HEP General Accelerator R&D (GARD) Sub-Program

August 22, 2018

L.K. Len
Office of High Energy Physics
The HEP GARD Program

- GARD supports accelerator science and technology R&D aimed at enabling HEP discovery science. It does so by developing new accelerator concepts, materials, designs and by pushing the performance limits, while acquiring and broadening the knowledge base of accelerator science.

- GARD funds medium and long term accelerator R&D primarily aimed at supporting the High Energy Physics mission. However, the long-term generic R&D may also benefit other applications—one can regard it as [small case] “accelerator stewardship”.
  - Medium term accelerator R&D refers to work performed in the support of possible new facilities or of upgrades to existing ones. This applies to facilities that possess a reasonable conceptual idea for implementation.
  - Long-term accelerator R&D refers to the development of ideas and underlying technologies that could support facilities for which we do not currently have an integrated implementing concept.
GARD vs Accelerator Stewardship

- **GARD** funds accelerator R&D primarily aimed at supporting the High Energy Physics mission. However, very often the long-term generic work will also benefit other applications, and this can be regarded as “accelerator stewardship”.

- **Accelerator Stewardship** is a separate, congressionally-authorized program that funds R&D that predominantly impacts non-HEP applications, and that has an identified non-HEP stakeholder.

**The differences, stated simply, are:**

<table>
<thead>
<tr>
<th>GARD</th>
<th>predominantly impacts the HEP R&amp;D mission</th>
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</thead>
<tbody>
<tr>
<td>accelerator stewardship</td>
<td>applies to GARD investments that impact both HEP and non-HEP applications, but non-HEP stakeholder is not yet clear</td>
</tr>
<tr>
<td><strong>Accelerator Stewardship</strong></td>
<td>predominantly impacts non-HEP applications; non-HEP stakeholder is clear and explicitly endorses the work</td>
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</tbody>
</table>

*Eric Colby will talk about Accelerator Stewardship at 9:00am tomorrow*
• **Supports 5 Research Thrusts:**
  - **Advanced Accelerator Concepts**
  - **Accelerator and Beam Physics**
    - Includes beam instrumentation and controls
  - **Particle Sources and Targets**
  - **RF Acceleration Technology (NC and SC RF)**
    - Includes RF sources, NCRF and SRF R&D
  - **Superconducting Magnets and Materials**

• **Support research efforts at:**
  - 7 DOE national labs
  - 1 Inter-agency Agreement
  - 35 university grants
FY 2018 GARD Research – % By Thrusts

GARD Facility Ops by Thrust ($34M)
- Advanced Accelerator Concepts: 36%
- RF Acceleration Technology (NC and SC RF): 44%
- SC Magnets and Materials: 14%
- Accelerator and Beam Physics: 6%

GARD Research by Thrust ($47M)
- Advanced Accelerator Concepts: 26%
- RF Acceleration Technology (NC and SC RF): 19%
- SC Magnets and Materials: 19%
- Particle Sources and Targets: 2%
- Accelerator and Beam Physics: 30%
- Other: 4%
FY 2018 GARD Grants – % By Thrusts

GARD Grant by Thrust ($10M)

- SC Magnets and Materials: 34%
- Advanced Accelerator Concepts: 27%
- Accelerator and Beam Physics: 23%
- Particle Sources and Targets: 0%
- RF Acceleration Technology (NC and SC RF): 13%
- Other: 3%
In 2014—The P5 report recommended moving forward with a focused Advanced Technology R&D strategy:

- Play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs
- Pursue accelerator R&D with a focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators
In 2015—Following P5, the Accelerator R&D Subpanel (charged to identify the most promising accelerator research areas to support the advancement of HEP) rolled out its report with 25 recommendations:

- provides prioritization advice to GARD on accelerator R&D towards the Next Steps [Medium-term] and Further Future [Long-term] accelerators

