Electroweak radiative corrections to Dark Matter relic density - effective couplings approach

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in collaboration with

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Outline


DARK MATTER
THE ULTIMATE POST-WORKOUT
MUSCLE GROWTH ACCELERATOR!
MHP
DARK
MATTER

Neutralino LSP as DM

DM - cosmology

- Observational evidence for Dark matter exists!
- Major aim - Accurate relic density determinations
- Precision cosmology
- Percent accuracy with Plank

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DM - calculations

- CDM scenario $\Rightarrow \Omega h^2 \propto \frac{1}{\sigma}$
- Loop corrections will change calculated Ωh^2
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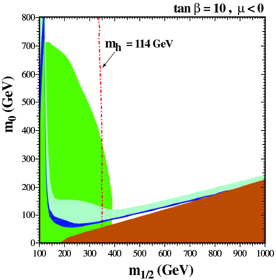
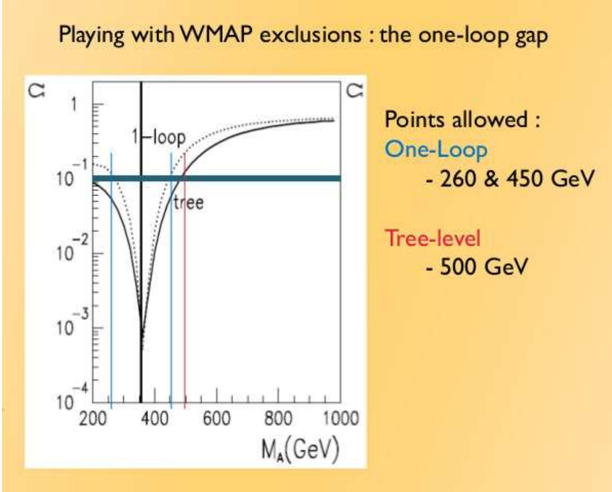
DM - collider

- Within framework of MSSM - Neutralino LSP
- Well studied at tree level



hep-ph/0404175v2

Neutralino LSP as DM



Shamelessly stolen from a talk by F. Boudjema

- Full one loop calculations in progress SLOOPS team, Annecy

Neutralino LSP as DM

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

$$\tilde{W}^\pm,\ \tilde{H}^\pm \quad \xrightarrow{\text{MIX}} \quad \tilde{\chi}^\pm_{i=1,2} \quad \text{Charginos}$$

$$\tilde{B}^0,\ \tilde{W}^0,\ \tilde{h}^0,\ \tilde{H}^0 \quad \xrightarrow{\text{MIX}} \quad \tilde{\chi}^0_{i=1,2,3,4} \quad \text{Neutralinos}$$

$$\mathcal{M}_{\mathcal{D}}{}^0 = N^* \mathcal{M} N^\dagger$$

Neutralino mass matrix

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

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

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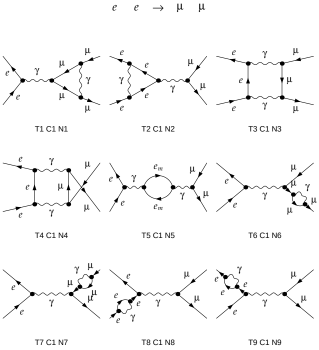
Higgsino

Back to the (grad)school

All possible one loop diagrams



Lagrangian $\mathcal{L}(e, m, g)$

$$
\begin{aligned}
m^{(1)} &\rightarrow m^{(0)} + \Delta m \\
g^{(1)} &\rightarrow g^{(0)} + \Delta g \\
e^{(1)} &\rightarrow e^{(0)} + \Delta e \\
\mathcal{L}^{(1)} &\rightarrow \mathcal{L}^{(0)} + \Delta \mathcal{L}
\end{aligned}
$$

$\Rightarrow$ Amplitude:

$$
\begin{aligned}
|\mathcal{M}^{(1)}|^2 &= |\mathcal{M}^{(0)}|^2 + |\Delta\mathcal{M}|^2 \\
&\quad + 2|\Delta\mathcal{M}||\mathcal{M}^{(0)}|
\end{aligned}
$$

- On-shell scheme: external particle masses are known, ideal for dark matter case
- number of neutralino annihilation diagrams for SUSY scenarios easily reach thousands

Beauty of broken SUSY - Non-decoupling effect

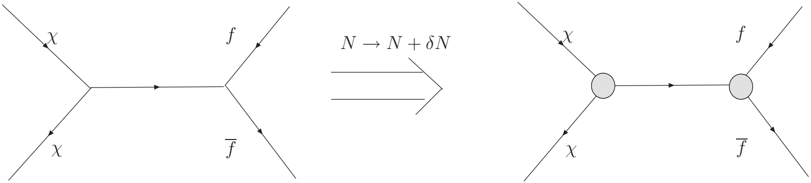
- Unbroken SUSY - equal couplings for the standard and SUSY particles
$$g(e\tilde{e}\tilde{\gamma}) = g(e\,e\gamma)$$
- SUSY breaking $\Rightarrow$ difference between SUSY and SM couplings grows with the SUSY breaking scale
- Same RGE above SUSY breaking scale, SUSY and SM particle decoupling at different scales due to mass hierarchy
- At one loop comparison between two couplings ($Q < m_{\tilde{q}}$)

$$\frac{\tilde{\alpha}(Q)}{\alpha(Q)} - 1 = \frac{\alpha(m_{\tilde{q}})}{\alpha(Q)} - 1 = \beta \log \frac{m_{\tilde{q}}}{m_q}, \qquad \mathrm{On-shell}$$

Can we use this to include the most dominant radiative corrections to Neutralino DM relic density?

