

# Muon $g - 2$ , Neutralino Dark Matter and Stau NLSP

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# Outline

- SUSY and MSSM
- Muon  $g - 2$  in MSSM
- Fundamental parameter space
- Experimental Constraints
- Mass Spectrum
- Dark Matter Implications
- Conclusion

- Resolution of the gauge hierarchy problem.
- Presence of non-baryonic dark matter (DM) candidates.
- Unification of the SM gauge couplings assuming TeV scale SUSY.
- Addresses muon  $g - 2$  anomaly  $\rightarrow \Delta a_\mu = (25.1 \pm 5.9) \times 10^{-10}$

$$SU(4)_c \times SU(2)_L \times SU(2)_R$$

- First example of quark-lepton unification.
- Electric charge quantization.
- Matter fields reside in  $(4, 2, 1)$  and  $(\bar{4}, 1, 2)$  representations.
- Absence of gauge boson mediated proton decay.
- If  $4 - 2 - 2$  is broken to the SM using tensor representations a  $Z_2$  gauge symmetry is left unbroken.

In a supersymmetric setting this is precisely “matter” parity  
 $\implies$  stable

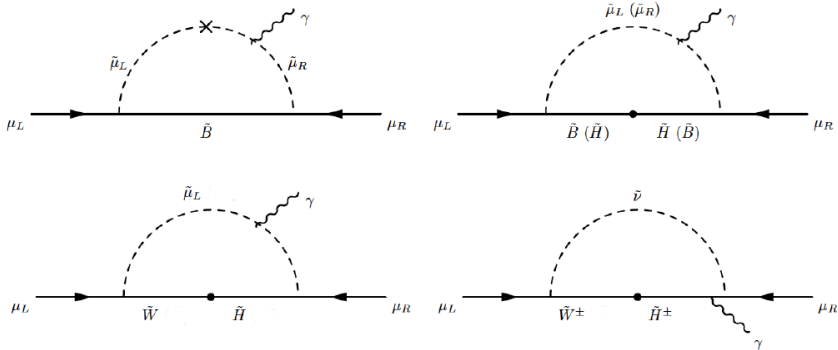
LSP dark matter candidate.

- In this talk, based on SUSY 4-2-2 I will assume that the soft SUSY breaking scalar and gaugino masses do not respect left-right symmetry but are flavor universal.
- Non-universal gaugino masses at the GUT scale:

$$M_1 = \frac{3}{5}M_{2R} + \frac{2}{5}M_4 ,$$

where  $M_{2R}$  and  $M_4$  denote the gaugino mass terms for  $SU(2)_R$  and  $SU(4)_c$ , respectively, and  $M_3 = M_4$  at  $M_{GUT}$ .

# Muon $g - 2$ in MSSM



$$\Delta a_\mu \approx C_\mu \text{sign}(\mu M_i) \left( \frac{500 \text{ GeV}}{M_{\text{SUSY}}} \right) \frac{\tan \beta}{40}, \quad C_\mu = \begin{cases} \frac{2.4\mu}{500 \text{ GeV}} \times 10^{-10} & \text{for BLR,} \\ 1.2 \times 10^{-10} & \text{for BHL,} \\ -2.4 \times 10^{-10} & \text{for BHR,} \\ 21 \times 10^{-10} & \text{for WHL.} \end{cases}$$

# Fundamental parameter space

Low Scale	GUT Scale
$m_{\tilde{\mu}_L}, m_{\tilde{\nu}}$	$m_L$
$m_{\tilde{\mu}_R}$	$m_R$
$M_{\tilde{B}}$	$M_1$
$M_{\tilde{W}}$	$M_2$
$\mu$	$m_{H_u}, m_{H_d}$
$A_\mu$	$A_0$
$\tan \beta$	$\tan \beta$

$$\begin{aligned}
 0 &\leq m_L && \leq 5 \text{ TeV} \\
 0 &\leq M_{2L} && \leq 5 \text{ TeV} \\
 -3 &\leq M_3 && \leq 5 \text{ TeV} \\
 -3 &\leq A_0/m_L && \leq 3 \\
 1.2 &\leq \tan \beta && \leq 60 \\
 0 &\leq x_{LR} && \leq 3 \\
 -3 &\leq y_{LR} && \leq 3 \\
 0 &\leq x_d && \leq 3 \\
 -1 &\leq x_u && \leq 2
 \end{aligned}$$

where,

$$\begin{aligned}
 m_R &= x_{LR} m_L \\
 M_{2R} &= y_{LR} M_{2L} \\
 m_{H_d}^2 &= x_d m_L^2 \\
 m_{H_u}^2 &= x_u m_L^2
 \end{aligned}$$

