Snowmass ILC paper review: drawing overall picture

— based on Chapter 13 & 14

preliminary!

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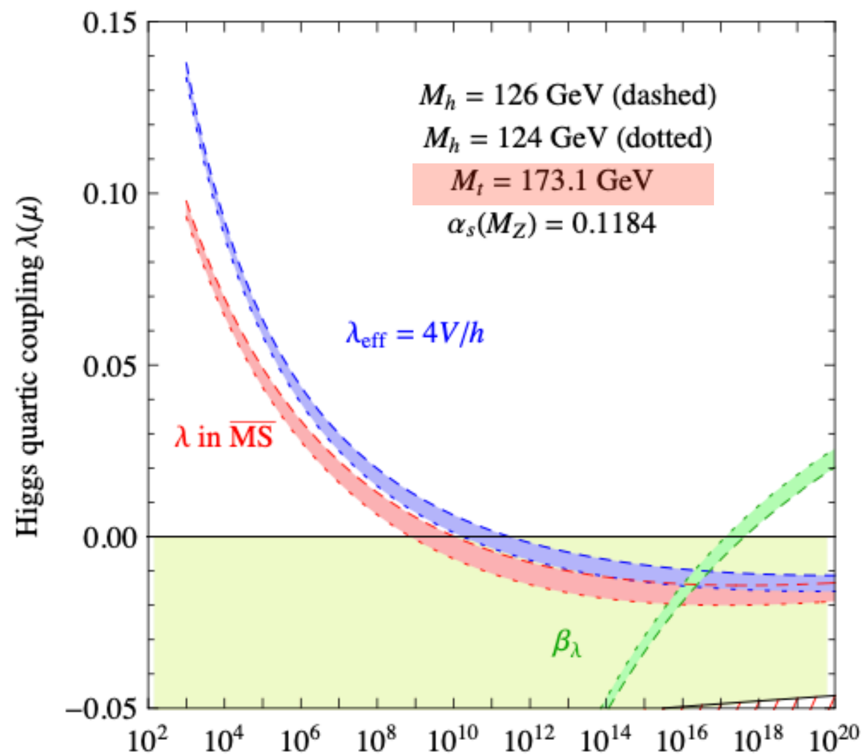
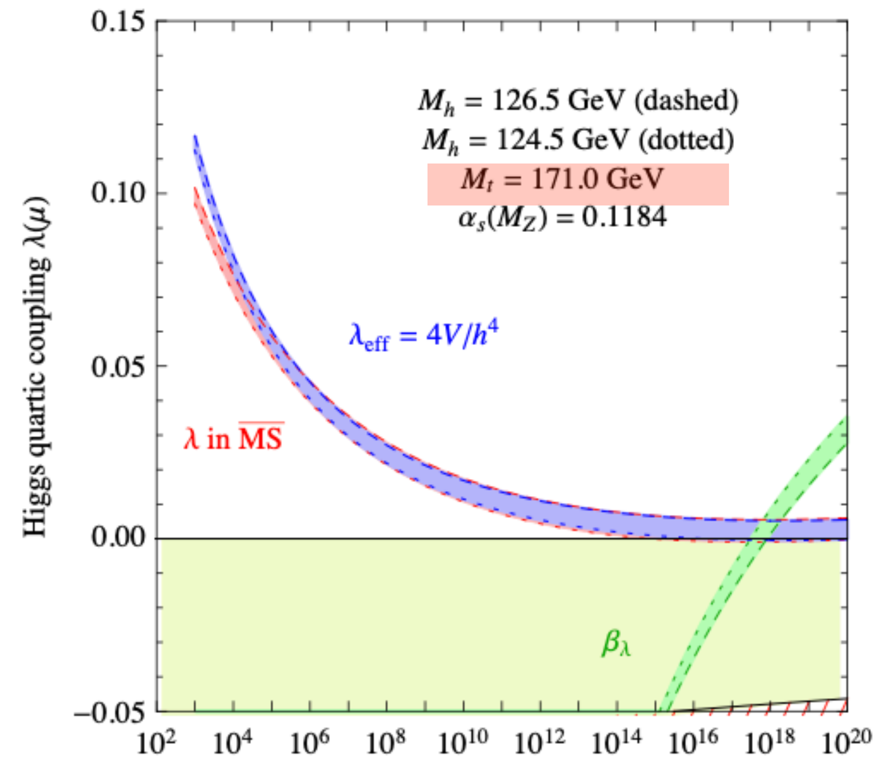
4th ILC-Japan General Physics Meeting, Sept. 4, 2023 @ U.Tokyo

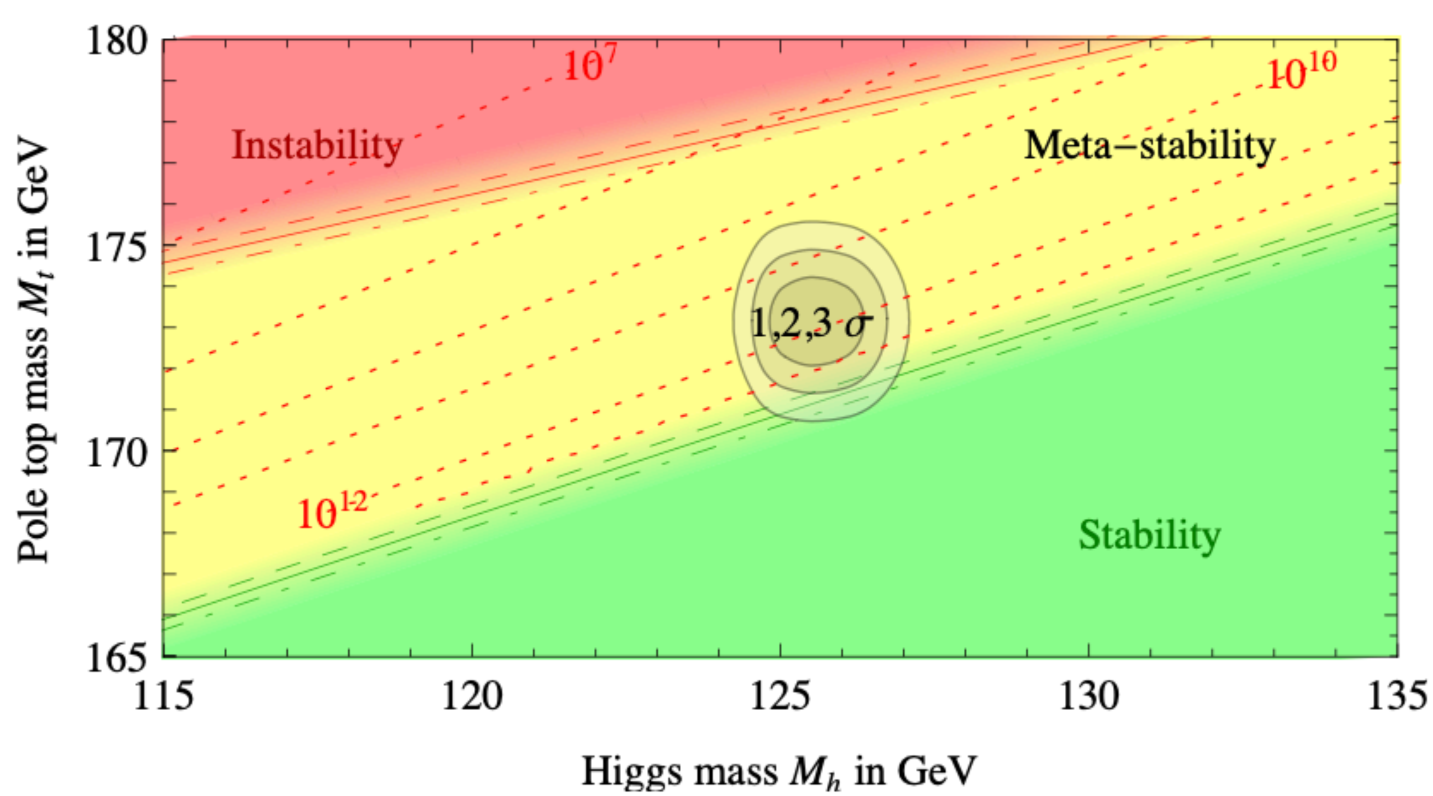
outline

1. Can the SM be exact to very high energies?

- from the angle of EW vacuum stability: λ < 0 at high scales?



