THE SUPERSYMMETRIC STANDARD MODEL

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30 years of supergravity

Paris, oct. 16, 2006

An introduction

Is there a

“<u>SUPERWORLD</u>” ?

of new particles ?

Could <u>half of the particles</u> (at least)

have escaped our direct observations ?

STANDARD MODEL

describes

strong, electromagnetic and weak interactions

of quarks and leptons

$\boldsymbol{SU(3) \times SU(2) \times U(1)}$ **gauge group**

spin-1 gauge bosons:	gluons,	$\underbrace{W^+,\ W^-,\ Z,\ \text{photon}}$
spin-$\frac{1}{2}$ fermions:		**quarks** and **leptons**

+ 1 (still unobserved)

spin-0 **Englert-Brout-Higgs boson**

associated with **spontaneous breaking**

of $SU(2) \times U(1)$ **electroweak symmetry**

– **remarkably successful**

– **but leaves many questions unanswered**

(a long list ...)

Among which

- why <u>fundamental Higgs fields</u> ?

(do they actually exist ?)

[many physicists, ignoring supersymmetry, long reluctant to accept fundamental spin-0 fields

$\longrightarrow$ technicolor $\longrightarrow$ extended technicolor, ...]

- why a <u>Higgs potential</u>

$$V(\varphi) \;=\; \lambda\, |\varphi|^4 \;-\; \mu^2\, |\varphi|^2 \quad ?$$

what is the mass of the Higgs boson ?

($m_{\text{Higgs}} \;=\; \mu\,\sqrt{2} \;=\; v\,\sqrt{2\,\lambda}$ ...)

what fixes μ ?

what fixes the <u>coupling constant λ</u> ?

- is the Higgs sector (if exists) the one of the SM

or a more complicated one ... ?

- <u>do new particles exist</u> ?

(maybe also new forces ?)

[after LEP, we think we know all (sequential) quarks and leptons]

this has become essential,

in view of growing evidence for

<u>non-baryonic dark matter</u>

Other interrogations :

- role of <u>gravity</u>

  (related to spacetime through general relativity)

  can it be more closely connected with particle physics ?

  can one get a consistent theory of quantum gravity ?

  question of cosmological constant Λ ...

- can interactions be unified ?

  approach of <u>grand-unification</u>:

  $SU(3) \times SU(2) \times U(1) \quad \subset$ simple gauge group, e.g. $SU(5)$

$$\left\{ \begin{array}{lcl} \text{gluons} & \longleftrightarrow & W^{\pm},\ Z,\ \gamma \quad (\text{ + other gauge bosons}) \\ \text{quarks} & \longleftrightarrow & \text{leptons} \end{array} \right.$$

  with its own questions ...

(Higgs potential and symmetry breaking, origin of hierarchy of mass scales, many coupling constants, relations between q and l masses ...

- can one relate particles of different spins ?

etc. ...

We now have a "new" tool,

SUPERSYMMETRY

BOSONS $\longleftrightarrow$ **FERMIONS**

(integer spins) **(half-integer spins)**

<u>SUPERSYMMETRY ALGEBRA</u> :

$$\begin{cases} \{ \, Q \, , \, \bar{Q} \, \} & = \; - \, 2 \; \gamma_\mu \, P^\mu \\ [\, Q, \; P^\mu \,] & = \; 0 \end{cases}$$

Gol'fand-Likhtman, Volkov-Akulov, <u>Wess-Zumino</u>, 1970-73

$\boldsymbol{P^\mu}$ $=$ **generator of space-time translations**

relation with spacetime

$\longrightarrow$ *connection with general relativity*

$\longrightarrow$ *supergravity* **(1976)**

a new structure

what to do with it ?

Why was SUSY algebra introduced ?

- **Gol'fand and Likhtman, 1970 :**

SUSY algebra, written as:

$$\{\ Q_L\,,\ \overline{Q_L}\ \}\ =\ -\,2\ \gamma_\mu\ \tfrac{1+i\,\gamma_5}{2}\ \ P^\mu$$

at the origin of <u>parity non-conservation</u> (in weak interact.) ?

- **Volkov and Akulov, 1973 :**

is the neutrino a Goldstone particle ?

$m_\nu = 0$ from SUSY algebra ... ?

(no ...)

V.A. model includes only fermions, no boson ..

