New hadronic currents in TAUOLA:

for confrontation with the experimental data

Z. Was*, T. Przedzinski, P. Roig, O. Shekhovtsova,

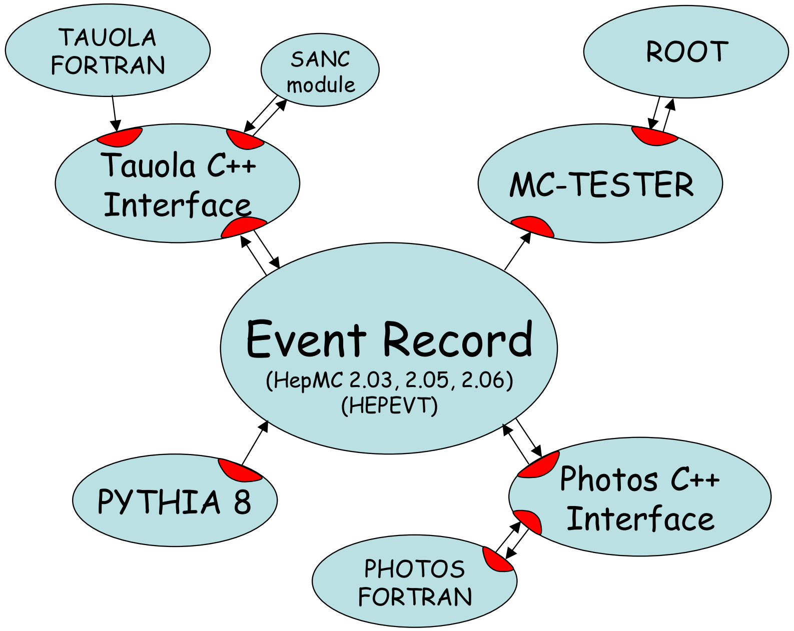
N. Davidson, G. Nanava, E. Richter-Was, Q. Xu

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

- **(1)** *LHC: large mass $\longrightarrow$ large Yukawa coupling $\longrightarrow$ window for new physics*
- **(2)** *Production and decay are separated perfectly: large lifetime.*
- **(3)** How to use τ decays **to measure hard proceeses**: *interface in C++. Transverse spin correlations, electroweak corrections, better steering options for TAUOLA and PHOTOS*
- **(4)** *from QCD point of view its mass is intermediate. Decay M.E. has to be taken from models and low energy experiments data.*
- **(5)** *Fascinating laboratory for intermediate energy QCD*
- **(6)** How to prepare MC and fits, to get most from low energy data. In a form of quality hadronic currents i.e. theoretical constraints not compromised.

LHC user: software organization.

Simulation parts communicate through event record:



- Parts:

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

- High precision achieved

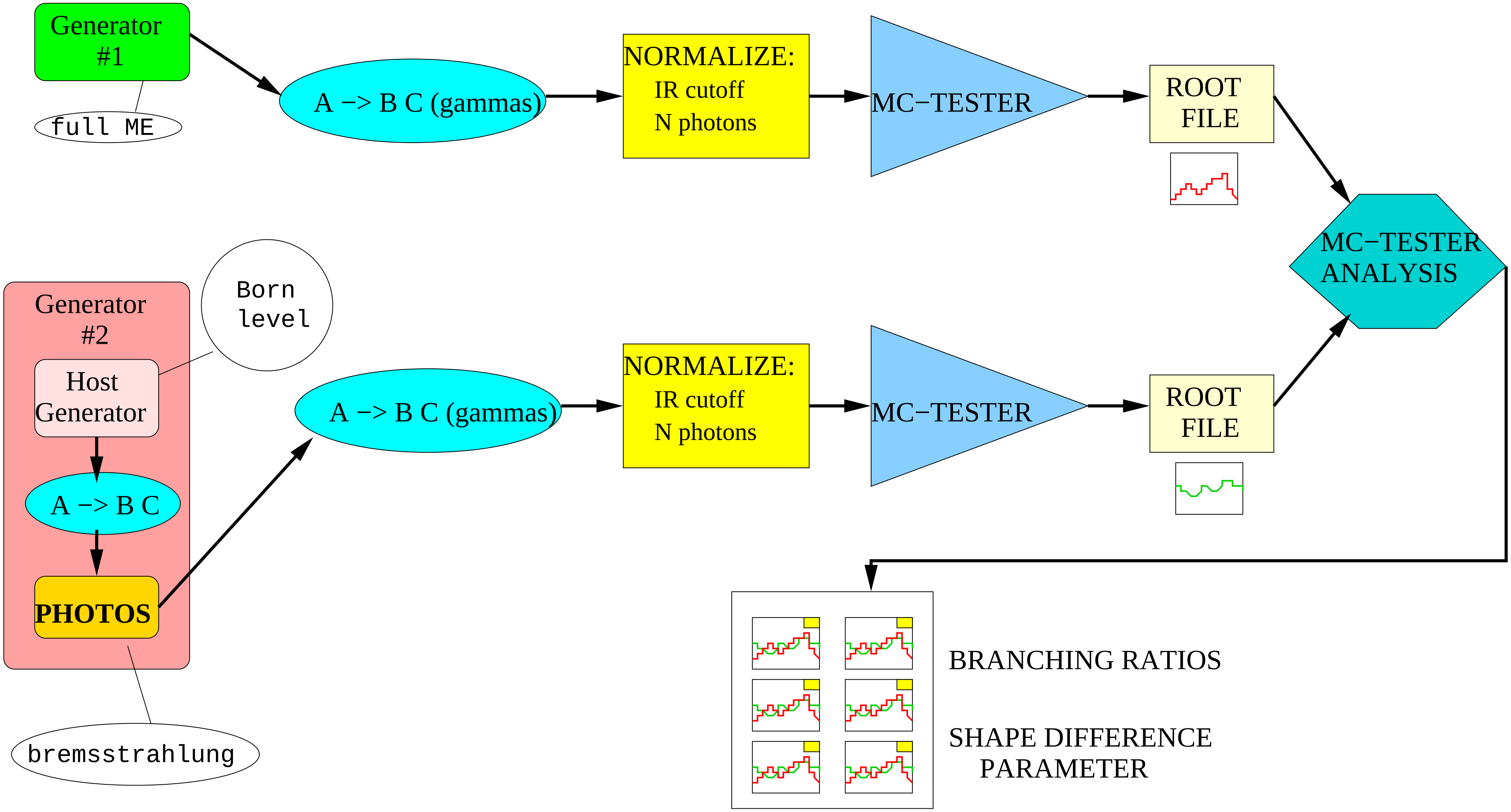
- Detector studies: acceptance, resolution lepton with or wihout photon.