<table>
<thead>
<tr>
<th>Intensity Frontier Accelerators</th>
<th>Hadron Colliders</th>
<th>$e^+e^-$ Colliders</th>
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<tbody>
<tr>
<td><strong>Current Efforts</strong></td>
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<tr>
<td>PIP</td>
<td>LHC</td>
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<tr>
<td>PIP-II</td>
<td>HL-LHC</td>
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<tr>
<td><strong>Next Steps</strong></td>
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<tr>
<td>Multi-MW proton beam</td>
<td>Very high-energy $pp$ collider</td>
<td>1 TeV class energy upgrade of ILC*</td>
</tr>
<tr>
<td><strong>Further Future Goals</strong></td>
<td></td>
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<tr>
<td>Neutrino factory*</td>
<td>Higher-energy upgrade</td>
<td>Multi-TeV collider*</td>
</tr>
</tbody>
</table>

*dependent on how physics unfolds
ARDS Recommendations – AAC

• Advanced Acceleration Concepts
  – Support development of the most promising concepts toward far-term accelerators as envisioned by P5
    ▪ Vigorously pursue PWFA of positrons at FACET ... preserve the momentum of PWFA research using other facilities. [7]
    ▪ Support LWFA experiments on BELLA at the current level. [8]
    ▪ Reduce funding for direct laser acceleration research activities. [9]
    ▪ Convene the university and laboratory proponents of advanced acceleration concepts to develop R&D roadmaps. [10]
    ▪ Develop, construct, and operate a next-generation facility for PWFA research and development. [C1b]

https://science.energy.gov/hep/community-resources/reports/
AAC – Research Roadmaps (LWFA)

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
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<td>Accelerators</td>
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<td>10 GeV module</td>
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<td>Phase space shaping, efficiency, diagnostics, tolerances</td>
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<td>GeV linac – kHz rep rate</td>
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<td>50-100 GeV linac(s) – O(1-10kHz)</td>
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<td>300 kW class</td>
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<td>Design of concepts for colliders</td>
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<td>Collider conceptual design report (CDR)</td>
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<td>Collider tech. design report (TDR)</td>
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Modeling and simulations with hi-fidelity, high speed codes

DOE HEP GARD, PI Meeting - 8/22/2018
### Beam Driven Plasma Accelerator Roadmap for HEP

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2020</th>
<th>2025</th>
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<th>2035</th>
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<td>PWFA-LC TDR</td>
<td>PWFA-LC Construction</td>
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<td>Beam Dynamics &amp; Tolerance Studies</td>
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<td>FFTBD Construction</td>
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<td>FFTBD Operation &amp; Collider Prototype</td>
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<td>Positron PWFA Concept Dev.</td>
<td>Positron PWFA in PWFA-LC Regime</td>
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<td>Driver Tech.</td>
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<td>Euro XFEL Construction</td>
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</table>

**Legend**
- Theory/Simulation/Design
- Engineering/Construction
- Experiments/Operations
AAC – Research Roadmaps (DWFA)

**DWFA LC 10 YEAR ROADMAP**

<table>
<thead>
<tr>
<th>2016</th>
<th>2018</th>
<th>2020</th>
<th>2022</th>
<th>2024</th>
<th>2026</th>
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<tr>
<td><strong>DWFA LC Baseline Technology (potential multi-fold cost reduction)</strong></td>
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<tr>
<td>Technology Consolidation Phase</td>
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<td>Technology Integration Phase</td>
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<td>Single Stage</td>
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<td>High Fidelity Staging</td>
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<td>Main Beam Source</td>
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<td>3GeV Acceleration Facility</td>
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<td>Bunch Shaping for Doubling RF-Beam Efficiency</td>
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<td>High Efficiency Klystron (Synergy efforts from CLIC/SLAC)</td>
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<td>CDR for LC</td>
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<tr>
<td><strong>DWFA Exploratory Studies (potentially order of magnitude cost reduction)</strong></td>
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<td>Science Discovery and Technology Invention Phase</td>
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<td>Ultralow Emittance e-</td>
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<tr>
<td>Ultralow Emittance e+ (Synergy efforts from LPWA)</td>
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</table>
ARDS Recommendations – ABP

