U.S. DEPARTMENT OF ENERGY | Office of Science

Whither Science at DOE?

Presentation to the National Research Council
Governing Board

November 10, 2010

Dr. W. F. Brinkman
Director, Office of Science
U.S. Department of Energy
www.science.doe.gov

The Administration's S&T Priorities for the FY 2011 Budget

"We double the budget of key agencies, including the National Science Foundation, a primary source of funding for academic research, and the National Institute of Standards and Technology, which supports a wide range of pursuits – from improving health information technology to measuring carbon pollution, from testing "smart grid" designs to developing advanced manufacturing processes. And my budget doubles funding for the Department of Energy's Office of Science which builds and operates accelerators, colliders, supercomputers, high-energy light sources, and facilities for making nano-materials. Because we know that a nation's potential for scientific discovery is defined by the tools it makes available to its researchers."

President Barack Obama
April 27, 2009

Today's National and International Scene: Challenges

- **Growing energy/climate crisis –**
  - ~85% of U.S. primary energy from fossil fuels
  - ~60% of oil imported
  - World energy consumption to increase 49% by 2035
- **Fossil fuel use threatens potentially catastrophic climate change**
  - To prevent global average surface temperature from rising by more than 2.5º C. by 2050, need factor of 8 emissions cut
- **Dependence on imported oil threatens U.S. national security and is drain on U.S. productivity and growth**
- **Global competitiveness: America today faces fierce international competition not only in economics, but across a wide spectrum of activities, including growing competition in science and in scientific facilities**

Today's Scientific Environment: Opportunities

- **Unprecedented capabilities to observe and manipulate matter at the atomic and molecular scales**
- **Breathtaking progress in high-performance computing**
- **Powerful new means of harnessing nature's most sophisticated systems in plants and microbes for practical applications**
- **A new generation of instruments (existing and planned) for probing some of the deepest secrets of matter and the cosmos**

The Indispensable Role of Basic Science

- **Fundamental research in the physical sciences will play a central role in meeting the challenges of the 21st century, including the challenges of energy and climate**
- **Basic research will address these challenges by taking advantage of rich new scientific opportunities across a broad range of fields**

DOE Office of Science (SC)

- **Largest U.S. funder of basic research in the physical sciences at both universities and DOE laboratories across the Nation**
- **Steward of 10 of the 17 DOE laboratories**
- **Main supporter of construction and operation of large-scale scientific facilities that define the highest capabilities of today's physical science research**
- **Lead federal agency for basic research on energy**

Office of Science FY 2011 Budget Request to Congress

(B/A in thousands)

	FY 2009		FY 2010	FY 2011		
	Current Base Approp.	Current Recovery Act	Current Approp.	Request to Congress	Request to Congress vs. FY 2010 Approp.	
Advanced Scientific Computing Research	358,772	161,795	394,000	426,000	+32,000	+8.1%
Basic Energy Sciences	1,535,765	555,406	1,636,500	1,835,000	+198,500	+12.1%
Biological & Environmental Research	585,176	165,653	604,182	626,900	+22,718	+3.8%
Fusion Energy Sciences	394,518	91,023	426,000	380,000	-46,000	-10.8%
High Energy Physics	775,868	232,390	810,483	829,000	+18,517	+2.3%
Nuclear Physics	500,307	154,800	535,000	562,000	+27,000	+5.0%
Workforce Development for Teachers & Scientists	13,583	12,500	20,678	35,600	+14,922	+72.2%
Science Laboratories Infrastructure	145,380	198,114	127,600	126,000	-1,600	-1.3%
Safeguards & Security	80,603	——	83,000	86,500	+3,500	+4.2%
Science Program Direction	186,695	5,600	189,377	214,437	+25,060	+13.2%
Small Business Innovation Research/Technology Transfer (SC)	104,905	18,719	——	——	——	——
Subtotal, Science	**4,681,572**	**1,596,000**	**4,826,820**	**5,121,437**	**+294,617**	**+6.1%**
Congressionally-directed projects	91,064	——	76,890	——	-76,890	-100.0%
Small Business Innovation Research/ Technology Transfer (DOE)	49,534	36,918	——	——	——	——
Use of prior year balances	-15,000	——	——	——	——	——
Total, Office of Science	**4,807,170**	**1,632,918**	**4,903,710**	**5,121,437**	**+217,727**	**+4.4%**

SC Supports Research at More than 300 Institutions Across the U.S.

The Office of Science supports:

- 27,000 Ph.D.s, graduate students, undergraduates, engineers, and technicians
- 26,000 users of open-access facilities
- 300 leading academic institutions
- 17 DOE laboratories

