

TAUOLA for simulation of tau decay and production: perspectives of precision low energy and LHC applications.

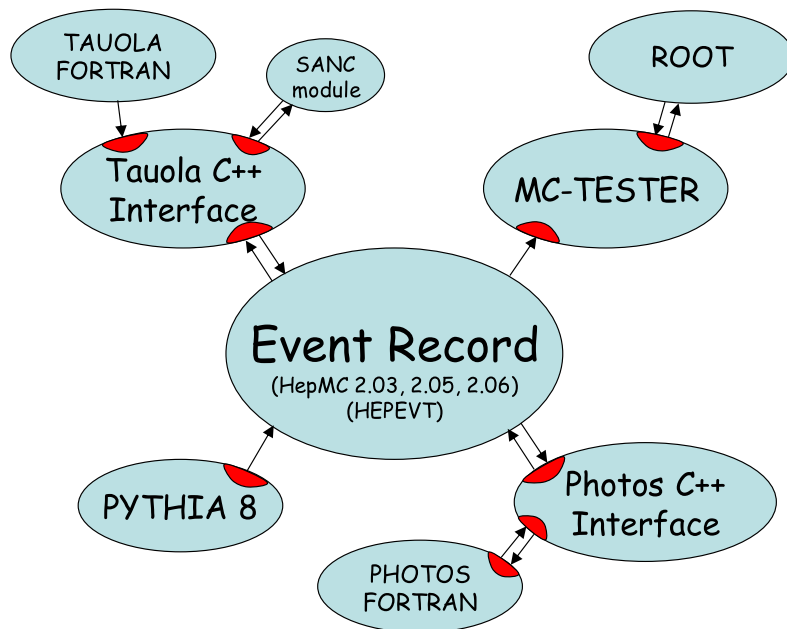
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- (1) *large mass* \rightarrow *large Yukawa coupling* \rightarrow *window for new physics*
- (2) *decays in detector* \rightarrow *its spin state can be measured* \rightarrow *window for parity*
- (3) *from QCD point of view its mass is intermediate. Decay M.E. has to be taken from models and low energy experiments data.*
- (4) *Production and decay are separated perfectly: large lifetime.*
- (5) How to use τ decays **to measure hard processes**: *interface in C++. Transverse spin correlations, electroweak corrections, better steering options for TAUOLA and PHOTOS*
- (6) How to improve fits to low energy data to improve quality of hadronic currents.

Supported in part by the EU grant Flavianet

Simulation parts communicate through event record:



- Parts:

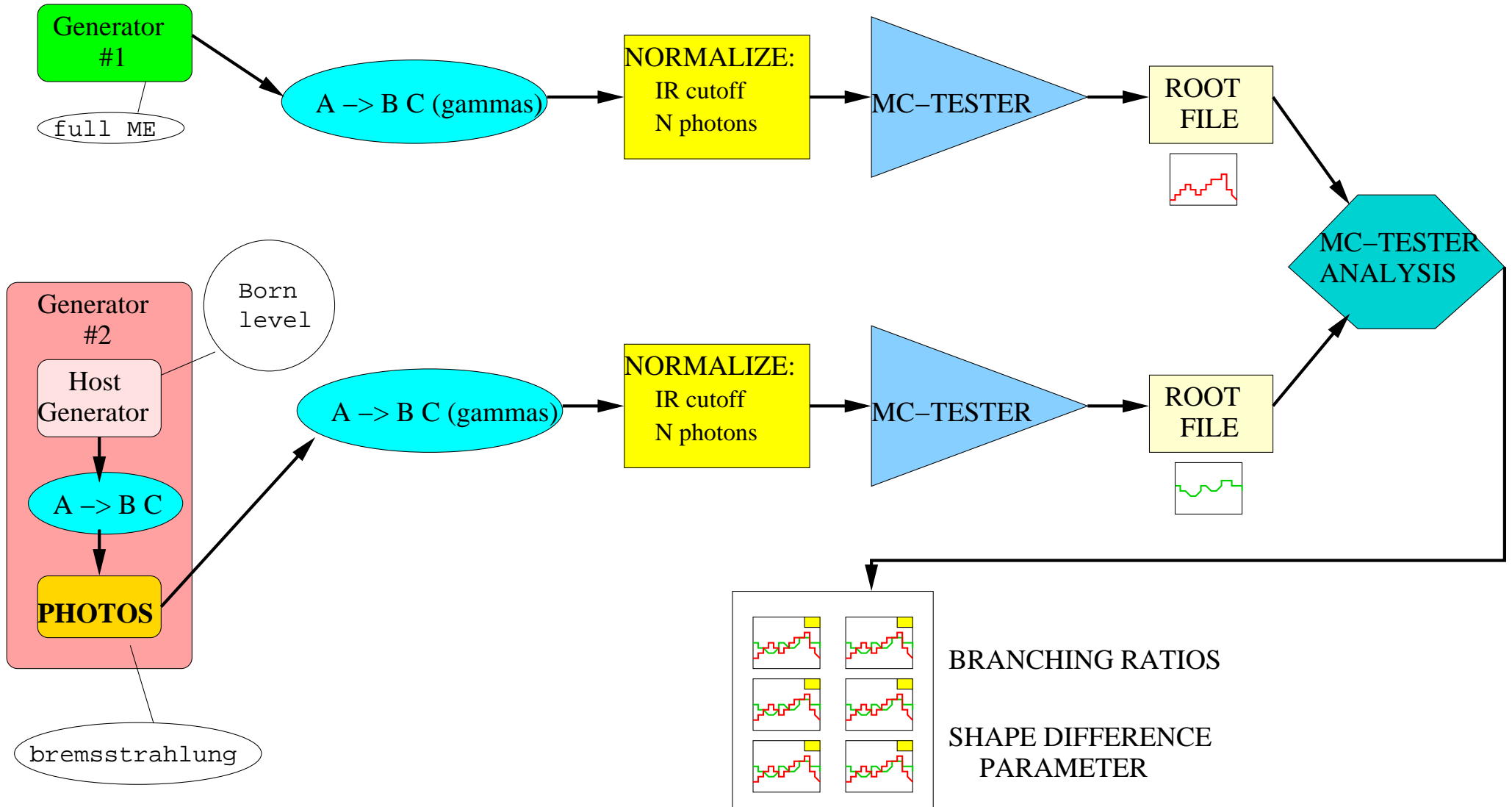
- hard process: (Born, weak, new physics),
- parton shower,
- τ decays
- QED bremsstrahlung
- High precision achieved
- Detector studies: acceptance, resolution lepton with or without photon.

Such organization requires:

- Good control of factorization (theory)
- Good understanding of tools on user side.

Seven distinct topics for my talk...

