Development of MgB_2 Superconducting Coils for Nuclear Physics Applications

DOE-NP SBIR/STTR Exchange Meeting
6-7 August 2014
Hilton Washington, DC North, Gaithersburg, Maryland

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Hyper Tech

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42,000 sq ft facility

And of course, our grant sponsor: DOE NP

Grant #DE-SC0007505

Outline

- ⌘ Motivation of SBIR project
- ⌘ Background on MgB_2 superconductors
  - Conductor properties
  - Applications
- ⌘ Phase II efforts
  - SBIR Phase II Objectives
  - 1st MgB_2 solenoid coil
  - Next steps

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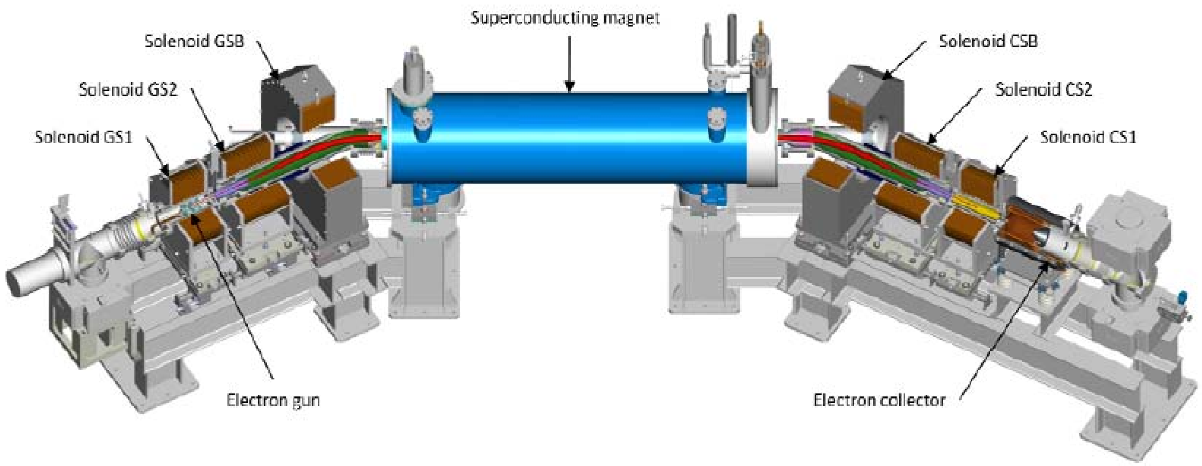
Motivation of project (1)

- An e-lens system is currently under construction at BNL to increase RHIC luminosity .
- It consists of room temperature copper and superconducting solenoids
- The optimization of the system is limited by the power consumption of the room temperature solenoids (currently limited to ½ MW).
- The proposed MgB_2 magnets can significantly increase the field to significantly improve the design and performance of the e-lens system while consuming little power.



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Motivation of project (2)

- A RHIC luminosity upgrade was endorsed by Nuclear Science Advisory Committee (NSCA) in its report published in 2007. The e-lens project has a goal to increase luminosity and reduce loss of the circulating proton beam in RHIC with head-on beam-beam compensation
- The size (σ of Gaussian distribution) of the beams in the interaction region should be adjustable within range of at least (0.28 - 1.0) mm.
- An electron beam with current around 1.0 A and energy 5-10 keV will be injected in the interaction region using dipole components of tilted solenoids. The electron beam is fully confined by the axial magnetic field from the cathode of the electron gun to the entrance into the electron collector.
- To get an electron beam with σ=0.8 mm in the interaction region one needs to have the ratio of magnetic fields in the interaction region to the cathode of 2.52. The field in the interaction region should be as high as possible to provide “rigidity” of the beam. The available power allows us to have maximum magnetic field on the cathode of 8 kG, which leaves us with approximately 2 T field in the interaction region, which is barely sufficient.

Motivation of project (3)

- The available electrical and cooling power of 500 kW at the location of these e-lenses is barely enough for operation of the e-lenses in the “nominal” regime with maximum magnetic field on a cathode of the electron gun 8 kG.
- Extending the range of the electron beam radius and “rigidity” of the central magnetic field would require operating in a “maximum” regime with total power in excess of 1 MW.
- Extending the power capability to this range would take substantial capital investment and time.

	Parameter	Gun coil (GS1)	Gun-transition coil (GS2)	Gun bending coil (GSB)	X-Dipole coil (GSX)	Y-Dipole coil (GSY)
Conductor	h_cond (mm)	14.0	14.0	14.0	6.35	6.35
	ID_water (mm)	9.0	9.0	9.0	4.75	4.75
	B_insul (mm)	0.3	0.3	0.3	0.65	0.65
Dimensions	ID (mm)	173.48	234.0	480.0	178.0	193.0
	OD (mm)	553.08	526.0	859.6	192.0	207.0
	Length (mm)	262.8	379.6	262.8	580.0	580.0
	N_layers	13	10	13	12	12
	N_pancakes	9	13	9		
Nominal regime						
M - field	B (Gauss)	8000.0	4468.0	3202.0	160.0 (5mm)	160.0 (5mm)
Power	P (watt)	58.0	25.6	45.0	1.2	1.5
Current	I (A)	1188.0	731.0	769.0	239.0	258.0
Total power consumed by all magnets in 2 E-lenses (kwatt)						525.2
Maximum regime (nominal+40%)						
M - field	B (Gauss)	11200.0	6256.0	4482.0		
Power	P (watt)	114.0	50.0	88	2.4	3.0
Current	I (A)	1663.0	1023.0	1077.0	334.0	361
Total power consumed by all magnets in 2 E-lenses (kwatt)						1029.6

