

TAUOLA — HADRONIC CURRENTS, SYSTEMATICAL ERRORS AND FITS*

JAKUB ZAREMBA

The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences
Radzikowskiego 152, 31-342 Kraków, Poland

(Received March 28, 2017)

TAUOLA — Monte Carlo event generator for τ -lepton decays, has recently undergone some updates. Summary on those recent developments and plans for future will be discussed. The main point of recent updates is initialization mirroring the one used by the BaBar Collaboration. Apart from that, tools to introduce modeling of chosen decays were introduced. Future plans include preparation for user framework of fitting theoretical models to experimental data. It is planned to be divided into two steps. First, environment allowing the fit of invariant masses of different combination of outgoing particles. This type of fits is most commonly used. Secondly, this fitting framework will be enriched by tools for fitting angular distributions. Such a tool should help to explore medium-energy QCD (0.5–2.0 GeV). In this energy region, the phenomenological description of processes is far less precise than experimental measurements.

DOI:10.5506/APhysPolB.48.1253

1. Introduction

Tau decays are often an underappreciated field of physics, because many people treat taus as simple objects. While tau lepton itself is “simple”, it decays in 65% into hadrons. Out of all hadronic decays, only those into one or two pions and tau neutrino can be considered as well-described. This means that roughly 40% of all tau decays is not fully understood. Almost half of those decay channels is populated by decays into three pions (both one-prong and three-prong). Because of that, later in this paper, we will focus on those channels.

* Presented at the Cracow Epiphany Conference “Particle Theory Meets the First Data from LHC Run 2”, Kraków, Poland, January 9–12, 2017.

To understand why taus are so interesting, we need to recall some of their physical aspects in relation to QCD. Tau has the mass of 1.777 GeV making it the only lepton heavier than lightest of hadrons, therefore the only lepton that can decay into hadrons. In addition, it is relatively long-living particle. This allows for easy separation between production and decay. On the other hand, we have Chiral Perturbation Theory, which is convergent at low energy (below 0.5 GeV) and QCD working well in high energy (above 2.0 GeV). An intermediate energy lacks good theoretical modeling. As taus have mass of 1.777 GeV and long lifespan, they are perfect tools to explore this energy regime and help us to develop new calculative schemes of QCD.

Our paper is organized as follows. Section 2 gives description of TAUOLA. Following subsections concentrate on recent updates introduced in TAUOLA and discuss modeling of $\tau^- \rightarrow (\pi\pi\pi)^-\nu_\tau$ decay. Section 3 is devoted to ongoing development of fitting framework aimed at tau decays into three hadrons and tau neutrino. Possible future improvements of this framework are discussed in Section 3.1. Section 4 closes the paper.

2. TAUOLA MC

TAUOLA is a library for Monte Carlo generator [1–3]. Its purpose is to generate events of decaying tau leptons with full topology of included particles. Event generation in TAUOLA is split into two independent parts: phase-space generator and matrix element. Phase-space calculation is strict and model-independent. Matrix element for leptonic decays is well-described by electroweak interactions, while matrix element in semileptonic decays does rely on modeling.

Precision of current experimental results exceeds that of theoretical models. Therefore, preparation of MC simulation needs to be experiment-oriented. Theoretical models should be easy to modify, replace and fit to experimental data. Recent updates of TAUOLA are aimed at simplifying this for the user, as well as giving better default modeling of decays.

2.1. *tauola-bbb*

Recently, a tarball with new version of TAUOLA has been released. Full in-detail description of changes is given in [4]. Here, only a short summary will be given.

Recent update of TAUOLA gives at user disposal initialization mimicking that of the BaBar experiment. The decay channel list has been vastly extended, and modeling of decay channels reproduces BaBar results of basic simulations within statistical errors of 2,6 billion event sample. Some optional models that used to be available in previous versions are still accessible via internal flags.

Together with the new default initialization, an interface for adding user-defined currents has been introduced. Now, the user can replace default modeling or add a new channel via pointer to the function of his/her own model. However, user-defined functions need to follow certain requirements on arguments and returned type. Technical details are given in Ref. [4].

2.2. Discussion of modeling the $\tau^- \rightarrow (\pi\pi\pi)^-\nu_\tau$ decays

Most important non-trivial decay channels are $\tau^- \rightarrow (\pi\pi\pi)^-\nu_\tau$. There have been few models trying to tackle this decay. Three particular models were at some point available in TAUOLA. Those models are: the model used by the CLEO Collaboration, the model used by the BaBar Collaboration, and the Resonance Chiral Lagrangian (RChL) model [5].

