Physics Cases For Muon Colliders

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(Brown University, Aug. 11, 2011)

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

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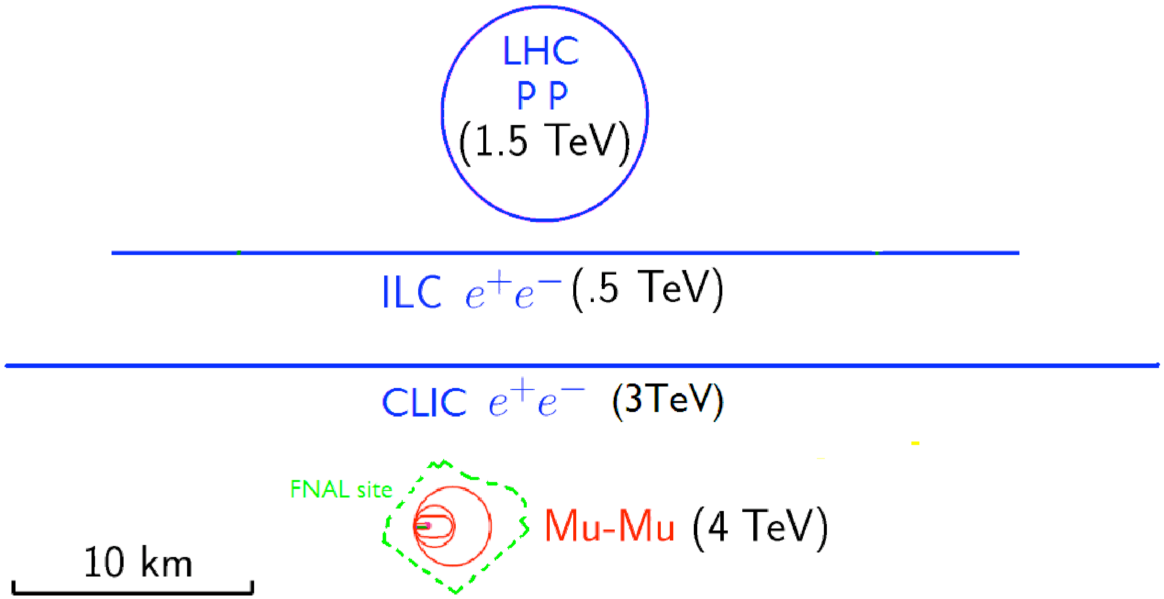

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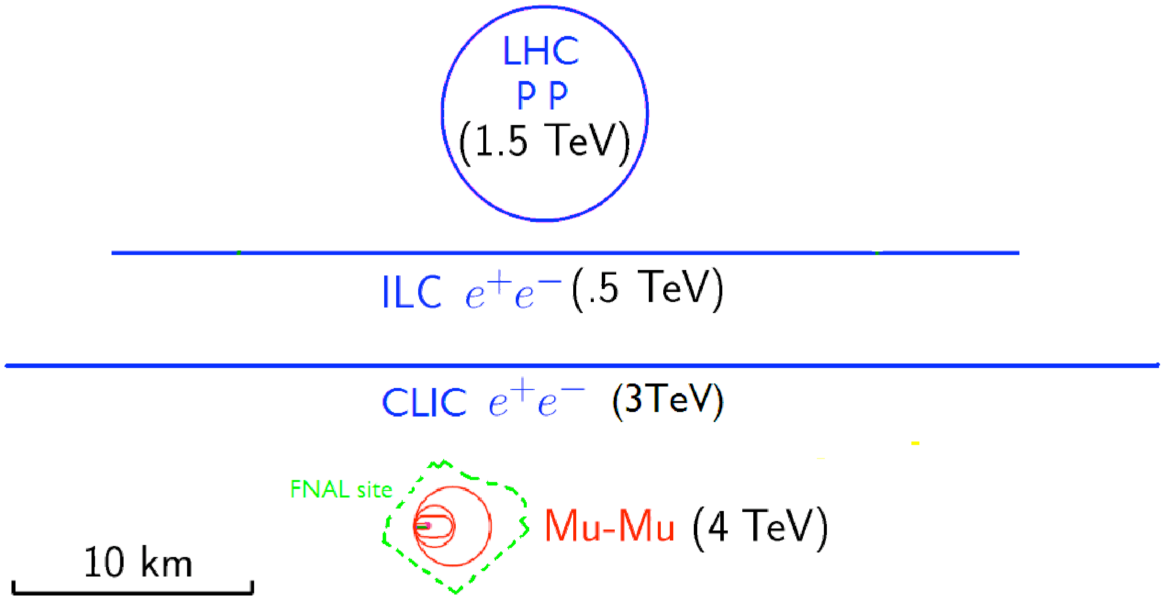

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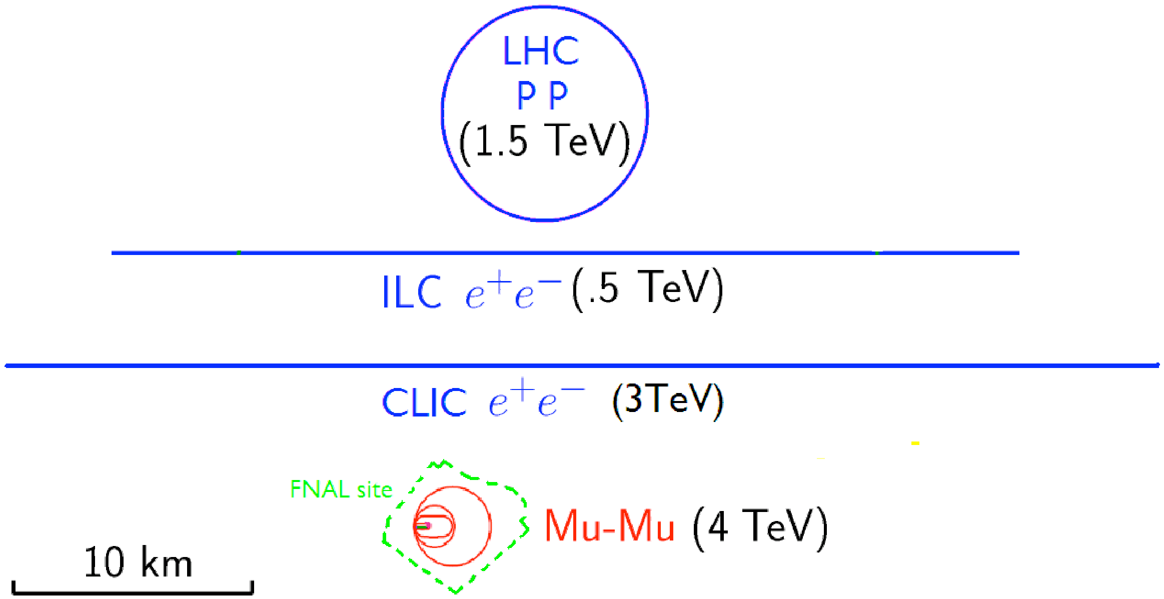

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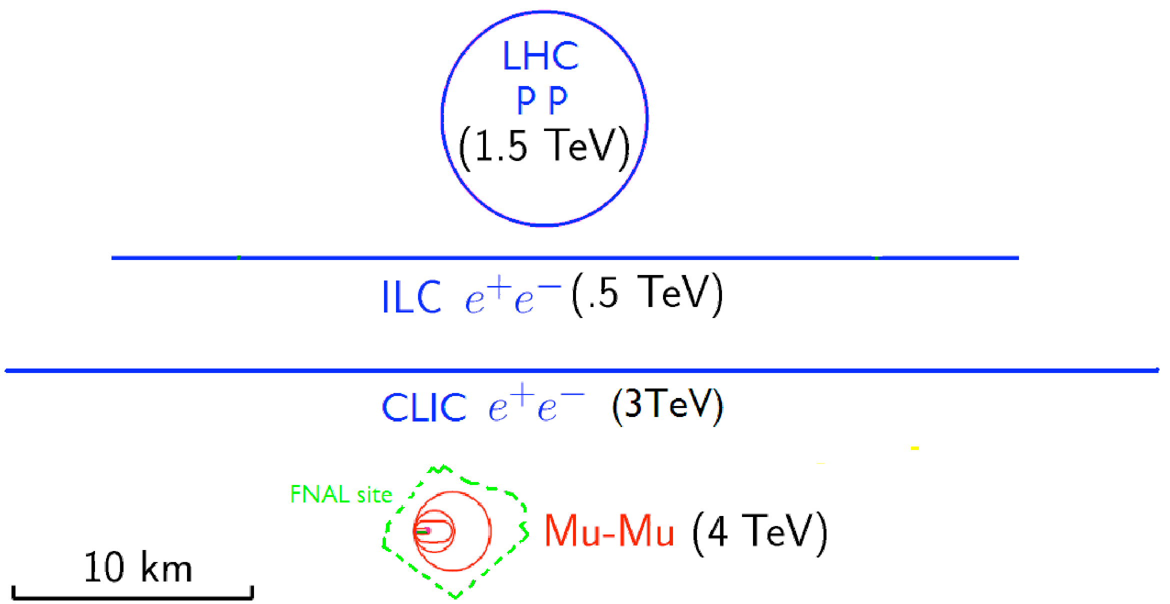

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(3). Challenges: "Never play with an unstable thing!"