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Motivation of project (4)

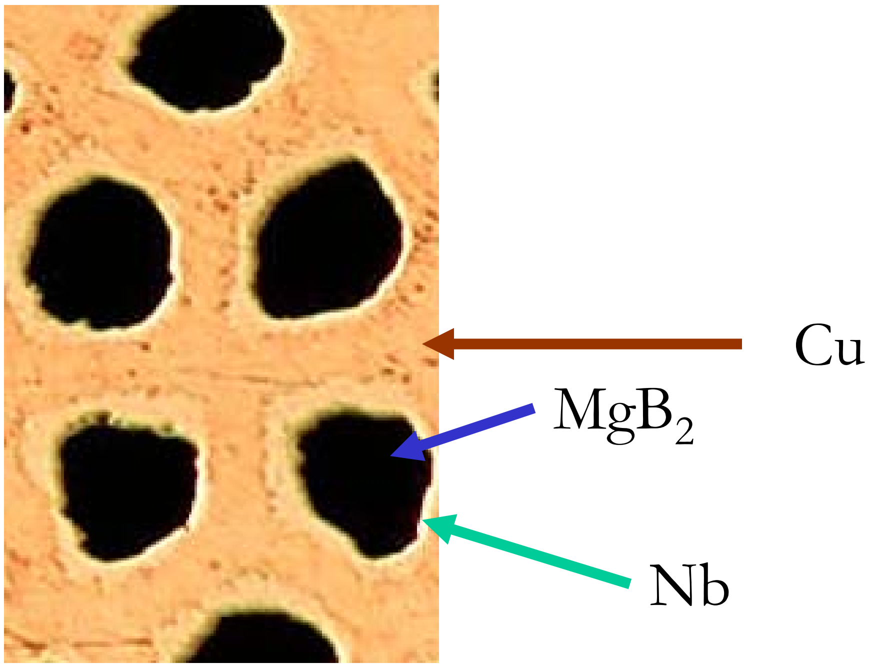
- Solenoids powered with copper coils provide the simplest and most inexpensive way to obtain axial magnetic fields.
- One option is to use solenoids with coils made with superconductors operating at ~4 K.
- Depending of field, capital cost of NbTi or Nb_3Sn magnets > Cu magnets.
- MgB_2 solenoids cooled by return (exhaust) helium gas of LTS solenoids without the need of adding new cryogenic facilities.

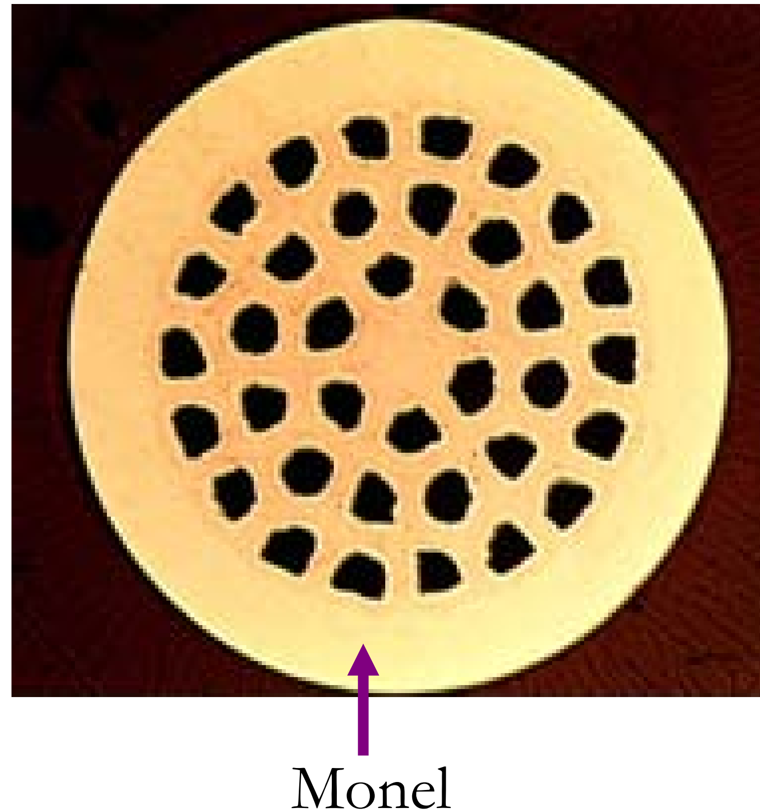
- **Therefore 10-25K MgB_2 solenoids can potentially allow the full optimization of e-lens system currently limited by the availability of power to energize copper solenoids**

- Also, with MgB_2 magnets BNL could realize savings in operating costs (electricity), and minimize the capital costs from upgrading infrastructure (transformers, switch gear, breakers, etc.).

Background on MgB_2 superconductors

- Superconductivity in MgB_2 was publicly announced in January 2001 by Japanese scientists





Lengths currently up to 5 km @ 0.8 mm, scaling up to over 60 km.