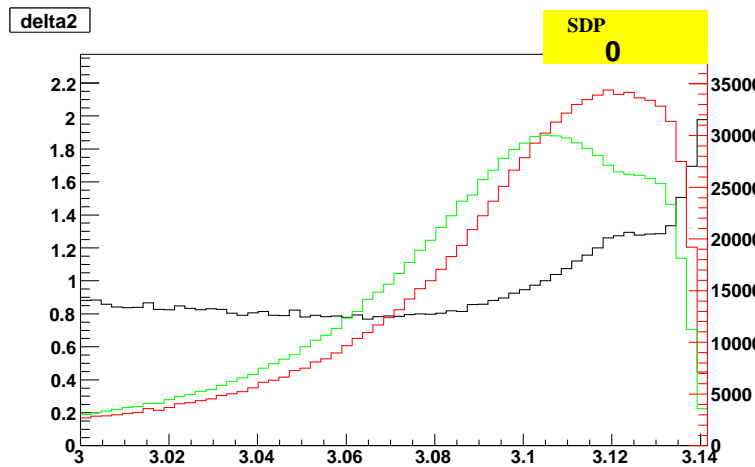
MC-TESTER to test PHOTOS/TAUOLA



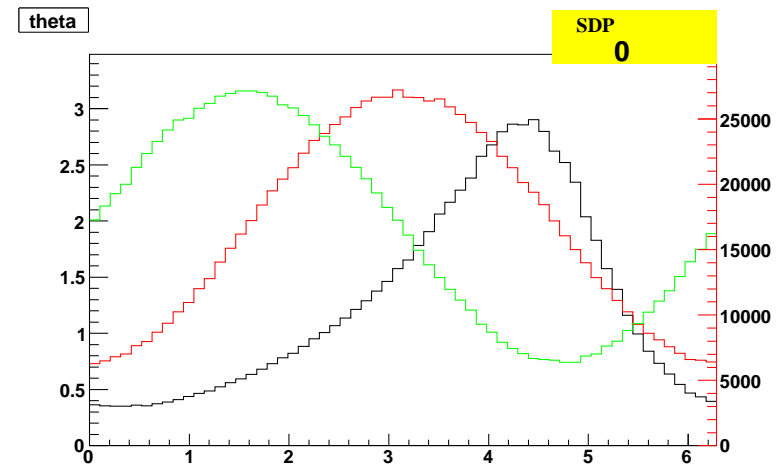
NEW

1. Documentation hep-ph 0812.3215 is up to date
2. Web page: <http://mc-tester.web.cern.ch/MC-TESTER/>
3. Project is mature now.
4. Interface to HepMC is available and is well checked thanks to its use in development of TAUOLA/PHOTOS C++ projects.
5. Not only invariant masses but user defined distributions can be collected.
6. [Use of root dictionaries is necessary/useful in that task.](#)

Distribution for Higgs parity



(a) $\pi^+\pi^-$ acollinearity distribution ($\approx \pi$)



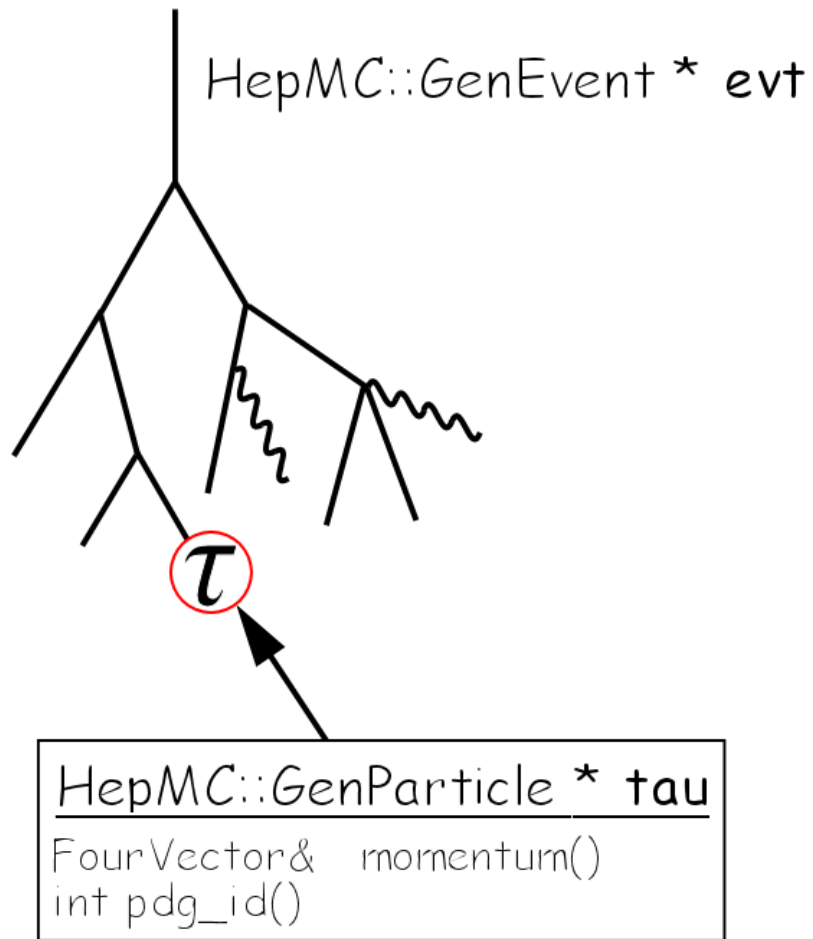
(b) $\pi^+\pi^-$ acoplanarity distribution

Figure 1: Transverse spin observables for the H boson for $\tau^\pm \rightarrow \pi^\pm \nu_\tau$. Distributions are shown for scalar higgs (red), scalar-pseudoscalar higgs with mixing angle $\frac{\pi}{4}$ (green) and the ratio between the two (black).

1. Internal τ decay dynamic is of secondary interest at LHC. It is challenging for low energy precision measurements: see hep-ph/0912.0749. That is why internal part of TAUOLA project remain in FORTRAN.
2. Event record interface is now also in C++ .
3. Physics quality of that HepMC interface is already better than its FORTRAN predecessor, but tests are less profound.
4. Web pages of TAUOLA C++
www.ph.unimelb.edu.au/~ndavidson/tauola/doxygen/index.html
5. Reference: arXiv:1001.0070 [hep-ph]

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

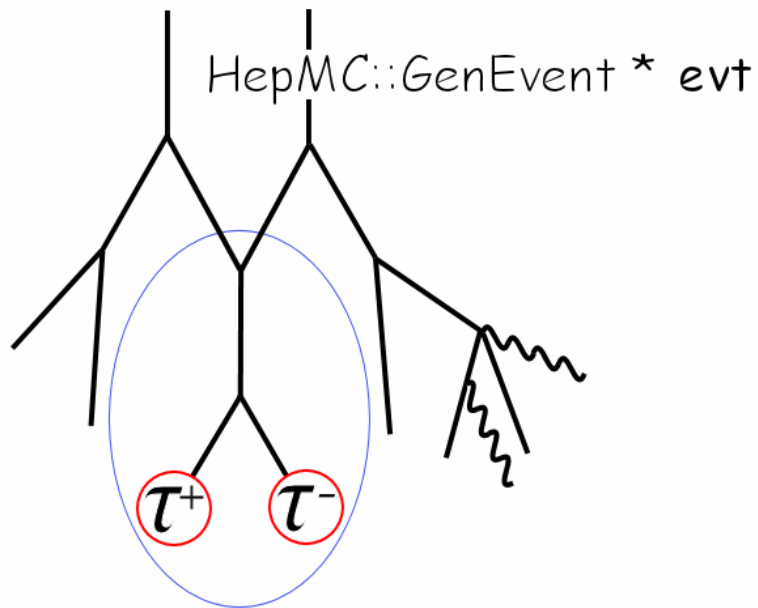
Single tau decay → **NEW**



Tauola::decayOne(tau);

- For the individual τ decay method `Tauola::decayOne()` is provided
- Pointer `tau` to τ in HepMC must be known.
- Unpolarized τ decay will be performed, decay products will be transferred to lab. frame using τ 4-momentum. Event record will be updated.
- Tau polarization vector, flag to re-decay already decayed τ and pointer to user defined method for boosting from τ rest-frame to lab frame can be passed as well.
- **Interface is prepared for use in user applications when exact spin effects are required (like in EvtGen if TAUOLA needed there).**

