Tau leptons for new and old physics, practical aspects.

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Main Topics:

- TAUOLA itself: versions
- MC-TESTER for decay tests.
- PHOTOS: radiative corrections in decays.
- KORALB/KORALZ/KKMC.
- Universal interface.
- summary and outlook.

Contributions to TAUOLA and related projects: G. Bower, R. Decker, S. Eidelman, P. Golonka, S. Jadach, M. Jeżabek, J.H. Kühn, T. Pierzchala, E. Richter-Was, N. Root, B.F.L. Ward, Z. W., M. Worek, contributions from ALEPH, CLEO, Delphi, Opal, L3 collabs, Karlsruhe th. group, and others.

My web page http://home.cern.ch/wasm

INTRODUCTION

Monte Carlo solution:

Due to the long τ lepton lifetime,

generation can be separated into production and decay as completely independent projects.

All spin effects of the Einstein-Rosen-Podolsky type can be handled this way.

τ decay generation consist of:

Interfaces to production generators

Bookkeeping and library for phase space generation.

Easy to replace matrix elements or hadronic currents

Hadronic Currents

H.C. originate from models of low energy hadronic interactions **and** experimental data

we get options, continuous improvements coordintation issues.

INTRODUCTION

τ lepton is exceptional:

As a lepton it is produced free of ambiguities of hadronic interactions,

decay is well separated from production by its lifetime.

τ decays either into μ, e or in 1 to 6 π/K (plus noeutrino(s))

In detector τ lepton looks often like a very poor hadronic jet plus missing momentum.

Very special case:

Special experimental techniques.

Special case for theory.

Exceptionally clean source of hadronic states:

For tests of QCD

For build of nice models of individual decay channels.

I will stay very practical

Tauola itself

Main references:

1. R. Decker, S.Jadach, M.Jeżabek, J.H.Kuhn, Z. Was, Comput. Phys. Commun. 76 (1993) 361, ibid. 70 (1992) 69, ibid. 64 (1990) 275
2. P. Golonka, T. Pierzchala, E. Richter-Was, Z. Was, M. Worek (upgraded TPJU 10/2000, hep-ph/0009302 at work), technical stuff only.

Also:

1. • Alain Weinstein www home page: http://www.cithep.caltech.edu/~ajw/korb_doc.html#files
2. • B. Bloch, private communications.
3. R. Decker, M. Finkemeier, P. Heiliger and H.H. Jonsson, Hep-ph/9410260, now standard 4π formfactors.
4. **New:** A. E. Bondar, S. I. Eidelman, A. I. Milstein, T. Pierzchala, N. I. Root, Z. Was and M. Worek, Comput. Phys. Commun. **146**, 139 (2002)
5. P. Abreu et al., Phys. Lett. B426 (1998) 411 (alternative 3π formf.)
6. Sherry Towers aternative formf. in K$\pi\pi$ modes, hep-ex/9908013

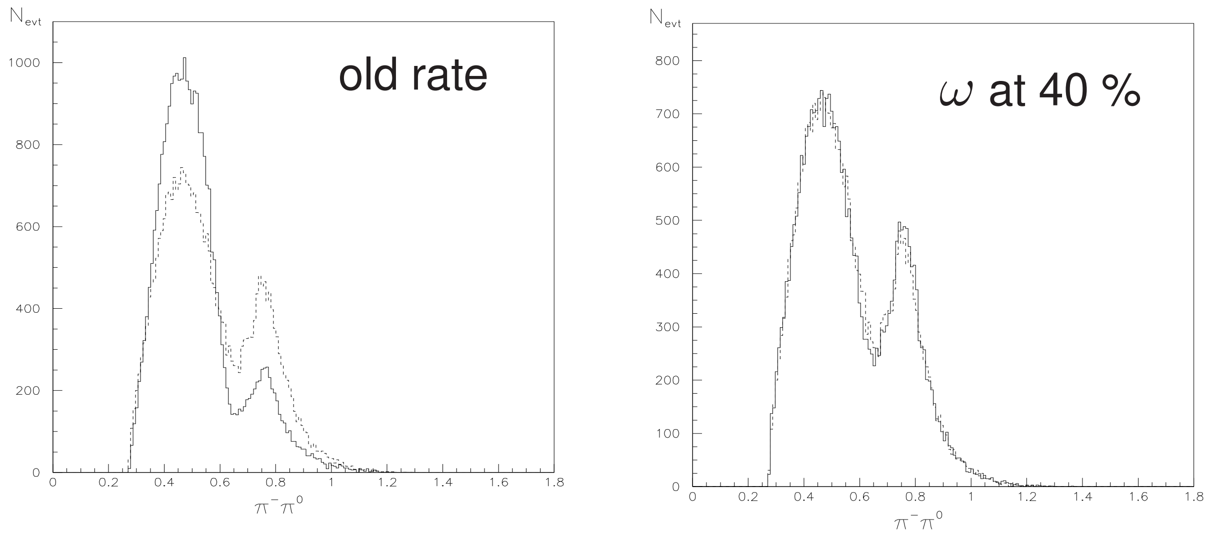
And as usual, references therein

I am nearly sure, I have forgotten something. The complete distribution directory can be found on: http://home.cern.ch/wasm

Tauola itself

$\pi^-\pi^0$ invariant mass distribution

$\tau \rightarrow \pi^+\pi^+\pi^-\pi^0\nu$ decay channel



- Difference between Cleo 1998 initialization and Novosibirsk initialization for 4π decay channel seemed sizable.
- But it is completelly washed out if quite trivial constant was updated in Cleo 1988 up to more to date Cleo measurement.
- I believe that either fine tining is not critical (eg. LC LHC studies) or is done within collaborations much better than I can do (CLEO Belle, BaBar)
- But I attempt to drag student into such work. I have in mind more theoretically involved subjects, model building anomalous couplings as well.

