Near-criticality in BSM model building

Thomas Steingasser

Massachusetts Institute of Technology
Black Hole Initiative at Harvard University

Motivation

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

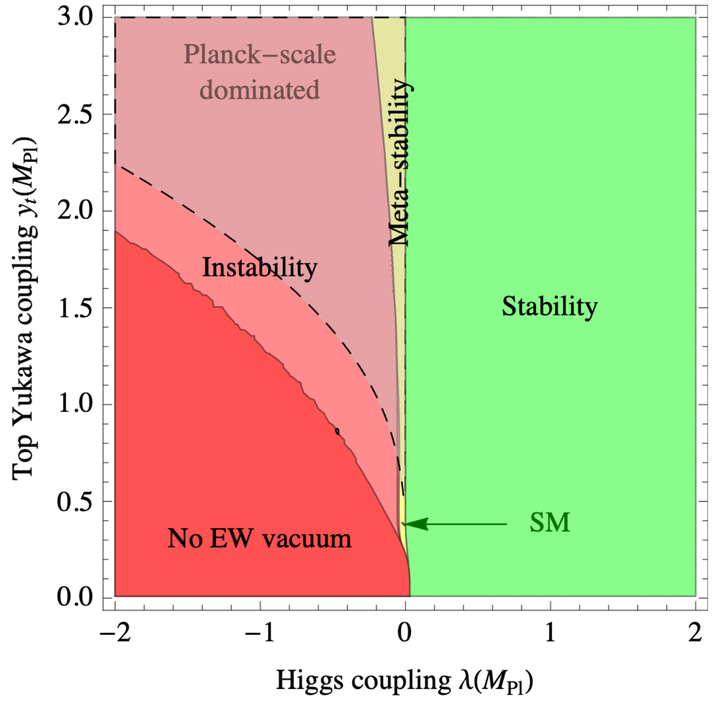
Cosmological constant problem

Hierarchy problem

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

Metastability of the EW vacuum

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 :	close to transition	"dS" ↔ "AdS"
m_{eff}^2 :	close to transition	"SSB" ↔ "no SSB"
λ_{eff} :	close to transition	"stable" ↔ "unstable"

"Critical values"

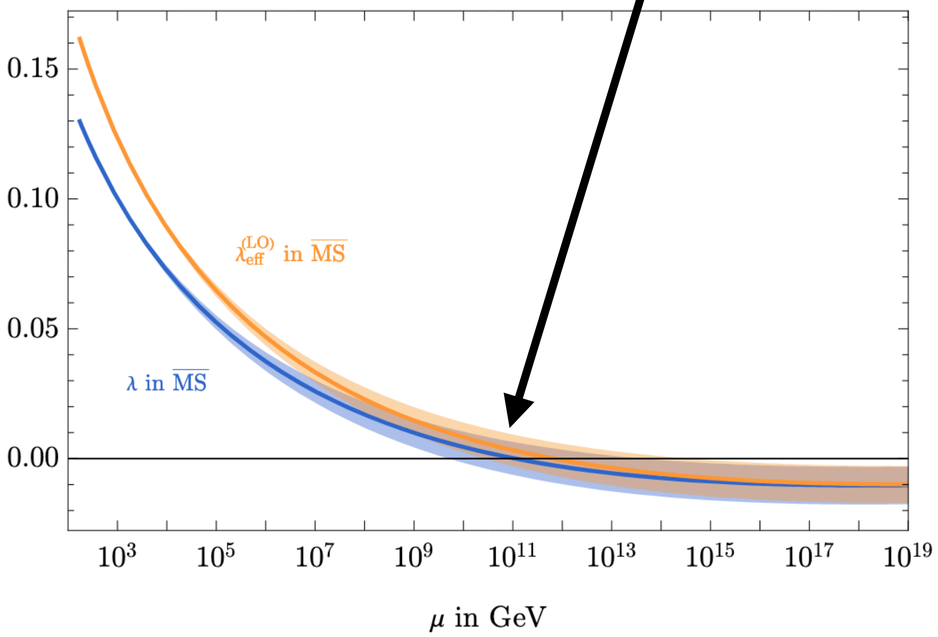
"**Quantum** phase transitions"

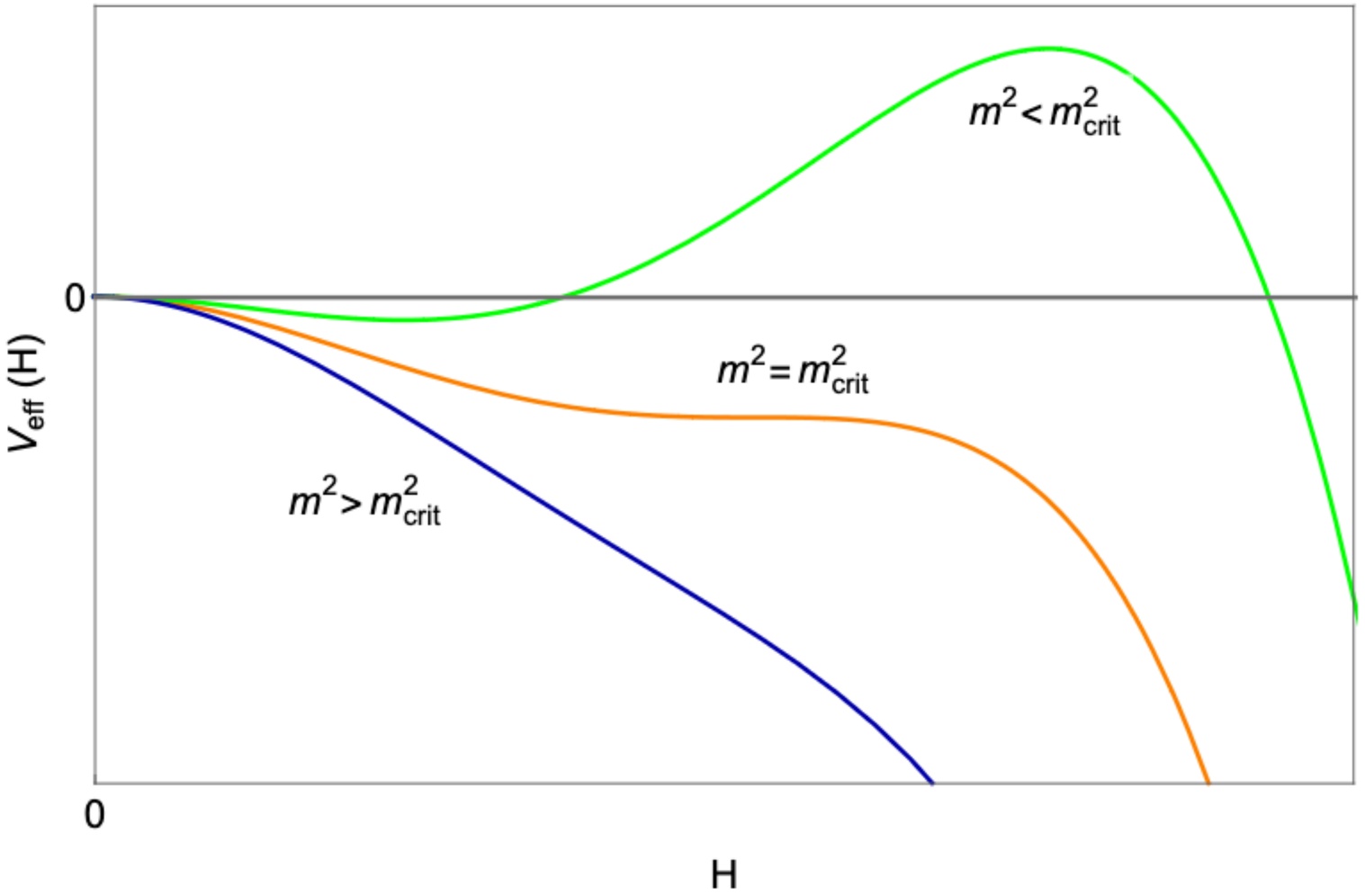
Dynamical explanation?