($\delta_{\rm SUSY}$ fermion = composite bosonic field made of two fermions ...)

SUSY without bosons !!!

$\longrightarrow$

(SUSY without superpartners ... *not the SUSY we know and like ...)*

- **Wess and Zumino, 1973 :**

Extend to 4 dim. “supergauge” transformations

acting on $2d$ string worldsheet

$$\longrightarrow$$

Construction of

renormalizable SUSY gauge theories

in 4 dimensions

Can supersymmetry actually be

a symmetry

of the fundamental laws of the world ?

It does not look like it !!!

(Situation in 1974)

Nature is "obviously"
not supersymmetric !

it seems

1 If supersymmetry:

bosons and fermions would have equal masses:

$$\underline{m_{\text{boson}} \equiv m_{\text{fermion}}} \quad !!$$

Possible answer: break (spontaneously) supersymmetry

But

spontaneous supersymmetry breaking did not seem possible !

(in contrast with ordinary symmetries, easy to break)

+ spontaneous breaking of supersymmetry

would generate massless spin-$\frac{1}{2}$ Goldstone fermion

where is the spin-$\frac{1}{2}$ Goldstone fermion of SUSY ?

– soft explicit breaking (much easier!) considered very early

(e.g. $\underline{m_0^2}$ $(\tilde{q}, \tilde{l})$ in 1976 ...)

– "rules of the game": generate susy-breaking terms spontaneously,

so that susy may be realized locally (within supergravity, after 1976)

2 Which **bosons** and **fermions** relate ??

e.g. ??

photon	$\overset{?}{\longleftrightarrow}$	*neutrino*
gluons	$\overset{?}{\longleftrightarrow}$	*quarks*
	...	

this does not work ...

3 SUSY theories systematically involve

(self-conjugate) **Majorana fermions**

while Nature only knows **Dirac fermions** !

3' Conserved quantum numbers B and L

carried by **fermions** (quarks and leptons),

not bosons !

this cannot be, in a supersymmetric theory ...

this seemed to make

supersymmetry **manifestly irrelevant**

to the description of the real world !!

- How to deal with <u>Majorana fermions</u>

of supersymmetric theories ?

- How to construct the <u>Dirac fermions</u> known in Nature ?

- How to attribute them <u>conserved quantum numbers</u>

(B and L) ?

\+ • How to obtain a <u>correct set of interactions</u>

i.e. weak, electromagnetic and strong interactions

due to the sole exchanges of

<u>$W^{\pm}$'s, Z's, photons and gluons</u>,

while avoiding

unwanted exchanges of <u>spin-0 particles</u> ?

This is related with the introduction of

$\boldsymbol{R}$-symmetry and $\boldsymbol{R}$-parity,

in Supersymmetric extensions

of the Standard Model,

which has essential consequences

for searches for the new

"supersymmetric particles"

as well as on the nature of the

non-baryonic dark matter

of the Universe

(neutralinos ...)

One had to find solutions to all previous problems.

Now that the main answers are,

to a large extent,

known and familiar to everybody,

(and accepted in the community)

they seem rather obvious !

- **Let us start with one of the main questions :**

Which bosons and fermions may be related ?

* * *

Could one relate the Fermions

constituants of matter

to Bosons, messengers of interactions ?

and arrive to some sort of

Unification between Forces and Matter ??

That would be very attractive, but ...

!! ...

Which BOSONS and FERMIONS may be <u>related</u>?

Are they fundamentally "of the same nature" ?

May be:

$$\boldsymbol{photon} \quad \overset{?}{\longleftrightarrow} \quad \boldsymbol{neutrino}$$

but which one: $\boldsymbol{\nu_e,\ \nu_\mu,\ \nu_\tau}$ **!!! ??**

$$\boldsymbol{W^-} \quad \overset{?}{\longleftrightarrow} \quad \boldsymbol{electron}$$

but what about $\boldsymbol{\mu}$ **and** $\boldsymbol{\tau}$ **??**

$$\boldsymbol{gluons} \quad \overset{?}{\longleftrightarrow} \quad \boldsymbol{quarks}$$

$$\mathbf{(8)} \qquad\qquad \mathbf{6 \times 3 \times 2}_{(\boldsymbol{L+R})}$$

(neutral) **charged**

...

this was tried ...

none of these direct associations suitable!

