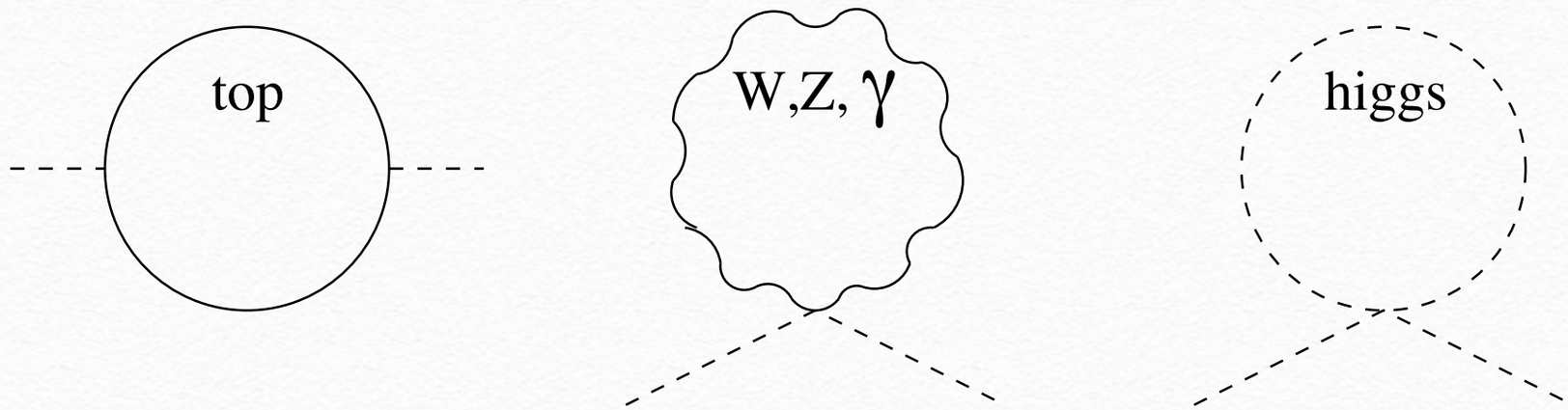
# Quest of BSM

- Many people attracted by particle physics because the standard model  is not incomplete.

  - SM  Higgs sector is not natural(fine tuning problem)
  - Dark matter candidate does not exist in SM.
  - Why three interactions? Why matter contents consistent with  gauge unifications
  - origin of Baryon number in our universe is not explained.

# New Physics, Clue I

## Fine tuning in the Higgs sector

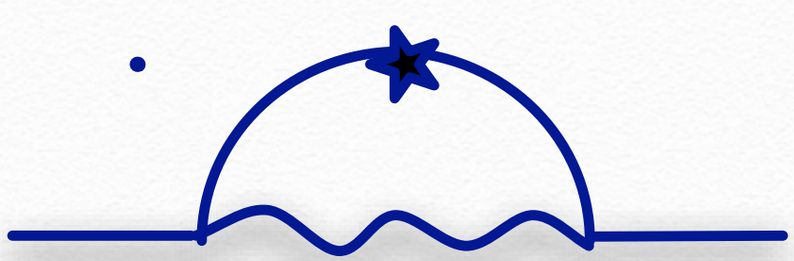



| | | | |
|---|---|---|---|
| top loop | $-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2$ | $\sim$ | $-(2\ \mathrm{TeV})^2$ |
| $SU(2)$ gauge boson loops | $\frac{9}{64\pi^2}g^2\Lambda^2$ | $\sim$ | $(700\ \mathrm{GeV})^2$ |
| Higgs loop | $\frac{1}{16\pi^2}\lambda^2\Lambda^2$ | $\sim$ | $(500\ \mathrm{GeV})^2$. |

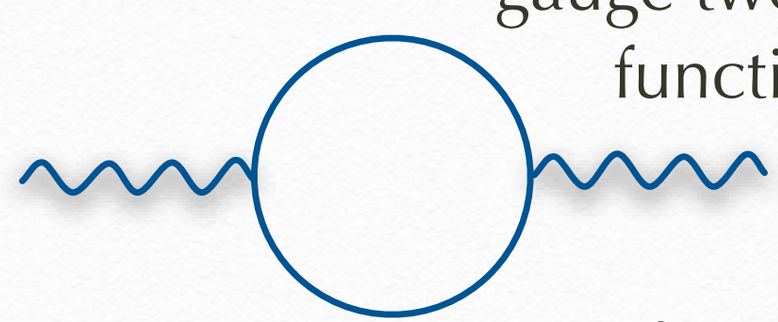
Others are reasonable

Why Higgs vev is O(200) GeV??

$m_f \log \Lambda$ fermion mass



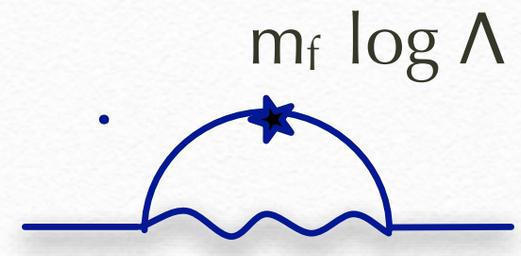
gauge two point function



$$\Pi_{\mu\nu} = (g_{\mu\nu}p^2 - p_\mu p_\nu)\Pi$$

# New Symmetry →New Particle

- Need control on  the radiative correction to the Higgs sector




- ideas
  - chiral symmetry (extended to boson sector)
  - global symmetry(little Higgs model)
  - gauge symmetry (gauge higgs unification)


- **Or planck scale  is low ( Extra dimension model)**

- On the other hand< we see no effect of BSM in radiative correction

$$\delta L = \frac{(h^\dagger D_\mu h)^2}{\Lambda^2} \quad \Lambda > 5\mathrm{TeV}$$

# Some remark

- "quadratic divergence" is regularization dependent
  - Cut off scheme
  - dimensional regularization
  - Supersymmetry O(MSUSY) --Later

$\propto \lambda_0 \Lambda^2$ momentum cut off→ $\propto$ MSUSY

$$\frac{\lambda_0}{2}\int \frac{d^4k}{(2\pi)^4}\frac{1}{k^2+m_0^2} \to \frac{\lambda_0}{2}\int \frac{d^Dk}{(2\pi)^D}\frac{1}{k^2+m_0^2}$$

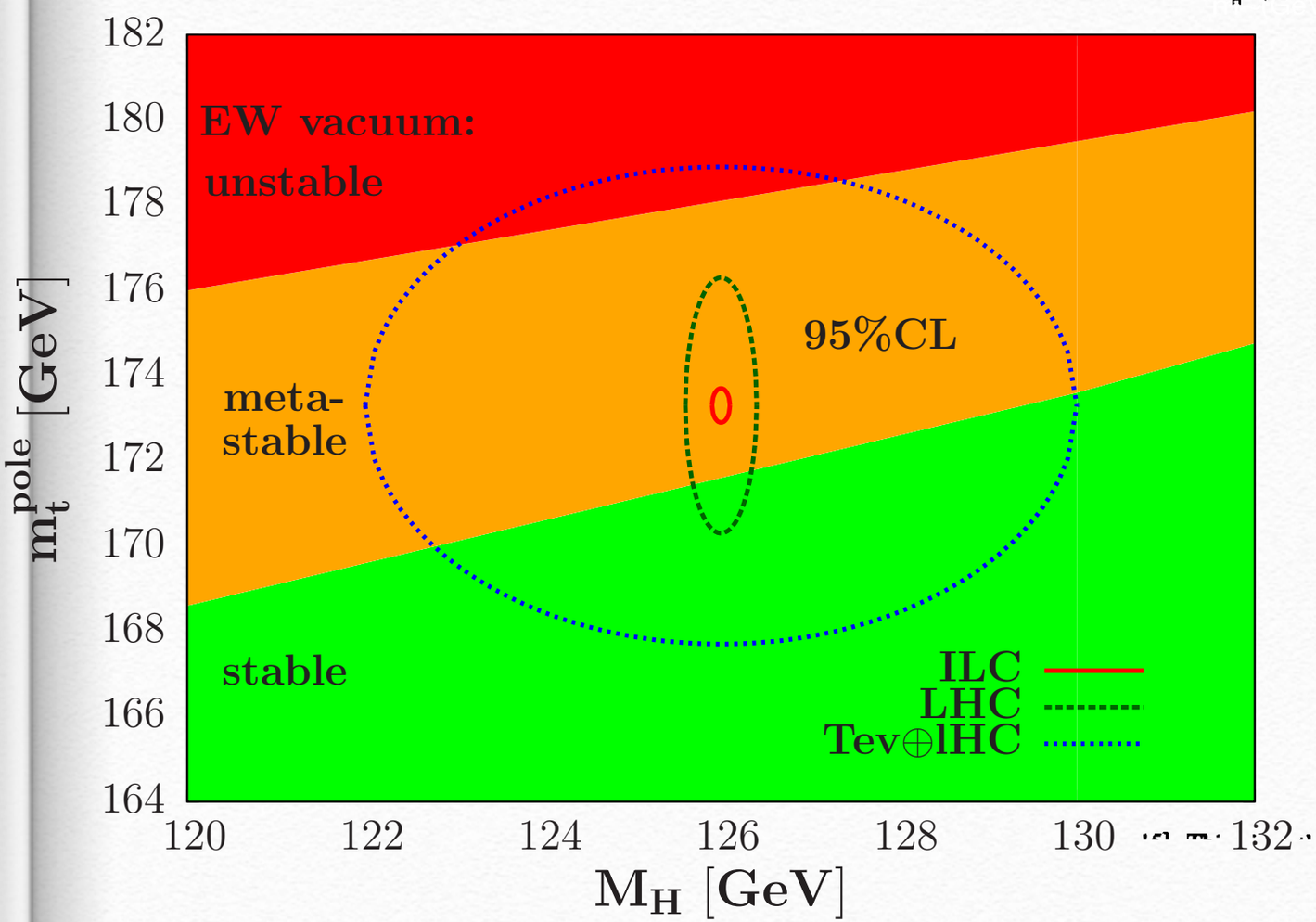
dimensional regularization

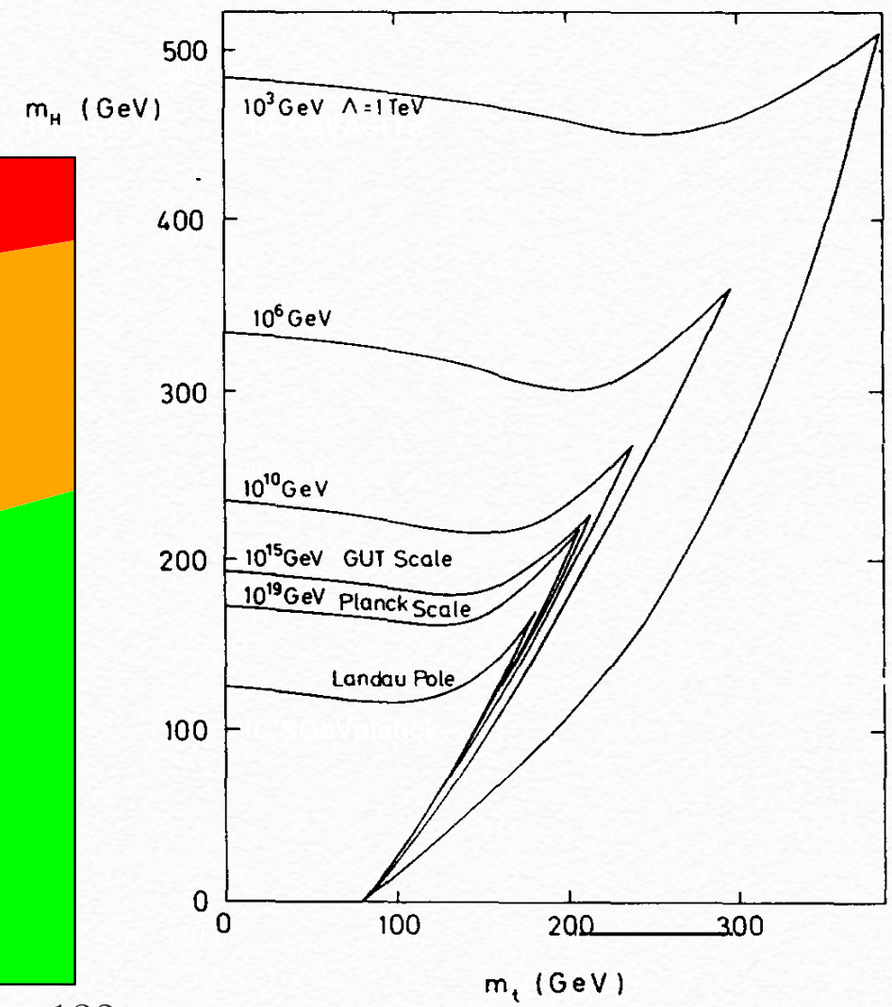
$$\frac{(\lambda_0\mu^{-2\epsilon})}{32\pi^2}m_0^2[-\frac{1}{\epsilon}+\gamma-1-\ln(\frac{\pi\mu^2}{4m_0^2})]$$

only log part remains

# anything in higgs 4 point coupling ?

are we in meta stable vacuum or there
are new physics in between?

