有限温度２ループ有効ポテンシャルに対する再和法の改善と一次相転移

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Motivation

電弱相転移(EWPT)の振舞

Higgs期待値を変数とする有効ポテンシャルの計算

有限温度の摂動計算の問題点

- 結合定数のベキ展開が必ずしも良くない

  最も温度依存性の大きなthermal massを取り込む

  --- resummed perturbation or optimized perturbation

- ループ積分がnoncovariant, 解析的にできない

  Hard Thermal Loop approximation

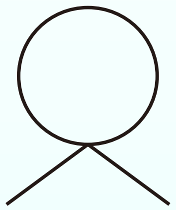
  ループ積分のHight Temperature Expansion (HTE)

`resummation'

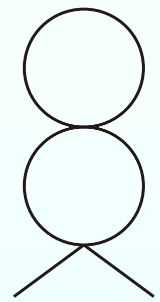
Parwani, PRD45; Arnold-Espinosa, PRD47; Chiku-Hatsuda, PRD58

e.g. ϕ^4-theory

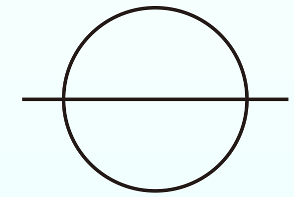
２点函数(mass²)への温度補正　（高温展開）　$a = \frac{m}{T} \ll 1$



$\propto \lambda T^2$

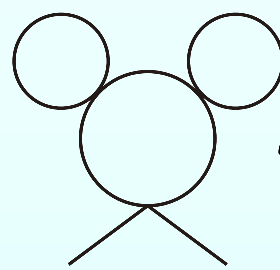


$\sim \lambda T^2 \frac{\lambda T}{m}$



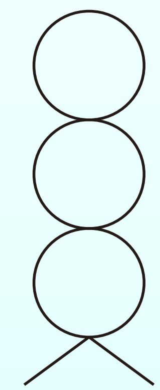
$\sim \lambda T^2 \lambda \log \frac{T}{m}$

$\times \frac{\lambda T^2}{m^2}$

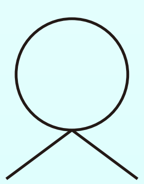


$\sim (\lambda T^2)^2 \frac{\lambda T}{m^3}$

$\times \frac{m}{T}$



$\sim \lambda T^2 \left(\frac{\lambda T}{m} \right)^2$



１つの因子について $\frac{\lambda T^2}{m^2}$ のべき　$\therefore T \gtrsim \frac{m}{\sqrt{\lambda}}$ で近似は**無効**