For example:

- **There is not one neutrino, but three ...**

difficult to select one (even a combination)
to associate to the photon ...

nevertheless, led to developing extended

$\underline{N=2}$, then $\underline{N=4}$, supersymmetric theories ...

more symmetry ! great ! (?)

but: → new (bigger) multiplets; more constraints

hypermultiplets, requiring central charges in algebra

possibility of "mirror particles", etc.

connection with extra spacetime dimensions ...

e.g. photon associated with two spin-$\frac{1}{2}$ fermions

(but not neutrinos! — now to be called "photinos")

and 2 "spin-0 photons",

now to be viewed as extra degrees of freedom for
the photon in a 6-dimensional spacetime.

Not the easiest way to go to a complete, and realistic, theory ...

Which degrees of freedom should actually be present in the low-energy theory?

We leave this for the time being, and return to ...

... "simple" ($N = 1$) supersymmetry ...

What should we do, then ?

- **If one neutrino could be associated with photon:**

SUSY generator would have to carry

one unit of the corresponding lepton number.

But it is a self-conjugate Majorana spinor...

How could a real object carry a "charge", i.e. one unit of a conserved additive quantum number ?

possible solution, and subsequent byproducts:

Led to introduce a continuous R-symmetry

acting "chirally" on the supersymmetry generator as:

$$Q \;\rightarrow\; e^{-\gamma_5 \alpha}\, Q$$

(Continuous) R-symmetry ($U(1)_R$) leads to further restrictions on possible (superpotential) interactions

Not all possible superpotentials are admissible ...

Further restrictions to be taken into account,

in addition to supersymmetry and gauge invariance...

Continuous R-symmetry the progenitor of R-parity ...

$\rightarrow$ *a stable dark matter candidate*

- **One more reason why the photon cannot be associated with one of the neutrinos:**

$$\text{If} \quad \underline{\nu \longleftrightarrow \gamma}\,,$$

ν interactions would be fixed by gauge invariance + SUSY,

This "ν" would <u>interact with charged particles only</u>,

and proportionally to their electric charge

(not the case for a normal neutrino (ν_e, ν_μ or ν_τ),

which interacts with Z ...)

Such a neutrino could not have weak-neutral-current interactions ...

This would-be "neutrino"

cannot be identified with ν_e (nor ν_μ or ν_τ),

but should be identified as a new particle,

a "<u>photonic neutrino</u>"

called in 1977 the | **"<u>photino</u>"** |

- **What about quarks and gluons?**

If quarks associated with gluons,

SUSY generator would have to carry color, and charge

transform like a color triplet

Would require a least 3 (or in fact 6 or more ...)

SUSY generators.

(→ would require very large multiplets with higher-spin fields, etc.)

More generally

- **Known <u>fermions</u> (q and l) correspond to**

$\boxed{90}$ degrees of freedom

(15 chiral fields for each family of q and l)

- **Known <u>bosons</u> (gluons, W^+, W^-, Z, γ) :**

only $\boxed{27}$ degrees of freedom

(+1 if we add the still-undiscovered spin-0 Englert-Brout-Higgs boson)

$\Longrightarrow$ **The SUSY idea seems to fail ...**

(or new fields are in any case required ...)

We have to accept, and take seriously the idea that

a large number of new fields

should be introduced.

$\Longrightarrow$ **all particles should be associated with**

new <u>superpartners</u>

photon	$\longleftrightarrow$	**spin-$\frac{1}{2}$**	***photino***
gluons	$\longleftrightarrow$	**spin-$\frac{1}{2}$**	***gluinos***
leptons	$\longleftrightarrow$	**spin-0**	***sleptons***
quarks	$\longleftrightarrow$	**spin-0**	***squarks***
	...		

this is the famous

"<u>doubling of the number of degrees of freedom</u>"

in susy theories

(within the framework of the "linear realisations" of susy)

SUSY does not relate directly known bosons and fermions !!

but:

Known bosons	$\longleftrightarrow$	**New fermions**
Known fermions	$\longleftrightarrow$	**New bosons**

It now seems obvious, although it was long mocked as a sign of the irrelevance of supersymmetry ...

... + Some additional ingredients

are still needed ...

encore ... ?!

why ... ?

