Constraints on SUSY breaking terms and Neutrino Masses

Takashi Shimomura (YITP, Kyoto U.)

based on

Constraints from Color and/or Charge Breaking Minima in the Supersymmetric Standard Model with right-handed neutrinos. T. Kobayashi and T.S. PRD82 (2010)

Constraints From Unrealistic Vacua in the Supersymmetric Standard Model with Neutrino Mass Operators. Y. Kanehata, Y Konishi, T Kobayashi and T.S. PRD (2010)

The Standard Model of Particle Physics

The Standard Model (SM) had been very successful to explain all experimental data.

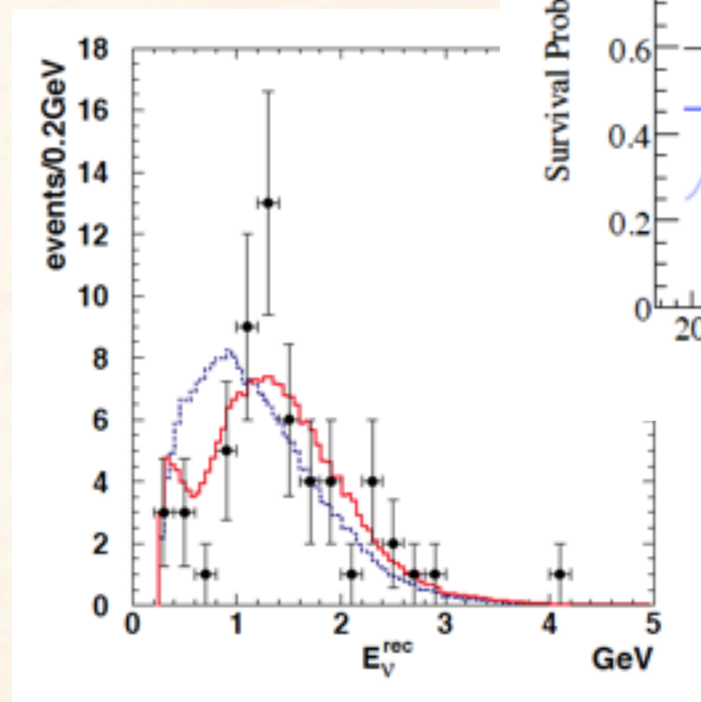
Interactions :	$SU(3) \times SU(2) \times U(1)_Y \rightarrow SU(3) \times U(1)_{em}$
gauge bosons :	$G,\ W^{\pm},\ Z^0,\ \gamma$
quarks :	$\begin{pmatrix} u \\ d \end{pmatrix}_L, \begin{pmatrix} c \\ s \end{pmatrix}_L, \begin{pmatrix} t \\ b \end{pmatrix}_L, \begin{matrix} +2/3 \\ -1/3 \end{matrix}$ $u_R,\ c_R,\ t_R,\ +2/3$ $d_R,\ s_R,\ b_R,\ -1/3$
leptons :	$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L, \begin{matrix} 0 \\ -1 \end{matrix}$ $e_R,\ \mu_R,\ \tau_R,\ -1$ No right-handed neutrinos = massless
Higgs scalar :	H^0 breaks ElectroWeak symmetry

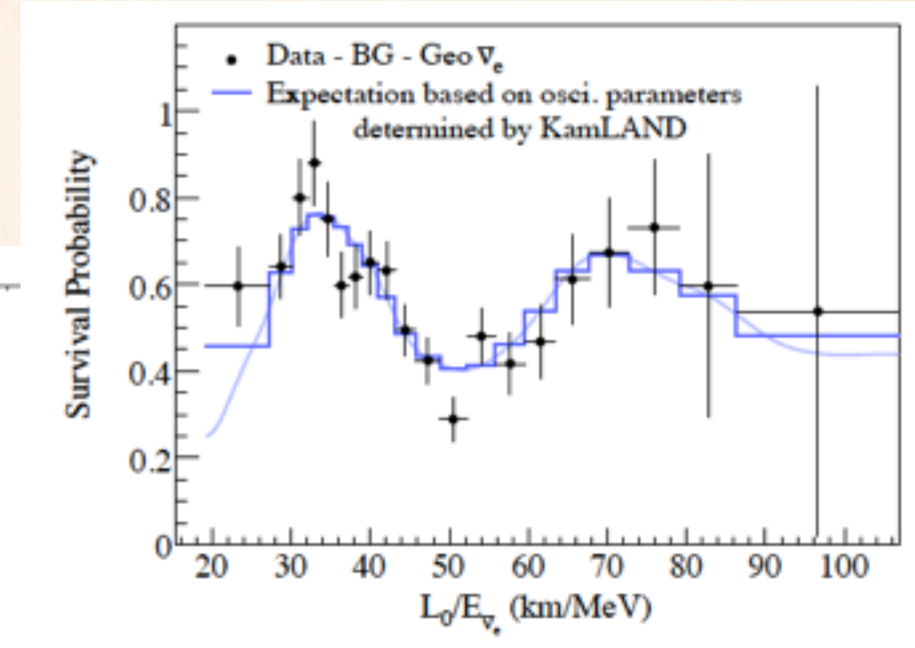
Neutrino Masses and Mixings, "neutrino oscillation"

