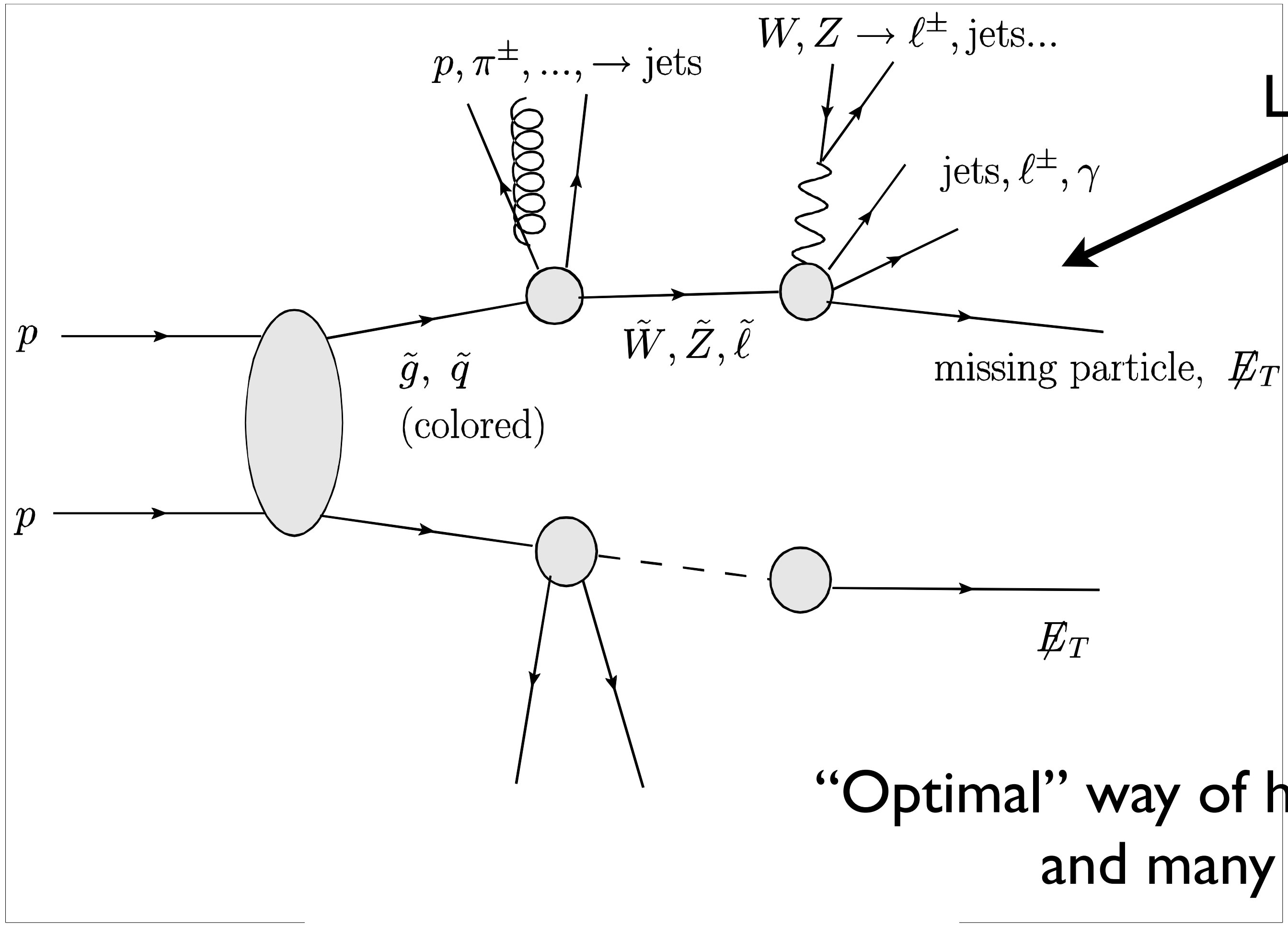
Prospects of BSM Model Discrimination (discovery) inTop Physics

Lian-Tao Wang
University of Chicago

TOP 2011, Sant Feliu de Guixols, Spain

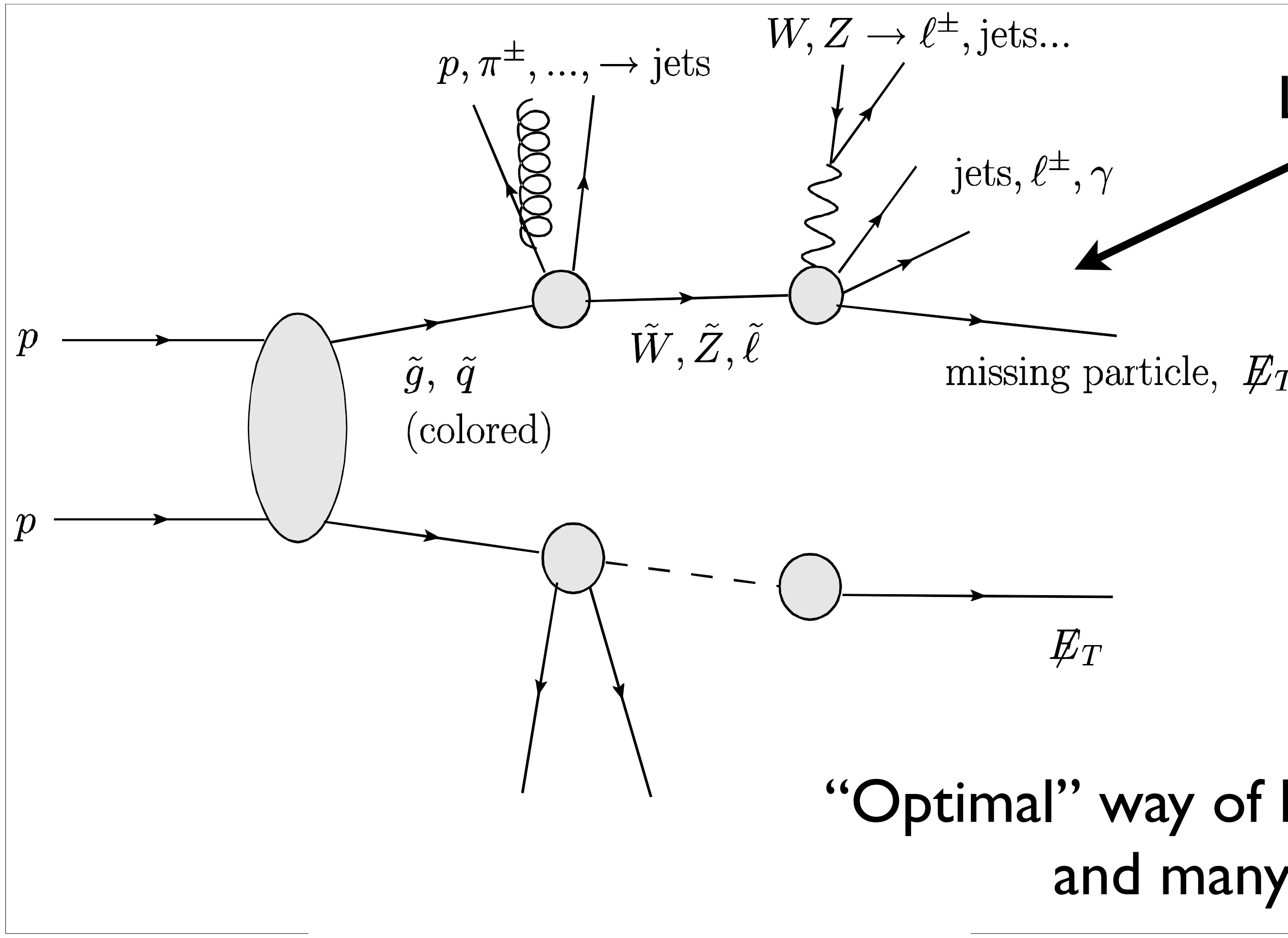
We used to wish



Long Decay chain

“Optimal” way of having both large production rate and many hard final state objects.

We used to wish



Long Decay chain

"Optimal" way of having both large production rate and many hard final state objects.

- "Well known", many studies in the past 2 decades.

- If we are reasonably lucky and partners are not too heavy, this can lead to early discovery.

$$\text{At 7 TeV and 1 fb}^{-1} : \sim 10^3\ \tilde{q} \text{ and } \tilde{g}\ (\sim 500 \text{ GeV})$$

But, Nature may not go out of its way to be kind to us.

But, Nature may not go out of its way to be kind to us.

What's more likely?

But, Nature may not go out of its way to be kind to us.

What's more likely?

New physics in top physics, top rich final states!

Top is special.

- $m_{top} \gg m_{u,d,c,s,b}$.
  - Top compositeness.
- Hierarchy problem and top partner.
  - Example: stop in SUSY, T' in little Higgs, etc.
- Top sector less explored, can always surprise us.
  - Forward backward asymmetry. (CDF and Dzero)
- Top gives unique challenge:
  - e.g., boosted tops Talks by Masetti, Spannowsky

Top is special.

- $m_{top} \gg m_{u,d,c,s,b}$.
  - Top compositeness.
- Hierarchy problem and top partner.
  - Example: stop in SUSY, T′ in little Higgs, etc.
- Top sector less explored, can always surprise us.
  - Forward backward asymmetry. (CDF and Dzero)
- Top gives unique challenge:
  - e.g., boosted tops Talks by Masetti, Spannowsky

Focus of this talk

Additional signals and related studies, see talks by
Aguilar-Saavedra, Delaunay, Holdom, Ko, Parke, Servant, Spannowsky...

In this talk:

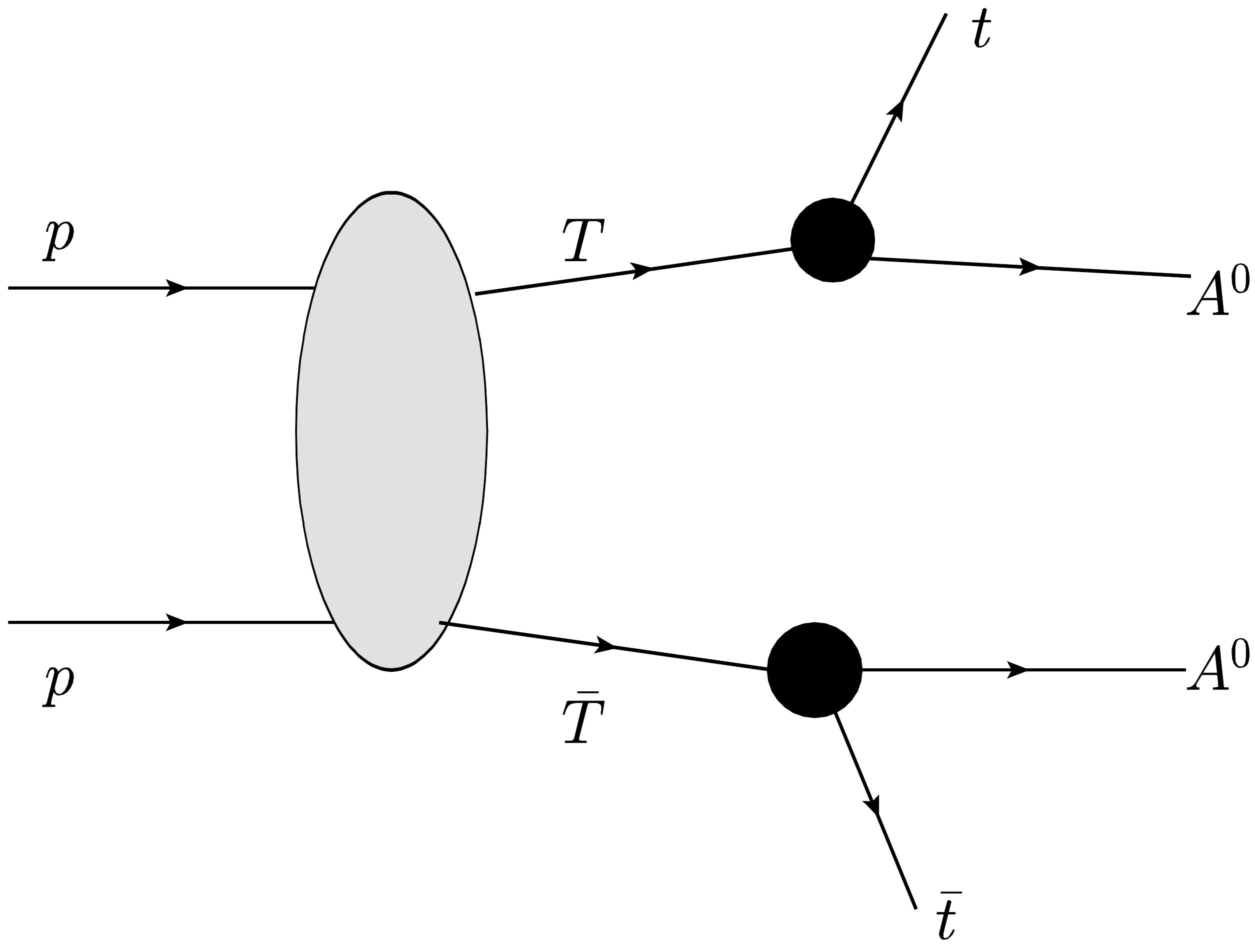
- Top partner
- Top rich channel in SUSY.
- Top AFB and polarization.

Top partner

Top partner.

- Hierarchy problem.
  - The largest contribution: large top-Higgs coupling.
- Introducing top partners.
  - Example: stop in SUSY, T' in little Higgs, etc.
- Another "standard" feature: a discrete parity
  - Good for precision test, flavor, CP.
    - R-parity, KK parity, T parity...
  - Dark matter candidate, lightest stable neutral NP state.

Signal of top partner.



$$t\ \bar{t} + \not{E}_T$$

$T(\bar{T})$ top partner : $\tilde{t},\ t^{\mathrm{KK}},\ t^{\mathrm{T}},\ \ldots$

A^0 missing neutral particle : LSP, LKP, LTP, ...