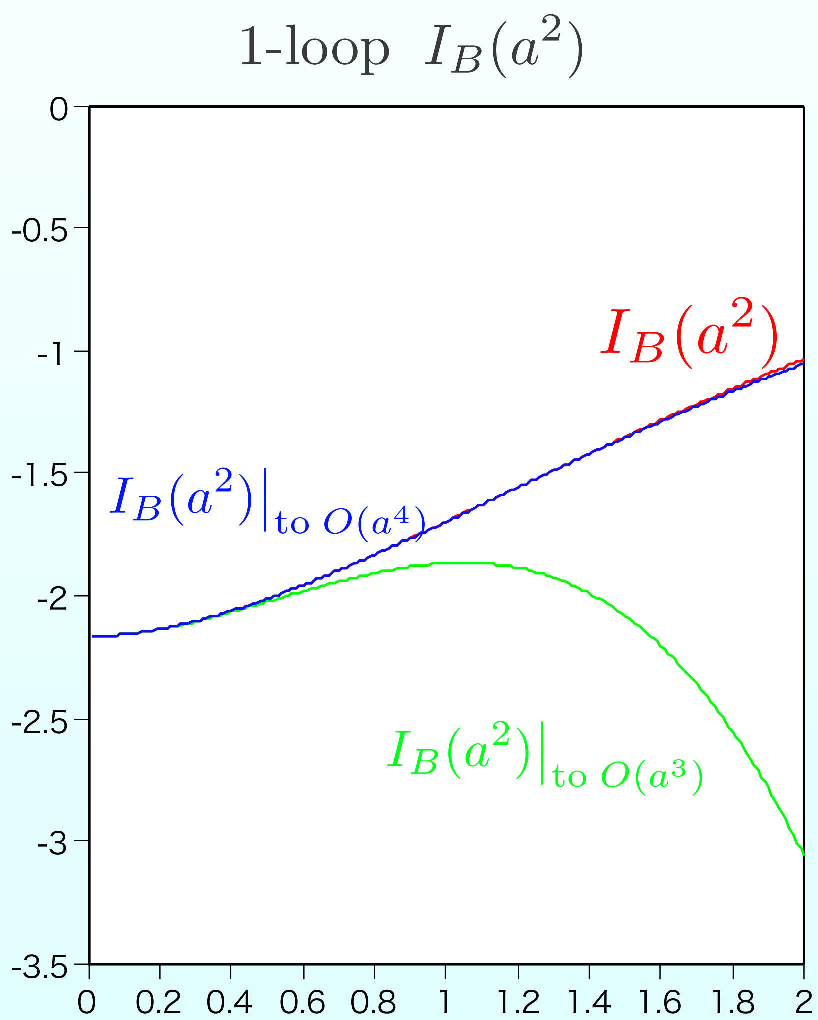
m^2に対するλT^2のleading correctionを取り入れる

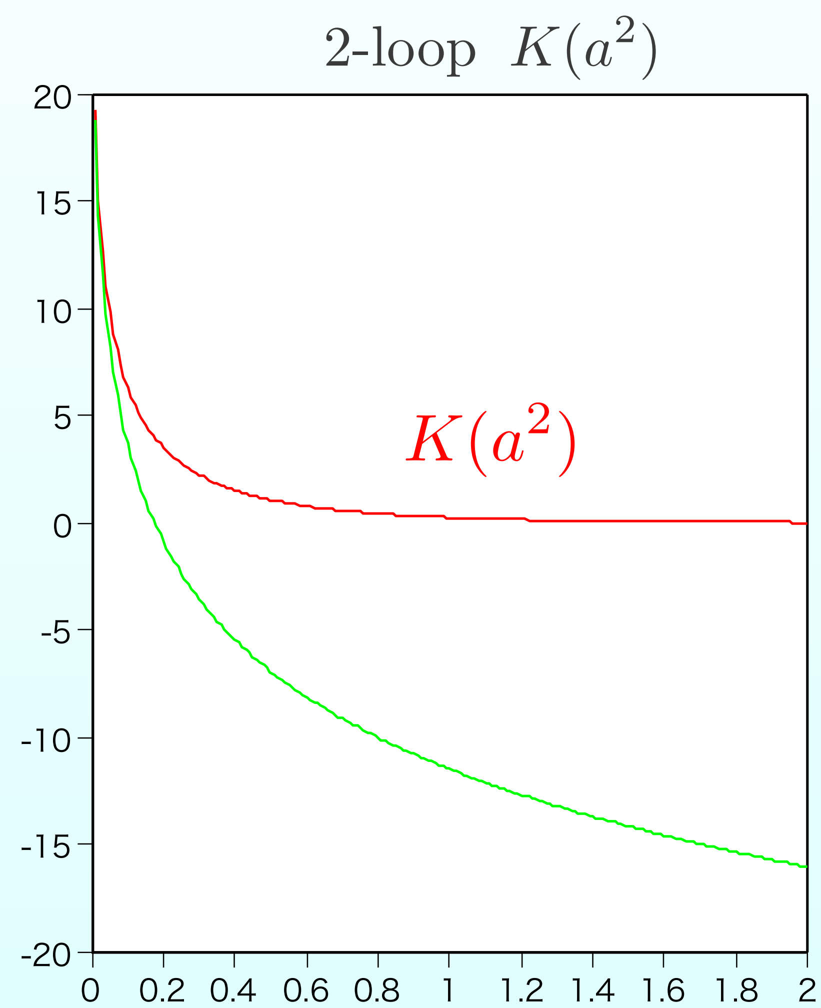
$$\mathcal{L}_B = \mathcal{L}_R + \mathcal{L}_{\mathrm{CT}} \longrightarrow \mathcal{L}_B = \mathcal{L}_R - \frac{1}{2}\Delta_T m^2 \phi^2 + \boxed{\mathcal{L}_{\mathrm{CT}} + \frac{1}{2}\Delta_T m^2 \phi^2}$$