Kamiokande, Gallex, Sage, SK, SNO have confirmed solar neutrino deficit.

Atmospheric neutrino anomaly was reported by SK and confirmed by K2K exp.

KamLAND measured reactor neutrinos and saw the oscillation.





present data :

$$\Delta m^2_{21} = (7.59 \pm 0.20) \times 10^{-5} \mathrm{eV}^2$$
$$|\Delta m^2_{32}| = (2.43 \pm 0.13) \times 10^{-3} \mathrm{eV}^2$$
$$\sin^2(2\theta_{12}) = 0.87 \pm 0.03$$
$$\sin^2(2\theta_{13}) > 0.19$$
$$\sin^2(2\theta_{23}) > 0.92$$

$$\sum m_i < 0.17 \text{ eV}$$

(Lyman alpha + etc)

$$\sum m_i < 1.3 \text{ eV}$$

(WMAP5)

How to generate tiny neutrino masses ?

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- Adding superheavy right-handed neutrinos with Majorana Mass term

  Seesaw mechanism

  neutrino mass term : $m_D \bar{\nu}_L \nu_R + \underline{M \bar{\nu^c_R} \nu_R} + h.c. \quad (M >> m_D)$

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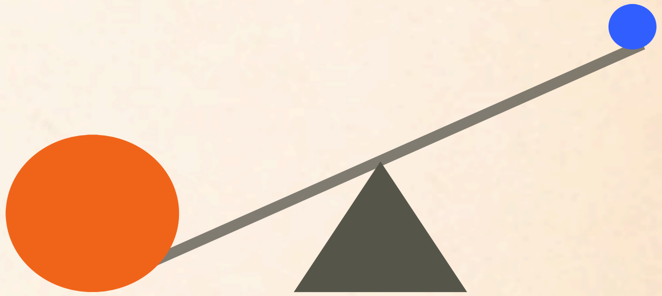
$$\begin{pmatrix} 0 & m_D \\ m_D & M \end{pmatrix} \rightarrow \begin{pmatrix} \frac{m_D^2}{M} & 0 \\ 0 & M \end{pmatrix}$$



$$\begin{array}{l} m_D \sim 100 \text{ GeV} \\ M \sim 10^{14} \text{ GeV} \end{array} \longrightarrow \frac{m_D^2}{M} \sim \mathcal{O}(0.1) \text{ eV}$$

Other Problems of the Standard Model

hierarchy problem

Huge radiative corrections make the EW scale unstable.

EW scale : $v_{EW} \sim \mathcal{O}(100)\ \mathrm{GeV} \propto \sqrt{\mu^2}$

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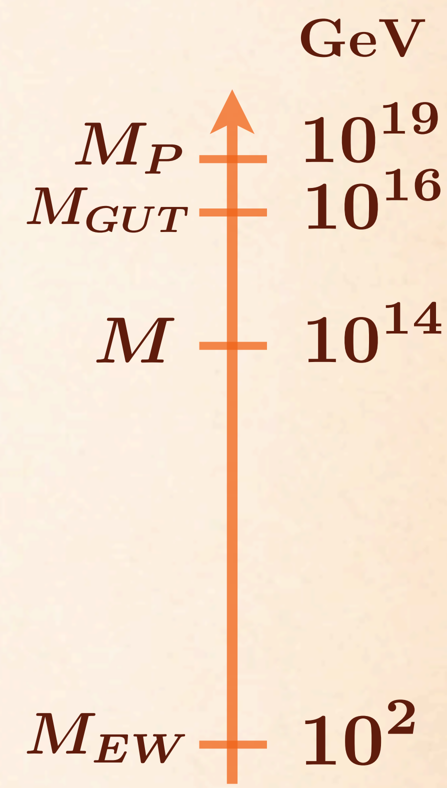
1-loop radiative correction

