Vacuum Stability of supersymmetric extended Higgs sector with a discrete symmetry

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Work in progress

● Introducion

The Higgs boson has discovered at LHC for m_h=126GeV!

→The Higgs sector is undetermined, minimal?, two higgs doulet model?, …

Inert Higgs model resolves dark matter and neutrino mass. MSSM resolves hierarchy problem.

Extended Higgs sector ⇔The solution of New Physics

We consider strongly coupled (λ~O(1)) supersymmetric extended Higgs sector with a discrete symmetry.
This model can solve dark matter , electroweak baryogenesis , neutrino mass at once below multi TeV scale(see①)
(unbroken Z_2, Inert scalars).

But the discrete Z_2 symmetry may be spontaneously broken .
We discuss the vacuum stability of this model(When Z_2 symmetry is spontaneously broken?).

● Conclusion

Unbroken Z_2 symmetry resolves dark matter, neutrino mass and m_h=126GeV.
When A-trems(scalar three point terms) are small and mass parameters are big , the Higgs potential is stabilize.

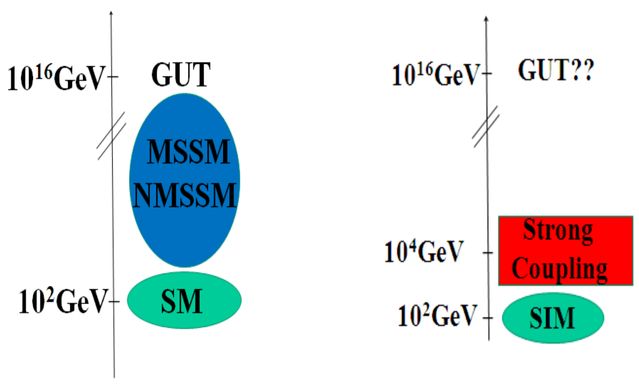
① Supesymmetric extented Higgs sector

MSSM : D+D
NMSSM : D+D+S

D: Doublet
S (Ω): (Charged)Singlet
D'(S'):Z2-odd doublet (singlet)

4HDM : D+D+D'+D' Aoki, Kanemura, Shindou , Yagyu (2011)
4HDMS : D+D+D'+D'+S' Aoki, Kubo, Okawa, Takano (2011)
4HDMΩ : D+D+D'+D'+ Ω'+ Ω' Kanemura , Shindou, Yagyu (2010)
Kanemura, Senaha , Shindou(2011)

Supersymmetric Inert Model (SIM)



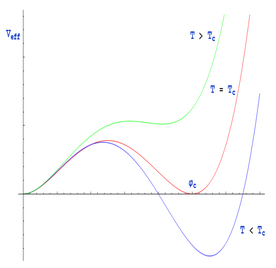
●Electroweak Baryogenesis

$$V_{\rm eff}(\varphi;T) \simeq D(T^2-T_0^2)\varphi - ET\varphi^3 + \frac{\lambda_T}{4}\varphi$$

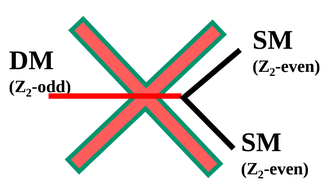
$$\lambda_{T_C} = \frac{m_h^2}{2v^2} + \text{correction} \qquad E = \frac{1}{12\pi v^3}(6m_W^3 + 3m_Z^3)$$

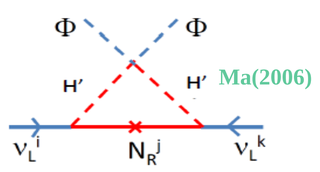
$$\frac{\varphi_C}{T_C} = \frac{2E}{\lambda_{T_C}} > 1 \qquad \boxed{\frac{\varphi_C}{T_C} \propto \frac{1}{m_h^2}}$$

**To explain electorweak baryogenesis in the SM ,
The Higgs boson mass must be lighter than 50GeV.**



●Dark Matter and Neutrino Mass

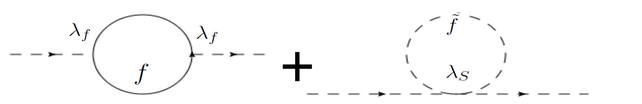




Ma(2006)

Z_2 symmetry can explain stabilityof dark matter and neutrino mass.

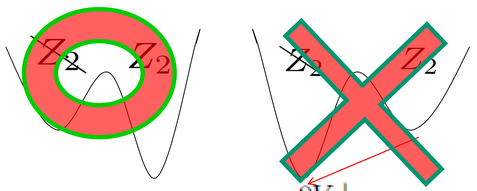
●Hierarchy Problem



$$\delta m_h^2 = N_f \frac{2|\lambda_f|^2 - \lambda_S}{16\pi^2}\Lambda_{\rm UV}^2 + \log\ \text{correction}$$

Supersymmetry can solve hierarchy problem.

