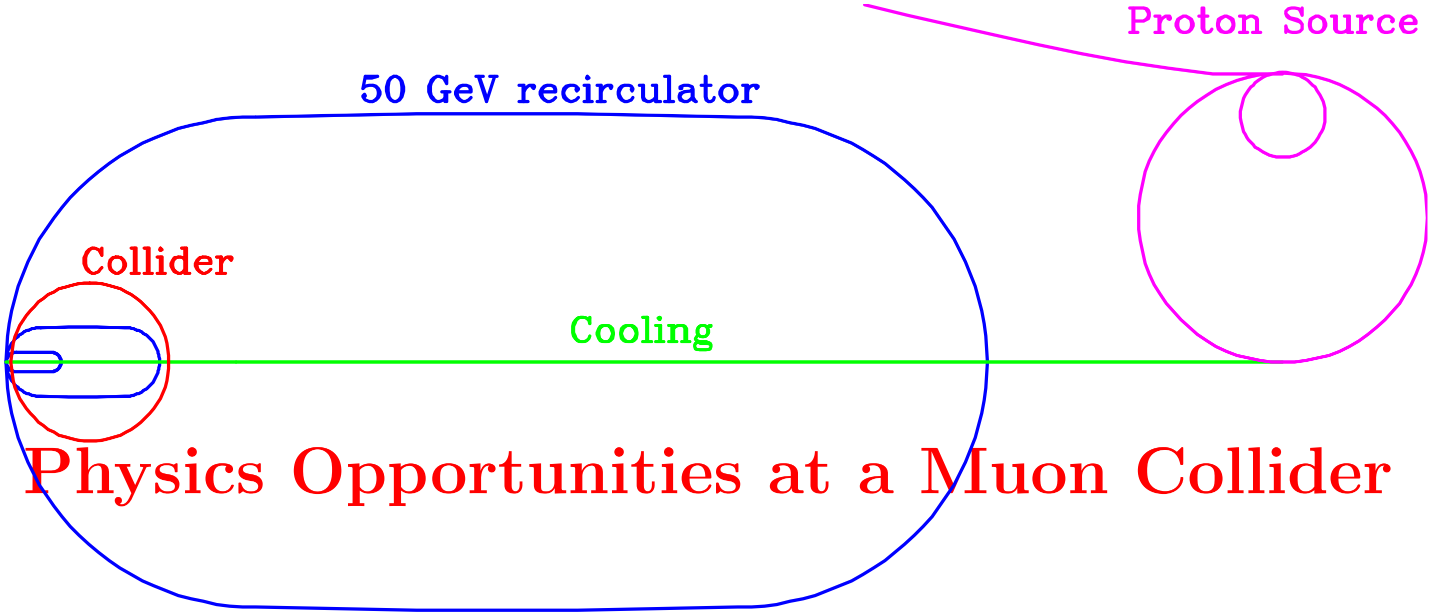

Physics Opportunities at a Muon Collider

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Seminar at Oak Ridge National Laboratory

Muon Collider main page:

`http://www.cap.bnl.gov/mumu/mu_home_page.html`

Muon Collider R&D Status Report:

`http://www.cap.bnl.gov/mumu/status_report.html`

Princeton Muon Collider page:

`http://puhep1.princeton.edu/mumu/`

AIP Conference Proceedings, Vols. 352, 372, 435 & 441

The Y2K Problem for Particle Physics

- Can elementary particle physics prosper for a 2nd century with laboratory experiments based on innovative particle sources?
- Can a full range of new phenomena be investigated:
  - Neutrino mass ⇒ a 2nd 3×3 (or larger?) mixing matrix.
  - Precision studies of Higgs bosons.
  - A rich supersymmetric sector.
  - ... And more ....
- Will our investment in future accelerators result in more cost-effective technology, that is capable of extension to 10's of TeV of constituent center-of-mass energy?

The Solution...

- A **Muon Collider** is the best option to accomplish the above!

What is a Muon Collider?

An accelerator complex in which

- Muons (both μ^+ and μ^-) are collected from pion decay following a pN interaction.
- Muon phase volume is reduced by 10^6 by ionization cooling.
- The cooled muons are accelerated and then stored in a ring.
- $\mu^+\mu^-$ collisions are observed over the useful muon life of $\approx$ 1000 turns at any energy.
- Intense neutrino beams and spallation neutron beams are available as byproducts.