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

[2105.08617]
(G. Giudice, M. McCullough, T. You)

"Self-organized localisation"

[2108.09315]
(J. Khoury, TS)

Metastability +SSB*

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

Landscape +crunching

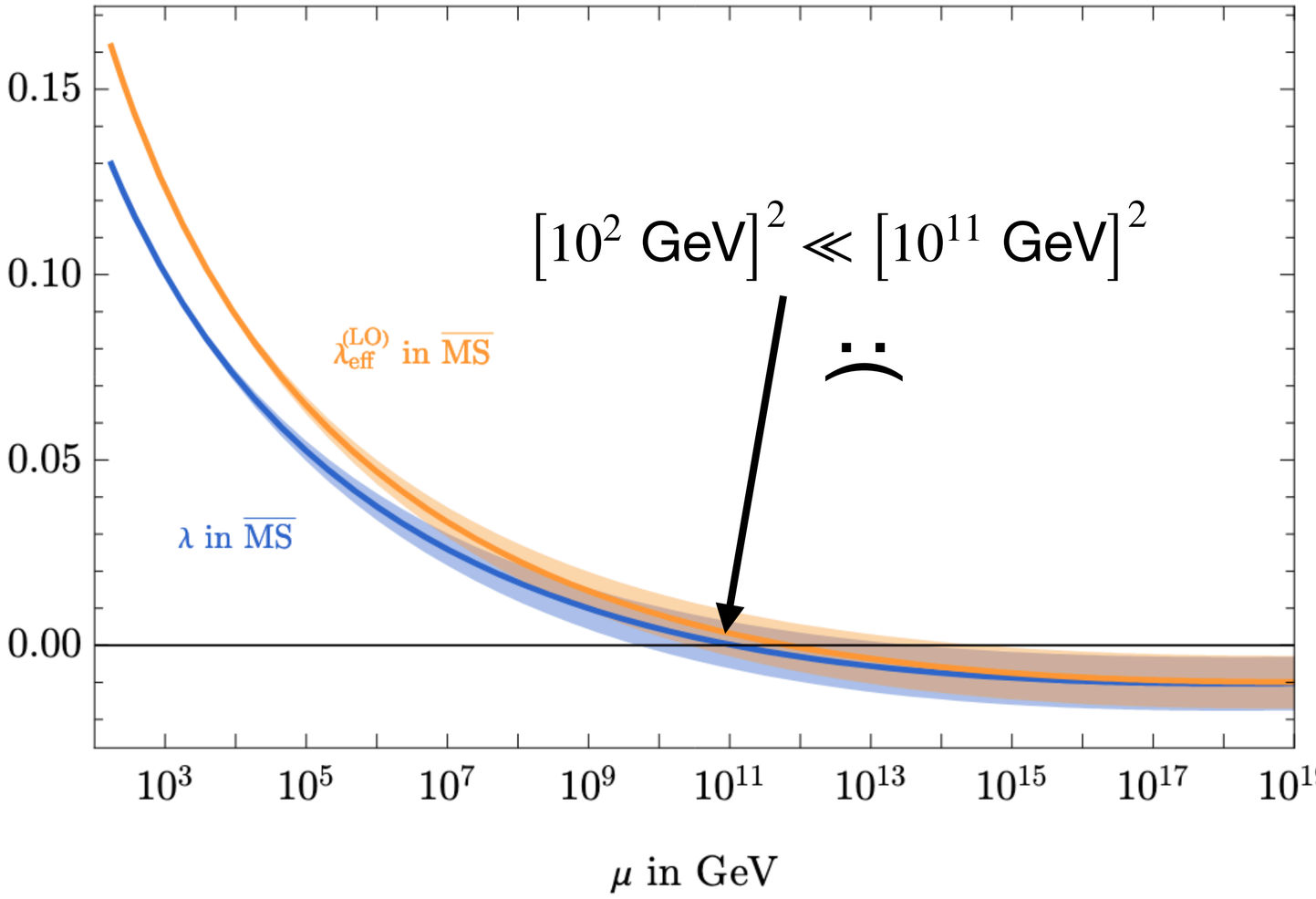
[2502.07876]
(S. Benevedes, A. Ismail, TS)

Landscape

[1907.07693]
(J. Khoury, O. Parrikar)

