Trilinear-Augmented Gaugino Mediation

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Based on Jan Heisig, JK, Nick Murphy, Inga Strümke, JHEP **05**, 003 (2017)
[arXiv:1701.02313]

Supersymmetry Solves Problems

- Hierarchy problem
- Dark matter
- Anomalous magnetic moment of the muon (?)
- Gauge coupling unification

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

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- Gravitino problem
- SUSY discovery problem $\rightsquigarrow$ unexpected mass spectrum?

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- Gravitino interacts via gravity
  $\rightsquigarrow$ extremely weakly
  $\rightsquigarrow$ lifetime $\sim 10^{-2}$ s . . . years
- Energetic decay products destroy nuclei produced in Big Bang Nucleosynthesis
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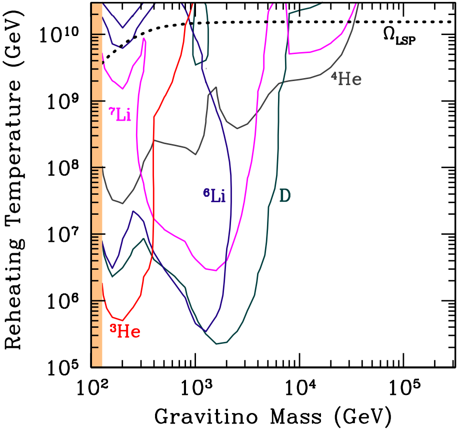

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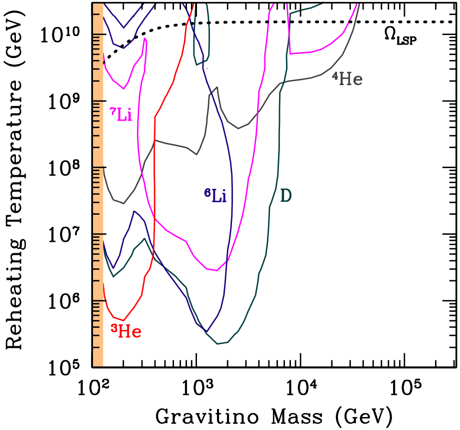

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⇝ $T_R \lesssim 10^7$ GeV or $m_{3/2} \gg 1$ TeV

⇝ Quite low T_R (leptogenesis: $T_R \gtrsim 10^9$ GeV) or unnatural spectrum

⇝ Motivation for gravitino LSP

Gravitino Production

- Thermal production at high temperature

$$\Omega_{3/2}^{\text{tp}} h^2 \simeq 0.12 \left(\frac{T_\text{R}}{10^9\,\text{GeV}} \right) \left(\frac{m_{\widetilde{g}}}{10^3\,\text{GeV}} \right)^2 \left(\frac{30\,\text{GeV}}{m_{3/2}} \right)$$

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- Observed dark matter abundance: $\Omega_\mathrm{DM} h^2 \simeq 0.12$

$\rightsquigarrow$ Gravitino LSP feasible candidate for cold DM

Big Bang Nucleosynthesis with Gravitino LSP

- NLSP long-lived $\rightsquigarrow$ still problems with BBN (and CMB)
- Charged NLSPs form bound states with nuclei
  $\rightsquigarrow$ BBN reaction rates change $\rightsquigarrow$ Overproduction of ^{6}Li
  Pospelov, PRL **98** (2007)
- Bounds depend on kind of NLSP and on Ω_{NLSP}
- Assume Ω_{NLSP} to be given by thermal relic density

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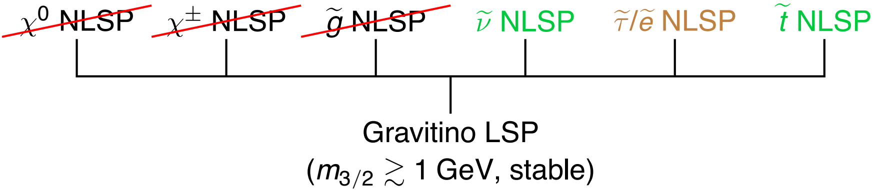
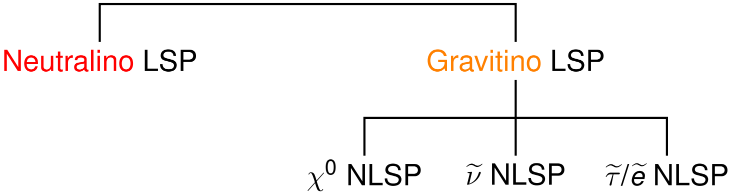


