# A Swarm of Bs – arxiv:1402.4481

Jared A. Evans

jaredaevans@gmail.com

New High Energy Theory Center
Department of Physics and Astronomy
Rutgers University

# Point of this talk

- To highlight a gap in existing LHC coverage
- To show a variety of new physics models that could live in the gap
- To present a *simple*, asymmetric study that could fill the gap
  - Asymmetric $=$ separate exclusion and discovery methods

# Point of this talk

- To highlight a gap in existing LHC coverage
- To show a variety of new physics models that could live in the gap
- To present a *simple*, asymmetric study that could fill the gap
  - Asymmetric $=$ separate exclusion and discovery methods

GAP: All-hadronic final states with many, many $b$-jets without $\not{E}_T$ or $\ell$s

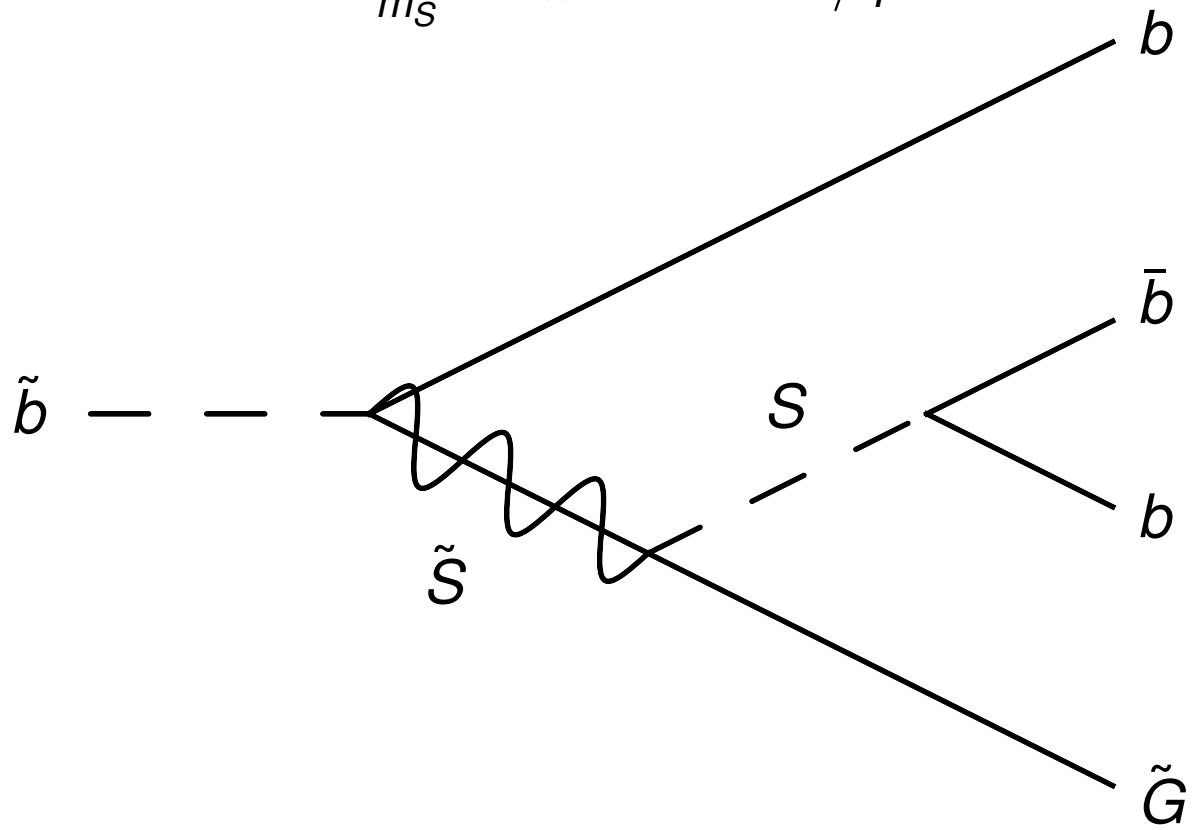
**New physics can hide in high $b$-jet multiplicity final states!**

