

The tauola-photos-F environment for the TAUOLA and PHOTOS packages, release II ☆,☆☆

P. Golonka^{a,b,*}, B. Kersevan^{c,d}, T. Pierzchała^e, E. Richter-Wąs^{b,f}, Z. Wąs^{b,g}, M. Worek^{b,h}

^a CERN, IT/CO-BE, CH-1211 Geneva 23, Switzerland

^b Institute of Nuclear Physics, Radzikowskiego 152, 31-342 Cracow, Poland

^c Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia

^d Jozef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

^e UCL-FYNU, Département de physique, Université catholique de Louvain, B-1348 Louvain-la-Neuve, Belgique

^f Institute of Physics, Jagellonian University, Reymonta 4, 30-059 Cracow, Poland

^g CERN, Theory Division, CH-1211 Geneva 23, Switzerland

^h Institute of Nuclear Physics, NCSR 'Demokritos', 15-310 Athens, Greece

Received 10 February 2004; received in revised form 16 December 2005; accepted 27 December 2005

Available online 15 February 2006

Abstract

We present the system for maintaining the versions of two packages: the TAUOLA of τ -lepton decay and PHOTOS for radiative corrections in decays. The following features can be chosen in an automatic or semi-automatic way: (1) format of the common block HEPEVT; (2) version of the physics input (for TAUOLA): as published, as initialized by the CLEO collaboration, as initialized by the ALEPH collaboration (it is suggested to use this version only with the help of the collaboration advice), new optional parametrization of matrix elements in 4π decay channels; (3) type of application: stand-alone, universal interface based on the information stored in the HEPEVT common block including longitudinal spin effects in the elementary $Z/\gamma^* \rightarrow \tau^+\tau^-$ process, extended version of the standard universal interface including full spin effects in the $H/A \rightarrow \tau^+\tau^-$ decay, interface for KKMC Monte Carlo, (4) random number generators; (5) compiler options. The last section of the paper contains documentation of the *programs updates* introduced over the last two years.

Program summary

Title of program: tauola-photos-F, release II

Catalogue identifier: ADXO_v1_0

Program summary URL: http://cpc.cs.qub.ac.uk/summaries/ADXO_v1_0

Programs obtainable from: CPC Program Library, Queen's University of Belfast, N. Ireland

Computer: PC running GNU/Linux operating system

Programming languages and tools used: CPP: standard C-language preprocessor, GNU Make builder tool, also FORTRAN compiler

No. of lines in distributed program, including test data, etc.: 194 118

No. of bytes in distributed program, including test data, etc.: 2 481 234

Distribution format: tar.gz

Catalogue identifier: ADXO_v2_0

Program summary URL: http://cpc.cs.qub.ac.uk/summaries/ADXO_v2_0

No. of lines in distributed program, including test data, etc.: 308 235

No. of bytes in distributed program, including test data, etc.: 2 988 363

☆ This paper and its associated computer program are available via the Computer Physics Communications homepage on ScienceDirect (<http://www.sciencedirect.com/science/journal/00104655>).

☆☆ Work supported by the Polish State Committee for Scientific Research Grant 1P03B 091 27 for years 2004–2006, the EU grant MTKD-CT-2004-510126, in partnership with the CERN Physics department and a Marie Curie Fellowship HPMD-CT-2001-00105 ('Multi-particle production and higher order correction').

* Corresponding author.

E-mail address: piotr.golonka@cern.ch (P. Golonka).

Distribution format: tar.gz

Does the new version supersede the previous version: Yes

Nature of the physical problem: The code of Monte Carlo generators often has to be tuned to the needs of large HEP Collaborations and experiments. Usually, these modifications do not introduce important changes in the algorithm, but rather modify the initialization and form of the hadronic current in τ decays. The format of the event record (HEPEVT common block) used to exchange information between building blocks of Monte Carlo systems often needs modification. Thus, there is a need to maintain various, slightly modified versions of the same code. The package presented here allows the production of ready-to-compile versions of TAUOLA [S. Jadach, Z. Wąs, R. Decker, J.H. Kühn, Comput. Phys. Comm. 76 (1993) 361; A.E. Bondar, et al., Comput. Phys. Comm. 146 (2002) 139] and PHOTOS [E. Barberio, Z. Wąs, Comput. Phys. Comm. 79 (1994) 291] Monte Carlo generators with appropriate demonstration programs. The new algorithm, universal interface of TAUOLA to work with the HEPEVT common block, is also documented here. Finally, minor technical improvements of TAUOLA and PHOTOS are also listed.

Method of solution: The standard UNIX tool: the C-language preprocessor is used to produce a ready-to-distribute version of TAUOLA and PHOTOS code. The final FORTRAN code is produced from the library of ‘pre-code’ that is included in the package.

Reasons for new version: The functionality of the version of TAUOLA and PHOTOS changed over the last two years. The changes, and their reasons, are documented in Section 9, and our new papers cited in this section.

Additional comments: The updated version includes new features described in Section 9 of the paper. PHOTOS and TAUOLA were first submitted to the library as separate programs. Summary details of these previous programs are obtainable from the CPC Program Library.

Typical running time: Depends on the speed of the computer used and the demonstration program chosen. Typically a few seconds.

© 2006 Elsevier B.V. All rights reserved.

PACS: 12.15.Lk; 12.20.-m; 13.35.Dx; 13.40.Ks; 13.88.+e

Keywords: Particle physics; Monte Carlo methods; Tau decays; TAUOLA; PHOTOS

1. Introduction

The TAUOLA [1,4,5] and PHOTOS [3,6] programs are computing projects that have a rather long history. Written and maintained by well-defined 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 currently in use. From the algorithmic point of view, they often differ only in a few small details, but incorporate substantial amount of specific results from the distinct τ -lepton measurements. The difference in the versions of the programs used is often due to the specific requirements of the interfaces to other packages in the simulation chain (for instance, the format of the event record has to be adjusted).

The present utility for constructing specific versions of TAUOLA and PHOTOS is prepared for software librarians and advanced users. The idea was to create a repository which allows them to include and keep main options of TAUOLA developed for different purposes. At the same time, the repository can provide the standard FORTRAN files, which can be handled later in the same way as the published versions of the packages. The other, relatively new project, which we will call TAUOLA universal interface, is also discussed here.

Our present document is not aimed to be the manual of the PHOTOS and TAUOLA packages. It is assumed that the user is familiar with the programs themselves and their documentation, see Refs. [1,3–6]. The purpose of the paper is to document how all parts of the code, including different versions and options, are combined into one distribution package. Improvements in the codes, since the time of publication, are also listed here. The paper is an extended and enlarged version of the earlier documentation [7] and supersedes it.

Since the time of submission of this article, the project evolved, and the updated version of the package was prepared. Therefore, the article we present here documents the two steps in the program evolution.¹ This is justifiable, because the older version is in widespread use, and the present one contains important improvements. That is why both versions are stored in the program library. That is also why we decided to leave the original contents of the paper, so that it can serve as documentation of the version from the time of submission, and provide the documentation for the up-to-date version of the package in form of *Program Update*, presented in the last section (Section 10 of this document).

Let us note that the contents of Sections 1 to 9 of this paper remains, in general, valid for both versions of the package, and should not be omitted in first reading, even if the reader is interested only in the up-to-date version. The material covered in the program update section assumes that the reader is acquainted with the concepts and knowledge presented in the previous sections. On the other hand, one should realize that certain information given in the first sections, such as packages’ version numbers, has been changed, and the up-to-date information should be found in the *Program Update* section.

Motivation

1. PHOTOS: Different versions of the FORTRAN code are necessary according to the different versions of the HEPEVT common block being in use in the HEP libraries (single/double precisions, dimension of matrices).

¹ The oldest version [7] does not need to be archived; it was never in wide use.

2. TAUOLA: Different versions of FORTRAN code are motivated by: (A) different versions of initialization of physics parameters; (B) interfaces with different Monte Carlo generators for the production of τ lepton(s); and (C) different versions of the HEPEVT common block:
 - (A) Different physics initializations:
 - (1) As published in [1], with improvements from Ref. [8];
 - (2) As initialized by ALEPH collaboration [9] (it is suggested to use this version only after asking the collaboration for advice);
 - (3) As initialized by CLEO collaboration [10] (see printout of this version for details);
 - (4) New parallel 4π channels of τ decay based on Novosibirsk data [2];
 - (5) New parallel 4π channels of τ decay based on Refs. [8,11].
 - (B) Different interfaces with MC generators:
 - (1) Old demo program as in published version [1];
 - (2) Interface to KKMC [12];
 - (3) New universal interface using HEPEVT common block including spin effects in the elementary $Z/\gamma^* \rightarrow \tau^+\tau^-$ process [13];
 - (4) The extended version of the standard universal interface including transverse spin effects in the $H/A \rightarrow \tau^+\tau^-$ decay [14–17].
 - (C) Different versions of the HEPEVT common block.
3. TAUOLA and PHOTOS: different versions of random number generators.
4. TAUOLA and PHOTOS: makefiles with different compiler flags.

The aim is to provide full backward compatibility at the level of the FORTRAN source with the various versions being at present in use. Standard Unix tools and infrastructure are used in the discussed setup: `cpp` the C-language preprocessor; its `#if`, `#elif` and `#include` directives, as well as symbolic links and `cat` command. It is expected that the user will employ this setup to create her/his version of TAUOLA and PHOTOS libraries (subdirectories `tauola/` and `photos/`) and that other subdirectories of the setup will be erased/stored separately.