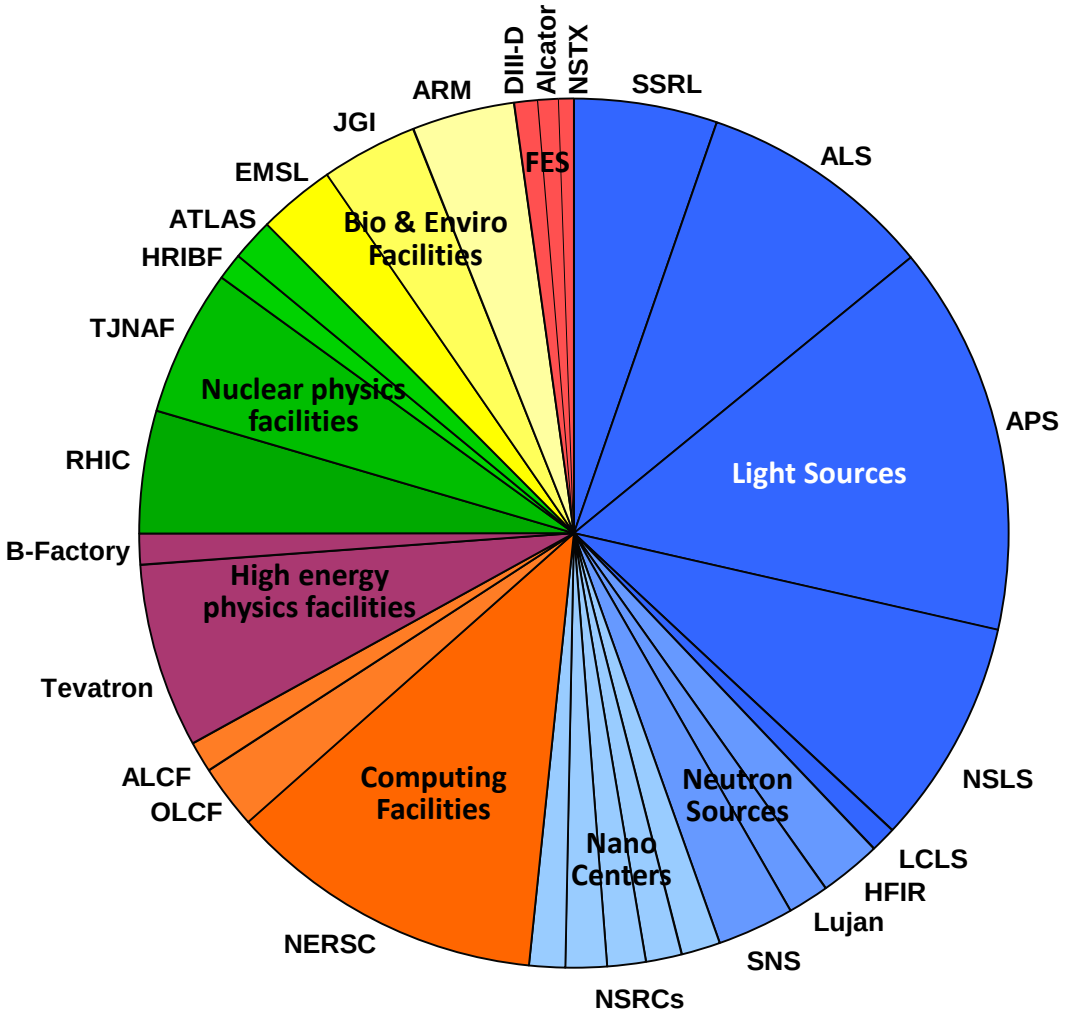
SC Supports World-Leading, Open Access Scientific User Facilities

User numbers continue to increase with more than 26,000 users expected in FY 2011

Numbers of Users at SC Facilities

	FY 2009	FY 2010 (Est)	FY 2011 (Est)
ASCR	3,696	3,850	4,025
BES	11,509	12,780	13,560
BER	2,716	2,690	2,690
FES	542	575	580
HEP	2,960	2,600	2,100
NP	3,170	3,260	3,300
Total	24,593	25,755	26,255

Breakdown of the expected users in FY 2011 by facility.



Office of Science Strategic Priorities

- **Advance discovery science and invest in science for national needs in energy, climate, and the environment; national scientific user facilities; and education and workforce development.**

The Energy/Climate Challenge

". . . Meeting the challenge will require new technologies for producing, storing, and using energy with performance levels far beyond what is now possible. Such technologies spring from scientific breakthroughs. . . ."

--Basic Energy Sciences Advisory Committee

- **Overcoming the energy/climate challenge will require accelerating both applied and basic research**
- **DOE has sought to accelerate basic research by strengthening portfolio with <u>new, more collaborative, team-based approaches</u>, to create "wholes" that are more than the "sum of their parts"**
  - DOE Bioenergy Research Centers (~$25 M/year each)
  - Energy Frontier Research Centers (~$2-$5 M/year)
  - Energy Innovation Hubs (~$25 M/year)

The Status of the DOE Energy Innovation Hubs

Three new Hubs launched in FY 2010 with SC leading the Fuels from Sunlight Hub

- **Modeled after the Office of Science Bioenergy Research Centers, the Energy Innovation Hubs focus on critical energy technology challenges by building creative, highly-integrated research teams that can accomplish more, faster, than researchers working separately.**

- **FY 2010 Hubs tackle three important energy challenges:**
  - Joint Center for Artificial Photosynthesis (SC)
  - Nuclear Energy Innovation Hub (NE)
  - Energy-Efficient Building Systems Design Hub (EERE)

Joint Center for Artificial Photosynthesis

- Selected on basis of competitive, merit review process
- Winning team led by Cal Tech in partnership with LBNL
- Additional partner institutions:
  - SLAC National Accelerator Laboratory
  - Stanford University
  - UC Berkeley
  - UC Santa Barbara
  - UC Irvine
  - UC San Diego
- Professor Nate Lewis leader
- Looking for a factor of 10 over nature
- Strong push to integrate processes to form a complete system

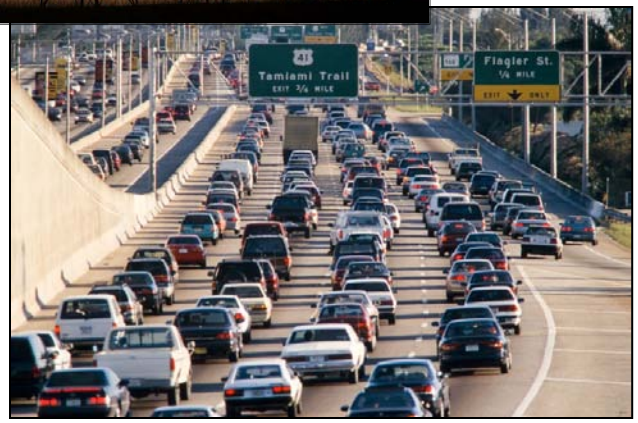
FY 2011 Energy Innovation Hub for Batteries and Energy Storage

Addressing science gaps for both grid and mobile energy storage applications

The Administration's Energy Plan has two goals that require improvements in the science and technology of energy storage:

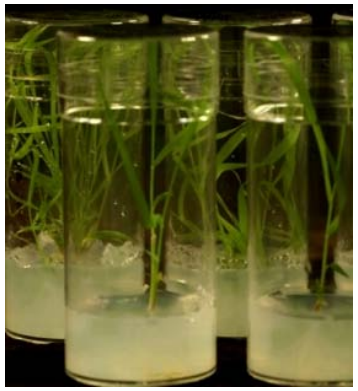
- Solar and wind providing over 25% of electricity consumed in the U.S. by 2025
- 1 million all-electric/plug-in hybrid vehicles on the road by 2015

- Grid stability and distributed power require innovative energy storage devices
  - Grid integration of intermittent energy sources such as wind and solar
  - Storage of large amounts of power
  - Delivery of significant power rapidly
- Enabling widespread utilization of hybrid vehicles requires:
  - Substantially higher energy and power densities
  - Lower costs
  - Faster recharge times

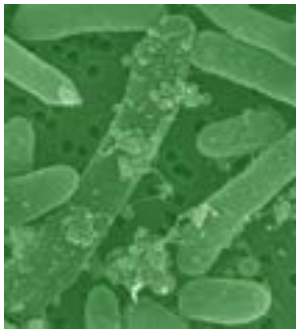


DOE Bioenergy Research Centers: Recent Highlights

- Identification of key lignin biosynthesis genes in switchgrass, providing potential targets for improving switchgrass as a bioenergy crop.



