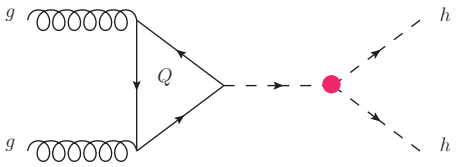
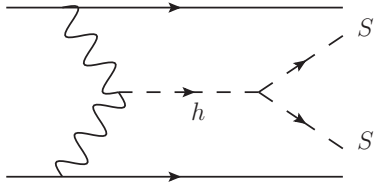
Probing Electroweak Baryogenesis at Future Colliders





FCC Higgs/EWSB WG meeting

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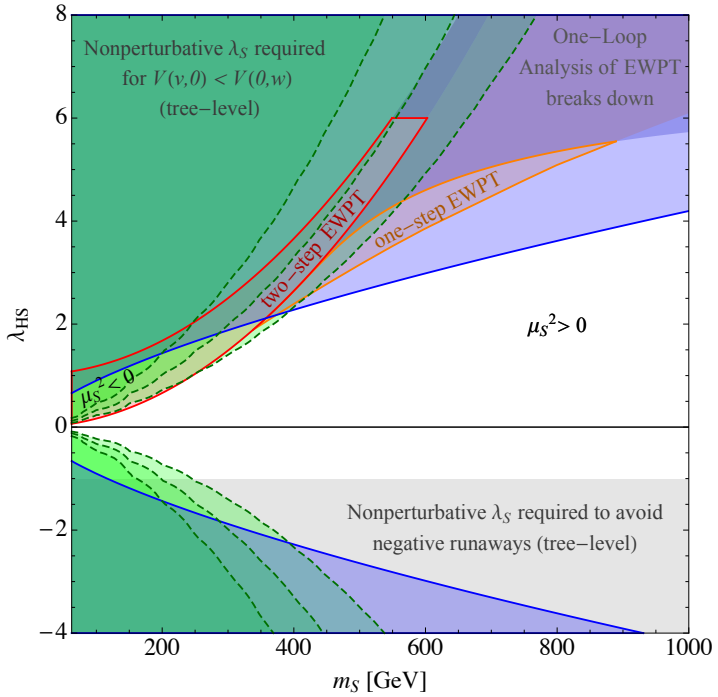
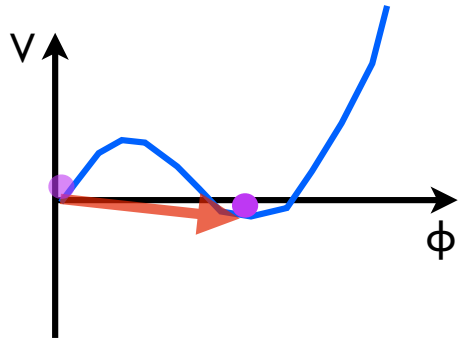
Partially based on 1409.0005 (DC, Patrick Meade, Tien-Tien Yu)



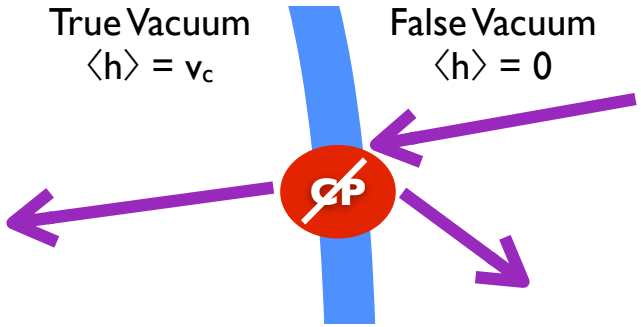
Electroweak Baryogenesis

EWBG requires two BSM ingredients:

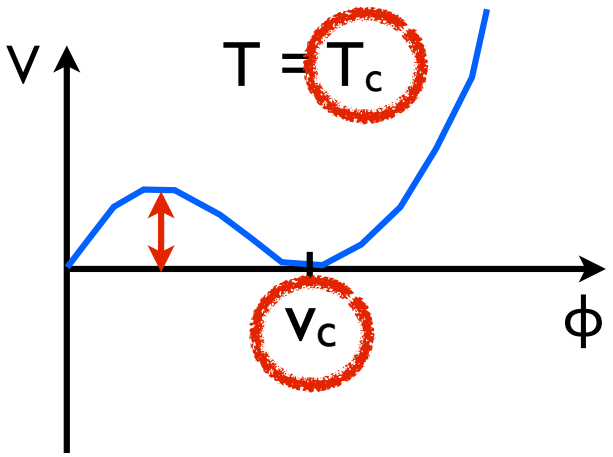
1. Modified higgs potential to make phase transition 1st order



2. Sizable CPV coupling between higgs and another particle (BSM or SM) that is thermally active in the plasma ($M \lesssim T$)



Can 100 TeV pp probe the PT?



