Two-loop SUSY QCD correction to the gluino pole mass

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- Gluino mass:

  precision measurement vs. radiative correction

- $O(\alpha_s^2)$ correction to the gluino pole mass

- Numerical results

Supersymmetry in the unified theory must be broken in our world.

Unified Theory

spontaneous SUSY breaking

$\Downarrow$

Low-energy effective theory (here assume MSSM)

soft SUSY breaking parameters

scalar masses, ϕ^3 couplings, gaugino masses $M_{3,2,1}$

Important clue to the SUSY breaking mechanism

Gaugino masses in the MSSM

Gauginos in MSSM

SU(3) gluino $\tilde{g}$, SU(2) wino $\widetilde{W}$, U(1) bino $\tilde{B}$

masses: $(M_3,\ M_2,\ M_1)$

In many candidates of the unified theories, these gaugino masses unify at GUT/Planck scale

- SUSY GUT with gauge-symmetric SUSY breaking
- minimal SUGRA
- dilaton-dominated SUSY breaking etc.

In other theories, $M_{3,2,1}$ do not unify but, instead, their ratios are predicted. (anomaly mediation ...)

To test these models, it is important to obtain precise values of $(M_3,\ M_2,\ M_1)$ in future studies at LHC and ILC

Physical observables $\Longleftrightarrow$ Lagrangian parameters

masses, cross-sections. . . of SUSY particles

$M_{1,2,3}(Q \sim 1\ \text{TeV})$

To probe the SUSY breaking mechanism by precision measurements, we need precise formulas of the relations between physical observables (masses etc.) and SUSY-breaking parameters in the lagrangian.

Here we consider the relation between the physical mass of the gluino $m_{\tilde{g}}$ and the tree-level mass M_3 in the lagrangian, to the two-loop order.

Two-loop correction to the gluino mass

Gluino $\tilde{g}$ is expected to be copiously produced at the LHC, then produce decay chains such as

$$\tilde{g} \to q\tilde{q} \to qq\tilde{\chi}_2^0 \to qqll\tilde{\chi}_1^0$$

Combined analysis of various decay chains of SUSY particles may determine $m_{\tilde{g}}$ ($= M_3$ at tree-level) quite precisely.

A simulation: (Chiorboli et al.)
for the parameter set SPS1a with $m_{\tilde{g}} \sim 600$ GeV
$\delta m_{\tilde{g}} = \pm 8$ GeV from the LHC ($\mathcal{L} \sim 300$ fb^{-1})
$\to 6.5$ GeV by combining with the ILC data
[$\sqrt{s} \leq 1$ TeV, $\mathcal{L} \sim 1000$ fb^{-1}]

On the other hand, $m_{\tilde{g}}$ receives large radiative corrections.

$O(\alpha_s)$ corr. $\sim O(10)$ %
$\Downarrow$
Naive expectation: $O(\alpha_s^2)$ corr. $\sim O(1)$ %
Comparable to experimental uncertainty?

We need explicit calculation of the two-loop correction to $m_{\tilde{g}}$.

Gluino pole mass $m_{\tilde{g}}$ at $O(\alpha_s^2)$

Given by the complex pole of the gluino propagator $s_p = (m_{\tilde{g}} - i\Gamma_{\tilde{g}}/2)^2$

$$m_{\tilde{g}} = M_3(Q) + \delta m_{\tilde{g}}^{(1)} + \delta m_{\tilde{g}}^{(2)}$$

$M_3(Q)$: running mass in the lagrangian

$\delta m_{\tilde{g}}$: Calculated from the self energy $i(\Sigma_K(p^2)\not{p} + \Sigma_M(p^2))$

For simplicity, we assume
◇ degenerate squark mass $m_{\tilde{q}}$
◇ $m_q \ll (m_{\tilde{g}}, m_{\tilde{q}})$
→ ignore m_q and $\tilde{q}_L$-$\tilde{q}_R$ mixing in the loops.

