Electroweak bremsstrahlung and indirect detection of Dark Matter by neutrino telescopes

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OUTLINE

- Electroweak brems. in Toy Models
- Electroweak brems. in Supersymmetry
- Neutrino flux at production
- Neutrino flux from the Sun to the Earth

TWO SIMPLE MODELS

BUILDING A SIMPLE DM MODEL

- Scalar interaction $B\tilde{\chi}\tilde{\chi}$ and $B\nu\bar{\nu}$ only $\Rightarrow$ Gauge dependent

  M. Kachelriess, P. D. Serpico, *Phys. Rev.* **D76** (2007) 063516, 0707.0209 [hep-ph].

  N. F. Bell, J. B. Dent, T. D. Jacques, T. J. Weiler, *Phys. Rev.* **D78** (2008) 083540, 0805.3423 [hep-ph]

  M. Kachelriess, P. D. Serpico, M. A. Solberg, *Phys. Rev.* **D80** (2009) 123533, [arXiv:0911.0001 [hep-ph]]

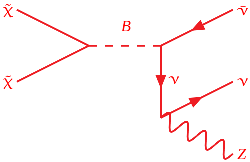
- Vector interaction $Z'\tilde{\chi}\tilde{\chi}$ and $Z'L\bar{L}$

  P. Ciafaloni, A. Urbano, 1001.3950 [hep-ph]

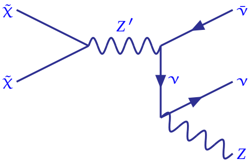
ELECTROWEAK BREMSSTRAHLUNG (EWBS)

$\tilde{\chi}\tilde{\chi} \to \nu\bar{\nu}Z$

Scalar

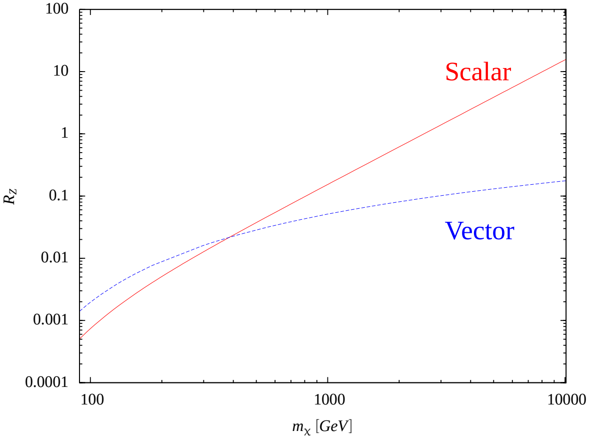


Vector



Gauge invariance issue

Ratio $R_Z = \sigma(\tilde{\chi}\tilde{\chi} \to \nu\nu Z)/\sigma(\tilde{\chi}\tilde{\chi} \to \nu\nu)$



Linear growth
at high energy
(gauge dependence)

$\Rightarrow$ Sizeable corrections due to Sudakov logs

EWBS in SUSY

Helicity suppression

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \nu\bar{\nu}$ is completely suppressed in the MSSM
Neutrinos can not be produced directly from a two-body final state reaction

EWBS enhancement

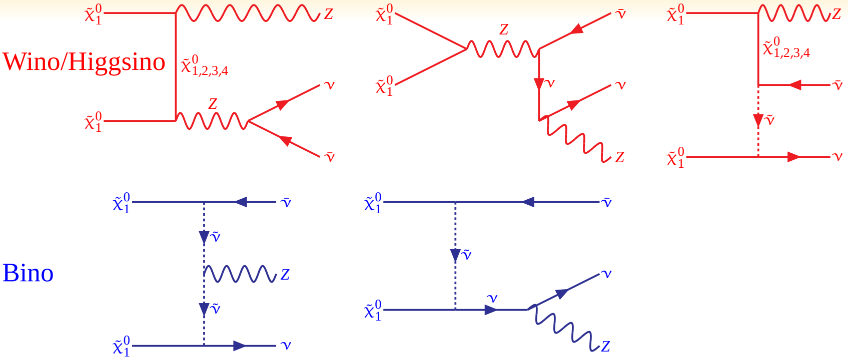
$2 \to 3$ processes: $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \nu\bar{\nu}Z, e\nu W$

Neutrino spectrum

$$\frac{d\Phi_\nu}{dE_\nu} = \Gamma \sum_f B_f \frac{dN_\nu^f}{dE_\nu}$$

B_f: branching ratio
Γ: astrophysics

Diagrams for $\nu\bar{\nu}Z$ final state

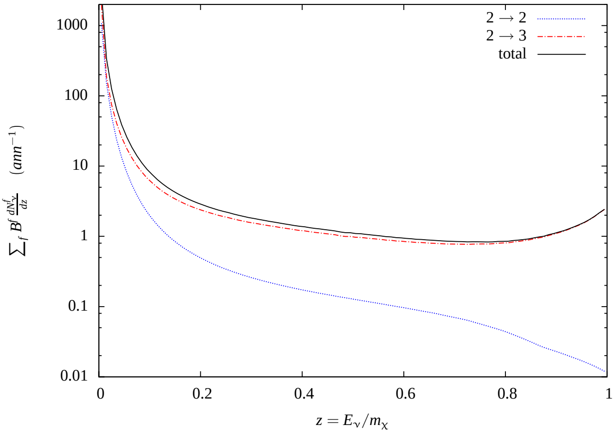


Choice of parameter points

- Higgsino/Wino neutralino: double counting with standard ZZ final state
  $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to ZZ \to \nu\bar{\nu}Z$
- Bino with rather light sneutrinos ($m_{\tilde{\nu}} \sim m_{\tilde{\chi}_1^0}$)
- Best enhancement expected for a bino neutralino with light sneutrinos

Neutrino spectrum within the MSSM

- 3 TeV bino-like neutralino



Spectrum at production

Overview of the numerical calculation

- DM particles trapped into the Sun
- Can we expect large corrections from EWBS in IceCube?