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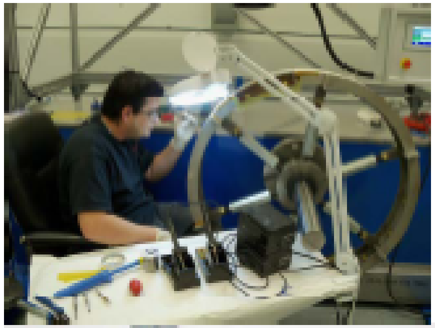
Manufacturing capabilities

Newly Added Process Equipment for "Wind and React" and "React and Wind" coils:

- Welded seam CTFF process for mono- and multi-filament wire (one shift 10,000 km/yr capacity)
- Large capacity twisting
- Wire-in-channel soldering
- Insulation braiding
- 1m+ coil winding capacity designed for strain-sensitive wire
- 6 km lengths (currently)
- Equipment in place for 60+km lengths
- Large conduction cooled coil testing available



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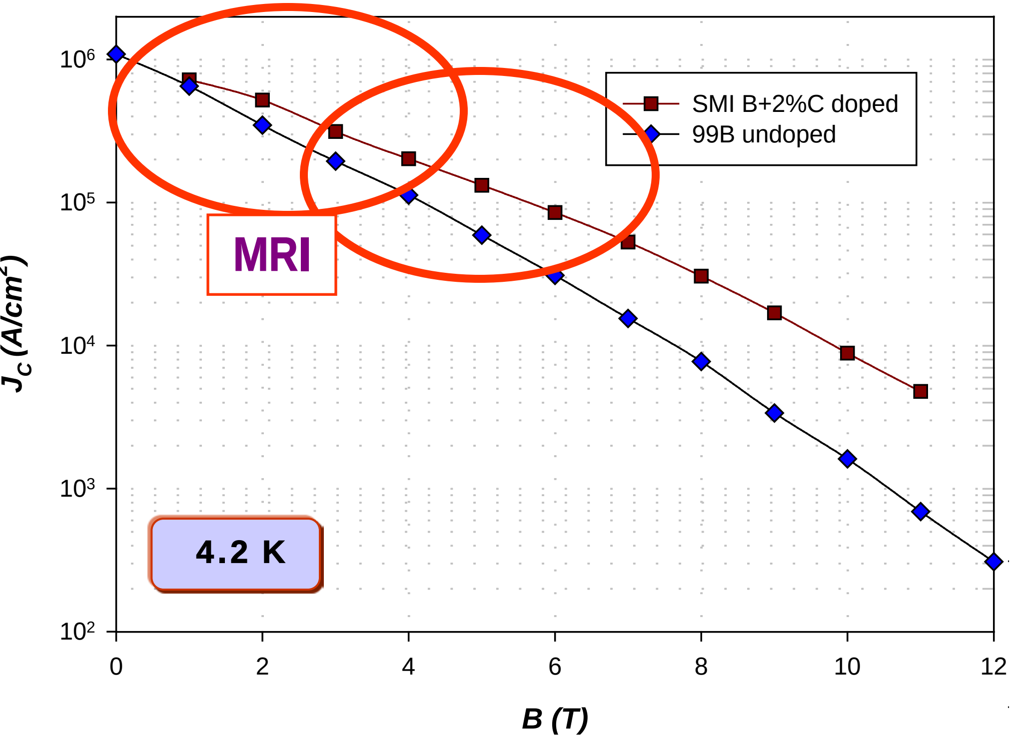
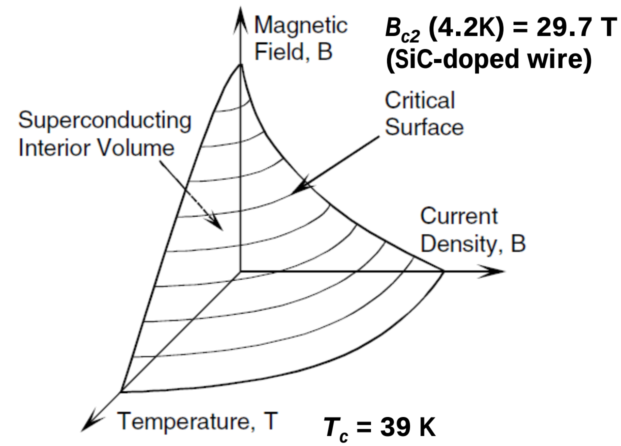
MgB_2 strand recipe: critical current



