STRINGY APPROACH TO THE MINIMAL SUPERSYMMETRIC STANDARD MODEL

Yu.M. Malyuta, T.V. Obikhod [*]

Institute for Nuclear Research National Academy of Sciences of Ukraine, 03068, Kiev, Ukraine

(Received March 10, 2010)

Superstring theory is applied to construct the Minimal Supersymmetric Standard Model. The mass spectrum, partial widths and production cross sections of superpartners are calculated. This approach gives concrete predictions for superpartner searches at the LHC.

PACS: 11.25.-w, 12.60.Jv, 02.10.Ws

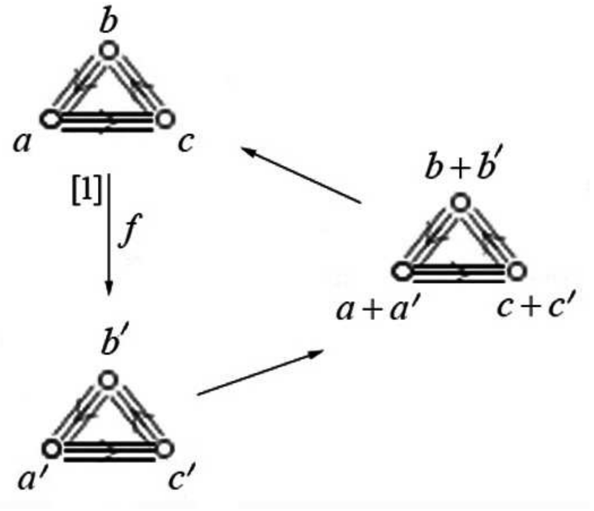
1. INTRODUCTION

The purpose of the present work is to construct the Minimal Supersymmetric Standard Model [1] from superstring theory [2]. This aim is achieved by using the notion of derived category [3]. Such approach allows to determine the mass spectrum, partial widths and production cross sections of superpartners.

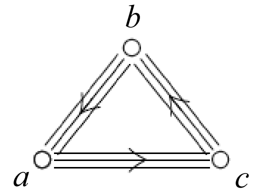
These predictions are important from experimental point of view as they are connected with searches for new physics at the LHC.

2. DERIVED CATEGORY

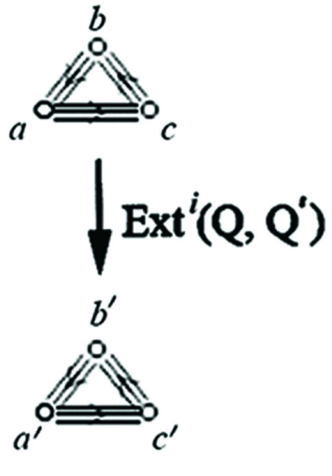
Derived categories are the mathematical foundation of superstring theory. We consider the derived category of distinguished triangles over the abelian category of McKay quivers [3]. Objects of this category are distinguished triangles



(numbers a, b, c and $a^{'}, b^{'}, c^{'}$ denote orbifold charges [4] characterizing McKay quivers); morphisms of this category are morphisms of distinguished triangles. In this approach D-branes are described by quivers Q :



and open superstrings are described by $\mathrm{Ext}^i(Q, Q^{'})$ groups determined by the diagram [3] :



3. PARTICLE CONTENT

It was shown in [5] that the moduli space of the open superstring has the form

$$\begin{aligned} \mathrm{Ext}^0(Q, Q^{'}) &= \mathbb{C}^{aa^{'}+bb^{'}+cc^{'}}, \\ \mathrm{Ext}^1(Q, Q^{'}) &= \mathbb{C}^{3ab^{'}+3bc^{'}+3ca^{'}}. \end{aligned} \tag{1}$$

Substituting in (1) orbifold charges

$$a = b = c = a' = b' = c' = 4$$

---

[*] Corresponding author E-mail address: obikhod@kinr.kiev.ua

and using the Langlands hypothesis [6], we obtain the realization of (1) in terms of $SU(5)$ multiplets

$$3 \times (24 + 5_H + \overline{5}_H + 5_M + \overline{5}_M + 10_M + \overline{10}_M) \ .$$

This result determines the particle content of the MSSM.

