Rare Meson Decays Into Light Neutralinos

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Outline

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Bounds On $m_{\tilde{\chi}_1^0}$

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2-Body Rare Meson Decays

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Introduction: The Minimal Supersymmetric Standard Model

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Standard Model in 4 commuting space-time dimensions

$+$ 4 anticommuting "dimensions"

$\Rightarrow$ double the number of particles, with the extras being 1/2 a unit of spin different from normal SM particles (plus an extra set of Higgs bosons and fermions for consistency).

Break supersymmetry softly and add R-parity to avoid lepton- and baryon-number-violating interactions $\Rightarrow$ the (usual) MSSM

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- 1 fermion from the electromagnetically neutral $SU(2)_L$ gauge boson W^3, the neutral wino (odd under R-parity): $\tilde{W}^0$
- 1 fermion from the $U(1)_Y$ gauge boson, the bino (odd under R-parity): $\tilde{B}$

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$\tilde{h}^0_d$, $\tilde{h}^0_u$, $\tilde{W}^0$ and $\tilde{B}$ mix into 4 mass eigenstates $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, $\tilde{\chi}^0_3$ and $\tilde{\chi}^0_4$ (odd under R-parity)

Neutralino Mass Matrix

$$(1/m_Z)\tilde{\chi}_i^{0\,T} M_{ij} \tilde{\chi}_j^0 =$$

$$(\tilde{B}\,\tilde{W}^0\,\tilde{h}_d^0\,\tilde{h}_u^0) \begin{pmatrix} M_1/m_Z & 0 & -s(\theta_W)c(\beta) & s(\theta_W)s(\beta) \\ 0 & M_2/m_Z & c(\theta_W)c(\beta) & -c(\theta_W)s(\beta) \\ -s(\theta_W)c(\beta) & c(\theta_W)c(\beta) & 0 & -\mu/m_Z \\ s(\theta_W)s(\beta) & -c(\theta_W)s(\beta) & -\mu/m_Z & 0 \end{pmatrix} \begin{pmatrix} \tilde{B} \\ \tilde{W}^0 \\ \tilde{h}_d^0 \\ \tilde{h}_u^0 \end{pmatrix}$$

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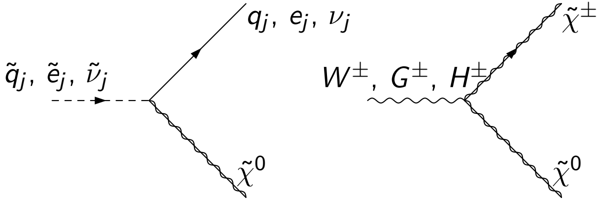
No GUT relation $\Rightarrow$ no bound on M_1 $\Rightarrow$ potentially massless $\tilde{\chi}_1^0$, almost completely $\tilde{B}$

Pre-Mixing Neutralino Couplings



$\tilde{\chi}^0 = \tilde{h}_d^0\ (d_j,\ e_j),\ \tilde{h}_u^0\ (u_j,\ \nu_j),$ $\tilde{W}^0\ (f_L),\ \tilde{B}\ (\text{all but } \nu_R)$

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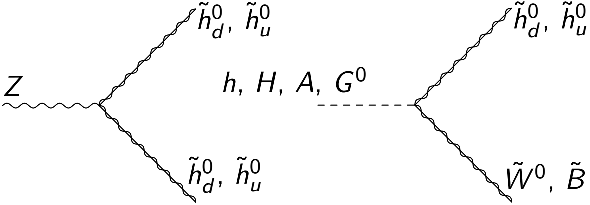

Bounds On $m_{\tilde{\chi}_1^0}$

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Colliders: masslessness of $\tilde{\chi}_1^0$ doesn't appreciably affect analyses with masses ≈ 100 GeV (bit bigger phase space)

Cosmology: $m_{\tilde{\chi}_1^0} > \mathcal{O}(10)$ GeV to have low enough relic density [D. Hooper and T. Plehn, Phys. Lett. B **562**, 18 (2003)], or $m_{\tilde{\chi}_1^0} < \mathcal{O}(1)$ eV to avoid disturbing large structure formation (hot DM candidate in this case) [U. Langenfeld, Ph. D. thesis, 2007]

So, assuming $m_{\tilde{\chi}_1^0} \approx 0$, is this allowed by rare meson decays?

