Tauola for tau leptons decays – and for LHC

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Main Topics:

- TAUOLA technicalities and its relation to data of other experiments
- PHOTOS for radiative correction in decays.
- universal interface of TAUOLA.
- application for Higgs boson parity measurement at LC (to show that production and decay of the Higgs boson are well separated).
- application for Higgs boson discovery estimates at LHC (to show that production and decay of the Higgs boson are in practicenot as well separated).
- Summary

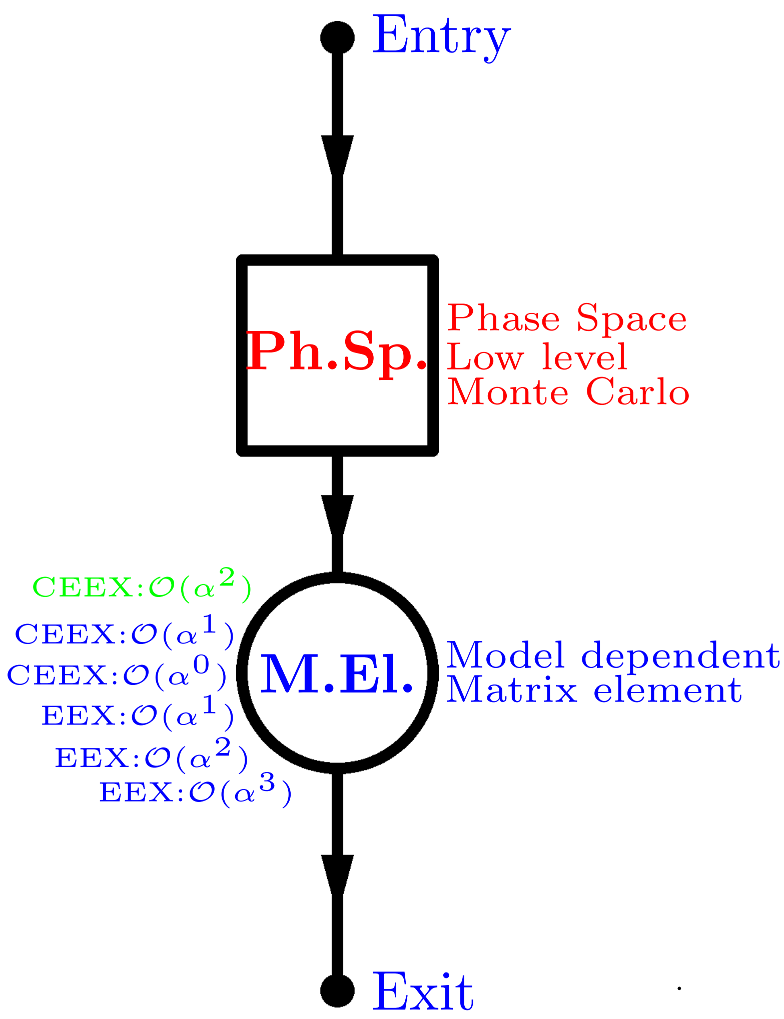
My web page is at http://home.cern.ch/wasm

Basic structure

and assumptions

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

Textbook principle "matrix element × 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.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

Often analysis within collaborations were relying on refits of form-factors, many versions were/are regularily created for more general, or specific purposes. I have seen only some of them.

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* %.

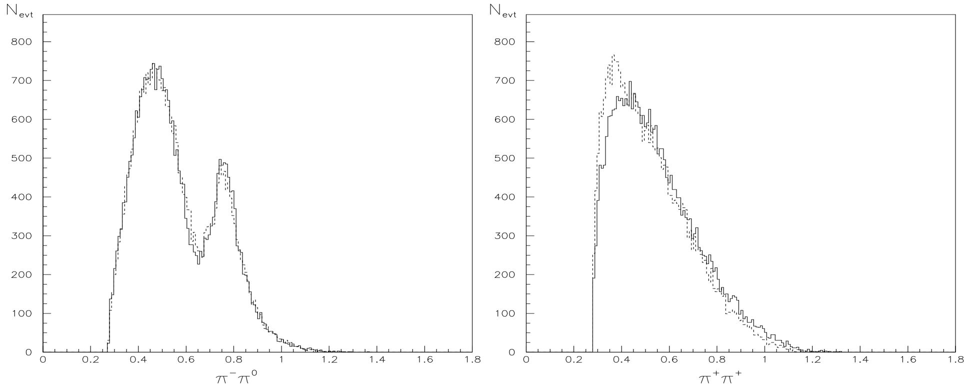


Figure 3: *The $\bar{\nu}_\tau \pi^+\pi^+\pi^-\pi^0$ channel. The Left-hand side plot $\pi^-\pi^0$ invariant mass distribution, right-hand side plot $\pi^+\pi^+$ invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*

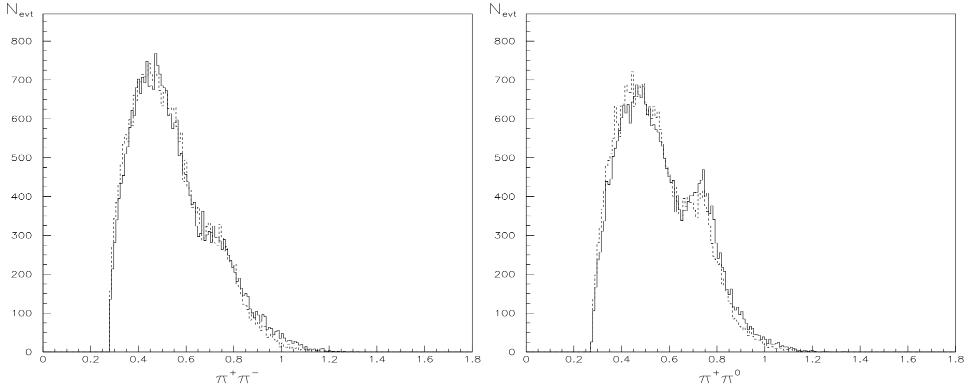


Figure 4: *The $\bar{\nu}_\tau \pi^+\pi^+\pi^-\pi^0$ channel. The Left-hand side plot $\pi^+\pi^-$ invariant mass distribution, right-hand side plot $\pi^+\pi^0$ invariant mass distribution. Continuous line for an old scaled down to 40 % CLEO current, dotted line for a new Novosibirsk current.*

Basic properties of TAUOLA solution

- **Phase space.**
- **Matrix element.**
- **Theoretical models.**
- **Hadronic currents.**
- **Fits to different data, LEP CLEO, low energy e^+e^-,**
- **also BELLE BaBar in future**
- **All will be available for LHC, not much ambiguities from that.**
- **Design precision and benchmarks.**

PHOTOS

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

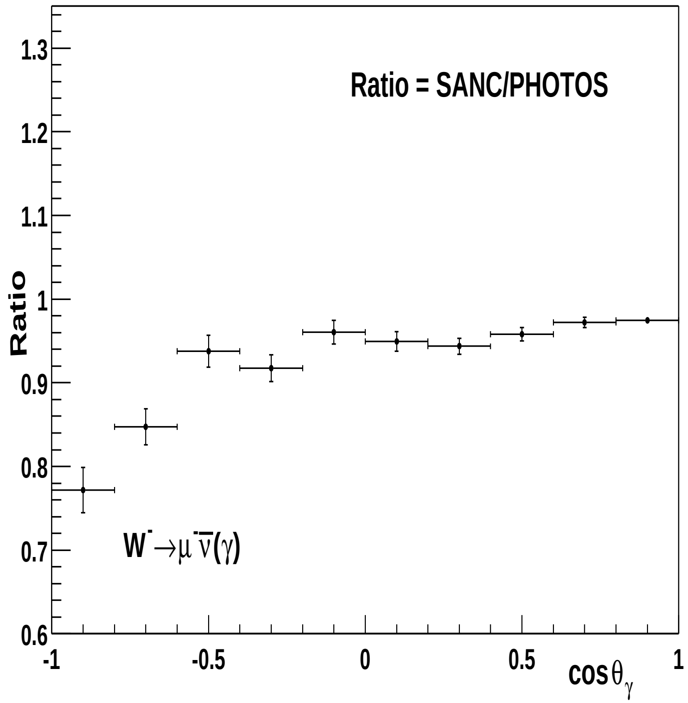
See also: P. Golonka et al. hep-ph/0312240

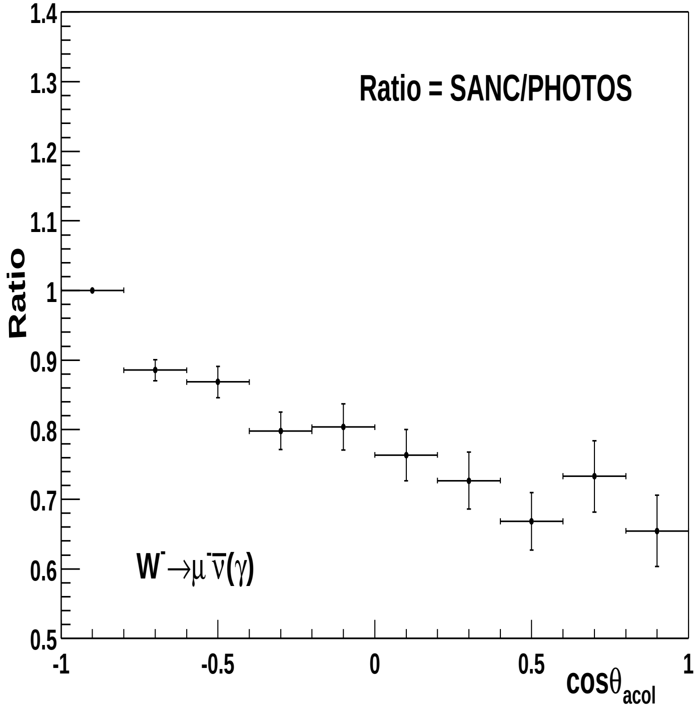
- It was developped as single photon emission. starting from MUSTRAAL (F. Berends, R. Kleiss, S. Jadach, Comput. Phys. Commun. (1982)) option for final state bremsstrahlung in Z decay only.
- Factorization of phase space for photonic variables and two-body decay phase space was studied.
- The same was 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 emission kernels 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^- was lost and re-introduced with approximation.
- The algorithm of the antenna type was created.

