TAUOLA as tau Monte Carlo

for future applications

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Main Topics:

- **TAUOLA technicalities and its relation to data.**
- **PHOTOS for radiative correction in decays.**
- **MC-TESTER for automated comparisons.**
- **universal interface of TAUOLA.**
- **application for Higgs boson parity measurement at LC.**
- **Plans for future, coordination.**
- **Summary**

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

Also TAU06 will bring lot of tau data

for that purpose

I will concentrate on technical properties of MC's Having in mind necessary changes

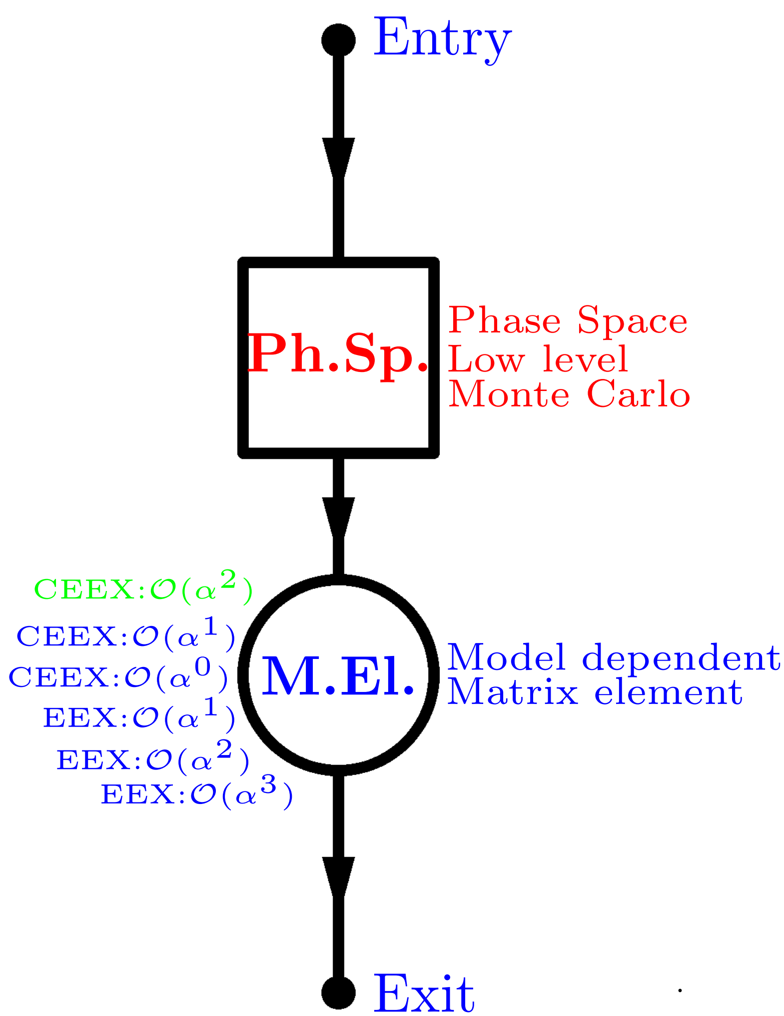
- New software configurations
- New applications
- C++ or may be not?
- Now it is time to review old solutions.
- Review recent developments
- Propose changes for future ...
- manpower issues.
- Feedback !!!!

TAUOLA: 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.**

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 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.

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 multiphoton bremsstrahlung PHOTOS can be used instead to check. In semileptonic channels, PHOTOS is the only option.
- 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 !
- For 6 pions or more flat space is only used so far.
- Spin treatment will be discussed later, on decay side H_μ are defined.
- 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 additional special cases!
- 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 (hep-ph/0312240), technical stuff mainly.

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, 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 were often relying on refits of form-factors, many versions were/are regularly created for more general, or specific purposes. I have seen only some of them.

Comparison of different parameterizations

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

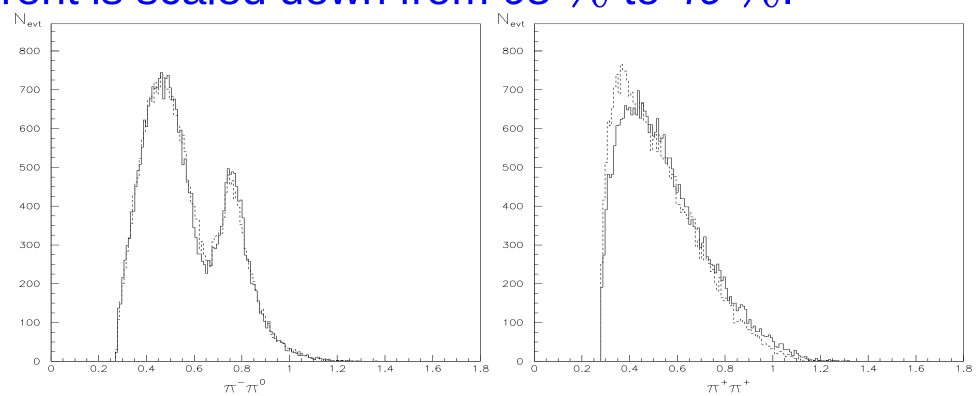


Figure 3: *The $\bar{\nu}_\tau\pi^+\pi^+\pi^-\pi^0$ channel. The Left-hand side plot $\pi^-\pi^0$ invariant mass distribution, right-hand side plot $\pi^+\pi^+$ invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*

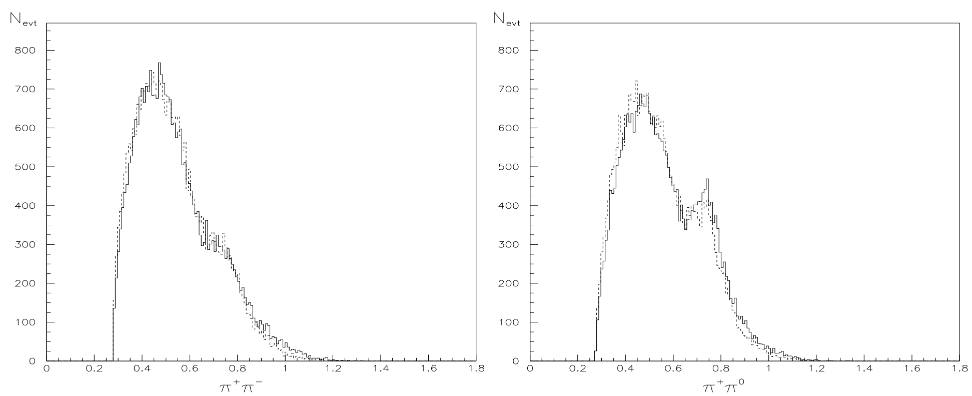


Figure 4: *The $\bar{\nu}_\tau\pi^+\pi^+\pi^-\pi^0$ channel. The Left-hand side plot $\pi^+\pi^-$ invariant mass distribution, right-hand side plot $\pi^+\pi^0$ invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*

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.
- The same is true for projects on PHOTOS developments.
- necessary tool for migration from Fortran to C++ (if requested).
- We will come to this tool later.

