

TauSpinner for re-weighting τ -lepton events in Z, W, H production and decays at LHC

Z. Was*

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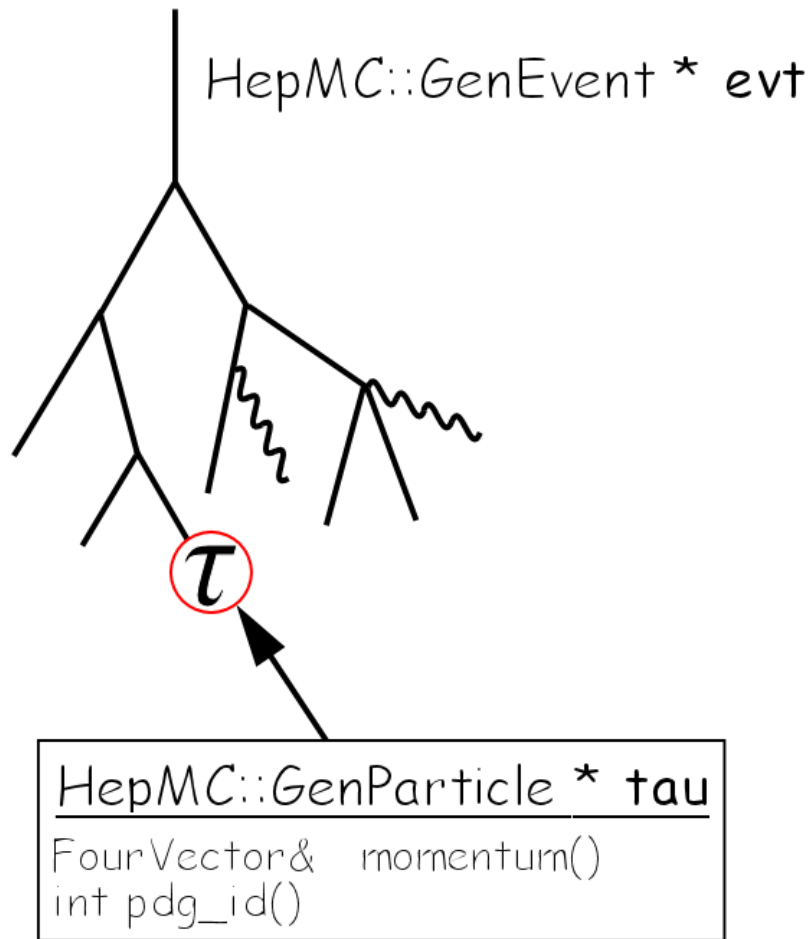
- **(1)** τ leptons can not be observed directly, also ν_τ escapes detection. This is a nuisance making observables difficult.

At the same time: τ is the only lepton of measurable spin state.

- **(2)** How to turn this complexity into advantage.
- **(3)** TauSpinner is a tool which is devoted to manipulation of spin effects on previously generated samples of events with the help of weights which can be calculated after events are generated and stored on production files.

1. To calculate weight = $\frac{|matrixelementnew|^2}{|matrixelementold|^2}$ one has to:
2. get phase space point at which weight is to be calculated
3. $|matrixelementold|^2$ with which this point was calculated.
4. That also means that variables used for calculation of matrix elements have to be reconstructed from information stored in event record or in production files.
5. This is possible, no numerical precision loss problems for present ATLAS/CMS production file formats.
6. **I will review main ideas behind such arrangements.** In a rather non-systematic way. Some formal considerations will be given in my PHOTOS talk later in a day.
7. Thanks to extremely narrow width of τ lepton its production and decay can be fully separated.
8. I will review (at least I will attempt) basic principle how TAUOLA interface work and how TauSpinner work.

