Overview of Advanced Accelerator R&D at LBNL

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HEPAP AARD Sub-panel

Palo Alto, CA

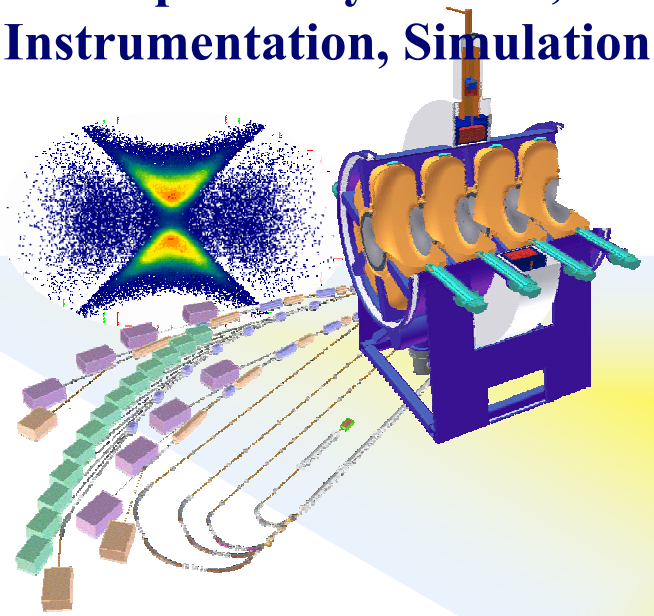
December 21, 2005

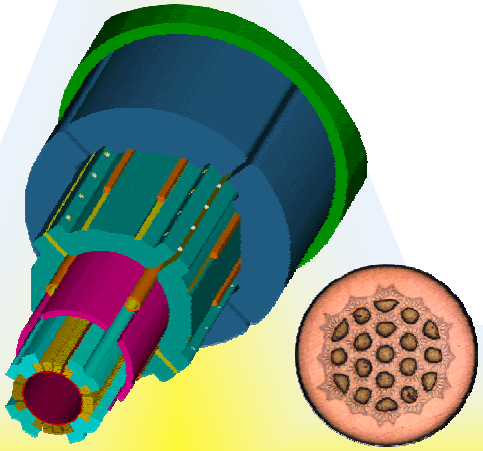
Comments on AARD

- **Discoveries in HEP are preceded by technological development**
- **Current and future facilities are more challenging and will depend even more on innovative R&D**
  - **Both *directed (short-range)* and "*undirected*" (medium- and long-range) R&D are necessary**
- **A robust Accelerator R&D program, distributed appropriately throughout the DOE complex is a critical part of the HEP R&D portfolio**
- **The AARD program at LBNL has provided and will continue to provide support for the integration of the laboratories and a move toward a "virtual" HEP laboratory complex**

HEP Imbedded in Large Synergistic AARD Program

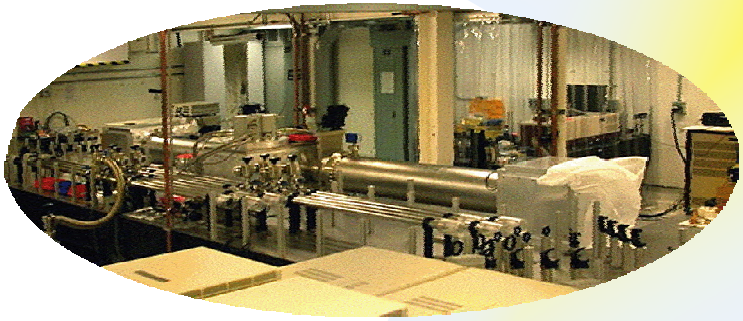
Exploratory Studies, Instrumentation, Simulation