Metastability bounds - BSM features

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



Metastability bounds - BSM features

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

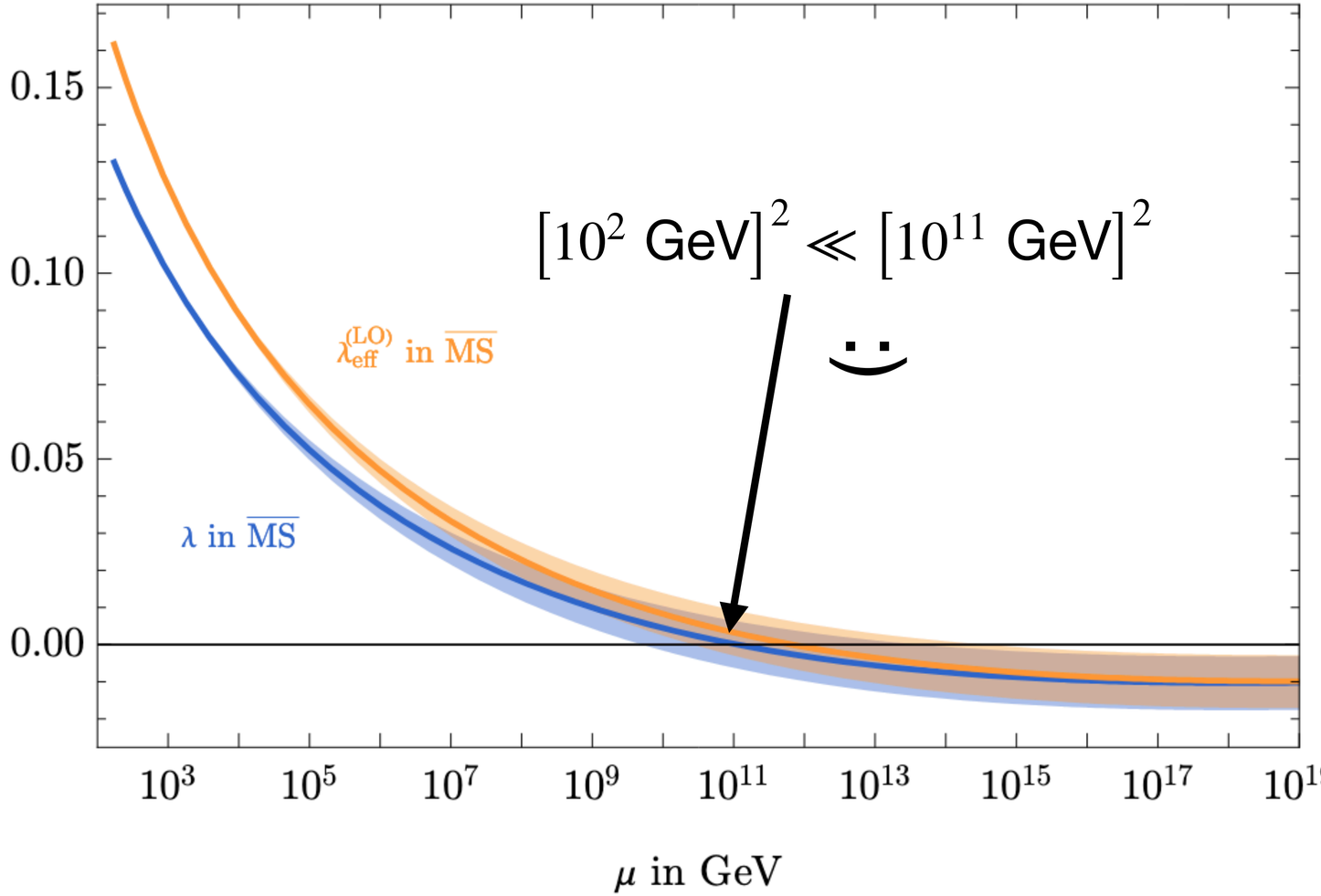
lowered by BSM physics?

VLFs
[2105.08617]
[2502.07876]
[2408.10297]

ALPs
[2412.03542]

Sparticles
[2502.07876]

Majoron
[2503.03825]



Metastability bounds - BSM features

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

lowered by BSM physics?

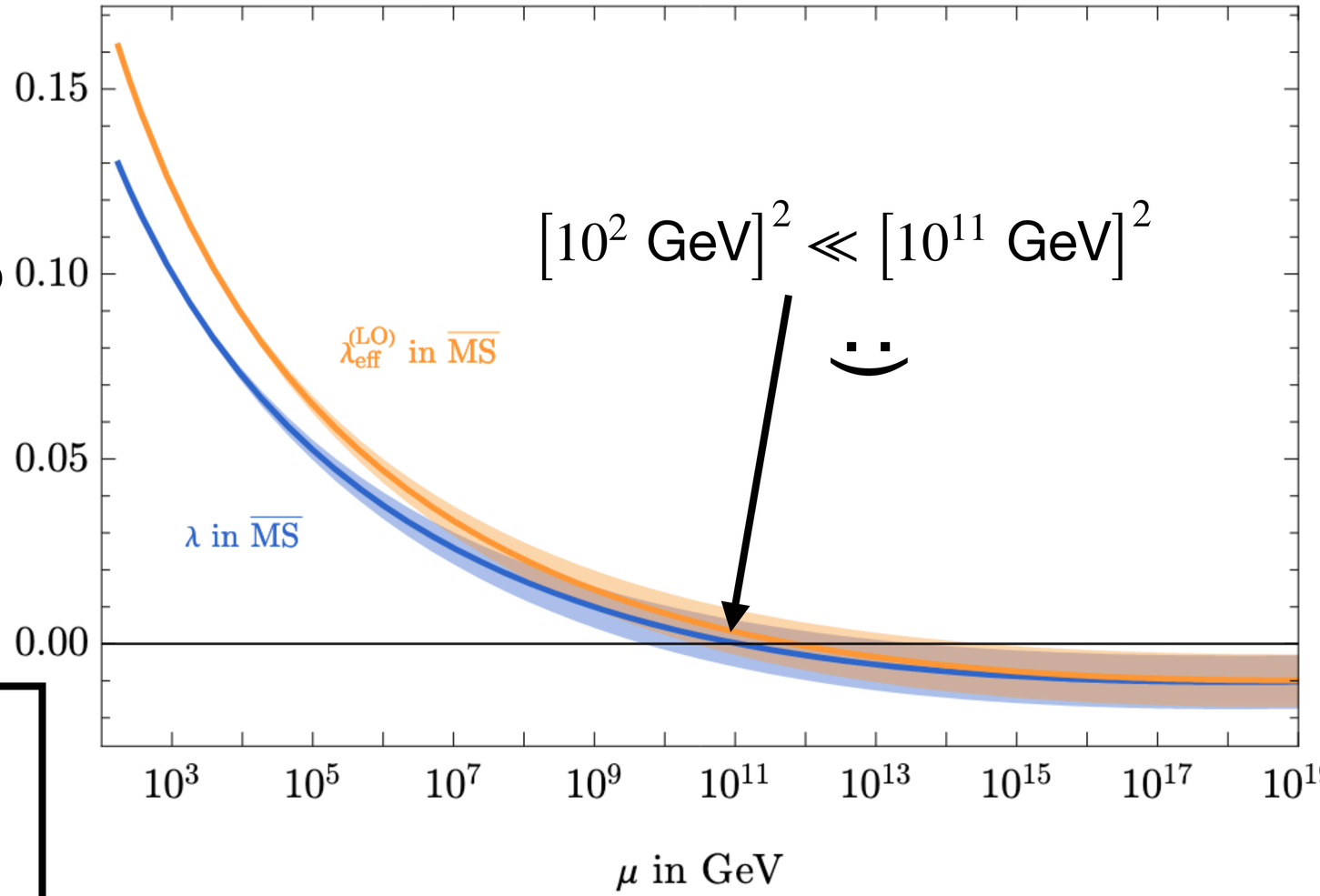
VLFs
[2105.08617]
[2502.07876]
[2408.10297]

