Agenda

Part 1: SLAC’s Science and Technology Strategy for the Future

• SLAC At a Glance
• Ongoing and Emerging Strategic Initiatives
• Laboratory Directed Research and Development
• Partnerships and Collaborations

Part 2: SLAC’s Mission Support Aligns With Laboratory Strategy

• Campus Strategy
• Cost of Doing Business
• Human Resources
SLAC is a vibrant multi-program laboratory located in Silicon Valley and operated by Stanford University

Our Mission

We explore how the universe works at the biggest, smallest and fastest scales and invent powerful tools used by scientists around the globe. Our research helps solve real-world problems and advances the interests of the nation.

Our People

- 1,602 FTEs
- 22 Joint Faculty
- 22 Visiting Scientists
- 2,931 Facility Users
- 145 Postdocs
- 207 Grad Students
- 120 Undergrads

FY18 Costs by Funding Source

- BER, $4.2
- ASCR, $1.0
- FES, $6.2
- HEP, $82.2
- NP, $1.1
- EERE, $8.9
- SPP, $18.0
- Other, $46.8

Cost Data in $M

- $592.9M Lab Operating Costs
- $574.9M DOE Costs
- $18M SPP Costs
- 3% SPP (as % of Total Lab Costs)
Core capabilities and cutting-edge competencies are our scientific foundation

• We advance our 6 existing core capabilities in support of our strategic initiatives:
  1. Particle Physics
  2. Accelerator Science and Technology
  5. Chemical & Molecular Science
  6. Plasma & Fusion Energy Science

And we develop emerging core capabilities in anticipation of future mission needs:
  ➔ Advanced Computer Science, Visualization and Data
  ➔ Biological Systems Science

• We support our core capabilities with a suite of cutting-edge technical competencies:

![Ultrafast lasers & X-ray optics](image1)
![Sensors & detectors](image2)
![ASICs](image3)
![Sample delivery methods](image4)
![Data management systems](image5)
![THz/High-power RF technologies](image6)

These competencies differentiate us from other labs with similar capabilities
We boldly pursue our laboratory goals to deliver visionary science and real impact

**LABORATORY GOALS**

1. Be the world leader in X-ray and ultrafast science and in our selected areas of accelerator science and high energy physics
2. Expand and increase our impact in Office of Science mission areas by leveraging our world-leading core capabilities and expertise
3. Broaden and strengthen our impact across critical national needs by using our position within Stanford and Silicon Valley
4. Be the “best-in-class” DOE lab for safe, efficient and innovative operations that align with and enable our research mission
Our strategic initiatives support our laboratory goals

**Ongoing Strategic Initiatives**

**Initiative 1:** Be the world leader in X-ray and ultrafast science

**Initiative 3:** Be an innovator for massive-scale data analytics

**Initiative 2:** Foster a frontier program in the physics of the universe

**Initiative 4:** Advance high energy density science

**Emerging Strategic Initiatives**

**Initiative 5:** Create a world-leading bioimaging program

**Initiative 6:** Advance DOE’s mission in quantum information science
Stanford continues to make significant investments in SLAC

- Transforming the SLAC site and providing new research infrastructure and capabilities

- In its 3rd year, our new M&O contract model is enhancing trust and partnership
  - Providing dozens of IT and HR solutions and processes and delivering key services such as the SLACafé and Stanford Guest House, reducing overhead costs

Stanford has invested more than $154M in SLAC over the past 7 years
Stanford support of SLAC’s science programs increases our impact

- Working with Stanford in 5 joint institutes and centers
- Teaming with Stanford to expand our science programs
- Playing an integral role in Stanford’s Long-Range Planning to identify the challenges and opportunities that lie before us
- Partnering with Stanford to train the next generation of leaders
  - Making our science education programs more rigorous, covering X-ray, accelerator, theory and instrumentation

World-class talent and intellectual leadership from Stanford set SLAC apart
Strategic initiative 1: Be the world leader in X-ray and ultrafast science

1. Unpeeling atoms and molecules from the inside out
2. Recording molecular movies of chemistry in action
3. Watching molecules “breathe”
4. Catching the birth of chemical bonds
5. Cracking the mysteries of photosynthesis
6. Mapping drug targets in motion
7. Uncovering the mechanics of biological machines
8. Chasing room-temperature superconductivity
9. Harnessing magnetism and electron behavior
10. Probing materials in extreme environments

10 ways SLAC’s X-ray laser has transformed science
X-ray lasers are driving a scientific revolution

- X-ray lasers will define X-ray science of the 21st century
  - Coherent, ultrafast X-rays
  - $10^9$ peak power: LCLS
  - $10^4$ average power: LCLS-II, LCLS-II-HE

- Scientific potential and significance of XFELs is recognized worldwide

LCLS-II and LCLS-II-HE will lead scientific discovery in this new era
SLAC and partner labs dealt with major setbacks in FY18/19
- Resolved cryomodule (CM) transportation issues
- Working through cryomodule receipt and installation problems now

Project is 85% complete with 95% of procurements awarded

Project has 13 months float to CD-4, with ~24% contingency
- But many high-consequence activities still lie ahead

Delivering LCLS-II on time and on budget is our highest priority.

