Higgs inflation in a radiative seesaw model

Takehiro Nabeshima
University of Toyama
Technische Universität München

Collaborator
S. Kanemura, T. Matsui (University of Toyama)
Phys.Lett. B723 (2013) 126-131

ECFA LC13 28 Mar. 2013

1.Introduction

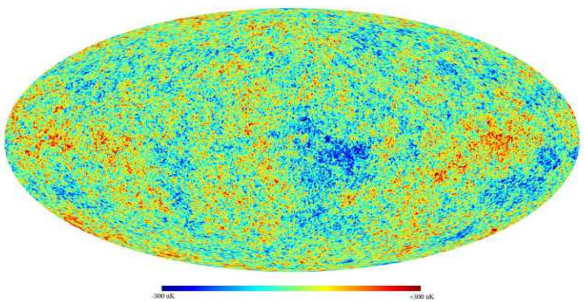
Why we need an inflation?

・**The flatness problem**

$$\Omega_0 = 1.002 \pm 0.011$$
$$|\Omega_P - 1| \lesssim O(10–60)$$

The Universe is flat
but the standard cosmology cannot explain this flatness.

・**The horizon problem**



The temperature of the CMB is almost the same value but light cone cover small region.

These problems can be solved by exponential expansion.

1.Introduction

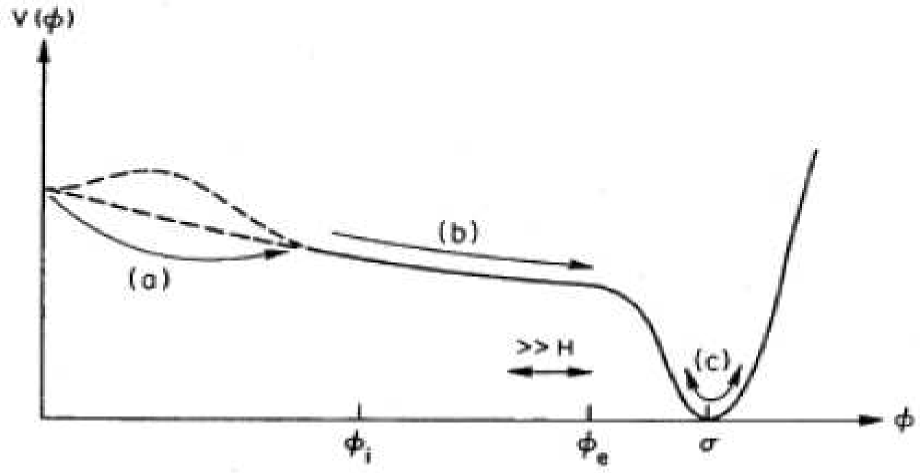
Inflation

We introduce a real scalar ϕ

$$\mathcal{L} = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$

$$\Downarrow$$

$$H^2 = \frac{V}{3M_P^2} \qquad \left(H = \frac{\dot{a}}{a} \right)$$



If H is a constant, The Universe expands by exponential.

$$\Rightarrow \quad \varepsilon \equiv \tfrac{1}{2} M_P{}^2 (V'/V)^2 << 1 \qquad \eta \equiv M_P{}^2 V''/V << 1$$

If potential satisfies the slow-roll condition, ϕ can act as an inflaton.

2.Higgs inflation

Inflaton＝Higgs

- Higgs boson mass (mh=126GeV)
- Slow-roll condition(ε, η)
- CMB temperature fluctuations (P_R)

$$\varepsilon \equiv \frac{1}{2} M_P{}^2 (V'/V)^2 << 1$$
$$\eta \equiv M_P{}^2 V''/V << 1$$

$$L_{\rm tot} = L_{\rm SM} - \frac{M^2}{2} R - \xi H^\dagger H R$$

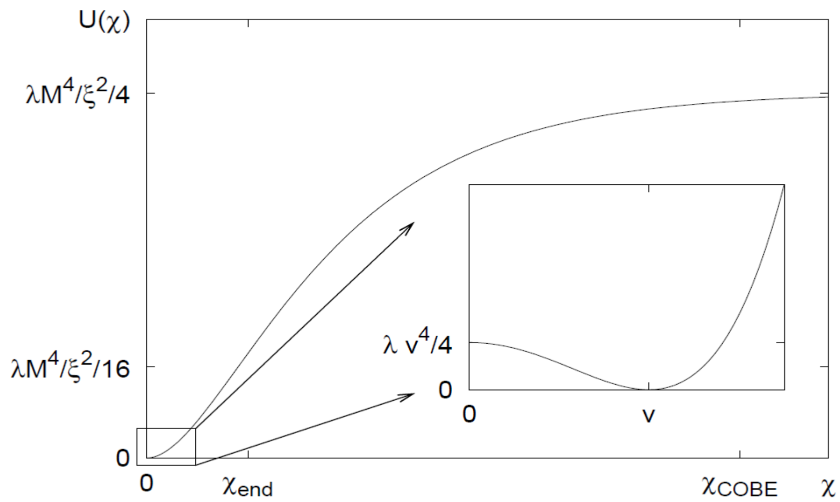
$$V(\chi) = \left(1 + \exp\left(-\frac{2\chi}{\sqrt{6} M_P}\right)\right)^{-2}$$

$$\left(\frac{d\chi}{dh} = \sqrt{\frac{\Omega^2 + 6\xi^2 h^2/M_P^2}{\Omega^4}}\right)$$