Tauola itself

Recent progress:

- Novosibirsk parametrizations for $4-\pi$ decay channels
- Parametrization from: H. Czyż, J. H. Kuhn, Eur. Phys. J. **C18**, (2001) 497, installed, but not tested.

Use of TAUOLA

Customized interface

- Approximate spin treatment, as in KORALZ (also in HERWIG)
- Complete spin as in KORALB or KKMC (probably also in future versions of HERWIG)

Universal

All present day Momte Carlo programs store events in data structures like HEPEVT PYJETS LUJETS. This offers opportunity for nice applications:

- Approximate spin treatment
- Complete spin (Higgs boson decay)
- Also PHOTOS for bremsstrahlung in decays.
- MC-TESTER for tests of decay programs.

MC—TESTER: a universal tool for comparisons of Monte Carlo predictions for particle decays in High Energy Physics

P. Golonka, T. Pierzchała, Z. Wąs

In TAUOLA already now are over 25 different τ decay channels, to develop the package it is necessary to perform quick comparisons. MC-TESTER works for TAUOLA or other decayers, provided events are stored in HEPEVT, PYJETS or LUJETS common block.

1. For the run of 'any' MC, MC—TESTER need to be loaded
2. Event after event, decay channels of particle ID are searched and histograms formed from all possible invariant masses produced from ID are filled.
3. Results from the runs of two programs generating ID decays (possibly as sub-process) can be then compared.
4. Comparison booklet is created.
5. For details see `http://cern.ch/Piotr.Golonka/MC/MC-TESTER`.
6. Program is not yet published, but early users are welcomed.

Example

MC-TESTER results for decays of particle τ^- (PDG code 15).

Piotr Golonka Tomasz Pierzchala Zbigniew Was

June 14, 2002

Results from generator 1.

TAUOLA LIBRARY: VERSION XX.YY
....
`You may replace this text in SETUP.C file.`

- From directory: `/home/piters/work/MC-TESTER/MC-TESTER/examples-F77/tauola/gen1`
- Code version (from `version` file): ALEPH
- Total number of analyzed decays: 10000000
- Number of decay channels found: 30

Results from generator 2.

TAUOLA LIBRARY: VERSION UU.VV
....
`You may replace this text in SETUP.C file.`

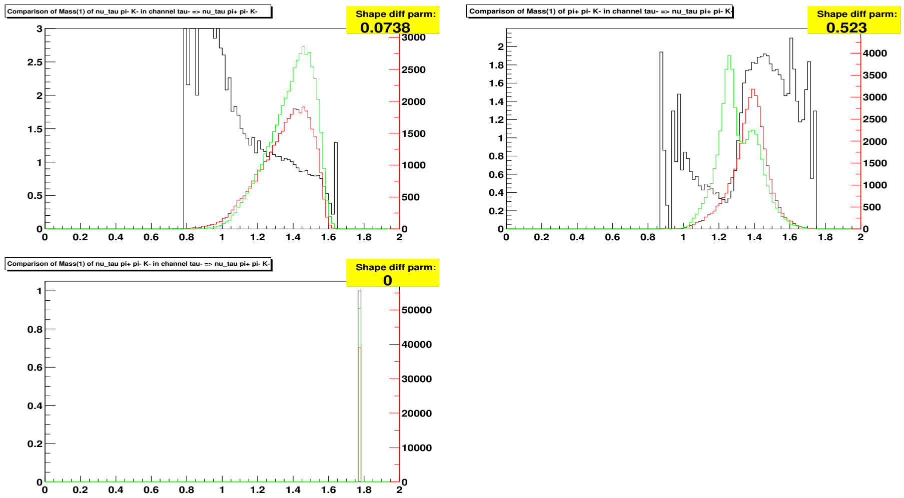
- From directory: `/home/piters/work/MC-TESTER/MC-TESTER/examples-F77/tauola/gen2`
- Code version (from `version` file): CLEO
- Total number of analyzed decays: 10000000
- Number of decay channels found: 30

1

Found decay modes:

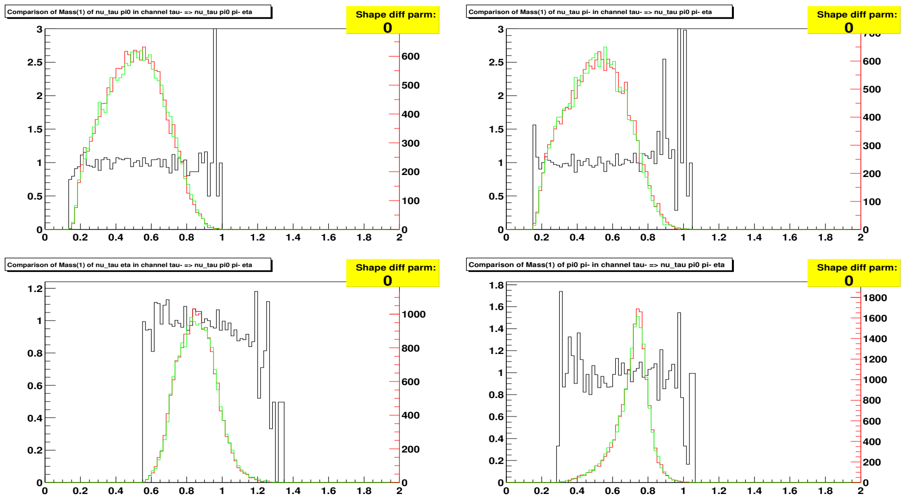
Decay channel	Branching Ratio ± Rough Errors Generator #1	Generator #2	Max. shape dif. param.
$\tau^- \to \nu_\tau \pi^0 \pi^-$	25.3683 ± 0.0159%	25.3085 ± 0.0159%	0.04375
$\tau^- \to e^- \widetilde{\nu_e} \nu_\tau$	17.8479 ± 0.0134%	18.1093 ± 0.0135%	0.00000
$\tau^- \to \mu^- \widetilde{\nu_\mu} \nu_\tau$	17.3866 ± 0.0132%	17.6326 ± 0.0133%	0.00000
$\tau^- \to \nu_\tau \pi^-$	11.0768 ± 0.0105%	11.1765 ± 0.0106%	0.00000
$\tau^- \to \nu_\tau \pi^0 \pi^0 \pi^-$	9.1865 ± 0.0096%	9.1171 ± 0.0095%	0.09413
$\tau^- \to \nu_\tau \pi^+ \pi^- \pi^-$	8.9837 ± 0.0095%	8.8828 ± 0.0094%	0.09368
$\tau^- \to \nu_\tau \pi^0 \pi^+ \pi^- \pi^-$	4.2973 ± 0.0066%	4.5319 ± 0.0067%	0.30310
$\tau^- \to \nu_\tau \pi^0 \pi^0 \pi^0 \pi^-$	1.0765 ± 0.0033%	1.0090 ± 0.0032%	0.00724
$\tau^- \to \nu_\tau K^-$	0.7202 ± 0.0027%	0.7138 ± 0.0027%	0.00000
$\tau^- \to \nu_\tau \pi^0 \pi^0 \pi^+ \pi^- \pi^-$	0.4990 ± 0.0022%	0.0897 ± 0.0009%	0.00000
$\tau^- \to \nu_\tau \pi^0 K^-$	0.4785 ± 0.0022%	0.4617 ± 0.0021%	0.00000
$\tau^- \to \nu_\tau K^0_L \pi^-$	0.4624 ± 0.0022%	0.4444 ± 0.0021%	0.00000
$\tau^- \to \nu_\tau \pi^- K^0_S$	0.4610 ± 0.0021%	0.4449 ± 0.0021%	0.00000
$\tau^- \to \nu_\tau \pi^+ \pi^- K^-$	0.3902 ± 0.0020%	0.5051 ± 0.0022%	0.52330
$\tau^- \to \nu_\tau \pi^0 \pi^- \eta$	0.1707 ± 0.0013%	0.1696 ± 0.0013%	0.00000
$\tau^- \to \nu_\tau \pi^- K^+ K^-$	0.1704 ± 0.0013%	0.1509 ± 0.0012%	0.07360
$\tau^- \to \nu_\tau \pi^0 K^0_L \pi^-$	0.1605 ± 0.0013%	0.2745 ± 0.0017%	0.92850
$\tau^- \to \nu_\tau \pi^0 \pi^- K^0_S$	0.1592 ± 0.0013%	0.2734 ± 0.0017%	0.93657
$\tau^- \to \nu_\tau \gamma \pi^0 \pi^-$	0.1559 ± 0.0012%	0.1303 ± 0.0011%	0.00000
$\tau^- \to \nu_\tau K^0_L \pi^- K^0_S$	0.1510 ± 0.0012%	0.0763 ± 0.0009%	0.00270
$\tau^- \to \nu_\tau K^0_L K^-$	0.1289 ± 0.0011%	0.0508 ± 0.0007%	0.00000
$\tau^- \to \nu_\tau K^0_S K^-$	0.1287 ± 0.0011%	0.0507 ± 0.0007%	0.00000
$\tau^- \to \nu_\tau \pi^0 \pi^0 \pi^0 \pi^+ \pi^- \pi^-$	0.1094 ± 0.0010%	0.0506 ± 0.0007%	0.00000
$\tau^- \to \nu_\tau \pi^+ \pi^+ \pi^- \pi^- \pi^-$	0.0803 ± 0.0009%	0.0401 ± 0.0006%	0.00000
$\tau^- \to \nu_\tau \pi^0 \pi^0 K^-$	0.0792 ± 0.0009%	0.0504 ± 0.0007%	0.29190
$\tau^- \to \nu_\tau K^0_L K^0_L \pi^-$	0.0760 ± 0.0009%	0.0372 ± 0.0006%	0.00854
$\tau^- \to \nu_\tau \pi^- K^0_S K^0_S$	0.0756 ± 0.0009%	0.0378 ± 0.0006%	0.01189
$\tau^- \to \nu_\tau \pi^0 K^0_L K^-$	0.0507 ± 0.0007%	0.0763 ± 0.0009%	0.85321
$\tau^- \to \nu_\tau \pi^0 K^0_S K^-$	0.0498 ± 0.0007%	0.0746 ± 0.0009%	0.87506
$\tau^- \to \nu_\tau \pi^0 \pi^+ \pi^+ \pi^- \pi^- \pi^-$	0.0186 ± 0.0004%	0.0293 ± 0.0005%	0.00000

