

Near-criticality at FCC

Thomas Steingasser

Massachusetts Institute of Technology
Black Hole Initiative at Harvard University

Motivation

Higgs Potential: $V_{\text{eff}}(\phi) = V_0 - \frac{1}{2}m_{\text{eff}}^2\phi^2 + \frac{1}{4}\lambda_{\text{eff}}\phi^4$

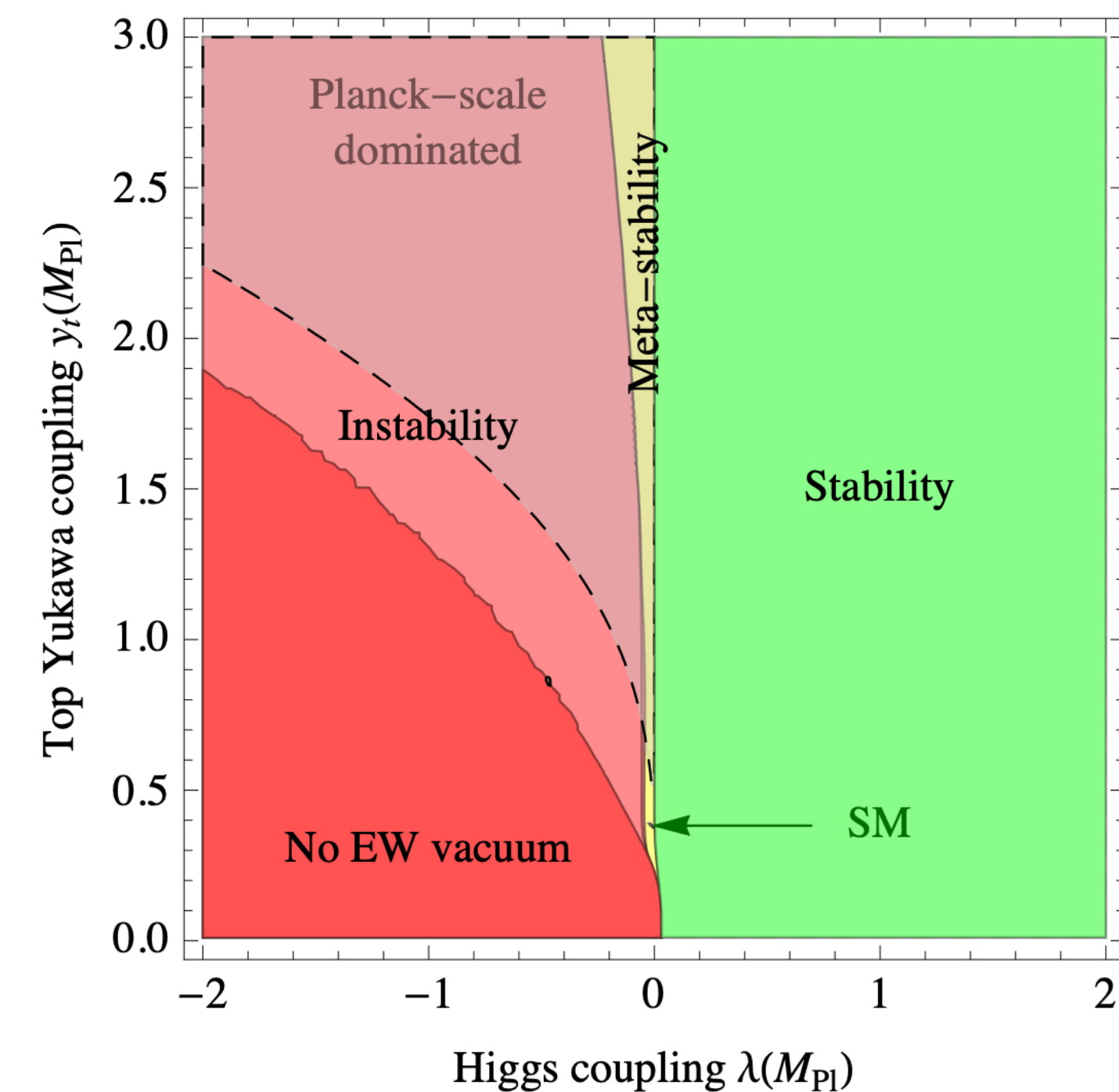
Cosmological
constant problem

Hierarchy problem

Metastability of the
EW vacuum

$$m_{\text{eff}}^2 \ll \Lambda_{\text{UV}}^2$$

Tuning* problems



Near-criticality in the SM

Higgs Potential:
$$V_{\text{eff}}(\phi) = V_0 - \frac{1}{2}m_{\text{eff}}^2\phi^2 + \frac{1}{4}\lambda_{\text{eff}}\phi^4$$

V_0 :
 m_{eff}^2 :
 λ_{eff} :

close to transition
close to transition
close to transition

“dS” ↔ “AdS”
“SSB” ↔ “no SSB”
“stable” ↔ “unstable”

“Critical values”

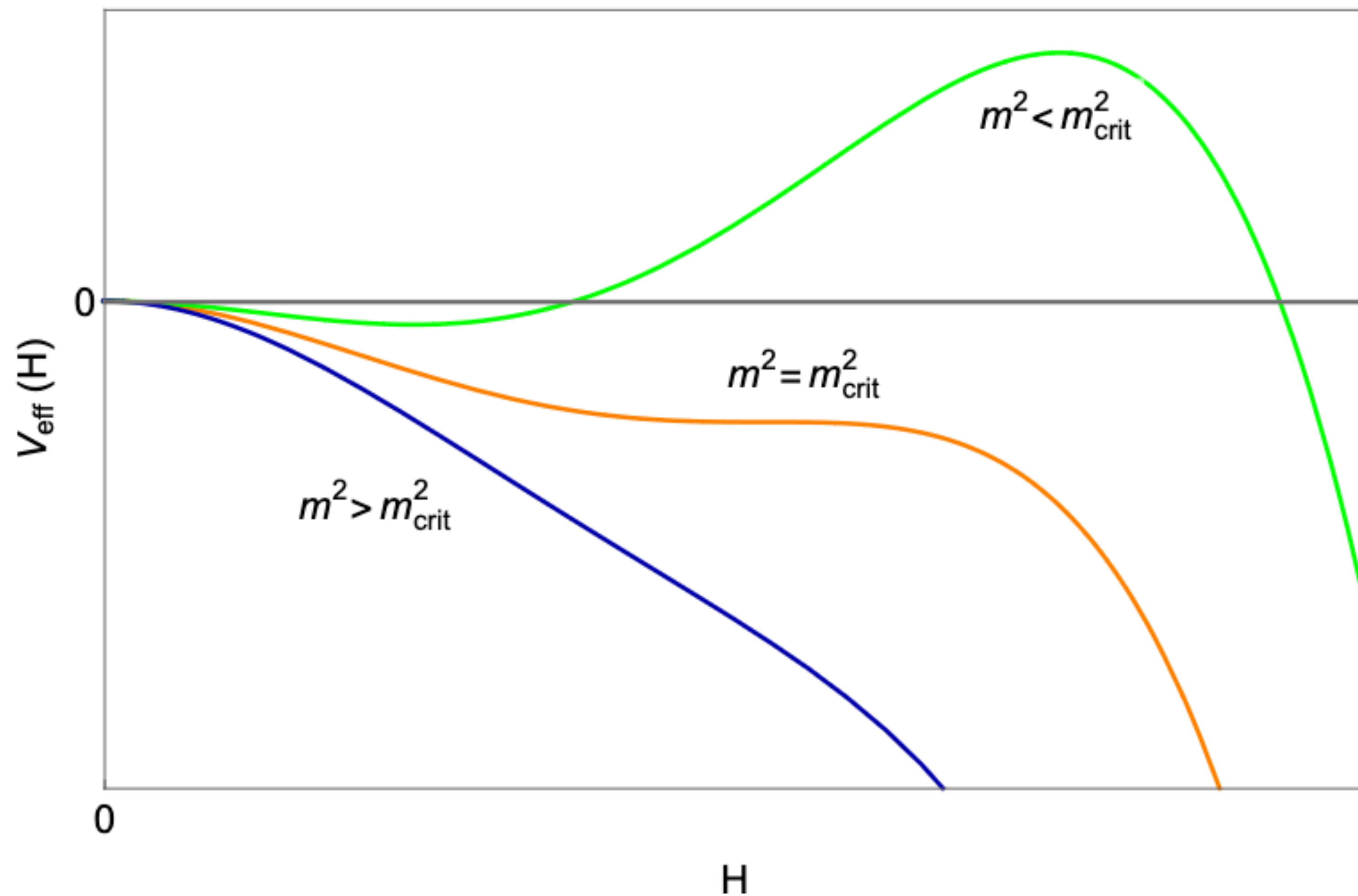
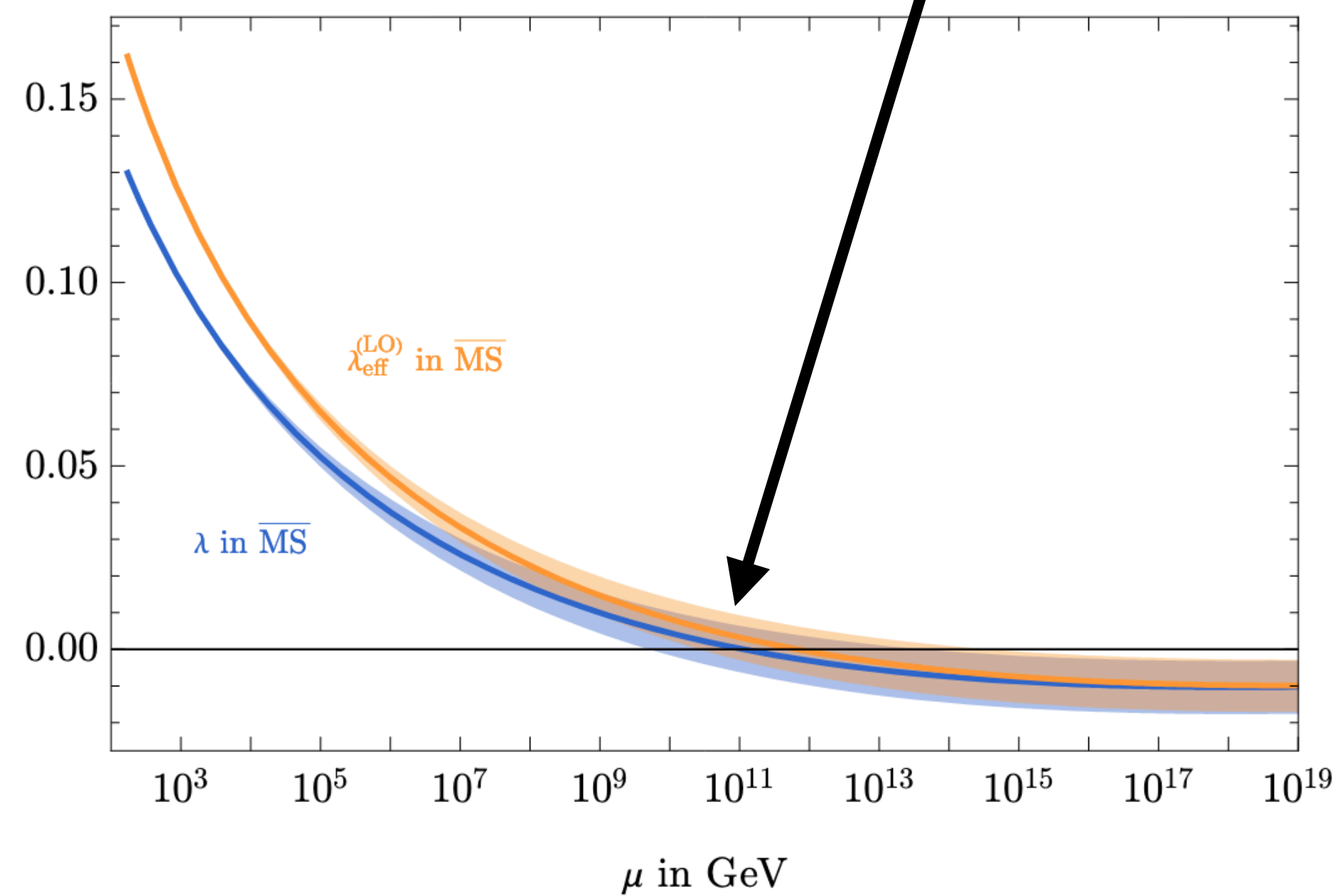
“Quantum phase transitions”