# High $b$-jet multiplicity

## A Stealth SUSY Example

$$\tilde{b} \to b\tilde{S} \to bS\tilde{G} \to b(b\bar{b})\tilde{G}$$

If $\frac{m_{\tilde{S}} - m_S}{m_S} \ll 1 \Rightarrow$ low $\not{E}_T$



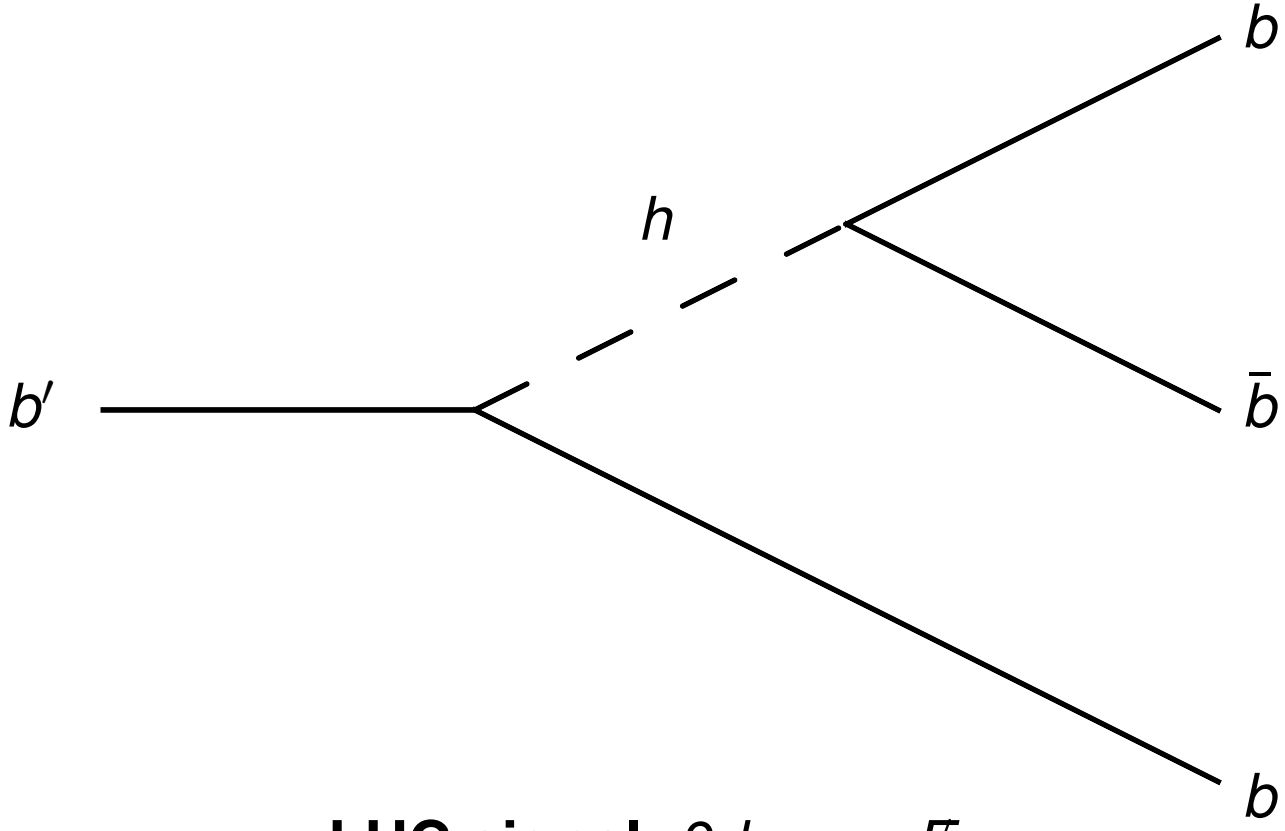

**LHC signal:** 6 $b$s, no $\not{E}_T$

# High $b$-jet multiplicity

## A Fourth Generation Example

$$b' \to bh \to b(b\bar{b})$$

(Only achievable in non-minimal models)