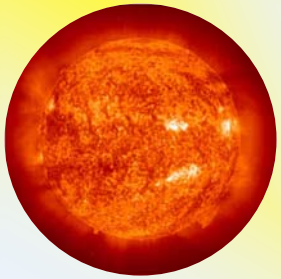


Superconducting Magnets & LARP

Ion Beam Technology



Laser-plasma Interactions



Inertial Fusion & High Energy Density

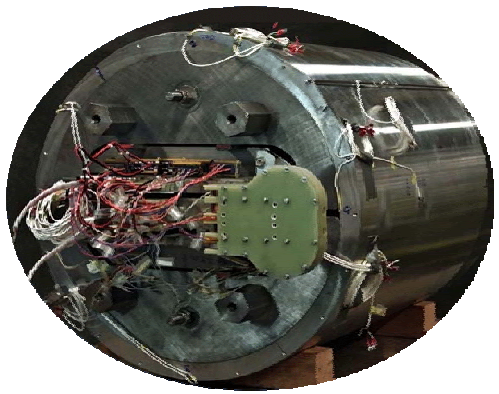
ALS Accelerator Physics

Excellent science is the best foundation for new programs & projects

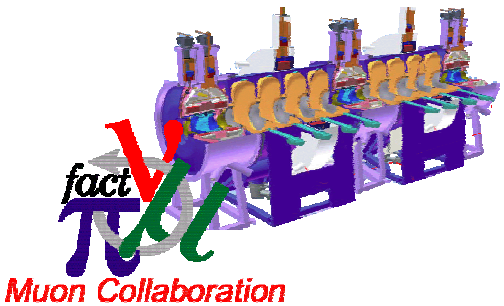
LBNL AARD for HEP

Accelerator R&D activities at LBNL directed to serving priorities of HEP

- **Present and recent past**
  - Tevatron complex
  - PEP-II
- **Future**
  - LHC
  - ILC
  - Neutrino factory/Muon Collider
  - Laser/plasma, beam diagnostics

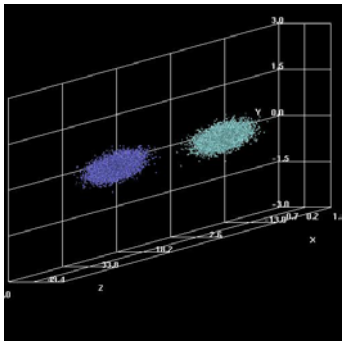


- **Facilities**
  - Lambertson Beam Electrodynamics Lab
  - Laser/plasma Lab
  - SC Magnet Fabrication and Testing

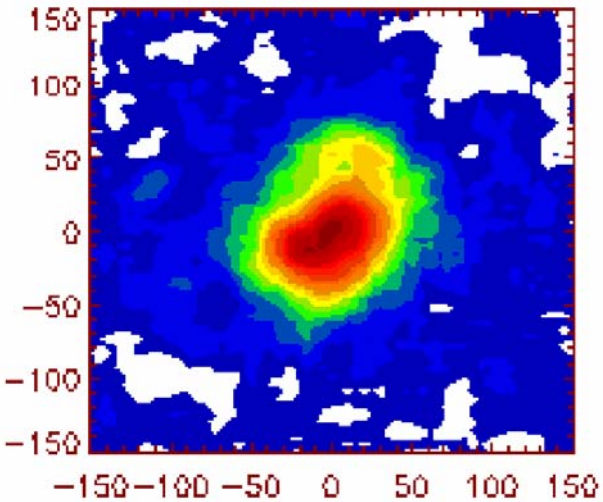


FY05/06 Results and Accomplishments

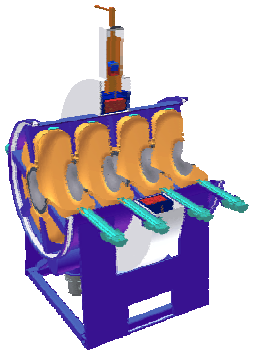
- **Laser/plasma accelerator**
  - New breakthrough in plasma wakefield accelerator development!



