Same-sign Top Quarks as Signature of Light Stops

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Based on: Sabine Kraml and ARR,

Phys. Rev. D73, 075002 (2006) [hep-ph/0512284].

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Plan

- Introduction & motivation
  - Baryogenesis
  - Dark matter
- How to dig out the stop
- Case study
- Conclusions

Why search for light stops

Scalar tops play a special role in the MSSM because of the large Yukawa coupling $\propto m_t$.

- Mixing of the left and right chiral states, $(\tilde{t}_L, \tilde{t}_R) \rightarrow (\tilde{t}_1, \tilde{t}_2)$, can give large mass splitting.
- Influence on RGE running; causing radiative EWSB.
- Influence on m_h through radiative corrections.

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Many scenarios prefer a very light stop; $\tilde{t}_1$ can be the NLSP:

- Electroweak baryogenesis (EWBG).
- Dark matter relic density.
- Reduced fine-tuning [R. Kitano, Y. Nomura, hep-ph/0602096].

Baryogenesis

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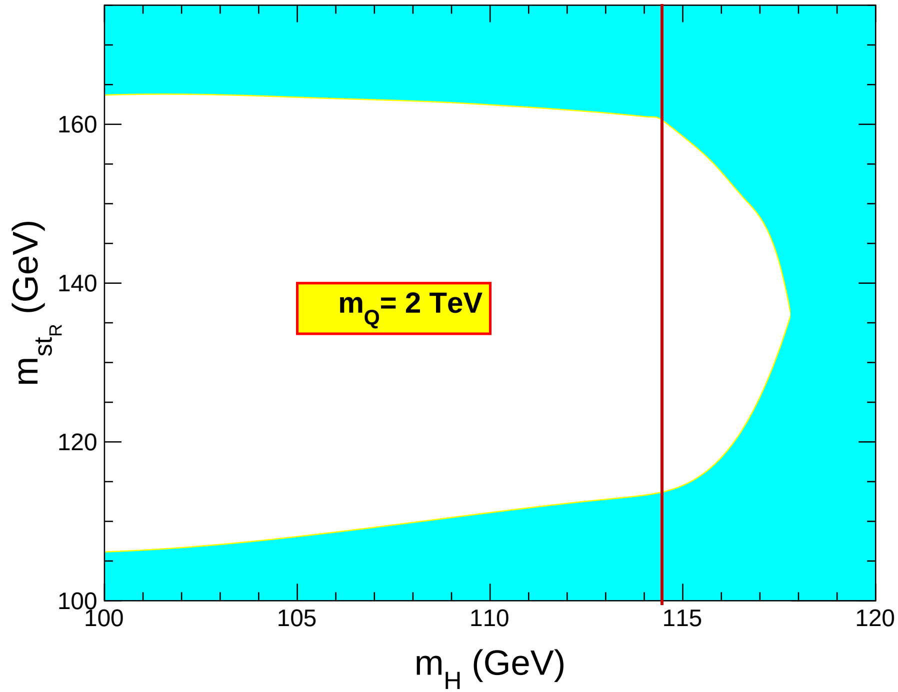

$m_h \lesssim 120$ GeV

$m_{\tilde{t}_1} \lesssim 180$ GeV

$\tan\beta \sim 2$–8

heavy $\tilde{t}_2 \simeq \tilde{t}_L$

[Carena, Quiros, Wagner, hep-ph/9710401]

[Balazs, Carena, Menon, Morrissey, Wagner, hep-ph/0412264]

Dark matter relic density

Fixing the gaugino and higgsino spectrum by setting

$$M_1 = 110 \text{ GeV}, \quad \mu = 300 \text{ GeV}, \quad \tan\beta = 7,$$

we calculate Ωh^2 (`MicrOMEGAs 1.3.2`), varying $m_{\tilde{t}_1}$ and $m_{\tilde{\tau}_1}$.

