125-126 GeV Higgs mass & scalar dark matter

FLASY2014, 17-21 June 2014

Naoyuki Haba (Shimane U, Japan)

H. Ishida, K. Kaneta, R. Takahashi, NH, arXiv:1406.0158 [hep-ph].

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§1 introduction

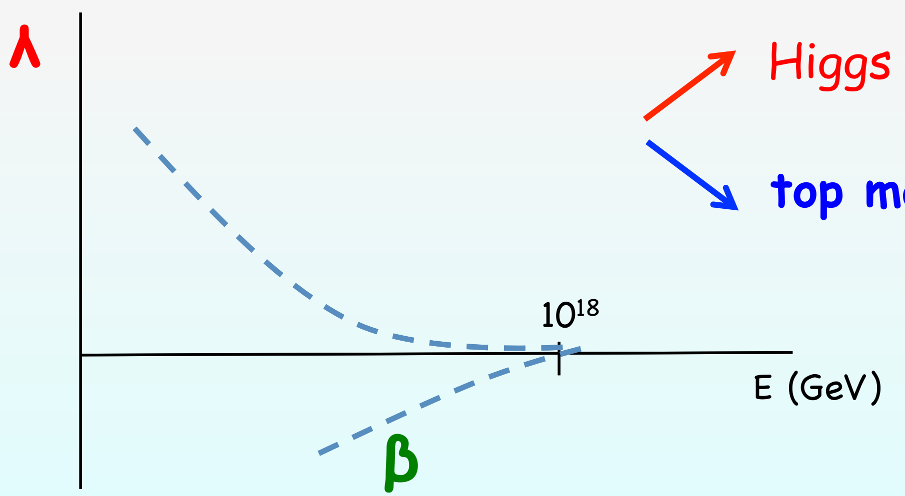
Higgs (but still no BSM) discovery at LHC

m_H=125.9$\pm$0.4 GeV, m_{top}=172.58~174.10 GeV in the SM

conbine LHC/Tevatron ~2σ (arXiv:1403.4427 [hep-ex])

RGE of Higgs self coupling

$$(4\pi)^2 \frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y_t^2 \underline{- 12 y_t^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{8}[2g^4 + (g'^2 + g^2)^2]$$



Higgs mass

top mass

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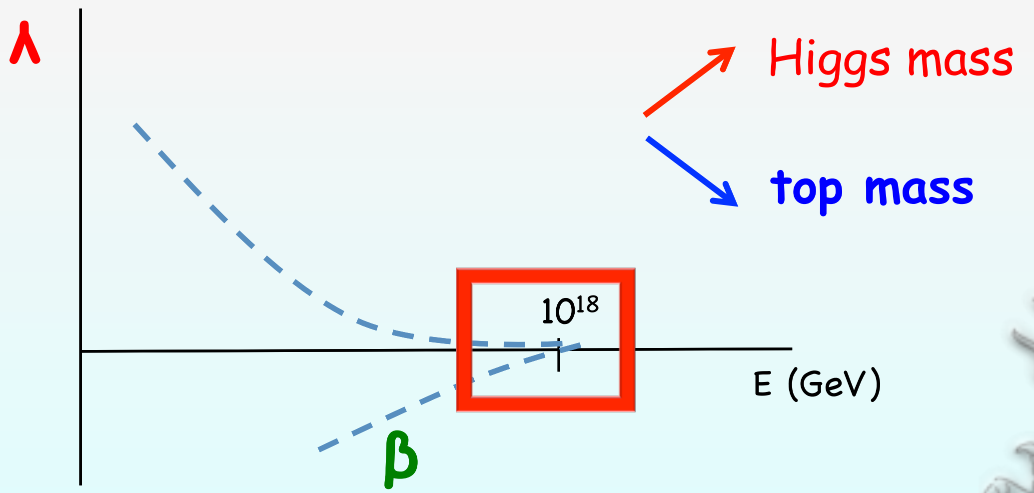

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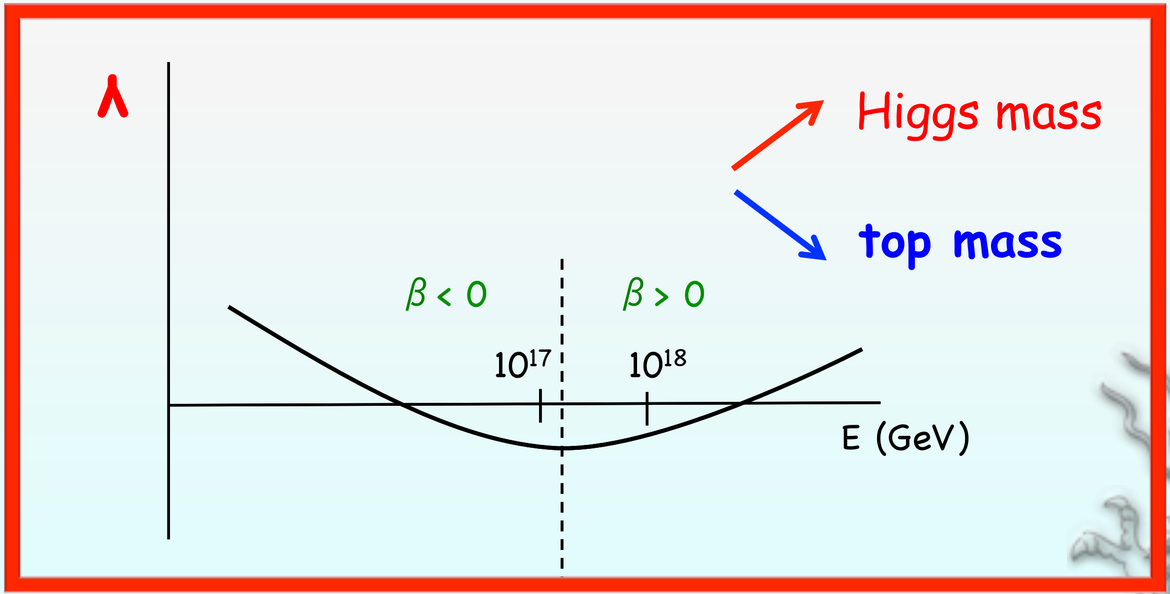

Higgs (but still no BSM) discovery at LHC

m_H=125.9±0.4 GeV, m_{top}=~~172.58~174.10~~ 171.081 GeV in the SM

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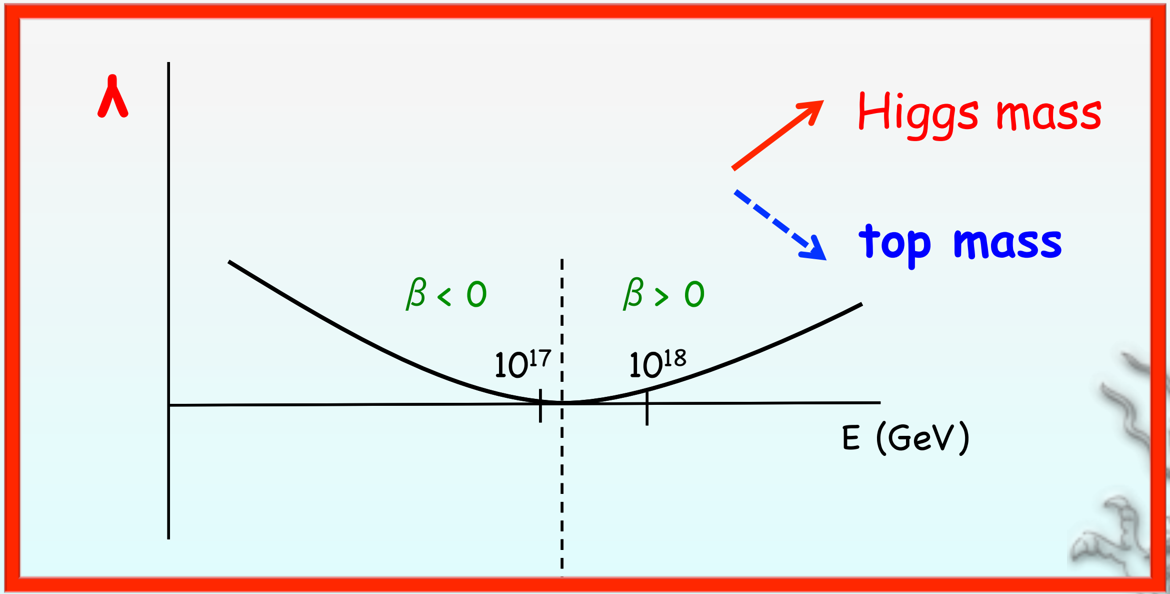

Higgs (but still no BSM) discovery at LHC

m_H=125.9$_{\pm 0.4}$ GeV, m_{top}=~~172.58~174.10~~ 171.079 GeV in the SM

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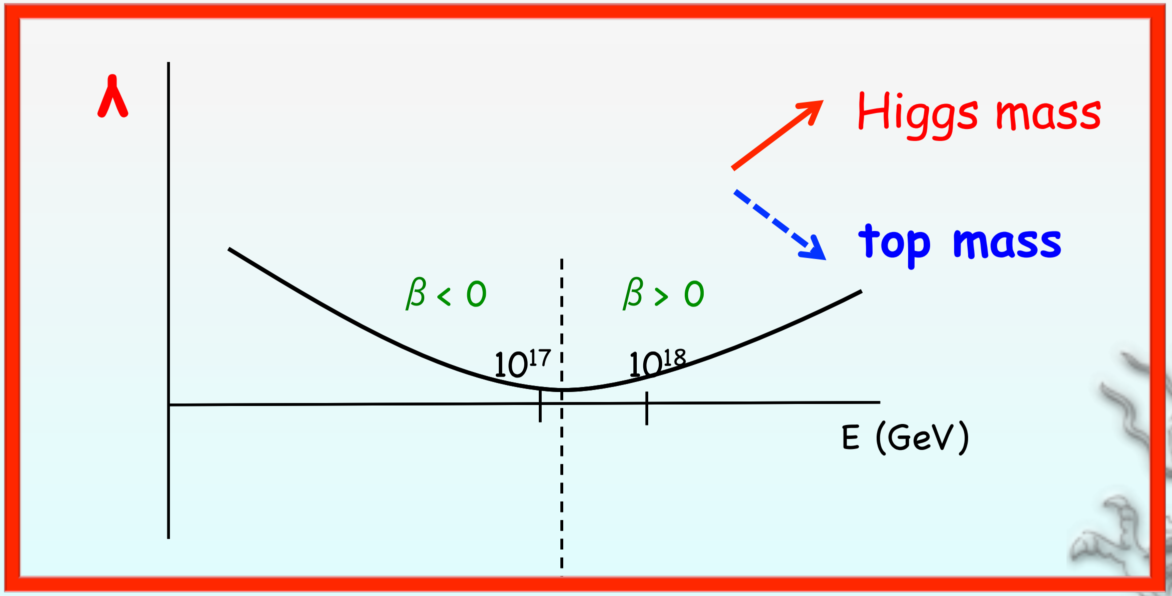

Higgs potential

$$V_{eff}(H) \sim \lambda(H) H^4$$

$$\to \frac{dV_{eff}(H)}{dH} \sim \lambda(H) H^3 + \frac{d\lambda(H)}{dH} H^4$$

$$\simeq (\lambda + \beta) H^3$$

⇕

$$\frac{dV_{eff}(H)}{dH} \sim (\lambda + \beta) H^3 \sim 0$$

$(1): \lambda > 0, \beta < 0$

$(2): \lambda = 0, \beta = 0$

$(3): \lambda < 0, \beta > 0$

$$|\lambda| \gg |\beta|$$

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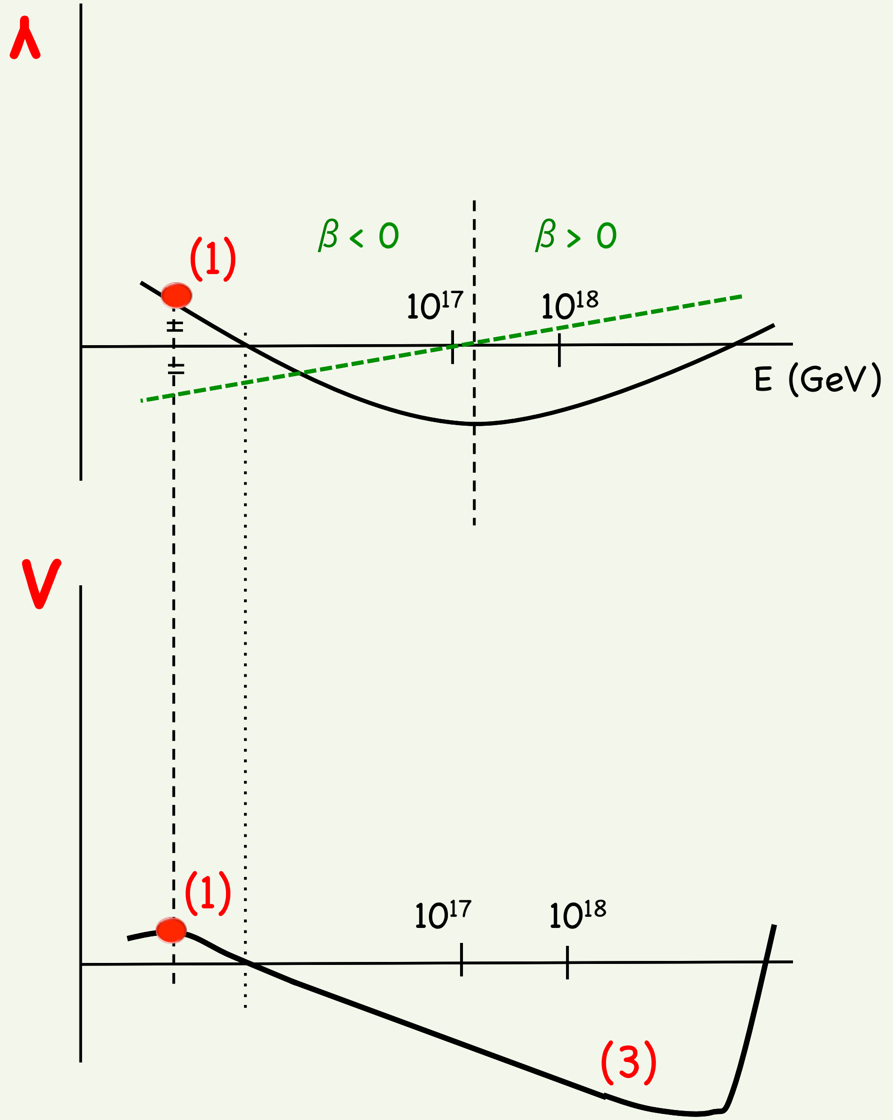
m_{top}>179 GeV

