Higgs as Tool for New Physics

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"PCTS Higgs Physics after Discovery"
25 April 2013

This Past Year has been Amazing

- Particle discovered with mass near 125 GeV
- Decays observed/evidence: $\gamma\gamma$,ZZ,WW,$\tau\tau$,bb(?)
- Production (gg fusion) consistent with top loop
- σxBR ratios “broadly” consistent with SM Higgs

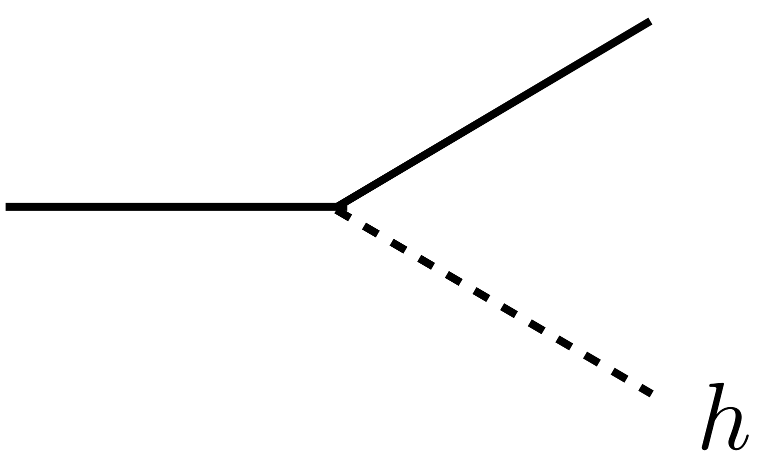
SM-like Higgs (to within tens of %)

Let’s use it as a tool to probe physics beyond the SM.

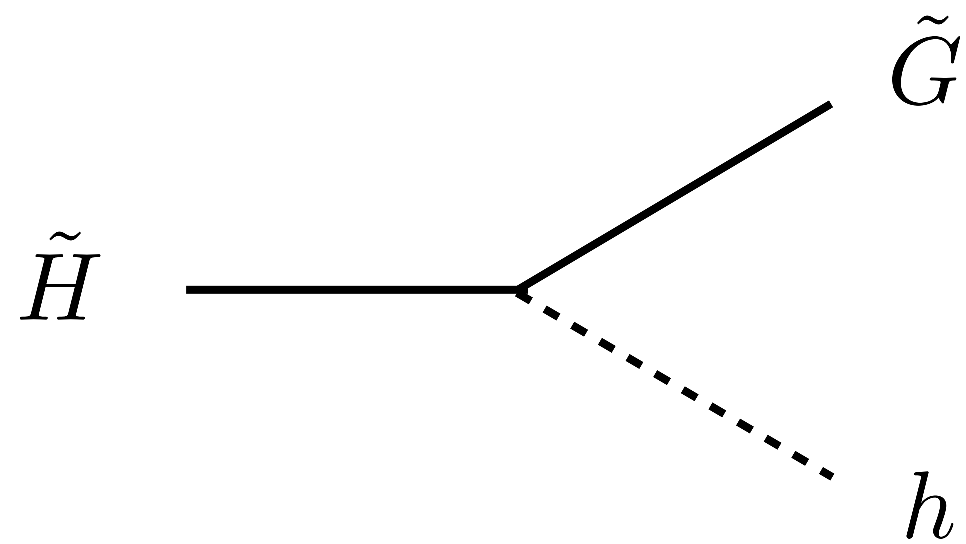
- Higgs in decays of BSM particles
- diHiggs production enhancement
- Higgses from annihilation “BSMonia”

Biased selection of topics...
(many more I don’t have time to cover)

Sources of Higgs in BSM Decays



Example 1: Supersymmetry - Higgsino NLSP



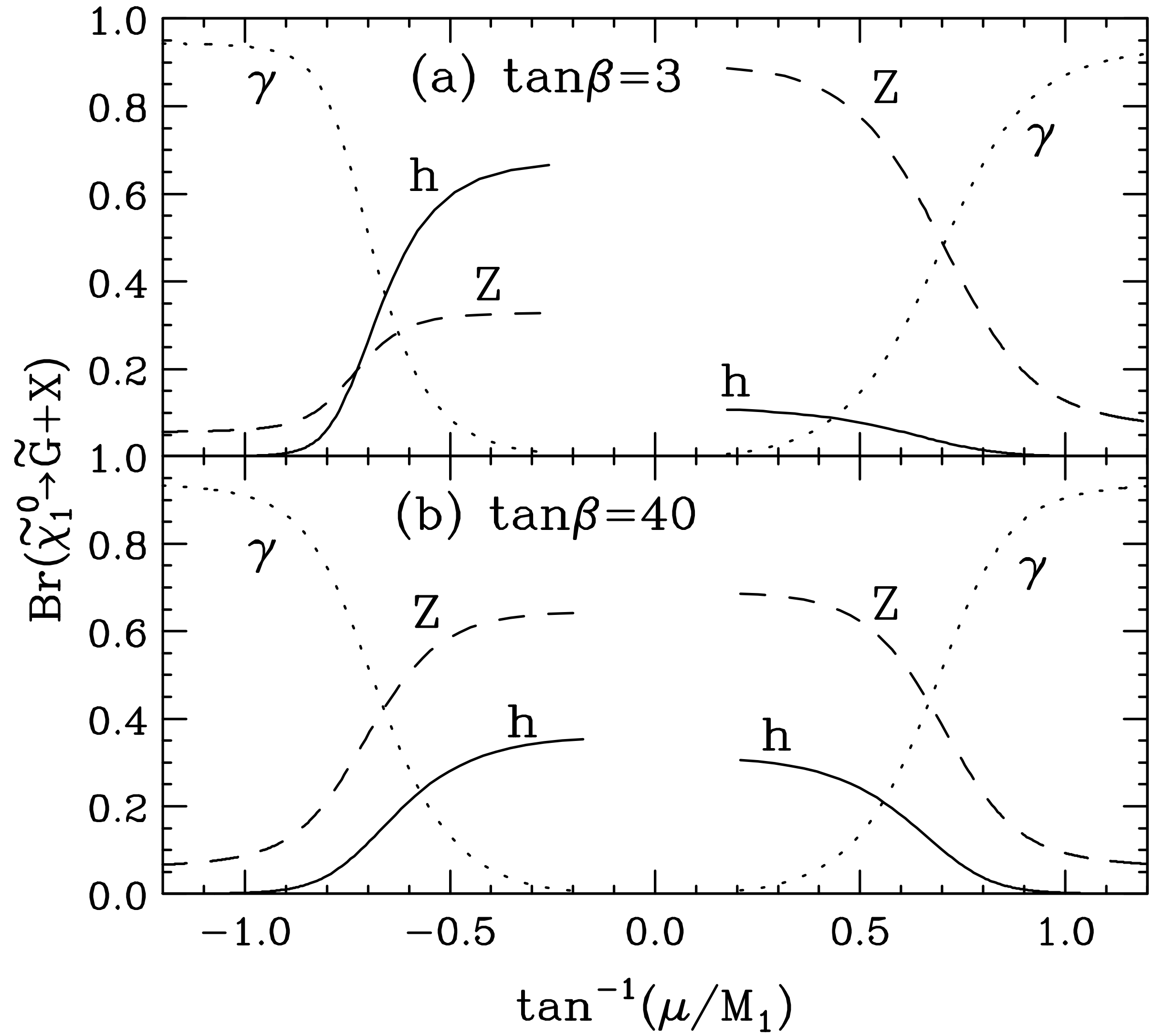


Figure 1: Branching ratios of the lightest neutralino $\mathrm{Br}(\tilde{\chi}_1^0 \to \tilde{G} + \gamma, h, Z)$ as a function of the neutralino mixing angle $\tan^{-1}(\mu/M_1)$, for a fixed mass $M_{\tilde{\chi}_1^0} = 160$ GeV and $m_h = 105$ GeV for (a) $\tan\beta = 3$ and (b) $\tan\beta = 40$.

Ambrosanio, Kane, Kribs, S Martin, Mrenna (1996)

Matchev, Thomas (1999)

Meade, Reece, Shih (2009)

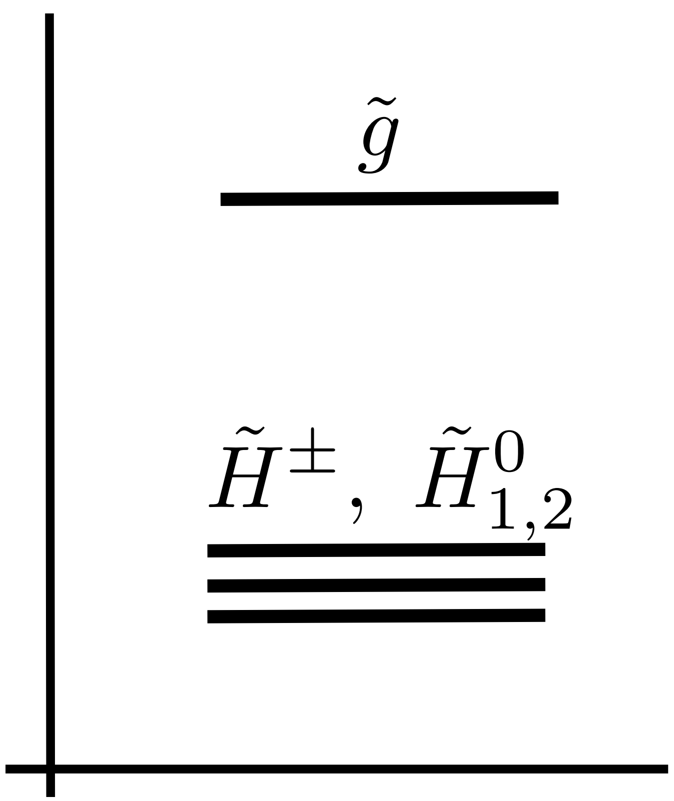
Kribs, A Martin, Roy, Spannowsky (2009,2010)

Ruderman, Shih (2011)

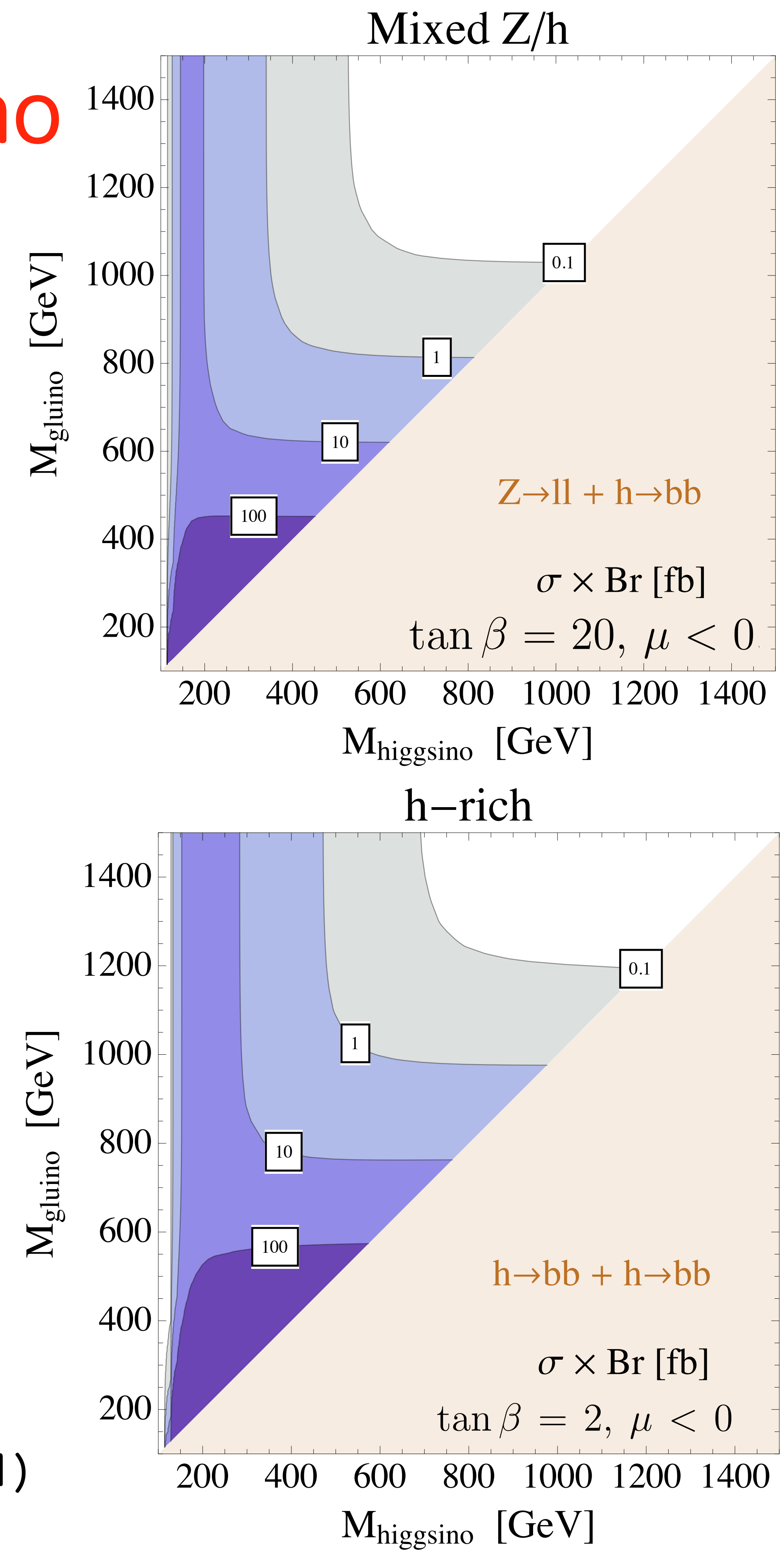
Thaler, Thomas (2011)

Matchev, Thomas (1999)

