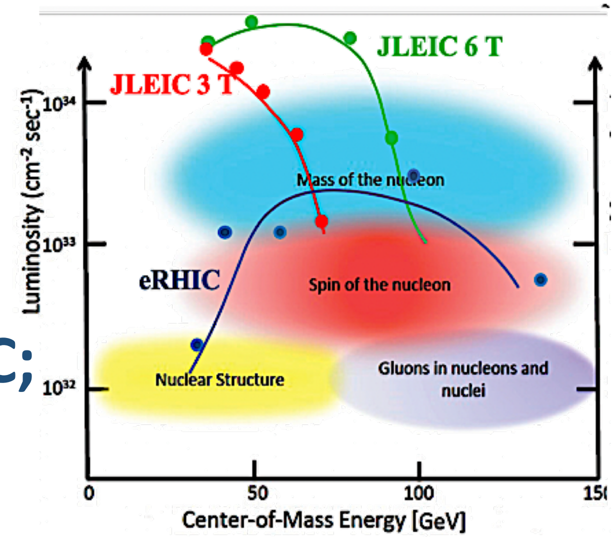
Magnets needed for EIC:

Physics drivers:

NAS assessment of R&D EIC needs (2018)

EIC physics needs more energy than baseline JLEIC;

More luminosity than baseline eRHIC:

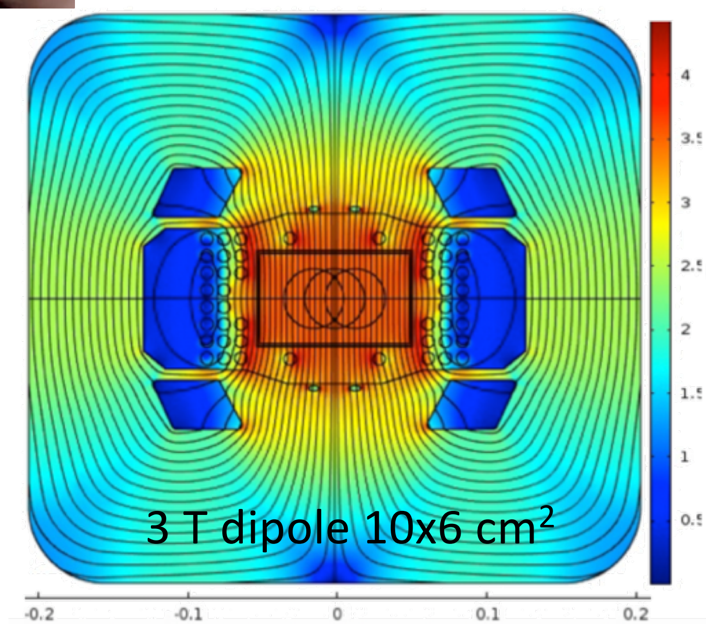


NAS assessment of R&D EIC needs (2018)

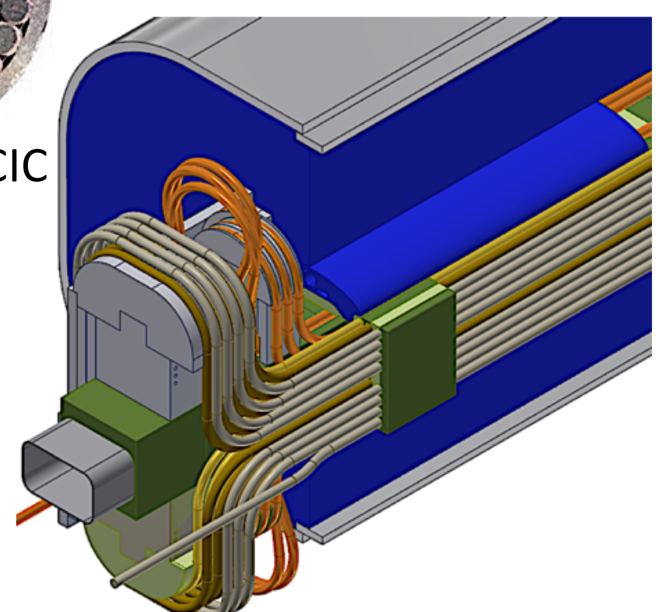
1. Double the energy of JLEIC Ion Ring: 3 T → 6 T