4. SUPERPOTENTIAL

The gauge invariant MSSM superpotential takes the form

$$\begin{aligned} W_{SU(5)} = \lambda^d_{ij} \cdot \overline{5}_H \times \overline{5}^{(i)}_M \times 10^{(j)}_M + \\ + \lambda^u_{ij} \cdot 5_H \times 10^{(i)}_M \times 10^{(j)}_M + \mu \cdot 5_H \times \overline{5}_H \ , \end{aligned} \qquad (2)$$

where 5_H and $\overline{5}_H$ are Higgs multiplets, $\overline{5}^{(i)}_M$ and $10^{(j)}_M$ are multiplets of quark and lepton superpartners, λ^d_{ij}, λ^u_{ij} are Yukawa coupling constants and μ is the Higgs mixing parameter.

5. MASS SPECTRUM

The analysis of Yukawa coupling constants, based on observational hints and theoretical considerations, allows to restrict the parameter space in (2) to five free parameters [7]:

$$\begin{aligned} \mathrm{M}_0 = 0.01 \text{ GeV} \ , \quad \mathrm{M}_{1/2} = 600 \text{ GeV} \ , \\ A_0 = 0 \ , \quad \tan\beta = 35 \ , \quad \mathrm{sgn}(\mu) = +1 \ . \end{aligned} \qquad (3)$$

Using this restricted parameter set it is possible to calculate the mass spectrum of superpartners by application of the computer program SOFTSUSY [8]. This MSSM spectrum is shown in Table 1.

Table 1. *Mass spectrum of superpartners*

	GeV		GeV		GeV
$\tilde{u}_R$	1187			$\tilde{g}$	1354
$\tilde{u}_L$	1232	$\tilde{\nu}_e$	391	$\tilde{\chi}^0_1$	249
$\tilde{d}_R$	1182	$\tilde{e}_R$	224	$\tilde{\chi}^0_2$	471
$\tilde{d}_L$	1235	$\tilde{e}_L$	398	$\tilde{\chi}^0_3$	727
$\tilde{c}_R$	1187			$\tilde{\chi}^0_4$	738
$\tilde{c}_L$	1232	$\tilde{\nu}_\mu$	391	$\tilde{\chi}^\pm_1$	470
$\tilde{s}_R$	1182	$\tilde{\mu}_R$	224	$\tilde{\chi}^\pm_2$	738
$\tilde{s}_L$	1235	$\tilde{\mu}_L$	398		
$\tilde{t}_1$	958			h^0	116
$\tilde{t}_2$	1155	$\tilde{\nu}_\tau$	379	A^0	671
$\tilde{b}_1$	1095	$\tilde{\tau}_1$	127	H^0	671
$\tilde{b}_2$	1148	$\tilde{\tau}_2$	408	$H^\pm$	676

6. PARTIAL WIDTHS

Using the parameter set (3) it is possible to calculate partial widths of superpartners by application of the computer program SDECAY [9]. These partial widths are shown in Tables 2, 3, 4, 5.

