Superconductor Wire, Coils and Systems at Hyper Tech

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Hyper Tech

Wires: MgB_2 , High Jc Nb_3Sn
Cables: MgB2, NbTi, Nb3Sn, YBCO
Coils: MgB_2, NbTi, Nb_3Sn, YBCO, BSCCO
Systems: MRI, SMES, FCL, Motors, Generators, Wind Turbine Generators

Other Areas Technology that might be of interest NP community.

Sister Company- Eden Cryogenics- Cryogenic Customer examples- Fermilab, JL, SLAC, NASA, ORNL, etc.

Sister Company -Global R&D Inc- nano thickness (less than 800 nm thickness- multiple layers) inorganic membranes for gas separation, SOFC, water filtration (funded by DOE- Advanced Manufacturing)

Better wires than Cu and Al – using graphene and CNT, funded by AF, Army, NASA

New way to reduce cost of making complicated permanent magnet shapes

Additive Manufacturing for making RF cavities for Qubit Shielding

Potential New Dynamic Forming Process for making RF cavities

MgB2 and YBCO Bulk Shapes (tubes) for beam shielding.

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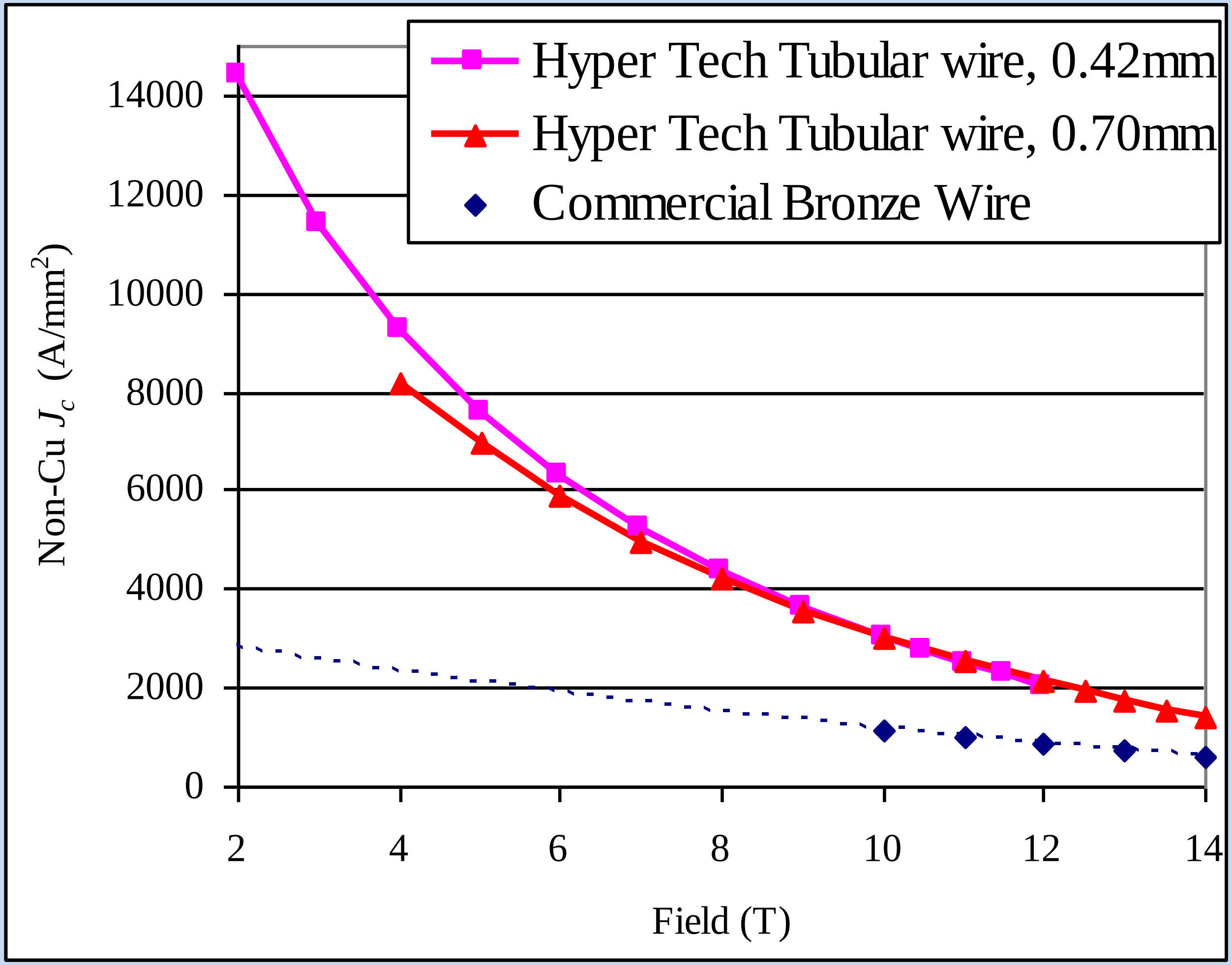
Developing for HEP, improved Nb3Sn superconductors the target is to double the non-Cu Jc

Present Commercial High Jc , low field stable, Nb3Sn superconductors

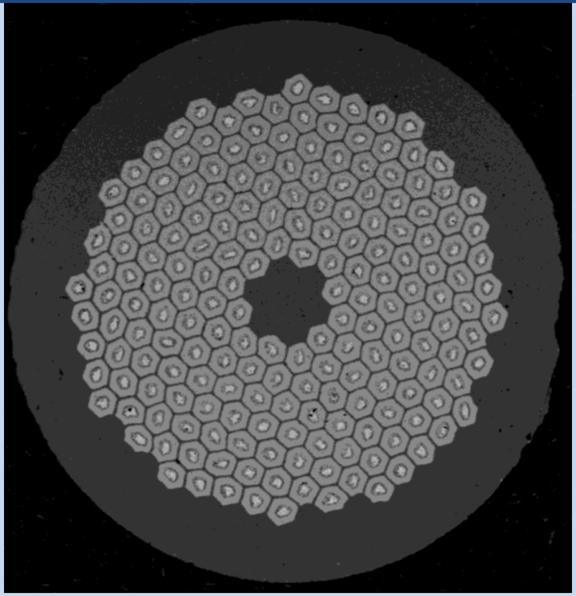


Patented
New Development

Potential for
Artificial Pinning
Centers (APC)

