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WWGENPV 2.0 - A Monte Carlo Event Generator for Four-Fermion Production at e^+e^- Colliders

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Program classification: 11.1

The Monte Carlo program WWGENPV, designed for computing distributions and generating events for four-fermion production in e^+e^- collisions, is described. The new version, 2.0, includes the full set of the electroweak (EW) tree-level matrix elements for double- and single-W production, initial- and final-state photonic radiation including p_T/p_L effects in the Structure Function formalism, all the relevant non-QED corrections (Coulomb correction, naive QCD, leading EW corrections). An hadronisation interface to JETSET is also provided. The program can be used in a three-fold way: as a Monte Carlo integrator for weighted events, providing predictions for several observables relevant for W physics; as an adaptive integrator, giving predictions for cross sections, energy and invariant mass losses with high numerical precision; as an event generator for unweighted events, both at partonic and hadronic level. In all the branches, the code can provide accurate and fast results.

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NEW VERSION SUMMARY

Title of new version: `WWGENPV` 2.0

Catalogue number:

Program obtainable from: CPC Program Library, Queen's University of Belfast, N. Ireland (see application form in this issue)

Reference to original program: `WWGENPV`; *Cat. no.:* ACNT; *Ref. in CPC:* **90** (1995) 141

Authors of original program: Guido Montagna, Oreste Nicrosini and Fulvio Piccinini

The new version supersedes the original program

Licensing provisions: none

Computer for which the new version is designed: DEC ALPHA 3000, HP 9000/700 series; *Installation:* INFN, Sezione di Pavia, via A. Bassi 6, 27100 Pavia, Italy

Operating system under which the new version has been tested: VMS, UNIX

Programming language used in the new version: FORTRAN 77

Memory required to execute with typical data: $\approx 250 - 450$Kb

No. of bits in a word: 32

No. of processors used: 1

The code has not been vectorized

Subprograms used: `CERNLIB` [1], `NAGLIB` [2], `JETSET` [3], `RANLUX` [4]

No. of lines in distributed program, including test data, etc.: ≈ 14000

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Keywords: e^+e^- collisions, LEP, W-mass measurement, radiative corrections, QED corrections, QCD corrections, Minimal Standard Model, four-fermion final states, electron structure functions, Monte Carlo integration/simulation,

hadronisation.

Nature of physical problem
The precise measurement of the W-boson mass M_W constitutes a primary task of the forthcoming experiments at the high energy electron–positron collider LEP2 ($2M_W \leq \sqrt{s} \leq 210$ GeV). A meaningful comparison between theory and experiment requires an accurate description of the fully exclusive processes $e^+e^- \to 4f$, including the main effects of radiative corrections, with the final goal of providing predictions for the distributions measured by the experiments.

Method of solution
Same as in the original program, as far as weighted event integration and unweighted event generation are concerned. Adaptive Monte Carlo integration for high numerical precision purposes is added. Optional hadronic interface in the generation branch is supplied.

Reasons for the new version
The most promising methods for measuring the W-boson mass at LEP2 are the so called "threshold" and "direct reconstruction" methods [5]. For the first one, a precise evaluation of the threshold cross section is required. For the second one, a precise description of the invariant-mass shape of the hadronic system in semileptonic decays is mandatory. In order to meet these requirements, the previous version of the program has been improved by extending the class of the tree-level EW diagrams taken into account, by including p_T/p_L effects both in initial- and final-state QED radiation, by supplying an hadronic interface in the generation branch.

Restrictions on the complexity of the problem
While the semileptonic decay channels are complete at the level of the Born approximation EW diagrams (`CC11/CC20` diagrams), neutral current backgrounds are neglected in the fully hadronic and leptonic decay channels. QED radiation is treated at the leading logarithmic level. Due to the absence of a complete $\mathcal{O}(\alpha)/\mathcal{O}(\alpha_s)$ diagrammatic calculation, the most relevant EW and QCD corrections are effectively incorporated according to the recipe given in [6]. No anomalous coupling effects are at present taken into account.

Typical running time
As adaptive integrator, the code provides cross section and energy and invariant-mass losses with a relative accuracy of about 1% in 8 min on HP 9000/735. As integrator of weighted events, the code produces about 10^5 events/min on the same system. The generation of a sample of 10^3 hadronised unweighted events requires about 8 min on the same system.

Unusual features of the program
Subroutines from the library of mathematical subprograms `NAGLIB` [3] for the numerical integrations are used in the program, when the adaptive integration branch is selected.

References

[1] CERN Program Library, CN Division, CERN, Geneva.

[2] NAG Fortran Library Manual Mark 16 (Numerical Algorithms Group, Oxford, 1991).

[3] T. Sjöstrand, Comp. Phys. Commun. **82** (1994) 74; Lund University Report LU TP 95-20 (1995).

[4] F. James, Comput. Phys. Commun. 79 (1994) 111.

[5] *Physics at LEP2*, CERN Report 96-01, Theoretical Physics and Particle Physics Experiments Divisions, G. Altarelli, T. Sjöstrand and F. Zwirner, eds., Vols. 1 and 2, Geneva, 19 February 1996.

[6] W. Beenakker, F. Berends et al., "WW cross-sections and distributions", in [5], Vol. 1, pag. 79.

