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WPHACT 1.0

A program for WW, Higgs and 4 fermion physics at e^+e^- colliders. [1]

Elena Accomando and Alessandro Ballestrero

INFN, Sezione di Torino, Italy
and
Dipartimento di Fisica Teorica, Università di Torino, Italy
v. Giuria 1, 10125 Torino, Italy.

Abstract

`WPHACT` (**W** W and Higgs Physics with **PHACT**) is a MC program and unweighted event generator which computes all Standard Model processes with four fermion in the final state at e^+e^- colliders. It is based on an helicity amplitude method which allows precise and fast evaluations of the matrix elements both for massless and massive fermions. Fermion masses for b quarks are exactly taken into account. QED initial state and Coulomb corrections are evaluated, while QCD final state corrections are included in an approximate formulation. Cuts can be easily introduced and distributions for any variable at parton level can be implemented. The contributions to the processes of neutral Standard Model or Susy Higgs can be included. Anomalous couplings effects for the triple coupling can be computed. An interface to hadronization is provided and Jetset can be directly called from the program.

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e-mail: ballestrero,accomando@to.infn.it

Program Summary

Title of program: WPHACT

Program obtainable by: anonymous ftp from ftp.to.infn.it in the directory pub/ballestrero.

Computer: DEC VAX, DEC ALPHA AXP, HP/APOLLO; *Installation:* INFN, Sezione di Torino, via P. Giuria 1, 10125 Torino, Italy

Operating system: VMS, OVMS, UNIX

Programming language used: FORTRAN 77

Memory required to execute with typical data: $\approx$ 500 KByte

No. of bits in a word: 32

Subprograms used: VEGAS[1], GAMMLN[2], RAN2[2].

No. of lines in distributed program: $\approx$ 15600

Keywords: high energy electron-positron collisions, four-fermion final state, W-pair production, Higgs, Z-pair production, LEP2, NLC, QED corrections, electron structure functions, Coulomb corrections, anomalous couplings.

Nature of physical problem
The forthcoming experiments at the high energy electron–positron collider LEP2 will be mainly concerned with WW physics and Higgs search. The production of two W's will allow the direct study of the triple-boson coupling and a precise measurement of the mass of the W. The search for the Higgs is of primary importance for understanding the problem of mass generation in the Standard Model (SM). Small deviations from the SM will be important for discovering possible new physics. Both WW and Higgs production will result in a four-fermion final state. It is therefore mandatory to have accurate predictions for all physical processes with a four fermion final state in order to have full control on signals as well as backgrounds to the processes of interest. The same kind of processes will also play a fundamental role in electron–positron accelerators at higher energy which will be able to extend Higgs search at higher values of the mass and probe triple gauge boson physics and gauge cancellations.

Method of solution
Full tree level matrix elements for all processes are computed by means of subroutines which make use of the helicity formalism of ref. [3]-[4]. The number of Feynman diagrams in the various channels varies from 3 to 144. The velocity in computing these amplitudes that the above mentioned method allows, becomes therefore essential to take exactly into account fermion masses and to obtain high precision in a reasonable amount of CPU time.

Different integration variables for the phase space are employed in order to dispose of the peak structure of the resonating diagrams for the different processes. The adaptive

routine VEGAS[1] is used for the numerical evaluation of the integrals.

Distributions can be produced to study the behaviour of any variable of interest. For simulation purposes, the program can also be used as an event generator that provides unweighted events. An interface to standard hadronization packages and specifically to Jetset[5] is provided.

Restrictions on the complexity of the problem
Only for processes with b's in the final state the masses of the fermions are accounted for. Final state radiation is not implemented. Initial state radiation (ISR) is included through Structure Functions and no photons p_t is computed. QCD corrections are introduced only in an approximate way.

Typical running time

The running time strongly depends on the process considered and on the precision requested. Some examples are reported in Table 1. For the typical final state $\mu^- \; \bar{\nu}_\mu \; u \; \bar{d}$ with ISR the time per call on AlphaStation 600 5/333 is $6. \times 10^{-5}$ sec. The longest time for call is $6. \times 10^{-4}$ sec. for $b \; \bar{b} \; b \; \bar{b}$. At Lep2 energies, 5 M calls (about 5 minutes) are used to obtain for $\mu^- \; \bar{\nu}_\mu \; u \; \bar{d}$ a cross section (with ISR) with a typical estimated relative error of 2×10^{-4} sec. The same process can be evaluated in about 40 sec. with less than 1 M calls at permill level. All above running times have to be multiplied approximately by a factor 3 for an AlphaServer 2100 4/200 computer.

Unusual features of the program:
`REAL*8` and `COMPLEX*16` variables and `STRUCTURE` declarations are used. Compilation on Hp/Apollo stations has to be performed with -k option.

Long Write-Up

1 Introduction

After LEP 1 precision measurements and top discovery at Tevatron, which have shown an impressive agreement of the Standard Model (SM) with data, a new era is starting in which the mechanism of spontaneous symmetry breaking and the non abelian structure of the model will be directly tested by the experiments. At LEP 2 it will be possible to measure the contribution of trilinear gauge boson couplings, and for the first time the production of two W's and two Z's will be seen. The properties of the W's will be measured with great accuracy and these will also contribute to put more stringent limits on the Higgs mass. At the same time, direct searches for the Higgs boson will allow to find it, if its mass is not greater than $\approx$ 100 GeV. These studies and the search for the Higgs will be extended to LHC and to the next e^+e^- collider which will presumably approach the TeV range. Theoretical arguments claim for the onset of a 'new physics' regime at this scale, so that LEP 2 and the future machines will search not only for new particles, like the MSSM Higgs, but for any deviation from the SM predictions.

It is evident in this scenario that theoretical predictions must reach a high accuracy to confront and analyze the data. WW and Higgs physics and their radiative corrections have been thoroughly studied in the past (for a complete review on this subject see ref.[6]). It has however been realized that on shell predictions may not be accurate enough, as the measured final states will not correspond to, say, two W's or a Higgs and a Z, but rather to 4 fermions. This implies that one has to deal with irreducible backgrounds, i.e. contributions to the matrix element for the envisaged final state which do not correspond for instance to two W's production and decay and cannot be separated from it, even if they can be reduced with appropriate cuts. Moreover many different final states are not experimentally distinguishable, and one has to take into account that the properties of the W and Higgs bosons can be only reconstructed by a careful analysis of all four fermion final states. For top physics, trilinear and quadrilinear coupling studies and for the Higgs, if it will be as heavy as to decay into two W's, also six fermion final states will have to be analyzed at future e^+e^- colliders.

Several codes for four fermion physics have been produced in the last years [7]-[8]-[9]-[10], and they have been used for phenomenological studies mainly concerning WW and Higgs Physics [11]-[12]-[13]. Only some of them can produce accurate results for all four fermion processes, with the inclusion of all the relative Feynman diagrams. During last year's LEP 2 Workshop the results produced by the different codes have been extensively compared [9]-[10]-[14]. The codes have very different characteristics. Some of them are classified (see ref.[9]) as semi-analytical [12] or as deterministic[8]. All the others belong to the broad Monte Carlo's (MC) class, where a further subdivision can be made among unweighted event generators and Monte Carlo integration programs. The semi-analytical codes perform as much as possible of the integrations analytically, leaving only low dimensional integration to be performed numerically. The MC and deterministic programs on the contrary perform the whole of the 9-dimensional

integration (including ISR) numerically. This implies that by their own nature the semi-analytical codes may easily reach an extreme precision, but they cannot implement all cuts: normally only those on the invariant masses are viable. The MC and Deterministic programs can implement all cuts, but of course they are normally slower and less precise. The deterministic program[8] implements all cuts analitically, while only few of them can be implemented in MC's as limits on the integration variables.

`WPHACT` belongs to the family of the MC integrators and event generators. It has been developed only in the last year but it has been compared and tested continuously both in LEP 2 Workshop [9]-[10]-[14] and in phenomenological studies[13]. One of the main characteristic of the code is that of using a new helicity amplitude formalism[3]-[4] which allows to compute matrix elements in a very fast and precise way. As a consequence, the code can reach high precision in a relatively short time. This is particularly useful for example when one wants to use `WPHACT` to produce distributions at parton level. If one requests that the range of a variable be divided in a large number of bins, of the order of 100 say, one can reach very low errors on each bin only producing a number of weighted events of the order of ten millions. And this is precisely what `WPHACT` can do in a reasonable time (see Table 1) even for the most complicated processes as $e^+e^- \to b\bar{b}b\bar{b}$ with all diagrams and taking b masses into account.

As already mentioned in the program summary, `WPHACT` allows to compute QED initial state and Coulomb corrections, and also QCD final state corrections in a 'naive' formulation, exact in the limit in which only double resonant diagrams are considered and no cuts are imposed. Possible cuts are explicitly provided and any distribution at parton level can be implemented. `WPHACT` is also an unweighted event generator. The events can be produced while evaluating the cross section and also after this has been computed. In this second case any number of events can a priori be requested. An interface to hadronization is in the code and it may be linked directly to Jetset. As far as 'new physics' is concerned, Anomalous Couplings effects for the triple coupling and cross sections for neutral MSSM Higgs h and A can be computed.

In presence of unstable gauge bosons the imaginary part of their propagators violates gauge invariance in tree level computations of processes like those we are considering. The way to restore it and get a reliable result is that of including relevant parts of fermionic corrections, thus fulfilling Ward identities[15]. From a numerical point of view these corrections become relevant only for some particular processes and cuts. For instance in the process $e^-\ \bar{\nu}_e\ u\ \bar{d}$ no discrepancy between approximate and correct computation is appreciable if a cut of the order or greater than $\approx 5^o$ is applied to the angle between the electron and the beam[13]. The present version of `WPHACT` does not include these corrections. Also final state radiation and effects due to transverse momenta of QED radiation are not computed at present by `WPHACT`. Subtle theoretical problems are connected to these issues and probably only a full computation $O(\alpha)$ can assess them. As far as final radiation is concerned, this can in any case be introduced via Jetset when `WPHACT` is used as an event generator.

In the following we will describe the main features of the code and the way to make use of it. Some useful examples of test runs will be given at the end.

2 General Features

2.1 Processes

WPHACT computes all SM processes with four fermion in the final state at e^+e^- colliders. Final states with t quarks are not considered, as the t's are known to decay immediately to 3 other fermions.

The processes are enumerated in Table 2 and 3. They are divided in 4 classes. The first (CC) and the third (NC) contain all processes which have only diagrams with charged or neutral currents respectively. In the second (Mix) they have both kind of diagrams. In the last class (NC+Higgs) we have included the processes with b's in the final state, where we may have important contributions from the Higgs. These are the only processes in which WPHACT accounts for Higgs diagrams and it treats the b quarks as massive both in the phase space and in the matrix elements.