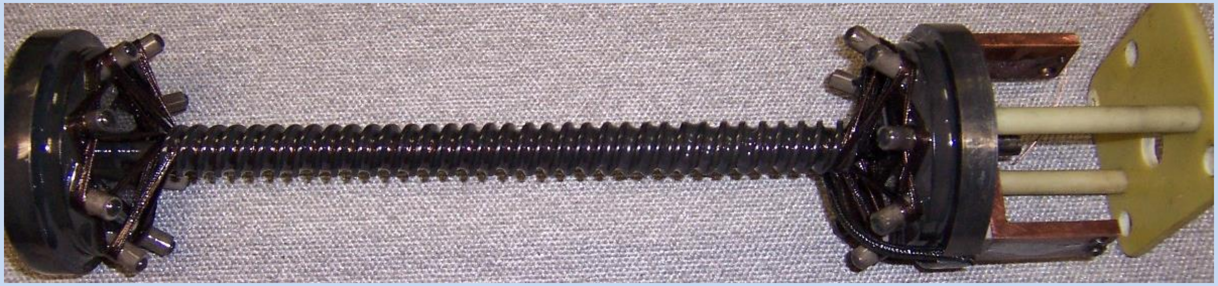
Goal is to Exceed
CERN specification
of 1500 A/mm2
Jc at 16T

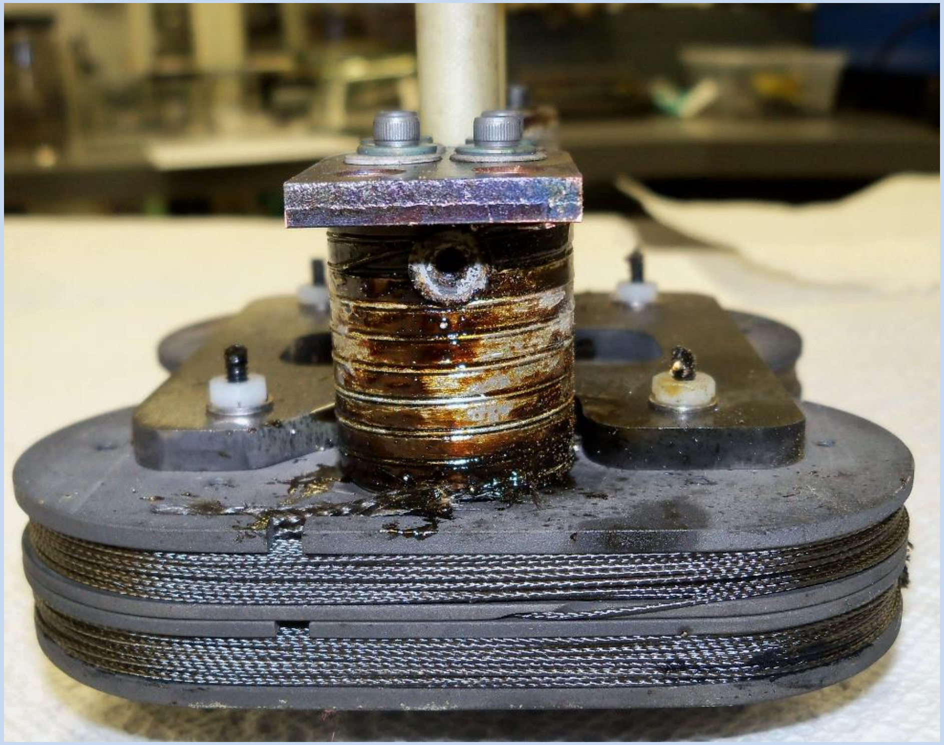
Applications on Short Period Undulators



192 restack wire at 0.5 mm
(filament size of 24 μm)

