

Bound States and Supersymmetry

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Outline

- Brief review of SUSY
- Scalar top physics
- Stoponium physics
- Higgs physics with SUSY bound states
- Conclusions & Future Work

Supersymmetry

- An additional spacetime symmetry relating particles of different spin.
- Many reasons why particle physicists believe SUSY might exist.
- Take the SM, double the spectrum and write down all terms consistent with symmetries and you have the MSSM.
- As defined here, MSSM has 124 parameters!

Supersymmetry

- Theorists have developed models that reduce this list of parameters to something experimentally testable. So far, nothing seen at LEP, Tevatron, LHC, ...
- Could be there is nothing there, but it could also be that the models we came up with so far need to be extended...

Top squarks (“stops”)

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Standard scenarios have $m_{\tilde{t}} > 640 \text{ GeV}$ to increase mass of the Higgs boson, making above decays very prompt, so no bound states.

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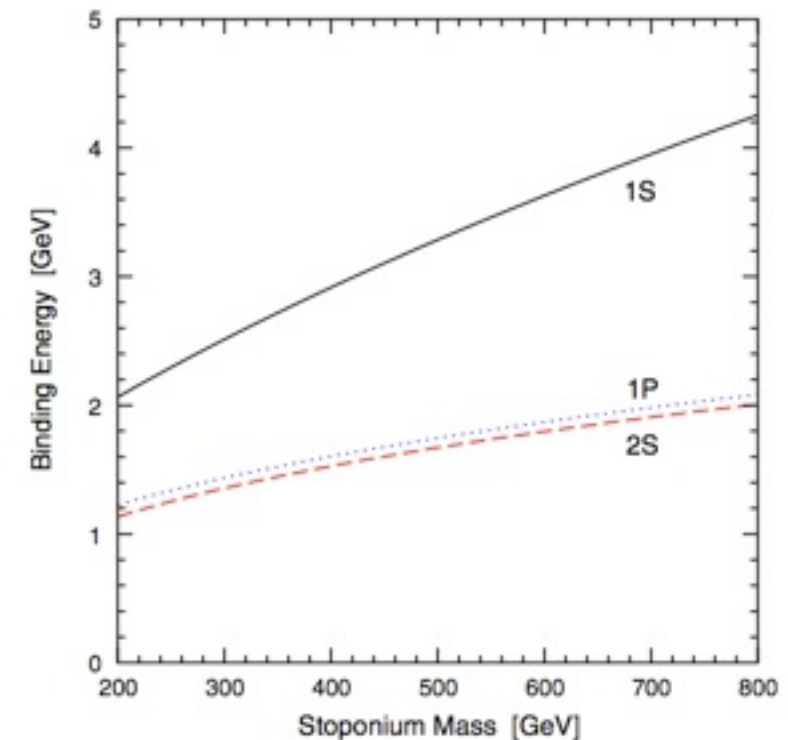
Ignoring indirect constraints (model dependent), the strongest constraints come from LEP, and only require $m_{\tilde{t}} > 71$ GeV and $|m_{\tilde{t}} - m_{\tilde{\chi}^0}| < 2$ GeV.

In this case, dominant single stop decay is given by $\tilde{t} \rightarrow c\tilde{\chi}^0$ whose rate is much smaller, so BS can form!

Assuming $m_{\tilde{t}_1} \ll m_{\tilde{t}_2}$, spectrum is simple. Spin of state tracks relative angular momentum of squarks.

Lightest state is 0^{++} state $\eta_{\tilde{t}_1}$.

Spectrum computed by S. Martin (right) assuming QCD binding potential.



Constraints on Parameters

To generate a stop hierarchy ($m_{\tilde{t}_2} = Z m_{\tilde{t}_1}$) requires that we set parameters according to the following formula:

m_i - (diagonal) mass of \tilde{t}_i .
 θ - stop mixing angle.

$$\frac{Z^2 + 1}{Z^2 - 1} \leq \frac{|(m_1^2 - m_2^2) \sec(2\theta)|}{m_1^2 + m_2^2} \leq 1$$

Measure of accepted tuning.

Needed to avoid tachyons.