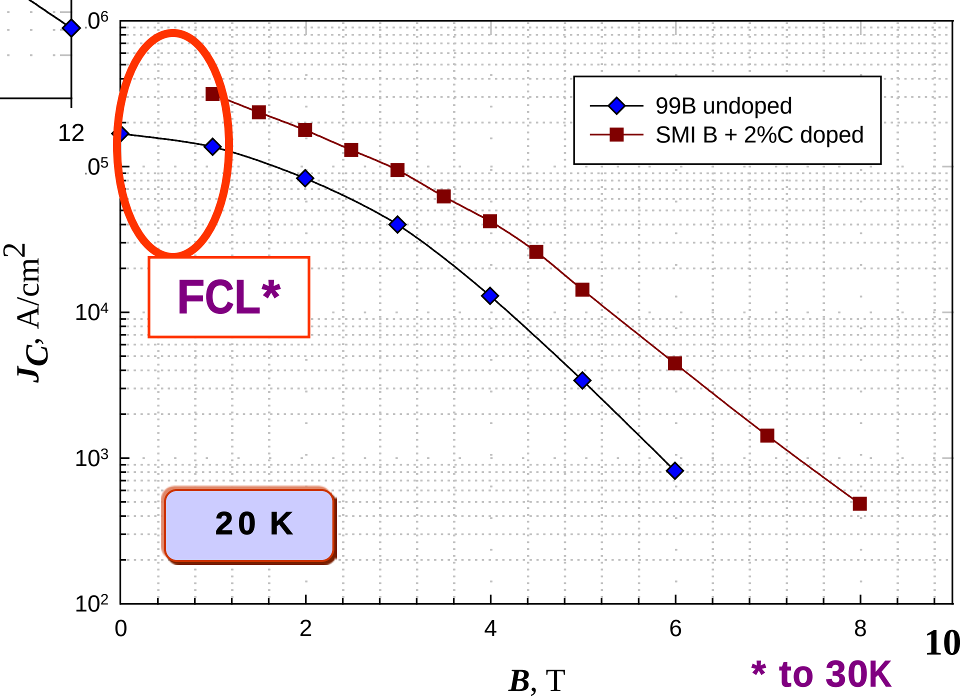
Commercial magnet pull: MRI & FCL



C-doped MgB_2
I_c based on 15% f.f.

4 K, 4 T:
J_c = 200,000 A/cm²
I_c = 245 A (0.83 mm)

20 K, 1 T:
J_c = 300,000 A/cm²
I_c = 350 A (1 mm)



* to 30K

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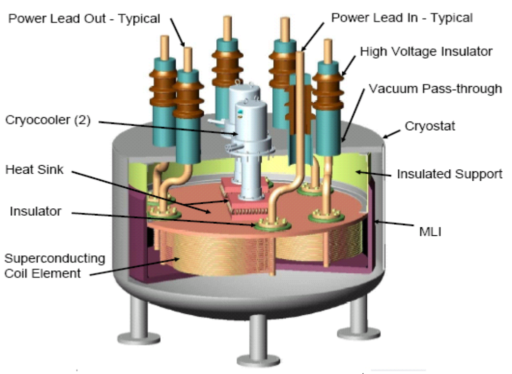
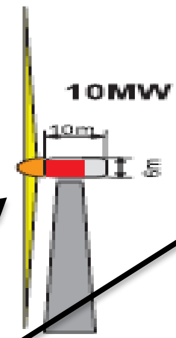
MgB_2 superconductor applications

Superconducting Fault Current Limiter



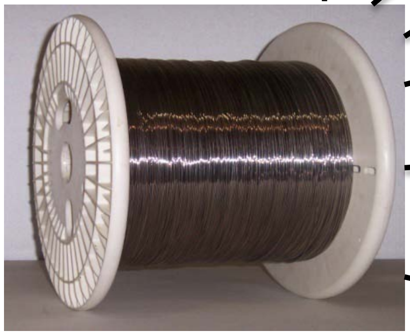
5-20MW wind turbine



1.5 & 3.0 T MRI

Specialty MRI

MgB_2 Superconducting Wire



Custom MgB_2 MRI magnet

CERN

Cable links

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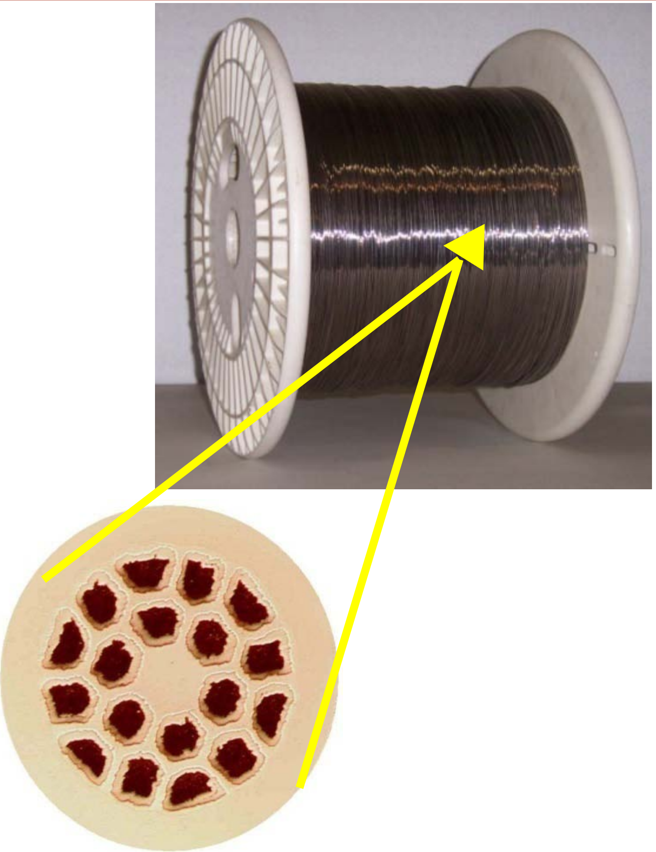
MRI applications



Hyper Tech Magnesium Diboride superconductors enables liquid helium free magnets.

MRI manufacturers' have stated MgB_2 wire is the only option in the time frame that is needed to convert to non-helium bath cooling.

$50 million industry effort to convert to MgB_2.

