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

Manuel Drees[1], Arindam Chatterjee[1], Fawzi Boudjema[2], Guillaume Drieu la Rochelle[2], **Suchita Kulkarni** [1,3]

[1]BCTP Bonn, University of Bonn

[2]LAPTh, Annecy

[3]LPSC, Grenoble

Based on Phys.Rev.D84:116001,2011, work in progress

Motivation

- CDM scenario $\Rightarrow \Omega h^2 \propto \frac{1}{\sigma}$
- Loop corrections to σ 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 $SU(2)_L \times U(1)_Y \to U(1)_{\rm EM}$:

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

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

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

Neutralino mass matrix

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

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

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]

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

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

Guasch et. al. JHEP 0210 (2002) 040

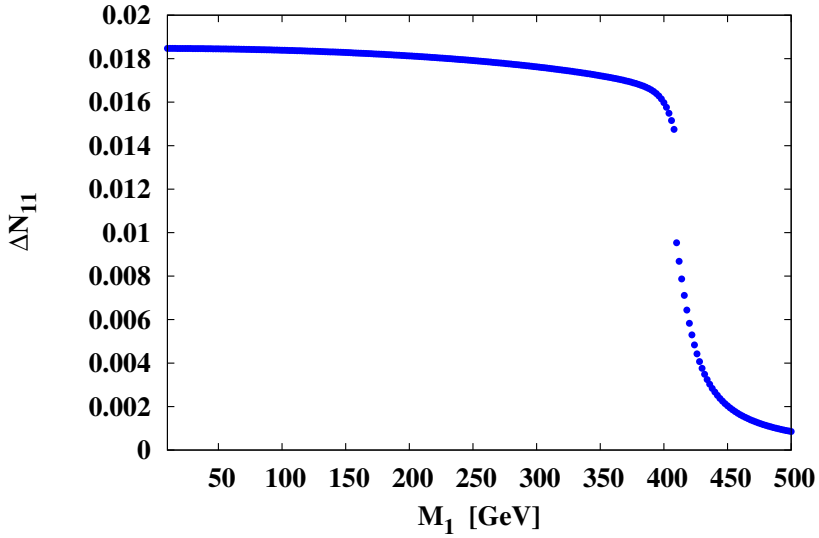
[1] *The above expressions are finite only for matter sector (s)particles in loops*

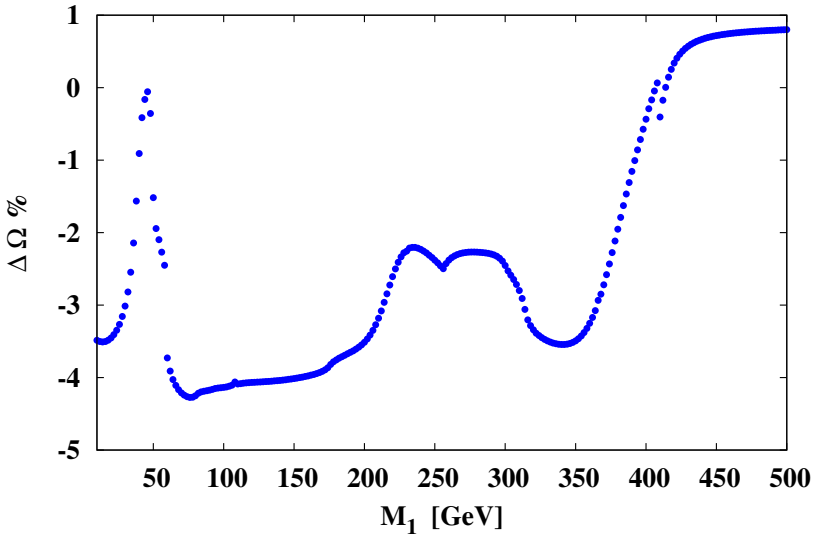
Benchmark point

- Electroweak scale input

Parameter	Value	Parameter	Value
M_1	90	Mu_2	800
M_2	200	Mu_3	800
M_3	800	Md_2	800
Ml_2	250	Md_3	800
Ml_3	250	A_f	0
Mr_2	110	MH_3	500
Mq_2	800	$\tan\beta$	5
μ	-600		

