**WOPPER, Version 1.3:**
A Monte Carlo Event Generator for
\[ e^+e^- \rightarrow (W^+W^-) \rightarrow 4f + n\gamma \]
at LEP-II and beyond*

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April 1995

**Abstract**

We describe the Monte Carlo event generator WOPPER for four fermion production through \(W\)-pairs including resummed leading logarithmic QED radiative corrections.

**Program Summary:**

- **Title of program:** WOPPER, Version 1.3 (April 1995)
- **Program obtainable from:** crunch.ikp.physik.th-darmstadt.de in the directory /pub/ohl/wopper (using anonymous Internet ftp)
- **Licensing provisions:** none
- **Programming language used:** FORTRAN-77
- **Computer/Operating System:** Any with a FORTRAN-77 environment

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• Memory required to execute with typical data: 80k words

• No. of bits in a word: 32

• Number of program lines in distributed program, including test data, etc.: ≈ 7000 (Including comments)

• Keywords: radiative corrections, W pair production, W decays, multiphoton radiation

• Nature of physical problem: Higher order leading logarithmic QED radiative corrections to W pair production and decay at high energy $e^+e^-$ colliders, including finite width of the $W$'s.

• Method of solution: Monte Carlo event generation

• Restrictions on the complexity of the problem: The matrix elements for the hard subprocess contain only the resonant contributions to $e^+e^- \to (W^+W^-) \to 4$ fermions in the Born approximation. The final state fermions from the W decays are generated at the parton level.

• Typical running time: ≈ 4 ms/event, depending on the energy, cuts and CPU. The test run takes approximately 50 CPU seconds on a 486DX2/66 running Linux 1.2 and 35 CPU seconds on an IBM RS/6000-520 running AIX 3.2.5.
1 Introduction

The spectacular success of the high energy electron positron colliders LEP at CERN and SLC at SLAC has confirmed the predictions of the Standard Model (SM) for the interactions between the gauge bosons and the fermions even at the level of electroweak radiative corrections. The high precision of the experimental data allows to put limits on parameters of yet unobserved particles like the Higgs boson through the appearance of these particles in weak loop corrections. On the other hand, the non-Abelian structure of the gauge sector of the SM predicts couplings between the electroweak gauge bosons which have not been tested directly. The forthcoming upgrade of LEP to LEP-II with a center of mass energy of up to \( \sqrt{s} \approx 200 \text{ GeV} \) and a future 0.5–1.5 TeV \( e^+e^- \) linear collider (NLC, for short) will in particular make the trilinear \( WW\gamma \) and \( WWZ \) couplings directly observable through their contribution to the production of \( W \) pairs.

The main task of LEP-II will be a precise determination of the mass and the width of the \( W \) and the production cross section in the threshold region. At NLC, a measurement of the total cross section, the \( W \) angular distributions and in particular of their longitudinal polarization component will give a handle on possible anomalous couplings among the electroweak bosons induced by new physics beyond the SM, and in turn reveal an insight into the mechanism of electroweak symmetry breaking.

However, possible new physics is already severely constrained by present LEP and SLC data, and the effects to be expected at NLC (even more so at LEP-II) are small. In order to extract these small effects, one has to have a precise knowledge of the radiative corrections within the SM.

The electroweak radiative corrections to the production of on-shell \( W \)'s to one-loop order are by now well established. The influence of the finite width of the \( W \)'s has been investigated. Also, the higher order QED corrections have been calculated in the leading log approximation (LLA) and their importance has been emphasized in ref. Recently an exhaustive overview of the standard model predictions has been provided.

Unfortunately, the experimental reconstruction of the \( W \)'s and the determination of their polarization is complicated by the fact that they may decay either into leptons with an escaping neutrino, or into hadrons, where the jet energies may be poorly known due to undetected particles. In addition, the radiative corrections due to emission of photons produce a systematic shift of the effective center of mass energy towards smaller values. Such effects may best be studied with the help of a Monte Carlo event generator.

Although quite a few semianalytical calculations of the corrections mentioned above have been available for some time, version 1.0 of WOPPER had been the first publicly available and complete Monte Carlo event generator. Reference reported a Monte Carlo generator implementation of the complete \( O(\alpha) \) corrections to the production of on-shell \( W \)'s. The matrix elements for single photon bremsstrahlung in the process \( e^+e^- \to (W^+W^-) \to 4 \) fermions and their implementation in a Monte Carlo generator is described in references, but the virtual corrections are not yet included there. In the meantime, two new programs have been released or are about to be released in the immediate future.

This paper describes version 1.3 of the Monte Carlo event generator WOPPER. It is based on the lowest order cross section for the process \( e^+e^- \to (W^+W^-) \to 3 \) fermions.
and focuses on QED radiative corrections in the LLA resummed to all orders in $\alpha$ and the effects of finite width of the $W$'s. The four-momenta of the exclusive hard photons are generated explicitly and treated with full kinematics. The $W$ decays into fermions are implemented at the parton level, including leading QCD corrections to the $W$ branching fractions.

This write-up is organized as follows: In section 2.1 we outline the physics underlying the algorithms implemented in WOPPER. The actual implementation is described in section 3. The parameters controlling the execution of WOPPER are discussed in detail in section 4 and the FORTRAN-77 interface is presented in section 5. Distribution notes, a listing of all external symbols and the output of a test run can be found in the appendices.

2 Theoretical Background and General Features

2.1 QED corrections at very high energies

In the structure function formalism [19, 20, 21] the expression for the radiatively corrected cross section reads

$$\sigma(s) = \int_0^1 dx_+ dx_- D(x_+, Q^2)D(x_-, Q^2) \hat{\sigma}(x_+ x_- s) ,$$

where $\hat{\sigma}$ is the Born level cross section of the hard process, $D(x, Q^2)$ are the structure functions for initial state radiation, and $Q^2$ is the factorization scale.

The structure functions $D$ sum the numerically most important leading logarithmic contributions

$$\frac{\alpha}{\pi} \log \left( \frac{s}{m_e^2} \right) \approx 6\% \quad \text{(at LEP-II and NLC energies)} \quad (2)$$

to the electromagnetic radiative corrections to all orders. They satisfy the QED evolution equation [19]

$$Q^2 \frac{\partial}{\partial Q^2} D(x, Q^2) = \frac{\alpha}{2\pi} \int_x^1 \frac{dz}{z} [P_{ee}(z)]_+ D \left( \frac{x}{z}, Q^2 \right)$$

$$P_{ee}(z) = \frac{1 + z^2}{1 - z} \quad (3)$$

with initial condition

$$D(x, m_e^2) = \delta(1 - x). \quad (5)$$

The solution to eq. (3) automatically includes the very important exponentiation of the soft photon contributions to the radiative corrections.