(see Ron Lipton's talk next)

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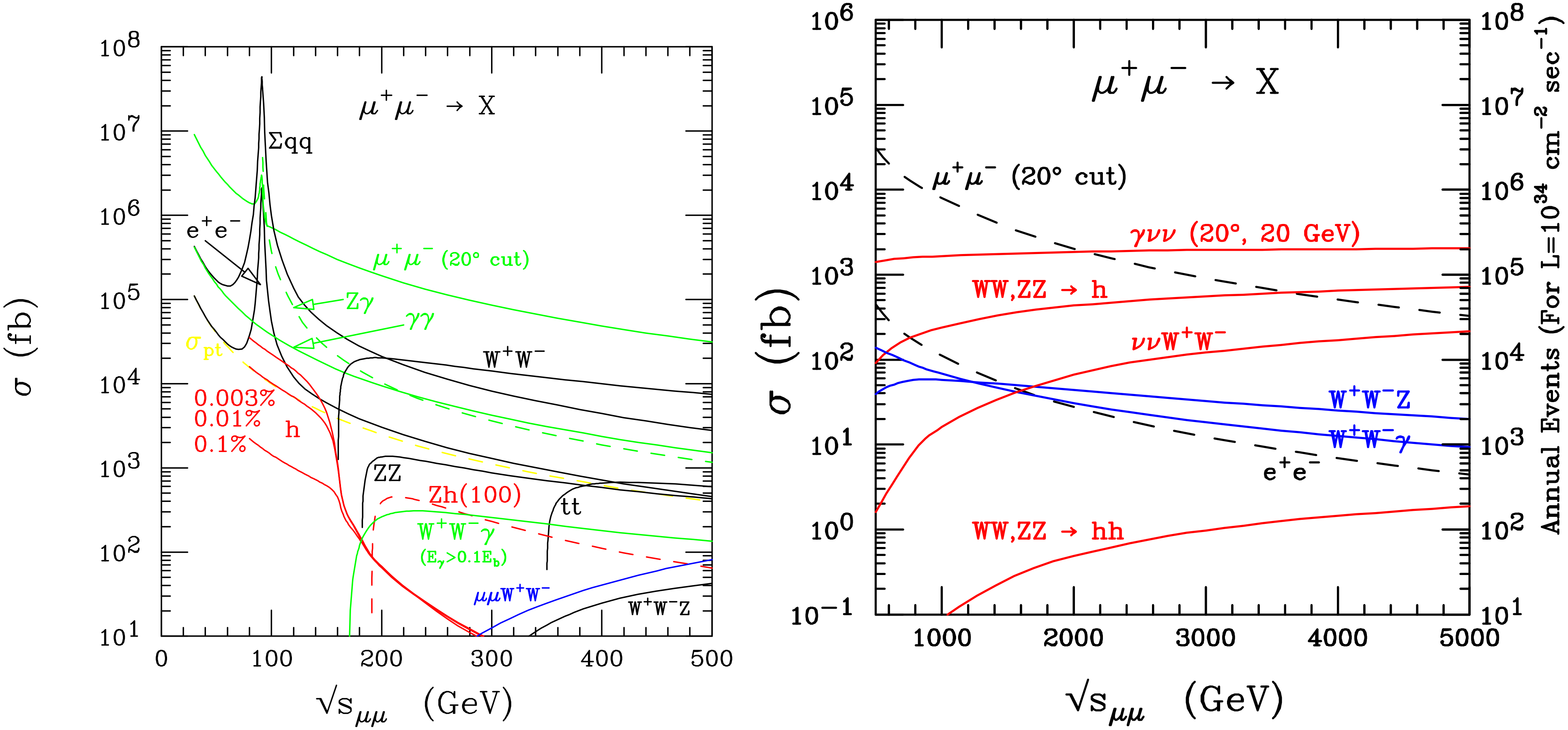
Physics at Muon Colliders



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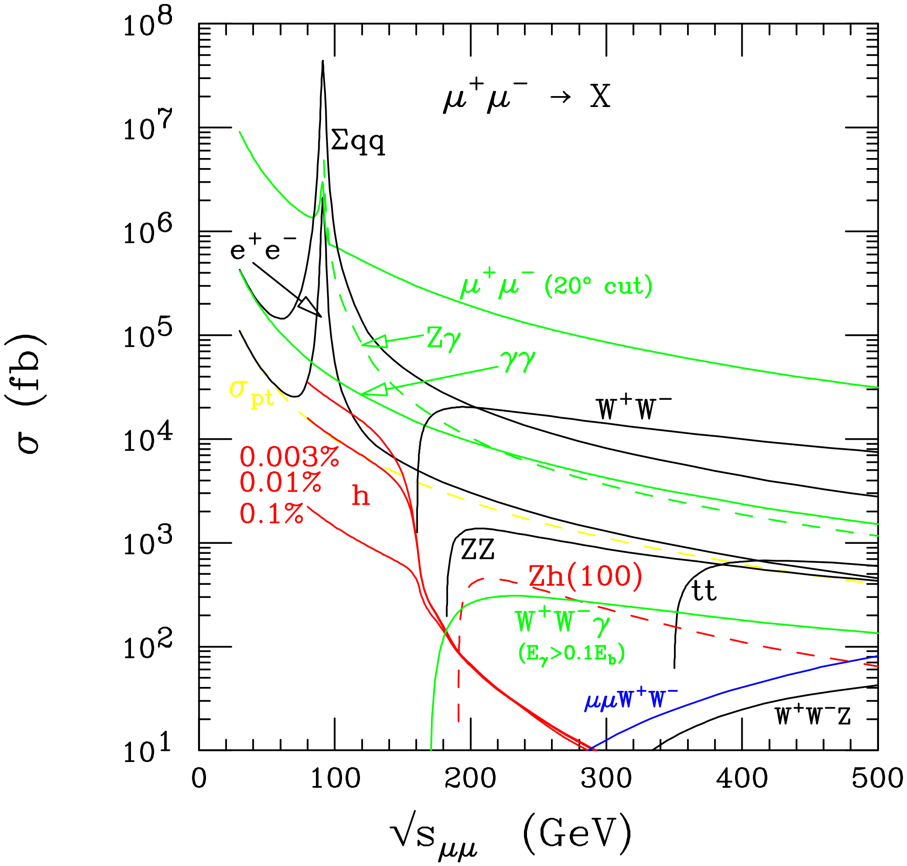
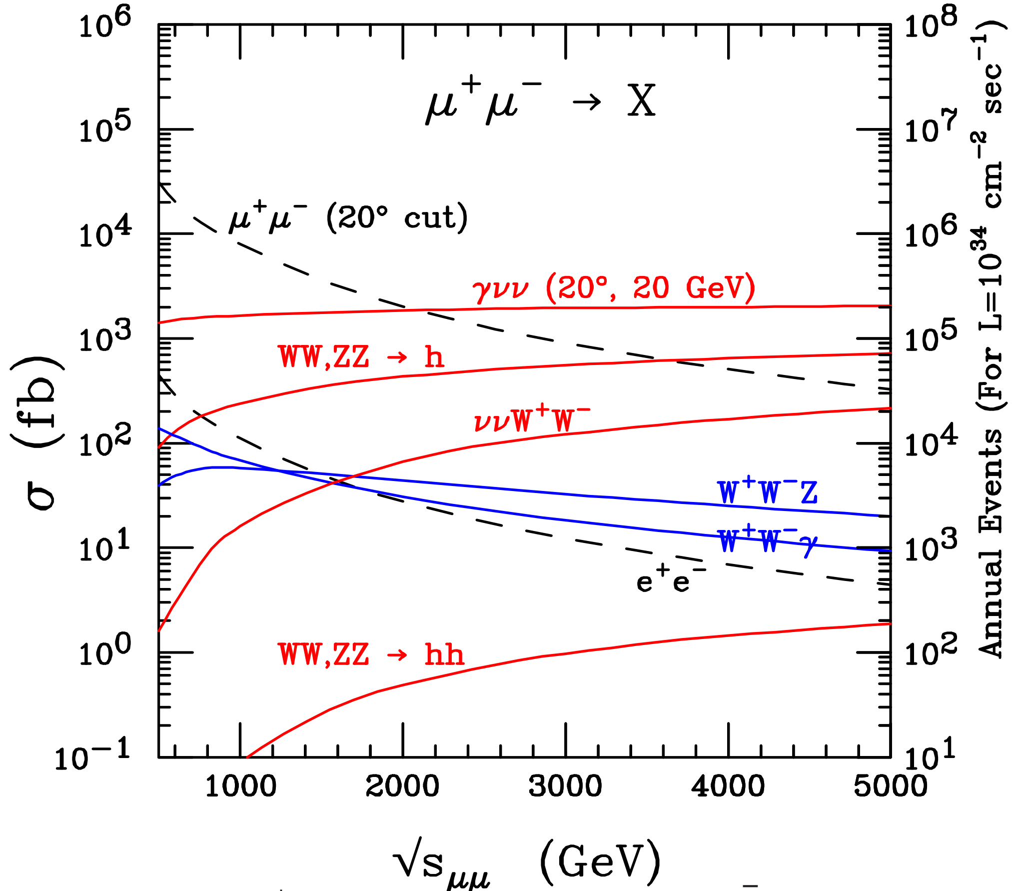
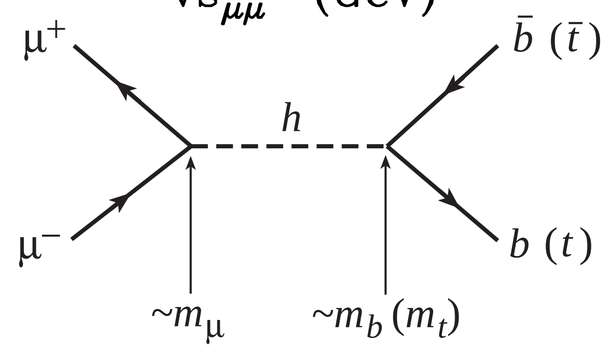