Dynamical explanation?

Metastability bound - idea

[1307.3536]
(D. Buttazzo et al)

$$m_h^2 \lesssim |\beta_\lambda| \mu_I^2$$



Metastability bound - motivation

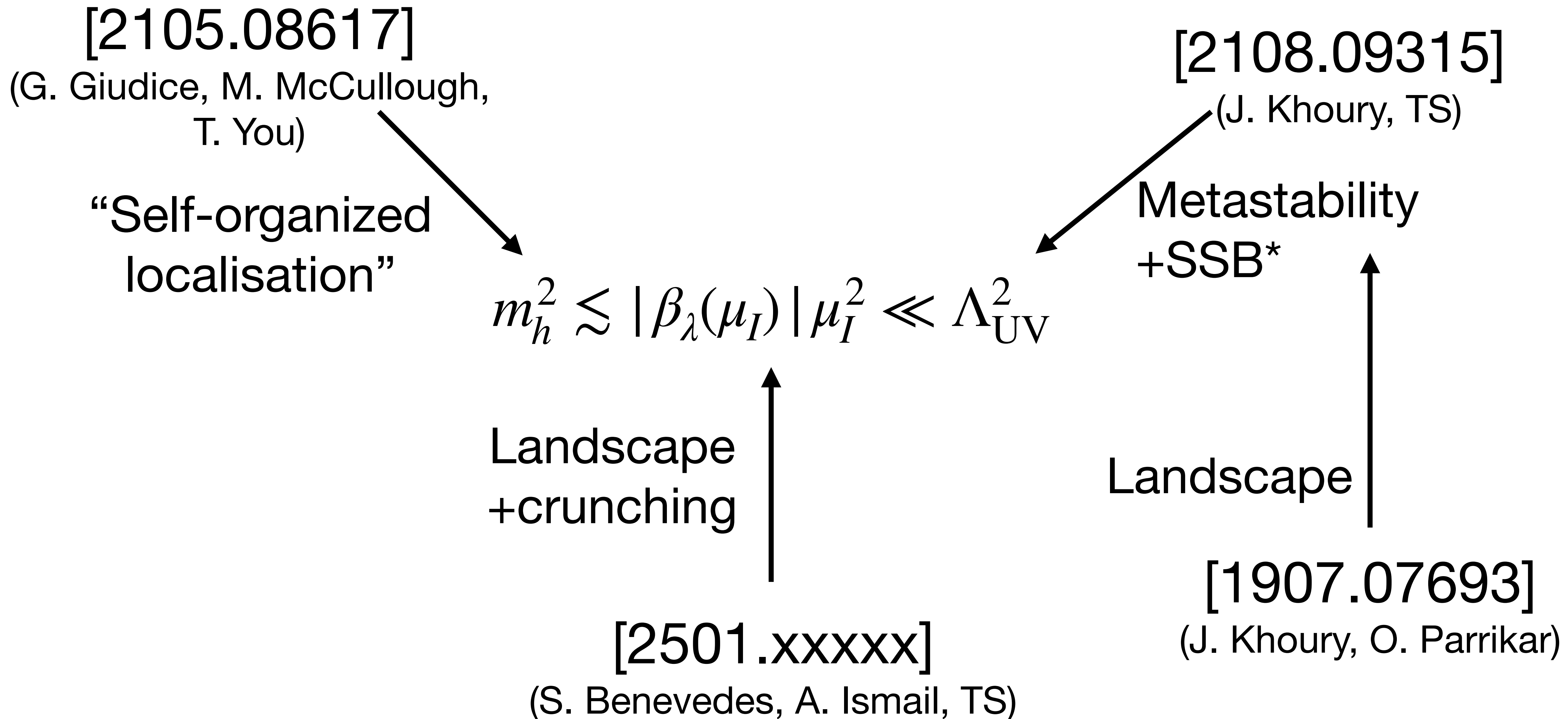
[2105.08617]

(G. Giudice, M. McCullough,
T. You)

“Self-organized
localisation”