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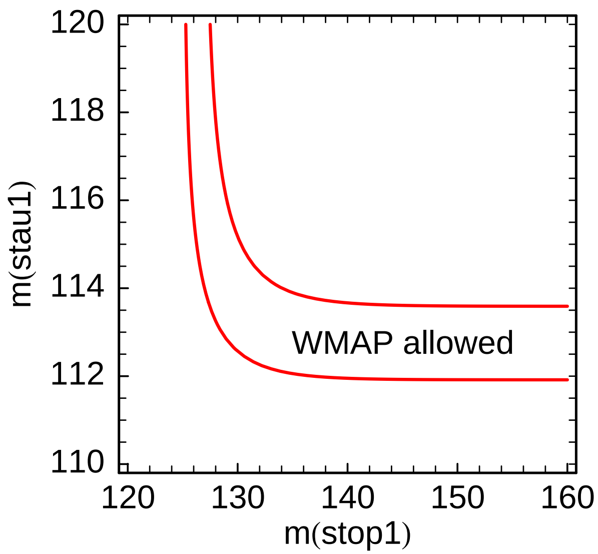

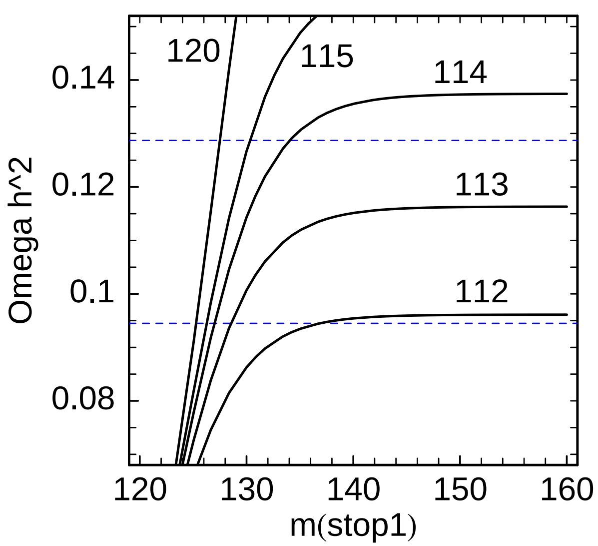

$$m_{\tilde{\chi}_1^0} = 105 \text{ GeV}$$

Dark matter relic density

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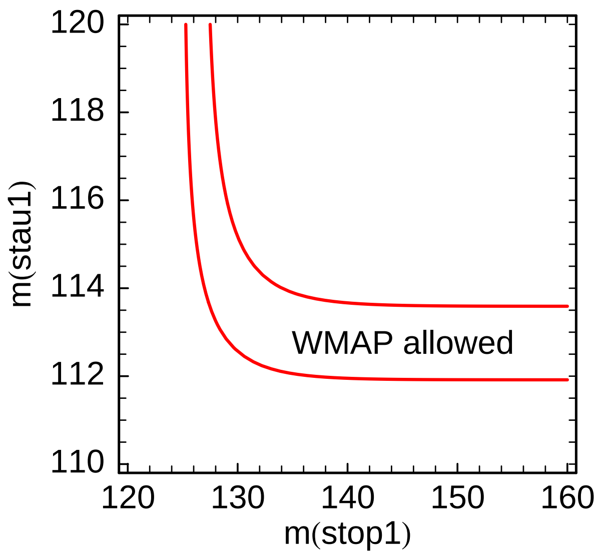

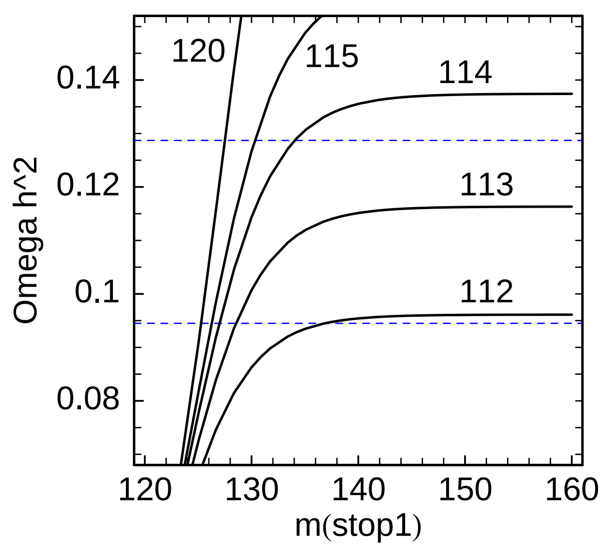

- Neutralino–stop coannihilation for $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \lesssim 25$ GeV.
- Neutralino–stau coannihilation for $m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} \lesssim 10$ GeV.
- Higgs funnel: $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to A \to b\bar{b}$ for $m_A \sim 250$ GeV.

