I. INTRODUCTION

The possibility of muon colliders was introduced by G. I Budker [1,2], Skrinsky et al. [3–5] and Neuffer [6,7]. More recently, a collaboration of over 100 members, led by Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (FNAL), Lawrence Berkeley National laboratory (LBNL), Budker Institute for Nuclear Physics (BINP), University of Mississippi, Princeton University and University of California at Los Angeles (UCLA) has been formed to coordinate studies on specific designs. The studies on the particle physics that could be done at the collider is led by the University of Wisconsin, University of California at Davis (UCD) and Indiana University. Work has been done on designs at 3-4 TeV, 0.4-0.5 TeV and $\approx$ 100 GeV [8–18]. A detailed feasibility study for a 4 TeV muon collider was presented at the SNOWMASS'96 workshop [19], [20].

The reason for interest in muon colliders comes from consequences of the muon behaving like a *heavy electron.* As for an electron, the full CoM energy is available in an interaction. But because of the large mass, there is essentially no synchrotron radiation from the muon (in comparison to electrons); consequently, the machine can be circular and much smaller than the current design of linear electron colliders and also much smaller than a hadron collider with the same *effective energy.* Of course, a muon collider requires successful solutions of many difficult physics and technical questions, but the cost of these solutions is not expected to be high. A further important consequence of the essential lack of synchrotron radiation is that the energy spread of the initial state at a muon collider can be very small; this opens up interesting particle physics possibilities.

For the first time, physicists are in a position to be able to effectively explore the Higgs mechanism for the origin of mass. We have the theoretical understanding to know where to look, we will soon have powerful enough accelerators to reach the requisite energy and we have the detectors that will allow us to study the subject. The first muon collider, that we describe here, is admirably suited for this task. Certainly, other machines can be, and will be, used to first determine some properties of the Higgs boson, but a detailed study of the Higgs–presumably the source of mass–will surely be called for, and this muon collider, as a copious producer of Higgs particles in the s-channel may be the ideal machine to perform that task. Table I gives the parameters of such colliders, and Figs. 1 and 2 show possible outlines of the 3 TeV and 100 GeV machines. The assumed integrated luminosities, for the low energy machine, are given in the table for three different energy spreads, $\mathcal{L}$=$1.2, 0.2, 0.1 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for $\frac{\Delta p}{p}\% = 0.12, 0.01, 0.003$, respectively. The average number of Higgs that could be produced per year is 1600 per year at 400 GeV and 4000 per year at 100 GeV.

TABLE I. Baseline parameters for high and low energy muon colliders.

CoM energy	TeV	3	0.4		0.1	
p energy	GeV	16	16		16	
p's/bunch		2.5×10^{13}	2.5×10^{13}		5×10^{13}	
Bunches/fill		4	4		2	
Rep. rate	Hz	15	15		15	
p power	MW	4	4		4	
μ/bunch		2×10^{12}	2×10^{12}		4×10^{12}	
μ power	MW	28	4		1	
Wall power	MW	204	120		81	
Collider circum.	m	6000	1000		300	
Depth	m	500	100		10	
Rms $\frac{\Delta p}{p}$	%	0.16	0.14	0.12	0.01	0.003
6d ϵ_6	$(\pi \mathrm{m})^3$	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}
Rms ϵ_n	π mm mrad	50	50	85	195	280
β^*	cm	0.3	2.3	4	9	13
σ_z	cm	0.3	2.3	4	9	13
σ_r spot	μm	3.2	24	82	187	270
Tune shift		0.043	0.043	0.05	0.02	0.015
Luminosity	$cm^{-2}s^{-1}$	5×10^{34}	10^{33}	1.2×10^{32}	2×10^{31}	10^{31}
CoM $\frac{\Delta E}{E}$		8×10^{-4}	8×10^{-4}	8×10^{-4}	7×10^{-5}	2×10^{-5}
Higgs/year				1.6×10^3	4×10^3	4×10^3

