A Tight Scrutiny Of Electroweak Phase Transitions

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Based on 1511±1.xxxxx with David Curtin & Patrick Meade

Baryogenesis problem

- Fact:The universe around us has excess matter over antimatter
- Baryon-Antibaryon asymmetry with symmetric initial conditions.

- Sakharov Conditions:

1. C&CP violation
2. B violating processes
3. Thermal inequilibrium

Finite Temperature Effective Potential

- Need Effective Potential V to talk about vev as its minimum.
- Tree level V gets corrections at 1-loop
- Captured by Coleman-Weinberg calculation
- Finite temperature:virtual interactions with plasma
- Imaginary Time formalism to modify potential

10 second crash course in FTFT

$$V_{CW} = \frac{1}{2}\int \frac{d^4k}{(2\pi)^4} Log[k_E^2 + M^2]$$

Good old CW potential

$$\int \frac{dk_4}{2\pi} f(k_4) \to T \sum_n f(k_4 = i\omega_n), \omega_n = 2\pi n T$$

Imaginary time formalism replacement

$$V_{CW} = V_{CW}^{T=0} + V_{CW}^{T\neq 0}$$

Splits neatly into T-dependent and T-independent parts

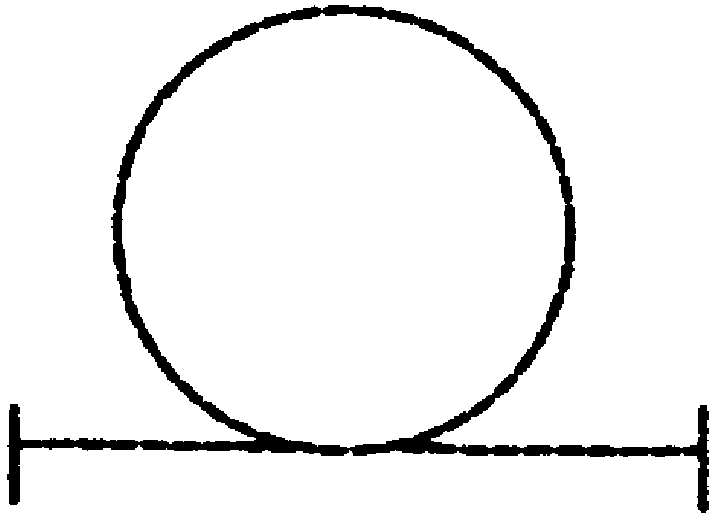
$$V_{CW}^{T\neq 0} = \frac{T}{2\pi^2}\int dp p^2 \log[1 - \exp[-\beta\sqrt{p^2 + M^2}]]$$

