Appendix A. Steering Group Charge and Membership

In his remarks to HEPAP, Undersecretary Orbach requested a dialog with the HEP community: *"In making our plans for the future, it is important to be conservative and to learn from our experiences. Even assuming a positive decision to build an ILC, the schedules will almost certainly be lengthier than the optimistic projections. Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building the machine could take us well into the mid-2020s, if not later. Within this context, I would like to re-engage HEPAP in discussion of the future of particle physics. If the ILC were not to turn on until the middle or end of the 2020s, what are the right investment choices to ensure the vitality and continuity of the field during the next two to three decades and to maximize the potential for major discovery during that period?"*

With the encouragement of the Office of Science and the support of Professor Mel Shochet, the chair of HEPAP, Fermilab will develop a strategic roadmap for the evolution of the accelerator-based HEP program, focusing on facilities at Fermilab that will provide discovery opportunities in the next two to three decades. This roadmap should keep the construction of the ILC as a goal of paramount importance. To guide this proposal, the Fermilab Director has appointed a Steering Group consisting of members from Fermilab and the national particle and accelerator physics community to insure that the plan serves national needs. The Steering Group will also engage additional constituents in the analysis of the various physics opportunities.

The Steering Group will build the roadmap based on the recommendations of the EPP2010 National Academy report and the recommendations of the P5 subpanel of HEPAP. The Steering Group should consider the Fermilab based facilities in the context of the global particle physics program. Specifically the group should develop a strategic roadmap that:

1. supports the international R&D and engineering design for as early a start of the ILC as possible and supports the development of Fermilab as a potential host site for the ILC;
2. develops options for an accelerator-based high energy physics program in the event the start of the ILC construction is slower than the technically-limited schedule; and
3. includes the steps necessary to explore higher energy colliders that might follow the ILC or be needed should the results from LHC point toward a higher energy than that planned for the ILC.

I am asking Deputy Director Kim to chair the Steering Group. Any recommendations that might be relevant to the FY09 budget should be transmitted as early as possible. The Steering Group's final report should be finished and delivered to the Fermilab Director by

August 1, 2007. This deadline would allow for presentations to the DOE and its advisory bodies before the structuring of the FY2010 budget.

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Appendix B. Community Input on the Physics Opportunities

The Fermilab Steering Group was called by Director Pier Oddone in March, 2007. Subsequently, subgroups were formed to advise the Steering Group on the best physics opportunities that could be exploited at the new facilities under consideration. These subgroups were composed of members of the US HEP community, and drew upon university and laboratory scientists from within and outside of the Fermilab community.

To obtain input from a broad spectrum of the US particle and accelerator physics community, a number of steps were taken. Deputy Director Kim gave presentations and conducted "town hall" style sessions at meetings of all the major collaborations at Fermilab (CDF, DZero, MINOS, MINERvA, MiniBooNE, SciBooNE, NOvA), at US

CMS and ILC TTC meetings, at the June 6-7 Annual Users Meeting of Fermilab, at the June 7 Users Meeting at SLAC, and at major laboratory seminars (ANL, BNL, and SLAC), and has communicated to the US particle and accelerator community through the DPF and DPB. These sessions advised the community of the Steering Group's purpose, the process it would follow, and the mechanism by which it planned to advise the Fermilab Director, and to provide input to P5, HEPAP, and the funding agencies. In addition, the Steering Group invited input on physics possibilities from the community either in the form of letters or in brief, 1-page, expressions of interest. In its two months of existence, the Steering Group received over 16 expressions of interest and 7 letters. Input from the community has demonstrated that there is broad community interest in having a domestic facility which enables a strong US accelerator-based program.

Fermilab has a long history of community input into its physics program and in years past has held numerous Summer Studies to consider the best options for the new accelerators being developed at the Laboratory. Given the short time available for the Steering Group report, such a Summer Study was not possible, but will be conducted once the decision to provide R&D support for Project X goes forward. The full span of physics enabled by the proposed high-intensity source will be the subject of a future formal call for proposals. The precise prioritization of such experiments, however, will be elucidated by the Fermilab PAC, and advisory panels such as P5 and HEPAP convened by the funding agencies.

