U.S. MAGNET DEVELOPMENT PROGRAM

Current Status of the US Magnet Development Program

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

Outline

- Guidance to the Technical Advisory Committee
  - Updated from last year
- High level program overview
  - Review of the program foundation
  - Management and technical oversight structure
  - Review of program goals and driving questions
- Overview of MDP-aligned collaborations
- Goals of the collaboration meeting
- Guidance to speakers
- Guidance to session chairs/moderators

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Charge questions for the Technical Advisory Committee

- The MDP priorities pursued over the last year are based on a balanced approach using available resources. Do the priorities reflect a reasonable approach to address the Program goals and Driving Questions given the current and projected funding levels and available resources? Comment on infrastructure improvements and their investment vs the R&D program.
- What elements or results of the current plan are most likely to have the highest near term impact? Which elements are critical for longer term program success?
- Comment on the progress on the HTS and Nb_3Sn efforts. Is the planning for hybrid magnet designs developing properly?
- Is the conductor roadmap adequate to address present needs and plan for future opportunities?
- Comment on progress in integrating the program between the labs
- Is the MDP approach to international collaborations at an appropriate level?

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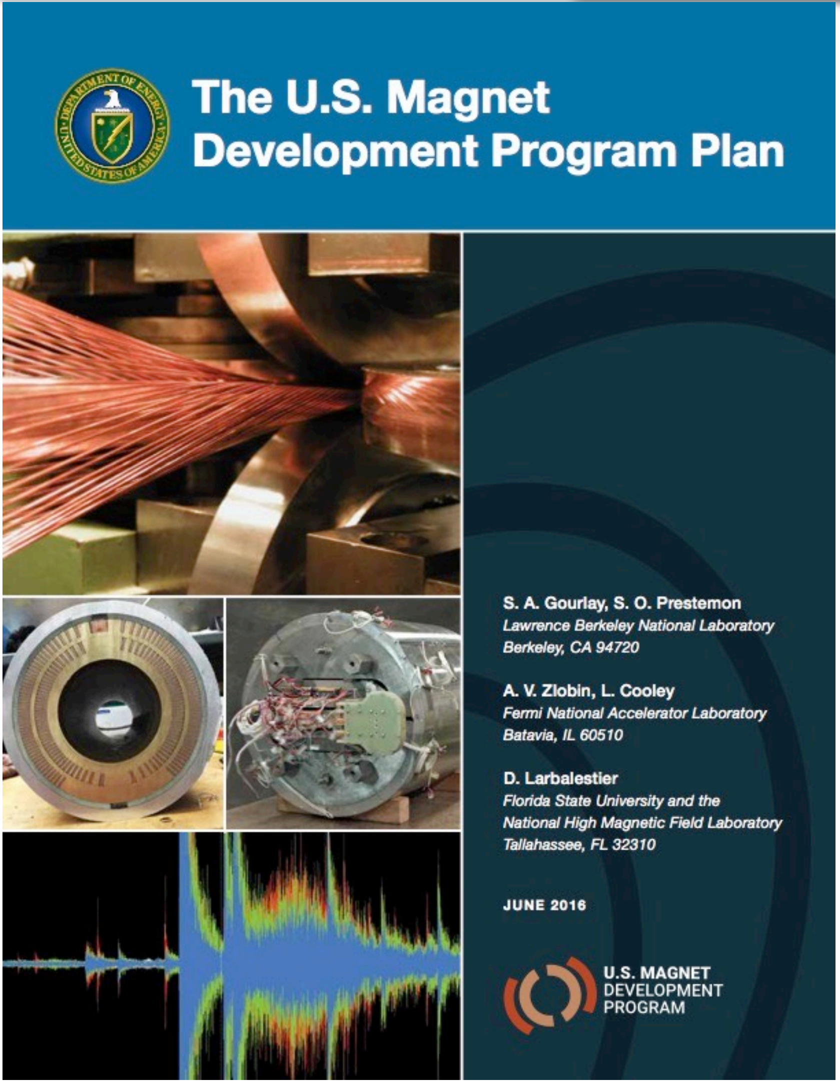
The US Magnet Development Program was founded by DOE-OHEP to advance superconducting magnet technology for future colliders



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.

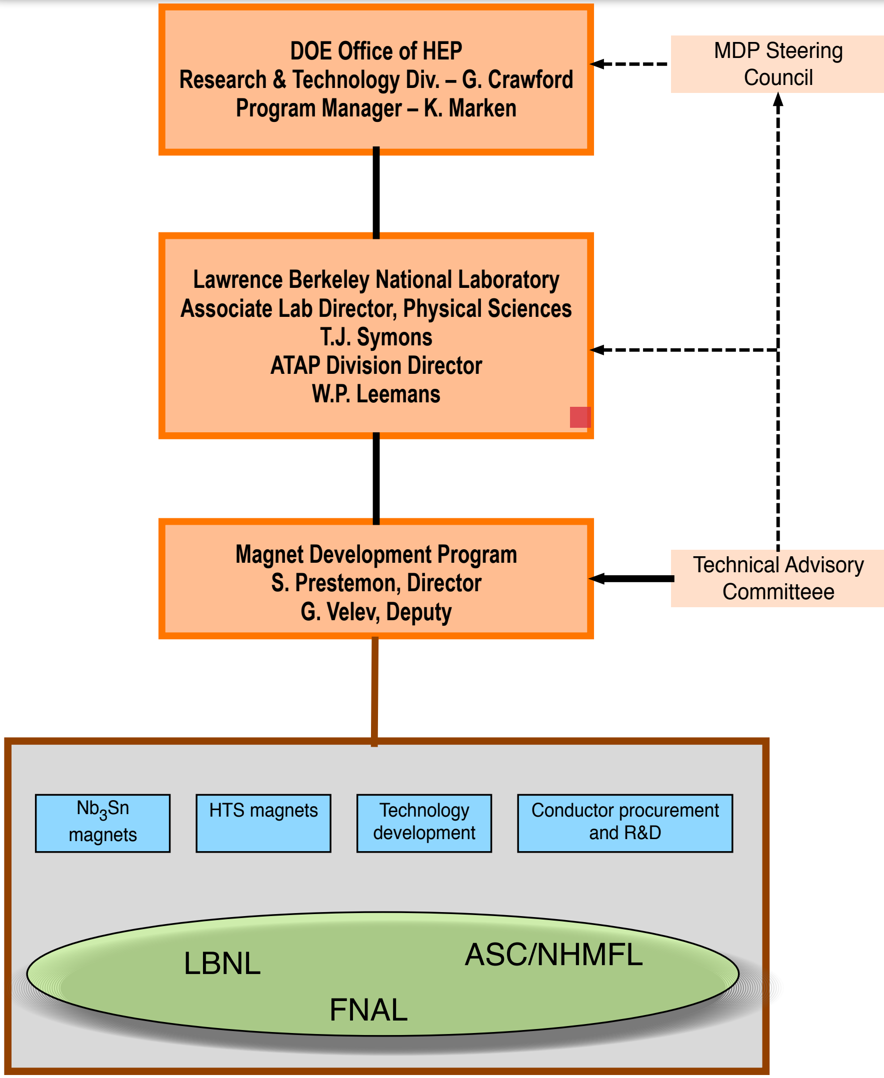
GOAL 3:

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.

One full year is now behind us…
The management structure of the MDP is well defined and the program is fully functioning



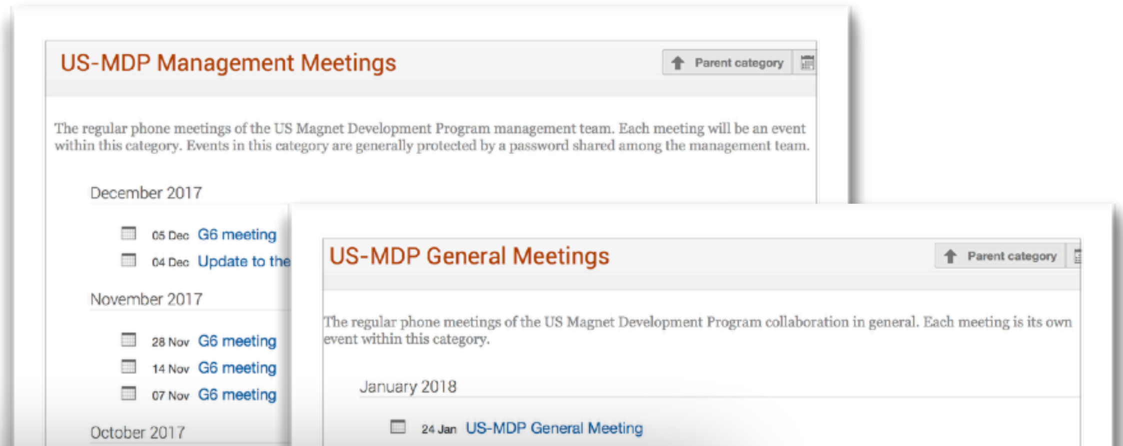
Technical Advisory Committee
Andrew Lankford, UC Irvine – ***Chair***
Davide Tommasini, CERN
Akira Yamamoto, KEK
Joe Minervini, MIT
Giorgio Apollinari, FNAL
Mark Palmer, BNL

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

Regular management and team meetings

- Internal management via "G6":
  - Prestemon (Director), Velev (Deputy), Cooley, Gourlay, Larbalestier, Zlobin
  - Meets weekly via videoconference

- Full MDP team meets regularly (~biweekly) with technical updates and discussion



US-MDP Management Meetings

Parent category

The regular phone meetings of the US Magnet Development Program management team. Each meeting will be an event within this category. Events in this category are generally protected by a password shared among the management team.

