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for

Particle Physics and Cosmology Research

by

A Faculty Group in

THE DEPARTMENT OF PHYSICS

HARVARD UNIVERSITY

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HARVARD UNIVERSITY
Laboratory for Particle Physics and Cosmology

George Brandenburg, Gary Feldman, Andrew Foland,
Melissa Franklin, John Huth, Masahiro Morii, Christopher Stubbs

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1 Overview

1.1 Our Motivation: Fundamental Physics

The quest to understand the fundamental laws of Nature stretches back over two millennia to the ancient Greeks. Newton's discovery of his laws of motion three hundred years ago showed that the underlying fundamental laws are most concisely and beautifully described in the language of mathematics, marking the birth of the modern era of physics. In the twentieth century, this journey continued with two revolutionary developments–relativity and quantum mechanics–and much of the latter half of the twentieth century was devoted to an attempt at a synthesis of these ideas. This culminated in the development of the Standard Model of particle physics, describing the weak and electromagnetic interactions within a unified framework that provides an astonishingly accurate description of these forces down to distances about a hundredth the size of a proton. In parallel with this, an understanding of the universe on the largest scales began with the discovery that the universe is expanding. The observation of the cosmic microwave background radiation confirmed a central prediction of the "Big Bang" cosmology, and provided a deep link between the study of physics at the largest and smallest scales.

Despite this progress, our description of the fundamental laws of Nature remains self-contradictory and incomplete. The essential questions are simple to state. For instance, how did the universe begin? Is there a unified description of all forces? How is the existence of gravity reconciled with quantum mechanics? What is the origin of mass? Is our universe unique? Do black holes destroy information? What are the origins of the energy and dark matter that seem to dominate the dynamics of the universe on the largest scales? These questions are all intimately related, and Fundamental Physics is devoted to unraveling these mysteries and others at the edges of our understanding of the fundamental laws of Nature. This will require intensive collaborative efforts between theorists and experimentalists in high-energy physics and cosmology. Here at Harvard this work is being undertaken by the Theoretical Institute on the Fundamental Laws of Nature and the Laboratory for Particle Physics and Cosmology (LPPC). This proposal describes the current programs and future plans of the physicists at LPPC.

We are on the threshold of an incredibly exciting new era in experimental particle physics: the next generation of particle accelerators will fully probe the weak scale, starting with the Large Hadron Collider (LHC) in Europe, set to begin operation in 2007. We expect the LHC will reveal some fundamentally new physical principles beyond the standard model. These might include the discovery of the first new spacetime symmetry since Einstein: supersymmetry, additional dimensions of space, or even observable effects of string theory. We have already made major contributions to the development and construction of the ATLAS muon system at the LHC and have been engaged in the development of the computing grid that will be necessary to analyze the voluminous data expected from ATLAS. Now we are eagerly anticipating the search for new physics.

Non-accelerator experiments have made tremendous advances over the past decade in the study of neutrino oscillations. We are now set to extend our understanding of these elusive particles, whose anomalously low masses can give us a window on the physics of grand unification and whose CP violation may be involved in the understanding of the matter dominance of the universe through leptogenesis. The Harvard group is playing a leading role in the MINOS experiment and the future NOνA experiment. These experiments are the first and second steps in a program to determine the mass ordering of neutrino states and to measure CP violation in the lepton sector.

Likewise the observation of the accelerating expansion of the Universe has been one of the most significant experimental result in fundamental physics of the last quarter century, and we have yet to come to terms with it. We intend to extend our participation in the experimental and observational projects that are being undertaken to study the nature of the dark energy. These initiatives include the Large Synoptic Survey Telescope (LSST), a ground-based facility now in the design stage, complemented by new satellite-borne facilities such as the Joint Dark Energy Mission (JDEM). For many years theorists assumed that some deep principle made the vacuum energy exactly zero, but five years ago, cosmological observations revealed a major shock: in fact the universe is now accelerating, and the mostly likely explanation is that the vacuum energy is not zero. Members of our Dark Energy group participated in this discovery, and we continue to play a leadership role in this important science. Understanding the dark energy is one of the most pressing outstanding problems in the physical sciences today, and we intend to be at the forefront of this research.

Our groups have participated in a number of other exciting discoveries and opportunities in the experimental exploration of fundamental physics. Our CDF group helped build the CDF detector and participated in the discovery of the top quark. Now they will be continuing their investigation of top and bottom quark physics until the start of the LHC. The Standard Model also predicts specific differences in the behavior of matter and anti-matter, which we are actively studying as members of the BaBar collaboration.

1.2 Our Approach: Diverse Techniques, Shared Infrastructure

We will use both astrophysical and particle physics techniques to address the most pressing open questions in fundamental physics. These two approaches have remarkably similar modes of research, and common infrastructure needs. Apparatus is developed on campus and then deployed to off-campus facilities for operation and data acquisition. In both cases, the projects typically involve large international collaborations. Once data are acquired, the results are brought back to campus for refined analysis. For both accelerator and telescope projects, data sets are in the Terabyte to Petabyte regime.