Summarizing then, a $\mu^+\mu^-$collider would have some unique physics advantages over other collider options:

1. The direct coupling of a fermion-fermion system to a Higgs boson has a cross section that is proportional to

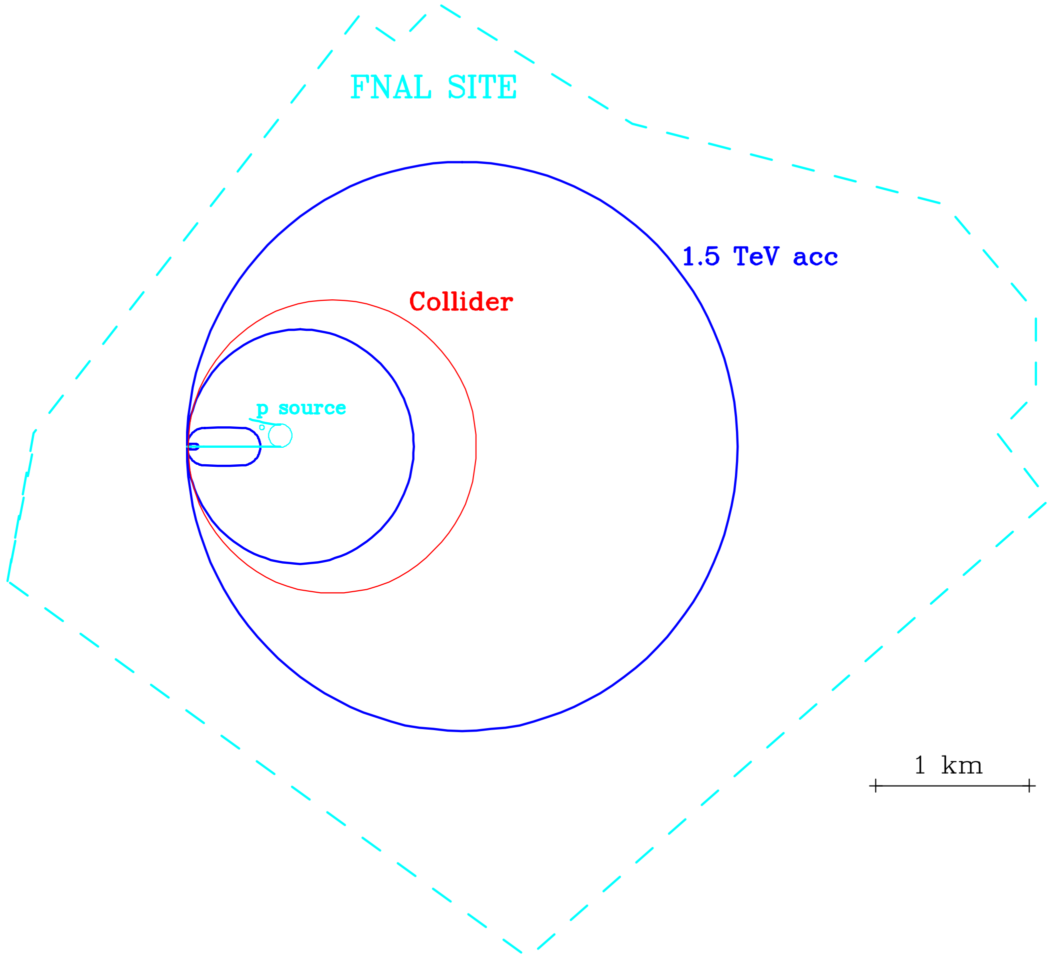

FIG. 1. Plan of a 3 TeV CoM Muon Collider shown on the Fermi National Laboratory site as an example.

the square of the mass of the fermion. As a result, the cross section for direct Higgs production from the $\mu^+\mu^-$system is 40,000 times that from an e^+e^-system.