Break down of P.T :Conventional wisdom

$$V_{CW}^{T\neq 0} = \frac{T^4}{2\pi^2} J_B(\frac{M^2}{T^2})$$

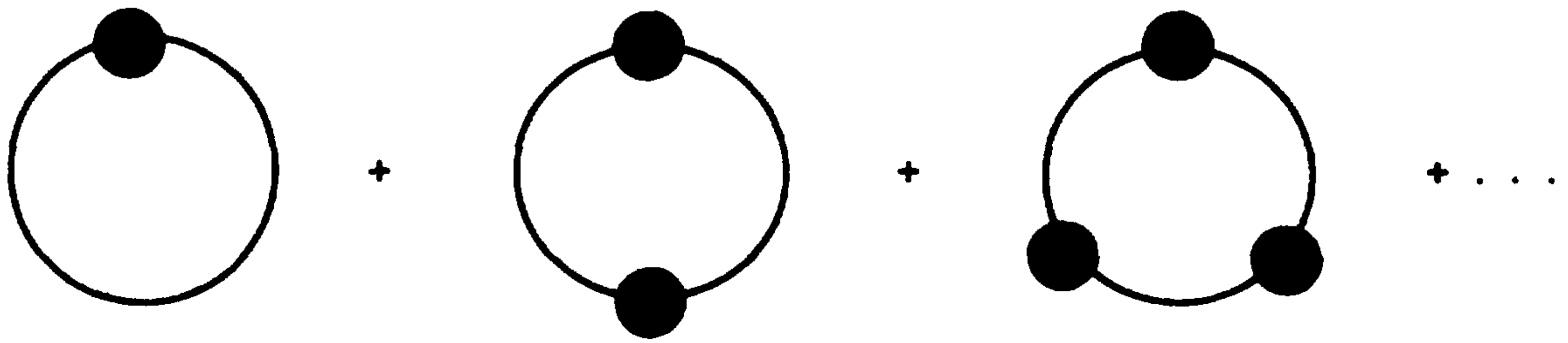
In the high T limit,

$$\Pi_1(T) = \frac{d^2 V_{CW}^{T\neq 0}}{dh^2} = \frac{\lambda}{4} T^2$$

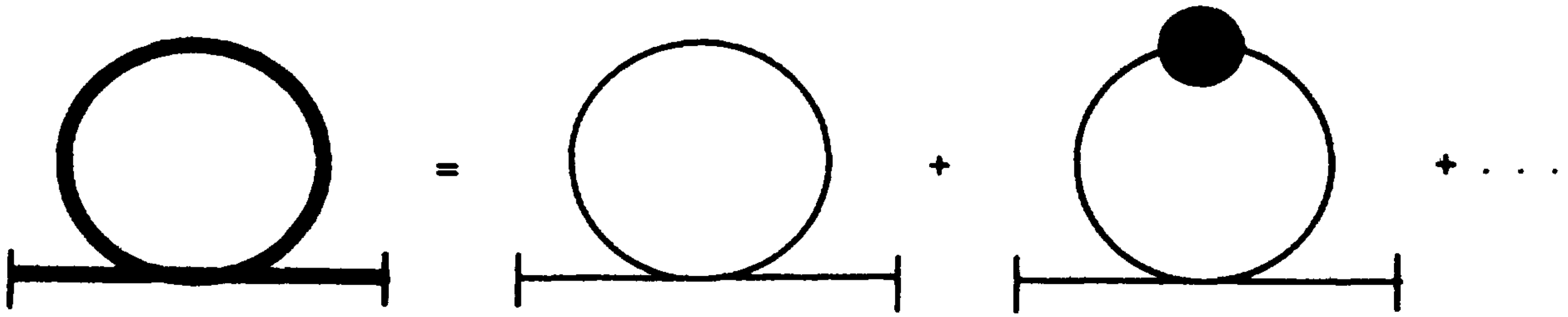


- the one loop generated thermal mass is much larger than the tree level mass.
- Break down in P.T.

Ring Terms



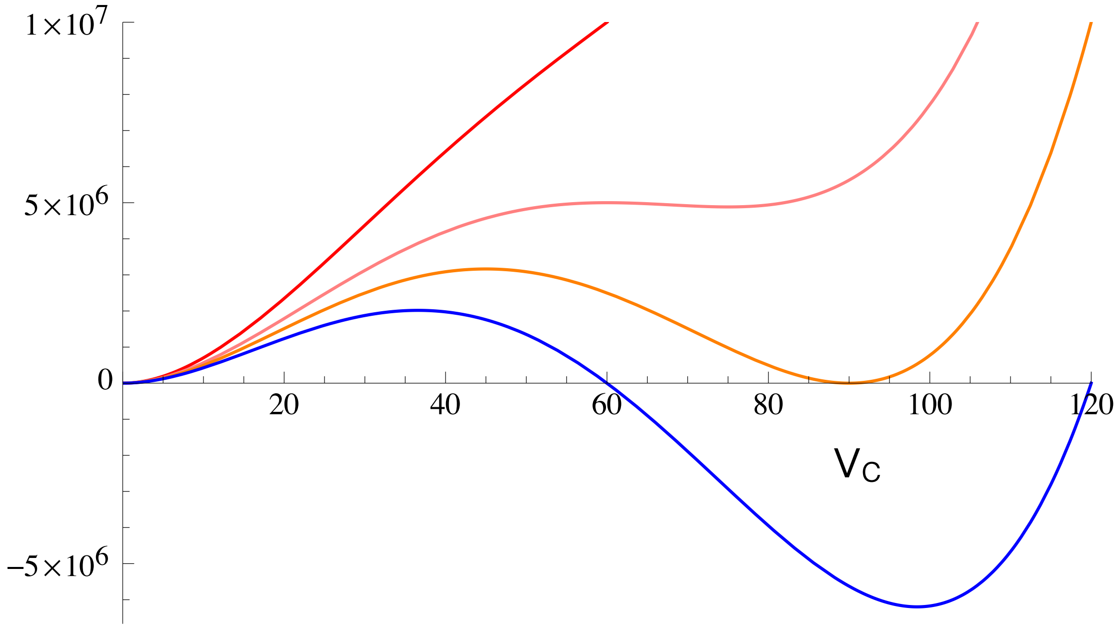
- contributions from all orders(called Daisy diagrams).
- to resum Daisies,replace $M^2 \rightarrow M^2 + \Pi$