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

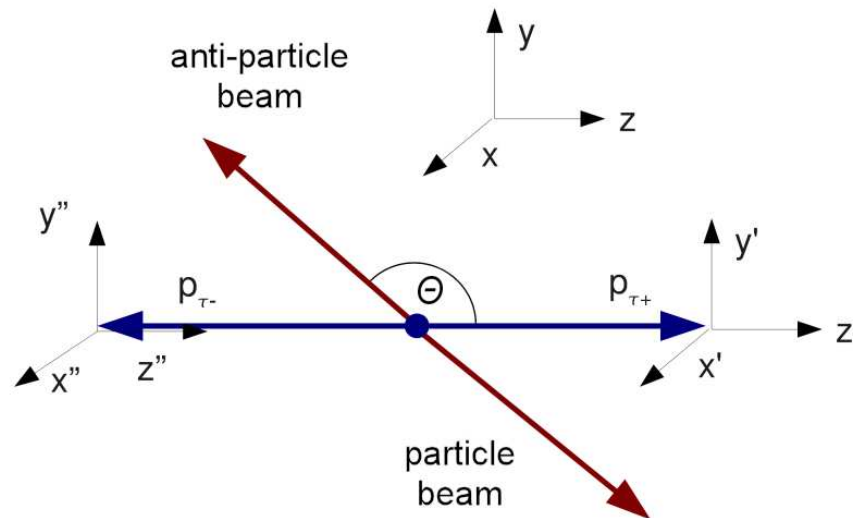


```
//Create object  
TauolaHepMCEvent t_evt(evt);  
//Decay taus  
t_evt.decayTaus();
```

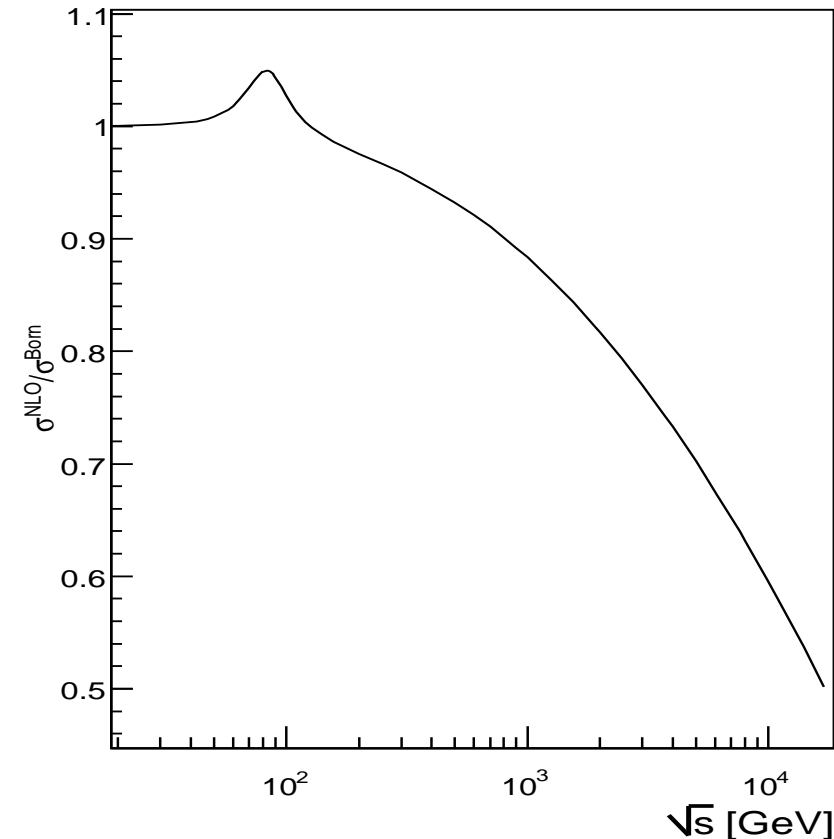
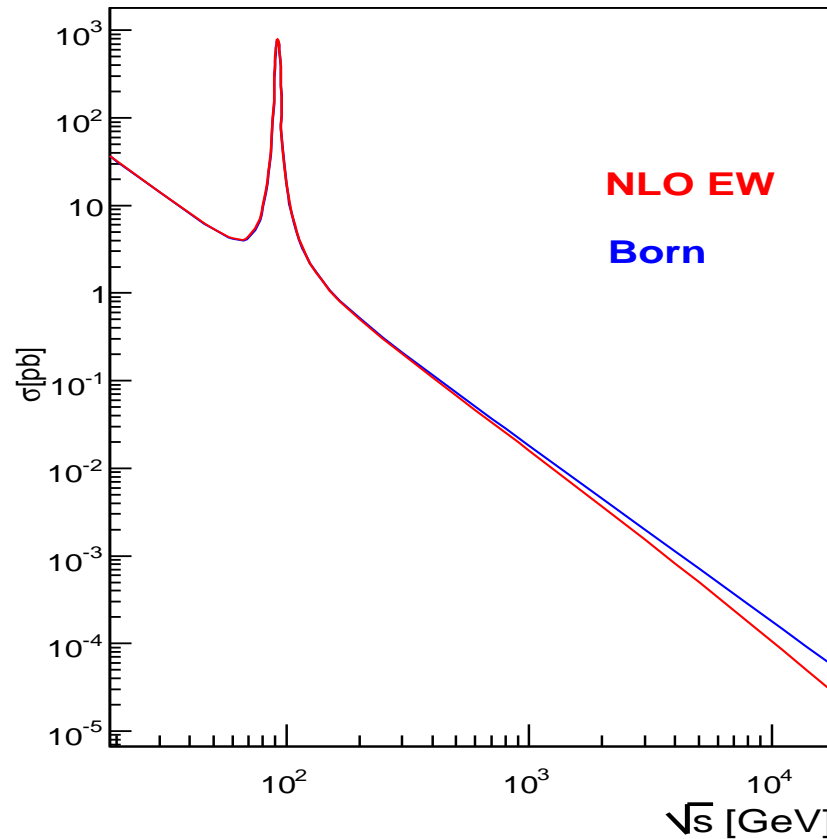
```
TauolaParticlePair - get  
mothers/grandmothers
```

- Create object `t_evt` of class `TauolaHepMCEvent` which inherit from abstract class `TauolaEvent` and use `evt` of `HepMC::GenEvent` class as parameter. Then apply `t_evt.decayTaus()`
- For method `.decayTaus()` 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.
- Interface was checked to work well with main processes as produced by PYTHIA 8.1.
- Further testing means checking correctness of HepMC trees.

