U.S. DEPARTMENT OF ENERGY | Office of Science

Technology Roadmaps and Basic Research Needs Workshops

High Energy Physics Advisory Panel

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CoV Recommendations on Optimization

- R.3 Work closely with the Laboratories and with Project Management and Program Management teams to develop a comprehensive strategic plan, consistent with P5 guidance, that anticipates the needs for future operating funds that will arise from improvement, upgrade and MIE projects. […] Develop a similar comprehensive plan for research efforts to maximize the scientific return
- R.6 Restore a balanced generic detector R&D program as soon as possible after the technical challenges of current high priority P5 projects are met.
- R.17 Work with the high energy physics community to generate a roadmap for investments in detector R&D based on future research needs of the field.
- R.28 Consider creating and implementing roadmaps to defining research priorities for the GARD research thrusts not yet mapped.
- R.29 Work to address the accelerator R&D subpanel recommendations to ensure a healthy and vigorous basic accelerator R&D portfolio

HEP Program Optimizaiton

- HEP has undertaken several steps recently to help further optimize program plans and budgets:
  - Lab Optimization (initial discussion at Nov HEPAP meeting, more updates to follow)
  - Portfolio Reviews (reports yesterday)
  - Basic Research Needs workshops (this talk)
  - Accelerator Technology Roadmaps (this talk)
  - Computing Infrastructure Working Group (discussed in Jim's talk yesterday)
- Taken together these processes aim to:
  - Improve the effectiveness and efficiency of HEP research programs and supporting technology infrastructure
  - Identify currently operating experiments that have the highest impact on P5 science drivers
  - Identify research and technology R&D areas that are ripe for additional investments

Adv. Tech. R&D: Research Roadmaps

- Following the release of the HEPAP Accelerator R&D Subpanel Report in April 2015, the General Accelerator R&D (GARD) Program has engaged its research community to address the Subpanel recommendations to develop research roadmaps for these thrust areas:
  - Superconducting High Field Magnets
    - Produced the U.S. Magnet Development Program Plan
  - Advanced Accelerator Concepts
    - Laser-driven plasma wakefield acceleration (LWFA)
    - Particle-beam-driven plasma wakefield acceleration (PWFA)
    - Dielectric wakefield acceleration (DWFA)
  - Radiofreqency Acceleration Technology
    - Superconducting RF
    - Normal Conducting RF
    - RF Sources

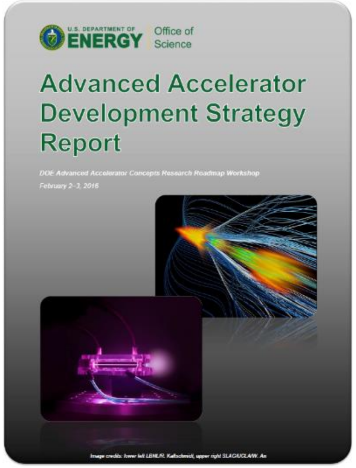
- Community-developed roadmaps include:
  - Pressing challenges to be addressed to move the field forward
  - Prioritized milestones aligned to the most compelling science

Advanced Accelerator Concepts

Advanced Accelerator Concepts

- Workshops have defined the U.S. path for Wakefield R&D and driving laser technologies
- 2013: Workshop on Laser Technology for Accelerators
  - January 2013 (w/BES, NP, DOD)*
  - Identified ultrafast laser R&D needed to support accelerator and radiation generation uses for SC
  - R&D roadmap
  - Conclusions reaffirmed by a community workshop in August 2017
  - *FES consulted: primary interest is long-pulse lasers (>ns)
- 2016: Workshop on Advanced Accelerator Development
  - February 2016 (w/BES, NP, NSF)
  - Identified 10- and 30-year R&D targets for advanced accelerator concepts
  - Near-term applications outside HEP
  - Supporting technology development
  - Long-term path to a HEP collider
  - R&D roadmaps for wakefield accelerators