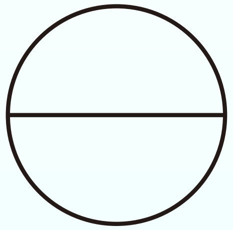
new counterterm

高温展開がよろしくない

SUSY-SMのEWPTでは、stop-stop-gluonのsunset diagramの寄与が一次転移を強くする　Espinosa, NPB475







$$I_B(a^2) \simeq -\frac{\pi^4}{45} + \frac{\pi^2}{12}a^2 - \frac{\pi}{6}a^3 - \frac{a^4}{16}\left(\log\frac{a}{4\pi} + \gamma_E - \frac{3}{4}\right)$$

$$K(a^2) \simeq -\frac{\pi^2}{3}\left(\log(a^2) + 3.48871\right)$$

QCDのようにスケールがない場合はよいが、

EWPTで興味があるのは、vc/Tc=1の辺り

- 温度に依存した発散が繰り込めるか？

  HTEではT-dep. divergenceは無視している

  HTEを使わずに、T-dep. div.を処理して有限項を抽出したい

- ゲージ場では縦波・横波でthermal massが異なる

$$D_{\mu\nu}(p) = \frac{-1}{p^2 - M^2} P_{\mu\nu} \qquad P_{\mu\nu} \equiv g_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}$$

$$\boldsymbol{D}_{\mu\nu}(p) = \frac{-1}{p^2 - M_T^2} T_{\mu\nu} + \frac{-1}{p^2 - M_L^2} L_{\mu\nu}$$

$$T_{00} = T_{0i} = T_{i0} = 0, \qquad T_{ij} = g_{ij} - \frac{p_i p_j}{-\boldsymbol{p}^2} \qquad L_{\mu\nu} = P_{\mu\nu} - T_{\mu\nu}$$

