November 11, 2010

Physics Advisory Committee Meeting

November 4–6, 2010

Comments and Recommendations

Introduction

The Fermilab Physics Advisory Committee (PAC) met to consider a number of proposals, all of which the Committee has considered previously in some form, such as Expressions of Interest or Letters of Intent. Topics addressed by these proposals ranged from new detector or upgrade proposals to requests for extensions of data collection. New detectors were proposed, one exploiting future use of the antiproton complex to explore hyperons, charm physics, and states such as the $X(3872)$; and a new neutrino experiment to supplement and provide better understanding of systematic uncertainties for the NOνA experiment, as well as measuring low-energy neutrino cross sections. An upgrade was requested for the previous MIPP experiment to cover a much wider range of beam and target species with increased precision and phase space. There was a proposal for support of continuation of the COUPP bubble-chamber program to search for dark-matter candidates, including development of a ton-scale chamber. Finally, MiniBooNE requested an extension of data collection with antineutrino beams from the Booster accelerator complex to further understand possible differences between electron neutrino and electron antineutrino appearance spectra.

The Committee greatly appreciates the time and effort of the proponents, as well as the quick responses to the Committee's questions.

Given the uncertainty in the implementation of a three-year Tevatron extension as recommended by the PAC and HEPAP, the Committee was charged with providing comments and recommendations separately under the assumptions of (i) no budgetary issues and (ii) if the Fermilab budget is severely constrained over the next four years (i.e., in the case of an extension).

The Committee also heard status reports on the rest of the Laboratory's physics program. The Energy Frontier continues to advance with an impressive flow of results and publications from CMS and the Tevatron experiments. Exciting physics results from a vibrant and diverse neutrino program were described, and progress on future plans for LBNE, DUSEL, and Project X was presented as part of the Intensity Frontier. The Laboratory's notable efforts on the

Cosmic Frontier in particle astrophysics were presented, as well as their context within the broader efforts and recommendations set forth in the recent Astro2010 Decadal Survey Report. The Committee warmly thanks representatives for the high quality of these presentations and reports.

Director Oddone also summarized news, the overall status of the Laboratory, and described scenarios for funding prospects from the agencies and Congress. He described his rationale for switching to antineutrinos upon resumption of operation following the recent replacement of the NuMI target.

COUPP-500 1–Ton Scale Detector Experiment (P-1009)

Astrophysical observations indicate the presence of large amounts of non-baryonic, non-luminous matter in the Universe. Determining the nature of this dark matter is one of the most pressing problems in particle physics and cosmology. A leading dark-matter candidate is the Weakly Interacting Massive Particle (WIMP), as a possible consequence of new physics at the TeV scale. A number of promising techniques have been proposed for WIMP direct detection. It is urgent to increase the sensitivity of such experiments by maintaining close to background-free operation as the target mass is increased, and simultaneously to explore the ultimate capability of the various approaches. Fermilab is involved in three complementary approaches: CDMS, which uses germanium detectors at very low temperature; DarkSide, which applies liquid argon technologies; and COUPP, which is discussed below.

COUPP is exploring an innovative approach based on room-temperature liquid bubble chambers. The apparatus detects single bubbles induced by high-dE/dx nuclear recoils, such as those induced by neutrons or WIMPs elastically scattering off target nuclei. The prospect for detecting WIMPs is very compelling, and there is an urgent need to explore accessible parameter space as quickly as possible. The COUPP technique has the very attractive feature that the detector can be made almost totally insensitive to electron and gamma radiation by adjusting the physical parameters of the chamber operation. The COUPP technique has demonstrated a rejection factor larger than other techniques. A major recent advance is the discovery that it is possible to identify residual alpha-particle scattering events, which also trigger the formation of bubbles, through acoustic discrimination. COUPP employs a relatively simple technique that allows for rapid setting of competitive upper limits on the rate of WIMP-induced recoils. If candidate events were observed, scanning in thermodynamic parameters would be necessary to estimate the recoil energy spectrum and to establish compatibility with WIMP expectations.

The team has successfully deployed a 4-kg chamber deep underground at SNOLAB. The preliminary data obtained without a full neutron shield indicates a background level that should translate into a significant sensitivity to WIMPs. The acoustic method of alpha rejection is

critical for achieving close-to-zero background. The Committee looks forward to seeing first results on spin-dependent and spin-independent cross-sections from the 4-kg chamber exposure.

In the first test of a 60-kg chamber in the NuMI hall, a so-far-unexplained progressive darkening of the operating fluid was observed. This darkening eventually made data-taking impossible. The purple coloration indicates an unacceptable decomposition of the liquid. Issues like these are not unusual at a new stage of a detector development, and the team has proposed possible origins of the problem. The Committee is optimistic that the causes of this unexpected effect will be found and that the problem will be solved. Following the recommendation of a previous PAC meeting, the Laboratory had approved the deployment of the COUPP-60 detector at SNOLAB. Obviously, stable operation of the 60-kg chamber is a prerequisite for deployment at SNOLAB.