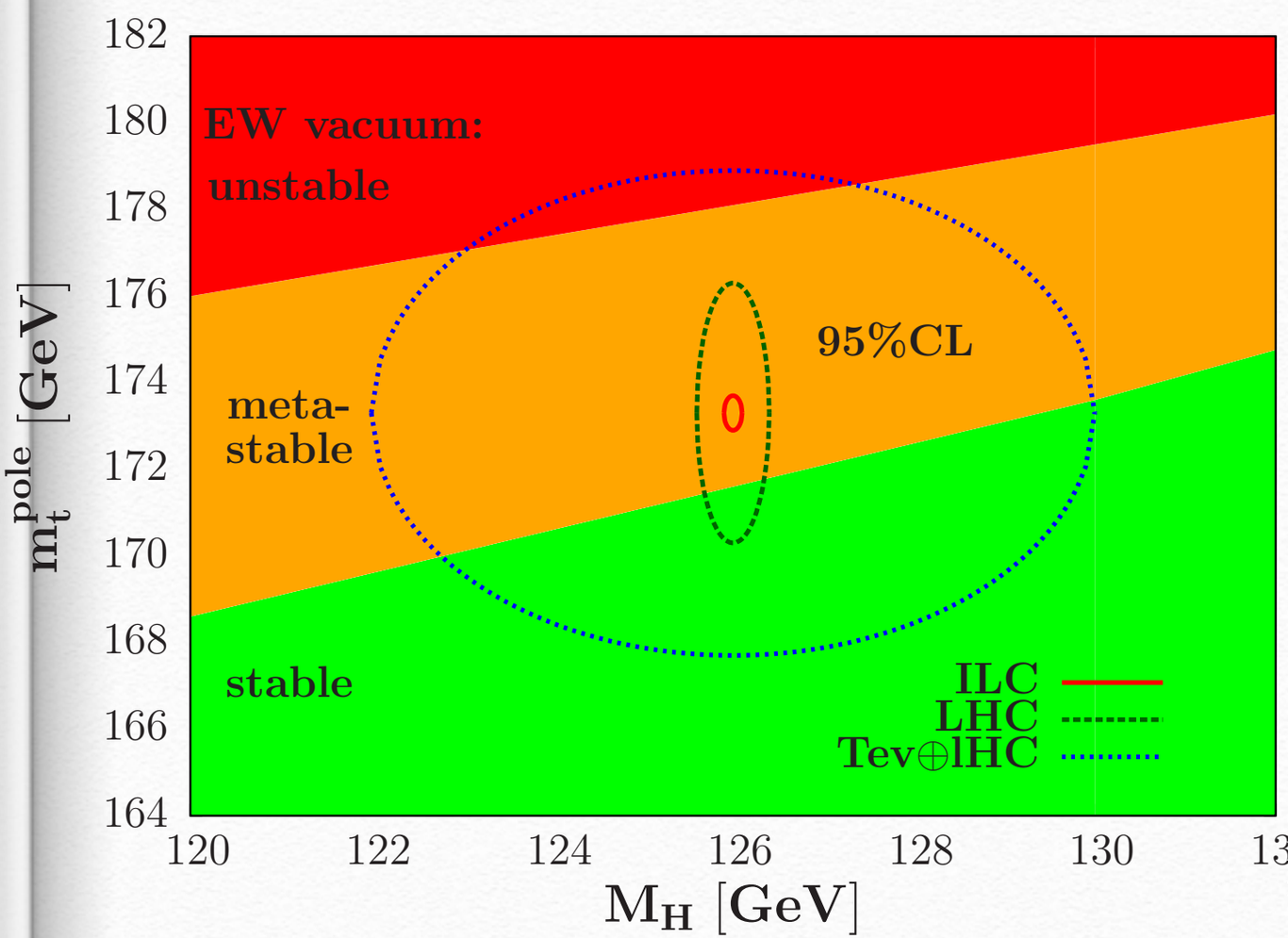



for “up to Planck scale”

# anything in higgs 4 point coupling ?

are we in meta stable vacuum or there
are new physics in between?



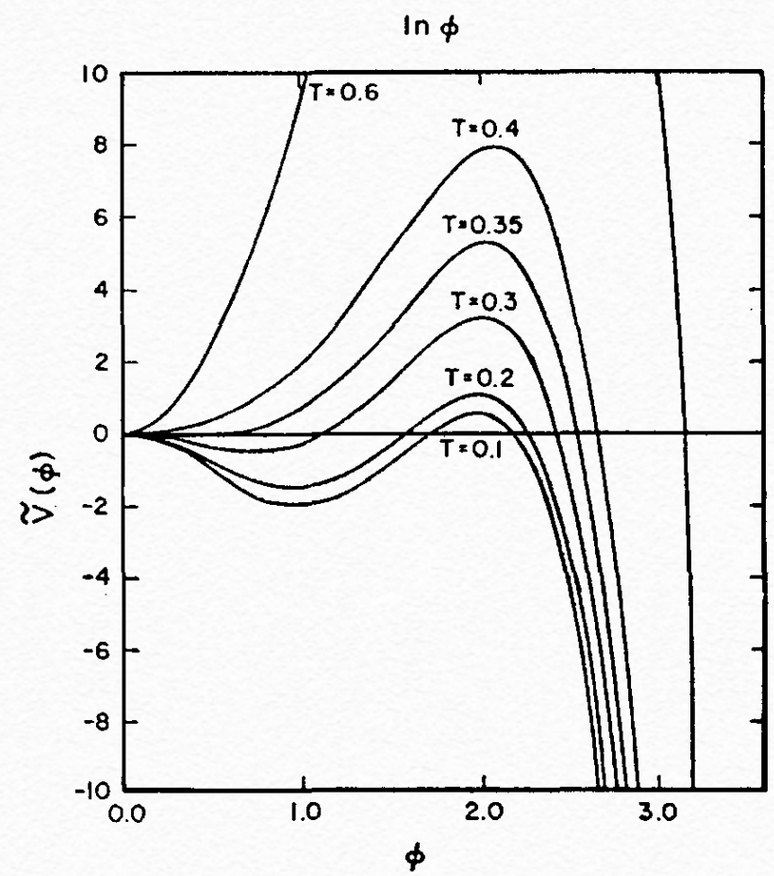
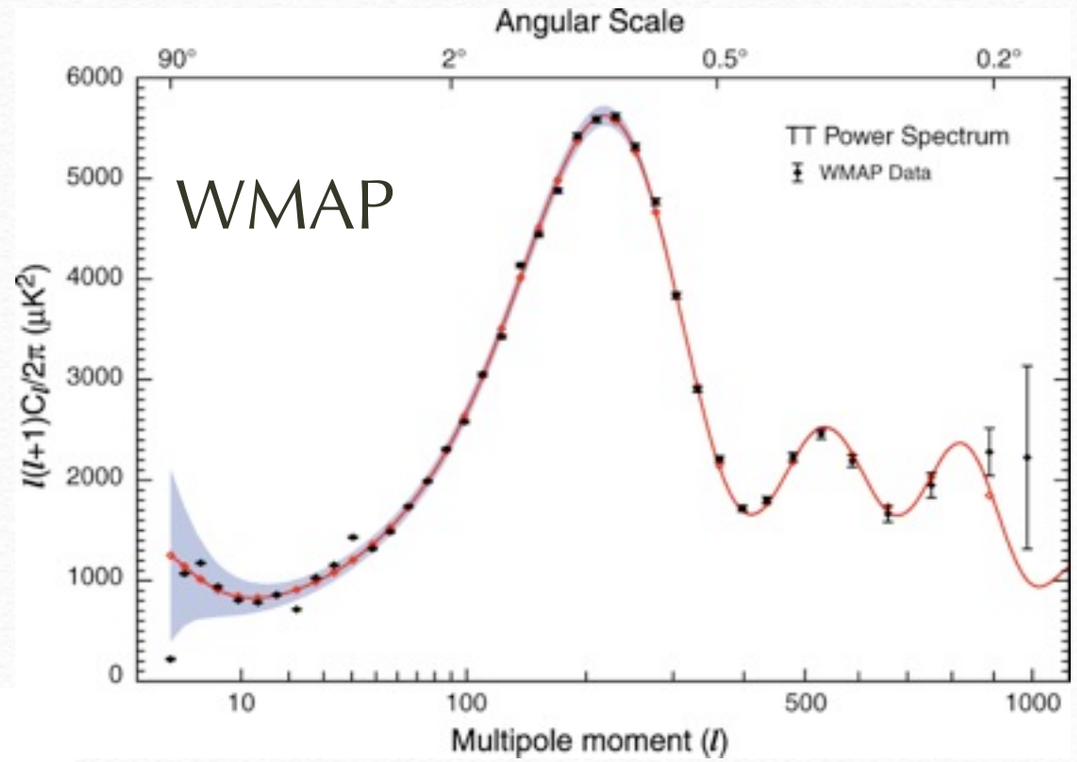




Fig. 18. The temperature dependent potential for $m_{Higgs} = 50$ GeV and for $m_t = 240$ GeV. Here, $\tilde{V} = 8V/m^2_{Higgs}$ and units of $\sigma = 1$ are used.

for "up to Planck scale"