Muons decay: $\mu \rightarrow e\nu \qquad \Rightarrow$

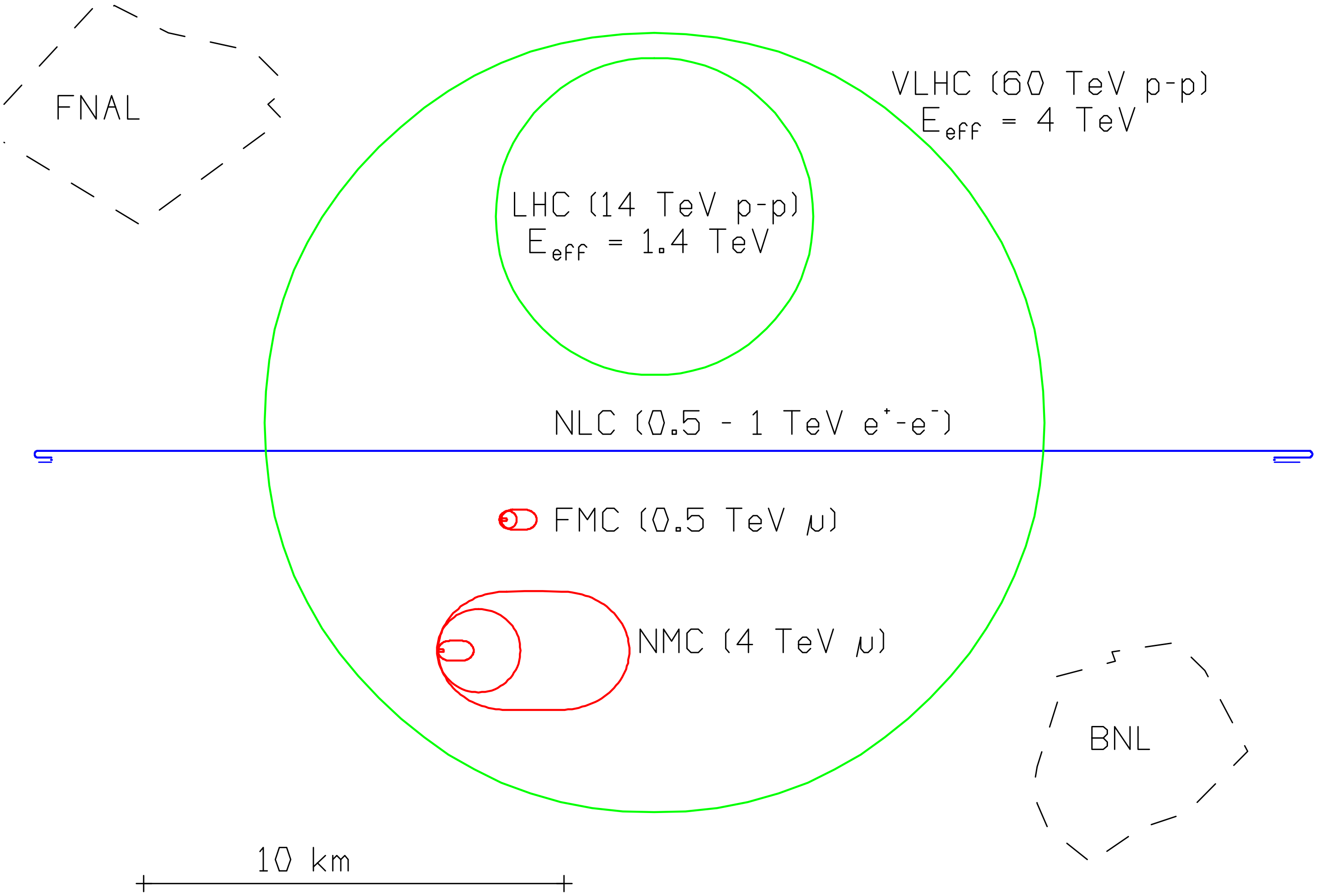
- Must cool muons quickly (stochastic cooling won't do).
- Detector backgrounds at LHC level.
- Potential personnel hazard from ν interactions.