- Used synthetic biology toolkit to construct the first microbes to produce an advanced biofuel directly from biomass.



- Characterized soil microbial community structure to understand impacts of biomass crop growth on marginal lands

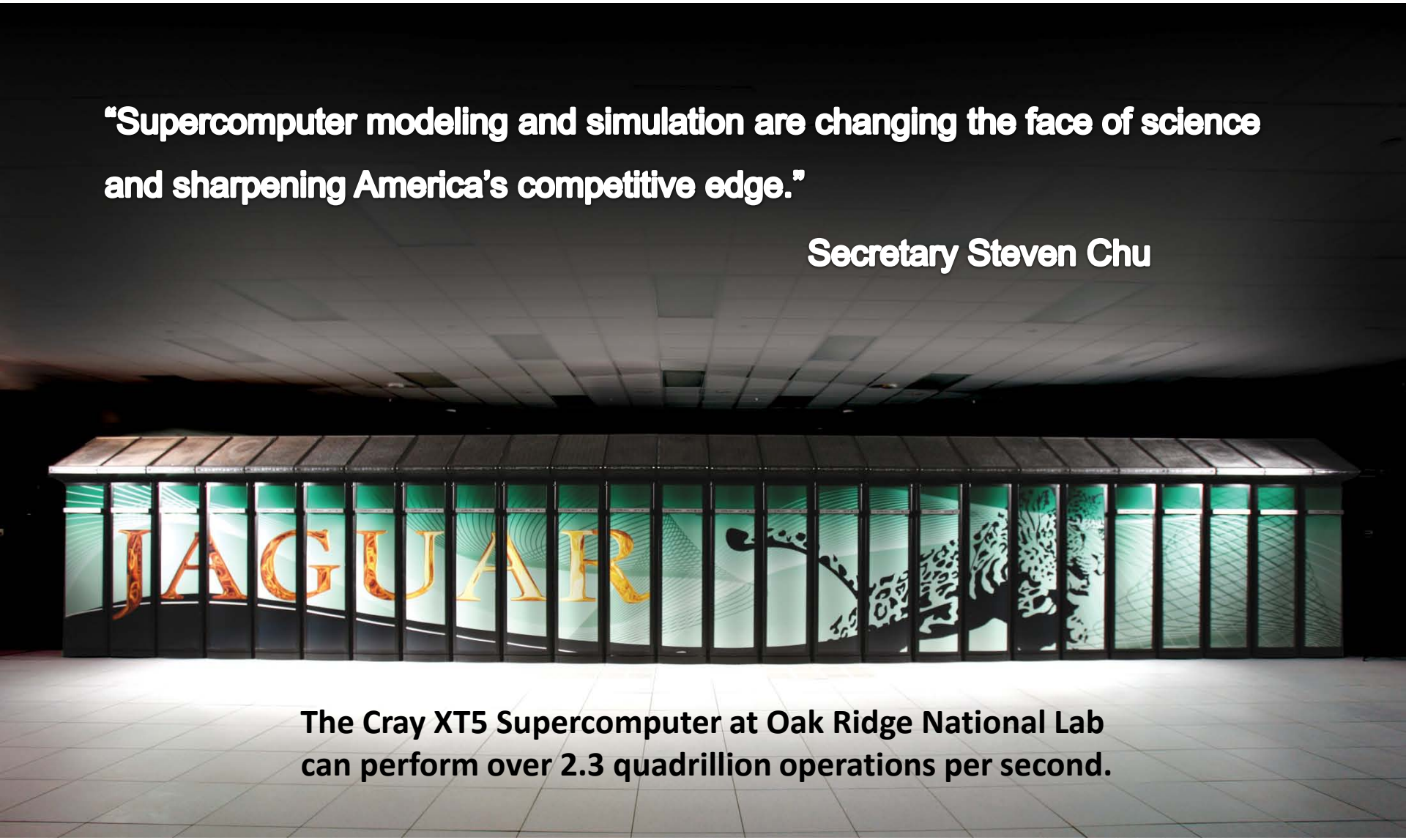
Climate Science for a Sustainable Energy Future

Enhanced activities in climate research to improve our predictive capability

- The demands on climate change modeling to inform policy and investment decisions are increasing. The current state of climate models is insufficient to predict with the detail and accuracy the future interactions between climate change and energy policy.
- New and enhanced activities will emphasize:
  - Research and atmospheric data collection for improving representation of the feedbacks produced by the indirect effect of aerosols
  - Enhanced uncertainty quantification for climate model simulations and predictions
  - Conversion of observational data sets into specialized, multi-variable data sets for Earth System Model testing and improvement.
  - Model development testbeds in which model components can be rapidly prototyped and evaluated
  - Atmospheric System Research and operation of new ARM Climate Research Facility instruments to provide data for improving representation of clouds and aerosols in climate models

Leadership Computing Facilities

The Office of Science leads the World in supercomputing capabilities

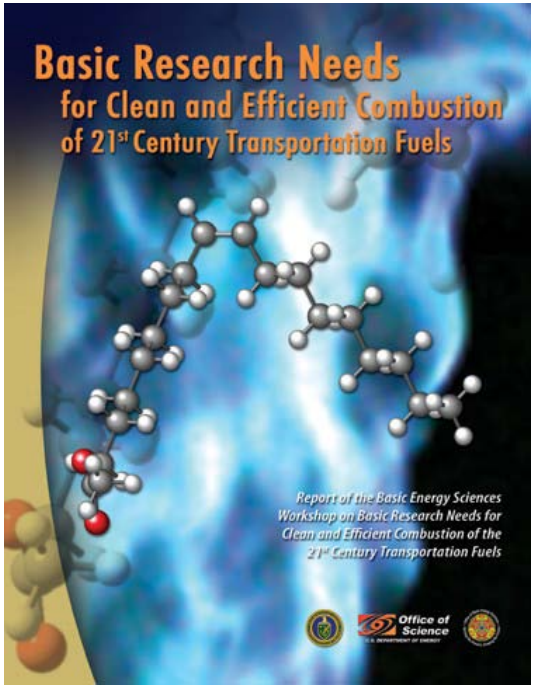


The Cray XT5 Supercomputer at Oak Ridge National Lab can perform over 2.3 quadrillion operations per second.

