KORALZ: PHYSICS MONTE CARLO FOR HIGH STATISTICS LEP I
TOWARD THE ULTIMATE VERSION

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ABSTRACT

In the following we will review briefly history and the status of the KORALZ Monte Carlo project for lepton phenomenology at LEP I energies. Special emphasis will be placed on the relation to other activities and the status of tests. Content of the new version will be also briefly presented.


Why Monte Carlo?

In the analysis of high statistics and high precision experimental data Monte Carlo programs are essential, since they provide theoretical predictions in a form similar to the non-analysed data. It is worth to recognise that the theoretical and technical precision of the Monte Carlo has direct consequences for the data analysis.

If \( \hat{z} \) denotes a physical event as it really happens, then, the response of the detector can be symbolically noted as an action of the operator \( B \) on \( \hat{z} \). The \( B \otimes \hat{z} \) should thus be understood as an electronic response of the detector before any triggering. Such a signal is later analysed and finally an event \( \hat{y} = A \otimes B \otimes \hat{z} \) is reconstructed - here \( A \) represents selection and analysis of the data. A difference \( \Delta = \hat{y} - \hat{z} \) represents an essential ingredient of the systematic error. Study of this error also requires a Monte Carlo for physics processes. With its help one can generate a series of events \( \{ z_i \} \) and later relying on the knowledge of the detector parts, generate a series of detector responses \( \{ B \otimes z_i \} \). This forms a perfect testing environment to study properties of the analysis and selection A. For idealised theoretical events \( z_i \), the difference \( \Delta = y_i - z_i \) can be explicitly calculated for every generated event. It is obvious that imperfections in our knowledge of \( B \) will introduce systematic imperfections in \( A \). An inappropriate choice of the theoretical sample \( \{ z_i \} \), for instance due to missing topologies of final states and, to some extent, due to crude approximations in the theoretical differential distribution, will also indirectly affect the study of \( A \) and contribute to the total systematic error. On the other hand, a Monte Carlo is also used in defining selection criteria, experimental cut-offs, etc. In this way the systematic error of the Monte Carlo will also enter the experimental data in an irreversible way.

In fact it is only in a very special case of a QED and/or electroweak perturbative calculation where the question of the theoretical systematic error can be addressed in a fully satisfactory way. In other cases, where hadronic low energy interactions play an important role, the situation is much less satisfactory. We discuss this point in context of \( \tau \) decay and production in more detail eg. in Ref. [1].

KORALZ Monte Carlo program

The unique property of the process \( e^+e^- \to \tau^+\tau^- \) is that it is possible to measure the spin polarization of the final state lepton \( \tau \). This can be done by inspection of the energy distributions of \( \tau \) decay products. The unstable nature of the \( \tau \), which on one hand constitutes its powerful virtue, on the other hand complicates the data analysis. The presented Monte Carlo program is aimed as a helpful tool in the \( \tau \) pair data analysis in SLC/LEP experiments.

In addition, after switching off \( \tau \) decays the program can be used to simulate the process of other fermion pair production in electron-positron annihilation \( e^+e^- \to f^+f^- (m_f) \), where the fermion may be a lepton, \( f = \mu, \nu \) or under certain restrictions a quark, \( q = u, d, s, c, b \).

More comprehensive presentation of KORALZ is out of scope of this talk, we refer the reader to Ref. [2] for more details. Let us list here briefly its main features, differences with respect to the old version [3], as well as its limitations and tests.

The following important effects are taken into account:

1. Multiple QED hard bremsstrahlung from the initial and final state.
2. \( O(\alpha) \) radiative corrections from the standard electroweak model.
3. Longitudinal spin polarization of the beams.
4. More than twenty distinct $\tau$ decay modes including $O(\alpha)$ bremsstrahlung in the leptonic decay modes, and single (or double) bremsstrahlung in the leading logarithmic approximation for other decay channels.

The present version of KORALZ differs from the previous version 3.8 [3] in the following respect:

1. The top mass dependence of the electroweak corrections important in the heavy top mass regime is introduced.
2. Multiphoton final state radiation is introduced.
3. New $\tau$ decay modes and refining on the existing ones are introduced. In particular, a matrix element algorithm for $O(\alpha)$ radiative corrections in leptonic decays is introduced.

The program has some limitations. Let us list them in the order of their importance:

1. The QED initial-final state bremsstrahlung interference in the presence of the multiple QED hard bremsstrahlung is not included.
2. The complete QED $O(\alpha)$ corrections to the $\tau$ decay are included only for the two $\bar{\nu}\nu e^\pm$, $\bar{\nu}\nu \mu^\pm$, leptonic decay channels.
3. There is no possibility to vary, from event to event, the flavour of the final state fermion and the energy of the beams.
4. The incoming $e^\pm$ and outgoing $\tau^\pm$ may have only longitudinal polarizations.
5. Precision of the program in the case of quarks as final states is restricted.

The KORALZ program has a modular structure. All of its basic parts, YFS2/YFS3 [5], TAUOLA [4], PHOTOS [6], DIZET/Z0POLE [7]/[8], were already published and are included in KORALZ either directly or with only minor changes. This separation assures a clear structure of the program. It is especially important in the case of electroweak corrections.

KORALZ includes spin polarization of the beams and the complete $O(\alpha)$ virtual corrections from the (electroweak) standard model [7, 8, 9], as well as hadronic and gluonic corrections. In the multi-bremsstrahlung mode KORALZ uses a multi-photon algorithm for QED bremsstrahlung [5]. In the single bremsstrahlung mode KORALZ emulates the program MUSTRAAL of Ref. [10].

QED corrections to the spin effects are implemented at the leading-log level only. With increasing precision of the experimental data, this approximation will require reexamination. A few remarks on the limitations of the program: The total centre of mass energy is restricted to the range from about 20 GeV to 150 GeV. One should keep in mind that the interference of bremsstrahlung from initial and final states can be neglected only close to the $Z$ resonance.* Let us remind the reader that the program KORALB of Ref. [11] for $\tau$ pair production at $\sqrt{s} \leq 30$ GeV includes all effects due to the finite mass of $\tau$ and due to transverse polarizations of $\tau^\pm$ and $e^\pm$. KORALZ neglects the transverse spin correlations in $\tau$ decays. KORALB may serve for checks on the importance of these correlations. KORALB includes $Z$ exchange at the Born level and single-bremsstrahlung only for $s$-channel $\gamma$ exchange.

The program of the size and complexity, as is the case with KORALZ, requires exhaustive testing before it can be considered reliable. So far the following tests and groups of tests were performed:

1. In Ref. [4] tests on the $\tau$ decays are reported and in Ref [6] tests of approximate algorithm for radiative corrections in decays.
2. In the description of the YFS2/YFS3 [5] generator for the multiphoton bremsstrahlung, some tests are reported. Some further tests are forthcoming.
3. Comparison of results by KORALZ with other $\nu$ generator can be found inRefs. [12].
4. The prediction of KORALZ for the forward backward asymmetry of muons is compared with the analytical calculations in Refs. [13], see also [14].
5. A multitude of comparisons with the semi-analytical calculation by the CALASY program, in particular the $\tau$ polarization observables, are presented in Ref. [15].
6. A multitude of other comparisons with the semi-analytical program CALASY, in particular for the total cross section, can also be found in Ref. [16].

We encourage the user to reproduce at least those of these tests which are most relevant for her or his applications. Note, that we are unable to quote single number for precision of our program. Due to the general principles it can be given only for well defined observables and experimental cuts [1].

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*For a precision better than 1%, in general, the size of the interference correction should be checked with the help of the single bremsstrahlung mode of KORALZ.
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References
