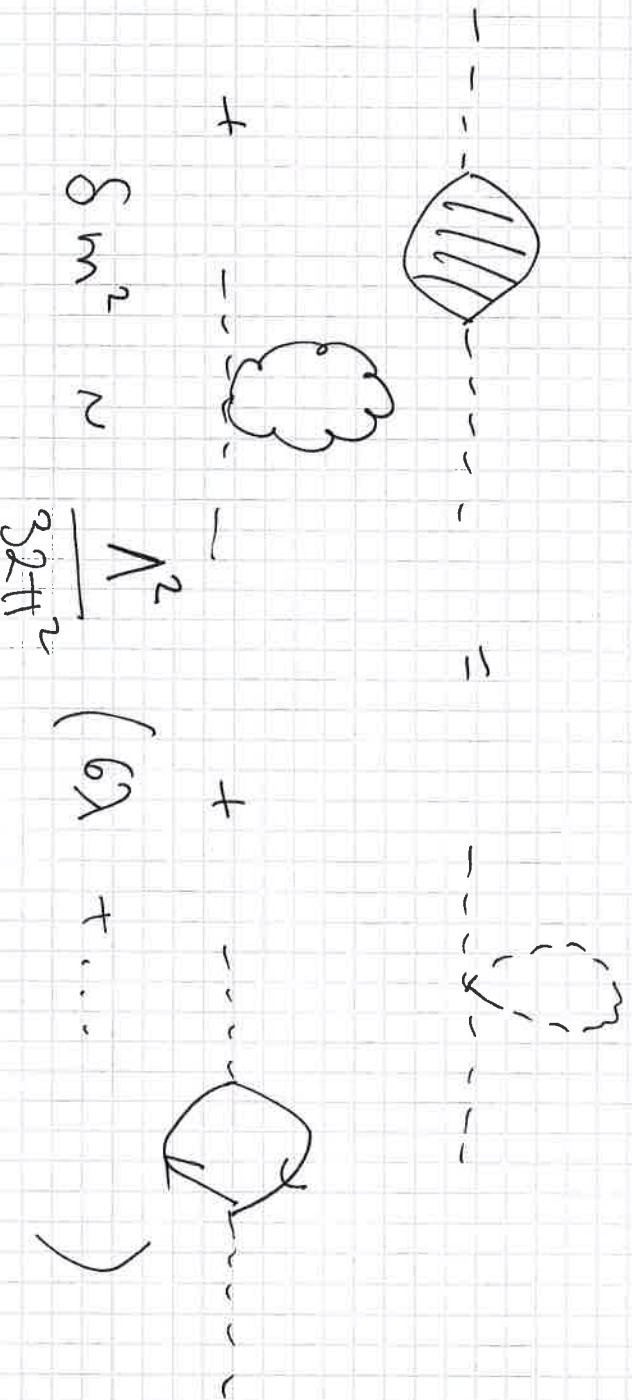


# BEYOND THE STANDARD

## MODEL

CSABA CSA'K I

### HIERARCHY PROBLEM



$$\int \frac{d^4 k}{(2\pi)^4}$$

$$\frac{1}{k^2 - m^2}$$

$\Lambda \gg 10 \text{ TeV}$

fermions:

new symmetry

$m_e \rightarrow 0$

$$\Delta m_e \propto m_e \log\left(\frac{\Lambda}{m_e}\right)$$

gauge bosons:

$$\Delta M_W^2 \propto M_W^2 \log\left(\frac{\Lambda}{M_W}\right)$$

Meaning of  $\Lambda^2$  sensitivity?

$\Lambda$  cutoff scale of validity of SM

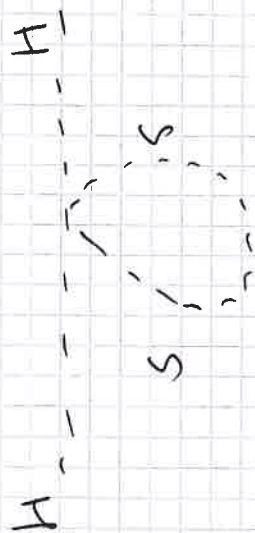
at scale  $\Lambda$  there will be new particles

(GUT bosons (...))

$\Lambda$  represents finite contributions of very heavy particles

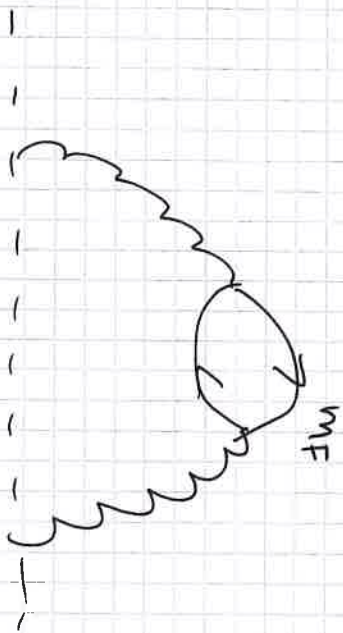
Ex. very heavy scalar

$$\lambda_S (H^\dagger H)^2 |S|^2$$



$$\delta_{MH}^2 = \frac{\lambda_S}{16\pi^2} \left[ \frac{A_{UV}^2}{m_S^2} - 2m_S^2 \log\left(\frac{A_{UV}}{m_S}\right) + \text{finite} \right]$$

$$\delta_{MH}^2 \sim \frac{g^4}{(16\pi^2)^2} \left[ m_F^2 \log\left(\frac{\Lambda}{m_F}\right) + \dots \right]$$



$$m_F \sim 10^{16} \text{ GeV}$$

is softing  $\rightarrow \delta_{MH}^2$

$$\sim (10^{16} \text{ GeV})^2$$

$$\downarrow (10^{16} \text{ GeV})^2$$

$$V = 246 \text{ GeV}$$

$$m_H^2 = m_{\text{other}}^2 + \delta_{MH}^2 \sim (246 \text{ GeV})^2$$



Usual Solutions to hierarchy:

$\Lambda \sim 1 \text{TeV}$  - few  $\text{TeV}$  & the new physics is special:

no additional large contributions

- SUSY relation between scalar & fermion

- relate scalar to gauge boson

- gauge - higgs unif.