LONG WRITE-UP

1 Introduction

The precise measurement of the W-boson mass M_W constitutes a primary task of the forthcoming experiments at the high energy electron–positron collider LEP2 ($2M_W \leq \sqrt{s} \leq 210$ GeV). A meaningful comparison between theory and experiment requires an accurate description of the fully exclusive processes $e^+e^- \to 4f$, including the main effects of radiative corrections, with the final goal of providing predictions for the distributions measured by the experiments. A large effort in the direction of developing tools dedicated to the investigation of this item has been spent within the Workshop "Physics at LEP2", held at CERN during 1995. Such an effort has led to the development of several independent four-fermion codes, both semianalytical and Monte Carlo, extensively documented in [1]. **WWGENPV** is one of these codes, and the aim of the present paper is to describe in some detail the developments performed with respect to the original version [2], where a description of the formalism adopted and the physical ideas behind it can be found.

As discussed in [3], the most promising methods for measuring the W-boson mass at LEP2 are the so called "threshold" and "direct reconstruction" methods. For the first one, a precise evaluation of the threshold cross section is required. For the second one, a precise description of the invariant-mass shape of the hadronic system in semileptonic and hadronic decays is mandatory. In order to meet these requirements, the previous version of the program has been improved, both from the technical and physical point of view.

On the technical side, in addition to the "weighted event integration" and "unweighted event generation" branches, the present version can also be run as an "adaptive Monte Carlo" integrator, in order to obtain high numerical precision results for cross sections and other relevant observables. In the "weighted event integration" branch, a "canonical" output can be selected, in which several observables are processed in parallel together with their most relevant moments [1]. Moreover, the program offers the possibility of generating events according to a specific flavour quantum number assignment for the final-state fermions, or of generating "mixed samples", namely a fully leptonic, fully hadronic or semileptonic sample.

On the physical side, the class of tree-level EW diagrams taken into account has been extended to include all the single resonant diagrams (`CC11/CC20`), in such a way that all the charged current processes are covered. Motivated by the physical relevance of keeping under control the effects of the transverse degrees of freedom of photonic radiation, both for the W mass measurement and for the detection of anomalous couplings, the contribution of QED radiation has been fully developed in the leading logarithmic approximation, going beyond the initial-state, strictly collinear approximation, to include p_T/p_L effects both for initial- and final-state photons. Last, an hadronic interface to `JETSET` in the generation branch has been added.

In the present version the neutral current backgrounds are neglected in the fully hadronic and leptonic decay channels, but this is not a severe limitation of the program since, at least in the LEP2 energy range, these backgrounds can be suppressed by means of proper invariant mass cuts. On the other hand, the semileptonic decay channels are complete at the level of the Born approximation EW diagrams (`CC11/CC20` diagrams), and this feature allows to treat at best those channels that are expected to be the most promising for the direct reconstruction of the W mass, because free of systematics such as the "color reconnection" and the "Bose-Einstein correlation" problems.

In the development of the code, particular attention has been paid to the possibility of obtaining precise results in relatively short CPU time. As shown in [1], `WWGENPV` is one of the most precise four fermion Monte Carlo's from the numerical point of view. This feature allows the use of the code also for fitting purposes.

2 The most important new features

In the following we list and briefly describe the most important technical and physical developments implemented in the new version of `WWGENPV`.

TECHNICAL IMPROVEMENTS

The present version of the program consists of three branches, two of them already present in the original version but upgraded in some respect, the third one completely new.

- Unweighted event generation branch. This branch, meant for simulation purposes, has been improved by supplying an option for an hadronisation interface (see more details later on).

- Weighted event integration branch. This branch, intended for computation only, includes as a new feature an option for selecting a "canonical" output containing predictions for several observables and their most relevant moments together with a Monte Carlo estimate of the errors. According to the strategy adopted in [1], the first four Chebyshev/power moments of the following quantities are computed: the production angle of the W^+ with respect to the positron beam (TNCTHW, N=1,2,3,4), the production angle ϑ_d of the down fermion with respect to the positron beam (TNCTHD), the decay angle ϑ_d^* of the down fermion with respect to the direction of the decaying W^- measured in its rest frame (TNCTHSR), the energy E_d of the down fermion normalized to the beam energy (XDN), the sum of the energies of all radiated photons (XGN) normalized to the beam energy, the lost and visible photon energies normalized to the beam energy (XGNL and XGNV), respectively, and, finally

$$< x_m > = \frac{1}{\sigma} \int \left(\frac{\sqrt{s_+} + \sqrt{s_-} - 2M_W}{2E_b} \right) d\sigma$$

where s_+ and s_- are the invariant masses of the W^+ and W^- decay products, respectively (XMN).

- Adaptive integration branch. This new branch is intended for computation only, but offers high precision performances. On top of the importance sampling, an adaptive Monte Carlo integration algorithm is used. The code returns the value of the cross section together with a Monte Carlo estimate of the error. Moreover, if QED corrections are taken into account, also the average energy and invariant mass losses are printed. The program must be linked to NAG library for the Monte Carlo adaptive routine. Full consistency between non-adaptive and adaptive integrations has been explicitly proven.