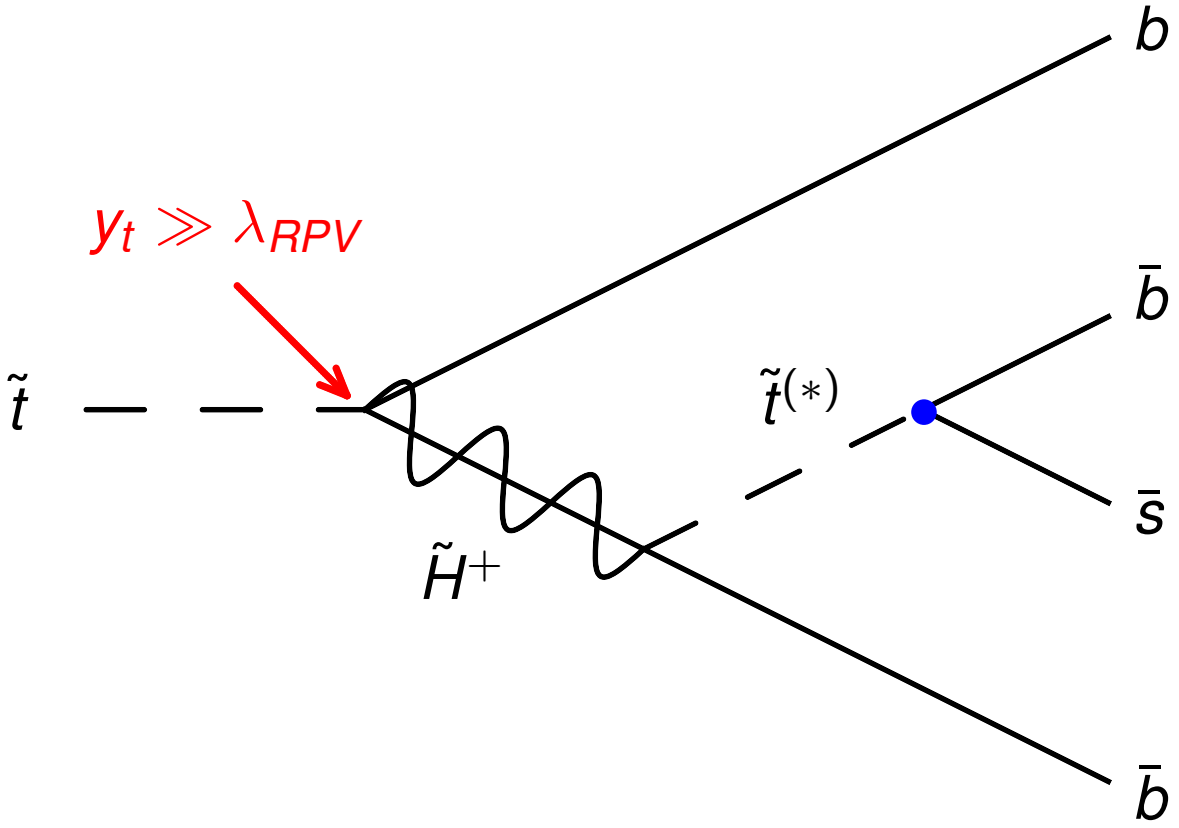

**LHC signal:** 6 $b$s, no $\not{E}_T$

# High $b$-jet multiplicity

## An MFV RPV SUSY Example (focus of this talk)

**UDD323:** $\tilde{t} \to b(\bar{b}\bar{b}j)$

$$\tilde{t} \to b\tilde{H}^+ \to b(\bar{b}\tilde{t}^{(*)}) \xrightarrow{RPV} b\bar{b}\bar{b}j$$