# Experimental Constraints

$$m_h = 123 - 127 \text{ GeV}$$

$$m_{\tilde{g}} \geq 2.1 \text{ TeV (800 GeV if it is NLSP)}$$

$$0.8 \times 10^{-9} \leq \text{BR}(B_s \rightarrow \mu^+ \mu^-) \leq 6.2 \times 10^{-9} \text{ (} 2\sigma \text{)}$$

$$2.99 \times 10^{-4} \leq \text{BR}(B \rightarrow X_s \gamma) \leq 3.87 \times 10^{-4} \text{ (} 2\sigma \text{)}$$

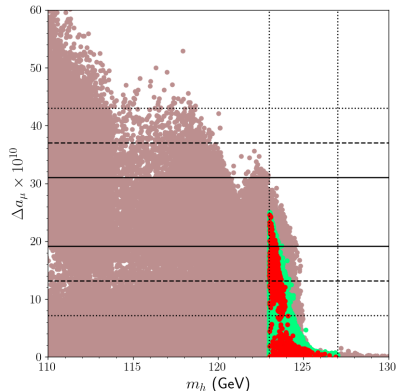
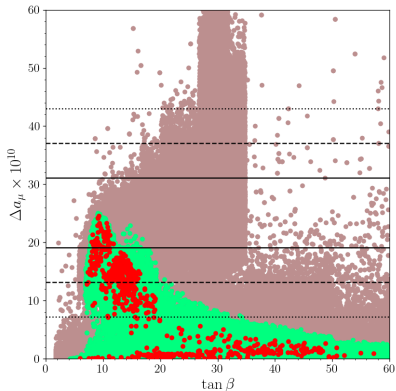
$$0.114 \leq \Omega_{\text{CDM}} h^2 \leq 0.126$$

$$m_t = 173.3 \text{ GeV}$$

$$\mu > 0$$

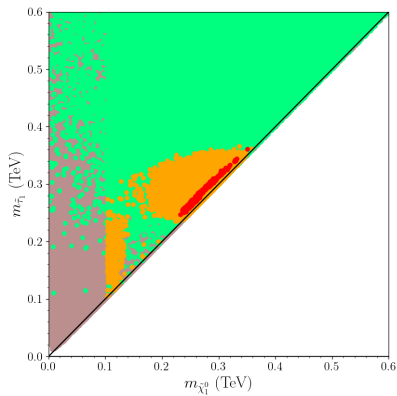
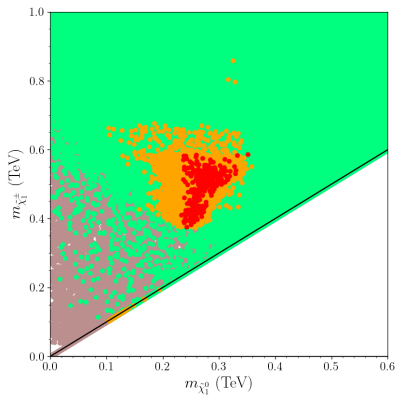


# $\tan \beta$ and Higgs mass

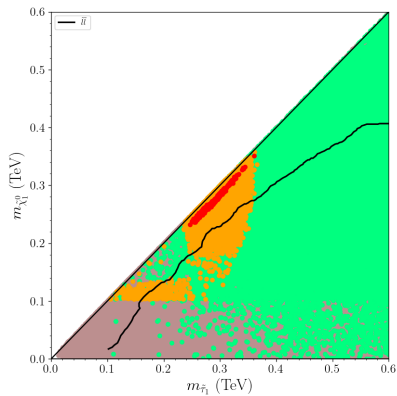
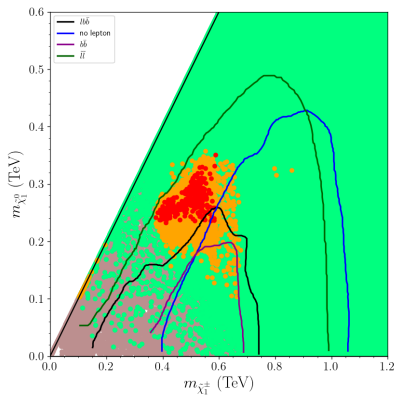


$$\Delta m_h^2 \simeq \frac{m_t^4}{16\pi^2 v^2 \sin^2 \beta} \frac{\mu A_t}{M_{\text{SUSY}}^2} \left[ \frac{A_t^2}{M_{\text{SUSY}}^2} - 6 \right] +$$
$$\frac{y_b^4 v^2}{16\pi^2} \sin^2 \beta \frac{\mu^3 A_b}{M_{\text{SUSY}}^4} + \frac{y_\tau^4 v^2}{48\pi^2} \sin^2 \beta \frac{\mu^3 A_\tau}{m_\tau^4}$$

