

Trilinear-Augmented Gaugino Mediation

Jörn Kersten



UNIVERSITY OF BERGEN

Based on Jan Heisig, JK, Nick Murphy, Inga Strümke, [arXiv:1701.02313](https://arxiv.org/abs/1701.02313)
(to appear in *JHEP*)

Supersymmetry Solves Problems

- Hierarchy problem
- Dark matter
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- Gauge coupling unification

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- Little hierarchy problem
- SUSY flavor problem
- SUSY CP problem
- μ problem
- Gravitino problem
- SUSY discovery problem

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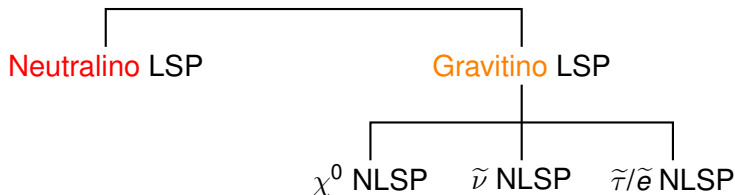
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- SUSY discovery problem \rightsquigarrow unexpected mass spectrum?

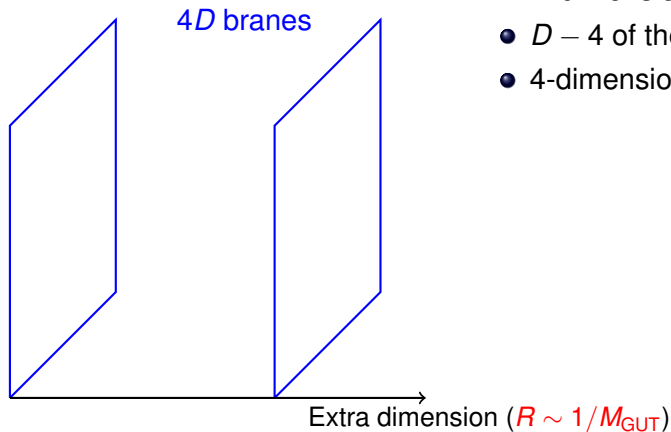
Gaugino-Mediated Supersymmetry Breaking

- Scenario for SUSY breaking without **flavor** and **CP** problems
Kaplan, Kribs, Schmaltz, PRD **62** (2000)
Chacko, Luty, Nelson, Pontón, JHEP **01** (2000)
- **Dark matter** candidate: **neutralino** or **gravitino**
- **Long-lived charged** slepton **NLSP** \rightsquigarrow unusual LHC phenomenology
- Squarks significantly heavier than sleptons



Buchmüller, JK, Schmidt-Hoberg, JHEP **02** (2006)

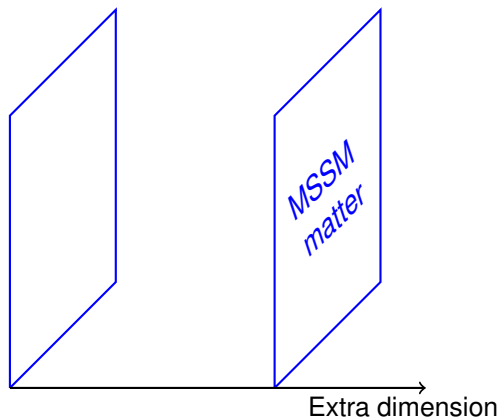
Setup



- D dimensions
- $D - 4$ of them compactified
- 4-dimensional branes

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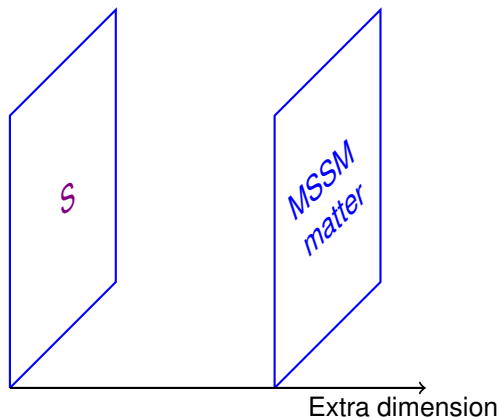
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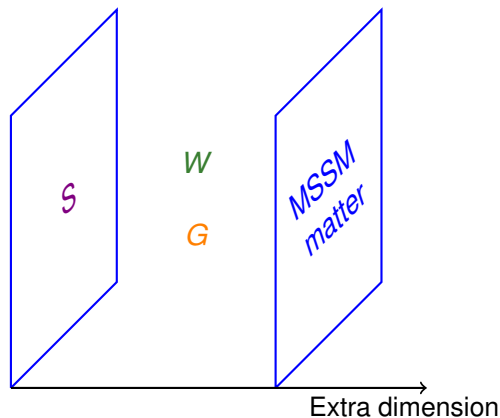
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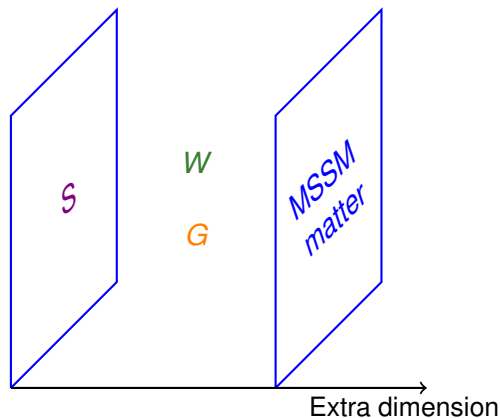
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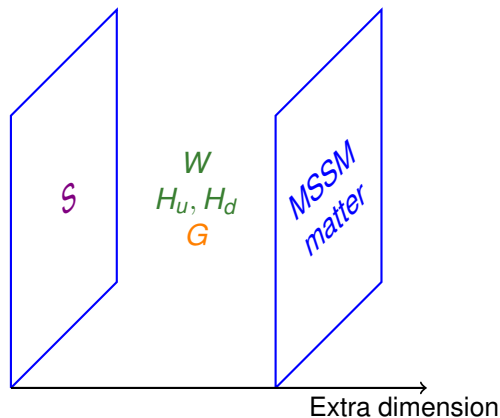
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- Soft masses for gauginos, gravitino
- No soft masses for squarks and sleptons
~> no flavor problem

