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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 1γ-bremsstrahlung; (2), electric charge screening in $1W$ production [5] – see also Ref. [6] in this connection.

2. Virtual Corrections to Hard Bremsstrahlung

For the process $e^+e^- \to \bar{f}f+\gamma$, we compare in Fig. 1 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 3×10^{-5} level in units of the Born $e^+e^- \to \bar{f}f$ cross section for an energy cut at $v_{max} = 0.9625$.

3. Electric Charge Screening Effects in 1*W* Production

Electric charge screening(ECS)/Leading Log scale transmutation(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

$$\mu^-(p_a) + \mu^+(p_b) \to \mu^-(p_c) + \mu^+(p_d) + \gamma(k) \tag{1}$$

the ECS corrected weight

$$\tilde{S}_{ab}(k) W_{\rm ECS}(k) \tag{2}$$

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

$$W_{\rm ECS}(k) = \frac{\tilde{S}_{abcd}(k)}{\tilde{S}_{ab}(k) + \tilde{S}_{cd}(k)}, \tag{3}$$

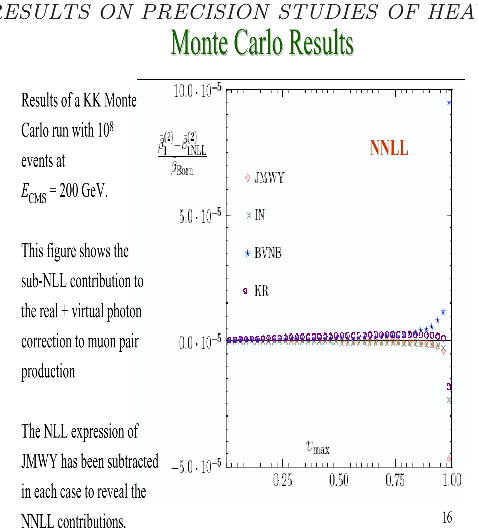

Fig. 1. Sub-NLL contribution $\beta_1^{(2)} - \beta_{1\mathrm{NLL}}^{(2)}$.

in a standard YFS notation. For the single W production $e^-e^+ \to f_c(p_c) + \bar{f}_d(p_d) + f_e(p_e) + \bar{f}_f(p_f)$ we find that we can do the same:

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

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 ϵ-dependence and compensates *approximately* for the normalization change due to the $\langle W_{\rm ECS}^{real}\rangle$ 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,$\gamma_r \equiv \frac{2\alpha}{\pi}(L(|r|) - 1), \bar{\gamma}_t \equiv \frac{1}{2}(\gamma_t + \gamma_s)$)

$$\begin{aligned} W_{ECS}^{norm} &= \exp\left(\frac{3}{4}(\bar{\gamma}_t - \gamma_s)\right)\exp\left(\Delta U(\epsilon)\right) \\ \Delta U(\epsilon) = U(\epsilon) - U_R(\epsilon), \;\; U(\epsilon) &= \int_{\epsilon\sqrt{s}/2}^{\sqrt{s}} \frac{d^3k}{k^0}\tilde{S}_{ab}(k), \;\; U_R(\epsilon) = \int_{\epsilon\sqrt{s}/2}^{\sqrt{s}} \frac{d^3k}{k^0}\tilde{S}_{ab}(k)w^R(k). \end{aligned} \tag{5}$$

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

The only purpose of the weight $W_{\rm ECS}^{real}$ is to restore the ECS effect due to ISR⊗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 $W_{\rm ECS}^{real} \to 1$ 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

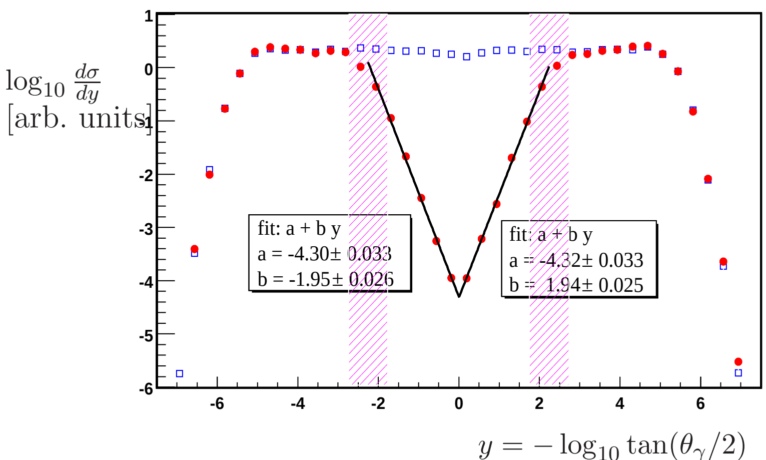

Fig. 2. $\log_{10}$ of $d\sigma/d\log_{10}\tan(\theta_\gamma/2)$ with (red dots) and without (blue open squares) the ECS correction, arbitrary units. In boxes the values of fits are shown.

PHOTOS [16] [a]. The precision tag of $\leq 2\%$ is realized [5] – good enough for final LEP2 data analysis.

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[a] Care has to be taken to implement ECS for FSR, if necessary.

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