Neutrino Physics Group

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Precision Physics Group

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Appendix C. Neutrino Science with 8 GeV and 800 GeV Protons

This section lists experiments with neutrino beams that could be carried out at the proton facility. Possible long-baseline programs for neutrino oscillation and CP violation are excluded.

Neutrino Science Experiments with 8 GeV Protons

The excess of low energy electron-neutrino-like events recently observed by MiniBooNE must arise either from new physics, not compatible with simple 2-flavor oscillations, or from a new kind of background that is of importance for oscillation experiments operating in this energy range. An experiment dubbed microBooNE with excellent low energy sensitivity provided by a liquid argon time projection chamber (LArTPC) is proposed to study individual final states producing events in the region of excess. This experiment would also be an extremely valuable step in demonstrating the effectiveness of liquid argon TPCs for sensitive discrimination of backgrounds to neutrino interactions. If the experiment is sited in the MINOS surface building, it would be exposed to both the BNB to accomplish MicroBooNE. It would also be exposed to a very off-axis NuMI beam, providing useful study of low-energy neutrinos, although it may be desirable to have a LAr detector down in the NuMI tunnel to act as a NOvA near detector. Both detector sitings would produce useful neutrino scattering measurements relevant for oscillation physics, as well as scattering measurements of relevance for nuclear physics. Smaller scale LAr experiments like this can provide very useful experience toward potential long-baseline detectors.

The strange quark contribution to nucleon spin (Δs) can be extracted from neutral current elastic (NC-elastic) scattering in the Booster neutrino beam with higher precision and less model-dependence than in deep-inelastic scattering measurements. In addition to providing the strange quark piece of the proton spin puzzle, the Δs measurement has cosmological implications, as NC-elastic interactions dominate in core-collapse supernovae. At present, Δs results from polarized, inclusive, lepton deep-inelastic scattering and from semi-inclusive leptonic deep-inelastic scattering are not consistent with each other. Although given additional run time beyond that currently approved, the SciBooNE experiment could better measure the ratio of NC-elastic scattering to charged current (CC) scattering events, a fully sensitive experiment might require detector upgrades to SciBooNE. required sensitivity is currently being studied.

Neutrino-nucleus cross-sections in the low energy (tens of MeV) regime for a number of nuclear targets pertinent to the process of supernova core collapse can be studied using a neutrino beam generated from stopped pions produced by very intense proton beams of 1-2 GeV, and an experiment similar to NuSNS at the Spellation Neutron Source (SNS). In addition, coherent elastic neutrino-nuclear scattering could possibly be measured, providing a precision test of the Standard Model not possible at the SNS because of neutron backgrounds.

Neutrino Science Experiments with 800 GeV Protons

Exciting experiments using high energy neutrinos produced in a TeVatron fixed target neutrino beam line could be performed if sufficient 120 GeV protons from the Main Injector are available to feed both the long-baseline neutrino program and the TeVatron. For example, a precision measurement of the weak mixing angle θ_W using muon neutrino scattering on electrons performed with a high energy neutrino beam could probe Beyond the Standard Model (BSM) physics in a way complementary to other electroweak measurements. Tension that presently exists in global electroweak fits perhaps hints at BSM effects. Only measurements of the invisible width of the Z in electron-positron collisions probe the Standard Model in the same way. Such a measurement of θ_W could be performed by an experiment dubbed NuSOnG that would utilize a new spectrometer in a pure muon neutrino or anti-neutrino beam generated by 800 GeV protons from the TeVatron with a sign-selected quadrupole train (SSQT). A measurement of $\sin^2(\theta_W)$ in neutrino-electron scattering to 0.7% could be produced with 2×10^{20} POT. Such an experiment could not be performed by any other neutrino beam at Fermilab, CERN, or JPARC.