Table 2. *Partial widths of superpartners*

	channel	BR	channel	BR
$\tilde{\nu}_e$	$\tilde{\chi}^0_1 \nu_e$	1.000		
$\tilde{e}_L$	$\tilde{\chi}^0_1 e$	1.000		
$\tilde{\nu}_\mu$	$\tilde{\chi}^0_1 \nu_\mu$	1.000		
$\tilde{\mu}_L$	$\tilde{\chi}^0_1 \mu$	1.000		
$\tilde{\nu}_\tau$	$\tilde{\chi}^0_1 \nu_\tau$	0.072	$\tilde{\tau}_1 W^+$	0.928
$\tilde{\tau}_2$	$\tilde{\chi}^0_1 \tau$	0.107	$\tilde{\tau}_1 Z$	0.527
	$\tilde{\tau}_1 h^0$	0.365		
$\tilde{u}_R$	$\tilde{\chi}^0_1 u$	0.997	$\tilde{\chi}^0_4 u$	0.002
$\tilde{u}_L$	$\tilde{\chi}^0_1 u$	0.013	$\tilde{\chi}^+_1 d$	0.646
	$\tilde{\chi}^0_2 u$	0.320	$\tilde{\chi}^+_2 d$	0.012
	$\tilde{\chi}^0_4 u$	0.008		
$\tilde{d}_R$	$\tilde{\chi}^0_1 d$	0.997	$\tilde{\chi}^0_4 d$	0.002
$\tilde{d}_L$	$\tilde{\chi}^0_1 d$	0.016	$\tilde{\chi}^-_1 u$	0.628
	$\tilde{\chi}^0_2 d$	0.317	$\tilde{\chi}^-_2 u$	0.027
	$\tilde{\chi}^0_4 d$	0.011		
$\tilde{c}_R$	$\tilde{\chi}^0_1 c$	0.997	$\tilde{\chi}^0_4 c$	0.002
$\tilde{c}_L$	$\tilde{\chi}^0_1 c$	0.013	$\tilde{\chi}^+_1 s$	0.646
	$\tilde{\chi}^0_2 c$	0.320	$\tilde{\chi}^0_2 s$	0.012
	$\tilde{\chi}^0_4 c$	0.008		
$\tilde{s}_R$	$\tilde{\chi}^0_1 s$	0.997	$\tilde{\chi}^0_4 s$	0.002
$\tilde{s}_L$	$\tilde{\chi}^0_1 s$	0.016	$\tilde{\chi}^-_1 c$	0.628
	$\tilde{\chi}^0_2 s$	0.317	$\tilde{\chi}^-_2 c$	0.027
	$\tilde{\chi}^0_4 s$	0.011		
$\tilde{t}_1$	$\tilde{\chi}^0_1 t$	0.216	$\tilde{\chi}^0_4 t$	0.032
	$\tilde{\chi}^0_2 t$	0.105	$\tilde{\chi}^+_1 b$	0.249
	$\tilde{\chi}^0_3 t$	0.171	$\tilde{\chi}^+_2 b$	0.227

Table 3. *Partial widths of superpartners*

	channel	BR	channel	BR
$\tilde{t}_2$	$\tilde{\chi}^0_1 t$	0.025	$\tilde{\chi}^+_1 b$	0.247
	$\tilde{\chi}^0_2 t$	0.111	$\tilde{\chi}^+_2 b$	0.165
	$\tilde{\chi}^0_3 t$	0.114	$\tilde{t}_1 h^0$	0.045
	$\tilde{\chi}^0_4 t$	0.213	$\tilde{t}_1 Z$	0.080
$\tilde{b}_1$	$\tilde{\chi}^0_1 b$	0.055	$\tilde{\chi}^-_1 t$	0.390
	$\tilde{\chi}^0_2 b$	0.220	$\tilde{\chi}^-_2 t$	0.183
	$\tilde{\chi}^0_3 b$	0.063	$\tilde{t}_1 W^-$	0.047
	$\tilde{\chi}^0_4 b$	0.041		
$\tilde{b}_2$	$\tilde{\chi}^0_1 b$	0.023	$\tilde{\chi}^-_1 t$	0.161
	$\tilde{\chi}^0_2 b$	0.091	$\tilde{\chi}^-_2 t$	0.425
	$\tilde{\chi}^0_3 b$	0.079	$\tilde{t}_1 W^-$	0.125
	$\tilde{\chi}^0_4 b$	0.095		
$\tilde{g}$	$\tilde{d}_L d^*$	0.019	$\tilde{c}_L c^*$	0.020
	$\tilde{d}^*_L d$	0.019	$\tilde{c}^*_L c$	0.020
	$\tilde{d}_R d^*$	0.038	$\tilde{c}_R c^*$	0.036
	$\tilde{d}^*_R d$	0.038	$\tilde{c}^*_R c$	0.036
	$\tilde{u}_L u^*$	0.020	$\tilde{b}_1 b^*$	0.078
	$\tilde{u}^*_L u$	0.020	$\tilde{b}^*_1 b$	0.078
	$\tilde{u}_R u^*$	0.036	$\tilde{b}_2 b^*$	0.054
	$\tilde{u}^*_R u$	0.036	$\tilde{b}^*_2 b$	0.054
	$\tilde{s}_L s^*$	0.019	$\tilde{t}_1 t^*$	0.097
	$\tilde{s}^*_L s$	0.019	$\tilde{t}^*_1 t$	0.097
	$\tilde{s}_R s^*$	0.038	$\tilde{t}_2 t^*$	0.043
	$\tilde{s}^*_R s$	0.038	$\tilde{t}^*_2 t$	0.043

