A Muon Collider as a Higgs Factory

David B. Cline*
University of California, Los Angeles
Gail G. Hanson†
Indiana University, Bloomington, Indiana

The first muon collider would be the best accelerator at which to study a light Higgs boson, suggested by experimental evidence. A new study is outlined here to develop a muon collider Higgs Factory using the results of recent feasibility studies for muon storage rings as neutrino factories and R&D on emittance exchange needed for longitudinal cooling at a high luminosity muon collider.

1. Physics of a Higgs Factory

Indirect information about the mass of the Standard Model Higgs boson can be obtained from fits to the precision electroweak data taken at the Z^0 resonance at LEP and the SLC, including the measured values of the top quark and W boson masses and neutrino–nucleon scattering data, which give [1] $m_H < 196$ GeV at 95% C.L. The recent likelihood analysis [2] of combined data from direct searches for the Standard Model Higgs boson at LEP2 shows a preference for a Higgs boson with a mass of 115.6 GeV, at which mass the probability for the background to generate the observed effect is 3.4%. The lower bound obtained is $m_H > 114.1$ GeV at 95% C.L. (115.4 GeV expected). The data favor a light Higgs boson.

Experiments at the Fermilab Tevatron and the LHC will determine whether there is such a light Higgs boson. If only one light Higgs boson is observed, it will be crucial to measure its properties to infer whether it is a Standard Model or supersymmetric Higgs [3, 4, 5, 6]. At a muon collider [7] the Higgs boson is produced through the s-channel, giving a production cross section that is much larger than at an e^+e^- linear collider, as shown in Figure 1 [6]. The small beam energy spread, with beam energy measurement to $\sim 10^{-6}$ using $g-2$ spin precession [8], will allow a measurement of m_H to a few hundred keV and a direct measurement of the width to about 1 MeV. The CP properties of the Higgs bosons can be measured through asymmetries with transversely polarized beams [9]. The large coupling to $\mu^+\mu^-$ may be necessary to observe heavy MSSM Higgs bosons.

A Higgs factory muon collider is also a step towards a high energy (3–4 TeV) muon collider.

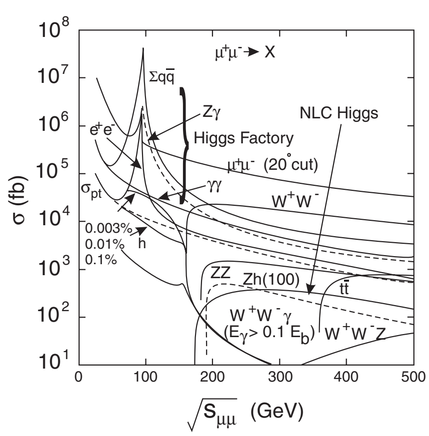

Figure 1: The cross sections as a function of energy for e^+e^- interactions and $\mu^+\mu^-$ interactions producing a Higgs boson and other systems.

*Electronic address: dcline@physics.ucla.edu
†Electronic address: gail@indiana.edu

2. A Scheme to Convert a Neutrino Factory to a Higgs Factory

We consider the possibility of staging the Neutrino Factory Muon Collider program by converting as much as possible of a Neutrino Factory to a Higgs Factory [9]. We take the example of Study II of the MC group to use BNL for the Neutrino Factory [10]. Figure 2 shows this current scheme. We show in Figure 2 that the addition of three rings may lead to the required beam properties and cooling for the Higgs Factory. The cooling is a major challenge. In Figure 3 we show the required longitudinal and transverse emittance for the Higgs Factory [9].

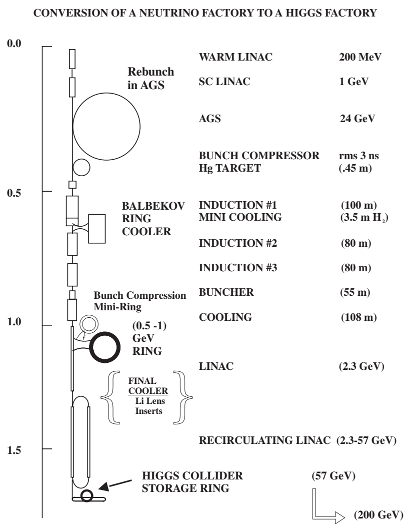

Figure 2: Scheme for converting a Neutrino Factory to a Higgs Factory.