Upgrade to the Fermilab Proton Facility

During the era of NOvA operations, neutrino experiments in Booster or TeVatron neutrino lines cannot be supported without compromising NOvA physics, unless upgrades are made to the Fermilab proton accelerator complex. The sNuMI upgrade, which would increase the Main Injector beam power by approximately 50% to 1.1 MW, would increase the sensitivity and physics reach of the NOvA program. It would also increase the competitiveness of NOvA with its contemporary neutrino oscillation experiments. The sNuMI upgrade, however, would not provide adequate 8 GeV beam power available for experiments such as microBooNE or SciBooNE with upgrades. A precision electroweak neutrino experiment, such as NuSOnG, would require about 5% of the sNuMI 120 GeV beam power. Project X, on the other hand, would provide ample proton beam power to provide both a greater than three-fold increase in 120 GeV beam power for NOvA and future long-baseline experiments and more than ample 8 GeV beam power for neutrino experiments. The 120 GeV beam power available with Project X would also allow operation of a TeVatron fixed-target neutrino line without noticeable impact on the long-baseline neutrino program. Thus, Project X would enable a program of neutrino experiments that would not otherwise be feasible, while greatly enhancing the physics reach of long-baseline neutrino oscillation experiments.

Appendix D: Precision Physics at the Proton Facility

This section lists experiments with muon and kaon beams that could be carried out at the proton facility.

Precision Physics Experiments with Muon Beams

A muon to electron conversion experiment could be based on the detailed technical design of the MECO experiment that was planned to be run at the BNL AGS operating at

8 GeV. With low cost modifications to the current accelerator complex, this experiment would detect LFV if $R_{\mu e}$ ($\Gamma(\mu^- N \rightarrow e^- N)/\Gamma(\mu^- N \rightarrow \nu N')$) is as small as 2×10^{-17}. It would collect data for 2-3 years with little or no impact on the beam available for the neutrino program, based on current plans to upgrade the 120 GeV beam to ~700 kW. The Fermilab beam implementation would be superior to that planned for BNL due to better duty factor (>90% vs. ~50%), superior micro time structure, and more running per year.

The MECO design has been reviewed for cost and technical feasibility in detail, and a new experiment based on MECO could be developed into a reviewable project at Fermilab with about one year of effort. Physics results at sensitivity below 10^{-16} would follow 4-5 years of construction and 2-3 years of running. Upgrades to use a more intense beam following the SNuMI or Project-X construction would be studied and then implemented following the first physics running period.

Precision Physics Experiments with Kaon Beams

The "KTeV-II" experiment described below is designed to make a precision measurement of the $K^+\rightarrow\pi^+\nu\nu$ branching fraction that matches the small theoretical uncertainty. In parallel with $K^+\rightarrow\pi^+\nu\nu$ running, the KTeV-II experiment can probe many other decay channels including precision measurement of $K^+\rightarrow e^+\nu$ and $K^+\rightarrow\pi\mu e$ searches which are both uniquely incisive probes of BSM physics. The "KOPIO" experiment described below is designed to discover and measure the ultra-rare $K^0\rightarrow\pi^0\nu\nu$ decay process which is very sensitive to CP-violating BSM amplitudes. Several BSM models can be discovered or excluded on the road to the Standard Model expected $K^0\rightarrow\pi^0\nu\nu$ branching fraction of 3×10^{-11}. Upon acquiring the Standard Model sensitivity the experiment then becomes sensitive to very high mass scale (>1000 TeV/c^2) and extra-dimensional models through precision measurement of the $K^0\rightarrow\pi^0\nu\nu$ branching fraction.