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

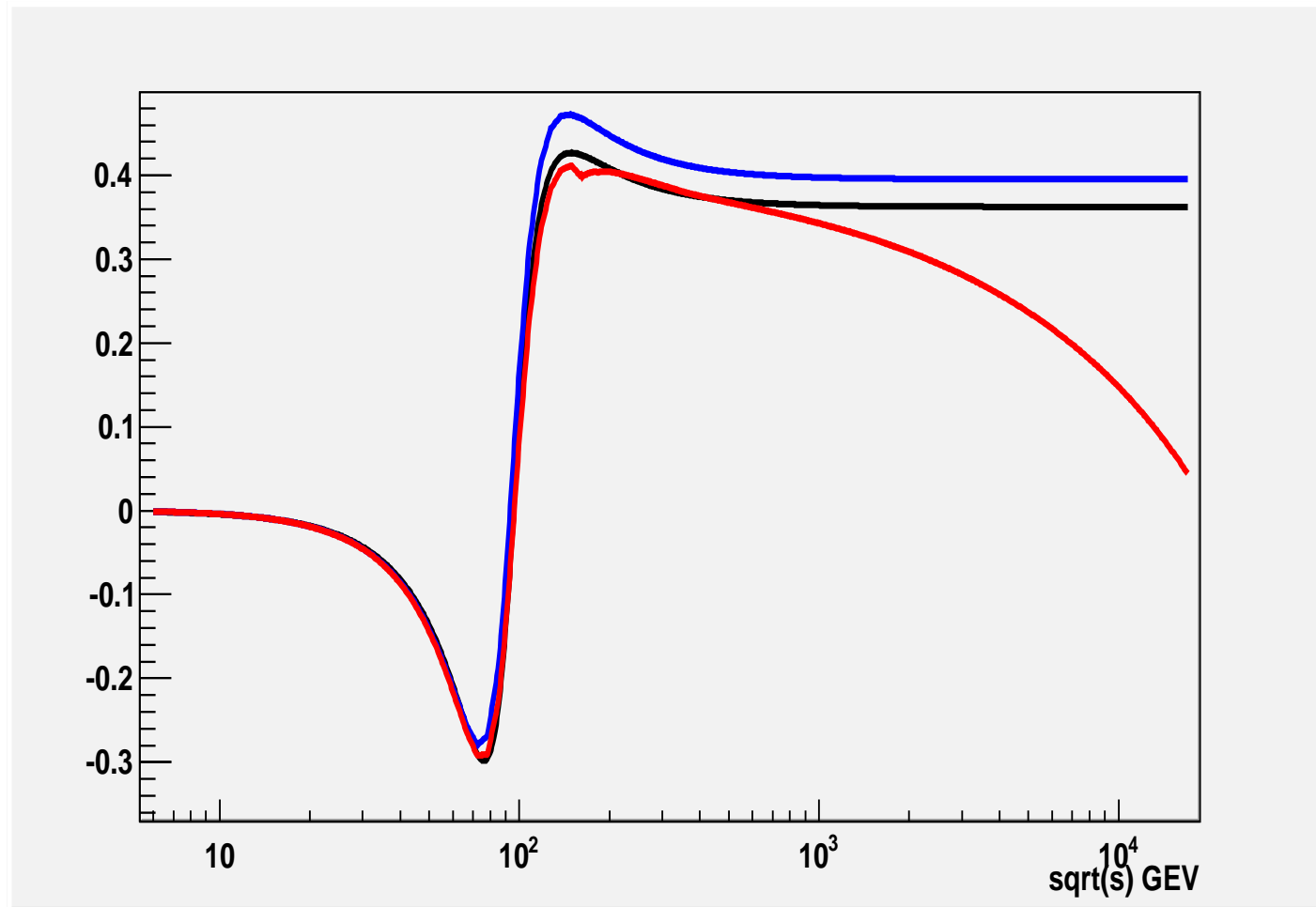


- Configuration of hard process: flavors and 4-momenta of incoming quarks and outgoing τ 's (ν_τ)
- **NEW:** algorithm for spin correlations has no approximation.
- However, method to calculate density matrix from that input usually will impose approximations.
- **NEW:** Density matrix including EW corrections is an option. This arrangement can be used to add Z' or to play with spin correlation component by component.
- **NEW:** Helicity states are attributed at the end (approximation is then used). Useful for some LEP style analyses.

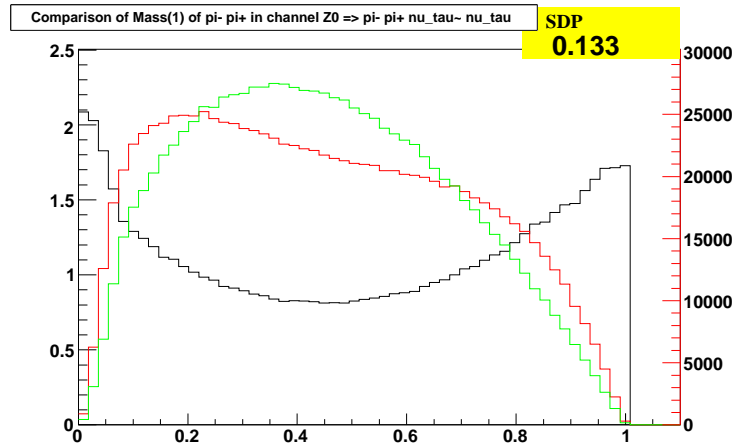


Effect of electroweak corrections on τ -pair production, up quarks, alpha scheme.

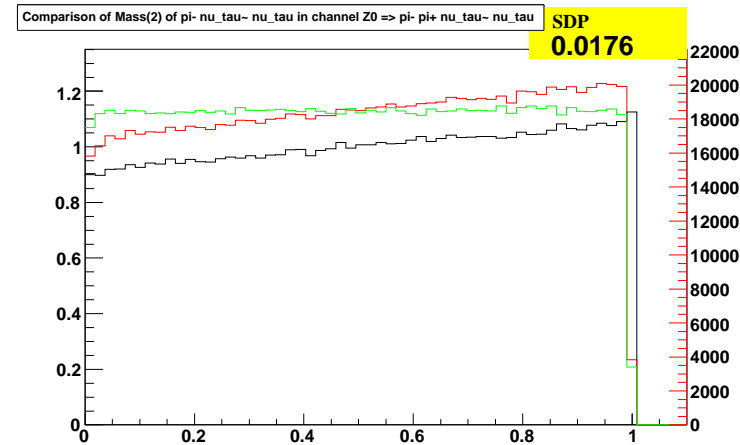
Q: What Born parameters are used in PYTHIA?



