International Journal of Modern Physics A

NEW RESULTS ON PRECISION STUDIES OF HEAVY VECTOR BOSON PHYSICS

B.F.L. WARD

Department of Physics, Baylor University, One Bear Place #97316
Waco, Texas 76798-7316, USA

C. GLOSSER

Department of Physics, Southern Illinois University, Box 1654
Edwardsville, IL 62026-1654, USA

S. JADACH

Institute of Nuclear Physics, ul. Radzikowskiego 152
31-342 Kraków, Poland
Theory Division, CERN
CH-1211 Geneva 23, Switzerland

W. PLACZEK

Institute of Computer Science, Jagellonian University, ul. Nawojki 11
Kraków, Poland

M. SKRZYPEK

Institute of Nuclear Physics, ul. Radzikowskiego 152
31-342 Kraków, Poland

Z. WĄS

Institute of Nuclear Physics, ul. Radzikowskiego 152
31-342 Kraków, Poland

S. A. YOST

Department of Physics, Baylor University, One Bear Place #97316
Waco, Texas 76798-7316, USA

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. [7–9, 11] at the ${\bar{\beta}_1}^{(2)}$ level for initial state radiation, where $\{\bar{\beta}_n\}$ are the standard YFS [12] residuals. The result by Ref. [7], labelled IN in the figure, is exact and fully differential but without complete mass corrections, the result in Ref. [8], labelled BVNB, is exact with the complete mass corrections but is integrated over the photon azimuthal angle, the result of Ref. [9], labelled JMWY, is fully differential with the complete mass corrections following the method of Ref. [10] whereas the exact result of Ref. [11], labelled 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 $\tilde{S}_{ab}(k)$ [12, 13] where

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

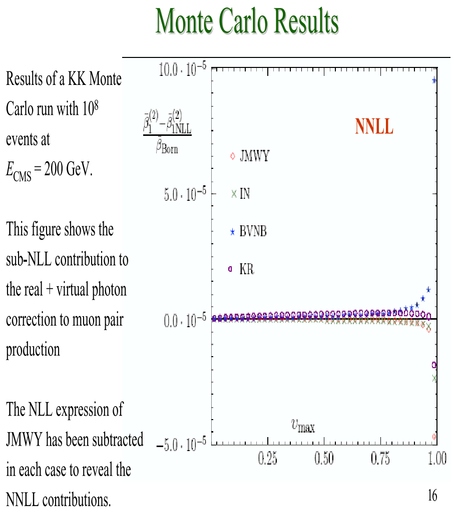

Fig. 1. Sub-NLL contribution $\beta_1^{(2)} - \beta_{1\rm NLL}^{(2)}$.

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:

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

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 $\langle W^{real}_{\rm ECS}\rangle$ 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,$\gamma_r \equiv \frac{2\alpha}{\pi}(L(|r|)-1), \bar\gamma_t \equiv \frac{1}{2}(\gamma_t+\gamma_s)$)

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

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

The only purpose of the weight $W^{real}_{\rm ECS}$ 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 $W^{real}_{\rm ECS} \to 1$ 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

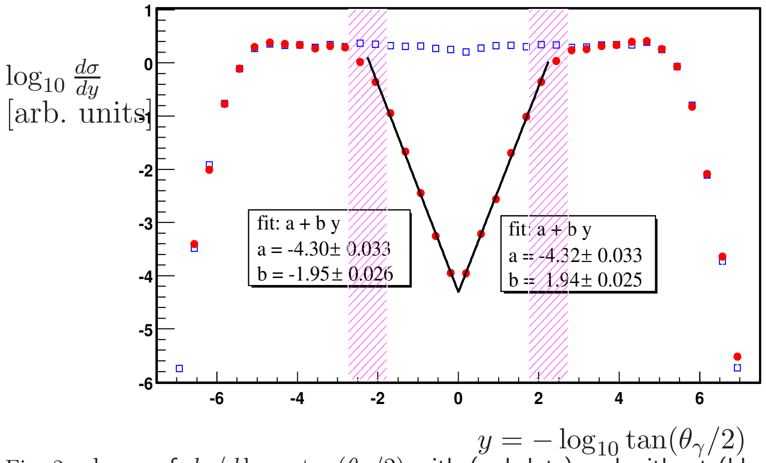

Fig. 2. $\log_{10}$ of $d\sigma/d\log_{10}\tan(\theta_\gamma/2)$ with (red dots) and without (blue open squares) the ECS correction, arbitrary units. In boxes the values of fits are shown.