in-stable tunneling amplitude is shorter than age of universe



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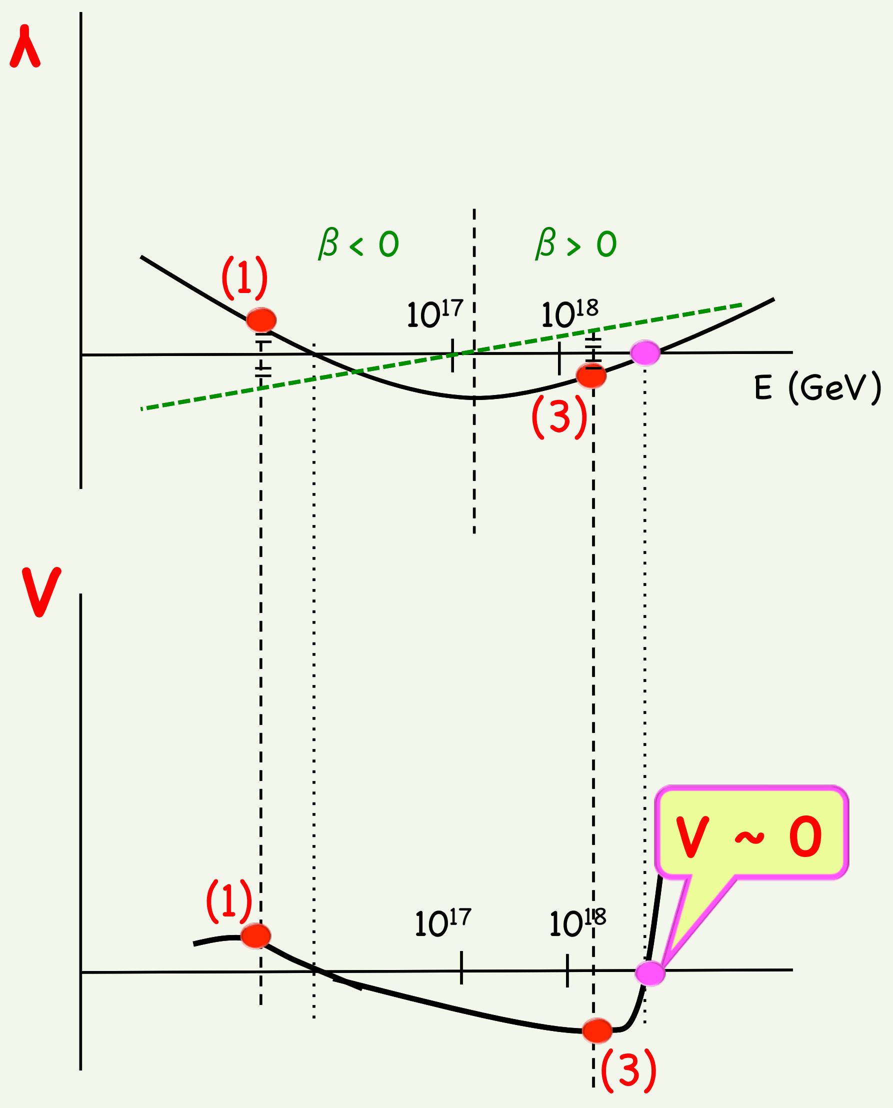
m_{top}=172.58~174.10 GeV

meta-stable



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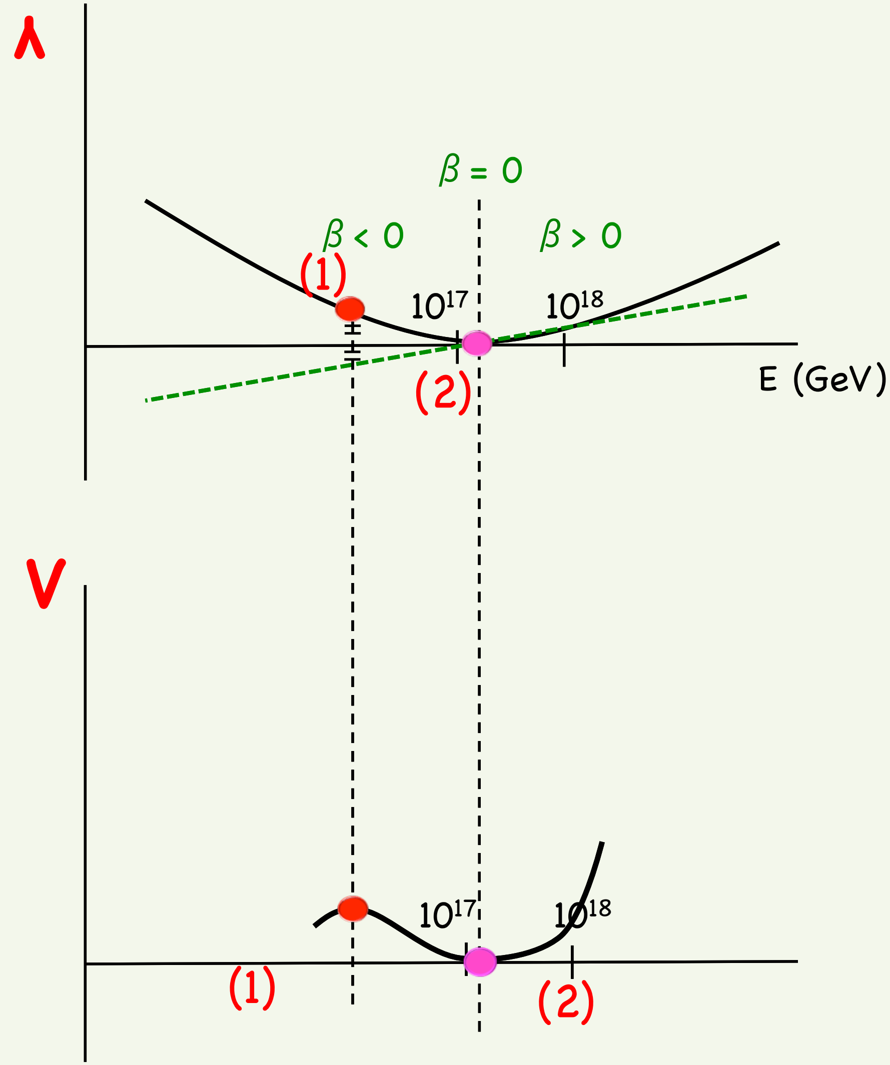
m_{top}=171.081 GeV

multiple-point critical principle (MPCP)



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$$\Updownarrow$$

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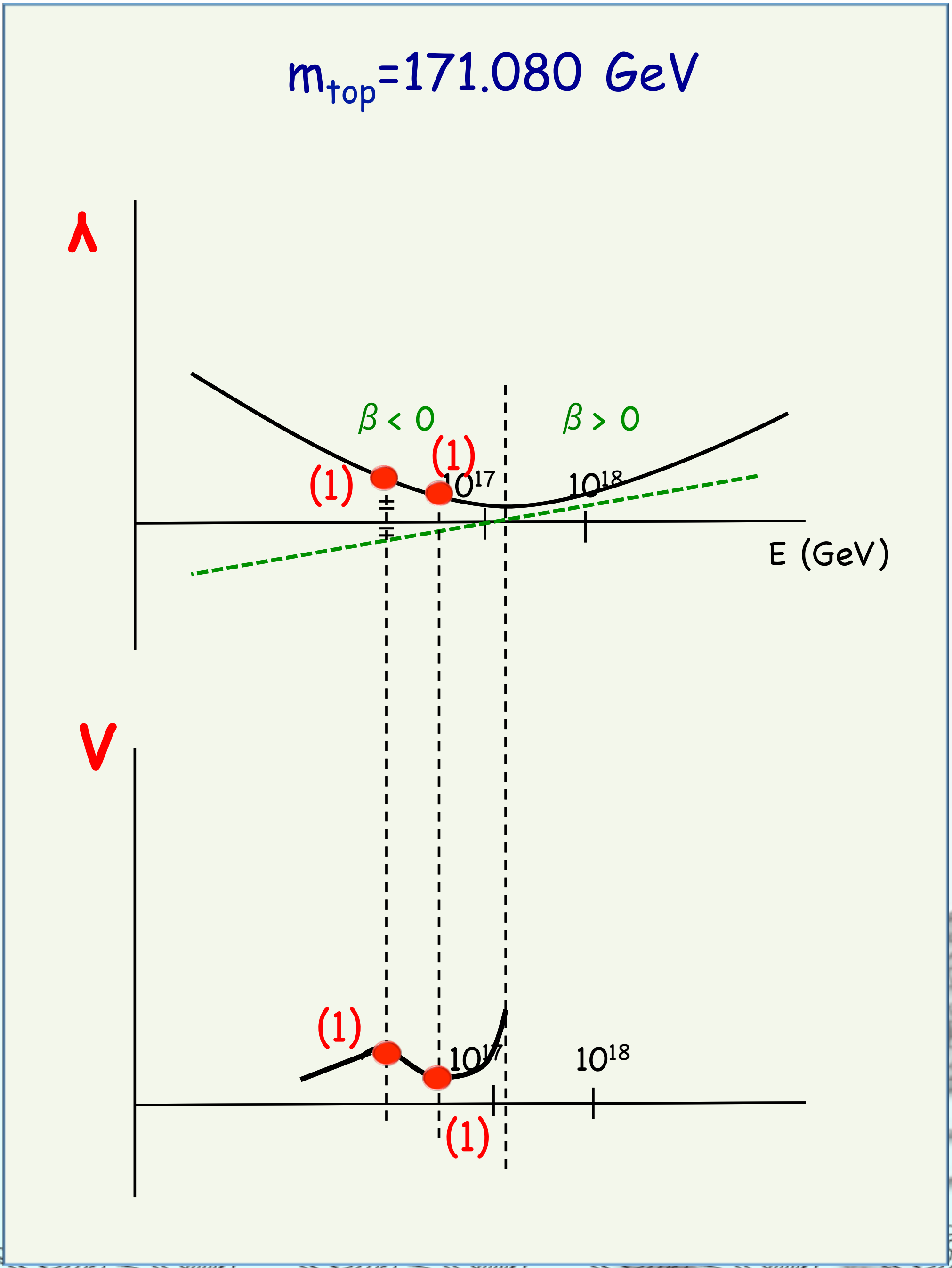

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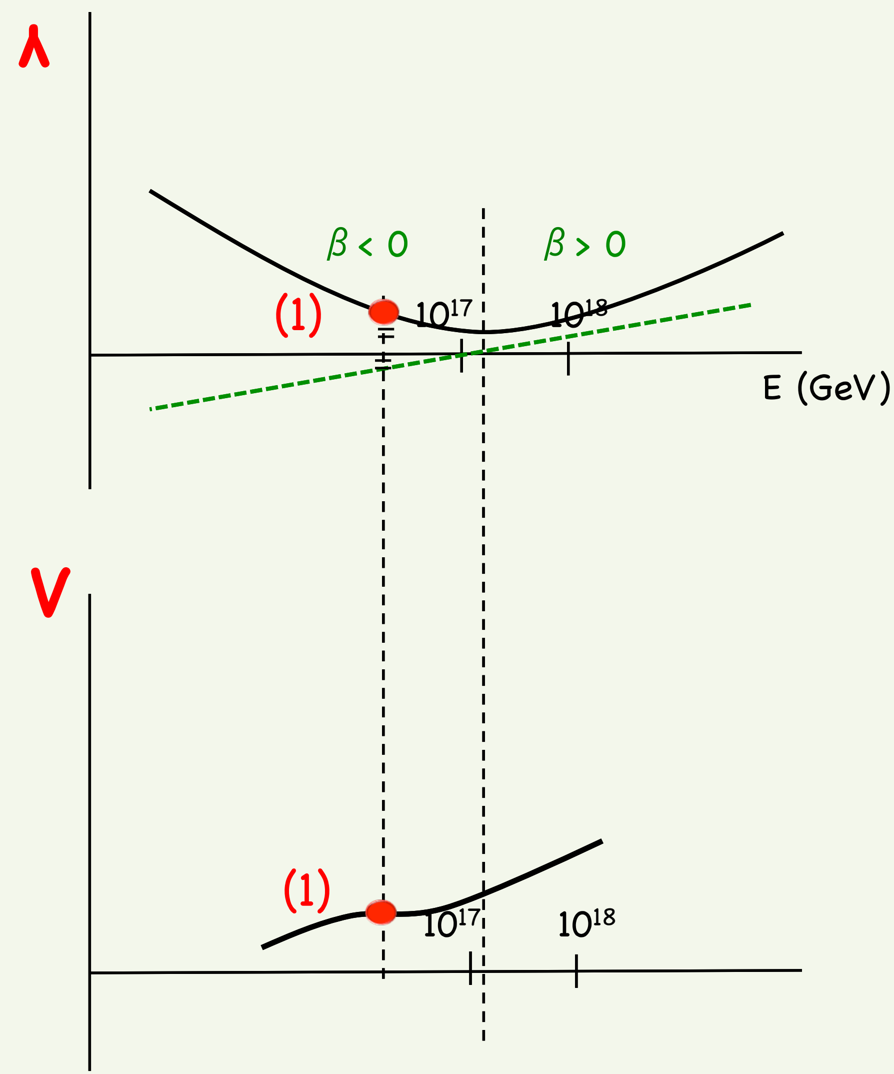
m_{top}=171.079 GeV

Higgs inflation?



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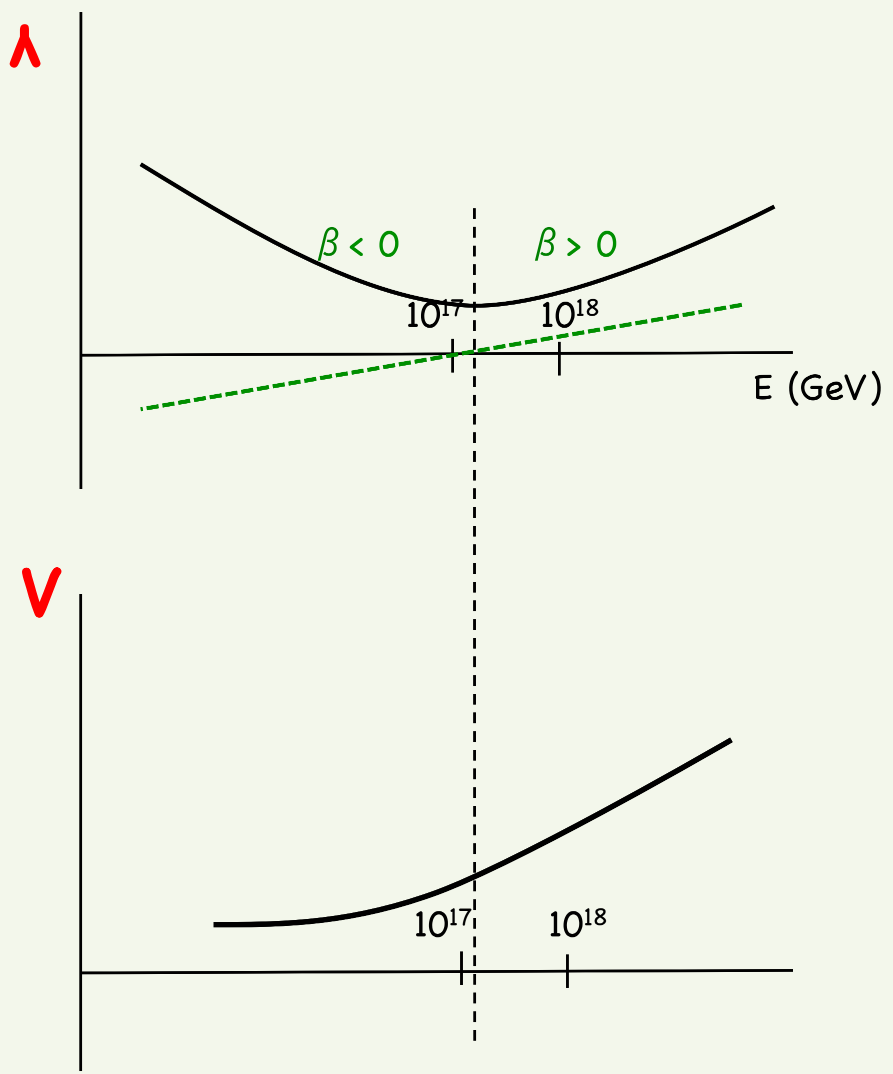
$M_{top} < 171.079$ GeV