www.ph.unimelb.edu.au/~ndavidson/photos/doxygen/index.html → PHOTOS C++/HepMC

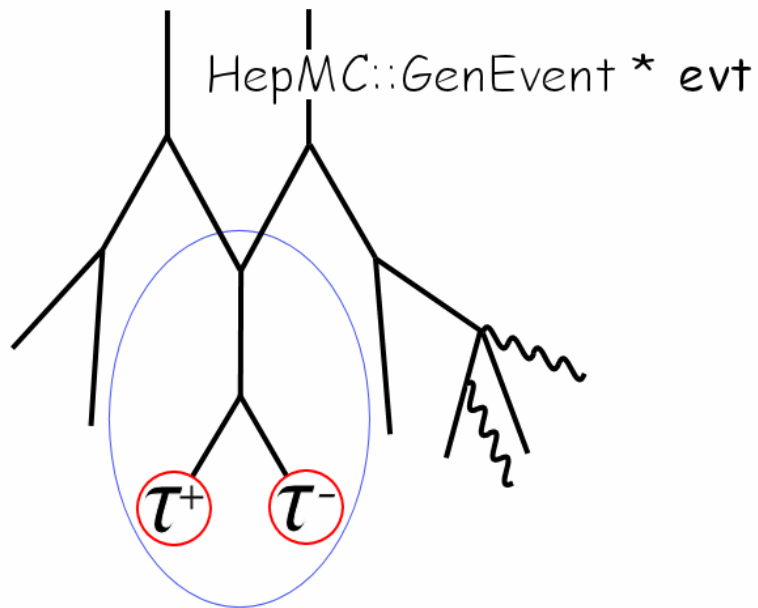


Tauola::decayOne(tau);

- For the individual τ decay method `Tauola::decayOne()` is provided
- Pointer `tau` to τ in HepMC as input.
- Unpolarized τ decay performed, decay products transferred to lab. frame using τ 4-momentum. Event record updated.
- Tau polarization vector, flag to re-decay already decayed τ can be passed.
- **Prepared for use in user applications when exact spin effects are required (like in EvtGen if TAUOLA needed there).**
- or in embedding single τ decay products (like in W decays)
- TauSpinner calculate spin weight for production vertex W^\pm or H^\pm .

Decay of $\tau^+\tau^-$ ($\tau^\pm\nu_\tau$) pair.

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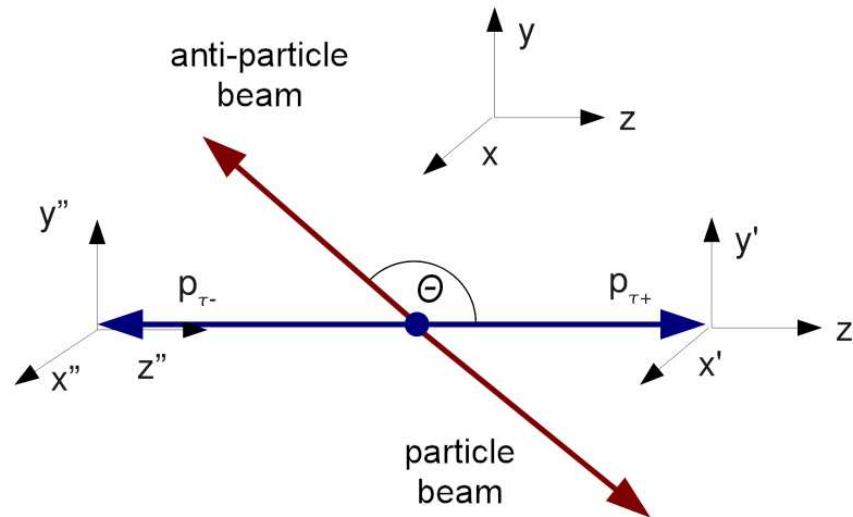


```
//Create object  
TauolaHepMCEvent t_evt(evt);  
//Decay taus  
t_evt.decayTaus();
```

```
TauolaParticlePair - get  
mothers/grandmothers
```

- Event record is searched for elementary processes like $1 \rightarrow 2$ (decays) or $2 \rightarrow 2$ or $2 \rightarrow 1 \rightarrow 2$ the s-channel production. For pairs found algorithm of next page is invoked.
- Transverse spin effects can be implemented and it is done for TAUOLA interface. For TauSpinner it is possible also, but then helicity states for taus can not be attributed.
- QUESTION: do you reconstruct π^0 's?
- TauSpinner can attribute helicity states to previously constructed events, calculate spin weight, calculate weight for matrix element change: electroweak corrections, New Physics etc.

Decay of $\tau^+\tau^-$ ($\tau^\pm\nu_\tau$) pair.



- Configuration of hard process: flavors and 4-momenta of incoming quarks and outgoing τ 's (ν_τ)
- **NOTE:** algorithm for spin correlations has no approximation.
- However, method to calculate density matrix from input usually will impose approximations. TauSpinner attributes incoming quarks as collinear to beams from PDF's \times quark-level-Born-cross-sections
- Density matrix including EW corrections is an option. For TauSpinner add Z' X2. One can play with spin correlations. Using weights for previously generated samples.