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 $\cos \theta = -0.2$

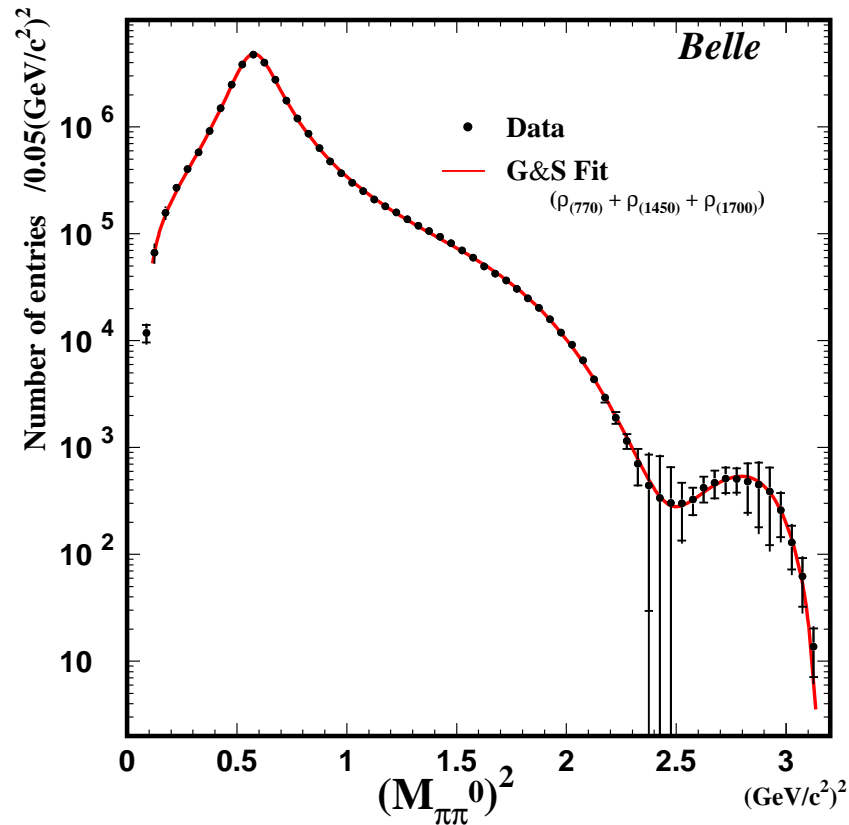


(a) $M_{\pi^+ \pi^-}$

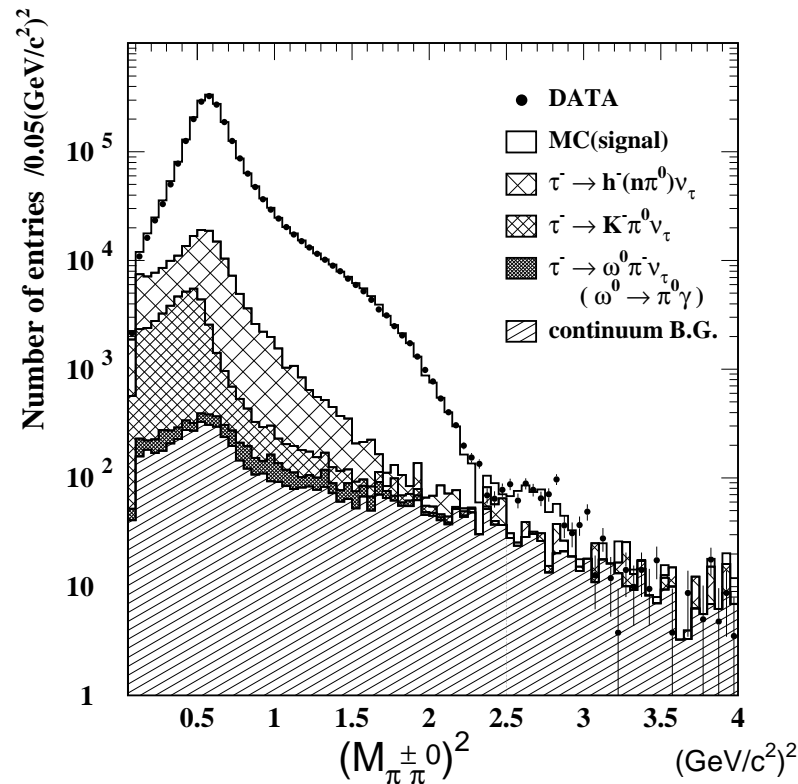


(b) $1 - 2 \frac{E_{\pi^+}}{M_Z}$

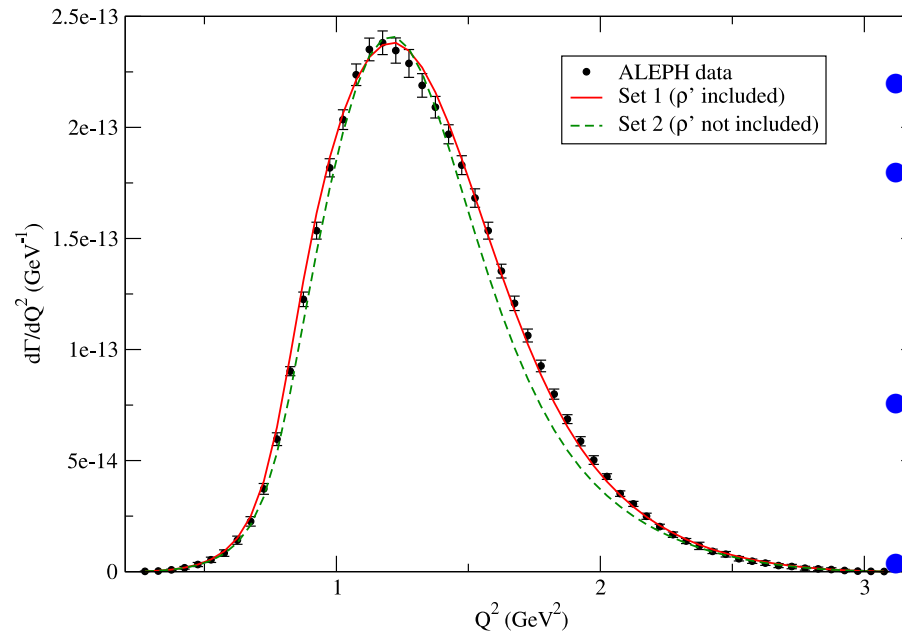
Figure 2: Longitudinal spin observables for the Z boson. Distributions are shown for spin effects switched on (red), spin effects switched off (green) and the ratio between spin on and off (black). Left plot show effect of correlation between τ^+ and τ^- decays, right one is for polarization. Figures are obtained with the help of MC-TESTER.



- We see that publicly available TAUOLA hadronic current is not perfect match of the experimental data.
- Quite in contrary, the internal Belle collaboration parametrization used in TAUOLA is making perfect match for invariant mass of $\pi^+\pi^0$ -pair in $\tau \rightarrow \pi^+\pi^0\nu$ decay channel.
- Correct simulation of τ decays for this mode and for LHC use!
- Single channel improvement bring real progress?



- Measured (Belle) distribution in interesting range has to be disentangled from background.
- At higher end of the spectrum background dominates over $\pi^+\pi^0\nu_{\tau}$.
- The same should be expected from LHC detectors.
- Correct simulation of τ decays for LHC applications and for Belle BaBar backgrounds as well!
- But, do it for all channels simultaneously!
- Who should play dominant role in validating final choices: model builders? MC authors? Experiments?
- Man power and coordination issues are essential too.



- The 3π decay mode is important contributor to τ decays. We install new currents into TAUOLA. We start from 0911.4436 [hep-ph].
- We attempt 0.05 % technical precision.
- Branching ratios are: Monte Carlo $4.2028 \cdot 10^{-13} \pm 0.015\%$ Semi analytical $4.202722 \cdot 10^{-13} \pm 0.006\%$
- Physics precision is not as good, but theoretical frame is there.
- Methods of porting the code to Belle BaBar to be discussed in context of precision fits are important.
- Only when this step is completed we can announce real progress.

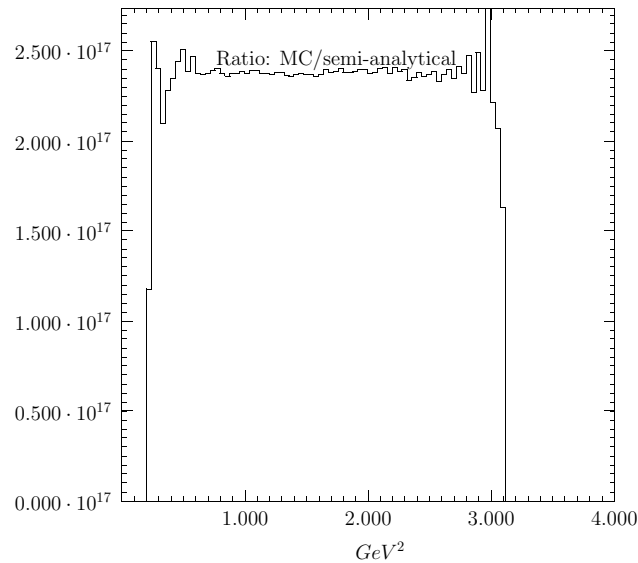
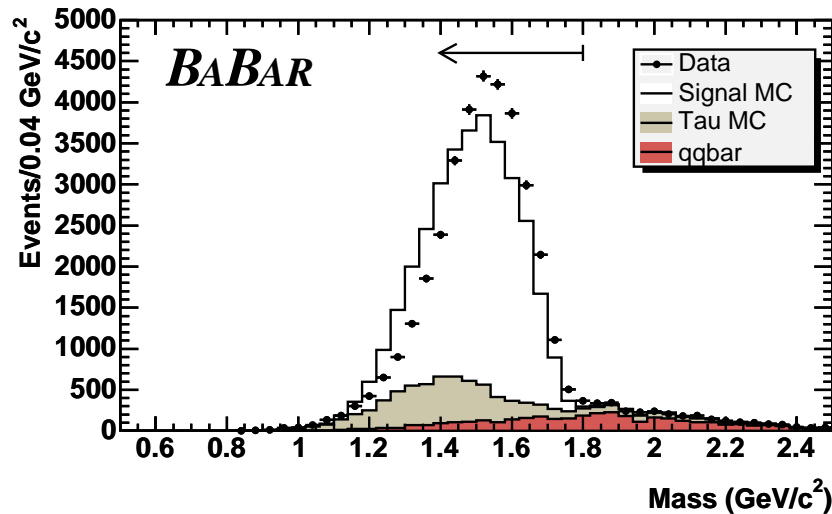


Figure 3: First attempt for comparison of Monte Carlo result with numerical calculation for spectrum of hadronic system invariant mass squared. Ratio of the two is shown. Statistical sample of 2.5M evts was used and semi-realistic initialization as explained in the section. Reasonable agreement between Monte Carlo and numerical integration is found.

