TAUOLA for simulation of tau decay and production: perspectives for precision low energy and LHC applications

Z. Was

aInstitute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Cracow, Poland

The status of Monte Carlo system for the simulation of τ-lepton production and decay in high-energy accelerator experiments is reviewed. Since previous τ-lepton conference in 2008 some practical modifications have been introduced: (i) For the TAUOLA Monte Carlo generator of τ-lepton decays, automated and simultaneous use of many versions of form-factors for the calculation of optional weights for fits was developed and checked to work in Belle and BaBar software environment. Work on alternative parameterizations of hadronic decays is advanced. (ii) the TAUOLA universal interface based on HepMC (the C++ event record) is now public. A similar interface for PHOTOS is now also public. (iii) Extension of PHOTOS Monte Carlo for QED bremsstrahlung in decays featuring kernels based on complete first order matrix element are gradually becoming widely available thanks to properties of the new, HepMC based interface. (iv) Tests of the programs systematized with the help of MC-TESTER are now available for FORTRAN and C++ users.

Presented here results illustrate the status of the projects performed in collaboration with Nadia Davidson, Piotr Golonka, Gizo Nanava, Tomasz Przedziński, Olga Shekhtsova, Elżbieta Richter-Was, Pablo Roig, Qingjun Xu and others.

Presented at International workshop on Tau Lepton Physics, TAU10 Manchester GB, September, 2010

preprint IFJPAN-IV-2011-1, January 2011

1. Introduction

The TAUOLA package [1,2,3,4] for the simulation of τ-lepton decays and PHOTOS [5,6,7] for the simulation of QED radiative corrections in decays, are computing projects with a rather long history. Written and maintained by well-defined (main) authors, they nonetheless migrated into a wide range of applications where they became ingredients of complicated simulation chains. As a consequence, a large number of different versions are presently in use. Those modifications, especially in case of TAUOLA, are valuable from the physics point of view, often did not found the place in the distributed versions of the program. Even if from the algorithmic point of view, versions differ only in details, they incorporate many specific results from distinct τ-lepton measurements or phenomenological projects. Such versions were mainly maintained (and will remain so) by the experiments taking precision data on τ leptons. Interesting from the physics point of view changes are expected to be developed in FORTRAN. That is why, significant part of the TAUOLA should remain in FORTRAN for the forthcoming several years.

However many new applications were developed recently, often requiring a program interface to other packages (e.g. generating events for LHC, LC, Belle or BaBar physics processes). Fortunately, co-existence with C++ is not a problem, at least not from the software point of view.

The programs structure, prepared for the convenience of FORTRAN users, was presented during previous τ conferences, and we will not repeat it here. This time, let us concentrate on new interfaces for applications based on HepMC event record. We will also report on progress in im-

*Supported in part by the Polish Government grant N202 06434 (2008-2011).
plementation (re-implementation) of techniques useful for fits. Analyses of high precision, high statistic data from Belle and BaBar are expected to progress from these solutions.

Our presentation is organized as follows: Section 2 is devoted to new interfaces of TAUOLA and PHOTOS to HepMC applications of C++, where genuine weak and transverse spin effects can be taken into account as well. Section 3 is devoted to the discussion of optional weights in TAUOLA and their use for fits to data at the level of comparison with raw data. Progress on the work on new currents for hardonic decays which can be confronted with (tuned to) data using such optional weights enabling simultaneous control of all experimental effects is mentioned too. In section 4 we present some new results for PHOTOS Monte Carlo for radiative corrections in decays. Section 5 is devoted to MC-TESTER, the program which can be used for semi-automatic comparisons of simulation samples originating from different programs.

Because of the limited space of the contribution, and sizable amount of other physically interesting results, some of them will be excluded from conference proceedings. They will find place in future works, possibly with collaborators mentioned in the Abstract. For these works, the present paper may serve as an announcement.

2. **TAUOLA universal interface and PHOTOS interface in C++**

In the development of packages such as TAUOLA or PHOTOS, questions of tests and appropriate relations to users’ applications are essential for their usefulness. In fact, user applications may be much larger in size and human effort, than the programs discussed here. Good example of such ‘user applications’ are complete environments to simulate physics process and control detector response at the same time. Distributions of final state particles distributions are not always of direct interest. Often properties of intermediate states such as spin state of \( \tau \)-lepton, coupling constants or masses of intermediate heavy particles are of prime interest. As a consequence it is useful that such intermediate state properties are under direct control of the experimental user and can be manipulated to understand detector responses. Our programs worked well with FORTRAN applications where HEPEVT event record was used. Now, for the C++ HepMC [8] case, interfaces had to be re-written, both for TAUOLA [11] and PHOTOS [12]. The interfaces are gradually enriched and for example for the PHOTOS improved kernel, is already available for the general use, as explained in ref. [13]. A complete (not longitudinal only) spin correlations are available for \( Z/\gamma^* \) decay in TAUOLA interface now. They are based on electroweak corrections taken from refs. [14,15]. See Fig. 1 for the scheme of programs communications. The size of the electroweak effects on longitudinal \( \tau \) polarization is shown in Fig. 2. Such modular organization opens ways for efficient algorithms to understand detector systematics, but at the same time responsability to control software precision must be shared by the user. For that purpose automatization of tests MC-TESTER was prepared [9]. New functionalities were introduced into the testing package [10]. In particular, it works now with the HepMC event record, the standard of C++ programs and the spectrum of available tests is enriched. For details see Section 5.