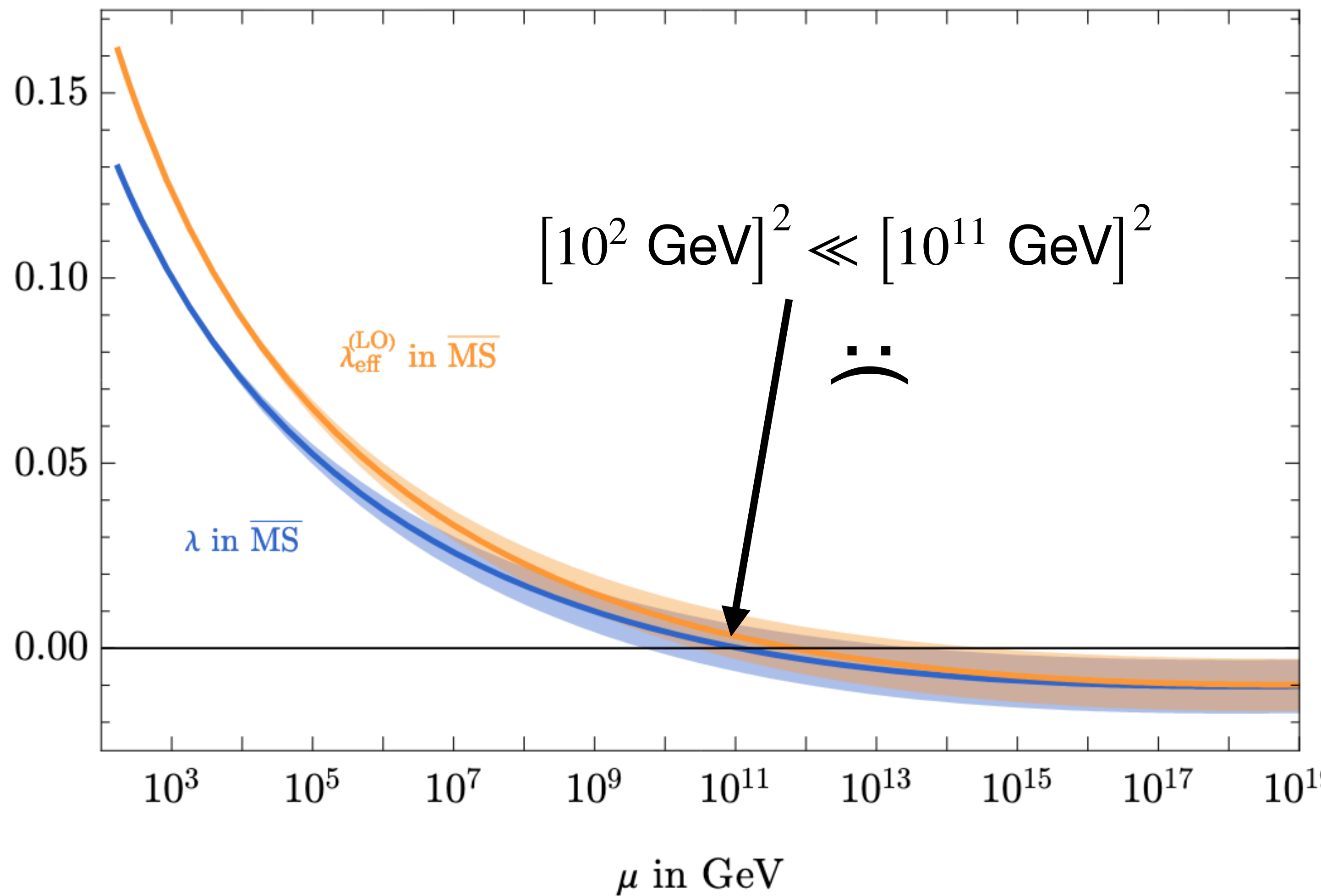

$$m_h^2 \sim |\beta_\lambda(\mu_I)| \mu_I^2$$

Metastability bound - motivation



Metastability bounds - BSM features

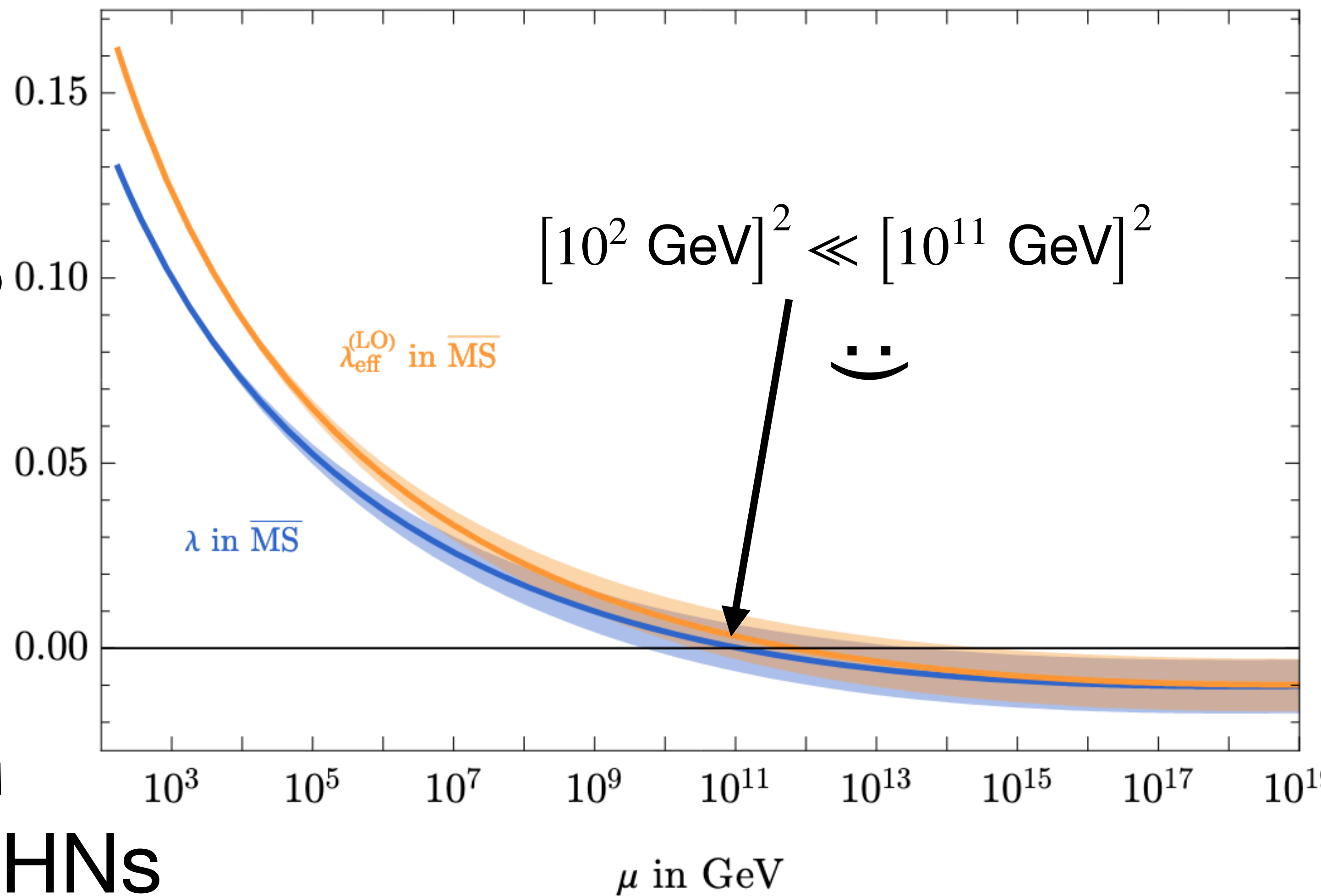
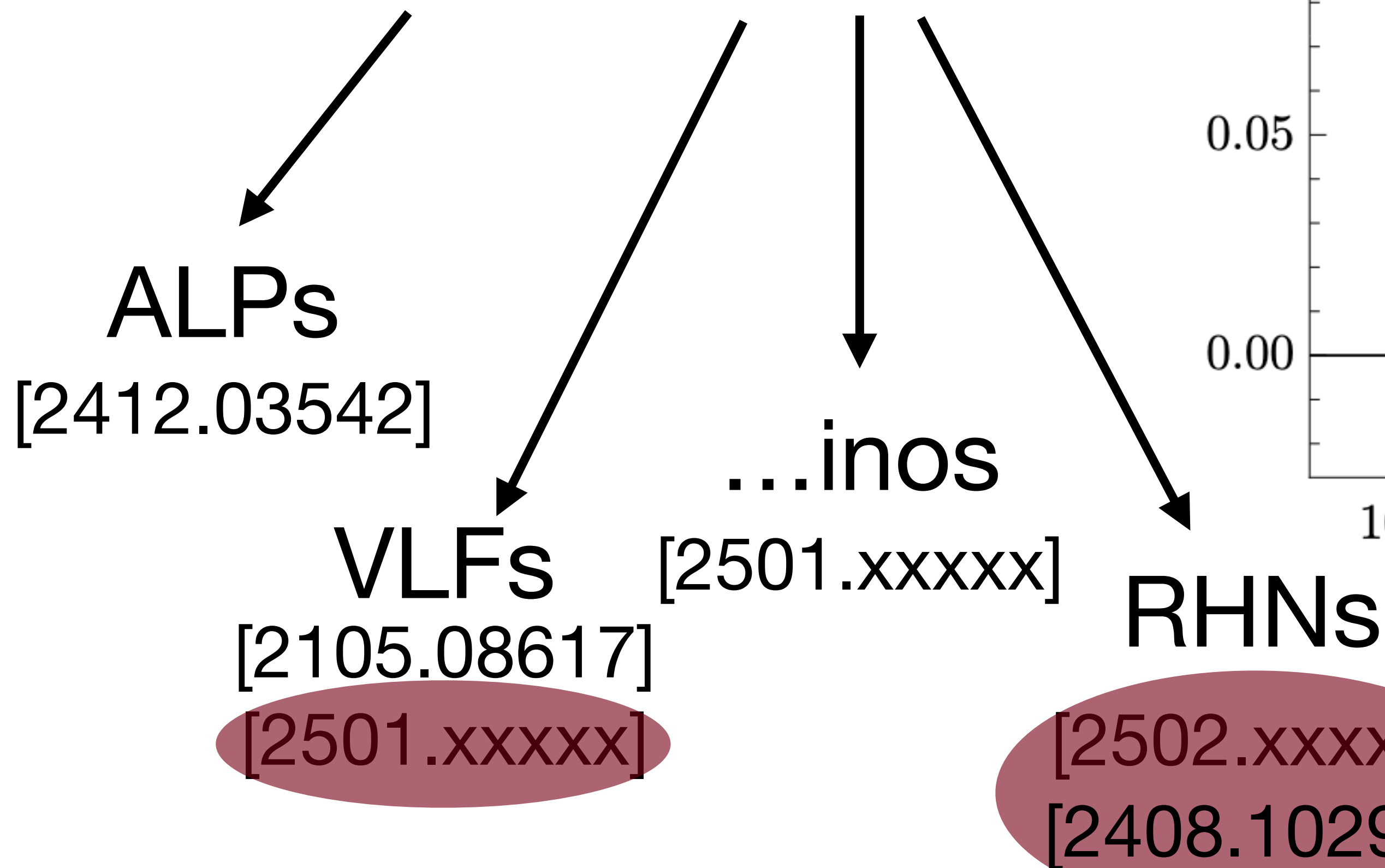
$$m_h^2 \lesssim |\beta_\lambda(\mu_I)| \mu_I^2 \ll \Lambda_{UV}^2$$



Metastability bounds - BSM features

$$m^2 \lesssim |\beta_\lambda(\mu_I)| \mu_I^2 \ll \Lambda_{UV}^2$$

lowered by BSM physics?



Metastability bounds - BSM features

General: Smaller $\mu_I \longrightarrow$ Shorter lifetime

$\mu_I \sim \mathcal{O}(\text{TeV}) \longrightarrow$ lifetime $<$ age of the universe

