Tauola and Photos –

general description

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Main Topics:

- **TAUOLA**
- **PHOTOS**
- **Pointers to other talks.**

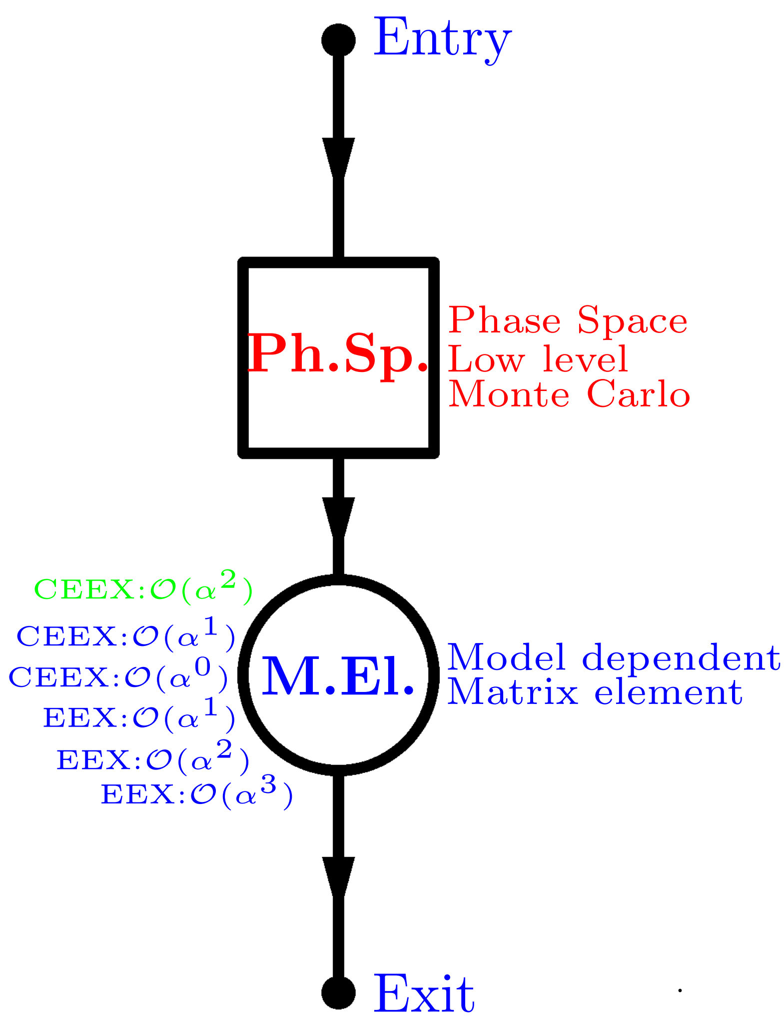
These and related slides/programs can be found from http://home.cern.ch/wasm

Basic structure

and assumptions

- **Phase space.**
- **Matrix element**
- **Electroweak vertex.**
- **Leptonic decays:** $\tau \to e(\mu)\nu_\tau\nu(\gamma)$**.**
- **Semileptonic decays: Hadronic current.**
- **Spin treatment, details delegated to tomorrow.**
- **Feedback from collaborations.**

Textbook principle "matrix element $\times$ full phase space" ASSUMED



In the Monte Carlo realization it means that:

- Universal Phase-space Monte Carlo simulator is a separate module producing "raw events" (including importance sampling for possible intermediate resonances)
- Library of several types of hadronic currents provides input for "model weight" which is another independent module
- Electroweak vertex $\tau - \nu_\tau - W$ is a separate sub-part of calculation of the "model weight"
- Caluclation of weights involving anomalous couplings come after of course; approximations are used there.
- This is exactly like in case of KORALZ or KKMC.

General formalism for semileptonic decays

- 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 formula 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.

General formalism for semileptonic decays

- Matrix element used in TAUOLA for semileptonic decay

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

- J_μ the current depends on the momenta of all hadrons

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

- If a more general coupling $v + a\gamma_5$ for the τ current and ν_τ mass $m_\nu \neq 0$ are expected to be used, one has to add the following terms 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 and semileptonic decays.

