Physics Advisory Committee Meeting

November 12-14, 2009

Comments and Recommendations

Introduction

The Fermilab Physics Advisory Committee (PAC) discussed a wide range of exciting proposed efforts focusing mainly on the Intensity Frontier and the Cosmic Frontier of the Fermilab physics program. The Intensity Frontier efforts included precision muon measurements, rare kaon decays, and neutrino experiments, while the Cosmic Frontier included efforts in particle astrophysics, the study of the structure of space-time, and the search for direct dark-matter interactions. In relation to the Energy Frontier, the CMS Upgrade proposal, in particular the roles of Fermilab and USCMS, was also presented. The Committee also benefited from presentations summarizing the recent report of the Particle Astrophysics Scientific Assessment Group (PASAG), as well as the activities of the *4th Workshop on Physics with a High Intensity Proton Source* (Project X, IC2), and the *Workshop on Muon Collider Physics, Detector, and Machine Background* held earlier in the week at Fermilab.

CMS Upgrade (Butler)

Physics at the Large Hadron Collider (LHC) is among the most compelling in all of particle physics, and most certainly fits in with the Fermilab core mission. The Committee heard a presentation on the possible role of Fermilab and USCMS in the CMS detector upgrades. Fermilab is involved in 11 of the 28 detector R&D upgrade proposals that have CMS approval. Fourteen Fermilab staff members are involved in detector upgrade activities, and these activities are well matched to Fermilab strengths and experience: the hadron calorimeter, simulation, tracking, and data acquisition. The physics case for each upgrade needs to be made. For each upgrade, what physics would be gained, and what would happen to the physics reach of CMS if this upgrade were not funded?

P-989 Design and Cost Update for New g-2 (Hertzog/Roberts)

The New g-2 Collaboration reviewed its proposal for an improved measurement of g-2 of the muon, with considerable cost-savings obtained by moving the E821 storage ring from BNL to Fermilab. It would use the beam from the Booster before the start of the Mu2e experiment and following the 15-Hz upgrade in a way so as not to interfere with any other efforts of the pre-Project-X program. The proponents presented updates on the current theoretical understanding and a revised cost estimate.

As stated by the HEPAP Particle Physics Project Prioritization Panel (P5) in its 2007 report, "there is an excellent physics case for this classic experiment." However, the g-2 experiment was given a relatively low priority by P5. Since the report, several things have changed. The cost is now significantly less than thought at that time. Also, the P5 report noted that the g-2 experiment could be pursued at JPARC in Japan with only a modest investment from the US. For technical reasons, that particular option is no longer present, and it appears that the experiment won't be done in the foreseeable future if it isn't done at Fermilab. This presents a window of opportunity. There are no other competing experiments in the same time frame. Making the measurement at JPARC using ultra-cold muons is under consideration, but it is only in a very preliminary conceptual design phase. P-989 offers the possibility for a continued leadership role on g-2 in the US, and the Japanese g-2 community has joined the Fermilab proposal. The timing of the new g-2 experiment fits well with the Fermilab program, and offers the possibility for near-term physics results after the end of the Collider program.

There have been significant advances in the theoretical understanding of g-2, although the uncertainty on the light-by-light contribution remains a worry. There is a worldwide effort to reduce the theoretical uncertainty from hadronic contributions. The addition of new experimental input of the measured low-mass hadronic spectrum provides an improved theoretical prediction. Further measurements from Frascati, Novosibirsk, BEPC, and the *B* factories are promising, including a potential low-mass two-photon mass spectrum measurement. The Collaboration expects to achieve a four-fold decrease in the total g-2 measurement uncertainty, and a 5-sigma measurement (for the same central value and no further improvements in the precision of the theoretical prediction). Well-motivated improvements in detector systems should allow for further reduction in experimental systematic uncertainties, and may allow the measurement of the electric dipole moment (EDM) of the muon in a first phase of such a program. The physics interest in the g-2 result is strong, as witnessed by the large number of recent citations of the BNL g-2 results. Almost any model of new physics will result in a contribution to g-2 and a deviation from the Standard Model prediction.