We will be interested in two values of mixing angle: $\theta = 0, 56^\circ$

No mixing.

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NOTE: In the MSSM, m_i and θ are given in terms of other parameters. To avoid model dependence, we treat these numbers as independent.

“Canonical Point” of Parameter Space

When doing model building, we need to choose one point in parameter space as our standard point. As we continue our analysis, we will scan over points near this region. This is in progress work, and should appear soon.

We choose the following point in parameter space as our canonical point:

$$m_{\tilde{\chi}_0} = 74 \text{ GeV}, \quad m_{\tilde{t}_1} = 75 \text{ GeV}, \quad m_h = 149 \text{ GeV}$$

$$m_A = m_H = 200 \text{ GeV}, \quad \tan \beta = 10, \quad \tan \theta = 1.5, \quad \mu = 100 \text{ GeV}, \quad A_t = 100 \text{ GeV}.$$

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$$\mathcal{V}_{\text{eff}} = \frac{1}{2}m_h^2 h^2 + \frac{1}{2}m_S^2 S^2 + (2m_{\tilde{t}_1} g_h f_S) h S$$

where m_S is the stoponium mass and f_S is the stoponium decay constant defined by

$$\langle 0|(\tilde{t}_1^* \tilde{t}_1)_1|\eta_{\tilde{t}}\rangle = f_S = \left(1 + \frac{\mathcal{B}}{m_S}\right)^{-1} \sqrt{\frac{6}{m_S}} \psi(0)$$

and \mathcal{B} is (negative of) the binding energy ($m_S = 2m_{\tilde{t}_1} - \mathcal{B}$).

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Thus the Higgs and stoponium states mix and there are two scalars ϕ_{\pm} with mass

$$m_{\pm}^2 = \frac{1}{2} \left[(m_h^2 + m_S^2) \pm \sqrt{(m_h^2 - m_S^2)^2 + 8m_{\tilde{t}_1} g_h f_S} \right]$$

For $m_S \sim m_h$, this mixing can be quite large.

More Binding Forces

In addition to QCD, there are two other sources of binding potential for stops:

- (1) Higgs exchange: Only relevant for squarks related to heavy fermions.
There are 3 Higgs bosons that could bind stoponium (h, H, A).
- (2) Contact interactions: Scalars must have quartic couplings, leading to delta function potentials. SUSY fixes the size of these couplings (**NOT** a free parameter!).

We will deal with these in turn...

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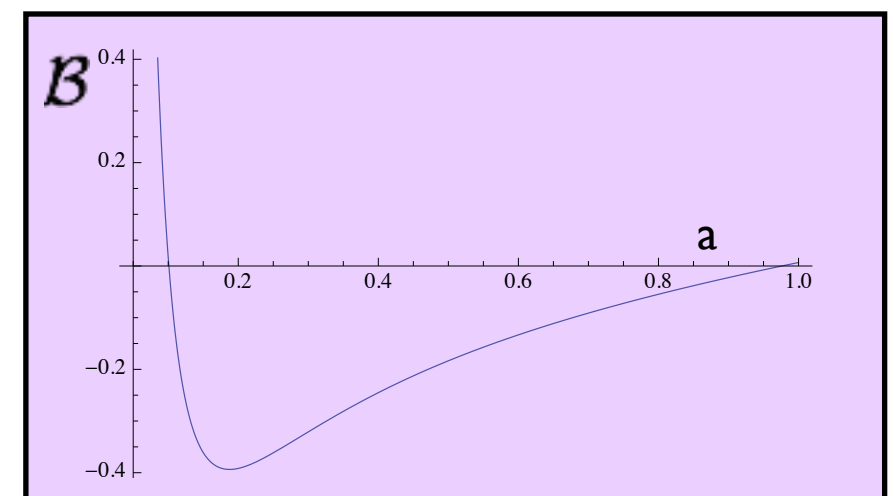
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Canonical point minimizes (Coulomb + Yukawa) at:

$$\bar{a} = 0.122 \text{ GeV}^{-1}, \quad \bar{\mathcal{B}} = 0.534 \text{ GeV}$$

within a factor of 3 of the naive Bohr radius.