2. Organization of the directory tree

Once unpacked, the main directory TAUOLA is created.
It contains README file and:

Subdirectories including FORTRAN precode

1. `photos-F/`: Main directory containing PHOTOS precode with options.
2. `tauola-F/`: Main directory containing TAUOLA precode with options.
3. `tauola-factory/`: Directory containing the `glue` program, which prepares the nonstandard directory `tauola-F/`.
4. `demo-factory/`: Directory for updating the input in demo files. For specialized use only, see Section 2.3.
5. `randg/`: Directory containing random number generators, which are kept separately from the rest of TAUOLA and PHOTOS source code. This should facilitate the replacement with the versions of random number generators favored by the user. Random number generators are kept in FORTRAN subroutines placed in files `photos-random.h` and `tauola-random.h`.
6. `include/`: Directory containing the `HEPEVT-xxx.h` files for different versions of the HEPEVT common block. The symbolic link `HEPEVT.h` to the one actually used will be placed in this directory at the time of initialization. The `phyfix.xxx` files with versions of FORTRAN subroutine `PHYFIX` used only by TAUOLA universal interface are also stored there. The version to be used needs to be copied into `phyfix.h`; for more details, see README-`phyfix`.

Subdirectories necessary to run demo and to install packages on different platforms

1. `glibk/`: Directory containing histogramming package, used by demos only.
2. `jetset/`: Directory containing JETSET MC package, used by demos only.
3. `jetset2/`: Directory containing PYTHIA MC package, used by demos only.
4. `eli/`: Directory containing files necessary to construct demo to be run with PYTHIA MC package.
5. `platform/`: Directory containing system-dependent versions of `make.inc` files for supported platforms.
6. `make.inc`: Symbolic link to the chosen `make-xxxx.inc` located in subdirectory `platform/`. The `make-xxxx.inc` files define machine-dependent flags for compilers etc. to be used by all makefiles.

The following directories are created once the actions of the setup are completed

1. `photos/`: Standard directory with FORTRAN code of PHOTOS library and its demo.
2. `tauola/`: Standard directory with FORTRAN code of TAUOLA library, its demos and example outputs.
 - (a) `tauola/demo-standalone`: Demo program for TAUOLA executed in a standalone mode.
 - (b) `tauola/demo-jetset`: Demo program for TAUOLA executed with universal interface and physics event generators using the HEPEVT common block. In this demo HEPEVT is filled by JETSET74 [18] Monte Carlo event generator.
 - (c) `tauola/demo-pythia`: Optionally, a demo program for TAUOLA executed with universal interface and HEPEVT common block filled by PYTHIA [18] Monte Carlo event generator can be created as well.
 - (d) `tauola/demo-KK-face`: Interface to KK Monte Carlo [12].

2.1. Options for PHOTOS Monte Carlo

The different options of PHOTOS that can be created, correspond solely to the different versions of the HEPEVT common block. The possible options are:

1. `KK-all`—for KK Monte Carlo, older versions
2. `2kD-all`—arrays dimension 2000, double precision
3. `4kD-all`—arrays dimension 4000, double precision
4. `2kR-all`—arrays dimension 2000, single precision
5. `10kD-all`—arrays dimension 10000, double precision

The action of preparing the required version of the library is performed with the help of `cpp` preprocessor. It creates a file `photos.f` from precode stored in `photos.F`. Once this is done, the symbolic link to the required version of the HEPEVT common block is defined. This link is used in the construction of the `tauola` library, see next section.

2.2. Options for TAUOLA Monte Carlo

Basic options for physics initializations are: `cpc`; `cleo`; `aleph`. As results of the action performed by the package:

1. The `tauola/` subdirectory is erased;
2. The directory structure of `tauola/` is rebuilt:
 - the `tauola/` directory is filled with the FORTRAN code, libraries and makefiles;
 - `tauola/demo-xx` are filled with the FORTRAN code of demos.

The three possible versions of created `tauola.f` correspond to formfactors and branching ratios defined respectively as in: (`cpc`) published version of TAUOLA [1,8]; (`aleph`) as adopted by ALEPH collaboration [9]; (`cleo`) as adopted by CLEO collaboration [10].

Remarks.

- The `makefile` files are prepared to run TAUOLA within the environment of the distribution TAUOLA directory; however the templates for makefiles are compatible with those of the KK Monte Carlo. Thus if the `tauola` directory is copied into its respective place in the KKMC distribution tree, and `make makflag` of `KK/ffbench/` is executed, it overwrites the `makefile` file in `tauola/`. The new ones are produced from `makefile.template` and match the KKMC structure.
- Additional parametrization for formfactors, which can be useful in some applications, are stored in the directory `TAUOLA/tauola-F/suppl`. They are not ready to use and some cross-checks are mandatory. At present, the code used in Refs. [19, 20] is stored there.

2.3. How to change the setting of TAUOLA input parameters

It is often necessary to change some of the TAUOLA input parameters, such as branching ratios, mass of the τ -lepton, etc. It is convenient to have it done once for all applications, i.e. `demo-KK-face`, `demo-jetset` and `demo-standalone`. The purpose of the `demo-factory` directory is exactly that. Here one can create the `.F` files for the interfaces, by the set of 'Paste' commands embodied in the script `klej`, out of the blocks of FORTRAN code. More precisely the following files can be re-created:

- For demo-KK-face: `./prod/Tauface.F`,
- For demo-jetset: `./prod/tauola_photos_ini.F`,
- For demo-standalone: `./prod/taumain.F`.

For details of the initialization routines, which are very similar in the three cases, see Refs. [1,4,5]. This requires special care from the physics point of view. In many cases, the input parameters are inter-related with the actual choice of form factors. The changes should thus be performed consistently.

How to proceed:

1. Some of the routines in directory `./source` have to be updated by hand first. They are stored in individual files. The ones that usually should not be modified are write-protected.
2. Later execution of the script `klej` will create the following files from the pieces stored in the directory `./source` simply by pasting them together:
 - `./prod/Tauface.F`,
 - `./prod/tauola_photos_ini.F`,
 - `./prod/taumain.F`.
 Automatic check (using `diff`) with the archive versions stored in the directory `./back` will also be executed.
3. Finally the following commands copy the files into the appropriate places:
 - (a) `cp prod/Tauface.F ./tauola-F/tauface-KK-F/Tauface.F`,
 - (b) `cp prod/tauola_photos_ini.F ./tauola-F/jetset-F/tauola_photos_ini.F`,
 - (c) `cp prod/taumain.F ./tauola-F/standalone-F/taumain.F`.

2.4. Random number generators

- PHOTOS and TAUOLA have their own copies of the random number generators. They are contained in the include files placed in the directory `randg`.
- The user who wants to implement her/his own generators, e.g. compatible with the ones used by the collaboration, should replace the files:
 - `./photos-random.h`,
 - `./tauola-random.h`
 by those including the appropriate wrappers of his/her own random generators (or empty files if the generators of the same name reside elsewhere).

2.5. Compiler flags, etc.

Platform-dependent parts of the makefiles are stored in the directory `platform/`. At present options are available for various distributions of the Linux platform only, but it is rather straightforward to extend them to the new ones.

3. Universal interface with HEPEVT common block

In the present section, we shall document for the first time, how to install and use the TAUOLA universal interface with ‘any’ production generator, to include spin effects in, e.g., the $Z/\gamma^* \rightarrow \tau^+\tau^-$ process [13,14]. The approximate spin correlations are calculated from the information stored in the HEPEVT common block [21] filled by ‘any’ τ production program. As a demonstration example it is interfaced with the JETSET generator; however, it works in the same manner with PYTHIA, HERWIG and should work with the ISAJET generator as well. In fact, such an interface can be considered as a separate software project, to some degree independent from both the specific problem of τ production and its decay. The aim of this interface is not to replace the matrix element calculations, but rather to provide a method of calculating/estimating spin effects in cases when these would not be taken into account at all.

3.1. HEPEVT common block and HEPEVT event record

The question of adapting the universal interface² to different versions of an HEPEVT event record goes beyond the technicalities discussed in Section 2.1. In fact it is quite involved, as it depends on specific needs due to the way the HEPEVT event record

² The question is even more serious in the case of PHOTOS.

is actually coded into the `HEPEVT common block`. It varies from application to application according to the physics requirement. During the MC4LHC Workshop [22] these issues were discussed and it was found, thanks to interaction with the users, that the `TAUOLA universal interface` works with all 3 basic options for `HEPEVT` filled by `PYTHIA 6.2 (MSTP(128)=0, 1, 2)`, as well as with `HERWIG (6.150)` [23]. In our example we keep only the working interface with `PYTHIA version 6.206` [24], the working example with other installations can be found, e.g., in [25].

The discussion of the related problems go beyond this document; we refer the reader to Section 8 for more details. We are also convinced that the problems, because they originate from physics, will appear in event records in other programming languages such as C++.

At this point, also the questions related to future porting of our algorithms to new event records need to be raised. At present, the most promising standardization of the `FORTRAN` code seems to be the solution based on proposal [26], however it is focused mostly on the topic of combining parton level hard process with shower algorithms. For our purpose, some specific technical points, especially those related to non-trivial spin correlations, should be specified in more detail.