Baseline Parameters

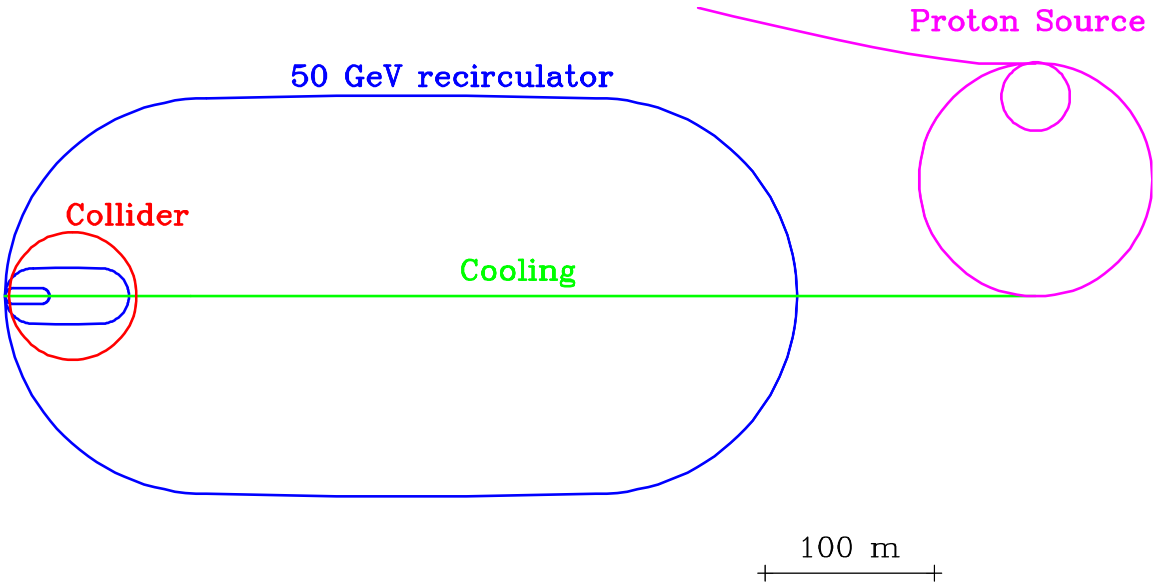
Table 1: Baseline parameters for high- and low-energy muon colliders. Higgs/year assumes a cross section $\sigma = 5 \times 10^4$ fb; a Higgs width $\Gamma = 2.7$ MeV; 1 year $= 10^7$ s.

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		350	
Ave bending field	T	5.2	4.7		3	
Depth	m	500	100		10	
Rms $\Delta P/P$	%	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	290
β^*	cm	0.3	2.6	4.1	9.4	14.1
σ_z	cm	0.3	2.6	4.1	9.4	14.1
σ_r spot	μm	3.2	26	86	196	294
σ_θ IP	mrad	1.1	1.0	2.1	2.1	2.1
Tune shift		0.044	0.044	0.051	0.022	0.015
n_{turns} (effective)		785	700	450	450	450
Luminosity	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	7×10^{34}	10^{33}	1.2×10^{32}	2.2×10^{31}	10^{31}
Higgs/year				1.9×10^3	4×10^3	3.9×10^3

Footprints



A First Muon Collider to study light-Higgs production:



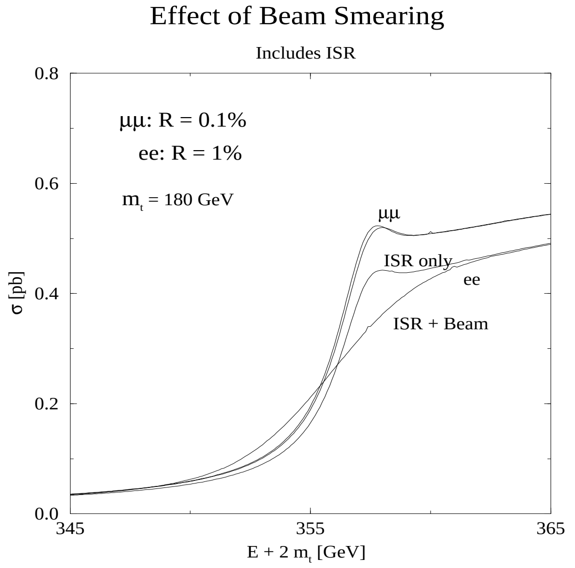
The Case for a Muon Collider

- More affordable than an e^+e^- collider at the TeV (LHC) scale.
- More affordable than either a hadron or an e^+e^- collider for (effective) energies beyond the LHC.
- Precision initial state superior even to e^+e^-.