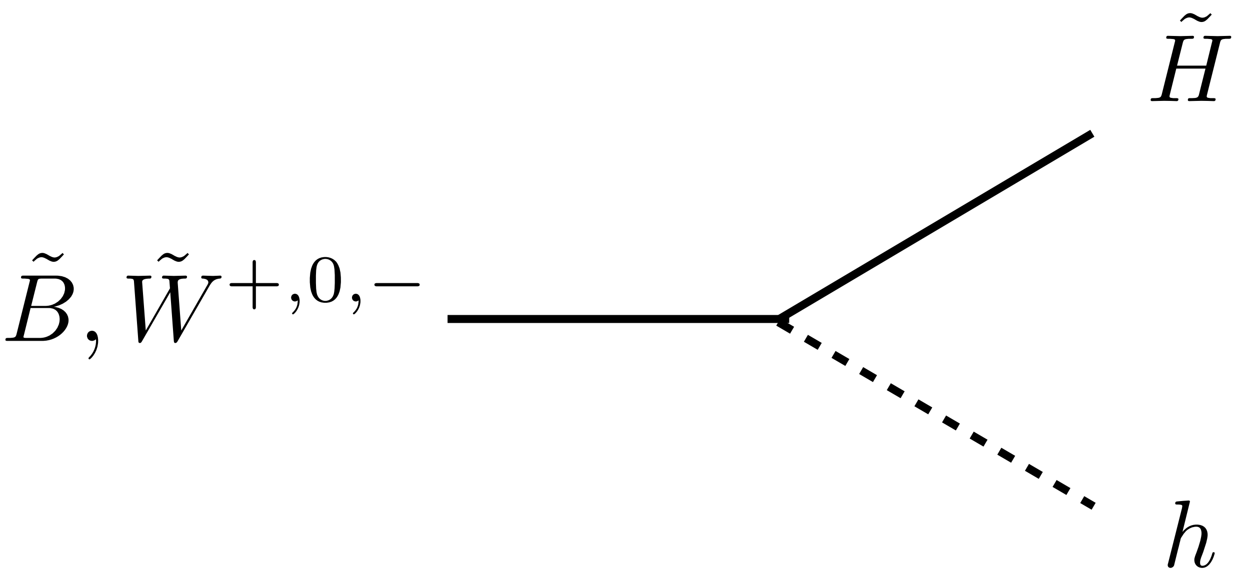
gluino -> Higgsino -> gravitino

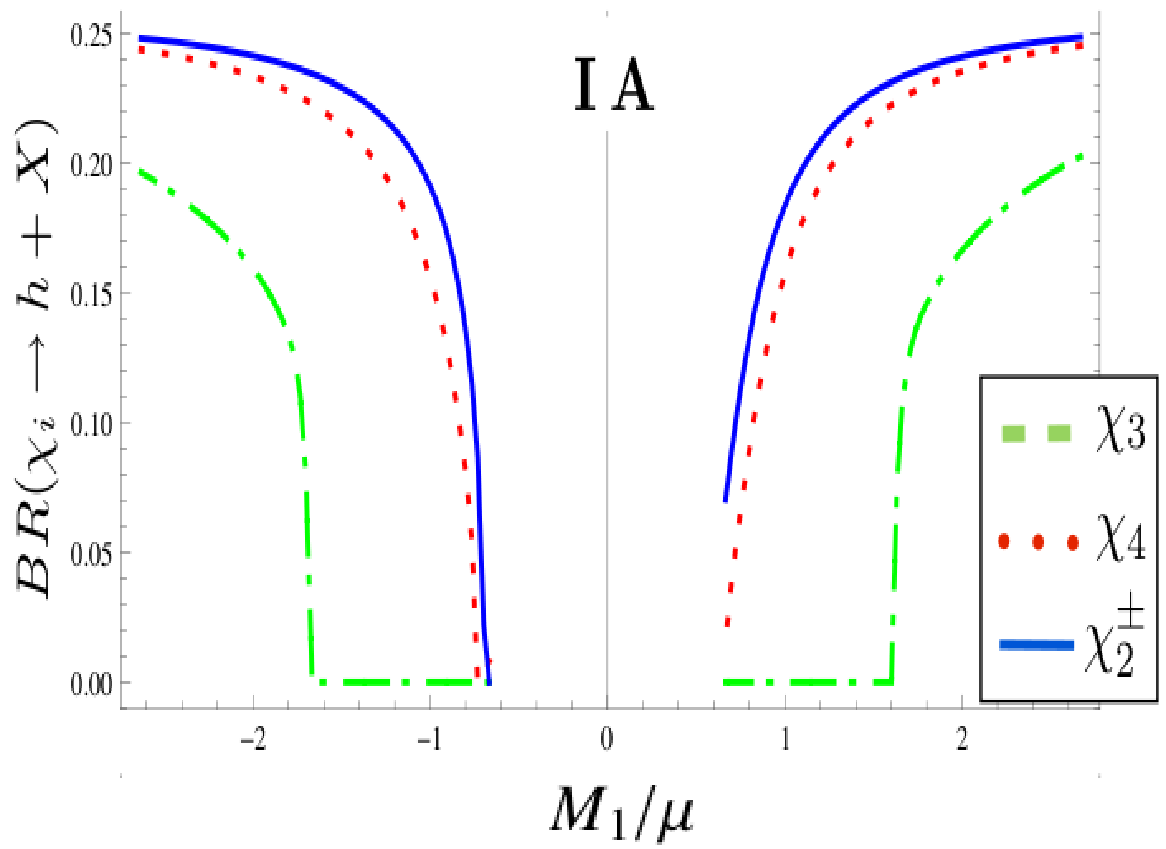


Ruderman, Shih (2011)



Example 2: Bino,Wino -> Higgsino + h





Production can be significantly enhanced if squarks produced, decay to Bino,Wino, which then decays to Higgsino + h.

Kribs, A Martin, Roy, Spannowsky (2009,2010)

Gori, Schwaller, Wagner (2011)

Squark -> q + h

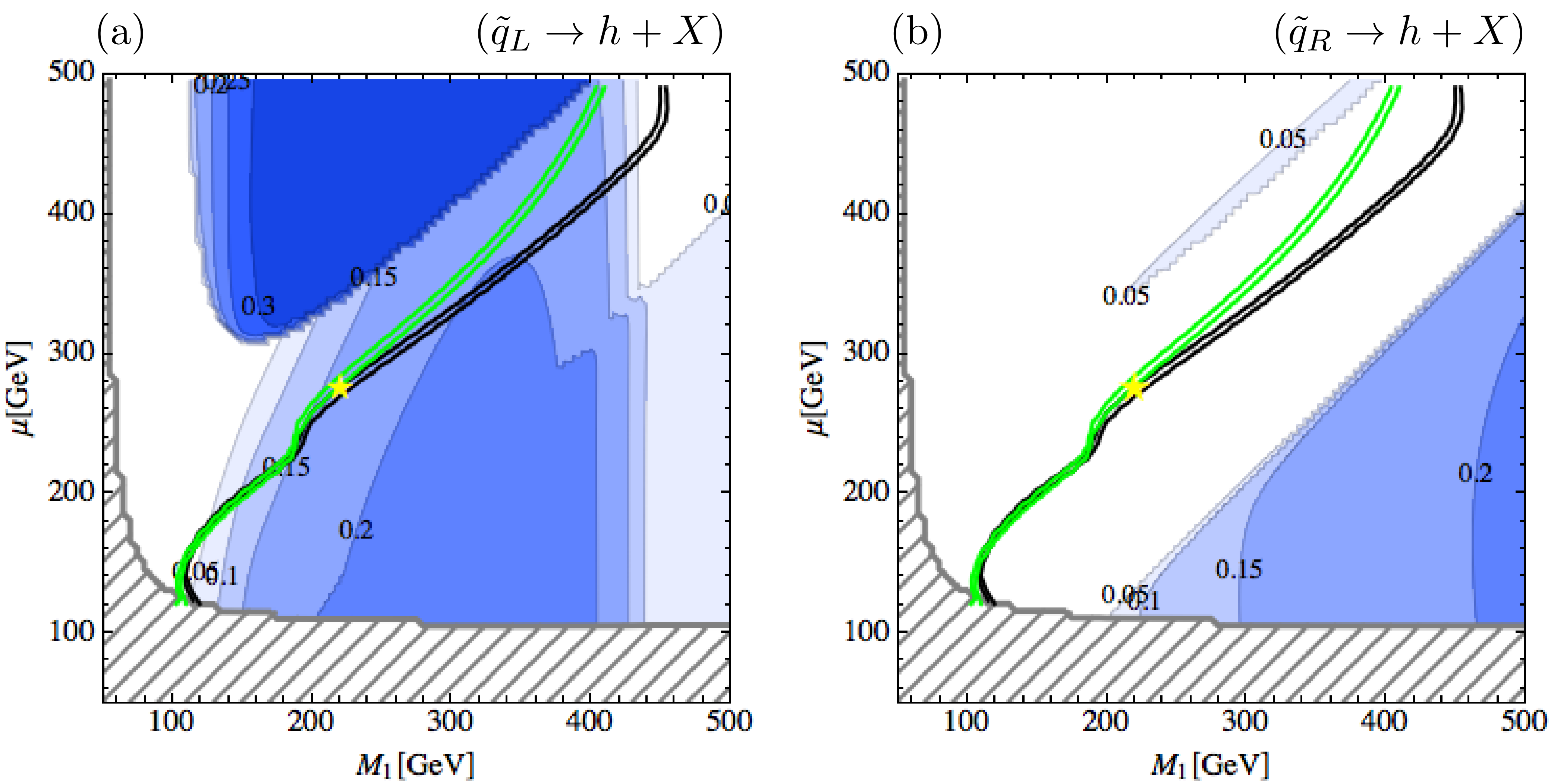
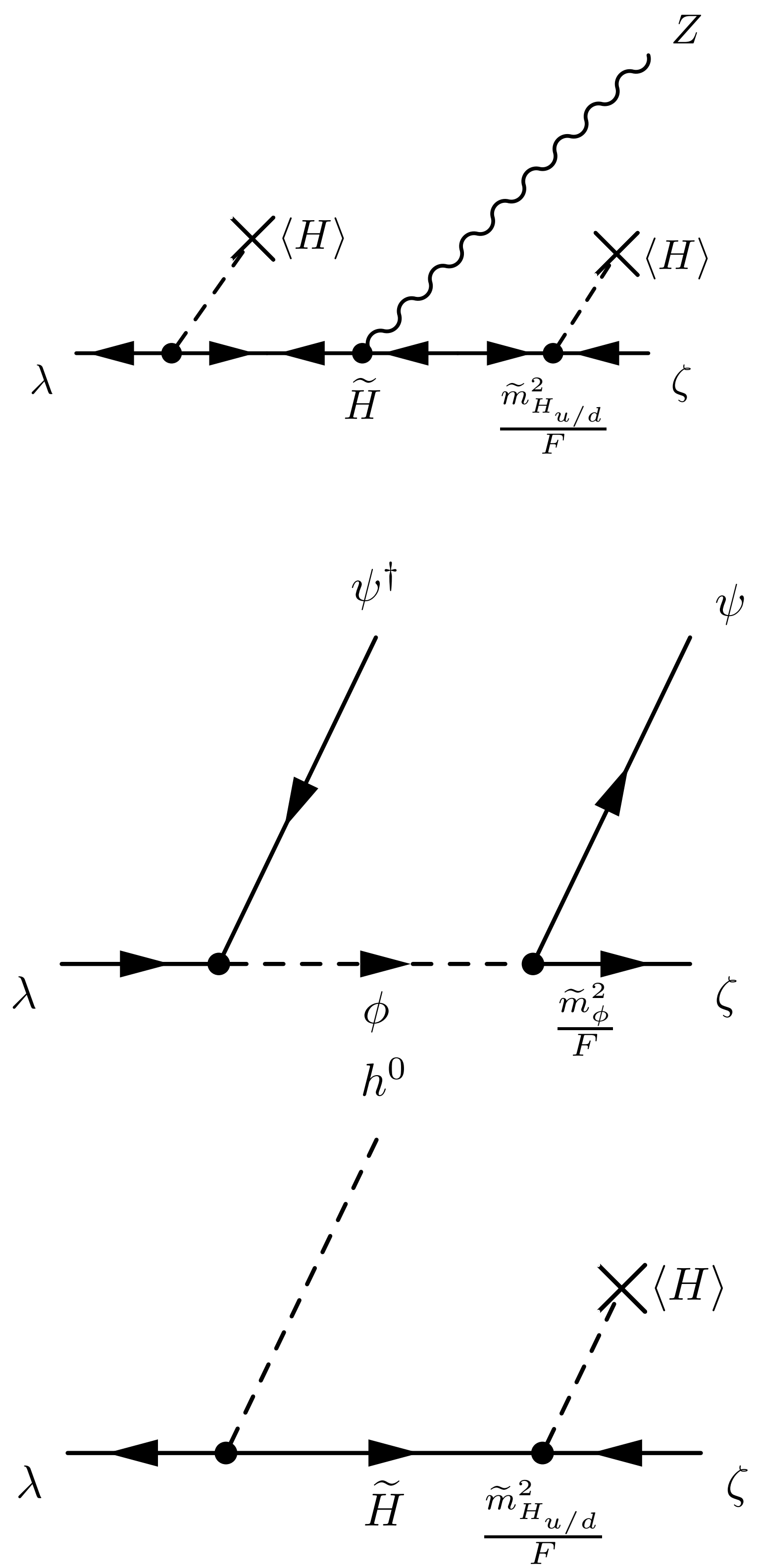
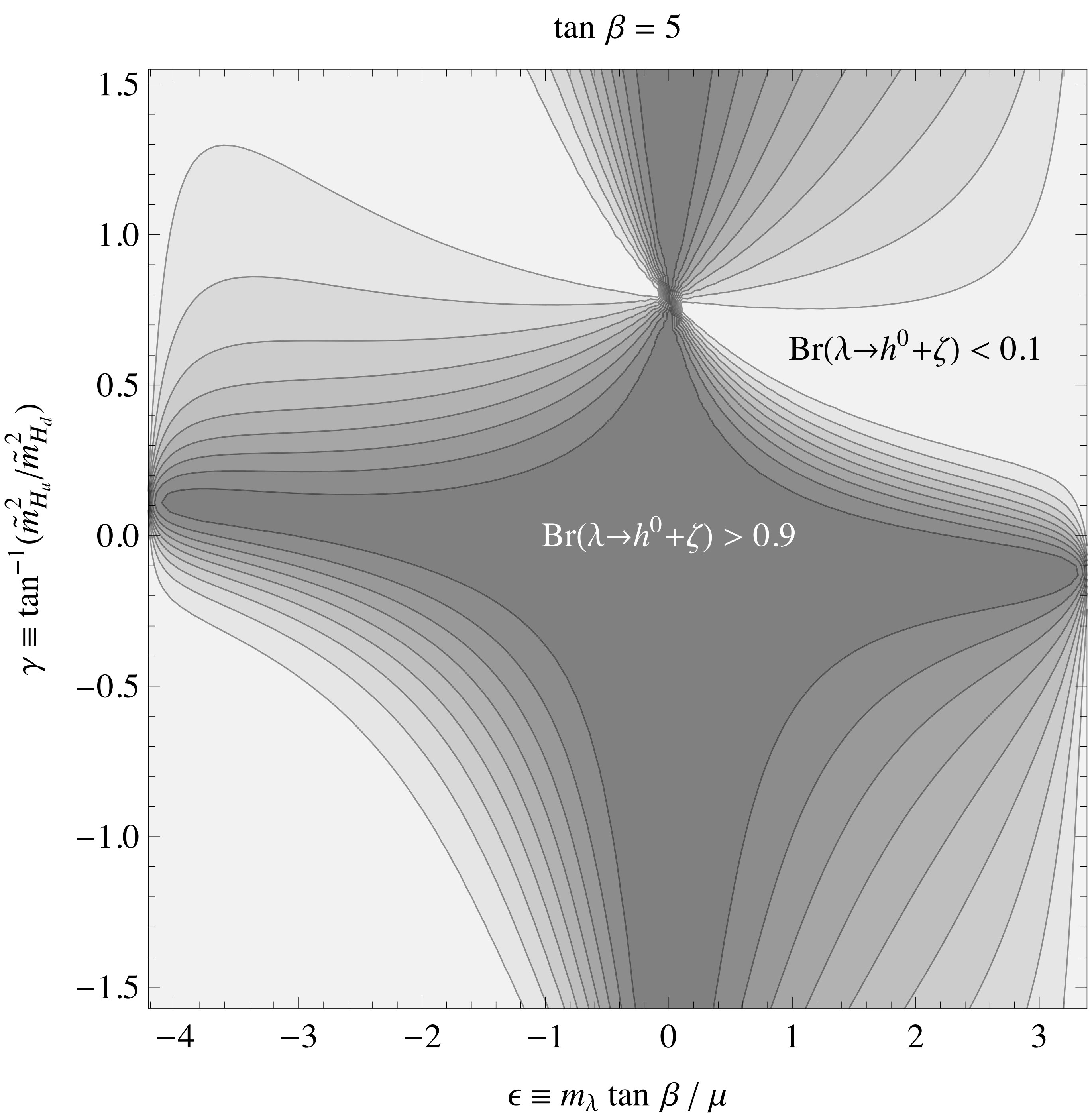