Our 'toy' light stop scenario

$$M_1 = 110 \text{ GeV}, \quad \mu = 300 \text{ GeV}, \quad \tan\beta = 7$$

$$\tilde{t}_1 \simeq \tilde{t}_R, \quad m_{\tilde{t}_1} = 150 \text{ GeV}$$

$$m_{\tilde{g}} = 660 \text{ GeV}$$

$$m_{\tilde{l}} \simeq 250 \text{ GeV}, \quad m_{\tilde{q}} \gtrsim 1 \text{ TeV}$$

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To achieve agreement with relic density:

$$m_A \simeq 250 \text{ GeV} \quad \text{or} \quad m_{\tilde{\tau}_1} \simeq 112 - 113 \text{ GeV}$$

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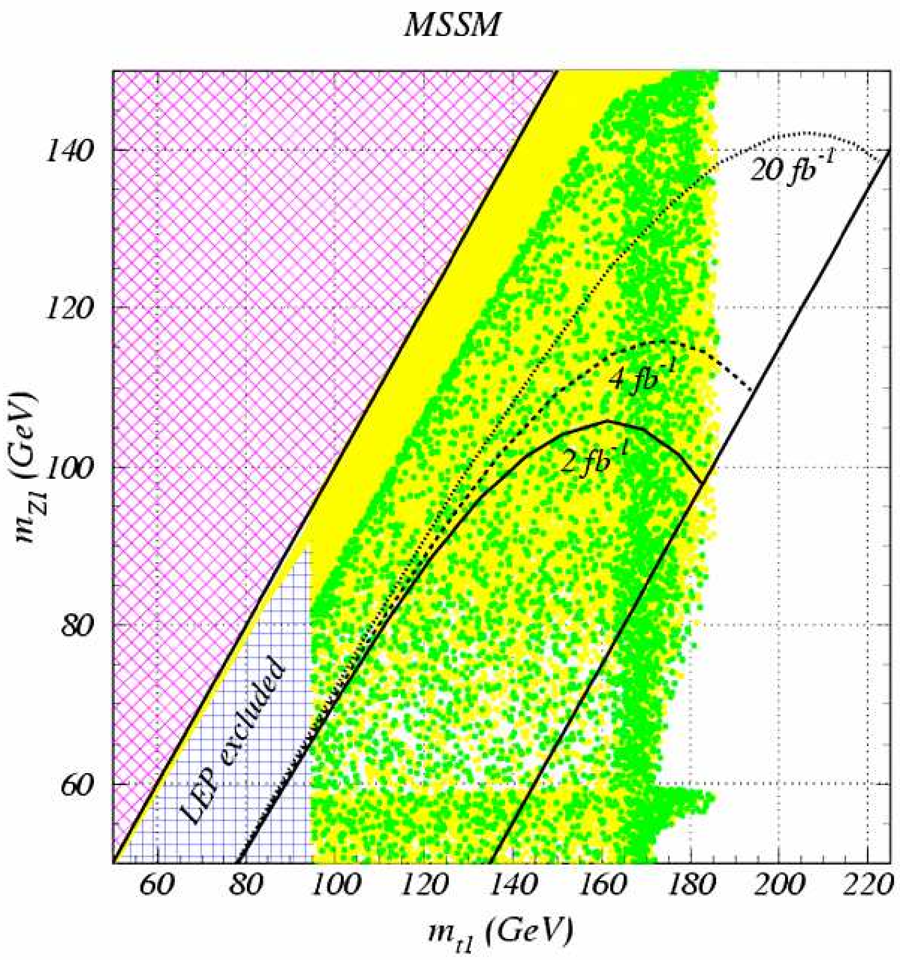
Largest SUSY (NLO) cross sections (`PROSPINO 2`):

$$\sigma(pp \to \tilde{t}_1 \tilde{t}_1^*) = 280\ \text{pb}, \quad \sigma(pp \to \tilde{g}\tilde{g}) = 5.4\ \text{pb}$$