We have reconfigured our management team and approach to critical activities.
Taking action to realize the full science potential of XFELs and their impact on DOE-SC science

- Harnessing SLAC/Stanford science programs and galvanizing the broader community
- We will initiate LCLS-II “science campaigns”
  - Target high-impact science areas
  - Anticipate using 10-20% of beamtime
  - Comprehensive efforts with multiple beamtimes
  - Opportune time: Increased XFEL competition and capacity
- An LCLS pilot of systematic award of beamtime was very effective (Photosystem-II)
  - Importance of strong SLAC involvement

Science campaigns will complement general user access, and enhance and accelerate the science impact of LCLS

- LCLS awarded beamtime each run to the PS-II teams, with high impact outcome
- LCLS-II lets us replicate this for 4-5 areas in parallel
Science campaign – example #1
Pushing the frontiers of imaging in space and time

Science Impact
• Enable imaging of charge dynamics on the natural time and length scale of electron correlation
• Elucidate earliest steps in photo chemistry/radiation damage, electron-electron interactions in quantum materials

Status/Next Steps
• Strong experimental team established at SLAC; coordinated and expanded theory effort will maximize scientific impact
• XLEAP sub-fs mode demonstrated at LCLS in FY19, orders of magnitude more light than high harmonic generation
• Available from the start of LCLS ops in 2020

Zn porphyrin charge dynamics
Govind et al., JCTC (2011)
Controlling catalytic reactivity with electronic excited states

Science campaign – example #2

Science Impact

• Establish new pathways to selective and efficient synthesis of high-value chemicals
• Discover design rules for efficient photo-sensitizers based on non-precious metals
• Develop ultrafast X-ray methods broadly applicable to the BES research mission

Status/Next Steps

• Demonstrated ultrafast X-ray methods capture reactive trajectories with unprecedented detail
• Growing area of research at SLAC with efforts in theory and experiment

Coordinated make-measure-model approach to achieve full scientific impact
Quantum materials control via coherent light-matter interaction

Science Impact

- Understand couplings and intertwined orders in quantum materials in the time domain
- Exploit tailored excitation and coherent light-matter interaction for new insight

Status/Next Steps

- Harness existing experiment and theory efforts into a cohesive program
- Near-term development of techniques and models
- Dedicated LCLS-II instrument at earliest opportunity

Identified by the community as a frontier of condensed matter research; priority focus for the SLAC materials program
LCLS-II-HE is motivated by the scientific need to understand complex matter at the atomic scale

Structural dynamics at the atomic scale
- Expand LCLS-II energy reach to 13 keV (20 keV)
- ~3,000x increase in average spectral brightness compared to LCLS

Drives massive-scale data analytics needs
- $10^8$ to $10^{10}$ X-ray snapshots per day

Status/Next Steps
- CD-1 review in September 2018
- CD-3a review preparation underway
Investments in X-ray and ultrafast science to fully exploit LCLS-II and LCLS-II-HE

**SLAC and Stanford Investments:**

- PD and LDRD projects in novel X-ray instrumentation and ultrafast pump-probe methodologies to open up new scientific opportunities
- Infrastructure and new capabilities, such as nano-fabrication of X-ray optics, for LCLS-II
- 4 Panofsky Fellowships supporting single particle imaging, catalysis, attosecond pulse generation and extreme materials science
- Wallenberg-Bienenstock Professorship, a joint SLAC-Stanford appointment

**Resource Requests of BES:**

- Provide operations funding to allow optimum exploitation of LCLS-II
- Support critical R&D to ensure robust experimental platform for LCLS-II, LCLS-II-HE early science
- Within X-ray and ultrafast science, fund programs in materials and chemical science across the user community to ensure our scientific leadership and complement our unique facilities
- Support a funding profile that will optimize cost and schedule for LCLS-II-HE
Strategic initiative 2: Foster a frontier program in the physics of the universe

- **Dark Energy**
- **Dark Matter**
- **Higgs Physics/BSM**
- **Neutrinos**

- Large Synoptic Survey Telescope camera
- SuperCDMS tower
- ATLAS coordinate measuring machine
- DUNE-PRISM near detector

SLAC has a robust HEP program spanning all P5 science drivers, delivering on commitments while looking toward the future.
Delivering dark energy science at LSST is our highest HEP priority

LSST will record deep images of 10B galaxies to observe the nature of dark energy

- Camera systems integration and testing on track for shipment to Chile in FY20
- Commissioning and transition to operations underway
- Dark Energy Science Collaboration (DESC) preparing for first light with mock data challenge
- Science systematics informed by deep knowledge of camera
- Data policy: 2-year proprietary with resource board (NSF/DOE) to manage intl. in-kind contributions

SLAC provides leadership across LSST camera and dark energy science program
SLAC expertise in detector technology advances searches for dark matter & new particle physics, studies of the Higgs

SuperCDMS-SNOLAB
- Transition-edge sensors propel search for low-mass WIMPS
- SLAC lead lab in strong partnership with Stanford
- Fabrication, installation and commissioning on track
- Detector innovations can further science reach

LZ
- Time projection chamber grid design advances search for high-mass WIMPS
- Large technical scope at SLAC with delivery of grids and purification system
- Leading offline analysis

ATLAS HL-upgrade
- Inner tracker (ITk) pixel design and assembly enable precision Higgs measurements
- SLAC staff serving as project management of U.S. ITk scope
- Specialized ML algorithm for clustering

SLAC is capitalizing on past investments in support of the P5 program
New investments and vision for SLAC HEP/NP over the coming decade: Advancing neutrino science

DUNE Near Detector
- Segmented liquid argon time projection chamber being prototyped and tested at SLAC Liquid Noble Test Facility
- DUNE-PRISM concept adopted by collaboration
- H. Tanaka leading near detector critical design review effort

Enriched Xenon Observatory
- EXO-200: Decommissioned and completing science analysis
- nEXO: Launch search for senior hire; defining technical roles and leadership

Machine learning allows for 3D oscillation data reconstruction

SLAC expertise in detector technology, reconstruction and machine learning benefits the DUNE neutrino program and plays key roles in nEXO
SLAC investments lead to strong proposals for new dark matter initiatives