WMAP:

$$P_R = 2.430 \pm 0.091 \times 10^{-9}$$

⇨ $\xi = 5 \times 10^4 \sqrt{\lambda}$



Bezrukov and Shaposhnikov (2008)

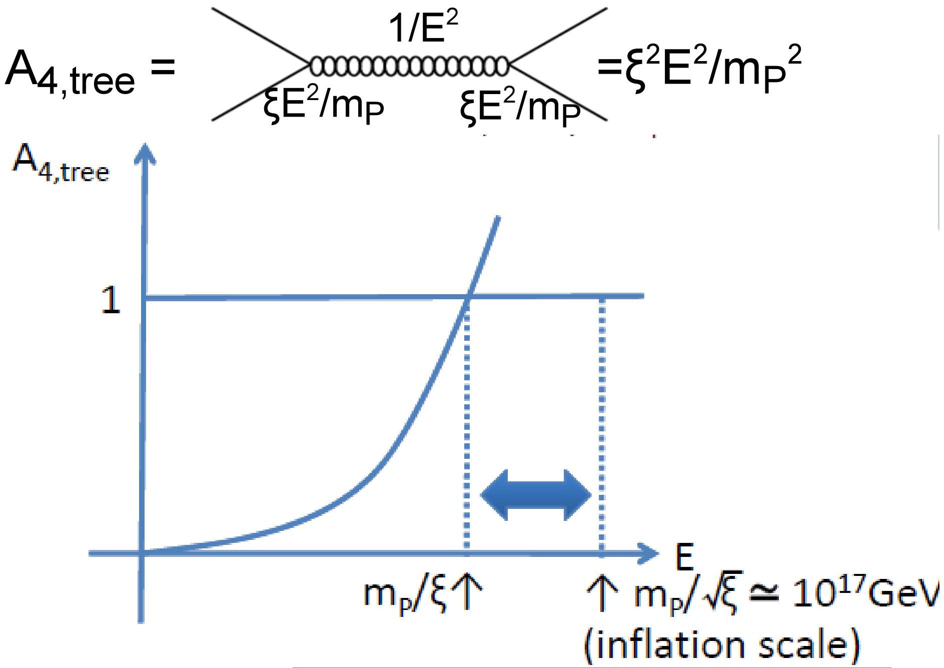
SM-Higgs satisfies ε, η and P_R !

Problems in the simplest case

But!

(Ⅰ)Unitarity

T. Han and S. Willenbtock, Phys. Lett. B 616, 215 (2005)

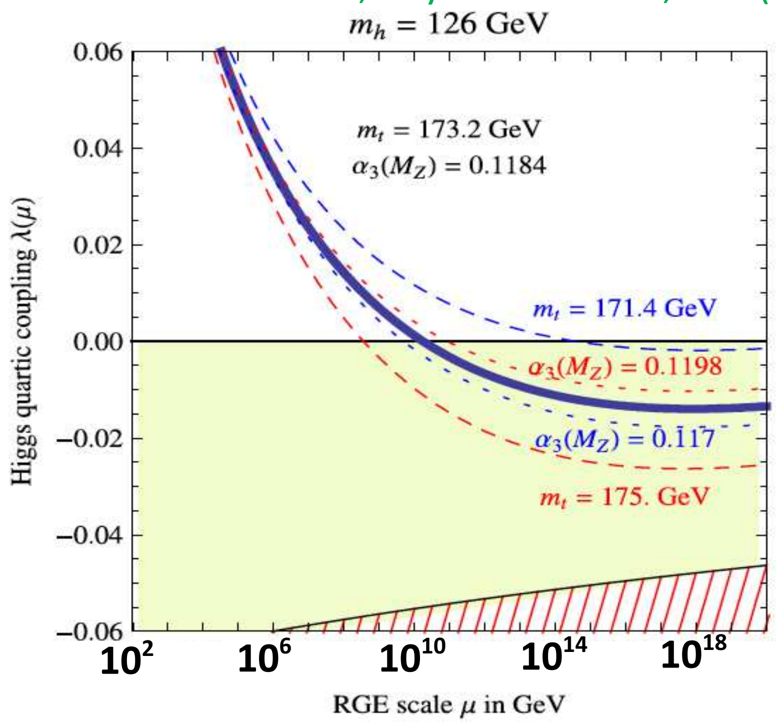


$\xi=O(10^4) \Rightarrow \Lambda \simeq m_P/\xi$

Unitarity is broken at $O(10^{15})$ GeV

(Ⅱ)Vacuum stability

J.Elias-Miro et al, Phys. Lett. B 709, 222 (2012)



m_h=126GeV$\Rightarrow \Lambda \simeq 10^{10}$GeV

Vacuum cannot be stabilized at $O(10^{10})$ GeV

⇒Simplest Higgs inflation cannot reach to the inflation scale

Solutions for the problems

(Ⅰ) **Unitarity**

G.F.Giudice, H.M.Lee, PLB694, 294(2011)