PHOTOS

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

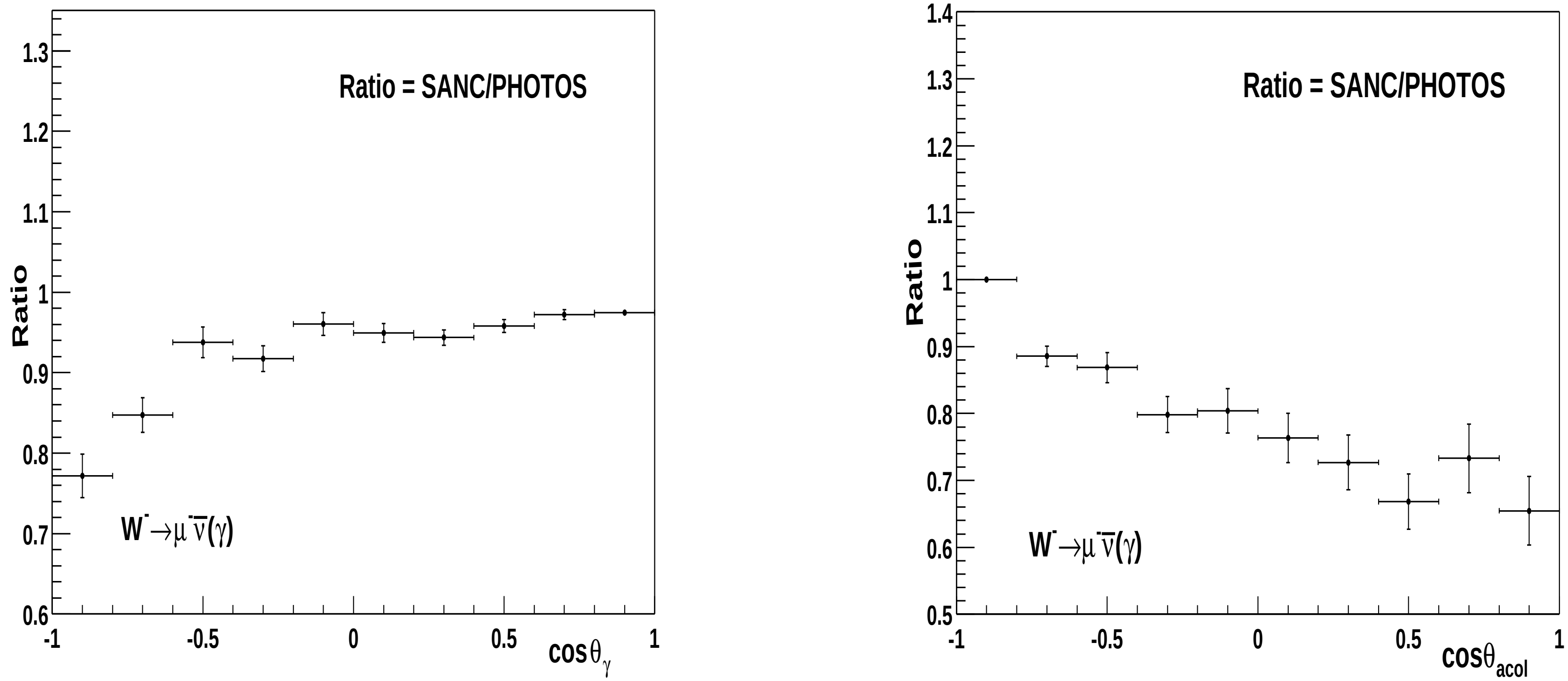
See also: P. Golonka et al. hep-ph/0312240

- It was developed as single photon emission. starting from MUSTRAAL (F. Berends, R. Kleiss, S. Jadach, Comput. Phys. Commun. (1982)) option for final state bremsstrahlung in Z decay only.
- 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 “photon emision event modificator” acting on previously generated events.
- The two kernels for emission where still dependent on hard process angle.
- To have process independent emission algorithm approximations affecting non-leading terms were introduced.
- Effects of interference between emission from μ^+ and μ^- were lost and re-introduced with approximation.
- The algorithm of the antenna type was created.

PHOTOS

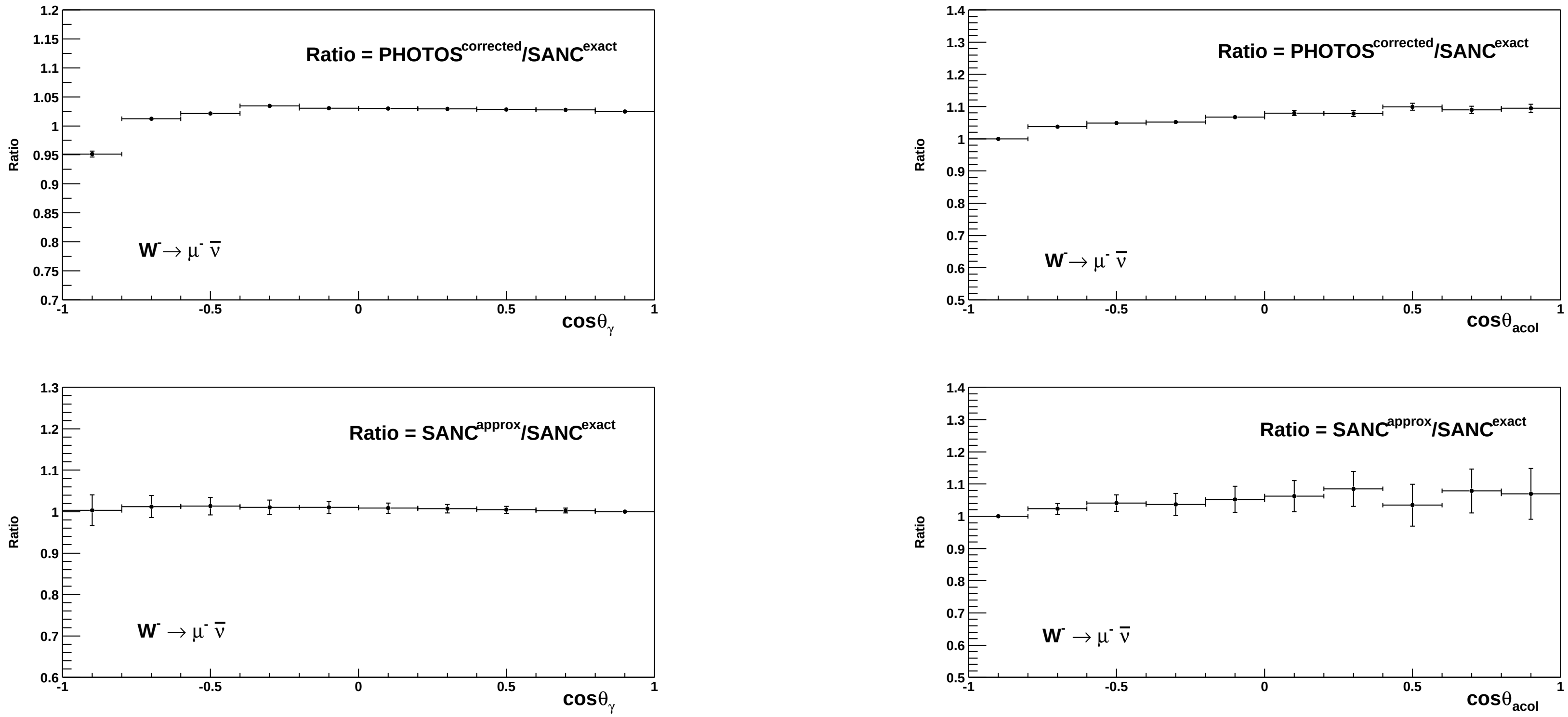
- To retain universal kernels PHOTOS (in principle), is not better than LL, improved with correct soft photon limit. Now it is true to all orders!
- Improvements beyond that point require special weights or at least comparisons with M.E. Monte Carlos like in cases:
- $\tau \to e\nu\bar{\nu}(\gamma)$, $\tau \to \pi\nu(\gamma)$, $Z \to \mu^+\mu^-(\gamma)(\gamma)$, $gg \to t\bar{t}(\gamma)(\gamma)$ ...
- PHOTOS uses mother-daughter relations in **HEPEVT**.
- C++ version is prepared but not yet distributed • Algorithm searches over the whole event record and may add bremsstrahlung emission at any branching.
- Appropriately modifies particles momenta of the whole cascade!
- Algorithm is vulnerable on the way *how* HEPEVT is filled in. Any new inconistency and ...
- In 1994 double bremsstrahlung emission was added, and improvements for decays into heavy particles were made.
- In 2003 improvements for W decay • In 2004 possibility of more than double photon emission (arbitrary number of photons)
- Lot of numerical tests.

$W \to l\nu$ Old PHOTOS vs. Matrix Element.



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. Example: correcting weight.



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.*

A lot of tests for W and Z decays with radiative corrrections are available at:

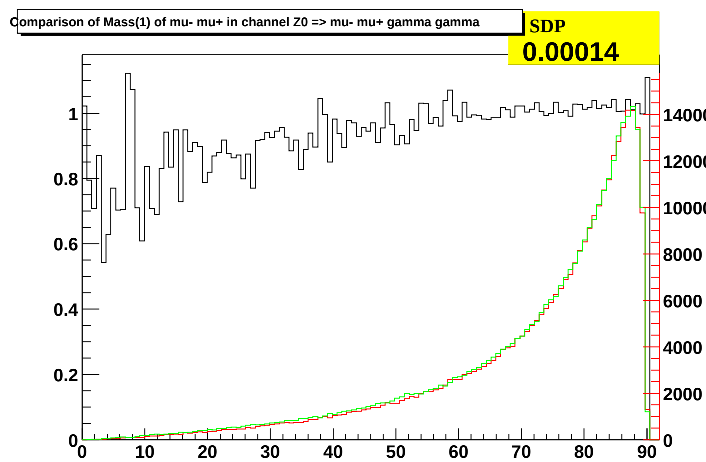
http://cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER

Hard bremsstrahlung in KK and PHOTOS - results

Comparison of KK and PHOTOS.
in Z->mu mu + bremsstrahlung process at Z mass

GENERATOR	Branching ratio					Maximum SDP					T1		T2		Booklet	
	test1		test2			test1		test2			test1	test2	test1	test2	test1	test2
(n photons) ->	0	1	0	1	2	0	1	0	1	2						
E_test=5.0																
KK			**91.672**	**8.037**	**0.290**											
KORAL-Z			91.739	7.980	0.281			0	0.0023	0.0009		0.132		0.018		
PHOTOS O(2)			91.593	8.087	0.320			0	0.0048	0.0136		0.157		0.041		
PHOTOS O(3)			91.584	8.115	0.301			0	0.0048	0.0028		0.175		0.039		
PHOTOS O(4)			91.581	8.117	0.302			0	0.0045	0.0029		0.181		0.036		
PHOTOS EXP																
E_test=1.0																
KK	**83.918**	**16.082**	**83.918**	**14.816**	**1.266**											
KORAL-Z	83.984	16.016	83.984	14.771	1.244	0	0.00208	0	0.00123	0.00124	0.133	0.133	0.033	0.019		
KORAL-Z O(1)	82.514	17.486				0	0.037				2.807		0.621			
PHOTOS O(1)	82.362	17.638				0	0.0314				3.111		0.528			
PHOTOS O(2)	83.925	16.075	83.925	14.630	1.445	0	0.0067	0	0.0035	0.0122	0.016	0.373	0.107	0.065		
PHOTOS O(3)	83.832	16.168	83.832	14.889	1.280	0	0.0038	0	0.0025	0.0080	0.172	0.172	0.061	0.046		
PHOTOS O(4)	83.836	16.164	83.836	14.871	1.293	0	0.0040	0	0.0027	0.0058	0.163	0.163	0.0635	0.045		
Preliminary results, to be replaced, because od slight inconsistency in input. Irrellevant for conclusions.																
PHOTOS EXP			83.77	14.92	1.31			0	0.00009	0.00014		0.151		0.0015		

A table on the left points to booklets with thousands of plots like the one below. This one presents the invariant of largest discrepancy between PHOTOS EXP and KKMC in Z decays. Events are referred to as 0, 1 or 2 photon configurations, when 0 1 or at least 2 photons with energy above E_{test} are present.



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

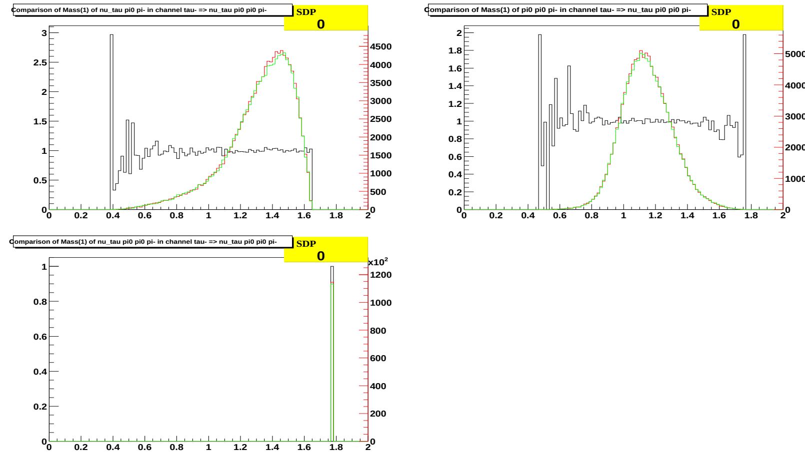
MC-TESTER booklet: Page 1

Found decay modes:

Decay channel	Branching Ratio ± Rough Errors		Max. shape dif. param.
	Generator #1	Generator #2	
$\tau^- \to \nu_\tau K^-$	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

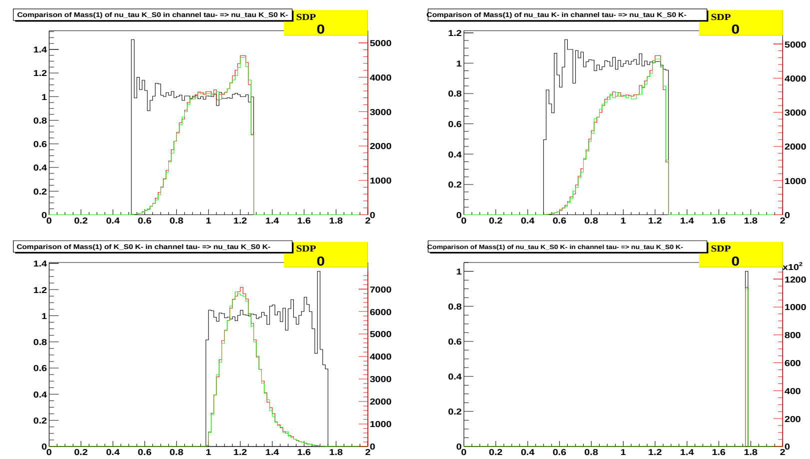
2

MC-TESTER booklet: Page 2



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

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



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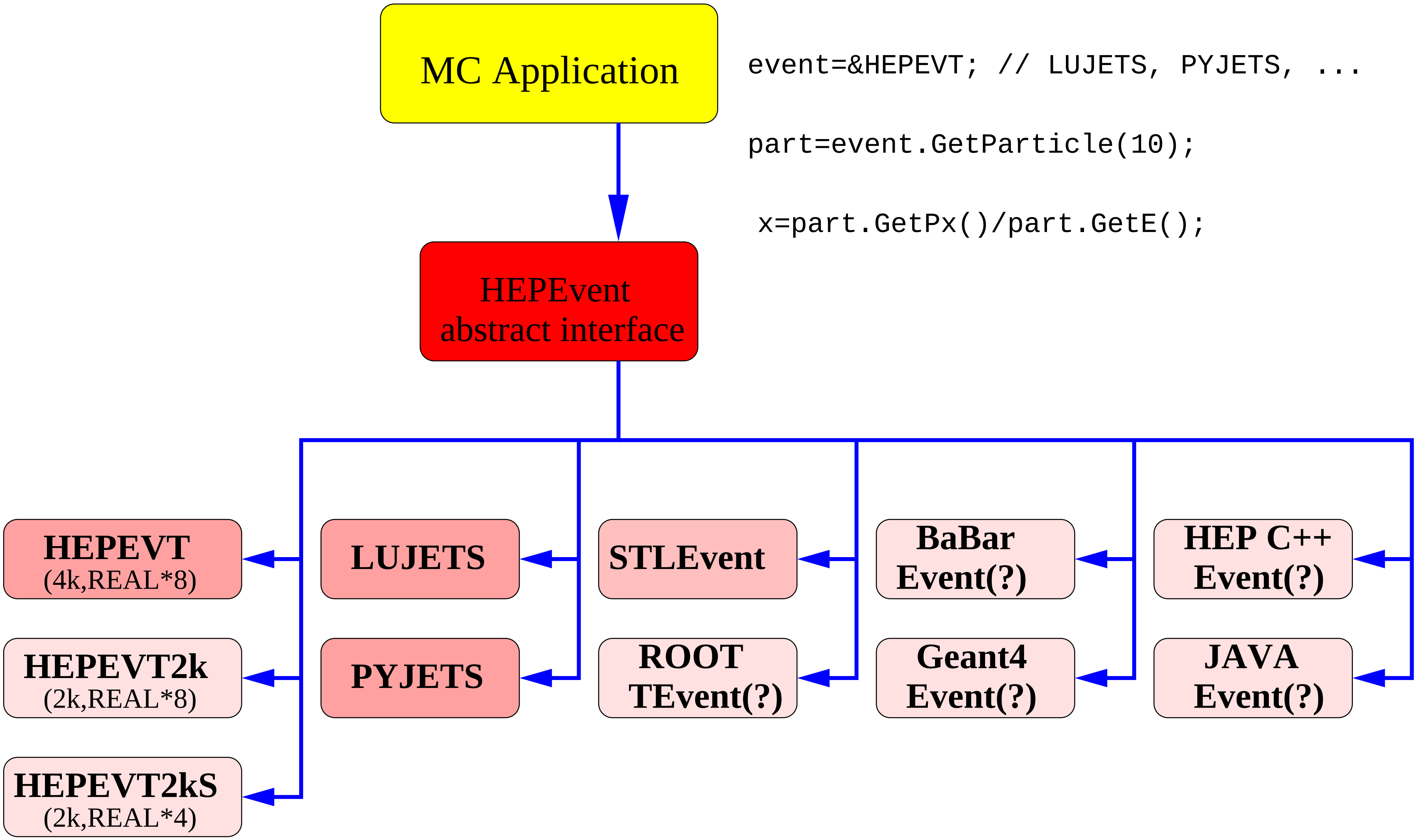
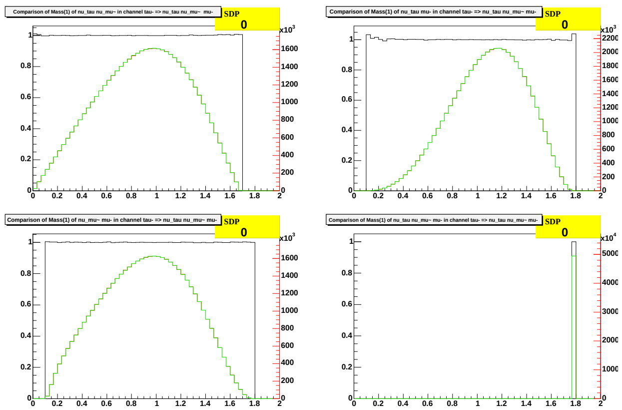
MC-TESTER booklet: Page 49

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++).



