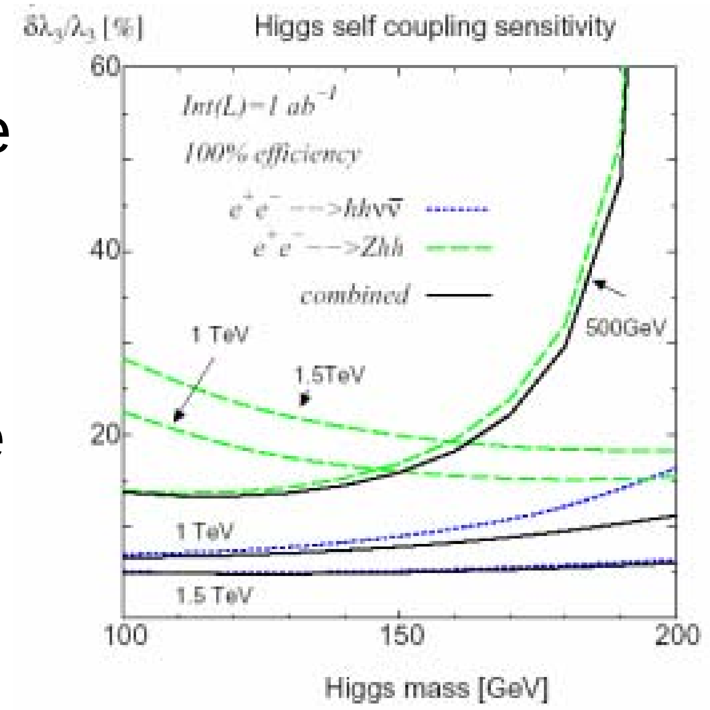
New Physics from Higgs self-coupling measurement

Yasuhiro Okada (KEK)

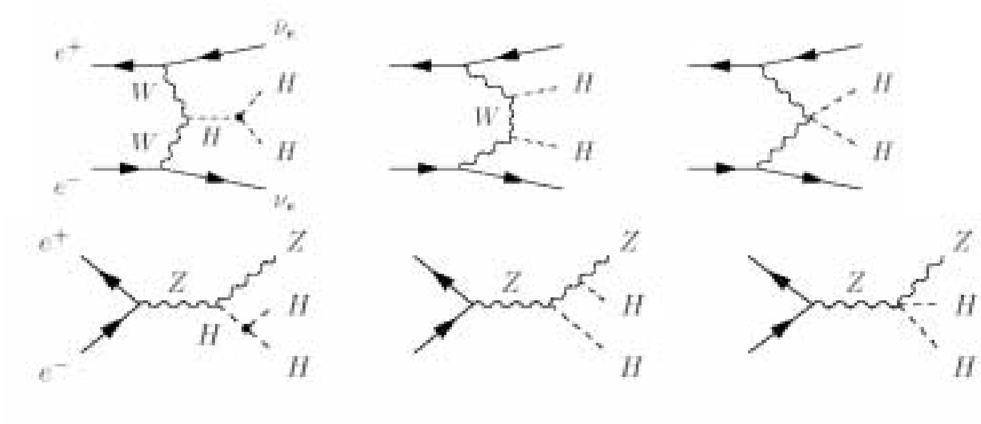
LCWS 04, April 20, 2004, Paris

Higgs self-coupling measurement

- Access to the Higgs potential.
- A few x10% determination of the triple Higgs coupling in the first stage of LC. (e+e- -> ZHH, γγ -> HH)
- Need a higher energy for precise determination.



Y. Yasui, et al, LCWS02



New physics effect to the self-coupling

The self-coupling is sensitive to the tree level structure of the Higgs sector as well as loop effects.

Suppose that a light SM-like Higgs boson is found at LHC and LC. What will be impact of the self-coupling measurement?

We consider 2HDM as an example.

1. Relation between the corrections to hhh and hVV coupling constants.
2. Connection to the electroweak baryogenesis scenario.