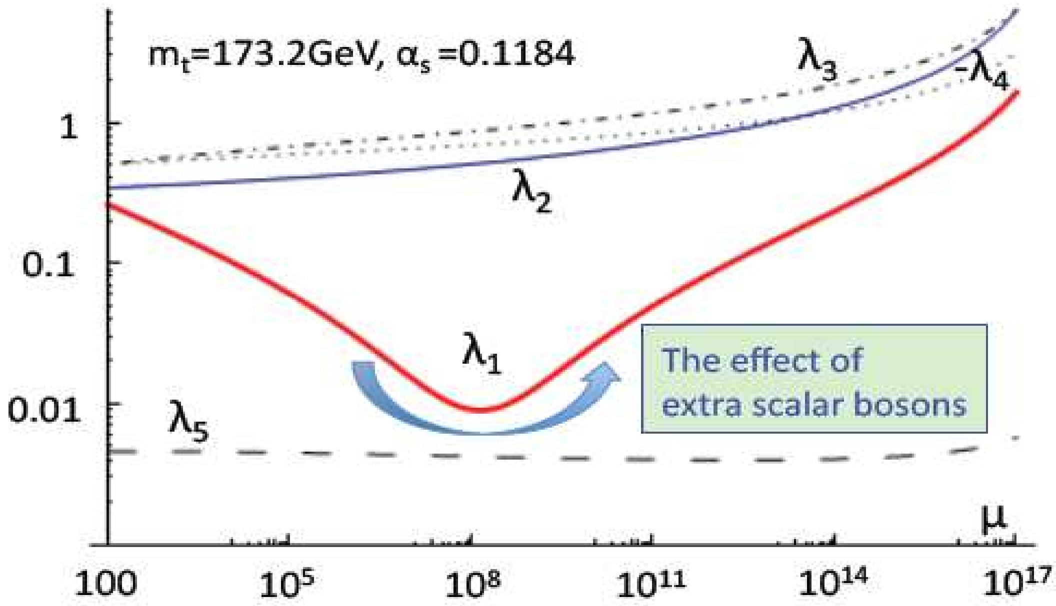
We add a heavy scalar particle saving unitarity.

(Ⅱ)Vacuum stability⇒Extended Higgs sector.

- **Renormalization group equations**

$$16\pi^2\mu\frac{d\lambda_1}{d\mu} \sim 12\lambda_1^2 - 12y_t^4 \underline{+A}$$

The new bosonic loop cancel the y_t effect!



2HDM

$$A = 2\lambda_3^2 + 2(\lambda_3+\lambda_4)^2 + 2\lambda_5^2 > 0$$

S.Kanemura, T.Kasai, Y.Okada, Phys.Lett. B471 (1999)

Previous work

The inert doublet model

Gong, Lee and Kang (2012)

$$V = \frac{M_P R}{2} + (\xi_1|\Phi_1|^2 + \xi_2|\Phi_2|^2)R + \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + [\frac{1}{2}\lambda_5((\Phi_1^\dagger\Phi_2)^2]$$

$$\Phi_1 = (\phi^+, \phi^0)$$
$$\Phi_2 = [H^+, (H^0 + iA^0)/\sqrt{2}]$$

$$m_h^2 = \lambda_1 v^2$$
$$m_{H^\pm}^2 = \mu_2^2 + \frac{1}{2}\lambda_3 v^2$$
$$m_H^2 = \mu_2^2 + \frac{1}{2}(\lambda_3 + \lambda_4 + \lambda_5)v^2$$
$$m_A^2 = \mu_2^2 + \frac{1}{2}(\lambda_3 + \lambda_4 - \lambda_5)v^2$$

Vacuum stability:

$$\lambda_1 > 0, \quad \lambda_2 > 0, \quad \lambda_3 + \lambda_4 + \lambda_5 + \sqrt{\lambda_1\lambda_2} > 0$$

Inflaton condition:

$$\lambda_2\xi_1 - (\lambda_3 + \lambda_4)\xi_2 > 0$$
$$\lambda_1\xi_2 - (\lambda_3 + \lambda_4)\xi_1 > 0$$
$$\lambda_1\lambda_2 - (\lambda_3 + \lambda_4)^2 > 0$$

CMB temperature fluctuations: $a \equiv \xi_1/\xi_2$

$$\xi_2\sqrt{\frac{2(\lambda_1 + a^2\lambda_2 - 2a(\lambda_3 + \lambda_4))}{\lambda_1\lambda_2 - (\lambda_3 + \lambda_4)^2}} \simeq 5 \times 10^4$$

$$\frac{\lambda_5}{\xi_2}\frac{a\lambda_2 - (\lambda_3 + \lambda_4)}{\lambda_1 + a^2\lambda_2 - a(\lambda_3 + \lambda_4)} \leq 4 \times 10^{-12}$$

Inflation can be explained

⇕

Dark matter and neutrino masses cannot be explained.