We are currently working with 5 MRI manufacturers.

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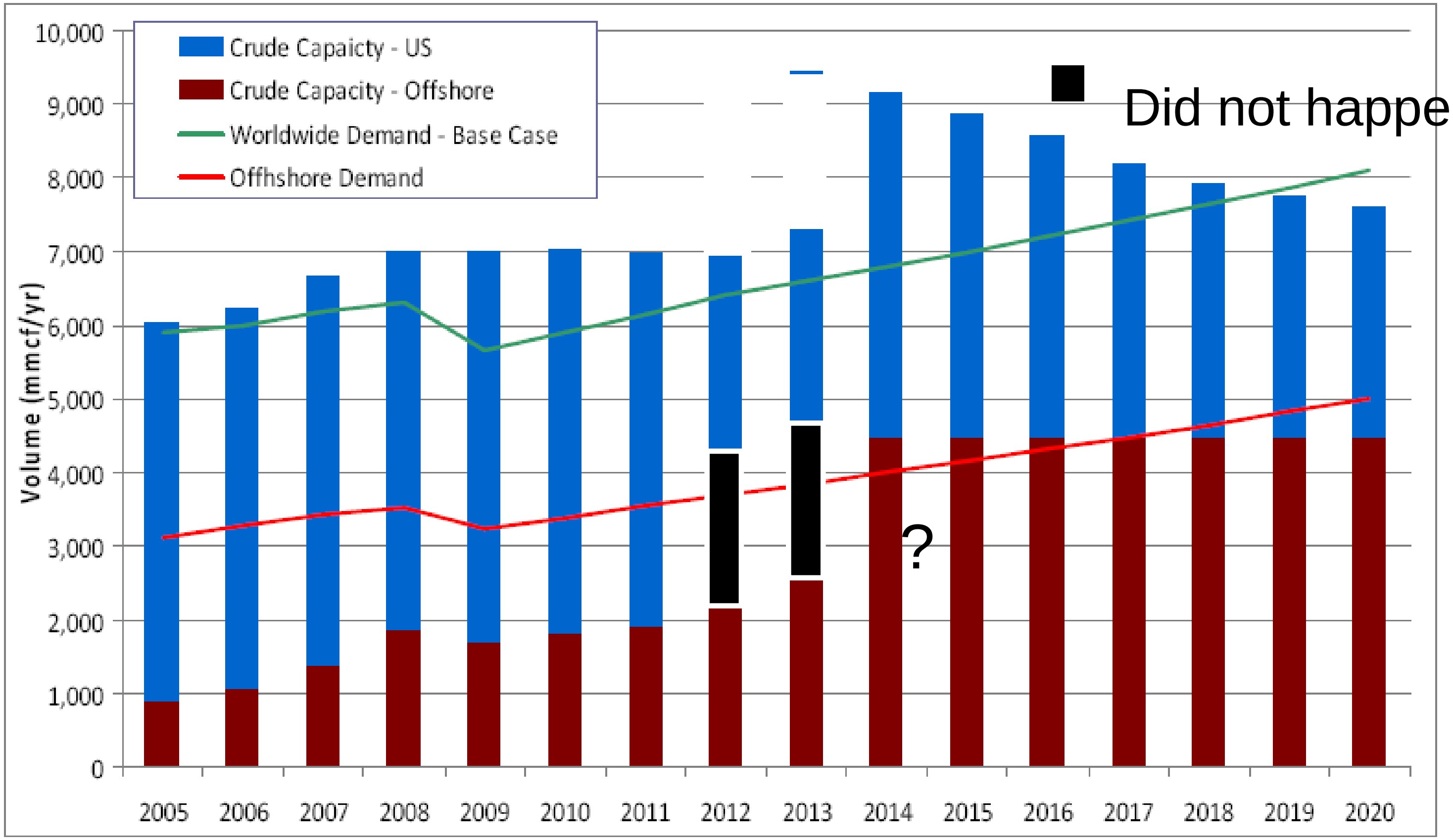
Availability of helium



Actual (2005 to 2008) and estimated (2009 to 2020) demand and capacity for crude helium in the United States and in other countries.

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Advantages of MgB_2 to MRI Manufacturers

Statement by MRI manufacturer: "We will commercialize regardless of liquid helium price increases" because:

Safety:

- Immune from helium vessel ruptures.
- Magnet requires no special measures to prevent helium from entering examination room.

Cost (lower cost MRI magnet system):

- Lower manufacturing cost due to fewer components.
- Reduced site cost: no quench infrastructure.
- No liquid helium replenishment on installation or in service if magnet quenches.
- No air shipping of magnets filled with liquid helium.

Scale-up in wire production will drive cost down. This will benefit niche applications with smaller wire volumes.

