U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. Research Activities Related to Future Colliders

FCC Week, Georgetown Marriott

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Outline

- Machines of Interest, Status & Priorities
- Technical Progress
- U.S. community participation in Global Efforts
- Future outlook

Future HEP Global Facilities

	Intense Frontier Accelerators	Hadron Colliders	Lepton Colliders
Current Efforts	PIP	LHC	
	PIP-II	HL-LHC	ILC
Next Steps	Multi-MW proton beam	100 TeV class *pp* collider	1 TeV class energy upgrade of ILC
Further Future Goals	Neutrino factory		Multi-TeV collider

**dependent on how physics unfolds*

Status and Priorities

- **HL-LHC is the highest U.S. priority large project in the near-term**
  - Discussions on U.S. contributions have been underway for some time
    - New U.S.-CERN Cooperation Agreement [Umbrella], covering bilateral contributions between U.S. and CERN, is now nearing signature
  - R&D on HL-LHC magnets is quite advanced via the LHC Accelerator Research Program (LARP)
- **The ILC is supported at some level in all P5 funding scenarios and is the subject of active discussion with the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT)**
  - R&D on SRF continues
    - Note that LCLS II construction begins soon and will provide valuable insight into some ILC construction issues
  - U.S. involvement on ILC accelerator R&D continues at modest level
- **PIP II is a vital part of global neutrino plans**
  - A major collaborative effort among FNAL, India, CERN, etc.
  - Synergy with SRF needs for LCLS II, ILC

Future Machines

- **The future machines laid out by P5 reflect the community consensus at Snowmass:**
  - **Multi-MW proton beam to build out global neutrino program**
  - **Upgrade of ILC if it is built**
  - **Very high energy proton-proton (VHEPP) collider**
- **Snowmass did not develop a full community consensus on machine parameters for a future VHEPP machine beyond the HL-LHC**
  - **Snowmass considerations favored the ILC over a circular e^+e^- collider due to the technical readiness of the ILC**
- **In order for any of these future machines to become global options, they must be prioritized by the regions and their energy and luminosity parameters must be agreed to, and supported by, the community at large**