PHOTOS

- To have universal kernels PHOTOS in principle is not better than LL,improved with correct soft photon limit.
- 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 records and may add bremsstrahlung emission at any branching.
- Appropriatelly 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 thand double photon emission (preliminary)

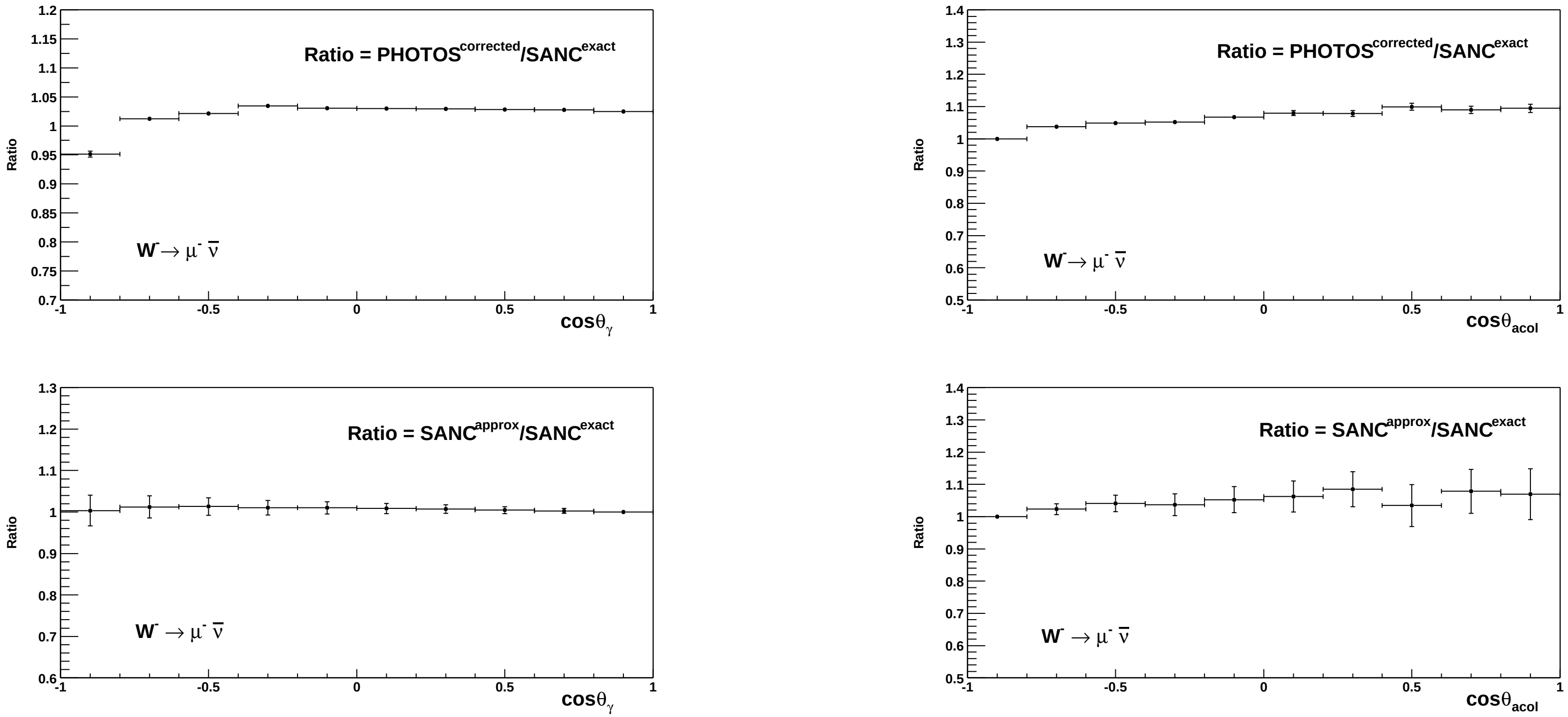
$W \to l\nu$ PHOTOS vs. Matrix Element, test





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.*

Preliminary results of analysis wit PHOTOS $\mathcal{O}(\alpha^4)$ and special (calorimetric) option of MC-TESTER, available at: **http://cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER**

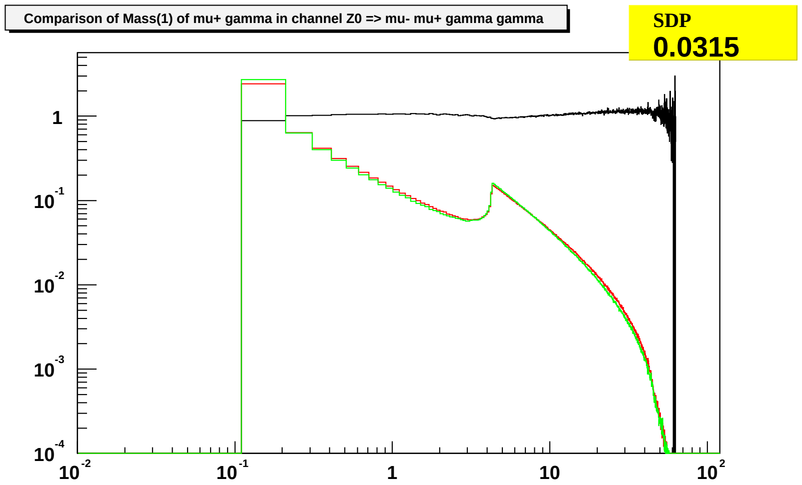
Hard Bremsstrahlung in KKMC, PHOTOS and PYTHIA

2 photon results:

MC-TESTER comparison of hard bremsstrahlung in KK and KK+PHOTOS.
Z0 (91.187 Gev) --> mu+ mu- (0,1,2) photons, 100M events

E_test	Generator type	Generator XPHCUT	Branching ratios for mu mu + n photons: 0 photons	1 photon	2 photons	Maximum SDP in comparison with KK: 0 photons	1 photon	2 photons	T1	T2
0.01	KK		58.94	32.22	8.84					
	KK+PHOTOS O(2)	0.01	80.32	17.36	2.32	0	0.916	1.370	42.77	10.44
		0.0001	65.52	24.86	9.62	0	0.014	0.081	14.72	0.817
		0.00001	65.52	24.86	9.62	0	0.014	0.081	14.73	0.815
		0.000005	65.52	24.86	9.62	0	0.014	0.081	14.72	0.819
		0.000001	65.52	24.86	9.62	0	0.014	0.081	14.73	0.820
	KK+PHOTOS O(3)	0.00001	64.07	29.13	6.80	0	0.018	0.020	10.27	0.321
	KK+PHOTOS O(4)	0.00001	64.23	28.50	7.27	0	0.017	0.003	10.59	0.186
.										
1.0	KK		80.87	17.54	1.59					
	KK+PHOTOS O(2)	0.01	83.93	14.63	1.445	0	0.008	0.021	6.115	0.155
		0.0001	83.93	14.62	1.446	0	0.008	0.020	6.115	0.153
		0.00001	83.93	14.63	1.445	0	0.008	0.020	6.107	0.153
		0.000005	83.93	14.63	1.44	0	0.008	0.020	6.113	0.158
		0.000001	83.92	14.63	1.45	0	0.008	0.021	6.103	0.158
.										
5.0	KK		88.83	9.81	0.366					
	KK+PHOTOS O(2)	0.01	91.60	8.08	0.32	0	0.004	0.018	3.538	0.038
		0.0001	91.60	8.08	0.32	0	0.002	0.017	3.532	0.020
		0.00001	91.59	8.08	0.320	0	0.002	0.016	3.527	0.021
		0.000005	91.60	8.08	0.319	0	0.002	0.017	3.542	0.022
		0.000001	91.60	8.08	0.319	0	0.002	0.017	3.534	0.022

Summary tables lead to detailed booklets with thousands of plots like this:



TAUOLA universal interface

- To run generator for tau decays it must be combined with part for tau production.
- I will concentrate on physics points.
- I will skip technicalities related to the way how HEPEVT common block is filled in 3 versions of PYTHIA conventions and HERWIG.
- 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 explicitely 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

$$wt \neq \Big(\sum_{i,j=0,3} R^A_i h^i \Big) \Big(\sum_{i,j=0,3} R^B_j h^j \Big)$$

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.