Are there signals within reach of near-future experiments?

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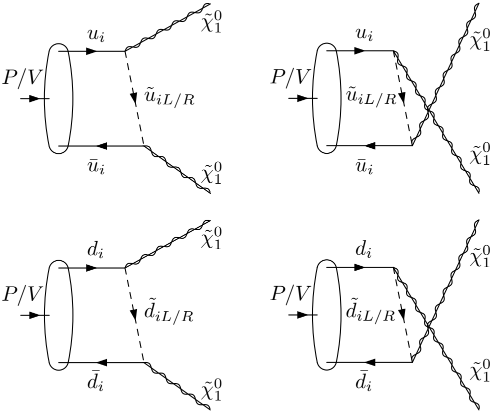
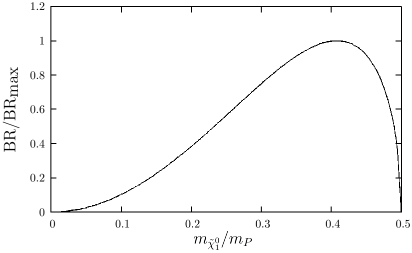
Are there signals within reach of near-future experiments?

H. K. Dreiner, S. Grab, D. Koschade, M. Krämer, U. Langenfeld, B. O'L.: rare meson decays into $\tilde{\chi}_1^0\tilde{\chi}_1^0$ (invisible) and into single lighter meson plus $\tilde{\chi}_1^0\tilde{\chi}_1^0$.

2-Body Rare Meson Decays Into $\tilde{\chi}_1^0 \tilde{\chi}_1^0$

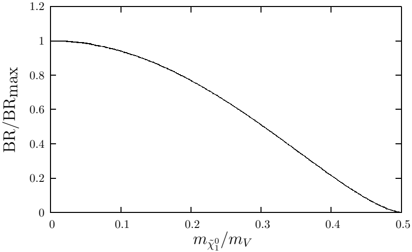


In following: conservative upper bounds, squarks decoupled or set to 100 GeV



Meson	BR($\rightarrow\tilde{\chi}_1^0\tilde{\chi}_1^0$)	Exp. bound
π^0	1.63×10^{-10}	2.7×10^{-7}
η	7.60×10^{-11}	6×10^{-4}
η'	3.83×10^{-12}	1.4×10^{-3}

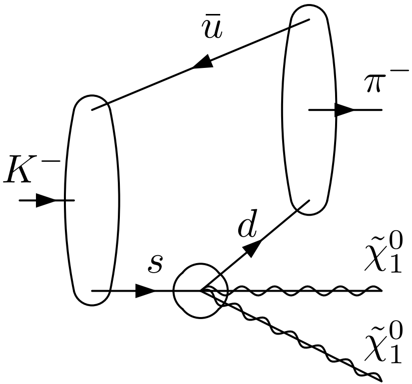
The branching ratio for a pseudoscalar $P\rightarrow\tilde{\chi}_1^0\tilde{\chi}_1^0$ against the ratio $m_{\tilde{\chi}_1^0}/m_P$ normalized to the peak branching ratio.



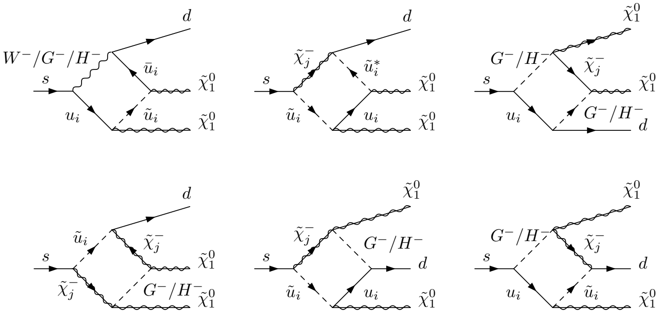
The branching ratio for a vector $V \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ against the ratio $m_{\tilde{\chi}_1^0}/m_V$ normalized to the peak branching ratio.