In each of these three branches the user is asked to specify the four-fermion final state which is required. The final states at present available are those containing CC03 diagrams as a subset. Their list, as appears when running the code, is the following:

```
PURELY LEPTONIC PROCESSES
[0]   ---> E+ NU_E E- BAR NU_E
[1]   ---> E+ NU_E MU- BAR NU_MU
[2]   ---> E- BAR NU_E MU+ NU_MU
[3]   ---> E+ NU_E TAU- BAR NU_TAU
[4]   ---> E- BAR NU_E TAU+ NU_TAU
[5]   ---> MU+ NU_MU MU- BAR NU_MU
[6]   ---> MU+ NU_MU TAU- BAR NU_TAU
[7]   ---> MU- BAR NU_MU TAU+ NU_TAU
[8]   ---> TAU+ NU_TAU TAU- BAR NU_TAU
SEMILEPTONIC PROCESSES
```

```
[9]  ---> E+ NU_E D BAR U
[10] ---> E- BAR NU_E BAR D U
[11] ---> E+ NU_E S BAR C
[12] ---> E- BAR NU_E BAR S C
[13] ---> MU+ NU_MU D BAR U
[14] ---> MU- BAR NU_MU BAR D U
[15] ---> MU+ NU_MU S BAR C
[16] ---> MU- BAR NU_MU BAR S C
[17] ---> TAU+ NU_TAU D BAR U
[18] ---> TAU- BAR NU_TAU BAR D U
[19] ---> TAU+ NU_TAU S BAR C
[20] ---> TAU- BAR NU_TAU BAR S C
HADRONIC PROCESSES
[21] ---> D BAR U BAR D U
[22] ---> D BAR U BAR S C
[23] ---> S BAR C BAR D U
[24] ---> S BAR C BAR S C
MIXED SAMPLES
[25] ---> LEPTONIC SAMPLE
[26] ---> SEMILEPTONIC SAMPLE
[27] ---> HADRONIC SAMPLE
```

It is worth noting that in the weighted event integration and unweighted event generation branches, besides the possibility of selecting a specific four-fermion final state, an option is present for considering three realistic mixed samples corresponding to the fully leptonic, fully hadronic or semileptonic decay channel, respectively. When the generation of a mixed sample is required, as a a first step the cross section for each contributing channel is calculated; as a second step, the unweighted events are generated for each contributing channel with a frequency given by the weight of that particular channel with respect to the total.

In the generation branch, if the hadronisation interface is not enabled, an n-tuple is created with the following structure:

```
'X_1','X_2','EB'          ! x_{1,2} represent the
                          ! energy fractions of incoming e^- and
                          ! e^+ after ISR; EB is the beam energy;
'Q1X','Q1Y','Q1Z','Q1LB' ! x,y,z components of the momentum
                          ! of particle 1 and the particle label
                          ! according to PDG; the final-state
                          ! fermions are assumed to be massless;
'Q2X','Q2Y','Q2Z','Q2LB' ! as above, particle 2
```

```
'Q3X','Q3Y','Q3Z','Q3LB' ! "  "           "   3
'Q4X','Q4Y','Q4Z','Q4LB' ! "  "           "   4
'AK1X','AK1Y','AK1Z'     ! x,y,z components of the momentum of
                         ! the photon from particle 1;
                         ! they are 0 if no FSR has been chosen
                         ! and/or if particle 1 is a neutrino;
'AK2X','AK2Y','AK2Z'     ! as above, particle 2
'AK3X','AK3Y','AK3Z'     ! "  "           "   3
'AK4X','AK4Y','AK4Z'     ! "  "           "   4
'AKEX','AKEY','AKEZ'     ! x,y,z components of the momentum of
                         ! the photon from the initial-state
                         ! electron; they are 0 if no ISR has
                         ! been chosen;
'AKPX','AKPY','AKPZ'     ! as above, initial-state positron;
```

If the hadronisation interface is enabled, fully hadronised events are instead made available to a user routine in the `/HEPEVT/` format (see below).

PHYSICAL IMPROVEMENTS

The main theoretical developments with respect to the original version concern the inclusion of additional matrix elements to the tree-level kernel and a more sophisticated treatment of the photonic radiation, beyond the initial-state, strictly collinear approximation. Moreover, an hadronisation interface to `JETSET` has been also provided.

Tree-level EW four-fermion diagrams – In addition to double-resonant charged-current diagrams `CC03` already present in the previous version, the matrix element includes also the single-resonant charged-current diagrams `CC11` for μ and τ's in the final state, and `CC20` for final states containing electrons. This allows a complete treatment at the level of four-fermion EW diagrams of the semileptonic sample, which appears the most promising and cleanest for the direct mass reconstruction method due to the absence of potentially large "interconnection" effects [3]. Concerning `CC20` diagrams, the importance sampling technique has been extended to take care of the peaking behaviour of the matrix element when small momenta of the virtual photon are involved. As a consequence of the fact that the tree-level matrix-element is computed in the massless limit, a cut on the minimum electron (positron) scattering angle must be imposed. The inclusion of such a cut eliminates the problems connected with gauge-invariance in the case of `CC20` processes, for which the present version does not include any so-called "reparation" scheme [4, 5]. Anyway, when for instance a set of "canonical cuts" [1] is used, the numerical relevance of such gauge-invariance restoring schemes has been shown [4, 5] to be negligible compared with the expected experimental accuracy.

