What do simplified models actually tell us about the stop mass?

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A popular approach used to put limits on the stop mass is to use simplified models.

Advantages

- Directly constrains physical masses so to interpret
- Bottom-up: no GUT-scale assumptions
- Allows experimentalists to highly optimise searches
- ...

But...

- Do simplified models actually constrain real SUSY models?
- How can limits from multiple simplified models be combined?

In this talk I will describe a new way to combine simplified models.

- Very quick and simple
- Does not require additional simulation
- Produces conservative, robust and model-independent limits
- Demonstrates the importance of a new simplified model for mixed decays

What are simplified models?

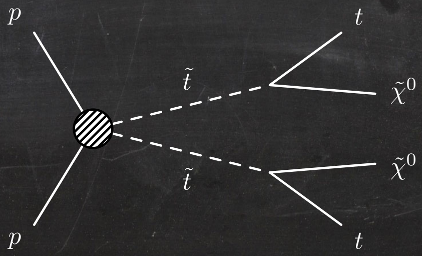
The basic idea is to decouple/ignore most particles in the model and concentrate only on a single process of interest.

What are simplified models?

Consider a simplified model for direct stop production

- Assume stops are pair produced at the LHC
- All stops decay to top-neutralino
- All other sparticles are decoupled

This results in a model with only one BSM process



What are simplified models?

An analysis is optimised on this process and we can search for the stops, e.g. by looking for tops and $\not{E}_T$.

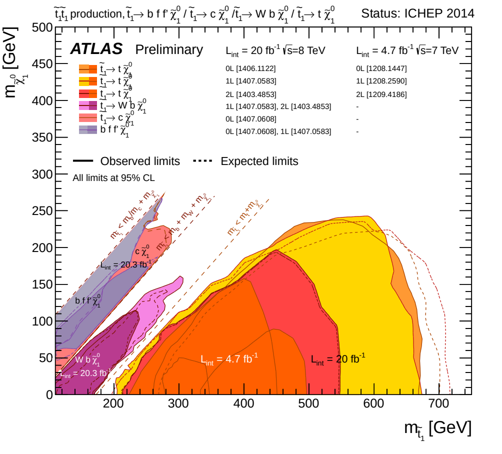
No events have been observed so an upper limit is put on the cross section for the overall process

$$\sigma(m_{\tilde{t}}, m_{\tilde{\chi}^0}) < \sigma_{\rm ex}(m_{\tilde{t}}, m_{\tilde{\chi}^0})$$

Given a very specific set of assumptions about the other SUSY parameters this gives a limit in the stop-neutralino mass plane.

What are simplified models?

Limits from top-neutralino decays

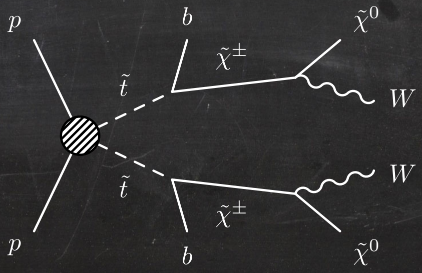


What are simplified models?

Stops can also decay to b-chargino.

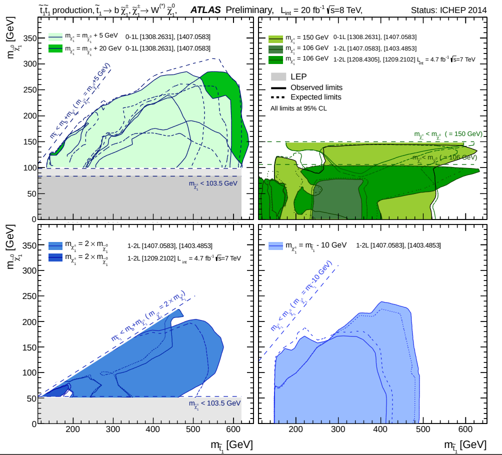
No problem. Add another simplified model

- Assume stops are pair produced at the LHC
- All stops decay to b-chargino
- All other sparticles (expect a neutralino) are decoupled



What are simplified models?