Early attempt [*Nucl. Phys.* B 90, 104 (1975)]

at a toy-model relating

- the **photon** with a would-be "neutrino", reinterpreted as a "**photino**"
- the W^- with a would-be "electron", reinterpreted as a "wino" or "**chargino**"

very instructive! It led to a

$SU(2) \times U(1)$ electroweak theory

with electroweak symmetry spont. broken by

a pair of chiral doublet Higgs superfields,
now known as H_1 and H_2 .

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} , \quad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

both left-handed

with $< h_1^0 > = \frac{v_1}{\sqrt{2}}$, $< h_2^0 > = \frac{v_2}{\sqrt{2}}$

and a mixing angle (initially called δ)

such that $$\tan\beta = \frac{v_2}{v_1} .$$

Why two doublet Higgs superfields

rather than a single one ?

- With only one Higgs doublet (H_1) :

$$\begin{cases} \quad \text{one charged Dirac "gaugino"} \quad \lambda^- = \lambda_L^- + \lambda_R^- \\ + \ \text{one chiral charged "higgsino" e.g.} \quad \psi_L^- \end{cases}$$

$\Longrightarrow$ one massive charged Dirac fermion $(\psi_L^- + \lambda_R^-)$

one charged chiral fermion (λ_L^-) *would stay massless*

- With two Higgs doublets, we get

two charged Dirac fermions,

which may be defined as

$$\begin{cases} \tilde{W}_1^- = \psi_L^- + \lambda_R^- \\ \tilde{W}_2^- = \lambda_L^- + \psi_R^- \end{cases}$$

now known as "charginos"

- We also get a massless Majorana fermion

$$\lambda_\gamma = \sin\theta \ \lambda_3 + \cos\theta \ \lambda'$$

partner of the photon field under supersymmetry

$(A^\mu = \sin\theta \ W_3^\mu + \cos\theta \ B'^\mu)$

now known as "photino"

These charged fermions are

gaugino/higgsino mixings with mass matrix

$$\mathcal{M} = \begin{pmatrix} (m_2 = 0) & \frac{g\,v_2}{\sqrt{2}} = m_W\sqrt{2}\,\sin\beta \\ \frac{g\,v_1}{\sqrt{2}} = m_W\sqrt{2}\,\cos\beta & \mu = 0 \end{pmatrix}$$

now called "**winos**" or "**charginos**".

This is familiar !

- for the time being:

  - no gaugino mass term: $m_2 = 0$

  [absent in global supersymmetry (unless radiatively generated)]

  - no "μ term"

  [$\mu\, H_1 H_2$ superpotential already replaced by trilinear coupling

  $\lambda\, H_1 H_2\, N$ with extra singlet chiral superfield N]

  as they would violate the continuous $U(1)_R$ symmetry

- will become allowed once we drop the continuous $U(1)_R$ symmetry

  reducing it to a discrete subgroup of **R-parity** transformations.

we shall come back to this later

Let us now move to the Higgs sector

there must now be

charged Higgs bosons !

as well as several neutral ones

"l'horreur" !

they were almost as badly considered

as the color-octet of Majorana fermions ("gluinos")

(gluinos were believed not to exist,

as they would violate the general principle of "triality" ...

once taken as a constraint to determine

which particles had a chance to exist,

and which ones could not possibly exist ...)

2 Higgs doublets $\Longrightarrow$

$$\begin{cases} \underline{\text{charged Higgses } H^{\pm}}, \\ \\ \underline{\text{several neutral ones}}, \text{ now known as } h, H, A, \ldots \end{cases}$$

Higgs potential:

$$\begin{aligned} V_{\text{Higgs}} &= \frac{\vec{D}^2}{2} + \frac{D'^2}{2} + \ldots \\ &= \frac{g^2}{8} \, (h_1^\dagger \, \vec{\tau} \, h_1 + h_2^\dagger \, \vec{\tau} \, h_2)^2 + \frac{g'^2}{8} \, (h_1^\dagger h_1 - h_2^\dagger h_2)^2 + \ldots \\ &= \frac{g^2 + g'^2}{8} \, (h_1^\dagger h_1 - h_2^\dagger h_2)^2 + \frac{g^2}{2} \, | h_1^\dagger h_2 |^2 + \ldots \, . \end{aligned}$$

$$\boxed{V_{\text{Higgs}} = \frac{g^2}{8} \, (\ldots)^2 + \frac{g^2 + g'^2}{8} \, (\ldots)^2 + \ldots}$$