Photonic corrections – As far as photonic effects are concerned, the original version, as stated above, included only leading logarithmic initial-state corrections in the collinear approximation within the SF formalism. The treatment has been extended in a two-fold way: the contribution of final-state radiation has been included and the p_T/p_L effects have been implemented both for initial- and final-state radiation. The inclusion of the transverse degrees of freedom has been achieved by generating the fractional energy x_γ of the radiated photons by means of resummed electron structure functions $D(x;s)$ [6] ($x_\gamma = 1 - x$) and the angles using an angular factor inspired by the pole behaviour $1/(p \cdot k)$ for each charged emitting fermion. This allows to incorporate leading QED radiative corrections originating from infrared and collinear singularities, taking into account at the same time the dominant kinematic effects due to non-strictly collinear photon emission, in such a way that the universal factorized photonic spectrum is recovered. According to this procedure, the leading logarithmic corrections from initial- and final-state radiation are isolated as a gauge-invariant subset of the full calculation (not yet available) of the electromagnetic corrections to $e^+e^- \to 4f$. Due to the inclusion of p_T-carrying photons at the level of initial-state radiation, the Lorentz boost allowing the reconstruction of the hard-scattering event from the c.m. system to the laboratory one has been generalized to keep under control the p_T effects on the beam particles. Final state radiation and p_T/p_L effects are not taken into account in the adaptive integration branch.

Non-QED corrections – Coulomb correction is treated as in the original version on double-resonant `CC03` diagrams. QCD corrections are implemented in the present version in the naive form according to the recipe described in [1, 5]. The treatment of the leading EW contributions is unchanged with respect to the original version.

Hadronisation – Final-state quarks issuing from the electroweak 4-fermion scattering are not experimentally observable. An hadronisation interface is provided to the `JETSET` package [7] to allow events to be extrapolated to the hadron level, for example for input to a detector simulation program. Specifically, the 4-fermion event structure is converted to the `/HEPEVT/` convention, then `JETSET` is called to simulate QCD partonic evolution (via routines `LUJOIN` and `LUSHOW`) and hadronisation (routine `LUEXEC`). In making this conversion, masses must be added to the outgoing fermions, considered massless in the hard scattering process. This is done by rescaling the fermion momenta by a single scale factor, keeping the flight directions fixed in the rest frame of the four fermion system. In the QCD evolution phase, strings join quarks coming from the same W decay. The virtuality scale of the QCD evolution is taken to be the invariant mass-squared of each evolving fermion pair. No colour reconnection is included by default, although it could be implemented by appropriate modification of routine WWGJIF if required. Bose - Einstein correlations are neglected in the present version. The resulting event structure is then made available to the user in the /HEPEVT/ common block via a routine WWUSER for further analysis, such as writing out for later input to a detector simulation program. The WWUSER routine is also called at program initialisation time to allow the user to set any non-standard JETSET program options, for example, and at termination time to allow any necessary clean-up. A dummy WWUSER routine is supplied with the program. The only JETSET option which is changed by WWGENPV from its default value controls emission of gluons and photons by final-state partons[1], turning off final-state photon emission simulation from JETSET if activated in WWGENPV, to avoid double counting.

All the new features of the program can be switched on/off by means of separate flags, as described in the following.

3 Input

Here we give a short explanation of the input parameters and flags required when running the program.

OGEN(CHARACTER*1)

It controls the use of the program as a Monte Carlo event generator of unweighted events (OGEN = G) or as a Monte Carlo/adaptive integrator for weighted events (OGEN = I).

RS(REAL*8)

The centre-of-mass energy (in GeV).

OFAST(CHARACTER*1)

It selects (OFAST = Y) the adaptive integration branch, when OGEN = I. When this choice is done, the required relative accuracy of the numerical integration has to be supplied by means of the REAL*8 variable EPS.

NHITWMAX(INTEGER)

[1] JETSET parameter MSTJ(41)

Required by the Monte Carlo integration branch. It is the maximum number of calls for the Monte Carlo loop.

`NHITMAX(INTEGER)`

Required by the event-generation branch. It is the maximum number of hits for the hit-or-miss procedure.

`IQED(INTEGER)`

This flag allows the user to switch on/off the contribution of the initial-state radiation. If `IQED = 0` the distributions are computed in lowest-order approximation, while for `IQED = 1` the QED corrections are included in the calculation.

`OPT(CHARACTER*1)`

This flag controls the inclusion of p_T/p_L effects for the initial-state radiation. It is ignored in the adaptive integration branch where only initial-state strictly collinear radiation is allowed.

`OFS(CHARACTER*1)`

It is the option for including final-state radiation. It is assumed that final-state radiation can be switched on only if initial-state radiation including p_T/p_L effects is on, in which case final-state radiation includes p_T/p_L effects as well. Ignored in the adaptive integration branch.

`ODIS(CHARACTER*1)`

Required by the integration branch. It selects the kind of experimental distribution. For `ODIS = T` the program computes the total cross section (in pb) of the process; for `ODIS = W` the value of the invariant-mass distribution $d\sigma/dM$ of the system $d\bar{u}$ (`IWCH = 1`) or of the system $\bar{d}u$ (`IWCH = 2`) is returned (in pb/GeV).

