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The Monte Carlo Program KORALZ, for the Lepton or Quark Pair Production at LEP/SLC Energies – From version 4.0 to version 4.04

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ABSTRACT

Brief information on new features of KORALZ version 4.04 with respect to version 4.0 is given. The main difference is that the new version could be used at LEP2 energies, i.e. up to 240 GeV centre-of-mass system energy. The possibility to switch on different classes of anomalous couplings is also included.

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UPDATE SUMMARY

Title of the program: KORALZ, version 4.04 .
Reference to original program: Comput. Phys. Commun. **79** (1994) 503
Authors of original program: S. Jadach, B.F.L. Ward and Z. Wąs
Operating system: UNIX, HP-UX 10.2
Programming language used: FORTRAN 77
High-speed storage required: < 1 MB
No. of bits in a word: 32
Peripherals used: Line printer
Keywords: Radiative corrections, heavy lepton τ, Monte Carlo simulation, quantum electrodynamics, spin polarization, electroweak theory, anomalous couplings.
Nature of the physical problem: Spin polarization of the τ in the process $e^+e^- \to \tau^+\tau^-(n\gamma)$, $\tau^\pm \to X^\pm$ is used as an important data point for precise tests of the standard electroweak theory. The effects due to QED bremsstrahlung and apparatus efficiency have to be subtracted from the data. The program may be applied also to the production of u, d, s, c, b quarks and neutrinos after appropriate redefinition of the coupling constants and masses. It may be used, as well, to simulate the muon pair production process. The precision of the program in the case of quarks and electron neutrino is restricted. Certain classes of anomalous couplings can be included for τ, q and ν final states.
Method of solution: The Monte Carlo simulation of the combined τ production and decay process is used to calculate the spin effects and effects of radiative corrections, including hard bremsstrahlung, simultaneously. Any experimental cut and apparatus efficiency may easily be introduced by rejecting some of the generated events.
Restrictions on the complexity of the problem: The incoming $e^\pm$ and outgoing $\tau^\pm$ may have only longitudinal polarizations. The total centre-of-mass energy is restricted to 240 GeV. The high precision of the program is assured only in the region of the Z, where interference of bremsstrahlung from initial and final states can be neglected.

The detailed description of how to use the Monte Carlo program KORALZ can be found in ref. [1] and references therein, or at its WWW home page [2]. The KORALZ version 4.04 Monte Carlo can be used for simulation of $e^+e^- \to 2f\ n\gamma$, $(f = \mu, \tau, u, d, c, s, b, \nu)$ processes, including YFS exclusive exponentiation of initial- and final-state bremstrahlung up to the LEP2 energy range. The differences with respect to the previously published version are not big. However, as the LEP phase 2 is approaching its final years and its collaborations will soon disappear, it is probably a good time to store and document, for future references and cross-checks, the final version of the KORALZ program. Let us note also that, in the future, KORALZ will be replaced by the different program KK2f [3], based on more powerful exponentiation at the spin amplitude level. The present paper is by no means an independent publication and it must be read as an appendix to [1].

In the following, we give the minimum information on the content of the present upgrade:

Standard Model Physics

The electroweak library DIZET version 5.0 [4] is used. This code includes WW and ZZ boxes and other non-QED corrections important at the LEP2 energy range. This library was interfaced to KORALZ and the maximum allowed centre-of-mass energy was shifted to 240 GeV. The pretabulation of the electroweak form factors used by the generator was extended to that range as well. It is of course straightforward to increase the maximum allowed energy to higher values, but only at the expense of a further increase of the initialization time and tests. Other, less important modifications, minor bug fixes, etc., were also introduced into KORALZ and its libraries.

The basic algorithm was not modified and as precision requirements at LEP2 energies are lower than at LEP1, where the program was extensively tested and used, only a limited set of tests were performed. Some of the numerical results of table 30 from ref. [5] were reproduced, as well as results from tables 1, 2, and 3 in the talk of G. Passarino [6].

There are two technical points that should be kept in mind. First, off the Z peak, QED bremsstrahlung interference correction is no longer suppressed below the permille level. The size of this interference effect, not included in the multiphotonic option of the program, can be checked by switching interference corrections on and off [7] in single bremsstrahlung runs of KORALZ. Finally, let us point out that it is necessary,for high centre-of-mass energies, to exclude from the generation the Born singularity region (where the invariant mass of the $2f$ pair is smaller than 2 GeV for example). This can be obtained by setting the KORALZ input parameter XPR(13)=VVMAX to a value smaller than 1.

Physics beyond the Standard Model

In the course of experimental data analysis, the possibility to switch on contributions from additional non-standard interactions on top of well controlled Standard Model predictions is of great practical importance. This is an essential ingredient of any experimental program of the "new physics" searches. Some of such applications were developed on the basis of KORALZ and are included in the present version of the code.