Search for top partner

- Hadronic channel: $b\bar{b}jjjj$ final states*†.
- We focus on the semi-leptonic channel $b\bar{b}jj\ell\nu$ (cleaner)*

$$pp \to T'\bar{T}' \to t\bar{t}A^0A^0X \to bj_1j_2\ \bar{b}\ell^-\bar{\nu}\ A^0A^0\ X$$

Potential SM backgrounds:

1. $t\bar{t} \to b\bar{b} + jj + \ell\nu$. (Huge rate ~ 800 pb.)
2. $t\bar{t}Z(\to \nu\nu)$ ("irreducible" ~ 1 pb $\sim 10\sigma_{T'\bar{T}'}$ for $M_{T'} \sim 1$ TeV)
3. $W(\to \ell\nu)bbjj$.

We are exploring a variety of kinematical cuts. We also want to understand the dependence of discovery reach on mass spectrum.

*P. Meade and M. Reece, hep-ph/0601124

†S. Matsumoto, M. M. Nojiri and D. Nomura, hep-ph/0612249

*T. Han, R. Mahbubani, D. Walker, LW, arXiv:0803.3820

For more recent studies,
J. Alwall, J. Feng, J. Kumar, S. Su, 1002.3366
T. Plehn, M. Spannowsky, M. Takeuchi, 1006.2833, 1102.0557 (boosted tops)

Top reconstruction as bkgd veto

SM: $t\bar{t} \to b\bar{b} + jj + \ell\nu$

•Using $\not{p}_T$, and $m_\nu = 0$, m_{W}, we can solve for p_ν.

•Remove ambiguity by $m_t^{\mathrm{had}} \sim m_t^{\mathrm{lep}}$, and/or minimizing $|(m_t^{\mathrm{had}}, m_t^{\mathrm{lep}}) - m_t|$.

•m_t^{lep} will have a peak around m_t whose width determined by the resolution.

For signal:

•We will assume (wrongly) that $\not{E}_T$ is from ν, and do the same reconstruction.

•Wrong, (often) complex solutions $\to$ signal!.

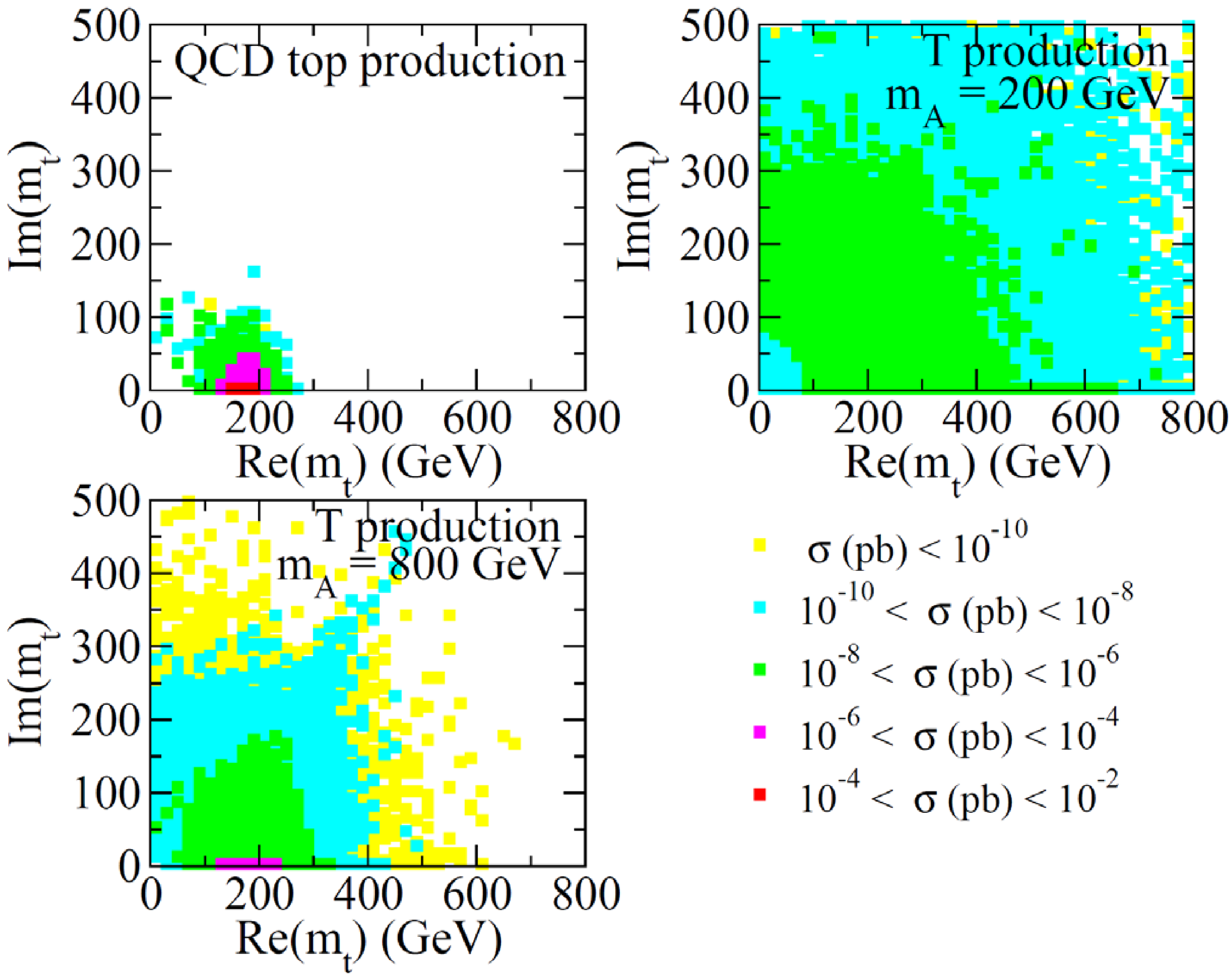
•Reconstruction of m_t^{had}, suppress $Wbbjj$.

Take all $b\bar{b}jj\ell + \not{E}_T$ events.

Reconstruction

Plot, for example, m_t^{lep} on the complex plane

Top reconstruction



Top rich channel in SUSY

The most promising SUSY discovery channel.

Heavy squarks $\tilde{u},\ \tilde{d},\ \ldots$

$\gg$ TeV $\tilde{t},\ \tilde{b}$

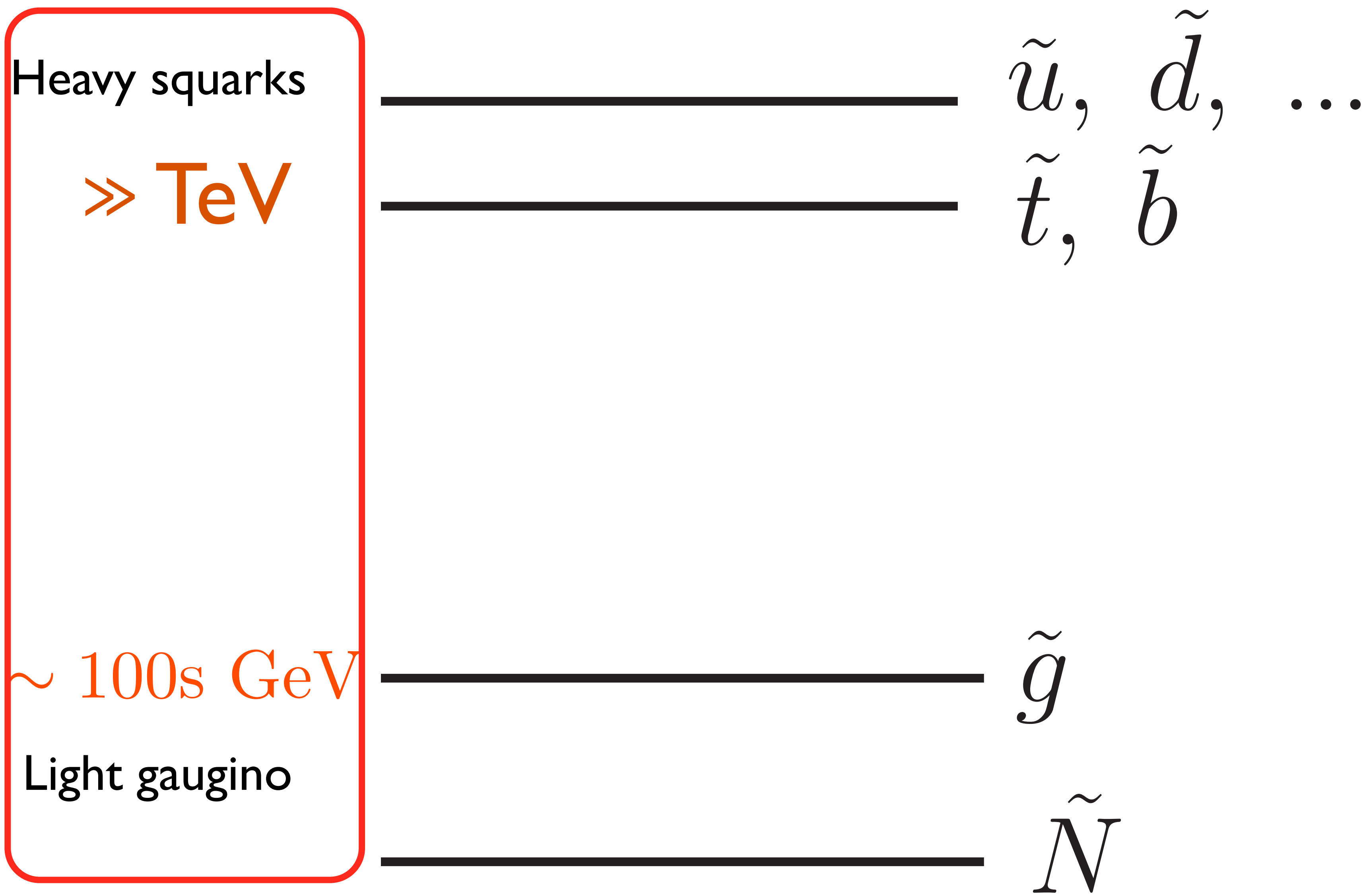
$$m_{\tilde{t},\tilde{b}} < m_{\tilde{u},\tilde{d}}$$

$\sim$ 100s GeV $\tilde{g}$

Light gaugino

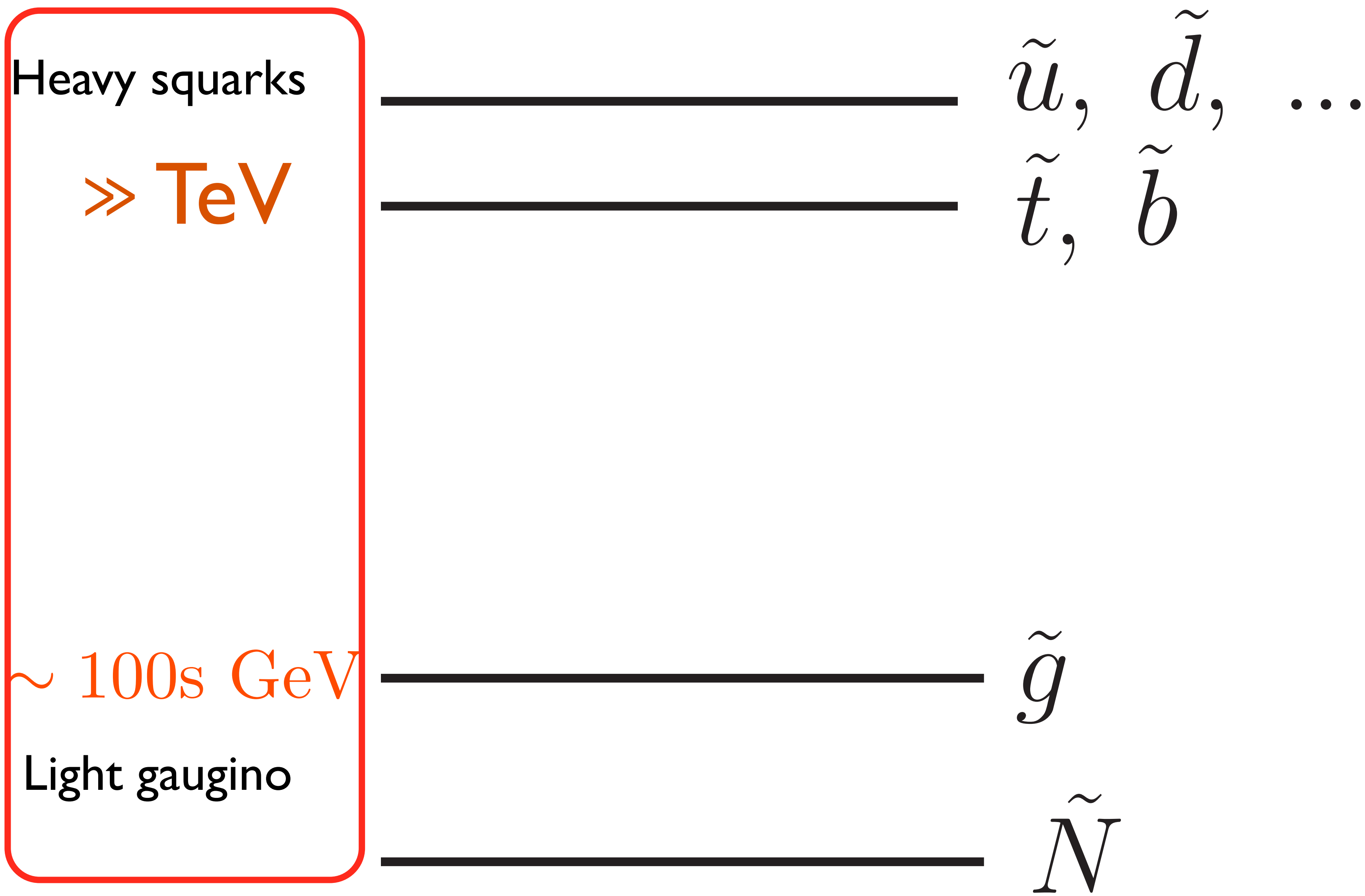
$\tilde{N}$

The most promising SUSY discovery channel.



$$m_{\tilde{t},\tilde{b}} < m_{\tilde{u},\tilde{d}}$$

The most promising SUSY discovery channel.



$$m_{\tilde{t},\tilde{b}} < m_{\tilde{u},\tilde{d}}$$

Why considering heavy scalars?

Why considering heavy scalars?

