Precision simulations with TAUOLA

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Main messages:

- **What is new or important for the users of our package TAUOLA**
- **Different perspectives:**
- TAUOLA decays into 5 scalars with full ME now, not real progress yet.
- MC-TESTER for automated comparisons and benchmark database.
- universal interface of TAUOLA, bridge between medium and high energy
- Practical problems of encapsulation. C or not to C: coordination
- **Summary**

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

TAUOLA: basic structure these assumptions remain!

- **Phase space.**
- **Matrix elements**
- **Leptonic decays:** $\tau \rightarrow e(\mu)\nu_\tau\nu(\gamma)$**.**
- **Electroweak vertex is clear and universal up to 0.1 $\%$ precision level..**
- **Semileptonic decays are different : Hadronic current need to remain experiments' property, in cases experiment wish so.**
- **The last point enforces constraint for program organization and requests good communication between experimentalists, model builders and TAUOLA authors.**
- **Also points to low energy e^+e^- data and models. Presence/absence of isospin symmetry need to be adressed.**

Semileptonic decays: Phase-space × weak-current × hadronic-current

- The differential partial width for the channel under consideration reads

$$d\Gamma_X = G^2 \frac{v^2+a^2}{4M} d\mathrm{Lips}(P; q_i, N)(\omega + \hat{\omega} + (H_\mu + \hat{H}_\mu)s^\mu)$$

- The phase space distribution is given by the following expression where a compact notation with $q_5 = N$ and $q_i^2 = m_i^2$ is used

$$d\mathrm{Lips}(P; q_1, q_2, q_3, q_4, q_5) = \frac{1}{2^{23}\pi^{11}} \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{Q^2_{3,min}}^{Q^2_{3,max}} dQ_3^2$$

$$\int_{Q^2_{2,min}}^{Q^2_{2,max}} dQ_2^2 \quad \times \quad \int d\Omega_5 \frac{\sqrt{\lambda(M^2, Q^2, m_5^2)}}{M^2} \int d\Omega_4 \frac{\sqrt{\lambda(Q^2, Q_3^2, m_4^2)}}{Q^2}$$

$$\times \quad \int d\Omega_3 \frac{\sqrt{\lambda(Q_3^2, Q_2^2, m_3^2)}}{Q_3^2} \int d\Omega_2 \frac{\sqrt{\lambda(Q_2^2, m_2^2, m_1^2)}}{Q_2^2}$$

$$Q^2 = (q_1 + q_2 + q_3 + q_4)^2, \quad Q_3^2 = (q_1 + q_2 + q_3)^2, \quad Q_2^2 = (q_1 + q_2)^2$$

$$Q_{min} = m_1 + m_2 + m_3 + m_4, \quad Q_{max} = M - m_5 \; Q_{3,min} = m_1 + m_2 + m_3, \quad Q_{3,max} = Q - m_4$$

$$Q_{2,min} = m_1 + m_2, \qquad Q_{2,max} = Q_3 - m_3$$

- These formulas if used directly, are inefficient for a Monte Carlo algorithm if sharp peaks due to resonances in the intermediate states are present. The changes affect the program efficiency, but the actual density of the phase space remains intact. No approximations are introduced. (presamples needed for tests!!)

General formalism for semileptonic decays

- Matrix element used in TAUOLA for semileptonic decay. Similar, but easier life than in PHOKARA. No ISR, no NNLO R. Kleiss limitations. QED gauge invariance?

$$\tau(P,s) \to \nu_\tau(N)X$$
$$\mathcal{M} = \frac{G}{\sqrt{2}}\bar{u}(N)\gamma^\mu(v + a\gamma_5)u(P)J_\mu$$

- J_μ the current depends on the momenta of all hadrons.
- I can provide only prototypes for J_μ. Here TAUOLA must be open to experiment interior. difficult in mixed C++ Fortran sofware, and many colab.

