Muon Collider and the Top Quark Mass

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Snowmass Top Quark Working Group

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It is these features: heavy mass, short lifetime that dictate the physics.

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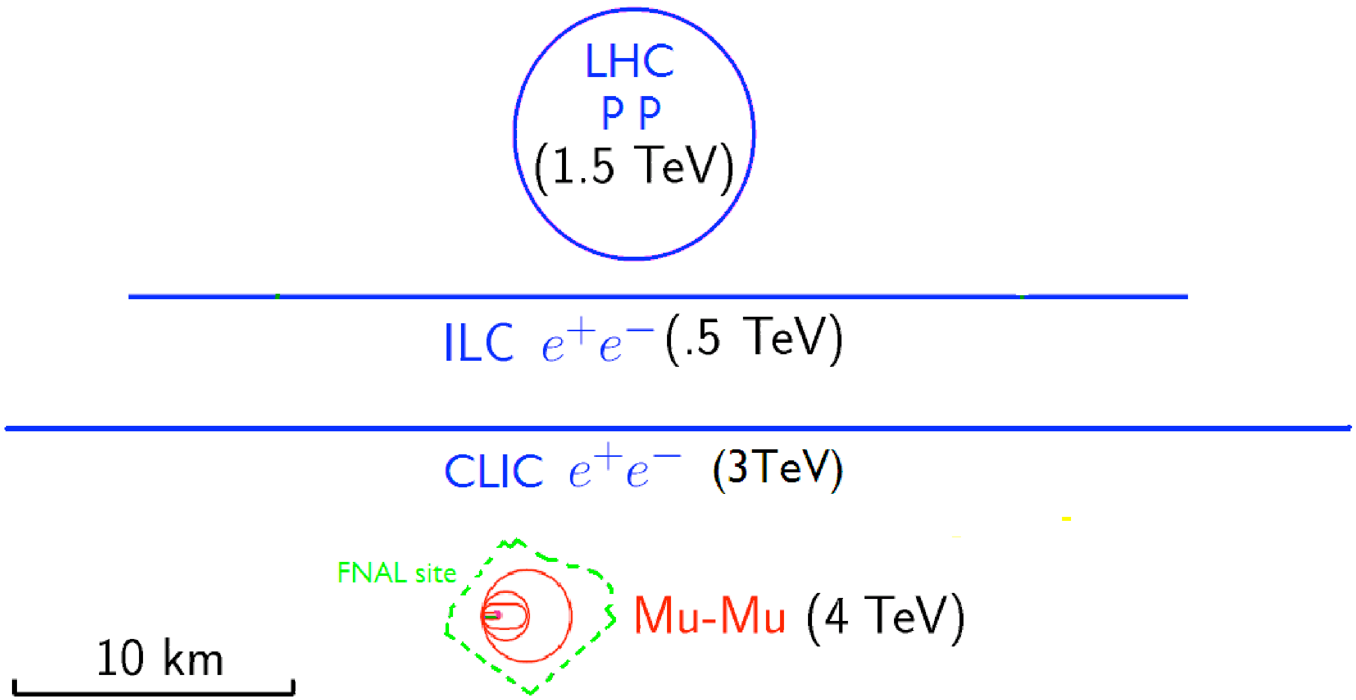

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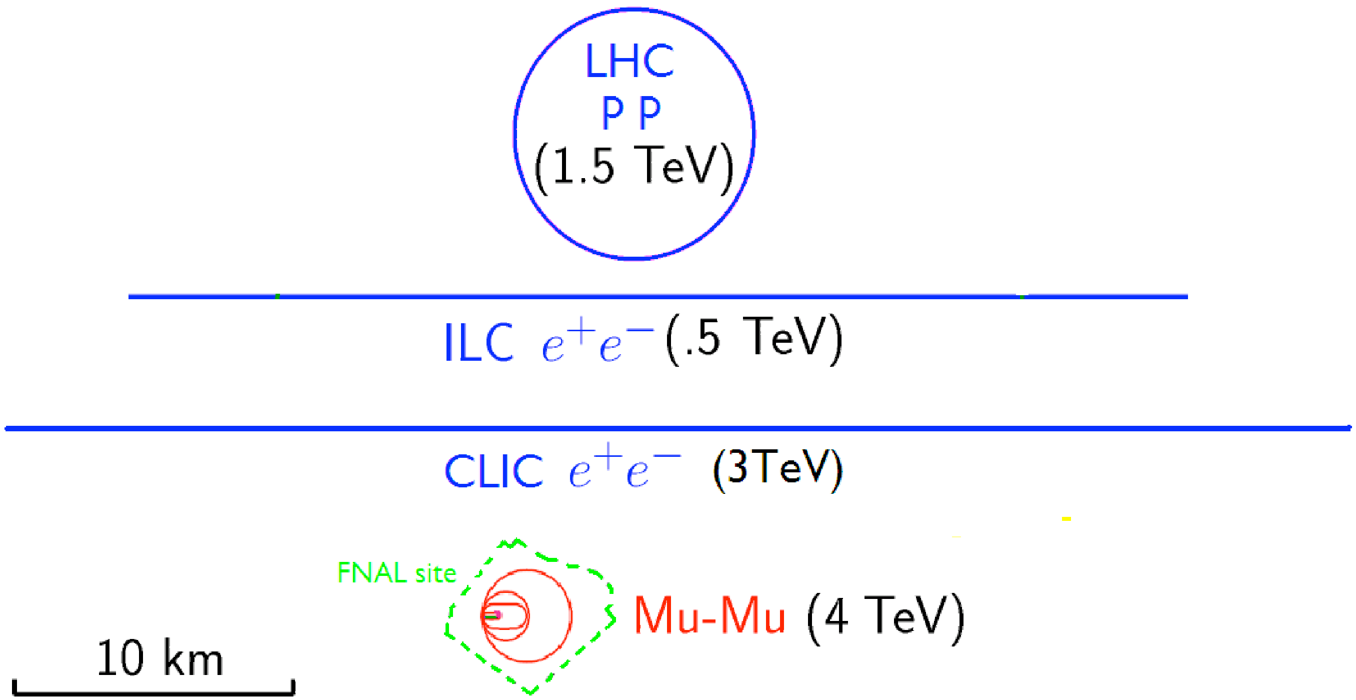