A comparison of those models shows the need for experimental analysis based on fully differential distributions. Figure 1 shows a comparison of two models typically used by experiments plots of invariant masses. Figure 2 shows a comparison of the same models but in effectively 3-dimensional

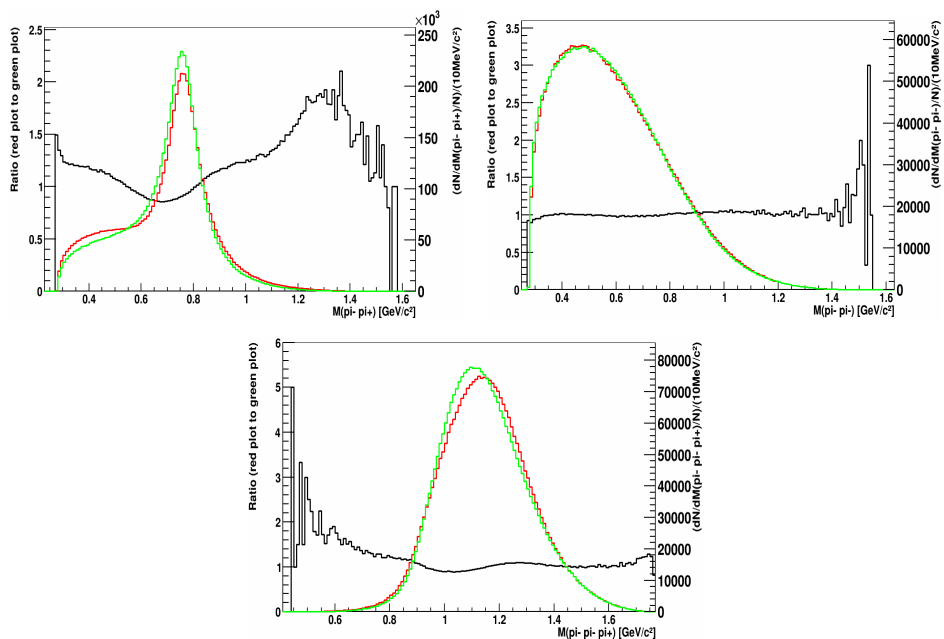


Fig. 1. (Color online) Invariant mass of $\pi^-\pi^+$ (top left), $\pi^-\pi^-$ (top right), $\pi^-\pi^-\pi^+$ (left) in RChL modeling (gray/red) and model used by the BaBar Collaboration (light gray/green). For black line which represents ratio of gray/red plot to light gray/green one, left-hand side scale should be used. Right-hand side scale represents number of events per bins of 10 MeV.

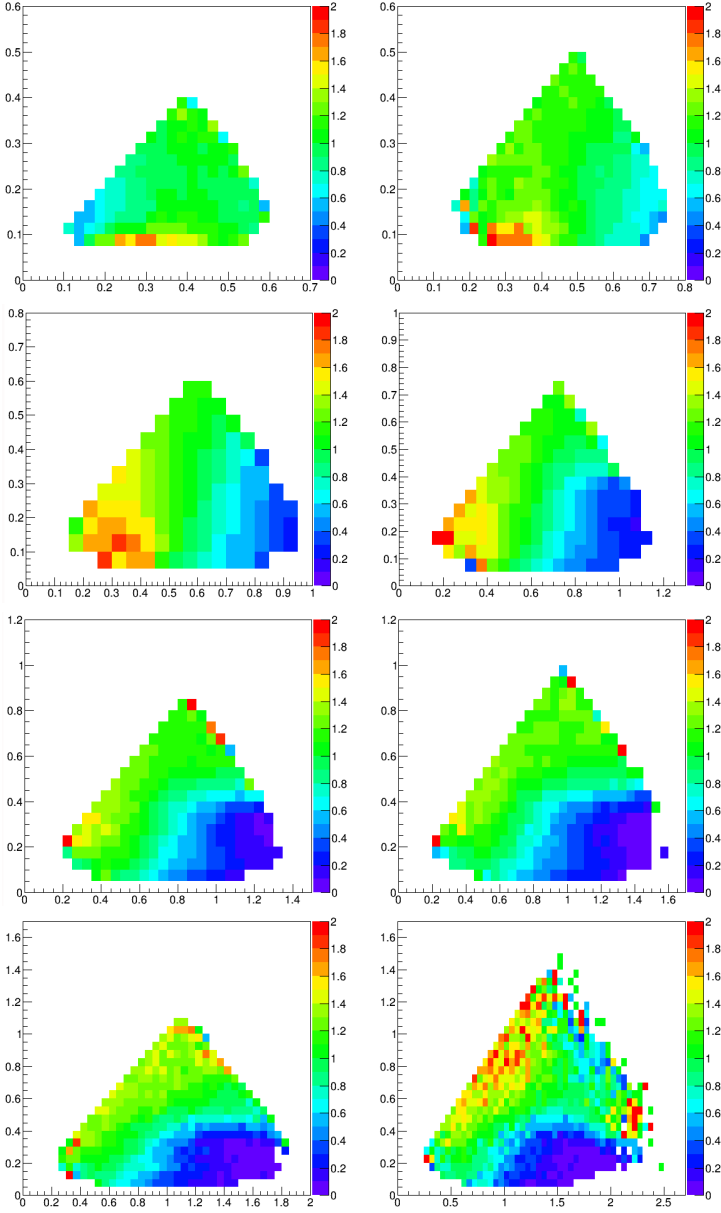


Fig. 2. Ratios (color scale) of Dalitz plots from the BaBar modeling to the RChL modeling in s_1 (horizontal scale), s_2 (vertical scale) variables (GeV^2 units). Consecutive plots correspond to slices in Q^2 : 0.36–0.81, 0.81–1.0, 1.0–1.21, 1.21–1.44, 1.44–1.69, 1.69–1.96, 1.96–2.25, 2.25–3.24 GeV^2 .

