LECTURE 2.

THE MSSM

Φ : chiral SF

V : vector SF

superpot'l

Lagrangian: $\displaystyle \int d^2\theta \, W(\phi) + \int \phi^\dagger \phi \, d^4\theta$

e.g. $W = \phi^3$

$$= \underbrace{|\partial \varphi|^2 + i \bar{\psi} \bar{\sigma}^\mu \partial_\mu \psi}_{\int \phi^\dagger \phi \, d^4\theta} - \underbrace{\frac{\partial^2 W}{\partial \varphi_i \partial \varphi_j} \psi_i \psi_j}_{\text{Yukawa couplings}} - \sum_i \left| \frac{\partial W}{\partial \varphi_i} \right|^2$$

ϕ carries $U(1)$ charge

$$\phi \to e^{-i\Lambda}\phi$$

under $U(1)$ Λ will be like a χSF

$$\phi^+\phi \to e^{\boxed{-i(\Lambda-\Lambda^+)}}\phi^+\phi$$

$$\int \phi^+ e^V \phi \, d^2\theta$$

V is vector SF.

$$\boxed{V \to V + i(\Lambda - \Lambda^+)}$$

$$A_\mu \to A_\mu + \partial_\mu \epsilon$$

$$V = -\theta\sigma^\mu\bar{\theta}V_\mu + i\theta^2\bar{\theta}\bar{\lambda} - i\bar{\theta}^2\theta\lambda + \frac{1}{2}\theta^2\bar{\theta}^2 D$$

(Wess-Zumino gauge)

Kinetic term for V?

formally make a χSF

$$W_\alpha = -\tfrac{1}{4} \bar{D}\bar{D} D_\alpha V$$

usual SF $\qquad V = V^\dagger$

$$\bar{D} W_\alpha = 0$$

$$\int W_\alpha W^\alpha d^2\theta =$$

$$= -\tfrac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda$$

WARMUP: Lagrangian for sQED?

U(1) gauge theory $\longrightarrow V \longrightarrow$ photon V_μ
photino λ

ϕ_- electron

ϕ_+ positron

kinetic term for gauge field + + gaugino

$$(1) = \int \tfrac{1}{4} \left(W_\alpha W^\alpha + h.c. \right) d^2\theta$$

$$(2) = + \int \left(\phi_+^\dagger e^{eV} \phi_+ + \phi_-^\dagger e^{-eV} \phi_- \right) d^4\theta$$

$$(3) = + \int \underbrace{m \phi_+ \phi_-}_{W(\phi)} d^2\theta + h.c.$$

<u>in component language</u> (keep F, D)

$$(1) = -\tfrac{1}{4} (F_{\mu\nu})^2 + i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda + \tfrac{1}{2} D^2$$

$$(2) = |D_\mu \varphi_+|^2 + |D_\mu \varphi_-|^2 + i \bar{\psi}_+ D_\mu \bar{\sigma}^\mu \psi_+ + i \bar{\psi}_- D_\mu \bar{\sigma}^\mu \psi_-$$
$$-\frac{ie}{\sqrt{2}} \left(\varphi_+ \bar{\psi}_+ \bar{\lambda} - \varphi_- \bar{\psi}_- \bar{\lambda} \right) + h.c. + \frac{e}{2} D \left(|\varphi_+|^2 - |\varphi_-|^2 \right)$$
$$+ F_+^\dagger F_+ + F_-^\dagger F_-$$

$$(3) = m\left(\varphi_+ F_- + \varphi_- F_+ - \psi_+ \psi_-\right) + \text{h.c.}$$

Dirac spinor with mass m

integrate out D & F

$$\frac{1}{2} D^2 + \frac{e}{2} D \left(|\varphi_+|^2 - |\varphi_-|^2\right)$$

$$V_D = \frac{e^2}{2}\left(|\varphi_+|^2 - |\varphi_-|^2\right)^2$$

Also integrate out F

$$V_F = \sum_i \left|\frac{\partial W}{\partial \varphi_i}\right|^2 = \underbrace{m^2\left(|\varphi_+|^2 + |\varphi_-|^2\right)}_{\text{same mass for selectron \& spositron!}}$$