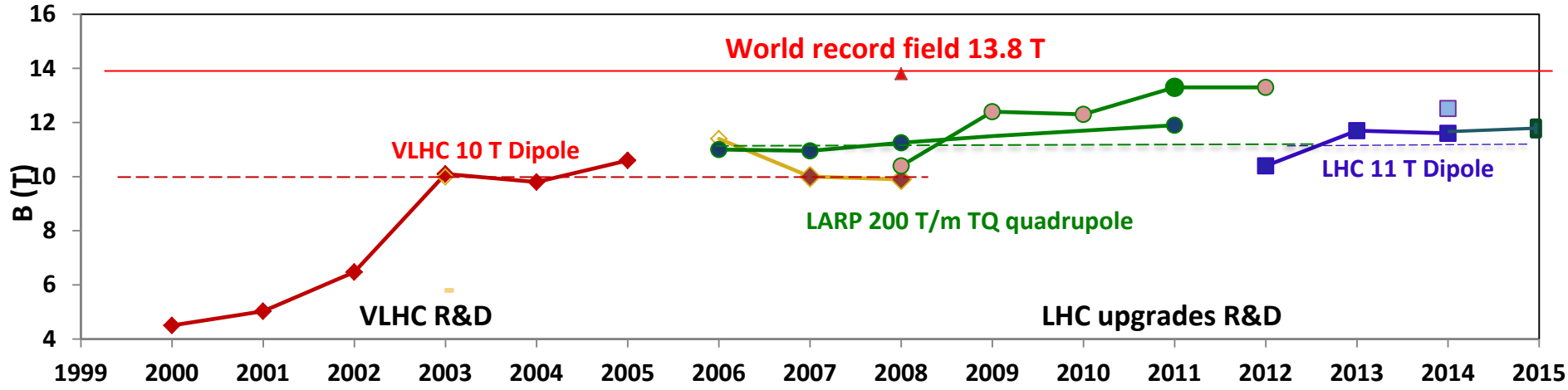
Circular Machines

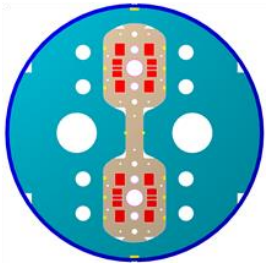
- **The technical challenges of building a VHEPP collider are large, and depend critically on parameter choices**
  - **Concurrent community studies of the physics reach (mostly theorists?) and accelerator issues are needed to provide a solid foundation for the accelerator R&D program for a VHEPP**
    - **Community must provide compelling arguments for the choice of energy and luminosity to inform subsequent discussions of tunnel length and other machine parameters**
- **Much more discussion would be needed from a U.S. perspective to support an intermediate step of a circular e^+e^- collider**
  - **P5 was clear that the long-term goal is a VHEPP**
  - **Science motivation must be the primary driver for the next machine, and a staged approach is feasible only if there are significant scientific advances at every stage**

TECHNICAL PROGRESS

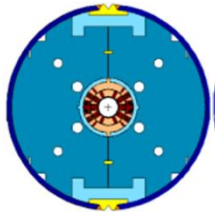
High Field Nb_3Sn Magnet R&D

- **U.S. collaborates with CERN and global partners in superconducting magnet R&D, with particular emphasis on Nb_3Sn technology**
  - **U.S. LHC Accelerator Research Program (LARP) aims to leverage this expertise to serve the needs of HEP community**

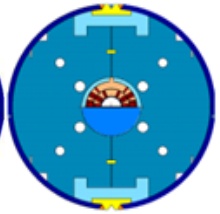




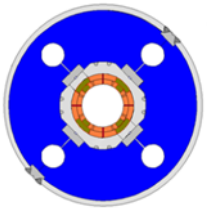
HFDC (R&W)
40 mm 10 T dipole



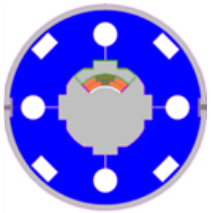
HFDA
43.5 mm
10 T dipole



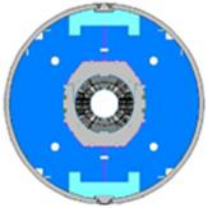
HFDM-LM
Dipole mirror



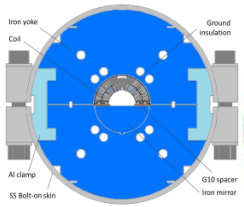
TQC
90 mm 200 T/m
quadrupole



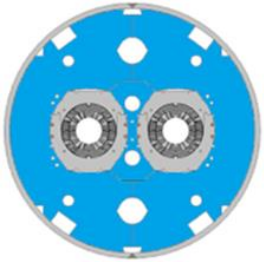
TQM-LQM
Quadrupole
mirror



MBHSP
60 mm 11 T dipole



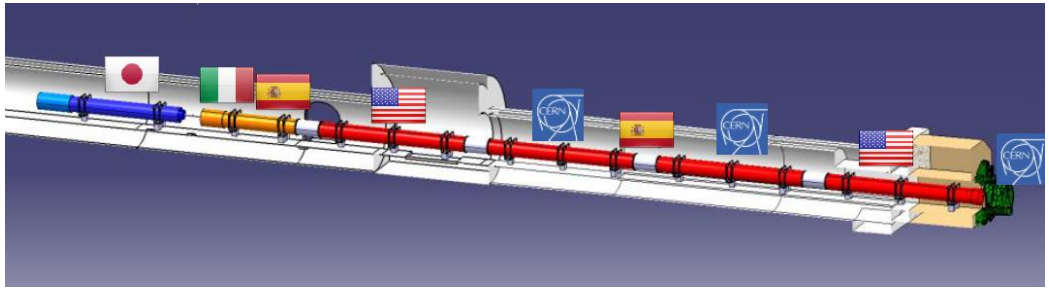
MBHSM
Dipole mirror



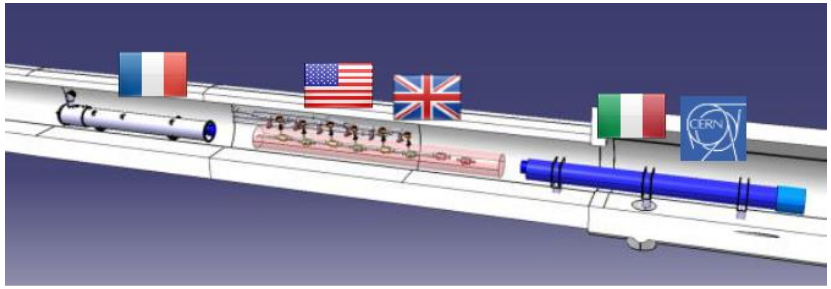
MBHDP
60 mm 11 T dipole

U.S. LHC Accelerator Research Program (LARP)