Table 4. *Partial widths of superpartners*

	channel	BR	channel	BR
A^0	bb^*	0.858	$\tilde{\tau}_1^-\tilde{\tau}_2^+$	0.004
	$\tau^+\tau^-$	0.130	$\tilde{\tau}_1^+\tilde{\tau}_2^-$	0.004
	tt^*	0.002		
H^0	bb^*	0.859	$\tilde{\tau}_1^-\tilde{\tau}_1^+$	0.003
	$\tau^+\tau^-$	0.130	$\tilde{\tau}_1^-\tilde{\tau}_2^+$	0.002
	tt^*	0.002	$\tilde{\tau}_1^+\tilde{\tau}_2^-$	0.002
H^+	cb^*	0.001	tb^*	0.818
	$\tau^+\nu_\tau$	0.169	$\tilde{\tau}_1^+\tilde{\nu}_\tau$	0.010
$\tilde{\chi}_1^0$	$\tilde{e}_R^-e^+$	0.032	$\tilde{\mu}_R^+\mu^-$	0.032
	$\tilde{e}_R^+e^-$	0.032	$\tilde{\tau}_1^-\tau^+$	0.436
	$\tilde{\mu}_R^-\mu^+$	0.032	$\tilde{\tau}_1^+\tau^-$	0.436
$\tilde{\chi}_2^0$	$\tilde{\chi}_1^0Z$	0.001	$\tilde{\tau}_2^-\tau^+$	0.037
	$\tilde{\chi}_1^0h^0$	0.010	$\tilde{\tau}_2^+\tau^-$	0.037
	$\tilde{e}_L^-e^+$	0.056	$\tilde{\nu}_e\nu_e^*$	0.064
	$\tilde{e}_L^+e^-$	0.056	$\tilde{\nu}_e^*\nu_e$	0.064
	$\tilde{\mu}_L^-\mu^+$	0.056	$\tilde{\nu}_\mu\nu_\mu^*$	0.064
	$\tilde{\mu}_L^+\mu^-$	0.056	$\tilde{\nu}_\mu^*\nu_\mu$	0.064
	$\tilde{\tau}_1^-\tau^+$	0.135	$\tilde{\nu}_\tau\nu_\tau^*$	0.081
	$\tilde{\tau}_1^+\tau^-$	0.135	$\tilde{\nu}_\tau^*\nu_\tau$	0.081
$\tilde{\chi}_3^0$	$\tilde{\chi}_1^0Z$	0.080	$\tilde{\chi}_2^0h^0$	0.007
	$\tilde{\chi}_2^0Z$	0.193	$\tilde{\tau}_1^-\tau^+$	0.088
	$\tilde{\chi}_1^+W^-$	0.211	$\tilde{\tau}_1^+\tau^-$	0.088
	$\tilde{\chi}_1^-W^+$	0.211	$\tilde{\tau}_2^-\tau^+$	0.051
	$\tilde{\chi}_1^0h^0$	0.016	$\tilde{\tau}_2^+\tau^-$	0.051