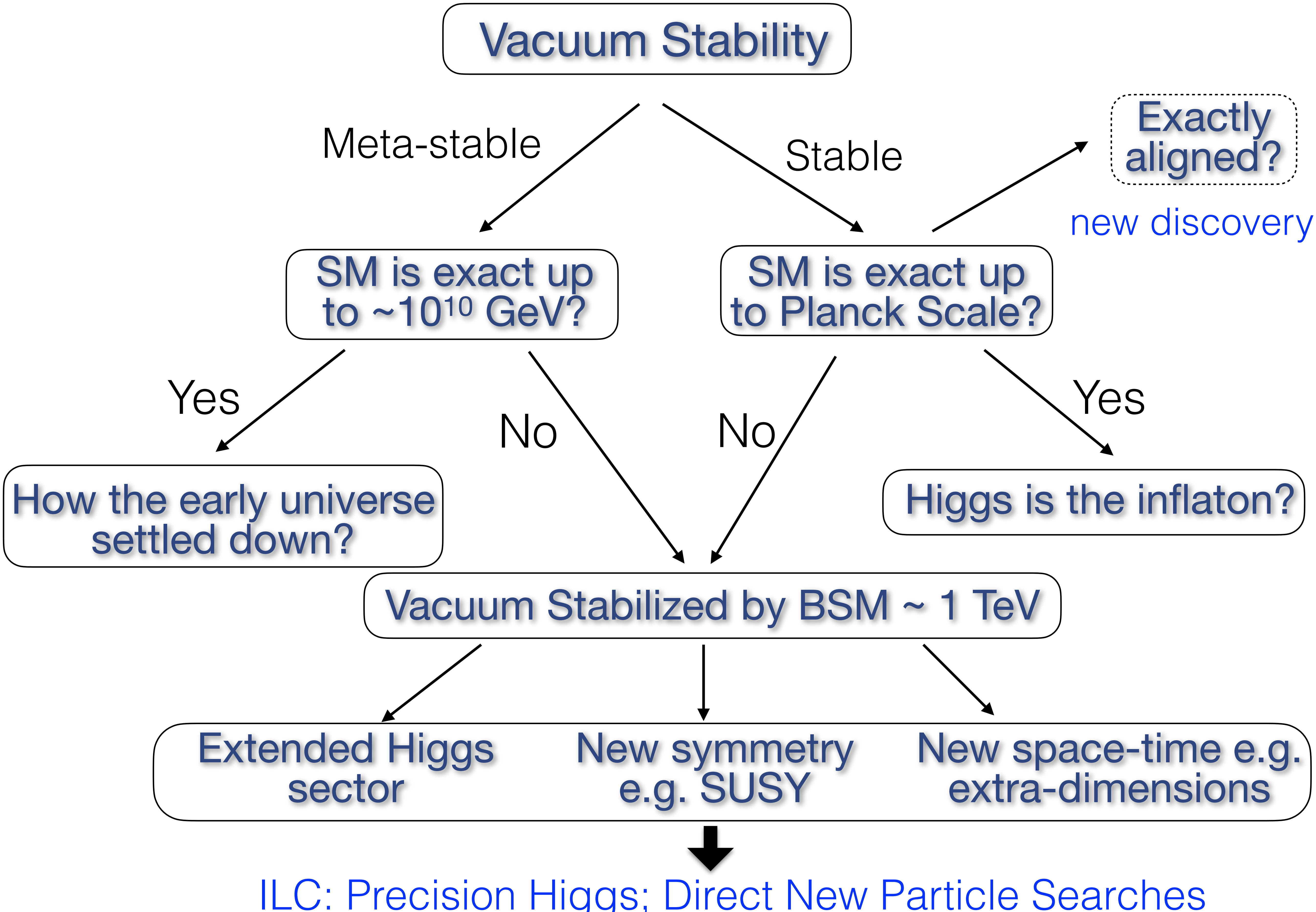




ILC (350)

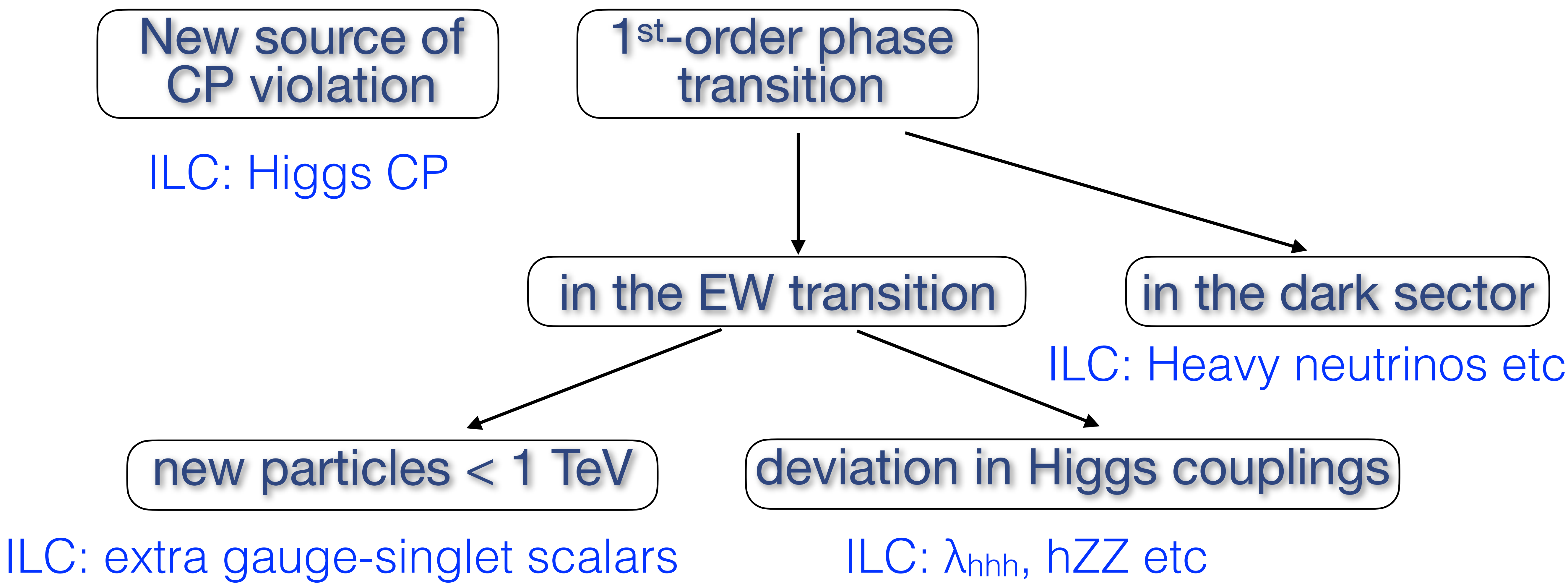
$\Delta m_t \sim 50$ MeV

$\Delta m_H \sim 14$ MeV

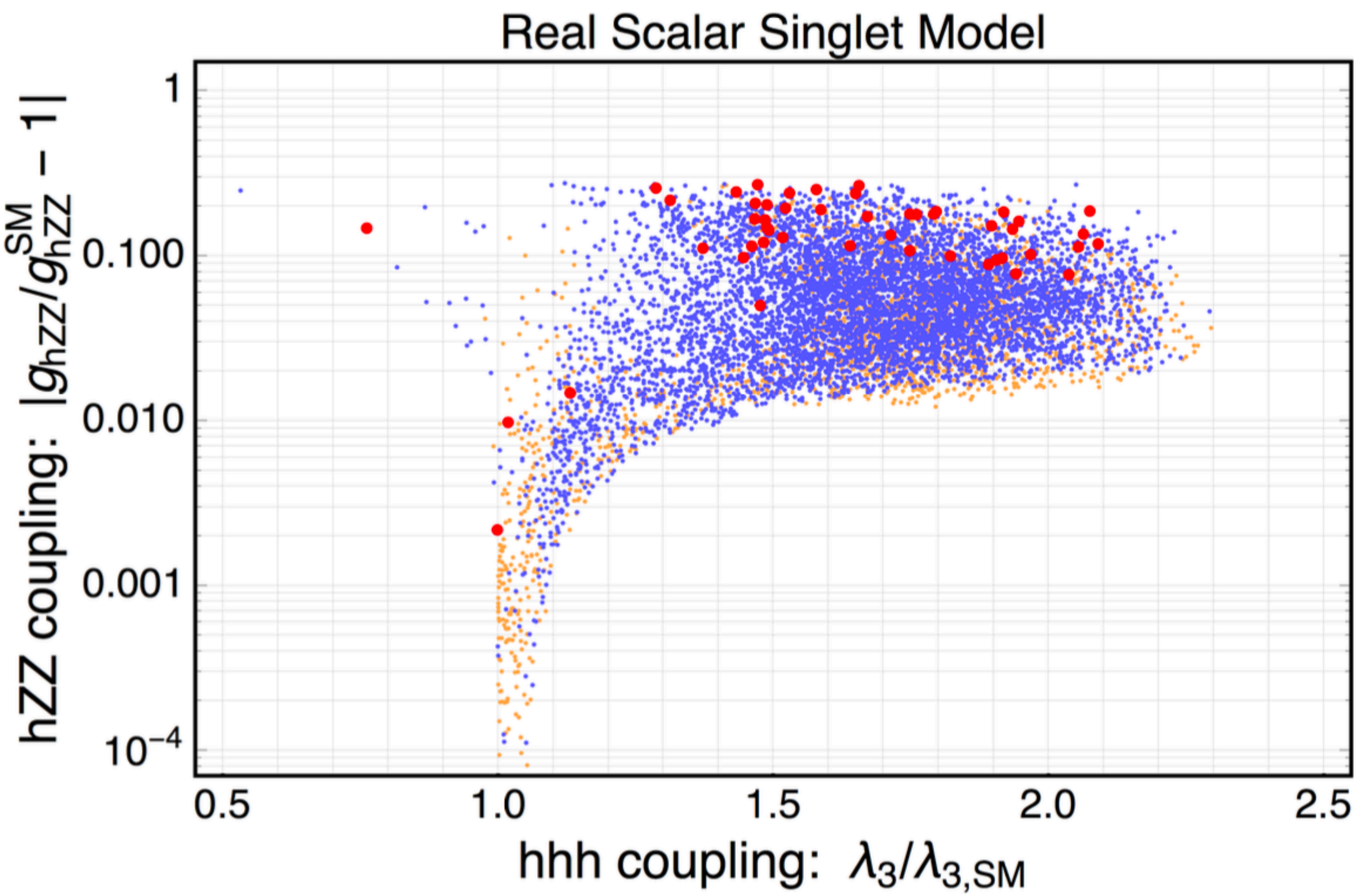

Vacuum Stability
Meta-stable
Stable
Exactly aligned?
new discovery
SM is exact up to ~10^10 GeV?
SM is exact up to Planck Scale?
Yes
No
No
Yes
How the early universe settled down?
Higgs is the inflaton?
Vacuum Stabilized by BSM ~ 1 TeV
Extended Higgs sector
New symmetry e.g. SUSY
New space-time e.g. extra-dimensions
ILC: Precision Higgs; Direct New Particle Searches

