The Orbifolder:
Additional material

H.P. Nilles[a], S. Ramos-Sánchez[b], P.K.S. Vaudrevange[c,d,e], A. Wingerter[f]

[a]*Bethe Center for Theoretical Physics and Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn, Germany*
[b]*Department of Theoretical Physics, Physics Institute, UNAM, Mexico D.F. 04510, Mexico*
[c]*Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany*
[d]*Physik-Department T30, Technische Universität München, James-Franck-Straße, 85748 Garching, Germany*
[e]*Arnold-Sommerfeld-Center for Theoretical Physics, Theresienstraße 37, 80333 München, Germany*
[f]*Laboratoire de Physique Subatomique et de Cosmologie, UJF Grenoble 1, CNRS/IN2P3, INPG, 53 Avenue des Martyrs, F-38026 Grenoble, France*

Abstract

The `orbifolder` is a program developed in `C++` that computes and analyzes the low-energy effective theory of heterotic orbifold compactifications. The program includes routines to compute the massless spectrum, to identify the allowed couplings in the superpotential, to automatically generate large sets of orbifold models, to identify phenomenologically interesting models (e.g. MSSM-like models) and to analyze their vacuum-configurations.

Keywords: Orbifold, string compactification, extra dimensions, particle spectrum, MSSM

1. Example files

Table 1: Example geometry file `Geometry_Z3_SU3^3.txt` for the $\mathbb{Z}_3$ orbifold.

Geometry_Z3_SU3^3.txt	description
point group 3 1	 $M = 3$ $N = 1$, hence $\mathbb{Z}_3$ point group
ZMxZN false	 this is a $\mathbb{Z}_M$ orbifold
lattice label SU(3)^3	 name of six-dim. lattice Γ, see `begin/end lattice`
begin twist 0/1 1/3 1/3 -2/3 end twist	 one twist vector $v = \left(0, \frac{1}{3}, \frac{1}{3}, -\frac{2}{3}\right)$ for $\mathbb{Z}_3$
begin twist space group generators 1 0 0 0 0 0 0 0 end twist space group generators	list all space group generators with twists $(\theta, 0)$
begin shift space group generators 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 . . . 0 0 0 0 0 0 0 1 end shift space group generators	list all space group generators without twists $(\mathbb{1}, e_1)$ $(\mathbb{1}, e_2)$ . . . $(\mathbb{1}, e_6)$
begin discrete symmetries new non-R symmetry 3 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 new non-R symmetry 3 0 0 0 1 1 0 0 0 0 0 0 0 1 0 0 0 0 . . . new R symmetry 3 -1/1 0 1 0 0 new R symmetry . . . end discrete symmetries	 next symmetry: non-R symmetry of order 3 superpotential charge is 0 (non-R) $\mathbb{Z}_3$ charge is k; point group symmetry generator of symmetry: $(\theta, 0)$ next symmetry: non-R symmetry of order 3 superpotential charge is 0 (non-R) $\mathbb{Z}_3$ charge is $n_1 + n_2$; space group in first torus generator of symmetry: $(\mathbb{1}, e_2)$ . . . next symmetry: R symmetry of order 3 (some R-charges might be fractional) superpotential charge is -1 (R) $\mathbb{Z}_3^R$ charge is R_1 next symmetry: R symmetry . . .
begin lattice	define the lattice Γ

Geometry_Z3_SU3^3.txt	description
next lattice vector	coordinates of lattice vector e_1 in $\mathbb{R}^6$
1.4142136	
0	
0	
0	
0	
0	
next lattice vector	coordinates of lattice vector e_2 in $\mathbb{R}^6$
-0.70710678	
1.2247449	
0	
0	
0	
0	
...	...
end lattice	
allowed order of Wilson lines	specify the order of each Wilson line; use order 1 for $W = \in \Lambda$
3	$3W_1 \in \Lambda$
...	...
3	$3W_6 \in \Lambda$
begin identical WLs	specify identified Wilson lines by their indices, i.e.
1 2	$W_1 = W_2$
3 4	$W_3 = W_4$
5 6	$W_5 = W_6$
end identical WLs	
begin constructing elements	list all inequivalent constructing elements
new sector	next sector: untwisted sector
0 0 0 0 0 0 0 0	constructing element $(\mathbb{1}, 0)$
new sector	next sector: $k = 1$ twisted sector
1 0 0 0 0 0 0 0	constructing element $(\theta, 0)$
1 0 0 0 0 0 0 1	constructing element (θ, e_6)
1 0 0 0 0 0 1 1	constructing element $(\theta, e_5 + e_6)$
...	...
new sector	next sector: $k = 2$ twisted sector
2 0 0 0 0 0 0 0	constructing element $\left(\theta^2, 0\right)$
...	...
end constructing elements	
begin centralizer elements	for every constructing element, list the centralizer
begin data	centralizer of the first constructing element $(\mathbb{1}, 0)$
1 0 0 0 0 0 0 0	$[(\theta, 0), (\mathbb{1}, 0)] = 0$
0 0 1 0 0 0 0 0	$[(\mathbb{1}, e_\alpha), (\mathbb{1}, 0)] = 0$
0 0 0 1 0 0 0 0	...
...	
end data	

