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Section A

Physics potential of a few hundred GeV $\mu^+\mu^-$ collider

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There is growing evidence that both a Standard Model and a SUSY Model Higgs should exhibit one resonance at a mass less than $2M_Z$. This is precisely in the mass range that is very difficult (but not impossible) to detect at the LHC and possibly beyond the reach of LEP II. At a $\bar{\mu}\mu$ collider the direct channel $\mu^+\mu^- \to h^0 \to b\bar{b}$ can be used to search for the Higgs. We discuss the collider requirements for this search on the $\mu\bar{\mu}$ collider luminosity and the detector. These results arose from a $\mu^+\mu^-$ Collider Workshop held in Napa Valley, California, November 1992.

1. Introduction

At the Port Jefferson Advanced Accelerator Workshop in the Summer of 1992, a group investigating new concepts of colliders studied anew the possibility of a $\mu^+\mu^-$ collider since e^+e^- colliders will be very difficult in the several TeV range [1]. A small group also discussed the possibility of a $\mu^+\mu^-$ collider. A special workshop was then held in Napa, California in the fall of 1992 for this study. There are new accelerator possibilities for the development of such a machine, possibly at an existing or soon to exist storage ring [2, 3]. For the purpose of the discussion here, a $\mu^+\mu^-$ collider is schematically shown in Fig. 1. In this brief note we study one of the most interesting goals of a $\mu^+\mu^-$ collider: the discovery of a Higgs boson in the mass range beyond that to be covered by LEP I & II ($\sim$ 80–90 GeV) and the natural range of the supercolliders $\gtrsim 2M_Z$ [4]. In this mass range, as far as we know, the dominant decay mode of the h^0 will be

$$h^0 \to b\bar{b}, \tag{1}$$

whereas the Higgs will be produced by the direct channel

$$\mu^+\mu^- \to h^0 \tag{2}$$

which has a cross section enhanced by

$$(M_\mu/M_e)^2 \sim (200)^2 = 4 \times 10^4 \tag{3}$$

larger than the corresponding direct product at an e^+e^- collider. However, we will see that the narrow width of the Higgs partially reduces this enhancement.

There is growing evidence that the Higgs should exist in this low mass range from

1) the original paper of Cabibbo et al., which shows that, when $M_t > M_Z$ and assuming a Grand Unification of Forces, $M_h < 2M_Z$ [4] (Fig. 2),

2) fits to LEP data, which imply a low mass h^0 could be consistent with $M_t > 150$ GeV [4],

3) the extrapolation to the GUT Scale that is consistent with SUSY also implies that one of the Higgs should have a low mass, perhaps below 130–150 GeV [4].

This evidence implies the exciting possibility that the Higgs mass is just beyond the reach of LEP II and in a range that is very difficult for the super-colliders to extract the signal from background, ie. 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 [5].

In this low mass region the Higgs is also expected to be a fairly marrow resonance and thus the signal should stand out clearly from the background from

$$\mu^+\mu^- \to \gamma \to b\bar{b}$$
$$\to Z_{\text{tail}} \to b\bar{b}. \tag{4}$$

In Fig. 3 we plot the Higgs resonance signals and various types of background for this mass range. While the cross sections are fairly large, the requirements on the beam energy resolution of the $\mu^+\mu^-$ collider are very constraining. In Fig. 4 we show the relationship between the Higgs width and the required machine energy resolution. If the resolution requirements can be met, the machine luminosity of $\sim 10^{31}$ cm^{-2} s^{-1} could be adequate to facilitate the discovery of the Higgs in the mass range of 100–180 GeV.

For masses above 180 GeV, the dominant Higgs decay is

$$H^0 \to W^+W^- \quad \text{or} \quad Z^0Z^0 \tag{5}$$

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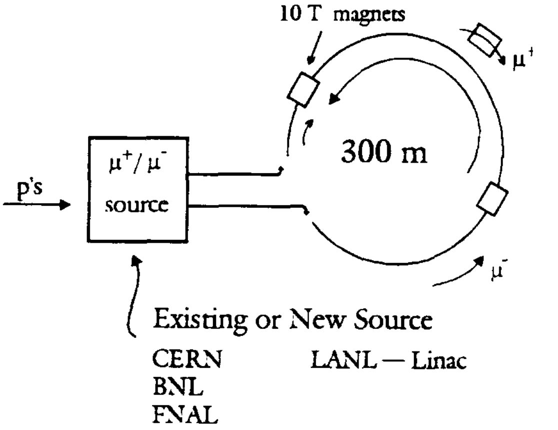

Fig. 1. Schematic of a possible $\mu\mu$ collider scheme (few hundred GeV).