2. Why is there more matter than anti-matter?

- Sakharov conditions: B, C, CP violations; out of thermal equilibrium
- SM: 2nd-order phase transition; CP-violating CKM angles not enough
- ILC role focused on Electroweak Baryogenesis models



2. Why is there more matter than anti-matter?



orange: first-order phase transition

blue: strongly first-order phase transition (v/T > 1.3)

red: very strongly first-order phase transition (GW @ eLISA)

2. Why is there more matter than anti-matter?

- Leptogenesis models are also possible; ILC plays a role as well

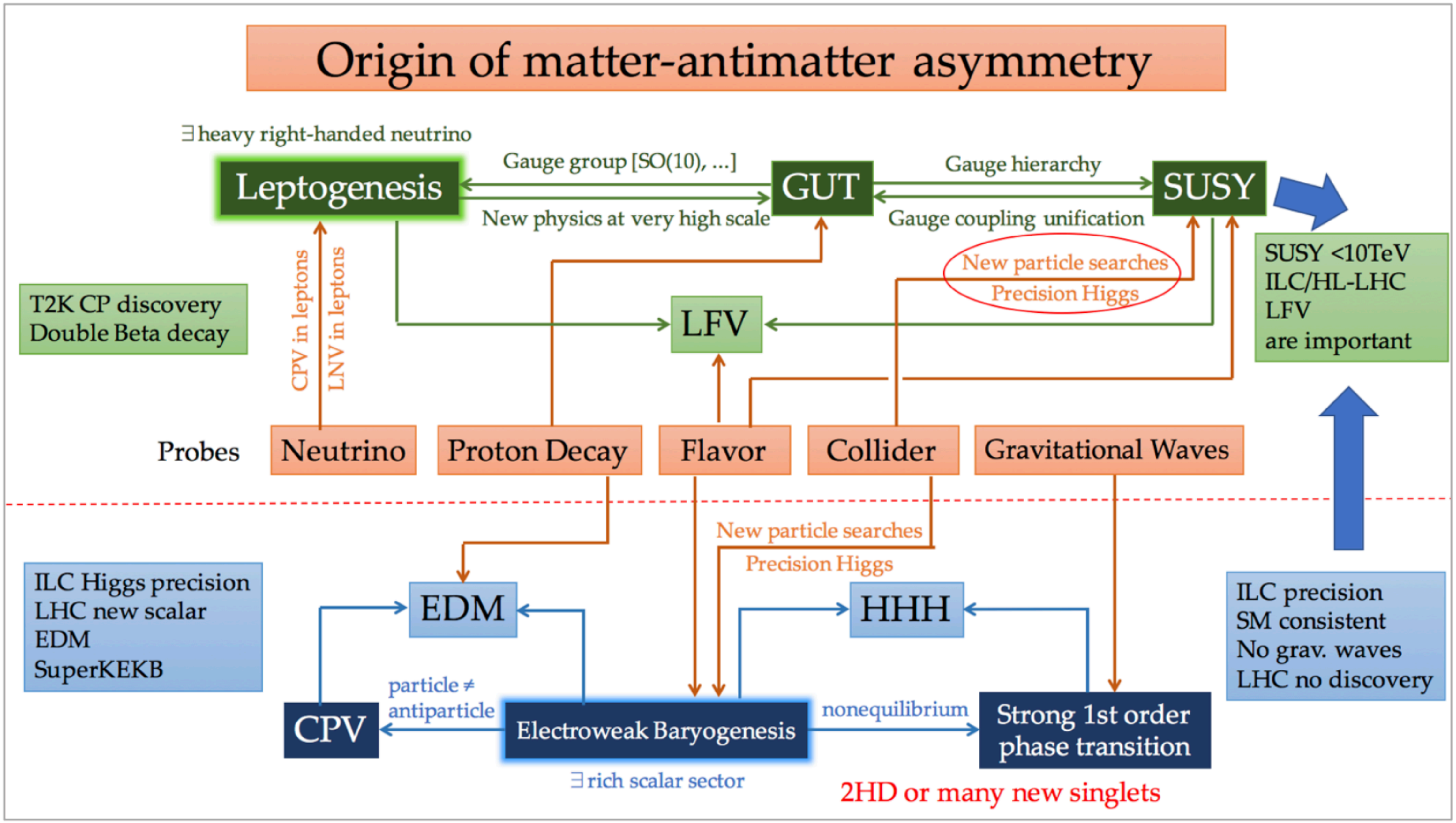
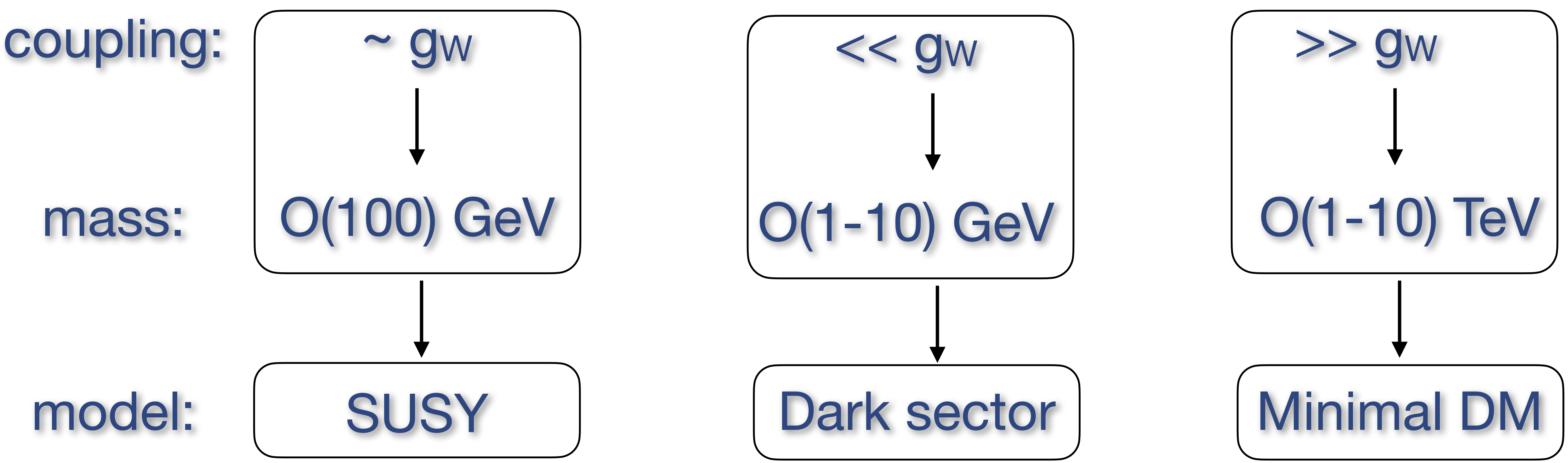


Figure 3: Origin of matter-antimatter asymmetry.

[S. Asai et al, ILC250 scientific case by JAHEP; arXiv: 1710.08639]

3. What is the dark matter of the universe?

- Viable enormous range of masses by 10s of orders
- ILC role focused thermal WIMP, GeV-TeV
- Guided by observed relic density, annihilation σ~1pb: WIMP masses and couplings fall into three categories



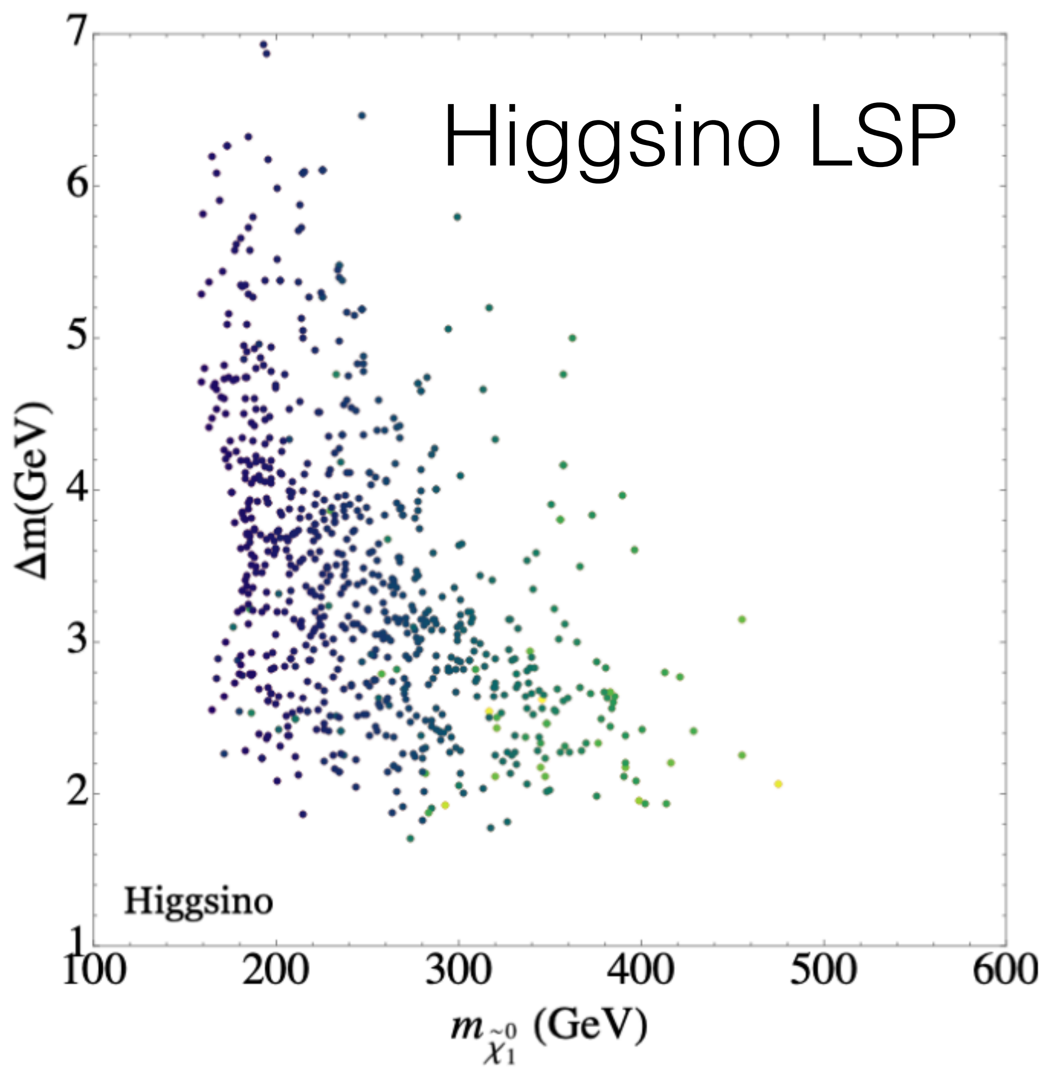
ILC: Higgsino, stau, loop hole-free search