Approximate spin generation

Example of reasonable approximation: KORALZ at LEP

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.

●This solution worked in all cases, except τ-lifetime measurement with impact parameter difference method and simulations for direct measurement of transverse spin correlations

- In all other cases correlations of transverse (with respect to $\tau^\pm$ dirrections) components of $\tau^\pm$ decay products momenta could be neglected
- Backup solution was however always at hand.
- Such solution is used by TAUOLA universal interface in all cases except Higgs boson.

Exact spin generation

Example: KORALB and KKMC

S. Jadach, Z. Was Comput. Phys. Commun. 64 (1991) 267

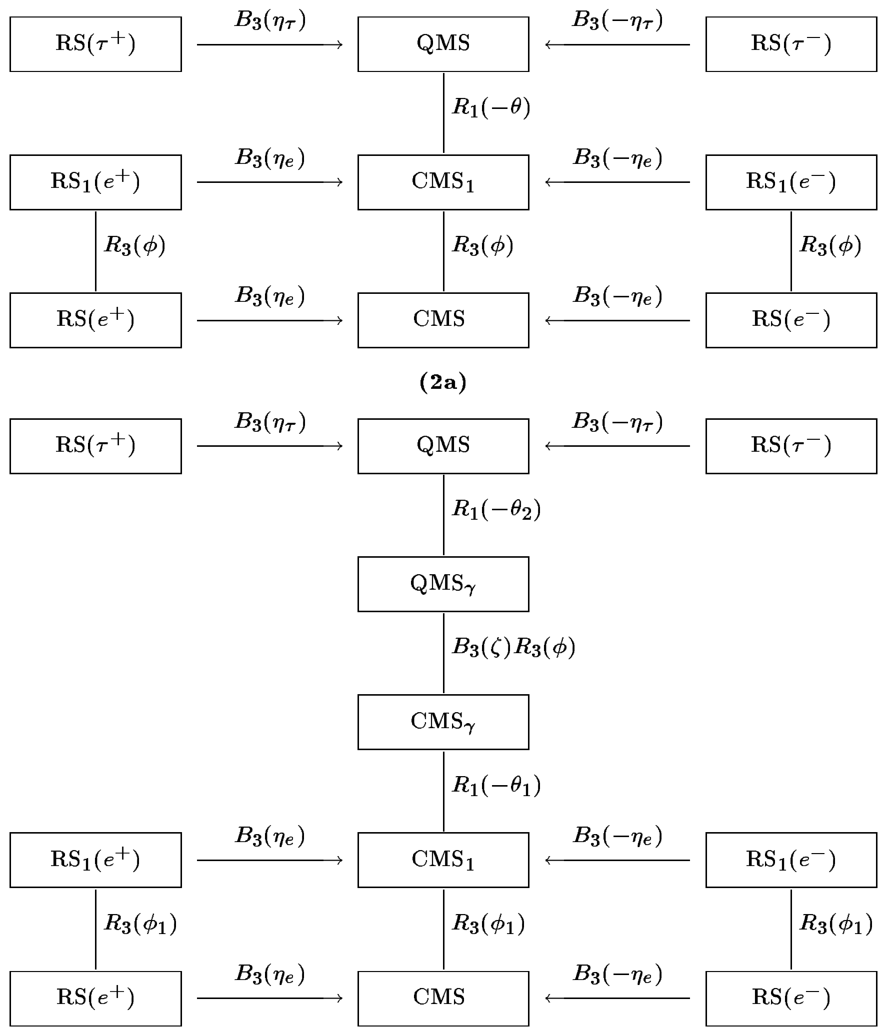
S. Jadach, B. F. L. Ward, Z. Was Comput. Phys. Commun. 130 (2000) 260

- 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.
- in KORALB density matrix for $2 \longrightarrow 2$ and $2 \longrightarrow 3$ processes was used.
- in KKMC more universal solution suitable to any process $2 \longrightarrow 2 + n$ was applied.
- Slightly different solution is used in HERWIG
- and in software of BaBar.
- such solution is used in TAUOLA universal interface for Higgs boson decays

Tree of KORALB boosts, used in spin quantization

Figure 2



(2a)

(2b)

Case of KKMC

- Refined solution like in KORALB is used.
- For details see S. Jadach, B.F.L. Ward, Z. Was Eur. Phys.J. **C22** (2001)423.

Monte Carlo And τ Leptons For Higgs Boson Parity At The Linear Collider

G. Bower (SLAC), K. Desch (Hamburg U.), A. Imhof (DESY)

T. Pierzchała (Silesia U.) Z. Was (Cracow, INP) and M. Worek (Cracow, INP)

Points:

- *Interface of the TAUOLA with complete spin effects for* $H/A^0 \to \tau^+\tau^-$.
- *Physical observable for* $\tau \to \rho\nu_\tau$.

Main References

- 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

Any LC programme must include Higgs boson parity measurement

1. There are many possibilities for the measurement.
2. There are many scenarios of Higgs mechanism: SM, MSSM, ...
3. We will concentrate on the measurement using $H \to \tau^+\tau^-$ decay; i.e. the measurement of Higgs boson couplings to fermions.
4. This measurement is to a large degree production independent.
5. I will skip details of motivation.

Higgs Boson Parity

- *Decay probability in formalism of Kramer et al.*

$$\Gamma(H/A^0 \to \tau^+\tau^-) \sim 1 - s_{\parallel}^{\tau^+} s_{\parallel}^{\tau^-} \pm s_{\perp}^{\tau^+} s_{\perp}^{\tau^-}$$

- s^{τ} *is the* τ *polarization vectors.*
- $\parallel$ / $\perp$ *denote components parallel / transverse to the Higgs boson momentum.*
- *The spin weight is given by the following formula*

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

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

- *Components for pure scalar and pseudoscalar Higgs boson respectively.*

Density matrix

Only transverse spin correlations between τ^+ and τ^- are different for scalar and pseudoscalar Higgs

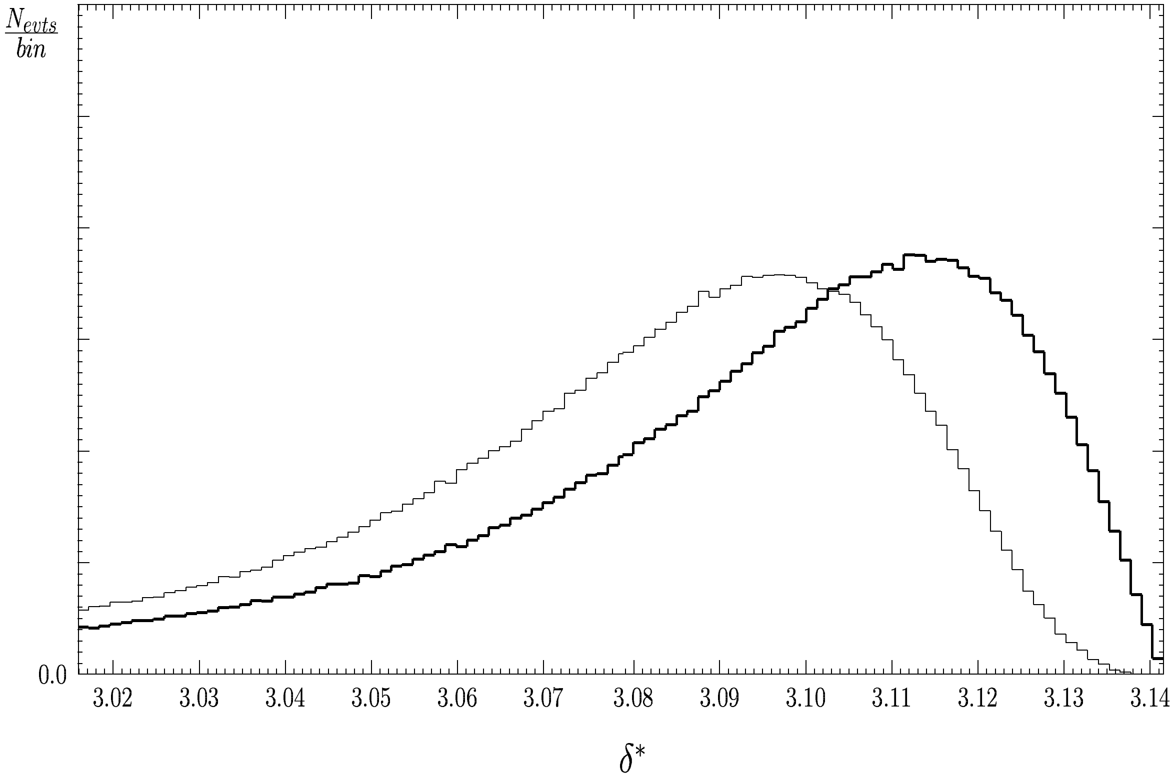
- The correlations can not be measured directly
- One need to measure distributions of τ decay products
- Precisely their transverse (to τ direction in Higgs boson rest frame) momenta
- Most sensitive to spin is $\tau^\pm \to \pi^\pm \nu$
- The largest branching ratio (25 %) has $\tau^\pm \to \pi^\pm \pi^0 \nu$