December 2017

05 Dec G6 meeting

04 Dec Update to the

November 2017

28 Nov G6 meeting

14 Nov G6 meeting

07 Nov G6 meeting

October 2017

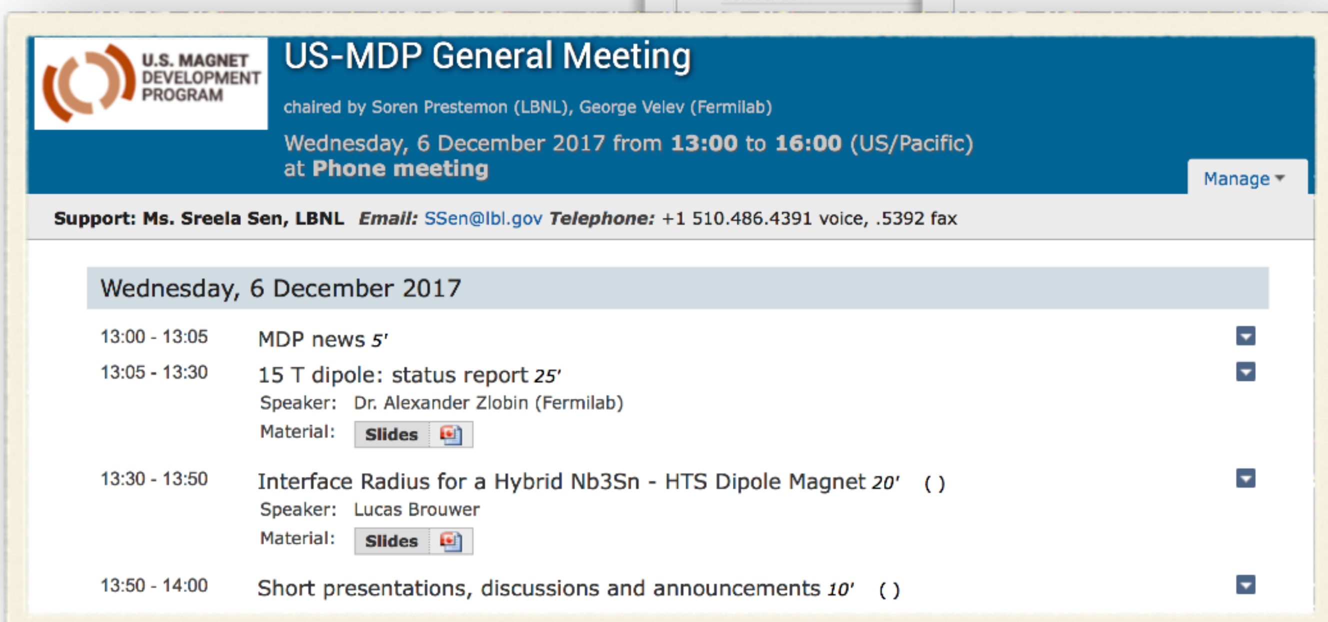
US-MDP General Meetings

Parent category

The regular phone meetings of the US Magnet Development Program collaboration in general. Each meeting is its own event within this category.

January 2018

24 Jan US-MDP General Meeting



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US-MDP General Meeting

chaired by Soren Prestemon (LBNL), George Velev (Fermilab)

Wednesday, 6 December 2017 from **13:00** to **16:00** (US/Pacific)
at **Phone meeting**

Manage

Support: Ms. Sreela Sen, LBNL ***Email:*** SSen@lbl.gov ***Telephone:*** +1 510.486.4391 voice, .5392 fax

Wednesday, 6 December 2017

13:00 - 13:05	MDP news *5'*
13:05 - 13:30	15 T dipole: status report *25'* Speaker: Dr. Alexander Zlobin (Fermilab) Material: **Slides**
13:30 - 13:50	Interface Radius for a Hybrid Nb3Sn - HTS Dipole Magnet *20'* ( ) Speaker: Lucas Brouwer Material: **Slides**
13:50 - 14:00	Short presentations, discussions and announcements *10'* ( )

Technical areas have leads who are responsible for coordination and planning

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Magnets	Lead
Cosine-theta 4-layer	Sasha Zlobin
Canted Cosine theta	Diego Arbelaez
Bi2212 dipoles	Tengming Shen
REBCO dipoles	Xiaorong Wang
Cond Proc and R&D	Lance Cooley

Nb_3Sn

Design Teams:
16 T Dipole design:
Leads: Zlobin and Sabbi
Utility Structure design:
Lead: Mariusz Juchno

HTS

Conductor R&D

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

Technology development

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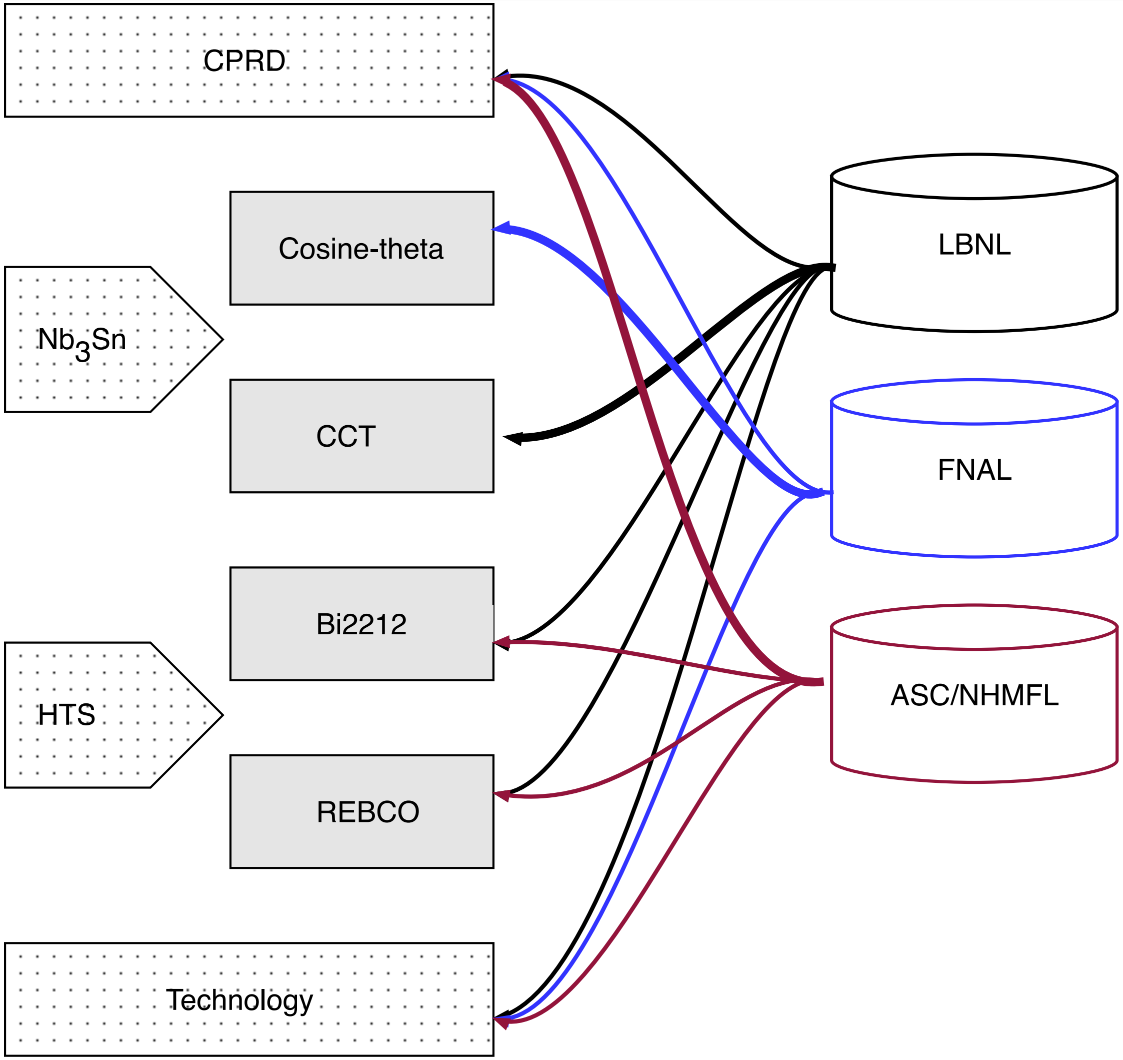
Building strong programatic interconnections

