Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

New Magnet Designs and R&D Programs (HEP/NP/FES/ARPA-E/SBIR, ...)

Ramesh Gupta

@BrookhavenLab

October 18, 2024

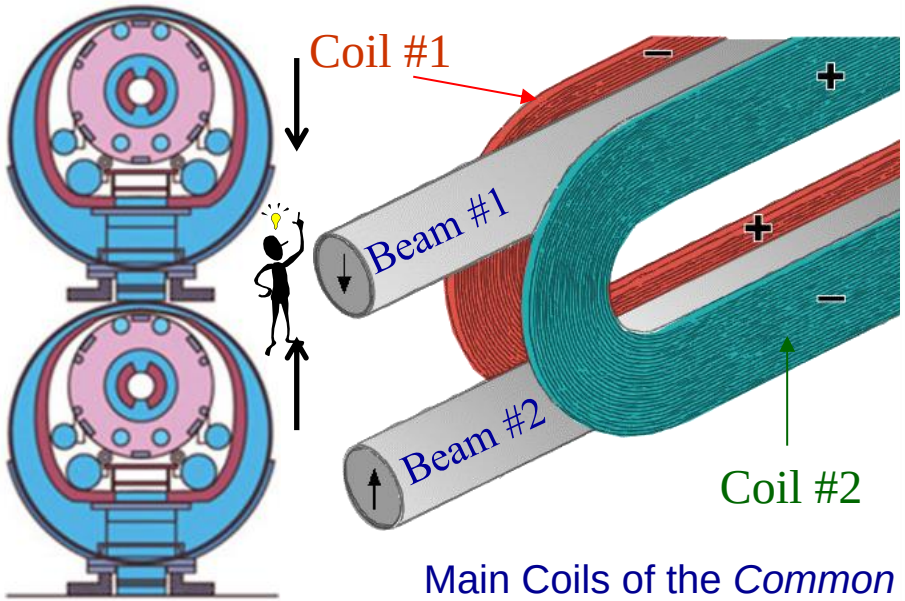
Overview

- In addition to designing and building reliable superconducting magnets, BNL Magnet Division has invented and/or initiated many designs and technologies. They are making a significant impact around the word now, and/or are poised to in future.
- These innovations are well recognized outside the laboratory; many resulted in record performances, and many have brought new fundings and that too from a variety of sources.
- Highlight of some of those programs and vision are presented here. Please visit https://wpw.bnl.gov/rgupta/ for more.

Common Coil Design and R&D Efforts

https://wpw.bnl.gov/rgupta/common-coil-design/

A BNL invention that is shaping the HEP hadron collider design



Main Coils of the *Common Coil Design (simple ends)*

Conventional design with complex ends

Very Large Hadron Collider

SLAC-R-591
Fermilab-TM-2149
June 4, 2001

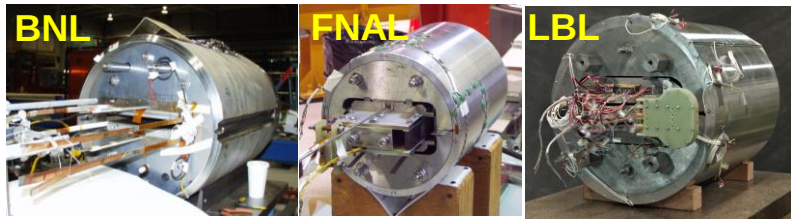
Design Study for a Staged Very Large Hadron Collider

Report by the collaborators of
The VLHC Design Study Group:
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Laboratory of Nuclear Studies, Cornell University
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
Stanford University, Stanford, CA, 94309

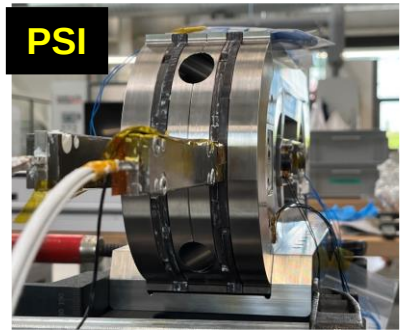
Used in US vlhc (2001) proposal

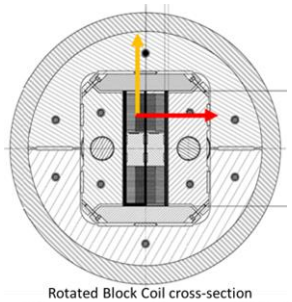
Work supported in part by the Department of Energy contract DE-AC03-76SF00515.

US R&D Programs



European R&D Programs





Concept of the 20T Dipole Magnet for SPPC

Q. Xu et al. — With common coil configuration — Reminder

20-T dipole magnet with common coil configuration
two Φ50 mm beam pipes; load line 80% @ 1.9 K

IHEP

a. Nb_3Sn outer coil
b. Nb_3Sn inner coil
c. HTS outer coil
d. HTS innerb coil

Main parameters of the magnet

Number of apertures	2
Aperture diameter (mm)	50
Inter-aperture spacing (mm)	333
Operating current (A)	14700
Operating temperature (K)	4.2
Operating field (T)	20
Peak field (T)	20.4
Margin along the load line (%)	11
Stored magnetic energy (MJ/m)	7.8
Inductance (mH/m)	72.1
Yoke ID (mm)	260
Yoke OD (mm)	800
Weight per unit length (kg/m)	3200
Energy density (coil volume) (MJ/m^3)	738
Force per aperture – X / Y (MN/m)	23.5/4.4
Peak stress in coil (MPa)	240
Fringe Field @ r = 750 mm (T)	0.02