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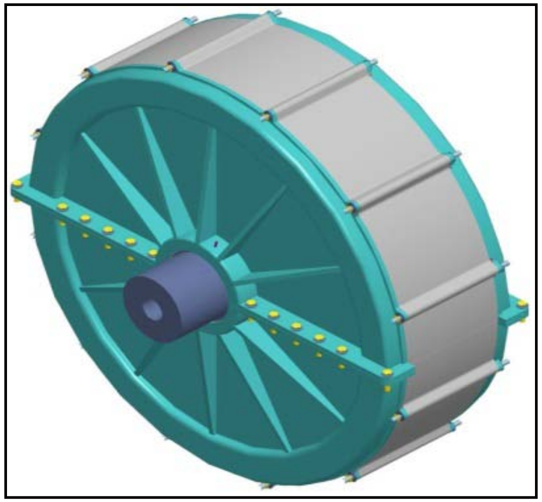
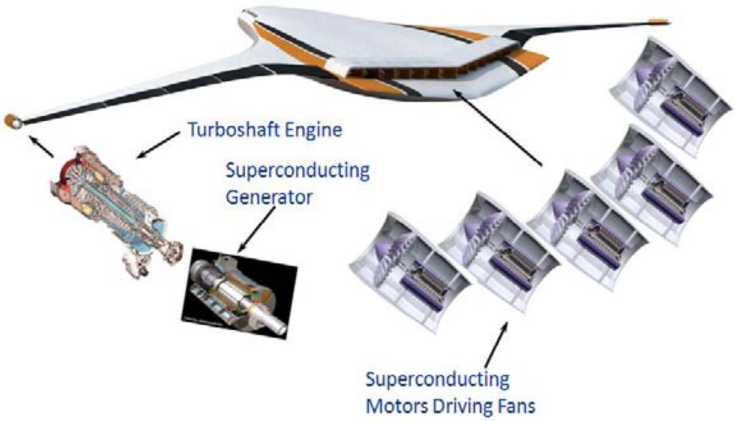
Motors and generators





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Advantages of MgB_2:

- Reduction of size and weight of machine
- Significant reduction of cost
- 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
- Persistent coils

Emerging power systems:

- Wind turbine generators (8-10 MW)
- Aircraft turbo-generators (8-10 MW)
- Offshore oil platform motors (5-10 MW)
- Marine propulsion and generation systems (4-20 MW)
- Portable emergency power systems (4–8 MW)

MgB_2 Fault Current Limiter

Advantages of MgB_2 for Fault Current Limiters

- **Low cost wire, especially as compared to ceramic superconductors**
- **Can vary the thermal conductivity by wide choice of resistive and conductive matrix materials**
- **Is in a wire form that can be wound bi-filar and can be twisted and/or braided to reduce AC loss**
- **“looks” like conventional wire [to the utility]**
- **Manufacturability (reliable, homogeneous and repeatable properties)**
- **Low equipment costs to scale wire manufacturing to large scale commercial production**
- **Is readily available in quantity and lengths required to support SFCLs**
- **Wire can be sized to designed current level**

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SBIR Phase II objectives

- **Demonstrate [MgB_2]technology to the National Laboratories**

- BNL will model and design larger appropriate MgB_2 coils for Nuclear Physics needs
- Hyper Tech will conduct R&D to develop the fabrication techniques for these MgB_2 coils
- Hyper Tech will build several MgB_2 coils
- BNL will incorporate these coils into their test cryostat
- BNL will carry out extensive life cycle testing of the MgB_2 coils over a large number of power, quench and thermal cycles and finally perform field quality measurements and other rigorous evaluation to confirm that coil performance and reliability is appropriate for this Nuclear Physics and other future accelerator facilities.

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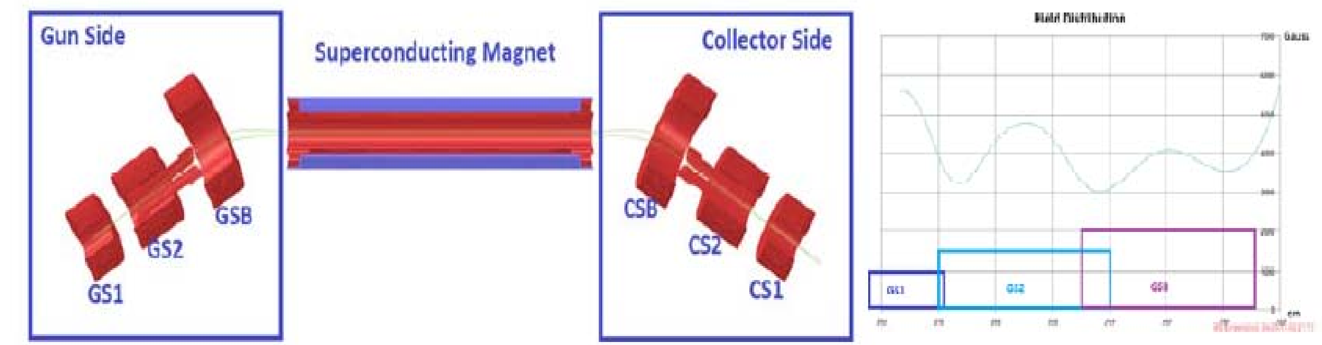
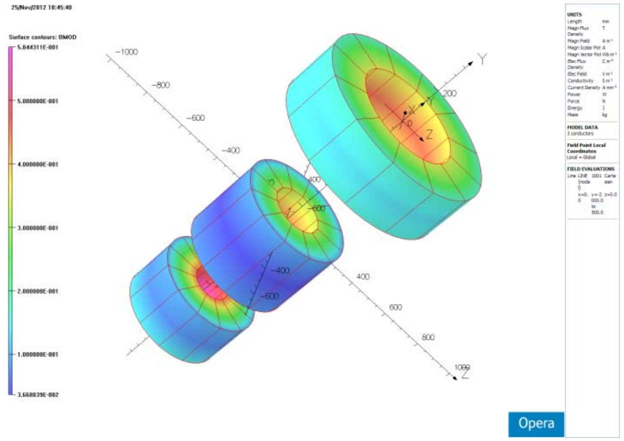
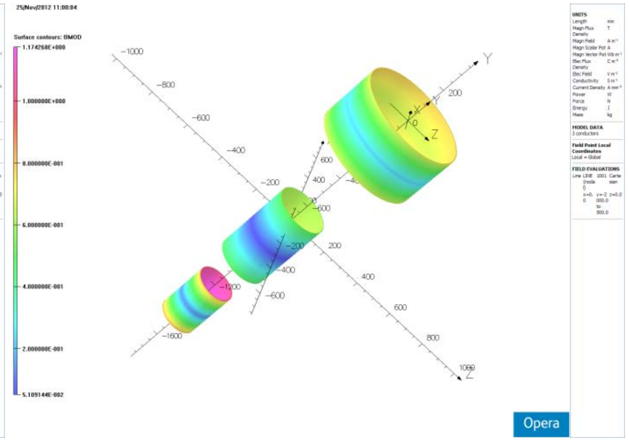
Modeling for MgB_2 solenoids (1)