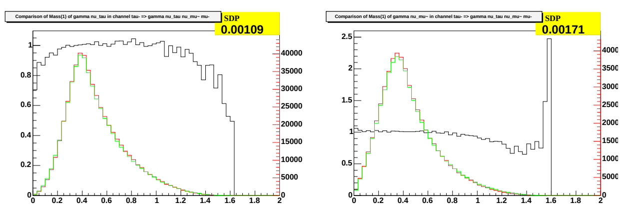
1 Decay Channel: $\tau^- \rightarrow \nu_\tau \tilde{\nu}_\mu \mu^-$

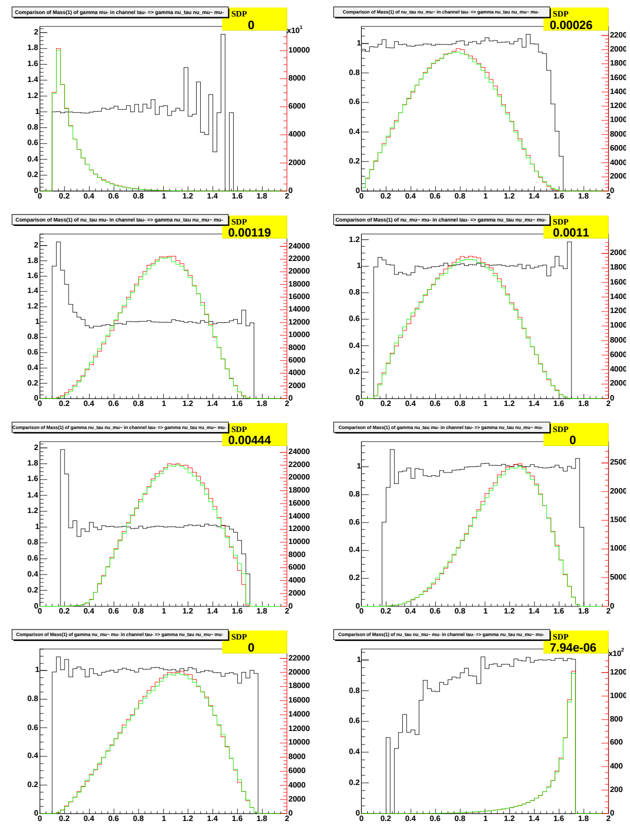
Number of events from generator 1: 49457885
Number of events from generator 2: 49463385



2 Decay Channel: $\tau^- \rightarrow \gamma \nu_\tau \tilde{\nu}_\mu \mu^-$

Number of events from generator 1: 542115
Number of events from generator 2: 536615

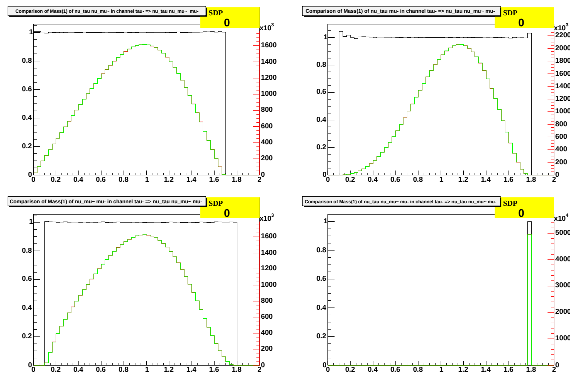




What is better for $\tau \rightarrow \mu\nu\bar{\nu}$? Bremstrahlung corrections from TAUOLA-ME and PHOTOS O(1) Largest SDP=0.00444.

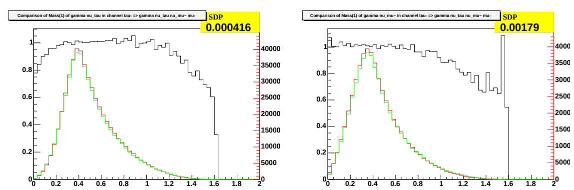
1 Decay Channel: $\tau^- \to \nu_\tau \tilde{\nu}_\mu \mu^-$

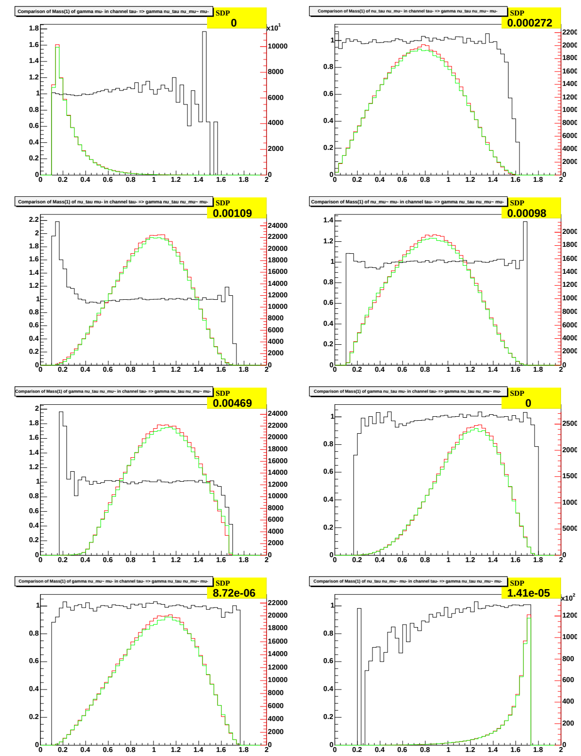
Number of events from generator 1: 49457885
Number of events from generator 2: 49467609



2 Decay Channel: $\tau^- \to \gamma \nu_\tau \tilde{\nu}_\mu \mu^-$

Number of events from generator 1: 542115
Number of events from generator 2: 532391





What is better for $\tau \to \mu\nu\bar{\nu}$? Bremstrahlung corrections from TAUOLA-ME or PHOTOS O(EXP) ? SDP=0.00469. We may conclude that for this channel complete ME is more important than higher orders.

TAUOLA universal interface

- To run, generator for tau decays must be combined with the part for tau production.
- In cases of our packages such as KORALB, KORALZ, KKMC host programs provide environment for TAUOLA use.
- I will concentrate on physics points in case when only information from event records is used.
- I will skip technicalities related to the way how HEPEVT common block is filled in 3 versions of PYTHIA conventions and HERWIG.
- also I will skip new developments in domain of event records.
- TAUOLA universal interface reads information from HEPEVT common block, there τ leptons to be decayed are found,
- and their spin states are calculated from kinematical configurations of hard processes leading to τ's.

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.

Main References for Higgs Boson Parity At The Linear Collider

- T. Pierzchala, E. Richter-Was, Z. Was and M. Worek, Acta Phys. Polon. B **32** (2001) 1277
- Z. Was and M. Worek, Acta Phys. Polon. B **33** (2002) 1875
- G. R. Bower, T. Pierzchala, Z. Was and M. Worek, Phys. Lett. B **543** (2002) 227
- K. Desch, Z. Was and M. Worek, Eur. Phys. J. C **29** (2003) 491
- K. Desch, A. Imhof, Z. Was and M. Worek, Phys. Lett. B **579** (2004) 157

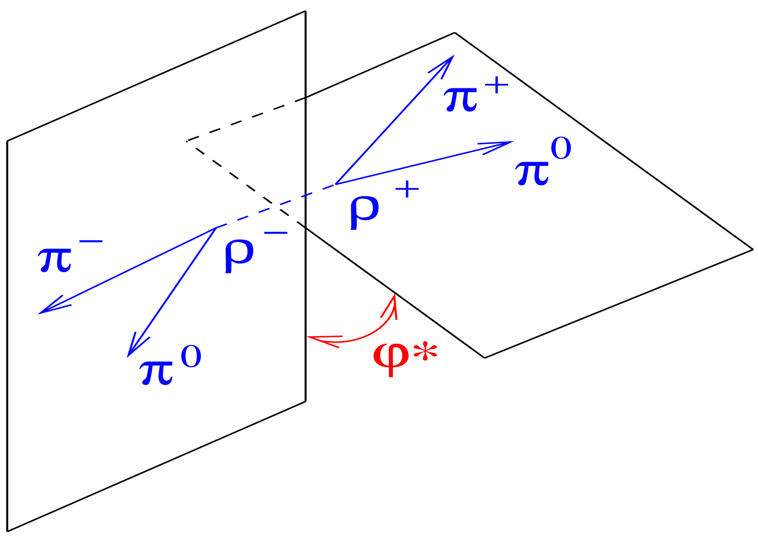
Pure Scalar And Pseudoscalar Higgs Boson

- Case of $\tau \to \rho\nu_\tau$ decay, $\mathcal{BR}(\tau \to \rho\nu_\tau) = 25\%$
- In def. of polarimeter vector h^i q denotes 4-vectors of $\pi^\pm$ minus π^0 and, N of ν_τ.

