The $\tau$ leptons theory and experimental data: Monte Carlo, fits, software and systematic errors$^\dagger,\ddagger$.

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Abstract

Status of $\tau$ lepton decay Monte Carlo generator TAUOLA is reviewed. Recent efforts on development of new hadronic currents are presented. Multitude new channels for anomalous $\tau$ decay modes and parametrization based on defaults used by BaBar collaboration are introduced. Also parametrization based on theoretical considerations are presented as an alternative. Lesson from comparison and fits to the BaBar and Belle data is recalled. It was found that as in the past, in particular at a time of comparisons with CLEO and ALEPH data, proper fitting, to as detailed as possible representation of the experimental data, is essential for appropriate developments of models of $\tau$ decays.

In the later part of the presentation, use of the TAUOLA program for phenomenology of $W, Z, H$ decays at LHC is addressed. Some new results, relevant for QED bremsstrahlung in such decays are presented as well.

Keywords: Tau physics Monte Carlo generator TAUOLA QED radiative corrections

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1 Introduction

The TAUOLA package \cite{1, 2, 3, 4} for simulation of $\tau$-lepton decays and PHOTOS \cite{5, 6, 7} for 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, even though they often did not find the place in the distributed versions of the program. From the algorithmic point of view, versions may differ only in details, but they incorporate many specific results from distinct $\tau$-lepton measurements or phenomenological projects. Such versions were mainly maintained (and will remain so) by the experiments taking precision data on $\tau$ leptons. Interesting from the physics point of view changes are still developed in FORTRAN. That is why, for convenience of such partners, part of the TAUOLA should remain in FORTRAN for a few forthcoming years.

The program structure did not change significantly since previous $\tau$ conference \cite{8}, nowadays however, the C++ implementation become dominant for many aspects of the project. In the following, we will concentrate on physics extensions and novel applications. We will stress importance of the three aspects of the work: (i) construction and implementation of hadronic currents for $\tau$ decay currents obtained from models (evaluated from QCD) (ii) presentation of experimental data in a form suitable to fits (iii) preparations of algorithms and definition of distributions useful for fits.

We have prepared two new set of currents, the first based mainly on theoretical consideration, the second on an effort of BaBar collaboration. They are ready to be integrated into main distribution tar-balls for FORTRAN and C++ applications. Further work in evaluation if such parametrizations are better suitable for physics purposes is on-going. Weighted event techniques useful for fits were studied as well. Analyses of high precision, high-statistics data from Belle and BaBar may find them useful, similar as LHC experiments.

Our presentation is organized as follows: Section 2 is devoted to presentation of optional initialization for TAUOLA which is based on the program version evolving in BaBar starting from a variant presented on $\tau$ conference of 2004 \cite{9}. This version is supplemented with multitude of anomalous $\tau$ decay modes as well as with parametization of our theoretical works of the last decay (of different level of theoretical sophistication depending on decay channel). Possibility to replace hadronic currents or matrix elements with the user provided C++ code is introduced. In Section 3 we concentrate on PHOTOS Monte Carlo for radiative corrections in decays. The new version of the program is now 100 \% in C++. Section 4 is for the interfaces of TAUOLA and PHOTOS based on HepMC and written in C++. Work on interface to genuine weak corrections, transverse spin effects and new tests and implementation bremsstrahlung kernels is presented as well. Next, the algorithm of TauSpinner is presented. It calculates weights to manipulate properties of the event sample accordingly to changed assumptions for the hard process dynamic, or due to changed level of implementation of spin effects. Summary Section 5, closes the presentation.

Because of the limited space of the contribution, some results will not be presented in the proceedings. They find their place in publications, prepared with co-authors listed in the References. For these works, the present paper may serve as an advertisement.

2 New currents in TAUOLA Monte Carlo

In other talks \cite{10, 11} of the conference, it was shown how Resonance Chiral Lagrangian approach was used for calculations of hadronic currents to be installed in TAUOLA. We do not need to repeat it here. In \cite{10} it was stressed that details, such as additional resonances, more specifically the $f_2(1270)$, $f_0(1370)$ and $a_1(1640)$, observed by CLEO long time ago \cite{12} can not be introduced if fits to one-dimensional invariant mass spectra of two- and three-pions systems are only used. In Ref. \cite{12} as an input for parametriza-
tion of TAUOLA currents (cleo parametrization, \[13\]), two-dimensional mass scattergrams were used. This should be considered as a minimum for the comparisons with the present day data as well. In fact, already CLEO used more detailed representation of the data in \[14\]. It may be of interest to repeat such data analysis, with the help of observables, as the ones presented in \[15\], but adopted to the case of relativistic tau-pair production of Belle or BaBar experiments.