**Dark Matter Radio**
- Quantum sensor technology enables novel axion searches
- Pathfinder yields first results

**Light Dark Matter Experiment**
- LCLS-II beam can be used to probe low-mass thermal dark matter
- S30XL engineering to start in FY19 with construction planned for FY20

SLAC/Stanford theory groups play key role in launching new probes for dark sector & axion dark matter, building on quantum sensors & electron beams
• **Significant Cosmic Microwave Background (CMB) science at SLAC/Stanford**
  - Science and technical leadership in BICEP program; laboratory investment prior to P5
  - Science connection to LSST optical survey and neutrino programs
  - Key technical expertise for DOE CMB-S4 contribution
  - World-leading inflation theory, starting with A. Guth at SLAC in 1981

• **Complex multi-agency, multi-lab project;** well matched to SLAC project expertise and ability to deliver

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**SLAC is building on investment and science foundations to complete preparations for major technical contributions and leadership**
Investment in dedicated cleanroom for superconducting devices: Anchor CMB-S4 detector deliverables

- **Detector Microfabrication Facility (DMF):**
  - New state-of-the-art facility for CMB, QIS, X-rays
  - Class 100 cleanroom for fabrication of superconducting quantum circuits
  - Dedicated tool suite for superconducting materials
  - Eliminate cross-contamination from incompatible fabrication processes
  - SLAC DMF team has world-leading expertise

SLAC is evaluating an investment strategy for this major technical contribution
Investments in physics of the universe to address key P5/NSAC questions

**SLAC and Stanford Investments:**

- PD and LDRD projects in CMB-S4, Dark Matter Radio, S30XL/LDMX, DUNE, LZ & new theory efforts
- Infrastructure, including the LZ liquid noble test platform that will support the DUNE Near Detector (ND), the ATLAS coordinate measuring machine, and the LSST clean room that will later serve both CMB-S4 and DUNE ND needs
- A major investment in the Detector Microfabrication Facility (DMF)
- 3 Panofsky Fellowships, 2 supporting ATLAS and 1 supporting CMB-S4

**Resource Requests of HEP and NP:**

- Fund LSST commissioning, facility and LSST-DESC operations, as well as SuperCDMS-SNOLAB operations, at the requested level
- Provide support for Detector Microfab Facility toward CMB-S4 & development of quantum sensors
- Accelerate support for CMB-S4 R&D and interim Project Office activities
- Collect resources to begin construction of the S30XL
- Transfer EXO-200 research funds to DUNE to complete the start-up package for Hiro Tanaka
- Provide funds to support the transfer of EXO-200 research personnel to our nEXO program, and for a senior scientist to provide leadership for that effort
Strategic initiative 3: Be an innovator for massive-scale data analytics

X-ray and Ultrafast
- X-ray scattering
- Up to 1,000 GB/s & 1,000 PFLOPS

Physics of the Universe
- Large Synoptic Survey Telescope
- 100 GB/s & 1 PFLOPS

Machine Learning
- Accelerator diagnostics
- 1 GB/s & 5 PFLOPS

HED Science
- Plasma simulation
- 5 GB/s & 5 PFLOPS

Bioimaging
- Cryo-EM
- 100 MB/s & 50 PFLOPS
SLAC programs continue to drive innovation in 3 key areas

1. **On-the-fly data reduction** from detectors generating data many orders of magnitude faster than today

2. **Real-time data analysis** via High-End Computing facilities (HECs) while an instrument is taking data

3. **Machine learning and other algorithmic developments** providing step-change capabilities for facility operation and novel data analysis

We’re developing integrated solutions across our data challenges
Progress in these 3 key areas since last year

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<tr>
<th>Area</th>
<th>Achievements</th>
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| 1. On-the-fly data reduction  | • Data reduction pipeline for LCLS-II prototype now operating at 100kHz  
                                    • Allocated compute capabilities for LCLS-II early science in SRCF  
                                    • Joint statement of needs prepared by the 5 BES light sources |
| 2. Real-time data analytics   | • LCLS accepted into the NERSC Exascale Science Applications Program (NESAP) for the upcoming NERSC-9 system  
                                    • ExaFEL demonstrated LCLS-II style data processing at multi-kHz using >50% of Cori-II; **extended to 2023** as part of Exascale Computing Project  
                                    • ESnet deployed interface to accommodate network bandwidth scheduling requests for real-time communication between beamlines and HEC |
| 3. Machine learning           | • Launched new machine learning initiative at SLAC |

Highly productive partnership between LCLS, NERSC and ESnet
LCLS-II and LCLS-II-HE with their high rate detectors will generate a formidable data challenge

Data Challenges

- Rapid growth in detector readout rate
- 20-plus scientific workflows
- Using a single scalable data system

Imaging Detector Development Path

Substantial hardware needed to support the high rate, massive throughput and intensive workflows
Machine learning will address critical challenges for SLAC’s highest impact science

- Launched new machine learning initiative to address rapidly developing future needs and leverage existing capabilities, resources, solutions across the lab

- Focused on machine learning for experimental data production, which differentiates us from machine learning efforts at other labs

Active grassroots machine learning community

1st ML-at-SLAC workshop (2019)

1st ICFA ML workshop for particle accelerators (2018)
Machine learning will have a transformative impact on LCLS-II and LCLS-II-HE

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<tr>
<th>Accelerator control</th>
<th>Accelerator diagnostics</th>
<th>Megapixel detector</th>
<th>X-ray diffraction image</th>
<th>Intensity map from multiple pulses</th>
<th>Interpretation of structure/dynamics</th>
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Accelerator optimization is slow
- Train ML model on archive, simulation and physics
- 10x faster than hand tuning