![Figure 1. Scheme of Monte Carlo simulation system with communication based on event record.](image)
Figure 2. Polarization of $\tau$ leptons produced from up quarks (Fig. (a)) and down quarks (Fig. (b)) at $\cos \theta = -0.2$ ($q\bar{q} \rightarrow \tau^+\tau^-$). For the red line genuine weak corrections are taken into account, the black represent Standard Born (default in the interface). The blue line is Born according to alpha scheme of [14,15]. The small bump on the red line on Fig. (a) is due to the WW threshold.

3. Optional weights for TAUOLA Monte Carlo

Physics of $\tau$ lepton decays requires sophisticated strategies for the confrontation of phenomenological models with experimental data. On one hand high statistics experimental samples are collected, and the obtained precision is high, on the other hand, there is a significant cross-contamination between distinct $\tau$ decay channels. Starting from a certain precision level all channels need to be analyzed simultaneously. Change of parametrization for one channel contribution to the background may be important for the fit of another one. This situation leads to a complex configuration where a multitude of parameters (and models) needs to be simultaneously confronted with a multitude of observables. One has to keep in mind that the models used to obtain distributions in the fits may require refinements or even substantial rebuilds as a consequence of comparison with the data. The topic was covered in detail in the $\tau$ Section of Ref. [16] earlier this year.

From the statistical point of view it is best to resolve such system in one automated step using for example a method such as [17,18]. This can be of course very dangerous from the point of view of systematic error control. But we will not elaborate on this point any further. From the technical point it is necessary, to calculate for each generated event (for each present in it: decay of $\tau^+$ and $\tau^-$ separately) alternative weights; the ratios of matrix element squared obtained with new currents provided by the user, and the one actually used in generation. Then the vector of weights can be obtained and used in fits. We have checked that such a solution not only can be easily installed into TAUOLA as a stand-alone generator but it can also be incorporated into the simulation frameworks of Belle and BaBar collaborations rather easily. The scheme as given in Fig. 3 was shown to work in real conditions.

At the present step of our work no new models of hadronic currents are prepared. Work on currents based on refs. [19,20,21] is taking shape mainly thanks to efforts by Olga Shekhovtsova. A dedicated patch is being prepared, to be later installed into users software environments.
Note that here the LL (NLL) denote collinear logarithms (or in case of differential predictions terms integrating in to such logarithms). The logarithms of soft singularities are taken into account to all orders. This is resulting from mechanisms of exclusive exponentiation \[24\] of QED. The algorithm used in PHOTOS Monte Carlo is compatible with exclusive exponentiation. Note that our LL/NLL precision level would even read as respectively NLL/NNNLL level in some naming conventions of QCD.

4. PHOTOS Monte Carlo for bremsstrahlung and its systematic uncertainties

Thanks to exponentation properties and factorization, the bulk of the final state QED bremsstrahlung can be described in a universal way. However, the kinematical configurations caused by QED bremsstrahlung are affecting in an important way signal/background separation. It may affect selection criteria and background contaminations in quite complex and unexpected ways. In many applications, not only in $\tau$ decays, such bremsstrahlung corrections are generated with the help of the PHOTOS Monte Carlo. That is why it is of importance to review the precision of this program as documented in Refs. \[49,57\]. For the C++ applications, the first version of the program is also available now, it is documented in Ref. \[22\].

In C++ applications, the complete first order matrix element for the two body decays of the $Z$ into pair of charged leptons \[13\] is now available. Kernels with complete matrix elements, for the decays of scalar $B$ mesons into a pair of scalars \[22\], for $W^\pm \to l^\pm \nu \gamma$ and for $\gamma^* \to \pi^+ \pi^-$ \[23\] are available for tests or specially oriented decay particles frames. It will be rather easy now to integrate NLO kernels into the main version of the program, because of better control of decay particle rest frame than in the FORTRAN interface.