Limits from b-chargino decays

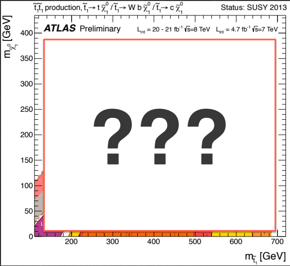


What are simplified models?

In most realistic models stops do not decay by the same decay mode 100% of the time.

What if stops decay to top-neutralino 50% of the time and to b-chargino 50% of the time?

The simplified model limits on the stop mass no longer apply.



Mass limits derived from a single simplified model are too strong.

Then what can simplified models tell us about the stop mass?

Combining simplified models

Simplified models constrain overall process cross sections for complete decay processes.

We can calculate the production cross section so simplified models constrain branching ratios for complete decay processes

$$b < \frac{\sigma_{\rm ex}(m_{\tilde{t}}, m_{\tilde{\chi}^0}, m_{\tilde{\chi}^\pm})}{\sigma_P(m_{\tilde{t}})} \equiv B(m_{\tilde{t}}, m_{\tilde{\chi}^0}, m_{\tilde{\chi}^\pm})$$

The constraints depend on $m_{\tilde{\chi}^0}$ and $m_{\tilde{\chi}^\pm}$ due to kinematics.

Combining simplified models

If top-neutralino and b-chargino are the only two decay modes open to stops then there are three complete decay processes

- Both stops decay to top-neutralino
- Both stops decay to b-chargino
- One stop decays to top-neutralino and the other to b-chargino

Combining simplified models

Suppose ATLAS or CMS have released a simplified model interpretation for each process, i.e. simplified models in which

- All stop pairs decay to top-neutralino
- All stop pairs decay to b-chargino
- All stop pairs decay via mixed decays, i.e. one stop decays via each decay mode

The last simplified model is unphysical but significantly extends the reach of stop searches.

These can be used as a basis to constrain any realistic model.

Combining simplified models

These simplified models constrain the branching ratios for all three complete decay processes

$$b_{00} < B_{00} \qquad b_{\pm\pm} < B_{\pm\pm} \qquad b_{0\pm} < B_{0\pm}$$

In terms of the decay mode branching ratios

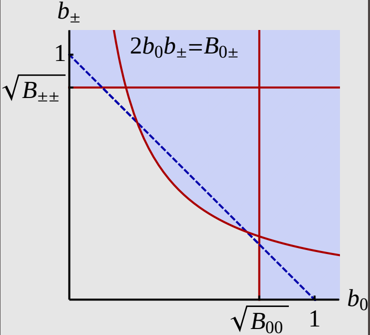
$$b_0^2 < B_{00} \qquad b_\pm^2 < B_{\pm\pm} \qquad 2b_0 b_\pm < B_{0\pm}$$

Any realistic model must also satisfy

$$b_0 + b_\pm = 1$$

Combining simplified models

Constraints on decay mode branching ratios



If the entire model line $b_0 + b_\pm = 1$ is in the excluded region there is no way of satisfying all constraints simultaneously.

The associated values of stop, neutralino and chargino mass are then excluded for all possible choices of branching ratios.

Combining simplified models

Simple exclusion conditions

$$\sqrt{B_{00}} + \sqrt{B_{\pm\pm}} < 1 \quad \text{or}$$

$$2\sqrt{B_{00}} - \sqrt{1 - 2B_{0\pm}} < 1 \quad \text{and} \quad 2\sqrt{B_{\pm\pm}} - \sqrt{1 - 2B_{0\pm}} < 1$$

Similar conditions can be applied when there are more than two decay modes.

Since simplified model studies already exist no additional simulation is required.

Now we can derive branching-ratio independent limits on the stop, neutralino and chargino masses.

Limits on the stop mass

Limits on mixed decays have not yet been derived.

To demonstrate their importance we performed our own simulations.

There are currently no analyses optimised for mixed decays.

