

FINAL STATE QED BREMSSTRAHLUNG IN RESONANCE DECAYS AND DETECTOR LEVEL UNIVERSALITY: PHENOMENOLOGICAL PRECISION TOOLS* **

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(Received May 6, 2011)

The status of Monte Carlo system for the simulation of bremsstrahlung in arbitrary decays and for the decay itself of τ -lepton is reviewed. During the last τ -lepton conference in 2010 several developments of the last two years have been presented: *(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. On-going work on alternative parameterizations of hadronic decays is presented too. *(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. Since then, further progress has been achieved. In particular, first order matrix element for Z decay is now installed into publicly available version of PHOTOS Monte Carlo. New parameterizations of hadronic τ decay currents, can now be confronted with the data. The programs found their first use for LHC applications too. Results presented here illustrate the status of the projects performed in collaboration with Nadia Davidson, Piotr Golonka, Gizo Nanava, Tomasz Przedziński, Olga Shekhovtsova, Elżbieta Richter-Wąs, Pablo Roig, Qingjun Xu and others.

DOI:10.5506/APhysPolB.42.1679

PACS numbers: 11.15.Pg, 13.40.Ks, 12.38.Cy

* Presented at the Cracow Epiphany Conference on the First Year of the LHC, Cracow, Poland, January 10–12, 2011.

** Supported in part by the Polish Government grant N202 06434 (2008–2011).

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, **TAUOLA** migrated into a wide range of applications where it became an ingredient of complicated simulation chains. As a consequence, a large number of different versions are presently in use. Those modifications are valuable from the physics point of view, even though they often were not included 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. Changes interesting from the physics point of view are expected to be developed in **FORTRAN**. That is why, significant part of the **TAUOLA** should remain in **FORTRAN** for the forthcoming years. **PHOTOS** Monte Carlo is usually used together with **TAUOLA** but it is used independently too. The way how the two programs communicate with other parts of simulation chain is, however, quite similar. **PHOTOS** is based on QED, the differences in existing versions result only from the requirements of the interfaces.

Many new applications for the two programs were developed recently, often requiring programs interface to other packages (*e.g.* generating events for LHC, LC and written in C++). Fortunately, co-existence of **FORTRAN** and C++ code is not a problem, at least not from the software point of view.

The programs structure, prepared for the convenience of **FORTRAN** users, will not be explained here. This time, let us concentrate on new interfaces for applications based on **HepMC** [8] event record. We will also report on progress in implementation (re-implementation) of techniques useful for fits. Analyses of high precision, high statistic data from Belle and BaBar are expected to profit from these solutions.

Our presentation (an update of the talk [9]) 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. 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 hadronic 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.

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. A 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 are not always of direct interest. Often properties of intermediate states such as spin state of τ -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 rewritten, both for TAUOLA [10] and PHOTOS [11]. The interfaces are gradually enriched and for example for the PHOTOS improved kernel, the interface is already available for the general use, as explained in Ref. [12]. The appropriate version of the code is available from the project web page. Complete (not longitudinal only) spin correlations are now available for Z/γ^* decay in TAUOLA interface. They are based on electroweak corrections taken from Refs. [13, 14], see Fig. 1 for the scheme of programs communications. The size of the electroweak effects on longitudinal τ polarization is shown in Fig. 2. Such modular organization opens ways for efficient algorithms to understand detector systematics, but at the same time the effort to control software precision must be shared by the user. For the purpose of autom-

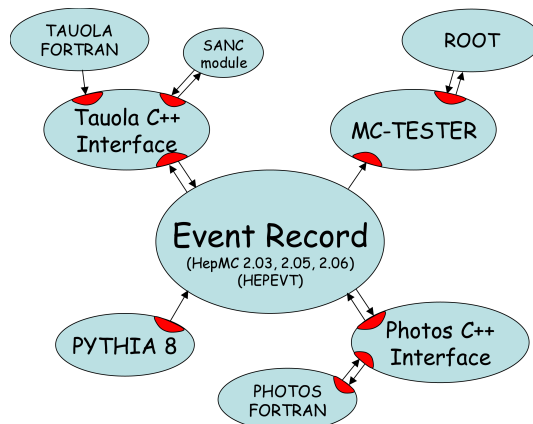


Fig. 1. Scheme of Monte Carlo simulation system with communication based on event record.

atization of the tests, special program, MC-TESTER, was prepared [15]. New functionalities were introduced into the testing package [16]. 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.