Results





- $\downarrow \Delta N_{11} \Rightarrow \uparrow \sigma \Rightarrow \downarrow \Omega$
- Annihilation channels

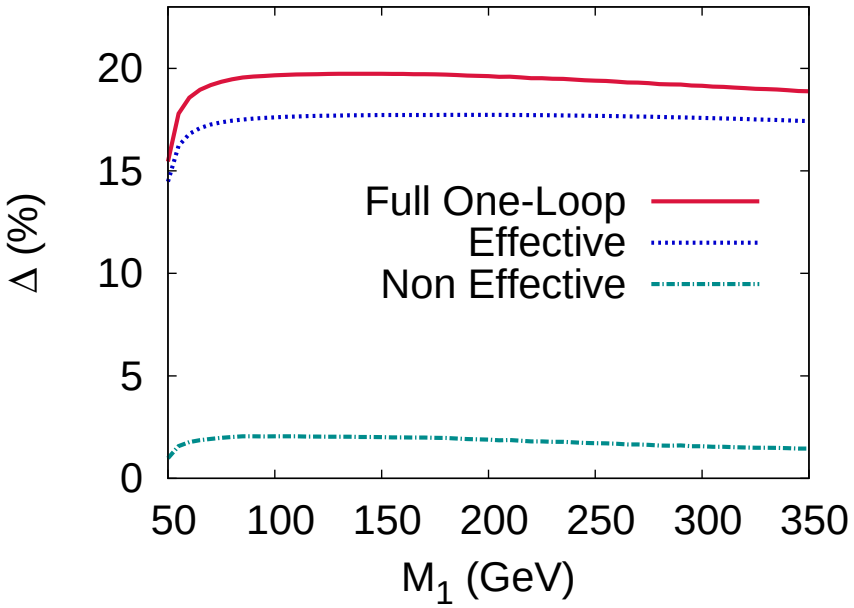
$$Z\,h \quad : \quad M_1 \approx 106\,GeV$$
$$W^+W^- \quad : \quad M_1 \approx 84\,GeV$$
$$Z\,Z \quad : \quad M_1 \approx 94\,GeV$$

$$Z\ pole \quad : \quad M_1 \approx 47\,GeV$$
$$Winolike\ \tilde{\chi}_1^0 \quad : \quad M_1 \approx 410\,GeV$$

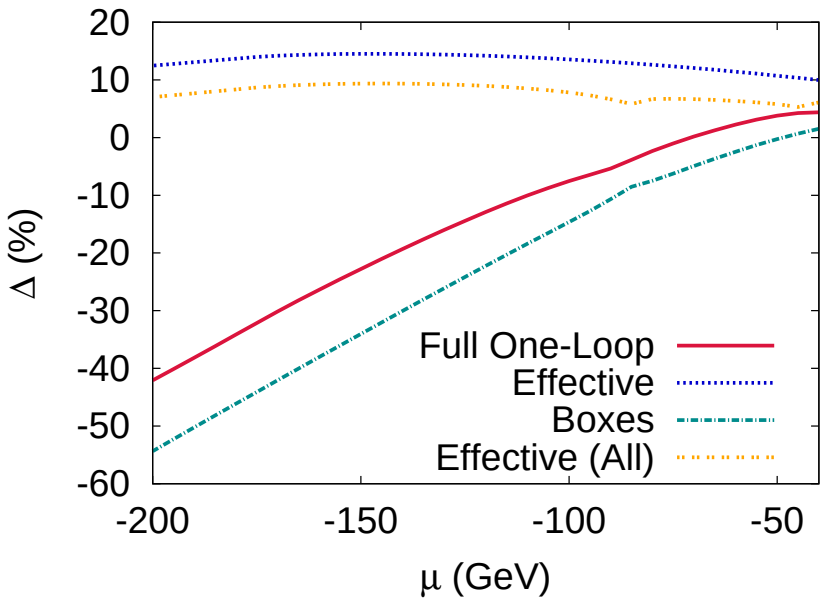
Results - comparison to full one loop

Toy process $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to \mu^+ \mu^-$

Binocase



Higgsinocase



- Binocase: $M_1 = 90, M_2 = 500, \mu = -600 GeV$ negligible vertex and box corrections
- Higgsinocase: $M_1 = -600, M_2 = 500, \mu = -100 GeV$ 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 chage 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