3.Our Model

Inert + ν_R

Our model can explain:

Inflation (inert doublet model)

Neutrino masses (radiative seesaw)

Dark matter (CP-odd scalar A)

The mass spectrum is almost determined from the current data.

Our model can be tested by measuring model parameters at collider experiments

3.Our Model

Inflation

Vacuum stability:

$$\lambda_1 > 0, \quad \lambda_2 > 0, \quad \lambda_3 + \lambda_4 + \lambda_5 + \sqrt{\lambda_1 \lambda_2} > 0$$

Inflaton condition:

$$\lambda_2 \xi_1 - (\lambda_3 + \lambda_4)\xi_2 \quad > \quad 0$$

$$\lambda_1 \xi_2 - (\lambda_3 + \lambda_4)\xi_1 \quad > \quad 0$$

$$\lambda_1 \lambda_2 - (\lambda_3 + \lambda_4)^2 \quad > \quad 0$$

CMB temperature fluctuations:

$$a \equiv \xi_1 / \xi_2$$

$$\xi_2 \sqrt{\frac{2(\lambda_1 + a^2\lambda_2 - 2a(\lambda_3 + \lambda_4))}{\lambda_1 \lambda_2 - (\lambda_3 + \lambda_4)^2}} \quad \simeq \quad 5 \times 10^4$$

$$\frac{\lambda_5}{\xi_2} \frac{a\lambda_2 - (\lambda_3 + \lambda_4)}{\lambda_1 + a^2\lambda_2 - a(\lambda_3 + \lambda_4)} \quad \leq \quad 4 \times 10^{-12}$$

$a\lambda_2 - (\lambda_3 + \lambda_4) \simeq$ O(10^{-1})

at the inflation scale.

⇩

$\lambda_5 \simeq$ O(10^{-6}) from the EW to the Inflation scale.

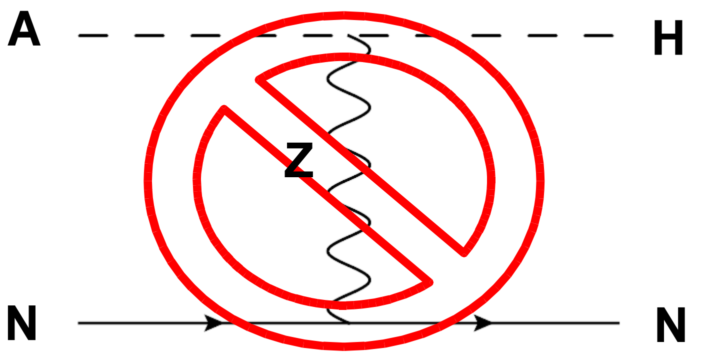
⇩

Masses of A and H are almost degenerated.

3.Our Model

Dark matter

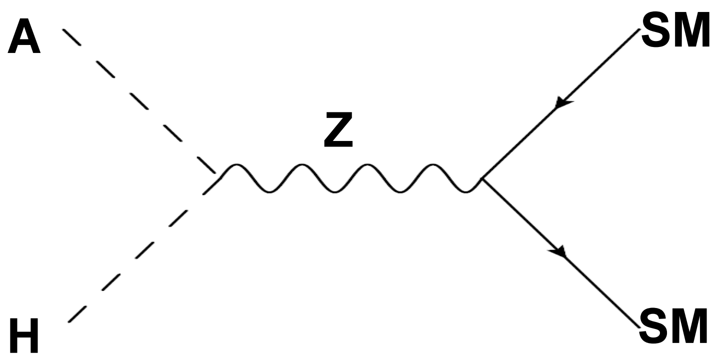
・For direct detection



$m_H - m_A \gtrsim O(100)$ KeV at the EW scale.

$\lambda_5 \gtrsim 10^{-6}.$

・For the dark matter abundance



128GeV < $m_A (\simeq m_H)$ < 138GeV at the EW scale.

3.Our Model

Mass spectrum

	10^2GeV	10^{17}GeV
$\lambda 1$	0.26	1.6
$\lambda 2$	0.35	6.3
$\lambda 3$	0.51	6.3
$\lambda 4$	-0.51	-3.2
$\lambda 5$	10^{-6}	1.2×10^{-6}

⇨

m_h=126GeV

m_H=130GeV

$m_{H^\pm}$=173GeV

m_A=130GeV

The mass difference between A and H is about 500KeV.

m_h=126GeV

128 GeV < $m_A \simeq m_H$ < 138GeV

$m_{H^\pm} \simeq m_A$+ 40GeV

Our model almost determines
the mass spectrum of inert scalar bosons !

