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

Z. Was[*], N. Davidson, G. Nanava, T. Przedzinski, E. Richter-Was, P. Roig, O. Shekhovtsova, Q. Xu

[*]Institute of Nuclear Physics, Krakow *and* CERN-PH, Geneva

- **(1)** *large mass → large Yukawa coupling → window for new physics*

- **(2)** *decays in detector → its spin state can be measured → 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 proceeses**: *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.

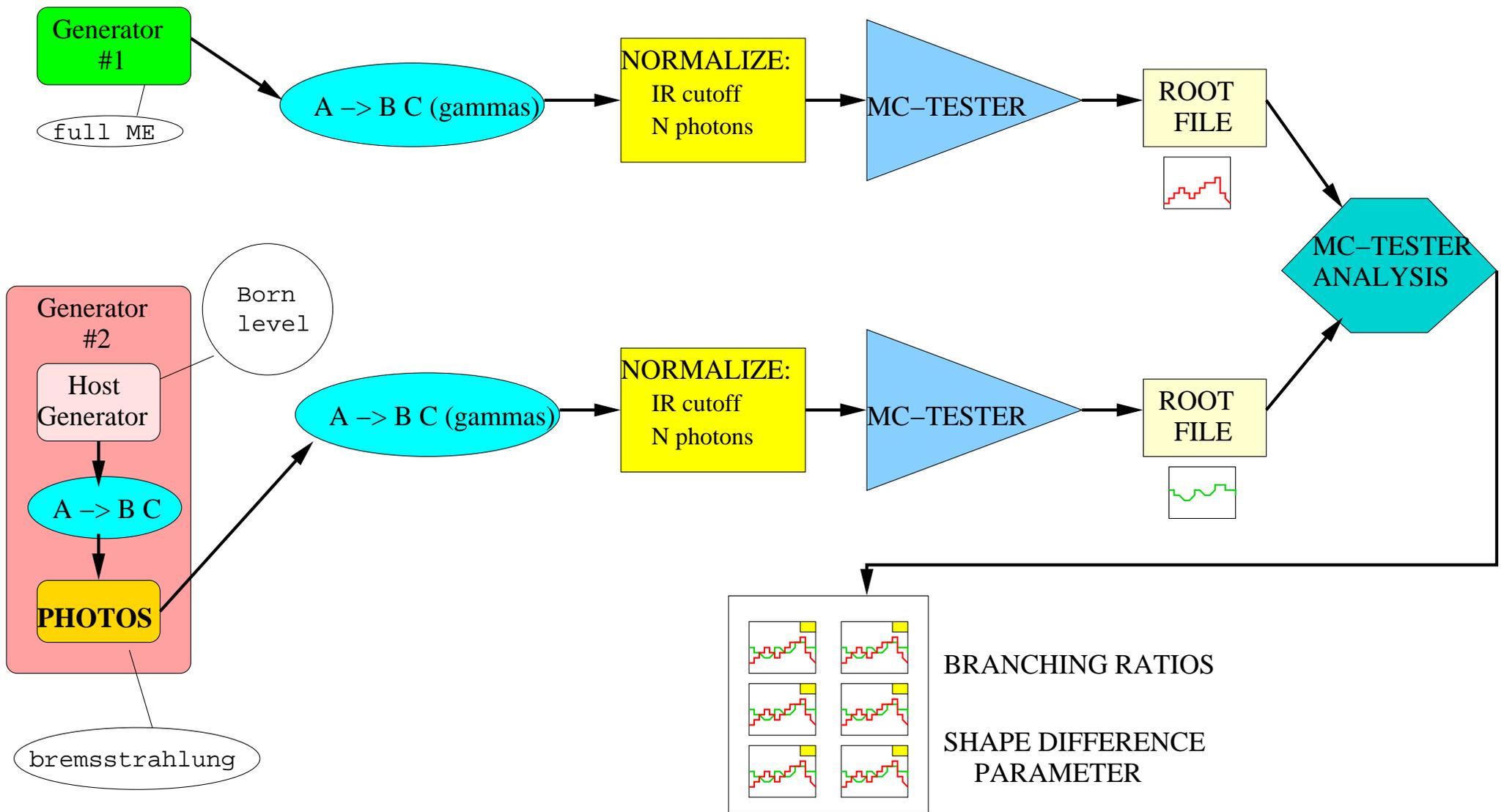**Simulation parts communicate through event record:**
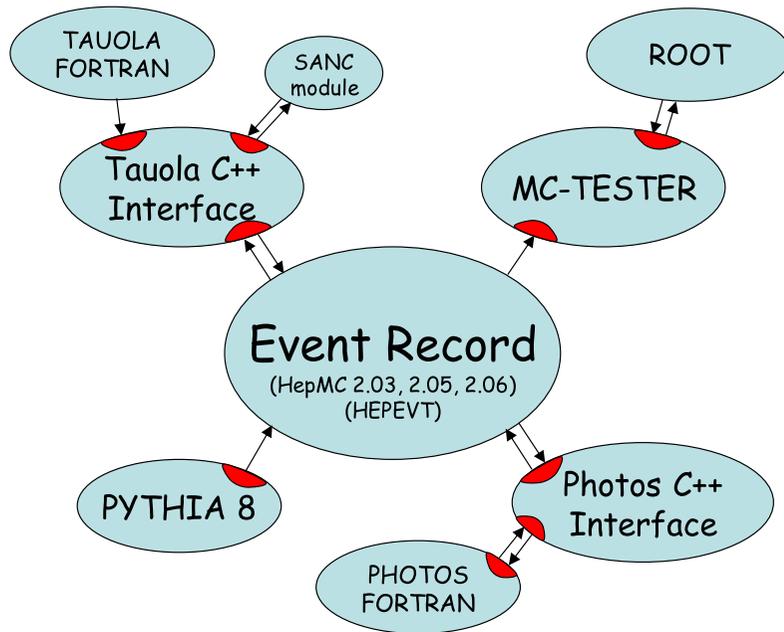
- **Parts:**