An explicitly regularized version of (3) used in the Monte Carlo implementation is given by

$$Q^2 \frac{\partial}{\partial Q^2} D(x, Q^2) = \frac{\alpha}{2\pi} \int_x^{1-\epsilon} \frac{dz}{z} P_{ee}(z)D \left( \frac{x}{z}, Q^2 \right)$$

$$- \frac{\alpha}{2\pi} \left[ \int_0^{1-\epsilon} dz P_{ee}(z) \right] D(x, Q^2) . \quad (6)$$
It is crucial to note that the characteristics of the generated event sample do not depend on $\epsilon$, if it is chosen well below the experimental threshold for the detection of soft photons. Theoretically, the cross sections will remain positive for all values of $\epsilon$, but limited storage for ultra soft photons and limited floating point range impose a lower limit.

The radiatively corrected cross section (1) is implemented in a Monte Carlo event generator by solving the integro-differential equation (6) by iteration and taking into account the energy loss in the hard cross section. It is very similar to algorithms for quark fragmentation in QCD [22]. As a by-product of the branching algorithm, the four-momenta of the radiated photons are generated explicitly.

The initial state branching algorithm has already been used in the Monte Carlo generator KRONOS [23] and an improved version in the generator UNIBAB [24], where the implementation has been described in detail.

The momenta of the electron and positron after initial state branching are then used as the input momenta for the subgenerator of the hard subprocess described below.

### 2.2 Born Cross Section

In the general case, there are many Feynman diagrams contributing to the process $e^+e^- \rightarrow 4$ fermions at high energies, even if one requires that the quantum numbers of the final state fermions be consistent with $W$ pair production. However, the contribution of the individual Feynman diagrams may be easily estimated by counting the number of ‘resonant’ propagators, where an intermediate vector boson may come close to its mass shell. Using this naive estimate, one finds that the contribution of these ‘background diagrams’ is suppressed by a factor $\Gamma_W/M_W \sim 2.5\%$ for each non-resonant boson propagator, and may be reduced further by appropriate cuts on the invariant masses of the reconstructed $W$’s.

In the current version 1.3 of WOPPER only the Feynman diagrams with two resonating $W$’s contributing to the process $e^-e^+ \rightarrow (W^+W^-) \rightarrow f_1f_2f_3f_4$ are taken into account. In fact, a full calculation [18] finds that this approach is numerically justified for LEP-II energies, unless electrons are in the final state and no invariant mass cuts are applied.

The implementation of the Born cross section in WOPPER is split into two steps, namely the production of the virtual (off-shell) $W$’s and their subsequent decay into fermions including the correlations from the polarization of the intermediate $W$’s.

This factorization in the resonant approximation can easily be seen as follows. Since the top quark is much heavier than the $W$, the virtual $W$’s will decay only into (almost) massless fermions. We choose the Landau gauge. The couplings of the would-be Goldstone bosons to the fermions are proportional to the fermion masses and may therefore be safely neglected. The numerator of the $W$ propagators is decomposed into a sum over three physical polarizations.

$$-g_{\mu\nu} + \frac{k_\mu k_\nu}{k^2} = \sum_{\lambda=1}^{3} \epsilon_{\mu}(k, \lambda) \epsilon^\ast_{\nu}(k, \lambda) , \quad k \cdot \epsilon(k, \lambda) = 0 , \quad \epsilon(k, \lambda) \cdot \epsilon^\ast(k, \lambda') = -\delta_{\lambda\lambda'}$$

(7)
Figure 1: The Feynman diagrams contributing to the process \( e^+e^- \rightarrow W^+W^- \).

As in ref. [7], we write the amplitude for
\[
e^{-}(p_1)e^+(p_2) \rightarrow W^-(k_-)W^+(k_+) \rightarrow f_1(q_1)f_2(q_2)f_3(q_3)f_4(q_4)
\]
as a coherent sum of a production and a decay amplitude for virtual \( W \)'s,
\[
\mathcal{M} = \sum_{\lambda_+,\lambda_-} \mathcal{M}_{e^+e^- \rightarrow W^+W^-}(p_1,p_2;k_-,\lambda_-;k_+,\lambda_+)
\times Z(k_-^2)^{-1} Z(k_+^2)^{-1} \mathcal{M}_{W^- \rightarrow f_1f_2}(\lambda_-;q_1,q_2) \mathcal{M}_{W^+ \rightarrow f_3f_4}(\lambda_+;q_3,q_4)
\]
where
\[
Z(k^2)^{-1} = \frac{1}{k^2 - M_W^2 + \Sigma_W(k^2)}.
\]

Although we are working in the Born approximation, we shall use the renormalized \( W \) self energy \( \Sigma_W(k^2) \) in this expression in order to obtain a realistic behavior of the amplitude when a \( W \) in the intermediate state comes close to its mass shell. For LEP-II energies and in the on-shell renormalization scheme, it is sufficient to take only the leading linear term of the energy dependence of the imaginary part of \( \Sigma_W \) into account and to neglect the real part.

\[
\text{Im} \, \Sigma_W(k^2) \equiv \sqrt{k^2} \cdot \Gamma_W(k^2) \approx \frac{k^2}{M_W^2} M_W \Gamma_W, \quad \text{Re} \, \Sigma_W(k^2) \approx 0
\]

Taking the modulus squared of (9) and integrating over the decay angles of the virtual \( W \)'s, one obtains the well known resonance formula [10, 26, 16] for the total cross section for production of virtual \( W \) pairs (see figure 1).
\[
\sigma_{\text{res}} = \int ds_+ds_- \frac{\sqrt{s_+} \Gamma_W(s_+)}{\pi D(s_+)} \frac{\sqrt{s_-} \Gamma_W(s_-)}{\pi D(s_-)} \sigma_{\text{off}}(s; s_+, s_-)
\]