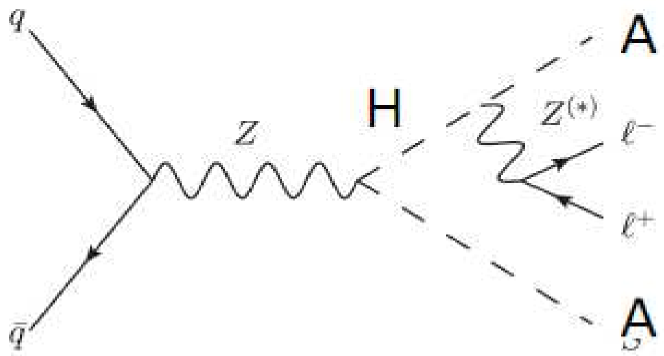
4.Phenomenology

LHC

E.Dolle, X.Miao, S.Su, B.Thomas, PRD81, 035003(2010)

Processes via $H^{\pm}$ cannot be detected at the LHC because background from W boson is large enough.

We consider A and H production process.

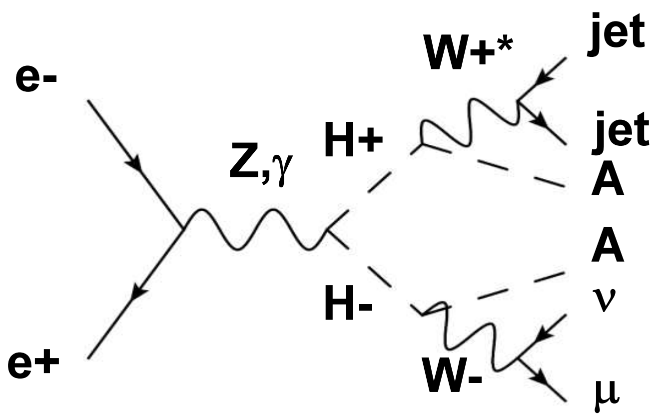


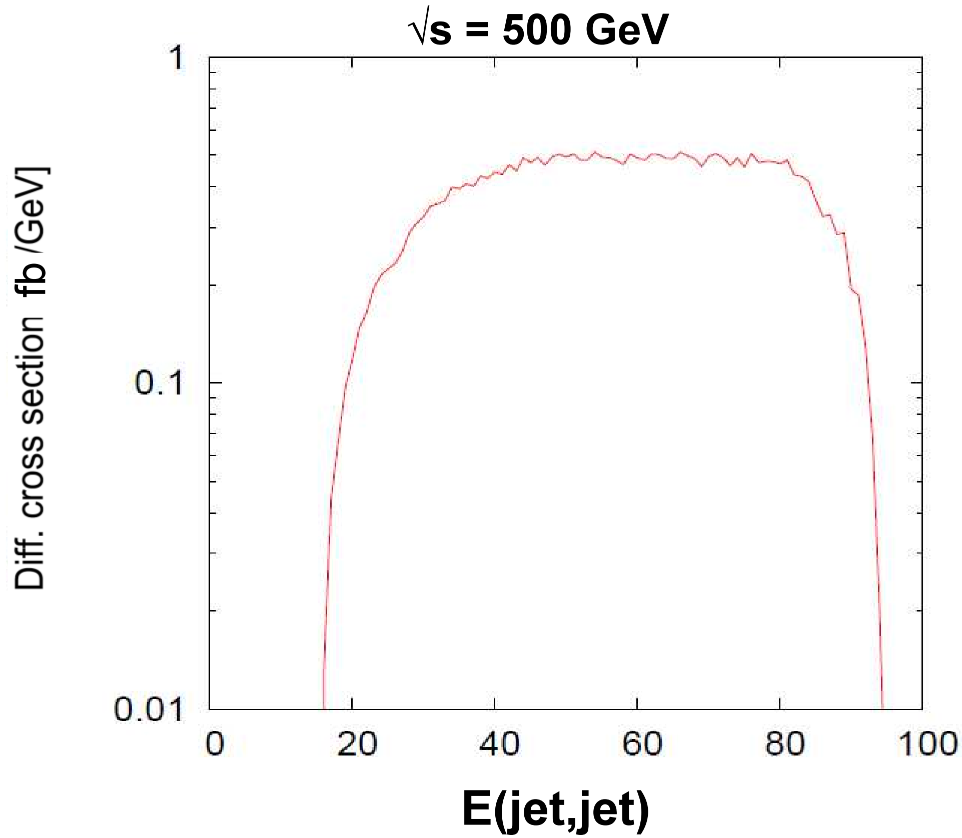
When masses of A and H are almost degenerated,
A and H cannot be detected at the detector because both of A and H do not decay in the detector.

LHC cannot test our mass spectrum.