`OWIDTH(CHARACTER*1)`

It allows a different choice of the value of the W-width. `OWIDTH = Y` means that the tree-level Standard Model formula for the W-width is used; `OWIDTH = N` requires that the W-width is supplied by the user in GeV.

NSCH(INTEGER)

The value of NSCH allows the user to choose the calculational scheme for the weak mixing angle and the gauge coupling. Three choices are available. If NSCH=1, the input parameters used are G_F, M_W, M_Z and the calculation is performed at tree level. If NSCH = 2 or 3, the input parameters used are $\alpha(Q^2), G_F, M_W$ or $\alpha(Q^2), G_F, M_Z$, respectively, and the calculation is performed using the QED coupling constant at a proper scale Q^2, which is requested as further input. The recommended choice is NSCH = 2, consistently with [1].

OCOUL(CHARACTER*1)

This flag allows the user to switch on/off the contribution of the Coulomb correction. Unchanged with respect to the old version of the program.

OQCD(CHARACTER*1)

This flag allows the user to switch on/off the contribution of the naive QCD correction.

ICHANNEL(INTEGER)

A channel corresponding to a specific flavour quantum number assignment can be chosen.

ANGLMIN(REAL*8)

The minimum electron (positron) scattering angle (deg.) in the laboratory frame. It is ignored when CC20 graphs are not selected.

SRES(CHARACTER*1)

Option for switching on/off single-resonant diagrams (CC11).

OCC20(CHARACTER*1)

Option for switching on/off single-resonant diagrams when electrons (positrons) occur in the final state (CC20).

OOUT(CHARACTER*1)

Option for "canonical" output containing results for several observables and their most important moments. It is active only in the Monte Carlo integration branch.

OHAD(CHARACTER*1)

Option for switching on/off hadronisation interface in the unweighted event generation branch.

4 Test run output

The typical new calculations that can be performed with the updated version of the program are illustrated in the following examples.

Sample 1
An example of adaptive integration is provided. The process considered is $e^+e^- \to e^+\nu_e d\bar{u}$ (`CC20`). The output gives the cross section, together with the energy and invariant-mass losses from initial-state radiation. "Canonical" cuts are imposed as in [1]. The input card is as follows:

```
OGEN = I
RS = 190.DO
OFAST = Y
EPS = 1.D-2
IQED = 1
OPT = N
OFS = N
ODIS = T
OWIDTH = Y
NSCH = 2
ALPHM1 = 128.07DO
OCOUL = N
OQCD = N
ICHANNEL = 9
ANGLMIN = 10.DO
SRES = Y
OCC20 = Y
OOUT = N
```

Sample 2
An example of weighted event integration is provided. Here the process considered is $e^+e^- \to \mu^+\nu_\mu d\bar{u}$ (`CC11`). "Canonical" cuts are imposed as before. The "canonical" output is provided. The input card differs from the previous one as follows:

```
RS = 175.DO
OFAST = N
NHITWMAX = 100000
OPT = Y
OFS = Y
OCOUL = Y
```

```
OQCD = Y
ICHANNEL = 13
OCC20 = N
OOUT = Y
```

Sample 3
An example of unweighted event generation including hadronisation is provided. A sample of 100 events corresponding to the full semileptonic channel is generated. The detailed list of an hadronised event is given. The input card differs from the first one as follows:

```
OGEN = G
RS = 175.D0
NHITMAX = 100
OPT = Y
OFS = Y
OCOUL = Y
OQCD = Y
ICHANNEL = 26
ANGLMIN = 5.D0
OHAD = Y
```

5 Conclusions

The program `WWGENPV 2.0` has been described. In its present version it allows the treatment of all the four-fermion reactions including the `CC03` class of diagrams as a subset. This means that all the semileptonic channels are complete from the tree-level diagrams point of view, whereas fully leptonic and fully hadronic channels are treated in the CC approximation. Since the most promising channels for the W mass reconstruction are the semileptonic ones, the present version of the code allows a precise analysis of such data. Moreover, NC backgrounds can be suppressed by proper invariant mass cuts, so that the code is also usable for fully hadronic and leptonic events analysis, with no substantial loss of reliability. Initial- and final-state QED radiation is taken into account within the SF formalism, including finite p_T/p_L effects in the leading logarithmic approximation. The Coulomb correction is included for the `CC03` graphs. Naive QCD and leading EW corrections are implemented as well. An hadronic interface to `JETSET` is also provided.

The code as it stands is a valuable tool for the analysis of LEP2 data, with particular emphasis to the threshold and direct reconstruction methods for the measurement of the W-boson mass. Speed and high numerical accuracy allow the use of the program also for fitting purposes.

The code is supported. Future releases of `WWGENPV` will include:

- an interface to the code `HIGGSPV` [1, 8] in order to treat all the possible four-fermion processes in the massless limit, including Higgs-boson signals;
- implementation of anomalous couplings;
- implementation of CKM effects;
- the extension of the hadronic interface to `HERWIG` [9].