- Complete first order QED corrections can be swithced on/off in $\tau \to e(\mu)\nu_\tau \nu$.
- For double bremsstrahlung effects PHOTOS can be used instead. Like in semileptonic channels.
- In semileptonic modes, for up to 5 final state scalars, any current can be easily installed/remodelled with automatic proper treatment of the rest (phase space, spin, leptonic $\tau - \nu_\tau - W$ current) assured. Thus many versions !
- For 6 pions or more flat space was only used so far.
- Spin treatment will be discussed tomorrow.
- In total well over 20 distinct τ decay modes installed.
- 3 versions of formfactors in authors hands CLEO 1998 ALEPH (lep1) and 'published CPC.
- 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.Ježabek, 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

Comparison between different parameterizations

- Version of comparison of CLEO and new Novosibirsk current in TAUOLA. The ω contribution in an old CLEO current is scaled down from *68* % to *40* %.

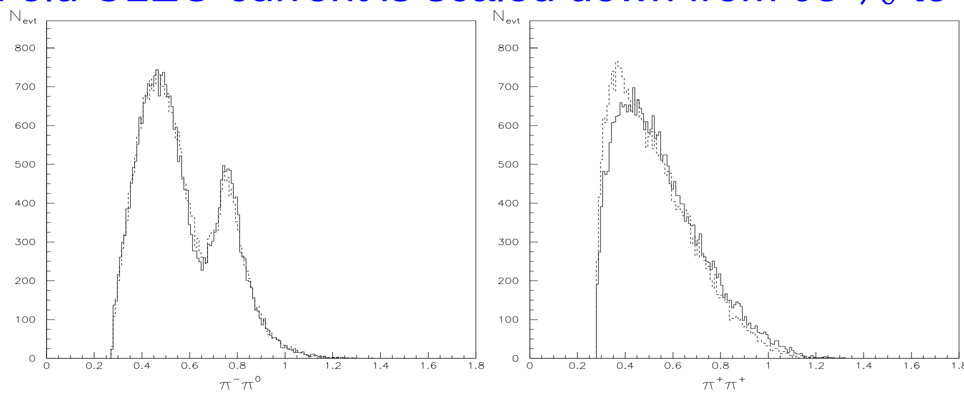


Figure 3: *The* $\bar{\nu}_\tau \pi^+\pi^+\pi^-\pi^0$ *channel. The Left-hand side plot* $\pi^-\pi^0$ *invariant mass distribution, right-hand side plot* $\pi^+\pi^+$ *invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*

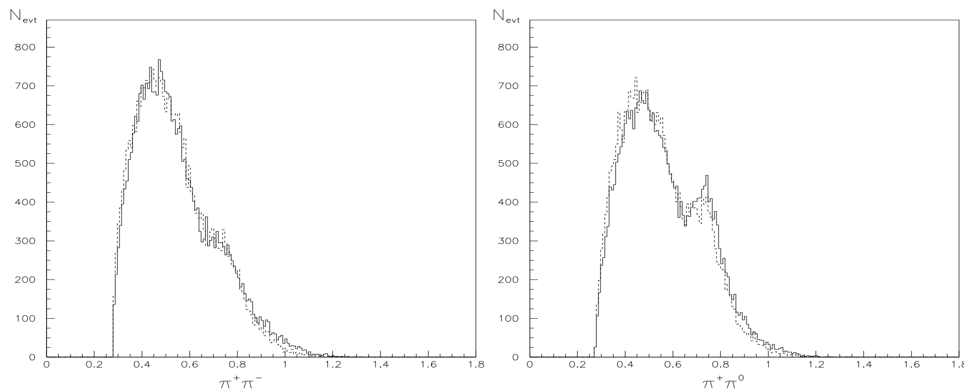
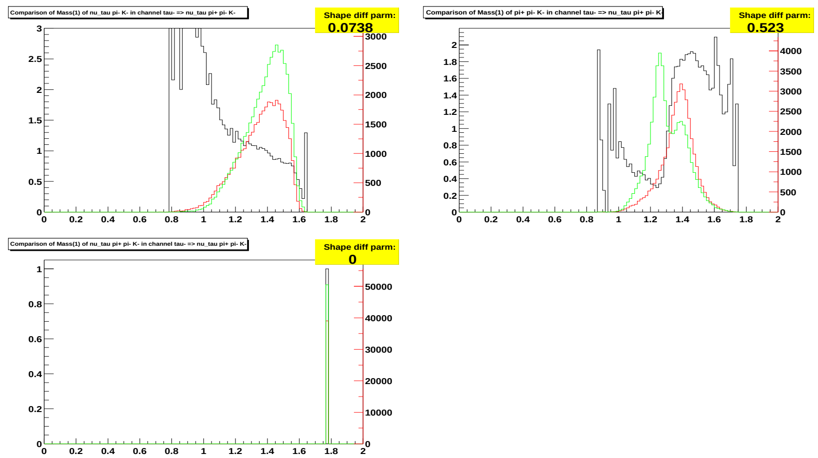
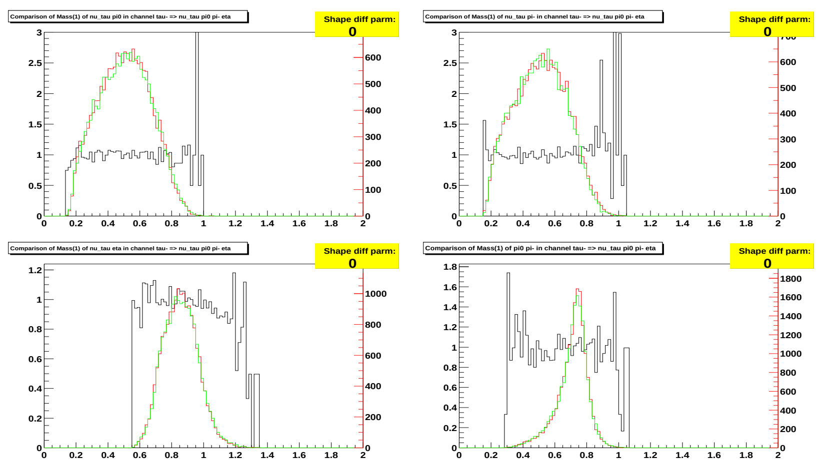