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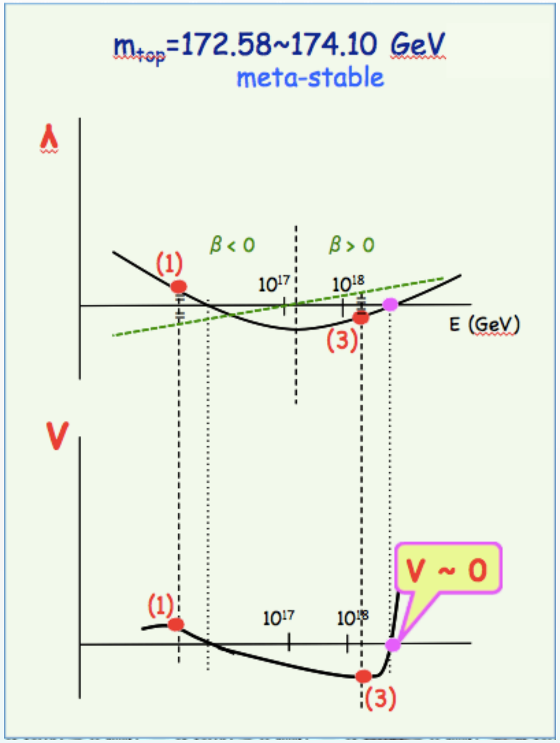
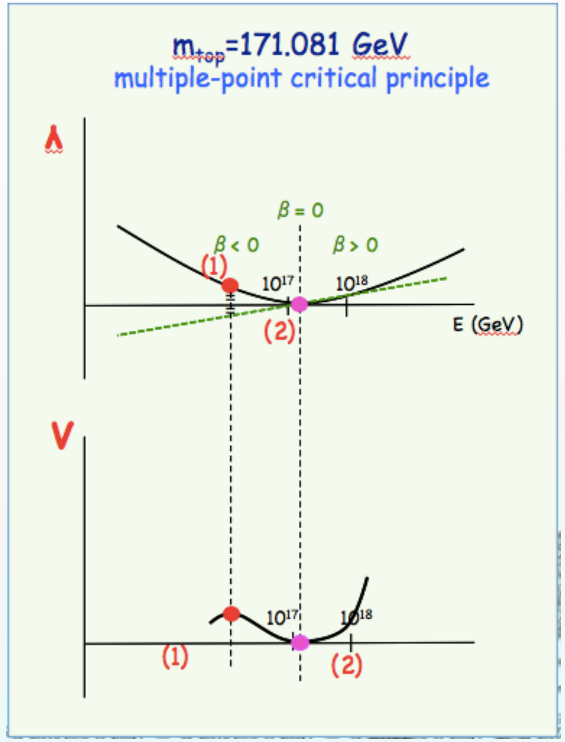
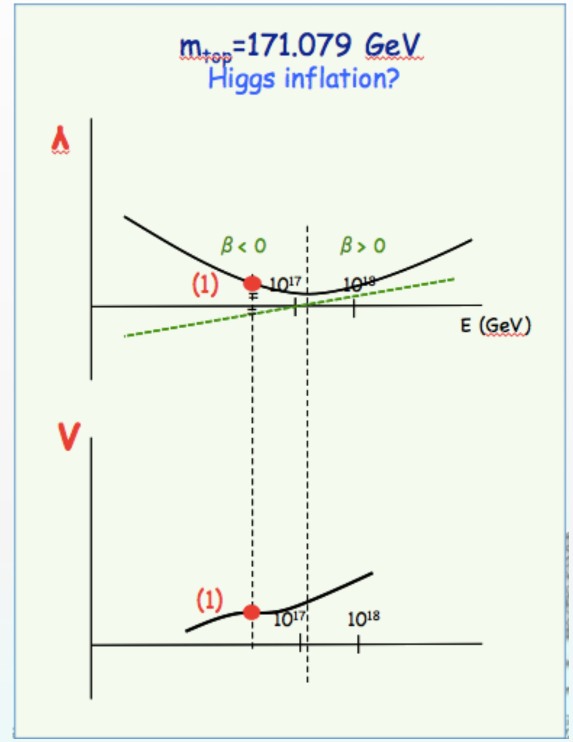






λ(Mp)=β(Mp)=0

(V(Mp)=0)

Higgs inflation

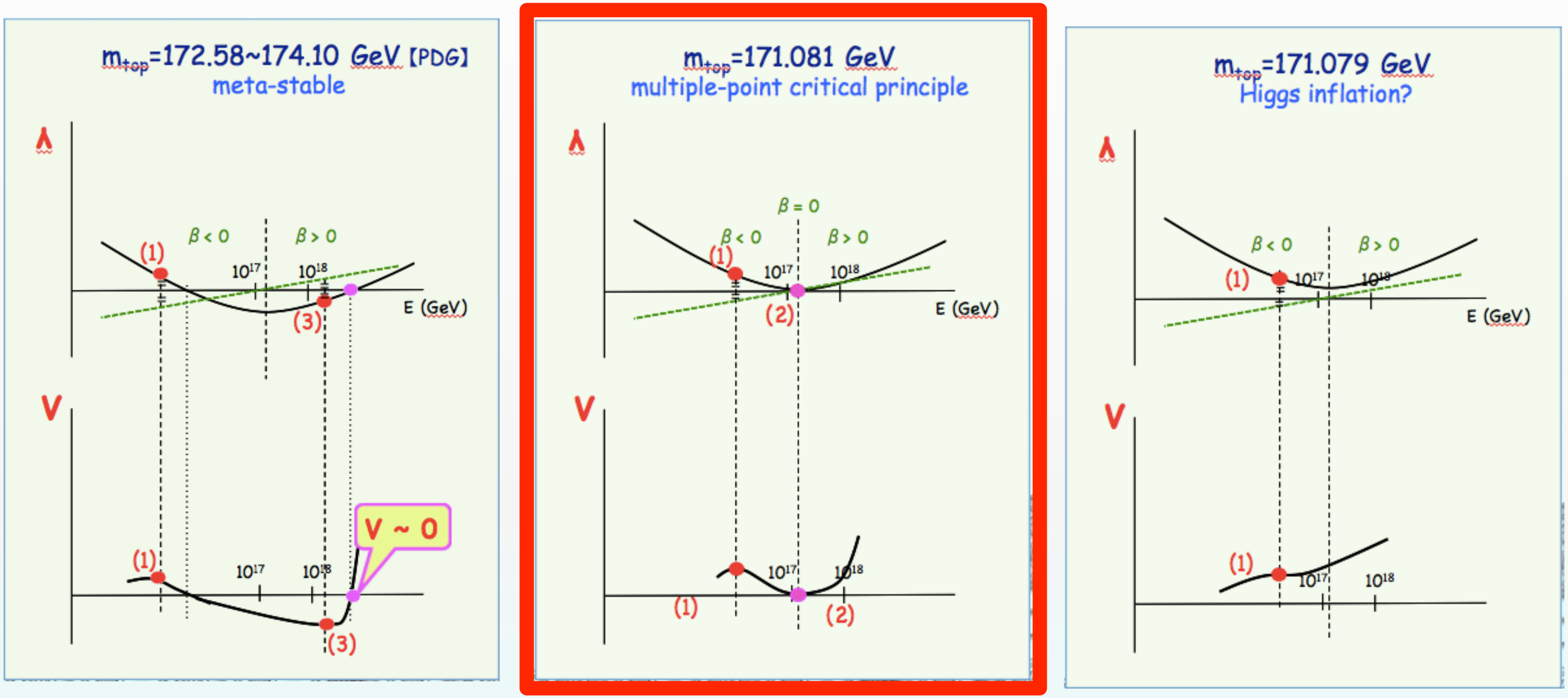
seem special

$$(4\pi)^2\frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y_t^2 \underline{- 12 y_t^4} - 3\lambda(g'^2+3g^2) + \frac{3}{8}[2g^4+(g'^2+g^2)^2]$$

scalar eff.

fermion eff.

m_H=125.9±0.4 GeV, m_{top}=172.58~174.10 GeV in the SM



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Higgs inflation

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$m_H = 125.9_{\pm 0.4}$ GeV, $m_{top} = 172.58 \sim 174.10$ GeV in the SM

seems roughly satisfies $\lambda \sim \beta \sim 0$ @ Mp, but not exact

could be directly connected to Mp if $\lambda = \beta = 0$ @ Mp (← Mp physics)

in addition, the SM has problems as

- no DM candidate
- ν mass, BAU?
- inflation?
- cosmological constant?
- charge quantization (gauge coupling unification)?
- strong CP ?

:

Higgs (but still no BSM) discovery at LHC

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in addition, the SM has problems as

minimal extension of SM

SM + scalar DM + ν_R

- no DM candidate
- ν mass, BAU? <- seesaw & leptogenesis
- inflation?
- cosmological constant?
- charge quantization (gauge coupling unification)?
- strong CP ?

:

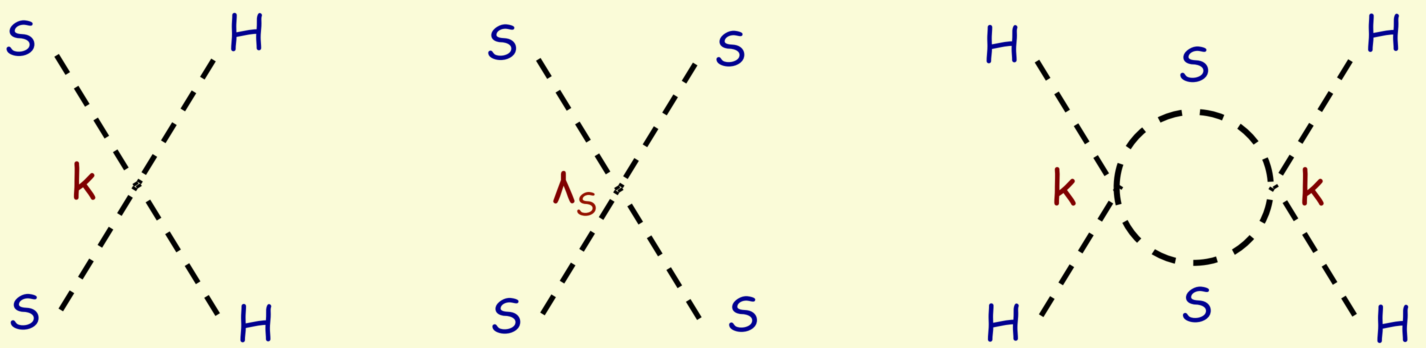
§2 SM + scalar DM + ν_R

arXiv:1312.2089 [hep-ph] (to appear JHEP)
NH, K. Kaneta, R. Takahashi,

☆SM + scalar DM☆

$$(L_{SM}+)\ L_{DM} = -\frac{m_{S0}^2}{2}\underline{S^2} - \frac{k}{2}|H|^2\underline{S^2} - \frac{\lambda_S}{4}\underline{S^4}$$

↖ **real scalar S is DM** [Z_2-odd (stable)]



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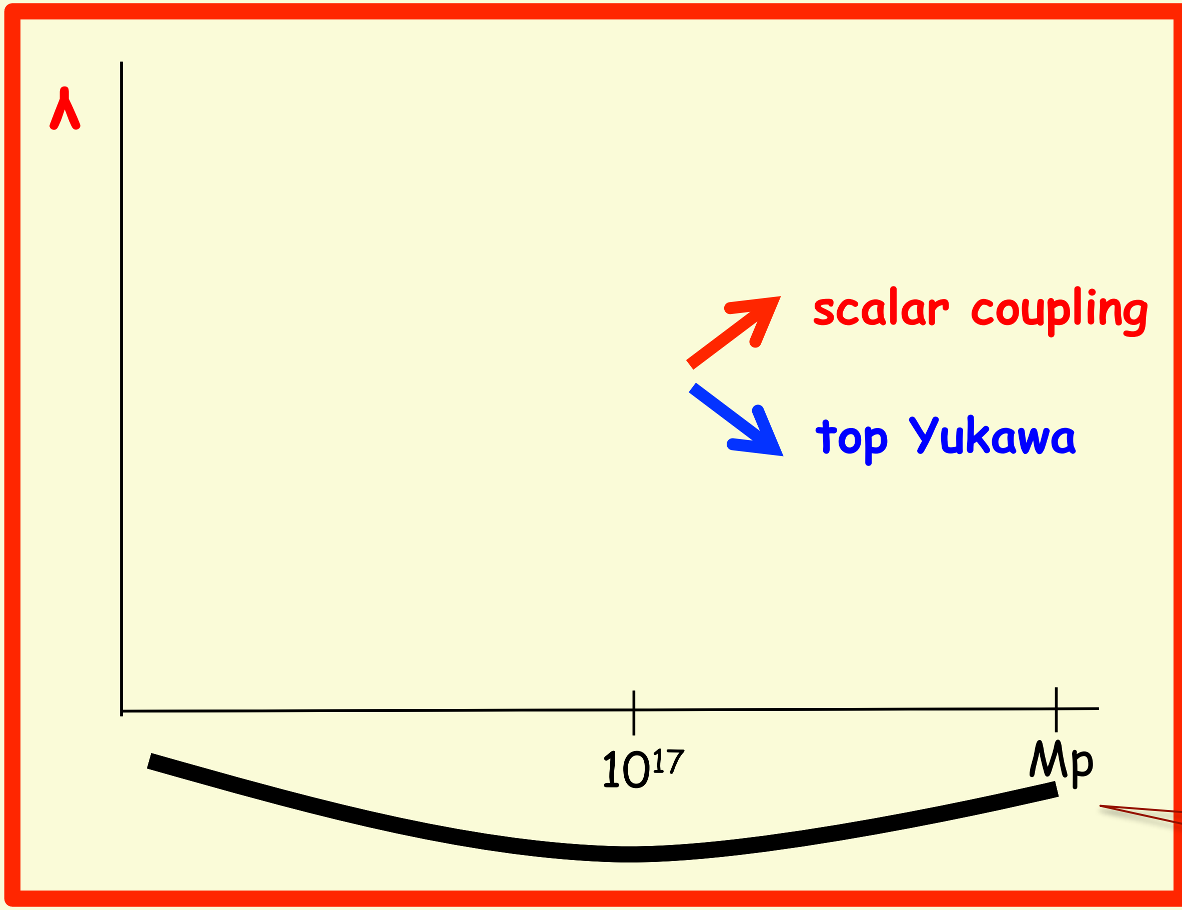
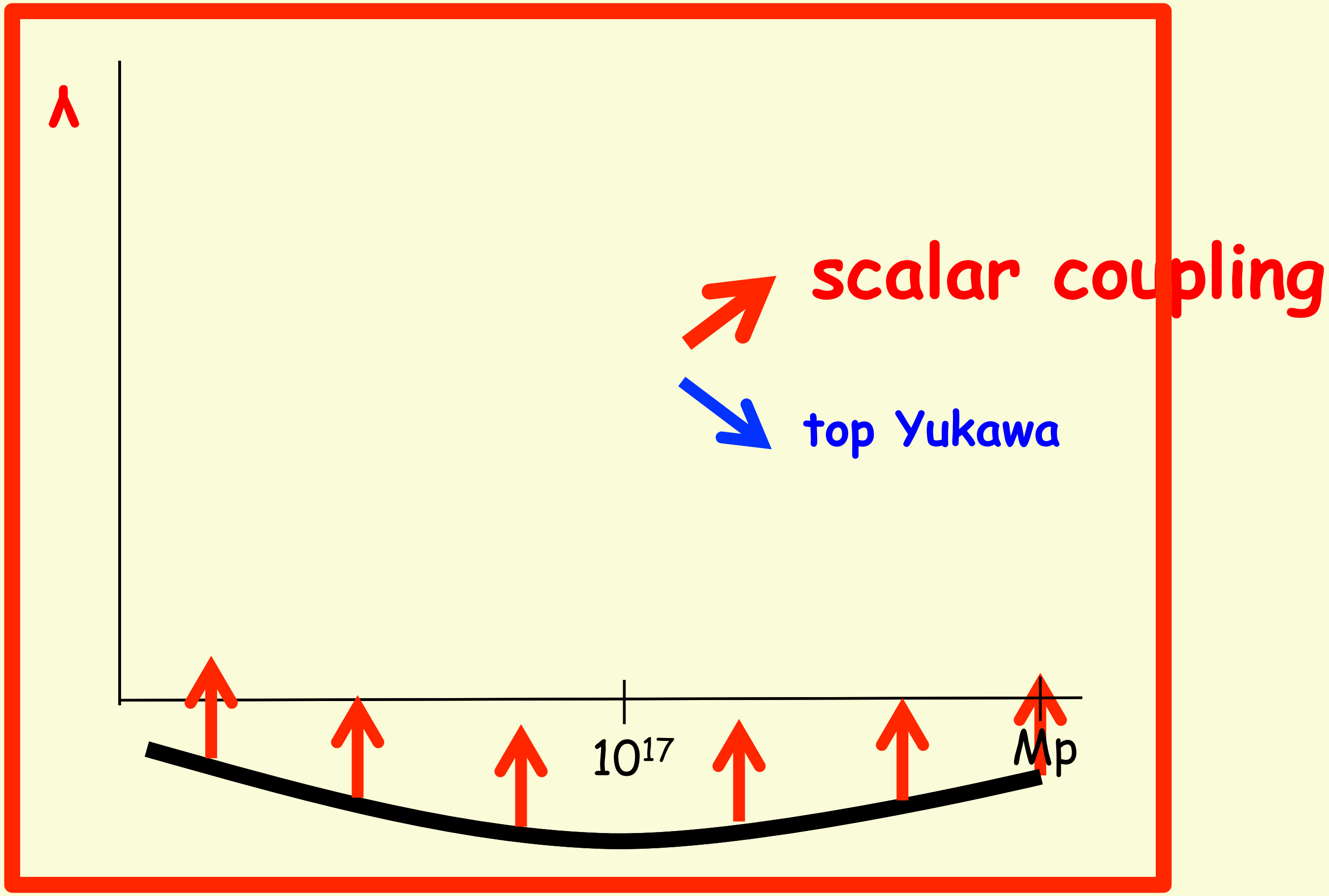
☆SM☆