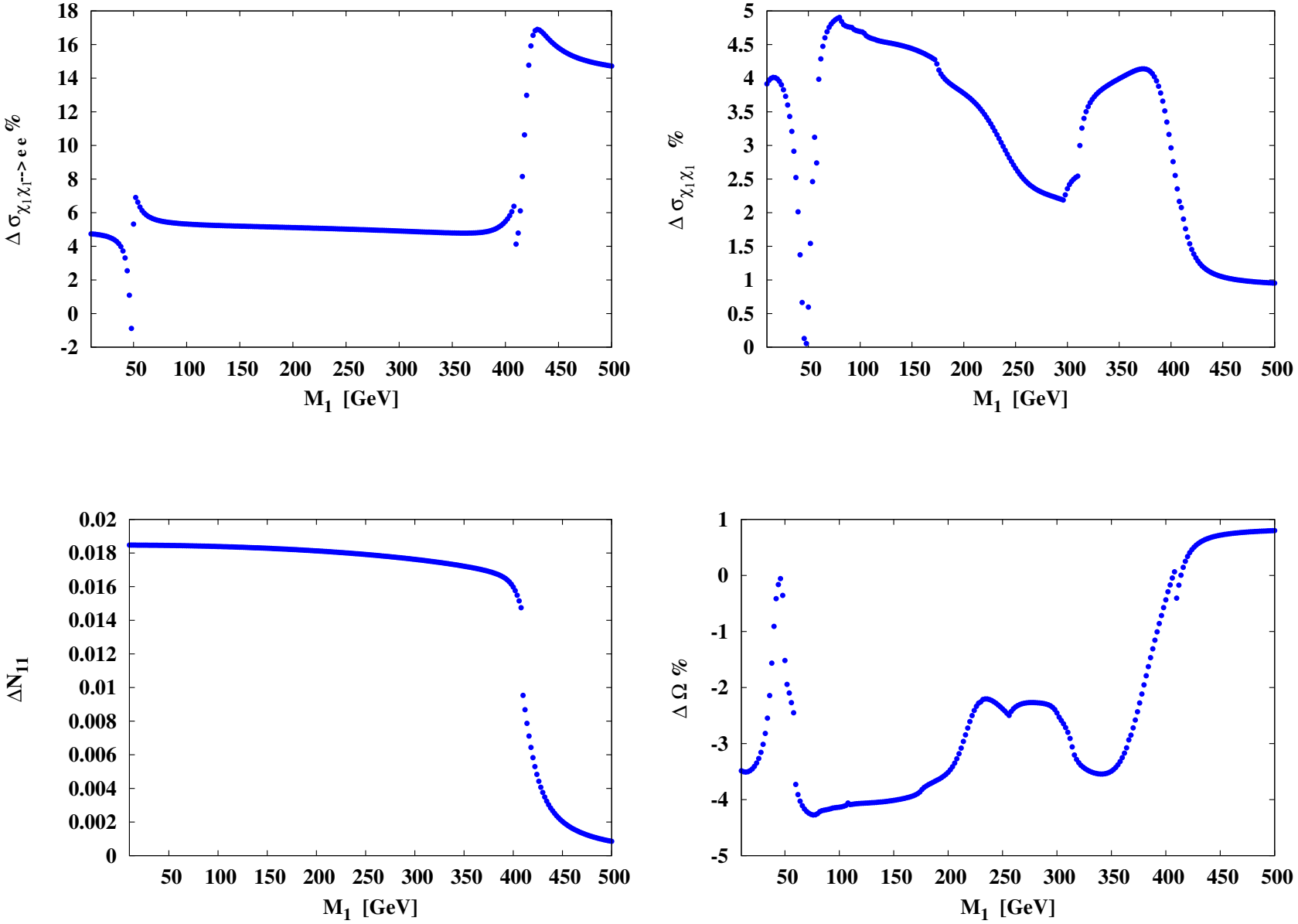
Back up

$$
\begin{aligned}
\Delta N_{\alpha 1} &\equiv N_{\alpha 1}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}+\frac{\delta t_W}{t_W}\right)+\sum_{\beta\neq\alpha} N_{\beta 1} Z_R^{\beta\alpha} \\
\Delta N_{\alpha 2} &\equiv N_{\alpha 2}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}\right)+\sum_{\beta\neq\alpha} N_{\beta 2} Z_R^{\beta\alpha} \\
\Delta N_{\alpha 3} &\equiv N_{\alpha 3}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}+\frac{1}{2}\frac{\delta M_W^2}{M_W^2}-\frac{\delta\cos\beta}{\cos\beta}\right)+\sum_{\beta\neq\alpha} N_{\beta 3} Z_R^{\beta\alpha}\ , \\