Classic approach

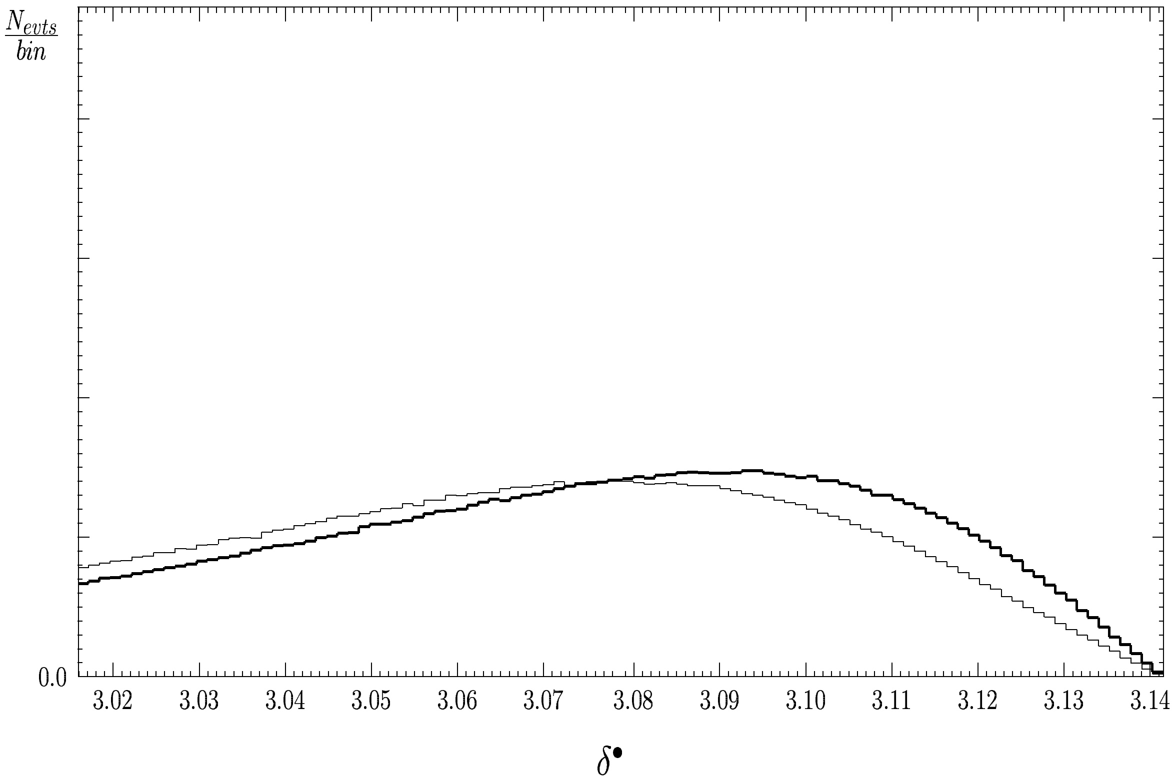
We take the most sensitive to spin $\tau^\pm \to \pi^\pm \nu$ decay channels and we look at $\pi^+\pi^-$ acollinearity in **Higgs boson rest-frame**.

We will reproduce analytical result of Kramer et al first.

Generator level look fine:



But once **beamstrahlung** and detector smearings are in ...



CMS 350 GeV, $e^+e^- \to ZH$, In LC experiments Higgs boson momentum can be measured from the balance of the total energy momentum conservation. That is why smearing of H momentum: ± 2 GeV for p_T, ± 5 GeV for p_{Long} must be assumed. Largest loss of sensitivity is from beamstrahlung.

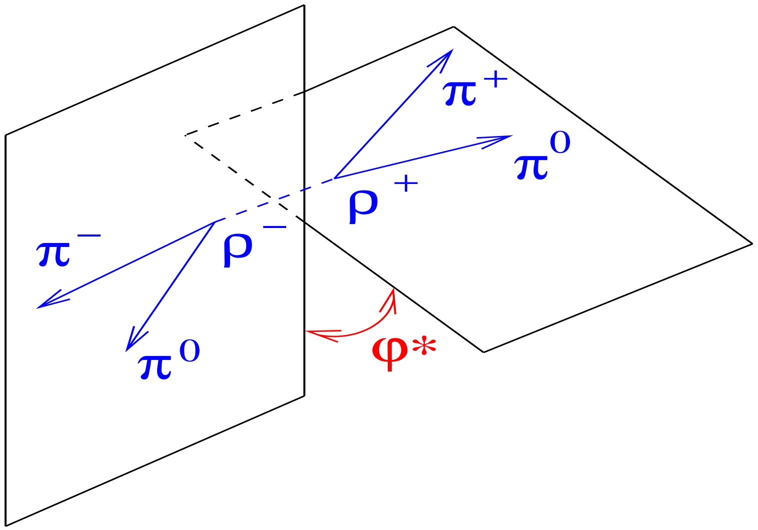
Pure Scalar And Pseudoscalar Higgs Boson

- *Case of* $\tau \longrightarrow \rho\nu_\tau$ *decay,* $\mathcal{BR}(\tau \rightarrow \rho\nu_\tau) = 25\%$
- *The polarimeter vector is given by the formula where* q *for* $\pi^\pm - \pi^0$, N *for* ν_τ.

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

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

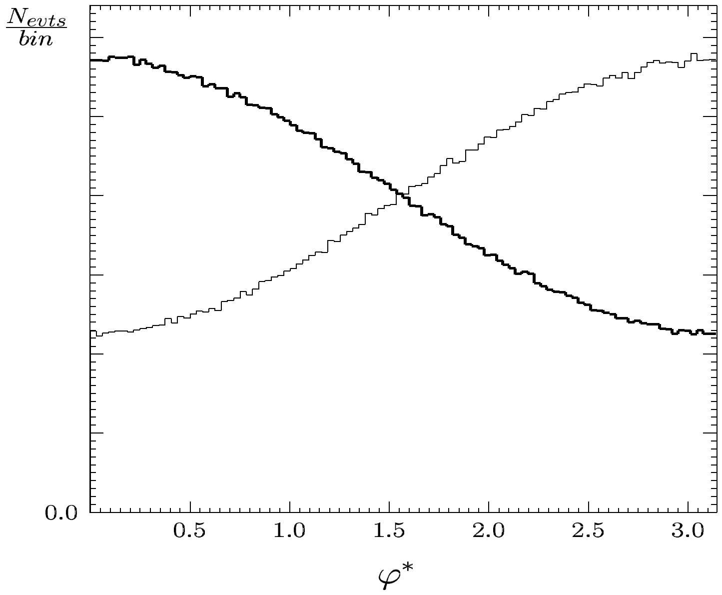
- *Acoplanarity of* ρ^+ *and* ρ^- *decay prod. (in* $\rho^+\rho^-$ *r.f.) and events separation.*

