U.S. MAGNET
DEVELOPMENT
PROGRAM

The
US Magnet Development Program
after one year

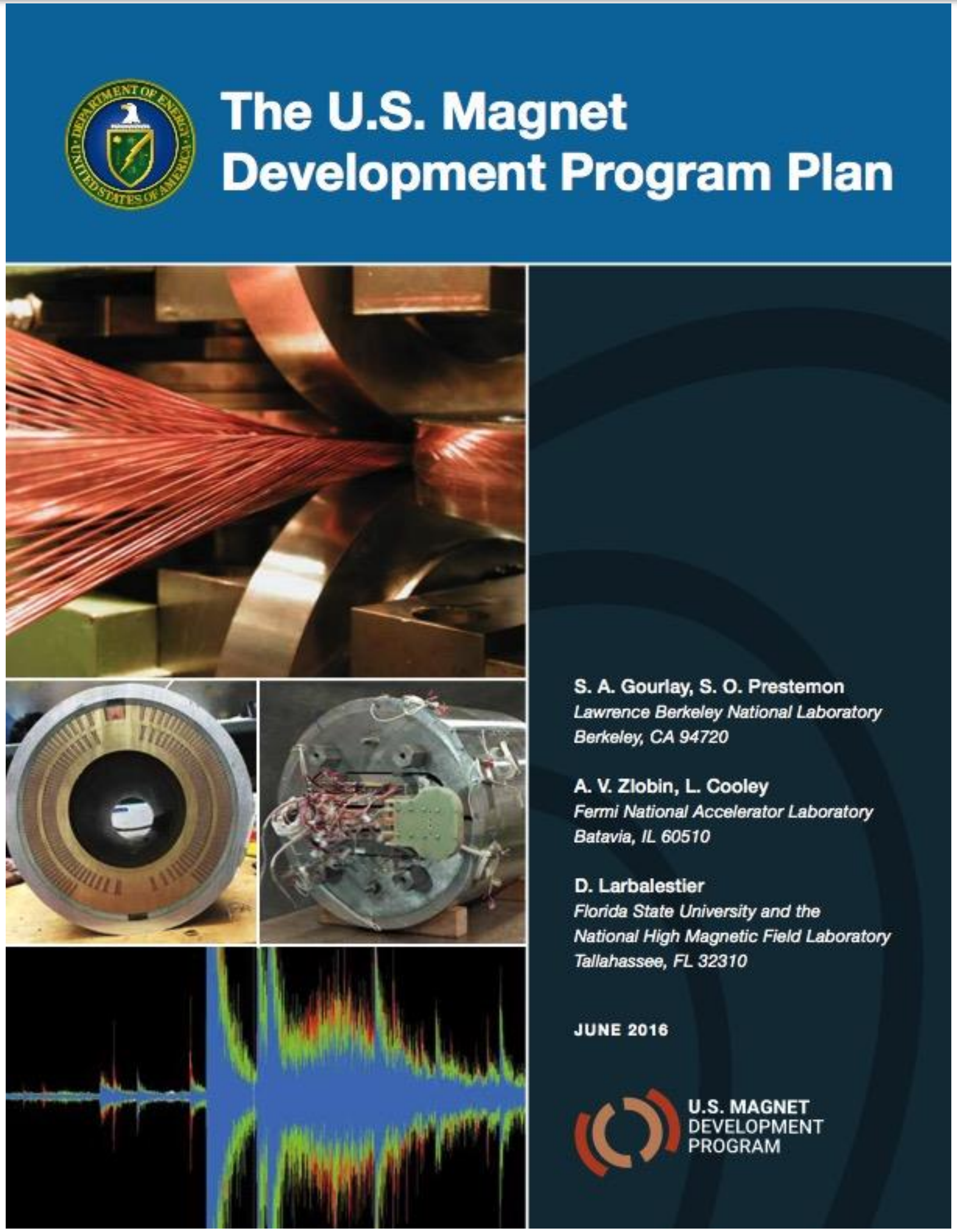
Soren Prestemon
Director, US Magnet Development Program
Lawrence Berkeley National Laboratory

For the US MDP Team

Outline

- High level program overview
  - o Review of the program foundation
  - o Management and technical oversight structure
- Progress on the MDP roadmap
- Flavor of some technology developments underway
- Overview of MDP-aligned collaborations
- Conclusions

The US Magnet Development Program was founded by DOE-OHEP to advance superconducting magnet technology for future colliders



Strong support from the Physics Prioritization Panel (P5) and its sub-panel on Accelerator R&D

A clear set of goals have been developed and serve to guide the program

Technology roadmaps have been developed for each area: LTS and HTS magnets, Technology, and Conductor R&D

US Magnet Development Program (MDP) Goals:

GOAL 1:

Explore the performance limits of Nb_3Sn accelerator magnets with a focus on minimizing the required operating margin and significantly reducing or eliminating training.

GOAL 2:

Develop and demonstrate an HTS accelerator magnet with a self-field of 5 T or greater compatible with operation in a hybrid LTS/HTS magnet for fields beyond 16 T.

GOAL 3:

Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction.

GOAL 4:

Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.

The program has well-defined goals, and is structured with leads who are responsible for delivery

Magnets	Lead
Cosine-theta 4-layer	Sasha Zlobin
Canted Cosine theta	Diego Arbelaez
Bi2212 dipoles	Tengming Shen
REBCO dipoles	Xiaorong Wang

Technology area	LBNL lead	FNAL lead
Modeling & Simulation	Diego Arbelaez	Vadim Kashikhin
Training and diagnostics	Maxim Martchevsky	Stoyan Stoynev
Instrumentation and quench protection	Emmanuele Ravaioli	Thomas Strauss
Material studies – superconductor and structural materials properties	Ian Pong	Steve Krave

Cond Proc and R&D	Lance Cooley

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We are building strong programmatic interconnections between the participating labs

- **Clear leadership roles in…**
  - **Cosine-theta: FNAL**
  - **CCT: LBNL**
  - **CPRD: ASC/NHMFL**

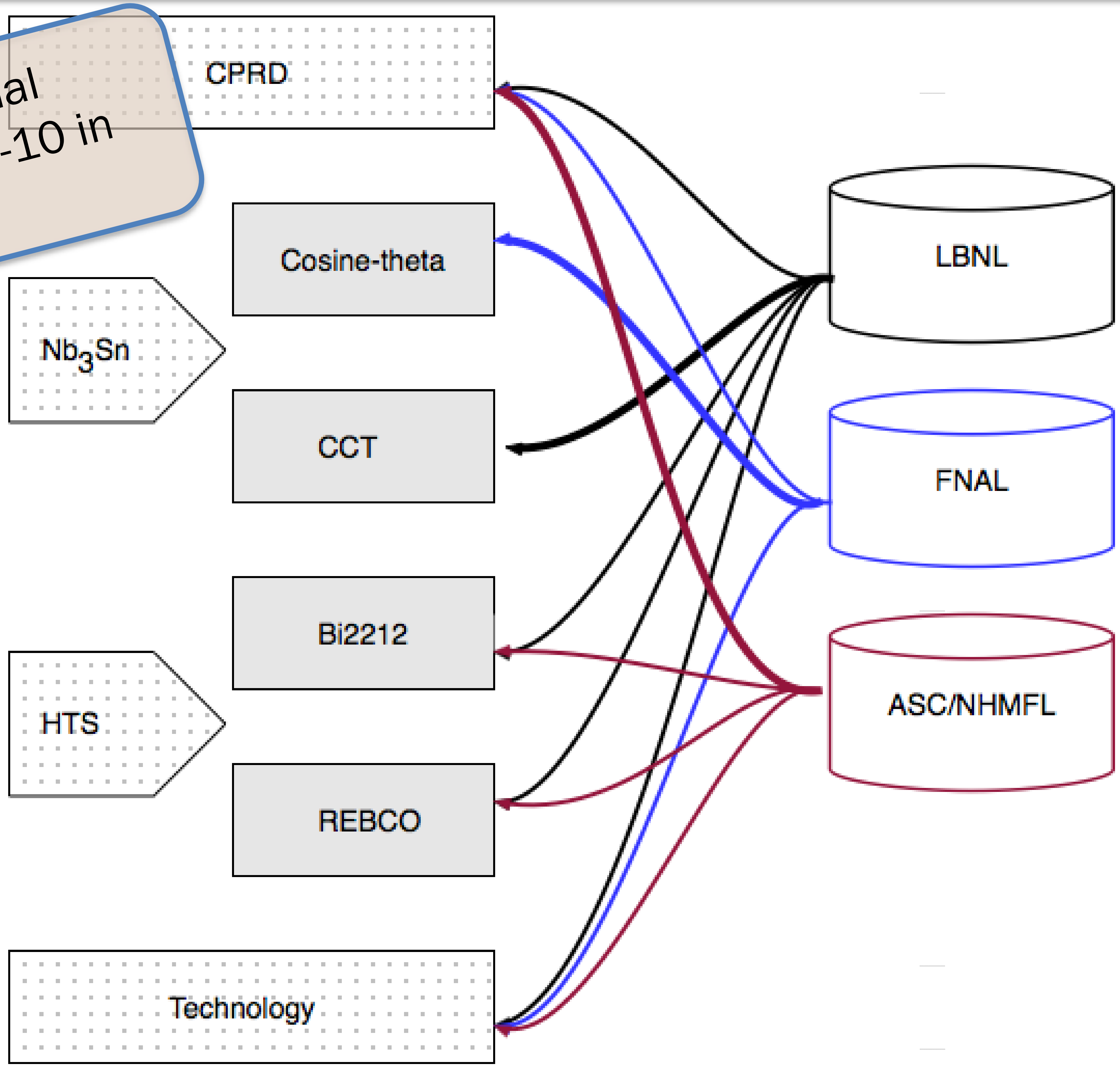
Just had our second annual collaboration meeting Feb 8-10 in Jacksonville, Fl

- **Joint advances on HTS and Technology**

- **Significant interaction on all fronts**

Overview

- Committee: Giorgio Apollinari, Joe Minervini, Mark Palmer, Davide Tommasini, Akira Yamamoto (excused), Andy Lankford (designated outsider)
- Very impressive progress and accomplishments during the past year.
  - As reported in an excellent set of presentations on a wide range of important, essential, challenging topics



The MDP team is progressing on the path for magnets outlined in the MDP Plan document

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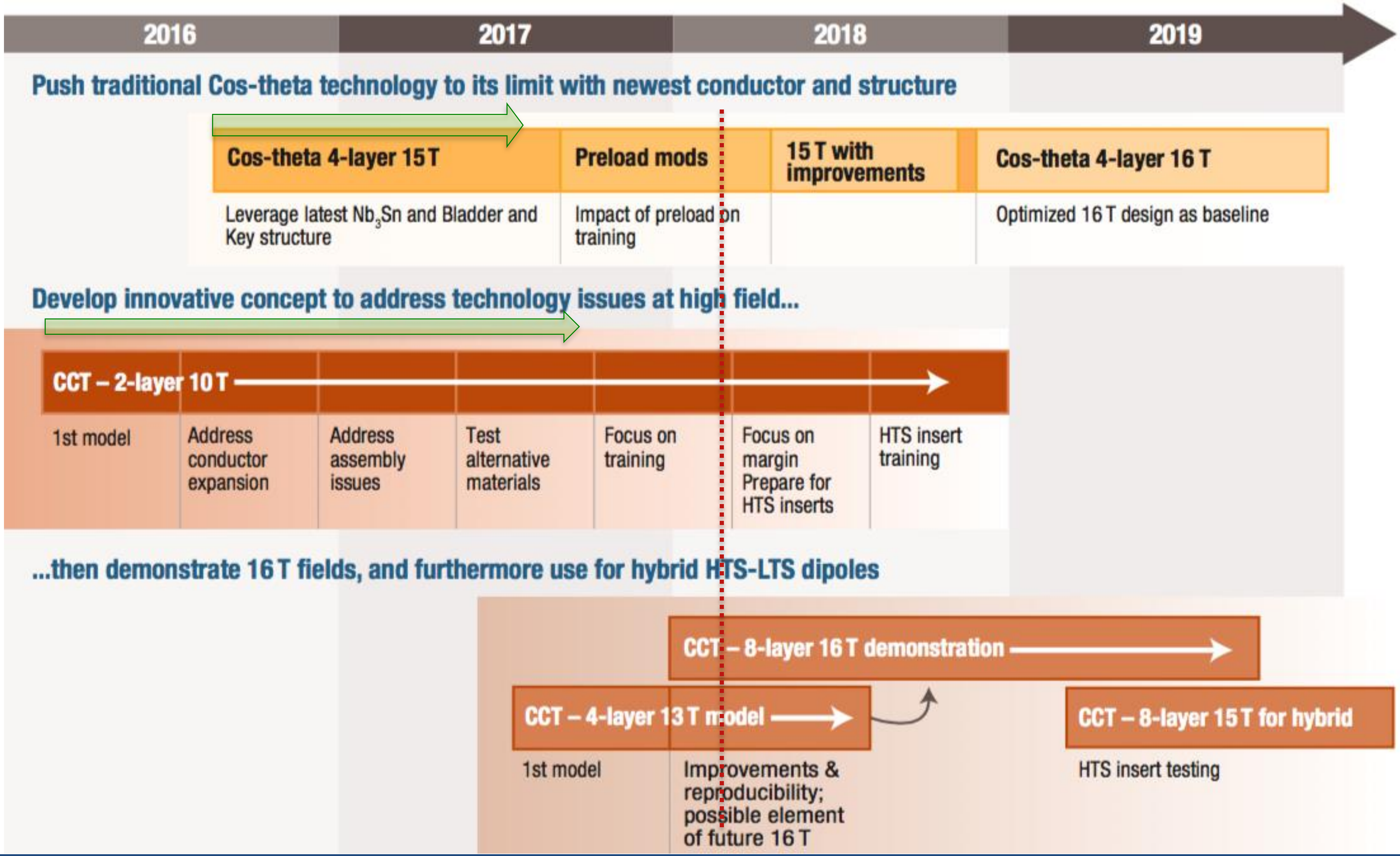
Area I:

Nb_3Sn magnets



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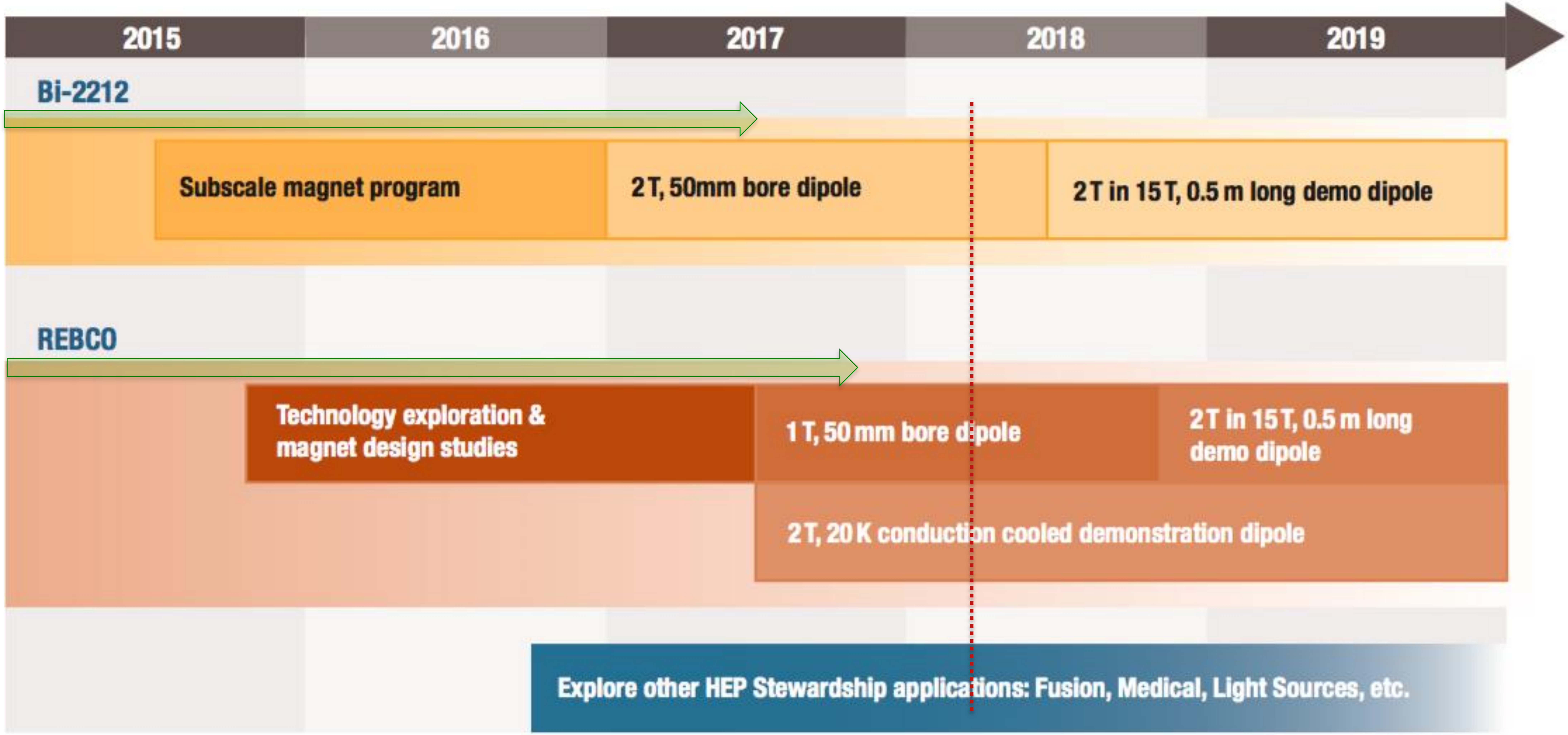
Area II:

HTS magnet technology



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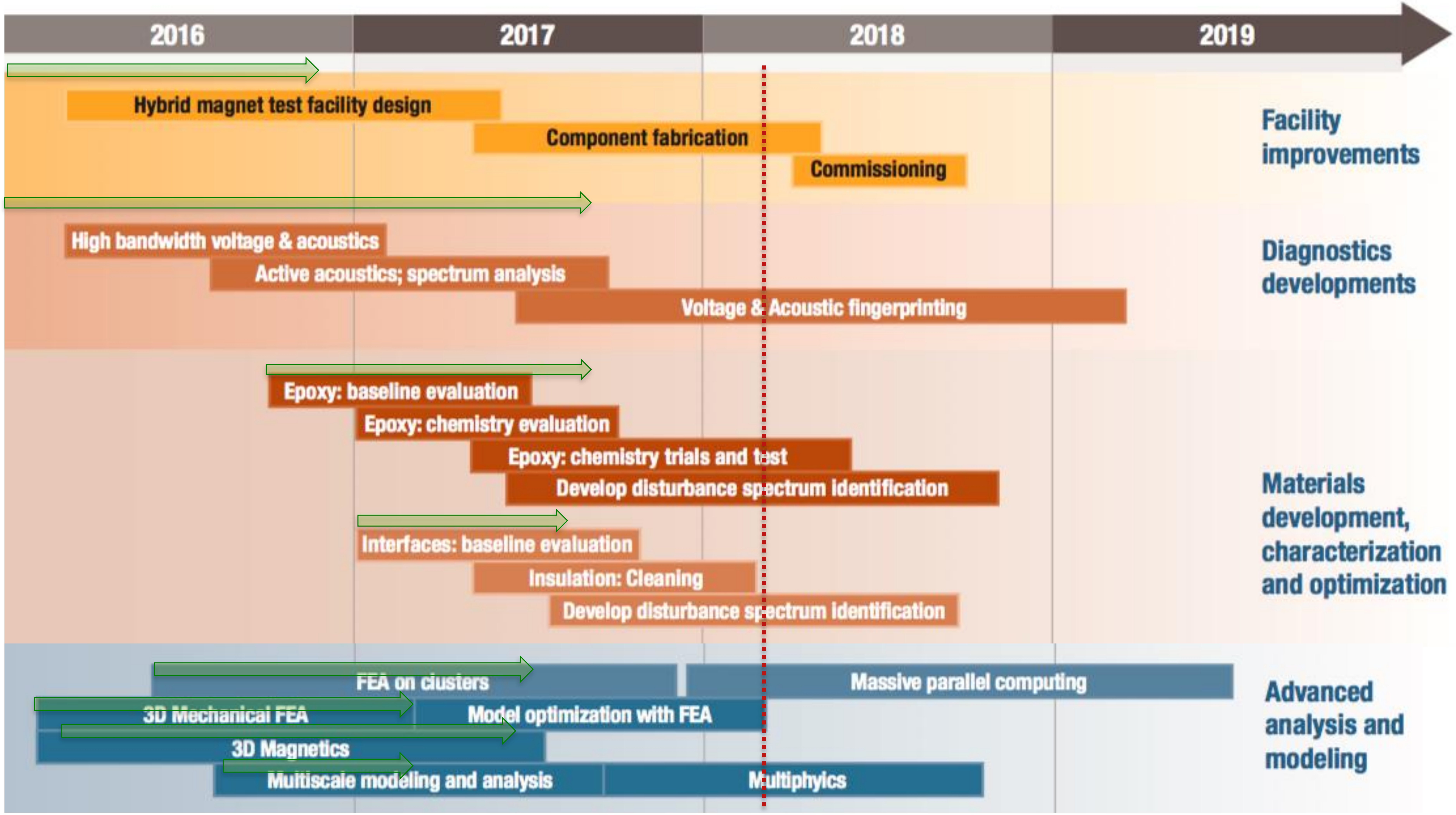
Key science components of the MDP Plan are Technology Development and Conductor R&D

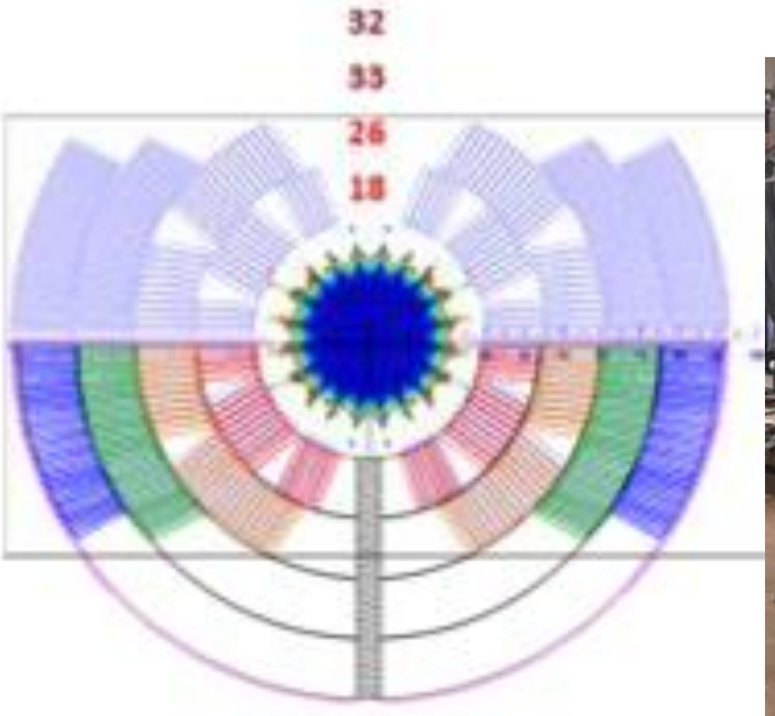
Area III:

The science of magnets: identifying and addressing the sources of training and magnet performance limitations via advanced diagnostics, materials development, and modeling

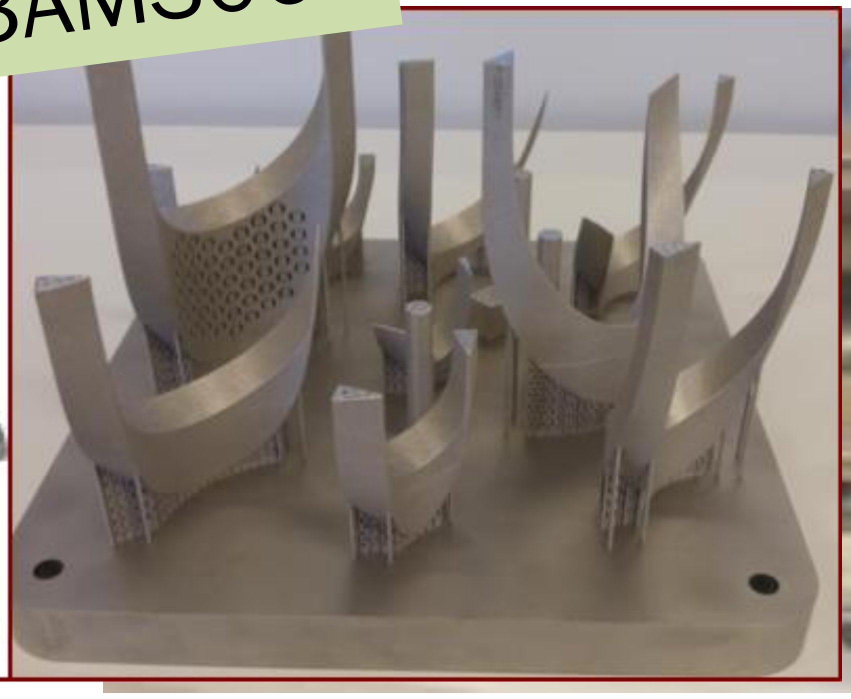
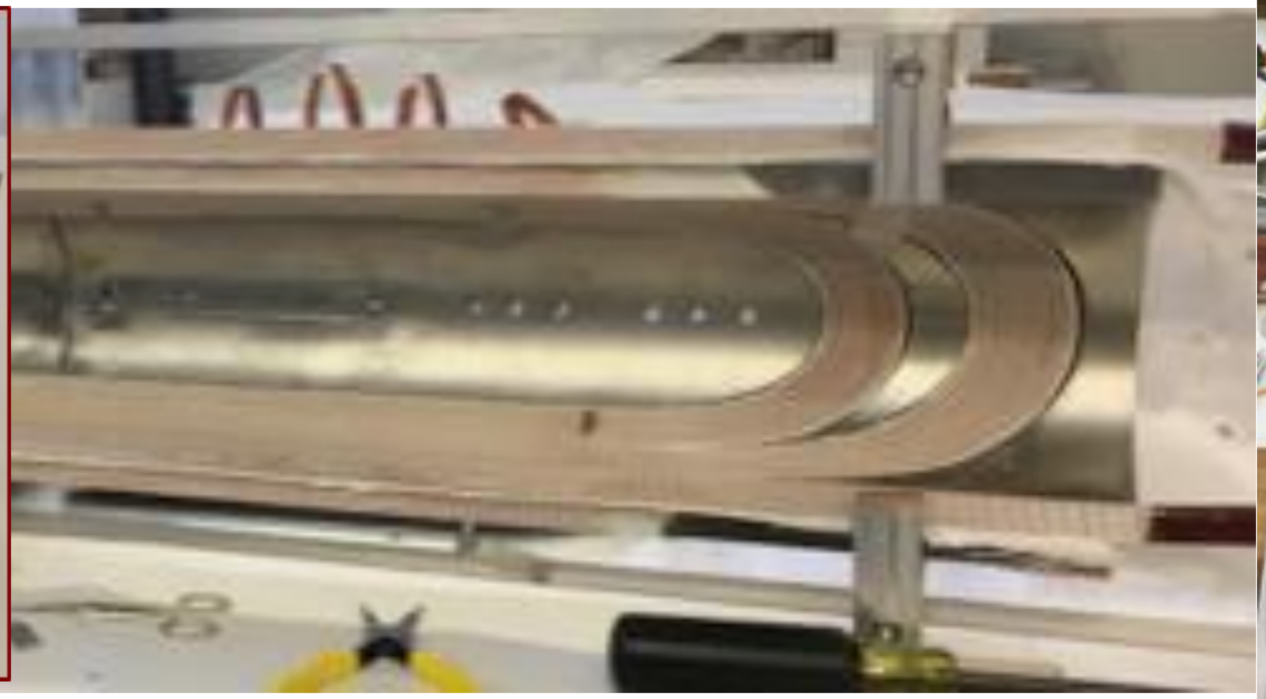
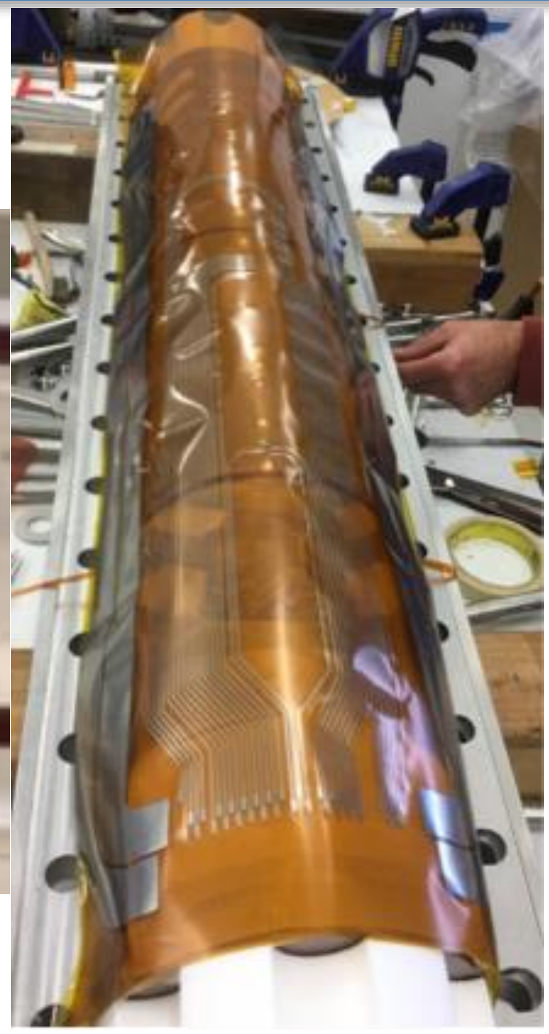


Progress on high-field magnet concepts

- Block Cosine-theta magnet fabrication is progressing well, with testing anticipated this year