Gaugino-Mediated Supersymmetry Breaking

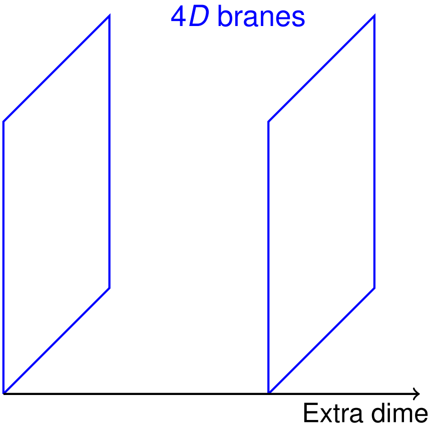
- Scenario for SUSY breaking without flavor and CP problems
  Kaplan, Kribs, Schmaltz, PRD **62** (2000)
  Chacko, Luty, Nelson, Pontón, JHEP **01** (2000)
- Dark matter candidate: neutralino or gravitino
- Long-lived charged slepton NLSP $\rightsquigarrow$ unusual LHC phenomenology
- Squarks significantly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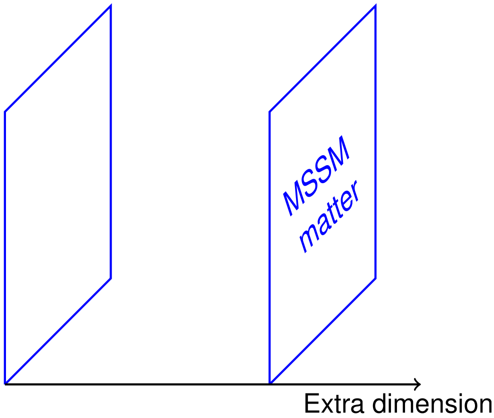

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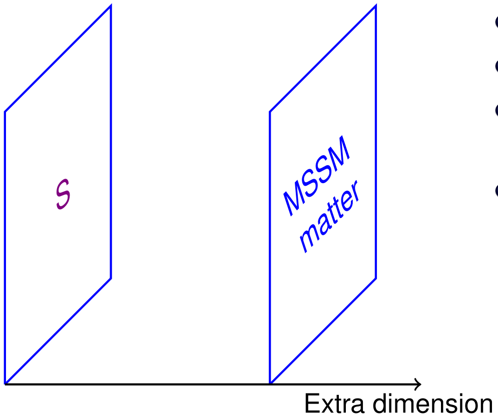

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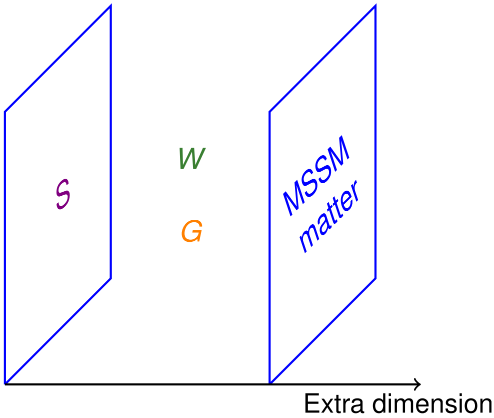

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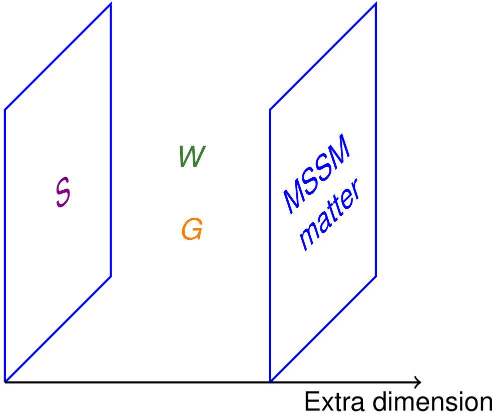

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- No soft masses for squarks and sleptons $\rightsquigarrow$ no flavor problem

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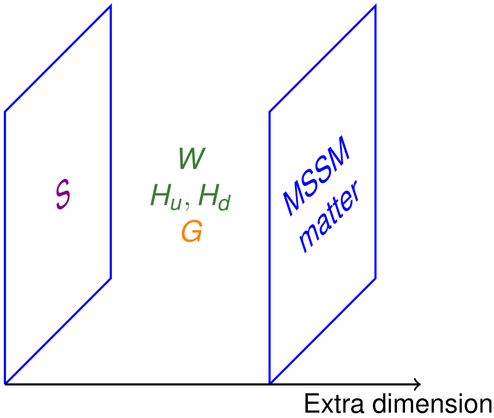

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- D dimensions
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- In the bulk: gauge and Higgs fields, gravity
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The Higgs Likes Trilinears

Light Higgs mass incl. dominant 1-loop corrections

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

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

Large trilinears favorable

Trilinears in Gaugino Mediation

- Original version I: Higgs fields on brane
  - $\rightsquigarrow$ vanishing trilinear scalar couplings A_0 (at high energy)
    Kaplan, Kribs, Schmaltz, PRD **62** (2000)
- Original version II: Higgses in bulk but only couplings $S^\dagger S\, H^\dagger_{u,d} H_{u,d}$
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    Chacko, Luty, Nelson, Pontón, JHEP **01** (2000)
- Bulk Higgses, all couplings allowed by symmetry (incl. $S\, H_{u,d}^\dagger H_{u,d}$)
  - $\rightsquigarrow$ Non-vanishing trilinears proportional to Yukawa matrices
    Brümmer, Kraml, Kulkarni, JHEP **08** (2012)
  - $\rightsquigarrow$ Different values possible in up and down sector
    Heisig, JK, Murphy, Strümke, JHEP **05** (2017)