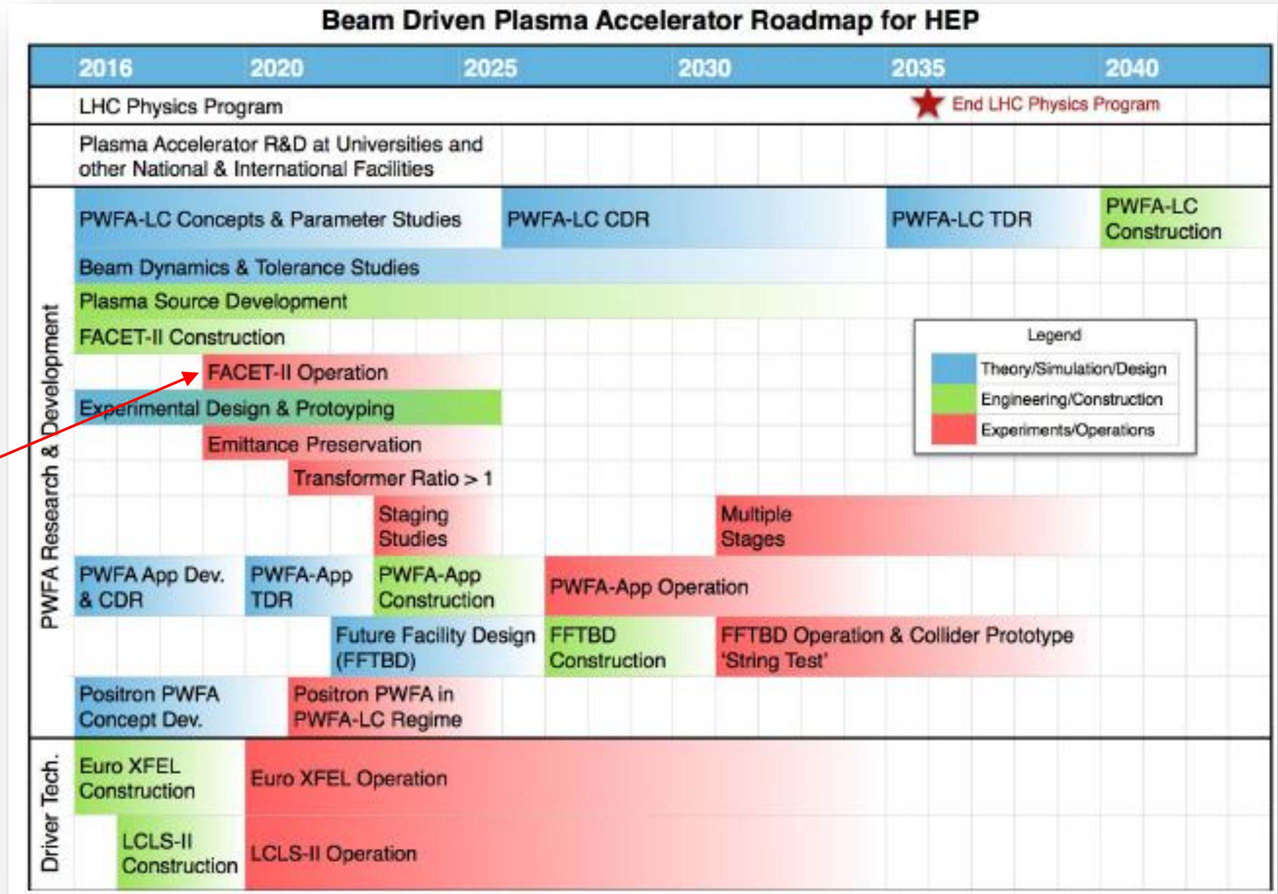
https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Lasers_for_Accelerators_Report_Final.pdf



https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Advanced_Accelerator_Development_Strategy_Report.pdf

Beam-Driven Plasma Wakefield Roadmap

- Near-term (10-yr) threshold applications and long-term HEP applications
- Primary facility was FACET at SLAC
  - FACET-II is needed to make advances in beam quality, staging, and positron acceleration
- Additional supporting R&D at UCLA, AWA, BNL-ATF



Advanced Accelerator Concepts Research Roadmap Workshop Report, G. Blazey Ed., February 2016.

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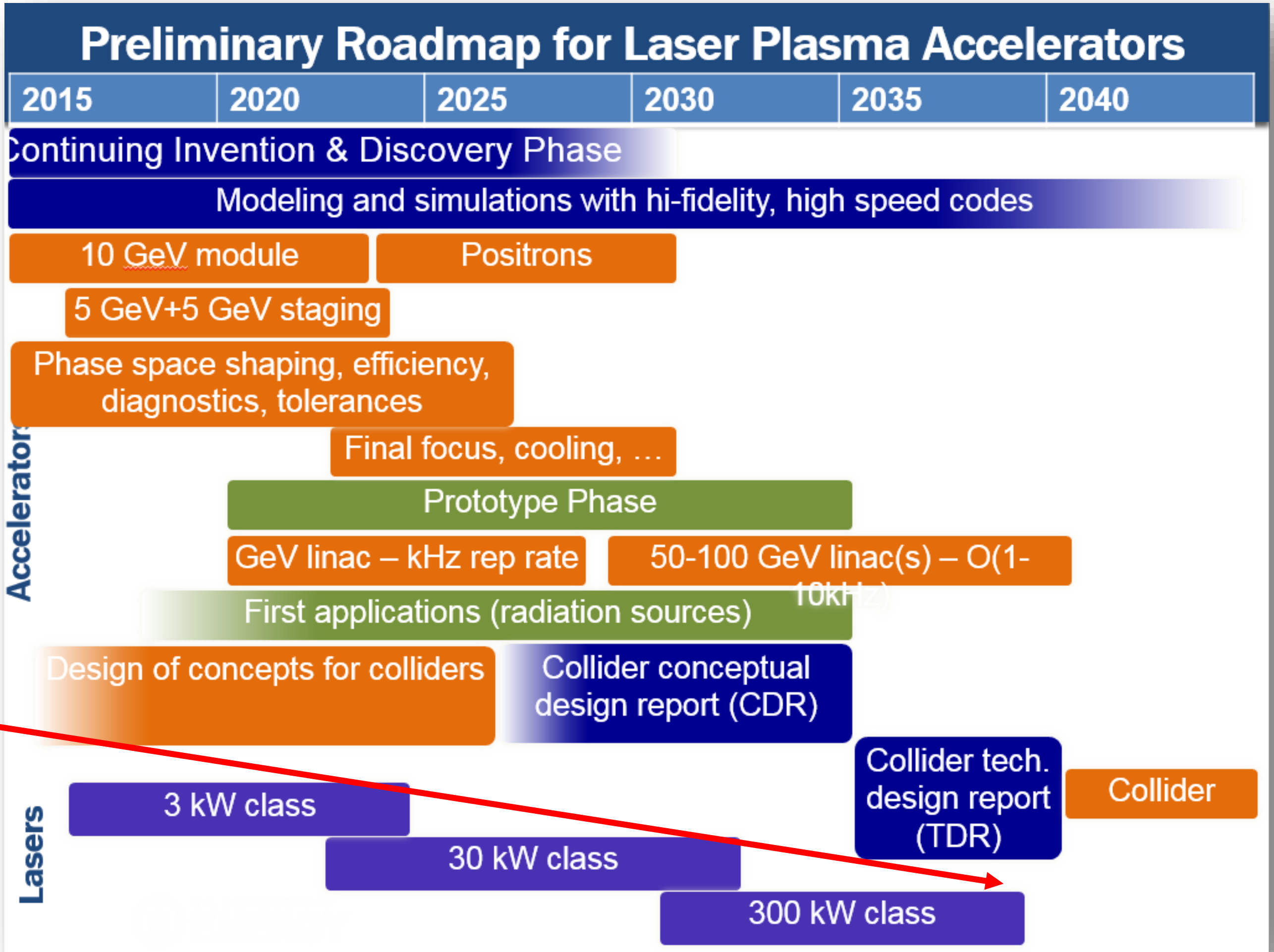
Laser-Driven Plasma Wakefield Roadmap