Funded by DOE- Basic Energy Sciences





Helical Undulators

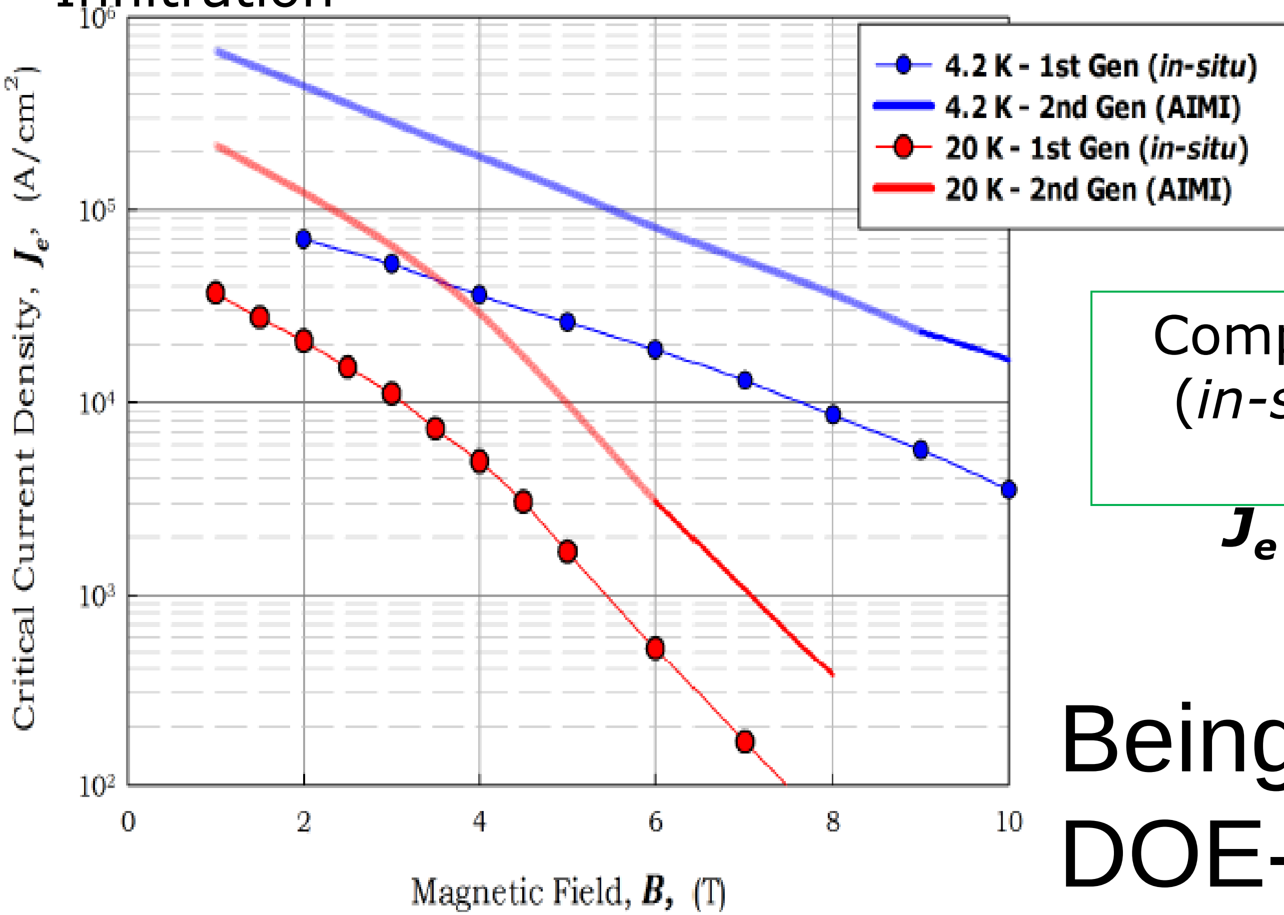
Period (λ)	14 mm
Winding bore	8.0 mm
Beam aperture	7.0 mm

Planar Undulators

Period (λ)	14.5 mm
Beam aperture	7.0 mm

2nd Generation MgB2 wire

"AIMI" refers to Advanced Internal Magnesium Infiltration



Comparison of 1st Gen (*in-situ*) and 2nd Gen (AIMI)

J_e at 4K and 20K

Being Funded by DOE- Fusion

Low AC Loss MgB2 superconductor wire

Looking at 114-filament MgB_2 wire vs 2-60 Hz frequency and 2 T on wire

Low AC Loss MgB2 Wire types	OD/d_f/L_p (mm/micron/mm)	Filament No.	Frequency, Hz	Ic, amps	Iop, amps (50% of Ic)	Jc at 2.0T,20 K, A/cm2	λ, %	Total (W/cm^3)	Total (W/m)
Round wire	0.85/28/5	114	2	150	75	178000	15	0.0281	0.0159
Round wire	0.85/28/5	114	8	150	75	178000	15	0.133	0.076
Round wire	0.85/28/5	114	16	150	75	178000	15	0.321	0.182
Round wire	0.85/28/5	114	60	150	75	178000	15	2.37	1.34

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Hyper Tech Research Inc.

Phase II Title: Long Length Welded NbTi -CIC Superconducting Cable for Accelerator Applications,

For Superconducting Dipoles and Quadrupoles for Thomas Jefferson Laboratory Electron Ion Collider

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Matt Rindfleisch

CJ Thong

Xuan Peng

Dean Panick

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Development partners

Accelerator Research Lab (ARL)
Accelerator Technology Corp. (ATC)

Dr. Peter McIntyre
Daniel Chavez

Dr. Mike Sumption

grant sponsor: DOE NP

Hyper Tech Research
Columbus, OH, USA
42,000 sq ft facility

Grant No. DE-SC0015198

Outline

- Motivation of SBIR project
- Phase II efforts
- Background on technology
    - CIC
    - NbTi Superconductors
    - MgB_2 superconductors
    - Nb_3Sn superconductors

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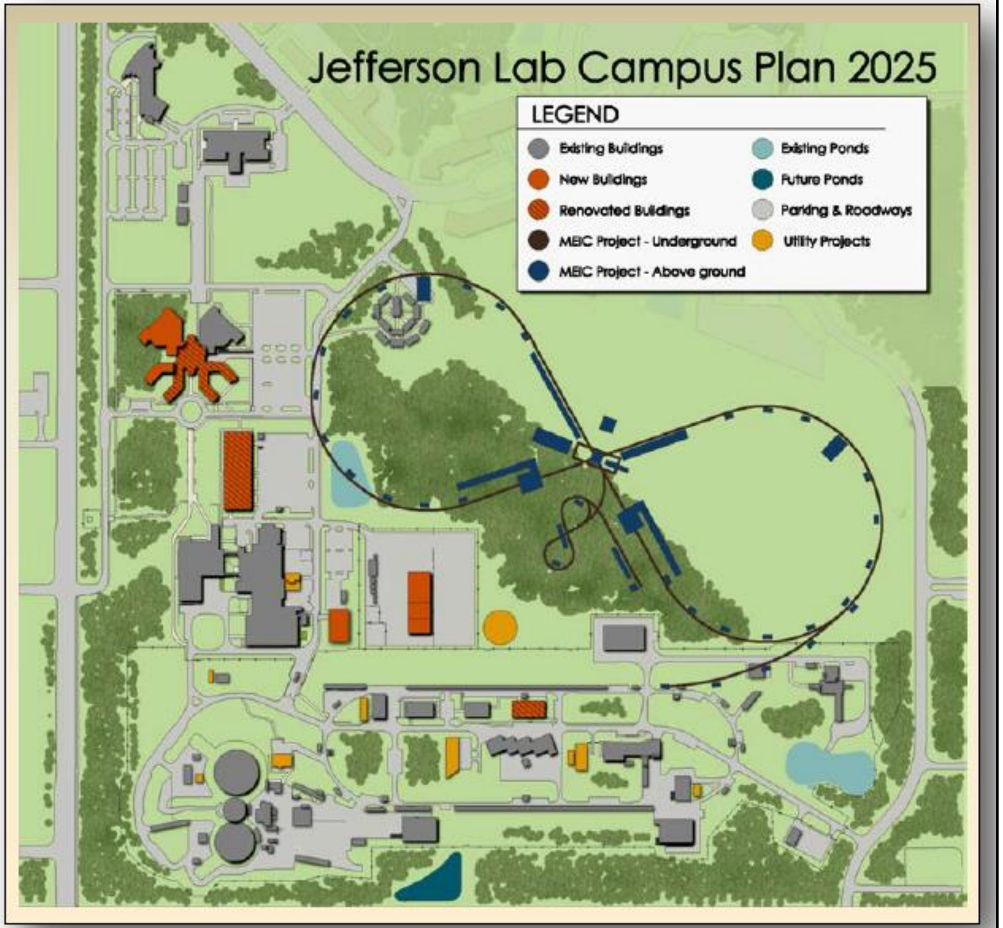
Motivation of project: JLab MEIC