- Clear leadership roles in…
  - Cosine-theta: FNAL
  - CCT: LBNL
  - CPRD: ASC/NHMFL
- Joint advances on HTS and Technology
- Significant interaction on all fronts



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Technical reviews have been held on specific elements of the program

HFM meeting - **15 T L1/L2 coil production readiness review**
Wednesday September 20, 2017
2:30 - 5:00 p.m.
IB3-A conference room

Agenda:

2:30 – 2:50	Magnet design, fabrication
2:50 – 3:15	Coil and tooling design, infr
3:15 – 3:35	Coil instrumentation plan (S
3:35 – 4:00	Cable and coil part inventor
4:00 – 4:30	Tour to IB3A - Questions, di
4:30 – 5:00	Review committee executiv

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US-MDP CCT Program Review

Monday, 1 May 2017 from **08:00** to **17:30** (US/Pacific)
at **B47 (Conference room)**
LBNL 1 Cyclotron Road Berkeley, CA 94720 USA

Manage

Description **US Magnet Development Program**

CCT Magnet Program

Review date: May 1st, 2017

Introduction: The US MDP is pursuing multiple eff magnet technology. One line of investigation, pursu is the investigation of the "Canted Cosine Theta" (C focused on identifying and addressing primary techn CCT configuration. To that end, a series of 2-layer n magnet, CCT4, is being readied for testing, and a fo Furthermore, a subscale CCT model program is bein design and fabrication issues.

Charge to the review committee: The goal of thi identify technical risks, and provide feedback on tec

1. Is the test plan for the CCT4 magnet sufficien that could further advance insight into magne
2. Are the design elements for CCT5 clearly defi
   1. Is the mechanical design sound, i.e. ha manner?
   2. Is the magnetic design sound, i.e. are t magnet performance and measurement
   3. Is there additional analysis that should
   4. Has the conductor and cable been prop appropriately defined?
3. Are the CAD, fabrication drawings, tooling an commence?

Review committee:

- Steve Virostek - Chair
- Helene Felice
- Shlomo Caspi
- Giorgio Ambrosio
- Sandor Feher

15 T Dipole Coil Internal Review

11 January 2018

On 11 January 2018 the Fermilab Magnet Systems Department conducted an internal review of the 15 T Dipole coil impregnation process in response to the damage incurred to the first 15 T Dipole L3-L4 coil, HFD-CL-002. The 15 T team has analyzed the failure, planned changes, and proposed a plan to replace the damaged coil.

Review questions:

1. Is the L3-L4 reaction/impregnation tooling and procedure well understood and adequate to produce high quality coils?
   The tooling and procedure are well understood. The committee believes, however, that expanding the procedure to include more dry runs and fit-ups might have caught the design flaw earlier.
2. Are the possible causes of the coil HFD-CL-002 damage during impregnation well understood?
   Yes.
3. Are the proposed improvements of the coil impregnation tooling, process, and quality control sufficient to achieve the required coil quality after impregnation?
   Yes, but It is critical to adhere to the discipline of the travelers and discrepancy reports.
4. Does the plan for coil replacement exist and is it optimal (new coil fabrication vs. fixing HFD-CL-003)?
   The proposed plan of repairing coil HFD-CL2-003 appears viable, and would be the most efficient course. The back-up plan of winding a new coil using cable recovered from HFD-CL-001 also appears viable, but would be slower and use more resources.