Megapixels x MHz = too much data; must compress data/throw away shots
- ‘Smart’ compression/rejection of data by 1,000x using ML on FPGAs

$10^8$-$10^{10}$ X-ray scattering snapshots/day of stochastic dynamics
- Map reaction pathways and capture rare events on complex PE landscapes

Either 10-fold improvement in linac tuning or 1,000-fold compression for LCLS-II, LCLS-II-HE data reduction pipeline
Investments in massive-scale data analytics to meet the data challenges of LCLS-II, cryo-EM/ET and other programs

SLAC and Stanford Investments:
- PD and LDRD projects in machine learning, data analytics and innovative computer systems
- Stanford seed-funded students jointly supervised by computer science faculty and SLAC staff
- In partnership with Stanford, establishing a robust local computing platform, including the potential expansion of the Stanford Research Computing Facility (SRCF)
- A planned tape storage system upgrade

Resource Requests of BES, ASCR and HEC Facilities:
- Resources required for an HEC to support SLAC data analytics needs: increased time allocation, disk storage, tape archiving, networking, federated accounts and real time queues
- Targeted R&D for ML and on-the-fly analysis
- Substantial hardware in the mid-2020 timeframe, to support the high rate, massive throughput and compute intensive workflows of the SLAC facilities and for ML development
- Funding support of a core team for the new SLAC-wide ML initiative
Beginning in 2020, LCLS-II will provide a major leap in performance both in high-energy and multi-bunch trains, greatly benefitting HED science.
Proposal to upgrade MEC for leadership in HED science

• In response to National Academy of Sciences report

• Expanded facility east of LCLS Far Experimental Hall for new lasers, multiple shielded target areas

• Combine LCLS-II with 10x higher power (petawatt laser) and energy (kilojoule laser) to enable extreme matter physics:
  – $10^{18}$ Pa light pressure
  – $10^{12}$ Pa material pressure

• Strongly supported by HED science community
  – High-power Laser and Brightest Light Initiative workshops

Project will position LCLS beyond HED science capability of any other XFEL
Our 3D particle in cell simulations predict new physics regimes important for discovery science and future technical applications.

**Science enabled by a petawatt laser at MEC**

**Pulsed high-flux neutron sources**
PW lasers deliver \(10^{11}\) neutrons/s in close proximity to materials.

**Access record magnetic fields**
PW driven B-fields reach \(10^9\) G; 1,000x larger than produced by pulsed power.

**Access cosmic particle accelerators**

P. Alves et al., *PRL* (2018)
Enable unprecedented high-pressure materials science and determine structural and physical properties to test models of planetary interiors
Investments in HED science to enable world-leading fusion discovery science

SLAC and Stanford Investments:

- PD and LDRD projects in dynamic compression and HED theory
- 1 Panofsky Fellow supporting HED science

Resource Requests of FES:

- Timely progression to CD-1 for the project to co-locate a world-leading petawatt laser with LCLS
- Support for early career researchers for the theory component and for the development of new LCLS-II experimental capabilities of the SLAC research effort in this area
- Opportunities for our new Panofsky Fellow to develop an HED science program
- Funding for advanced detector development to make full use of the novel multi-bunch mode of LCLS that is particularly beneficial for breakthrough research for FES
Strategic initiative 5: Create a world-leading bioimaging program

Cryo-EM facility is up and running and producing high-impact science

Generating 3D images at nearly atomic resolution of viruses, molecules and complex biological machines inside the cell

- 3.2 Å cryo-EM structure of CRISPR protein-ssRNA complex
- 1.8 Å cryo-EM structure of human apoferritin
- Solar cell battery electron beam-sensitive hybrid organic-inorganic halide perovskite

Revealing molecular details of materials at near atomic resolution
Starting high-resolution 3D imaging of cells to address challenges in biology

Using deep learning to annotate subcellular features

Advancing BER mission with world-class multi-modal bioimaging capabilities

3D tomogram of a parasite made with cryo-EM

Plant cell wall dynamics

Plant ubiquitin stress signaling

The future is developing new image processing protocols to retrieve high-resolution 3D structures of molecular components
Integrative bioimaging and biocomputation are essential to achieve our long-term vision.

Bioengineering altered stress responses for plant cells in extreme environments

Distinct ubiquitin signals recognize their protein substrates

Ubiquitinated proteins bind receptor complexes and change their shape

Molecular substates functionally localize in the cell

Atomic simulations – machine learning

Coarse-grained simulations – machine learning

Deep learning

A multi-scale approach to deciphering the plant ubiquitin code
SLAC’s entry into biosecurity in connection with Stanford

Working with Stanford bioengineers, we will use cryo-EM to advance functional understanding of life, secure biodesign & synthetic cell building.