Two Higgs doublet model

Higgs potential

$$V_{2\mathrm{HDM}} = m_1^2|\varphi_1|^2 + m_2^2|\varphi_2|^2 - m_3^2\left(\varphi_1^\dagger\varphi_2 + \varphi_2^\dagger\varphi_1\right) + \frac{\lambda_1}{2}|\varphi_1|^4 + \frac{\lambda_2}{2}|\varphi_2|^4$$
$$+\lambda_3|\varphi_1|^2|\varphi_2|^2 + \lambda_4\left|\varphi_1^\dagger\varphi_2\right|^2 + \frac{\lambda_5}{2}\left\{\left(\varphi_1^\dagger\varphi_2\right)^2 + \left(\varphi_2^\dagger\varphi_1\right)^2\right\},$$

Physical Higgs bosons: $h, H, A, H^\pm$

Two cases

Heavy Higgs boson masses

$$m_\Phi^2 \simeq M^2 + \lambda_i v^2$$

$$M = m_3/\sqrt{\cos\beta\sin\beta}$$

$$\tan\beta = \langle\phi_2\rangle / \langle\phi_1\rangle$$

(1) Decupling case: $M^2 \gg 0(\lambda_i v^2)$

The couplings of hVV, hff, and hhh approach to the SM values.
Loop corrections are suppressed by 1/M^2.

(2) Non-decoupling case: $M^2 \leq O(\lambda_i v^2)$

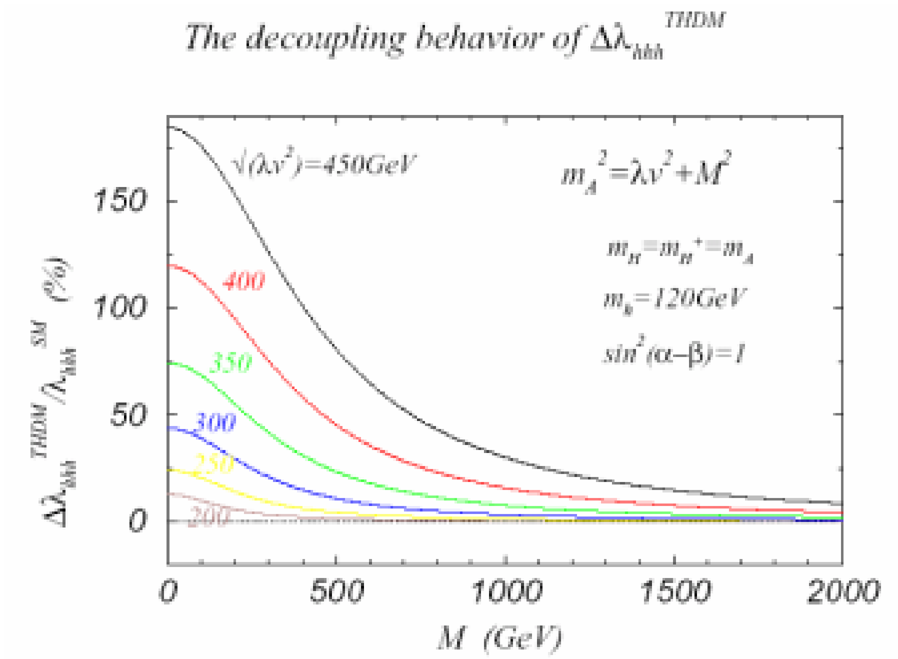
Large loop corrections due to the self coupling constants are possible,

Large loop correction to hhh coupling

In the limit that the tree level hVV coupling is the same as the SM value, the triple Higgs coupling can receive O(100%) radiative correction through heave Higgs boson loop diagrams.

$$\sin(\beta-\alpha)\to 1$$

α: Mixing angle between neutral CP even Higgs bosons.



