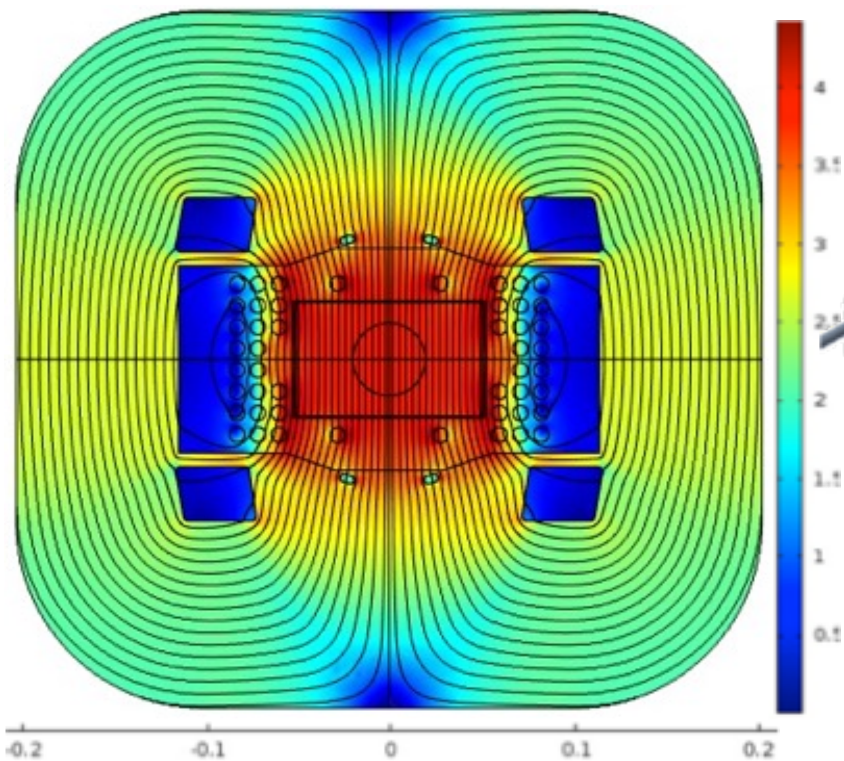
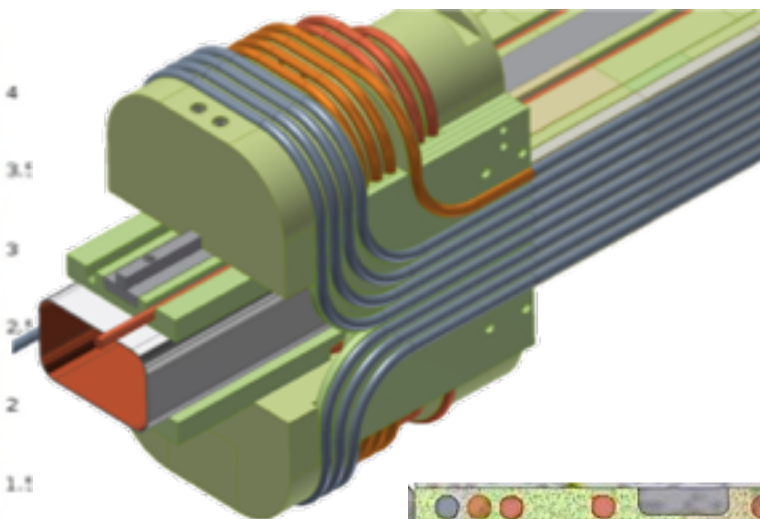
Dipoles for Ion Ring of JLEIC

Peter McIntyre
Accelerator Research Lab – Texas A&M University
collaboration with
Accelerator Technology Corp.
HyperTech Research, Inc.