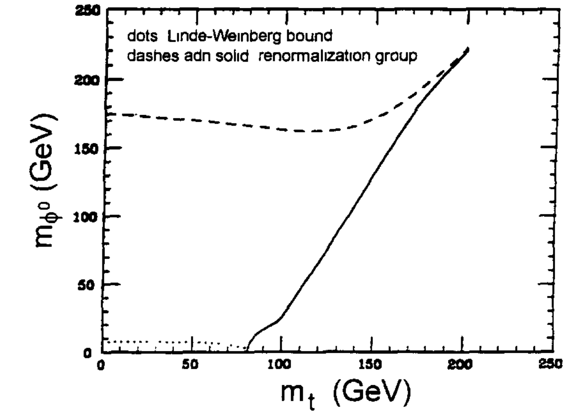

Fig. 2. Upper and lower bounds on $m_{\phi}^{-}0$ as a function of m_t, coming from the requirement of a perturbative theory [4].

giving a clear signal and a larger width; the machine energy resolution requirements could be relaxed somewhat!

Another possibility for the intermediate Higgs mass range is to search for

$$\mu^+\mu^- \to Z^0 + H^0 \tag{6}$$

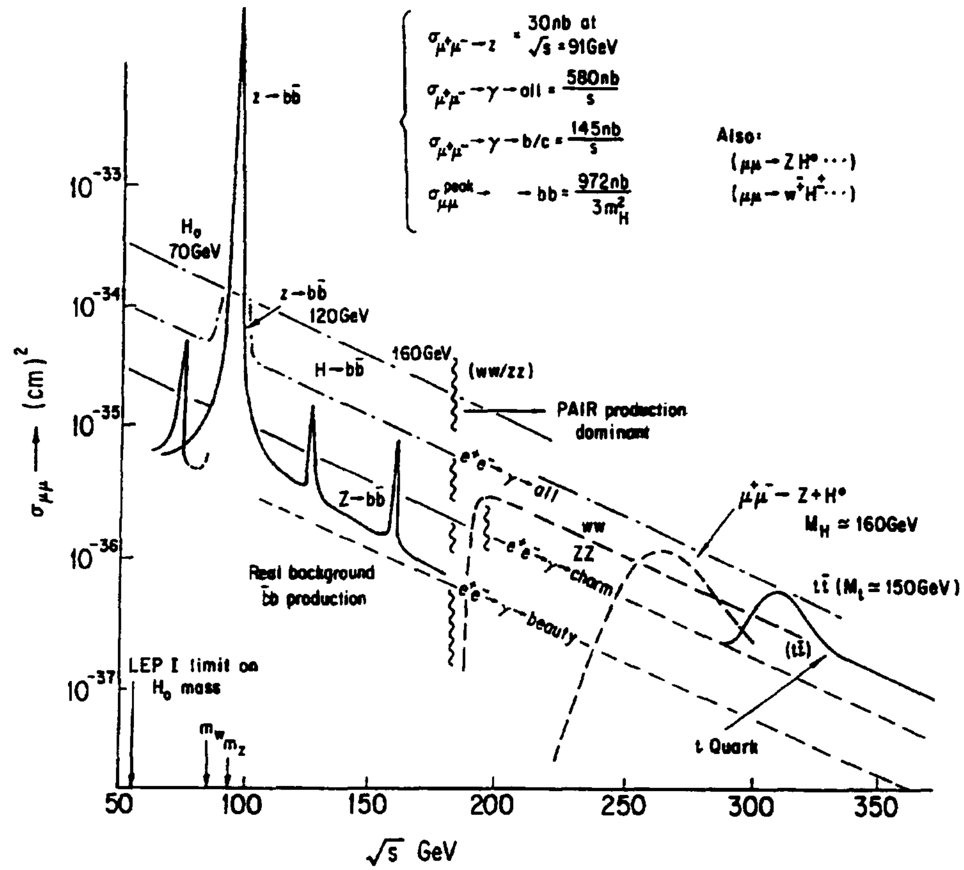

Fig. 3. Estimated cross sections and backgrounds for Higgs production in the direct channel or by associated production for various Higgs mass.

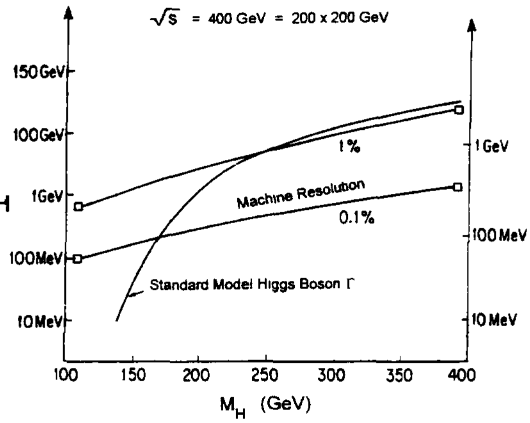

Fig. 4. Higgs search at a $\mu^+\mu^-$ collider. Required machine resolution and the expected Higgs width.

using a broad energy sweep. The corresponding cross section is small (see Figs. 3 and 5). Once an approximate mass is determined, a strategy for the energy sweep through the resonance can be devised. The study of the t quark through $t\bar{t}$ production would also be interesting.