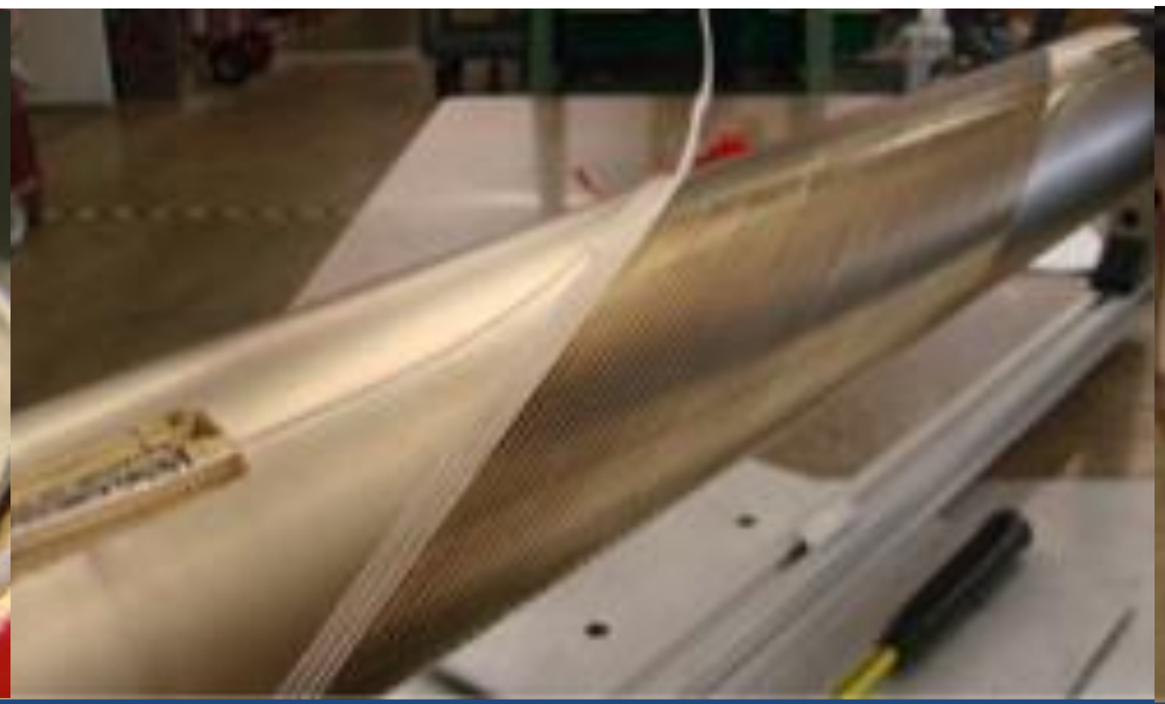


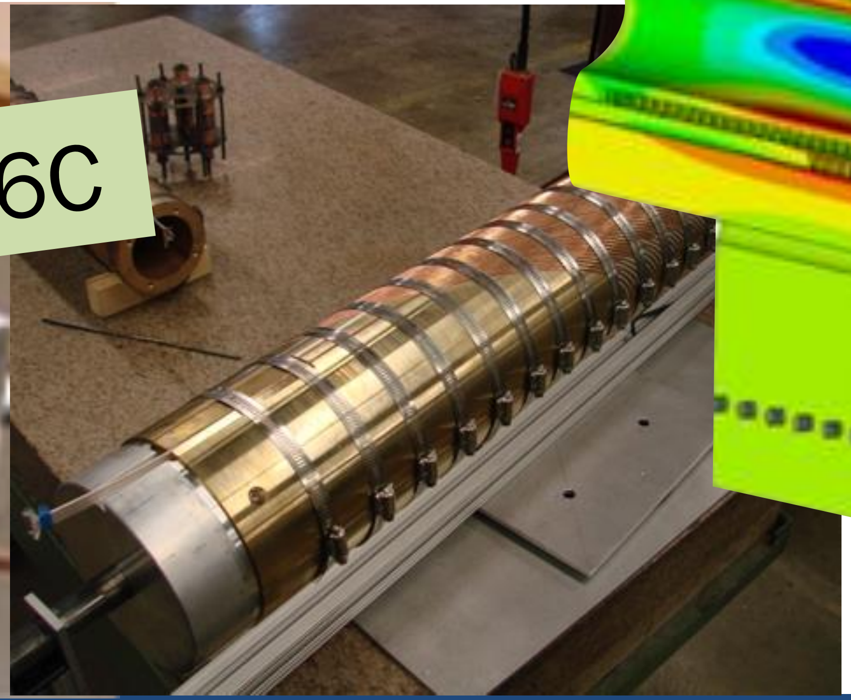
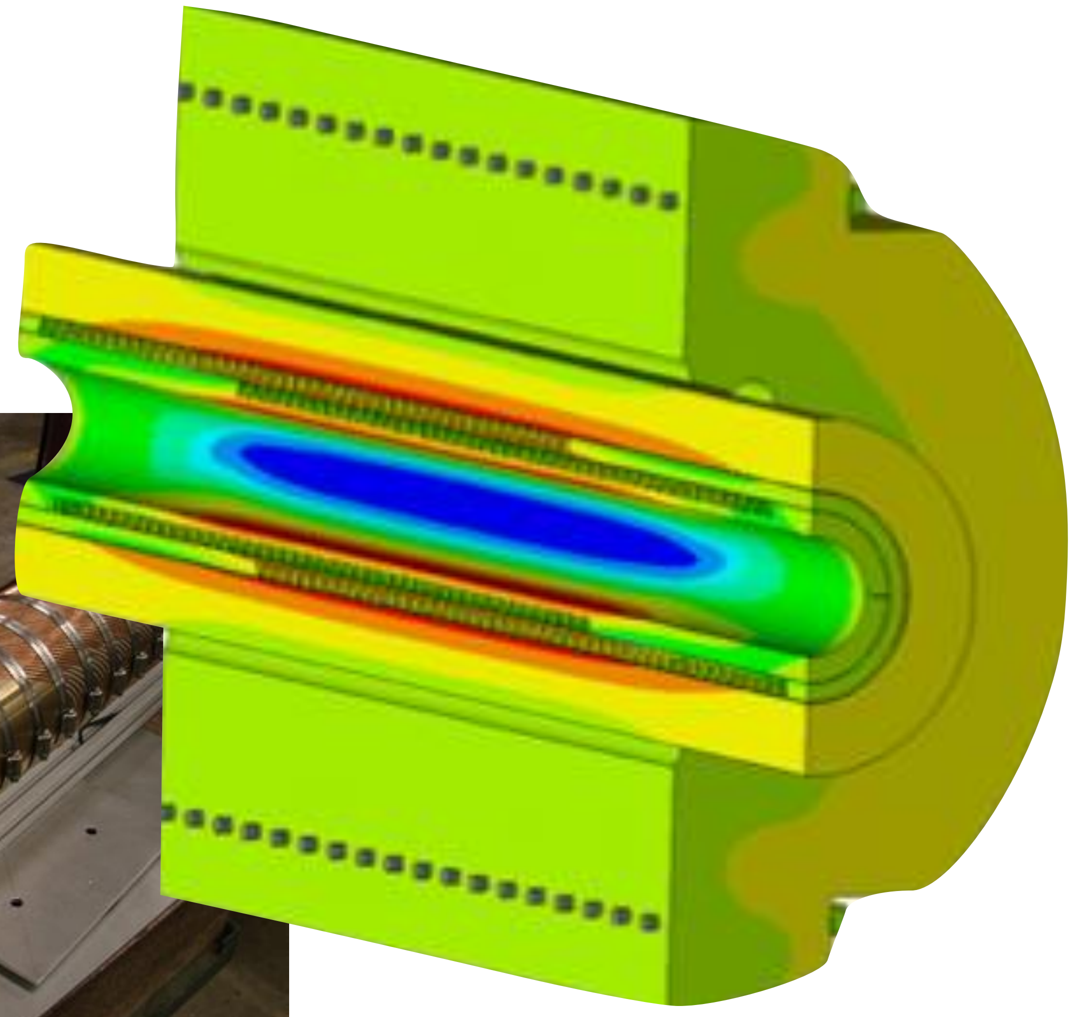


Zlobin/Barzi 3AMS06B

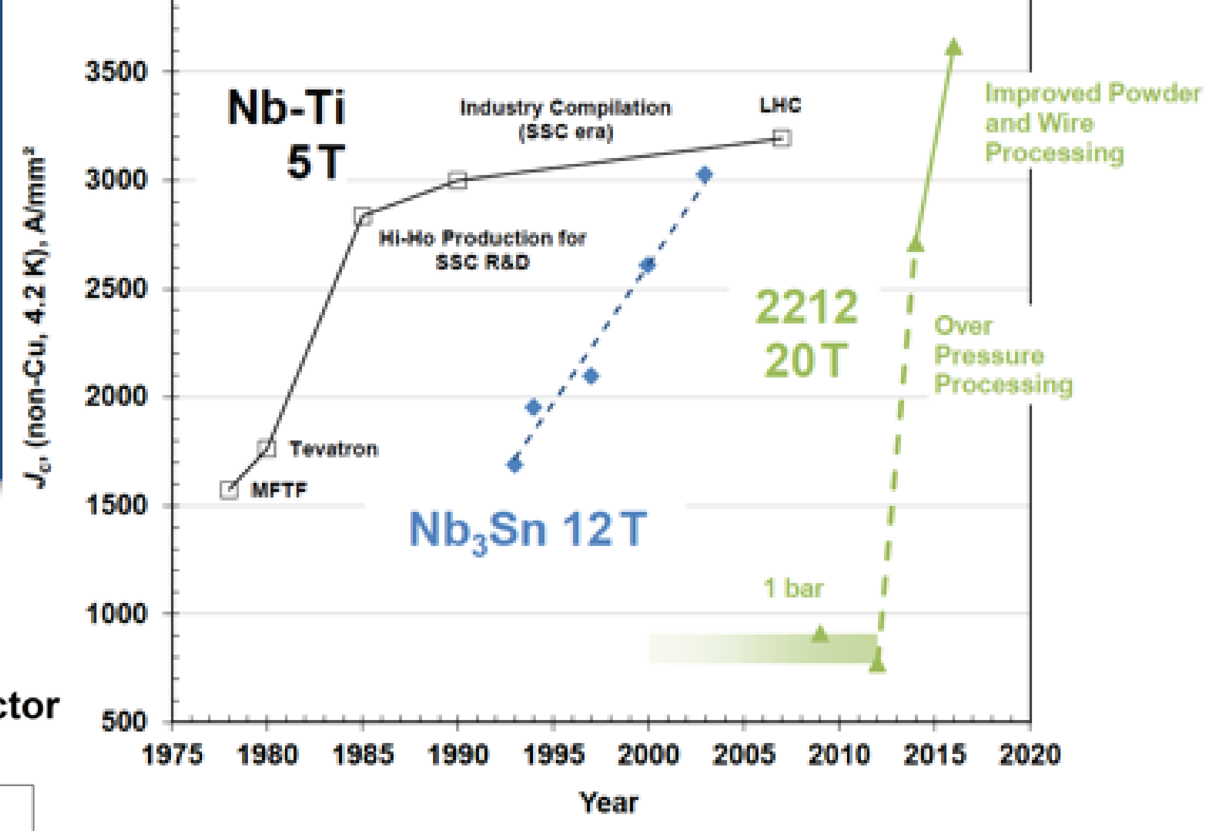
- Canted Cosine-theta:
  - Subscale CCT currently being pursued for fast turn-around technology development
  - CCT4 (the second Nb_3Sn CCT 2-layer magnet) was tested, and thermally cycled
  - CCT5 is in design, incorporating feedback from CCT4