Multi-Scale Simulation of Internal Combustion Engines

A new initiative to develop the science base for computational design of advanced engines

Predictive simulation of combustion in an evolving fuel environment is essential for developing more efficient and cleaner engines.



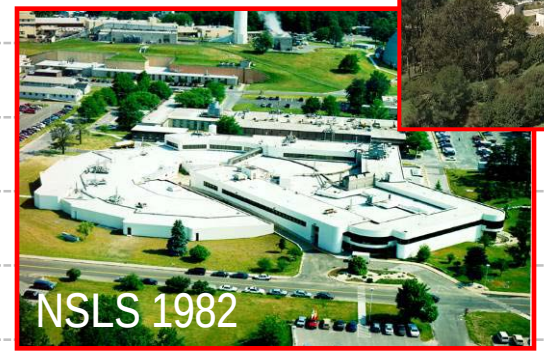
The scientific community has provided a roadmap via:

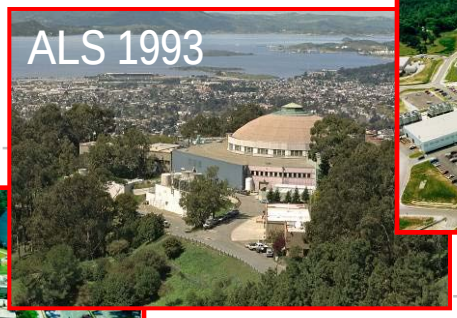
- BES workshop: *Basic Research Needs for Clean and Efficient Combustion*, October 2006
- ASCR/BES workshop: *Discovery in Basic Energy Sciences: The Role of Computing at the Extreme Scale*, August 2009
- SC ongoing collaboration with EERE's Vehicle Technology Program

The new BES activity will provide:

- **Models that span vast scale ranges:** coupling of combustion chemistry with turbulent flow requiring simulation over 9 orders of magnitude in space and time.
- **Improved understanding of fundamental physical and chemical properties:** multi-phase fluid dynamics, thermodynamic properties, heat transfer, and chemical reactivity.
- **Engine simulation:** science-based predictive simulation and modeling design

The 4 BES Synchrotron Light Sources Serve Nearly 10,000 Users



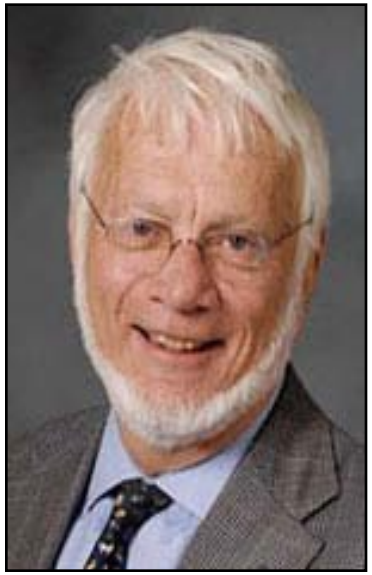


3 Nobel Prizes in 6 Years with X-Ray Crystallography

The prize-winning work used all four SC/BES synchrotron radiation light sources

2009 Prize in Chemistry: Venkatraman Ramakrishnan, Thomas Steitz, and Ada Yonath) "for studies of the structure and function of the ribosome." *Used all 4 light sources.*

Venkatraman Ramakrishnan



Thomas Steitz

Ada Yonath

2006 Prize in Chemistry: Roger Kornberg "for his studies of the molecular basis of eukaryotic transcription." *Used SSRL macromolecular crystallography beamlines.*

2003 Prize in Chemistry: Roderick MacKinnon for "structural and mechanistic studies of ion channels." *Used NSLS beamlines X25 and X29.*

Linac Coherent Light Source (LCLS) at SLAC

Already producing new science today, the LCLS is the world's first x-ray free electron laser

LCLS is SC's newest x-ray light source user facility, providing an unprecedented combination of high spatial and temporal resolution for the investigation of atomic-scale structure and processes.

On target for an on time, within budget completion in FY 2010

- Time between first start up and first light was, remarkably, under two hours!

Meeting or exceeding design specifications to enable new science

- Peak brightness 10 orders of magnitude greater than existing x-ray sources
- X-ray pulses as short as 2 millionths of a nanosecond (2 femtoseconds)

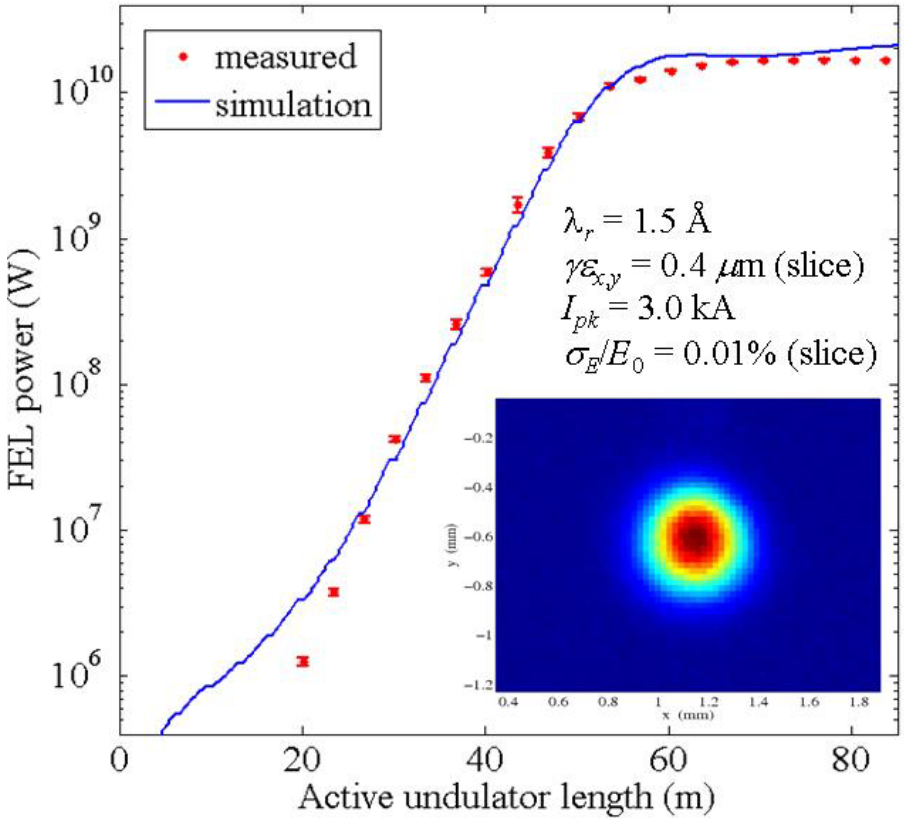
Overwhelming demand for access

- More than 850 researchers have applied for time on LCLS during the early access experimental runs, prior to CD-4

