Advanced Accelerator Concepts R&D at DOE Office of High Energy Physics

L.K. Len

AAC’16 Workshop
National Harbor, Maryland
August 1, 2016
• **GARD = General Accelerator Research & Development** 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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>accelerator stewardship</strong></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>
</tr>
</tbody>
</table>
Five Research Thrusts:

- Advanced Accelerator Concepts
- Accelerator and Beam Physics
- Particle Sources and Targets
- RF Acceleration Technology (NC and SC RF)
- Superconducting Magnets and Materials

Support research efforts at:

- 7 DOE national labs
- 30 university grants
FY 2016 GARD Research – % By Thrusts

- **Advanced Accelerator Concepts**: 26.1%
- **Accelerator and Beam Physics**: 18.8%
- **RF Acceleration Technology (NC and SC RF)**: 29.0%
- **SC Magnets and Materials**: 21.1%
- **Particle Sources and Targets**: 2.4%
- **Other**: 2.5%
FY 2016 GARD AAC – % Distribution

- Facility Ops: 45.4%
- Laboratory Research: 42.0%
- University Research: 12.6%
HEPAP Recommendations

• P5 Report “Building for Discovery” was issued by HEPAP in May 2014: among other things, it recommended
  
  – [23] Support the discipline of accelerator science through advanced accelerator facilities and through funding university programs. Strengthen national laboratory-university R&D partnerships, leveraging their diverse expertise and facilities.
  
  – [26] Pursue accelerator R&D with high priority at levels consistent with budget constraints. Align the present R&D program with the P5 priorities and long-term vision, with an appropriate balance among general R&D, directed R&D, and accelerator test facilities and among short-, medium-, and long-term efforts. Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators.

• Following the P5 Report, HEPAP was charged to form an Accelerator R&D Subpanel to assess and identify the most promising research areas for the GARD program

HEPAP Recommendations

- The HEPAP Accelerator Subpanel Report “Accelerating Discovery” was issued in April 2015, with 17 specific recommendations.
- Most relevant to AAC are
  - [2] Construct the IOTA ring, and conduct experimental studies of high-current beam dynamics in integrable non-linear focusing systems.
  - [3] 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.
  - [7] Vigorously pursue particle-driven plasma wakefield acceleration of positrons at FACET in the time remaining for the operation of the facility. Between the closing of FACET and the operation of a follow-on facility, preserve the momentum of particle-driven wakefield acceleration research using other facilities.
  - [8] Continue to support laser-driven plasma wakefield acceleration experiments on BELLA at the current level.
  - [9] Reduce funding for direct laser acceleration research activities.
  - [10] Convene the university and laboratory proponents of advanced acceleration concepts to develop R&D roadmaps with a series of milestones and common down-selection criteria towards the goal of constructing a multi-TeV $e^+e^-$ collider.
• **Continue…**
  
  – **[11]** Continue research on high-efficiency power sources and high-gradient normal conducting RF structures.
  
  – **[12]** Make NLCTA available for RF structure tests using its RF power and beam sources.
  
  – **[13]** Focus normal conducting RF R&D on developing a multistage prototype based on high-gradient normal conducting RF structures and high-efficiency RF power sources to demonstrate the effectiveness of the technology for a multi-TeV $e^+e^-$ collider.
  
  – **[14]** Continue accelerator and beam physics activities and beam instrumentation and control R&D aimed at developing the accelerators defined in the Next Steps and the Further Future Goals. Develop coordination strategies, both nationally and internationally, to carry out these studies in an efficient manner.
  
  – **[15]** To ensure a healthy, broad program in accelerator research, allocate a fraction of the budget of the Accelerator Physics and Technology thrust to pursue fundamental accelerator research outside of the specific goals of the Next Steps and Further Future Goals. Research activities at universities should play a particularly important role.
  
  – **[C1b]** Develop, construct, and operate a next-generation facility for particle-driven plasma wakefield acceleration research and development, targeting a multi-TeV $e^+e^-$ collider, in order to sustain this promising and synergistic line of research after the closure of the FACET facility.

As recommended by the Accelerator Subpanel (#10), the AAC wakefield accelerator community was mobilized to draft up its research roadmaps.

A series of preparatory workshops was organized:
- October 2015, FACET-II Workshop on Science Opportunities at SLAC National Accelerator Laboratory.
- December 2015, DWFA Multi-TeV Linear Collider Roadmap Workshop at Argonne National Laboratory.
- January 2016, Plasma-Based Accelerator Concepts for Colliders Workshop at Lawrence Berkeley National Laboratory.