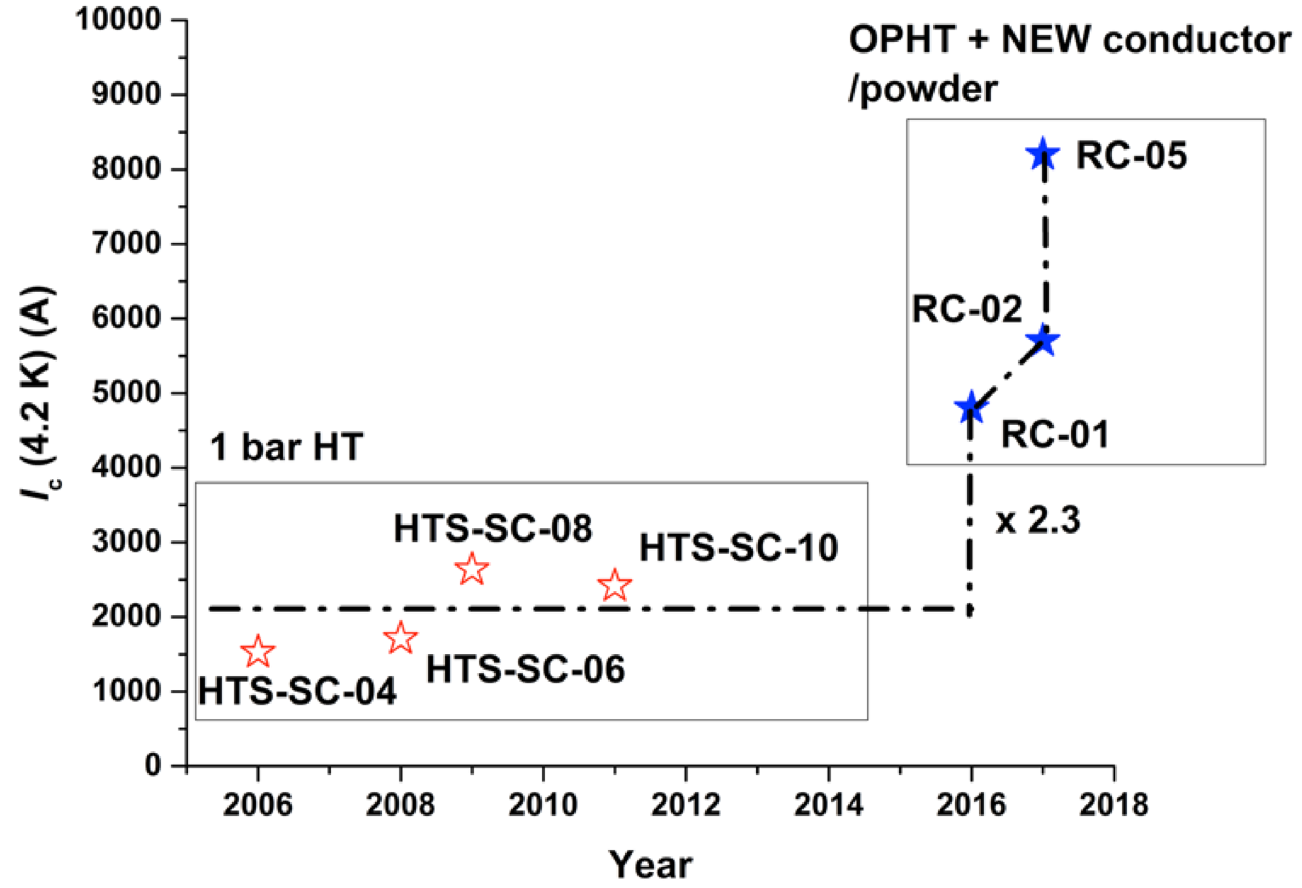



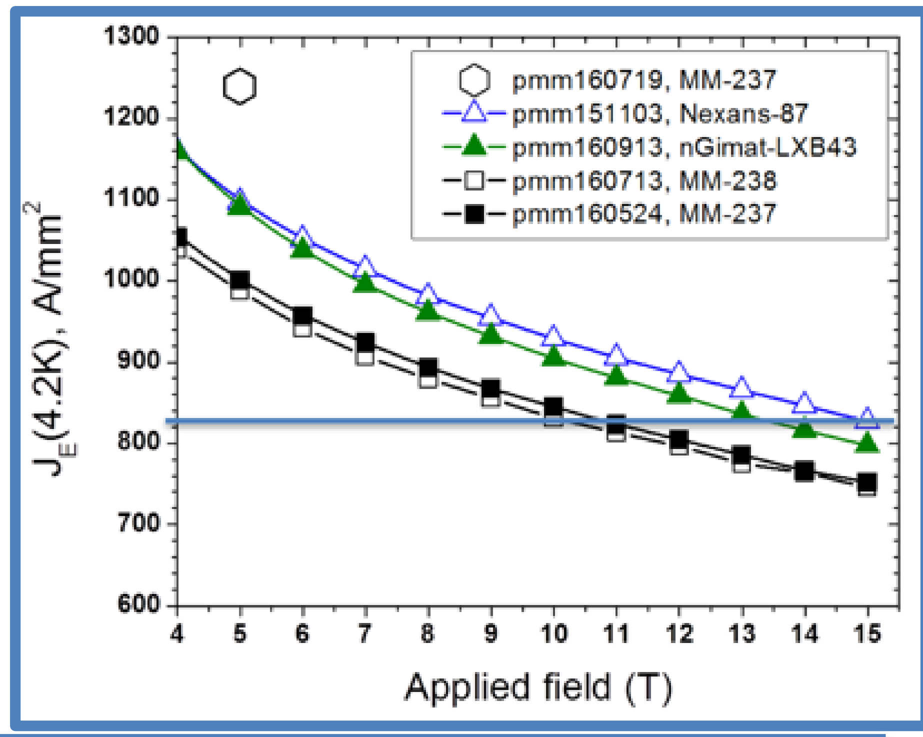
Caspi 3AMS06C

Progress on HTS magnet front

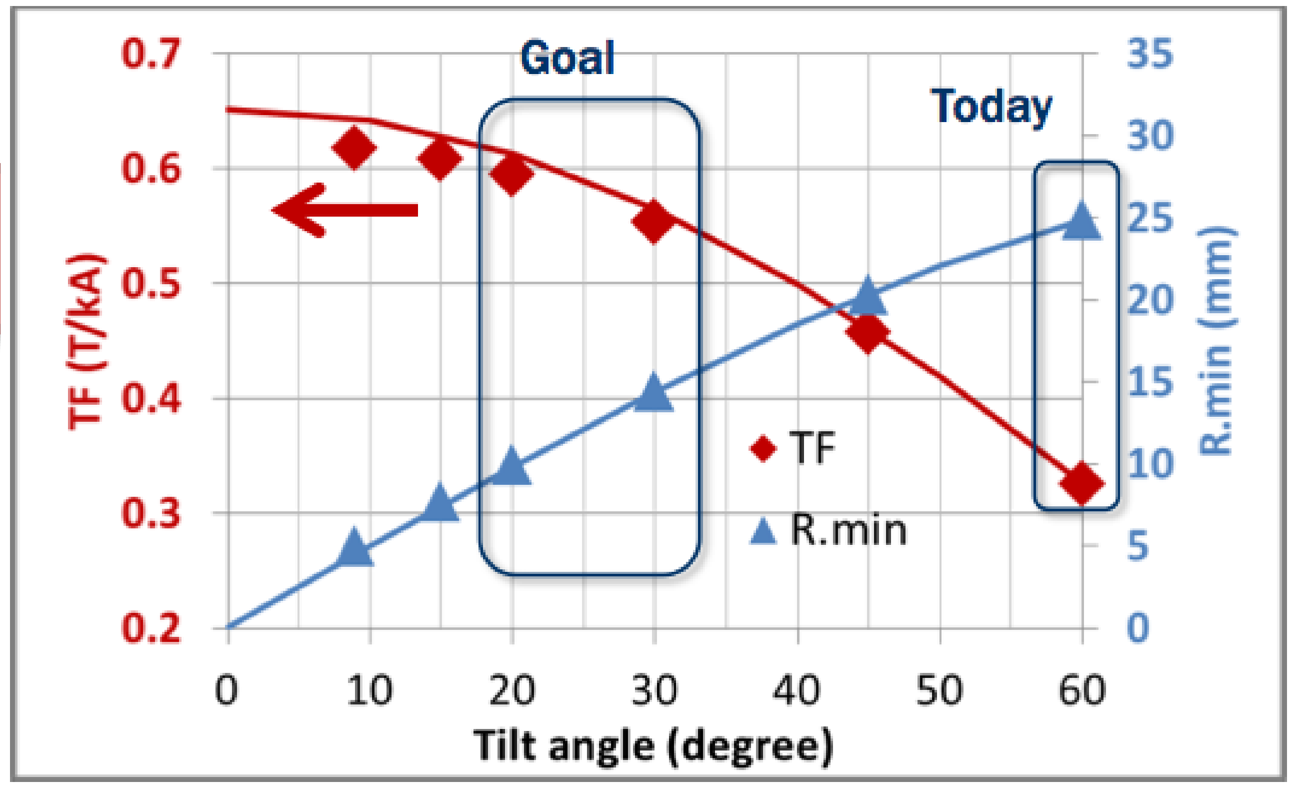


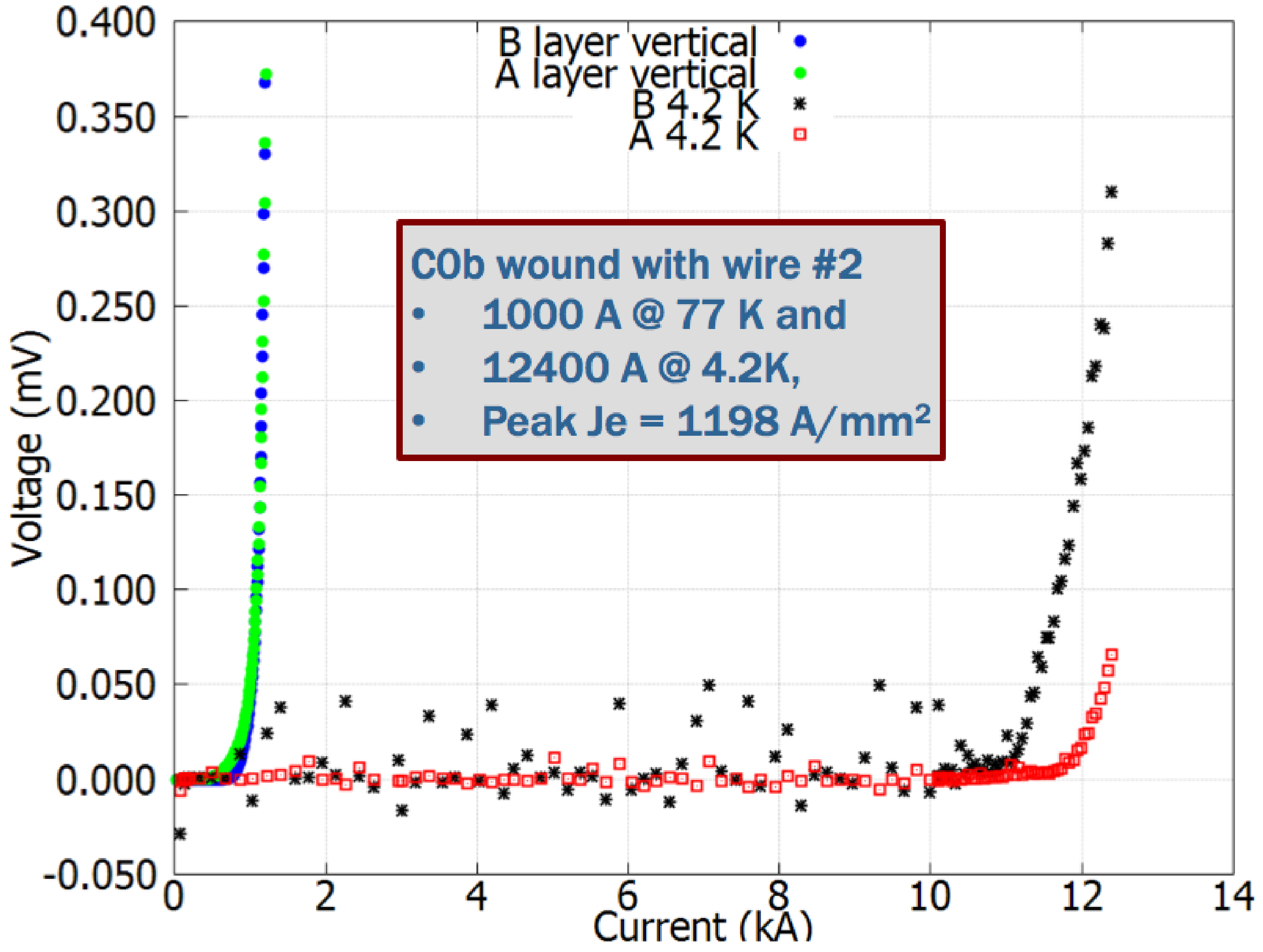
- Bi2212 has made dramatic strides in J_c over last 3 years –ready for magnets
  - Wire has been cabled and tested in racetrack configuration (RC5)
  - First Bi2212 CCT dipole has been wound; reaction and testing soon
  - Roadmap integrates Bi2212 CCT in a high-field hybrid magnet design





- REBCO development focused on CORC® cables and magnet technology development
  - 3-turn C0 "dipole" was used to develop winding tooling, fabrication processes
  - 40-turn C1 dipole was then fabricated and tested
  - Anticipate >x3 improvement in tape J_E and transfer function





We are looking closely at options for future high-field magnet designs that build on current efforts

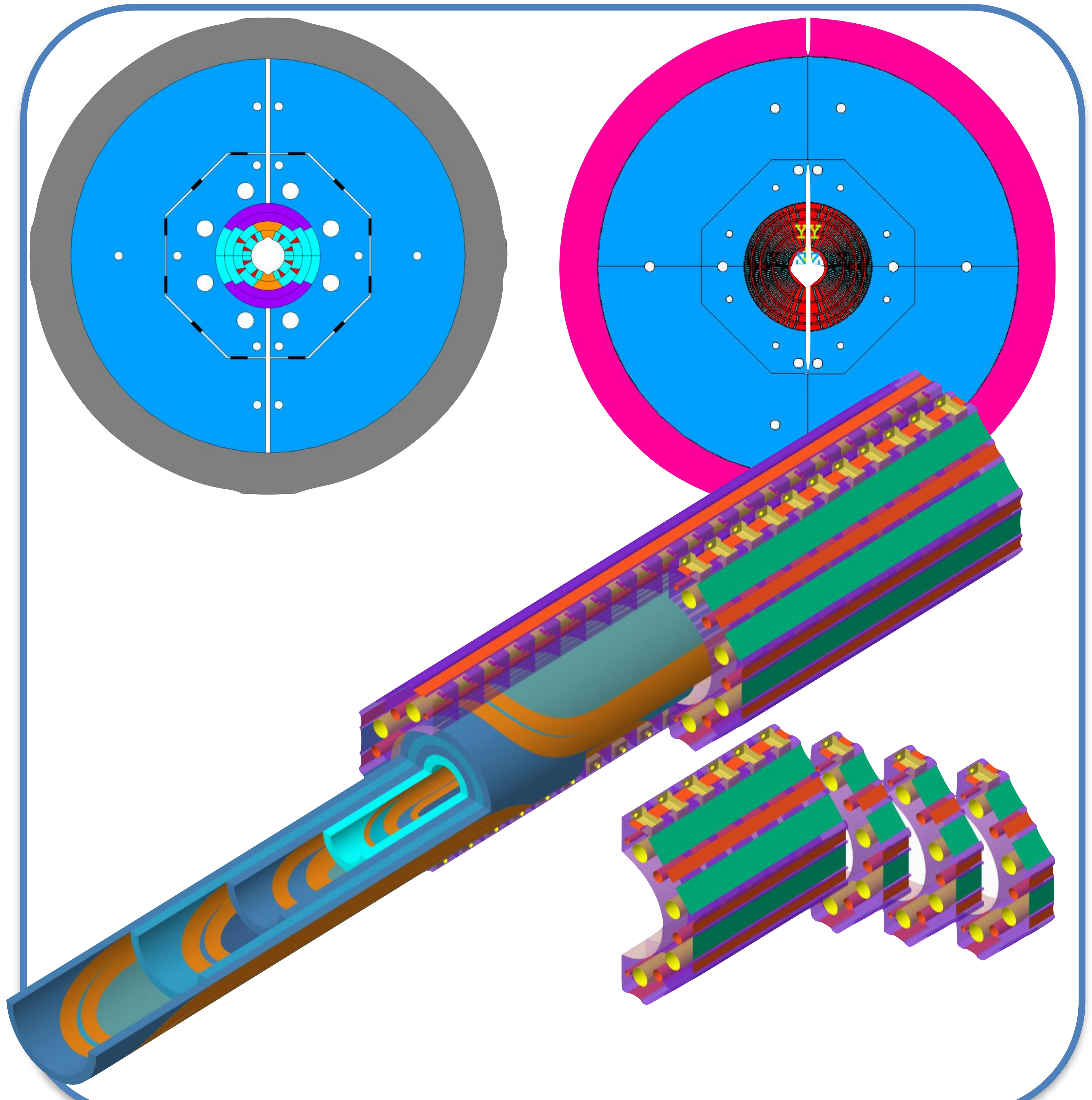
Design Team
16 T Dipole design:
Leads: Zlobin and Sabbi

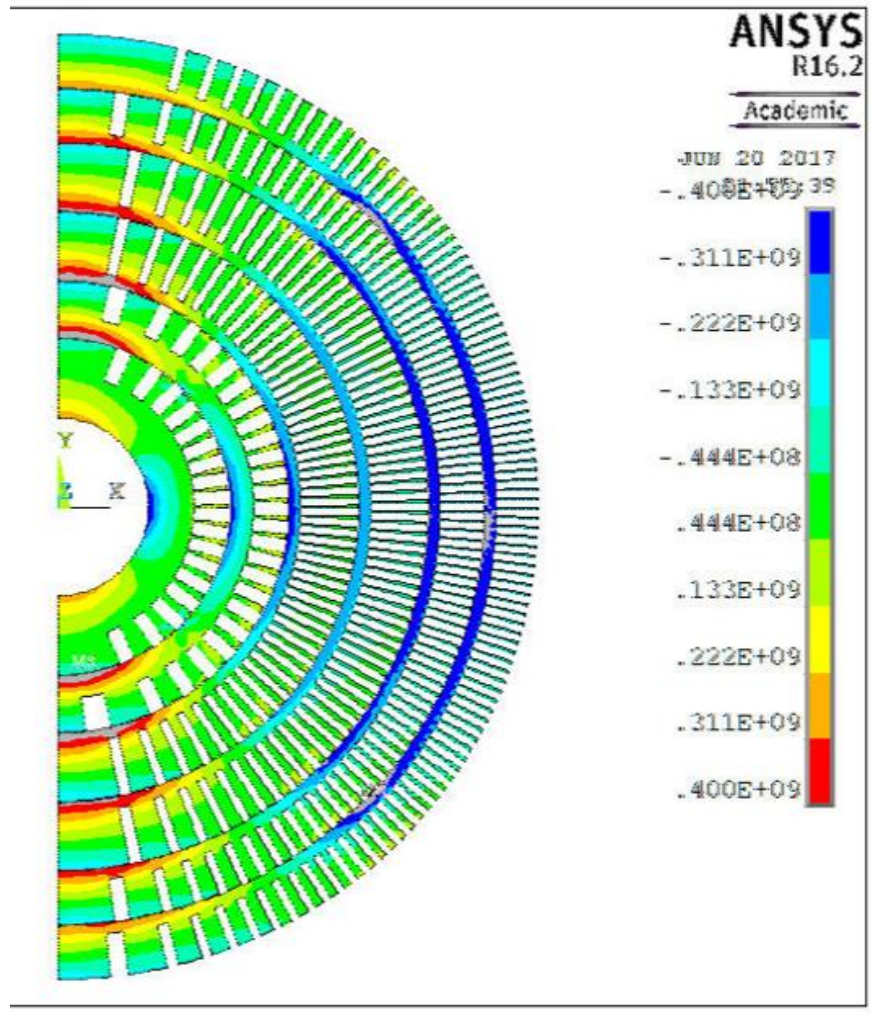
Design Team
Utility Structure design:
Lead: Mariusz Juchno

First look at Hybrid designs
Caspi, Brouwer, et al

Nb_3Sn design targets

1. Each magnet concept should provide
   - Description of magnet design including
     - Strand, cable and insulation (before and after reaction)
     - Coil cross-section (number of layers, number of turns, conductor weight/m/aperture)
     - Coil end design concept
     - Magnet support structure including transverse and axial support
     - Quench protection system in the case of no energy extraction
   - Maximum magnet bore field B_{max} at conductor SSL for 1.9 K and 4.5 K
   - Dependence of B_{max} on conductor J_c(16T,4.2K)
   - Calculated geometrical field harmonics, coil magnetization and iron saturation effects in magnet straight section at R_{ref}=17 mm for B=1-16 T
   - Stress distribution in coil and structure at room and operation temperatures and at the nominal (16 T) and design (17 T) fields
   - Coil-pole interface (gap) at the nominal (16 T) and design (17 T) fields
   - Coil maximum temperature and coil-to-ground voltage during quench w/o energy extraction
   - Cost reduction opportunities





	I0 (kA)	By-bore	Bmod (HTS)	Bmod (CCT)	Bmod (CT)
ANSYS	11	19.5	19.66	16.94	15.5
Opera2D	11	19.716	19.87	17.08	15.89
%diff		1.10	1.06	0.82	2.45
Poisson (Neumann boundary)	11	20.600	20.77	17.96	16.90
Poisson (parallel boundary)	11	19.370	19.58	16.80	15.82
Poisson (Average)		19.985	20.18	17.38	16.36
%diff		1.35	1.51	1.73	2.87