- hard process: (Born, weak, new physics),

- parton shower,

- τ decays

- QED bremsstrahlung

- High precision achieved

- Detector studies: acceptance, resolution

lepton with or wihout 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

Generator #1 — full ME → A –> B C (gammas) → NORMALIZE: IR cutoff N photons → MC–TESTER → ROOT FILE

Generator #2 — Host Generator → A –> B C → PHOTOS — Born level, bremsstrahlung → A –> B C (gammas) → NORMALIZE: IR cutoff N photons → MC–TESTER → ROOT FILE

MC–TESTER ANALYSIS

BRANCHING RATIOS

SHAPE DIFFERENCE PARAMETER

Z. Was

Manchester, September, 2010

MC-TESTER

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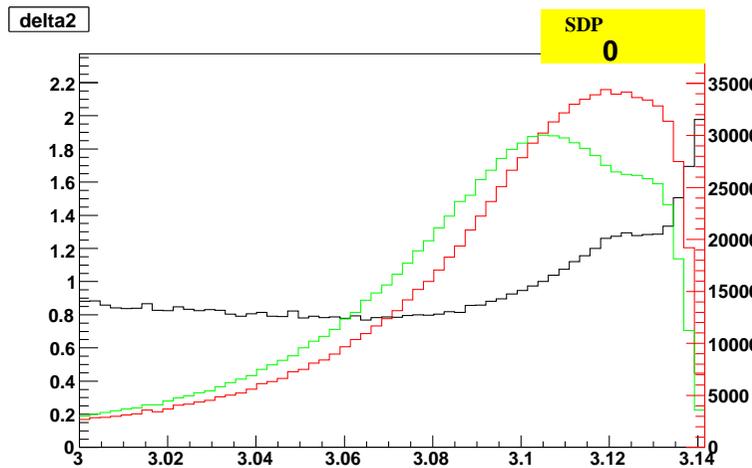
(a) $\pi^+\pi^-$ acollinearity distribution ($\approx \pi$))
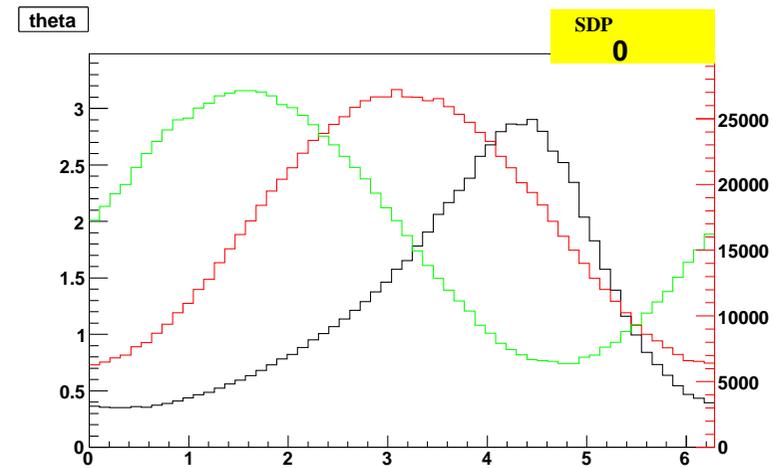
(b) $\pi^+\pi^-$ acoplanarity distribution

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

HepMC::GenEvent * evt

HepMC::GenParticle * tau

FourVector& momentum()
int pdg_id()
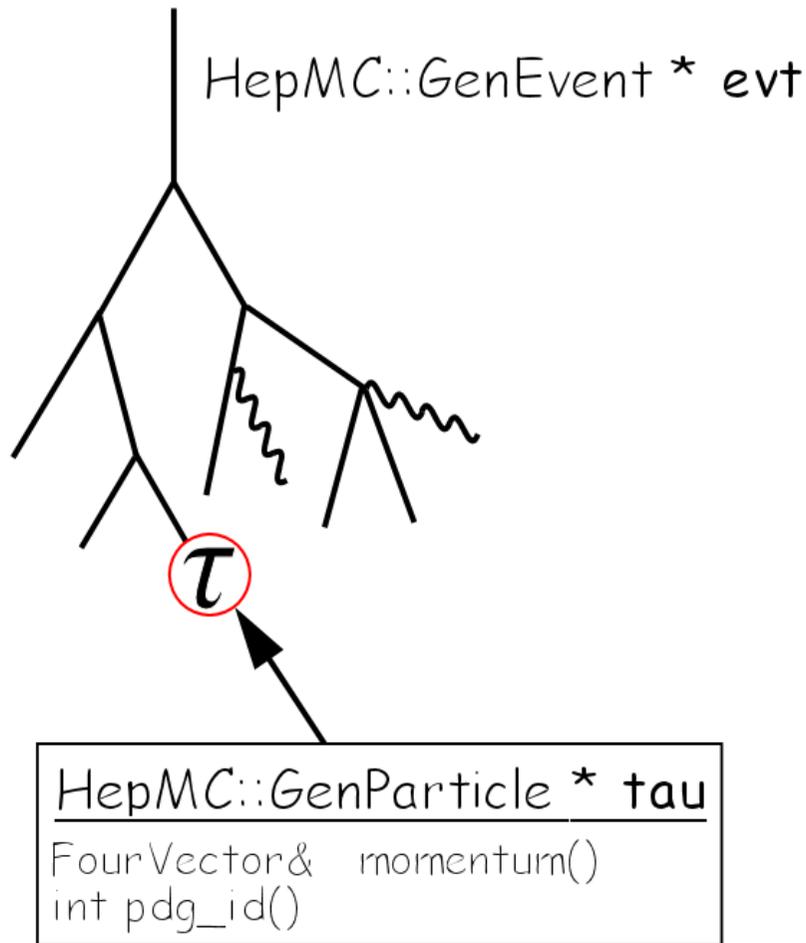
Tauola::decayOne(tau);

- 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).