1-layer NbTi CIC

2-layer NbTi CIC



3 T dipole 10x6 cm^2



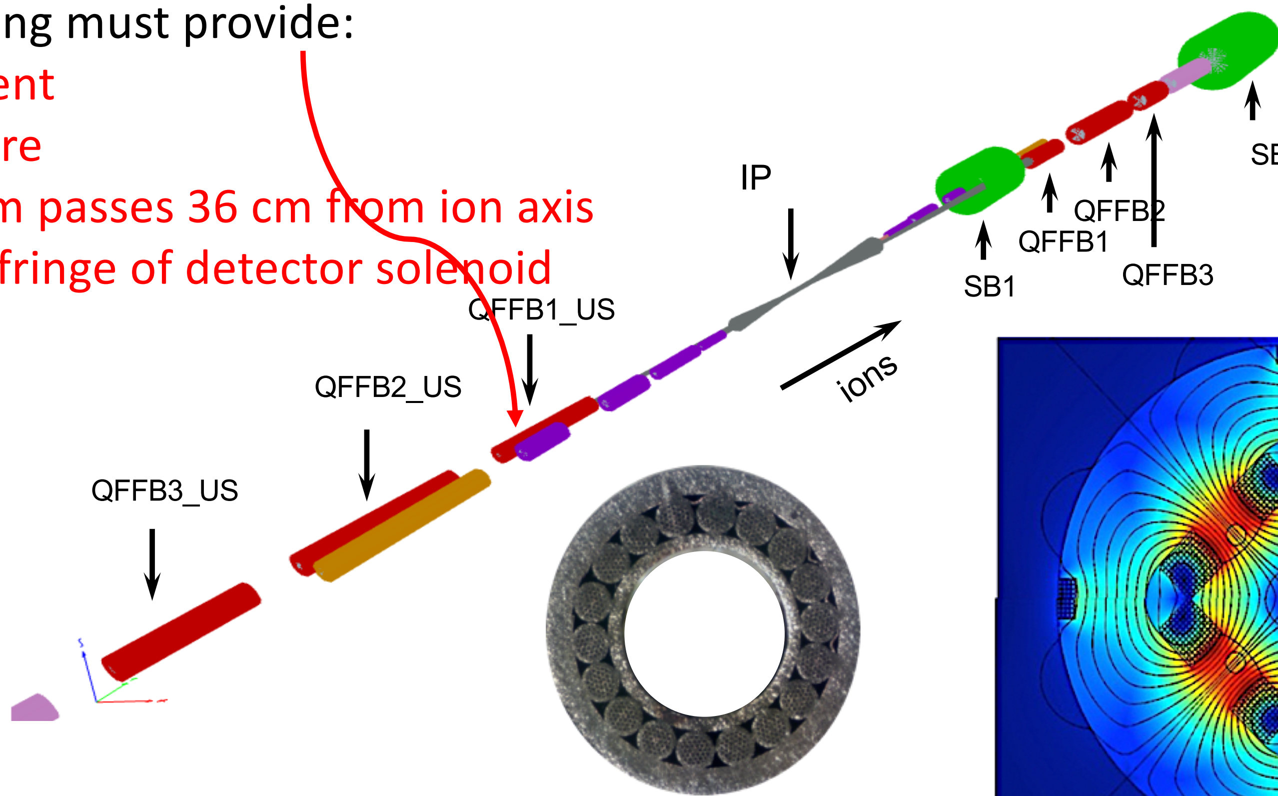
6 T dipole 10x6 cm^2

Magnets needed for EIC:

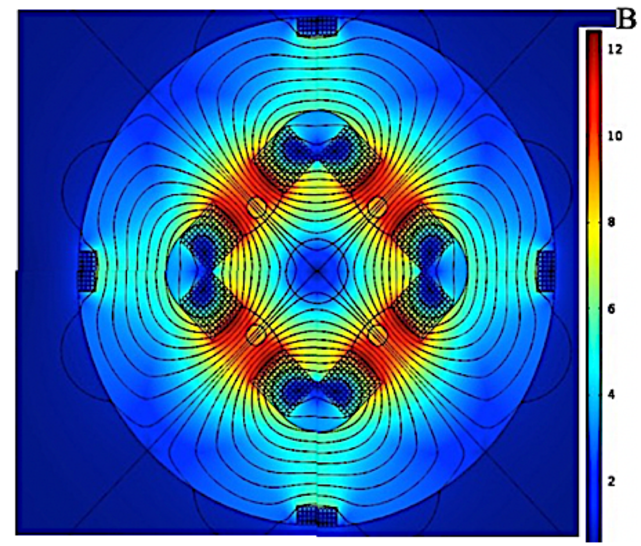
2. High-gradient, large-aperture quads for final focus

Q1 in FF of ion ring must provide:

- 90 T/m gradient
- 18 cm aperture
- Electron beam passes 36 cm from ion axis
- Operation in fringe of detector solenoid



1-layer NbTi CIC

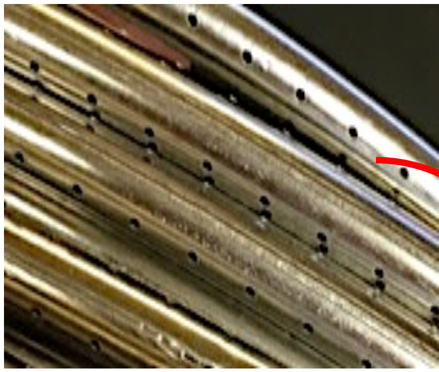


90 T/m, 180 mm bore, B=0 @ 36 cm

We have developed the 1-layer Nb_3Sn CIC and its coil technology for Q1, and a magnetic design that meets all requirements for EIC FF.

We have developed the 2–layer NbTi CIC and its coil technology for the JLEIC dipoles, and a magnetic design that meets all requirements for a 6 T JLEIC.

SuperCIC Fabrication



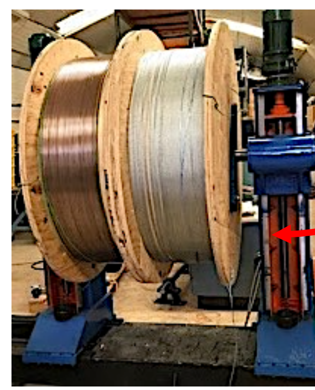
perforated center tube;

cable superconducting wires onto center tube;

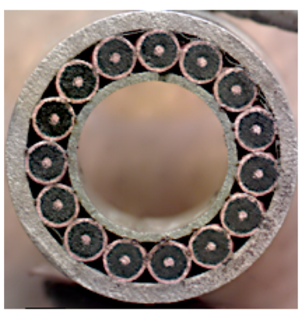
apply foil over-wrap;

pull straight 150 m cable through sheath tube with loose fit;

draw sheath tube onto cable;



150 m single-layer SuperCIC ready for building 3 T dipole.