Figure 4: *The* $\bar{\nu}_\tau \pi^+\pi^+\pi^-\pi^0$ *channel. The Left-hand side plot* $\pi^+\pi^-$ *invariant mass distribution, right-hand side plot* $\pi^+\pi^0$ *invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*



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



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See talk by Piotr later today

Basic structure

and assumptions

- Starting point.
- Phase space.
- Matrix element.
- HEPEVT searches.
- Interference corrections.
- Double bremsstrahlung.
- Special cases of correction weights.
- Design precision and benchmarks.

PHOTOS

E. Barberio, B. van Eijk, Z. Was, Comput. Phys. Commun. (1991) ibid. (1994)

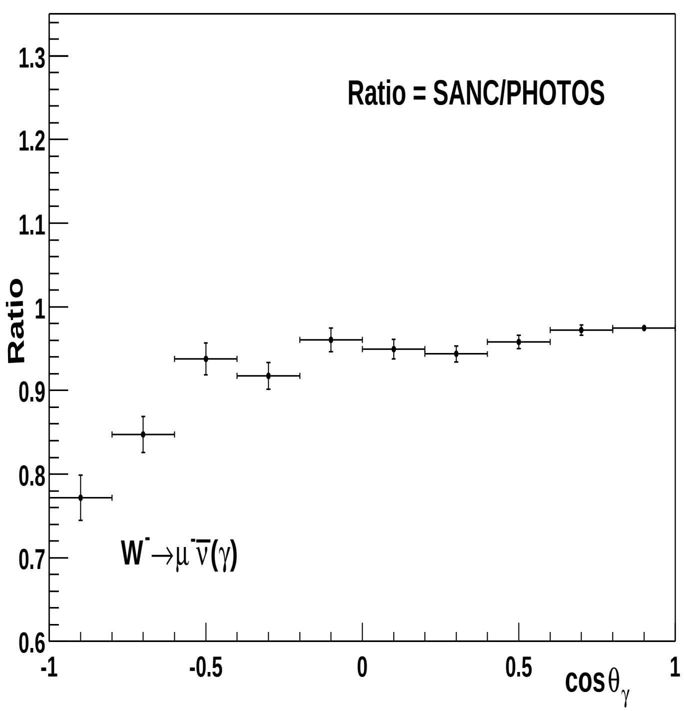
- It was developped as single photon emission. starting from MUSTRAAL (F. Berends, R. Kleiss, S. Jadach, Comput. Phys. Commun. (1982)) final state bremsstrahlung only, then effectively for Z decay.
- Factorization of phase space for photonic variables and two-body decay phase space was studied.
- The same was studied for matrix element.
- Then the algorithm was re-written to have a form of generator of 2 body decay $Z \to \mu^+\mu^-$ and subsequent 'photon emision event modificator"
- The two emission kernels where still dependent on hard process angle.
- To have process independent emission algorithm approximation affecting non-leading terms were introduced.
- Effects of interference between emission from μ^+ and μ^- was lost and re-introduced with approximation.

