SINGLE-W

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Abstract
Contributions of the Pavia/`ALPHA` group to the subject of single-W production are summarized.

1. DESCRIPTION OF THE METHOD

1.1 Hard-scattering matrix element

The exact matrix elements for single-W production are computed by means of the `ALPHA` algorithm [1] for the automatic evaluation of the Born scattering amplitudes. Fermion masses are exactly accounted for in the kinematics and dynamics. The contribution of anomalous trilinear gauge couplings is also taken into account. The anomalous gauge boson couplings Δk_γ, λ_γ, δ_Z, Δk_Z and λ_Z are implemented according to the parameterization of refs. [2, 3]. The fixed width scheme is adopted as gauge-restoring approach, as motivated in comparison with other gauge-invariance-preserving schemes in ref. [4].

1.2 Radiative corrections

Leading-log (LL) QED radiative corrections are implemented via the Structure Function (SF) formalism in the collinear approximation [5]. The Q^2-scale entering the SF $D(x, Q^2)$ is fixed by comparing the $O(\alpha)$ expansion of the SF method with the analytic results obtained for the LL photonic corrections as given by soft-photon bremsstrahlung from the external legs, its virtual counterpart and hard-photon radiation collinear to the final-state particles. For example, for the process $e^+e^- \to e^-\bar{\nu}u\bar{d}$, this comparison translates in two Q^2-scales as follows (two initial-state (IS) SFs are assumed: Q^2_- refers to the SF attached to the incoming electron, while Q^2_+ to the SF attached to the incoming positron) [6]

$$Q^2_- = 4E^2\frac{(1-c_-)^2}{\delta^2}\ , \quad Q^2_+ = 2^{\frac{14}{9}}E^2\frac{((1-c_{\bar{d}})(1-c_u)^2)^{\frac{2}{3}}}{((1-c_{u\bar{d}})^2\delta^5)^{\frac{2}{9}}} \tag{1}$$

where E is the beam energy, c_- the cosine of the electron scattering angle, c_u and $c_{\bar{d}}$ the cosine of the quark scattering angles with respect to the initial positron, $c_{u\bar{d}}$ the cosine of the relative angle between the quarks, δ the half-opening angle of the electromagnetic jet (calorimetric angular resolution). Also a naive ansatz for the two scales, as motivated by an analysis of the single-W process in terms of the Weizsäcker-Williams approximation, can be given as follows [6]

$$Q^2_{-,\mathrm{naive}} = |q^2_{\gamma^*}|\ , \quad Q^2_{+,\mathrm{naive}} = M^2_W \tag{2}$$

where $q^2_{\gamma^*}$ is the squared momentum transfer in the $ee\gamma^*$ vertex and M_W is the mass of the W boson.

The effect of vacuum polarization is also taken into account in our calculation, by including the contribution of leptons, heavy quarks and light quarks, the latter according to the standard parameterization of ref. [7].

1.3 Computational tool

The theoretical features sketched above have been implemented into a massive MonteCarlo (MC) program, named `SWAP` (`S`ingle `W` process with `A`lpha & `P`avia). The multi-channel importance sampling technique is employed to perform the phase-space integration. The code supports realistic event selections and can be employed either as a cross-section calculator or as a true event generator.