In WPHACT the momenta of the particles in the final state, as reported in the tables, are respectively $p3$, $p4$, $p5$, $p6$. The order of the final particles is important when one wants to choose a certain set of cuts for the final state, or to ask the program to compute some distribution at parton level. It has to be noticed that for CC and Mixed processes the order in which the momenta are passed to the high energy standard COMMON/HEPEVT[16] and hence also to Jetset may be different from the one used by the program: in the common particles 3 and 4 are respectively the particle and the antiparticle that correspond to a W^+, 5 and 6 to a W^-.

Many different final states give the same cross section at parton level. This is the case for instance of $\mu^-\ \mu^+\ d\ \bar{d}$ and $\tau^-\ \tau^+\ s\ \bar{s}$ if the mass differences are neglected. For this reason to each final state two flags are attributed, iproc and ich, which serve to identify it. The first refers to the group which has the same diagrams (whose number is indicated in the first column) and cross section, the second to the specific final state of the group. It has to be noticed that for CC processes charge conjugate final states belong to the same iproc. The amplitudes for a CC final state and its charge conjugate for a given set of four momenta, are not equal. To obtain the same amplitude one must consider the parity transformed final state of the charge conjugate. This implies that if the cuts are not invariant under parity transformation (i.e. both a set of final four momenta and its parity transformed are accepted or not accepted) the two cross sections will be slightly different. An example of this is given by $e^+e^- \to \mu\bar{\nu}_\mu u\bar{d}$ and $e^+e^- \to \mu^+\nu_\mu\bar{u}d$ when in both processes the cut angle of the μ with e^+ is different from that with e^-. WPHACT accounts exactly also for these slight differences. The main reason to specify the exact final state instead of just indicating the group is however to distinguish among final states when hadronization via Jetset is performed, as this depends on the final state particles.

The production of two W's which decay in two fermions each is described by 3 Feynman diagrams. The cross section corresponding to these 3 diagrams only is often referred to as CC3[9]. Of course CC3 does not correspond to physical processes, and the three diagrams alone do not constitute a gauge invariant set, but for some energies and final states and cuts they might be a reasonable approximation. For all CC and CC+NC final states, WPHACT can compute the complete process or the CC3 contribution

to it.

All neutral current processes are normally computed at order α^4. When there are four quarks in the final state, there are however contributions $O(\alpha^2\alpha_s^2)$ of diagrams in which a gluon is exchanged between the two quark lines. This contribution is of course enhanced by the coupling and can be relevant for some processes, energies and cuts. For instance we have found[10] that for $\sigma(e^+e^- \to b\bar{b}b\bar{b})$ at $E_{cm} = 175$ GeV and with $m_{b\bar{b}} \geq 20$ GeV, it is more than twice the pure electroweak contribution, while it becomes only about one third at $E_{cm} = 192$ GeV. `WPHACT` may or not include this contribution. If one includes it, one must be aware that part of it may also be accounted for by two quarks final state computations if parton shower and hadronization are added. The interplay among these two ways of treating such a contribution is surely strongly dependent on cuts used and deserves a careful analysis case by case.

2.2 Helicity amplitudes

All amplitudes for the processes computed by `WPHACT` are evaluated with the helicity formalism of ref. [3], which is based on the insertion in spinor lines of a complete set of states for every fermion propagator. These states are eigenstates of $\not{p}$, where p is the momentum flowing in the fermion propagator. They are chosen to be generalizations of the spinors used in ref.[17]. In this way one needs not to decompose every $\not{p}$ in terms of the external momenta, as it is the case for some other helicity method, and the numerator of the fermion propagator assumes a very simple expression. The computation is in this way reduced to the evaluation of one τ matrix for every vertex and to combine them together. For the definition of these 4×4 matrices we refer again to ref. [3]. In this base the matrix corresponding to the numerator of every fermion propagator is diagonalized for massless lines and for massive lines the non zero off diagonal elements are simply given by the mass itself. It has to be noticed that a τ matrix fully describes the vertex both in the case of insertion of an external particle and in that of the insertion of a whole piece of diagram. Moreover, combining together two τ matrices corresponding to two vertices, one obtains a new τ matrix corresponding to the two vertices and so on. These simple facts allow to achieve a great modularity in the computation, to keep track of partial results and to set up a recursive scheme which computes and stores for later use subdiagrams of increasing size and complexity. Moreover the massive case is not more complicated than the massless one. Only more helicity indices are of course needed. As a consequence, the codes for massive amplitudes written in this way are not much slower, as it is normally the case, than those with massless fermions.

The code for `WPHACT` amplitudes has been completely written with the help of PHACT [4] (**P**rogram for **H**elicity **A**mplitudes **C**alculations with **T**au matrices). This program implements the method described above in a fast and efficient way. It essentially writes directly the optimized fortran code for every τ matrix corresponding to a vertex and for combining τ matrices together. It also writes the code for external gauge boson polarization vectors, triple couplings, and so on. With it, one avoids as much as possible computing expressions which will turn out to be zero. Moreover in the computations of the amplitudes we have avoided any call to external subroutines and functions which might be time consuming for such a repetitive part of the program.

This of course leads to a somewhat longer program than usual.

2.3 Phase space and integration variables

To describe the phase space, the four final fermions are divided in two couples. Every couple corresponds to two particles that can decay from a W in CC, from a Z or a Higgs in NC contributions. Take for instance the case in which f_3 f_4 and f_5 f_6 are grouped together. Natural variables are then the two invariant masses $m_{34} = \sqrt{(p3+p4)^2}$, $m_{56} = \sqrt{(p5+p6)^2}$ and the decay angles of one particle for each couple $\theta_3^*, \phi_3^*, \theta_5^*, \phi_5^*$ in the rest frame of the couple itself.

Whenever the energy is such that a couple of particles can have an invariant mass m equal to M, the mass of a real W or Z or Higgs, the corresponding amplitude squared will be almost proportional to a Breit-Wigner peak:

$$\frac{1}{(m^2-M^2)^2+\gamma^2}. \tag{1}$$

It is therefore convenient to use instead of the invariant mass m of the couple an integration variable proportional to :

$$x = arctg\frac{M^2-m^2}{\gamma}. \tag{2}$$

Every variable is always transformed to the interval $0 \div 1$. When substitution (2) is performed on both invariant masses, we refer to it as double resonant mapping. If only one or no substitution is performed we have respectively a single resonant or non resonant mapping. In `WPHACT` there is the possibility to choose among these mappings. Most of the results at LEP 2 energies are better obtained with the double resonant phase space. For some processes one might have a peak also for low invariant masses, due to photon propagator contributions. Whether or not this peak becomes relevant depends strongly on the cuts. When such is the case, one has a variable m to which there correspond two peaks: the Breit-Wigner and the photonic one. After having tried different mappings, we have found that, given the fact that `VEGAS` is an adaptive routine, it is better just to use a non resonant mapping for m in this case.

When one has to deal with a Mixed (or NC+Higgs) process, the peaking structure of CC (Higgs) and that of NC contributions is different. In such cases `WPHACT` automatically integrates separately the two contributions. To one of them it is added the interference.

The contribution to $e^+e^- \to b\bar{b}b\bar{b}$ of diagrams with h A intermediate states and that of h Z give two (A and Z) Breit Wigner peaks on the same variable m. In this case a double mapping of the type (2) is performed simultaneously on it.

With ISR two more integrations are to be performed and we use also for this case a change of variables to level the form of the distribution functions, as we will see in the following section.

All integrals are computed with `VEGAS`. For this routine it is convenient to use normally more than one iteration. In every iteration the integral is evaluated and at

the end the various results are combined together. This allows to optimize the number of points computed in the various regions of the integration variables. It may also be useful to perform some thermalizing iteration with a lower number of points to be evaluated. The thermalizing iterations are just used to adjust the grid and not for the final result.

The adaptivity of `VEGAS` is such that, even if most cuts are implemented in the program with the use of `if` statements which act as θ functions, usually this does not correspond to a sensible lost in time and precision. The cuts on the invariant masses which are function of integration variables are implemented directly on integration limits.

2.4 QED and QCD corrections

QED initial state radiation is taken into account in `WPHACT` via the structure function approach[18]. In it, the cross section $\sigma(s)$ is obtained by means of a convolution with functions $D(x,s)$ which account for the radiative emission by the initial particles of a fraction x of their energy:

$$\sigma(s) = \int dx_1\, dx_2\, D(x_1,s) D(x_2,s)\, \sigma(x_1 x_2 s) \tag{3}$$

The expression for the $O(\alpha^2)$ $D(x,s)$ in leading log approximation used by `WPHACT` is:

$$\begin{aligned} D(x,s) &= \frac{\exp\left[\left(\frac{3}{8}-\frac{\gamma_E}{2}\right)\beta\right]}{2\,\Gamma\left(1+\frac{1}{2}\beta\right)}\,\beta(1-x)^{\beta/2-1} - \frac{\beta}{4}(1+x) \\ &+ -\frac{1}{32}\beta^2\left[4(1+x)\ln(1-x) + \frac{1+3x^2}{1-x}\ln x + 5 + x\right], \end{aligned} \tag{4}$$

with $\beta = 2\,\alpha/\pi\,(\ln(s/m_e^2)-1)$ and γ_E the Euler constant.

Given this form of structure functions, it is convenient for the MC to perform a change of variables in order to flatten out the peak of the distributions near $x = 1$. Thus we have chosen instead of x_1 and x_2 the integration variables

$$y_i = (1-x_i)^{\beta/2} \qquad (i = 1,2) \tag{5}$$

Another important QED correction to be accounted for is the so called Coulomb singularity, which is due to the electromagnetic interaction of the two W bosons at low velocity. It regards of course only CC and Mixed processes near the threshold energy for production of two W's. In that region however its correction amounts to a few percent. In `WPHACT` this correction is computed with the method of ref.[19].

Final state QCD corrections are taken into account by means of the so called 'naive' approach. In it, the various contributions to the amplitude are multiplied by the corrections relative to the decay width of the W's, of the Z's or of the Higgs. This approach disregards all corrections to non resonant diagrams and corrects exactly the

decay vertices only if no cuts are applied. Nevertheless they represent at present an estimate of a sizeable effect.

For NC, CC and Mixed processes the QCD corrections appear in an overall factor: $(1+\frac{\alpha_s}{\pi})$ for semi-leptonic case and $(1+2\frac{\alpha_s}{\pi})$ for non-leptonic one. Gluon exchange diagrams and $CC(NC)\otimes QCD$ interference are not multiplied by a correction factor as we only consider the first order in α_s. For the processes involving b quarks, Higgs exchange diagrams receive the following strong correction: $(1+5.67\frac{\alpha_s}{\pi})$ for semi-leptonic case and $(1+6.67\frac{\alpha_s}{\pi})$ for non-leptonic one. The $NC\otimes Higgs$ interference is multiplied by $(1+3.335\frac{\alpha_s}{\pi})$ for semi-leptonic case and $(1+4.335\frac{\alpha_s}{\pi})$ for non-leptonic one. By default α_s in the preceding formulas is taken at M_W scale for CC diagrams, at M_Z scale for NC and NC+Higgs ones. Its value can however be changed in a `DATA` statement. For consistency, when corrections are applied to the vertices they should also be present in the same way in the widths appearing in the propagators of the bosons. This is surely achieved if one chooses to let `WPHACT` compute the corresponding total widths.