The KTeV-II experiment is based on the conceptual design of the CKM experiment (Charged Kaons at the Main injector). Driving the experiment in the NuMI or SNuMI era with the high duty-factor Tevatron stretcher simultaneously reduces detector rates by x3 and the proton tax on the Main Injector neutrino program from 30% to 5%. The lower detector rates reduce the technical risk of the experiment and supports scaling of the CKM design to much higher sensitivity in the Project-X era. The high energy separated kaon beam based on ILC crab cavity technology drives this next step in ultra-rare K^+ sensitivity with samples of 100-200 $K^+\rightarrow\pi^+\nu\nu$ decays per year within reach. Project-X can further increase the rare-decay sensitivities by x3 while maintaining a small 5% tax on the Main Injector neutrino program. The CKM conceptual design has been technically reviewed in detail, and could be developed into a reviewable project with one year of effort. Several years (3-4) of funding and construction would then be necessary to start detector operations 5 years following a decision to proceed with this opportunity.

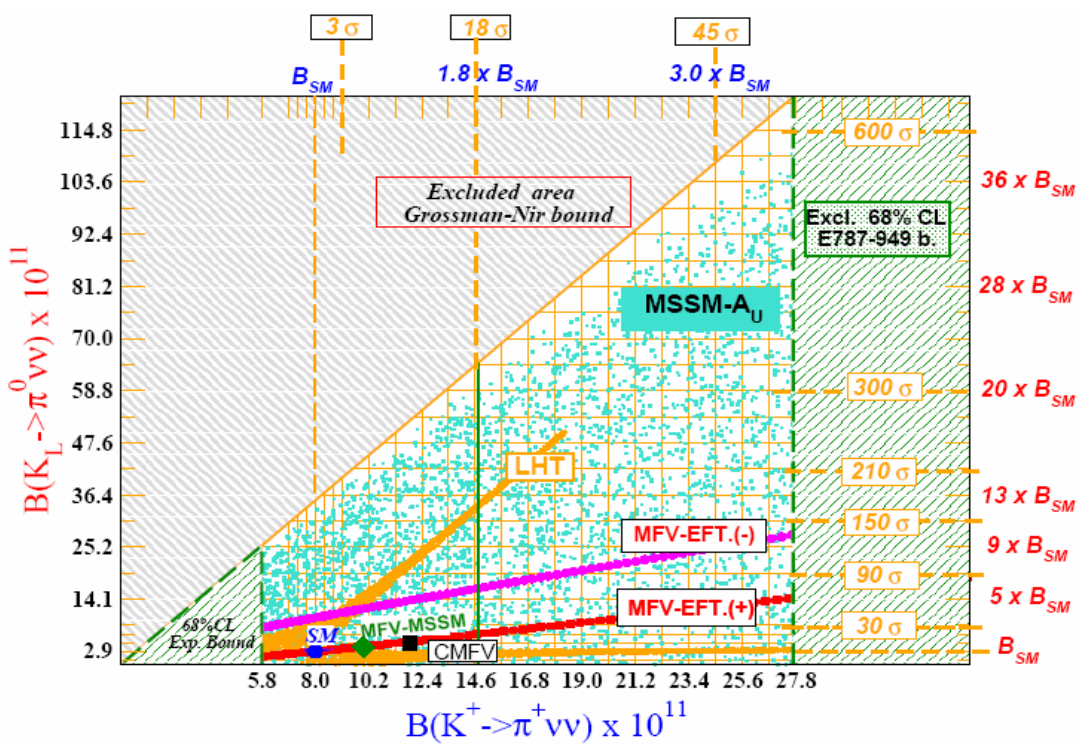

Illustration of the $K \rightarrow \pi\nu\nu$ sensitivity space for BSM physics compiled by F. Mescia for the CKM-2006 Workshop. The reach above the Standard Model in units of current (2007) theoretical certainty of the Standard Model prediction is indicated in orange, and is a space of about (50σ x 600σ) for (charged x neutral) modes. The current measurement of $K^+ \rightarrow \pi^+\nu\nu$ based on 3 events by the BNL E787-949 experiment is x1.8 the Standard Model prediction. Several BSM models are indicated: Minimal SUSY (MSSM), "Little Higgs Theories" (LHT), and "Minimal Flavor Violation" (MFV).