\longrightarrow Additional bosons to partially stabilize

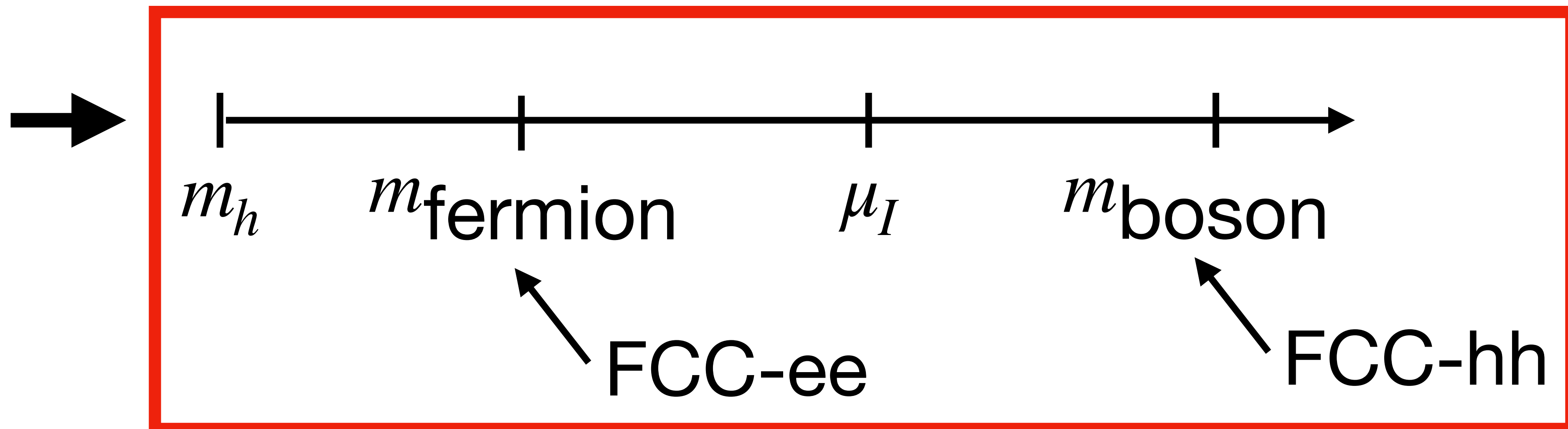


Metastability bounds - BSM features

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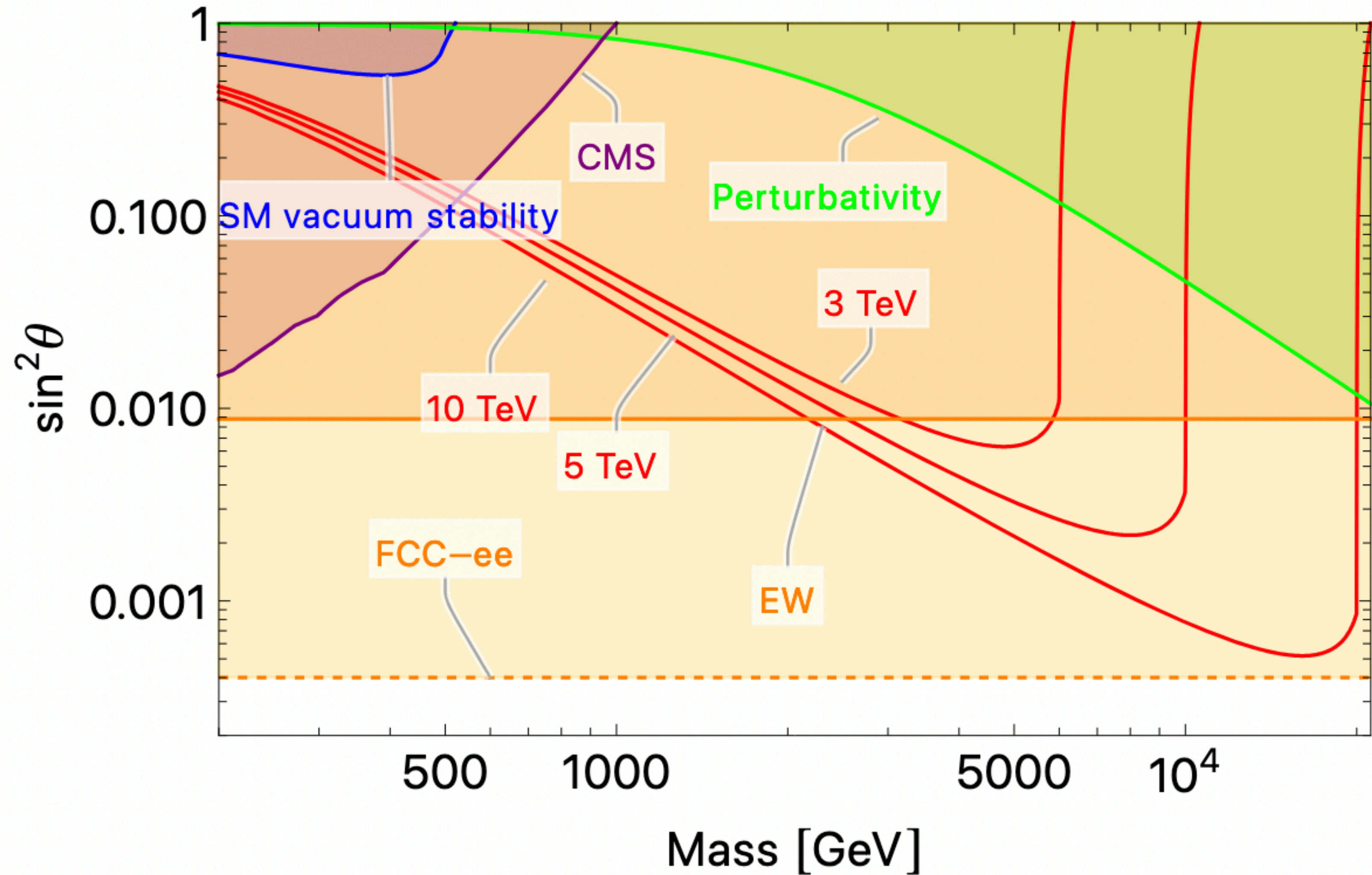


Metastability bounds @FCC - Heavy Neutral Lepton

$$\mathcal{L}_\psi = i\bar{\psi}_L \not{\partial} \psi_L + i\bar{\psi}_R \not{\partial} \psi_R - \left(m\bar{\psi}_L \psi_R + y_i \bar{L}_i \tilde{H} \psi_R \right)$$

$$\sin \theta = \frac{y\nu}{\sqrt{y^2\nu^2 + m^2}}$$

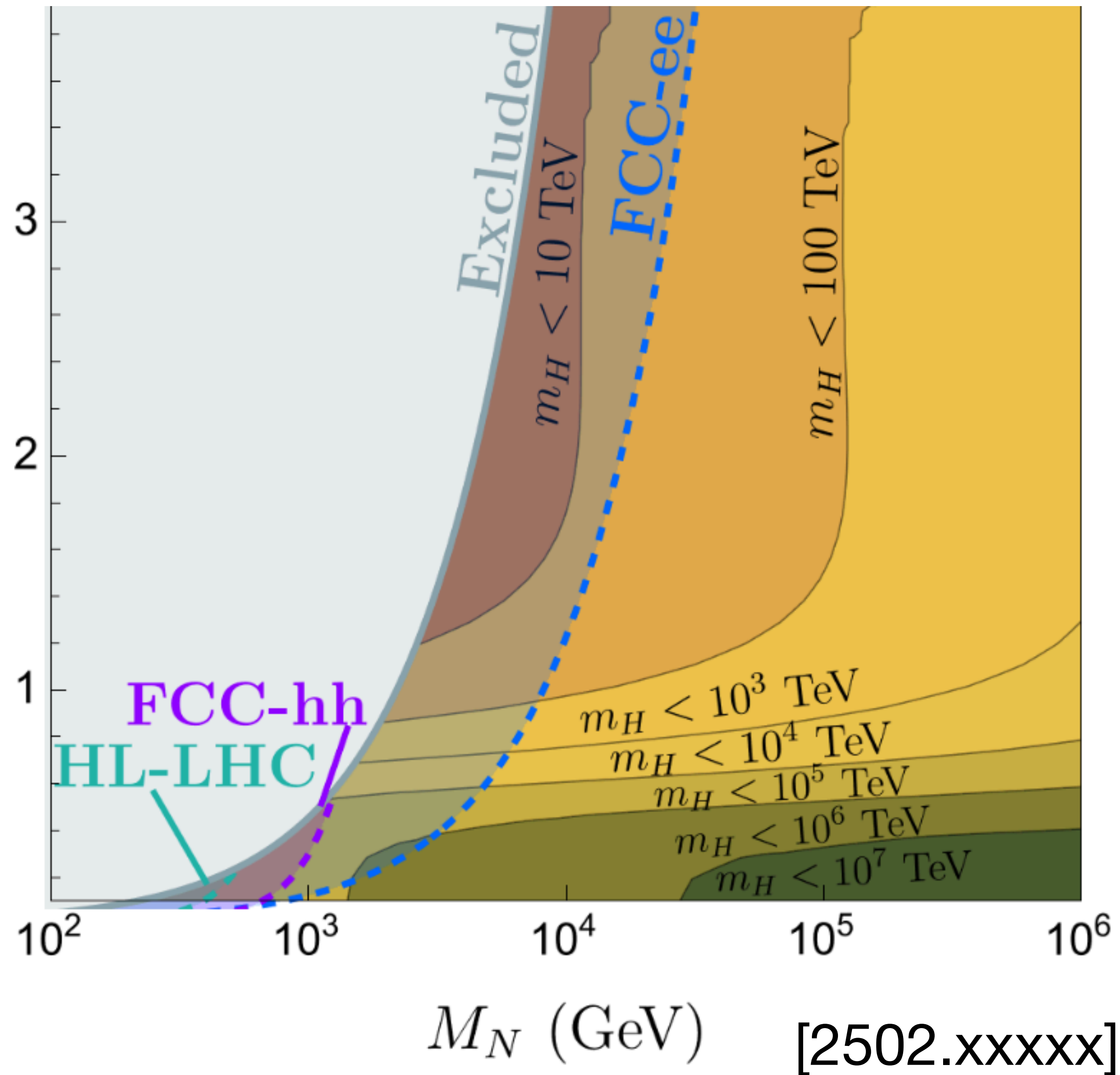
3rd generation only



Metastability bound @FCC - RHNs

$$\begin{aligned}
 \mathcal{L}_{\nu_R} = & \sum_i \bar{\nu}_{R,i} \not{\partial} \nu_{R,i} \\
 & - \sum Y_{\nu}^{ai} \bar{\ell}_L^a \tilde{H} \nu_{R,j} \\
 & - \frac{1}{2} \sum_{i,j} \mathbf{M}_N^{ij} \bar{\nu}_{R,i}^c \nu_{R,j}
 \end{aligned}$$

$\nearrow Y_{\nu}$
 $Tr(\mathbf{Y}_{\nu}^{\dagger} \mathbf{Y}_{\nu})^{1/2}$



Metastability bounds - Majoron model

Open questions:

- specific ordering of scales?
- lifetime of vacuum?
- why is running necessary?



“You have to be brave
and write a model”

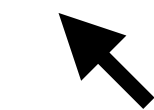
Metastability bounds - Majoron model

Open questions:

- specific ordering of scales?
- lifetime of vacuum?
- why is running necessary?



➔ Majoron Model



[2502.xxxxx]

(V. Enguita, B. Gavela, TS)

$$V = -m_H^2 |H|^2 + \lambda_H |H|^4 - m_S^2 |S|^2 + \lambda_S |S|^4 + \kappa |H|^2 |S|^2$$

$$\rightarrow M_S = \sqrt{\lambda_S} \langle S \rangle$$

$$\rightarrow M_N \sim Y_R \langle S \rangle$$

coupling
to RHNs

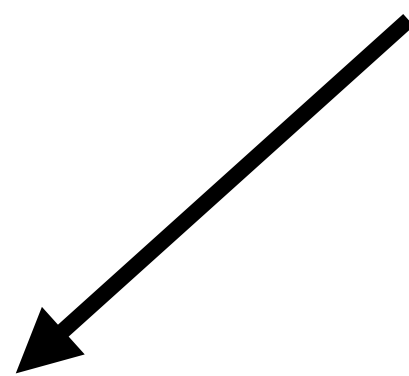
Metastability bounds - Majoron model

$$V = -m_H^2 |H|^2 + \lambda_H |H|^4 - m_S^2 |S|^2 + \lambda_S |S|^4 + \kappa |H|^2 |S|^2$$