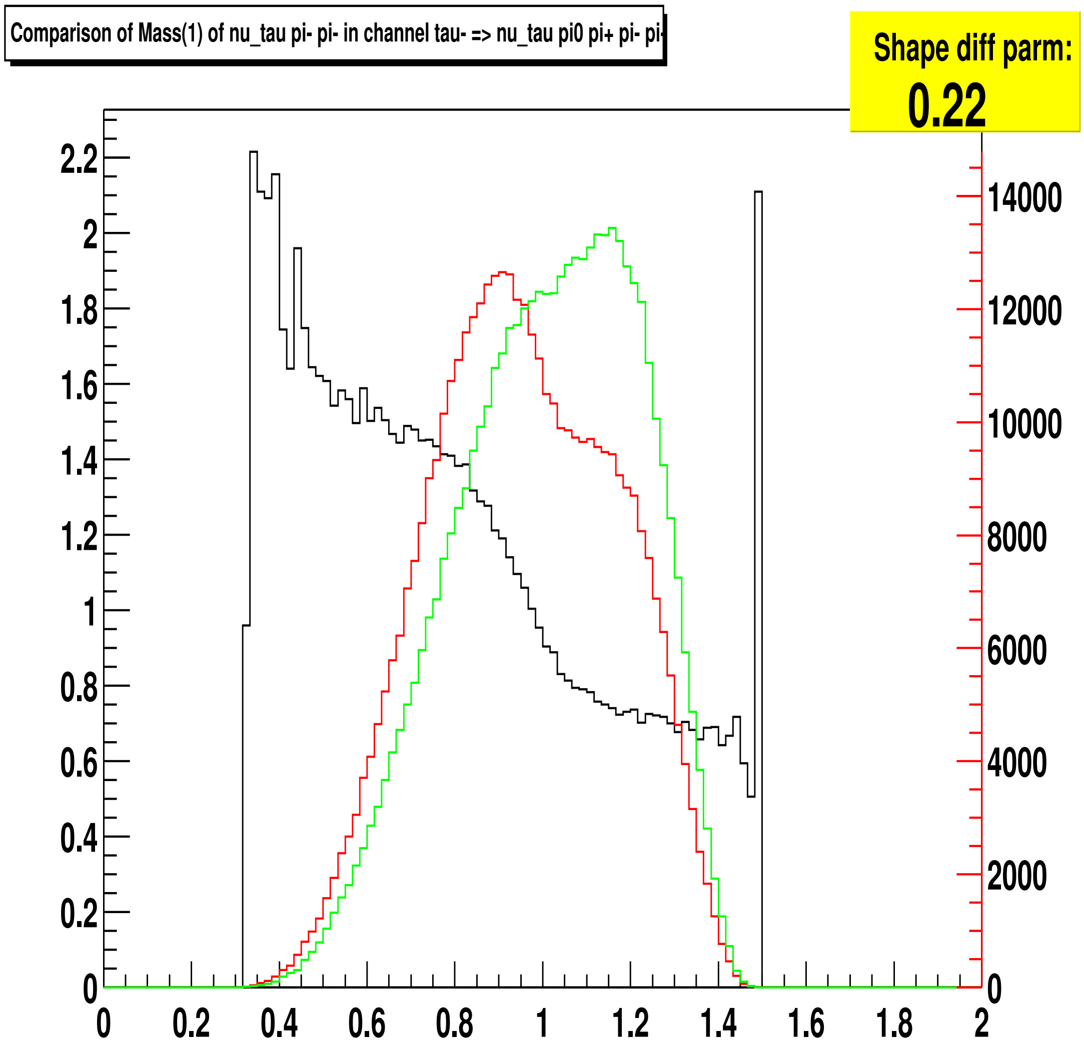
2



15 Decay Channel: $\tau^- \to \nu_\tau \pi^0 \pi^- \eta$

Number of events from generator 1: 17067
Number of events from generator 2: 16962




Comparison of Mass(1) of nu_tau pi- pi- in channel tau- => nu_tau pi0 pi+ pi- pi-
Shape diff parm:
0.22
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2000
4000
6000
8000
10000
12000
14000

PHOTOS bases on mother-daughter tree

E. Barberio, B. van Eijk, Z. Was, Comput. Phys. Commun. (1991) .

It was developped starting from the careful downgrading from the full treatment of M.E. in MUSTRAAL (F. Berends, R. Kleiss, S. Jadach, Comput. Phys. Commun. (1982)) For the decay of Z to obtain 'factorizable' form.

Extended to work for the decay of 'any' particle or resonance.

It heavily uses mother-daughter relations in `HEPEVT`

- Thus it is bound to be not better than LL (may be NLL)
- Safety backup: Comparisons with M.E. Monte Carlos whenever available.
- E.g. $\tau \to e\nu\bar{\nu}\gamma$, $\tau \to \pi\nu\gamma$, $Z \to \mu^+\mu^-\gamma(\gamma)$, $gg \to t\bar{t}\gamma\gamma$.

In many cases tests are not available ... but there is progress, *ACAT'2002, 24-28 June, 2002, Moscow, Russia*