- Near-term (10-yr) threshold applications (soft XFEL) and long-term HEP applications
- Primary facility is BELLA at LBNL
  - Significant laser upgrades are needed to make advances in beam current and develop the applications
- Additional supporting R&D at UCLA, UMD, NRL, UT-Austin



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U.S. Magnet Development Program Plan

U.S. Magnet Development Program Plan

- P5 report identified critical need for trans-formational high-field magnet R&D focused on substantially increasing performance and lowering the cost per Tesla-m

- U.S. Magnet Development Program 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.

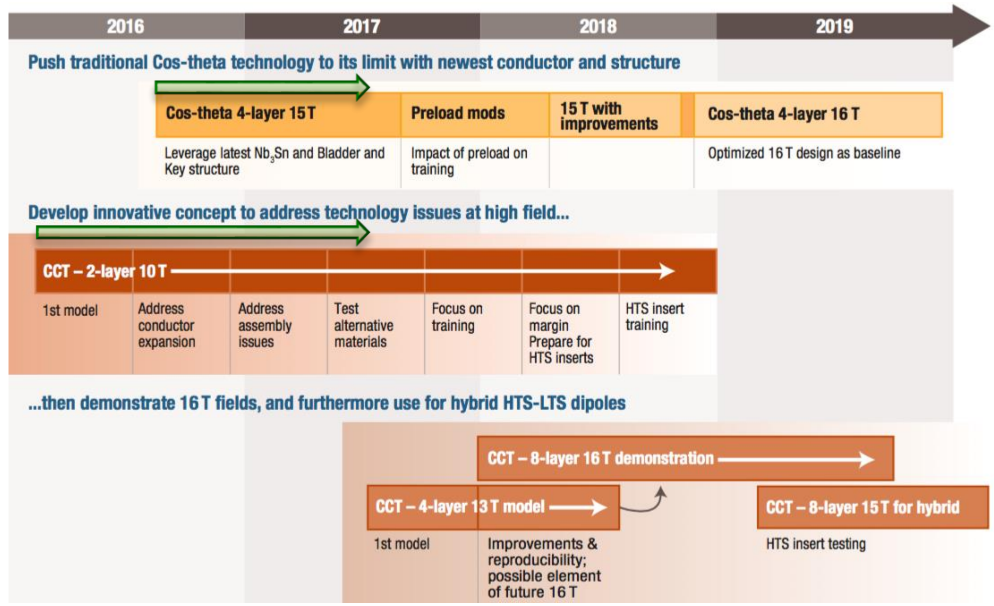
MDP Program Plan Overview

- Timeline and milestones developed in four thrust areas:
  - Nb_3Sn Magnets (Canted-Cosine Theta, Cosine-Theta)
    - **Aiming for demonstrator 16 T dipole magnets**
  - HTS Magnets (Bi-2212, REBCO)
    - **Aiming for magnet inserts of 2 T in a 15 T background**
  - Technology Development
    - Feeds Magnet Development areas through **facility improvements, diagnostic development, material characterization, analysis/modeling**
  - Conductor Development
    - **Procurement to supply conductors needed for magnets**
    - Research to support industrial advances in HTS manufacturing
      - Builds on long running Conductor Development Program that fed into successful LHC Accelerator Research Program (LARP)

Magnet Development Plan Timeline

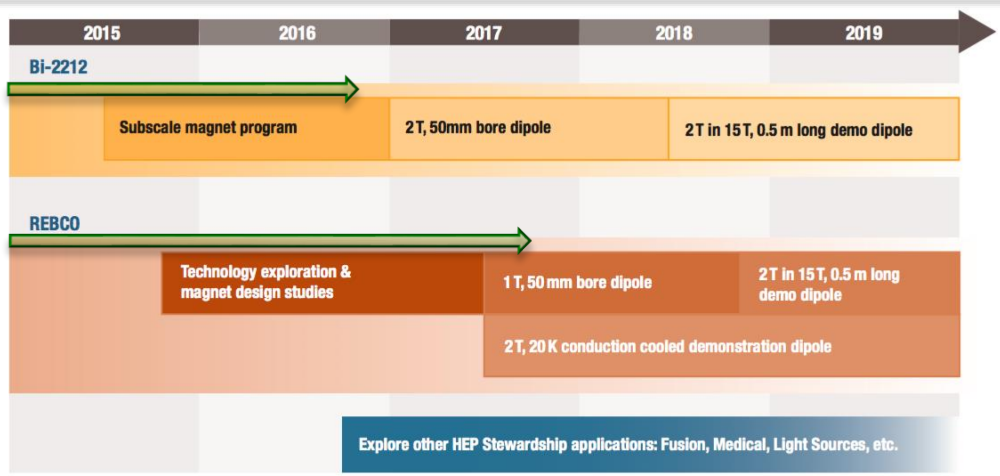
Area I:

Nb$_3$Sn magnets



Area II:

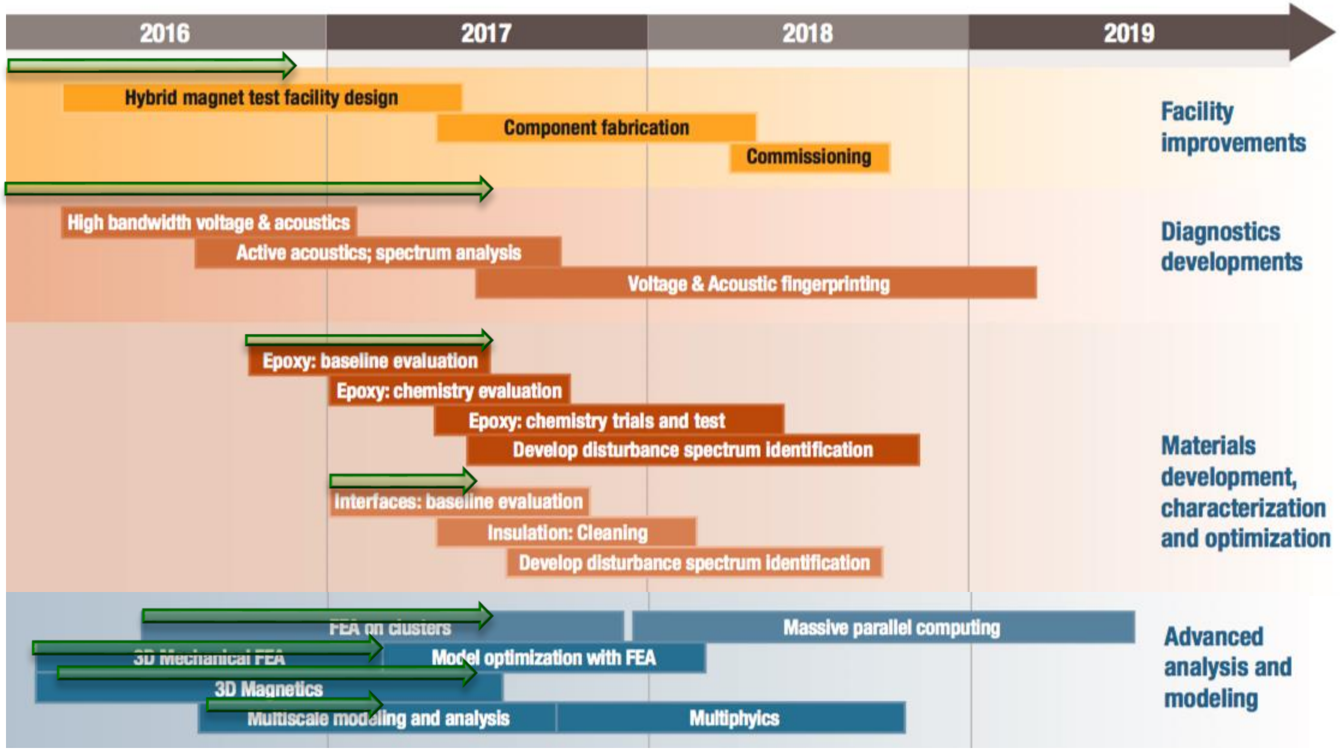
HTS magnet technology



Magnet Development Plan Timeline

Area III:

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



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.

RF Research Roadmap

HEP GARD RF Research Roadmap

- Workshop held in 2017 to develop a 10-year comprehensive research roadmap with appropriate milestones and metrics for the HEP GARD RF Acceleration Technology Thrust, unifying the following research technology development areas:
  - Superconducting RF
  - Normal Conducting RF
  - RF Sources
- Also considered needed testing infrastructures, simulation/modeling tools, synergies between sub-thrusts and other domestic/international programs

GARD-SRF Research Roadmap

GARD-SRF R&D and related/synergistic fields

Main R&D

Doping and Flux Expulsion: E_{acc} to 70 MV/m with Q (2K) > 3e10

Layered structures and advanced concepts on fundamental field limits: E_{acc} > 100 MV/m

Nb_3Sn: E_{acc} up to 90 MV/m with Q (4K) > 3e10

Advanced normal conducting materials and manufacturing for >300 MV/m

Multi-frequency accelerating structures with > 200 MΩ/m

RF Sources with >70% efficiency delivering 200 MW/m peak or 100 kW average power

Companion R&D

Field emission, Microphonics, Couplers, Dampers, Tuners, Circulators

R&D Progress →

HEP Accelerators →

PIP-II	ILC 1st Stage 250 GeV	CLIC	PIP-III	ILC 2nd Stage 1 TeV	FCC, CEPC	Multi-TeV Collider

Synergies: FELs, ADS, Quantum Computing, Compact Accelerators, etc.