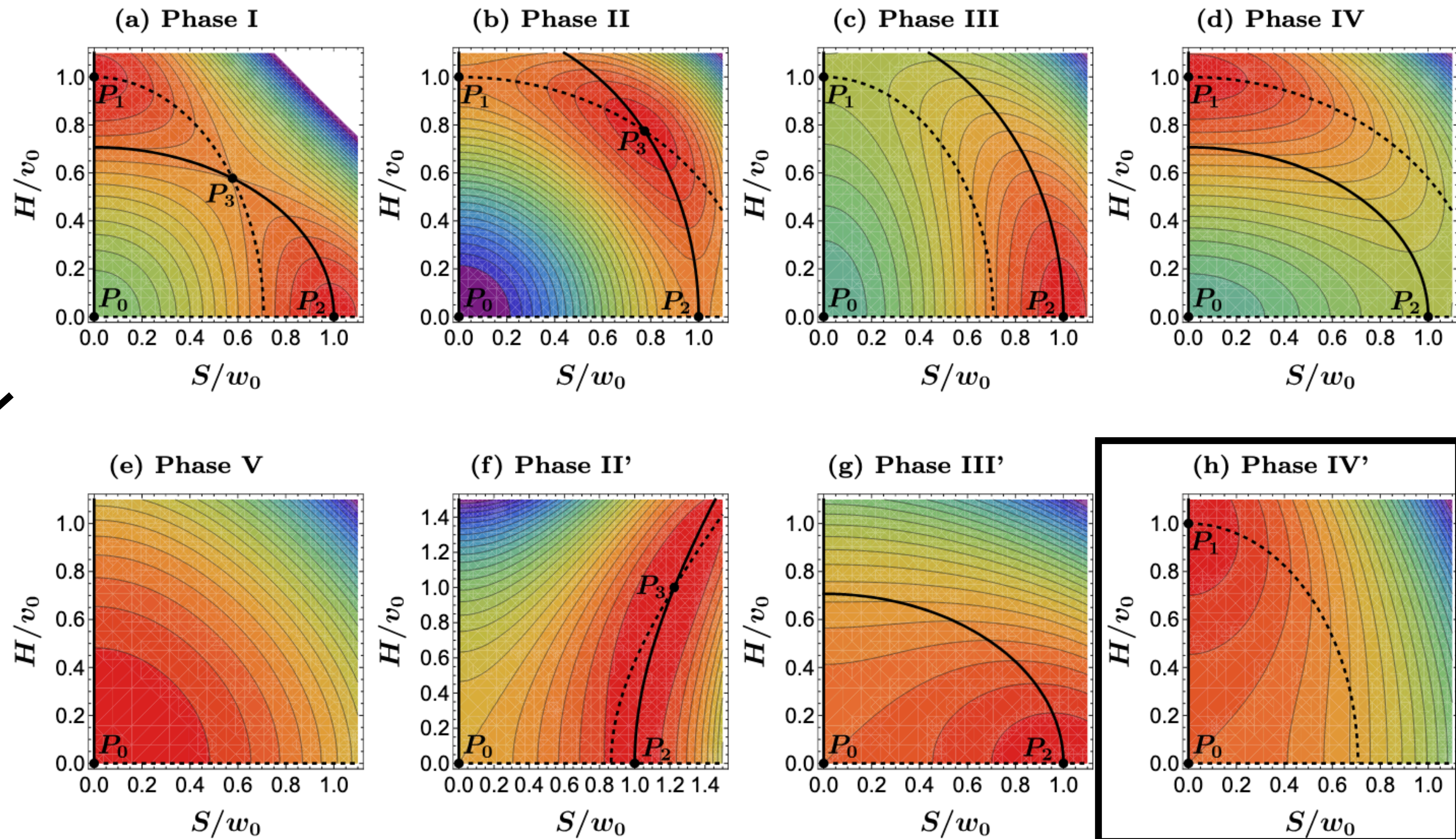
assuming
SSB



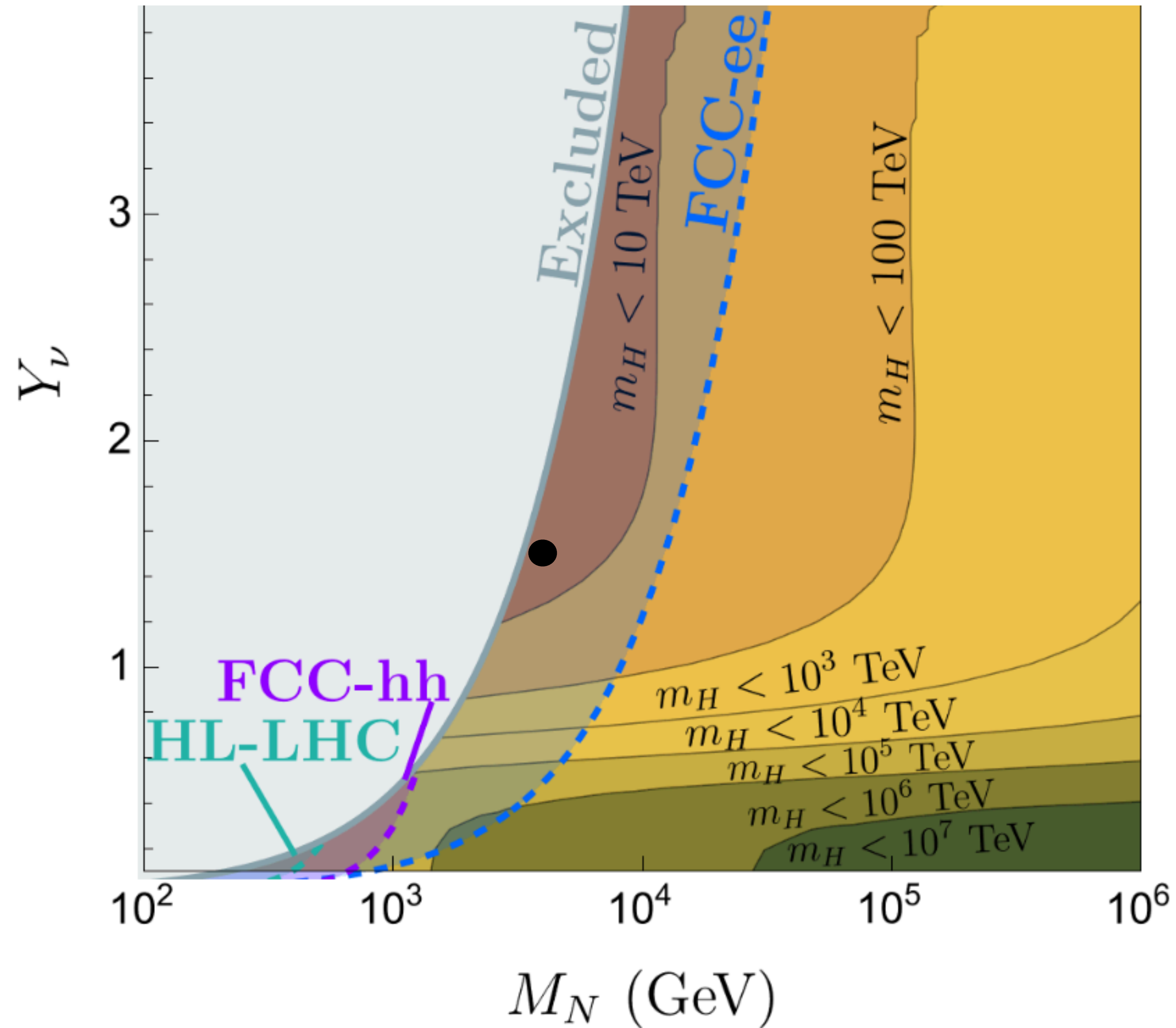
running effects
necessary!



calculate
tunneling
rates!



Metastability bound @FCC - RHNs

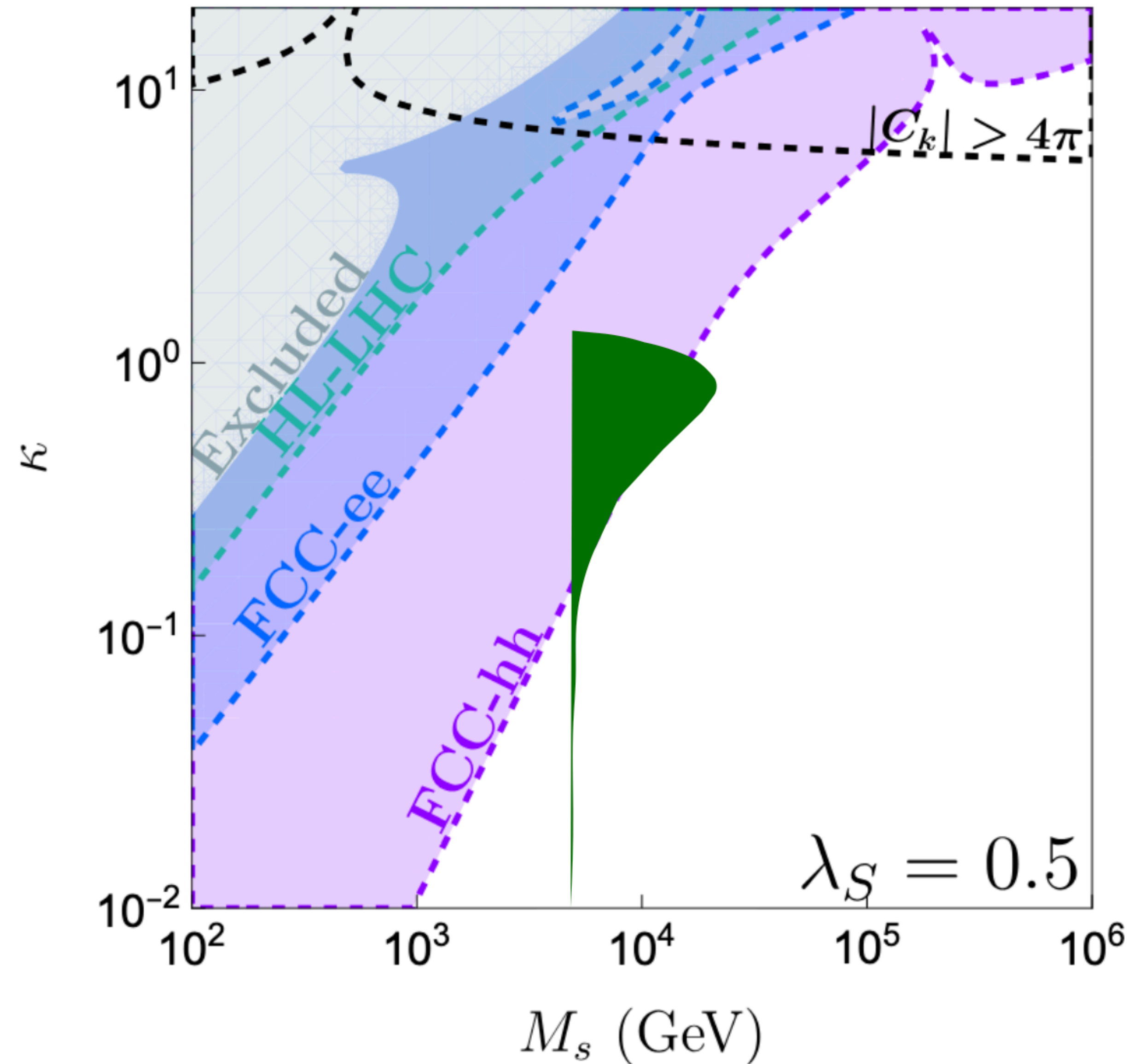
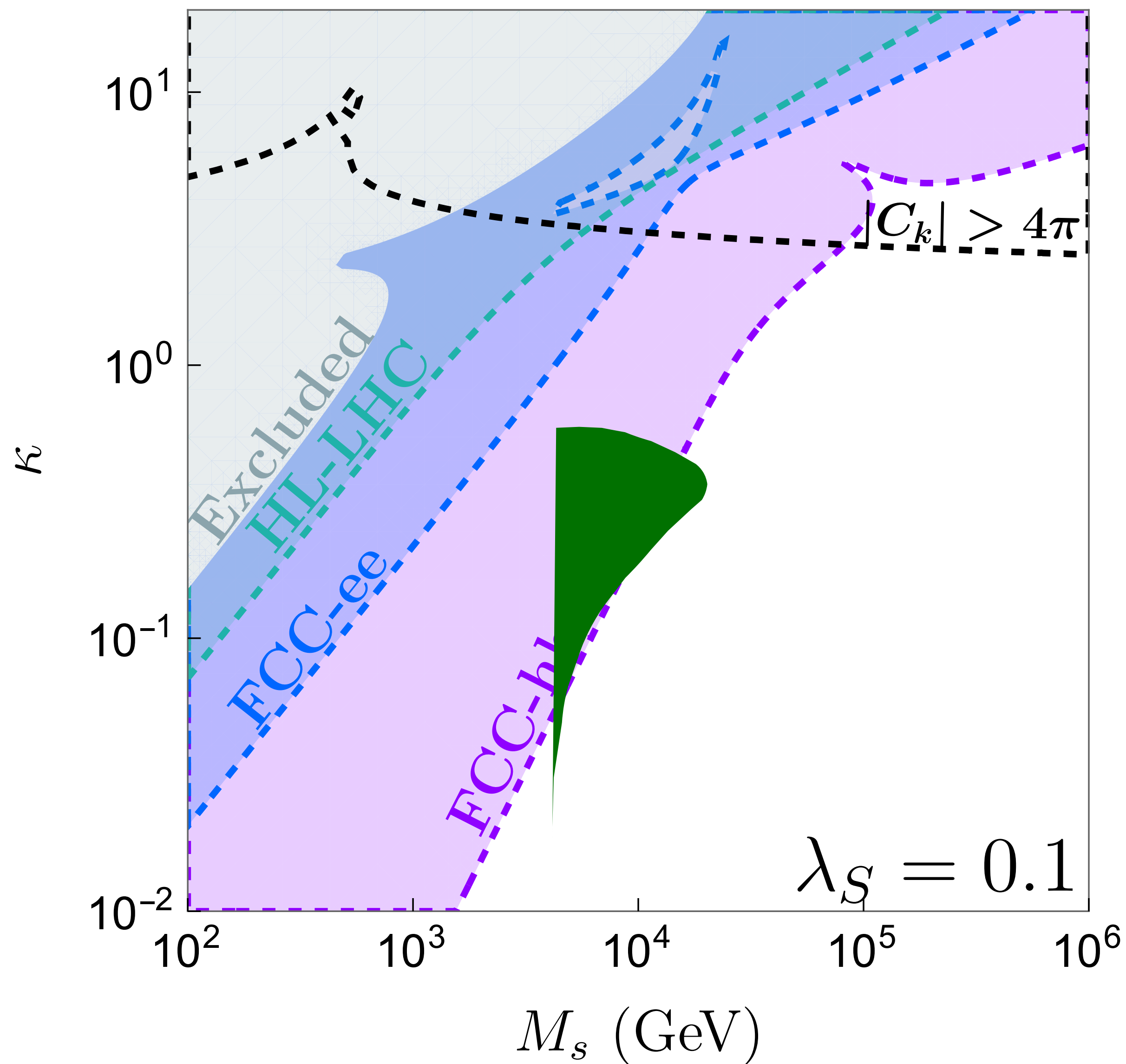