We assume that a $\tilde{t}_1$ NLSP with $m_{\tilde{t}_1} < m_W + m_{\tilde{\chi}_1^0}$ has

$$BR(\tilde{t}_1 \to c\tilde{\chi}_1^0) \approx 1$$

Tevatron reach for $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$



[Balazs, Carena, Wagner, hep-ph/0403224]
[Demina, Lykken, Matchev, Nomerotski, hep-ph/9910275]

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Since the gluino is a Majorana particle, it can decay either into $t\tilde{t}_1^*$ or into $\bar{t}\,\tilde{t}_1$. Therefore, we get

$$\tilde{g}\tilde{g} \to t\bar{t}\,\tilde{t}_1\tilde{t}_1^*, tt\,\tilde{t}_1^*\tilde{t}_1^*, \,\overline{tt}\,\tilde{t}_1\tilde{t}_1$$

and hence like-sign tops in half of the gluino-to-stop decays!

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$$\tilde{g}\tilde{g} \to t\bar{t}\,\tilde{t}_1\tilde{t}^*_1, tt\,\tilde{t}^*_1\tilde{t}^*_1, \,\overline{tt}\,\tilde{t}_1\tilde{t}_1$$

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Together with $t \to bW$ and the W decaying leptonically, we get a peculiar signature:

$$pp \to bb\,l^\pm l^\pm \; + \text{jets} + \not{E}_T$$

Isolating the signature

NLO cross sections [pb]:

$\sigma(\tilde{t}_1\tilde{t}_1)$	$\sigma(\tilde{g}\tilde{g})$	$\sigma(\tilde{g}\tilde{q})$	$\sigma(\tilde{q}\tilde{q})$	$\sigma(\tilde{q}\tilde{q}^*)$	$\sigma(t\bar{t})$
280	5.39	4.98	0.666	0.281	737

We generate events equivalent to $30\ \mathrm{fb}^{-1}$ with `PYHTIA 6.321` and simulate a generic LHC detector with `AcerDET-1.0`.

Cuts used:

- Require four jets, $p_T^{\text{jet}} > 50$ GeV, two of which are b-tagged.
- Require two same sign leptons, with $p_T^{\text{lep}} > 20$ GeV.
- Require $\not{E}_T > 100\ \mathrm{GeV}$.
- Require two comb. of leptons and b-jets with $m_{bl} < 160\ \mathrm{GeV}$.