References

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Test Run Output

Test run output 1

```
SQRT(S) =  190.0  GEV
M_Z =  91.1888  GEV
G_Z =  2.4974  GEV
M_W =  80.23  GEV
G_W =  2.03367033063195  GEV
STH2 =  .2310309124510679
GVE =  -1.409737267299689E-02
GAE =  -.185794027211796
GWF =  .230409927395451
GWWZ =  -.571479454308384


IFAIL=  0
NCALLS =  120592
XSECT FOR WEIGHTED EVENTS
XSECT =  .6133752577743349 +-  3.741996226354238E-03 (PB)

IFAIL=  0
NCALLS =  239448
ENERGY LOSS
ENL =  2.10061682664439 +-  3.009086376029191E-02 (GEV)

IFAIL=  0
NCALLS =  246756
INVARIANT MASS LOSS
IML =  2.08936495443206 +-  2.905625928853976E-02 (GEV)
```

Test run output 2

```
SQRT(S) =  175.0  GEV
M_Z =  91.1888  GEV
G_Z =  2.4974  GEV
M_W =  80.23  GEV
G_W =  2.03367033063195  GEV
STH2 =  .2310309124510679

GVE =  -1.409737267299689E-02
GAE =  -.185794027211796
GWF =  .230409927395451
GWWZ =  -.571479454308384

NCALLS =  95214 100000

XSECT FOR WEIGHTED EVENTS

EFF(Y) =  .9240040758891746
EFF(N) =  .9704498034839147
XSECT(Y) =  .4757101931318581 +-  2.533828802525367E-03 (PB)
XSECT(N) =  .4839578519633417 +-  2.552018837243229E-03 (PB)

                      CANONICAL OUTPUT

OBSERVABLE CUTS DIAGRAMS   RS      VALUE     MC ERROR

SIGMA (PB)  Y     CC11    175.0  .4757101  2.53383E-03
SIGMA (PB)  N     CC11    175.0  .4839578  2.55202E-03
T1CTHW      Y     CC11    175.0  .3077387  5.94105E-03
T2CTHW      Y     CC11    175.0  -.217813  2.65517E-03
T3CTHW      Y     CC11    175.0  -.149287  4.88436E-03
T4CTHW      Y     CC11    175.0  -.130416  3.47127E-03
T1CTHW      N     CC11    175.0  .3102274  5.91031E-03
T2CTHW      N     CC11    175.0  -.215368  2.65276E-03
T3CTHW      N     CC11    175.0  -.149196  4.84336E-03
T4CTHW      N     CC11    175.0  -.130814  3.43812E-03
T1CTHMU     Y     CC11    175.0  .333774  5.53691E-03
T2CTHMU     Y     CC11    175.0  -.318545  2.08559E-03
T3CTHMU     Y     CC11    175.0  -.218236  5.39418E-03
T4CTHMU     Y     CC11    175.0  -8.06308E-02  3.77469E-03
T1CTHMU     N     CC11    175.0  .3325118  5.47350E-03
T2CTHMU     N     CC11    175.0  -.32043  2.05915E-03
T3CTHMU     N     CC11    175.0  -.21926  5.36138E-03
T4CTHMU     N     CC11    175.0  -8.09428E-02  3.74979E-03
T1CTHSR     Y     CC11    175.0  .148885  4.59988E-03
T2CTHSR     Y     CC11    175.0  -.311119  2.31110E-03
T3CTHSR     Y     CC11    175.0  -8.34748E-02  4.69059E-03
T4CTHSR     Y     CC11    175.0  -7.81930E-02  3.84710E-03
```

T1CTHSR	N	CC11	175.0	.1486743	4.56510E-03
T2CTHSR	N	CC11	175.0	-.309691	2.30747E-03
T3CTHSR	N	CC11	175.0	-8.26744E-02	4.65586E-03
T4CTHSR	N	CC11	175.0	-7.80504E-02	3.81642E-03
XMU1	Y	CC11	175.0	.5250259	5.99384E-03
XMU2	Y	CC11	175.0	.2888953	3.56491E-03
XMU3	Y	CC11	175.0	.1652849	2.21269E-03
XMU4	Y	CC11	175.0	9.76726E-02	1.42417E-03
XMU1	N	CC11	175.0	.525016	5.93588E-03
XMU2	N	CC11	175.0	.2889403	3.53242E-03
XMU3	N	CC11	175.0	.1653616	2.19389E-03
XMU4	N	CC11	175.0	9.77576E-02	1.41285E-03
XG1	Y	CC11	175.0	1.28590E-02	2.11471E-04
XG2	Y	CC11	175.0	1.10076E-03	2.30737E-05
XG3	Y	CC11	175.0	1.53589E-04	4.44690E-06
XG4	Y	CC11	175.0	3.17221E-05	1.49813E-06
XG1	N	CC11	175.0	1.28810E-02	2.09985E-04
XG2	N	CC11	175.0	1.10500E-03	2.30841E-05
XG3	N	CC11	175.0	1.55089E-04	4.49931E-06
XG4	N	CC11	175.0	3.23389E-05	1.50661E-06
XG1L	Y	CC11	175.0	1.28590E-02	2.11471E-04
XG2L	Y	CC11	175.0	1.10076E-03	2.30737E-05
XG3L	Y	CC11	175.0	1.53589E-04	4.44690E-06
XG4L	Y	CC11	175.0	3.17221E-05	1.49813E-06
XG1L	N	CC11	175.0	1.28810E-02	2.09985E-04
XG2L	N	CC11	175.0	1.10500E-03	2.30841E-05
XG3L	N	CC11	175.0	1.55089E-04	4.49931E-06
XG4L	N	CC11	175.0	3.23389E-05	1.50661E-06
XG1V	Y	CC11	175.0	.0	.0
XG2V	Y	CC11	175.0	.0	.0
XG3V	Y	CC11	175.0	.0	.0
XG4V	Y	CC11	175.0	.0	.0
XG1V	N	CC11	175.0	.0	.0
XG2V	N	CC11	175.0	.0	.0
XG3V	N	CC11	175.0	.0	.0
XG4V	N	CC11	175.0	.0	.0
XM1	Y	CC11	175.0	-1.26840E-02	3.40080E-04
XM2	Y	CC11	175.0	1.99478E-03	5.72397E-05
XM3	Y	CC11	175.0	-3.12925E-04	1.31033E-05
XM4	Y	CC11	175.0	7.41696E-05	3.73455E-06
XM1	N	CC11	175.0	-1.28271E-02	3.38555E-04
XM2	N	CC11	175.0	2.02728E-03	5.73580E-05
XM3	N	CC11	175.0	-3.24971E-04	1.33342E-05
XM4	N	CC11	175.0	7.87204E-05	3.86960E-06

