

# On High Energy Physics and Quantum Information <sup>1</sup>

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<sup>1</sup>High Energy Physics Workshop in Morocco, Tanger

Very happy with 20 years, working on theoretical high energy physics

# Collaborations in High Energy Physics: 1997-2017

- ▶ Developing scientific collaborations in **High Energy Physics** and related subjects in Morocco
  1. Mohammed V University, **Rabat**  
Collaborators: Hassan El Saidi
  2. CNESTEN, **Rabat**  
Collaborators: Bouchra Belhorma, Hassan El Saidi
  3. Ibn Tofail University, **Kenitra**  
Collaborators: Moulay Brahim Sedra
  4. Cadi Ayyad University, **Marrakesh**  
Collaborators: Mohamed Chabab
  5. Ibn Zohr University, **Agadir**  
Collaborators: Hasan El Moumni
  6. Sultan Moulay Simane University, **Beni Mellal**  
Collaborators: Nourdine Askor, Bouzid Manaut
- ▶ Collaborating with European, North American and International Institutes  
**Spain, Chile, Canada, ...**

## Rabat:1997-2011

- ▶ Scientific contributions in HEP and related topics
  1. String/M-theory
  2. Particle physics
  3. Mathematical tools applied to High Energy Physics
  4. Mathematical physics
- ▶ Participation to supervising PhD-students on HEP
- ▶ Scientific projects in collaboration with national and international experts on HEP
- ▶ Invitation of scientists and international experts:  
A. Segui, M. P. Garcia del Moral, B. B. Janssen, P. Diaz, M. Asorey, L. J Boya, C. Hoyos, S. Montanez, J. Walcher, D. Cremades, K. Landsteiner, E. Lopez, J. Rasmussen, C. Gomez, J.J. Manjarin, A. Sebbar, J. McKay.
- ▶ Building Scientific Bridge between Europe and HEP in Rabat.

- ▶ Scientific contributions in HEP and theoretical physics
  - 1. Black holes in String/M-Theory
  - 2. Quantum Information Theory
  - 3. Symmetry and Physics
- ▶ Scientific publications
- ▶ Co-supervising PhD-students on HEP
  - 1. Zarakiae Benslimane (2014-2018)
  - 2. Mohammed Bensed (2016-2019)
- ▶ Invitation of scientists and international experts
  - 1. C. A. R. Herdeiro

# Marrakesh

- ▶ Scientific contributions in HEP and theoretical physics
  - 1. Black holes in string/M-theory
  - 2. Phenomology in F-theory
- ▶ Collaborating with PhD-students on HEP
- ▶ Publications
- ▶ Scientific visits.

# Beni Mellal: 2013-

- ▶ Scientific contributions in HEP and theoretical physics
  1. Black holes in string/M-theory
  2. Extended Standard Model
  3. Quantum Information
- ▶ Publications on HEP
- ▶ Organization of national workshops on HEP and Mathematical physics
  1. Arougou meeting (2014)
  2. Arougou meeting (2015)
- ▶ Talks on HEP, mathematical physics, and Lie symmetry.

# Theoretical physics activities in Beni Mellal

- ▶ 5 professors
  1. Bouzid Manaut
  2. Soaud Taz
  3. Khalid El Rahmani
  4. Mostapha Mansor
  5. AB
- ▶ working on
  1. Atomic and nuclear physics
  2. Standard Model and particle physics
  3. String theory and related topics
  4. Quantum Information theory
  5. Material physics .
- ▶ Scientific publications
- ▶ PhD students
- ▶ Master on modern physics

# Plan

- ▶ Introduction
- ▶ Qubit systems
- ▶ String theory/qubit systems
  - ▶ Real manifold  $T^n$  in String Theory
  - ▶ Real supermanifold  $T^{n|n}$  in String Theory
  - ▶ Calabi-Yau Manifolds in M-theory.
- ▶ Discussion