②Stability of Z2 symmetric vacuum



Vacuum Condition $\left.\frac{\partial V}{\partial \varphi_i}\right|_{\langle\varphi_i\rangle=v_i} = 0$

Mass Matrix $\left.\frac{\partial^2 V}{\partial\varphi_i\partial\varphi_j}\right|_{\langle\varphi_{i(j)}\rangle=v_{i(j)}} = M_{\rm ij}^2$

Z2 symmetric vacuum satisfies

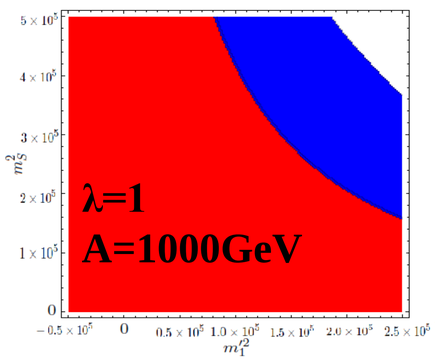
$$Det|M_{\rm ij}^2| > 0 \quad \text{and} \quad V_{\not Z_2} > V_{Z_2}$$

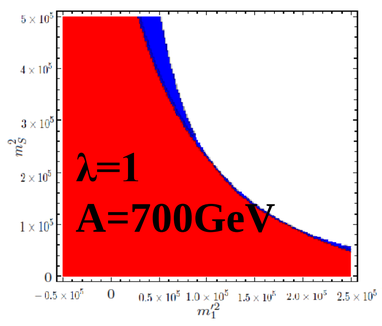
③Vacuum Stability of Toy Model

	$SU(2)_L$	$U(1)_Y$	Z_2
H_1'	2	$+\frac{1}{2}$	−
H_2	2	$-\frac{1}{2}$	+
S	1	0	−

$$W = \frac{\mu_s}{2}S^2 + \lambda H_1'\cdot H_2 S$$

$$-\mathcal{L}_{\rm soft} = m_1'^2|H_1'|^2 + m_2^2|H_2|^2 + m_S^2 S^2 + A H_1'\cdot H_2 S$$





Red Region : Realistic vacuum is tachyonic.
Blue Region : Realistic vacuum is not global minimum.

When A-term is small and mass parameters are big , the potential is stabilize.

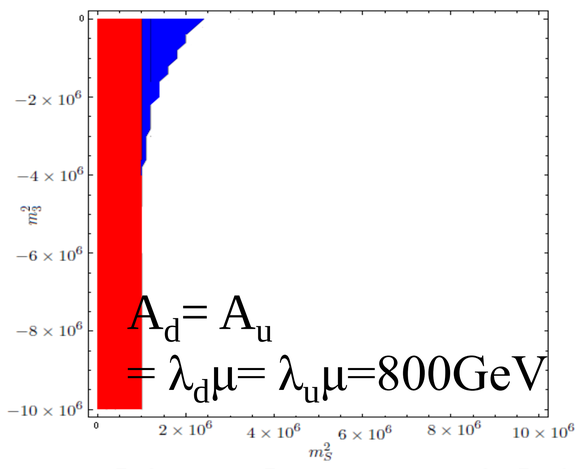
④Vacuum Stability of 4HDMS

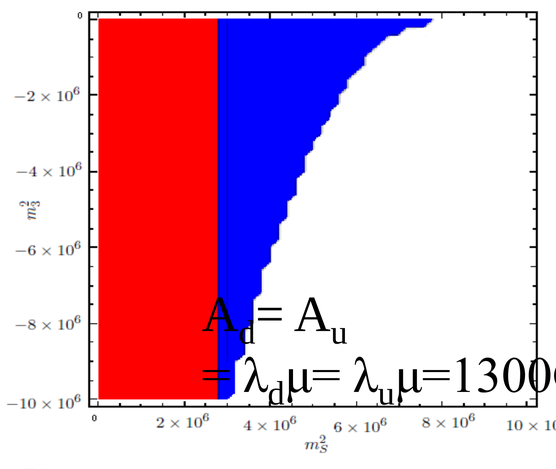
$$W = -\mu H_d\cdot H_u + \lambda_d H_d\cdot\Phi_u S + \lambda_u H_u\cdot\Phi_d S$$

$$-\mathcal{L}_{\rm soft} = M_d^2|H_d|^2 + M_u^2|H_u|^2 + M_d'^2|\Phi_d|^2 + M_u'^2|\Phi_u|^2 + \frac{M_s^2}{2}|S|^2$$
$$+ (B\mu H_d\cdot H_u + A_d H_d\cdot\Phi_u S + A_u H_u\cdot\Phi_d S + \text{h.c.})$$

$$\lambda_d = \lambda_u = 1$$
$$m_1'^2 = m_2'^2 = 300^2\,\text{GeV}^2$$
$$m_A^2 \propto -m_3^2 \equiv B\mu$$

	$SU(2)_L$	$U(1)_Y$	Z_2	$U(1)_g$
H_d	2	$-\frac{1}{2}$	+	0
H_u	2	$+\frac{1}{2}$	+	0
Φ_d	2	$-\frac{1}{2}$	−	+1
Φ_u	2	$+\frac{1}{2}$	−	+1
S	1	0	−	−1





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