LCLS Performance Exceeds Specifications

Energy, pulse width, and other key parameters exceed design specs

- The LCLS lased on April 10, 2009
- Full design performance was achieved throughout the design range 820-8,200 eV, and lasing was also demonstrated from 540-10,000 eV.
- X-ray pulse energy routinely exceeds design goals by 50%-100% throughout the design spectral range.
- The x-ray pulse can be adjusted from the design goal of 300 femtoseconds to shorter than 10 femtoseconds!
- In one set of experiments by a collaboration of German research institutions, single-shot imaging was conducted on nanoscale particles such as single virus particles and submicron-size protein crystals. Voluminous frames of scattering data were collected. The analysis of the data will continue for some months, but the “raw data” show regular scattering patterns as is required for inversion of a scattering image to determine the structure of the scattering object.



Prediction vs. measurement of gain for 8 keV operation. The vertical axis shows energy of the x-ray pulse in arbitrary units. The horizontal axis shows the distance that the electron beam travels along the undulator system. Energy in the x-ray pulse grows exponentially up to about 45 meters, after which the laser output approaches saturation. (Courtesy Z. Huang & Daniel F. Ratner)

The Genomic Revolution

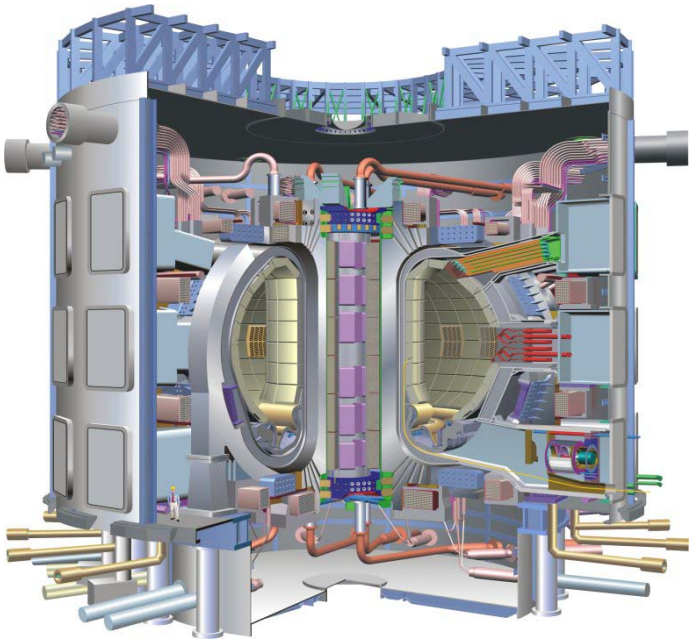
Advances in DNA sequencing and analysis have revolutionized the study of biology

Sequencing the 3 billion base-pair human genome took 13 years and multiple national and international partners. Today the DOE Joint Genome Institute sequences over a trillion base pairs annually.

- DNA sequencing and analysis capabilities and the availability of genome data in the 1990s led to functional genomics, proteomics, metabolomics, systems biology, and synthetic biology.
- Genomic sequence information has dramatically increased our understanding of the biological processes of microbes and plants—knowledge that is being used to develop solutions for clean energy production, sequestration of atmospheric CO_2, and remediation of contaminated environments.
- Recent accomplishments:
  - **Sequencing the 1.1 billion base-pair soybean genome**—The largest plant project sequenced at JGI and the largest plant sequenced by the whole genome shotgun strategy, the soybean sequence will accelerate crop improvements for energy production and environmentally sustainable food and feed production for agriculture.
  - **DOE JGI publishes the Genomic Encyclopedia of Bacteria and Archaea**—The initial 56 microbial genomes sequenced resulted in the discovery of tens of thousands of genes that provide insights into natural environmental processes and advance biotechnology.
  - **Viable microbes in toxic subsurface environments—**Genetic techniques demonstrate that micoorganisms of the *Anaeromyxobacter* family, known to enzymatically reduce uranium to a less mobile form, can be detected in the most heavily contaminated environments and likely play a role in reducing the mobility of uranium in groundwater.

ITER

- ITER (Latin for “the way”) is a first of a kind major international research collaboration on fusion energy.
- ITER Goals
  - Designed to produce 500 MW of fusion power ($Q \geq 10$) for at least 300-500 seconds
  - *Burning plasma* dynamics and control
    - U.S. emphasizes the value of ITER, its flexibility, and its diagnostics as a scientific instrument: develop a predictive capability of the burning plasma state
  - Will optimize physics and integrate many of key technologies needed for future fusion power plants
- The *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project*, entered into force in October 2007 for a period of 35 years.