In [8] additional non-standard interactions introduced into KORALZ are due to the leptoquarks manifesting themselves in the channel $e^+e^- \to q\bar{q}(n\gamma's)$. A study of such an interaction was of great interest in itself at some time. Now it can serve as an example of how to implement any "new physics" interaction into the process of fermion-pair production (with higher-order bremsstrahlung corrections). In the table, we list the appropriate input parameters for this particular non-standard interaction:

Parameter	Meaning
`NPR(13)=ifleptok`	Switch of leptoquarks 1/0 (on/off)
`NPR(14)=inter`	Type of the leptoquark interactions `inter=`1, 2, −1,−2 corresponds respectively to the model 1, 2, 3, 4 of ref. [8] in case of vector leptoquarks (or 3, 4, 1, 2 for scalar leptoquarks; this second option is however not directly available to the user. The hard-coded flag `iskal` in function `BORNDZ` has to be changed from 1 to 0 for that purpose).
`XPR(19)=xmx`	Mass of the leptoquark.
`XPR(20)=delta`	Additional parameter defining the size of the leptoquark couplings.
`NPR(15)=ifkalin`	Different, anomalous extensions of the Standard Model predictions,not discussed in this paper. The ifkalin=0 denotes these contributions switched off. The ifkalin=1 denotes SM and anomalous $WW\gamma$ couplings for $e^+e^- \to \nu\bar{\nu}\gamma$ and ifkalin=2 anomalous gamma couplings for $e^+e^- \to \tau^+\tau^-\gamma$.

The input parameters are transmitted into the program with the help of the standard KORALZ input matrices `XPR`, `NPR` (see [1]).

Two additional interactions due to SM [1] and anomalous $W - W - \gamma$ couplings in the channel $e^+e^- \to \nu\bar{\nu}(n\gamma' s)$ and anomalous $\tau - \tau + \gamma$ couplings in the channel $e^+e^- \to \tau^+\tau^-(n\gamma' s)$ are described separately in refs. [9] and [10] respectively. The appropriate fortran code is included in the present program version, respectively in directories `korz_new/nunulib` and `korz_new/ttglib`. The corresponding interactions are activated with the key `NPR(15)` as explained in the table.

Example demonstration programs

The demonstration program `DEMO1.f` for the run when leptoquarks are included can be found in the directory `korz_new/february` and the output `DEMO1.out`[2] can be found in thedirectory `korz_new/february/prod1`. The Standard Model `DEMO.f` and its output `DEMO.out` are also included in these directories.

Technical notes on KORALB and libraries used by KORALZ

For the sake of completeness, let us mark that up-to-date versions of the τ decay library TAUOLA [11] and KORALB program [12] for fermion pair production at less than 30 GeV centre-of=mass energies are also included in the distribution file. They differ from the respective published ones by minor bug-fixing only, flexibility extensions, etc. In the case of TAUOLA three new decay modes were introduced: ($\tau^+ \to K^+K^0$, $\tau^+ \to 2\pi^+, \pi^-, 3\pi^0$, and $\tau^+ \to 2\pi^+, \pi^-, 3\pi^0$). But, as usual, no tuning of the decay parameters to the actual data is included. The demonstration program of KORALB `dist.f` can be found in the directory `korb/korb22/september` and its output `dist.output` in `korb/korb22/september/prod1`. For TAUOLA the corresponding files are respectively `tauola/june/TAUDEMO.f` and `tauola/june/prod1/taudemo.out`.

An up to date version of PHOTOS [13] is included in the directory `lib/photos.f` and its demonstration program `phodem.f` in the directory `photos`. The differences with respect to the published version are mainly technical. The present version is quite easy to adopt to the varying dimensions of the HEPEVT [14] common block, and its internal variables are in double precision. A special routine devoted to the reparation of a kinematical configuration, affected, for instance, by the rounding errors, is also provided[3] although it is not activated. The interference correction in the case of two-body decays into particles of different masses is now included.

[1] At high energies the Standard Model $WW\gamma$ interaction becomes important in the $e^+e^- \to \nu\bar{\nu}(n\gamma' s)$ channel. The option `ifkalin=1` has to be used.

[2] The output `DEMO1.out-no-leptoq`, with identical parameter settings but leptoquarks switched off, can also be found there.

[3] It is necessary in case of PHOTOS operation on events including ultrarelativistic (TeV-range) decaying light particles stored in the single precision variables.

The DIZET library for the calculation of genuine electroweak non-QED corrections [4], version 5.0, is placed in the directory `korz_new/diz4_9` (the older version 4.9 is also placed there) together with the interface. An even older version can be found in the directory `korz_new/diz4_6`; the electroweak library Z0POLE [15], with its demonstration program, output and documentation, is in the directory `korz_new/z0pole`. In the actual runs of our demonstration programs, DIZET version 5.0 is used, but it can be rather easily replaced with any of the others. However, not all options of KORALZ operations will then be assured.

There are two versions of YFS3 multiphoton generator included in KORALZ. The version 3.0 [16] was actually used in most of the KORALZ applications until now. The version 3.4 is most up to date; it has an improved treatment of the configurations with very hard photons. It is thus an intermediate step toward KK2f [3]. The demonstration outputs were produced with the YFS version 3.4, but were checked to work with version 3.0 as well.

The description of libraries of anomalous γ couplings [9] and [10] are up to date. The libaries are placed in directories: `korz_new/nunulib` and `korz_new/ttglib`.

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