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

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

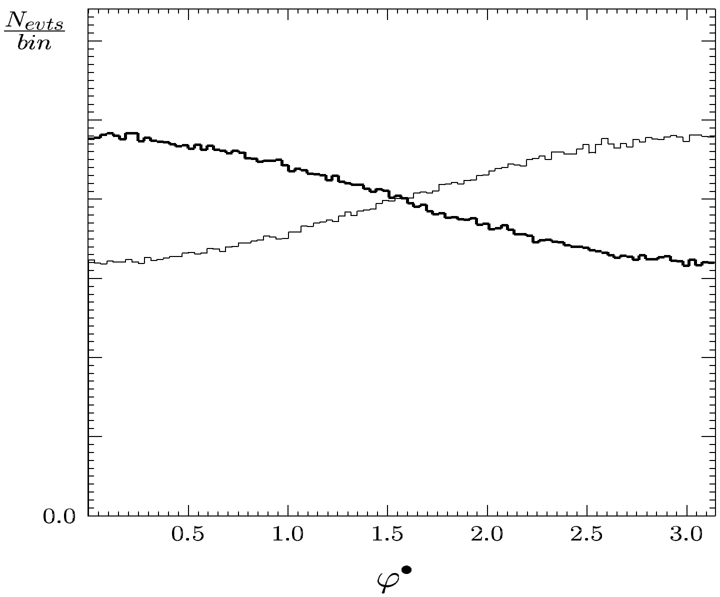
- Acoplanarity of ρ^+ and ρ^- decay prod. (in $\rho^+\rho^-$ r.f.) and events separation.

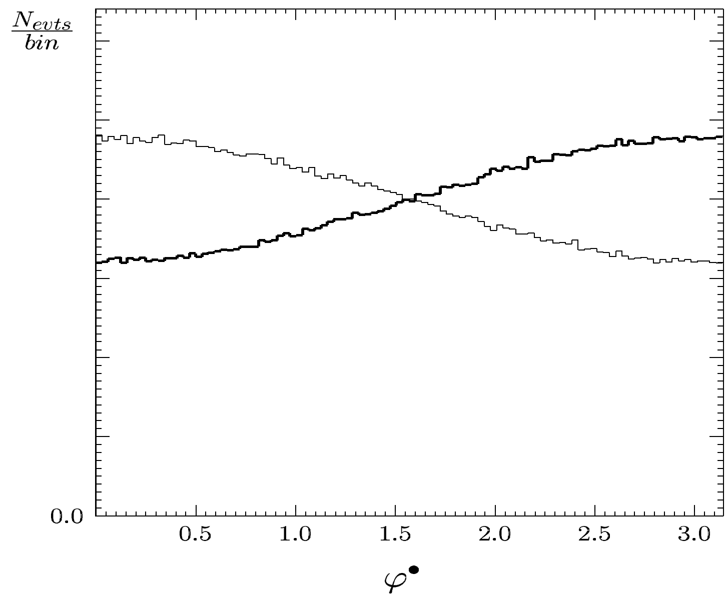


$$y_1 y_2 > 0\,; \qquad y_1 y_2 < 0 \text{ (in } \tau^\pm \text{ r.f.'s)}$$

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

Results With Detector Effects





- *Gaussian spreads of the 'measured' quantities with respect to the generated.*
- *Resolutions verified with SIMDET. Replacement $\tau^{\pm}$ r.f.'s were used for $y_{1,2}$.*
- *Clearly distinguish the different parity states $-$ 3σ effect (0.5 ab^{-1}).*

$e^+e^- \to ZH \to \mu^+\mu^- H$

$m_H = 120\ GeV$

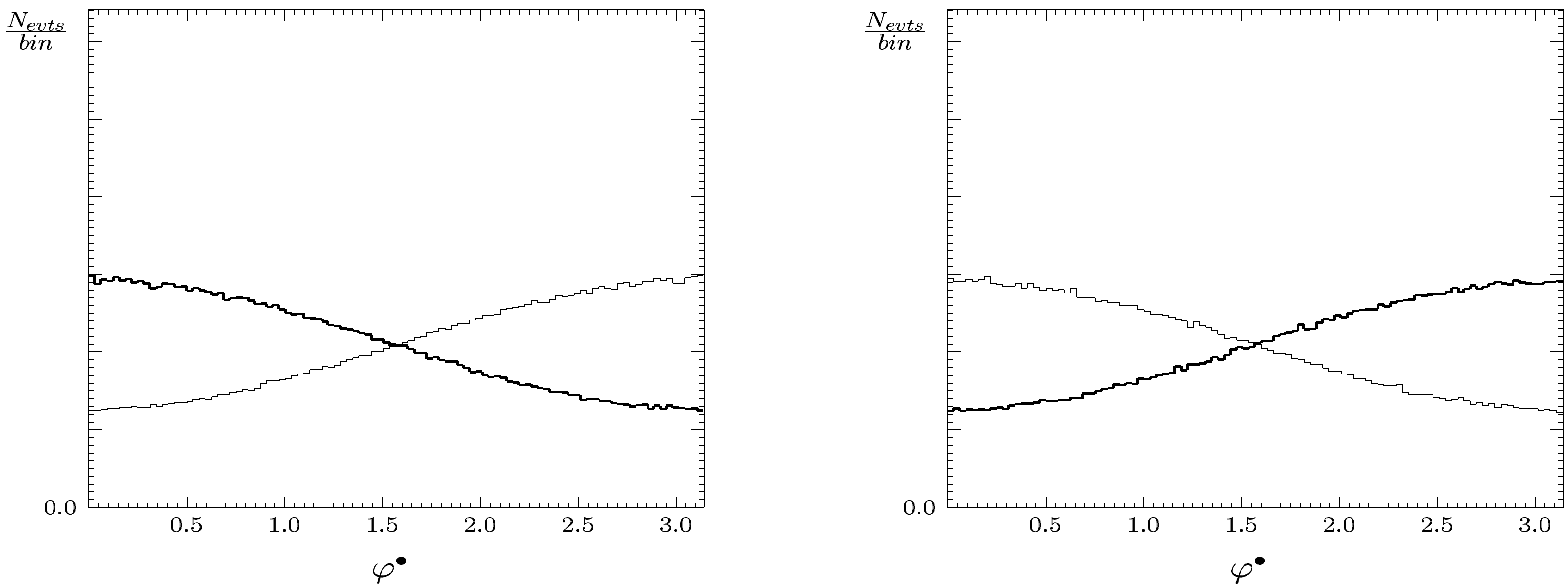
$\sqrt{s} = 500\ GeV$

Replacement τ Rest Frame

- Take just laboratory frame instead of $\tau^{\pm}$ r.f.'s.
- Invisibly better replacement τ rest frames:
  - In the restframe of $\rho^+\rho^-$ pair define $\tau^{\pm}$ momenta along direction of $\rho^{\pm}$,
  - For $\tau^{\pm}$ energies take half of the Higgs boson mass.
  - Boost replacement $\tau^{\pm}$ momenta to the lab frame.
- Many more, equally "good" options checked. The problem is that we can not determine direction of the ν_τ because of Beamstrahlung.

Here we used MC to understand observable build from 24 dimensions

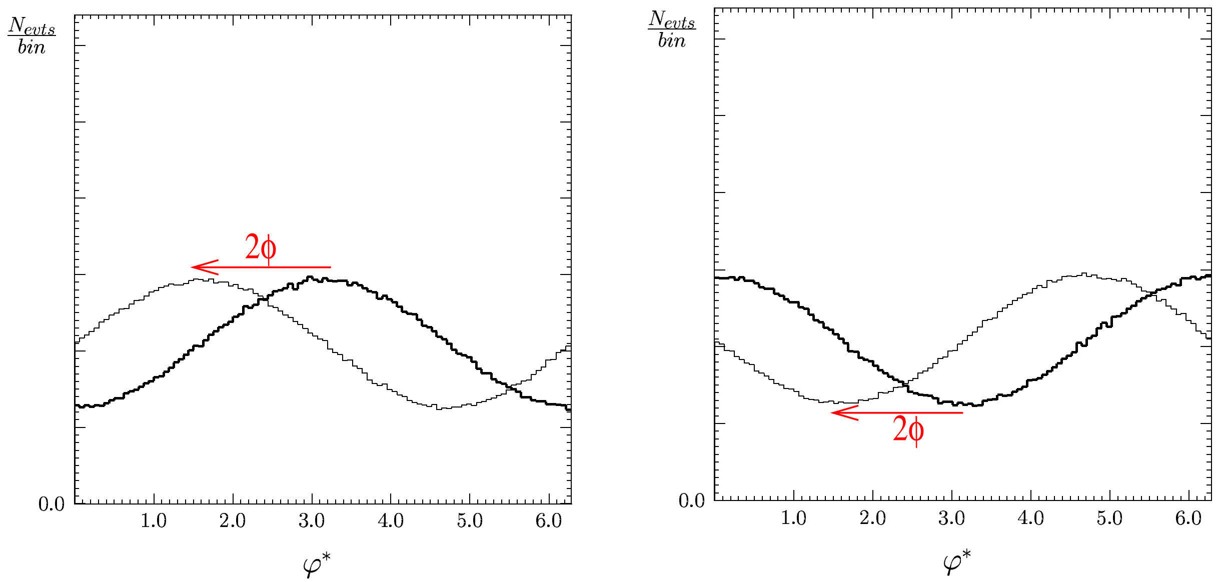
Results With τ Impact Parameter – Additional Cuts