Such organization requires:

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

I will concentrate today on box `TAUOLA-FORTRAN`

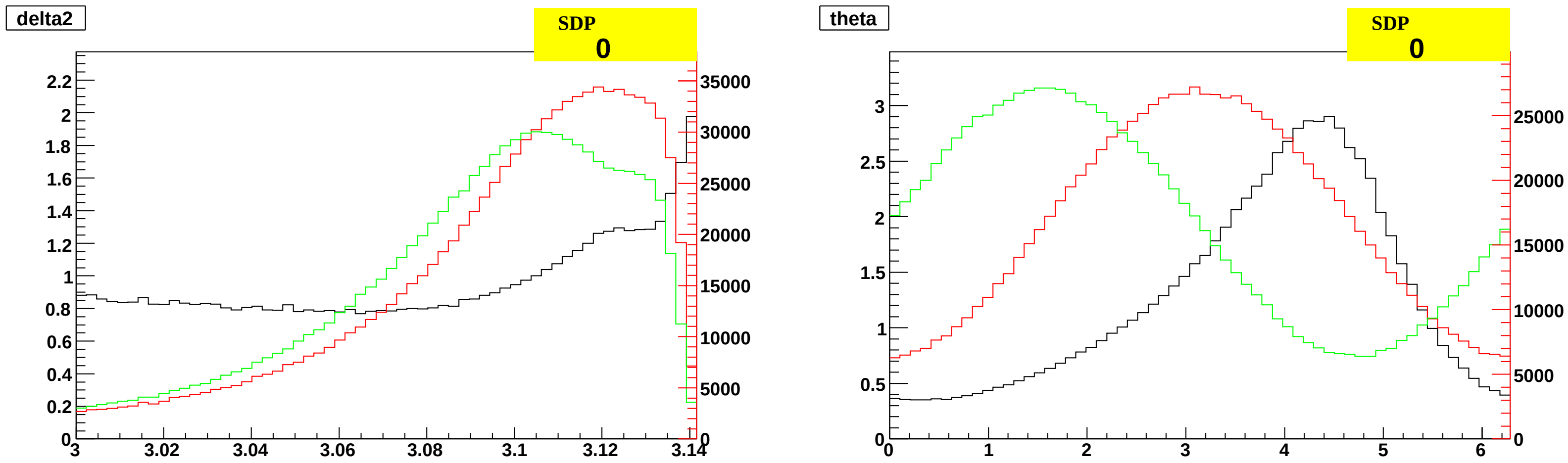
MC-TESTER to test PHOTOS/TAUOLA



NEW

1. **Published in CPC**
2. **Web page: http://mc-tester.web.cern.ch/MC-TESTER/**
3. **Project is mature for all users low/high energy C++/F77**
4. **Interfaces to** `HepMC` **C++ or** `HEPEVT` **F77**
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