Integrated field quality

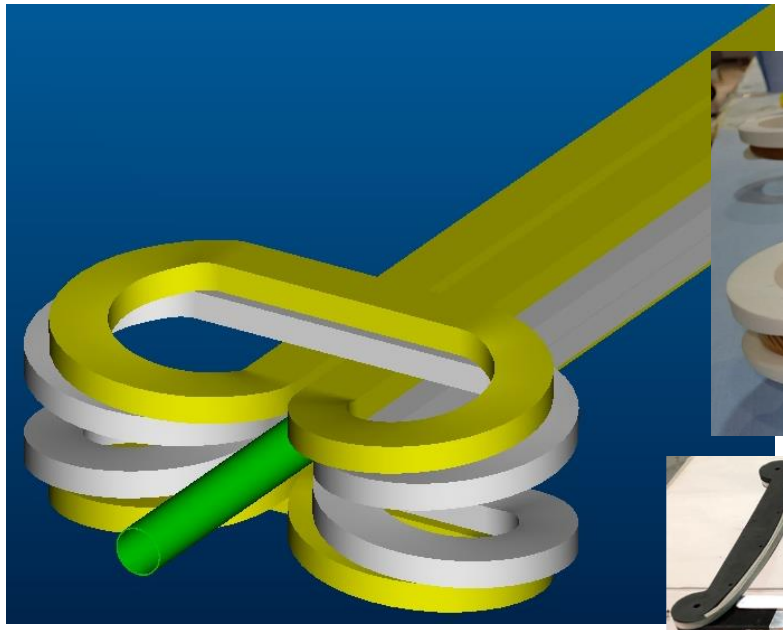
Integrated b_n & a_n	Value (10^{-4})
b3	0.14
b5	1.42
b7	-0.40
a2	-0.29
a4	-1.81
a6	0.03

Magnet with Common Coil Configuration: Main Characteristics and Challenges, IEEE Trans. Appl. Supercond., VOL. 26, NO. 4, 2016, 4000404

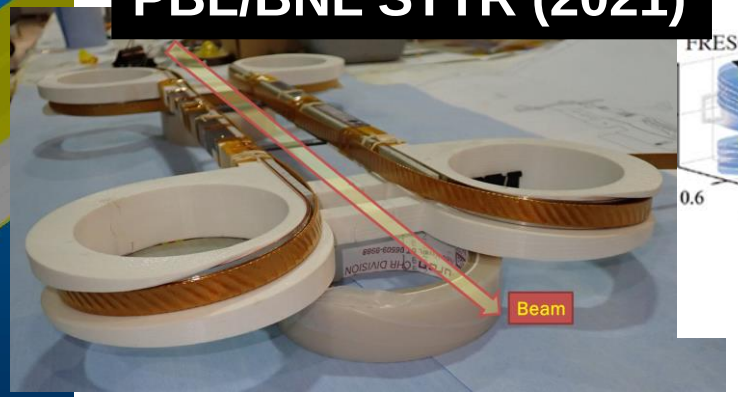
We will continue to provide limited support to international collaboration via MDP

OverPass/UnderPass Design for Single Aperture Magnet

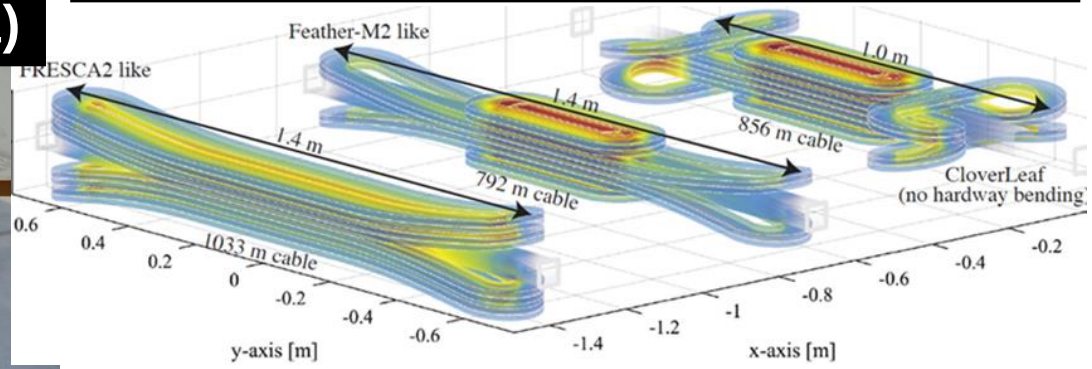
https://wpw.bnl.gov/rgupta/overpass-underpass/



PBL/BNL STTR (2021)



Collaboration with CERN (MDP)



(aka: Clover-leaf design)

Highway Driving

- **No lifting of conductor in hard way bend**
- **Lower strain**
- **Shorter length of end**

Conductor friendly design for high field conductors

Both BNL (SBIR) and CERN built and tested HTS coils based on this design

This could become part of muon collider magnet R&D

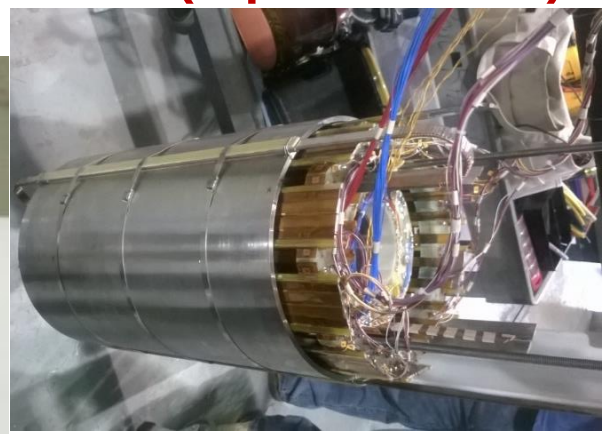
HTS Solenoid Program for Several Applications