It is promising but no final plot. Following is missing On Monte Carlo side: 0.07 % events are overweighted, maximum weight and/or presampler parameters have to be tuned, size of the overweighting need monitoring. Plot need normalization.

- Ratio of Monte Carlo obtained $\frac{d\Gamma}{dQ^2}$ and semi analytical formula is shown.
- Agreement looks perfect.
- Physics precision is not as good, also $\frac{d\Gamma}{dQ^2}$ represents an input to the model parametrization.
- Differential distributions and full data need to be confronted.
- How to parametrize differences between model and data if it is needed?



The invariant mass of five charged particles for $\tau^- \rightarrow 3h^- 2h^+ \nu_\tau$ at BaBar.
How to improve in systematic way?

- For multi-scalar final states challenge: simultaneous fits of many complex form-factors of many variables into massively multi-dimensional distributions. Theoretical constraints apply (or not)
- I hope that this challenge will be addressed by Belle and BaBar.
- But it is not going to be easy.
- On the technical side, that is the reason why parts of TAUOLA will remain in FORTRAN until this work is finished.
- We have prepared some software which may be helpful. Let me explain how it works.

General formalism for semileptonic decays

- Matrix element used in TAUOLA for semileptonic decay

$$\tau(P, s) \rightarrow \nu_\tau(N) X$$

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

- J_μ the current depends on the momenta of all hadrons

$$|\mathcal{M}|^2 = G^2 \frac{v^2 + a^2}{2} (\omega + H_\mu s^\mu)$$

$$\omega = P^\mu (\Pi_\mu - \gamma_{va} \Pi_\mu^5)$$

$$H_\mu = \frac{1}{M} (M^2 \delta_\mu^\nu - P_\mu P^\nu) (\Pi_\nu^5 - \gamma_{va} \Pi_\nu)$$

$$\Pi_\mu = 2[(J^* \cdot N) J_\mu + (J \cdot N) J_\mu^* - (J^* \cdot J) N_\mu]$$

$$\Pi^{5\mu} = 2 \text{Im} \epsilon^{\mu\nu\rho\sigma} J_\nu^* J_\rho N_\sigma$$

$$\gamma_{va} = -\frac{2va}{v^2 + a^2}$$

$$\hat{\omega} = 2 \frac{v^2 - a^2}{v^2 + a^2} m_\nu M (J^* \cdot J)$$

$$\hat{H}^\mu = -2 \frac{v^2 - a^2}{v^2 + a^2} m_\nu \text{Im} \epsilon^{\mu\nu\rho\sigma} J_\nu^* J_\rho P_\sigma$$

- Improvements for ρ channel are technically straightforward: single distribution to be fitted with real function to fit:

$$J^\mu = (p_{\pi^\pm} - p_{\pi^0})^\mu F_V(Q^2) + (p_{\pi^\pm} + p_{\pi^0})^\mu F_S(Q^2) \quad (F_S \simeq 0).$$

- For 3scalar channels: 4 complex function of 3 variables to fit. Role of theoretical assumptions (oversimplifications?) is essential. Agreement on 1 dim distribution is just a consistency check.
- No go for model independent measurements? Not necessarily. Use of all dimensions for data distributions: invariant masses Q^2 , s_1 , s_2 as arguments of formfactors. angular asymmetries help to separate currents: scalar $J_4^\mu \sim Q^\mu = (p_1 + p_2 + p_3)^\mu$, vector $J_1^\mu \sim (p_1 - p_3)^\mu|_{\perp Q}$ and $J_2^\mu \sim (p_2 - p_3)^\mu|_{\perp Q}$ and finally pseudovector $J_5^\mu \sim \epsilon(\mu, p_1, p_2, p_3)$.
- Model independent methods can be used, if: (i) enough data, (ii) absolute precision, (iii) no background, (iv) full detector coverage can assured. We need that for orthogonality conditions.
- It is a challenge but worth a try.

Map for fifo communicating executables

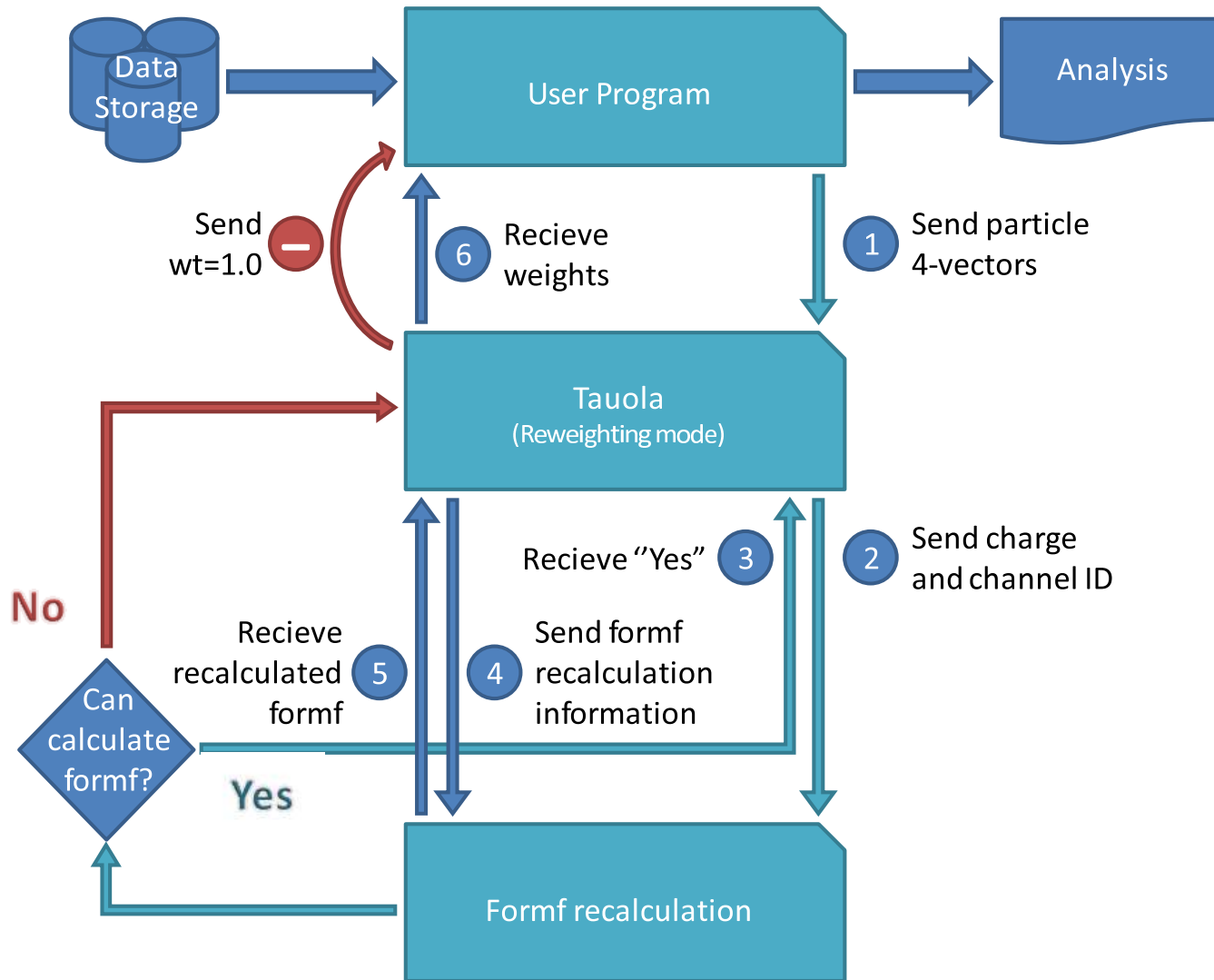
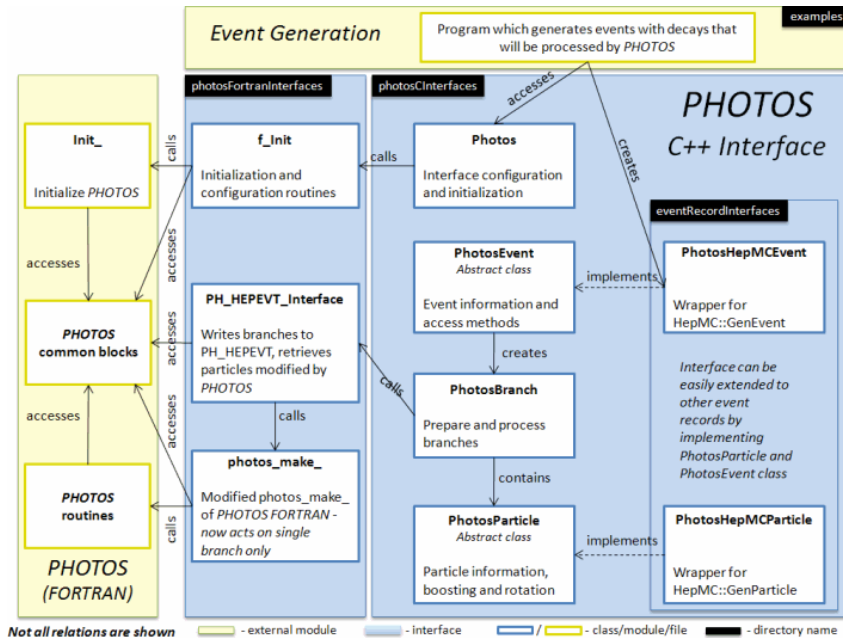
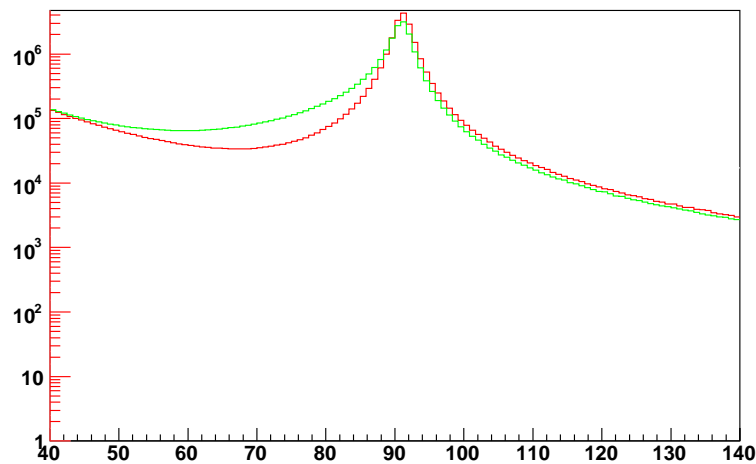