$$|\mathcal{M}|^2 = G^2\frac{v^2+a^2}{2}(\omega + H_\mu s^\mu)$$
$$\omega = P^\mu(\Pi_\mu - \gamma_{va}\Pi^5_\mu), \qquad H_\mu = \frac{1}{M}(M^2\delta^\nu_\mu - P_\mu P^\nu)(\Pi^5_\nu - \gamma_{va}\Pi_\nu)$$
$$\Pi_\mu = 2[(J^*\cdot N)J_\mu + (J\cdot N)J^*_\mu - (J^*\cdot J)N_\mu]$$
$$\Pi^{5\mu} = 2\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma}J^*_\nu J_\rho N_\sigma, \qquad \gamma_{va} = -\frac{2va}{v^2+a^2}$$

- If τ coupling $v + a\gamma_5$ and $m_{\nu_\tau} \neq 0$ is allowed, one has to add to ω and H_μ:

$$\hat{\omega} = 2\frac{v^2-a^2}{v^2+a^2}m_\nu M(J^*\cdot J)$$
$$\hat{H}^\mu = -2\frac{v^2-a^2}{v^2+a^2}m_\nu\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma}J^*_\nu J_\rho P_\sigma$$

Leptonic (easy to arrange) and semileptonic decays.

- Complete first order QED corrections can be swithced on/off in $\tau \rightarrow e(\mu)\nu_\tau\nu$.
- In semileptonic modes, for up to 5 final state scalars, any current can be easily installed/remodelled. Proper treatment of the rest (phase space, spin, leptonic $\tau - \nu_\tau - W$ current) is assured. Thus many versions and organization constraints!
- For 6 pions or more flat space is only used so far.
- Spin treatment and program organization remain as usual.
- In total well over 20 distinct τ decay modes installed.
- 3 more or less complete versions of formfactors in authors hands: CLEO 1998 ALEPH (LEP1) and published CPC plus **MANY** additional special, often private cases!
- In semileptonic channels, PHOTOS is the only option for radiative corr..
- Such organization of the code is OK if non-factorizable electroweak corrrections of order $\frac{\alpha}{\pi}$ can be neglected.

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, B. Kersevan ,T. Pierzchala, E. Richter-Was, Z. Was, M. Worek, Comput.Phys.Commun.174:818-835,2006
3. J.H.Kuhn, Z. Was, hep-ph/0602162 (5-pions)

Also:

1. • Alain Weinstein www home page: http://www.cithep.caltech.edu/˜ajw/korb_doc.html#fi les
2. • B. Bloch, private communications.
3. R. Decker, M. Finkemeier, P. Heiliger and H.H. Jonsson, Z. Phys. C **70** (1996) 247, now standard 4π formfactors.
4. 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 alternative formf. in $K\pi\pi$ modes, hep-ex/9908013, Eur. Phys. J. **C13** (2000) 197.

Formfactors secret life

The studies within collaborations often rely on private form-factors, wealth of versions regularly created for general, or specific purposes. I have seen only some. Private collaboration codes.

MC-TESTER was developped to automate comparisons

- It was essential in our work on TAUOLA, and we expect it to be even more essential in the future, also for debugging.
- The same is true for our projects on PHOTOS developments.
- necessary tool for migration from Fortran to C++ (once requested).
- Also useful for debugging and comparing installation.
- Benchmark reference web page with root files exist.

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

Piotr Golonka   Tomasz Pierzchala   Zbigniew Was

May 22, 2004

Results from generator 1.

tauola-cleo starting point no modifications in any case `May 19 2004.`

- From directory:
`/home/wasm/y2004/TAUOLA-all/nowa-tauola/TAUOLA/tauola-old/demo-standalone/prod`
- Total number of analyzed decays: 5000000
- Number of decay channels found: 32

Results from generator 2.

tauola-cleo new version new channels installed, brs=*0.001 `May 22 2004.`

- From directory:
`/home/wasm/y2004/TAUOLA-all/nowa-tauola/TAUOLA/tauola-new/demo-standalone/prod`
- Total number of analyzed decays: 5000000
- Number of decay channels found: 32 + 8