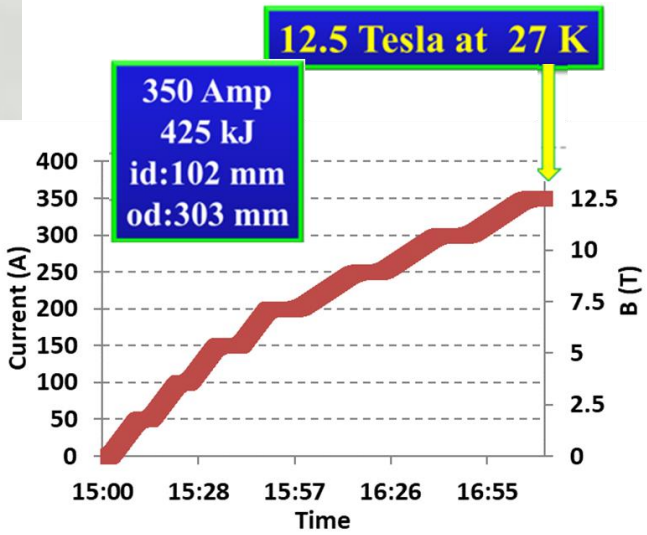
https://wpw.bnl.gov/rgupta/hts-magnet-program/

For muon collider (via SBIR with PBL)

➢ **Record field (2012): ~16 T (original target: 10-12T)**

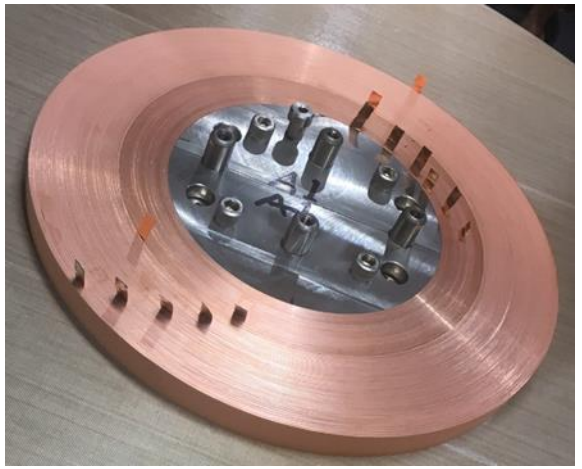
SMES (arpa-e funded)



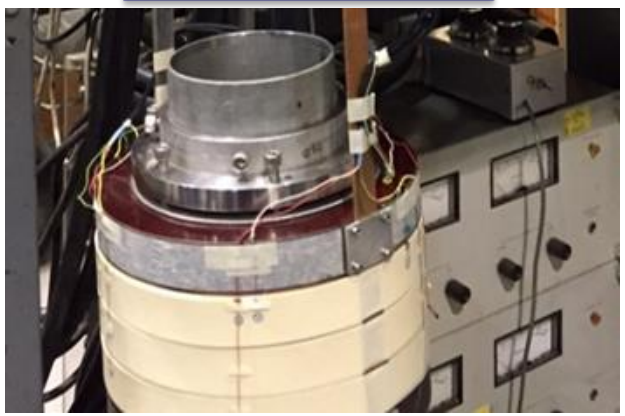


Record field/energy at 10 K or higher *(referenced in fusion proposals)*

Two grants from IBS Korea (initially funded for ~4.5M$)