2.5 Susy and Anomalous couplings

Besides SM Higgs processes in two b's and two other fermions, `WPHACT` computes also Susy neutral Higgs production in the same final channels. The only MSSM process which cannot be deduced just changing coupling constants with respect to the SM is $e^+e^-\to hA\to b\bar{b}b\bar{b}$, where h is the lightest CP-even and A the CP-odd Susy Higgs. The cross section for the above diagram is computed as well as all other contributions to 4 b's final state. As for all other Higgs processes, the contributions of all diagrams containing the Higgses can be optionally separated from the rest. The Susy parameters to be given in input are the mass of the pseudoscalar Higgs A, and the ratio between the two vacuum expectation values $tg(\beta)$. In the simplest version of the MSSM, all Higgs masses are predicted in terms of these two parameters. At one–loop these predictions are substantially modified and an additional dependence on the top mass m_t and on the common squark mass $m_{\tilde{t}}$ is introduced. We have used the following relations:

$$\begin{aligned} M_h^2 &= \frac{1}{2}[M_A^2+M_Z^2+\epsilon/\sin^2\beta] \\ &\quad -\frac{1}{2}\left\{[(M_A^2-M_Z^2)\cos 2\beta+\epsilon/\sin^2\beta]^2+(M_A^2+M_Z^2)^2\sin^2 2\beta\right\}^{1/2}, \end{aligned} \tag{6}$$

where

$$\epsilon=\frac{3e^2}{8\pi^2 M_W^2\sin^2\theta_W}m_t^4\ln\left(1+\frac{m_{\tilde{t}}^2}{m_t^2}\right). \tag{7}$$

The squark mass scale $m_{\tilde{t}}$ has been chosen to be 1 TeV. The mixing angle α in the CP–even sector, which together with β determines all couplings of the MSSM Higgses, is defined by

$$\tan 2\alpha=\frac{(M_A^2+M_Z^2)\sin 2\beta}{(M_A^2-M_Z^2)\cos 2\beta+\epsilon/\sin^2\beta}. \tag{8}$$

As far as Anomalous Couplings computations are concerned, we have implemented those relative to the trilinear vertex. Starting from the most general effective

lagrangian[20], one gets for them nine possible couplings just imposing Lorentz and electromagnetic invariance. These are further reduced to 6 if CP invariance is imposed, and 5 of them are separately C and P invariant. Among the various possible parametrizations of these 6 quantities, we have implemented that of ref[21].

2.6 Distributions and unweighted event generation

One of the main purposes of a dedicated code as `WPHACT` is to perform phenomenological studies and confront theoretical predictions with experiments. To this aim, the possibility of computing differential cross sections or distributions is extremely important. Special care has been devoted to this aspect and practically any distribution at parton level can be computed while the total cross section is evaluated. Explanations of how to request and implement distributions are given in section 3.1. In practice, one has just to write down in an include file the definition of the variables to be distributed in terms of the 4-momenta of the outgoing particles and to specify in input the number of bins and the interval for every such variable. Files with the extension .dat will contain in output the cross section and the evaluated statistical error relative to every single bin. A large amount of bins (of the order of 100) per variable with a low statistical error can easily be achieved.

If the distribution refers to leptons in the final state, it will correspond to some directly measurable variable. For quarks, the hadronization process might prevent this possibility. Distributions at parton level are however much faster to obtain than the ones with particles which have to be computed after parton shower and hadronization. They constitute a very effective tool to study the physical problem at hand and to deconvolute perturbative effects from non perturbative ones. Examples of two distributions obtained with `WPHACT` are given in figs. 1,2.

With `WPHACT` it is also possible to generate unweighted events and to store their 4-momenta. From them one can of course successively produce any distribution. To reach low statistical errors in this way a high number of events has to be stored, but they can be produced in a reasonable time: for instance after having evaluated the cross section, it takes 48 min. to produce 500000 unweighted events for MIX19 $e^+e^- \to \mu^- \mu^+ \nu_\mu \bar{\nu}_\mu$.

`WPHACT` can generate unweighted events with the hit or miss method while evaluating the integral. In that case the first effective iteration after thermalization is used to find the maximum and the second to generate unweighted events. One may also produce them after having evaluated the integral. This feature can be used both to readjust the maximum if some event exceeded it with the first method, or to ask for a predetermined number of events to generate. When unweighted events are produced, they may be passed directly to Jetset using the routine `AB_LU4FRM`. So one can for instance run the first time just to find an appropriate maximum and a correct cross section (and eventually to produce parton distributions). Afterwards one verifies whether it is convenient to multiply the maximum for an appropriate factor and with a second run one generates the desired number of events. To save time, the parton shower and hadronization procedure with the link to JETSET may be activated only in this second run.

As explained in sect. 2.3 , the integration of Mixed and NC+Higgs complete processes is performed in two steps, with different mappings of the phase space. Also the event generation will be performed in two steps in these cases. This implies that the events that come first will have been selected with the CC (Higgs) contribution and the remaining with the NC contribution. The resulting sample will have the right proportion of events, but from them one cannot take away an arbitrary part. If for some reason it is necessary to diminish the generated events and still have an umbiased sample for the whole process, this must be done choosing at random which events are to be taken.

3 Program Structure

In the following two sections we will explain how to use the input parameters to exploit the various possibilities of `WPHACT`, and the meaning of the various subroutines and functions of the code. At the end of the paper we report and briefly comment some significant examples of test runs.

3.1 Input

The way the input parameters must be given in the command file is easily understood just looking at the program lines containing the `READ` statements. We therefore reproduce them and explain their meaning in the following.

Every parameter whose initial is `i` or `n` is `integer*4`. All others are `real*8`. When a variable has a yes/no option the value `1` corresponds to `YES`, `0` to `NO`. All energies must be expressed in GeV.

```
READ*,e_cm
```
`e_cm` is the centre of mass energy.

```
READ*,iproc
READ*,ich
```
The value for these two parameters must be read directly from Table 2 and 3. `iproc` selects the group of processes with the same cross section at parton level with symmetric cuts, while `ich` selects among them the specific final state. The choice of `ich` is relevant only if hadronization is performed via Jetset or if in CC processes cuts are considered for which a final configuration and its charge conjugate behave differently. In all other cases `ich=1` gives the same results as any other value indicated in the tables.

```
IF(iproc.GE.33)THEN
  READ*,rmb
  READ*,icch
  IF(icch.NE.2)THEN
    READ*,isusy
    IF(isusy.EQ.0)THEN
      READ*,rmh
```

```
    ELSE
      READ*,rma
      READ*,tgb
    ENDIF
  ENDIF
ENDIF
```

The processes for which `iproc` $\geq$ `33` are those with massive b's in the final state. `rmb` fixes the b mass for the phase space and the matrix elements. The b mass in the Higgs coupling may be different from `rmb` and it has to be set in the `DATA`. In these processes one can have diagrams with SM or Susy MSSM neutral (A or h) Higgs. One has the possibility of choosing to compute only these diagrams (Higgs signal: `icch=1`), only those without Higgs (to which we refer as Higgs background: `icch=2`) or the whole set of diagrams (Higgs+Background+interference: `icch=3`).
`isusy=0` corresponds to SM Higgs, `isusy=1` to Susy Higgs. In the first case one has to specify the Higgs mass (`rmh`), in the second the mass of the pseudoscalar Higgs A (`rma`), and the ratio between the two vacuum expectation values $tg(\beta)$ (`tgb`).

```
IF (iproc.GE.6.AND.iproc.LE.8) THEN
  READ*,iccnc
ENDIF
```

The processes for which `6` $\leq$ `iproc` $\leq$ `8` are those which have both CC and NC diagrams (Mixed). For these one may choose to compute only the CC contribution (`iccnc=1`), the NC one (`iccnc=2`) or the total process including CC+NC+interference (`iccnc=3`).

```
READ*,ips_cc
READ*,ips_nc
```

`ips_cc` and `ips_nc` allow to choose among the various phase space mappings for the integration. `ips_cc` refers to the phase space of CC or Higgs signal contributions. `ips_nc` to NC contributions. Of course when only CC processes or only Higgs signal are considered `ips_nc` is irrelevant. The same happens to `ips_cc` when only neutral processes without Higgs are computed. Both parameters can assume 3 values: `1` for double resonant mapping, `2` for single resonant, `3` for non resonant. When `2` is chosen the invariant mass over which a transformation is performed to take care of the resonant peak is that formed by particles 3 and 4.

```
READ*,icc3
```

yes/no CC3 contribution only. When `icc3` is set to `1` only the three double resonant diagrams (CC3) corresponding to WW production and decay are computed. If `icc3=0` all CC contributions are computed.

```
READ*,isr
```

yes/no ISR: initial state radiation (ISR) is included when `isr=1`, not computed if `isr=0`.

```
READ*,ipr
```

yes/no running widths: this flag selects among running or constant Z, W, Higgs widths in s-channel propagators:

`ipr=0` Z, W, Higgs boson constant width

`ipr=1` Z, W, Higgs boson s-dependent width

`READ*,iswgcomp`

yes/no $sin^2\theta_W$ and g computed. If this flag is set to `1`, it is used the renormalization scheme in which $sin^2\theta_W$ and g are computed from Z mass, W mass, G_f. If it is set to `0`, the values for $sin^2\theta_W$ and α_{em} are taken from the `DATA`. The relation between g and α_{em} is always $g^2 = 4\pi\alpha_{em}/sin^2\theta_W$.

`READ*,igwcomp,igzcomp,ighcomp`

yes/no W, Z, H width computed. When one of these flags is `=1`, the corresponding W, Z or Higgs width is computed by standard formulas. If it is `=0`, the value for the corresponding width is the one given in the `DATA`.

`READ*,icoul`

Coulomb corrections may (`icoul=1`) or not (`icoul=0`) be computed.

`READ*,istrcor`

yes/no 'naive' QCD corrections to the cross sections. It has to be noticed that, if `istrcor=0` and quarks are present in the final state, the eventual width computations (performed when `igwcomp, igzcomp or ighcomp` is `=1`) do not include QCD corrections.

`READ*,iqu`

yes/no QCD diagrams for 4-quarks NC. The order at which one computes four fermion diagrams is α^2. There are some diagrams in NC processes $O(\alpha\alpha_s)$ whose contribution can be important and can be included choosing `iqu=1`.

```
READ*,icut
IF(icut.EQ.1)THEN
  READ*,e_min
  READ*,e_max
  READ*,rm_min
  READ*,rm_max
  READ*,pt_min
  READ*,pt_max
  READ*,icos
  READ*,thbeam_min
  READ*,thbeam_max
  READ*,thsep_min
  READ*,thsep_max
ENDIF
```

Cuts may (`icut=1`) or not (`icut=0`) be implemented. If `icut=1` all default cuts of the above list must be specified.