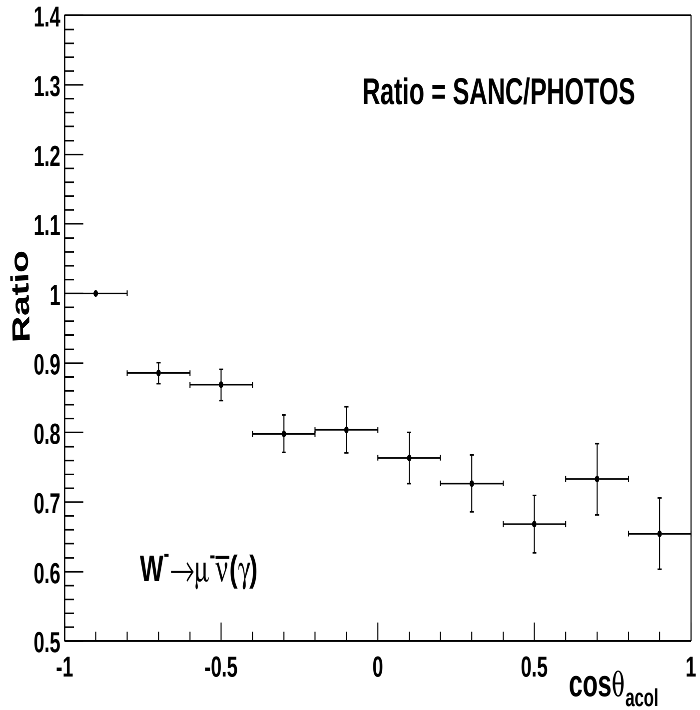
PHOTOS

- Thus it is bound to be not better than LL (may be NLL), at least in principle.
- Algorithm was however extended to work for the decay of 'any' particle or resonance.
- It heavily uses mother-daughter relations in HEPEVT' Algorithm searches over whole event records and if allowed may add bremsstrahlung emission at any branching. Appropriatelly modifying particles momenta !
- Algorithm is vulnerable on the way *how* HEPEVT is filled in. Any new inconistency and ...
- Later (1994) double bremsstrahlung emission was added, also correction terms, to improve limit of bremsstrahlung in decay into heavy particles was added
- Safety backup: Comparisons with M.E. Monte Carlos whenever available; cases of single and double bremstrahlung:
- $\tau \to e\nu\bar{\nu}(\gamma)$, $\tau \to \pi\nu(\gamma)$, $Z \to \mu^+\mu^-(\gamma)(\gamma)$, $gg \to t\bar{t}(\gamma)(\gamma)$ ...
- Program is *shy* on hadronic initial state interactions, does not depend on the way how they are installed generated, that is why convenient e.g. in case of W or t production and decay in protron colliders.

In many cases tests are not available, even though framework is there ..., let us provide one example for $W^\pm \to l^\pm\nu$ decay.