S.Kanemura, S.Kiyoura, Y.O. ,E.Senaha,C.P.Yuan, 02

$$\lambda_{hhh}^{eff}(THDM) = \frac{3m_h^2}{v}\left\{1+\frac{m_H^4}{12\pi^2 m_h^2 v^2}\left(1-\frac{M^2}{m_H^2}\right)^3 + \frac{m_A^4}{12\pi^2 m_h^2 v^2}\left(1-\frac{M^2}{m_A^2}\right)^3 + \frac{m_{H^\pm}^4}{6\pi^2 m_h^2 v^2}\left(1-\frac{M^2}{m_{H^\pm}^2}\right)^3 - \frac{N_c m_t^4}{3\pi^2 m_h^2 v^2} + \cdots\right\}$$

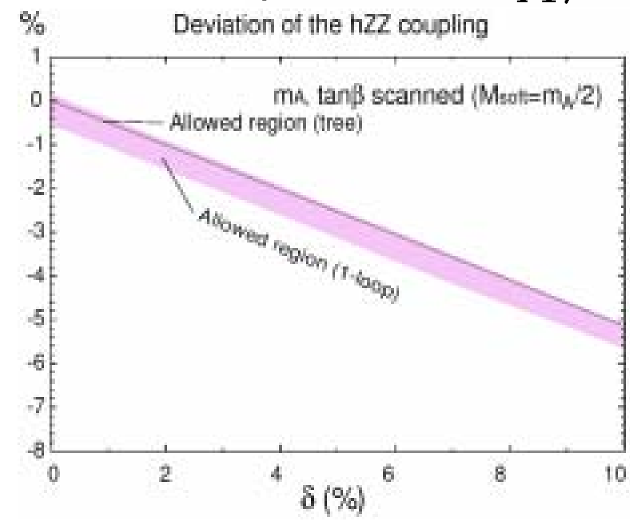
Correction to hhh and hVV couplings

$$(M = m_A/2)$$

S.Kanemura, Y.O. ,E.Senaha,C.P.Yuan

We extend the analysis to sin(β–α) <1.
We consider :

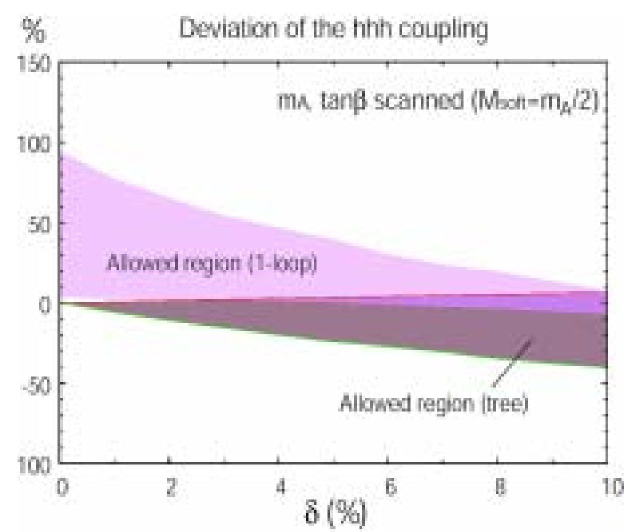
(1) loop corrections to the hVV vertex as well as the hhh vertex,
(2) change of the hhh coupling from the tree level formula. J.F.Gunion, H.E.Haber,03



Possible range of the hhh and hVV couplings under the condition that perturbative unitarity of VV->VV scattering amplitudes. $(\lambda_i/4\pi \leq O(1))$

Results

- One loop correction for hVV coupling is O(1%).
- Tree formula reduces the hhh coupling for $\delta > 0$, while one loop correction is mostly positive.

