CALCULATIC THE RELIC DENSITY AT ONE-LOOP

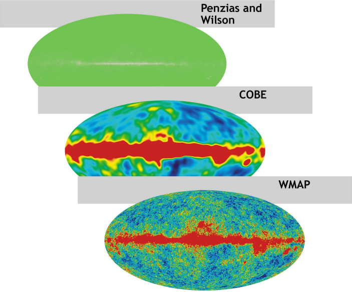
Nans BARO

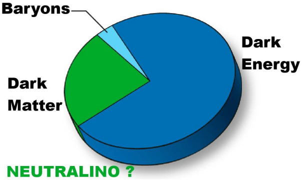
Institut für Theoretische Physik E (Aachen)

in collaboration with
Guillaume CHALONS and Sun HAO (LAPTH)

GDR TERASCALE - Grenoble [01/04/09]

Relic density of Dark Matter





$0.088 < \Omega h^2 < 0.120$

WMAP @ 10% → PLANCK @ 2 %

$\Omega h^2 \propto 1/ < \sigma(\chi\chi \rightarrow SM)v > \Rightarrow$ Need to know precisely σ

Radiative corrections are important

SOME PREVIOUS WORK AT ONE-LOOP IN SUSY

EW+QCD corrections

- $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \gamma\gamma, Z\gamma, gg,$ Boudjema, Semenov, Temes, *Phys. Rev.* **D72**, 055024 (2005), hep-ph/0507127
- $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-/Z^0Z^0,$ B., Boudjema, Semenov, *Phys. Lett.* **B660** (2007), 0710.1821[hep-ph]
- $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tau^+\tau^-, \tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b},$ B., Boudjema, Semenov, *Phys. Lett.* **B660** (2007), 0710.1821[hep-ph]
- Coannihilation with $\tilde{\tau}$, B., Boudjema, Semenov, *Phys. Lett.* **B660** (2007), 0710.1821[hep-ph]

QCD corrections

- Coannihilation with $\tilde{t}$, Freitas *Phys. Lett.* **B652** (2007), 0705.4027 [hep-ph]
- Annihilation into massive quarks,

  Herrmann, Klasen, Kovarik *Phys. Rev.* **D79** (2009) , 0901.0481 [hep-ph]

PRESENT STUDY: RELIC DENSITY DOMINATED BY THE ANNIHILATION PROCESS $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W^+W^-$

- Higgsino or wino neutralino could “explain” the PAMELA/ATIC data

  Nagai, Nakayama, 0807.1634[hep-ph]

  Lattanzi, Silk, 0812.0360[hep-ph]

- Coannihilation with a chargino
- Calculating the relic density including coannihilation effects can significantly change the results
- Region of parameters difficult to probe (in mSUGRA) in colliders are regions where coannihilation comes into account for the relic density

CHARGINO/NEUTRALINO SECTOR

- Chargino/neutralino mass matrix

$$X = \begin{bmatrix} M_2 & \sqrt{2}M_W s_\beta \\ \sqrt{2}M_W c_\beta & \mu \end{bmatrix}, \quad Y = \begin{bmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{bmatrix}$$

- Diagonalisation: $\tilde{X} = UXV^\dagger$, $\tilde{Y} = NYN^\dagger$
- Decomposition: $\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W} + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$
- At one-loop: δM_1, δM_2, $\delta\mu$
- Need three renormalisation conditions.
  For example, we could choose three masses: $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_1^+}$, $m_{\tilde{\chi}_2^+}$ but other choices are possible...

HOW TO DEFINE $\tan(\beta)$?

t_β doesn't represent a physical/measurable quantity

We have many different ways/schemes to define it:

$\overline{DR}$

δt_β is a pure divergence

DCPR

δt_β is defined by the condition: $\hat{\Sigma}_{A^0 Z^0}(m^2_{A^0}) = 0$

MH

δt_β is defined from the measurement of the heaviest CP-even Higgs mass m_{H^0} (we loose a correction but the definition is physical)

$A\tau\tau$

δt_β is defined from the decay $A^0 \to \tau^+\tau^-$ (vertex $\propto m_\tau t_\beta$)