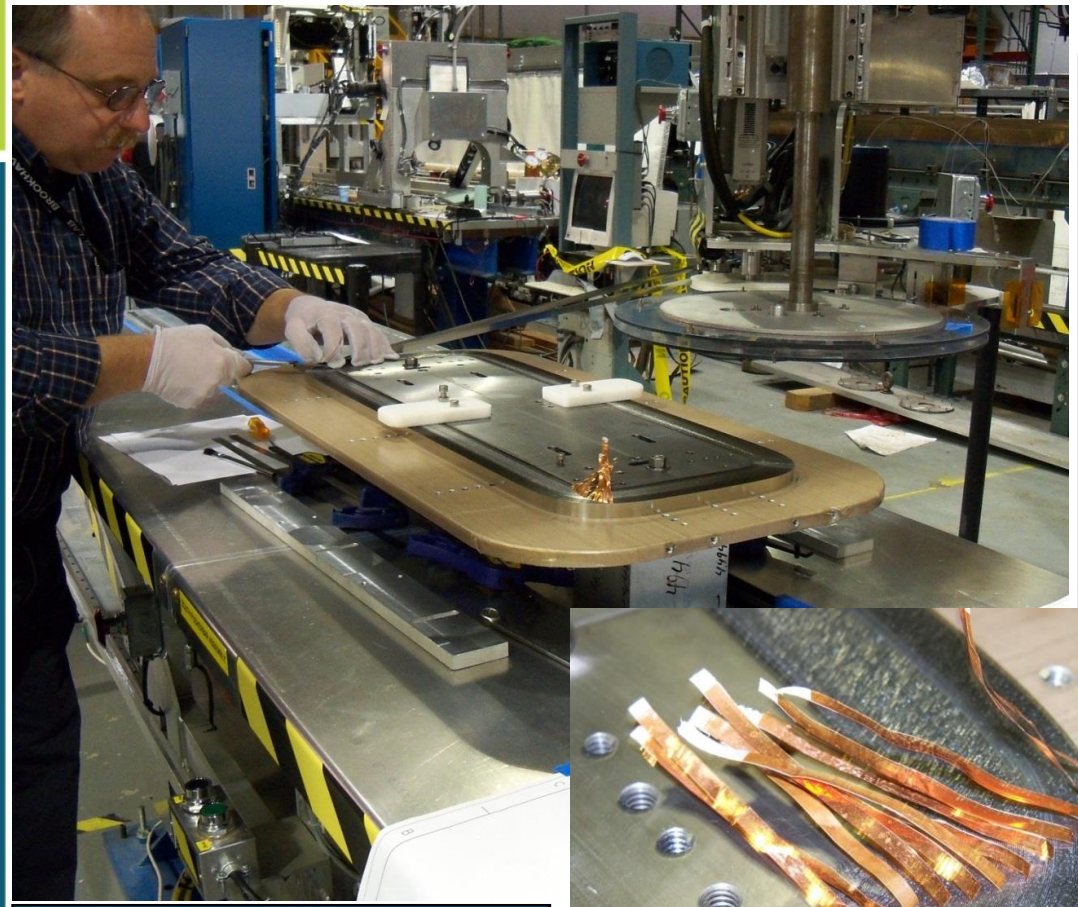
10.8 T Peak Field



High field HTS solenoid are crucial to muon collider

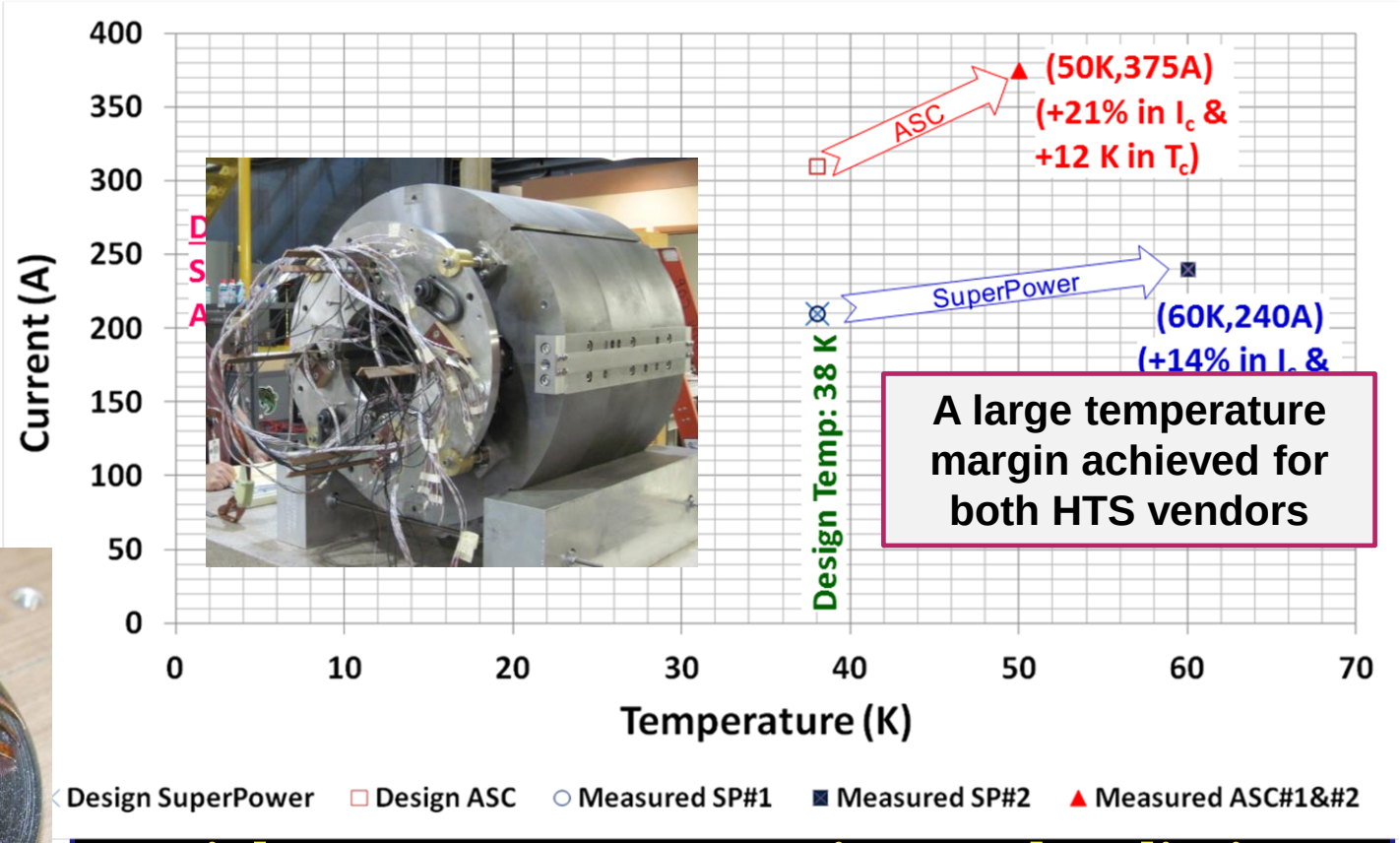
High Operating Temperature and Radiation-resistant HTS Magnets

(R&D performed for three RIA/FRIB HTS Magnet Programs)



Four large heavily instrumented coils

https://wpw.bnl.gov/rgupta/frib-ria-papers/



A large temperature margin achieved for both HTS vendors

High temperature operation, and radiation tolerant magnets are relevant to Muon Collder

- **BNL has a large inventory of HTS racetrack and solenoid coils that could be useful for quench protection and other generic HTS magnet R&D programs.**

Common Coil Test Facility (CCTF)

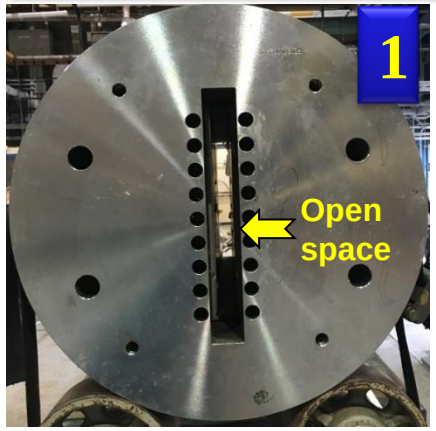
A unique magnet R&D and test facility at BNL

