3.a Science Strategy *L.3.a, M.3.a*

Elementary-particle physics is on the verge of a revolution in our understanding of the fundamental nature of matter, energy, space, and time. The opportunities for discoveries that profoundly advance our understanding of the Universe have not been greater in at least 50 years, if not a century.

FRA's science strategy for FNAL addresses the high-level High-Energy Physics goal provided in the DOE Strategic Plan: "…*to establish world-class scientific research capacity to advance high-energy physics*." In concordance with the DOE Strategic Plan, the Office of Science Strategic Plan has adopted as the primary goal for high energy physics "…*the exploration of the fundamental interactions of energy, matter, space and time*." Under this goal, there are two subsidiary goals: "*to explore the unification of forces"* and to "*understand the cosmos*." Underlying these DOE goals are the deep connections between the world of the very small and the world of the very large. The smallest distance scales and high mass particles we study in accelerators connect us directly to the earliest moments of the universe. These earliest moments are also imprinted in the grand scale of the Universe we observe today in its geometry, structures and composition.

These grand goals are at the core of FRA's overall science strategy. In direct response, we will attack the most profound scientific questions of our time along three discovery frontiers. In order of priority, they are 1) the energy frontier, 2) the neutrino frontier, and 3) the particle astrophysics frontier. These are the three frontiers where high energy physicists will make the most important discoveries in the next two decades. These are also the areas where Fermilab has both a rich history of discovery and key core competencies.

Figure 3.a–1 summarizes our science strategy. As illustrated in the figure, radiating from the core DOE goals are the scientific activities that FRA will pursue, the scientific facilities we will build, and the S&T developments needed for the long-term. FRA's decision to center our strategy on these three frontiers follows from the aspirations of the scientific community, as expressed by its various advisory committees. The most recent strategic framework for the field in the US has been developed by the EPP 2010 Panel of the National Academy of Sciences. Its report, *Revealing the Hidden Nature of Space and Time (EPP2010),* recommends strategic priorities for the field. Similarly, the *European Strategic Plan,* developed under the aegis of the CERN Council, provides recommendations for the development of particle physics in Europe. The high-level priorities in these two strategic plans are very similar and support the DOE Office of Science (DOE SC) strategy goals (***Figure 3.a–2)***.

Both plans are future-oriented and emphasize the need for a broad, ambitious program. The first-priority recommendation in both strategic plans centers on the energy frontier: the LHC is the immediate opportunity and top priority for both plans. The next priority, also at the energy frontier, is the development of future colliders—in particular, the ILC (EPP2010), CLIC, and ILC (European Strategy). The EPP 2010 places particle astrophysics as the next priority, followed by neutrinos, whereas the European Strategy gives higher priority to neutrinos than astrophysics. In Asia, there is no corresponding global plan outlining a comprehensive strategy, but the Japanese strategy can be deduced from the investments they make. Japan has a strong interest in the LHC

EPP 2010	EU Strategy
❖ LHC ❖ ILC development ❖ Host ILC in the US ❖ Astrophysics with other agencies ❖ Global Neutrino Program ❖ Flavor Physics	❖ LHC ❖ Accelerator R&D: beyond LHC (CLIC) ❖ ILC ❖ Global Neutrino Program ❖ Astrophysics with other agencies ❖ Flavor Physics ❖ Nuclear Physics/HEP connections

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*Figure **3.a–2**. EPP 2010 and EU Recommendations. FRA's science strategy for FNAL is informed by both sets of recommendations and is broad enough to meet the full range of associated program requirements.*

and the Linear Collider R&D (energy frontier), the T2K Program in JPARC (neutrino frontier), and the Asymmetric B Factory (quark-flavor frontier).

With the Energy Frontier as FRA's first priority, we then select neutrinos as the second priority because an accelerator laboratory such as FNAL can make unique contributions in this area and has a responsibility to support this research community. The third priority in FRA's strategy is particle astrophysics. Today, many of the most interesting questions in particle physics lie at the intersection of astrophysics and cosmology, including the nature of dark matter and dark energy and the origin of the Universe.

All current plans give a lower priority to the quark-flavor frontier that addresses the details of the Standard Model and searches for new phenomena indirectly through precision measurements. FRA's vision is that progress in the latter arena will come from projects at the energy and the neutrino frontiers: FRA will not emphasize the quark-flavor frontier in our named future priorities, but will exploit the opportunities as they arise.

Our overall goal is for FNAL to be at the forefront in these three areas of discovery science—providing the leadership, facilities, and know-how to support the US particle physics community and to achieve DOE's goals (***Figure 3.a–3)***. The three-prong strategy we propose will ensure a vibrant Fermilab in the near-, mid-, and long-term future, with neutrinos and particle astrophysics playing the primary role in maintaining a vital on-shore program when the energy frontier moves to the LHC.

3.a.1 Long-Term Strategy to Support DOE Missions

Today, FNAL is the primary laboratory for elementary particle physics and is the only laboratory solely dedicated to this field; the success of this part of DOE's mission is inextricably linked to the future of FNAL. FRA has a vision and a strategy for FNAL to realize the scientific potential for the field—one that will accomplish the DOE mission in elementary particle physics and maintain US leadership in this important area of discovery science.

FRA's Long-Term Strategy to Support DOE Mission

FRA will extend the world-class program already in place at FNAL; maintain US leadership through a strong on-shore program during the LHC era; and lead the local, state, national, and international planning necessary for FNAL to host the ILC. Our long-term strategy is founded on attracting and retaining best-in-the-world scientific, engineering, technical, and administrative talent to FNAL to deliver on DOE's goals for the elementary particle physics program.

FRA builds our long-term strategy through implementation of four general approaches:

1. Apply URA and UChicago strengths to assemble the best staff in the world. As first-tier research institutions guided by a common passion for excellence, the member universities of URA and UChicago are committed to attracting the best scientists, engineers, research associates, graduate students, and administrators to FNAL. In the scientific arena, FRA's compelling vision—developed with the elementary particle physics community, URA, and UChicago—is a key element in attracting the best staff to FNAL. Corporate resource commitments most visibly include a series of joint appointments between FNAL and the Illinois universities. The opportunity to attack the most profound questions in physics represents a powerful inducement for talented young scientists, as well as a powerful recruiting tool (discussed in ***Section 4.a.1***).

2. Establish a rigorous strategic-planning process led by the Deputy Director that aligns our programs and plans with DOE goals and particle physics community objectives. This process, discussed in ***Section 4.a***, involves the development and evaluation of new ideas, the alignment of those ideas with the recommendations of advisory panels and DOE goals, and the development of specific implementation plans.

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Complete the Standard Model:

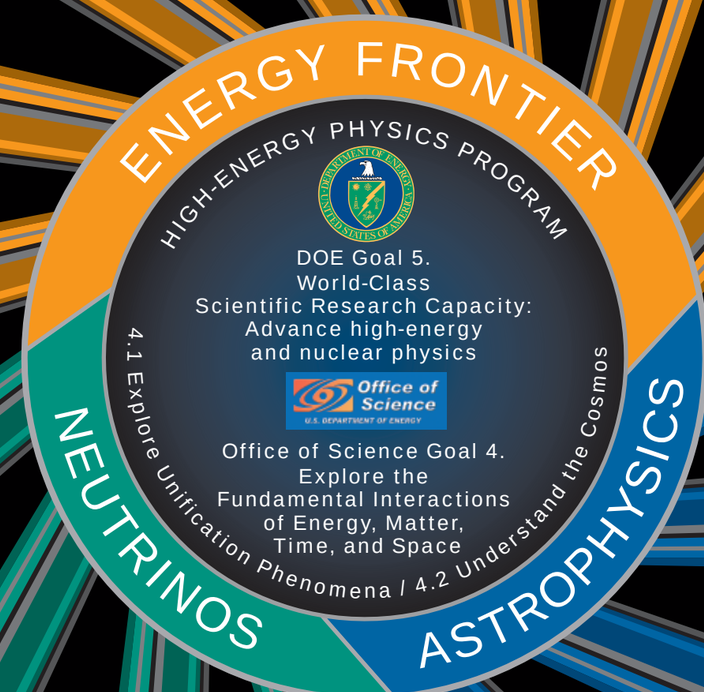
- ❖Measure properties and interactions of the top quark to understand its role in the Standard Model (2009)
- ❖Use precision measurement of the top quark mass to constrain the mass of the Higgs particle (2009)
- ❖Elucidate matter/antimatter symmetry violation
- ❖Measure Standard Model features in masses, decay rates, and lifetimes

Discover New Symmetries of Nature or Extra Dimensions of Space:

- ❖Discover or set limits for supersymmetry, Higgs mechanism, new dimensions, or other phenomena in the:
  - – Tevatron (2009)
  - – LHC/CMS (2012)
  - – ILC (2022)
- ❖Connect measurements of lightest supersymmetric particle to dark matter
- ❖Search for evidence of grand unification in LHC and ILC experiments

Develop and Exploit Energy Frontier Accelerators:

- ❖Improve and operate the Tevatron through 2009
- ❖Lead US participation in LHC accelerator
- ❖Lead development of SCRF technology and site-specific design for ILC
- ❖Pursue advanced accelerator development
  - – High luminosity collider (LHC)
  - – High energy muon collider
  - – High intensity neutrino sources
- ❖Pursue detector development and provide test beams for LHC upgrades and ILC



Discover Dark Matter:

- ❖Search for supersymmetric particles in the Tevatron, LHC, and ILC
- ❖Use CDMS and extensions to search directly for dark matter particles (2015)
- ❖Study large-scale structure of the Universe using SDSS and DES (2015)
- ❖Develop new technologies for dark matter searches (2016)

Observe Nature's Highest Energy Particles:

- ❖Complete Pierre Auger array in the southern hemisphere (2007)
- ❖Study the spectrum of the highest energy cosmic rays to understand their origin (2010)
- ❖Determine whether there are sources that would require the development of a northern hemisphere array (2010)

Discover the Nature of Dark Energy:

- ❖Use SDSS to improve measurement of the acceleration parameters (2008)
- ❖Build and exploit the Dark Energy Survey (DES) on the Blanco Telescope (2010)
- ❖Partner in the Joint Dark Energy Mission (JDEM) on a space-based telescope (2015)
- ❖Develop the theoretical understanding of dark energy: is dark energy a failure of general relativity? (2020)

Use Neutrinos to Probe the Origin of Mass and Unification of Forces:

- ❖Complete the MINOS study of neutrino oscillations (2010)
- ❖Initiate NOvA to resolve the neutrino mass hierarchy (2015)
- ❖Measure critical neutrino cross-sections for future neutrino experiments with MINERVA and SciBooNE (2012)

Search for Additional Neutrinos and Complete the Inventory of Quarks and Leptons:

- ❖Complete MiniBooNE to settle the existence of additional neutrinos (2010)
- ❖Develop a theoretical understanding of quark/lepton masses (2020)

Elucidate the Existence of Matter and Absence of Antimatter in the Universe:

- ❖Develop accelerator and detector technology for a long baseline neutrino program to exploit DUSEL Underground Laboratory (2015)

Figure 3.a–1. Supporting DOE's High-Energy Physics Mission. *FRA's approach emphasizes research and discovery in three areas critical to the DOE mission: the energy frontier, the study of properties of neutrinos, and the connections between particle physics and astrophysics.*

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Features of FRA's Science Strategy	Benefits to DOE
Long-Term Science Strategy	
Organize strategy into 3 "frontiers": 1) Energy Frontier (ILC, CMS); 2) Neutrinos (NOvA, Global Planning); and 3) Particle Astrophysics (New Center Structure)	Optimal support for DOE and Office of Science high-level goals
Understanding Laboratory Current Capabilities and Core Competencies	
Nurture and enhance current capabilities needed for the future program	Core competencies matched to FNAL mission; increased agility and scalability to transition to LHC and ILC support
Develop SCRF Core Competency	Successful US involvement in ILC; develops general capability in support of DOE future facilities
Enhance Advanced Accelerator R&D Core Competency and establish the Accelerator Physics Center; enhance interactions with ANL through the Illinois Accelerator Research Center (IARC)	Increases advanced accelerator R&D needed to develop future facilities and accelerator concepts and systems
New Directions and Solutions to Major Challenges	
Successfully transition from Tevatron to LHC by well-planned deployment of human and technical resources	Demonstrates DOE's capability to deliver on its major science programs; delivers on the development of LHC, the major investment in particle physics by the US in past two decades
Play a lead role in development of the ILC	Development of ILC technology and design that will lead to a positive decision to build the ILC—in collaboration with global partnership supporting ILC construction
Restructure Particle Astrophysics Center and exploit URA/UChicago/ANL connections	Provide the premier group to achieve DOE's mission in particle astrophysics
Opportunities to Position/Strengthen FNAL's Role in Supporting DOE Missions	
Enhance SCRF capabilities in Illinois through partnerships with ANL, the local Illinois Research Universities, and the State of Illinois	Strong technical base for the ILC in Illinois
Leverage URA's broad reach into its 90 partnering universities, the Linear Collider Forum of America, and the national and international relations of UChicago, ANL, and URA to establish a national consensus to build the ILC	Broad national support for ILC with industry and research universities
FNAL's Role as an Integral Component within DOE's System of Laboratories	
Develop central role in accelerator R&D to support DOE's missions; establish Accelerator Physics Center	Establishes FNAL as principal agent in the development of accelerator technology for all scientific disciplines
Establish feasibility of remote operations and data analysis centers	Develops concepts necessary to make use of global facilities like LHC and ILC
Maximize science of existing facilities and train the next generation of scientists	Demonstrates commitment of the OHEP in delivering its programs; establishes US as reliable international partner
Relationships that would Further Enhance FNAL Capabilities to Address Scientific Missions	
Leverage FRA-related organizations to advance FNAL capabilities	Increased joint appointments, fellowships, and related programs; expanded capabilities to support evolving FNAL mission
Expand international connections to other laboratories, universities, and agencies	US viewed as a good partner across a broad front of activities as precursor to the ILC

Figure 3.a–3. Science Strategy Features and Benefits. *Our comprehensive, flexible approach will help FNAL retain its position at the center of high-energy physics for decades to come.*

3. Provide the outstanding ES&H, project management, and operations and business management systems needed to support a world center for particle physics. As discussed in ***Section 4.b***, FRA will deliver integrated, flexible, and agile business systems that ensure continued safe operations, increased efficiency, and the scalability needed to support the LHC, ILC, and other future programs. Our initiatives in this area include creation of a Laboratory Collaboration Council (LCC)

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to achieve scientific synergies and operational efficiencies by coordinating programs between ANL and FNAL, the Office of Quality and Best Practices to ingrain best practices and a culture of quality throughout FNAL, and our Dashboard Initiative to put all necessary information at the fingertips of our authorized FRA and DOE managers.

FRA New Initiative 10

4. Act to optimize the DOE program in concert with multiple partners throughout the scientific community. The strengths of URA and UChicago are enhanced through a concentric set of connections and influence. With FRA at the center, the first circle of influence is formed by the local Illinois universities: Northwestern University, the Illinois Institute of Technology, the University of Illinois, and Northern Illinois University have made major commitments toward the success of FNAL in Illinois (discussed in ***Section 8***). The second circle of influence is the national network of 90 URA research universities that will participate in FNAL's programs and are committed to the success of FNAL. The third circle of influence involves the several national and international institutions, with which both URA and UChicago have partnered, and will bring value to current and future FNAL programs.

These four foundational approaches enable FNAL to capitalize on future opportunities and respond effectively to changing circumstances in the field. In the following sections, we describe FRA's initial strategic plan that places FNAL and the US particle physics community in a leadership position in three frontiers: energy **(Section 3.a.1.1)**, neutrino **(Section 3.a.1.2)**, and particle astrophysics **(Section 3.a.1.3)**.

3.a.1.1 Strategy for Study of the Energy Frontier

Central to our science vision is maintaining leadership at the energy frontier. As shown in ***Figure 3.a–4***, the roadmap for the energy frontier, the Tevatron with CDF and DZero provides the earliest look at the terascale, but only at relatively low masses. The LHC will follow, exploring a far broader range of the terascale with seven times the energy of the Tevatron and up to 100 times the luminosity. Finally, the ILC, an accelerator of unprecedented power and precision, will build on the discoveries at the LHC to achieve the most comprehensive exploration of the terascale. The ILC's extraordinary power for discovery arises from the annihilation of an electron and positron into a remarkably pure state: 500 GeV of energy packed into a single photon of light. Hosting the ILC in the US represents the greatest future opportunity for the national program and is central to FRA's strategy for FNAL.