- On general round, scalar tends to be heavier.
  - From Kahler potential, hard to suppress its couplings to SUSY breaking.
  - R-symmetry tends to protect gaugino mass terms.

Why considering heavy scalars?

- On general round, scalar tends to be heavier.
  - From Kahler potential, hard to suppress its couplings to SUSY breaking.
  - R-symmetry tends to protect gaugino mass terms.
- Examples: F-term SUSY breaking.
  - With R-symmetry broken. But gauginos are sequestered (geometry, etc.) at tree level.
  - Gaugino mass from AMSB.

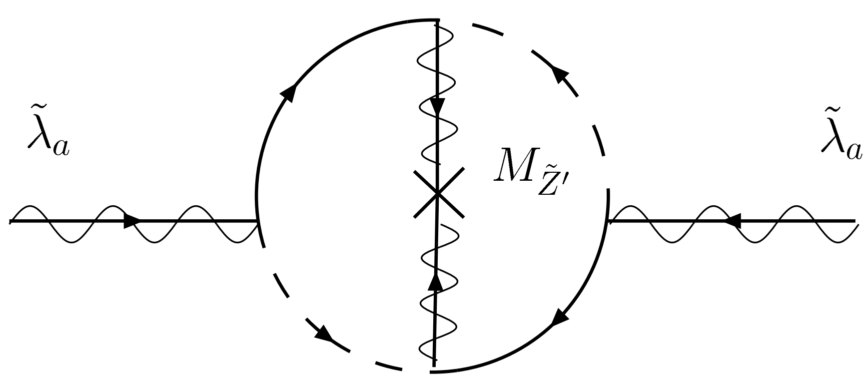
$$m_{\tilde{q},\tilde{\ell}} \sim m_{2/3}, \quad m_{1/2} \sim \frac{1}{16\pi^2} m_{2/3}$$

Zprime-ino mediation.

- Gaugino mediation through an extra U(1)′

$$\int d^2\theta \frac{X}{M} W_{Z'} W_{Z'} \to m_{\tilde{Z}'} = \frac{F_X}{M}$$

$$m^2_{\tilde{q},\tilde{\ell}} \sim \frac{g^2_{Z'}}{16\pi^2} \frac{F^2_X}{M^2}, \quad m^{\rm MSSM}_{1/2} \sim \frac{g^2 g'^2_Z}{(16\pi^2)^2} \frac{F_X}{M}$$



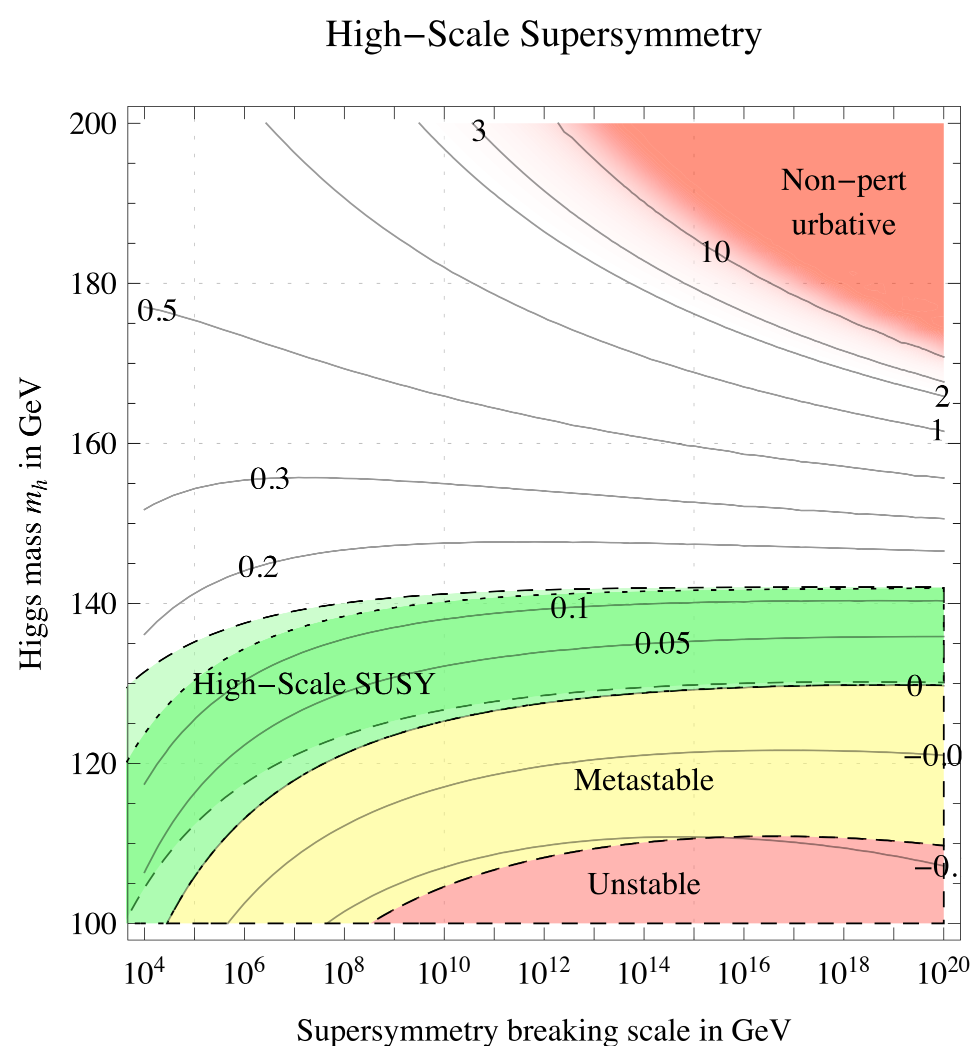
$$\frac{m_{\rm scalar}}{m_{\rm MSSM\ gaugino}} \sim (4\pi)^3$$

Langacker, Paz, LTW, Yavin, 0710.1632,
Verlinde, LTW, Wijnholt, Yavin, 0711.3214

Heavy scalar benefits.

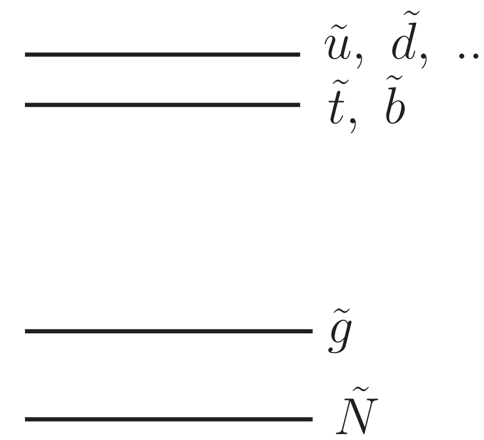
- Better consistency with constraints:
  - flavor, CP: $\propto 1/(16\pi^2\ m^2_{squark})$

- Higgs mass: $\approx m_Z^2 + 3/(2\pi^2)\ |y_t\ m_t|^2\ \log[(m_{stop})/m_t$



Giudice and Strumia, 1108.6077

3rd vs first two generations



- RGE.

$$\frac{dm^2_{\tilde{t},\tilde{b}}}{dt} = \frac{1}{16\pi^2}|y_{t,b}|^2(m^2_{H_{u,d}} + m^2_{Q_3} + m^2_{\tilde{t}_R,\tilde{b}_R}) + \boxed{....}$$

same as 1, 2 gen.

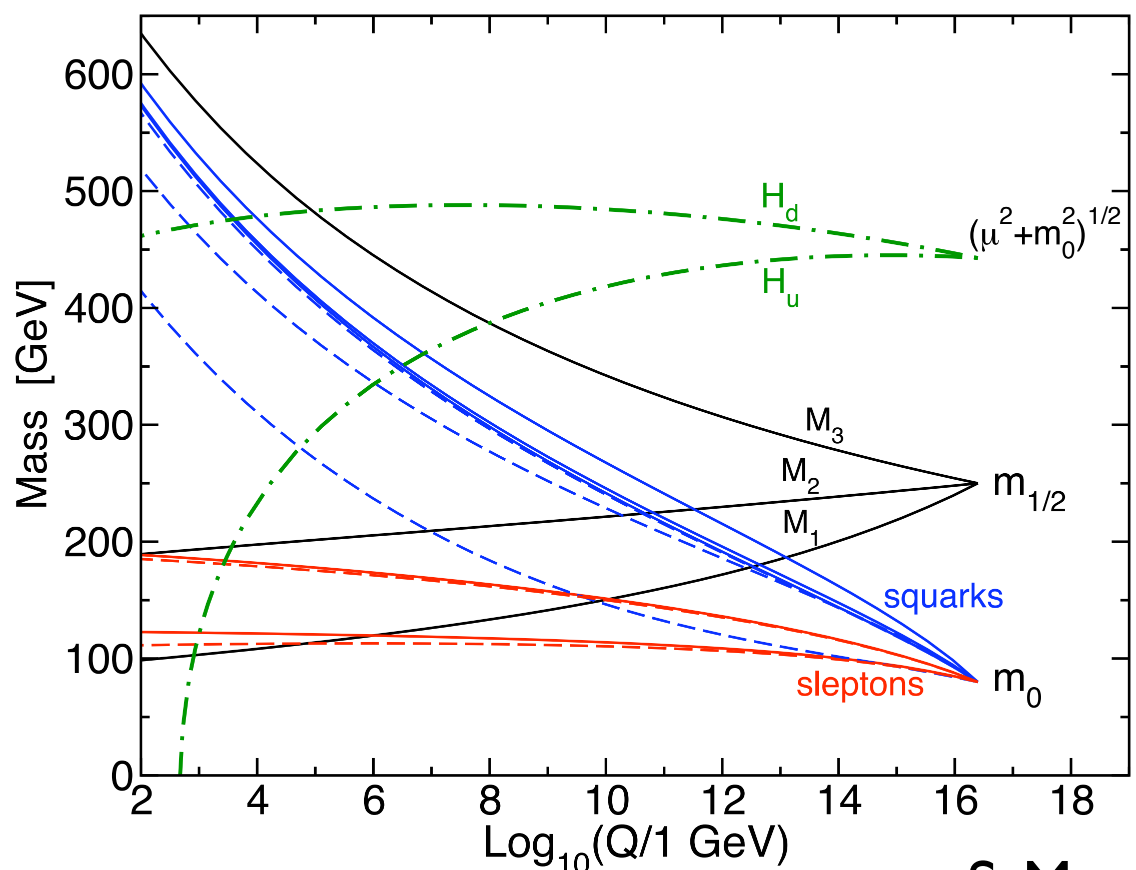
3rd vs first two generations

$$\tilde{u},\ \tilde{d},\ \ldots$$
$$\tilde{t},\ \tilde{b}$$
$$\tilde{g}$$
$$\tilde{N}$$

- RGE.

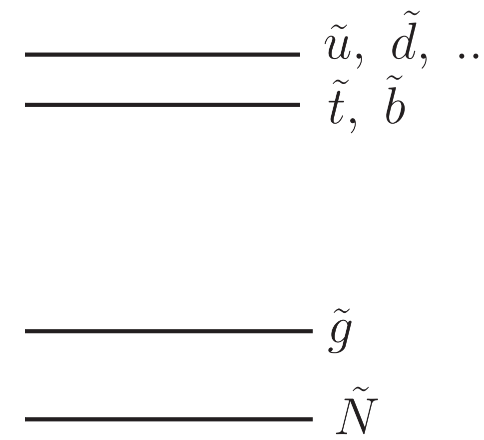
$$\frac{dm^2_{\tilde{t},\tilde{b}}}{dt} = \frac{1}{16\pi^2}|y_{t,b}|^2(m^2_{H_{u,d}} + m^2_{Q_3} + m^2_{\tilde{t}_R,\tilde{b}_R}) + \boxed{\ldots.}$$

same as 1, 2 gen.



S. Martin

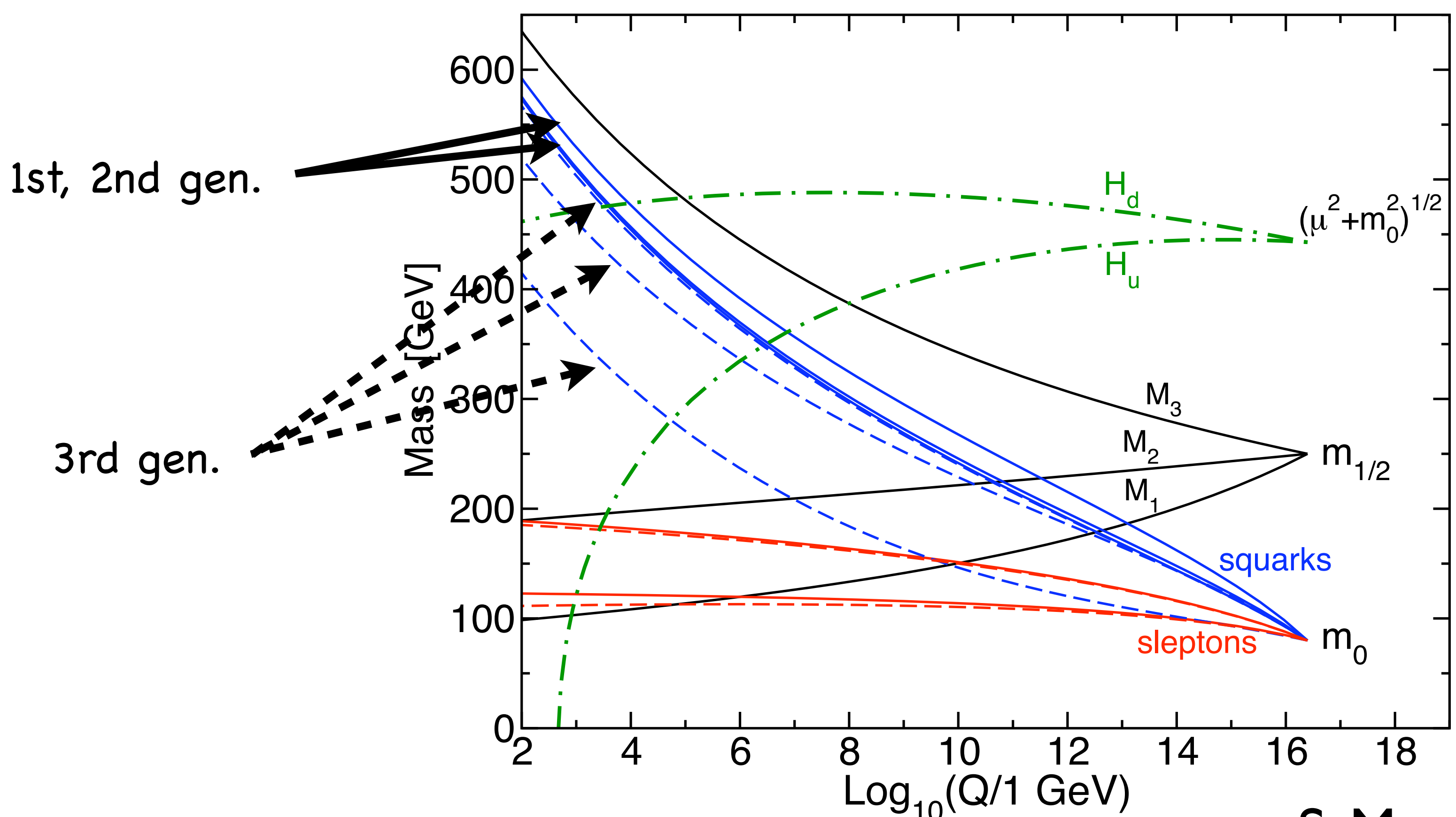
3rd vs first two generations



- RGE.

$$\frac{dm^2_{\tilde{t},\tilde{b}}}{dt} = \frac{1}{16\pi^2}|y_{t,b}|^2(m^2_{H_{u,d}} + m^2_{Q_3} + m^2_{\tilde{t}_R,\tilde{b}_R}) + \boxed{....}$$

same as 1, 2 gen.