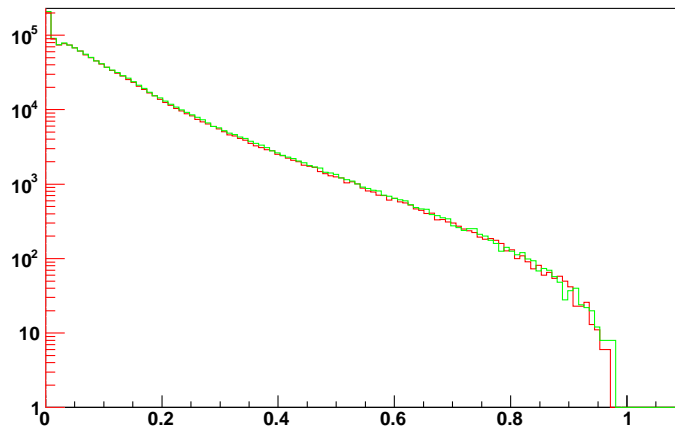
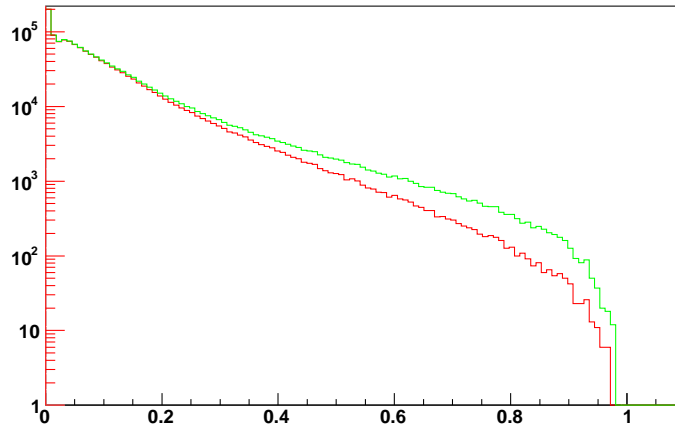
Figure 3: Flow chart for fifo communication. Verified to be compatible with Belle and BaBar software.



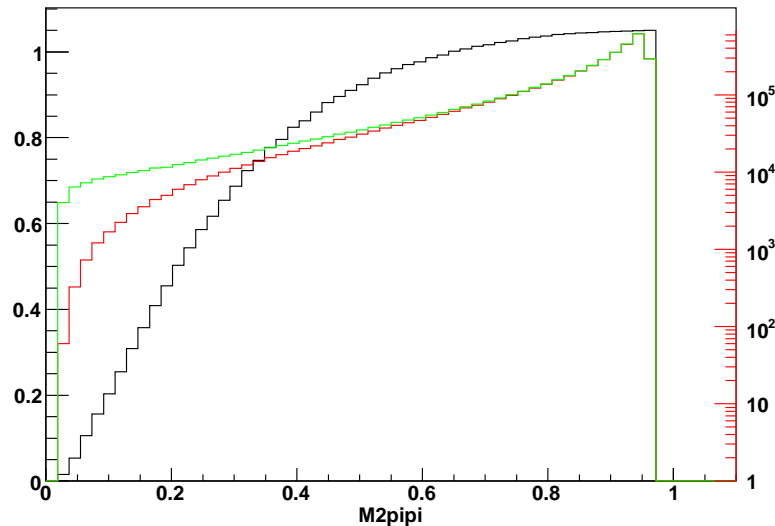
- Version in C++ available and complete. Methods to control emissions prepared: No brem in particular channel etc.
- All physics of FORTRAN version is in. Better access to decaying particle frame. Prepared for installation of process dependent matrix elements.
- All material for documentation collected, but editorial work must go on.
- Web page www.ph.unimelb.edu.au/~ndavidson/photos/doxygen/index.html is regularly updated. Tar ball is available from that web page.
- First release planned for October.



Distribution of bare e^+e^- invariant mass. (Bare means that photons collinear with e^+ or e^- are not included in mass calculation.) Green line represent results when final state bremsstrahlung is generated (with the help of PHOTOS Monte Carlo). For red line FSR bremsstrahlung is absent. Event sample is generated with the help of PYTHIA 8.1. Simulation of pp collision at 14 TeV Center of Mass system energy is performed. Z/γ mediated hard process is used. These plots has been created using custom `UserTreeAnalysis` of MC-TESTER. They can be recreated by performing the test located in `examples/testing/Zee` directory, see `examples/testing/README-plots` for technical details.



- Phase space; complete and exact.
- matching consecutive emission from the same charged line. Essence of NLO parton shower. Study with second order matrix element.
- Z decay: hard $\gamma\gamma$ pair mass (scaled to Z mass). Red line: exponentiation with second order matrix element. Upper plot green line: exponentiation + first order matrix element. Lower plot green line: PHOTOS. Second order effects are reproduced. Proper iteration.