1

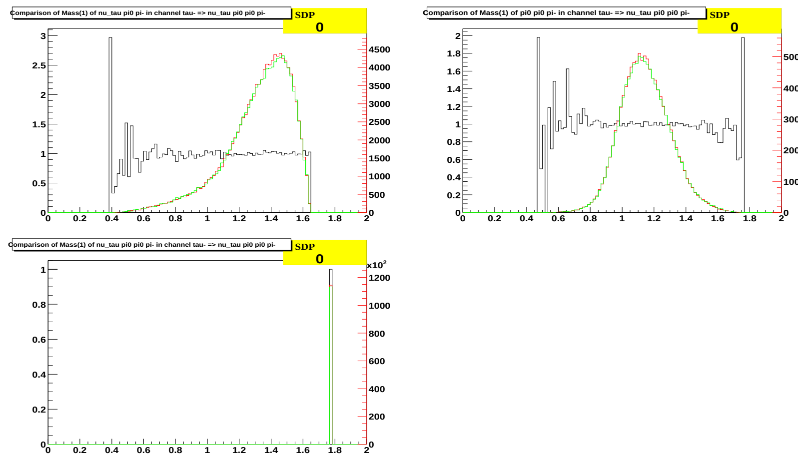
MC-TESTER booklet: Page 1. Run like for installation tests.

Found decay modes:

Decay channel	Branching Ratio ± Rough Errors Generator #1	Generator #2	Max. shape dif. param.
$\tau^- \to \nu_\tau K^-$	4.5460 ± 0.0095%	4.5500 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^0\pi^+\pi^-\pi^-$	4.5460 ± 0.0095%	4.5425 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^+\pi^+\pi^-\pi^-\pi^-$	4.5457 ± 0.0095%	4.5303 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^0\pi^0\pi^+\pi^-\pi^-$	4.5449 ± 0.0095%	4.5271 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^0\pi^0\pi^-$	4.5416 ± 0.0095%	4.5366 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^+\pi^-\pi^-$	4.5392 ± 0.0095%	4.5371 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \gamma\pi^0\pi^-$	4.5368 ± 0.0095%	4.5160 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^0 K^-$	4.5268 ± 0.0095%	4.5468 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^-\eta$	4.5236 ± 0.0095%	4.5154 ± 0.0095%	0.00000
$\tau^- \to \mu^-\tilde{\nu}_\mu\nu_\tau$	4.3942 ± 0.0094%	4.3919 ± 0.0094%	0.00000
$\tau^- \to e^-\tilde{\nu}_e\nu_\tau$	3.8276 ± 0.0087%	3.8245 ± 0.0087%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^0\pi^-$	2.2907 ± 0.0068%	2.2669 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau K^0_S K^-$	2.2832 ± 0.0068%	2.2582 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau \pi^0 K^0_L K^-$	2.2825 ± 0.0068%	2.2698 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau K^0_L K^-$	2.2795 ± 0.0068%	2.2725 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau \pi^0 K^0_L \pi^-$	2.2756 ± 0.0067%	2.2680 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau K^0_L \pi^- K^0_S$	2.2756 ± 0.0067%	2.2667 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau \pi^0 K^0_S K^-$	2.2717 ± 0.0067%	2.2606 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^- K^0_S$	2.2582 ± 0.0067%	2.2663 ± 0.0067%	0.00000
$\tau^- \to \nu_\tau \pi^+\pi^-\pi^-$	2.2449 ± 0.0067%	2.2822 ± 0.0068%	0.00000
$\tau^- \to \nu_\tau \pi^0 K^-$	1.5545 ± 0.0056%	1.5441 ± 0.0056%	0.00000
$\tau^- \to \nu_\tau \pi^- K^0_S$	1.5047 ± 0.0055%	1.4819 ± 0.0054%	0.00000
$\tau^- \to \nu_\tau K^0_L \pi^-$	1.5019 ± 0.0055%	1.4915 ± 0.0055%	0.00000
$\tau^- \to \nu_\tau \pi^- K^+ K^-$	4.5561 ± 0.0095%	4.5349 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^-$	4.5501 ± 0.0095%	4.5291 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^+\pi^- K^-$	4.5465 ± 0.0095%	4.5461 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^-$	4.5528 ± 0.0095%	4.5405 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau K^0_L K^0_L \pi^-$	1.1407 ± 0.0048%	1.1324 ± 0.0048%	0.00000
$\tau^- \to \nu_\tau \pi^0\pi^+\pi^+\pi^-\pi^-\pi^-$	4.5557 ± 0.0095%	4.5381 ± 0.0095%	0.00000
$\tau^- \to \nu_\tau \pi^- K^0_S K^0_S$	1.1340 ± 0.0048%	1.1404 ± 0.0048%	0.00000
$\tau^- \to e^-\tilde{\nu}_e\nu_\tau\gamma$	0.7181 ± 0.0038%	0.7164 ± 0.0038%	0.00000
$\tau^- \to \mu^-\tilde{\nu}_\mu\nu_\tau\gamma$	0.1507 ± 0.0017%	0.1489 ± 0.0017%	0.00000