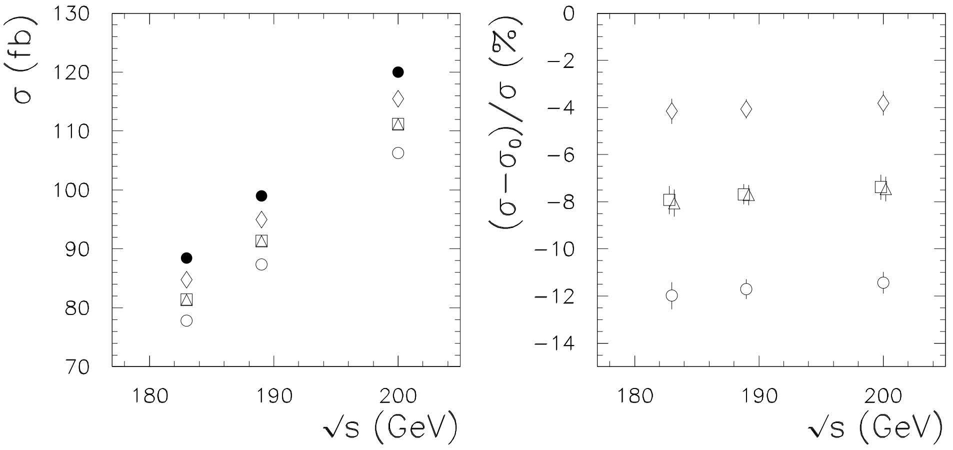

Fig. 1: The effect of LL QED corrections to the cross section of the single-W process $e^+e^- \to e^-\bar{\nu}u\bar{d}$ for different choices of the Q^2-scale in the electron/positron SF. Left: absolute cross section values; Right: relative difference between QED corrected cross sections and the Born one. The marker • represents the Born cross section, ○ represents the correction given by $Q^2_\pm = s$ scale, ◇ represents the correction given by $Q^2_\pm = |q^2_{\gamma^*}|$ scale, △ the correction given by the scales of eq. (1), □ the correction given by the naive scales of eq. (2). The entries correspond to $\sqrt{s} = 183, 189, 200$ GeV.

2. RESULTS OBTAINED

The main results obtained in our study can be summarized as follows:

- critical analysis of the energy scale for QED radiation (see Fig. 1);
- evaluation of the effect of running of α_{QED} (see Fig. 2);
- tuned comparisons with other codes (see Sec. 3.).

Input parameters and cuts used to obtain the numerical results shown in the following are those of the $4f$ proposal for the process $e^+e^- \to e^-\bar{\nu}u\bar{d}$ ($|\cos\vartheta_e| > 0.997, M_{u\bar{d}} > 45$ GeV). For Fig. 1 the value of δ parameter entering eq. (1) is $\delta = 5°$, but it has been checked that the numerical results are very marginally affected by its actual value.

Scales & QED radiation. In Fig. 1 the numerical impact of different choices of the Q^2-scale on the cross section of the single-W process $e^+e^- \to e^-\bar{\nu}u\bar{d}$ is shown. The marker • represents the Born cross section, ○ represents the correction given by $Q^2_\pm = s$ scale for both IS SFs, ◇ represents the correction given by $Q^2_\pm = |q^2_{\gamma^*}|$ scale for both IS SFs, △ the correction given by the scales of eq. (1), □ the correction given by the naive scales of eq. (2). It can be seen that neither the s scale, as implemented in computational tools used for the analysis of the single-W process, nor the $|q^2_{\gamma^*}|$ scale, as recently proposed in ref. [8], are able to reproduce the effects due to the scales of eq. (1) and eq. (2). These two scales are in good agreement and both predict a lowering of the Born cross section of about 8%, almost independent of the c.m. LEP2 energy.

Running of α_{QED}. Because G_F, M_W and M_Z are the agreed input parameters in the $4f$ proposal, the value of the e.m. coupling constant α is fixed at tree-level to a high energy value as

$$\alpha_{G_F} = 4\sqrt{2}\frac{G_F M_W^2 s_W^2}{4\pi} , \qquad \text{with} \qquad s_W^2 = 1 - \frac{M_W^2}{M_Z^2} . \tag{3}$$

On the other hand, the single W process is a $q^2_{\gamma^*} \simeq 0$ dominated process and therefore the above high-energy evaluation of α, α_{G_F}, needs to be rescaled to its correct value at small momentum transfer. In order to take into account the effect of the running of α in a gauge invariant way, a "reweighting" procedure can be adopted, by simply rescaling the differential cross section $d\sigma/dt$ ($t \equiv q^2_{\gamma^*}$) in the