$$M_T^2 = M_0^2 + \Delta_T M_T^2 \qquad M_L^2 = M_0^2 + \Delta_T M_L^2$$

$$M_0^2 = m_W^2(v),\ m_Z^2(v) \qquad \text{for the weak bosons}$$

$$M_0^2 = 0 \qquad \text{for the photon and gluons}$$

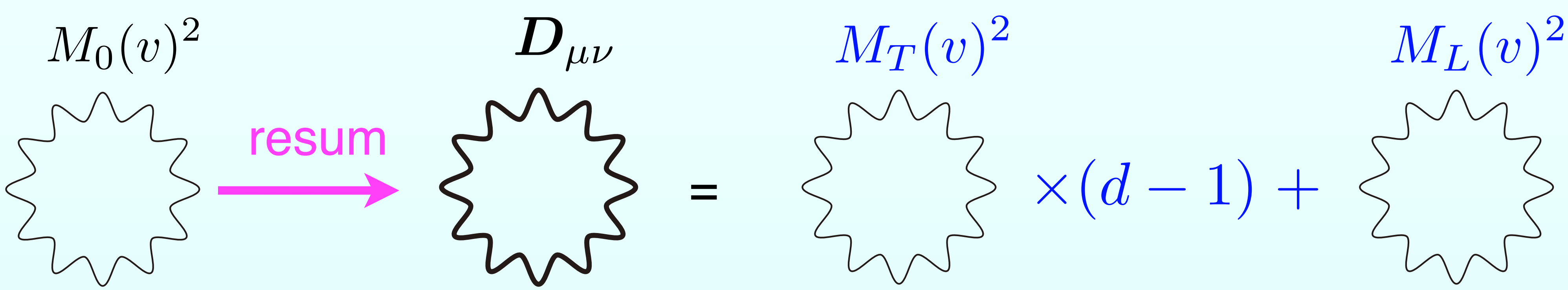
perturbation based on

$$\mathcal{L}_B = \mathcal{L}_R + \frac{1}{2}\Delta_T M_T^2 A^\mu T_{\mu\nu}(i\partial) A^\nu + \frac{1}{2}\Delta_T M_L^2 A^\mu L_{\mu\nu}(i\partial) A^\nu + \mathcal{L}_{\rm CT} - \cdots$$

→ resummed propagator $\boldsymbol{D}_{\mu\nu}(p) = \frac{-1}{p^2 - M_T^2} T_{\mu\nu} + \frac{-1}{p^2 - M_L^2} L_{\mu\nu}$

Effective potential: $V_{\rm eff}(v;T)$

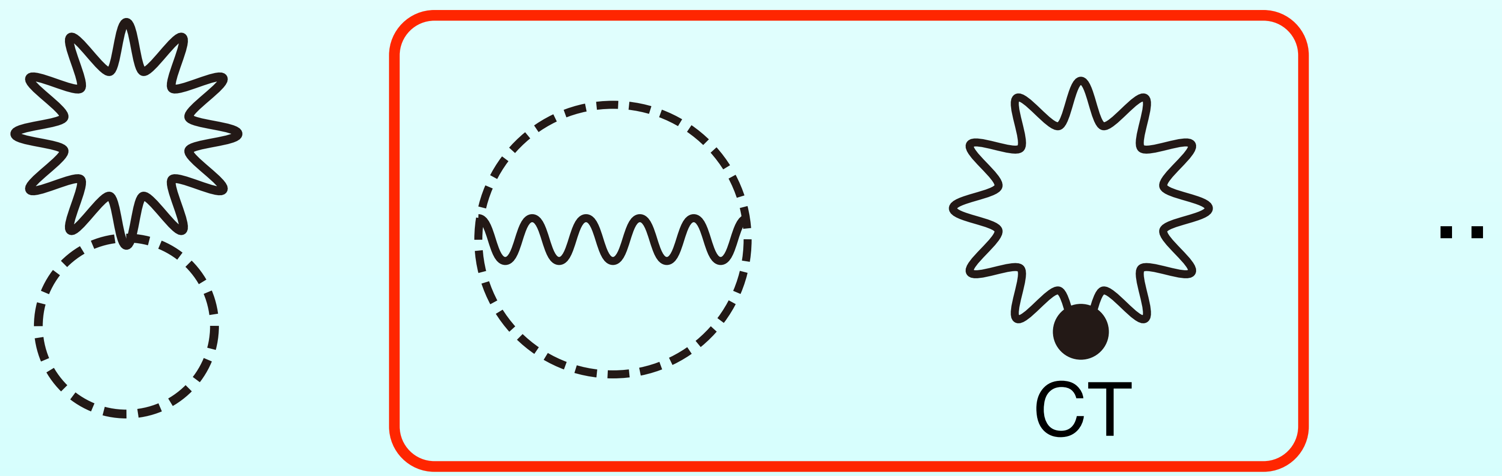
$d = 4 - \epsilon$



covariant

有限温度なのでループ積分はnon-covariant

resummed
2-loop contribution $\ni$



non-covariant!