P-989 is being proposed by a strong and experienced collaboration of highly competent physicists in this field, using a well-tested technique. A notable reinforcement of the effort is the securing of the promise from BNL of technical support with specialized experience with the E821 experiment. The Committee believes that the experiment could achieve the proposed sensitivity.

The Committee appreciates the excellent work involved in producing the detailed project cost estimates by the Collaboration and Fermilab. These project cost estimates are on a much firmer footing than previously.

The experiment meets the criteria for Stage I approval. However, the Laboratory currently has very limited available resources (both financial and human) to execute P-989. The proponents should be strongly encouraged to pursue commitments of substantial funding from non-DOE sources. The experiment would produce important physics and would be the start of a precision muon program at the Laboratory. There is the potential for the experiment to continue into the Project-X era, thereby increasing the diversity of the Project-X physics program. The Committee recommends that the Laboratory clarify with DOE the prospects for obtaining support for P-989.

P-996 Measurement of the $K^+ \to \pi^+ \nu\bar{\nu}$ Decay at Fermilab (Bryman/ Tschirhart)

The P-996 Collaboration presented a proposal to measure 1000 events of the decay $K^+ \to \pi^+ \nu\bar{\nu}$ with a precision of 5% on the branching ratio. A 1000-event experiment was endorsed by P5, which stated that "such experiments would be a major component of a future high-sensitivity physics program at Fermilab and their implementation should be pursued" [in a scenario where the high-energy physics budget doubles in ten years]. P-996 is being proposed by a strong and experienced collaboration of highly competent physicists in this field who propose to use the experimental techniques from BNL experiments E787 and E949. The success of these experiments adds to the credibility of the estimated sensitivity of the proposed experiment. P-996 offers the possibility for a US leadership role in the area of future kaon physics—the charged-kaon experiment could potentially be followed by a neutral-kaon experiment, building a kaon community at Fermilab for the Project-X era.

The physics case for the charged-kaon experiment is strong and the theoretical prediction for the Standard Model rate has a small theoretical uncertainty that is well understood. A measurement of the decay $K^+ \to \pi^+ \nu\bar{\nu}$ is sensitive to many types of new physics. Such an experiment is complementary to the discovery of high-mass phenomena at the Tevatron or LHC. In some scenarios this decay is sensitive to the 100-TeV mass scale, beyond the reach of even the LHC. There is competition from the NA62 experiment at CERN which uses a different technique. Even in the scenario in which P-996 proceeds immediately, NA62 could have 50-100 events, sensitive to a possible highly significant departure from the Standard Model prediction before P-996 begins taking data.

The Collaboration presented a detector cost of order $50M. The Tevatron's capabilities would need to be preserved beyond the end of Collider running. Also, the Tevatron would have to be kept at liquid nitrogen temperatures until the start of the experiment. The experiment requires the slow-extraction of a 150 GeV beam and supporting Tevatron operations for the five-year duration of the experiment, adding significantly to the total experiment cost and the requirements for technical resources. It would be very useful to have a thorough review by the Laboratory of the total project cost, necessary resources, and required accelerator operations, similar to what was done for g-2. The usefulness of a 150 GeV beam for fixed-target experiments beyond a kaon program appears limited due to its relatively low energy.

The experiment meets the criteria for Stage I approval. However, the Laboratory currently has very limited available resources (both financial and human) to execute P-996. The experiment would contribute to the evolution of a strong kaon program as part of the long-term

Project-X-physics strategy. The Committee judges that the physics case for P-996 is strong, but the experiment requires very significant resources. The Committee recommends that, because of the competition from NA62, the Laboratory expeditiously clarify with DOE the prospects for obtaining support for P-996 and for Tevatron operations after the Collider era.

P-1002 Letter of Intent to Build a MiniBooNE Near Detector: BooNE (Louis)

The presentation by the proponents of P-1002 included new MiniBooNE results on electron-antineutrino appearance from antineutrino running. These new results use 50% more data than the previously published result. This new data continues to be inconclusive on the question of whether there is a low-energy excess in the electron-antineutrino appearance channel. The proponents submitted a Letter of Intent to build a new detector or move the current detector to 200 m from the source. At this time, the Committee does not see a compelling reason to proceed to a full proposal for a MiniBooNE near detector. The Laboratory could revisit this issue when new results from MiniBooNE/SciBooNE and MINOS antineutrino running are available.