2. Because of the lack of beamstrahlung, a $\mu^+\mu^-$collider can be operated with an energy spread of as little as 0.003 %. Furthermore, it will be possible to determine the absolute muon-beam energy to an accuracy of 10^{-6} or better [21] by observing the decay asymmetry of the naturally polarized muon beam (sec. VII-E,). It should thus be possible to use a $\mu^+\mu^-$collider to make precision measurements of masses and direct measurements of the Higgs width (predicted to be ≈ 2 MeV) that would be otherwise impossible.

Machines with energies higher than 3-4 TeV, have significant beam-current constraints from off-site neutrino-induced-radiation limits (sec. VIII). If the required luminosities are to be reached without unacceptable hazards, then significant improvements in 6-dimensional muon emittance over the current baseline values are needed. There is, however, reason to believe such improvements are achievable, and machines with a center of mass energy of 10 TeV and luminosities of $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and above have begun to be studied [22]. For energies below 3 TeV CoM and fixed muon currents, this radiation varies as the cube of the energy, and it should not be an issue for machines with energies of 1.5 TeV or less.

To minimize cost, a small initial machine is desirable, which would serve as a demonstration of the technology of muon colliders. A machine of 100-GeV scale could be commissioned at the Z^0 pole, and would have major physics impact should the mass of the Higgs boson be in this range.

The remainder of this report is organized as follows: Section II gives an overview of muon colliders and their physics potential; then there are sections on the proton driver (sec. III), the target, pion production, capture and phase rotation, polarization (sec. IV), ionization cooling (sec. V), acceleration (sec. VI), the collider ring lattice, and magnet design for the ring, muon beam energy calibration (sec. VII), neutrino health effects (sec. VIII), a nd detector background (sec. IX). Sec. X contains conclusions.

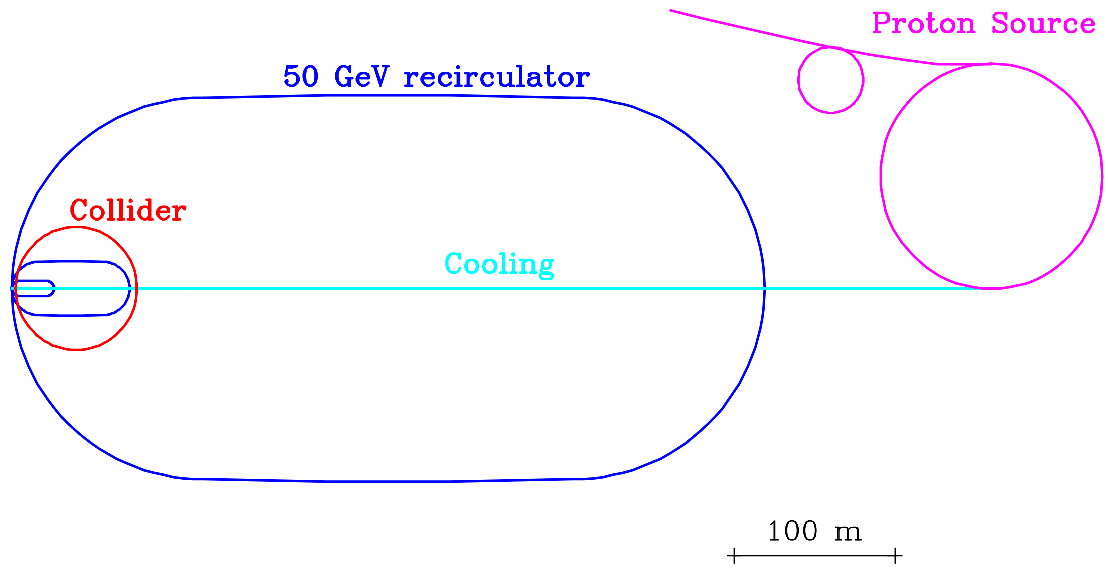

FIG. 2. Plan of a 100 GeV CoM Muon Collider.

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