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BREAKDOWN OF CONVENTIONAL FACTORIZATION FOR ISOLATED PHOTON CROSS SECTIONS

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Using $e^+e^- \to \gamma + X$ as an example, we show that the conventional factorization theorem of perturbative QCD breaks down for isolated photon cross sections in a specific part of phase space. Implications are discussed.

Much of the predictive power of perturbative QCD derives from factorization theorems [1]. *Conventional* factorization expresses a physical quantity as the convolution of a partonic part with a nonperturbative matrix element, and it requires that the perturbatively calculated partonic part be infrared safe order by order in α_s. Predictions then follow when processes with different hard scattering but the same matrix elements are compared. Using $e^+e^- \to \gamma X$ as an example, we demonstrate that the perturbatively calculated partonic part for the isolated photon cross section is not infrared safe in a well-defined phase space.

The essence of isolation is that a cone of half-angle δ is drawn about the direction of the photon's momentum, and the isolated cross section is defined for photons accompanied by less than a specified amount of hadronic energy in the cone, *e.g.*, $E_h^{cone} \leq E_{\max}$.

At high energy, photons can result from long-distance fragmentation of quarks and gluons, themselves produced in short-distance hard collisions. In such fragmentation contributions, hadronic energy in the isolation cone has two sources: a) energy from parton fragmentation, E_{frag}, and b) energy from non-fragmenting final-state partons, $E_{partons}^{cone}$, that enter the cone. When the maximum hadronic energy allowed in the isolation cone is saturated by the fragmentation energy, $E_{\max} = E_{frag}$, there is no allowance for energy in the cone from other final-state partons. In particular, if there is a gluon in the final state, the phase space for this gluon becomes restricted. By contrast, isolation does not affect the virtual gluon exchange contribution. Therefore, for isolated photons, there is a possibility that the infrared singularity from the virtual contribution may not be cancelled completely by the restricted real contribution. We showed [2,3] that such incomplete cancellation of infrared singularities appears first at next-to-leading order (NLO) in the quark fragmentation con-

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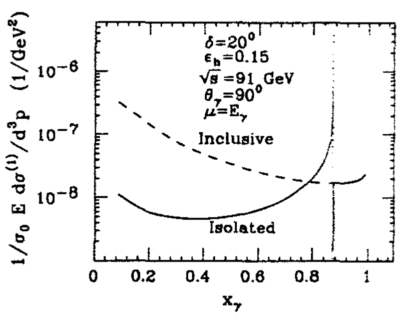

Figure 1: Comparison of the one-loop quark fragmentation contributions to the isolated cross section and the inclusive cross section in $e^+e^- \to \gamma X$ as a function of $x_\gamma = 2E_\gamma/\sqrt{s}$.

tributions.

If conventional factorization were true, the fragmentation contributions to the cross section for isolated photons would be expressed in the factorized form

$$E_\gamma \frac{d\sigma^{iso}_{e^+e^-\to\gamma X}}{d^3\ell} = \sum_c \int_{\max\left[x_\gamma, \frac{1}{1+\epsilon_h}\right]}^1 \frac{dz}{z}\, E_c \frac{d\hat{\sigma}^{iso}_{e^+e^-\to cX}}{d^3p_c}\left(x_c = \frac{x_\gamma}{z}\right) \frac{D_{c\to\gamma}(z,\delta)}{z}\,; \tag{1}$$

$x_\gamma = 2E_\gamma/\sqrt{s}$, $x_c = 2E_c/\sqrt{s}$, $\epsilon_h = E_{\max}/E_\gamma$, and the sum extends over $c = q, \bar{q}$ and g. $D_{c\to\gamma}(z,\delta)$ is the nonperturbative function that describes fragmentation of parton "c" into a photon. The lower limit of integration results from the isolation requirement with the assumption that all fragmentation energy is in the isolation cone [3]. Because of the isolation condition, the phase space constraints are different in three regions: a) $x_\gamma < 1/(1+\epsilon_h)$, b) $x_\gamma = 1/(1+\epsilon_h)$, c) $x_\gamma > 1/(1+\epsilon_h)$. We show below that the next-to-leading order partonic hard part for quark fragmentation, $E_q d\hat{\sigma}^{iso}_{e^+e^-\to qX}/d^3p_q$, is infrared sensitive.