- **LARP is a national R&D program managed from Fermilab with the goal of preparing the U.S. to actively participate in the LHC High Luminosity Upgrade**
  - Collaborating U.S. National Laboratories: BNL, FNAL, LBNL, SLAC
- **Goals of the national program include:**
  - Build and test 5 prototype Intersection Region (IR) quadrupoles
  - Commission the tooling production
  - Deliver crab cavities for SPS test
  - Deliver Wide Band Feedback System for SPS test
  - Support studies of hollow electron beam lens
  - Prepare for meeting milestones of the DOE Project Management process for U.S. contributions to the HL-LHC



HL-LHC Intersection Region Magnets



HL-LHC Crab Cavities

SC Magnet Fabrication and Testing Facilities

- **LARP leverages U.S. infrastructure to meet R&D goals**
  - **Nb_3Sn IR quadrupole magnet efforts build on strand and cable technology developed by the U.S. HFM R&D program**
  - **With the HFM 11-Tesla dipole, the IR quads will be the first Nb_3Sn accelerator magnets**

Short Coil Winding Table

Coil Reaction Oven

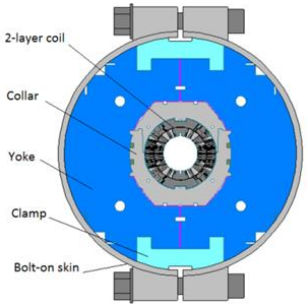
Strand and Cable Lab

Coil Forming Press

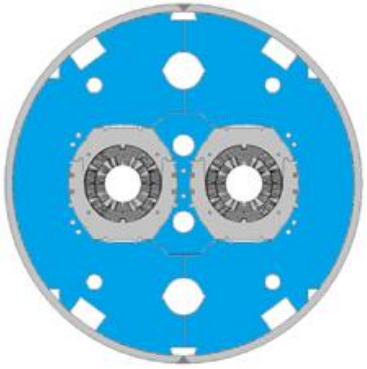
Vertical Magnet Test Facility

Recent Progress: 11 T Dipoles

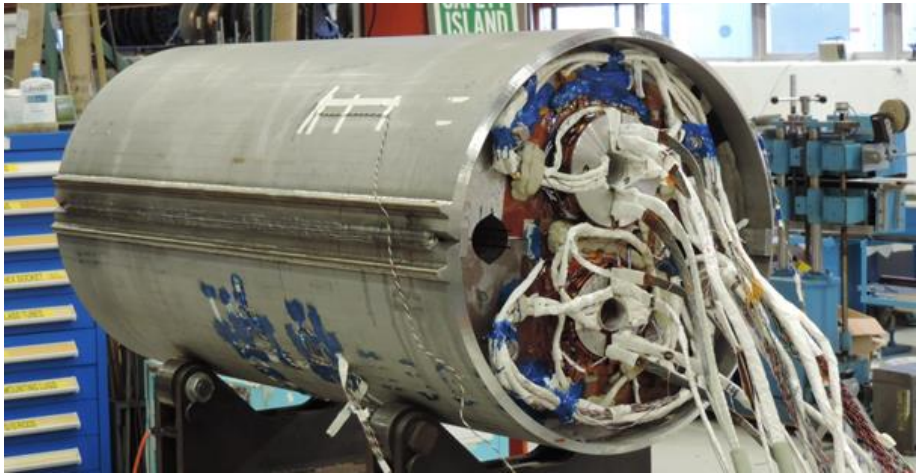
- **Recent progress in R&D of 11 T Dipoles for LHC Upgrades**
  - Twin-aperture model MBHDP01:
    - B_{max}=11.5 T (2D calc. TF)
  - Single-aperture models MBHSP02, MBHSP03:
    - B_{max}=11.6 T (meas. TF)