JLab MEIC Figure 8 Concept

- **Initial configuration:**
  - 3-10 GeV on 20-100 GeV ep/eA collider
  - Optimized for high ion beam polarization:
    - polarized deuterons
  - Luminosity:
    - up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- **Low technical risk**
- **Upgradable** to higher energies
  250 GeV protons on 20 GeV electrons
- **Flexible** timeframe for Construction
  consistent w/running 12 GeV CEBAF
- Thorough cost estimate completed
  presented to NSAC EIC Review
- Cost effective **operations**

→ Fulfills White Paper Requirements



Current Activities

- Site evaluation (VA funds)
- Accelerator, detector R&D
- Design optimization
- Cost reduction

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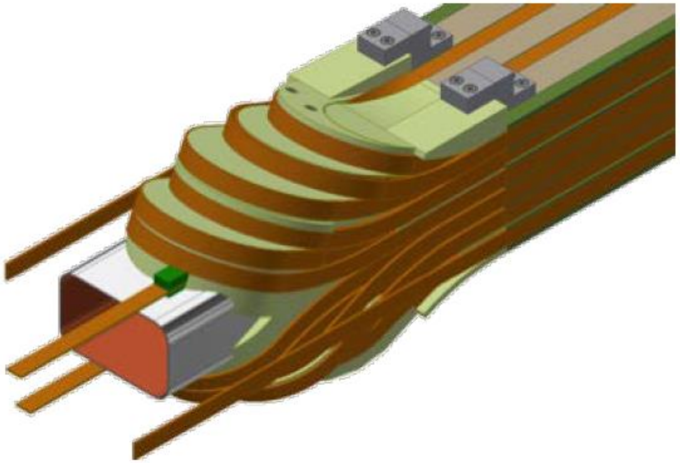
Slide from 2015 Dr. F. Pilat presentation

Motivation of project: MEIC Magnet R & D

- JLab is collaborating with Texas A&M for the design and prototyping of super-ferric magnets for the ion collider ring and for the booster
- Design and prototyping of high field, large aperture, compact super-conducting magnets for the collider Interaction Regions and Final Focus

- Texas A&M developed 2 approaches to winding cable for the super-ferric magnets:

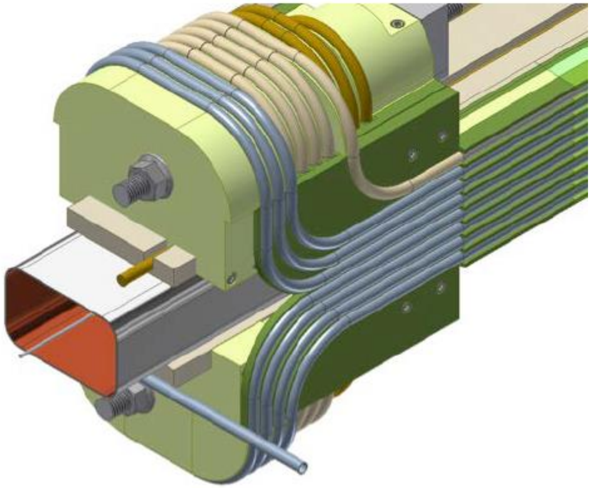
NbTi Rutherford cable



Pros: Uses mature cable technology (LHC).

Cons: Ends tricky to support axial forces.