The opportunities for revolutionary discoveries—at the Tevatron, at the LHC, and especially at the ILC—are unprecedented. First, the mechanism for the generation of mass for all elementary particles should become accessible in the terascale energy range. Second, the discovery of whether there are a number of hidden spatial dimensions by detecting small disturbances in the behavior of ordinary particles. Finally, the discovery of a whole hidden world of massive particles and supersymmetric particles, linked to the familiar quarks and leptons, could be entirely accessible through the combination of LHC and ILC.

Initial experimental evidence pointing to the unification of forces, including gravity, could also be accessible in the terascale energy range. The matter-antimatter asymmetry in the universe could be exposed by the ILC by observing mixing in the decays of Higgs multiplets expected in a minimally supersymmetric theory (MSSM). In fact, the expectations for the terascale energy range are so enormous that it could amount to a remarkable revolution in our understanding of the physical world, akin to the revolution at the beginning of the last century with the discovery of relativity and quantum mechanics.

FRA's strategy for capturing the ILC rests on exploiting FNAL's enormous advantages. URA has developed a world-class staff in accelerators, detectors, computing and theory, as well as the project management expertise to construct large-scale equipment and infrastructure. It has a distinguished record of

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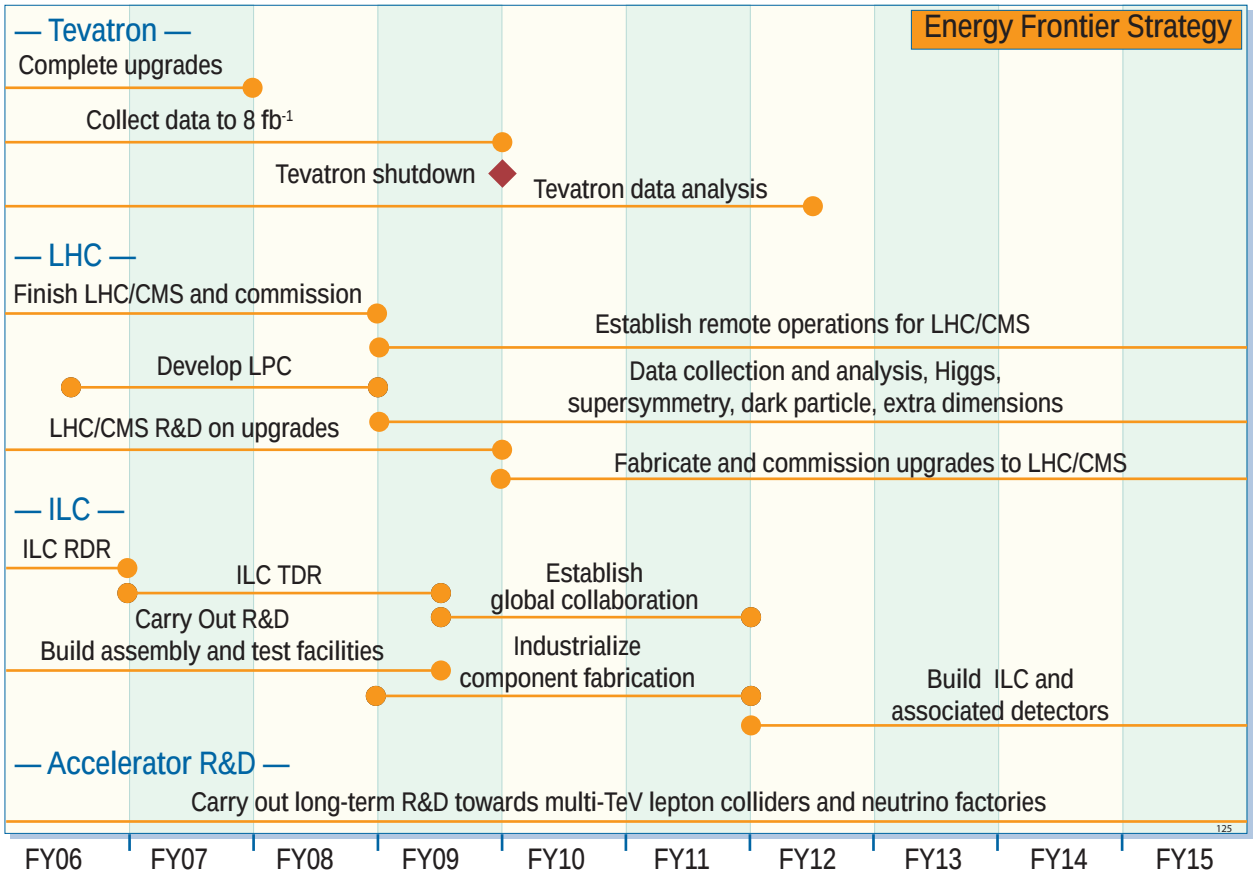

*Figure **3.a–4**. Timeline for Impementation of FRA's Strategy for the Energy Frontier.*

discovery that it has shared with many partnering institutions. It has extensive cryogenic experience, having built and successfully operated the pioneering cryogenic hadron collider. URA has also cultivated collaborations worldwide. FRA now adds the possibility of tightly coordinated programs with another, nearby DOE National Laboratory—ANL. FNAL and ANL have excellent relations with the surrounding communities and the State of Illinois; working together, FNAL and ANL provide the necessary R&D resources and the requisite scale to promote and host the ILC in Northern Illinois. As the mechanism to focus collaborative efforts on the ILC strategy, FRA, LLC and UChicago Argonne, LLC, will establish a Laboratory Collaboration Council (LCC) within 60 days of contract award. FNAL Director Pier Oddone and ANL Director Robert Rosner will rotate chairmanship of the Council annually. The LCC will create working groups chartered by joint action of the Laboratory Directors. Two LCC working groups, the R&D Working Group and the Technology Transfer Working Group (described in ***Section 4.a***), will provide critical support to the ILC mission.

In carrying out the strategy for the energy frontier, we face several key decisions. First is the timing of the Tevatron collider closure. This key decision will depend on the effectiveness of the Tevatron program and the state of the LHC towards the end of the decade. Promising hints of new physics from the Tevatron would have to be pursued by running the accelerator longer. Until the LHC is fully commissioned, the Tevatron provides the world with the most compelling opportunities for discovery. At present, the planned shutdown of the Tevatron would occur at the end of FY09, at which time the closure of the Tevatron would allow a large redirection of effort towards the ILC.

The most consequential decision, of course, is whether the Government decides that the US should host the ILC. FRA, with its broad coalition of partners in nearly all states of the

nation, is in a unique position to build the national and international consensus that will be required. FRA will also advocate the role of the ILC in maintaining leadership in the physical sciences. The decision to host the ILC at FNAL will require a successful bid-to-host process with federal and state agencies working together to make an attractive package. FRA has the experience with the community and state agencies to contribute to this process. The final decision to build the ILC will depend on results from the LHC, the successful conclusion of the bid-to-host process, and satisfactory arrangements for the international governance of the ILC project.

To stay at the leading edge of the energy frontier and attract the ILC to the US and to FNAL, the following eight strategic elements must be completed successfully. Since Strategic Elements 3–7 all pertain to the ILC, we have combined their associated timelines in a single graphic presented later in this section—***Figure 3.a–5***.

Strategic Element 1. *Deliver on the present world-class program carried out at FNAL*
FRA will ensure that until the Tevatron is shut down, we continue to deliver the luminosity and the physics results commensurate with being the highest energy machine in the world. FRA's approach to developing and retaining our scientific personnel—see ***Section 4.a.1***—will ensure that the talent and resources to deliver the needed integrated luminosity remain at the Tevatron accelerator. FRA will track the transition of personnel and resources from the Tevatron experiments CDF and DZero to the LHC experiments (ATLAS and CMS), ensuring that resources commensurate with the physics opportunities remain at the Tevatron. Further, FRA will build on URA's initiative to create an international fellows program and will continue FNAL's close coordination with DOE and NSF to support domestic research associates and students working at the Tevatron. Finally we will work with UChicago and affiliate universities to ensure that FNAL's scientific agenda continues to attract and retain the best people as we bridge the Tevatron-ILC eras.

Strategic Element 2. *Contribute in a major way to making the LHC accelerator and the CMS detector at CERN successful enterprises*
FRA understands that success at the LHC will be critical to realizing the next generation of particle physics accelerators. To help make this a reality, FRA will carry out initiatives across many fronts, including:

- Creating the CMS Center to gather all the resources associated with CMS under one umbrella, reporting directly to the Associate Director for Research. Three departments will report to the leader of the CMS Center: the LHC Physics Center (LPC), the CMS Software Group, and CMS Operations
- Creating a physics center for data analysis—the LHC Physics Center (LPC) under the CMS Center—will create the critical mass of expertise and users to make the US community in CMS a vital contributor to LHC physics. The center will have co-leaders from FNAL and the community to insure optimal effectiveness for all CMS. It will use FNAL's state-of-the-art Feynman and Grid Computing Centers along with the newly created CMS Tier 1 Computing Center. The LPC is already making an impact and bringing US CMS collaborators together for training and expertise building. The weekly VRVS "ALL USCMS" meetings are a valuable coordination and communication venue.
- Providing experienced accelerator physicists for the commissioning of the LHC accelerator at CERN and developing jointly with CERN the future LHC upgrades
- Leveraging the remote operations center being created at FNAL that will allow accelerator physicists at FNAL to contribute their experience and intellectual leadership in making the LHC a reality
- Applying additional strength from UChicago's Computation Institute and experts from ANL, including expertise in handling large data sets, writing Grid software, and providing the infrastructure and networking bandwidth that make the Chicago area well connected nationally and internationally.

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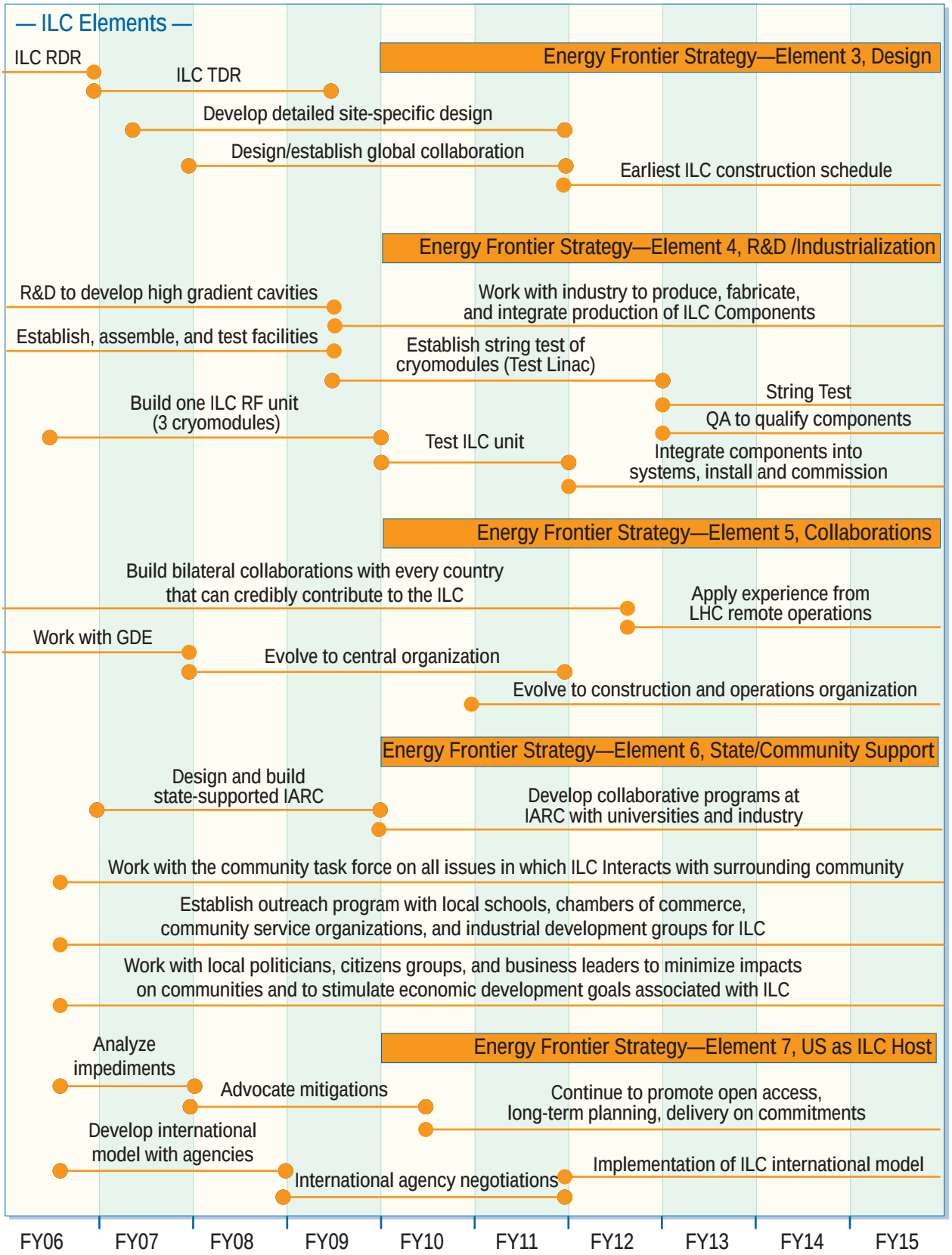

*Figure **3.a–5**. ILC Planning Elements. FRA combines URA and UChicago science and technology expertise with a disciplined planning process to help attract the ILC to the US and to FNAL.*

The LHC will benefit from these initiatives because they bring the experience of FNAL staff and its users to the LHC: i.e., many of the same people who made the Tevatron a success will now focus their expertise to make the LHC a success. DOE will benefit because the success of the LHC will demonstrate that the largest investment in particle physics by DOE in the last two decades was justified. FNAL also leads the LHC Accelerator Research Program (LARP) to commission the LHC and to develop future upgrades. The timing for implementing upgrades to the LHC is likely to be beyond 2010, but the technology R&D must be completed during the next few years.

***Strategic Element 3**. Lead in the design of the ILC*

As part of the collaboration with the Global Design Effort (GDE), along with other national and international laboratories and universities, FRA will develop the design of the ILC and understand all of its components, as needed, to qualify as a host site. In particular, as an element of the analysis of various possible sites, FRA will develop a design suitable for a site at or near FNAL. During 2006, FRA will provide resources to support the international cost estimate to be produced by the GDE as the Reference Design Report (RDR). Following the RDR, FRA will continue to shift technical resources from the present program to the ILC to complete the Technical Design Report (TDR) by 2009. As part of this effort, FRA will conduct detailed geological studies and construction modeling to optimize the location of the ILC near the present laboratory. We will apply lessons learned by UChicago, in the creation of major facilities such as the Advanced Photon Source (APS), and by URA, on the NuMI and Main Injector projects, to the development of the site-specific design. Timelines for this element are shown in ***Figure 3.a–5.***

***Strategic Element 4**. Develop the principal technology necessary for the ILC—namely, the fabrication and operation of high-gradient superconducting RF cavities and associated components*

FRA will develop the FNAL ILC Program Office to take the lead in ILC R&D, with the sponsorship of the Laboratory Director, by managing the R&D effort as a discrete project with priority support from all resources of the Laboratory.

FRA will also help to create an industrial base in the US able to support ILC needs. The primary area of concentration for FNAL will be in the development of the Superconducting RF (SCRF) technology and test facilities to support the industrialization and development of the linear accelerator. The facilities to be developed include assembly and cleaning facilities, high power test stands for cavities and cryo-modules, and a test string of several cryo-modules that will transport electron beams. FRA's approach to creating the industrial base to support the ILC is to create R&D and Technology Transfer Working Groups under the Laboratory Collaboration Council (LCC) during the first six months of the new contract. The Argonne Accelerator Institute (AAI) will provide its expertise through the R&D Working Group. Argonne's Office of Technology Transfer (OTT) will apply its resources through the Technology Transfer Working Group to identify and encourage collaborations toward involving industry in ILC development.