Here \( \sigma_{\text{off}}(s; s_+, s_-) \) denotes the off-shell cross section for the production of two \( W \)'s, and \( \Gamma_W(s_\pm) \) is the effective decay width of the virtual \( W \)'s into light fermions according to eq. (11). The resonance factors are essentially Breit-Wigner functions, but with energy-dependent width
\[
\frac{1}{D(s_\pm)} = \frac{1}{(s_\pm - M_W^2)^2 + s_\pm \Gamma_W^2(s_\pm)}.
\]
For the actual implementation it is useful to apply the mappings \( \gamma \equiv \Gamma_W/M_W \)

\[
\xi_{\pm} = \arctan \left( \frac{(1 + \gamma^2) s_{\pm} - M_W^2}{\gamma M_W^2} \right)
\]

(14)

to eq. (12) in order to get a smooth integrand suitable for a Monte Carlo rejection algorithm:

\[
\sigma_{\text{res}} = \int d\xi_+ d\xi_- \left[ \frac{1}{\pi M_W^2} \frac{1}{\pi M_W^2} \sigma_{\text{off}}(s; s_+, s_-) \right]_{s_{\pm} = M_W^2 \cdot (1 + \gamma \tan \xi_{\pm})/(1 + \gamma^2)}
\]

(15)

The angular distribution of the virtual \( W \)'s in the center of mass frame is generated from the differential cross section \( d\sigma(s; s_+, s_-; \theta)/d\Omega \) by a standard mapping and rejection algorithm.

### 2.3 Coulomb singularity

Another class of universal corrections, which is important near threshold, is the so-called Coulomb singularity. We implement the correction

\[
\sigma_{\text{Coulomb}} = \sigma_{\text{Born}} \frac{\alpha \pi}{2\beta} \left( 1 - \frac{2}{\pi} \arctan \left( \frac{|\beta_M + \Delta|^2 - \beta^2}{2\beta \text{Im} \beta_M} \right) \right)
\]

(16)

to the off shell total cross section.

### 2.4 Decays of the virtual \( W \)'s

After the momenta of the virtual \( W \)'s have been fixed, it is straightforward to generate the decays of the \( W \)'s in the center of mass system.

The measure of the integrations over the \( W \)-decay angles is independent of the other kinematical variables, thus leading to the simple form of eq. (12). Hence, the decay angle distributions for fixed virtualities and production angles of the \( W \)'s are proportional to the modulus squared of the amplitude (9), which is a sufficiently smooth function of the decay angles and therefore suitable for a rejection algorithm.

The final state fermions of the decay \( W \to f \bar{f} \) are simply chosen with a probability according to the branching fractions obtained from the tree-level formulas. Inclusive QCD corrections to the \( W \) decays to quarks are taken into account to first order in \( \alpha_S \). The branching fractions for hadronic decays into \( u, d, c, s, \) and \( b \) quarks are given by the corresponding CKM matrix elements, while decays into \( t \) quarks are assumed to be kinematically forbidden because of \( |m_t - M_W| \gg \Gamma_W \). Currently, the fermion masses are only taken into account kinematically and not in the matrix elements.

### 2.5 Hadronization

If one or both of the \( W \)'s have decayed \( \gamma \) into quarks, they can optionally be hadronized using either the LUND string model \( [27] \) or the HERWIG cluster
model \cite{28}. In the present version it is not possible\footnote{Unless one makes the necessary changes to the \textsc{Wopper} sources in routines \texttt{wwlund()} and \texttt{wwhwig()}.} to study color-rearrangement effects in purely hadronic decays. Both $W$ decays are handled separately.

The hadronization model can be switched at run time with the parameter \texttt{qcdmc}, which takes the values 0, 1 and 2. These correspond to no QCD MC, \textsc{Jetset} \cite{27} and \textsc{Herwig} \cite{28} respectively.

## 3 Implementation of \textsc{Wopper} 1.3

Like almost all Monte Carlo event generators, \textsc{Wopper} is divided into three parts: initialization, event generation, and termination. These are described in this section. For ease of use, \textsc{Wopper} comes with two application interfaces, so that a direct call to the lower level parts in this section will never be necessary. These interfaces will be explained in section \textit{5}.

### 3.1 Initialization

The initializations in \textsc{Wopper} are used for computing the value of variables that will be used frequently during event generation. Examples are the calculation of electroweak couplings, the maximum of the off-shell Born cross section and other internal steering parameters from the input parameters. This is accomplished by a call to the subroutine \texttt{wwinit} after setting the Monte Carlo parameters. Since \textsc{Wopper} does not yet include weak corrections, most of the initializations performed are quite trivial.

Finally, a standard \texttt{/hepevt/} initialization record \cite{29} is written, which may be used by the analysis program.

### 3.2 Event Generation

The routine \texttt{wwgen} produces an event on every call. The four momenta of all generated particles as well as supplemental information is written to a standard \texttt{/hepevt/} event record, where it can be read by user supplied analyzers. See section \textit{3.4} below for details on \textsc{Wopper}'s extensive use of \texttt{/hepevt/}.

The first step is the generation of the initial state radiation by the branching routine \texttt{wwbini} using the algorithm of section \textit{2.1} and of the virtual masses of the $W$'s occurring in the intermediate state. According to the cross section \cite{15}, the rejection weight is calculated from the ratio of the actual off-shell cross section to the maximum determined in the initialization step, and the event is accepted with a probability according to this weight.

After the effective center of mass energy and the $W$ virtualities have been fixed, the angular distribution of the virtual $W$'s occurring in the intermediate state. According to the cross section \cite{15}, the rejection weight is calculated from the ratio of the actual off-shell cross section to the maximum determined in the initialization step, and the event is accepted with a probability according to this weight.

After the effective center of mass energy and the $W$ virtualities have been fixed, the angular distribution of the virtual $W$'s occurring in the intermediate state. According to the cross section \cite{15}, the rejection weight is calculated from the ratio of the actual off-shell cross section to the maximum determined in the initialization step, and the event is accepted with a probability according to this weight.

Finally, the decay of the intermediate $W$'s into the final state fermions is accomplished in the subroutine \texttt{wwgdec}.
3.3 Termination

The cross section for the generated events is obtained in the subroutine \texttt{wwclos} from the standard formula

\[
\sigma_{\text{tot}}(s) = \max_{s' \xi_+ \xi_-} \left\{ \tilde{\sigma}(s'; \xi_+, \xi_-) \right\} \cdot \frac{\# \text{ of successful trials}}{\# \text{ of trials}} \tag{17}
\]

where \(\tilde{\sigma}\) is the off-shell cross section from eq. (15). \(s'\) varies between 0 and \(s\), and \(\xi_\pm\) in the range allowed by the specified cuts. The corresponding statistical error from the Monte Carlo integration is given by

\[
\Delta \sigma_{\text{tot}}(s) = \max_{s' \xi_+ \xi_-} \left\{ \tilde{\sigma}(s'; \xi_+, \xi_-) \right\} \cdot \sqrt{\frac{\text{(total # of trials} - \text{# of successful trials)} \cdot \text{# of successful trials}}{\text{(total # of trials)}^3}} \tag{18}
\]

The cross section and the error on the cross section are placed into \texttt{/hepevt/}, where they may be read by the user-supplied analyzer.