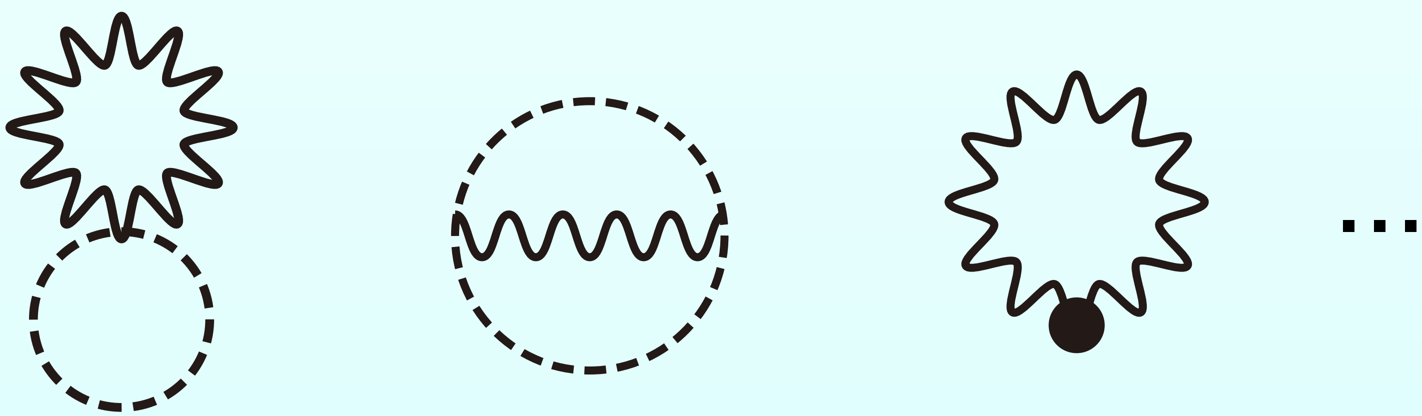
$$\boldsymbol{D}_{\mu\nu}(p) = \frac{-1}{p^2 - M_T^2} T_{\mu\nu} + \frac{-1}{p^2 - M_L^2} L_{\mu\nu}$$

$$({}^\forall r \in \mathbf{R})$$

$$= \underbrace{\left(\frac{-r}{p^2 - M_T^2} + \frac{-(1-r)}{p^2 - M_L^2} \right) P_{\mu\nu}}_{\text{covariant}} + \underbrace{\left(\frac{-1}{p^2 - M_T^2} - \frac{-1}{p^2 - M_L^2} \right)}_{\text{less UV-divergent}} \underbrace{(T_{\mu\nu} - r P_{\mu\nu})}_{\text{non-covariant}}$$

$$r \to \frac{d-2}{d-1}$$

$$= \underbrace{\frac{1}{d-1} \left(\frac{-(d-2)}{p^2 - M_T^2} + \frac{-1}{p^2 - M_L^2} \right) P_{\mu\nu}}_{D^{\mathrm{cov}}_{\mu\nu}(p)} + \underbrace{\left(\frac{-1}{p^2 - M_T^2} - \frac{-1}{p^2 - M_L^2} \right) \left(T_{\mu\nu} - \frac{d-2}{d-1} P_{\mu\nu} \right)}_{\delta D_{\mu\nu}(p)}$$



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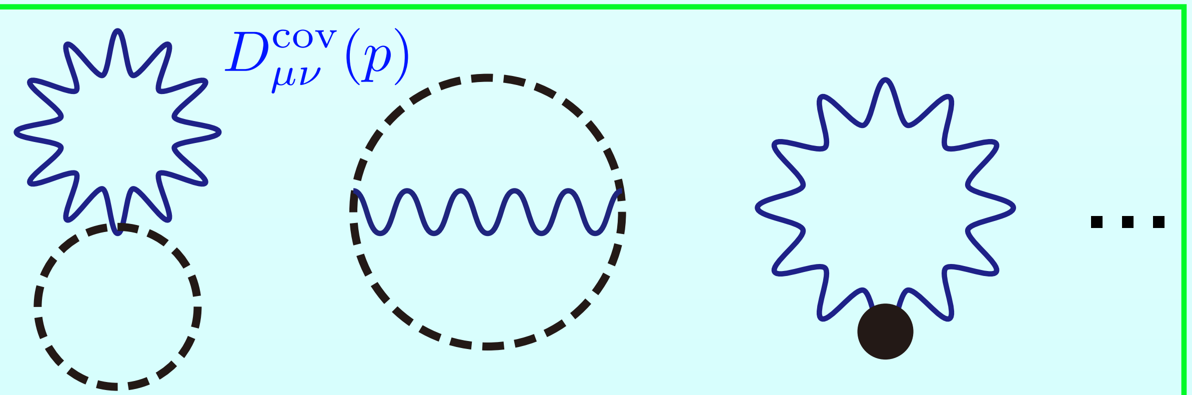
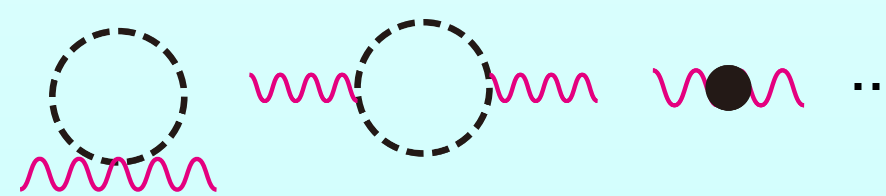


