International Journal of Modern Physics A

THRESHOLD CORRECTIONS IN PRECISION LHC PHYSICS: QED⊗QCD

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

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

With an eye toward LHC processes in which theoretical precisions of 1% are desired, we introduce the theory of the simultaneous YFS resummation of QED and QCD to compute the size of the expected resummed soft radiative threshold effects in precision studies of heavy particle production at the LHC. Our results show that both QED and QCD soft threshold effects must be controlled to be on the conservative side to achieve such precision goals.

Keywords: QCD; QED; Resummation.

1. Introduction

At the LHC/ILC, the precision requirements for soft multiple gluon (n(g)) effects will be even more demanding than at FNAL, where the uncertainty on m_t [1], $\delta m_t = 4.3$ GeV, receives a soft n(g) uncertainty $\sim$ 2-3 GeV, and soft n(g) MC exponentiation results will be an important part of the necessary theory – YFS exponentiated $\mathcal{O}(\alpha_s^2)L$ calculations, *in the presence of parton showers*, on an event-by-event basis.

As many authors [2] prepare the necessary results that would lead to such a precision on QCD for LHC processes, the QED corrections need to be addressed as well. Estimates by Refs. [3–7] show that one gets few per mille effects from QED corrections to structure function evolution. In this paper, estimate the size of QED corrections at threshold at the LHC.

Treating simultaneously QED and QCD in the respective YFS [8,9] exponentiation we discuss threshold effects at the LHC in the candidate luminometry [10,11] processes $pp \to V + n(\gamma) + m(g) + X \to \bar{\ell}\ell' + n'(\gamma) + m(g) + X$, where $V = W^{\pm}, Z$,and $\ell = e, \mu,\ \ell' = \nu_e, \nu_\mu(e, \mu)$ respectively for $V = W^+(Z)$, and $\ell = \nu_e, \nu_\mu,\ \ell' = e, \mu$ respectively for $V = W^-$.

2. YFS Theory and its Extension to QCD

In Refs. [9] the renormalization group improved YFS theory [12] for $e^+(p_1)e^-(q_1) \to \bar{f}(p_2)f(q_2) + n(\gamma)(k_1, \cdot, k_n)$ is realized by Monte Carlo methods, where the respective cross section $d\sigma_{exp}$ and all of the attendant IR functions, $\{B, \tilde{B}, D, \tilde{S}\}$, and hard photon residuals ,$\{\bar{\beta}_n(k_1, \ldots, k_n)\}$, are specified in Refs. [9]. In Refs. [13,14] we have extended the YFS theory to QCD: the net result is that in the analogous YFS theory we have the replacements $2\alpha\, Re\, B + 2\alpha\, \tilde{B} \to SUM_{IR}(QCD)$, $D \to D_{\text{QCD}}$, and $\bar{\beta}_n(k_1, \ldots, k_n) \to \tilde{\bar{\beta}}_n(k_1, \ldots, k_n)$, where the QCD YFS functions are defined in Ref. [13] and the gluon residuals [13] $\tilde{\bar{\beta}}_n(k_1, \ldots, k_n)$ are free of all infrared divergences to all orders in $\alpha_s(Q)$. The genuine non-Abelian IR physics is encoded [13] here in the $\tilde{\bar{\beta}}_j$. The YFS resummation which we discuss here is fully consistent with that of Refs. [15,16]. See Ref. [17] for more discussion of this point.

3. Extension to QED⊗QCD and QCED

Simultaneous exponentiation of QED and QCD higher order effects gives [17]

$$d\hat{\sigma}_{\text{exp}} = e^{\text{SUM}_{\text{IR}}(\text{QCED})} \sum_{m,n=0}^{\infty} \int \prod_{j_1=1}^{m} \frac{d^3 k_{j_1}}{k_{j_1}} \prod_{j_2=1}^{n} \frac{d^3 {k'}_{j_2}}{{k'}_{j_2}} \int \frac{d^4 y}{(2\pi)^4}$$
$$e^{iy\cdot(p_1+q_1-p_2-q_2-\sum k_{j_1}-\sum {k'}_{j_2})+D_{\text{QCED}}} \tilde{\bar{\beta}}_{m,n}(k_1, \ldots, k_m; k'_1, \ldots, k'_n) \frac{d^3 p_2}{p_2^0} \frac{d^3 q_2}{q_2^0}, \tag{1}$$

where the new YFS functions, $SUM_{IR}(QCED)$, D_{QCED} and $\tilde{\bar{\beta}}_{m,n}(k_1, \ldots, k_m; k'_1, \ldots, k'_n)$, where the latter has m hard gluons and n hard photons, are defined in Ref. [17]. The infrared algebra QCED [17] obtains: the average Bjorken x values for the QED and QCD emissions imply [17] that QCD dominant corrections happen an order of magnitude earlier than those for QED so that the leading $\tilde{\bar{\beta}}_{0,0}^{(0,0)}$-level gives a good estimate of the size of the effects we study.

4. QED⊗QCD Threshold Corrections at the LHC

For the basic formula (we use the standard notation here [17])

$$d\sigma_{exp}(pp \to V + X \to \bar{\ell}\ell' + X') = \sum_{i,j} \int dx_i dx_j F_i(x_i) F_j(x_j) d\hat{\sigma}_{exp}(x_i x_j s), \tag{2}$$

we use the result in (1) for $V = Z$ here with semi-analytical methods and structure functions from Ref. [24]. See also the work of Refs. [18–23]. A Monte Carlo realization will appear elsewhere [25], wherein we will ultimately use HERWIG [26], PYTHIA [27] and /or the new shower algorithm in Ref. [29] in lieu of the $\{F_i\}$ and thereby, in principle, improve on the shower/exact result combination in Ref. [28]. Due to its lack of the appropriate color coherence [30], we do not consider ISAJET [31] here.