- Report on present NP grant to develop long-length CIC cable and structure for 3 T dipole
- Tasks remaining to assemble 3 T model dipole ready to test
- Design and plan for developing a 6 T dipole using same CIC technology

We are developing a superferric 3 T dipole using NbTi CIC conductor

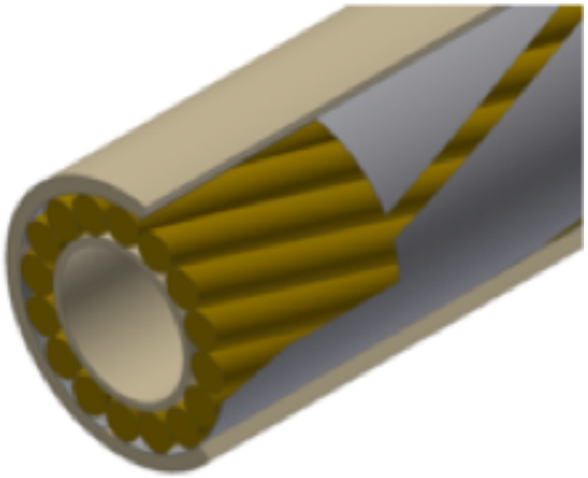




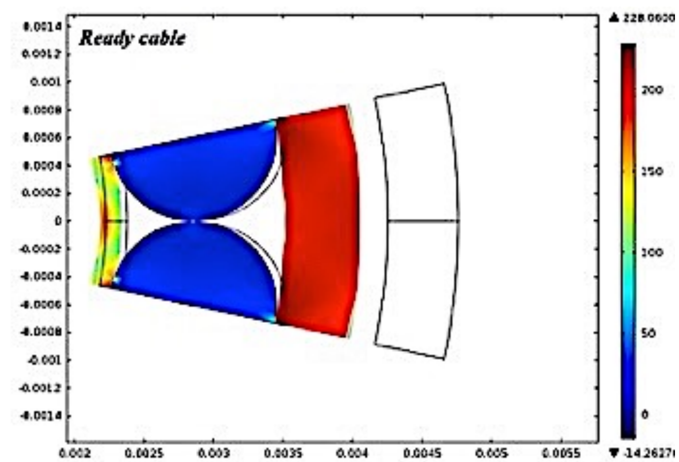
This development to date has validated key aspects of the CIC dipole:

- the CIC cable technology preserves full performance of the superconducting wires;
- Motorized bend tools are used to precisely form flared ends on a winding;
- Structural supports preserve position tolerances on all turns to <50 μm;.
- Supercritical He (SCHe) flows within each CIC conductor, bathes all strands

CIC Cable Technology at Texas A&M and ATC



15 NbTi/Cu wires are cabled onto a perforated spring tube.

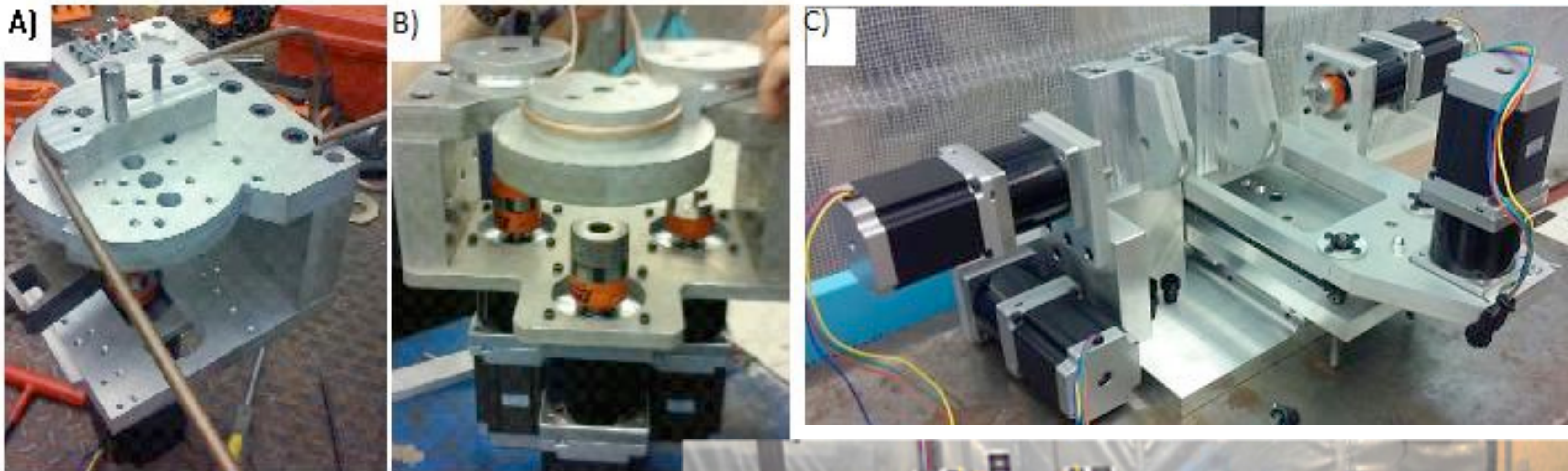


The cable is inserted in a sheath tube, and the sheath is drawn onto the cable to just compress the wires against the spring tube.