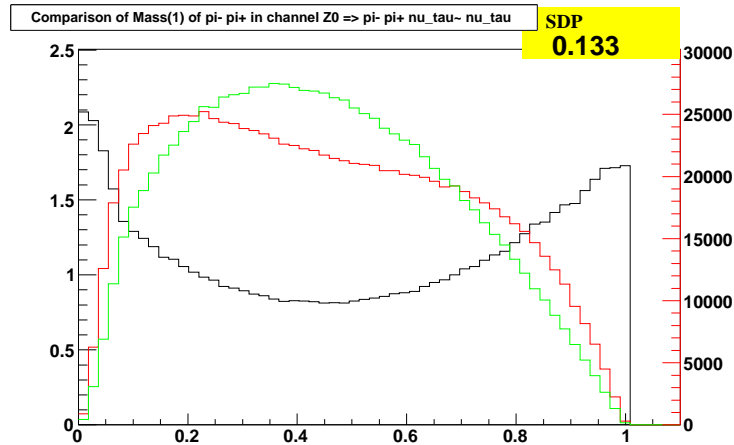
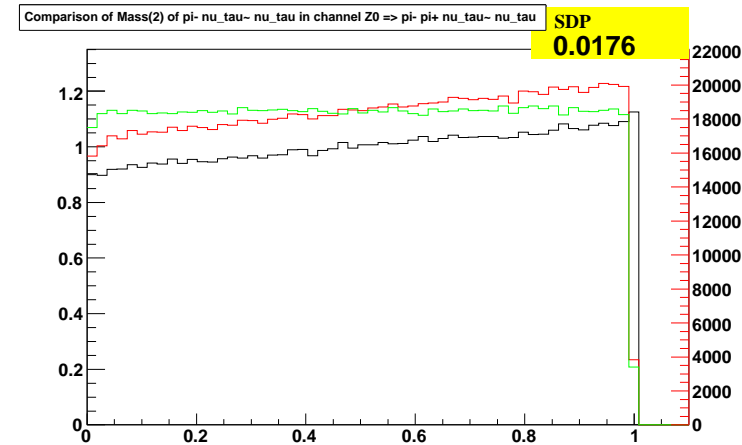
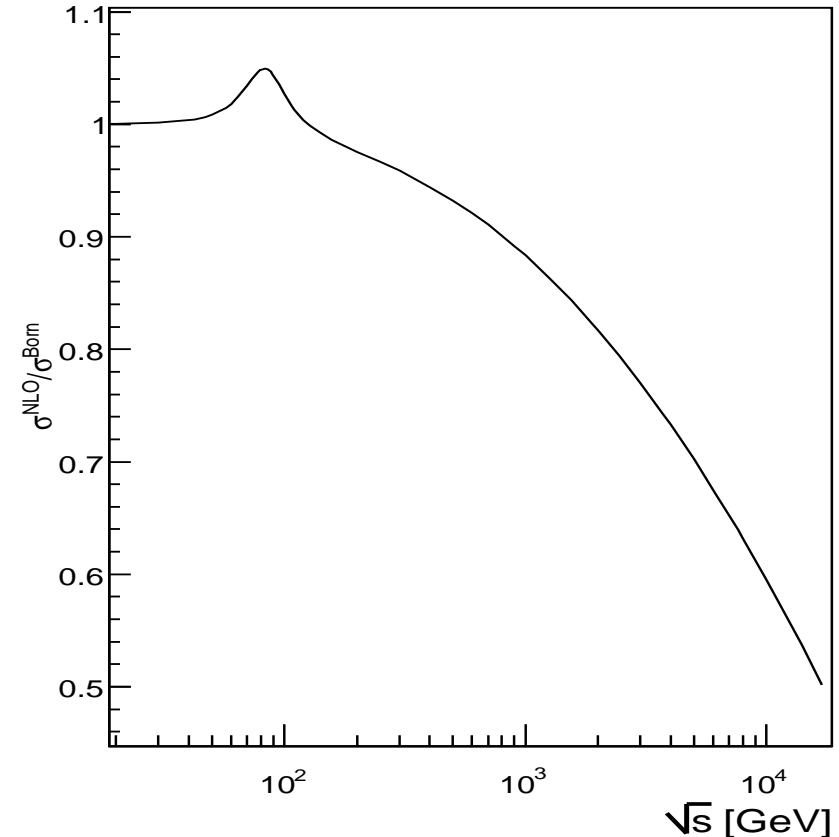