• Accelerator and Beam Physics
  – Maintain accelerator science core competence and support high intensity proton beam physics R&D
    ▪ Construct the IOTA ring, and conduct experimental studies of high-current beam dynamics in integrable non-linear focusing systems. [2]
    ▪ Support a collaborative framework among laboratories and universities that assures sufficient support in beam simulations and in beam instrumentation to address beam and particle stability including strong space charge forces. [3]
    ▪ Continue ABP R&D aimed at developing the accelerators defined in the Next Steps and the Further Future Goals. [14]
ARDS Recommendations – PST

- Particle Sources and Targets
  - Develop plan to support high-power target for Intensity Frontier
    - Fund generic high-power component R&D at a level necessary to carry out needed thermal shock studies and ionizing radiation damage studies on candidate materials that are not covered by project-directed research. [1]
ARDS Recommendations – RF

• RF Acceleration Technology
  – Support high-efficient RF source development and high-gradient research
    ▪ Invest in SRF R&D in order to inform the selection of the acceleration technology for the multi-MW proton beam at Fermilab. [4]
    ▪ Increase SRF R&D funding to significantly reduce the cost of a 1-TeV-ILC. 80 MV/m accel gradients with new materials over 10 years. [6]
    ▪ Continue research on high-efficiency power sources and high-gradient NCRF structures. [11]
    ▪ Make NLCTA available for RF structure tests using its RF power and beam sources. [12]
    ▪ Focus NCRF R&D on developing a multistage prototype based on high-gradient NCRF structures and high-efficiency RF sources to demonstrate the technology for a multi-TeV e+e- collider. [13]
# GARD-RF – Research Roadmaps

## Advancing RF Accelerating Structures

### 2018
- Super Conducting High Q Roadmap
  - Physics of Surface Resistance, Doping, New Materials, Magnetic Flux Losses
  - \( Q > 3 \times 10^3 \) at \( E_{acc} > 35 \) MV/m via doping
  - Explore Nb3Sn multicell

### 2023
- Super Conducting High Gradient Roadmap
  - Fundamental Limits, Niobium, Nb3Sn, New Structure Topologies, Other Superconductors
  - \( H_{pk} > H_{th} \) of bulk niobium
  - \( E_{acc} = 70 \) MV/m
  - Outpace time scales of vortex dissipation, \( E_{acc} > 100 \) MV/m

### 2028
- Nb3Sn cryomodule

## Normal Conducting Structures Roadmap: Accelerator topologies / Advanced materials and manufacturing / New regimes of operation in temperature and frequency / Virtual prototyping

- Develop Accelerators w/ Advanced Materials
- Advances with Multi-frequency, >200 MΩ/m

## RF Sources and Auxiliary Systems

### RF Source Roadmap: High perveance, low voltage, high efficiency, multi-dimensional beams / Efficient modulators / Virtual prototyping tools / Prototypes

- Discrete Architecture
- Distributed Architecture
- Energy Recovery Concepts

- High power SRF couplers / Broadband HOM dampers / Active cavity tuners / Circulators for high peak and high average power sources

- High repetition rate and high brightness e-source

- Polarized emitters

## Timeline

<table>
<thead>
<tr>
<th>2018</th>
<th>2023</th>
<th>2028</th>
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**DOE HEP GARD, PI Meeting - 8/22/2018**
ARDS Recommendations – SCM

- Superconducting Magnet and Materials
  - Support a balanced portfolio magnet and materials efforts; LTS and HTS conductors
    - Support accelerator design and simulation activities that guide and are informed by the SC magnet R&D program for a VHEPP collider. [5a]
    - Form a U.S. HFM R&D collaboration that is coordinated with global design studies for a VHEPP collider. The over-arching goal is a large improvement in cost-performance. [5b]
    - Aggressively pursue the development of Nb$_3$Sn magnets suitable for use in a VHEPP collider. [5c]
    - Establish and execute a HTS material and magnet development plan with appropriate milestones to demonstrate the feasibility of cost-effective accelerator magnets using HTS. [5d]
US Magnet Development Program (MDP) Goals:

— **GOAL 1:** Explore the performance limits of Nb$_3$Sn 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$_3$Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.
### SCM – Research Roadmaps/Goals