Working with the State of Illinois, URA and UChicago have obtained support for this program. The Governor of the State has submitted to the State legislature a request to establish the Illinois Accelerator Research Center (IARC) at FNAL to provide facilities where FNAL, ANL, industry, universities, and other national laboratories can develop SCRF technology collaboratively. The timelines for this element are shown in ***Figure 3.a–5.***

***Strategic Element 5**. Build a national and international consensus to build and host the ILC in the US by making FNAL the site of choice*

FRA will expand current URA efforts to build collaborations with institutions in several countries. We will use multiple vehicles to enhance our collaborations nationally and internation-

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ally. The first element is to work closely with our international partners within the Global Design Effort framework. In addition, FRA will contribute to European developments through the participation of accelerator physicists and experimenters in the LHC program. FNAL has a long-standing collaboration with DESY (Germany) on SCRF technology. FRA will collaborate with Asian nations, in particular with Japan, to coordinate the neutrino program to optimize mutual success. FRA will establish and monitor a country-by-country program to ensure that FNAL is viewed as an optimal partner to host the ILC by the countries likely to be partners in the ILC project.

Moving forward, FRA will support DOE's ILC efforts by working to attract the ILC to the US and beginning "next step" activities (***Figure 3.a–6.***). The timeline for this element is shown in **Figure *3.a–5***.

Strategic Element 6*. Work with surrounding communities, the State of Illinois, and regional organizations/businesses to create a welcoming home for the ILC*

FRA will build on UChicago and URA's successful efforts to develop regional, state, and/or local support for infrastructure and other contributions to large-scale S&T initiatives. UChicago has partnered with local and state stakeholders on several projects in support of science and technology, including: 1) basic and applied science programs at ANL; 2) the APS Guest House; 3) the Center for Nanoscale Materials; 4) the Protein Crystallization Facility; and 5) efforts to attract the Rare Isotope Accelerator (RIA) effort to Illinois.

In the initial phase of this effort:

- The Governor of Illinois has requested funds in the State budget for the construction of the Illinois Accelerator Research Center (IARC) at FNAL

Supporting DOE Efforts to Attract the ILC

FRA will support the ILC Technical Design Report (TDR) by:

- Developing a US site-specific machine design (e.g., at FNAL)
- Developing US site-specific civil design
- Demonstrating to US HEP funding agencies that the ILC technology is ready for a multi-billion dollar project
- Showing that US industry can provide the required US technical components
- Developing a credible plan and schedule using plausible US resources and in-kind contributions from outside the US
- Developing a detailed cost estimate for the US share of the ILC machine and detector to help convince DOE, OSTP, and OMB that the US costs are known
- Developing an international management plan acceptable to DOE and the international community

FRA's Next Steps…

- Develop a US ILC R&D plan with achievable milestones and realistic cost estimates
- Develop US industrial capability
- Support efforts to "bid-to-host" in FY07
- Reach consensus on the large-scale technology demonstrations needed to show that we are ready to build this large project in the US and how this might fit into the project timeline
- Work with our international partners to develop the ILC design and prepare an ILC design optimized for US site near FNAL
- Develop a US ILC resource-loaded construction schedule with achievable milestones

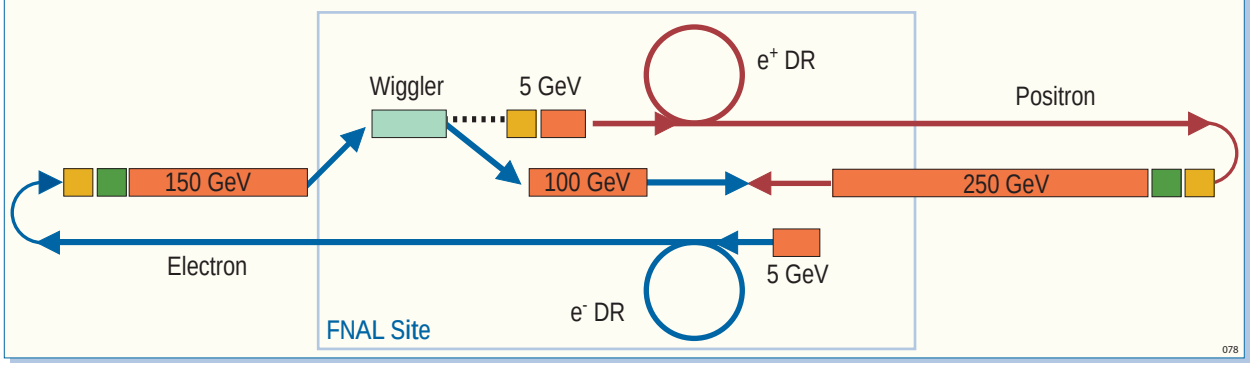

*Figure **3.a–6.** Providing ILC Leadership. FRA will work proactively to help attract the ILC to the US.*

- A community task force has been established to enable laboratory representatives to work together with members of the community in dealing with the many issues associated with building a facility beyond the present boundaries of the laboratory
- FRA will continue working closely with the community on issues such as tritium management to ensure that the community has complete trust in FNAL

The timelines for this element are shown in ***Figure 3.a–5.*** FRA will continue to work with the State in attracting the ILC and in developing a capture strategy for the ILC. UChicago is committed to leveraging its State of Illinois relationships to keep the focus on the benefits to Illinois of attracting the ILC, and to obtain further resource commitments whenever possible. The State of Illinois played a critical role in attracting FNAL to Illinois at the beginning of the laboratory's history making financial commitments and carrying out the land acquisition. We anticipate that the state will again play a leading role in attracting the ILC to the US. FRA will concentrate on site-specific design issues as follows:

- A surface appearance that is acceptable to the surrounding FNAL community
- Minimization of land acquisition costs
- Acquisition of environmental permits, community issues, etc.
- Integration of the design with existing infrastructure

Strategic Element 7*. Work with Federal agencies to ensure that challenges associated with hosting a global machine in the US are anticipated—and mitigated effectively—should they occur.*
FRA understands that there are special issues that make the US less-than-ideal for foreign partners in the ILC. One aspect is the year-to-year funding of our scientific program that does not ensure an enduring commitment to a long-term project like ILC. Other issues with visas and export and import controls also place limitations on collaborations. Working closely with our partner institutions, FRA will develop and present solutions to the Federal government that, while respecting the national security needs of the US, will promote scientific development in an atmosphere of free exchange and collaboration. The involvement of universities and American industry has been essential in preserving the freedoms that allow international collaboration—continuing URA practices in this area, FRA will be a significant part of this initiative. The timeline for this element is shown in ***Figure 3.a–5***.

Strategic Element 8. *Develop an advanced accelerator R&D program aimed at the design, in the long term, of a multi-TeV muon collider*
The need for a lepton-lepton collider well beyond the energy of the ILC is a certainty. The need for such a machine could come early if the LHC results point to a higher energy scale than can be reached by the ILC. More likely, the LHC will demonstrate that the region to be explored by the ILC is rich with new physics phenomena. Even in the latter case, there will be a need to follow the ILC program with higher energy machines after a couple of decades.

There are only two approaches that appear feasible at this time. One is the "two beam accelerator" such as the proposed Compact Linear Collider (CLIC) being pursued at CERN. The other is to develop a muon collider. Either approach may face insurmountable problems for very different reasons, as the concepts are totally different, but both present formidable challenges. Both approaches will require a long-term R&D program. The muon collider approach is attractive because it leads to a relatively compact machine that could fit well within the FNAL campus, potentially reach an energy several times the energy of the ILC, and avoid the difficult problems of massive photon radiation at the interaction point of multi-TeV electron-positron colliders; this approach is also relatively economical for the energy reach that it provides.

R&D in support of muon colliders would use all other principal R&D efforts at the laboratory: for example, 1) an intense proton source to produce the muons; 2) ILC-like acceleration sections for accelerating muons; and 3) expertise in RF manipulations of cold beams ac-

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quired at the Tevatron. It is important to realize that the ILC R&D will develop technology that could be applied profitably to this approach.

To enable this kind of long-term R&D in the presence of the operational demands of running accelerators, FRA will create the Accelerator Physics Center. The Center will report to the Associate Director for Accelerators. It will contain FNAL's advanced accelerator R&D efforts, it will serve the accelerator physics needs of R&D programs such as the ILC, and it will aid in solving complex issues associated with operating accelerators such as the antiproton stacking rate in the Tevatron.

3.a.1.2. Strategy for Study of the Properties of Neutrinos

We will provide leadership in the measurement of neutrino masses and in their mixing and possible CP violation—the difference between neutrino and anti-neutrino properties—by providing world-class neutrino beams and developing the massive detectors necessary to exploit them.

Since the inception of the laboratory, neutrinos have been the subject of study and discovery at FNAL. The early program centered on the fixed target program, with both a wide-band beam and narrow momentum band beam. Over the past few years, the observation of neutrino flavor oscillations has established the fact that neutrinos have mass. This is the first phenomenon that is experimentally outside the Standard Model and may provide information on grand unified theories. While several non-accelerator experiments like SuperKamiokande, Kamland, and the Sudbury Neutrino Observatory (SNO) experiments have pioneered these efforts, neutrinos are so elusive that their oscillation properties will not be fully understood until powerful experiments are carried out with intense accelerator beams.

Of the many open questions in neutrino physics, a number can be addressed with accelerators. In particular, the oscillation of muon neutrinos into electron neutrinos, the "mass hierarchy," which is the ordering of the masses of the neutrinos, and the matter-antimatter asymmetry between neutrinos and anti-neutrinos are essential elements of the neutrino sector that must be sought before a complete understanding emerges. The facilities that support the study of neutrinos at FNAL consist of the Main Injector and the NuMI beamline. Together, they represent an investment of over $500M that constitutes the foremost neutrino facility in the world. A facility of comparable reach is being developed in Japan at J-PARC that will use the existing Superkamiokande detector and is expected to be fully operational in 2011.

The roadmap (***Figure 3.a–7***) proposed by FRA for the neutrino program is shown below. In the next few years of the program, FRA will

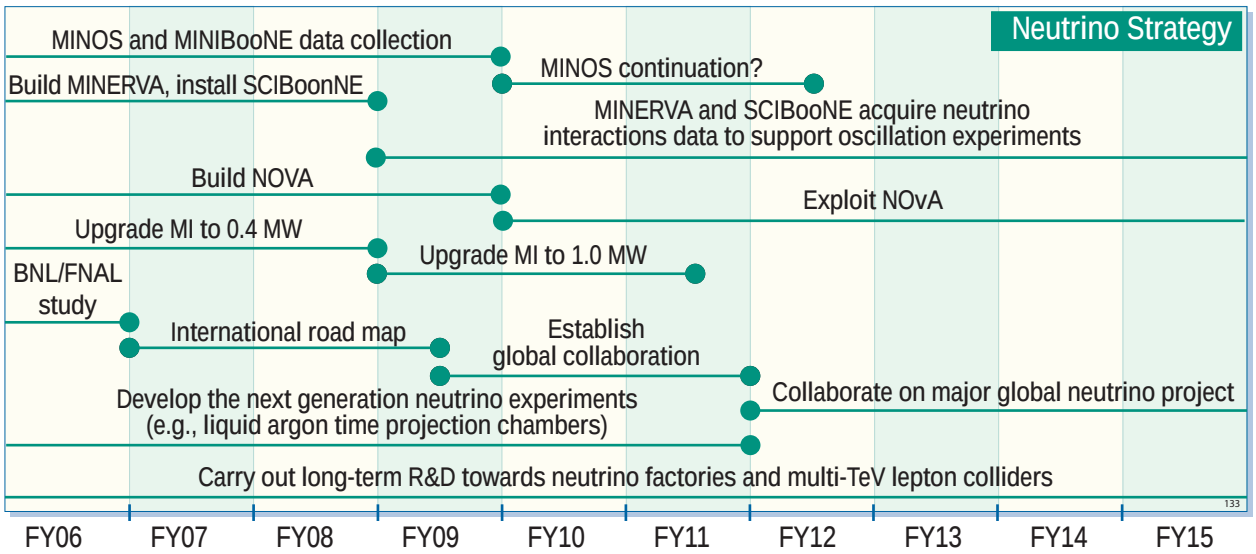

Figure 3.a–7. FRA's Neutrino Strategy.

exploit the existing detectors—MINOS and MiniBooNE—by providing an unprecedented amount of data before the end of the decade. The measurements from MINOS and MiniBooNE could revolutionize our understanding of neutrinos. With conclusion of the foregoing program, scheduled for the end of the decade, the NOvA detector, which is sensitive to the appearance of electron neutrinos, will be necessary to maintain a vital program in neutrino physics. This program will complement the Japanese effort, since it can measure parameters that cannot be reached at T2K. To carry out this program, FRA expects that funding will be approved to build NOvA.

It is possible that NOvA and T2K may not be sufficient to explore the neutrino sector if some of the mixing parameters are too small. In this case NOvA and T2K combined will provide vital information for the planning of next-generation facilities. Director Oddone has initiated planning for these future facilities with a joint FNAL and Brookhaven National Laboratory (BNL) study. In the meantime, FRA will carry out an accelerator R&D and detector R&D programs in these areas.

Our long-term strategy is to provide leadership in the study of the properties of neutrinos, including measurements of the mass hierarchy, mixing parameters, and possible CP violation. Our approach is to work with our national and international partners in developing a roadmap for the long term, while exploiting the opportunities offered by the combined programs of T2K and NOvA by optimizing the program with the input of both detectors. Over the long term, experiments could include a superbeam aimed at a deep underground laboratory such as the Deep Underground Science and Engineering Laboratory (DUSEL) being developed by the NSF. A collaboration of FNAL and BNL is currently studying such possibilities.

Our strategy builds collaborations with INFN on the NOvA program and future extensions, while at the same time coordinating the program with the Japanese particle physics community. The FRA strategy in neutrinos consists of the following seven elements:

Strategic Element 1. *Deliver on the present neutrino program with MINOS and MiniBooNE*
Currently, FNAL has the most intense neutrino beams in the world and will continue the program of MINOS until the end of the decade. This will allow the most precise measurements of neutrino oscillations in the “atmospheric region.” MiniBooNE will complement its present run with an anti-neutrino run to determine if additional neutrinos (sterile neutrinos) exist.

Strategic Element 2*. Develop NOvA as part of a staged, international plan for neutrino oscillations measurements*
The oscillations from muon neutrinos to electron neutrinos is yet unobserved. A finite rate for this oscillation is a requirement to study the arrangement of neutrino masses (mass hierarchy) and CP violation. NOvA provides a complementary program to the Japanese program at J-PARC and together they comprise the most comprehensive program through 2020.

Strategic Element 3. *Develop an international roadmap for future, long-baseline experiments*
Beyond NOvA and T2K it may be necessary to develop superbeams and detectors operating at very long baselines or to extend the off-axis exploitation of the NuMI beam. A long-baseline neutrino study has been initiated with BNL. We will engage Japanese and European colleagues to create a coherent international program.

Strategic Element 4. *Provide the basic engineering measurements for cross sections with modest experiments like MINERVA and SciBooNE*
The major and costly detectors like NOvA and T2K, and even larger detectors that might follow them, need precise measurements of topological cross sections in order to minimize systematic errors. Modest experiments like MINERVA and SciBooNE running in the very intense FNAL neutrino beams will provide the reference values for the world program. Similar arguments motivate hadron production experiments such as MIPP.

Strategic Element 5. *Develop the Main Injector to deliver 1 MW of power for NOvA*
To develop the full potential of NOvA, we are

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developing an economic upgrade of the existing complex that will provide a megawatt of power in a proton beam. This will produce a beam of neutrinos four times more powerful than the present beam to MINOS.

Strategic Element 6. *Carry out R&D for future intense proton sources usable for neutrino superbeams or neutrino factories*

The precision of neutrino experiments is determined by a combination of beam power and detector mass. Very powerful proton sources will be important for the long range program in neutrinos. These would be useful for neutrino super-beams, neutrino factories and eventually muon beams and muon colliders. FRA will continue the R&D program for such sources in collaboration with ANL, BNL, and LBNL. The initial application could be a beam to the Deep Underground Scientific Laboratory proposed by the NSF (DUSEL).

Strategic Element 7. *Develop detector technology for future mega-detectors of increased sensitivity and resolution*

One of the principal limitations in neutrino physics is that the high mass required for the detectors forces the use of very simple detectors to make them affordable. It is important therefore to develop massive detectors that are very powerful and at the same time inexpensive. In collaboration with Italian groups and INFN, FRA will continue to develop a program of R&D on Liquid Argon TPC detectors for future neutrino and proton decay detectors.

