Multicritical Point Principle and Its Phenomenology

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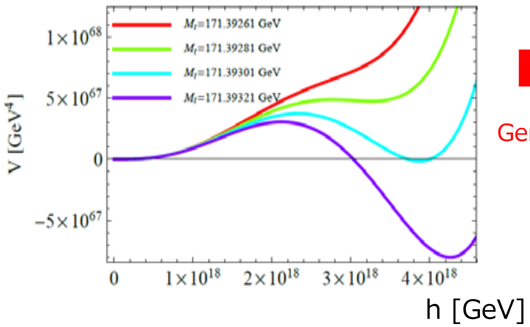
Multicritical point principle (MPP)?

Froggatt & Nielsen (1995)

$m_h \sim 125$ GeV and $m_t \sim 171$ GeV can indicate criticality.

$$V_{\rm eff} = \frac{\lambda_{\rm eff}(h)}{4} h^4$$

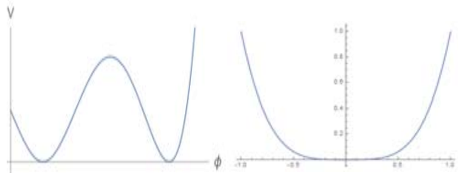
Hamada, Kawai, Oda, Park (2015)



Generalize

MPP: Parameters are tuned to one of the multicritical points of vacua.

E.g., 1 parameter tuning



Deg. vacua

$V' = V'' = 0$

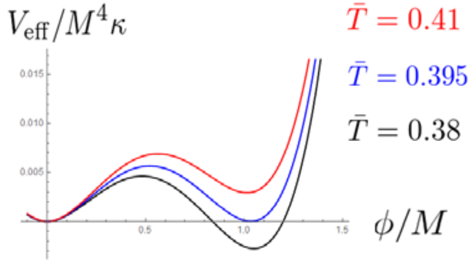
We propose a minimal model for DM and dim. transmutation in the MPP.

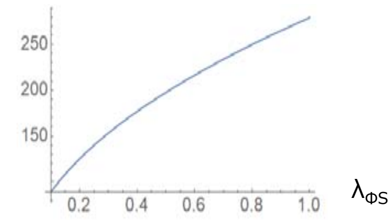
Potential at finite temperature

$$\kappa = \frac{3}{16\pi^2}\lambda_{\phi S}^2$$

$$\bar{T} = \frac{T}{M}\frac{1}{\sqrt{2\pi}}\left(\frac{3}{\kappa}\right)^{1/4} = \frac{T}{M}\sqrt{\frac{2}{\lambda_{\phi S}}}$$

$$V_{\rm eff}(\bar\phi, T) = V_{\rm eff}(\bar\phi, T=0) + \Delta V_{\rm eff}(\bar\phi, T)$$
$$= \kappa M^4\left[-\frac{\bar\phi}{18e^{25/4}} - \frac{\bar\phi^2}{8e^{25/6}} - \frac{\bar\phi^3}{6e^{25/12}} + \frac{\bar\phi^4}{48}\ln\bar\phi^2 + \frac{2\bar{T}^4}{3}\int_0^\infty dx\, x^2 \ln\left(1 - e^{-\sqrt{x^2+\bar\phi/\bar{T}^2}}\right)\right]$$





Critical temperature (T_c) is determined only by $\lambda_{\Phi S}$.

1st order phase transition can be realized! → GWs?

Minimal model with MPP

- SM + Φ & S (real scalars, singlet under SM) with a Z_2 sym.
  - S → -S (to be DM)
  - Others → even
- Scalar potential with a maximal criticality:

Trigger the EWSB when Φ develops a VEV

$$V_{\rm MPP} = \frac{\lambda_H}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!}S^4 \boxed{- \frac{\lambda_{\phi H}}{2}\phi^2(H^\dagger H)} + \frac{\lambda_{\phi S}}{4}\phi^2 S^2 + \frac{\lambda_{SH}}{2}S^2(H^\dagger H) + V_\phi \qquad \bar\phi \equiv \frac{\phi}{M}$$

$$V_\phi = \mu_1^3\phi + \frac{\mu_2^2}{2}\phi^2 + \frac{\mu_3}{3!}\phi^3 + \frac{m_S^4(\phi)}{64\pi^2}\ln\frac{\phi^2}{M^2} = \frac{3\lambda_{\phi S}^2}{16\pi^2}M^4\left[-\frac{\bar\phi}{18e^{25/4}} - \frac{\bar\phi^2}{8e^{25/6}} - \frac{\bar\phi^3}{6e^{25/12}} + \frac{\bar\phi^4}{48}\ln\bar\phi^2\right]$$

$$m_S^2(\phi) \equiv \frac{\lambda_{\phi S}}{2}\phi^2$$

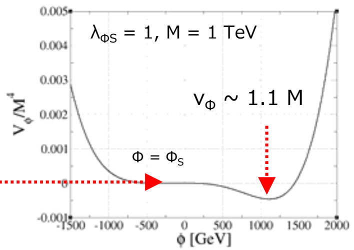
Maximal (triple) criticality

*M is a scale where λ_Φ (coef. of Φ^4) vanishes.

$$M \sim \Lambda_{\rm pl}\exp\left[-\frac{16\pi^2}{3}\frac{\lambda_\phi}{\lambda_{\phi S}^2}\right]_{\mu=\Lambda_{\rm pl}}$$

Dim. transmutation

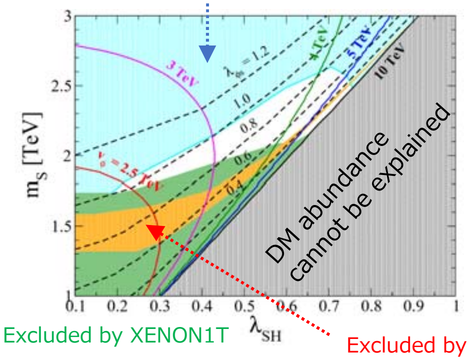
$$\left.\frac{dV_\phi}{d\phi}\right|_{\phi=\phi_S} = \left.\frac{d^2V_\phi}{d\phi^2}\right|_{\phi=\phi_S} = \left.\frac{d^3V_\phi}{d\phi^3}\right|_{\phi=\phi_S} = \left.\frac{d^4V_\phi}{d\phi^4}\right|_{\phi=\phi_S} = 0$$



Results

- Model parameters: λ_H, $\lambda_{\Phi H}$, $\lambda_{\Phi S}$, λ_{SH}, M (λ_S : not relevant to pheno.)
  → m_h~125 GeV, v~246 GeV, m_S (DM mass), v_Φ, λ_{SH}

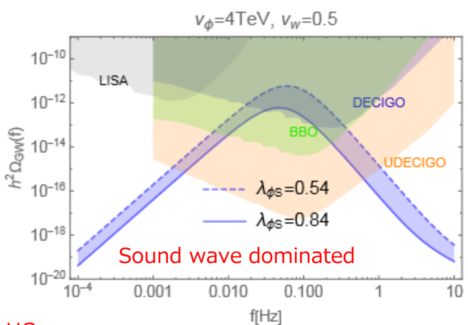
Landau pole below 10^{18} GeV



Excluded by XENON1T

Excluded by LHC

Gravitational wave spectrum



DM mass is well predicted to be ~ 2 TeV and GW signature can be detected at DECIGO and/or BBO.

Questions/Comments are welcome! → yagyu@het.phys.sci.osaka-u.ac.jp