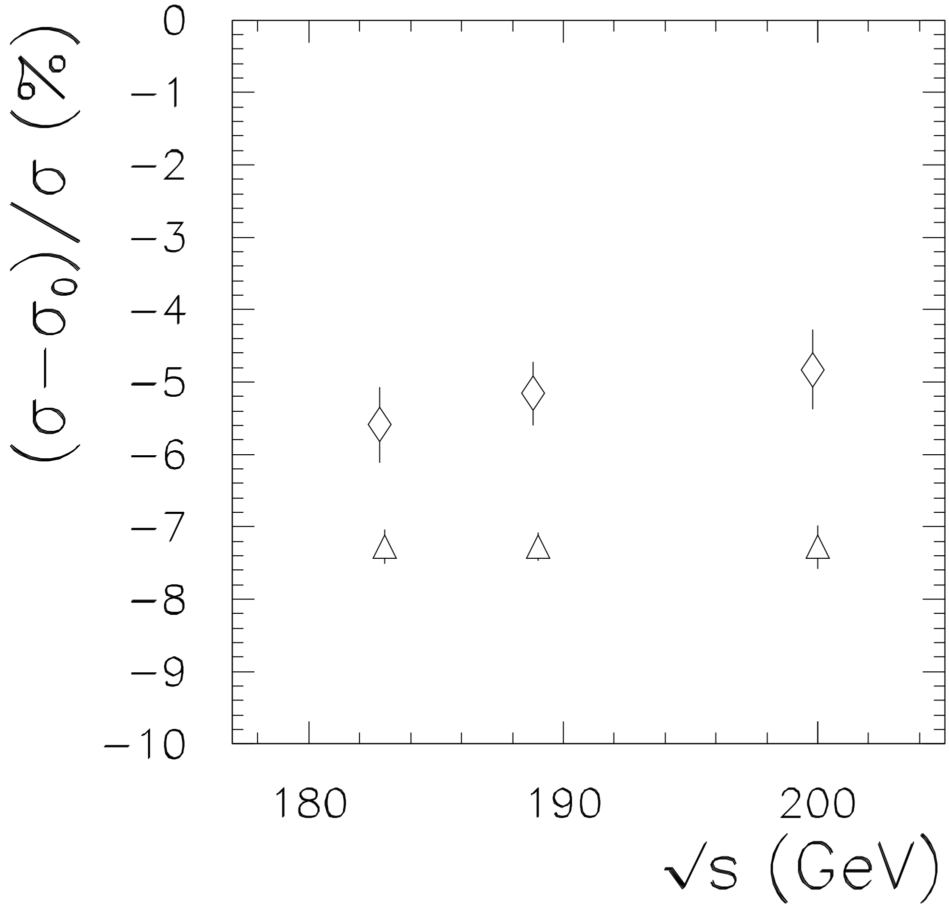

Fig. 2: The effects of the rescaling of α_{QED} from α_{G_F} to $\alpha(q^2_{\gamma^*} = 0)$ ($\triangle$) and $\alpha(q^2_{\gamma^*})$ ($\diamond$) on the integrated cross section of the single-W process $e^+e^- \to e^-\bar{\nu}u\bar{d}$. σ_0 is the cross section computed in terms of α_{G_F}. The entries correspond to $\sqrt{s} = 183, 189, 200$ GeV.

following way

$$\frac{d\sigma}{dt} \to \frac{\alpha^2(0)}{\alpha^2_{G_F}} \frac{d\sigma}{dt} \, ,$$
$$\frac{d\sigma}{dt} \to \frac{\alpha^2(t)}{\alpha^2_{G_F}} \frac{d\sigma}{dt} \, , \tag{4}$$

where $\alpha(0), \alpha(t)$ is the QED running coupling computed at virtuality $q^2_{\gamma^*}$ equal to 0 and t, respectively. Fig. 2 shows the effects of the above reweighting preocedure. The $\triangle$ represent the relative difference between the integrated cross section computed in terms of α_{G_F} and the cross section computed in terms of $\alpha(0)$, while $\diamond$ is the relative difference between the integrated cross section computed in terms of α_{G_F} and the cross section computed in terms of $\alpha(t)$. As can be seen, the rescaling from α_{G_F} to $\alpha(t)$ introduces a negative correction of about 5-6% in the LEP2 energy range. The difference between $\triangle$ and $\diamond$, which is about 2-3%, is a measure of the running of α_{QED} from $q^2_{\gamma^*} = 0$ to $q^2_{\gamma^*} = t$.

A detailed numerical analysis of the effect of the running couplings in single-W production has been very recently performed in ref. [9], based on the theoretical results of the massive fermion-loop scheme of ref. [10]. Our results for the running of α_{QED}, as shown in Fig. 2, are in agreement with those of ref. [9].