β(Mp)>0

$$(4\pi)^2 \frac{d\lambda}{dt} = \underline{24\lambda^2} + 12\lambda y_t^2 \underline{- 6y_t^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{8}[2g^4 + (g'^2 + g^2)^2]$$

☆SM + scalar DM☆



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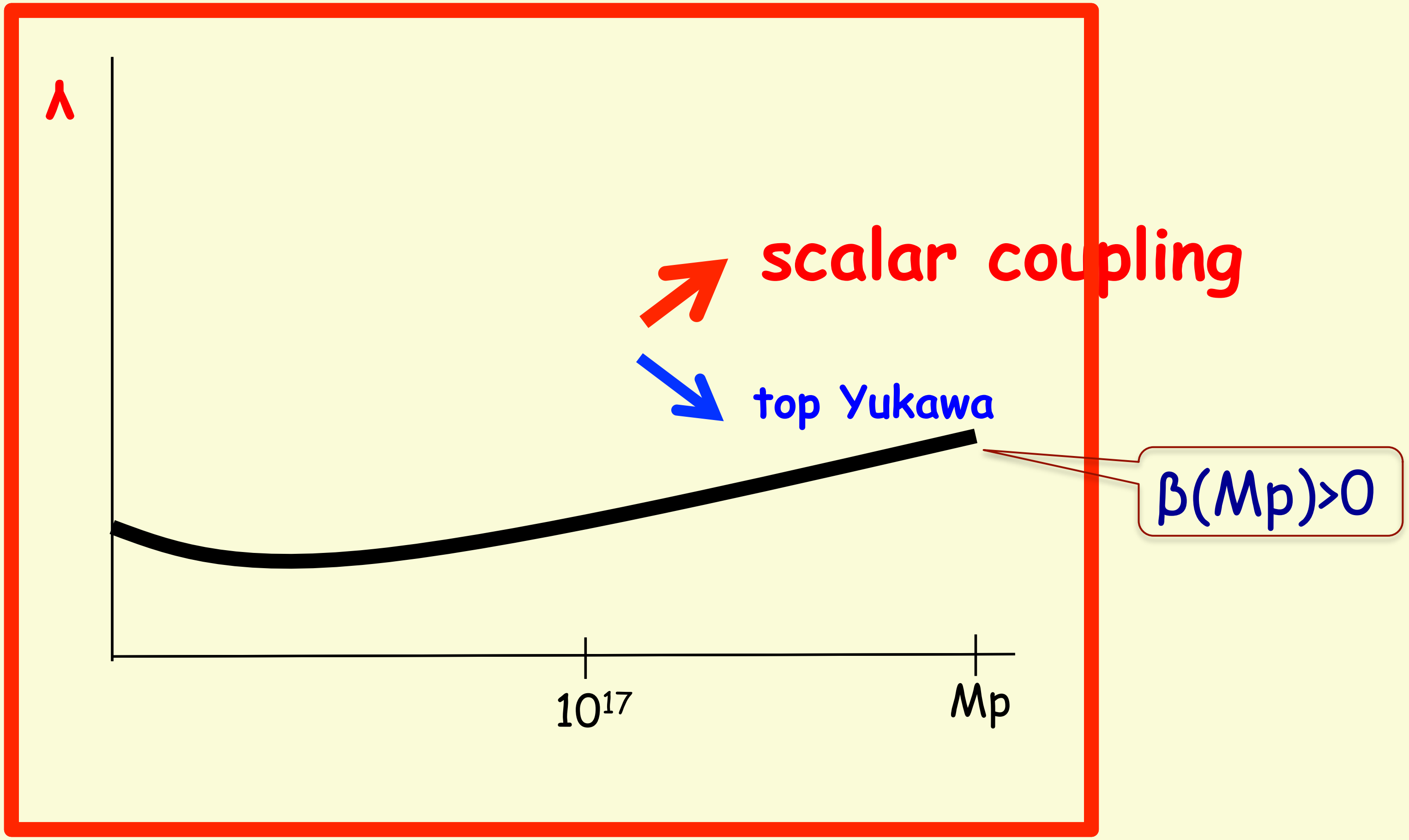

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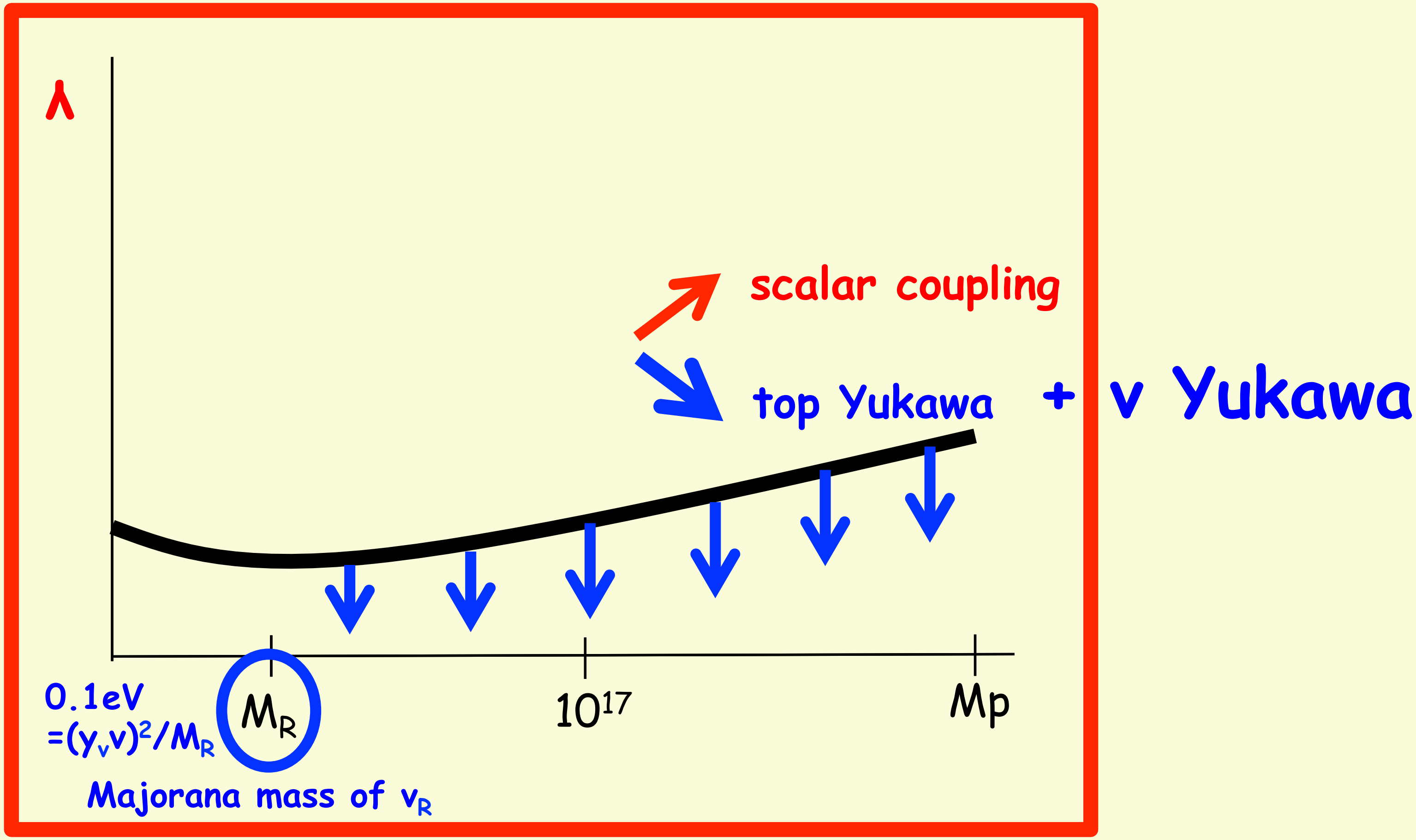
☆SM + scalar DM + ν_R☆



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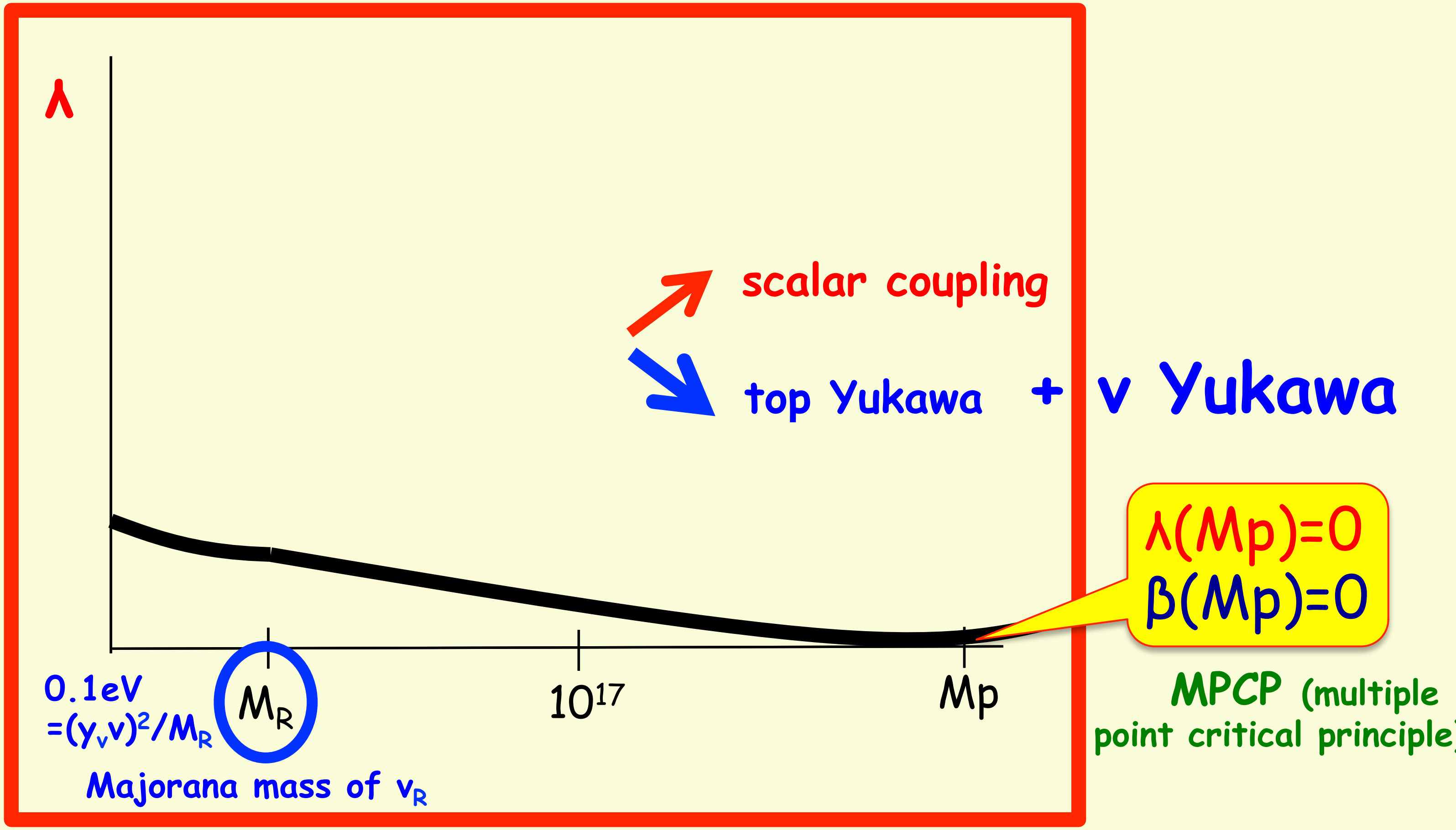
☆SM + scalar DM + ν_R☆



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$$-2y_\nu^4+4\lambda y_\nu^2$$

§3 numerical analyses

☆SM + scalar DM☆

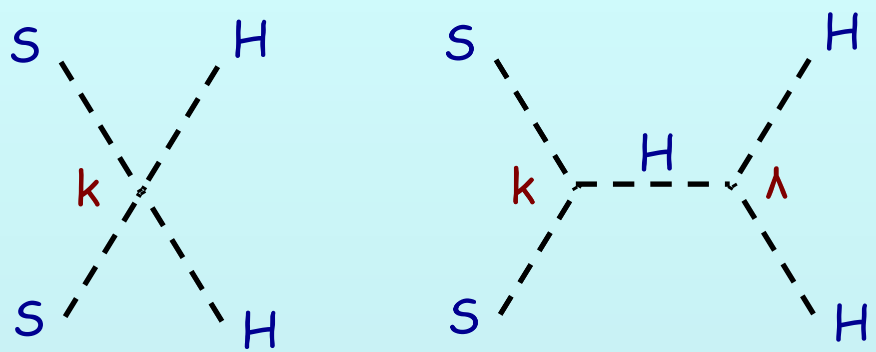
$$(L_{SM}+)\ L_{DM} = -\frac{m_{S0}^2}{2}\underline{S^2} - \frac{k}{2}|H|^2\underline{S^2} - \frac{\lambda_S}{4}\underline{S^4}$$