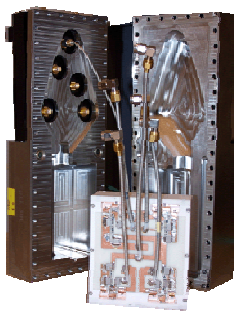
- **Tevatron Run-II**
  - AP2 transfer line (chromatic effects)
    - Improved understanding of beam dynamics in transfer lines
- **PEP-II**
  - Transverse feedback systems
    - All digital system to cope with saturation
    - Instability and beam-beam studies
- **SciDAC**
  - State-of-the-art modeling codes



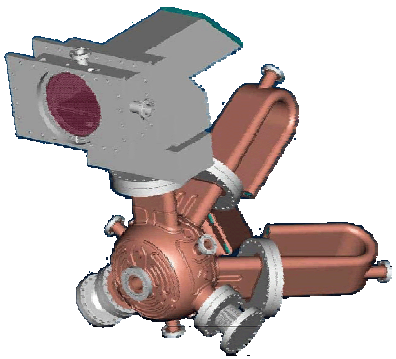
FY05/06 Results and Accomplishments

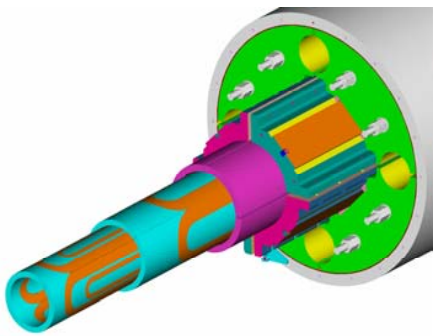


- **Muon Collaboration**
  - Ionization cooling; analysis and hardware
- **LHC**
  - Luminosity Monitor; modeling and hardware
  - Early Nb_3Sn quad development



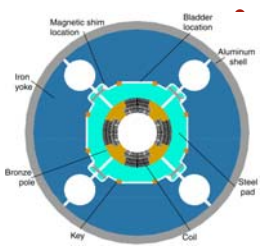
- **International Linear Collider**
  - Damping rings
  - IR quadrupoles



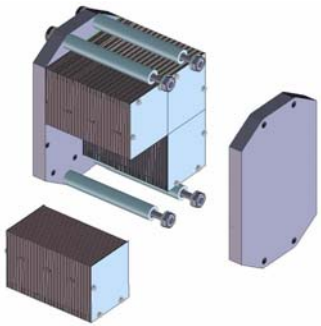


LBNL Contributions to LHC

- **LHC Construction Project**
  - Expertise applied to feedboxes and absorbers
- **LHC Accelerator Research Program (LARP)**
  - LBNL has extensive expertise relevant to bringing the LHC online and achieving or improving performance goals



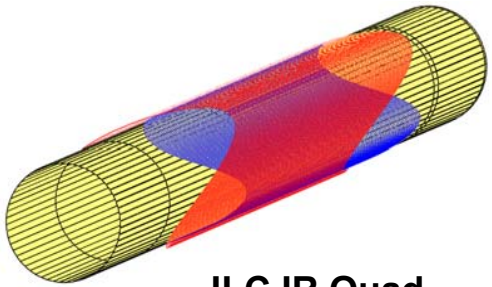
- **Magnet Technology**
  - Foundation of LHC luminosity and energy upgrades
- **Accelerator Theory and Modeling**
  - Electron cloud
  - Beam-beam



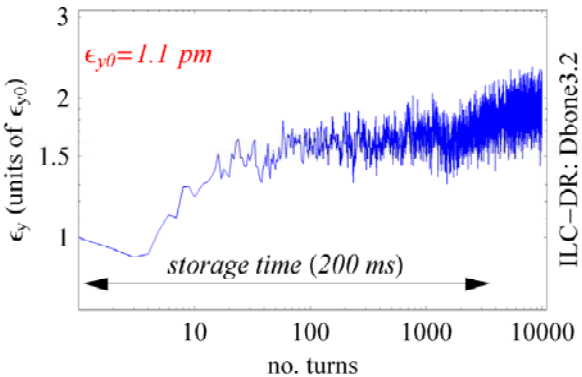
- **Beam Diagnostics and Instrumentation**
  - Luminosity monitor for real-time bunch-bunch diagnostics
- **Hardware and Beam Commissioning**
  - Based on Tevatron, PEP-II, ALS, SNS experience