- little Higgs models

- pseudo-GB higgs

- Technicolor, higgsless  $\times$

EWSB w/o elementary scalar

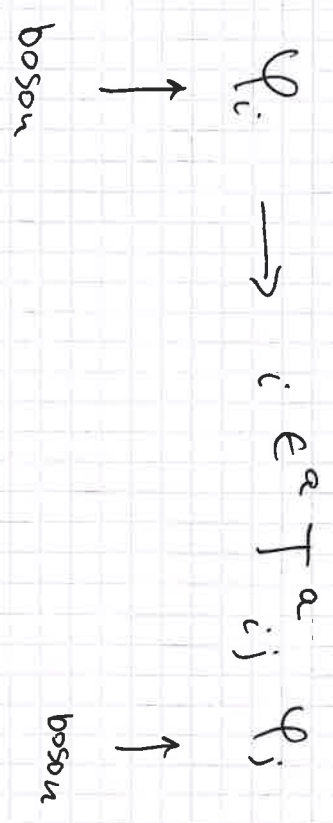
- composite Higgs

- fundamental scale  $\Lambda = 1 \text{TeV}$  (no other high scale)  
large extra dimensional models

# INTRO TO SUSY

Ordinary symmetries : invariance of Lagrangian

$\left\{ \begin{array}{l} \text{Internal symmetries:} \\ \text{Space-time symmetries:} \end{array} \right.$



non-SUSY : spin does not change

SUSY : generators of symmetries are fermionic  
mix fermions & bosons among each other!

Edelman - Mandala : no way to mix internal & space-time symmetries

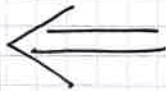


SUSY

2 types of T's

$$\{Q_{\alpha}, Q_{\alpha}^{\dagger}\} = 2P_{\mu} (\delta_{\mu\alpha})_{\alpha\beta}$$

SUSY algebra



I.	# fermions	= # of bosons
II	mass fermion	= mass of boson
III	If SUSY unbroken	$\langle 0 H 0\rangle = 0$

Basic building blocks for SUSY theories!

$P^0$

# SUPER FIELDS

basic

objects

'representations'

1.) Chiral Superfield

— 1 complex scalar

— 2 component spinor (Weyl spinor)

2.) vector superfield

— massless gauge boson

(Spin 1 object)

— 2 component spinor

$A_\mu \rightarrow 2 \text{ DOF}$

$\rightarrow 2 \text{ DOF}$   
(particle + anti-particle + helicity)

Off-shell

chiral SF

complex scalar

2 DOF

Weyl spinor

4 DOF

auxiliary field F

2 DOF

VECTOR SF

Weyl spinor

4 DOF

$A_\mu$

3 DOF

D auxiliary

1 DOF



Fix interaction

& obtain a SUSY Lagrangian?

Superfield :

$\varphi, \chi$

$\Rightarrow$

to build

$\Phi$

Superspace

$$x^\mu x^\nu P_\mu + \theta^\alpha Q_\alpha + \bar{\theta}^{\dot{\alpha}} \bar{Q}_{\dot{\alpha}}$$

$$G(\theta, \bar{\theta}, \chi, \bar{\chi}) F(x, \theta, \bar{\theta})$$

$$(x + i\theta\sigma\mu\bar{\theta}, \theta + \bar{\chi}, \bar{\theta} + \bar{\chi})$$

how much SUSY rotation

Superfield

function

$$F(x, \theta, \bar{\theta})$$

fermionic

only contain finite # of terms!



$$F(x, \theta, \bar{\theta}) = f(x) + \theta \psi(x) + \bar{\theta} \bar{\psi}(x) + \theta^2 m(x) + \bar{\theta}^2 \bar{m}(x) + \theta \sigma^{\mu\nu} \bar{\theta} \sigma_{\mu\nu}(x) + \theta^2 \bar{\theta} \lambda + \bar{\theta}^2 \theta \lambda + \theta^2 \bar{\theta}^2 d$$

$\theta^\alpha$

$$\bar{\theta}^{\dot{\alpha}} = \theta^{\dot{\alpha}} \cdot \theta^\alpha$$

contains both vector & chiral

Impose a condition that is SUSY

$$V = V^\dagger \rightarrow \text{vector SF}$$

$$\partial_\mu \rightarrow D_{\mu\alpha} = \frac{\partial}{\partial \theta^\alpha} + i \bar{\theta}^{\dot{\alpha}} \sigma_{\mu\dot{\alpha}\alpha} \partial_\mu$$

$$\tilde{D} \Phi = 0 \rightarrow \text{chiral SF}$$

$$\Phi(y, \theta) = \varphi(y) + \sqrt{2} \theta \psi(y) + \theta^2 F(y)$$