Sparticles
[2502.07876]

ALPs
[2412.03542]

Majoron
[2503.03825]

“complete models”

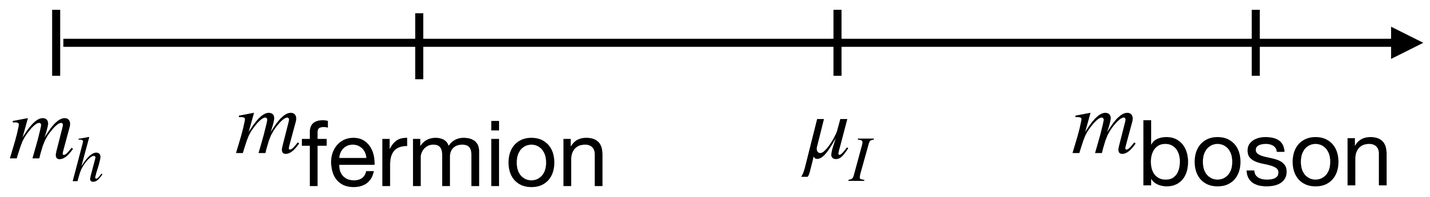


Metastability bounds - BSM features

General: Smaller μ_I → Shorter lifetime

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

→ bosons to partially stabilize

→ 

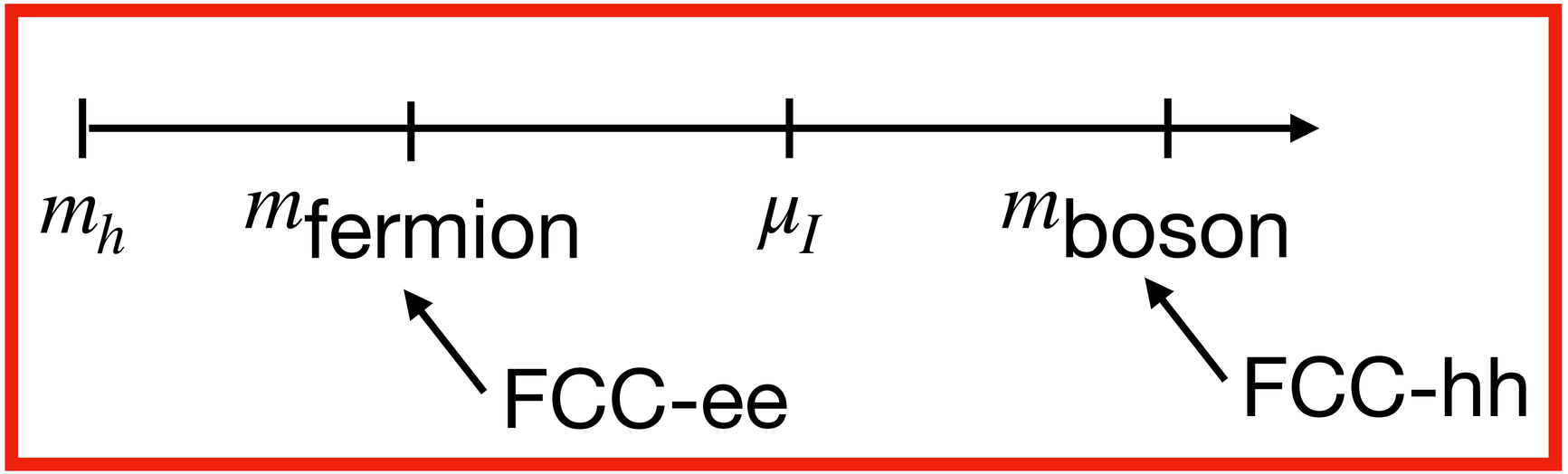
Metastability bounds - BSM features

General: Smaller μ_I → Shorter lifetime

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

→ bosons to partially stabilize

→



Metastability bounds - Majoron model

Important subtleties:

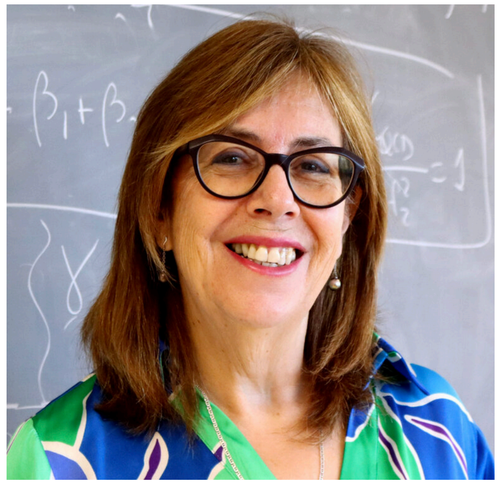
- specific ordering of scales?
- lifetime of vacuum?
- why is running necessary?

Metastability bounds - Majoron model

Important subtleties:

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

→ Majoron model: [2503.03825]
(V. Enguita, B. Gavela, TS)