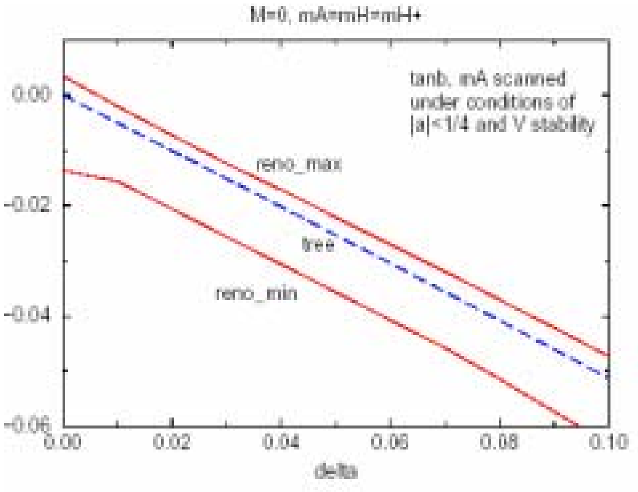


$$\delta \equiv \cos^2(\beta - \alpha)$$

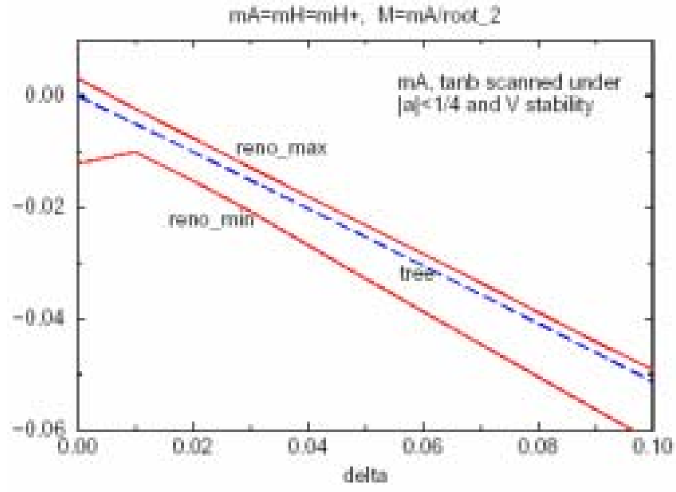
$M = 0$

$M = m_A/\sqrt{2}$

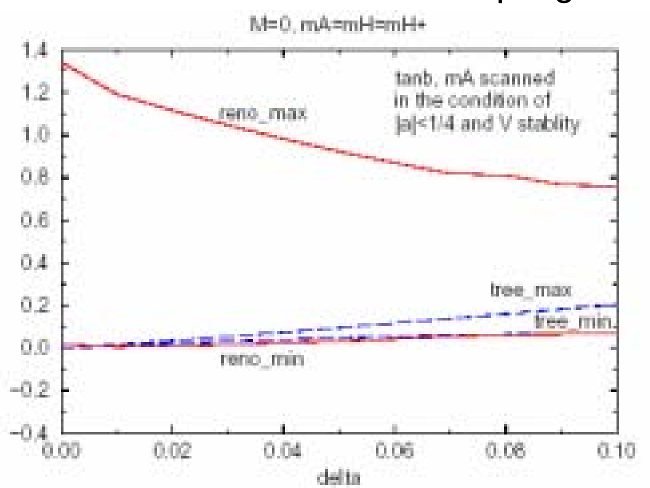
Deviation of the hZZ coupling



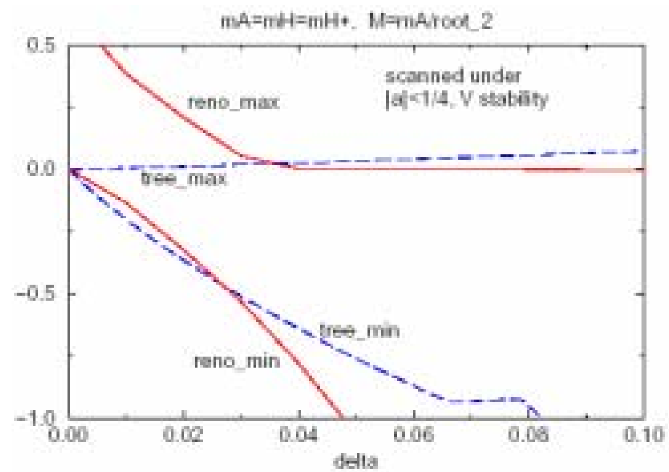
Deviation of the hZZ coupling



Deviation of the hhh coupling



Deviation of the hhh coupling



Electroweak baryogenesis in 2HDM

- Baryogenesis: Explain the baryon-to-photon ratio from zero baryon number. $n_B/s = 10^{-11} - 10^{-10}$
- A basic fact: B+L violation at high temperature n the SM.
- Two scenarios:

  (1) B-L generation above the EW phase transition (leptogenesis, etc).

