An effective coupling approach to neutralino dark matter relic density at one loop

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Motivation

- CDM scenario $\Rightarrow \Omega h^2 \propto \frac{1}{\sigma}$
- Loop corrections to $\sigma$ will change relic density at one loop level
- **Aim:** To improve the relic density calculations by improving annihilation cross-section of neutralino
- **This work:** Including electroweak corrections to neutralino annihilation cross-section in effective coupling formalism and assessing the validity
- **Advantage:** Requires computing a few hundred loop diagrams as opposed to few thousands for full one loop
Who is this Neutralino?

After $SU(2)_L \times U(1)_Y \rightarrow U(1)_{\text{EM}}$:

\[ \tilde{W}^\pm, \tilde{H}^\pm \xrightarrow{\text{MIX}} \chi_{i=1,2}^{\pm} \quad \text{Charginos} \]

\[ \tilde{B}^0, \tilde{W}^0, \tilde{h}^0, \tilde{H}^0 \xrightarrow{\text{MIX}} \chi_{i=1,2,3,4}^0 \quad \text{Neutralinos} \]

Neutralino mass matrix

\[
M_D^0 = N^* M N^\dagger
\]

Neutralino mass matrix

\[
M = \begin{pmatrix}
M_1 & 0 & -M_Z c_\beta & M_Z s_\beta \\
0 & M_2 & M_Z c_\beta & 0 \\
-M_Z c_\beta & M_Z c_\beta & 0 & -\mu \\
M_Z s_\beta & -M_Z s_\beta & -\mu & 0 \\
\end{pmatrix}
\]

\[
\tilde{\chi}_0^1 = N_{11} \tilde{B}^0 + N_{12} \tilde{W}^0 + N_{13} \tilde{h}^0 + N_{14} \tilde{H}^0
\]
Effective couplings

Set of flavor independent (universal) corrections to the cross-section and are similar to oblique corrections in the Standard Model

Exploit the non-decoupling behavior of SUSY particles

Non-decoupling behavior: \( m_f < Q < m_{\tilde{f}} \)

\[
\frac{\tilde{g}(Q)}{g(Q)} - 1 = \frac{g(m_{\tilde{f}})}{g(Q)} - 1 = \beta \log \frac{m_{\tilde{f}}}{Q}
\]

Effective couplings \(^1\)

\[
\Delta N_{\alpha 1} \equiv N_{\alpha 1} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{\delta t_W}{t_W} \right) + \sum_{\beta \neq \alpha} N_{\beta 1} Z_{R}^{\beta \alpha}
\]

\[
\Delta N_{\alpha 2} \equiv N_{\alpha 2} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} \right) + \sum_{\beta \neq \alpha} N_{\beta 2} Z_{R}^{\beta \alpha}
\]

\(^1\) The above expressions are finite only for matter sector (s)particles in loops

Guasch et. al. JHEP 0210 (2002) 040
Benchmark point

- Electroweak scale input

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<th>Value</th>
<th>Parameter</th>
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<td>$\mu$</td>
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Results

\[ \downarrow \Delta N_{11} \Rightarrow \uparrow \sigma \Rightarrow \downarrow \Omega \]

- **Annihilation channels**

  \[ Z h : \ M_1 \approx 106 \text{GeV} \]
  \[ W^+ W^- : \ M_1 \approx 84 \text{GeV} \]
  \[ Z Z : \ M_1 \approx 94 \text{GeV} \]

  \[ Z \text{ pole} : \ M_1 \approx 47 \text{GeV} \]

  \[ \text{Winolike} \ \tilde{\chi}_1^0 : \ M_1 \approx 410 \text{GeV} \]
Toy process $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \mu^+ \mu^-$

Binocase: $M_1 = 90, M_2 = 500, \mu = -600 \text{GeV}$ negligible vertex and box corrections

Higgsinocase: $M_1 = -600, M_2 = 500, \mu = -100 \text{GeV}$ sizable non-universal components
Conclusions

- Effective couplings is a good way to include dominant one loop electroweak corrections
- Neutralino fermion sfermion vertex in this spirit was corrected
- The relic density can change by as much as 4% after implementation
- They work well for binolike neutralino but not so well for winolike neutralino
- Further work for correcting other neutralino annihilation vertices is ongoing
\[
\Delta N_{\alpha 1} \equiv N_{\alpha 1} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{\delta t_W}{t_W} \right) + \sum_{\beta \neq \alpha} N_{\beta 1} Z_{\beta \alpha}^R
\]
\[
\Delta N_{\alpha 2} \equiv N_{\alpha 2} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} \right) + \sum_{\beta \neq \alpha} N_{\beta 2} Z_{\beta \alpha}^R
\]
\[
\Delta N_{\alpha 3} \equiv N_{\alpha 3} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{1}{2} \frac{\delta M_W^2}{M_W^2} - \frac{\delta \cos \beta}{\cos \beta} \right) + \sum_{\beta \neq \alpha} N_{\beta 3} Z_{\beta \alpha}^R
\]
\[
\Delta N_{\alpha 4} \equiv N_{\alpha 4} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{1}{2} \frac{\delta M_W^2}{M_W^2} - \frac{\delta \sin \beta}{\sin \beta} \right) + \sum_{\beta \neq \alpha} N_{\beta 4} Z_{\beta \alpha}^R
\]
Renormalization scheme

- On-shell renormalization
- Most binolike neutralino and two charginos on shell
- Do not consider renormalization of (s)fermion sector
- $\tan \beta$ from $A^0 Z^0$ transitions
- $M_W$ and $M_Z$ onshell
- Corrections for light quark masses in $\alpha$ taken into account
Corrections to cross-sections

\[ \Delta \sigma_{\chi_0 \chi_0 \rightarrow e e} \% \]

\[ \Delta \sigma_{\chi_1 \chi_1 \rightarrow e e} \% \]

\[ \Delta N_{11} \]

\[ \Delta \Omega \% \]

\[ M_1 \text{ [GeV]} \]
Non-decoupling behavior

\[ \tan \beta = 10, \ M_A = 500, \ M_1 = 100 \]
\[ M_2 = 300, \ M_3 = 1200, \mu = 600, \ A = 0 \]
common soft SUSY breaking sfermion masses