Next to new Minimal Standard Model

Scalars 2013, 11 – 16 Sept. 2013

Naoyuki Haba (Shimane U, Japan)

NH, K. Kaneta, R. Takahashi,

arXiv:1309.1231 [hep-ph]
(arXiv:1309.3254 [hep-ph])

contents

§1 introduction

- LHC shows no evidence of BSM.

  no SUSY, no extraD,···

- LHC shows no evidence of BSM.

  no SUSY, no extraD, $\cdots$

- SM ($m_H \sim$126GeV, $m_t \sim$173 GeV) can be a final theory?

- LHC shows no evidence of BSM.

  no SUSY, no extraD, ···

- SM ($m_H \sim 126$GeV, $m_t \sim 173$ GeV) can be a final theory?

  maybe No

- LHC shows no evidence of BSM.

  no SUSY, no extraD,···

- SM ($m_H \sim 126$GeV, $m_t \sim 173$ GeV) can be a final theory?

  maybe No, because

- LHC shows no evidence of BSM.

no SUSY, no extraD, ···

- SM ($m_H \sim 126$GeV, $m_t \sim 173$ GeV) can be a final theory?

maybe No, because

Problems in SM

- hierarchy problem
- dark matter
- ν mass, BAU
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

- LHC shows no evidence of BSM.

  no SUSY, no extraD,···

- SM ($m_H \sim 126$GeV, $m_t \sim 173$ GeV) can be a final theory?

  maybe No, because

Problems in SM

- hierarchy problem
- dark matter
- ν mass, BAU
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

  ⋮

let us reconsider various possibility of BSM once again,
since we do not know the answer what is BSM.

hierarchy problem?

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/Mp^4 \sim 10^{120}$

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/Mp^4 \sim 10^{120}$
- quadratic divergence is simply subtracted (b.c. @ M_P) ?
  (physically meaningful value is distant from critical line & not location of critical line itself.)

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/Mp^4 \sim 10^{120}$
- quadratic divergence is simply subtracted (b.c. @ M_P) ?
  (physically meaningful value is distant from critical line & not location of critical line itself.)
- $m_H \sim 126$ GeV, $m_{top} \sim 173$ GeV in the SM
  → triple coincidence @ Mp

(M. Lindner's talk)

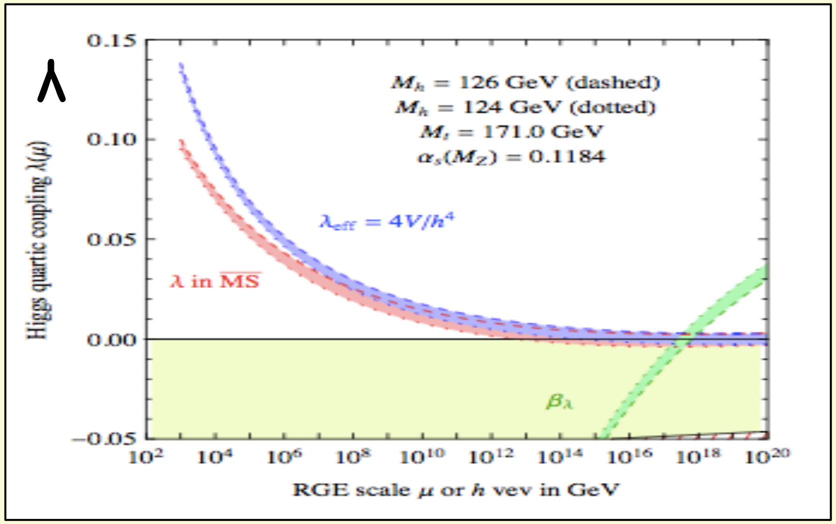
Froggah Nielsen (96)
M.Shaposhnikov (07)

$$\begin{cases} m_H \propto [\lambda - y_t^2 + 3g_2^2/8 + g_1^2/8]\,\Lambda^2 \sim 0 \text{ (Veltman condition)} \\ \beta_\lambda \sim [\lambda^2 - \lambda(g_1^2/8+3g_2^2/8-y_t^2/2)+g_1^4/64+g_1^2g_2^2/32+3g_2^4/64-y_t^4/4] \sim 0 \\ \lambda \sim 0 \end{cases}$$

-> Higgs potential is flat @M_p
  (induced only radiative correction)
  (Higgs inflation)

-> SUSY$\sim 10^{10}$GeV (I. Antoniadis' talk)

-> conformal sym? shift sym?



G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/M_p^4 \sim 10^{120}$
- quadratic divergence is simply subtracted (b.c. @ M_P) ?
  (physically meaningful value is distant from critical line & not location of critical line itself.)
- $m_H \sim 126$ GeV, $m_{top} \sim 173$ GeV in the SM
  (M. Lindner's talk)
  → triple coincidence @ Mp
  Froggah Nielsen (96)
  M.Shaposhnikov (07)

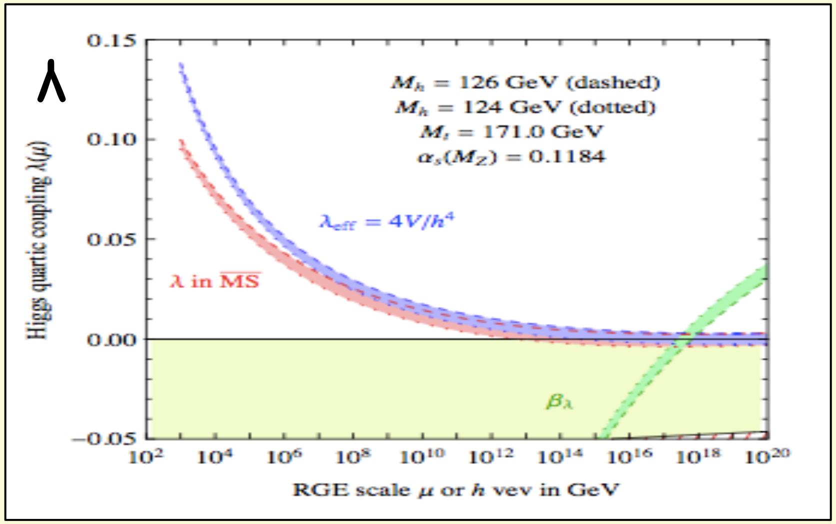
$$\begin{cases} m_H \propto [\lambda - y_t^2 + 3g_2^2/8 + g_1^2/8]\,\Lambda^2 \sim 0 \text{ (Veltman condition)} \\ \beta_\lambda \sim [\lambda^2 - \lambda(g_1^2/8 + 3g_2^2/8 - y_t^2/2) + g_1^4/64 + g_1^2 g_2^2/32 + 3g_2^4/64 - y_t^4/4] \sim 0 \\ \lambda \sim 0 \end{cases}$$

-> Higgs potential is flat @M_p
(induced only radiative correction)
(Higgs inflation)

-> SUSY$\sim 10^{10}$GeV (I. Antoniadis' talk)

-> conformal sym? shift sym?

- nature chooses fine-tuning?
  (CNO-cycle, size of sun-moon from earth…)



G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/Mp^4 \sim 10^{120}$
- quadratic divergence is simply subtracted (b.c. @ M_P) ?
  (physically meaningful value is distant from critical line & not location of critical line itself.)
- $m_H \sim 126$ GeV, $m_{top} \sim 173$ GeV in the SM
  → triple coincidence @ Mp

(M. Lindner's talk)

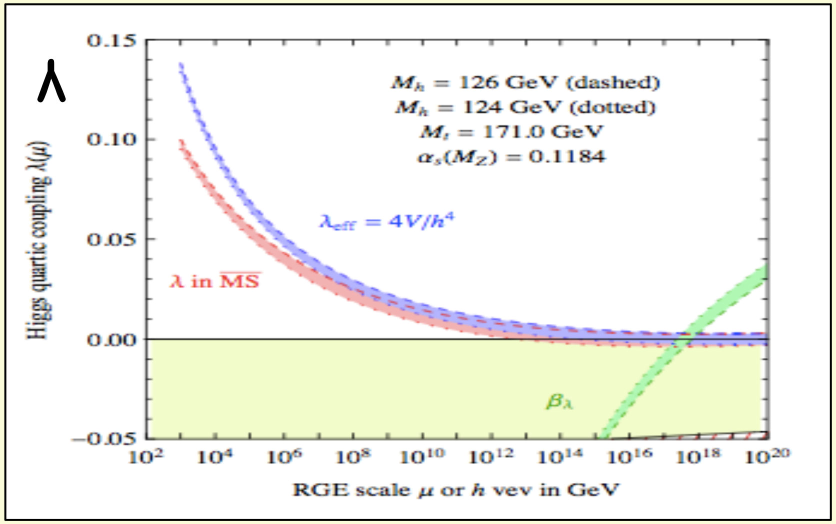
Froggah Nielsen (96)
M.Shaposhnikov (07)

$$\begin{cases} m_H \propto [\lambda - y_t^2 + 3g_2^2/8 + g_1^2/8]\, \Lambda^2 \sim 0 \text{ (Veltman condition)} \\ \beta_\lambda \sim [\lambda^2 - \lambda (g_1^2/8+3g_2^2/8-y_t^2/2)+g_1^4/64+g_1^2 g_2^2/32+3g_2^4/64-y_t^4/4] \sim 0 \\ \lambda \sim 0 \end{cases}$$

-> Higgs potential is flat @M_p
(induced only radiative correction)
(Higgs inflation)

-> SUSY$\sim 10^{10}$GeV (I. Antoniadis' talk)

-> conformal sym? shift sym?



G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

- nature chooses fine-tuning?
  (CNO-cycle, size of sun-moon from earth…)
- multiverse? no fine-tuning problem
  (Y. Nomura's talk)

hierarchy problem?

- much better than cosmological constant terrible fine-tuning $\Lambda^4/Mp^4 \sim 10^{120}$
- quadratic divergence is simply subtracted (b.c. @ M_P) ?
  (physically meaningful value is distant from critical line & not location of critical line itself.)
- $m_H \sim 126$ GeV, $m_{top} \sim 173$ GeV in the SM
  → triple coincidence @ Mp

(M. Lindner's talk)

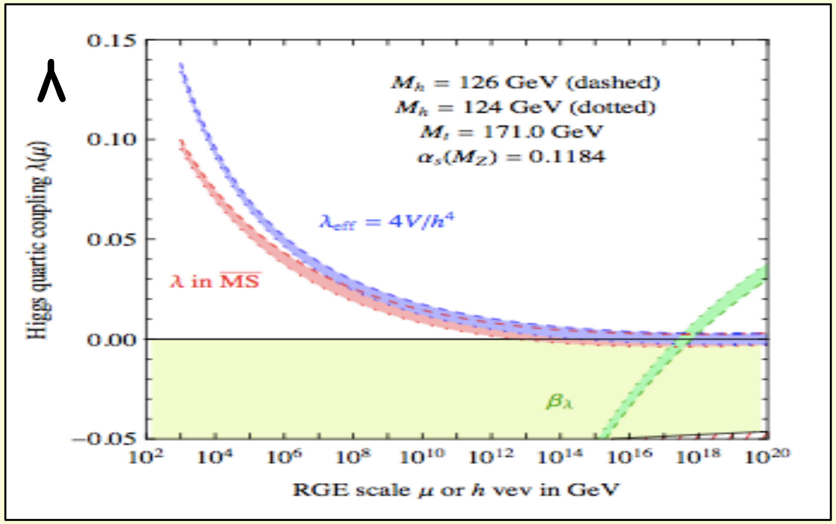
Froggah Nielsen (96)
M.Shaposhnikov (07)

$$\begin{cases} m_H \propto [\lambda - y_t^2 + 3g_2^2/8 + g_1^2/8]\,\Lambda^2 \sim 0 \text{ (Veltman condition)} \\ \beta_\lambda \sim [\lambda^2 - \lambda(g_1^2/8+3g_2^2/8-y_t^2/2)+g_1^4/64+g_1^2g_2^2/32+3g_2^4/64-y_t^4/4] \sim 0 \\ \lambda \sim 0 \end{cases}$$

-> Higgs potential is flat $@M_p$
(induced only radiative correction)
(Higgs inflation)

-> SUSY $\sim 10^{10}$GeV (I. Antoniadis' talk)

-> conformal sym? shift sym?



G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

- nature chooses fine-tuning?
  (CNO-cycle, size of sun-moon from earth…)
- multiverse? no fine-tuning problem
  (Y. Nomura's talk)

"hierarchy problem" is really a problem?

Forgetting hierarchy problem,

Forgetting hierarchy problem, let us try to explain other

Problems in SM

- hierarchy problem
- dark matter
- ν mass, BAU
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

by introducing minimal new fields (& parameters)

Forgetting hierarchy problem, let us try to explain other

Problems in SM

- hierarchy problem
- dark matter
- ν mass, BAU
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Forgetting hierarchy problem, let us try to explain other

Problems in SM

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Forgetting hierarchy problem, let us try to explain other

Problems in SM

- hierarchy problem
- dark matter → introduce real scala
- ν mass, BAU → introduce two ν_R & leptogenesis
- inflation
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Forgetting hierarchy problem, let us try to explain other

Problems in SM

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU → introduce two ν_R
- inflation → introduce real scalar inflaton (chaotic)
- cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

$$L_{Infration} = -m^2\varphi^2 - \mu\varphi^3 - \kappa\varphi^4$$

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Forgetting hierarchy problem, let us try to explain other

Problems in SM

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU → introduce two ν_R & leptogenesis
- inflation → introduce real scalar in
- cosmological constant → add cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

$$L_{CC} = (2.3 \times 10^{-3} eV)^4$$

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

§2 next to new minimal standard model

Forgetting hierarchy problem, let us focus on solving other problems

Problems in SM

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU → introduce two ν_R & leptogenes
- inflation → introduce real scalar inflaton (chaotic)
- cosmological constant → add cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

  :

by introducing minimal new fields (& parameters)

⇓

New Minimal SM

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Forgetting hierarchy problem, let us focus on solving other problems

Problems in SM

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU → introduce two ν_R & leptogenes
- inflation → introduce real scalar inflaton (chaotic)
- cosmological constant → add cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

by introducing minimal new fields (& parameters)

⇓

Next to **New Minimal SM**

Forgetting hierarchy problem, let us focus on solving other problems

Problems in SM

- hierarchy problem
- dark matter → introduce real scalar DM
- ν mass, BAU → introduce two ν_R & leptogenes
- inflation → introduce real scalar inflaton (chaotic)
- cosmological constant → add cosmological constant
- charge quantization (gauge coupling unification)
- strong CP

:

by introducing minimal new fields (& parameters)

⇓

Next to New Minimal SM

cf) SUSY: DM & GCU

New Minimal SM:

$$L_{NMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -m^2\varphi^2 - \mu\varphi^3 - \kappa\varphi^4$$

$$L_{CC} = (2.3\times 10^{-3} eV)^4$$

+h.c. + Kinetic terms

H.Davoudiasl, R.Kitano, T.Li and H.Murayama, PLB609 (2005) 117

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Renormalizable OPs

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

introduce Z_2-sym, odd: S

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Renormalizable OPs

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3} eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^{\dagger}H^{\dagger}E$$

introduce Z_2-sym, odd: S, λ_3, λ_2

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Renormalizable OPs

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

introduce Z_2-sym, odd: S, λ_3, λ_2

Chaotic → CW-type

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Renormalizable OPs

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3} eV)^4$$

+h.c. + Kinetic terms

☆ $$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

introduce Z_2-sym, odd: S, λ_3, λ_2

Chaotic → CW-type

SU(3) adjoint fermion

SU(2) adjoint fermion

nth vector-like Lepton doublets

Setup: $M_3=M_2=M_L$

Renormalizable OPs

☆GCU sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3 \lambda_3^2 + M_2 \lambda_2^2 + M_{L_i} \overline{L}_i L_i + y_L L \widetilde{H} E + y_L \overline{L}^\dagger H^\dagger E$$

- SU(3) & SU(2) adjoint fermion + $(L+\overline{L})\times n$ (MSSM like)

☆GCU sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L}_i L_i + y_L L\widetilde{H}E + y_L \overline{L}^{\dagger} H^{\dagger} E$$

- **SU(3) & SU(2) adjoint fermion + (L+$\overline{\text{L}}$)×n (MSSM like)**
  - n=1: no GCU

☆GCU sector in NNMSM:

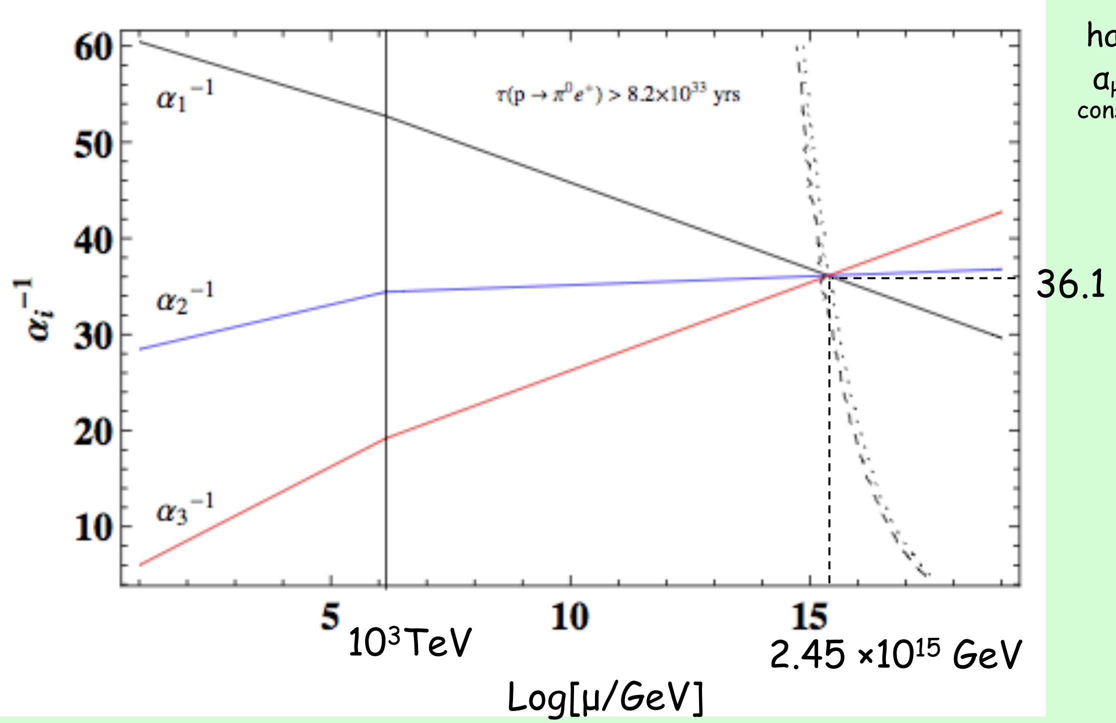
$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L \overline{L}^{\dagger} H^{\dagger} E$$

- **SU(3) & SU(2) adjoint fermion + (L+$\overline{L}$)×n (MSSM like)**
  - n=1: no GCU
  - n=2: good! with 10^3 TeV $\lambda_{2,3}$, L, $\overline{L}$

→ α^{-1}~36.1 @ GCU scale 2.45 × 10^{15} GeV

close to present bound ($p \to \pi^0 e^+$) → can be detected at HK



hadronic matrix element
α_H=-0.0112±0.0034 GeV^2
conservative bound is not cleared

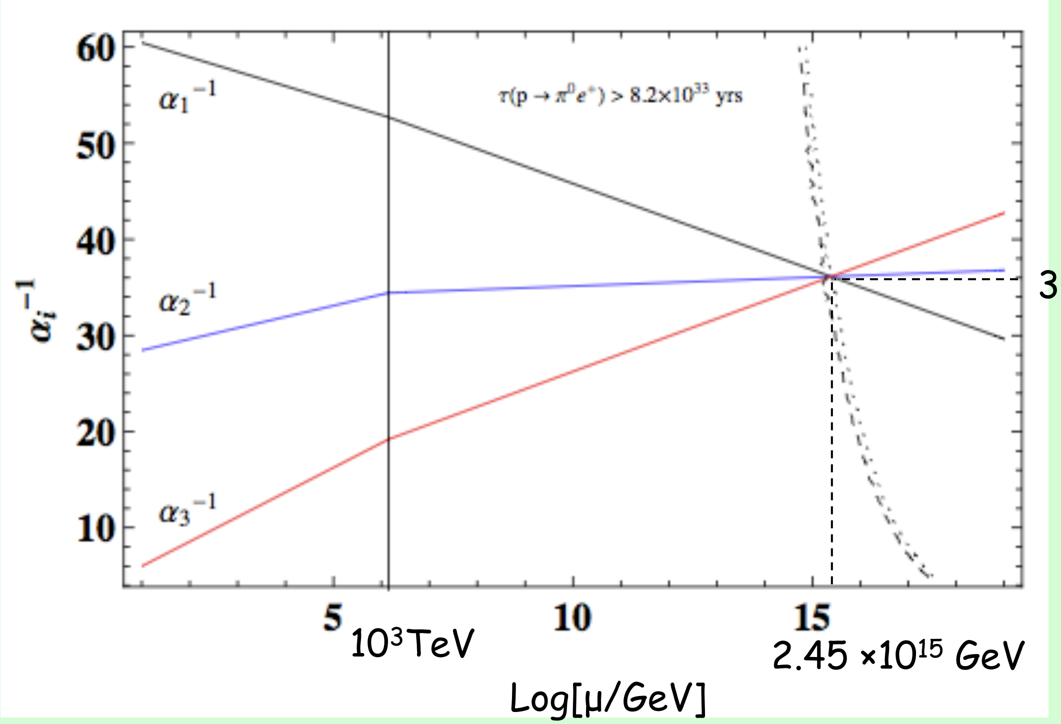
☆GCU sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L \overline{L}^\dagger H^\dagger E$$

・SU(3) & SU(2) adjoint fermion + $(L+\overline{L})\times n$ (MSSM like)

- n=1: no GCU
- n=2: good! with 10^3 TeV $\lambda_{2,3}$, L, $\overline{L}$
  - → $\alpha^{-1} \sim 36.1$ @ GCU scale 2.45×10^{15} GeV
  - close to present bound ($p \to \pi^0 e^+$) → can be detected at HK



hadronic matrix element
$\alpha_H = -0.0112 \pm 0.0034$ GeV^2
conservative bound is not cleared

- n>2: rapid proton decay

☆GCU sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3 \lambda_3^2 + M_2 \lambda_2^2 + M_{L_i} \overline{L}_i L_i + y_L L \widetilde{H} E + y_L \overline{L}^\dagger H^\dagger E$$

- SU(3) & SU(2) adjoint fermion + $(L+\overline{L}) \times n$ (MSSM like)

  - n=2: good! with 10^3 TeV $\Lambda_{2,3}$ & L, $\overline{L}$

    stable in renormalized OPs

☆GCU sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{GCU} = M_3 \lambda_3^2 + M_2 \lambda_2^2 + M_{L_i} \overline{L}_i L_i + y_L L \widetilde{H} E + y_L \overline{L}^\dagger H^\dagger E$$

・SU(3) & SU(2) adjoint fermion + (L+$\overline{L}$)×n (MSSM like)

・n=2: good! with 10^3 TeV $\lambda_{2,3}$ & L, $\overline{L}$

stable in renormalized OPs

→ let us consider low reheating temperature

$T_R < 10^3$ TeV/40 ~ 25 TeV

their productions as particles are very few -> negligible

(L, $\overline{L}$ can also decay to leptons through Yukawa ints.)

cf.) when N' (light Z_2-odd singlet) is introduced, λ can be decay through dim6 OP as $Q\lambda QN'/\Lambda^2$ but, $\Lambda < 10^{13}$ GeV for decay before BBN (1s), this scale is unwanted additional scale.