potential allows for
metastability bound

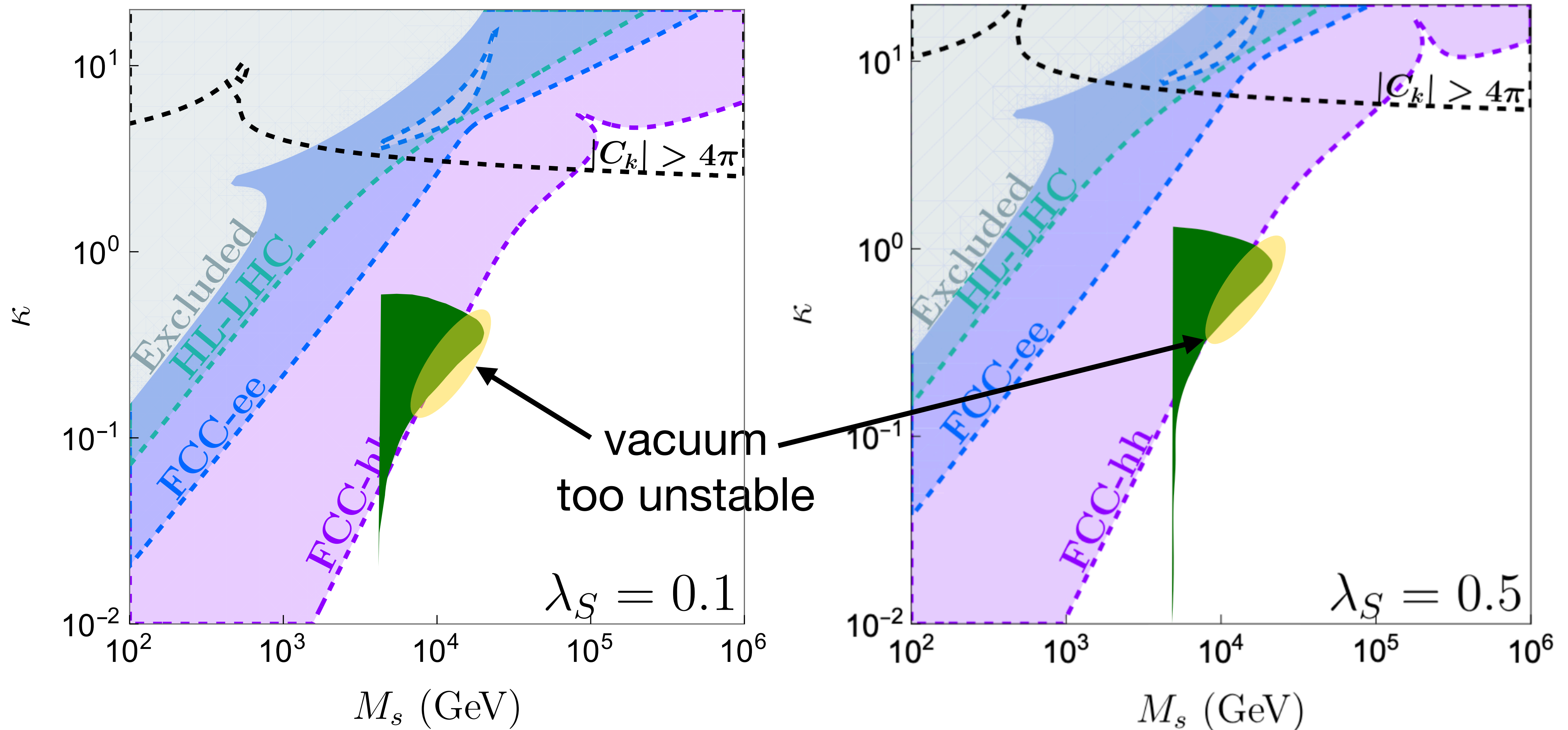


potential bounded
from below

Metastability bound @FCC - Majoron



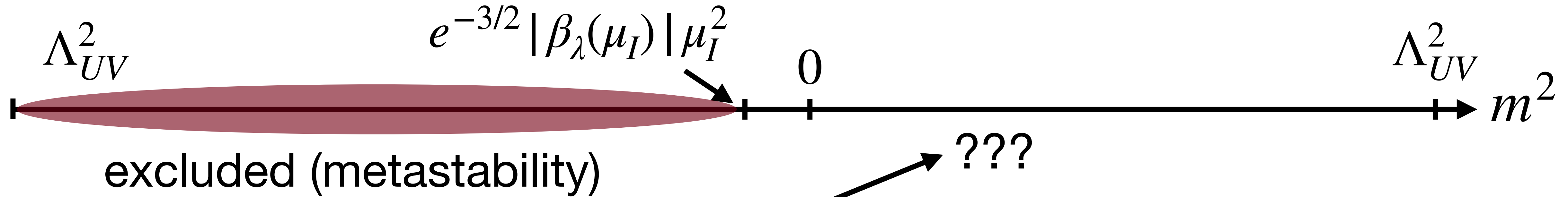
Metastability bound @FCC - Majoron



Thank you for your attention!