Our experimental program is based at Harvard's Laboratory for Particle Physics and Cosmology (LPPC), which has computing facilities for data analysis, engineering support for detector R&D, and shops for the fabrication of detectors and their readout systems. This year we changed our name from High Energy Physics Laboratory to reflect the diversification of our program. Our educational efforts are concentrated in graduate and postdoctoral education, where we are requesting support for twelve research students. In addition, undergraduate students work on projects at LPPC part-time during the academic year and full-time over the summer. We have recently moved to new quarters: our offices and computers are located in historic Palfrey House, while our machine shop and test labs are located in the former Cambridge Electron Accelerator. In several years we plan to be moving into a larger and more modern space in the NW interdisciplinary science building which is now being built.

The faculty group leading the LPPC research program at Harvard includes:

Dr. George Brandenburg is a Senior Research Fellow and the Director of LPPC. He has been working on both BABAR and ATLAS, but will be full time on ATLAS as of this summer. On ATLAS he was responsible for the development and production of muon system front-end electronics, and will now be concentrating on muon software and the commissioning of the muon system.

Prof. Gary Feldman leads our Neutrino group on the MIPP, MINOS, and NOνA experiments. He is concentrating all of his research efforts toward the study of neutrino oscillations. He is serving as co-spokesperson for NOνA.

Prof. Andrew Foland is currently devoting his full effort to collection and analysis of the data from the CDF detector at the Tevatron. He has been concentrating on building the tools and techniques for detailed characterization of top properties. Over the next three years, Professor Foland will be transitioning to the neutrino physics effort on NOvA as students on the CDF experiment finish their theses.

Prof. Melissa Franklin is the Chair of the LPPC Faculty Committee. She has been a member of the CDF collaboration since 1983. Having worked on three detectors, the plug calorimeter, the central muon extension and the central outer tracker, and numerous a physics analyses from early studies of the Z boson through measurements of the W mass to studies of the top quark. She will continue to contribute to the data taking and anaylsis of CDF over the next few years, while ramping down her involvement. Professor Franklin has recently become interested in exploring the subject of dark matter and dark energy and is currently working on a project with Professor Stubbs involving the measurement of red shifts of galactic clusters in conjunction with the SZ Galactic Survey Array. Over the next three years she will move her major research focus to dark matter/dark energy as a collaborator on one of a number of proposed projects.

Prof. John Huth works on ATLAS where he is the U.S. Associate Project Manager for Physics and Computing. His research interests are the search for supersymmety, extra dimensions, and other physics beyond the standard model. He is currently in the second year of a three-year term as Physics Department Chair.

Prof. Masahiro Morii currently focuses his research in the analysis of the physics data from the BaBar experiment. He will maintain his main responsibility with the experiment—coordination of the analysis of B semileptonic decays—for the immediate future. In the next three years, Morii plans to increase his involvement with the ATLAS experiment as the BaBar experiment completes its data taking runs.

Prof. Christopher Stubbs' research program focuses on the astrophysical evidence for physics beyond the standard model, in particular the pressing open questions of dark energy and dark matter. He is playing a scientific and technical leadership role in the Large Synoptic Survey Telescope (LSST), an ambitious ground-based facility that is being designed to probe the nature of the dark energy.

In addition to the faculty group responsible for our program there are currently five postdoctoral research associates: Dr. Kevin Black with the ATLAS group, Drs. Sebastian Grinstein, and João Guimarães da Costa with the CDF group; Dr. Jinwei Wu with the BABAR group; and Dr. Mayly Sanchez with the Neutrino group.

1.3 LPPC Shared Facilities

The Laboratory for Particle Physics and Cosmology facilities are available to all the groups on an equal basis. Our engineers and shops are capable of designing and building state of the art detector systems and their associated readout electronics. We have produced prototypes for detector R&D as well as complete major systems for all of our groups. Examples of projects completed in the machine shop include the CDF Central Tracker Upgrade, CDF Central Muon System Extension, a redesigned Interaction Region for CLEO, and the NOMAD Hadron Calorimeter. We are currently completing the production of ATLAS Muon Drift Tube chambers. The electronics shop has produced readout electronics for most of our detectors, most recently the CDF and CLEO silicon vertex detectors, the front end electronics for the MINOS far detector, and a tracking trigger upgrade for the BABAR detector. We have recently completed the readout system for the ATLAS muon detector and have begun work planning the LSST and NOνA readout electronics. Details of current projects are given in the group summaries.

The LPPC engineering staff consists of an electronics engineer, Dr. John Oliver, his assistant, Nathan Felt, and an engineering physicist, Dr. Peter Hurst. The remaining technical staff consists of an electronics technician, a machinist, and a mechanical technician. The administrative staff consists of the lab director and an administrative assistant.

In addition to engineering and shops, LPPC has workstations, personal computers, and associated peripherals which are available to all the groups for data analysis, documentation, and communication with collaborators. About half of the computers are located at our experiments for the use of our postdocs and students. This year we are requesting funds expand the linux cluster that is the main computing resource for all of the groups. The cluster currently consists of eight 2.5 GHz nodes together with 4 TBytes of RAID storage. Finally, LPPC has a video conferencing system for participation in meetings at other labs and universities, resulting in savings of both time and travel funds.