Finally, another possibility is to use the polarization of the $\mu^+\mu^-$ particles orientated so that only scalar interactions are possible (thus eliminating the background from single photon intermediate states as shown in Fig. 3) [6]. However, there would be a trade-off with luminosity and thus a strategy would have to be devised to maximize the possibility of success in the energy sweep through the resonance.

At the Napa workshop the possibility of developing a $\mu^+\mu^-$ collider in the 10^{31} cm^{-2} s^{-1} region was considered and appears feasible. It is less certain that the high energy resolution required for the Higgs sweep can be

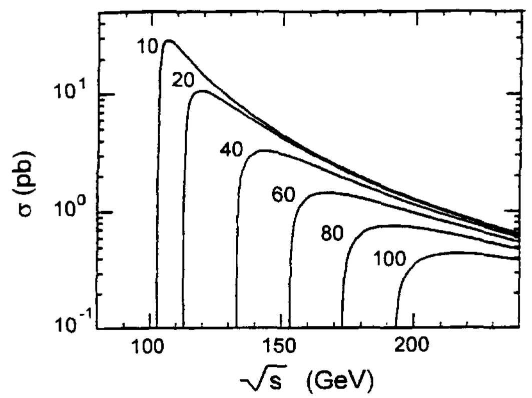

Fig. 5. Total cross section for $\mu^+\mu^- \to \phi^0$ Z as a function of $\sqrt{s}$ for the fixed $m\phi_0$ values indicated by the numbers (in GeV) beside each line. (Adapted from Ref. [4].)

Table 1
Key issues in the Higgs search

There is growing evidence that one Higgs particle is below 2 M_Z
SUSY Higgs – 3 Higgs – one near M_Z (possibly up to ~130 GeV); extremely hard to detect
Hadron machines can search for these Higgs provided: i $\int \mathscr{L}\,dt \geq 10^5$ pb (LHC); ii the background for $H \to \gamma\gamma$ is small enough
A $\mu^+\mu^-$ collider with $\mathscr{L} \geq 10^{31}$ cm^{-2} s^{-1} operating between 100–180 GeV could discover the Higgs in 2000+ provided sufficient energy resolution is achieved

obtained. We summarize in Table 1 some of the key issues in the Higgs search.

$\mu^+\mu^-$ colliders could also be very important in the TeV energy range; however, since the cross sections for new particle production are much smaller, the luminosity requirements would be $\mathscr{L}_{\mu^+\mu^-} \geq 10^{33}$ cm^{-2} s^{-1}. This is the energy range where e^+e^- linear colliders are extremely difficult to develop [1]. This possibility will be the subject of a second Napa workshop to be held in 1994.

Acknowledgement

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References

[1] M. Tigner, presented at the 3rd Int. Workshop on Advanced Accelerator Concepts, Port Jefferson, NY, (1992); other paper to be published in AIP, 1992, ed. J. Wurtle.

[2] Early references for $\mu\mu$ colliders are: E.A. Perevedentsev and A.N. Skrinsky, Proc. 12th Int. Conf. on High Energy Accelerators eds. F.T. Cole and R. Donaldson, 1983, p. 485; D. Neuffer, Proc. 12th Int. Conf. on High Energy Accelerators, eds F.T. Cole and R. Donaldson, 1983, p. 481; D. Neuffer, Particle Accel. 14 (1983) 75; D. Neuffer, in: Advanced Accelerator Concepts, AIP Conf. Proc. 156 (1987) 201.

[3] Reports from the Napa Workshop: D. Neuffer, $\mu^+\mu^-$ Colliders: Possibilities and Challenges; W. Barletta and A. Sessler, Characteristics of a high energy $\mu^+\mu^-$ collider based on electro-production of muons.

[4] See for primary references to the theoretical estimates here S. Dawson, J.F. Gunion, H.E. Haber and G.L. Kane, The Physics of the Higgs Bosons: Higgs Hunter's Guide (Addison Wesley, Menlo Park, 1989).

[5] For example the Compact Muon Solenoid detector at the LHC, CERN reports.

[6] This possibility came up in discussion with K. McDonald, Princeton.