Input:

$\lambda(M_Z)$=0.131 (m_h=126GeV), **top pole mass=172.58~174.10 GeV**

DM relic density, $\Omega_S h^2$=0.119 (depends on λ & k (not λ_S))

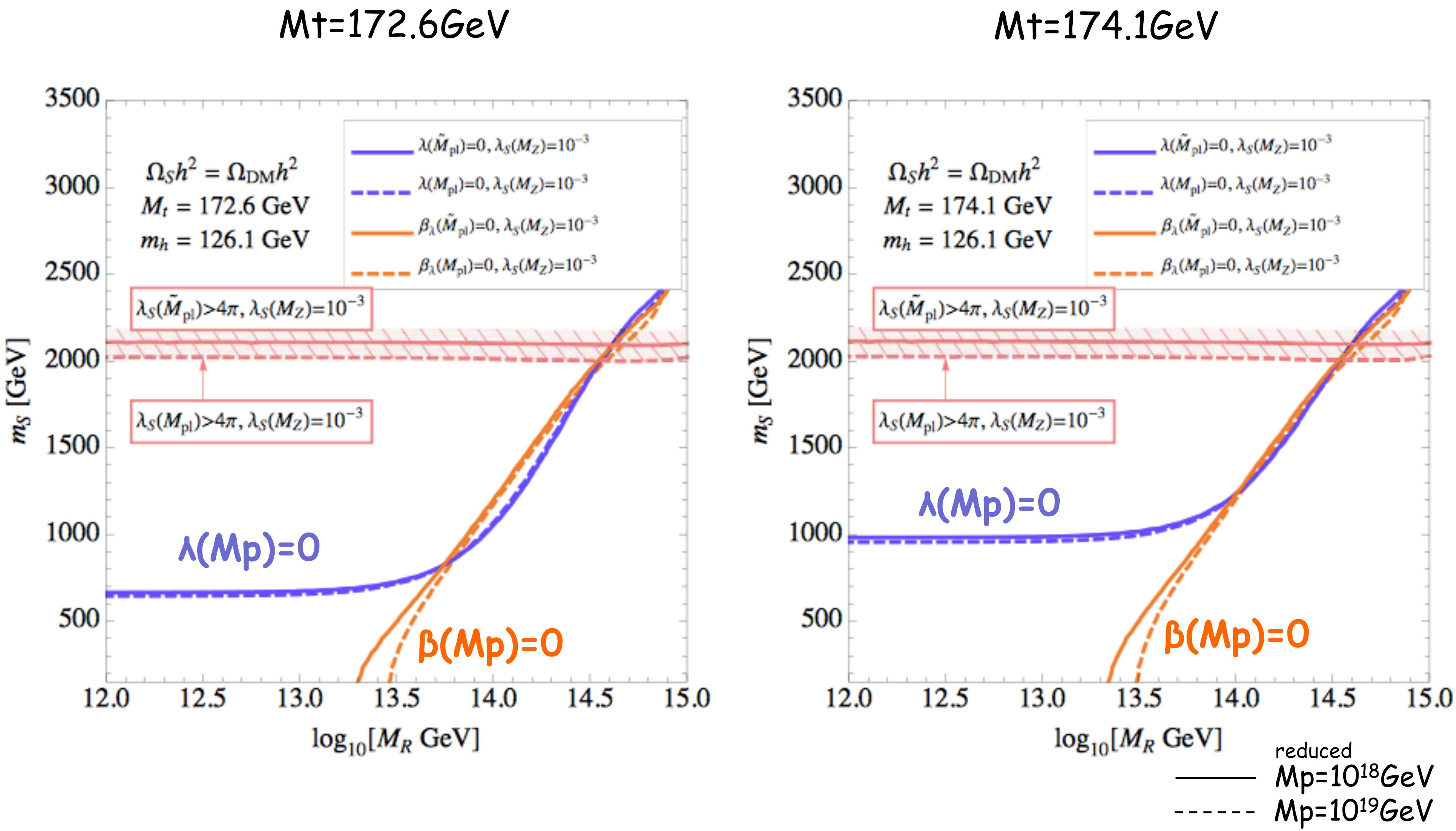
→ pair annihilation process



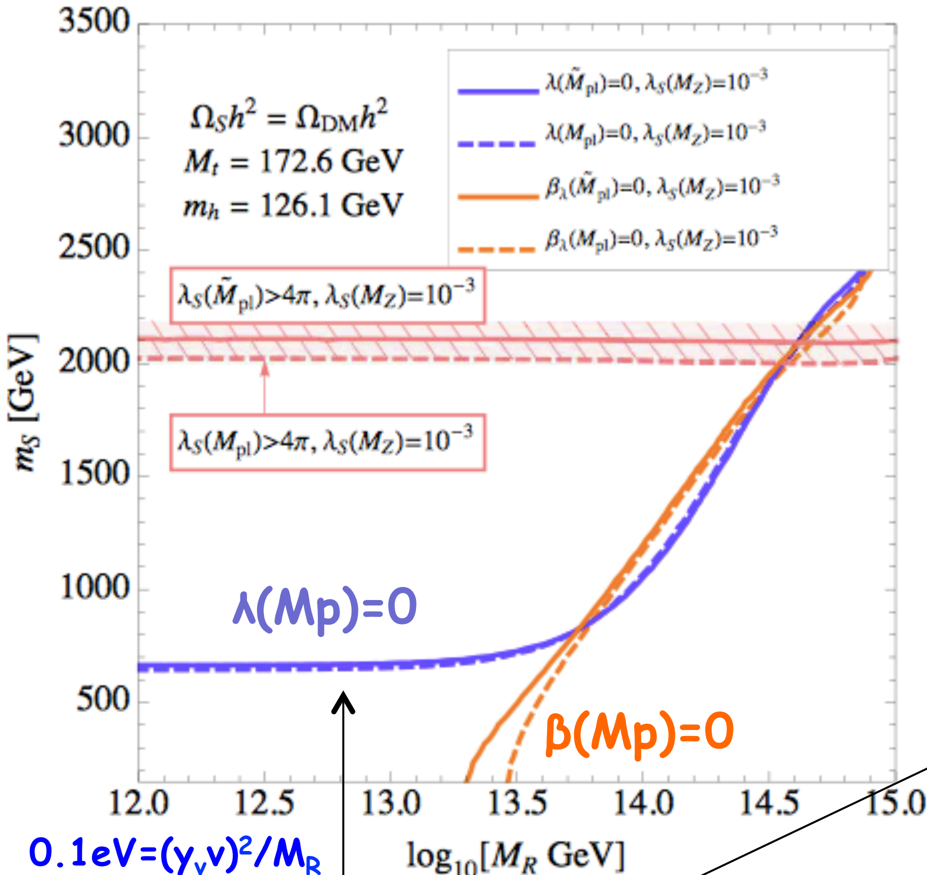
- cross section ∝ k & $1/m_S^2$

- k-> large (small) and/or m_S-> small (large), $\Omega_S h^2$-> small (large) 【strong (weak) pair annihilation】

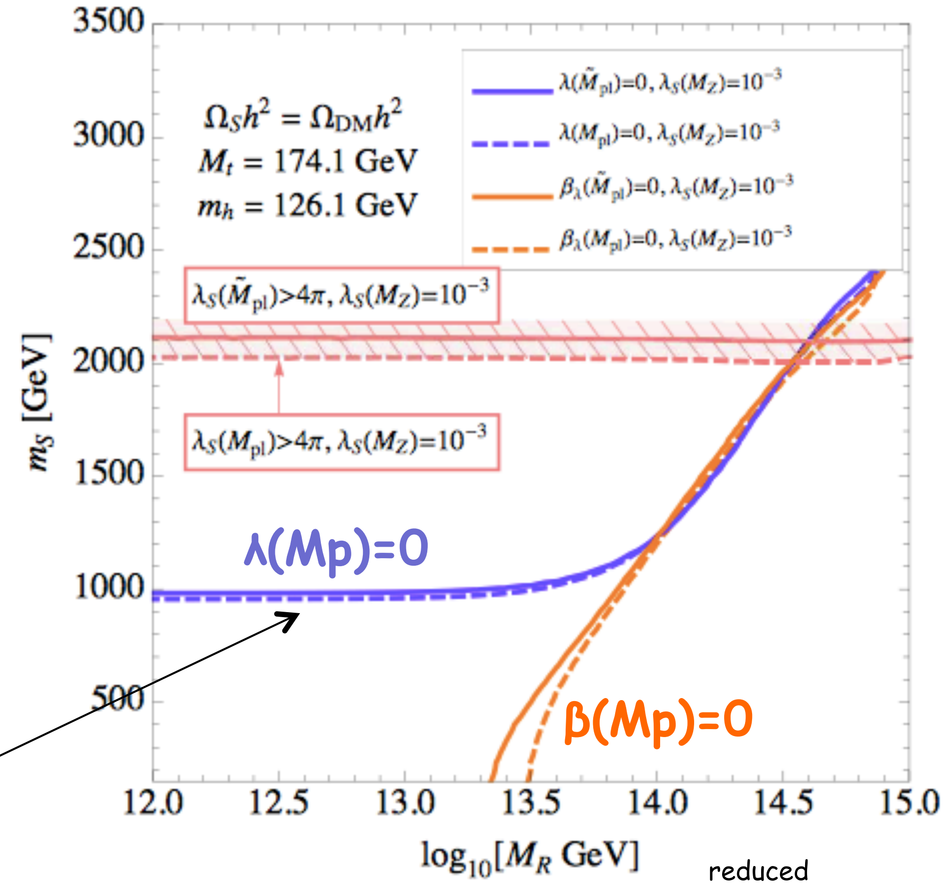
-> to keep $\Omega_S h^2$=0.119, k ∝ m_S [k-> large (small) with m_S-> large (small)]


Mt=172.6GeV
Mt=174.1GeV
$\Omega_S h^2 = \Omega_{DM} h^2$
M_t = 172.6 GeV
m_h = 126.1 GeV
M_t = 174.1 GeV
$\lambda(\tilde{M}_{pl})=0, \lambda_S(M_Z)=10^{-3}$
$\lambda(M_{pl})=0, \lambda_S(M_Z)=10^{-3}$
$\beta_\lambda(\tilde{M}_{pl})=0, \lambda_S(M_Z)=10^{-3}$
$\beta_\lambda(M_{pl})=0, \lambda_S(M_Z)=10^{-3}$
$\lambda_S(\tilde{M}_{pl})>4\pi, \lambda_S(M_Z)=10^{-3}$
$\lambda_S(M_{pl})>4\pi, \lambda_S(M_Z)=10^{-3}$
λ(Mp)=0
β(Mp)=0
m_S [GeV]
$\log_{10}[M_R$ GeV]
reduced
Mp=10^{18}GeV
Mp=10^{19}GeV

Mt=172.6GeV



Mt=174.1GeV



$0.1\,\mathrm{eV}=(y_\nu v)^2/M_R$

reduced

——— $M_p=10^{18}$GeV

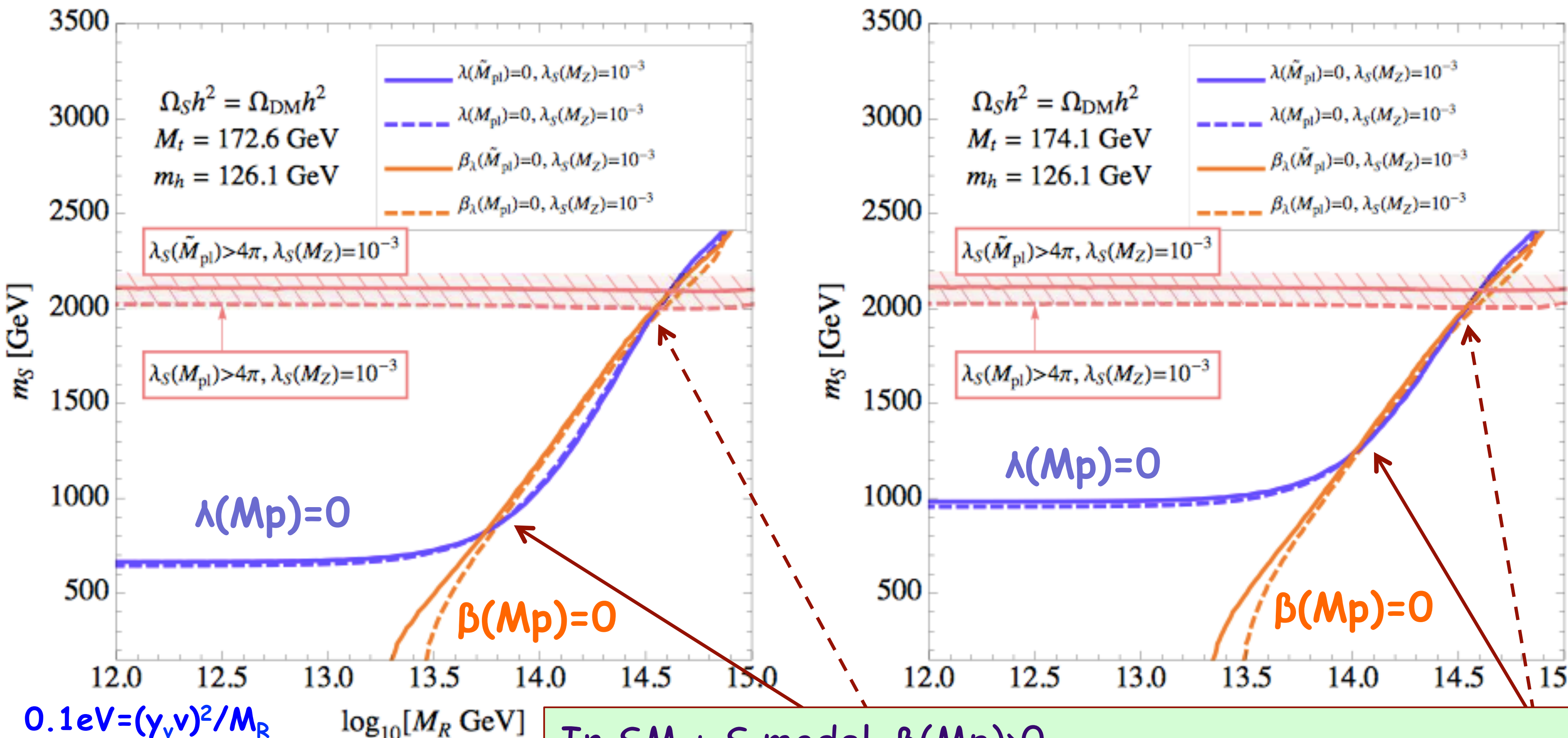
- - - - - $M_p=10^{19}$GeV

small M_R ↔ small y_ν
same as SM+S model,
[λ=0 is realized by
yt & k cancellation
with definite values.
($k \propto m_S$)

$$(4\pi)^2 \frac{d\lambda}{dt} = 24\lambda^2 + 12\lambda y_t^2 - 6y_t^4 - 3\lambda(g'^2+3g^2) + \frac{3}{8}[2g^4 + (g'^2+g^2)^2] + \frac{1}{2}k^2$$

large yt -> large k (in order to get λ=0)
-> large m_S ($m_S^2 = m_{S0}^2 + kv^2/2$, $\Omega_S h^2(k)$ = 0.119)