\Delta N_{\alpha 4} &\equiv N_{\alpha 4}\left(\frac{\delta g}{g}+\frac{\delta Z_R^{\alpha}}{2}+\frac{1}{2}\frac{\delta M_W^2}{M_W^2}-\frac{\delta\sin\beta}{\sin\beta}\right)+\sum_{\beta\neq\alpha} N_{\beta 4} Z_R^{\beta\alpha}
\end{aligned}
$$

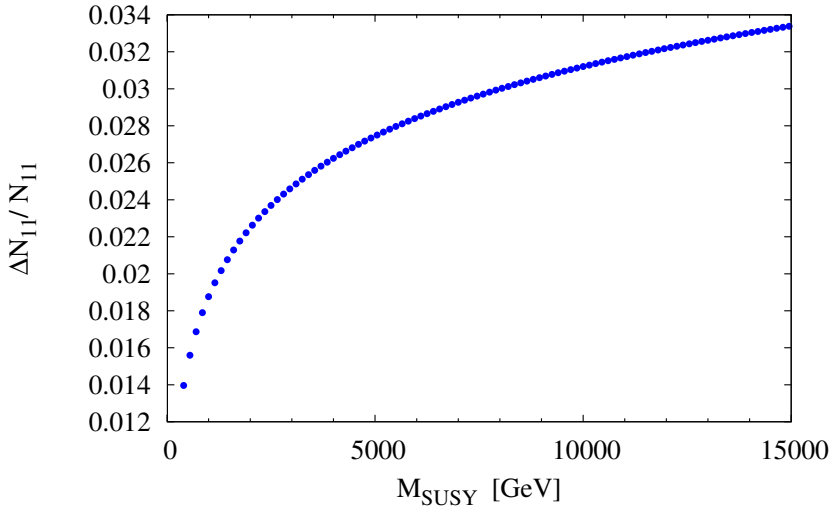
Renormalization scheme

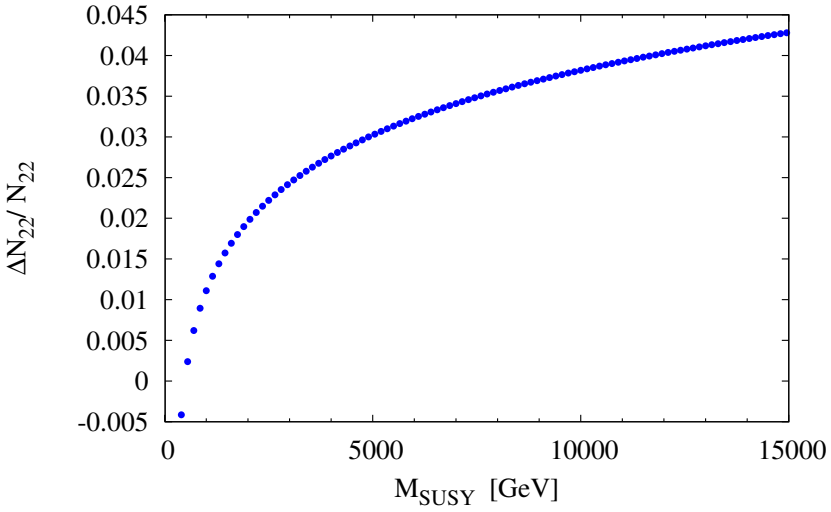
- On- shell renormalization
- Most binolike neutralino and two charginos on shell
- Do not consider renormalization of (s)fermion sector
- $\tan\beta$ from $A^0 Z^0$ transitions
- M_W and M_Z onshell
- Corrections for light quark masses in α taken into account

Corrections to cross-sections



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