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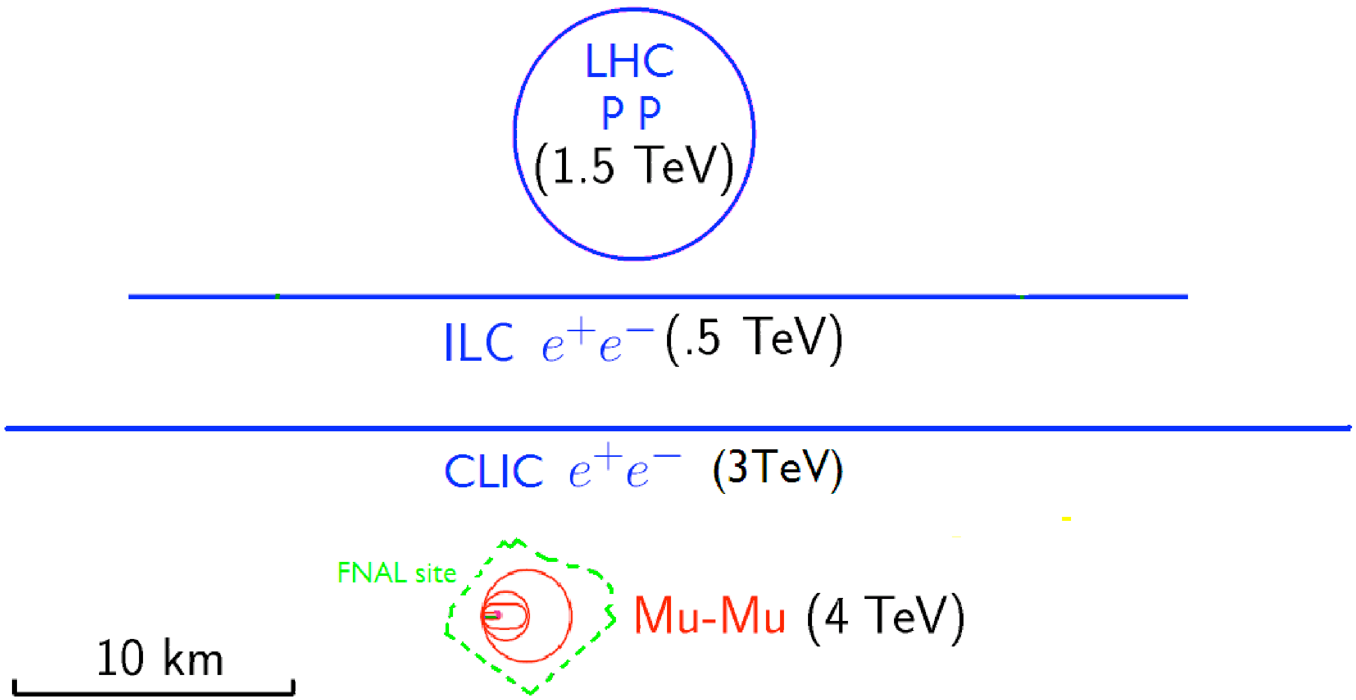

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(2). Some natural beam-polarization via $\pi^- \to \mu^- \; \bar{\nu}$.

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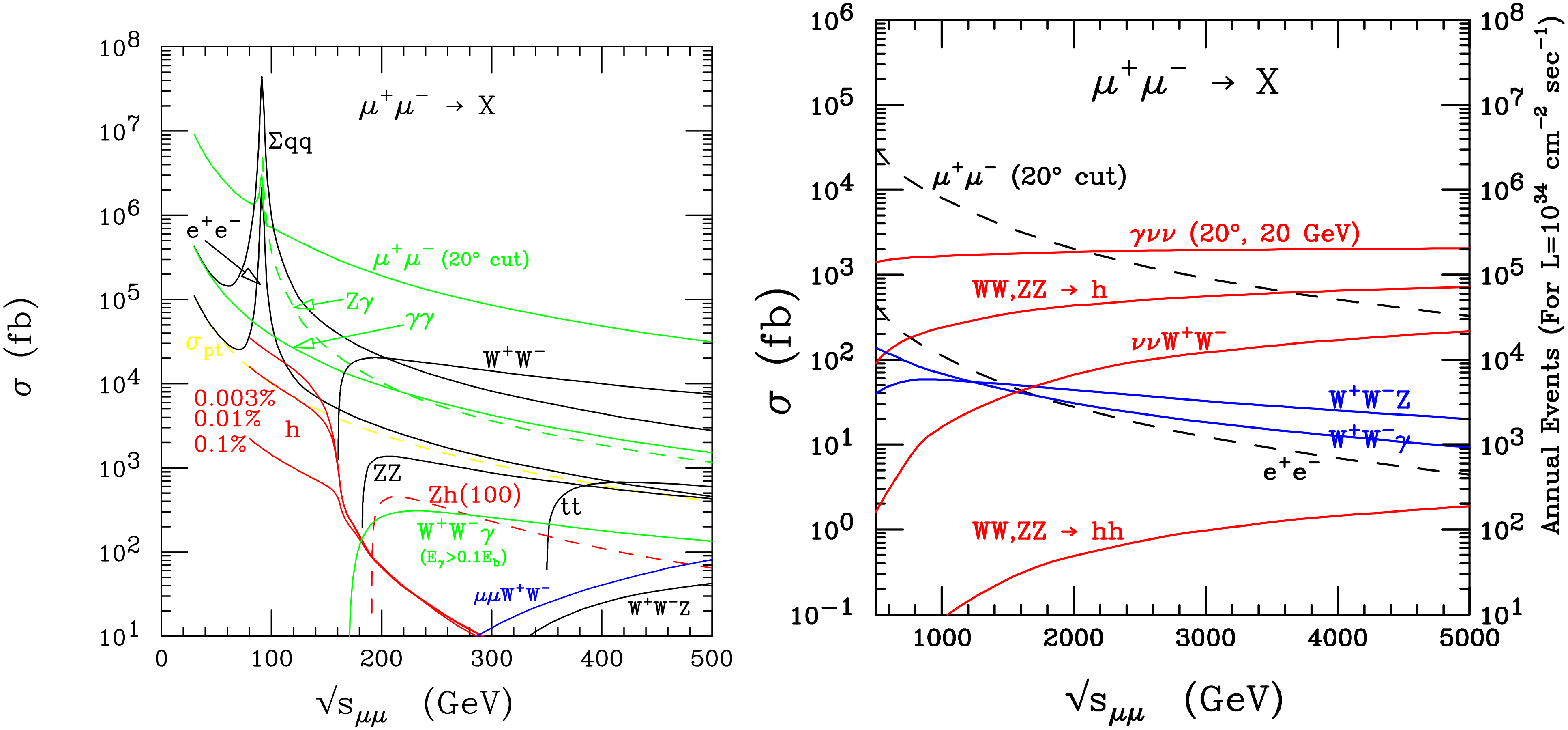
(3). Neutrino hazard: When E_{cm} reaching Multi-TeV.