**LHC signal:** 8 jets, 6 $b$s, no $\not{E}_T$ & BR $=$ 100% realistic

# Recast Searches – (no searches with MVA, BDT, Neural Net)

**ATLAS** **CMS**

| Final State | $\sqrt{s}$ | $\mathcal{L}$ | Reference |
|---|---|---|---|
| $3\ell$+jets+MET | 8 | 13.0 | CONF-2012-151 |
| $3\ell$+MET (old) | 8 | 13.0 | CONF-2012-154 |
| $3\ell$+MET | 8 | 20.7 | CONF-2013-035 |
| $4\ell$ (old) | 8 | 13.0 | CONF-2012-153 |
| $4\ell$+MET | 8 | 20.7 | CONF-2013-036 |
| 3-$4\ell$ | 8 | 19.5 | PAS-SUS-13-003 |
| $3\ell$ | 8 | 19.5 | PAS-SUS-13-008 |
| $4\ell$ | 8 | 19.5 | PAS-SUS-13-010 |
| $b'$ ($3\ell$) | 7 | 4.9 | arXiv:1204.1088 |
| $3\ell$ | 7 | 1.02 | CONF-2011-158 |
| $4\ell$ | 7 | 1.02 | CONF-2011-144 |
| $3\ell$+MET | 7 | 2.06 | arXiv:1204.5638 |
| $3\ell$+MET | 7 | 4.7 | arXiv:1208.3144 |
| $4\ell$+MET | 7 | 2.06 | CONF-2012-001 |
| 3-$4\ell$ | 7 | 4.98 | arXiv:1204.5341 |
| SS DIL+MET | 8 | 5.8 | CONF-2012-105 |
| SS DIL w/$b$ (SUSY) | 8 | 20.7 | CONF-2013-007 |
| SS DIL w/$b$ (Exo.) | 8 | 14.3 | CONF-2013-051 |
| SS DIL w/$b$ | 8 | 10.5 | arXiv:1212.6194 |
| SS DIL | 8 | 19.5 | PAS-SUS-13-013 |
| $t'$ (SS DIL) | 8 | 19.6 | PAS-B2G-13-015 |
| SS DIL | 7 | 4.98 | arXiv:1205.6615 |
| SS DIL w/$b$ | 7 | 4.98 | arXiv:1205.3933 |
| SSSF DIL | 7 | 4.98 | arXiv:1207.6079 |
| SSSF DIL | 7 | 1.6 | arXiv:1201.1091 |
| SS DIL | 7 | 4.7 | arXiv:1210.4538 |
| SS DIL+jets+MET | 7 | 2.05 | arXiv:1203.5763 |
| SS DIL+MET | 7 | 1.04 | arXiv:1110.6189 |
| $b'$ (SS DIL) | 7 | 4.7 | CONF-2012-130 |
| $b'$ (SS DIL) | 7 | 4.9 | arXiv:1204.1088 |

| Final State | $\sqrt{s}$ | $\mathcal{L}$ | Reference |
|---|---|---|---|
| $t'$ (OS DIL) | 8 | 19.6 | PAS-B2G-13-015 |
| OS DIL+MET | 7 | 1.04 | arXiv:1110.6189 |
| OS DIL+jets+MET | 7 | 4.7 | arXiv:1208.4688 |
| OS DIL+MET | 7 | 4.98 | arXiv:1206.3949 |
| leptonic $m_{T2}$ | 7 | 4.7 | arXiv:1209.4186 |
| $Z$+jets+MET | 7 | 4.98 | arXiv:1204.3774 |
| $Z$+jets+MET | 7 | 2.05 | arXiv:1204.6736 |
| $\ell$+jets+MET | 8 | 5.8 | CONF-2012-104 |
| $\ell$+3$b$+jets+MET | 8 | 20.1 | CONF-2013-061 |
| $\ell$+$b$+6$j$+MET | 8 | 19.4 | PAS-SUS-13-007 |
| $\ell$+7$j$+MET | 7 | 4.7 | CONF-2012-140 |
| $\ell$+jets+MET | 7 | 4.7 | PAS-SUS-12-010 |
| $\ell$+jets+MET | 7 | 4.7 | CONF-2012-041 |
| $\ell$+$b$+jets+MET | 7 | 2.05 | arXiv:1203.6193 |
| $\ell$+$b$+jets+MET | 7 | 4.98 | PAS-SUS-11-027 |
| $\ell$+$b$+jets+MET | 7 | 4.98 | PAS-SUS-11-028 |
| $1/2\tau$+jets+MET | 8 | 20.7 | CONF-2013-026 |
| $4\ell$+MET w/$\tau$ | 8 | 20.7 | CONF-2013-036 |
| 3-$4\ell$ w/$\tau$ | 8 | 19.5 | PAS-SUS-13-003 |
| $1/2\tau$+jets+MET | 7 | 4.7 | arXiv:1210.1314 |
| $\tau+\ell$+jets+MET | 7 | 4.7 | arXiv:1210.1314 |
| $\tau$+jets+MET (old) | 7 | 2.05 | CONF-2012-005 |
| $2\tau$+jets+MET (old) | 7 | 2.05 | arXiv:1203.6580 |
| OS DIL+MET w/$\tau$ | 7 | 4.98 | arXiv:1206.3949 |
| SS DIL w/$\tau$ | 7 | 4.98 | arXiv:1205.6615 |
| 3-$4\ell$ w/$1\tau$ | 7 | 4.98 | arXiv:1204.5341 |
| 3-$4\ell$ w/$2\tau$ | 7 | 4.98 | arXiv:1204.5341 |
| $t\bar{t}$ xsec (DIL) | 8 | 2.4 | PAS-TOP-12-007 |
| $t\bar{t}$ xsec (DIL) | 7 | 0.70 | arXiv:1202.4892 |
| $t\bar{t}$ xsec (DIL) | 7 | 2.3 | arXiv:1208.2671 |
| $t\bar{t}$ xsec (DIL w/$\tau$) | 7 | $\sim$ 2 | arXiv:1203.6810 |
| $t\bar{t}$+jet (LJ) | 7 | 5.0 | PAS-EXO-11-056 |
| $t\bar{t}$+$m_T$ (LJ) | 7 | 1.04 | arXiv:1109.4725 |