Table 5. *Partial widths of superpartners*

	channel	BR	channel	BR
$\tilde{\chi}_4^0$	$\tilde{\chi}_1^0Z$	0.016	$\tilde{\mu}_R^-\mu^+$	0.001
	$\tilde{\chi}_2^0Z$	0.009	$\tilde{\mu}_R^+\mu^-$	0.001
	$\tilde{\chi}_1^+W^-$	0.208	$\tilde{\tau}_1^-\tau^+$	0.061
	$\tilde{\chi}_1^-W^+$	0.208	$\tilde{\tau}_1^+\tau^-$	0.061
	$\tilde{\chi}_1^0h^0$	0.069	$\tilde{\tau}_2^-\tau^+$	0.058
	$\tilde{\chi}_2^0h^0$	0.171	$\tilde{\tau}_2^+\tau^-$	0.058
	$\tilde{e}_L^-e^+$	0.005	$\tilde{\nu}_e\nu_e^*$	0.009
	$\tilde{e}_L^+e^-$	0.005	$\tilde{\nu}_e^*\nu_e$	0.009
	$\tilde{e}_R^-e^+$	0.001	$\tilde{\nu}_\mu\nu_\mu^*$	0.009
	$\tilde{e}_R^+e^-$	0.001	$\tilde{\nu}_\mu^*\nu_\mu$	0.009
	$\tilde{\mu}_L^-\mu^+$	0.005	$\tilde{\nu}_\tau\nu_\tau^*$	0.010
	$\tilde{\mu}_L^+\mu^-$	0.005	$\tilde{\nu}_\tau^*\nu_\tau$	0.010
$\tilde{\chi}_1^+$	$\tilde{\nu}_ee^+$	0.135	$\tilde{\mu}_L^+\nu_\mu$	0.108
	$\tilde{\nu}_\mu\mu^+$	0.135	$\tilde{\tau}_1^+\nu_\tau$	0.261
	$\tilde{\nu}_\tau\tau^+$	0.176	$\tilde{\tau}_2^+\nu_\tau$	0.067
	$\tilde{e}_L^+\nu_e$	0.108	$\tilde{\chi}_1^0W^+$	0.010
$\tilde{\chi}_2^+$	$\tilde{\nu}_ee^+$	0.009	$\tilde{\tau}_2^+\nu_\tau$	0.051
	$\tilde{\nu}_\mu\mu^+$	0.009	$\tilde{\chi}_1^+Z$	0.206
	$\tilde{\nu}_\tau\tau^+$	0.105	$\tilde{\chi}_1^0W^+$	0.079
	$\tilde{e}_L^+\nu_e$	0.020	$\tilde{\chi}_2^0W^+$	0.214
	$\tilde{\mu}_L^+\nu_\mu$	0.020	$\tilde{\chi}_1^+h^0$	0.183
	$\tilde{\tau}_1^+\nu_\tau$	0.104		

7. CROSS SECTIONS

Using the parameter set (3) it is possible to calculate production cross sections of superpartners by application of the computer program PYTHIA [10]. These cross sections at center-of-mass energy $\sqrt{s} = 14$ TeV are shown in Table 6.

Table 6. *Cross sections of superpartners*

channel	cross section
$gg \to \tilde{g}\tilde{g}$	$\sigma_{\tilde{g}\tilde{g}} = 0.307$ pb
$gu \to \tilde{g}\tilde{u}$	$\sigma_{\tilde{g}\tilde{u}} = 0.891$ pb
$du \to \tilde{d}\tilde{u}$	$\sigma_{\tilde{d}\tilde{u}} = 0.466$ pb
$\overline{u}u \to \tilde{\chi}_1^+\tilde{\chi}_1^-$	$\sigma_{\tilde{\chi}_1^+\tilde{\chi}_1^-} = 0.157$ pb
$\overline{d}u \to \tilde{\chi}_1^+\tilde{\chi}_2^0$	$\sigma_{\tilde{\chi}_1^+\tilde{\chi}_2^0} = 0.208$ pb