$\rightarrow$ **quartic Higgs potential of "MSSM"**

quartic Higgs couplings fixed by

$$\frac{g^2 + g'^2}{8} \quad \text{and} \quad \frac{g^2}{2} \, .$$

We now learn something on "ordinary" particles

(not superpartners):

Quartic Higgs coupling(s) no longer arbitrary

(as in standard model)

fixed by $SU(2) \times U(1)$ gauge couplings g and g'

→ **many relations (equalities or inequalities) between masses:**

between $m_{H^\pm}$ and $m_{W^\pm}$, like $m^2_{H^\pm} = m^2_{W^\pm} \pm ...$

between masses of neutral Higgses, and m_Z ... like

$$m^2_{H \text{ or } h} = m^2_Z \pm ...$$

(details of relations depend on how SUSY gets broken)

→ **one can also have, in special situations**

gauge invariance spontaneously broken with SUSY still conserved,

particles organised in massless or massive multiplets of SUSY

→ **massive gauge multiplets of SUSY**

- **1 massive spin-1 gauge boson**
- **2 spin-$\frac{1}{2}$ inos**
- **1 spin-0 Higgs boson**

→ **possibility of relating massive gauge bosons ($W^\pm$, Z)**
and Higgs bosons ($H^\pm$ and H/h)

gauge boson – Higgs boson unification

Higgs bosons as
extra spin-0 degrees of freedom of massive gauge bosons.
(even without considering extra dimensions, yet ...)

Altogether, all particles should be associated with

new <u>superpartners</u>

photon	$\longleftrightarrow$	*photino*
gluons	$\longleftrightarrow$	*gluinos*
leptons	$\longleftrightarrow$	spin-0 *sleptons*
quarks	$\longleftrightarrow$	spin-0 *squarks*
	...	

with, in addition,

<u>Two</u> doublet Higgs superfields H_1 and H_2

for electroweak breaking,

<u>exactly</u> as needed to give

masses to charged leptons and quarks,

through **<u>trilinear superpotential couplings</u>** $\propto$:

$$\begin{cases} H_1 \,.\, \bar{E}\, L & \longrightarrow \text{ charged lepton masses} \\ H_1 \,.\, \bar{D}\, Q & \longrightarrow \text{ down quark masses} \\ H_2 \,.\, \bar{U}\, Q & \longrightarrow \text{ up quark masses} \end{cases}$$

Basic ingredients of

Supersymmetric Standard Model

(Phys. Lett. 64B (1976) 159; 69B (1977) 489)

1) $SU(3) \times SU(2) \times U(1)$ gauge superfields

2) chiral quark and lepton superfields

3) two doublet Higgs superfields H_1 and H_2
for electroweak breaking

4) trilinear superpotential for q and l masses

• Superpotential constrained to be

<u>even function</u> of quark and lepton superfields!

includes

$$h_e\, H_1 \,.\, \bar{E}\, L \;+\; h_d\, H_1 \,.\, \bar{D}\, Q \;-\; h_u\, H_2 \,.\, \bar{U}\, Q$$

• Otherwise: introduces unwanted (and dangerous)

<u>B and/or L violations</u>!

associated with unwanted exchanges of new spin-0 sparticles!

"<u>R-parity-violating</u>" superpotential excluded from beginning

No utility, only a source of problems,

+ philosophy is to restrict $\mathcal{L}$ by symmetries,

not write as many contributions as possible ...

Minimal particle content of

Supersymmetric Standard Model

Spin 1	Spin 1/2	Spin 0
gluons g photon γ	gluinos $\tilde{g}$ photino $\tilde{\gamma}$	
$W^{\pm}$ Z	winos $\widetilde{W}^{\pm}_{1,2}$ zinos $\widetilde{Z}_{1,2}$ higgsino $\tilde{h}^0$	$H^{\pm}$ H h, A } Higgs bosons
	leptons l quarks q	sleptons $\tilde{l}$ squarks $\tilde{q}$

2 neutral gauginos + 2 neutral higgsinos mix into 4 neutralinos

+ possible additional ingredients

(depending on specific version considered)

additional singlet chiral superfield ("NMSSM"),
with trilinear $\lambda\, H_1\, H_2\, N\; +\; \ldots$ superpotential

and/or, possibly, extra $U(1)$ gauge superfield

"hidden sector" associated with supersymmetry-breaking

new "vectorlike" families of quarks and leptons ...