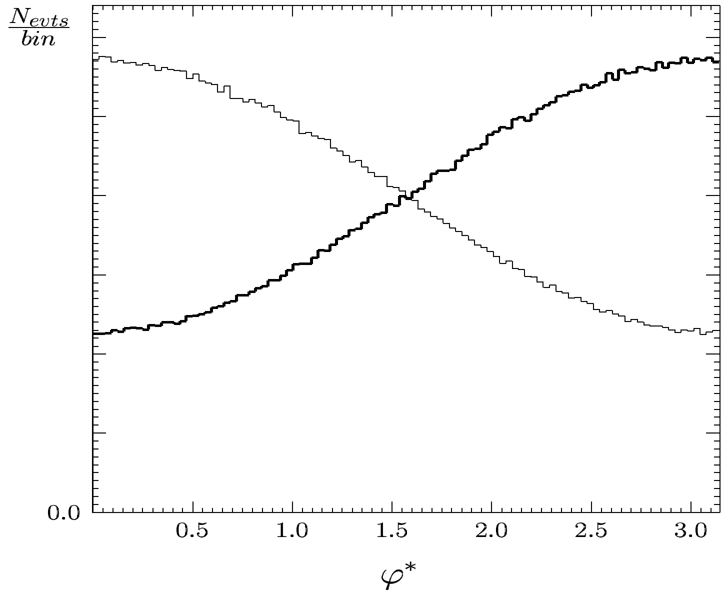


$$y_1 y_2 > 0\,; \qquad y_1 y_2 < 0 \text{ (in } \tau^\pm \text{ r.f.'s)}$$

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

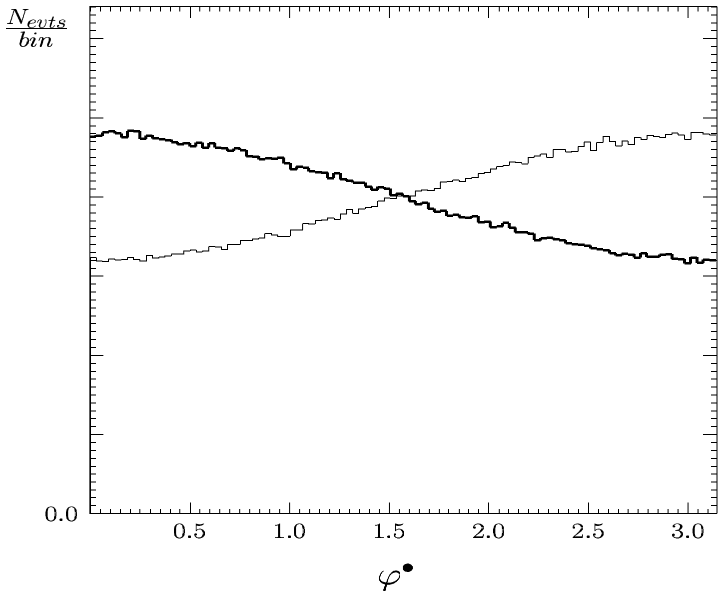
Results Without Smearing

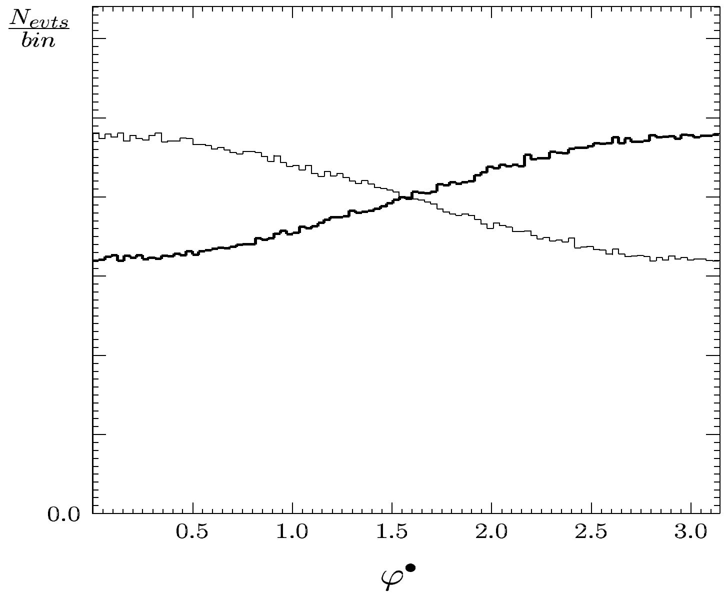




- *The $\rho^+\rho^-$ decay products' acoplanarity distribution without any smearing .*
- *Selection $y_1 y_2 > 0$ is used in the left plot, $y_1 y_2 < 0$ is used for the right plot.*
- *Thick line denote the case of the scalar Higgs and thin lines the pseudoscalar.*
- *Complete spin correlations of $h \to \tau^+\tau^-$, $\tau^\pm \to \rho^\pm\nu$, $\rho^\pm \to \pi^\pm\pi^0$ incl.*

$\mathcal{R}$esults $\mathcal{W}$ith $\mathcal{D}$etector $\mathcal{E}$ffects





- *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}).*

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

$m_H = 120\ GeV$

$\sqrt{s} = 500\ GeV$

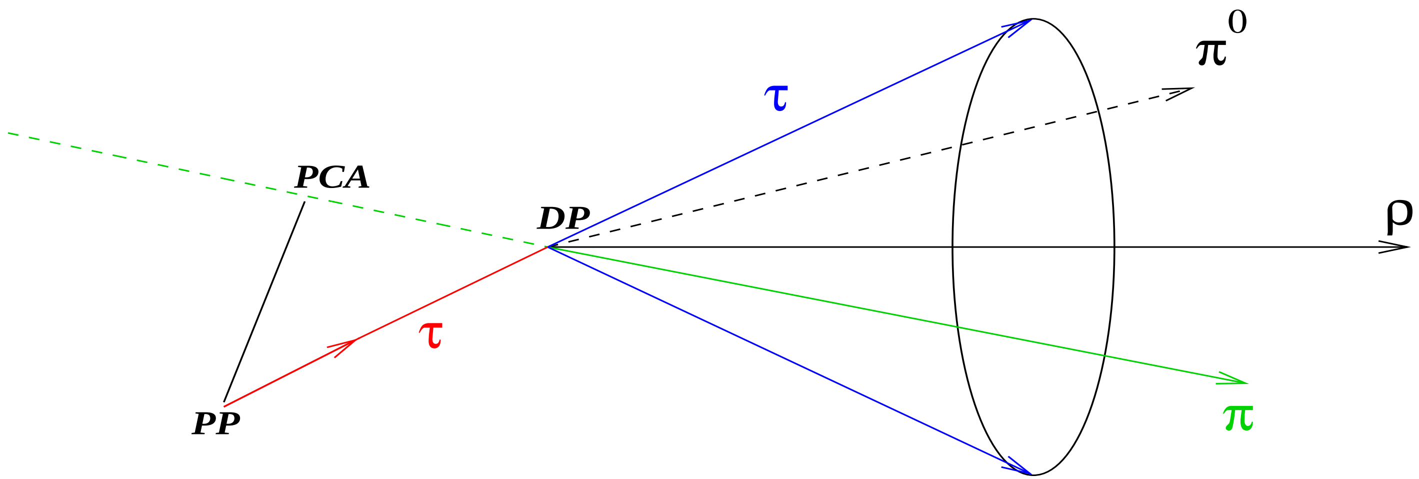
Replacement τ Rest Frame

- Take just laboratory frame instead of $\tau^{\pm}$ r.f.'s.
- Better (but by invisible amount) 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. Problem is that we can not determine direction of ν_τ because of Beamstrahlung.

Here we used MC to understand observable build from 24 dimensions

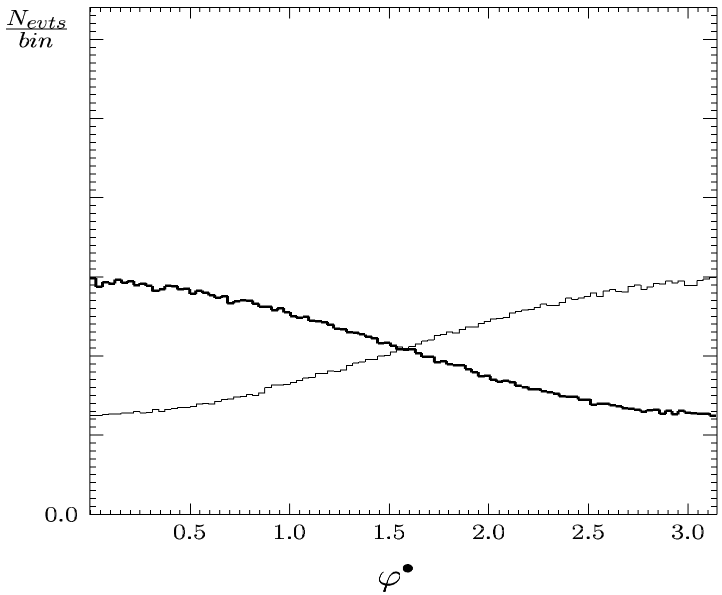
τ Impact Parameter – Method Optimization

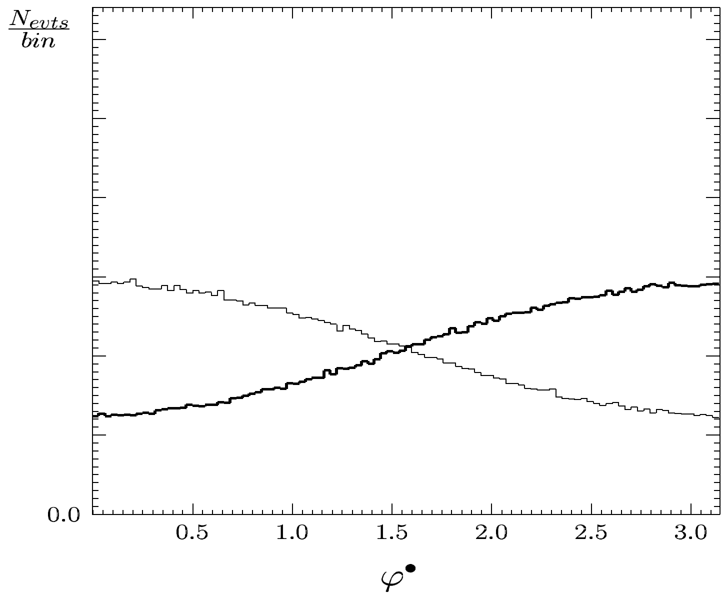
- *To a few GeV τ energy can be determined from CMS and Higgs mass constraints. τ momentum must be localized on a circle around ρ.*



- *Direction of the τ impact parameter, with respect to the $\pi^{\pm}$ track, can help.*
- *Alternative way to find the difference of $\pi^{\pm}$, π^{0} energies in $\tau^{\pm}$ rest frames.*