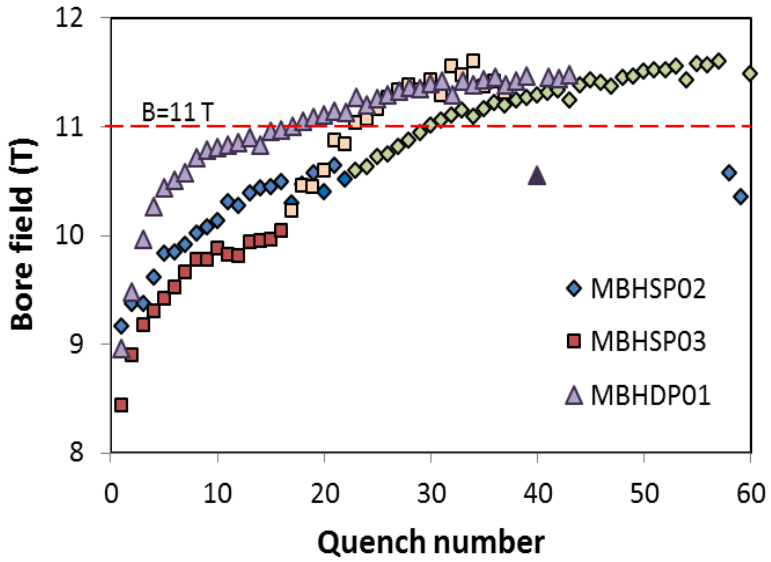


MBHSP02, MBHSP03

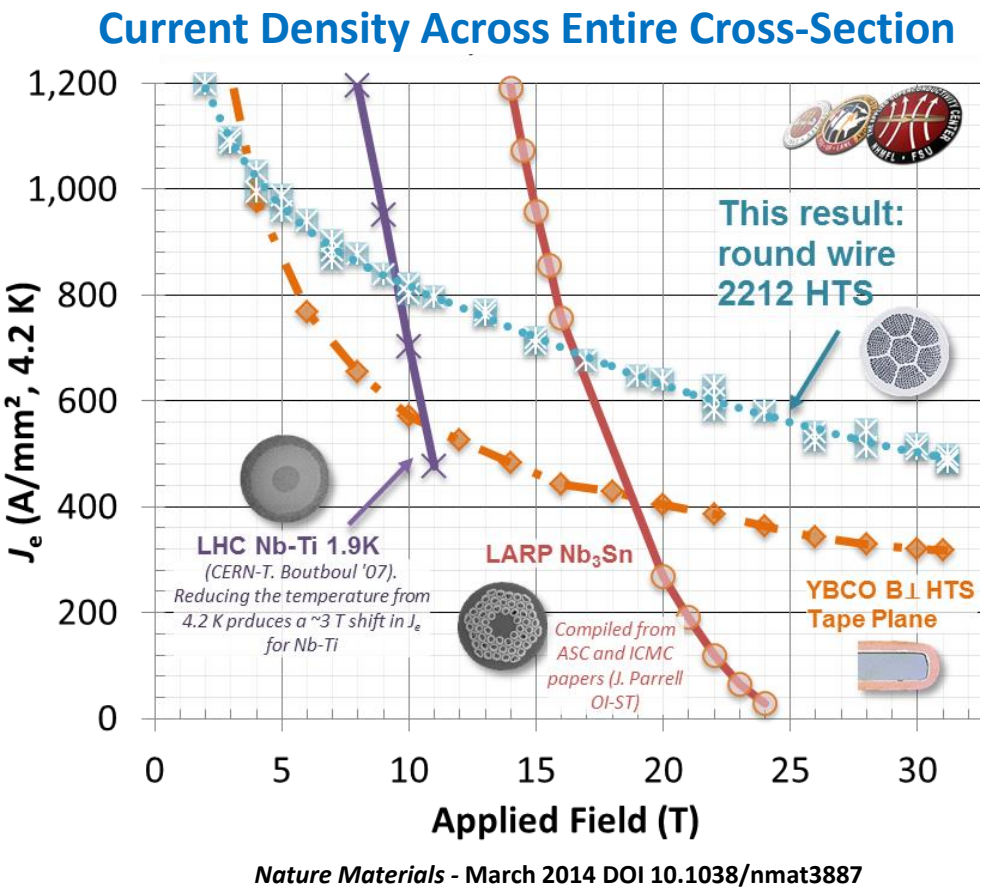


MBHDP01





Record Current in High-Temperature Superconductor (HTS)