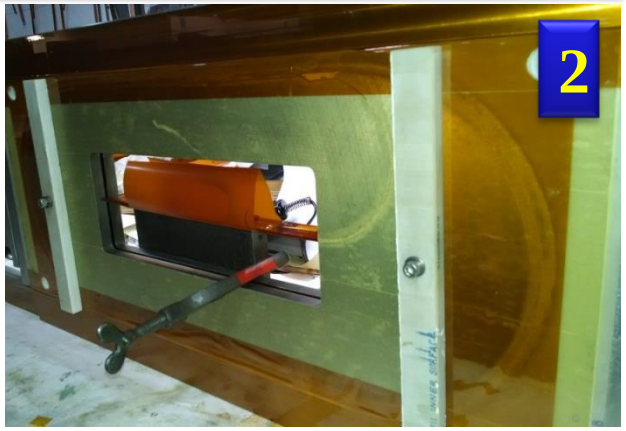
Based on the highest field (10.2 T) React & Wind Nb_3Sn dipole

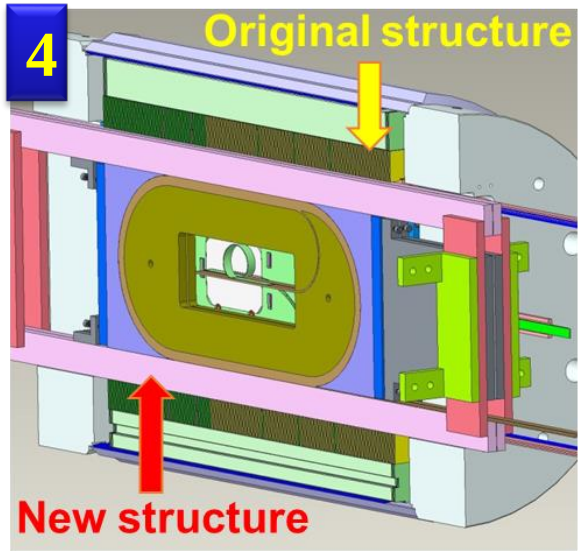
https://wpw.bnl.gov/rgupta/the-dcc017-story/

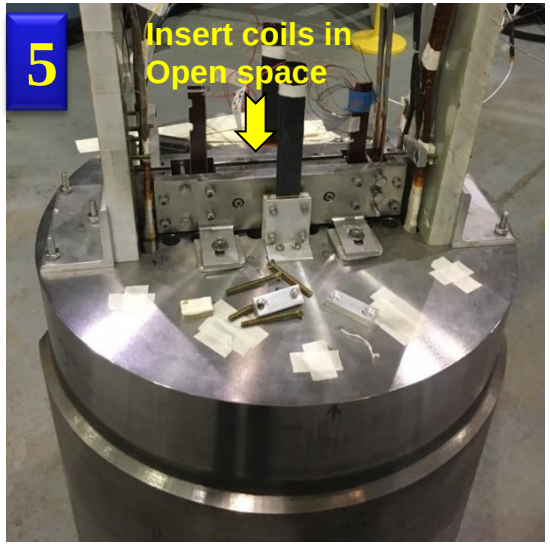
- **A unique magnet with a large open space for insert coil and high field cable test in field**
- **Unique facility to allow technology demonstrations**
- **Rapid-turn-around and low-cost R&D=> changes the way we do innovative and systematic R&D**
- **Used by HEP, Fusion, and R&D programs around the world**