# New Physics Clue II
# Dark matter




density in our neighborhood
0.3GeV/cm$^3$

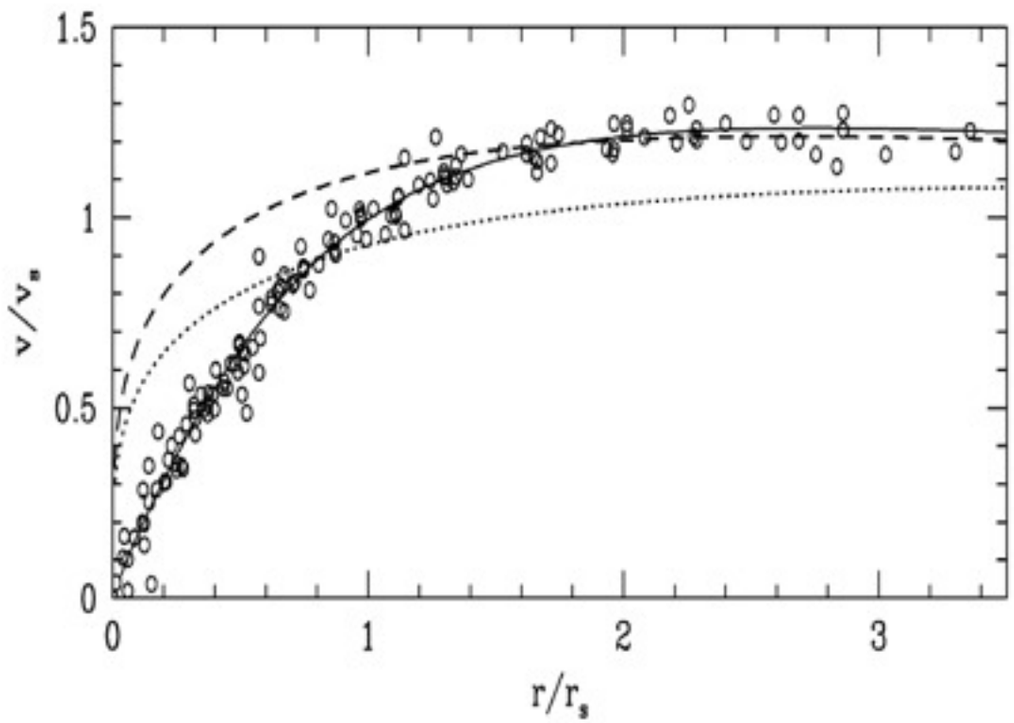
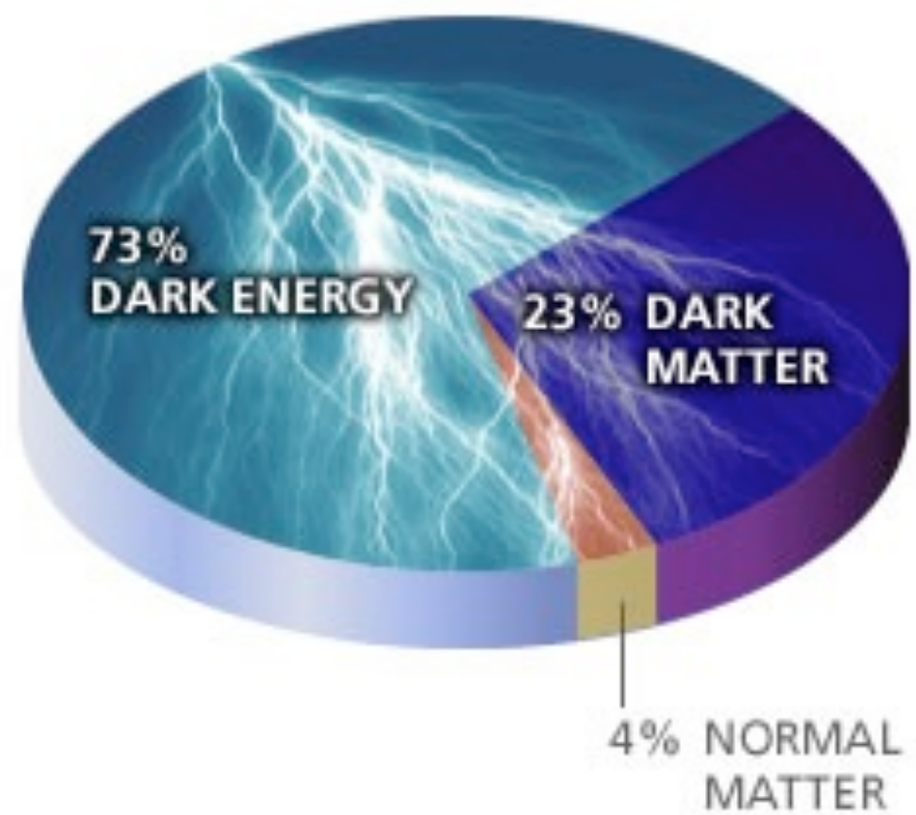



**Figure 2.** The rotation curves of galaxies, from dwarf spirals to giant LSB galaxies, scaled to fit the universal density profile of equation 1. The solid curve shows the rotation curve that results

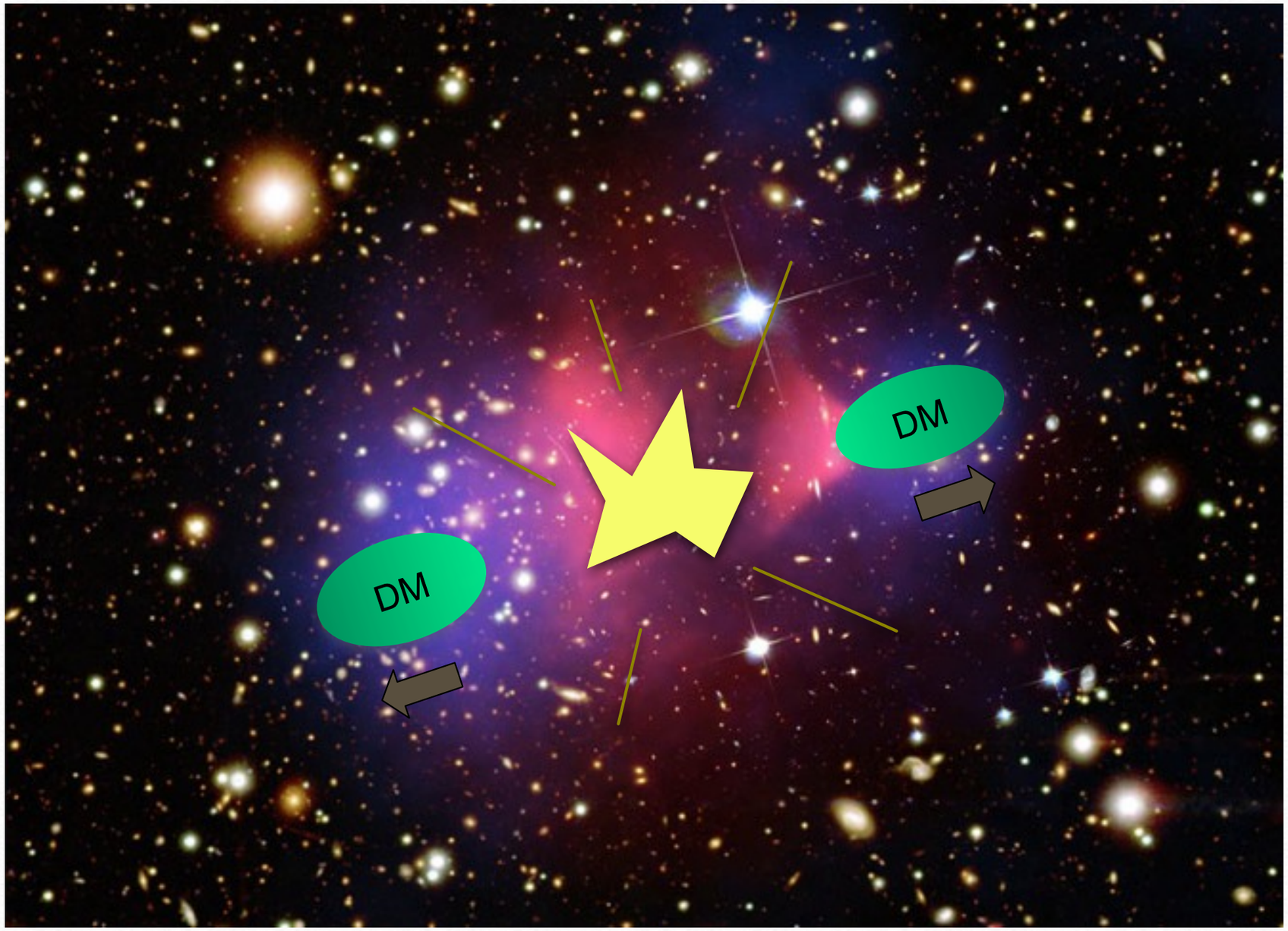
NASA



# And they are particles

- Strong evidence that they are not “modified gravities”

# And they are particles




- Strong evidence that they are not “modified gravities”

# DM requires lots to particle physics

- Why they are stable/How they appear in our Universe
- $10^{10}$ years=$10^{17}$ sec $\rightleftarrows 10^{-43}$ GeV$^{-1}$ while 1GeV /Mpl$^2$ =$10^{-38}$ GeV$^{-1}$
- The big bang →thermal relic density requires weakly interacting particles.
- for SM, proton and electron is stable due to the gauge symmetry.

# New Physics Clue III

- SM particle contents → grand unification

gauge group SU(3)xSU(2)x U(1)-> SU(5)

$$SU(3): \begin{pmatrix} \frac{1}{2}\lambda^a & 0 \\ 0 & 0 \end{pmatrix}, SU(2): \begin{pmatrix} 0 & 0 \\ 0 & \frac{1}{2}\sigma^a \end{pmatrix},$$

$$U(1): \frac{1}{2\sqrt{15}} \begin{pmatrix} -2 & 0 \\ 0 & 3 \end{pmatrix}$$

matter (SU(3), SU(2))$_{U(1)}$

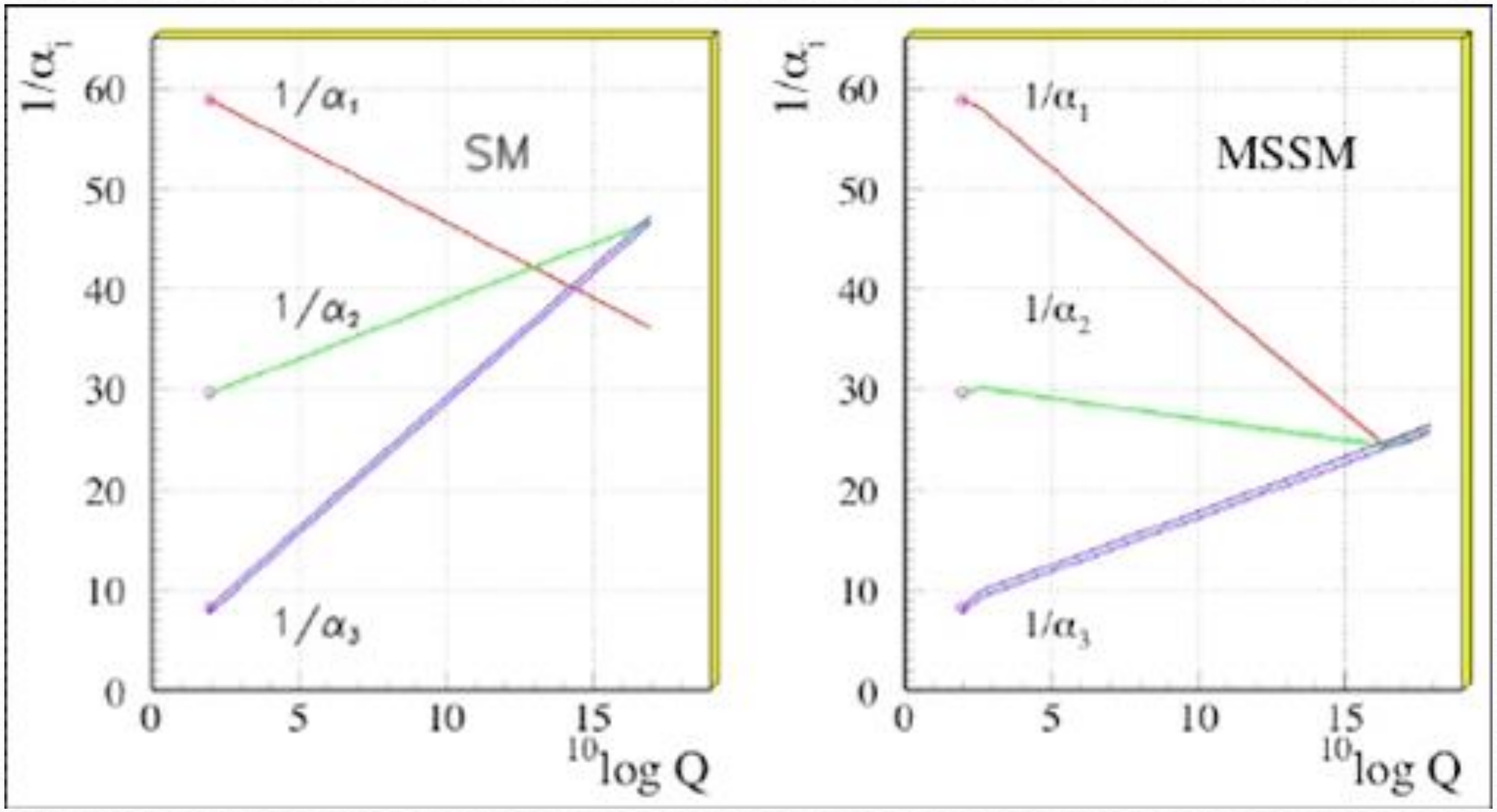
quark (3,2)1/6 , (3,1)$_{-1/3}$ (3,1)$_{2/3}$

lepton (1,2)$_{-1/2}$ (1,1)$_{-1}$

$$5^* = (d^c, e^- - \nu_e)$$

$$10 = \sqrt{1/2} \begin{bmatrix} 0 & u^{c3} & -u^{c2} & u^1 & d^1 \\ -u^{c3} & 0 & u^{c1} & u^2 & d^2 \\ u^{c2} & -u^{c1} & 0 & u^3 & d^3 \\ u^1 & u^2 & u^3 & 0 & e^+ \\ d^1 & d^2 & d^3 & -e^+ & 0 \end{bmatrix}_L$$