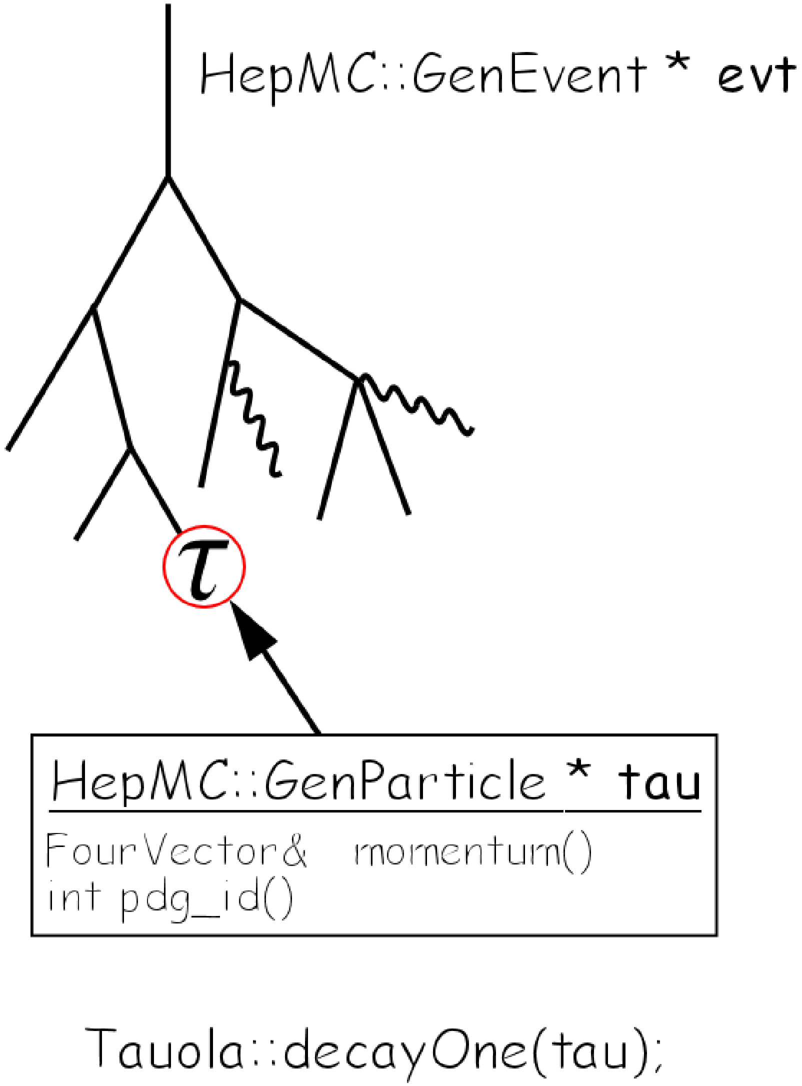
Figure 1: Transverse spin observables for the H boson for $\tau^\pm \to \pi^\pm \nu_\tau$. Distributions are shown for scalar higgs (red), scalar-pseudoscalar higgs with mixing angle $\frac{\pi}{4}$ (green) and the ratio between the two (black).

TAUOLA C++

1. Internal τ decay dynamic is of secondary interest at LHC. It is challenging for low energy precision measurements, see later in this talk and in talk of Pablo Roig. Internal part of TAUOLA project left 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.
4. Web pages of TAUOLA C++
   www.ph.unimelb.edu.au/˜ndavidson/tauola/doxygen/index.html
5. Reference: arXiv:1001.0070 [hep-ph]
6. Spin reweight algorithm
   `//hibiscus.if.uj.edu.pl/˜przedzinski/tau-reweight/`

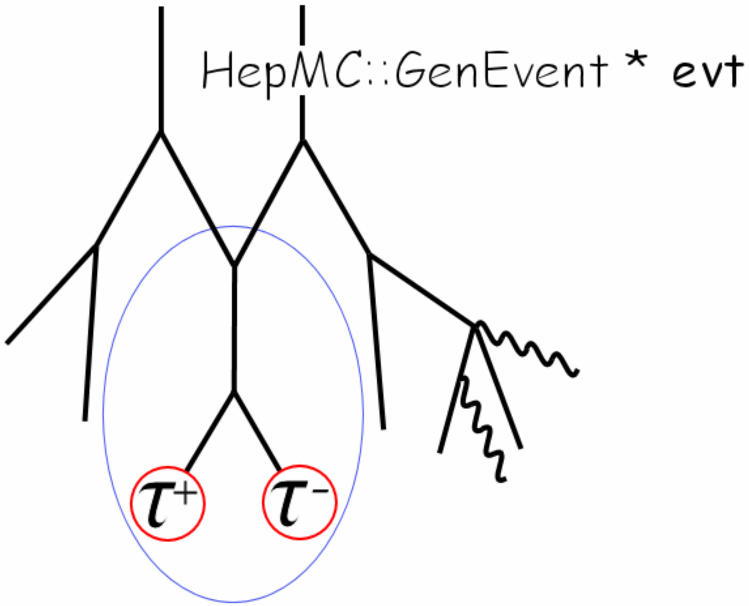
www.ph.unimelb.edu.au/˜ndavidson/photos/doxygen/index.html$\longrightarrow$ PHOTOS C++/HepMC

Single tau decay → **NEW**



- 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.