plots. Similar plots can be drawn for each combination of models, but the conclusion remains the same. One-dimensional distributions give only limited insight into physics of investigated decay channels. Ratios for models in three-dimensional plots exhibit areas of high discrepancies spawn over sizable region of phase space. This is the reason why we want to prepare tools allowing the user to examine fully differential plots in a simple and fast way. A detailed discussion of this problem is given in [6]. It is also worth mentioning that the systematic error of experimental analysis is strongly dependent on modeling of physical process. It is usually estimated as a difference between two theoretical models. Comparisons, such as the one described in this section, show that the systematic error can reach really troubling values.

3. Fitting framework

As we have seen, theoretical models for tau decays are imperfect. Therefore, they heavily depend on fitting to experimental data. We also know that it might be required to switch between multiple models. With that in mind, the fitting framework is prepared. The goal is to allow plugging in a user-defined model (similarly to the interface for introducing hadronic currents into TAUOLA mentioned earlier). The first step is to make a simple tool where the user defines (apart from datafile): the function of theoretical model, the function producing analytical distributions to be fitted, and the function for changing parameters of the model. The second step is to prepare a tool for making simple distributions (like those presented in this paper) automatically. Third, the hardest step is to prepare tools for making fully differential distributions.

In the framework, the fitting will be handled by commonly used and trusted libraries like `minuti2` [7] package of ROOT [8]. Support for multicore calculation is prepared.

3.1. Projection operators

Projection operators are a way to obtain fully differential distributions for a selected decay channel. It was developed in [9] but without a method to reconstruct neutrino momentum. This is an obstacle for τ leptons produced relativistically. We use here a concept similar to geometrical projection of multidimensional objects on the paper. But, in our case, we want to project hadronic current described in a space stretched over form factors (imaginary functions depending on for momenta of out-coming particles). Each form factor contains contribution from a specific type of an intermediate state. Without going into details¹, we could, in principle, separate the data con-

¹ Reader is referred to [9].

tributions from each type of intermediate currents². For this, however, we need to find a decent way to reconstruct, or at least estimate, the direction of the tau neutrino, which is not measured in present-day experiments. In experiments like CLEO, where taus were produced at rest, those projection operators were used [10], but report on their use was never published. Similar methods as the one used for Higgs parity in the $H \rightarrow \tau\tau$ channel may be helpful [11].

4. Summary

Information on recent developments of TAUOLA were given. Much emphasis was put on reasoning why such modifications are needed, and how they can benefit the users. A road-map for future projects related to but independent of TAUOLA has also been presented.

I would like to thank my co-workers and partners, especially Zbigniew Wąs, Olga Shekhovstova, Marcin Chrzęszcz for all their help.

REFERENCES

- [1] S. Jadach, J.H. Kühn, Z. Wąs, *Comput. Phys. Commun.* **64**, 275 (1990).
- [2] S. Jadach, Z. Wąs, R. Decker, J.H. Kühn, *Comput. Phys. Commun.* **76**, 361 (1993).
- [3] N. Davidson *et al.*, *Comput. Phys. Commun.* **183**, 821 (2012).
- [4] M. Chrzęszcz, T. Przedzinski, Z. Was, J. Zaremba, [arXiv:1609.04617 \[hep-ph\]](#).
- [5] I.M. Nugent *et al.*, *Phys. Rev. D* **88**, 093012 (2013).
- [6] Z. Wąs, J. Zaremba, *Eur. Phys. J. C* **75**, 566 (2015) [*Erratum ibid.* **76**, 465 (2016)].
- [7] F. James, M. Roos, *Comput. Phys. Commun.* **10**, 343 (1975).
- [8] I. Antcheva *et al.*, *Comput. Phys. Commun.* **180**, 2499 (2009).
- [9] J.H. Kühn, E. Mirkes, *Z. Phys. C — Particles and Fields* **56**, 661 (1992).
- [10] D.M. Asner *et al.*, *Phys. Rev. D* **61**, 012002 (2000).
- [11] G.R. Bower, T. Pierzchała, Z. Wąs, M. Worek, *Phys. Lett. B* **543**, 227 (2002).

² Namely: scalars, pseudo-scalars, vectors, axial vectors.