Executive Summary

The physics program that could be pursued at a high-energy lepton collider has captured the imagination of the world high energy physics community. A lepton collider with sufficient energy and luminosity would facilitate:

- understanding the mechanism behind mass generation and electroweak symmetry breaking
- searching for, and perhaps discovering, supersymmetric particles and confirming their nature
- hunting for signs of extra space-time dimensions and quantum gravity.

Past studies have motivated lepton colliders with multi-TeV center-of-mass energies and luminosities of the order of 10^{34} $cm^{-2}s^{-1}$. Physics results obtained from CERN's Large Hadron Collider on the time scale of ~2013 are expected to establish the desired energy for the next lepton collider and refine our knowledge of the required luminosity. The Particle Physics Project Prioritization Panel (P5) has recommended[a] *"…R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established."* At present, the alternatives for a multi-TeV collider are: *a*) a $\mu^+\mu^-$ collider (MC); *b*) a normal-conducting RF e^+e^- linear accelerator (X-band NLC-type or two-beam CLIC-type); or *c*) a plasma wakefield e^+e^- linear accelerator driven either by lasers or by short electron bunches. Since muons—being much heavier particles than electrons—emit negligible synchrotron radiation, the MC promises superior attributes in a number of areas compared with either e^+e^- scheme. The absence of synchrotron radiation allows high-energy muon bunches to be stored in a compact collider ring, so a MC complex would fit conveniently on the site of an existing laboratory, e.g., Fermilab. Moreover, the radiation of particles in the collision of muon bunches is orders of magnitude lower than in e^+e^- collisions, and hence the $\mu^+\mu^-$ collisions would be more monochromatic. These attributes could well prove decisive in selecting the technology of the lepton collider to follow LHC.

To achieve the desired luminosity, a MC will need a muon source capable of delivering $O(10^{21})$ muons per year within the acceptance of an accelerator. In addition to facilitating a MC, a muon source with this capability[b] would also enable a new type of neutrino facility in which muons decaying in a storage ring with long straight sections produce a neutrino beam with unique properties. It has been shown that the resulting Neutrino Factory (NF) would deliver unparalleled performance in studying neutrino mixing and provide tremendous sensitivity to new physics in the neutrino sector. Both the MC and NF require similar—perhaps identical—front ends, and hence much of their associated R&D is in common.

Muon Collider and Neutrino Factory R&D has been supported in the U.S. for the last decade. The main R&D accomplishments include: *a*) the construction and successful

[a] See http://www.science.doe.gov/hep/files/pdfs/P5_Report%2006022008.pdf

[b] Prospects for a MC and/or a NF in the U.S. have recently improved due to the possibility of launching an 8 GeV SC RF proton linac project (Project-X) at Fermilab, since the upgraded linac could serve as the required proton driver.

completion of an international proof-of-principle MC/NF high-power target experiment (MERIT); *b*) the launching of an international muon ionization cooling experiment (MICE); and *c*) a series of MC and NF design and simulation studies that have progressively improved the performance and cost-effectiveness of the simulated NF design and prepared the way for a corresponding MC end-to-end design and initial cost estimate. Neutrino Factory R&D is now being pursued by an international community that has launched the "International Design Study of a Neutrino Factory (IDS-NF)", and aspires to deliver a Reference Design Report (NF-RDR) for a baseline design by 2012. The U.S. MC and NF R&D community is making key contributions to many aspects of the IDS-NF, with an emphasis on those common to both MC and NF designs. Since a MC requires a much more ambitious muon cooling scheme, MC R&D is less advanced. Present MC cooling channel designs employ components with assumed performance that in some cases has not yet been achieved.