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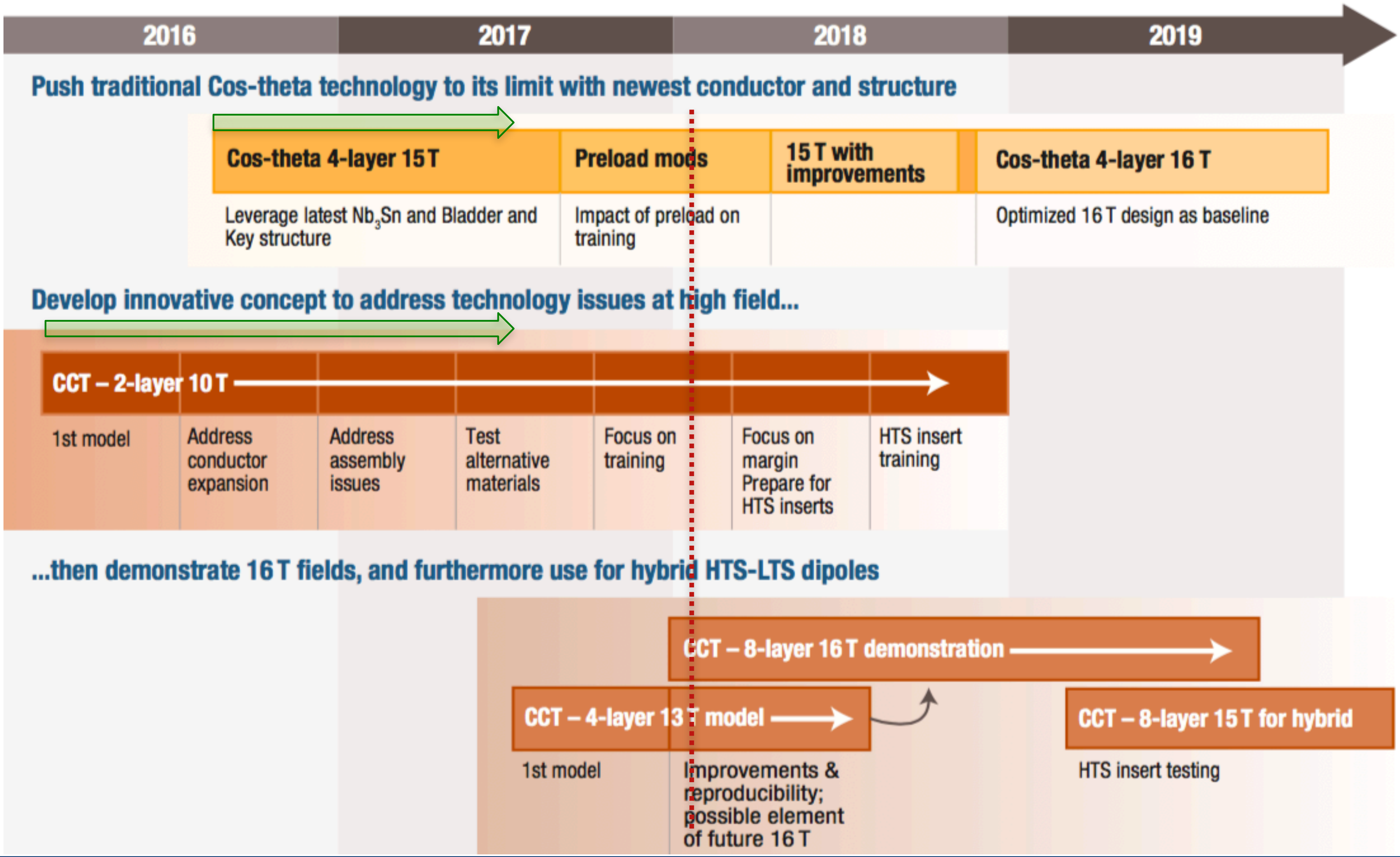
The MDP team is progressing on the path for magnets outlined in the MDP Plan document