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

Acknowledgments

Five of the authors (S.J.,W.P.,M.S.,B.F.L.W.,Z.W.) would like to thank Prof. G. Altarelli of the CERN TH Div. and Prof. D. Schlatter and the ALEPH, DELPHI, L3 and OPAL Collaborations, respectively, for their support and hospitality while part of this work was completed. B.F.L.W. would like to thank Prof. C. Prescott of Group A at SLAC for his kind hospitality while part of this work was in its developmental stages. Work supported in part by US DoE contract DE-FG05-91ER40627, by NATO grants PST.CLG.97751,980342, by Polish Government grants KBN 5P03B09320, 2P03B00122, by European Commission 5-th framework contract HPRN-CT-2000-00149 and by the Polish-French Collaboration within IN2P3 through LAPP Annecy.

References

1. S.L. Glashow, *Nucl. Phys.* **22** (1961) 579; S. Weinberg, *Phys. Rev. Lett.* **19** (1967) 1264; A. Salam, in *Elementary Particle Theory*, ed. N. Svartholm (Almqvist and Wiksells, Stockholm, 1968), p. 367; G. 't Hooft and M. Veltman, *Nucl. Phys.*B **44**, 189 (1972) and **B50**, 318 (1972); G. 't Hooft, *ibid.* **35**, 167 (1971); M. Veltman, *ibid.* **7**, 637 (1968).
2. D. J. Gross and F. Wilczek, *Phys. Rev. Lett.* **30** (1973) 1343; H. David Politzer, *ibid.***30** (1973) 1346; see also , for example, F. Wilczek, in *Proc. 16th International Symposium*

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

on Lepton and Photon Interactions, Ithaca, 1993, eds. P. Drell and D.L. Rubin (AIP, NY, 1994) p. 593, and references therein.
3. D. Abbaneo *et al.*, hep-ex/0212036; see also, M. Gruenewald, hep-ex/0210003, in *Proc. ICHEP02*, eds. S. Bentvelsen *et al.* (North-Holland, Amsterdam, 2003) 280.
4. See J. G. da Costa, in *Proc. ICHEP04*, in press; D. Denisov, , *ibid.*, and refrences therein.
5. S. Jadach, W. Placzek, M. Skrzypek, B.F.L. Ward and Z. Was, *Eur. Phys. J.* **C27**, 19 (2003).
6. Nucl. Phys.**B578**, 3 (2000);**B619**, 313 (2001), and references therein.
7. M. Igarashi and N. Nakazawa, *Nucl. Phys.* **B288**, 301 (1987).
8. F.A. Berends, W.L. Van Neerven and G.J.H. Burgers, *Nucl. Phys.* **B297**, 429 (1988) and references therein.
9. S. Jadach, M. Melles, B.F.L. Ward and S.A. Yost,*Phys. Rev. D***65**, 073030 (2002).
10. F.A. Berends, P. De Causmaecker, R. Gastmans, R. Kleiss, W. Troost and T.T. Wu, *Nucl. Phys.* **B264** (1986) 243, 265.
11. H. Kuhn and G. Rodrigo, Eur.Phys.J. **C25**, 215 (2002); H. Czyz, A. Grzelinska, J.H. Kuhn and G. Rodrigo, Eur.Phys.J. **C33**, 333 (2004).
12. D. R. Yennie, S. C. Frautschi, and H. Suura,*Ann. Phys.* **13**, 379 (1961); see also K. T. Mahanthappa, *Phys. Rev.* **126**, 329 (1962), for a related analysis.
13. See S. Jadach *et al.*,*Comput. Phys. Commun.* **102**, 229 (1997); *ibid.* **70**, 305 (1992); S. Jadach, M. Skrzypek and B.F.L. Ward,*Phys.Rev.D* **55**, 1206 (1997), and references therein.
14. B.F.L. Ward,*Phys. Rev. D***36** (1987) 939.
15. S. Jadach *et al.*, *Comp. Phys. Commun.***119**, 272 (1999); *ibid.***140**, 475 (2001).
16. E. Barberio and Z. Was, *Comp. Phys. Commun.***79**, 291 (1994), and references therein.