Another standard, the C++ based `HepMC` event structure of [27] will become of importance once the C++ versions of `HERWIG` and `PYTHIA` are available and established in use; until then, the inclusion of this standard seems superfluous since at present, our programs are interfaced to `FORTRAN` codes of `PYTHIA` and `HERWIG` via the `HEPEVT` interface itself, for example.

Let us stop our discussion on possible future developments of event record standards here; instead, let us refer the interested reader to Refs. [28,29] and Ref. [25], Sections 6.4 and 6.5.

3.2. Longitudinal spin effects

We start with the simpler case, when only longitudinal spin degrees are included. Then the interface acts in the following way:

- The user has to verify if the τ lepton is forced to be stable in the package performing generation of the τ production.
- The contents of the `HEPEVT common block` is searched for all τ leptons and τ neutrinos.
- It is checked if there are τ flavor pairs (two τ leptons or a τ lepton and a τ neutrino) originating from the same mother(s).
- The decays of the τ flavor pairs are performed with the subroutine `TAUOLA`. Longitudinal spin correlations are generated in the case of the τ produced from the decay of: $W \rightarrow \tau \nu$, $Z/\gamma^* \rightarrow \tau \tau$, and the charged Higgs boson $H^\pm \rightarrow \tau \nu$ (for the neutral Higgs boson the full spin correlations are used, see Section 3.4). Parallel or antiparallel spin configurations are generated, before calling on the τ decay, and then the decays of 100% polarized τ 's are executed.
- In the case of the Higgs boson (for the spin correlations to be generated) the identifier of the τ mother must be that of the Higgs boson. The particle code convention as that used by the `PYTHIA 5.7` [30] Monte Carlo is adopted, but it can be changed by the user, as explained later in this section.
- In the case of the W and Z/γ^* , this is not necessary, because the interface assumes these production mechanisms as defaults, even if the W or Z/γ^* bosons are not explicitly present in the event record. For example if from the same mother as that of the τ , a ν_τ is also produced, the W (of the momentum equal to the sum of τ and ν_τ) will be taken as the true mother of the τ . Similarly, if another τ with opposite charge is produced from the same mother, the Z/γ^* is assumed to be the mother of the τ pair.
- The spin effects in the states of τ^+ , τ^- produced from explicit or implicit Z/γ^* states are upgraded up to nearly `KORALZ` standards [31,32]. If bremsstrahlung photons are present in the event record (as sisters of Z), then they have to be merged either with beams or with τ 's, accordingly to approximation explained in [13]. Photon radiation in the decay is performed with `PHOTOS` package [3,6].

Let us note that the calculation of the τ polarization created from the Z and/or virtual γ^* (as a function of the direction) represents a rather non-trivial extension if high precision is required. Generally, the dedicated study of the production matrix elements of the host generator is necessary in every individual case. The method applied here is based on approximations [13,14].

3.3. Organization of the interface

The `TAUOLA` interface is organized in a modular form to be used conveniently in 'any environment'.

3.3.1. Initialization

Initialization is performed with the `CALL TAUOLA(MODE,KEYSPIN)`, `MODE=-1`. All necessary input is directly coded in the subroutine `TAUOLA` placed in a file `tauface-jetset.f`.

The input parameters set at this call are presented in Table 1. We omit those, which are standard input for `TAUOLA` as defined in its documentation. They are hard-coded in the subroutine.

Table 1
TAUOLA input parameters

Parameter	Meaning
POL	Internal switch for spin effects in τ decays and only for the longitudinal case. Normally the user should set POL=1.0, and when POL=1.0 spin polarization effects are absent.
KFHIGGS(3)	KF=25, 35, 36 Flavor code for h, H, A ; see footnote ¹ for details
KFHIGCH	KF=37 Flavor code for H^+ ; see footnote ² for details
KFZ0	KF=23 Flavor code for Z^0
KFGAM	KF=22 Flavor code for γ
KFTAU	KF=15 Flavor code for τ^-
KFNEU	KF=16 Flavor code for ν_τ
xmtau	τ -lepton mass, used only for KFHIGGS(3), see Section 3.4
xmh	Higgs boson mass, used only for KFHIGGS(3)
psi	Mixing scalar–pseudoscalar angle, this angle is used only for Higgs boson with flavor code equal KFHIGGS(3)

¹ For our purpose, h, H denote scalar particle and A pseudoscalar, or with optional initialization (mixing angle ψ) particle with mixed scalar-pseudoscalar coupling. Advanced user can replace the numerical values for identifiers KFHIGGS(3) and use interface for decay of any other scalar object.

² In the case of charged Higgs decay, only longitudinal spin correlations are taken into account, i.e. that spin of Higgs boson is zero. Once the code KFHIGCH would be replaced by the user, the interface can be applied to the decay of any other charged scalar particle.

3.3.2. Event generation

For every event generated by the production generator, all τ leptons will decay with the single CALL TAUOLA(0,KEYSPIN) (KEYSPIN=1/0 denotes spin effects switched on/off). In its execution, all τ leptons will be first localized, their positions stored in internal common block TAUPOS, and the information necessary for calculating the τ spin state will be read from HEPEVT common block. The spin state for the given τ (or τ pair) will be generated later, and finally the decay of the polarized τ will be performed with the standard TAUOLA action. In particular, the decay products of τ will be boosted to the laboratory frame and added to the complete event configuration stored in the HEPEVT common block.

3.3.3. Calculation of the τ spin state

Once CALL TAUOLA(0,KEYSPIN) is executed and τ leptons are found, the spin states have to be calculated.

First, we look in HEPEVT for the position of τ 's mothers and store them in matrix IMOTHER(20). Each mother giving τ lepton(s) is stored only once, independently of the number of produced τ 's. Later, for every IMOTHER(i) we execute the following steps:

1. The daughters, which are either τ leptons or ν_τ , are searched for.
2. The daughters are combined in pairs, and the case of more than 1 pair is not expected to be important; ad hoc pairing is then performed.
3. The two main cases are thus $(\tau\tau)$ or $(\tau\nu_\tau)$.
4. The default choices in these two main cases are, respectively, Z/γ^* or W , unless the identifier of IMOTHER(i) is different and explicitly defined, e.g., as a neutral (or charged) Higgs boson.
5. Calculation of the spin parameters is independent from kinematic variables and straightforward in all cases except Z/γ^* (see [13]).
6. For Z/γ^* , the polarization function P_Z [13] is calculated with the help of the function PLZAPX(HOPE,IM0,NP1,NP2). The HOPE is the logical parameter defined in subroutine TAUOLA placed in the file tauface-jetset.f. It tells whether spin effects can be calculated or not. If available information is incomplete, HOPE is set to .false.. Then PLZAPX(HOPE,IM0,NP1,NP2) returns 0.5. The IM0 denotes the position of the τ mother in HEPEVT common block, the NP1 denotes the position of τ^+ and the NP2 denotes the position of τ^- .
7. To calculate the reduced $2 \rightarrow 2$ body kinematical variables s and $\cos\theta$, the subroutine ANGULU(PD1,PD2,Q1,Q2,COSTHE) is used. Four-momenta of the incoming effective beams and outgoing τ^+ and τ^- are denoted by PD1, PD2, Q1, Q2, respectively. The variables s and $\cos\theta$ are then used in the function P_Z .

3.3.4. Run summary

After the series of events is generated the optional CALL TAUOLA(1,KEYSPIN) can be executed. The information on the whole sample, such as the number of generated τ decays, branching ratios calculated from matrix elements, etc. will be printed.

3.3.5. Demonstration program

Our main program demo.f is stored in the subdirectory demo-jetset. It reads in the file init.dat, which includes some input parameters for the particular run, such as the number of events to be generated (by JETSET/PYTHIA), or the type of the

```

*****
*                               *****TAUOLA UNIVERSAL INTERFACE: *****                               *
*                               *****VERSION 1.10, November 2003 *****                               *
*                               **AUTHORS: P. Golonka, B. Kersevan, ***                               *
*                               **T. Pierzchala, E. Richter-Was, *****                               *
*                               ***** Z. Was, M. Worek *****                               *
*                               **USEFUL DISCUSSIONS, IN PARTICULAR ***                               *
*                               *WITH C. Biscarat and S. Slabospitzky**                               *
*                               ***** are warmly acknowledged *****                               *
*                               *****                               *
*                               *****  INITIALIZATION  *****                               *
*                               1.00000 tau polarization switch must be 1 or 0                               *
*                               1.57080 Higgs scalar/pseudo mix CERN-TH/2003-166                               *
*****

```

Fig. 1. Printout of TAUOLA universal interface initialization.

```

*****
*                               *****TAUOLA UNIVERSAL INTERFACE: *****                               *
*                               *****VERSION 1.10, November 2003 *****                               *
*                               **AUTHORS: P. Golonka, B. Kersevan, ***                               *
*                               **T. Pierzchala, E. Richter-Was, *****                               *
*                               ***** Z. Was, M. Worek *****                               *
*                               **USEFUL DISCUSSIONS, IN PARTICULAR ***                               *
*                               *WITH C. Biscarat and S. Slabospitzky**                               *
*                               ***** are warmly acknowledged *****                               *
*                               *****  END OF MODULE OPERATION  *****                               *
*****

```

Fig. 2. Printout of TAUOLA universal interface end-of-run messages.

interaction it should use to produce τ 's. We address the reader directly to the code for more details. It is self-explanatory. The printouts at the interface initialization has the form presented in Fig. 1, while that at the end of the execution has the form presented in Fig. 2.