3. AVAILABLE COMPARISONS

Tuned comparisons between the predictions of `SWAP` and those of other independent codes, namely `CompHEP, NEXTCALIBUR, WPHACT` and `WTO`, are available as documented in the talk by G. Passarino at CERN meeting on 12/10/99, `http://www.to.infn.it/ giampier/lep2.html`.

This comparison covers single-W Born cross sections and distributions, including also leptonic final states, and in the presence of both invariant mass and energy cuts.

In order to assess the theoretical uncertainty relative to the treatment of photonic corrections, it would be quite important and certainly useful to compare the predictions of `SWAP`, as given in Sect. 2., with those of other codes, based on SF, Parton Shower or YFS method.

4. ESTIMATE OF TU

The difference shown in Fig. 1 between the predictions given by the two set of Q^2-scales of eq. (1) and eq. (2) is of the order of 1% (*higher precision is needed!, work in progress*) and it may be considered as a first estimate of the theoretical error in the treatment of QED radiation, which could be corroborated by the comparison with the results of other groups. QED corrections missing in the present approach are beyond the LL approximation.

5. RECOMMENDATIONS

The present study shows that the choice $Q^2_\pm = s$ as scale in the IS QED SFs can lead to over-estimate the effect of LL photonic corrections by a factor of 1.5, implying an under-estimate of the QED corrected cross section of about 4%. Also the choice of fixing the scale to $Q^2_\pm = |q^2_{\gamma^*}|$ for both the IS SFs, as recently suggested [8], leads to an under-estimate of the photon correction of about 4%. Since these effects are not negligible in the light of the expected theoretical accuracy, it is recommended to adopt the Q^2-scales as given in eq. (1) or eq. (2), which are motivated by the arguments sketched in Sec. 1.2.

Further, the effect of rescaling α_{QED} from the high-energy value α_{G_F} of eq. (3) to $\alpha(q^2_{\gamma^*})$ amounts to a negative correction of about 5-6$\%$, to be taken into account carefully.

References

[1] F. Caravaglios and M. Moretti, Phys. Lett. B358 (1995) 332.

[2] K. Gaemers and G. Gounaris, Z. Phys. C1 (1979) 259.

[3] K. Hagiwara, K. Hikasa, R.D. Peccei and D. Zeppenfeld, Nucl. Phys. B282 (1987) 253.

[4] E. Accomando, A. Ballestrero and E. Maina, Non-conserved currents and gauge-restoring schemes in single-W production, `hep-ph/9911489`

[5] E.A. Kuraev and V. Fadin, Sov. J. Nucl. Phys. 41 (1985) 466;
G. Altarelli and G. Martinelli, in *Physics at LEP*, J. Ellis and R. Peccei eds., CERN 86-02, Geneva, 1986), Vol. 1 p. 47;
O. Nicrosini and L. Trentadue, Phys. Lett. B196 (1987) 551, Z. Phys. C39 (1998) 479; F.A. Berends, G. Burgers and W.L. van Neerven, Nucl. Phys. B297 (1988) 429;
S. Jadach and M. Skrzypek, Z. Phys. C49 (1991) 577; M. Skrzypek, Acta Phys. Pol. B23 (1992) 135;
M. Cacciari, A. Deandrea, G. Montagna and O. Nicrosini, Europhys. Lett. 17 (1992) 123.

[6] A. Pallavicini, On photon radiation in single-W process, talk given at CERN meeting on 12/10/99, `http://www.to.infn.it/ giampier/lep2.html`;
G. Montagna, M. Moretti, O. Nicrosini, A. Pallavicini, F. Piccinini, paper in preparation.

[7] S. Eidelman and F. Jegerlehner, Z. Phys. C67 (1995) 585.

[8] E.E. Boos and M.N. Dubinin, Single W-boson production at Linear Colliders, hep-ph/9909214.

[9] G. Passarino, Single-W production and Fermion-Loop scheme: numerical results, hep-ph/0001212.

[10] G. Passarino, Unstable particles and non-conserved currents: a generalization of the fermion-loop scheme, hep-ph/9911482.