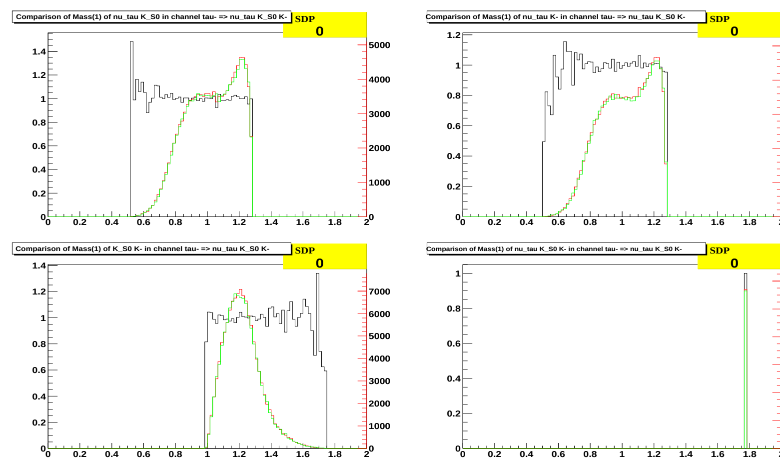
2

MC-TESTER booklet: Page 2. Run like for installation tests.



13 Decay Channel: $\tau^- \rightarrow \nu_\tau K^0_S K^-$

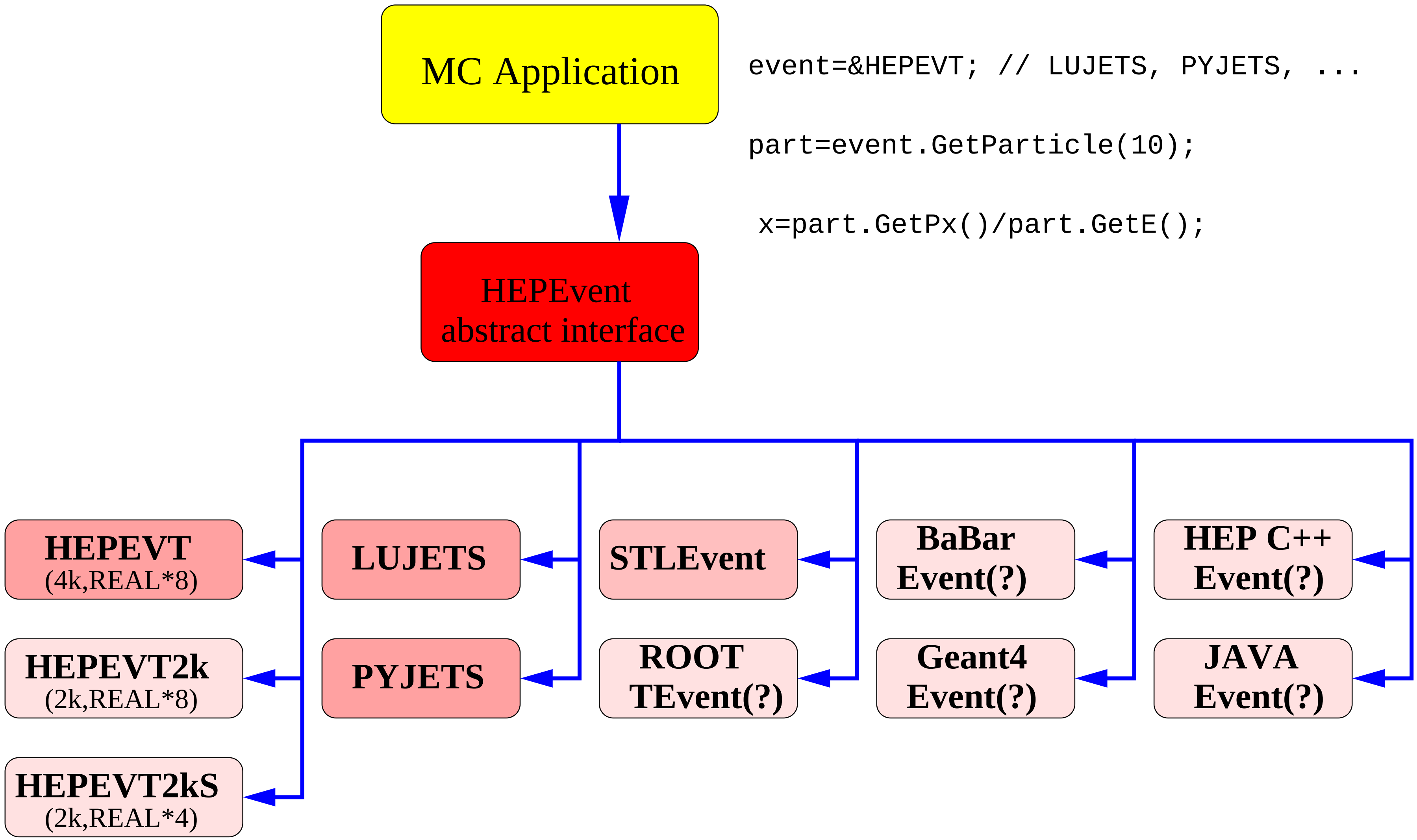
Number of events from generator 1: 114161
Number of events from generator 2: 112908



49

MC-TESTER booklet: Page 49. Run like for installation tests.

This tool can be used for any MC storing events in standard common blocks: HEPEVT, PYJETS, ... It may also be extended to adopt new event-record data-structures (i.e. in C++). Recent attempt to have standard: T. Sjostrand et al. A standard format for Les Houches Event Files, hep-ph/0609017. Is it going to be useful and accepted (this time)?




```
event=&HEPEVT; // LUJETS, PYJETS, ...

part=event.GetParticle(10);

 x=part.GetPx()/part.GetE();
```

Final states with 5-pions

J.H.Kuhn, Z. Was, Decays to Five Mesons in TAUOLA, hep-ph/0602162

For multitude of benchmark plots see: P. Golonka and Z.Was

http://annapurna.ifj.edu.pl/˜wasm/test-BBB.ps

- Simple current for $2\pi^-\pi^+2\pi^0$ decay mode saturated with the three decay chains

$\tau^- \to a_1^-\nu \to \rho^-(\to \pi^-\pi^0)\omega(\to \pi^-\pi^+\pi^0)\nu$,
$\tau^- \to a_1^-\nu \to a_1^-(\to 2\pi^-\pi^+)f_0(\to 2\pi^0)\nu$, and
$\tau^- \to a_1^-\nu \to a_1^-(\to \pi^-2\pi^0)f_0(\to \pi^+\pi-)\nu$.

- Similar amplitudes (no $\rho\omega$ contributions) are adopted for the $\pi^-4\pi^0$ and $3\pi^-2\pi^+$ modes.
- These decay modes were used for technical tests.
- But some physics output should be mentioned.
- It is important observation for algorithm construction
- Nasty effects due to Γ/M corrections to intermediate states saturated by resonances.
- In the table results of lines 1,2 should equal 3,4 and they do not.
- In the table results of lines 4 plus 5 should equal 6 and they do!

Interference can be constructive destructive or neutral.