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + \underline{L_{Infration}} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$\star\, L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3}\,eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^\dagger H^\dagger E$$

☆Inflation sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + \underline{L_{Infration}} + L_{CC} + L_{GCU}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

- **consistent with T_R<25 TeV (CW-type inflation model)**
- In NMSM, $L_{Inflation}=-m^2\varphi^2-\mu\varphi^3-\kappa\varphi^4$ (Chaotic Inflation model),
  (e-folds N~60 is consistent with today's cosmological observations (μ≒κ≒0))

  but, today's cosmological observations is not consistent with T_R < 25 TeV (small e-folds), so it is no good.

☆Inflation sector in NNMSM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{Infration} = -B\varphi^4 \left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2} \right] - B\sigma^4 - \mu_1 \varphi |H|^2 - \kappa_H \varphi^2 |H|^2 - \kappa_S \varphi^2 S^2$$

Set tiny for slow-row & not affect RGE

- **consistent with T_R<25 TeV (CW-type inflation model)**
- In NMSM, $L_{Inflation}$=-$m^2\varphi^2$-$\mu\varphi^3$-$\kappa\varphi^4$ (Chaotic Inflation model),
  (e-folds N~60 is consistent with today's cosmological observations (μ≒κ≒0))

  but, today's cosmological observations is not consistent with T_R < 25 TeV (small e-folds), so it is no good.

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times 10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^{\dagger}H^{\dagger}E$$

☆ν_R sector & BAU

$$L_{NNMSM} = L_{SM} + L_{DM} + \underline{L_{\nu R}} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{\nu R} = -M\,\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

- minimal setup is introducing two ν_R

  → lightest ν is massless

☆ν_R sector & BAU

$$L_{NNMSM} = L_{SM} + L_{DM} + \underline{L_{\nu R}} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{\nu R} = -M\,\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

- minimal setup is introducing two ν_R
  → lightest ν is massless
- BAU must work under low T_R (< 25 TeV)
  → ex). resonant leptogenesis

☆ν_R sector & BAU

$$L_{NNMSM} = L_{SM} + L_{DM} + \underline{L_{\nu R}} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

- minimal setup is introducing two ν_R
  - → lightest ν is massless
- BAU must work under low T_R (< 25 TeV)
  - → ex). resonant leptogenesis

→ mass of ν_R < 25 TeV

☆ν_R sector & BAU

$$L_{NNMSM} = L_{SM} + L_{DM} + \underline{L_{\nu R}} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{\nu R} = -M\,\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

- minimal setup is introducing two ν_R

  → lightest ν is massless

- BAU must work under low T_R (< 25 TeV)

  → ex). resonant leptogenesis

  → mass of ν_R < 25 TeV → $\mathbf{y_\nu < 10^{-5}}$

☆ν_R sector & BAU

$$L_{NNMSM} = L_{SM} + L_{DM} + \underline{L_{\nu R}} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

- minimal setup is introducing two ν_R
  → lightest ν is massless
- BAU must work under low T_R (< 25 TeV)
  → ex). resonant leptogenesis

  → mass of ν_R < 25 TeV → $Y\nu < 10^{-5}$ → **negligible in RGE of λ**

Next to New Minimal SM:

$$L_{NNMSM} = L_{SM} + L_{DM} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

$$L_{\nu R} = -M\overline{N^c}N + y_\nu L\widetilde{H}\overline{N}$$

$$L_{Infration} = -B\varphi^4\left[\ln\left(\frac{\varphi^2}{\sigma^2}\right) - \frac{1}{2}\right] - B\sigma^4 - \mu_1\varphi|H|^2 - \kappa_H\varphi^2|H|^2 - \kappa_S\varphi^2 S^2$$

$$L_{CC} = (2.3\times10^{-3}eV)^4$$

+h.c. + Kinetic terms

$$L_{GCU} = M_3\lambda_3^2 + M_2\lambda_2^2 + M_{L_i}\overline{L_i}L_i + y_L L\widetilde{H}E + y_L\overline{L}^{\dagger}H^{\dagger}E$$

☆DM sector & vacuum in NNMSM:

$$L_{NNMSM} = \underline{L_{SM}} + \underline{L_{DM}} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 \underline{S}^2 - k|H|^2 \underline{S}^2 - \lambda_S \underline{S}^4$$ ← **real scalar S is DM** [Z_2-odd (stable)]

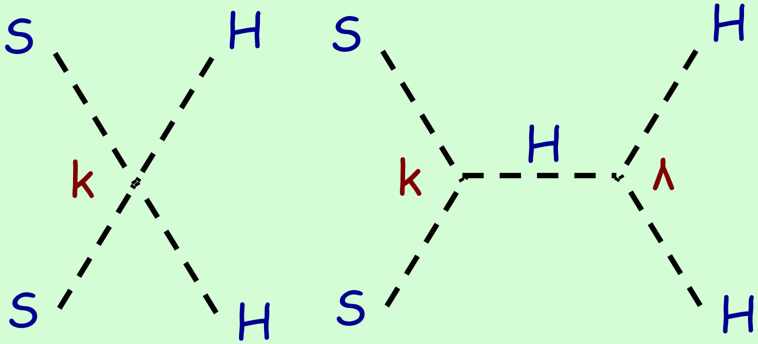
☆DM sector & vacuum in NNMSM:

$$L_{NNMSM} = \underline{L_{SM}} + \underline{L_{DM}} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

$$L_{DM} = -m_S^2 \underline{S}^2 - k|H|^2 \underline{S}^2 - \lambda_S \underline{S}^4$$ ← **real scalar S is DM** [Z_2-odd (stable)]

DM relic density **depends on λ & k** (not λ_S)



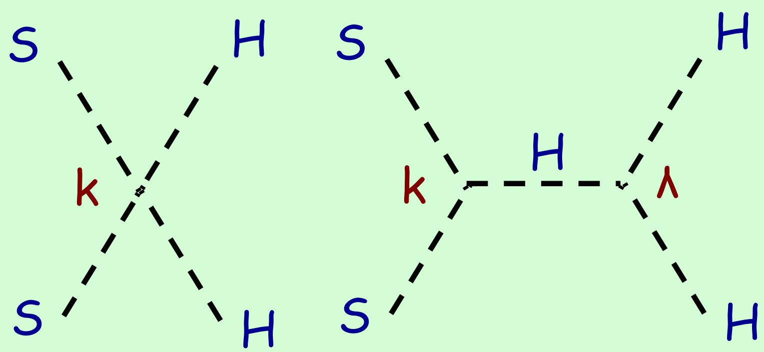
☆DM sector & vacuum in NNMSM:

$$L_{NNMSM} = \underline{L_{SM}} + \underline{L_{DM}} + L_{\nu R} + L_{Infration} + L_{CC} + L_{GCU}$$

$$L_{SM} \supset -\lambda(|H|^2 - v^2)^2$$

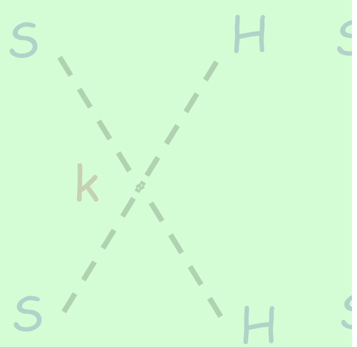
$$L_{DM} = -m_S^2 \underline{S}^2 - k|H|^2 \underline{S}^2 - \lambda_S \underline{S}^4$$ ← **real scalar S is DM** [Z_2-odd (stable)]

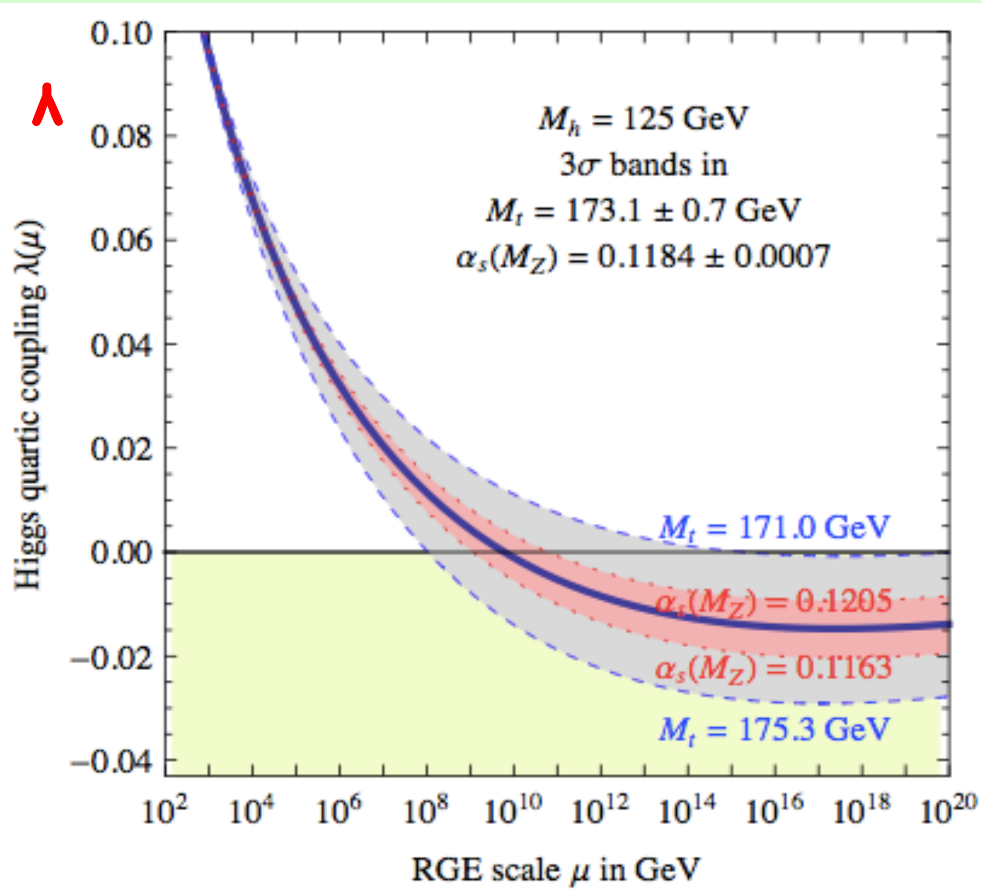
DM relic density **depends on λ & k** (not λ_S) & stability-triviality do **Y_t, [M_t = 173.5 ± 1.4 GeV]**



$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12 y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

DM relic density **depends on** λ & k (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ± 1.4 GeV]**

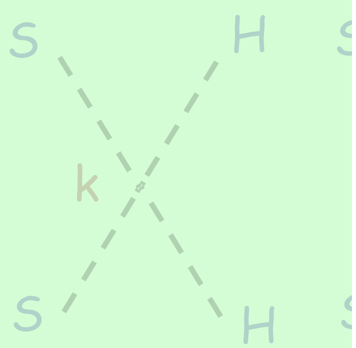


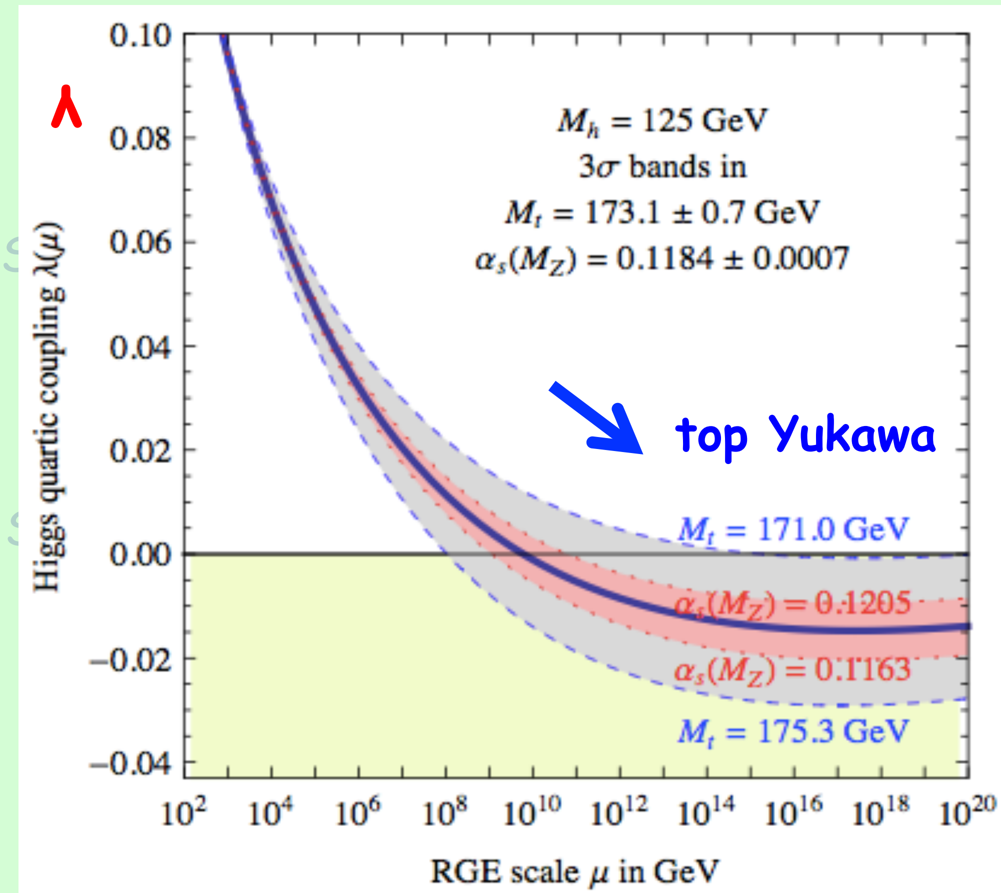


G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 \underline{- 12y^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

DM relic density **depends on** λ & k (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ± 1.4 GeV]**

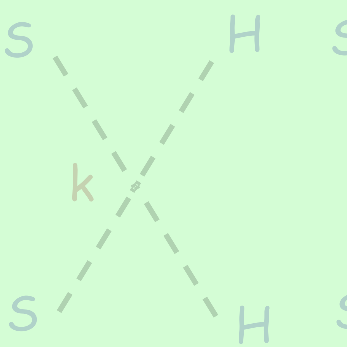


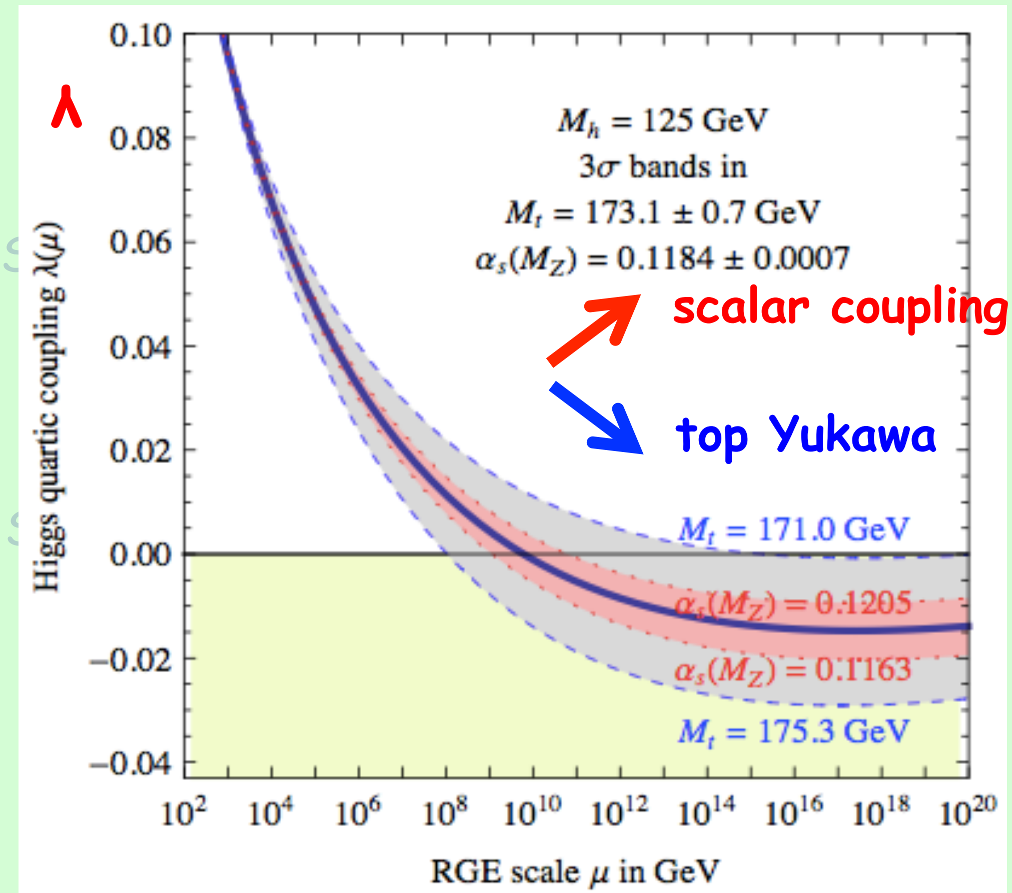


G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

DM relic density **depends on** λ & k (not λ_S) & stability-triviality do Y_t, [M_t = 173.5 ± 1.4 GeV]

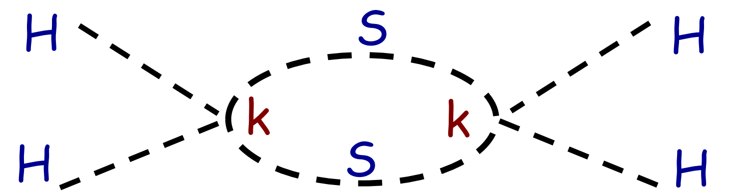




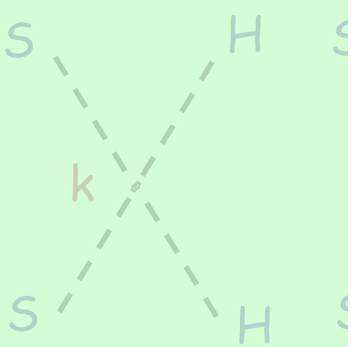
G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