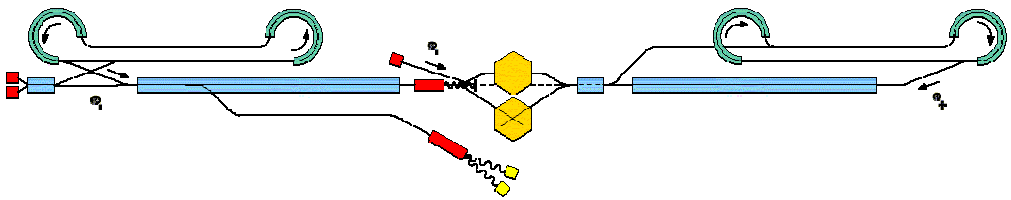
LBNL Contributions to the ILC

- **Design of Linear Collider damping rings and bunch compressors**
  - **Major responsibilities and leadership (GDE, R&D Board, Area rep for damping rings)**
  - **Natural extension of NLC work**
    - **Design and evaluation of NLC Damping Rings**
      - **Lattice design**
      - **Beam dynamics**
      - **RF**
      - **Impedance**
      - **Collective Effects**
  - **Low profile IR quadrupoles (Nb_3Sn or HTS)**



ILC IR Quad





Funding Overview

- **Almost a decade of flat-flat funding**
  - **Effective use of available funds and resources with outstanding contributions**
  - **Synergy with other programs**
  - **Help from LDRD and other sources**
  - **No attrition recovery**

Base provides leverage to respond to projects

But we are heading toward less than critical mass

Needs revitalization

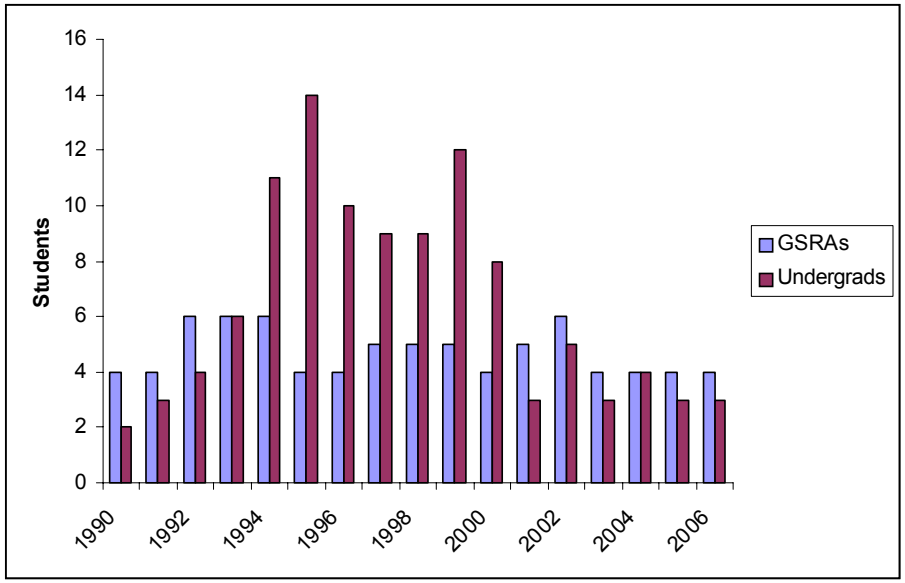
Budget details in handout

Students and PhDs

1980 - 2005

Post Docs	40
GSRAs	80
Undergrads	113
PhDs thru HEP	14

1990 - 2006



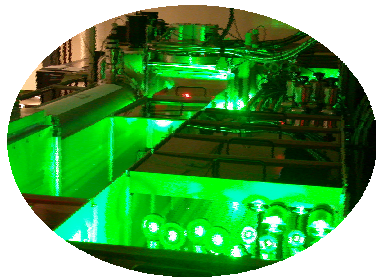
Strategic Timeline
(Designed to match 20-year Roadmap)