P-1003 SciNOνA: A Measurement of Neutrino-Nucleus Scattering in a Narrow-Band Beam (Messier/Tayloe)

The Committee was intrigued by this Expression of Interest to move and reinstrument the SciBar detector in front of the NOνA Near Detector in the NuMI hall. The Committee recommends that the proponents clarify and expand on the following two issues: (1) What is the complementarity and synergy with the MINERνA experiment on cross section measurement; and (2) In more detail, how does this detector help the NOνA experiment understand its off-axis neutrino beam? The Committee also recommends that the proponents confirm the availability of the SciBar detector in the near future.

Strategic Planning of the Fermilab Center for Particle Astrophysics (FCPA)

The PAC has commented extensively in its previous reports on the strategic planning process of the Fermilab Center for Particle Astrophysics (FCPA), and its earlier recommendations remain relevant.

The Committee was pleased to see the continued progress in developing a focused short-term program and in shaping a long-term strategy. The near-term plans of the Center have crystallized around a series of ongoing projects that are well-aligned with the mission of the Laboratory at the Cosmic Frontier and with the program and recommendations contained in the recently released report of the Particle Astrophysics Science Assessment Group (PASAG). The ongoing efforts and near-term plans for the FCPA dark-matter direct-detection program are particularly strong and broad, and are positioning the Laboratory to be a major player in the next-generation experiments of this exciting field. FCPA scientists are also planning to play a significant and unique role in the QUIET II experiment search for the signature of inflationary gravitational waves in the polarization of the cosmic microwave background (CMB). Such an observation would be a potential test of inflation and of physics at the GUT scale. CMB

polarization observations, and specifically Fermilab's involvement in the QUIET II collaboration, were endorsed by PASAG in all budget scenarios. FCPA scientists are also centrally engaged in the dark-energy problem, combining theoretical efforts, strong participation in the analysis of existing surveys, a major hardware responsibility in the Dark Energy Survey (DECam), and the proposed JDEM Science Operations Center.

Overall, the FCPA program is developing very well. Creative ideas to explore the Cosmic Frontier are suggested at an impressive rate. Clearly, not all projects can be pursued, especially within current fiscal constraints. The FCPA has therefore selected a subset of projects to pursue in the short term. Also, significant progress was made in the formulation of the long-term strategic plan, and in the management of this complex operation, in particular with the appointment of a deputy director. The Committee comments below on the individual proposed projects.

In addition to the PASAG, the Decadal Survey of Astronomy and Astrophysics (Astro2010) is reviewing aspects of particle astrophysics. It is noteworthy that DOE, along with NSF and NASA, is supporting Astro2010, and that the survey committee includes members of the particle-astrophysics community. While direct detection of dark matter is not explicitly included in Astro2010, the report will have profound bearings on the rest of the FCPA program. The FCPA Director indicated his intention to convene a post-Astro2010 workshop to assess the impact of the report on the Fermilab long-term strategy. The PAC supports the idea of such a workshop.

The Committee appreciates the efforts of the FCPA to reach out and involve the larger community. Workshops such as the recent "Annihilation and the Interstellar Medium" and "Science with Fast Radio Telescopes" are effective in raising the visibility of the FCPA on the national level, and to bridge the particle-astrophysics and the more traditional particle-physics communities. The Committee also was pleased to see the trend toward the increased use of reviews with external expertise for FCPA projects. The Committee encourages expanding these efforts.

P-997 Auger North (Mantsch)

The leading cosmic-ray experiment at present is the Pierre Auger Observatory in Argentina (Auger South). From its beginning, the Auger Collaboration envisaged a second detector in the North. The proposed Pierre Auger Observatory at a site in southeast Colorado (Auger North) intends to target the ultra-high-energy cosmic-ray frontier with an aperture seven times greater than that of Auger South, and to complete full sky coverage. A major goal is to identify individual sources of high-energy cosmic rays. Thanks to its acceptance and reach in energy, the proposed Auger North observatory is unique in the field, with no competition. The technical aspects of the Auger North design have been optimized and are well understood.