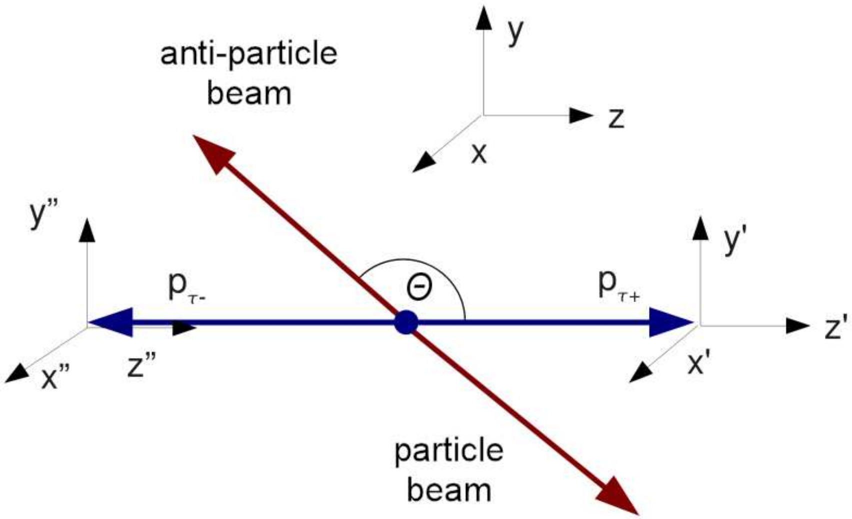



```
//Create object
TauolaHepMCEvent t_evt(evt);
//Decay taus
t_evt.decayTaus();

TauolaParticlePair - get
mothers/grandmothers
```

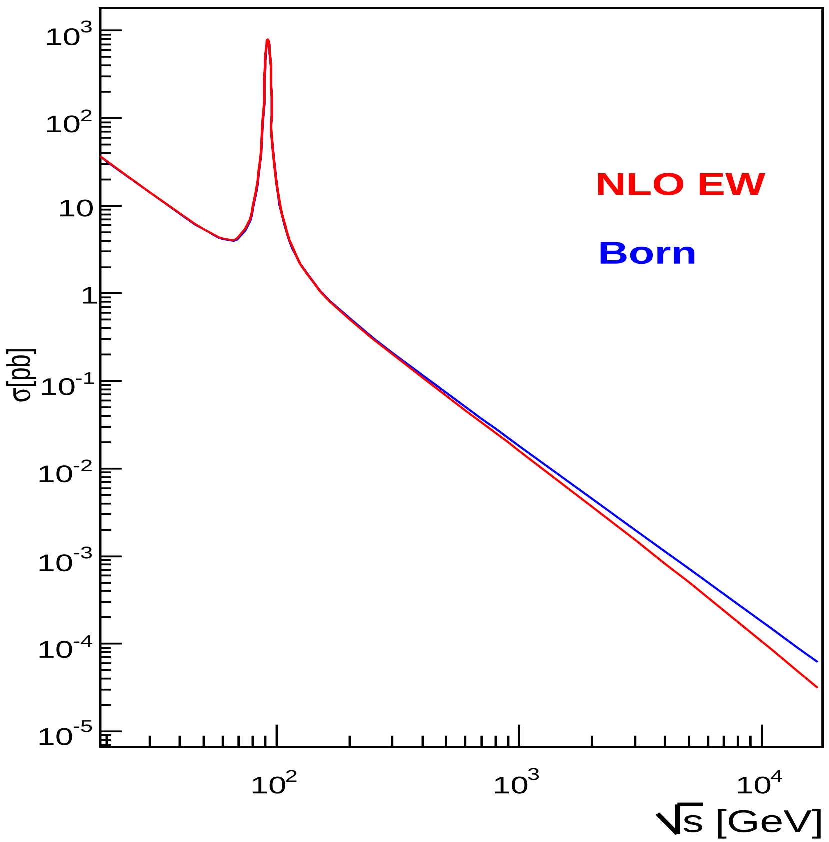
- Create object `t_evt` of class `TauolaHepMCEvent` which inherit from abstract class `TauolaEvent` and use `evt` of `HepMC::GenEvent` class as parameter. Then apply `t_evt.decayTaus()`
- For method `.decayTaus()` event record is searched for elementary processes like $1 \to 2$ (decays) or $2 \to 2$ 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.

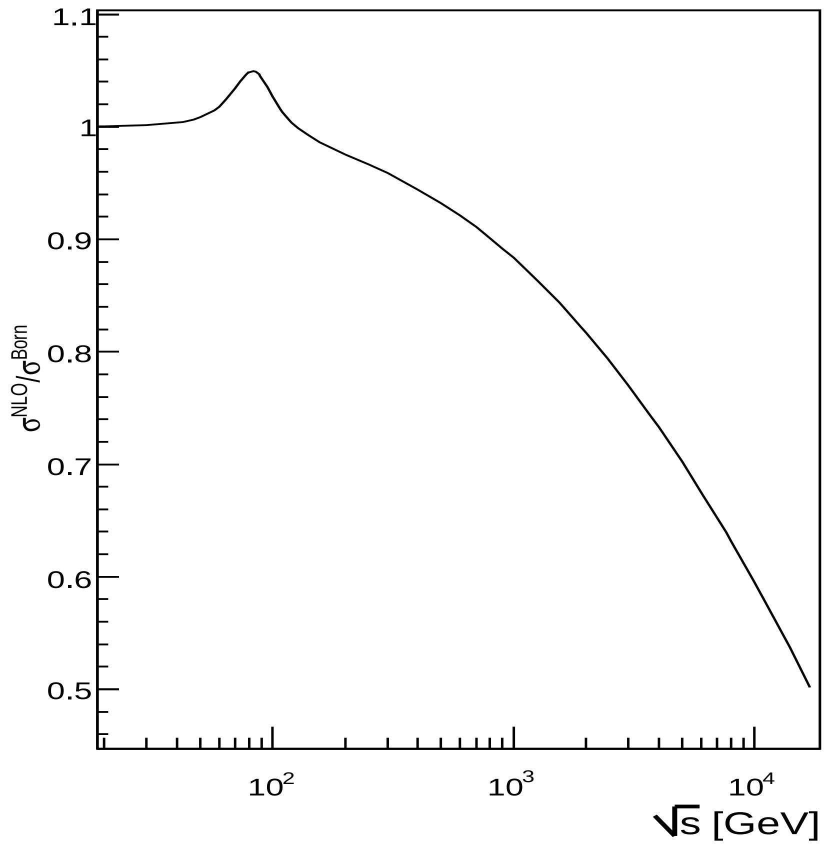
Decay of $\tau^+\tau^-$ ($\tau^\pm\nu_\tau$) pair.