3.4. Transverse spin effects

The extended version of the standard `universal interface`, of the TAUOLA τ -lepton decay library, includes the complete spin effects for τ leptons originating from the spin zero particle, i.e. in $H/A \rightarrow \tau^+\tau^-$ decay [14–16]. As usual, the interface is expected to work with any Monte Carlo generator providing production (and subsequent decay into pair of τ leptons) of the Higgs boson. Since the Higgs boson spin is zero, the spin correlations of its decay products do not depend at all on the mechanism of the Higgs boson production. Technical difficulties related to the choice of τ^+ and τ^- spin quantization frames, present in the case of $e^+e^- \rightarrow Z/\gamma^* \rightarrow \tau^+\tau^-$ [33,34] (initial state bremsstrahlung effects included or not), are not present. The analytical form of the density matrix is simple. To calculate the density matrix for the pair of τ -leptons it is thus enough to: know their four-momenta, know that they indeed originate from the Higgs boson, and assume the type of the Yukawa interaction. Such information is stored in the `HEPEVT` common block [21] used by practically all Monte Carlo generators for Higgs boson production.

The interface acts in the following way and according to principles described in [4]:

- The algorithm is organized in two steps. In the first step, the τ lepton pair is generated and the τ leptons decay in their respective rest frames, as if there were no spin effects at all. In the second step, the spin weight is calculated and rejection is performed. If the event is rejected, only the generation of the τ lepton decays is repeated.
- The spin weight for Higgs boson decay into $\tau^+\tau^-$ is given by the following formula

$$wt = \frac{1}{4} \left(1 + \sum_{i=1}^3 \sum_{j=1}^3 R_{ij} h_1^i h_2^j \right). \quad (1)$$

- The components of the density matrix R_{ij} are equal $R_{33} = -1$, $R_{11} = \pm 1$, $R_{22} = \pm 1$, respectively, for pure scalar and pseudoscalar Higgs boson, and all other components are zero. The h^i and h^j are the polarimetric vectors of the τ^\pm leptons (they are calculated by TAUOLA).

- In general, the Yukawa coupling can be written as $\bar{\tau}(a + ib\gamma_5)\tau$. With our choice of quantization frames, the following non-zero components of R_{ij} are obtained (see Ref. [17]):

$$R_{33} = -1, \quad R_{11} = R_{22} = \frac{a^2\beta^2 - b^2}{a^2\beta^2 + b^2}, \quad R_{12} = -R_{21} = \frac{2ab\beta}{a^2\beta^2 + b^2}, \quad (2)$$

where $\beta = \sqrt{1 - 4m_\tau^2/m_H^2}$. With Yukawa coupling written in the form $\bar{\tau}N(\cos\phi + i\sin\phi\gamma_5)\tau$ and with the limit $\beta \rightarrow 1$, the expressions reduce to the components of the rotation matrix by an angle -2ϕ :

$$R_{11} = R_{22} = \cos 2\phi, \quad R_{12} = -R_{21} = \sin 2\phi. \quad (3)$$

The following changes had to be introduced to the algorithm explained in Ref. [13]:

- The quantization frames for the spin states of τ^+ and τ^- need to be properly oriented with respect to each other. In our solution they are simply connected by the boost along the τ lepton momenta as defined in the Higgs boson rest frame. At the technical level this is enforced by the TRALOR routine [4], which defines the relation of the τ^\pm spin quantization frames with the laboratory frame. As an intermediate step this routine uses the Higgs boson rest frame.
- The density matrix for the pure scalar/pseudoscalar case was taken from Ref. [35], and in the most general case in Ref. [36]. We have adapted it to the quantization frames as specified previously. Two cases are implemented: pure scalar Higgs boson and Higgs boson with mixed scalar–pseudoscalar coupling.
- Generation of τ^+ and τ^- decays is implemented in the subroutine SPINHIGGS placed in the file `tauface-jetset.f` and performed following the method explained and used in Refs. [4,34].
- The function `wthiggs(IPSEUDO, HH1, HH2)` is used to calculate the spin weight. The HH1 and HH2 are the τ^+ and τ^- polarimetric vectors calculated inside the subroutine DEKAY placed in the file `tauola.f`. The IPSEUDO is a logical parameter, defined in the subroutine TAUOLA and placed in the file `tauface-jetset.f`. It tells whether spin effects are calculated for the scalar or for the mixed scalar–pseudoscalar Higgs boson. If we have pure scalar Higgs boson it is set to `.false.`. If we have mixed scalar–pseudoscalar case it is set to `.true.`. The pure pseudoscalar case is for $\phi = \frac{\pi}{2}$.
- We have assumed that production generator provides two-body Higgs boson decays to τ leptons. In particular, that it does not provide any bremsstrahlung corrections. Instead, PHOTOS [3,6] (see also [37]) can be used for that purpose, once the generation of τ^\pm decays is completed.
- A more complete inclusion of bremsstrahlung corrections would require a substantial rewriting and extension of the program to the solution presented in Ref. [12] or a similar one.

4. How to use the package

1. Start with `make Clean` from main directory to secure against mismatches.
2. Check platform-dependent makefiles.
 - Go to subdirectory `platform/`.
 - Determine if `make-xxx.inc` file specific for your computer is present there: for Linux it is `make-linux.inc`; for others it needs to be adapted.
 - Erase the symbolic link `make.inc` which exists in this directory and create a new one, which points at the chosen `make-xxx.inc`:


```
- rm make.inc,
- for Linux: ln -s make-linux.inc make.inc.
```

 Afterwards check whether a link to the `make.inc` is present in the main directory.
3. The settings of TAUOLA input parameters can be changed for all implemented applications, see Section 2.3 for details.
4. PHOTOS and TAUOLA have their own private random generators. If you wish to replace them, you should do it at this point, see Section 2.4.
5. Create required versions of `photos/` and `tauola/` directories. It is mandatory to create `photos/` directory first, i.e. before creating `tauola/`.
 - Go to the directory `photos-F`
 - Type one of the following commands to choose the required version of HEPEVT:


```
- make KK-all
- make 2kD-all
- make 4kD-all
- make 2kR-all
- make 10kD-all
```

- Go to directory `tauola-F`
- Type one of the following commands to choose the required version of TAUOLA initialization:
 - `make cpc`
 - `make cleo`
 - `make aleph`
 The user can then type
 - `make pythia`
 to construct the additional demo executable with PYTHIA. In this demonstration program, old PYTHIA version 6.206 [24] is used. The user is anyway expected to attach the package to a new software, up to date at the time of installation. In this example, the matching of the common block dimensions is not automatically assured. The option `make 4kD-all` has to be used.
- 6. The required version of PHOTOS and TAUOLA will reside in newly (re)created directories `./photos` and `./tauola`.
- 7. The following demos can be invoked from those directories:
 - Demo for PHOTOS resides in `./photos/demo`, and can be invoked by command `make` followed by `make run`.
 - Demo for TAUOLA stand-alone resides in `./tauola/demo-standalone`, and can be invoked by the command `make` followed by `make run`.
 - Demo for TAUOLA with JETSET being a host Monte Carlo resides in `./tauola/demo-jetset`, and can be invoked by the command `make` followed by `make run`.
 - Demo for TAUOLA with PYTHIA being a host Monte Carlo resides in `./tauola/demo-pythia`, and can be invoked by the command `make` followed by `make run`.
 - Interface to KKMC resides in `./tauola/KK-face/Tauface.f`. It has to be moved to `./KK2f/Tauface.f` of distribution directory of KKMC [12]. The rest of the `./tauola` directory should replace the original one of the KK Monte Carlo distribution.

Finally, let us remark that most of the TAUOLA tree is not necessary and can be erased at this point. Code and makefiles of the directories `./tauola` and `./photos` are sufficient. To execute demo programs, the directories `./jetset` and `./glibk` need to be kept or replaced by the appropriate links. The `make.inc` symbolic link pointing to the `make-xxxx.inc` file in the directory `./platform` also needs to be kept. The file `make-xxxx.inc` defines appropriate compiler flags.

5. New hadronic currents for $\tau \rightarrow 4\pi$ channels of τ decay

The parametrization of formfactors developed for 4π channels of τ decay and based on Novosibirsk data has been coded in a form suitable for the TAUOLA Monte Carlo package [2]. There exist two 4π final states in τ^- decay (i.e. $\tau^- \rightarrow \nu_\tau \pi^- \pi^0 \pi^0 \pi^0$, $\tau^- \rightarrow \nu_\tau \pi^- \pi^- \pi^+ \pi^0$). Both are available as parallel decay modes in the `cpc`, `cleo` or `aleph` versions. To get the new 4π channels of τ decay (BINP version) one should act in the following way:

1. Go to directory `tauola-factory`.
 - There is a glue program that prepares a FORTRAN ‘precode’ of TAUOLA library and places it in the directory `./tauola-F`.
 - Type the following command to see the parameters of the glue program:
 - `./glue`
 - Type the following command to choose the BINP version:
 - `./glue binp`
 - Type the following command to come back to the standard version:
 - `./glue standard`
2. Go to the main directory.
3. Act according to the instructions described in the previous chapter.
4. The required TAUOLA version (`cpc`, `cleo` or `aleph`) with new 4π channels of τ decay (BINP version) will reside in newly (re)created directory `./tauola`.

