Natural Susy Endures

Andreas Weiler (DESY)

Implications of LHC results for TeV-scale physics: WG2 meeting 11/1/11

In collaboration w/ Michele Papucci & Josh Ruderman (Berkeley) <u>arXiv:1110.6926</u>

The next 16 minutes

- Nima's talk
 Reminder about bottom-up naturalness: Which super-partners need to be light?
- Current status of SUSY searches
- Our Limits
 - Method & Caveats
 - Stop limits
 - +Gluino limits

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- \rightarrow Nima's talk • Reminder about bottom-up naturalness: Which super-partners need to be light?
- Current status of SUSY searches
- Our Limits
 - Method & Caveats

Stop limits
+Gluino limits
Which current searches
work best?

Natural EWSB & SUSY * valid beyond MSSM

$$\frac{m_{Higgs}^2}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

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$$||oop| \qquad \delta m_H^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2 \right) \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

$$2loop \qquad \delta m_H^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

Natural EWSB & SUSY* * valid beyond MSSM

$$\frac{m_{Higgs}^2}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$
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$$\begin{aligned} \text{Iloop} \quad \delta m_H^2|_{stop} &= -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2 \right) \log \left(\frac{\Lambda}{\text{TeV}} \right) \\ \text{stops, sbottom} \\ \text{Stops, sbottom} \\ \text{2loop} \quad \delta m_H^2|_{gluino} &= -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2 \left(\frac{\Lambda}{\text{TeV}} \right) \\ \text{gluino} \end{aligned}$$

Bottom-uphatural spectrum



Fig. from L.Hall's recent talk @ LBL

Bottom-uphatural spectrum



Fig. from L.Hall's recent talk @ LBL

Current status



ew. 1.04 ID

 \leq

MSUGRA/CMSSM: $tan\beta = 10, A_0 = 0$

$$m_{\tilde{g}} \le 800 \text{ GeV} \quad m_{\tilde{q}} \le 850 \text{ GeV}$$

 $m_{\tilde{g}} = m_{\tilde{q}}$

$$m_{\tilde{g}} = m_{\tilde{q}}$$

Current status



ew. 1.04 ID



$$m_{\tilde{g}} = m_{\tilde{q}}$$

Current status



 U_{1}





Tevatron:

FIG. 3: (color online). (a) The 95% C.L. expected (dashed line) and observed (points plus solid line) a function of m_{LQ} for the pair production of third-generation leptoquarks where B is the branching theory band is shown in grey with an uncertainty range as discussed in the text. The long-dashed line in suppression of $\sigma \times B^2$ above the $t\tau$ threshold for equal $b\nu$ and $t\tau$ -couplings. (b) The 95% C.L. excl

Stops can still be $\lim_{k \to 1}^{m_{\tilde{k}_1}} (even 120-180 \text{ GeV})$ I light (even 120-180 GeV)

expected from known SM processes. We set limits on the cross section multiplied by square of the branching Sbottoms should for B25th 6 the state as a function of leptoquark mass. These results are interpreted as mass limits and give a limit of 247 GeV for B = 1 for the production of charge-1/3 third-generation scalar leptoquarks. We also exclude the production of bottom squarks to september 29.201 FOM (The Netherlands); S' a range of values in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0})$ mass plane such as $m_{\tilde{b}_1} > 247 \text{ GeV for } m_{\tilde{\chi}_1^0} = 0 \text{ and } m_{\tilde{\chi}_1^0} > 110 \text{ GeV for } 160 < m_{\tilde{b}_1} < 200 \text{ GeV}$. These limits significantly extend previous results.

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FIG. 3: (color online). (a) The 95% C.L. expected (dashed line) and observed (points plus solid line) a function of m_{LQ} for the pair production of third-generation leptoquarks where B is the branching theory band is shown in grey with an uncertainty range as discussed in the text. The long-dashed line in suppression of $\sigma \times B^2$ above the $t\tau$ threshold for equal $b\nu$ and $t\tau$ -couplings.- (b) The 95% C.L. excl $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0})$ plane. Also shown are results from previous searches at LEP [23] and the Tevatron [7, 24].

Stops can still be light (even 120-180 GeV)



Direct stop prod. with 1/fb ?



Direct stop prod. with 1/fb ?



"The experiments haven't covered my favorite model"

Relax & Wait?



VS.

* not his real attitude.

"The experiments haven't covered my favorite model"

Relax & Wait?



VS.



Check yourself!

* not his real attitude.



B

 $\tilde{\mathbf{x}}$



Our Limits

today:<u>*arXiv:1110.6926*</u> M. Papucci, J. Ruderman, AW

decoupled SUSY



Calibration

"theorist limits"

To calibrate compare: 1) key kinematical distributions 2) limits



Check:

- kinematic distortions (shape)
- signal $\epsilon \times \mathcal{A}$ (normalization)
- + compare to all available limit plots...
 - ~ 50 GeV accuracy (usually better)

Large signature space

	ATLAS		CMS			
	channel	$\mathcal{L} [\mathrm{fb}^{-1}]$	ref.	channel	$\mathcal{L} [\mathrm{fb}^{-1}]$	ref.
jets + E_T	2-4 jets	1.04	[1]	α_T	1.14	[11]
	6-8 jets	1.34	[2]	$H_T, \not\!\!H_T$	1.1	[12]
	1b, 2b	0.83	[3]	$m_{T2} (+b)$	1.1	[13]
b -jets $(+ l's + \not\!\!E_T)$	b+1l	1.03	[4]	1b, 2b	1.1	[14]
				$b'b' \rightarrow b + l^{\pm}l^{\pm}, 3l$	1.14	[15]
				$t't' \to 2b + l^+l^-$	1.14	[16]
	1l	1.04	[5]	1l	1.1	[17]
	$\mu^{\pm}\mu^{\pm}$	1.6	[6]	SS dilepton	0.98	[18]
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	4l	1.02	[9]	$3l, 4l + \not\!\!E_T$	2.1	[21]
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non susy analyses

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non susy analyses

too recent

arXiv:1110.6926

Stops (sbottom) + Higgsinos



Stops can act as "sbottom" (bjet+ χ) !