Most unique of all at a muon collider:
the s-channel scalar resonance.†



†Barger, Berger, Gunion, Han

A Higgs Factory

The s-channel resonant production:

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

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

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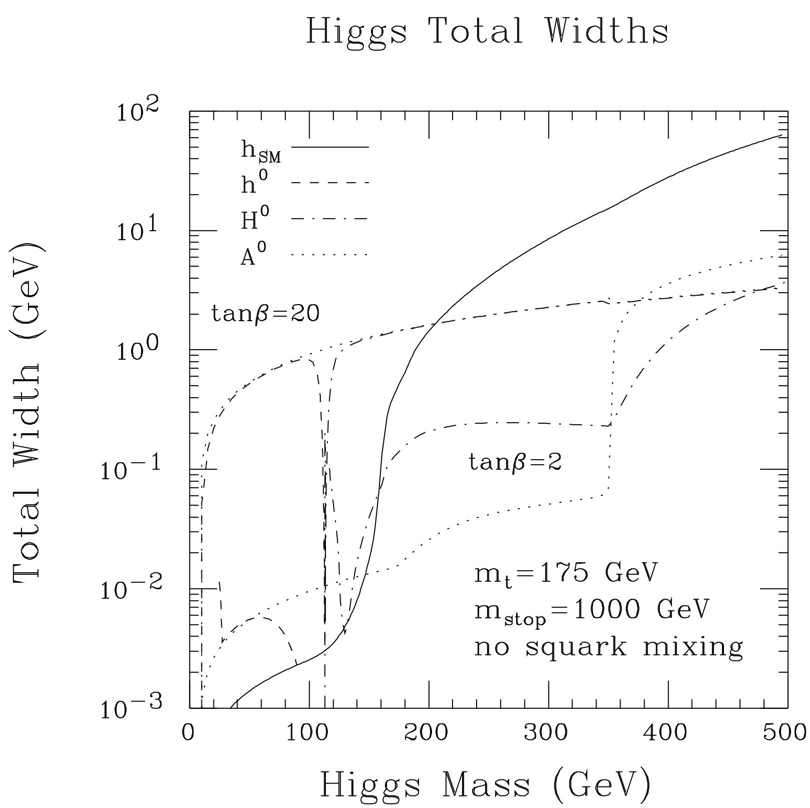
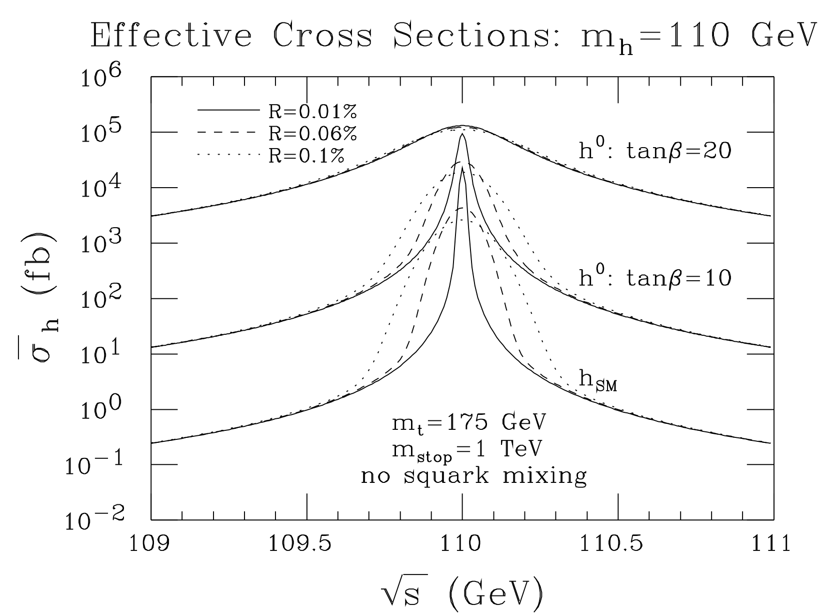
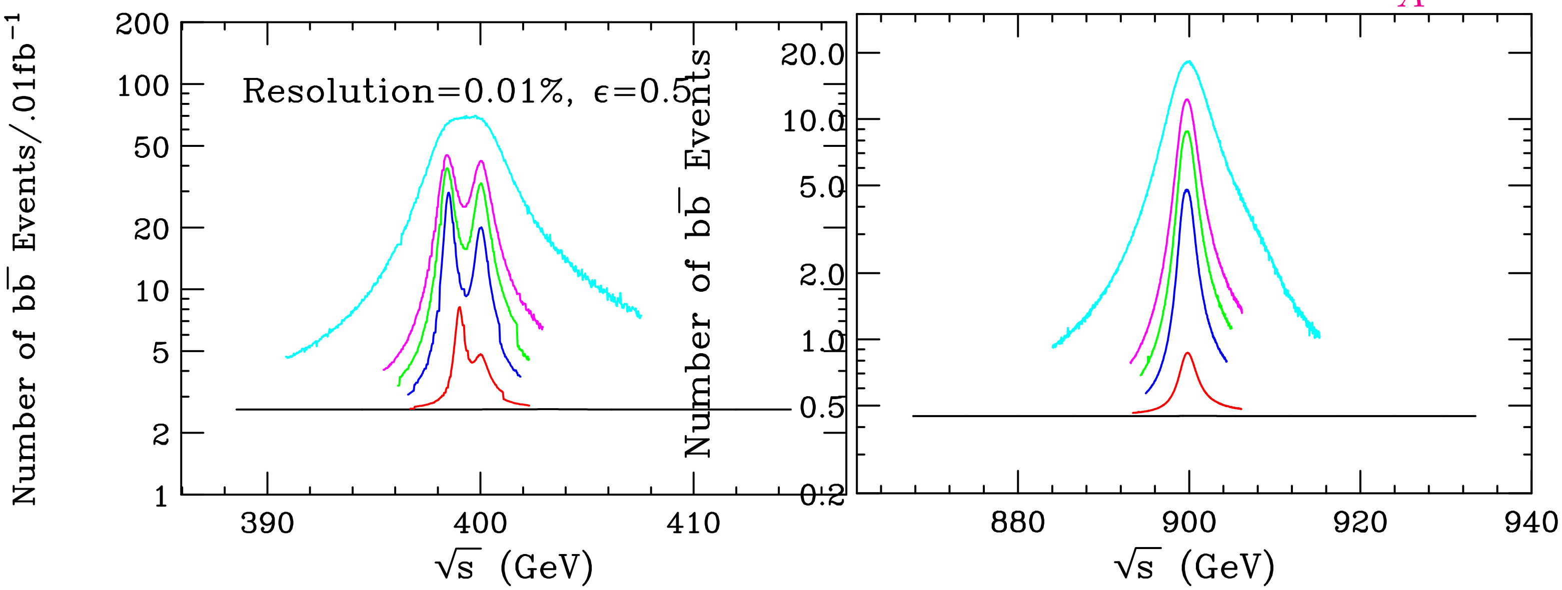




Heavy Higgs degenerate as M_A large: $\delta M \approx \frac{M_Z^2}{2M_A} \sin^2 2\beta$.