Cooling with supercritical He: remove 14 W from 4 m dipole (220 m CIC): 0.3 m/s flow velocity, ΔP = 2 psi across dipole.

CIC coil technology

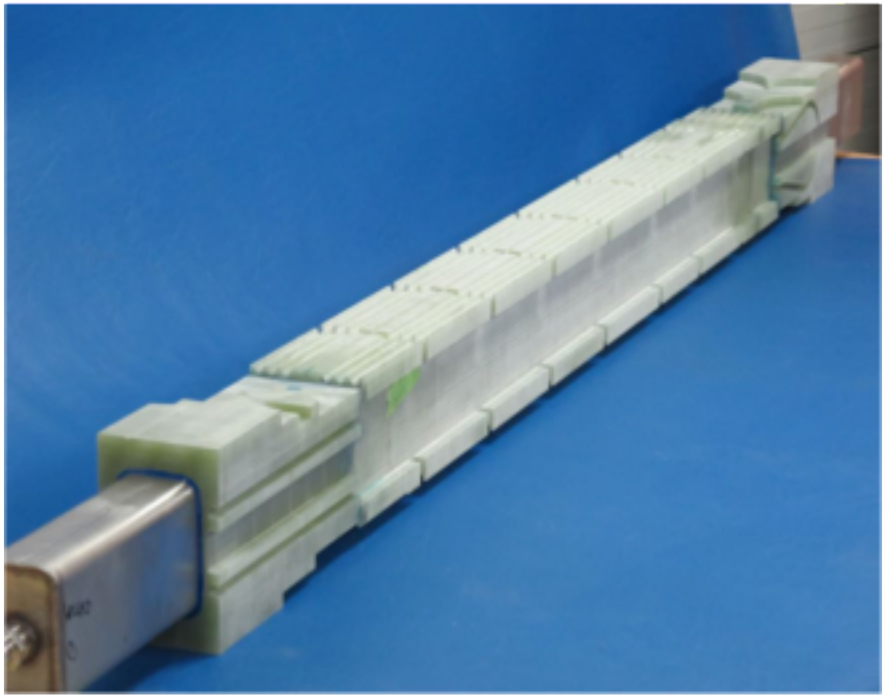
Three motorized benders make it possible to precisely form saddle-geometry ends with reproducible shape, no cable deformation, no degradation of superconductor:

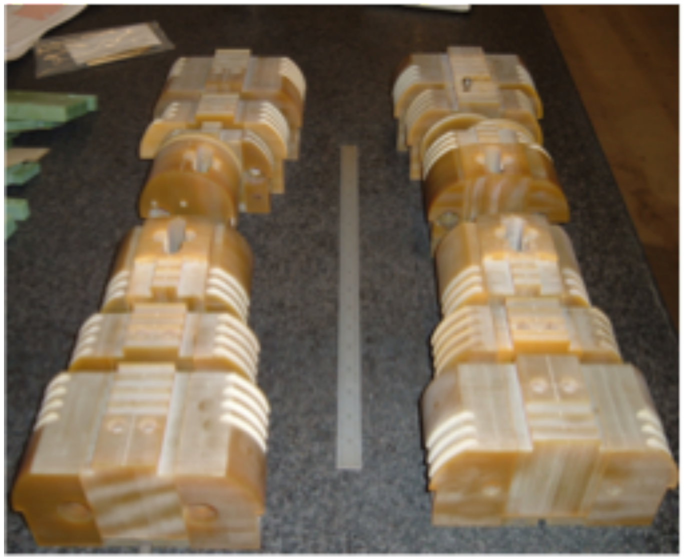


Completed 24-turn winding for a 1.2 m model dipole of the 3 T CIC dipole for JLEIC