Test run output 3

```
 HADRONISATION VIA JETSET
 WWGJIF: Initialising WWGENPV to JETSET interface
 PHOTON FSR WILL BE HANDLED BY WWGENPV:
 TURNING OFF PHOTON FSR FROM JETSET
1
 SQRT(S) =  175.0  GEV
 M_Z =  91.1888  GEV
 G_Z =  2.4974  GEV
 M_W =  80.23  GEV
 G_W =  2.08823657515165  GEV
 STH2 =  .2310309124510679

 GVE =  -1.409737267299689E-02
 GAE =  -.185794027211796
 GWF =  .230409927395451
 GWWZ =  -.571479454308384
```

Event listing (summary)

I	particle/jet		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e+!		21	-11	0	.000	.000	-87.500	87.500	.001
2	!e-!		21	11	0	.000	.000	87.500	87.500	.001
3	!e+!		21	-11	1	.000	.000	-87.500	87.500	.001
4	!e-!		21	11	2	.000	.000	87.500	87.500	.001
5	gamma		1	22	1	.000	.000	.000	.000	.000
6	nu_e		1	12	0	45.589	-8.504	-7.296	46.945	.000
7	e+		1	-11	0	-32.518	1.009	-24.213	40.555	.001
8	gamma		1	22	7	-.063	-.003	-.054	.083	.000
9	(c~)	A	11	-4	0	-6.482	5.087	-14.629	16.844	1.350
10	(g)	V	11	21	0	-.912	-.166	-1.330	1.621	.000
11	(g)	A	11	21	0	-1.717	2.148	.149	2.754	.000
12	(g)	V	11	21	0	-.404	-.150	-.153	.457	.000
13	(g)	A	11	21	0	.524	.257	-.485	.759	.000
14	(g)	V	11	21	0	.568	5.813	-3.909	7.028	.000
15	(g)	A	11	21	0	-.833	.123	-.634	1.054	.000
16	(g)	V	11	21	0	-1.616	-.218	.984	1.904	.000
17	(g)	A	11	21	0	-.893	-.594	-.345	1.127	.000
18	(g)	V	11	21	0	-.064	-1.133	.124	1.141	.000
19	(u)	A	11	2	0	-1.275	-.657	4.823	5.032	.006
20	(u~)	V	11	-2	0	-1.276	.758	3.201	3.528	.006
21	(g)	A	11	21	0	.733	-.103	2.158	2.281	.000
22	(g)	V	11	21	0	.691	-.234	2.326	2.438	.000
23	(g)	A	11	21	0	.410	-1.788	16.927	17.027	.000
24	(s)	V	11	3	0	-.461	-1.646	22.354	22.420	.199
25	(string)		11	92	9	-13.104	10.511	-15.404	39.722	32.532