1-layer NbTi → 3 T dipole

2-layer → 6 T dipole

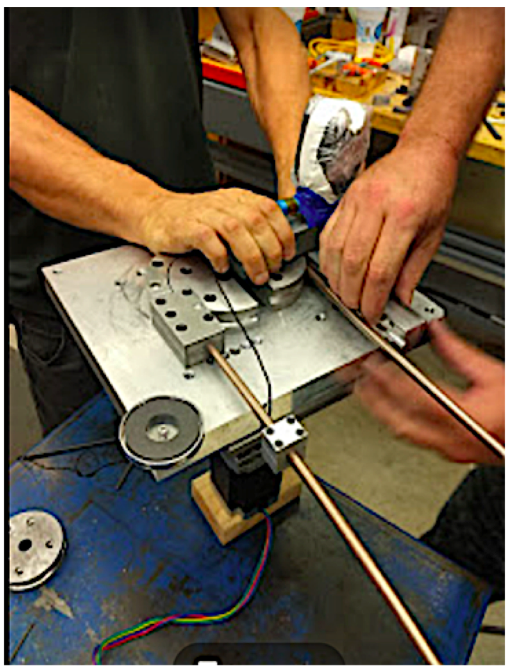
ATC now manufactures 1--layer and 2-layer SuperCIC in lengths up to 150 m as a manufactured product.

SuperCIC Coil Technology

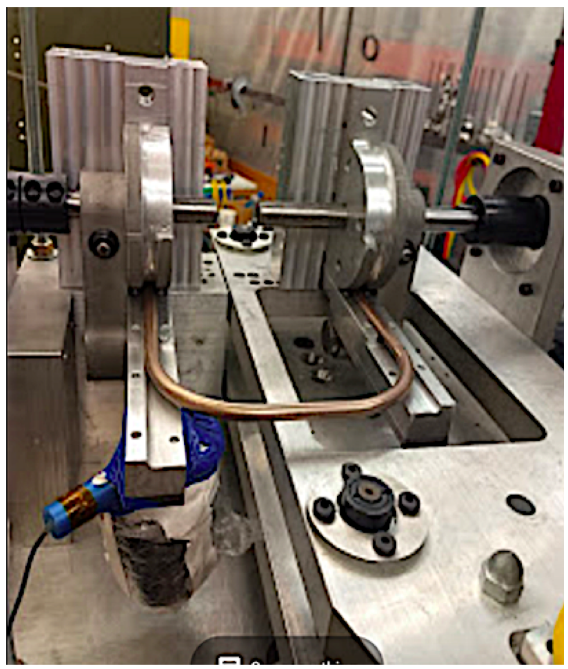
Small-radius bends are required for a dipole or quad. Three challenges:

- The bend tooling must ***keep the sheath tube round through bend.***
- The wires must be cabled with twist pitch equal to the arc length of the bend. ***Every wire has the same catenary length around the bend***.
- Provide a ***slip surface to permit wires to re-arrange during bend***.

Robotic bend tooling:



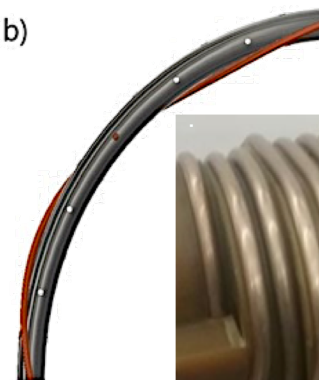
180° U-bend

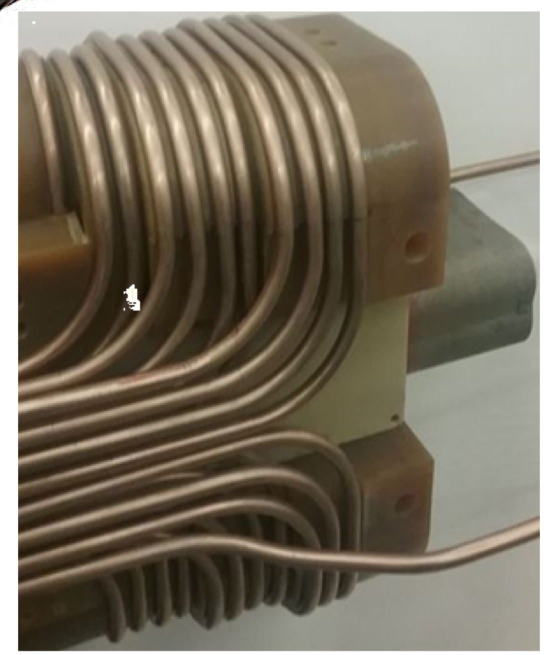


90° flare of U-bend

a)

b)





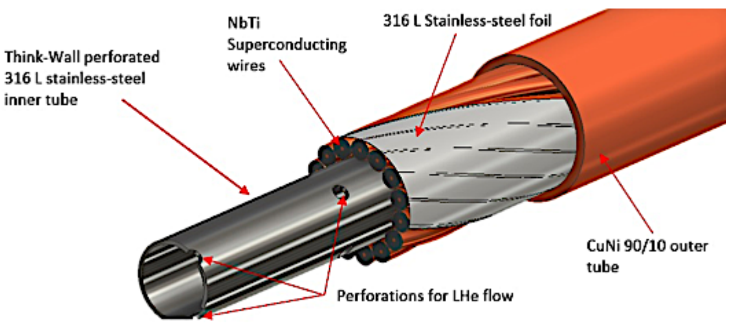
Completed 24-turn winding

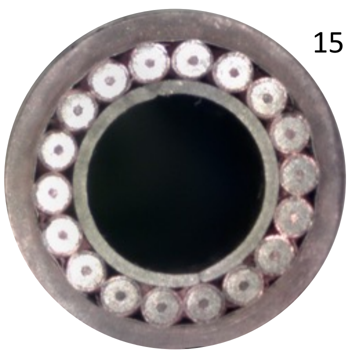
Verified that we can make the necessary bends: no strand breakage, no I_c degradation.