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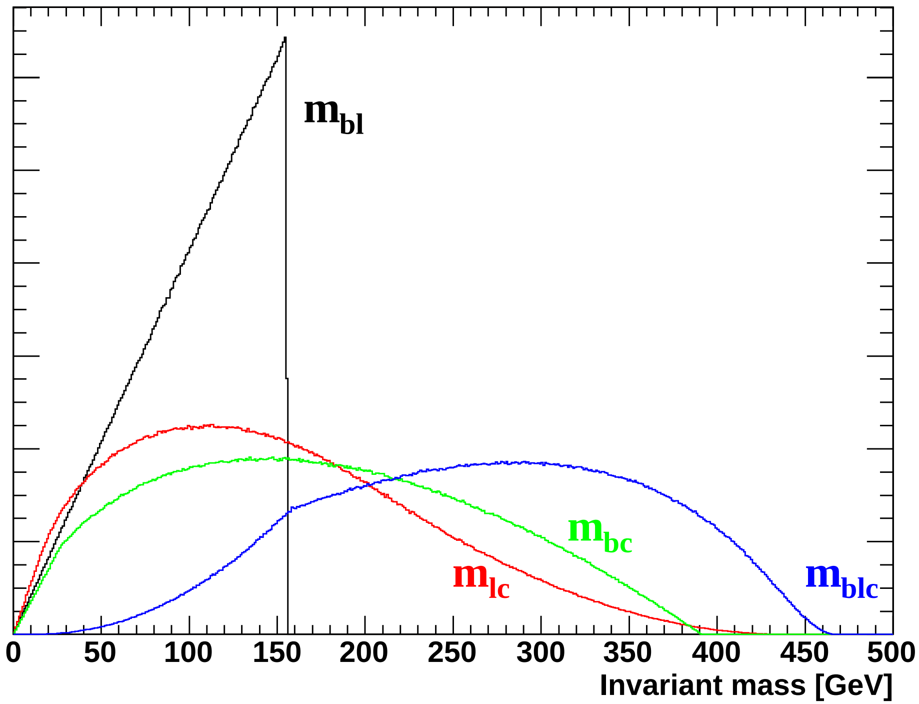
Cut	2lep 4jet	p_T^{lep}	p_T^{jet}	2b	$\not{E}_T$	2t	SS
$\tilde{g}\tilde{g}$	10839	6317	4158	960	806	628	330
Backg.							
SUSY	1406	778	236	40	33	16	5
SM	25.3M	1.3M	35977	4809	1787	1653	12