The specific proposal that was presented for consideration at this meeting has three components: (1) a request for engineering time to develop the design of the COUPP-500 chamber to a level where its cost can be firmly established; (2) support to continue operation of the 4-kg chamber in SNOLAB; and (3) support to execute "calibration and R&D" tasks that will guide the design of the ton-scale device.

The bubble-chamber technique looks very promising, and the Committee recommends in both budget scenarios of the charge that the resources requested be allocated by the Laboratory, contingent on a satisfactory solution of the 60-kg chamber issues, as judged by the Laboratory management. The main goal of this engineering effort should be a reliable cost estimate of a ton-scale chamber, an important component to the development of a full COUPP-500 proposal. The latter should include detailed background estimations based on the experience gained by running the 4-kg and 60-kg chambers.

Medium-Energy Antiproton Physics with The Antiproton Annihilation Spectrometer (TApAS) at Fermilab (P-986)

The Committee considered a proposal to search for hyperon and charm meson CP violation and rare decays, and to study the $X(3872)$ in antiproton-annihilation events at the Fermilab Antiproton Accumulator. The proposed experiment had been previously considered by the PAC as a Letter of Intent at the March 2009 meeting. At that time the PAC wrote: *The Committee would welcome a more detailed comparison of the physics potential with that of the super-B factories and the tau/charm factory. To proceed further, it would be necessary to substantially develop the physics case and the plan for the detector configuration, and strengthen the Collaboration.*

Mixing in charm mesons is now well established, with a rate at the upper end of standard model expectations. However, CP violation in that mixing has only been probed at the percent

level to date. The discovery of CP violation in charm meson mixing at the 10^{-3} level would be clear evidence for physics beyond the standard model. The total charm production cross section for 8 GeV antiprotons on proton and nucleon targets is unknown, and estimates vary by an order of magnitude. If the cross section is in the middle of the expected range, then of order 10^8 tagged $D^{*-} \rightarrow D^0 \pi^-$ decays may be reconstructed per year in TApAS. This is similar in size to the data sets expected by LHCb per year, and the upgraded KEK-B /Belle II by the end of the decade. A more detailed understanding of the systematic limits of the proposed experiment through full Monte Carlo simulations would be needed to understand how competitive TApAS is for charm CP-violation searches.

The CP asymmetries of hyperon decays could be affected by physics beyond the standard model. However, the asymmetries cannot be reliably predicted and their observation would be difficult to interpret. The most sensitive search to date was performed at Fermilab by HyperCP (E-871). A two-sigma deviation from the standard model was found in the CP asymmetry of the decay angular distribution for $\Xi^- \rightarrow \Lambda \pi^-$. TApAS proposes to study the decay-rate asymmetry of omega hyperons from omega-antiomega pairs produced just above threshold. The total production cross section for 5.4 GeV antiprotons on proton and nucleon targets is also unknown. The proponents estimate of order 10^8 omega-antiomega pairs may be reconstructed per year. This would allow the asymmetry, which has not previously been measured, to be probed to a few times above the value expected in the standard model. The Committee does not find the goal of reaching this level of sensitivity to be compelling.

TApAS also proposes to search for rare decays in both the charm and hyperon runs.

Using the Fermilab Antiproton Source, E-760 and E-835 made the most precise measurements of charmonium masses and widths. The $X(3872)$ is a resonance whose nature is poorly understood; that could be interpreted as a D^*D molecule or other exotic state. TApAS proposes to use the same technique to measure the $X(3872)$ mass, width, and lineshape, as well as other resonances. Such measurements are interesting and could not be done with the proposed precision elsewhere at this time.

The proposed TApAS detector would reuse the electromagnetic calorimeter of E-760/835. For the charm studies, particle identification will be crucial, and the currently proposed TOF system with challenging picosecond-scale resolution is not yet demonstrated. A muon detector would be advantageous, although one is not currently proposed. The cost estimate provided is a rough estimate, and the Committee expects that the actual cost would be substantially higher. In addition, the experiment will be difficult to fund from university sources alone, as proposed.

The experiment cannot begin until running of the Tevatron has ended, and must be complete before the accelerator modifications for the Mu2e experiment begin. There is also a potential conflict with the proposed g-2 experiment. The construction and operation of the

TApAS experiment would be a major undertaking, unlikely to be completed on this timescale. Although the Collaboration has grown since the Committee first considered P-986, it remains far from the strength necessary to carry out the experiment and extract the physics.

The Committee does not recommend that this proposal go forward under either of the funding scenarios in the charge.