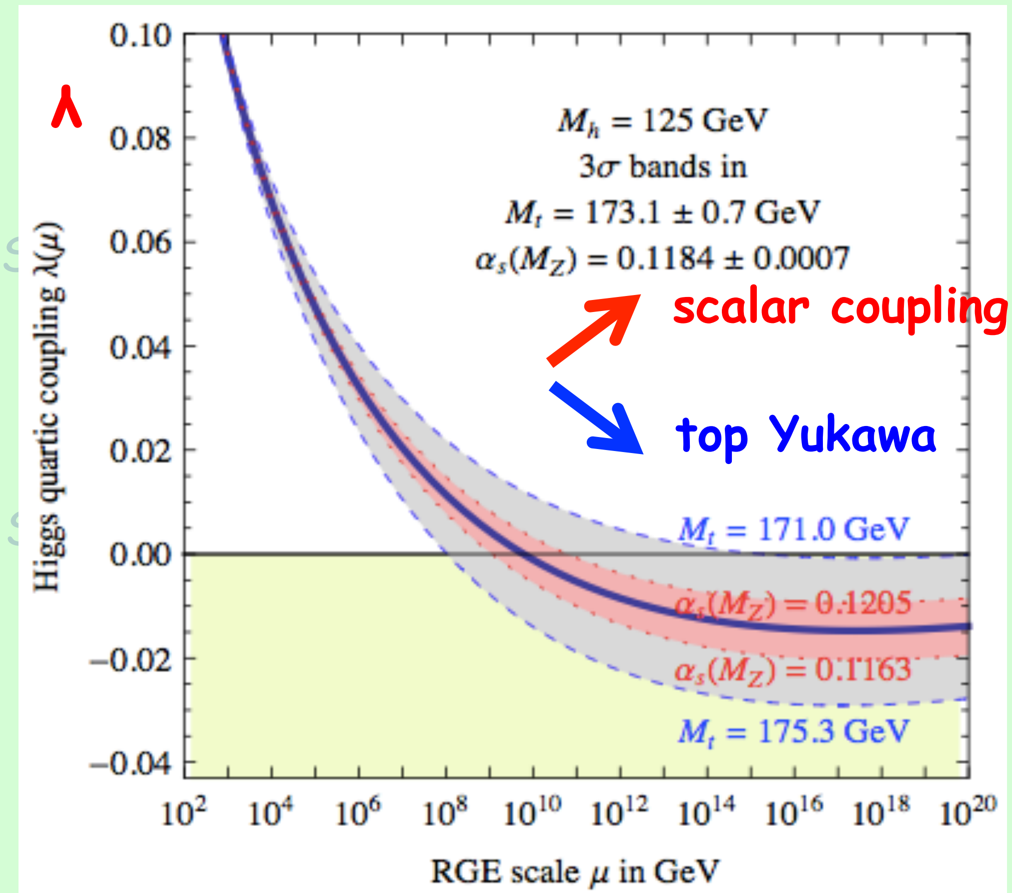
$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

$$L_{DM} = -m_S^2 S^2 - k \mid H \mid^2 S^2 - \lambda_S S^4$$



DM relic density depends on λ & k (not λ_S) & stability-triviality do Y_t, [M_t = 173.5 ± 1.4 GeV]

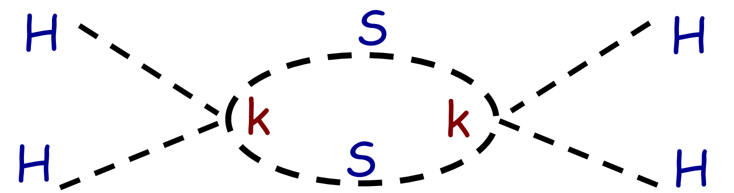




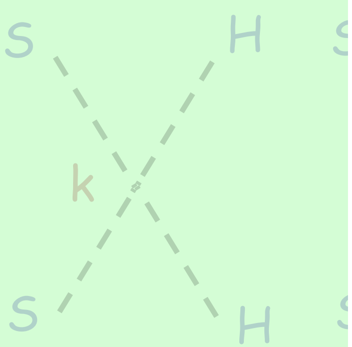
G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

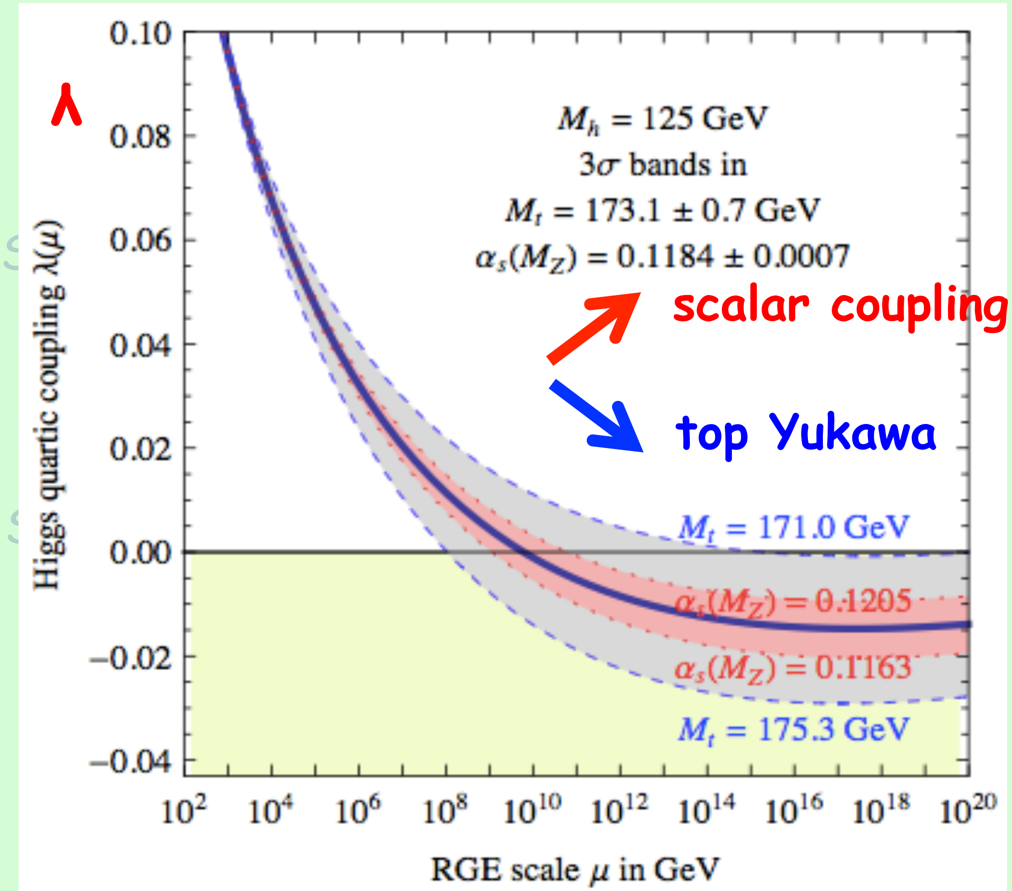
$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**

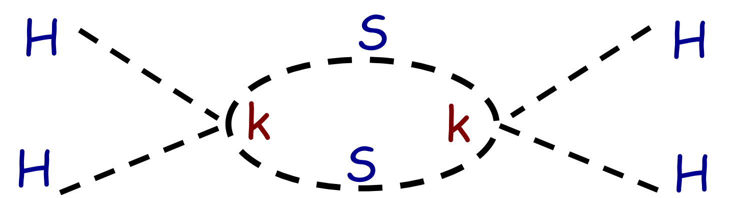




G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

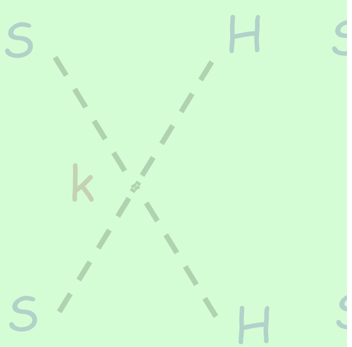
$$(4\pi)^2\frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y^2 \underline{-12y^4} - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4+(g'^2+g^2)^2\right] \underline{+k^2},$$

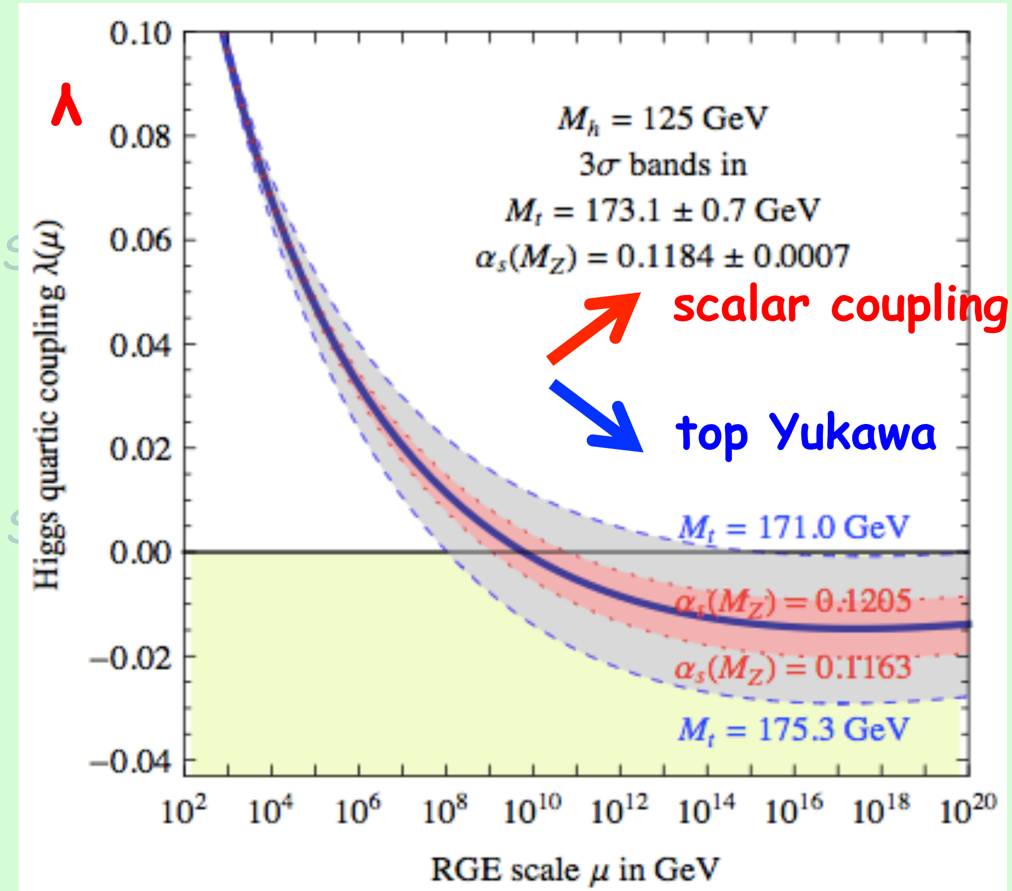
small y_t → blow up → triviality



$$L_{DM} = -m_S^2 S^2 - \underline{k} \mid H \mid^2 S^2 - \lambda_S S^4$$

DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**

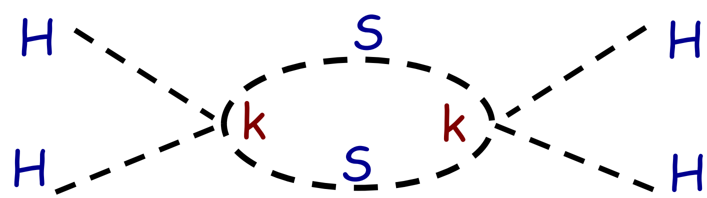




G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

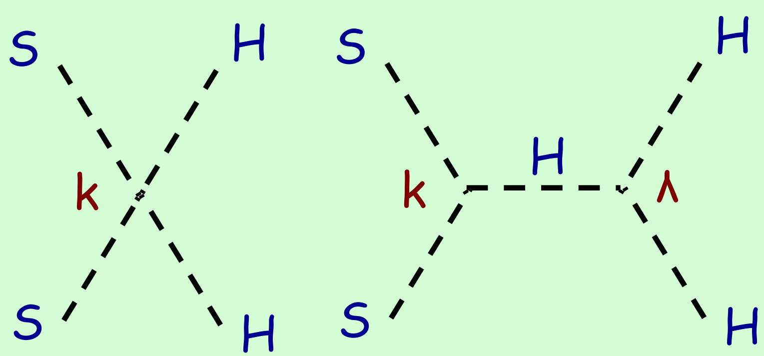
$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

small y_t → blow up → triviality

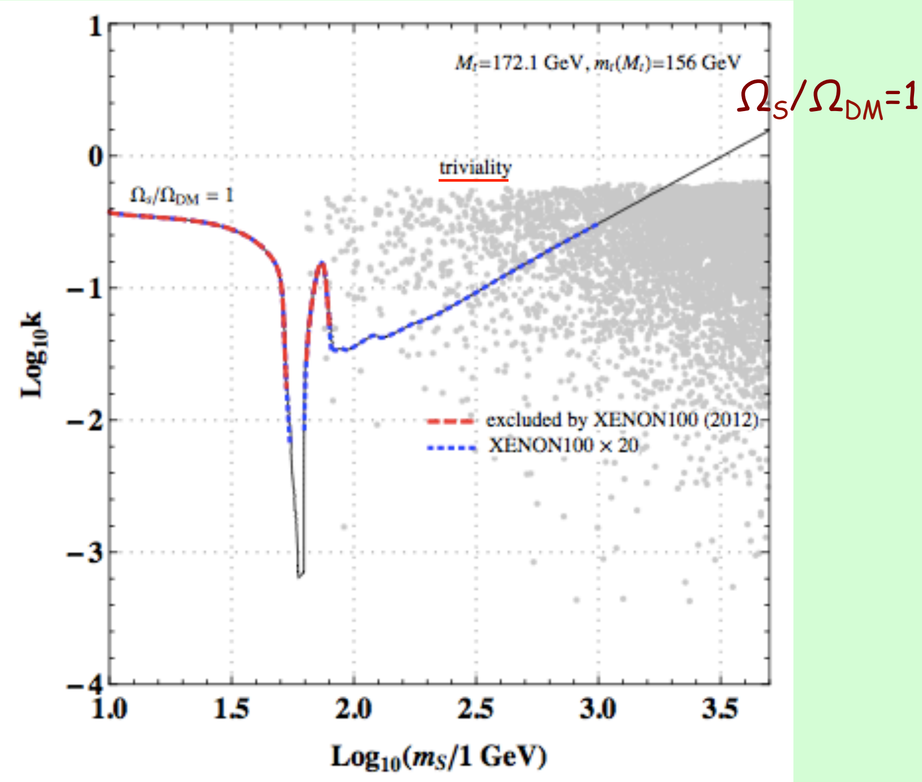


$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$

DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**



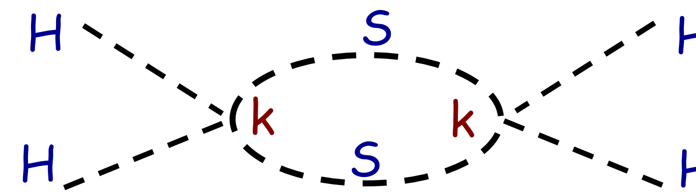
λ_S is randomly scanned, [0, 4π]



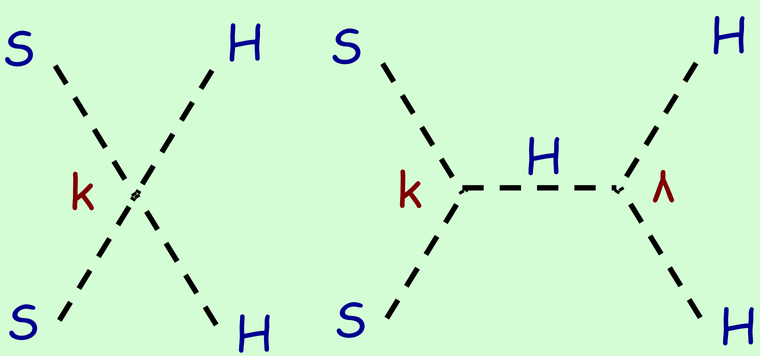
$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

small y_t → blow up → triviality

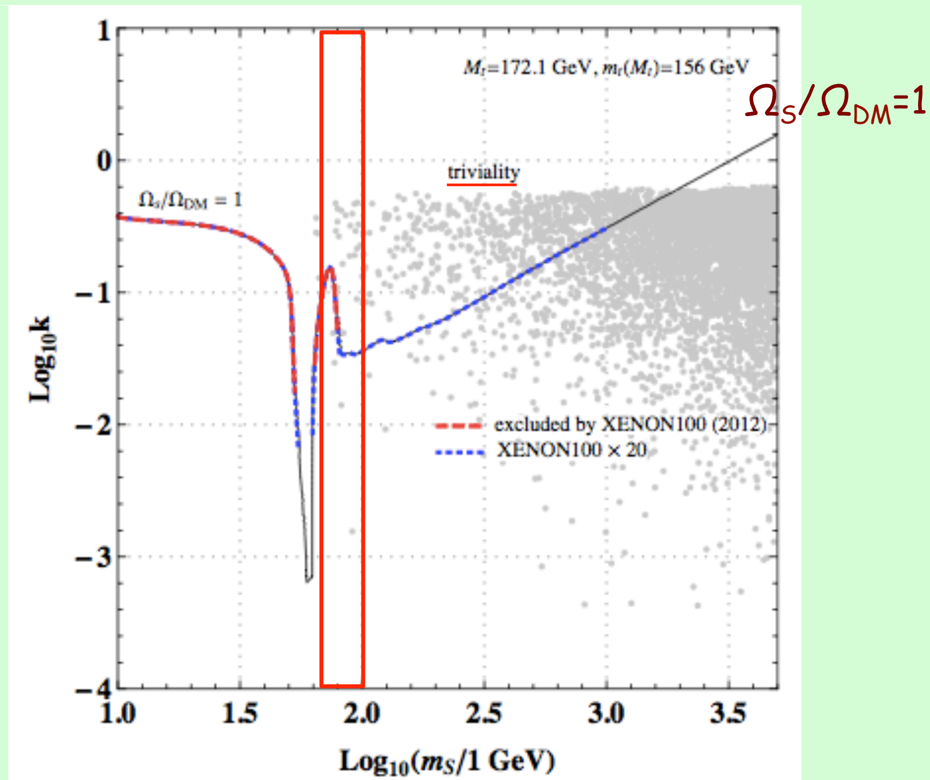
$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, [M_t = 173.5 **- 1.4** GeV]



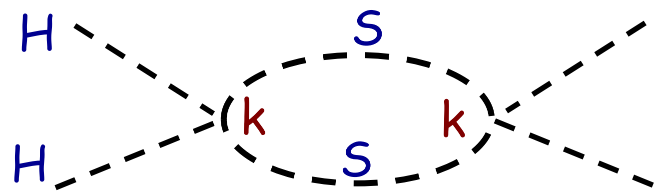
λ_S is randomly scanned, [0, 4π]



