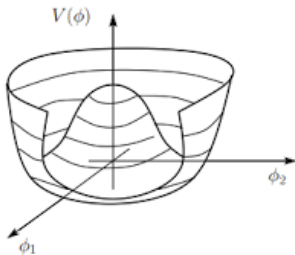


# A gauge invariant description of phase transitions



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## Phase transitions via the effective potential

Transition from phase  $A$  to phase  $B \implies$  Critical temperature, latent heat,...

Inconsistent power counting  $\implies$  Gauge dependence, IR divergences, missing terms,...

### Resummations

$N$ -loop diagrams scale as

$$V_N \sim T m^3 \left( \frac{\lambda T^2}{m^2} \right)^{N-1}$$

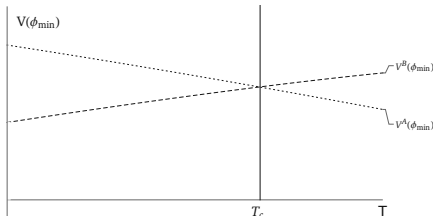
$\implies$  Needs to be resummed

Resummations must be done consistently

$V(\phi_{min})$  is physical

Should be finite and gauge independent

Must be evaluated carefully



### Observables at $T_c$

The phase transition occurs at  $T = T_c$ :

$$[V^A - V^B]_{T_c} = 0$$

## Perturbative Calculations

$$V(\phi) = V_{\text{LO}}(\phi) + \hbar V_{\text{NLO}}(\phi) + \dots$$

Only extrema of  $V(\phi)$  are physical ( $\partial V = 0$ )

$\hbar$ -expansion

Traditional method

### Find $V_{\text{min}}$ order-by-order

$$\phi_{\text{min}} = \phi_{\text{LO}} + \hbar \phi_{\text{NLO}} + \dots$$

$$[\partial V_{\text{LO}}]_{\phi=\phi_{\text{LO}}} = 0,$$

$$\left[ \partial V_{\text{NLO}} + \phi_{\text{NLO}} \partial^2 V_{\text{LO}} \right]_{\phi=\phi_{\text{LO}}} = 0$$

$\vdots$

### Find $V_{\text{min}}$ "numerically"

$$\partial V(\phi)_{\phi_{\text{min}}} = 0$$

Both  $\phi_{\text{min}}$  and  $V(\phi_{\text{min}})$  are gauge dependent

### Critical temperature

$$\left[ V^A - V^B \right]_{T_c, \phi_{\text{min}}} = 0.$$

### Critical temperature

The two phases coincide when

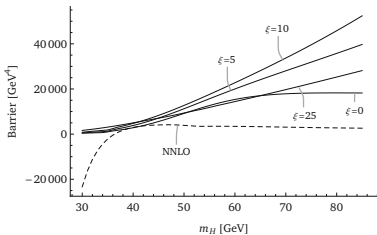
$$T_c = T_{\text{LO}} + \hbar T_{\text{NLO}}$$

$$\left[ V_{\text{LO}}^A - V_{\text{LO}}^B \right]_{T=T_{\text{LO}}, \phi=\phi_{\text{LO}}} = 0,$$

$\vdots$

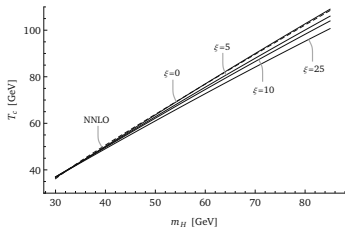
$\implies T_c$  and  $\phi_{\text{min}}$  used to evaluate other observables

$\implies$  Spurious gauge dependence



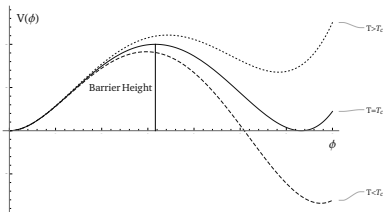
## Comparison

Traditional vs  $\hbar$ -expansion



## Barrier height

Gauge dependent  
Large finite pieces



## Critical temperature

Result coincide with the  
 $\hbar$ -expansion  
Small radiative corrections