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
<td><strong>Facility improvements</strong></td>
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<tr>
<td>2016</td>
<td>Hybrid magnet test facility design</td>
<td>Component fabrication</td>
<td>Commissioning</td>
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<tr>
<td>2017</td>
<td>High bandwidth voltage &amp; acoustics</td>
<td>Active acoustics; spectrum analysis</td>
<td>Voltage &amp; Acoustic fingerprinting</td>
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<tr>
<td>2018</td>
<td>Epoxy: baseline evaluation</td>
<td>Epoxy: chemistry evaluation</td>
<td>Develop disturbance spectrum identification</td>
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<tr>
<td>2019</td>
<td>Interfaces: baseline evaluation</td>
<td>Insulation: Cleaning</td>
<td>Develop disturbance spectrum identification</td>
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</tbody>
</table>

**Diagnostics developments**

- Epoxy: baseline evaluation
- Epoxy: chemistry evaluation
- Interfaces: baseline evaluation
- Insulation: Cleaning
- Interfaces: surface optimization

**Materials development, characterization and optimization**

- Interfaces: baseline evaluation
- Insulation: Cleaning
- Interfaces: surface optimization
- Develop disturbance spectrum identification

**Advanced analysis and modeling**

- FEA on clusters
- 3D Mechanical FEA
- Model optimization with FEA
- 3D Magnetics
- Multiscale modeling and analysis
- Multiphysics
In the past, all DOE/HEP proposals responding to the general Office of Science call would come in at different time during the fiscal year, and were individually peer-reviewed by independent experts.

Started in FY 2012, OHEP began a new process of comparative grant reviews, with its own dedicated Funding Opportunity Announcement (FOA), for ongoing research grants which were scheduled for renewal in that particular FY (+ new proposals).

As before, the proposals are individually peer-reviewed by independent experts, but, in addition, they are further reviewed collectively by a panel of reviewers.

The goal of this effort is to improve the overall quality and efficacy of the HEP research program by identifying the best proposals.
Review Criteria

1. Scientific and/or Technical Merit of the Project
2. Appropriateness of the Proposed Method or Approach
3. Competency of Applicant's Personnel and Adequacy of Proposed Resources
4. Reasonableness and Appropriateness of the Proposed Budget
5. Relevance of The Proposed Research to the HEP Program Priority
## FY14-18 Comparative Review Data

<table>
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<th>FY</th>
<th># Proposal</th>
<th># Awards</th>
<th>$ Requested</th>
<th>$ Awarded</th>
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<td>29 (20 new)</td>
<td>11 (4 new)</td>
<td>13.8M</td>
<td>4.2M</td>
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<td>2015</td>
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<td>9 (5 new)</td>
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<td>4.3M</td>
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<td>2016</td>
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<tr>
<td>2017</td>
<td>23* (18 new)</td>
<td>8 (5 new)</td>
<td>7.1M [11.3M eff]</td>
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<tr>
<td>2018</td>
<td>15* (8 new)</td>
<td>9 (5 new)</td>
<td>5.3M [9.5M eff]</td>
<td>4.4M</td>
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* Includes NRL and/or PPPL proposals
Full Funding of Multi-Year Grants

- On January 17, 2014, the President signed the 2014 Consolidated Appropriations Act (CAA): Section 310(D) requires full funding of multi-year grants and/or cooperative agreements received from academic institutions with total cost less than $1M.
  - “Full funding” implies funds for the entire award for the proposal’s project period is obligated at the time the award is made, instead of funding year-by-year.

- Logistics on full funding:
  - Process applies to new, renewal, or supplemental grant awards that are made after the merit review process.
  - No other exemptions from this provision apply other than grants and cooperative agreements are of total cost less than $1M – integrated over the project period approved for the proposal.

- During the submission of a proposal along with conducting its merit review and making decisions on the award:
  - There will be no change to how an applicant applies for a grant or cooperative agreement.
  - There will be no change to the merit review process.
  - There will be no change to DOE Program Managers requesting revised budgets from PIs.

- DOE Program Managers (PM) will continue to have oversight of the research program by requiring PIs to submit an annual research performance progress report that must be approved by the PM prior to any funds being accessed by the PI the following year.

