Supergravity phenomenology : minimal VS no-scale

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JRJC 09

Outline

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It's (almost) all about symmetry

Building Standard model Lagrangian

- Symmetries (Space-time, interactions)
- Renormalizability

$$\begin{cases} \phi \rightarrow U\phi \\ \delta S = 0 \end{cases}$$

Doesn't change the physics

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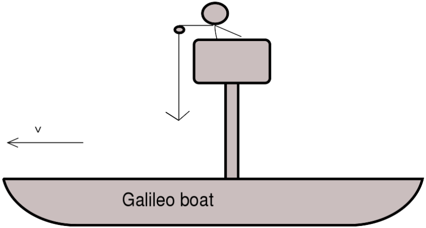
Space-time symmetries

It started with a boat



Physics is the same in a all inertial frames

Poincaré group

- Lorentz group : Antisymmetric operator $M_{\mu\nu}$
  - Rotation in space-coordinates
  - Lorentz boost : rotation in space and time coordinates
- Translation

Global and local symmetry

Example of gauge interactions in Standard Model (QED)
Global phase transformation

$$\begin{cases} \phi \longrightarrow e^{i\theta}\phi \\ \overline{\phi} \longrightarrow e^{-i\theta}\overline{\phi} \end{cases} \quad \Rightarrow \delta(\overline{\phi}\partial_\mu\phi) = 0$$

Covariant derivative

$$\partial_\mu \longrightarrow D_\mu = \partial_\mu + iA_\mu$$

$$\begin{cases} \phi \longrightarrow e^{i\theta(x)}\phi \\ D_\mu\overline{\phi} \longrightarrow e^{-i\theta(x)}D_\mu\overline{\phi} \end{cases}$$

Restore local symmetry $\Rightarrow$ introduce new field and interaction

Global and local symmetry

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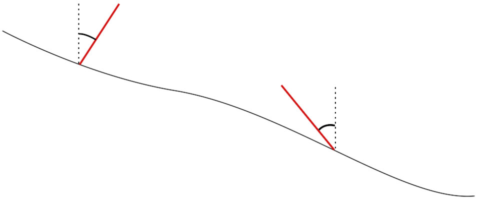
Restore local symmetry ⇒ introduce new field and interaction

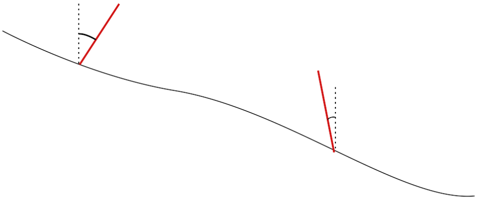
What really happens ?

Global : same phases everywhere



What really happens ?

Local : not the same everywhere



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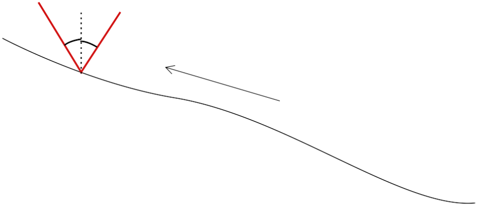

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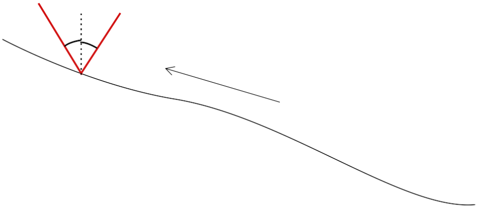
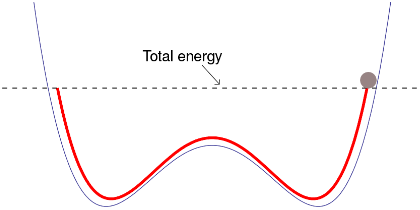


Transport to the same place

Symmetries may be broken : $SU(2)_L \times U(1)_Y \to U(1)_{EM}$

Higgs potential : Before



$$\phi\phi WW$$

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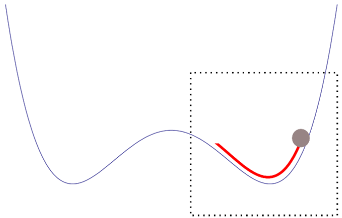
Higgs potential : After



$$v^2 WW + 2vhWW + hhWW$$

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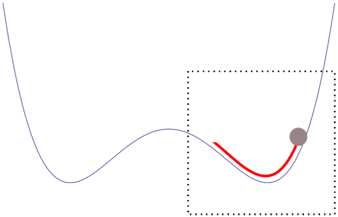

$$v^2 WW + 2vhWW + hhWW$$

It's a bird, it's a plane, no it's a mass term

Important ideas

- Symmetries are everywhere
- Global $\rightarrow$ Local : new field
- Scalar field at *low energy* :
  - Field $\rightarrow$ vev $+$ small fluctuation
  - Effective interactions : mass terms appears

Outline

The question

Looking for operator Q such that

$$Q\,\phi(j) = \phi'(j' \neq j)$$

Changing the spin $\Rightarrow [Q_i, \text{rotation operator}] \neq 0$

Only supersymmetry :
anti-commuting algebra

$$\begin{cases} Q_i Q_j + Q_j Q_i = 0 \\ Q|j >= |j \pm \frac{1}{2} > \end{cases}$$

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Symmetry between bosons fermions

- each SM fermion : scalar partner
- each gauge boson : fermion partner
- And the Higgs ? scalar : fermion partner

partners have same masses

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The Minimal Suspersymmetric Standard Model

Minimal extension of standard model

- SM $\rightarrow$ super-partner
  - fermions $\rightarrow$ sfermions
  - gauge bosons $\rightarrow$ gauginos
- Higgs $\times$ 2
  - $H \rightarrow H_u, H_d$
- additional terms for masses and interactions (broken susy) lifting degeneracy (For instance :$m_{sfermion} = m_{fermion} + \Delta m$)

How to generate such terms?