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The Higgs Likes Trilinears

Light Higgs mass incl. dominant 1-loop corrections

$$m_h^2 = m_Z^2 \cos^2 2\beta + m_t^2 \left[\log \frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12M_S^2} \right) \right] \cdot \text{const.}$$

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- $A_t = 0 \rightsquigarrow$ heavy superparticles needed
- $|A_t| \gtrsim 2M_S \rightsquigarrow$ SUSY in LHC reach

Large trilinears favorable

Trilinears in Gaugino Mediation

- Original version I: Higgs fields on **brane**
 - ↪ **vanishing trilinear** scalar couplings A_0 (at high energy)
Kaplan, Kribs, Schmaltz, PRD **62** (2000)
- Original version II: Higgses in **bulk** but only couplings $S^\dagger S H_{u,d}^\dagger H_{u,d}$
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Chacko, Luty, Nelson, Pontón, JHEP **01** (2000)
- **Bulk** Higgses, all couplings allowed by symmetry (incl. $S H_{u,d}^\dagger H_{u,d}$)
 - ↪ **Non-vanishing trilinears proportional to Yukawa matrices**
Brümmer, Kraml, Kulkarni, JHEP **08** (2012)
 - ↪ Different values possible in up and down sector
Heisig, JK, Murphy, Strümke, arXiv:1701.02313

Boundary Conditions at Compactification Scale

Assuming $1/R \sim M_{\text{GUT}}$:

- Gauge couplings $g_1 = g_2 = g_3 = g \simeq 1/\sqrt{2}$
- Gaugino masses $M_1 = M_2 = M_3 = m_{1/2}$
- Gravitino mass $m_{3/2}$
- Squark and slepton masses $\simeq 0$
- Trilinear couplings $A_0 \leq 0$
- Soft Higgs masses $m_{H_u}^2, m_{H_d}^2 \geq 0$
- $\tan \beta$
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Running generates non-zero masses at low energies

Calculated using SPHENO 3.3.8

Porod, Comput. Phys. Commun. **153** (2003)

Porod & Staub, Comput. Phys. Commun. **183** (2012)

Calculated using FEYNHIGGS 2.12.2

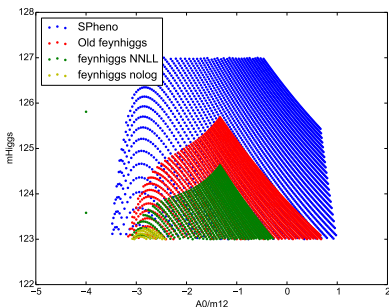
Heinemeyer, Hollik, Weiglein, EPJC **9** (1999), Comput. Phys. Commun. **124** (2000)

Degrassi, Heinemeyer, Hollik, Slavich, Weiglein, EPJC **28** (2003)

Frank, Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, JHEP **02** (2007)

Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, PRL **112** (2014)

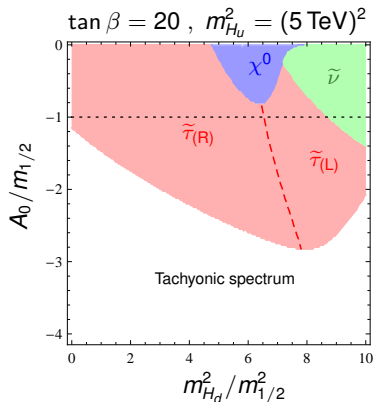
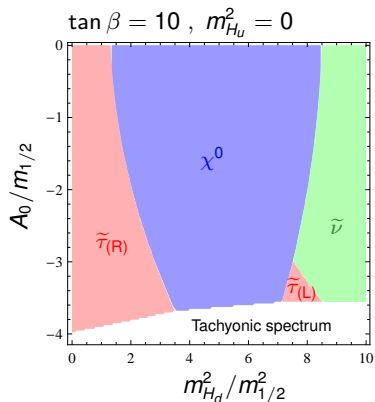
Bahl & Hollik, EPJC **76** (2016)