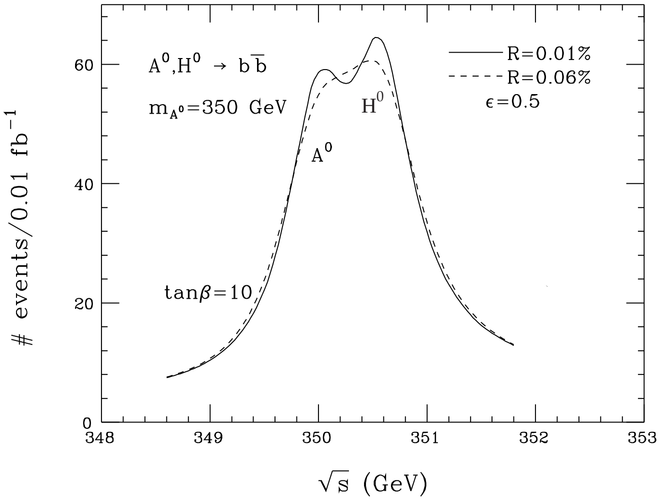
  Muon polarization $\approx 25\%$,

  $\Rightarrow$ Can determine E_{beam} to 10^{-5} via $g-2$ spin precession.

$t\bar{t}$ threshold:



Nearly degenerate A^0 and H^0:



- Initial machine could produce light Higgs via s-channel:

  Higgs coupling to μ is $(m_\mu/m_e)^2 \approx 40,000\times$ that to e.

  Beam energy resolution at a muon collider $< 10^{-5}$,

  $\Rightarrow$ Measure Higgs width.

  Add rings to 3 TeV later.

- Neutrino beams from μ decay about 10^4 hotter than present.

  Initial scenario in a low-energy muon storage ring.

  Study CP violation via CP-conjugate initial states:

$$\mu^+ \longrightarrow e^+ \overline{\nu}_\mu \nu_e$$

$$\mu^- \longrightarrow e^- \nu_\mu \overline{\nu}_e$$

Future Frontier Facilities

(A Personal Assessment)

- Hadron collider (LHC, SSC): ≈ \$100k/m [magnets].

  ≈ 2 km per TeV of CM energy.

  Ex: LHC has 14-TeV CM energy, 27 km ring, ≈ \$3B.

- Linear e^+e^- collider (SLAC, NLC(?)): ≈ \$200k/m [rf].

  ≈ 20 km per TeV of CM energy;

  But a lepton collider needs only ≈ 1/10 the CM energy

  to have equivalent physics reach to a hadron collider.

  Ex: NLC, 1.5-TeV CM energy, 30 km long, ≈ \$6B (?).

- Muon collider: ≈ \$1B for source/cooler + \$100k/m for rings

  Well-defined leptonic initial state.

  $m_\mu/m_e \approx 200 \Rightarrow$ Little beam radiation.

  $\Rightarrow$ Can use storage rings.

  $\Rightarrow$ Smaller footprint.

  Technology: closer to hadron colliders.

  ≈ 6 km of ring per TeV of CM energy.

  Ex: 3-TeV muon collider ≈ \$3B (?).

HEPAP Subpanel Report on
PLANNING FOR THE FUTURE OF U.S. HIGH-ENERGY PHYSICS

February 1998

Recommendation on R&D for a Muon Collider

The Subpanel recommends that an expanded program of R&D be carried out on a muon collider, involving both simulation and experiments. This R&D program should have central project management, involve both laboratory and university groups, and have the aim of resolving the question of whether this machine is feasible to build and operate for exploring the high-energy frontier. The scale and progress of this R&D program should be subject to additional review in about two years.

CERN-EP/98-03
CERN-SL 98-004 (AP)
CERN-TH/98-33

Options for Future Colliders at CERN

J. Ellis, E. Keil, G. Rolandi

January 23, 1998

6 RECOMMENDATIONS

3. CERN should launch technical studies of $\mu^+\mu^-$ colliders, notably in the areas of the source and beam cooling, and should explore the possibility of locating such machines on or in the neighbourhood of the CERN site.

6. These studies should be carried out in collaborations with other laboratories, since most technical problems do not depend on the site. CERN's goal in these collaborations should be to contribute to the global pool of technologies for future collider options. It should confirm its reputation as a valuable and reliable partner in the international collaborations that will form to develop