$$\mu^2_{eff} = \mu^2 \quad - \quad \frac{Y_f^2}{8\pi^2}\Lambda^2 \cdots \sim \mathcal{O}(100^2)\ \mathrm{GeV}^2$$

$$(100\cdots0100)^2 - (100\cdots0000)^2$$



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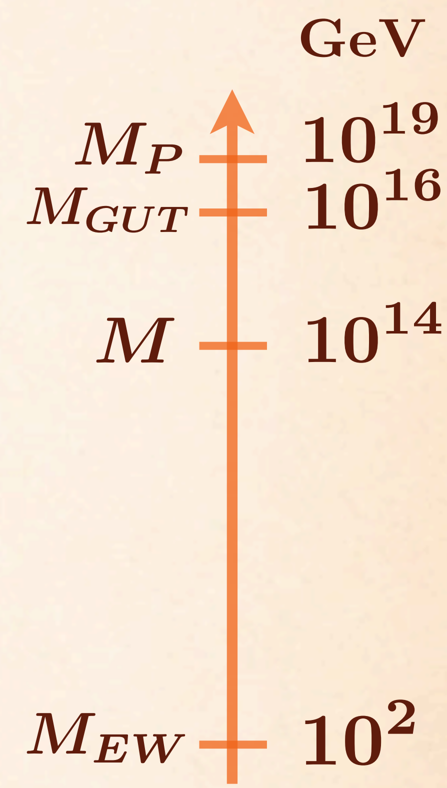
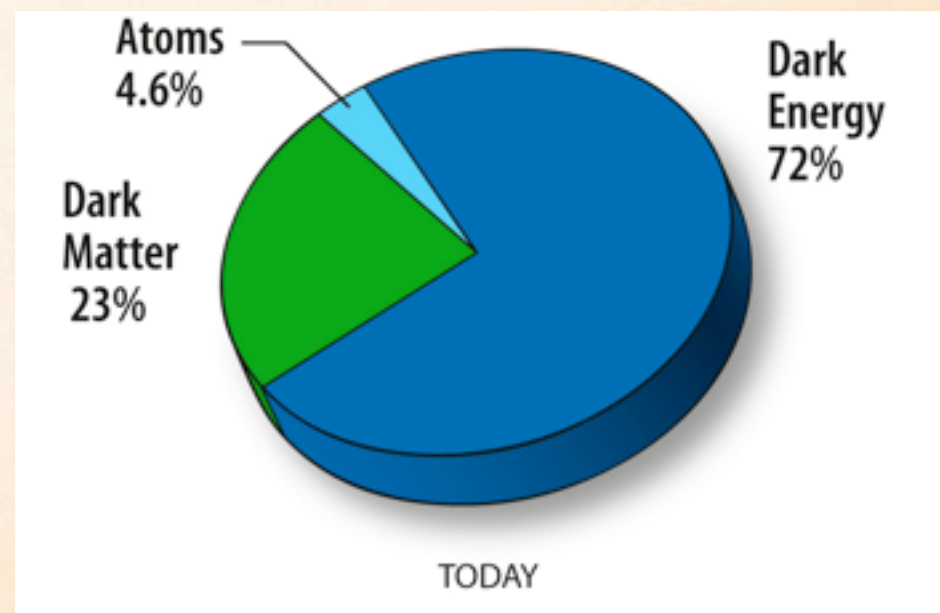


dark matter

electrically and color neutral.
very weakly interacting.
massive of order 100 GeV

No candidate in the SM !



Beyond the Standard Model, "Supersymmetry" with Seesaw mechanism

fermions	bosons
	$G,\ W^{\pm},\ Z^{0},\ \gamma$
Q_L	
u_R d_R	
L	
e_R ν_R	
	$H_1,\ H_2$

the SM matters

Beyond the Standard Model, "Supersymmetry" with Seesaw mechanism

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superpartners　　the SM matters

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The EW scale is stabilized by cancellations of loop contributions among the SM fermions and their partners.

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The lightest superpartner can be a good candidate of the dark matter.

