Group M1 Response to the Snowmass 2001 Charge

Working Group M1: Muon-Based Accelerators
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A worldwide effort is under way to elucidate the unique particle physics opportunities presented by intense muon beams and the neutrino beams derived from their decay. Groups in the US, Europe, and Japan are engaged in a vigorous R&D program aimed at resolving the critical machine and beam design issues for both a Neutrino Factory based on a muon storage ring and a Muon Collider. To make progress in a time frame compatible with the needs of the physics program requires adequate R&D support; for the US program this is about $15M per year.

Physics Motivation and Staging Scenario: Recent experimental results have confirmed neutrino oscillations as the only established example of physics beyond the standard model. The most effective way to fully explore the new physics is to construct a Neutrino Factory—this is our goal. However, to start immediately on the physics program, and to permit progress with a lower peak funding requirement, the neutrino physics community has developed a staged construction scenario that progresses rapidly toward a better understanding of neutrino oscillations, Higgs physics, and, ultimately, multi-TeV physics. The stages are:

1. a neutrino "superbeam" from a high-intensity (1–4 MW) proton driver;
2. a low-emittance, low-energy-spread muon beam at 200 MeV/*c*;
3. a roughly 3 GeV muon beam;
4. a Neutrino Factory based on a 20–50 GeV muon storage ring; and finally
5. a Muon Collider operating as a Higgs Factory or at higher energy.

The US Neutrino Factory and Muon Collider Collaboration R&D activities support this program.

With a modest investment of resources, the first stage of this scenario could begin quickly (within 2–3 years) at either BNL or Fermilab. We believe that this initial stage should be included as a high priority item in the near-term plans of the community, as it will advance high-intensity meson and muon studies as well as neutrino physics. Later stages of the scenario will further advance a variety of muon studies sensitive to new physics at high mass scales. Depending on the outcome of upcoming neutrino experiments (especially MiniBooNE and KamLAND), the subsequent upgrade of the facility into a Neutrino Factory could allow definitive studies of the parameters of neutrino mixing and CP violation; the physics case for this stage should solidify within the next few years. Stage 5 should be undertaken if further physics studies, technology R&D, and experimental results establish a Muon Collider as both feasible and desirable. Our vision is that the above scenario will ultimately be adopted and carried out by a national laboratory or international collaboration.

Accelerator Physics and Technology Issues: For a Neutrino Factory, key accelerator physics and technology issues include the development of: targets capable of handling a proton beam power of 1–4 MW; radiation-resistant solenoids or focusing horns; cost-effective longitudinal manipulation and ionization cooling techniques for reducing transverse emittance; and rapid and efficient acceleration techniques that accommodate large longitudinal and transverse beam emittances. Validating the design parameters arising from Feasibility Studies I and II (sponsored by Fermilab and BNL, respectively) involves testing of high-field, large-bore solenoids, high-gradient rf cavities (both normal-conducting, NC, and superconducting, SC), high-power LH_2 energy absorbers, induction linac units, and beam diagnostics devices. Good progress is being made in all areas. Continued development of sophisticated simulation tools to evaluate system performance and analytical theories to guide the design effort are crucial items in our work.

For a Muon Collider, the same issues are relevant, but requirements are more severe. Emittance reduction must include longitudinal cooling ("emittance exchange") and demands 6D cooling several orders of magnitude beyond that needed for a Neutrino Factory. Current Muon

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Collider scenarios require beams of μ^+ and μ^- with single-bunch intensities of $\approx 10^{13}$ muons, leading to potential space-charge effects. Additional technologies required for a Muon Collider may include: a ring cooler, a helical wiggler, or a bent-solenoid channel for longitudinal cooling; wedge-shaped absorbers; lithium lenses; and higher-frequency rf cavities for the later stages of cooling as well as for acceleration. The collider ring requires a low β^*, although not beyond today's achievements, a nearly isochronous lattice, and an interaction region design that minimizes backgrounds from muon decay products. Progress is being made, but significant R&D will be needed to reduce these challenges to engineering problems.

Evolution from Neutrino Factory to Muon Collider: The technically simpler Neutrino Factory is a step toward a Muon Collider. Many of the difficult technical aspects of the collider would be addressed in constructing a Neutrino Factory. Whether a Neutrino Factory can, or should, be converted to a Muon Collider is presently under study. Clearly, cost savings would result if Neutrino Factory components could be reused for the collider.

R&D Time Scale and Risks: A detailed R&D plan for the Neutrino Factory has been developed. With adequate funding ($15M per year), the technical work needed to begin a CDR requires about 5 more years; with less funding the program would take longer. We are confident that this program will be successful. The required solenoids are within today's capabilities. NC rf cavity gradient parameters are aggressive and must be demonstrated, but other pulsed rf systems have worked in a similar parameter regime. The same can be said of the LH_2 absorbers, at least at the 1-MW intensity level. The SC rf cavity parameters for the acceleration section are likewise aggressive and must be tested. However, there is every reason to expect that a suitable technical solution can be found.

The time scale for the Muon Collider R&D program is less certain; it depends on developing practical techniques for longitudinal cooling and for more transverse cooling than is needed for a Neutrino Factory. An assessment of the time scale awaits R&D activities that will happen over the next several years.

International Activities: We are in close contact with groups in Europe and Japan working on alternative approaches to intense muon beams. At the present level of understanding, all approaches look viable, and more detailed studies and cost estimates will be required to identify the best approach. Because the Japanese FFAG scheme does not lend itself easily to cooling, it may advance only some of the technologies needed for a Muon Collider. The time scale for a European Neutrino Factory is comparable to what we envision in the US. As is the case in the US, the European R&D program is resource limited. They do not expect to be ready for project approval until after the LHC financial commitment ends. The Japanese proton driver is approved and will be ready in 2007; it is not known when the beam will become available for neutrino production. A start on a Japanese Neutrino Factory is hoped for in the same time frame as for the other regions. To our knowledge, neither Europe nor Japan is currently contemplating a Muon Collider.

Cooling Experiment: Though the physics of the cooling process is well understood, and we have done detailed simulations of the process with several independent computer codes, it is prudent to demonstrate cooling, and the required component performance, in a realistic setting. We plan an international cooling demonstration experiment involving our colleagues in Europe and Japan. As presently envisioned, the initial phase would cost in the neighborhood of $10–20M, to be shared among the three regions. We hope to begin taking data in 2004 if funding is made available.

Muon Collider Performance: As discussed above, the technical and physics performance of the Muon Collider cannot yet be quantified. Continued R&D support over the next few years will permit doing so.