HepMC::GenEvent * evt

τ^+ τ^-
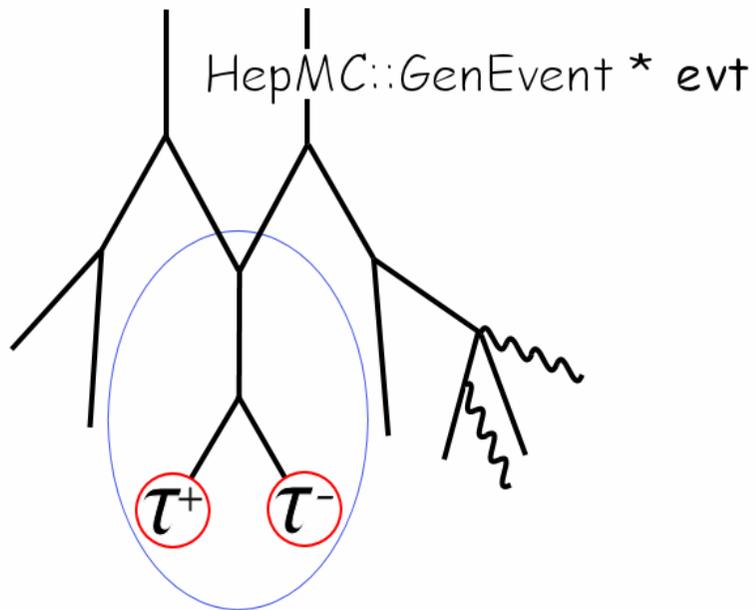
//Create object
TauolaHepMCEvent t_evt(evt);
//Decay taus
t_evt.decayTaus();

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 $1 \to 2$ (decays) or $2 \to 2$ or $2 \to 1 \to 2$ 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.
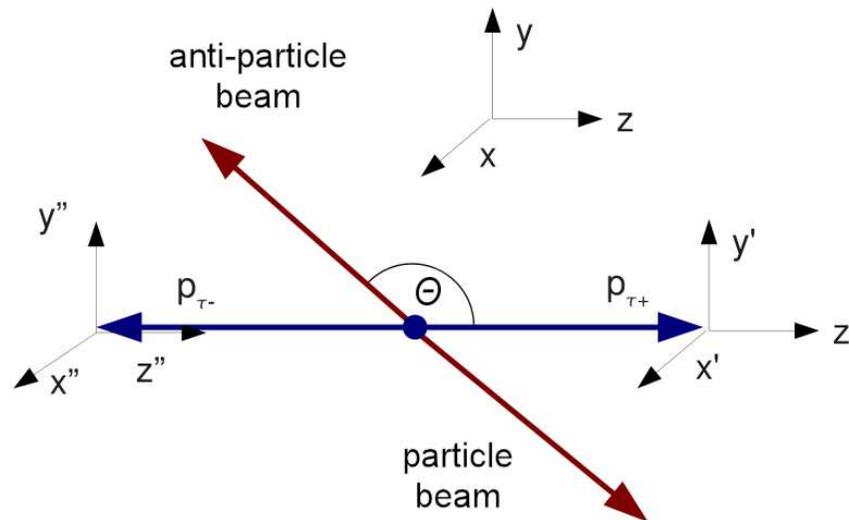
- Configuration of hard process: flavors and 4-momenta of incoming quarks and outgoing τ's (ν_τ)

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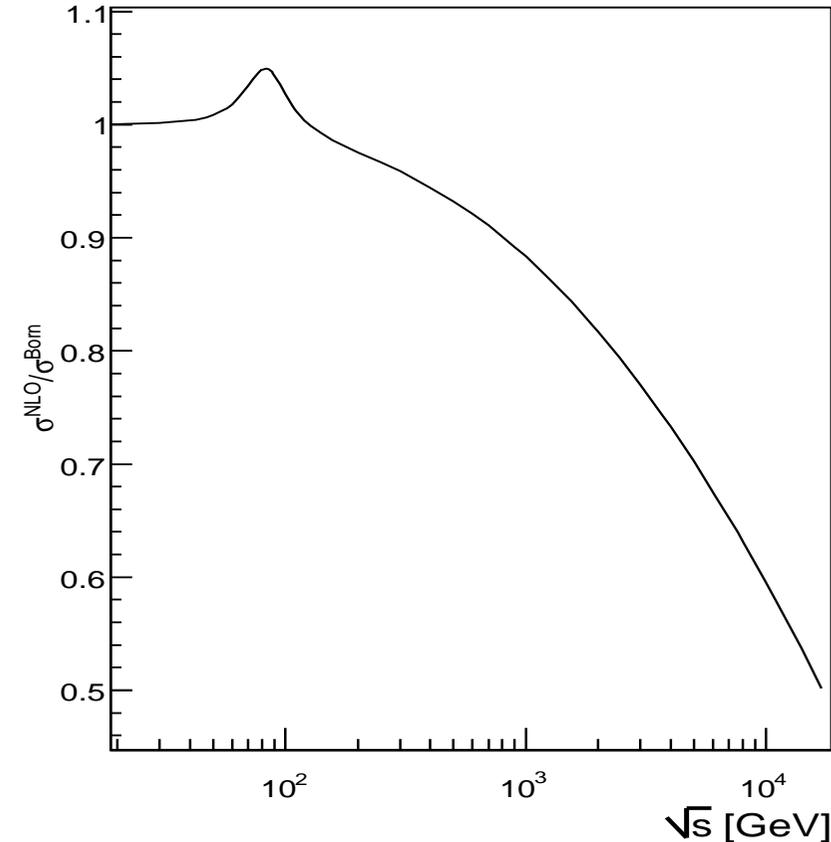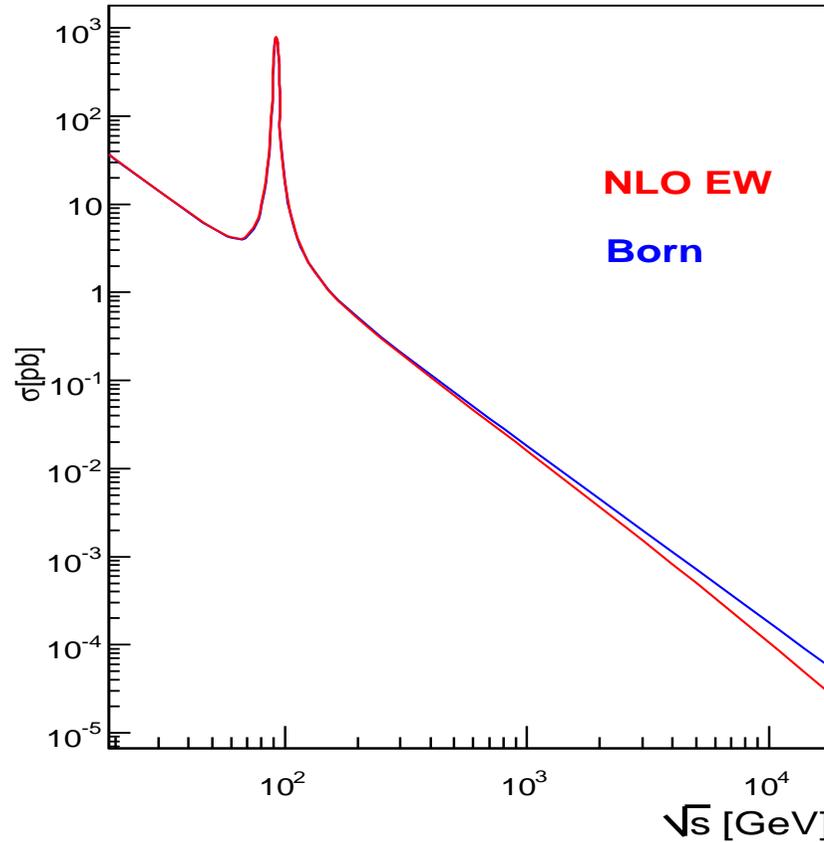
Effect of electroweak corrections on τ-pair production, up quarks, alpha scheme.

