Tuned comparison of precision calculations for Drell–Yan-like W- and Z-boson production at the LHC

Stefan Dittmaier (MPI Munich)

Work done within the "Standard Model & Higgs Working Group"
of the Les Houches workshop "Physics at TeV Colliders"

1 Input parameters

The relevant input parameters are

$$
\begin{array}{llllll}
G_\mu & = 1.16637\times10^{-5}\,\mathrm{GeV}^{-2}, & \alpha(0) & = 1/137.03599911, & \alpha_\mathrm{s} & = 0.1187, \\
M_\mathrm{W} & = 80.425\,\mathrm{GeV}, & \Gamma_\mathrm{W} & = 2.124\,\mathrm{GeV}, & & \\
M_\mathrm{Z} & = 91.1876\,\mathrm{GeV}, & \Gamma_\mathrm{Z} & = 2.4952\,\mathrm{GeV}, & M_\mathrm{H} & = 115\,\mathrm{GeV}, \\
m_\mathrm{e} & = 0.51099892\,\mathrm{MeV}, & m_\mu & = 105.658369\,\mathrm{MeV}, & m_\tau & = 1.77699\,\mathrm{GeV}, \\
m_\mathrm{u} & = 66\,\mathrm{MeV}, & m_\mathrm{c} & = 1.2\,\mathrm{GeV}, & m_\mathrm{t} & = 178\,\mathrm{GeV}, \\
m_\mathrm{d} & = 66\,\mathrm{MeV}, & m_\mathrm{s} & = 150\,\mathrm{MeV}, & m_\mathrm{b} & = 4.3\,\mathrm{GeV}, \\
|V_\mathrm{ud}| & = 0.975, & |V_\mathrm{us}| & = 0.222, & & \\
|V_\mathrm{cd}| & = 0.222, & |V_\mathrm{cs}| & = 0.975, & &
\end{array}
\qquad (1)
$$

which essentially follow [1]. For the top-quark mass m_t we have taken the more recent value of [2]. The masses of the light quarks are adjusted to reproduce the hadronic contribution to the photonic vacuum polarization of Ref. [3]. The CKM matrix is included via global factors to the partonic cross sections as described in Ref. [4].

The lowest-order cross section is parametrized in the "G_μ scheme" as defined in [4], i.e. the electromagnetic coupling α is derived according to $\alpha_{G_\mu} = \sqrt{2}G_\mu M_\mathrm{W}^2(1-M_\mathrm{W}^2/M_\mathrm{Z}^2)/\pi$, so that the results are practically independent of the masses of the light quarks. Moreover, this procedure absorbs the corrections proportional to $m_\mathrm{t}^2/M_\mathrm{W}^2$ in the fermion–W-boson couplings and the running of $\alpha(Q^2)$ from $Q^2=0$ to the electroweak scale. In the relative radiative corrections, however, $\alpha(0)$ is used as coupling parameter, which is the correct effective coupling for real photon emission. Note that the $\mathcal{O}(\alpha)$ corrections in the G_μ scheme receive a constant contribution from the quantity Δr, as described in [4]. The W- and Z-boson resonances should be treated with fixed widths without any running effects.

The recently released $\mathcal{O}(\alpha)$-improved set of PDFs "MRST2004QED" [5] is used throughout. The factorization of the photonic initial-state quark-mass singularities should be done in the DIS-like factorization scheme, i.e. *not* in the $\overline{\mathrm{MS}}$ scheme as frequently done in the past, because photon radiation off incoming quarks was ignored in the F_2 fit to HERA data [6].

2 Phase-space cuts and event selection

We propose to use the same set of phase-space and event selection cuts as described in [4] for W-production at the LHC ($\sqrt{s} = 14\,\mathrm{TeV}$):

For the experimental identification of the process $\mathrm{pp} \to \mathrm{W}^+ \to \nu_l l^+(+\gamma)$ we take the set of phase space cuts

$$p_{\mathrm{T},l} > 25\,\mathrm{GeV}, \qquad \not{p}_{\mathrm{T}} > 25\,\mathrm{GeV}, \qquad |\eta_l| < 1.2, \tag{2}$$

where $p_{\mathrm{T},l}$ and η_l are the transverse momentum and the rapidity of the charged lepton l^+, respectively, and $\not{p}_{\mathrm{T}} = p_{\mathrm{T},\nu_l}$ is the missing transverse momentum carried away by the neutrino. Note that these cuts are not "collinear-safe" with respect to the lepton momentum, so that observables in general receive corrections that involve large lepton-mass logarithms of the form $\alpha \ln(m_l/M_{\mathrm{W}})$. This is due to the fact that photons within a small collinear cone around the charged lepton momentum are not treated inclusively, i.e. the cuts assume a perfect isolation of photons from the charged lepton. While this is (more or less) achievable for muon final states, it is not realistic for electrons. In order to be closer to the experimental situation for electrons, we additionally consider the following photon recombination procedure:

1. Photons with a rapidity $|\eta_\gamma| > 2.5$, which are close to the beams, are treated as invisible, i.e. they are considered as part of the proton remnant.