Outline

Supergravity

Symmetry $\rightarrow$ doesn't change the physics

$\epsilon \rightarrow \epsilon(x^\mu)$ space-time dependant

$$\delta S_0 \sim \int dx^4 \partial_\mu \epsilon^a K_a^\mu$$

$$S = S_0 + S_G$$
$$\delta S_0 + \delta S_G = 0$$

Restore symmetry, introduce $S_G \sim \int dx^4 K_a^\mu \Psi_\mu^a$

$$\Psi_\mu^a \rightarrow \Psi_\mu^a - \partial_\mu \epsilon^a$$

Introducing gravitino field (spin $\frac{3}{2}$)

Gravity multiplet

Completing supersymmetry :

- Introduce gravitino to restore local supersymmetry
- add kinetic term for gravitino
- add partner of gravitino

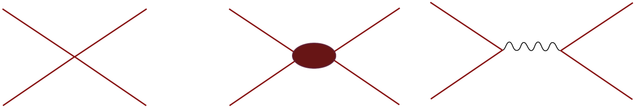
spin 2 graviton

Renormalizability

Non-renormalizable operators

$$L_{NR} \supset \frac{O_{grav}^{d+n}}{M_{Planck}^{n}}$$

Like Fermi weak theory



Effective gravity theory
$L_{NR} \to 0$ when $M_{Planck} \to \infty$

Effective theory : link between high and low scales

- Lagrangian we construct start just below M_{Planck}
- Gravitational quantum effects are already integrated
- Real quantum gravity theory beyond M_{Planck}(string or ...)
- Next stop : GUT scale (grand unification)

Outline

Scalar Potential

Phenomenology is encoded in :

$$V \sim e^{G}\left(G^{i}(G^{-1})_{i}^{\bar{j}}\ G_{\bar{j}} - 3\right) + \frac{1}{2} f_{ab} D_a D^a$$

- $W(\phi)$: Superpotential, analytic in ϕ, encode scalar masses and yukawas interactions
- $K(\phi^i, \overline{\phi}^{\bar{j}})$: Kähler function, appears in kinetic terms $K_{i\bar{j}} \partial_\mu \phi^i \partial^\mu \phi^{\bar{j}}$ with $K_{i\bar{j}} = \partial_i \partial_{\bar{j}} K$
- $G(\phi, \overline{\phi}) = K(\phi, \overline{\phi}) + \ln |W(\phi)|^2$
- f_{ab} : gauge kinetic function

scalar masses shift (partner of fermions and higgs)

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gauginos masses shift (partner of gauge bosons)

Breaking and hidden sector

- Breaking → $m_{\frac{3}{2}} \neq 0$
- need scalar vev : hidden field $< z >$

Gravitino mass → local supersymmetry breaking
Hidden field vev → $m_{\frac{3}{2}}$
Hidden sector decouples at *low energy*

Outline

Masses in minimal supergravity

$$\begin{cases} K = \phi^i \overline{\phi}^{\bar{j}} \\ f_{ab} = \delta_{ab} \end{cases}$$

$$M_{Planck} \rightarrow \infty$$

Effective potential at lower scale (usually unification scale)

$$V(<z>, \phi^i) \sim \sum |\partial_i W|^2 + m_{\frac{3}{2}}{}^2 \sum |\phi^i|^2 + m_{\frac{3}{2}} \left(\sum \phi^i \partial_i W \; + (A-3) W + h.c. \right)$$

soft mass term lifting degeneracy between fermion and scalar

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mSugra issues

Light version

- $V = 0$ put by hand
- Fine-tuning the cosmological constant
- necessary to identify $m_{\frac{3}{2}}$ as a gravitino mass

no-scale supergravity

Light version 2

- Non-minimal Kähler : $K = -3\log(z + z^*)$
- Naturally $V = 0$
- Undetermined vacuum expectation value
- Flat potential at GUT scale
- no scalar masses, only gauginos

This kind of Kähler potential appears in some string theories after compactification

Renormalization group equations

High scale parameters (usually unification scale $\sim 10^{16} GeV$)

RGE

Low scale parameters (EW scale)

Ordinary differential equations
Evolution of parameters with energy scale

Boundary conditions

mSugra, no-scale, or any other give us parameters at Grand Unification scale

Universality condition

1. m_0: one mass for all scalar at GUT scale
2. $m_{\frac{1}{2}}$: one mass for all gauginos at GUT scale

ElectroWeak scale

- Spectrum at low scale
- Correct parameters to induce ElectroWeak Symmetry Breaking (EWSB)
- Impose all constraints

$$V = m_1^2|H_1|^2 + m_2^2|H_2|^2 + B\mu\left(H_1 H_2 + H_1^* H_2^2\right) + \frac{g^2+g'^2}{8}\left(|H_1|^2 - |H_2|^2\right)^2$$

Parameters driven from high energy to low energy

SuSy breaking $\Rightarrow$ EW breaking

My work

How can no-scale models survive ?
Main phenomenological issue
$m_0 = 0 \rightarrow$ charged LSP
(*Many others, but not enough space*)

Hard to find parameters such that good dark matter candidate

Outlook

Thunderbird

- Trying to enlarge Poincaré $\rightarrow$ supersymmetry
- Local supersymmetry $\rightarrow$ Supergravity
- Natural frame for Standard Model, EWSB, dark matter...
- Still don't know the correct breaking mechanism

Supergravity, what else?