ITER Tokamak – Cross Sectional View

ITER

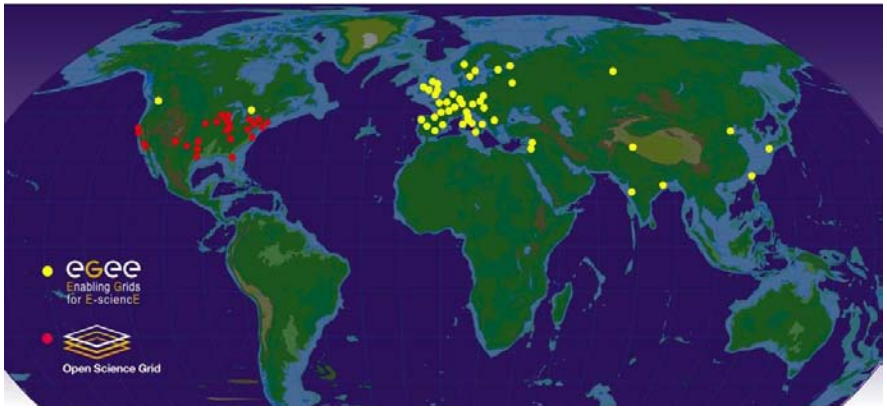
- **The ITER Organization, located at Cadarache, France, has been established as an independent international legal entity comprising personnel (~400) from all of the Members.**

- **Like all non-host Members, the U.S. share for ITER's construction is 1/11th (9.09%) of the total value estimate.**
  - Roughly 80% will be in-kind components manufactured largely by U.S. industry – and beyond that, the United States has agreed to fund 13% of the cost for operation, deactivation, and decommissioning.
  - At Critical Decision-1 (January 2008), the Total Project Cost (TPC) range for the U.S. share of the Construction Phase was estimated to be $1.45-2.2 B
  - Peak funding will be in the range of $300-350 M/yr for four years.

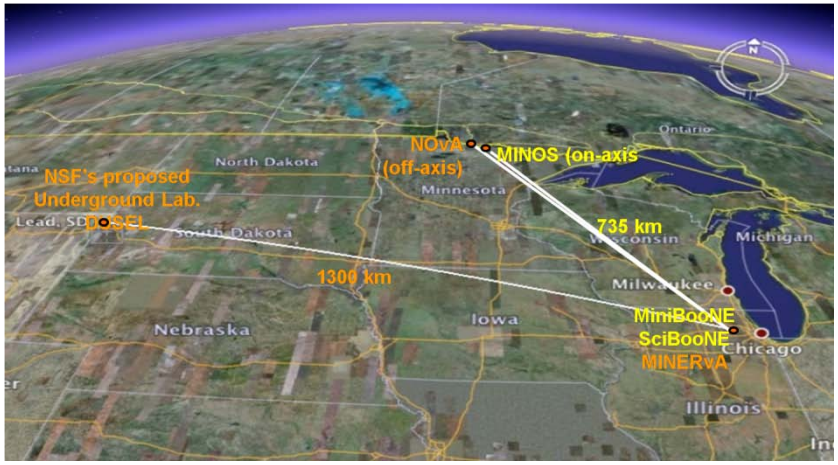
The U.S. High Energy Physics Program

The U.S. is uniquely positioned for a world-leading program in neutrino physics

The U.S. is a critical and strategic partner in global scientific collaborations that push the boundaries of High Energy Physics. The U.S. has developed components for the Large Hadron Collider at CERN and hosts centers for data analysis.



Network sites of the Open Science Grid and Enabling Grids for E-sciencE used for transmitting experimental data from the LHC to scientists worldwide.

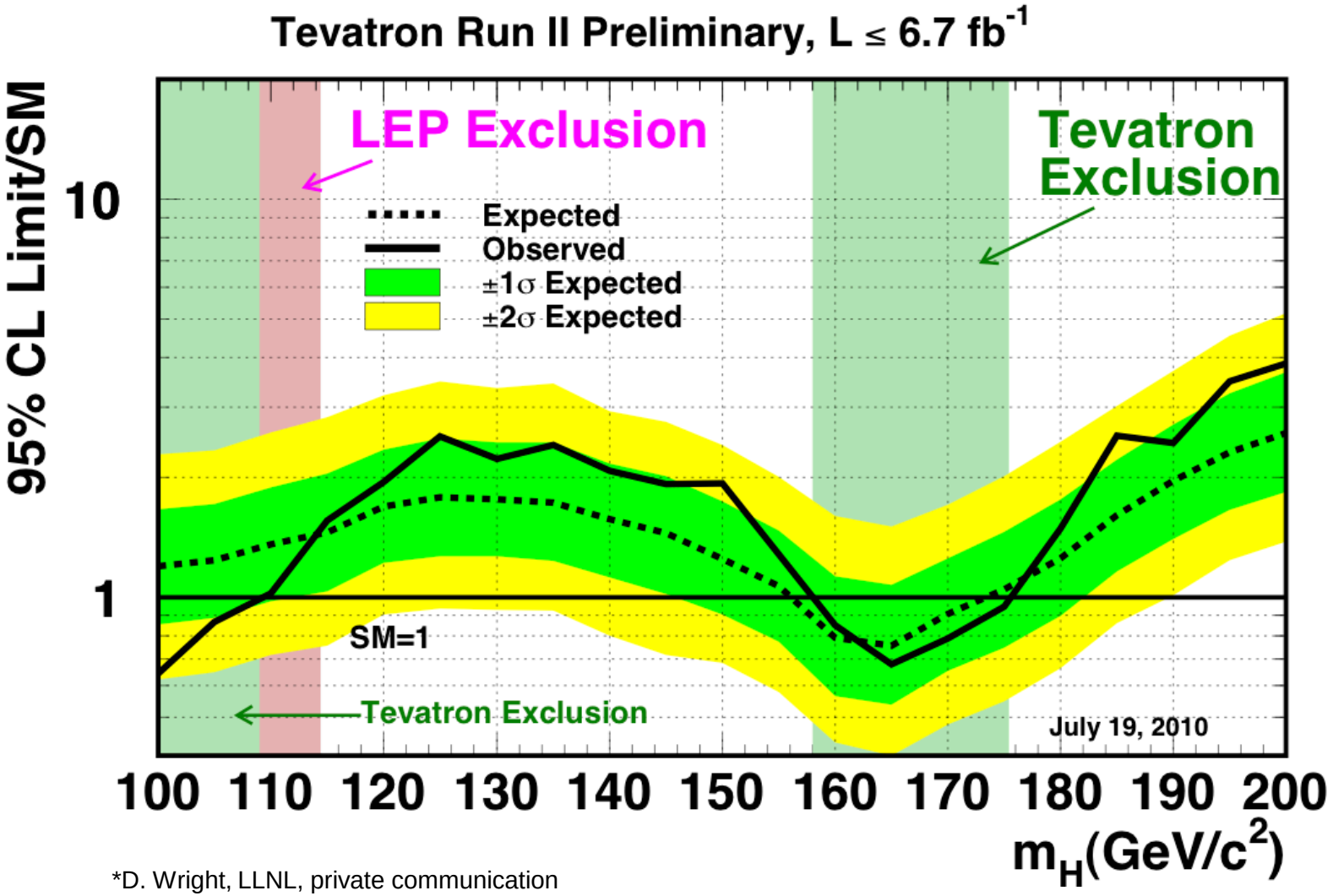


The NuMI beamline provides the world's most intense neutrino beam for the MINOS experiment and proposed NOvA and LBNE experiments

At home, HEP builds on its investments in tools and facilities to capture the unique opportunities of neutrino science. These opportunities are fundamental to the science of particle physics.