Mt=172.6GeV Mt=174.1GeV



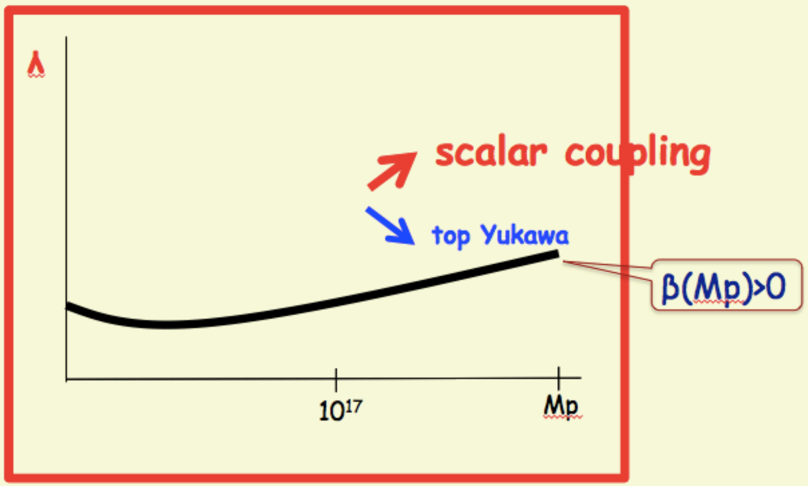
In SM + S model, β(Mp)>0.
In SM + S + ν_R model, large y_ν can make β(Mp)=0, but k must be also large to keep β(Mp)=0. ($k \propto m_S$)

$$(4\pi)^2 \frac{d\lambda}{dt} = 24\lambda^2 + 12\lambda y_t^2 - 6y_t^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{8}[2g^4 + (g'^2 + g^2)^2] + \frac{1}{2}k^2$$

$$-2y_\nu^4 + 4\lambda y_\nu^2$$

Mt=174.1GeV

☆SM + scalar DM☆



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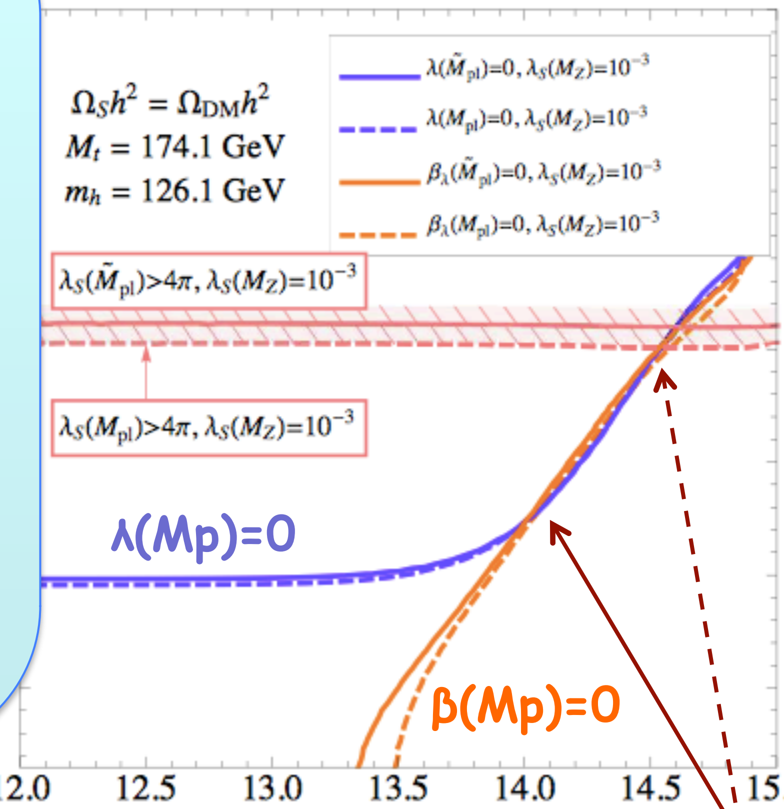

m_S [GeV]

12.0 12.5 13.0 13.5 14.0 14.5

$0.1\text{eV}=(y_\nu v)^2/M_R$

$\log_{10}[M_R\ \text{GeV}]$

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In SM + S + ν_R model, large y_ν can make β(Mp)=0, but k must be also large to keep β(Mp)=0. ($k \propto m_S$)

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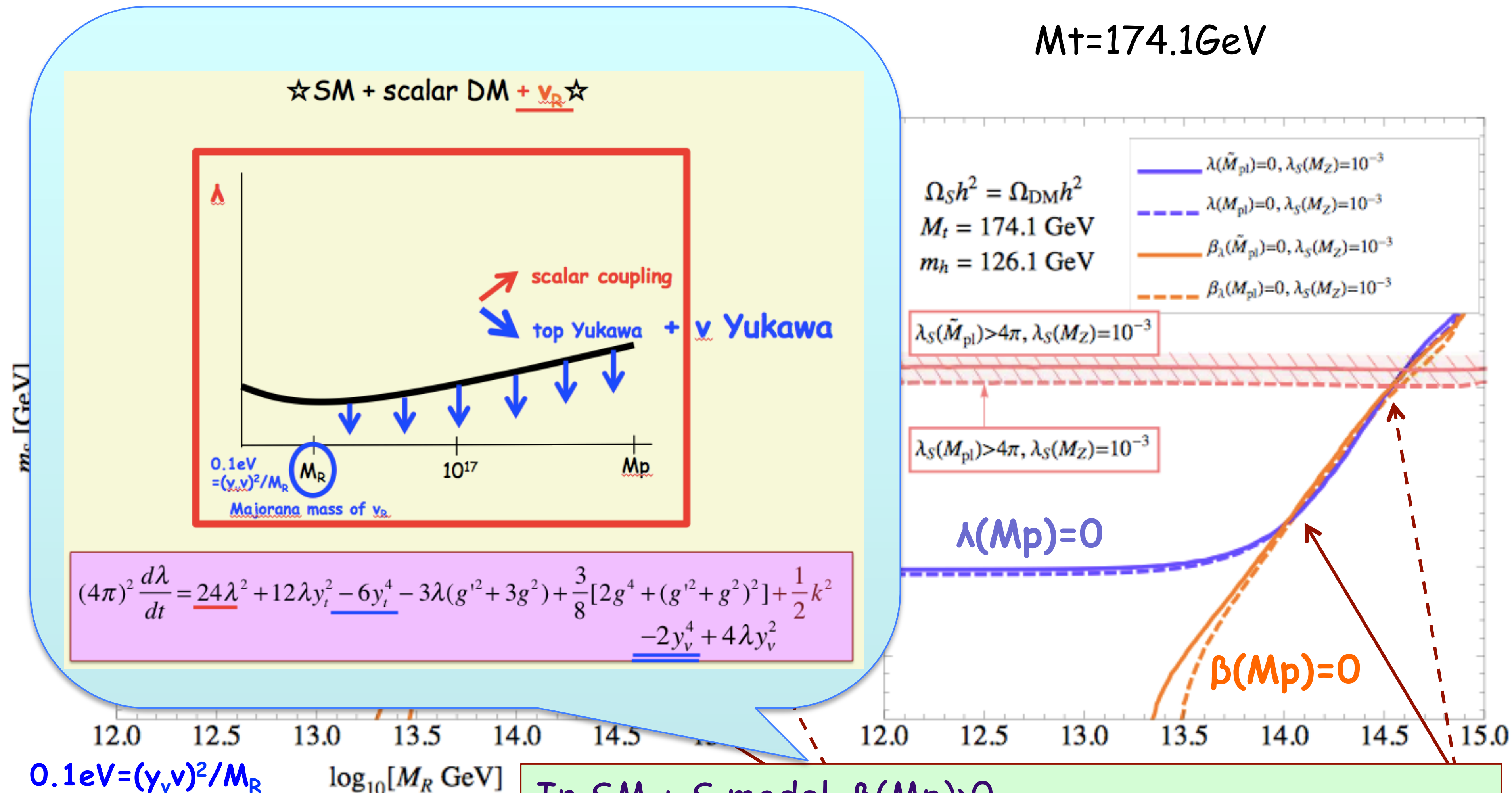
Mt=174.1GeV



0.1eV=$(y_\nu v)^2/M_R$

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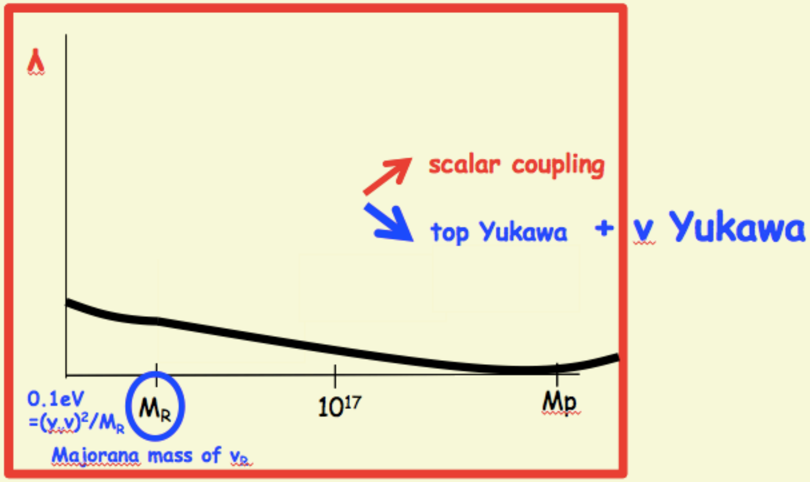
In SM + S + ν_R model, large y_ν can make β(Mp)=0, but k must be also large to keep β(Mp)=0. ($k \propto m_S$)

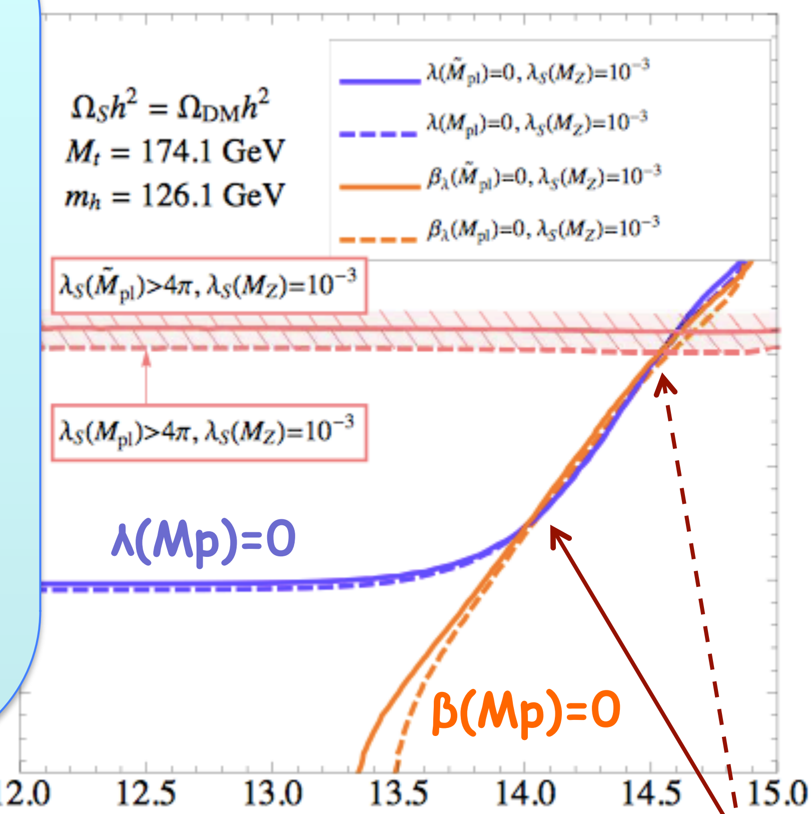
$$(4\pi)^2\frac{d\lambda}{dt}=24\lambda^2+12\lambda y_t^2-6y_t^4-3\lambda(g'^2+3g^2)+\frac{3}{8}[2g^4+(g'^2+g^2)^2]+\frac{1}{2}k^2$$
$$-2y_\nu^4+4\lambda y_\nu^2$$

Mt=174.1GeV

☆SM + scalar DM + ν_R☆



$$(4\pi)^2 \frac{d\lambda}{dt} = 24\lambda^2 + 12\lambda y_t^2 - 6y_t^4 - 3\lambda(g'^2+3g^2) + \frac{3}{8}[2g^4+(g'^2+g^2)^2] + \frac{1}{2}k^2 - 2y_\nu^4 + 4\lambda y_\nu^2$$