Q: What Born parameters are used in PYTHIA?
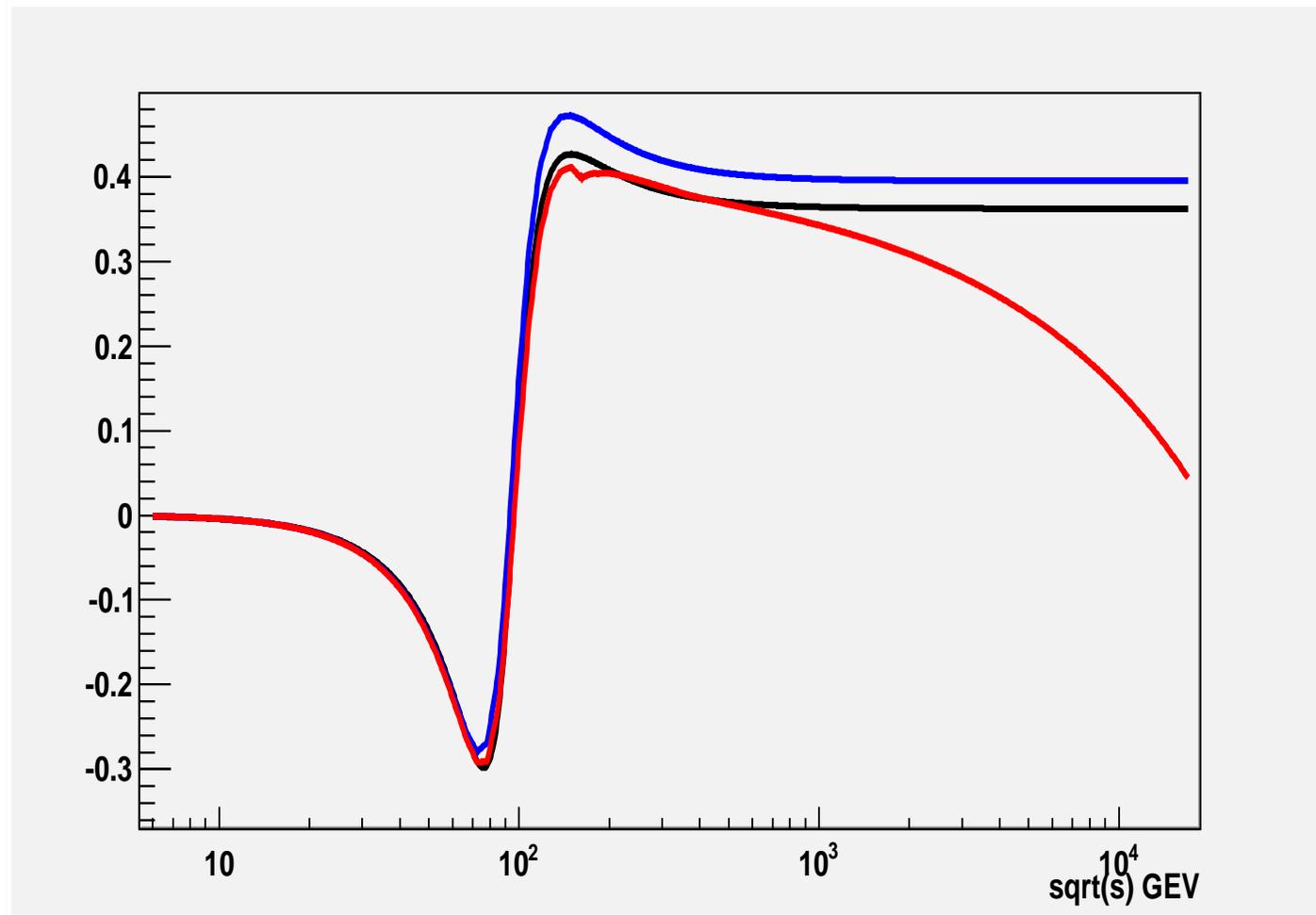
Effect of electroweak corrections on τ-polarization, up quarks. Red line includes electroweak corrections, Black is TAUOLA standard