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: $\sim 4.5\sigma$

Phenomenology Of General Case

- Higgs boson Yukawa coupling expresed with the help of the scalar–pseudoscalar mixing angle ϕ

$$\bar{\tau} N(\cos\phi + i \sin\phi \gamma_5)\tau$$

- *Decay probability for the mixed scalar–pseudoscalar case*

$$\Gamma(h_{mix} \to \tau^+\tau^-) \sim 1 - s_{\parallel}^{\tau^+} s_{\parallel}^{\tau^-} + s_{\perp}^{\tau^+} R(2\phi)\; s_{\perp}^{\tau^-}$$

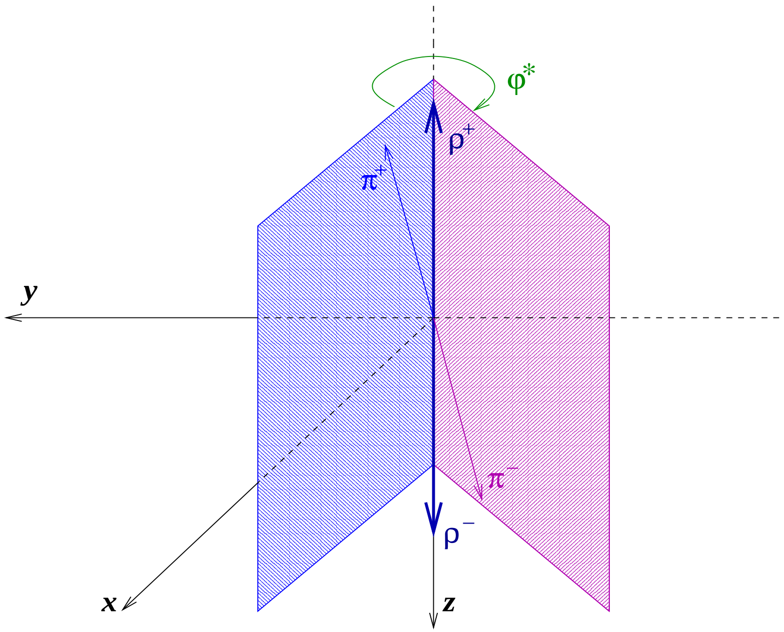
- $R(2\phi) -$ *operator for the rotation by angle* 2ϕ *around the* $\parallel$ *direction.*

$$R_{11} = R_{22} = \cos 2\phi \qquad R_{12} = -R_{21} = \sin 2\phi$$

- *Pure scalar case is reproduced for* $\phi = 0$*.*
- *For* $\phi = \pi/2$ *we reproduce the pure pseudoscalar case.*

Observable For Mixed Scalar–Pseudoscalar Case

- For mixing angle ϕ, transverse component of τ^+ spin polarization vector is correlated with the one of τ^- rotated by angle 2ϕ.
- Acoplanarity $0 < \varphi^* < 2\pi$ is of physical interest, not just $\arccos \mathbf{n}_- \cdot \mathbf{n}_+$.
- Distinguish between the two cases $0 < \varphi^* < \pi$ and $2\pi - \varphi^*$
- If no separation made the parity effect would wash itself out.



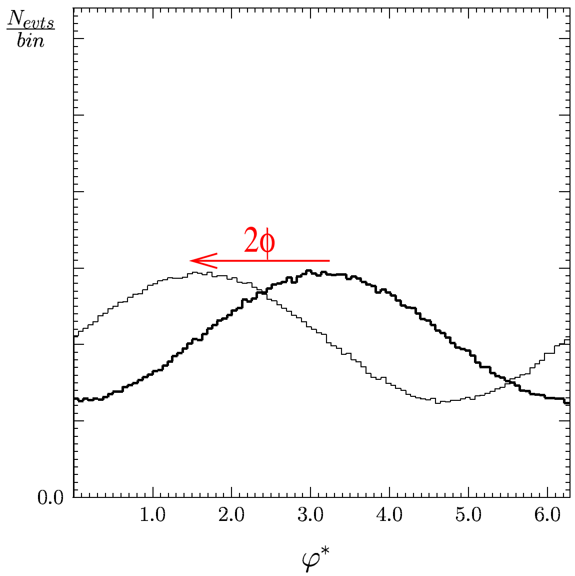
Normal to planes: $\mathbf{n}_\pm = \mathbf{p}_{\pi^\pm} \times \mathbf{p}_{\pi^0}$

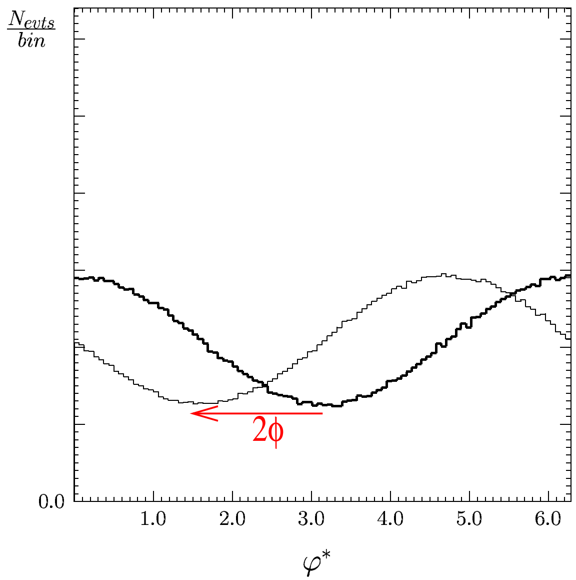
Find the sign of $\mathbf{p}_{\pi^-} \cdot \mathbf{n}_+$

Negative $0 < \varphi^* < \pi$

Otherwise $2\pi - \varphi^*$

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

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

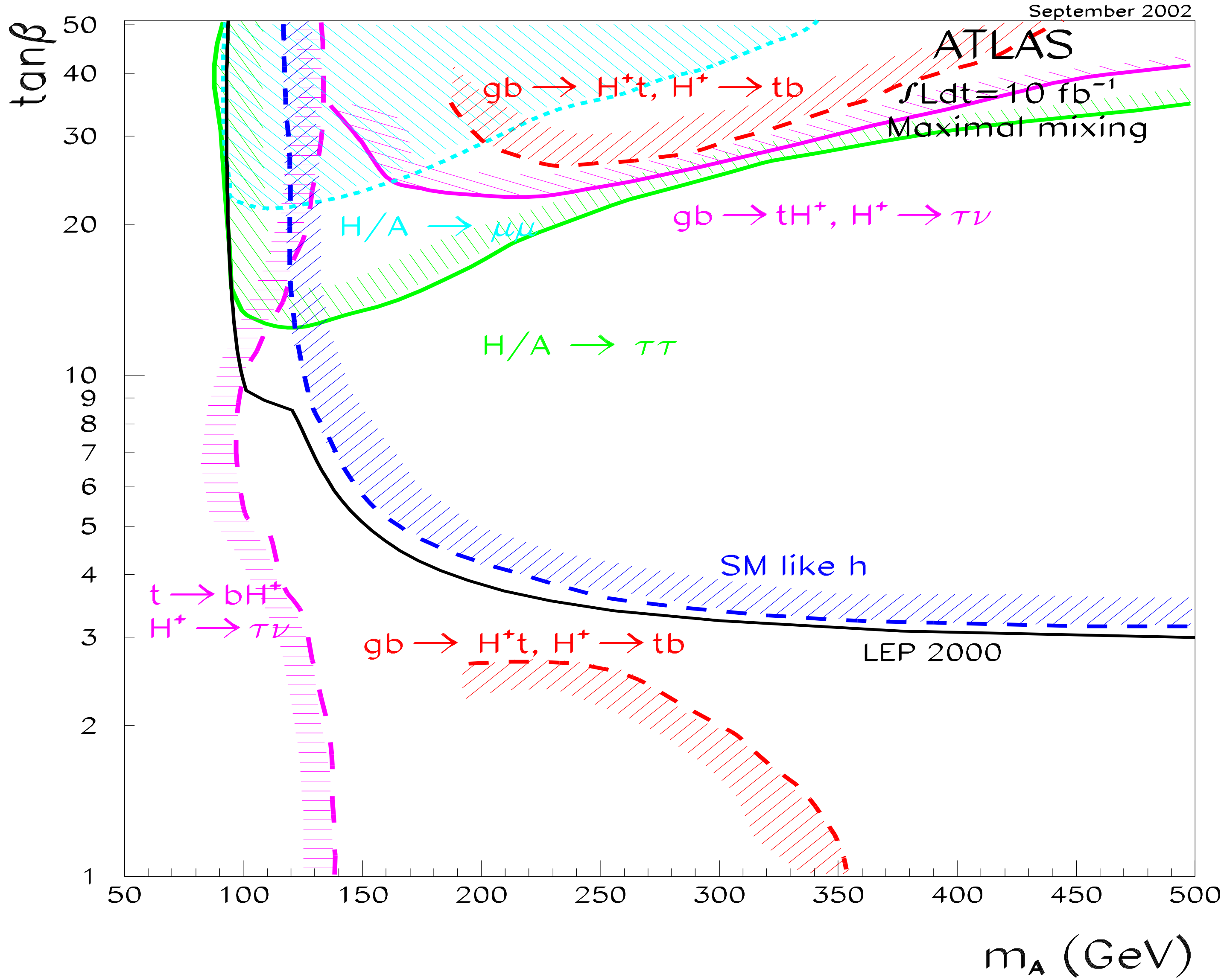
In case of MSSM $m_H = 100 - 200 GeV$ Higgs boson it is the key signature, see plot on the next transparency.