Five steps for testing new design







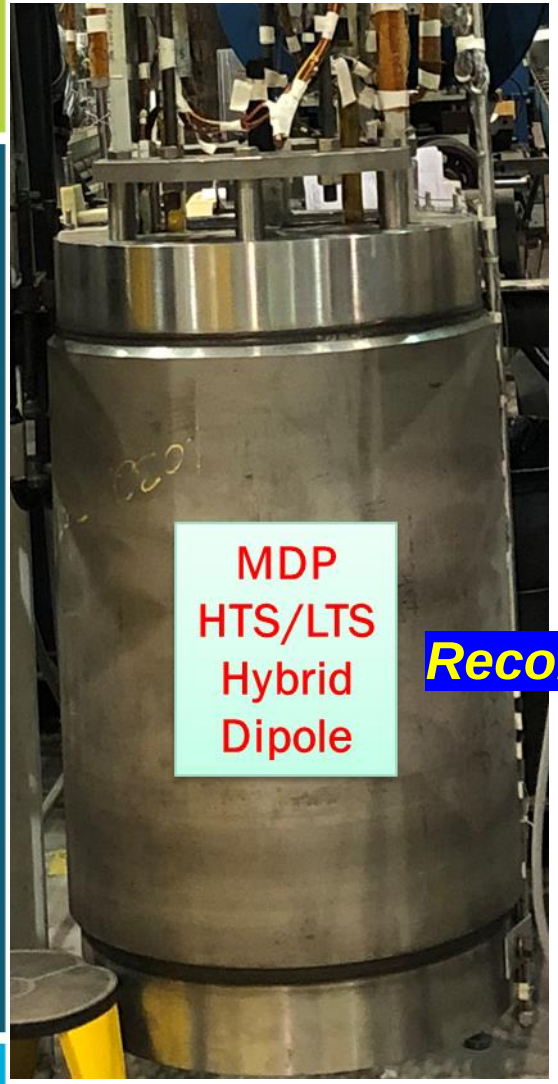


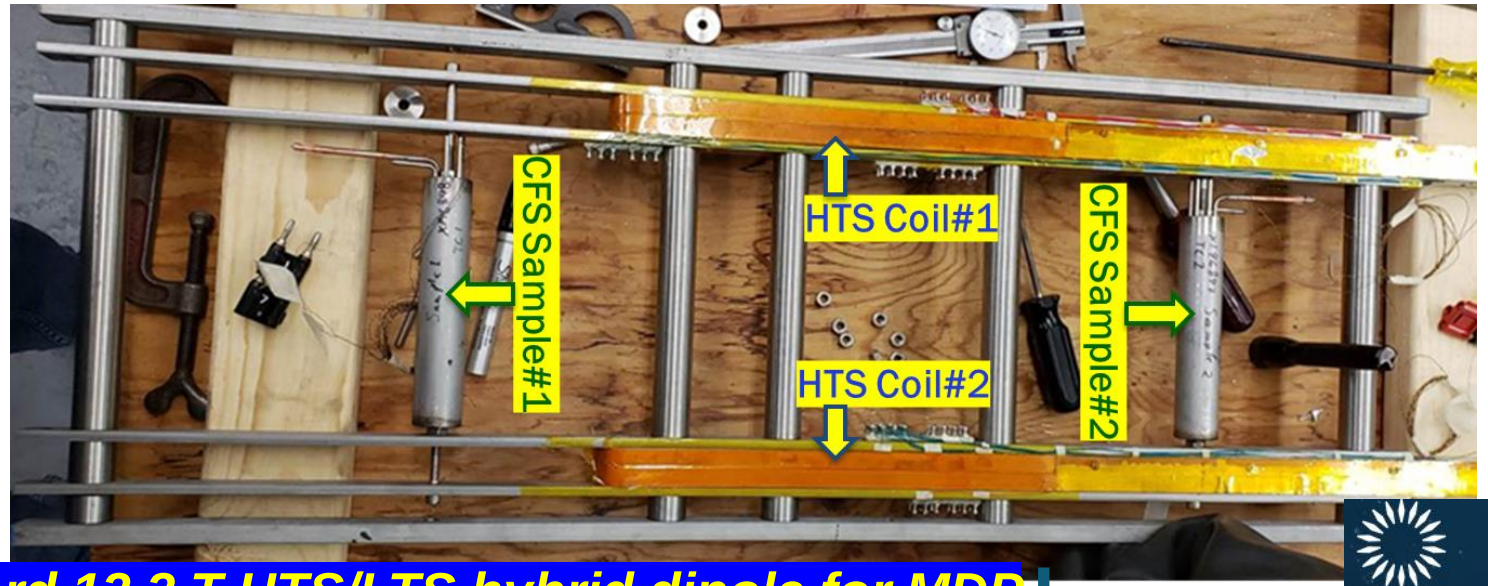
1. **Magnet (dipole) with a large open space**
2. **Coil for high field testing**
3. **Slide coil in the magnet**
4. **Coils become an integral part of the magnet**
5. **Coil test becomes a magnet test at a lower cost and faster turn-around**

HEP/FES Synergy at CCTF– 2 HEP Coils and 2 FES Samples

4 tests in one go: record hybrid field for HEP, crucial cable test for FES

https://wpw.bnl.gov/rgupta/fusion-programbnl/



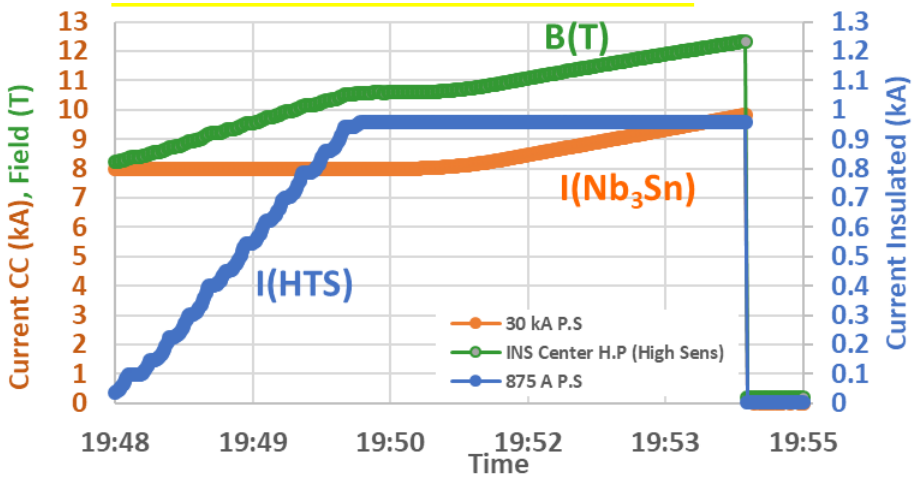


CFS

SPARC

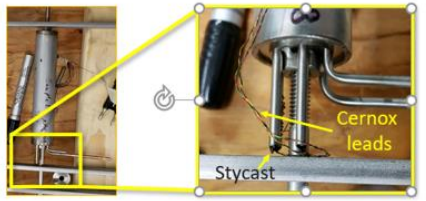
Commonwealth Fusion Systems

Record 12.3 T HTS/LTS hybrid dipole for MDP

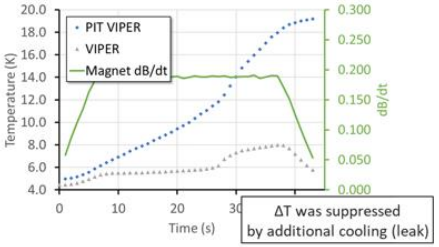


Program goals

1. Characterize PIT VIPER cable AC losses at relevant dB/dt
   Note: induced currents from the changing magnetic field are heating up the sample (AC losses).
2. Characterize and qualify novel quench detection systems.
   Note: quench detection systems are not being qualified with transport current, only heat pulses.