3.a.1.3 Strategy for Studying Connections Between Particle Physics and Astrophysics

Over the past two decades, the scientific agendas for astrophysics and particle physics have come together: knowledge of the fundamental laws and particles of nature has become essential to understanding how the Universe began, how it operates today, and what its destiny will be. And conversely, the Universe offers unique environments that allow nature to be probed in ways that simply can not be accomplished in terrestrial laboratories. Beginning with the late David N. Schramm and the founding leaders of the FNAL Theoretical Astrophysics Group—i.e., Edward W. Kolb and UChicago faculty member Michael Turner—scientists at FNAL have been pioneers in pursuing the science at the intersection of Inner Space and Outer Space. The FNAL group has set the scientific agenda and trained many of those now working in this exciting interdisciplinary field.

Strong connections with UChicago were critical to the founding of the FNAL astrophysics group in 1983, and those connections have continued to grow. Currently, five FNAL scientists hold part-time faculty appointments at UChicago (Scott Dodelson, Josh Frieman, Nick Gnedin, Steve Kent, and Edward Kolb) and two Chicago faculty have appointments at FNAL (Richard Kron and Michael Turner). A world-class particle astrophysics program is flourishing at FNAL:

- FNAL and UChicago scientists are playing leading roles in the second phase of the Sloan Digital Sky Survey (SDSS-II), with Richard Kron directing the project. SDSS-II is mapping out the large scale structure of the Universe to test inflation and probe neutrino mass.
- FNAL scientists collaborate on the world's most sensitive, direct search for dark matter, the Cryogenic Dark Matter Search (CDMSII) experiment in the Soudan mine. CDMSII is in the midst of its high-sensitivity multiyear science run and is beginning the first serious test of the hypothesis that the dark matter is composed of the lightest supersymmetric particle, the neutralino.
- FNAL scientists and UChicago faculty James Cronin and Angela Olinto are playing leading roles in the Pierre Auger Observatory, the world's largest cosmic-ray detector designed to help reveal the nature and origin of the highest energy cosmic rays. Auger was conceived by James Cronin and Alan Watson of the University of Leeds (UK), and designed at FNAL; the project is managed by FNAL.
- FNAL, UChicago, and University of Illinois scientists are leading the development of the Dark Energy Survey (DES), a ground-based telescope experiment that will employ a new wide-field instrument on the CTIO 4-meter telescope in Chile to probe dark energy via clusters, weak gravitational lensing, baryon acoustic oscillations, and supernovae. To

measure clusters, DES will work in concert with the South Pole Telescope (SPT), a cosmic microwave background experiment led by UChicago faculty John Carlstrom.

- FNAL is a key partner in DOE's SuperNova Acceleration Probe (SNAP). SNAP is DOE's concept for the Joint Dark Energy Mission (JDEM)—a two-meter-class space telescope dedicated to discovering and measuring supernovae out to redshifts z ~ 2 and measuring weak gravitational lensing to pin down the equation of state of dark energy and measure its possible time variation.
- FNAL has the world's leading theoretical group at the interface of cosmology and astrophysics with elementary particle physics. This group, founded by Edward Kolb and Michael Turner and now led by Scott Dodelson, has helped set the worldwide scientific agenda for particle astrophysics through its research, training of students and research associates, and leadership activities (e.g., the NRC's *Quarks to the Cosmos* Report and the report of the DOE/NASA/NSF *Dark Energy Task Force*).

Taken together, the particle astrophysics programs at FNAL and UChicago are widely considered the world's leading research effort at the interface of particle physics with cosmology.

A vigorous particle astrophysics program at FNAL is crucial to achieving the scientific goals of elementary particle physics and the intellectual vitality of FNAL in fundamental physics (***Figure 3.a–8***). The FRA vision for particle astrophysics at FNAL is to:

- Successfully complete the particle astrophysics projects already in place
- Initiate new programs and/or projects that address the most compelling scientific questions as part of a vibrant on-shore national program during the LHC era
- Plan for longer term projects that will complement the scientific agenda of the ILC and continue US world leadership in particle astrophysics

Scientific goals driving this particle astrophysics program are central to DOE's mission in fundamental physics and have been emphasized in EPP2010 and other planning documents:

- Directly detect the dark matter particles that comprise the dark halo of our own Milky Way galaxy

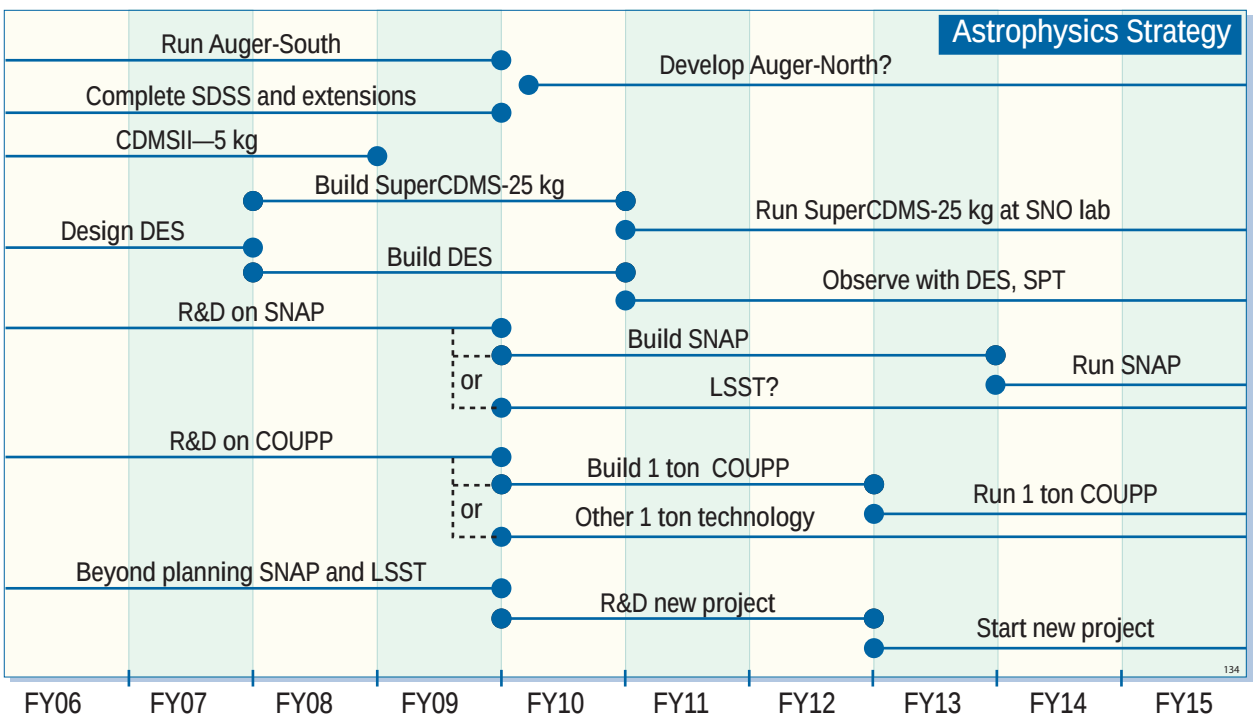

Figure 3.a–8. FRA's Timeline for the Exploration of the Astrophysics Strategy.

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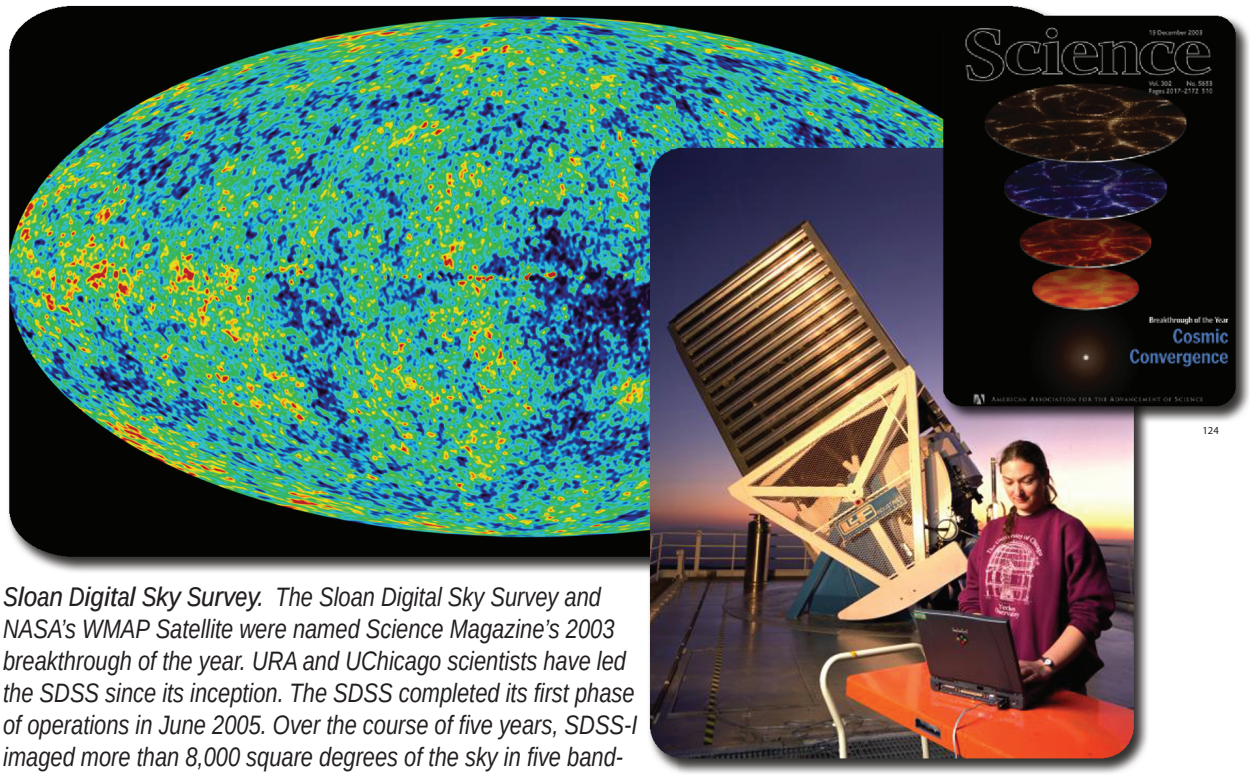

Sloan Digital Sky Survey. *The Sloan Digital Sky Survey and NASA's WMAP Satellite were named Science Magazine's 2003 breakthrough of the year. URA and UChicago scientists have led the SDSS since its inception. The SDSS completed its first phase of operations in June 2005. Over the course of five years, SDSS-I imaged more than 8,000 square degrees of the sky in five band-passes, detecting nearly 200 million celestial objects, and measured spectra of more than 675,000 galaxies, 90,000 quasars, and 185,000 stars. Data have supported studies ranging from asteroids and nearby stars to the large-scale structure of the universe.*

- Understand the role that dark matter played in shaping the structure of our galaxy and of the entire Universe
- Elucidate the properties of the mysterious dark energy that is causing the expansion of the Universe to speed up
- Test the theory of cosmic inflation and shed light upon the physical mechanism of inflation
- Use nature's highest energy particles to probe the unification of the fundamental forces and particles of nature

FRA's strategy to achieve these ambitious and important science goals central to DOE's mission in fundamental physics contains the following elements:

Strategic Element 1. *Make the Particle Astrophysics Center at FNAL the world's leading center for particle astrophysics, with strong ties to UChicago and other local universities and synergistic partnerships with other DOE Laboratories (ANL, BNL, SLAC, and LBNL)*
Director Oddone has restructured the Particle Astrophysics Center and has elevated its position within the organization. To strengthen ties between UChicago and FNAL, and to attract a world-class scientist to lead the Particle Astrophysics Center, FRA will establish a joint senior position in astrophysics. One or more joint hires with UChicago and other local institutions at the junior, tenure-track level will also be initiated. The new head of the Particle Astrophysics Center will initiate a strategic planning process for particle astrophysics at FNAL. While the detailed elements of the strategic plan will emerge from that process, it will build upon the strong programs in theoretical and experimental particle astrophysics and will include further strengthening ties with UChicago, establishing new connections with ANL and other local universities, and creating partnerships with other DOE laboratories active in particle astrophysics (especially SLAC and LBL).

FRA New Initiative 15

Strategic Element 2. *Complete the strong program in place while planning for and initiating the Dark Energy Survey and SuperCDMS-25*
Once complete, the strong experimental particle astrophysics program now in place—CD-

MSII, Auger South, and SDSS-II—will lead to significant progress in addressing all of the scientific goals underlying the particle astrophysics program. The Dark Energy Survey (DES) has significant non-DOE funding in place and recently received the endorsement of the HEPAP P5 sub panel to move forward to construction. DES will use clusters, baryon acoustic oscillations, weak lensing, and supernovae to push the limits of what can be learned about dark energy in the intermediate term. SuperCMDS-25 is a scaled-up version of CDMSII—25 kg of active detector—designed to operate in the Sudbury Laboratory (SNO). It will extend sensitivity to supersymmetric dark matter candidates by more than an order of magnitude. It too has received the endorsement of P5 to proceed and is in the process of getting its joint NSF/DOE funding in place.

Strategic Element 3. *Work with DOE and other National Laboratories to create a coherent national program in particle astrophysics that addresses the most pressing scientific questions and provides the infrastructure and project management needed to enable university researchers to participate in large-scale particle astrophysics projects*

Particle astrophysics has become a significant facet of the DOE mission and is critical to addressing the most compelling questions and realizing the most exciting opportunities in elementary-particle physics. In addition to FNAL, two other DOE laboratories have strong programs in particle astrophysics: SLAC, through its recently created Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) and LBNL, through its involvement in IceCube and SNAP.

Other laboratories, including ANL, LLNL, BNL, and LANL, are involved in particle astrophysics or have aspirations to be so. Under FRA's leadership, the FNAL Particle Astrophysics Center will work closely with DOE and the other DOE laboratories to achieve a coherent program whose whole is greater than the sum of its individual pieces in furthering the DOE mission, and one which enables university researchers to be involved in projects beyond the scale accessible to individual universities.

Strategic Element 4. *Strongly support the DOE candidate (SNAP) for the Joint Dark Energy Mission*

The Joint Dark Energy Mission is critical to understanding the nature of dark energy. FNAL is a major member of SNAP, the DOE candidate for the JDEM. FNAL is playing leadership roles in electronics, data storage, cosmic ray shielding, simulations, and photometric calibration, and is exploring a major leadership role in CCD packaging and testing. In conjunction with LBL (the lead laboratory for SNAP/JDEM), FRA will work to make SNAP the successful candidate for JDEM, and thereafter to successfully implement the mission and realize the spectacular science.

Strategic Element 5. *Identify and initiate a project or program that is complementary to JDEM and the ILC and consistent with DOE's mission during the LHC era*

Central to a strong on-shore national program during the LHC-era as well as to advancing the DOE mission in fundamental physics is the initiation of one or more major Particle Astrophysics projects during the LHC era. FRA will carry out planning for and participate in such a project in the context of the strategic plan developed by the Particle Astrophysics Center. Candidates for such a project include: Auger North; a CMB Polarization experiment (e.g., a space mission), aimed at detecting gravity waves from inflation; involvement in another major dark energy experiment following DES (e.g., LSST); and experiments in the Deep Underground Scientific and Engineering Laboratory that NSF is planning to create (e.g., a ton-class dark matter experiment, a novel dark matter detector along the lines of COUPP or a proton decay experiment). This experimental program would be complemented by a major new effort in computational cosmology aimed at advancing the understanding of the formation of structure and supporting the analysis of dark energy experiments.

Shaping the Program with DOE's Mission and an Evolving Advisory Structure

In addition to partnering with UChicago and other universities and engaging synergistically with other DOE Laboratories described above,

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the successful execution of FRA's Particle Astrophysics strategic plan for FNAL will require working effectively with the various advisory committees which provide community input, guidance and oversight as well as DOE's Office of Science. The advisory and oversight structure for particle astrophysics is not yet as mature as that for accelerator-based particle physics and is a relatively new addition to the Office of Science's portfolio.

Two NRC reports provide the scientific vision and priorities: *Quarks to the Cosmos* and *EPP2010.* On the horizon and also potentially important is the upcoming NRC Decadal Survey for Astronomy and Astrophysics. Two other tactical documents are very relevant: the reports of the DOE/NASA/NSF Task Forces on CMB and Dark Energy. Among the relevant advisory bodies that must be involved in shaping the program are: HEPAP and its P5 sub panel, the primary FACA Advisory Committee for elementary particle physics; and the Astronomy and Astrophysics Advisory Committee (AAAC), which reports to DOE, NASA, NSF, and the Congress on the coordination of the three agencies' programs in astrophysics.