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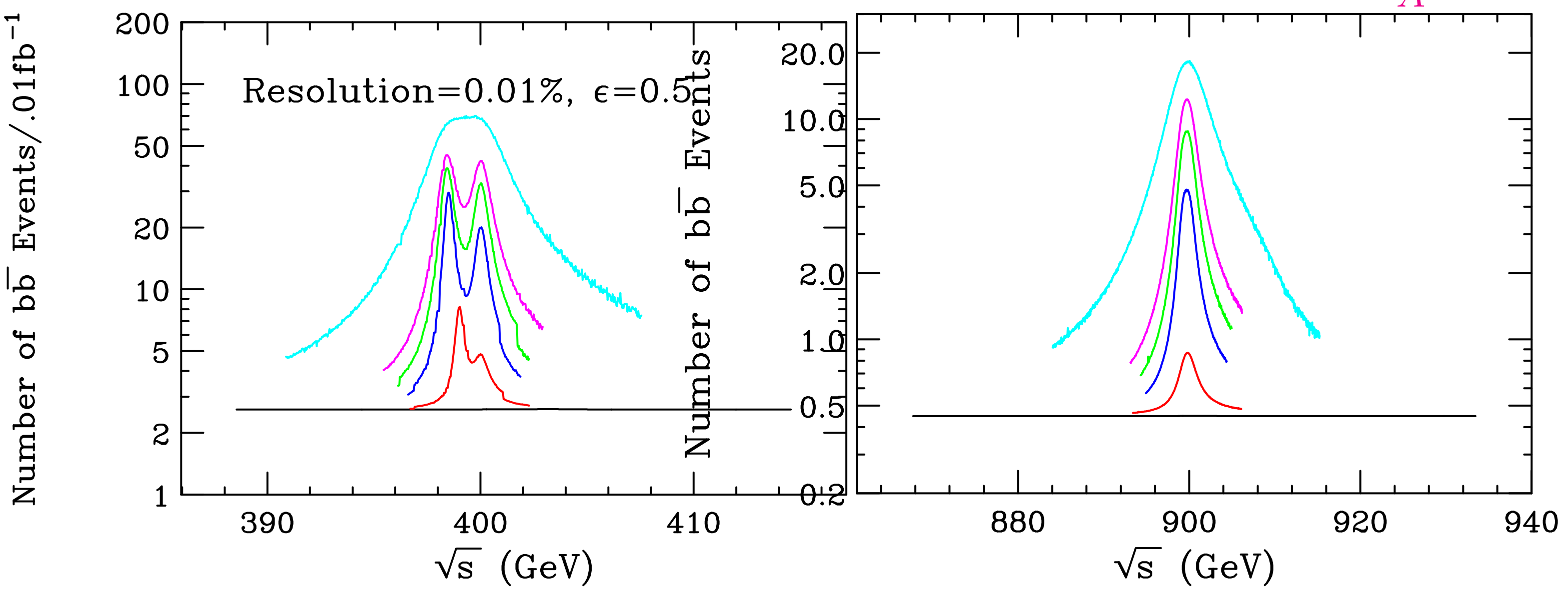

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Even at high mass, there is sufficient info understanding the Higgs sector:

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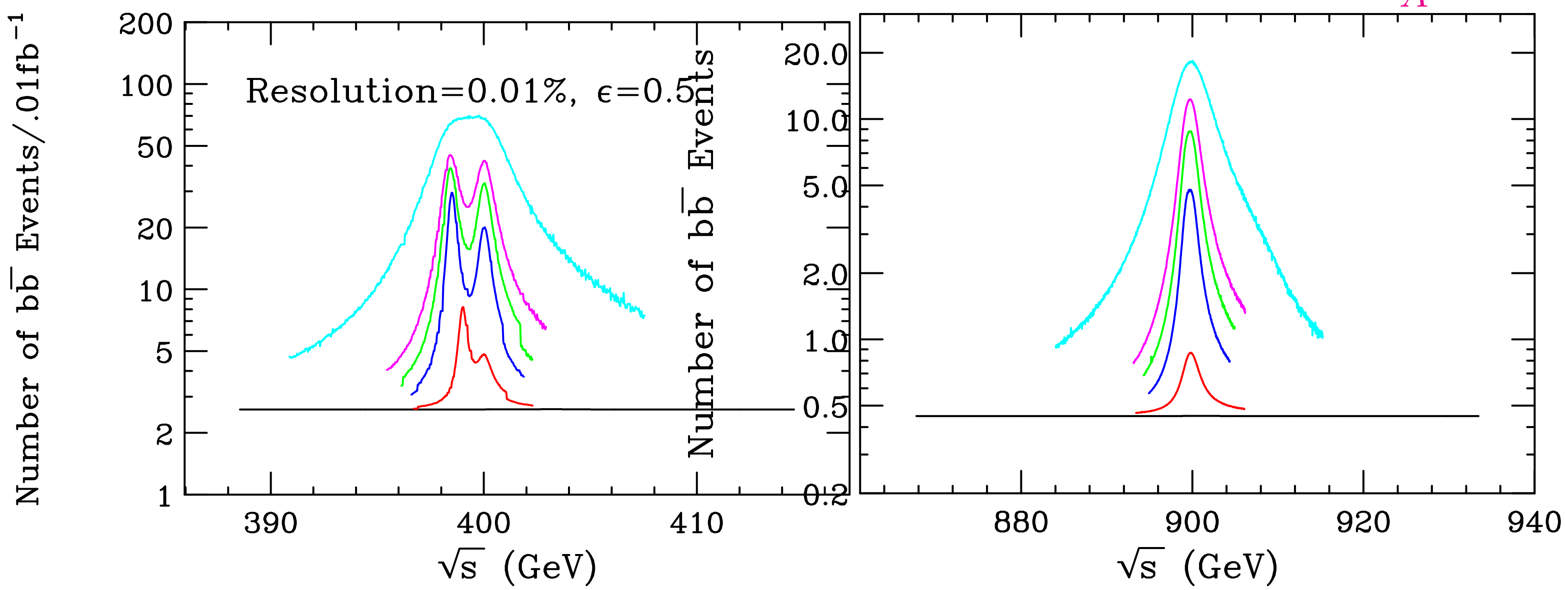

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- M_H: peak, accurate!
- Γ_{tot}: profile, accurate by scanning!
- $\overline{\sigma}^{measured}$: $(b\bar{b})/(t\bar{t}) \approx (m_b^2/m_t^2)\tan^4\beta$, $(b\bar{b})/(\tau\tau) \approx 3m_b^2/m_\tau^2$ upto radiative corrections.
- $\overline{\sigma}^{tot} = (b\bar{b}) + (t\bar{t})$+(smaller ones) $\Rightarrow \Gamma(\mu^+\mu^-)$ upto missing channels.