Physics at Muon Colliders



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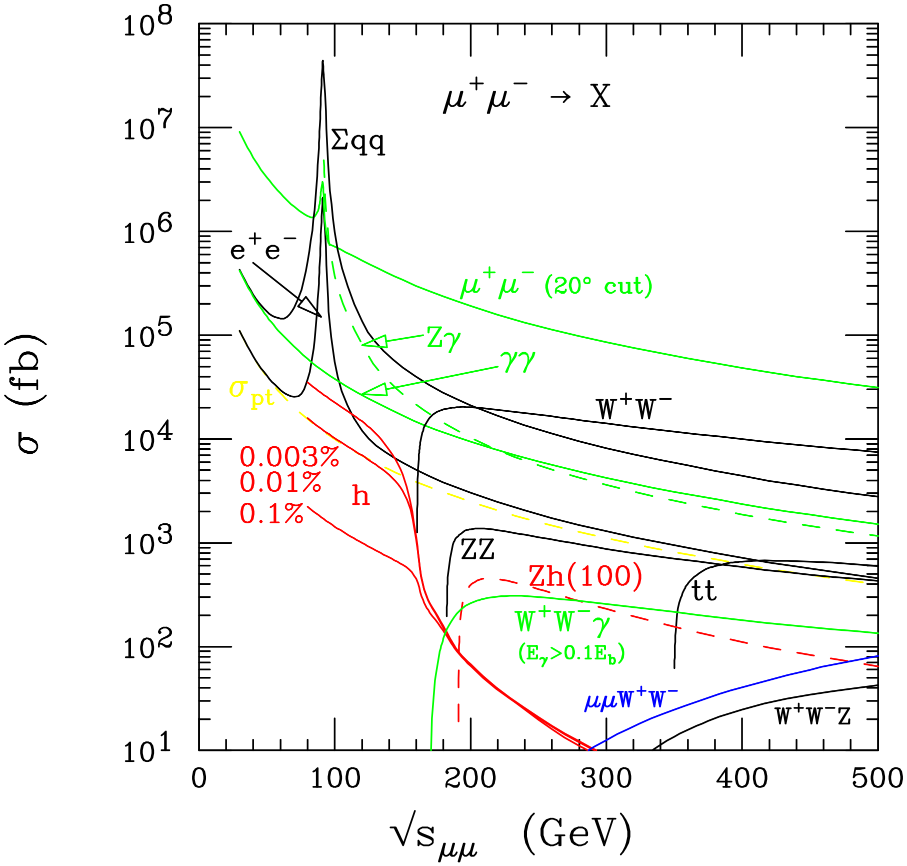
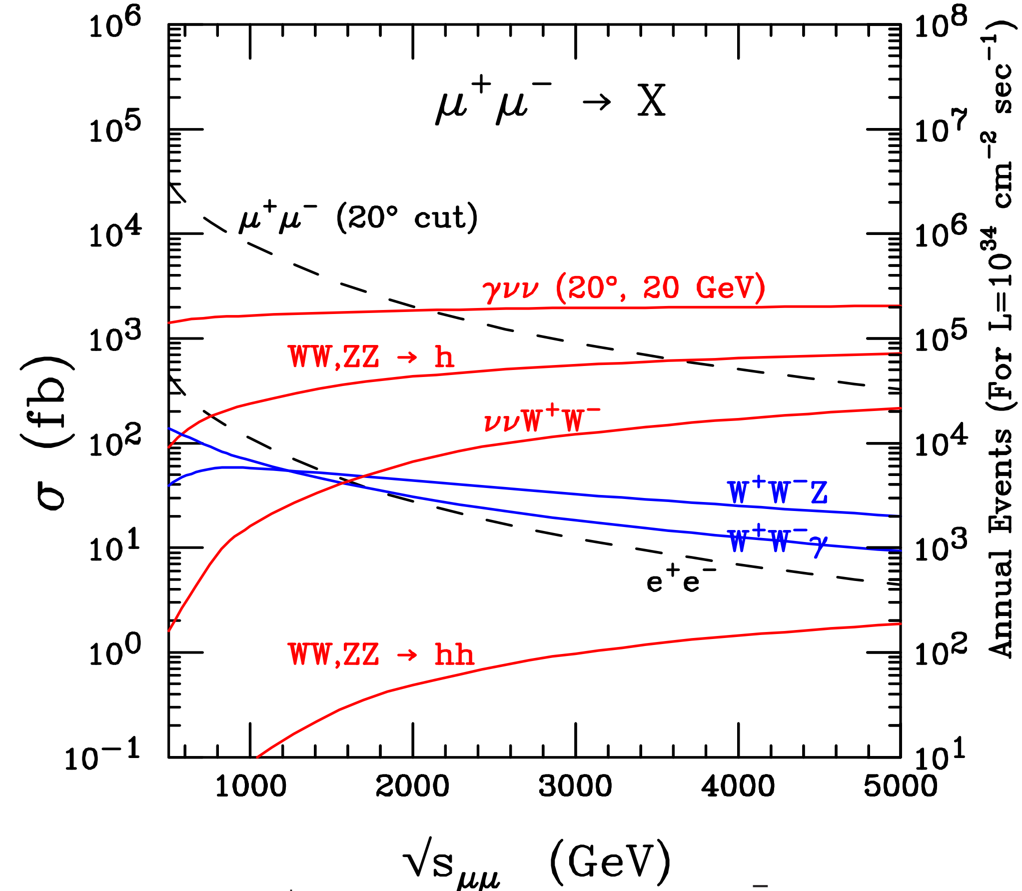
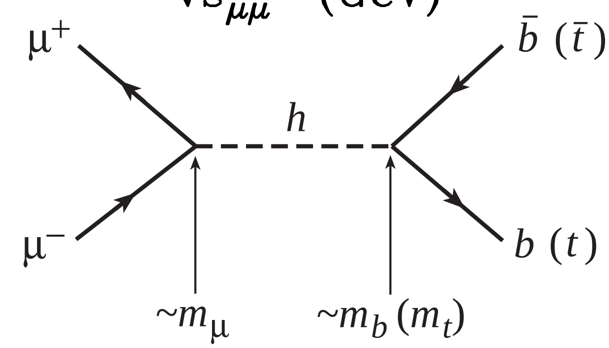