  (2) Baryogenesis at the EW phase transition.
- EW baryogenesis is difficult in the minimal SM.
- 2HDM is a simple viable model. A.Nelson, D.B.Kaplan, A.G.Cohen, 91, M.Joyce, T.Prokopec,and N.Turok 91; J.M.Cline,K.Kainulainen,A.P.Vischer,96

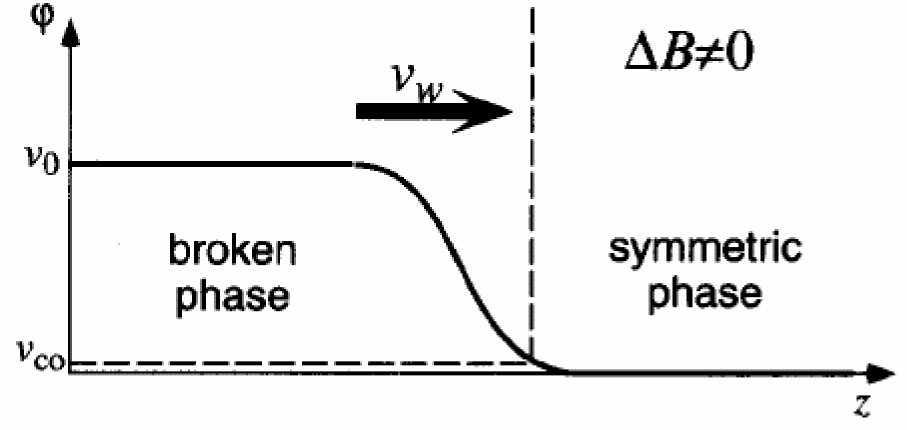
Connection between collider physics and cosmology

$$\boxed{V_{eff}(\phi) \leftrightarrow V_T(\phi, T)}$$

Baryon number generation at the electroweak phase transition

- Strong first order phase transition.
- Expansion of a bubble.
- Charge flow of fermions due to CP violation at the wall.
- Baryon number violation in the symmetric phase.

In the minimal SM, the phase transition is not a strong first order, and CP violation from the Kobayashi-Maskawa phase is too small.



In 2HDM, we consider the following simplified case.

$$m_1^2 = m_2^2, \lambda_1 = \lambda_2, \leftrightarrow (\sin(\beta - \alpha) = \tan\beta = 1)$$

Vacuum expectation values at a finite temperature

$$\Phi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \phi(x)^{[i\theta(x)/2]} \end{pmatrix} \quad \Phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \phi(x)^{[-i\theta(x)/2]} \end{pmatrix}$$

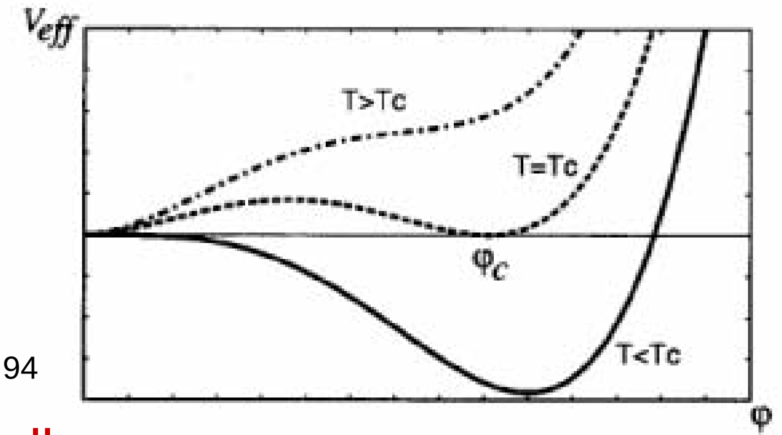
Conditions for successful baryogenesis

(1) Strong first order phase transition.

Not to erase the baryon number after the transition by the sphaleron process.

$$\phi_c/T_c > 1.4$$

K.Funakubo,A.Kakuto,K.Takenaga,94,
A.T.Davies,C.D.Froggatt, G.Jenkins, R.G.Moorhouse 94



(2) Non-trivial phase rotation in the bubble wall.

Various possibilities:

Spontaneous CP violation only at finite temperature, explicit CP violation.