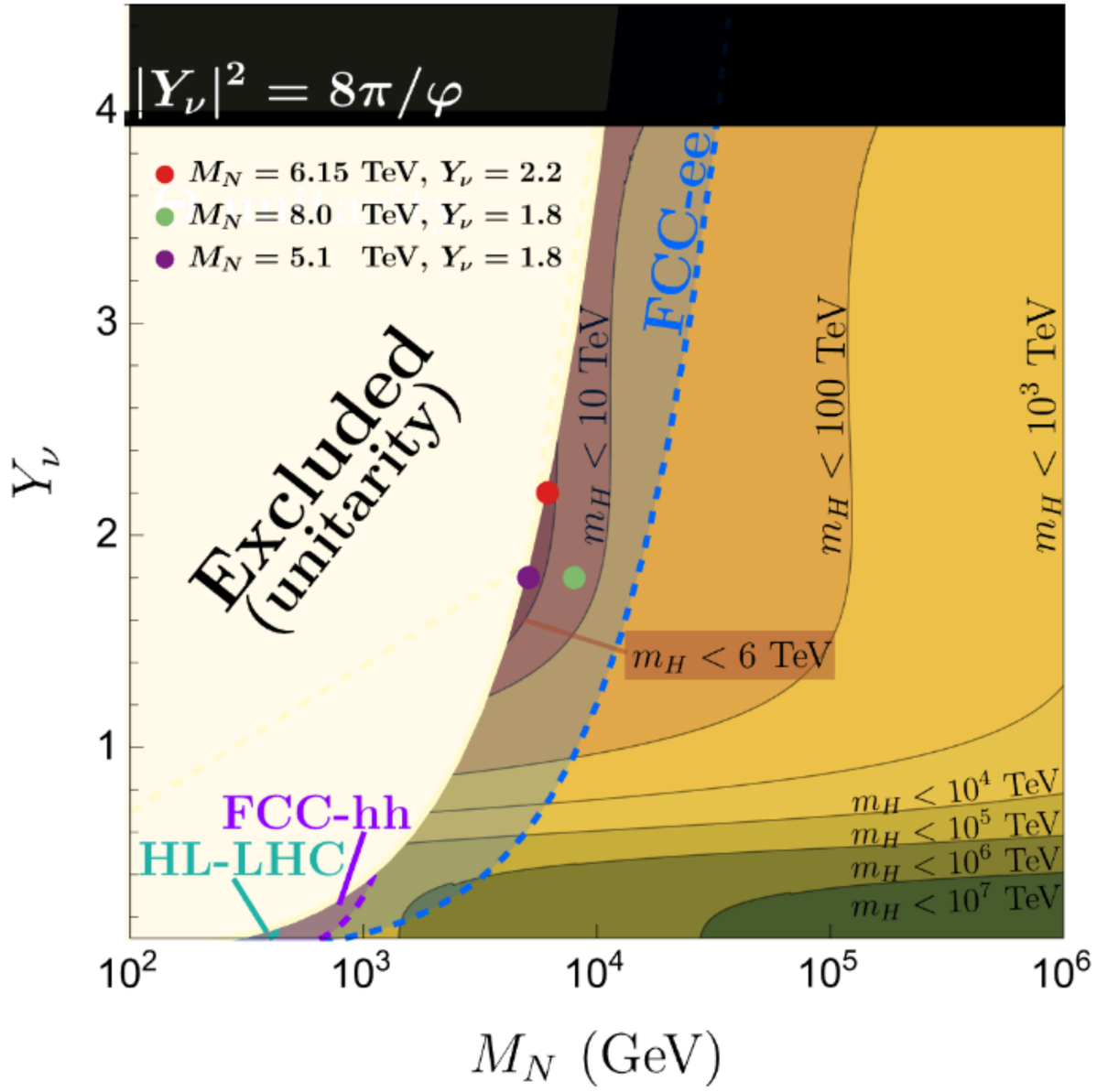
$$V = -m_H^2 |H|^2 + \lambda_H |H|^4$$
$$-m_S^2 |S|^2 + \lambda_S |S|^4 + \kappa |H|^2 |S|^2$$

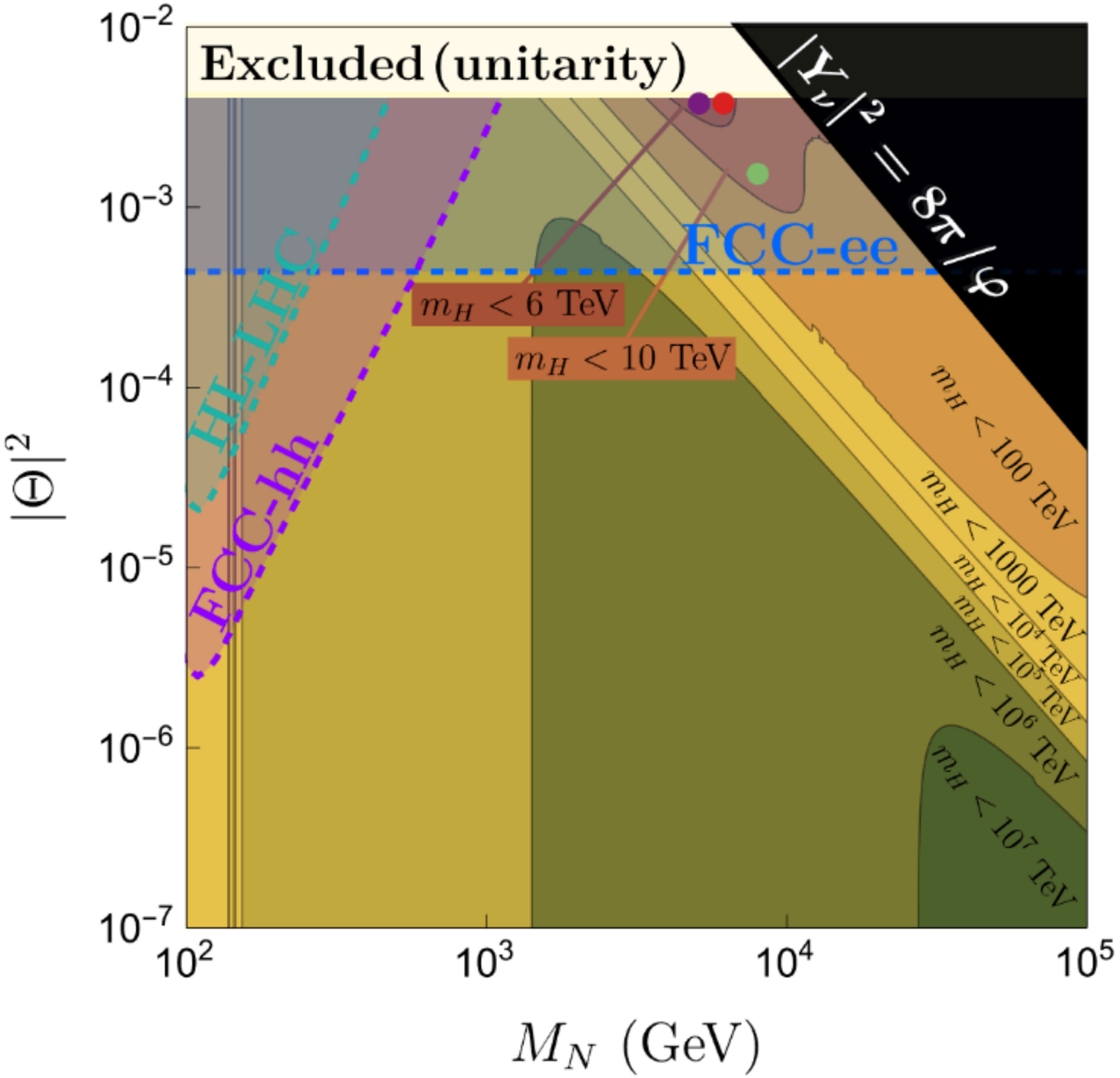
→ $M_S = \sqrt{\lambda_S}\langle S \rangle$