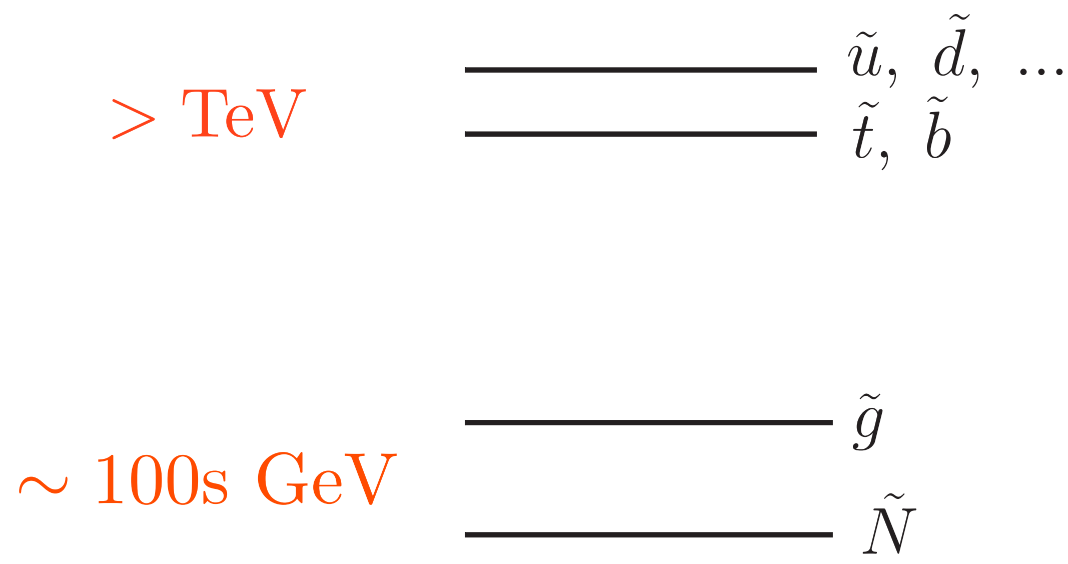


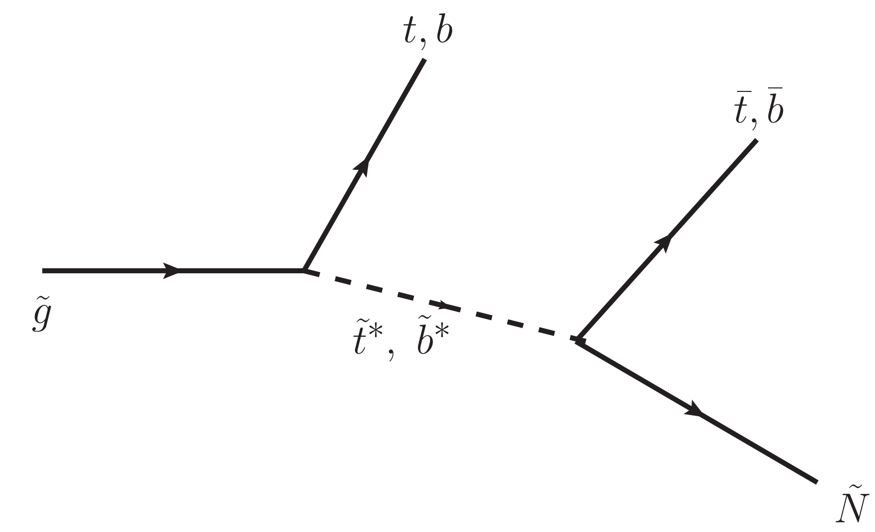
S. Martin

Recent Models

- Langacker, Paz, LTW, Yavin, 0710.1632
- Verlinde, LTW, Wijnholt, Yavin, 0711.3214
- Acharya, Bobkov, Kane, Kumar, 0801.0478
- Nakamura, Okumura, Yamaguchi, 0803.3725
- Everett, Kim, Ouyang, Zurek, 0806.2330
- Hackman, Vafa, 0809.3452
- Sundrum, 0909.5430
- Barbieri, Bertuzzo, Farina, Lodone, Rappadopulo, 1004.2256

A promising, and complicated, scenario.





The Dominant channel

$$p\, p \to \tilde{g}\tilde{g} \to t\bar{t}t\bar{t}(\text{or } t\bar{t}b\bar{b},\ t\bar{t}t\bar{b}\ \ldots)$$

$$\tilde{g} \to t\bar{t}(b\bar{b}) + \tilde{N},\ \text{or}\ \ t\bar{b} + \tilde{C}^- \quad t \to b\ell^+\nu$$

- Multiple b, multiple lepton final state.
  - Good early discovery potential.
  - Challenging to interpret: top reconstruction difficult.

Our study.

Benchmark models

	Branching ratios		
	$\tilde{g} \to t\bar{t}\chi_1^0$	$\tilde{g} \to b\bar{b}\chi_1^0$	$\tilde{g} \to t\bar{b}\chi_1^+ + h.c.$
A	1	0	0
B	0.5	0.5	0
C	.08	0.22	0.7

Simulation: Madgraph + pythia6 + PGS

Event selection:

$$\not{E}_T > 100 \;\; \mathrm{GeV}$$

$$\textit{cut-1} : n_j(p_T \geq 50\,\mathrm{GeV}) \geq 4$$
$$\textit{cut-2} : n_j(p_T \geq 30\,\mathrm{GeV}) \geq 4$$

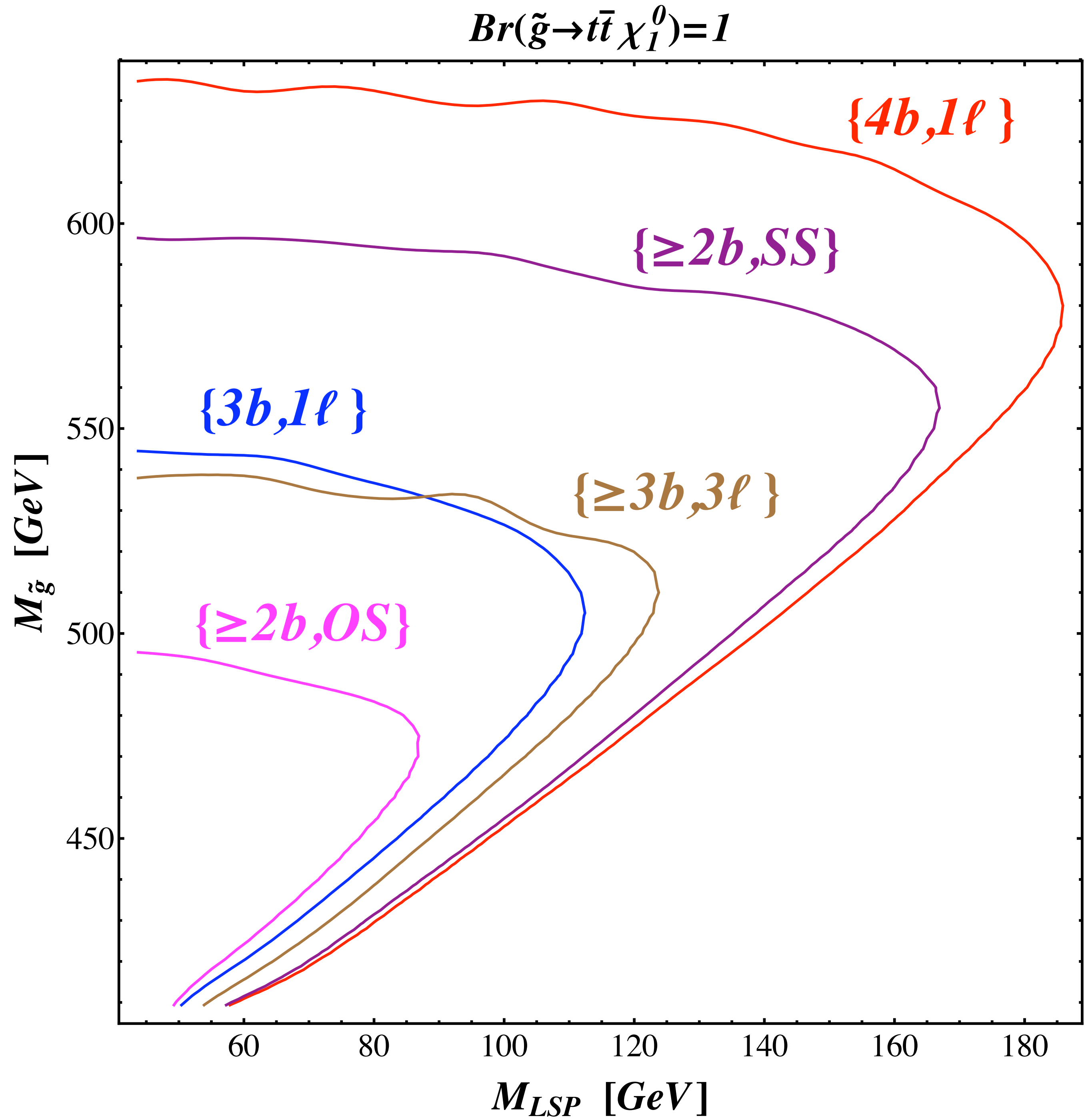
Winning by rate and multiplicity.

Process	σ [fb]	σ_{L1}[fb]	σ_1[fb]	σ_2[fb]
$b\bar{b} + \gamma/Z + \text{jets}$	4.69×10^5	1.41×10^4	34.0	107.8
$b\bar{b} + W^\pm + \text{jets}$	2.41×10^4	5.39×10^2	7.71	13.3
$t\bar{t} + \gamma/Z + \text{jets}$	1.54×10^3	7.69×10^2	42.3	95.4
$t\bar{t} + W^\pm + \text{jets}$	2.25×10^2	1.31×10^2	14.3	27.6
$t\bar{b} + \gamma/Z + \text{jets} + h.c.$	1.34×10^3	8.09×10^2	7.37	26.6
$b\bar{b} + VV + \text{jets}$	1.14×10^3	2.33×10^2	1.45	3.94
$t\bar{t} + \text{jets}$	1.60×10^5	6.60×10^4	2076.7	5905.6
$VV + \text{jets}$	1.03×10^5	1.03×10^5	108.6	377.7
Model A	1.19×10^3	9.48×10^2	403.8	508.1
Model B	1.19×10^3	1.03×10^3	505.2	703.1
Model C	1.19×10^3	5.80×10^2	300.5	420.5

$$\textit{cut-1} : n_j(p_T \geq 50\,\text{GeV}) \geq 4$$

$$\textit{cut-2} : n_j(p_T \geq 30\,\text{GeV}) \geq 4$$

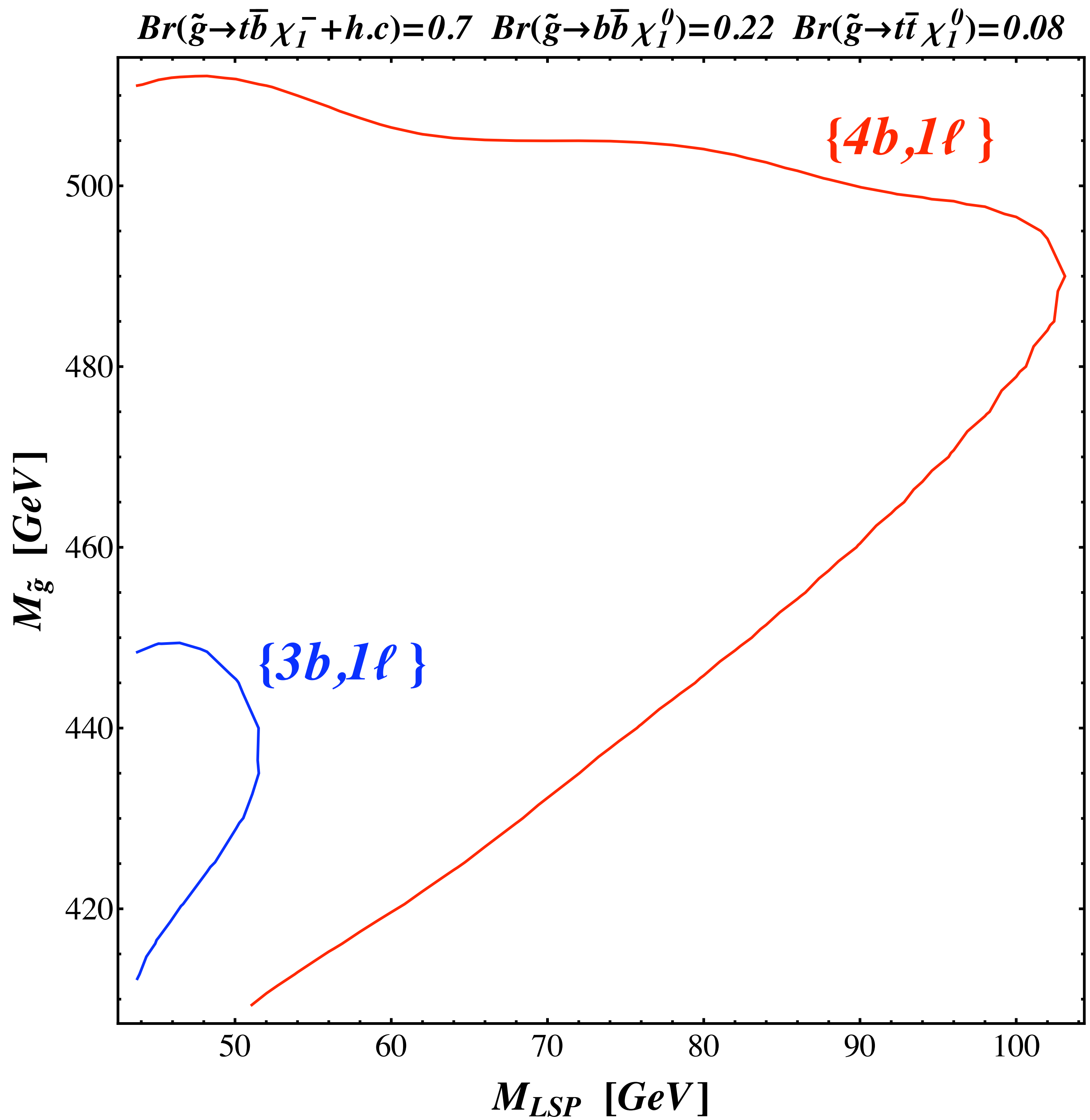
Reach at 7 TeV and one inverse fb.