One-loop correction (Martin, Vaughn; Pierce, Papadopoulos; . . .)

$$\begin{aligned}
\delta m_{\tilde{g}}^{(1)} &= -\mathrm{Re}[M_3 \Sigma_K^{(1)}(M_3^2) + \Sigma_M^{(1)}(M_3^2)] \\
&= \frac{C_V \alpha_s(Q)}{4\pi} M_3(Q) \left(5 - 6\log\frac{M_3(Q)}{Q}\right) \\
&\quad + \frac{\alpha_s(Q)}{\pi} N_q T_F M_3(Q) B_1(M_3(Q)^2, 0, m_{\tilde{q}}(Q)) + O(\alpha_s m_q^2/m_{\tilde{q}}^2)
\end{aligned}$$

$C_V = 3$, $T_F = 1/2$, $N_q = 6$

typically $\delta m_{\tilde{g}}^{(1)}/m_{\tilde{g}} = O(10)$ %

Enhanced by

- large α_s
- large SU(3) representation (C_V(octet) $\gg$ T_F(doublet))

(α_s, M_3, $m_{\tilde{q}}$) in $\delta m_{\tilde{g}}^{(1)}$: precise definition needed to give $\delta m_{\tilde{g}}^{(2)}$

Here $\overline{\mathrm{DR}}'$ parameters at $Q \sim M_3$ are used.

Two-loop $O(\alpha_s^2)$ correction to $m_{\tilde{g}}$

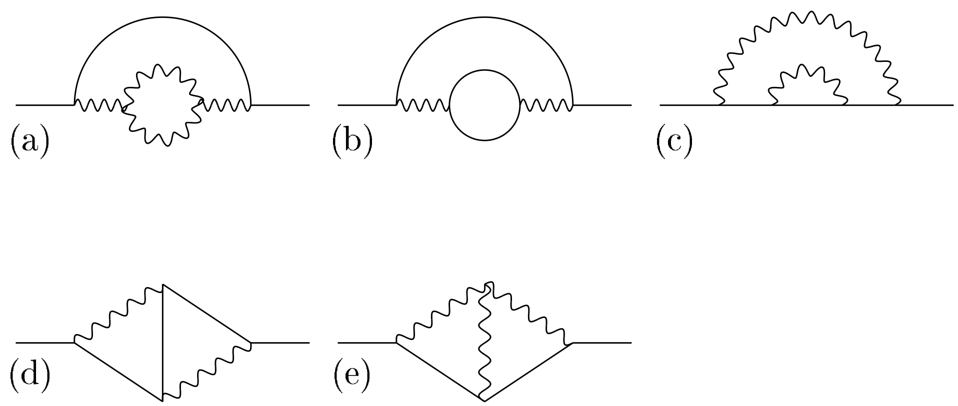
$$
\begin{aligned}
\delta m_{\tilde{g}}^{(2)} &= -\mathrm{Re}[M_3 \Sigma_K^{(2)}(M_3^2) + \Sigma_M^{(2)}(M_3^2)] \\
&\quad + \mathrm{Re}\left[\{M_3 \Sigma_K^{(1)}(M_3^2) + \Sigma_M^{(1)}(M_3^2)\}\{\Sigma_K^{(1)}(M_3^2) + 2M_3^2 \dot{\Sigma}_K^{(1)}(M_3^2) + 2M_3 \dot{\Sigma}_M^{(1)}(M_3^2)\}\right]
\end{aligned}
$$

$\delta m_{\tilde{g}}^{(2)} = \delta m_{\tilde{g}}^{(2,1)} + \delta m_{\tilde{g}}^{(2,2)}$: function of $(M_3, \alpha_s, m_{\tilde{q}})$

$\delta m_{\tilde{g}}^{(2,1)}$: loops with only gluons and gluinos ($m_{\tilde{q}}$ indep.)