12.0 12.5 13.0 13.5 14.0 14.5

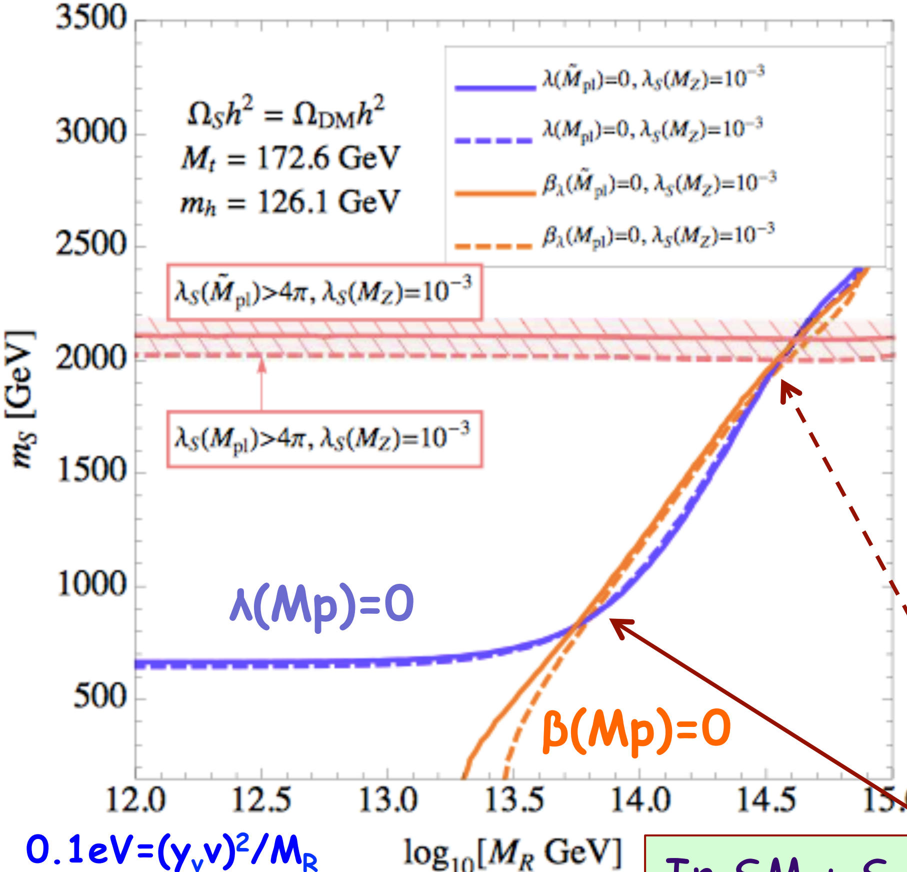
$0.1\,\text{eV}=(y_\nu v)^2/M_R$

$\log_{10}[M_R\ \text{GeV}]$

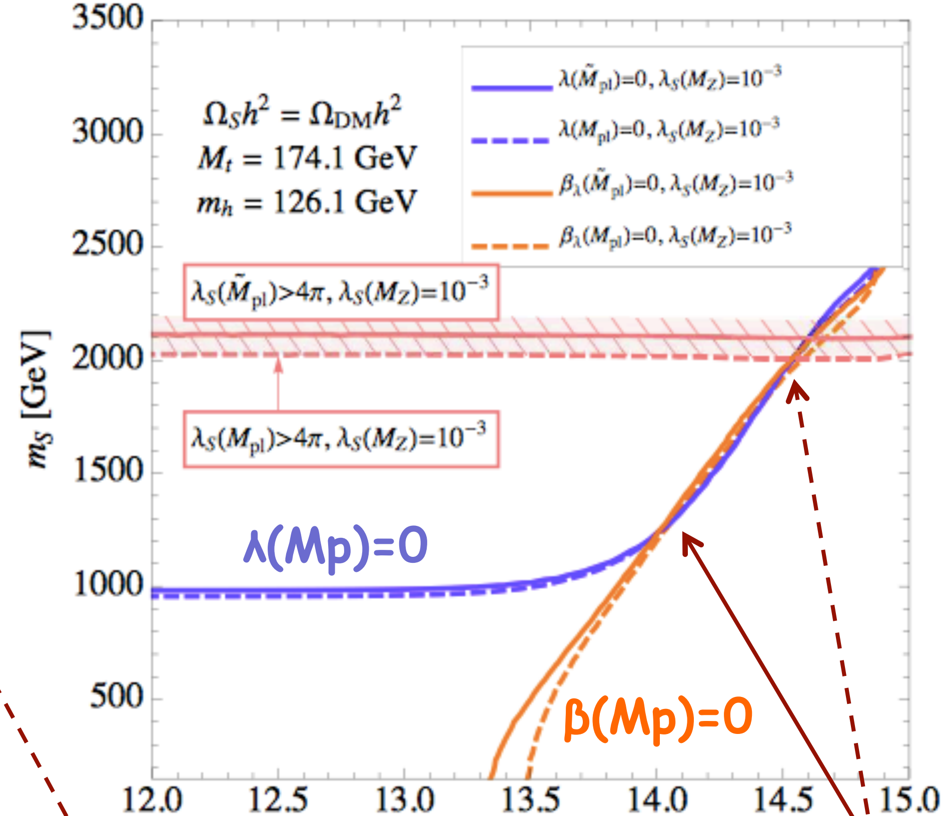
In SM + S model, β(Mp)>0.
In SM + S + ν_R model, large y_ν can make β(Mp)=0, but k must be also large to keep β(Mp)=0. ($k \propto m_S$)

$$(4\pi)^2 \frac{d\lambda}{dt} = 24\lambda^2 + 12\lambda y_t^2 - 6y_t^4 - 3\lambda(g'^2+3g^2) + \frac{3}{8}[2g^4+(g'^2+g^2)^2] + \frac{1}{2}k^2 - 2y_\nu^4 + 4\lambda y_\nu^2$$

Mt=172.6GeV



Mt=174.1GeV



$0.1\mathrm{eV}=(y_\nu v)^2/M_R$

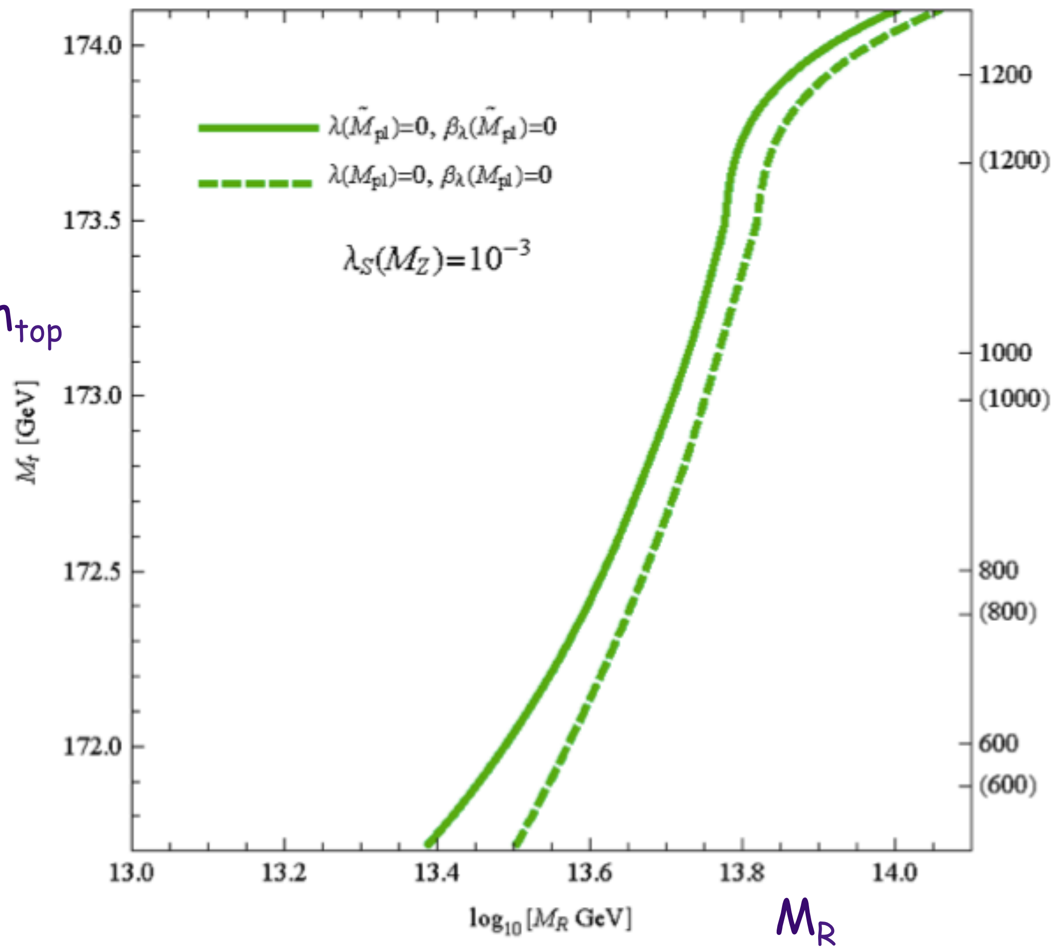
In SM + S model, β(Mp)>0.
In SM + S + ν_R model, large y_ν can make β(Mp)=0, but k must be also large to keep β(Mp)=0. ($k \propto m_S$)

$$(4\pi)^2 \frac{d\lambda}{dt} = 24\lambda^2 + 12\lambda y_t^2 - 6y_t^4 - 3\lambda(g'^2+3g^2) + \frac{3}{8}[2g^4 + (g'^2+g^2)^2] + \frac{1}{2}k^2$$

$$-2y_\nu^4 + 4\lambda y_\nu^2$$

m_S (M_t) & M_R which satisfy $\lambda=\beta=0$

m_S & M_R are determined ! (uniquely)



m_{top}

m_S

M_R

reduced

——— $Mp=10^{18}$GeV

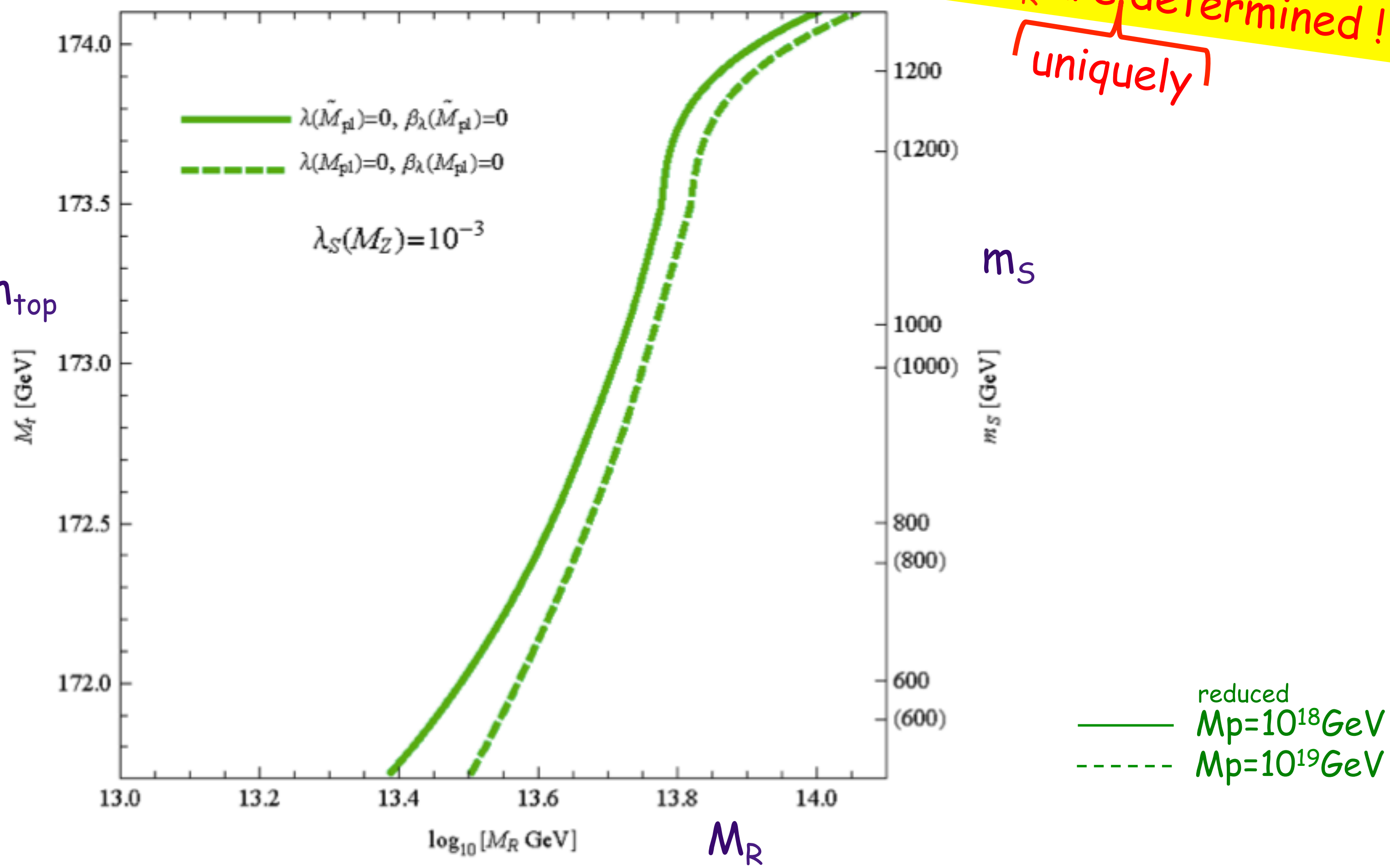
- - - - - $Mp=10^{19}$GeV

parameters: λ, k, λ_S, y_t, y_ν, m_S, M_R

- λ ↑ fixed by Higgs mass
- k ↑ eliminate by $\Omega_S h^2(k) = 0.119$
- λ_S fix
- y_t fix
- y_ν ↑ eliminate by $0.1\text{eV}=(y_\nu v)^2/M_R$
- m_S, M_R: $\lambda=\beta=0$

m_S (M_t) & M_R which satisfy $\lambda=\beta=0$

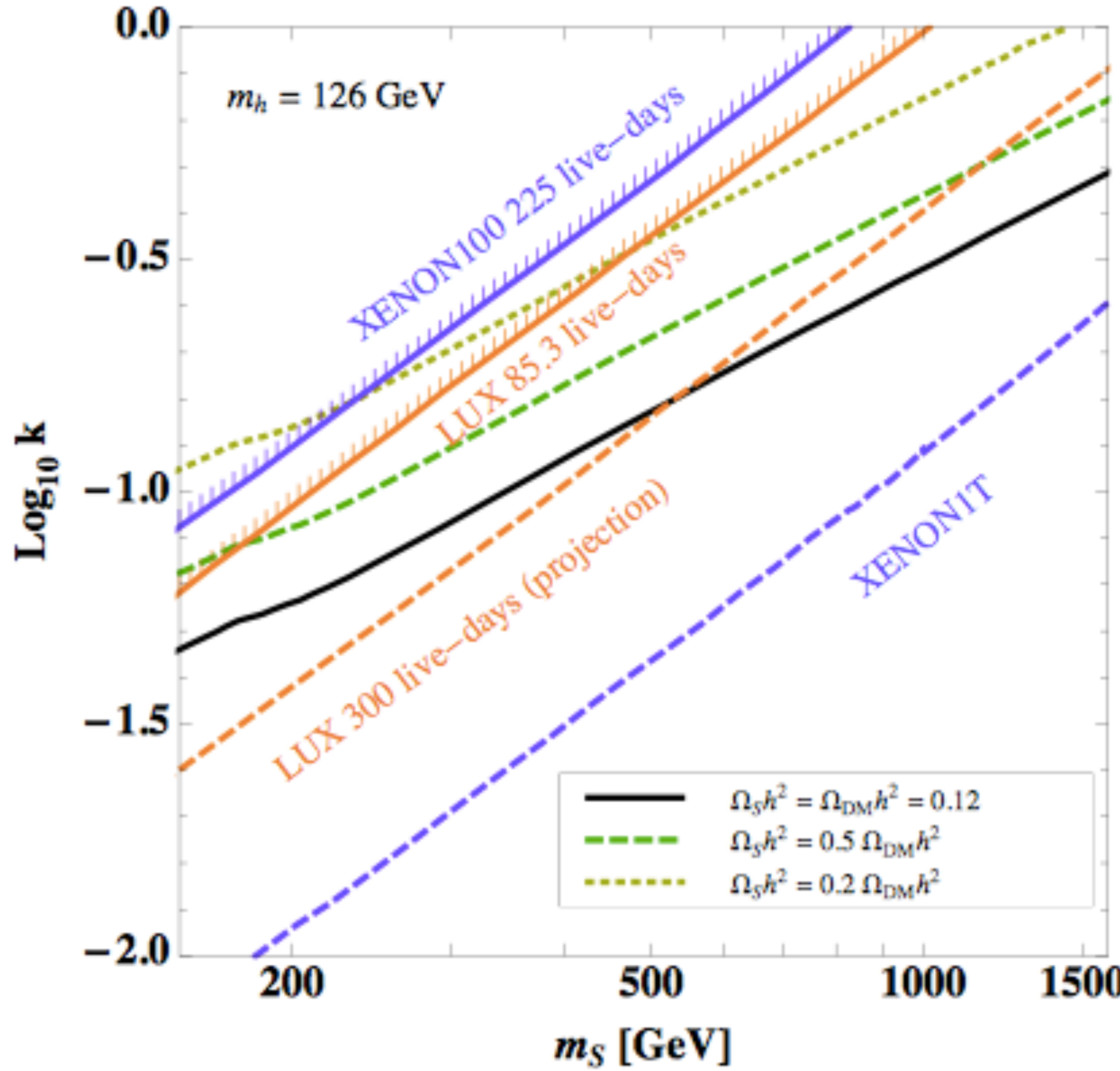
m_S & M_R are determined ! uniquely



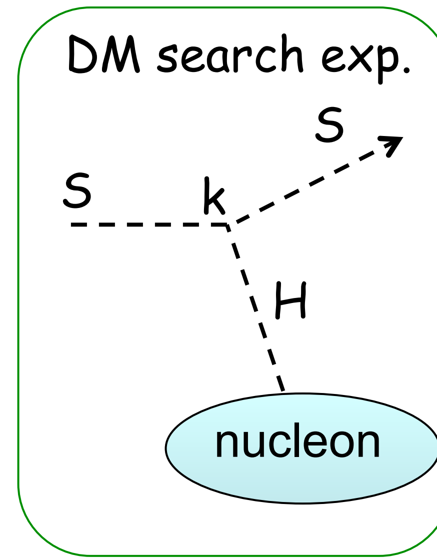
As Mt = 172.58~174.10 GeV , $\lambda(Mp)=\beta(Mp)=0$ satisfying point runs