NbTi Cable-in-Conduit

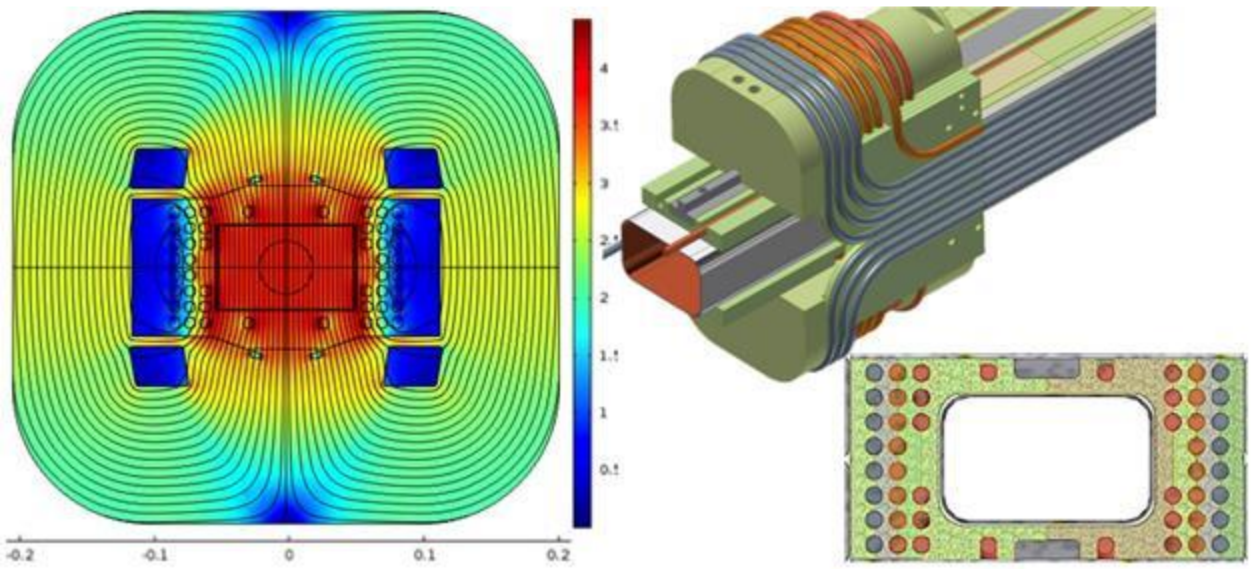


Pros: - Semi-rigid cable makes simpler end winding.
- Semi-rigid round cable can be precisely located.
- Cryogenics contained within cable.

Cons: Cable requires development and validation.

Cable-in-conduit technology

The ARL group has developed a design for a superferric dipole that utilizes a round NbTi cable-in-conduit (CIC) conductor. ARL has completed a Conceptual Design for the magnet and its conductor, and ARL has built a mockup winding to develop the fabrication tooling and methods.



3.5 T CIC-based design for the Ion Ring arc dipole: magnetic field design (*left*); winding design (*upper right*); cross-section of winding structure (*lower right*).

The CIC innovation has the enormous benefit that it eliminates the cryostats (the CIC cable is the cryostat), gives robust structure to the windings, and dramatically simplifies the interconnections for cryogenics.

Motivation behind current project

cabling wires onto perforated spring tube

cutaway showing foil over-wrap

Cross section showing NbTi strands

- Challenge: the cable must be pulled into a sheath tube, and the sheath tube must be drawn down onto the cable to compress the superconducting wires against the perforated spring tube core. ARL has made short segments (few meters).

- But each 4-m long MEIC arc dipole will require a ~400 m long continuous length of CIC conductor. What is needed is a method to continuously form a tube onto the cable and longitudinally weld the seam to make an arbitrarily long CIC segment.

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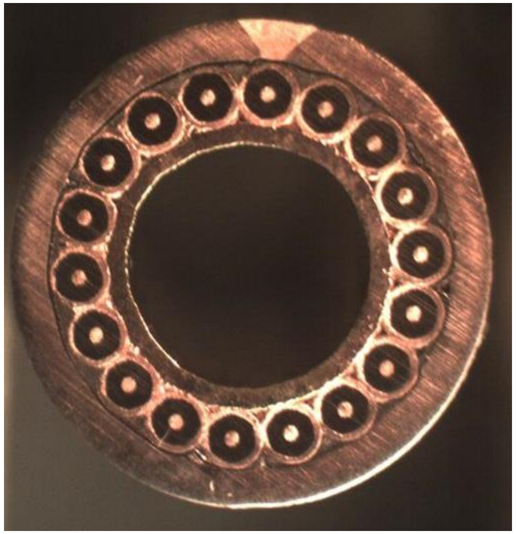
Laser-welded CIC-CTFF NbTi cables

- The feasibility of manufacturing long length CIC cables has been demonstrated under this STTR grant for small diameter NbTi CIC cables.
- CuNi outer sheath formed around cable and laser welded in tube form at Hyper Tech.
- Both TAMU and Hyper Tech have performed leak and bend tests on cables manufactured at Hyper Tech.



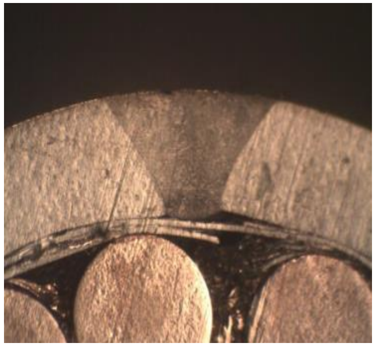
CIC-CTFF Cabling Steps

Perforated Inner Tube

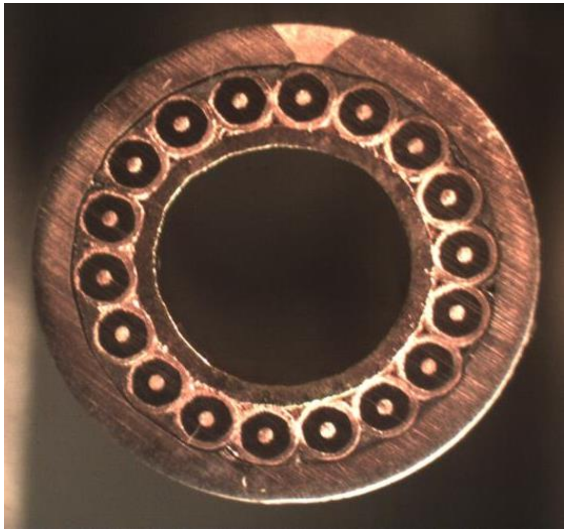
Stranding and Tape Wrapping

Pre-Cable

Continuous Tube Forming and Filling Machine



Laser Weld of Outer Sheath



Cross Section of Final NbTi Cable

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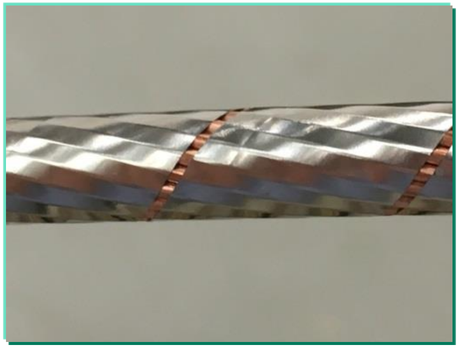
CIC-CTFF Cable Length Demonstrations