→ $M_N \sim Y_R \langle S \rangle$

coupling to RHNs

Metastability bound @FCC - RHNs





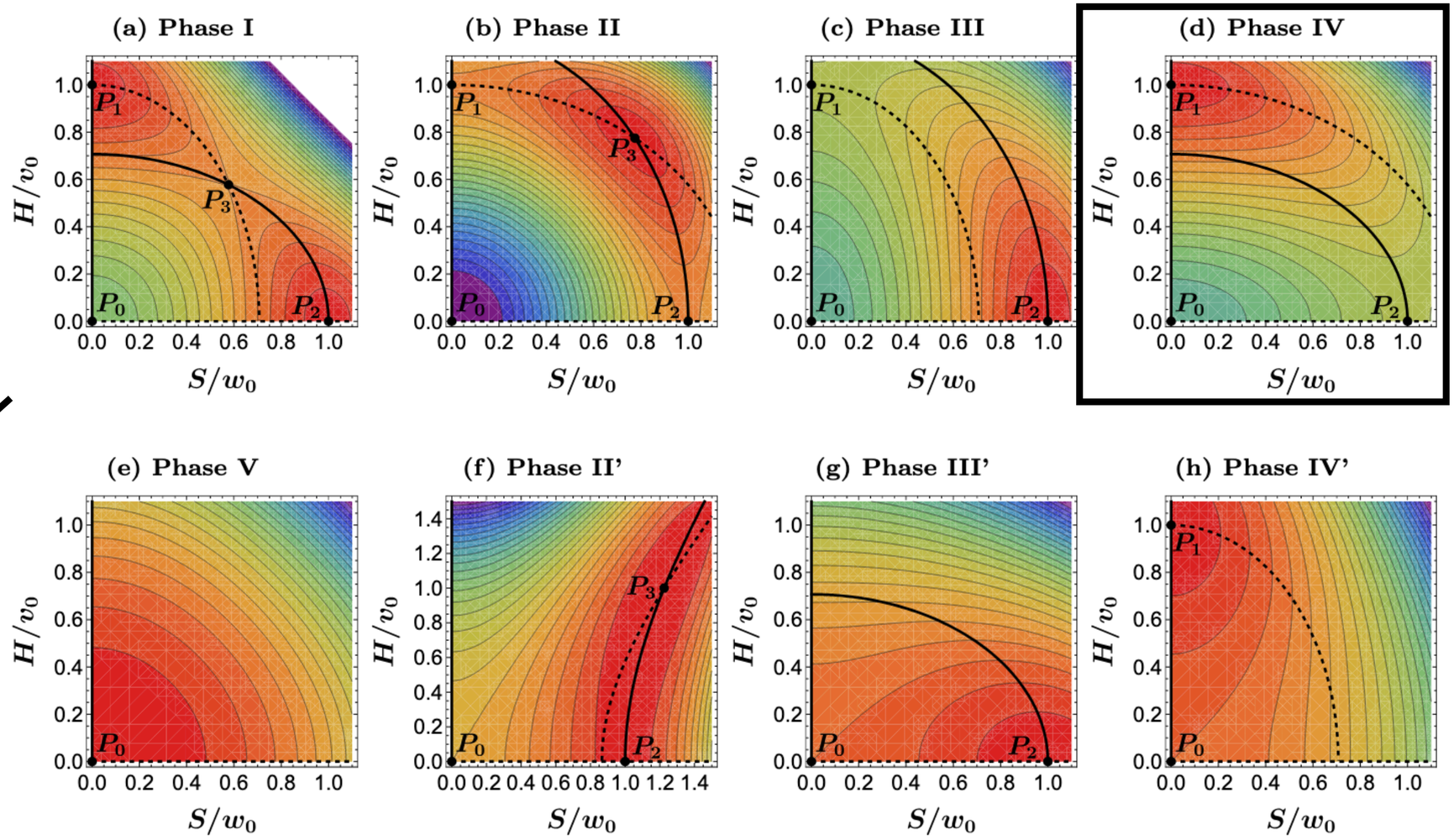
Metastability bounds - Majoron model

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

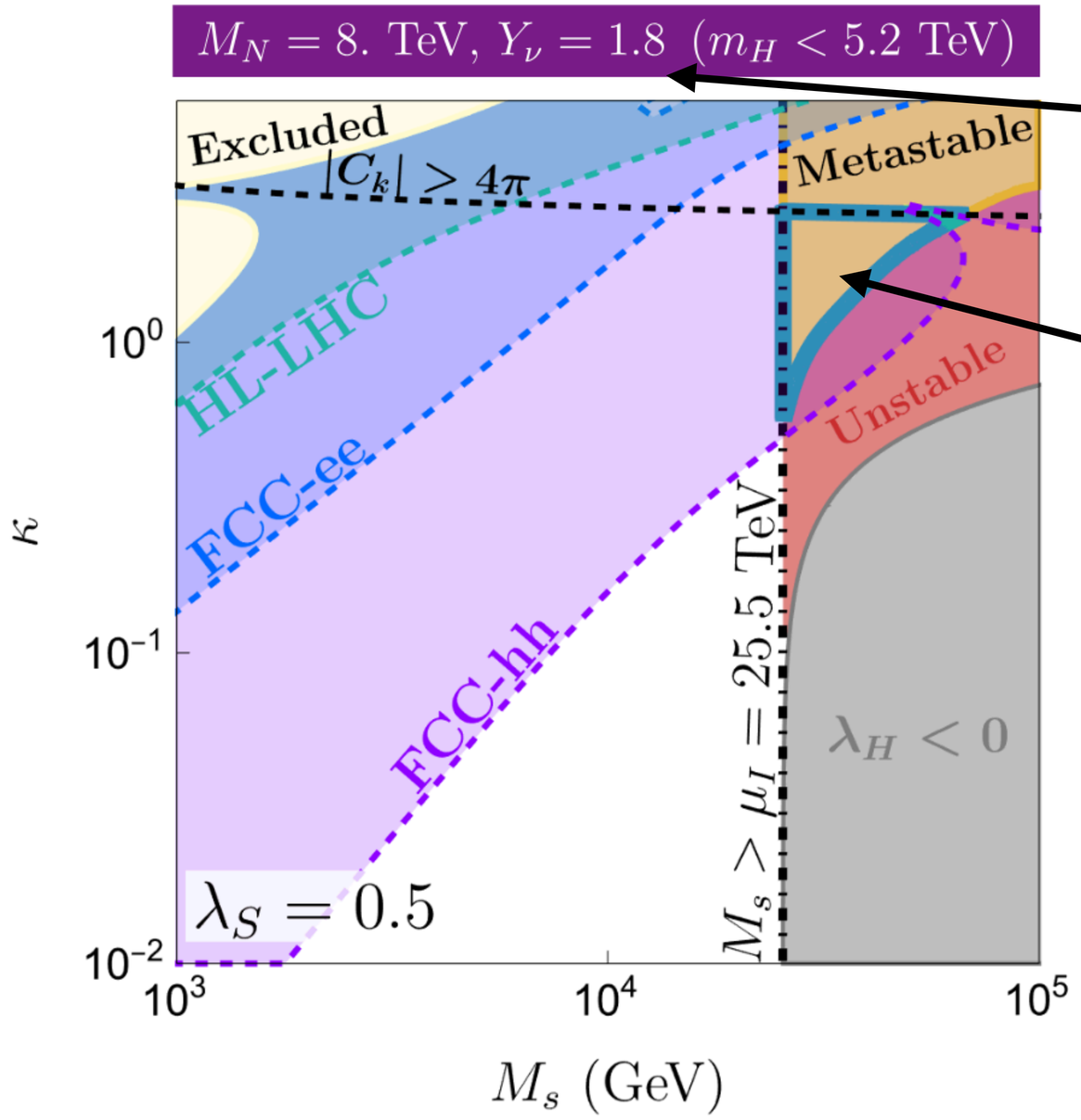
assuming SSB

running effects necessary!

calculate tunneling rates!



Metastability bound @FCC - Majoron



strong destabilization

↓

strong stabilization

↕

large κ or “small” M_S

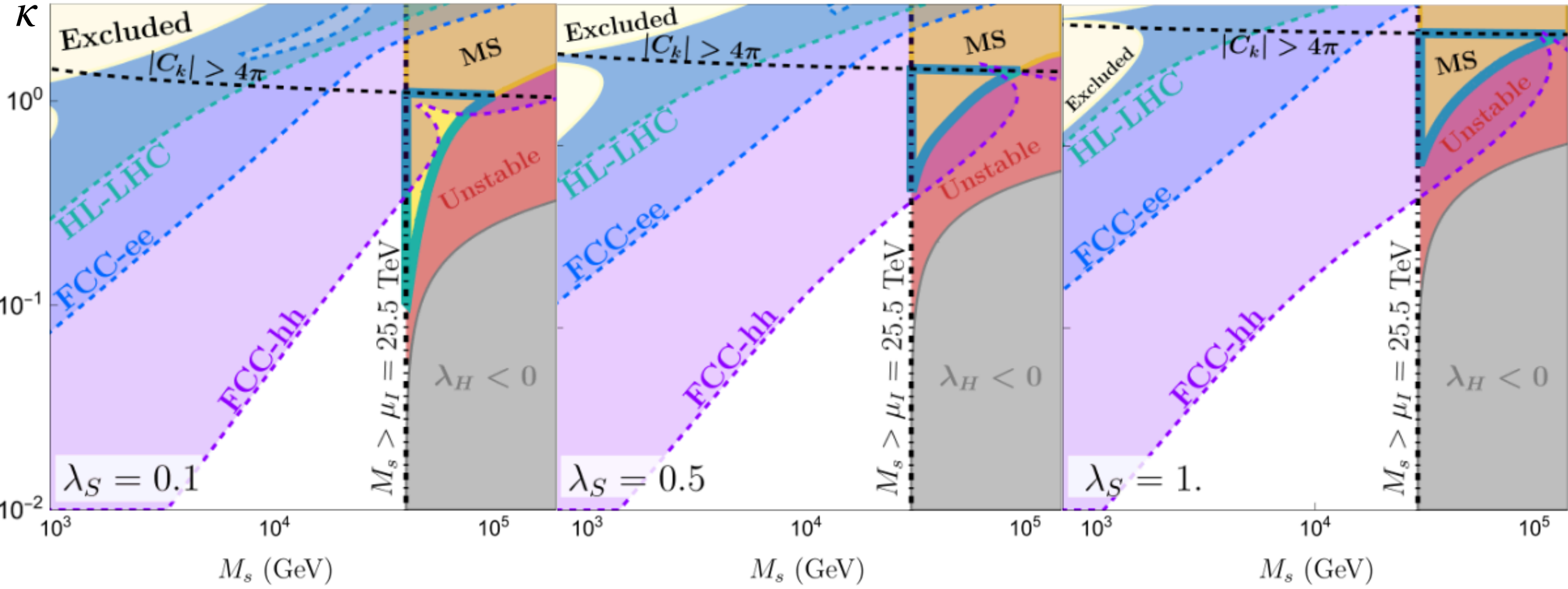