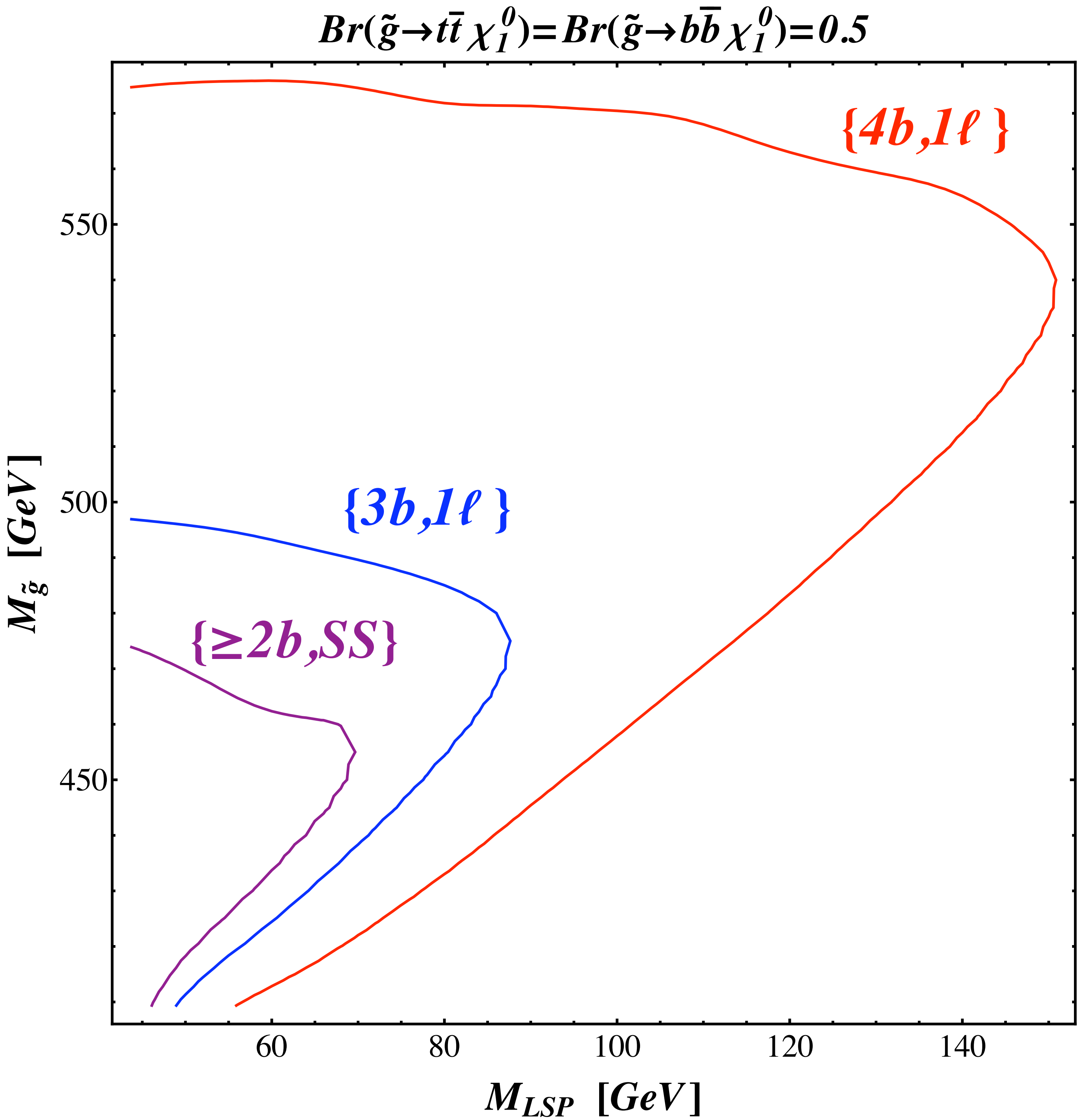


Important:
High b-multiplicity, leptons

Kane, Kuflik, Lu and LTW, 1101.1963

Reach at 7 TeV and one inverse fb:



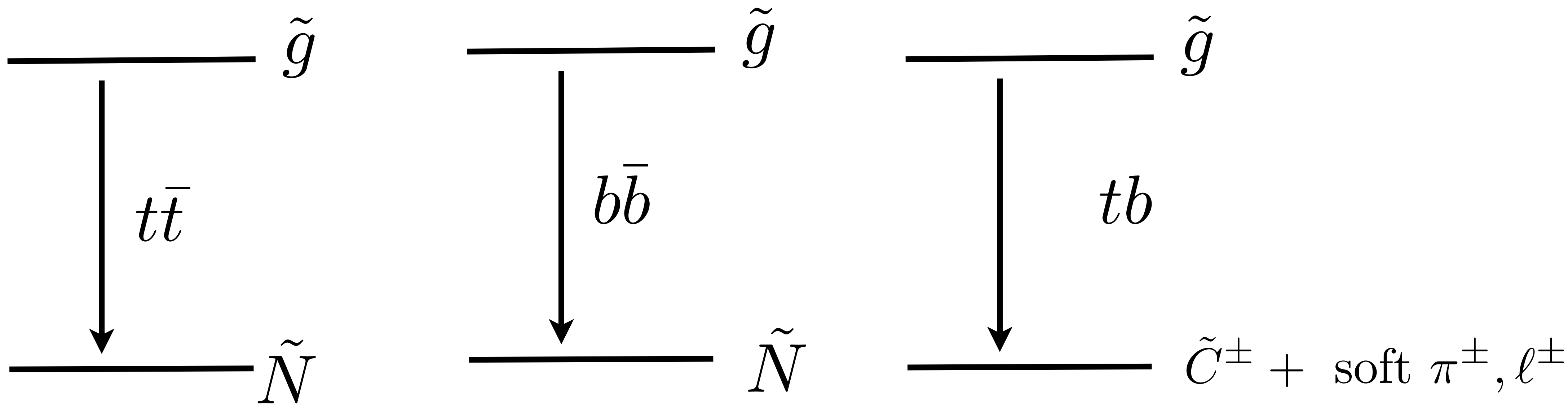


$Br(\tilde{g}\to t\bar{t}\,\chi_1^0)=Br(\tilde{g}\to b\bar{b}\,\chi_1^0)=0.5$
{4b,1ℓ }
{3b,1ℓ }
{≥2b,SS}
550
500
450
60
80
100
120
140
$M_{\tilde{g}}$ [GeV]
M_{LSP} [GeV]

Can we understand what's going on?

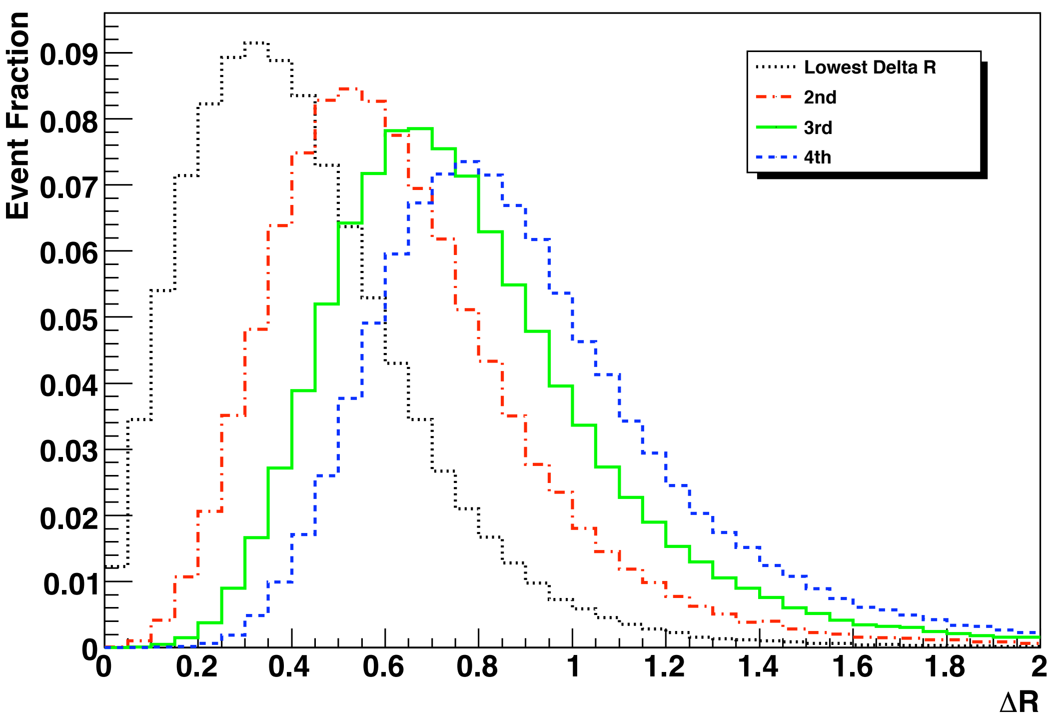
- bs and leptons, MET → tops?

- Several possibilities.

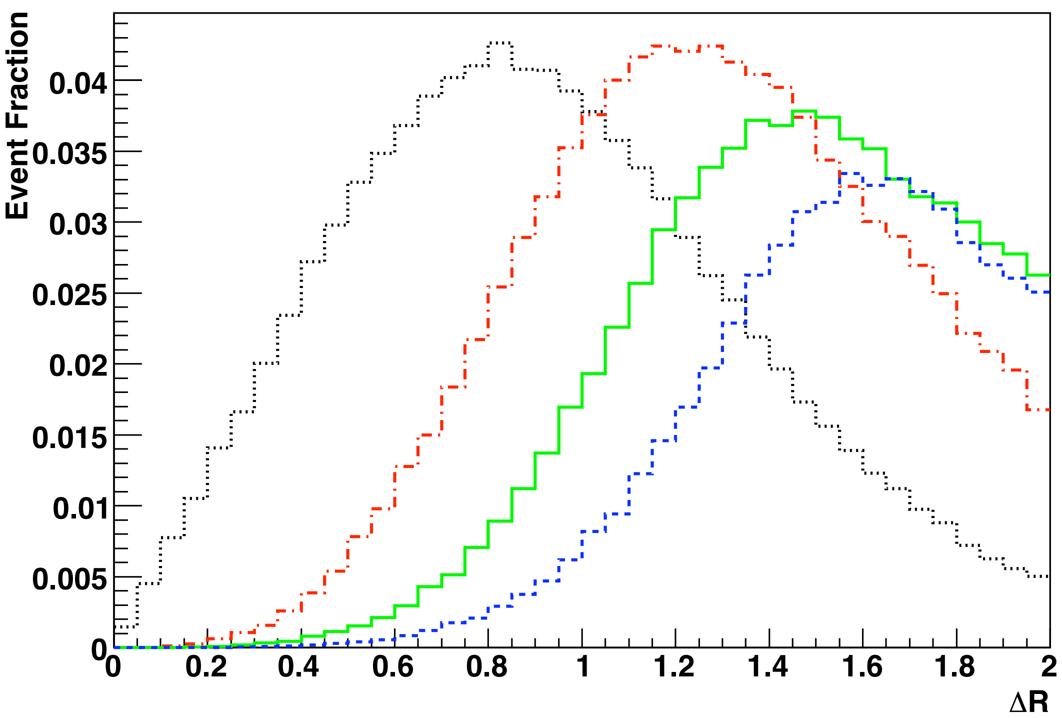


- Careful reconstruction?
  - Possible, but probably requires large statistics.

Direct reconstruction.