- 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.

Numerical results, tests.

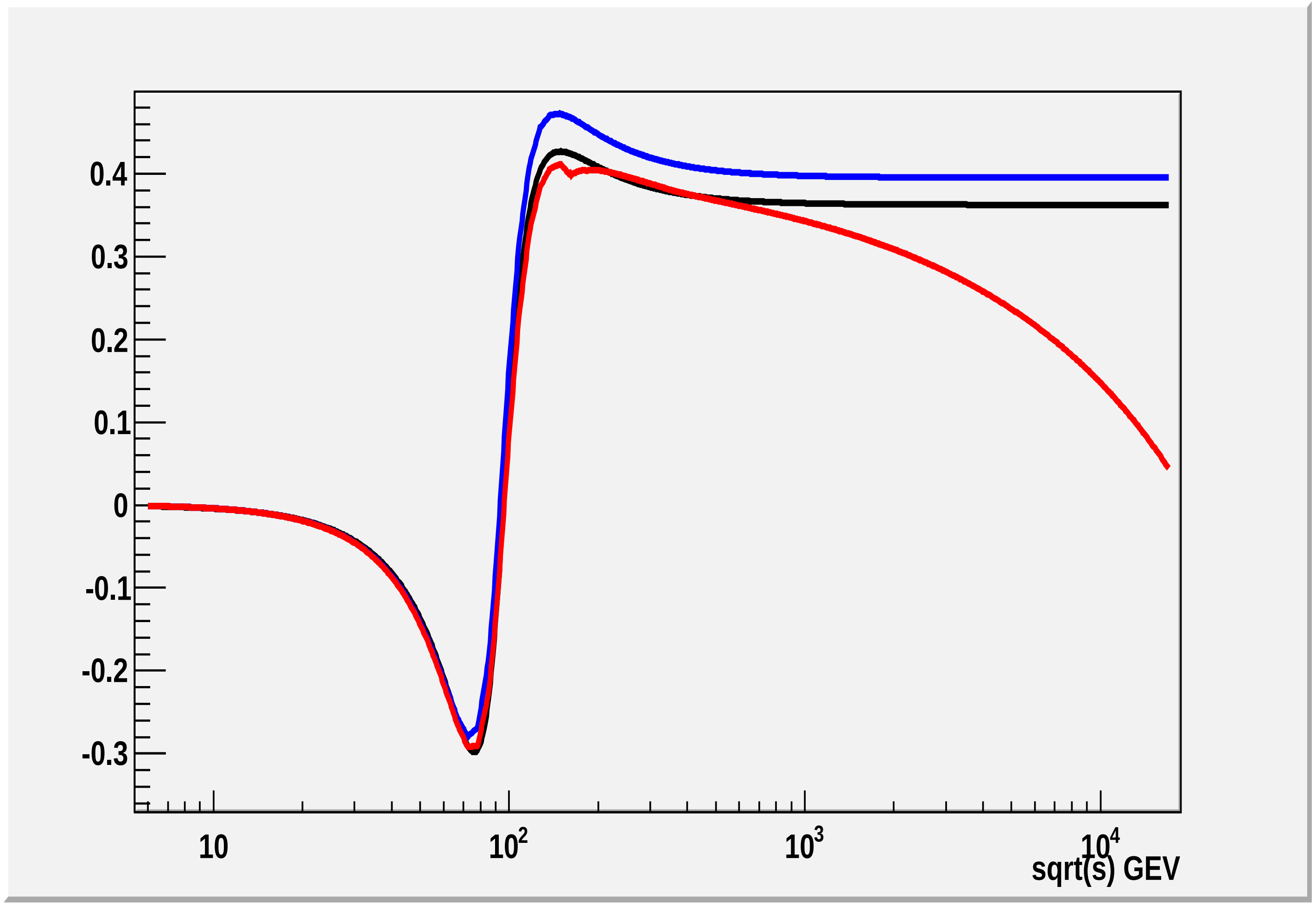




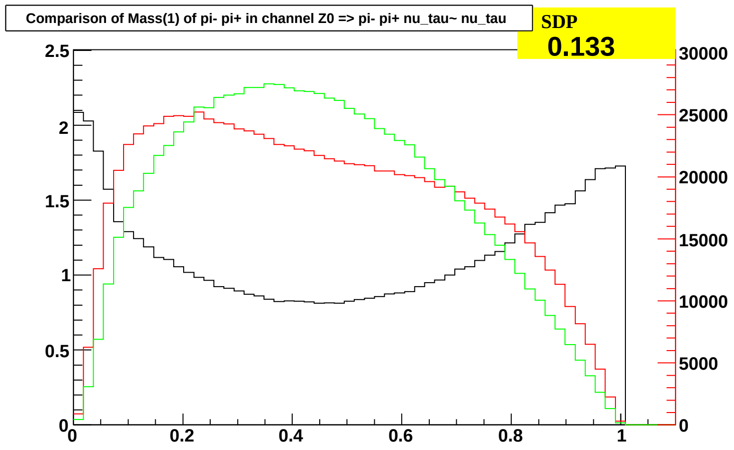
Effect of electroweak corrections on τ-pair production, up quarks, alpha scheme.

Q: What Born parameters are used in PYTHIA?

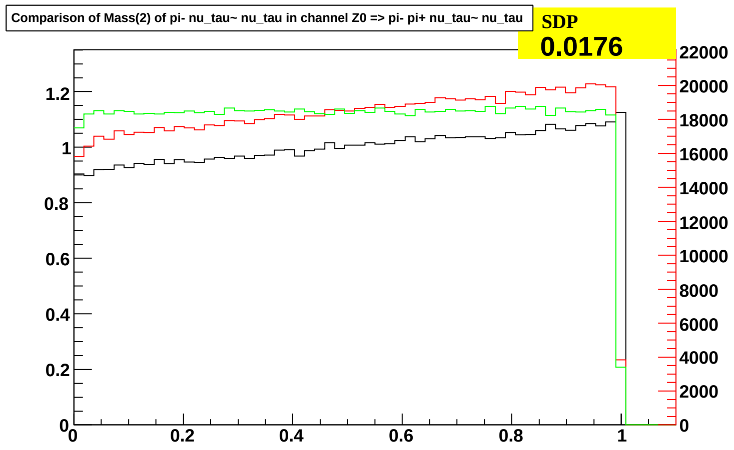
Numerical results, tests.