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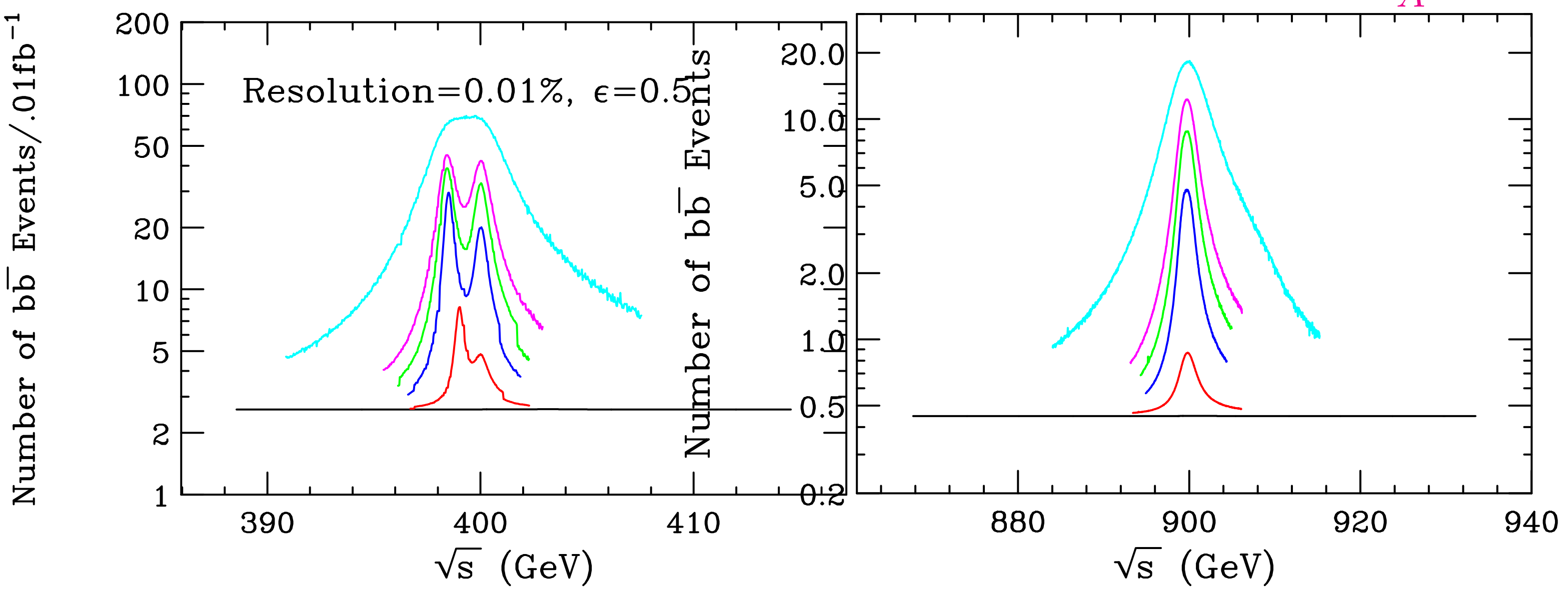

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- $\overline{\sigma}^{tot} = (b\bar{b}) + (t\bar{t})+$(smaller ones) $\Rightarrow \Gamma(\mu^+\mu^-)$ upto missing channels.
- Compare with theory: $\Gamma(H,A \to \mu^+\mu^-)$, learn how many H, A's contributing.
- If $t\bar{t}$, $\tau\tau$ decay kinematics reconstructed, hope to see CP violation!

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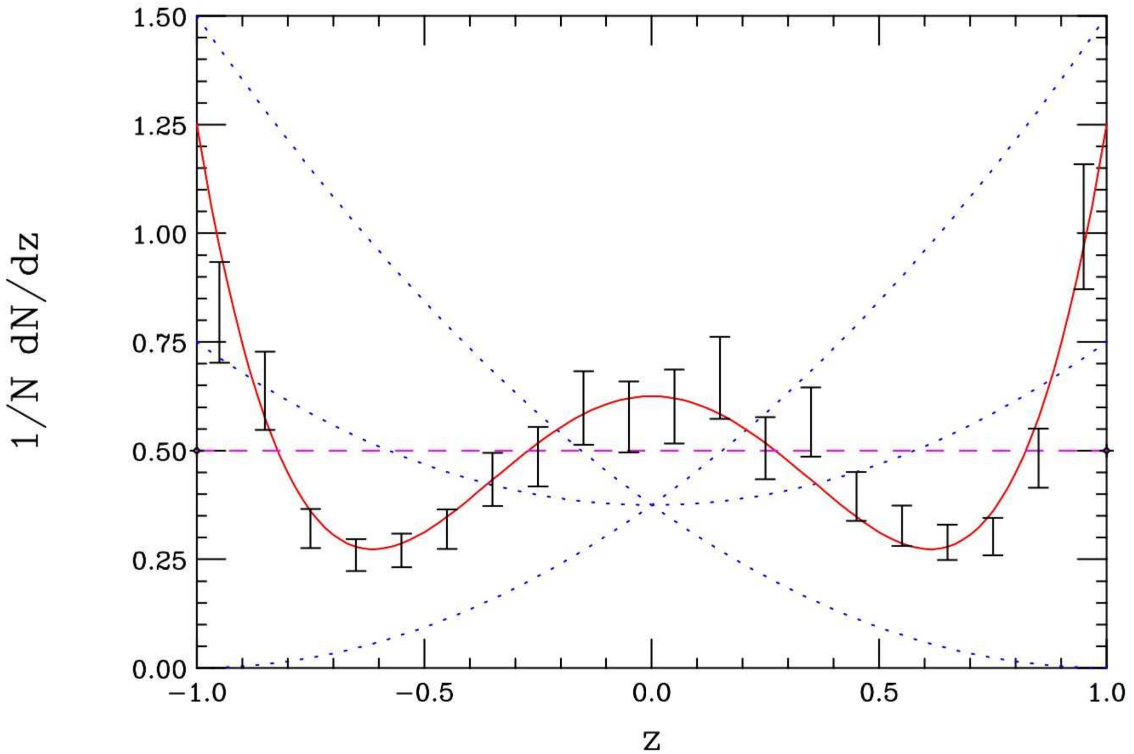
A Z' Factory

Or any resonance R, that couples to a muon

$$\sigma(\mu^+\mu^- \to R \to X) \;\approx\; \frac{4(2J+1)\pi\Gamma(R \to initial)\;\Gamma(R \to X)}{\Gamma^2 M^2}.$$



for various couplings and spins (1, 2).§

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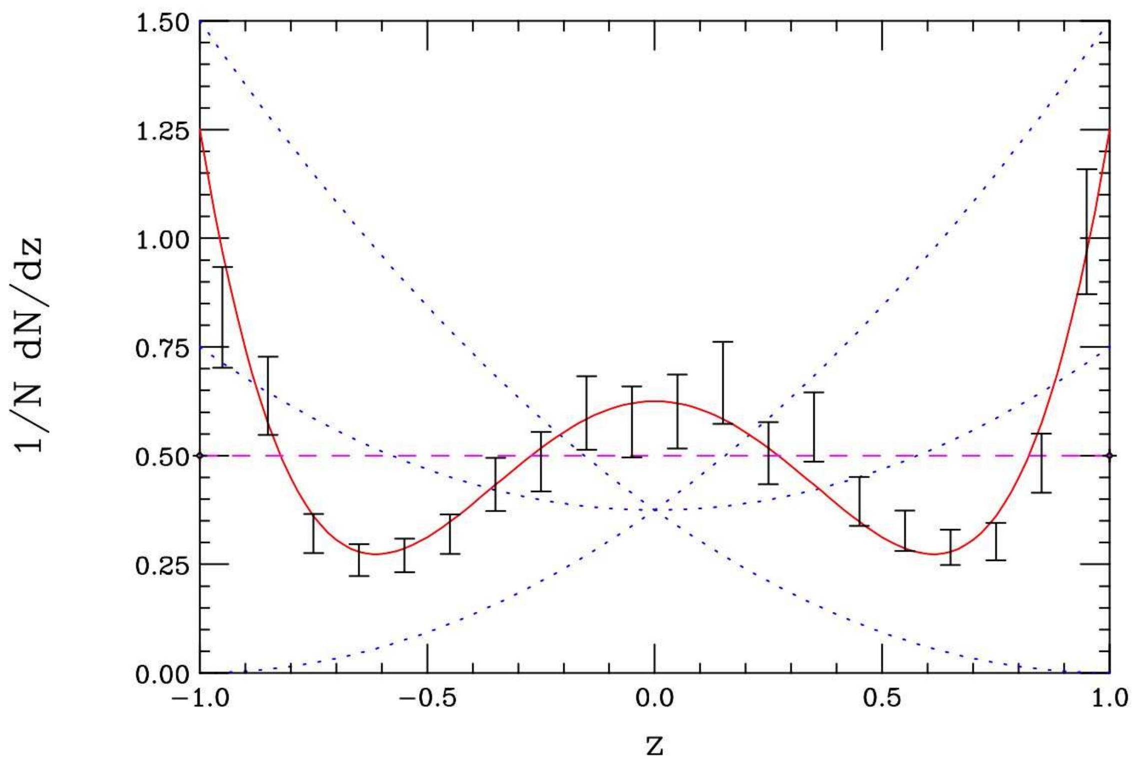