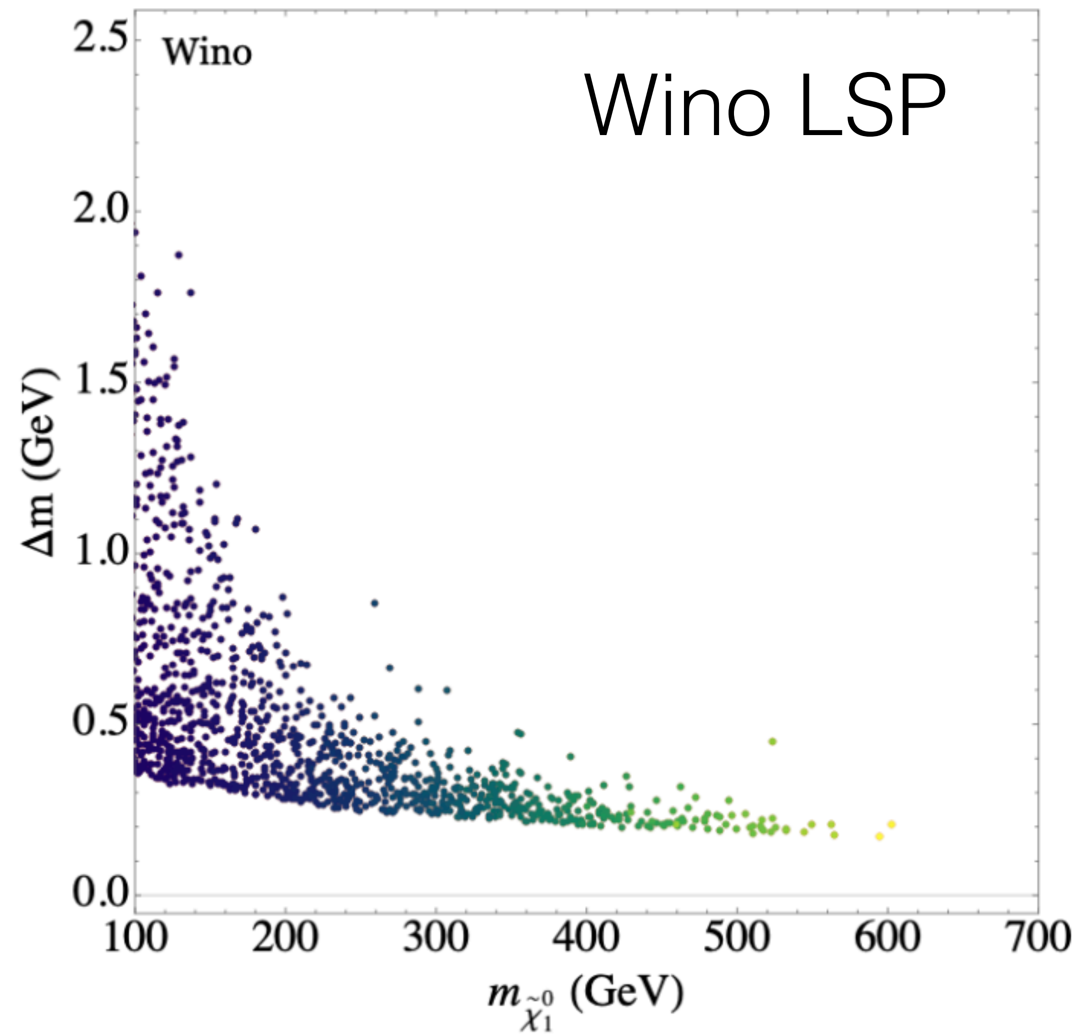
ILC: “Portal” by photon, Higgs, neutrinos, Fixed Target exp.

ILC: long-term future

3. What is the dark matter of the universe?

Scan of MSSM parameters: consistent with constraints from $(g\text{-}2)_\mu$



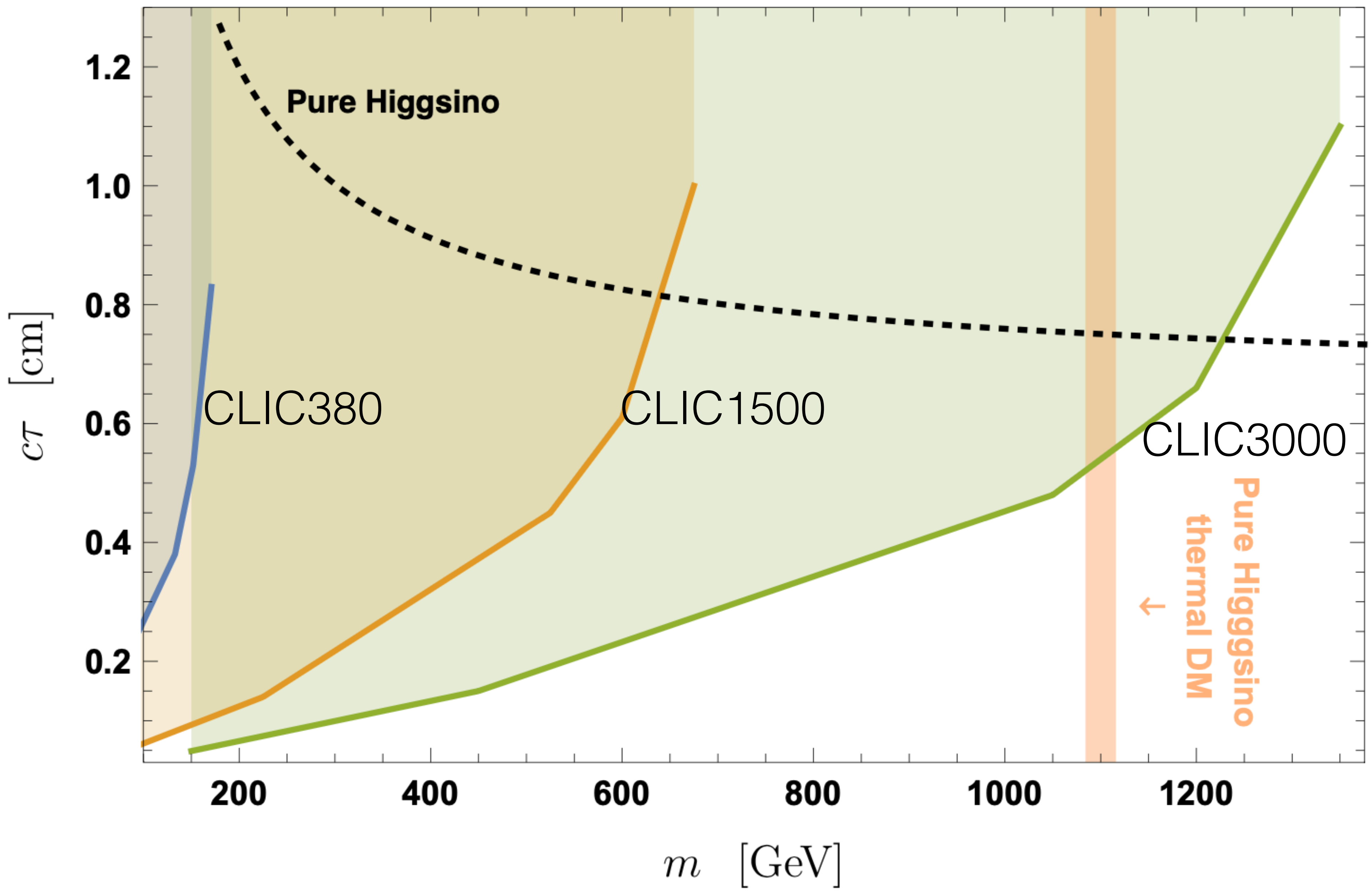


color: value of the LSP dark matter density

full coverage by ~ ILC (1000)