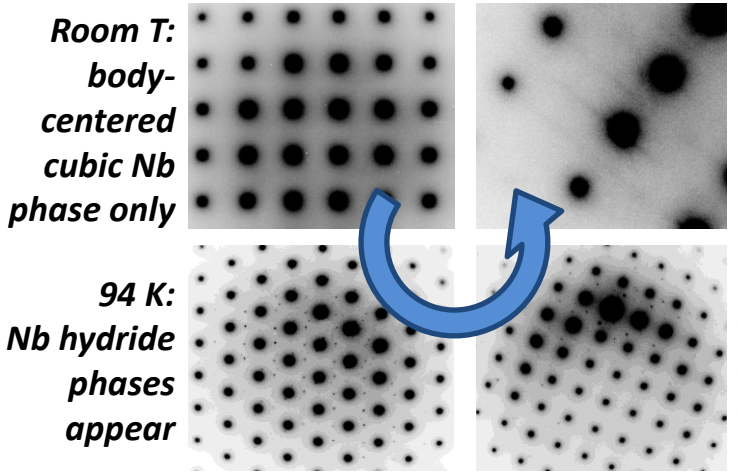
Nature Materials - March 2014 DOI 10.1038/nmat3887

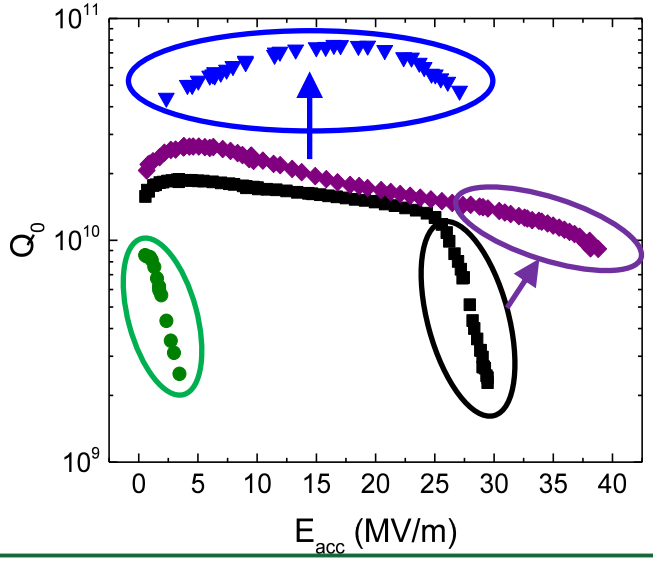
- Achieved 500 A/mm² at 30 T, 4.2K in $Bi_2Sr_2CaCu_2O_{8-x}$ (Bi-2122)
  - Existing state-of-the art conductors (Nb_3Sn for LARP) sustain this performance only to 18 T
  - LHC NbTi conductors sustain this performance only to 11 T
  - This practical HTS magnet material is an isotropic round wire which can be cabled on existing machines
  - Competing HTS materials are anisotropic tapes and not easily made into magnet cables

- Impact
  - This level of current density could technically enable magnetic field levels that double existing particle collision energies

