A Light Singlet in Gauge Mediation

Robert Ziegler (LPTHE)

based on work with

B. Allanach, M. Badziak, C. Hugonie

(to appear)

Introduction

The Higgs weighs 125 GeV → **Why is the Higgs so light ???**

Supersymmetry! → **Why is the Higgs so heavy ?**

MSSM

$m_h|_{\text{tree}} \leq M_Z$

need large loop corrections

Beyond MSSM

new tree-level contributions:

F-terms / D-terms / **Mixing**

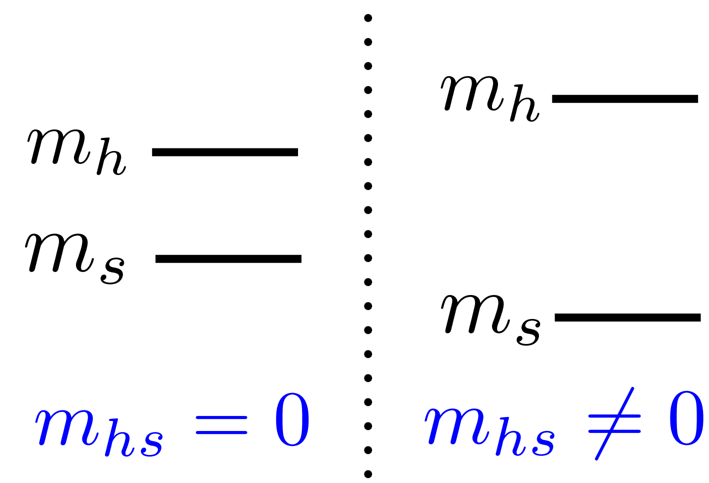
Mixing in the NMSSM

Add singlet to MSSM
to solve mu-problem

$$W_{\rm NMSSM} = \lambda S H_u H_d - \frac{\kappa}{3} S^3$$

Can mix with Higgs:
if lighter mass push-up

$$\begin{pmatrix} m_h^2 & m_{hs}^2 \\ m_{hs}^2 & m_s^2 \end{pmatrix} \xrightarrow{m_h > m_s}$$



Strongest constraints
come from LEP

$\sin\theta \lesssim 0.5$ for $m_s \sim (90 \div 100)$ GeV

Contribution to Higgs mass can be sizable ~ 8 GeV

Badziak, Olechowski, Pokorski '13

The NMSSM and Gauge Mediation

Study mixing scenario in simple & predictive framework of SUSY breaking:

Gauge Mediation $W_{\rm GM} = X\, \underbrace{\bar{\Phi}_i \Phi_i}_{\text{messengers}}$

[NMSSM also easiest solution for $\mu - B_\mu$ problem!]

Minimal Gauge Mediation does not work: soft singlet mass too small (3-loop)

The DGS Model

Delgado, Giudice, Slavich '07

Direct couplings singlet-messengers

$$W_{\rm DGS} = \xi S \underbrace{\bar{\Phi}_1 \Phi_2}_{\text{messengers}}$$

Give new contribs to NMSSM soft terms

$$A_\lambda \sim A_\kappa \sim \xi^2 \tilde{m} \qquad m_S^2 \sim \xi^4 \tilde{m}^2$$