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 $\cos\theta = -0.2$

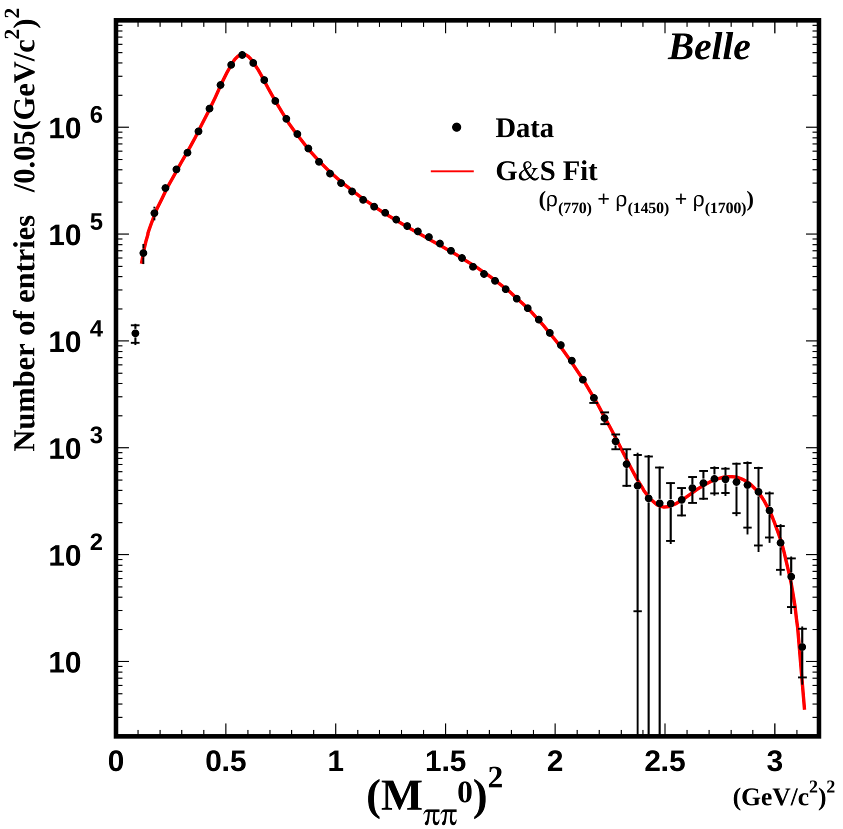


(a) $M_{\pi^+\pi^-}$

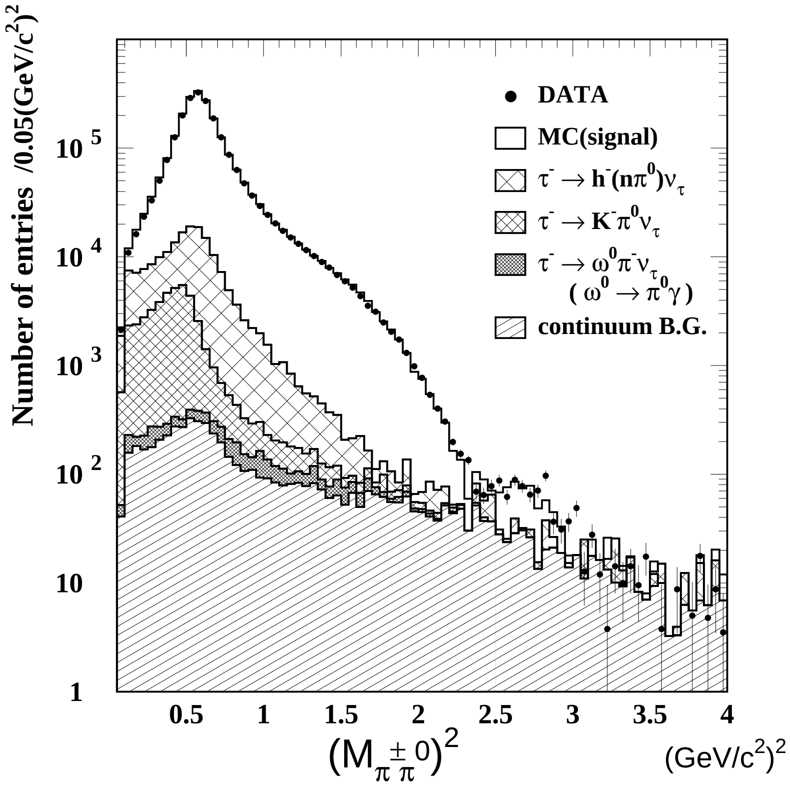


(b) $1-2\frac{E_{\pi^+}}{M_Z}$

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.



- WARNING: publicly available TAUOLA hadronic current is not as good match for the 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.
- **Single channel improvement is it all we need?**
- Also: theoretical constraints, other channels τ or e^+e^-.



- Measured (Belle) distribution in interesting range has to be disentangled from background.
- At higher end of the spectrum background dominates over $\pi^+\pi^0\nu_\tau$.
- Correct simulation of τ decays is needed for τ decay channels contributing to backgrounds as well!
- Who should play dominant role in validating final choices: model builders? MC authors?Experiments?
- Man power and coordination issues are essential too. To be discussed in MC meeting.

Channel	Width [GeV]	reference	In `tauola/RChL-currents` directory channel's current: `file` $\longrightarrow$ `routine`
$\pi^- \pi^0$	$5.2678 \cdot 10^{-13} \pm 0.01\%$	Subsection 2.4	`frho_pi.f` $\longrightarrow$ `CURR_PIPI0`
$K^- \pi^0$	$5.853 \cdot 10^{-15} \pm 0.02\%$	Subsection 2.4	`fkpipl.f` $\longrightarrow$ `CURR_KPI0`
$\pi^- K^0$	$1.1025 \cdot 10^{-14} \pm 0.03\%$	Subsection 2.4	`fkpipl.f` $\longrightarrow$ `CURR_PIK0`