Meson	BR($\to \tilde{\chi}_1^0 \tilde{\chi}_1^0$)	Exp. bound
ρ^0	8.01×10^{-15}	n/a
ω	7.51×10^{-14}	n/a
ϕ	1.57×10^{-13}	n/a
J/ψ	5.12×10^{-9}	5.9×10^{-4}
Υ	4.47×10^{-8}	2.5×10^{-3}

3-Body Rare Meson Decays Into $\tilde{\chi}_1^0\tilde{\chi}_1^0$ Other Meson



Overview of the decay $K^- \to \pi^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$.

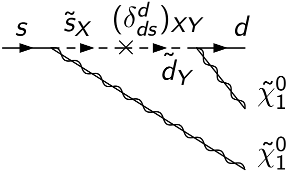


Box Feynman diagrams for the decay $s \rightarrow d\tilde{\chi}_1^0\tilde{\chi}_1^0$.

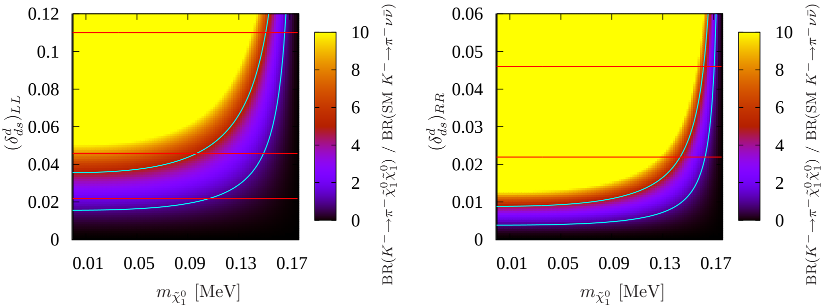
$$\begin{aligned}\mathcal{M} \;=\;& C_{11}\bar{u}(k_1)\not{F}\gamma^5 v(k_2) \\ & + C_{22}\frac{F\cdot k_1}{m_K^2}\bar{u}(k_1)\not{p}_s\gamma^5 v(k_2) + C_{23}\frac{F\cdot(p_K - p_\pi)}{m_K(m_s+m_d)}\bar{u}(k_1)\not{p}_s\gamma^5 v(k_2) \\ & + C_{32}\frac{F\cdot k_1}{m_K}\bar{u}(k_1)P_L v(k_2) + C_{33}\frac{F\cdot(p_K - p_\pi)}{(m_s+m_d)}\bar{u}(k_1)P_L v(k_2) \\ & + C_{42}\frac{F\cdot k_1}{m_K}\bar{u}(k_1)P_R v(k_2) + C_{43}\frac{F\cdot(p_K - p_\pi)}{(m_s+m_d)}\bar{u}(k_1)P_R v(k_2)\end{aligned}$$

C_{11}	C_{22}	C_{23}	C_{32}	C_{33}	C_{42}	C_{43}	BR	BR/exp
-2.1×10^{-13}	-7.9×10^{-17}	0.0	-5.0×10^{-18}	0.0	-2.5×10^{-18}	0.0	1.3×10^{-15}	8.9×10^{-6}

Numerical values for pseudo-SPS1a (all Cs in GeV^{-2}).



If minimal flavor violation is not assumed, this decay can take place at tree-level too.



BR$(K^- \to \pi^- \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ normalized to BR$(K^- \to \pi^- \nu\bar{\nu}) = 8.0 \times 10^{-11}$ (squark mass of 500 GeV).
Upper turquoise line = exp. BR $+2\sigma$, lower = SM prediction.
Red lines = upper bounds on $(\delta^d_{ds})_{LL}$ from K^0–$\bar{K}^0$ for different ratios of squark and gluino masses.

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