| Final State | $\sqrt{s}$ | $\mathcal{L}$ | Reference |
|---|---|---|---|
| 2-6 jets+MET | 8 | 20.3 | CONF-2013-047 |
| 2-6 jets+MET (old) | 8 | 5.8 | CONF-2012-109 |
| 7-10 jets+MET w/$b$ | 8 | 20.3 | CONF-2013-054 |
| 7-10 jets+MET w/$M_J^{\Sigma}$ | 8 | 20.3 | CONF-2013-054 |
| 6-9 jets+MET | 8 | 5.8 | CONF-2012-103 |
| jets+MET | 8 | 19.5 | PAS-SUS-13-012 |
| $b$+jets+MET | 8 | 19.4 | arXiv:1305.2390 |
| 3$b$+jets+MET (old) | 8 | 12.8 | CONF-2012-145 |
| 3$b$+jets+MET | 8 | 20.1 | CONF-2013-061 |
| jets w/$\alpha_T$ w/$b$ | 8 | 11.7 | arXiv:1303.2985 |
| monojet+MET | 8 | 19.5 | PAS-EXO-12-048 |
| monojet+MET | 8 | 10.5 | CONF-2012-147 |
| 2-6 jets+MET | 7 | 4.7 | CONF-2012-033 |
| 6-9 jets+MET | 7 | 4.7 | CONF-2012-037 |
| jets+MET | 7 | 4.98 | arXiv:1207.1898 |
| jets+MET (old) | 7 | 1.1 | PAS-SUS-11-004 |
| $b$+jets+MET | 7 | 2.05 | arXiv:1203.6193 |
| $b$+jets+MET | 7 | 4.98 | arXiv:1208.4859 |
| $b$+jets+MET (old) | 7 | 1.1 | PAS-SUS-11-006 |
| 3$b$+jets+MET | 7 | 4.7 | CONF-2012-058 |
| jets w/$\alpha_T$ w/$b$ | 7 | 4.98 | PAS-SUS-11-022 |
| jets w/$\alpha_T$ (old) | 7 | 1.14 | arXiv:1109.2352 |
| $\ell$+$b$+jets (low MET)* | 7 | 5.0 | arXiv:1210.7471 |
| $\ell$+3$b$+jets (low MET) | 8 | 14.3 | CONF-2013-018 |
| 6-7 jets (no MET) | 8 | 20.3 | CONF-2013-091 |
| 6 jets (no MET) | 7 | 4.6 | arXiv:1210.4813 |
| up to 10 objects ("BH") | 8 | 12.1 | arXiv:1303.5338 |
| $(\mu j)(\mu j)$ | 8 | 19.6 | PAS-EXO-12-042 |
| $(\tau b)(\tau b)$ | 7 | 4.8 | PAS-EXO-12-002 |