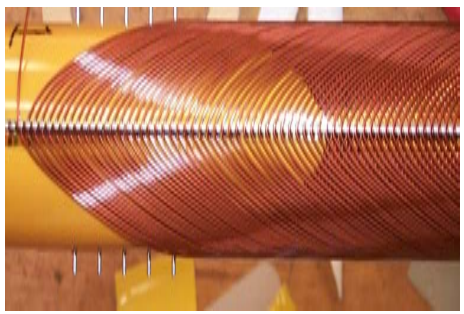
LHC Comm | ILC TDR | LHC Lumi Upgrade

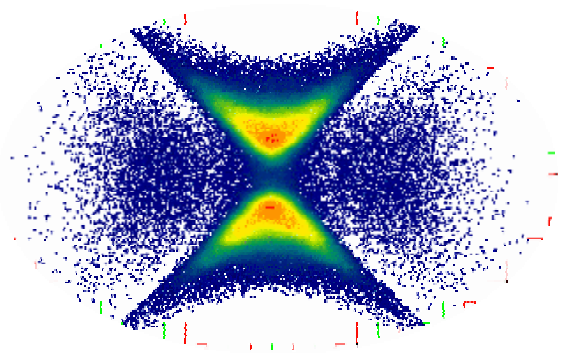
Program element	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Accelerator technology ***(Limits of accelerator based HEP?)***	*16 Tesla dipole * Current Density > 3,000 A/mm2		Prototype ILC Quad	15 T Dipole for Cable Test Facility * Scale-up production processes of fine filament Nb_3Sn strand for high field accelerator magnets	High Temperature SC coils show path for >18 T	> 17 T model, field-quality dipole demonstrates full potential of Nb_3Sn technology	Demonstrate practical, full length large aperture, quadrupole for LHC luminosity upgrade		20 T Dipole Prototype for LHC Energy Upgrade		
Collider science ***(How do we optimize the next generation of colliders?)***				Luminosity monitors enable rapid commissioning of LHC and early physics results Complete damping ring design for Linear Collider		Develop beam instrumentation suitable for Linear Collider	* Demonstrate Muon beam cooling by 100x		red = LARP		
Laser acceleration ***(How small can we make energy frontier accelerators?)***	* Demonstrate acceleration of low energy spread electron beams to ~ 1 GeV		* Channel extension experiments yield multi-GeV beams				* Demonstrate polarized electron trapping and acceleration		* Measure positron production and acceleration in laser-plasma system		
Supporting facilities	Complete l'OASIS upgrade to 100 TW 10 HZ operation			Complete renovation of Superconducting Magnet Test Laboratory (2007) Laser upgrade for 10 GeV module (2007 - 2010)			Magnet Fabrication Facility Scale-up				
Accelerator modeling ***(Optimize existing machines, design next generation, explore advanced concepts)***			Terascale beam-beam interaction application to current machines		Fully self-consistent simulations of LHC, including diffusion, beam-beam, impedance, & electron-cloud effects, supports rapid & safe commissioning Proton driver design (if needed)				Full petascale simulation of HEP accelerators		

HEP Scope of work at LBNL

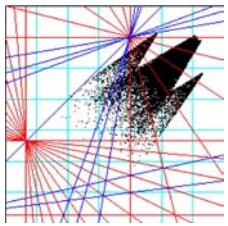
- **Short-range**
  - — LHC instrumentation and commissioning
  - — Produce GeV electron beam from all-optical accelerator
  - — Continue Tevatron and PEP-II improvements
  - — Critical physics and technology for ILC damping rings
  - — High gradient normal conducting RF R&D
  - — Cable test facility for US magnet program
  - — Modeling to maximize performance of existing and future facilities
  - — Begin HTS magnet development