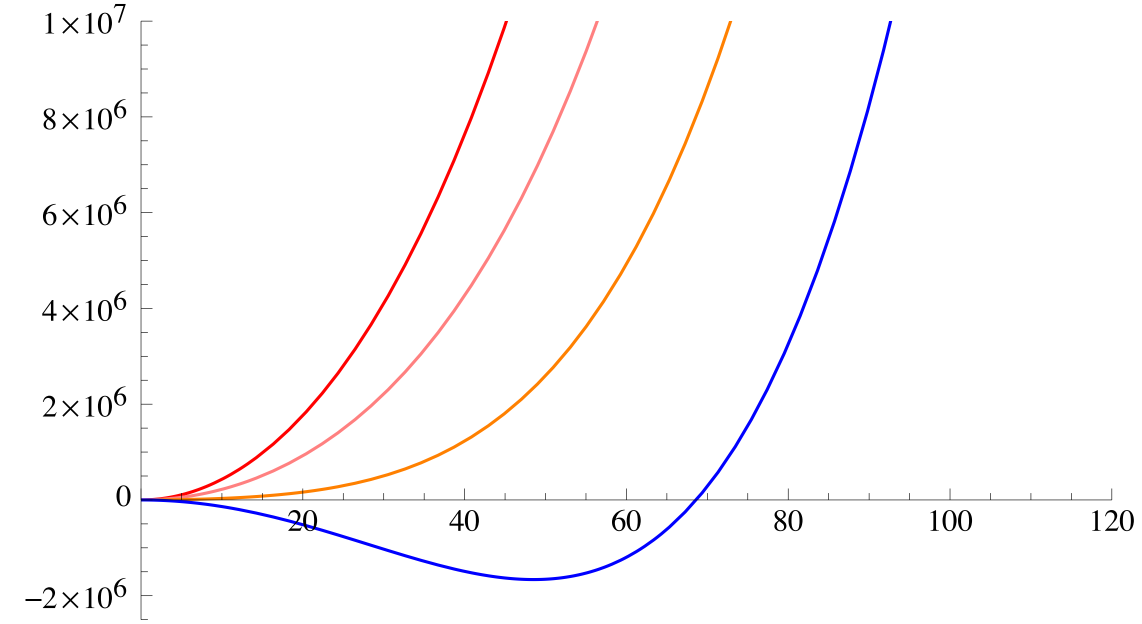
Incapable standard model

- Not enough CP violation
- Could EWSB(h=0 -> h=v) provide thermal in-equilibrium?
- Phase transition required to be first order to prevent Baryon washout
- Standard model provides only second order phase transition