Another parametrization of form factors for 4π channels based on Refs. [8,11] is available as well. It can be installed, similar the case described above. The only difference is that flag `binp` has to be replaced with `Karlsruhe`.

6. Universal tool for HEP Monte Carlo generator comparison: MC-TESTER

Within the scope of the TAUOLA-PHOTOS project work, a pilot project of MC-TESTER tool for semi-automatic comparisons of Monte Carlo generators has been deployed. Initially, the project was targeted to be a part of this package: it was intended to be used as a debugging/analysis tool for comparing the results produced by various versions of TAUOLA and PHOTOS code.

We decided however to publish MC-TESTER as an independent project [38]. The scope of its possible use spans far beyond its original use case. We have however preserved the relationship between the two projects: we include two versions of TAUOLA code (that may be produced using TAUOLA-PHOTOS) in the MC-TESTER distribution (versions 1.0 and 1.1) as a test that verifies the correctness of MC-TESTER installation.

More information and the code of MC-TESTER is available from its web page [39].

7. Minor upgrades in TAUOLA and PHOTOS

There is no need to publish the new versions of the programs: since the last publication, the upgrades are minor. Nonetheless let us list here the main improvements collected over the years. The list of fixes for numerically rather insignificant bugs, as well as necessary changes due to the evolution of compilers, will not be given here. For that purpose we refer the reader to the comments in the code, to the README files included in the distribution and to the package web page [40].

7.1. TAUOLA

Apart from the modifications listed in Section 1, no changes were introduced in the `cpc` and `aleph` initializations of TAUOLA since the time they became available. In the case of `cleo` initialization, a change was introduced in the $\tau \rightarrow \nu\pi^+\pi^+\pi^-\pi^0$ channel; normalization of the ω current was adjusted to experimental data [41]. To this end, the ω contribution was diminished from 68% down to 40% of the total rate for the $\tau \rightarrow \nu\pi^+\pi^+\pi^-\pi^0$ channel. The new version of TAUOLA 2.7, was nonetheless introduced, which is marked in all initialization printouts, to document progress in bug fixing etc. The creation dates printed in the outputs are retained. They mark the time when the bulk of the work was done.

Since publication [2] a careful analysis of a hadronic current for 4π final states was performed; related extensive studies and comparisons are documented in Ref. [42]. The new parametrization based on Refs. [8,11] was also installed in TAUOLA. Different options of models discussed in Ref. [2] were probed. Let us list changes with respect to [2], which are now installed in the TAUOLA code if used with the `binp` option. We will use the opportunity to list misprints found in Ref. [2] as well:

1. In Table 4 of Ref. [2] in all columns of function arguments, $\sqrt{Q^2}$ were listed rather than Q^2 , as written in the table header.
2. Formula (20) of Ref. [2] should read $g_\sigma(s) = (1 - 4m^2/s)^{1/2}$, rather than $g_\sigma(s) = (s - 4m^2/s)^{1/2}$.
3. All propagators derived from formula (18) of Ref. [2], should be normalized to -1 at $q^2 = 0$; also imaginary part should be set to zero below opening of the appropriate decay channel (i.e. typically for $q^2 < 4m^2$).
4. In the definition of the ρ propagator in formula (18) of Ref. [2], the term $dm(q^2)$ was neglected. The full ρ propagator should read

$$D_\rho(q^2) = q^2 - M_\rho^2 - M_\rho \Gamma_\rho dm(q^2) + i M_\rho \Gamma_\rho \frac{g_\rho(q^2)}{g_\rho(M_\rho^2)},$$

$$dm(q^2) = \left(h_\rho(q^2) - h_\rho(M_\rho^2) - (q^2 - M_\rho^2) \frac{dh_\rho(q^2)}{dq^2} \Big|_{q^2=M_\rho^2} \right) / g_\rho(M_\rho^2), \quad (4)$$

where

$$h_\rho(q^2) = \begin{cases} \frac{\sqrt{1 - \frac{4m^2}{q^2}} \ln \left(\frac{1 + \sqrt{1 - \frac{4m^2}{q^2}}}{1 - \sqrt{1 - \frac{4m^2}{q^2}}} \right) (q^2 - 4m^2)}{\pi} & \text{for } q^2 > 4m^2, \\ -\frac{8m^2}{\pi} & \text{for } q^2 = 0 \text{ GeV}^2, \\ 0 & \text{otherwise.} \end{cases} \quad (5)$$

5. The full ω propagator should read (the $g_\omega(q^2)/g_\omega(M_\omega^2)$ was approximated by 1):

$$D_\omega(q^2) = q^2 - M_\omega^2 + i M_\omega \Gamma_\omega \frac{g_\omega(q^2)}{g_\omega(M_\omega^2)}, \quad (6)$$

$$\frac{g_\omega(q^2)}{g_\omega(M_\omega^2)} = \begin{cases} \max \left(\begin{aligned} &1 + 17.560(\sqrt{q^2} - M_\omega) + 141.110(\sqrt{q^2} - M_\omega)^2 \\ &0, +894.884(\sqrt{q^2} - M_\omega)^3 + 4977.35(\sqrt{q^2} - M_\omega)^4 \\ &+7610.66(\sqrt{q^2} - M_\omega)^5 - 42524.4(\sqrt{q^2} - M_\omega)^6 \end{aligned} \right) & \text{for } \sqrt{q^2} < 1.0 \text{ GeV}, \\ -1333.26 + 4860.19\sqrt{q^2} - 6000.81(\sqrt{q^2})^2 + 2504.97(\sqrt{q^2})^3 & \text{otherwise.} \end{cases} \quad (7)$$

Function (7) is involved, because of effects due to three-body phase space, threshold effects of pion masses as well as opening of the resonant ρ channel in ω decay.

6. In formula (16) of Ref. [2] the overall sign was missing.

7. In formula (21) of Ref. [2], the coefficient in front of the second line should include s instead of a .
8. We have recalculated, using two methods, the outcome from formula (21) of Ref. [2]. We have found some numerical difference with respect to the one used before. The size of the difference is small, except the region above 1.3 GeV, which is not important anyway (see Ref. [42]).
9. In the comment for formula (21) of Ref. [2] it should be stated that three-vectors and energies are defined in the a_1 (3π) system rather than in the $\tilde{\rho}$ (4π) system.
10. In formula (25) of Ref. [2], the overall coefficient z_{mix} was missing, but it was set in the code to $z_{\text{mix}} = 1$ anyway.
11. At the beginning of Section 5 in Ref. [2] the numerical constant $\Lambda^2 = 1.2$ GeV should be defined, rather than Λ alone.

All points from the above list do not change the numerical content of the code, except for point 8, which brings a modification, and consequently leads to numerically small compensating changes of the content of the tables of functions G presented in Ref. [2].

We found, while playing with different versions of the TAUOLA code describing the Novosibirsk hadronic current, that we had for some time an overall sign error in the space-like component of the current. For all distributions involving pions only, it was fully compensated by the choice of the fit functions $G(Q^2)$ (formulae (14), (15) and (22)–(24) of Ref. [2]). Also all figures in Ref. [2] are correct.

However, as a consequence of the bug, the distributions involving ν_τ were affected in TAUOLA BINP. The effect was not large enough for comparisons with TAUOLA CLEO to hint for the problem. The differences were within the expected systematic errors of the two parametrization. We have also found an additional misprint in the numerical value for our fit functions: $G_{\pi^+\pi^-\pi^+\pi^0}$, $G_{\pi^+\pi^-\pi^+\pi^0}^\omega$ and $G_{\pi^+\pi^0\pi^0\pi^0}$ (see Table 4, Ref. [2]). An overall constant or function was missing. Once corrections are taken together, the values in Table 4 should be multiplied respectively by:

$$\frac{76.565\sqrt{0.71709 * \sqrt{Q^2} - 0.27505}}{M_\rho^4\sqrt{Q^2}} \quad \text{for } G_{\pi^+\pi^-\pi^+\pi^0}(Q^2), \quad (8)$$

$$\frac{886.84\sqrt{0.70983 * \sqrt{Q^2} - 0.26689}}{M_\rho^4\sqrt{Q^2}} \quad \text{for } G_{\pi^+\pi^-\pi^+\pi^0}^\omega(Q^2), \quad (9)$$

$$\frac{96.867|z_{\text{formal}}(Q^2)|\sqrt{0.70907 * \sqrt{Q^2} - 0.26413}}{M_\rho^4\sqrt{Q^2}} \quad \text{for } G_{\pi^+\pi^0\pi^0\pi^0}(Q^2) \quad (10)$$

before being used in formulae (14), (15) and (22)–(24) of Ref. [2]. Numerical values of the $|z_{\text{formal}}(Q^2)|$ function are tabulated in the new TAUOLA function ZFA1TAB(Q2), as was the case with the functions G .