$$\tilde{m} \equiv 1/(16\pi^2)\, F/M \approx m_{\tilde{g}}/2$$

Only 4 parameters: $\lambda, \ \tilde{m}, \ \xi, \ M$

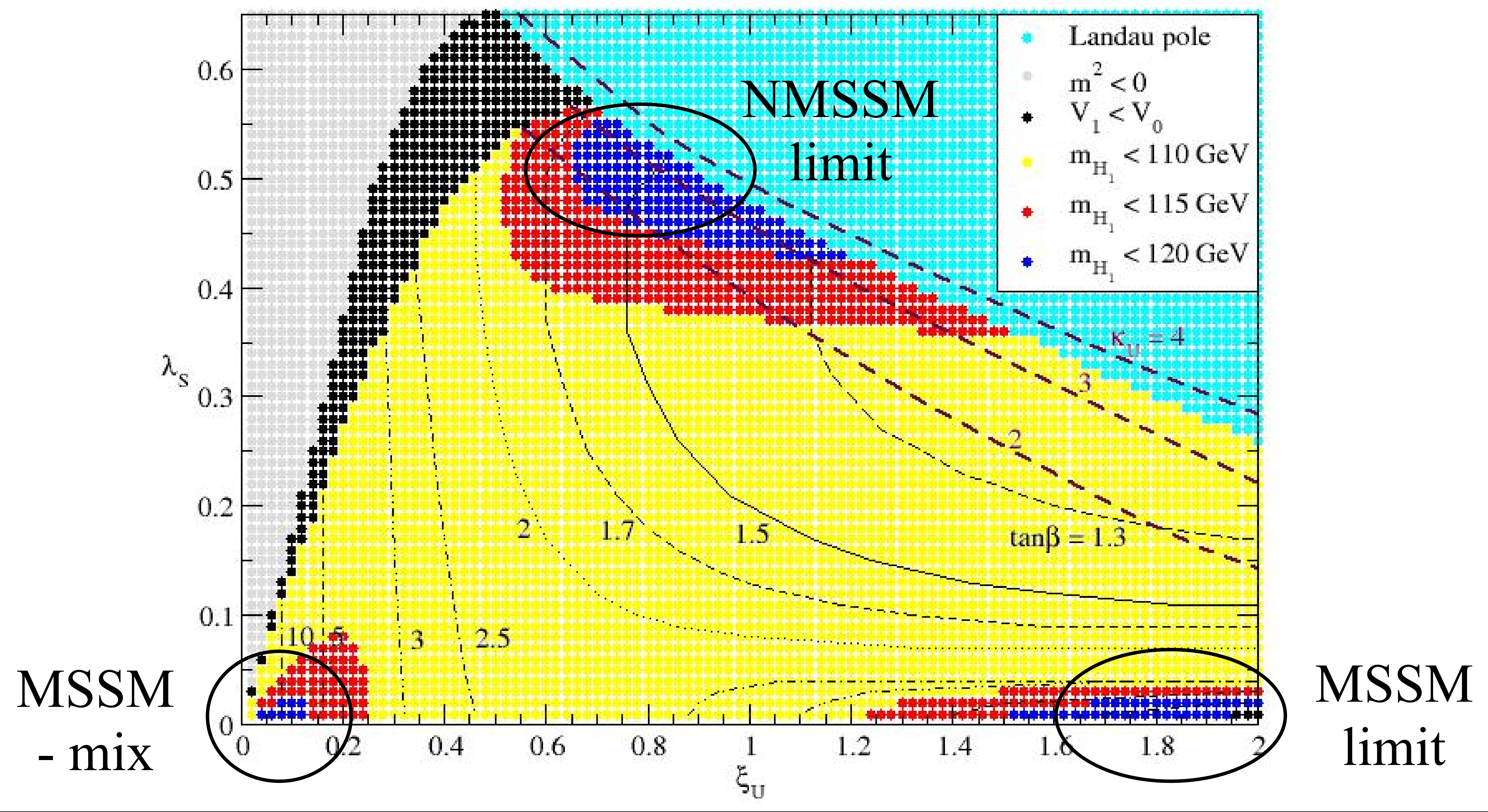
[correct EWSB fixes κ and $\tan\beta$]