Figure 3: Probability for a Higgs boson in squark decay chains, for $M_A = 1000$ GeV. From lightest to darkest blue, the probabilities are 5%, 10%, 15%, 20%, 25%, 30%. The gray hatched area is excluded by LEP. Superimposed are the regions of correct relic density for $\tan\beta = 10$ (black) and $\tan\beta = 50$ (green). The constraints from dark matter direct detection are not shown. The yellow

Gori, Schwaller, Wagner 1103.4138

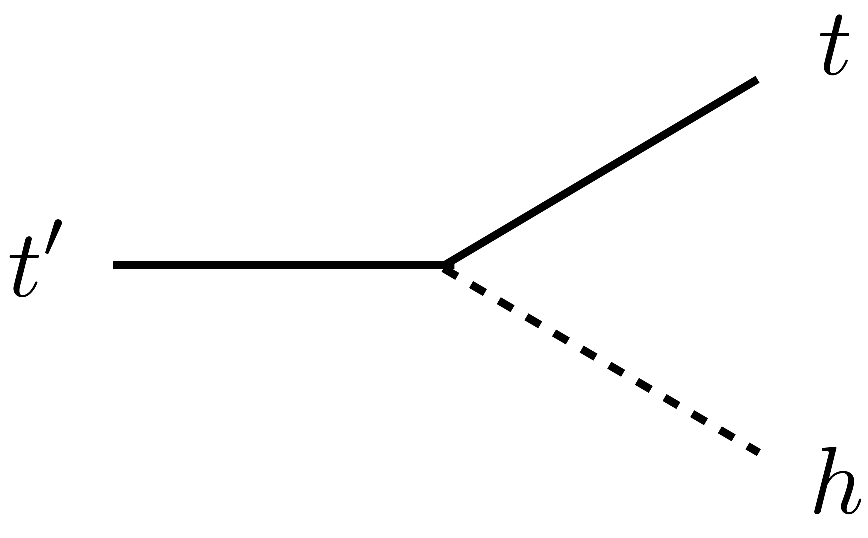
Example 3: Bino -> Goldstini h





Thaler, Thomas (2011)

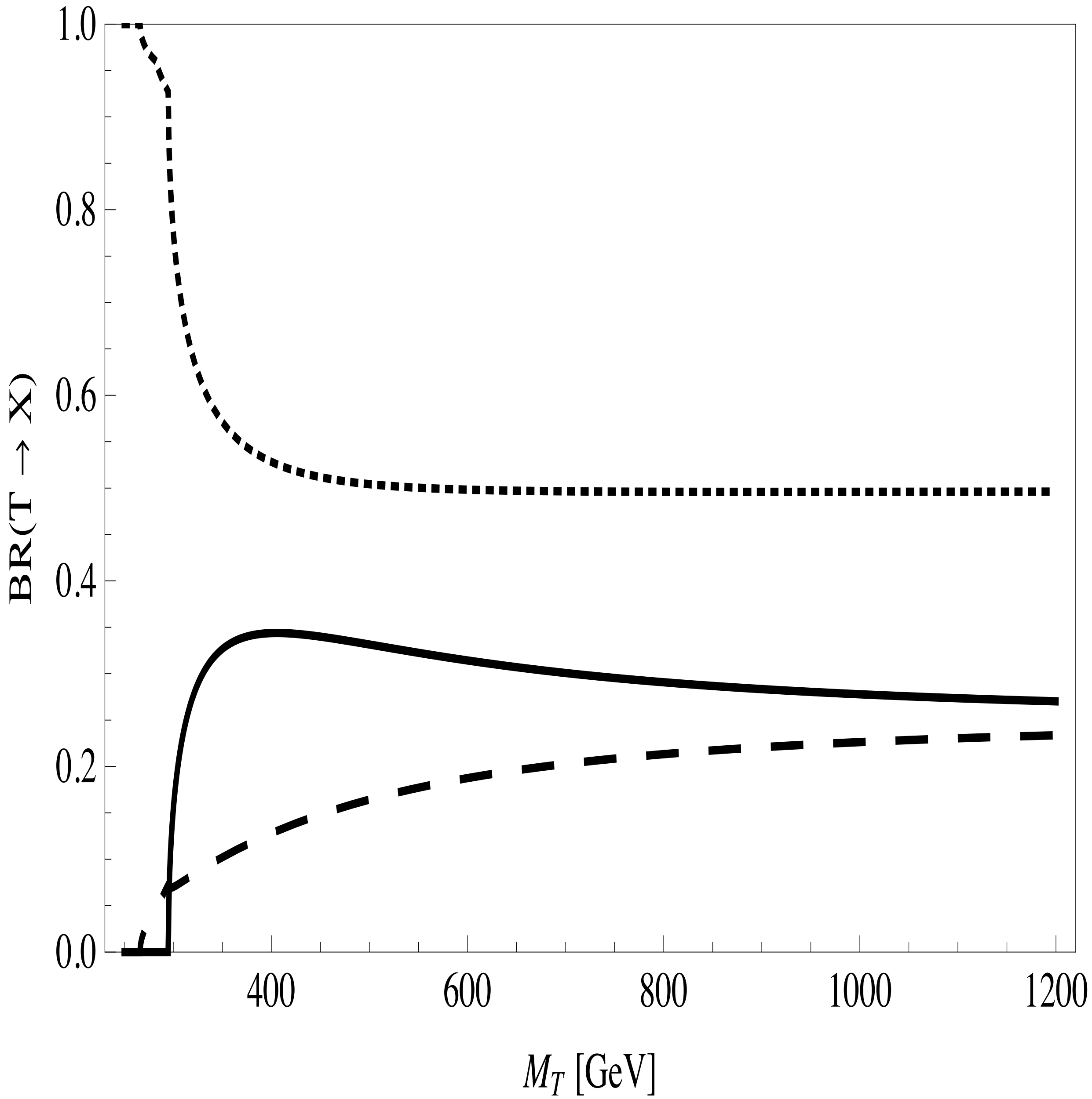
Example 4: Top Partners: t' -> t h



Perelstein, Peskin, Pierce (2002)

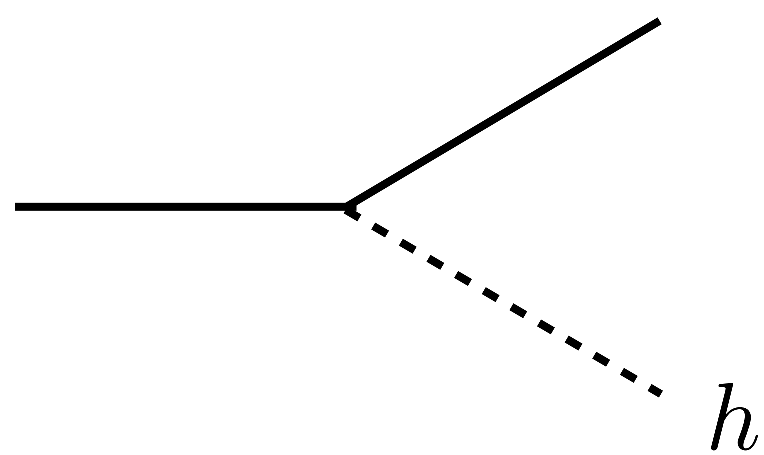
Han, Logan, McElrath, Wang (2003)

Kribs, A Martin, Roy (2010)



Kribs, A Martin, Roy (2010)

Searching for Higgs in Decays



Exploit Boosted h -> $b\bar{b}$

Butterworth et al (2007,2009)

Butterworth, Davison, Rubin, Salam (2008)

Kribs, Martin, Roy, Spannowsky (2009,2010)

Chen et al (2010)

Plehn et al (2010,2011)

Kribs, Martin, Roy (2010)

Katz,Son,Tweedie (2010)

Bellazzini, Csaki, Hubisz, Shao (2010)

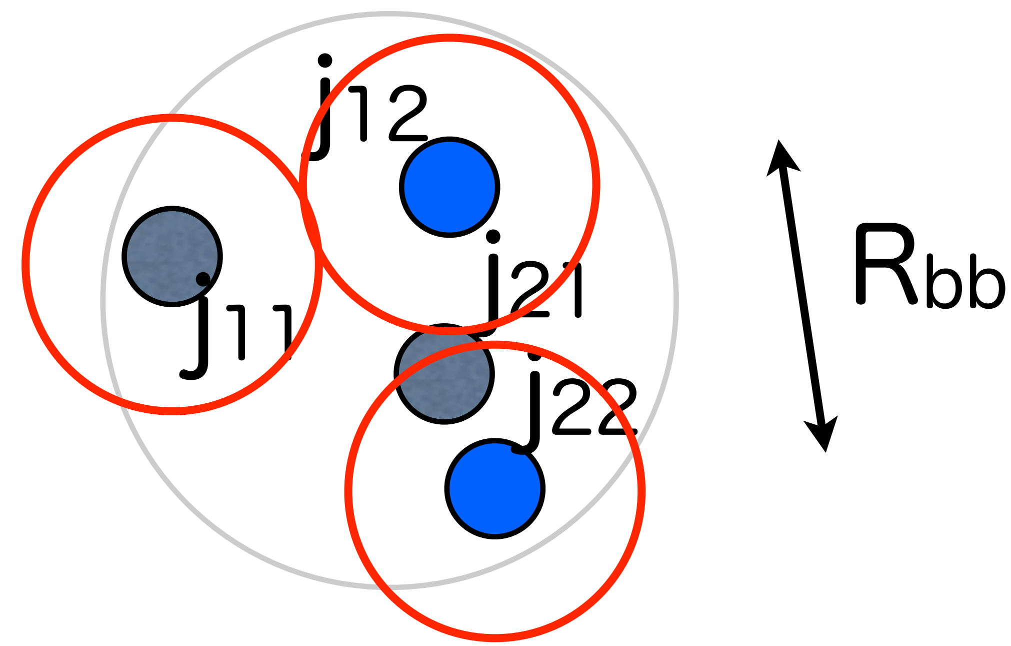
Fan, Krohn, Mosteiro, Thalapillil, Wang (2011)

Bandyopadhyay, Huitu (2011)

Chen (2011)

Son, Spethmann, Tweedie (2012)

...