`e_min` and `e_max` correspond to the 4 lower and upper energies for particle 3, 4, 5, 6 respectively.
`rm_min` and `rm_max` are the 6 invariant mass lower and upper limits respectively. They must be given in the following order: m(34), m(35), m(36), m(45), m(46), m(56).
`pt_min` and `pt_max` are the 4 lower and upper values of the transverse momenta. The order is as before 3, 4, 5, 6.
`icos = 1` implies that the following angular cuts must be expressed in terms of the cosines of the angles. With `icos = 0` one must instead specify the angles in degrees.
`thbeam_min` and `thbeam_max` are the 4 lower and the 4 upper limits for the angle that particles 3,4,5,6 produce with the beam (e^+).
`thsep_min` and `thsep_max` are the 6 lower and the 6 upper limits for particle-particle angles: the order is again (3 4), (3 5), (3 6), (4 5), (4 6), (5 6).

```
READ*,ianc
IF(ianc.EQ.1)THEN
  READ*, delz,xf,xz,yf,yz,zz
ENDIF
```

Anomalous Couplings contributions may (`ianc=1`) or not (`ianc=0`) be computed. If one wants to compute them, he must also specify the values of the parameters $\delta_Z, x_\gamma, x_Z, y_\gamma, y_Z, z_Z$ defined in ref. [21]

```
READ*,idistr
IF(idistr.EQ.1)THEN
  READ*,ndistr
  DO i=1,ndistr
    READ*,nsubint(i)
    READ*,(distr_estrinf(i,j),j=1,nsubint(i)+1)
    READ*,(nbin_number(i,j),j=1,nsubint(i))
  ENDDO
ENDIF
```

Distributions at parton level can be easily implemented. If one wants to use this possibility the flag `idistr` must be `=1`, `=0` otherwise. In the program there is the line:
`*     include 'abdis.dis'`
which must be uncommented before compiling if one choose `idistr=1`. In this case the file `abdis.dis` must be written for implementing distributions, as in the following example:

```
      string(1)='Distribution: bb~ invariant mass'
      distr_var(1)=sqrt((p3(0)+p4(0))**2-(p3(1)+p4(1))**2-
     &  (p3(2)+p4(2))**2-(p3(3)+p4(3))**2)
      string(2)='Distribution: Charged lepton energy '
      distr_var(2)=p5(0)
```

In it, the title of the ith distribution is given in the `character*60 string(i)` and the ith quantity to be distributed in bins, computed from the particle momenta, is assigned to `distr_var(i)`. The resulting cross sections corresponding to every single bin will be

stored in the file `abdis.dat`. Each line will contain 3 numbers: the value of the central point of the bin, the distribution for the bin (cross section divided by the width of the bin, in order to reproduce $d\sigma/dx$ for a distribution of the variable x) and the estimated statistical error.
`ndistr` is the number of distributions defined in `abdis.dis`.
For each distribution `i`, one must specify:

`nsubint(i)`, the number of sub-intervals with different binning in the ith distribution (=1 when all bins are of the same length). The subintervals must be contiguous.

`(distr_estrinf(i,j),j=1,nsubint(i)+1)`, the lower limits of each subinterval (which coincide with the upper limit of the previous one as they must be contiguous) and, as last entry, the upper limit of the last subinterval. In case all bins are of the same length, this corresponds only to the lower and upper limit of the interval for the distribution.

`(nbin_number(i,j),j=1,nsubint(i))`, the number of bins in each subinterval.

```
READ*,iflat
IF(iflat.EQ.1)THEN
  READ*,scalemax
  READ*,istorvegas
  READ*,irepeat
  IF(irepeat.eq.2)THEN
    READ*, nflevts
  END IF
  READ*,istormom
  READ*,ijetset
  IF(iproc.GE.6.AND.iproc.LE.8)THEN
    READ*,interf
  ENDIF
ENDIF
```

One may choose (`iflat=1`) or not (`iflat =0`) to generate unweighted events. In the first case, the number of iterations (`itmx`) which must be specified in the following must be `2`. The integration routine will perform the requested number of iterations for thermalization (see `iterm, ncall_term,itmx_term` below) and then the two iterations in which the integral is evaluated. In the first iteration the maximum for the hit-or-miss procedure will be determined and used in the second iteration where the unweighted generation will take place. After the run the .log file will report as usual the result of the integration and its error. It will also report the maximum used for the hit-or-miss procedure, the maximum found in the second iteration, and the number of events which were greater than the maximum used.
There is also the possibility to repeat the generation just starting directly from the second iteration. This might be useful if too many events exceeded the maximum chosen, or to generate a predetermined number of events.

`scalemax` is the coefficient by which the maximum of the first iteration can be multiplied, in order to vary the efficiency of the hit-or-miss procedure or in order to avoid

values exceeding the maximum.
VEGAS data are (if istorvegas=1) or not (if istorvegas=0) stored after the first iteration in ABVEGAS.DAT (in ABVEGAS_CC.DAT and ABVEGAS_NC.DAT for Mixed and Higgs+background processes). Stored VEGAS data are necessary if one wants to rerun the program to generate again unweighted events. When the program is rerun using VEGAS data stored, the maximum of the second iteration will be automatically used as the new maximum.
irepeat has to be set to 0 for the first run. It has to be set to 1 if one wants to rerun exactly with the same input starting from the second iteration. In this case the same weighted points will be reproduced. irepeat=2 has to be chosen if one wants to rerun with the same input and grid as before, but letting the program run until a requested number of events nfltevts is reached. For both cases irepeat=1 and 2 one might of course vary scalemax, ijetset and istormom with respect to the first run with irepeat=0.
The momenta of the unweighted events are written in ABMOM.DAT (or ABMOM_SIGN.DAT and ABMOM_BACK.DAT) file if istormom=1, they are not written if istormom=0. ABMOM_SIGN.DAT is used for CC or Higgs events, ABMOM_BACK.DAT for NC events when mixed or Higgs+background processes are computed.
Every unweighted event is passed to the standard COMMON HEPEVT. If ijetset=1 the subroutine AB_LU4FRM is called for interfacing Jetset. If ijetset=0, HEPEVT is still filled but the interface to Jetset not called.
One may choose to produce events for mixed processes in which the interference is added to CC (interf= 1), or to NC (interf=0). This implies that also the interference will be considered to have the same colour structure of CC or NC respectively (see section 5.3 of ref. [16].

```
READ*,acc
READ*,iterm
READ*,ncall_term
READ*,itmx_term
READ*,ncall
READ*,itmx
```

These parameters specify how the integration will be performed by VEGAS.
acc is the integration accuracy. When this accuracy is reached after a certain integration iteration, the remaining iterations are not performed.
If iterm=1 a certain number of integration iterations (=itmx_term) are used only for adapting the integration grid. Their result is not used for the final integral. Each thermalizing iteration makes use of a maximum of ncall_term evaluations of the amplitude. If iterm=0 these iterations are skipped. One or two itmx_term with few ncall_term are often useful.
itmx is the maximum number of iterations used to evaluate the integral. Each iteration makes use of a maximum of ncall evaluations of the amplitude. Normally it is better not to use more than about five iterations. If higher precision is requested it is convenient to increase ncall and not itmx
As a final remark about the choice of these parameters, one must be aware of the fact

that final results with a χ^2 much greater than the number of iterations are not to be trusted. When this happens, one has to increase `ncall`.

In addition to the parameters in input, other parameters are fixed in the main program by the following `DATA` statement and may be eventually changed.

```
      DATA rmw/80.26d0/, rmz/91.1884d0/, rmt/175.d0/, rmc/0.75d0/,
     &     rmtau/1.78d0/, rmb_run/2.9d0/,
     &     gamw/2.08d0/, gamz/2.4974d0/, gamh/1.278d-03/,
     &     gf/1.1663892199930875d-05/, alfainv/128.07d0/,
     &     alfas_cc/0.1255d0/, alfas_nc/0.1230d0/,
     &     s2w/0.231030912451068d0/, rms/1000.d0/
```

`rmw`, `rmz`, `rmt`, `rmc`, `rmtau` are respectively the W, Z, top, c and tau masses.
`rmb_run` is the quark b mass used for the Higgs coupling.
`gamw`, `gamz`, `gamh` are the total W, Z and Higgs width.
`gf` is the Fermi coupling constant; `alfainv` is $1/\alpha_{em}$ at the appropriate scale; `alfas_cc` and `alfas_nc` are $\alpha_s(M_W)$ and $\alpha_s(M_Z)$.
`s2w` is the Weinberg $\sin^2(\theta_W)$ and `rms` the SUSY scale.

3.2 Program implementation

In this section, `WPHACT` subroutines and functions are briefly described.

```
      double precision FUNCTION fxn(x,wgt)
      COMMON/abpara/rmx1,gamx1,gx1,rmx2,gamx2,gx2,beta,rlim,s_col,
     &  x1_min,x2_min,xm,smin,emcoupl,estrinf1,estrinf2,estrmed2,
     &  rmx3,gamx3,gx3
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &            qcdcor_cc,qcdcor_nc
      COMMON/abopzi/isr,ipr,ips,iccnc,iproc,ich,ichcj,ips_cc,ips_nc,
     &  icos,icch,isusy,icut,igwcomp,igzcomp,ighcomp,iswgcomp
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
      COMMON/abhigg/rmb,rmb2,rmh,rmh2,gamh,rhzz,rhww,rhbb
      COMMON/absusy/rma,rma2,rzha
      COMMON/abcuts/e_min(3:6),e_max(3:6),thbeam_min(3:6),
     &  thbeam_max(3:6),thsep_min(6),thsep_max(6),rm_min(6),rm_max(6),
     &  beamcut_min(3:6),beamcut_max(3:6),sepcut_min(6),sepcut_max(6),
     &  rm_min2(6),rm_max2(6),pt_min(3:6),pt_max(3:6),e_cm
      COMMON/abstat/ncall_eff
      COMMON/abdist/distr_estrinf(ndismax,nestrmax),bin_width(ndismax,
     &  nintmax),distr_local(ndismax,nbinmax,nitmax),distr_loc_mix
     &  (ndismax,nbinmax,nitmax),dev_local(ndismax,nbinmax,nitmax),
     &  dev_loc_mix(ndismax,nbinmax,nitmax),tail_local(ndismax,nitmax),
     &  tail_loc_mix(ndismax,nitmax)
```

```
      COMMON/abidis/ncallbin(ndismax,nbinmax,nitmax),
     &  ncallbin_mix(ndismax,nbinmax,nitmax),nbin_number(ndismax,
     &  nintmax),nbin_sum(ndismax,nintmax),nsubint(ndismax),ndistr,
     &  idistr,it1,it2,init
      COMMON/abcdis/string(ndismax)
      COMMON/abflat/rmaxfxn,rmaxfxn_1it,rmaxfxn_2it,rmaxfxn_cc_1it,
     &  rmaxfxn_cc_2it,rmaxfxn_nc_1it,rmaxfxn_nc_2it,scalemax
      COMMON/abifla/itmx,novermax,iflat,iseed,istorvegas,istormom,iterm,
     &  ijetset,interf
      COMMON/abfla2/irepeat,nevent,nflevts
      COMMON /abrann/ idum
      COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
      COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
     &  JMOHEP(2,NMXHEP),JDAHEP(2,NMXHEP),PHEP(5,NMXHEP),VHEP(4,NMXHEP)
      EXTERNAL ee_4f,ee_bbvv,ee_bbmumu,ee_bbbb,ee_bbee
```