4.Phenomenology

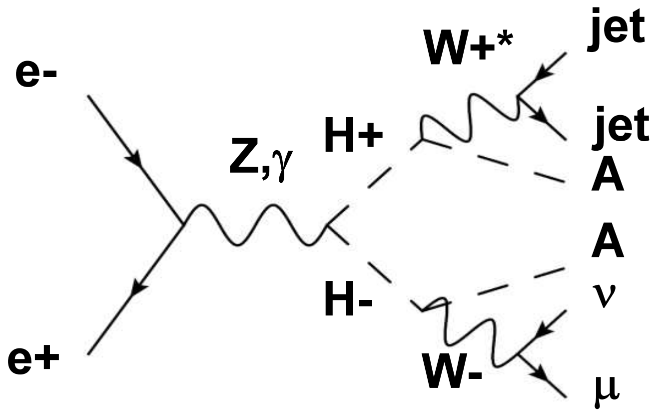
ILC

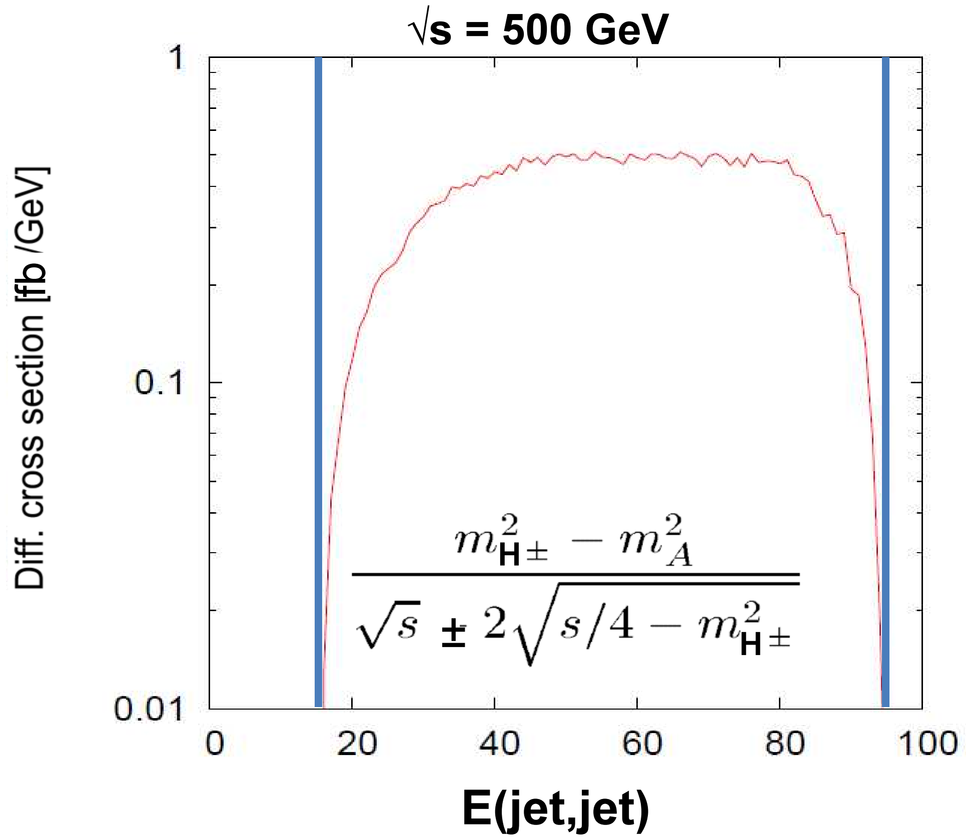




4.Phenomenology

ILC





Masses of H± and A could be measured at the ILC!