Fermilab’s contributions to the construction of Auger North would include management, engineering, computing, and data analysis. The project management, in particular, is a unique contribution well-suited to a national laboratory. Fermilab’s experience building Auger South would be very valuable to Auger North. Fermilab scientists involved in Auger South have

expressed a strong interest in the Auger North proposal, and Auger North fits in the Fermilab mission.

Auger North was recently reviewed by PASAG. The report notes, "Establishing the high-energy cutoff in the cosmic ray spectrum was a great achievement of the past decade. This also fundamentally changed the intellectual landscape for the study of the highest-energy cosmic rays, removing the need to explain them with new physics such as exotic, massive particles or topological defects at the GUT scale. Now, the scientific focus is on finishing the quest to determine the astrophysical origin of the highest energy cosmic rays." PASAG recommended that Auger North be funded substantially from high-energy physics sources only under the best budget scenarios, C and D. PASAG also noted that the Astro2010 survey is ongoing, and wrote "Auger North may be highly ranked in that survey, in which case astronomy and astrophysics agencies will presumably then plan to fund it and the costs to HEP will be lower."

The PAC wrote in June 2009: "The Pierre Auger North project proposal is currently under review by the community, in both the PASAG and the Astro2010 Decadal Survey. If it is highly ranked and moves forward, the Committee would welcome hearing a detailed presentation at a future meeting about the plans for Fermilab involvement." The Astro2010 report is not expected until summer 2010.

P-990 The Fermilab Holometer: A Program to Measure Planck Scale Indeterminacy (Hogan)

Craig Hogan has recently suggested that the holographic principle could lead to measurable fluctuations in the position of macroscopic objects. This opens the fascinating possibility of probing the Planck scale, and of investigating the quantum structure of space.

The Committee reviewed the updated proposal "The Fermilab Holometer: A Program to Measure Planck Scale Indeterminacy" to perform an experiment to detect holographic noise. A pair of laser interferometers would be used to search for the predicted spatial fluctuations and disentangle them from other noise sources. Specifically, holographic noise must be correlated in a pair of co-located interferometers, and would vanish when the interferometers are spatially separated by more than their size. To the best of our knowledge, the type of noise the holometer is sensitive to has not been excluded by other experiments. The Committee reasserts that the Planck scale physics addressed by this proposal fits squarely in the intellectual mission of the Laboratory. If the experiment were successful in detecting holographic noise, it would be a ground-breaking discovery. In addition, the transfer of optical cavity expertise to Fermilab may be important for other Laboratory experiments (e.g., for a future axion experiment). Therefore the proposed experiment would be a coherent addition to the Fermilab particle-astrophysics and particle-physics programs. The experiment has no known comparable dual-interferometer competitor at this time. The sensitivity of the single interferometer, GEO600, is close to the appropriate level of sensitivity, and it may be possible for it to rule out holographic noise at the predicted level. The Fermilab experiment is challenging, but the Fermilab Holometer Collaboration is experienced–with members also drawn from LIGO and GEO600. The Fermilab role in the proposed holometer is unique, important, and significant. As stated above, the idea for the experiment originated at Fermilab, and the Laboratory would provide engineering and

technical support and host the apparatus at a nearby off-site warehouse. The estimated cost is approximately $2M. (These costs are for equipment, materials, services, and engineering.)

Since the last PAC meeting, the proponents have provided answers to the PAC questions from that time, and the proposal has been reviewed by a panel including experimentalists from the gravitational wave community and a Fermilab theorist. The panel's report, which was favorable but identified concerns which the Committee shares, was made available to the PAC. The Committee asked the proponents to address the concerns identified in the report. The proponents did this at this meeting, and the Committee found their answers to be adequate.