$\delta m_{\tilde{g}}^{(2,2)}$: loops including quarks and squarks

Correction with only gluinos and gluons

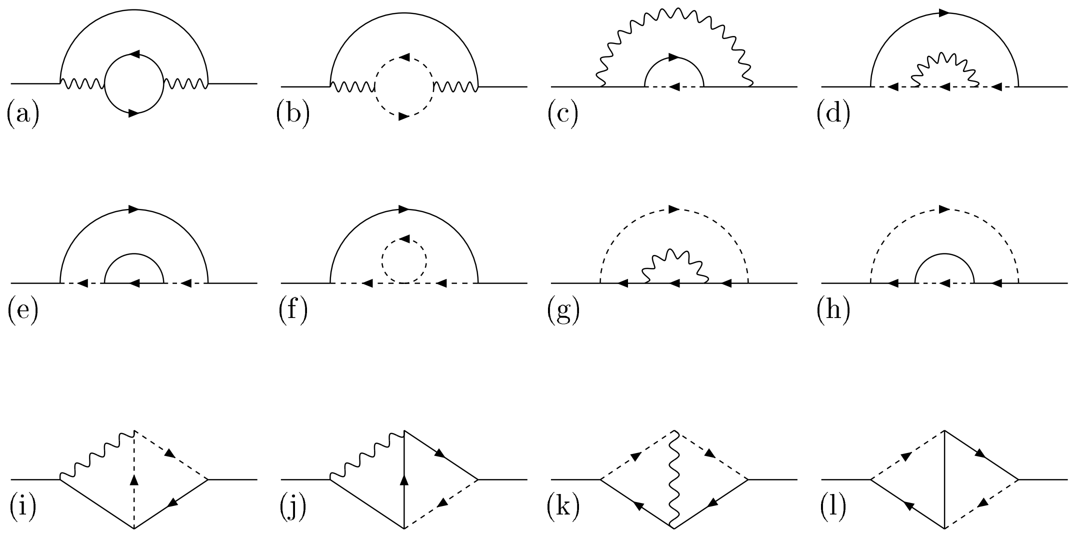


$$\delta m_{\tilde{g}}^{(2,1)} = \left(\frac{C_V \alpha_s}{4\pi}\right)^2 M_3 \left(-48 \log \frac{M_3}{Q} + 36 \log^2 \frac{M_3}{Q} + 26 + 5\pi^2 - 4\pi^2 \log 2 + 6\zeta_3\right)$$

At $Q = M_3$, $\delta m_{\tilde{q}}^{(2,1)}/M_3 \sim 31(\alpha_s/\pi)^2 \sim 0.03$.

cf. $\delta m_{\tilde{g}}(\text{exp.})/m_{\tilde{g}} \sim 1.3$ % for $m_{\tilde{g}} \sim 600$ GeV (SPS1a)

Correction including quarks/squarks



solid line with an arrow: quark, dashed line with an arrow: squark

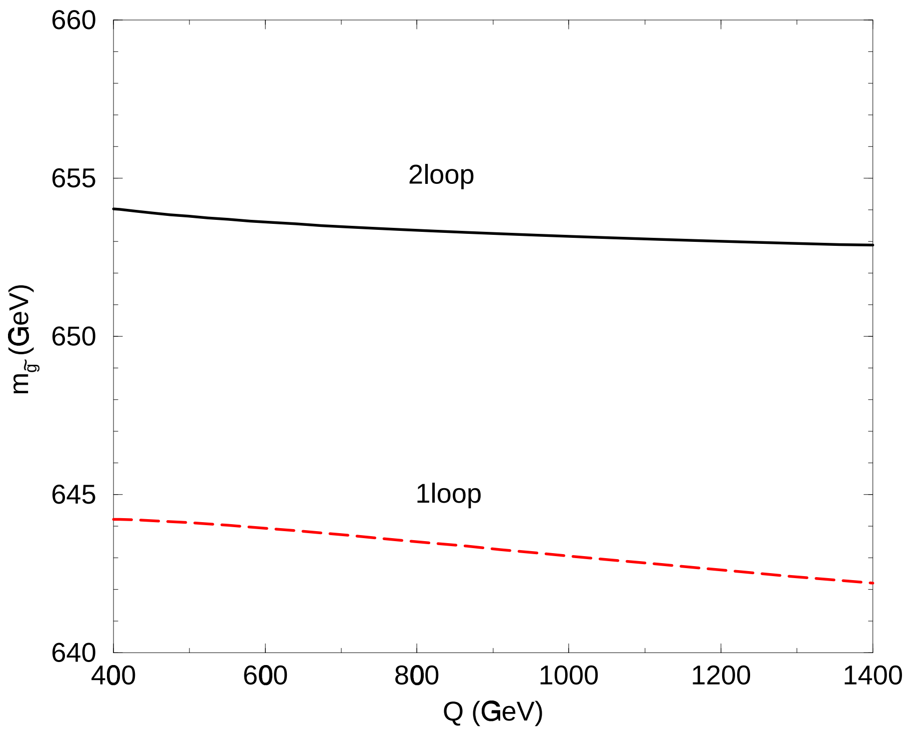
$\delta m_{\tilde{g}}^{(2,2)}$: complicated function of $(M_3, \alpha_s, m_{\tilde{q}})$