Tasks of present JLab Subcontract

1. FRP Structure Fabrication - complete





- Precision metrology of all 24 cable channels yields all random multipoles <<1 unit
- *Ready for coil-winding*

Δb_0	Δb_1	Δb_2	Δb_3	Δb_4	Δb_5	Δb_6	Δb_7	Δb_8	Δb_9	Δb_{10}
7.2E-05	1.8E-01	-2.6E-02	8.0E-03	6.6E-03	3.7E-03	4.0E-03	4.9E-04	-3.9E-05	-2.1E-04	-8.2E-05

units (10^{-4})

2. 125 m CICC Fabrication - complete by July 2018

- 24-strand cabling machine installed and commissioned
- Long-length sheathing and drawing installed
- Feed, take-up spools for cable, CIC have been fabricated and installed.

3. Short length winding of CICC onto the FRP Structure – complete August 2018

- Bender 1 modification complete, commissioned into operation
- Bender 2 modification in progress.

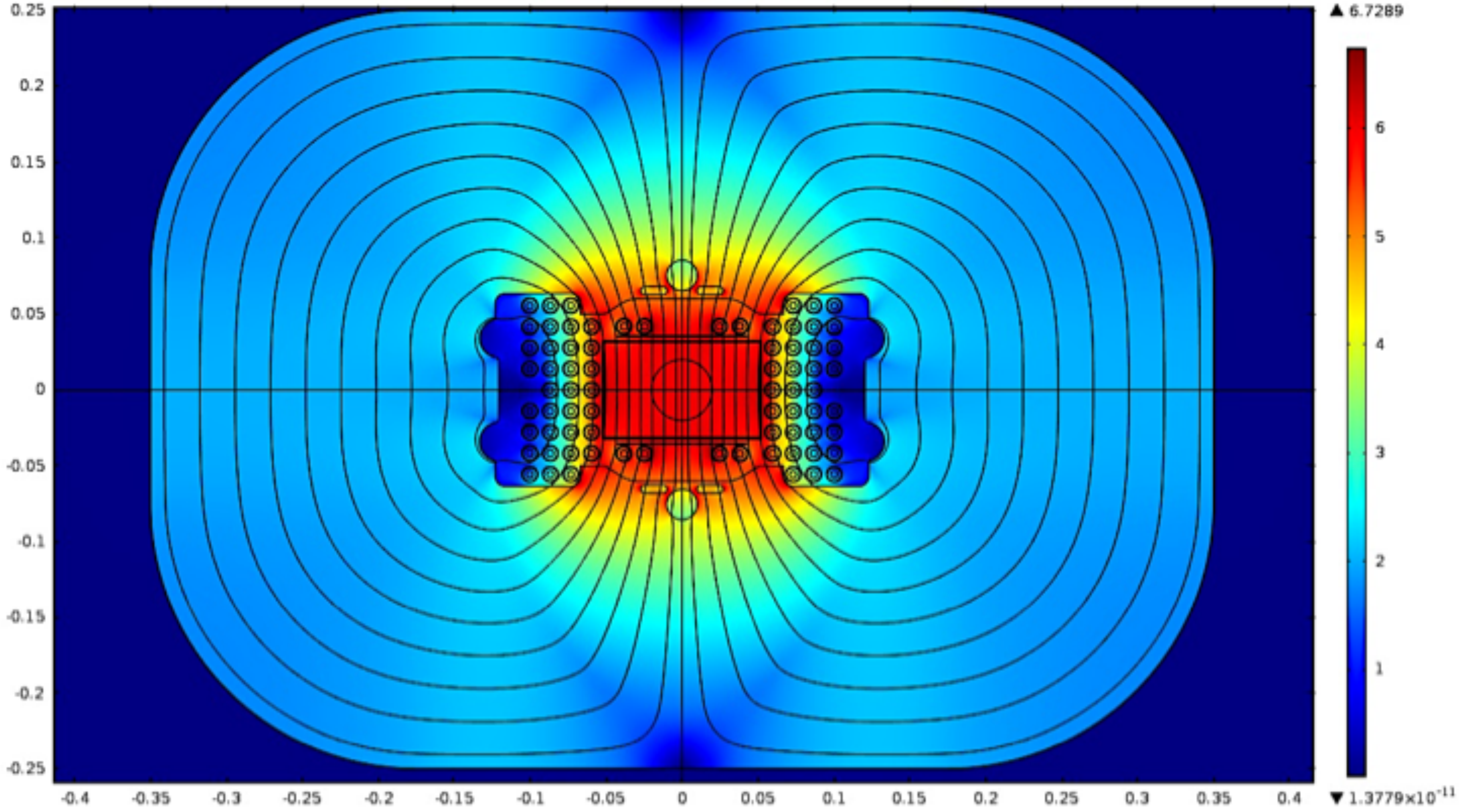
These three tasks will be complete on-schedule, on budget, on-spec.
That will be the end of presently funded work at Texas A&M for JLEIC.

