DM Relic density at one loop - effective coupling approach

Work in progress

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Outline

- Dark matter the standard stuff
- SUSY - non decoupling
- Idea of effective couplings
- Renormalization framework
- Current implementation plan
- How exactly - the technicalities
- Current status of our work
- The future
$\frac{dY}{dx} = \frac{-x\langle \sigma_{\chi\bar{\chi} \rightarrow X\bar{X}v} \rangle}{H(m)} \left( Y^2 - Y_{eq}^2 \right)$

\[\downarrow\]

$Y_\infty = \frac{3.79(n + 1)x_f^{n+1}}{(g_s/g_*)^{1/2}m_{pl}m_{\sigma_0}}$

\[\downarrow\]

$\Omega_\chi h^2 \propto \frac{1}{\sigma}$
Yeah! We all know it!

\[
\frac{dY}{dx} = \frac{-x \langle \sigma \chi \bar{\chi} \rightarrow X \bar{X} v \rangle}{H(m)} \left( Y^2 - Y_{eq}^2 \right)
\]

\[
\Downarrow
\]

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\Downarrow
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\[
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\]

- Precision cosmology
- Percent accuracy with Plank
- Collider interplay
The beauty of broken SUSY

- Unbroken SUSY - equal couplings for the standard and SUSY particles
  \[ g(e \tilde{e} \tilde{\gamma}) = g(e e \gamma) \]

- SUSY breaking \( \Rightarrow \) difference between SUSY and SM couplings grows with the SUSY breaking scale

- Same RGE above SUSY breaking scale, SUSY and SM particle decoupling at different scales due to mass hierarchy

- At one loop comparision between two couplings
  \[
  \frac{\tilde{\alpha}(Q)}{\alpha(Q)} - 1 = \frac{\alpha(m_{\tilde{q}})}{\alpha(Q)} - 1 = \beta \log \frac{m_{\tilde{q}}}{m_q}, \quad \text{On - shell}
  \]
Can we use this property of SUSY breaking to perform calculations at one loop?
Renormalization scheme

-ino -fermion -sfermion process renormalized
On-shell scheme in the -ino and sfermion sector
Inputs - Chargino and bino-like neutralino masses in -ino sector

Requires consistant on-shell renormalization scheme
Renormalization of \( \tan \beta \) - simplest not unique, nor the best
The most bino-like neutralino on-shell, not necessarily LSP

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>-ino</th>
<th>Other</th>
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<tbody>
<tr>
<td>SM</td>
<td>( M_w, M_z )</td>
<td>( M_{\tilde{f}_i} )</td>
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<td></td>
<td>( \alpha_{em} )</td>
<td>( \tan \beta )</td>
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<td>( M_{\chi_1}^-, M_{\chi_2}^- )</td>
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<td>( M_{\chi_i}^0 )</td>
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Effective couplings - this work

A finite set of counter-terms introduced to the bare Lagrangian

\[ \Delta N_{\alpha_1} \equiv N_{\alpha_1} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{\delta t_W}{t_W} \right) + \sum_{\beta \neq \alpha} N_{\beta_1} Z_{R}^{\alpha \beta} \]

\[ \Delta N_{\alpha_2} \equiv N_{\alpha_2} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} \right) + \sum_{\beta \neq \alpha} N_{\beta_2} Z_{R}^{\alpha \beta} \]

\[ \Delta N_{\alpha_3} \equiv N_{\alpha_3} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{1}{2} \frac{\delta M_w^2}{M_w^2} - \frac{\delta \cos \beta}{\cos \beta} \right) + \sum_{\beta \neq \alpha} N_{\beta_3} Z_{R}^{\alpha \beta} \]

\[ \Delta N_{\alpha_4} \equiv N_{\alpha_4} \left( \frac{\delta g}{g} + \frac{\delta Z_R^\alpha}{2} + \frac{1}{2} \frac{\delta M_w^2}{M_w^2} - \frac{\delta \sin \beta}{\sin \beta} \right) + \sum_{\beta \neq \alpha} N_{\beta_4} Z_{R}^{\alpha \beta} \]

hep-ph/0207364v2, Guasch, Hollik, Sola
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Neutralino coupling matrices corrected

Since -ino sfermion fermion coupling \( \propto \) mixing matrix, these are called effective coupling

Only include all two point correlation functions

Process dependent corrections

hep-ph/0207364v2, Guasch, Hollik, Sola
How exactly - the technicalities
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Spectrum generator (SLHA o/p)

micrOMEGAs

Calchep session (with modified vertices - NEW!!)

One loop effective vertex calculation external library (NEW!!)

Relic density at one loop
First results

- EWSB scenario
  \[ \mu = -600, \]
  \[ M_2 = 200, M_1 = 90, \]
  \[ \tan \beta = 5, A_f = 0 \]

- Dominant leptonic channel annihilation

- Rich structure associated with the nature of LSP
First results

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  \[ \mu = -600, \quad M_2 = 200, \quad M_1 = 90, \quad \tan \beta = 5, \quad A_f = 0 \]

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Future Plans

- Effective couplings - process dependent in MSSM
- Need to include the higgs -ino -ino couplings as well
- No known way to find effective coupling for this vertex so far
- A comparison to full one loop relic density calculations necessary
- Effect of initial and final state radiation

We expect the final results in near future . . .
Reconstruction of parameters
Reconstruction of parameters

- SLHA accord not gauge invariant
- Threshold corrections to masses but MSSM parameters in $\overline{DR}$
- Higgsino - wino nature of $\tilde{\chi}^+$ determined by couplings
- $M_1$ extracted via bino-like neutralino