High Q R&D: 10-year roadmap

2018 | 2020 | 2022 | 2024 | 2026 | 2028

Physics of RF Surface Resistance

- Understand the field dependence of BCS surface resistance and effect of different impurities
- Apply gained knowledge and develop new understanding for alternative materials
- Understand origin of residual resistance and its field dependence
- Understand trapped magnetic flux losses and flux trapping

Doping

- Continue exploration with nitrogen in Nb at different temperatures
- Doping for new materials
- Probing the ultimate limits of Nb RF surface resistance by doping with different impurities
- Study Nb doping at different frequencies and temperatures

Potential of Nb material: *Q* (2 K) ~ 1×10^{11} @ 1.3 GHz

Nb_3Sn or other new materials

- Pursue current promising path forward for material in bulk form (Nb_3Sn) – explore and optimize coating techniques and treatments for single cell / multi-cell cavities
- Nb_3Sn studies for cryomodule operation
- Explore SIS for Nb_3Sn
- Evaluate alternative materials, bulk or film (NbN, NbTiN, MgB_2) first on samples, then on cavities

Potential of Nb_3Sn material: *Q* (4 K) ~ 1×10^{11} @ 1.3 GHz

Magnetic Flux Losses

- Drastically reduce sensitivity to magnetic flux for Nb and new materials
- In situ removal of trapped magnetic field (in cryomodule)
- Develop Materials Specs to ensure maximum flux detrapping

Impact:
- Retain 1×10^{11}
- Sustain very high gradients

Goals

- $Q > 4\times10^{10}$ at 2 K, 1.3 GHz and $E_{acc} > 35$ MV/m
- Nb_3Sn: $E_{acc} > 20$ MV/m with $Q_0 > 1\times10^{10}$ at 1.3 GHz, 4.2 K
- *Residual resistance < 1 nΩ in cryomodule*
- *Nb_3Sn cryomodule ready technology*

High Gradient R&D: 10-year Roadmap

2018 | 2020 | 2022 | 2024 | 2026 | 2028

Fundamental Limits
- Probing the fields above H_{sh} on samples
- Probing the limits of accelerating field on sub-nanosecond time scales
- Evaluate feasibility of > DC H_{sh} fields for up to ~GV/m scale gradients

Niobium
- Produce dirty surface layer on clean bulk to enhance superheating field
- Probing and altering by doping the ultimate limiting cavity field
- Potential of Nb material:
  - H_{sh} limit: 70 MV/m
  - Above DC H_{sh}: > 70 MV/m

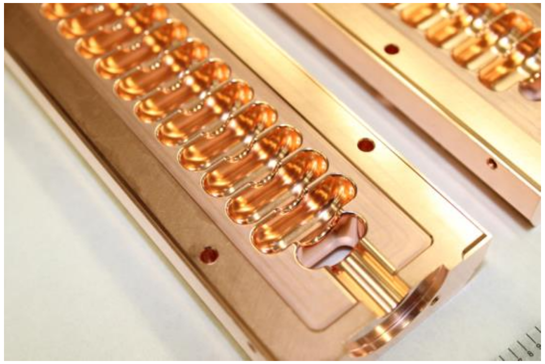
Nb_3Sn
- Pursue current promising paths forward for material in bulk form
- Evaluate superconductor-superconductor structure to delay flux entry
- Evaluate superconductor-insulator-superconductor structure to delay flux entry
- Potential of Nb_3Sn material:
  - H_{sh} limit: 90 MV/m
  - Above DC H_{sh}: > 120 MV/m

Other super-conductors
- Use theoretical and experimental expertise to evaluate promising options for SRF materials (bulk and films), develop sample coating and test tools
- For materials that show B_{pk} > 50 mT with R_s < 300 nΩ, develop cavity coating tools

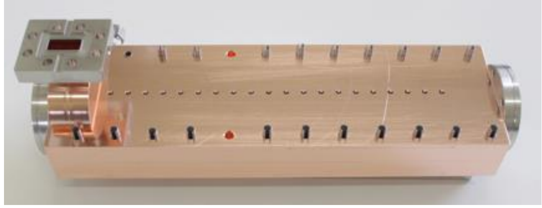
Goals
- Development of techniques to prevent and mitigate field emission
- $H_{pk} > H_{sh}$ of bulk niobium
- E_{acc} = 70 MV/m
- Measure and outpace time scales of vortex dissipation $E_{acc} \gg 120$ MV/m

Compact Microwave Accelerators

- Normal conducting RF accelerators have achieved >100 MV/m, allowing more compact MeV-class x-ray sources for medical, industrial, and security applications.
  - Could provide compact, university-scale sources of radiation (*e.g.* tunable γ-rays)
- Have achieved TRL-5, and are ready for development into specific applications
  - DNDO already actively seeking 10-100kW x-ray sources
  - NNSA interested in Co60 source replacements
  - NIH interested in Co60 alternatives to improve patient outcomes, and in Very High Electron Energy treatment (~100-150 MeV) of cancer
- Will conduct a workshop within the next year with NNSA, DHS, and NIH to explore these applications, identify high impact applications, technical gaps, and an R&D roadmap
  - Will then discuss roles and interests with the Agencies, following with SC taking on R&D through ~TRL4, and applied agencies carrying the work forward from there.



