A MUON COLLIDER AS A HIGGS FACTORY

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Abstract

Evidence from the LEP experiments for a Higgs boson at a mass of 115 GeV has recently been presented at CERN [1]. The first muon collider would be the best accelerator at which to study such a Higgs boson. The cross section for direct Higgs production is much larger than the associated production with a Z, which is an advantage for the muon collider. The storage ring would be 350 meters in circumference with a luminosity of 2×10^{31} cm^2 s^{-1} and an energy spread of 0.0001 [Δ E/E]. Feasibility studies for muon storage rings as neutrino factories have been undertake. In addition, further R&D has been done on emittance exchange needed for longitudinal cooling at a high luminosity muon collider. Using the results of these R&D efforts, a new study to develop a muon collider Higgs factory is underway. The current status of this study will be presented.

1 PHYSICS OF A HIGGS FACTORY

The major purpose of the Higgs factory is to find the exact Higgs mass (or masses) and then measure the important parameters, such as the width(s) and the common and rare branching fractions [2,3,4,5]. This concept is based mainly on a relatively low-mass Higgs (below 300 GeV). In the low-mass region (below 150 GeV), the Higgs could well be supersymmetric (SUSY), and the width measurement will be crucial. Above 150 GeV, the Higgs could be more of a standard-model type. However, this will once again lead to the issue of what keeps the scalar system stable, which might be answered by the study of rare decays of the Higgs particles (in progress). In the near future, there could be evidence for the Higgs mass obtained from precise electroweak parameter measurements and later from the LHC. (Recent results from LEP2 are not fully conclusive [6].) This will be a crucial input for the development of the Higgs factory. In addition, if Nature is supersymmetric, there will be additional SUSY-Higgs particles to study and, thus, the Higgs factory concept will include the search for and study of the SUSY Higgses. This is an experimental issue; theory can only take us just so far!

From all we now know about elementary particle physics, the scalar or SUSY scalar sector is the key to future understanding. A complete understanding of this sector is really the goal of the Higgs factory and of nearly all elementary particle physics these days. The Higgs factory is designed to first give the exact Higgs mass using an energy scan and then measure the general properties of the Higgs, such as the total width, largest branching fractions, etc. It would produce 10^4 6 4×10^3 Higgs/yr and could investigate rare branching modes. If there are more Higgses, the Higgs factory would be used to scan and find and study these in detail as well (see Table 1).

We expect the supercollider LHC to extract the signal from background (i.e., seeing either $h^0 \to \gamma\gamma$ or the very rare $h^0 \to \mu\mu\mu\mu$ in this mass range, since $h \to b\bar{b}$ is swamped by hadronic background). However, detectors for the LHC are designed to extract this signal. In this low mass region, the Higgs is also expected to be a fairly narrow resonance and, thus, the signal should stand out clearly from the background from

$$\mu^+ \mu \to \gamma \to b\bar{b} \quad . \tag{1}$$

For masses above 180 GeV, the dominant Higgs decay is

$$h^0 \to W^+W^- \text{ or } Z^0Z^0 , \tag{2}$$

and the LHC should easily detect this Higgs particle [4,5]. Thus the $\mu^+ \mu^-$ collider is better adapted for the low mass region.

In Fig. 1, we show a comparison of the Higgs factory $\mu^+ \mu^-$ collider and an $e^+ e^-$ collider (NLC) that could also study the Higgs [5]. Note the very great differences in cross sections, indicating that the $e^+ e^-$ collider must have very high luminosity. There is also a possibility to search for CP violation in the Higgs sector as we discussed at a recent UCLA workshop [6]. The machine research reported here came from the following: V. Balbekov, A. R. Fernow, Y. Fukui, A. Garren, C. Johnstone, D. Neuffer, A. Sessler, and D. Summers.

Table 1. Logic of Detailed Study of the Higgs Sector.