3.4 Additional information in \texttt{/hepevt/}

Because \textsc{Wopper} uses the standard \texttt{/hepevt/} event record internally, not only stable particles with \texttt{istep(i) = 1} will be present. Adapting the conventions of the \textsc{Herwig} Monte Carlo \cite{28}, we use the following status codes

- 101: \(e^-\) beam (positive \(z\)-direction),
- 102: \(e^+\) beam (negative \(z\)-direction),
- 103: center of mass system of the collider,
- 110: \(e^+e^-\) hard scattering center of mass system,
- 111: \(e^-\) before hard scattering,
- 112: \(e^+\) before hard scattering,
- 113: virtual \(W^-\) after hard scattering,
- 114: virtual \(W^+\) after hard scattering.

However, these entries have \textit{no} physical significance and should \textit{never} be used in any analysis (an exception to this rule are the beam particles 101 and 102, which are convenient for defining the reference frame and are used e.g. by the analyzer \texttt{hepawk} \cite{30} for this purpose). Only the particles with status code 1 belong to the final state as predicted by \textsc{Wopper}.

If no hadronization Monte Carlo is active, final state quarks will be entered as “stable” particles with status code 1.

4 Parameters

The parameters controlling \textsc{Wopper} version 1.3 are summarized in tables 1 and 2. They will be described in the following subsections.
| Variable name | semantics | Default value |
|---------------|-----------|---------------|
| ebeam         | $e^+/e^-$ beam energy | 250 GeV |
| epol          | longitudinal $e^-$ beam polarization | 0 |
| ppol          | longitudinal $e^+$ beam polarization | 0 |
| scheme        | renormalization scheme | 1 |
| ahpla         | $1/\alpha_{QED}(4M_W^2)$ | 128 |
| ahpla0        | $1/\alpha_{QED}(0)$ | 137.0359895 |
| mass1e        | $m_{e\pm}$ | $0.51099906 \cdot 10^{-3}$ GeV |
| mass1w        | $M_{W\pm}$ | 80.22 GeV |
| gamma1w       | $\Gamma_W$ | 2.08 GeV |
| mass1z        | $M_{Z^0}$ | 91.187 GeV |
| gamma1z       | $\Gamma_Z$ | 2.492 GeV |
| gfermi        | $G_F$ | $1.16639 \cdot 10^{-5}$ GeV |
| sin2w         | $\sin^2 \theta_W$ | 0.2261 |
| alphas        | $\alpha_{QCD}(M_W^2)$ | 0.12 |
| ckmvus         | $V_{us} = \sin \theta_C$ | 0.2196 |
| ckmcvcb       | $V_{cb}$ | 0.0400 |
| ckmvub         | $V_{ub}$ | 0.0032 |

Table 1: Physics parameters controlling \textit{WOPPER}.  


| Variable name | semantics | Default value |
|--------------|-----------|--------------|
| cutmin       | minimum $W^\pm$ virtuality | 0 GeV |
| cutmax       | maximum $W^\pm$ virtuality | $\sqrt{s} = 2E_{\text{Beam}}$ |
| nevent       | Number of events | 10000 |
| cc           | apply canonical cuts | .false. |
| cclvl        | level of canonical cuts | 0 |
| ccver        | version of canonical cuts | 1 |
| bstyle       | Key for QED radiation | 1 |
| epsiln       | Internal infrared cutoff | $10^{-5}$ |
| coulom       | Include final state coulomb corrections | .false. |
| qcdmc        | Key for QCD Monte Carlo | 0 |
| rangen       | Random number generator | 1 |
| rseed        | Random number seed | 54217137 |
| rlux         | ‘Luxury’ of ranlux | 3 |
| errmax       | maximum error count | 100 |
| verbos       | verbosity | 0 |
| runid        | run identification | |
| stdin        | standard input | 5 |
| stdout       | standard output | 6 |
| stderr       | standard error | 6 |

Table 2: Technical parameters controlling WOPPER.
4.1 Electroweak Parameters

Since the present version of WOPPER does not include an electroweak library, the electroweak parameters, namely the masses of the electroweak bosons (mass1w, mass1z), their widths (gamm1w, gamm1z) and the Weinberg angle (sin2w) are treated as independent parameters. They enter an effective Born cross section and may be set directly by the user. As a special case, setting gamm1w to 0 reproduces the narrow-width approximation with on-shell W’s in the intermediate state.

The bulk of the non electromagnetic radiative corrections can be incorporated into the hard cross section by using the running QED coupling $\alpha_{QED}(4M_W^2) \approx 1/128$ at the W scale. This value is, however, not correct for the initial state radiation of on-shell photons, where $\alpha_{QED}(0) \approx 1/137$ has to be used. The inverse of the former value can be changed with ahpla and that of the latter with ahlapl0.

The presence of initial state radiation can be toggled using the parameter bstyle. The supported supported values are 0 and 1, corresponding to no QED radiative corrections and LLA resummed initial state QED radiative corrections.

Since version 1.3 it is possible to choose canonical input parameters for benchmarking LEP2 Monte Carlos [31] by changing the value of scheme. The follow values are supported:

- **scheme = 0**: “free scheme”, all parameters are taken from the input and treated as independent parameters.