Hard copper, brazeless fabrication



120 MV/m → 30 MeV in 25 cm

Many Overlapping, Synergistic R&D Areas with NCRF

Roadmaps Summary

- Technology R&D Roadmaps are already having an impact in the HEP program
  - Laboratory and University communities are aligning their efforts to meet the roadmap goals
  - Technology R&D Subprogram is using the roadmaps to guide program implementation
  - Progress and alignment will be assessed in upcoming lab accelerator R&D comparative review this summer
- Roadmaps have also identified opportunities for possible applications of HEP Technology R&D to other program offices in the Office of Science
  - Discussions are underway for opportunities where investments would have broad benefits

Basic Research Needs Workshops

Basic Research Needs Workshops (BRNs)

- SC's Office of Basic Energy Sciences initiated this approach with the *Basic Research Needs to Assure a Secure Energy Future* workshop in October 2002. This resulted in a comprehensive, 420-page report that identified 37 Proposed Research Directions.
- Numerous (~20) subsequent topically-focused BRNs have helped to define directions and make the case for major new efforts such as Energy Frontier Research Centers and Innovation Hubs
- While there are some variations and there has been some evolution, many BRNs have involved:
  - Production of a <u>Technology Perspectives Factual Document</u> prior to the workshop
  - Definition of a set of <u>Priority Research Directions</u> that address the technology R&D challenges
  - Definition of a set of <u>Science Grand Challenges</u> that, if solved, might result in transformational changes

BRN process and structure

- Targeted topics defined by, and workshop charge issued by, SC program office
- Attendance is limited and by invitation
- Participants will have considerable work to do before, during, and after the meeting
- Workshop Chair and Co-Chairs develop agenda and select panel leads (with program office input)
- Typical structure: Opening plenary sessions, panel breakout sessions that develop priority research directions, closing plenary session, and extended writing session – draft report completed before departure!
- Prompt output: final report released typically 60-90 days after the workshop

BRN impacts

- BRN reports are expected to serve as reference documents with a long shelf life, and to be readily accessible
- Post-workshop outreach activities often include communication of the results to the broader community by co-chairs and the SC program, and briefings by federal staff to other interested federal parties (within and beyond DOE)
- BRNs may, individually or collectively, serve as the basis for subsequent funding opportunities. Examples:
  - The 2003 workshop report on Basic Research Needs for the Hydrogen Economy was referenced in and supported an FY2004 solicitation on Basic Research for the Hydrogen Fuel Initiative.
  - An FY2007 FOA on Basic Research for Advanced Nuclear Energy Systems was based directly on the corresponding BRN, stating specifically that "The workshop report is a current source of information and summarizes the interests of BES."
  - The original FY2009 solicitation for the Energy Frontier Research Centers (up to $100M/yr total) centered on the 11 BRNs that SC-BES had held to date.
  - An FY2011 FOA from Fusion Energy Sciences on High Energy Density Laboratory Plasmas specifically sought applications addressing the research needs identified by the Basic Research Needs for High Energy Density Laboratory Physics workshop report and two prior reports.
  - The most recent FY2018 Energy Frontier Research Centers FOA (up to $98.9M/yr total) *requires* that applications address Priority Research Directions in one or more of 12 reports, 11 of which were BRNs.

HEP Basic Research Needs Workshops I

- BRN workshop on **Compact Accelerators for Security and Medicine** is in the planning stages for late summer 2018
  - Focused on near-term applications (3-5 years) of compact accelerator technologies to security and medical applications
  - Will identify high impact applications, technical gaps requiring basic R&D, and the primary barriers to technology adoption
  - Will identify required application-side R&D
  - Engage the other stakeholder federal agencies and provide a roadmap for near-term compact accelerator R&D, with particular attention given to technology transfer to industry
  - Will be by invitation only

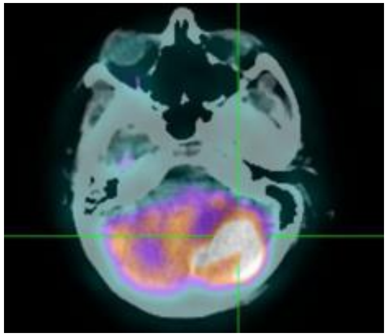


Image credit: 10.3390/ijms15069878

Image credit: LLNL

HEP Basic Research Needs Workshops II

- BRN workshop on **New Opportunities for Dark Matter**
  - March 2017 community workshop held to determine scientifically compelling areas to search and possible concepts for new experiments or studies
    - *White Paper: https://arxiv.org/abs/1707.04591*
  - Considering P5 recommendations and the current landscape, HEP will hold a BRN on Dark Matter in late Summer 2018 to:
    - Identify priority science opportunities for new directions and areas of phase space that will provide significant science return and advancement.
    - Of these:
      - Which technology needs for which concepts for new small projects could be ready to go in the near term?
      - Which would be best carried out using DOE infrastructure and capabilities?
  - Co-Chairs have been identified and are starting to organize
- **Detector R&D** is being considered for a future BRN workshop

Other HEP News

Diversity and Inclusion

- HEP CoV Recommendation 19: Develop a plan for increasing diversity in the programs HEP supports.
  - HEP is working with the Office of Science (SC) and other SC program offices to identify and implement effective practices to improve diversity and inclusion
  - This process is ongoing and we aim to report results at a future HEPAP meeting
- All PAMS users may voluntarily provide demographic information regarding gender, race, and ethnicity
  - DOE does not use this information as a basis for any funding decisions
  - Providing this information enables DOE to examine the distribution of awards across various demographic categories

Communications

- Community groups and Steve Ritz updated content on usparticlephysics.org
  - Coordinated effort of DPF Executive Committee, Fermilab UEC, SLUO, and USLUA
    - With help from AAAS S&T Policy Fellow Andrea Peterson
  - New material includes brochure on STEM connections of particle physics
- DOE provides opportunities to highlight results or amplify articles
  - University Research stream on Office of Science Webpage
  - Science Highlights articles
    - Contact: Michael.Cooke@science.doe.gov

HEP Office News

- Coming and Going:
  - Karen Byrum began as Detailee in Cosmic Frontier in January 2018
  - Michael Salamon retired Feb 2018
  - Laurence Littenberg began as Detailee in Intensity Frontier in March 2018
- "Hiring freeze" has lifted but no DOE Federal positions open at this time
- Aiming for HEP PI Meeting in late Summer
  - Considering August 2018 timeframe, prior to proposal deadlines for next HEP comparative review process
  - Stay tuned for further details