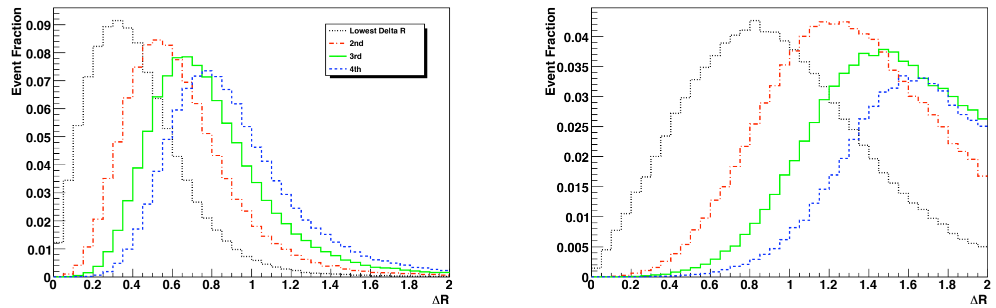


(a)

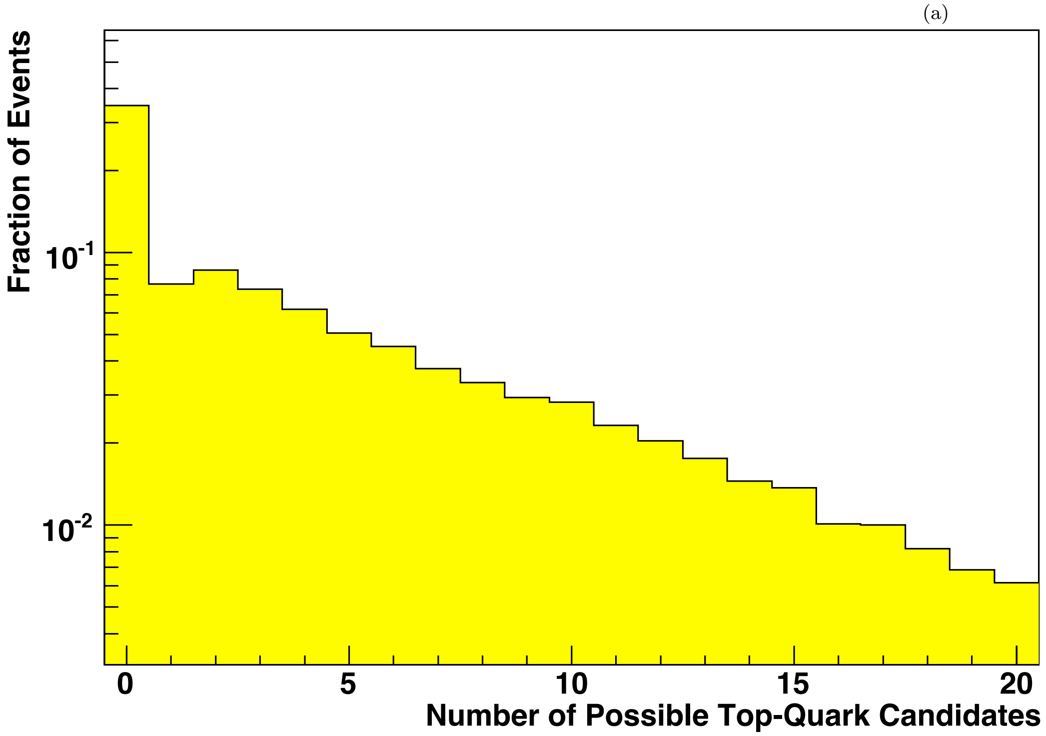


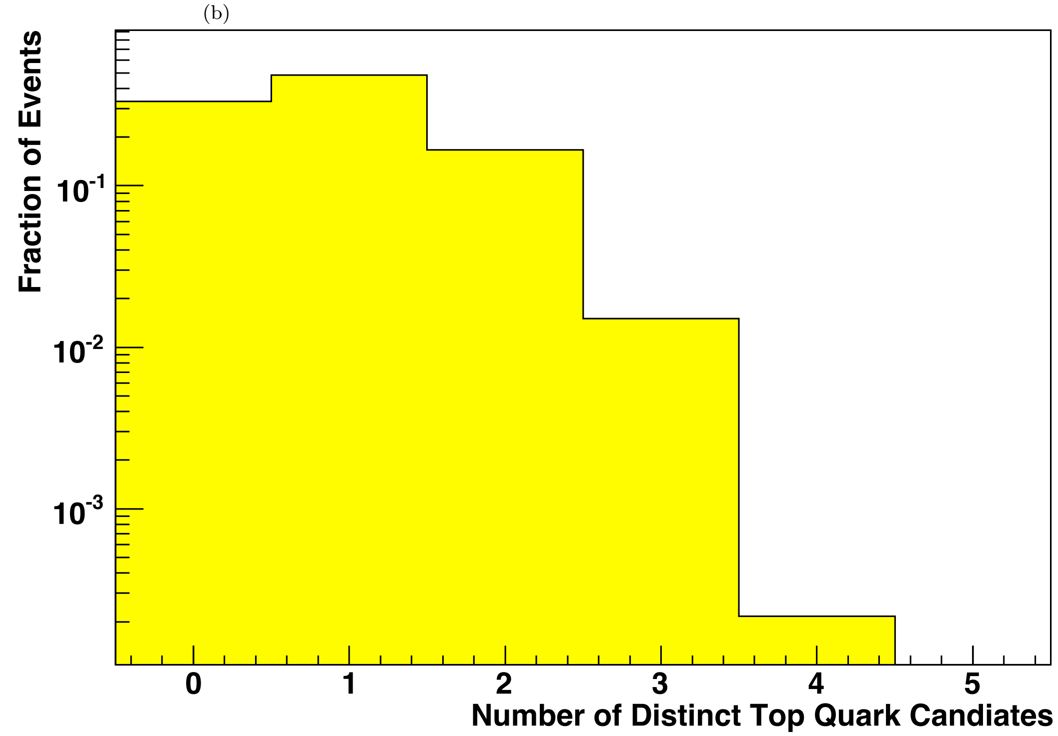
(b)

Direct reconstruction.



(a) (b)





Similar results obtained with more sophisticated reconstruction: Gregoire, Katz, Sanz, 1101.1294

A fitting method.

- Assuming 3 underlying topologies.
  - Each topology predict different multiplicities of leptons.
  - Generate events for each topology, used as templates.
- Treating the branching ratios as free parameters.
- Fit the templates to the final signature counts to figure out the the branching ratios.

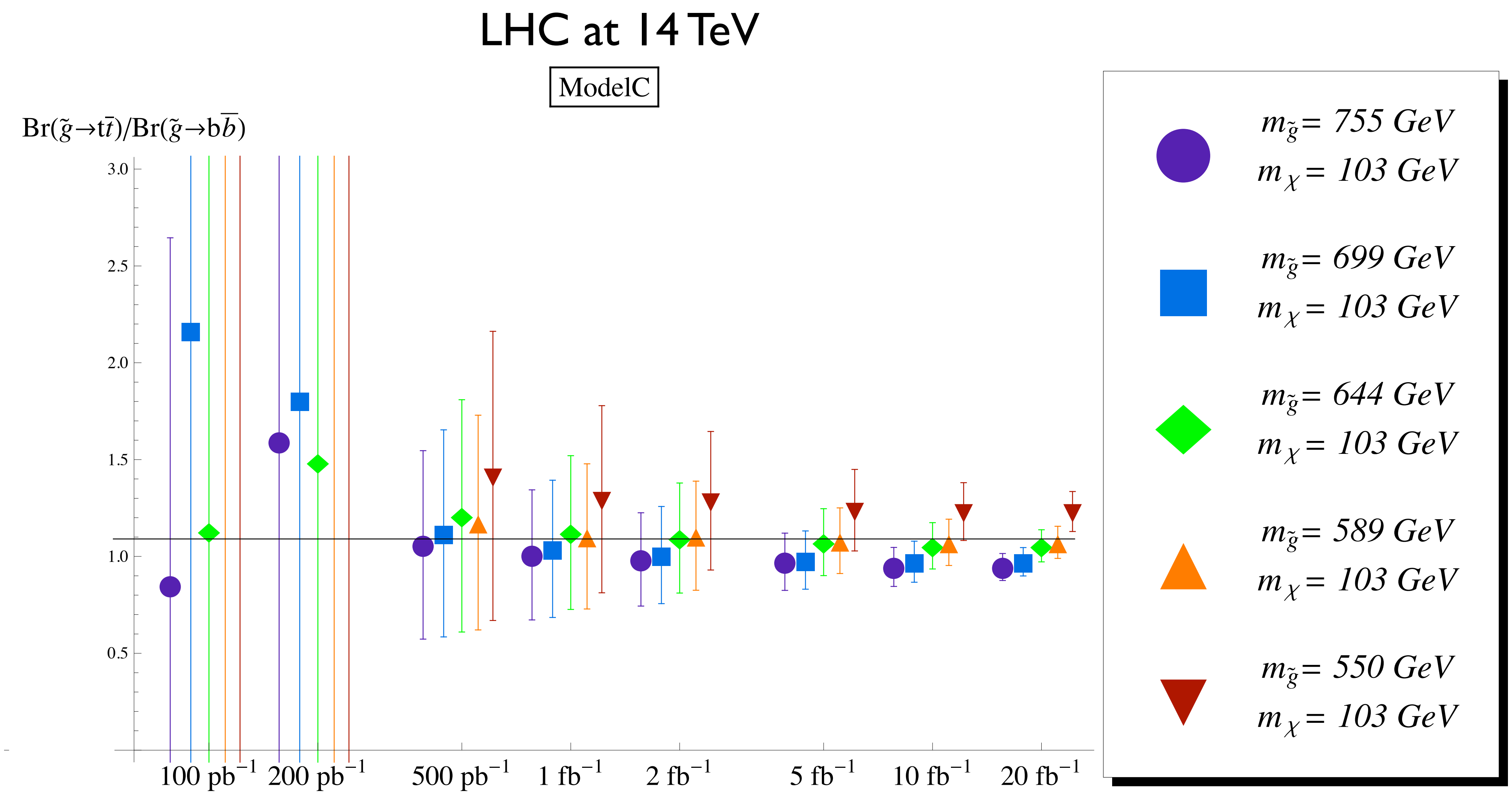
Acharya, Grajek, Kane, Kuflik, Suruliz, LTW, 0901.3367

Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

Testing this idea.

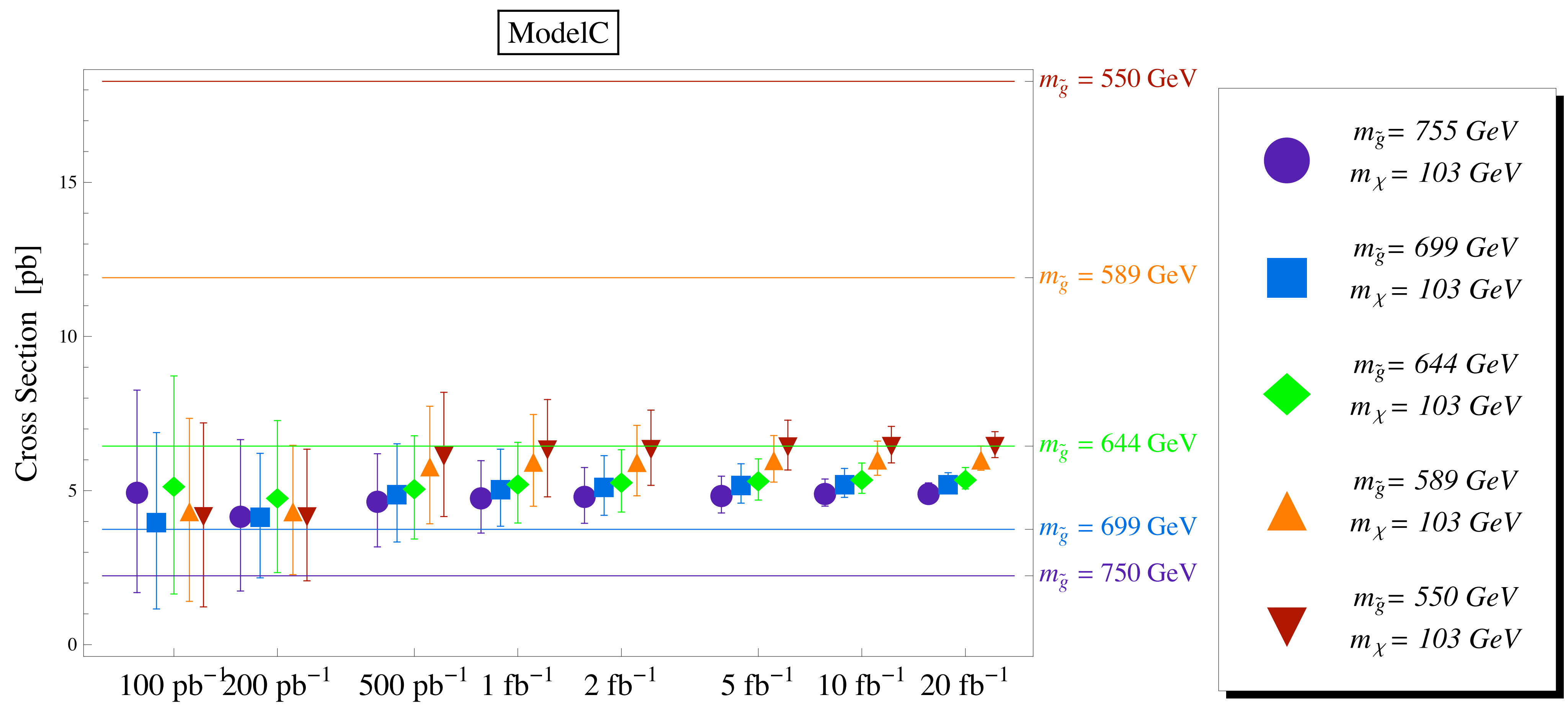
	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69



Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

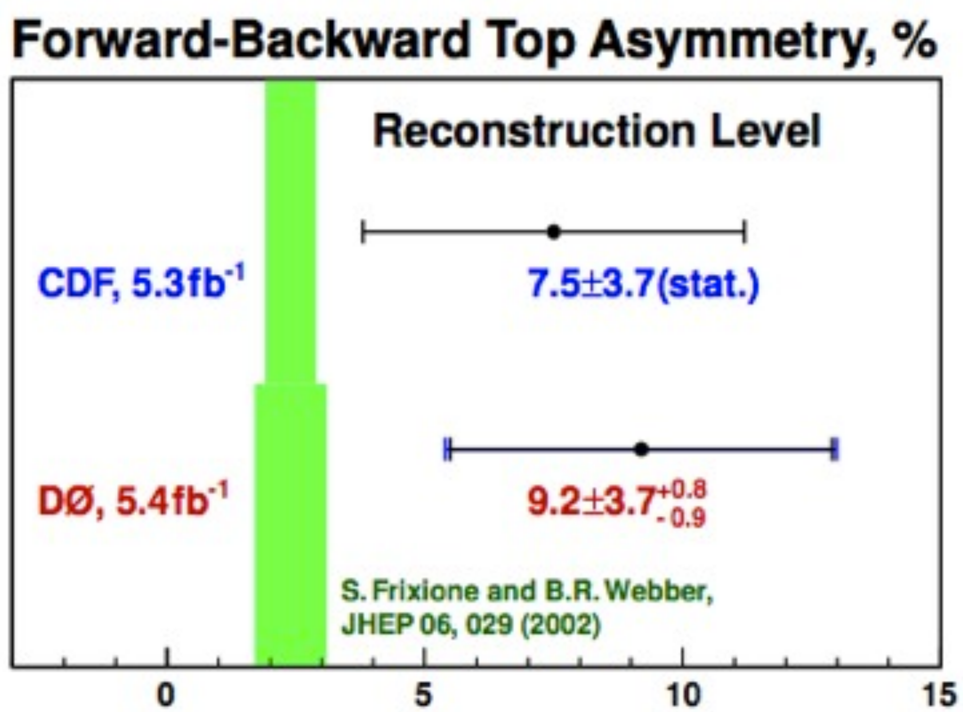
LHC at 14 TeV



Top AFB and polarization.