- *Only events where the signs of y1 and y2 are the same whether calculated using the method without or with the help of the τ impact parameter.*
- *Improvement* $\sim 107\%$.
- *Only* $\sim 52\%$ *events are accepted.*

Improvement: $\sim 4.5\sigma$

Results For Mixed Scalar–Pseudoscalar Case



- *Only events where the signs of y1 and y2 are the same whether calculated using the method without or with the help of the τ impact parameter.*
- *Detector-like set-up is included (SIMDET).*
- *The thick line corresponds to a scalar Higgs boson, the thin line to a mixed one.*

Precision on $\phi \sim 6^\circ$, for $1ab^{-1}$ and 350 GeV CMS.

H *produced at LHC from* $b\bar{b}H$ *Yukawa coupling*

In case of MSSM and Higgs boson $m_H = 100 - 200GeV$, it is the key signature.

That is why I will recall results from the following papers:

- E. Richter-Was, T. Szymocha and Z. Was, “Why do we need higher order fully exclusive Monte Carlo generator for Higgs boson production from heavy quark fusion at LHC?,” arXiv:hep-ph/0402159.
- E. Richter-Was, T. Szymocha, “The light Higgs decay into τ-lepton pair: reconstruction in different production processes”, ATL-COM-PHYS-2004, in preparation.

Issues of overall normalizations clarified

Let me just mention theoretical points I do not want to talk today:

- Cross section for the process $b\bar{b} \to H$ was calculated at NNLO by R. V. Harlander and W. B. Kilgore within, so called, variable flavour number scheme (VFS).
- It was also calculated at the NLO for the parton level process $gg(q\bar{q}) \to b\bar{b}H$ within fixed flavour scheme (FFS), eg.by Spira
- Willenbrock et al. choose to start from $gb \to bH$.
- Results obtained in these schemes for inclusive cross sections seem to become compatible with each other.
- Nonetheless, just to be on the safe side, let us look at how the experimental signatures may look like.

- For simulation PYTHIA, TAUOLA combined with our universal interface can be used.
- None of the production processes implemented in PYTHIA is expected to be modelled at present sufficiently well. We will use the standard options (corresponding roughly to the lowest orders of aproaches listed in previous transparency) to check if the choice may affect some conclusions or not.
- The choices correspond to lowest order in different approaches for calculation of inclusive cross sections.
- Detector effects are simulated with the help of AcerDET (hep-ph/0207355) by B. Kersevan and E. Richter-Was.
- Significant amount of work by LHC collaboration and over years, should be mentioned. That is why, there is also technical reason to use PYTHIA.
- Selection cut-offs etc. are not defined by me but by the collaborations. Some of them may be changed easily some other not ... This is beyond this talk.