# Prediction of GUT




from http://www.pha.jhu.edu/~gbruhn/IntroSUSY.html

We need something beyond standard mode

# Classic Solution:Supersymmetry

- exchange boson and fermion.

$$\phi \leftrightarrow \psi$$

  - sfermions(0), gaugino(1/2), higgsinos(1/2)

- boson and fermion is in the same multiplet. chiral symmetry extended to bosons

- No new dimensionless coupling and no quadratic divergence $\lambda\psi_L\psi_R H \to \lambda\phi_L\psi_R\tilde{H} + \lambda\psi_L\phi_R\tilde{H}$

- SUSY change "dimension" (1 for boson 3/2 for fermion), relate mass and couplings

$$\Phi = \frac{1}{g^2} + M\theta^2 \qquad \Phi WW = \frac{1}{g^2}F_{\mu\nu}F^{\mu\nu} + M\tilde{g}\tilde{g}$$

- R parity conservation. New stable particle→ DM candidate.

# What is SUPERSYMMETRY

$$\{Q_\alpha \ \bar{Q}_{\dot{\beta}}\} \quad = \quad 2(\sigma^\mu)_{\alpha\dot{\beta}} P_\mu$$

$$\{Q_\alpha \ Q_\beta\} \quad = \quad \{\bar{Q}_{\dot{\alpha}} \ \bar{Q}_{\dot{\beta}}\} = 0$$

$$[Q_\alpha \ P_\mu] \quad = \quad [\bar{Q}_{\dot{\alpha}}, P_\mu] = 0$$

Q: spin 1/2 mass dim 1/2

α, β =1,2(corresponding two spin up and down

operation to massive state

$$\{Q_\alpha \ \bar{Q}_{\dot{\beta}}\} = \delta_{\alpha\dot{\beta}} 2M$$

two fermion system (as quantum mechanics)

spin 1/2 up

|0>
spin 0

(Q1Q2)|0>
spin 0

spin 1/2 down

spin 1 massive gauge boson

|1/2>
spin 1/2

(Q1Q2)|1/2>

spin 0
higgs?

Number of boson and fermion are the same

# supersymmetric representation II

**massless multiplet** $P = (p, 0, 0, p)$

$$\{Q_\alpha, \bar{Q}_{\dot{\alpha}}\} = 2(\sigma_\mu)_{\alpha\dot{\alpha}} P^\mu = 4p \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \qquad (1)$$

$$\begin{aligned} a &= Q_1/\sqrt{4p}, \qquad a^\dagger = \bar{Q}_{\dot{1}}/\sqrt{4p} \\ b &= Q_2/\sqrt{4p}, \qquad b^\dagger = \bar{Q}_{\dot{2}}/\sqrt{4p} \\ \{a, a^\dagger\} &= 1, \qquad \{b, b^\dagger\} = 0 \end{aligned} \qquad (2)$$

mass less state is Helicity eigenstate

$$|\lambda\rangle \to |\lambda + 1/2\rangle, b^\dagger|\lambda\rangle = b|\lambda\rangle = 0 \qquad (3)$$

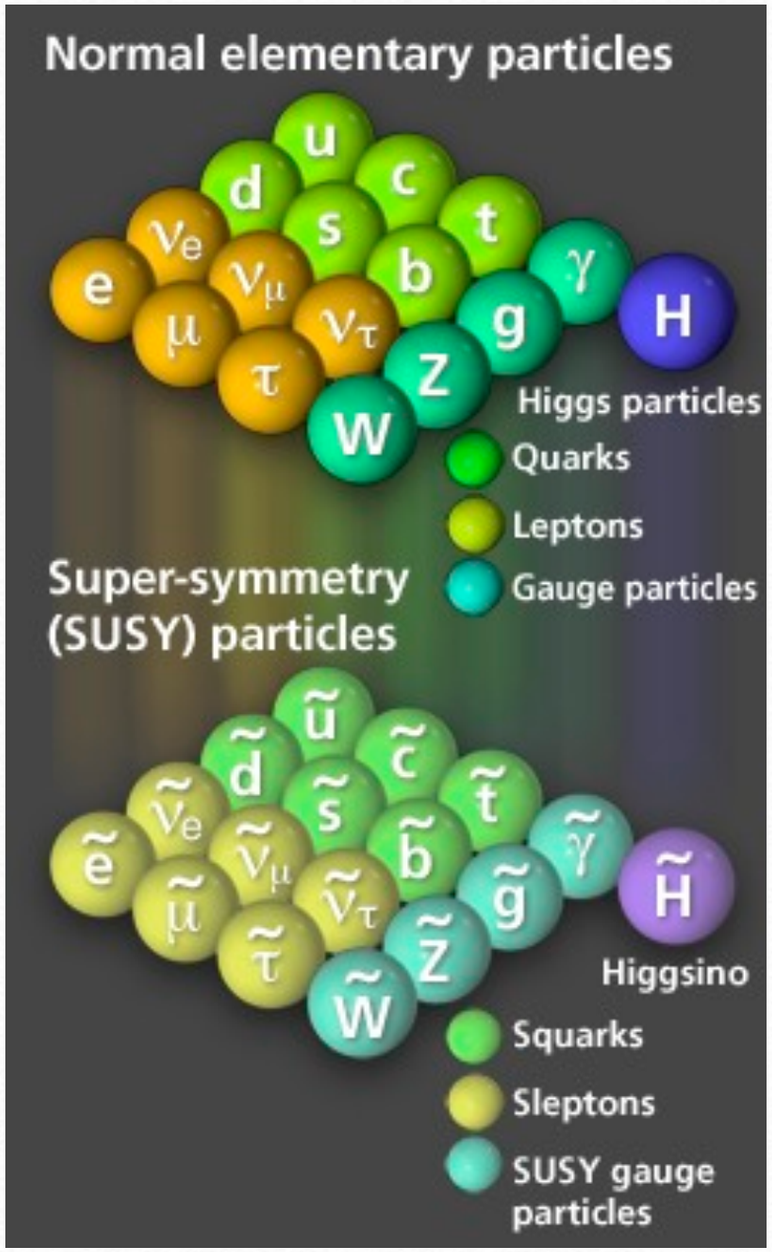
# matter content of MSSM

| | quark | squarks |
|---|---|---|
| $(3,2)_{1/6}$ | $q_L = (u,d)_L$ | $\tilde{q}_L = (\tilde{u}_L \tilde{d}_L)$ |
| $(3^*,1)_{-2/3,1/3}$ | $u^c, d^c$ | $\tilde{u}^c, \tilde{d}^c$ |
| | lepton | slepton |
| $(1,2)_{1/2}$ | $l_L = (\nu, e)_L$ | $\tilde{l}_L = (\tilde{\nu}_L, \tilde{e}_L)$ |
| $(1,1)_1$ | $l_R = e_R^c$ | $\tilde{e}_R^c$ |
| | higgsino | higgs |
| $(1,2)_{-1/2}$ | $(\tilde{H}_1^0, \tilde{H}_1^-)$ | $H_1 = (H_1^0, H_1^-)$ |
| $(1,2)_{1/2}$ | $(\tilde{H}_2^+ \tilde{H}_2^0)$ | $H_2 = (H_2^+, H_2^0)$ |

vector multilets

$G_\mu, W_\mu, B_\mu \leftrightarrow \tilde{G}, \tilde{W}, \tilde{B}$ (gluino, wino, bino)

gravity $\tilde{\psi}^\mu$ (gravitino), $g_{\mu\nu}$ (graviton)



# Supersymmetric field theory

## Compact notation (superfield)

$$\Phi_{(+)}(y^+,\theta) = \exp\left(-i\theta\partial\!\!\!/\bar\theta\right)\tilde\phi_{(+)}(x,\theta)$$

$$\tilde\phi_{(+)}(x) = \phi + \sqrt{2}\theta\psi + \theta\theta F$$

$$\tilde\phi_{(-)}(x) = \phi^* + \sqrt{2}\bar\theta\bar\psi + \bar\theta\bar\theta F^*$$

Kinetic terms

$$\partial\phi\partial\phi^* + \bar\psi\sigma\partial\psi + \boxed{F^*F}$$

$$\Phi^\dagger\Phi|_{\theta\theta\bar\theta\bar\theta}$$

transformation

$$\begin{aligned}\delta\phi &= \sqrt{2}\alpha\psi\\ \delta\psi &= -i\sqrt{2}\partial\!\!\!/\phi\bar\alpha + \boxed{\sqrt{2}F\alpha}\\ \delta F &= -i\sqrt{2}\bar\alpha\bar\partial\!\!\!/\psi\end{aligned}$$

$$(\alpha S + \alpha\bar S)\ \ \Phi_{(+)}(y^+,\theta)$$

$$S_\alpha = \frac{\partial}{\partial\theta^\alpha} + i(\partial\!\!\!/\bar\theta)_\alpha$$

interactions

$$(F_1(x)\phi_2(x)\phi_3(x) + F_2(x)\phi_1(x)\phi_3(x) + F_3(x)\phi_1(x)\phi_2(x)$$
$$-\psi_1(x)\psi_2(x)\phi_3(x) - \psi_2(x)\psi_3(x)\phi_1(x) - \psi_3(x)\psi_1(x)\phi_2(x))$$

$$\Phi_1\Phi_2\Phi_3|_{\theta\theta}$$

$$(F_1(x)\phi_2(x) + F_2(y)\phi_1(x)) - \psi_1(x)\psi_2(x))$$

$$\Phi_1\Phi_2|_{\theta\theta}$$

# Matter interaction

$$W = -\mu H_1 \cdot H_2 - Y_e H_1 \cdot E^c L - Y_d H_1 \cdot D^c Q - Y_u H_2 \cdot U^c Q$$

R=1: SM particles
R=-1: SUSY particles
Θ→ R=-1

R parity violating interactions are lepton and baryon number violating and vetoed by hand.

$$\begin{aligned} W_L &= L \cdot H_2 + L \cdot E^c L \\ W_Q &= L \cdot D^c Q + D^c_R D^c_R U^c_R \end{aligned}$$

| | quark | squarks |
|---|---|---|
| $(3,2)_{1/6}$<br>$(3^*,1)_{-2/3,1/3}$ | $q_L = (u,d)_L$<br>$u^c, d^c$ | $\tilde{q}_L = (\tilde{u}_L \tilde{d}_L)$<br>$\tilde{u}^c, \tilde{d}^c$ |
| | lepton | slepton |
| $(1,2)_{1/2}$<br>$(1,1)_1$ | $l_L = (\nu, e)_L$<br>$l_R = e^c_R$ | $\tilde{l}_L = (\tilde{\nu}_L, \tilde{e}_L)$<br>$\tilde{e}^c_R$ |
| | higgsino | higgs |
| $(1,2)_{-1/2}$<br>$(1,2)_{1/2}$ | $(\tilde{H}^0_1, \tilde{H}^-_1)$<br>$(\tilde{H}^+_2 \tilde{H}^0_2)$ | $H_1 = (H^0_1, H^-_1)$<br>$H_2 = (H^+_2, H^0_2)$ |