Most unique of all at a muon collider:
the s-channel scalar resonance.†



†Barger, Berger, Gunion, Han, (Phys. Rep. 1995)

A Higgs Factory

The s-channel resonant production:

$$\sigma(\mu^+\mu^- \to H, A \to X) = \frac{4\pi\Gamma(H, A \to \mu^+\mu^-)\ \Gamma(H, A \to X)}{(s - M_H^2)^2 + \Gamma_H^2 M_H^2}$$

$$\bar{\sigma}(s) = \int d\sqrt{s}\ \sigma(\mu^+\mu^- \to H, A \to X)\ \frac{dL}{d\sqrt{s}}$$

$$\propto \begin{cases} \Gamma_h^2 B/[(s - m_h^2)^2 + \Gamma_h^2 m_h^2] & (\Delta \ll \Gamma_h), \\ B \exp[\frac{-(m_H - \sqrt{s})^2}{2\Delta^2}](\frac{\Gamma_h}{\Delta})/m_h^2 & (\Delta \gg \Gamma_h). \end{cases}$$

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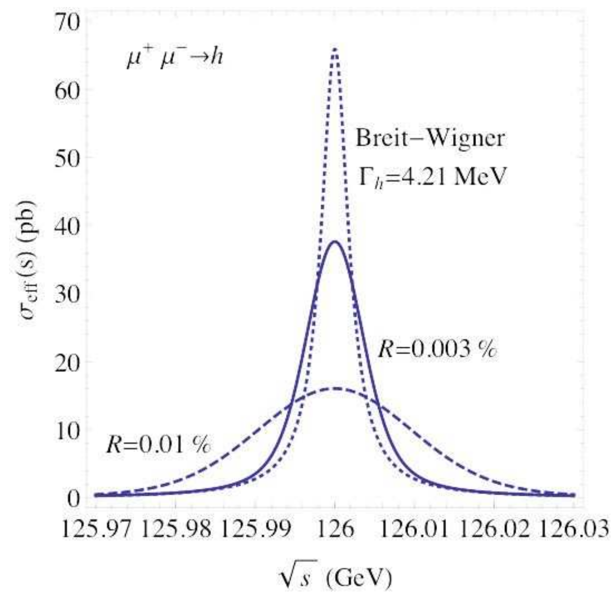


Model-independent width measurement:

$R = 0.01\% - 0.003\%,\ 1\ fb^{-1} \Rightarrow \delta\Gamma \approx 0.15 - 0.35$ MeV.[‡]

[‡]TH, Z. Liu, 2012.

Energy Frontier: $E_{cm} \sim 3 - 6$ TeV

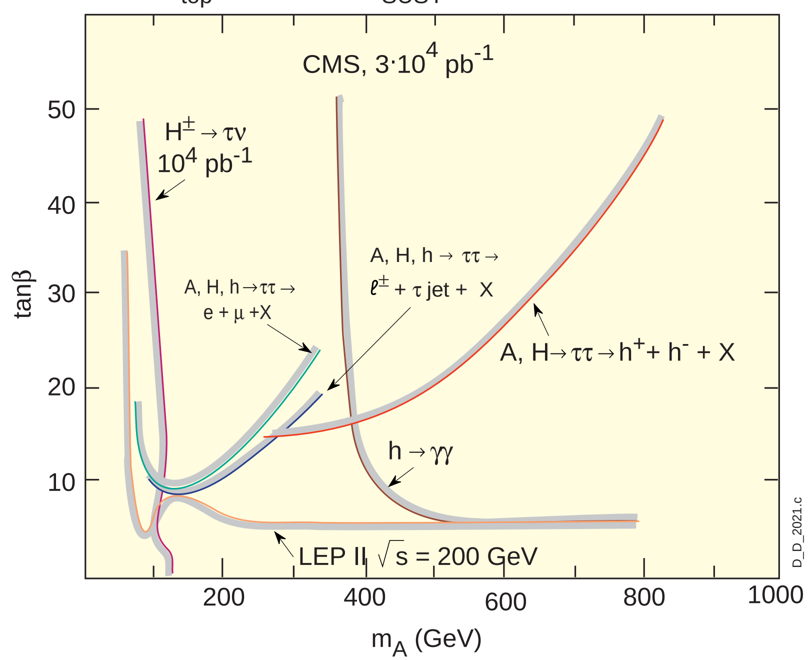
(1). At LHC, h_{SM} fully covered, but H, A, $H^{\pm}$ may not.