# MFV RPV Stops

8 jets, 6 of which are $b$s – no $\not{E}_T$, no $\ell$s

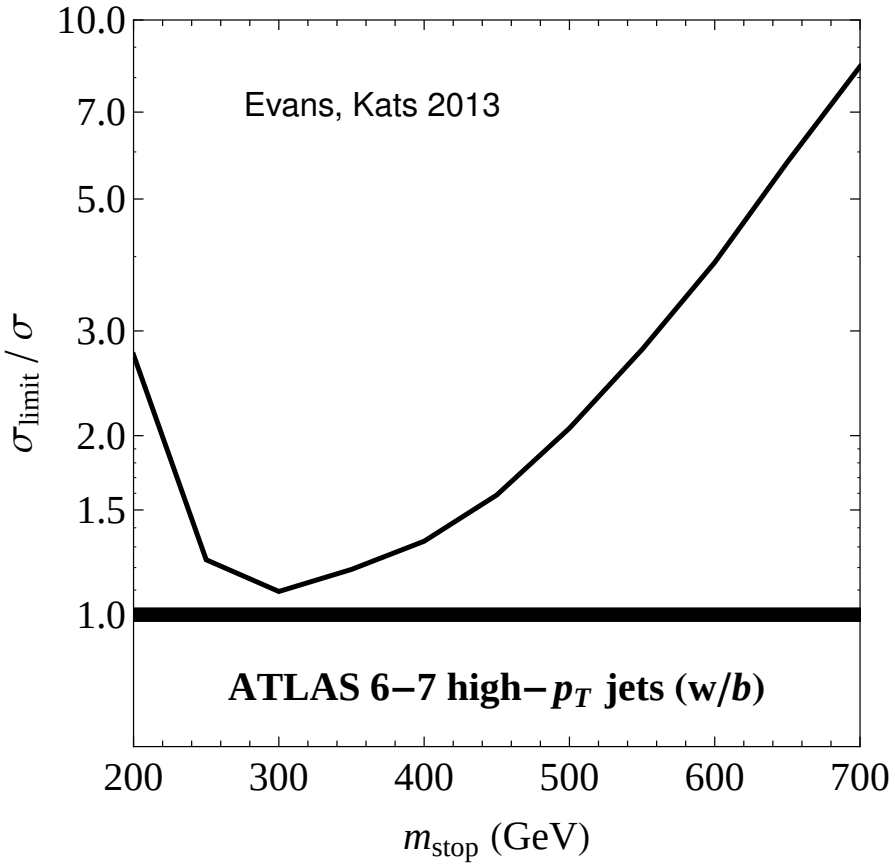
**NO SENSITIVITY!!!**

Atlas 6-7 jets w/ 2 $b$-tags
is close to exclusion

3 $b$-tag bin could set limits now!

**5 $b$-tags could do *MUCH* better**

SM background uncertain
$\Rightarrow$ use asymmetric method



# A swarm of *bs*

## Exclusion

| Preselection Cuts |
|---|
| $H_T(p_T > 40; \lvert\eta\rvert < 2.5) > 750$ GeV |
| No isolated leptons with $p_T > 20$ GeV, $\lvert\eta\rvert < 2.4$ and $I_{rel} < 0.15$ |

| Cuts | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 |
|---|---|---|---|---|---|
| $H_T$ (GeV) | 750 | 1000 | 1250 | 1500 | 1750 |
| $b_{eff}$ (%) | 50 | 60 | | 70 | |
| $c_{eff}$ (%) | 4.0 | 9.0 | | 19 | |
| $j_{eff}$ (%) | 0.07 | 0.30 | | 1.5 | |
| $n_b$ | $\geq 5$ $b$-tagged jets w/ $p_T > 30$ GeV and $\lvert\eta\rvert < 2.5$ | | | | |

| Backgrounds | K-factor | # events in 20 fb$^{-1}$ at 8 TeV | | | | |
|---|---|---|---|---|---|---|
| | | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 |
| $b\bar{b}b\bar{b} + \{\text{jets}\}$ | 3 | 5.3 | 4.3 | 1.3 | 1.4 | 0.5 |
| $b\bar{b}b\bar{b}b\bar{b}$ | 3 | 0.5 | 0.2 | $< 0.1$ | $< 0.1$ | $< 0.1$ |
| $b\bar{b}b\bar{b}c\bar{c}$ | 3 | 0.1 | 0.1 | $< 0.1$ | $< 0.1$ | $< 0.1$ |
| $t\bar{t}b\bar{b}$ | – | 0.9 | 1.3 | 0.5 | 0.7 | 0.3 |
| Total | | **6.8** | **5.9** | **1.9** | **2.1** | **0.7** |