Cooling Down



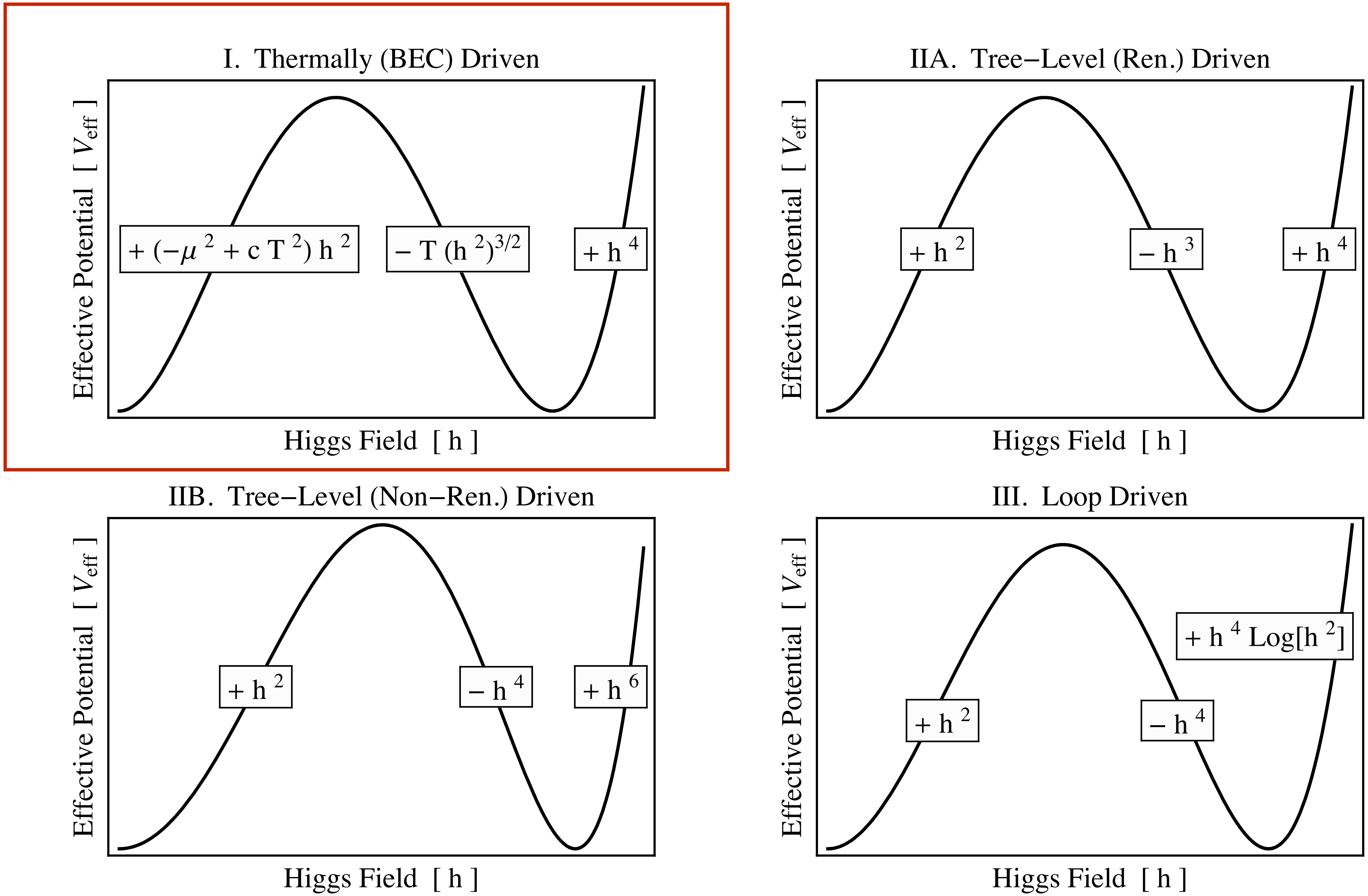
1st order Phase Transition



2nd order Phase Transition

Left is good, further $v_C/T_C > 1$

Extensions to Higgs



Chung et.al.1209.1819

Why is Type 1 special?

- only type where Temperature produces the cubic coupling.
- All other types affect the Higgs tri-linear coupling
- Requires precision thermal field theory.

High temperature approximation
Ring induced phase transition

- add new singlet : $\Delta L = -\frac{1}{2}\mu_s^2 s^2 + \frac{1}{2}\lambda_{hs} h^2 s^2 + \frac{1}{4}\lambda_s s^4$
- now, at high T, $V_{CW}^{T\neq 0} = -\frac{T^4}{90} + \frac{T^4}{24}\frac{M^2}{T^2} - \boxed{\frac{T^4}{12\pi}(\frac{M^3}{T^3})}$
- replacing, $M^2 \to M^2 + \Pi$ for an extra singlet coupled to the Higgs,
- you get $(M_s^2 + \Pi)^{3/2} = (-\mu_s^2 + \lambda_{hs} h^2 + \Pi)^{3/2}$
- and then $(M_s^2 + \Pi)^{3/2} = (\cancel{-\mu_s^2} + \lambda_{hs} h^2 + \cancel{\Pi})^{3/2} = \lambda_{hs}^{(3/2)} h^3$

Wait What?

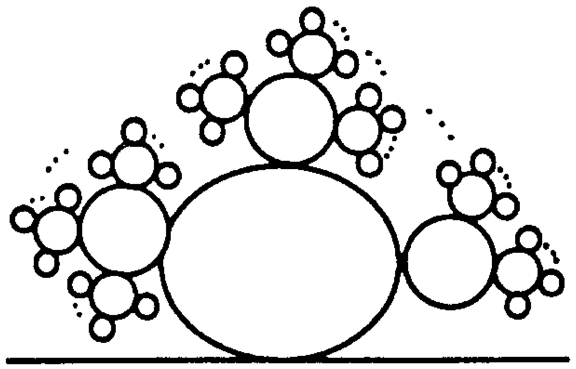
- How is high T limit valid? T~ EW scale and so are all masses
- In fact typically the extra scalar is more massive
- Mass is h dependent.
- regions where M is small:approximation valid
- regions where M ~ T, thermal mass small for small coupling

$$\boxed{\Pi = \frac{\lambda_{hs}}{2} T^2}$$

Problems with

$$\boxed{\Pi = \frac{\lambda_{hs}}{2} T^2}$$

- Thermal mass doesn't decouple as Ms becomes massive
- Thermal mass seems to be h independent
- Super-Daisy terms not taken into account.