Magnetic model of the basic e-lens system showing copper solenoids and a dipole coil on either side of the superconducting solenoid (right) and magnetic field in Gauss along the central trajectory (right)





Field in Tesla superimposed on the Cu coils on left and MgB_2 coils on right.

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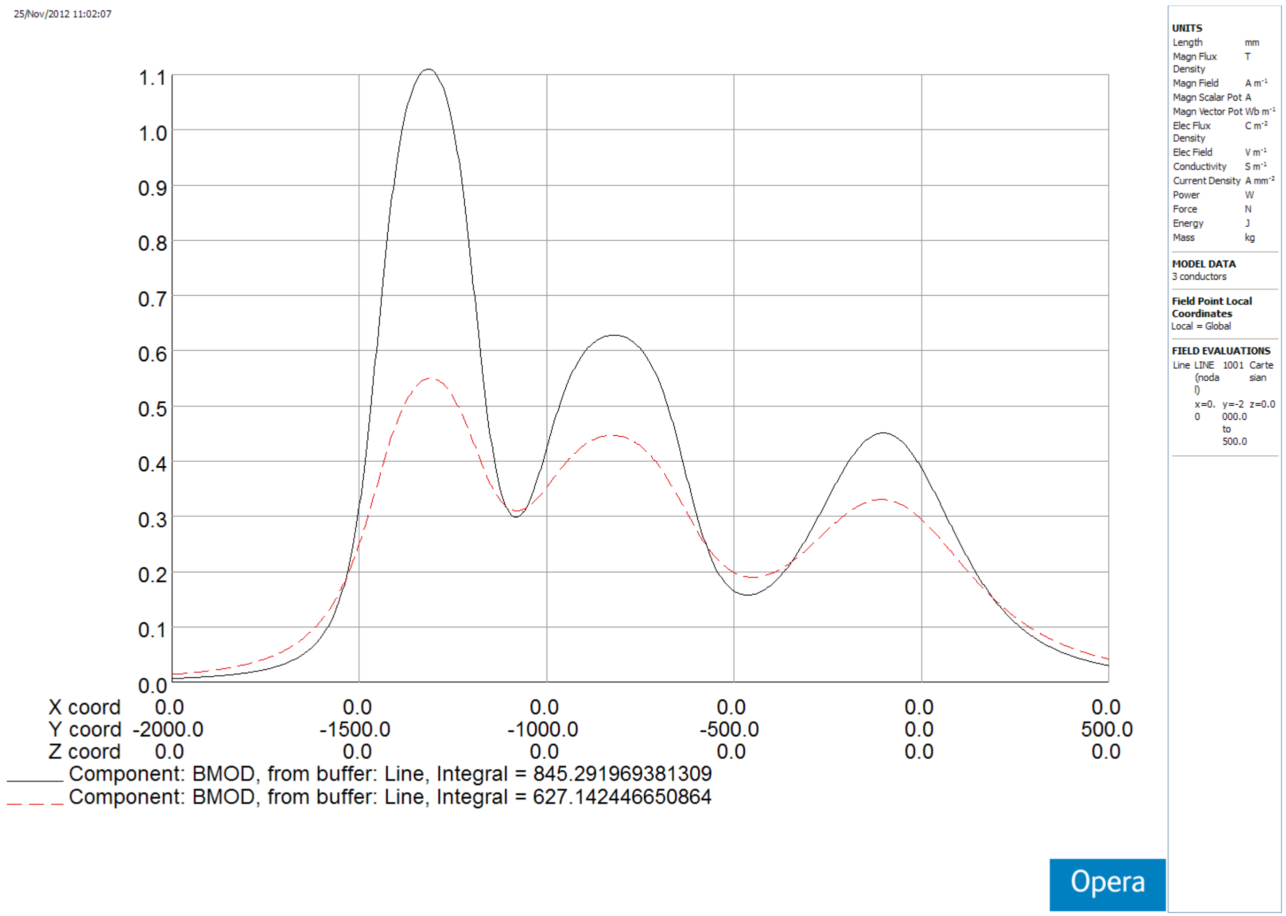
Modeling for MgB_2 solenoids (2)



Field in Tesla on the axis created by MgB_2 coils (solid black) and copper coils (dash red) in RHIC e-lens system.