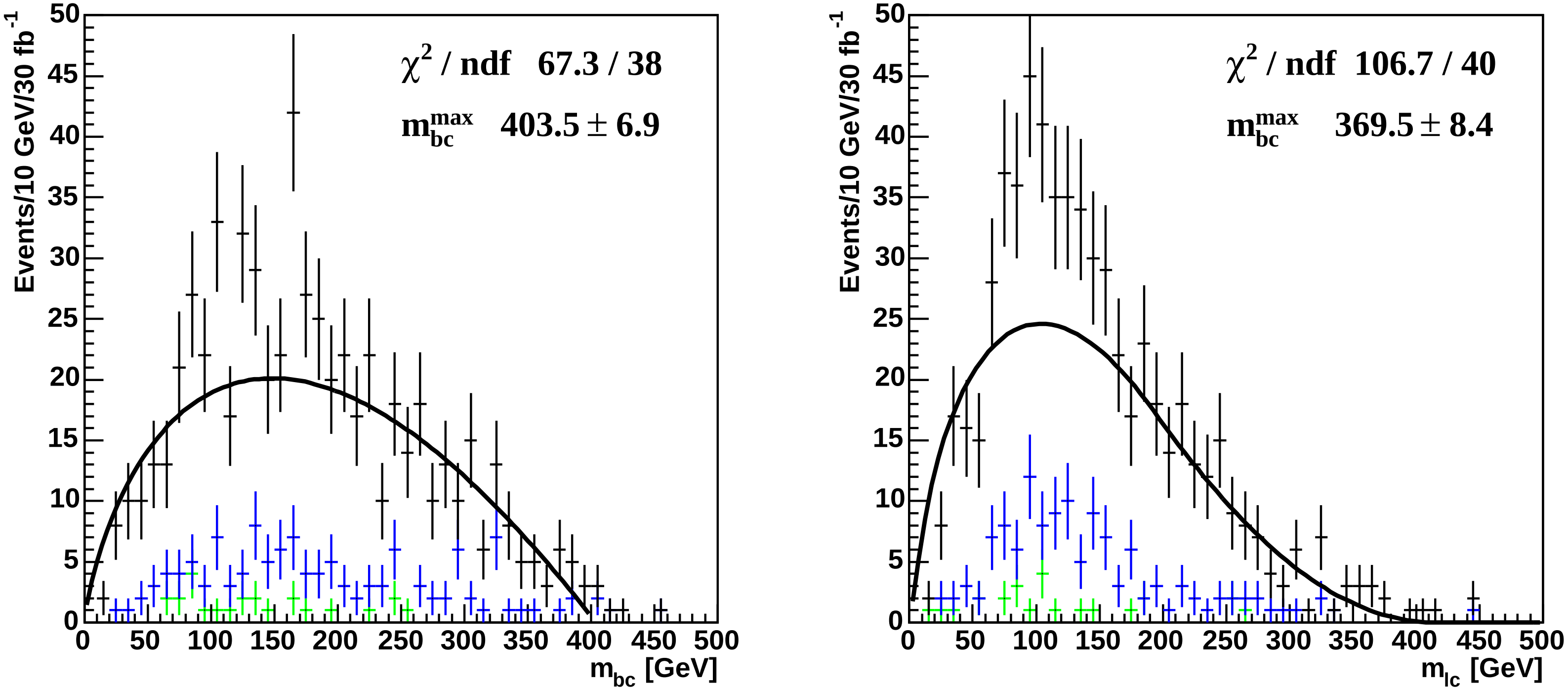
Determining masses

With very little background, can we determine masses?
Difficult to find traditional endpoints of SM invariant masses.



Can however find analytical description of the shape of the invariant masses and do fits. [D.J. Miller, P. Osland, ARR, hep-ph/0510356].

Determining masses



We can determine the value of m_{bc}^{max}, which relates the masses of the gluino, light stop and lightest neutralino.