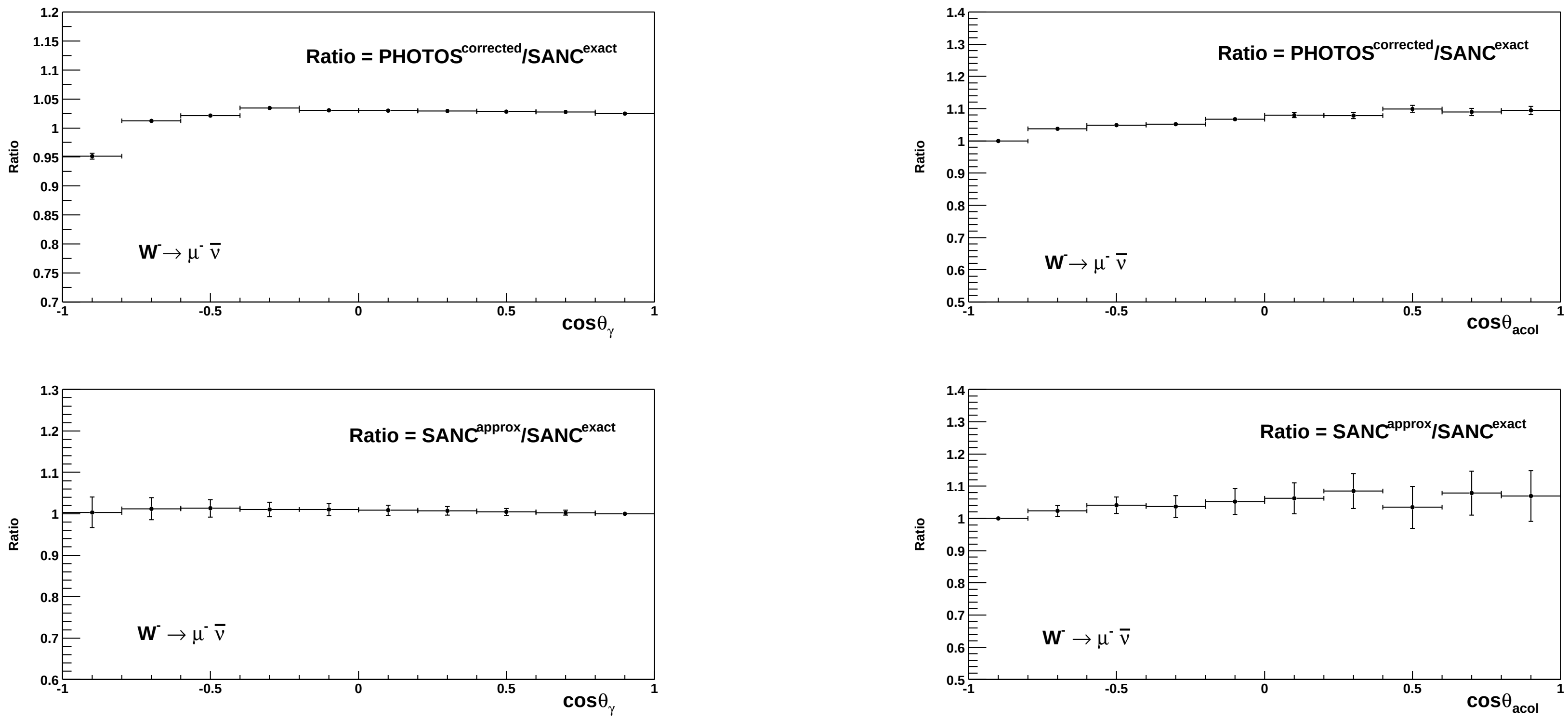
$W \to l\nu$ PHOTOS vs. Matrix Element, test





Comparisons (ratios) of the SANC *and* PHOTOS *predictions for the W decay. Observables* **C** *and* **D***: ratios of the photon angle with respect to μ^- (left-hand side) and $\mu^- \mu^+$ acollinearity (right-hand side) distributions from the two programs. The dominant contribution is of infrared non-leading-log nature for the left-hand side plot, and non-infrared non-leading-log nature for the right-hand side one. From paper by D. Bardin et al..*

$W \to l\nu$ PHOTOS vs. Matrix Element, test and improvement



Comparisons (ratios) of the complete SANC and corrected PHOTOS *predictions for the* W *decay. Observables* **C** *and* **D***: ratios of the photon angle with respect to* μ^- *(left-hand side) and* $\mu^- \bar{\nu}$ *acollinearity (right-hand side) distributions from the two programs. The dominant contribution is of infrared non-leading-log nature for the left-hand side plot, and non-infrared non-leading-log nature for the right-hand side one. In the lower part of the plots similar comparisons for the complete* SANC *and truncated–corrected with* δ SANC *predictions are given. From paper by G. Nanawa and Z. Was.*

Basic structure

and assumptions

- Internal issues related to TAUOLA were presented.
- Internal issues related to PHOTOS were presented.
- Testing tool for the package will be presented today by P. Golonka
- How the interface of TAUOLA work, and how it uses information from HEPEVT common block will be presented tomorrow by Malgorzata Worek, in particular spin sensitive distributions will be shown.
- Practical issues related to the way how HEPEVT common block is filled in 3 versions of PYTHIA conventions and also HERWIG will be adressed by Borut Kersevan, also tomorrow.