Area I: Nb_3Sn magnets



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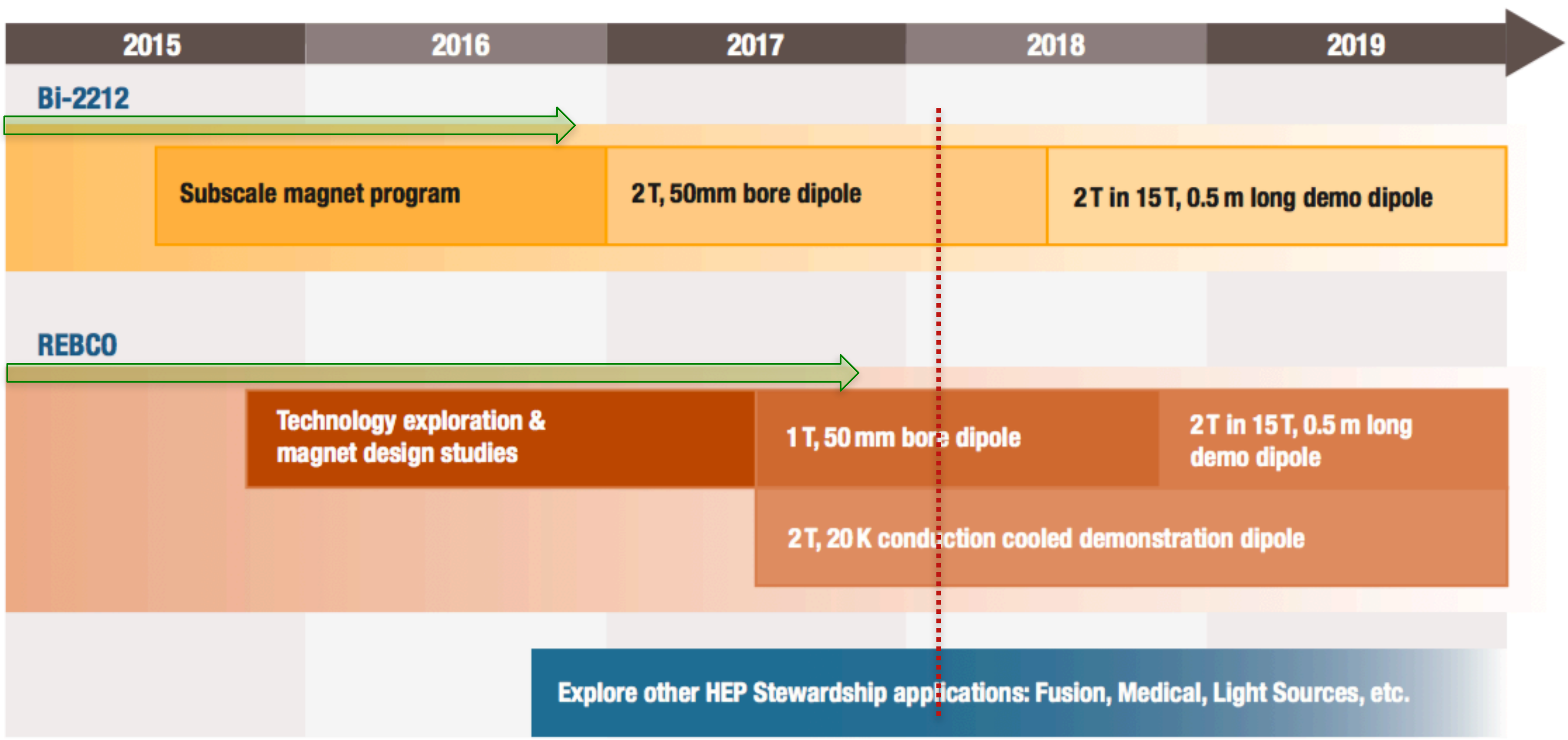
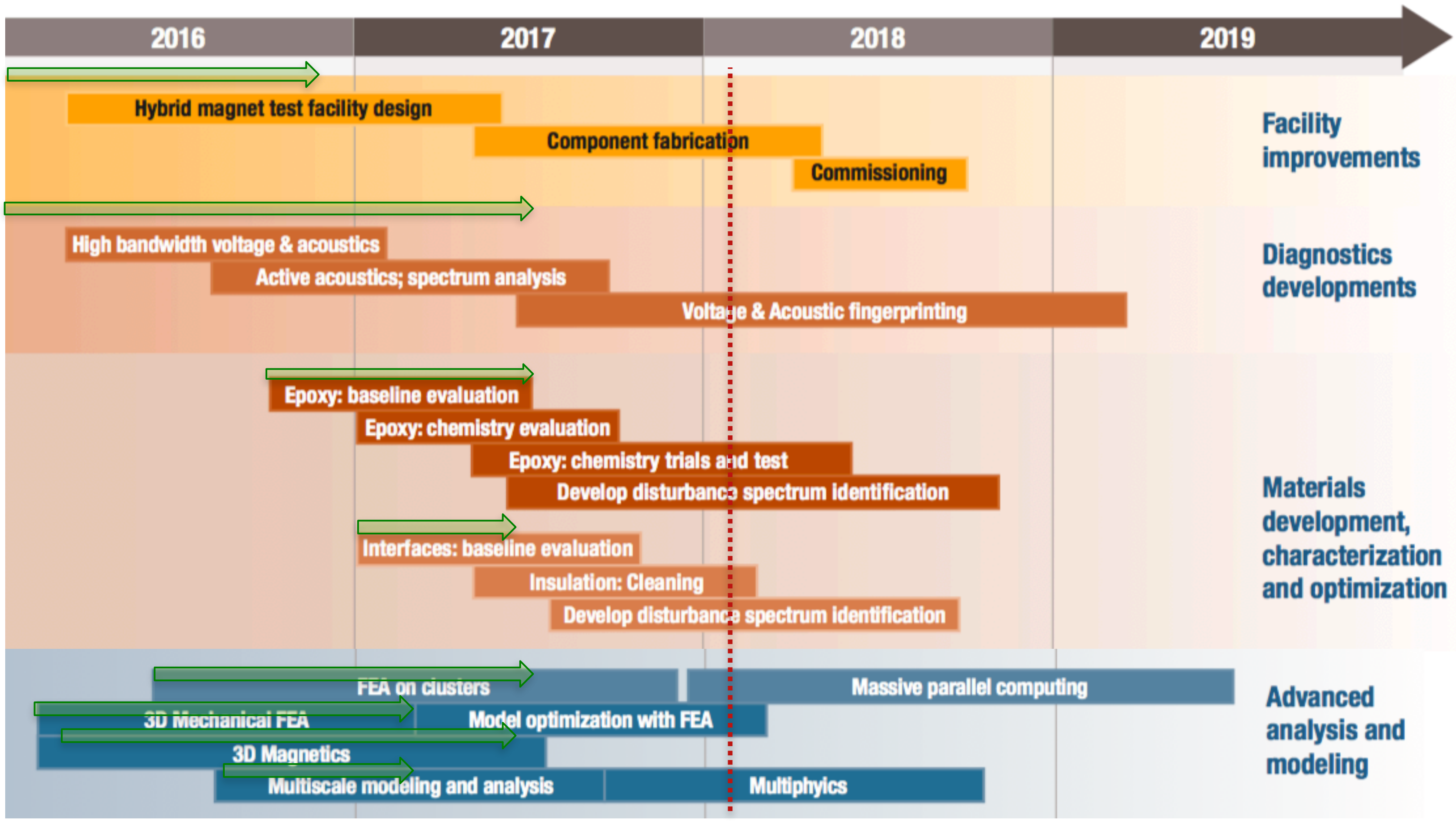
The MDP team is progressing on the path for magnets outlined in the MDP Plan document

Area II: HTS magnet technology



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*



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

The **research and development** purpose of CPRD is to anticipate future magnet development needs including both LTS and HTS wires and cables. *Conductor development leads magnet development by 5 years or more* and CPRD must also envision conductor needs 10 to 20 years out, which could be conductors for magnets beyond the capability of Nb_3Sn, or for magnets that do not require liquid helium, since helium is likely to become increasingly more expensive.

ASC NATIONAL MAGLAB

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US HEP Magnet Development Program
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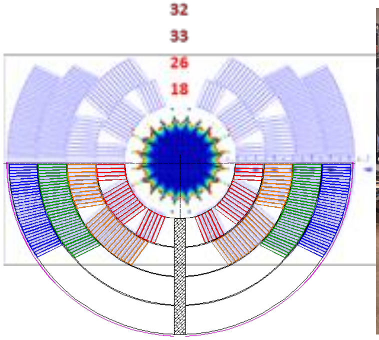
ldcooley@asc.magnet.fsu.edu