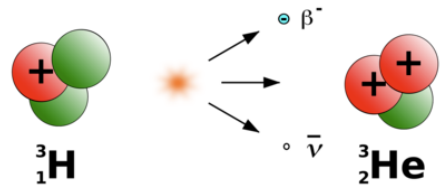
0.183 T/s to 7.49 T



Project 8: Measurement of Neutrino mass by double beta decay in Tritium

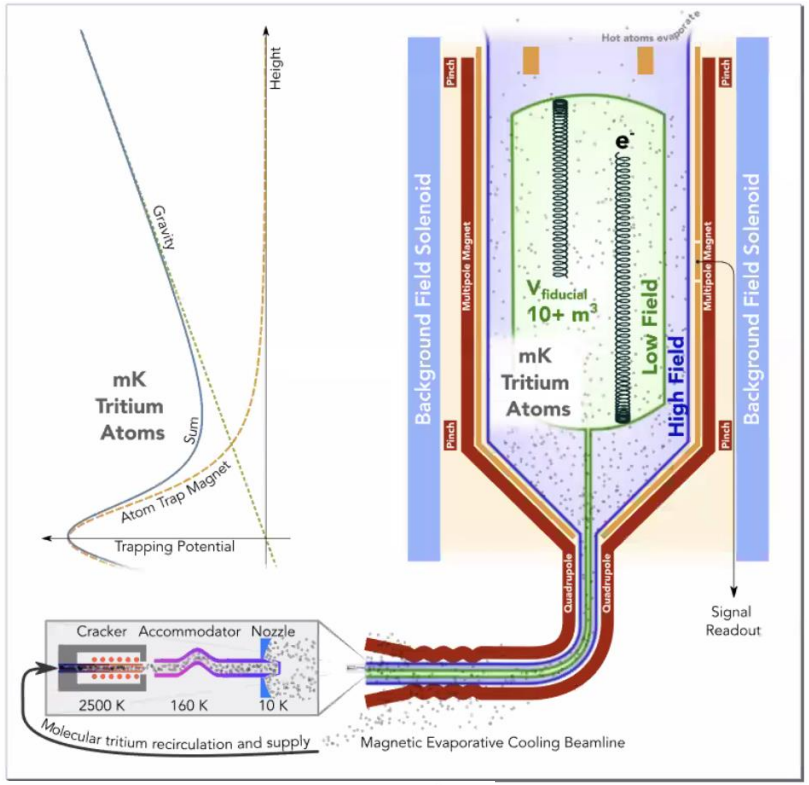
Vikas Teotia

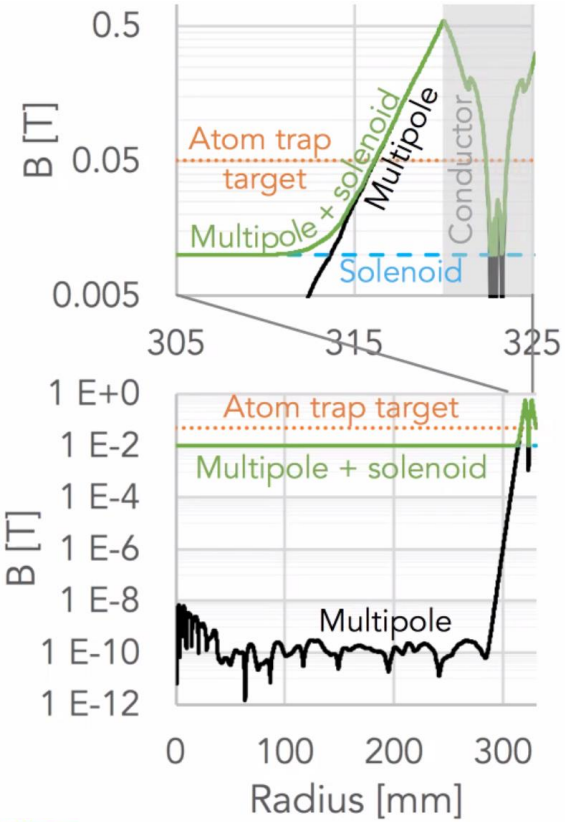
Tritium Beta Spectrum Measurement and Neutrino Mass Limit from Cyclotron Radiation Emission Spectroscopy

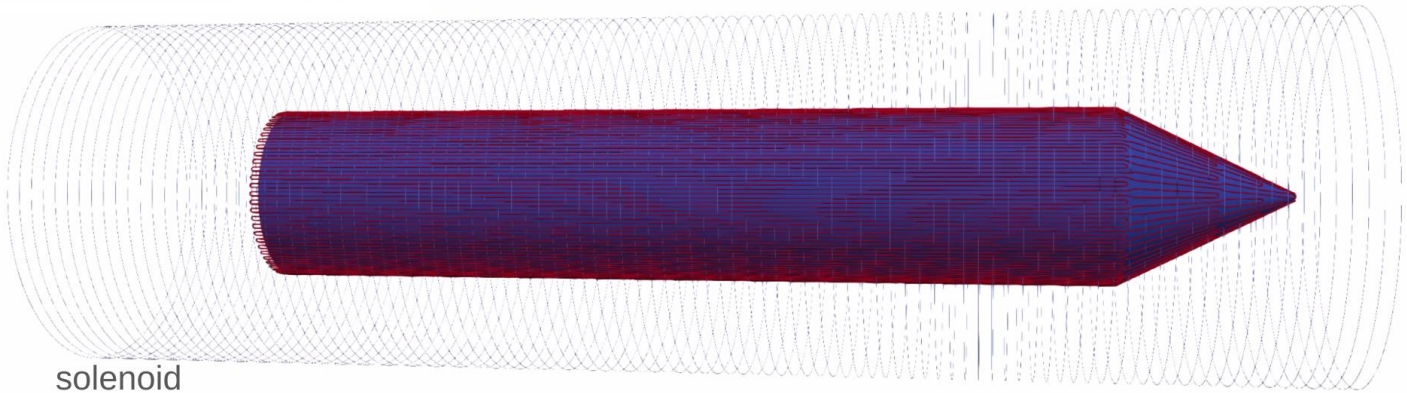


Cyclotron Radiation Emission Spectroscopy (CRES)

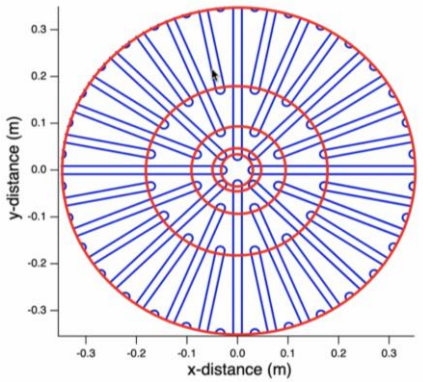
$$f_\gamma = \frac{eB}{2\pi m_e \left(1 + \frac{K}{m_e c^2}\right)}$$







solenoid



Loffe Magnet

A few slides on collaboration

A Partial List of Collaborators

Research Institutions

- MSU/FRIB
- CERN
- KEK, Japan
- University of Kyoto, Japan
- IBS, Korea
- RISP, Korea
- PSI, Switzerland
- IHEP, China
- University of Houston
- Texas A&M
- LBNL
- Fermilab
- SSC