- **Make “fail-safe” organisms; create global benchmarking for gene and genome construction**

- **Help elucidate remaining unknown functions essential for life; use advanced imaging to enable synthetic cell building**

- **Synthetic genetic code expected to select against all random point mutations in any protein**

- **From ad hoc synthetic DNA to validated DNA and SYNPACK**

- **Late stage of a viral infection**

- **Hydrodynamic models exploring unknown functions essential for life**

- **Transition biosecurity from reacting to emerging risks to a well-grounded strategic posture based on full functional understanding**
Growing and supporting the BER science community at SSRL and LCLS

- **Expand their toolbox via BER-funded SSRL postdoc** to enable, support and advance the science projects of select BER-funded investigators
  - X-ray imaging/spectroscopy; links to cryo-EM, crystallography, small-angle X-ray scattering

- **Targeted outreach**
  - Workshops: Connect BER Genome Science Program (GSP) leaders with synchrotron scientists
  - BER GSP and Environmental System Science (ESS) PI meetings: Talks, posters, one-on-ones
  - Joint developments/projects with the DOE Joint Genome Institute and the DOE Environmental Molecular Sciences Laboratory: Outreach platforms to attract their BER users (and others) to SSRL and LCLS
  - Scientific collaborations with BER funded investigators: Showcases
Investments in bioimaging to address challenges, explore opportunities in biology

**SLAC and Stanford Investments:**

- Investments in cryo-EM capabilities, including faculty, Building 6 facility & Arrillaga Science Center
- 1 Panofsky Fellow to merge X-ray and cryo-EM/ET; cell membranes; machine learning for data analysis; time-resolved cryo-EM imaging

**Resource Requests of BER:** Accelerate growth of SLAC research in BER science mission areas

- Funding for an application scientist to solve 3D structures of macromolecular machines and subcellular structure within the context of bioenergy and biofuel production, using the established cryo-EM facilities and the new cryo-FIB-SEM capabilities
- Funding to develop software for cryo-EM/ET, including hiring a senior scientist to lead and develop algorithms for integrative big data analytics in each & across different imaging modalities
- Invest in an integrative biocomputation program to connect molecular and cellular scale data into models of microbial metabolism at cellular and community scales
Strategic initiative 6:
Advance DOE’s mission in quantum information science

Quantum Devices
- Superconducting sensors & Josephson junction devices

Quantum Optics
- Color centers; silicon-vacancy diamondoids

Quantum Materials
- Topological insulator

Simulation/Theory of Quantum Systems
- Floquet band in graphene

SLAC expertise in precision measurements and quantum materials is the origin of our emerging QIS initiative
SLAC envisions new directions to advance the Office of Science mission in QIS

New material platforms for improved qubits

Light from excitons localized at sites in a 2D material

Quantum simulations of fundamental physics

Non-local couplings for toy models of quantum gravity

Complete the QCD axion search with quantum advantage

Q=148,000 in first run, limited by calibration system

Dark Matter Radio Pathfinder

Bringing together our QIS efforts to form a coherent strategy
Unique SLAC facilities underpin our capabilities to meet the needs of QIS R&D

Integration of light sources and device fabrication for closed-loop engineering of quantum materials and devices

SSRL + LCLS-II + Cryo-EM
Realization of quantum spin hall state in monolayer

LCLS + UED
Controlling topological materials for fault-tolerant quantum computing

Nano-X + DMF (Arrillaga Science Center)
Integrated photonics and superconductors for quantum network nodes
SLAC and Stanford joint Q-FARM initiative delivers a strong QIS portfolio

SLAC and Stanford have complementary strengths in QIS; Q-FARM opens new pathways for connecting with industry.
We will address critical issues in quantum computing and other applications of quantum technology.

SLAC-Stanford Q-FARM initiative is a vehicle for delivering unmatched value to partners across a broad spectrum of QIS disciplines.

- Transduction, interconnects and coherence
- Local startups & industrial partners
- Commercial quantum computing platforms
- DOE quantum computing testbeds
- National laboratories
- Simulating chemistry with quantum algorithms
- Develop sensors to pinpoint decoherence; engineer qubit material
- Strongly engaged with Silicon Valley partners

SLAC-Stanford Q-FARM initiative is a vehicle for delivering unmatched value to partners across a broad spectrum of QIS disciplines.
Investments in quantum information science to advance DOE’s mission

**SLAC and Stanford Investments:**

- SLAC-Stanford Q-FARM initiative
- LDRD projects in Dark Matter Radio and diamondoids enabled quantum sensor development for dark matter searches and material growth for silicon and nitrogen vacancy center qubits
- A major investment in the Detector Microfabrication Facility (DMF) at SLAC

**Resource Requests of Office of Science:**

- SLAC is evaluating a major investment in the DMF at the laboratory. Our request to DOE is to supplement SLAC’s investment.
Partnerships and Collaborations

Pocket-sized antenna could enable mobile communication in situations where conventional radios don’t work
Growing and diversifying Strategic Partnership Projects to broaden SLAC impact on DOE mission areas and beyond

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<th>FY18 Actual</th>
<th>FY19 Estimate</th>
<th>FY19 Planned</th>
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<td>$22M</td>
<td>$30M</td>
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- 70% growth from FY17 actuals of $13M
- SPP program growth is focused on:
  - Using state-of-the-art facilities and unique integrated research capabilities to conceive, design, build, test, operate and commercialize
  - Broadening and sustaining DOE impact by providing unique expertise and technology to other U.S. government agencies, Silicon Valley projects and major multinational endeavors

FY18 SPP Actuals of $22M

- Stanford* 40%
- DoC 14%
- University/Institute 12%
- State 11%
- Other NonFed 17%
- DoD 5.5%
- DHS 0.5%

*Some of our federally sponsored projects, including the NIH Cryo-EM project, are contracted through Stanford with DOE agreement
Major SPP collaborations enable key competencies, facilities and projects

- **SPP is essential to ensure long-term vitality of technical competencies**
  - RF accelerator technology and detector/instrumentation
  - Groundbreaking Very Low Frequency (VLF) communications
  - Advancing grid technology, specialized electronics and battery capabilities
  - Quantum sensor development and X-ray cameras

- **State-of-the-art cryo-EM instruments and facilities**
  - A national center for 3D electron microscopy from macromolecules to whole cells, data collection towards atomic resolution structure determination of biochemically purified single particles