The function `fxn` is called by `VEGAS` and evaluates the phase space and ISR. After momenta reconstruction, it eventually implements the cuts and then calls the appropriate functions to compute the matrix elements. It also performs all calculations relative to distributions, it fills the common `HEPEVT`, and if necessary it calls the interface to Jetset, `AB_LU4FRM`.

```
      double precision FUNCTION ee_4f(p1,p2,p3,p4,p5,p6)
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &  qcdcor_cc,qcdcor_nc
      COMMON/abparc/czipr,ccz,cwipr,ccw,chipr,cch,caipr,cca
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &       f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
```

`ee_4f` computes the amplitude for all the processes with massless four fermions in the final state. It also evaluates Coulomb, QCD corrections and Anomalous Couplings. It is called by `fxn`.

```
      double precision FUNCTION ee_bbvv(p1,p2,p3,p4,p5,p6)
      COMMON/abhigg/rmb,rmb2,rmh,rmh2,gamh,rhzz,rhww,rhbb
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &  qcdcor_cc,qcdcor_nc
      COMMON/abparc/czipr,ccz,cwipr,ccw,chipr,cch,caipr,cca
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abcopl/zvl,zvr,fqdl,fqdr,zqdl,zqdr,fqul,fqur,zqul,zqur
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
```

`ee_bbvv` is called by `fxn` and gives the massive amplitude relative to the processes:
$e^+e^- \to b\bar{b}\nu_l\bar{\nu}_l \qquad l{=}(e,\mu,\tau).$

```
      double precision FUNCTION ee_bbmumu(p1,p2,p3,p4,p5,p6)
```

```
      COMMON/abhigg/rmb,rmb2,rmh,rmh2,gamh,rhzz,rhww,rhbb
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &  qcdcor_cc,qcdcor_nc
      COMMON/abparc/czipr,ccz,cwipr,ccw,chipr,cch,caipr,cca
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abcopl/zvl,zvr,fqdl,fqdr,zqdl,zqdr,fqul,fqur,zqul,zqur
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
```

ee_bbmumu is called by fxn and computes the massive amplitude relative to the processes:

$e^+e^- \to b\bar{b}q\bar{q} \quad q{=}(u,d,c,s)$
$e^+e^- \to b\bar{b}l^-l^+ \quad l{=}(\mu,\tau)$

```
      double precision function ee_bbee(q1,q2,q3,q4,q5,q6)
      COMMON/abhigg/rmb,rmb2,rmh,rmh2,gamh,rhzz,rhww,rhbb
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &  qcdcor_cc,qcdcor_nc
      COMMON/abparc/czipr,ccz,cwipr,ccw,chipr,cch,caipr,cca
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abcopl/zvl,zvr,fqdl,fqdr,zqdl,zqdr,fqul,fqur,zqul,zqur
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
```

ee_bbee is called by fxn and gives the massive amplitude relative to the process :

$e^+e^- \to b\bar{b}e^-e^+$

```
      double precision FUNCTION ee_bbbb(p1,p2,p3,p4,p5,p6)
      COMMON/abopzi/isr,ipr,ips,iccnc,iproc,ich,ichcj,ips_cc,ips_nc,
     &  icos,icch,isusy,icut,igwcomp,igzcomp,ighcomp,iswgcomp
      COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
     &  qcdcor_cc,qcdcor_nc
      COMMON/abparc/czipr,ccz,cwipr,ccw,chipr,cch,caipr,cca
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abcopl/zvl,zvr,fqdl,fqdr,zqdl,zqdr,fqul,fqur,zqul,zqur
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
      COMMON/abhigg/rmb,rmb2,rmh,rmh2,gamh,rhzz,rhww,rhbb
      COMMON/absusy/rma,rma2,rzha
```

ee_bbbb computes the massive amplitude relative to the process $e^+e^- \to b\bar{b}b\bar{b}$. It contains both SM (hZ) and MSSM ($hZ + hA$) Higgs diagrams. It is called by fxn.

```
      Subroutine AB_LU4FRM(ichar,IRAD,ITAU,IERR)
      COMMON/LUJETS/N,K(4000,5),P(4000,5),V(4000,5)
      COMMON/LUDAT1/MSTU(200),PARU(200),MSTJ(200),PARJ(200)
```

This routine is an interface to Jetset that we have produced modifying the subroutine LU4FRM by T. Sjöstrand to adapt it to WPHACT. The comment lines of the routine AB_LU4FRM may be useful.

```
      SUBROUTINE vegas(region,ndim,fxn,init,ncall,itmx,nprn,tgral,sd,
     *  chi2a,acc,xi,it,ndo,si,swgt,schi)
      EXTERNAL fxn
      COMMON/abresl/resl(10),standdevl(10)
      COMMON /abrann/ idum
      COMMON/abchia/calls
      COMMON/abstat/ncall_eff
      COMMON/abfla2/irepeat,nevent,nflevts
```

This subroutine by P. Lepage [1] performs the multidimensional integrations. It has been modified in order to obtain unweighted event generation, distributions and separated integration of CC (or Higgs) and NC contributions both for MIX and massive b processes. It is called by the main program and it calls the function fxn.

```
      FUNCTION ran2(idum)
      COMMON/absalv/iv,iy,idum2
```

This function is a random number generator. Both VEGAS and WPHACT make use of it.

```
      SUBROUTINE rebin(rc,nd,r,xin,xi)
```

This routine is used by VEGAS.

```
      double precision FUNCTION gammln(xx)
```

It computes the logarithm of the Γ function entering in the electron structure functions.

```
      SUBROUTINE initialize
      COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
     &  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
      COMMON/abcopl/zvl,zvr,fqdl,fqdr,zqdl,zqdr,fqul,fqur,zqul,zqur
      COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
     &  imix,icoul,istrcor,idownl,idownr,ianc
      COMMON/abflat/rmaxfxn,rmaxfxn_1it,rmaxfxn_2it,rmaxfxn_cc_1it,
     &  rmaxfxn_cc_2it,rmaxfxn_nc_1it,rmaxfxn_nc_2it,scalemax
      COMMON/abifla/itmx,novermax,iflat,iseed,istorvegas,istormom,iterm,
     &  ijetset,interf
      COMMON/abfla2/irepeat,nevent,nflevts
      COMMON/abopzi/isr,ipr,ips,iccnc,iproc,ich,ichcj,ips_cc,ips_nc,
     &  icos,icch,isusy,icut,igwcomp,igzcomp,ighcomp,iswgcomp
      COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
     &  JMOHEP(2,NMXHEP),JDAHEP(2,NMXHEP),PHEP(5,NMXHEP),VHEP(4,NMXHEP)
```

For a process chosen by means of input parameters, this subroutine, called by the main program, computes all chiral coupling constants and it initializes all variables to be passed to other parts of the program and to the common HEPEVT.

```
 SUBROUTINE printer(rmh,gamh,rma,gama,tgb,rmb)
 COMMON/abopzi/isr,ipr,ips,iccnc,iproc,ich,ichcj,ips_cc,ips_nc,
&  icos,icch,isusy,icut,igwcomp,igzcomp,ighcomp,iswgcomp
 COMMON/abparb/rmw2,gamw,rmz2,rmt2,rcotw,pi,alfa_me,qcdcoupl,
&            qcdcor_cc,qcdcor_nc
 COMMON/abcoup/fer,fel,zer,zel,f3l,f4l,f5l,f6l,z3l,z4l,z5l,z6l,
&  f3r,f4r,f5r,f6r,z3r,z4r,z5r,z6r,wcl,delz,xf,xz,yf,yz,zz
 COMMON/abflag/icc,icc3,i3e,i4e,i3q,i5q,iqu,i34e,i56ve,ibbveve,iid,
&  imix,icoul,istrcor,idownl,idownr,ianc
 COMMON/abcuts/e_min(3:6),e_max(3:6),thbeam_min(3:6),
&  thbeam_max(3:6),thsep_min(6),thsep_max(6),rm_min(6),rm_max(6),
&  beamcut_min(3:6),beamcut_max(3:6),sepcut_min(6),sepcut_max(6),
&  rm_min2(6),rm_max2(6),pt_min(3:6),pt_max(3:6),e_cm
 COMMON/abinpu/rmw,rmz,rmb_run,rmc,rmc_run,rmtau,gamz,gf,s2w,
&  alfainv,alfas_cc,alfas_nc
 COMMON/abflat/rmaxfxn,rmaxfxn_1it,rmaxfxn_2it,rmaxfxn_cc_1it,
&  rmaxfxn_cc_2it,rmaxfxn_nc_1it,rmaxfxn_nc_2it,scalemax
 COMMON/abifla/itmx,novermax,iflat,iseed,istorvegas,istormom,iterm,
&  ijetset,interf
 COMMON/abfla2/irepeat,nevent,nflevts
```

This subroutine is devoted to write in the output file all the essential informations about the selected process, input, options and variables defined in the DATA. It is called by the main program.

4 Conclusions

We have described version 1.0 of WPHACT . The program computes all processes with a 4 fermion final state. All its main features and options are listed in the Program Summary. The way of using it is mainly explained in the input section 3.1, and some useful examples can be found in the test runs.

WPHACT is a MC integrator and event generator portable and self contained. For the amplitudes computation it makes use of a rather new helicity method which allows fast evaluations. This we consider to be an essential ingredient, together with careful mappings of the integration variables, in order to combine the usual advantages of MC's with high precision and reliability.

Acknowledgments

We are extremely grateful to Dima Bardin and Giampiero Passarino. With them we had continuous discussions and comparisons among our program, GENTLE/4fan and WTO. The intrinsic difference of the three approaches has allowed the most useful tests. In particular WTO and WPHACT had the unique chance to be developed contemporarily

and we have surely benefited of the intense day by day collaboration with Giampiero Passarino. We like to thank all our colleagues of the LEP2 WW working group and in particular the two coordinators Ronald Kleiss and Dima Bardin for the live atmosphere of the group as well as for comparisons and exchange of informations. We gratefully acknowledge in particular friendly and useful discussions with Roberto Pittau. Finally we thank Roberto Contri for his advises and collaboration in testing `WPHACT`.

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Test runs

We report here two significant test runs for CC and NC+Higgs processes with different options.

Run 1:
This run computes the cross section and two distributions for the full CC20 process $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$. A double resonant phase space on the W masses has been chosen to perform the integration over the 9 variables. ISR, Coulomb and QCD corrections have been included as well as Anomalous Couplings. The following cuts are implemented: $E_{e^-,u,\bar{d}} \geq 20$ GeV, $M_{u\bar{d}} \geq 10$ GeV, $|cos(\theta_{beam})|_{e^-,u,\bar{d}} \leq 0.9$, $|cos(\theta_{u\bar{d}})| \leq 0.9$.
Distributions of the M_{W^+} invariant mass and the outgoing electron energy are calculated. The corresponding plots are reported in figs. 1,2. They contain 51 and 150 bins respectively. The relative statistical errors are a few permill for every bin. They are not visible in the figures.
The relative error obtained is 0.019%. The total CPU time on AlphaStation 600 5/333 is 24 min and 36 sec, which corresponds to $0.6E-04$ sec. per call.