We compute , with and without QED, the ratio $r_{exp} = \sigma_{exp}/\sigma_{Born}$ to get the results (We stress that we *do not* use the narrow resonance approximation here.)

$$r_{exp} = \begin{cases} 1.1901 & ,\text{QCED} \equiv \text{QCD+QED},\ \text{LHC} \\ 1.1872 & ,\text{QCD},\ \text{LHC} \\ 1.1911 & ,\text{QCED} \equiv \text{QCD+QED},\ \text{Tevatron} \\ 1.1879 & ,\text{QCD},\ \text{Tevatron}. \end{cases} \tag{3}$$

QED is at the level of .3% at both LHC and FNAL [a]. We agree with the results in Refs. [18–22]. The QED effect is similar in size to structure function results in Refs. [3–7].

Acknowledgments

Two of us (S.J. and B.F.L.W.) thank Profs. S. Bethke and L. Stodolsky for the support and kind hospitality of the MPI, Munich, while a part of this work was completed. This work was supported partly by US DoE contract DE-FG05-91ER40627 and by NATO grants PST.CLG.97751,980342.

References

1. J. G. da Costa, in *Proc. ICHEP04*, in press; D. Denisov, , *ibid.*.
2. See for example T. Gehrmann, in *Proc. LP2003*, ed. C.Sazama (FNAL, 2004), in press; J. Stirling, in *Proc. ICHEP04*, in press, and references therein.
3. S. Haywood, P.R. Hobson, W. Hollik and Z. Kunszt, in *Proc. 1999 CERN Workshop on Standard Model Physics (and more) at the LHC, CERN-2000-004*, eds. G. Altarelli and M.L. Mangano,(CERN, Geneva, 2000) p. 122.
4. H. Spiesberger,*Phys. Rev.* D**52**, 4936 (1995).
5. W.J. Stirling,”Electroweak Effects in Parton Distribution Functions”, talk presented at ESF Exploratory Workshop, *Electroweak Radiative Corrections to Hadronic Observables at TeV Energies* , Durham, Sept., 2003.
6. M. Roth and S. Weinzierl,*Phys. Lett.* **B590**, 190 (2004).
7. J. Stirling, in *Proc. ICHEP04*, in press.
8. 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.
9. See also S. Jadach *et al.*,*Comput. Phys. Commun.* **102**, 229 (1997); S. Jadach, M. Skrzypek and B.F.L. Ward,*Phys.Rev.* D**55**, 1206 (1997); S. Jadach, B.F.L. Ward and Z. Was,*Phys. Rev.* D**63**, 113009 (2001); S. Jadach, B.F.L. Ward and Z. Was, *Comp. Phys. Commun.* **130**, 260 (2000); S. Jadach *et al.*, *ibid.***140**, 432, 475 (2001).

---

[a] This is stable under scale variations [17].

10. M. Dittmar, F. Pauss and D. Zurcher,*Phys. Rev.* D**56**, 7284 (1997); M. Rijssenbeek, in *Proc. HCP2002*, ed. M. Erdmann,(Karlsruhe, 2002)p. 424; M. Dittmar, *ibid.*,p.431.
11. S. Klimenko, in *Proc. HCP2002*, ed. M. Erdmann,(Karlsruhe, 2002) p.413.
12. B.F.L. Ward,*Phys. Rev.* D**36**, 939 (1987).
13. B.F.L. Ward and S. Jadach, *Acta Phys.Polon.* **B33**, 1543 (2002); in *Proc. ICHEP2002*, ed. S. Bentvelsen *et al.*,(North Holland, Amsterdam, 2003) p. 275.
14. B.F.L. Ward and S. Jadach,*Mod. Phys. Lett.* A **14**, 491 (1999).
15. G. Sterman,*Nucl. Phys.*B **281**, 310 (1987).
16. S. Catani and L. Trentadue, *Nucl. Phys.*B **327**, 323 (1989); *ibid.* **353**, 183 (1991).
17. C. Glosser *et al.*,*Mod. Phys. Lett.* A **19**, 2119 (2004).
18. U. Baur *et al.*, *Phys. Rev.* D **57**, 199 (1998); *ibid.***59**, 013002 (1998); *ibid.***65**, 033007 (2002), and references therein.
19. S. Dittmaier and M. Kramer, *Phys. Rev.* D**65**, 073007 (2002), and references therein.
20. Z. A. Zykunov,*Eur. Phys. J.*C**3**, 9 (2001), and references therein.
21. R. Hamberg, W. L. van Neerven and T Matsuura, *Nucl. Phys.*B**359**, 343 (1991).
22. W.L. van Neerven and E.B. Zijlstra, *Nucl. Phys.* B**382** (1992) 11; *ibid.***680**, 513 (2004).
23. C. Anastasiou *et al.*,*Phys. Rev.* D**69**,094008 (2004).
24. A.D. Martin et al., *Phys. Rev.* D**51**, 4756 (1995).
25. S. Jadach *et al.*, to appear.
26. G. Corcella et al., hep-ph/0210213, and refrences therein.
27. T. Sjostrand et al., hep-ph/0308153.
28. S. Frixione and B. Webber, hep-ph/0402116, and references therein.
29. S. Jadach and M. Skrzypek, *Acta Phys. Pol.* **B35**, 735 (2004).
30. M. Michelangelo, private communication, 2004.
31. F. Paige et al., hep-ph/0312045, and references therein.