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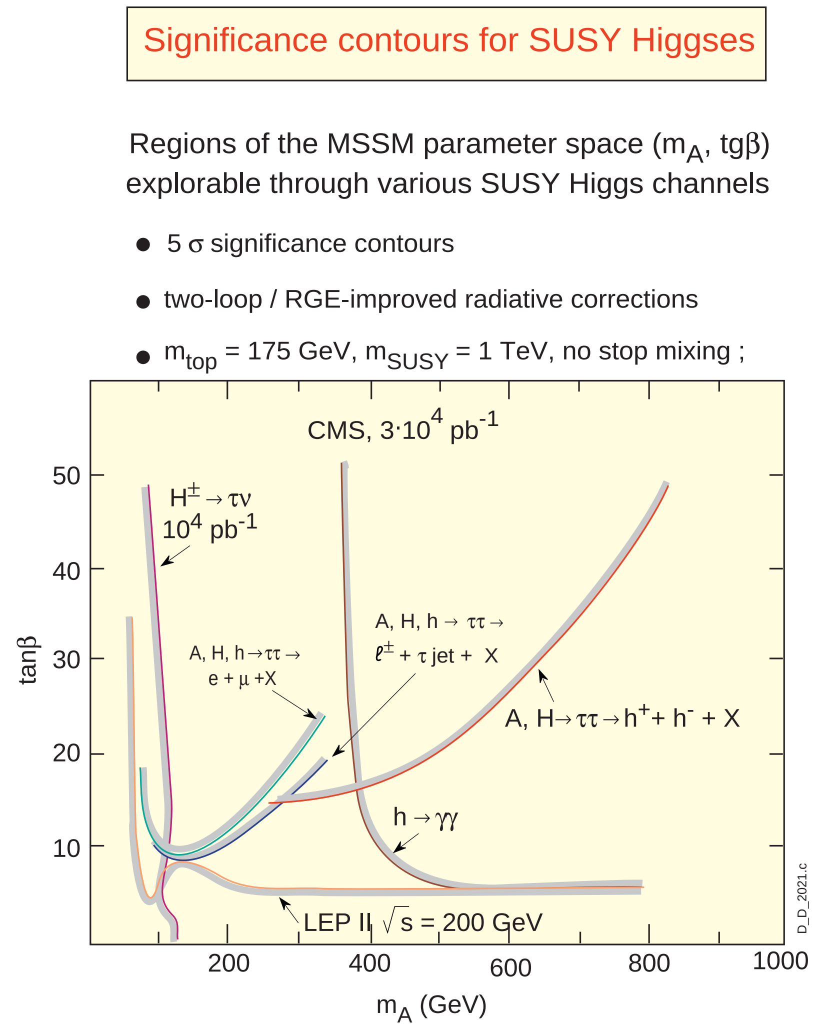
Comment: The LHC will have the full coverage upto $M_{Z'} \sim 4 - 6$ TeV, which will soon motivate/define the machine needs (or otherwise).

§Hewett, Rizzo

Electro-Weak Particle Pairs

(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:¶



¶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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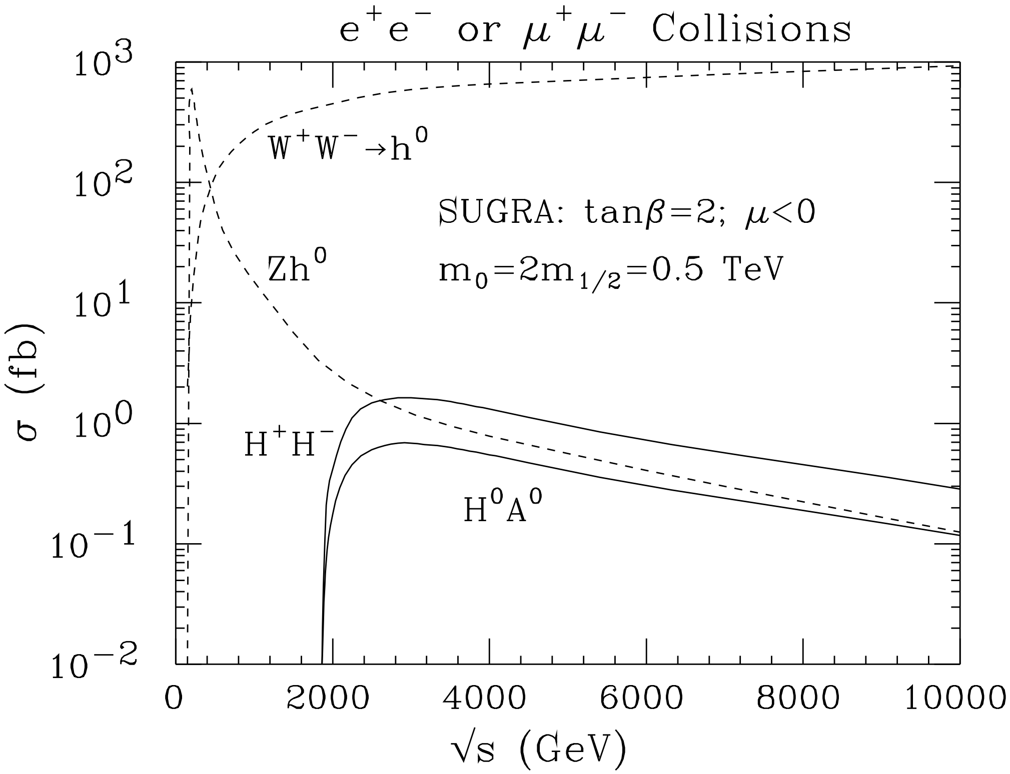