The phase transition has to be strong enough to suppress sphaleron washout of the generated baryon number in the broken phase.

$$\frac{v_c}{T_c} > 0.6 - 1.6$$

Normally given as ~1, this more accurate figure is from Patel, Ramsey-Musolf, 1101.4665

Very simple criterion to determine if EWBG is at least *possible* with a given higgs potential.

Achieving a strong PT

How can you modify the SM higgs potential to get $v_c/T_c \gtrsim 1$?

$$V_{\rm eff}(h,T) = V_0(h) + V_0^{CW}(h) + V_T(h,T)$$

tree-level potential | loop correction | finite temperature corrections

1. Thermal Effects

   add new BOSONS to the plasma to generate barrier (analogous to W and Z contributions).

   (See Andrey's talk just before this one :).)
   Needs light dof < 200 GeV. SHOULD BE DISCOVERABLE: direct production, σ_{Zh} ~ 1%, h^3 coupling shift ~ 10%.

2. Loop Effects

   add particles whose loops reduce the 'depth of the higgs potential well', so W and Z contributions can make a barrier.

   (2) and (3) DO NOT necessarily require very light new particles to induce strong phase transition!

3. Tree Effects

   add scalars to modify tree-level higgs potential and create a barrier

Tree and Loop-driven PT

Consider SM + single real scalar

$$V_0^{T=0}(H,S) = -\mu^2 \left(H^\dagger H\right) + \lambda \left(H^\dagger H\right)^2 + \frac{a_1}{2}\left(H^\dagger H\right) S + \frac{a_2}{2}\left(H^\dagger H\right) S^2 + \frac{b_2}{2}S^2 + \frac{b_3}{3}S^3 + \frac{b_4}{4}S^4.$$

In generality, this scalar mixes with the higgs after EWSB.

$\Rightarrow$ - direct production in (heavy) higgs searches
- exotic higgs decays h→ss (if light enough)
- EW precision tests
- higgs precision coupling measurement constraints
- modifications to higgs self-couplings

100 TeV measurement possibilities

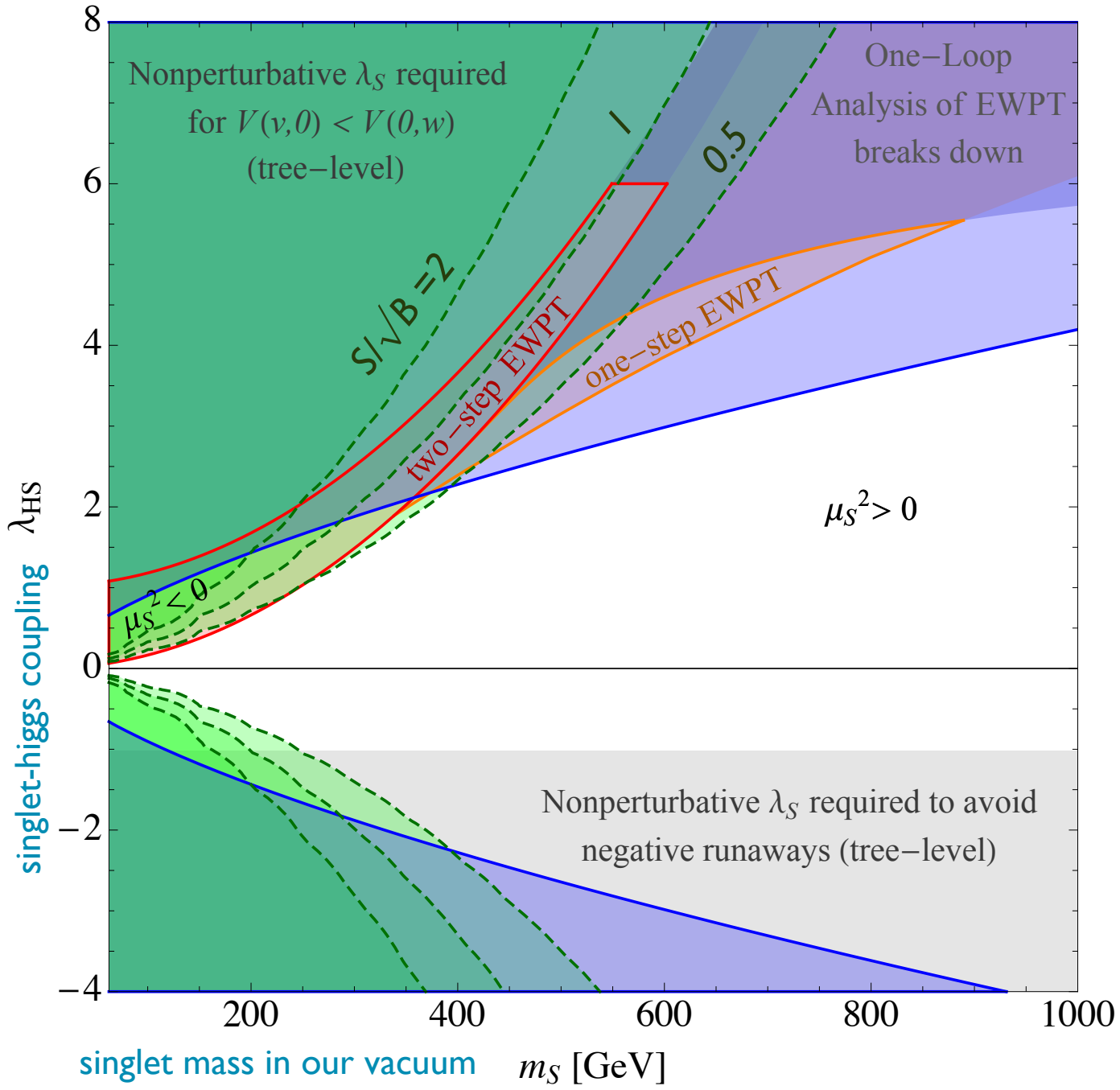
A lot of handles for discovery!