3.a.2 The Role of Theory and Computing in Support of FRA's Strategy

The aim of all science is to organize, systematize and refine our knowledge of nature into a set of tested fundamental principles. Theory and scientific computing are central to this program. Without a theoretical framework, experiment results cannot be interpreted and signals cannot be separated from "background." Without advanced computing the vast amounts of data generated by modern particle physics experiments cannot be analyzed; and, without simulation, modern complex detectors and accelerators cannot be designed, nor can theory progress far into fully nonlinear regimes.

Both theory and scientific computing have an important existence in their own right. Theory provides the foundation for understanding the data, for guiding the next generation of experiments, and for providing the motivation for new experimental directions. Without theory, there would be no standard model of particle physics

Theory and Computing in Support of FRA's Strategy

Theory and scientific computing are FNAL core competencies that are critical to achieving FRA's science goals for FNAL. Within the scientific strategy, they are both critical in support of achieving the scientific goals and important scientific endeavors in their own right.

and no hunt for a Higgs particle. The search for new physical phenomena at the energy frontier, and with it a deep understanding of nature, is motivated and guided by well-defined theoretical theories—supersymmetry, extra dimensions, and unification of the forces. Likewise, astrophysical theory plays a critical role in analyzing CMB data and the large-scale structure to extract physical parameters and to understand the early evolution of the Universe. Theoretical studies in cosmology have been central to designing and optimizing the return from experiments—e.g., CMB anisotropy experiments and the Sloan Digital Sky Survey (SDSS)—as well as motivating and guiding the search for new phenomena including dark energy and particle dark matter.

Computing plays an even more integral role in the science of FNAL: accelerator design and tuning relies increasingly on simulations and our understanding of modern detectors (and thus both their design and their operation) is commonly based on simulation of detector response. The output of the present and planned HEP detectors can only be dealt with by using massive parallel computers to reduce and analyze the vast data streams. Quantitative experimental predictions of modern particle theory using lattice gauge calculations rely entirely on massive parallel computations. Modern astrophysical and cosmological research relies on computations to deal with the experimental reduction and analysis of the data (such as from the SDSS) and theoretical predictions of, for example, structure formation derived from cosmological models, Type Ia supernovae light curves and spectra, and quantitative properties of the diffuse cosmological microwave background. Thus, computations are key both to the design, construction and operation of the experiments, and to the quantitative connection between experimental and observational results and theory.

FRA will leverage its core competencies in theory and scientific computing in support of its strategic science thrusts—energy frontier, neutrinos and particle astrophysics—through the following strategic actions:

Strategic Element 1. Build upon the fundamental theory and phenomenology strengths at FNAL (including our leadership in lattice gauge theory) through national and international collaborations and the partnership with UChicago, the other local Illinois universities, and ANL to enable the most powerful attack on the three frontier areas of discovery science: understanding the energy frontier science at the Tevatron, LHC and the ILC; connecting the result of neutrino experiments to the underlying grand unified theories; and understanding dark matter and dark energy will bring breakthrough gains in our understanding of matter, energy, space and time.

Strategic Element 2. Build upon the astroparticle strength at FNAL, and strengthen the synergies between particle and astroparticle theory, through collaboration and partnership with UChicago, other local Illinois universities, ANL, and other institutions to support the analysis of current astroparticle experiments, and spark new directions for experiments. The connections of astroparticle theory to experimentation, to advanced computing and data mining, and to particle theory are essential components to realize the scientific opportunities that lie at the interface of particle physics and astrophysics.

Strategic Element 3. Build upon FNAL's current strengths in scientific computing by partnering with the leadership computational capabilities already in place and now being further developed at ANL to develop the scientific computational capabilities for carrying out analysis and simulations in support of current and future experiments. The world-class Tier 1 Computing Center, enhanced Grid computing, powerful simulation and analysis environments, scalable data management systems, and a secure networking and computing infrastructure will make FNAL the center for data analysis in the LHC era and a powerful contributor to the US particle and astroparticle theoretical and experimental efforts.

Strategic Element 4. Leverage FRA's abilities through URA and UChicago to involve universities across the US and around the world to enhance FNAL's role as a world center for particle and astroparticle theory through visitor programs, summer schools, and graduate education.

3.a.3 Risks and Mitigations Related to FRA's Long-term Strategy

The highest risk to the US program would be to *not* pursue the ILC, since this would abdicate leadership in the field and undermine American competitiveness. The opportunities offered by the ILC are great, and place the ILC in a central role for the US particle physics future.

FRA's basic strategy to mitigate the risks connected with the ILC is to have a varied program of research beyond the ILC that provides exciting physics results while the R&D for the ILC is carried out, and later while the construction is taking place. This complementary program must provide the possibility for exciting physics results while maintaining large resources devoted to the ILC development.

Our second basic strategy to mitigate risks is the hiring, retention and development of a world-class staff that has the flexibility to adapt to the changing circumstances of the field. The partners in FRA are committed to make FNAL and the Northern Illinois region the most attractive for particle and accelerator physics. The steps that FRA is taking in this connection are explained in greater detail in ***Section 4.a.1***. Beyond these basic strategies, FRA has established a set of strategies to mitigate the risks specific to the ILC. These risks occur on sev-

Risks and Mitigations Related to FRA's Long-Term Strategy

FRA will mitigate the risks associated with its ambitious long-term aspirations for FNAL by attracting and retaining the best scientific talent to maintain innovation, by supporting a broad program of discovery science and by developing a set of specific measures to mitigate the ILC risks.

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eral fronts: physics, technical, organizational, financial and international ***(Figure 3.a–9)***.

3.a.4 Understanding the Laboratory's Current Capabilities and Core Competencies

FRA is in the best position to optimize FNAL's scientific output. We will build on the solid core competencies established by URA at FNAL over the past four decades. URA today has developed at FNAL the most complex and challenging accelerator complex in the world. URA has demonstrated that it can overcome major difficulties. For example, support from university and laboratory-based experts in its major advisory and oversight councils, such as the expertise provided by URA partnering institutions, allowed FNAL to resolve challenges in the Tevatron Run II operations. The added bench strength provided by UChicago and ANL will greatly enhance this ability.

FNAL's Current Capabilities and Core Competencies

FRA will leverage our parent organizations' core competencies in scientific research and the design, construction, and facilities operations that support particle physics research and URA's in-depth experience at FNAL to strike an optimal balance between research and technology in support of the DOE mission.

FRA will nurture established core competencies that are needed to satisfy the strategic

FRA Mitigation Approach	Impact / Value
Risk—Physics reach is too low at 500 GeV after the results of LHC are known	
Design a machine that is extendable to 1 TeV with the same SCRF technology; implement vigorous development program to lower cost of the superconducting Linac; maintain a low-level program of R&D towards future lepton colliders at energies greater than 1 TeV	Low-cost solutions for SCRF technology will enable a number of different machines to be built economically; the R&D on future lepton colliders will be useful if the energy needs to be higher than 1 TeV and, in any case, it will be needed as a follow-on to the ILC.
Risk—Technical risk that the gradients will not be achieved	
The greatest unknown at present is whether the voltage gradient specified for superconducting cavities is realistic. To mitigate this risk, we will maintain FNAL's collaborations with universities and laboratories to study the material science of niobium surfaces to understand the ultimate limits on the gradient.	Building broad collaboration with universities (presently Cornell, MSU, and Penn, and expanding to Northwestern and UIllinois), ANL and other national and international laboratories brings a broad technical base to solve ILC problems; it provides the basis for development of future accelerators.
Risk—Budgetary risk that the ILC is considered too costly	
The first internationally agreed-upon cost estimate will exist at the end of 2006 with the completion of the RDR. FRA's strategy is to be deeply involved in the costing study. Presently, an FNAL physicist leads this study, and numerous FNAL engineers work on it. Beyond understanding the present cost, FRA will continue a vigorous R&D program to lower costs of the Linac and associated technology.	FRA is leading the preparations to industrialize the technology of the most expensive components. If a high cost estimate delays the project, FRA is carrying out R&D on high intensity proton sources that could be coupled with an ILC-like Linac to produce an intense beam of protons; this would permit the development of technology while producing a scientific machine for neutrino physics and rare decays.
Risk—Political risk concerning opposition in the community for excavating tunnels beyond the site boundary	
Be completely open and transparent with the surrounding communities regarding all ILC activities. In particular, continue URA's practice of establishing a community task force to advise the laboratory in its interactions with the community.	Continued strong, two-way FNAL relationship with local community to facilitate ILC siting near FNAL; utilize local universities to develop a broad outreach program.
Risk—Organizational and international risk that a great delay ensues as a result of protracted negotiations on organization and financing of the ILC	
Closely monitor and participate in the international and organizational negotiations; propose physics initiatives of a smaller scale that do not affect the ultimate outcome of the ILC, yet provide physics results while the world waits for the ILC.	Smaller efforts like DES and SuperCDMS-25, and the neutrino efforts in NOvA and MINERVA, would produce important physics opportunities while the world waits for the start of the ILC.
Risk—Cost and schedule risk of a major construction project	
FRA strategy is to engage the Office of Project Management Oversight to train project managers and help implement quality and best practices.	Culture of quality and responsibility that, coupled with technical depth and project management experience, provides assurance of success in the construction of facilities.

Figure 3.a–9. ILC Risk Mitigation. Our approach provides DOE with the highest level of assurance that the laboratory's long-term physics, technical, budgetary, and other risks are identified and managed.

plan. It will use the OHAP process described in ***Section 4.a.1*** to match the needs of FNAL programs to the personnel requirements. In the sections below, we show how the existing core competencies support FNAL's strategic plan, and we point out where additional strengths must be developed.

FRA's analysis shows two areas where there is a clear need for strengthening. The first is to develop a core competency in SCRF R&D. The second is to build a stronger core competency in advanced accelerator R&D.

FRA's strategy to enable scientific inquiry leverages FNAL core competencies:

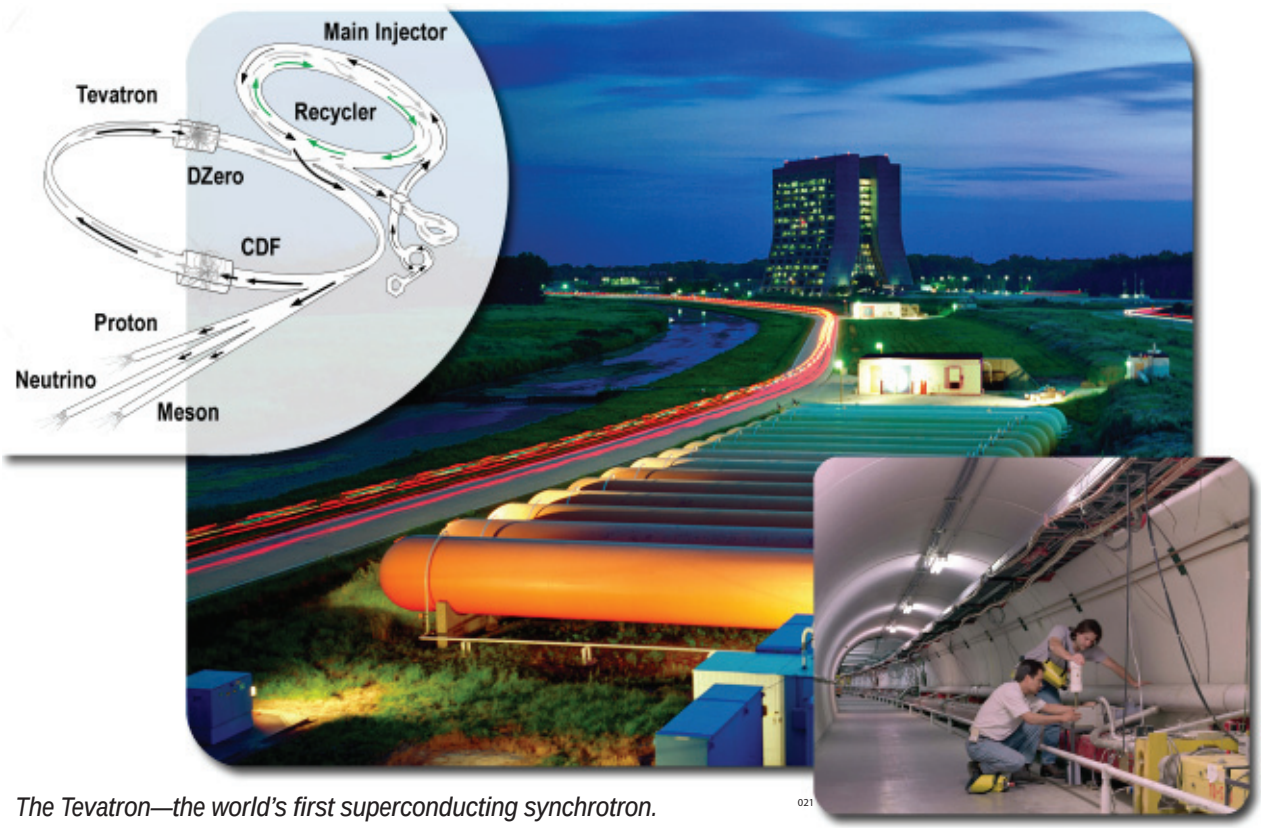
- Construction and operation of accelerator facilities for particle physics
- Construction and operation of experimental facilities for particle physics and particle astrophysics, including user support
- Research, design, and development of accelerator technology
- High-performance scientific computing and networking
- International scientific collaboration
- Theoretical particle physics and astrophysics
- Management expertise and experience capable of completing large scale, technically complex scientific projects within their specifications, on schedule, and on budget
- Proven ES&H program that protects employees, subcontractors, visitors, and the environment

3.a.4.1 Capabilities and Core Competencies in Study of the Energy Frontier

This area is the most challenging, both technologically and operationally, yet it holds by far the greatest promise for revolutionary discoveries. This area also exercises and stretches nearly all the core competencies of the laboratory. Access to UChicago and ANL technical expertise and infrastructure improves the ability of FNAL to solve complex technical and management problems.

Tevatron Run II

At Run II, FNAL is engaged in operating the current accelerator complex to provide colliding proton-antiproton beams at the highest



The Tevatron—the world's first superconducting synchrotron.

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Tevatron Run II Capabilities/Functions	FRA Focus/Notes
Construction and operation of accelerator facilities	❖ Assure reliability of Tevatron operations to maximize the integrated luminosity ❖ Perform an extensive analysis of systems and system failures when they occur to optimize the effective operational time ❖ Maintain URA's proven record of operating this complex facility (i.e., 9 accelerators and 200,000 controllable elements) ❖ Apply FRA continuous improvement process to optimize performance
Construction and operation of experimental facilities	❖ While the detectors are now completed, the exploitation of the detectors requires high reliability and quality control to ensure the integrity of the data ❖ The collaborations and the laboratory have demonstrated their command of this issue, producing results within a few months after the completion of a data taking run
Research, design, and development of accelerator technology	❖ Although Tevatron operations are now routine, further improvements in the instantaneous luminosity by a factor of 50% to 100% are both possible and desirable ❖ Improvements in the stacking rate of antiprotons is still a challenge in the development of the machine and a limiting factor; expertise developed in this area over the years will be essential in addressing this challenge
High-performance scientific computing and networking	❖ By the time the Tevatron Run II is completed, there will be a factor of 5 more data; this will present a very large challenge in computing, with farms providing many teraflops and storage requirements of many petabytes ❖ Analyze data across the broad international collaboration to maintain optimal productivity, enhanced by the great expertise in distributed and grid systems developed by URA and by UChicago at ANL
International scientific collaboration	❖ Adopt URA's successful model for international collaboration—e.g., the large foreign component in DZero and CDF ❖ In addition to the hardware and personnel contribution of the many foreign institutions, the International Financing Committees for both experiments plan for common items of support
Theoretical particle physics and astrophysics	❖ Underpinning the many measurements and discoveries at the Tevatron, there is a deep understanding of the possible signals and the many backgrounds introduced by Quantum Chromodynamic interactions ❖ URA has developed at FNAL the foremost phenomenology group in the world in the study of hadronic interactions—FRA will build on this foundation
Proven ES&H program that protects employees, subcontractors, visitors, and the environment	❖ Safety is key for the success of CDF, DZero, and Tevatron operations. FRA will maintain and continuously improve FNAL's outstanding ES&H record achieved under URA management

Figure 3.a–10. Optimizing Tevatron Run II. FRA's approach maintains high levels of operating efficiency with fewer resources.

energies and intensities in the world. FRA will be responsible for maintaining the effective and safe operation of the two experiments that utilize CDF and DZero.