At the heart of the DOE HEP program is the *NuMI beamline* at Fermilab, the world's most intense neutrino source, which serves MINERvA and MINOS and will support NOvA and the proposed LBNE (+$12,000K, HEP, initiated in FY 2011).

Progress Toward the Higgs Particle*

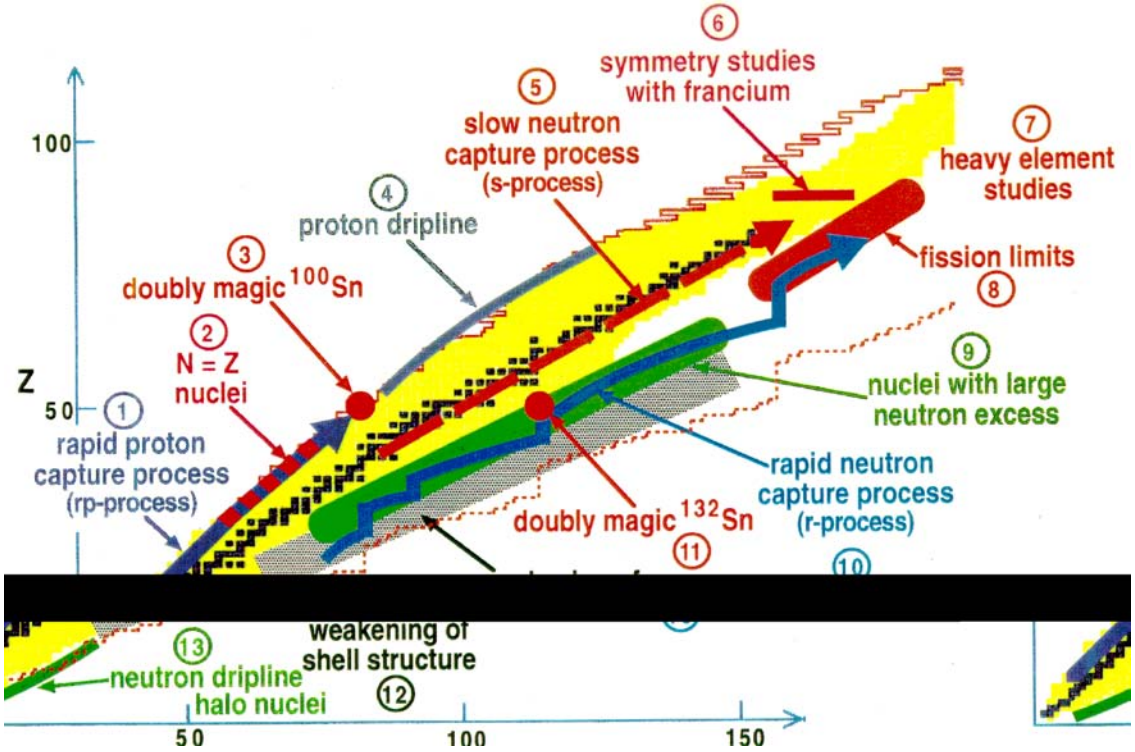


*D. Wright, LLNL, private communication

The DOE Nuclear Physics Program

Charting new directions at the frontiers of nuclear science

The U.S. is a leader in studying the compelling questions of nuclear science, advancing our knowledge of the world, and leading to applications in energy research, medicine, national security, and isotopes for a wide variety of purposes.



- **The Relativistic Heavy Ion Collider (RHIC)** is the only dedicated machine in the world colliding heavy ions at near light speed.
- **The Continuous Electron Beam Accelerator Facility (CEBAF)** is the world's most powerful probe for studying the nucleus of the atom.
- Investments in **Radioactive Ion Beam** experiments and capabilities (such as the **Facility for Rare Isotope Beams—FRIB**), probe the properties of rare nuclear isotopes to better understand the origin of the elements and fundamental symmetries of nature

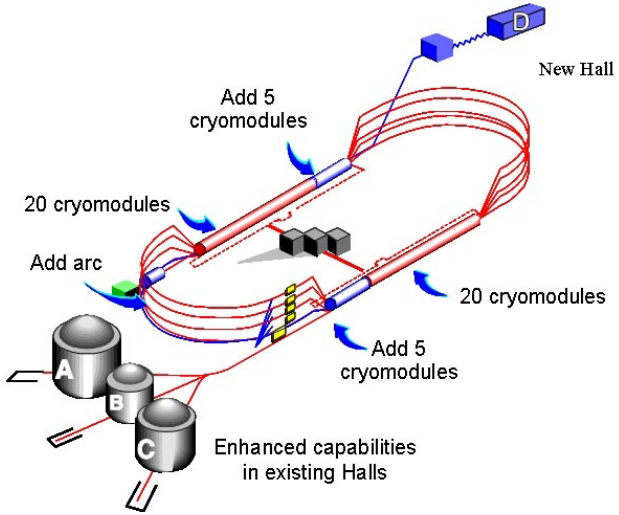
The DOE Nuclear Physics Program

New science follows the completion of the 12 GeV Upgrade at TJNAF

With the completion of the 12 GeV Upgrade, researchers will address:

- The search for exotic mesons—a quark and an anti-quark held together by gluons, but unlike conventional mesons, the gluons are excited
- Physics beyond the Standard Model via high precision studies of parity violation
- The spin and flavor dependence of valence parton distributions—the heart of the proton, where its quantum numbers are determined
- The structure of atomic nuclei, exploring how the valence quark structure is modified in a dense nuclear medium
- Nuclear tomography to discover and explore the three-dimensional structure of the nucleon