Based on works with

1. Mohammed Bensed, Kénitra
2. Zakariae Benslimane, Kénitra
3. Moulay Brahim Sedra, Kénitra
4. Antonio Segui, Zaragoza.

# Introduction

- ▶ Black holes/ qubit systems
- ▶ Lie superalgebra/ superqubits.
- ▶ Many papers on quantum information
  - ▶ Supersymmetry and Supermanifolds
  - ▶ Quantum physics
  - ▶ String theory
  - ▶ M-theory

# Qubit systems

- ▶ Classical bit:

0      1

- ▶ Quantum bit (qubit)

$$\begin{aligned} 0 &\rightarrow |0\rangle \\ 1 &\rightarrow |1\rangle \end{aligned}$$

- ▶ Dirac notation of one-qubit

$$|\psi\rangle = c_0|0\rangle + c_1|1\rangle$$

- ▶ Vector of two dimensional Hilbert space
- ▶ Normalization condition

$$|c_0|^2 + |c_1|^2 = 1.$$

# Remarks on 1-qubit system

- ▶ Physics

- ▶ Hydrogen atom with two states.
- ▶ Spin  $\frac{1}{2}$  particles.
- ▶ Photons in four dimensions.
- ▶ ....

- ▶ Mathematics

$$|c_0|^2 + |c_1|^2 = 1.$$

- ▶  $SU(2)$  Lie group.
- ▶ One dimensional projective space:  $CP^1 \equiv S^2$
- ▶ .....

## *n*-qubit systems

- ▶ Two-qubits are four configuration systems:

$$|\psi\rangle = c_{00}|00\rangle + c_{10}|10\rangle + c_{01}|01\rangle + c_{11}|11\rangle$$

1. Vector of 4 dimensional Hilbert space
2. Normalization condition

$$|c_{00}|^2 + |c_{10}|^2 + |c_{01}|^2 + |c_{11}|^2 = 1.$$

- ▶ *n*-qubits:

$$|\psi\rangle = c_{0\dots 0}|0\dots 0\rangle + c_{10\dots 0}|10\dots 0\rangle + \dots + c_{1\dots 1}|1\dots 1\rangle$$

1.  $2^n$  configuration state systems
2. Vectors of  $2^n$  dimensional Hilbert space.

# Realization of qubits

## ► Motivations

1. Graphic representation of  $n$ -qubits
2.  $2^n$ .

## ► Frameworks

1. String theory compactification
2. Clifford algebras.

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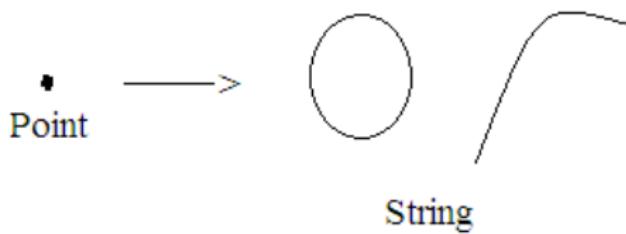
1. String theory compactification
2. Clifford algebras.

# Ordinary physics

- ▶ Ordinary physics
  - ▶ Treating the objects (particles) as **material points**
- ▶ Particle Physics
  - ▶ Fundamental Interactions of Nature
    1. Strong interaction
    2. Weak interaction
    3. Electromagnetic interaction
    4. Gravitation interaction.
  - ▶ Gauge Theories: Grand Unified theory (GUT)
- ▶ The main problem is the gravity theory.

# String Theory

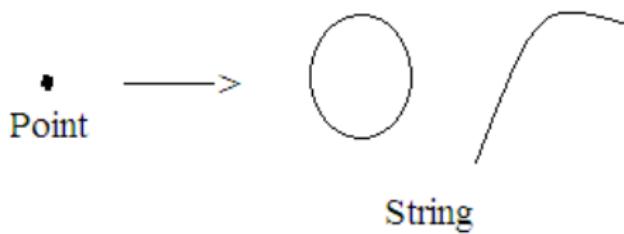
- ▶ Ordinary physics
  - ▶ Treating the objects (particles) as **material points**
- ▶ String theory
  - ▶ The motion of particles (zero dimensional objects) should be extended to the motion of one dimensional objects: **strings**.