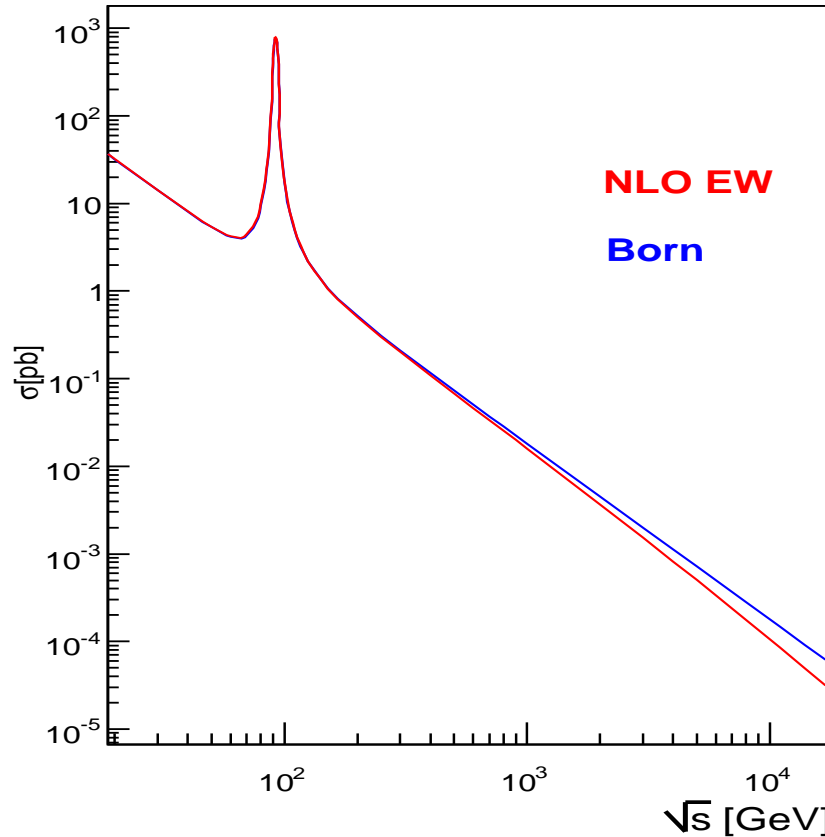
(a) $M_{\pi^+\pi^-}$ (b) $1 - 2 \frac{E_{\pi^+}}{M_Z}$