Input file:

```
$r wphact
190.d0                                ! centre of mass energy
4                                     ! selects the kind of process
1                                     ! selects the channel
1                                     ! CC( or Higgs signal) phase space
1                                     ! NC phase space
0                                     ! yes/no CC3 only
1                                     ! yes/no ISR
1                                     ! yes/no running widths
0                                     ! yes/no s2w and g computed
1 0 0                                 ! yes/no W, Z, Higgs width computed
1                                     ! yes/no Coulomb corrections
1                                     ! yes/no QCD corrections
0                                     ! yes/no QCD diagrams
1                                     ! yes/no cuts
20.d0 0.d0 20.d0 20.d0                ! 4 energy lower cuts
300.d0 300.d0 300.d0 300.d0           ! 4 energy upper cuts
0.d0 0.d0 0.d0 0.d0 0.d0 10.d0        ! 6 invariant mass lower limits
300.d0 300.d0 300.d0 300.d0 300.d0 300.d0 !6 invariant mass upper limits
0.d0 0.d0 0.d0 0.d0                   ! 4 transverse momenta lower cuts
300.d0 300.d0 300.d0 300.d0           ! 4 transverse momenta upper cuts
1                                     ! angular cuts in deg (0) or cos (1)
0.9d0 1.d0 0.9d0 0.9d0                ! 4 particle-beam angle lower cuts
-0.9d0 -1.d0 -0.9d0 -0.9d0            ! 4 particle-beam angle upper cuts
1.d0 1.d0 1.d0 1.d0 1.d0 0.9d0        ! 6 particle-particle angle lower cuts
-1.d0 -1.d0 -1.d0 -1.d0 -1.d0 -0.9d0 !6 part-part angle upper cuts
1                                     ! yes/no anomalous couplings
-0.5d0 0.d0 0.d0 0.d0 0.d0 0.d0       ! anomalous couplings parameters
1                                     ! yes/no distributions
2                                     ! number of distributions
3                                     ! sub-intervals number with different binning
```

```
75.71d0 78.21d0 82.31d0 84.81d0    ! limits of each sub-interval
5 41 5                             ! number of bins in each sub-interval
1                                  ! sub-intervals number with different binning
15.d0 90.d0                        ! limits of each sub-interval
150                                ! number of bins in each sub-interval
0                                  ! yes/no flat generation
0.0001d0                           ! integration accuracy
1                                  ! yes/no thermalization
2000000                            ! thermalization calls per iteration
2                                  ! thermalization iterations
10000000                           ! integration calls per iteration
2                                  ! integration iterations
$exit
```

File abdis.dis :

```
        string(1)='Distribution: Mw+'
        distr_var(1)=sqrt((p5(0)+p6(0))**2-(p5(1)+p6(1))**2-
     &  (p5(2)+p6(2))**2-(p5(3)+p6(3))**2)
        string(2)='Distribution: Lepton energy'
        distr_var(2)=p3(0)
```

Output file:

```
-----------------------------------------------------

CC20 )  e-(p3) ve~(p4) u(p5) d~(p6)
WW signal + background

INPUT
cm energy             =          0.1900000D+03 GeV

DATA
Z mass                =          0.9118840D+02 GeV
W mass                =          0.8026000D+02 GeV
Z width               =          0.2497400D+01 GeV
Gf                    =          0.1166389D-04 GeV-2
s2w                   =          0.2310309D+00
1/alfa_em             =          0.1280700D+03
alfas_cc              =          0.1255000D+00

DERIVED QUANTITIES
W width               =          0.2088612D+01 GeV

OPTIONS
both Z and W boson s-dependent width
Born + QED
Coulomb corrections included
Naive QCD corrections included
Double resonant "CC" phase space

Anomalous coupling parameters:
------------------------------
```

```
 delz = -0.5    xf =  0.0
 xz   =  0.0    yf =  0.0
 yz   =  0.0    zz =  0.0

Cuts :
-----------------
ENERGY_MIN(3,4,5,6)           =(  20.00,  0.00, 20.00, 20.00 ) GeV
ENERGY_MAX(3,4,5,6)           =(  300.00, 300.00, 300.00, 300.00 ) GeV
MASS_MIN(34,35,36,45,46,56)   =(   0.00,  0.00,  0.00,  0.00,  0.00, 10.00 ) GeV
MASS_MAX(34,35,36,45,46,56)   =(  300.00, 300.00, 300.00, 300.00, 300.00, 300.00 ) GeV
PT_MIN(3,4,5,6)               =(   0.00,  0.00,  0.00,  0.00 ) GeV
PT_MAX(3,4,5,6)               =(  300.00, 300.00, 300.00, 300.00 ) GeV
COSBEAM_MAX(3,4,5,6)          =(   0.90,  1.00,  0.90,  0.90 )
COSBEAM_MIN(3,4,5,6)          =(  -0.90, -1.00, -0.90, -0.90 )
COSSEP_MAX(34,35,36,45,46,56) =(   1.00,  1.00,  1.00,  1.00,  1.00,  0.90 )
COSSEP_MIN(34,35,36,45,46,56) =(  -1.00, -1.00, -1.00, -1.00, -1.00, -0.90 )
--------------------------------------------------


Thermalization

input parameters for vegas:  ndim=  9  ncall=    1835008.
                             it=    1  itmx=    2

iteration no.  1:            effective ncall=    1052601
iteration no.  1: integral = 0.4101226    +/-  0.50E-03
all iterations:   integral = 0.4101226    +/- 0.503E-03 chi**2/it'n = 0.12E-07

iteration no.  2:            effective ncall=    1273154
iteration no.  2: integral = 0.4100550    +/-  0.29E-03
all iterations:   integral = 0.4100716    +/- 0.249E-03 chi**2/it'n = 0.13E-01

CC process

input parameters for vegas:  ndim=  9  ncall=    9765625.
                             it=    1  itmx=    2

iteration no.  1:            effective ncall=    6914065
iteration no.  1: integral = 0.4101164    +/-  0.11E-03
all iterations:   integral = 0.4101164    +/- 0.110E-03 chi**2/it'n = 0.00E+00

iteration no.  2:            effective ncall=    6934162
iteration no.  2: integral = 0.4100655    +/-  0.11E-03
all iterations:   integral = 0.4100908    +/- 0.774E-04 chi**2/it'n = 0.11

--------------------------------------------------

Sigma = 0.4100908D+00 +/- 0.774D-04 (pb)

--------------------------------------------------------------------------------
```

Run 2:
This output refers to NC25 process $e^+e^- \to b\bar{b}\mu^-\mu^+$ with massive b's in the final state.

The cross section receives contributions both from Higgs and Background NC diagrams integrated by means of two phase spaces accounting for ZH and ZZ peak structure respectively. ISR and QCD corrections are included. The cuts are: $M_{b\bar{b}} \geq 50$ GeV and $M_Z - 25$ GeV $\leq M_{\mu\mu} \leq M_Z + 25$ GeV. This output shows in particular two possible examples of unweighted events generation: the first run produces unweighted events (which are stored in `ABMOM_SIGN(BACK).DAT`) with an efficiency of a few percent. Making use of the Vegas data saved in `VEGAS_CC(NC).DAT` during the first run, a second run allows to generate a prefixed number of 50000 unweighted events in a short CPU time.
The relative error obtained is 0.0028%. The total CPU time for the both runs on AlphaStation 600 5/333 is 4 h 4 min and 5 sec.

First input file:

```
$r wphact
190.d0                                ! centre of mass energy
36                                    ! selects the kind of process
1                                     ! selects the channel
2.9d0                                 ! quark "b" mass
3                                     ! icch (=1 Higgs, =2 Backg., =3 Higgs+Backg.)
0                                     ! yes/no SUSY
80.d0                                 ! Higgs mass
1                                     ! CC( or Higgs) phase space
1                                     ! NC phase space
0                                     ! yes/no CC3 only
1                                     ! yes/no ISR
1                                     ! yes/no running widths
1                                     ! yes/no s2w and g computed
1 0 1                                 ! yes/no W, Z, Higgs width computed
0                                     ! yes/no Coulomb corrections
1                                     ! yes/no QCD corrections
0                                     ! yes/no QCD diagrams
1                                     ! yes/no cuts
0.d0 0.d0 0.d0 0.d0                   ! 4 energy lower cuts
300.d0 300.d0 300.d0 300.d0           ! 4 energy upper cuts
50.d0 0.d0 0.d0 0.d0 0.d0 66.1888d0 ! 6 invariant mass lower limits
300.d0 300.d0 300.d0 300.d0 300.d0 116.1888d0 !6 invariant mass upper limits
0.d0 0.d0 0.d0 0.d0                   ! 4 transverse momenta lower cuts
300.d0 300.d0 300.d0 300.d0           ! 4 transverse momenta upper cuts
0                                     ! angular cuts in deg (0) or cos (1)
0.d0 0.d0 0.d0 0.d0                   ! 4 particle-beam angle lower cuts
180.d0 180.d0 180.d0 180.d0           ! 4 particle-beam angle upper cuts
0.d0 0.d0 0.d0 0.d0 0.d0 0.d0         ! 6 particle-particle angle lower cuts
180.d0 180.d0 180.d0 180.d0 180.d0 180.d0 !6 part-part angle upper cuts
0                                     ! yes/no anomalous couplings
0                                     ! yes/no distributions
1                                     ! yes/no flat generation
1.1d0                                 ! scale factor for the maximum
1                                     ! yes/no data VEGAS stored
0                                     ! yes/no second iteration repeated
1                                     ! yes/no flat momenta stored
0                                     ! yes/no Jetset program tied
```

```
0.0005d0                          ! integration accuracy
1                                 ! yes/no thermalization
1000000                           ! thermalization calls per iteration
2                                 ! thermalization iterations
20000000                          ! integration calls per iteration
2                                 ! integration iterations
$exit
```