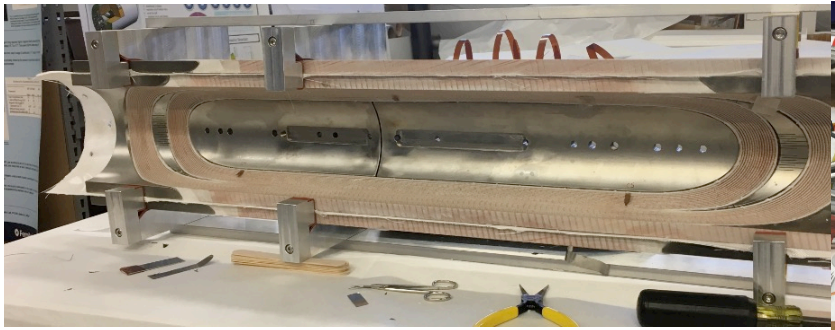
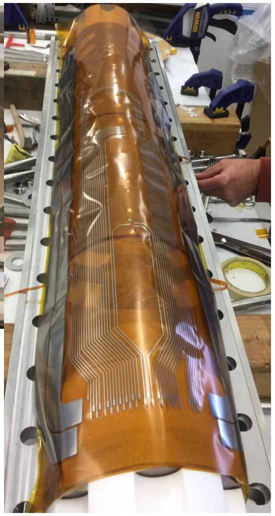
Roadmap for Conductor Procurement, Research and Development
October 6, 2017

Covering DOE FY 2018

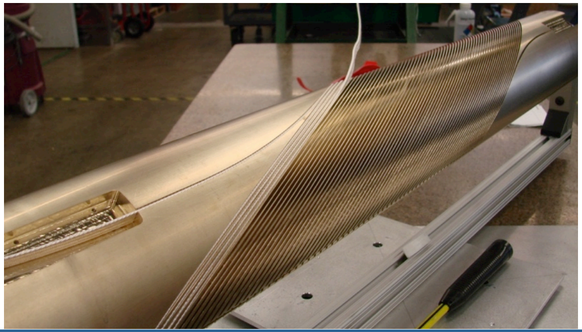
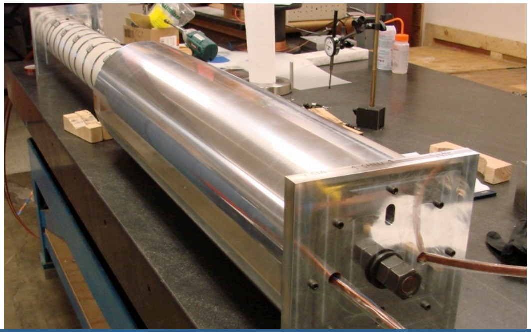
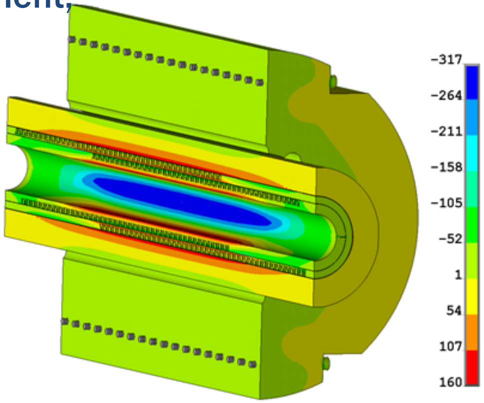
Progress on high-field magnet concepts

- Block Cosine-theta magnet fabrication progressing - some delays due to curing and potting issues



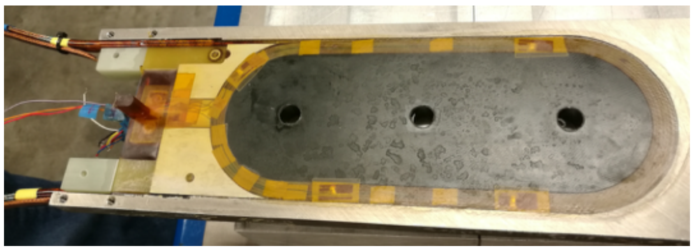




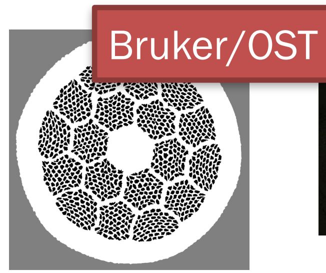
- Canted Cosine-theta:
    - CCT4 (the second Nb_3Sn CCT 2-layer magnet) was tested, and thermally cycled
    - CCT5 is in design, incorporating feedback from CCT4
    - Subscale CCT currently being pursued for fast turn-around technology development;
        - will guide CCT5 design details

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 in next 2-3 months
  - Roadmap being developed to integrate 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 both tape performance and magnet transfer function

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

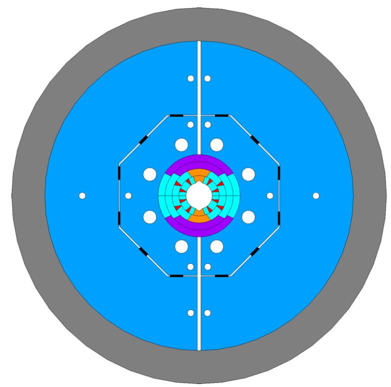
Design Team
16 T Dipole design:
Leads: Zlobin and Sabbi

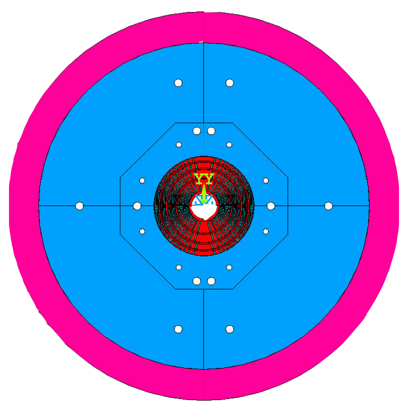
Design Team
Utility Structure design:
Lead: Mariusz Juchno