and blue is Born, alpha scheme. Scattering angle $\cos\theta = -0.2$
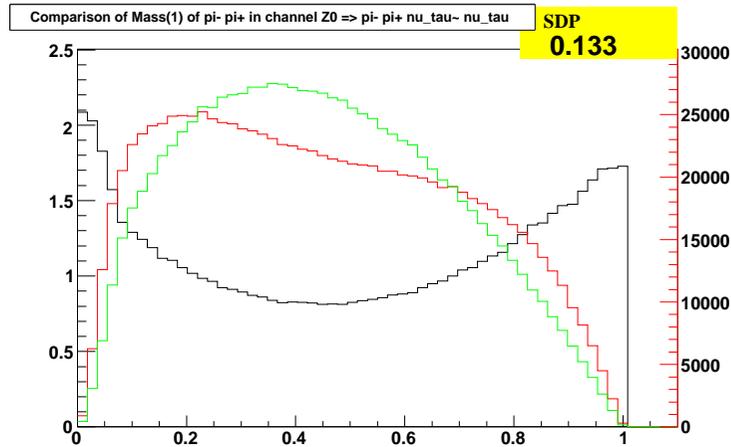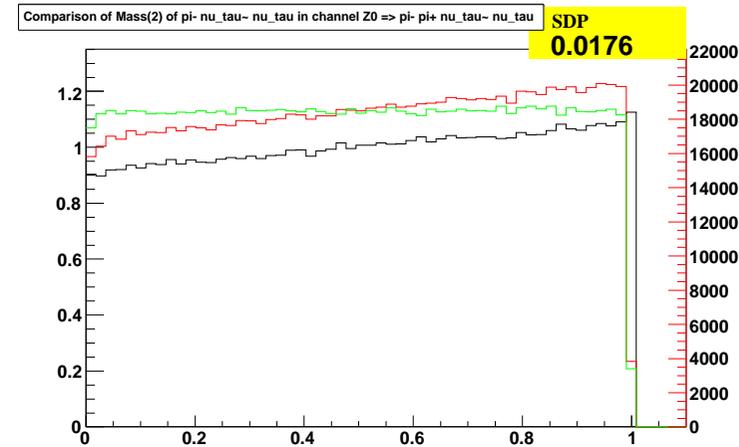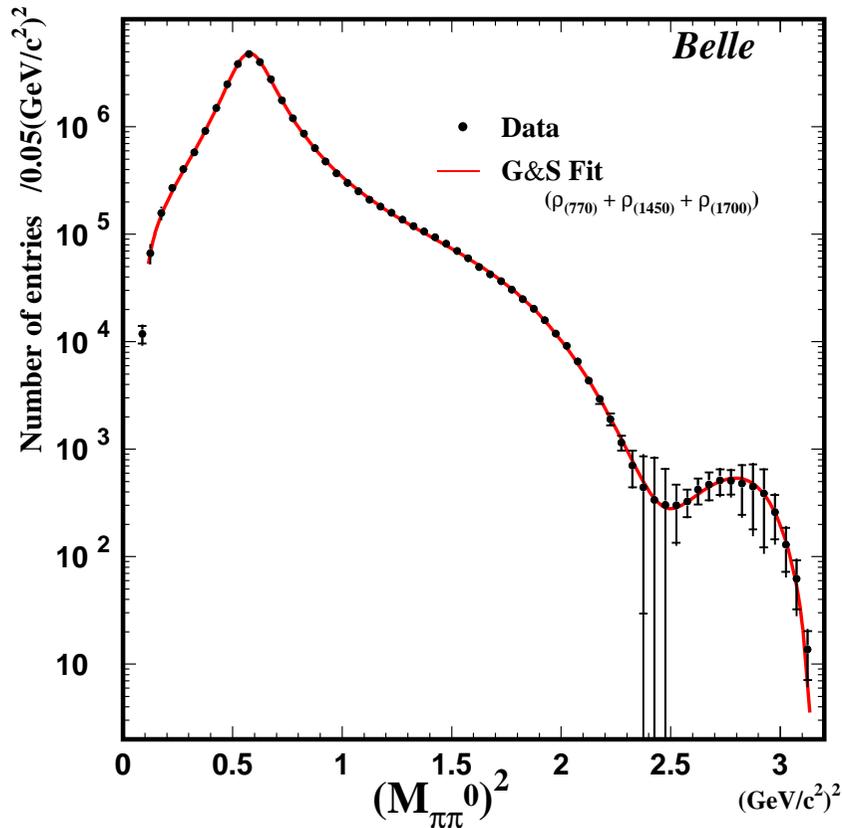
(a) $M_{\pi^+\pi^-}$