The Committee re-asserts that it is important that members of the external theory community be given an opportunity to comment on the theoretical basis for the proposed measurement. The concept of the inferred holographic fluctuations of the relative position of macroscopic objects is based on plausible arguments about information limits in the quantum definition of space. However, the concept unfortunately is not grounded in a fundamental theory. No agreement has yet emerged in the theory community about the soundness of the hypothesis under test. In addition, there is no active engagement of scientists outside the proposing group in refining the theoretical framework. Accordingly, the Committee recommends that a critical review of the theory underpinning this proposal be undertaken by the external theory community. If this review were to be positive, the Committee recommends that the Laboratory proceed expeditiously with the proposed Fermilab Holometer.

P-998 QUIET Phase II – The Search for B-Mode Polarization in the Cosmic Microwave Background Using Coherent HEMT Detectors (Nguyen)

Cosmic microwave background (CMB) measurements have been very important for astrophysics, cosmology, and particle physics. The scientific importance to particle physics continues to grow. The detection of the B modes imprinted in the cosmic microwave background polarization by gravitational waves could provide the most direct probe of the extremely high-energy physics of inflation, and is therefore well aligned with the particle astrophysics program of Fermilab. The ancillary CMB science is also important for particle physics. The detection at smaller angular scale of the B modes generated by gravitational lensing by the intervening mass distribution would probe the mass spectrum and constrain the sum of the masses of the neutrinos. This fits well scientifically with the astrophysics and neutrino programs at Fermilab. As with all CMB measurements, the experimental challenges are great.

QUIET II, a proposed CMB experiment located in Chile, approaches the observational challenges using a novel radiometer technology (Monolithic Microwave Integrated Circuits – MMICs) to make sensitive measurements of the CMB polarization over intermediate angular scales. This technology is complementary to bolometry, the method adopted by most of the field. QUIET II would have sufficient sensitivity at 90 GHz for a meaningful measurement, and has unique sensitivity at lower frequencies, providing an important handle on the foregrounds.

A $23M proposal is under review by NSF (Astronomy and Physics) and DOE for the experiment. A relatively small level of support (~$2M) for Fermilab participation has been proposed. There is strong scientific interest in the Laboratory, both by experimentalists and theorists.

The Fermilab participation in QUIET II was positively reviewed by PASAG. Fermilab participation in QUIET II strongly satisfied the prioritization criteria of PASAG, and was therefore recommended in all funding scenarios. The PAC concurs. Fermilab would have a large and visible impact, both with key technical expertise on large-scale detector integration and on data analysis and interpretation. The Committee was impressed by the Fermilab QUIET II team.

Pending a positive result of the NSF/DOE review of the project, the Committee strongly supports the involvement of the Laboratory in QUIET II.

Dark Matter Effort

Deciphering the nature of dark matter is a central scientific problem at the intersection of cosmology, particle physics, and gravity. In particular, a number of arguments point to the possibility that dark matter could arise from particle physics at the TeV scale, and could be made of Weakly Interactive Massive Particles (WIMPs). These particles would concentrate in the halo of our galaxy and be detectable in underground laboratories through their scattering on a suitable target. Such direct detection requires detectors with keV energy sensitivity, ultra-low radioactive background, and active recognition of the nuclear recoils expected to be produced by the WIMPs. This approach is complementary to the search for WIMP annihilation products in the cosmos and WIMP production at colliders.

P-999 A Proposal to Operate the COUPP-60 Bubble Chamber at SNOLAB (Collar)

In this meeting, the Committee reviewed the COUPP program, an innovative approach based on room temperature bubble chambers maintained for hours in a metastable state. COUPP involves Laboratory scientists and postdocs, and is supported by Fermilab at a level comparable to CDMS. Particle interactions in the liquid lead to the formation of bubbles that are detected optically. This technology, so far demonstrated with 2-kg and 4-kg chambers, has the advantage of simplicity. Furthermore, the thermodynamic conditions can be chosen so that the detector is not sensitive to electron recoils, the main radioactive background. Neutrons are efficiently rejected through their multiple interactions. The main background originates from alpha particles, which deposit large enough energy density to create bubbles, and it is necessary to purify the liquid to levels comparable to Borexino (10^{-15} g/g of U/Th) and to use high purity silica as a container. Although the detector does not measure energy directly, a rough energy spectrum, and hence a WIMP mass estimate, can be obtained through the scanning of thermodynamic conditions. Although this results in the need for significantly more mass than for technologies directly measuring the energy spectrum (running over the same time period), the approach can, in principle, provide large masses very cheaply, more than compensating for this scanning penalty. Moreover, it has been shown recently that significant alpha rejection can be obtained through the acoustic detection of the bubbles, a promising advance that may allow the rejection of the remaining alpha background.