Geometry_Z3_SU3ˆ3.txt	description
begin data	centralizer of the next constructing element $(\theta, 0)$
1 0 0 0 0 0 0 0	$[(\theta, 0)\,, (\theta, 0)] = 0$
2 0 0 0 0 0 0 0	...
end data	
begin data	centralizer of the next constructing element (θ, e_6)
1 0 0 0 0 0 0 1	$[(\theta, e_6)\,, (\theta, e_6)] = 0$
2 0 0 0 0 0 -1 0	...
end data	
...	...
end centralizer elements	

Table 2: Example geometry file `Geometry_Z2xZ2_DW1-3_Example.txt` for the $\mathbb{Z}_2\times\mathbb{Z}_2$ orbifold model (1-3) of [1]. The set of constructing elements, centralizer elements and the relations between Wilson lines will be determined automatically. The result will be saved in the file `Geometry_Z2xZ2_DW1-3_Example.txt`.

Geometry_Z2xZ2_DW1-3_Example.txt	description
point group	
2	$M = 2$
2	$N = 2$, hence $\mathbb{Z}_2\times\mathbb{Z}_2$ point group
ZMxZN	
true	this is a $\mathbb{Z}_M\times\mathbb{Z}_N$ orbifold
additional label	
DW1-3Example	
begin twist	
0 0 1/2 -1/2	two twist vectors v_1 and v_2 for $\mathbb{Z}_2\times\mathbb{Z}_2$
0 -1/2 0 1/2	
end twist	
lattice label	
SU(2)ˆ6	name of six-dim. lattice Γ, see `begin/end lattice`
begin lattice	define the lattice Γ
next lattice vector	coordinates of lattice vector e_1 in $\mathbb{R}^6$
1.41421360	
0.00000000	
0.00000000	
0.00000000	
0.00000000	
0.00000000	
next lattice vector	coordinates of lattice vector e_2 in $\mathbb{R}^6$
0.00000000	
1.41421360	
0.00000000	
0.00000000	

Geometry_Z2xZ2_DW1-3_Example.txt	description
0.00000000 0.00000000 ... end lattice	 ...
begin twist space group generators 1 0 0 0 0 0 0 0 0 1 0 0 0 0 1/2 0 end twist space group generators	list all space group generators with twists $(\theta, 0)$ $\left(\omega, \frac{1}{2}e_5\right)$
begin shift space group generators 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 ... 0 0 0 0 0 0 0 1 0 0 0 1/2 0 1/2 0 1/2 end shift space group generators	list all space group generators without twists $(\mathbb{1}, e_1)$ $(\mathbb{1}, e_2)$ ... $(\mathbb{1}, e_6)$ $\left(\mathbb{1}, \frac{1}{2}(e_2 + e_4 + e_6)\right)$
find Wilson lines relations	automatically determine the order of the Wilson lines and relations between them
create constructing elements	create all inequivalent constructing elements
create centralizer elements	for all constructing elements create a set of commuting elements

Table 3: Example model file `modelZ3.txt` containing one orbifold, the $\mathbb{Z}_3$ orbifold.

modelZ3.txt	description
begin model	
Label:Z3StandardEmbedding	label of this orbifold model
SpaceGroup:Geometry/Geometry_Z3_SU3ˆ3.txt	geometry file where the space group is defined
Lattice:E8xE8	gauge lattice (`E8xE8` or `Spin32`)
Program filename:printsummary.txt	optional: script file containing commands that will be executed automatically after loading this model
Shifts and Wilsonlines: 1/3 1/3 -2/3 0/1 $\cdots$ 0/1 0/1 0/1 0/1 0/1 $\cdots$ 0/1 0/1 0/1 0/1 0/1 $\cdots$ 0/1 0/1 0/1 0/1 0/1 $\cdots$ 0/1 ... 0/1 0/1 0/1 0/1 $\cdots$ 0/1	eight gauge embeddings (16 dim. vectors) corresponding to θ, ω and e_α, $\alpha = 1, \ldots, 6$ shift V_1 for θ shift V_2 for ω; $V_2 = 0$ for $\mathbb{Z}_M$ Wilson line W_1 for e_1 Wilson line W_2 for e_2 ... Wilson line W_6 for e_6
begin U1 generators number of U1s:N 1/1 0/1 0/1 0/1 $\cdots$ 0/1 ...	optional: specify the first `N` U(1) generators 16 dim. vector for the first U(1) ...