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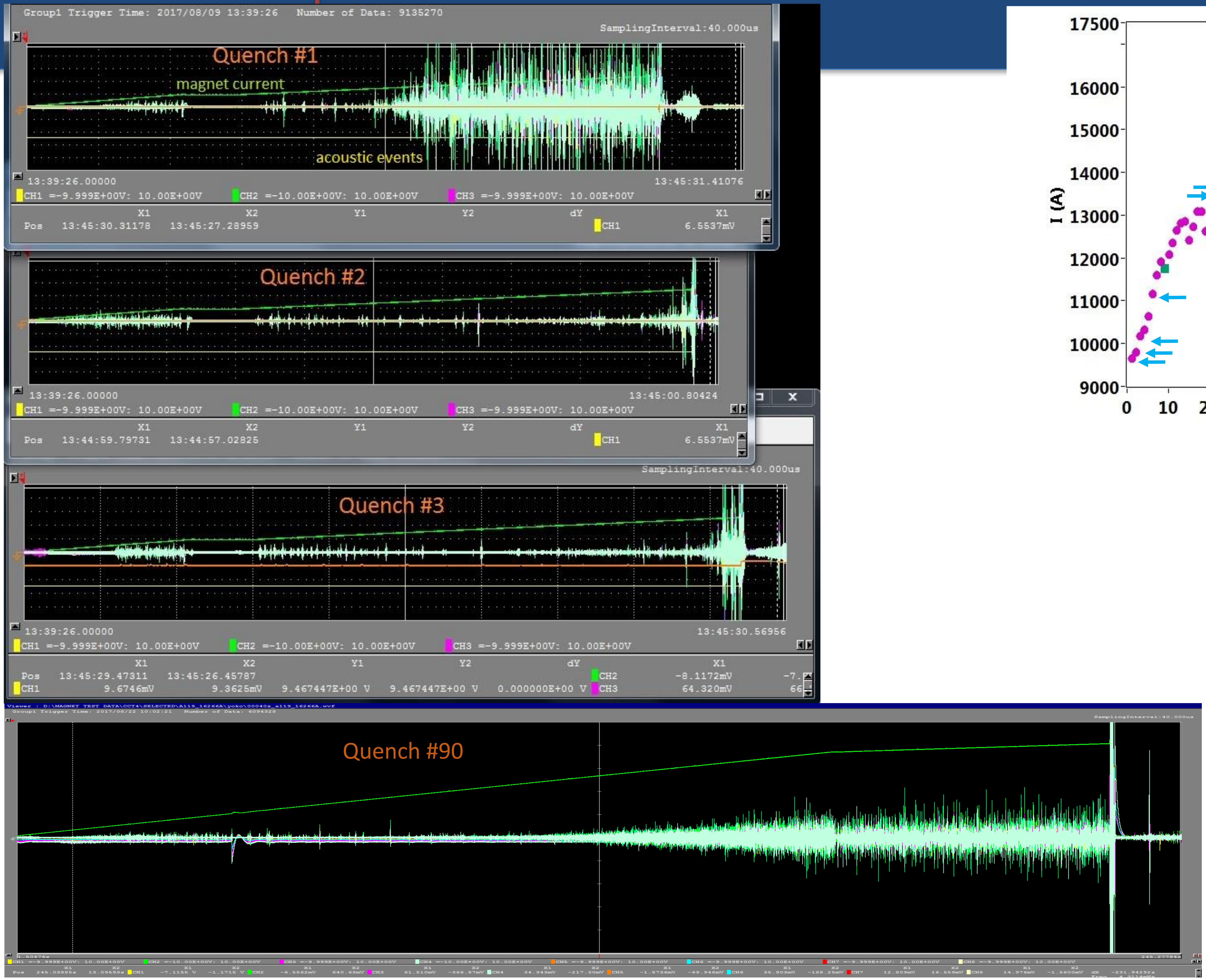
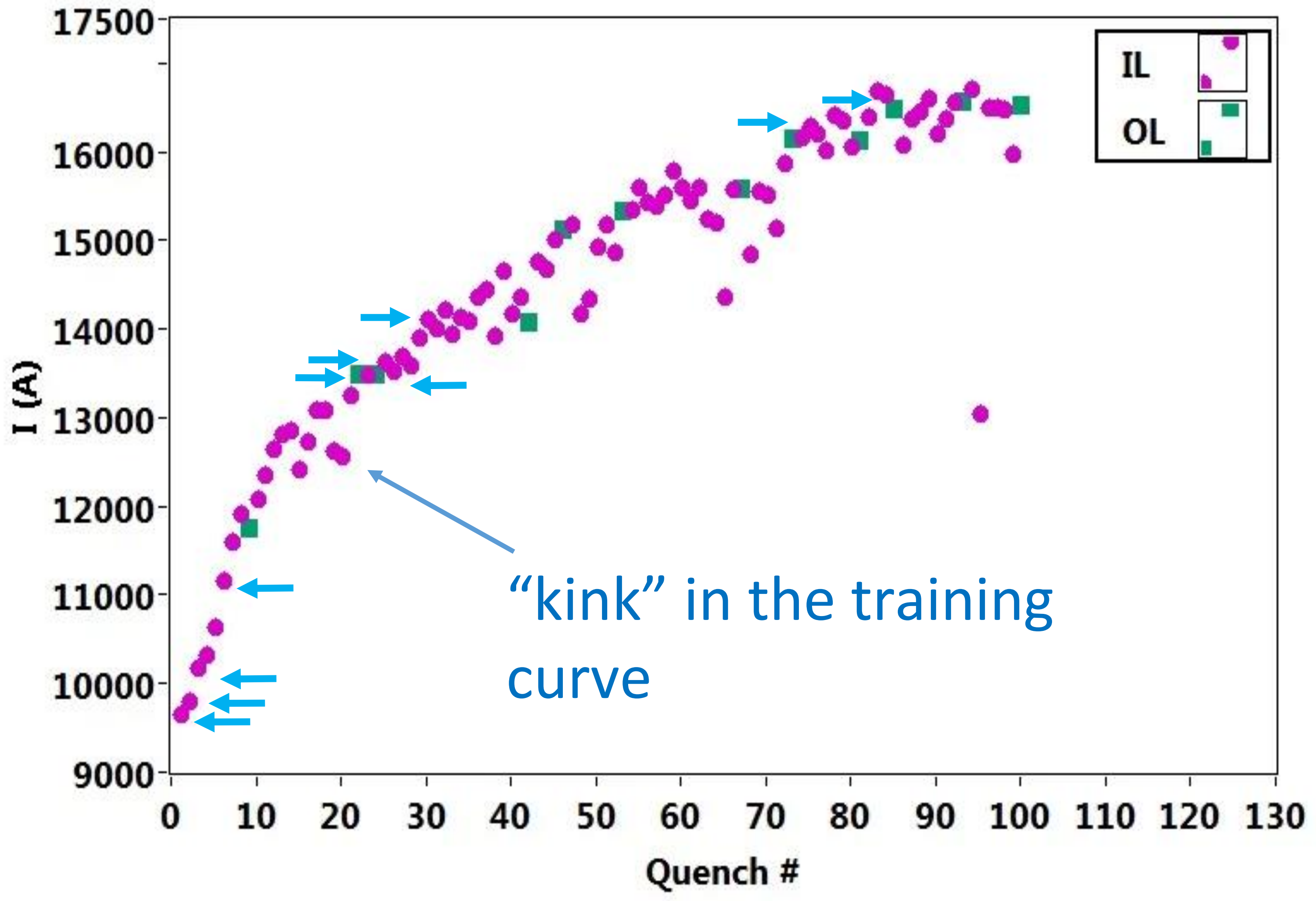
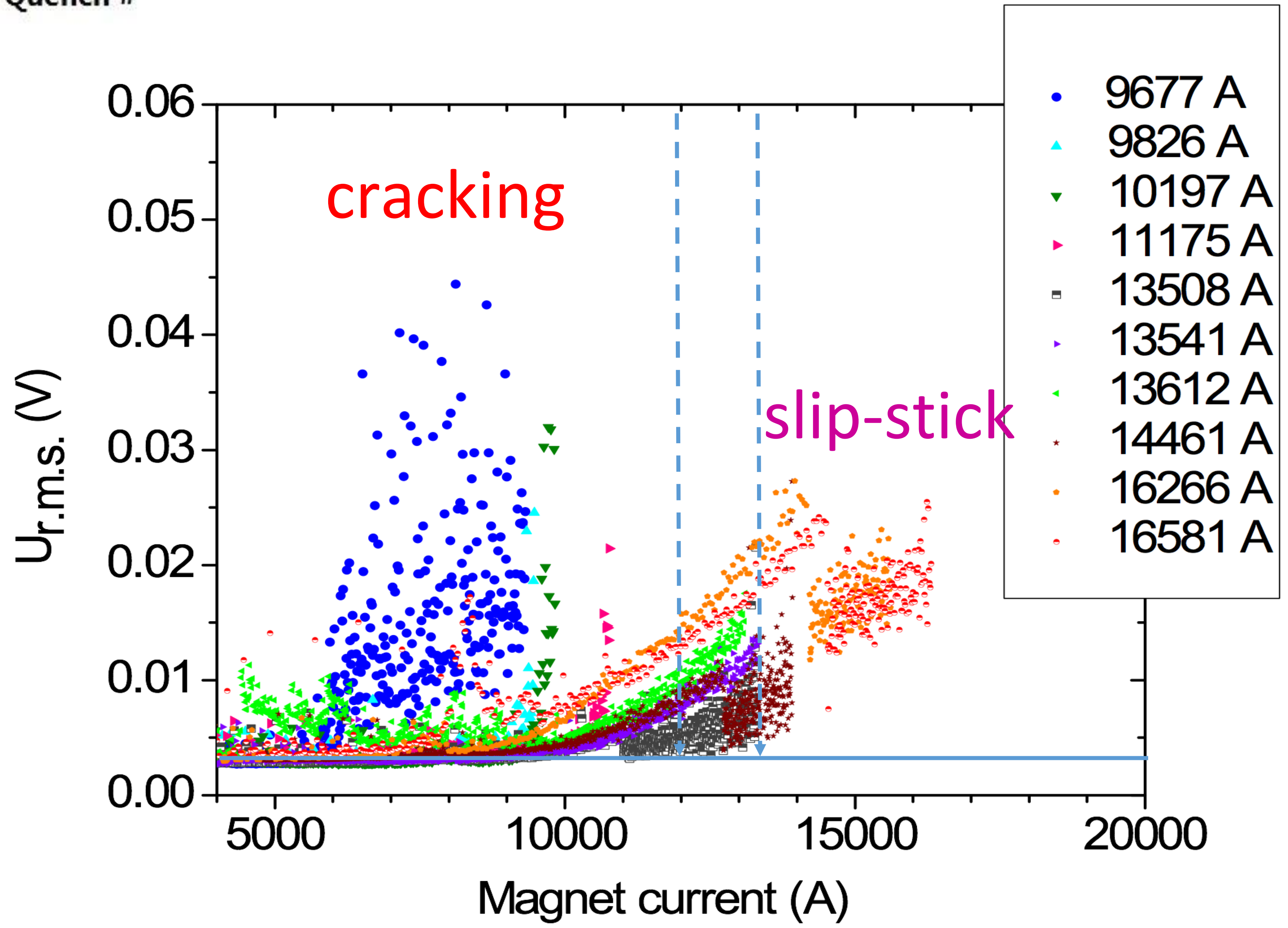
Quench memory and two distinct training regimes

Marchevsky, LBNL

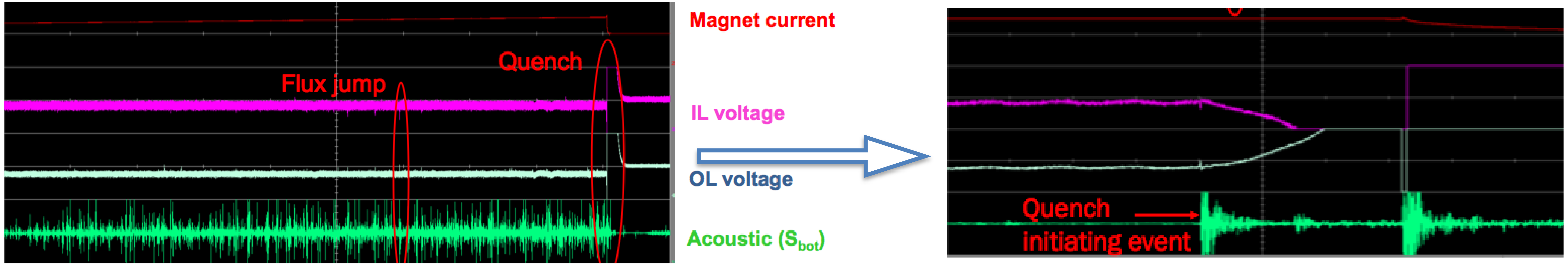


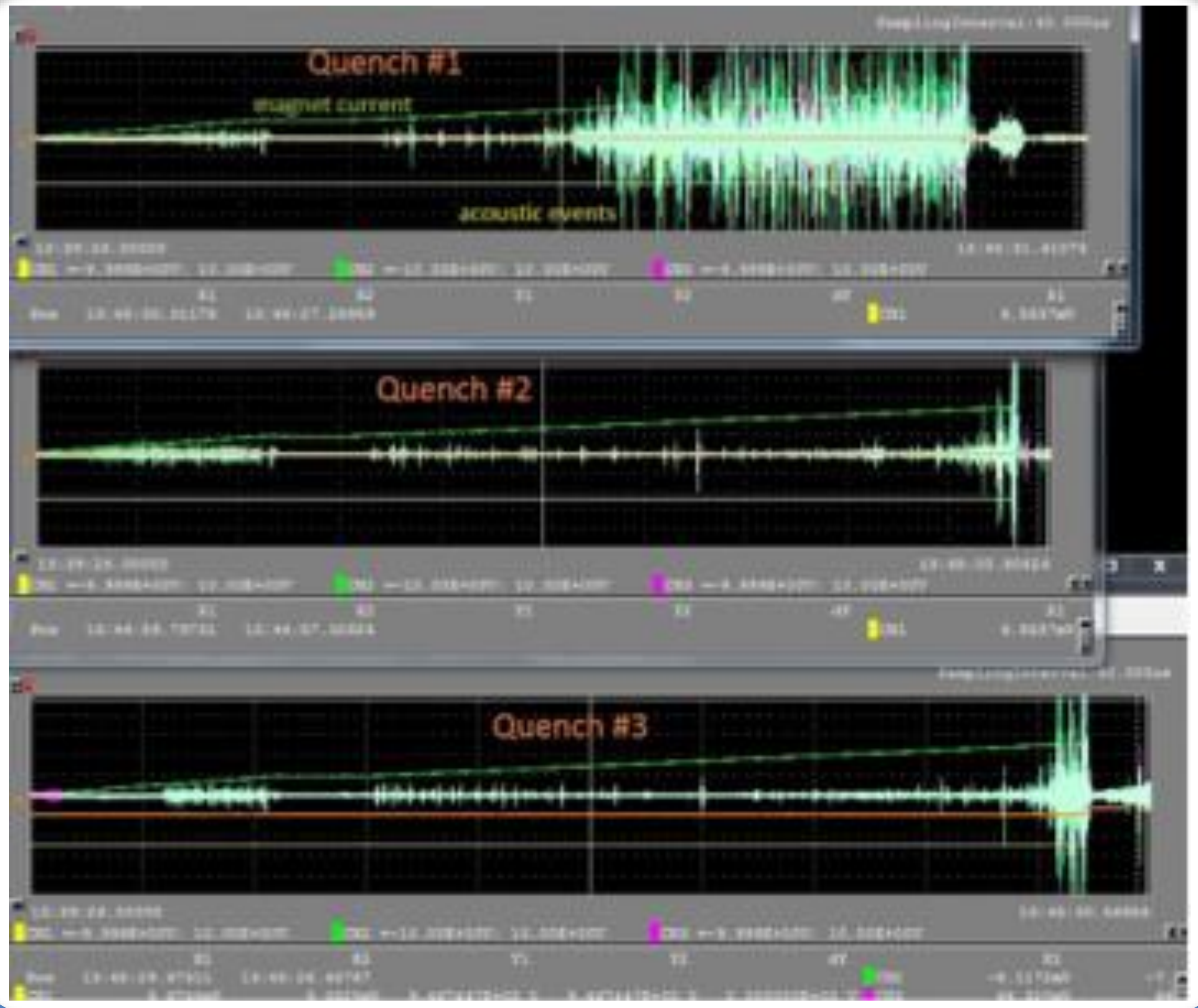




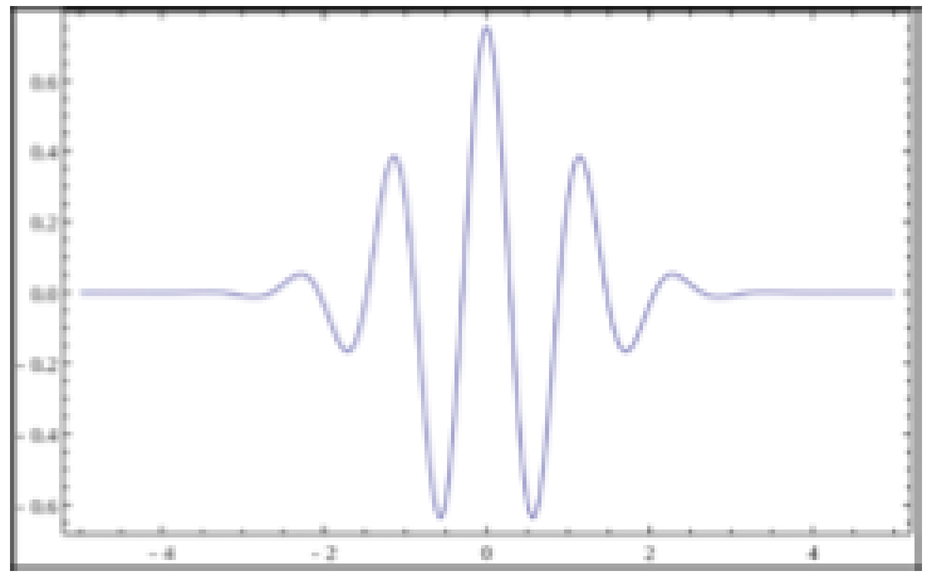
Progress on Technology front - Application of high-bandwidth acoustic sensors on magnets opens avenue for new insights into magnet behavior

- Large number of acoustic events occur during magnet ramping - potentially contain valuable insight into magnet behavior and the disturbance spectrum that initiates quenches