↕

strong signal:

$$\mathscr{L}_{H\Box} = -\frac{\kappa^2}{4\lambda_S M_S^2} |H|^2 \Box |H|^2$$

Metastability bound @FCC - Majoron

$$M_N = 8.\ \text{TeV},\ Y_\nu = 1.8\ \ (m_H < 5.2\ \text{TeV})$$



Summary

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

lowered by BSM physics?

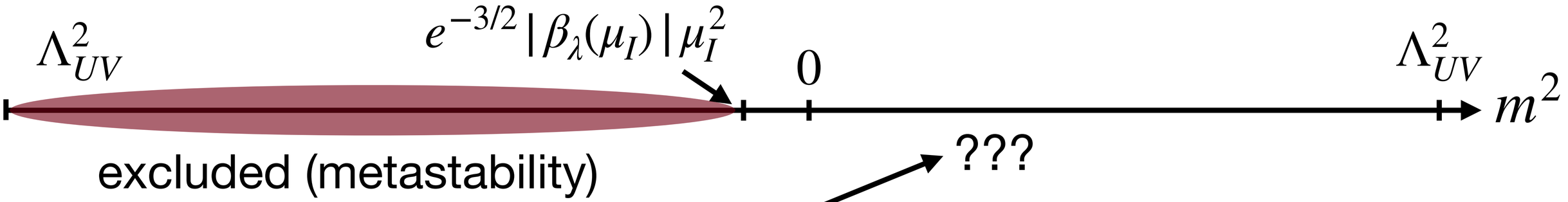
→ check vacuum stability → additional constraints

Majoron model:
- RHNs in FCC-ee
- Scalar plausibly in FCC-hh

Thank you for your attention!