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Coil #1 (based on GS1)

"Ball-park" parameters of MgB_2 for GS1 coil producing 1 T

GS1 Starting Parameters		
Amp.turns	260000	260000
Amp	200	100
turns	1300	2600
IR(m)	0.088	0.088
Radial Spacing (mm), approx	1	1
Axial spacing (mm), approx	1	1
Joverall (A/mm^2)	200	100
Length of the Solenoid (m)	0.263	0.263
Number of Layers	5	10
Number of turns/layer	260	260
OR (m)	0.091	0.093
Average radius	0.089	0.091
Average circumference (m)	0.560	0.568
Conductor Length(m)	729	1478
Approximate Cost/m($)?	10	10
Approximate Total cost ($)	7286	14777

Actual parameters of MgB_2 solenoid

- **B_0 = 0.7 T (20 K)**
- **86 A**
- **J_e = 170 A/mm^2 (20 K)**
- **IR = 0.0876 m**
- **Length of solenoid = 0.263 m**
- **2180 turns**
- **8 layers**
- **272.5 turns/layer**
- **Conductor length = 1229 m**

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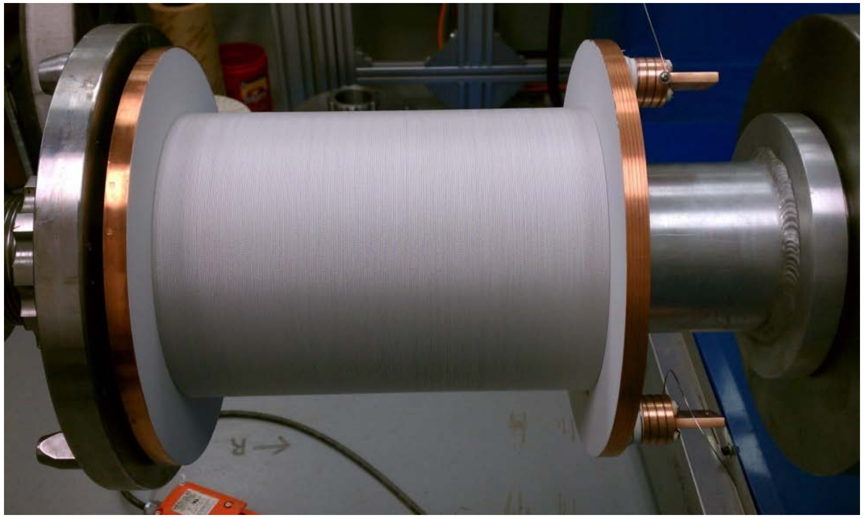
Coil #1 fabrication



On winding machine

After epoxy impregnation

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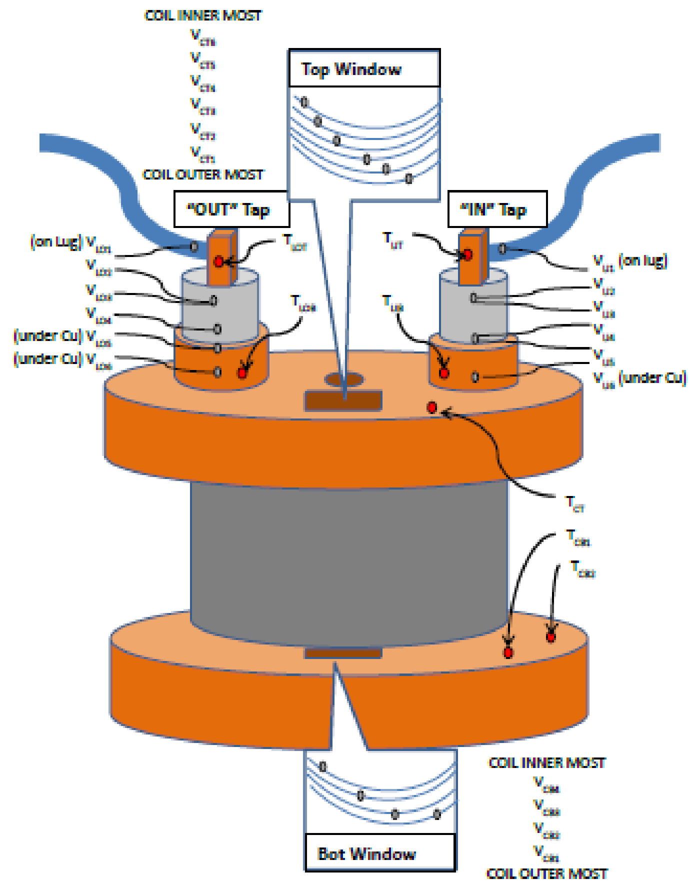
Coil #1 – characterization at OSU

Coil dewar internal assembly

Coil instrumentation schematic



Next steps

- **Life time cycle tests will be performed on the G1 MgB_2 coil at BNL:**
  - Power up and down cycle to 90% of the short sample
  - Thermal cycles
  - Over-current cycle hitting quench detection threshold. It is important to learn that the model coils developed in the Phase II are robust enough to handle quenches non-destructively.
  - Quench propagation and other related studies

- **2nd coil based on GS coil**
  - React and wind technology *vs*. W & R
  - Conduction cooled

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---- thank you for your attention