New Work

What we did

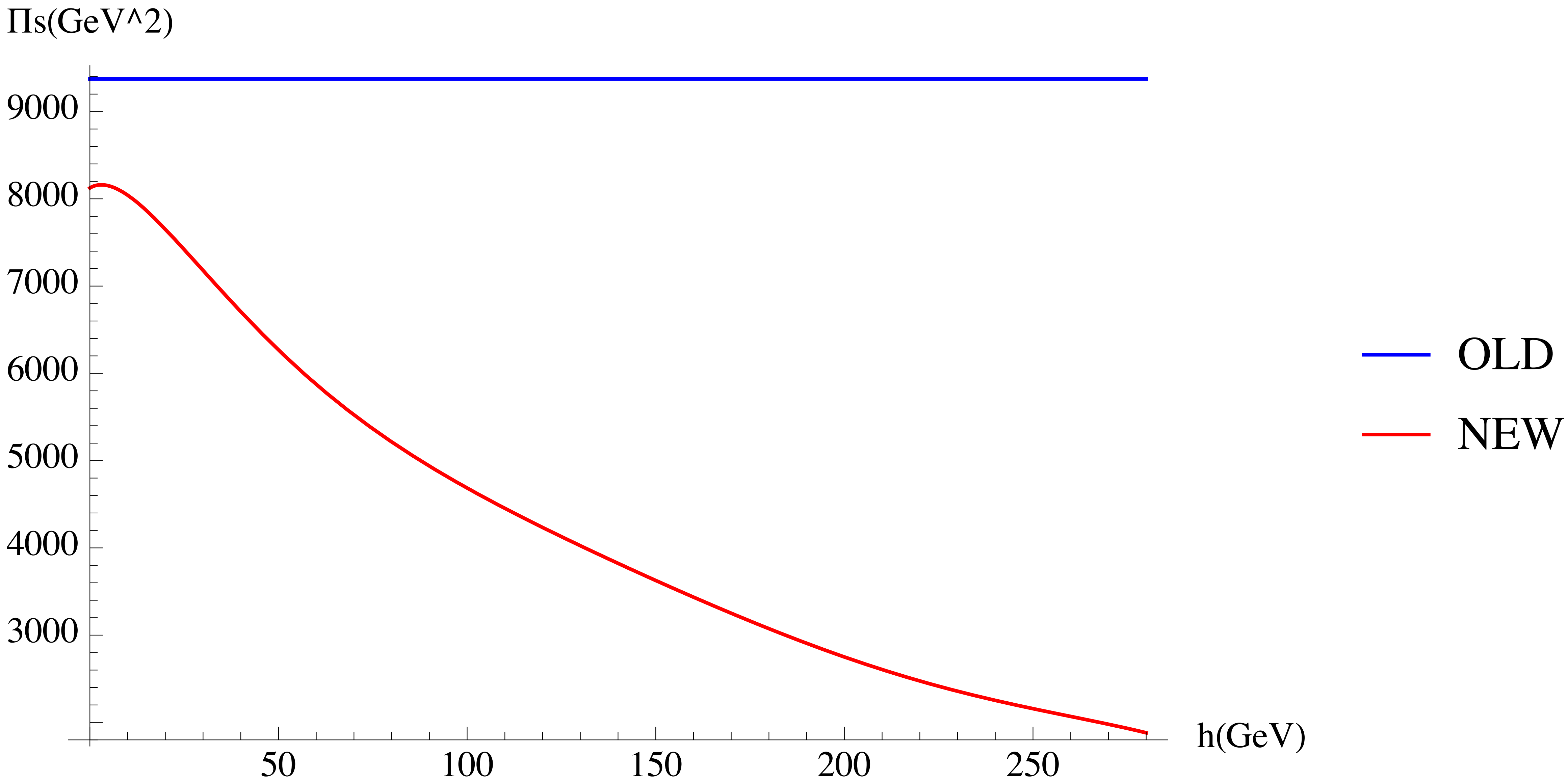
- Computed thermal mass accurately.(no high-T expansion)
- How about new thermal mass after substitution?