- **scheme = 1** (default): “$G_F$ scheme”

$$\sin^2 \theta_W = \frac{\pi \alpha_{QED}(4M_W^2)}{\sqrt{2} G_F M_W^2}$$

$$\Gamma_W = \frac{G_F M_W^2}{\sqrt{8\pi}} \left( 3 + \frac{2\alpha_{QCD}}{\pi} \right)$$

- **scheme = 2**: “$\sin \theta_W^{\text{eff.}}$ scheme”

$$G_F = \frac{\pi \alpha_{QED}(4M_W^2)}{\sqrt{2} \sin^2 \theta_W M_W^2}$$

$$\Gamma_W = \frac{G_F M_W^2}{\sqrt{8\pi}} \left( 3 + \frac{2\alpha_{QCD}}{\pi} \right)$$

- **scheme = 3**: “Born scheme”, tree level formulas, independent $\sin \theta_W$, $G_F$, $\alpha_{QED}(4M_W^2) = \alpha_{QED}(0)$ and

$$\Gamma_W = \frac{G_F M_W^2}{\sqrt{8\pi}} \left( 3 + \frac{2\alpha_{QCD}}{\pi} \right)$$

- **scheme = -1, -2, -3**: same as the positive values, except for $\Gamma_W$ which is not calculated from the standard model expression but taken from gamm1w instead.
4.2 Cuts

In the present version 1.3 of WOPPER, only cuts in the virtualities of the intermediate $W^\pm$'s are implemented in the event generation:

- $\text{cutmin}$: minimum virtuality of the intermediate $W^\pm$'s,
- $\text{cutmax}$: maximum virtuality of the intermediate $W^\pm$'s.

The cuts in virtualities have to satisfy the following conditions:

$$0 \leq \text{cutmin} < \text{cutmax} \leq \sqrt{s} = 2E_{\text{Beam}} \quad (24)$$

A value of 0 for $\text{cutmax}$ will automatically be reset to the available maximum, namely $2E_{\text{Beam}}$.

Since version 1.3 it is possible to apply the canonical cuts for benchmarking LEP2 Monte Carlos \[31\] to the event record by setting $cc$ to .true.. These cuts will be reflected in the calculated total cross section.

4.3 Monte Carlo Parameters

The remaining, more technical Monte Carlo parameters should be almost self-explaining. Since our branching algorithm automatically includes soft photon exponentiation, the results will not depend on the value of the internal infrared cutoff $\epsilon$ (which is measured in units of the beam energy), provided it is kept well below the experimental energy resolution. However, it is not advisable to set it many orders of magnitude lower than the default value, because this may result in too high photon multiplicities that will overflow internal tables.

A note on the random number generators available: the default value 1 of the parameter $rangen$ corresponds to the standard \texttt{RANMAR} \[32\] generator, that has been the generator of choice for quite some time. Recently, the quality of the random numbers generated by \texttt{RANMAR} has been questioned and unwanted correlations have been found, that caused large systematic errors in solid state physics simulations \[44\]. A superior variation \texttt{RANLUX} has been proposed \[45\], which is however much slower. Setting $rangen$ to 2 switches to \texttt{RANLUX} which can be used at the 5 “luxury levels” 0 to 4. At the highest “luxury levels”, \texttt{WOPPER} will spend more than half of the total computer time in the random number generator.

However, since event generation involves a lot of decisions that effectively randomize the subsequences used by themselves, we do not expect that the correlations in \texttt{RANMAR} have any significant effect on the event samples generated by \texttt{WOPPER}. The \texttt{RANLUX} option has been added to \texttt{WOPPER} for some experimentation only. It is left in only because there is no particular reason for throwing it out again.

4.4 QCD Parameters

The parameters for \texttt{JETSET} should be accessed through \texttt{WOPPER}'s \texttt{lugive} command, which is translated directly to \texttt{JETSET}'s \texttt{LUGIVE()} subroutine. See the \texttt{JETSET} manual \[27\] for a comprehensive description of the available parameters and their effects.
### Table 3: HERWIG parameters accessible from WOPPER.

| WOPPER | HERWIG | semantics                     | Default value |
|--------|--------|------------------------------|---------------|
| hwqcdl | QCDLAM | $\Lambda_{QCD}/\text{GeV}$ | 0.18          |
| hwrms1 | RMASS(1) | $m_d/\text{GeV}$           | 0.32          |
| hwrms2 | RMASS(2) | $m_u/\text{GeV}$           | 0.32          |
| hwrms3 | RMASS(3) | $m_s/\text{GeV}$           | 0.5           |
| hwrms4 | RMASS(4) | $m_c/\text{GeV}$           | 1.8           |
| hwrms5 | RMASS(5) | $m_b/\text{GeV}$           | 5.2           |
| hwrms6 | RMASS(6) | $m_t/\text{GeV}$           | 100.00        |
| hwrm0  | RMASS(13)| $m_{\gamma f}^c/\text{GeV}$| 0.75          |
| hwvqcu | VQCUT  | Quark virtuality cutoff     | 0.48          |
| hwvgcu | VGCUT  | Gluon virtuality cutoff     | 0.10          |
| hwvpcu | VPCUT  | Photon virtuality cutoff    | -1.00         |
| hwclma | CLMAX  | Max. cluster mass parameter | 3.35          |
| hwpspl | PSPLT  | Split cluster parameter     | 1.00          |
| hwqdiq | QDIQK  | Max. scale for $g \rightarrow$ diquark | 0.00 |
| hwpdiq | PDIQK  | $g \rightarrow$ diquark rate parameter | 5.00 |
| hwqspa | QSPAC  | Spacelike evolution cutoff  | 2.50          |
| hwptrm | PTRMS  | Intrinsic $p_T$             | 0.00          |

*Negative values will translate to $\sqrt{s}$.\(^a\)

Since HERWIG does not sport the equivalent of the LUGIVE() routine, its parameters have to be accessed through the standard WOPPER access mechanisms. Tables 3 and 4 provide a list of the available HERWIG parameters and the names under which they are known to WOPPER. See the HERWIG manual \(^28\) for a comprehensive description of the effects of these parameters.

## 5 FORTRAN-77 Interface

WOPPER version 1.3 provides two application program interfaces on different levels. The higher (preferred) level consists of the command interpreter wwdcm1 that accepts commands in form of character*(*) strings. This driver communicates with the analyzer hepawk \(^30\) by default. The lower level consists of two FORTRAN-77 subroutine calls: wwpser and wopper.
Table 4: Technical HERWIG parameters accessible from WOPPER.

5.1 Higher Level Interface

The simple commands understood by wwdcmd are (here keywords are typeset in typewriter font and variables in italics; vertical bars denote alternatives)

- **initialize**
  
  Force initialization of WOPPER and write an initialization record into the /hepevt/ event record, which should trigger the necessary initializations in the analyzer.

- **generate \[n\]**

  * wopperappl.f

  ...  
  call wwdcmd ('init') \hspace{1cm} initialize the generator 
  ...  
  call wwdcmd ('generate 10000') \hspace{1cm} generate 10000 events 
  ...  
  call wwdcmd ('close') \hspace{1cm} cleanup 
  ...

Figure 2: Higher level FORTRAN-77 interface
Generate `n` events and call `hepawk` to analyze them. If the optional parameter `n` is supplied, `n` is set to its value.