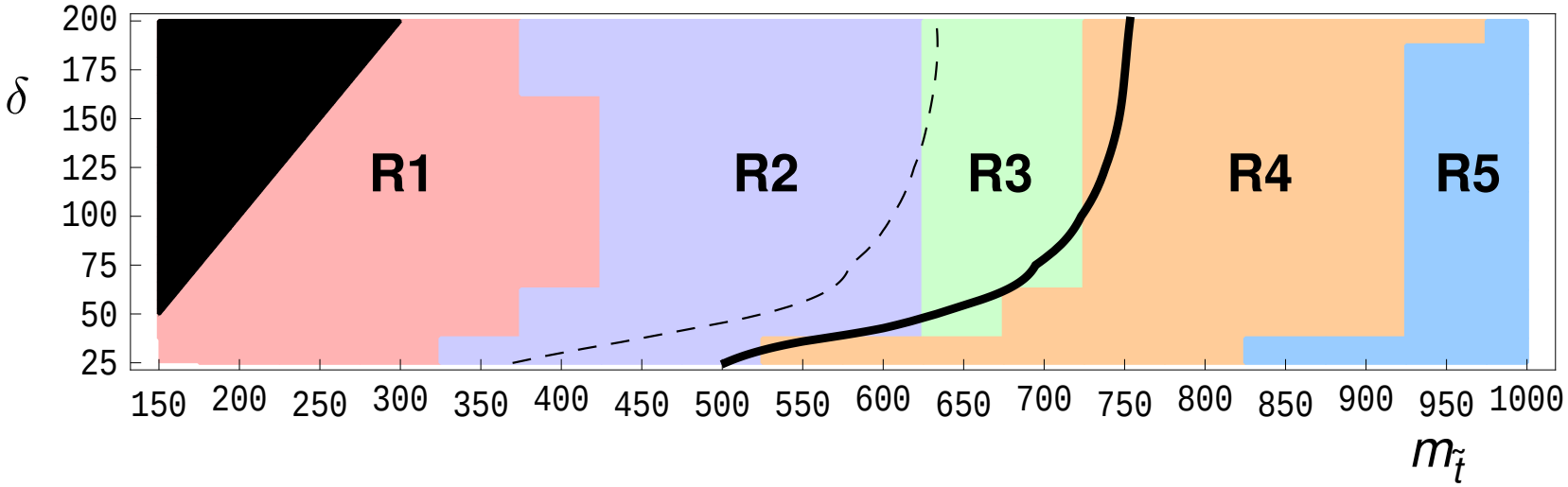
| Signal | | # events in 20 fb$^{-1}$ at 8 TeV | | | | |
|---|---|---|---|---|---|---|
| $m_{\tilde{t}}$ (GeV) | $m_{\tilde{\chi}^\pm}$ (GeV) | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 |
| 150 | 100 | **63.7** | 18.3 | 5.1 | 3.9 | 1.3 |
| 300 | 200 | **109.5** | 78.0 | 22.2 | 15.9 | 5.1 |
| 500 | 350 | 44.5 | **50.0** | 19.7 | 15.2 | 5.7 |
| 700 | 600 | 6.0 | 12.6 | **8.1** | 7.9 | 3.4 |
| 800 | 600 | 2.7 | 6.1 | 5.1 | **6.0** | 2.9 |
| 900 | 875 | 0.2 | 0.6 | 0.6 | 1.1 | **0.7** |

# A swarm of *bs*

## Exclusion

| Preselection Cuts | | | | | |
|---|---|---|---|---|---|
| $H_T(p_T > 40; \lvert\eta\rvert < 2.5) > 750$ GeV<br>No isolated leptons with $p_T > 20$ GeV, $\lvert\eta\rvert < 2.4$ and $I_{rel} < 0.15$ | | | | | |
| **Cuts** | **Region 1** | **Region 2** | **Region 3** | **Region 4** | **Region 5** |
| $H_T$ (GeV) | 750 | 1000 | 1250 | 1500 | 1750 |
| $b_{eff}$ (%) | 50 | 60 | | 70 | |
| $c_{eff}$ (%) | 4.0 | 9.0 | | 19 | |
| $j_{eff}$ (%) | 0.07 | 0.30 | | 1.5 | |
| $n_b$ | $\geq 5$ *b*-tagged jets w/ $p_T > 30$ GeV and $\lvert\eta\rvert < 2.5$ | | | | |

$m_{\tilde{t}}$ vs. $\delta \equiv m_{\tilde{t}} - m_{\tilde{\chi}^\pm}$




Assume zero background (or $\delta_{bckd} \to \infty$) $\Rightarrow$ conservative limits