DGS Parameter Space

Only 3 regions with sizable Higgs mass

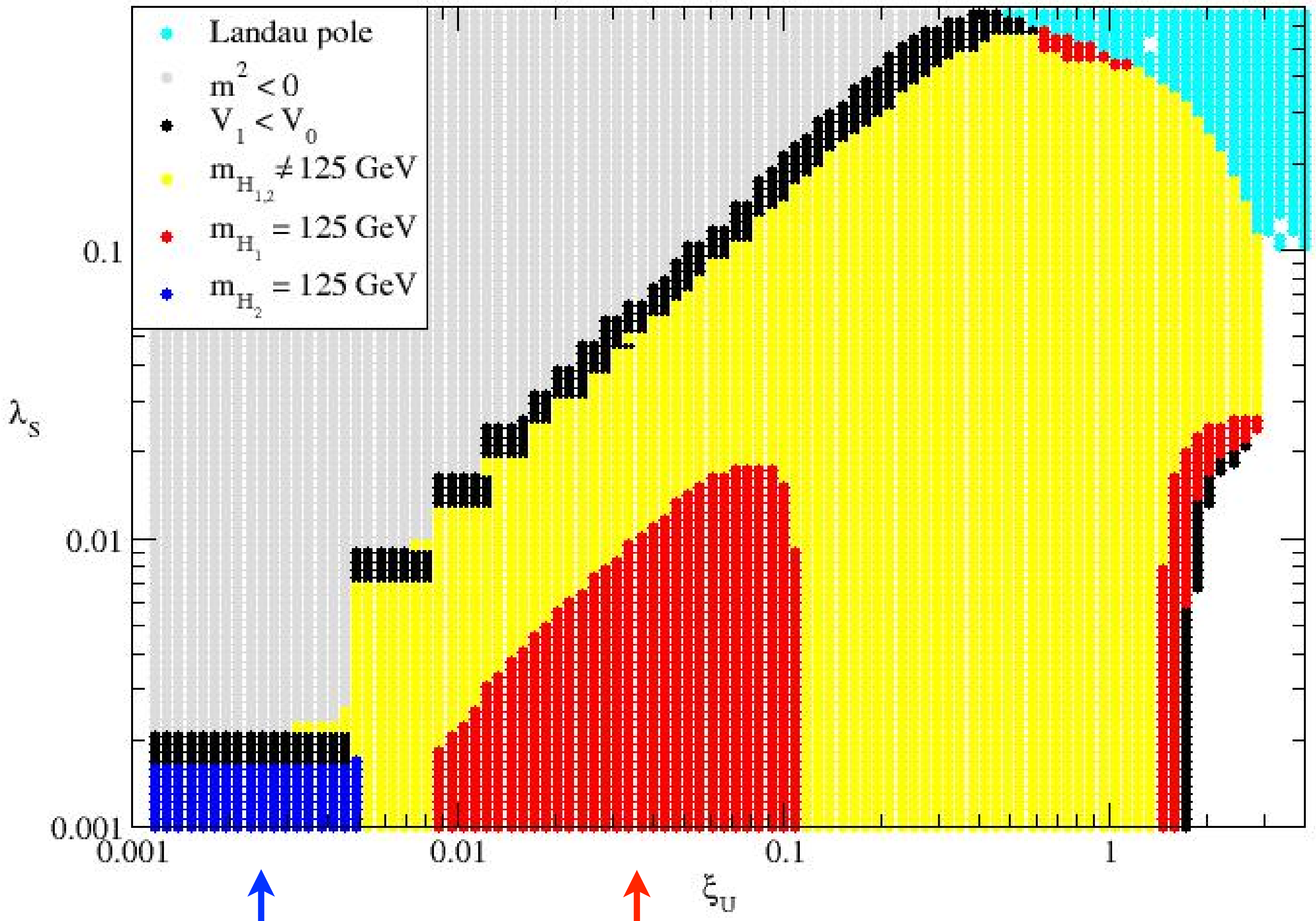
$$m_h^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + m_{h,\text{mix}}^2 + m_{h,\text{loop}}^2$$

bounded by M_Z^2 (perturbativity up M_{GUT})



The Push-Up Region

Want positive mixing contrib: $m_h > m_s$



$h_{\rm SM} \approx h_2$ $h_{\rm SM} \approx h_1$

→ **Need** $\xi \ll 1, \lambda \ll 1$

Higgs Spectrum

Higgs sector fixes 3 from 4 parameters

$m_s \sim 90 - 100\,\mathrm{GeV}$

$m_h \sim 122 - 128\,\mathrm{GeV}$

$\sin\theta = \max \lesssim 0.5$

→

$\xi \sim 0.02$

$\tilde{m} \sim 600\,\mathrm{GeV}$

$\lambda \sim 0.01$

Determines remaining spectrum

Pseudoscalar $m_{a_1} \sim m_s/3$

Singlino NLSP $m_{\tilde{s}} \sim m_s$

Only free parameter is messenger scale M

determines **Gravitino=LSP** couplings and NNLSP

Two Benchmarks

	$\tilde{m}$ (GeV)	M (GeV)	$\lambda(M_S)$	$\xi_U(M_{\text{GUT}})$	$\kappa(M_S)$	$\tan\beta$
Point 1	592	8.8×10^{14}	9.1×10^{-3}	3.2×10^{-2}	5.7×10^{-4}	16
Point 2	746	1.4×10^{6}	1.0×10^{-2}	1.2×10^{-2}	7.0×10^{-4}	25

	m_{h_1}	m_{h_2}	m_{a_1}	$m_{\tilde{N}_1}$	$m_{\tilde{N}_2}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{g}}$	$m_{\tilde{u}_R}$	$m_{\tilde{t}_1}$	$m_{\tilde{G}}$
Point 1	94	122	40	104	251	433	1367	1364	1064	20
Point 2	92	122	26	101	321	283	1720	1787	1631	4×10^{-8}
	Higgs			NLSP	NNLSP		colored sparticles [mGM: > 3 TeV]			LSP