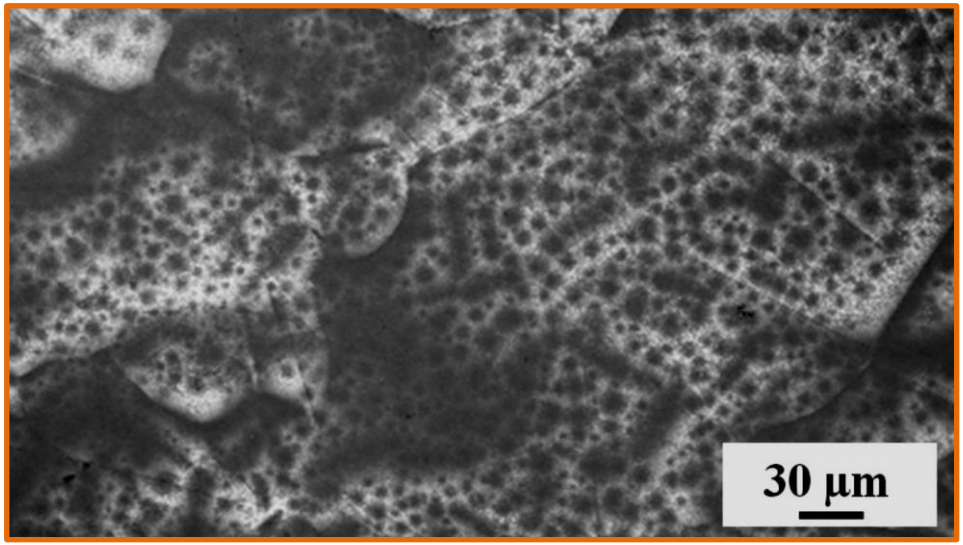
Advances in SRF Performance

- Recent SRF advancements have been driven by fundamental understanding of the underlying physics of the cavity surface
  - Microscopic mechanism of "Q-disease"
  - Origin of the "high field Q slope"
  - Mechanism of the "120 C baking"
  - Nitrogen doping to increase Q
  - Effect of cooling dynamics on Q



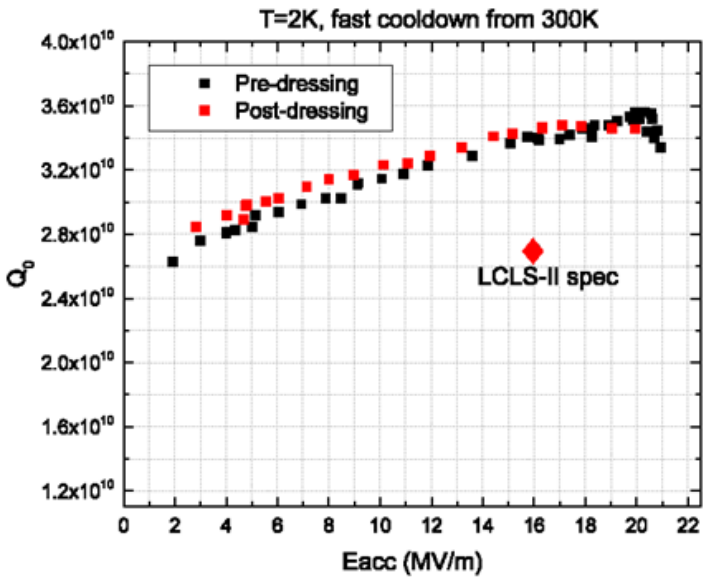


Trapped magnetic vortices imaged via Bitter Decoration

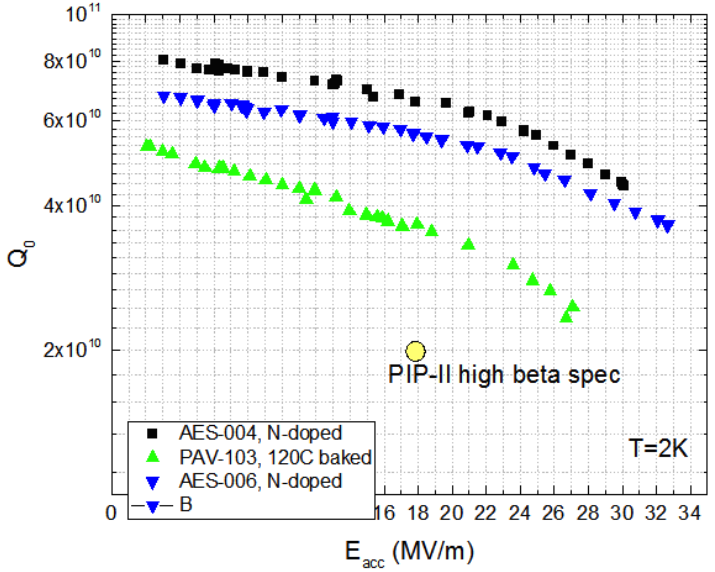


SRF Advances Widely Benefit DOE SC Program

- **Lower loss (higher Q_0) SRF cavities will reduce the cryogenic plant capital cost and long-term operating cost of future accelerators**
  - **The BES LCLS-II project will be the first beneficiary**
  - **Process applied to PIP-II 650 MHz (β=0.9) cavities leads to double Q_0 compared to 120 C bake (standard surface treatment ILC/XFEL)**
    - **World record Q_0 of ~7e10 at 2 K, 17 MV/m attained at this frequency!**