26	(D~0)	11	-421	25	-6.057	4.073	-13.996	15.894	1.865
27	(pi0)	11	111	25	-1.112	1.280	-.302	1.728	.135
28	(rho-)	11	-213	25	-1.158	1.158	-2.172	2.803	.676
29	(omega)	11	223	25	-.792	.558	.401	1.303	.774
30	(Sigma*~+)	11	-3114	25	.123	2.038	-1.332	2.787	1.351
31	(K*-)	11	-323	25	.319	1.963	-1.639	2.729	.896
32	(Delta+)	11	2214	25	-.155	1.330	-1.314	2.263	1.266
33	(rho-)	11	-213	25	-1.026	.221	.345	1.292	.670
34	(pi0)	11	111	25	-.256	.036	-.546	.619	.135
35	(rho0)	11	113	25	-.488	-.118	.538	1.103	.822
36	pi+	1	211	25	-.420	.013	-.275	.521	.140
37	pi-	1	-211	25	-.612	-.620	.002	.882	.140
38	(rho+)	11	213	25	-.474	-1.082	1.048	1.662	.520
39	(rho0)	11	113	25	-.997	-.339	3.839	4.136	1.122
40	(string)	11	92	20	.096	-3.014	46.967	47.695	7.733
41	p~-	1	-2212	40	-.233	.669	3.532	3.723	.938
42	p+	1	2212	40	.259	-.320	2.633	2.826	.938
43	(Delta~--)	11	-2224	40	-.208	-.282	7.298	7.431	1.357
44	pi+	1	211	40	.568	-.518	3.830	3.909	.140
45	(Lambda0)	11	3122	40	-.290	-2.562	29.673	29.806	1.116
46	(K*+)	11	323	26	-3.673	2.525	-9.054	10.129	.875
47	(rho-)	11	-213	26	-2.384	1.548	-4.942	5.765	.856
48	gamma	1	22	27	-1.055	1.186	-.310	1.617	.000
49	gamma	1	22	27	-.058	.094	.008	.111	.000
50	pi-	1	-211	28	-.837	1.095	-1.923	2.370	.140
51	(pi0)	11	111	28	-.321	.063	-.249	.433	.135
52	pi+	1	211	29	-.610	.314	.197	.727	.140
53	pi-	1	-211	29	-.236	.248	.217	.429	.140
54	(pi0)	11	111	29	.055	-.005	-.014	.146	.135
55	(Lambda~0)	11	-3122	30	.085	1.705	-.918	2.237	1.116
56	pi+	1	211	30	.038	.333	-.414	.551	.140
57	(K~0)	11	-311	31	.462	1.760	-1.507	2.414	.498
58	pi-	1	-211	31	-.143	.203	-.133	.315	.140
59	n0	1	2112	32	.123	.910	-1.024	1.665	.940
60	pi+	1	211	32	-.277	.420	-.290	.598	.140
61	pi-	1	-211	33	.005	.082	.159	.227	.140
62	(pi0)	11	111	33	-1.031	.138	.186	1.065	.135
63	gamma	1	22	34	-.201	-.017	-.301	.362	.000
64	gamma	1	22	34	-.055	.053	-.245	.257	.000
65	pi-	1	-211	35	-.071	-.134	.622	.655	.140
66	pi+	1	211	35	-.417	.016	-.084	.448	.140
67	pi+	1	211	38	.032	-.277	.386	.497	.140
68	(pi0)	11	111	38	-.506	-.804	.661	1.166	.135
69	pi-	1	-211	39	-.186	.113	.094	.275	.140
70	pi+	1	211	39	-.811	-.452	3.745	3.861	.140
71	p~-	1	-2212	43	-.135	-.544	5.493	5.600	.938
72	pi-	1	-211	43	-.073	.262	1.805	1.831	.140
73	n0	1	2112	45	-.262	-2.385	26.596	26.721	.940
74	(pi0)	11	111	45	-.028	-.177	3.077	3.085	.135

```
  75  (K0)          11    311   46   -2.419    1.634   -6.536    7.176     .498
  76  pi+            1    211   46   -1.253     .891   -2.517    2.953     .140
  77  pi-            1   -211   47    -.404     .604   -1.633    1.792     .140
  78  (pi0)         11    111   47   -1.980     .945   -3.310    3.973     .135
  79  gamma          1     22   51    -.223     .051    -.091     .246     .000
  80  gamma          1     22   51    -.098     .012    -.158     .187     .000
  81  gamma          1     22   54     .048    -.066     .004     .082     .000
  82  gamma          1     22   54     .006     .062    -.017     .064     .000
  83  p~-            1  -2212   55     .064    1.274    -.756    1.755     .938
  84  pi+            1    211   55     .021     .431    -.161     .482     .140
  85  (K_S0)        11    310   57     .462    1.760   -1.507    2.414     .498
  86  gamma          1     22   62    -.111     .044    -.011     .120     .000
  87  gamma          1     22   62    -.920     .094     .197     .945     .000
  88  gamma          1     22   68    -.034    -.065     .012     .074     .000
  89  gamma          1     22   68    -.472    -.740     .649    1.091     .000
  90  gamma          1     22   74    -.035    -.088    2.449    2.451     .000
  91  gamma          1     22   74     .007    -.089     .628     .634     .000
  92  (K_S0)        11    310   75   -2.419    1.634   -6.536    7.176     .498
  93  gamma          1     22   78   -1.877     .868   -3.149    3.768     .000
  94  gamma          1     22   78    -.103     .077    -.160     .205     .000
  95  pi-            1   -211   85     .270     .383    -.379     .618     .140
  96  pi+            1    211   85     .192    1.377   -1.128    1.796     .140
  97  pi+            1    211   92    -.563     .463   -2.034    2.165     .140
  98  pi-            1   -211   92   -1.857    1.171   -4.502    5.011     .140
                  sum:    .00          .000     .000     .000  175.000  175.000
NHIT =  100

XSECT FOR UNWEIGHTED EVENTS

EFF =  1.887112905965163E-03
XSECT =  6.79360646147459 +-  .6787193283232224 (PB)
NBIAS/NMAX =  .0
 USER TERMINATION
 A TOTAL OF  100 EVENTS WERE GENERATED
 THE TOTAL CROSS-SECTION WAS: 6.793606281280517E-09 MB
```