Effective couplings - a closer look

- Analogous to Oblique corrections in the Standard Model
- Effective couplings - extracting a set of dominant flavor independent corrections to gaugino -fermion -sfermion couplings
- Does not work for higgsinos because the Yukawa couplings are not flavor blind
- Such corrections can be expressed as a finite shift in the neutralino mixing matrices (with only matter sector in the loops)



- No vertex corrections in this case
- Include the fermion -sfermion non-decoupling effects

Effective couplings - a closer look

- chargino/neutralino -fermion -sfermion process renormalized

Input parameters	
SM	M_w, M_z α_{em}
-ino	$M^-_{\chi_1}$, $M^-_{\chi_2}$ $M^0_{\chi_i}$
Other	$\tan\beta$ $M_{\tilde{f}_i}$

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

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

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

$$\Delta N_{\alpha 3} \equiv N_{\alpha 3}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}+\frac{1}{2}\frac{\delta M_w^2}{M_w^2}-\frac{\delta\cos\beta}{\cos\beta}\right)+\sum_{\beta\neq\alpha} N_{\beta 3} Z_R^{\alpha\beta}$$

$$\Delta N_{\alpha 4} \equiv N_{\alpha 4}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}+\frac{1}{2}\frac{\delta M_w^2}{M_w^2}-\frac{\delta\sin\beta}{\sin\beta}\right)+\sum_{\beta\neq\alpha} N_{\beta 4} Z_R^{\alpha\beta}$$

How exactly - technical details

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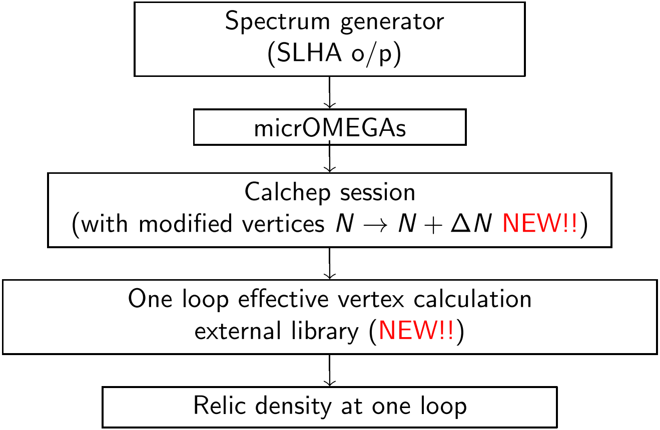
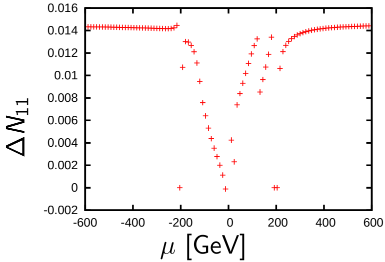
- Including dominant radiative corrections essentially reduces to calculating two point functions
- Total number of diagrams need to be calculated ≈ 400 (≈ 6000 in full one loop)
- Work the best for a gaugino -fermion -sfermion couplings
- In most of the mSUGRA parameter space observationally compatible Neutralino DM is binolike - we expect the effective couplings to work

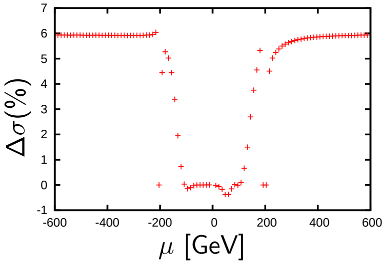
How exactly - technical details

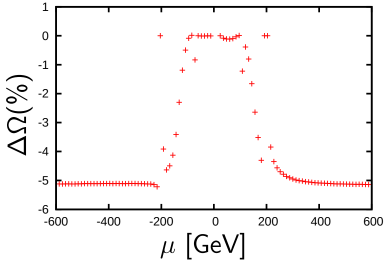


- Used FeynArts, FormCalc, LoopTools for loop calculations

Results

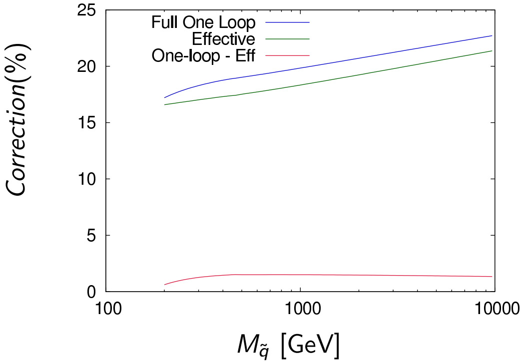






- EWSB scenario $M_2 = 200,\ M_1 = 90,$ $\tan\beta = 5,\ A_f = 0$
- Dominant leptonic channel annihilation

Comparisons to full one loop - squark mass variation



- Bino case $M_1 = 90$; $M_2, \mu \gg M_1$
- Binolike neutralino 99%
- Sizable improvement
- Non-effective part stays small and flat

In preparation with G. Drieu-Larochelle, F. Boudjema

Conclusions

If Neutralino is Dark Matter . . .

- Electroweak corrections to Neutralino Dark Matter relic density should be taken into account
- Relic density gets corrected upto $\approx 4 - 5\%$ in some regions of parameter space
- Effective couplings work the best for a binolike neutralino
- Comparisons with full one-loop calculations for a binolike neutralino show a percent level match
- Formalism needs to be extended to capture the Yukawa corrections as well