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

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 $\tau \to \pi^+\pi^0\nu$ decay channel.

- Correct simulation of τ decays for this mode and for LHC use!

- Single channel improvement bring real progress?
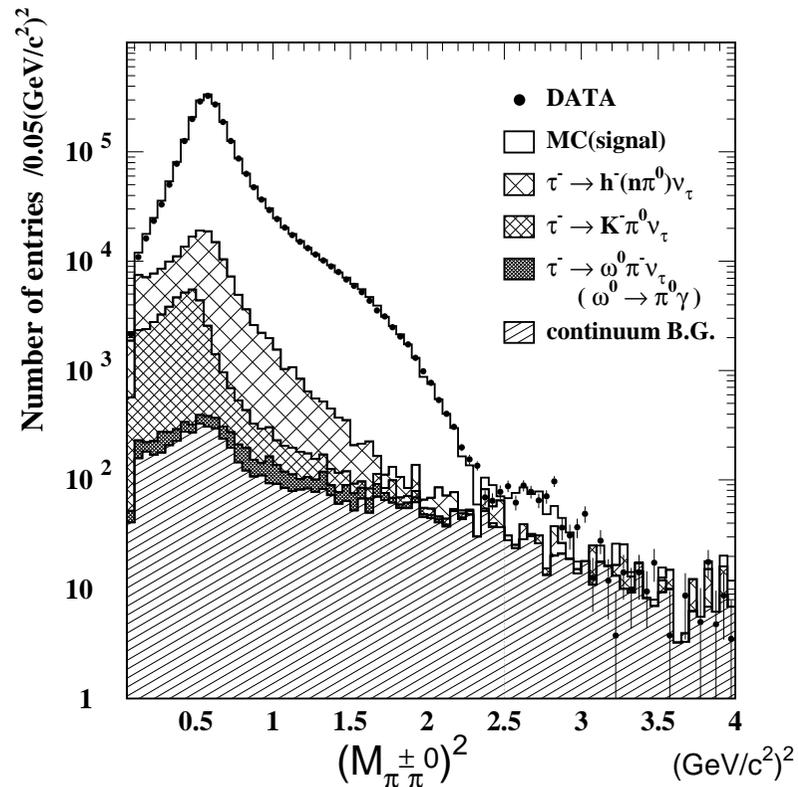
- Measured (Belle) distribution in interesting range has to be disentangled from background.

- 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.
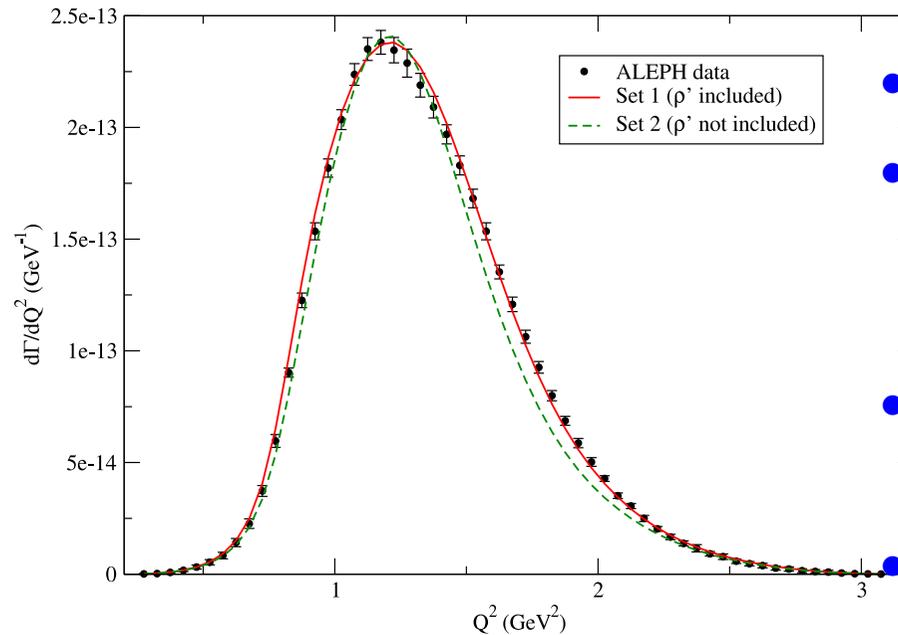
- The 3π decay mode is important contributor to τ decays. We install new currents into TAUOLA. We start from 0911.4436 [hep-ph].

- We attempt 0.05 % technical precision.

- Branching ratios are: Monte Carlo $4.2028\ 10^{-13} \pm 0.015\%$ Semi analytical $4.202722\ 10^{-13} \pm 0.006\%$

- 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.

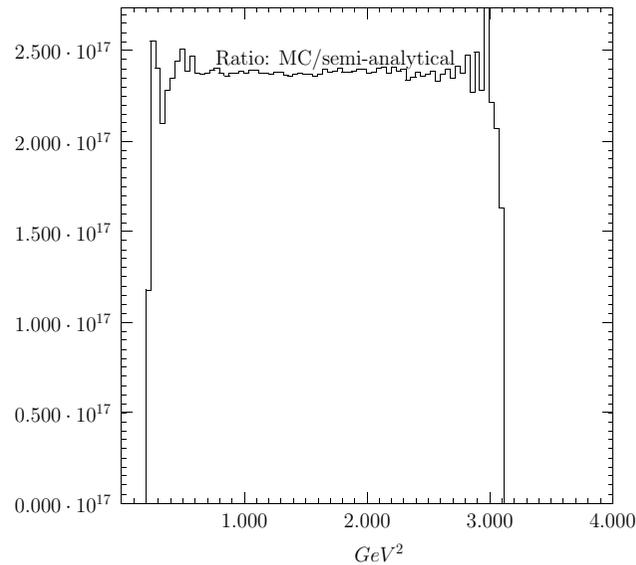- Only when this step is completed we can announce real progress.

Figure 3: First attempt for comparison of Monte Carlo result with numerical calculation for spectrum of hadronic system invariant mass sqared. 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/ot presampler parameters have to be tuned, size of the owerweighting need monitoring. Plot need normalization.

5

- 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?

Z. Was   *Manchester, September, 2010*
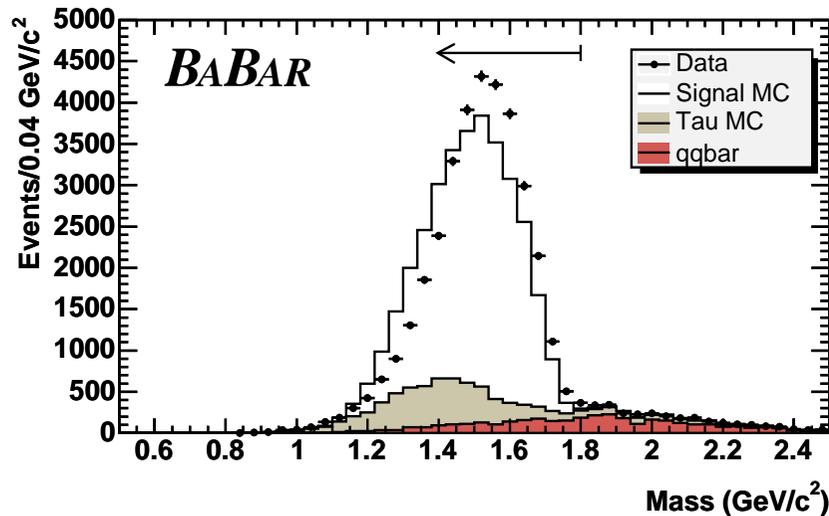
The invariant mass of five charged particles for $\tau^- \to 3h^- 2h^+ \nu_\tau$ at BaBar. How to improve in systematic way?