Developing the 6 T dipole for JLEIC doubler

Phase 1 SBIR at Accelerator Technology Corp. – in progress

1 - Develop 2-layer cable with 6 cm bend radius

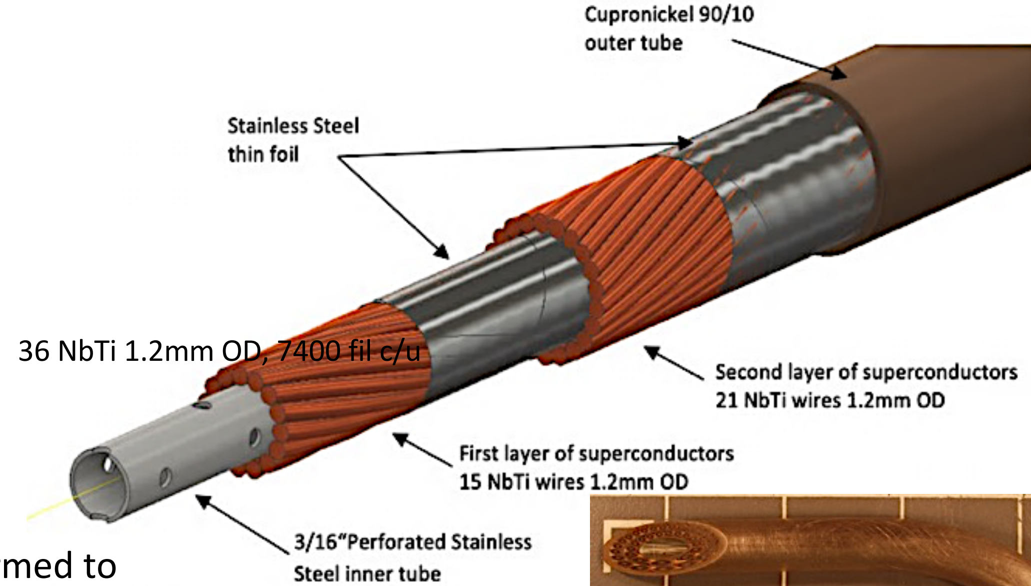




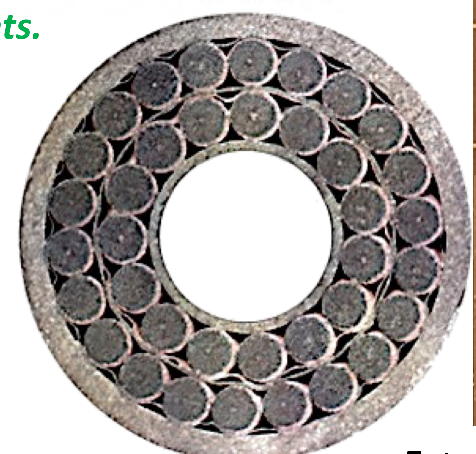
15 NbTi 1.2 mm OD, 7400 fil c/u

Extracted strands from CIC formed to
5 cm bend radius. ***No broken filaments.***
Etched to detect broken filaments.
Measured I_c. ***No I_c degradation.***

Dipole		3 T dipole	6 T dipole	
Bore tube dimensions		10x6	10x6	cm^2
Coil current	I_0	13	23	kA
Operating temp	T_0	4.5	4.5	K
Max bore field @S.S.	B_{max}	3.6	6.45	T
# turns/pole		12	19	
Stored energy		0.06	0.7	MJ/m
Inductance		0.68	2.5	mH/m
Cable-in-Conduit				
CIC diameter		8.1	11	mm
#strands inner+outer		15	15+21	
Strand diameter	d_{strand}	1.2	1.2	mm
Cu:SC stabilizer		1.5:1	1:1	



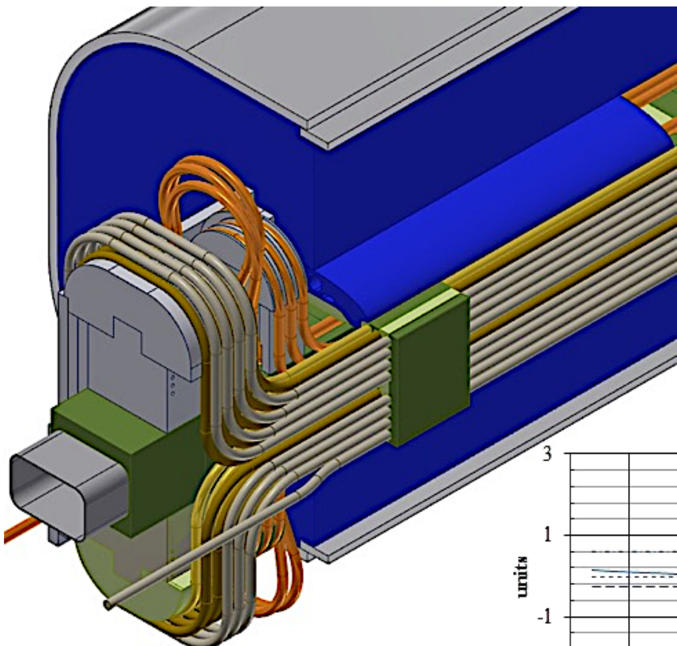
36 NbTi 1.2mm OD, 7400 fil c/u

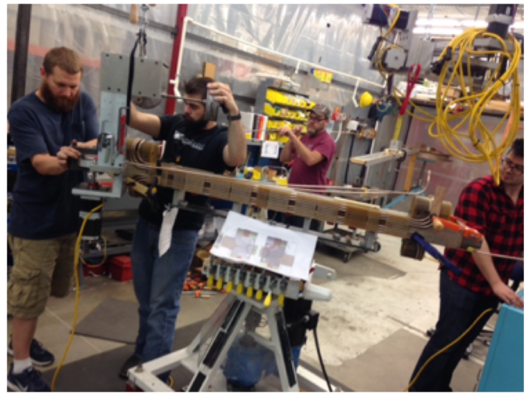


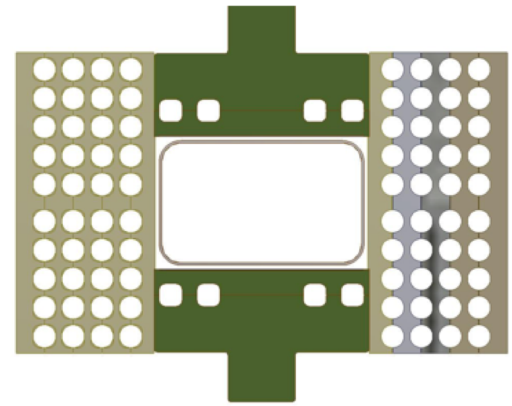
Extracted strands from CIC formed to
6 cm bend radius. ***No broken filaments.***
Etched to detect broken filaments.
Measured I_c. ***No I_c degradation.***