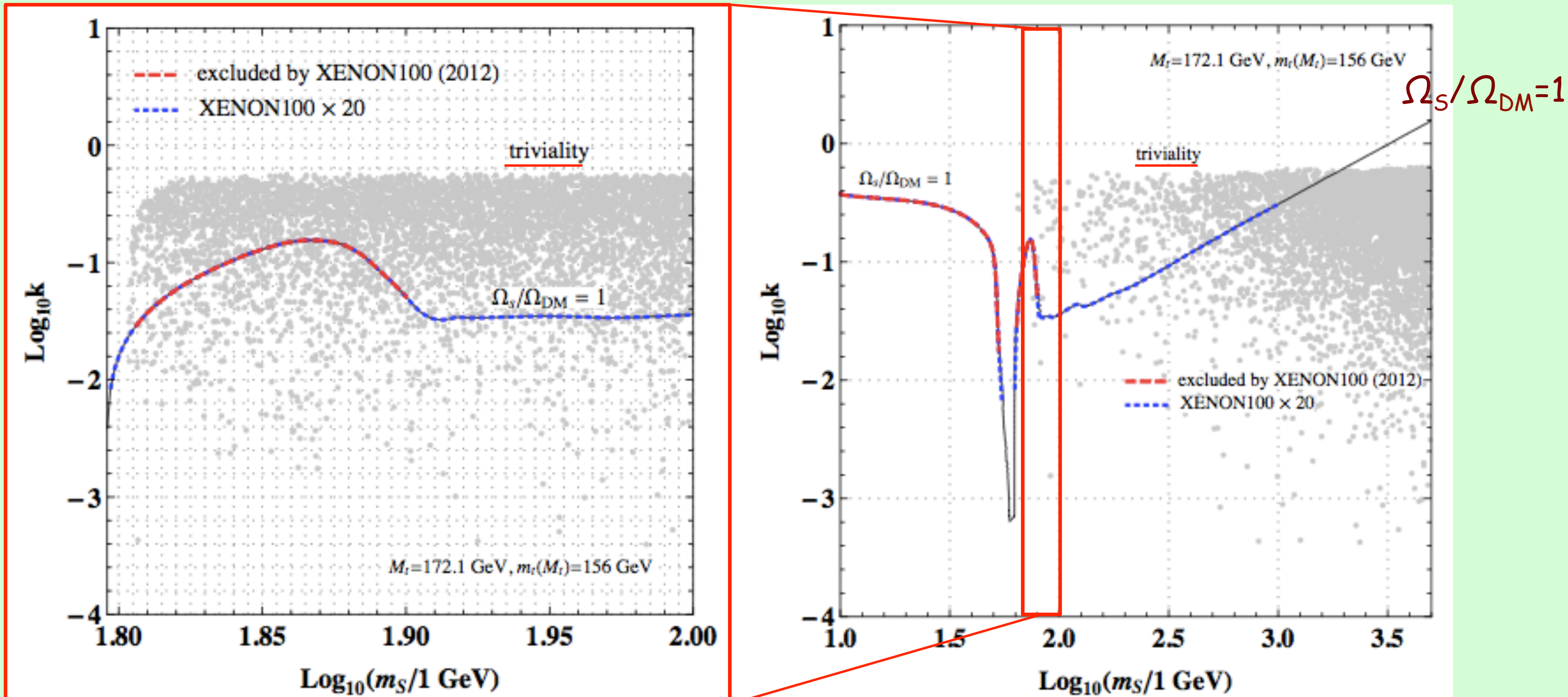
$$(4\pi)^2\frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y^2 \underline{- 12y^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] \underline{+ k^2},$$

small y_t → blow up → triviality

$$L_{DM} = -\underline{m_S^2} S^2 - \underline{k} |H|^2 S^2 - \underline{\lambda_S} S^4$$



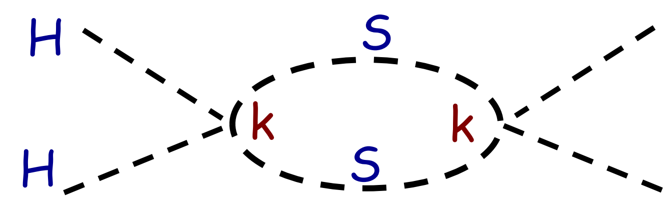
DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**



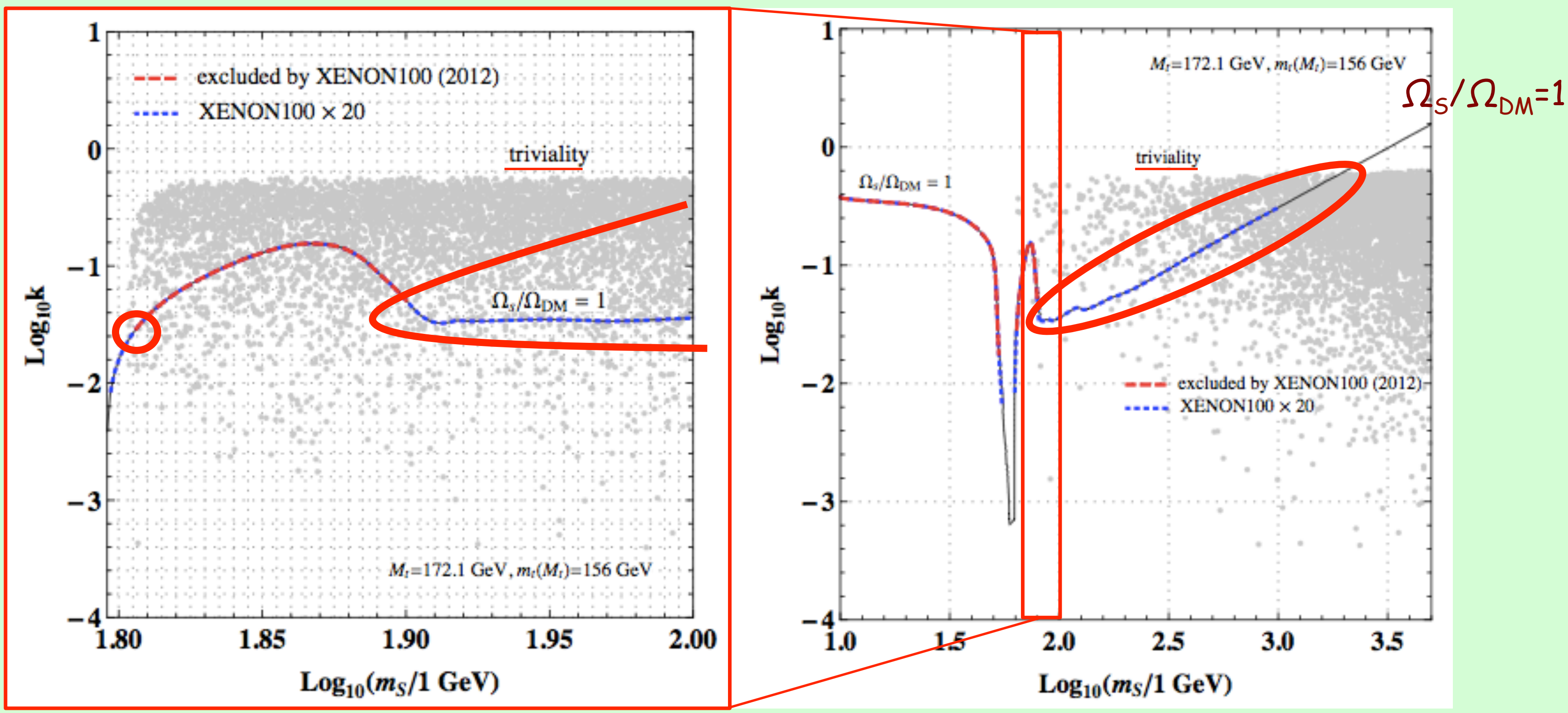
$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

small y_t → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



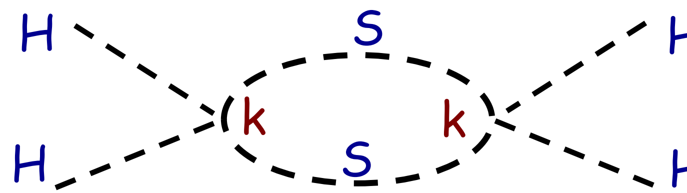
DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**



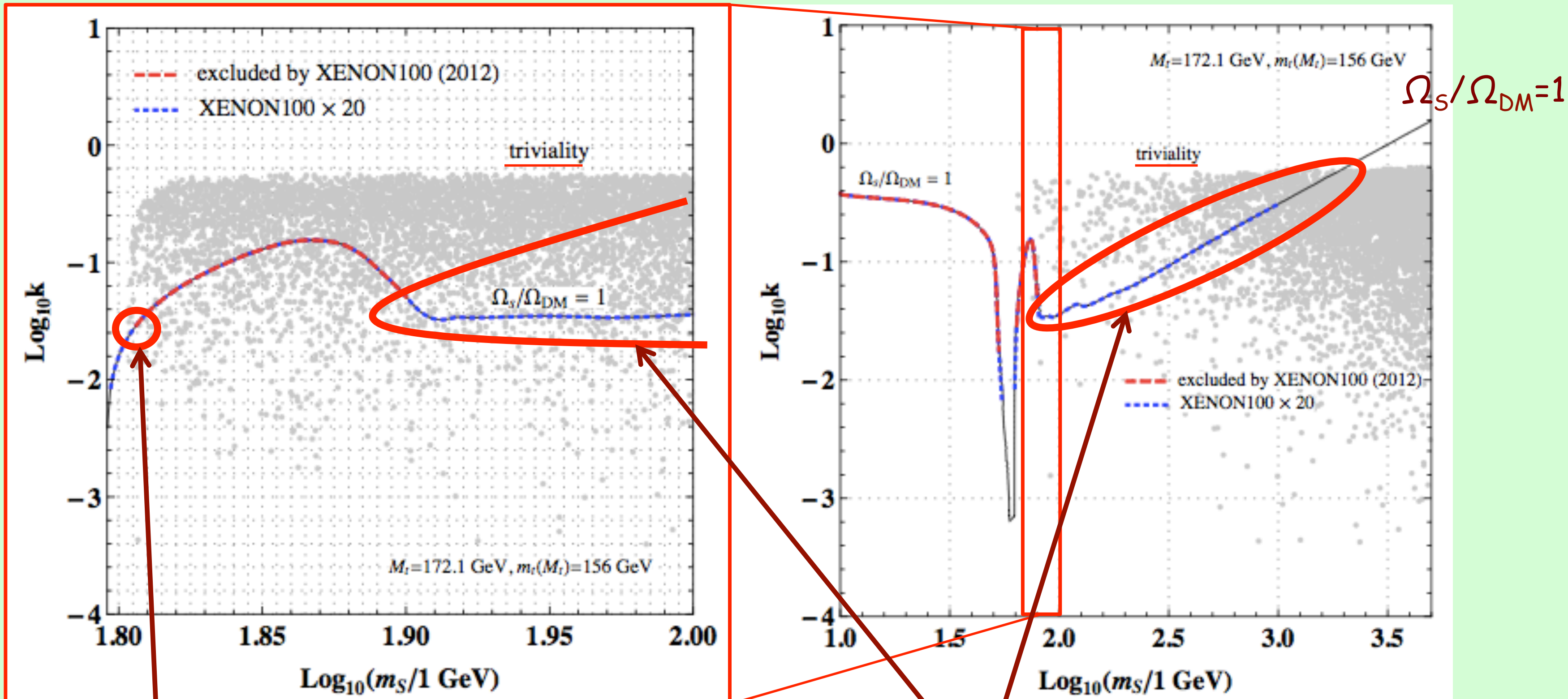
$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

small y_t → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**



m_S=63.5～64.5 GeV

m_S=81.2～2040 GeV

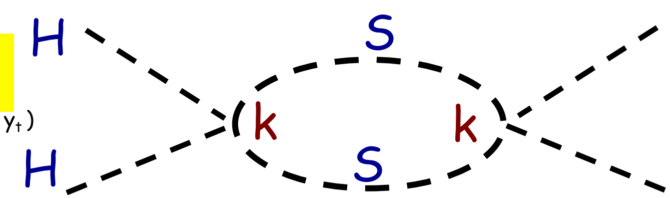
$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

small y_t → blow up → triviality

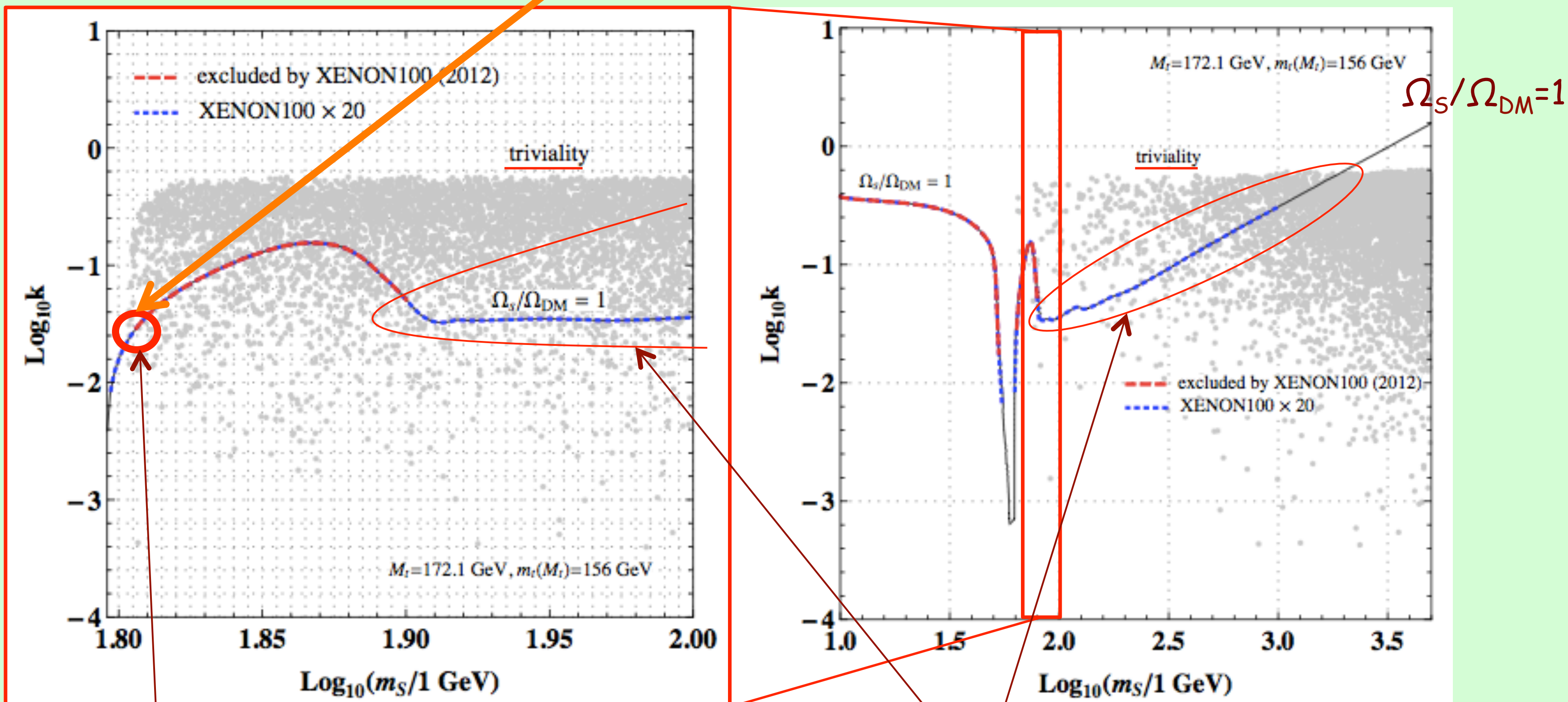
small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$

(independent of small error of y_t)



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 - 1.4 GeV]**



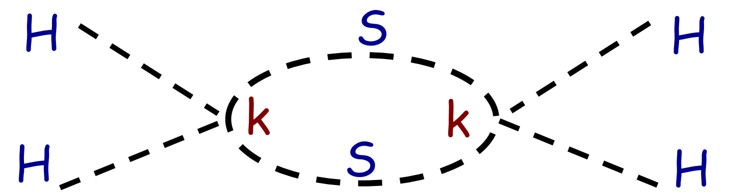
m_S=63.5～64.5 GeV

m_S=81.2～2040 GeV

$$(4\pi)^2\frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y^2 \underline{- 12y^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] \underline{+ k^2},$$

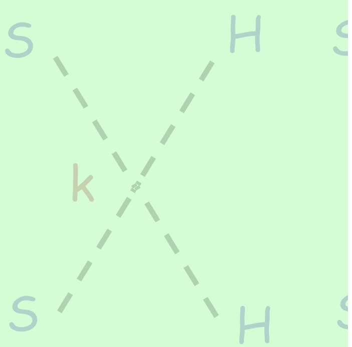
large y_t → instability

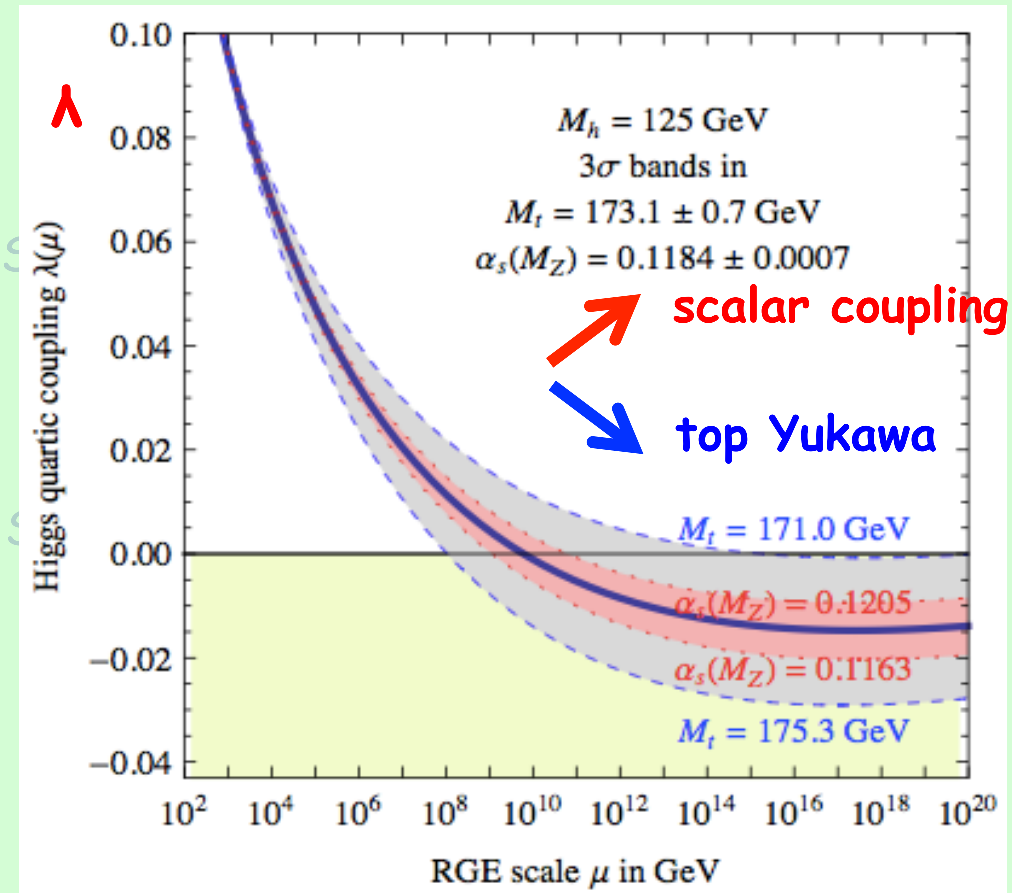
small m_S → blow up → triviality



$$L_{DM} = -\underline{m_S^2} S^2 - \underline{k} \, | H |^2 \, S^2 - \underline{\lambda_S} S^4$$

DM relic density depends on λ & k (not λ_S) & stability-triviality do Y_t, [M_t = 173.5 - 1.4 GeV]





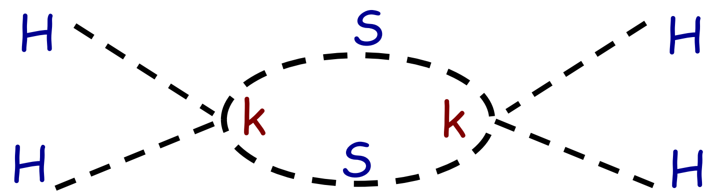
G.Degrassi, S.Di Vita, J.Elias-Miro, J.R.Espinosa, G.F.Giudice, G.Isidori and A.Strumia, JHEP1208 (2012) 098

$$(4\pi)^2 \frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y^2 \underline{- 12y^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] \underline{+ k^2},$$