Timeline for Updating the U.S. Strategy

- The May 2014 P5 report was successful because it was well informed by the science community, including information from:
  - 2010 New Worlds, New Horizons in Astronomy and Astrophysics
  - 2012 Report of the Subcommittee on Future Projects of High Energy Physics (Japan)
  - 2013 European Strategy for Particle Physics Report
  - 2013 U.S. Particle Physics Community-driven "Snowmass" process
- The timeline of processes that impact strategic planning is:
  - 2018: Anticipated Japanese decision on ILC
  - 2018-20: New NAS Astronomy and Astrophysics Decadal Survey
  - 2019: Start of European Strategy for Particle Physics process
  - 2020: Release of updated European Strategy for Particle Physics
  - 2020: Earliest opportunity for National Science Board to approve obligating MREFC for HL-LHC
- From a DOE perspective, the earliest that new "Snowmass," NAS Elementary Particle Physics Decadal Survey, and P5 processes could begin is 2020
  - Relative timing of Snowmass, P5, and NAS EPP Decadal survey to be determined
  - Enables receiving new P5 recommendations in time to inform the FY 2024/25 budget
- U.S. community encouraged to work with international collaborators in developing other regional plans with a global vision for particle physics

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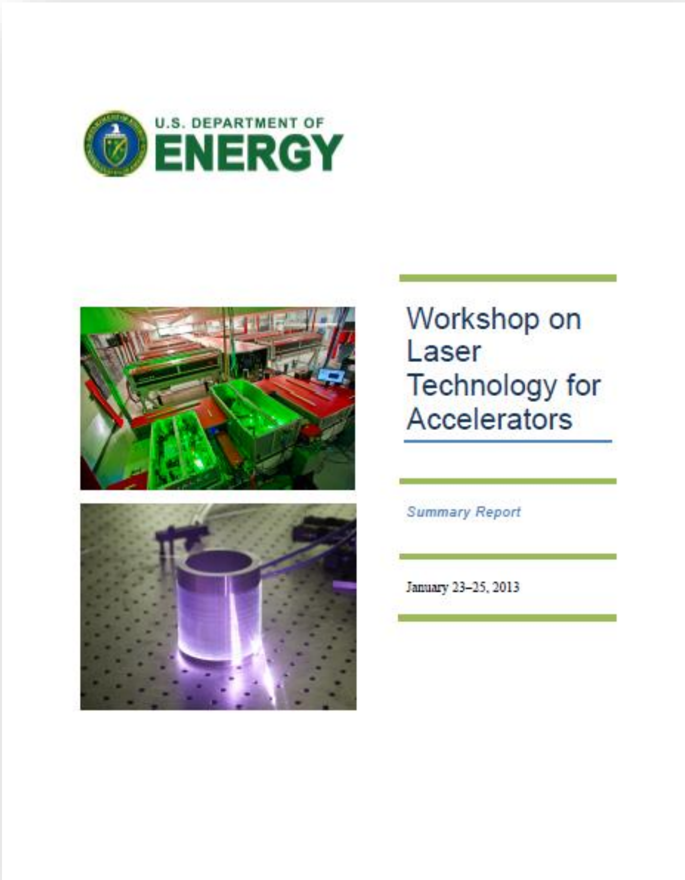
Laser Technology for Accelerators



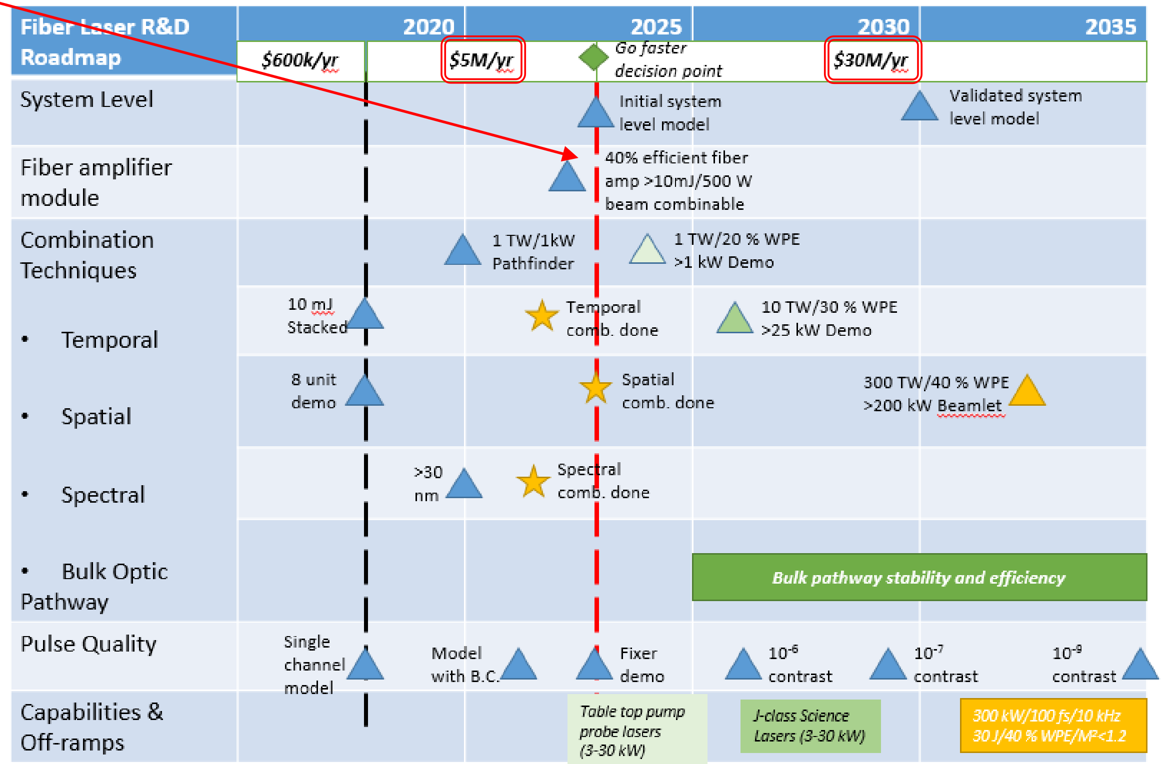
https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Lasers_for_Accelerators_Report_Final.pdf