Successful completion of these experiments will depend upon maintaining these performance standards despite additional budget constraints and the imminent conclusion of the project. FRA will:

- Implement the recommendations of the Joint CDF/DZero Task Force at the laboratory and engage the DOE, NSF, and international sponsors on the recommendations made by the task force for action by the agencies
- Incorporate lessons learned by UChicago, at ANL and elsewhere, about facilities transition
- Implement recommendations from our industrial subcontractor EG&G/URS based on benchmarking commercial best practices
- Retain the outstanding Run II Team through processes and procedures described in ***Section 4.a***—first to complete the Tevatron program and then to transition to the LHC and ILC.

Understanding the functioning of experiments and personnel requirements can only be derived from the in-depth, day-to-day expertise developed in operating these experiments.

FRA will apply FNAL capabilities to successfully complete the Tevatron program (***Figure 3.a–10***).

LHC

The US, and FNAL in particular, are significant participants in the LHC project at CERN. FNAL's role has been to:

- Lead the construction of the US contribution magnets for the accelerator, in particular the "low-beta" quadrupoles that focus the beams onto the collision point
- Serve as the host laboratory for the US participation in the CMS experiment, including the construction of key detector components and participation in the CMS experiment and data analysis

Looking forward, FNAL will also serve as the US "Tier 1" computing center, the major computing center in the US for the support of CMS. Associated with this effort, FNAL will support a number of Tier 2 centers in the US and will provide key personnel and leadership to the global software effort for CMS. FRA will develop the LHC Physics Center (LPC) as part of the CMS center to support US involvement in the computing and data analysis and to promote US contributions to final publication of results.

Through active LHC participation, DOE will retain a role at the energy frontier for the experimental community in the US once the Tevatron is eclipsed and before the ILC comes online. Early physics results at the LHC will reinforce the case for the ILC. Discoveries at the LHC will provide the foundation for further discoveries at the ILC. Demonstrating our critical involvement in the LHC is important to convince the world particle physics community that the US will be a worthy and successful host for the ILC. FRA will apply the laboratory's capabilities to actively support the LHC (***Figure 3.a–11).***

LHC Quadrupoles. Assembly of LHC low-beta quadrupole magnets at the industrial center building. 080

GDE/ILC Accelerator R&D

UChicago and URA both have long experience in developing and siting accelerator facilities (e.g., the Tevatron, Main Injector, and APS). FRA, supported by our parent organizations, thus has the expertise necessary to prepare a bid-to-host for an ILC sited at or near FNAL. The initial phases have involved close coordination with the Global Design Effort both in the costing study and in the initial design of the accelerator. The Reference Design Report (RDR), to be delivered at the end of 2006, will set the stage for further developments in the ILC R&D program.

Following the decision to unite the world's efforts behind the Tesla-developed technology, there is a massive redirection of the US effort in SCRF technology. In response to this development, FRA will continue to build the expertise needed for FNAL to be a major contributor to the ILC—and, in particular, to serve as the host laboratory. Developing a core competency in SCRF R&D and engineering is a principal goal for FRA. FRA will also exploit the long-standing capabilities developed by UChicago at ANL in the processing of superconducting cavities, and FNAL's cryogenic expertise and infrastructure, a legacy from 25 years of Tevatron construction and operations. FRA will manage the FNAL/ANL collaboration through the R&D Working Group under our LCC (described in ***Section 3.a.3.1***).

To carry this accelerator R&D forward, FRA will develop collaborations both nationally and internationally to bring the best talent to bear on the many complex issues presented by the design of the ILC. Nearly all the core competencies of FNAL will be involved in the development of the ILC, as shown in ***Figure 3.a–12.***

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LHC Capabilities/Functions	FRA Focus/Notes
Construction and operation of accelerator facilities	❖ Apply FNAL's unique expertise in operating high-energy hadron colliders ❖ Particularly important will be the understanding of machine protection systems, since the stored energy of the LHC beams is 300 times larger than that of the Tevatron
Construction and operation of experimental facilities	❖ Apply the experience and insight gained in the construction of CMS—a successful project that has met CD-4 requirements—to future detector upgrades ❖ FNAL's expertise on silicon detectors is now crucial to finish the central pixel detector
Research, design, and development of accelerator technology	❖ Continue to improve LHC luminosity so as to keep the doubling time for integrated luminosity short ❖ Develop state-of-the-art Niobium Tin superconducting magnets to improve the focusing of the LHC beams and increase the luminosity beyond its original design
High-performance scientific computing and networking	❖ Integrate the resources at FNAL with other national and international resources to provide the most advanced capabilities anywhere in the world ❖ Apply the expertise developed by URA and by UChicago at ANL over the years to integrate and optimize this function
International scientific collaboration	❖ LHC is by far the most international science project ever undertaken; URA's experience in maintaining and enhancing international collaborations gives the laboratory the experience to be effective collaborators, and to support other US collaborators, in this complex environment
Theoretical particle physics and astrophysics	❖ Elucidate the connection of discoveries at the LHC to cosmological mysteries like dark matter; the theoretical and astrophysics groups at FNAL will be a great asset in making the LHC Physics Center (LPC) a success at FNAL. FRA, with its connections with URA and UChicago, will further strengthen these groups
Management expertise in completing large-scale, technically complex science projects	❖ The CMS detector, the LHC, and further upgrades of the LHC are complex projects on which URA has demonstrated the ability to deliver on budget and schedule
ES&H program to protect employees, subcontractors, visitors, and environment	❖ Experience with CDF and DZero provides the basis for protecting FRA and other constituencies' workers on CMS

Figure 3.a–11. Optimizing LHC Support. Through active LHC participation, DOE will retain a role at the energy frontier for the experimental community in the US.

3.a.4.2 Capabilities and Core Competencies in Study of Neutrinos

The laboratory is operating the NuMI beam and the MINOS detector to execute a detailed measurement of the recently established phenomenon of neutrino mass oscillations. Over the next few years, we will upgrade the existing proton source and add new detectors to maintain FNAL's position at the forefront of neutrino research.

The major items in this program are the upgrading of the Main Injector to have four times the power of the present beam and the development of the totally active NOvA detector. These programs are smaller in scope than the programs at the energy frontier, yet they require careful engineering and scientific analysis. Many of the laboratory's competencies will be involved (***Figure 3.a–13).***

3.a.4.3 Capabilities and Core Competencies in the Study of Particle Astrophysics

For the last two decades, FNAL has had a leading program at the interface of particle physics and astrophysics. The Sloan Digital Sky Survey has produced a remarkable data set used by the world-wide community, leading to many important discoveries such as the measurements of baryon oscillations. The Pierre Auger observatory, in which FNAL and UChicago have played a leading role, is successfully assembling the largest sample of the highest energy cosmic ray showers. The astrophysics theory group has set the agenda in cosmology, developed the techniques to test

GDE/ILC Accelerator R&D Capabilities/ Functions	FRA Focus/Notes
Construction and operation of accelerator facilities	❖ Building in reliability and ease of repair from the beginning will be an important component of the design of the ILC ❖ Apply URA's in-depth experience at FNAL over the past decade in the operation of the most complex set of accelerators ever
Construction and operation of experimental facilities	❖ Important challenges to the design of detectors, which include obtaining the maximum position resolution from vertex detectors, high momentum resolution from tracking devices, and accurate calorimetry using particle flow algorithms ❖ In collaboration with national and international partners, apply the formidable detector capabilities developed by URA at FNAL to the design of the experimental program and develop the foremost beam test facilities using the Main Injector beams into the Meson Hall
Research, design, and development of accelerator technology	❖ Exploit the expertise of FNAL's Technical Division in the industrialization of components as an essential part of the US effort ❖ Build expertise in Superconducting RF to fill the gap that now exists in the US program compared with other international efforts
High-performance scientific computing and networking	❖ Solving challenges for the LHC will position FNAL to deal with ILC data acquisition and analysis ❖ Ensure that maximum efficiency is possible despite potentially high electromagnetic backgrounds by exhaustively simulating the interaction area and the detector ❖ Capitalize on the grid technology expertise that URA and UChicago have developed at FNAL and ANL, respectively, as an essential component of this international effort ❖ Apply simulation efforts to the accelerator proper, exploiting FNAL's participation in the advanced accelerator simulation initiative (SciDAC initiative)
International scientific collaboration	❖ Over the years, URA has developed a successful model for international collaboration, with a large foreign component in CDF and DZero and with major participation on the LHC—both in the accelerator and detector areas ❖ Leverage UChicago and URA experience as international partners to help bring together the world collaboration behind the ILC
Theoretical particle physics and astrophysics	❖ Simulate the measurements that are possible in the ILC, both in terms of possible physics models and detector performance—connecting possible observations with fundamental models
Proven ES&H program that protects employees, subcontractors, visitors, and the environment	❖ Safety is key to the success of an international enterprise where many partners must have full confidence in the ES&H program established in the US if we host the machine ❖ URA's successful ES&H program at FNAL will serve as a model for the ILC ❖ URA and UChicago expertise in tritium and with radionuclides produced by beams will be essential in assuring government agencies and the local community that our operations are safe—this is especially important for a machine like the ILC, which will dump beams of 20 megawatts underground, an unprecedented level of beam power

Figure 3.a–12. Optimizing GDE/ILC Accelerator R&D. UChicago and URA will apply our expertise in developing national and international collaborations to tackle the myriad complex issues associated with the design of the ILC.

the theoretical framework, and determined cosmological parameters.

The future experimental programs will concentrate on dark matter and dark energy. FRA is proposing experiments like DES and CDMSII that are an economical way to make great progress in this area. Much more ambitious projects will follow after extensive R&D.

FRA's strategy is to develop modest, yet significant initiatives that take advantage of FRA's great physics reach without interfering with the extraordinary budget requirements of attacking the energy frontier. In developing this program several key core competencies come into play ***(Figure 3.a–14)***.

3.a.5 New Directions and Solutions to Major Challenges

FRA will build on the strengths of the existing FNAL program and staff to create a vibrant future. Our strategy focuses on three inter-

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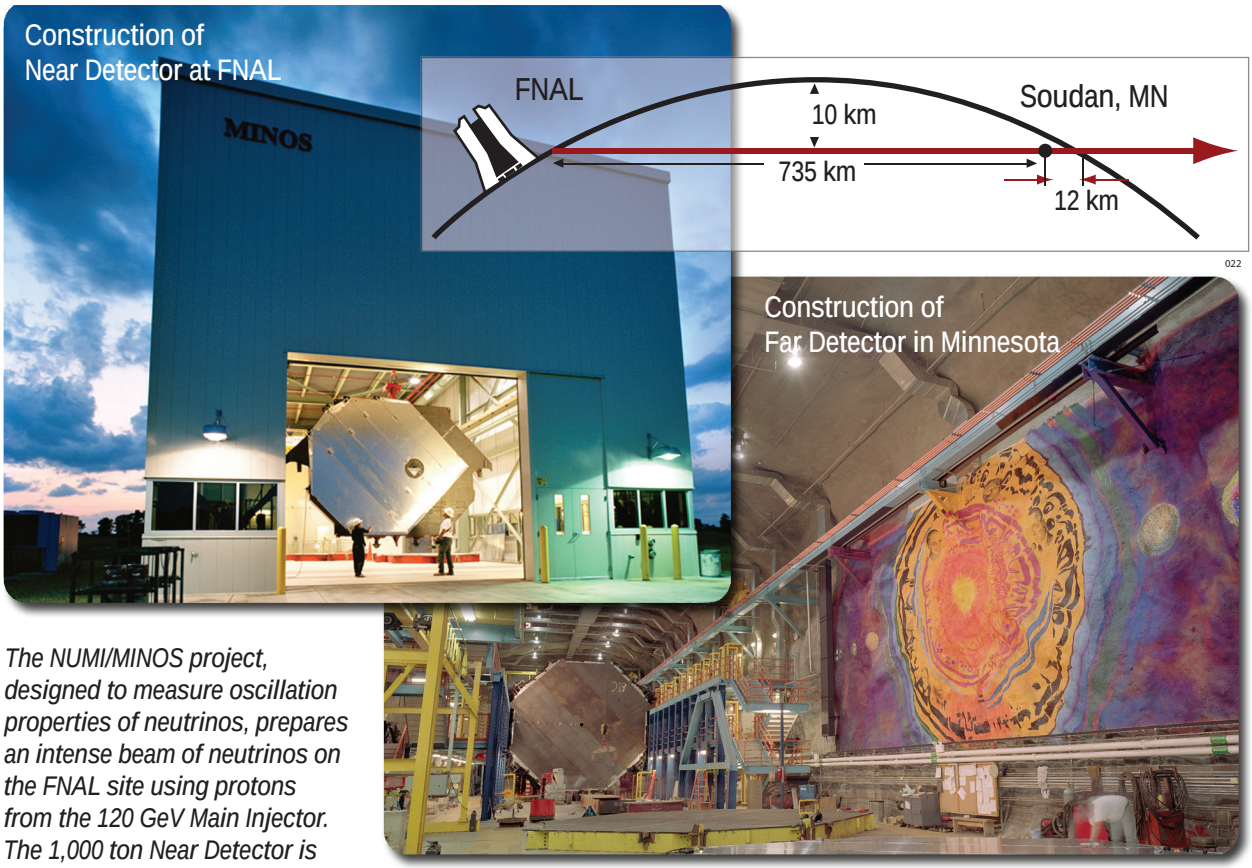

The NUMI/MINOS project, designed to measure oscillation properties of neutrinos, prepares an intense beam of neutrinos on the FNAL site using protons from the 120 GeV Main Injector. The 1,000 ton Near Detector is located in a new cavern 300 feet below grade at FNAL, while the 6,000 ton Far Detector is located in a new cavern in a deep iron mine 735 KM away in Minnesota.

related programmatic challenges that require new directions:

- Provide leadership in investigating and understanding physics at the TeV scale where the Standard Model is known to be incomplete and where new phenomena are sure to appear
- Provide leadership in the study of the properties of the neutrinos, including measurements of their mass differences and mixing and possible CP violation (i.e., the difference between neutrino and anti-neutrino properties)
- Provide leadership in the particle astrophysics program that addresses the most exciting areas in the study of dark matter, dark energy and the evolution of the universe.

3.a.5.1 New Directions and Solutions to Major Challenges in Study of the Energy Frontier

FRA will provide leadership in investigating and understanding physics at the TeV scale by attracting a critical mass of researchers to FNAL to build the most productive energy frontier center in the world. To take advantage of these opportunities, FRA plans to:

- Successfully complete current Tevatron experiments
- Be a major contributor in the LHC program, both to lend key expertise to the project and to establish the basis for truly international (rather than merely regional) collaboration in the construction and operation of a major accelerator and its experiments

New Directions and Solutions to Major Challenges

FRA offers a prioritized strategy that focuses on solutions to major challenges, which will yield the greatest potential for scientific discovery in support of DOE missions. Led by the Deputy Director, and involving broad participation of the particle physics community, the FNAL strategic plan will be a living document, constantly adapting to and optimizing the national program.

Neutrino Program Capabilities/Functions	FRA Focus/Notes
Construction and operation of accelerator facilities	❖ Modifications to the accelerator complex to produce increased beam power are technically challenging but of relatively modest scale ❖ Expertise developed over the years by URA at FNAL with high power proton beams will ensure that FRA delivers on this project
Construction and operation of experimental facilities	❖ The NOvA detector is massive but technically less complex than CDF, DZero, or CMS ❖ URA at FNAL has developed detector capabilities needed for this project ❖ The most important challenge is the mechanical engineering associated with building a 25-kiloton detector made of plastic tubes and liquid scintillator, for which we are well prepared
High-performance scientific computing and networking	❖ Computing requirements are modest compared to those for the LHC or Tevatron ❖ Development of pattern recognition that allows the determination of the right kind of interactions will be the primary challenge ❖ The challenge of developing the new software necessary is well within the capabilities already developed by URA at FNAL
International scientific collaboration	❖ Exploit URA's previously developed, successful model for international collaboration, especially with Italian groups supported by INFN that are now interested in NOvA ❖ Use FRA's international expertise to establish a broad collaboration to develop an international program as recommended by the EPP2010 Committee
Theoretical particle physics and astrophysics	❖ Optimize the placement of the detectors and the combined physics productivity of T2K and NOvA with necessary theoretical input ❖ Connect the observations to the underlying theories and determine the level of precision necessary in the various measurements ❖ The level of theoretical involvement at FNAL and in collaborating institutions is adequate
ES&H program that protects employees, subcontractors, visitors, and environment	❖ The neutrino program presents the most difficult safety and environmental issues with the most intense beams—many highly radioactive components in the target hall that have to be handled remotely and the production of radionuclides underground that must be controlled ❖ Maintain FNAL's successful ES&H experience in this area achieved under URA management

Figure 3.a–13. Optimizing the Neutrino Program. We will apply URA's experience to maintain FNAL's position at the forefront of neutrino research.