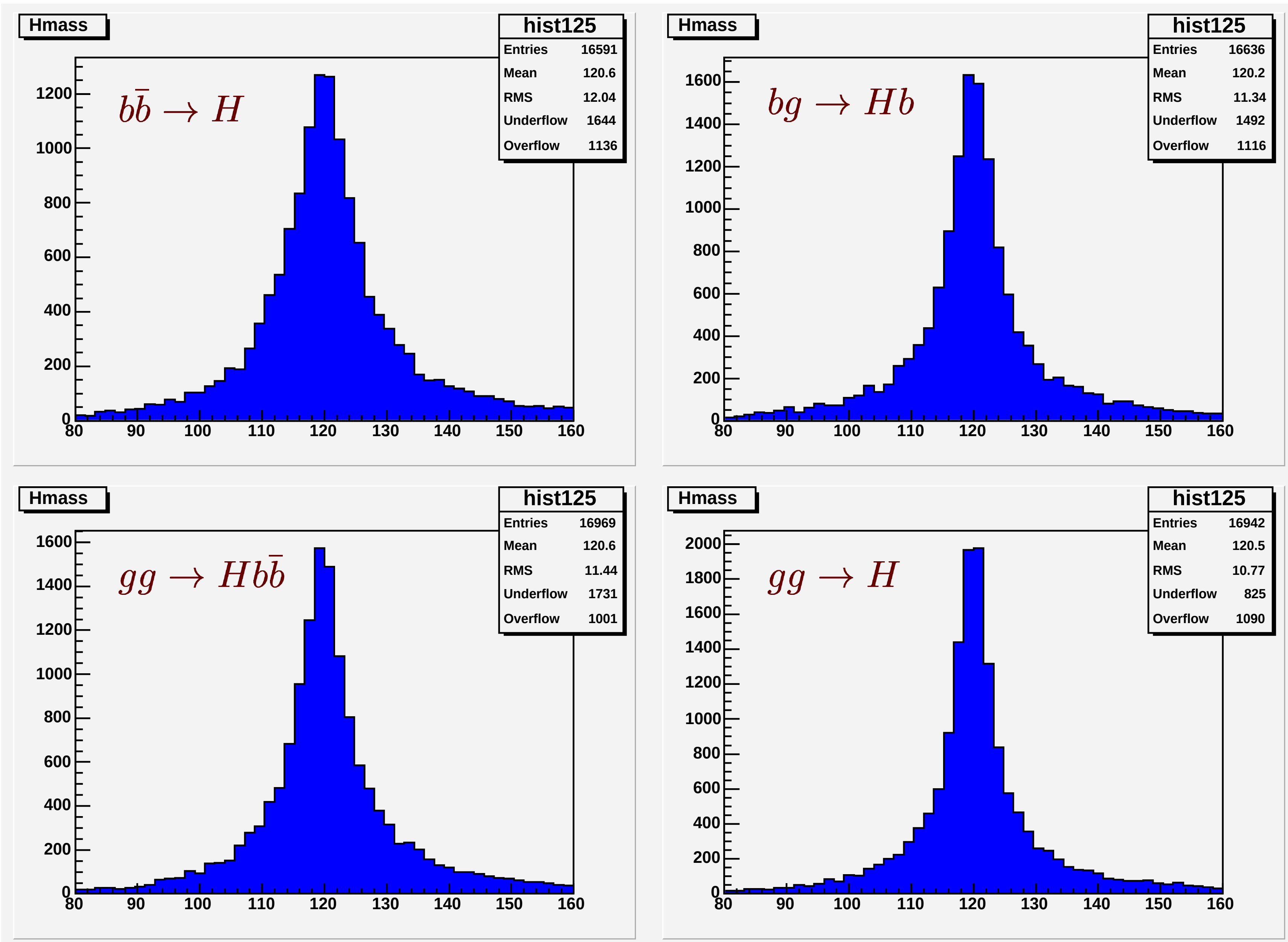
Let us now show numerical results

Caption for the table on the next transparency

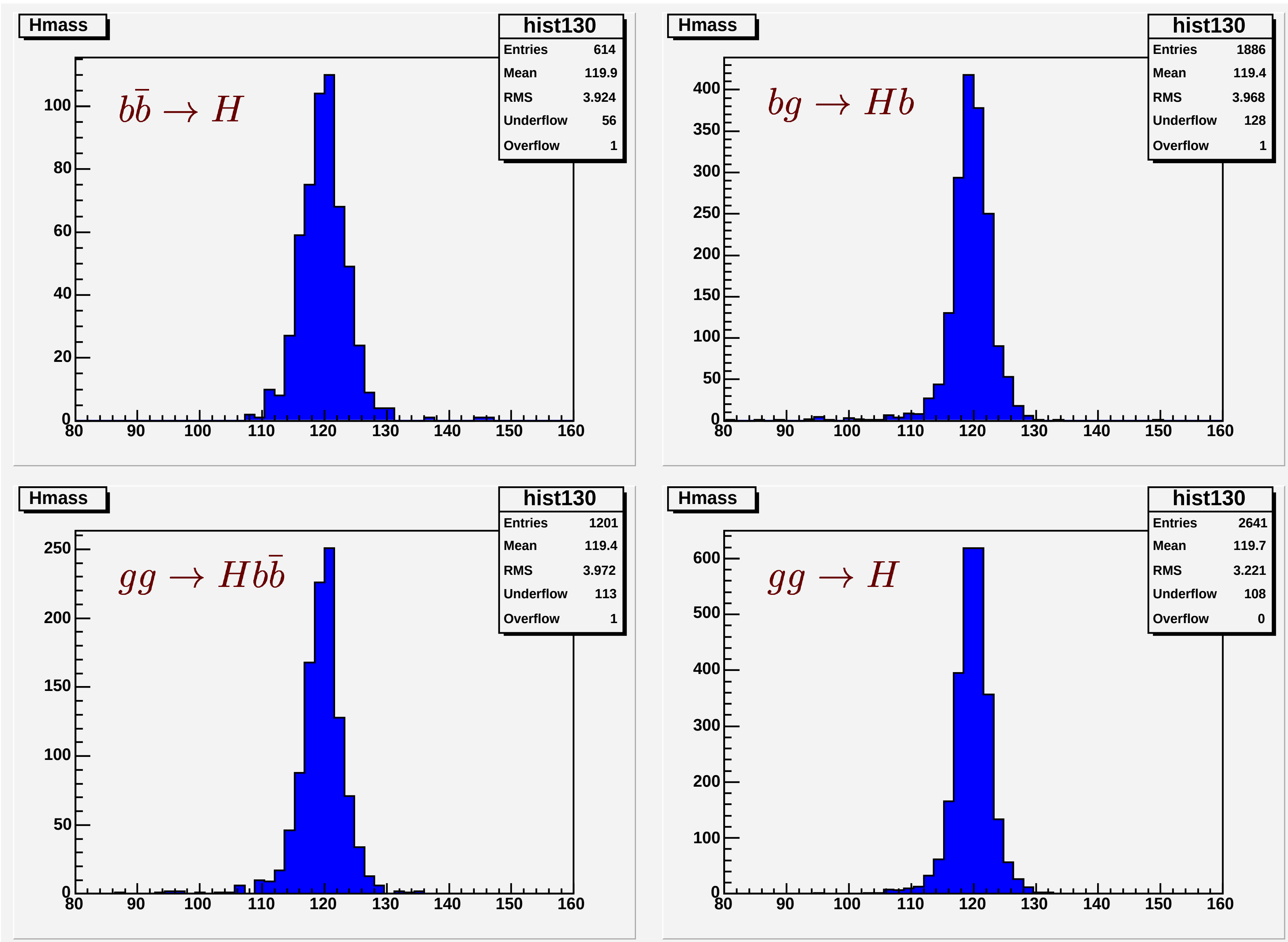
1. Let us look at the case when one of the τ's decays hadronically and second leptonically, then the final signature is $(\ell\ \tau\text{-jet}\ E_T^{miss})$.
2. The cumulative acceptances for the selection criteria and for different approaches of modelling production process will be shown
3. For each subsequent line effect of the additional cut off is added. Separate blocks correspond:
4. Particle level only
5. Detector effects included
6. There is small technical point. Tau-leptons are not observed directly neutrino momenta have to be reconstructed from kinematical fit.
7. Small tau-mass limit is used and condition of momentum conservation in transverse plane, that is: $p_T^{mis} = p_T^{\nu_\tau} + p_T^{\bar\nu_\tau} + p_T^{\ell}$
8. Acceptance denotes fraction of events which pass selection cuts.

Selection	$b\bar{b} \to H$	$gb \to bH$	$gg \to b\bar{b}H$	$gg \to H$	$--$
1 iso ℓ, $p_T^\ell > 20$ GeV 1 τ-jet, $p_T^{\tau-jet} > 30$ GeV	$19.5 \cdot 10^{-2}$	$19.3 \cdot 10^{-2}$	$19.7 \cdot 10^{-2}$	$19.5 \cdot 10^{-2}$	
PARTICLE level					
resolved neutrinos	$16.6 \cdot 10^{-2}$	$16.6 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	**A**
$\lvert sin(\Delta\phi_{\ell\ \tau-jet})\rvert > 0.2$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$8.9 \cdot 10^{-2}$	$9.7 \cdot 10^{-2}$	$8.9 \cdot 10^{-2}$	$9.8 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$1.3 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$8.5 \cdot 10^{-3}$	$2.2 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	$3.1 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$6.1 \cdot 10^{-3}$	$1.9 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	**B**
DETECTOR level					
resolved neutrinos	$11.0 \cdot 10^{-2}$	$11.6 \cdot 10^{-2}$	$11.1 \cdot 10^{-2}$	$12.5 \cdot 10^{-2}$	**C**
$\lvert sin(\Delta\phi_{\ell\ \tau-jet})\rvert > 0.2$	$5.9 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$	$6.5 \cdot 10^{-2}$	$8.2 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$5.5 \cdot 10^{-2}$	$6.6 \cdot 10^{-2}$	$6.2 \cdot 10^{-2}$	$7.6 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$9.1 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$6.5 \cdot 10^{-3}$	$1.8 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	$2.7 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$4.9 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$9.3 \cdot 10^{-3}$	$2.3 \cdot 10^{-2}$	**D**