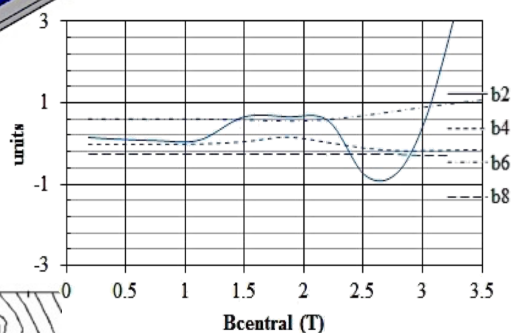
Developing the 6 T dipole for JLEIC doubler

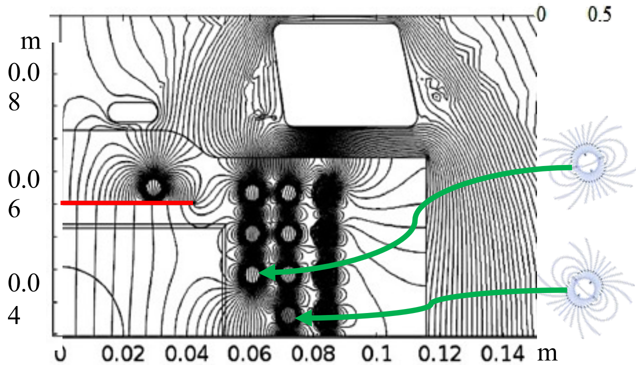
2 – Magnetic design, structure for JLEIC requirements





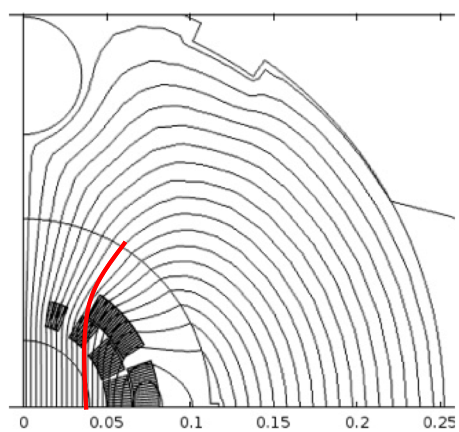




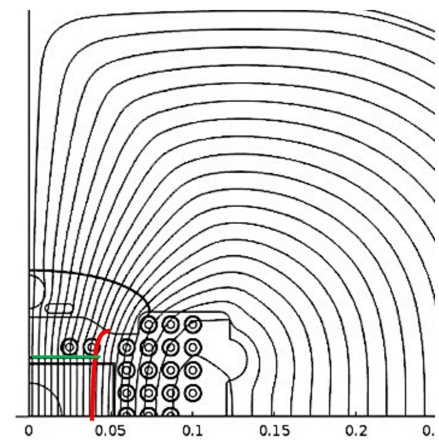


Steel flux plate suppresses persistent-current multipoles and snap-back ***x10***.

Two dipoles with same operating field (6 T) and aperture (10 cm):



cos θ dipole for SIS-300



CIC dipole for JLEIC.

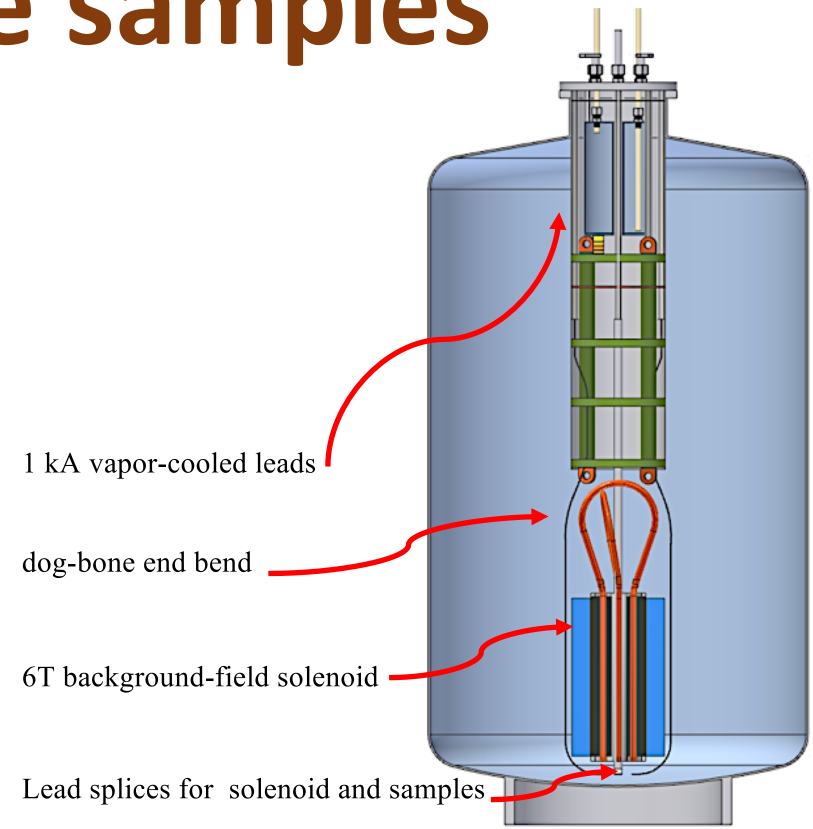
Cost-driver parameters for 3 T, 6 T CIC dipoles and 6 T cos θ dipole:

	3 T CIC	6 T CIC	6 T cos θ
Aperture	10 x 6 cm^2	10 x 6 cm^2	10 cm round
# turns/bore	12	19	71
Wire cross-section	2.0 cm^2	9.0 cm^2	13.5 cm^2

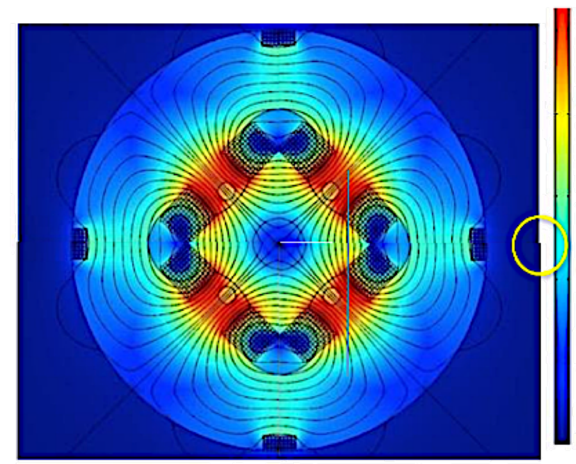
Preparing to test cable samples with U-bend end

Test 2-layer SuperCIC segments with 6 cm radius U-bends
Test SuperCIC segment contains 2 NbTi wires (1 inner, 1 outer), balance Si bronze wires.

Test cryostat nearing completion:
6 T background field solenoid,
1 kA vapor-cooled leads.



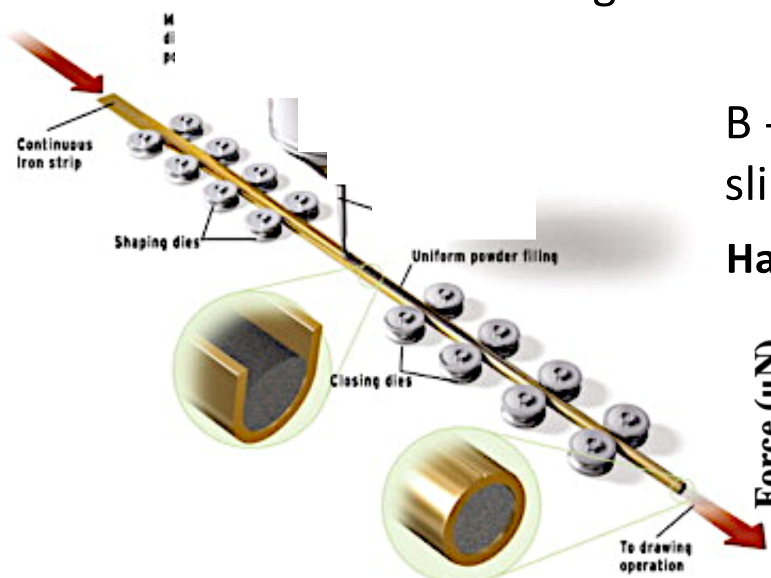
Developing the IR quad for EIC Final Focus



1– Develop 1-layer Nb_3Sn SuperCIC

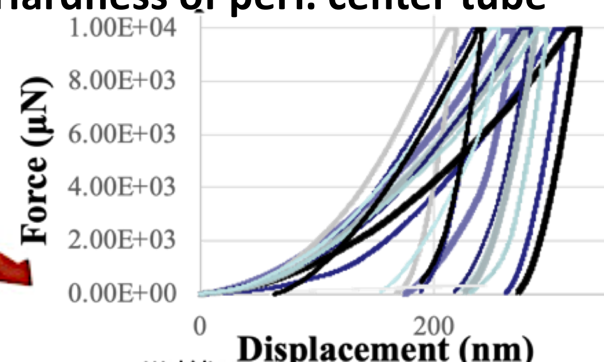
Phase 1 SBIR at HyperTech Research

A - Develop Nb_3Sn SuperCIC using HyperTech's Continuous Tube-Forming of the sheath tube

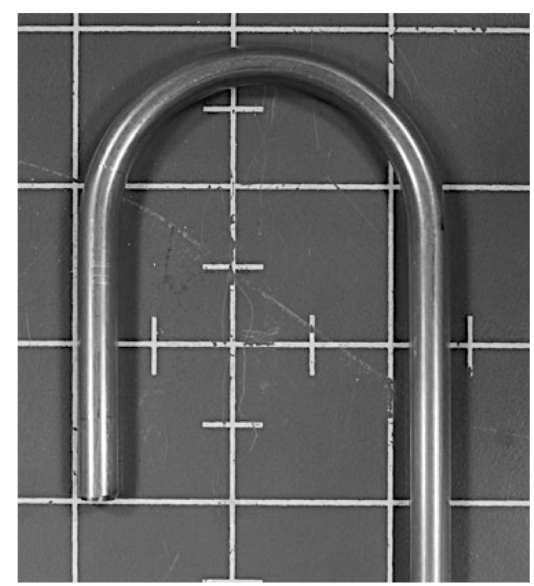


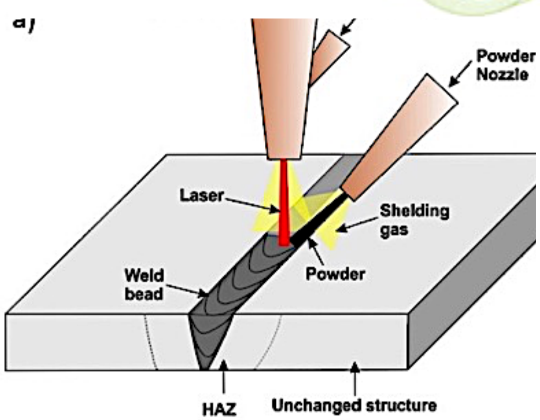
B - Develop ***functionalized multi-layer over-wrap*** to provide slip-surface so wires can re-arrange as U-bend is formed.

