The NMSSM dark sector constraints. The annihilation cross-section of the pair of lightest neutralino in NMSSM with CP-violation

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Abstract: Authors consider the NMSSM with CP-violation in the Higgs sector and its affect on the sector dark matter. There are calculation of neutralino mass and its annihilation cross sections into gamma quants. The report also contains an investigation of free parameters values in this model.

☞ There are two types of possible candidates for dark matter: massive astrophysical compact halo objects of the Galaxy (MACHOs) and weakly interacting massive particles (WIMPs) [1].

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Some evidence of dark matter:

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The field structure of the MSSM and NMSSM

	superfield	field	spin	superpartner	spin
quarks/ squarks	$\hat{Q}$	$Q = \begin{pmatrix} U_\alpha \\ D_\alpha \end{pmatrix}_L$	$\frac{1}{2}$	$\tilde{Q} = \begin{pmatrix} \tilde{U}_\alpha \\ \tilde{D}_\alpha \end{pmatrix}_L$	0
	$\hat{U}$	$U_{\alpha R}$	$\frac{1}{2}$	$\tilde{U}_{\alpha R}$	0
	$\hat{D}$	$D_{\alpha R}$	$\frac{1}{2}$	$\tilde{D}_{\alpha R}$	0
leptons/ sleptons	$\hat{L}$	$L_{\alpha L}$	$\frac{1}{2}$	$\tilde{L}_{\alpha L}$	0
	$\hat{E}$	$E_{\alpha R}$	$\frac{1}{2}$	$\tilde{E}_{\alpha R}$	0
the gauge bosons / Gauge supermultiplets	$\hat{G}$	G^a_μ	1	$\tilde{G}^a_\mu$	$\frac{1}{2}$
	$\hat{W}$	$W^\pm, W^0$	1	$\tilde{W}^\pm, \tilde{W}^0$	$\frac{1}{2}$
	$\hat{B}$	B^0	1	$\tilde{B}^0$	$\frac{1}{2}$
Higgs/ Higgsino,	$\hat{H}_1$	$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$	0	$\tilde{H}_1 = \begin{pmatrix} \tilde{H}_1^0 \\ \tilde{H}_1^- \end{pmatrix}$	$\frac{1}{2}$
	$\hat{H}_2$	$H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$	0	$\tilde{H}_2 = \begin{pmatrix} \tilde{H}_2^+ \\ \tilde{H}_2^0 \end{pmatrix}$	$\frac{1}{2}$
S field / singlino	$\hat{S}$	S	0	$\tilde{S}$	$\frac{1}{2}$

α - generation ($\alpha = 1, 2, 3$), a - color combination ($a = 1...8$).

Candidate for WIMPs: Neutralino

☞ MSSM: the superposition of states: $\tilde{B}^0$, $\tilde{W}^3$, $\tilde{H}_1^0$, $\tilde{H}_2^0$

NMSSM: the superposition of states: $\tilde{B}^0$, $\tilde{W}^3$, $\tilde{H}_1^0$, $\tilde{H}_2^0$, S

$\chi_1^0\chi_1^0 \to \gamma\gamma$ in the MSSM

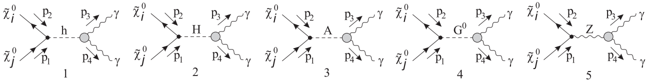

Fig.1. The system of Feynman diagrams determining the amplitude of the process $\chi_i^0\chi_j^0 \to \gamma\gamma$ in the MSSM.

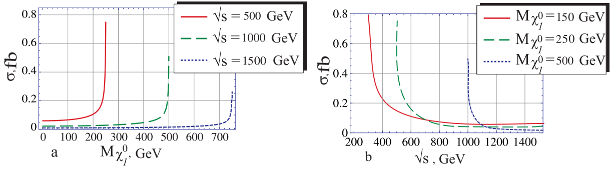

Fig.2. The total cross section: a) depending on the mass of the neutralino $\sigma(M_{\chi_1^0})$; b) depending on the scale of energy $\sigma(\sqrt{s})$.

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Motivations for researches of CP-violation into the Higgs sector:

- problem of the vacuum stability;
- the explanation of the baryon asymmetry.