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 parameterization for one channel contributing to the background to another one may be important for the fit of its currents. This situation leads to a complex configuration where a multitude of parameters (and models) needs to be simultaneously 

due for each generated event (separately for decay of $\tau$ and/or $\tau^-$) alternative weights; the ratios of the matrix element squared obtained with new currents, 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. For practical reasons use of semi analytical distributions is much easier. It enables much faster calculation of errors for fit parameters including correlations, but experimental distributions must be available in unfolded form. This was an important ingredient of our work for fits of $3\pi$ currents obtained in \[17\]. We have found that modifications of the currents were necessary to obtain results given in \[18\]. It is not clear, if such fitting, without additional help of observables as in \[15\] can be used for the $KK\pi\nu$, and $K\pi\pi\nu$, $\tau$ decay channel, even if two-dimensional scattergrams are available. One has to keep in mind that if experimental data are available as one or at most two dimensional histograms then resulting currents rely on the models. With the present day precision of the data, even an approach of Resonance Chiral Lagrangian should not be expected to have sufficient predictive power to describe multidimensional distributions from the constraints of fits to one or two dimensional histograms. This limitation is clearly visible in results for $4-\pi$’s currents of ref. \[19\].

Keeping all these limitations in mind, we have nonetheless prepared currents for TAUOLA based on Refs. \[18\] \[19\] \[20\] \[21\], respectively for $3$, $4$, $2$ and $5 \pi$’s final states. This is now available (upon individual requests) for FORTRAN and C++ users, together with further possibility that user introduces own C++ currents and together with BaBar initialization of currents.

3 PHOTOS Monte Carlo for bremsstrahlung; its systematic uncertainties

Over the last two years no major upgrades for functionalities were introduced into PHOTOS Monte Carlo. On the other hand, technical changes were introduced. In the last couple of months, for the version of the code prepared for the C++ environment \[22\], transition to C++ was completed.

Also work on numerical tests and new applications, especially in domain of LHC applications was completed. The results are collected in Refs. \[23\] \[24\] \[25\]. A precision up to sub-permille level was confirmed.

\[1\] Note that for this parametrization, differences between hadronic currents of $\tau \to \pi^+\pi^-\pi^-\nu$ and $\tau \to \pi^-\pi^0\pi^0\nu$ were ignored; isospin symmetry was imposed ($\rho\tau$ dominance). Version of the current without this constraint is nonetheless distributed with TAUOLA (all versions), but as an non-active option. On the other hand, it not only was developed and used by CLEO, but existed (as one of options) in BaBar software. I am thankful to Swagato Banerjee for clarification.
4 TAUOLA universal interface and TauSpinner

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 efforts 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 are not always of direct interest. Often properties of intermediate states, such as a 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.

In that perspective, an algorithm of TauSpinner to study detector response to spin effects in $Z, W$ and $H$ decays, represents an important development. The program is calculating weights corresponding to changes of the physics assumption. As an input, events stored on the data file are used. At present, the program can calculate: spin correlation, production matrix element and decay matrix element weights from the kinematical configurations for events previously generated and stored on the datafile. In this way detector response to variants of physics model used in the production process can be studied. Following original publication, the TauSpinner was first enriched with the option to study effects of new physics, such as effects of spin-2 states in $\tau^{+}\tau^{-}$ pairs produced at LHC. This work was later continued, and in an option to study transverse spin effects, important for the Higgs parity measurements was developed. Work on systematic tests was being performed as well. Electroweak corrections taken from Refs. can be also used with the help of the weights. Also, as it was found to be the case for evaluation of systematic errors for the measurement of $e^{+}e^{-} \rightarrow \tau^{+}\tau^{-}$ BaBar cross section, improvements in precision of $\tau$-decays as discussed in Section 2, may be of importance for LHC observables as well.

All our programs are available through the LHC Computing Grid (LCG) Project. See GENSER webpage, Ref. for details. This is the case for TAUOLA, TauSpinner and for PHOTOS as well. The FORTRAN predecessors are available in this way too.

5 Summary and future possibilities

Versions of the hadronic currents available for the TAUOLA library until now, were all based on old models and experimental data of 90’s. The alternative implementation of new currents, based on the Resonance Chiral Lagrangian, or other approaches is now prepared and tested for the decay channels to 2, 3, 4 and 5 pions. For each of these groups of decay channels, different level of theoretical sophistication and quality of comparisons with the $\tau$ decay data was used. On top of it, parametrizations used for the default simulations in BaBar collaboration became available. The particular advantage of this option is a multitude of rare and anomalous $\tau$ decay channels. In fact this list was extended even further. With the help of C++ interface, user provided hadronic current(s) or decay matrix element(s), can replace, the ones of the library.

In contrary, methods for detailed confrontation with the experimental data are not developing that fast. We still rely on comparison of results with one (at most two) dimensional histograms of invariant masses for sub-groups of $\tau$ decay products, defined for each decay channel separately and unfolded from the background by experiments, prior to comparisons. Even though it was postulated already in that it may not be optimal.

The status of associated projects: TAUOLA universal interface and TauSpinner was reviewed. Also new results for the high-precision version of PHOTOS for QED radiative corrections in decays, were referenced. All these programs are ready for C++ applications thanks to the HepMC interfaces.

Presentation of the TAUOLA general-purpose C++ interface was given. Electroweak corrections can be
used in calculation of complete spin correlations in \( Z/\gamma^* \) mediated processes. An algorithm for study, with the help of weights calculated from kinematic of events stored on data files, detector responses to: spin effects and production process variants in \( Z, W \) and \( H \) decays was shown. The corresponding program \textit{TauSpinner}, is useful, eg. to study Higgs parity sensitive observables at LHC.

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