- Focus on regaining the energy frontier by becoming the site for the ILC
- Carry out a long-term accelerator R&D program towards multi-TeV lepton colliders

The most important challenge associated with the Tevatron is to maintain the smooth operation of the detectors and the accelerator as we prepare to close the machine. In the accelerator arena FRA's initiative on hiring and retaining the best personnel ***(Section 4.a)*** will allow FNAL to bring scientific and technical help as the requirements of the Tevatron evolve. FRA will carefully monitor the scientific and technical needs of the Tevatron to ensure effective operation. These include the requirements of high luminosity at the Tevatron, and the effective accumulation and analysis of data by the detector collaborations. URA and UChicago bring vast experience to these tasks since they have operated complex facilities (Tevatron, CDF, DZero, APS, ANL's ATLAS, UChicago Hospital) with demonstrable success. In addition, Director Oddone has established an International Fellows program to bring scholars from many countries to both exploit the current opportunities at the Tevatron and to establish long term collaborations. FRA will implement recommendations of a CDF/DZero task force on the requirements to maintain a productive physics program at the Tevatron.

The most important new direction for discovery will be with the LHC, and then with the ILC. These two accelerators, with their complementary capabilities, have the potential to revolutionize our understanding of the physical world. The challenges at the LHC are formidable. To achieve its goals, the LHC must achieve a very high luminosity with very intense beams. These beams carry an energy of 300 Mega Joules—enough to destroy a large section of the machine. Thus the reliability of the machine and its fail-safe systems

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Particle Astrophysics Capabilities/Functions	FRA Focus/Notes
Construction and operation of experimental facilities	❖ Non-accelerator facilities in this area pose challenging problems in ultra cold detectors (CDMSII) and in the modification of telescopes (the Blanco) ❖ Partner with institutions that have expertise in these areas (which are not common in high energy physics) ❖ Collaborate with these institutions to enhance our engineering and operational capabilities
High-performance scientific computing and networking	❖ Like SDSS, the DES project will produce massive amounts of data that need to be provided to the scientific community ❖ Partner with the NCSA at the University of Illinois to provide this data service and to utilize FNAL networking and data mining capabilities
International scientific collaboration	❖ Continue URA's work with the large international collaboration carrying out the Pierre Auger observatory—applying the leading expertise of UChicago in this area ❖ Partner with the NSF, and with British, Spanish, and Chilean agencies and university groups in the development of DES
Theoretical particle physics and astrophysics	❖ Theoretical input will be necessary to guide the observations and to interpret the results ❖ Close working relations with the theoretical astrophysicists makes the experimental program far more powerful—as it is guided by the principal needs of narrowing down the underlying models
Proven ES&H Program that Protects Employees, Subcontractors, Visitors, and the Environment	❖ Apply URA's and UChicago's proven ES&H programs to these experiments, which operate mostly remotely and in some cases deep underground

Figure 3.a–14. Optimizing Particle Astrophysics. We will continue to apply FNAL and UChicago leadership in this area—connecting and developing collaborations between the world-class groups at FNAL and UChicago.

will have to be extraordinary. FNAL contributes to the solution of these challenges as the lead laboratory for the US contributions to the LHC accelerator through LARP. FRA will work to support the collaboration with BNL, LBNL, and SLAC to bring US expertise to help commission and upgrade the LHC. The principal know-how anywhere in the world resides now at FNAL, since it is the only laboratory that has developed and operated a hadron collider in the past two decades.

Another major challenge is to ensure a vital role for the US HEP community in the exploitation of the LHC physics program. FRA will establish the LHC Physics Center as part of the CMS Center (discussed in ***Section 4.c***) to bring together a critical mass of scientists and technical support at FNAL to make it possible to contribute significantly from our remote site at FNAL. As part of this program, FRA will establish remote operation centers for both the accelerator and the detector. FRA will also work closely with ANL to make sure the grid infrastructure supports the US participation in both CMS and ATLAS. However, beyond the grid infrastructure this applies to all elements of common support that enhance the participation of the US community in the LHC. This will be a principal area of focus for the FNAL/ANL Laboratory Collaboration Council (LCC).

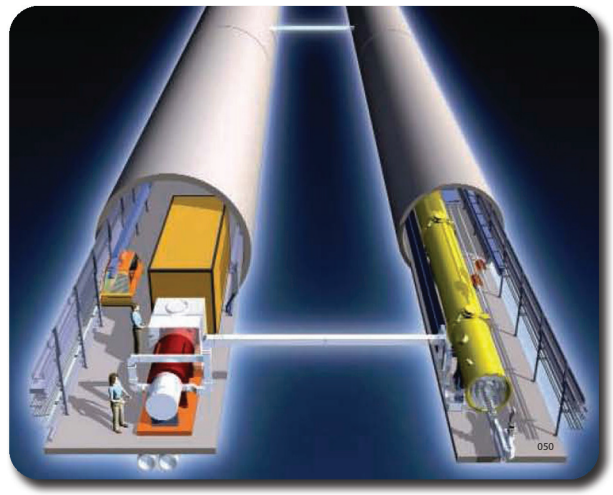
The major focus of FRA's strategy for FNAL is to position the US and the laboratory to host the ILC. The brilliant physics opportunities and reach of the ILC would allow the US to maintain a leadership position for decades to come. A large number of challenges exist in acquiring the ILC. FRA is in a unique position to address these challenges: we fully understand the capabilities of the laboratory, the human resources, and the assets existing at the site that can be applied to a successful bid-to-host; further, the participation of UChicago as manager of ANL brings the ability to coordinate programs across both laboratories to increase scientific productivity and to improve operations. This will create a larger base and make the region most attractive to host the ILC. This effort will also be a principal area of focus for the FNAL/ANL Laboratory Collaboration Council.

FRA provides DOE with the best opportunity to capture the world-class ILC project due to our:

- Parent organizations' experience in managing large, first-of-a-kind S&T projects
- Expertise in hosting international collaborations
- Expertise and existing skill base in designing and building accelerators and detectors
- Strong relationships with other US national laboratories that will need to be involved in the ILC construction
- Deep understanding of the laboratory's existing and needed skills to provide a match of personnel to the program challenges
- Unique ability to articulate and champion the scientific case for the ILC with governmental, academic, scientific, and industrial leaders and other stakeholders

FRA recognizes that DOE, and other government agencies play the key role in negotiating the details of this first-of-a-kind, international project to be hosted in the US. FRA also understands that it has a special role in supporting the agencies. FRA's role is to develop and enhance FNAL and its international collaborations and to be the primary driver supporting outreach and advocacy for the ILC with all US constituencies and international partners.

Finally, beyond the ILC lies the tantalizing possibility of reaching multi-TeV lepton-lepton collisions. FRA is launching an initiative to explore possibilities in this arena. One promising avenue developed in principle over the last few years has been the collision of intense muon beams that have been dampened using ionization cooling. The theoretical advance over the last couple of years has been in concepts to cool muon beams more rapidly, leading to the possibility of practical muon colliders. The present concepts would use ILC technology, in particular Superconducting RF technology at 1.3 Giga Hertz, just as that developed for the ILC Linac. This work will be carried out in collaboration with the Muon Collaboration that includes BNL, LBNL, many universities, and foreign partners. The Accelerator Physics Center will play a key role in gathering the resources, developing a strategy and implementing plans to develop long range plans in this area.



ILC. Deep underground and aiming at FNAL, the tunnels of the ILC would bring electrons and protons into collison at our present 6,800 acre site. This rendition shows the twin tunnels of one of the Linacs: one tunnel with the cryomodules and accelerating structures, and the other containing the klystrons, modulators, and electrical supplies that power the machine.

3.a.5.2 New Directions and Solutions to Major Challenges in the Study of the Properties of Neutrinos

FRA provides leadership in the study of the properties of the neutrinos, including measurements of their mass differences, mixings and possible CP violation by building the foremost neutrino detector now and working internationally to create the future global neutrino program.

Dramatic discoveries in the last few years have revolutionized our understanding of neutrinos. Primary among these discoveries is the observation of a non-zero neutrino mass by the presence of oscillations. Much remains to be discovered in this area, including the arrangement of masses, the transition between electron and muon neutrinos and CP violation. FNAL recently brought online a new neutrino beam and a new set of detectors aimed at making the most accurate measurements to date of the characteristics of neutrino oscillations. Over the next several years, operation of this beam, and the establishment of a new primary direction with a massive off-axis detector, NOvA, will keep FNAL and DOE's science program at the forefront of this field. FRA will implement new ideas for improvements to the existing accelerator complex to achieve

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higher intensities. The scale of these ideas is much smaller than the ILC, compatible with the higher priority effort to launch the ILC—yet reflective of the creativity and insight of the FNAL staff over the years in forging new scientific directions.

The main challenge of studying neutrinos is that they are very elusive. To overcome this elusiveness, one must use extremely powerful beams with the consequent challenge of dealing with highly radioactive environments and massive detectors and with the consequent challenge of being very expensive. FRA will continue efforts to establish an international collaboration to build the NOvA detector. This detector has unique features that make it possible to have a powerful combined program between the US and Japan. FRA will also continue working closely with the University of Minnesota, a URA-member university, to build the remote laboratory, and with the funding agencies to plan the project. Recently the Particle Physics Project Prioritization Panel (P5) has recommended a construction start for the project. FRA will apply the well-developed management expertise at FNAL (through the Office of Project Management Oversight (OPMO)) and at ANL to ensure that the project meets safety, technical, cost, and schedule goals.

Exploration of the world of neutrinos has led to surprising and astounding discoveries in the past and is likely to do so in the future. The new detector, NOvA, is more likely the beginning of a new phase than the completion of the neutrino program. There is a great challenge in planning and preparing for the future neutrino program beyond NOvA and the complementary T2K program in Japan. The National Academy Committee EPP2010 report calls for the internationalization of the future neutrino program. In order to plan future phases of the program, FRA will continue to carry out a joint study with BNL on long baseline neutrinos. This study will be expanded to include international partners.

Common to all future programs is the need for more intense neutrino sources. FRA is planning an R&D program in the development of effective, low-cost proton sources. It will build on the established, collaborative program with ANL, BNL and LBNL. Furthermore, it will participate in an R&D program for the development of intense cold muon beams suitable for a neutrino factory in collaboration with the international muon collaboration. Such a factory would be a global enterprise and would come as a result of an international plan.

3.a.5.3 New Directions and Solutions to Major Challenges in Studying the Connections Between Particle Physics and Astrophysics

Our astrophysics program addresses areas of overlap with particle physics by bringing together powerful experimental and theoretical groups to answer the main questions in making connections of “quarks to the cosmos.”

Profound connections exist between astrophysics and particle physics and together these provide great opportunities for discovery. At the earliest instances of the universe, the temperature was so high that only elementary particles could exist. At such high energies, it is believed that the laws of physics were particularly simple and “symmetric” and only later, when the universe expanded and cooled to much lower energies, did the various types of interactions take on the pattern of differences we observe today. Thus, particle physics is essential to our understanding of the origin of the universe. At the same time, astrophysical observations can constrain and inform the development of particle theory. Moreover, the observation of cosmic radiation can teach us about both particle physics and astrophysics, using experimental techniques and detectors drawn from both disciplines.

The principal new directions in this area are connected with the study of dark matter and dark energy. These studies are a major challenge since relatively few approaches exist. FRA’s solution to these challenges involves both the exploitation of accelerator-based experiments and the observation of the phenomena using non-accelerator techniques in a staged program.

The observation of neutralinos at the LHC could indicate that at least some of the dark matter is associated with low-lying supersymmetric states. The ILC, with its greater scope for measurements of the couplings of supersymmetric particles, could teach us that all the dark matter is a single type of relic supersymmetric particle—or it may prove the converse, that dark matter is made of multiple diverse components. Ultimately, it will be important to detect these particles directly. FRA has a well-developed strategy aimed at the direct detection of dark matter. In particular, FRA will develop SuperCDMS-25kg to explore the immediate region of supersymmetric WIMPS as may be discovered at the LHC. Following the development of SuperCDMS-25kg, FRA will explore new techniques that would increase the mass of detectors one to two orders of magnitude further.

The greatest challenge is to discover the nature of dark energy. The Dark Energy Survey will address the study of dark energy with terrestrial telescopes. FRA will develop DES to do the next level exploration of dark energy and to establish technologies that will permit subsequent more powerful experiments in the next decade—such as SNAP or LSST. FRA's expertise in international collaborations will be brought to bear on DES since this activity will take place using the Blanco 4m telescope at Cerro Tololo, Chile as part of a large international collaboration led by FNAL. Beyond DES major detectors like SNAP or LSST are a possibility.

UChicago has been an essential partner in establishing the pioneering particle astrophysics program at FNAL and now will be in a position to formally develop and oversee the program through its direct involvement in FRA. The strong connections between the two programs will be enhanced by the restructuring of the Particle Astrophysics Center. The center will be led by a preeminent particle astrophysicist. This recruitment will be performed jointly by FRA and UChicago's Astronomy and Astrophysics Department. The development of the UChicago/FNAL connection in astrophysics is a strong goal of FRA for the benefit of FNAL's future program.

3.a.6 Opportunities to Position/Strengthen FNAL's Role in Supporting DOE Missions

The 10 DOE Office of Science laboratories cover a broad range of scientific missions. To continue to be an integral component of the DOE system of laboratories, FNAL must perform as the central support for the particle physics mission of DOE and be managed to the highest standards. This involves both the development of a compelling national strategy and the execution of that strategy in an effective and efficient manner.

Our science strategy for FNAL keeps the laboratory vital by proposing and organizing goals that maintain our position as the leading HEP research center in the world. The FRA organization enables greater collaboration with ANL to establish a more coordinated and powerful approach to the challenges posed by high energy physics research. It also broadens the base for collaborations with other institutions nationally and internationally by adding the connections brought by UChicago to those currently established by URA. Our approach to position FNAL to host the ILC, while retaining a broad program aimed at answering the most pressing scientific questions in particle physics, allows DOE to play a key role in maintaining the High Energy Physics Program at the cutting edge worldwide. In addition, the project stretches accelerator technology, thereby creating opportunities in the development of other scientific opportunities within the programs funded by the department. FRA will pursue several major opportunities to strengthen FNAL's role in support of DOE missions.

Opportunity 1—Create the Base for the ILC in Illinois

It is critical to develop a bid-to-host that is attractive to our international partners. FNAL brings great assets as a site for the ILC with its extraordinary 6800-acre site and physical facilities, its great scientific and technical talent, and its excellent community relations.

An important component of a bid-to-host will be the investment of the State of Illinois and local communities in making an attractive home for the ILC. The State has a history of

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support and enthusiasm for FNAL from the earliest days of the laboratory. FRA will work closely with the State of Illinois and local communities to create an optimal base for a US bid-to-host the ILC—emphasizing the advantages of locating the facility in the Chicago area (***Figure 3.a–15***).

In particular, FRA will implement a strategy to develop the industrial base for SCRF technology in the US (discussed in ***Section 3.a.1.1***). As part of this industrial development, through the strong State support developed by URA and UChicago for the ILC, the Governor of the State of Illinois has submitted to the legislature in Springfield a budget supporting the construction of the Illinois Accelerator Research Center (IARC) at FNAL. This $35M dollar building would provide the research and testing facilities necessary for the laboratory to work with its partner universities, industries, and ANL in the industrialization of the SCRF technology. The initial funding for the design in the amount of $3M has been included in the Governor's submission for FY07 that starts July 2006. FRA will continue to leverage the connections of its affiliated organizations to promote the ILC to the State of Illinois towards obtaining further support.