- **Providing code and sensors capability to Simons Observatory**
  - Will map over 40% of the southern sky from Chile and Antarctica starting in 2020
Broadening DOE impact in Silicon Valley; intellectual property and technology transfer are increasing

- **Silicon Valley**
  - Quantum Insights Big Data analysis tool with applications such as diagnostic discovery from medical datasets
  - TibaRay commercializing new accelerator technology for cancer therapy equipment
  - Zoox CRADA extended for additional 3 years
  - Strong engagement on **data science and ML** programs

- **Intellectual Property and Tech Transfer Licenses**
  - CPI: SLAC klystron designs
  - BiRa Systems: Networked power supply controller module
  - SiFive: Circuit blocks for custom ASICs
  - Ouster: LIDAR technology for 3D mapping, self-driving cars

Zoox autonomous vehicle

Time-of-flight real-time histogramming ASIC w/ integrated Single Photon Avalanche Diodes (SPADs)
Discovery enabled by LDRD opens a new path to engineering high temperature superconductors
We optimize our LDRD program investments for maximum impact on our mission and strategy.

- SLAC’s current LDRD portfolio consists of 27 projects with a total multi-year budget of ~$20M
- 55% of LDRD funds go toward targeted projects and the other 45% go toward high-risk/high-reward exploratory concepts
- 75% of LDRD projects are led by early career investigators (including 8 Panofsky Fellows)
- ~50% of LDRD projects bring together multi-disciplinary collaborations
- SLAC requests an authorization of 2% for LDRD
LDRD bolsters our core capabilities through cutting-edge research and development

Our core capabilities leverage our next-generation facilities to advance the state of the art in respective scientific fields

**Chemical and molecular science example**

- **Project**: High-resolution X-ray Fourier holography in gas phase using XFELs
  
  - **Impact**: Capturing 3D images of nanoparticles offers important insights into ultrafast dynamics in a range of processes from atmospheric physics to biology, nanophotonics and materials science

**FY19 LDRD distribution across core capabilities**

- Chemical & Molecular Science: 27%
- Particle Physics: 23%
- Accelerator Science & Technology: 20%
- Condensed Matter & Mat Science: 5%
- Plasma & Fusion Energy Science: 9%
- Adv Comp Sci, Vis & Data (emerging): 16%

![Graph showing distribution across core capabilities](image)
Nearly 90% of our LDRD investment advances ongoing and emerging strategic initiatives.

Massive-scale data analytics examples:

- **Accelerator control**: 10x faster tuning of LCLS
- **Big data acquisition**: 1,000x compression with edge-machine learning for LCLS-II

Over 50% of our LDRD investment advances our top two strategic initiatives.
LDRD supports the development of our talent and future scientific leadership across DOE mission areas

75% of our LDRD projects are led by early career investigators

X-ray and Ultrafast Science
- S. Carbajo
- T. Van Driel

Data Analytics
- D. Ratner
- J. Duris

HED Science
- E. Nanni, TID

Bioimaging
- Weatherford, TID

QIS
- Karunadasa, ESD/SIMES

Other
- P. Welander, TID

Early career talent development is a primary objective of our LDRD program and has been recognized through DOE Early Career Awards
Our expanded Panofsky Fellowship Program is bringing the best early career talent to the laboratory.
Part 1 summary

• SLAC’s highest priority is successfully completing LCLS-II

• SLAC is taking an integrated approach to ensure high-impact science from LCLS

• SLAC is delivering on our commitments across all P5 science drivers and investing to support future High Energy Physics and Nuclear Physics projects

• SLAC is leveraging our facilities to expand our impact in Fusion Energy Sciences and Biological and Environmental Research

• SLAC and Stanford combine our strengths and facilities with our connections to Silicon Valley to address critical issues in quantum information science

• SLAC continues to develop solutions to our massive-scale data challenges, with a new machine learning initiative and strong partnerships with NERSC/ESnet
SLAC’s central campus, featuring a bird’s eye view of the newly renovated quad
Mission ready, reliable infrastructure aligned with our strategic initiatives

<table>
<thead>
<tr>
<th>Current</th>
<th>2020-2023</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission</strong></td>
<td><strong>Mission</strong></td>
</tr>
<tr>
<td>Be the world-leader in X-ray and ultrafast science</td>
<td>Advance high energy density science</td>
</tr>
<tr>
<td>Infrastructure investments for LCLS-II and HE</td>
<td>Create a world-leading bioimaging program</td>
</tr>
<tr>
<td>Nano-X fab facility for optics</td>
<td>Advance DOE's mission in quantum information science</td>
</tr>
<tr>
<td>Arrillaga Science Center (ASC)/PSLB</td>
<td>Infrastrucure investments for Petawatt Laser</td>
</tr>
<tr>
<td>Detector Microfabrication Facility</td>
<td>ASC</td>
</tr>
<tr>
<td>Expansion of cryo-EM capabilities</td>
<td>Detector Microfabrication Facility</td>
</tr>
</tbody>
</table>

**Current Projects**
- Large Scale Collaboration Center
- Critical Utilities Infrastructure Revitalization
- Campus Building Renovation Project
- Site Security Improvements

**Future Projects**
- Foster a frontier program in the physics of the universe
- Be an innovator for massive-scale data analytics
- Be the world-leader in X-ray and ultrafast science
- Advance high energy density science
Mission readiness priorities

1. Revitalize utilities to reduce highest risks and ensure mission readiness
   - Ensure distribution systems achieve high reliability for science by modernizing cooling water, electrical and underground utility systems

