Berkeley Center for Magnet Technology and EIC Collaboration

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EIC Workshop – Promoting Collaboration on the Electron-Ion Collider
October 7, 2020

Presentation Outline

1. Berkeley Center for Magnet Technology
   - Overview, Capabilities, Organization, Activities and Projects
2. EIC IR Magnet Requirements, Technical Challenges and Design Features
   - Large Aperture Hadron Quadrupoles
3. Potential BCMT Contributions to EIC Magnets
   - Superconducting Cable Design and Fabrication
   - Design and Analysis: Magnetic, Mechanical, Quench Protection
   - Advanced test instrumentation and data analysis

BCMT Overview

- The Berkeley Center for Magnet Technology (BCMT) serves LBNL and the larger DOE community as a full-spectrum resource for both R&D and schedule- and cost-driven, project-oriented production of advanced magnet systems.
- The BCMT is an interdivisional organization managed jointly by the Accelerator Technology and Applied Physics (ATAP) and the Engineering Divisions of LBNL. It integrates accelerator physicists and magnet researchers, magnet design engineers, and fabrication teams to foster rapid progress in the development and reliable delivery of new magnet technology.
- The BCMT combines an internationally recognized R&D component with LBNL Engineering's core capabilities in magnet design, mechanical integration, fabrication, performance testing, and quality assurance. The combination provides a solid framework to plan and execute research and projects related to magnet technology.

https://bcmt.lbl.gov/

Capabilities

- Broad expertise, encompassing diversified magnetics and associated vacuum, cryogenic, mechatronic, and precision mechanical aspects, for partner programs at LBNL and other DOE facilities.
- State of the art measurement and testing facilities, encompassing measurement and testing, cryogenic, helium recovery, and quality control capabilities to foster design capability, characterization, testing, and tuning of conventional electromagnets, permanent magnets, hybrid, and superconducting magnets.
- Fabrication facilities, including mechanical shops, coil winding, and ovens for high-quality magnet production of magnetics, cryogenics, mechanical, and vacuum system components.
- Quality control capabilities, including coordinate measurement machines and QC procedures for magnet production.
- Process control and engineering process framework

Organization and Activities

Science and Technology

Magnets for Light Sources	Superconducting Accelerator Magnets	Advanced Concepts and Materials
R. Schlueter	S. Prestemon P. Ferracin, Deputy	G.L. Sabbi
DOE/SC: Office of Basic Energy Sciences	DOE/SC: Office of High Energy Physics	DOE/SC: Offices of Fusion Energy Sciences, Nuclear Sciences
Programs/Projects	Programs/Projects	Programs/Projects
ALS ALS-U LCLS-II	High field conductor and magnet R&D (GARD/MDP) HL-LHC IR Quads (LARP, AUP)	High performance ECR, EIC magnets, high-field cable testing, medical and other applications

Program and Project Delivery

Testing/QA
Eric Wallen / Maxim Marchevsky

Production/Projects
D. Leitner

EIC IR Magnet Design Requirements

Experimental:

- Acceptance of charged and neutral particles in the forward direction of the hadron beam
- Operation in a wide range of beam energy
- Limit background and detector damage from e-beam synchrotron radiation

Accelerator and IR magnets:

- Combined large aperture and gradient in downstream ion quadrupoles for acceptance and small beam size at the IP
- Good field quality from low to high current
- Compact designs and/or interleaved electron and ion magnets in order to minimize crossing angle and crab cavity system requirements
- Control magnet fringe fields to minimize perturbations on adjacent beam
- Individually optimized magnets to address local constraints and maximize performance: limit development cycle (models/prototypes) and go directly to production units

Large Aperture IR Quadrupoles

Needed in the hadron forward direction:

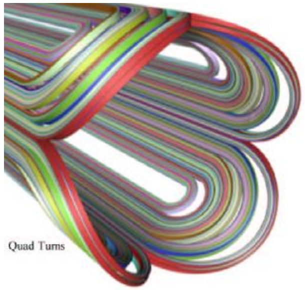
- Large aperture, pole tip field 4-5 T -> large forces and stored energy
- Challenging space constraints, both transverse and longitudinal
- Cos (2θ) coil layout, strong (collar-based) mechanical structure, high pre-load

<u>NbTi Large Aperture Quadrupole References</u>

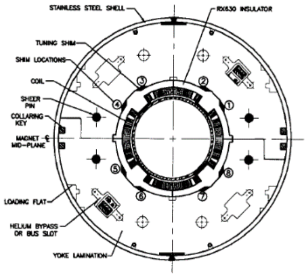
Magnet	Gradient (T/m)	Bore ID (m)	FoD* – G^2R^3 $(T/m)^2m^3$
RHIC IRQ	48	0.13	5.1
CERN ISR	40	0.20	12.8
JLAB Hall C, Q3	7.9	0.6	13.5
AHF Case II	10.3	0.51	14.1
JLAB Hall C, Q2	11.8	0.6	30.1
HIF RPD FFQ	24.2	0.51	77.7

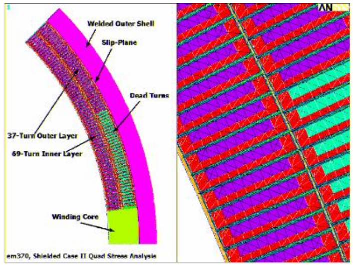
(*) Ref: J. Waynert et al, IEEE Trans. Appl. Supercond. Vol. 11, March 2001, pp. 1522