(2) Contact Interactions

As mentioned earlier, there will be a (repulsive) delta function term in the Hamiltonian from quartic interactions of the scalar fields, required by SUSY:

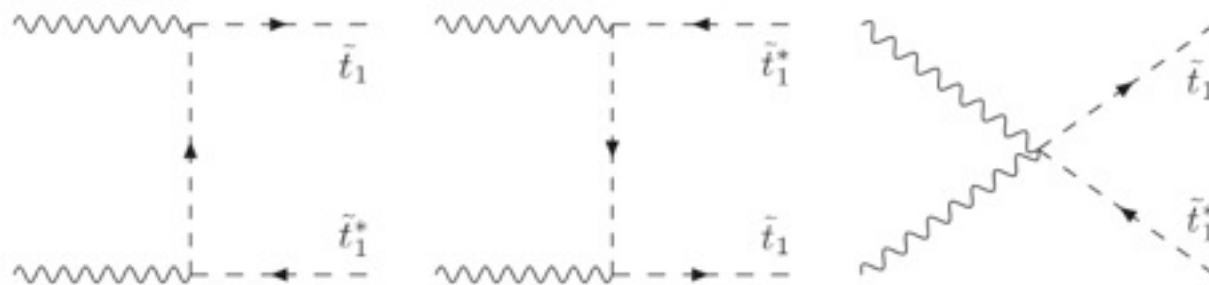
$$V_c(r) = \mathcal{A} \delta^{(3)}(\mathbf{r}), \quad \mathcal{A} = \frac{1}{4m_{\tilde{t}}^2} \left[\frac{1}{6} g_s^2 + y_t^2 \sin^2 \theta \cos^2 \theta \right] + \dots$$

In the case of stoponium, contact terms are small, although this might not be true in general.

For the sake of this analysis, we treat them perturbatively - should only affect S states.

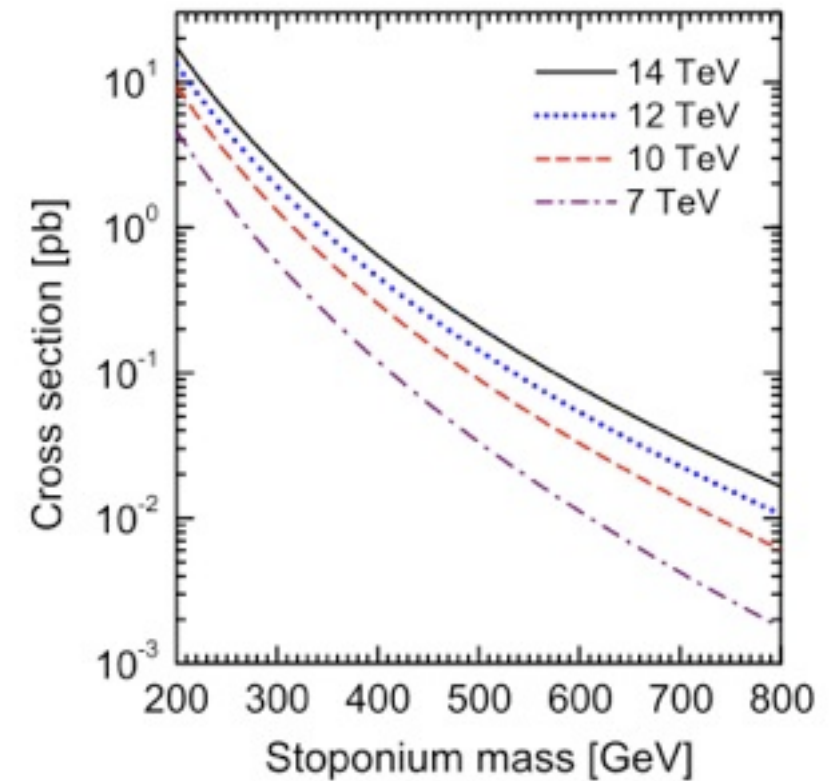
Stoponium Production & Decay

Production occurs mostly through gluon fusion at LHC.