In all of these cases the universal kernel of PHOTOS is replaced with the one matching exact first order matrix element. In this way terms necessary for NLO/NLL precision level are implemented\[1\]. A discussion relevant for control of program systematic uncertainty in $\tau \to \pi \nu$ decay can be found in Ref. \[25\].

The algorithm covers the full multiphoton phase-space and becomes exact in the soft limit. This is rather unusual for NLL compatible algorithms. One should not forget that PHOTOS generates weight-one events too, and does not require any phase space ordering. There is a full phase space overlap between the one where hard matrix element is used and the one for iterative photon emissions. All interference effects (between consecutive emissions and emissions from distinct charged lines) are implemented with the help of internal weights.

The results of all tests of PHOTOS with a NLO kernel confirm sub-permille precision level. This is very encouraging, and points to the possible extension of the approach outside of QED (scalar QED). In particular to the domain of QCD or if phenomenological lagrangians for interactions of photons need to be applied. For that work to be completed spin amplitudes need to be further studied. Let us point to Ref. \[26\] as an example.

Kernels necessary for NLO are only available at present as options for tests only. They can be uploaded from the PHOTOS web page \[27\]. In the C++ applications they will be gradually installed into the main version of the program. The first step was the case of $Z/\gamma^*$ decay and is already completed now. This opens the way to discuss

\footnote{Note that here the LL (NLL) denote collinear logarithms (or in case of differential predictions terms integrating into such logarithms). The logarithms of soft singularities are taken into account to all orders. This is resulting from mechanisms of exclusive exponentiation \[24\] of QED. The algorithm used in PHOTOS Monte Carlo is compatible with exclusive exponentiation. Note that our LL/NLL precision level would even read as respectively NLL/NNNLL level in some naming conventions of QCD.}
systematic errors in user defined acceptance regions. This will be an important supplement to tests-comparisons with other programs such as KKMC \cite{KKMC}, see Fig. 4.

5. **MC-TESTER and user defined tests.**

Our work on MC-TESTER \cite{MC-TESTER} reached maturity. As in the past, the program main purpose remain benchmarking the decay part of different Monte Carlo chains. Generated events have to be stored in event records: be it of FORTRAN or C++. Default distributions consist of all possible invariant masses which are automatically generated and stored for each found decay channel of the particle under test. Then, at the analysis step, information from a pair of such runs may be compared and represented in the form of tables and plots. At present, users macros can be easily installed, in particular all demo distributions given in papers on C++ interfaces for TAUOLA \cite{TAUOLA} and PHOTOS \cite{PHOTOS} can be obtained in that way. Set-up’s for benchmarking the interfaces, such as interface between $\tau$-lepton production and decay, including QED bremsstrahlung effects can be prepared in that way.

The updated version of MC-TESTER was found useful for FORTRAN \cite{FORTRAN} and for C++ \cite{C++} examples where spurious information (on soft photons) was removed.

Finally, let us mention that the program is available through the Grid Project LCG/Genser web page, see Ref. \cite{GridProject} for details. This is the case for TAUOLA C++ and for PHOTOS C++ in the near future as well. The FORTRAN predecessors have already been available for some time.

6. **Summary and future possibilities**

The status of the computer programs for the decay of $\tau$ leptons TAUOLA and associated projects TAUOLA universal interface and MC-TESTER was reviewed. The high-precision version of PHOTOS for radiative corrections in decays, was presented also. All these programs are available now for C++ applications thanks to the HepMC interfaces.

New results for PHOTOS were mentioned. For the $Z$ decay channel the complete next-to-leading collinear logarithms effects can now be simulated in C++ applications. However, in most cases these effects are not important, leaving the standard version of PHOTOS sufficient. The example is important for the general case, it helps to better understand questions related to matching hard emission matrix elements with parton showers without the necessity to introduce any boundaries within the phase space. Thanks to this work the path for fits to the data of electromagnetic form-factors is opened. The effects of these form-factors may be significantly larger and physically more interesting than complete next-to-leading order effects of QED or scalar QED.

The presentation of the TAUOLA general-purpose interface in C++ was given. It is now more refined than the FORTRAN predecessor. Electroweak corrections can be used in calculation of complete spin correlations in $Z/\gamma^*$ mediated processes.

Distinct versions of the hadronic currents for TAUOLA library are available for the FORTRAN distribution. Work on new ones and on refinements of old strategies of fits using alternative weights and projection operators is progressing.

The new version of MC-TESTER is stable now. It not only works with HepMC of C++ but enables user defined tests in experiments’ software environments.

**Acknowledgements**

Discussions with members of the Belle and BaBar collaborations are acknowledged. Exchange of e-mails and direct discussions with S. Banerjee, S. Eidelman, H. Hayashii, K. Inami, A. Korchin, J. H. Kühn and M. Roney was a valuable input to present and future steps in projects development.