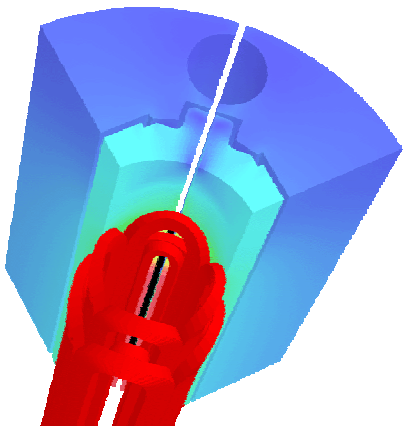


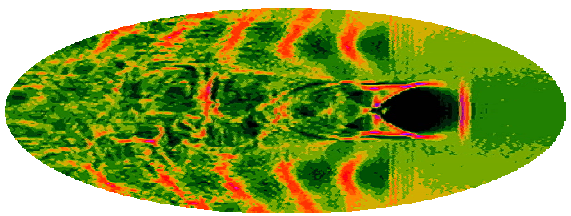


HEP Scope of work at LBNL



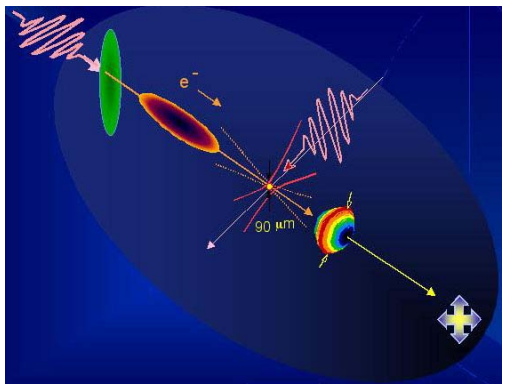
- **Medium-range**
  - Demonstrate length scale-up for Nb_3Sn
  - Compact laser-driven sources for 10 GeV test beams
  - Hardware for Muon Ionization Cooling Experiment (MICE)
  - Continued leadership in ILC damping rings
  - Optical stochastic cooling
  - Engineering design of the ILC damping rings
  - ILC IR magnets

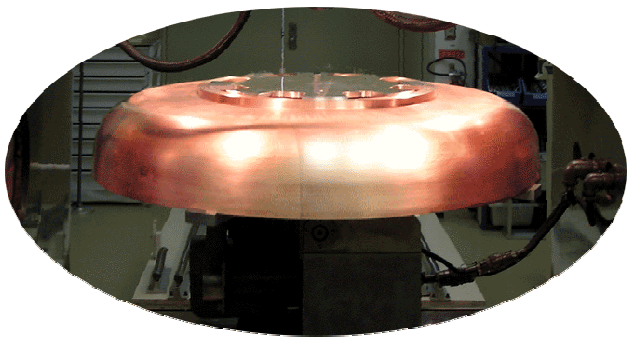


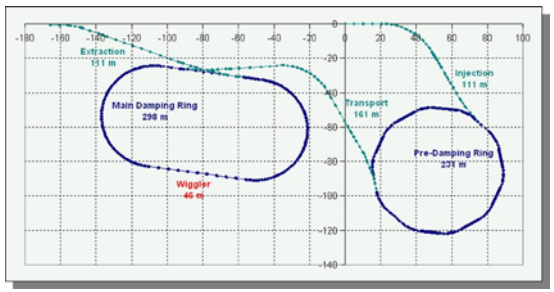


HEP Scope of work at LBNL

- **Long-range**
  - All-optical particle production and acceleration at the energy frontier
  - Physics and technology for future hadron colliders
  - Start-to-end modeling and optimization of frontier facilities
  - ILC commissioning
  - High Temperature superconductor inserts for fields of 18 – 20 T (LHC doubler)
  - Design for the neutrino factory/muon collider