# A swarm of *bs*

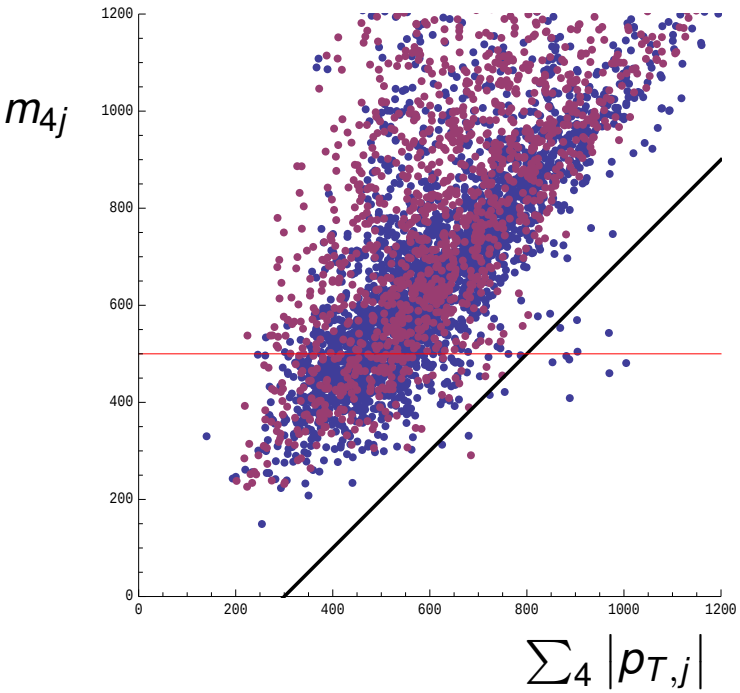
## Discovery

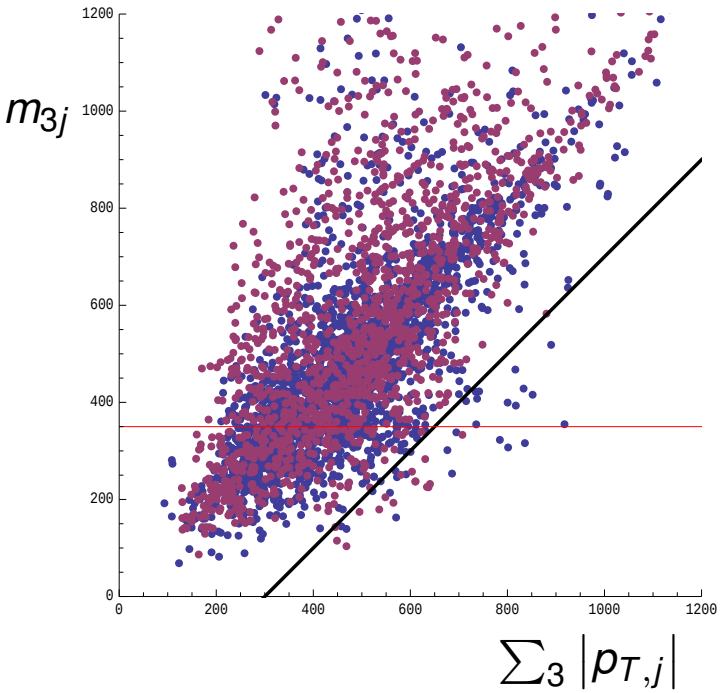
Conservative exclusion method cannot be used for discovery

$$m_{\tilde{t}} = 500 \text{ GeV} \qquad m_{\chi^\pm} = 350 \text{ GeV} \qquad (\mathbf{R2})$$

Use CMS jet ensemble technique

Signal $\sim$ 50 events  Background $\sim$ 5.9 events scaled to 50



# Conclusions

- An array new physics models could be hiding in many *b*-jets

# Conclusions

- An array new physics models could be hiding in many *b*-jets
- MFV RPV stops – a great benchmark for study

# Conclusions

- An array new physics models could be hiding in many *b*-jets
- MFV RPV stops – a great benchmark for study
- This is an outstanding GAP in the LHC *program*

# Conclusions

- An array new physics models could be hiding in many *b*-jets
- MFV RPV stops – a great benchmark for study
- This is an outstanding GAP in the LHC *program*
- Limits could be set now by looking for $\geq 5$ *b*-jets

# Conclusions

- An array new physics models could be hiding in many *b*-jets
- MFV RPV stops – a great benchmark for study
- This is an outstanding GAP in the LHC *program*
- Limits could be set now by looking for $\geq 5$ *b*-jets
- Backgrounds are likely tiny, but very uncertain

# Conclusions

- An array new physics models could be hiding in many *b*-jets
- MFV RPV stops – a great benchmark for study
- This is an outstanding GAP in the LHC *program*
- Limits could be set now by looking for $\geq 5$ *b*-jets
- Backgrounds are likely tiny, but very uncertain
- An asymmetric study can probe this, but someone needs to do it!