The specific proposal that was presented was for a 60-kg setup, which has been constructed and is nearly ready to be moved to a 300-meter-water-equivalent depth at the NuMI

hall on the Fermilab site. If operation there is successful and demonstrates low enough alpha background, the setup would be moved to SNOLAB. The Committee understands that there would be significant financial and technical support from SNOLAB. The project successfully underwent a Laboratory internal review.

If the alpha backgrounds are kept under control, COUPP could provide a major advance in sensitivity in the spin-dependent WIMP search (for unpaired protons) and reach sensitivity comparable to the currently published limits for spin-independent interactions. PICASSO, a similar technology but based on metastable droplets, is the main potential competitor for spin-dependent interactions. The proponents indicated that PICASSO has similar sensitivity goals. COUPP benefits from a homogeneous medium which may be easier to purify and from the visual detection of the bubbles. COUPP is investigating the acoustic rejection of alphas initially demonstrated by PICASSO.

The Committee strongly endorses this program, and enthusiastically recommends Stage I approval. The Committee stresses the importance of implementing the plan expeditiously in order to remain competitive with techniques that do not suffer from the scanning penalty (Ge, liquid xenon, and liquid argon). The Committee recommends rapid deployment at NuMI, and if the criteria are successfully met, installation in SNOLAB.

The Committee also stresses the need to address the issues identified by the internal review, such as the need for more rigorous project management.

P-1000 DarkSide (Galbiati)

The Committee reviewed the DarkSide proposal to develop a 50-kg 2-phase liquid-argon WIMP detector which measures both the far UV scintillation light and the ionization produced by particle interactions. This approach promises to achieve very high background rejection with the combined use of scintillation pulse shape information and the ratio of scintillation light to ionization. The program is based on two promising developments: the possibility of obtaining underground argon depleted in ^{39}Ar, and the use of QUartz Photon Intensifying Detectors (QUPIDs), an innovative hybrid phototube with extremely low radioactive background. The proponents also propose a borated liquid scintillator shield inside a water gamma shield, to efficiently detect neutrons from fission, or alpha-n from the remaining U/Th contamination of internal components and the surrounding rock, and from muon interactions. These innovative approaches may enable sensitivity gains beyond WARP and ArDM, reaching 10^{-45} cm^2 per nucleon in a three-year exposure. This will be competitive and complementary to CDMS, EDELWEISS, and the liquid xenon detectors (Xenon 100, LUX, and XMASS)

The Committee enthusiastically recommends Stage I approval for this interesting experiment. The Committee recommends that the team address two questions: Is 50 kg the optimal size for such a detector at this stage, and what are the advantages and drawbacks of each of the SNOLAB and Gran Sasso sites?

Dark Matter: Strategic Aspects

A presentation was also made to the Committee describing the MAX Collaboration R&D proposal (P-1001), a merging of the efforts to develop multi-ton liquid argon (closely related to the DarkSide experiment) and liquid xenon dark-matter detectors as part of the S4 solicitation associated with DUSEL.

With the above efforts and the long-term involvement of Fermilab in CDMS, the Laboratory will be centrally involved in three of the most promising technologies for the detection of WIMPs. This program is well aligned with the recommendations of PASAG. The Laboratory is positioning itself in a strategic way, not only for the second generation of dark matter experiments, but also for an important scientific component of the DUSEL program. The three programs have received NSF S4 awards (under the names GEODM, COUPP and MAX) for the engineering of experiments for DUSEL, and it is appropriate that Fermilab provides support for the preliminary design stages in a timely manner.