3. What is the dark matter of the universe?

Pure Higgsino

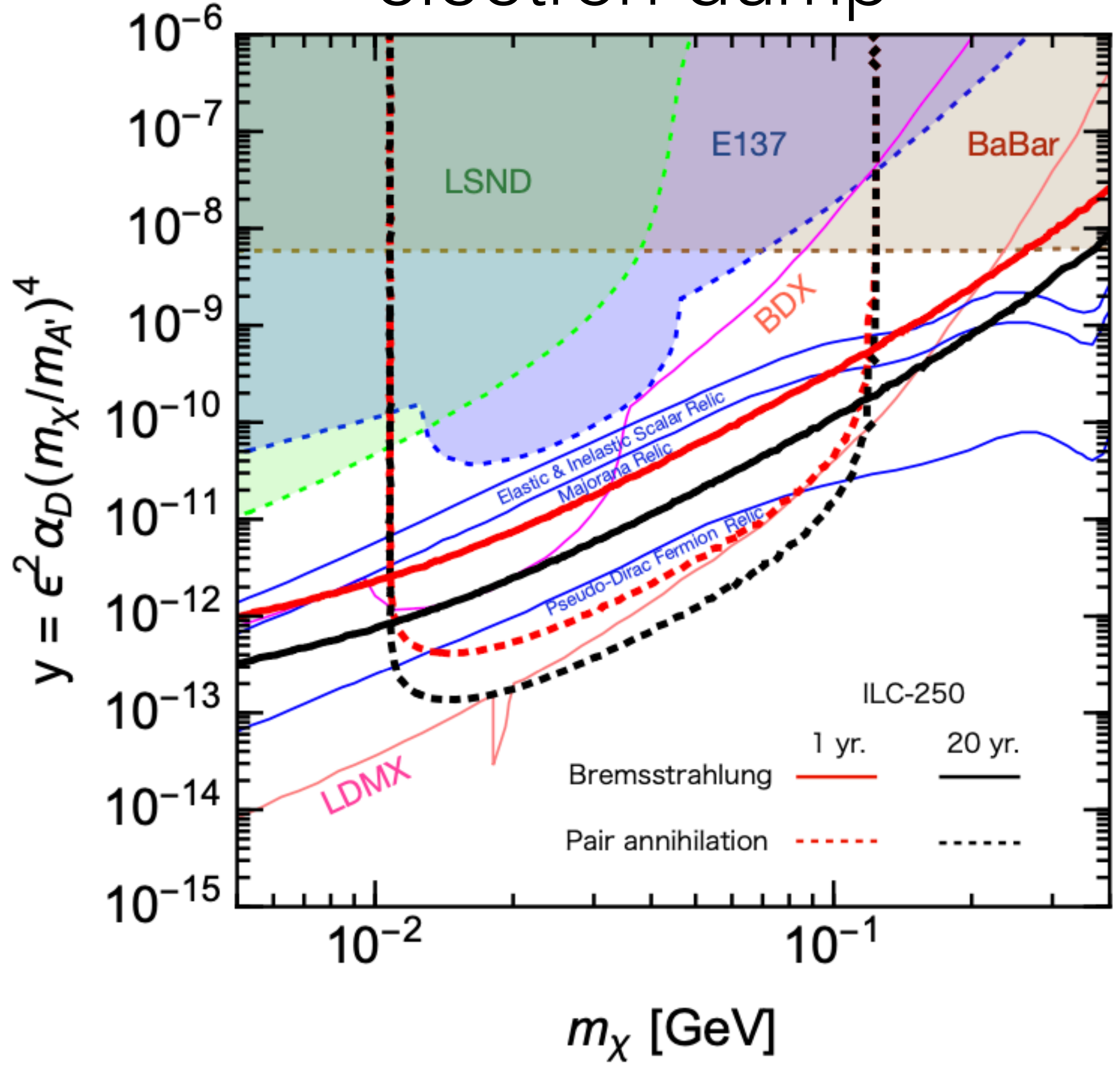


covered by ~ ILC multi-TeV

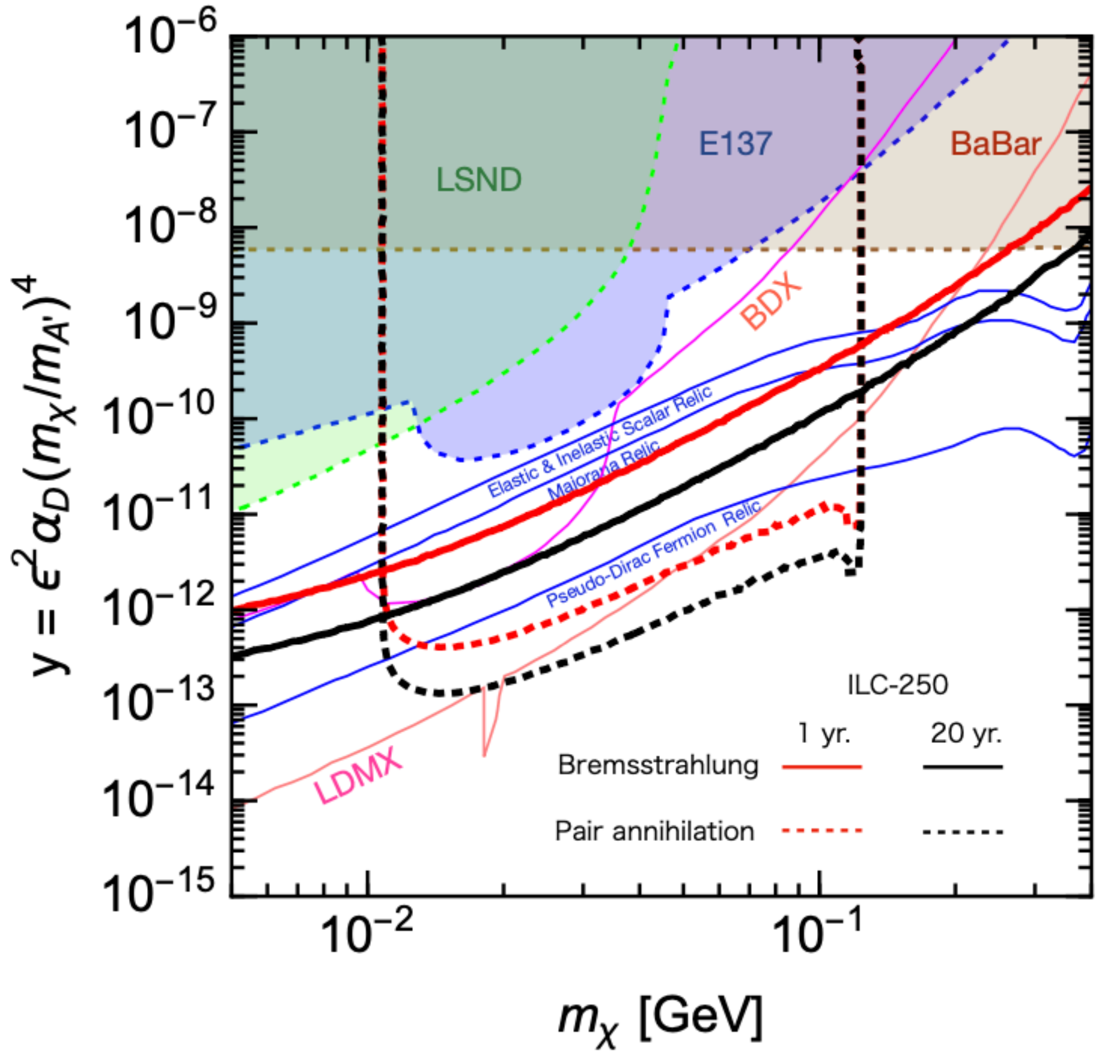
3. What is the dark matter of the universe?

Dark photon portal

electron dump



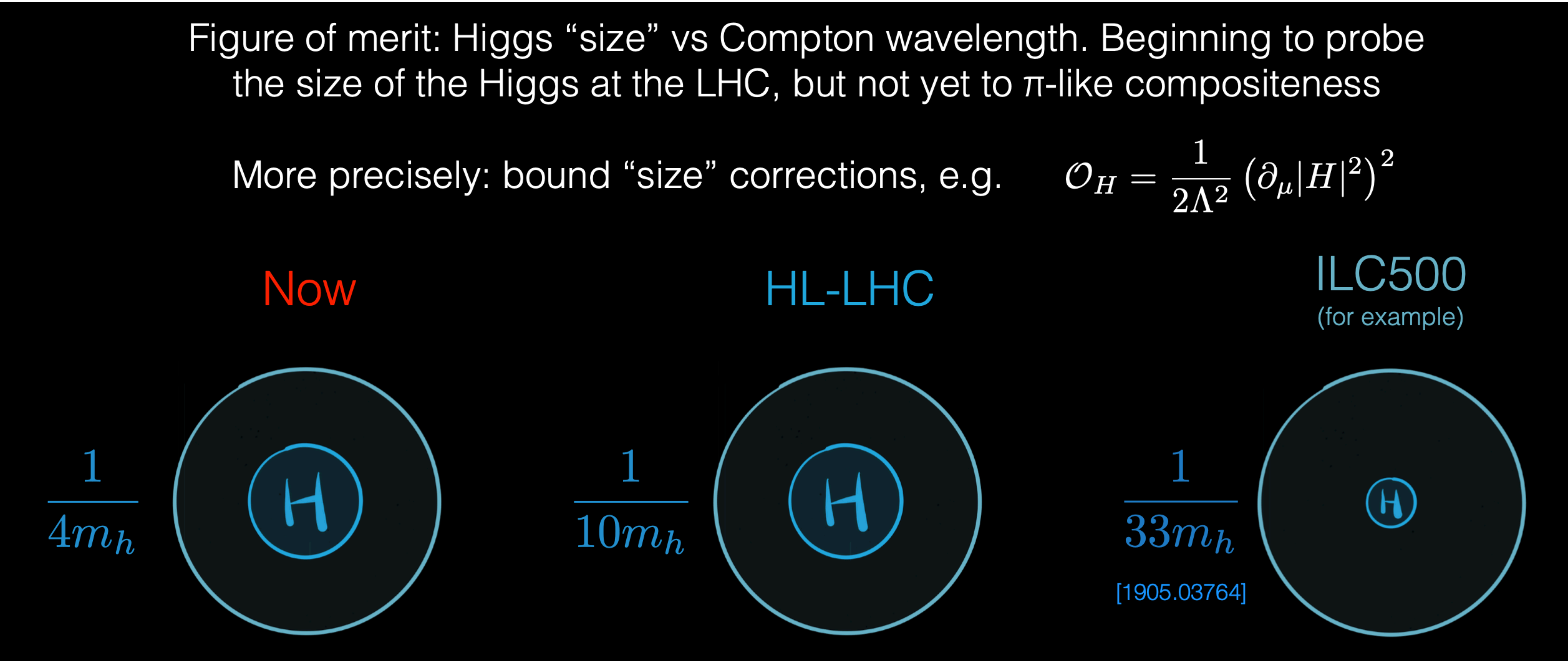
positron dump



covered by ~ ILC fixed target experiment

4. What is the energy scale of new physics?

- Deviation from SM will tell us the new physics scale
- EFT approach by Wilson coefficient: for c~O(1), 1% level deviation will indicate O(1TeV) new mass scale