2. If the photon survived the first step, and if the resolution $R_{l\gamma} = \sqrt{(\eta_l - \eta_\gamma)^2 + \phi_{l\gamma}^2}$ is smaller than 0.1 (with $\phi_{l\gamma}$ denoting the angle between lepton and photon in the transverse plane), then the photon is recombined with the charged lepton, i.e. the momentum of the photon and l are added and associated with the momentum of l, and the photon is discarded.

3. Finally, all events are discarded in which the resulting momentum of the charged lepton does not pass the cuts given in (2).

While the electroweak corrections differ for final-state electrons and muons without photon recombination, called "bare" leptons in the following, the corrections become universal in the presence of photon recombination, since the lepton-mass logarithms cancel in this case, in accordance with the KLN theorem.

3 Observables for W production

We propose to compare results for integrated cross sections as given in Table 2 of [4], i.e. for $\mathrm{pp} \to \mathrm{W}^+ \to \nu_l l^+(+\gamma)$ with the different lower cuts on $p_{\mathrm{T},l}$: 25 GeV, 50 GeV, 100 GeV, 200 GeV, 500 GeV, 1000 GeV. It should be sufficient to consider muons in the final state, $l = \mu$.

Moreover, the distributions in $p_{\mathrm{T},l}$ and the transverse-invariant-mass $M_{\mathrm{T},\nu_l l} = \sqrt{2 p_{\mathrm{T},l} \not{p}_{\mathrm{T}} (1 - \cos\phi_{\nu_l l})}$, where $\phi_{\nu_l l}$ is the angle between the lepton and the missing momentum in the transverse plane, should be compared. These distributions were shown in Figs. 8 and 9 of [4]. Precisely, the shown ranges are $25\,\mathrm{GeV} < p_{\mathrm{T},l} < 50\,\mathrm{GeV}$ and

$50\,\mathrm{GeV} < M_{\mathrm{T},\nu_l l} < 100\,\mathrm{GeV}$ with 50 histagram bins each. For data files I propose the format:
left corner of the bin – Born prediction – corresponding error – $\mathcal{O}(\alpha)$-corrected prediction – corresponding error – best prediction – corresponding error

In a first step, only $\mathcal{O}(\alpha)$ corrections, i.e. no QCD corrections, should be taken into account. We propose to provide results on the cross-section contributions from the photon distribution function of MRST2004QED separately; it is sufficient to compare these particular contributions for integrated cross sections only. Finally, apart from these tuned results, we propose that each group delivers also "best" results that include as many corrections as possible in addition (photon-induced process, higher-order radiation effects, higher-order universal corrections, etc.).

4 Observables for Z production

We propose to compare results for integrated cross sections of $\mathrm{pp} \to \mathrm{Z}/\gamma \to l^+l^-(+\gamma)$ (again with $l = \mu$) with the different lower cuts on the dilepton mass $M_{l^+l^-} = \sqrt{(p_{l^+} + p_{l^-})^2}$: $50\,\mathrm{GeV}$, $100\,\mathrm{GeV}$, $200\,\mathrm{GeV}$, $500\,\mathrm{GeV}$, $1000\,\mathrm{GeV}$, $2000\,\mathrm{GeV}$.

Moreover, the distribution in $M_{l^+l^-}$ should be compared within the range $60\,\mathrm{GeV} < M_{l^+l^-} < 120\,\mathrm{GeV}$ with 60 histogram bins.

As in the case for the W boson, only $\mathcal{O}(\alpha)$ corrections, i.e. no QCD corrections, should be taken into account, and results on the cross-section contributions from the photon distribution function should be provided separately. Finally, apart from these tuned results, each group should provide "best" results that include as many corrections as possible in addition.

References

[1] S. Eidelman *et al.* [Particle Data Group Collaboration], Phys. Lett. B **592** (2004) 1.

[2] P. Azzi *et al.* [CDF and D0 Collaborations, and Tevatron Electroweak Working Group], hep-ex/0404010.

[3] F. Jegerlehner, DESY 01-029, LC-TH-2001-035, hep-ph/0105283.

[4] S. Dittmaier and M. Krämer, Phys. Rev. D **65** (2002) 073007 [hep-ph/0109062].

[5] A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C **39** (2005) 155 [hep-ph/0411040].

[6] V. Lendermann, H. Spiesberger, J. Stirling and A. Tapper, private communications.