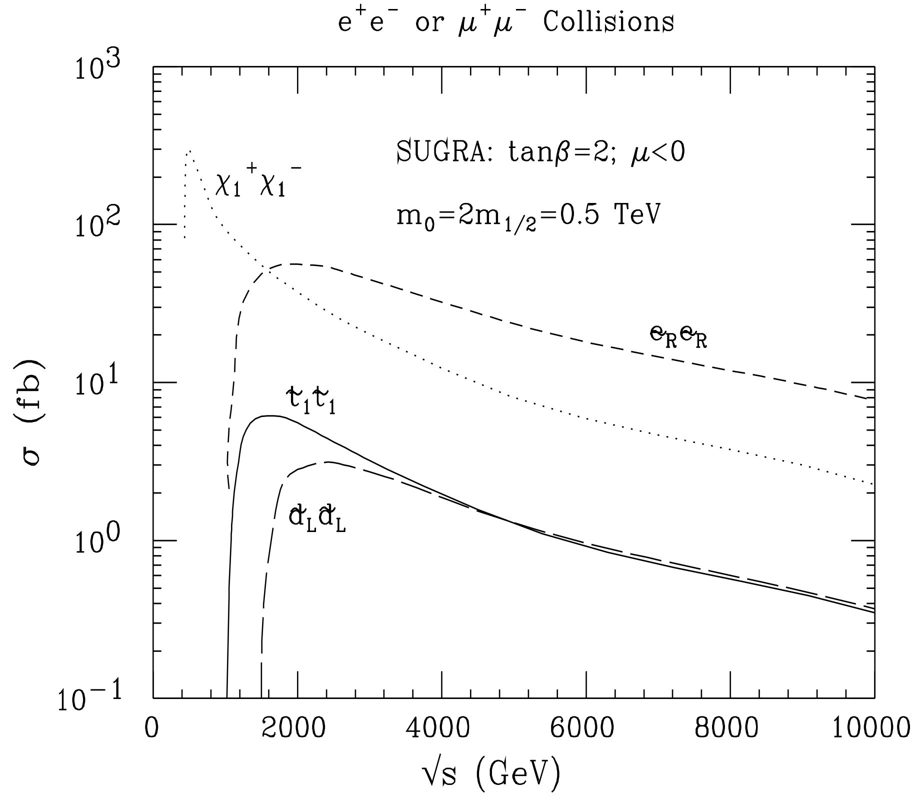

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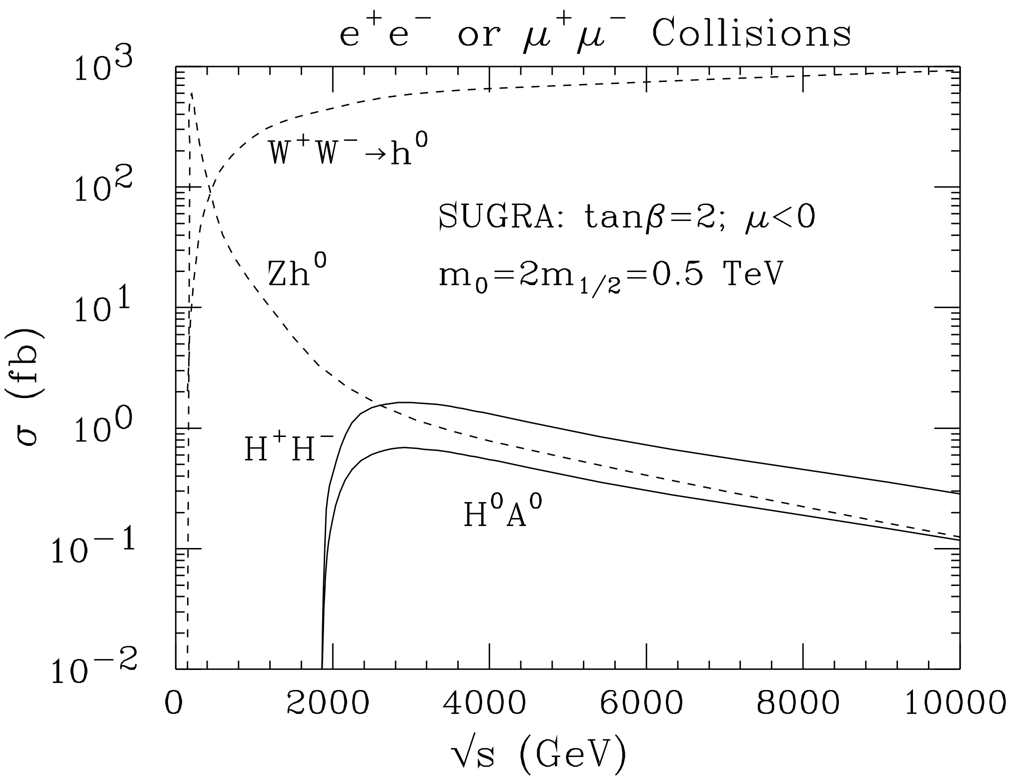

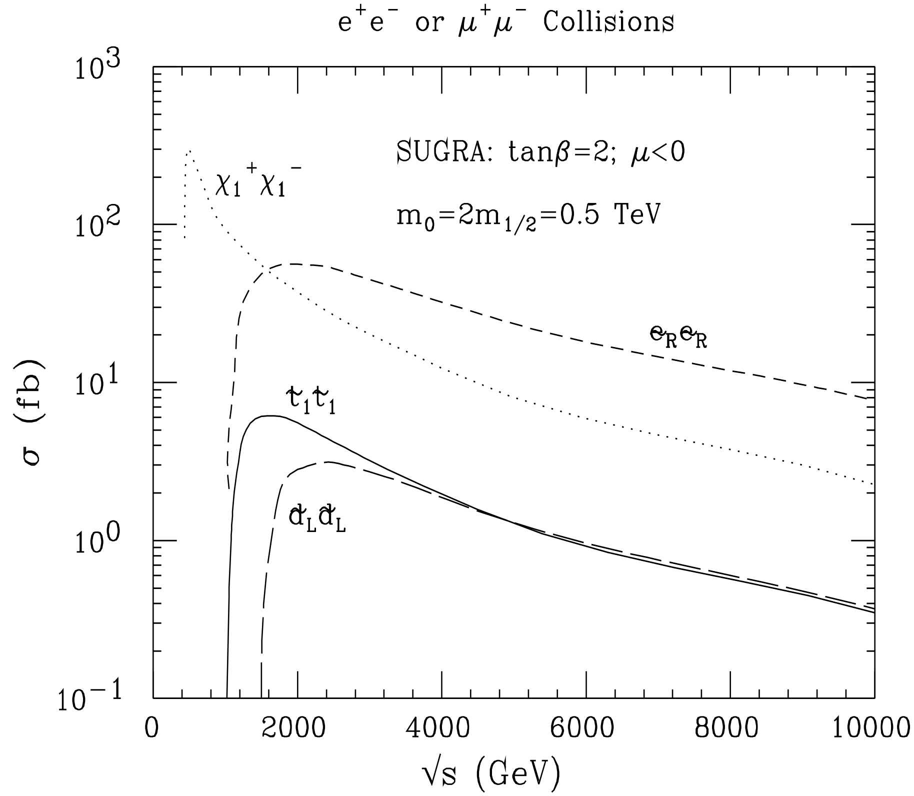

Once crossing the pair threshold, observation straightforward.
(rather model-independent, like in Two-Higgs Doublet model etc.)

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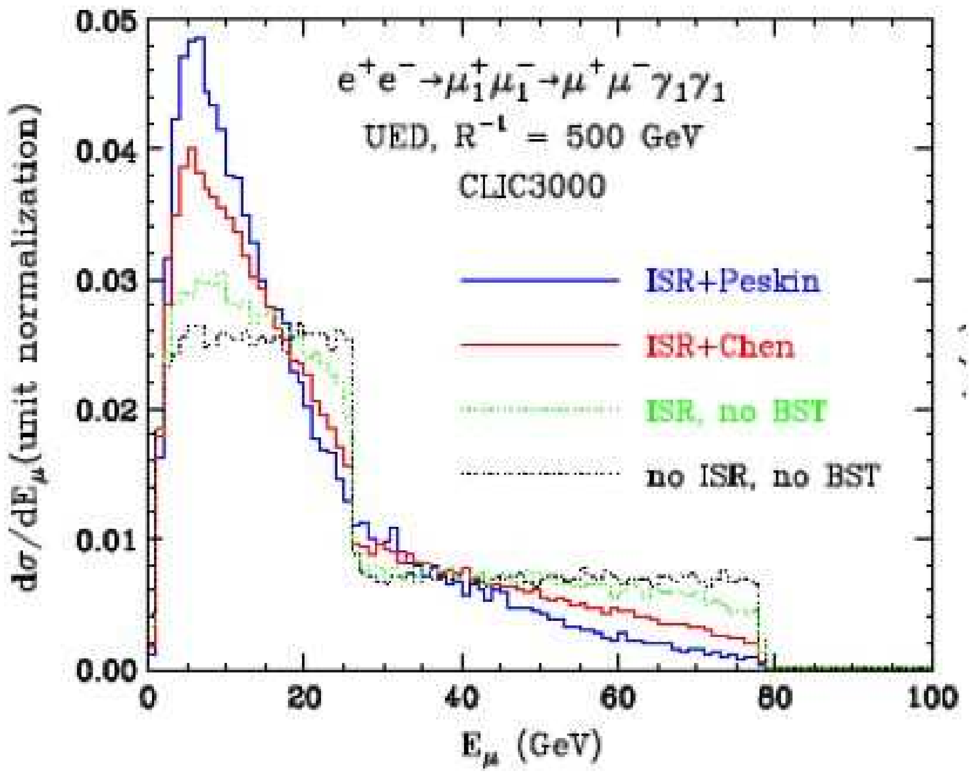
Energy edges in chain decays:[‖]

$\mu^+\mu^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^- + E^{miss}$ $(\tilde{\chi}_0\tilde{\chi}_0)$



$$E_{max,\ min} = \frac{\sqrt{s}}{4}\left(1 - \frac{M_\chi^2}{M_{\tilde{\mu}}^2}\right)(1 \pm \beta), \qquad \beta = \left(1 - \frac{4M_{\tilde{\mu}}^2}{s}\right)^{1/2}.$$

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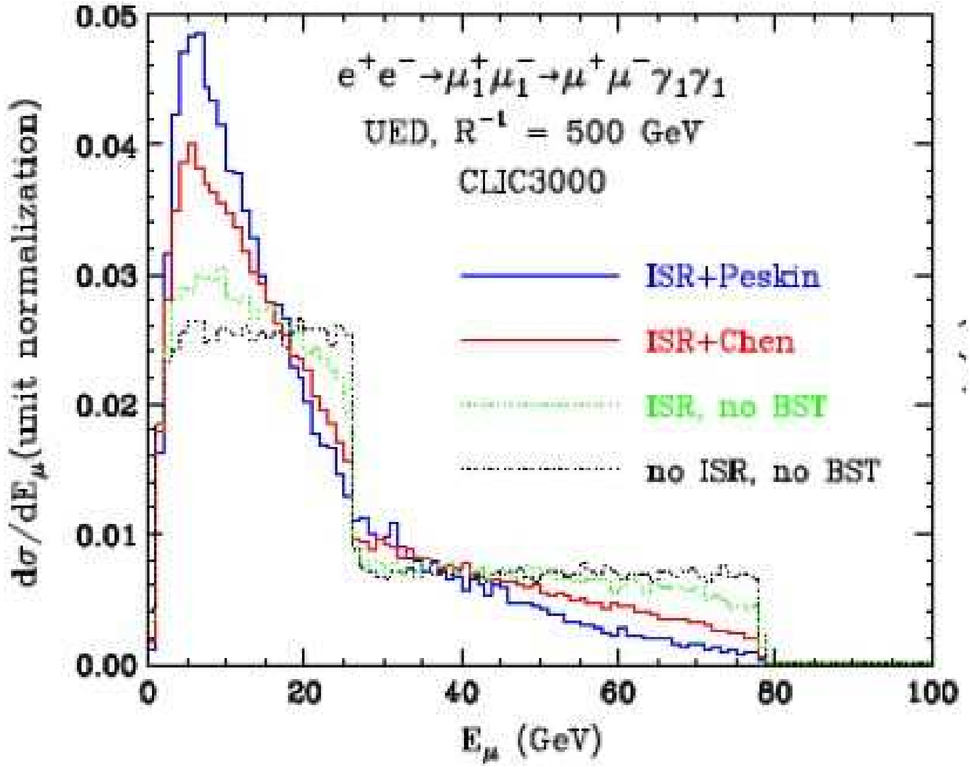