2. Provide research and collaborative spaces to exploit compelling new science opportunities
   - Advance scientific discovery across the spectrum of DOE grand challenges through our facilities, strategic initiatives, core capabilities and expertise

3. Modernize existing facilities to support strategic initiatives
   - Enable an efficient and effective workforce for current and future science through major renovation of existing facilities
Current and planned priority infrastructure

**Campus Building Renovation Project (CBRP)**
- CD-0 in FY21
- $96M TPC (SLI-LI)

**Site Security & Access Improvements**
- CD-0 in FY20
- $8.5M TPC (S&S)

**Petawatt Laser**
- CD-1 in FY20 (FES)

**Critical Utility Infrastructure Revitalization (CUIR)**
- CD-0 in FY19
- $189M TPC (SLI-LI)
- (ACROSS ENTIRE SITE)

**Medium Low Voltage Revitalization (MLVR) Project**
- Complete in FY20
- $10M TPC (SLI-GPP)

**Construct and Replace Low Conductivity Water (LCW) Cooling Water System**
- Complete in FY19
- $8.8M TPC (SLI-GPP)

**Construct and Replace Cooling Tower (CT)**
- Complete in FY20
- $9.4M TPC (SLI-GPP)

**Large Scale Collaboration Center (LSCC)**
- CD-1 in FY19
- $62M TPC (SLI-LI)

**Cryo-EM $6.3M TPC (Indirect)**
- DMF $TBD

**Revitalize Utilities Program Support**
- Collaboration Spaces
- Modernize Facilities
- Program Support

**Stanford (SU) Guest House Expansion Feasibility Study**
- in ~FY20
- ~$38M (SU)

**Stanford SRCF-II Conceptual Design**
- in ~FY20
- ~$52M (SU)

Mission-ready priorities drive our investment strategy
Priority 1: Revitalize utilities to reduce highest risks and ensure mission readiness

Utility systems across the site are our biggest risk to enable science through operational reliability, flexibility and sustainability.

- **Electrical Systems**
  - Started in FY15-16

- **Cooling Water Systems**
  - Started in FY18-19

- **Underground Utilities**
  - Start in FY21/22
Planned SLI-LI: Critical Utilities Infrastructure Revitalization (CUIR)

**Supports:** BES, HEP, BER, FES, ASCR

**Investment:** $189M SLI-LI

**Schedule:** CD-1 FY20; Complete FY25

- Electrical systems at risk – failing components
- Cooling towers cannot meet demand
- Corroded domestic water/fire protection throughout site
- Corroded storm drain piping and pumps throughout site

**Utility Systems**
- Electrical Distribution
- Chilled Water
- Cooling Tower Water
- Sanitary Sewer
- Domestic Water
- Storm Drain
Priority 2: Provide research and collaborative spaces to exploit compelling new science opportunities

2

Continuing our partnership to provide state-of-the-art facilities to support the DOE mission

Arrillaga Science Center (PSLB fit-out)

Expansion of Cryo-EM Capabilities

Large Scale Collaboration Center (LSCC)
PSLB/ASC: SLI supporting multiple programs

1st floor Nano-X cleanroom

1st floor metrology cleanroom

2nd floor synthesis + electrochem

Chemistry & Materials Science

LCLS & Biology

Future Detector Microfabrication Facility

Laser Lab

Nano-X Cleanroom

Cryo-EM (under construction)

Detector & Metrology Cleanroom

Laser Lab

1st floor ASC

2nd floor ASC
Planned SLI-LI: Large Scale Collaboration Center (LSCC)

Supports: BES, HEP, BER, FES, ASCR

Investment: $62M SLI-LI

Schedule: CD-1 FY19; Complete FY25
Priority 3: Modernize existing facilities to support our strategic initiatives

Enable an efficient and effective workforce for current and future science through major renovation of existing facilities

Campus Building Renovation Project (CBRP)

Site & Security Access Improvements (S&S)
Planned SLI-LI: Campus Buildings Renovation Project (CBRP)

Supports: BES, HEP, BER, FES, ASCR

Investment: $96M

Schedule: CD-0 FY21; Complete FY26
Our overall asset condition is notably improving

Proposed Status: 150 Buildings

Adequate: 122
Substandard: 23
Inadequate: 5
Prioritizing deferred maintenance reduction

Current DM (FY18 Year End Data)

DM Reduction Forecast (FY18-FY30)

Highest risks are critical infrastructure = 87% of DM

With SLI support, the lab is making substantial progress retiring DM

<table>
<thead>
<tr>
<th>FY17 Year End</th>
<th>FY18 Year End</th>
<th>DM Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>$80.3M</td>
<td>$76.2M</td>
<td>$4.1M (5.1%)↓</td>
</tr>
</tbody>
</table>
Project execution: Challenges and mitigations

**Staffing Resources**
- Hire additional PMs
- Cross train FCM and PMs
- Provide a pool of PM/FCM term applicants
- Cultivate experienced project directors

**Schedule Delays**
- Evaluate resource impacts on project delays
- Implement Last Planner® on all projects

**Effective Subcontract or Oversight**
- Develop procurement strategies to enhance performance
- Improve quality management/oversight
- Partner with sub-contractors for mutual success
Cost of Doing Business
Our costs are aligned with our goals and strategic initiatives