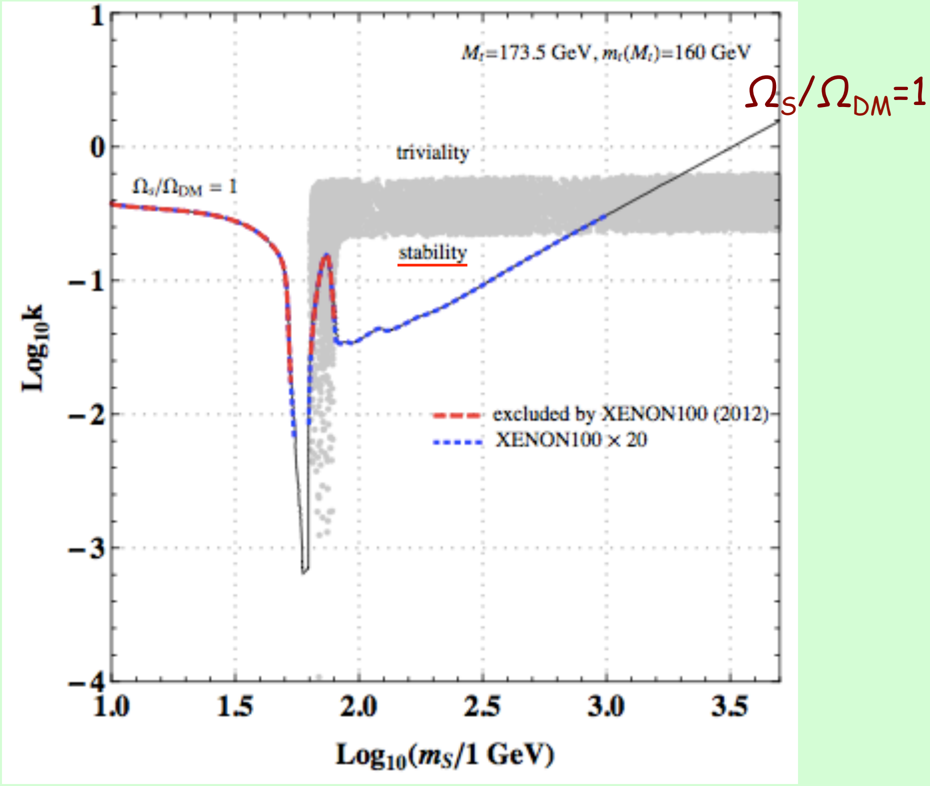
large $y_t \rightarrow$ instability

small $m_S \rightarrow$ blow up $\rightarrow$ triviality

$$L_{DM} = -\underline{m_S^2} S^2 - \underline{k} \mid H \mid^2 S^2 - \underline{\lambda_S} S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**

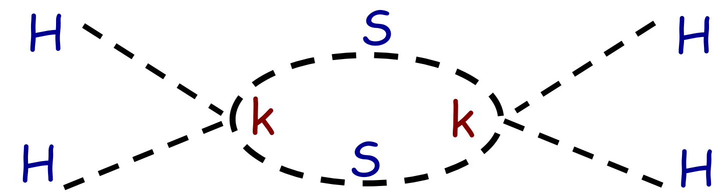


$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

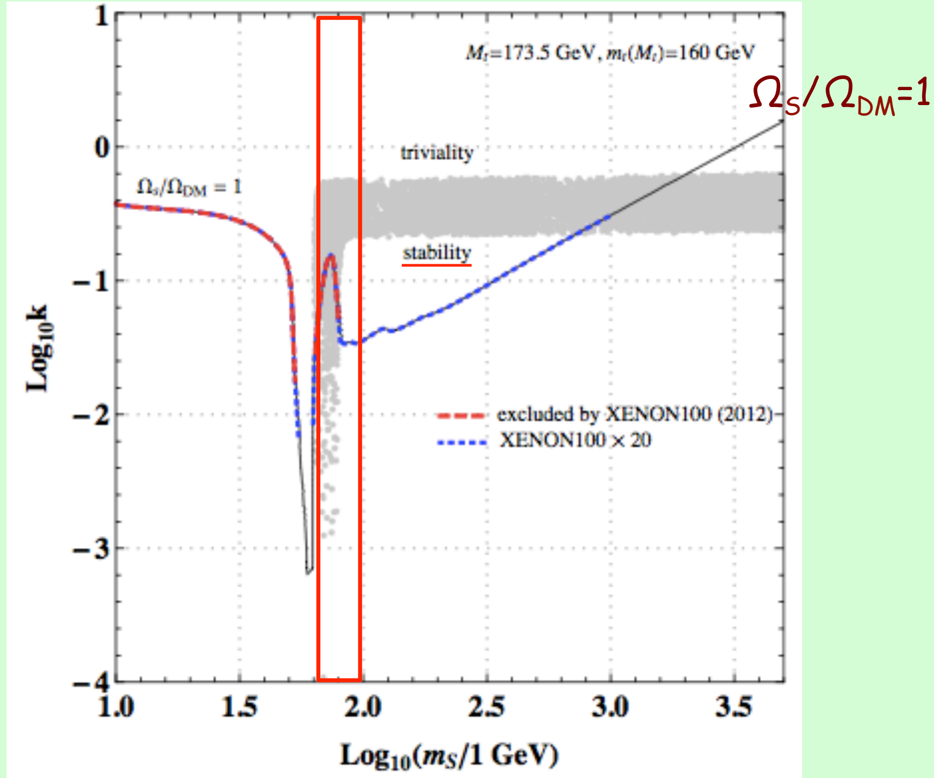
large $y_t \to$ instability

small $m_S \to$ blow up $\to$ triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**

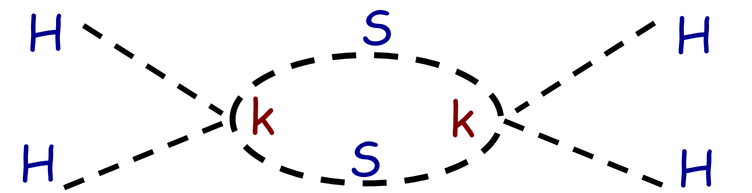


$$(4\pi)^2 \frac{d\lambda}{dt} = \underline{12\lambda^2} + 12\lambda y^2 \underline{- 12y^4} - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] \underline{+ k^2},$$

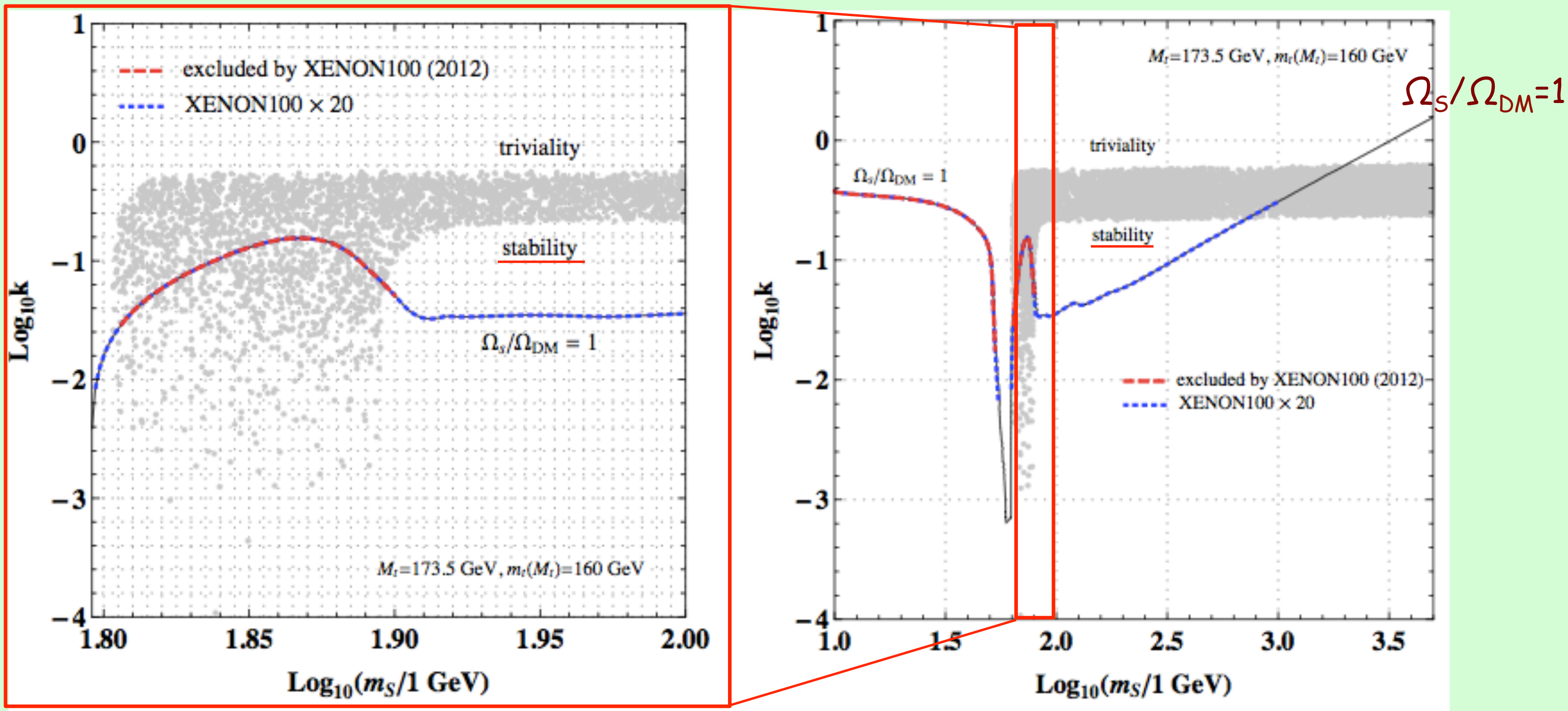
large $y_t \rightarrow$ instability

small $m_S \rightarrow$ blow up $\rightarrow$ triviality

$$L_{DM} = -\underline{m_S^2} S^2 - \underline{k} |H|^2 S^2 - \underline{\lambda_S} S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**

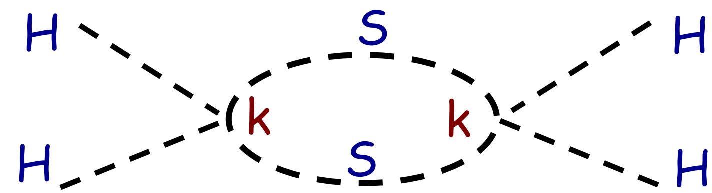


$$(4\pi)^2 \frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

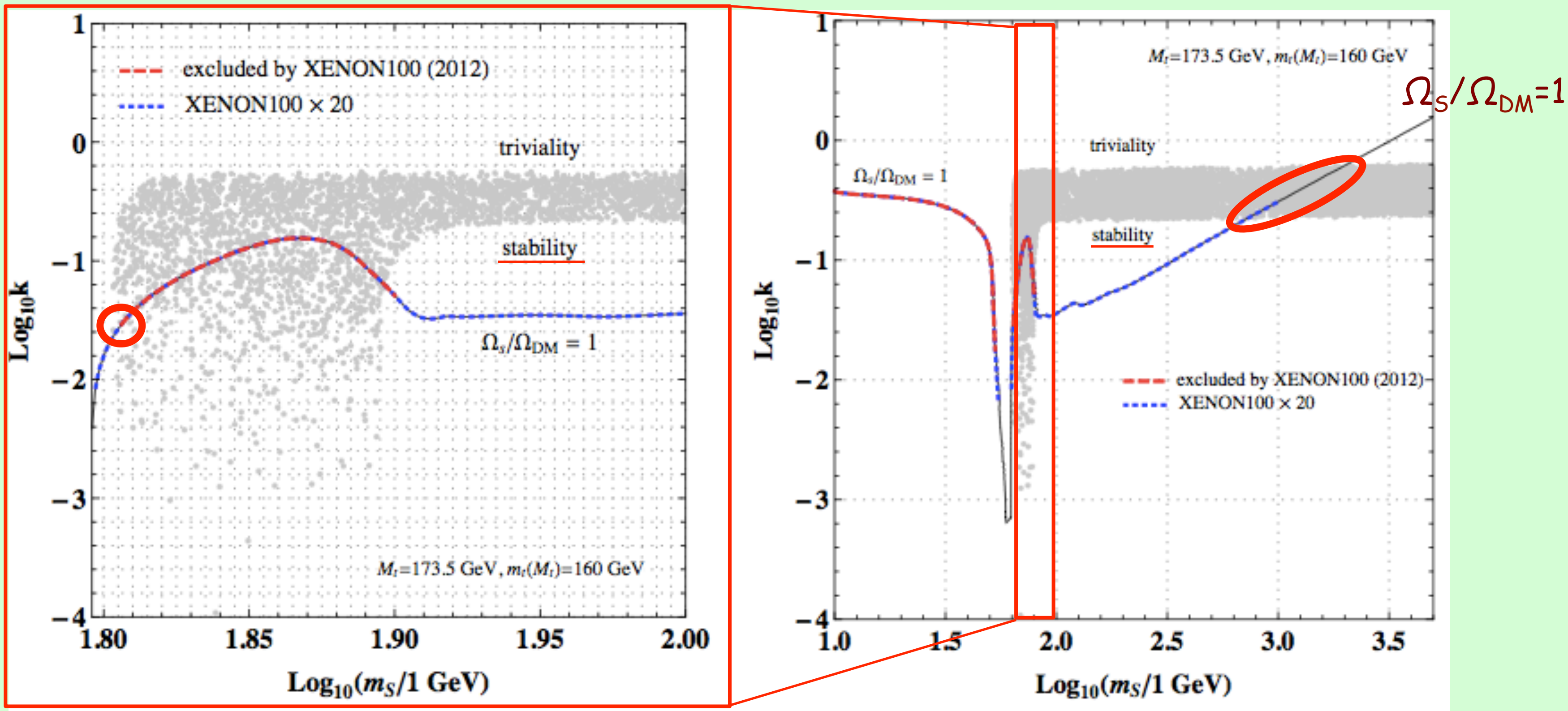
large $y_t \rightarrow$ instability

small $m_S \rightarrow$ blow up $\rightarrow$ triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**

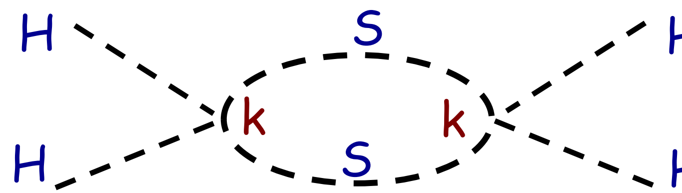


$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

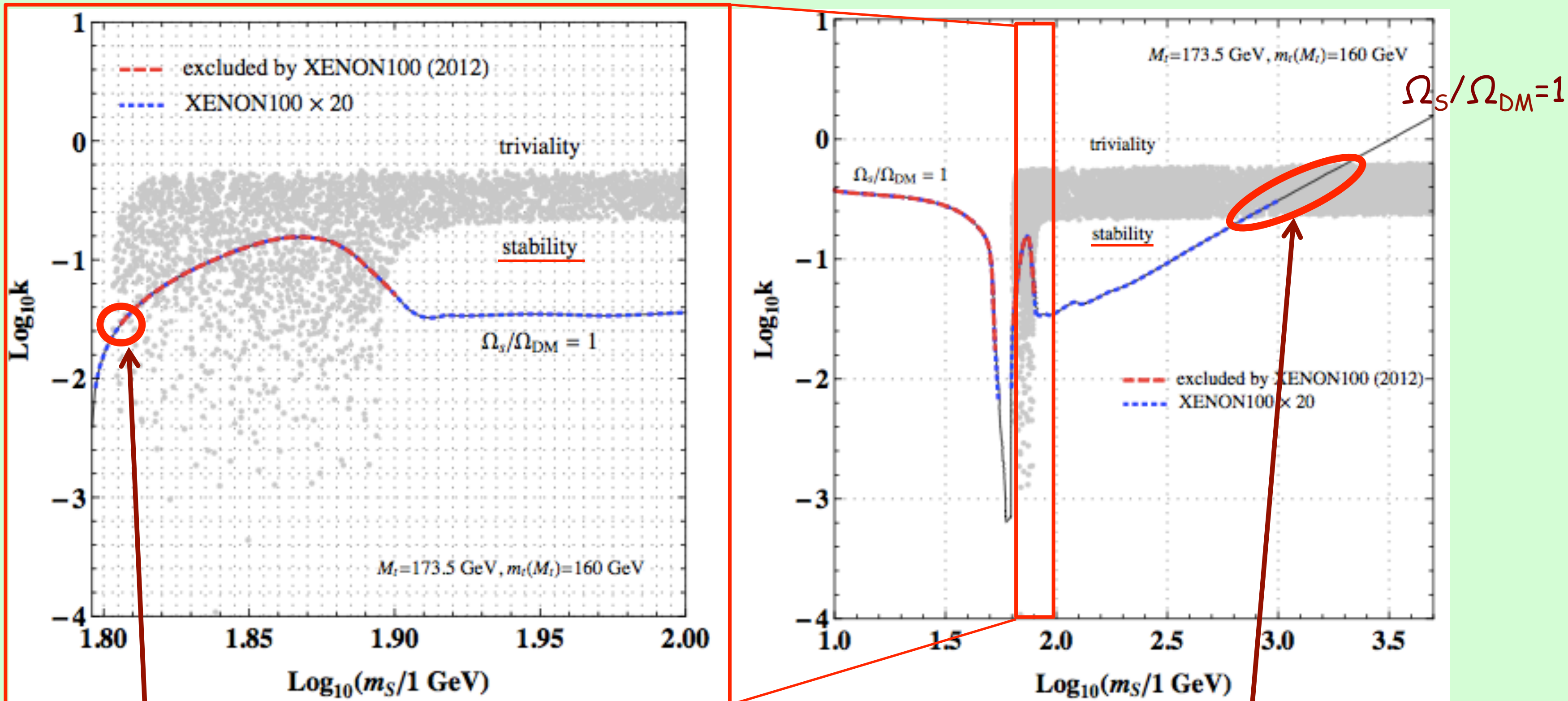
large y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**



m_S=63.5~64.5 GeV

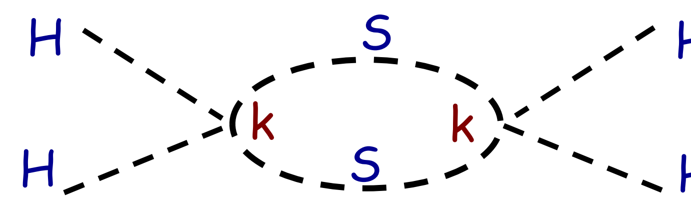
m_S=708~2040 GeV

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

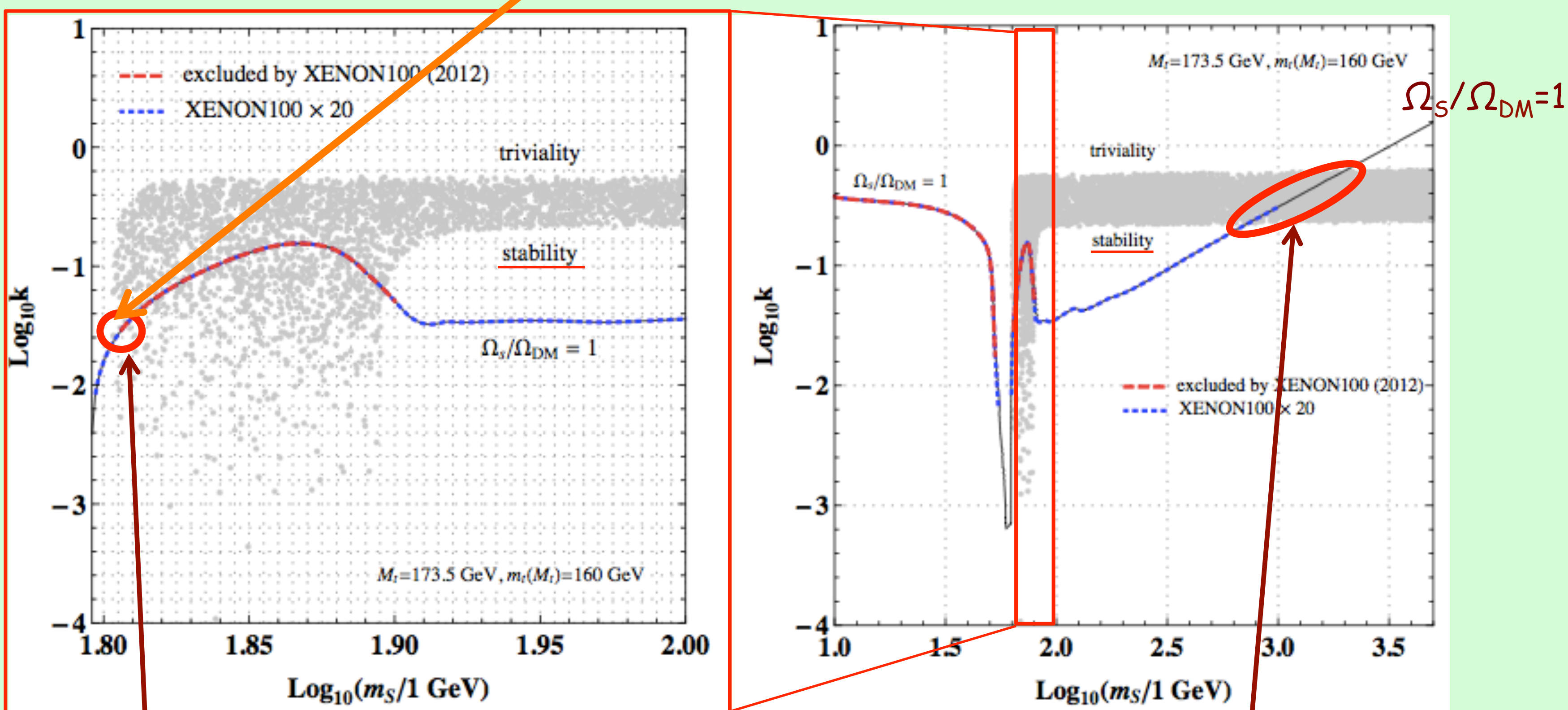
large y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 ~~± 1.4~~ GeV]**



m_S=63.5~64.5 GeV

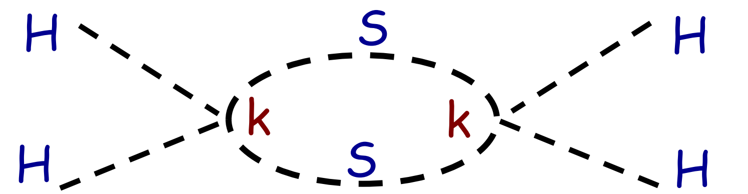
m_S=708~2040 GeV

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4+(g'^2+g^2)^2\right] + k^2,$$

larger y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$



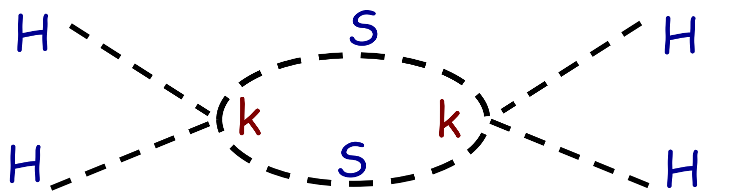
DM relic density **depends on λ & k** (not λ_S) & stability-triviality do **Y_t**, **[M_t = 173.5 + 1.4 GeV]**