$K^- K^0$	$2.415 \cdot 10^{-15} \pm 0.02\%$	Subsection 2.4	`fk0k.f` $\longrightarrow$ `CURR_KK0`
$\pi^- \pi^- \pi^+$	$2.08 \cdot 10^{-12} \pm 0.017\%$	Subsection 2.1	`f3pi_rcht.f` $\longrightarrow$ `F3PI_RCHT`*
$\pi^0 \pi^0 \pi^-$	$2.126 \cdot 10^{-12} \pm 0.017\%$	Subsection 2.1	`f3pi_rcht.f` $\longrightarrow$ `F3PI_RCHT`*
$K^- \pi^- K^+$	$3.8467 \cdot 10^{-15} \pm 0.04\%$	Subsection 2.2	`fkkpi.f` $\longrightarrow$ `FKKPI`*
$K^0 \pi^- \bar{K}^0$	$3.5935 \cdot 10^{-15} \pm 0.03\%$	Subsection 2.2	`fkkpi.f` $\longrightarrow$ `FKKPI`*
$K^- \pi^0 K^0$	$2.769 \cdot 10^{-15} \pm 0.04\%$	Subsection 2.3	`fkk0pi0.f` $\longrightarrow$ `FKK0PI0`*
			* The F_i of formfactors.

Table 1: Collection of numerical results from paper: O. Shekhovtsovaa, T. Przedzinski, P. Roig and Z. Was *Resonance chiral lagrangian currents and τ decay Monte Carlo*, IFJPAN-IV-2011-6, UAB-FT/695 . References to subsections of our paper. Last column includes references to routines of the currents code.

- New hadronic currents, more than 88 % of hadronic τ decay width.
- The 0.05 % technical tag:
  O. Shekhovtsovaa, T. Przedzinski, P. Roig and Z. Was *Resonance chiral lagrangian currents and τ decay Monte Carlo*, IFJPAN-IV-2011-6, UAB-FT/695
- Physics precision is not as good as 0.05 %, see summary of mine and P. Roig talks, but ...
- ... we work on preparing confrontation env. with the data keeping precision in mind.