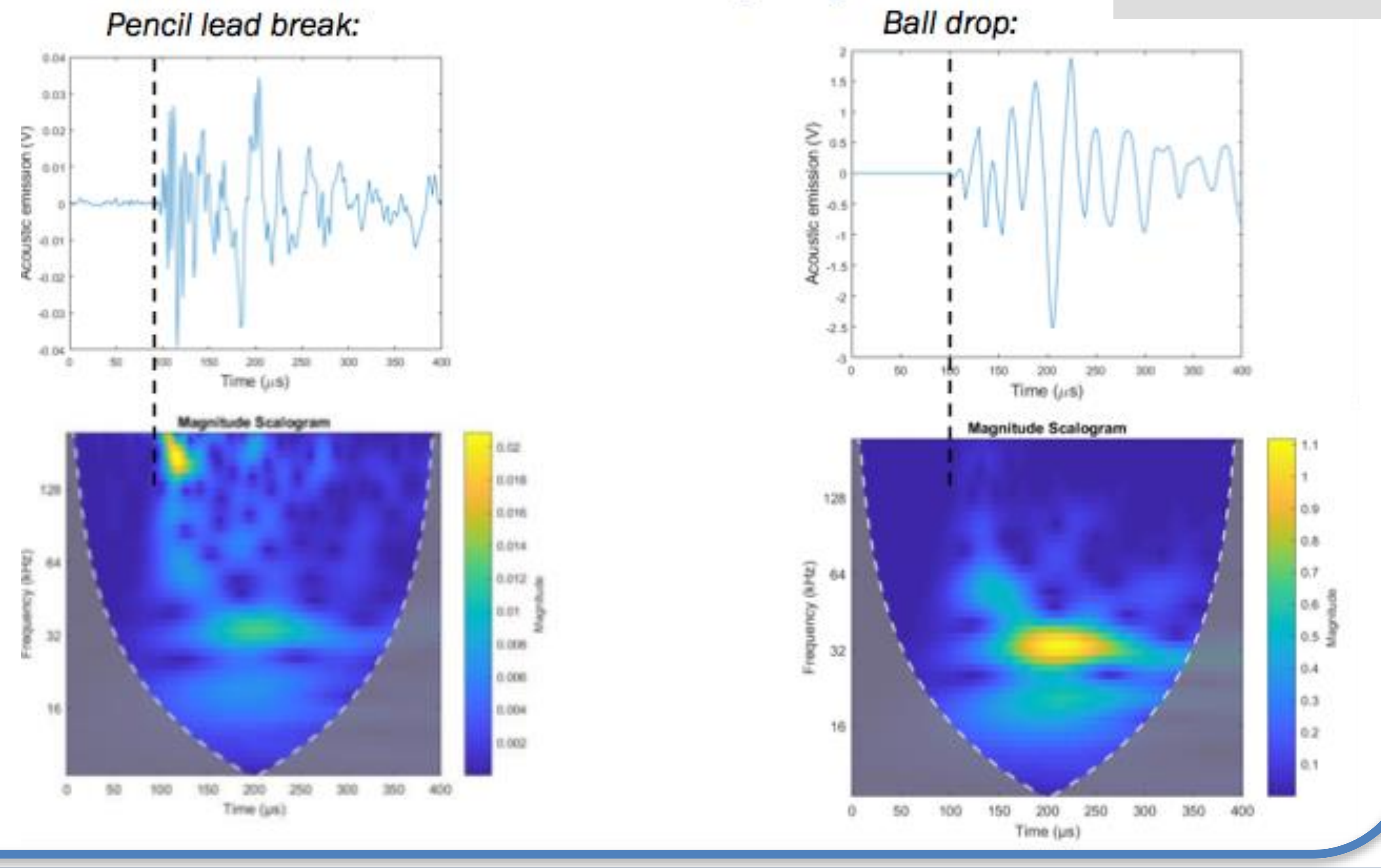


Wavelet analysis provides robust mathematics platform for transient signal analysis



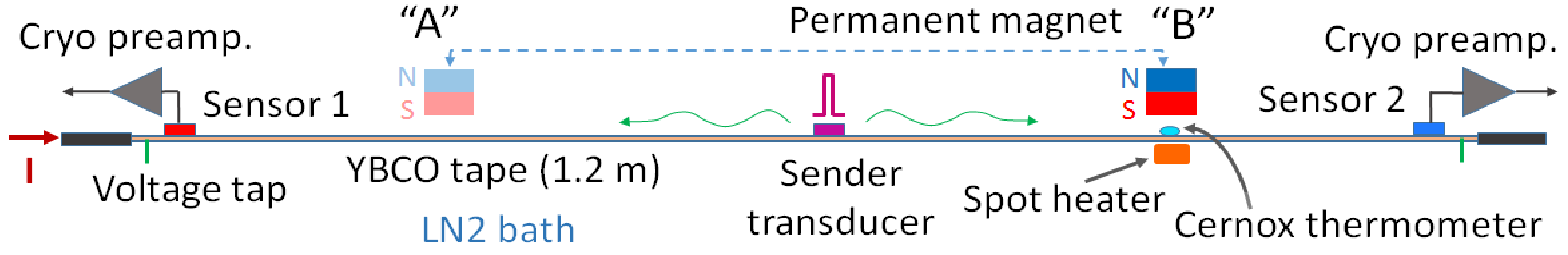
- Events have different frequency content:

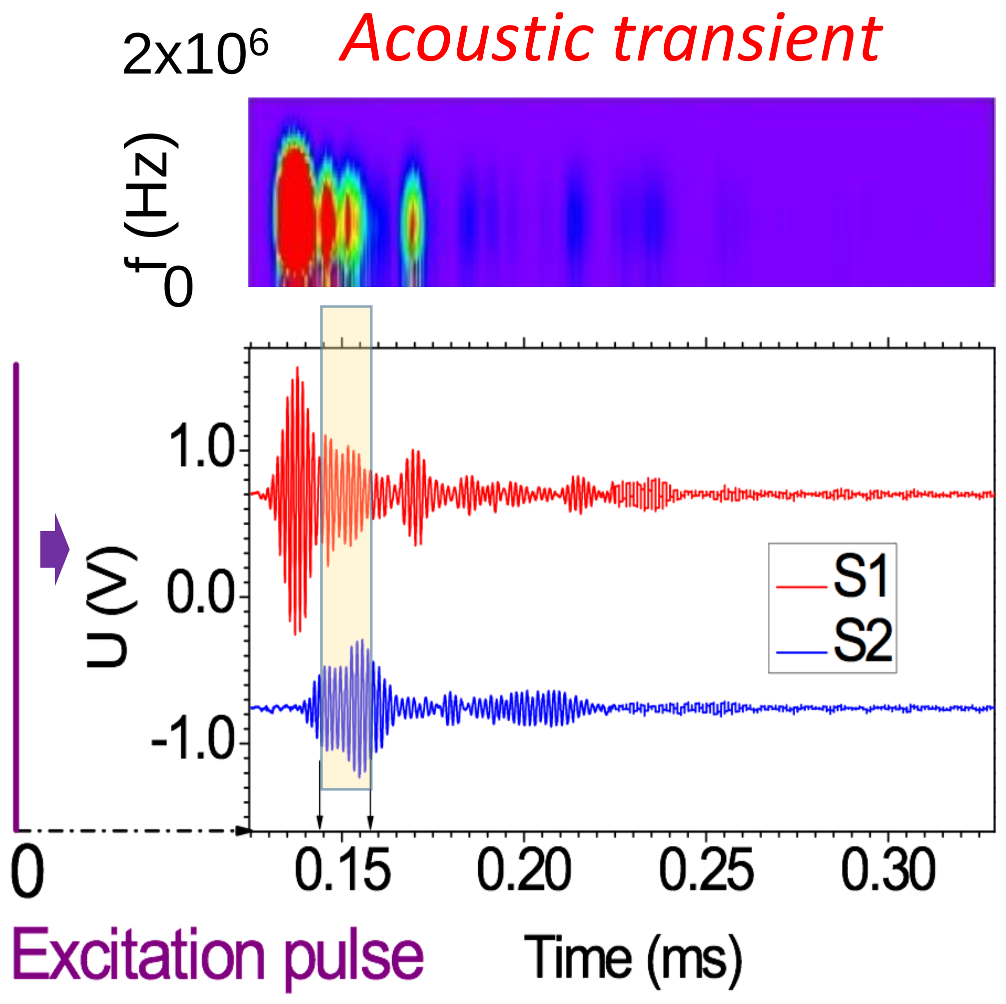
E. Nillson CERN/LBNL

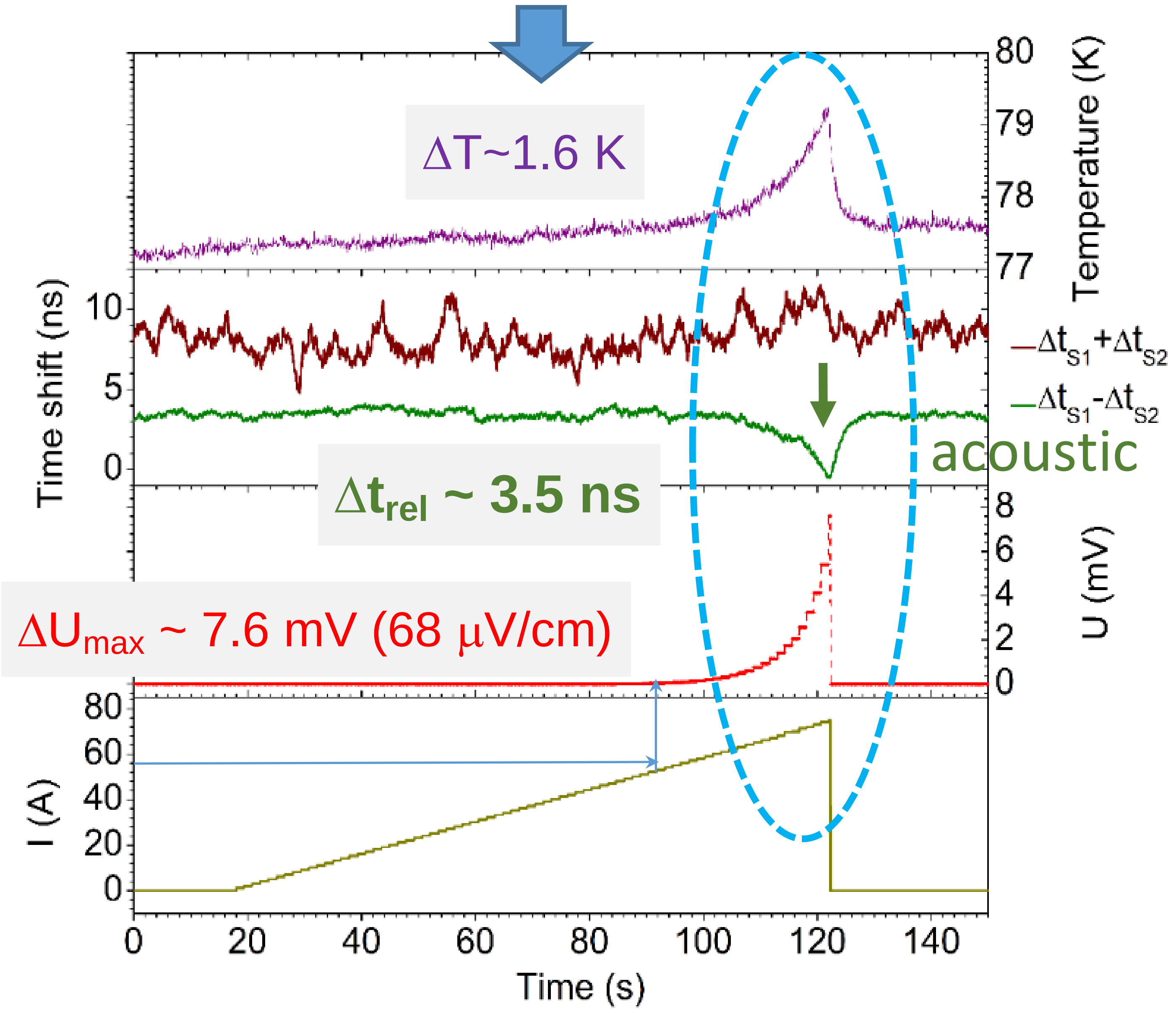


Acoustic thermometry for quench detection in HTS

New acoustic quench detection technique was developed and benchmarked against temperature and voltage measurements