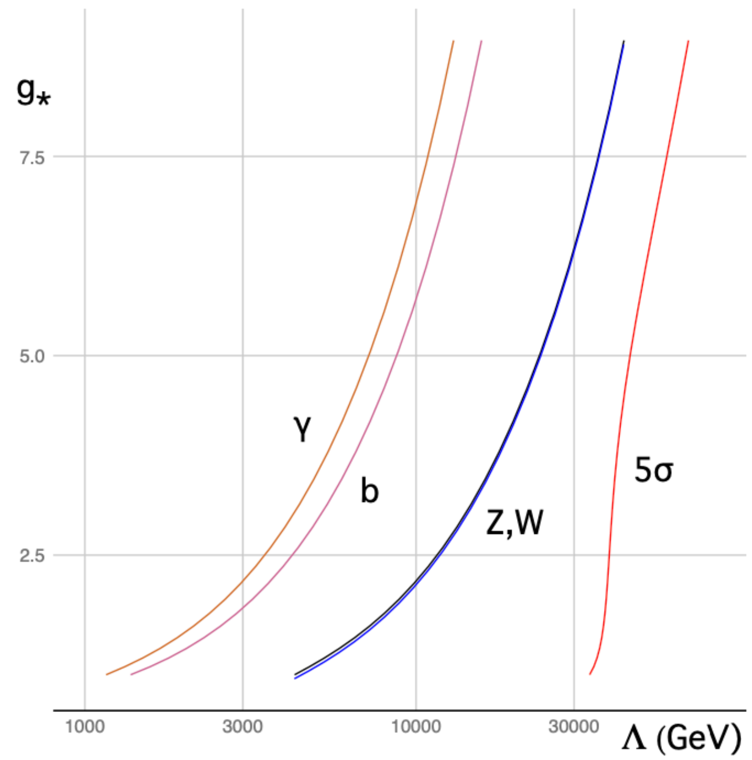


[N. Craig, LCWS 2023]

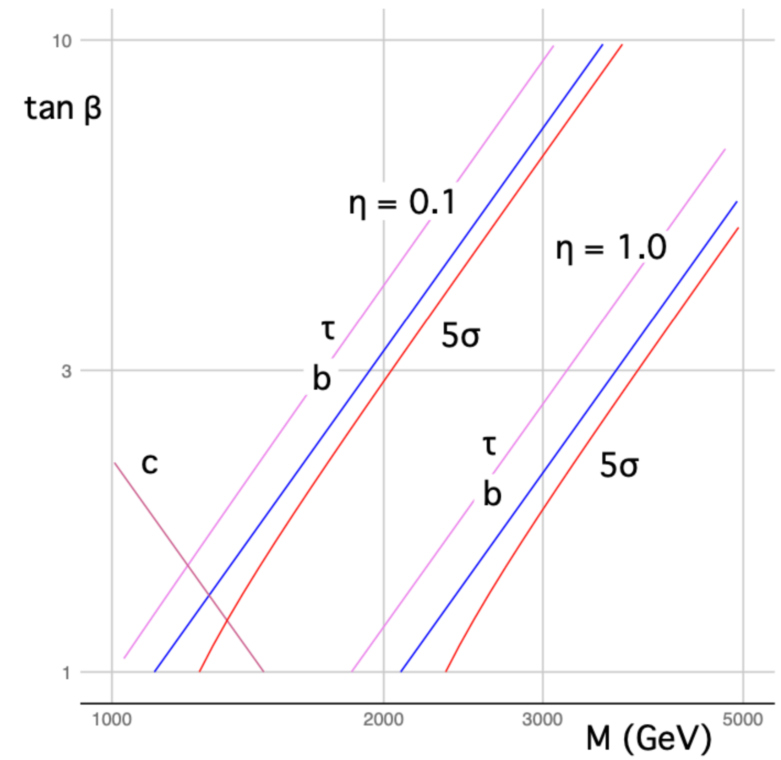
4. What is the energy scale of new physics?

