

Introduction to Supersymmetry.

- ❖ **Symmetry in physics.**
- ❖ **Why not SM?**
- ❖ **What is SUSY.**
- ❖ **The simplest SUSY lagrangian.**
- ❖ **SUSY breaking.**
- ❖ **MSSM particles.**

Why not SM?

- ❖ **hierarchy problem.**
- ❖ **why we have three generations.**
- ❖ **SM bosons arise naturally from gauge theories and have spin 1. The only spin 0 multiplet in SM is Higgs doublet that is introduced just for electroweak symmetry breaking without any microscopic explanations.**

Hierarchy problem



$$\Delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2} \left[-2\Lambda_{UV}^2 + 6m_f^2 \ln\left(\frac{\Lambda_{UV}}{m_f}\right) \right]$$

$$\Delta m_H^2 = \frac{\lambda_s}{16\pi^2} \left[\Lambda_{UV}^2 - 2m_s^2 \ln\left(\frac{\Lambda_{UV}}{m_s}\right) \right]$$

What is SUSY?

SUSY is a symmetry that relates fermions and bosons. The simplest possible transformation is:

$$\delta\phi = \varepsilon\psi \quad \delta\phi^* = \varepsilon^+\psi^+,$$

where ε^α is an infinitesimal, anticommuting fermion object.

$\partial_\mu \varepsilon = 0$, so ε is a constant, and we have a global symmetry.

Since we assume that SUSY is an existing symmetry, lagrangian must be invariant under the transformation.

$$L = L_{fermion} + L_{scalar}$$

Free lagrangian.

$$L_{scalar} = (-\partial^\mu \phi^* \partial_\mu \phi) \rightarrow (-\partial^\mu \phi^* \partial_\mu \phi) + (-i\psi^+ \bar{\sigma}^\mu \partial_\mu \psi)$$

$$\delta L_{scalar} = -\varepsilon \partial^\mu \psi^* \partial_\mu \phi - \varepsilon^+ \partial^\mu \psi^{+\mu} \partial_\mu \phi$$

$$\delta \psi_\alpha = i(\sigma^\mu \varepsilon^+) \partial_\mu \phi \quad \delta \psi^+_\alpha = -i(\varepsilon \sigma^\mu)_\alpha \partial^\mu \phi^*$$

$$\begin{aligned} \delta L_{fermion} &= -\varepsilon \sigma^\mu \bar{\sigma}^\nu \partial_\nu \psi \partial_\mu \phi^* + \psi^+ \bar{\sigma}^\nu \sigma^\mu \varepsilon^+ \partial_\mu \partial_\nu \phi = \\ &= \varepsilon \partial^\mu \psi^* \partial_\mu \phi + \varepsilon^+ \partial^\mu \psi^{+\mu} \partial_\mu \phi - \partial_\mu (\varepsilon \sigma^\mu \bar{\sigma}^\nu \psi \partial_\nu \phi + \psi^+ \varepsilon^+ \partial^\mu \phi) \end{aligned}$$

$$L_{auxiliary} = F^* F \quad \delta F = i\varepsilon \bar{\sigma}^\mu \partial_\mu \psi \quad \delta F^* = -i\partial_\mu \psi^+ \bar{\sigma}^\mu \varepsilon$$

$$\delta \psi_\alpha = i(\sigma^\mu \varepsilon^+) \partial_\mu \phi + \varepsilon F \quad \delta \psi^+_\alpha = -i(\varepsilon \sigma^\mu)_\alpha \partial^\mu \phi^* + \varepsilon^+ F^*$$

Interactions.

$$L_{\text{int}} = \frac{1}{2} W^{ij} \psi_i \psi_j + W^i F_i + \text{c.c.}$$

$$F_i = -W_i^* \quad F^{*i} = -W^i \quad \text{equations of motion}$$

$$L = -\partial^\mu \phi^* \partial_\mu \phi - i \psi^+ \bar{\sigma}^\mu \partial_\mu \psi - \frac{1}{2} (W^{ij} \psi_i \psi_j + W^{*ij} \psi^+ \psi^+) - W^i W_i^*$$

$$W^{ij} = \frac{\delta^2}{\delta\phi_i \delta\phi_j} W \quad W^i = \frac{\delta}{\delta\phi_i} W$$

$$W = \frac{1}{2} M^{ij} \phi_i \phi_j + \frac{1}{6} y^{ijk} \phi_i \phi_j \phi_k - \text{superpotential}$$

M^{ij} – mass matrix

y^{ijk} – Yukawa couplings

SUSY breaking.

- ❖ No SUSY particles found \Rightarrow SUSY must be broken.
- ❖ Super partners can have larger mass (starting from ~ 100 GeV).
- ❖ SUSY breaking mechanism must exist.
- ❖ No SUSY signatures found \Rightarrow SUSY particles must be produced in pairs.
- ❖ There is a special symmetry (R-parity) that is conserved.
- ❖ R-parity is conserved \Rightarrow lightest SUSY particle (LSP) is stable.

SUSY breaking.

Soft SUSY breaking.

$m_{ij}^2 A_i^* A_j$ – mass term for the sfermions .

$M\lambda\lambda$ – mass term for the gauginos .

$\frac{1}{2}b_{ij}\mu_{ij}A_iA_j$ – bilinear soft breaking term.

$a_{ijk}\lambda_{ijk}A_iA_jA_k$ – trilinear soft breaking term.

Fermion partners.

SM particles.

Spin $\frac{1}{2}$

leptons

$$\begin{pmatrix} e_L \\ \nu_{eL} \end{pmatrix} - \begin{pmatrix} \mu_L \\ \nu_{\mu L} \end{pmatrix} - \begin{pmatrix} \tau_L \\ \nu_{\tau L} \end{pmatrix}$$

e_R μ_R τ_R

quarks

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} - \begin{pmatrix} c_L \\ s_L \end{pmatrix} - \begin{pmatrix} t_L \\ b_L \end{pmatrix}$$

$u_R d_R c_R s_R t_R b_R$

SUSY particles.

Spin 0

sleptons

$$\begin{pmatrix} \tilde{e}_L \\ \tilde{\nu}_{eL} \end{pmatrix} - \begin{pmatrix} \tilde{\mu}_L \\ \tilde{\nu}_{\mu L} \end{pmatrix} - \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\nu}_{\tau L} \end{pmatrix}$$

\tilde{e}_R $\tilde{\mu}_R$ $\tilde{\tau}_R$

squarks

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} - \begin{pmatrix} c_L \\ s_L \end{pmatrix} - \begin{pmatrix} t_L \\ b_L \end{pmatrix}$$

$$\tilde{u}_R \tilde{d}_R \tilde{c}_R \tilde{s}_R \tilde{t}_R \tilde{b}_R$$

Boson partners.

SM particles.

SUSY particles.

Spin 1
gauge bosons

Spin $1/2$

neutralinos

W^+W^-

$\tilde{W}^+ \tilde{W}_{1,2,3}^0 \tilde{W}^0 \tilde{B}^0$

$W^0 B^0 (\gamma Z^0)$

charginos

gluons

$\tilde{\chi}_{1,2}^{\pm}$

g

higgsinos

Spin 0

Higgs bosons

$\tilde{H}_u^0 \tilde{H}_u^{+\delta} \tilde{H}_d^0 \tilde{H}_d^-$

$H_u H_d$