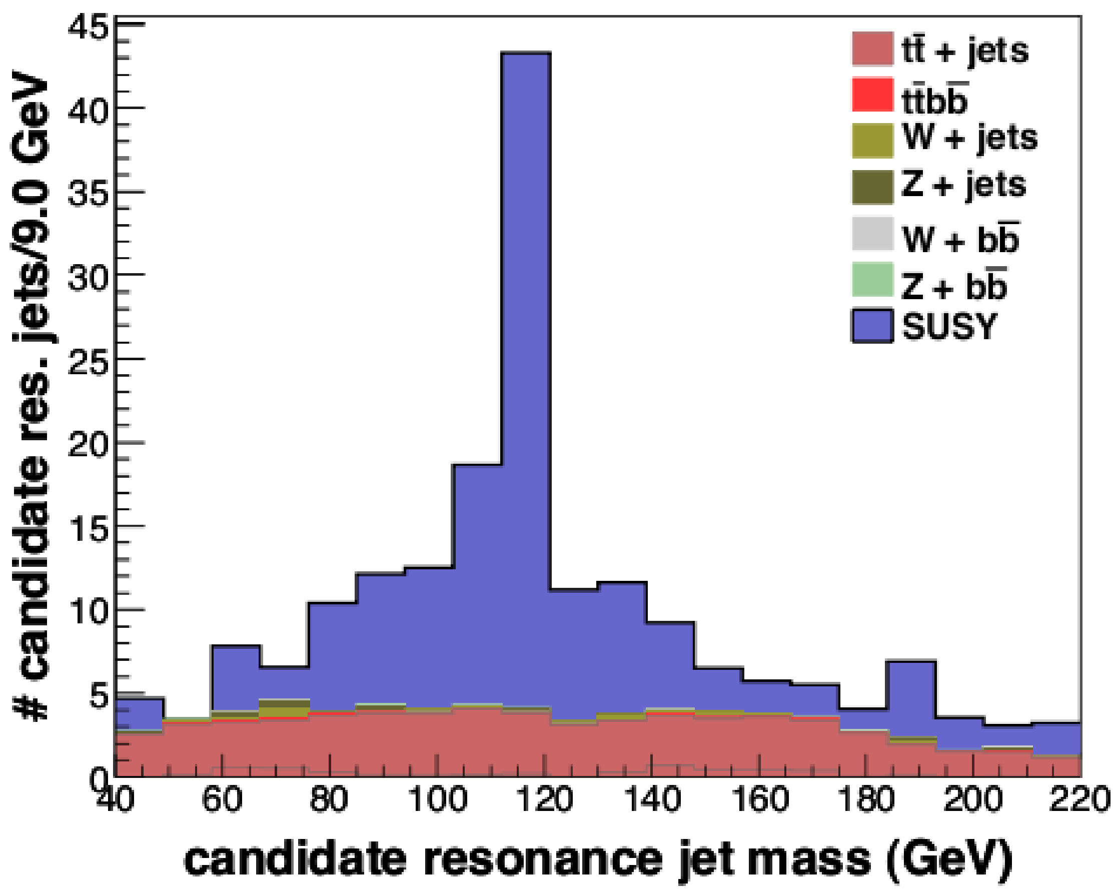


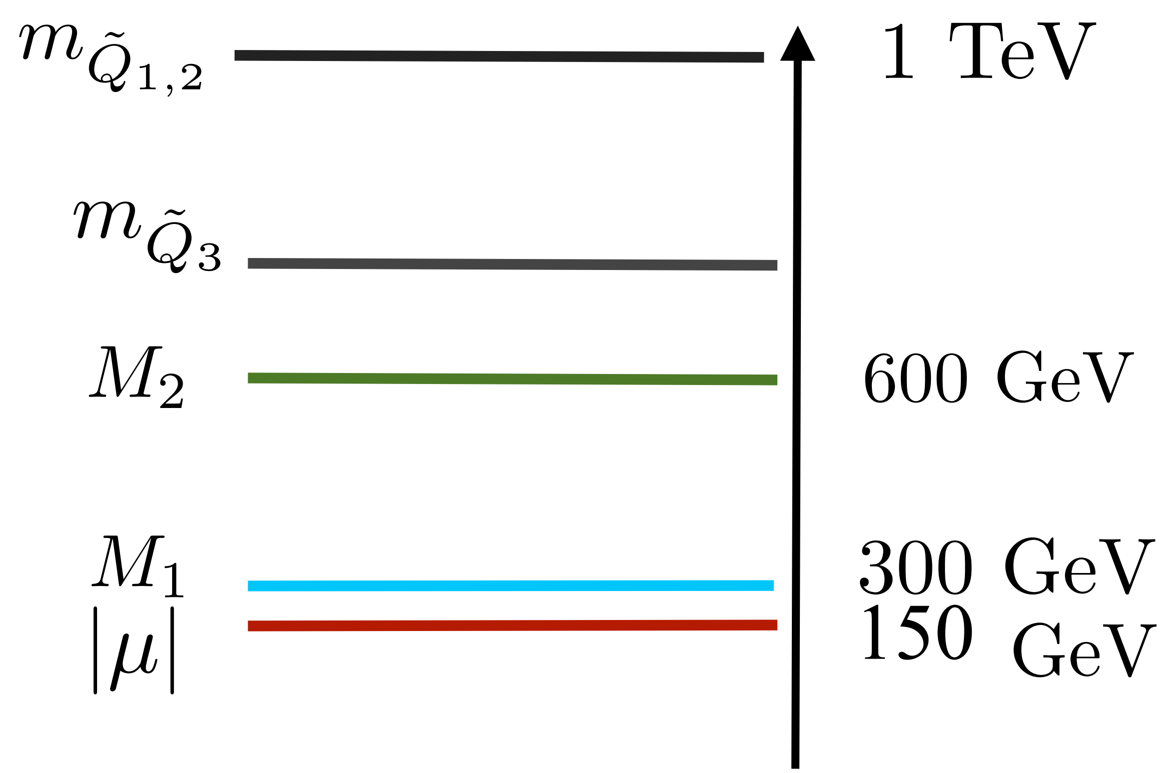
- Fat jet
- Filtering
- Mass Drop
- y-cut
- b-tag jets

SUSY Example: Boosted h -> $b\bar{b}$

sq -> Bino, Wino -> Higgsino + h

10 fb^{-1} @ 14 TeV





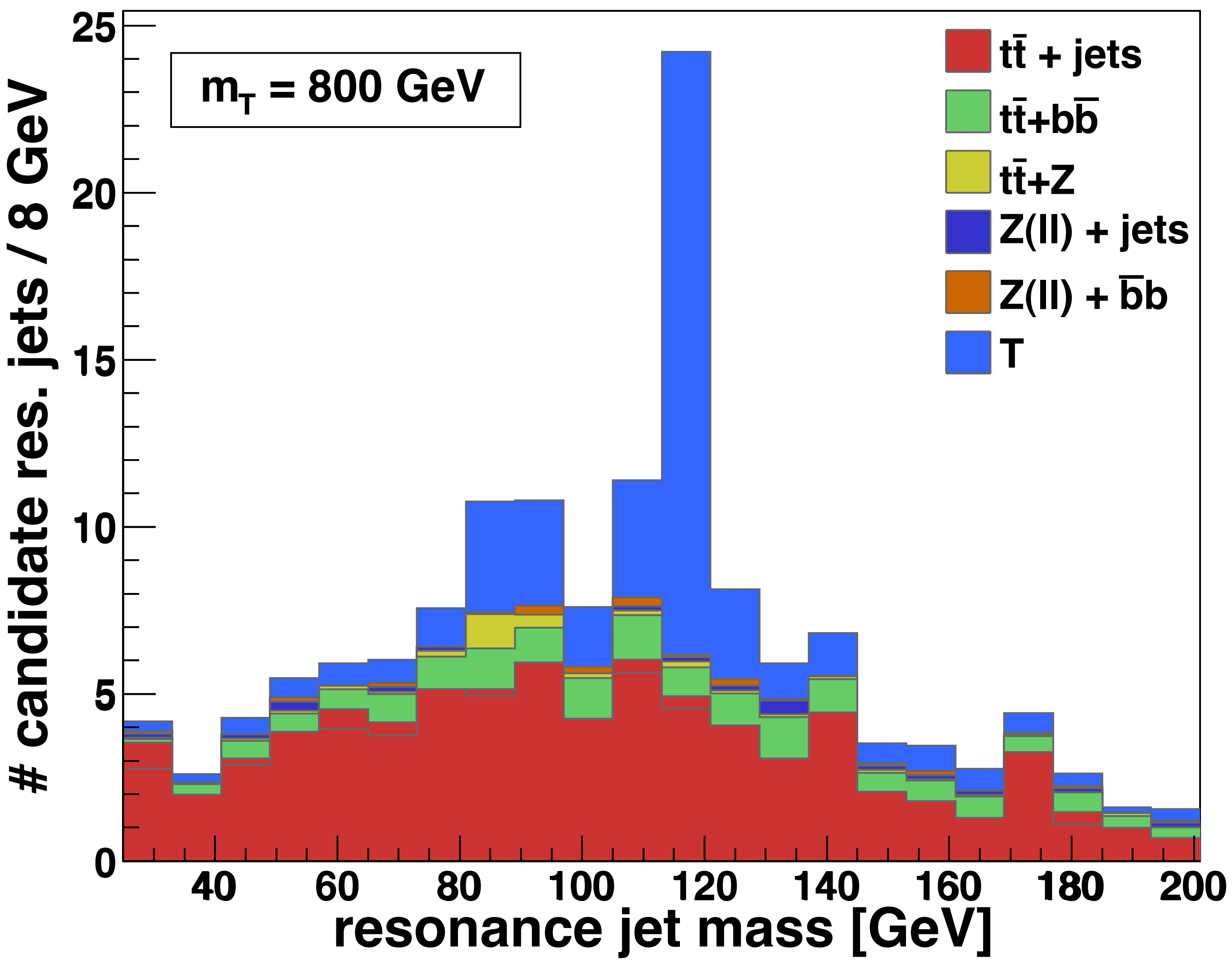
MET > 300 GeV, H_T > 1 TeV, 3+ jets,
no lepton, + 1 "tagged" Higgs

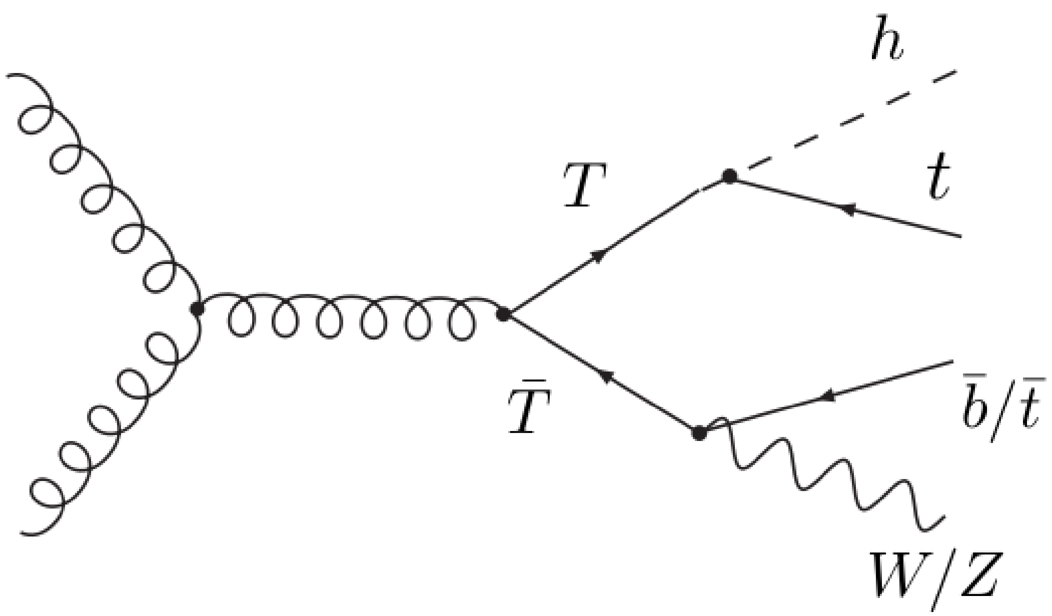
$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 23\%$$
$$BR(\tilde{u}_R, \tilde{d}_R \to h + X) \sim 16\%$$

Kribs, Martin, Roy, Spannowsky (2010)

Top Partner Example: Boosted $h \to b\bar{b}$

10 fb^{-1} @ 14 TeV

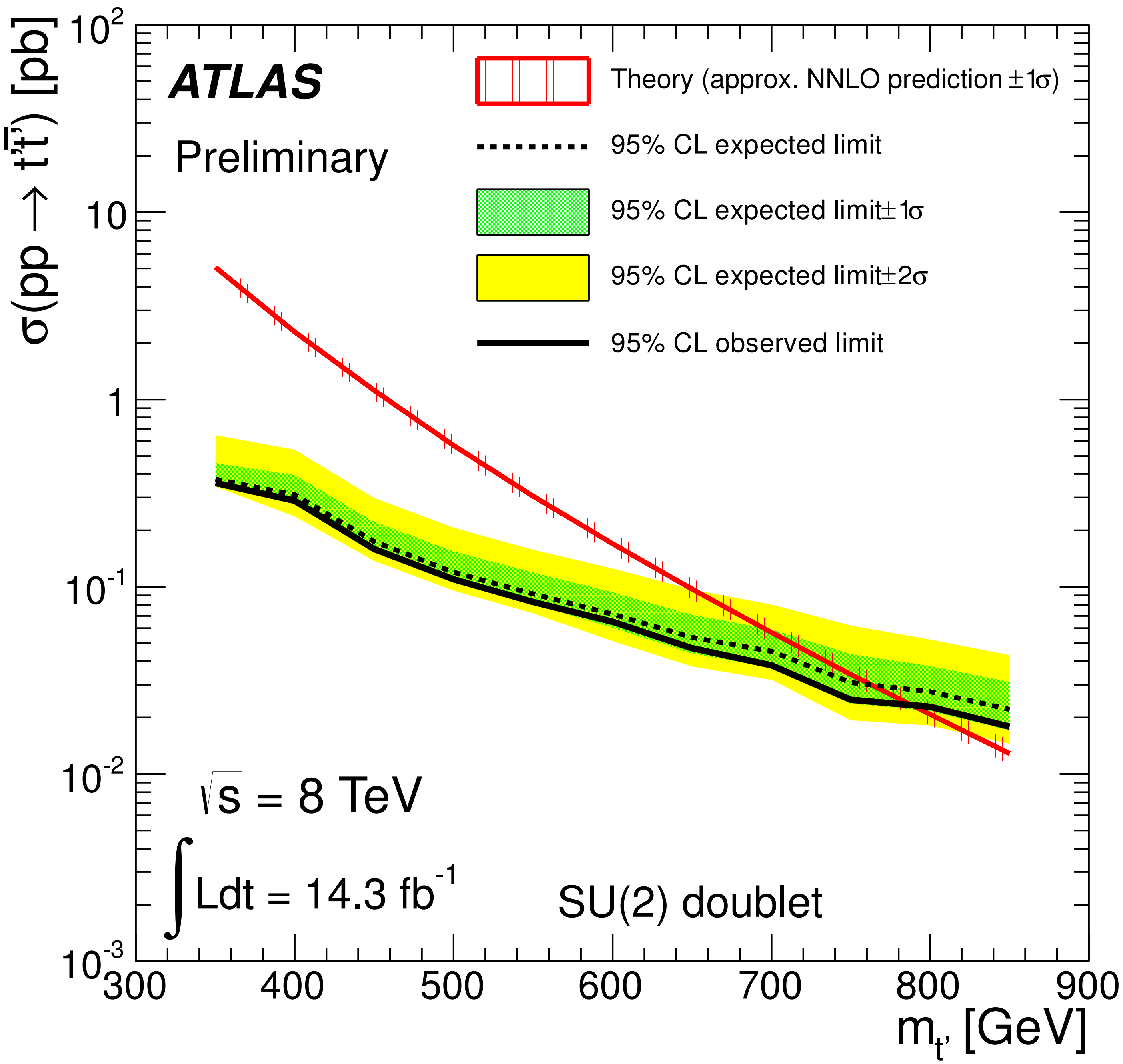




Kribs, Martin, Roy (2010)

ATLAS Search for t’

Data are analysed in the lepton +jets final state, characterised by an isolated electron or muon with moderately high transverse momentum, significant missing transverse momentum, and at least six jets. The search exploits the high total transverse momenta of all final state objects and the high multiplicity of b jets characteristic of signal events with at least one Higgs boson decaying into $b\bar{b}$, to discriminate against the dominant background from top quark pair production.