We have built a 25 kA CIC conductor that uses same strand as the 3 T dipole, and could produce 6 T operating field

Two Layer CIC		
# strands	15+21	
D_{strand}, mm	1.2	mm
Cu/Sc	1	

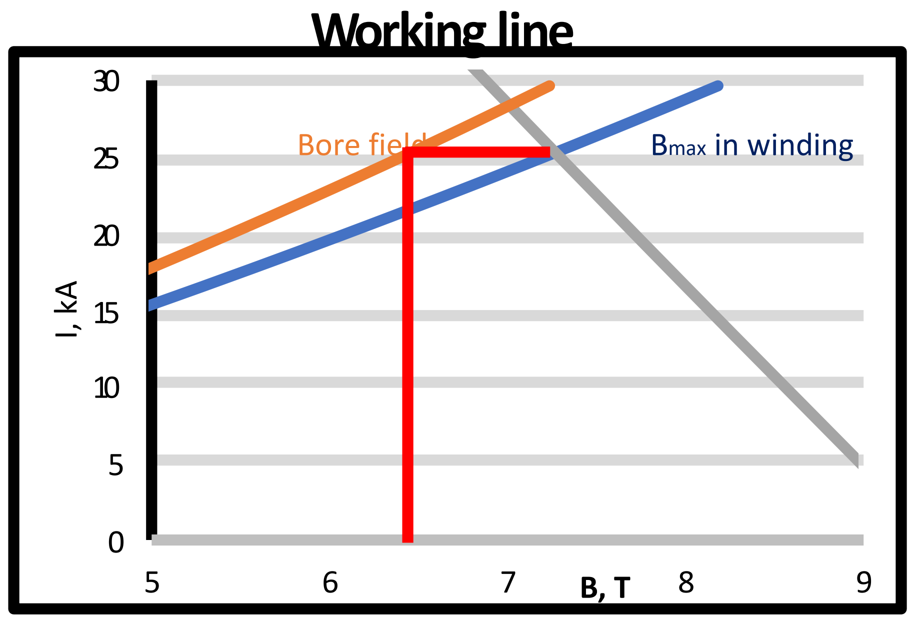
- We have successfully cabled 15 strands on inner layer, 17 strands on outer layer, with SS tape over-wrap between layers and between outer layer and sheath.
- We have successfully formed the 2-layer CIC in a 5 cm diameter U-bend required for the 6 T dipole winding.
- The interior structure remains intact throughout the bend, with proper registration among strands.

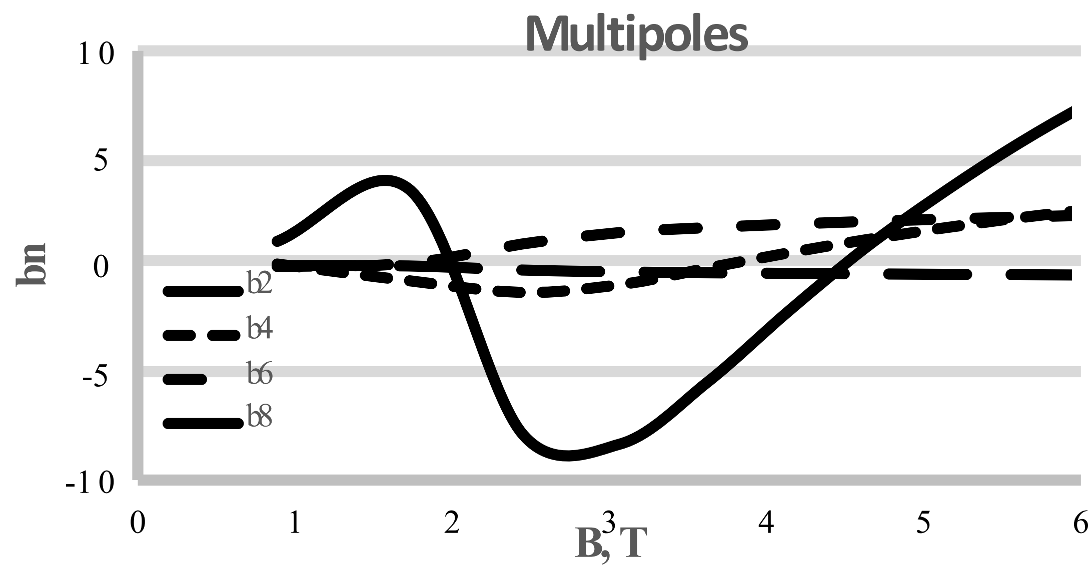
Preliminary magnetic design for a 6 T dipole using the 2-layer NbTi CIC