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 $m^2_{H_u}, m^2_{H_d} \geq 0$
- $\tan\beta$
- $\text{sign}(\mu) = +1$

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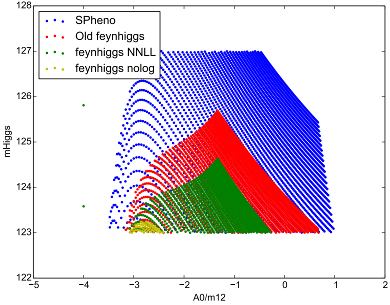
Running generates non-zero masses at low energies
Calculated using SPHENO 3.3.8

Porod, Comput. Phys. Commun. **153** (2003)
Porod & Staub, Comput. Phys. Commun. **183** (2012)

Calculated using FeynHiggs 2.12.2

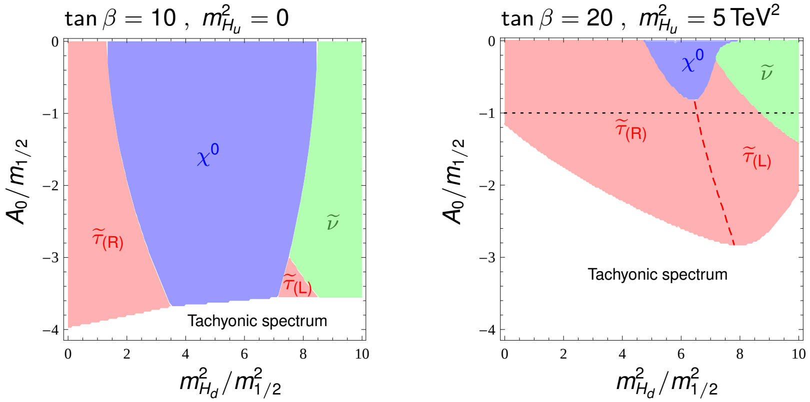
Heinemeyer, Hollik, Weiglein, EPJC **9** (1999), Comput. Phys. Commun. **124** (2000)
Degrassi, Heinemeyer, Hollik, Slavich, Weiglein, EPJC **28** (2003)
Frank, Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, JHEP **02** (2007)
Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, PRL **112** (2014)
Bahl & Hollik, EPJC **76** (2016)



- FeynHiggs value $\simeq$ 3 GeV smaller than SPheno 3
- Agreement with SPheno 4
  Staub & Porod, EPJC **77** (2017)
- Downward shift by $\simeq$ 1 GeV between FH 2.11 and 2.12 (mid-2016)
- Main reason: more accurate calculation of electroweak corrections to $\overline{\text{MS}}$ top mass
  Bahl & Hollik, EPJC **76** (2016)

NLSP Candidates

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



Heisig, Kersten, Murphy, Strümke, JHEP **05** (2017)

LHC Constraints

- 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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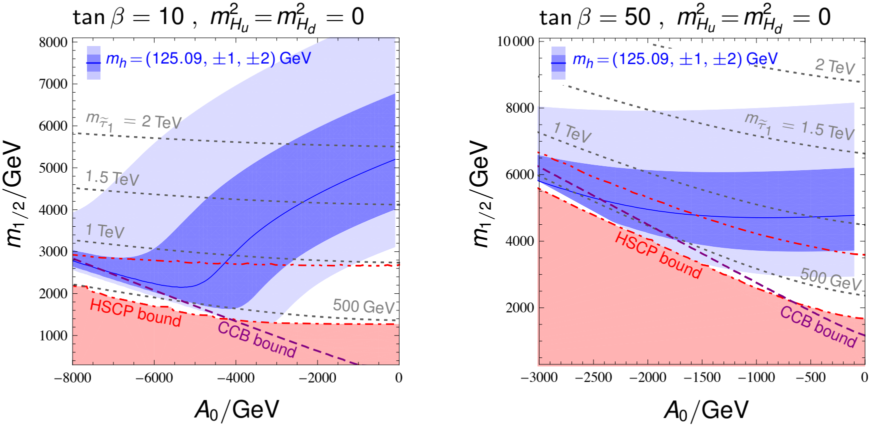

Heisig, Kersten, Murphy, Strümke, JHEP **05** (2017)

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 $m_{\text{NLSP}} \sim (400 \ldots 1400)$ GeV
- Neutral NLSP too heavy for LHC
- Stau NLSP metastable $\rightsquigarrow$ accessible in HSCP searches at LHC

Couplings to Hidden Sector

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