AHF Case II

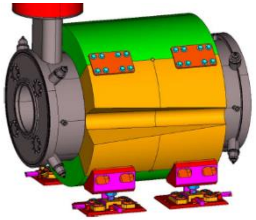


RHIC





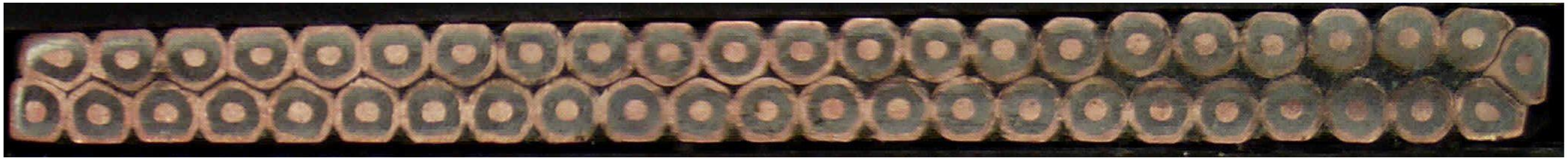
SHMS Q2



EIC Collaboration: Superconducting Cable

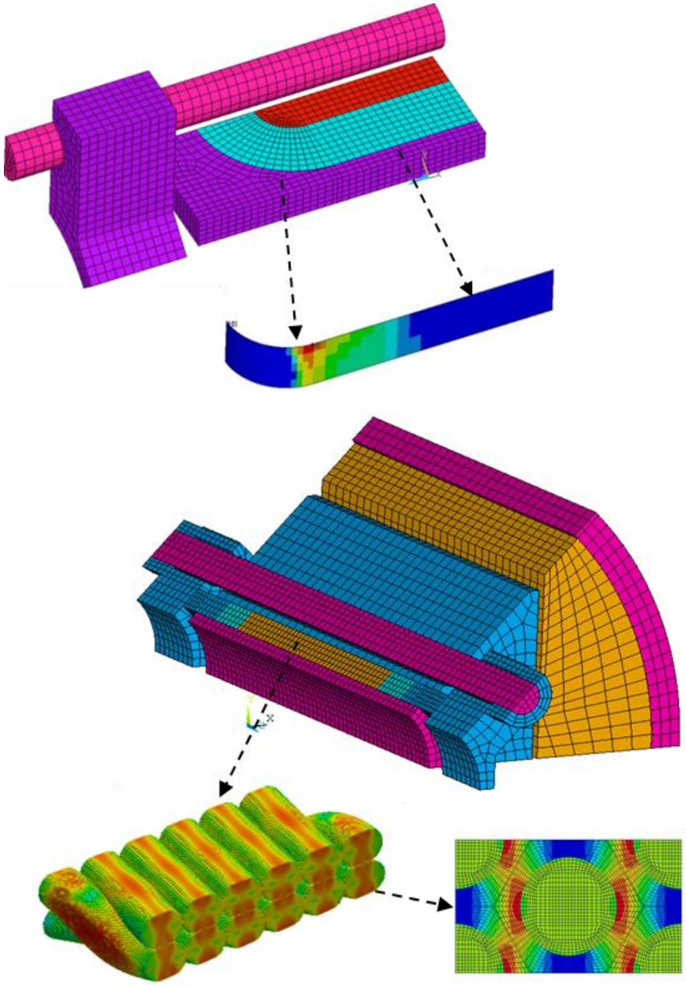
- Leadership in superconducting strand and cable development for accelerator magnets
- Performed cabling for FNAL, BNL, LARP, TAMU, CARE, CERN, Univ. Twente, Showa
- All LARP cables fabricated at LBNL
- Cable fabrication for HL-LHC AUP:

Required	Cable Length
10 x QXFS	150 m
5 x QXFP	430 m
102 x QXFA	455 m



EIC Collaboration: Design and Analysis

- Full integration of CAD & analysis tools
- Coupled magnetic, mechanical, and thermal analysis across different platforms
- Modeling of the mechanical behavior of the 3D structure from assembly to excitation: coil end displacements and gaps
- 3D quench propagation modeling, computation of the thermal stress
- Analysis of the interfaces between structural components (friction, frictionless, bonded)
- Evaluation of frictional energy dissipation during excitation cycles
- Hierarchical models to correlate macroscopic & microscopic properties