At $\sqrt{s} = 14$ GeV, still a large hole, especially $M_{H,A} > 500$ GeV:§

Significance contours for SUSY Higgses

Regions of the MSSM parameter space (m_A, tgβ) explorable through various SUSY Higgs channels

- 5 σ significance contours
- two-loop / RGE-improved radiative corrections
- m_{top} = 175 GeV, m_{SUSY} = 1 TeV, no stop mixing ;



§Denegri

(2). At LHC, heavy EW pairs are difficult to search for

$$\mu^+\mu^- \to H_1 H_2,\ \tilde{H}^+\tilde{H}^-,\ \tilde{H}^0\tilde{H}^0,\ \tilde{\ell}\tilde{\ell}.$$

IF no help from colored states $\tilde{g} \to q\tilde{q} \to qq'\ \tilde{\chi}^{0,\pm}$ ...

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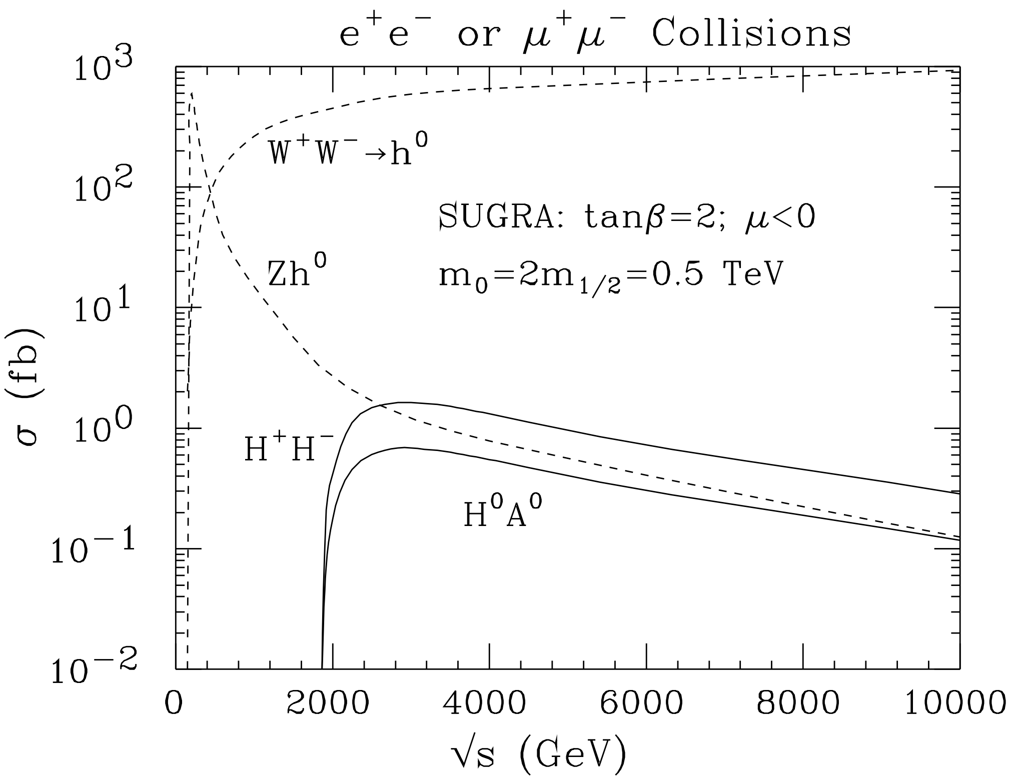