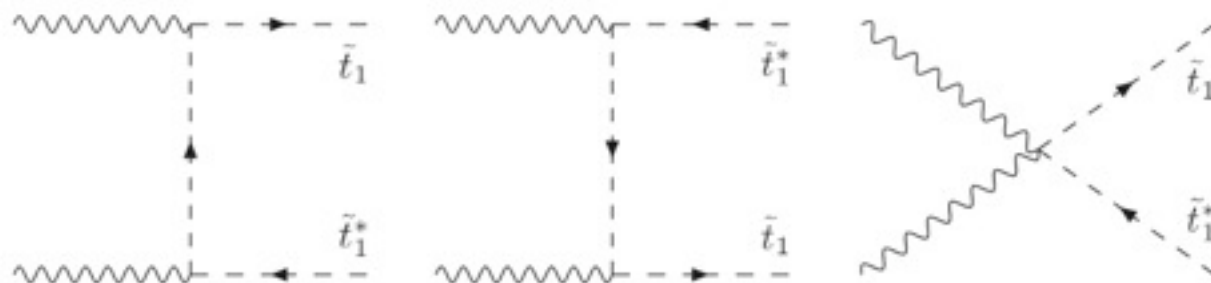
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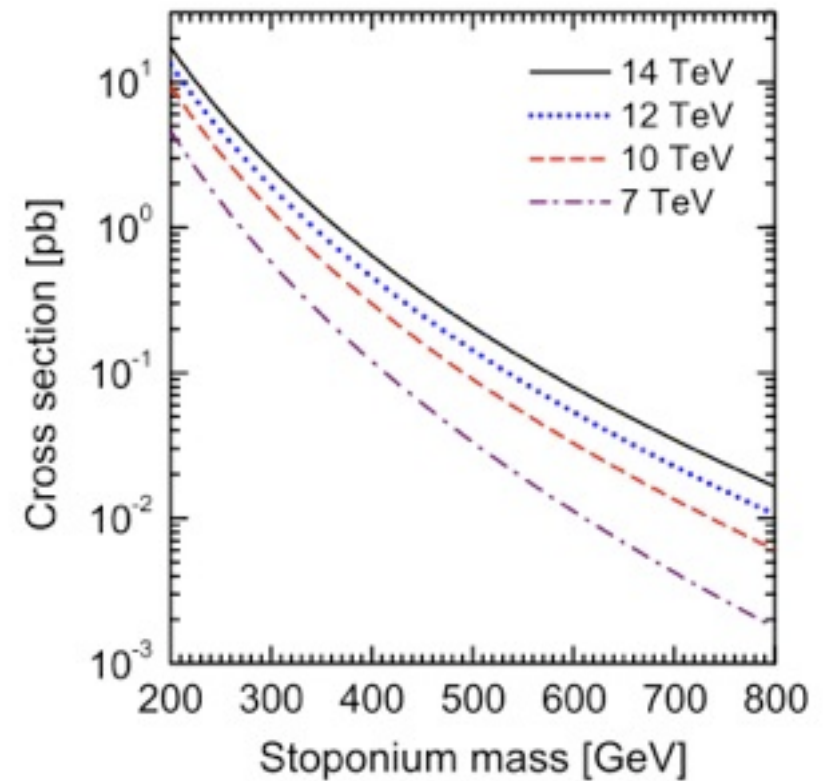
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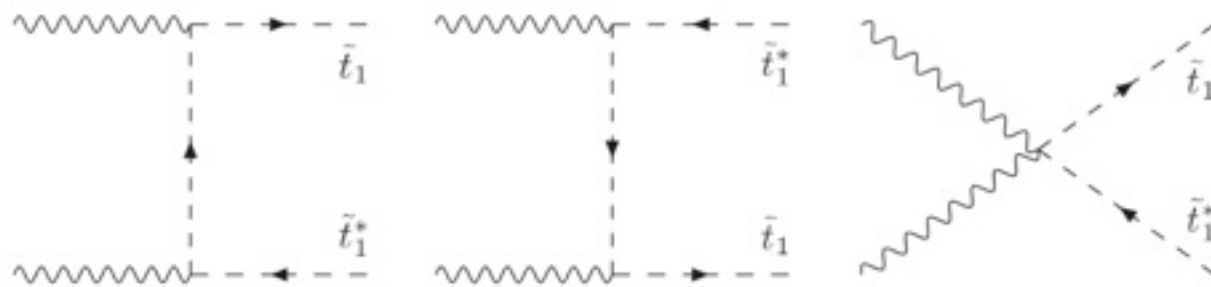