The 6 T CIC dipole operates with about the same margins as the 3T dipole

6 T dipole parameters		
operating point:		
B_{bore}	6.0	T
B_{coil}	6.7	T
I_{op}	22.8	kA
T_{op}	4.5	K
J_{SC} @ B_{coil}, T_{op}	1.12	kA/mm^2
J_{cu}@ quench	1.12	kA/mm^2
Stored Energy	0.66	MJ/m
Inductance	2.5	mH/ m
B_{bore} max	6.45	T
T_{op} max	5.03	K





b_2 is still too large. But it was about that value in early development of the 3 T design, and the refinement of magnetics reduces it to <1 unit at all fields.

We can project the impact of doubling the field on the cost of the CIC dipole

	3 T	6 T	
Materials			
NbTi/Cu wire	8	31	cm^2
Steel laminations	360	875	cm^2
Labor			
# turns in winding	24	38	
# SCHe flow paths	1	2	

It is plausible that a 6 T CIC dipole could cost no more than twice the cost of a 3 T CIC dipole.
It is the only dipole technology for that could be true.

Texas A&M/ATC/HyperTech offer to complete the 3 T model dipole and develop a 6 T model dipole

Three phases:

1. Complete the 3 T dipole, ready to test.

2a. Develop the 2-layer CIC cable and test short U-bend segments at the FNAL cable test facility.

2b. Develop the 6 T magnetic design and characterize multipoles, structure, quench.

3. Build long-length 2-layer CIC, build structure for 6 T dipole, wind coil, complete dipole.

1. Complete the 3 T dipole, ready to test

- Wind 24-turn coil using existing 125-m CIC
- Fabricate compaction shells, assemble on coil, preload
- Warm measurements of multipoles, shim as necessary
- Stack/weld two steel half-cores for flux return
- Fabricate piece-parts and instrumentation for final assembly
- Assemble dipole, install/check all instrumentation
- Preload, impregnate end regions

Cost: $470K **Time to complete: 9 months**

2a. Develop 2-layer CIC cable, test short U-bend segments at the FNAL cable test facility

- Take the development of cable micro-structure and bend tooling through same trail we did with 1-layer CIC.
- Optimize parameters of the cable – perforated center-tube, SS tape over-wrap, sheath tube.
- We have validated that slight modifications of the parameters that worked for 1-layer CIC work with 2-layer, but we must validate with short-sample tests of extracted strands.
- Stage U-bend samples on the sample holder for the FNAL cable test facility.

2b. Develop the 6 T magnetic design, characterize multipoles, structure, quench

- We know the work that was required to optimize the magnetic design, winding strategy, quench simulation, and mechanical/cryogenic design for the 3 T design.
- Major parameters are very similar for the 6 T design.

3. Build long-length 2-layer CIC, build structure for 6 T dipole, complete dipole

Strategic questions for JLEIC

- Do you consider completion and testing of the 3 T CIC dipole important for your pre-CDR process?
- Do you consider a 6 T dipole design for the Ion Ring important for the competitive stature of JLEIC w.r.t. e-RHIC?
- If so, would development of the magnetic design and validation of current-carrying performance of the 2-layer CIC conductor be sufficient? (Task 2 above)

- We will soon complete our present subcontract with complete success, on schedule, on budget.
- What comes after that is up to you.