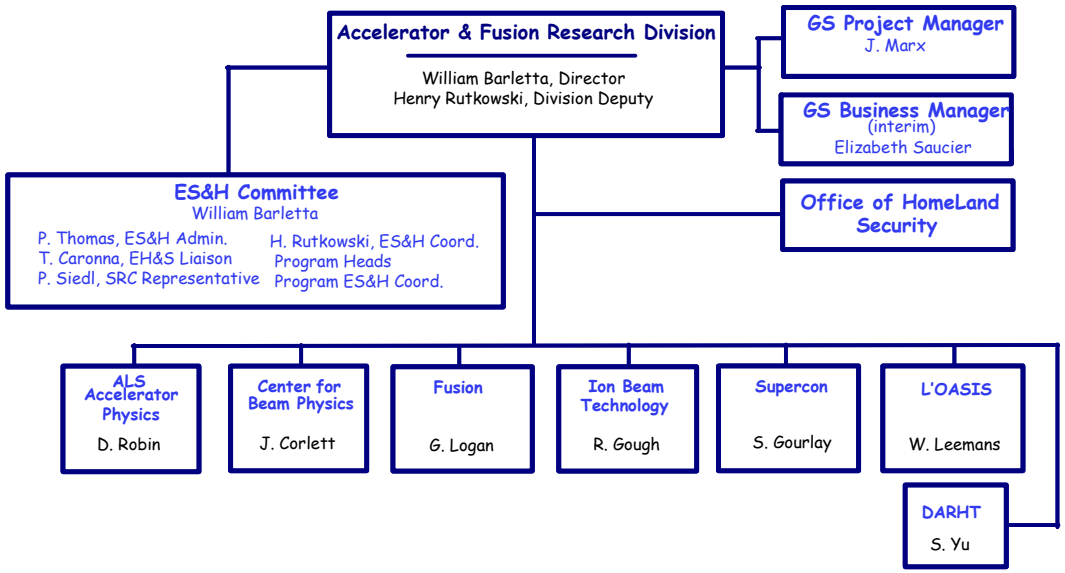




Program Management

- **Annual Reviews**
  - **DOE/HEP program review held jointly with physics program**
  - **Director's review of Accelerator and Fusion Research Division**
  - **Superconducting magnet review**
  - **Annual budget review**

Accelerator & Fusion Research Division



William Barletta
Director, AFRD
Lawrence Berkeley National Laboratory
May 2005

Phil Debenham, Acting Senior Program Manager
Bruce Strauss, Program Manager, Advanced Technology R&D Liaison to LBNL

Summary

- AFRD activities are aligned with HEP priorities
  - An incubator of new ideas
  - Increased flexibility, agility and breadth
    - Priorities can change more quickly than R&D programs can be created
  - Provide core technical resources that are responsive to community needs
    - Can meet challenges of the field
- A robust and successful HEP program needs to maintain an environment that nurtures and protects the development of new technologies that are the foundation of our science

Adequate funding must be restored to realize the full potential of the program

Internal Assessments (CBP)

- **2005 review of AFRD :**
  - **"CBP has made and continues to make significant contributions to the design of damping rings for a future linear collider."**
  - **"CBP has greatly contributed to increasing awareness about the deleterious effects of the electron cloud effect in accelerators."**
  - **"… the very impressive work in the Beam Electrodynamics Group on laser and beam synchronization …"**
- **2004 review of AFRD :**
  - **"The CBP is clearly the "idea factory" for accelerator and laser based science for LBNL and is also recognized on the world stage for this as well."**
  - **"The management deserves praise for the vision of making CBP a center of excellence for accelerator simulation."**
  - **"The Center for Beam Physics is a unique operation that serves as an "accelerator science knowledge base and resource pool" for LBNL and the accelerator community at large."**