- Concrete model approach

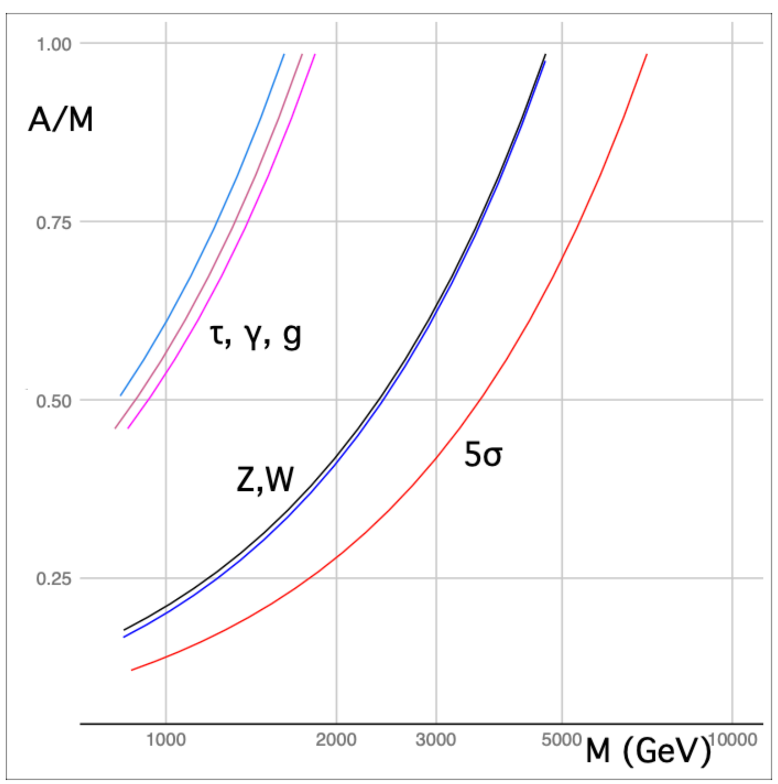
SILH



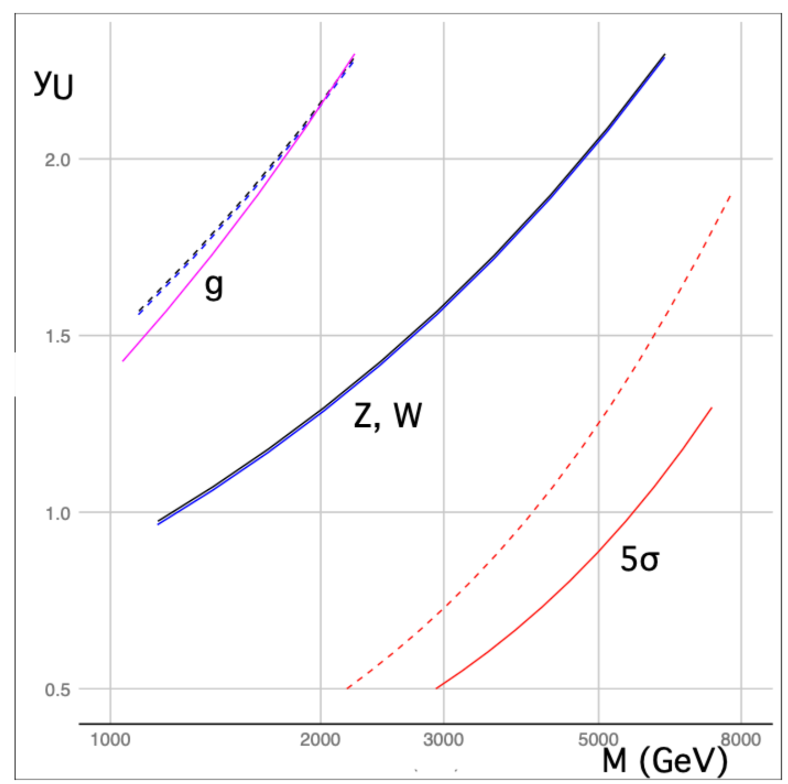
2HDM



scalar singlet



vector-like quark

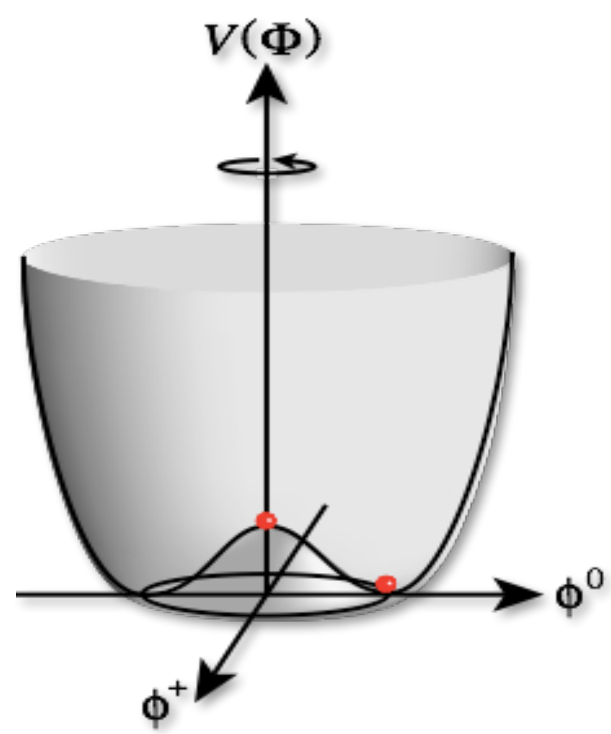


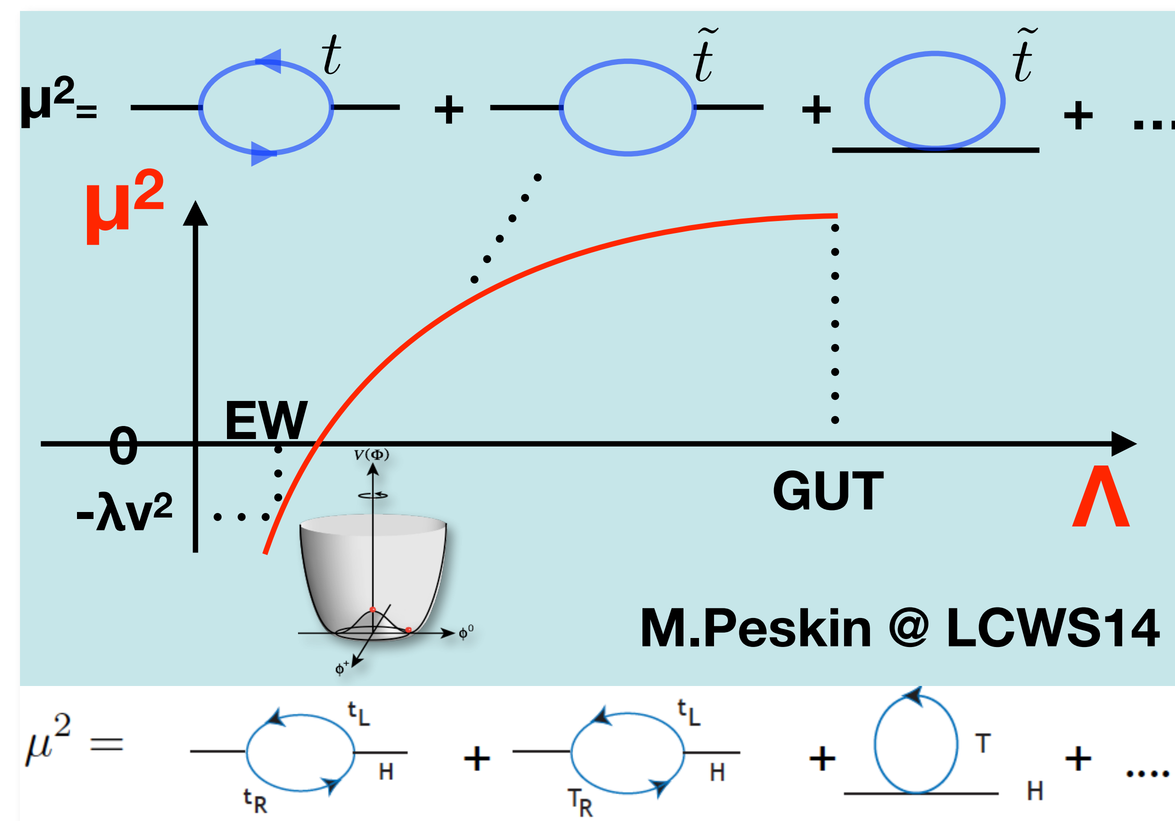
ILC can discover new physics scale well above multi-TeV

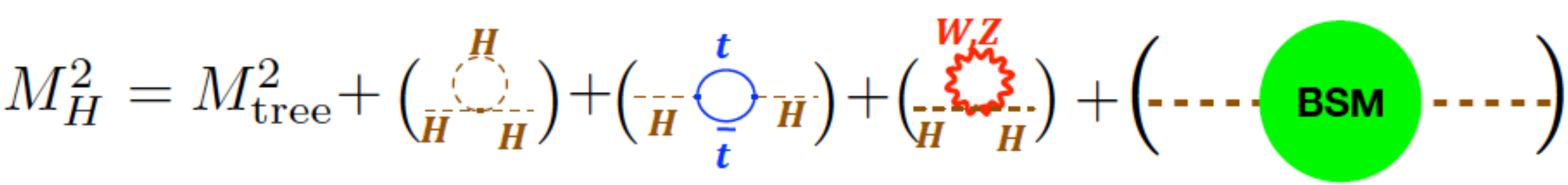
5. Why is electroweak symmetry breaking?

- Why μ2 < 0?
- Underling physics responsible for generating it ~ TeV
- ILC: deviations by MSSM, Composite, Extra Dimensions