When $x_\gamma < 1/(1+\epsilon_h)$, subprocesses with two-body final states do not contribute. Therefore, there is no leading-order quark (or antiquark) fragmentation contribution, and one-loop virtual diagrams do not contribute. The well-known $1/(1-x_q)$ infrared singularity of the real gluon emission diagrams, as $x_q = x_\gamma/z \to 1$, will remain in $\hat{\sigma}^{iso}_{e^+e^-\to qX}$. After convolution with $D_{q\to\gamma}(z)$, this inverse power infrared sensitivity yields a logarithmic divergence proportional to $\ell n(1/x_\gamma-(1+\epsilon_h))$. As shown in Fig. 1, as $x_\gamma \to 1/(1+\epsilon_h)$, the isolated cross section becomes larger than the inclusive cross section, which is certainly not physical. This infrared sensitivity in $\hat{\sigma}^{iso}_{e^+e^-\to qX}$ signals a breakdown of conventional perturbative factorization.

When $x_\gamma = 1/(1+\epsilon_h)$, $x_q = x_\gamma/z = 1$ is possible. Therefore, the one-loop virtual diagrams, which are proportional to $\delta(1-x_q)$ will contribute. However, isolation constraints limit the phase space of real gluon emission in the real subprocess, $e^+e^- \to q\bar{q}g$. Consequently, the infrared divergences in the real and virtual contributions do not cancel completely in the isolated case, unlike the inclusive case. In $n = 4 - 2\epsilon$ dimensions, we find [3]

$$E_q \frac{d\sigma^{(1)iso}_{e^+e^- \to qX}}{d^3p_q} \sim \left\{ \frac{1}{\epsilon^2} + \frac{1}{\epsilon}\left(\frac{3}{2} - \ell n \frac{\delta^2}{4}\right)\right\} \delta(1 - x_q) \; + \text{finite terms} \; . \qquad (2)$$

At $x_q = 1$, corresponding to $x_\gamma = 1/(1 + \epsilon_h)$, the partonic part for quark fragmentation in Eq. (2) is infrared divergent, and the perturbative calculation is not well-defined. Conventional perturbative factorization again breaks down.

When $x_\gamma > 1/(1 + \epsilon_h)$, due to the finite cone size, there is a very small region of phase space where the isolated cross section is not exactly equal to the inclusive cross section. This region of phase space is proportional to $\epsilon_h \delta^2/4$. In this narrow region above $x_\gamma = 1/(1 + \epsilon_h)$, all one-loop contributions to the isolated cross section have a logarithmic divergence $\ell n(1 + \epsilon_h - 1/x_\gamma)$ as $x_\gamma \to 1/(1 + \epsilon_h)$ from above [3].

In summary, the NLO partonic part for the quark fragmentation contribution to the isolated cross section, calculated in perturbative QCD, is infrared sensitive when $x_\gamma \leq 1/(1 + \epsilon_h)$. Conventional perturbative factorization for the cross section of isolated photons in e^+e^- annihilation breaks down for x_γ in the neighborhood of $1/(1 + \epsilon_h)$. Breakdown of factorization means that the isolated cross section cannot be calculated reliably in perturbative QCD near $x_\gamma = 1/(1+\epsilon_h)$. This result challenges theorists to find a modified factorization scheme.

References

1. J. C. Collins, D. E. Soper and G. Sterman, in *Perturbative Quantum Chromodynamics*, ed. A. H. Mueller (World Scientific, Singapore, 1989).
2. E. L. Berger, X. Guo and J. Qiu, *Phys. Rev. Lett.* **76**, 2234 (1996).
3. E. L. Berger, X. Guo and J. Qiu, Argonne report ANL-HEP-PR-96-37, hep-ph/9605324, *Phys.Rev.* D, in press.

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