ATLAS (2013)

Exploit h -> $\gamma\gamma$

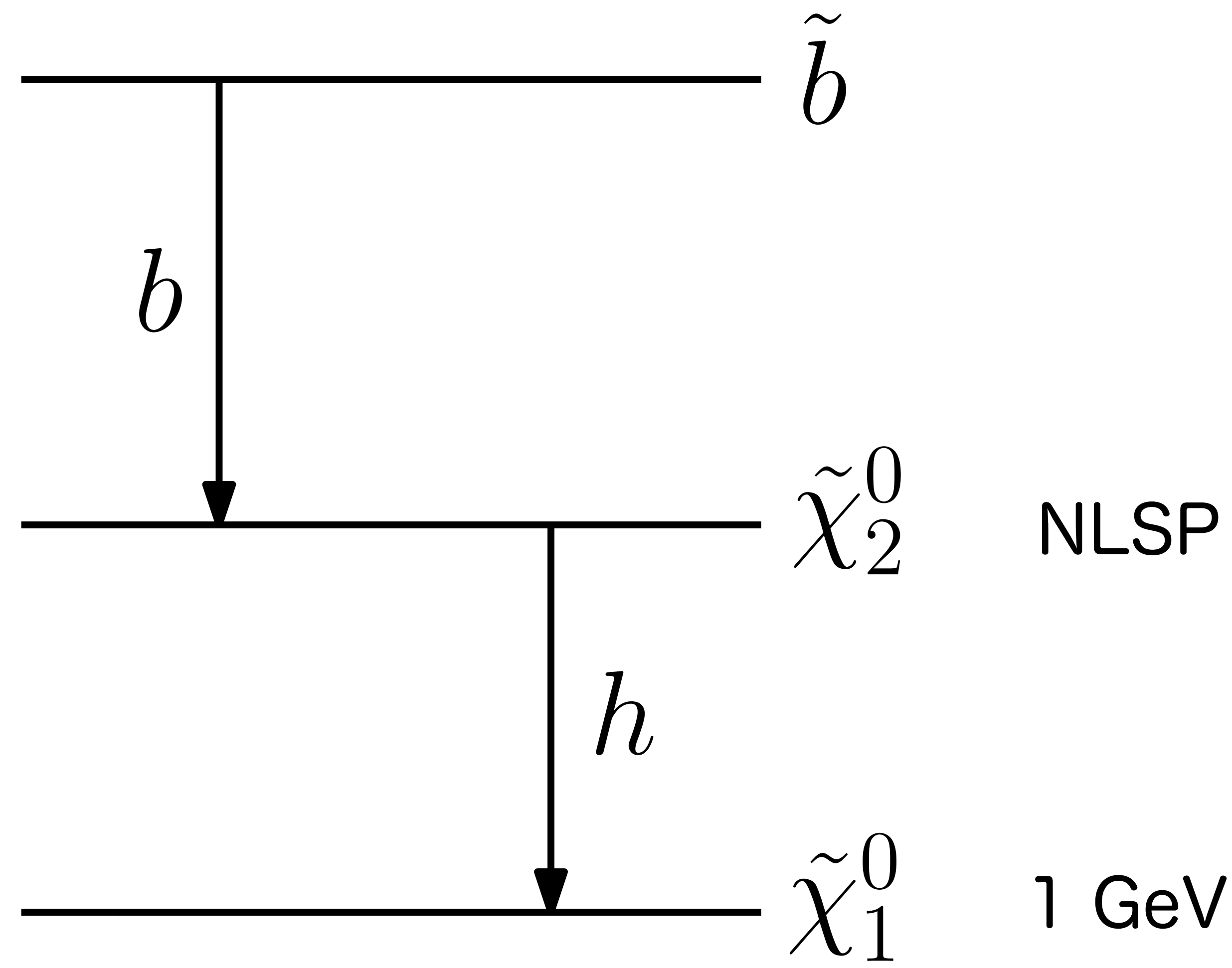
Howe, Saraswat (2012):
Simplified model involving
sbottom production and decay.

Assumed

$$BR(\tilde{b} \rightarrow b\tilde{\chi}^0_2) = 100\%$$

and

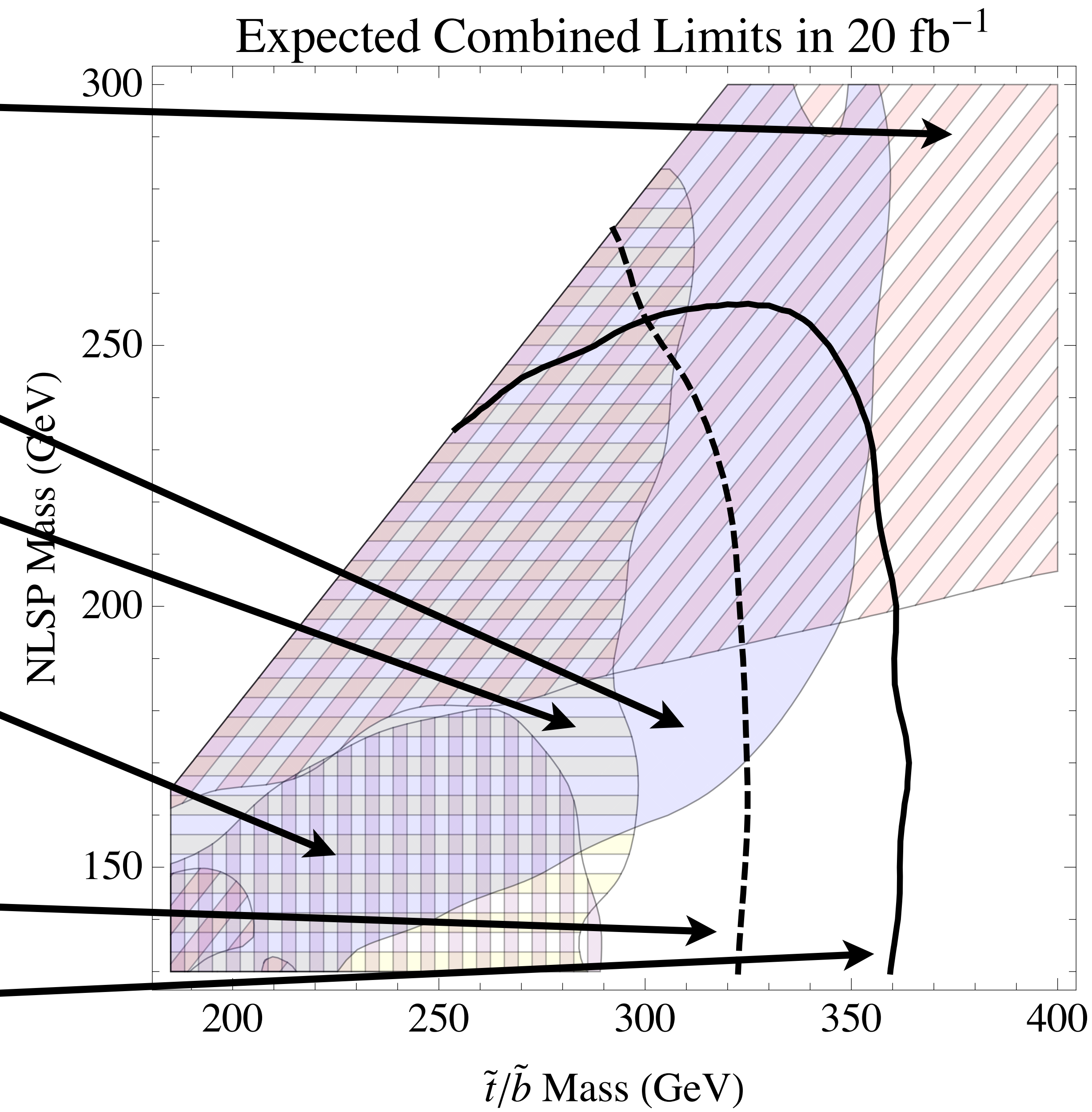
$$BR(\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 h) = 100\%$$



Howe, Saraswat (2012)

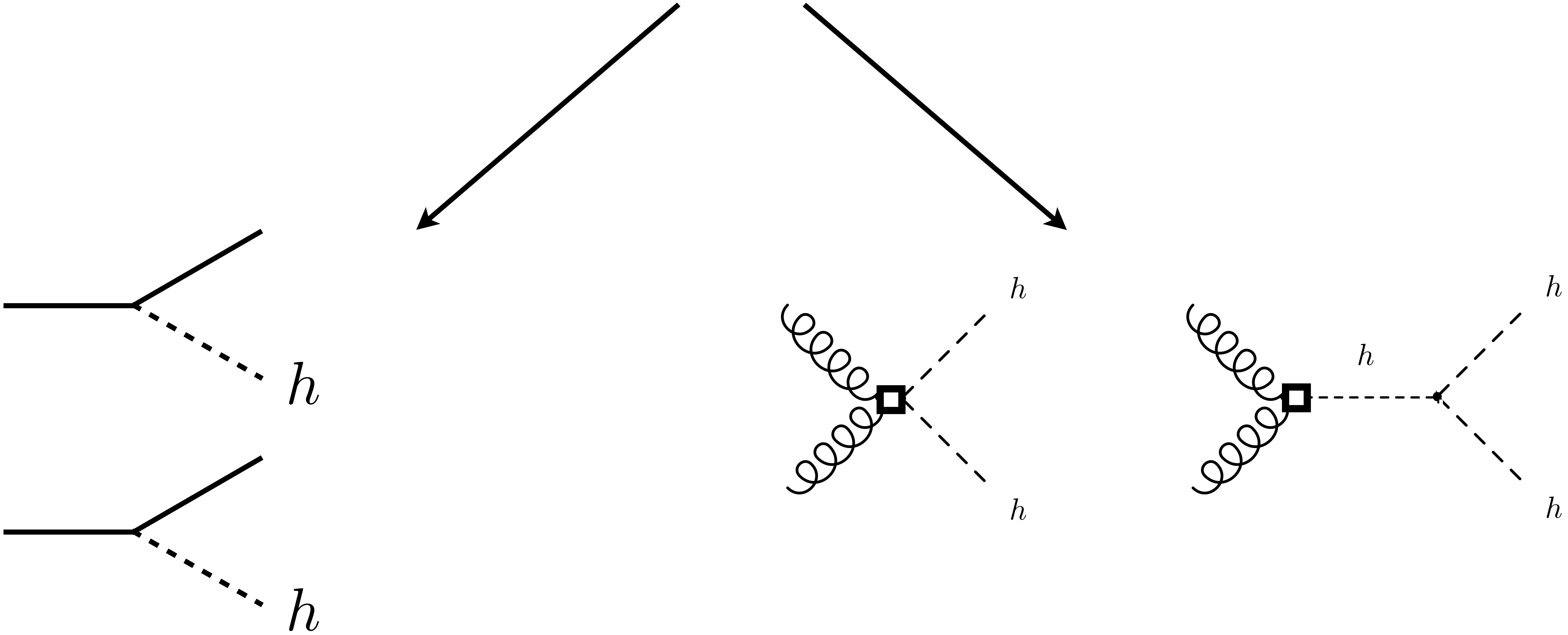
Exploit h -> $\gamma\gamma$

- CMS8 3b + MET
- CMS8 $\gamma\gamma$+ MET
- CMS7 multilepton
- CMS8 SS + 2b
- Projected $\gamma\gamma$+1b
  $\gamma\gamma$+2b

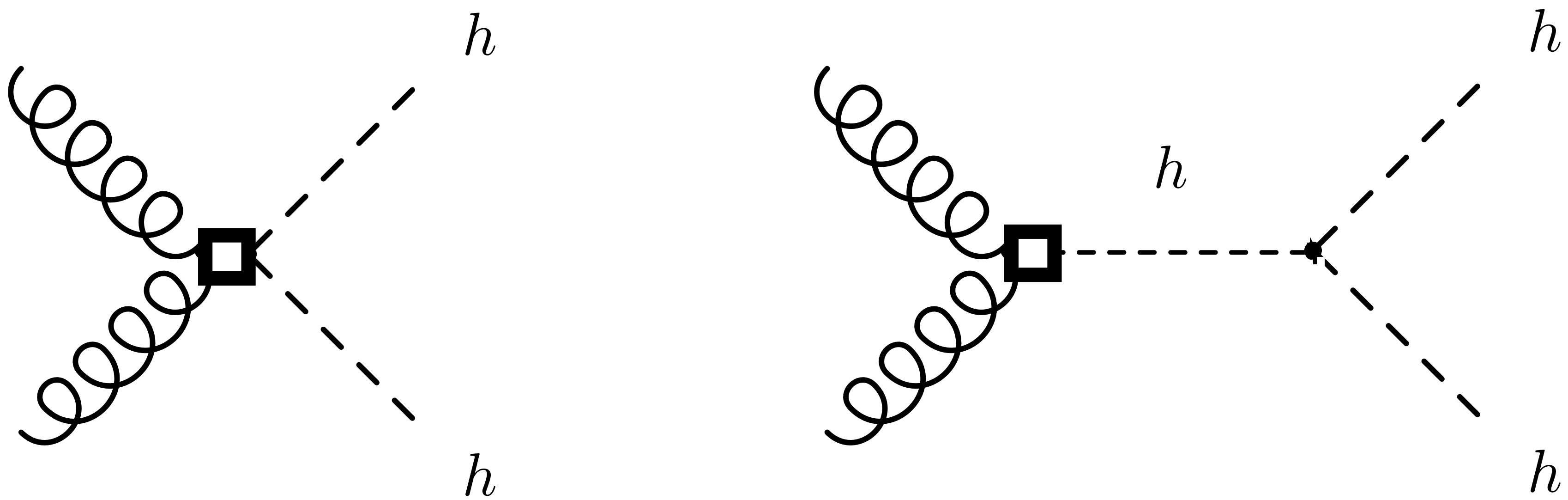


Howe, Saraswat (2012)