- For multi-scalar final states challenge: simultaneous fits of many complex form-factors of many variables into massively multi-dimensional distributions. Theoretical constrains apply (or not)

- I hope that this challenge will be adressed 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

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

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

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

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

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

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

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

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

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

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

- 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 precison, (iii) no background, (iv) full detector coverage can assured. We need that for orthogonality conditions.

- It is a challenge but worth a try.
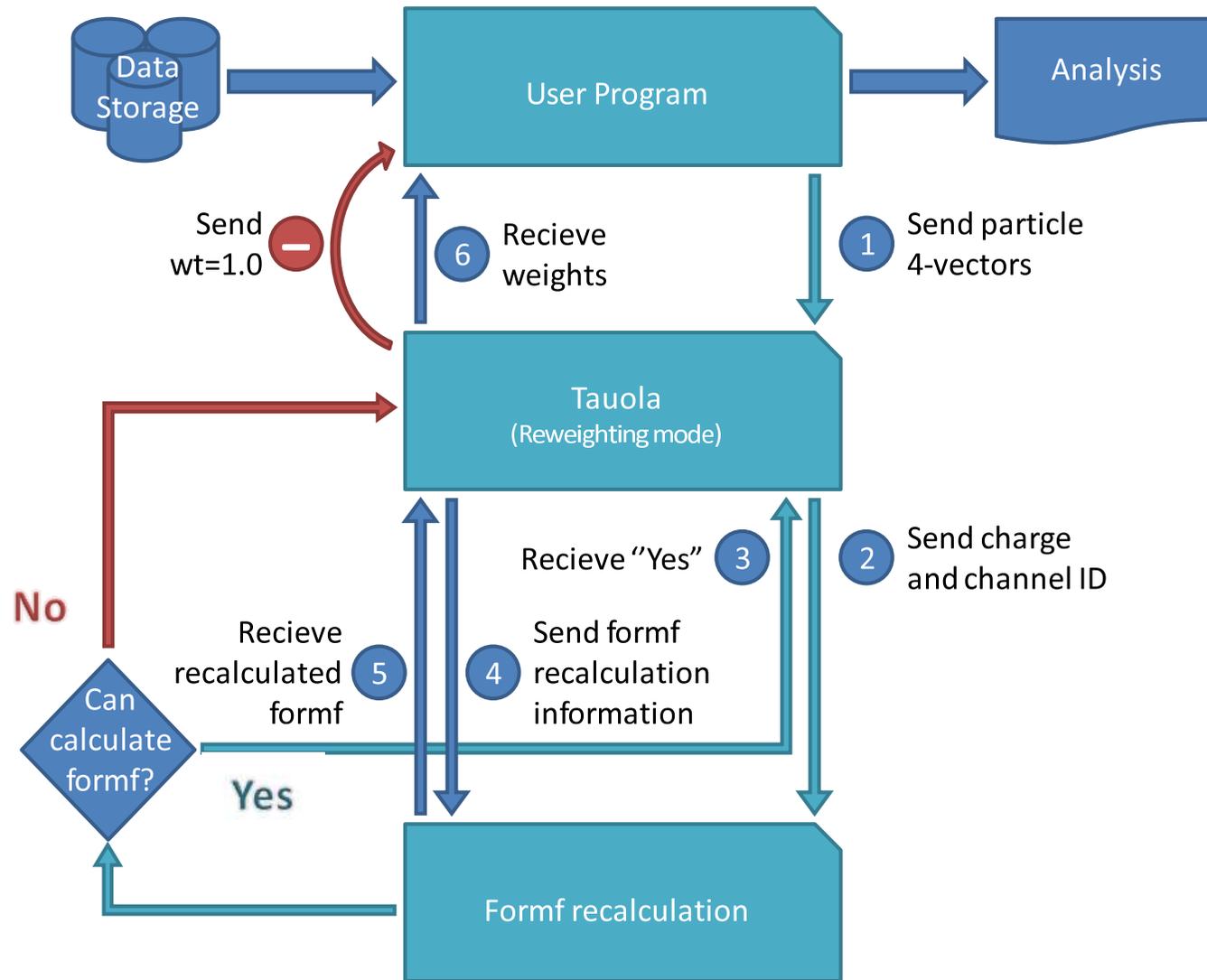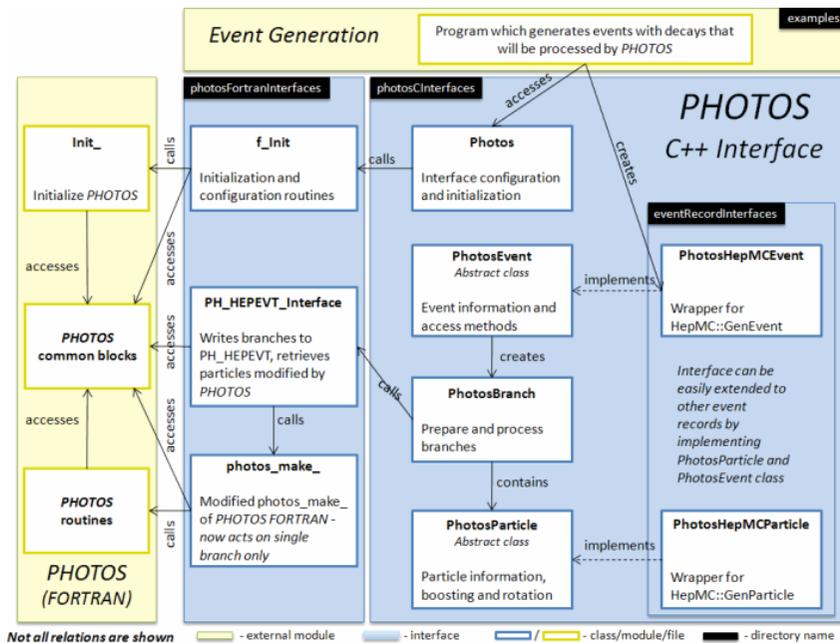
Map for fifo communicating executables

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 regurarly updated. Tar ball is available from that web page.