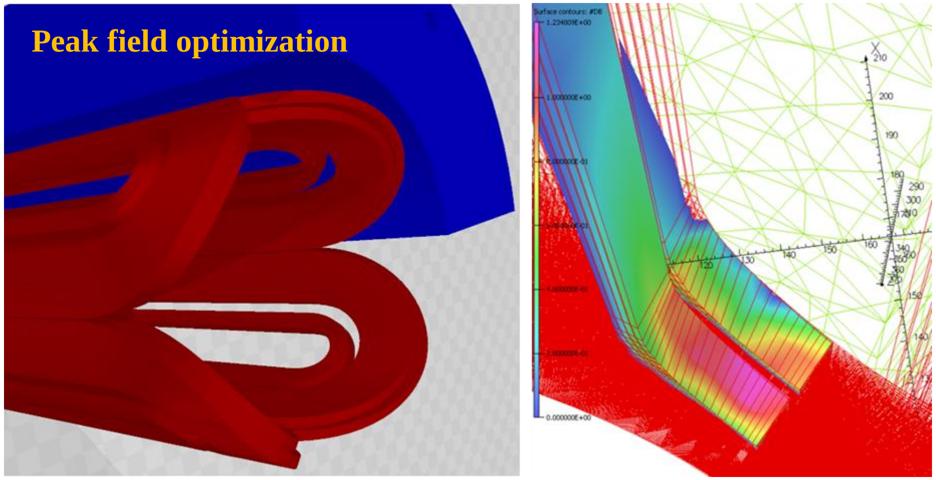


Driving progress in high field accelerator magnet modeling & analysis

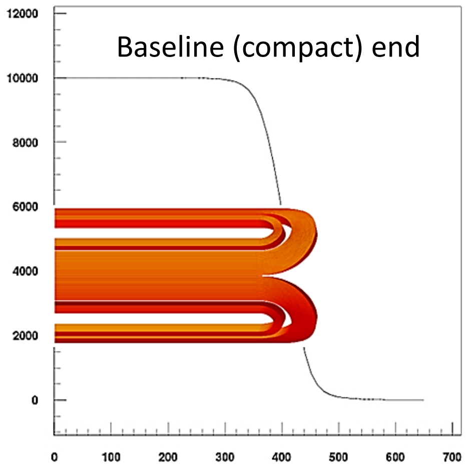
Magnetic Design Optimization

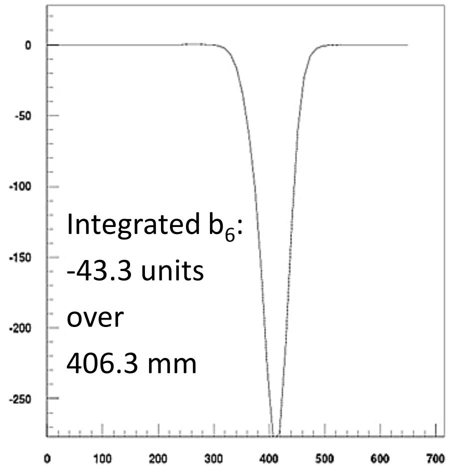
Longitudinal space optimization:

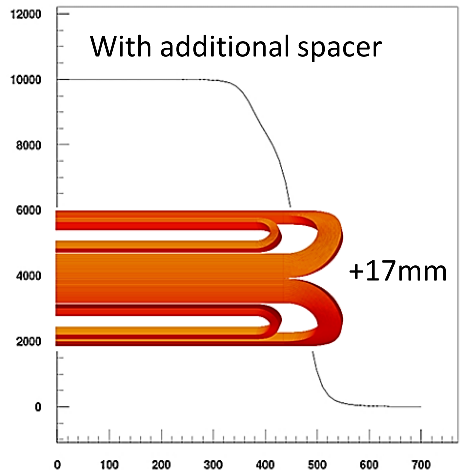
- Spacers to control peak field and field quality make the coil end less compact
- Include engineering features: leads, axial force support, cryostat
- Estimate field quality and allocate space for correctors based on DA calculations
- Option to increase operating gradient is limited by NbTi properties