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Scalar potential of SUSY models

V = (quadratic) + (trilinear) + (quartic)

(quadratic) = $m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 + m_3^2 H_1 H_2$

$+m_{\tilde{Q}}^2 \tilde{Q}_L^\dagger \tilde{Q}_L + m_{\tilde{u}}^2 \tilde{u}_R^\dagger \tilde{u}_R + m_{\tilde{d}}^2 \tilde{d}_R^\dagger \tilde{d}_R$

$\cdots$

(trilinear) = $A_d Y_d H_1 \tilde{Q} \tilde{d}_R^* + A_u Y_u H_2 \tilde{Q} \tilde{u}_R^*$

$+A_e Y_e H_1 \tilde{L} \tilde{e}_R^*$

SUSY breaking

(quartic) = $|Y_u|^2 |\tilde{u}_L|^2 |\tilde{u}_R|^2 + |Y_d|^2 |\tilde{d}_L|^2 |\tilde{d}_R|^2 \cdots$

Scalar potential of SUSY models

V = (quadratic) + (trilinear) + (quartic)

+ (5th power) + (6th power)

(quadratic) = $m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 + m_3^2 H_1 H_2$

$+ m_{\tilde{Q}}^2 \tilde{Q}_L^\dagger \tilde{Q}_L + m_{\tilde{u}}^2 \tilde{u}_R^\dagger \tilde{u}_R + m_{\tilde{d}}^2 \tilde{d}_R^\dagger \tilde{d}_R$

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SUSY breaking

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$-\frac{1}{2} c' (H_2 \tilde{L})^2$

(5th) = $Y_u |\tilde{u}_L| |\tilde{u}_R| |H_2| |\tilde{\nu}_L|^2$

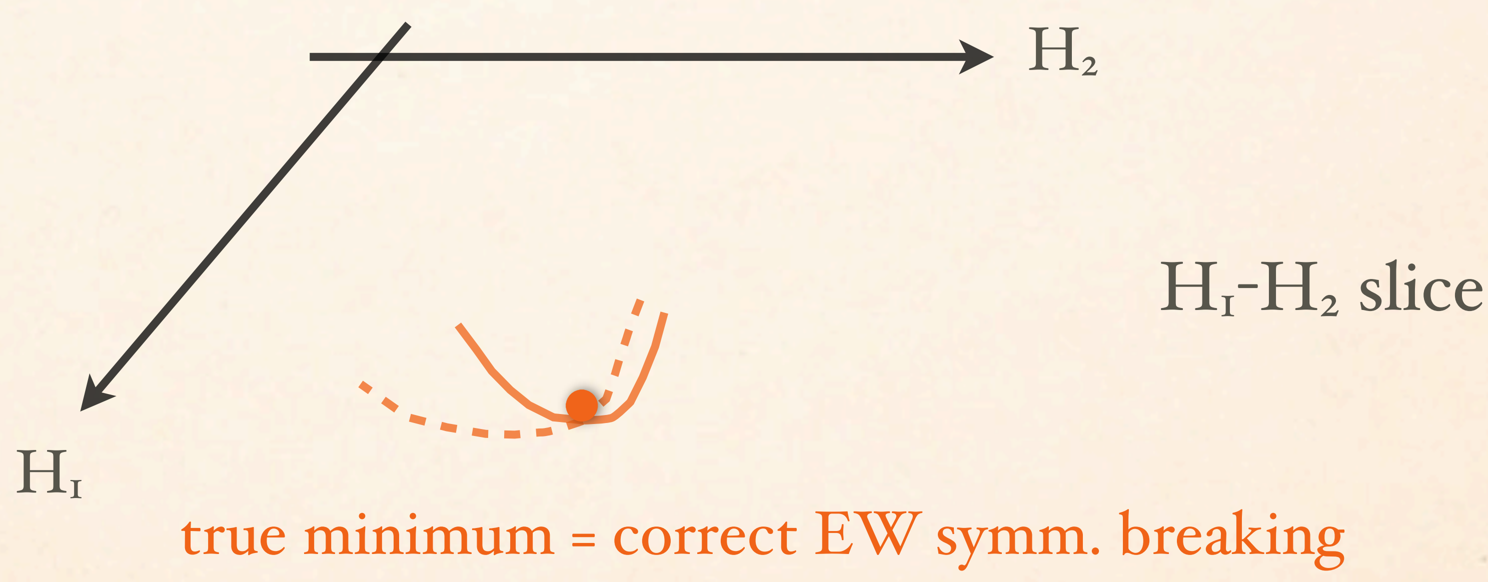
(6th) = $c^2 |H_2|^4 |\tilde{\nu}_L|^2 + c^2 |H_2|^2 |\tilde{\nu}_L|^4$