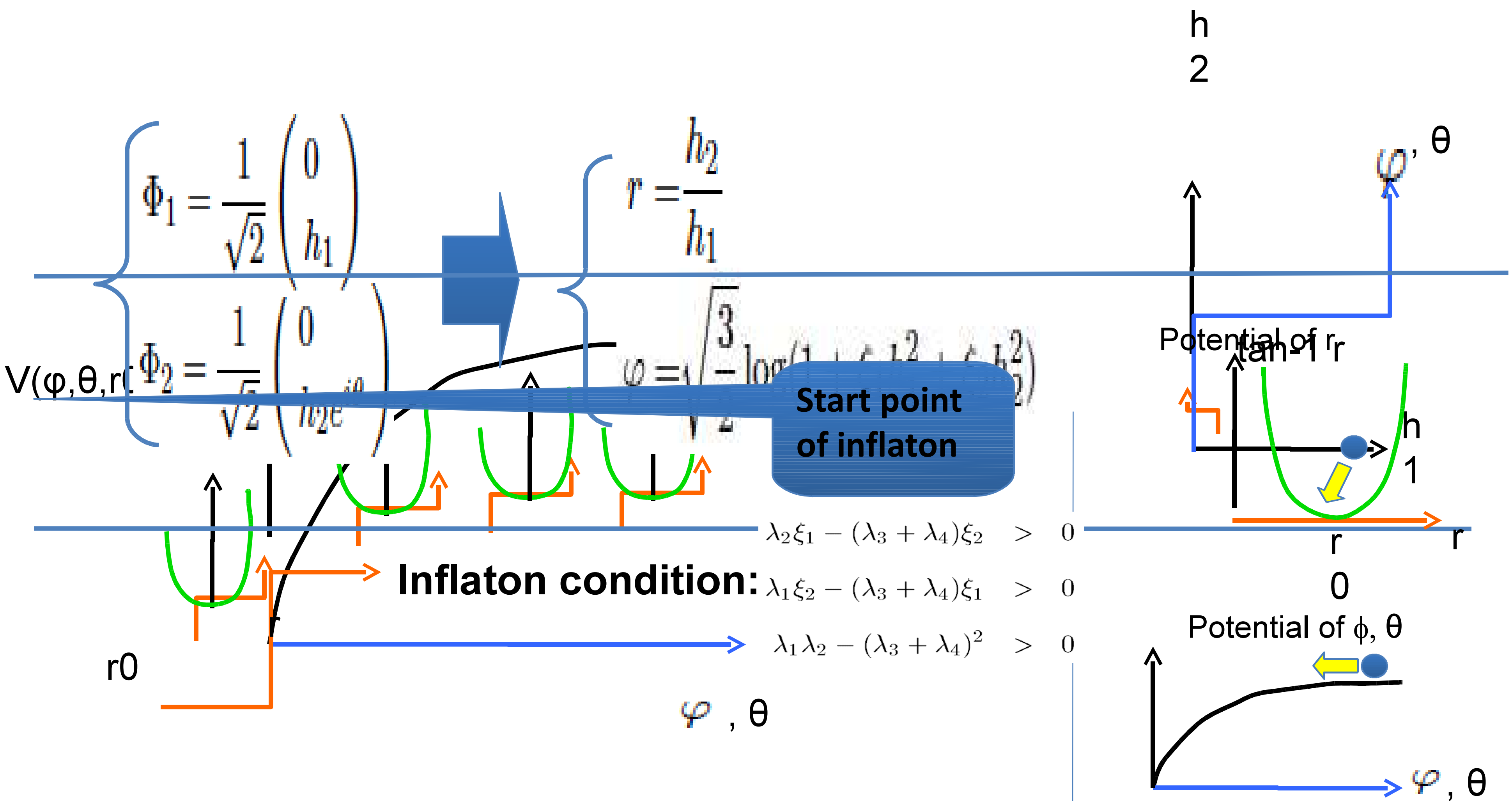
If we detect $H^{\pm}$ but we cannot detect the clue of A and H production, it seems to be masses of A and H are almost the same value.

5.Conclusion

①We consider the case of the Higgs inflation.
②It is difficult that SM act as the inflation
③We show that inflation, dark matter and neutrino masses can be explained simultaneously by the inert doublet with right handed neutrinos.
④Our model predicts mass spectrum of inert scalar boson.
⑤This mass spectrum could be tested at the ILC.
⑥If Higgs and inert doublet components act as an inflaton, this case could be tested at the ILC.

Back up

Inflation of inert doublet model



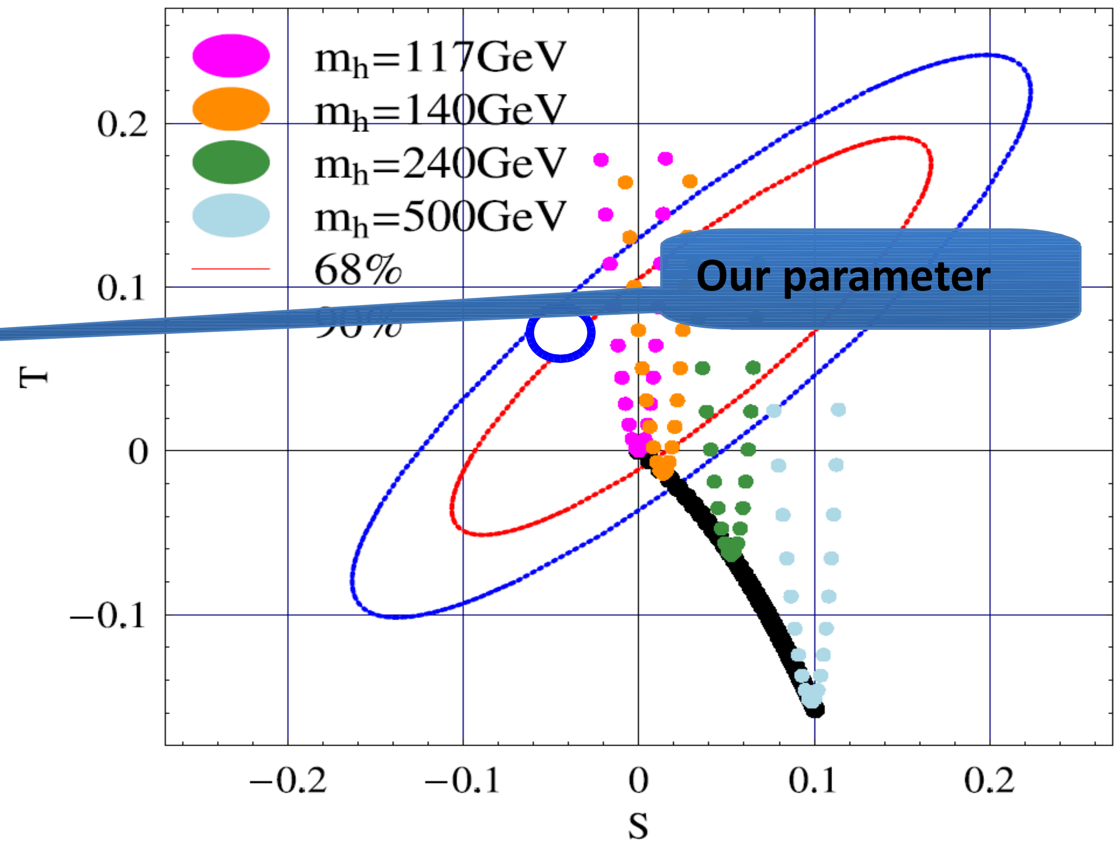
$$\Phi_1 = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ h_1 \end{pmatrix}, \quad \Phi_2 = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ h_2 e^{i\theta} \end{pmatrix} \quad \Rightarrow \quad r = \frac{h_2}{h_1}, \quad \varphi = \sqrt{\frac{3}{2}}\log(1 + \xi_1 h_1^2 + \xi_2 h_2^2)$$