Preliminary research roadmaps were used as input to the DOE AAC Research Roadmap Workshop held in Washington DC in February 2016.
- Invited participants consist of representatives from each of the three technology groups (PWFA, DWFA, and LWFA) as well as other laboratory, university, and international invitees who bring knowledge in collider requirements, expertise in beam physics, simulation, diagnostic and accelerator applications, along with agency observers.
- The workshop report has been received by DOE and is now posted on the HEP website.
Some Highlights from the Report

• **Common challenges identified during the workshop:**
  - Higher energy staging of electron acceleration with independent drive beams, equal energy, and 90% beam capture;
  - Understanding mechanisms for emittance growth and developing methods for achieving emittances compatible with colliders;
  - Completion of a single electron acceleration stage at higher energy;
  - Demonstration and understanding of positron acceleration; and
  - Continuous, joint development of a comprehensive and realistic operational parameter set for a multi-TeV collider, to guide operating specifications for AAC.

http://science.energy.gov/hep/community-resources/reports/
Some Highlights (LWFA)

Roadmap for the development of a LWFA based collider

<table>
<thead>
<tr>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
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<tbody>
<tr>
<td><strong>Continuing Invention &amp; Discovery Phase</strong></td>
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<td>Modeling and simulations with hi-fidelity, high speed codes</td>
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<tr>
<td>10 GeV module</td>
<td>Positrons</td>
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<td>5 GeV+5 GeV staging</td>
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<td>Phase space shaping, efficiency, diagnostics, tolerances</td>
<td>Final focus, cooling, …</td>
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<tr>
<td><strong>Prototype Phase</strong></td>
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<tr>
<td>GeV linac – kHz rep rate</td>
<td>50-100 GeV linac(s) – O(1-10kHz)</td>
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<tr>
<td><strong>First applications (radiation sources)</strong></td>
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<tr>
<td>Design of concepts for colliders</td>
<td>Collider conceptual design report (CDR)</td>
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<tr>
<td><strong>Lasers</strong></td>
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<tr>
<td>3 kW class</td>
<td>Collider tech. design report (TDR)</td>
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<tr>
<td>30 kW class</td>
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<td>300 kW class</td>
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U.S. DEPARTMENT OF ENERGY
Office of Science
# Some Highlights (PWFA)

## Beam Driven Plasma Accelerator Roadmap for HEP

<table>
<thead>
<tr>
<th>2016</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
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<tbody>
<tr>
<td>LHC Physics Program</td>
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<td><em>End LHC Physics Program</em></td>
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<tr>
<td>Plasma Accelerator R&amp;D at Universities and other National &amp; International Facilities</td>
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<td>PWFA-LC Concepts &amp; Parameter Studies</td>
<td>PWFA-LC CDR</td>
<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>Plasma Source Development</td>
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<td>FACET-II Construction</td>
<td>FACET-II Operation</td>
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<td>Experimental Design &amp; Prototyping</td>
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<td>Staging Studies</td>
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<td>Multiple Stages</td>
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<td>Emittance Preservation</td>
<td>Transformer Ratio &gt; 1</td>
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<tr>
<td>PWFA App Dev. &amp; CDR</td>
<td>PWFA-App TDR</td>
<td>PWFA-App Construction</td>
<td>PWFA-App Operation</td>
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<tr>
<td>Future Facility Design (FFTBD)</td>
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<td>FFTBD Construction</td>
<td>FFTBD Operation &amp; Collider Prototype ‘String Test’</td>
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<tr>
<td>Positron PWFA Concept Dev.</td>
<td>Positron PWFA in PWFA-LC Regime</td>
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<tr>
<td>Driver Tech.</td>
<td>Euro XFEL Construction</td>
<td>Euro XFEL Operation</td>
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<tr>
<td>LCLS-II Construction</td>
<td>LCLS-II Operation</td>
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</table>

**Legend**
- Theory/Simulation/Design
- Engineering/Construction
- Experiments/Operations
## Some Highlights (DWFA)

### DWFA LC 10 YEAR ROADMAP

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2018</th>
<th>2020</th>
<th>2022</th>
<th>2024</th>
<th>2026</th>
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<tbody>
<tr>
<td><strong>DWFA LC Baseline Technology (potential multi-fold cost reduction)</strong></td>
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<td><strong>Technology Consolidation Phase</strong></td>
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<td><strong>Technology Integration Phase</strong></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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<tr>
<td><strong>Science Discovery and Technology Invention Phase</strong></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>

Note: the color fading is proportional to the effort. Timeline is subject to funding level. Cost reduction compared to current LC technology.
### FY 2017 Research Opportunities in High Energy Physics

**Announcement Number:** DE-FOA-0001604  
**Post Date:** July 26, 2016  
**Close Date:** September 20, 2016  

**Notes:**

- Letter of Intent Due Date: August 23, 2016, at 5 PM Eastern Time  
  (A Letter of Intent is highly encouraged)  
- Application Due Date: September 20, 2016, at 5 PM Eastern Time

### Early Career Research Program

**Announcement Number:** DE FOA 0001625  
**Post Date:** July 28, 2016  
**Close Date:** November 14, 2016  
**Companion Announcement:** LAB 16-1625  

**Notes:**

- Pre-Application Due Date: 09/08/2016 at 5 PM Eastern Time  
  (A Pre-Application is required)  
- Encourage/Discourage Date: 10/06/2016 at 5 PM Eastern Time  
- Application Due Date: 11/14/2016 at 5 PM Eastern Time

### Frequently Asked Questions
DOE National Laboratory Announcements

Proposals submitted by DOE National Laboratories in response to the below program announcements will be subjected to formal merit review (peer review). National Laboratory proposals submitted to these solicitations do not compete against grant applications submitted by the private sector.