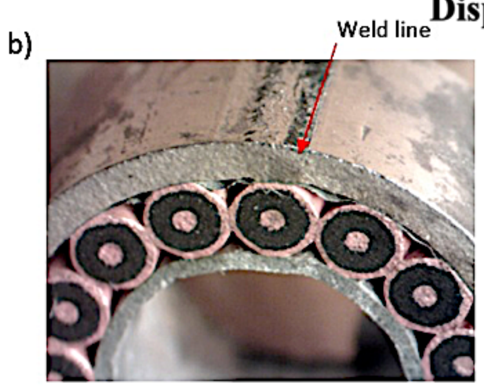
Hardness of perf. center tube

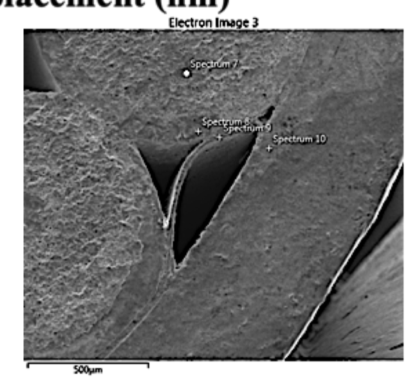


Extracted strands from CIC formed to 5 cm bend radius. ***No broken filaments.***
Etched to detect broken filaments.
Measured I_c. ***No I_c degradation.***









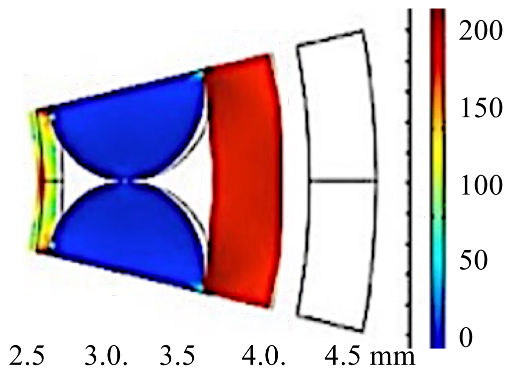
Developing the IR quad for EIC Final Focus

2 – Magnetic design, structure for EIC requirements:

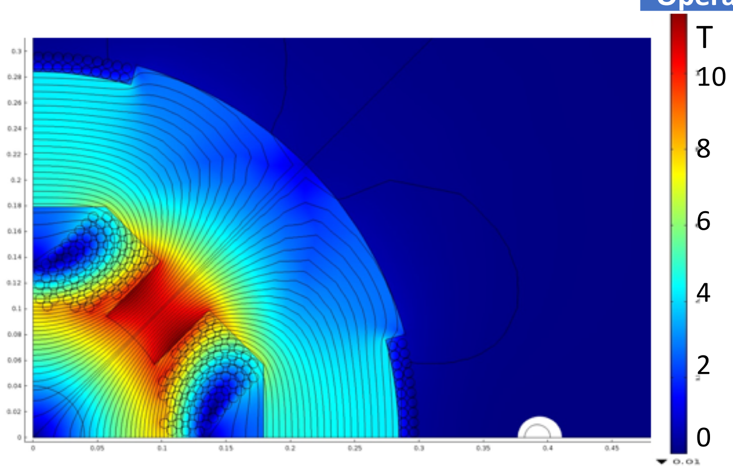
90 T/m; 18 cm bore; B=0 @36 cm;

suppress fringe from detector solenoid

NbTi reverse-field windings in slots on outer surface of flux return: 'tuck in' the fringe field.

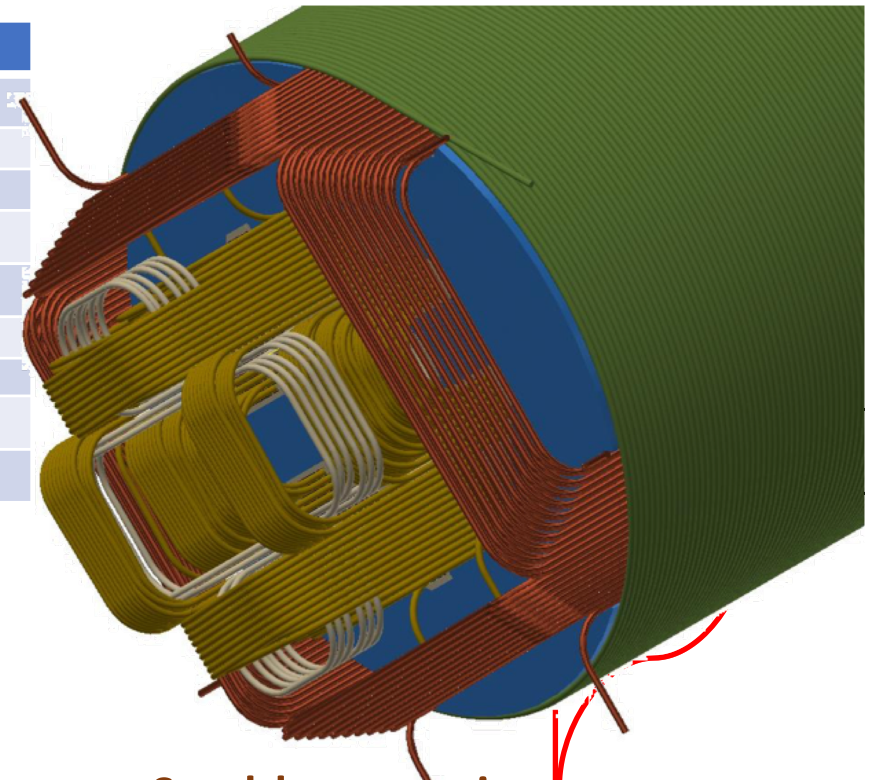


Stress management at cable level



Field/gradient	89	T/m
Strand diameter	1.1	mm
Cu:SC ratio	1.5	
# strands	15	
Cable diameter	5.8	mm
Center tube OD	3/16	"
# Turns/pole	120	
Coil current	9.0	kA
B_{max} in winding	11.5	T
Operating temp	4.2	K

