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) [arXiv:1110.6926](http://arxiv.org/pdf/1110.6926)

The next 16 minutes

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

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	-
	-

• Stop limits • +Gluino limits } Which current searches work best?

Natural EWSB & SUSY* * valid beyond MSSM

Do not want tuning in (Higgs mass) 2

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

Natural EWSB & SUSY* * valid beyond MSSM

Do not want tuning in (Higgs mass)²

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2^{*} *µ <* 1 EWSB & SL masses. In particular in pa

Do not want tuning in $(Higgs mass)^2$ Do not want tuning in (Hig

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 Higgsinos

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

2loop
$$
\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)
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\n**Stops, sbottom**

\n**2loop**

\n
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$$
\n**gluino**

A *Natural Spec*)*u*m Bottom-up hatural spectrum

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

A *Natural Spec*)*u*m Bottom-up hatural spectrum

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

Current status

 $\mathsf{U}(W, \mathsf{U}(1, U))$

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

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

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

Current status Phenomenological#MSSM#squark4gluino#grids:#

Jets+ET

 $\mathsf{C} \mathsf{W}$ $\mathsf{C} \mathsf{L} \mathsf{C} \mathsf{L} \mathsf{C} \mathsf{C} \mathsf{C}$

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

Current status Phenomenological#MSSM#squark4gluino#grids:# \blacksquare

Jets+ET

 Cov . 1.0410

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 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 suppression of $\sigma \times B^2$ above the $t\tau$ threshold for equal by and $\epsilon \tau$ couplings. (b) The 95% C.L. exclusion

• Stops can still be light (even 20 -180 GeV) $\frac{1}{20}$ of $\frac{1}{20}$ and the Tevatron [7, 24].

• Sbottoms should $\stackrel{\text{the cross section multiplied}}{\text{quark mass. These results as}}$ expected from known SM processes. We set limits on the cross section multiplied by square of the branching f **ex** θ **for the bu-final** 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 as $\frac{1}{2}$, \frac a range of values in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0})$ mass plane such as $m_{\tilde{b}_1} > 247\,\,{\rm GeV}\,\,{\rm for}\,\, m_{\tilde{\chi}_1^0} = \tilde{0} \,\,{\rm and}\,\, m_{\tilde{\chi}_1^0} > 110\,\,{\rm GeV}\,\,{\rm for}\,\,$ $160 < m_{\tilde{b}_1} < 200$ GeV. These limits significantly extend previous results.

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- $\lceil a \rceil$ M. T. Plehn, M. Spira, Phys. Ph

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Tevatron:

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

Direct stop prod. with 1/fb ?

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"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.

 \tilde{X}

Our Limits

today:*arXiv:1110.6926* M. Papucci, J. Ruderman, AW

natural SUSY intervalsed SUSY

Calibration

"theorist limits"

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

Check:

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

Large signature space

non susy analyses

Large signature space

non susy analyses

too recent

arXiv: 1110.6926 *arXiv:1110.6926*

Stops (sbottom) + Higgsinos

Stops can act as "sbottom" (bjet+χ) !

Chargino-neutralino splitting irrelevant for present searches

by the Lehat Stops (sbottom) + Higgsinos

Strongest bounds from jets + MET LHC surpasses Tevatron:

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} > $110 GeV$

Adding gluinos

quasi-degenerate 3-rd gen'

Adding the gluinos

Gluino bounded (again) by jets+MET, and 1lep searches Gluino mostly bounded by Same Sign searches

Adding the squarks, too

- Bounds similar to the **ATLAS/CMS plots** (800GeV-1TeV)
- Decoupling not effective until $1.2 - 1.4$ TeV

Squashed spectrum

MSSM little hierarchy problem

- Higgs mass lifted by large A-terms \rightarrow 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...

model dependent dependent provider *MSSM* higgs: LEP2 tuning vs. direct stop 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

TABLE III: A summary of limits that we found in scenarios with gluinos. The full limits are shown *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

parameters:	μ , $\tan \beta$	\tilde{B}	$\tilde{c}_{i,\tilde{c}_{i}}$
m_{Q_3}, m_{u_3}, A_t	\tilde{W}	$\tilde{q}_{1,2}, \tilde{u}_{1,2}, \tilde{d}_{1,2}$	
\tilde{g}	\tilde{w}	\tilde{v}_{R}	
\tilde{g}	\tilde{t}_L	\tilde{t}_R	
\tilde{v}_L	\tilde{t}_R	\tilde{t}_R	
\tilde{m}	does not matter much for naturalness & can be heavier		
\tilde{H}	dotural SUSY	decoupled SUSY	

Calibrate w/ limit plots

- broad range of kinematical configurations
- even with 50% accuracy of $\epsilon \times 4$ (*n* λ • even with 50% accuracy of $\epsilon\times\mathcal{A}$ (mostly better) limit are very similar (thanks to $\mathsf{ndf}'\mathsf{sl}$) $r = \frac{1}{2}$ is compared to previous $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ are same to $\frac{1}{2}$ limits are very similar (thanks to pdf's!) $\epsilon \times \mathcal{A}$

 G Caveat: if efficiency very sensitive to cut : wouldn't are heavier than the gluino, which decays exclusively into the gluino, which decays exclusively 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: $m_H > 114$ GeV Therefore need $m_{stop} \sim O(1 \text{ TeV})$. But at minimum,

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

 $m_{\tilde{Z}}^2$ *Z* 2 = *|µ|* ² *^m*² $\frac{2}{H_u}\tan^2\beta - m_{H_d}^2$ $\tan^2\beta$ $\thickapprox -m_{H_u}^2$ δm^2_{L} $\frac{2}{H}u(\text{loop}) = -\frac{3y_t^2}{8\pi^2}$ $\frac{9y_t}{8\pi^2}m_{\rm s}^2$ $\frac{2}{\text{stop}}\ln\frac{1}{m^2}$ $m^2_{\rm stop}$ ≈ 600 $m_{\tilde{Z}}^2$ *Z* 2 Little High^{wa} $\frac{\tan^2\beta-m_{H_d}^2}{\tan^2\beta-m_{H_d}^2}$

$$
\delta m_{Hu}^2 \text{(loop)} = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2}
$$

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

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o Lower the cut-off ? c) NMSSM (large SHuHd coupling 㱺 ΛLandau ≪ *M*Gut) d) Find rationale why Λ=(protection scale **f**)~ O(TeV) (i.e. little Higgs like protection)