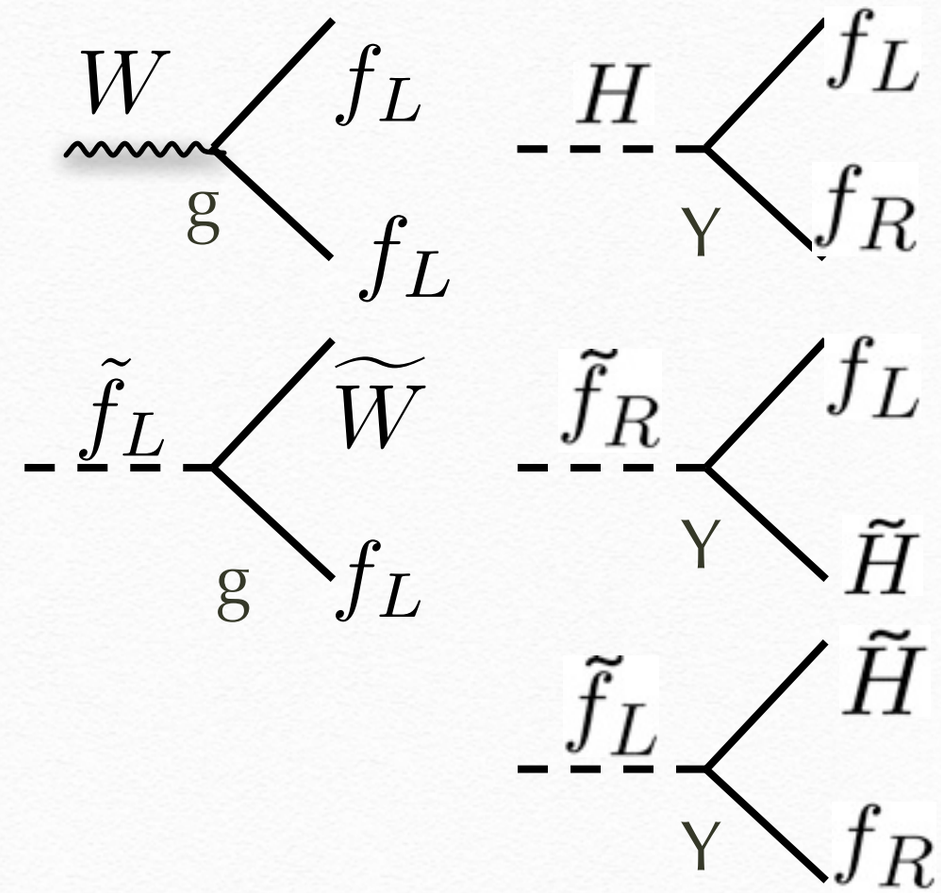
vector multilets

$G_\mu, W_\mu, B_\mu \leftrightarrow \tilde{G}, \tilde{W}, \tilde{B}$ (gluino, wino, bino)

gravity $\tilde{\psi}^\mu$ (gravitino), $g_{\mu\nu}$ (graviton)

# R parity, SUSY relation

- R parity conservation
  - SUSY particles will be pair produced.
  - SUSY particles decay into SUSY particles -> Lightest SUSY particle can be dark matter
- There are no new dimensionless couplings
  - gaugino interaction is gauge coupling
  - Higgsino matter interaction is yukawa coupling




Higgino-gaugino mix
sfermion left night also
mix due to sclar 4 point
couplings

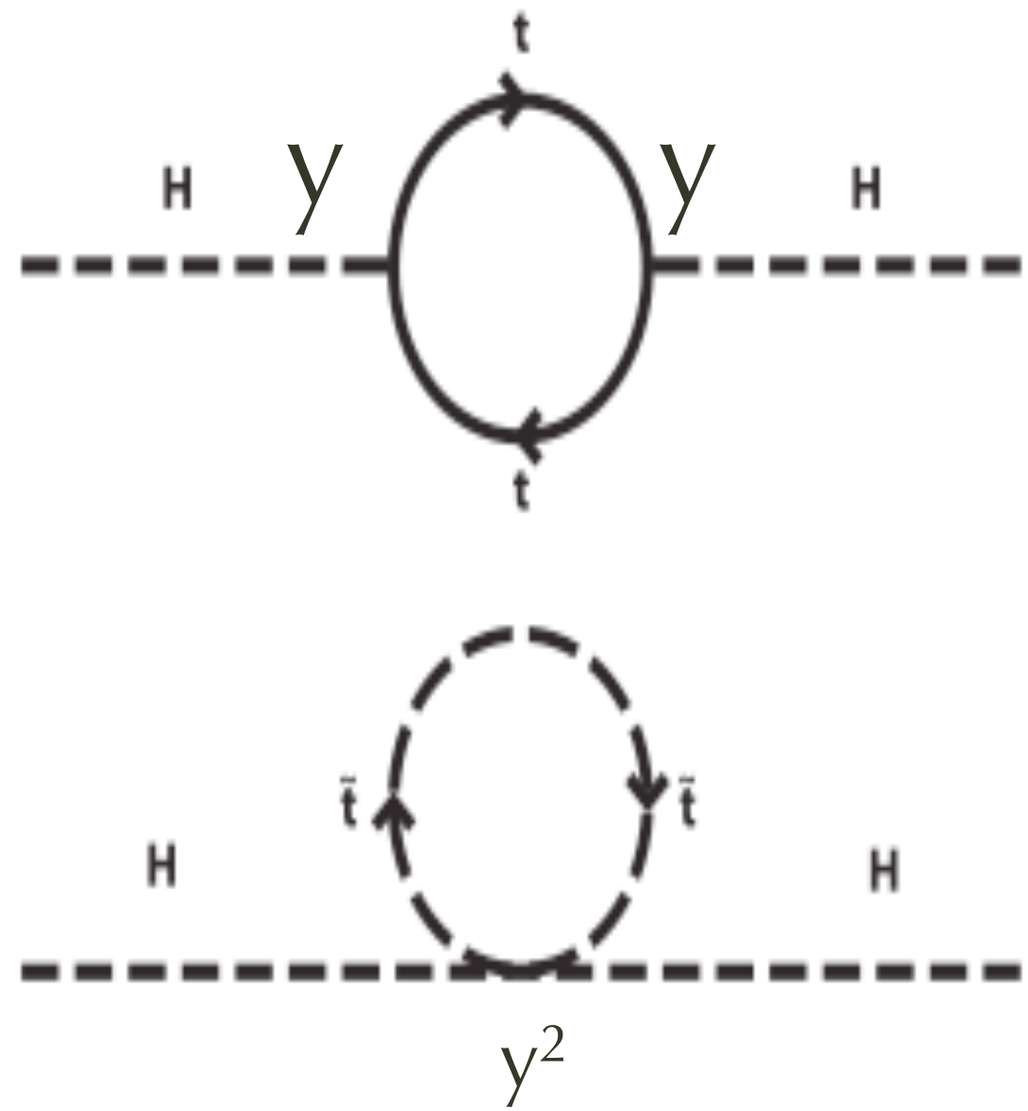
# cancellation of divergence

from kinetic term and
super potential

$$FF^* + F\partial W/\partial\phi + F(\partial W/\partial\phi)^\dagger = 0$$

scalar 4 point equation is
proportional to (yukawa)^2
(stop loop cancel top loop)

There is something similar
for gauge interactions
Higgs 4 point interaction
is proportional to g^2




$y^2$

# BSM scenario 2
# Dynamical symmetry breaking ?

- Technicolor→ Little Higgs model
  - Higgs boson is goldstone boson of a large symmetry. SU(5)→SO(5)
  - Decide we do not ask the origin of symmetry breaking for a moment, but it is dynamical symmetry breaking and around at 10Tev
  - There are so many NG boson, extand Gauge symmetry: $SU(2)_1 x SU(2)_2 x U(1)_1 x U(1)_2$
  - quadratic correction to Higgs sector starts from 2 loop
    - top sector must be extended (extra top quark). afterall top-higgs coupling is the source of fine tuning.

$$(g_1, g_2, g_1', g_2')$$

$$\chi = (b_3, t_3, \tilde{t}) \quad \tilde{t}, \tilde{t}'$$

# Lessons from chiral lagrangian

QCD at Low energy -> Theory of meson and hadrons

below 1GeV→ theory of pions, Goldstone boson of

$SU(2)_L \times SU(2)_R \to SU(2)_V$ breaking

symmetry transformation ⇄ goldstone boson
vev

From symmetry only , low energy action is given as ...

$$U(x) = \exp[2i\pi^a(x)T_a/f_\pi]$$

$$\mathcal{L} = \frac{1}{4} f_\pi^2 Tr \partial^\mu U \partial_\mu U \qquad U \to LU(x)R^\dagger$$

The mass of π is protected by the symmetry of the theory
Could this be Higgs boson?

# First of all what is Technicoloer

Unknown strong interaction (Technicolor) and technifermion that couple to it

Mass of proton, neutron comes from strong dynamics, not from higgs boson

Instead of higgs boson, the bound state of quark antiquark took vev

$$< \bar{q}q > \sim 200 GeV$$

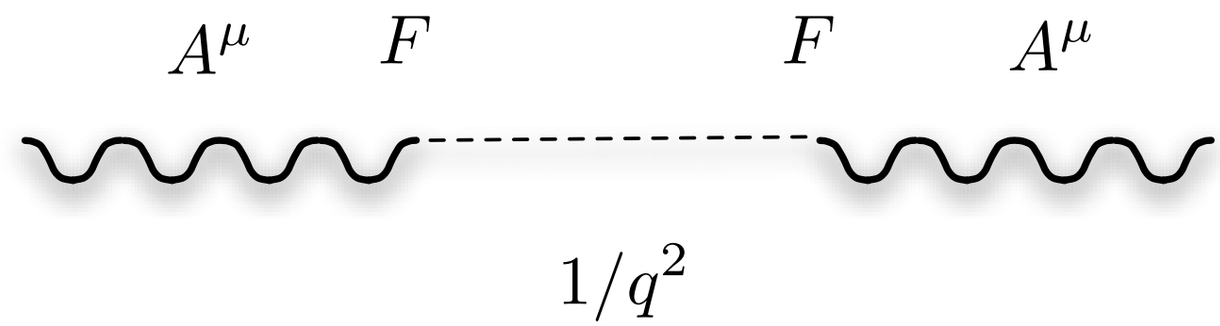
breaking of SM gauge symmetry

# The model

- SU(2)LxU(1)xSU(3)CxSU(3)TC
- matter content

$$\begin{pmatrix} U_L \\ D_L \end{pmatrix} \sim (2, 1/6, 1, 3)$$

$$U_R \sim (1, 2/3, 1, 3), \;\; D_R \sim (1, -1/3, 1, 3)$$




- Symmetry breaking and NG boson.