The long-term MC development plan presented to P5 comprises three important steps toward bringing the high-energy physics frontier back to the U.S.: *i*) a study to demonstrate MC feasibility by 2013; *ii*) a subsequent program of muon beam demonstration experiments, component tests, and prototyping over the following 7–10 years; and *iii*) the start of MC construction in the early to mid 2020s. In parallel with this MC effort, the medium-term Neutrino Factory development plan presented to P5 comprises: *i*) completing the MICE experiment and participating in the IDS-NF to deliver a NF-RDR by 2012; and (assuming the community wishes to proceed) *ii*) pre-construction R&D for the next few years with an option to begin construction in the late 2010s. This document describes a proposal for a unified, national Muon Accelerator R&D program for the coming 5 years (2009–2013)—the first step in the plan presented to P5.

The main deliverables of the national Muon Accelerator R&D program will be:

1. A Design Feasibility Study Report (DFSR) for a multi-TeV MC including a physics and detector study that refines our understanding of the required performance and documents the associated physics reach, an end-to-end simulation of the MC accelerator complex using demonstrated, or likely soon-to-be demonstrated, technologies, a defensible cost estimate, and an identification of further technology R&D that should be pursued to improve the performance and/or the cost effectiveness of the design.

2. Component development and experiments that are needed to inform the MC-DFSR studies, and enable an initial down-selection of candidate technologies for the required ionization cooling and acceleration systems.

3. Participation in the International Neutrino Factory Design Study (IDS-NF) to produce a Reference Design Report (RDR) for a NF by 2012. The emphasis of the proposed U.S. participation is on: *a*) design, simulation and cost estimates for those parts of the NF front-end that are (or could be) in common with a MC; *b*) studying how the evolving Fermilab proton source can be used for the Neutrino

Factory RDR design; and *c*) studying how the resulting NF would fit on the Fermilab site.

The present annual level of support for all MC- and NF-related R&D in the U.S. is about $7M. The projected funding for the 5-year program proposed here reaches about $22M/yr, i.e., a threefold increase (see table below). With this increased support[c], we expect to demonstrate feasibility of the MC based on a credible design, an end-to-end simulation of the full accelerator complex, and a first cost estimate. We will also accomplish sufficient hardware R&D (RF, magnets, and cooling section prototyping) to guide, and give confidence in, our simulation studies.

Previous-year (FY08) support for the NF and MC R&D, and the requested level of support for the unified national 5-year plan of the Muon Accelerator R&D program.

	FY08	FY09	FY10	FY11	FY12	FY13
Effort (FTE)	37	48	79	81	79	43
SWF ($M)	5.5	9	14	15	15	8
M&S ($M)	1.6	4	7	7	6	4
Total ($M)	7.1	13	21	22	21	12

The program is foreseen to comprise participants from the three sponsoring U.S. laboratories (BNL, FNAL, LBNL) and a number of other U.S. laboratories, universities and SBIR companies. Significant international collaboration with the UK, and with other countries, to understand, develop and exploit the accelerator science and technology of muon accelerators is also anticipated. Most of the support is envisioned to come from the DOE/OHEP Accelerator Science budget, with small (~12%) contributions from the DOE/OHEP Detector R&D budget and from the DOE SBIR/STTR and University grants.

By ~2013 we expect that new physics results from the LHC and from the next generation of neutrino experiments (Double Chooz, Daya Bay, T2K, and Nova) will be available. These will provide the worldwide HEP community with the knowledge it needs to identify which types of facilities are best suited to fully exploit the exciting new physics opportunities that will undoubtedly arise. In particular, we expect that the physics cases for both a multi-TeV lepton collider and a Neutrino Factory will be more fully understood in this time frame. Our proposed work will give clear answers to the questions of expected capabilities and performance of muon-based facilities, and will provide defensible estimates for their cost. This information will allow the HEP community to make well-informed decisions regarding the optimal choice of new facilities. We believe that this work is an absolutely critical part of any broad strategic program in accelerator R&D and, as the P5 panel has recently indicated, is essential for the long-term health of high-energy physics.

[c]The present level of support will only suffice to enable us to meet our existing commitments to the international R&D program, namely MICE and the IDS-NF, and to pursue a reduced-scope version of the RF R&D program described in our proposal.