- FEYNHIGGS value $\simeq 3$ GeV smaller than SPHENO 3
- Agreement with SPHENO 4
Staub & Porod, arXiv:1703.03267
- Downward shift by $\simeq 1$ GeV between FH 2.11 and 2.12 (mid-2016)
- Main reason: more accurate calculation of electroweak corrections to \overline{MS} top mass
Bahl & Hollik, EPJC **76** (2016)

NLSP Candidates

- With gravitino LSP: **neutralino**, **stau**, or **sneutrino** NLSP
- Mainly depends on A_0 and $m_{H_d}^2$
- Large stau mixing possible



Heisig, Kersten, Murphy, Strümke, [arXiv:1701.02313](https://arxiv.org/abs/1701.02313)

- Monte Carlo simulation (PYTHIA 6 + MADGRAPH5_AMC@NLO)
Sjöstrand, Mrenna, Skands, JHEP **05** (2006)
Alwall et al., JHEP **07** (2014)
- **Stau NLSP: Heavy Stable Charged Particle**
 - Applied 8 TeV CMS search (18.8 fb^{-1}) CMS, EPJC **75** (2015)
 - Estimated 13 TeV reach (300 fb^{-1})
- **Neutralino LSP/NLSP, sneutrino NLSP: missing energy**
 - Tested against ATLAS searches using CHECKMATE 1
Drees, Dreiner, Schmeier, Tattersall, Kim, Comput. Phys. Commun. **187** (2015)

Charge and Color Breaking

- Minimum of scalar potential can be at **non-zero sfermion vev**
- Simple but unreliable bound

$$A_\tau^2 < 3 (m_{H_d}^2 + |\mu|^2 + m_{L_3}^2 + m_{\bar{e}_3}^2)$$

Frère, Jones, Raby, NPB **222** (1983)

Kounnas, Lahanas, Nanopoulos, Quiros, NPB **236** (1984)

Derendinger & Savoy, NPB **237** (1984)

- **Large $\tan \beta$: additional constraint on $\mu \tan \beta$**

Kitahara & Yoshinaga, JHEP **05** (2013)

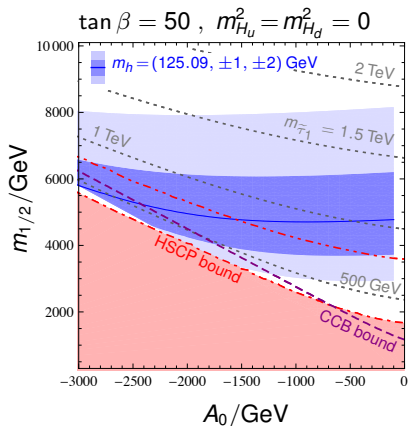
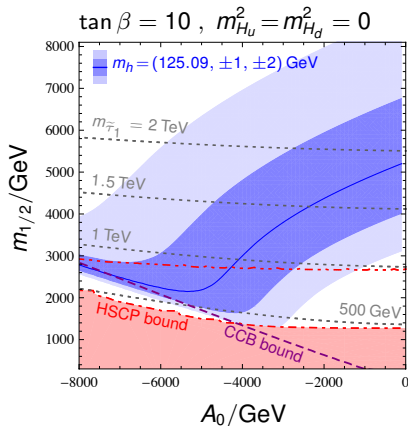
- **More sophisticated analysis needed (waiting for VEVACIOUS 2)**

Results

- Parameter space with stau NLSP probed by LHC
- Neutral (N)LSP : no points forbidden, little hope for discovery

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Heisig, Kersten, Murphy, Strümke, [arXiv:1701.02313](https://arxiv.org/abs/1701.02313)

Conclusions

- Gaugino-mediated SUSY breaking allows for large trilinears
- No flavor and CP problems
- Alleviated gravitino problem with gravitino dark matter
- Neutralino or slepton NLSP
- Observed Higgs mass reached for $m_{\text{NLSP}} \sim (400 \dots 1400) \text{ GeV}$
- Neutral NLSP too heavy for LHC
- Stau NLSP metastable \rightsquigarrow accessible in HSCP searches at LHC

Couplings to Hidden Sector

$$\begin{aligned} \mathcal{L} \supset & \frac{1}{V_{D-4}} \left\{ \frac{1}{M^{D-3}} \left[\frac{h}{4} S W^\alpha W_\alpha \right]_F + \text{h.c.} \right. \\ & + \frac{1}{M^{D-3}} \left[S \left(a H_u^\dagger H_d^\dagger + b_u H_u^\dagger H_u + b_d H_d^\dagger H_d \right) + \text{h.c.} \right]_D \\ & \left. + \frac{1}{M^{D-2}} \left[S^\dagger S \left(c_u H_u^\dagger H_u + c_d H_d^\dagger H_d + (d H_u H_d + \text{h.c.}) \right) \right]_D \right\} \end{aligned}$$