$$V(|\Phi|) = \mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$$



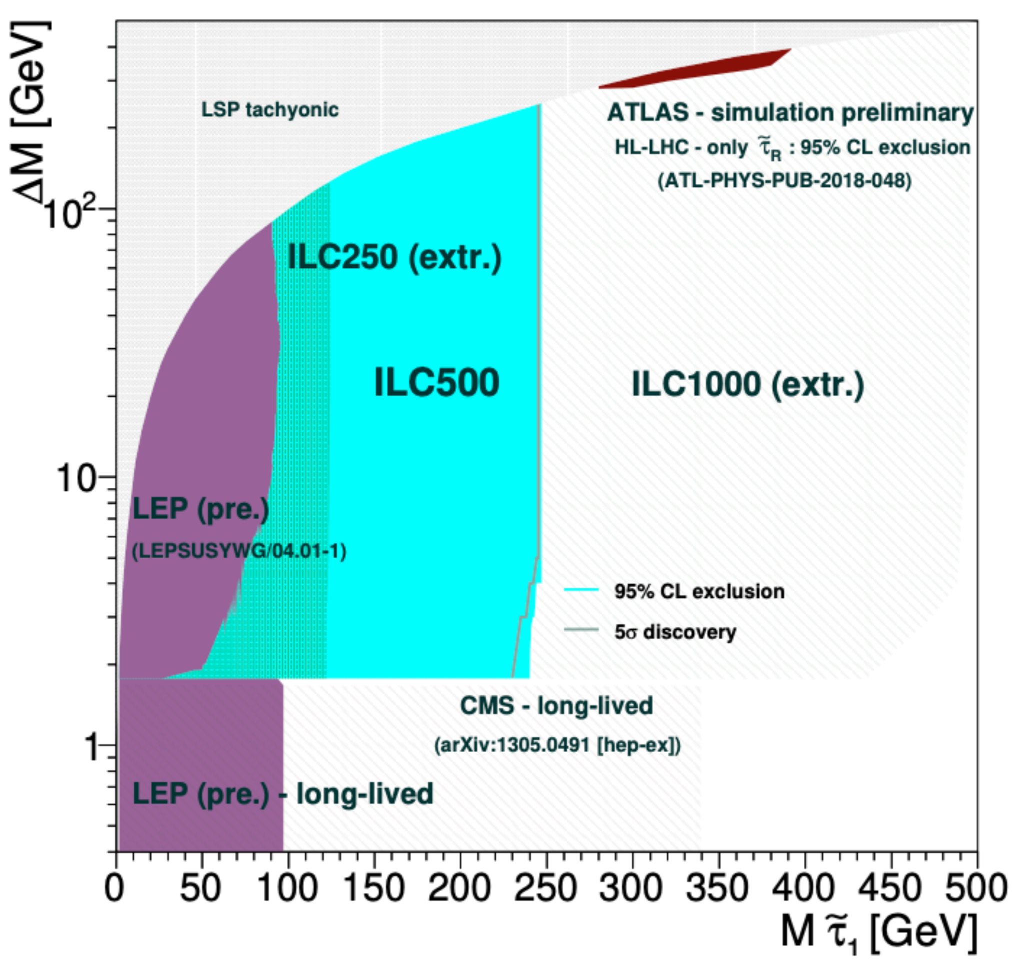


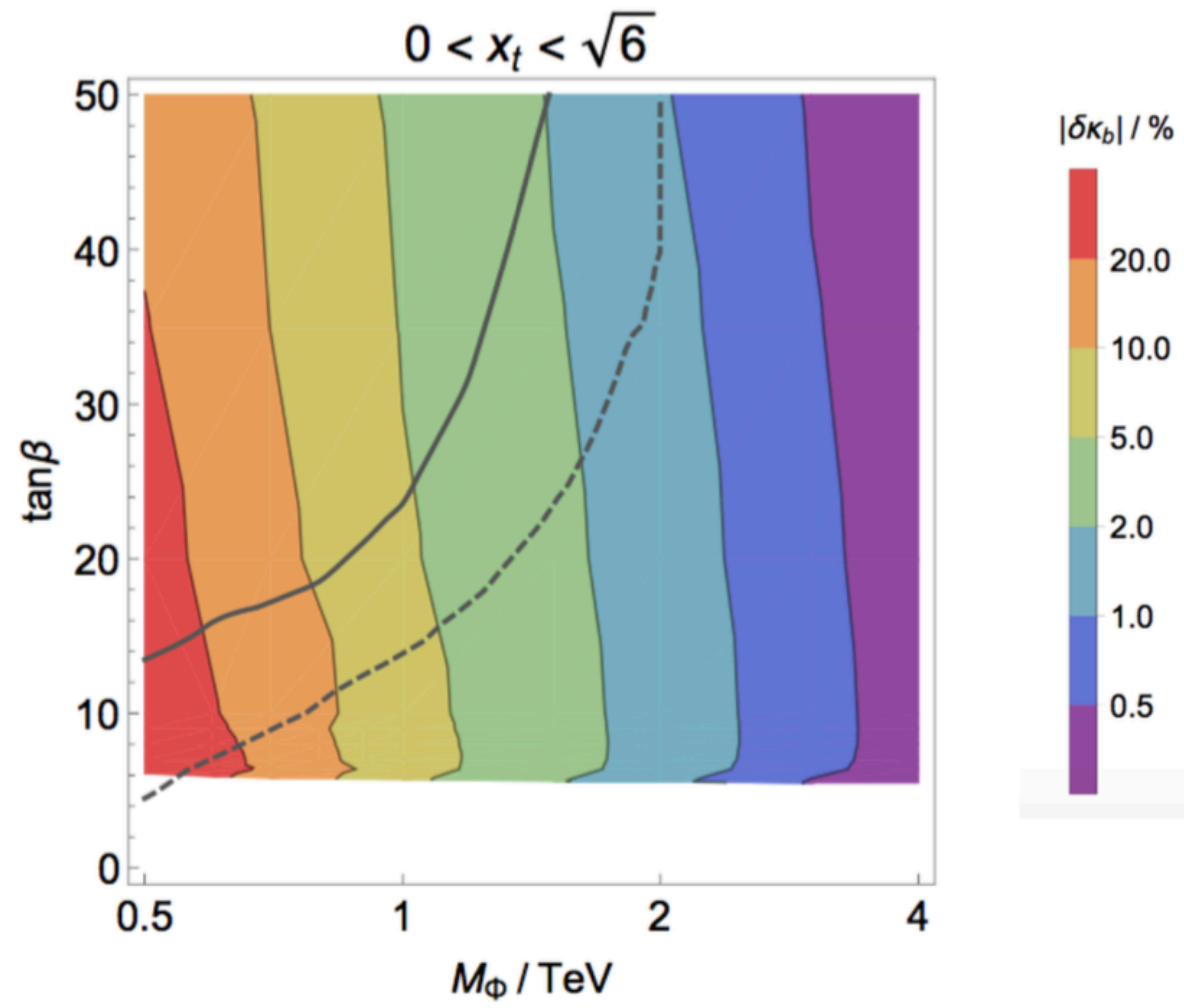


6. Concrete Models: ILC & SUSY

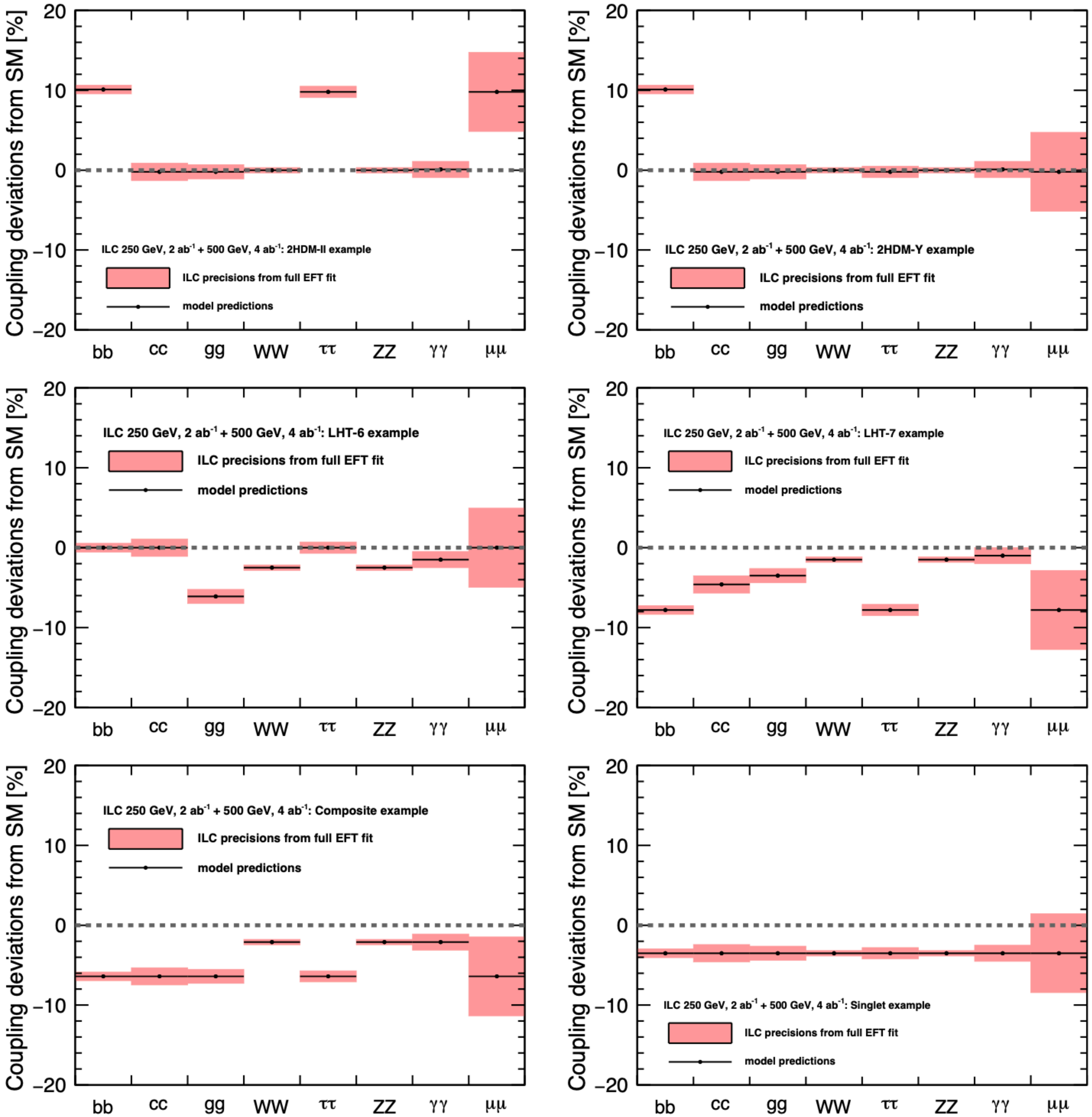
Direct Search

Indirect by precision Higgs coup.



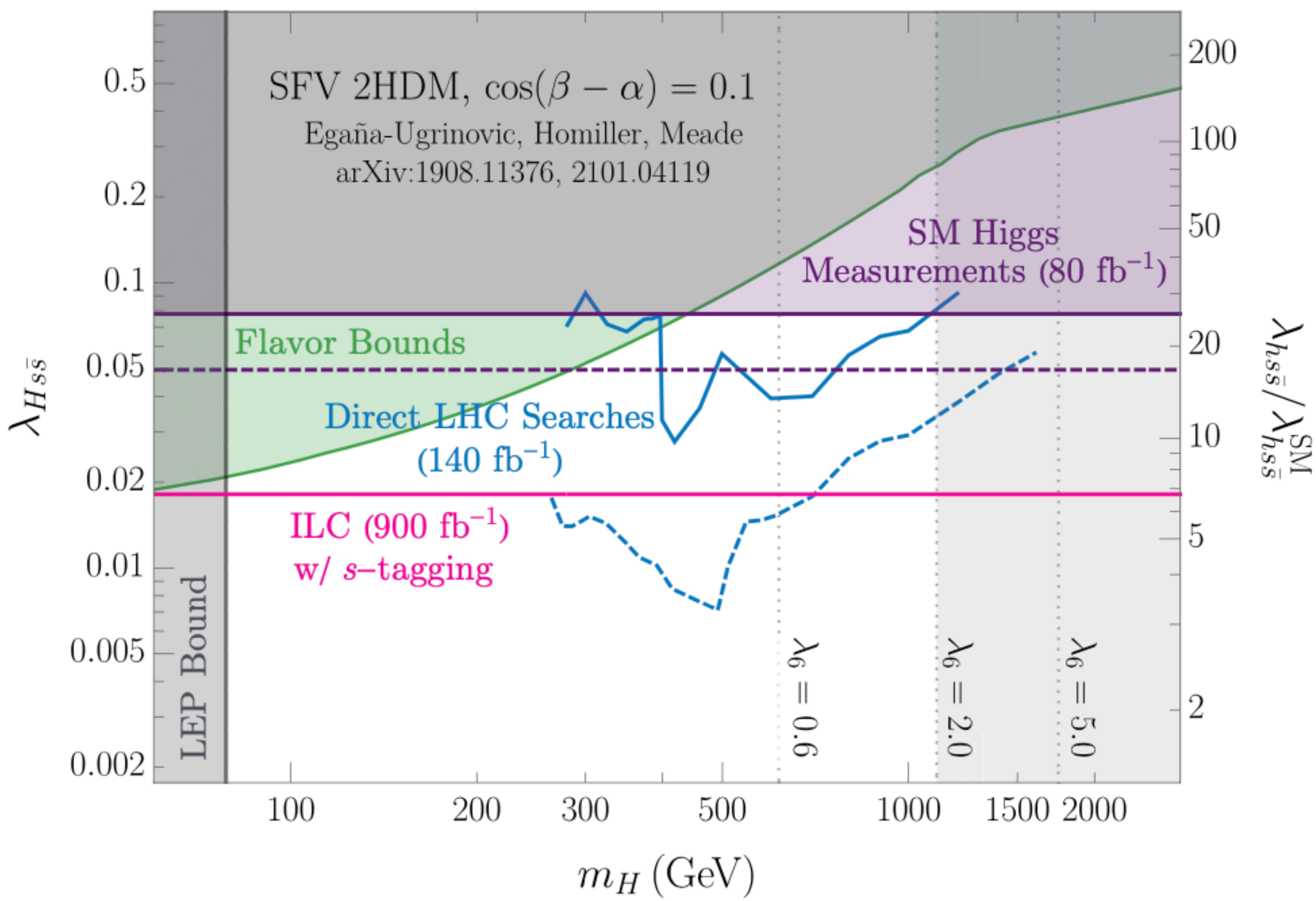


7. Higgs Inverse Problem



8. ILC and flavor

- Origin of fermion masses: ILC can measure Yukawa couplings to top, b, τ, c, μ, (s)
- Test of CMK unitarity: ILC W hadronic branching gives a tight constraint on first two rows of CKM elements



Summary