- **close**
  Write a termination record to `/hepevt/`, which should trigger the necessary cleanups in the analyzer.

- **statistics**
  Print performance statistics (this is usually only useful for the WOPPER developers, who are tuning internal parameters).

- **quit**
  Terminate WOPPER without writing a termination record.

- **exit|bye**
  Write a termination record and terminate WOPPER.

- **set variable ival|rval**
  Set physical or internal parameters. See the tables 1 and 2 for a comprehensive listing of all variables. For example, the command `set alpla 127.0` will set the QED fine structure constant to $1/127$.

- **print variable|all**
  Print the value of physical or internal variables. Specifying the special variable `all` causes a listing of all variables known to WOPPER.

- **debug|nodebug flag**
  Toggle debugging flags.

- **testran**
  Test the portability of the random number generator. We use a generator of the Marsaglia-Zaman variety [32], which should give identical results on almost all machines.

- **banner**
  Print a string identifying this version of WOPPER.

- **echo message**
  Print `message` on standard output.

- **lugive string**
  Pass `string` to JETSET’s LUGIVE() routine. See [21] for details.

Unique abbreviations of the keywords are accepted, i.e. `g 1000` generates 1000 events. The tokens are separated by blanks. Blank lines and lines starting with a `#` are ignored and may be used for comments. For portability, only the first 72 characters of each line are considered.

On UNIX systems WOPPER reads the default startup files `.wopper` in the user’s home directory and the current directory, if they exist.
* wwdcmd.f
  subroutine wwdcmd (cmdlin)
    character*(*) cmdlin

... else if (cmdlin.eq.'init')
    call wopper (0)
    call hepawk ('scan')
else if (cmdlin.eq.'generate')
    do 10 n = 1, nevent
      call wopper (1)
      call hepawk ('scan')
  10 continue
else if (cmdlin.eq.'close')
    call wopper (2)
    call hepawk ('scan')
else
  end

Figure 3: Event generation loop

5.2 Lower Level Interface

The subroutine wopper (code) has a single integer parameter. The parameter code is interpreted as follows:

- 0: initialize the generator and write an initialization record to /hepevt/.
- 1: generate an event and store it in /hepevt/. If WOPPER has not been initialized yet, the necessary initializations are performed, but no initialization record is written.
- 2: perform final calculations and write the results to /hepevt/.

Figure 3 displays excerpts from a simplified version of wwdcmd that make the correspondences between the two levels of the FORTRAN-77 interface explicit.

WOPPER’s parameters can be accessed on the lower level by the subroutine wwpsrv (result, action, name, type, ival, rval, dval, lval). The parameter is specified by its (lowercase) name in the character*(*) string name. The string action is either ‘read’ or ‘write’ corresponding to whether the parameter is to be inspected or modified. The type of the parameter (‘int’, ‘real’, ‘dble’, or ‘lgcl’) is specified in type; it is an input parameter for ‘read’ and an output parameter for ‘write’. Depending on this type the value is passed in ival, rval, dval, or lval, respectively. The following error codes will be returned in the string result: ‘ ’: no error, ‘enoarg’: invalid action, ‘enoent’: no such parameter, ‘enoperm’: permission denied, and ‘enotype’: invalid type.

The protection scheme implemented with this parameter handling has been described in [23]. Its main purpose is to guarantee consistency of user defined and computed parameters in the generation phase of the Monte Carlo.
6 Conclusions

We have presented version 1.3 of the Monte Carlo event generator WOPPER for W pair production and decays into four fermions at high energy $e^+e^-$ colliders. The distinguishing feature of WOPPER is the inclusion of higher order electromagnetic corrections including soft photon exponentiation and explicit generation of exclusive hard photons. In contrast to fixed order calculations which have to be exponentiated by hand, WOPPER handles the multiphoton effects explicitly.

The present version does not contain weak corrections. Forthcoming versions of the Monte Carlo generator will include weak corrections in the framework of effective Born cross sections [35]. Anomalous couplings for the $\gamma W W$ and $ZW W$ vertices may also be included in a future version of the generator.

Acknowledgments

We are grateful to

- Hywel Phillips of DELPHI for help with the JETSET interface and for tireless bug hunting.
- Tjörn Sjöstrand (CERN/TH) for JETSET and for supporting it.
- Frits Erne of L3 for pointing out a bug to us.
- The members of the W-physics working group of the 1995 LEP2 workshop for appreciating our efforts.

A Distribution

The latest release of WOPPER is available by anonymous ftp from

```
crunch.ikp.physik.th-darmstadt.de
```

in the directory

```
pub/ohl/wopper
```

or on the World Wide Web at the URL

```
http://crunch.ikp.physik.th-darmstadt.de/monte-carlos.html#wopper
```

Important announcements (new versions, fatal bugs, etc.) will be made through the mailing list

```
wopper-announce@crunch.ikp.physik.th-darmstadt.de
```

Subscriptions can be obtained from

```
majordomo@crunch.ikp.physik.th-darmstadt.de
```

(send a message consisting of help to majordomo for instructions on how to subscribe, don’t send such messages to the list itself).
B  Installation

WOPPER is distributed in PATCHY format [36]. Plain FORTRAN-77 versions can be made available on request. Since the FORTRAN-77 source conforms to ANSI X3.9-1978, it should run without modifications on all platforms.

B.1 UNIX Systems

On UNIX systems, the configuration, compilation and installation can be performed automatically according to the following familiar sequence:

$ ./configure
$ make
$ make test
$ make install

Figure 4 shows the command line options of the configure script for WOPPER on UNIX systems. This configure script has been created by the popular GNU Autoconf [37] package and should work on all UNIX variants.

B.2 Non-UNIX Systems

For non-UNIX systems configuration and compilation has to be performed manually from the CARDS file and the cradles.

C  External Symbols: Common Blocks and Subroutines

To avoid possible name clashes with other packages, all external symbols exported by WOPPER begin with the two letters WW, except for the routine wopper itself and the /hepevt/ common block.

• Common Blocks:
  The following common blocks are used by WOPPER.

  - /hepevt/, /hepspn/: standard common blocks for passing generated events [29].
  - /wwpcom/: main parameter common block, holds all physical parameters. Application programs should access this common block through the wwpsrv routine.
  - /wwchbn/: internal parameters used for born cross section.
  - /wwdec/: internal parameters used for W decays.
  - /wwcevt/: internal parameters used for event generation.
  - /wwcsta/: statistics.
  - /wwctri/: storage for keyword lookup.