Decays typically go through gg , $\gamma\gamma$, γZ , WW , ZZ , $b\bar{b}$, $t\bar{t}$, hh

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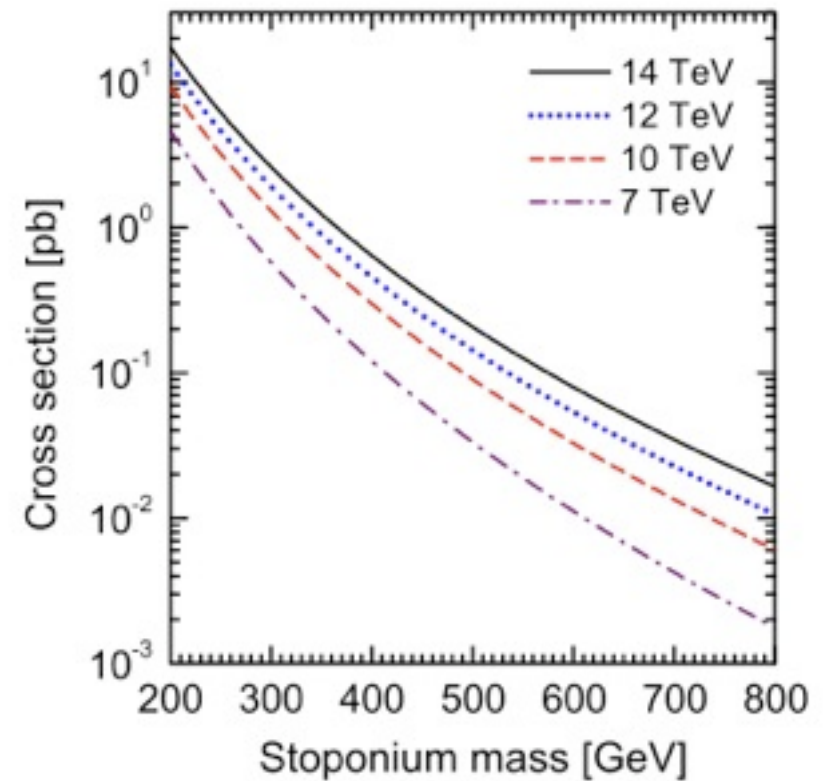
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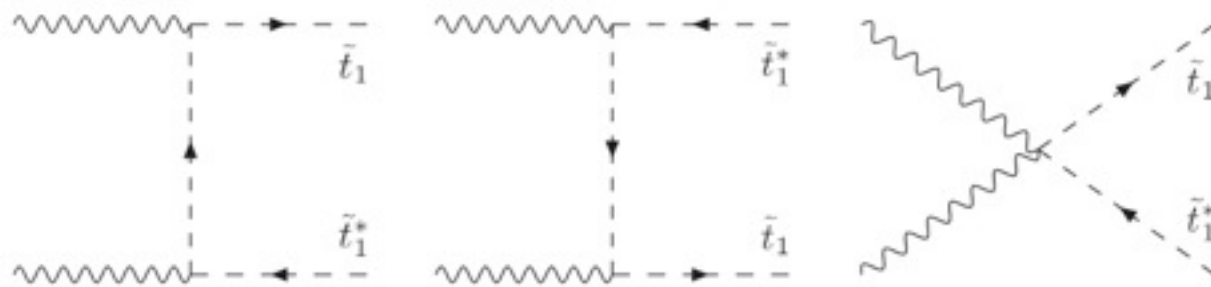
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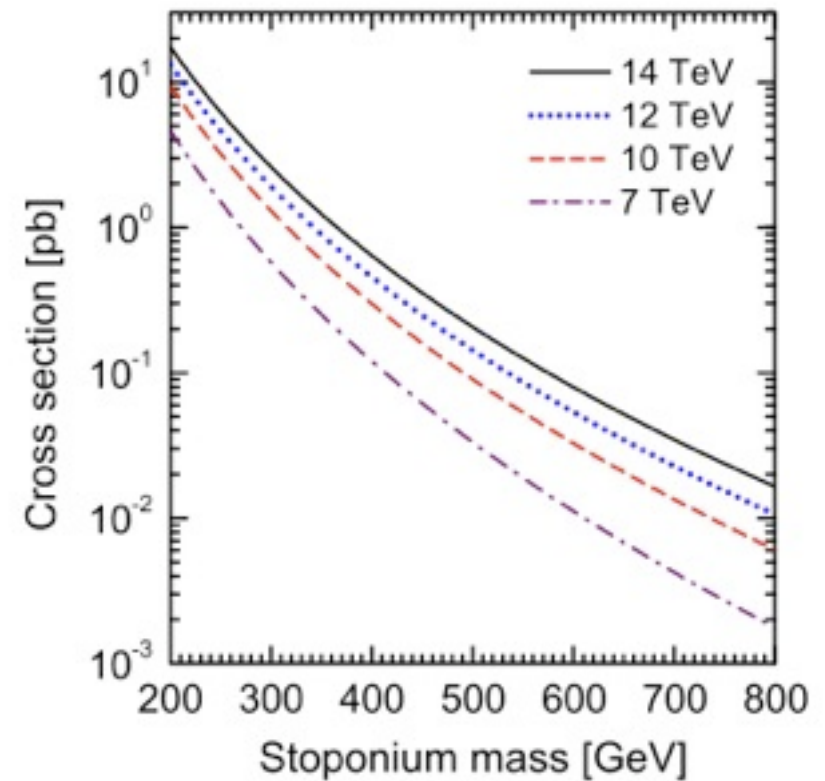
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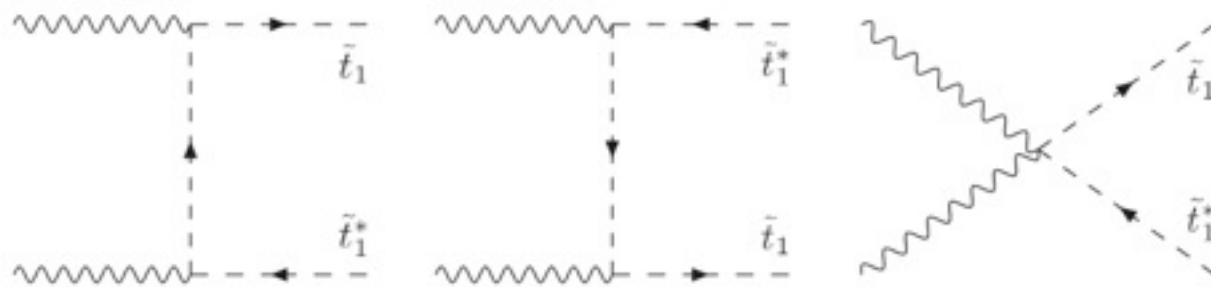
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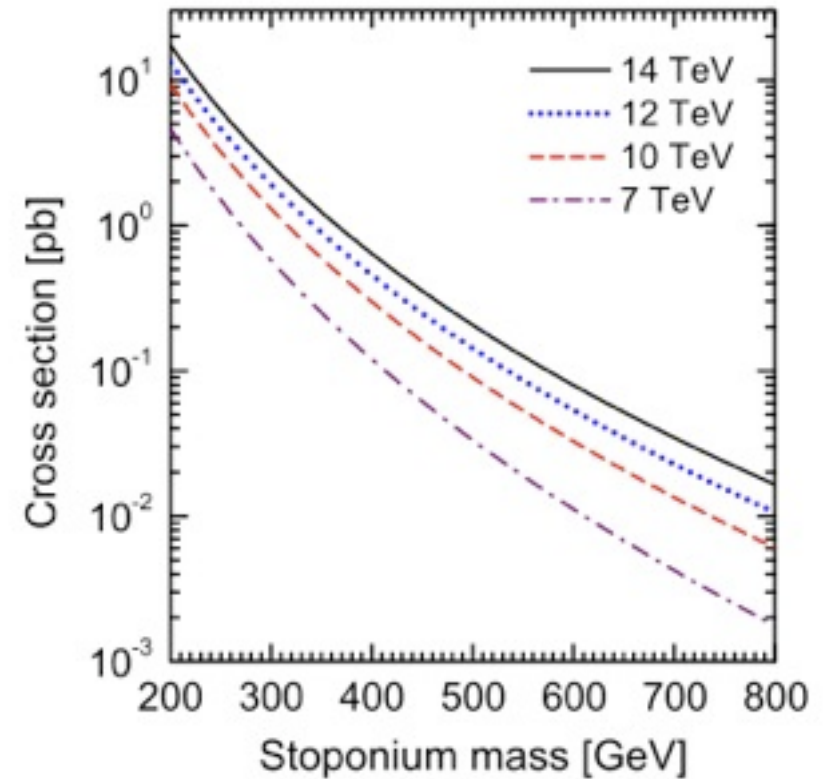