- ▶ Two configurations
  1. Open string theory
  2. Closed string theory

# String Theory

- ▶ Ordinary physics
  - ▶ Treating the objects (particles) as **material points**
- ▶ String theory
  - ▶ The motion of particles (zero dimensional objects) should be extended to the motion of one dimensional objects: **strings**.



- ▶ Two configurations
  1. Open string theory: **Gauge theories**
  2. Closed string theory: **Gravity theory**.

# String Theory

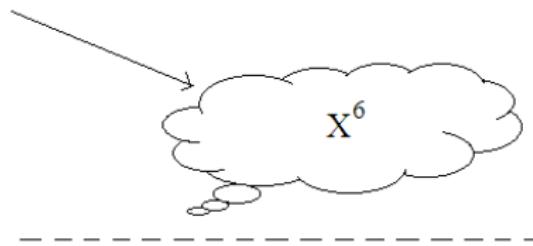
- ▶ Good things
  - ▶ Possible unified theory of fundamental interactions of nature
  - ▶ Gravitons, photons,....
  - ▶ Quantum version of gravity theory.
- ▶ Bad things
  - ▶ Five models.
  - ▶ Big gauge symmetries:  $E_8 \times E_8$ ,  $so(32)$  Lie algebras.
  - ▶ Dimension of the space-time :  $D = 10 = 1 + 9$ .
- ▶ References
  1. M. Green, J. Schwarz and E. Witten, Superstring Theory, 2 Vols., Cambridge U.P.1987.
  2. A. Belhaj, Introduction to String Theory, arXiv:0808.2957.

# String compactification

- ▶ Partial solutions

$$R^{1,9} \rightarrow R^{1,3} \times X^6$$

Compact



$$R^{1,3}$$



Space-time

# Toroidal compactification

- ▶  $T^n$ : trivial fibration of  $n$  circles

$$x_i \equiv x_i + 1, \quad i = 1, \dots, n.$$

- ▶ Real Hodge diagrams

$$h^{e_1, \dots, e_n} \longrightarrow \bigwedge_{\ell=1}^n (\bar{e}_\ell + e_\ell dx_\ell),$$

$e_\ell$ : binary number taking either 0 or 1.

- ▶  $\bigwedge_{\ell=1}^n (\bar{e}_\ell + e_\ell dx_\ell)$  is a real differential form, on  $T^n$ , of degree  $k$

$$k = \sum_{\ell=1}^n e_\ell.$$

# $T^n$ Geometry/qubit correspondence

- ▶ Cycles/qubits

$$h^{e_1, \dots, e_n} \longrightarrow \text{node} = (e_1, \dots, e_n) \longrightarrow |e_1, \dots, e_n\rangle.$$

- ▶ The number of the nodes in the  $k$ -level

$$\text{nbr}(k\text{-level nodes}) = C_n^k = b_k(T^n).$$

- ▶ Total number of the cycles, in  $T^n$ , is the total number of the nodes

$$\text{nbr(cycles)} = \sum_{k=0}^n C_n^k = 2^n.$$

*Example :  $T^2$*



*Example :  $T^2$*



$T^2$	Adinkra	qubit system	Black hole system
1	(00)	$ 00\rangle$	D0-brane
$dx_1$	(10)	$ 10\rangle$	F-string
$dx_2$	(01)	$ 01\rangle$	F-string
$dx_1 dx_2$	(11)	$ 11\rangle$	D2-brane

**Table:** Correspondence between the eight dimensional black hole, Adinkra and qubit systems.

# $T^{n|n}$ supergeometry and superqubits

- ▶ Superqubit can take three values:

0,    1,    §.