δt_β DEPENDENCE IN THE GAUGINO SECTOR

Neutralino counterterms:

$$\delta\tilde{Y}^{t_\beta} = N \begin{pmatrix} M_1^{t_\beta} & 0 & y_{13}^{t_\beta} & y_{14}^{t_\beta} \\ 0 & M_2^{t_\beta} & y_{23}^{t_\beta} & y_{24}^{t_\beta} \\ y_{13}^{t_\beta} & y_{23}^{t_\beta} & 0 & -\mu^{t_\beta} \\ y_{14}^{t_\beta} & y_{24}^{t_\beta} & -\mu^{t_\beta} & 0 \end{pmatrix} N^\dagger \delta t_\beta / t_\beta$$

$$\begin{aligned} M_1^{t_\beta} &= \frac{1}{N_{11}^2}\left(-2M_Z c_\beta s_\beta (N_{13}s_\beta + N_{14}c_\beta)(N_{11}s_W - N_{12}c_W) - N_{12}^2 M_2^{t_\beta} + 2N_{13}N_{14}\mu^{t_\beta}\right) \\ M_2^{t_\beta} &= \frac{1}{\Delta}N_{11}^2(-\sqrt{2}M_W c_\beta s_\beta)\left(V_{12}V_{22}(U_{11}U_{22} - U_{12}U_{21})c_\beta - U_{12}U_{22}(V_{11}V_{22} - V_{12}V_{21})s_\beta\right) \\ \mu^{t_\beta} &= \frac{1}{\Delta}N_{11}^2(-\sqrt{2}M_W c_\beta s_\beta)\left(U_{11}U_{21}(V_{11}V_{22} - V_{12}V_{21})c_\beta - V_{11}V_{21}(U_{11}U_{22} - U_{12}U_{21})s_\beta\right) \end{aligned}$$

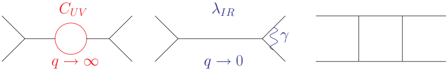
$$\Delta = U_{11}U_{22}V_{11}V_{22} - U_{12}U_{21}V_{12}V_{21}$$

PROCEDURE AND INGREDIENTS FOR ONE-LOOP CALCULATIONS: $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-(\gamma)$

Tree Level

[8]

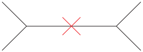
Loops



$\int \frac{d^4q}{(2\pi)^4}\frac{q_\mu q_\nu \ldots q_\rho}{D_0 D_1 \ldots D_{N-1}} \supset C_{UV}, \lambda_{IR}$

[1677,3635,1622]

Counterterms



C_{UV}

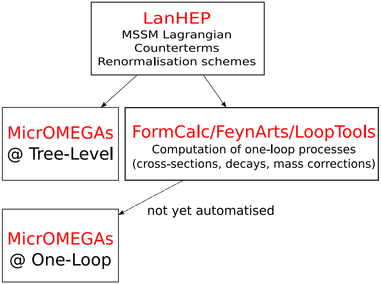
[45]

Soft$_{(E_\gamma < k_c)}$ / Hard$_{(E_\gamma > k_c)}$

λ_{IR}

[56]

CODE



LanHEP
MSSM Lagrangian
Counterterms
Renormalisation schemes

MicrOMEGAs @ Tree-Level

FormCalc/FeynArts/LoopTools
Computation of one-loop processes
(cross-sections, decays, mass corrections)

not yet automatised

MicrOMEGAs @ One-Loop

A code for the calculation of loop diagrams in the MSSM with application to collider physics, astrophysics and cosmology.

- Complete and coherent renormalisation of the MSSM (On-Shell scheme)
- Modularity between different renormalisation schemes

SET OF PARAMETERS

Coannihilation with a chargino

Main contributions

- Set I: Bino like
  $\tilde{\chi}_1^0 = 0.94\tilde{B} - 0.20\tilde{W} - 0.27\tilde{H}_1^0 - 0.09\tilde{H}_2^0.$

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
110	134.5	-245	600	600	0	600	10

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \longrightarrow W^+W^-[45\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \longrightarrow u\bar{d}/c\bar{s}[8\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \longrightarrow ZW^+[5\%]$
$\tilde{\chi}_1^0\tilde{\chi}_2^0 \longrightarrow W^+W^-[5\%]$

- Set II: Higgsino like
  $\tilde{\chi}_1^0 = 0.58\tilde{B} - 0.11\tilde{W} + 0.58\tilde{H}_1^0 - 0.56\tilde{H}_2^0.$

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
565	1000	550	1200	1700	0	1350	4

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \longrightarrow W^+W^-[19\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \longrightarrow ZZ[13\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \longrightarrow u\bar{d}/c\bar{s}[9\%]$