SRF cavity performance exceeds LCLS-II specifications



PIP-II cavity performance after N doping

U.S. COMMUNITY PARTICIPATION IN GLOBAL EFFORTS

U.S. International Situation

- **In 2012, the manner in which DOE national laboratories operate with respect to foreign collaborative R&D efforts was changed by then-Secretary Chu**
  - **Before 2012, the U.S. Lab directors had wide discretion in choosing which collaborative R&D efforts they supported**
  - **Since 2012, DOE headquarters must sign off on all foreign collaborative R&D efforts, including when the labs support 'work for others' with a foreign entity**
    - **The key element DOE looks for in such arrangements is a clear 'mutual benefit' to both the DOE and the foreign sponsor**
- **A true collaborative global R&D effort that takes best advantage of U.S. and foreign strengths will have strong arguments for approval in the current environment**
  - **A 'mutually beneficial' R&D collaboration provides the most solid foundation for U.S. participation with DOE support**

Future Machines Must Be Global

- **Future machines under discussion must be global efforts to have a chance at success**
  - **The sooner we can converge in all 3 regions on what parameters these machines should have and the key elements of the physics cases, the sooner we can fully coordinate the R&D programs to support their development**
  - **Each region should bring all their technical strengths to the table to support the global effort**
    - **We envision these machines as *global partnerships;* the community must help ensure this partnership is not one region exploiting developments in the others to promote regional/national goals**
    - **R&D efforts must have an appropriate balance of international and national goals**
- **The Funding Agencies for Large Colliders (FALC) provides a model for coordination among the agencies and labs during the R&D period**

FUTURE OUTLOOK

DOE Goals for FCC work

- **Participation by U.S. scientists in FCC planning is aligned with P5 goals, but investments must match priority levels**
  - **HL-LHC remains the highest priority large offshore project in the near term and there are other more immediate priorities**
  - **The HEPAP Accelerator R&D Subpanel Report will provide guidance on the prioritization of R&D efforts towards future machines**
- **Participation will be needed by U.S. University and Laboratory experts to envision a coordinated plan for how to best prioritize and execute efforts needed to solve the technical issues that stand in the way of realizing any of these machines**
- **A critical first step is for active U.S. theorists to do their part to guide agreement in the U.S. (and global?) community on VHEPP energy and luminosity while fleshing out physics goals and driving discussion in the U.S.**
  - **The HEP community may want to establish a Snowmass-like process in this focused area to help engage the community in these studies**
  - **A limited, focused effort is required, since we must maintain balance with the current DOE program dedicated to implementing the exciting but challenging program that has been laid out for us by P5**

DOE Goals for FCC Work: SC Magnets

- Though R&D must be driven by the community consensus on the energy and luminosity parameters needed for a VHEPP to meet its physics goals, superconducting magnets will be the key technology that defines the accelerator
- DOE looks forward to receiving a white paper from the U.S. high-field magnet community for coordinated U.S. participation in an international R&D activity on SC magnets for VHEPP colliders
  - Establishing a coordinated plan within the U.S. and with international partners is crucial for implementing a successful program
  - Builds on the successful collaboration on the LHC and HL-LHC magnets
  - Such a R&D effort would be aligned with the P5 recommendations
- Eventual technical involvement in other R&D subjects will be informed by the HEPAP Accelerator R&D Subpanel Report

DOE Goals for ILC Work

- Japan has expressed interest in hosting the International Linear Collider (ILC) and is actively working through a decision making process
- As recommended in the P5 strategic plan, DOE plans to provide modest and appropriate support through the period of Japanese decision making
  - U.S. has played key roles in the design of the ILC accelerator, including leadership in the Global Design Effort
  - Continued intellectual contributions to the accelerator and detector design are still necessary to enable a site-specific bid proposal
  - P5 recommended ILC support at some level in all budget Scenarios through a decision point within the next 5 years
- DOE is making an effort to maintain ILC accelerator activities in balance with other programmatic priorities

Collaborative Future

- **Collaboration with our foreign partners has always been and always will be a hallmark of the U.S. HEP program**
  - **Such collaboration is the keystone of the P5 plan, and is essential to the success of the HEP program globally**
- **In recent years, our 'offshore' collaborative efforts have seen tremendous technical success in developing gateway technologies in accelerators, detectors, and computing for moving the HEP program ahead**
- **We look forward to close cooperation and collaboration with our traditional international partners on future machines, and with additional nations wishing to join the worldwide HEP partnership**