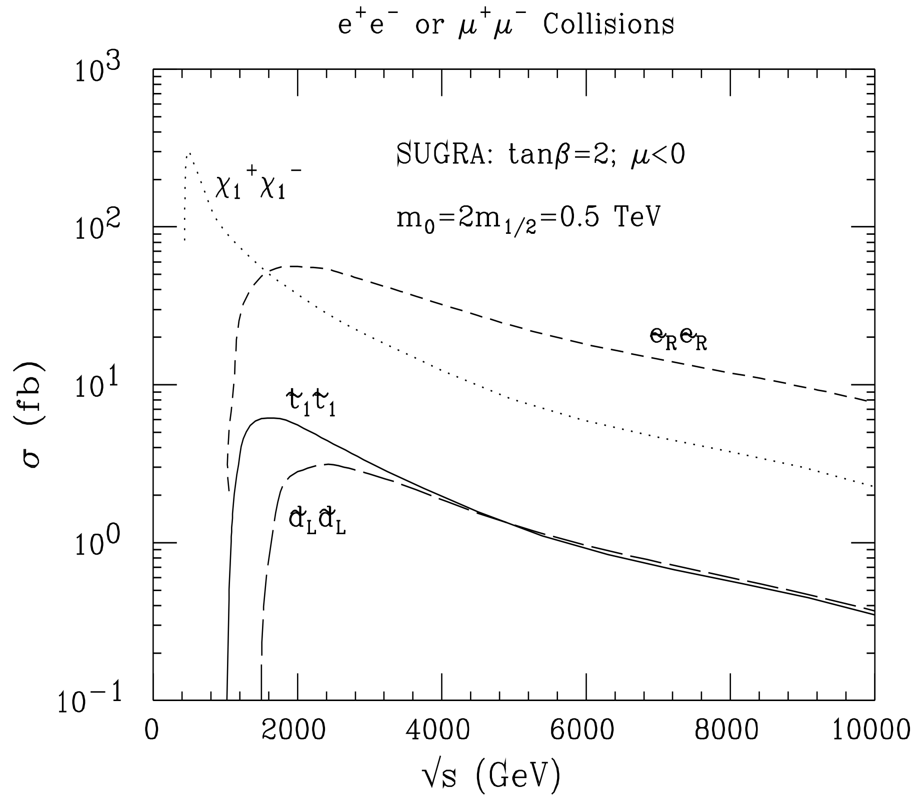

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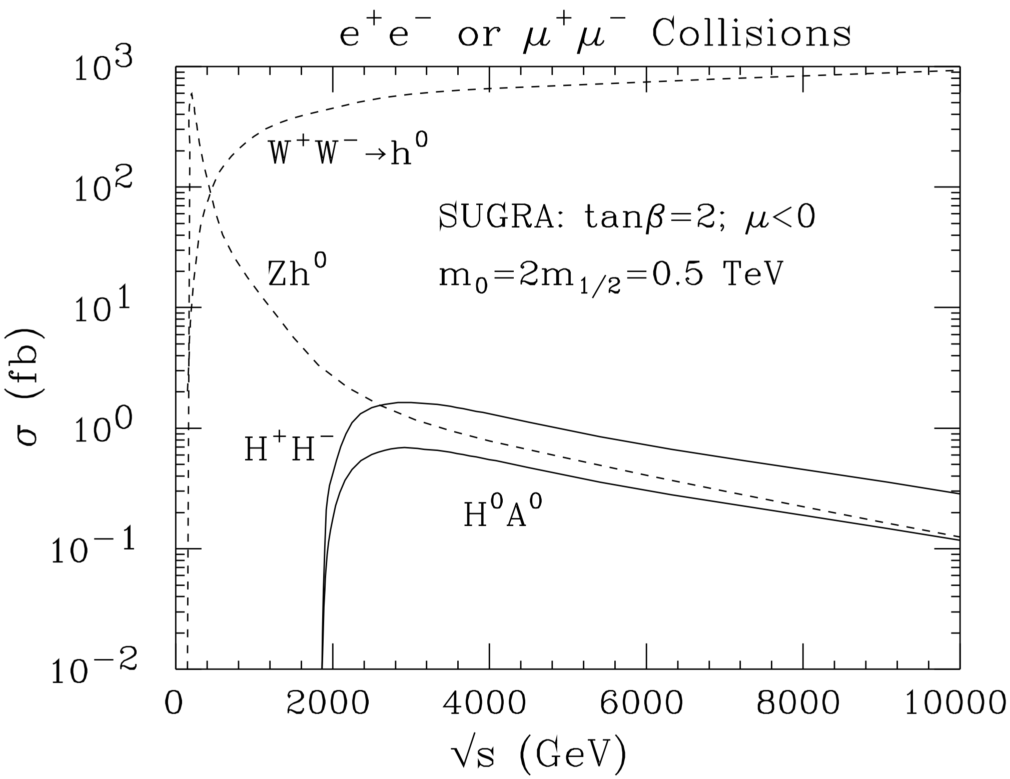

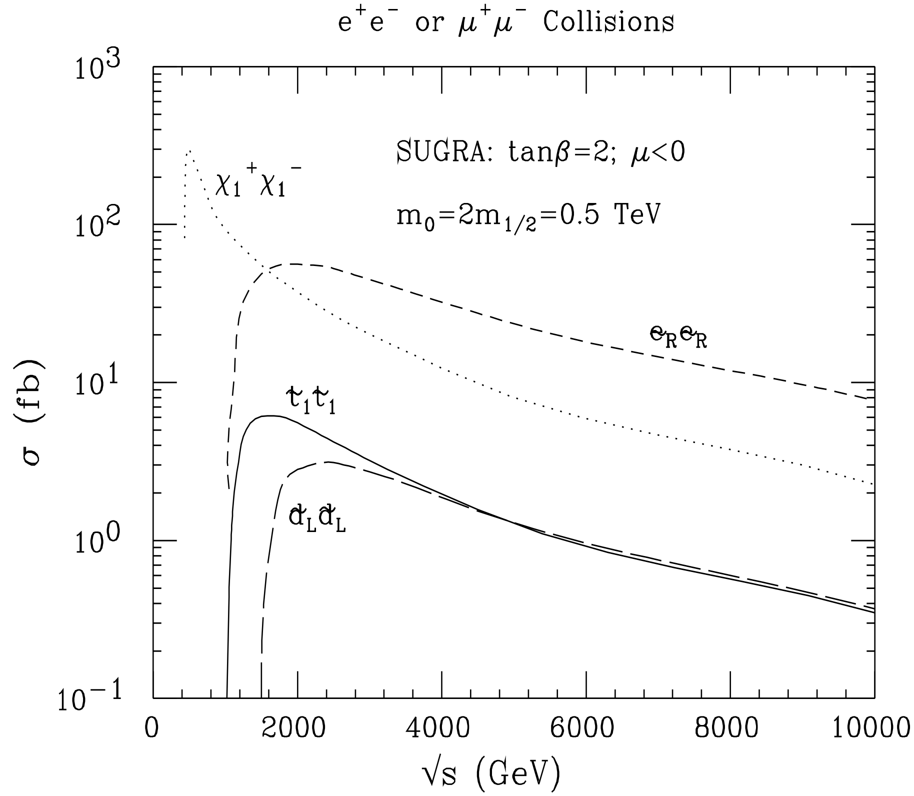

Once crossing the pair threshold, observation straightforward.
(rather model-independent, like in Two-Higgs Doublet model etc.)