Chargino-neutralino splitting irrelevant for present searches

Stops (sbottom) + Higgsinos



LHC surpasses Tevatron: Strongest bounds from jets + MET

Stops (sbottom) + Bino (gravitino)





jets+MET searches powerful here too

 RH stop→Bino: top-like final state. Weak bound around 200GeV, but we don't trust it too much. Further (exp') study needed...

Un-Splitting the spectrum



Un-Splitting the spectrum



stronger bound on the left due to light sbottom

TeVatron bounds not shown b/c they have no sensitivity for m_{LSP} > 110GeV

Adding gluinos



quasi-degenerate 3-rd gen'

Adding the gluinos



Gluino bounded (again) by jets+MET, and Ilep searches

Gluino mostly bounded by Same Sign searches

Adding the squarks, too



- Bounds similar to the ATLAS/CMS plots (800GeV-ITeV)
- Decoupling not effective until I.2-I.4 TeV

Squashed spectrum



MSSM little hierarchy problem

- Higgs mass lifted by large A-terms → split stop spectrum,
 I stop may be light and constrained by searches
- Compare to constraints from the Higgs mass bound?
- CAVEAT: only for higgsinos (higgsinos+binos) lighter than stops...

MSSM higgs: LEP2 tuning vs. direct stop



$$\delta m_H^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2 \right) \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

MSSM higgs: LEP2 tuning vs. direct stop



Maximal mixing (for light Higgsino case) probed by the LHC... interesting interplay with Higgs searches.

Summary

production	LSP	\tilde{t} limit [GeV]	figure
$\tilde{t}_L + \tilde{b}_L$	\tilde{H}	~ 250	3
${ ilde t}_R$	\tilde{H}	~ 180	3
$\tilde{t}_L + \tilde{b}_L$	\tilde{B}	$\sim 250 - 350$	5

scenario	$\left \tilde{g} \text{ limit [GeV]} \right $	\tilde{t} limit [GeV]	figure
$ ilde{H}$ – LSP	$\sim 650 - 700$	~ 280	10
$ ilde{B}$ - LSP	~ 700	~ 270	10
somewhat squashed	$\sim 600 - 700$	_	11
split \tilde{t}	$\sim 550-650$		11
flavor degen.	1200 (fixed)	600 - 900	16
gaugino unify	$\sim 750-800$	~ 260	16

arXiv:1110.6926

Outlook

- Next frontier: Heavy flavor themed naturalness (Eder's & Andrey's talks), EW-inos (Shufang's talk)
- Natural SUSY not in trouble yet (and won't be before shutdown).Trouble only for high-scale, flavor universal models
- LHC will cover very exciting ground in the coming years

Backup

Projections?



dashed - perfect bgd's

solid - statistics
improves, systematics
same fraction

* Large uncertainty
 * Targeted searches
 do likely better.







this part of the spectrum does not matter much for naturalness & can be heavier

decoupled SUSY

parameters:
$$\mu$$
, tan β
 m_{Q_3} , m_{u_3} , A_t
 M_3 $\underline{\tilde{B}}$
 \tilde{W} $\underline{\tilde{L}}_i, \tilde{e}_i$
 $\tilde{Q}_{1,2}, \tilde{u}_{1,2}, \tilde{d}_{1,2}$
 \dots
 \tilde{b}_R $\underline{\tilde{g}}$
 \dots $\underline{\tilde{g}}$
 \tilde{b}_L this part of the spectrum
does not matter much for
naturalness & can be heavier $\underline{\tilde{H}}$
natural SUSYdecoupled SUSY

Calibrate w/ limit plots



- broad range of kinematical configurations
- even with 50% accuracy of $\epsilon \times A$ (mostly better) limits are very similar (thanks to pdf's!)

Caveat: if efficiency very sensitive to cut : wouldn't trust it (ATOM flags that).

Back to the flavor degenerate case



Hard to investigate more squashed spectra (+ additional tuning due to squashing...)





Tuning in the MSSM $m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\text{stop}}^2}{m_t^2}$

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Negative search at LEP: $m_H > 114 \text{ GeV}$ Therefore need $m_{stop} \sim O(1 \text{ TeV})$. But at minimum,

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$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1} \approx -m_{H_u}^2$$

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 $\delta \eta$

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$$m_{H_u}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2} \approx 600 \cdot \frac{m_Z^2}{2}$$

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o Raise tree-level Higgs mass ? *m*_{stop} reduced !
a) F-Term (NMSSM)
b) D-term (extended gauge structure)

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a) F-Term (NMSSM)
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o Lower the cut-off?
c) NMSSM (large SH_uH_d coupling ⇒ Λ_{Landau} ≪ M_{Gut})
d) Find rationale why Λ=(protection scale f)~ O(TeV) (i.e. little Higgs like protection)