- Emissions from many lines. Interference weight \rightarrow exact matrix element.
- Quest for precision in PHOTOS: decay channel dependent effects
- Effects $\sim 0.3\%$ bremsstrahlung or new process: 0906.4052 [hep-ph]
- Is it indeed bremsstrahlung there? Formulas (based on ChPT) for $K \rightarrow l\nu\pi$ from V. Cirigliano, M. Giannotti and H. Neufeld, “Electromagnetic effects in $Kl3$ decays,” JHEP **0811** (2008) 006, are closer to PHOTOS’s than to scalar QED.
- we start from $\gamma^* \rightarrow \pi^+\pi^-(\gamma)$. It is of interest by itself and as building block of amplitudes for many decays.

- New version of MC-TESTER released and documented.
- New version of TAUOLA interface (C++/HepMC) released and documented.
- **TAUOLA C++ interface is richer than its FORTRAN predecessor:**
 - Electroweak corrections are available for Z/γ mediated τ pair production.
 - algorithm for single τ decay is provided.
 - Special MC methods prepared: optional weights, helicity states info etc.
- parts remain in F77: low energy projects.
- FORTRAN TAUOLA universal interface will be serviced as long as needed.
- Analogous status should become available for PHOTOS C++ in October.

- **TAUOLA**

- Model of Pablo Roig for $\pi^+ \pi^+ \pi^-$ is pre-installed. level of technical tests of installation: below 0.05 % Work on software organization continues.
- Further decay modes: $\pi^+ \pi^0$, $K \pi$, $\pi^0 \pi^0 \pi^+$, $K \pi \pi$, $K K \pi$, $\eta \pi \pi$ etc. at work.
- TAUOLA with weights for alternative models and use in fits to the data prepared as patch to Belle/BaBar software prepared.

- **PHOTOS**

- infrastructure for public extensions with process dependent weights prepared.
- Examples for two body decays W, Z, H, B, γ^* and also $K \rightarrow \pi \pi l \nu$ and $K \rightarrow \pi l \nu$ available.

Tauola means CLEO frm 1996. Mismatch expected ?

Cabibbo suppressed decays



- ▣ Cabibbo suppressed (strange) τ decays are important for the determination of V_{us} , m_s plus non-p-QCD parameters at low- Q^2
- ▣ Status of V_{us} is nicely summarized by Sobie/Swagato
- ▣ There is a systematic difference between the one determined by Kaon decays and one using τ inclusive decays.
- ▣ V_{us} determination using Inclusive τ strange decays is the cleanest theoretically.



✓ -We will need measurements of **Br** of all strange decays also need **Spectral Functions** for theoretical consistency check. (Maltman Tau08).

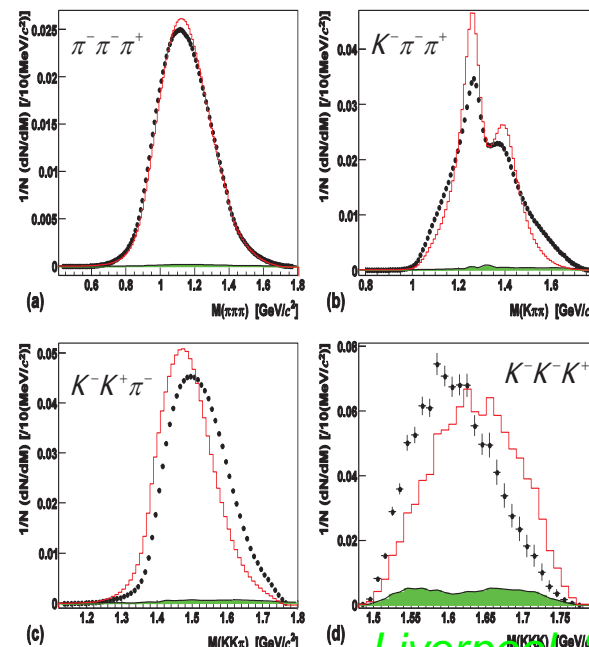
Recently, Belle provides precise unfolded mass spectrum for 2 strange decay modes; $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau$, $K^- K^+ K^- \nu_\tau$ and 2 non-strange decays $\pi^- \pi^+ \pi^- \nu_\tau$, $K^- K^+ \pi^- \nu_\tau$

• Green band is the systematic errors, including dependence of the resonance model for efficiency determination. Red histogram TAUOLA

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• The mass spectrum with Kaon does not agree with TAUOLA.

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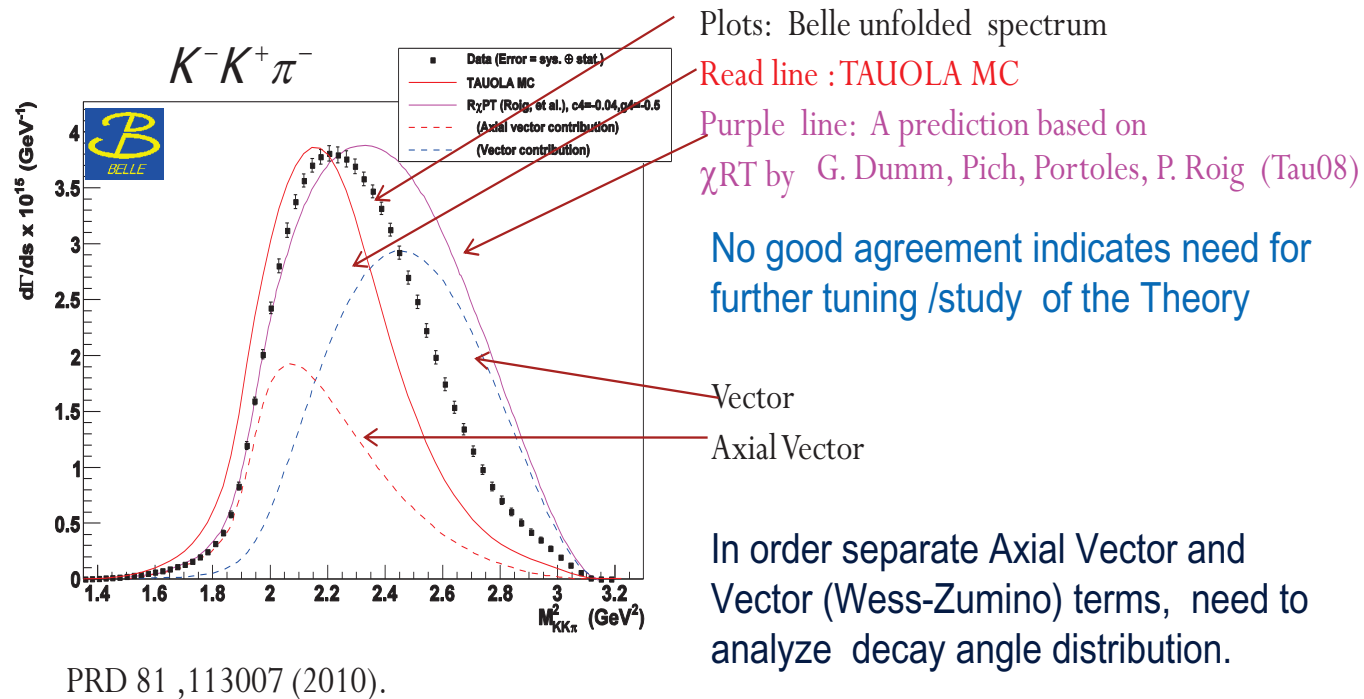


Liverpool, September, 2010

How model adaptation should be worked out. Resonsabilities are with ...

A comparison with $R_{\chi T}$ prediction

Exclusive hadron spectrum is useful for a test of theoretical models in resonance region.



TAUOLA for simulation of tau decay and production: perspectives are good or bad?

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- (1) *Many people but part time or disappearing*
- (2) *In principle routine established and things should move*
- (3) *But even low precision things are not done*
- (4) *Man power ?*
- (5) *Share of responsibility?*
- (6) Local support and grants ...