Top AFB

- Motivated by potential experimental evidence.



- Many studies and models.
  - Talks by Aguilar-Saavedra, Delaunay, Ko, Pecjak...

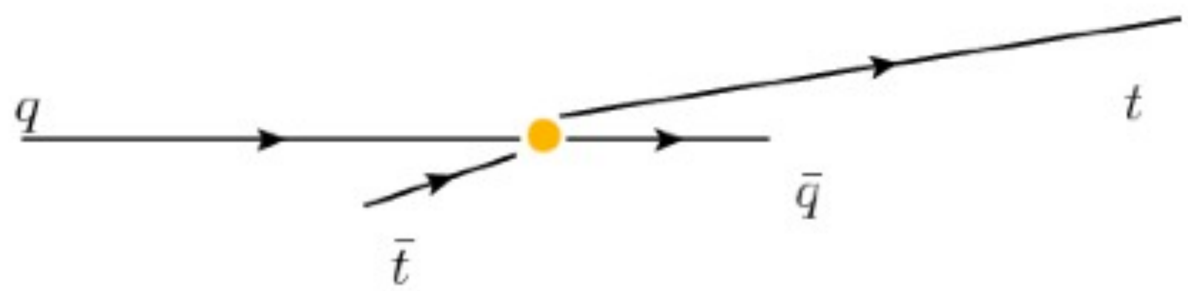
My focus here

D. Krohn, T. Liu, J. Shelton, and LTW, 1105.3743

- Sensitivity of measuring top AFB at (early) LHC.
- Potential of distinguishing possible models.
  - Polarization and leptonic charge asymmetries.
  - Tevatron and LHC.

Top AFB at the LHC.

- q qbar initial state is not symmetric.



- Asymmetry in c.m. frame can be defined as

$$\mathcal{A}_{FB} = \frac{N(\cos\hat{\theta}_t > 0) - N(\cos\hat{\theta}_t < 0)}{N(\cos\hat{\theta}_t > 0) + N(\cos\hat{\theta}_t < 0)}$$

$\hat{\theta}_t$ defined w.r.t. the boost of the event

Our analysis

- Dileptonic channel.
- Reconstruction of ttbar, after shower and hadronization.
- Selection cuts, adapted from CMS, 1010.5994.
- Looking at 450 GeV < m_{tt} < 1.5 TeV.
  - Non-resonant part, less model dependence.
- Enhancing the qqbar relative to gg.
  - $|y(t)+y(\bar{t}\text{bar})| \geq 2$ See also Aguila-Saavedra, Juste, Rubbo, 1109.3710
- Further optimization of cuts possible.

Our analysis

- Reference models.

Model	M [TeV]	Γ [TeV]	g_1^A	g_1^V	g_3^A	g_3^V	g^A	g^V
G_A	2.0	1.40	-2.3	0.0	3.35	0.0	/	/
G_L	2.0	1.40	-2.3	0.0	3.35	3.35	/	/
G_R	2.0	1.40	-2.3	0.0	3.35	-3.35	/	/
W'	0.40	0.04	/	/	/	/	-0.90	0.90

- Our simulation
  - Madgraph + Pythia + PGS.

LHC @ 7 TeV, 5 fb^{-1}

	G_A(%)	G_L(%)	G_R(%)	W'(%)	SM(%)
Selection cuts	3	2	4	14	1 (±1.2)
$m_{t\bar{t}} > 450$ GeV	5	3	6	20	0 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	8	5	12	36	1 (±3.2)

1σ statistical error for 5 fb^{-1}

- Early LHC data sensitive to AFB.
- W′ model: low NP scale, larger signal.

Top polarization as a probe of NP.

Talk by Parke

- New physics typically gives different top polarizations.
  - e.g. some AFB model prefers right-handed couplings.
- Direct measurement of polarization after accurate reconstruction.
  - Powerful, probably need larger statistics.

Polarization: LHC

$$\mathcal{P}_n = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$$

- Select helicity basis as the polarization axis

	G_A(%)	G_L(%)	G_R(%)	W'(%)	SM(%)
Selection cuts	1	-1	4	18	1 (±1.2)
$m_{t\bar{t}} > 450$ GeV	2	-2	6	26	0 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	0	-4	3	19	-2 (±3.2)

- Select beam basis as the polarization axis

	G_A(%)	G_L(%)	G_R(%)	W'(%)	SM(%)
Selection cuts	4	-1	5	9	2 (±1.2)
$m_{t\bar{t}} > 450$ GeV	1	-4	4	11	0 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	2	-5	7	15	1 (±3.2)

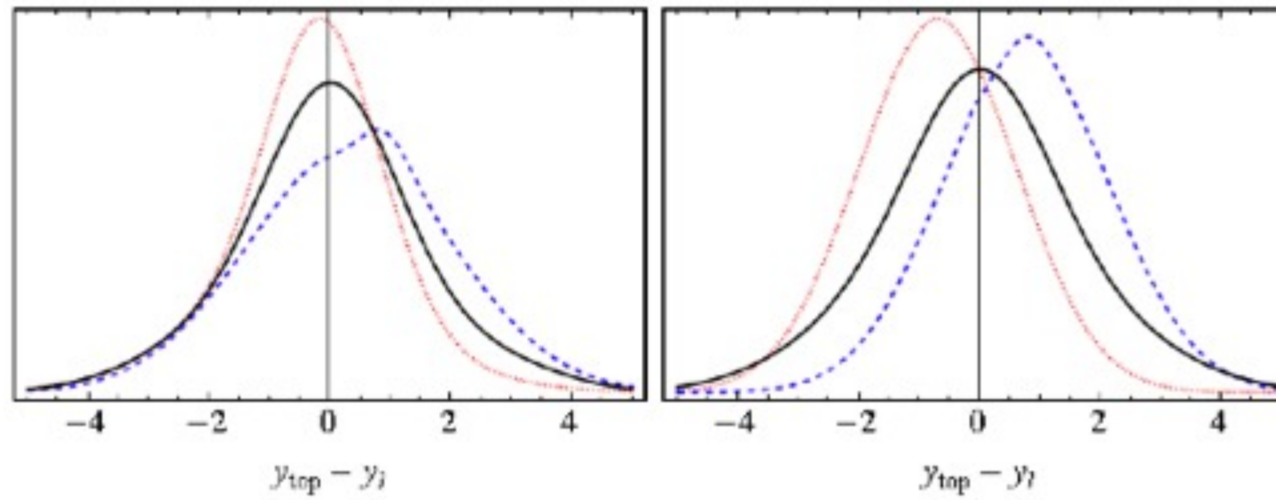
- The GR and W' models can be distinguished from the SM at a C.L. > 3 sigma in the helicity basis
- The left- chiral, right-chiral models and the SM can be distinguished from each other at a C.L. > 2 sigma in the beam basis

See our paper for more details

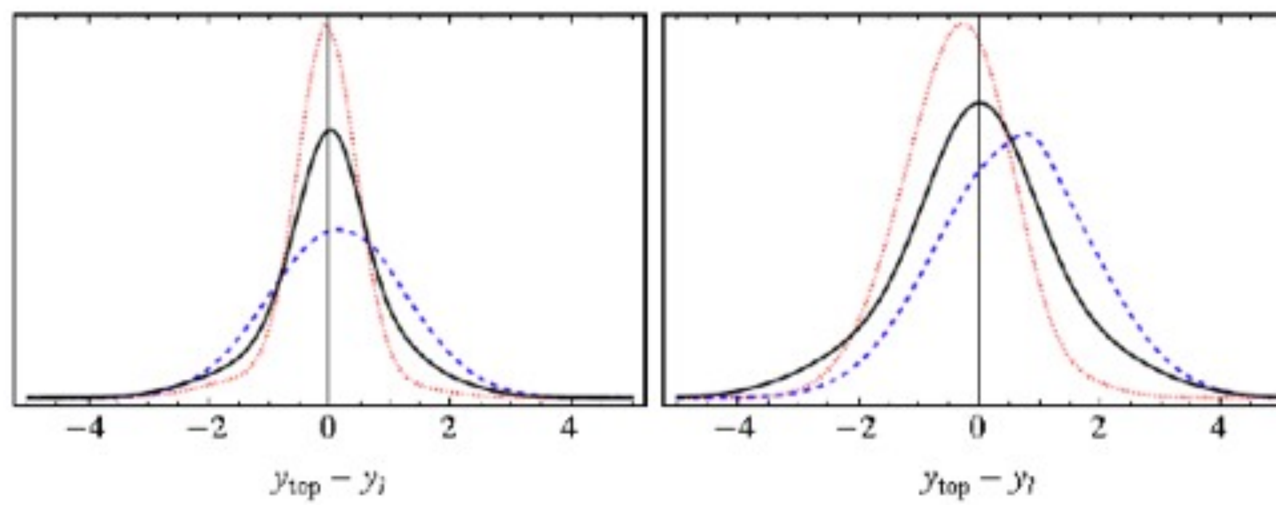
Using leptons

- Charge leptons "follows" the direction of top. Probes AFB.
- (left) right-polarized top leads to (anti)boosted leptons. Probes chiral coupling.

red: RH, blue: LH, black: SM



(a) $\beta_t = 0.5,\ \cos\theta_t = 0.4$ (b) $\beta_t = 0.5,\ \cos\theta_t = 0.9$



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{i,n}} = \frac{1}{2}(1 + \mathcal{P}_n \kappa_i \cos\theta_{i,n})$$

$$\kappa_{\rm lepton} = 1$$

$$\mathcal{P}_n = 1(-1),\ \text{right(left)-handed}$$

Tevatron.

	frame and mass range	$t\bar{t}$ asymmetry	Lepton asymmetry	stat. sig. (5.3 fb^{-1})
G_A	lab, sel. cuts	9 %	4 %	1.1
	lab, $m_{t\bar{t}} > 450$ GeV	17 %	9 %	1.9
	CM, sel. cuts	12 %	6 %	1.7
	CM, $m_{t\bar{t}} > 450$ GeV	19 %	12 %	2.4
G_L	lab, sel. cuts	7 %	-3 %	0.9
	lab, $m_{t\bar{t}} > 450$ GeV	14 %	-1 %	0.2
	CM, sel. cuts	13 %	-4 %	1.4
	CM, $m_{t\bar{t}} > 450$ GeV	20%	-3 %	0.6
G_R	lab, sel. cuts	9 %	12 %	3.9
	lab, $m_{t\bar{t}} > 450$ GeV	14 %	18 %	5.0
	CM, sel. cuts	9 %	16 %	3.5
	CM, $m_{t\bar{t}} > 450$ GeV	15 %	22 %	4.4
W'	lab, sel. cuts	15 %	13 %	3.9
	lab, $m_{t\bar{t}} > 450$ GeV	26 %	22 %	4.9
	CM, sel. cuts	20 %	16 %	4.4
	CM, $m_{t\bar{t}} > 450$ GeV	31 %	26 %	5.3

$$\mathcal{A}^{\ell}_{FB} = \frac{N(q_\ell y_\ell > 0) - N(q_\ell y_\ell < 0)}{N(q_\ell y_\ell > 0) + N(q_\ell y_\ell < 0)}$$

- The GL model is hard to distinguish from the SM
- The other ones can be distinguished at a significance level ~ or > 2 sigma

LHC

$$\mathcal{A}_{FB}^{\Delta\ell} = \frac{N((y_{\ell^+} - y_{\ell^-}) > 0) - N((y_{\ell^+} - y_{\ell^-}) < 0)}{N((y_{\ell^+} - y_{\ell^-}) > 0) + N((y_{\ell^+} - y_{\ell^-}) < 0)}$$

	G_A(%)	G_L(%)	G_R(%)	W'(%)	SM(%)
Selection cuts	2	0	5	13	0 (±1.2)
$m_{t\bar{t}} > 450$ GeV	4	2	7	19	-1 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	7	2	14	35	1 (±3.2)

- 7 TeV LHC, 5/fb of data
- The GL model is not easy to distinguish from the SM
- The other ones can be distinguished at a C.L. > or ~3 sigma

Conclusions.

