Problem set 4

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Problem 8: Sneutrinos

In addition to the neutralino, the MSSM contains another potential dark matter candidate: the *sneutrino* $\tilde{\nu}$, i.e. the spin-0 superpartner of the left-handed neutrino. Sneutrinos have the same gauge interactions as left-handed neutrinos, as well as two further interaction vertices: The first involves a sneutrino, a Standard Model neutrino and a neutralino $\tilde{N}$; the second involves a sneutrino, a charged Standard Model lepton and a chargino $\tilde{C}$. The coupling constants associated to these two vertices depend on the composition of the neutralinos and charginos. For the case of winos, the coupling is given by the weak coupling constant $\alpha_\mathrm{w} \approx 0.03$.

a) Draw the Feynman diagrams for all processes contributing to $\tilde{\nu}\bar{\tilde{\nu}} \to f\bar{f}$. Be careful to distinguish fermionic and scalar particles and to ensure that charge and angular momentum is conserved at each vertex.

b) Using dimensional analysis, and assuming $\sigma v \propto m_{\tilde{\nu}}^2$, identify the diagrams that give the dominant contribution in the case that $m_{\tilde{\nu}} \ll m_Z \ll m_{\tilde{N}}, m_{\tilde{C}}$.

c) Draw the diagram corresponding to the process $\tilde{\nu}\tilde{\nu} \to \nu\nu$, which involves no anti-particles.

d) In contrast to the processes considered above, this new diagram leads to a cross section that is independent of $m_{\tilde{\nu}}$. Under what condition does the new diagram give the dominant contribution to the total annihilation cross section?

e) Show that sneutrinos do not have to respect the Lee-Weinberg bound (see problem 6), i.e. even sub-GeV sneutrinos can have an acceptable relic abundance, provided $m_{\tilde{N}}$ is not too large.

Light left-handed sneutrinos have been excluded experimentally by collider searches and direct detection experiments. However, if the Standard Model is extended to include also right-handed neutrinos (for example to explain neutrino oscillation experiments), their superpartners would be viable dark matter candidates.

Problem 9: Simplified models and effective field theories

Consider the simplified model given by

$$\mathcal{L} \supset g_\chi \, \phi \bar{\chi} \chi + g_f \sum_f \frac{m_f}{v_{\text{EW}}} \, \phi \bar{f} f \; , \tag{1}$$

where the sum includes all Standard Model fermions, m_f denotes the respective fermion masses and $v_{\text{EW}} \approx 246\,\text{GeV}$ is the electoweak vacuum expectation value. This simplified model can be mapped onto the effective field theory

$$\mathcal{L} \supset \frac{1}{\Lambda^3} \sum_f m_f \, \bar{\chi} \chi \, \bar{f} f \; . \tag{2}$$

a) Determine Λ as a function of the parameters of the simplified model.

b) Using results from the lecture, find the total dark matter annihilation cross section by summing over all Standard Model final states.

c) Calculate the dark matter relic abundance as a function of Λ for $m_\chi = 20$, 60, 200, 600 GeV. Hint: Include only those final states that give a relevant contribution.

d) Determine the corresponding values of Λ that yield the observed dark matter relic abundance. For which combinations of m_χ and Λ is the effective field theory result reliable?