Demonstration of cable lengths for 3T magnet cable

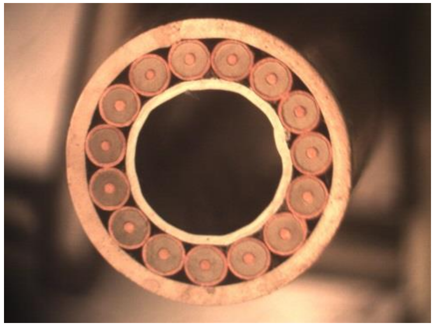
- 2 meter lengths of NbTi cable completed
- 10 meter lengths of NbTi cable being worked on
- 125 meter length of NbTi cable to be fabricated
- ATC winding coil using the 125 meter cable



Picture of Pre-Cable

Welded CIC-CTFF Cable

10 meter cable length



Cross Section

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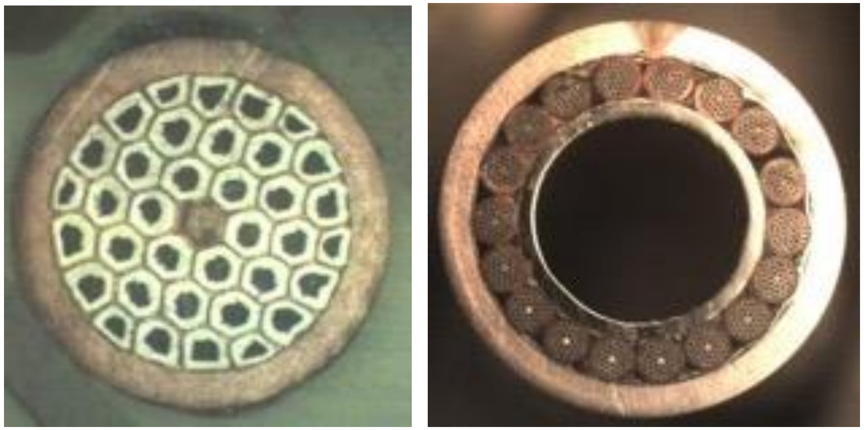
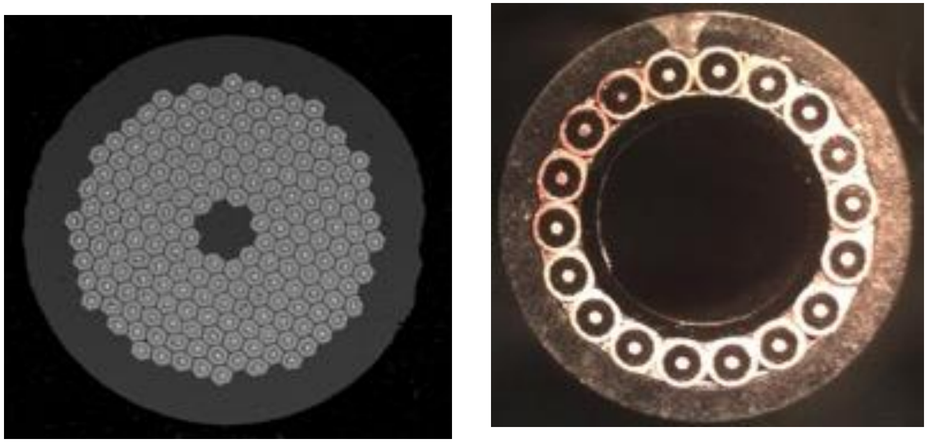
Cross Section of CIC-CTFF cables, MgB2 wires and Nb3Sn wires

Under a NP SBIR Phase I we demonstrated CIC-CTFF MgB2 and Nb3Sn cables, in future we intend to apply the cable approach to round (Re)BCO superconductors



MgB2 strand and CIC-CTFF Cable



Nb3Sn strand and CIC-CTFF Cable

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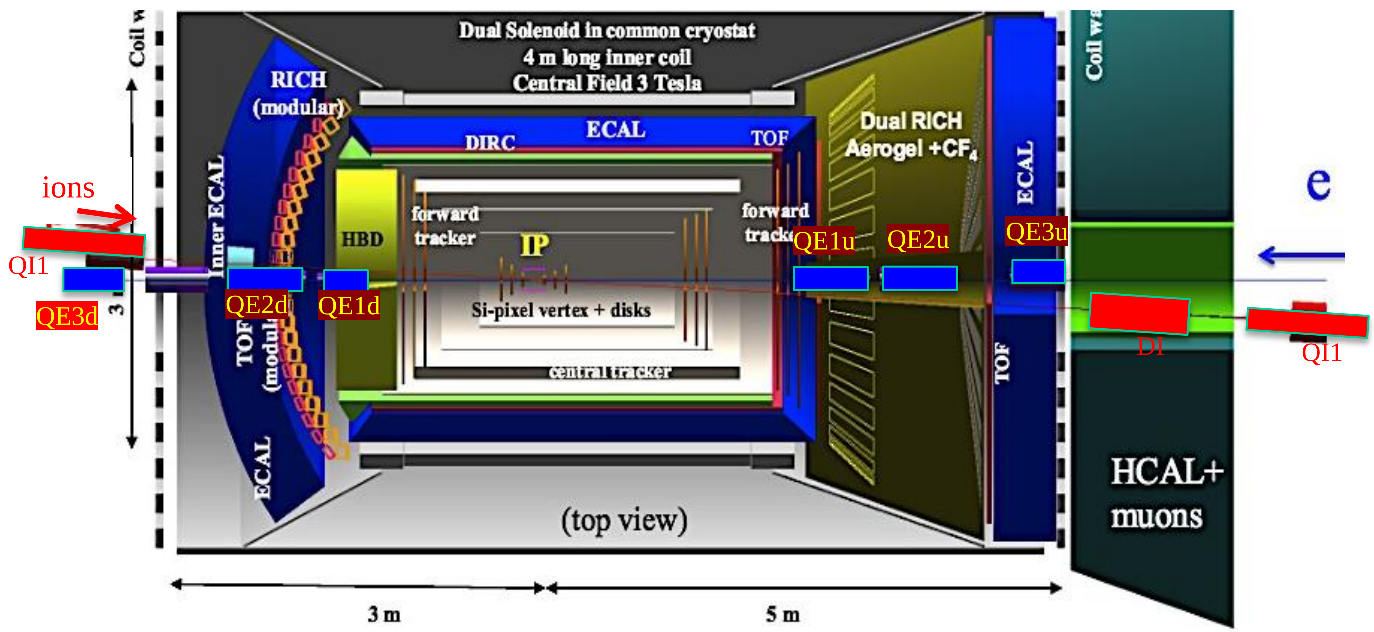
Coils designed using MgB_2 and Nb_3Sn