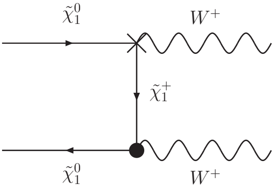
- Set III: Wino like
  $\tilde{\chi}_1^0 = 0.00\tilde{B} - 1.00\tilde{W} + 0.02\tilde{H}_1^0 - 0.02\tilde{H}_2^0.$

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
3500	1800	4500	5000	500	0	5000	15

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \longrightarrow W^+W^-[10\%]$
$\tilde{\chi}_1^+\tilde{\chi}_1^+ \longrightarrow W^+W^+[10\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \longrightarrow t\bar{b}[9\%], u\bar{d}/c\bar{s}[9\%]$
$\tilde{\chi}_1^0\tilde{\chi}_1^+ \longrightarrow ZW^+[9\%]$
$\tilde{\chi}_1^+\tilde{\chi}_1^- \longrightarrow ZZ[6\%], W^+W^-[6\%]$

SCHEME DEPENDENCE OF $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-$

$$\mathcal{L}^1 = g\bar{\tilde{\chi}}_i^0 \gamma^\mu \left(l_{ij}^1 P_L + r_{ij}^1 P_R\right) \tilde{\chi}_j^+ W_\mu^+$$

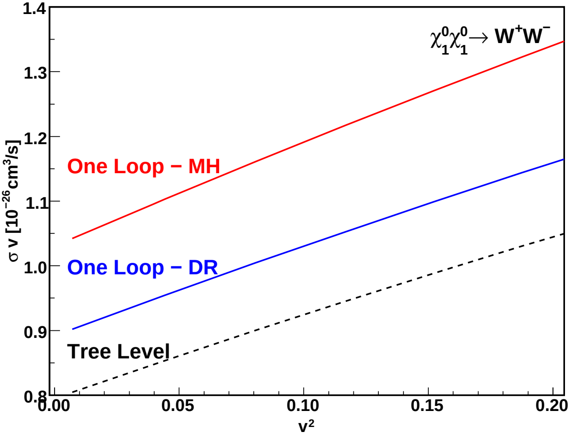


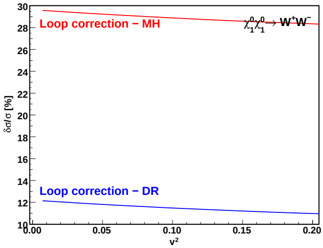
$$\begin{aligned}
l_{ij}^1 &= l_{ij}\left(1 + \frac{\delta g}{g} + \frac{1}{2}\delta Z_{WW} + \frac{1}{2l_{ij}}\left(\sum_{k=1}^{4}\delta Z_{kj}^n l_{ik} + \sum_{k=1}^{2}\delta Z_{ki}^L l_{kj}\right)\right)\\
r_{ij}^1 &= r_{ij}\left(1 + \frac{\delta g}{g} + \frac{1}{2}\delta Z_{WW} + \frac{1}{2r_{ij}}\left(\sum_{k=1}^{4}\delta Z_{kj}^n r_{ik} + \sum_{k=1}^{2}\delta Z_{ki}^R r_{kj}\right)\right)
\end{aligned}$$

We could extract the δt_β dependence in the cross-section:

$$\delta\sigma^{t_\beta}/\sigma = -2\left(\frac{2}{m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}} \frac{l_{11}l_{21} + r_{11}r_{21}}{l_{11}^2 + r_{11}^2}\right)\delta\tilde{Y}_{21}^{t_\beta}$$

SET I: BINO LIKE

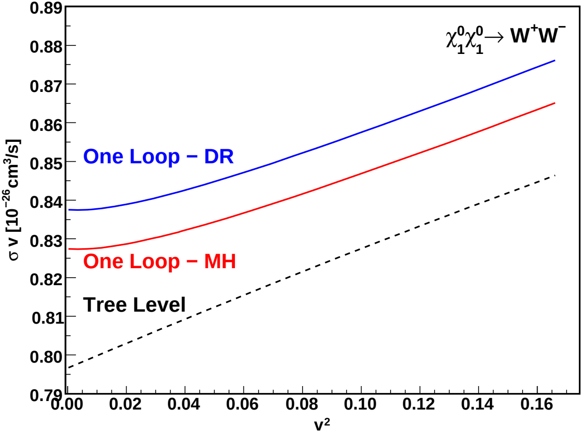


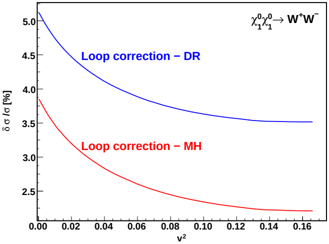


- $\delta\sigma^{t_\beta}/\sigma \simeq +19\%$ expected
- Large t_β scheme dependence
- Large corrections