diHiggs



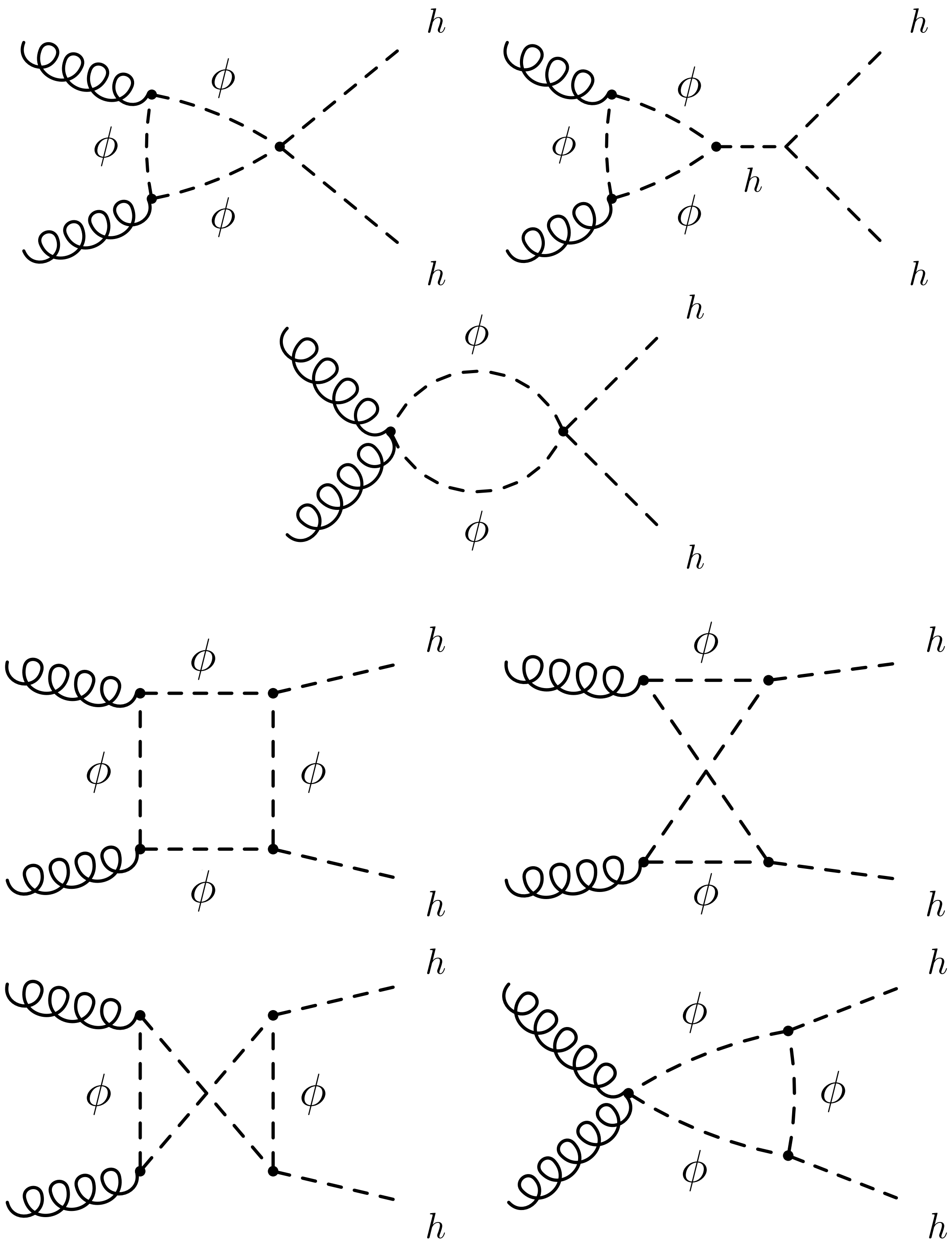
diHiggs Enhancement

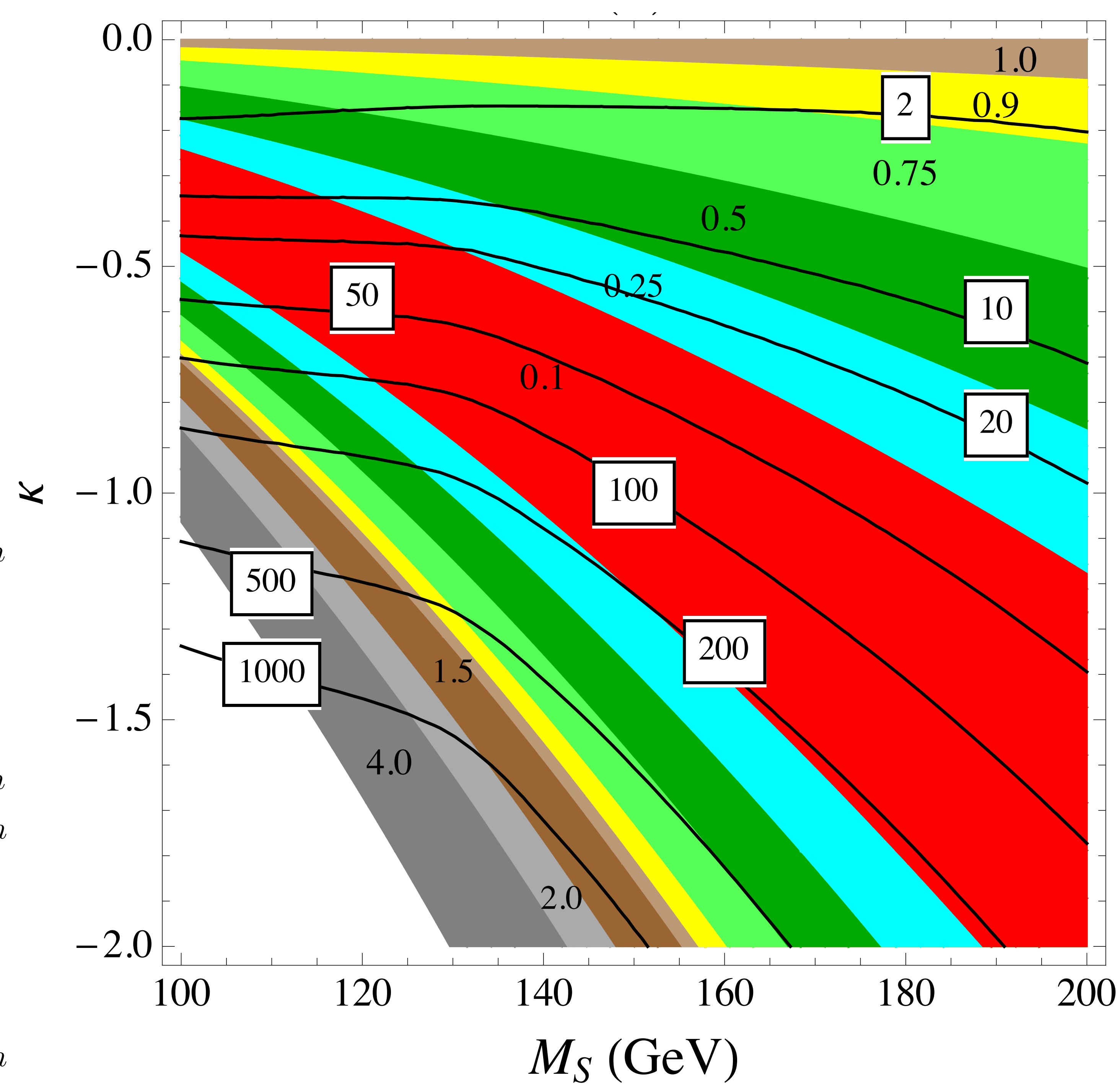


SM accidentially small; large enhancements possible through effective operators that can have simple UV completions.

Pierce, Thaler, Wang (2006)
Giudice, Grojean, Pomarol, Rattazzi (2007)
A Martin, Kribs (2012)
Dawson, Furlan, Lewis (2012)
Dolan, Englert, Spannowsky (2012)
Craig, Evans, Gray, Kilic, Dolan, Park, Somalwar, Thomas (2012)

diHiggs Enhancement: real color octet*



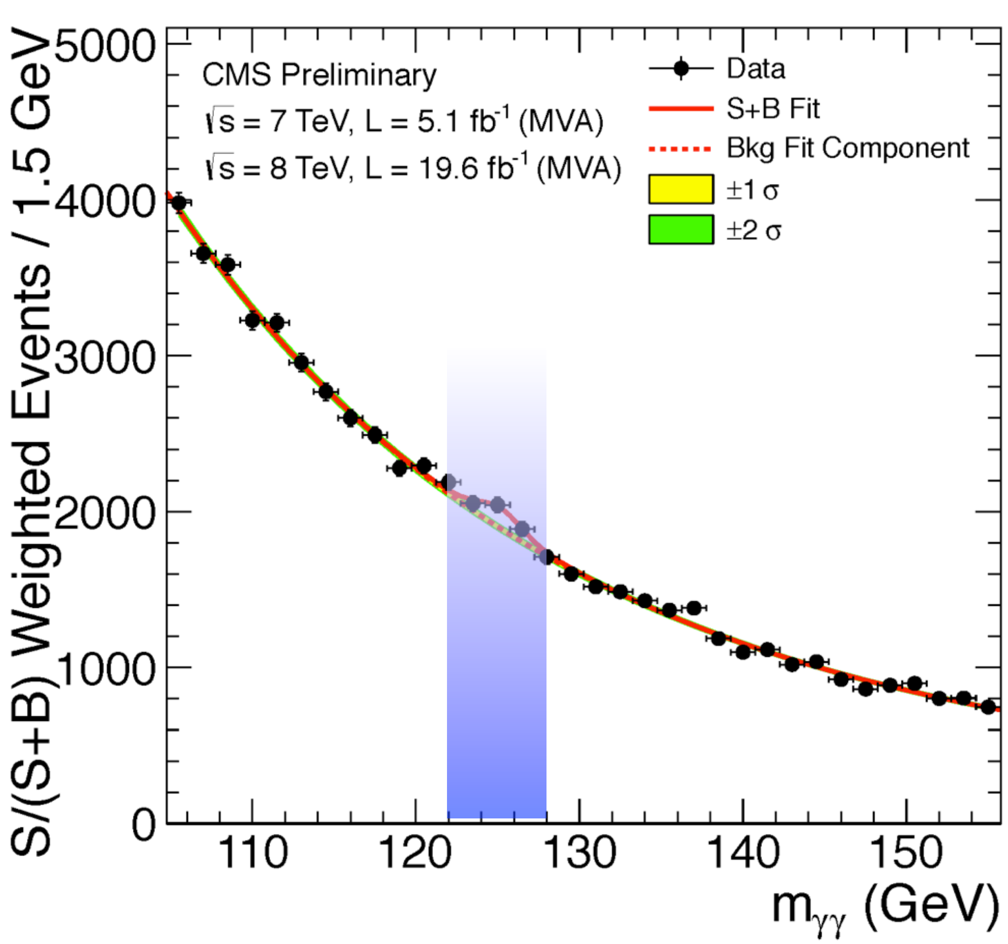


*Direct search bounds...

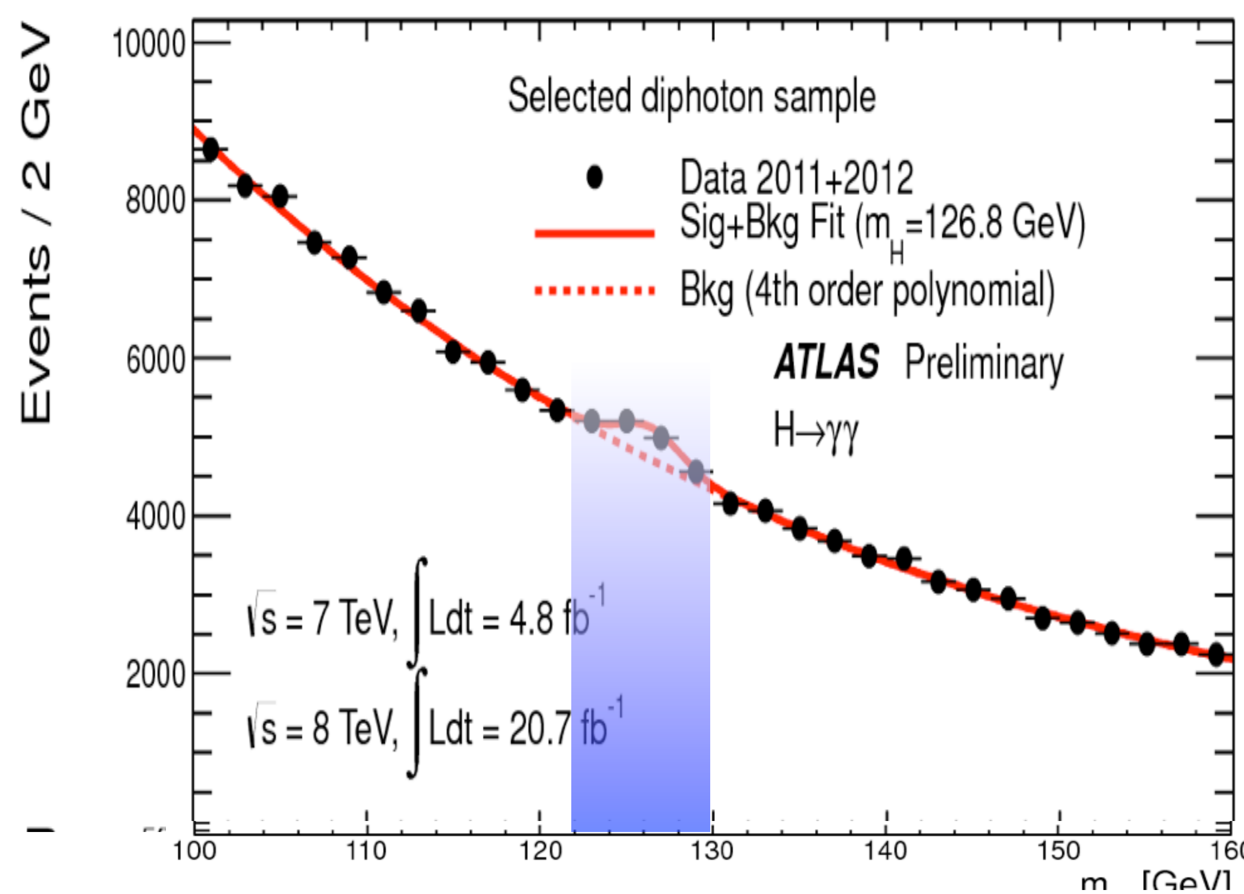
A Martin, Kribs (2012)

diHiggs Enhancement Signal

	final state	rates in fb 8 TeV	14 TeV
$m_h = 125$ GeV	$\gamma\gamma + \bar{b}b$	$0.019\,X$	$0.084\,X$
	$\tau^+\tau^- + \bar{b}b$	$0.53\,X$	$2.4\,X$
	$\tau^+\tau^-\tau^+\tau^-$	$0.029\,X$	$0.13\,X$



CMS (2013)



ATLAS (2013)

Higgs in Annihilation

Stoponium

Bound state of

$$(\tilde{t}_1 \tilde{t}_1^*)$$

Quirkonium

Bound state of

$$(q\bar{q})$$

In principle can annihilate into hh,Wh,Zh,γh

Drees, Nojiri (1993)

S Martin (2008)

S Martin, Younkin (2009)

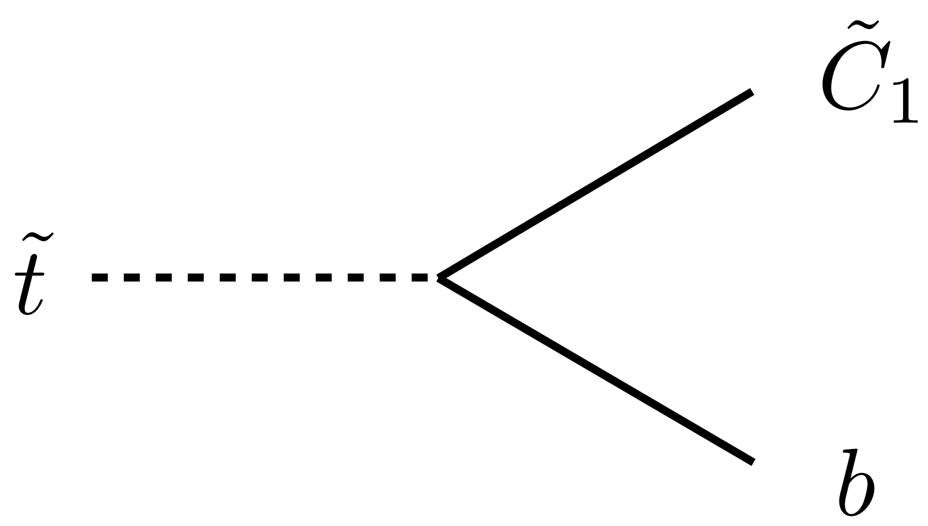
Kang, Luty (2008)

