I. THE PHYSICS POTENTIAL OF MUON COLLIDERS

The physics opportunities and possibilities of muon colliders have been well documented in the Feasibility Study [1] and other papers, see ref. [2]. This section begins with a brief overview of the current theoretical and experimental status of High Energy Physics (HEP), then summarizes the contributions that muon colliders could make to extending our knowledge of elementary particles physics.

A. Brief Theoretical Overview

We could summarize the current status of HEP by stating that the observed pattern of properties of all known elementary particles has been accurately characterized by the standard model (SM), a well tested but cumbersome phenomenological theory containing 19 independent experimentally determined parameters. However, the SM is known to be an incomplete theory that gives inconsistent predictions when extrapolated to experimentally inaccessible mass scales, and even its predictions for the next generation of collider experiments are uncertain.

Today's colliders have reached the threshold of an extremely interesting and fundamental mass scale in the SM: the electroweak symmetry breaking (EWSB) scale – at masses of order 100 GeV to 1 TeV. In the SM this is associated with the origin of the masses of all elementary particles through the so-called Higgs mechanism.

Recent collider experiments have already discovered and studied two of the three particles predicted by the SM at the EWSB mass scale, namely, the W and Z bosons that are the carriers of the weak force. However, the Higgs boson itself – the particle thought to be directly responsible for particle masses – still eludes detection.

Because the SM is known to be only an incomplete and phenomenological theory, we simply do not know if its prediction of a single Higgs particle at the EWSB scale is correct. In contrast, the most popular class of alternative theories, known as supersymmetric theories (SUSY), predict the possibility of an entirely new and rich spectrum of particles at this mass scale, including perhaps 5 types of Higgs bosons [2].

B. Potential Capabilities of Current Colliders

The discovery of the Higgs particle, if its mass is low enough, might be possible in the next few years at the LEP collider at CERN or at the FNAL Tevatron. Both of these colliders are currently taking data. Beyond this, the most powerful collider currently under construction is the Large Hadron Collider (LHC) at the European laboratory CERN, a proton-proton collider at 14 TeV center-of-mass (CoM) energy. The LHC is scheduled for completion in 2005 and will probably discover the Higgs boson if it exists and has not already been discovered elsewhere.

The LHC and other proton colliders offer the most established technology for reaching the high energy frontier of elementary particles. However, the physics potential of proton colliders is somewhat compromised because protons themselves are not elementary particles. The interesting physics interactions take place between their quark and gluon sub-components, so only a fraction of the CoM energy is available in each interaction and the interpretation of the interaction is more difficult. Further, the very large proton-proton cross section for soft interactions – of order 100 millibarns – produces an enormous event rate, so the interesting physics events must be disentangled from a huge pile-up of uninteresting background events. This problem becomes more acute at higher energies where the falling fundamental cross sections should dictate higher luminosities leading to even higher event rates and radiation levels.

C. The Need for Muon Colliders

Because of the experimental difficulties associated with proton colliders and the potential for other physics processes not explored in proton collisions, a strong case can be made for the complementary physics studies that can be done at high energy lepton colliders – either muon colliders or linear electron-positron colliders.

The physics reach of the two types of lepton colliders has a large overlap, but there are also differences. Some of these differences result from differences in the physics processes, while others result from the completely different technical specifications of the colliders. Thus, their potential roles are also somewhat complementary, and studies at a muon collider would be able to provide important additional information, even if a new high energy linear electron collider were built. An example of this is the unique potential of muon colliders for very narrow CoM energy spreads that makes them particularly suited for both resonance production and threshold studies of elementary particles at energy scales of around 100 GeV and above.

D. Additional Physics Possibilities with Muon Beams

Further types of hybrid colliders become possible with the addition of muons to the menu of high energy particle beams. One possibility which is generating increased interest is muon-proton colliders [3]. This becomes a natural extension when a muon collider complex is built at a site already including a high energy proton machine, such as FNAL, CERN or DESY.

Additional collider possibilities that have been considered are same-sign muon colliders ($\mu^-\mu^-$ or $\mu^+\mu^+$) [3] or even muon-electron colliders.

The intense beams of muons and neutrinos in the complex also offer many opportunities for new physics. Rare muon decay or conversion experiments would be ideally suited for such a facility, while the neutrino beams might be several orders of magnitude stronger than existing beams. Neutrino studies [4,5] that could be greatly extended with such uniquely powerful beams include searches for neutrino oscillations, precise indirect measurements of the W boson mass and measurements of nucleon structure functions and the parameters of the CKM matrix. These and other areas of research have been recently summarized [6].

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[1] Muon Collider Collaboration, in *Proceedings of the 1996 DPF/DPB Summer Study on High-Energy Physics Snowmass'96,* New Directions for High-Energy Physics (Stanford Linear Accelerator Center, Menlo Park, CA, 1997), for updated information, see the Muon Collider Collaboration WEB page at the URL, http://www.cap.bnl.gov/mumu/. See Ref. [8].

[2] V. Barger M. Berger J. Gunion et al., a collection of all relevant papers is listed at the URL http://www.fnal.gov/projects/muon_collider/physics/physics.html.

[3] Presentations at the Workshop on Physics at the First Muon Collider and at the Front End of the Muon Collider, FNAL, Nov. 1997; available at the URL http://fnphyx-www.fnal.gov/conferences/femcpw97/plenary/talks.html.

[4] S. Geer, presentation at the Workshop on Physics at the First Muon Collider and at the Front End of the Muon Collider, FNAL, Nov. 1997; available at the URL http://www.fnal.gov/projects/muon_collider/talks/steves_nu_talk.ps.

[5] B. King, presentation at the Workshop on Physics at the First Muon Collider and at the Front End of the Muon Collider, FNAL, Nov. 1997; available at the URL http://pubweb.bnl.gov/people/bking/sf97.

[6] set of transparencies from the Workshop on Physics at the First Muon Collider and at the Front End of the Muon Collider, FNAL (unpublished) (1997).

[7] R. B. Palmer A. Sessler and A. Tollestrup, in *Proceedings of the 1996 DPF/DPB Summer Study on High-Energy Physics Snowmass'96,* New Directions for High-Energy Physics (Stanford Linear Accelerator Center, Menlo Park, CA, 1997).