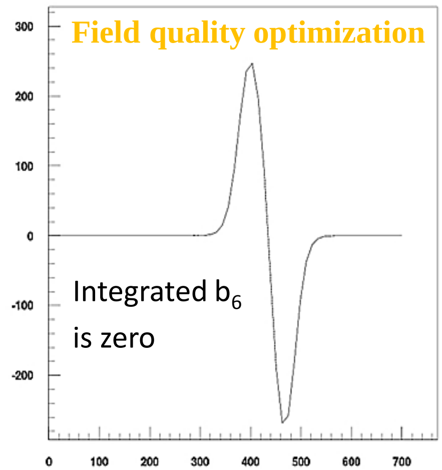


Space and fringe field constraints to end field optimization





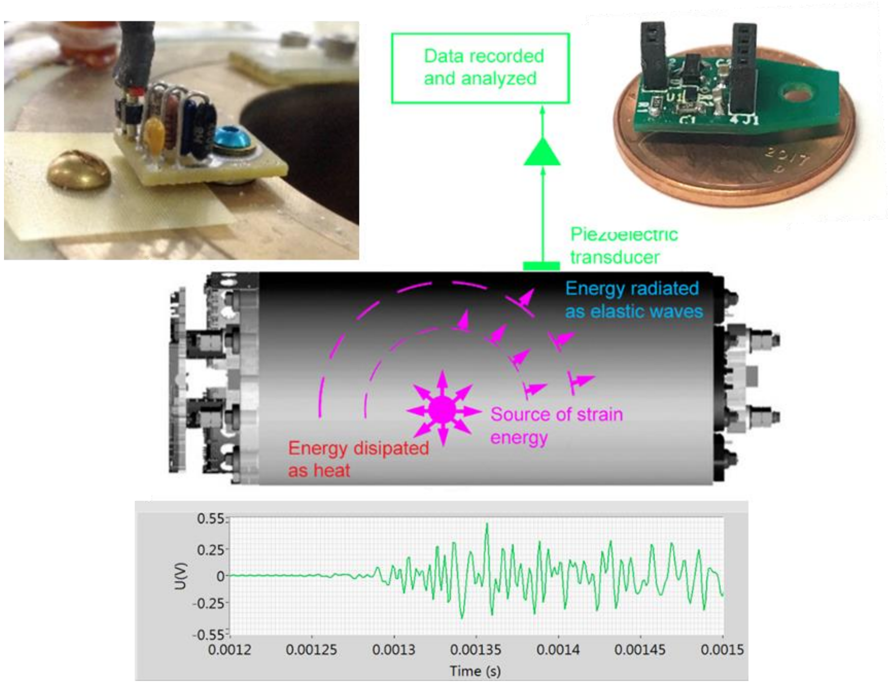




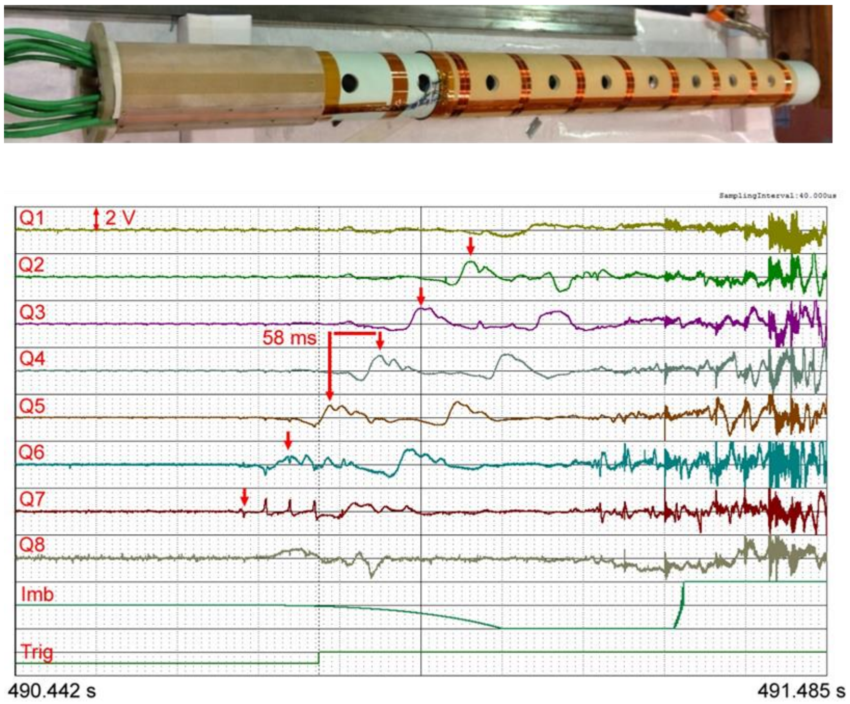
EIC Collaboration: Test Instrumentation

- EIC IR layout requires many different magnet designs to be fabricated in single units
- Limited opportunity to develop and test specially instrumented short models and prototypes prior to production units
- Advanced diagnostics techniques can replace traditional instrumentation to characterize and address observed performance limitations

Acoustic emission



Quench Antenna



Summary: BCMT and the EIC Collaboration

- BCMT has a broad range of capabilities and infrastructure relevant to EIC
- For the last several years, we have worked in close collaboration with the EIC partners to advance the IR magnet design and technology
- The large aperture downstream IR ion quadrupoles offer several opportunities for effective BCMT contributions:
  - Superconducting cable design and fabrication
  - Magnet design and analysis
  - Advanced instrumentation
- These examples are just a starting point: we need to engage in detailed discussions to find out how to best apply BCMT expertise to benefit the EIC project.