$$+ \ \frac{1}{2} \sum\!\!\!\!\!\!\int_q \left[\Gamma^{\mu\nu}(q) + \Gamma^{\mu\nu}_{\mathrm{CT}}(q) \right] \delta D_{\mu\nu}(q)$$



従来の処方で繰り込み可能

$$\frac{1}{2}\sum\!\!\!\!\!\!\int_q \boxed{\left[\Gamma^{\mu\nu}(q)+\Gamma^{\mu\nu}_{\mathrm{CT}}(q)\right]}\,\delta D_{\mu\nu}(q)$$

- ☆ finite
- ☆ subleading of the HTE $\quad \because\ -\Delta_T m_T^2 T^{\mu\nu} - \Delta_T m_L^2 L^{\mu\nu} \in \Gamma^{\mu\nu}_{\mathrm{CT}}$

被積分函数はnon-covariantな$\delta D_{\mu\nu}(q)$を含むが、tensor structureはsimple

$\because$ 一般にゲージ場２点函数は次の形：

$$\Gamma^{\mu\nu}(q)+\Gamma^{\mu\nu}_{\mathrm{CT}}(q)=\Pi_0(q^2)P^{\mu\nu}+\Delta\Pi_T(q^0,\boldsymbol{q})T^{\mu\nu}+\Delta\Pi_L(q^0,\boldsymbol{q})L^{\mu\nu}$$

$$P^{\mu\nu}\delta D_{\mu\nu}\propto T^{\mu}{}_{\mu}-\frac{d-2}{d-1}P^{\mu}{}_{\mu}=0$$

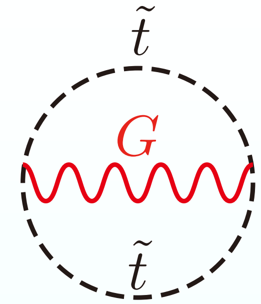
$$T^{\mu\nu}\delta D_{\mu\nu}=-L^{\mu\nu}\delta D_{\mu\nu}=\frac{d-2}{d-1}\left(\frac{-1}{q^2-M_T^2}-\frac{-1}{q^2-M_L^2}\right)$$

$$\longrightarrow\ \frac{1}{2}\frac{d-2}{d-1}\sum\!\!\!\!\!\!\int_q (\Delta_T\Pi_T(q)-\Delta_T\Pi_L(q))\left(\frac{-1}{q^2-M_T^2}-\frac{-1}{q^2-M_L^2}\right)$$

finite !

Model: abelian-Higgs + “stop-gluon”