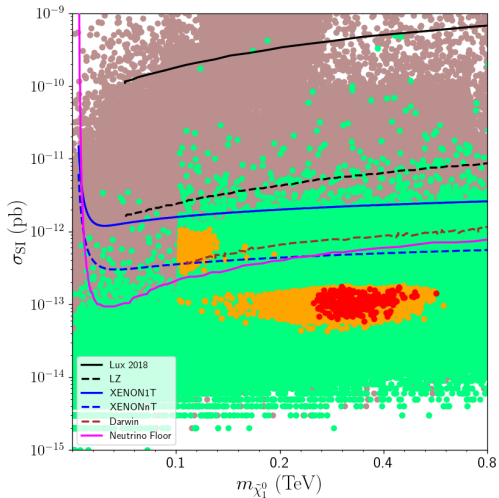
# Stau Coannihilation



# Bounds from the collider searches



# Dark Matter Implications



# Benchmark table

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
$m_{\tilde{L}}$	335.319	375.605	311.513	377.107	330.994	361.925
$M_1$	616.148	672.019	633.965	767.804	787.614	1282.26
$M_{2L}$	731.027	747.131	603.037	721.392	698.554	327.194
$M_3$	4819.28	4920.39	4274.83	5067.11	4789.29	4505.82
$A_0/m_{\tilde{L}}$	-1.87	-1.71	-2.93	-1.52	-1.52	0.73
$\tan \beta$	9.08099	11.7627	16.1768	9.44659	7.63402	18.6131
$x_{LR}$	0.79	0.88	2.12	0.88	0.86	2.2
$y_{LR}$	-2.99	-2.89	-2.97	-2.91	-2.69	-2.65
$m_{\tilde{R}}$	265.065	329.393	660.442	331.076	285.988	795.804
$M_{2R}$	-2185.94	-2160.23	-1793.28	-2098.4	-1880.17	-866.78
$\mu$	4875.83	4951.28	4402.88	5098.57	4839.6	4493.68
$\Delta a_\mu \times 10^{10}$	<b>24.28</b>	19.8	15.05	16.99	14.91	13.92
$m_h$	123.07	123.142	123.031	<b>123.541</b>	123.03	123.215
$m_H$	4999.35	5061.57	4404.11	5222.41	5062.4	4498.81
$m_A$	4999.31	5061.55	4404.11	5222.38	5062.35	4498.81
$m_{H^\pm}$	4996.57	5058.82	4401.99	5219.5	5059.58	4496.11
$m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}$	<b>238, 543</b>	<b>263, 557</b>	<b>250, 441</b>	<b>305, 532</b>	<b>315, 514</b>	<b>194, 530</b>
$m_{\tilde{\chi}_3^0}, m_{\tilde{\chi}_4^0}$	4991, 4992	5068, 5069	4504, 4505	5219, 5220	4956, 4957	4607, 4607
$m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}$	544, 4992	557, 5069	442, 4505	532, 5220	515, 4957	<b>195, 4607</b>
$m_{\tilde{g}}$	9549	9741	8555	10017	9501	9032
$m_{\tilde{u}_1}, m_{\tilde{u}_2}$	8049, 8050	8210, 8211	7231, 7259	8437, 8439	8012, 8012	7630, 7677
$m_{\tilde{t}_1}, m_{\tilde{t}_2}$	6979, 7525	7123, 7670	6267, 6724	7319, 7886	6945, 7492	6712, 7126
$m_{\tilde{d}_1}, m_{\tilde{d}_2}$	8051, 8055	8212, 8216	7231, 7262	8438, 8444	8012, 8018	7630, 7678
$m_{\tilde{b}_1}, m_{\tilde{b}_2}$	7518, 8031	7662, 8177	6713, 7196	7878, 8417	7484, 8001	7117, 7598
$m_{\tilde{\nu}_e, \mu}, m_{\tilde{\nu}_\tau}$	430, 418	459, 438	369, 331	451, 437	403, 394	293, 246
$m_{\tilde{e}_1, \tilde{\mu}_1}, m_{\tilde{e}_2, \tilde{\mu}_2}$	368, 437	447, 465	377, 703	445, 458	410, 446	303, 937
$m_{\tilde{\tau}_1}, m_{\tilde{\tau}_2}$	<b>255, 484</b>	<b>284, 535</b>	<b>268, 690</b>	<b>320, 523</b>	<b>325, 489</b>	<b>200, 919</b>
$\sigma_{SI}(pb)$	$1.15 \times 10^{-13}$	$7.7 \times 10^{-14}$	$6.7 \times 10^{-14}$	$1.05 \times 10^{-13}$	$1.71 \times 10^{-13}$	$4.86 \times 10^{-13}$
$\sigma_{SD}(pb)$	$1.05 \times 10^{-10}$	$1.04 \times 10^{-10}$	$1.69 \times 10^{-10}$	$8.97 \times 10^{-11}$	$1.06 \times 10^{-10}$	$2.58 \times 10^{-9}$
$\Omega h^2$	0.118	0.119	0.116	0.115	0.115	0.001

# Conclusion

- Higgs mass problematic for  $\tan\beta \gtrsim 17$
- Stau-neutralino Coannihilation
- A Bino-like Dark Matter
- Spin-independent scattering cross-sections on the order of  $10^{-13}$  pb.
- Testable in the near future.