First output file:

```
-----------------------------------------------------

NC25 )  b(p3) b~(p4) mu-(p5) mu+(p6)
Higgs signal + background

INPUT
cm energy             =          0.1900000D+03 GeV
Higgs mass            =          0.8000000D+02 GeV
b mass                =          0.2900000D+01 GeV

DATA
Z mass                =          0.9118840D+02 GeV
W mass                =          0.8026000D+02 GeV
c mass                =          0.7500000D+00 GeV
tau mass              =          0.1780000D+01 GeV
Z width               =          0.2497400D+01 GeV
Gf                    =          0.1166389D-04 GeV-2
alfas_nc              =          0.1230000D+00

DERIVED QUANTITIES
W width               =          0.2090172D+01 GeV
Higgs width           =          0.1937374D-02 GeV
s2w                   =          0.2253258D+00
1/alfa_em             =          0.1312146D+03

OPTIONS
both Z and H boson s-dependent width
Born + QED
Naive QCD corrections included
Double resonant "Higgs signal" phase space
Double resonant "Higgs background" phase space
Cuts :
-----------------
ENERGY_MIN(3,4,5,6)           =(   0.00,  0.00,  0.00,  0.00 ) GeV
ENERGY_MAX(3,4,5,6)           =(  300.00, 300.00, 300.00, 300.00 ) GeV
MASS_MIN(34,35,36,45,46,56)   =(  50.00,  0.00,  0.00,  0.00,  0.00, 66.19 ) GeV
MASS_MAX(34,35,36,45,46,56)   =(  300.00, 300.00, 300.00, 300.00, 300.00, 116.19 ) GeV
PT_MIN(3,4,5,6)               =(   0.00,  0.00,  0.00,  0.00 ) GeV
PT_MAX(3,4,5,6)               =(  300.00, 300.00, 300.00, 300.00 ) GeV
THBEAM_MIN(3,4,5,6)           =(   0.00,  0.00,  0.00,  0.00 ) deg
THBEAM_MAX(3,4,5,6)           =( 180.00,180.00,180.00,180.00 ) deg
THSEP_MIN(34,35,36,45,46,56)  =(   0.00,  0.00,  0.00,  0.00,  0.00,  0.00 ) deg
```

```
THSEP_MAX(34,35,36,45,46,56)  =( 180.00,180.00,180.00,180.00,180.00,180.00 ) deg
-----------------------------------------------------

Flat events generation
VEGAS data stored in ABVEGAS_CC(NC).DAT
Maximum scale factor = 0.110D+01
Flat events stored in ABMOM_SIGN.DAT
Flat events stored in ABMOM_BACK.DAT

Thermalization

input parameters for vegas:  ndim=  9  ncall=     786432.
                             it=    1  itmx=    2

iteration no.  1:            effective ncall=     743476
iteration no.  1: integral = 0.1661491E-01+/-  0.75E-05
all iterations:   integral = 0.1661491E-01+/- 0.745E-05 chi**2/it'n = 0.00E+00

input parameters for vegas:  ndim=  9  ncall=     786432.
                             it=    1  itmx=    2

iteration no.  1:            effective ncall=     743476
iteration no.  1: integral = 0.7878380E-02+/-  0.61E-05
all iterations:   integral = 0.7878380E-02+/- 0.608E-05 chi**2/it'n = 0.00E+00

iteration no.  2:            effective ncall=     776518
iteration no.  2: integral = 0.7882914E-02+/-  0.37E-05
all iterations:   integral = 0.7881695E-02+/- 0.315E-05 chi**2/it'n = 0.40

Higgs signal

input parameters for vegas:  ndim=  9  ncall=   19531250.
                             it=    1  itmx=    1

iteration no.  1:            effective ncall=   19292845
iteration no.  1: integral = 0.1661659E-01+/-  0.78E-06
all iterations:   integral = 0.1661659E-01+/- 0.784E-06 chi**2/it'n = 0.00E+00

Higgs backg + Higgs sign-backg interference

input parameters for vegas:  ndim=  9  ncall=   19531250.
                             it=    1  itmx=    1

iteration no.  1:            effective ncall=   19345150
iteration no.  1: integral = 0.7879024E-02+/-  0.62E-06
all iterations:   integral = 0.7879024E-02+/- 0.621E-06 chi**2/it'n = 0.00E+00

Higgs signal

input parameters for vegas:  ndim=  9  ncall=   19531250.
                             it=    2  itmx=    2

iteration no.  2:            effective ncall=   19317393
iteration no.  2: integral = 0.1661579E-01+/-  0.76E-06
```

```
all iterations:   integral = 0.1661618E-01+/- 0.545E-06 chi**2/it'n = 0.54

Higgs backg + Higgs sign-backg interference

input parameters for vegas:  ndim=  9  ncall=   19531250.
                             it=    2  itmx=    2

iteration no.  2:            effective ncall=   19355281
iteration no.  2: integral = 0.7877976E-02+/-  0.60E-06
all iterations:   integral = 0.7878485E-02+/- 0.433E-06 chi**2/it'n =  1.5

-----------------------------------------------------

Sigma = 0.2449466D-01 +/- 0.696D-06 (pb)
Informations about flat events generation:
         ----------------------
Maximum after first VEGAS iteration = 0.309D-07
Maximum after second VEGAS iteration = 0.215D-07
Flat events number =    720755
number of function values over maximum =         0
-----------------------------------------------------
```

Second input file:
We report only the input changed with respect to the first input.

```
1.d0                              ! scale factor for the maximum
0                                 ! yes/no data VEGAS stored
2                                 ! yes/no second iteration repeated
50000                             ! number of unweighted events generated
1                                 ! yes/no flat momenta stored
```

Second output file:
We do not report here `INPUT`, `DATA`, `DERIVED QUANTITIES`, `OPTIONS` and cuts which are the same as in the first output.

```
-------------------------------------------------------------------------------

NC25 )  b(p3) b~(p4) mu-(p5) mu+(p6)
Higgs signal + background

........

-----------------------------------------------------

Flat events generation
Maximum scale factor = 0.100D+01
Flat events stored in ABMOM_SIGN.DAT
Flat events stored in ABMOM_BACK.DAT

Higgs signal

Flat events number =     33917
```

```
Higgs backg + Higgs sign-backg interference

Flat events number =     16083

---------------------------------------------------

Sigma = 0.2449466D-01 +/- 0.696D-06 (pb)
Informations about flat events generation:
         ----------------------
Maximum =   1.330188364059000E-008
Flat events number =     50000
number of function values over maximum =         0
-------------------------------------------------------------------------------
```

Table Caption

Table 1 DEC AlphaStation 600 5/333 CPU time, accuracy and effective calls (in millions) for some representative four fermion processes with ISR.

Table 2 Charged Current and Mixed Charged + Neutral Current four fermion processes. `iproc` and `ich` are the two flags by which the appropriate final state is singled out in `WPHACT`.

Table 3 Neutral Current and Neutral Current + Higgs four fermion processes. `iproc` and `ich` are the two flags by which the appropriate final state is singled out in `WPHACT`.

CPU time				
process	final state	calls(M)	precision	hh:mm:ss
CC10	$\mu^-\ \bar{\nu}_\mu\ u\ d$	5.4	0.0002	00:05:09
CC20	$e^-\ \bar{\nu}_e\ u\ d$	5.3	0.0002	00:06:16
Mix56	$d\ d\ u\ \bar{u}$	40	0.0001	00:52:17
Mix56	$e^-\ e^+\ \nu_e\ \bar{\nu}_e$	37	0.0010	01:31:58
NC48	$e^-\ e^+\ u\ \bar{u}$	44	0.0010	01:28:13
NC64	$u\ \bar{u}\ u\ \bar{u}$	27	0.0008	01:00:32
NC144	$e^-\ e^+\ e^-\ e^+$	47	0.0010	03:39:10
NC21	$b\ b\ \nu_e\ \bar{\nu}_e$	11	0.0001	00:15:24
NC25	$b\ b\ \mu^-\ \mu^+$	22	0.0001	00:54:08
NC84	$b\ b\ b\ b$	24	0.0001	03:49:10

Table 1

CC					
process type	iproc	ich	final state	ich	final state
CC9	1	1	$\mu^-\ \bar{\nu}_\mu\ \nu_\tau\ \tau^+$	2	$\mu^+\ \nu_\mu\ \bar{\nu}_\tau\ \tau^-$
CC18	2	1	$e^-\ \bar{\nu}_e\ \nu_\mu\ \mu^+$	3	$e^+\ \nu_e\ \bar{\nu}_\mu\ \mu^-$
		2	$e^-\ \bar{\nu}_e\ \nu_\tau\ \tau^+$	4	$e^+\ \nu_e\ \bar{\nu}_\tau\ \tau^-$
CC10	3	1	$\mu^-\ \bar{\nu}_\mu\ u\ d$	5	$\tau^-\ \bar{\nu}_\tau\ u\ d$
		2	$\mu^-\ \bar{\nu}_\mu\ c\ \bar{s}$	6	$\tau^-\ \bar{\nu}_\tau\ c\ \bar{s}$
		3	$\mu^+\ \nu_\mu\ \bar{u}\ d$	7	$\tau^+\ \nu_\tau\ \bar{u}\ d$
		4	$\mu^+\ \nu_\mu\ \bar{c}\ s$	8	$\tau^+\ \nu_\tau\ \bar{c}\ s$
CC20	4	1	$e^-\ \bar{\nu}_e\ u\ d$	3	$e^+\ \nu_e\ \bar{u}\ d$
		2	$e^-\ \bar{\nu}_e\ c\ \bar{s}$	4	$e^+\ \nu_e\ \bar{c}\ s$
CC11	5	1	$s\ \bar{c}\ u\ d$	2	$\bar{s}\ c\ \bar{u}\ d$
MIX					
process type	iproc	ich	final state	ich	final state
MIX19	6	1	$\mu^-\ \mu^+\ \nu_\mu\ \bar{\nu}_\mu$	2	$\tau^-\ \tau^+\ \nu_\tau\ \bar{\nu}_\tau$
MIX56	7	1	$e^-\ e^+\ \nu_e\ \bar{\nu}_e$		
MIX43	8	1	$d\ d\ u\ \bar{u}$	2	$s\ \bar{s}\ c\ \bar{c}$