**Early Career Research Program**  (375KB)

<table>
<thead>
<tr>
<th>Announcement Number:</th>
<th>LAB_16-1625</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Date:</td>
<td>July 28, 2016</td>
</tr>
<tr>
<td>Close Date:</td>
<td>November 14, 2016</td>
</tr>
<tr>
<td>Companion Announcement:</td>
<td>DE-FOA-0001625</td>
</tr>
</tbody>
</table>

**Notes:**

- Pre-Proposal Due Date: 09/08/2016 at 5 PM Eastern Time
  (A Pre-Proposal is required)
- Encourage/Disourage Date: 10/06/2016 at 5 PM Eastern Time
- Proposal Due Date: 11/14/2016 at 5 PM Eastern Time

**Frequently Asked Questions**  (160KB)

For full details: [http://science.energy.gov/hep/funding-opportunities/](http://science.energy.gov/hep/funding-opportunities/)
The Accelerator R&D Stewardship Program

• **Mission:** Support fundamental accelerator science and technology development of relevance to many fields and to disseminate accelerator knowledge and training to the broad community of accelerator users and providers

• **Strategies:**
  – **Improve access to national laboratory accelerator facilities**
    • BNL Accelerator Test Facility—is operated as a National User Facility for stewardship use
    • **Accelerator Stewardship Test Facility Pilot Program**—funds “outside use” of lab accelerator test infrastructure
  – **Develop innovative solutions to critical problems**
    • Annual calls for proposals—2 so far, resulting in 15 total awards
  – **Broaden and strengthen the community**
    • Basic Research Needs Workshops to bring stakeholders together—3 so far
    • National Academies Studies—1 so far on ultra-intense laser science & technology

• **Process:**
  – Technical objectives and award selections are coordinated with stakeholder agencies
    • DOE/BES, DOE/NP, NSF/MPS, NSF/CBET, DOD/ONR, NIH/NCI, and DHS/DNDO
  – Detailed technical input to identify high-impact stewardship topics comes from community workshops and requests for information
    • Reports and RFIs may be found at: [http://science.energy.gov/hep/research/accelerator-stewardship/workshop-reports/](http://science.energy.gov/hep/research/accelerator-stewardship/workshop-reports/)
Stewardship Awards

Awards from the 2015-2016 Calls for Proposals

- **Use-Inspired Basic R&D Awards (“Track 1”)**
  - Technologies for Particle Beam Therapy
    - Superconducting FFAG Gantry Design and Magnet Prototype (LBNL/Varian/PSI)
    - Diamond Beam Position and Dose Monitor (Stony Brook/BNL/BMI)
  - Ultrafast Laser Technology R&D
    - Coherent Combining in Space, Time, and Frequency (LBNL/LLNL/U Mich)
    - Cryo Yb:YAG amplifiers, high damage threshold coatings (CSU/LLNL/UMD)
    - High power beam quality control and enhancement (U Mich)
  - **Energy & Environmental Applications**
    - High efficiency klystrons (SLAC/CPI)
    - 3 Design Studies for MW-class electron accelerators (FNAL/CSU/NIU/CCR/Euclid/AES/MWRDC, SLAC/GA/TAMU, JLAB/AES/GA)

- **Basic R&D Awards (“Track 2”)**
  - Advanced algorithms for accelerator controls (Cornell)
  - Ironless variable-energy cyclotrons for proton therapy (MIT/ProNova)
  - Beam dynamics studies of high power cyclotrons (TAMU)
  - New sources of particles and radiation (UCLA)
  - Fundamental studies of niobium superconductors (MSU/FSU/OSU/ASU/NHMFL/JLAB)

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Accelerator R&D Test Facility Awards

- HGRF ion linac prototype testing
- Elliptic SRF ERL cavity prototype
- L-PVD vacuum getter coatings
- Wireless high power for implants
- Conduction cooling of SRF cavities
- UNX diamond cathode testing
- High reliability SRF coupler testing

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Coordinated SBIR Awards

**Phase I Awards**

- High Power Yb:PCF fiber laser (Optical Engines)
- Lu2O3 powders for ceramic lasers (nGimat)
- Simulation tools for diffractive optics (KJ Innovation)
- Large-Aperture PPLN xtal for OPCPA (AdvR)
- High power high efficiency L-band klystron (Omega-P)
- High power novel topology circulator (CCR)

**Phase II Awards**

- Fiber-based CO2 seed laser (Agiltron)
- Edge Pumped Disk Laser at 2 μ (Aqwest)
- HE Pump diodes at 1.5, 1.9 μ (Freedom Photonics)
- Optical cross-correlator for attosecond timing synchronization (AdvR)