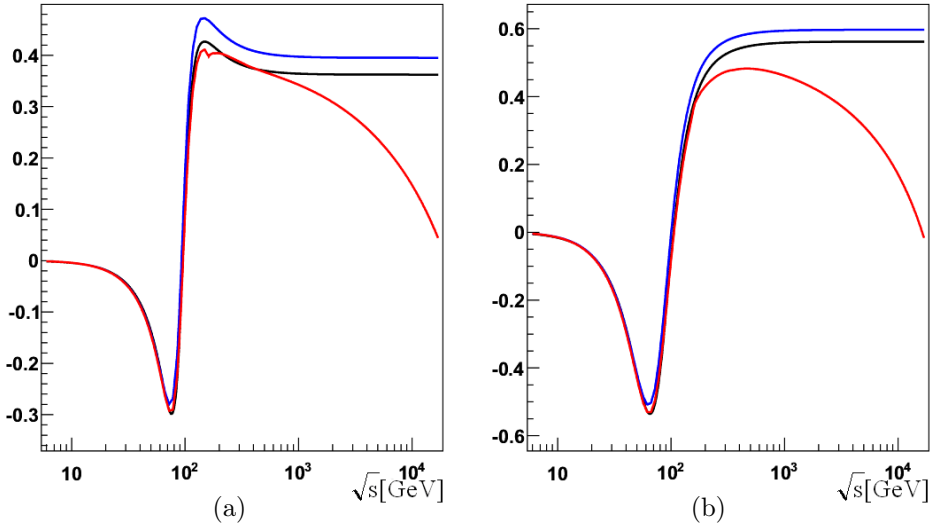


Fig. 2. Polarization of τ leptons produced from up quarks (a) and down quarks (b) at $\cos \theta = -0.2$ ($q\bar{q} \rightarrow \tau^+\tau^-$). For the lowest at high $\sqrt{s}$ (red (lighter grey)) line genuine weak corrections are taken into account, the black represent Standard Born (default in the interface). The top at high $\sqrt{s}$ (blue (darker grey)) line is Born according to alpha scheme of [13, 14]. The small bump on the red line on (a) is due to the WW threshold.

3. Optional weights for TAUOLA Monte Carlo

Physics of τ lepton decays requires sophisticated strategies for the confrontation of phenomenological models with experimental data. On the 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 τ 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 τ section of Ref. [17] 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 [18, 19]. 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 τ^+ and τ^- 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.

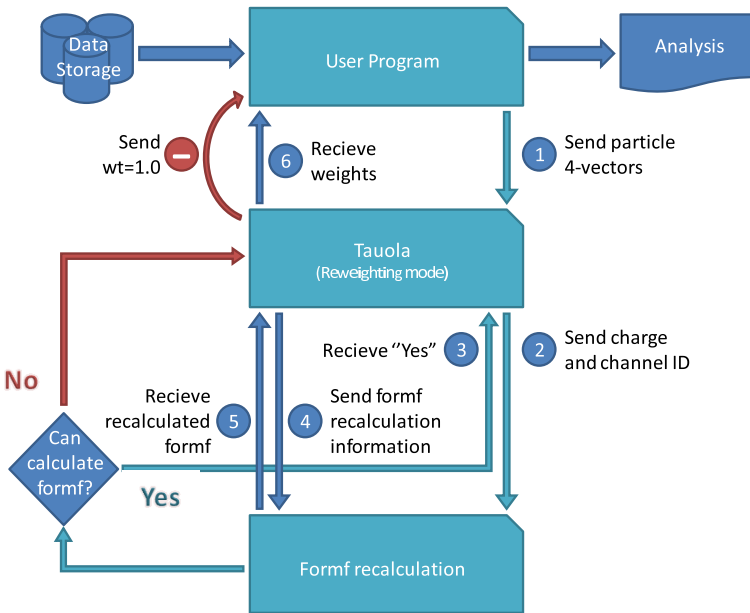


Fig. 3. Flow chart for fifo communication and reweighting **TAUOLA** matrix elements, verified to be compatible with Belle and BaBar software.

At the present step of our work no new models of hadronic currents are prepared. Work on currents based on Refs. [20, 21, 22] is taking shape mainly thanks to efforts by Olga Shekhovtsova. A dedicated patch is being prepared, to be later installed into users software environments. The technical part of the work is completed and the first comparisons with the data are already available, see Fig. 4.