modelZ3.txt	description
end U1 generators	
discrete torsion 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1 0/1	optional: specify the parameters of discrete torsion [2] a b_α with $\alpha = 1, \ldots, 6$ c_α with $\alpha = 1, \ldots, 6$ next six lines: $d_{\alpha\beta}$ with $\alpha, \beta = 1, \ldots, 6$ and $d_{\alpha\beta} = -d_{\beta\alpha}$
end model	

2. Example: input and output

Table 4: Example input and output for the $\mathbb{Z}_3$ orbifold model with standard embedding.

input/output	description
i: `localdirectory/> ./orbifolder modelZ3.txt`	start program and load model file `modelZ3.txt`
o:	
o: `###########################################################################`	
o: `#  The C++ Orbifolder                                                      #`	
o: `#  Version: 1.0                                                            #`	
o: `#  by H.P. Nilles, S. Ramos-Sanchez, P.K.S. Vaudrevange and A. Wingerter  #`	
o: `###########################################################################`	
o:	
o:	
o: `Load orbifolds from file "modelZ3.txt".`	
o: `Orbifold "Z3StandardEmbedding" loaded.`	
o:	
o:`/>`	
i: `cd Z3StandardEmbedding`	go to directory `Z3StandardEmbedding` for the $\mathbb{Z}_3$ model
o:`/Z3StandardEmbedding>`	
i: `dir`	show commands of the current directory
o:	
o: `special commands of this directory:`	
o: `change directory:`	
o: `cd model` `change directory to /model>`	input data (twists, shifts, Wilson lines,..) of the $\mathbb{Z}_3$ model
o: `cd gauge group` `change directory to /gauge group>`	details of the gauge group
o: `cd spectrum` `change directory to /spectrum>`	details of the spectrum
o: `cd couplings` `change directory to /couplings>`	generate the superpotential and mass matrices
o: `cd vev-config` `change directory to /vev-config>`	tools to analyze vev-configs of the model
o: `cd vev-config/labels` `change directory to /labels>`	assign labels to the fields
o:	

input/output	description
o: `general commands:`	
o: `dir` `show commands`	
o: `help` `optional: ...`	
o: `cd ..` `leave this directory`	
o: `exit` `exit program`	exit the program
o:	
o:/Z3StandardEmbedding>	
i: `cd gauge group`	go to directory `gauge group` (shortcut: `gg`)
o:/Z3StandardEmbedding/gauge group>	
i: `print gauge group`	display the gauge group
o:	
o: `Gauge group in vev-configuration "TestConfig1": E_6 x SU(3) and E_8`	
o:	
o:/Z3StandardEmbedding/gauge group>	
i: `print simple roots`	display (a choice of) the simple roots
o:	
o: `Simple roots:`	
o: `( 0 0 0 1 -1 0 0 0)...`	
o: `( 0 0 0 0 1 -1 0 0)...`	
...	
o:/Z3StandardEmbedding/gauge group>	
i: `cd ..`	go back one directory
o:/Z3StandardEmbedding>	
i: `cd spectrum`	go to directory `spectrum` (shortcut: `s`)
o:/Z3StandardEmbedding/spectrum>	
i: `print summary`	print all left-chiral matter fields
o:	
o: `Gauge group in vev-configuration "TestConfig1": E_6 x SU(3) and E_8`	
o:	
o: `3 (-27, 3, 1)_l`	`-27` denotes $\overline{\mathbf{27}}$ of E_6 and the
o: `27 (-27, 1, 1)_l`	subscript `_l` denotes left-chiral
o: `81 ( 1, -3, 1)_l`	
o:	

input/output	description
o:/Z3StandardEmbedding/spectrum>	
i: cd ~	go back to the main directory
o:/>	
i: create random orbifold from(Z3StandardEmbedding) #models(10) print info	create ten $\mathbb{Z}_3$ orbifolds randomly
o: New child process "PID 4026" from command "create random orbifold	process started
o: from(Z3StandardEmbedding) #models(10) print info".	
o: Note that details of newly created orbifold models can only be seen	
o: after process "PID 4026" has finished.	
o:/>	
o: Orbifold model "Random1":	first random model
o: E6 + A2 and D4	gauge group: $E_6 \times \mathrm{SU}(3) \times \mathrm{SO}(8)$
o: 81 (1, -3, 1)	
o: 3 (-27, 3, 1)	
o: 3 (-27, 1, 1)	
...	nine more random models
o: Models created without problems.	process finished
o: PID 4026 done: "create random orbifold from(Z3StandardEmbedding)	
o: #models(10) print info" TIME: 00:00:06	

[1] R. Donagi and K. Wendland, “On orbifolds and free fermion constructions,” *J.Geom.Phys.* **59** (2009) 942–968, 0809.0330.
[2] F. Plöger, S. Ramos-Sánchez, M. Ratz, and P. K. Vaudrevange, “Mirage Torsion,” *JHEP* **0704** (2007) 063, hep-th/0702176.