Table 7. *Lower limits on masses reached at colliders*

particle		Condition	Lower limit (GeV)	Source
$\tilde{\chi}_1^\pm$	gaugino	$M_{\tilde{\nu}} > 200$ GeV	103	LEP 2
		$M_{\tilde{\nu}} > M_{\tilde{\chi}^\pm}$	85	LEP 2
		any $M_{\tilde{\nu}}$	45	Z width
	Higgsino	$M_2 < 1$ TeV	99	LEP 2
	GMSB		150	D0 isolated photons
	RPV	LL$\overline{E}$ worst case	87	LEP 2
		LQ$\overline{D}$ $m_0 > 500$ GeV	88	LEP 2
$\tilde{\chi}_1^0$	indirect	any tanβ, $M_{\tilde{\nu}} > 500$ GeV	39	LEP 2
		any tanβ, any m_0	36	LEP 2
		any tanβ, any m_0, SUGRA Higgs	59	LEP 2 combined
	GMSB		93	LEP 2 combined
	RPV	LL$\overline{E}$ worst case	23	LEP 2
$\tilde{e}_R$	$e\tilde{\chi}_1^0$	$\Delta M > 10$ GeV	99	LEP 2 combined
$\tilde{\mu}_R$	$\mu\tilde{\chi}_1^0$	$\Delta M > 10$ GeV	95	LEP 2 combined
$\tilde{\tau}_R$	$\tau\tilde{\chi}_1^0$	$M_{\tilde{\chi}_1^0} < 20$ GeV	80	LEP 2 combined
$\tilde{\nu}$			43	Z width
$\tilde{\mu}_R$, $\tilde{\tau}_R$		stable	86	LEP 2 combined
$\tilde{t}_1$	$c\tilde{\chi}_1^0$	any $\theta_{\text{mix}}, \Delta M > 10$ GeV	95	LEP 2 combined
		any $\theta_{\text{mix}}, M_{\tilde{\chi}_1^0} \sim \frac{1}{2}M_{\tilde{t}}$	115	CDF
		any θ_{mix}, and any ΔM	59	ALEPH
	$bl\tilde{\nu}$	any $\theta_{\text{mix}}, \Delta M > 7$ GeV	96	LEP 2 combined
$\tilde{g}$	any $M_{\tilde{q}}$		195	CDF jets+E_T
$\tilde{q}$	$M_{\tilde{q}} = M_{\tilde{g}}$		300	CDF jets+E_T

8. COMPARISON WITH EXPERIMENTS

Comparison of the predicted MSSM spectrum with experimental data obtained at the LEP and TEVATRON [11] (see Table 7) shows, that the calculated masses exceed the lower limits on masses reached at colliders. New searches for superpartners will be made at the LHC.

References

1. H.E. Haber. Introductory low-energy supersymmetry // arXiv: hep-ph/9306207.
2. C. Vafa, et al. Stringy reflections on LHC // http://www.claymath.org/workshops/lhc/.
3. P.S. Aspinwall. D-branes on Calabi-Yau manifolds // arXiv: hep-th/0403166.
4. M.R. Douglas, B. Fiol and C. Römelsberger. The spectrum of BPS branes on a noncompact Calabi-Yau // *JHEP.* 2005, **09**, p.1-57.
5. S. Katz, T. Pantev, and E. Sharpe. D-branes, orbifolds, and Ext groups // *Nucl. Phys.* 2003, **B673**, p.263-300.
6. W. Schmid. Homogeneous complex manifolds and representations of semisimple Lie groups // *Proc. Natl. Acad. Sci. USA.* 1968, **69**, p.56-59.
7. J.J. Heckman, and C. Vafa. F-theory, GUTs, and the weak scale // arXiv:0809.1098 [hep-th].
8. B.C. Allanach. SOFTSUSY2.0: a program for calculating supersymmetric spectra // *Comput. Phys. Commun.* 2002, **143**, p.305-331.
9. M. Muhlleitner, A. Djouadi, and Y. Mambrini. SDECAY: a fortran code for the decays of the supersymmetric particles in the MSSM // *Comput. Phys. Commun.* 2005, **168**, p.46-70.
10. T. Sjöstrand, S. Mrenna and P. Skands. PYTHIA 6.4 Physics and Manual // *JHEP.* 2006, **05**, p.1-26.
11. M. Schmitt. Supersymmetry, Part II (Experiment) // *Phys. Lett.* 2004, **B592**, p.1014-1023.

СТРУННЫЙ ПОДХОД К МИНИМАЛЬНОЙ СУПЕРСИММЕТРИЧНОЙ СТАНДАРТНОЙ МОДЕЛИ

Ю.М. Малюта, Т.В. Обиход

Теория суперструн применена для построения Минимальной суперсимметричной стандартной модели. Проведены вычисления спектра масс, парциальных ширин и сечений рождения суперпартнеров. Этот подход дает конкретные предсказания для поиска суперпартнеров на LHC.

СТРУННИЙ ПІДХІД ДО МІНІМАЛЬНОЇ СУПЕРСИМЕТРИЧНОЇ СТАНДАРТНОЇ МОДЕЛІ

Ю.М. Малюта, Т.В. Обіход

Теорію суперструн застосовано для побудови Мінімальної суперсиметричної стандартної моделі. Виконано обчислення спектра масс, парціальних ширин і перерізів народження суперпартнерів. Цей підхід дає конкретні передбачення для пошуку суперпартнерів на LHC.