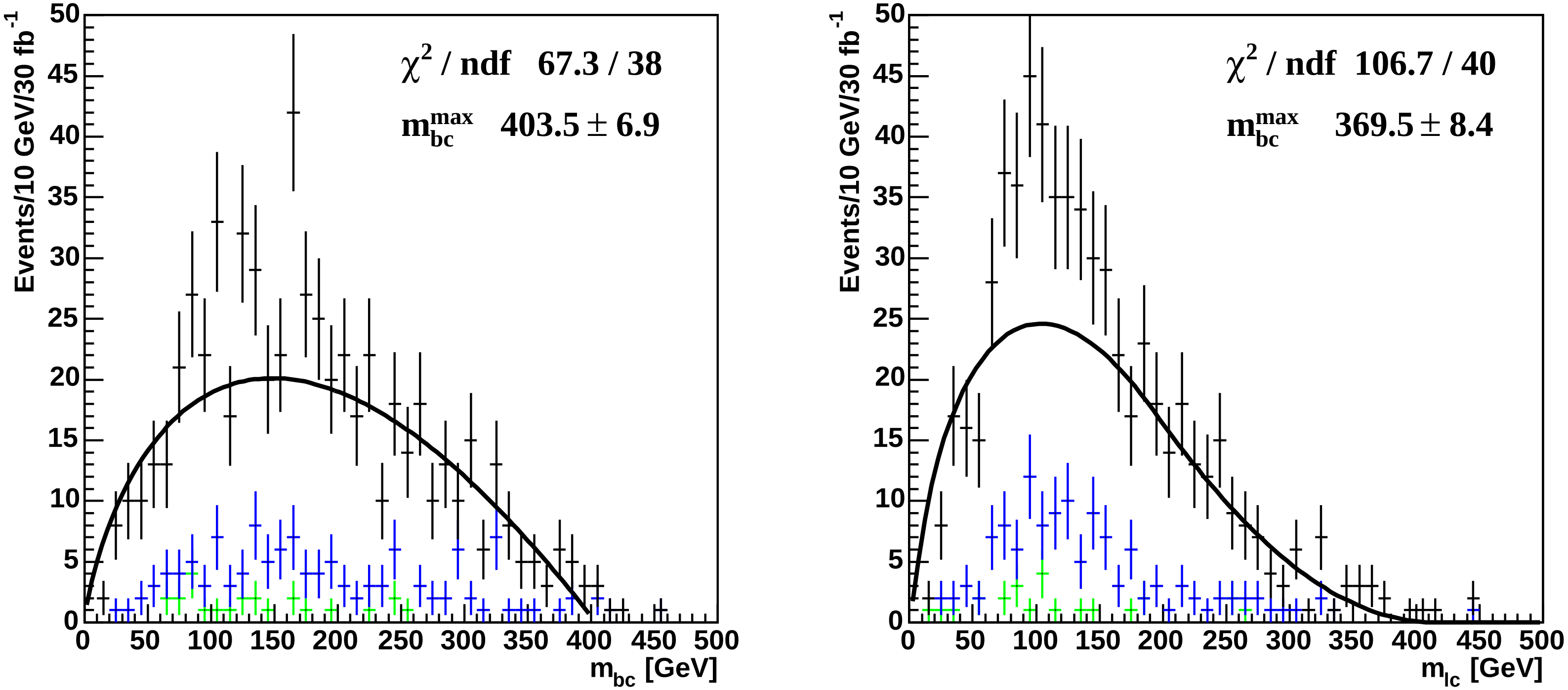
Determining masses

$$(m_{bc}^{\max})^2 = \frac{(m_t^2 - m_W^2)}{m_t^2} \frac{(m_{\tilde{t}_1}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{t}_1}^2} \frac{(m_1^2 + m_2^2)}{2}$$

where

$$m_1^2 = m_{\tilde{g}}^2 - m_t^2 - m_{\tilde{t}_1}^2 \quad \text{and} \quad m_2^4 = m_1^4 - 4m_t^2 m_{\tilde{t}_1}^2$$

Determining masses



Taken together these two distributions give

$$m_{bc}^{\max} = 388.3 \pm 6.1\ \text{GeV},$$

compared to the nominal value of $m_{bc}^{\max} = 391.1$ GeV.

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- Promising signature in same-sign tops from gluinos. Low SM background.
- Mass extraction more difficult, but seems doable.
  - No clear endpoints: Need to fit to shapes.
  - Important systematics: W decays to τ, combinatorics...

Conclusions

- Light stops interesting for both Baryogenesis and Dark Matter. (and fine tuning too!)
- Promising signature in same-sign tops from gluinos. Low SM background.
- Mass extraction more difficult, but seems doable.
- Robust discovery channel for light stops at the LHC. (While an excess of same-sign top events should not be interpreted as stops without further evidence, the fit to the expected kinematical distributions of the decay chain strengthens the stop case.)

Conclusions

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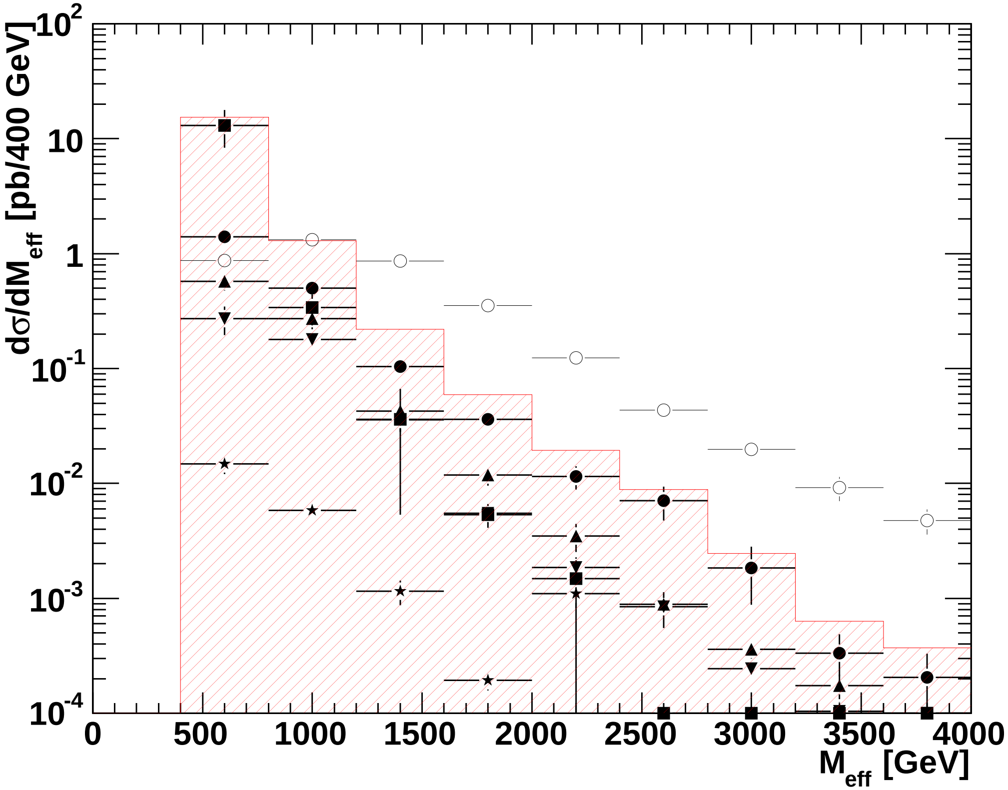
- Promising signature in same-sign tops from gluinos. Low SM background.
- Mass extraction more difficult, but seems doable.
- Robust discovery channel for light stops at the LHC.
- 5σ significance for $m_{\tilde{g}} \lesssim 900$ GeV.
  We have also tested $m_{\tilde{t}_1} = 120$ GeV and $m_{\tilde{b}_1} < m_{\tilde{g}}$, finding an only slightly worse signal to background ratio.