<table>
<thead>
<tr>
<th>Composition of Total Lab Costs</th>
<th>FY18</th>
<th>FY19</th>
<th>FY20</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>80%</td>
<td>25%</td>
<td>75%</td>
</tr>
<tr>
<td>29%</td>
<td>71%</td>
<td>29%</td>
<td>71%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indirect Costs ($Ms):</th>
<th>FY17  (Actual)</th>
<th>FY18  (Actual)</th>
<th>FY19  (Est)</th>
<th>FY20  (Est)</th>
<th>FY21  (Est)</th>
<th>Avg chg FY17-21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managing the Lab</td>
<td>$15.5</td>
<td>$16.4</td>
<td>$17.9</td>
<td>$18.5</td>
<td>$19.0</td>
<td>6%</td>
</tr>
<tr>
<td>Operating and Investing in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure &amp; Facilities</td>
<td>$29.8</td>
<td>$27.2</td>
<td>$33.1</td>
<td>$34.3</td>
<td>$35.6</td>
<td>5%</td>
</tr>
<tr>
<td>Providing Business Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp; Mission Support</td>
<td>$45.4</td>
<td>$48.4</td>
<td>$51.0</td>
<td>$52.6</td>
<td>$54.1</td>
<td>5%</td>
</tr>
<tr>
<td>Keeping the Lab Safe and</td>
<td>$17.1</td>
<td>$15.9</td>
<td>$19.3</td>
<td>$19.9</td>
<td>$20.5</td>
<td>5%</td>
</tr>
<tr>
<td>Secure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investing in the Mission</td>
<td>$8.6</td>
<td>$9.8</td>
<td>$9.1</td>
<td>$9.7</td>
<td>$10.2</td>
<td>5%</td>
</tr>
<tr>
<td>Management Fees and Taxes</td>
<td>$4.6</td>
<td>$4.3</td>
<td>$4.4</td>
<td>$4.6</td>
<td>$4.6</td>
<td>0%</td>
</tr>
<tr>
<td>Total Indirect</td>
<td>$120.9</td>
<td>$122.0</td>
<td>$134.8</td>
<td>$139.5</td>
<td>$144.0</td>
<td>5%</td>
</tr>
</tbody>
</table>

| Benefit Costs* – Active       | $54.8          | $57.4          | $61.7      | $63.9      | $66.1      | 5%              |
| Employees                     |                |                |            |            |            |                 |
| Benefit Costs* – Retirees     | $1.7           | $.9            | $.9        | $1.0       | $1.0       | -12%            |

| Direct Costs                  | $481.5         | $482.2         | $410.8     | $344.3     | $304.0     | -11%            |

*Benefit costs are included in Direct and Indirect costs reported here, and are also itemized for informational purposes.

Nearly 1/3 of our indirect resources are directed toward our strategic initiatives and maintaining/improving our site
**Our investments as a % of total indirect reflect priorities for maintaining/improving our infrastructure and capabilities**

### Operating and Investing in Infrastructure & Facilities

<table>
<thead>
<tr>
<th>2/3 Operations &amp; Maintenance</th>
<th>1/3 Renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linac roof repair</td>
<td>Cryo-EM</td>
</tr>
<tr>
<td>New cooling water piping</td>
<td>Nano-X cleanroom</td>
</tr>
</tbody>
</table>

SLAC invests ~$33M/year in the operation, maintenance and renewal of our infrastructure.

### Investing in the Mission

SLAC invests ~$10M/year in refreshing and expanding our capabilities to achieve our mission.

---

We are preparing for future capabilities in alignment with our strategic plan.
SLAC effectively mitigates the cost drivers associated with our local market conditions: Construction and labor.

While our average salaries are high among the SC labs (+15%) due to the Bay Area job market, we have aggressively managed our indirect costs to have the lowest labor multiplier by controlling our indirects.

Infrastructures investments and workforce costs continue to be our major cost drivers, but careful balance of overhead costs makes us highly competitive.
Human Resources
Recent key science and operations appointments

Continued previous year trend of internal promotions for key operations appointments (shown below), relying on our talent development program.

We continue to face challenges bringing in leadership from outside the region, which emphasizes the ongoing importance of talent development.
We continue to address ongoing top workforce challenges

Evolving workforce needs for SLAC’s future:
• Limited pool of specialized expertise, e.g. superconducting accelerator technology
• Lacking a pipeline of qualified technicians (e.g., apprenticeships → journeymen)
• Forecasting and assessing future needs through business planning
• Refining annual talent review and planning process
• Employing succession plans
• Ensuring quality development plans for early career science, high potentials and top talent
  – DOE Project Leadership Institute, Oppenheimer Science & Energy Leadership Program
• Using and expanding internship programs

High cost of living in Silicon Valley; competitive workforce & rewards environment:
• Market competition against Silicon Valley and San Francisco Bay Area engineering demand
• Benefit from Stanford’s FY19 compensation equity increase
• Continue to partner with Stanford on housing support where possible
• Dovetail with Stanford’s long-range planning efforts for creative solutions
We’ve made initial progress in mission support; still a long way to go in science

Ongoing Diversity & Inclusion program

We hold line management accountable to help meet our D&I goals:

- SMT annual incentive goal: Increase directorate-level diversity focus; consistently engage in SLAC bias mitigation measures
- Diverse interview panels
- Panel reviews bias mitigation refresher at start of process
- Vacancies posted for enough time for visibility and to allow talent to express interest

Other D&I activities:

- Internship programs with diversity criteria
- Bias awareness presentations and panel events for/by management
- Employee Resource Group executive sponsorship and mentoring participation
Part 2 summary

• SLAC’s investments are driven by our science priorities and initiatives

• Investments from the Office of Science, SLAC and Stanford have transformed the laboratory over the past decade

• Modernization of our infrastructure will significantly reduce our deferred maintenance and risk to mission

• Careful management of our overhead has helped counter cost of labor

• Human capital is critical for mission readiness – talent and succession planning is bearing fruit

• SLAC is challenged with a competitive workplace market and the need to make better strides in improving our diversity and inclusion