Finally, during the work, as a byproduct, we have switched on the interference between the ω and non- ω parts of this current. This changed the overall rate, mainly because of the interference of small, spread over all phase space tails of the ω Breit–Wigner propagator. The numerical effect is not visible in the differential distribution, but it affects the total rate by 1.017(1). We changed the normalization of $G_{\pi^+\pi^-\pi^+\pi^0}(Q^2)$ and $G_{\pi^+\pi^-\pi^+\pi^0}^\omega(Q^2)$ by the same factor, so as to reproduce the total 4π rate as in PDG 2000. Note that the interference of the ω current with the remaining part provides 1.7% effect on the total rate.

7.2. PHOTOS

The changes we have introduced are collected in the following subsections.

7.2.1. Subroutine PHCORK

During the test phase of the PHOTOS+ [43], a C++ implementation of the PHOTOS algorithm, it turned out that the generation becomes unstable for events produced at TeV energies. The use of PHOTOS at this energy range was then studied for the first time. The kinematics of events produced by PYTHIA 5.7 was often not precise enough, because of rounding errors for (REAL*4) floating-point variables.

The particles described by a tree-structured event record (i.e. HEPEVT common block used by PHOTOS), form decay ‘branches’ composed of a ‘mother’—the decaying particle, and ‘daughters’—its decay products. When the kinematics of a branch is not correct (the sum of 4-momentum of decay products does not match the 4-momentum of the mother particle or the particles momenta are off shell), numerical instabilities are encountered. It is not possible to perform boosts of the particles correctly if the boost parameters are large (in certain of the events where errors occurred, we found, for instance, a pion with momentum of order of TeV/c).

A special routine PHCORK, which corrects these kinds of inconsistencies, have been developed and inserted to PHOTOS code.³

The routine works in one of four modes, selected at the initialization of PHOTOS:

³ This routine became available in 1999 and can be found in the CERNLIB version of PHOTOS.

- mode 1: no correction performed,
- mode 2: energy is corrected from mass,
- mode 3: mass is corrected from energy,
- mode 4: energy is corrected from mass for particles up to a mass of 0.4 GeV, for heavier ones: mass is corrected.

In cases, where a branch (sub-cascade starting from certain particles) has two mothers, the first mother's momentum is corrected according to the sum of its children momenta and the momentum of the second mother.

The default mode is 1, which means that no correction is applied, and full compatibility with older implementations is retained.

Correction is performed in two steps. First, all daughters' energies (or masses, depending on the requested mode of correction) are corrected to fulfill the $E^2 - p^2 = M^2$ constraint.

In the second step, the sum of all daughters' 4-momenta is calculated. The mother's momentum is corrected to this value. In cases where two mothers are present, only the first mother's 4-momentum is corrected to a value:

$$P_{\text{mother}_1} = \left(\sum_{\text{daughters}} P_{\text{daughter}} \right) - P_{\text{mother}_2}.$$

7.2.2. Interference correction

In the published version of PHOTOS [3] the interference between photon emission from two sources was available only for two-body decays into particles of opposite charge and equal mass. Since then, the interference correction was extended to work also in the case of decays into particles of distinct masses. On the technical side the interference correction was re-coded to work more efficiently. For example, this should prevent the program to stop in case of double bremsstrahlung and interference corrections in the decay of the very heavy $Z/\gamma^* \rightarrow e^+e^-$ state.

7.2.3. Enabling flags

For some users, it is convenient to block/enable PHOTOS generation in some cases, for tests or because of unphysical coding of events into the HEPEVT common block. Flags to block/enable PHOTOS generation in $\pi^0 \rightarrow e^+e^-\gamma$ and in W decay into quarks were introduced. The flags are initialized in the subroutine PHOINI.

7.2.4. Weight correction in the decay $W \rightarrow l\nu_l$

For the leptonic decays of the W boson, PHOTOS predictions were carefully compared with the results from the first order matrix element generator [37]. It was found that even though the leading corrections were properly modeled by PHOTOS, the non-leading missing effects were relatively large. The origin of these discrepancies was understood, and the appropriate correcting weight was introduced into PHOTOS. With these changes the agreement with the matrix element calculation improved sizably [44], especially in regions of phase space populated with hard non-collinear photons. A new option was introduced, to initialize this correcting weight. It can be switched on/off with the new flag IFW, initialized in subroutine PHOCIN. The method can easily be extended to other processes where the matrix element is available from QED calculations or from modeling based on experimental data.

7.2.5. PHOTOS 2.07

Once all these modifications are installed, the new version 2.07 of PHOTOS was created.

8. Issues related to distinct event record schemes

Let us note that the packages presented here work with the standard HEPEVT event record, where the tree structure of the event evolution is properly coded into a unique tree structure. Generally this is not the case. However, the programs were shown to work properly with the extension of the standard of the type as originating from PYTHIA [24] with $\text{MSTP}(128) = 0, 1, 2$. Necessary adjustments turned out to be non-trivial and in fact correctness of their action cannot be guaranteed in the general case [45]. The case of HERWIG [23] turned out to be even more complex. Even though in this case the HEPEVT common block is used as standard event record, the mother–daughter pointers are nonetheless used in a different way. As a consequence, events generated by HERWIG are far from the design format of the HEPEVT event record. We were able to tune the working of the TAUOLA universal interface to the requirements of operating with HERWIG; however, the interfacing of PHOTOS turned out to be rather more difficult.

The principal issue from which difficulties with the HEPEVT decoding arise is that PYTHIA as well as HERWIG produce a new copy of the participating particles each time a physical effect (e.g., final state radiation) is added; consequently several copies of particle entries are produced, which cannot be consistently put in the HEPEVT structure. In order to circumvent this problem, the JMOHEP and/or JDAHEP entries are *overloaded*, i.e. the information stored in them is used for other purposes than their original one. For example, PYTHIA with $\text{MSTP}(128) = 0$ setting uses the JMOHEP entry to point to the copies of a particle (cf. Fig. 3)

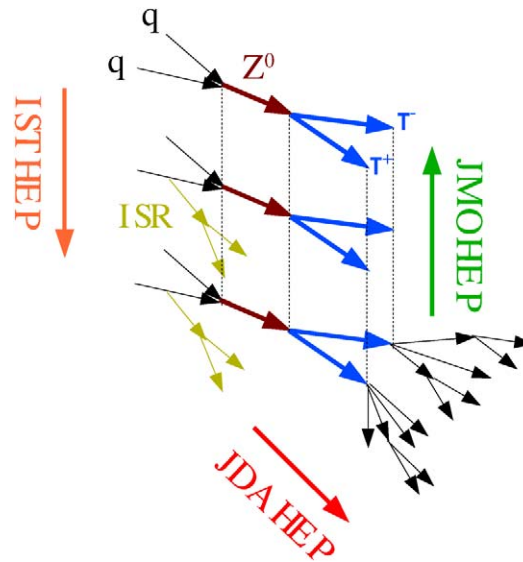


Fig. 3. The usage of JMOHEP and JDAHEP pointers in PYTHIA with $MSTP(128)=0$ setting. While PYTHIA keeps the JDAHEP entries to point in the direction of event evolution, the JMOHEP is used to point to the copies of a particle produced when perturbative effects, such as initial state radiation (ISR) or τ decays are added; the particle copies at different stages of event simulation are consistently distinguished by the ISTHEP tags.

and HERWIG uses the JMOHEP (2, I) entries to store the color information of the particle flow. A generic interface thus has to be informed of these possibilities and to correct for them for the TAUOLA and PHOTOS procedures to work properly.

At present a working version of modified PHOTOS routines, which appears to work with HERWIG, can be found in the distribution of AcerMC [25]. However rigorous testing is necessary before these modifications can be included in the official PHOTOS distribution. The original PHOTOS code had to be modified due to the ‘overloaded’ HEPEVT record, since its requirements for matching mother–daughter pointers were too strict for either PYTHIA or HERWIG. The modification was limited to PHOTOS_MAKE and PHOBOS routines. In addition the tracking of the IDHW array was added to PHOTOS_MAKE to accommodate the HERWIG event record. A further modification was however necessary in the PHOIN routine since in HERWIG the entry JMOHEP (2, I) is not empty but filled with color flow information, which in turn inhibited PHOTOS radiation off participating particles.⁴

It has to be stressed that implementing the HERWIG–PHOTOS interface is desirable because, up to version 6.5, HERWIG did not have any QED radiation implemented in the decays. In the later releases PHOTOS is used for decays (and hadronic production) of t -quarks and in W decays. This is done, however, through special interfaces embodied within the HERWIG code.

Other issues are related to double counting. If there is no information passed from the host program, and the common block PHOQED of PHOTOS is not filled appropriately, then there is no way for PHOTOS to determine that in some decays it should not generate bremsstrahlung (again) and thus ‘double counting’ will appear. While the question is not relevant for HERWIG, since no photon bremsstrahlung is implemented, it can become an issue for PYTHIA, for some specific processes. Indeed, one can generally switch off the photon radiation off leptons (by setting a high limit on PARJ (90), cf. [24]); however, one cannot do it on the basis of specific processes and/or decays.

The issue does not appear in the TAUOLA universal interface. There, if the decay of τ was already generated by other program, the universal interface will prevent the repeated generation of the decay.

9. Summary and future possibilities

We presented the system for creating the required version of PHOTOS and TAUOLA packages from their master versions. The master versions are structured in a relatively compact form without code duplications, etc. The minor modifications of the programs, introduced since their publication, were also explained.