tstngssr@mit.edu

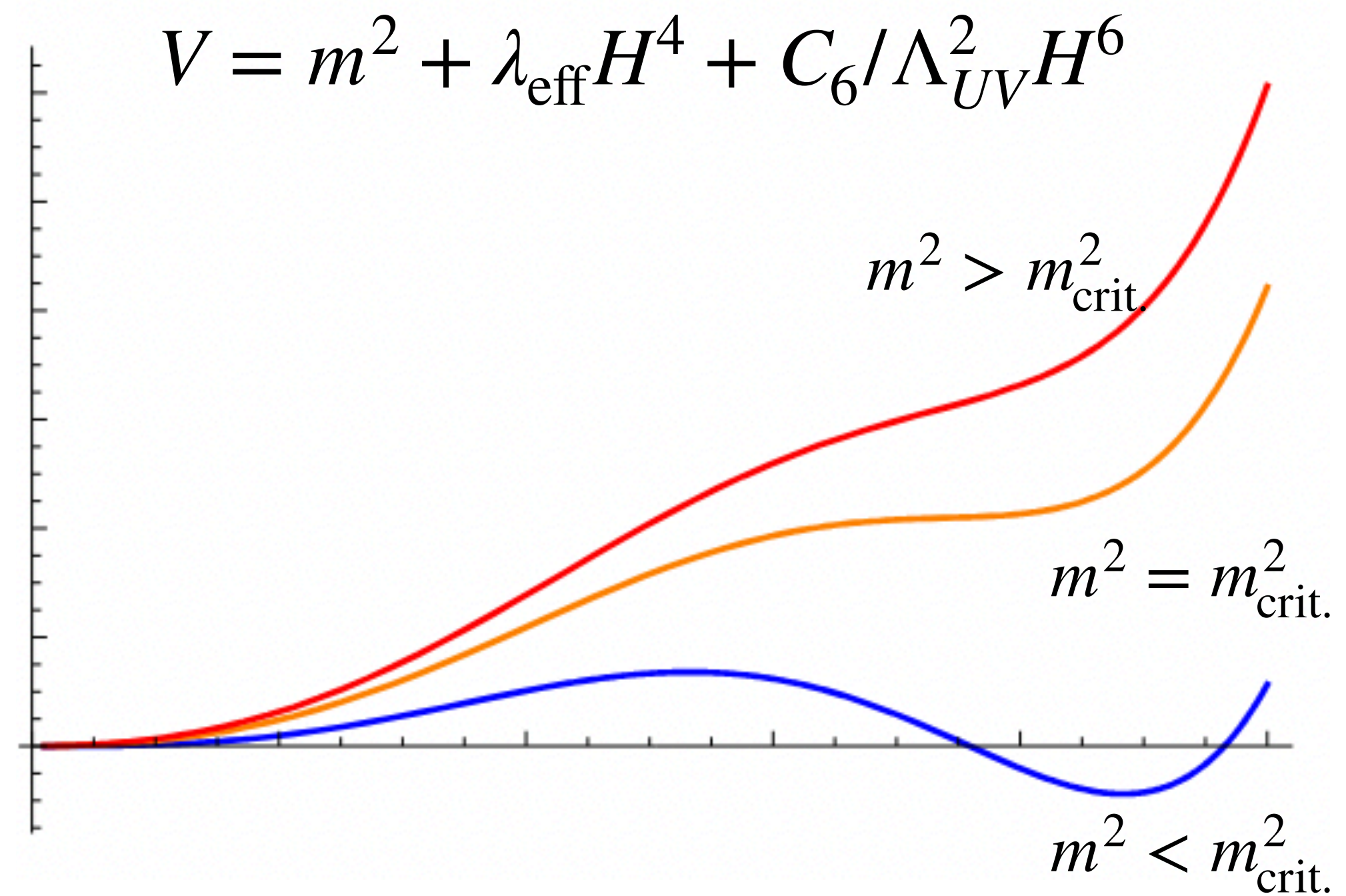
Extended metastability bounds - explaining SSB?



[2408.10297]

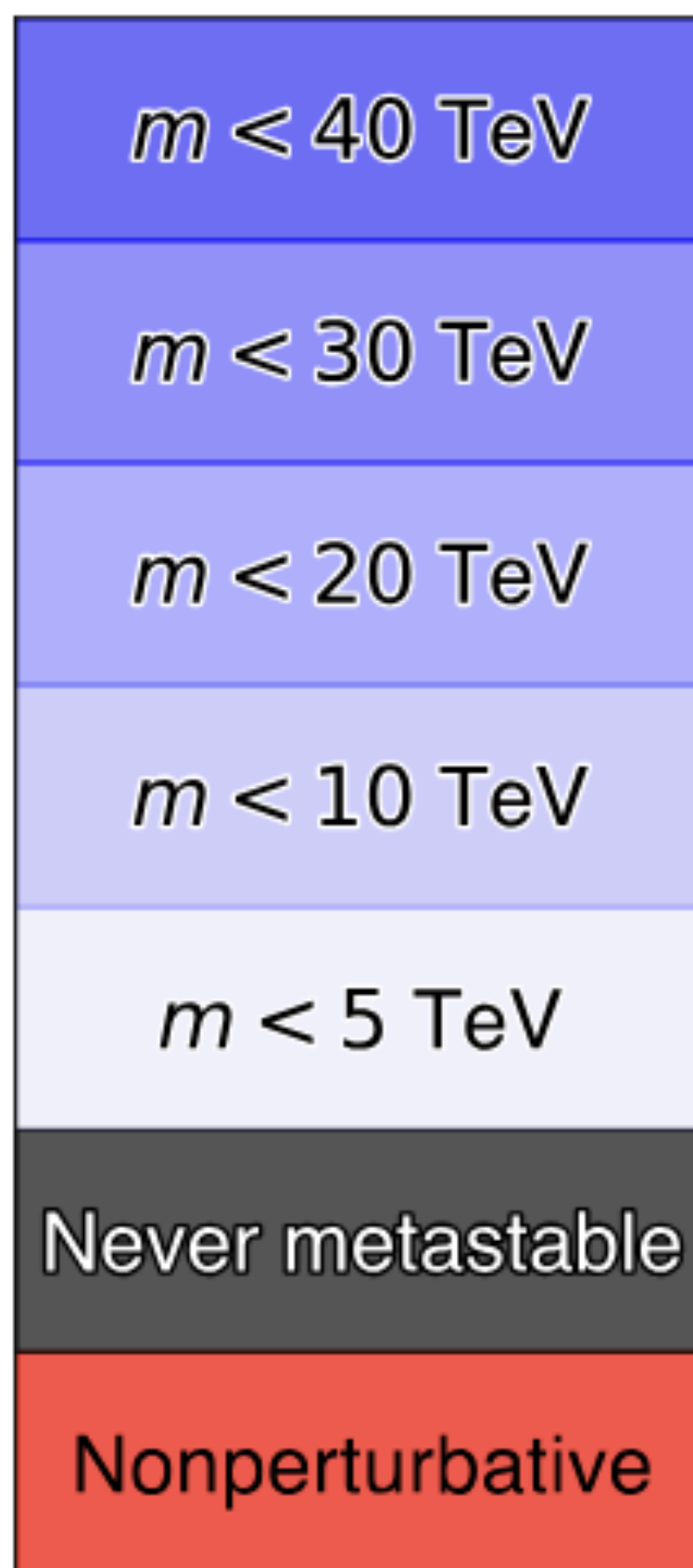
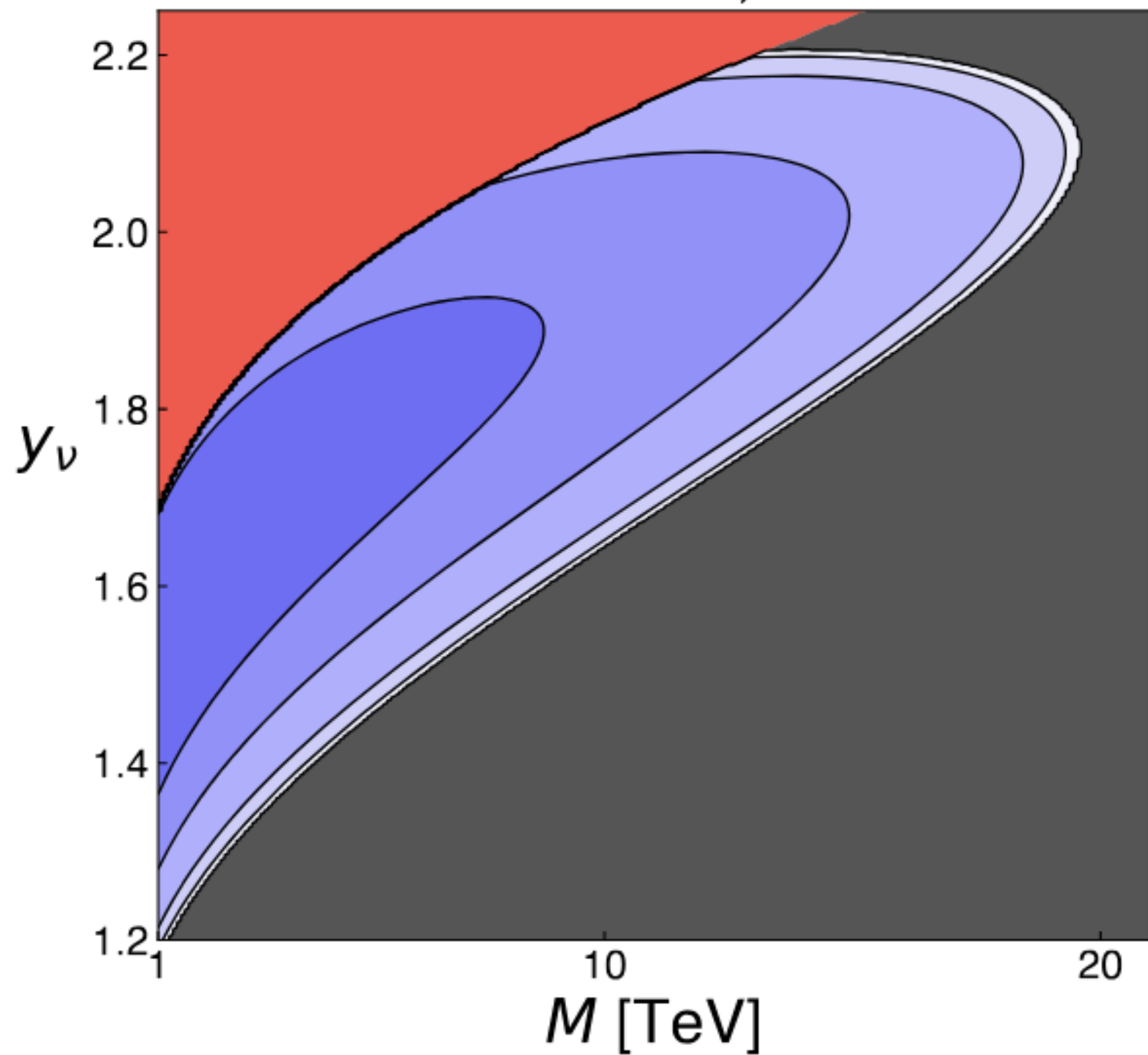
(S. Benevedes, S. Trifinopoulos, TS)