$Mp=10^{18}$ GeV: m_S = 800 GeV ~ 1.2 TeV, $M_R = 6.3\times10^{13} \sim 1.6\times10^{14}$ GeV

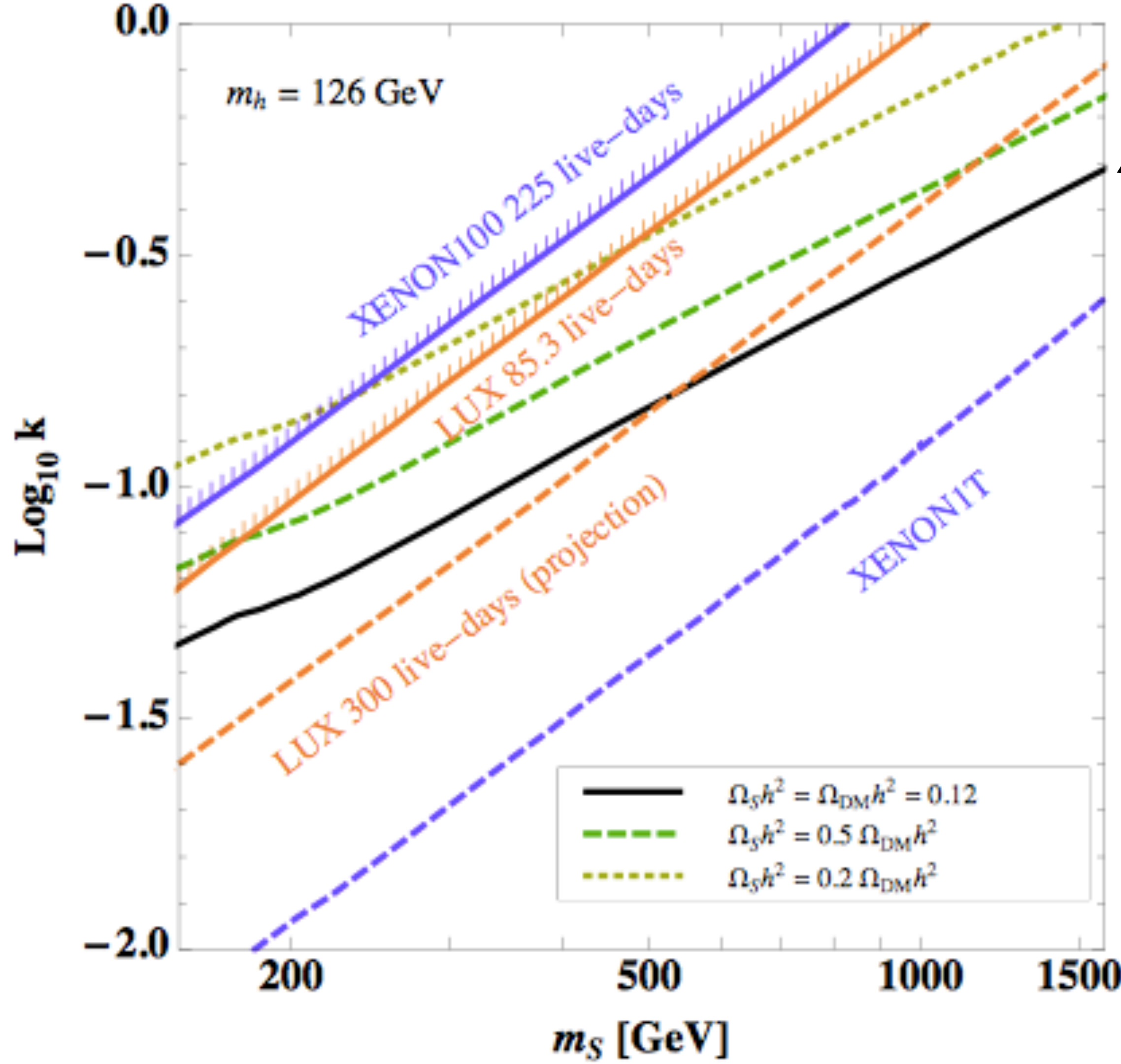
$Mp=10^{19}$ GeV: m_S = 850 GeV ~ 1.4 TeV, $M_R = 5.5\times10^{13} \sim 1.2\times10^{14}$ GeV current experimental bounds on k & m_S



line of $\Omega_S h^2$=0.119

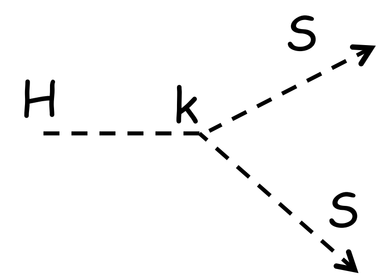


to keep constant $\Omega_S h^2$=0.119, k ∝ m_S [k-> large (small) with m_S-> large (small)] current experimental bounds on k & m_S



line of $\Omega_S h^2$=0.119

collider exp.



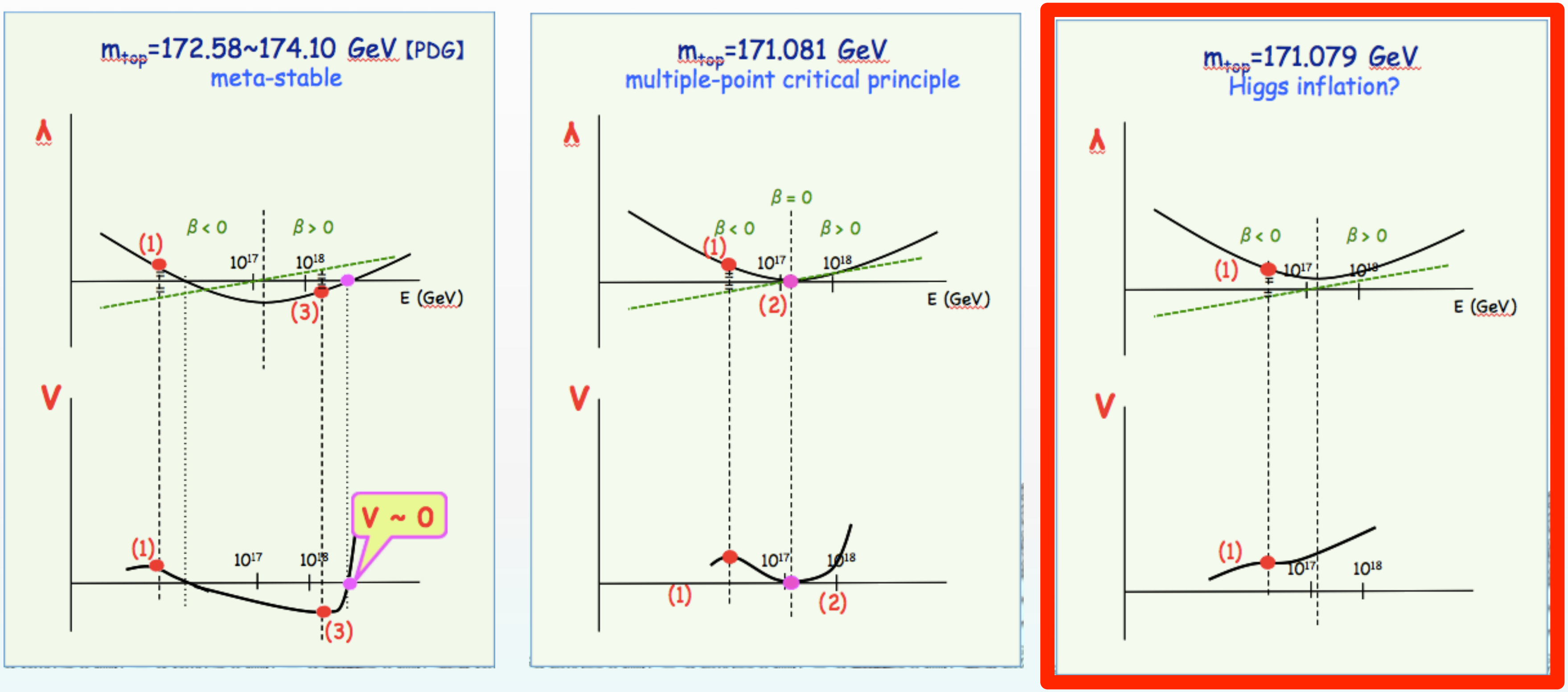
to detect at collider exp., k > 1 (but seems excluded DM search (& perturbativity))

to keep constant $\Omega_S h^2$=0.119, k ∝ m_S [k-> large (small) with m_S-> large (small)]

§4 Higgs inflation

arXiv:1404.4737 [hep-ph], NH, R. Takahashi
arXiv:1405.5738 [hep-ph], NH, H. Ishida and R.Takahashi,

m_H=125.9±0.4 GeV, m_{top}=171.83~174.31 GeV in the SM



λ(Mp)=β(Mp)=0
(V(Mp)=0)

Higgs inflation

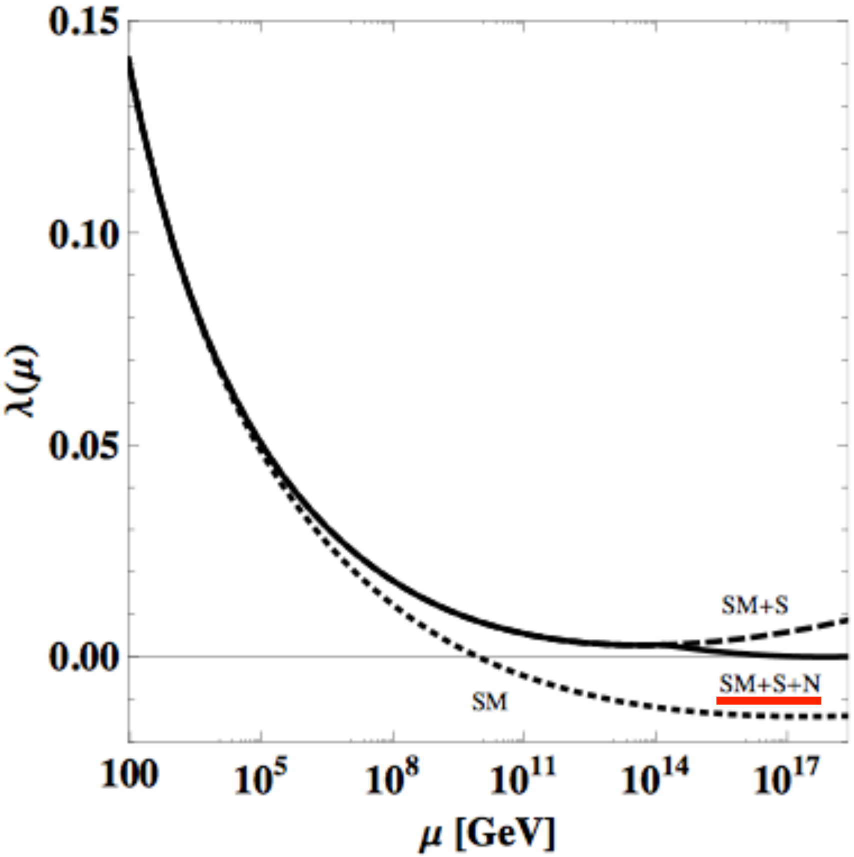
seem special

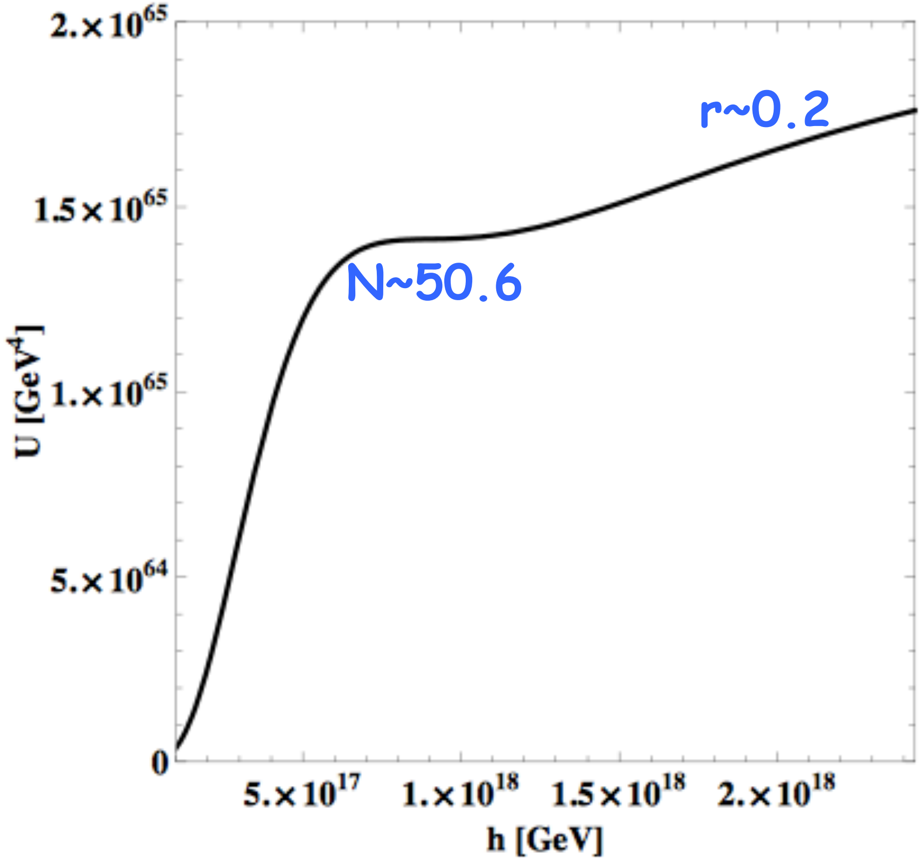
$$(4\pi)^2 \frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y_t^2 \underline{-12 y_t^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{8}[2g^4 + (g'^2 + g^2)^2]$$

scalar eff.

fermion eff.

suitable Higgs inflation





m_{top} = 173.34 GeV, m_H = 125.6 GeV, $m_S \simeq$ 1029 GeV, $M_R \simeq 1.58 \times 10^{14}$ GeV, $k(M_Z) \simeq 0.325$, and y_N (MZ) = $[m_\nu M_R]^{1/2}/v \simeq 0.512$, ξ=10.1

$$S_G = \int d^4x\sqrt{-g}\left\{ -\frac{M_P^2}{2}R - \frac{\xi h^2}{2}R \right\}$$

→ R. Takahashi's talk

§5 summary

summary

SM Higgs & top mass roughly implies

λ~0, β~0 @ Mp (<- expect Mp scale physics(?)

but, not accurate (current top mass), nor no DM (tiny m_ν, BAU) in SM
(& still no evidence of BSM @ LHC)

-> SM + scalar DM + ν_R model

λ=β=0 @ Mp -> determine m_S & M_R, and

Mp=10^{18} GeV: m_S = 800 GeV ~ 1.2 TeV, M_R = 6.3×10^{13} ~ 1.6×10^{14} GeV

Mp=10^{19} GeV: m_S = 850 GeV ~ 1.4 TeV, M_R = 5.5×10^{13} ~ 1.2×10^{14} GeV

-> Higgs inflation (consistent with BICEP2) can also possible in another option.