Stealth magnetics: solenoid winding excludes flux from detector solenoid



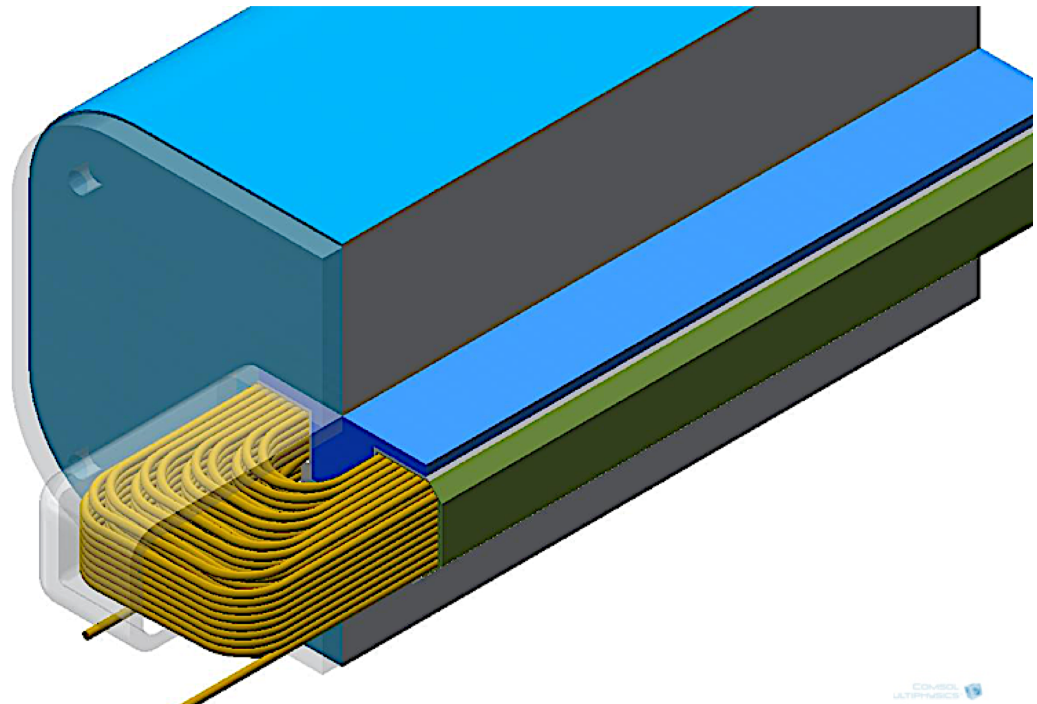
Stealth magnetics:
NbTi reverse-current windings cancel fringe field @ e-beam

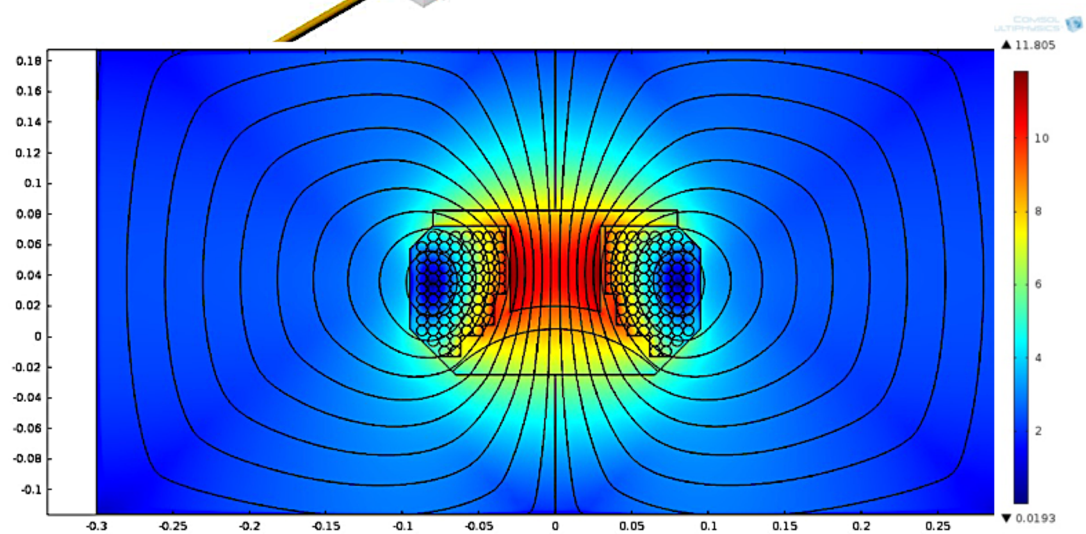
Validate the SuperCIC IR quad:

ATC proposes to build/test a dipole containing one quadrant winding of the FF quad:

- B @ windings is same in the model dipole as in the quad.
- Texas A&M, ATC, and HyperTech will collaborate to develop the model dipole.

The model 6 T dipole and the single-winding model for the FF quad will be tested at BNL.





We request the strong support of the EIC Collaboration for this Phase 2 SBIR proposal.

ATC plans to submit a Phase 2 SBIR proposal in 12/2019:

- **Build/test short-model 6 T dipole**
  - ATC has commissioned its SuperCIC fab line, fabricated 150 m piece length.
  - ATC has vendor quote $75,000 for complete structure assembly.
  - ATC will fab the windings, Texas A&M will vac-impreg.
- **Build/test single-quadrant winding for IR quad**
  - Texas A&M has perfected the Nb_3Sn SuperCIC
  - ATC will fabricate long-length SuperCIC for winding.
  - ATC fabricate structure, fab the quadrant winding
  - ATC will heat treat and vacuum-impreg the winding.

We request the strong support of the EIC Collaboration for this Phase 2 SBIR proposal.