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4+(g'^2+g^2)^2\right] + k^2,$$

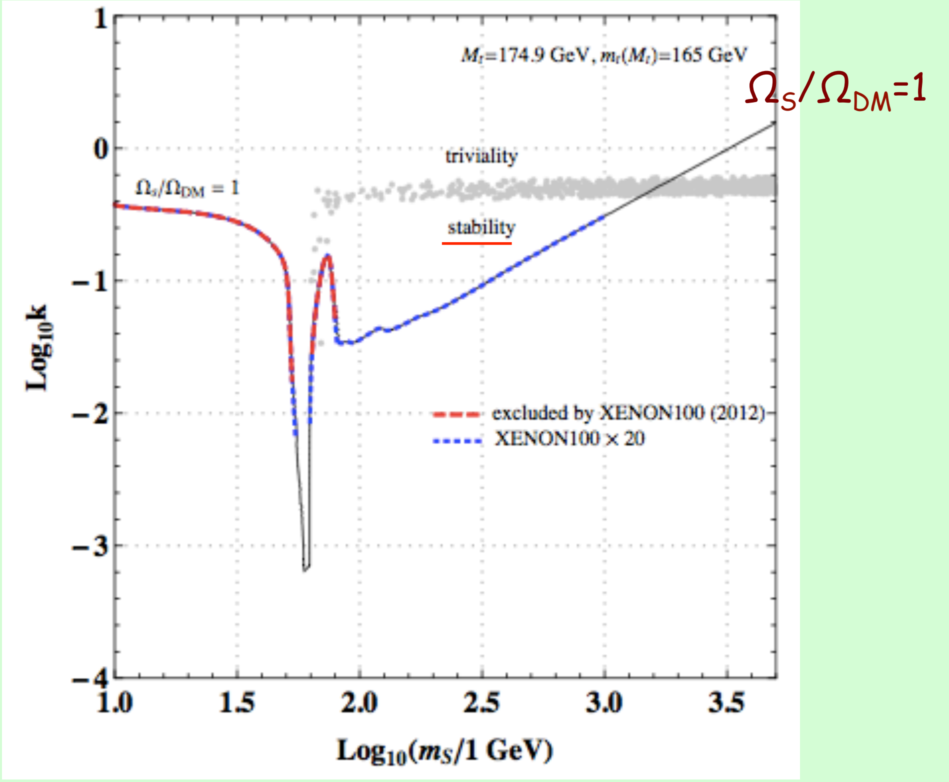
larger y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 + 1.4 GeV]**

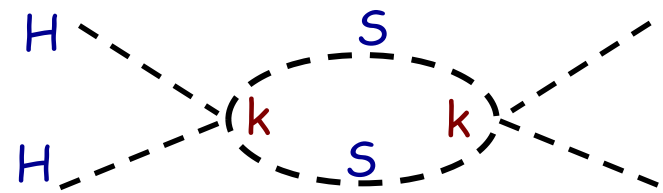


$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4+(g'^2+g^2)^2\right] + k^2,$$

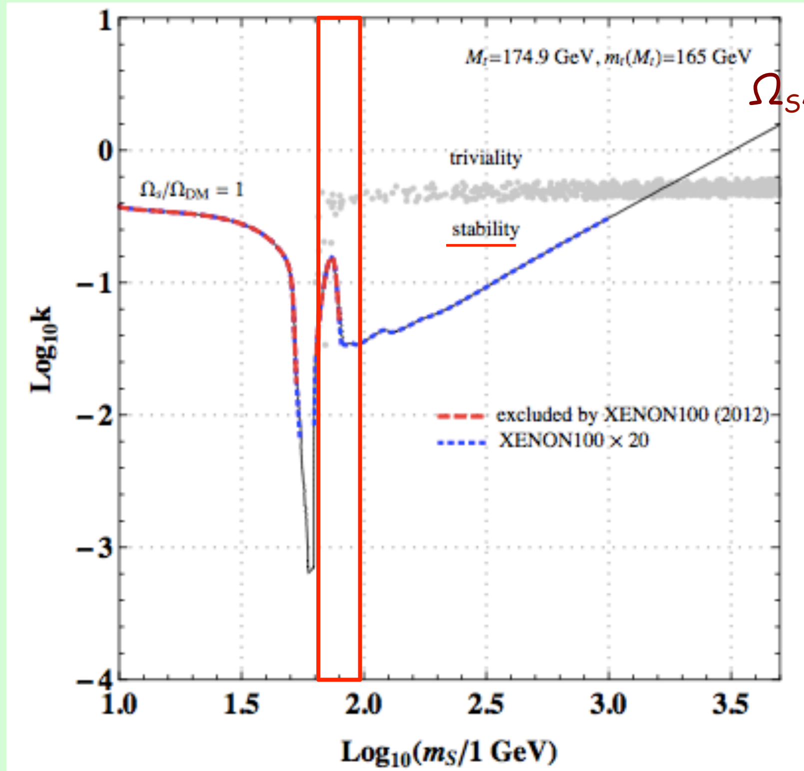
larger $y_t \rightarrow$ instability

small $m_S \rightarrow$ blow up $\rightarrow$ triviality

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 + 1.4 GeV]**



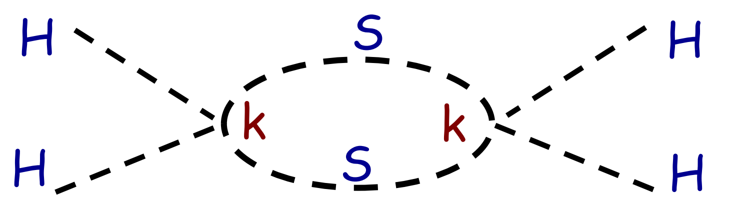
Ω_S/Ω_{DM}=1

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

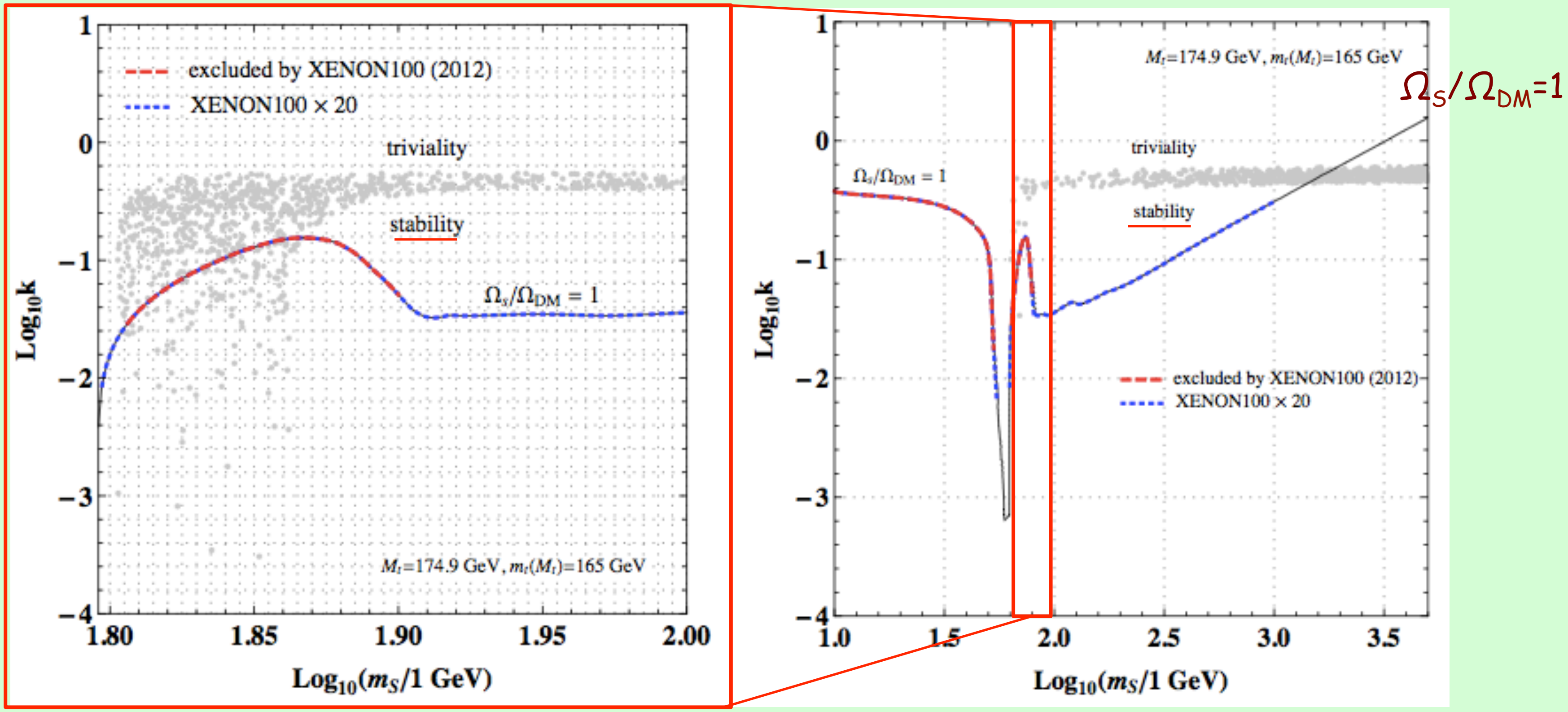
larger y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t. **[M_t = 173.5 + 1.4 GeV]**

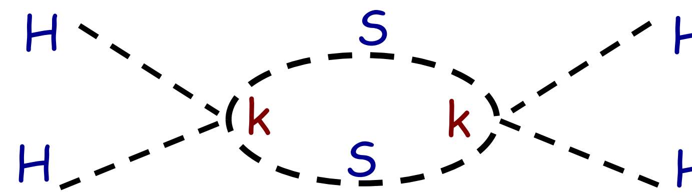


$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

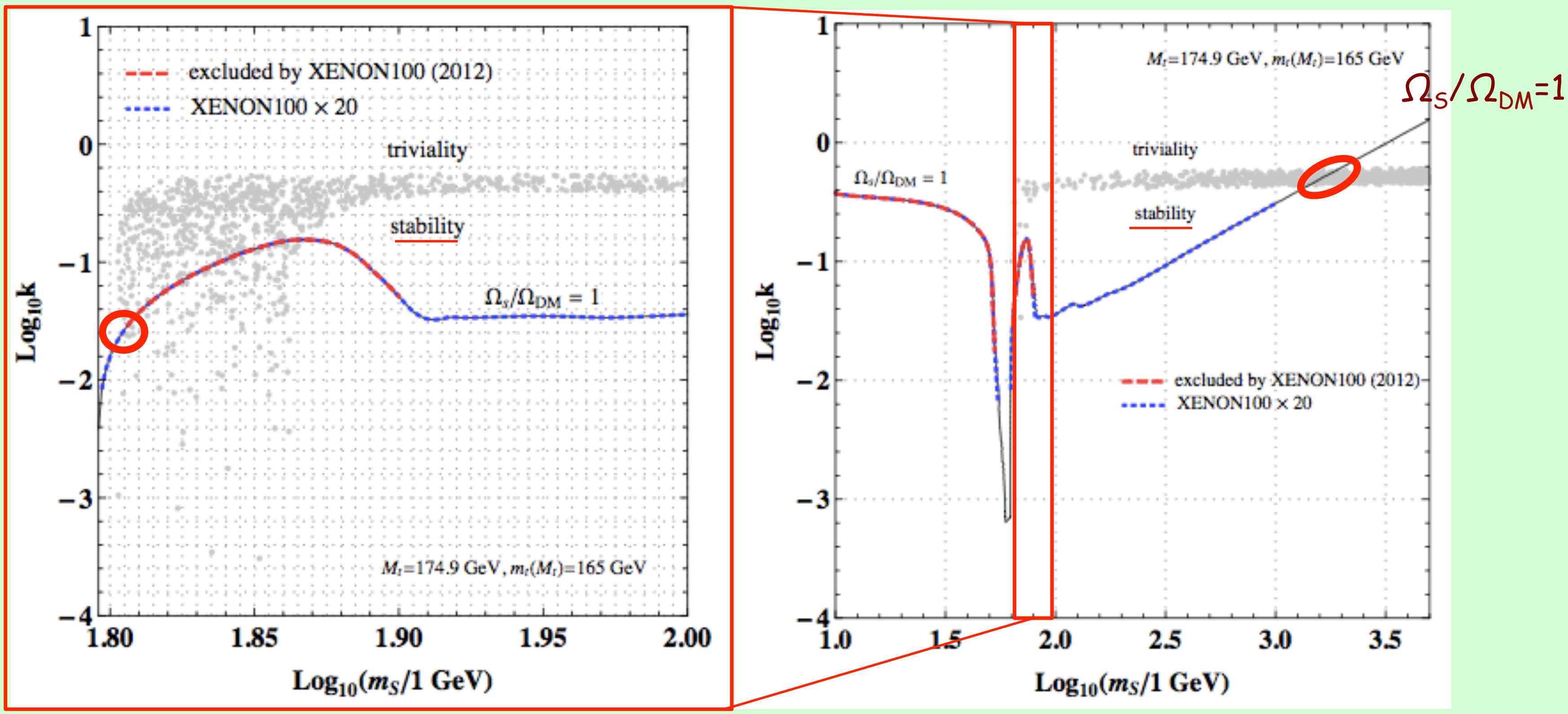
larger y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do **Y_t**, **[M_t = 173.5 + 1.4 GeV]**

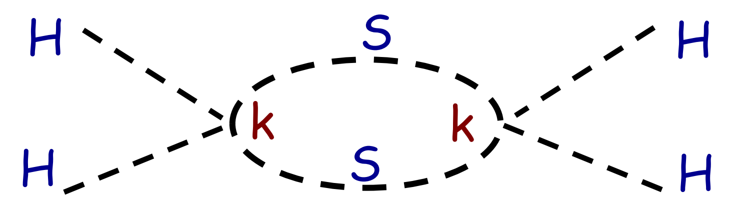


$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4 + (g'^2+g^2)^2\right] + k^2,$$

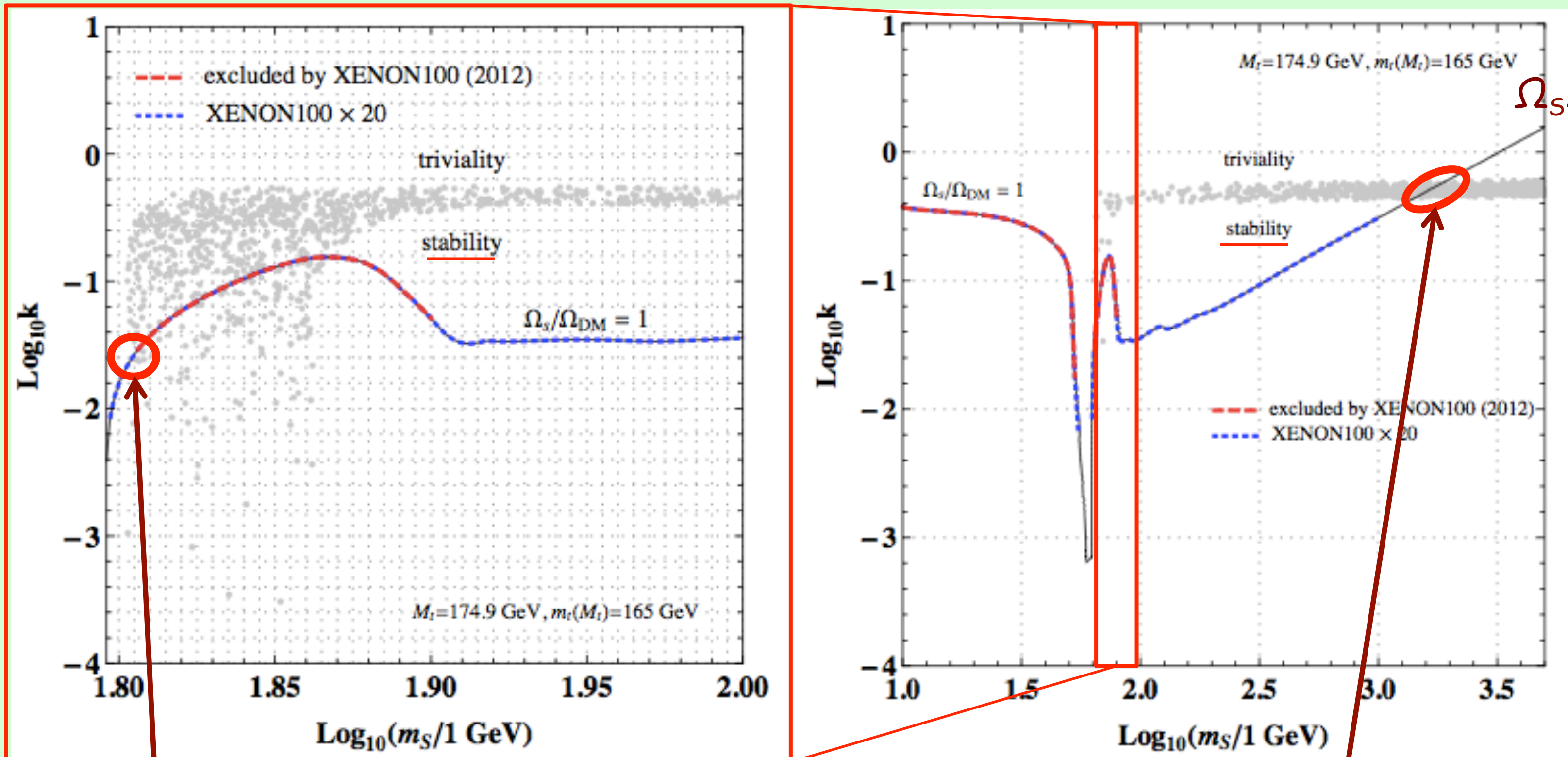
larger $y_t \to$ instability

small $m_S \to$ blow up $\to$ triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 + 1.4 GeV]**