MAGNET					CABLE				
Magnetic field	90 T/m	2.3 T	60 T/m		Superconductor	Nb_3Sn	MgB_2	MgB_2	
turns/pole	120	84	20		d_{strand}	0.8	1	0.8	mm
operating current	9.0	4	1.0	kA	Non-SC/SC	1.5	10	10	
B_{max}	11.55	2.47	2	T	# strands	15	18	6	
J_{sc}	3000	2830	3200	A/mm^2	d_{CIC}	5.79	7.8	3	mm
stored energy	2.9	0.264	0.003	MJ/m	Dia of inner tube	1/8	3/16	0.0315	inch
operating temp	4.2	10	10	K	Dia of outer tube	1/4	3/8	1/8	inch
					Wall thickness	0.02	0.02	0.01	inch

- Quadrupole FF magnet QI1 requires Nb_3Sn.
- DI, QE1, QE2, and QE3 magnets require MgB_2.



MEIC IP1 central detector. The nine closest magnetic elements are shown.

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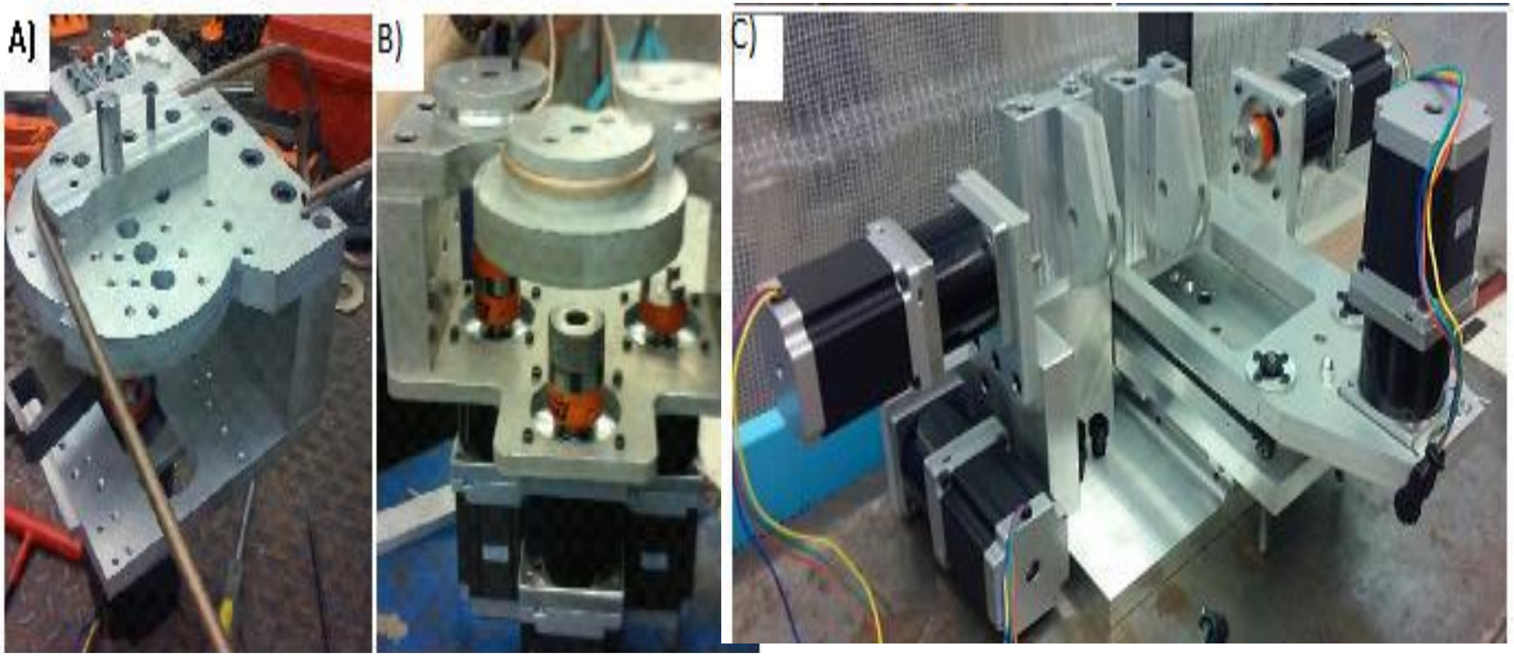
Bending Tools for Dipole Magnets



Motorized bending tools: a) bender to form 180° U-bend while maintaining round sheath; b) bender to form a dog-bone end for the sextupole winding turn; c) bender to flare the U-bend to form a 90° end winding.

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During our Phase II we will make coil using 125 meters of the CIC-CTFF cable

Mockup winding of coil at ATC- uses copper tubing as the simulated CIC cable.

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Eddy Current Device for Detecting Flaws in the Laser Welded Tube

Controller

Pick-Up Coil

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Test that has been performed on CIC-CTFF Cable

1.-Helium leak check the as fabricated cable.
2.-High pressurize test to 600 psi and helium leak check again.
3.-Dunk the cable in LN2 and helium leak check again.
4.-Bend samples 180° (+ 27° over-bend), one with weld facing the compaction side and the other the expansion side of the weld. Bend test were performed at an angular velocity of 150°/min. After bending, the samples are tested again for helium leaks.
5.-The bent cable is then tested at high pressurize to 600psi and then helium leak checked again.
6.-The bent cable is dunked in LN2 and then helium leaked check again.