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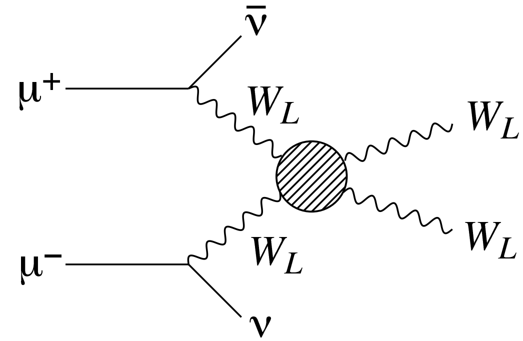
Comment: very difficult at LHC due to under-constrained kinematics.

‖Data, Kong, Matchev

Strong Electroweak Dynamics

$W_L W_L$ scattering



The scattering amplitude behaves as

$$A \sim \begin{cases} m_H^2/v^2 & \text{if light Higgs}, \\ s_{WW}/v^2 & \text{if no light Higgs}. \end{cases}$$

Partial wave unitarity implies: m_H or $\sqrt{s_{WW}} \leq 1.2$ TeV.

$$\Rightarrow \sqrt{s_{\mu\mu}} \sim (4)\sqrt{s_{WW}} \gtrsim 4 \text{ TeV}.$$

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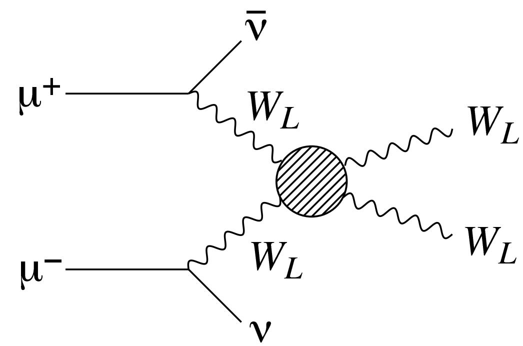

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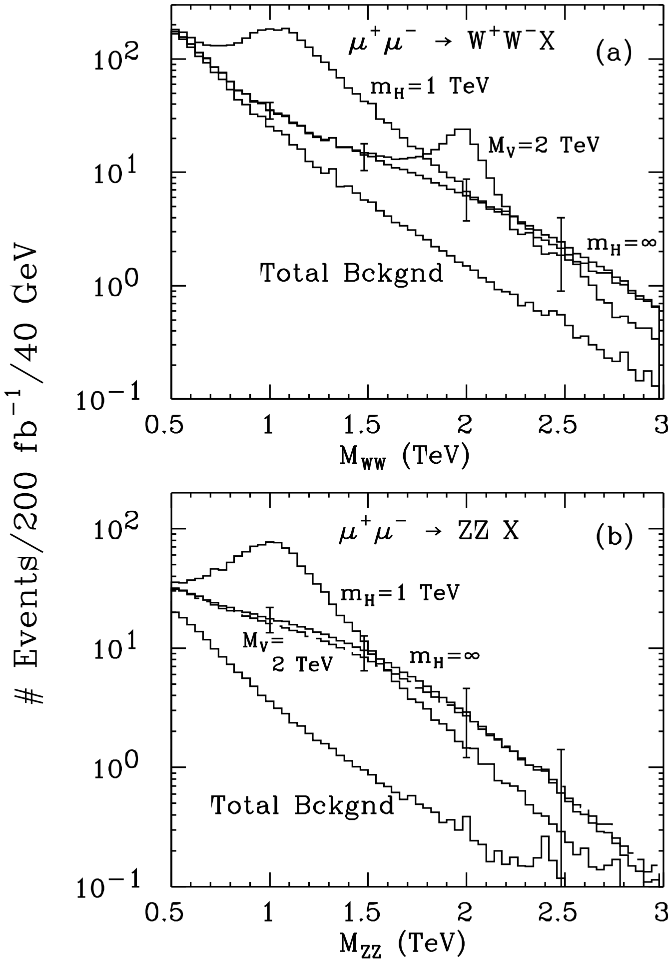
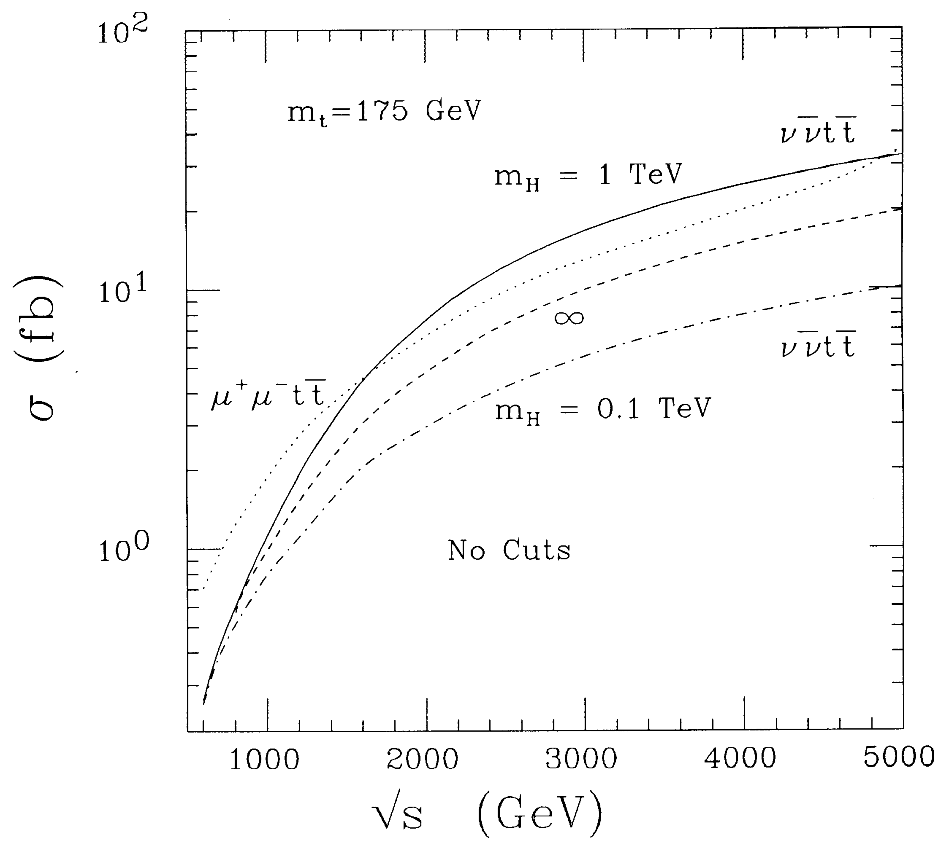
For model connections:

$$\frac{\sigma(W_L^+W_L^- \to W_L^+W_L^-)}{\sigma(W_L^+W_L^- \to Z_L Z_L)} \begin{cases} \sim 2 & \text{scalar } H^0, \\ \gg 1 & \text{vector } \rho^0_{TC}, \\ \sim 2/3 & \text{LET } \sqrt{s} \ll M. \end{cases}$$

Consider $\mu^+\mu^- \to \nu\nu W^+W^-$, $\nu\nu ZZ$ and $\nu\nu t\bar{t}$ via H, V or non-resonance at $\sqrt{s} = 4$ TeV.





Comment: This would be very challenging to test at the LHC.**

**Bagger et al.

Benchmark Processes

Recent meeting at Telluride, CO, *Muon Collider 2011*:
http://conferences.fnal.gov/muon11

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(6) Contact interactions

Comparative Remarks:

Representative Physics Reach:

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Need to take advantage of the complementarity!