m_S=63.5~64.5 GeV

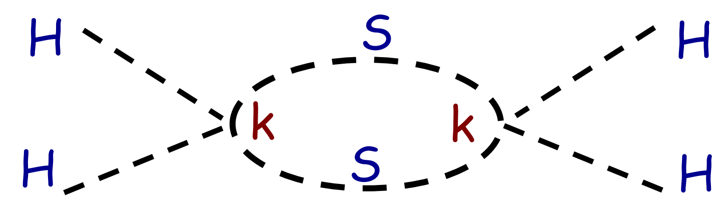
m_S=1320~1950 GeV

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

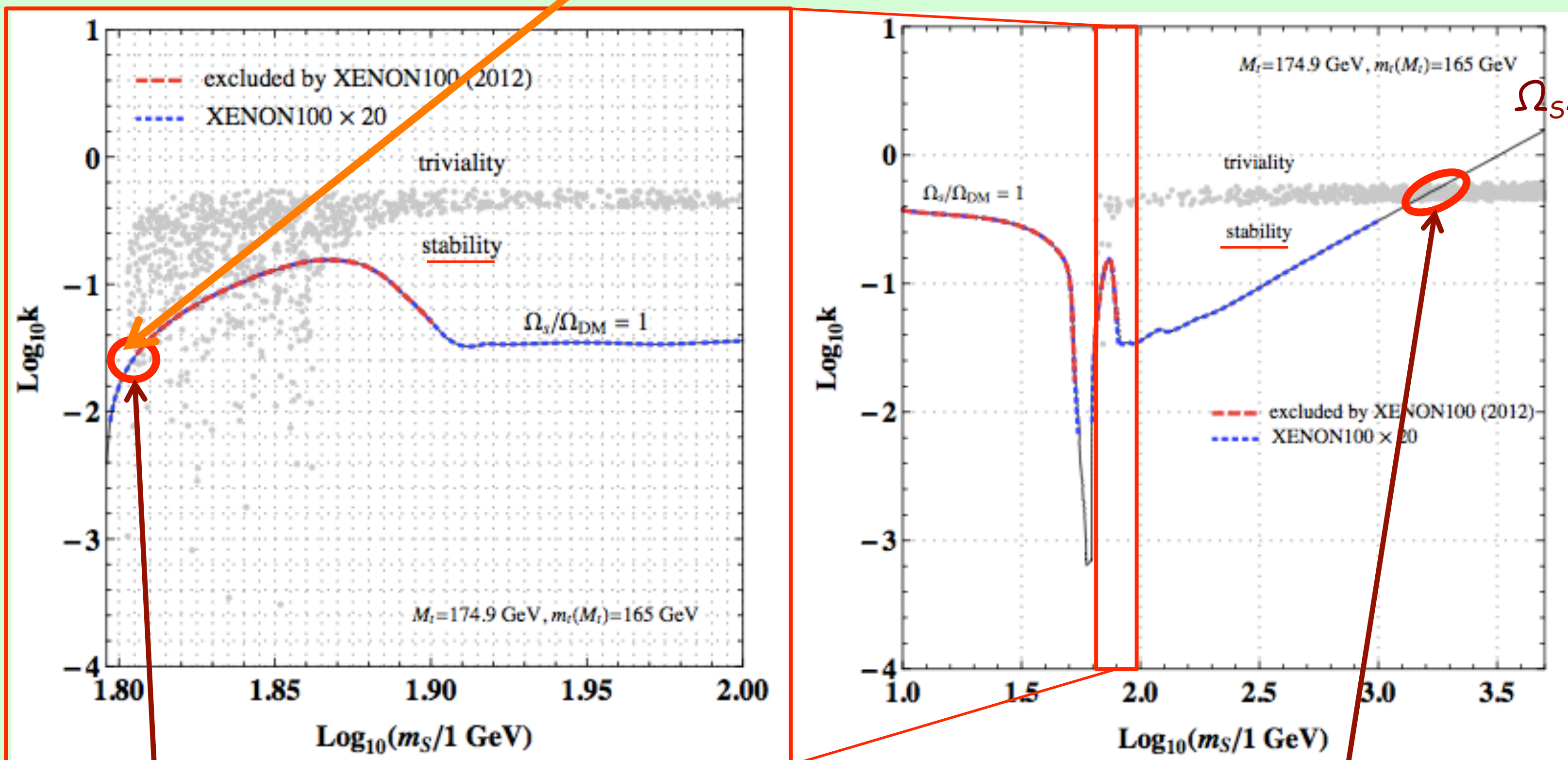
larger y_t → instability

small m_S → blow up → triviality

$$L_{DM} = -m_S^2 S^2 - k|H|^2 S^2 - \lambda_S S^4$$



DM relic density **depends on λ & k** (not λ_S) & stability-triviality do Y_t, **[M_t = 173.5 + 1.4 GeV]**



m_S=63.5~64.5 GeV

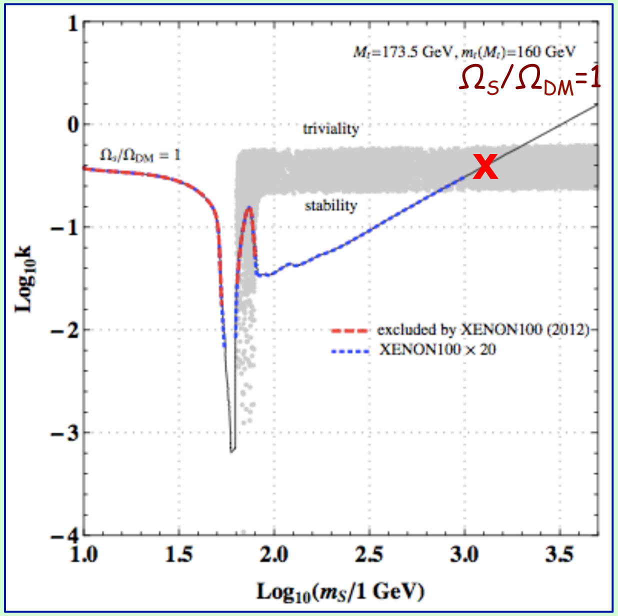
m_S=1320~1950 GeV

♡ An example of RGE running

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2 + 3g^2) + \frac{3}{4}\left[2g^4 + (g'^2 + g^2)^2\right] + k^2,$$

$$(4\pi)^2\frac{dk}{dt} = k\left[4k + 6\lambda + \lambda_S + 6y^2 - \frac{3}{2}(g'^2 + 3g^2)\right],$$

$$(4\pi)^2\frac{d\lambda_S}{dt} = 3\lambda_S^2 + 12k^2.$$



Mt = 173.5 GeV

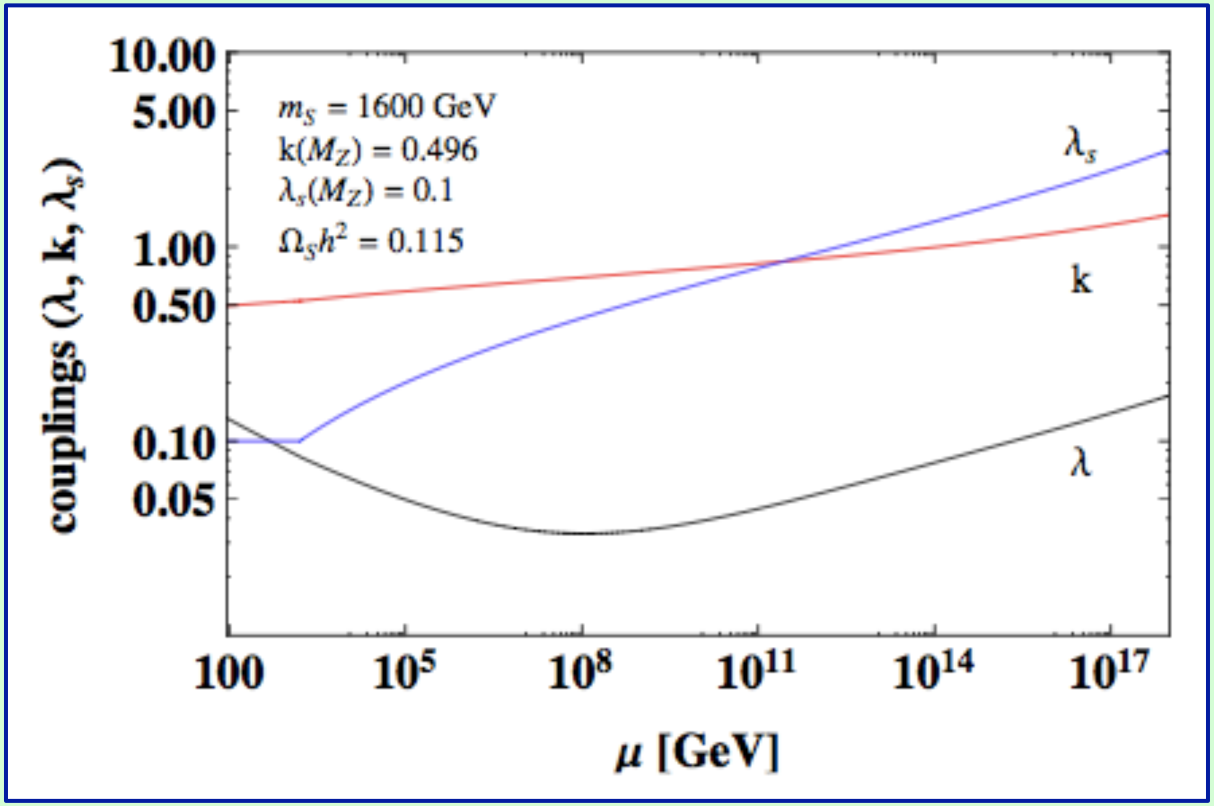
$$L_{DM} = -m_S^2 S^2 - k\,|H|^2 S^2 - \lambda_S S^4$$

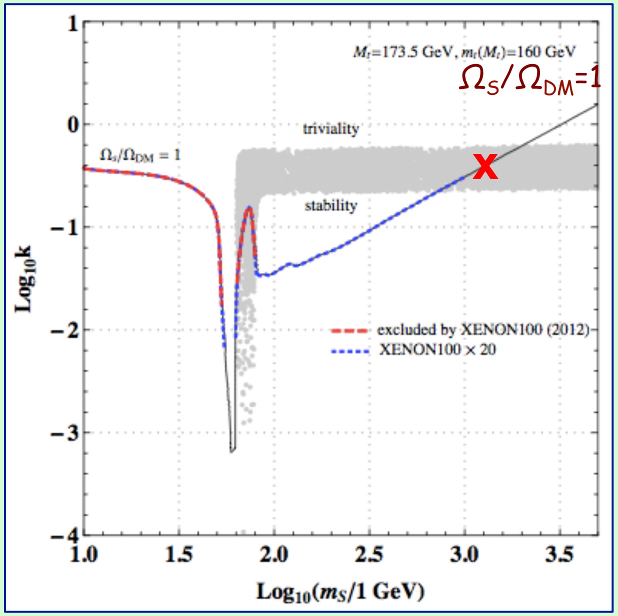
♡ An example of RGE running

$$(4\pi)^2\frac{d\lambda}{dt} = 12\lambda^2 + 12\lambda y^2 - 12y^4 - 3\lambda(g'^2+3g^2) + \frac{3}{4}\left[2g^4+(g'^2+g^2)^2\right] + k^2,$$

$$(4\pi)^2\frac{dk}{dt} = k\left[4k + 6\lambda + \lambda_S + 6y^2 - \frac{3}{2}(g'^2+3g^2)\right],$$

$$(4\pi)^2\frac{d\lambda_S}{dt} = 3\lambda_S^2 + 12k^2.$$





Mt = 173.5 GeV

$$L_{DM} = -m_S^2 S^2 - k\,|H|^2\,S^2 - \lambda_S S^4$$

§3 summary

summary

- still no evidence of BSM, but problems exist in SM

summary

- still no evidence of BSM, but problems exist in SM

  → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + $\nu_R \times 2$]

summary

- still no evidence of BSM, but problems exist in SM

  → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]

  → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + ($L+\bar{L}$) ×2]

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L})$ ×2]
- NNMSM

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + $\nu_R \times 2$]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L}) \times 2$]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + ($L+\bar{L}$) ×2]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + $\nu_R \times 2$]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\overline{L}) \times 2$]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + ($L+\bar{L}$) ×2]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions

GCU sector

ν_R & BAU sector

inflation sector

DM sector

Higgs sector
(stability & non triviality)

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + $\nu_R \times 2$]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L}) \times 2$]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions

GCU sector

T_R < 25 TeV

ν_R & BAU sector

inflation sector

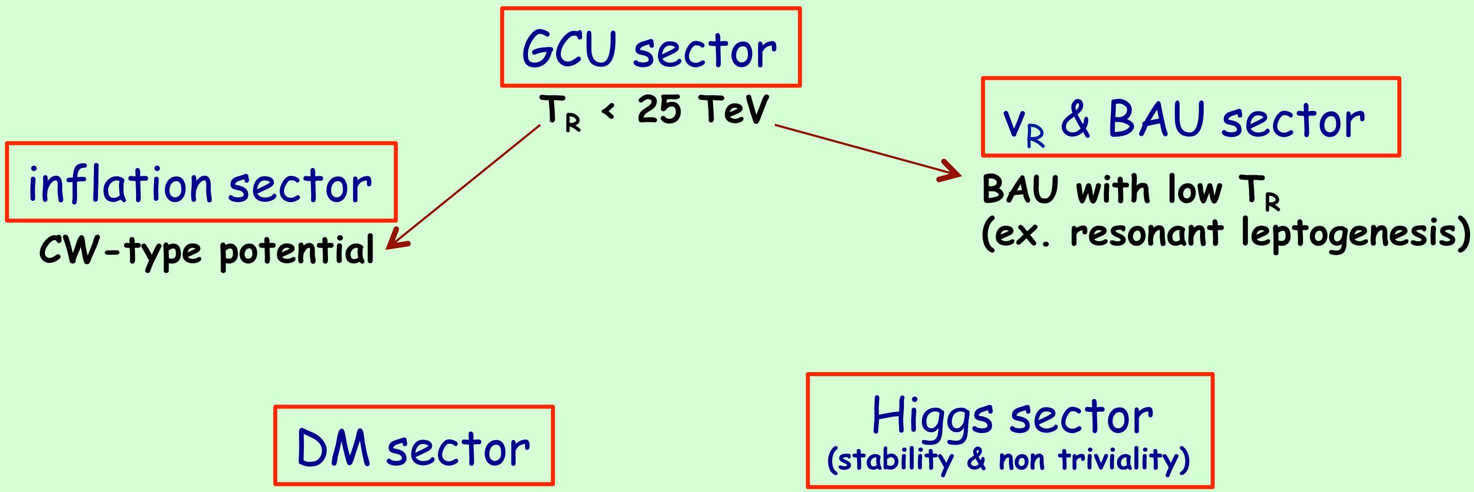
DM sector

Higgs sector
(stability & non triviality)

)

summary

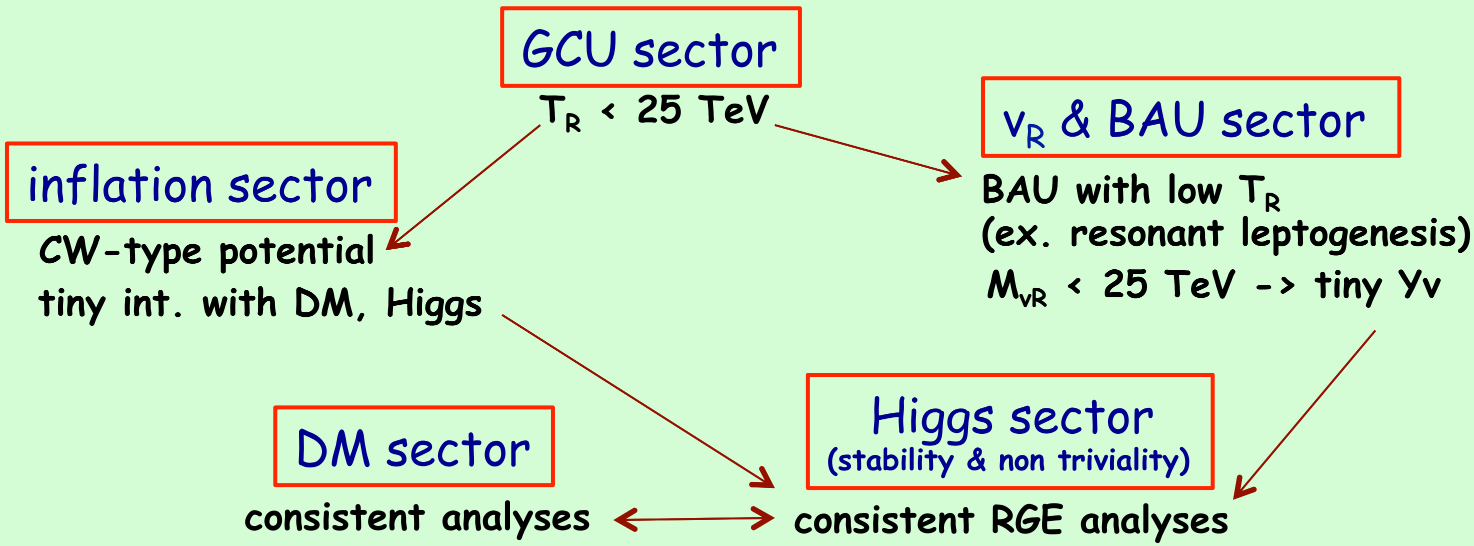
- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L})$ ×2]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions



)

summary

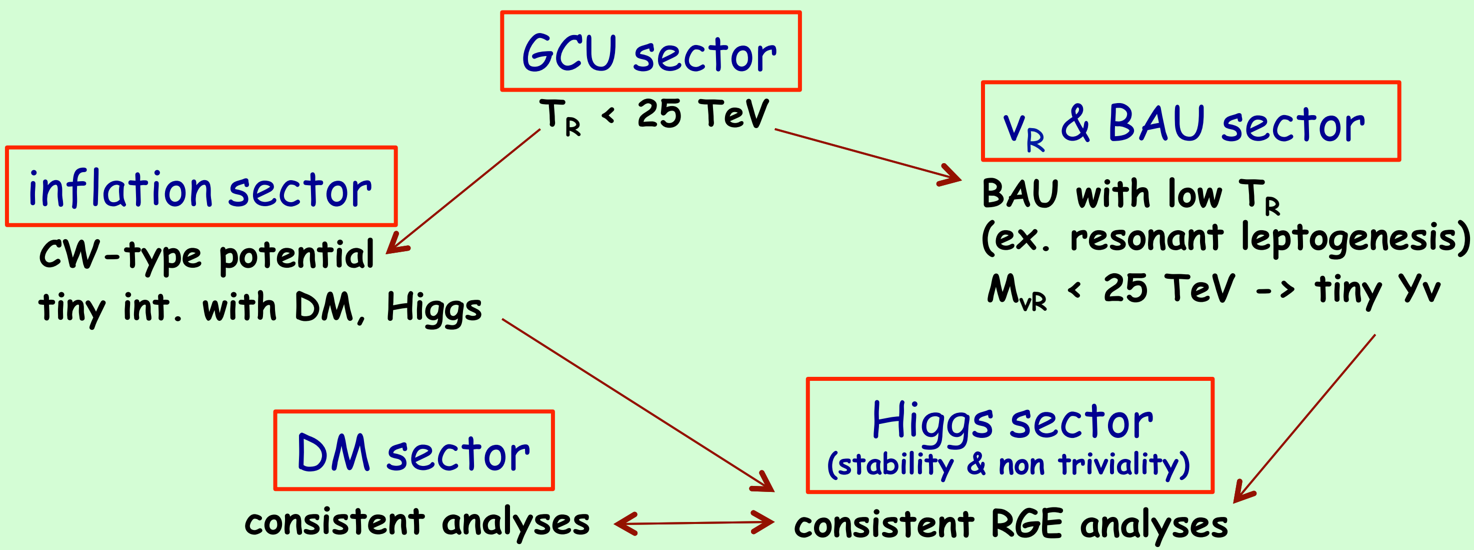
- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + $\nu_R \times 2$]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L}) \times 2$]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions



)

summary

- still no evidence of BSM, but problems exist in SM
  - → new minimal SM (DM, inflation, ν mass) [SM + S(DM) + φ(Inf) + ν_R×2]
  - → next to NMSM (+GCU) [NMSM + $\lambda_{2,3}$ + $(L+\bar{L})$ ×2]
- NNMSM
  - proton decay ($p \to \pi^0 e^+$) will be observed at HK.
  - low T_R (< 25 TeV) → low energy baryogenesis (ex. resonant leptogenesis)
  - consistent with DM relic density & λ's stability and non triviality conditions



)

It's just a cut-and paste model, but total research from wide point of view is important, since we can understand their correlation !

discussions

→ other setup scenarios (R. Takahashi's talk yesterday)

[NNMSM-II]