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 lihght Higgs decay into τ-lepton pair: reconstruction in different production processes”, ATL-COM-PHYS-2004, in preparation.

After one year of LHC (2007/8) in search of H/A ...

That is why we will need to understand signature quickly, when detector will not be understood in full.



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.

Case for LHC

- 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 cuts-offs etc. are not defined by me but by the collaborations. Some ofd 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

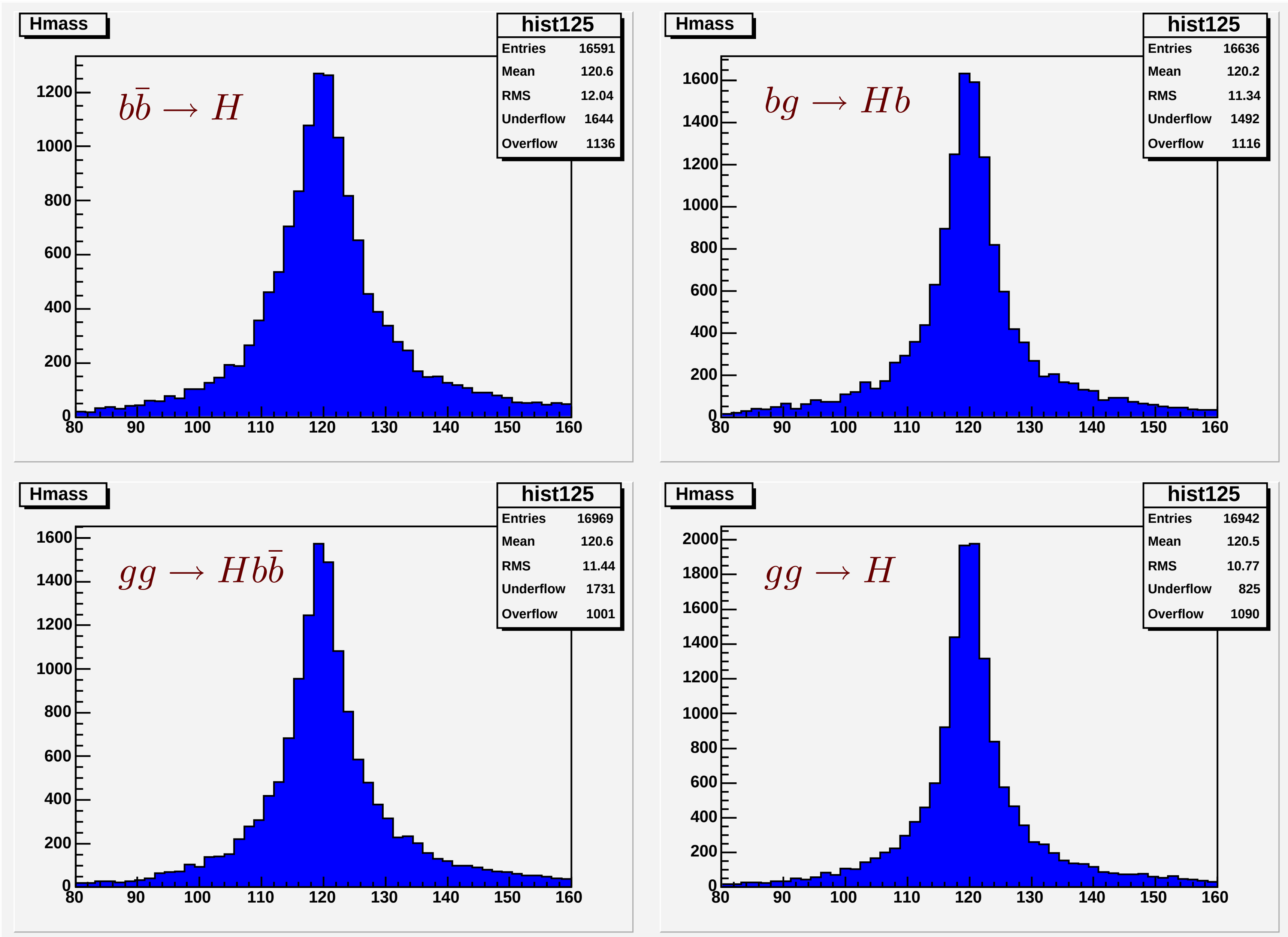
1. Let us look at the case when one of the τ's decays hadronically and second leptonically, then the final signature is thus $(\ell\ \tau$-jet $E_T^{miss})$.
2. The cumulative acceptances for the selection criteria and for different approaches of modeling production process will be shown
3. For each 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.

Case for LHC

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**
$\vert sin(\Delta\phi_{\ell\ \tau-jet})\vert > 0.2$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	$9.4 \cdot 10^{-2}$	$10.4 \cdot 10^{-2}$	
$m_T^{\ell,miss} <$ 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**
$\vert sin(\Delta\phi_{\ell\ \tau-jet})\vert > 0.2$	$5.9 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$	$6.5 \cdot 10^{-2}$	$8.2 \cdot 10^{-2}$	
$m_T^{\ell,miss} <$ 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**