$$\langle \bar{Q}Q \rangle \neq 0 \quad \pi_i = \bar{Q}\gamma_5\tau^i Q$$

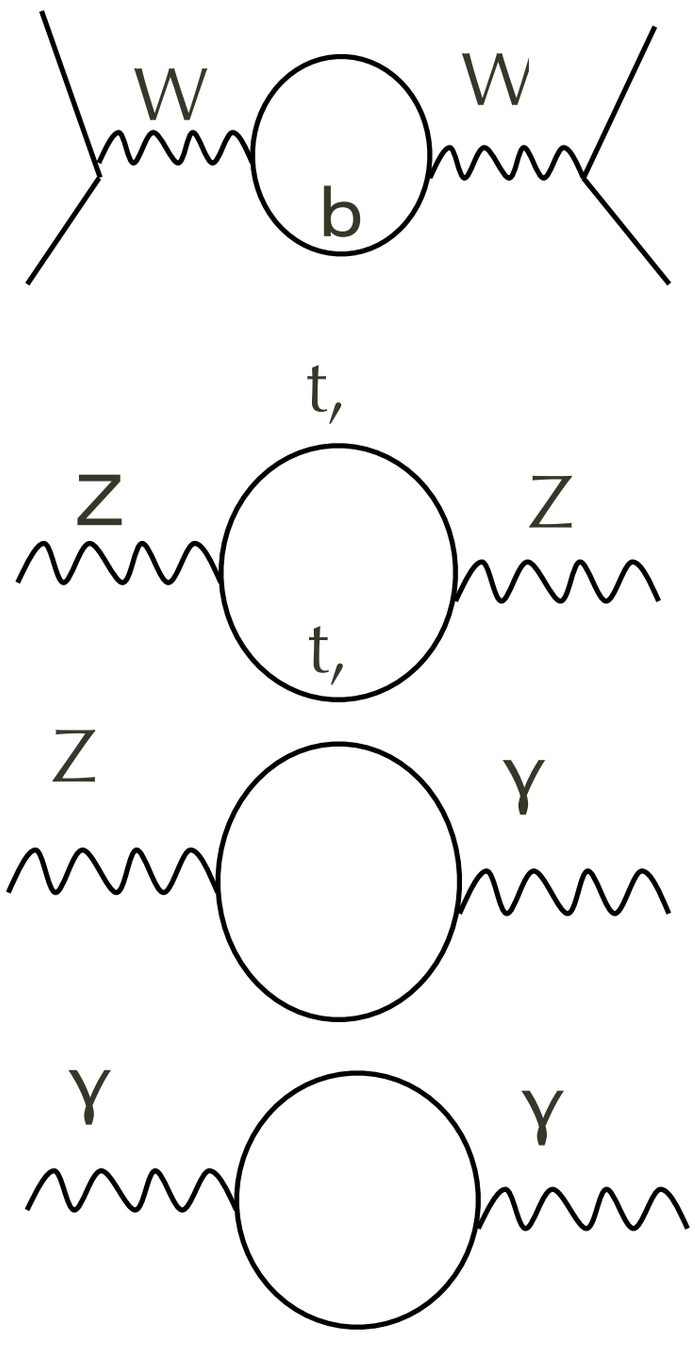
$$i\Pi^{\mu\nu}(q^2)(\equiv \langle J^\mu J^\nu \rangle) = i(q^2 g^{\mu\nu} - q^\mu q^\nu)\Pi(q^2)$$

$$\frac{-i}{q^2(1-\Pi(q^2))}\left(g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) + \ldots.$$

$$\Pi(q^2) = \frac{F^2}{q^2} \Longrightarrow q^2(1-\Pi) \to q^2 - F^2$$

# LEP precision measurement

- The sector that breaks SM gauge symmetry appears in gauge two point function
- The sector must be rather heavy
- Expand two point function by momentum and identify leading deviation.




$$\Pi(q^2) = \Pi_{SM}(q^2) + \Pi^{\text{new}}(0) + \Pi'\text{new}(0)q^2 + \frac{1}{2}\Pi''\text{new}(q^2)(q^2)^2 \quad (1)$$

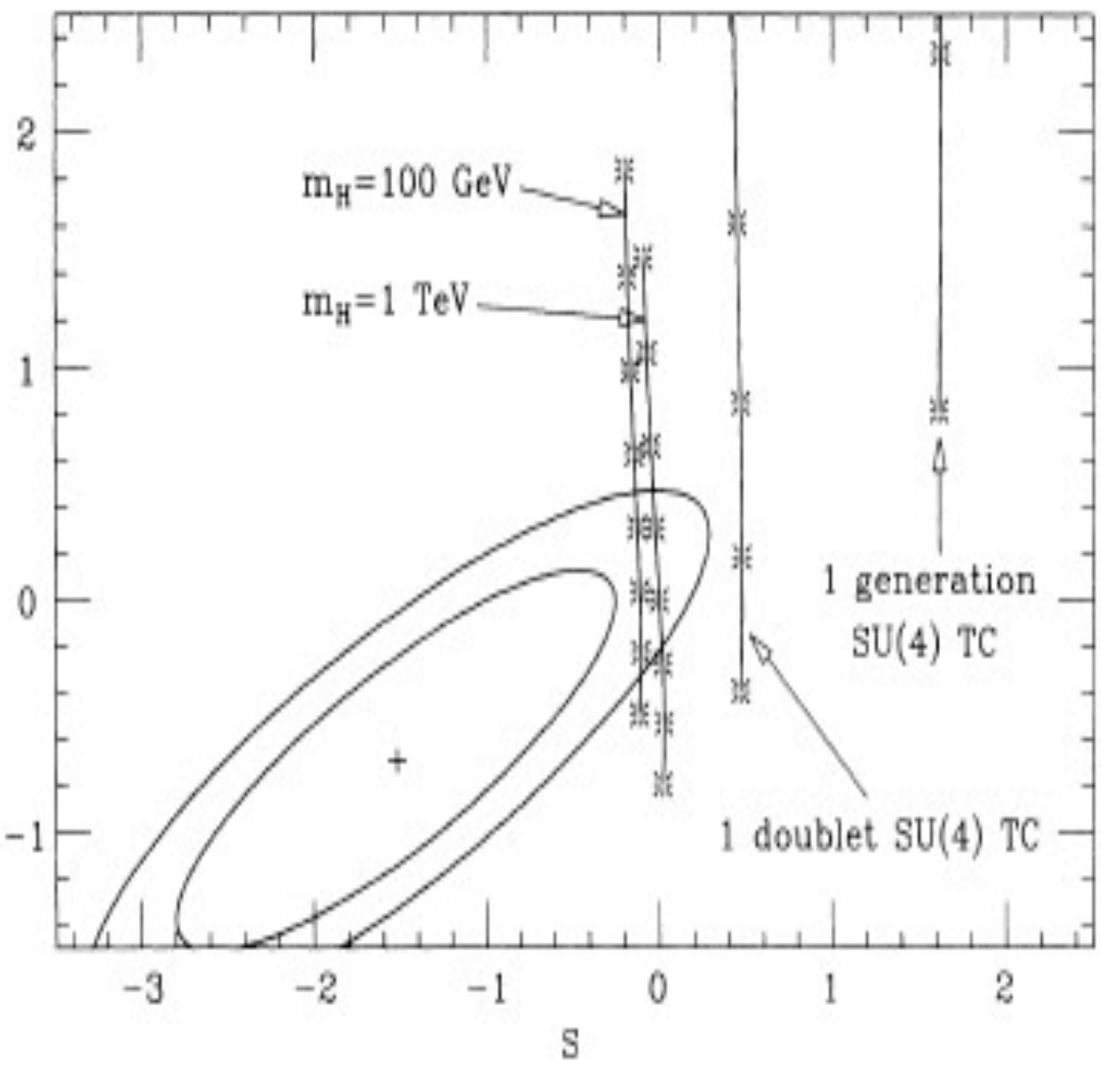
Peskin Takeuchi の STU parameter

$$T \propto \Pi_{11}(0) - \Pi_{33}(0), \quad S \propto \Pi'_{33}(0) - \Pi'_{3Q}(0) \quad (2)$$

one doublet の寄与

$$\delta S = \frac{1}{6\pi}\left[1 - Y \log(m_N^2/m_E^2)\right] \quad (3)$$

# Technicolor vs. S parameter



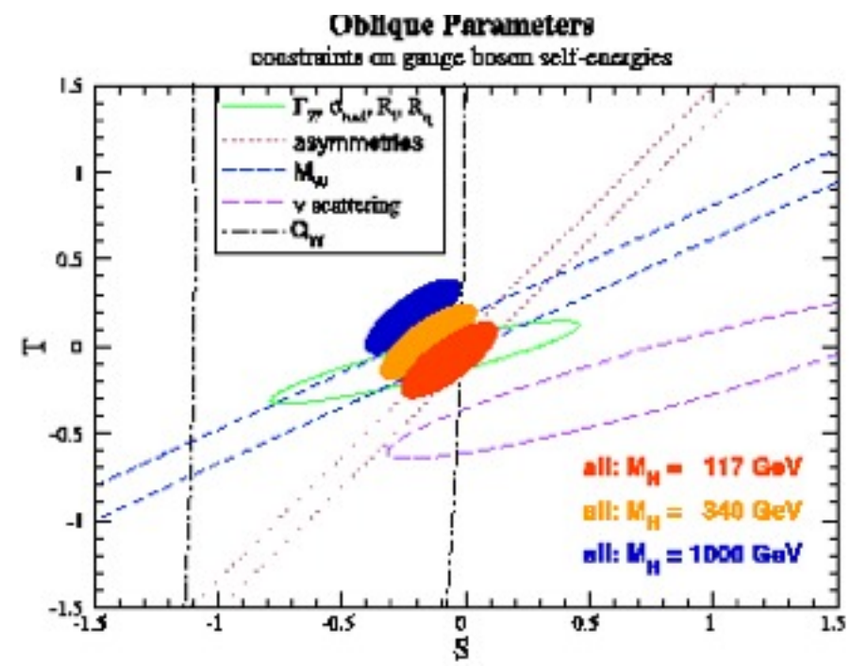




**Figure 10.3:** 1 $\sigma$ constraints (39.35%) on $S$ and $T$ from various inputs. $S$ and $T$ represent the contributions of new physics only. (Uncertainties from $m_t$ are included in the errors.) The contours assume $M_H = 117$ GeV except for the central and upper 90% CL contours allowed by all data, which are for $M_H = 340$ GeV and 1000 GeV, respectively. Data sets not involving $M_W$ are insensitive to $U$. Due to higher order effects, however, $U = 0$ has to be assumed in all fits. $\alpha_s$ is constrained using the $\tau$ lifetime as additional input in all fits. See full-color version on color pages at end of book.

There is no simple parametrization that is powerful enough to describe the effects of every type of new physics on every possible observable. The $S$, $T$, and $U$ formalism describes many types of heavy physics which affect only the gauge self-energies, and it

# explicit model

global: $SU(5) \to SO(5)$

local: $[SU(2) \times U(1)]^2 \to SU(2)_L \times U(1)_Y$

NGB: $\mathbf{1_0}$, $\mathbf{3_0}$(absorbed by heavier gauge bosons)

$$\mathbf{2}_{\pm 1/2} \quad h = (h^+, h^0),$$

$$\mathbf{3}_{\pm 1} \quad \phi = \begin{pmatrix} \phi^{++}, \phi^+/\sqrt{2} & \\ \phi^+/\sqrt{2} & \phi^0 \end{pmatrix}$$

global symmetry when gauge interaction 2 is killed

$$\text{vev } \Sigma_0 = \begin{pmatrix} & 1 & 1_{2\times 2} \\ 1_{2\times 2} & & \end{pmatrix}, \quad \Sigma = e^{i\Pi/f}\Sigma_0 e^{i\Pi^T/f}, \quad \Pi = \begin{pmatrix} & h^\dagger/\sqrt{2} & \phi^\dagger \\ h/\sqrt{2} & & h/\sqrt{2} \\ \phi & h^T/\sqrt{2} & \end{pmatrix}$$

gauge generator

$$Q_1^a = \begin{pmatrix} \sigma^a/2 & \\ & 0_{3\times 3} \end{pmatrix}, \quad Y_1 = \frac{1}{10}\begin{pmatrix} -3 & & & & & \\ & -3 & & & & \\ & & 2 & & & \\ & & & 2 & & \\ & & & & 2 & \\ & & & & & 2 \end{pmatrix},$$

symmetry when interaction 1 is killed

$$Q_2^a \begin{pmatrix} 0_{3\times 3} & \\ & -\sigma^{a*}/2 \end{pmatrix}, \quad Y_2 = \frac{1}{10}\begin{pmatrix} -2 & & & & & \\ & -2 & & & & \\ & & -2 & & & \\ & & & 3 & & \\ & & & & 3 & \\ & & & & & 3 \end{pmatrix}$$