The creation of the system was the first step towards future attempts to develop packages without loss of their present physics contents. Some experience, already collected in that direction, is summarized in [43]. We find the question of the language translation for the fixed program version relatively easy. On the contrary, the question of project continuity into further upgrades motivated by the physics needs to be thought over carefully. Matching the programming styles of the C++ experts with the strategies of testing numerical correctness of consecutive versions is a crucial issue, which has to be addressed. Tools and methods embodied in FORTRAN code survive such translation with difficulty.

⁴ PHOTOS expects the non-zero second mother JMOHEP (2, I) entry only for $gg(qq) \rightarrow t\bar{t}$ process, which is treated by a set of dedicated routines; this in turn clashes with HERWIG overloaded JMOHEP (2, I) entry.

At a certain moment, the necessary strategy may thus require fluency in the use of FORTRAN, Object-Orientated programming and physics content of the project to be possessed by the same person. Platform-independent tools for mixing code in FORTRAN and OO languages might be of great help.

In this paper we also documented, for the first time, the technical side of the universal interface for the TAUOLA package. From now on, its version number 1.10 is printed in the output.

10. Documentation of program update

Since the time of first submission for publication (2003), significant changes have been introduced into the package. They are motivated by the evolution of the software environments in which the package is used at present and also by the evolution of the physics content of the package itself. As mentioned in the introduction, both versions: the one from 2003, and the present one are in widespread use, hence both need to be documented. In this subsection we briefly document the changes that differentiate the present version of the package from the version of the end of year 2003.

10.1. Changes in TAUOLA

There were no important changes developed for the TAUOLA library of τ lepton decay. From that perspective the contents of the TAUOLA-F directory (see Section 7) remain unchanged. The directory is used to construct TAUOLA version 2.7.

An optional new version that generates the TAUOLA-BBB directory has been prepared. From the TAUOLA-BBB directory TAUOLA version 2.9 can be constructed. The use of the TAUOLA-BBB part of the package is exactly as of TAUOLA-F; it is prepared to manage the new versions of TAUOLA physical initialization: *authors*, *BaBar* and *Belle*. The framework for these new versions is prepared as a starting point for physical initializations which may be developed by Belle and BaBar collaborations, on the basis of their data. At present, these new versions are not expected to be used outside those experiments, except for the cases of high precision and high luminosity τ measurements. A multitude of new decay modes has been introduced, yet without any physics initialization. The exception are five-pion final states, where new currents and a proper matrix element implementation is provided (see Ref. [46] for details), however, still without fits to the data, thus of limited interest to the user outside the domain of precise measurements of τ decays taking data now.

10.2. Changes in TAUOLA universal interface

TAUOLA universal interface has been updated now from version 1.10 to version 1.21. Most of the changes were motivated by bug-fixing or developing methods to overcome difficulties with the input through the HEPEVT common block being performed in a non-standard way by the generators for τ lepton(s) production.

The decays of π^0 , K_S and η can now be generated from within of the TAUOLA universal interface. These decays are activated with the help of new switches `ION(1)`, `ION(2)`, `ION(3)` defined in the routine TAUOLA.

The purpose of this extension may not seem obvious. Previously, other generators, such as PYTHIA [24], were used for that secondary decays and sufficient precision was assured. Such organization required the translations of the data between various event record standards (i.e. between HEPEVT and PYJETS common blocks for PYTHIA). Unlike the case of FORTRAN, where the routines for such translations are available and well-tested, problems were encountered in the C++ wrapper routines used in the LHC collaboration software. Due to modular arrangements of these wrappers performing such translations back-and-forth (between FORTRAN and C++ codes) became cumbersome.

The new non- τ decays should not be expected to provide high precision results. Their sole purpose is to enable the modularity in the code organization for cases when consecutive, interleaved execution of FORTRAN and C++ wrapper packages is not convenient. Anyway, in near future, most probably, simulation of those decays will be performed by dedicated C++ code.

10.3. Changes in PHOTOS

We document here the updates in PHOTOS up to the version 2.15. Physics features of this new version are documented in Ref. [48], and some theoretical concepts in [47]. The changes are quite extensive and program precision and sophistication was significantly improved because of demands both from physics of B/D/K mesons decays and Z , W , H as well.

Here let us summarize the options and switches available in version 2.15 of PHOTOS. This section can thus serve as a technical reference guide for librarians and end-users. The complete, technical description of the algorithm, with its recent improvements, is presented elsewhere [49,50].

In the default configuration the new options are not active and PHOTOS 2.15 behaves much like PHOTOS 2.0 from 1994 [3].⁵ No changes are required in old interfaces. In most applications it will produce results that differ little with respect to previous versions,

⁵ The default initialization is chosen for backward-compatibility, and not for the best performance.

Table 2

Standard PHOTOS switches and configuration parameters. (exp) denotes the switches and values that are specific to exponentiated mode

Subroutine	Parameter	Default	Description
Options for photon multiplicity selection			
PHOCIN	ISEC	.TRUE.	Switch to enable double emission
PHOCIN	ITRE	.FALSE.	Switch to enable triple/quartic emission
PHOCIN	IEXP	.FALSE.	Switch to enable exponentiated, multiphoton mode
Options related to interference			
PHOCIN	INTERF	.TRUE.	Switch to enable universal interference weight
PHOCIN	IFW	.TRUE.	Switch to enable dedicated interference weight for $W \rightarrow l\nu(\gamma)$ decays
PHOCIN	FINT	2.D0	Maximum interference weight. The value may need to be adjusted to 2^{n-1} , where n is the maximal multiplicity of charged decay products of any elementary branching
Other technical options			
PHOCIN	CALL PHCORK (n)	n=1	Switch to select kinematics correction mode: n=1: no correction n=2: corrects energy from mass n=3: corrects mass from energy n=4: corrects energy from mass for particles up to 0.4 GeV mass, for heavier ones corrects mass n=5: most complete correction for mother and daughter particles; required for (exp)
PHOCIN	XPHCUT	0.01 1D-7 (exp)	Infrared cut-off parameter: minimal photon energy expressed as fraction of decaying particle mass
PHOCIN	IFTOP	.TRUE.	Switch to enable emission in the hard process $gg(q\bar{q}) \rightarrow t\bar{t}$

with the exception of the QED interference effects which are now simulated by default in every decay. As in previous versions, the initialization parameters, which are subject to user modifications, should be configured in the subroutine PHOCIN. An optimal choice of options are supposed to be set by the user according to his needs.⁶

10.4. Standard settings

In Table 2 we summarize all switches used in standard PHOTOS setups. The names of the options that are new (or need special care) in version 2.15 are typed in bold font.

10.4.1. Exponentiated multiple-photon mode

The exponentiated mode has been implemented starting from version 2.09 of PHOTOS; it may be activated using the IEXP flag. By eliminating the problem of negative probabilities we were able to lower the default value for XPHCUT parameter to 10^{-7} for that mode. Nevertheless, multiple iteration of emission kernel puts higher demands on numerical precision: aggregating rounding errors and initially insignificant numerical deficiencies in energy-momentum conservation of the input data, may lead to significant problems with numerical stability. Therefore a new option for kinematics corrections of the data in the event record was implemented.⁷ The new option, activated with CALL PHCORK(5) is activated automatically for the exponentiated mode. It corrects momenta four-vectors of all particles taking part in photon generation: at first, the energies of all daughter particles are corrected in such a way that $E_i^2 = p_i^2 + M_i^2$; then the four-momentum of the mother-particle is recalculated to ensure energy-momentum conservation.

10.4.2. Universal interference weight

Up to version 2.12 of PHOTOS, QED interference was implemented for dedicated decay channels only, namely neutral particle decaying into a pair of opposite-charge particles.⁸ For other channels⁹ the interference effects were not taken into account.

Starting from version 2.13 a new, universal algorithm calculating interference effects for all processes is present in PHOTOS. By default, as in previous versions, this algorithm (implemented internally as the Monte Carlo interference weight) is active and may be controlled using INTERF flag. To use this new interference weight, it is required that the value of the FINT parameter be

⁶ We are grateful to Mikhail Kirsanov for pointing out the importance of stressing this point.

⁷ This is the extension of the kinematic correction schemes described in Section 7.2.1.

⁸ This requirement was relaxed slightly in PHOTOS 2.07. Since then the pair of decay products could be of different masses. See Section 7.2.2 for details.

⁹ Except for leptonic W decays, where a dedicated interference weight was implemented in version 2.07 (see Section 7.2.4).

Table 3
Advanced PHOTOS switches and configuration parameters

Subroutine	Parameter	Default	Description
PHTYPE	IFOUR	.TRUE.AND.(ITRE)	Switch to enable quartic emission
PHOCIN	EXPEPS	1D-4	Residual probability for multiple iteration, “stop criteria” for crude generation
Selection of weighting algorithm variant			
PHOCIN			Select the variant of weighting algorithm
PHOMAK			code. May be altered by proper commenting
PHOPRE			of code blocks denoted with <code>VARIANT A</code>
PHOENE			and <code>VARIANT B</code> comments.
PHOINT			For use by experts only.

adjusted in such a way that the maximum weight in the Monte Carlo rejection is increased to 2^{n-1} , where n denotes the maximal expected multiplicity of charged particles in decays processed by PHOTOS.