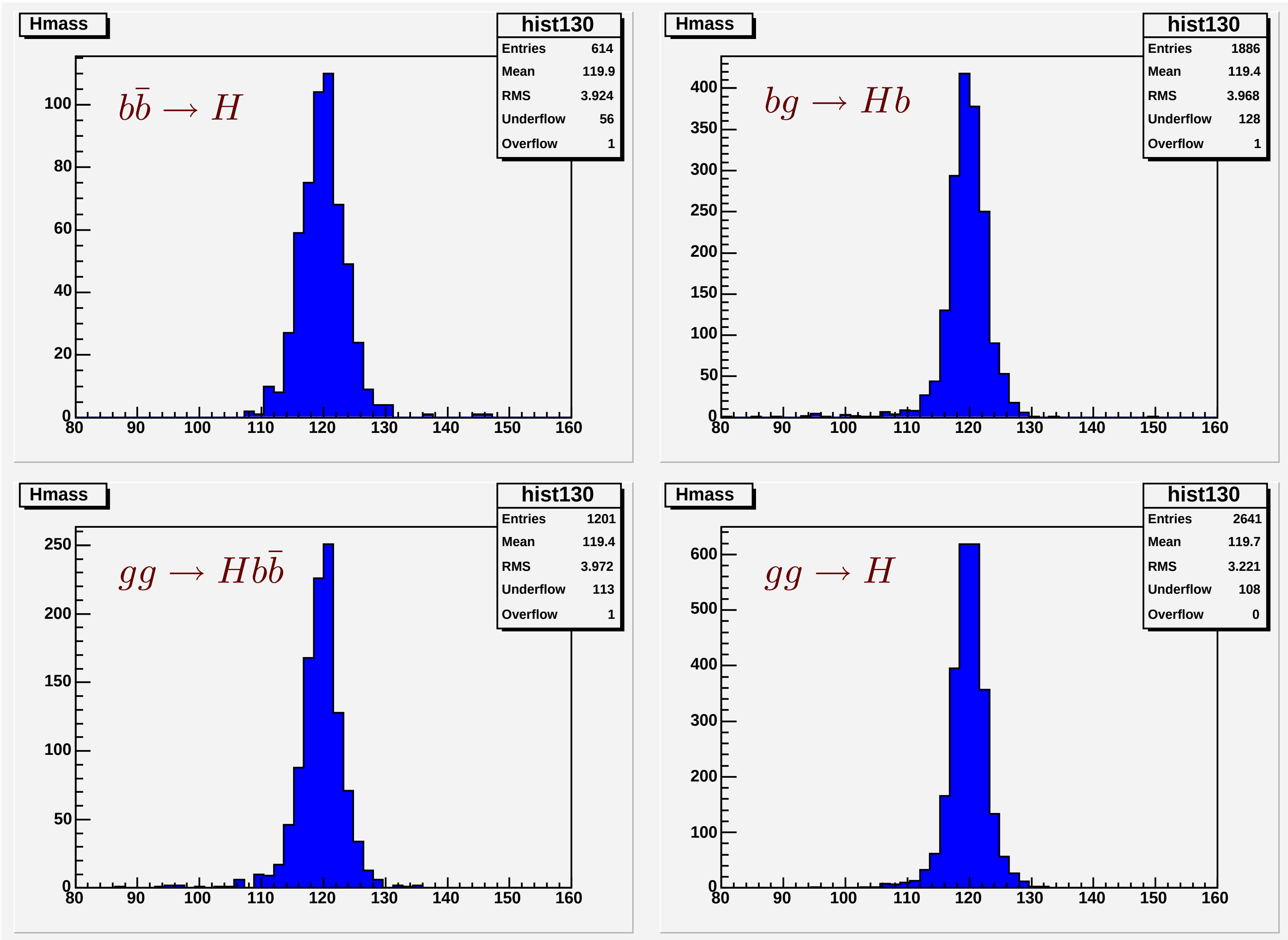
Case for LHC

Reconstructed Higgs peak, selection A



Case for LHC

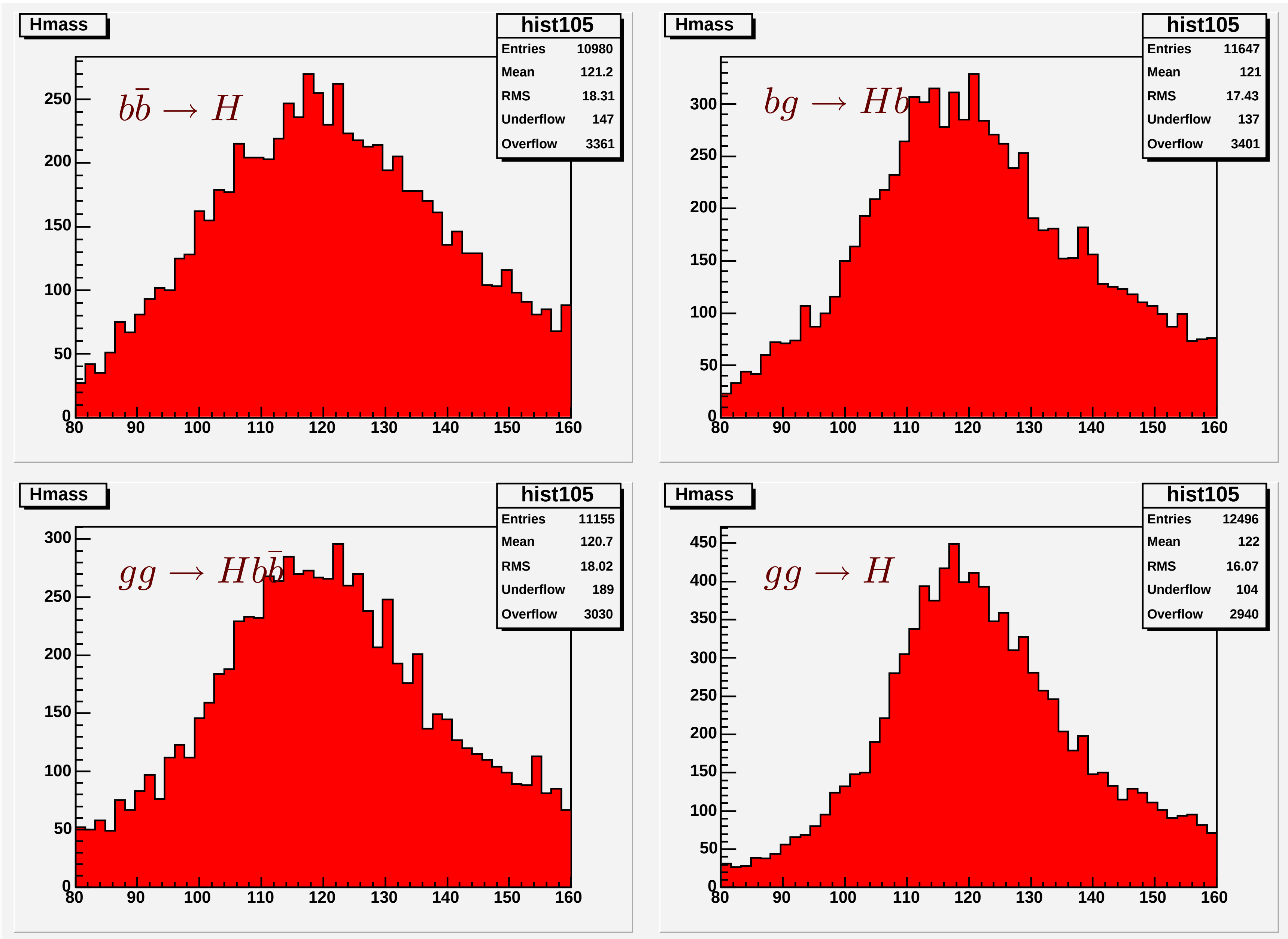
Reconstructed Higgs peak, selection B



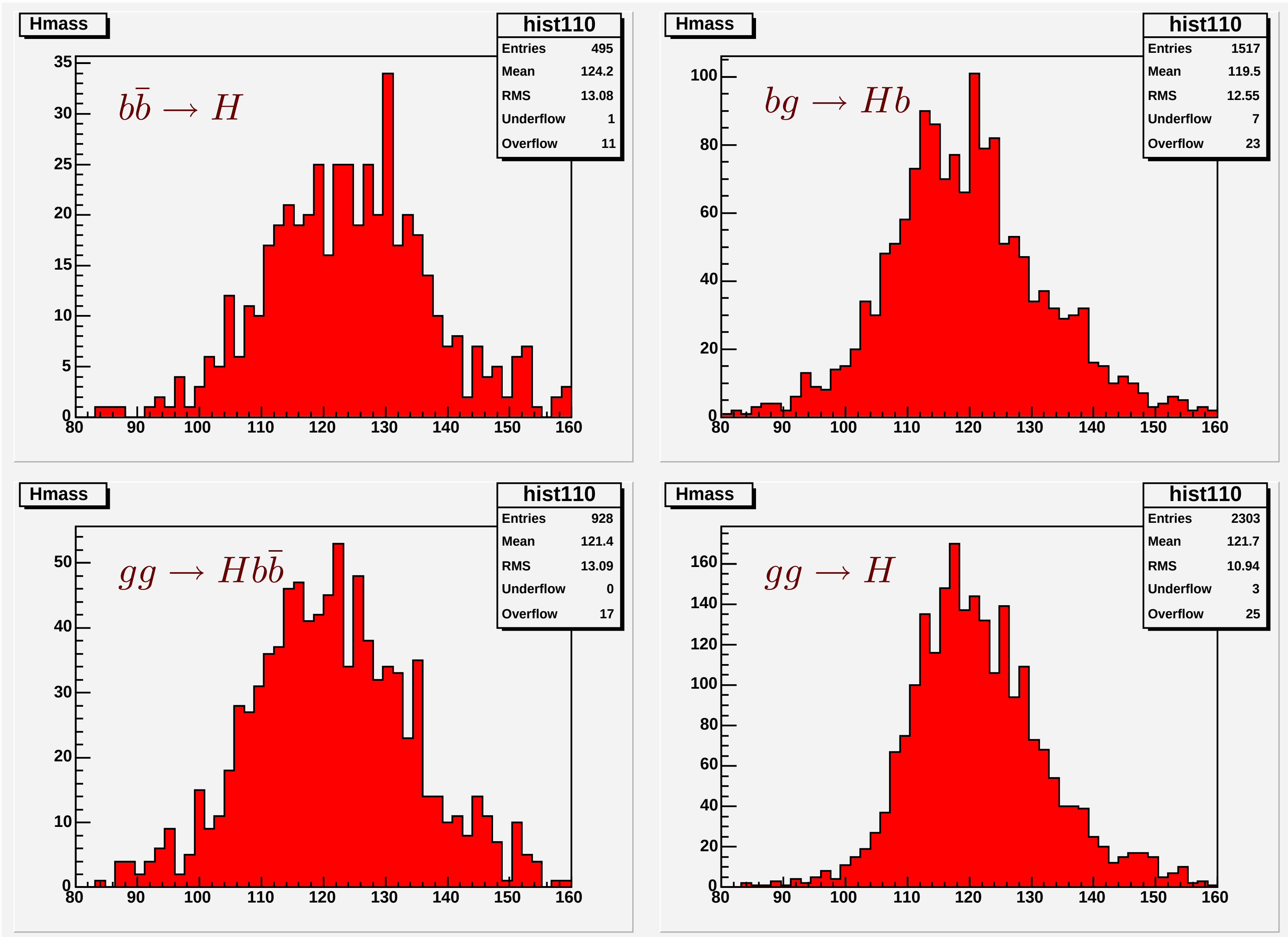
Mini Conclusions for Particle Level

- *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



Case for LHC

Selection	$b\bar{b} \rightarrow H$	$gb \rightarrow bH$	$gg \rightarrow b\bar{b}H$	$gg \rightarrow H$	$--$
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* $\longrightarrow$
  3. *improve experimental analysis* $\longrightarrow$
- *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:
  - TAOLA as generator for τ decays
  - TAUOLA interfaces for applications in different conditions.
  - PHOTOS as generator for radiative corrections in decays.
- With the help of the tools we have shown applications:
  - For LC where separation for production and decay of Higgs could be exploited.
  - For LHC and Higgs boson in $b\bar{b} \to h \to \tau^+\tau^-$ where separation seem to break because of combined theoretical and experimental effects on p_T^{mis}.
- we conclude that control of systematic errors for MC simulations may be important for LHC
- we do not conclude that it must be done from theoretical calculations, it may come from any source, HERA data for example.

Summary

- **I have skipped completelly the questions related to systematic errors**
- **That is nonetheless essential part of the work.**