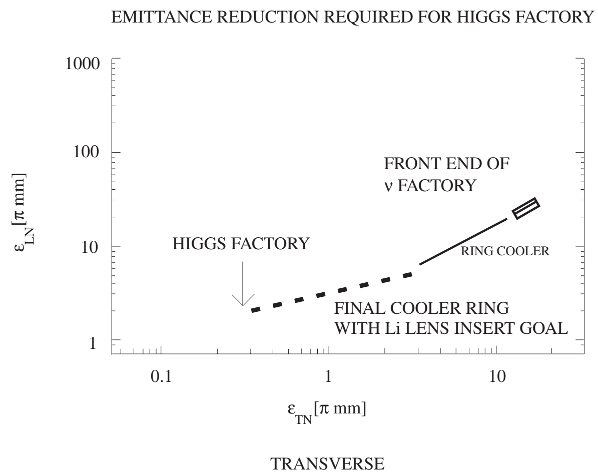

Figure 3: Emittance reduction needed for a Higgs Factory.

Table I Baseline parameters for Higgs factory muon collider. Higgs/year assumes a cross section of 5×10^4 fb, Higgs width of 2.7 MeV, 1 year = 10^7 s. From [7].

COM energy (TeV)		0.1	
p energy (GeV)		16	
p's/bunch		5×10^{13}	
Bunches/fill		2	
Rep. rate (Hz)		15	
p power (MW)		4	
μ/bunch		4×10^{12}	
μ power (MW)		1	
Wall power (MW)		81	
Collider circum. (m)		350	
Ave bending field (T)		3	
rms $\delta p/p$ (%)	0.12	0.01	0.003
6D $\varepsilon_{6,N}$ $(\pi \mathrm{m})^3$	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}
rms ε_n (π mm mrad)	85	195	290
β^* (cm)	4.1	9.4	14.1
σ_r spot (μm)	86	196	294
σ_θ IP (mrad)	2.1	2.1	2.1
Tune shift	0.051	0.022	0.015
n_{turns} (effective)	450	450	450
Luminosity (cm^{-2} s^{-1})	1.2×10^{32}	2.2×10^{31}	10^{31}
Higgs/yr	1.9×10^3	4×10^3	3.9×10^3

3. Parameters of the Higgs Factory

The projected parameters of the Muon Collider Higgs Factory are given in Table I [7, 9]. The key to achieving these parameters is the final cooler as described in the next section.

4. Balbekov Ring Cooler and a Storage Ring Final Cooler

The keys to the conversion of a Neutrino Factory to a Higgs Factory are shown in Figure 2. We consider these two rings to be a Balbekov Cooler Ring [11] and a Storage Ring Cooler [9, 12].

The basic concept is that the Balbekov ring (Figure 4) reduces the emittance as shown in Figure 3 to a level that allows the beam to be injected into a storage ring cooler (Figure 5). This final cooler ring could have lithium lens inserts or hydrogen wedges as shown. Four such cooling modules could be placed in each long straight section of a 1 GeV 300-m racetrack-shaped storage ring, taking and restoring 240 MeV from the particles each turn.

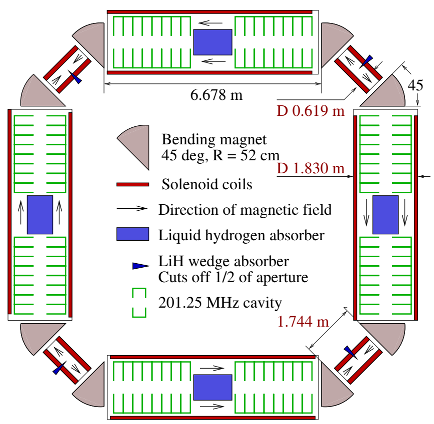

Figure 4: The Balbekov cooling ring.

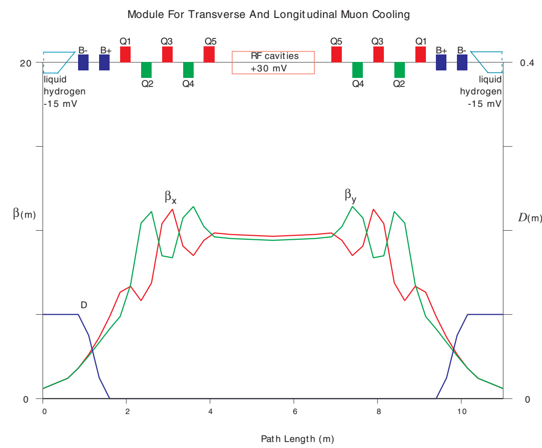

Figure 5: Cooling module of a storage ring cooler.

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