• Driver Program:
Usage: configure [options] [host]
Options: [defaults in brackets after descriptions]

Configuration:
--cache-file=FILE cache test results in FILE
--help print this message
--no-create do not create output files
--quiet, --silent do not print ‘checking...’ messages
--version print the version of autoconf that created configure

Directory and file names:
--prefix=PREFIX install architecture-independent files in PREFIX
[>/usr/local]
--exec-prefix=PREFIX install architecture-dependent files in PREFIX
[same as prefix]
--srcdir=DIR find the sources in DIR [configure dir or ..]
--program-prefix=PREFIX prepend PREFIX to installed program names
--program-suffix=SUFFIX append SUFFIX to installed program names
--program-transform-name=PROGRAM run sed PROGRAM on installed program names

Host type:
--build=BUILD configure for building on BUILD [BUILD=HOST]
--host=HOST configure for HOST [guessed]
--target=TARGET configure for TARGET [TARGET=HOST]

Features and packages:
--disable-FEATURE do not include FEATURE (same as --enable-FEATURE=no)
--enable-FEATURE[=ARG] include FEATURE [ARG=yes]
--with-PACKAGE[=ARG] use PACKAGE [ARG=yes]
--without-PACKAGE do not use PACKAGE (same as --with-PACKAGE=no)
--x-includes=DIR X include files are in DIR
--x-libraries=DIR X library files are in DIR

--enable and --with options recognized:
--with-g77 use GNU Fortran 77
--enable-verbose-patchy display all patchy output
--enable-internal do not use this!
--enable-notime do not use timing functions
--enable-pedantic no IMPLICIT NONE
--with-libpath=PATH use PATH for libraries
--with-srcpath=PATH use PATH for source files (CARs)
--with-hepawk use HEPAWK
--with-jetset use JETSET
--with-herwig=CAR use HERWIG CAR file
--with-cernlib use CERNLIB
--enable-paper-a4 use European (A4) paper
--enable-paper-us use US (letter) paper

Figure 4: Commandline options of the configure script for WOPPER on UNIX systems.
– **wwdriv:** sample main program, which reads commands from standard input and feeds them into **wwcmd.**

– **wwloo:** command loop, reading command from a terminal or file and executing them.

– **wopper:** the low level entry point into the generator for application programs.

– **wwcmd:** WOPPER’s command interpreter, the preferred entry point for application programs. Executes a single command.

– **wwlxi, wdlxd, wdlxs:** Utility routines: tokenization of input.

– **wwdsig:** UNIX signal handler.

– **isatty:** check if this job is run interactively.

**Parameter Management:**

These routines are used to control the parameters common block **/wpc/.**

– **wwpsrv:** server handling parameter changing requests.

– **wwpini:** block data supplying default values.

– **wwpprn:** print parameters.

**Initialization:**

– **wwinit:** main entry point for initializations.

– **wwigsw:** initialization of electroweak parameters.

– **wwicut:** initialization of internal Monte Carlo parameters.

– **wwibmx:** finds maximum of Born cross section.

– **wwibn:** auxiliary function for finding maximum of on-shell cross section.

– **wwibns:** auxiliary function for finding maximum of cross section for symmetric virtualities.

– **wwibna:** auxiliary function for finding maximum of cross section for one W on-shell.

– **wwibnv:**

**Final calculations:**

– **wwclos:** calculate total cross section, errors and close the generator.

– **wwstat:** statistics.

**Hard Subprocess Generation:**

– **wgen:** main entry point for hard subprocess generation.

– **wggt:** generation of angular distribution of virtual W’s.

– **wgprr:** generate four-momenta of virtual W’s.

– **wwgdec:** generate final state fermions from W decays.

– **wwqfl:** select quark flavors in W decay.

**Branching:**
- \texttt{wbini}: generates the initial state photon radiation.

- **Cross Sections:**
  - \texttt{wwhel}: helicity amplitudes for $W$ pair production.
  - \texttt{wwtot}: total off-shell cross section.
  - \texttt{wwint}: auxiliary function for integration over virtual $W$ masses.

- **Accessing /hepevt/:**
  - \texttt{weeni}: enter identification of Monte Carlo and run.
  - \texttt{weens}: write summary record
  - \texttt{weent}: enter one particle
  - \texttt{wenul}: enter null particle
  - \texttt{wenew}: clear /hepevt/

- **Hadronization:**
  - \texttt{wpart}: leave partons alone.
  - \texttt{wlund}: JETSET interface code
  - \texttt{whwig}: HERWIG interface code
  - \texttt{hwaend}: HERWIG abnormal end routine

- **Random Numbers:**
  - \texttt{wrgen}: returns a double precision uniform deviate.
  - \texttt{wrmz}: random number generator RANMAR.
  - \texttt{wrlux}: random number generator RANLUX.
  - \texttt{wrtst}: test the portability of the random number generator.
  - \texttt{wrtmz}: test RANMAR.
  - \texttt{wrtlx}: test RANLUX.
  - \texttt{wrchk}: used in testing RANLUX.
  - \texttt{rluxat}, \texttt{rluxgo}, \texttt{rluxin}, \texttt{rluxut}: additional RANLUX entry points which are not used by WOPPER.

- **Utilities:**
  - \texttt{umsg}: messages and error exit.
  - \texttt{ulwr}: convert input to lower case.
  - \texttt{uboo}: boost a four vector.
  - \texttt{utim}: still available CPU time for this job.
  - \texttt{uamo}: multidimensional minimization.
  - \texttt{umin}: onedimensional minimization.
  - \texttt{uons}: Gram-Schmidt procedure.
  - \texttt{uort}: another Gram-Schmidt procedure.

- **Canonical cuts:**
– **adloth**: apply canonical cuts in `/hepevt/`.
– **adloip**: inner product of vectors in `/hepevt/`.
– **adloan**: angle to beam in `/hepevt/`.
– **adload**: add four momenta in `/hepevt/`.

• **Keyword search:**
  (using the dynamic tries described in [38]).
  – **wwtins**: insert a new keyword.
  – **wwtlup**: look up a (possibly abbreviated) keyword.
  – **wwtnew**: insert new a node into the trie.
  – **wwtlen**: calculate length of keyword.
  – **wwtc2a**: convert keyword from `character(*)` to `integer(*)`.  


