NEW RESULTS ON PRECISION STUDIES OF HEAVY VECTOR BOSON PHYSICS

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We present new results for two important heavy vector boson physics processes: (1), virtual corrections to hard bremsstrahlung which are relevant to precision predictions for the radiative return process in Z boson production at and beyond LEP2 energies; and, (2), electric charge screening effects in single W production with finite $p_T$, multiple photon radiation in high energy collider physics processes. In both cases we show that we improve the respective precision tag significantly. Phenomenological implications are discussed.

Keywords: Bremsstrahlung; W/Z Bosons; Screening.
1. Introduction

Electroweak (EW) [1] and QCD [2] loop corrections are established: precision LEP [3] physics, \( m_t [4] \), . . . , set a stage for 1 GeV - 1 TeV high precision Standard Model [1,2] tests via theoretical predictions for both signal and background processes in high energy colliding beam environments. In the EW sector, this now requires exact \( \mathcal{O}(\alpha^2) \), \( \mathcal{O}(\alpha^3 L^3) \), where \( L \) is the respective big log, on an event-by-event basis in such studies as radiative return from 1-2 GeV to the \( \pi\pi \) resonance regime in Daphne and the asymmetric B-Factories, radiative return from 200 GeV to the \( Z \) pole in final LEP2 data analysis, \( Z \) factory physics at ILC, . . . .

In this paper, we present new results on two aspects of such precision studies: (1), the virtual correction to 1\( \gamma \)-bremsstrahlung; (2), electric charge screening in 1\( W \) production [5] – see also Ref. [6] in this connection.

2. Virtual Corrections to Hard Bremsstrahlung

For the process \( e^+e^- \rightarrow \bar{f}f+\gamma \), we compare in Fig. the calculations in Refs. [7–10] at the \( \bar{\beta}_1^{(2)} \) level for initial state radiation, where \( \{\bar{\beta}_n\} \) are the standard YFS [11] residuals. The result by Ref. [7], labeled IN in the figure, is exact and fully differential but without complete mass corrections, the result in Ref. [8], labeled BVNB, is exact with the complete mass corrections but is integrated over the photon azimuthal angle, the result of Ref. [9], labeled JMWY, is fully differential with the complete mass corrections following the method of Ref. [12] whereas the exact result of Ref. [10], labeled KR, is also fully differential with complete mass corrections included in an entirely different way from that used in Ref. [9]. The agreement shown in the figure is at the \( 3 \times 10^{-5} \) level in units of the Born \( e^+e^- \rightarrow \bar{f}f \) cross section for an energy cut at \( v_{max} = 0.9625 \).

3. Electric Charge Screening Effects in 1W Production

Electric charge screening\( (\text{ECS})/\text{Leading Log scale transmutation}\)\( (\text{LLST}) [5,6] \) is known from low angle Bhabha scattering [13] \( - L(s) \equiv \ln \frac{s}{m_e^2} \Rightarrow L(|t|) \) in the LL expansion. In Ref. [5], we have found in the toy model

\[
\mu^-(p_a) + \mu^+(p_b) \rightarrow \mu^-(p_c) + \mu^+(p_d) + \gamma(k)
\]

the ECS corrected weight

\[
\tilde{S}_{ab}(k)W_{\text{ECS}}(k)
\]

for the ISR IR emission factor \( \tilde{S}_{ab}(k) [11,13] \) where

\[
W_{\text{ECS}}(k) = \frac{\tilde{S}_{abcd}(k)}{\tilde{S}_{ab}(k) + \tilde{S}_{cd}(k)}
\]
in a standard YFS notation. For the single W production $e^- e^+ \rightarrow f_c(p_c) + \bar{f}_d(p_d) + f_e(p_e) + f_f(p_f)$ we find that we can do the same:

$$W_{ECS}^{real} = \prod_i w^R(k_i), \quad w^R(k) = \frac{\tilde{S}_{ab}(k) + \tilde{S}_{CD}(k) + \tilde{S}_{aC}(k) + \tilde{S}_{bD}(k) + \tilde{S}_{aD}(k) + \tilde{S}_{bc}(k)}{S_{ab}(k) + S_{CD}(k)}.$$ (4)

for the effective [5] final particles 'C' and 'D' close to the incoming beams, as we illustrate in Fig. 2. A factor $\exp(\Delta U)$ cancels exactly the dummy [5] IR $\epsilon$-dependence and compensates approximately for the normalization change due to the $W_{ECS}^{real}$ weight and the effective coupling is also that at $|t|$, by standard renormalization group [14] arguments; this all is realized [5] with the normalization correction (here, $\gamma_r = \frac{2\pi}{\alpha}(L(|t|) - 1), \gamma_t = \frac{1}{2}(\gamma_t + \gamma_s)$)

$$W_{ECS}^{norm} = \exp \left( \frac{3}{4}(\gamma_t - \gamma_s) \right) \exp(\Delta U(\epsilon))$$

$$\Delta U(\epsilon) = U(\epsilon) - U_R(\epsilon), \quad U(\epsilon) = \int_{\epsilon/\sqrt{\pi}}^{\sqrt{\pi}} \frac{d^3k}{(2\pi)^3} \tilde{S}_{ab}(k), \quad U_R(\epsilon) = \int_{\epsilon/\sqrt{\pi}}^{\sqrt{\pi}} \frac{d^3k}{(2\pi)^3} \tilde{S}_{ab}(k) w^R(k).$$ (5)

to maintain the exact IR cancellation in the MC (KoralW [5, 15], for example).

The only purpose of the weight $W_{ECS}^{real}$ is to restore the ECS effect due to ISR$\otimes$FSR interference. We do not aim at re-creating the FSR. This would be formally possible with a similar weight; however, the resultant weight distribution would be bad and the attendant MC calculation would not be convergent. We get $W_{ECS}^{real} \rightarrow 1$ for photons collinear with the FS effective fermions $C$ and $D$. This ensures a very good weight distribution. The FSR can be treated separately, either inclusively (calorimetric acceptance) or exclusively, generated with the help of
Fig. 2. \( \log_{10} \frac{da}{dy} \) [arb. units] with (red dots) and without (blue open squares) the ECS correction, arbitrary units. In boxes the values of fits are shown.

\[ y = -\log_{10} \tan(\theta_\gamma/2) \]


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aCare has to be taken to implement ECS for FSR, if necessary.
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