CIC cable technology potential

Commercialization possibilities:

- Cables - NbTi, Nb_3Sn, MgB_2 , and YBCO for physics applications
- Low AC loss cables for SMES,
- Cables for 10-20MW wind turbine generators
- Cables for high speed motors and generators for passenger aircraft

Advantages

- Thermal: internal cooling
- Mechanical: robust outer sheath and cable design
- Multiple number of strand conductors in the cable

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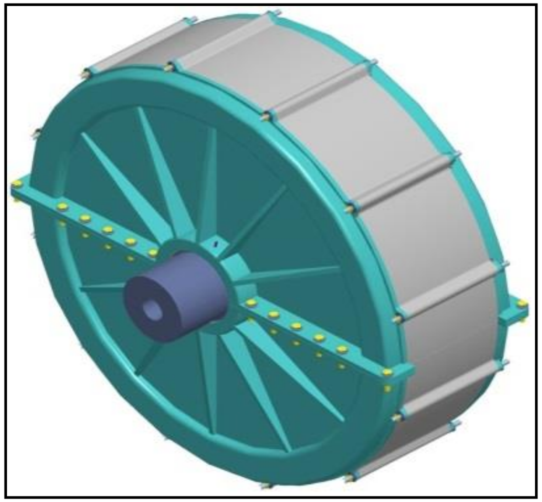
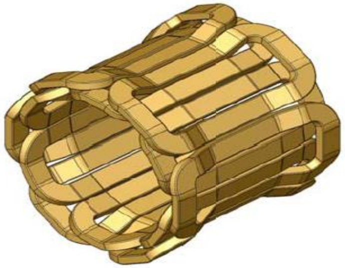
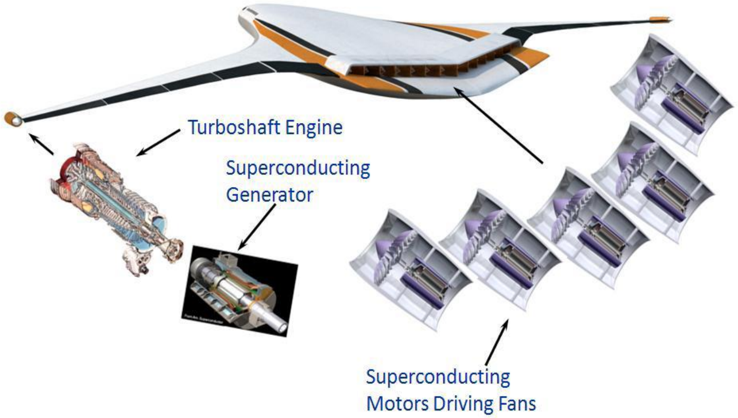
Motors and generators



Advantages of MgB_2:

- Reduction of size and weight of machine
- No joints in rotor pole (long length conductor)
- Faster normal zone propagation
- Meets current density requirements (< 4T)
- Made round to be easier to configure into complex coil geometries
- Significant reduction of cost
- Persistent coils





Concepts and projects using MgB_2:

- Hyper Tech has designed a modular 5 MW land based direct drive wind turbine generator that is transportable, sponsored by DOE
- All cryogenic 10 MW Superconducting wind turbine rotor and stator, S. Kalsi (2014 *IEEE Transactions of Applied Superconductivity* **24**)
- NASA 1-2 MW high speed motor demonstrator
- Studies in being conducted in Europe-electric aircraft

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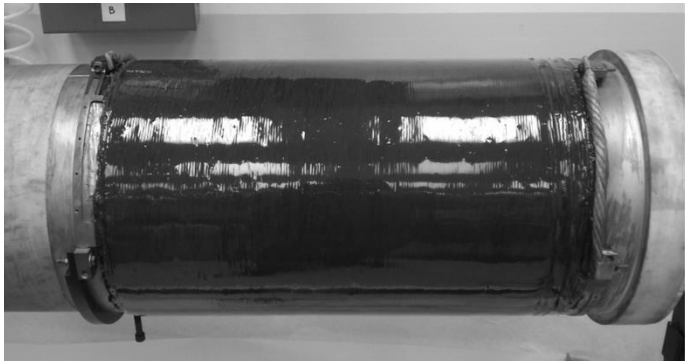
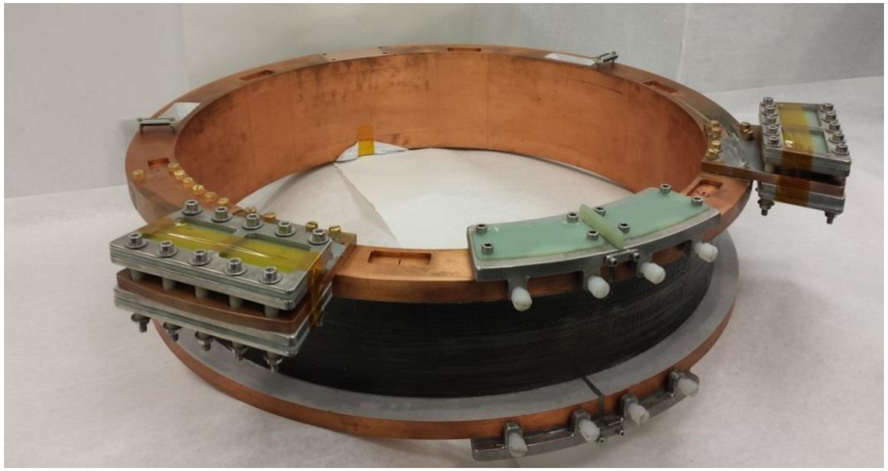
MgB_2 Fault Current Limiter

Coil for resistive SFCL



Coil for inductive SFCL



Conduction cooled cryostat at Ohio State University for testing both inductive and resistive SFCL coils

Advantages of MgB_2:

- **Low cost wire, much lower than HTS**
- **Can vary thermal conductivity by wide choice of resistive & conductive materials**
- **Is in a wire form that can be wound bi-filar and can be twisted and/or braided to reduce AC loss**
- **Is readily available in quantity and lengths**
- **Wire can be sized to designed current level**

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---- thank you for your attention