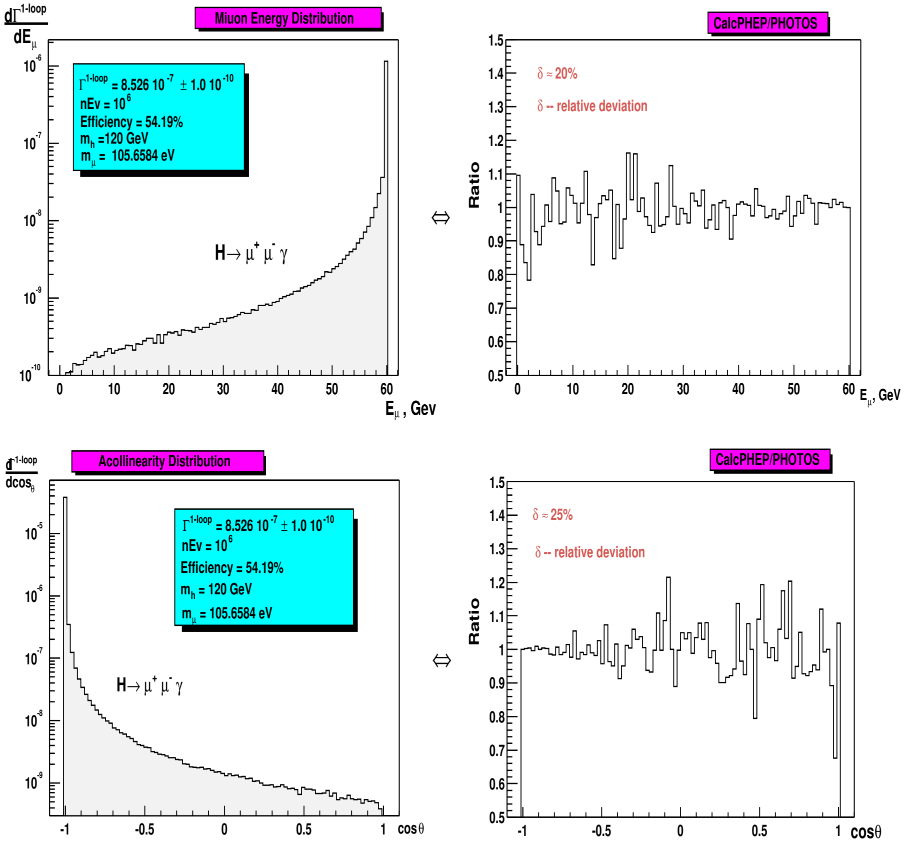
A Monte Carlo simulation of decays within the CalcPHEP project

The library of Monte Carlo programs for simulation of two particle leptonic and quark decays of the W,Z and H(Higgs) bosons with single bremsstrahlung photon emission as a part of CalcPHEP system is described. The QED and EW $O(\alpha)$ radiative corrections are implemented without any approximation, keeping the masses of decay product particles. The decay amplitudes are evaluated numerically using Kleiss&Stirling helicity amplitude method. The comparison with PHOTOS — A universal Monte Carlo simulator for QED radiative corrections is also presented.

G. Nanava.

Laboratory of Nuclear Problems, joint institute for Nuclear Research

news on PHOTOS



The CalcPHEP Monte Carlo rezults for miuon energy and acollinearity distribution in decay $H \to \mu^+\mu^-\gamma$.

Comparison with PHOTOS

Helicity states.

Approximate spin generation

Example: KORALZ at LEP, Monte Carlo program for production of τ-lepton pairs and decay, including QED bremssstrahlung corrections

S. Jadach, B.F.L. Ward, Z. Was Comput. Phys. Commun. 79 (1994) 503

- Generates first pair of τ leptons
- Generates helicity states of both τ^+ and τ^- i.e. approximation is used
- Provides helicty states and relation between τ's restframe and LAB to TAUOLA
- TAUOLA performs decay of 100 % polarized τ's.
- In (nearly) all cases at LEP such approach was sufficient.

That is standard solution used very often, advocated in general idea of `HEPEVT` common block since many years and also recently in discussions for e.g. data structure for LHC and c++.

Helicity states.

Exact spin generation

Example: KORALB and KKMC, Monte Carlo program for production of τ-lepton pairs and decay, including QED bremssstrahlung corrections

S. Jadach, Z. Was Comput. Phys. Commun. 64 (1991) 267 S. Jadach, B. F. L. Ward, Z. Was Comput. Phys. Commun. 130 (2000) 260

- Generate first pair of τ leptons, no polarization
- Calculate density matrix for the two-τ (plus photon(s))quantum state
- TAUOLA performs decay of unpolarized τ's.
- Spin weight is calculated from production and decay variables.

- Complete spin effects are introduced by rejection.

Warning: Due to nature of QM it is impossible to generate τ leptons in some quantum state, and decay them later individually.

Universal interface

HEPEVT common block

T. Pierzchala, E. Richter-Was, Z. Was, M. Worek, Acta Phys. Polon. B32 (2001) 1277

It is often convenient to decay τ leptons easy and quickly. We do exactly like that. Once event is generated and HEPEVT common block is filled it is enough to CALL TAUOLA(0,IDUM) and all undecayed τ leptons will be decayed and stored into HEPEVT.

Some minimum care of the spin is taken at the longitudinal approximation:

1. Cases of τ produced from: W (virtual), Z/γ, Higgs, Charged Higgs are distinguished in spin correlations.
2. For Z/γ case τ polarization as a function of effective $\cos\theta$, s and initial state flavour is used.
3. For Higgs boson decay full spin effects can be included.

Universal Interface – Longitudinal

- The approximation consists of reconstructing information of the elementary $2 \rightarrow 2$ body process $f\bar{f} \rightarrow (Z/\gamma) \rightarrow \tau^+\tau^-$, buried inside multi-body production process such as for example $f\bar{f} \rightarrow gZ$, $f\bar{f} \rightarrow \gamma Z$, $fg \rightarrow fZ$, $f\gamma \rightarrow fZ$ etc. The additional particles are grouped (summed) into effective quarks and leptons. Such an approach is consistent in the case of photons or gluons emission within the leading log approximation.

The principle of calculating kinematic variables

- The 4-momenta of the $2 \rightarrow 2$ body process have to be found.
- The 4-momenta of the outcoming τ's are used directly.
- Initial state momenta are constructed from the incoming and outcoming momenta of the particles accompanying production of the Z/γ state.
- The Z/γ state does not need to be explicitly coded in the `HEPEVT` common block.