If particles in the scalar sector are ever discovered, it will be essential to determine their properties, which will give direct information about the nature of the particle and the underlying theory. Three simple examples can be cited:

1. Suppose a Higgs-like particle is discovered with mass 120 GeV. This could either be the standard model (SM) Higgs or an SM Higgs. A measurement of the width of the state would presumably tell the difference. However, the SM width is 5 MeV, a formidable measurement!
2. Suppose a Higgs-like particle is discovered with a mass of 160 GeV. This is presumably beyond the MSSM bound, but it could be an NMSSM or an SMHiggs. Ameasurement of the width could presumably resolve the issue.
3. Suppose a Higgs-like particle of mass 180 GeV is discovered. This is presumably even beyond the NMSSM limits. If this is an SM Higgs, can we learn more by the study of the rare decay modes?

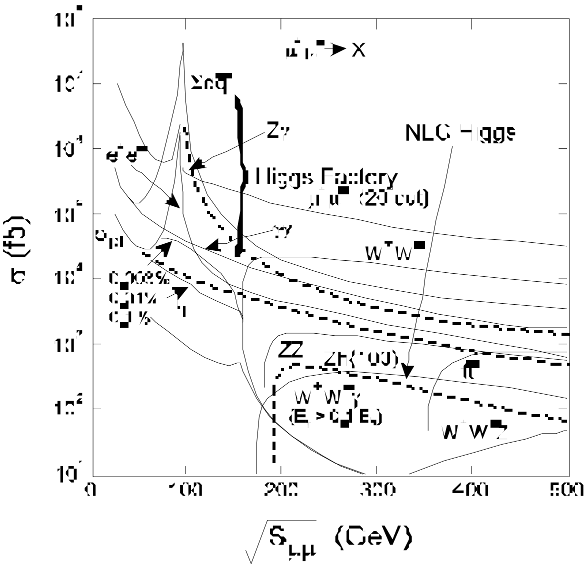

Figure 1. The cross sections as a function of energy for $e^+ e^-$ and $\mu^+ \mu^-$ interactions producing a Higgs boson and other systems.

2 A SCHEME TO CONVERT A NEUTRINO FACTORY TO A HIGGS FACTORY

We consider the possibility of staging the Neutrino Factory [6] Muon Collider program by converting as much as possible of a Neutrino Factory to a Higgs Factory. We take the example of Study II of the MC group to use BNL for the Neutrino Factory [8]. Figure 2 shows this current scheme. We show in Figure 2 that the addition of 3 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 [6].

3 PARAMETERS OF THE HIGGS FACTORY

The projected parameters of the Muon Collider Higgs Factory are given in Table 2 [6,7]. 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:

1) A Balbekov Cooler Ring [9]

2) A Storage Ring Cooler [10,11]

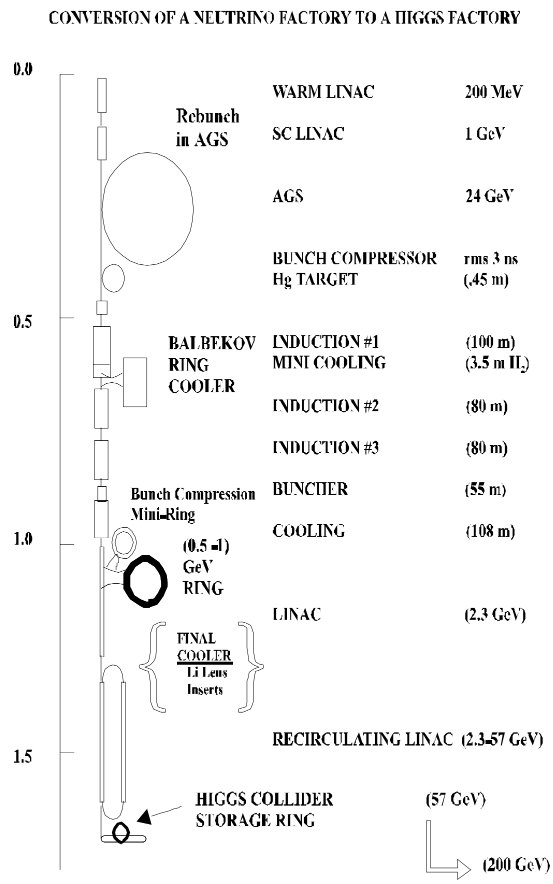

Figure 2. Schema for converting a Neutrino Factory to a Higgs Factory.