No.	Final state	Current	$\Gamma_X/\Gamma_e \times 10^3$ (TAUOLA)	$\Gamma_X/\Gamma_e \times 10^3$ (experiment)	Γ_X/Γ_e (narrow width)
1	$2\pi^-\pi^+2\pi^0$	A ; no sym.	24.04 $\pm$0.1%	25 ± 3	–
2	$2\pi^-\pi^+2\pi^0$	B ; no sym.	9.28 x$\pm$0.1%	25 ± 3	–
3	$2\pi^-\pi^+2\pi^0$	A ; symetriz.	25.30 $\pm$0.1%	25 ± 3	–
4	$2\pi^-\pi^+2\pi^0$	B ; symetriz.	6.05 $\pm$0.2%	6.2 ± 2	2192 ± 22
5	$2\pi^-\pi^+2\pi^0$	A+B ; symetriz.	31.35 $\pm$0.1%	31 ± 2	–
6	$\pi^-4\pi^0$	B ; symetriz.	9.37 $\pm$0.1%	$5.5^{+3.4}_{-2.8}$	788 ± 4
7	$3\pi^-2\pi^+$	B ; symetriz.	11.03 $\pm$0.1%	4.6 ± 0.3	1469 ± 7

Table 2: *Test results of the generator for realistic choices of parameters; see the text of the paper. Note that interference between current A and B seem to be zero (or very small) for total rate. Nice result for modular arrangement of currents!*

Current A: $\tau^- \longrightarrow a_1^-\nu \longrightarrow \rho^-(\longrightarrow \pi^-\pi^0)\omega(\longrightarrow \pi^-\pi^+\pi^0)\nu$,

Current B: $\tau^- \longrightarrow a_1^-\nu \longrightarrow a_1^-(\longrightarrow \pi^-, \pi^-\pi^+(2\pi^0))f_0(\longrightarrow 2\pi^0(\pi^+\pi^-))\nu$.

Note factor $x = f(m_{\pi^0}, m_{\pi^\pm}, \ldots)\frac{3}{4}$, it complicates interpretation.

Warning from BaBar

The new current fi t better data than flat phase space

That is nearly the end of good news ...

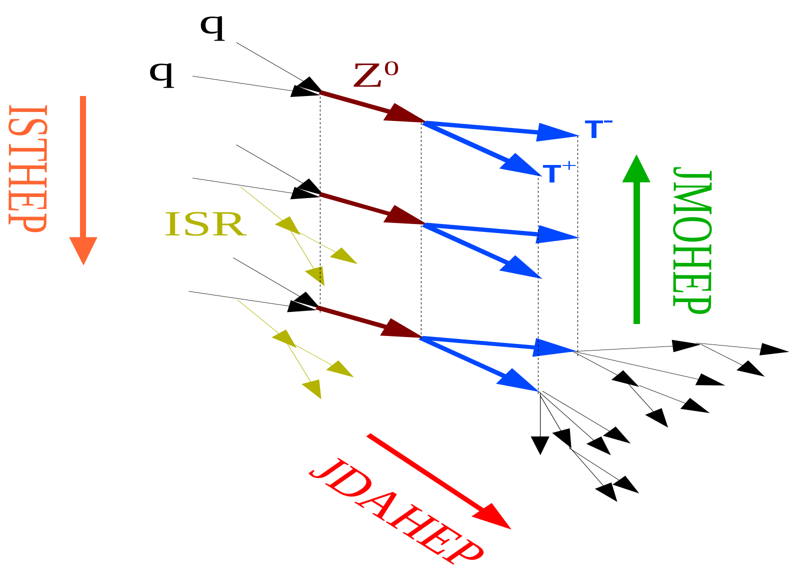
... except that frame is there.

Just picture need to be painted.

That is tough job for models and fitting:

counterintuitive interferences thresholds detector backgrounds etc.

less Problems With Event Record than for PHOTOS



1. Hard process
2. with shower
3. after hadronization
4. Event record overloaded with physics beyond design $\longrightarrow$ gramar problems.
5. Here we have basically LL phenomenology only.

This Is Physics Not F77!

Similar problems are in any use of full scale Monte Carlos, lots of complaints at MC4LHC workshop, `HEPEVTrepair` utility (C. Biscarat and ZW) being probed in D0.