An omission in adjusting this parameter often results in PHOTOS stopping with an error message indicating too high a value of summary weight. On the other hand, putting the value of `FINT` too high may significantly increase the CPU time consumed by PHOTOS because of Monte Carlo rejection not being effective. An option for having the actual value of `FINT` automatically calculated for each event is being considered for implementation in the future, if motivated by sufficient demand.

10.5. Advanced settings

In Table 3 we summarize the switches and options dedicated for advanced users. We strongly recommend to contact the authors before these settings are altered.

At an intermediate step of development, a more effective Monte Carlo weight for crude probability in interference calculation was implemented in PHOTOS 2.07: instead of doubling the crude distribution for photon emission from each charge, a flat, parallel channel was added. Despite the results being satisfactory, this solution turned out to suffer from problems with stability when used with universal interference weight for more than three-body decays. We therefore reverted the code to the original implementation. For the purpose of preserving this interesting technical development and maintaining the compatibility with PHOTOS versions 2.07–2.12, released in 2003–2005, we leave this optimized code as an option to be activated by advanced users. The two options are marked in the code by `VARIANT A` and `VARIANT B`, the former being currently active, the latter being commented-out. Due to elimination of numerical instabilities, we were able to lower the value of `XPHCUT` for fixed to 10^{-4} for variant B, and perform important tests. Such tests are not possible in the default variant A, because the value of `XPHCUT` has to be kept at 10^{-2} .

Finally, let us point out the changes in the `PHLUPA` (`IPOINT`) debugging facility. In earlier versions it was controlled with hard-coded statements. At present, because of requirements induced by C++ wrappers, it is more convenient to introduce a common block `COMMON /PHLUPY/ IPOIN, IPOINM` defining the range of `IPOINT` for which debugging messages are printed by `PHLUPA`. Such organization enables the activation of those printing statements encoded in PHOTOS through the C++ wrapper, thus without changes in the FORTRAN code. This solution is convenient for the end user of the complex experimental simulation framework. The contents of the event record passed to (and later consecutively changed inside) PHOTOS can be monitored this way, without the necessity to modify and recompile the code of PHOTOS.

Acknowledgements

Authors are grateful to ALEPH, CLEO, DELPHI and OPAL collaborations for providing their appropriate versions of the whole or parts of TAUOLA initialization. Useful discussions and suggestions from B. Bloch, C. Biscarat, S. Jadach, J.H. Kühn, M. Peskin, S. Slabospitzky and A. Weinstein are also acknowledged.

References

- [1] S. Jadach, Z. Wąs, R. Decker, J.H. Kühn, Comput. Phys. Comm. 76 (1993) 361.
- [2] A.E. Bondar, et al., Comput. Phys. Comm. 146 (2002) 139, hep-ph/0201149.
- [3] E. Barberio, Z. Wąs, Comput. Phys. Comm. 79 (1994) 291.
- [4] S. Jadach, J.H. Kühn, Z. Wąs, Comput. Phys. Comm. 64 (1990) 275.
- [5] M. Jeżabek, Z. Wąs, S. Jadach, J.H. Kühn, Comput. Phys. Comm. 70 (1992) 69.
- [6] E. Barberio, B. van Eijk, Z. Wąs, Comput. Phys. Comm. 66 (1991) 115.
- [7] P. Golonka, E. Richter-Wąs, Z. Wąs, hep-ph/0009302.
- [8] R. Decker, M. Finkemeier, P. Heiliger, H.H. Jonsson, Z. Phys. C 70 (1996) 247, hep-ph/9410260.
- [9] ALEPH Collaboration, B. Bloch, to contact send a mail to Brigitte.Bloch-Devaux@cern.ch.
- [10] CLEO Collaboration, A. Weinstein, see http://www.cithec.caltech.edu/~ajw/korb_doc.html#files.

- [11] H. Czyż, J.H. Kühn, Eur. Phys. J. C 18 (2001) 497, hep-ph/0008262.
- [12] S. Jadach, B.F.L. Ward, Z. Wąs, Comput. Phys. Comm. 130 (2000) 260, hep-ph/9912214.
- [13] T. Pierzchała, E. Richter-Wąs, Z. Wąs, M. Worek, Acta Phys. Polon. B 32 (2001) 1277, hep-ph/0101311.
- [14] Z. Wąs, M. Worek, Acta Phys. Polon. B 33 (2002) 1875, hep-ph/0202007.
- [15] G.R. Bower, T. Pierzchała, Z. Wąs, M. Worek, Phys. Lett. B 543 (2002) 227, hep-ph/0204292.
- [16] K. Desch, Z. Wąs, M. Worek, Eur. Phys. J. C 29 (2003) 491, hep-ph/0302046.
- [17] K. Desch, A. Imhof, Z. Wąs, M. Worek, Phys. Lett. B 579 (2004) 157, hep-ph/0307331.
- [18] T. Sjöstrand, M. Bengtsson, Comput. Phys. Comm. 43 (1987) 367.
- [19] OPAL Collaboration, G. Abbiendi, et al., European Phys. J. C 13 (2000) 197, hep-ex/9908013.
- [20] DELPHI Collaboration, P. Abreu, et al., Phys. Lett. B 426 (1998) 411.
- [21] Particle Data Group Collaboration, C. Caso, et al., European Phys. J. C 3 (1998) 1.
- [22] C.W. Pokorski, N. Brook, session on decay packages of “CERN Workshop on Monte Carlo tools for the LHC”, July 7–August 1 2003, CERN Geneva, <http://agenda.cern.ch/fullAgenda.php?ida=a031540>.
- [23] G. Corcella, I.G. Knowles, G. Marchesini, S. Moretti, K. Odagiri, P. Richardson, M.H. Seymour, B.R. Webber, JHEP 0101 (2001) 010, hep-ph/0011363.
- [24] T. Sjöstrand, et al., Comput. Phys. Comm. 135 (2001) 238, hep-ph/0010017.
- [25] B.P. Kersevan, E. Richter-Wąs, AcerMC-1.4 version on <http://cern.ch/Borut.Kersevan/AcerMC.Welcome.html>; published version in Comput. Phys. Comm. 149 (2003) 142.
- [26] E. Boos, et al., hep-ph/0109068.
- [27] M. Dobbs, J.B. Hansen, Comput. Phys. Comm. 134 (2001) 41.
- [28] Z. Wąs, hep-ph/0402129.
- [29] Z. Wąs, hep-ph/0203217.
- [30] T. Sjöstrand, Comput. Phys. Comm. 82 (1994) 74.
- [31] S. Jadach, B.F.L. Ward, Z. Wąs, Comput. Phys. Comm. 79 (1994) 503.
- [32] S. Jadach, B.F.L. Ward, Z. Wąs, Comput. Phys. Comm. 124 (2000) 233, hep-ph/9905205.
- [33] S. Jadach, B.F.L. Ward, Z. Wąs, European Phys. J. C 22 (2001) 423, hep-ph/9905452.
- [34] S. Jadach, Z. Wąs, Acta Phys. Polon. B 15 (1984) 1151.
- [35] M. Kramer, J.H. Kühn, M.L. Stong, P.M. Zerwas, Z. Phys. C 64 (1994) 21, hep-ph/9404280.
- [36] B. Grzadkowski, J.F. Gunion, Phys. Lett. B 350 (1995) 218, hep-ph/9501339.
- [37] A. Andonov, S. Jadach, G. Nanava, Z. Wąs, Acta Phys. Polon. B 34 (2003) 2665, hep-ph/0212209.
- [38] P. Golonka, T. Pierzchała, Z. Wąs, Comput. Phys. Comm. 157 (2004) 39, hep-ph/0210252.
- [39] <http://cern.ch/Piotr.Golonka/MC/MC-TESTER>.
- [40] <http://www.cern.ch/wasm/goodies.html>.
- [41] Particle Data Group Collaboration, K. Hagiwara, et al., Phys. Rev. D 66 (2002) 010001.
- [42] T. Pierzchała, The extension of TAUOLA Monte Carlo library, simulating τ lepton decays, PhD Thesis, Silesian University 2004; see home page at <http://hpjmiady.ifj.edu.pl/~pierzchala>.
- [43] P. Golonka, MSc Thesis written under the supervision of Z. Wąs, see home page at <http://cern.ch/Piotr.Golonka/MC/photos>.
- [44] G. Nanava, Z. Wąs, Acta Phys. Polon. B 34 (2003) 4561, hep-ph/0303260.
- [45] Talks by B. Kersevan and M. Worek, presented at the Workshop on Monte Carlo tools for the LHC, CERN, July 2003.
- [46] J.H. Kühn, Z. Wąs, τ -Decays to Five Mesons in TAUOLA, in preparation, draft of the paper is already available in program distribution directory.
- [47] P. Golonka, Z. Wąs, hep-ph/0508015.
- [48] P. Golonka, Z. Wąs, European Phys. J. C 45 (2005) 97–107, hep-ph/0506026.
- [49] P. Golonka, Z. Wąs, in preparation.
- [50] P. Golonka, PhD thesis, Institute of Nuclear Physics, Cracow, 2006 Written under supervision of Prof. Z. Wąs, 2006, in preparation; Draft will be available at <http://cern.ch/Piotr.Golonka/MC/PhD>.