Finite temperature effective potential in 2HDM

We calculate the finite temperature effective potential for the ϕ direction to determine the first order phase transition.

For example, in the case of M=0 and high temperature expansion,

$$V_T(\phi, T) = D(T^2 - T_0^2)\phi^2 - ET\phi^3 + \frac{\lambda_T}{4}\phi^4 + ...$$

$$E = \frac{1}{12\pi v^3}(6m_W^3 + 3m_Z^3 + m_h^3 + m_H^3 + m_A^3 + 2m_{H\pm}^3)$$

$$\phi_c / T_c = 2E/\lambda_{T_c}$$

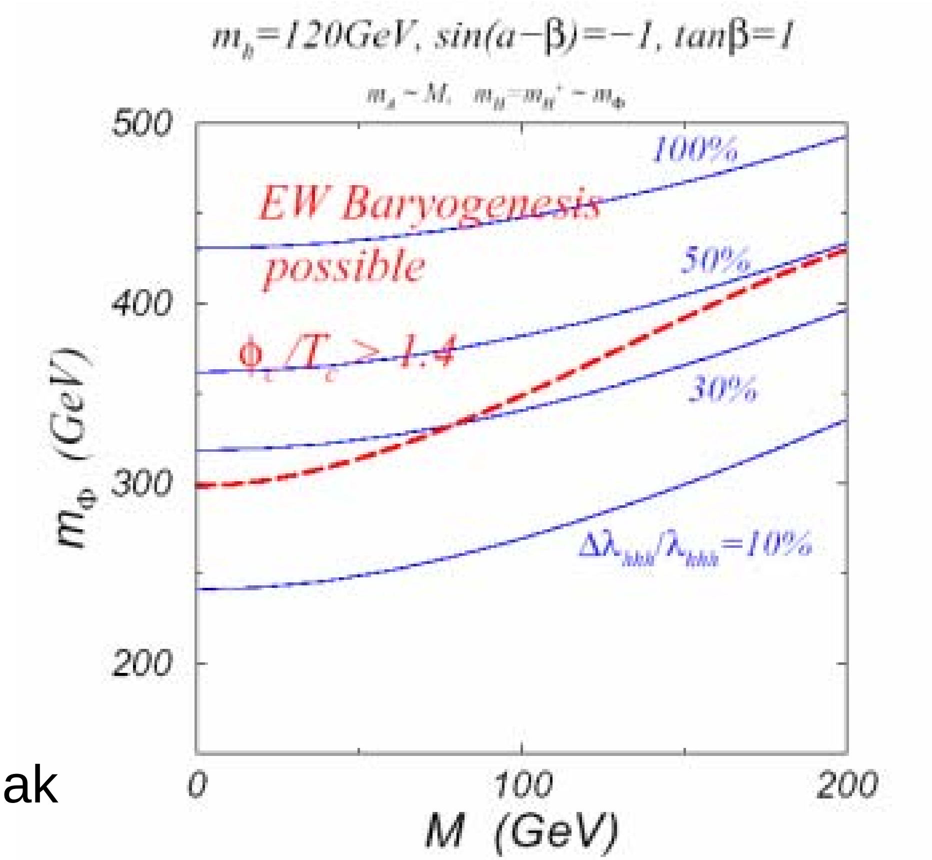
Strong first order phase transition
<-> "Non-decoupling" effects of heavy Higgs bosons
<-> Correlation with a large corrections to the hhh coupling at zero temperature

Numerical calculation

S.Kanemura, Y.O., E.Senaha

We calculate the finite temperature effective potential without the high temperature expansion for M>0.

We also study the loop correction to the hhh coupling constant.



The Higgs self-coupling receives correction of more than 30 % in the parameter region where the electroweak baryogenesis is possible.

Correlation between zero temperature and finite temperature potentials.

Connection between cosmology and collider signals.

Summary

- The triple Higgs coupling can receive O(1) radiative correction due to non-decoupling effects of heavy Higgs boson loops in 2HDM.
- A large correction to the self-coupling is expected, if the electroweak baryogenesis is realized in 2HDM.