Reconstructed Higgs peak, selection A



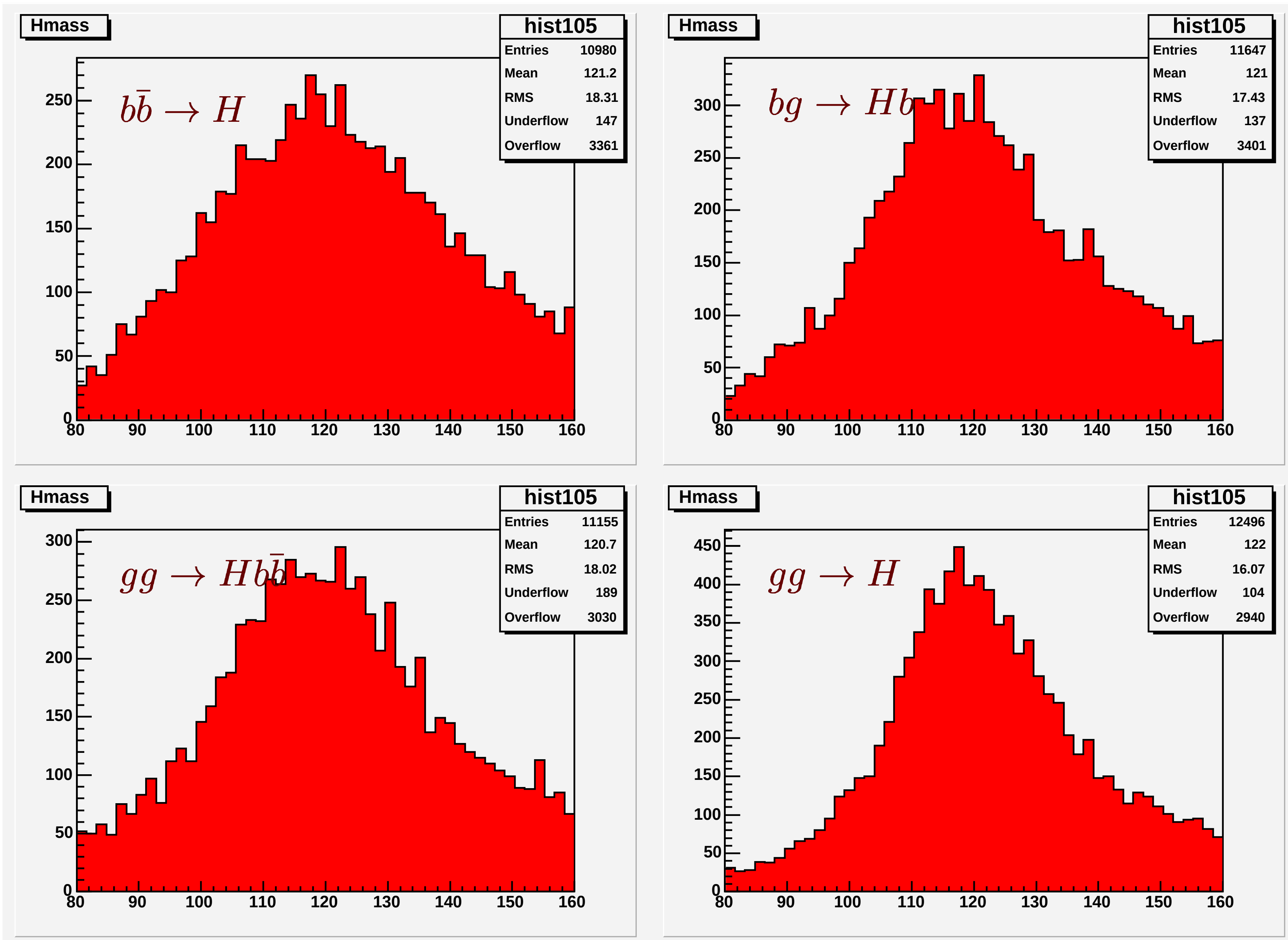
Reconstructed Higgs peak, selection B



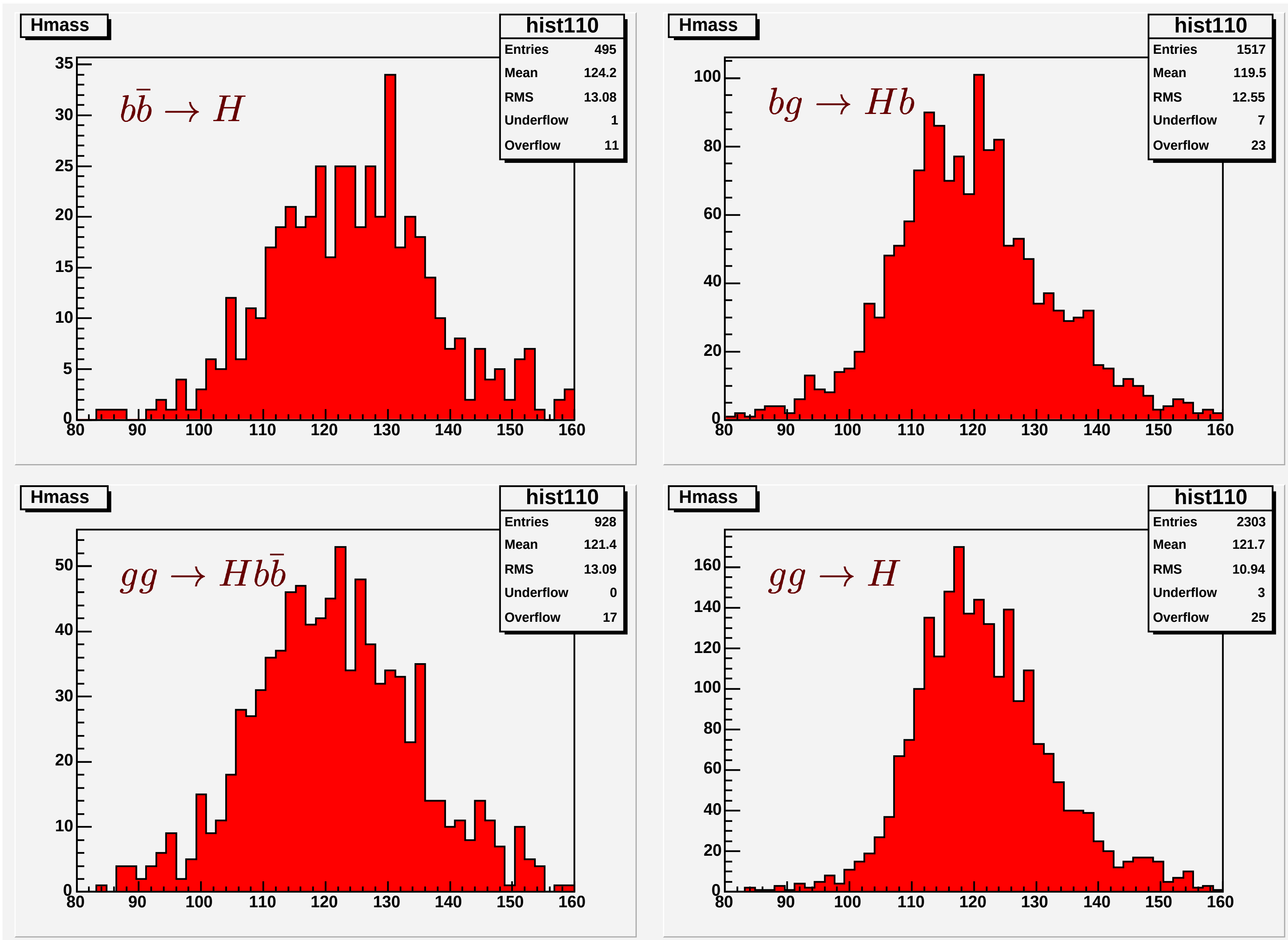
Mini Conclusions for Particle Level

- *At Particle Level (A) all look like confirmed nice thing,*
- *Peaks for Higgs resonance are clearly visible tails are small.*
- *Acceptances are independent of the hard process used in PYTHIA.*
- *Clearly production of the Higgs, decay of the Higgs and detection separate nicely, as should be.*
- *At Particle Level (B) we get even sharper peaks, because of additional selection,*
- *It look like doubtful improvement, acceptance becomes hard process dependent.*
- *Unnecessary complication ?*
- *Let's move to the case when full detector effects are on ...*

Reconstructed Higgs peak, selection C



Reconstructed Higgs peak, selection D



Selection	$b\bar{b} \to H$	$gb \to bH$	$gg \to b\bar{b}H$	$gg \to H$	$--$
1 iso ℓ, $p_T^{\ell} > 20$ GeV 1 τ-jet, $p_T^{\tau-jet} > 30$ GeV	$19.5 \cdot 10^{-2}$	$19.3 \cdot 10^{-2}$	$19.7 \cdot 10^{-2}$	$19.5 \cdot 10^{-2}$	
PARTICLE level					
resolved neutrinos	$16.6 \cdot 10^{-2}$	$16.6 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	$16.9 \cdot 10^{-2}$	**A**
$\lvert sin(\Delta\phi_{\ell\ \tau-jet})\rvert > 0.2$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$8.9 \cdot 10^{-2}$	$9.7 \cdot 10^{-2}$	$8.9 \cdot 10^{-2}$	$9.8 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$1.3 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$8.5 \cdot 10^{-3}$	$2.2 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	$3.1 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$6.1 \cdot 10^{-3}$	$1.9 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$	$2.6 \cdot 10^{-2}$	**B**
DETECTOR level					
resolved neutrinos	$11.0 \cdot 10^{-2}$	$11.6 \cdot 10^{-2}$	$11.1 \cdot 10^{-2}$	$12.5 \cdot 10^{-2}$	**C**
$\lvert sin(\Delta\phi_{\ell\ \tau-jet})\rvert > 0.2$	$5.9 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$	$6.5 \cdot 10^{-2}$	$8.2 \cdot 10^{-2}$	
$m_T^{\ell,miss} < 50$ GeV	$5.5 \cdot 10^{-2}$	$6.6 \cdot 10^{-2}$	$6.2 \cdot 10^{-2}$	$7.6 \cdot 10^{-2}$	
Additional selection					
$p_T^{miss} > 30$ GeV	$9.1 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	
$cos(\Delta\phi_{\ell\ \tau-jet}) > -0.9$	$6.5 \cdot 10^{-3}$	$1.8 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	$2.7 \cdot 10^{-2}$	
$R_{\ell\ \tau-jet} < 2.8$	$4.9 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$9.3 \cdot 10^{-3}$	$2.3 \cdot 10^{-2}$	**D**

Mini Conclusions for Detector Level

- *At Detector Level (C) all look like confirmed nice thing,*
- *Acceptances are independent of the hard process used in PYTHIA.*
- *Production, decay,and detection of Higgs separate nicely (C) -line acceptances equal.*
- *But peaks for Higgs resonance nearly disapeared.*
- *At Detector Level (D) we get peaks back, because of additional selection,*
- *But acceptance becomes hard process dependent up to a factor of 4 !!!*
- *We need to:*
  1. *ask for money for better detector*
  2. *improve theoretical control of the predictions* $\rightarrow$
  3. *improve experimental analysis* $\rightarrow$
- *Definitely Monte Carlo is essential in such a studies.*
- *Which solution seem to be feasible? Where can I help?*

Summary

- *We have reviewed tools for simulation of final state physics:*
  - *TAUOLA as generator for τ decays*
  - *TAUOLA interfaces for applications in LC LHC.*
  - *PHOTOS as generator for radiative corrections in decays.*
  - *MC-TESTER*
- *With the help of the tools we have shown specific applications:*
  - *For LC*
  - *For LHC*
- *This is on top of usual applications in τ physics stand-alone.*
- *Let us turn now to possible future extensions in TAUOLA.*

Future

- 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.
- Some “cross talk” may be useful. Non-tau experiments like LHC may profit.
- From discussions with J.H. Kuhn, A.Weinstein, R. J. Sobie, T. Ohshima I understood that it is time to decide how TAUOLA will be handled in future.
- I have prepared, see http://hpjmiady.ifj.edu.pl/ wasm/tauola.html such updated version, with open slots for many new channels, also with possible spin effects for 5 scalars final states (J. H. Kuhn and myself have some modest plans into that direction).
- Manpower constraints. Struggle with priorities...
- Let us have private discussions now.