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The procedure of mixing states Higgs in the NMSSM

$$H_1 = \begin{pmatrix} \frac{1}{\sqrt{2}}(\upsilon_1 + \phi_1^0 + i\chi_1) \\ \phi_1^- \end{pmatrix}, \quad H_2 = e^{i\theta} \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(\upsilon_2 + \phi_2^0 + i\chi_2) \end{pmatrix}, \tag{1}$$

$$S = \frac{1}{\sqrt{2}} e^{i\varphi} (\upsilon_3 + \phi_3^0 + i\chi_3)$$

I step. Going into the basis H, h, A^0, G^0:

$$\begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix} = \begin{pmatrix} cos\beta & -sin\beta \\ sin\beta & cos\beta \end{pmatrix} \begin{pmatrix} H \\ h \end{pmatrix}; \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix} = \begin{pmatrix} cos\beta & -sin\beta \\ sin\beta & cos\beta \end{pmatrix} \begin{pmatrix} G^0 \\ A^0 \end{pmatrix}$$

II step. Additional rotation with matrix mixing A_{ij}.

$$\begin{pmatrix} H \\ A^0 \\ h \\ \phi_3^0 \\ \chi_3^0 \end{pmatrix} = A \begin{pmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \\ h_5 \end{pmatrix} \tag{2}$$

The interaction of Higgs bosons with fermions NMSSM

$$\overline{u} u h_j : \quad \frac{\mathrm{g} 2 M_u \left(\left(-\cos(\theta) + i\gamma^5 \sin(\theta) \right) \left(\mathrm{A}_{1j} s_\beta + \mathrm{A}_{3j} c_\beta \right) + \mathrm{A}_{2j} c_\beta \left(\sin(\theta) + i\gamma^5 \cos(\theta) \right) \right)}{2 m_W s_\beta}$$

$$\overline{d} d h_j : \quad \frac{g 2 M_d \left(-\mathrm{A}_{1j} c_\beta + s_\beta \left(\mathrm{A}_{3j} + i\gamma^5 \mathrm{A}_{2j} \right) \right)}{2 c_\beta m_W}$$

Scenario of the Higgs boson with mass ~ 125 GeV

$Parameters$	$Values$
λ	0.7
κ	0.1
$\mathrm{tg}\,\beta$	50
A_λ, GeV	100
A_κ, GeV	-20
m_{H_1}, GeV	$125,7$
m_{H_2}, GeV	$352,9$
m_{H_3}, GeV	$357,8$
θ	$\frac{3\pi}{2}$
φ	$\frac{\pi}{15}$
$\Gamma(H_1) \to \gamma\gamma \times 10^{-7}$, GeV	0.17
$\Gamma(H_2) \to \gamma\gamma \times 10^{-7}$, GeV	2.6
$\Gamma(H_3) \to \gamma\gamma \times 10^{-7}$, GeV	2.6

Differential and total cross sections for annihilation in the NMSSM

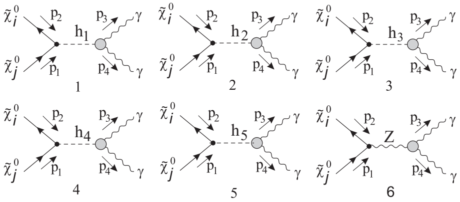

Fig.3. The system of Feynman diagrams determining the amplitude of the process $\chi_i^0 \chi_j^0 \to \gamma\gamma$ in the NMSSM.

$$A_{[i \to f]} = \sum_{n=1}^{6} A_n \tag{3}$$

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s(s - 4M_{\chi_1^0}^2)} \left|A_{[i \to f]}\right|^2. \tag{4}$$

$$\sigma_{tot} = \int_{t_{min}}^{t_{max}} \left[\frac{d\sigma}{dt}\right] dt, \; t_{\{min,max\}} = M_{\chi_1^0}^2 - \frac{s}{2} \mp \frac{s}{2}\kappa \tag{5}$$

Comparison of results

$$< \sigma v >= \frac{\int_0^{\varepsilon_{\gamma 0}} \sigma v \, d\varepsilon}{\int_0^{\varepsilon_{\gamma 0}} d\varepsilon} \tag{6}$$

MSSM: $< \sigma v > \sim 10^{-35} \mathrm{cm}^3/\mathrm{c}$

$< \sigma v > \sim 10^{-28} \mathrm{cm}^3/\mathrm{c}$ [20]

NMSSM: $< \sigma v > \sim 10^{-36} \mathrm{cm}^3/\mathrm{c}$

$< \sigma v > \sim 10^{-25} \mathrm{cm}^3/\mathrm{c}$ [21].

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Conclusion

In this work:

☞ There is calculation of the annihilation cross section of the lightest neutralino $\chi_1^0\chi_1^0 \to \gamma\gamma$ with one-loop correction in the NMSSM with CP-violation.

☞ The calculation corresponds to the set of parameters that satisfy the lightest Higgs boson with mass 125 GeV.

☞ Additional sources of CP violation decrease the value of the neutralino annihilation cross-section, which makes this particle even more unobservable.

Thank you for your attention!