$$\Pi_{\mathrm{super}} = \frac{dV'_T}{dh}[M^2 \to M^2 + \Pi_{\mathrm{super}}]$$

- Solved iteratively to take into account super-daisy

RESULTS

Old vs New Thermal Mass



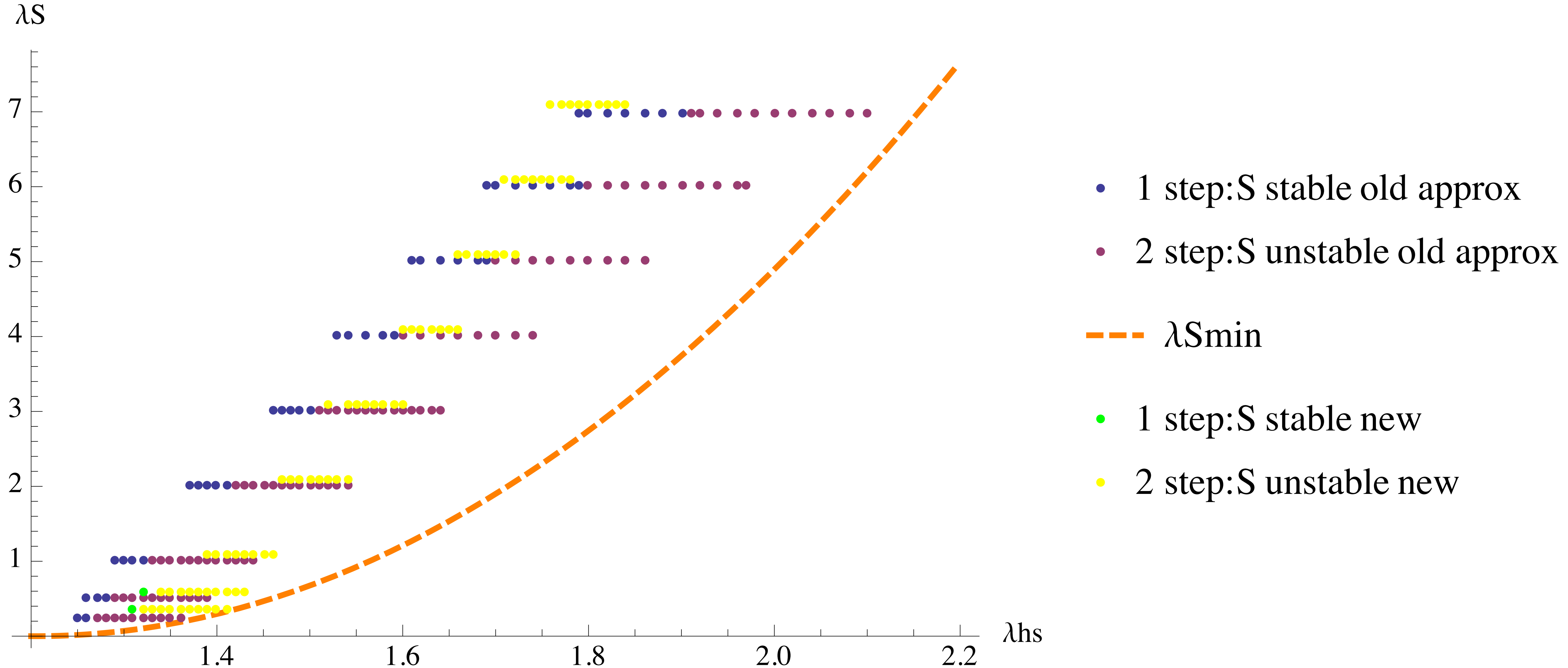
Procedure

- Account for accurate thermal mass in potential
- Cool down to find critical temperature
- is S still stable?, i.e. $M_s^2 + \Pi_s > 0$
- is $v_C/T_C > 1$

RESULTS

Parameter space where ring induced 1st-order phase transition feasible

M_S=270 GeV



RESULTS-IDM

Parameter space where ring induced 1st-order phase transition feasible

	M_H	M_A	$M_{H^{+-}}$	λ_L	λ_T	v_c/T_c(old)	v_c/T_c(new)
BM1	66	300	300	0.01	0.01	1.5	1.1
BM2	200	400	400	0.01	0.01	1.5	1.2
BM3	5	265	265	-0.006	0.01	1.3	1.0

for v_C/T_C(old) refer 1504.05949

Summary

- FTFT required to handle EWPT
- in some regimes high T approx not valid
- Full iteration based computation the way out
- Leads to drastically reduced parameter space for thermally induced phase transition

The Ring has awoken, its heard its masters call