Internal Assessments (CBP)

- **2003 review of AFRD :**
  - **"The Center for Beam Physics is an important resource for LBNL and the country."**
- **2002 review of AFRD :**
  - **"The Center for Beam Physics continues to produce excellent research…"**
- **1999 review of LBNL HEP program:**
  - **"The AFRD maintains leading edge R&D efforts in well-chosen areas of expertise that benefit HEP programs."**
  - **"AFRD contributions to the commissioning of the PEP-II Low Energy Ring has been impressive."**
  - **"Overall, the work of the CBP continues to be of high quality over a wide range of activities, with clear scientific and programmatic goals."**
- **1999 review of AFRD :**
  - **"[CBP ...] has an outstanding staff … a key resource in the generation of ideas for significant new ventures …"**

Internal Assessments (SC Magnet Program)

Director's Review of AFRD 2002 - 2004

". . . a complete research and development venture, the results of which to date are outstanding . ."

". . the program has become the yardstick by which all other like efforts must be measured".

". . . AFRD, is now in the undisputed possession of a unique asset, the only completely integrated high field superconducting magnet research program, certainly in the US and most likely the world, . . . at the very leading edge of this technology."

". . .a number of innovative ideas in magnet design have been explored with outstanding success and international recognition. . . . The result is the undisputed leadership in this field as well as in the associated cabling technology."

Internal Assessments (LOASIS)

Director's Review of AFRD 2004 - 2005

"The pioneering work on LOASIS may eventually provide the front-end of an accelerator and, if successful, a multi-GeV beam..."

"The success of LOASIS is clearly one of the highlights of the Division. The program has demonstrated that laser-plasma technology has the potential to develop into a "breakthrough" accelerator technology, enabling a new class of high current electron beam sources"

"The work at l'OASIS is world class, opening up entirely new areas of science".

Internal Assessments (LARP)

Director's Review of AFRD 2003 - 2005

"LARP presents an excellent opportunity for superconducting magnet development beyond the base program, for HEP instrumentation in high radiation environments, and for accelerator physics to participate in the commissioning of the LHC and to contribute to the continuing machine development studies."

"A potential danger is the reduction in the base program as LARP funds become available. This must be avoided."

"The superconducting magnet program at LBNL has been very successful. The base program was established a number of years ago to provide support for niobium-tin high fiel magnet research and development. As such, divorced from a mission oriented, schedule driven project, the base program has provided a favorable environment to create, . . . The results are indisputable; niobium-tin, while still a difficult material to work with, is no longer a laboratory curiosity."

"The highly successful magnet R&D program at LBNL was the catalyst, which led to the launch of US LHC Accelerator Research Program (LARP)."

Endorsements (LARP)

- Electron-cloud build-up simulations and heat-load predictions by M. Furman and co-workers at LBNL with the code POSINST provide an extremely valuable independent benchmark for similar simulations performed at CERN using a different program. The LBNL simulations have revealed some interesting features, like a strong sensitivity to the presence of re-diffused electrons and an oscillatory electron-density evolution, which need to be further followed up.

- Another effort at LBNL is directed towards the construction of a fully self-consistent 3-dimensional program, modeling the beam-electron interaction including ions and a dynamic gas density. If this ambitious, but high-risk effort is successful, also in terms of affordable computing time, it would deliver a unique tool by which many critical questions could be studied, such as the collusion of build up and instability, or the dynamic interplay of electrons and ions.

— Frank Zimmerman, CERN

Endorsements (LARP)

- ". . . A real quadrupole, although short, working at 11 – 12 T peak field is of utmost importance to establish that the plan we are going to do in 2005 – 06 for the LHC upgrade . . ."

- "The manufacturing of a successful prototype for 2009 is real vital to the whole magnet program, on both side of the Atlantic."

  — Lucio Rossi, CERN