< 0 for $m_{\tilde{q}} \sim m_{\tilde{g}}$

Residual dependence of $m_{\tilde{g}}$ on the renormalization scale

$M_3(580\text{GeV}) = 580$ GeV, $m_{\tilde{q}}(580\text{GeV}) = 800$ GeV,

cf. tree-level mass: $M_3(400) = 589$ GeV $\rightarrow$ $M_3(1400) = 559$ GeV

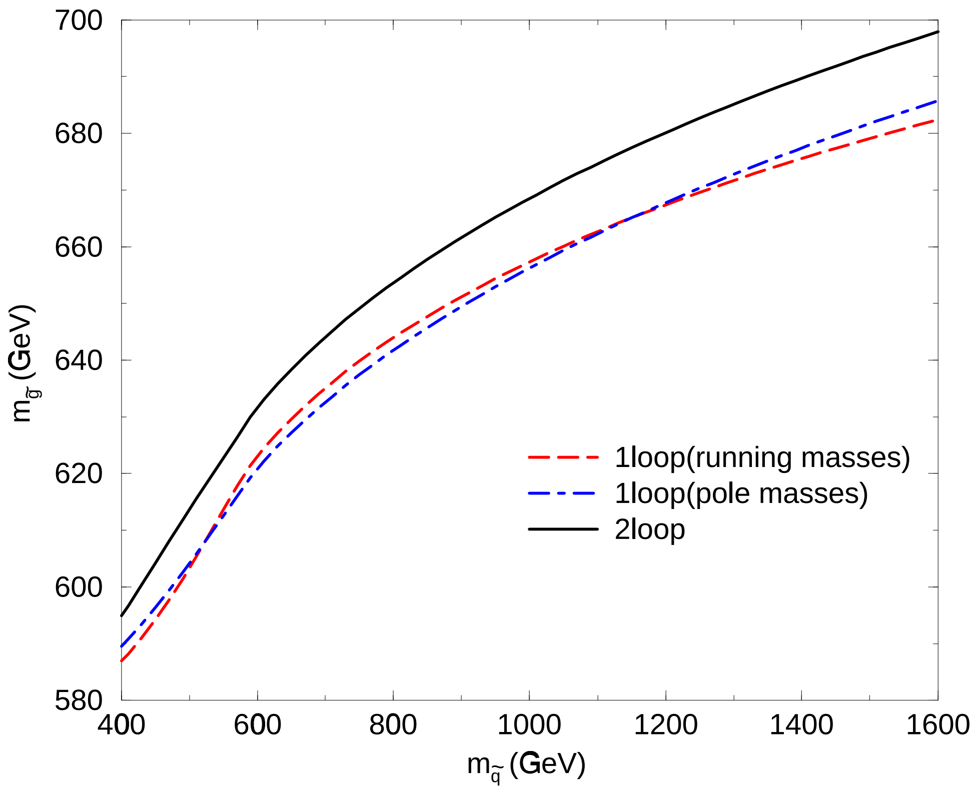


slight improvement by $\delta m_{\tilde{g}}^{(2)}$

$|\delta m_{\tilde{g}}^{(2)}| \gg$ (Q dependence of $m_{\tilde{g}}^{(1)}$)

Gluino pole mass at one- and two-loops

(tree: $M_3(M_3) = 580$ GeV)



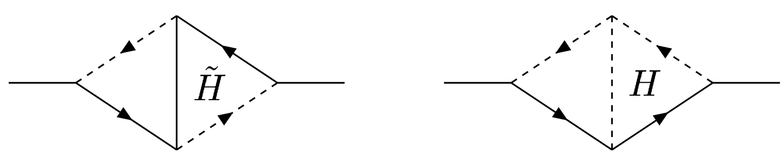
$1-2$ % increase of $m_{\tilde{g}}$ by $O(\alpha_s^2)$ corr. $\geq \delta m_{\tilde{g}} \sim 1$ % at LHC/ILC(expected)

Things to do

* realistic cases with nondegenerate squark masses

* contribution of m_q and $\tilde{q}_L - \tilde{q}_R$ mixing to $\delta m_{\tilde{g}}^{(2)}$
  suppressed by $m_q^2/(m_{\tilde{g}}^2, m_{\tilde{q}}^2)$
  may be important for light gluino/squarks

* $O(\alpha_s h_q^2)$ corrections involving Higgs bosons/higgsinos



(related to renorm. of m_q and $\tilde{q}_L - \tilde{q}_R$ mixing in $\delta m_{\tilde{g}}^{(1)}$)

Work in progress

Conclusion

* The pole mass of the gluino $m_{\tilde{g}}$ has been calculated as a function of the lagrangian parameters ($M_3(Q)$ ...) to $O(\alpha_s^2)$.

* The two-loop corrrection to $m_{\tilde{g}}$ for a given $M_3(Q)$ is typically 1–2 %, which may be larger than the expected uncertainty in precision mass determination at future colliders.