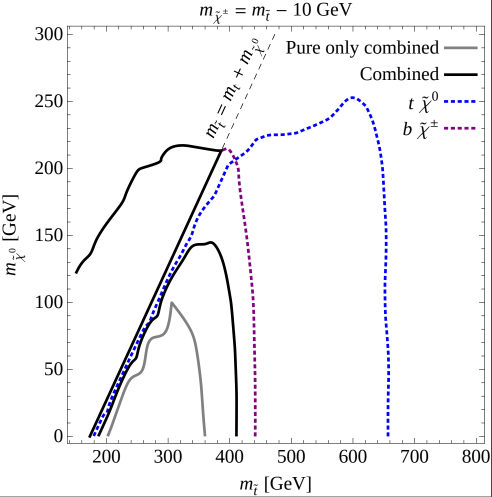
We used the existing, pure decay analyses.

The limits could be made much stronger with a dedicated analysis.[1]

[1] Graesser, Shelton - 1212.4495

Limits on the stop mass

Example: $m_{\tilde{\chi}^\pm} = m_{\tilde{t}} - 10$ GeV



Limits on the stop mass

Conclusions

- Branching-ratio independent limits are weaker
- The limits are still non-trivial
- Mixed decays are definitely significant
- A dedicated analysis for them is well worth doing

Limits on the stop mass

Rather than stick to slices of parameter space we can consider general values of the chargino mass.

We simulated a 'cube' of chargino mass values

$$m_{\tilde{\chi}^0} + 10 \text{ GeV} < m_{\tilde{\chi}^\pm} < m_{\tilde{t}} - 10 \text{ GeV}$$

This ensures

- Top-neutralino and b-chargino decays are both on shell
- Kinematic degeneracies are not encountered

Limits on the stop mass

Limits on the branching ratios are derived for each point in the cube (these are publicly available).

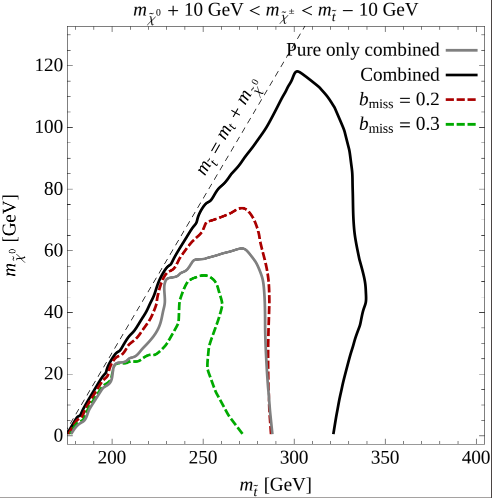
Our exclusion conditions are applied at each point in the cube.

A point in the stop-neutralino mass plane excluded for all values of chargino mass is excluded independently of the branching ratios and chargino mass.

We also consider a branching ratio b_{miss} into other channels.

Limits on the stop mass

Generalised limits



Limits on the stop mass

Conclusions

- The limits are still non-trivial even for non-zero b_{miss}
- Mixed decays remain significant

Summary

Individually, simplified models produce overly optimistic limits on the stop mass.

By combining simplified models one can quickly and easily derive limits that are independent of the stop branching ratios.

No additional simulation is required to do this.

Mixed decays are very important and a dedicated analysis would greatly improve the range of existing limits.

Even now the LHC is producing non-trivial limits that are broadly independent of branching ratios and the chargino mass.


WRONG
WAY
GO BACK

Rigorous combination

Assume:

- Orthogonal analyses for all three decay processes
- Each analysis observes exactly five events
- Each analysis has an acceptance-times-efficiency of 50% for signal events
- 1 fb^{-1} of LHC data
- A single light stop

95% CL_s limits

b_0	0	0.1	0.2	0.3	0.5
σ_{ex} [pb]	0.011	0.012	0.013	0.014	0.014
$m_{\tilde{t}}$ limit [GeV]	670	660	650	645	645

Our limit is 580 GeV.

Rigorous combination

95% CL_s limits without mixed decays

b_0	0	0.1	0.2	0.3	0.4	0.5
σ_{ex} [pb]	0.011	0.014	0.018	0.022	0.026	0.028
$m_{\tilde{t}}$ limit [GeV]	670	645	620	605	580	590

Our limit is 525 GeV.