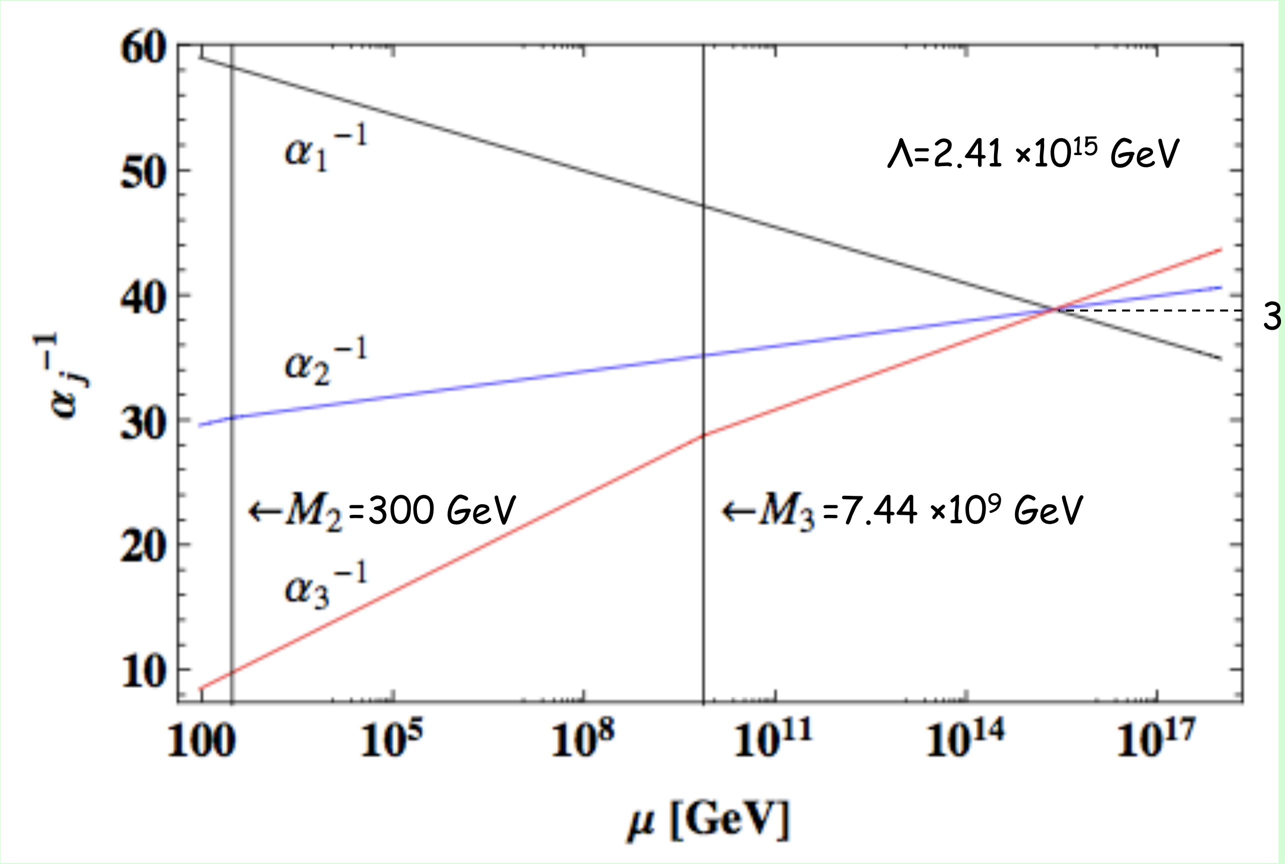
- $M_3 \neq M_2$ & ~~no need of $(L + \overline{L}) \times 2$~~

discussions

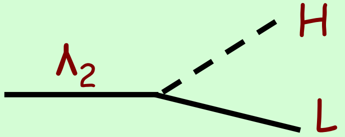
→ other setup scenarios (R. Takahashi's talk yesterday)

[NNMSM-II]

- $M_3 \neq M_2$ & ~~no need of $(L + \overline{L}) \times 2$~~



- $T_R < 10^8$ GeV
- Λ_2 (Z_2-even) decays to L & H

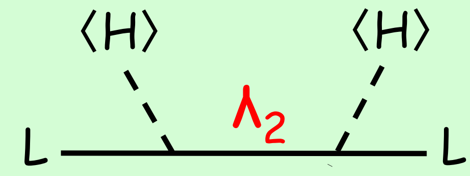


discussions

→ other setup scenarios

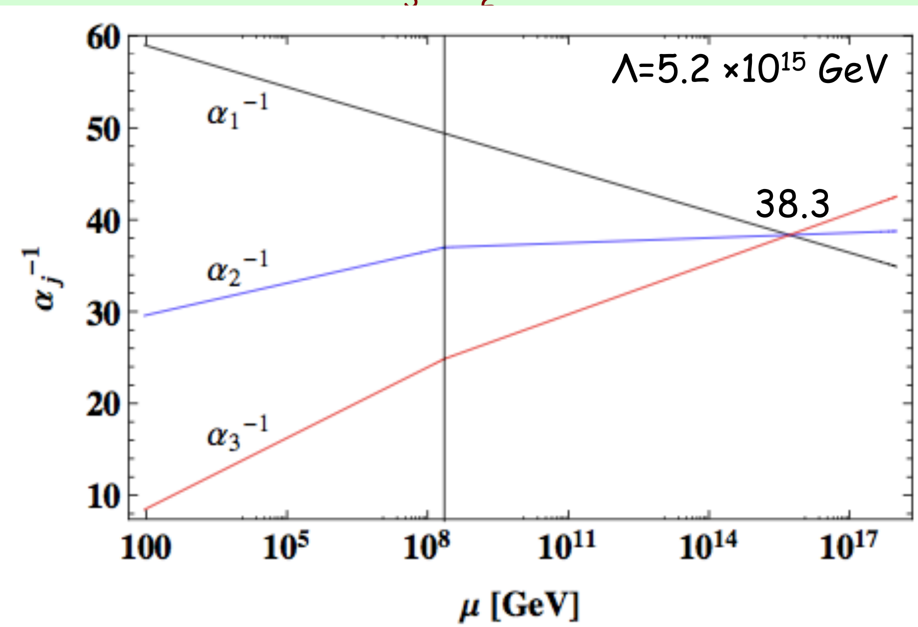
[NNMSM-III]

- $\lambda_2 \times 2$ (Z_2-even) & ~~no need of $(L + \bar{L}) \times 2$ nor $\nu_R \times 2$~~



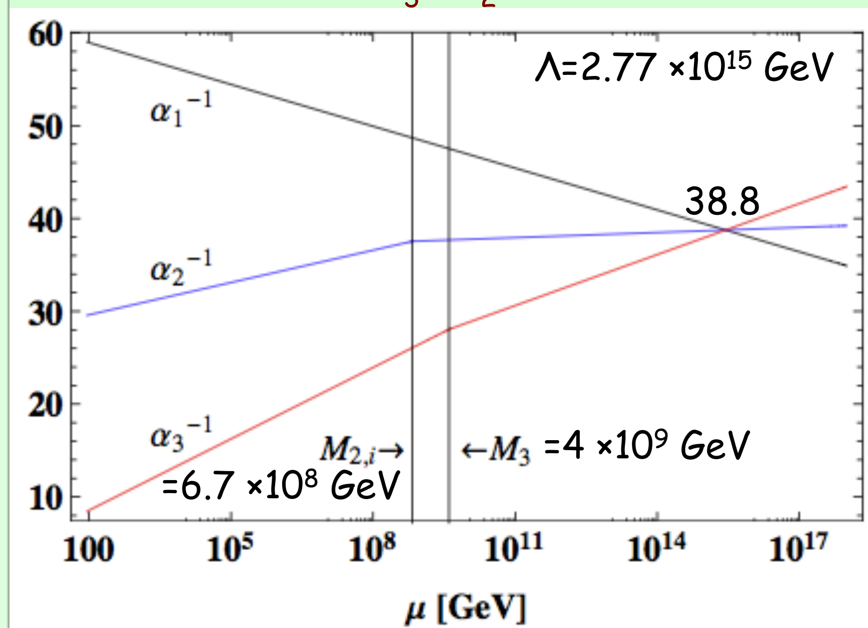
↪ another BAU scenarios (not leptogenesis)

$M_3 = M_2$



- $T_R < 10^6$ GeV

$M_3 \neq M_2$



- $T_R < 10^8$ GeV

♡ DOF

- NMSM: DM, inflation, ν mass

  SM + S (1) + φ (1) + ν_R ×2 (2×2) (+6)

- NNMSM: + GCU

  - NNMSM-I: NMSM + Λ_3 (8×2) + Λ_2 (3×2) + $[L, \overline{L}]$ ×2 (2×2×2×2) (+38)
  - NNMSM-II: NMSM + Λ_3 (8×2) + Λ_2 (3×2) (+22)
  - NNMSM-III: NMSM + Λ_3 (8×2) + Λ_2 (3×2×2) – ν_R (2×2) (+24)

DOF: SM < NMSM < NNMSM-II < NNMSM-III < NNMSM-I

♡ DOF

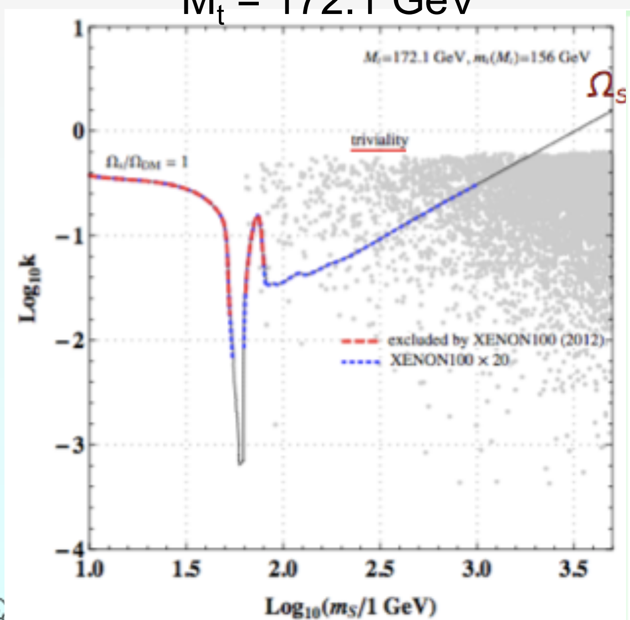
- NMSM: DM, inflation, ν mass

  SM + S (1) + φ (1) + ν_R ×2 (2×2) (+6)

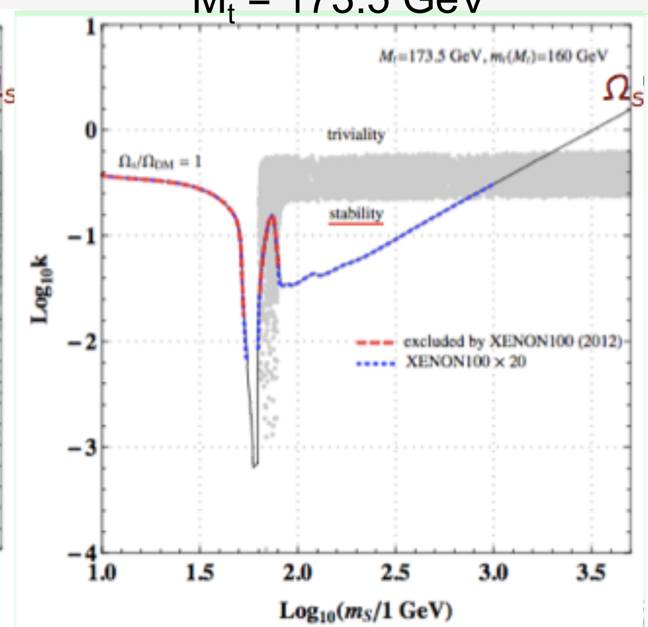
- NNMSM: + GCU

  - NNMSM-I: NMSM + λ_3 (8×2) + λ_2 (3×2) + $[L, \bar{L}]$ ×2 (2×2×2×2) (+38)
  - NNMSM-II: NMSM + λ_3 (8×2) + λ_2 (3×2) (+22)
  - NNMSM-III: NMSM + λ_3 (8×2) + λ_2 (3×2×2) − ν_R (2×2) (+24)

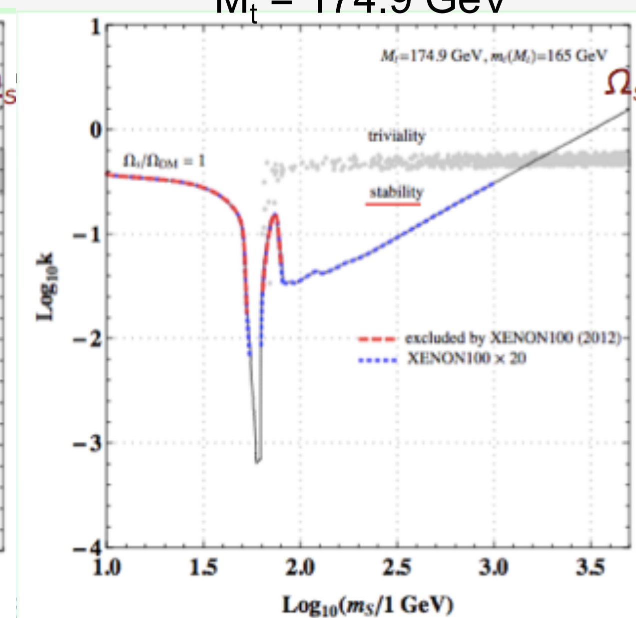
M_t = 172.1 GeV



M_t = 173.5 GeV



M_t = 174.9 GeV



♡ NNMSM-IIa (M_{3i}=M_{2j}) other non-minimum setup possibilities

N_{λ_3}	N_{λ_2}	M_{NP} [GeV]	$\Lambda_{\rm GCU}$ [10^{15} GeV]	$\alpha^{-1}_{\rm GCU}$	τ [10^{33} years]
1	3^*	2.21×10^{11}	1.41	39.3	$< 8.2 \times 10^{33}$ years
2	$1,2^\dagger$	-	-	-	-
	3	5.80×10^{9}	99.2	36.4	$2.88^{+3.06}_{-1.19} \times 10^{7}$
	4	1.09×10^{12}	5.20	38.3	$1.89^{+2.00}_{-0.78} \times 10^{2}$
	$\geq 5^*$	$\geq 6.47 \times 10^{12}$	≤ 1.90	≥ 39.0	$< 8.2 \times 10^{33}$ years
3	$1\text{-}3^\dagger$	-	-	-	-
	$4^\ddagger$	1.33×10^{11}	$> M_{\rm pl}$	34.6	$> \mathcal{O}(10^{35})$ years
	5,6	$(0.52 - 1.83) \times 10^{13}$	$(5.20 - 23.0)$	$(37.3 - 38.3)$	$> \mathcal{O}(10^{35})$ years
	7	3.47×10^{13}	2.45	38.8	$8.94^{+9.49}_{-3.68}$
	$\geq 8^*$	$\geq 5.11 \times 10^{13}$	≤ 1.55	≥ 39.1	$< 8.2 \times 10^{33}$ years
4	$1\text{-}4^*$	-	-	-	-
	$5^\ddagger$	2.74×10^{12}	$> M_{\rm pl}$	32.8	$> \mathcal{O}(10^{35})$ years
	6-8	$(2.39 - 7.51) \times 10^{13}$	$(5.20 - 99.2)$	$(36.4 - 38.3)$	$> \mathcal{O}(10^{35})$ years
	9	9.49×10^{13}	2.85	38.7	$16.4^{+17.4}_{-6.75}$
	$\geq 10^\dagger$	$\geq 1.11 \times 10^{14}$	≤ 1.90	≥ 39.0	$< 8.2 \times 10^{33}$ years
5	$1\text{-}5^*$	-	-	-	-
	$6^\ddagger$	5.11×10^{12}	$> M_{\rm pl}$	31.0	$> \mathcal{O}(10^{35})$ years
	7-10	$(1.75 - 7.51) \times 10^{14}$	$(5.20 - 417)$	$(35.5 - 38.3)$	$> \mathcal{O}(10^{35})$ years
	11	1.85×10^{14}	3.15	38.7	$24.6^{+26.1}_{-10.1}$
	12	1.93×10^{14}	2.20	38.9	$5.76^{+6.61}_{-2.37}$
	$\geq 13^\dagger$	$\geq 1.99 \times 10^{14}$	≤ 1.68	≥ 39.1	$< 8.2 \times 10^{33}$ years
6	$1\text{-}6^*$	-	-	-	-
	$7,8^\ddagger$	$(4.76 - 8.67) \times 10^{14}$	$> M_{\rm pl}$	(29.3-34.6)	$> \mathcal{O}(10^{35})$ years
	9-12	$(3.09 - 3.85) \times 10^{14}$	$(5.20 - 99.2)$	$(36.4 - 38.3)$	$> \mathcal{O}(10^{35})$ years
	13	2.99×10^{14}	3.39	38.6	$32.8^{+34.9}_{-13.5}$
	14	2.92×10^{14}	2.45	38.8	$8.90^{+9.45}_{-3.66}$
	$\geq 15^\dagger$	$\geq 2.86 \times 10^{14}$	≤ 1.90	≥ 39.0	$< 8.2 \times 10^{33}$ years
7	$1\text{-}7^*$	-	-	-	-
	$8,9^\ddagger$	$(0.204 - 1.34) \times 10^{16}$	$> M_{\rm pl}$	$(27.7 - 33.7)$	$> \mathcal{O}(10^{35})$ years
	10-14	$(0.462 - 1.04) \times 10^{15}$	$(5.20 - 259)$	$(35.8 - 38.3)$	$> \mathcal{O}(10^{35})$ years
	15	4.27×10^{14}	3.57	38.6	$40.8^{+43.3}_{-16.8}$
	16	4.02×10^{14}	2.66	38.8	$12.5^{+13.3}_{-5.14}$
	17	3.83×10^{14}	2.10	38.9	$4.83^{+5.13}_{-1.99}$
	$\geq 18^\dagger$	$\leq 3.68 \times 10^{14}$	≤ 1.74	≥ 39.1	$< 8.2 \times 10^{33}$ years

* : ruled out by p-decay
† : not realize GCU
‡ : realize GCU above MP

♡ NNMSM-IIb ($M_{3i} \neq M_{2j}$) other non-minimum setup possibilities

$N_{\lambda_3}(M_{3,i})$	$N_{\lambda_2}(M_{2,i})$	$\Lambda_{\rm GCU}$ [10^{15} GeV]	$\alpha^{-1}_{\rm GCU}$
1 ($M_3 \lesssim 4 \times 10^9$ GeV)	3 ($M_{2,i} \lesssim 1.08 \times 10^{11}$ GeV)	2.77	38.8
	4 ($M_{2,i} \lesssim 1.36 \times 10^{12}$ GeV)		
	5 ($M_{2,i} \lesssim 6.26 \times 10^{12}$ GeV)		
	6 ($M_{2,i} \lesssim 1.73 \times 10^{13}$ GeV)		
	7 ($M_{2,i} \lesssim 3.57 \times 10^{13}$ GeV)		
	8 ($M_{2,i} \lesssim 6.14 \times 10^{13}$ GeV)		
	9 ($M_{2,i} \lesssim 9.39 \times 10^{13}$ GeV)		
2 ($M_{3,i} \lesssim 3 \times 10^{12}$ GeV)	1* ($M_{2,i} \lesssim 126$ GeV)	2.91	38.7
	2 ($M_{2,i} \lesssim 6.08 \times 10^{8}$ GeV)		
	3 ($M_{2,i} \lesssim 1.03 \times 10^{11}$ GeV)		
	4 ($M_{2,i} \lesssim 1.34 \times 10^{12}$ GeV)		
	5 ($M_{2,i} \lesssim 6.22 \times 10^{12}$ GeV)		
	6 ($M_{2,i} \lesssim 1.73 \times 10^{13}$ GeV)		
	7 ($M_{2,i} \lesssim 3.61 \times 10^{13}$ GeV)		
	8 ($M_{2,i} \lesssim 6.26 \times 10^{13}$ GeV)		
	9 ($M_{2,i} \lesssim 9.60 \times 10^{13}$ GeV)		
3 ($M_{3,i} \lesssim 3 \times 10^{13}$ GeV)	1* ($M_{2,i} \lesssim 124$ GeV)		
	2 ($M_{2,i} \lesssim 6.05 \times 10^{8}$ GeV)		
	3 ($M_{2,i} \lesssim 1.03 \times 10^{11}$ GeV)		
	4 ($M_{2,i} \lesssim 1.33 \times 10^{12}$ GeV)		
	5 ($M_{2,i} \lesssim 6.22 \times 10^{12}$ GeV)		
	6 ($M_{2,i} \lesssim 1.74 \times 10^{13}$ GeV)		
	7 ($M_{2,i} \lesssim 3.62 \times 10^{13}$ GeV)		
	8 ($M_{2,i} \lesssim 6.27 \times 10^{13}$ GeV)		
	9 ($M_{2,i} \lesssim 9.61 \times 10^{13}$ GeV)		
4 ($M_{3,i} \lesssim 9 \times 10^{13}$ GeV)	1* ($M_{2,i} \lesssim 78.3$ GeV)	3.27	38.6
	2 ($M_{2,i} \lesssim 5.06 \times 10^{8}$ GeV)		
	3 ($M_{2,i} \lesssim 9.42 \times 10^{10}$ GeV)		
	4 ($M_{2,i} \lesssim 1.28 \times 10^{12}$ GeV)		
	5 ($M_{2,i} \lesssim 6.16 \times 10^{12}$ GeV)		
	6 ($M_{2,i} \lesssim 1.75 \times 10^{13}$ GeV)		
	7 ($M_{2,i} \lesssim 3.70 \times 10^{13}$ GeV)		
	8 ($M_{2,i} \lesssim 6.48 \times 10^{13}$ GeV)		
	9 ($M_{2,i} \lesssim 1.00 \times 10^{14}$ GeV)		

* : ruled out by collider direct search of SU(2) adjoint fermion experiments