САМАРСКИЙ УНИВЕРСИТЕТ
SAMARA UNIVERSITY

The annihilation cross-section of the pair of lightest neutralino in NMSSM with CP-violation

Gurskaya A.V., Dolgopolov M.V.

Nalchik, 2017

☞ 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].

[1] K. Griest The Search for the Dark Matter: WIMPs and MACHOs. - Annals of the New York Academy of Sciences. vol 688. 15 June 1993: 390-407.

Some evidence of dark matter:

[2] Clowe, D. A direct empirical proof of the existence of dark matter / D. Clowe, M. Bradac, A.H. Gonzalez, M. Markevitch et al. // Astrophys. J. – 648. – 2006. – L109-L113.

[3] Bernabei, R. On a further search for a yearly modulation of the rate in particle dark matter direct search / Bernabei R. et al. // Phys. Lett. – 1999. – V.B450. – P. 448-455.

[4] Abdo, A.A. Measurement of the Cosmic Ray e++e- Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope / A.A. Abdo et. al. – Phys. Rev. Lett. – 2009. – V.102. – P. 181101 (6pp).

[5] J. Chang, An excess of cosmic ray electrons at energies of 300-800 GeV / J. Chang, J.H. Adams, H.S. Ahn, G.L. Bashindzhagyan et. al. – Nature. – 2008. – V.456. – P. 362-365.

[6] CMS Collaboration / CMS-SUS-14-014, CERN-PH-EP-2015-033; ATLAS Collaboration / CERN-PN-EP-2015-038

The field structure of the MSSM and NMSSM

	superfield	field	spin	superpartner	spin
quarks/	$\hat{Q}$	$Q = \begin{pmatrix} U_\alpha \\ D_\alpha \end{pmatrix}_L$	$\frac{1}{2}$	$\tilde{Q} = \begin{pmatrix} \tilde{U}_\alpha \\ \tilde{D}_\alpha \end{pmatrix}_L$	0
squarks	$\hat{U}$	$U_{\alpha R}$	$\frac{1}{2}$	$\tilde{U}_{\alpha R}$	0
	$\hat{D}$	$D_{\alpha R}$	$\frac{1}{2}$	$\tilde{D}_{\alpha R}$	0
leptons/	$\hat{L}$	$L_{\alpha L}$	$\frac{1}{2}$	$\tilde{L}_{\alpha L}$	0
sleptons	$\hat{E}$	$E_{\alpha R}$	$\frac{1}{2}$	$\tilde{E}_{\alpha R}$	0
the gauge	$\hat{G}$	G^a_μ	1	$\tilde{G}^a_\mu$	$\frac{1}{2}$
bosons /	$\hat{W}$	$W^\pm, W^0$	1	$\tilde{W}^\pm, \tilde{W}^0$	$\frac{1}{2}$
Gauge supermultiplets	$\hat{B}$	B^0	1	$\tilde{B}^0$	$\frac{1}{2}$
Higgs/	$\hat{H}_1$	$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$	0	$\tilde{H}_1 = \begin{pmatrix} \tilde{H}_1^0 \\ \tilde{H}_1^- \end{pmatrix}$	$\frac{1}{2}$
Higgsino,	$\hat{H}_2$	$H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$	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 ($a = 1 \ldots 8$).

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

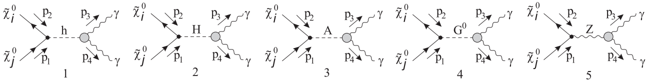

Fig.1. The system of Feynman diagrams determining the amplitude of the process $\chi_i^0\chi_j^0 \to \gamma\gamma$ in the MSSM.

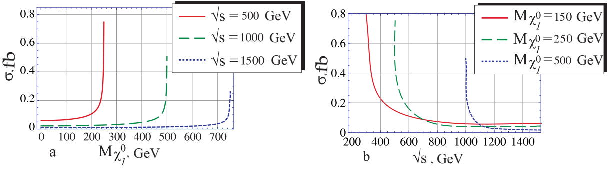

Fig.2. The total cross section: a) depending on the mass of the neutralino $\sigma(M_{\chi_1^0})$; b) depending on the scale of energy $\sigma(\sqrt{s})$.

[7] Gurskaya, A.V. The annigilation cross-section of pairof the lightest neutralino of MSSM into two gamma quantum // MPA2́012, Samara

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

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

[8] Pilaftsis A., WagnerC.E.M. Higgs Bosons in the Minimal Supersyminetry Standard Model with Explicit CP Violation // Nucl. Phys. B. 1999. V. 553. P. 3-42.

[9] Choi S. K, Lee J.S. Decays of the MSSM Higgs Bosons with Explicit CP-Violation // Phys. Rev. D. 2000. V. Gl. P. 015003.

[10] Carena M. et al Higgs-Boson Pole Masses in the MSSM with Explicit CP Violation // NucL Phys. B. 2002. 625. P. 345-371.

[11]E.N. Akhmetzyanova, M.V. Dolgopolov, M.N. Dubinin Violation of CP invariance in the two-doublet Higgs sector of the MSSM // Physics of Particles and Nuclei. 2006. V. 37, Iss. 5. P.677-734

[12] Elias-Miro J. Higgs mass implications on the stability of the electroweak vacuum / J. Elias-Miro [et al.] // e-print: arXiv:1112.3022v1.

[13] Degrassi G. Higgs mass and vacuum stability in the Standard Model at NNLO / G. Degrassi [et al.] // e-print: arXiv:1205.6497v2.

...

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

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

$$\overline{d}dh_j : \ \frac{g2M_d\left(-\mathrm{A}_{1j}c_\beta + s_\beta\left(\mathrm{A}_{3j} + i\gamma^5\mathrm{A}_{2j}\right)\right)}{2c_\beta m_W}$$

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

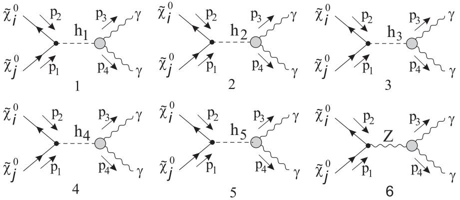

Fig.3. The system of Feynman diagrams determining the amplitude of the process $\chi_i^0 \chi_j^0 \to \gamma\gamma$ in the NMSSM.

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

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

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

Comparison of results

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

MSSM:

$$< \sigma v > \sim 10^{-35} \text{см}^3/\text{с}$$

$$< \sigma v > \sim 10^{-28} \text{см}^3/\text{с} \ [20]$$

NMSSM:

$$< \sigma v > \sim 10^{-36} \text{см}^3/\text{с}$$

$$< \sigma v > \sim 10^{-25} \text{см}^3/\text{с} \ [21].$$

[20] Hooper, D. Determining supersymmetric parameters with dark matter experiments /D. Hooper, A. M. Taylor // JCAP – 2006. – V. 2007. – P. 017.

[21] Ferrer, F. Indirect detection of light neutralino dark matter in the NMSSM / F. Ferrer et. al. // Phys.Rev.D. – 2006. – V. 37. – P. 115007.

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!