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Test Run

WOPPER version 1.3 is distributed together with a sample command file and hepawk script, which are given below. To run this example, the user will need to link WOPPER with the CERN library, because histogramming is done by HBOOK

The file sample.wopper is read from standard input (unit stdin, which is initialized to 5), and sample.hepawk is read from the file SCRIPT (i.e. under MVS from the file which has been allocated to the DDNAME SCRIPT and under UNIX from the file script or from the value of the environment variable SCRIPT).

sample.wopper

Here is a simple WOPPER command file, setting up parameters and generating 10000 events.

# sample.wopper -- sample WOPPER command file

# parameters
set ebeam 87.5

# run
init
gen 10000
close
quit

sample.hepawk

This is a small hepawk script that counts the muons from the W decays and plots a histogram of their energy distribution. The first generated event is dumped to illustrate the usage of the /hepevt/ common block.

# sample.hepawk -- sample HEPAWK analyzer for WOPPER.

BEGIN
{
    printf("\nWelcome to the WOPPER test:\n\n");
    printf("***************************\n\n");

    printf("Monte Carlo Version: %s\n", REV);
    printf(" Run: %d\n", RUN);
    printf(" Date: %s\n", DATE);

    E_max = 100;
    N_chan = 50;

    h_muon_energy = book1 (0, "Muon-energy", N_chan, 0, E_beam);
    nr_muons = 0; # initialize counter
    dumped_an_event = 0;
}

26
if (dumped_an_event == 0)
{
    dump ("vs");                       # Dumping first event
    dumped_an_event++;
}

for (@p in LEPTONS)
{
    if (abs(@p:id) == _pdg_muon)
    {
        fill (h_muon_energy, @p:p:E);
        nr_muons++;
    }
}

END
{
    # Dump some numbers
    printf ("RESULTS:\n");
    printf ("********\n
");
    printf ("Total events: %d, total cross section: %g pb\n",
            NEVENT, XSECT * 1e9);
    printf ("Number of muons: %d\n", nr_muons);

    plot();
    printf ("ndone.\n");
}
The following output should result from the input files above, up to small round-off errors and different FORTRAN-77 default output formats.

wwdcmd: message: Starting WOPPER, Version 1.02/99, (build 0/0000)
hepawk: message: starting HEPAWK, Version 1.6
wwigsw: message: **********************************************
wwigsw: message: "GF scheme" selected:
wwigsw: message: Using GFERMI and ALPHA as input, calculating SIN2W.
wwigsw: message: Using derived W width.
wwigsw: message: Parameters used in this run:
wwigsw: message: AHPLA = 128.00000 ( = 1/alpha(2 M_W) )
wwigsw: message: SIN2W = .23121 (effective mixing angle)
wwigsw: message: GFERMI = .116639E-04 GeV**(-2)
wwigsw: message: ALPHAS = .12000
wwigsw: message: GAMM1W = 2.08468 GeV (S.M. value, used)
wwigsw: message: CKMVUS = .21960 CKM Matrix (Cabibbo angle)
wwigsw: message: CKMVCB = .04000 CKM Matrix
wwigsw: message: CKMVUB = .00320 CKM Matrix
wwigsw: message: Z-e-e couplings:
wwigsw: message: g_V = -.01396
wwigsw: message: g_A = -.18579
wwigsw: message: W-e-nu coupling:
wwigsw: message: g = .23038
wwigsw: message: Z-W-W coupling:
wwigsw: message: g_ZWW = .57134
wwigsw: message: gamma-W-W coupling:
wwigsw: message: g_gWW = .31333
wwigsw: message: Using energy-dependent width for W and Z propagators.
wwigsw: message: **********************************************

Welcome to the WOPPER test:

Monte Carlo Version: v01.02 (*** 00 00:00:00 1900)
   Run: 1035996352
   Date: Apr 10 03:40:00 1995

Dumping the event record for event # 1
There are 13 entries in this record:

Entry # 1 is an incoming (HERWIG convention) electron
p: ( .8750E+02; .0000E+00, .0000E+00, .8750E+02), m: .0000E+00

Entry # 2 is an incoming (HERWIG convention) positron
p: ( .8750E+02; .0000E+00, .0000E+00, -.8750E+02), m: .0000E+00

Entry # 3 is the CMS system (HERWIG convention)
p: ( .1750E+03; .0000E+00, .0000E+00, .0000E+00), m: .17500E+03

Entry # 4 is a null entry.

Entry # 5 is a null entry.
Entry # 6 is a null entry.

Entry # 7 is reserved for model builders.

Entry # 8 is reserved for model builders.

Entry # 9 is an existing photon
  p: ( .1554E+00; .6972E-03, -.1679E-03, -.1554E+00), m: .0000E+00
  The mother is the positron # 5.

Entry # 10 is an existing electron
  p: ( .5965E+02; .5462E+02, .1940E+02, .1411E+02), m: .5110E-03
  The first mother is the W- # 7.
  The other mother is the anti-electron-neutrino # 11.

Entry # 11 is an existing anti-electron-neutrino
  p: ( .2912E+02; -.2804E+02, -.3085E+01, -.7203E+01), m: .0000E+00
  The first mother is the W- # 7.
  The other mother is the electron # 10.

Entry # 12 is an existing up-quark
  p: ( .3692E+02; .1710E+02, -.3106E+02, .1030E+02), m: .5000E-02
  The first mother is the W+ # 8.
  The other mother is the anti-down-quark # 13.

Entry # 13 is an existing anti-down-quark
  p: ( .4915E+02; -.4368E+02, .1474E+02, -.1705E+02), m: .1000E-01
  The first mother is the W+ # 8.
  The other mother is the up-quark # 12.

RESULTS:
*******
Total events: 10000, total cross section: 12.98 pb
Number of muons: 2194

1Muon-energy

HBOOK  ID = 1  DATE 10/04/95

|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 160| 156| 152| 148| 144| 140| 136|
| 7 X| XXX| XXX| XXX| 2 XXX5| X XXX| X2XXXX72|
| 132| 128| 124| 120| 116| 7XXXXXXX| XXXXXXXXX|
D Revision History

Version 1.3, April 1995

• Canonical cuts and input parameters.
• Fixed inconsistent phase conventions, which resulted in wrong angular
distributions.

Version 1.2, July 1994

- Coulomb correction.
- Improved JETSET and HERWIG interfaces.

Version 1.1, February 1994

- Hadronization, JETSET and HERWIG interfaces.
- Minor bug fixes.

Version 1.0, 1993

First official release, submitted to the Computer Physics Communication Library.