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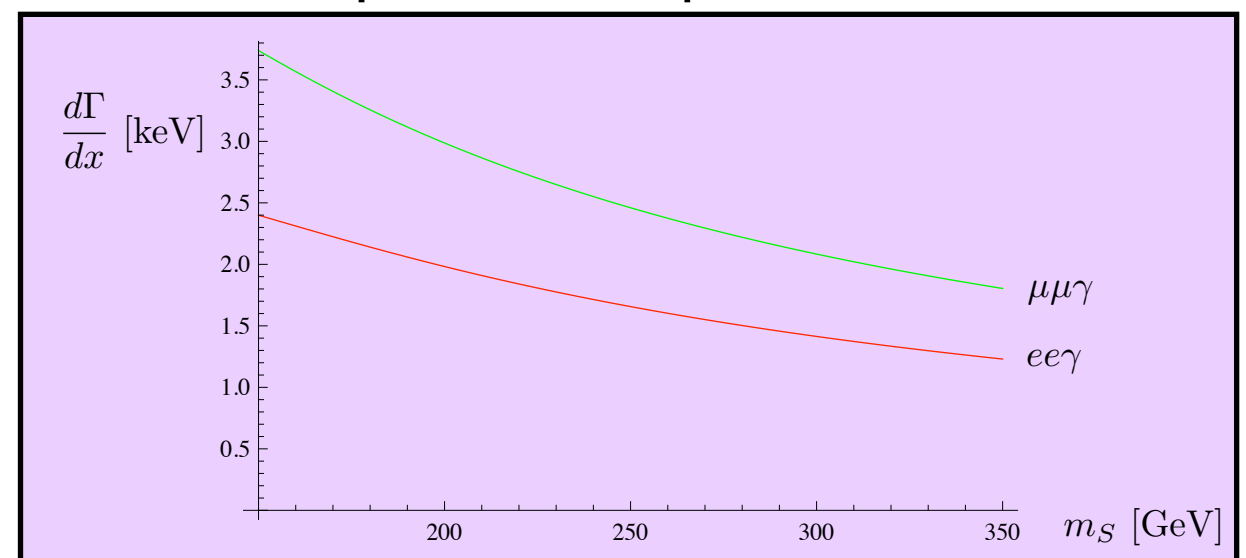
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Thus: if stoponium mixes with the Higgs, it could enhance the three body lepton channels (which are still mass suppressed in Higgs decays).



Conclusions & Future Work

Stoponium has been known about since the 1990's but has not been considered in this region of parameter space.

Could have interesting new signals that change the Higgs program at the LHC, as well as novel signatures of SUSY itself.

Purely theoretical grounds: stoponium is an interesting testing ground for models of bound states, etc.

We are completing our scans of parameter space and hope to have the results published in the next few weeks.

Also including effects on Higgs searches.

Conclusions & Future Work

Can generalize this to other theories of scalar fields (color octet scalars, technibosons, etc...).

Consider heavier stoponia states mixing with the H^0 ; sbottomonium states for large $\tan \beta$.

Other exotic squark bound states: $(\tilde{t}\tilde{b})$ - “stobottonium.”
Bound by and mixes with the A^0 .