Benchmark Processes

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http://conferences.fnal.gov/muon11

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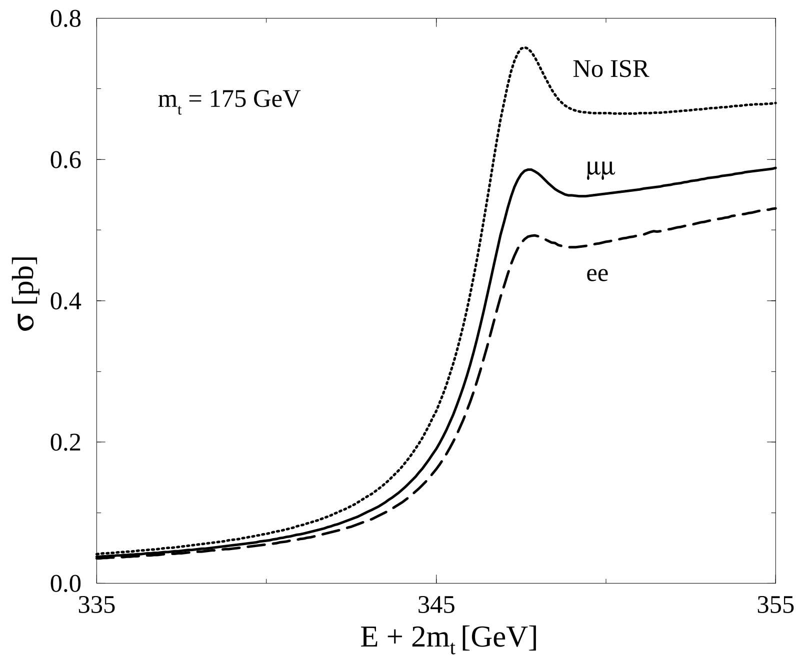

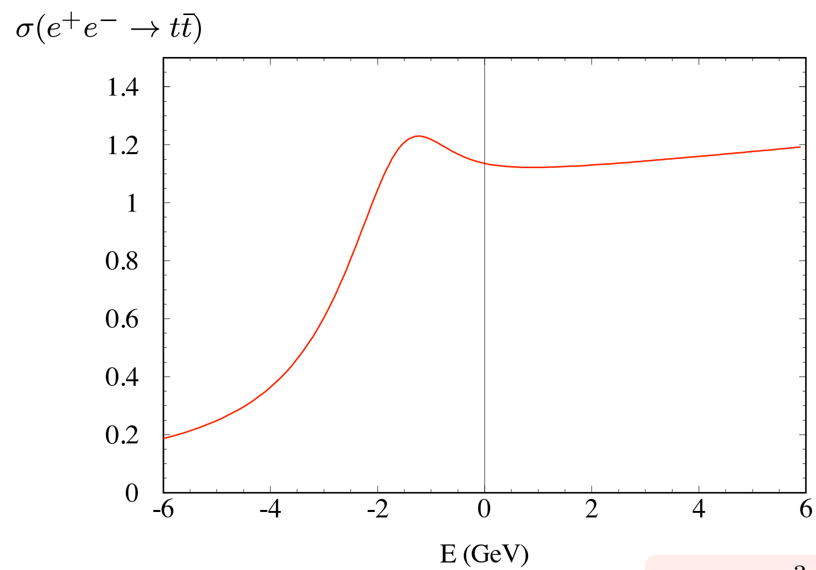

$$\sigma_{\rm res} \sim \frac{\alpha_s^3}{m_t\Gamma_t}, \quad E_{\rm res} \sim \alpha_s^2 m_t$$

Sensitive to m_t, $\Gamma_t(V_{tb})$, α_s and weakly m_h. ¶

¶Penin's talk.

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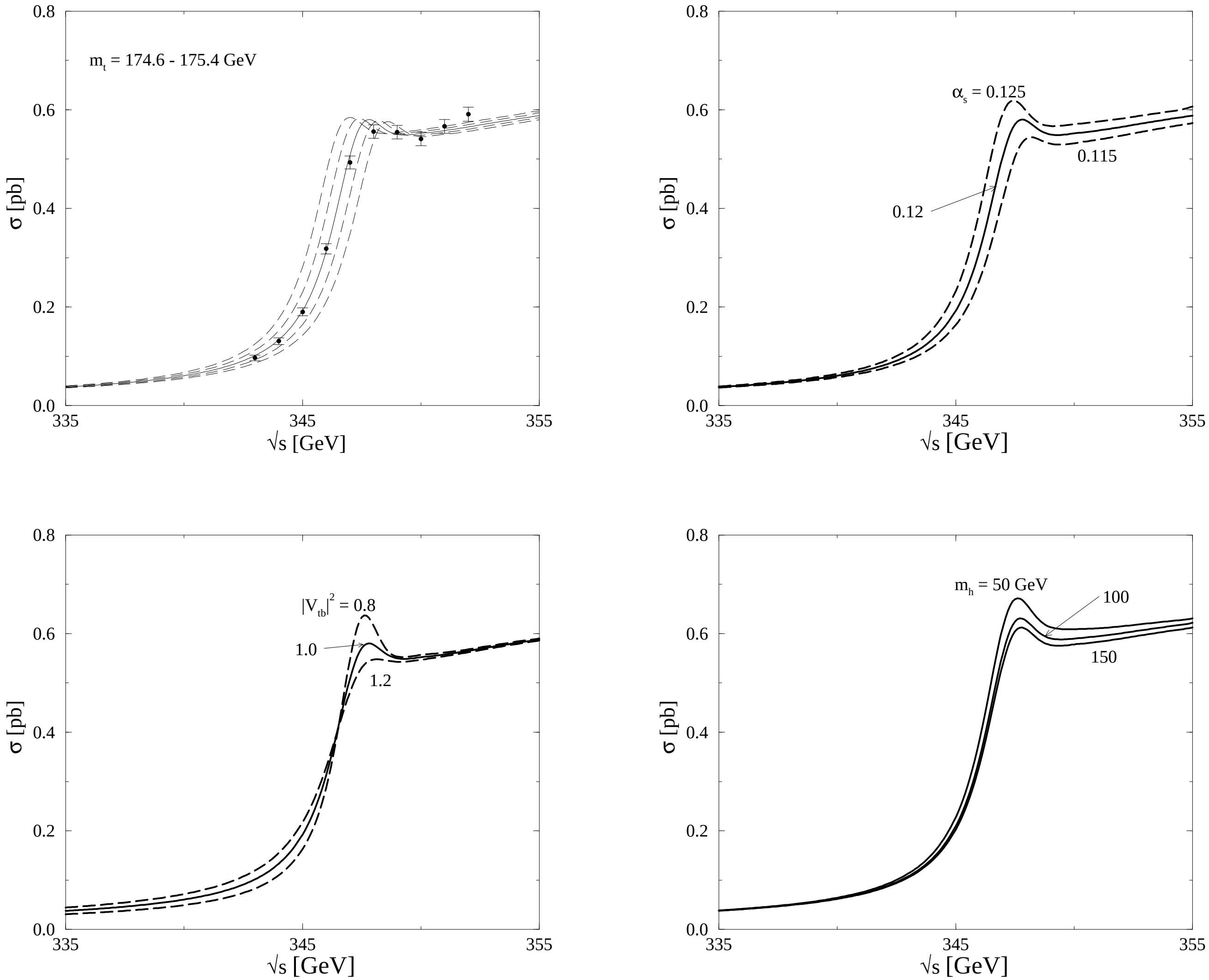