Table 2

NC					
process type	iproc	ich	final state	ich	final state
NC6	9	1	$\nu_\mu\ \bar{\nu}_\mu\ \nu_\tau\ \bar{\nu}_\tau$		
NC12	10	1	$\nu_\mu\ \bar{\nu}_\mu\ \nu_e\ \bar{\nu}_e$	2	$\nu_\tau\ \bar{\nu}_\tau\ \nu_e\ \bar{\nu}_e$
NC12	11	1	$\nu_\mu\ \bar{\nu}_\mu\ \nu_\mu\ \bar{\nu}_\mu$	2	$\nu_\tau\ \bar{\nu}_\tau\ \nu_\tau\ \bar{\nu}_\tau$
NC36	12	1	$\nu_e\ \bar{\nu}_e\ \nu_e\ \bar{\nu}_e$		
NC10	13	1	$u\ \bar{u}\ \nu_\mu\ \bar{\nu}_\mu$	3	$c\ \bar{c}\ \nu_\mu\ \bar{\nu}_\mu$
		2	$u\ \bar{u}\ \nu_\tau\ \bar{\nu}_\tau$	4	$c\ \bar{c}\ \nu_\tau\ \bar{\nu}_\tau$
NC19	14	1	$u\ \bar{u}\ \nu_e\ \bar{\nu}_e$	2	$c\ \bar{c}\ \nu_e\ \bar{\nu}_e$
NC64	15	1	$u\ \bar{u}\ u\ \bar{u}$	2	$c\ \bar{c}\ c\ \bar{c}$
NC32	16	1	$u\ \bar{u}\ c\ \bar{c}$		
NC10	17	1	$\mu^-\ \mu^+\ \nu_\tau\ \bar{\nu}_\tau$	2	$\tau^-\ \tau^+\ \nu_\mu\ \bar{\nu}_\mu$
NC20	18	1	$e^-\ e^+\ \nu_\mu\ \bar{\nu}_\mu$	2	$e^-\ e^+\ \nu_\tau\ \bar{\nu}_\tau$
NC19	19	1	$\mu^-\ \mu^+\ \nu_e\ \bar{\nu}_e$	2	$\tau^-\ \tau^+\ \nu_e\ \bar{\nu}_e$
NC24	20	1	$\mu^-\ \mu^+\ u\ \bar{u}$	3	$\tau^-\ \tau^+\ u\ \bar{u}$
		2	$\mu^-\ \mu^+\ c\ \bar{c}$	4	$\tau^-\ \tau^+\ c\ \bar{c}$
NC48	21	1	$e^-\ e^+\ u\ \bar{u}$	2	$e^-\ e^+\ c\ \bar{c}$
NC19	22	1	$d\ d\ \nu_e\ \bar{\nu}_e$	2	$s\ \bar{s}\ \nu_e\ \bar{\nu}_e$
NC10	23	1	$d\ d\ \nu_\mu\ \bar{\nu}_\mu$	3	$d\ d\ \nu_\tau\ \bar{\nu}_\tau$
		2	$s\ \bar{s}\ \nu_\mu\ \bar{\nu}_\mu$	4	$s\ \bar{s}\ \nu_\tau\ \bar{\nu}_\tau$
NC32	24	1	$s\ \bar{s}\ u\ \bar{u}$	2	$d\ d\ c\ \bar{c}$
NC24	25	1	$\mu^-\ \mu^+\ \tau^-\ \tau^+$		
NC48	26	1	$e^-\ e^+\ \mu^-\ \mu^+$	2	$e^-\ e^+\ \tau^-\ \tau^+$
NC48	27	1	$\mu^-\ \mu^+\ \mu^-\ \mu^+$	2	$\tau^-\ \tau^+\ \tau^-\ \tau^+$
NC144	28	1	$e^-\ e^+\ e^-\ e^+$		
NC64	29	1	$d\ d\ d\ d$	2	$s\ \bar{s}\ s\ \bar{s}$
NC48	30	1	$e^-\ e^+\ d\ d$	2	$e^-\ e^+\ s\ \bar{s}$
NC24	31	1	$\mu^-\ \mu^+\ d\ d$	3	$\tau^-\ \tau^+\ d\ d$
		2	$\mu^-\ \mu^+\ s\ \bar{s}$	4	$\tau^-\ \tau^+\ s\ \bar{s}$
NC32	32	1	$d\ d\ s\ \bar{s}$		
NC+HIGGS					
process type	iproc	ich	final state	ich	final state
NC21	33	1	$b\ b\ \nu_e\ \bar{\nu}_e$		
NC11	34	1	$b\ b\ \nu_\mu\ \bar{\nu}_\mu$	2	$b\ b\ \nu_\tau\ \bar{\nu}_\tau$
NC33	35	1	$b\ b\ u\ \bar{u}$	2	$b\ b\ c\ \bar{c}$
NC25	36	1	$b\ b\ \mu^-\ \mu^+$	2	$b\ b\ \tau^-\ \tau^+$
NC50	37	1	$b\ b\ e^-\ e^+$		
NC33	38	1	$b\ b\ d\ d$	2	$b\ b\ s\ \bar{s}$
NC84	39	1	$b\ b\ b\ b$		

Table 3

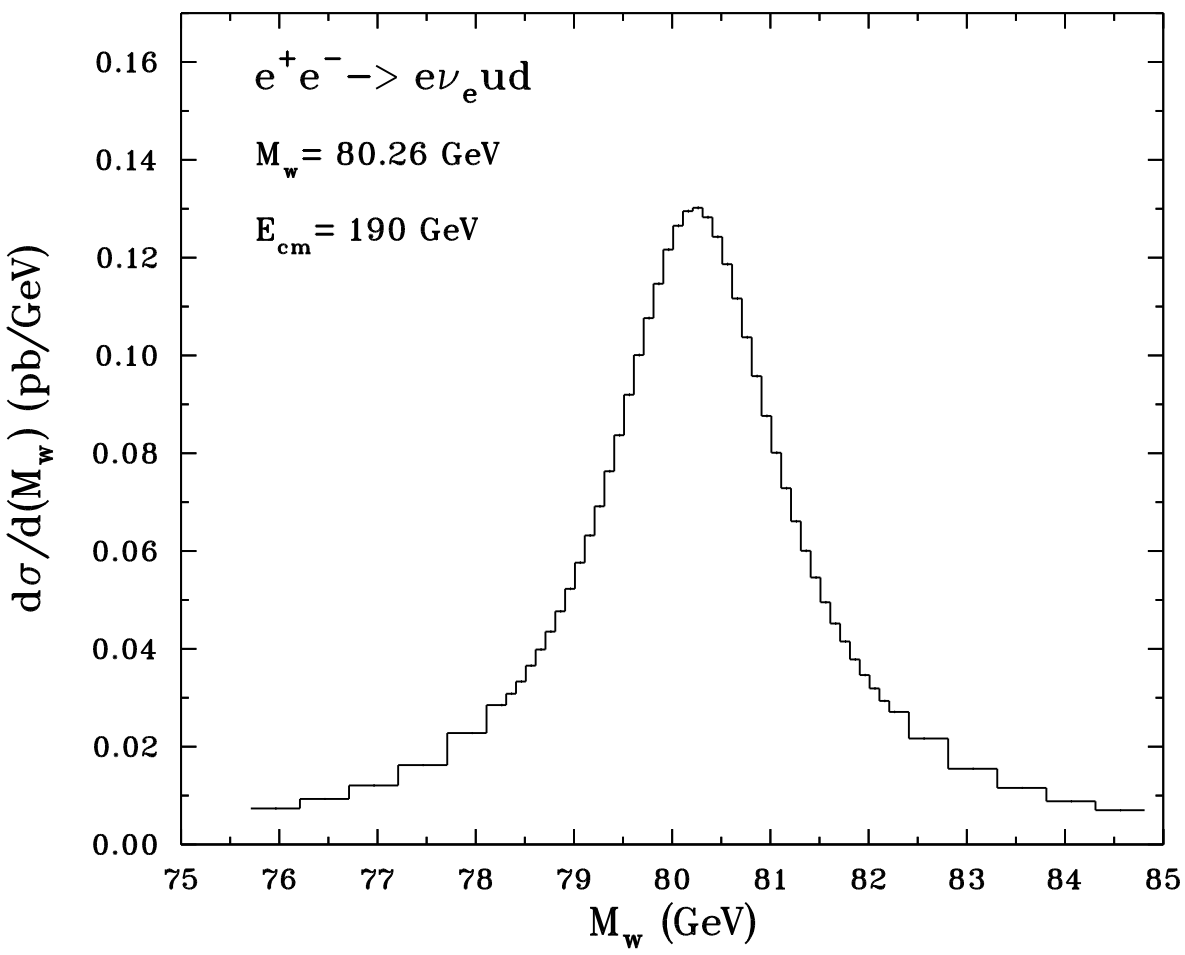

Figure 1: Distribution of the invariant mass corresponding to M_{W^+}, computed in test run 1.

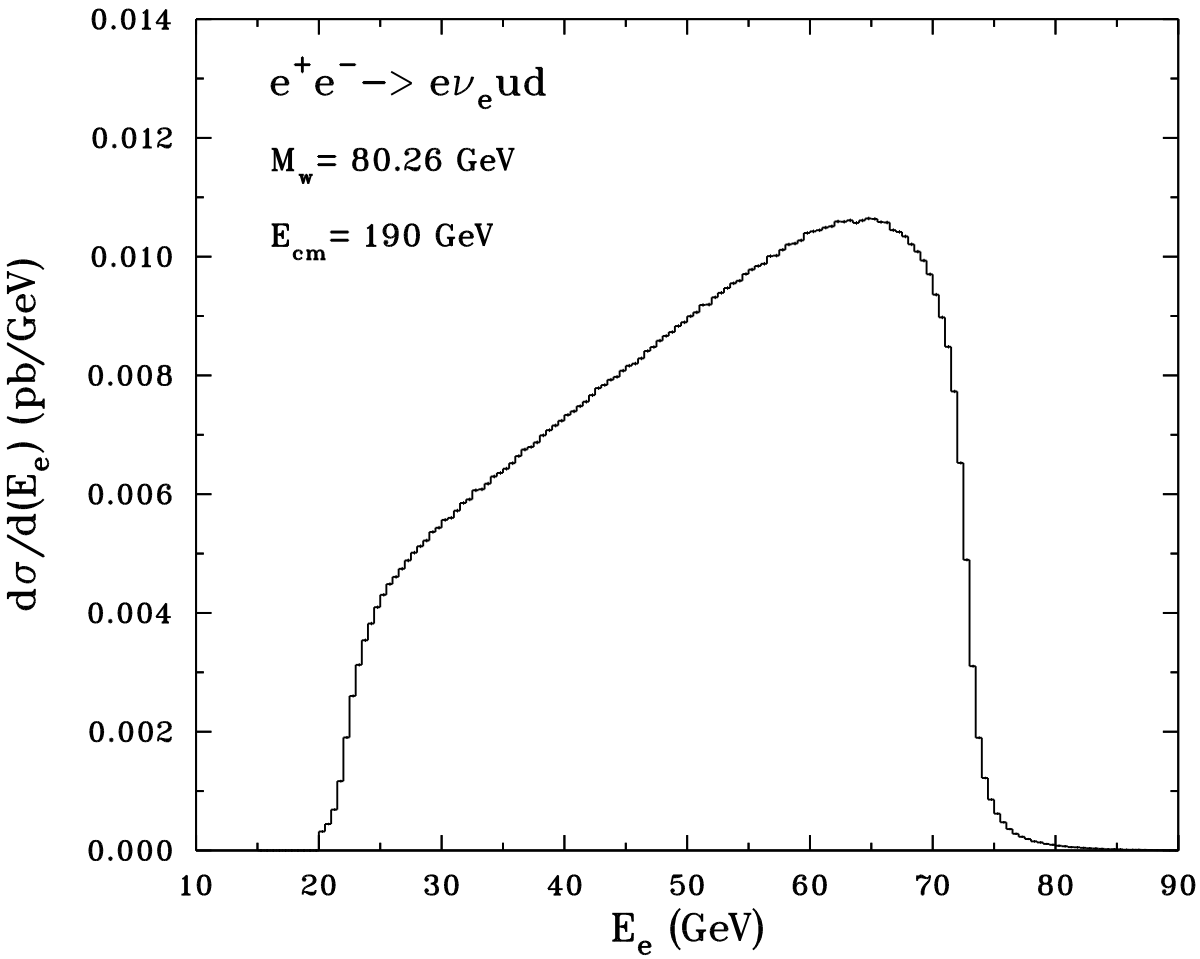

Figure 2: Distribution of the energy of the outgoing electron computed in test run 1.