2-body final state: $\tilde{\chi}\tilde{\chi} \longrightarrow X_1 X_2$

S. Ritz, D. Seckel, *Nucl. Phys.* **B304** (1988) 877

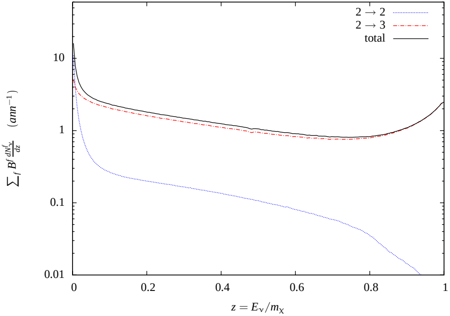
M. Cirelli, N. Fornengo, T. Montaruli, I. Sokalski, A. Strumia, F. Vissani, *Nucl. Phys.* **B727** (2005) 99, [Erratum-ibid. **B790** (2008) 338], hep-ph/0506298 J. Ellis, K. A. Olive, C. Savage, V. C. Spanos, 0912.3137 [hep-ph].

- Standard calculation
- Back-to-back reaction: $E_1 = E_2 = m_{\tilde{\chi}_1^0}$
- Already implemented in `DarkSUSY`

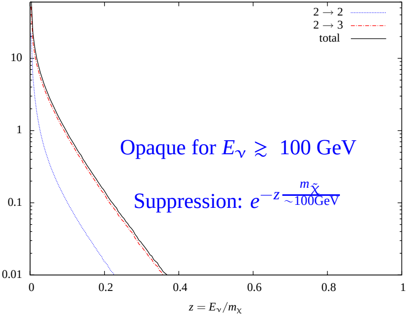
3-body final state: $\tilde{\chi}\tilde{\chi} \longrightarrow X_1 X_2 X_3$

- Complicated structure
- $E_1 \neq E_2 \neq E_3 \Rightarrow$ Spectrum is model dependent
  $\Rightarrow$ Difficult to test all the MSSM parameter space
- `PYTHIA` used to evaluate neutrino spectrum at the center of the Sun
- Modified version of the package `WimpSim` / `WimpEvent`

- 3 TeV bino-neutralino scenario



At the center of the Sun



At the surface of the Sun

Detection at the Earth

Annihilation rate in the Sun Γ

- Depends on the neutralino mass
- Depends on the nature of the neutralino (through $\sigma_{p\tilde{\chi}}^{SI,SD}$)

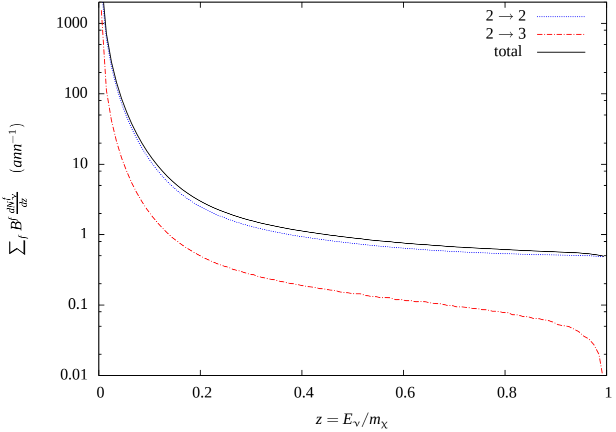
Neutrino flux

- 3 TeV bino: $\Phi_{\nu_\mu} = 6.99 \times 10^{-4}\text{km}^{-2}\text{yr}^{-1}$ (80% of correction)
- 0.5 TeV bino: $\Phi_{\nu_\mu} = 6.10 \times 10^{3}\text{km}^{-2}\text{yr}^{-1}$ (13% of correction)

Undetectable with IceCube

Same game with WWZ/ZZZ final states

- Secondary production of neutrinos
- 3 TeV mixed-like neutralino



Spectrum at production

SAME GAME WITH WWZ/ZZZ FINAL STATES

REAL EMISSION ONLY

Neutrino flux is: $\Phi_{\nu_\mu} = 4.67 \times 10^8 \mathrm{km}^{-2}\mathrm{yr}^{-1}$ (10% of correction)
Neutrino-induced muon flux is detectable with IceCube

VIRTUAL CORRECTIONS HAVE TO BE ADDED

- Loop corrections are also important for $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-$
- Sommerfeld enhancement
- Work to do to disentangle Sudakov logs from Sommerfeld enhancement

Conclusion

Primary neutrino production $\nu\bar{\nu}Z$, $e\nu W$

- "No-go theorem" for a possible EWBS enhancement for indirect detection in IceCube

Secondary neutrino production WWZ, ZZZ

- Annihilation into three gauge bosons interesting for indirect detection
- Requires virtual corrections