Neutrino masses

Dangerous vacua in SUSY model

scalar potential : a function in 49 dimensional scalar space.

$$V = V(H_1, H_2, \tilde{Q}_L, \tilde{u}_R, \cdots)$$



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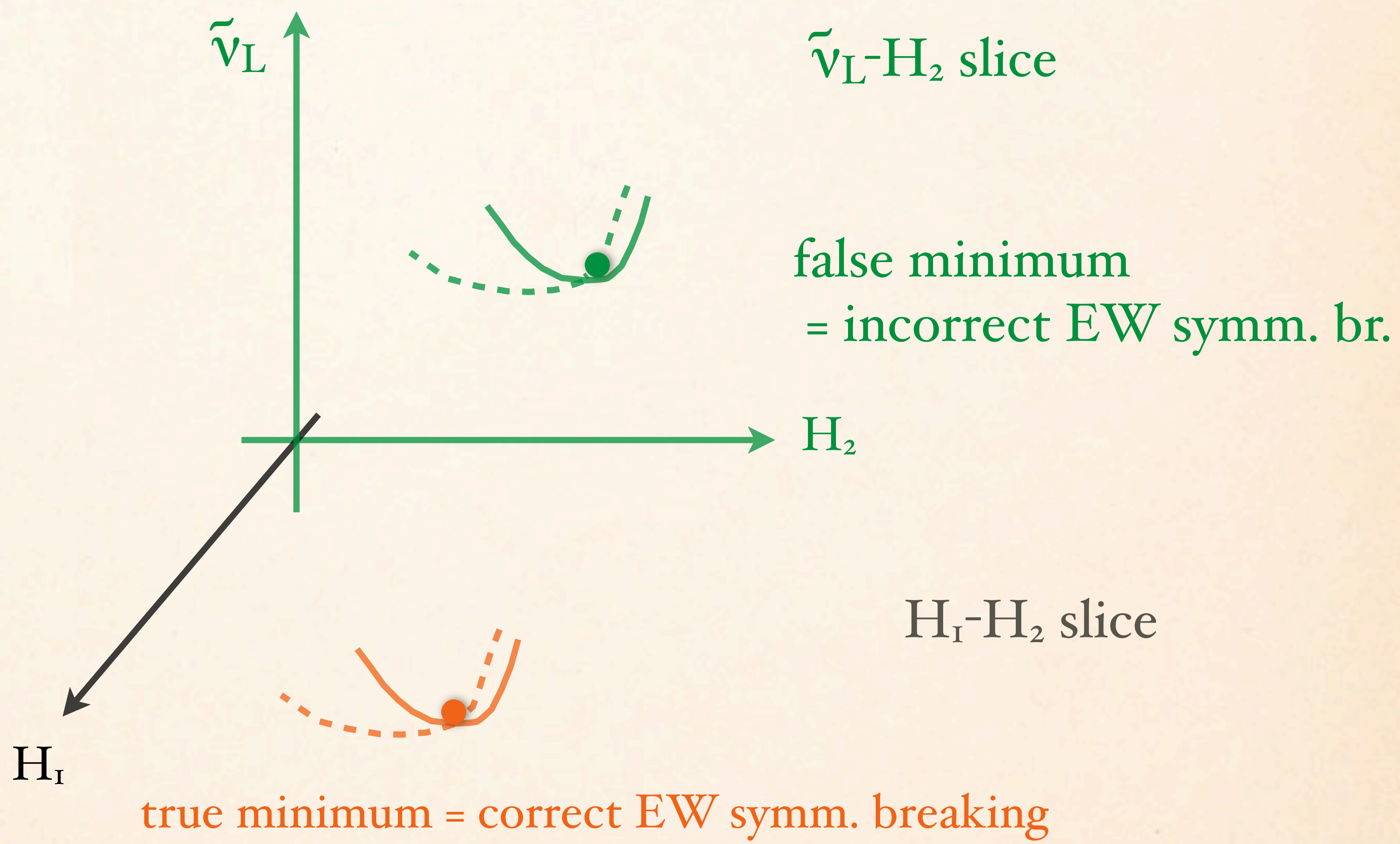