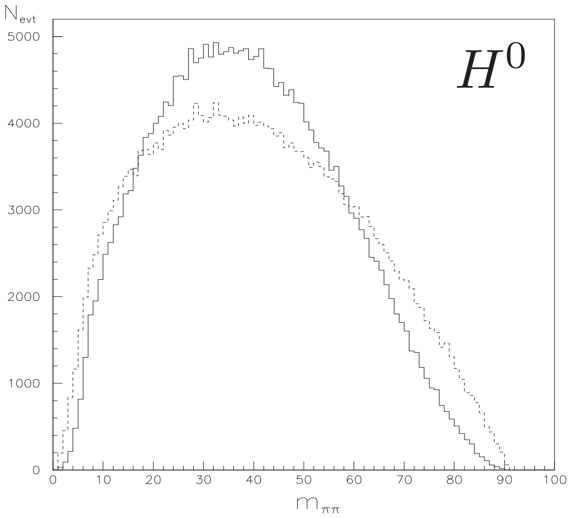
Separation of the H^0 and Z/γ background

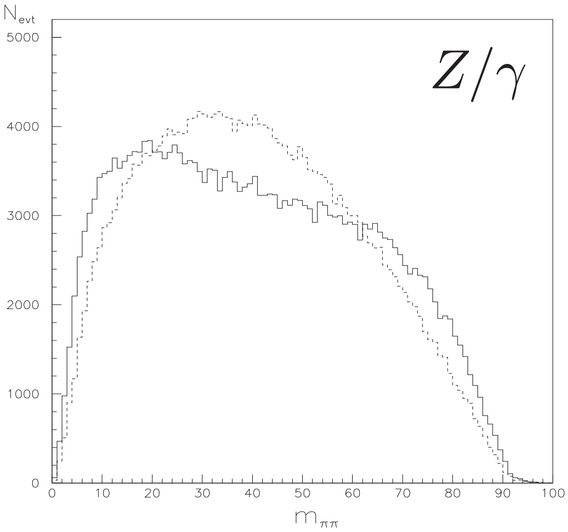
- The polarisation of the τ lepton can be exploited to identify a neutral Higgs bosons via the decay $H^0 \to \tau^+\tau^-$.
- The background is $Z/\gamma \to \tau^+\tau^-$ decay.
- There exists a simple polarisation correlation test which will cleary indicate the presence of τ pairs of Higgs origin among the background $Z/\gamma \to \tau^+\tau^-$ events.
- The τ pairs are produced with the well defined spin configurations:

  $+\ +$ or $-\ -$ for vector bosons

  $+\ -$ or $-\ +$ for neutral Higgs boson.
- The polarisation correlation test can be performed using the distributions of the final decay products which are sensitive to the admixture of the H^0 and Z/γ parentage of the τ pairs.
- The case of τ decays to $\pi\nu$ is the most sensitive to the spin correlations.

The $\pi^+\pi^-$ invariant mass distribution





- The $\pi^+\pi^-$ invariant mass distribution for H and for Z/γ state. In the two cases respectively $\sqrt{s} = m_H = m_Z$.
- In the case of Higgs boson, the mass distribution is peaked centrally, whereas in the case of Z/γ shoulders of the distributions are more profound.
- If all polarisation effects are switched off (dashed lines) the distributions in the two cases are identical.
- The distribution of invariant mass built from the visible decay products of the τ's, can be helpful in separating Higgs boson signal from Z/γ background.

Summary of this point

- The algorithm for the interfacing of the τ lepton decay package TAUOLA with "any" production generator including spin effects in the elementary $Z/\gamma \to \tau^+\tau^-$ process is available (PYTHIA HERWIG checked in at least one case, not complete tests performed so far, but see web page of Catherine Biscarat http://home.cern.ch/cbiscara/tauola_valid.html).
- The interface use information stored in the HEPEVT common block only
- The invariant mass distributions presented here, sensitive to the $\tau^+\tau^-$ spin correlations, can be possibly used for the MSSM Higgs boson searches at LC/LHC to enhance sensitivity of the signal or to verify the hypothesis of the spin zero nature of the Higgs boson.

The Higgs boson's parity

- H/A parity information can be extracted from the correlations between τ^+ and τ^- spin components which are further reflected in correlations between the τ decay products in the plane transverse to the $\tau^+\tau^-$ axes.
- The decay probability

$$\Gamma(H/A \to \tau^+\tau^-) \sim 1 - s_{\parallel}^{\tau^+} s_{\parallel}^{\tau^-} \pm s_{\perp}^{\tau^+} s_{\perp}^{\tau^-}$$

  is sensitive to the $\tau^{\pm}$ polarization vectors s^{τ^-} and s^{τ^+} (defined in their respective rest frames). The symbols $\parallel$,$\perp$ denote components parallel/transverse to the Higgs boson momentum as seen from the respective $\tau^{\pm}$ rest frames.
- This suggests that the experimentally clean $\tau^+\tau^-$ final state may be the proper instrument to study the parity of the Higgs boson.
- This spin case is technically easy, because 'Higgs spin' is blind on Higgs origin. Z. Was, M. Worek, Acta Phys. Polon. B33 (2002) 1875.

The Higgs boson's parity

- The algorithm is organized in two steps. In the first step, the τ lepton pair is generated and the τ leptons are decayed 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 is given by the following formula

$$wt = \frac{1}{4}\Big(1 + \sum_{i,j=1,3} R_{ij} h^i h^j\Big)$$

where the components

$$R_{33} = -1, \quad R_{11} = \pm 1, \quad R_{22} = \pm 1$$

respectively for scalar and pseudoscalar and all other components are zero.