The question of gluino masses

What about our initial

continuous $U(1)$ R-symmetry ?

It acts chirally on gluinos

$$g \longrightarrow e^{\gamma_5\,\alpha}\, g$$

and would force them to be massless ...

Unbroken continous R-invariance

$$\Longrightarrow$$

massless GLUINOS !!!

which don't seem to exist !!

Massless (or light) gluinos would form light

R-hadrons

$(q\ \bar{q}\ \tilde{g}\ ,\quad q\ q\ q\ \tilde{g}\ )$

expected to decay

R-hadron $\longrightarrow$ hadrons + neutralino

(1978)

signature:

"missing energy-momentum"
carried away by unobserved neutralinos

not observed !!

No light R-hadrons. No light gluinos.

Need mechanism to generate gluino masses.

Requires { SUSY breaking
+ absence of continuous R-invariance }

local SUSY breaking $\Longrightarrow$ massive spin-$\frac{3}{2}$ gravitino

gravitino mass term $m_{3/2}$ (in particular)

breaks continuous R-invariance, reducing it to R-parity

(now also allows for gaugino mass terms $m_{1/2}$)

Phys. Lett. 70B (1977) 461

Allows for a discrete symmetry to remain unbroken

$$\boxed{\boldsymbol{R}\text{-parity} \quad = \quad (-1)^{\boldsymbol{R}}}$$

also identified as

$$\boxed{\boldsymbol{R_p} \quad = \quad (-1)^{\,2S}\,(-1)^{\,3B+L}}$$

relates conservation (or non-conservation) of $\boldsymbol{R}$-parity

with conservation (or non-conservation of $\boldsymbol{B}$ and/or $\boldsymbol{L}$ (or $\boldsymbol{B-L}$)

if indeed conserved:

- **look for pair-production (+ decays) of SUSY particles**

  at colliders

  (... , LEP, FNAL, LHC, NLC, ...)

- **lightest one (LSP)**

  probably a <u>neutralino</u>, should be absolutely stable

lightest neutralino one of the best candidate
for the <u>non-baryonic dark matter</u>
of the Universe ...

dark matter searches complementary to accelerator searches

...

- **Other essential effects of the new particles:**

(superpartners + 2 Higgs doublets + higgsinos)

influence evolution of $SU(3) \times SU(2) \times U(1)$ gauge couplings

crucial role for **discussion of unification**

(cf. next talk)

depending on which particles actually present in "low-energy" spectrum

- **SUSY breaking**

squark and slepton mass terms $- \sum_{\tilde{q}, \tilde{l}} m_0^2 \; (\tilde{q}^\dagger \tilde{q} + \tilde{l}^\dagger \tilde{l})$

considered very early

such terms, + gaugino masses $m_{1/2}$, etc.

should be generated spontaneously

(if SUSY algebra is to be realized locally)

How ?

"gravity-induced" SUSY-breaking ?

other "hidden sector" ?

possible contributions from extra $U(1)$'s ?

possible role of extra dimensions ?

- **we now consider "soft-breaking terms" as parametrisation of our ignorance about SUSY breaking mechanism !!**

- **price to pay: many arbitrary parameters ...**

Extended supersymmetry :

$$N = 1 \quad \longrightarrow \quad N = 2 \quad \longrightarrow \quad N = 4$$

$\Longrightarrow$ **Rôle of possible**

extra (compact) dimensions of spacetime

- **extremely small ??**

$\sim L_{\text{Planck}} \simeq 10^{-33}$ cm (or fixed by the GUT scale ?) ???

- **or significantly larger ?**

$\sim 10^{-16}$ or 10^{-17} cm $\leftrightarrow$ **TeV scale ?**

The size of extra dimensions

may determine **supersymmetry-breaking**

and the mass scale of the various superpartners

cf. $\quad m_{3/2} = \frac{\pi\,\hbar}{L\,c} \quad$ (or $\frac{1}{2R}$) using

discrete boundary conditions involving ***R*-parity!**

$\rightarrow$ relations like $\quad m^2(\text{winos}) = m_W^2 + \frac{\pi^2}{L^2}$, etc. (85)

optimistic point of view :

Both **supersymmetry** and **extra dimensions** could show up at particle colliders !!

many scenarios possible

we would already be happy with supersymmetry !

We are eagerly waiting for experimental data especially from LHC ...