- Top rich final states are well motivated in search for BSM NP.
- In this talk
  - Top partner.
  - Top rich channel in SUSY
  - Top AFB
- It has good early discovery potential.

extras

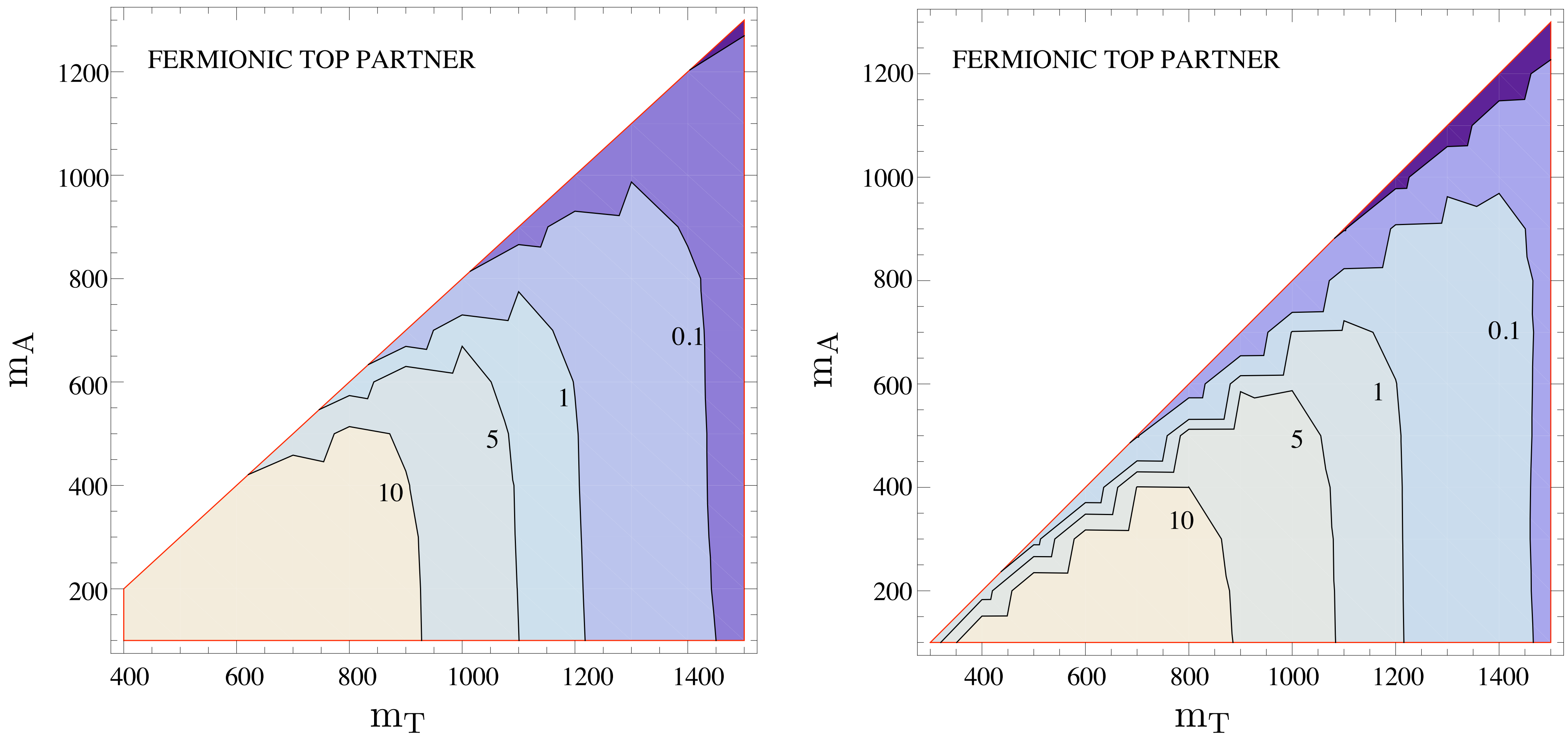
Basic selection cuts for gluino pair to tops.

Inclusive isolated lepton (muon, electron) 30 GeV
Lepton (muon, electron) plus jet (20 GeV, 100 GeV)
Isolated dileptons (mumu,ee) 15 GeV
Dileptons (mumu,ee) plus jet (10 GeV, 100 GeV)
Isolated dileptons (emu) 10 GeV

Isolated lepton (muon,electron) plus isolated tau (15 GeV, 45 GeV)
Isolated ditau 60 GeV
Inclusive isolated photon 80 GeV
Isolated diphoton 25 GeV

Inclusive MET 90 GeV
Inclusive single-jet 400 GeV
Jet plus MET (180 GeV, 80 GeV)
Acoplanar jet and MET (100 GeV, 80 GeV, 1<Dphi<2)
Acoplanar dijets (200 GeV, Dphi<2)

Top partner reach, 14 TeV, 100 fb^{-1}



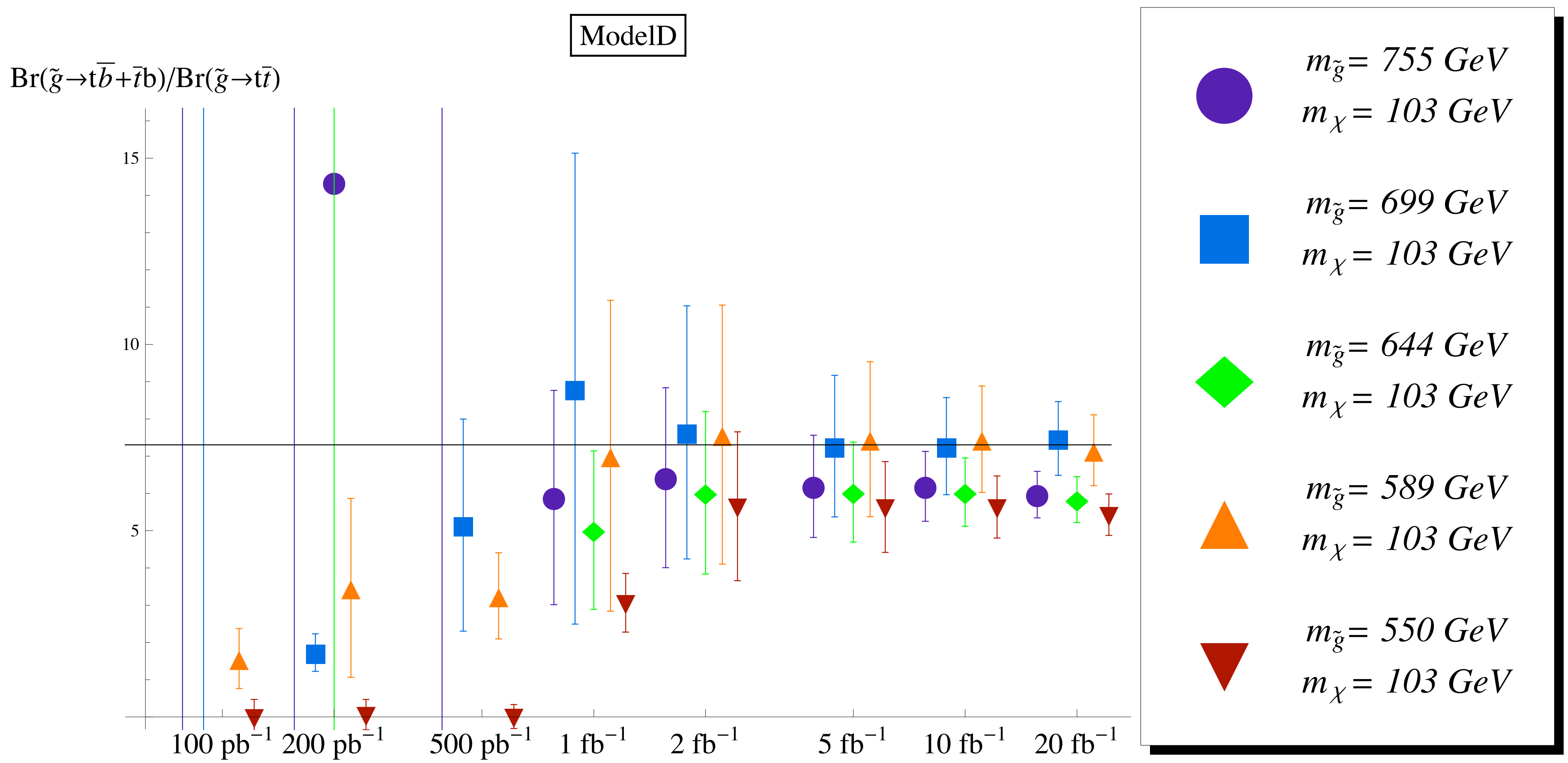
Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

LHC at 14 TeV



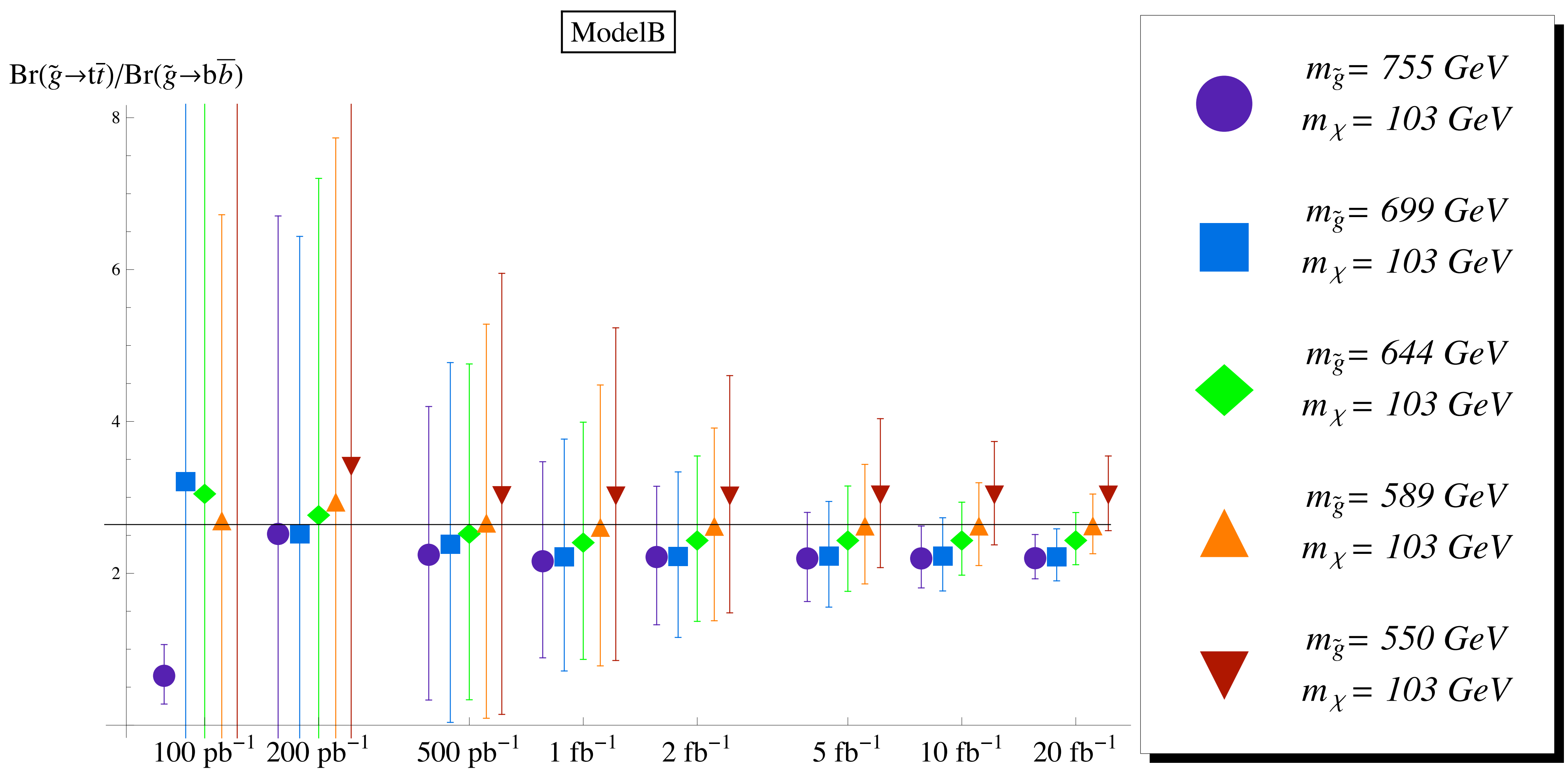
Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

Testing this idea.

	Model parameters (TeV)							Branching ratios		
	$m_{\tilde{g}}$	$m_{\tilde{q}_{1,2}}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{N},\tilde{C}}$	$(\tilde{g} \to t\bar{t})$	$(\tilde{g} \to b\bar{b})$	$(\tilde{g} \to tb)$
A	0.65	8	1.3	8	2.5	8.1	0.1	0.92	0.07	0
B	0.65	4	0.8	0.93	0.87	4	0.1	0.71	0.27	0
C	0.65	4	0.64	0.9	0.72	4	0.1	0.52	0.47	0
D	0.65	4	0.63	0.9	0.72	4	0.1	0.09	0.22	0.69

LHC at 14 TeV



Examples for heavy scalar.

- F-term breaking, with R-symmetry preserved.

$$W = \mu^2 X + ..., \quad K = XX^\dagger + \frac{(XX^\dagger)^2}{M^2} + ...$$

$$R[X] = 2, \quad F_X = \mu^2, \quad \langle X \rangle = 0$$

$$\int d^4\theta \frac{XX^\dagger}{M^2} Q^\dagger Q \to m_{\tilde{Q}}^2 = \frac{\mu^4}{M^2}$$

$$\int d^4\theta \frac{XX^\dagger}{M^3} W_\alpha W^\alpha r \to m_{1/2} = \frac{\mu^4}{M^3} r$$

r: additional R-symm breaking spurion

- Similar story for D-term breaking.

Polarization: Tevatron

	Semileptonic		Dileptonic	
	sel. cuts	$m_{t\bar{t}} > 450$ GeV	sel. cuts	$m_{t\bar{t}} > 450$ GeV
SM	4 % (3 %)	7 % (5 %)	4 % (6.5 %)	6 % (10 %)
G_A	5 %	7 %	5 %	7 %
G_L	2 %	-1 %	1 %	-1 %
G_R	8 %	12 %	8 %	12 %
W'	15 %	22 %	14 %	21 %

- Note: both semileptonic and dileptonic modes are included for the Tevatron analysis:
- Semileptonic mode: 5.3/fb; dileptonic mode: 5.1/fb
- Selection cuts (CDF collaboration (2011))
- The GL, GA models and the SM are not easy to distinguish
- The other ones can be distinguished at 1~ 4 sigma

Spin correlation at the LHC

- Help distinguish s-channel and t-channel models
- Top spin correlation

$$\mathcal{A}^{\ell}_{c_1 c_2} = \frac{N(c_1 c_2 > 0) - N(c_1 c_2 < 0))}{N(c_1 c_2 > 0) + N(c_1 c_2 < 0))}$$

- At 7 TeV LHC, 5/fb of data

	$G_A(\%)$	$G_L(\%)$	$G_R(\%)$	$W'(\%)$	SM(%)
Selection cuts	-2	-3	-2	7	-4 (±1.2)
$m_{t\bar{t}} > 450$ GeV	1	0	1	12	-2 (±1.7)
$\lvert y(t) + y(\bar{t})\rvert > 2$	3	0	0	12	3 (±3.2)

- The W' model can be distinguished from the other ones at a C.L. > 6 sigma