- ▶ Bosonic and the fermionic states
  - ▶ Total number of states

$$3^n = \frac{3^n - 1}{2} + \frac{3^n + 1}{2}.$$

- ▶ Odd and even geometries on  $T^{n|n}$

## $T^{n|n}$ supergeometry

- ▶ Supermanifold is a generalization of the manifold concept motivated by supersymmetry.
  - ▶ In physics, it is a manifold with both bosonic and fermionic coordinates
  - ▶ These coordinates are denoted by

$$(x_i, \theta_i, \bar{\theta}_i)$$

$x_i$  = spacetime vectors

$\theta_i$  and  $\bar{\theta}_i$  = Grassmann-valued spinors.

- ▶ Example:  $T^{n|n}$  supergeometry
- ▶ Real Hodge diagram of  $T^{n|n}$

$$h^{e_1, \dots, e_n | \alpha_1, \dots, \alpha_n} \longrightarrow \prod_{\ell=1}^n (\overline{e_\ell} + e_\ell dx_\ell) \prod_{\alpha=1}^n (\overline{e_\alpha} + e_\alpha d\theta_\alpha).$$

- Formal supersymmetry structure

$$BB = B$$

$$BF = F$$

$$FB = F$$

$$FF = B$$

$B$  and  $F$ : bosonic and the fermionic generators respectively.

- Bosonic states

$$\text{Number of bosonic states} = \frac{3^n + 1}{2}.$$

- Fermionic states

$$\text{Number of fermionic states} = \frac{3^n - 1}{2}.$$

## Example: $T^{2|2}$

- ▶ Diff. forms on  $T^{2|2}$ 
  1. Bosonic forms 1,  $dx_1$ ,  $dx_2$ ,  $dx_1 dx_2$ ,  $d\theta_1 d\theta_2$ .
  2. Fermionic forms  $d\theta_1$ ,  $d\theta_2$ ,  $dx_1 d\theta_2$ ,  $d\theta_1 dx_2$ .
- ▶ Correspondence

$T^{2 2}$	Adinkra	qubit system	black hole system
1	(00 00)	$ 00 00\rangle$	Bosonic D0-brane
$dx_1$	(10 00)	$ 10 00\rangle$	Bosonic F-string
$dx_2$	(01 00)	$ 01 00\rangle$	Bosonic F-string
$dx_1 dx_2$	(11 00)	$ 11 00\rangle$	Bosonic D2-brane
$d\theta_1$	(00 10)	$ 00 \S0\rangle$	Fermionic F-string
$d\theta_2$	(01 00)	$ 01 0\S\rangle$	Fermionic F-string
$d\theta_1 dx_2$	(01 10)	$ 01 \S0\rangle$	Fermionic F-string
$d\theta_2 dx_1$	(10 01)	$ 10 0\S\rangle$	Fermionic D2-brane
$d\theta_1 d\theta_2$	(00 11)	$ 00 \S\S\rangle$	Bosonic D2-brane

## Discussions

- ▶ One to one correspondence between:  
qubit systems, Adinkras, Toroidal compactification, extremal  
black holes, branes.
- ▶  $n$  qubits/Real manifold  $T^n$ .
- ▶  $n$  superqubits/Real supermanifold  $T^{n|n}$ .
- ▶ Many open questions related to quantum information theory.
  - ▶ Gates
  - ▶ Entropy
  - ▶ .....

# Connection with Calabi-Yau manifolds

- ▶ M-theory compactification on the K3 surface (Two dimensional Calabi-Yau manifold).
- ▶ Interplay between the three scalar submanifold factors and the extremal black holes obtained from M2-branes.
- ▶ The corresponding black hole charges are linked to one, two and four qubit systems.
- ▶ Related works:
  - ▶ AB, Zakaria Benslimane, Moulay Brahim Sedra, Antonio Segui, [Qubits from Black Holes in M-theory on K3 Surface](#), [arXiv:1601.07610](#).
  - ▶ AB, Mohammed Bensed, Zakaria Benslimane, Moulay Brahim Sedra, Antonio Segui [Dyonic black solutions in type II Superstrings](#) .

Thank you