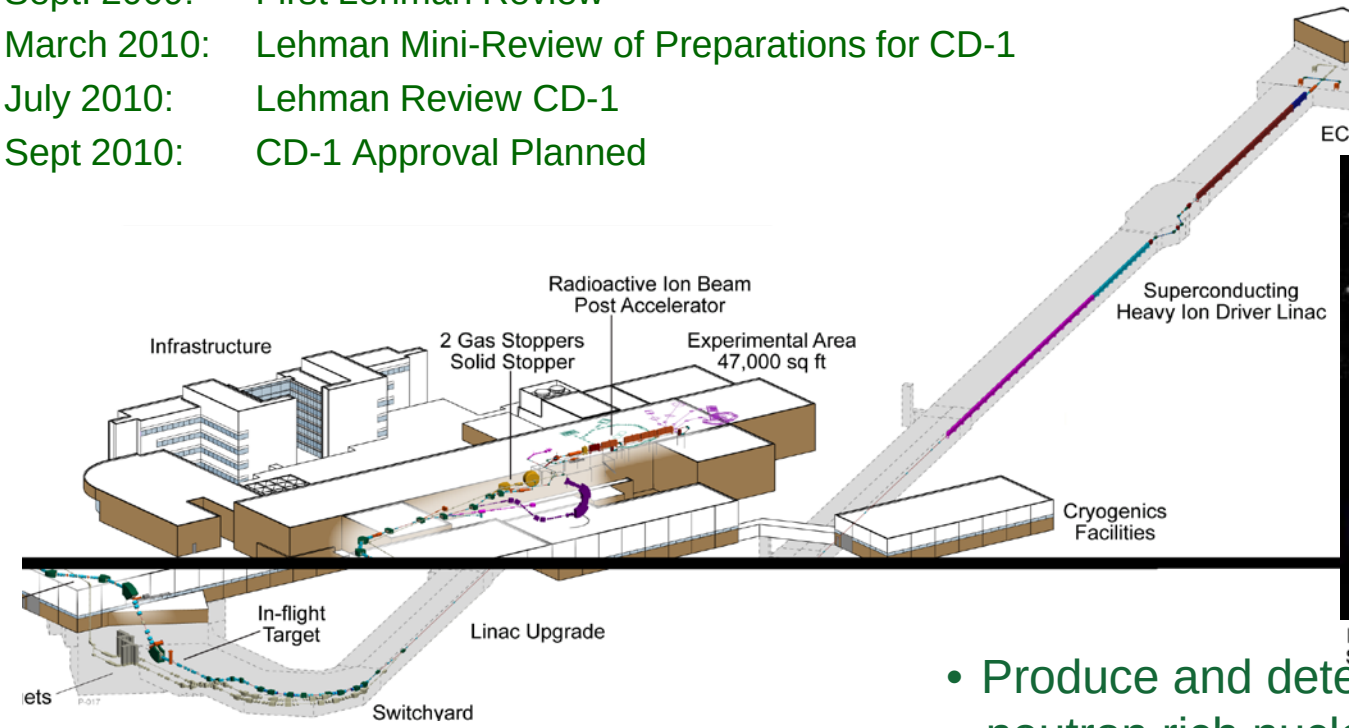
Pouring the foundation for the Hall D complex.

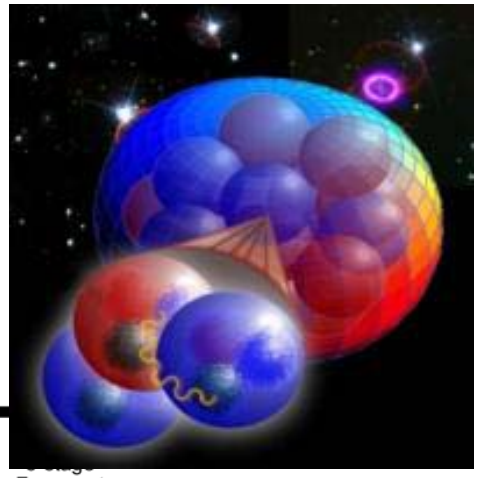


The DOE Nuclear Physics Program

Status of the Facility for Rare Isotope Beams

Dec. 2008:	DOE selects MSU to establish FRIB
June 2009:	Cooperative Agreement between DOE and MSU
Sept. 2009:	First Lehman Review
March 2010:	Lehman Mini-Review of Preparations for CD-1
July 2010:	Lehman Review CD-1
Sept 2010:	CD-1 Approval Planned





- Produce and determine properties of neutron rich nuclei
- Astrophysics of heavy element production

Engineering design scheduled to start in FY 2011

Office of Science Early Career Research Program

Investment in FY 2011 will bring 60 new scientists into the program

$16 million requested in FY 2011 to fund about 60 additional Early Career Research Program awards at universities and DOE national laboratories.

Purpose: To support individual research programs of outstanding scientists early in their careers and to stimulate research careers in the disciplines supported by the Office of Science

Eligibility: Within 10 years of receiving a Ph.D., either untenured academic assistant professors on the tenure track or full-time DOE national lab employees

Award Size:

- University grants $150,000 per year for 5 years to cover summer salary and expenses
- National lab awards $500,000 per year for five years to cover full salary and expenses

FY 2010 Results:

- 69 awards funded via the American Recovery and Reinvestment Act
- 1,750 proposals peer reviewed to select the awardees
- 47 university grants and 22 DOE national laboratory awards
- Awardees are from 44 separate institutions in 20 states

FY 2011 Application Process:

- Funding Opportunity Announcement issued in Spring 2010
- Awards made in the Second Quarter of 2011

http://www.science.doe.gov/SC-2/early_career.htm

DOE Office of Science Graduate Fellowships

The FY 2011 request doubles the number of graduate fellowships in basic science

$10 million requested in FY 2011 to fund about 150 additional fellowships

Purpose: To educate and train a skilled scientific and technical workforce in order to stay at the forefront of science and innovation and to meet our energy and environmental challenges

Eligibility:

- Candidates must be pursuing advanced degrees in areas of physics, chemistry, mathematics, biology, computational sciences, areas of climate and environmental sciences important to the Office of Science and DOE mission
- Candidates must be U.S. citizens

Award Size:

- The three-year fellowship award, totaling $50,500 annually, provides support towards tuition, a stipend for living expenses, and support for expenses such as travel to conferences and to DOE user facilities.

FY 2010 Results:

- 150 awards made in August with FY 2010 and American Recovery and Reinvestment Act funds.

FY 2011 Application Process:

- Funding Opportunity Announcement issued in Fall 2010
- Awards expected in Spring 2011