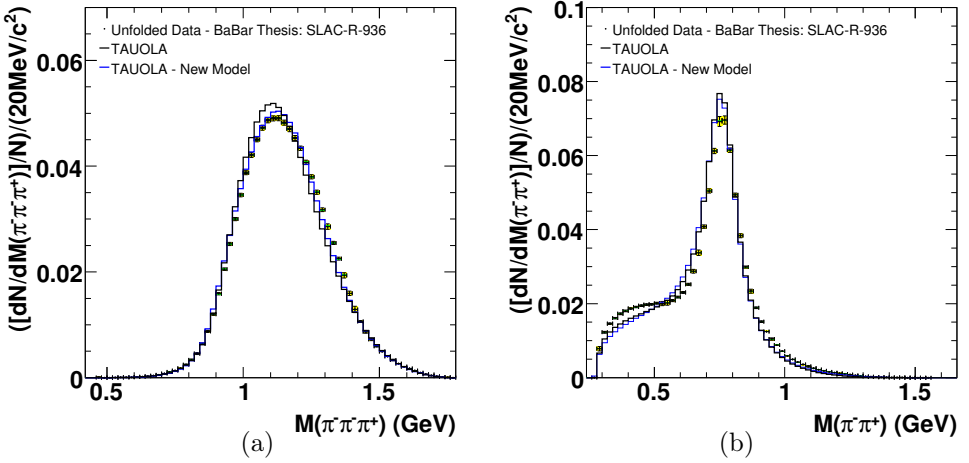


Fig. 4. Comparison of unfolded data taken from Ref. [23] and prediction from the old and new [20] model for $\tau \rightarrow \pi^\pm \pi^\pm \pi^\mp \nu$ decay. In (a) and (b), respectively, invariant masses of $\pi^\pm \pi^\mp$ and $\pi^\pm \pi^\pm \pi^\mp$ are given. Note that actual fits to the data are not yet performed. In particular, scalar contribution to the current is not taken into account. Blue (slightly thinner) line is for the new model.

4. PHOTOS Monte Carlo for bremsstrahlung and its systematic uncertainties

Thanks to exponentiation 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 signal/background separation in an important way. It may affect selection criteria and background contaminations in quite complex and unexpected ways. In many applications, not only in τ 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. [5, 6, 7]. For the C++ applications, the first version of the program is also available now, it is documented in Ref. [11].

In C++ applications, the complete first order matrix element for the two body decays of the Z into pair of charged leptons [12] is now available. Kernels with complete matrix elements, for the decays of scalar B mesons into a pair of scalars [24], for $W^\pm \rightarrow l^\pm \nu \gamma$ and for $\gamma^* \rightarrow \pi^+ \pi^-$ [25] 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, due to the 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 implemented¹. A discussion relevant for control of program systematic uncertainty in $\tau \rightarrow \pi\nu$ decay can be found in Ref. [27].

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. [28] as an example.

Kernels necessary for NLO are at present available as options for tests only. They can be uploaded from the PHOTOS web page [29]. In the C++ applications they will be gradually installed into the main version of the program. The first step was the case of Z/γ^* decay and is already completed now. This opens the way to discuss systematic errors in user defined acceptance regions. This will be an important supplement to tests-comparisons with other programs such as KKMC [30], see Fig. 5.

5. MC-TESTER and user defined tests

Our work on MC-TESTER [16] has reached maturity. As in the past, the program main purpose remains benchmarking of 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 the each found decay channel of the tested particle. Then, at the analysis step, information from a pair of such runs may be compared and represented in the form

¹ Note that here the LL (NLL) denote collinear logarithms (or in the 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 [26] 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/NNLL level in some naming conventions of QCD.

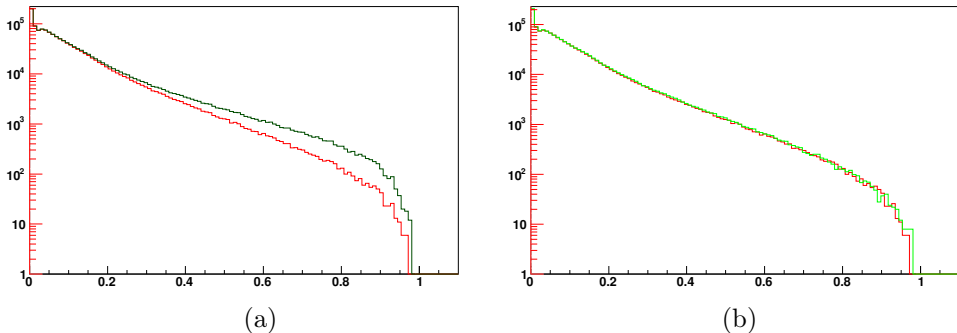


Fig. 5. The spectrum of the $\gamma\gamma$ invariant mass in $Z \rightarrow \mu^+\mu^-n\gamma$ decay. Events with two hard photons, both of energy above 1 GeV in the Z rest frame are taken and the invariant mass of the photon pair, normalized to Z mass is shown: for CEEX2 and CEEX1 (case a), and CEEX2 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 [30], the second order matrix element must be taken into account. (b) was obtained with the help of `examples/testing/Zmumu` PHOTOS demonstration example (as documented in Ref. [11]). CEEX2 predictions are given by the light grey lines.

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 [10] and PHOTOS [11] can be obtained in that way. Set-ups for benchmarking the interfaces, such as interface between τ -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 [7, 12] and for C++ [11] 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. [31] 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 τ 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/γ^* mediated processes.

Multiple versions of the hadronic currents for TAUOLA library are available for the FORTRAN distribution only. Work on the new ones and on refinements of old strategies of fits using alternative weights and projection operators is progressing. First numerical results are available now. This work, at present, is of no urgency for C++ high energy users.

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. Program is now published in the journal.

Finally, let us stress that the practical advantage of the methods based on event record modification consists of correlated samples: effects of bremsstrahlung in decays can be switched on or off. Similarly, spin effects for τ decays can be manipulated as well. This is one of the reason why the programs were found to be useful, see *e.g.* [32, 33], in recent publications on LHC data.

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.

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