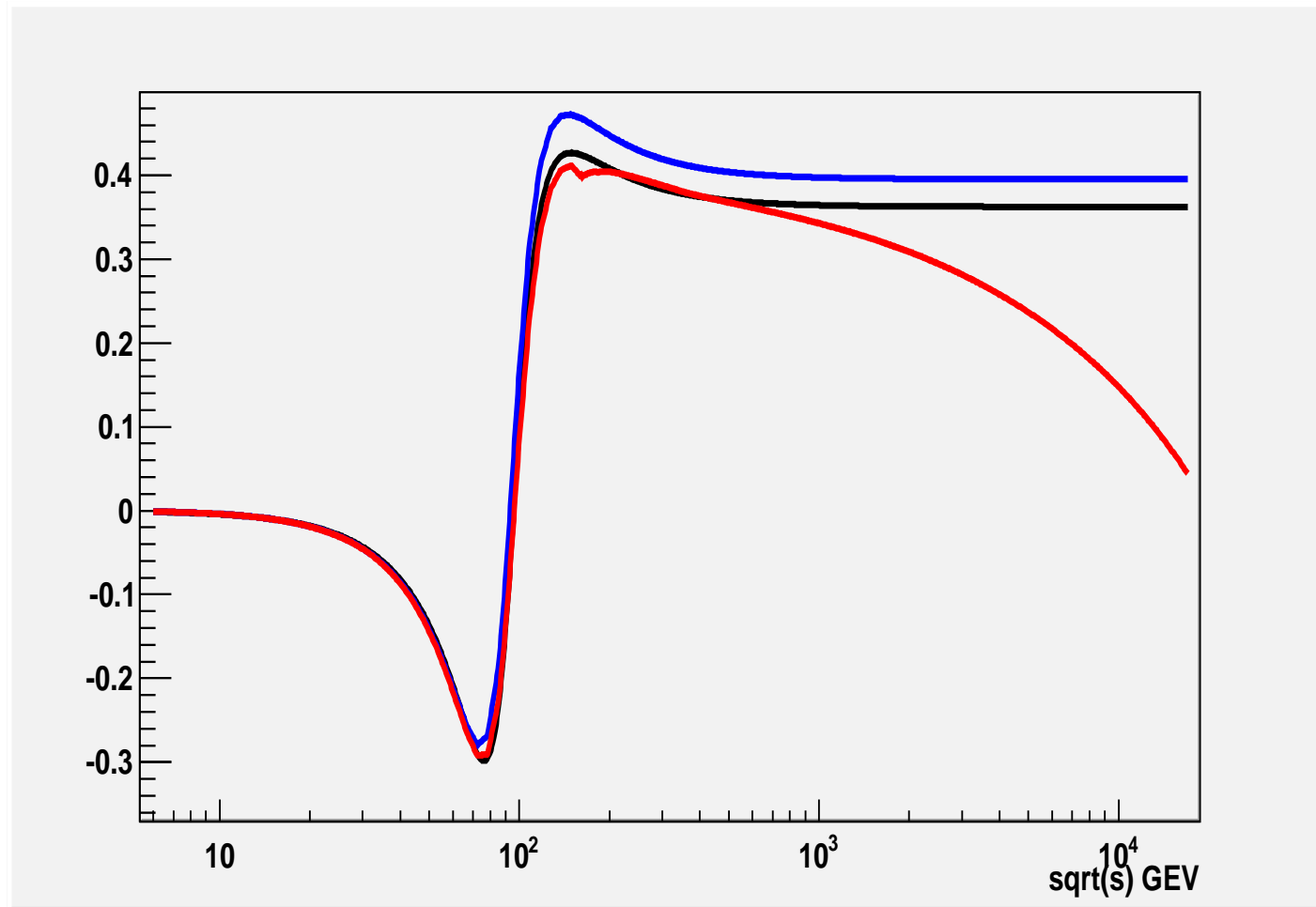
Figure 1: Longitudinal spin observables for the Z boson. Distributions are shown for spin effects switched on (red), spin effects switched off (green) and the ratio between spin on and off (black). Left plot show effect of correlation between τ^+ and τ^- decays, right one is for polarization. Figures are obtained with the help of MC-TESTER.