**radiative correction appears from two loop**

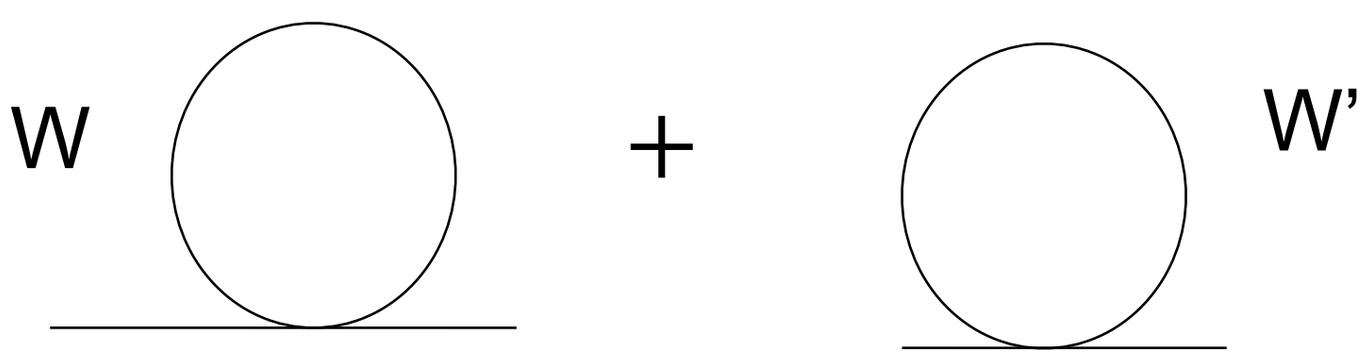
# cancellation of higgs radiative correction

Mass eigenstate

$$W = sW_1 + cW_2, B = s'B_1 + c'B_2, \ (s = g_2/\sqrt{g_1^2 + g_2^2})$$

$$\begin{aligned} L(W', W) \ = \ & \frac{g^2}{4}\left[W_\mu^a W^{b\mu} - \frac{c^2 - s^2}{sc} W_\mu^a W'^{b\mu}\right] Tr\left[h^\dagger h \delta^{ab} + 2\phi^\dagger \phi \delta^{ab} + 2\sigma^a \phi^\dagger \sigma^{bT} \phi\right] \\ & -\frac{g^2}{4}\left[W_\mu'^a W'^{a\mu} Tr\left[h^\dagger h + 2\phi^\dagger \phi\right] - \frac{c^4 + s^4}{2s^2c^2} W_\mu'^a W'^{b\mu} Tr\left[2\sigma^a \phi^\dagger \sigma^{bT} \phi\right]\right] \end{aligned}$$

**radiative correlction from WW**hh and **W'W'hh has opposite signs**




=LOG divergence

# LEP Anchor

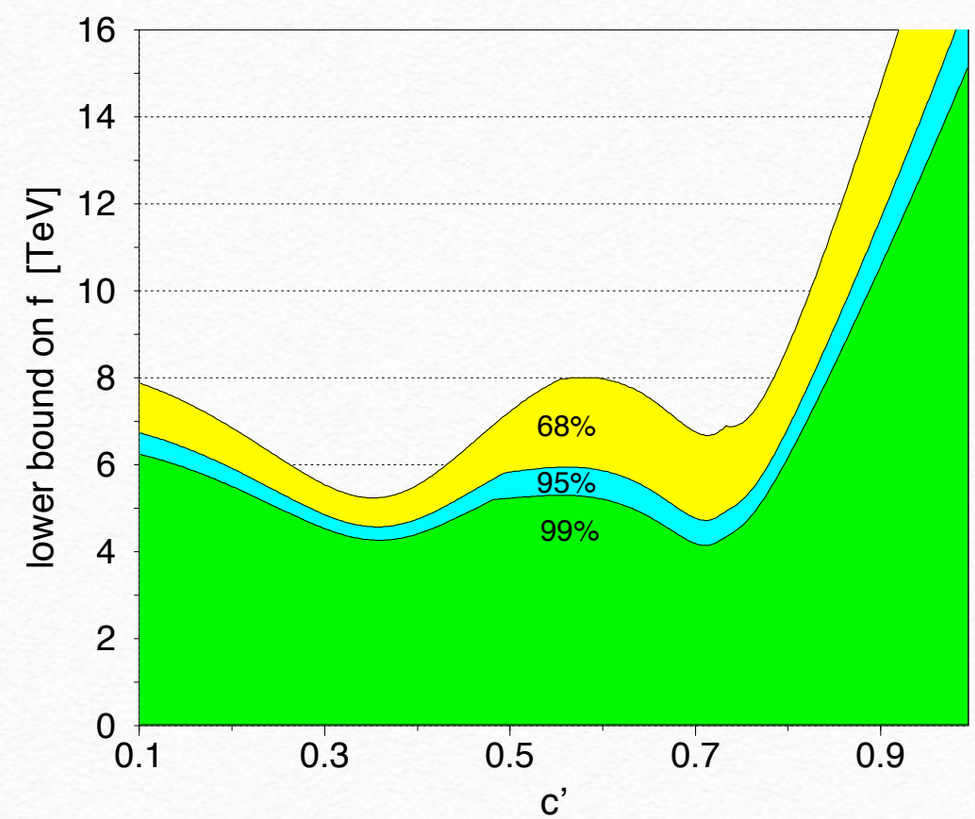
Quadratic divergence is OK but there are still finite corrections
"difficulty" comes from tree level Heavy-Light mixing

$$L_2 \to -\frac{g_1 g_2 (g_1^2 - g_2^2)}{4(g_1^2 + g_2^2)} W^a_{\mu L} W^{a\mu}_H h^2 \quad \longrightarrow \quad -\frac{g^2 (s^2 - c^2)^2}{8 f^2} W_L W_L h^4$$

$$(W^a_L = s W^a_1 + c W^a_2)$$

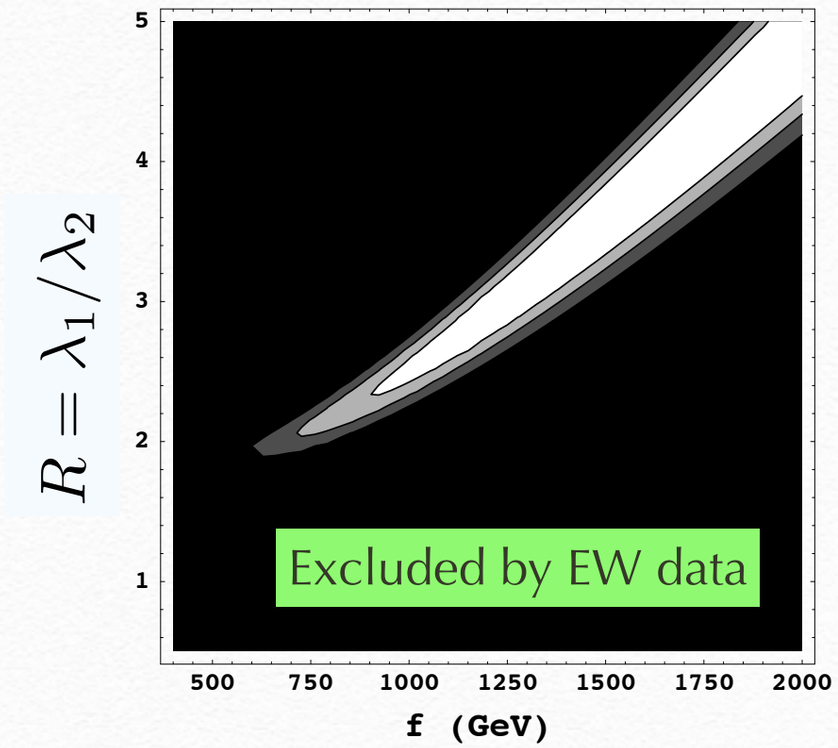
Csaki et al hep-ph/0211124

- Various $v^2/f^2$ corrections. proportional to the coupling difference, $\Delta g = g_1 - g_2$
- $M^2(W_H) = (g_1^2 + g_2^2)\, f^2/4 \sim (gf/2)^2 > 2.7\text{TeV}$
- $f > 4\text{TeV}$ $m(t') > 7\text{TeV}$, (Hewett et al JHEP, 2003) Fine turning is reintroduced



# Little Higgs with T-parity

Hubisz et al 0411264




$$m_{T_-} = \lambda_2 f$$

- gauge groups and matter contents respect T parity. $SU(2)_1 \rightleftarrows SU(2)_2$ $U(1)_1 \rightleftarrows U(1)_2$
- T-odd matters are introduced. Looks like SUSY without gluino
- LEP constraint is weaker.
    - Heavy gauge bosons and triplet higgs boson live in T-odd sector. No tree level mixing
- **Need more attempts to construct a model including symmetry breaking sector. ( cf. the study of SUSY breaking sector. )**
- UED has similar nature.

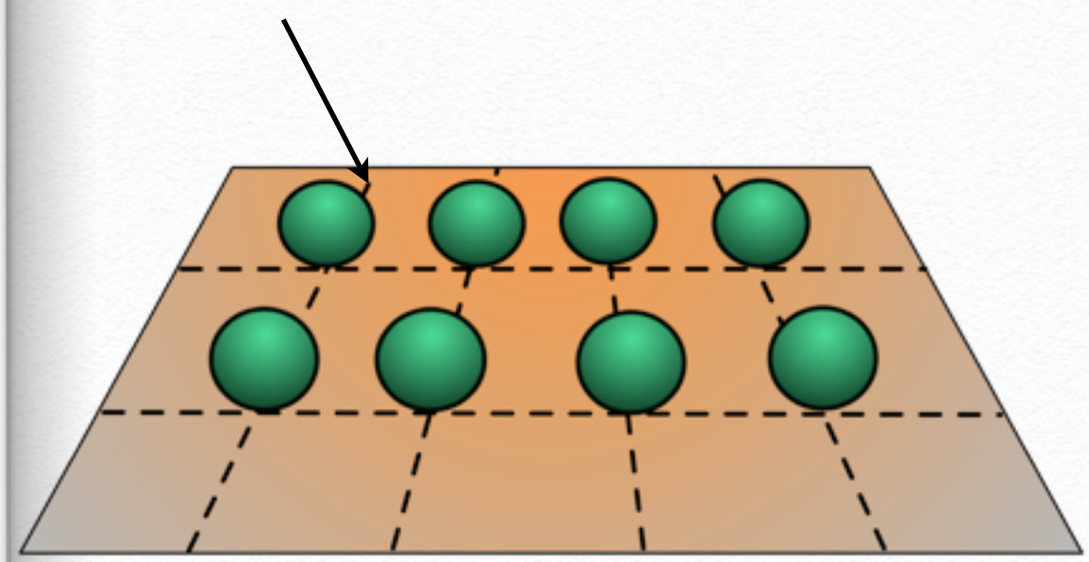
# The Lesson is .....

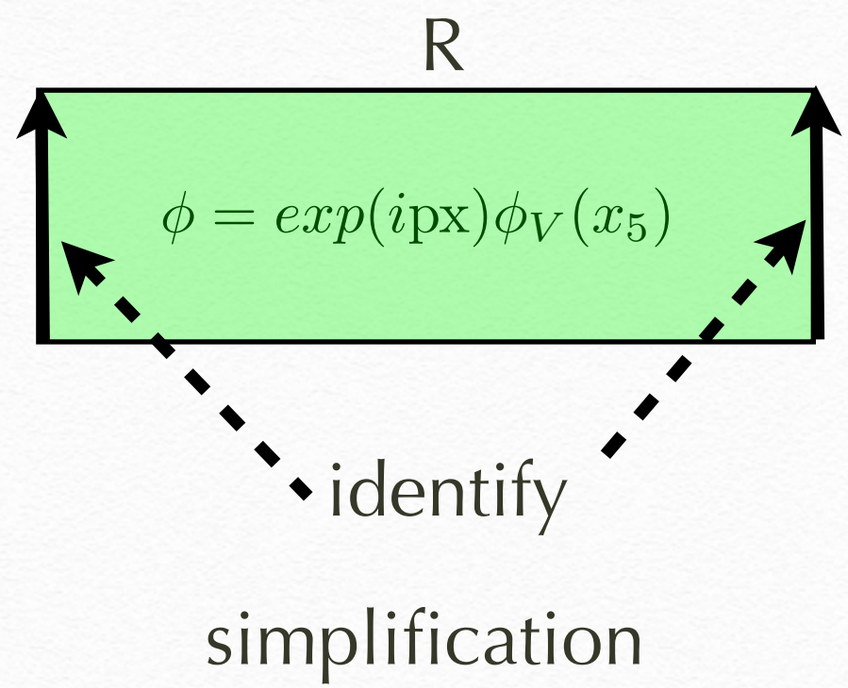
- LEP constraint (small radiative correction)
  - New Physics scale Λ is high, suggesting fine tuning.
  - Need symmetry to cancel divergence
  - top partner → top must be involved in the symmetry.
- "DM" and "radiative correction"→parity structure

LHC signature:strongly interacting particle decay into DM (and flavor sector involving b quark.....)