MIPP-II (P-960)

The Main Injector Particle Production (MIPP-I) experiment (E-907) was approved in 2001. During the data-taking period in 2005-2006, MIPP-I accumulated a data sample of 18M hadroproduction events with various particle beams and targets. The analysis of this data set resulted in five Ph.D. theses over the years, as well as two papers, of which one has been submitted recently for publication and the other is in preparation.

The proposed MIPP-II upgrade is geared towards increasing the data rate from 20 Hz to 3 kHz, which would result in a capability of recording 5M events/day. MIPP-II would require an upgrade of the data-acquisition system that takes advantage of the electronics developed for the ALICE experiment at CERN, as well as other substantial improvements and additions. The upgraded detector would take data using six different beams on over 30 target nuclei. This represents a more comprehensive program than that of MIPP-I, as well as those of the HARP and NA61 experiments at CERN.

The Committee recognizes that the output of this experiment would be of use to a wide physics community. In particular, Monte Carlo generators (GEANT4, MARS, etc.) would benefit from improved precision in the hadroproduction measurements. The collaboration aims to create a library of events that would be available to the entire physics community, and could be used to tune shower generators. In addition, this data would be helpful to neutrino experiments to normalize the neutrino flux coming from their targets.

Unfortunately, the experimental apparatus needed to achieve the physics goals is very complex, mainly due to use of several devices needed for particle identification in a wide kinematic range and the non-trivial effects due to the magnetic field of the experiment. While the MIPP Collaboration has made some progress in increasing the number of collaborating institutions over the years, the Committee believes that it is still not strong enough to deal with the complexity of the detector and to successfully and expeditiously complete the analysis of the data.

The Committee was presented with an ambitious list of physics publications in progress that the Collaboration plans to publish in the next year and beyond. In October 2006 the PAC reviewed the proposal for the MIPP upgrade and recommended deferring its consideration until

"*the Collaboration [has demonstrated] that the existing data can provide high-quality physics results with substantial impact*." Since then, only one analysis has been submitted for publication. Thus, the Committee is particularly concerned about the Collaboration's capability to perform a timely data analysis. The Committee recommends that the Collaboration concentrate on completing the analysis of existing data. The Committee suggests that this goal could be achieved through an increased involvement of the neutrino community at Fermilab in the MIPP-I data analysis.

Although the Committee recognizes the usefulness of the proposed measurements, these measurements are of lower priority compared to the other efforts at the Laboratory. Given the high level of sustained effort needed for a successful MIPP-II research program, the Committee recommends against approval of the MIPP-II proposal under both funding scenarios in the charge.

Sci NOνA (P-1003)

The SciNOνA Collaboration proposes to install a finely-segmented scintillator detector upstream of the NOνA Near Detector. The proposed physics goals include contributions to nuclear-physics cross-section measurements and to reduction in the uncertainty on NOνA results. There are three primary physics measurements cited as goals: low-background quasi-elastic scattering at 2 GeV; π^0 production rate in neutral-current interactions that are a background to muon-neutrino-to-electron-neutrino oscillations; and checks on the NOνA background measurement for electron-neutrino appearance and muon-neutrino disappearance measurements. Of these, the NOνA-related measurements could be compelling if it is clearly demonstrated that these measurements lead to a significant reduction in the background systematic errors. SciNOνA-type measurements could also help substantially as a risk-reduction strategy for the flagship NOνA experiment. The cross-section measurements would not obviously yield vital new information. The Committee notes that MINERνA will produce data with several points in the same energy regime.

The Committee did not see the urgency to proceed with SciNOνA as a separate project. Instead, the Committee suggests that the Laboratory and the NOνA Collaboration now explore ways to produce and install a modified NOνA Near Detector "bookend" to preserve the option of inserting a second near detector. The NOνA Collaboration can then assess whether the systematic error and risk reduction provided by the additional detector is of sufficient priority to proceed.

MiniBooNE Antineutrino Run Extension (E-944)

MiniBooNE was designed to address an anomaly reported by LSND. In neutrino running, MiniBooNE did not report any excess consistent with the reported LSND signal in electron-antineutrino appearance (above a neutrino energy of 475 MeV). However, below 475 MeV, an unexplained excess of events was observed. In antineutrino running MiniBooNE reported a statistically inconclusive excess of events for antineutrino energies above 475 MeV while there is no evidence for the low-energy excess seen in the neutrino mode. Collecting additional antineutrino data is of interest to reduce the statistical uncertainty in comparison with the neutrino data and the LSND anomaly. Complementary information on the LSND anomaly could be provided by the MINOS near detector running in antineutrino mode, however the relevance of the results is model-dependent.

The Committee recommends that antineutrino running for MiniBooNE continue at lower priority than NuMI and Tevatron running as long as significant resources or compromises to other programs are not required.