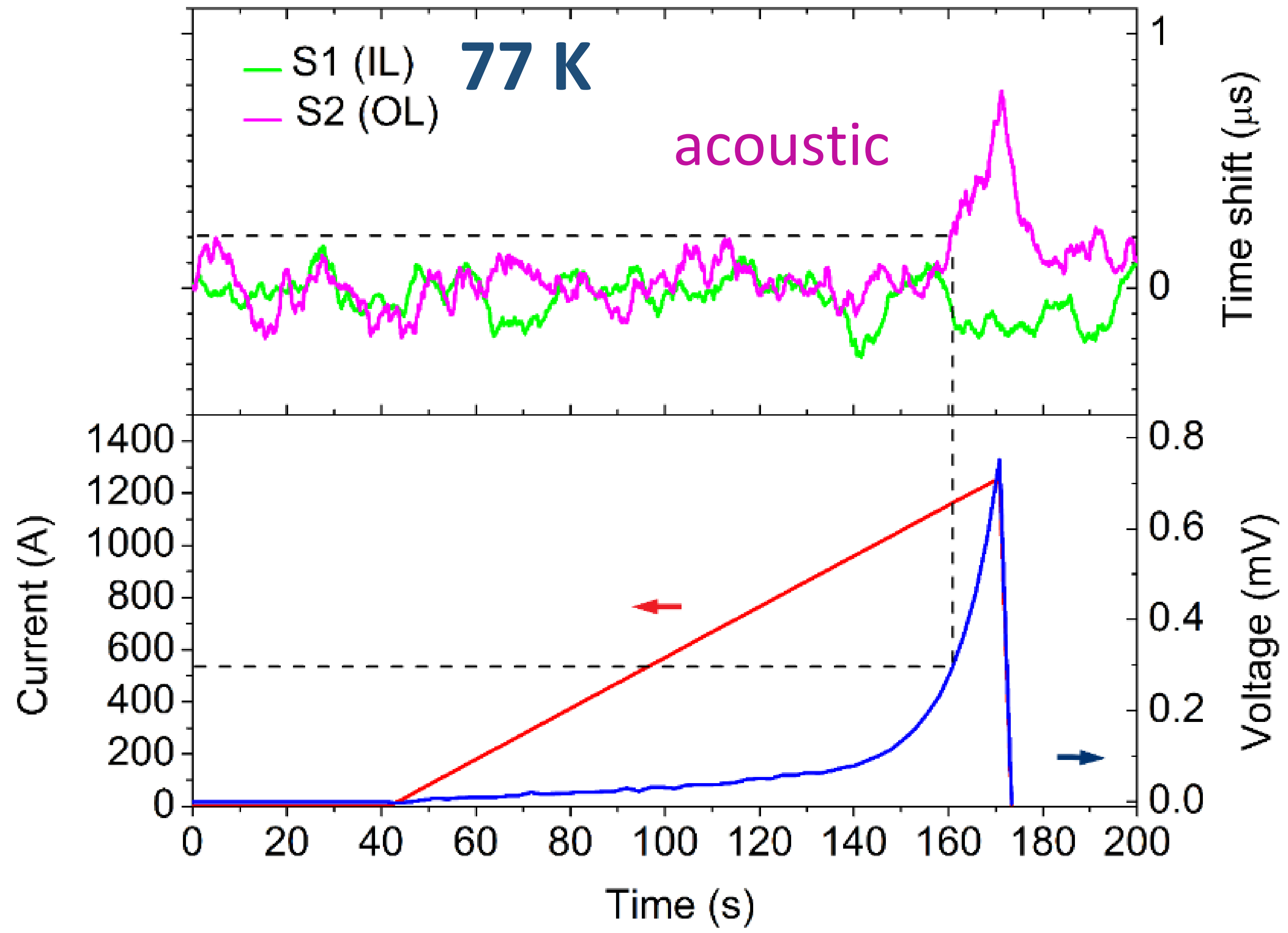






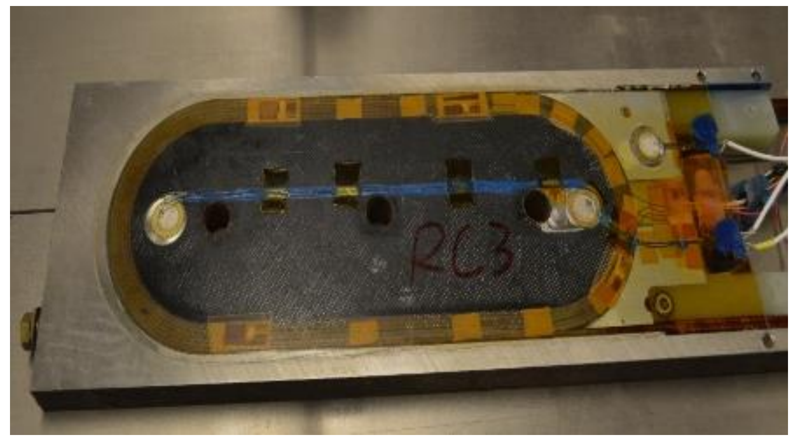
ReBCO CORC coil

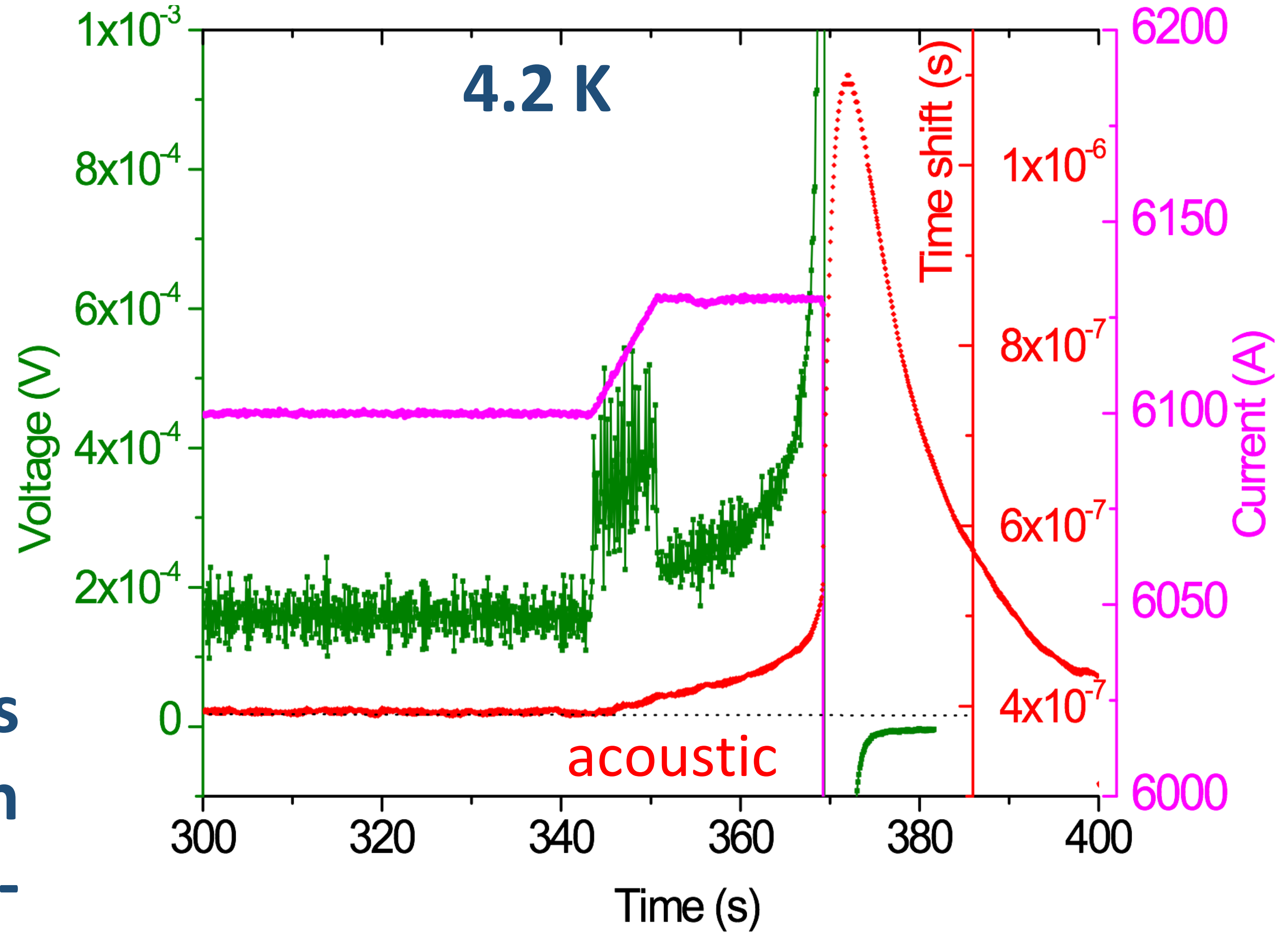
(X. Wang)



Bi-2212 coil RC3

(K. Zhang, T. Shen)





Technique was successfully tested in ReBCO CORC and Bi-2212 HTS subscales

- "**Acoustic thermometry for detecting quenches in superconducting coils and conductor stacks**," M. Marchevsky and S. A. Gourlay, *Appl. Phys. Lett.*, vol. 110, p. 012601, (2017), doi:10.1063/1.4973466
- "**Quench Detection for High-Temperature Superconductor Conductors using Acoustic Thermometry** ", M. Marchevsky et al., *IEEE Trans Appl. Supercond.* vol 28, issue 4 (2018), doi:10.1109/TASC.2018.2817218

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Progress on Technology front - Modeling capabilities continue to be developed that have broad applicability to superconducting magnet technology

- Advanced multi-physics coupling using custom elements, and leveraging of computing clusters with FEA

Geometry Generation
Meshing
Boundary conditions
Loads

Solution →

Post processing
Load transfer between models

Replace code which builds element matrices: uel.f, uec.f -> compile custom ANSYS.exe

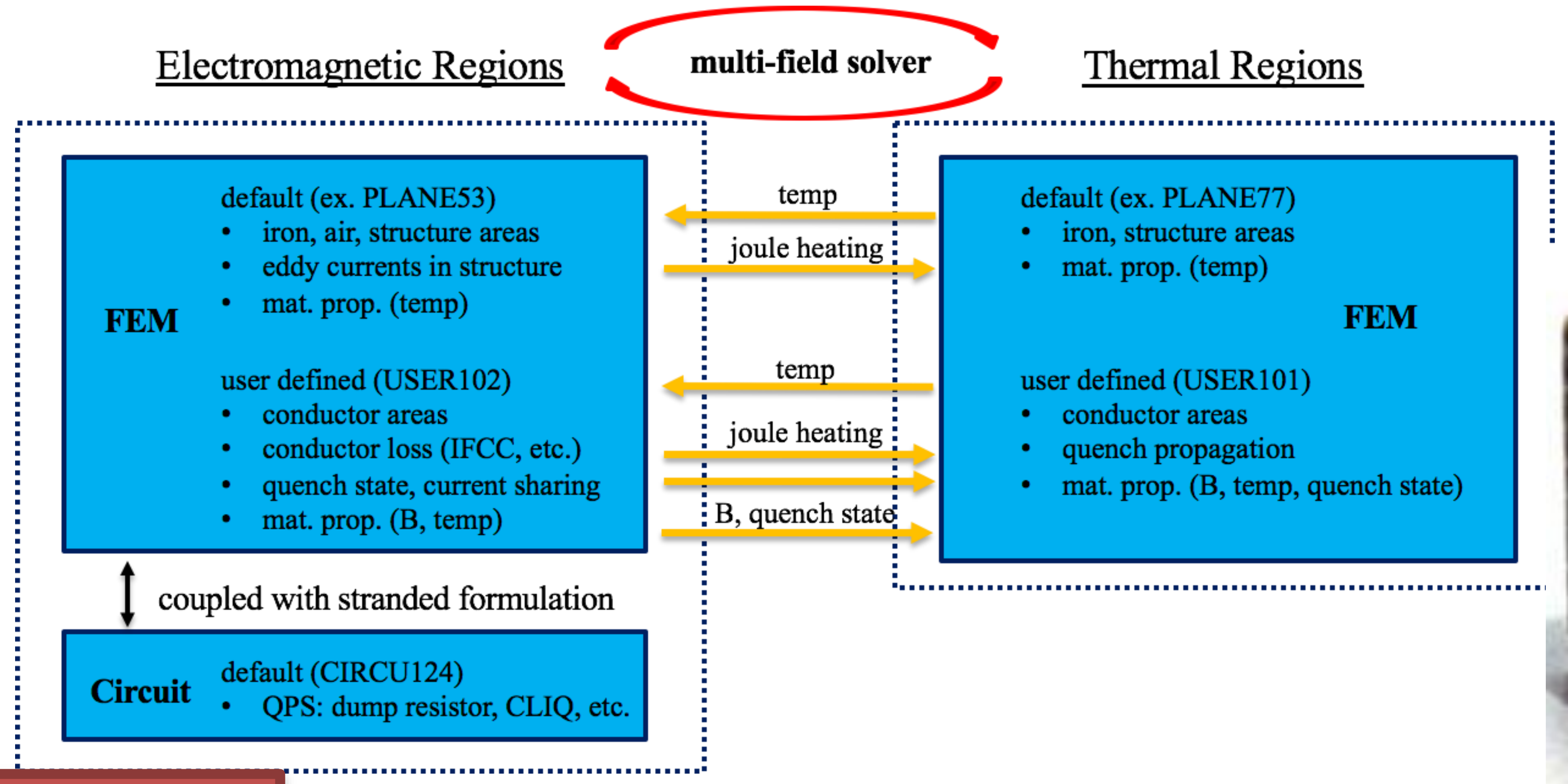
Available
- node location
- loads
- node temperature
- material prop.
- ANSYS functions

→

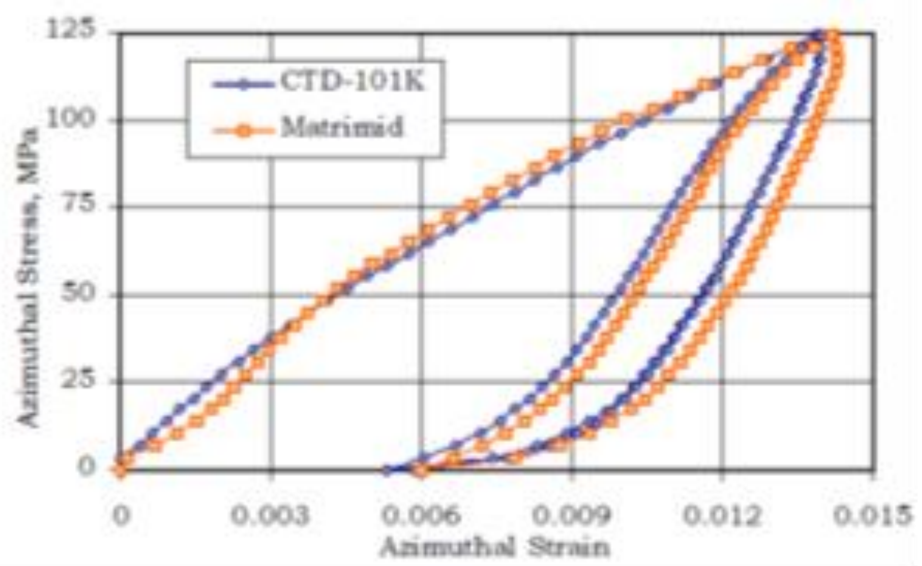
Element customized by defining
- element shape functions
- material properties: if complex function desired (T,B,Jc,etc.)
- formulation

→

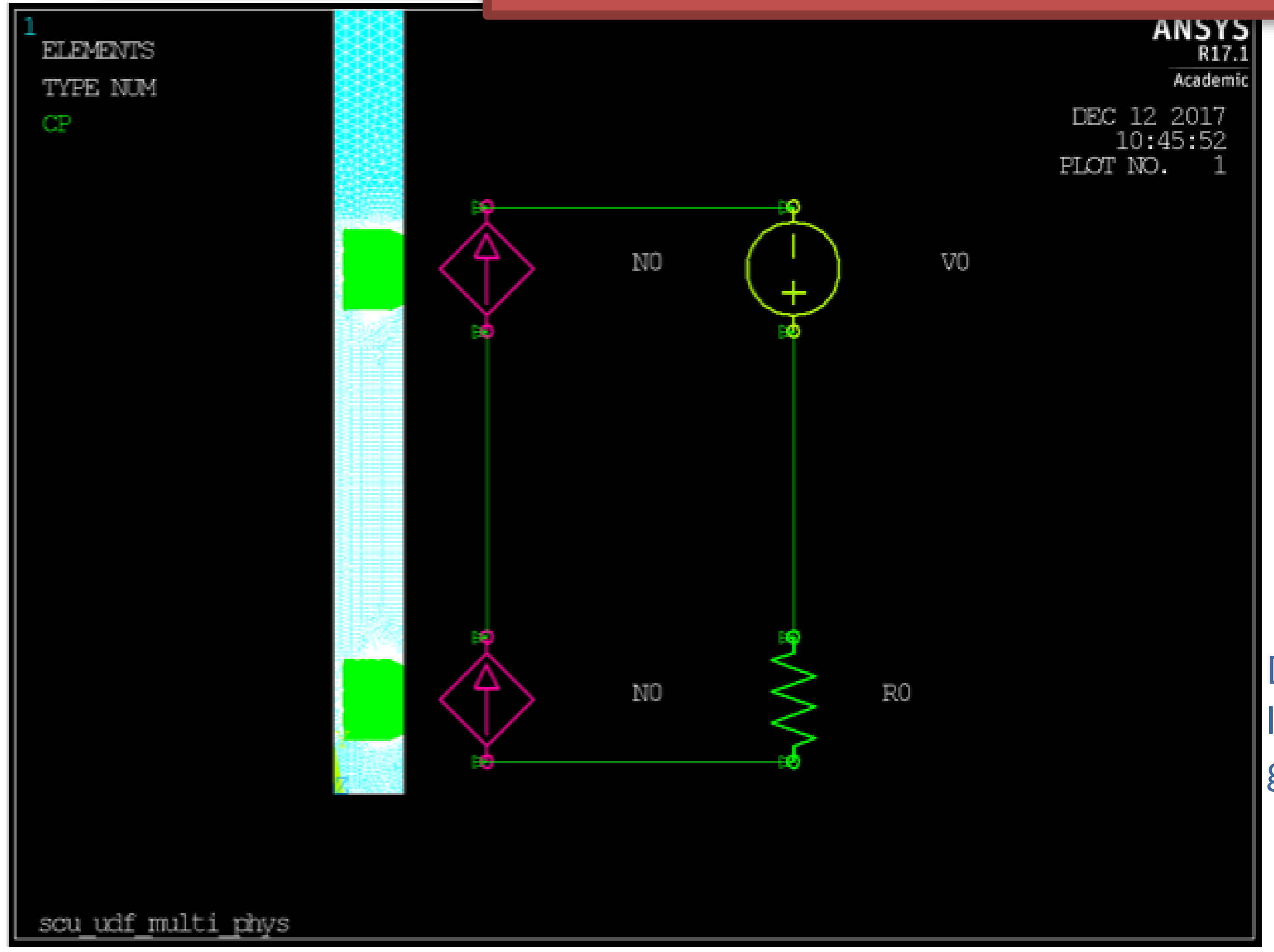
Element matrix generation is now determined by user program
- stiffness, damping, etc.