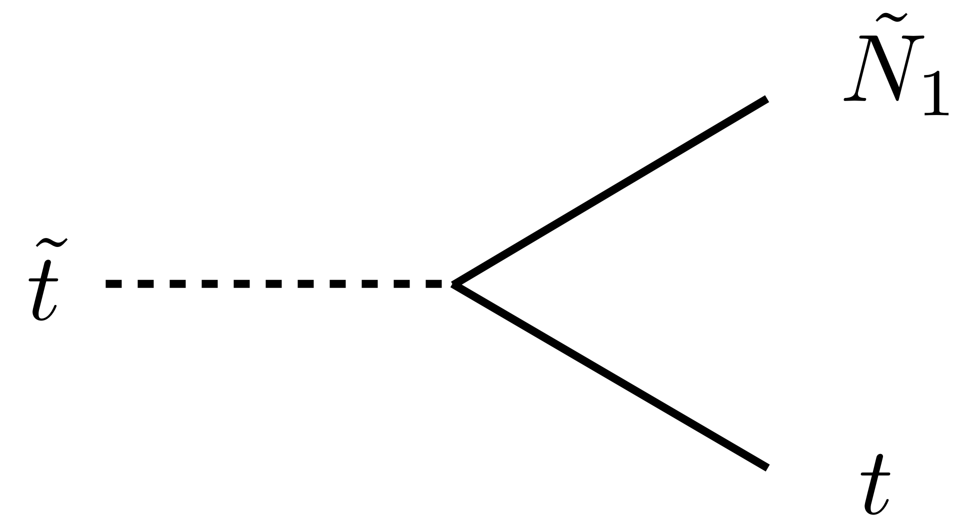
Cheung, Keung, Yuan (2008)

Fok, Kribs (2011)

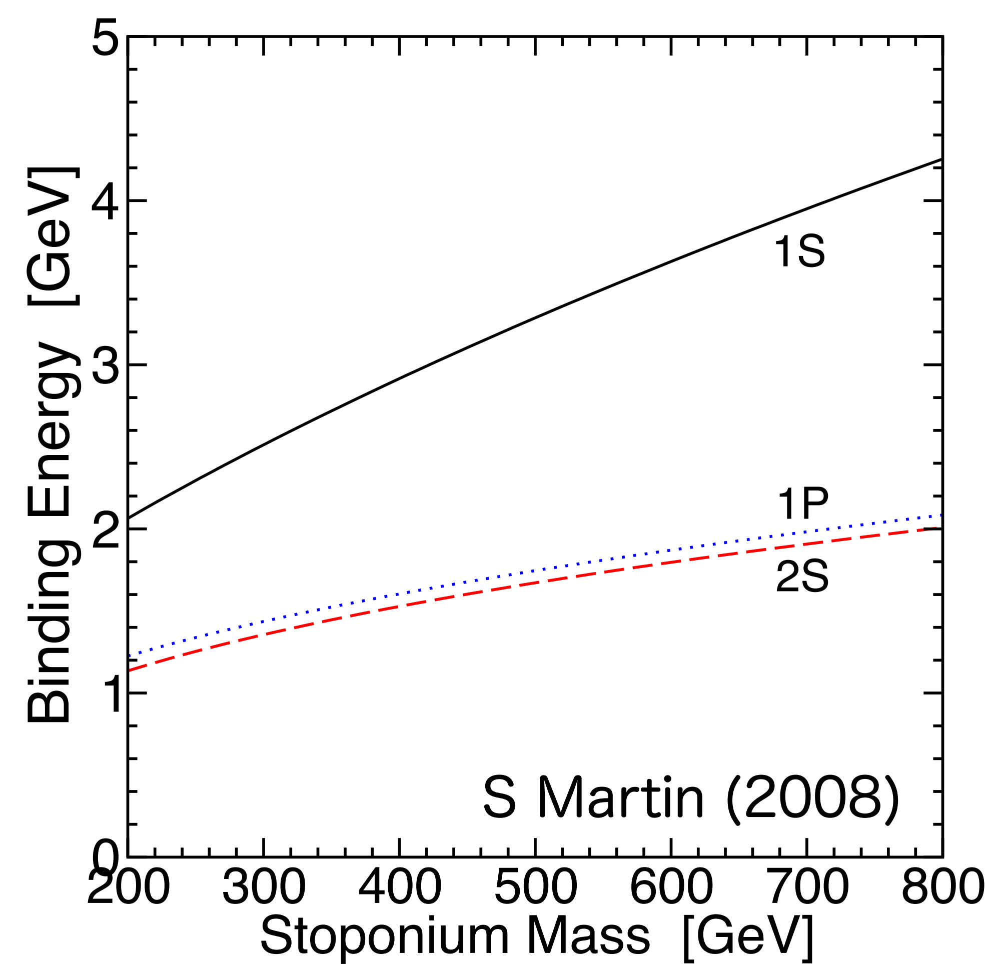
Example 1: Stoponium

Basic idea: if 2-body decays

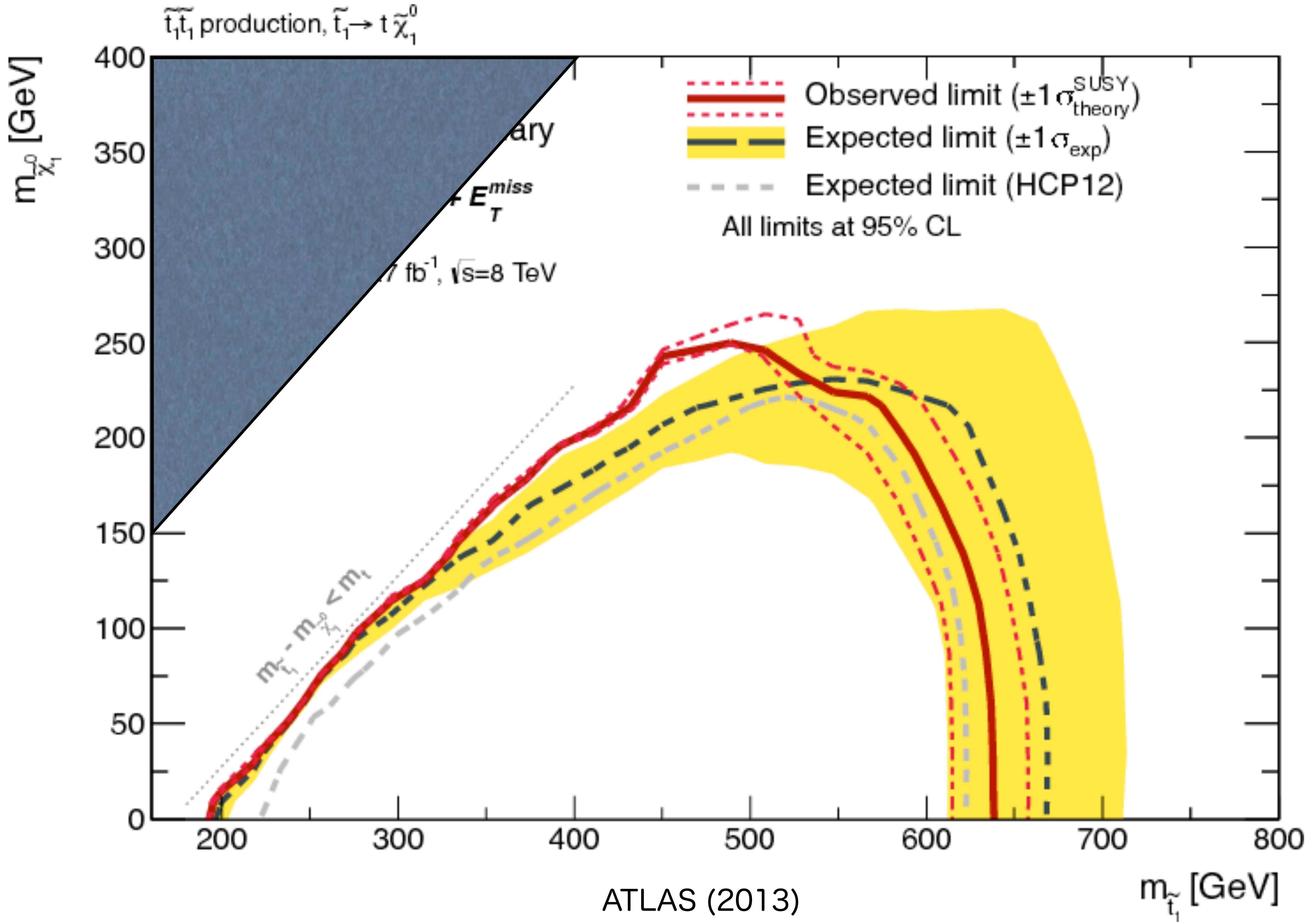




are not kinematically possible, then remaining 3-body, 4-body, and flavor-violating stop decays have widths smaller than binding energy of stoponium.

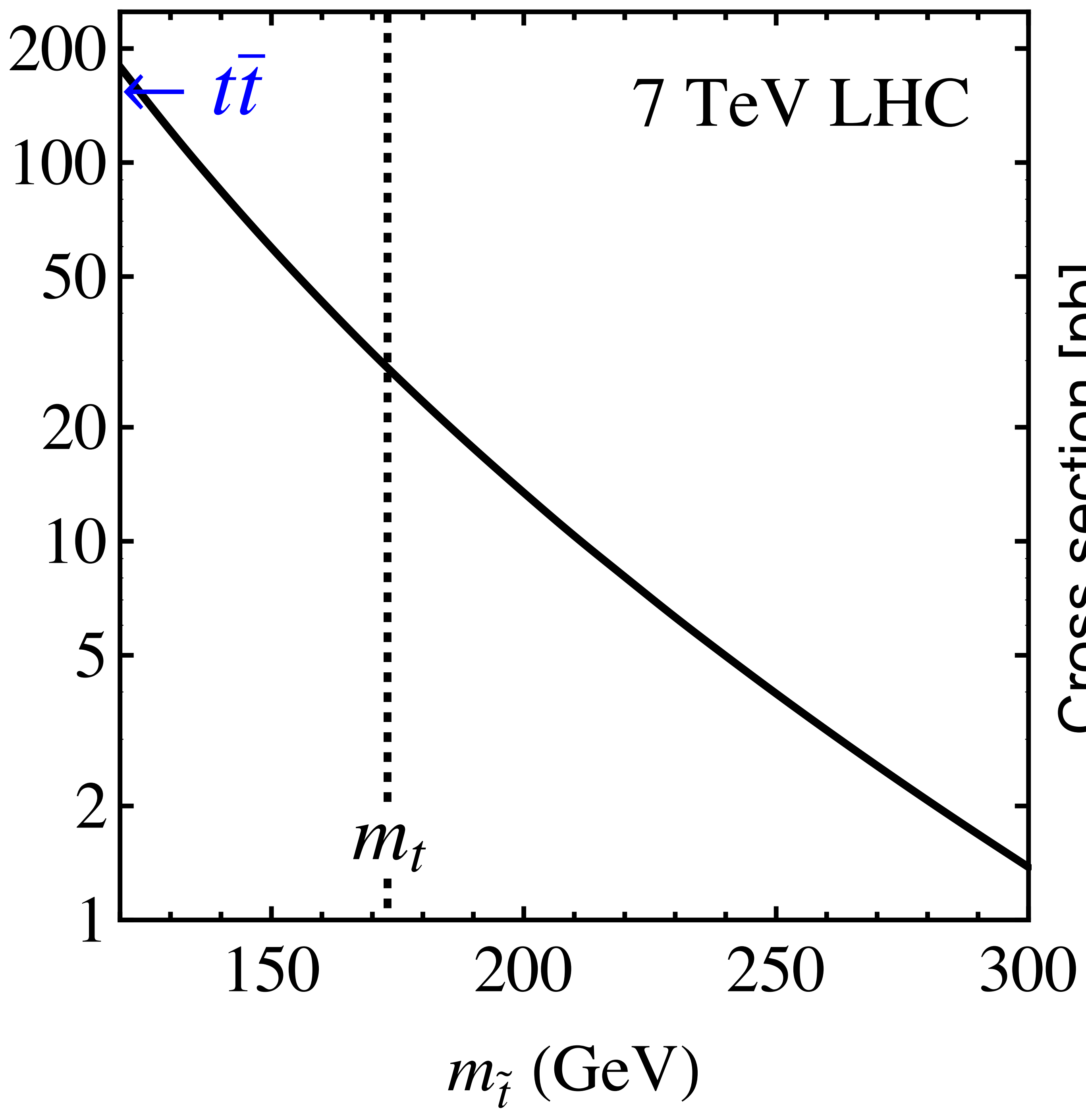


Stoponium



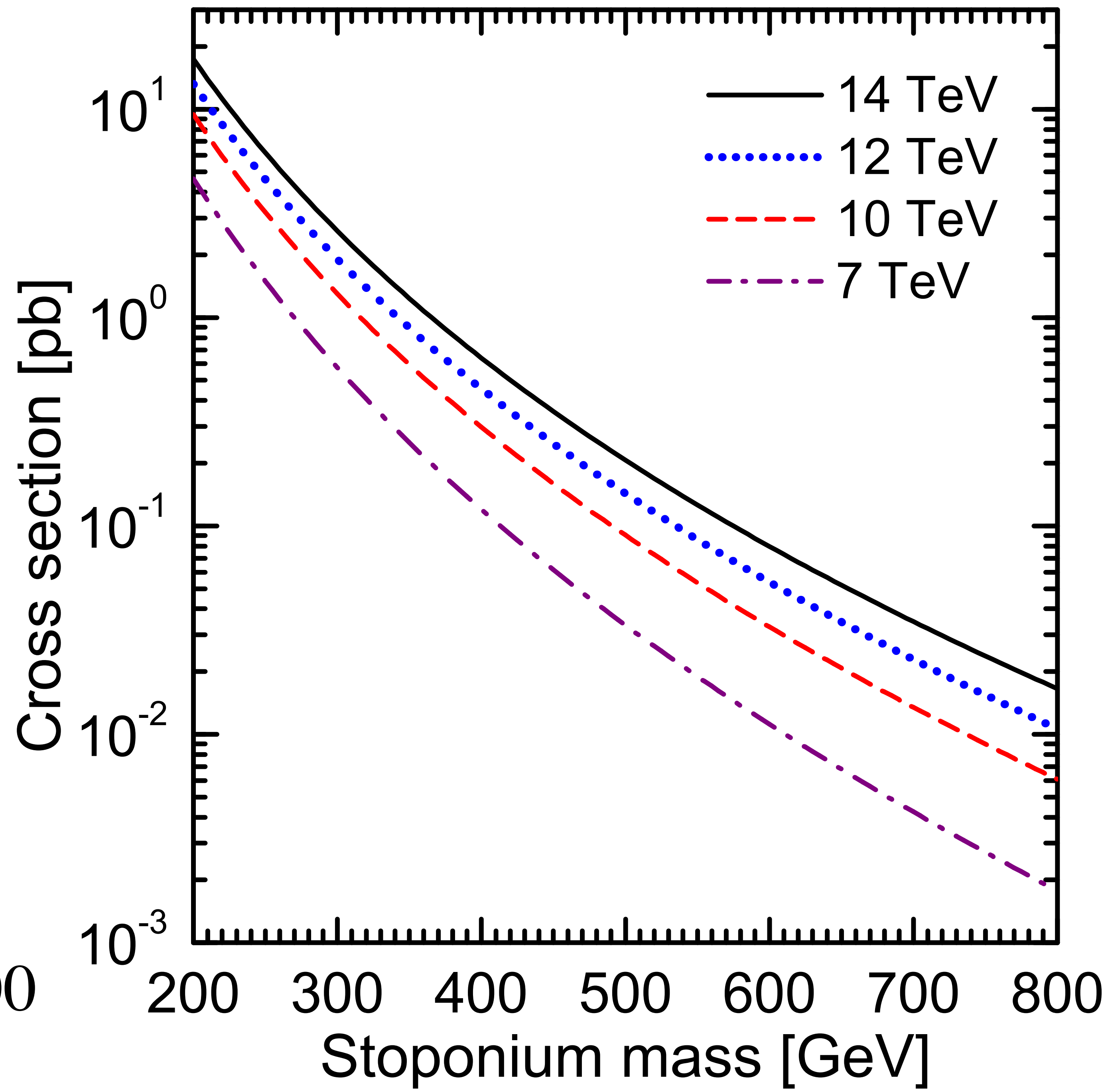
ATLAS (2013)