# BSM scenario 3
# 4dim space to n dim space

Each point has internal space






KK mode $\quad p_5 R \;=\; 2\pi n \rightarrow p_5 = 2\pi n/R$

$$E_n^2 = \mathrm{p}^2 + p_5^2 = \mathrm{p}^2 + (2\pi)^2(\frac{n}{R})^2$$

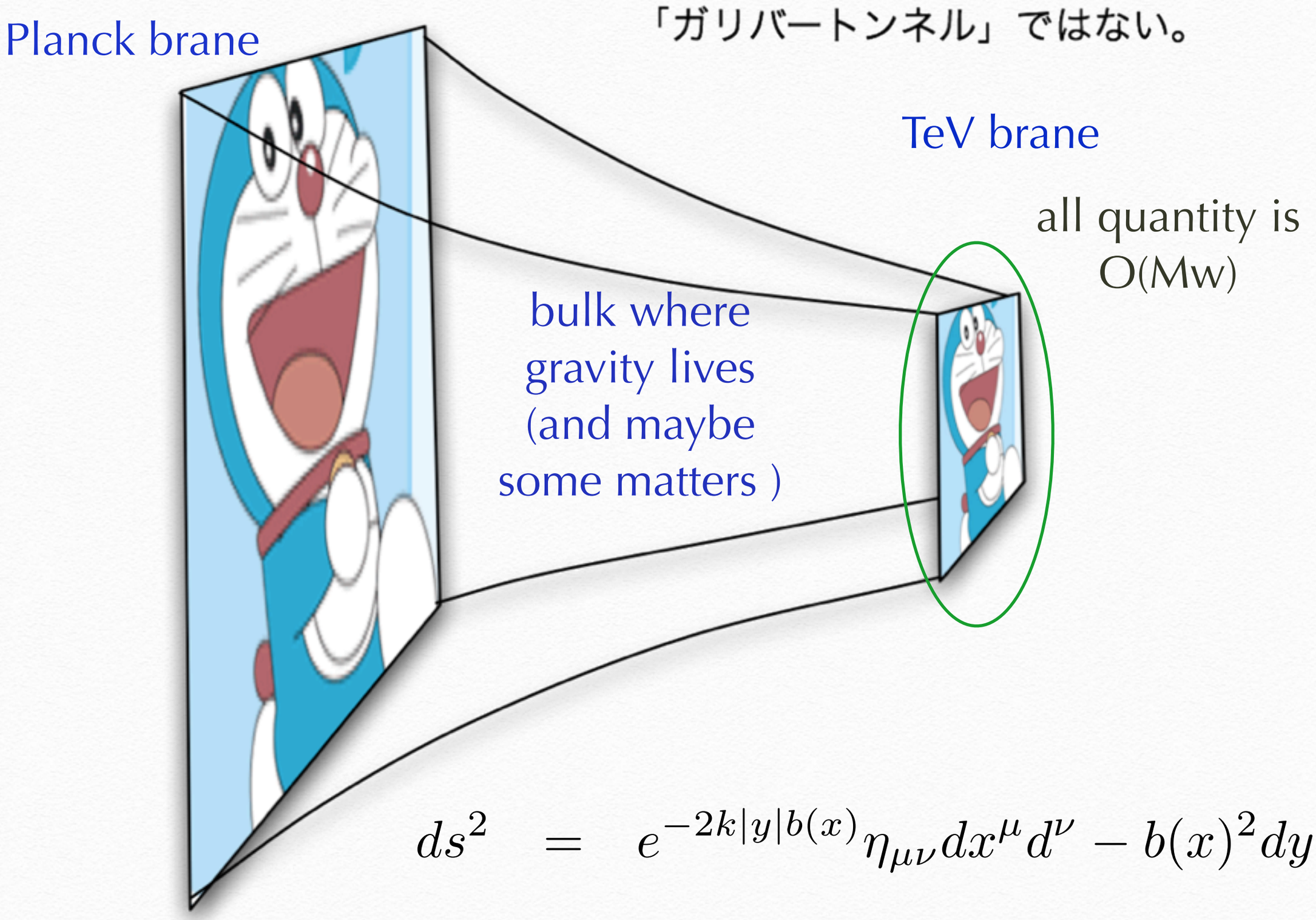
coupling 5dim -> 4dim

$$\int dx dx_5 \frac{1}{g_5^2} F_{\mu\nu}F^{\mu\nu} \quad \rightarrow \quad g_4 = \frac{g_5}{\sqrt{R}}$$

gravity → gauge and scalar

$$\begin{pmatrix} G_{\mu\nu} & A_{\mu D} \\ A_{\nu D} & R_{DD} \end{pmatrix}$$

# New image of space Extra dimension




$$ds^2 = e^{-2k|y|b(x)}\eta_{\mu\nu}dx^\mu d^\nu - b(x)^2 dy^2$$

# Extra dimension (History)

- Brane in string theory (gauge theory on it)

- Toy model that we live on boundary and gravity live in the bulk

$$\delta(x_5) = \frac{1}{2\pi}\int dp_5 exp(ip_5 x_5)$$

- the relation between 5dim gravitational coupling and 4 dim gravitational coupling is

$$\frac{m_1 m_2}{r^2} \to \frac{m_1 m_2}{r^{n+2}} \qquad G_{N(4)} = \frac{S_{(3+n)}}{4\pi}\frac{G_{N(4+n)}}{V_n}$$

- GN is large if extra dim is large! gravity KK mode at collider (extremely light particles)

- Does not work after all, extra dim is too large

$$r_n = 2\times 10^{31/n-16} mm \times \left(\frac{1TeV}{M_{4+n}}\right)^{1+2/n} \qquad T_* < 10^{(6n-15)/(n+5)} MeV$$

# Randall Sundrum model

Assume 5 dim is non trivial

$$ds^2 = e^{-2\sigma(\phi)}\eta_{\mu\nu}dx^\mu dx^\nu + r_c^2 d\phi^2$$

$$\begin{aligned} S &= S_{gravity} + S_{vis} + S_{hid} \\ S_{gravity} &= \int d^4x \int_{-\pi}^{\pi} d\phi \sqrt{G} -\Lambda + 2M^3 R \\ S_{vis} &= \int d^4x \sqrt{-g_{vis}}\{L_{vis} - V_{vis}\} \\ S_{hid} &= \int d^4x \sqrt{-g_{hid}}\{L_{hid} - V_{hid}\} \end{aligned}$$

$$\sigma \equiv= kr_c\phi = r_c|\phi|\sqrt{\frac{-\Lambda}{24M^3}}$$

$$ds^2 = e^{-2kT(x)}\left[\eta_{\mu\nu} + \bar{h}_{\mu\nu}(x)\right]dx^\mu dx^\nu + T^2(x)d\phi^2$$

fundamental parameter is planck scale

$$M_{Pl}^2 = M^3 r_c \int_{-\pi}^{\pi} d\phi e^{-2kr_c|\phi|} = \frac{M^3}{k}\left[1 - e^{-2kr_c\pi}\right]$$

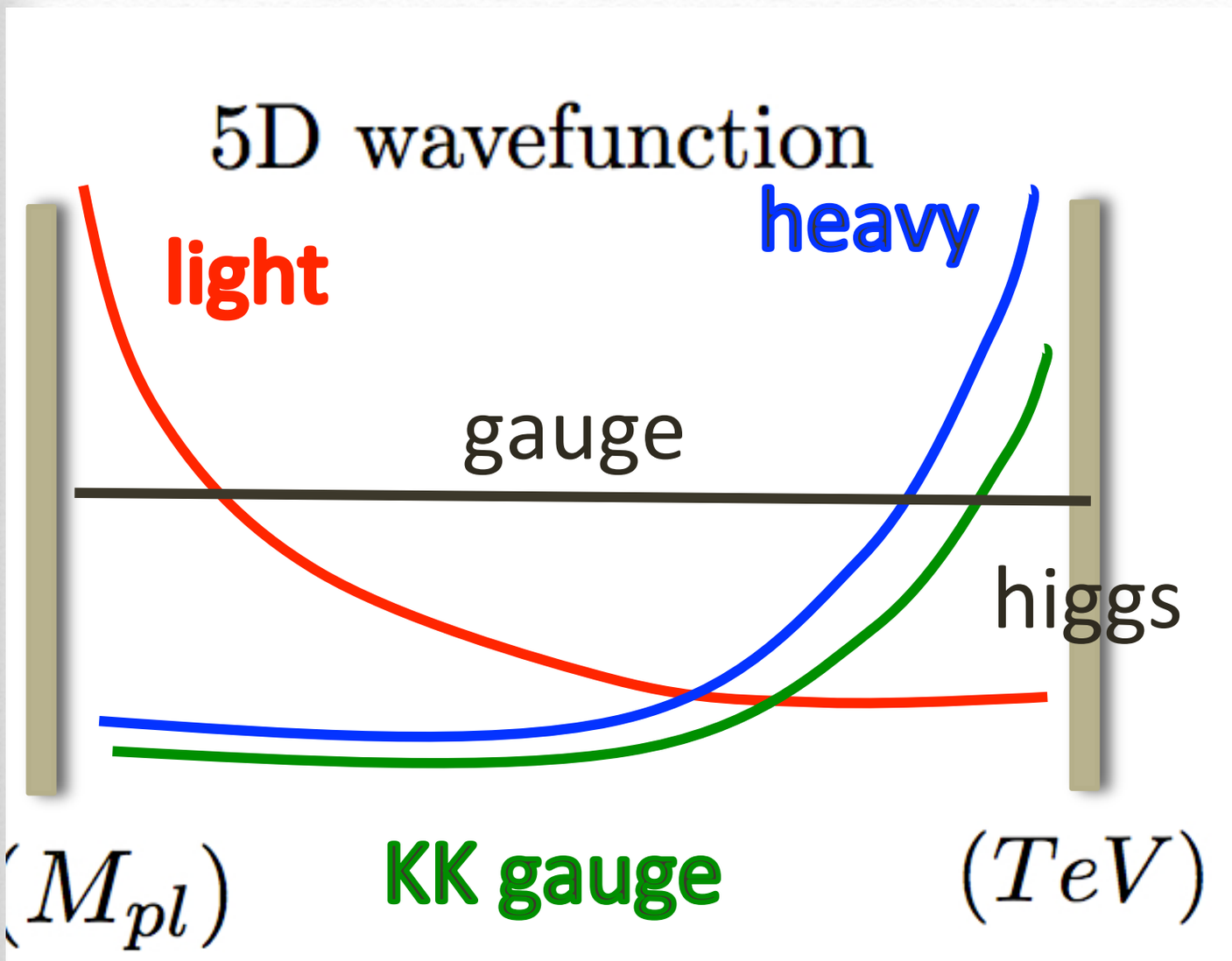
$$S_{vis} \to \int d^4x \sqrt{-\bar{g}_{vis}} e^{-4kr_c\pi} \times \{g_{vis}^{\mu\nu} e^{2kr_c\pi} D_\mu H^\dagger D_\nu H - \lambda(|H|^2 - v_0^2)^2\}$$

KK mode mass is TeV order with non trivial profile peaked at visible brane

# interactions are controlled by geometry

- Higgs boson lives only in TeV brane: Yukawa interaction are controlled by geometric profile

- Light KK mode has profile close to TeV brane.




ex. top yukawa large → profile overlap on TeV

ex gauge KK decays dominantly into top quark
gluino KK-> ttbar

geometry is important ingredient of model building