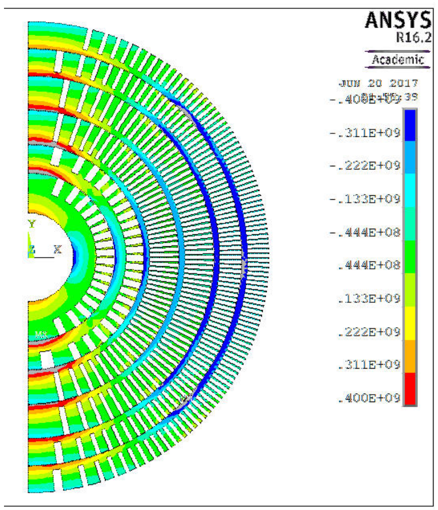
First look at Hybrid designs
Caspi, Brouwer, et al

Nb_3Sn design specifications

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

Progress on Technology front

- Development of active acoustic sensors on magnets opens avenue for new insights into magnet behavior
- Acoustic sensors used on CCT4 – enable insight into magnet performance
- Thermo-mechanical properties of cable/insulation/epoxy
- Interface bonding, shear, peel strength of epoxy-metal interfaces currently being measured
- Modeling capabilities continue to be developed, particularly for advanced multi-physics coupling and leveraging of computing clusters with FEA

Progress on Conductor Procurement and R&D front

- Advances in Bi2212 powder processing + overpressure processing
- 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 our understanding of the chemistry associated with Nb_3Sn heat treatment has lead to significant improvement in J_c for small-filament RRP conductors
  - Equal-channel angular extrusion (CDP order) being completed by OST
- Investigate potential for APC Nb_3Sn
  - Ohio State, FNAL LDRD, FSU
- REBCO development focused on leveraging SBIR and complementary programs; MDP provides measurements and conductor performance feedback to developers and vendors

Issues and concerns and their mitigation: Magnets

- Need to push on magnet front:
  - Need to get Cosine-theta to test (without compromising quality!)
  - Need to demonstrate improved training on CCT
  - Need to maintain, and build upon, progress on HTS magnets

- Keep/build momentum on Cos(t) magnet
  - But not let schedule pressure compromise success
  - Focus on…
    - fabricating good coils, and spares
    - thorough testing of the mechanical structure prior to final assembly
- Develop and progress on a CCT program that…
  - addresses technical hurdles, e.g. training
  - provides maximum science/understanding
  - aligns with future program strategy (hybrid magnets)
- Maintain fast progress on HTS magnet development:
  - Further focus efforts towards insert-ready magnets
  - Work closely with wire/tape and CORC cable manufacturers to develop accelerator-magnet optimized solutions

Issues and concerns: Technology

- We need to invest more in technology area, and collaborate more closely in that arena
  - leverage capabilities and expertise, internal “tech transfer”, build next generation of scientists
  - Excellent area to develop University interest for collaboration

- Early investment in technology is beginning to pay off:
  - New diagnostics are being incorporated throughout MDP, and beyond
  - Expect modeling developments to impact design work throughout MDP, and beyond

Issues and concerns: Flat funding

- Funding is flat for FY18
  - lack of growth means our progress continues to lag from the original plan

- Some promising signs from DOE OHEP: we need to continue to provide evidence that
  - their investments are effective, and
  - enhanced funding would translate into faster progress

Issues and concerns: Infrastructure

- Some investment in infrastructure is needed to allow rapid development of the technology
  - Support for expanded Bi2212 furnace at ASC - top near-term priority!
  - Support for test pit with larger diameter cryostat at FNAL => provide access to 1.8K testing of MDP high field magnets
  - Investment in new liquifier for faster, more efficient test throughput at LBNL (benefits MDP as well as other DOE-SC programs)
  - Two-PS based testing capabilities for hybrid magnets (IGBT-based extraction systems, active protection circuits, etc)

- Develop detailed plans for infrastructure upgrades:
  - clear justification for need
  - well defined scope of work
  - detailed cost and schedule
  - work with lab management and DOE-OHEP to identify funding source(s)

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

Activity	MDP Relevance	Collaborating Institution	Contact(s)	MDP Contact
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 OHEP-Funded				
Magnetization studies	Conductor R&D	OSU	Sumption, M.	Wang, X.
Fiber Optic Quench Detection	HTS	PSU/Lupine Materials and Technology		Shen, T.

Goals for the collaboration meeting are designed to keep the program focused on effectiveness

- Identify near term milestones for each element of the program
- Identify hurdles/issues encountered over the last year and solutions to address them in the future (lessons-learned)
- Identify possible technical breakthroughs that would have the most significant impact on the program
- For technology developments, identify broader potential, i.e. beyond the core mission of MDP, where appropriate
- Identify infrastructure investments needed, and prioritize

Guidance to speakers is designed to support goals of the collaboration meeting

- **Magnet talks:**
  - Where were we at the last collaboration meeting
  - What have we accomplished/learned over the last year
  - Where do we see ourselves in a year (and milestones to get there)
  - What conductors are being used in the magnet, and what conductor is needed/wanted moving forward,

  and….
  - What issues were encountered (e.g. technical hurdles, staffing issues, funding constraints, etc.)
  - What worries you the most
  - What technology elements/advances can best support your plans
  - What infrastructure is needed to deliver on the milestones
- **Technology talks:**
  - What is the driving consideration, i.e. put the technology development into context
  - What have we accomplished/learned over the last year
  - Where do we see ourselves in a year (and milestones to get there)
  - What is the potential of the work - how far can it go, and what does it take to get there
  - Show broader potential, i.e. beyond the core mission of MDP, where appropriate
  - What infrastructure is needed to deliver on the milestones
  - Each talk should have a slide with milestones; what constitutes completion/success?

Conclusions

- We are following the MDP roadmap
- We have a fully functioning management structure
- We have regular management and technical staff meetings
  - Working to develop a strong team spirit
- We are balancing our efforts: limited budget while maintaining progress on multiple fronts
- A coherent conductor R&D roadmap has been fleshed out