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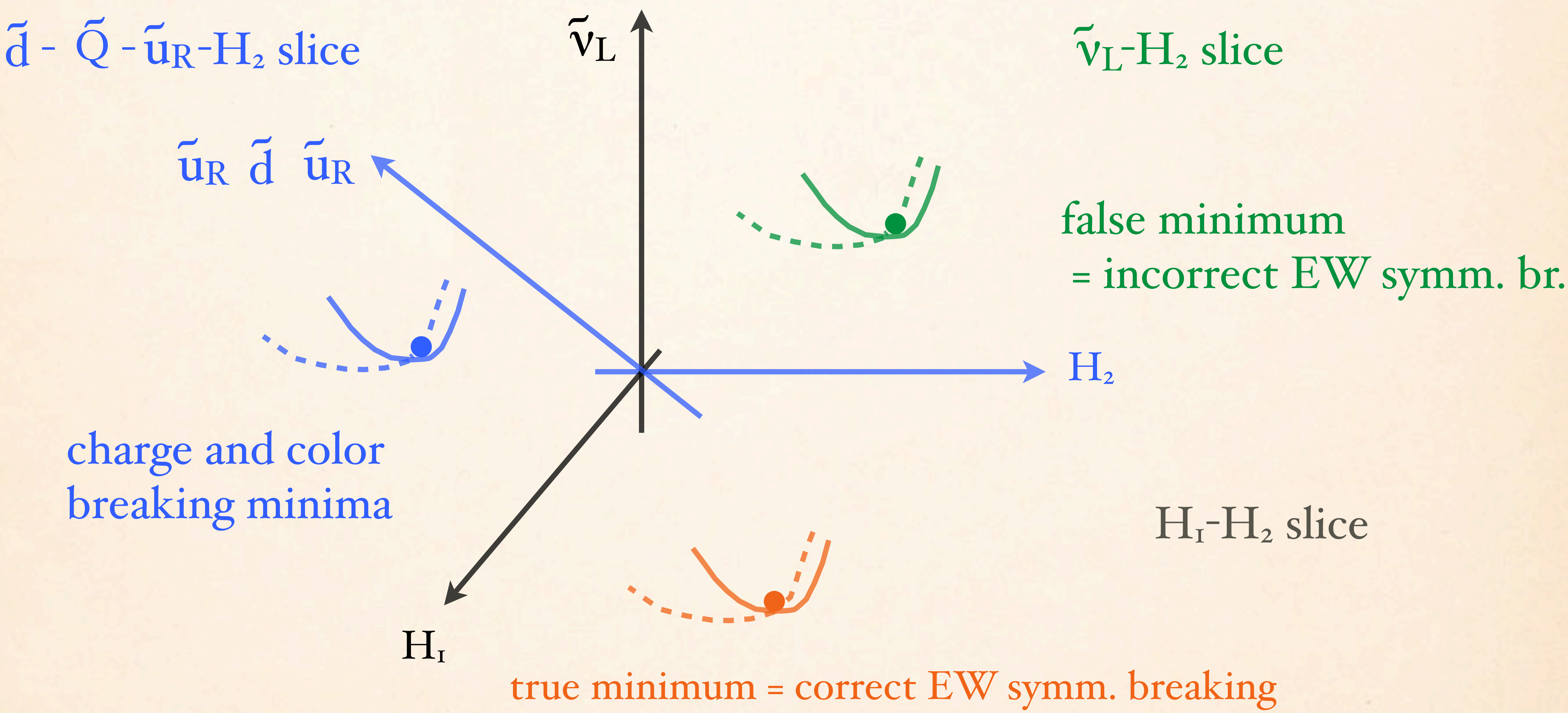

Constraints in the MSSM with neutrino mass operators

direction: $H_2,\ \tilde{\nu}_L \neq 0$

$$\frac{|c'|^2}{|c|^2} \leq 8(m_2^2 - |\mu|^2 + m_{\tilde{L}}^2).$$

direction: $H_2,\ \tilde{Q}_L,\ \tilde{u}_R, \tilde{d} \neq 0$

$$\frac{|c'|^2}{|c|^2} \leq 4\frac{2-\alpha^2}{1-\alpha^2}\hat{m}^2(\alpha)$$

where

$$\hat{m}^2(\alpha) = m_{H_2}^2 + \alpha^2(m_{\tilde{Q}_L}^2 + m_{\tilde{u}_R}^2) + (1-\alpha^2)m_{\tilde{L}}^2$$

These constraints will be useful to explore the origin of SUSY breaking and neutrino masses.