**REFERENCES**

1. S. Jadach, J. H. Kuhn, and Z. Was, *Comput. Phys. Commun.* 64 (1990) 275.
2. M. Jezabek, Z. Was, S. Jadach, and J. H. Kuhn, *Comput. Phys. Commun.* 70 (1992) 69.
3. S. Jadach, Z. Was, R. Decker, and J. H. Kuhn,
4. P. Golonka et al., *Comput. Phys. Commun.* 174 (2006) 818–835, [hep-ph/0312240](http://arxiv.org/abs/hep-ph/0312240).
5. E. Barberio, B. van Eijk, and Z. Was, *Comput. Phys. Commun.* 66 (1991) 115.
6. E. Barberio and Z. Was, *Comput. Phys. Commun.* 79 (1994) 291–308.
7. P. Golonka and Z. Was, *Eur. Phys. J.* C45 (2006) 97–107, [hep-ph/0506026](http://arxiv.org/abs/hep-ph/0506026).
8. M. Dobbs and J. B. Hansen, *Comput. Phys. Commun.* 134 (2001) 41–46, https://savannah.cern.ch/projects/hepmc/.
9. P. Golonka, T. Pierzhala, and Z. Was, *Comput. Phys. Commun.* 157 (2004) 39–62, [hep-ph/0210252](http://arxiv.org/abs/hep-ph/0210252).
10. N. Davidson, P. Golonka, T. Przedzinski, and Z. Was, [0812.3215](http://arxiv.org/abs/0812.3215).
11. N. Davidson, G. Nanava, T. Przedzinski, E. Richter-Was, and Z. Was, [1002.0543](http://arxiv.org/abs/1002.0543).
12. N. Davidson, T. Przedzinski, and Z. Was, [1011.0937](http://arxiv.org/abs/1011.0937).
13. P. Golonka and Z. Was, *Eur. Phys. J.* C50 (2007) 53–62, [hep-ph/0604232](http://arxiv.org/abs/hep-ph/0604232).
14. A. Andonov et al., [0812.4207](http://arxiv.org/abs/0812.4207).
15. A. Andonov et al., *Comput. Phys. Commun.* 174 (2006) 481–517, [hep-ph/0411186](http://arxiv.org/abs/hep-ph/0411186).
16. S. Actis et al., *Eur. Phys. J.* C66 (2010) 585–686, [0912.0749](http://arxiv.org/abs/0912.0749).
17. A. Hoecker, P. Speckmayer, J. Stelzer, F. Tegenfeldt, H. Voss, K. Voss, et al., http://tmva.sourceforge.net/.
18. A. Hocker et al., *PoS ACAT* (2007) 040, [physics/0703039](http://arxiv.org/abs/physics/0703039).
19. P. Roig, *Nucl. Phys. Proc. Suppl.* 189 (2009) 78–83, [0810.5764](http://arxiv.org/abs/0810.5764).
20. D. G. Dumm, P. Roig, A. Pich, and J. Portoles, *Phys. Rev.* D81 (2010) 034031, [0911.2640](http://arxiv.org/abs/0911.2640).
21. D. G. Dumm, P. Roig, A. Pich, and J. Portoles, *Phys. Lett.* B685 (2010) 158–164, [0911.4438](http://arxiv.org/abs/0911.4438).
22. G. Nanava and Z. Was, *Eur. Phys. J.* C51 (2007) 569–583, [hep-ph/0607019](http://arxiv.org/abs/hep-ph/0607019).
23. G. Nanava, Q. Xu, and Z. Was, *Eur. Phys. J.* C70 (2010) 673–688, [0906.4052](http://arxiv.org/abs/0906.4052).
24. S. Jadach, B. F. L. Ward, and Z. Was, *Phys. Rev.* D63 (2001) 113009, [hep-ph/0006359](http://arxiv.org/abs/hep-ph/0006359).
25. Z.-H. Guo and P. Roig, *Temporary entry*,
Figure 4. The spectrum of the $\gamma\gamma$ invariant mass in $Z \rightarrow \mu^+\mu^-n\gamma$ decay. Events with two hard photons, both of energy above 1 GeV in the Z rest frame are taken and the invariant mass of the photon pair, normalized to Z mass is shown: for CEEX2 and CEEX1 (case a), and CEEX2 and PHOTOS (case b). The prediction from PHOTOS is clearly superior for applications aiming at simulations for Higgs boson backgrounds than CEEX1. In the case of solution based on YFS exponentiation, the second order matrix element must be taken into account. Fig. b was obtained with the help of examples/testing/Zmumu PHOTOS demonstration example (as documented in Ref. [12]).