The experiment was originally designed and optimized for the BNL AGS 24 GeV proton source. The KOPIO proponents have estimated the K^0 flux at the Fermilab Booster energy of 8 GeV and have found the flux to be comparable to the BNL AGS. The limited proton intensity of the AGS drove the KOPIO design to an unusually large solid-angle kaon beam in order to collect sufficient kaon decays to measure the $K^0 \rightarrow \pi^0\nu\nu$ process. This large beam complicated the detector design and contributed technical risk to the experiment. The very large proton intensity of Project-X (x12 Booster intensity) motivates a re-optimization based on a much smaller solid angle beam which could deliver sufficient kaon decays. This smaller beam could significantly simplify the experiment and reduce technical risk. An experiment optimized for Project-X intensities could still have sufficient sensitivity to discover the $K^0 \rightarrow \pi^0\nu\nu$ process in early running during the NuMI (no Nova proton tax) or SNuMI (10% Nova proton tax) era using the Fermilab Booster as a proton driver. The lower intensities of the Booster driving a smaller kaon beam would provide a natural timeline to develop and commission this challenging experiment. The KOPIO conceptual design has been reviewed in detail, and could be developed into a reviewable project with one year of effort. Several years (3-4) of funding and construction would then be necessary to start detector operations 5 years following a decision to proceed with this opportunity.

Appendix F. Facilities Considered

The Steering Group considered about twelve facilities. The table below lists the facilities that were not described in Section 4.

Facility	Description	Performance Parameters	Physics Program	ILC Synergy
Proton Facilities				
LHC Luminosity Upgrade	Luminosity Upgrade based on high performance IR quadruoples based on Nb_3Sn technology.	$L>1\times10^{35}$ $cm^{-2}sec^{-1}$	High energy frontier	No
Proton Complex Upgrade	New 8 GeV Booster fed by a new 1 GeV linac	2.3 MW beam power at 120 GeV (23×10^{20} protons/year) 8 GeV slow spill available by diverting protons from the 120 GeV program	Neutrino science and Precision Physics	No
Antiproton Facility	Continued operations of the Antiproton Source	2×10^{11} protons/hour at 8 GeV. Operated in storage mode. Incompatible with SNuMI. Minor hit on proton availability from Project X.	Precision physics	No
High Energy, High Power ν Beam	480 GeV dual aperture accelerator constructed in the Tevatron tunnel. Based on superferric magnet.	~5 MW beam power at 480 GeV (25×10^{20} protons/year)	Neutrino Science	No
Electron Facilities				
6 GeV ILC Linac	ILC 1% systems test in ILC like tunnel	ILC beam parameters 9ma x 1ms x 5Hz	NA	Yes
Giga-Z	90 GeV linear collider based on ILC technology	10^9 Z's $L>1\times10^{33}$ $cm^{-2}sec^{-1}$	Precision Physics	Yes
Super B Factory (*)	Asymmetric (4 GeV × 7 GeV) e+e- collider in the Tevatron tunnel	$L>1\times10^{36}$ $cm^{-2}sec^{-1}$	Precision Physics	No, unless converted ILC Damping Ring
ILC Damping Ring	5 GeV ILC damping ring in the Tevatron tunnel.	ILC Damping Ring Parameters	NA, unless converted to use as B factory	Yes

* B physics with Super B Factory A second generation B factory with luminosity above $10^{36}/cm^2/s$ providing data samples of 50-100 ab^{-1} can explore a wide range of physics

beyond the Standard Model. In many scenarios, the physics reach extends beyond the TeV scale and the pattern of deviation from Standard Model predictions can help distinguish between models. The possibility of constructing a super-B factory at Fermilab should be re-examined sometime around 2012 in light of LHC discoveries, progress on ILC development, and worldwide plans for super-B factories elsewhere.