- Workshop held January 2013
- Charge:
  - Identify laser-based accelerator applications
  - Assess laser specifications for each
  - Identify technical gaps
  - Specify R&D activities needed to bridge gaps
  - Assess the proposed U.S. R&D activities against global laser R&D efforts
- Attended by ~50 participants; ~10 industry, ~5 international, including members of DOE-HEP, DOE-BES, DOD, NSF, CRS.
- Focused on ultrafast lasers (<1 ps) operating at high average power (>1 kW), and highest power efficiency (>20%) as flexible, tunable, laboratory-based systems
- Technology Gaps Identified
  - No PW/kW gain materials; need more robust optics
  - Costly, inefficient pumps
  - Little experience coherently combining ultrafast lasers
  - Pulse contrast and optical phase noise

Ultrafast Laser R&D Roadmap

- The kW-class demonstrator, built from fiber technology, is estimated to be a ~$30M investment, including the R&D costs
- Currently funding a preparatory effort at ~$700k/year

A preliminary roadmap has been worked out for key R&D towards future high average power lasers based on fiber technology and coherent pulse combining



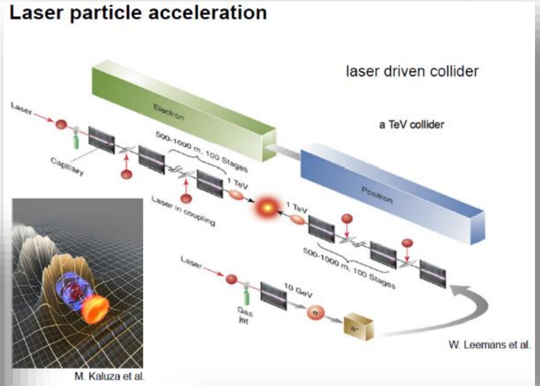
This plan assumes $5m/yr R&D for system development starting in FY18

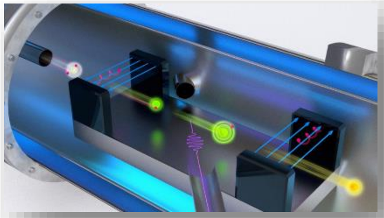
W. Leemans (LBNL), J. Dawson (LLNL), A. Galvanauskas (UoM), presentation to DOE December 21, 2016.

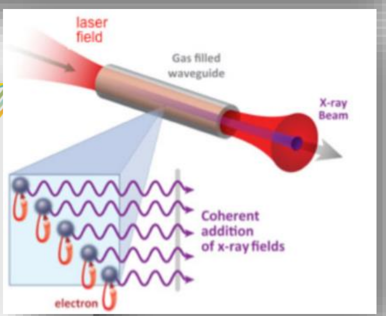
SC Applications of Ultrafast Lasers

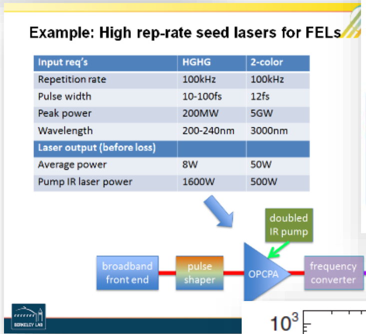
- HEP:
  - Laser plasma based e+/e- collider
    - 100-kW class IR lasers
  - Multi-MW-class proton sources
    - kW-class UV lasers
- BES:
  - HHG x-ray sources
  - Laser THz sources
  - XFEL seeding
  - Sources for XFEL pump-probe

  } kW-class IR and mid-IR lasers
- NP:
  - Compact ion sources
    - 10-100 kW-class IR lasers
  - Compton sources
    - kW-class IR lasers









Example: High rep-rate seed lasers for FELs

Input req's	HGHG	2-color
Repetition rate	100kHz	100kHz
Pulse width	10-100fs	12fs
Peak power	200MW	5GW
Wavelength	200-240nm	3000nm
Laser output (before loss)		
Average power	8W	50W
Pump IR laser power	1600W	500W

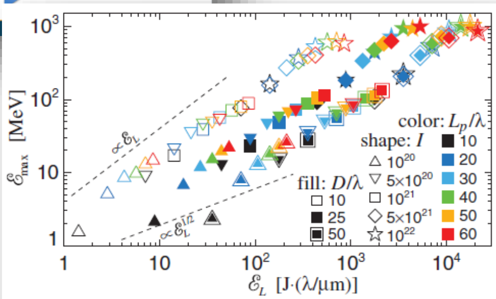


FIG. 3 (color). Proton maximum energy vs laser pulse energy for $I = \lambda$, $n_e = 100 n_{cr}$. The dashed lines exemplify possible scalings.