Perturbation-theory corrections to $\sigma_{tot}(e^+e^-\to$hadrons) in supersymmetry quantum chromodynamics

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The cross section $\sigma_{tot}(e^+e^-\to\gamma^*\to$hadrons) is calculated at the two-loop level in supersymmetry quantum chromodynamics. The three-loop corrections for the production of a gluon pair accompanied by two-jet quark—antiquark events are given.

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There is increasing interest in the phenomenological predictions of supersymmetry models[1] in which quarks and gluons are put on an equal footing with their supersymmetry partners: two multiplets of colored scalars of left-hand and right-hand chirality (L and R squarks) and an octet of Majorana gluinos λ^a. Analysis of the PETRA experimental data rules out the existence of squarks with masses[1] $m \lesssim 16$

GeV. On the other hand, there is the real possibility of observing the thresholds for the production of such squarks at the higher energies attainable on the LEP and SLC e^+e^- colliders. It is thus definitely of interest to calculate the perturbation-theory corrections to $R(s) = \sigma_{\rm tot}(e^+e^- \to \gamma^* \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ in supersymmetry quantum chromodynamics.

We consider energies above the thresholds for the production of scalar particles (we assume $m_L = m_R > m_\lambda$); at such energies, supersymmetry is effectively restored, and mass effects are inconsequential. The Lagrangian of the model is[1]

$$\begin{aligned}\mathcal{L} = \mathcal{L}_{QCD} &+ \frac{i}{2}\bar{\lambda}^a \hat{D} \lambda^a \\ &+ (D_\mu L)^+ D_\mu L + (D_\mu R)^+ D_\mu R \\ &+ ig\sqrt{2}(\lambda_L^a L^+ T^a q_L + \lambda_R^a R^+ T^a q_R + \text{e.f.}) \\ &- \frac{1}{2} g^2 (L^+ T^a L - R^+ T^a R)^2 \\ &+ \text{a term fixing the gauge} \\ &+ \text{a ghost term,}\end{aligned} \tag{1}$$

where $q_L = \Pi^+ q$ ($q_R = \Pi^- q$) are the quarks of left-hand (right-hand) chirality, and $\Pi^\pm = (1 \pm \gamma_5)/2$.

When the left-right symmetry of massless supersymmetry (SUSY) QCD is taken into account, we find that seven additional diagrams (beyond those in the QCD case) contribute to the photon propagator which is coupled by unitarity with $R(s)$ at the two-loop level. Four of these additional diagrams are generated by the purely scalar part of Lagrangian (1), and the other three are generated by its Yukawa term. The final two-loop result in the $\overline{MS}$ model is

$$R(s) = R_{\rm QCD} + R_{\rm SUSY}$$

$$= \Sigma Q_i^2 \left(1 + \frac{\alpha_s}{\pi} + O(\alpha_s^2)\right) + \tag{2.1}$$

$$+ \frac{N_s}{4} \Sigma Q_i^2 \left(1 + \frac{2\alpha_s}{\pi} + O(\alpha_s^2)\right), \tag{2.2}$$

where $N_s = 2$ is the number of scalar multiplets, and the effective coupling constant $\alpha_s/\pi = [b \ln(s/\Lambda^2_{\overline{MS}}]^{-1}$ is expressed in terms of the first coefficient of the β function of supersymmetry QCD, $b = (11 - 2f/3 - 2 - N_s f/6)/4$, in which the last two terms correspond to the contributions of gluinos and squarks.

Supersymmetry in a theory generally presupposes a regularization through a dimensional reduction[2] ($\overline{DR}$), which preserves this symmetry up to a certain order of the perturbation theory.[3] Repeating all the calculations in $\overline{DR}$, we have found that there is no change in results (2.1) and (2.2). This conclusion agrees with the assertion that a transition can be made from $\overline{MS}$ to $\overline{DR}$ in the quark channel through the substitution $\alpha_s^{MS} = \alpha_s^{DR}(1 - \alpha_s^{DR}/4\pi + ...)^4$.

It is interesting to compare (2.2) with the calculations of the corresponding corrections in the realistic model of strong interactions with scalar quarks,[5] which is QCD supplemented with a multiplet of fractional-charge colored scalar fields (see Ref. 6 for a review):

$$R(s) = R_{\rm QCD} + R_{\rm SQUARKS} ,$$

$$R_{\rm SQUARKS} = \frac{N_s}{4}\Sigma Q_i^2\left(1 + \frac{4\alpha_s}{\pi} + O(\alpha_s^2)\right), \tag{2.3}$$

where $N_s = 1$. Result (2.2) differs from (2.3) in containing the contributions from the three additional diagrams generated by the Yukawa term of Lagrangian (1). These additional diagrams reduce the two-loop correction (2.3). At the three-loop level, the number of additional diagrams is more than 50. Calculations presently being carried out will show whether the terms specific to supersymmetry will significantly reduce the large correction of Ref. 7, $O(\alpha_s^2)$, to $R_{\rm SQUARKS}$.

By using the replacement $f \to f + 3$ we can look in an independent way at how the production of a pair of gluinos with a mass $m_\lambda < m_L = m_R$ affects the magnitude of the correction $O(\alpha_s^2)$ to $R_{\rm QCD}$ (Ref. 8). The result in the $\overline{MS}$ model is

$$R_{\rm QCD} = \Sigma Q_i^2\left[1 + \frac{\alpha_s}{\pi} + \left(\frac{\alpha_s}{\pi}\right)^2 (1.986 - 0.115f - 0.345)\right] . \tag{3}$$

The transition to the $\overline{DR}$ case is made by means of this replacement.[4] Again in this case, we might note, the supersymmetry increment improves the convergence of the perturbation-theory series.

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After writing this paper, we received a preprint by Altarelli *et al.*,[9] in which two-loop corrections to $R_{\rm SUSY}$ were calculated in the case with masses. In the massless limit their result becomes the same as ours.

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