- First release planned for October.
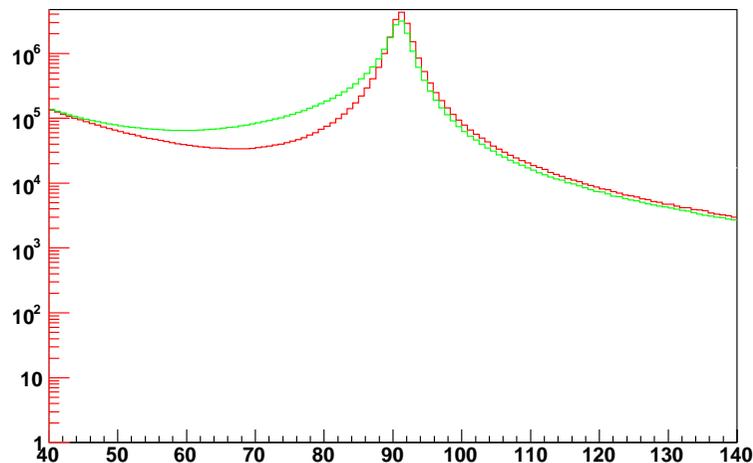
Distribution of bare e^+e^- invariant mass. (Bare means that photons collinear with e^+ or e^+ are not included in mass calculation.) Green line represent results when final state bremsstrahlung is generated (with the help of `PHOTOS` Monte Carlo). For red line FSR bremsstrahlung is absent. Event sample 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.
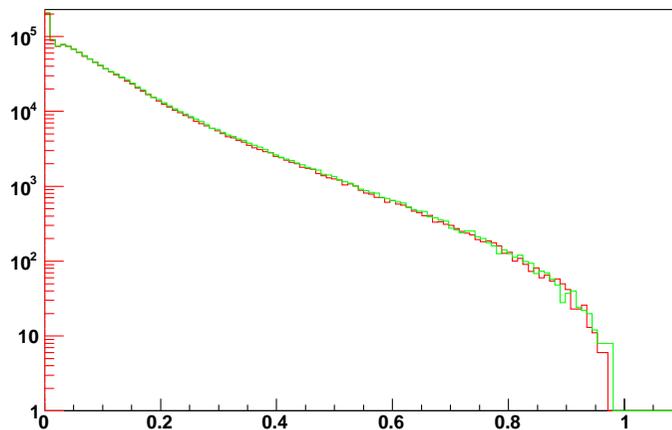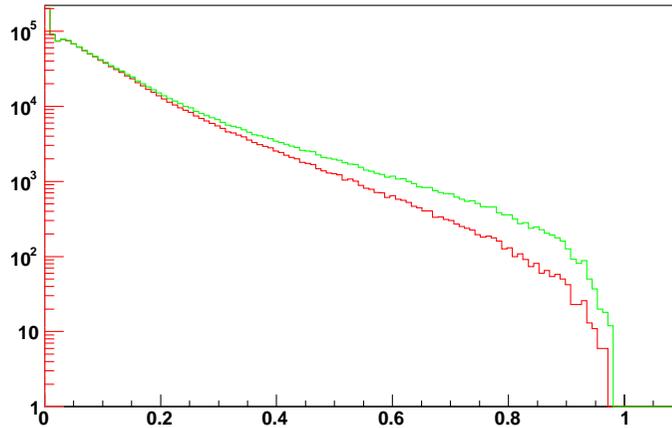
- Phase space; complete and exact.

- 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. Low plot green line: PHOTOS. Second order effects are reproduced. Proper iteration.
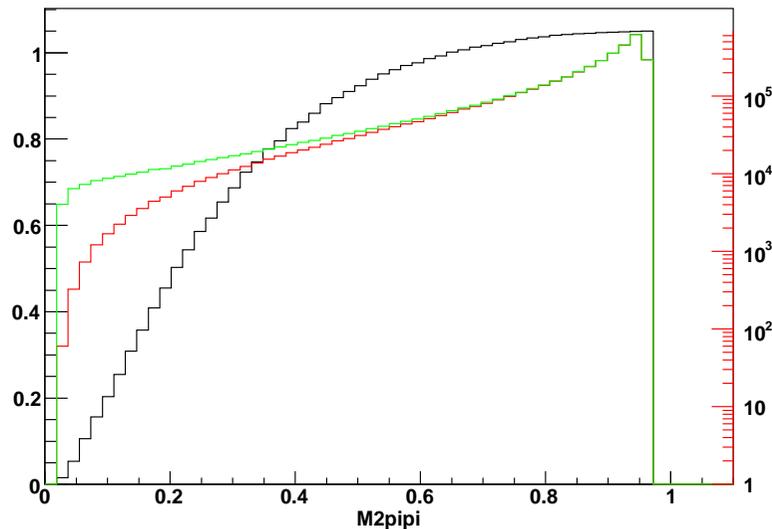
- Emissions from many lines. Interference weight $\rightarrow$ exact matrix element.

- 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: $\pi^+\pi^0$, $K\pi$, $\pi^0\pi^0\pi^+$, $K\pi\pi$,$KK\pi$, $\eta\pi\pi$ 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.