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
110	134.5	-245	600	600	0	600	10

SET II: HIGGSINO LIKE

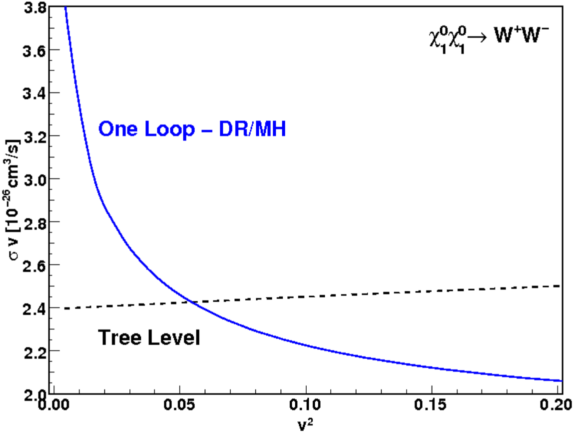


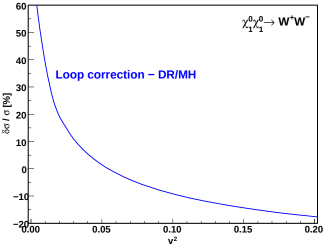


- $\delta\sigma^{t_\beta}/\sigma \simeq -1\%$ expected
- Small t_β scheme dependence
- Small corrections

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
565	1000	550	1200	1700	0	1350	4

SET III: WINO LIKE





- $\delta\sigma^{t_\beta}/\sigma \sim 10^{-6}\%$ expected
- No t_β scheme dependence
- Large corrections
- Sommerfeld effect

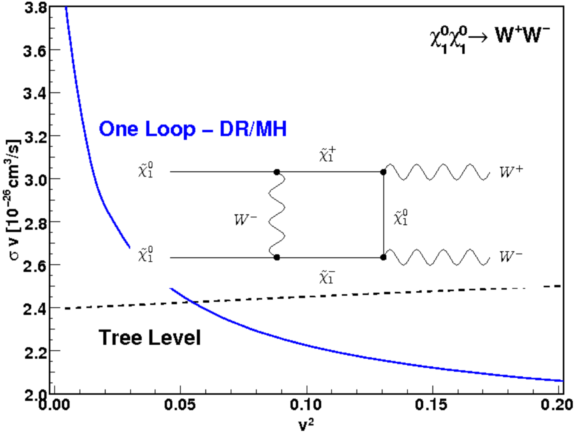
  $m_{\tilde{\chi}_1^0} \simeq m_{\tilde{\chi}_1^+}$ with TeV masses

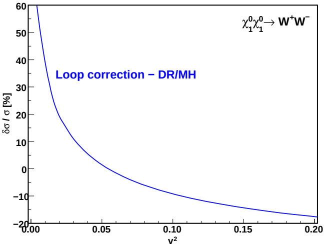
  same effect for $\tilde{\chi}_1^+\tilde{\chi}_1^+ \to W^+W^+$

  $\tilde{\chi}_1^+\tilde{\chi}_1^- \to W^+W^-$

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
3500	1800	4500	5000	5000	0	5000	15

SET III: WINO LIKE





- $\delta\sigma^{t_\beta}/\sigma \sim 10^{-6}\%$ expected
- No t_β scheme dependence
- Large corrections
- Sommerfeld effect
  $m_{\tilde{\chi}_1^0} \simeq m_{\tilde{\chi}_1^+}$ with TeV masses
  same effect for $\tilde{\chi}_1^+\tilde{\chi}_1^+ \to W^+W^+$
  $\tilde{\chi}_1^+\tilde{\chi}_1^- \to W^+W^-$

M_1	M_2	μ	M_3	$M_{\tilde{f}_{L,R}}$	A_f	M_{A^0}	t_β
3500	1800	4500	5000	5000	0	5000	15

CONCLUSION AND PERSPECTIVES

- Complete renormalisation of the MSSM and modularity with different schemes
- Investigation of various scenarios where gauge pair production channel is dominant
- Well understanding of the t_β scheme dependence
- Mixed Bino scenario gets large corrections
- Higgsino scenario with TeV masses gets large enhancement due to the Sommerfeld effect
- First steps done for the connection with micrOMEGAs
- Influence of the gaugino scheme
- Other scenarios should be computed soon

Public/Private website: http://code.sloops.free.fr/