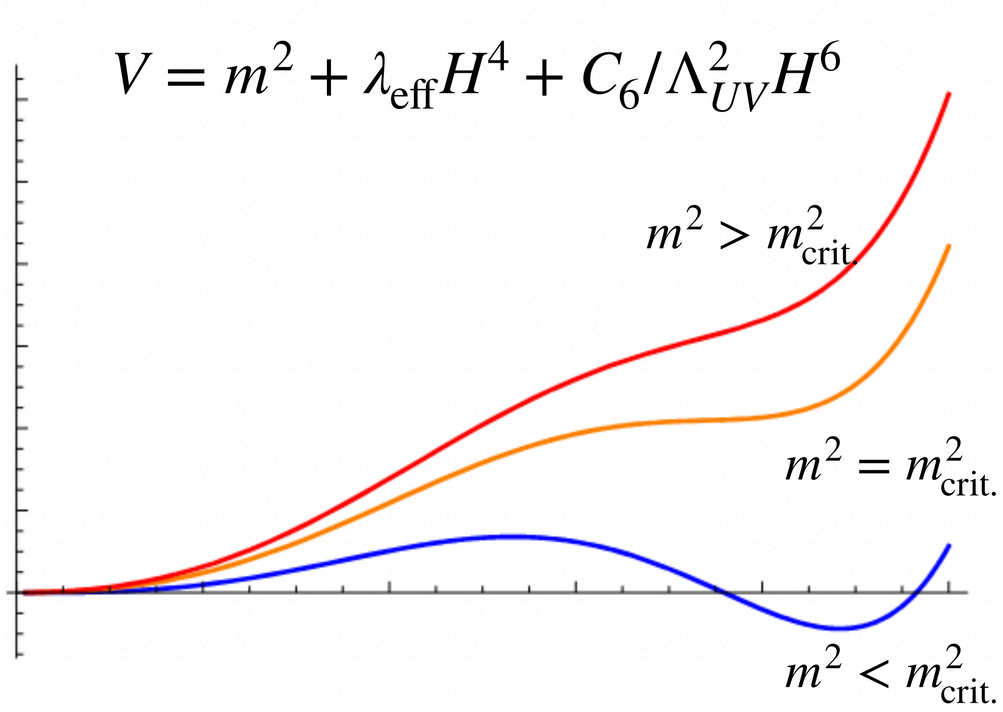
tstngssr@mit.edu

Extended metastability bounds - explaining SSB?

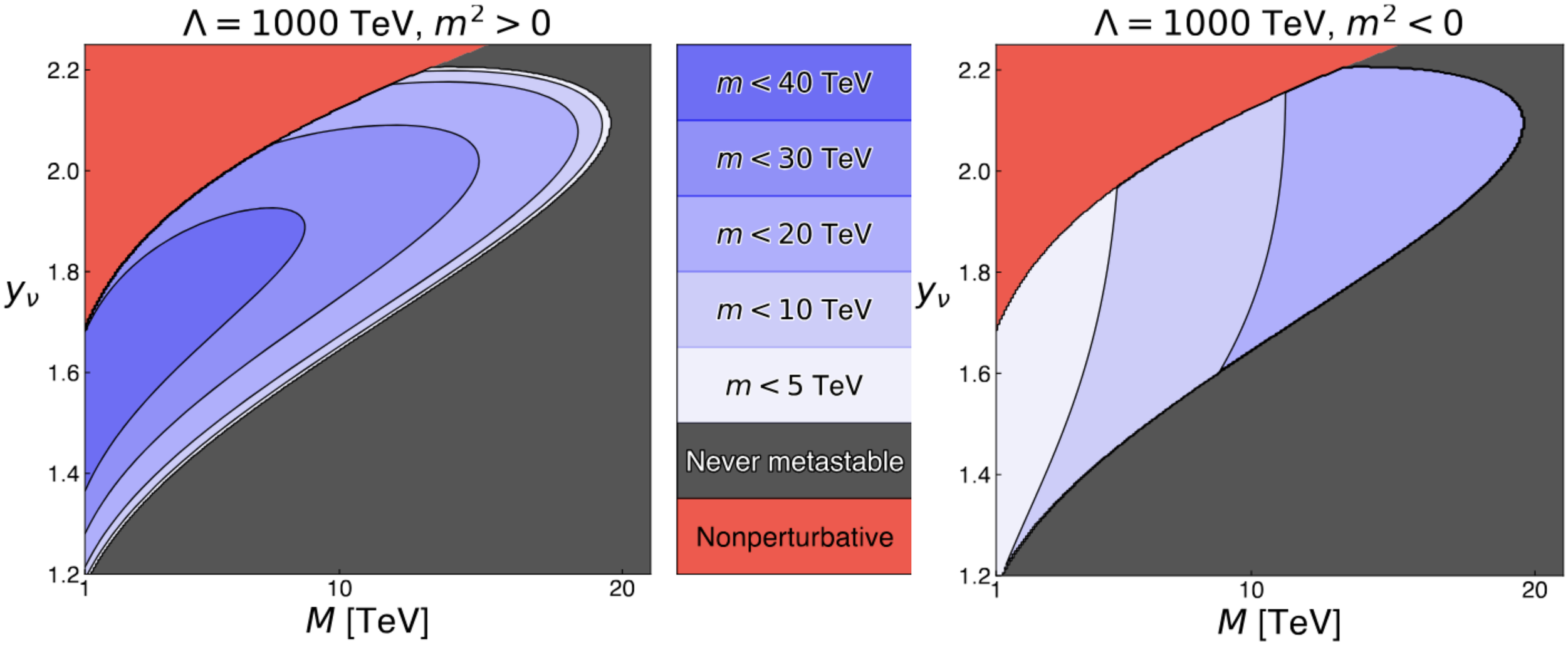


[2408.10297]
(S. Benevedes, S. Trifinopoulos, TS)

$$m^2 \lesssim |\beta_\lambda(\mu_I)|^2 \Lambda^2_{\rm UV}$$



Extended metastability bounds - results



Extended metastability bounds - explaining SSB!