Inflaton condition:

$$\lambda_2\xi_1 - (\lambda_3 + \lambda_4)\xi_2 > 0$$
$$\lambda_1\xi_2 - (\lambda_3 + \lambda_4)\xi_1 > 0$$
$$\lambda_1\lambda_2 - (\lambda_3 + \lambda_4)^2 > 0$$

Inflation is happened on minimum value of r

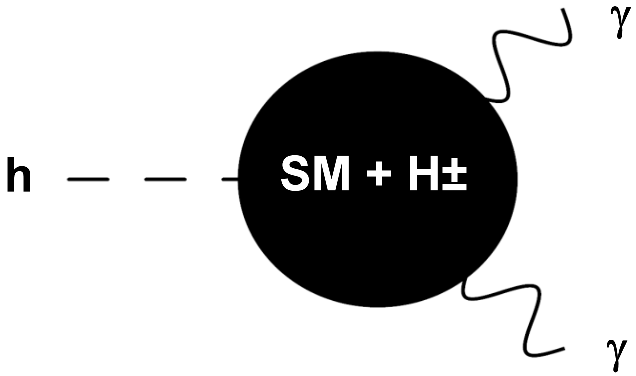
LEP bound



Our parameter consistent with LEP bound

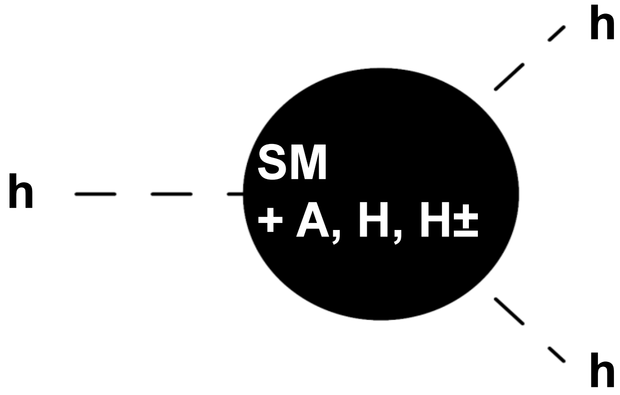
4.Phenomenology

h to γγ



$$\frac{BR[h_1 \to \gamma\gamma]}{BR[h_{SM} \to \gamma\gamma]} \approx 0.982$$

ληηη



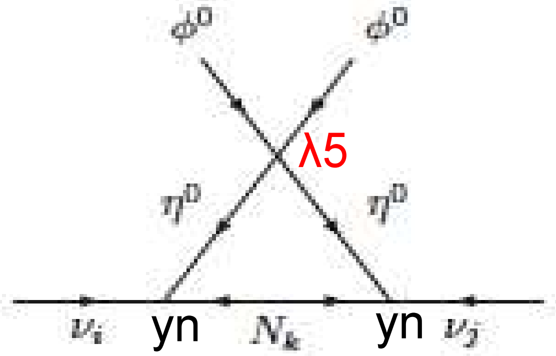
$$\frac{\lambda_{hhh} - \lambda_{hhh}^{SM}}{\lambda_{hhh}^{SM}} \approx 0.0118$$

3.Our model

Inert + vR

- Inflation
- Dark matter
- neutrino masses

Ma model



$$m_\nu = \frac{\lambda_5 v^2}{8\pi^2} \frac{y_n^2}{M} (\ln \frac{M^2}{m_0^2} - 1)$$

M:majorana mass of Nk,
m0:mass of inert higgs (η0)

E. Ma, Phys. Rev. D **73**, 077301 (2006)

Our model can explain these problem and would be tested at collider experiments