Penin's summary:

Top precision measurements from threshold scan

✔ Top quark mass

total uncertainty ~ 100 *MeV* ➪ *beats direct reconstruction*

✔ Top quark width

total uncertainty ~ 34 *MeV*

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total uncertainty $\sim 3\%$

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factor 2 uncertainty ➪ *cannot compete with Higgs production*

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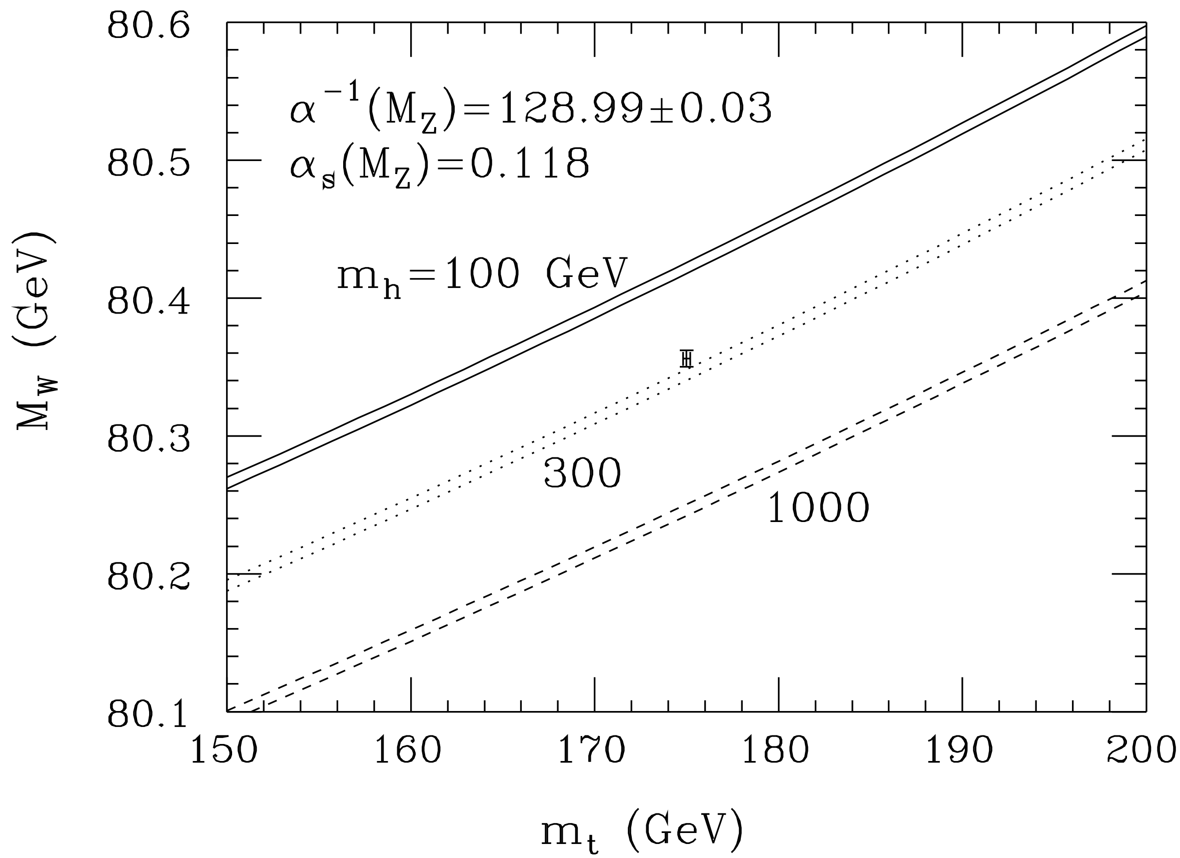
Table II: Comparison for the achievable precision in M_W and m_t measurement at different future colliders.

	LEP2		Tevatron		LHC	NLC	$\mu^+\mu^-$	
$\mathcal{L}$ (fb^{-1})	0.1	2	2	10	10	50	10	100
ΔM_W (MeV)	144	34	35	20	15	20	20	6
Δm_t (GeV)	–	–	4	2	2	0.2	0.2	0.07

Precision plot: M_W versus m_t:



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Lepton collider energy frontier.

(2) A muon collider is NOT a competitor for ILC.
The latter is mature and ready to go.

(3) A muon collider could be our future.
It will be (a lot) smaller, and possibly cheaper.
(if technically feasible.)

Future Energy Frontier: Comparison

Representative Physics Reach:

	Higgs(es)	SUSY	Strong Dynamics	Exotics	Astro/Cosmo
LHC $E_{qq} \approx 1.5 - 3$ TeV 300 fb^{-1}	$\surd$ partial	$\surd$ partial	$\surd\times$ non-resonance?	$\surd\surd$ ΔL	$\surd\times$ missing mass? CP-V ?
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The main difference between CLIC and μC:

1. Muon collider: s-channel scalar resonances, Higgs or alike.
2. Flavor dependent physics e versus μ.
3. Muon collider: large decay background.