M_{eff}

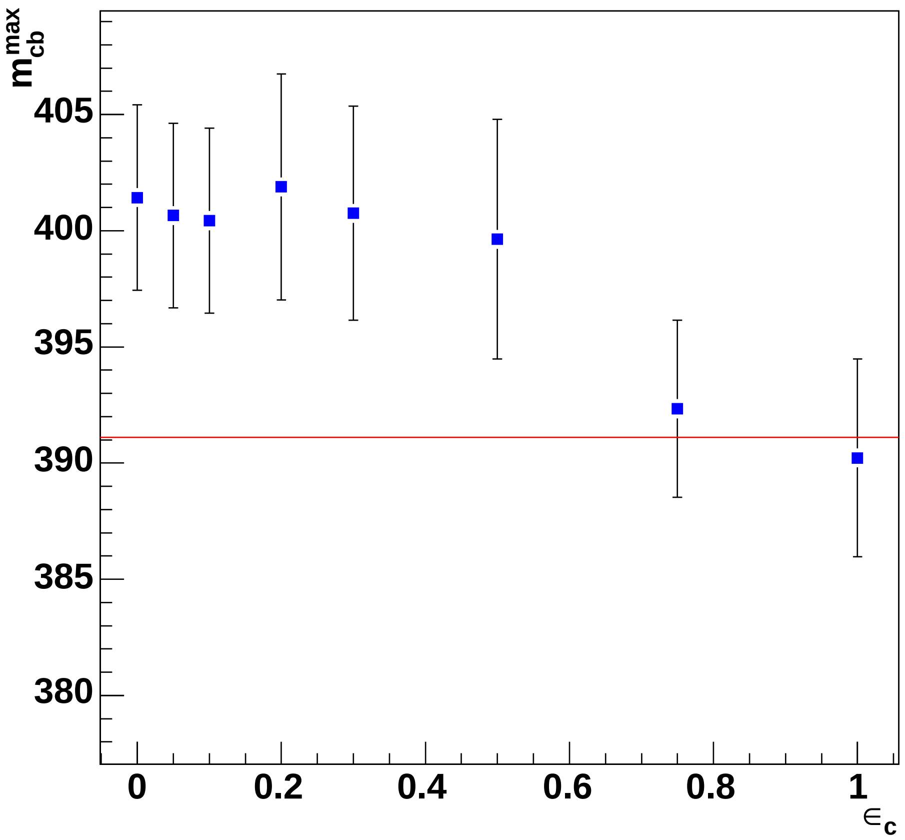
Distribution of effective mass M_{eff} for LST1:



Gives an effective SUSY mass scale $M^{\mathrm{eff}}_{\mathrm{susy}} = \mathbf{523 \pm 157}$ GeV

[D.R. Tovey, hep-ph/0006276]

c-tagging



p_T of c-jets

LST2: $m_{\tilde{t}_1} = 125$ GeV, we have $\Delta M = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} = 20$ GeV!