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FRA, through UChicago, will leverage ANL's expertise in chemistry and material sciences—e.g., to produce the ultra smooth and pure surfaces necessary for high gradient cavities. In addition, FRA can capitalize on ANL's experience to industrialize cavity processing and in building cryo-modules. Strong collaborations are evolving in the design of the ILC itself between accelerator physicists and engineers at ANL and at FNAL. These collaborations are complementary to collaborations with the other laboratories and universities, and support a strong central role necessary for the ILC in the Illinois region.

The local universities in Illinois—UChicago, the University of Illinois, Illinois Institute of Technology, Northwestern University, and Northern Illinois University—are making major commitments to the success of FNAL in the form of joint faculty positions as well as financial commitments to the development of joint programs (see ***Section 8***). The Presidents of these universities will be members of the FRA Board of Directors. These financial commitments will be devoted initially to the participation of university faculty in the development of the ILC and related detectors, strengthening the links and support of the universities

Support from the Chicago Area's S&T Base
Chicago is the only major metropolitan area that has two major laboratories located within 20 miles of each other. This close geographical alignment provides great opportunities for collaboration between the two laboratories as the US seeks to become the host nation for the ILC. Both FNAL and ANL have expertise in accelerator technology. FNAL is home to a complex of nine different accelerators, while ANL operates the advanced photon source (APS), North America's brightest X-ray source, and other accelerator-based research facilities.

Support from the State of Illinois
The Illinois Governor has submitted a budget to the legislature that funds the construction of the Illinois Accelerator Research Center (IARC) at FNAL. This $35M building would provide the laboratories and testing facilities for FRA and our university and industry partners to capitalize on SCRF technology. Initial funding of $3M for the design was included in the Governor's budget submission for FY07.

*Figure **3.a–15**. FRA Support for an ILC Based at FNAL. Combining FNAL and ANL capabilities provides optimal leadership, resources, and capabilities to DOE and the international physics community.*

for FNAL and the ILC. These universities will greatly strengthen the connection of FNAL with the State of Illinois and will be advocates for the ILC.

Opportunity 2—Build Broad National Support for the ILC

An important element of the strategy to host the ILC is to develop broad national consensus in support of hosting the ILC that includes state and federal governments, academia, scientific communities, industry, organized labor and other stakeholders. The level of funding necessary for the ILC is large enough within DOE's SC that broad support is needed across the country from all of these interests. Our university partners are important institutions and will be a vital component of this campaign.

The support of such a broad constituency is crucial not only in raising the necessary financial support within the Administration and Congress but also for the support of the ancillary steps that the US must take to be a desirable host. For example, mechanisms must be developed to assure the partners in the ILC global enterprise of the enduring commitment of the US to the project. Another example is the necessity of arrangements for foreign scientists to easily come into the country to develop and use such a facility. In developing these national requirements, the universities will play a critical role because of their reach across the US and their existing relationships with state and federal government officials.

FRA will work closely to coordinate national efforts with the Linear Collider Forum of America (LCFOA). The Forum is an organization with more than 60 industries interested in participating in and contributing to the development of the ILC. Broad support from the industrial and commercial sectors will be necessary to sustain large investments by the nation to the ILC over the construction period. The State support for the Illinois Accelerator Research Center at FNAL, as a place to develop technology jointly with industry, is an important aspect of our connection with LCFOA.

FNAL's Role within DOE's System of Laboratories

FRA will ensure that FNAL's great human and technical resources in the area of accelerator physics, accelerator design, and accelerator operations are leveraged for the benefit of the DOE system of laboratories.

Another aspect of a coordinated approach will be the work of FRA with the Linear Collider Steering Group of the Americas (LCSGA) to ensure that there is a coherent and coordinated approach to outreach and advocacy across the nation.

3.a.7 FNAL's Role as an Integral Component Within DOE's System of Laboratories

FRA will maximize the role of FNAL as an integral component of the national laboratory system by bringing FNAL's competencies to bear on broad areas of DOE's mission.

Opportunity 3—Develop Central Role in Accelerator R&D

As the only DOE laboratory devoted solely to particle physics, FNAL will play a key role in future accelerator R&D programs that impact science beyond particle physics. The approach that FRA will take is to create broad national and international collaborations in various aspects of accelerator R&D. The HEP program in DOE has been, and is likely to continue to be, the principal supporter of accelerator R&D in the nation. As we look towards the future, there will be a shift from operational demands of existing accelerators to R&D on the ILC and superconducting RF technology, intense proton sources, and facilities at the limit of our imagination such as muon colliders.

The FRA strategy is to bring the best talent available through collaborations and to attract the best staff to the Accelerator Physics Center that will serve as a focal point for accelerator R&D. FRA will further develop our strong collaborations with other national laboratories and will work with DOE to establish cooperation to exploit the expertise of the entire federal system on the ILC project. Finally, FRA is well-positioned to attract university-based re-

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searchers, and those at national laboratories, in the US and worldwide, to the ILC project and future R&D efforts.

In the ILC we are already integrated into the Global Design Effort. The main assembly and test facilities in the US will be developed at FNAL by FRA in collaboration with a large group of laboratories and universities. In particular, strong collaborating laboratories are SLAC, BNL, ANL, JLAB, and Cornell. The results of this R&D will touch every accelerator built in the future, be it FELs for material sciences, biology and chemistry; heavy ion accelerators for nuclear physics; or intense proton sources for super-neutrino beams, spallation neutron sources, or future muon based facilities. In the development of magnets for future facilities we lead a collaboration with BNL and LBNL. In the commissioning and upgrading of the LHC we lead a collaboration with SLAC, BNL, LBNL, and ANL. In the development of intense proton sources we lead in collaboration with BNL, LBNL, and ANL. FRA will nurture all these initial steps to make FNAL an important partner in the development of technology for many of the SC projects.

The Illinois Accelerator Research Center building will be a location where universities, laboratories and industry come together to develop future technologies. The initial area of concentration will naturally be the ILC R&D program. The intent is to build these relationships into an enduring framework that will be applicable broadly to all SC programs.

Opportunity 4—Remote Operations and Data Analysis Centers

An important element of FRA's long-term strategy is to develop the ability to have remote control and data-analysis centers for global detectors and accelerators. This approach offers the possibility of engagement in the commissioning, operating and data analysis phases of global projects. The immediate test bed for such an approach is the LHC Remote Operations Center at FNAL. There will be several components that, in combination, make a power program:

- The LHC Accelerator Research Program (LARP) is involved in the commissioning of the accelerator components and systems. The remote operations center will put at the fingertips of our accelerator physicists all the tools and data necessary for them to contribute equally to the development of the LHC as their colleagues situated in Geneva.
- The CMS commissioning and data-taking center adjacent to the accelerator control consoles will create an atmosphere in which physicists will be virtually present at the LHC and will be able to take data shifts.
- A strong physics center (LPC) directed by co-leaders from the laboratory and the user community to allow national users to be as, or more, effective by carrying out their work at FNAL than in Geneva. The LPC Center will be developed under the overall CMS Center.

Both ANL and UChicago are members of the second energy frontier detector, ATLAS, and have contributed to the development of the GRID technology that supports both CMS and ATLAS, thus synergizing the technical IT support of both detectors. This collaboration between CMS and ATLAS would include the other partnering laboratories, but the close connection of UChicago and ANL with their strength in computer and computational technology is a special attribute of FRA.

Opportunity 5—Maximum Science for Particle Physics

This example discusses how we plan to implement the strategy of producing maximum science with the accelerator-based experiments that are in place at FNAL and that are currently at the forefront of HEP. This is an essential role for FNAL as it becomes the only laboratory providing accelerator facilities to the US community.

We will continue to operate the Tevatron and the CDF and DZero experiments at least through 2009 (***Figure 3.a–16***). After the discovery of the Top quark at FNAL in 1995, the government and the field of particle physics developed a plan to produce a large sample of Top quark events and to search for the Higgs boson. The most economical way to produce this science was to upgrade the luminosity of

the Tevatron and to upgrade the existing experiments to accommodate higher data rates and increased particle production rates. These upgraded experiments are now producing breakthrough science at the highest energies and luminosities in the world. Through 2006, these experiments have produced hundreds of research papers. The experiments also provide the data for over 100 Ph.D. theses per year.

We will develop metrics to monitor programs in terms of machine performance, human resources and physics output. Goals for the integrated luminosity to be delivered to the Tevatron experiments on a total and year-by-year basis have been developed on the basis of what is possible to achieve and what is needed to produce certain key physics results, including the discovery of a Standard Model Higgs and low lying supersymmetric states. URA has established the metrics for this program and FRA will take the necessary steps to achieve goals developed in concert with DOE and external groups. FRA will ensure that the detector and data analysis programs meet all scientific and performance benchmarks. Specific attention by the Board of Directors, the Accelerator Advisory Committee and the FRA Visiting Committee will be focused in this area.

The present program in neutrino physics will be optimized for the MINOS experiment that can yield the most precise data on neutrino oscillation in the “atmospheric region” discovered by SuperKamiokande. MINOS has already confirmed these oscillations with approximately 1/16th of the data that it will acquire through the rest of the decade. FRA will ensure enough resources are available to complete this world class program. At the same time, FRA will ensure that MiniBooNE will receive enough neutrinos to make a conclusive measurement on whether sterile neutrinos exist—neutrinos that neither mix with the three presently known neutrinos nor interact through the usual weak interactions. The discovery of sterile neutrinos would dramatically change the study of the neutrino sector. FRA has developed metrics to monitor these programs on a year-by-year basis and it will work with both the MINOS and MiniBooNE collaborations to ensure that the program is effective and accomplishes all its goals.

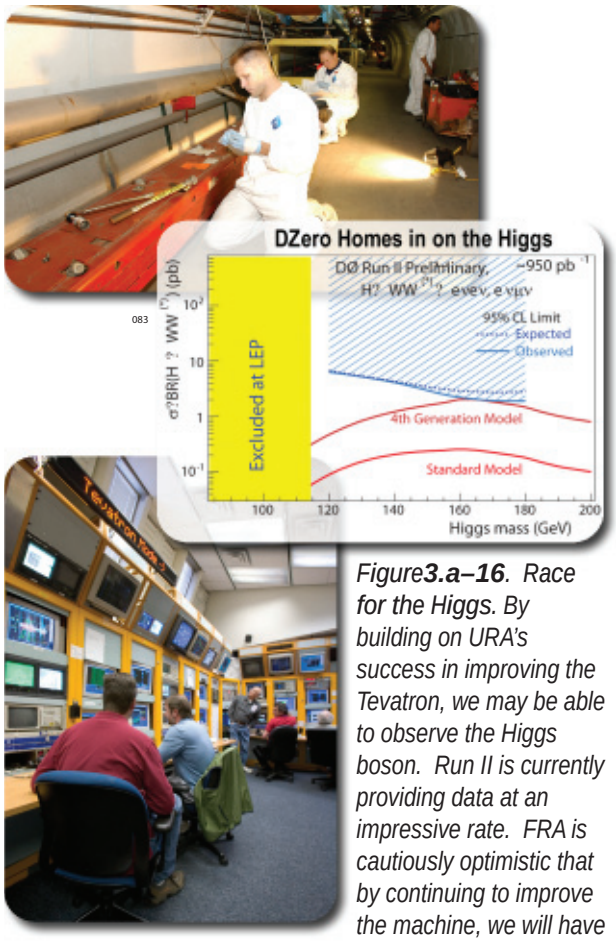

*Figure**3.a–16**. Race for the Higgs. By building on URA’s success in improving the Tevatron, we may be able to observe the Higgs boson. Run II is currently providing data at an impressive rate. FRA is cautiously optimistic that by continuing to improve the machine, we will have enough data by 2009 to spot the Higgs boson—i.e., up to 8 inverse femtobarns of data, which may allow us to glimpse Higgs if its mass is less than approximately 125 GeV as predicted.*

Maximizing the current physics opportunities gives FNAL the greatest role in the training of graduate students in experimental, theoretical and accelerator physicists. More than 100 Ph.D. students graduate per year, influencing the development of the field for years to come.

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3.a.8 Relationships that Would Further Enhance FNAL's Capabilities to Address Scientific Missions

Opportunity 6. Leverage URA Consortium
The URA consortium of over 90 of the leading research universities in the US and elsewhere has been a vital interface between the government-owned laboratory and the university users served by the laboratory. To enhance the value to the government, FRA will assess an annual fee from each member of the URA consortium, which will be used to enhance the university connection by providing $2M in seed funding over the life of the contract for university researchers to come to FNAL to work on FNAL programs, especially ILC R&D, and also to support their outreach activities in their own states. Similarly, UChicago will provide $2M in support over the life of the contract for similar activities associated with building the connection with UChicago and local universities, and introducing management and training initiatives. ***(See Section 8.)***

The connection with UChicago through its commitment to FNAL will lead to a number of joint appointments. The Deputy Director (since July 1, 2006) is Professor Young-Kee Kim of UChicago—one of the leading particle physicists of her generation with the vision and leadership required to become a national laboratory director—and we are proceeding with the next appointment, the head of the Particle Astrophysics Center, through a national search for a joint appointment. Such a joint appointment enhances FRA's ability to obtain top talent for FNAL since the University connection is attractive. FRA contemplates several more joint appointments in the five-year period of the contract in areas of particle astrophysics, theoretical and experimental physics.

The member institutions of the consortium have had scientists and students performing fundamental research in HEP at FNAL throughout its history. By investing in the R&D needed to bring the next generation of accelerators to FNAL, they will help assure ongoing access to forefront HEP research resources for their scientists and students. Together

Enhancing FNAL's Scientific Mission Capabilities

FRA will leverage the relationships of URA, UChicago, and EG&G/URS with state and local government and organizations, the university community, and industry to execute its strategy to ensure US leadership in particle physics research. We will accomplish this by partnering in the development and implementation of FNAL's strategic plan.

FRA, UChicago, other Illinois universities, and the URA universities will provide $12.1M over the life of the contract for activities which include joint appointments, seed funding, discretionary funds, outreach activities, and educational activities. ***(See Section 8.)*** The seed funding would be initially devoted to accelerator and detector development associated with the ILC. These outreach activities in various States, supported by FRA, will develop the resources and databases needed to advocate the benefits of attracting the ILC to the US.

Opportunity 7—Build International Connections to Laboratories, Universities and Funding Agencies
UChicago and URA are both experienced in developing support from multiple agencies domestically and abroad. There were substantial foreign contributions to the original construction of the Tevatron experiments and upgrades, and those have been ongoing in the form of operating contributions under the guidance of appropriate International Finance Committees (IFCs). There have been major contributions to the detector programs of the Tevatron by Japan under the US-Japan agreement on particle physics. UChicago and ANL have also developed international collaborations across a broad front, leading to a team that is extraordinarily experienced in developing international collaborations.

FRA's strategy is to enhance these relations in the next years to support ongoing experiments and help establish FNAL as the preferred site for the ILC. A recent trip to India was organized by URA, which was a first stage in building a strong collaboration with India on the ILC. The visit involved the highest levels of government agencies as well as the principal Indian laboratories. The Director of FNAL

visited Korea during the last year to enhance collaborations. The Deputy Director has deep connections in the Korean scientific establishment and is a national figure in Korea. There has been a standing collaboration with China through many years of the US-China agreement, and FRA will enhance those collaborations in the coming years by involving the Institute of High Energy Physics in Beijing, China's principal high energy physics laboratory, in the ILC R&D program. Through the US-Japan agreement, there have been many fruitful collaborations with Japan leading to major investments in the Tevatron program. FRA will focus special attention on extending those collaborations to the development of a coordinated neutrino program.

Connections in Europe—the long-standing collaboration with DESY in Germany, with INFN institutions in Italy, with French institutions supported by IN2P3 and CEA, with British Institutions supported by PPARC, and many others—are well-established, and FRA will have the opportunity to enhance them through its major contributions to the LHC and CMS. We will also continue to contribute through the participation of senior managers in international bodies:

- Deputy Director Young-Kee Kim
  - DESY Physics Advisory Committee, Germany
- Associate Director for Research Hugh Montgomery
  - Helmholz Society, Particle Physics Review Committee, Germany; INFN Internal Review Committee, Italy; PPAR Atlas Oversight Committee, UK
- Associate Director for Accelerators Steve Holmes
  - DESY Scientific Council, Germany; Chair, Accelerator Advisory Committee, JPARC, Japan; Accelerator Science Advisory Board, CCLRC, UK

The knowledge that FNAL's managers gain through participation in these international planning committees is invaluable in building collaborations and in making the FNAL program an integral part of a global program.

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