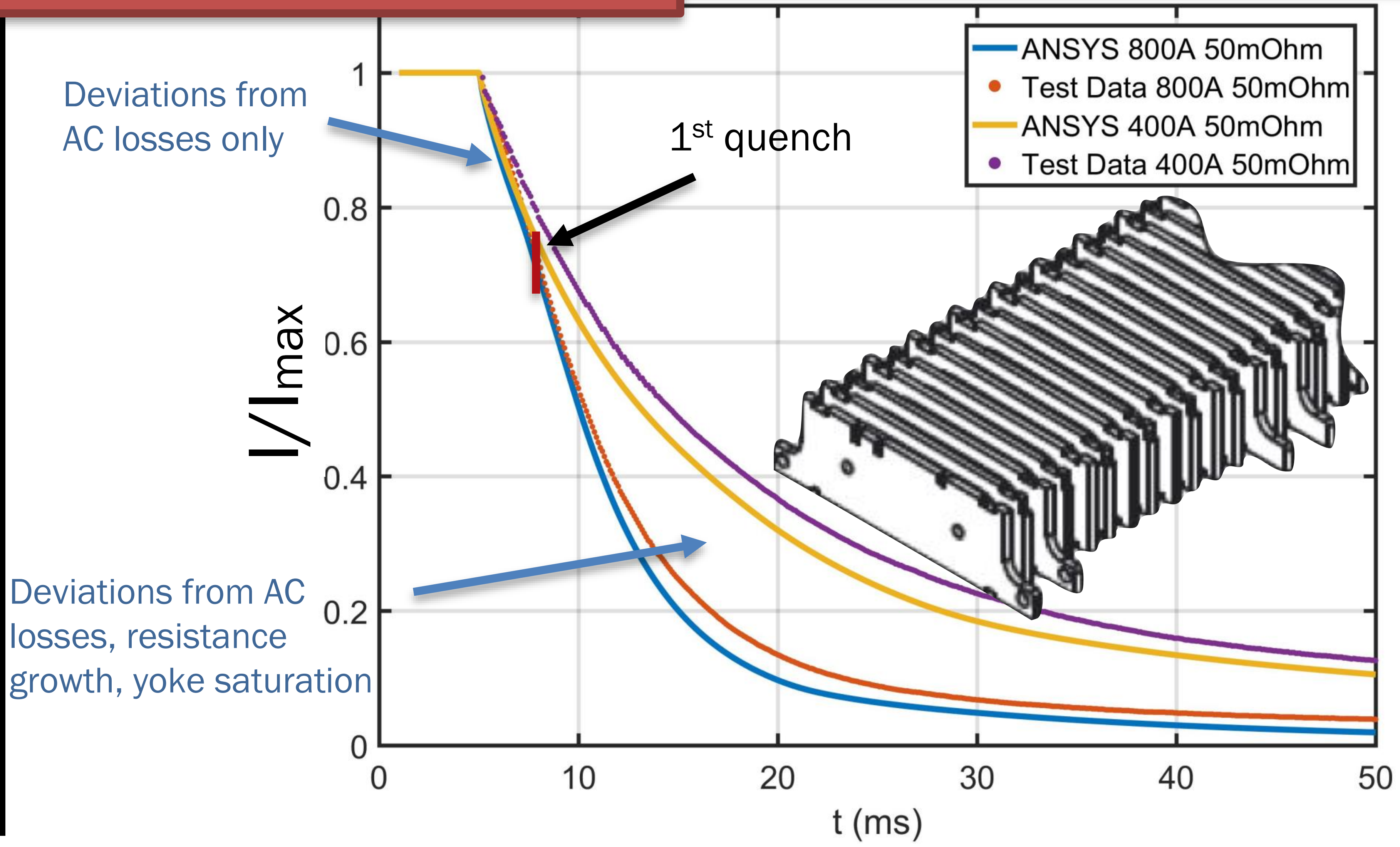


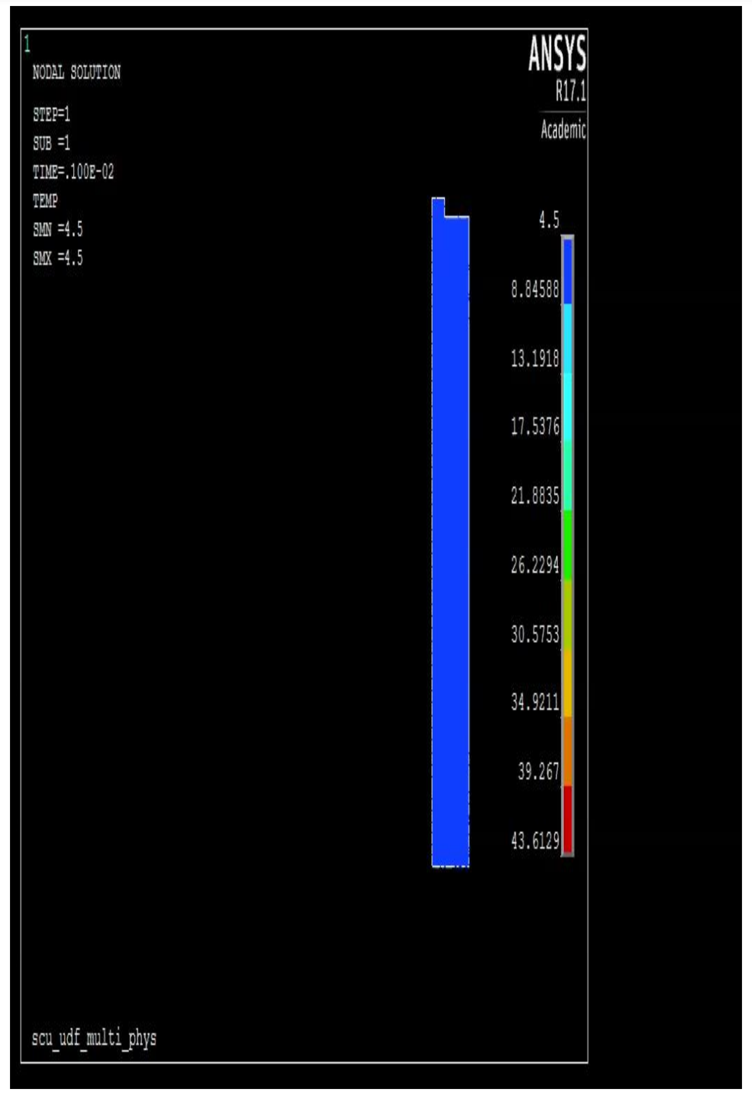
S. Krave, FNAL

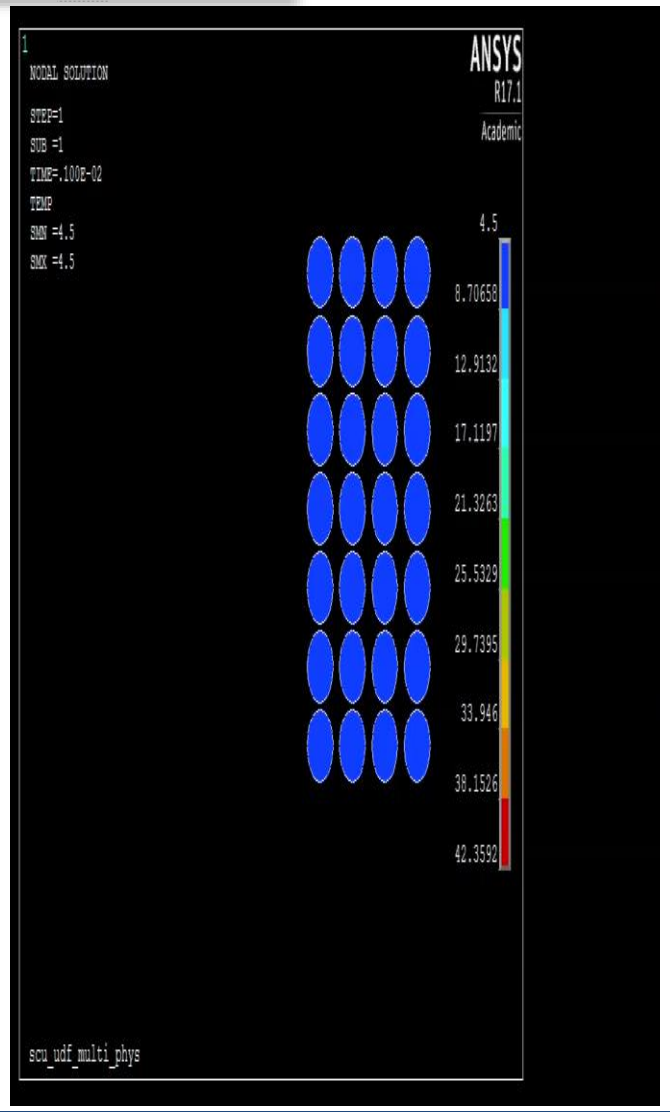


Brouwer, LBNL; Auchmann, PSI/CERN









CPRD:
Balanced effort of supplying sufficient conductor for magnet R&D and serving as catalyst for the next generation conductor

Area IV: *Continue the extremely successful paradigm of OHEP's Conductor Development Program*


NATIONAL MAGLAB

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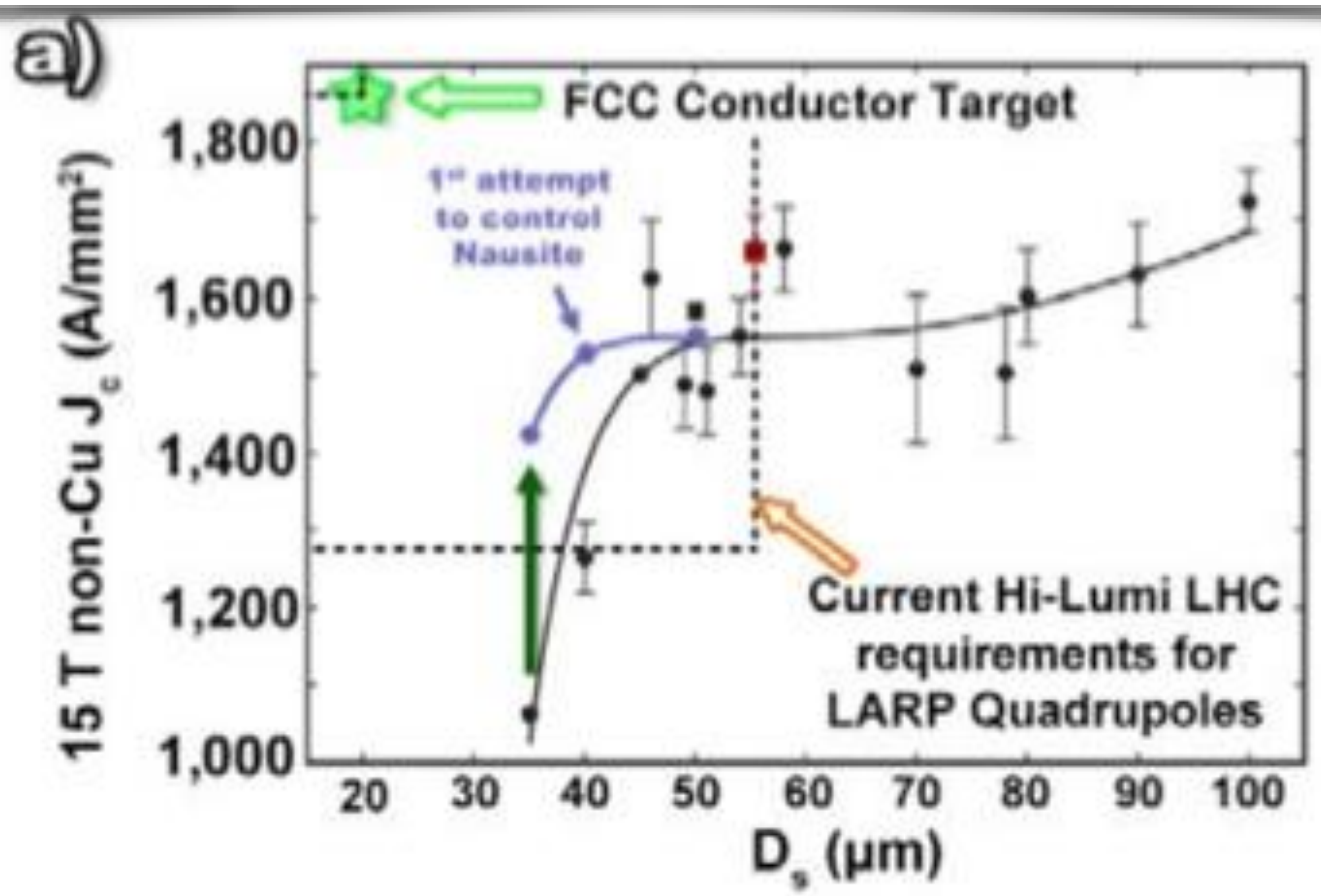
Lance Cooley, Ph.D.
Head, Conductor Procurement and R&D Program
US HEP Magnet Development Program
Applied Superconductivity Center, National High Magnetic Field Laboratory
2031 E. Paul Dirac Dr, Tallahassee, FL 32310-3711 USA
ldcooley@asc.magnet.fsu.edu

Roadmap for Conductor Procurement, Research and Development
October 6, 2017

Covering DOE FY 2018

Larbalestier 2AMS07A

Lee 2AMS05A



- A Roadmap has been developed to clarify CPRD's vision of furthering conductor development, supporting ongoing magnet development needs, and coordinating critical R&D from other funding sources in support of MDP goals
- Nb_3Sn advances continue to be pushed
  - Advances in understanding of the chemistry of Nb_3Sn heat treatment ⇒ significant improvement in J_c for small d_{eff}
  - Equal-channel angular extrusion evaluation by Bruker/OST
- Investigate potential for APC Nb_3Sn
  - Ohio State, FNAL LDRD, FSU

Barzi 2AMS07B

- Advances in Bi2212 powder processing + overpressure processing
- REBCO development focused on leveraging SBIR and complementary programs;
  - MDP provides measurements and conductor performance feedback to developers and vendors

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International and industrial collaborations are underway in support of the MDP mission

Activity	MDP Relevance	Collaborating Institution	Contact(s)	Contact(s)
International				
Provide coil parts	15T Dipole	EuroCirCol/CERN	Tommasini, D., Shoerling, D.	Zlobin, A.
Mechanical analysis	15T Dipole	CERN/U. Patras		Zlobin, A.
History and Documentation of Nb3Sn Magnet R&D	MDP Nb3Sn Program	EuroCirCol	Schoerling, D.	Zlobin, A.
CCT Development	Nb3Sn CCT	PSI	Auchmann, B.	Brouwer, L.
CCT Instrumentation	Nb3Sn CCT	PSI	Auchmann, B., Montenero, G.	Marchevsky, M.
Acoustic Sensor Development	Technology Development	Danish Technological Institute	Zangenberg, N.	Marchevsky, M.
Acoustic Sensor Development	Technology Development	CERN	Willering, G.	Marchevsky, M.
Acoustic Sensor Development	Technology Development	CERN	Kirby, G.	Marchevsky, M.
Industry				
CPRD	Conductor R&D	B-OST/Hypertech		Cooley, L.
High-Cp Nb3Sn development	Nb3Sn Conductor R&D	B-OST	Parell, J.	Barzi, E.
CORC Development	Conductor R&D	ACT	Van der Laan, D.	Wang, X.
Development of High Performance Bi-2212 Precursor powder	Conductor R&D	nGimat LLC		Shen, T.
Other DHEP-Funded				
Magnetization studies	Conductor R&D	OSU	Sumption, M.	Wang, X.
Fiber Optic Quench Detection	HTS	PSU/Lupine Materials and Technology		Shen, T.

Conclusions

- We are following the MDP roadmap to develop high field accelerator magnets for DOE-OHEP

- We have a fully functioning management structure

- We are balancing our efforts to maintain progress on multiple fronts
  - Significant progress on Nb_3Sn magnets
  - HTS magnet development - on both Bi2212 and REBCO fronts
  - Critical technology developments that guide magnets… and of value to the broader community

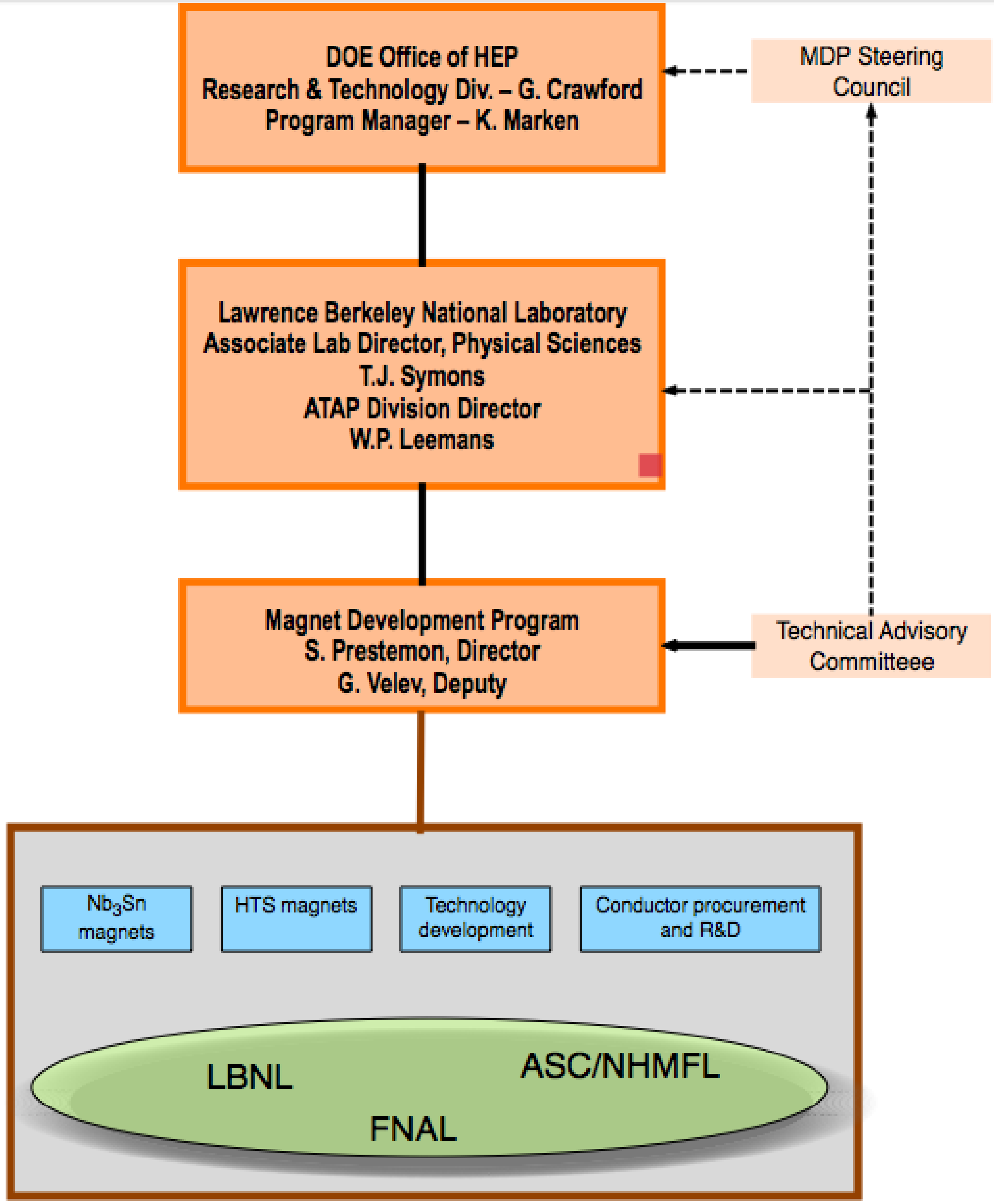
- We have developed a coherent conductor R&D roadmap

- We have a strong, and growing, list of national and international collaborations

BACKUP

One full year is now behind us…

The management structure of the MDP is well defined and the program is fully functioning



Technical Advisory Committee
Andrew Lankford, UC Irvine – ***Chair***
Davide Tommasini, CERN
Akira Yamamoto, KEK
Joe Minervini, MIT
Giorgio Apollinari, FNAL
Mark Palmer, BNL

MDP Management Group
S. Prestemon, LBNL
G. Velev, FNAL
L. Cooley, FSU
S. Gourlay, LBNL
D. Larbalestier, FSU
A. Zlobin, FNAL