Stop Pair Production



Katz,Shih (2011)

Stoponium Production



S Martin (2008)

Stoponium Annihilation

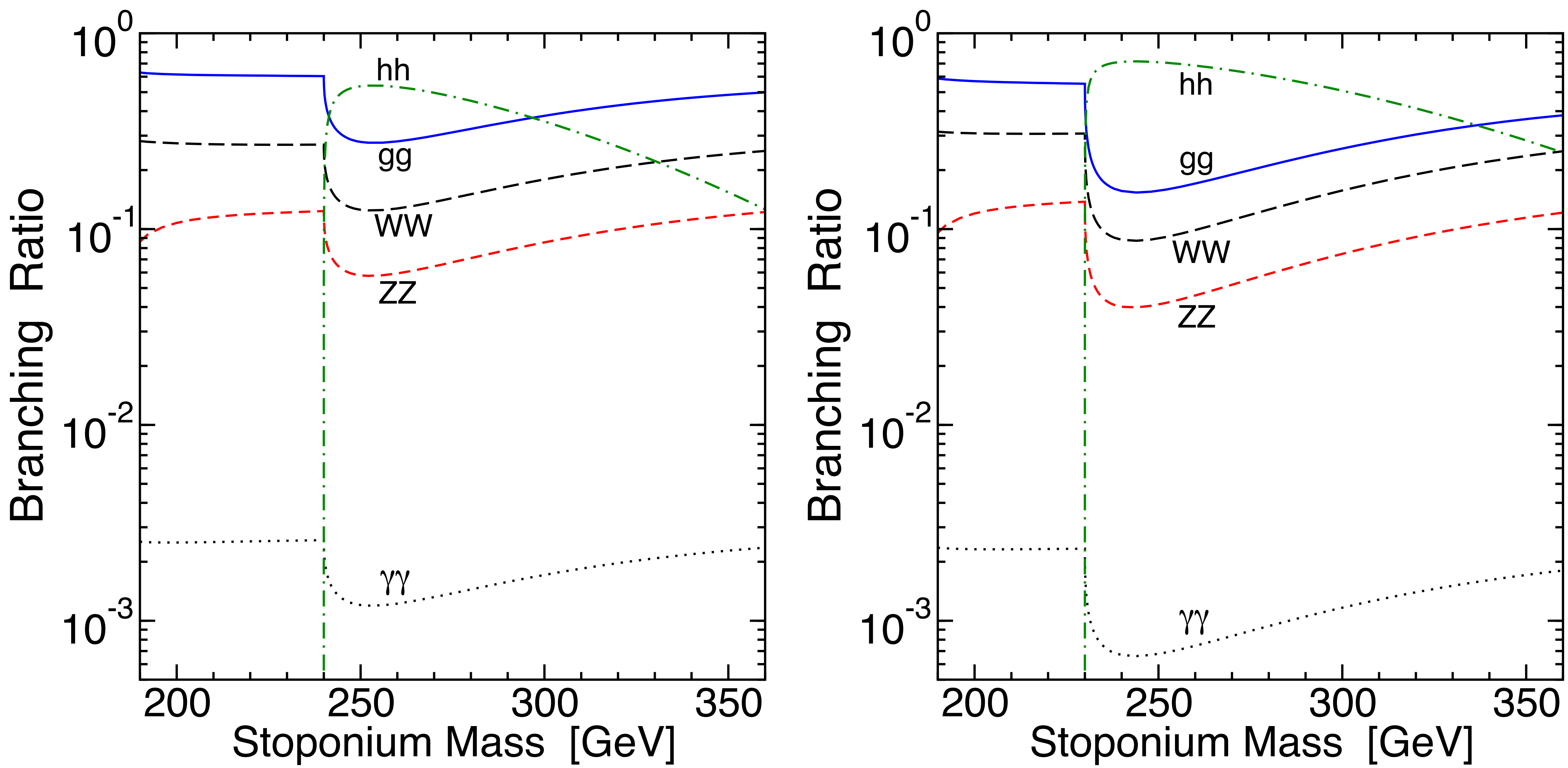


FIG. 8: The branching ratios of scalar stoponium into gg, $\gamma\gamma$, W^+W^-, ZZ, and h^0h^0 final states, for model lines motivated by electroweak-scale baryogenesis, as described in the text, with varying $m_{\tilde{t}_1}$. The left panel depicts a relatively optimistic case with $m_{h^0} = 115$ GeV, $|X_t|/m_{\tilde{t}_2} = 0.3$ and the right panel a pessimistic case with $m_{h^0} = 120$ GeV, $|X_t|/m_{\tilde{t}_2} = 0.5$. The range that can lead to electroweak-scale baryogenesis in the MSSM includes roughly 235 GeV $< m_{\eta_{\tilde{t}}} <$ 270 GeV.

S Martin (2008)

Example 2: Quirkonium Annihilation

This also happens with "quirkonium", the bound states of new fermions that transform under a new strongly coupled sector "infracolor".

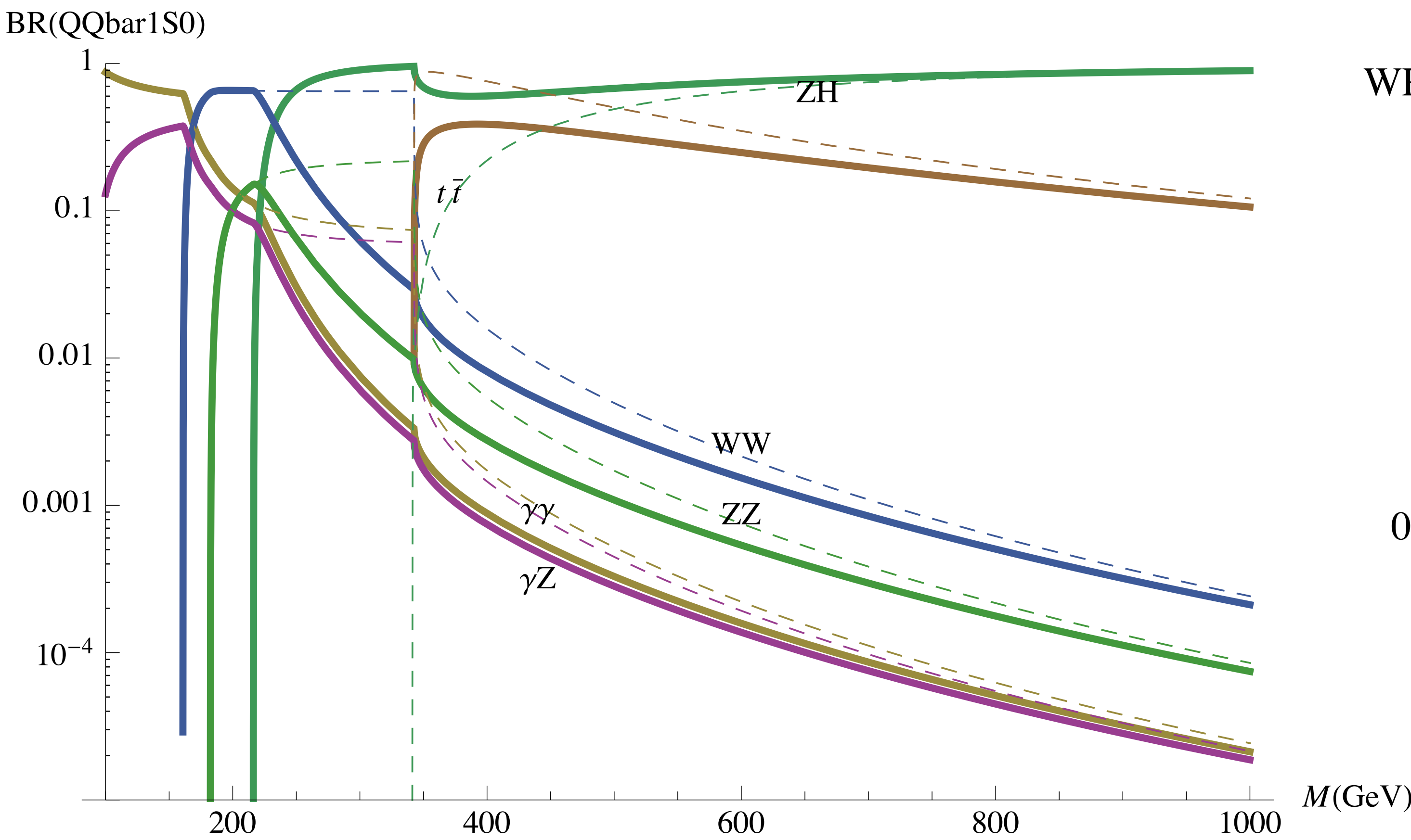
Kang, Luty (2008)

One interesting class of quirky theories have "chiral" quirk masses...

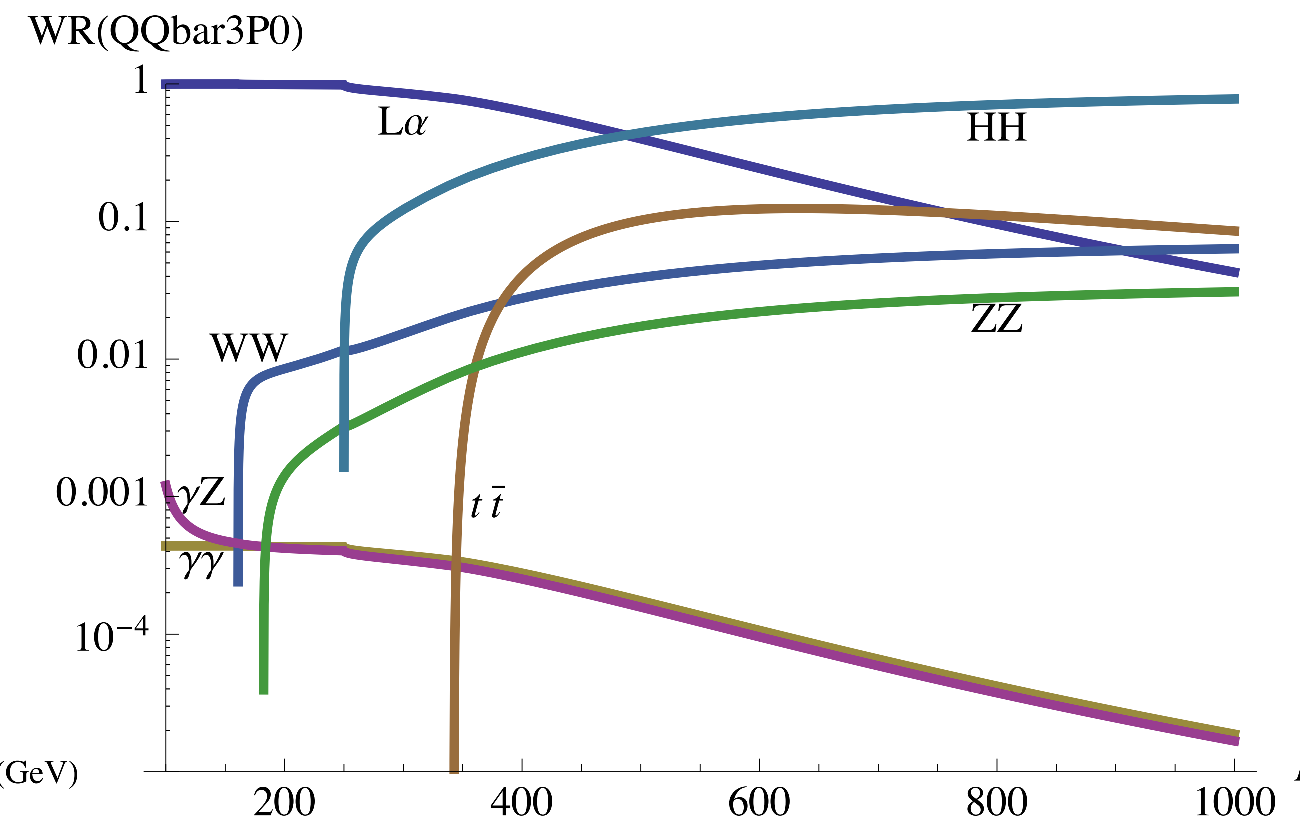
Kribs, Roy, Terning, Zurek (2009)

Fok, Kribs (2011)

(Chiral) Quirkonium Annihilation



(a) $^1S_0$



(c) $^3P_0, M_H = 125$ GeV

Fok, Kribs (2011)

Summary

- Higgs in supersymmetric decays remains an exciting probe of several decay scenarios
  - "boosted" h -> bb
  - h -> $\gamma\gamma$ + X

- Single Higgs production well known to be very sensitive to new physics (top loop, $\gamma\gamma$ loop, b & τ couplings)
  -> diHiggs production also very sensitive new physics

- 1 or 2 Higgs in annihilation of quirkonium & stoponium
  - signal appears precisely in the traditionally difficult "compressed-wedge" window