In contrast to Minimal Gauge Mediation in MSSM

colored sparticles in reach of LHC

due to large mixing contrib to Higgs mass $\Delta m_h \approx 6\,\text{GeV}$

Phenomenology

SUSY decay chains pass through NNLSP and NLSP

	large M		small M	
....	↓		↓	
NNLSP	$\tilde{N}_2$		$\tilde{\tau}_1 \ (\tilde{e}_R, \tilde{\mu}_R)$	
	↓ ↦	$h_{1,2} \rightarrow b\bar{b}$	↓ ↦	$\tau \, (e, \mu)$
NLSP	$\tilde{N}_1$		$\tilde{N}_1$	
$c\tau$ depends on M:	displaced/outside detector		displaced/prompt	
	↓ ↦	$a_1 \rightarrow b\bar{b}$	↓ ↦	$a_1 \rightarrow b\bar{b}$
LSP	$\tilde{G}$		$\tilde{G}$	

Summary

- Re-analyzed DGS model for GMSB + NMSSM: New regions in parameter space with light singlet
- Large mixing with SM-like Higgs gives large contribution to tree-level Higgs mass ~ 6 GeV
- Allows for light colored SUSY spectrum ~ 1-2 TeV in LHC reach, in contrast to mGMSB + MSSM
- Singlino NLSP & Gravitino LSP lead to interesting collider pheno with additional (displaced) final states

Backup

The complete DGS model

$$W = W_{\rm NMSSM} + W_{\rm GM} + W_{\rm DGS}$$

$$W_{\rm NMSSM} \;=\; \lambda S H_u H_d - \frac{\kappa}{3} S^3 \,,$$

$$W_{\rm GM} \;=\; X \sum_{i=1,2} \left(\kappa_i^D \bar{\Phi}_i^D \Phi_i^D + \kappa_i^T \bar{\Phi}_i^T \Phi_i^T \right)$$

$$W_{\rm DGS} \;=\; S \left(\xi_D \bar{\Phi}_1^D \Phi_2^D + \xi_T \bar{\Phi}_1^T \Phi_2^T \right)$$

$$\xi = \xi_D(M_{\rm GUT}) = \xi_T(M_{\rm GUT})$$

The complete soft terms in DGS

$$
\begin{aligned}
M_i &= 2g_i^2\tilde{m}\,, \\
m_{\tilde{f}}^2(M) &= 4\sum_{i=1}^{3} C_i(f)\; g_i^4\tilde{m}^2\,,
\end{aligned}
$$

$$
A_\lambda = \frac{A_\kappa}{3} = -\tilde{m}\left(2\xi_D^2 + 3\xi_T^2\right)
$$

$$
\begin{aligned}
\tilde{m}_S^2 &= \tilde{m}^2\left[8\xi_D^4 + 15\xi_T^4 + 12\xi_D^2\xi_T^2\right] \\
&- \tilde{m}^2\left[\xi_D^2(\frac{6}{5}g_1^2 + 6g_2^2) + \xi_T^2(\frac{4}{5}g_1^2 + 16g_3^2)\right] \\
&- \tilde{m}^2\left[4\kappa^2\left(2\xi_D^2 + 3\xi_T^2\right)\right]\,,
\end{aligned}
$$

$$
\Delta\tilde{m}_{H_u}^2 = \Delta\tilde{m}_{H_d}^2 = -\tilde{m}^2\lambda^2\left(2\xi_D^2 + 3\xi_T^2\right)
$$

Approximate Relations

$$\xi \sim \frac{m_s}{4\sqrt{2} g_3 \tilde{m}} \qquad \lambda \sim \frac{m_h^2 - m_s^2}{4 v \tilde{m}} \sin 2\theta$$

$$\frac{m_{a^s}}{m_s} \approx \sqrt{\frac{45\sqrt{8}\xi}{32 g_3}} \qquad m_{\tilde{s}}^2 \approx m_s^2 + \frac{1}{3} m_{a^s}^2$$

$$m_{3/2} = 38\,\mathrm{eV} \left(\frac{\tilde{m}}{\mathrm{TeV}}\right) \left(\frac{M}{10^6\,\mathrm{GeV}}\right)$$

$$c\tau_{\tilde{N}_1} \approx 2.4\,\mathrm{cm} \left(\frac{100\,\mathrm{GeV}}{M_{\tilde{N}_1}}\right)^5 \left(\frac{M}{10^6\,\mathrm{GeV}}\right)^2 \left(\frac{\tilde{m}}{\mathrm{TeV}}\right)^2$$