The MSSM matter content

	$SU(3)$	$\times\, SU(2)_L$	$\times\, U(1)_Y$
L	1	2	$-1/2$
$\bar{E}$	1	1	$+1$
Q	3	2	$1/6$
$\bar{U}$	$\bar{3}$	1	$-2/3$
$\bar{D}$	$\bar{3}$	1	$+1/3$
H_u	1	2	$1/2$
H_d	1	2	$-1/2$

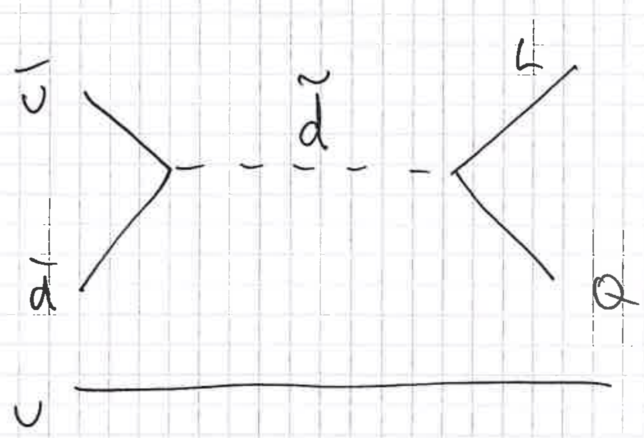
anomaly free!

$$W = \,?$$

$$W^{(\text{good})} = \lambda_u\, Q H_u \bar{U} + \lambda_d\, Q H_d \bar{D} + \lambda_e\, L H_d \bar{E} + \mu\, H_u H_d$$

$$W^{(bad)} = \underbrace{\lambda' Q L \bar{D} + \lambda L L \bar{E} + \tilde{\mu} L H_u}_{\Delta L = 1} + \underbrace{\lambda'' \bar{U} \bar{D} \bar{D}}_{\Delta B = 1}$$

give rise to proton decay



$p^+ \to e^+ \pi^0$

Impose additional Z_2 symmetry! <u>Matter parity</u>

$Q, L, \bar{U}, \bar{D}, \bar{E} \longrightarrow - \quad (\quad)$

$H_{u,d} \longrightarrow + \quad (\quad)$

$$P_M = (-1)^{3(B-L)}$$

$$P_R = \boxed{(-1)^{3(B-L)}}^{+2S}$$

S spin of component.

Lorentz sym. every vertex even # of fermions

<u>R- parity!</u>

$$\left.\begin{array}{l} (\text{SM fields}) \longrightarrow +1 \\ (\text{superpartners}) \longrightarrow -1 \end{array}\right\}$$

- every vertex $\rightarrow$ even # of superpartners!
  - Superpartners have to be pair produced!
  - LSP must be stable!
  - SUSY predicts WIMP candidate!

SUSY breaking

SUSY not exact!

Should be broken

$\langle 0|H|0\rangle = 0$ SUSY unbroken

$\langle 0|H|0\rangle > 0$ SUSY broken.

$$V = V_F + V_D$$

$$V_F = \sum_i \left|\frac{\partial W}{\partial \varphi_i}\right|^2, \qquad V_D = \frac{g^2}{2}\left|\sum_i \phi_i^\dagger T^a \phi_i\right|^2$$

SUSY unbroken

$$\boxed{\mathrm{STr}\, M^2 = 0}$$

particles & sparticles ←

bad relation

- renormalizable interactions
- tree-level

Still at least one superpartner has to be lighter than ordinary particle!

MUST break sum rule?

<u>Assumption:</u> 2 sectors: ~~SUSY~~ = "hidden sector"

MSSM = "visible sector"

Only non-renormalizable interactions mediate ~~SUSY~~!

- gravity is the interaction mediating ~~SUSY~~
- Messenger sector interacts both with ~~SUSY~~ & SM.