Universal Interface – Complete

$\tau^\pm \longrightarrow \rho^\pm\nu$ decay

G.R. Bower, T. Pierzchala, Z. Was, M. Worek, Phys. Lett. B543 (2002) 227

- Branching ratio 25%.
- In comparison to $\tau^\pm \longrightarrow \pi^\pm\nu$ decay, its polarimetric force is more than a factor of 2 smaller but in many cases this can be improved if information on the ρ decay products are used.
- The polarimetric vector is given by the formula

$$h^i = \mathcal{N}\Big(2(q\cdot N)q^i - q^2 N^i\Big)$$

where q is the four-momentum of $\pi^\pm - \pi^0$ and N is the four-momentum of ν_τ.

- In the τ lepton rest frame, when $m_{\pi^\pm} = m_{\pi^0}$ is assumed we have

$$q\cdot N = (E_{\pi^\pm} - E_{\pi^0})m_\tau .$$

- To exploit this part of the polarimetric vector, we need to have some handle on the difference of the $\pi^\pm$ and π^0 energies in their respective τ leptons rest frames.

The Monte Carlo set up

- All the Monte Carlo samples have been generated with the TAUOLA library.
- For the production of the τ lepton pairs the Monte Carlo program PYTHIA 6.1 is used.
- The production process $e^+e^- \to ZH \to \mu^+\mu^- H$ has been chosen. Higgs boson mass $120\ GeV$ and center-of-mass energy $500\ GeV$.
- The effects of initial state bremsstrahlung were included in the PYTHIA generation.
- For the τ lepton pair decay with full spin effects included in the $H \to \tau^+\tau^-$, $\tau^\pm \to \rho^\pm \bar{\nu}_\tau(\nu_\tau)$, $\rho^\pm \to \pi^\pm\pi^0$ chain, our interface was used.
- All numerical results were obtained also from second independent simulation using the PANDORA Monte Carlo generator.

Universal Interface – Complete

The acoplanarity of the ρ^+ and ρ^- decay products

- In the Higgs rest frame the ρ momentum represents a larger fraction of the Higgs's energy than the neutrino.
- Instead of the reconstruction of the Higgs boson rest frame we use the $\rho^+\rho^-$ rest frame which has the advantage that it is built only from directly visible decay products of the ρ^+ and ρ^-.
- We take for both ρ's the $\pi^\pm\pi^0$ decay channel.

- In the rest frame of the $\rho^+\rho^-$ system we define the acoplanarity angle, φ^*, between the two planes spanned by the immediate decay products (the $\pi^\pm$ and π^0) of the two ρ's.

The optimal variable

- The variable φ^* alone does not distinguish the scalar and psuedoscalar Higgs.
- The $\tau \to \pi^\pm \pi^0 \nu$ spin sensitivity is proportional to the energy difference of the charged and neutral pion (in the τ rest frame).
- Separate events into two zones:

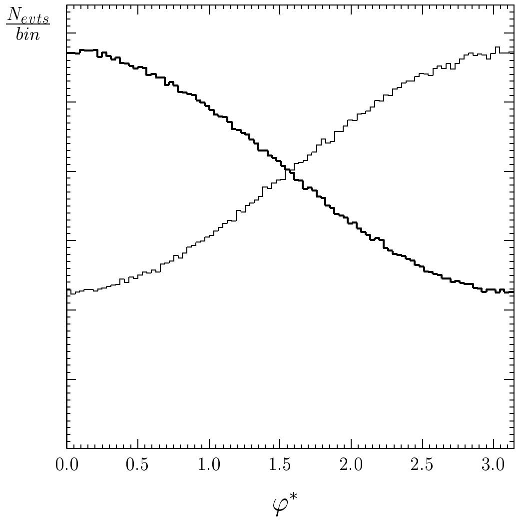
$$y_1 y_2 > 0$$

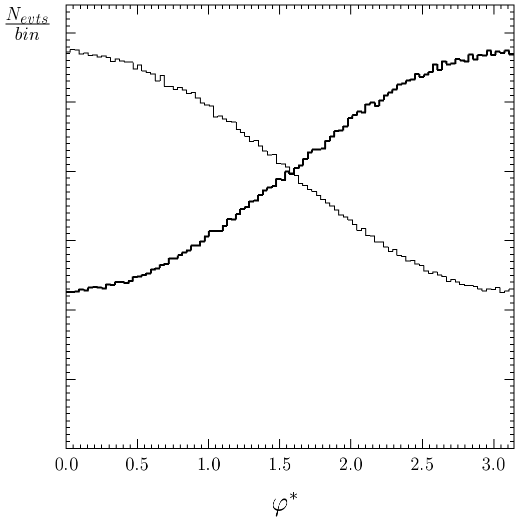
$$y_1 y_2 < 0$$

$$y_1 = \frac{E_{\pi^+} - E_{\pi^0}}{E_{\pi^+} + E_{\pi^0}}\ ; \qquad y_2 = \frac{E_{\pi^-} - E_{\pi^0}}{E_{\pi^-} + E_{\pi^0}}.$$

- $E_{\pi^\pm}$ and E_{π^0} are the $\pi^\pm, \pi^0$ energies in the respective $\tau^\pm$ rest frames.

Results





- The $\rho^+\rho^-$ decay products' acoplanarity distribution angle, φ^*, in the rest frame of the $\rho^+\rho^-$ pair. A cut on the differences of the $\pi^\pm$ π^0 energies defined in their respective $\tau^\pm$ rest frames to be of the same sign, selection $(E_{\pi^+} - E_{\pi^0})(E_{\pi^-} - E_{\pi^0}) > 0$, is used in the left plot and the opposite sign, selection $(E_{\pi^+} - E_{\pi^0})(E_{\pi^-} - E_{\pi^0}) < 0$, is used for the right plot. No smearing is done. Thick lines denote the case of the scalar Higgs boson and thin lines the pseudoscalar one.