extra $U(1)$

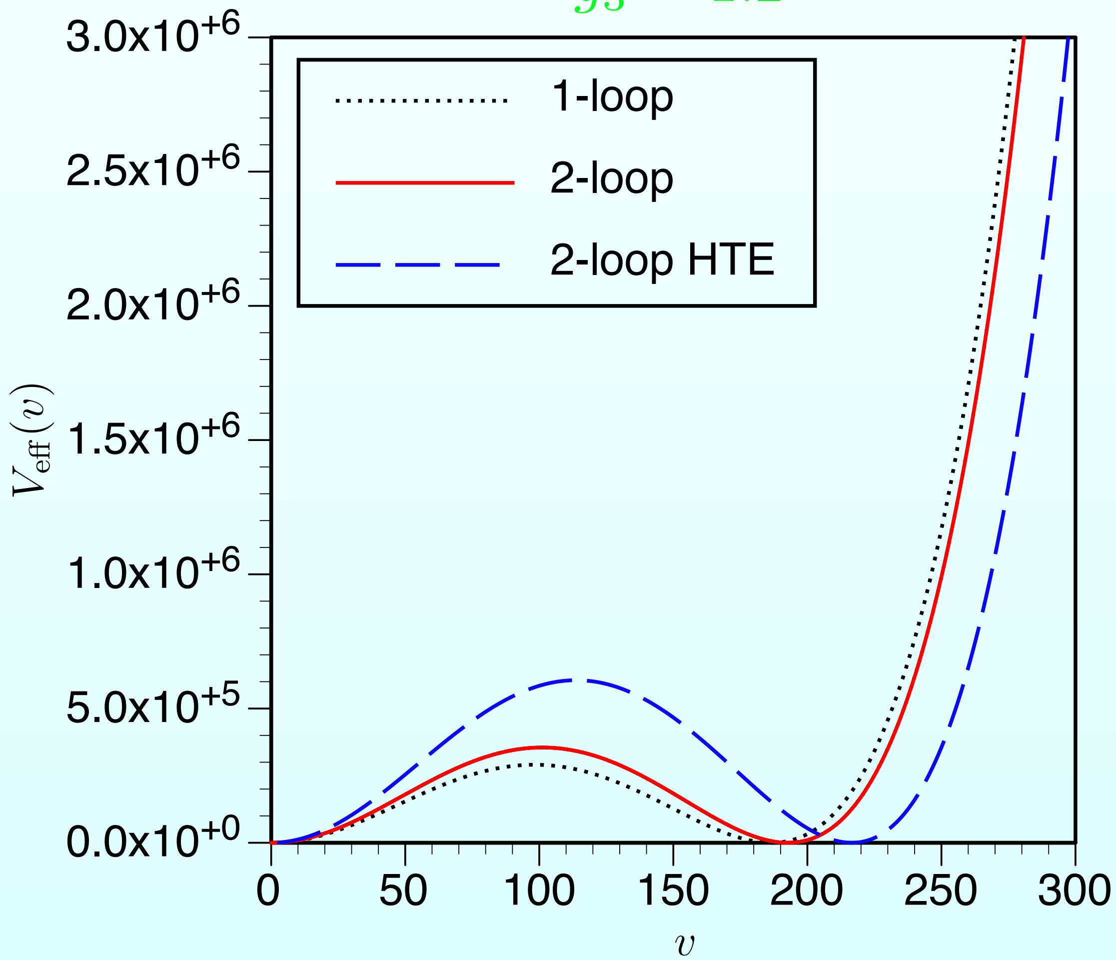


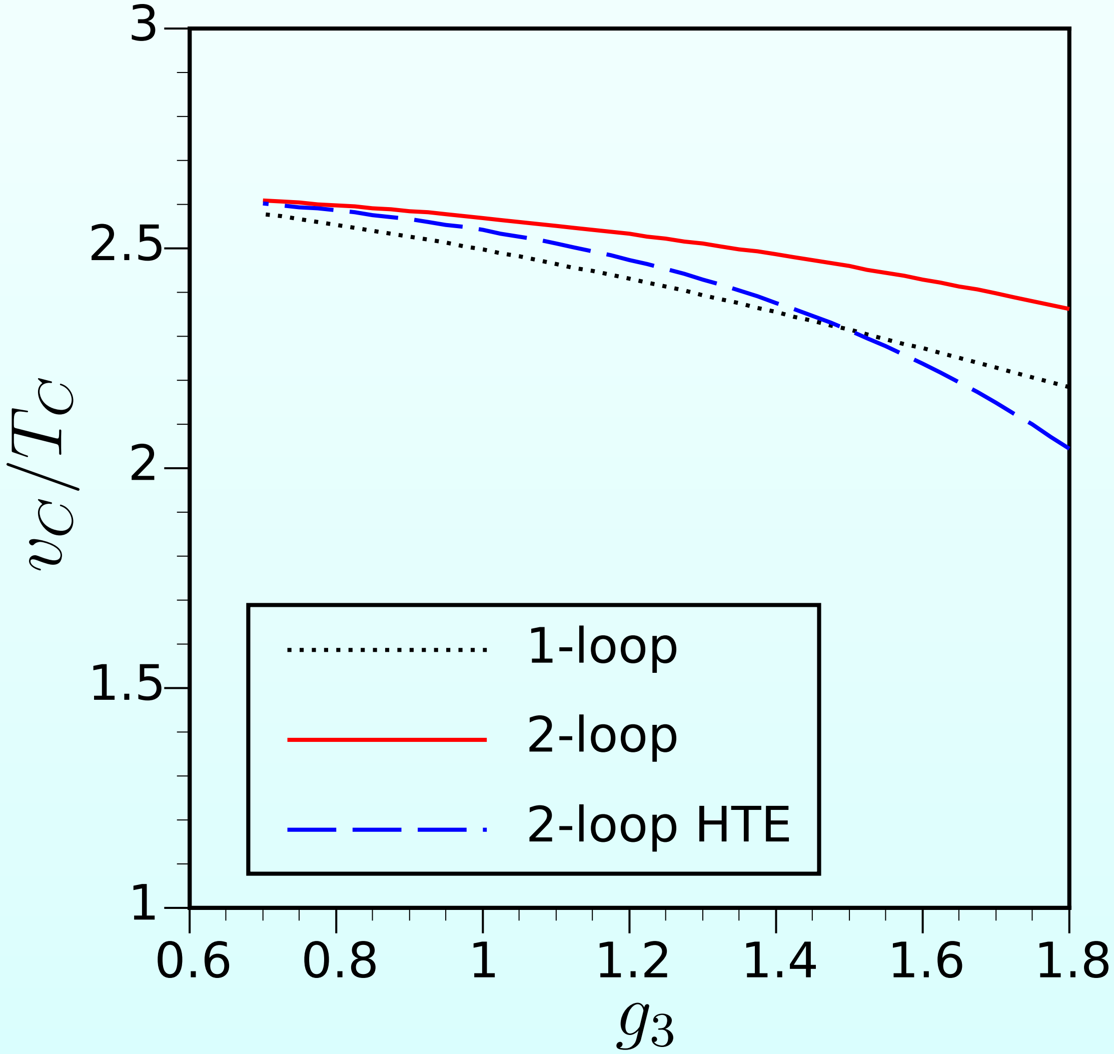
の効果を見る

$$m_{\tilde{t}}^2(v) = m_0^2 + \frac{T^2}{12}\left(3g_3^2 + y_t^2 + \lambda_t\right) + \frac{y_t^2}{2}v^2$$

$v_0 = 246\mathrm{GeV},\ m_h = 35\mathrm{GeV},\ e = 0.5,\ m_0 = 0,\ y_t = 1,\ \lambda_t = 0.3$

$g_3 = 1.2$





	v_C (GeV)	T_C (GeV)
1-loop	186.5	76.8
2-loop	192.7	76.1
2-loop HTE	216.6	87.5

2-loopがvc/Tcをenhance

g3が大きいとthermal massも大

Summary

- SM, SUSY-SM, ...における電弱相転移を、HTEを使わずに2-loopレベルで解析する手法を確立した

  gauge boson thermal massのresummationを工夫して、
  covariantなループ被積分函数とnon-covariantな有限項に分離

  2-loopに限らず、一般的に示せないか検討

- MSSM-like modelの数値解析

  2-loop補正が相転移点でのvc/Tcを大きくするケースを見たが、
  他のパラメータ領域では逆のケースもある。

  MSSM, NMSSMの現実的なパラメータ領域での数値解析