Effect of electroweak corrections on τ -pair production, up quarks, alpha scheme.

Q: What Born parameters are used in PYTHIA?

What effects are (are not) in EW segment. Discussion with Gizo today.

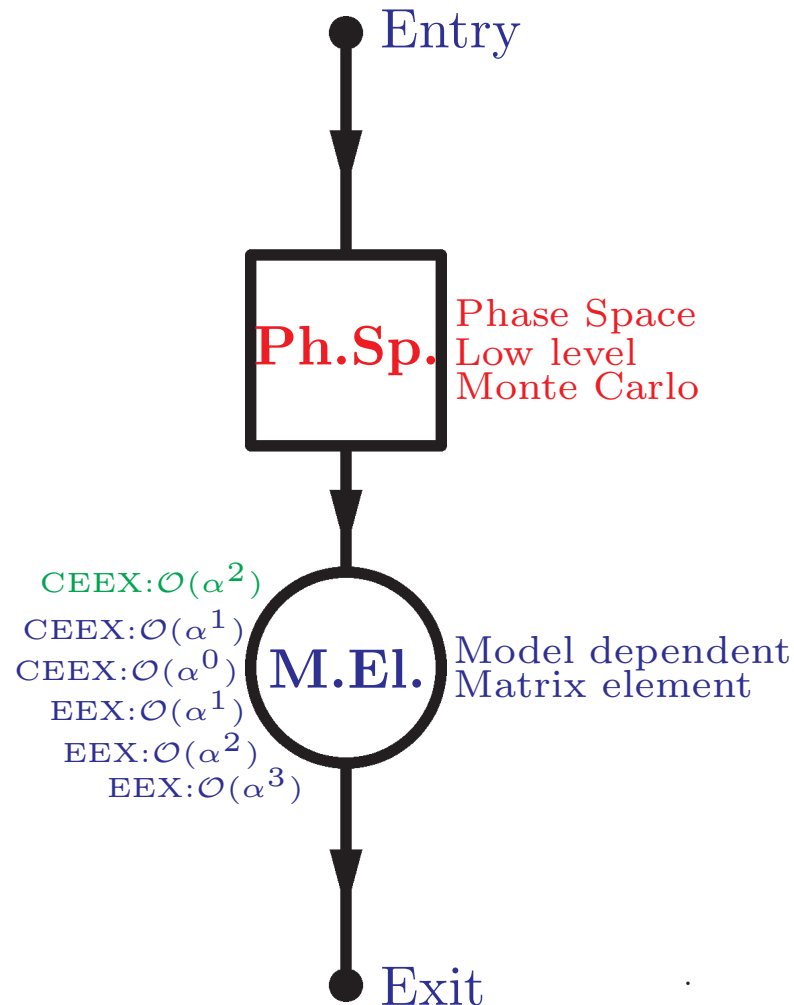


Effect of electroweak corrections on τ -polarization, up quarks. Red line includes electroweak corrections, Black is TAUOLA standard and blue is Born, alpha scheme. Scattering angle $\cos \theta = -0.2$

TAUOLA: 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.

Textbook principle “matrix element \times full phase space” ASSUMED



In the Monte Carlo realization it means that:

- Phase-space Monte Carlo simulator is a separate module producing “raw events” (including importance sampling for possible intermediate resonances)
- τ production matrix element can be replaced for TauSpinner weights (hadronic currents for fitting RChL currents as discussed yesterday).
- This is exactly like in case of KORALZ or KKMC of LEP time, also TauSpinner TAUOLA interface.

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

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

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

- Formula for the cross section can be re-written

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

- where

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

$$R_{00} = 1, \quad \langle wt \rangle = 1, \quad 0 \leq wt \leq 4.$$

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

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

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

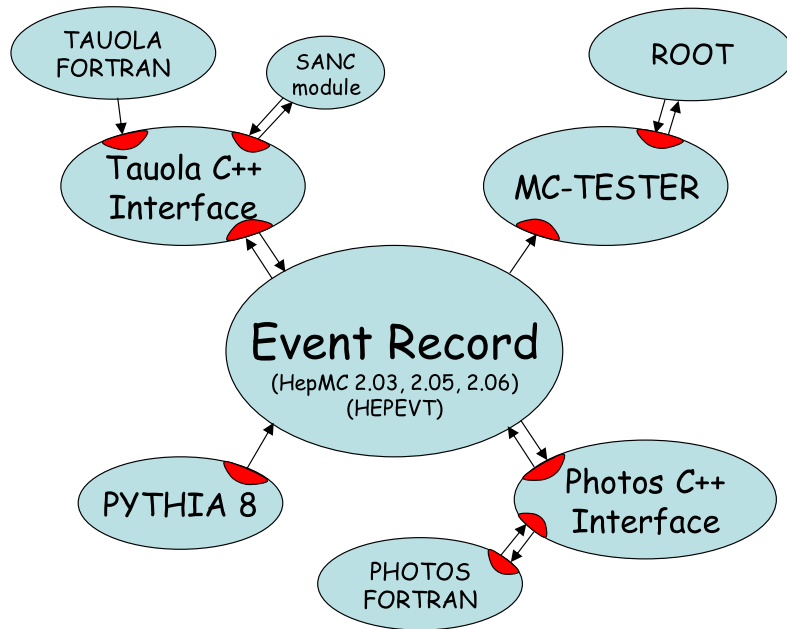
that means it is impossible to generate first τ^+ and τ^- first in some given 'quantum state' and later perform separately decays of τ^+ and τ^-

- It can be done only if approximations are used !!! (like in TauSpinner at present, no transverse spin effects. Critical topic: reconstruction of π^0 's.
- Spin weight can be calculated after event is constructed, detector response simulated and stored in file. It can be even embedded τ event.

What do we need to calculate spin and/or matrix element weight?

1. To calculate matrix element for τ decay we need 4-momenta of τ decay products.
2. to calculate hard process we need to know flavours and 4-momenta of incoming quarks/gluons.
3. incoming quarks/gluon states can be attributed stochastically on the basis of quark level matrix elements and PDF's.
4. then weights for distinct assumptions on spin and/or hard processes can be attributed.

Simulation parts communicate and store information in event record:



- Parts:

- hard process: (Born, weak, new physics),
- parton shower,
- τ decays

- QED bremsstrahlung

- High precision achieved

- Detector studies: acceptance, resolution lepton with or without photon.

Such organization requires:

- Good control of factorization (theory)
- Good understanding of tools on user side.
- **Sufficiently precise datafiles for TauS-pinner to work and replace matrix elements of segments using weights ...**