Businesses

- Particle Beam Lasers, Inc. (PBL)
- Muons, Inc.
- HyperTech
- General Atomics (GA)
- Commonwealth Fusion Systems (CFS)
- Renaissance Inc., USA
- Solid Material Systems (SMS)
- Columbus Superconductor, Italy
- Showa, Japan
- SuperPower, US
- American Superconductor Corporation
- Advanced Conductor Technology
- ABB

Topics of Collaboration

- Common coil dipole
- Optimum integral design
- Overpass/Underpass magnets
- Open midplane dipole
- Modular quadrupole design
- HTS dipoles/quadrupoles/curved magnets
- High field HTS solenoids for many applications (muon collider, SMES, Axion search, neutron scattering)
- Superconducting shielding
- Recent fusion and HEP research with rapid-turn-around R&D facility with uniquely designed and built magnet DCC017

Multiple Awards with a Single Collaborator - Particle Beam Lasers, Inc.

(to show that collaborators keep coming back, we must be doing something right)

https://wpw.bnl.gov/rgupta/pbl-bnl-awards/

1.	A 6-D Muon Cooling System Using Achromat Bends and the Design, Fabrication and Test of a Prototype High Temperature (HTS) Solenoid for the System.	DE-FG02-07ER84855	August 2008	$850,000
2.	Study of a Final Cooling Scheme for a Muon Collider Utilizing High Field Solenoids.	DE-FG02-08ER85037	June 2008	$100,000
3.	Design of a Demonstration of Magnetic Insulation and Study of its Application to Ionization Cooling.	DE-SC000221	July 2009	$100,000
4.	Study of a Muon Collider Dipole System to Reduce Detector Background and Heating.	DE-SC0004494	June 2010	$100,000
5.	Study of a Final Cooling Scheme for a Muon Collider Utilizing High Field Solenoids: Cooling Simulations and Design, Fabrication and Testing of Coils.	DE-FG02-08ER85037	August 2010	$800,000
6.	Innovative Design of a High Current Density Nb_3Sn Outer Coil for a Muon Cooling Experiment.	DE-SC0006227	June 2011	$139,936
7.	Magnet Coil Designs Using YBCO High Temperature Superconductor (HTS).	DE-SC0007738	February 2012	$150,000
8.	Dipole Magnet with Elliptical and Rectangular Shielding for a Muon Collider.	DE-SC000	February 2013	$150,000
9.	A Hybrid HTS/LTS Superconductor Design for High-Field Accelerator Magnets.	DE-SC0011348	February 2014	$150,000
10.	A Hybrid HTS/LTS Superconductor Design for High-Field Accelerator Magnets.	DE-SC0011348	April 2016	$999,444
11.	Development of an Accelerator Quality High-Field Common Coil Dipole Magnet.	DE-SC0015896	June 2016	$150,000
12.	Novel Design for High-Field, Large Aperture Quadrupoles for Electron-Ion Collider.	DE-SC00186	April 2018	$150,000
13.	Field Compensation in Electron-Ion Collider Magnets with Passive Superconducting Shield.	DE-SC0018614	April 2018	$150,000
14.	HTS Solenoid for Neutron Scattering.	DE-SC0019722	February 2019	$150,000
15.	Quench Protection for a Neutron Scattering Magnet.	DE-SC0020466	February 2020	$200,000
16.	Overpass/Underpass Coil Design for High-Field Dipoles.	DE-SC002076	June 2020	$200,000
17.	A New Medium Field Superconducting Magnet for the EIC.	DE-SC0021578	February 2021	$200,000
18.	A New Medium Field Superconducting Magnet for the EIC.	DE-SC0021578	April 2022	$1,1500,000

Summary

- **Magnet Division has been a leader in inventing and/or initiating R&D on new designs and technologies. In the limited time available, only a select few of our visionary ideas were presented, to give you a flavor.**
- **Magnet Division also takes initiatives in engaging with many US and overseas collaborators, both in research institutions and in industries.**
- **While advancing the superconducting magnet technology, these efforts have also brought a significant new funding from a variety of sources.**
- **The unique common coil test facility (CCTF), not only offers a new approach to lower-cost, rapid-turn-around R&D, it also creates an R&D and testing environment which is not available anywhere in the world.**

Extra Slide(s)

Ramesh Gupta – Magnet Divisi

https://wpw.bnl.gov/rgupta/ 90%

EIC IR Magnets - Docu... | US-MDP Technical Me... | Pages ‹ Ramesh Gupta... | PeopleSoft TimeCards | Magnet Repository - ... | Roxie | Home - Workday | Time - Workday | Other Bookmarks

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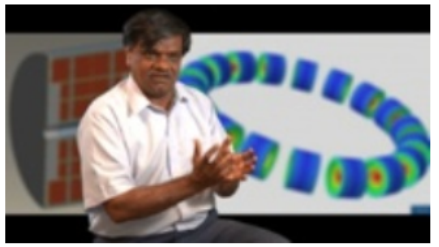
Ramesh Gupta's Homepage at Magnet Division



About me

New Designs and Technologies:

- Common Coil Design (The DCC017 Story)
- Common Coil Test Facility (CCTF)
  – a unique facility for testing insert coils and cables in high dipole fields
- Overpass/Underpass (Cloverleaf) Design
- Open Midplane Dipole Design
- Optimum Integral Design
- Tuning Shims for Extra-high Field Quality
- HTS Magnet R&D at BNL

RHIC Magnets (Highlights, Papers, Presentations, Notes)

Contact Info

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