Universal Interface – Complete

“Detector effects”

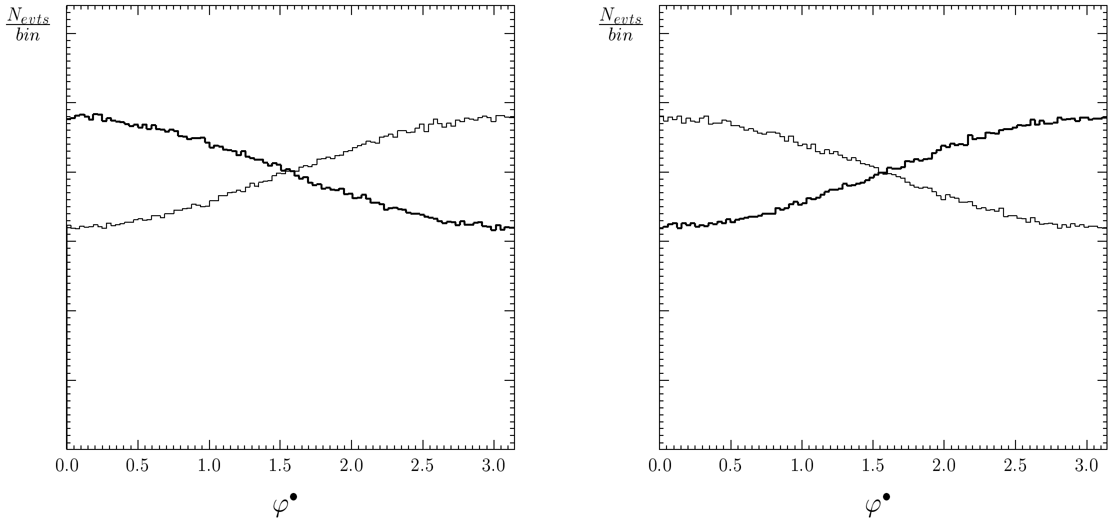
- We assume Gaussian spreads of the ‘measured’ quantities with respect to the generated ones.
- Charged pion momentum:
  0.1% spread on its energy and direction.
- Neutral pion momentum:
  energy spread of $\frac{5\%}{\sqrt{E_\pi[GeV]}}$. For the θ and ϕ angular spread we assume $\frac{1}{3}\frac{2\pi}{1800}$.
- The replacement τ lepton rest frames and the $\pi^\pm$ and π^0 energy differences:
  define replacement four-momenta, $p_\pm$, for the unmeasurable $\tau^\pm$ four-momenta in the $\rho^+\rho^-$ rest frame:
  a) Define $p_+^0 = p_-^0 = m_H/2$.
  b) Define the direction of the p_+ and p_- three-momenta to be the direction of the ρ^+ and ρ^- three-momenta in the $\rho^+\rho^-$ rest frame, respectively.
  c) Define the magnitude of the $p_\pm$ three-momenta so that $p_+^2 = p_-^2 = m_\tau^2$.

Universal Interface – Complete

"Detector effects"

- Boost the $\pi^+, \pi^0, \pi^-, \pi^0$ momenta to the respective rest frames, p_+ and p_-, of their replacement τ^+ and τ^-.
- The π energies defined this way are used in the energy difference cuts.
- When we compare predictions for scalar and pseudoscalar, we should consider not only properties of its decay, but we should take care of the possible differences in the production mechanisms as well.
- We have excluded this point from our study.
- We use Higgsstrahlung production mechanism both for the scalar and pseudoscalar Higgs boson.
- Except for the size of the cross section, our analysis and its conclusions do not depend on the choice.

After detector effects ...



- The $\rho^+\rho^-$ decay products' acoplanarity distribution angle, $\varphi^\bullet$, in the rest frame of the $\rho^+\rho^-$ pair. A cut on the differences of the $\pi^\pm\,\pi^0$ energies defined in their respective replacement $\tau^\pm$ rest frames to be of the same sign, selection $(E_{\pi^+} - E_{\pi^0})(E_{\pi^-} - E_{\pi^0}) > 0$, is used in the left plot and the opposite sign, selection $(E_{\pi^+} - E_{\pi^0})(E_{\pi^-} - E_{\pi^0}) < 0$, is used for the right plot. All smearing is included. Thick lines denote the case of the scalar Higgs boson and thin lines the pseudoscalar one.

Summary on this point

- This technique is both model independent and independent of the Higgs production mechanism and depends only on good measurements of the Higgs decay products.
- This method may be applicable to other production channels, also those available at proton colliders as well as at electron colliders. Higgs boson must be discovered first ...
- Several improvements are still possible. Other multi-meson final states such as $\tau \rightarrow \pi^+\pi^+\pi^-\nu$ can be used to increase the statistical samples.
- The measurement of the τ flight direction may turn out to be helpful.
- Note that observable relies on full spin correlations spaning over 3 levels of decay chain: $H \rightarrow \tau\tau$, $\tau \rightarrow \rho\nu$ and $\rho \rightarrow \pi^\pm\pi^0$.

Conclusions

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- There were several aspects of τ Monte Carlo presented.
- I presented them like telephone book.
- I have omiteed completelly the issues of technical/physical precision of the programs.
- In particular QED exponentiation, issues of factorization and corrections to it were omitted, even though that is where 70 % of our effort go.
- From that perspective measurement of H/A parity need a lot of refinements to get full control over uncertainties, especially if precision of observations will turn better than expected.