- SC program offices, including HEP, will aim to carry out the transition in a way that minimizes impacts on the scientific community and the mission needs served by the office.
Outline

• Overview of the GARD program
• Programmatic strategy
• Grant proposal process
• GARD Laboratory programs/facilities
  – opportunities for collaboration and experiments
# Lab GARD Activities

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<th>Adv Acc Concepts</th>
<th>Particle Src &amp; Targety</th>
<th>RF Acc Technology</th>
<th>Supercon Mag/Mat’l</th>
<th>User &amp; Test Facility Ops</th>
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- Laboratory programs and user/test facilities (ATF, AWA, BELLA, FACET-II, FAST-IOTA, MDP, SRF...) offer opportunities to
  - Join other user groups in their experiments
  - Submit you own user experiments
  - Collaborate with the in-house laboratory research programs
  - Collaborate with lab group to carry out your research.
Advanced Accelerator Concepts – LWFA

- BELLA Center at LBNL
  - Most powerful 1Hz laser
  - Highest accelerated beam (~8 GeV)
  - LPA staging @low energy (high energy soon)
  - Tunable injection in a jet with a sharp shock

- Active plasma lens

- Pulse front tilt and electron beam steering
Advanced Accelerator Concepts – PWFA

- FACET → FACET-II at SLAC
  - 9 GeV e-beam acceleration
  - e+ beam gain 4 GeV/1.3m, 1.8% dE/E
  - Hollow plasma channel for e+
  - >1 GeV e+ acceleration in quasi-linear regime

FACET-II Users/PAC Meeting Oct 8-12, 2018
Advanced Accelerator Concepts – Argonne Wakefield Accelerator

- Two-Beam and Coaxial Wakefield Acceleration concepts
Phase I (electron beam)—concentrate on the science aspects of single-particle motion stability.

Phase II (proton beam)—will relocate existing 2.5MeV (HINS) RFQ to FAST to inject into IOTA ring for intense-beam and space-charge studies.

Research will focus on high-intensity proton rings: space-charge effects, instability mitigation, beam loss control, beam cooling.
Particle Sources and Targets (GARD Research Roadmap Workshop coming soon)

➢ RaDIATE Collaboration (*Radiation Damage In Accelerator Target Environments*)

➢ LBNF graphite target/Ti cooling tube

- Ti-1: $1.42 \times 10^{20}$
  - 0.17 DPA (MARS)

- Ti-2: $5.22 \times 10^{20}$
  - 0.42 DPA (MARS)

➢ Ti OTR foils
RF Acceleration Technology—SRF

- State-of-the-art equipment @FNAL
- Nitrogen doping/infusion and better understanding of magnetic flux losses
  → SRF cavities with
  - High $Q_0$
  - High accelerating gradient
- $\text{Nb}_3\text{Sn}$, Niobium with S-S structures, Nb and non Nb multilayer structures → high efficiency
RF Acceleration Technology—NCRF

- Better understanding RF breakdown → dramatic increase in accel gradient
- Massively parallel computing tools enable virtual RF design
- High efficiency RF sources

Breakdown Probability [1/pulse/meter] vs. Accelerating Gradient [MV/m]

- Hard CuAg#3
- Soft Cu
- Hard Cu
- Hard CuAg#1
- Cu@45K

RF test stands: ASTA, Lead-mini bunker, Low-voltage source test, Cryogenic material test

RF optimization and full structure modeling

Machined in two halves
Superconducting Magnets and Materials

- GARD SC magnet and conductor development at BNL, FNAL, and LBNL → LHC upgrades.
- Explore new design—Canted Cosine Theta (CCT) at LBNL

- Develop HTS technology—
  - Round Bi2212 wire
  - REBCO tape and CORC cables
Summary

• The GARD Program
  – supports a broad spectrum of R&D in Accelerator Science and Technology
  – supports many research efforts that are world-leading and continues to push their frontiers
  – is implementing the ARDS recommendations within its budget and programmatic constraints
  – is developing research roadmaps for each of its research thrusts

• Many opportunities at the lab programs/facilities for grant PIs to collaborate and carry out user experiments
Thank you for coming!

Program Managers are available to answer any questions you may have, either here or during your face-to-face meeting later.