But the model still has many parameters. Can EWBG be completely excluded?

Study a minimal model with just one real *unmixed* singlet scalar.
→ 'maximally' stealthy PT!

DC, Patrick Meade, Tien-Tien Yu 1409.0005

100 TeV pp could exclude EWBG!



100 TeV Collider

8% Higgs triple-coupling measurement

(95%CL exclusion, ~10% is achievable with 30/ab)

Direct detection of VBF h* →SS

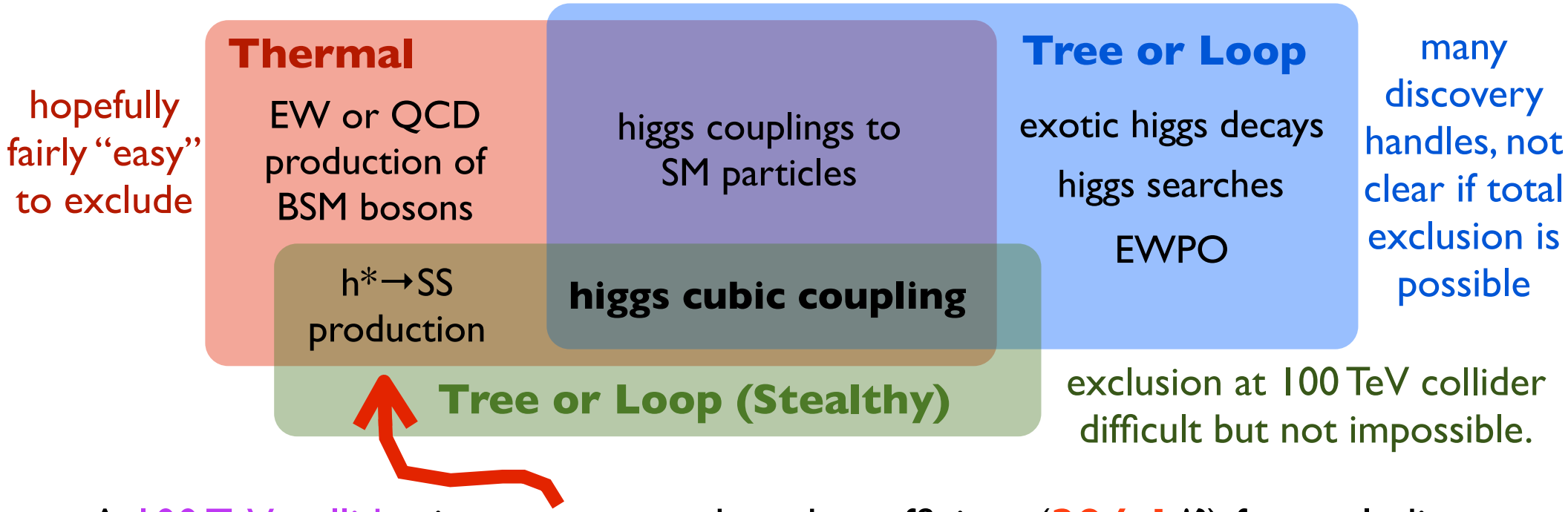
($S/\sqrt{B} \sim 1$)

100 TeV collider is both necessary and *maybe* sufficient to detect EWBG

Conclusions

- Future colliders give us access to the Uncolored TeV scale. Might allow us, for the first time, to meaningfully probe the electroweak phase transition in a general sense, so we can test whether electroweak baryogenesis is possible.

- We investigate the *entire parameter space* of a maximally stealthy "nightmare scenario" for EWBG (SM + unmixed real singlet) to investigate possibility of no-lose theorem for excluding a strong phase transition (PT).



- A 100 TeV collider is necessary and maybe sufficient (**30/ab**!?) for excluding strong PT. Lepton collider is also necessary for higgs precision and possibly higgs cubic.