$$m^2 \lesssim |\beta_\lambda(\mu_I)|^2 \Lambda_{UV}^2$$

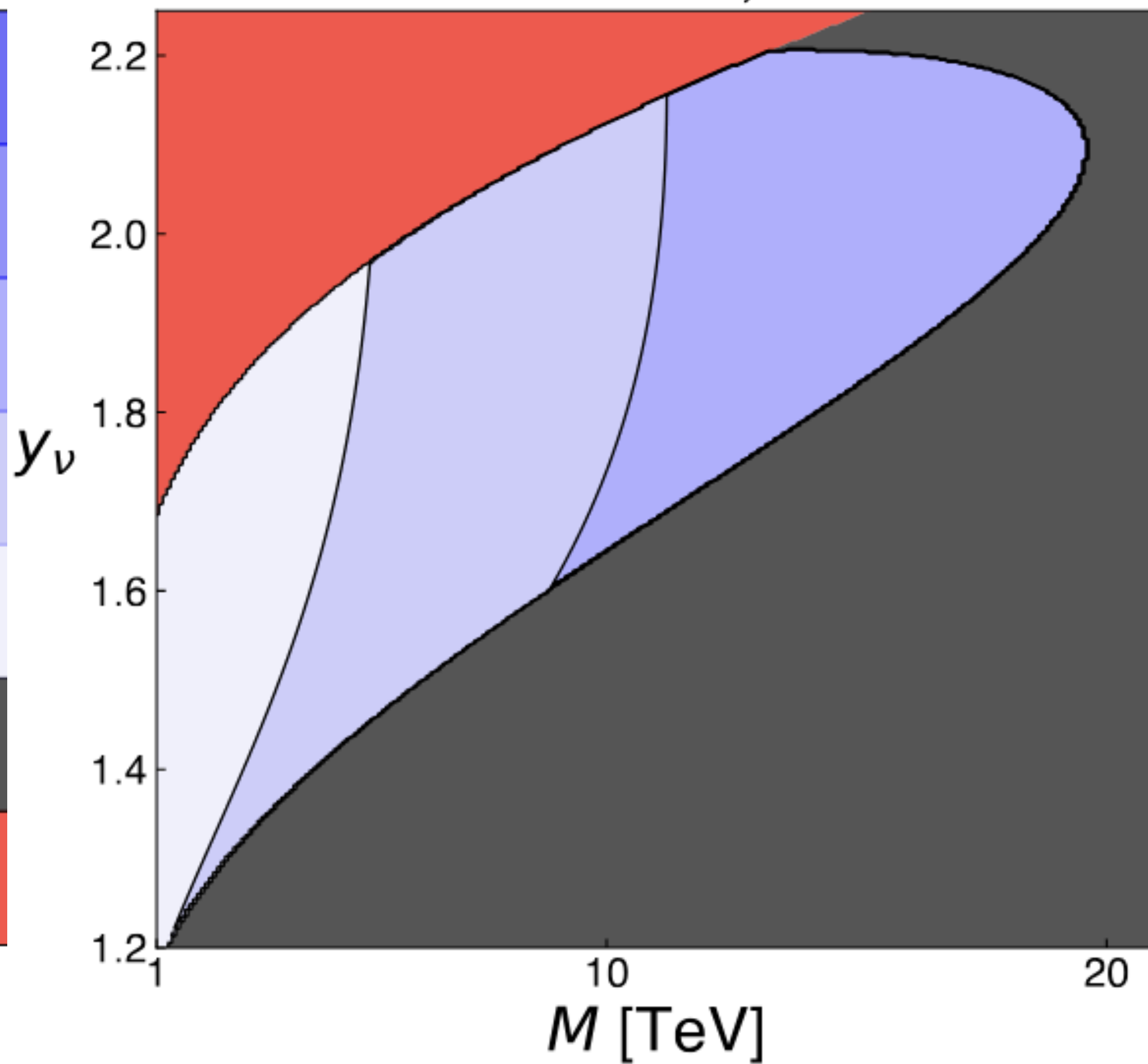


Extended metastability bounds - results

$\Lambda = 1000 \text{ TeV}, m^2 > 0$

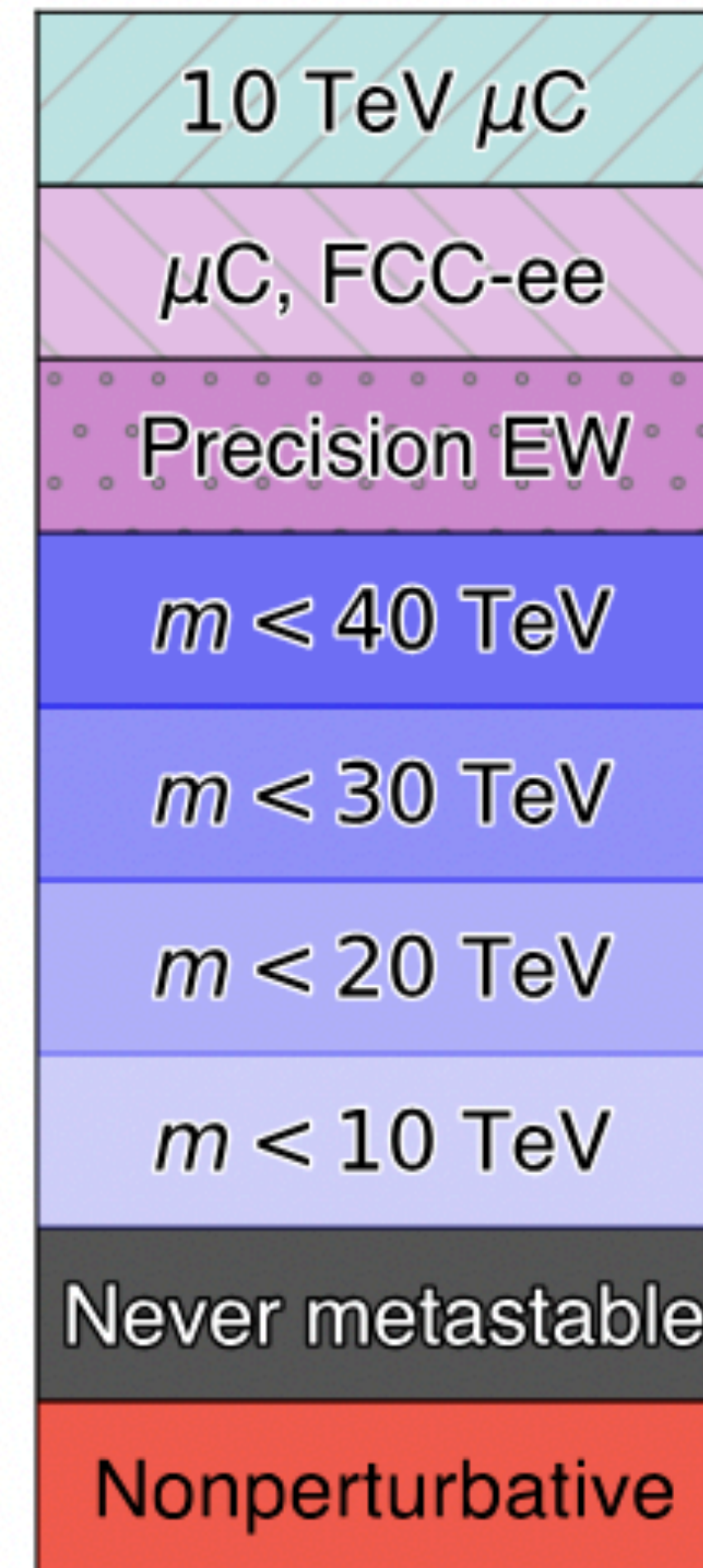
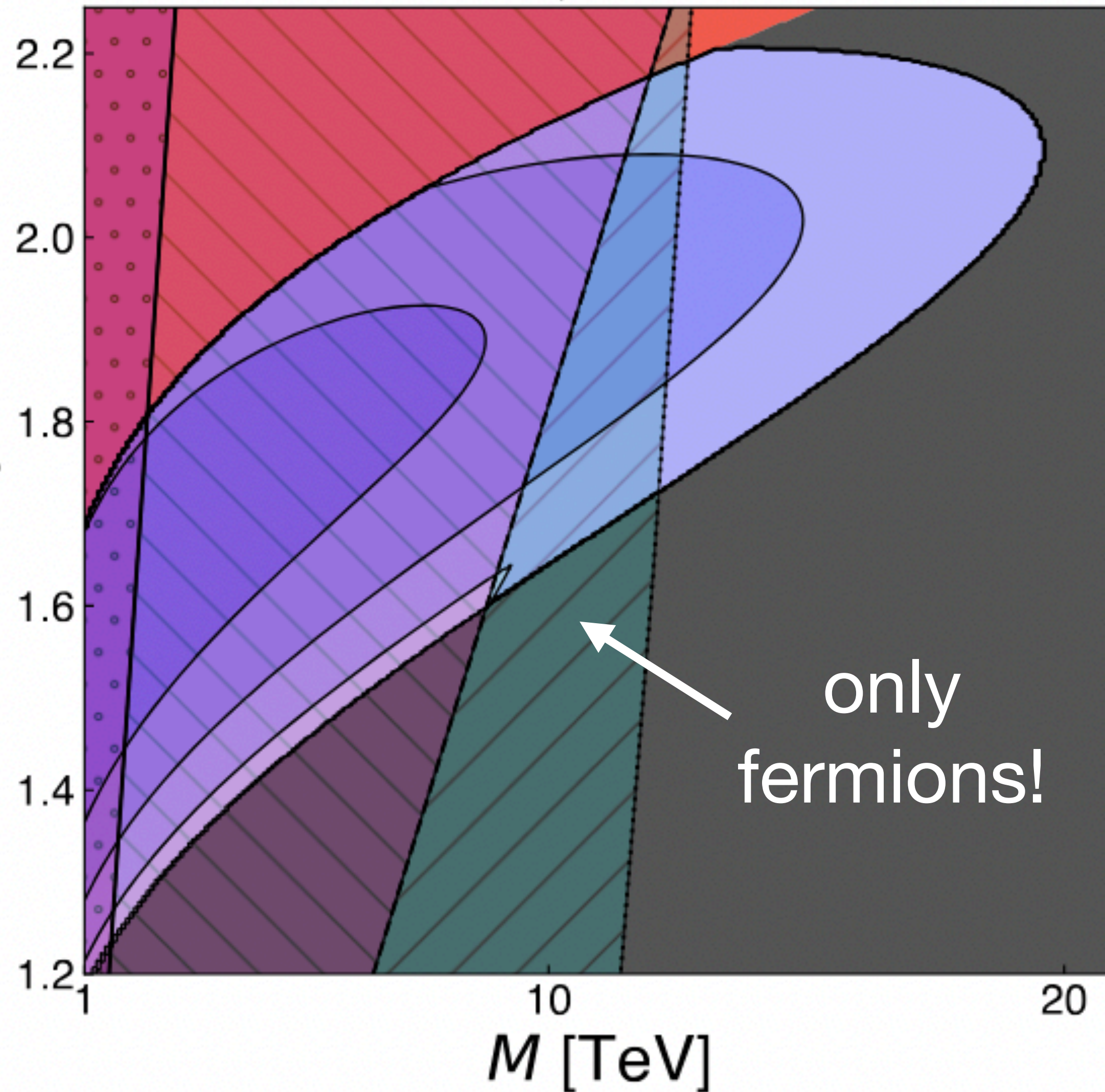


$\Lambda = 1000 \text{ TeV}, m^2 < 0$



Extended metastability bounds @ FCC

$\Lambda = 1000$ TeV, combined bound



[2408.10297]: y_ν

Extended metastability bounds - explaining SSB!