The basic concept is that the Balbekov ring 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 in Figure 5.

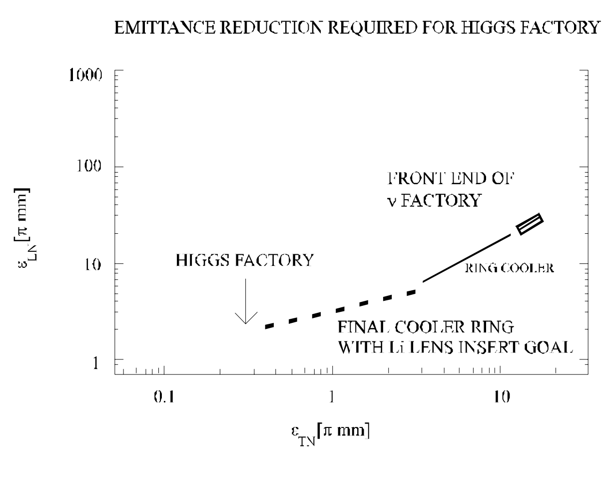

Figure 3. Emittance reduction needed for a Higgs Factory

We believe that Balbekov's design of a low-energy cooling ring shows a very promising approach, and the use of such rings at higher energies may also be very useful. We are presently exploring this possibility [11]. A conceptual example of a cooling module is shown in Figure 5. Four such 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. Thus each mode may be damped by a factor of 1/3 in about 6 turns, or one quarter of the muon lifetime. We thank K. Lee and D. MacLaughlan-Dumes for their help.

Table 2. 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 [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 $\delta p/p$ (%)	0.01
β^* (cm)	9.4
σ_z (cm)	9.4
σ_τ spot (μm)	196
σ_θ IP (mrad)	2.1
Tune shift	0.022
n_{turns} (effective)	450
Luminosity (cm^{-2} s^{-1})	2.2×10^{31}
Higgs/yr	4×10^3

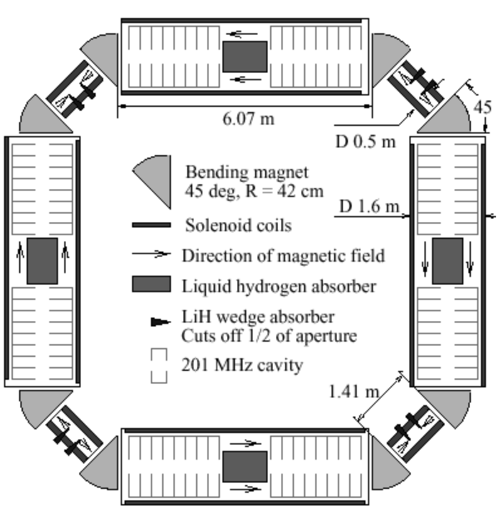

Figure 4. The Balbekov cooling ring.

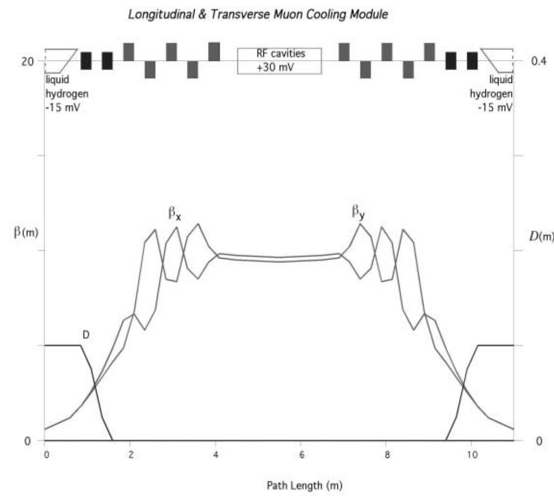

Figure 5. Cooling module of a storage ring cooler.

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