Design of event structure WITH some grammar requirements AND WITHOUT neglecting possible physics is needed NOW to avoid large problems later.

TAUOLA universal interface

- **To run, generator for tau decays must be combined with the part for τ production: τ has long lifetime clear separation in spin states.**
- **In cases of our packages such as KORALB, KORALZ, KKMC host programs provide environment for TAUOLA use.**
- **TAUOLA universal interface reads information from HEPEVT common block, there τ leptons to be decayed are found,**
- **their spin states are calculated from kinematical configurations of hard processes producing τ's.**
- **At the end of the day event record should include information available from measurements only.**

Formalism for $\tau^+\tau^-$

- Because narrow τ width approximation can be obviously used for phase space , cross section for the process $f\bar{f} \to \tau^+\tau^- Y; \tau^+ \to X^+\bar{\nu}; \tau^- \to \nu\nu$ reads:

$$d\sigma = \sum_{spin} |\mathcal{M}|^2 d\Omega = \sum_{spin} |\mathcal{M}|^2 d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- This formalism is fine, but because of over 20 τ decay channels we have over 400 distinct processes. Also picture of production and decay are mixed.

- but (only τ spin indices are explicitly written):

$$\mathcal{M} = \sum_{\lambda_1\lambda_2=1}^{2} \mathcal{M}^{prod}_{\lambda_1\lambda_2}\; \mathcal{M}^{\tau^+}_{\lambda_1} \mathcal{M}^{\tau^-}_{\lambda_2}$$

- Formula for the cross section can be re-written

$$d\sigma = \Big(\sum_{spin} |\mathcal{M}^{prod}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^+}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^-}|^2\Big) wt\; d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- where

$$wt = \Big(\sum_{i,j=0,3} R_{ij} h^i h^j \Big)$$

$$R_{00} = 1, \quad < wt >= 1, \quad 0 \leq wt \leq 4.$$

R_{ij} can be calculated from $\mathcal{M}_{\lambda_1 \lambda_2}$
and h^i, h^j respectively from $\mathcal{M}^{\tau^+}$ and $\mathcal{M}^{\tau^-}$.

- Bell inequalities tell us that it is impossible to re-write wt in the following form

$$wt \neq \Big(\sum_{i,j=0,3} R_i^A h^i \Big) \Big(\sum_{i,j=0,3} R_j^B h^j \Big)$$

that means it is impossible to generate first τ^+ and τ^- first in some given ‘ quantum state’ and later perform separatelly decays of τ^+ and τ^-

- It can be done only if approximations are used !!!
- May be often reasonable, but nonetheless approximations.
- As a matter of fact observables for CP parity measurements are NOT reasonable.

CP in $B \to \tau^+\tau^-$ decays

1. I should mention Piotr H. Chankowski et al. ‘CP violation in $B^0(d) \to \tau^+\tau^-$ decays, Nucl. Phys. B **713** (2005) 555.
2. It is an excellent example of use of TAUOLA universal interface.
3. Unfortunately the decay channel is not discovered yet ...
4. So it is probably wise to skip the subject now.
5. May be until discoverey of Higgs next fall?

Summary

- *We have reviewed news on the following tools for simulation of τ physics:*
  - *TAUOLA as generator for τ decays: aspects and constraints for fits, decays into 5 scalars*
  - *benchmark distribution strategies and MC-TESTER*
- *We have mentioned problems with shifting to C*
  - *stability of C++ event records*
  - *encapsulation and inconvenience for end users.*

$\mathcal{F}$uture

- **TAUOLA and associated programs seem to be a living project**
- **As in the past different parametrizations will be developed within collaborations. Also, as in the past, will function as private code. Huge machinery.**
- **Some "cross talk" with PHOKARA and e^+e^-.**
- **Non-tau experiments like LHC may profit.**
- **We have prepared, updated TAUOLA version, with open slots for many new channels, also with possible spin effects for 5 scalars final states (our paper is mainly technical test).**
- **Manpower and coordination. Struggle with priorities...**
- **Fortran to C++ shift is mainly community issue, technicaly it is not a problem.**