- Status
- Methods of porting the code to Belle BaBar env. are prepared and pre-tested.
- simultaneous use of old and new currents (model replacing weights) envisaged.
- web page http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm
- web page, is with lots of tests, documentation and tar-ball for TAUOLA update.
- Numerical stability issues need to to be fixed. We need several days before we put tar ball on web page.

New currents, preprint IFJPAN-IV-2011-6, UAB-FT/695

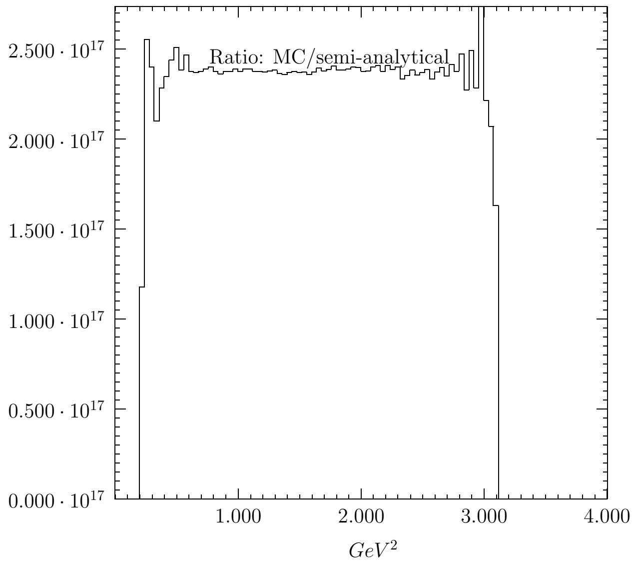


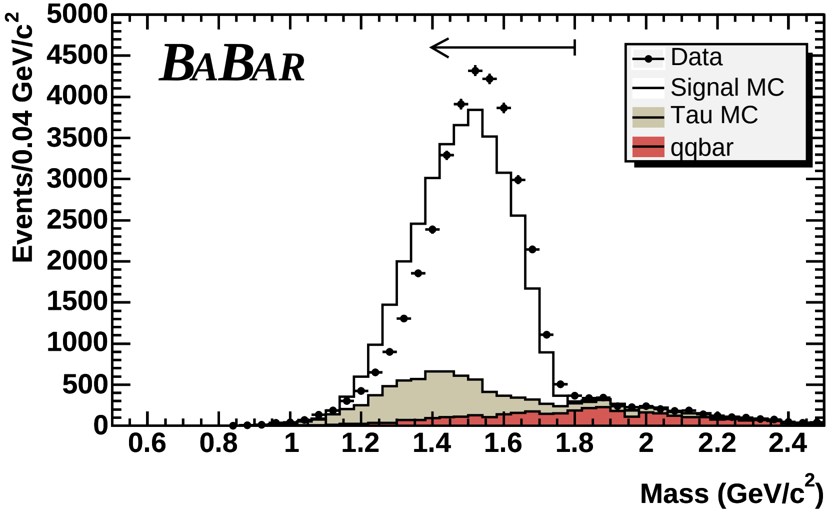
Figure 3: First attempt for comparison of Monte Carlo result with numerical calculation for spectrum of hadronic system invariant mass sqared. Ratio of the two is shown. Statistical sample of 2.5M evts was used and semi-realistic initialization as explained in the section. Reasonable agreement between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

- Example from our web page: ratio of Monte Carlo obtained $\frac{d\Gamma}{dQ^2}$ and semi analytical formula is given on or web page for every channel.
- Perfect technical agreement.
- Physics precision is not as good, also $\frac{d\Gamma}{dQ^2}$ represents an input to the model parametrization.
- Differential distributions are shown with the help of `MC-TESTER` and `root`.
- To parametrize differences between several models and data use weighted events or projection operators like in paper of J. Kuhn, E. Mirkes (Z. Phys. C56 (1992)).

Post simulation weights $\longrightarrow$ RMC meeting



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

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

- J_μ the current depends on the momenta of all hadrons

$$|\mathcal{M}|^2 = G^2 \frac{v^2+a^2}{2}(\omega + H_\mu s^\mu)$$
$$\omega = P^\mu (\Pi_\mu - \gamma_{va}\Pi^5_\mu)$$
$$H_\mu = \frac{1}{M}(M^2\delta^\nu_\mu - P_\mu P^\nu)(\Pi^5_\nu - \gamma_{va}\Pi_\nu)$$
$$\Pi_\mu = 2[(J^* \cdot N) J_\mu + (J \cdot N) J^*_\mu - (J^* \cdot J) N_\mu]$$
$$\Pi^{5\mu} = 2 \,\mathrm{Im}\, \epsilon^{\mu\nu\rho\sigma} J^*_\nu J_\rho N_\sigma$$
$$\gamma_{va} = -\frac{2va}{v^2+a^2}$$
$$\hat{\omega} = 2\frac{v^2-a^2}{v^2+a^2} m_\nu M (J^* \cdot J)$$
$$\hat{H}^\mu = -2\frac{v^2-a^2}{v^2+a^2} m_\nu \,\mathrm{Im}\, \epsilon^{\mu\nu\rho\sigma} J^*_\nu J_\rho P_\sigma$$

Post simulation weights and projections

- 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.

Algorithm for weight calculation.

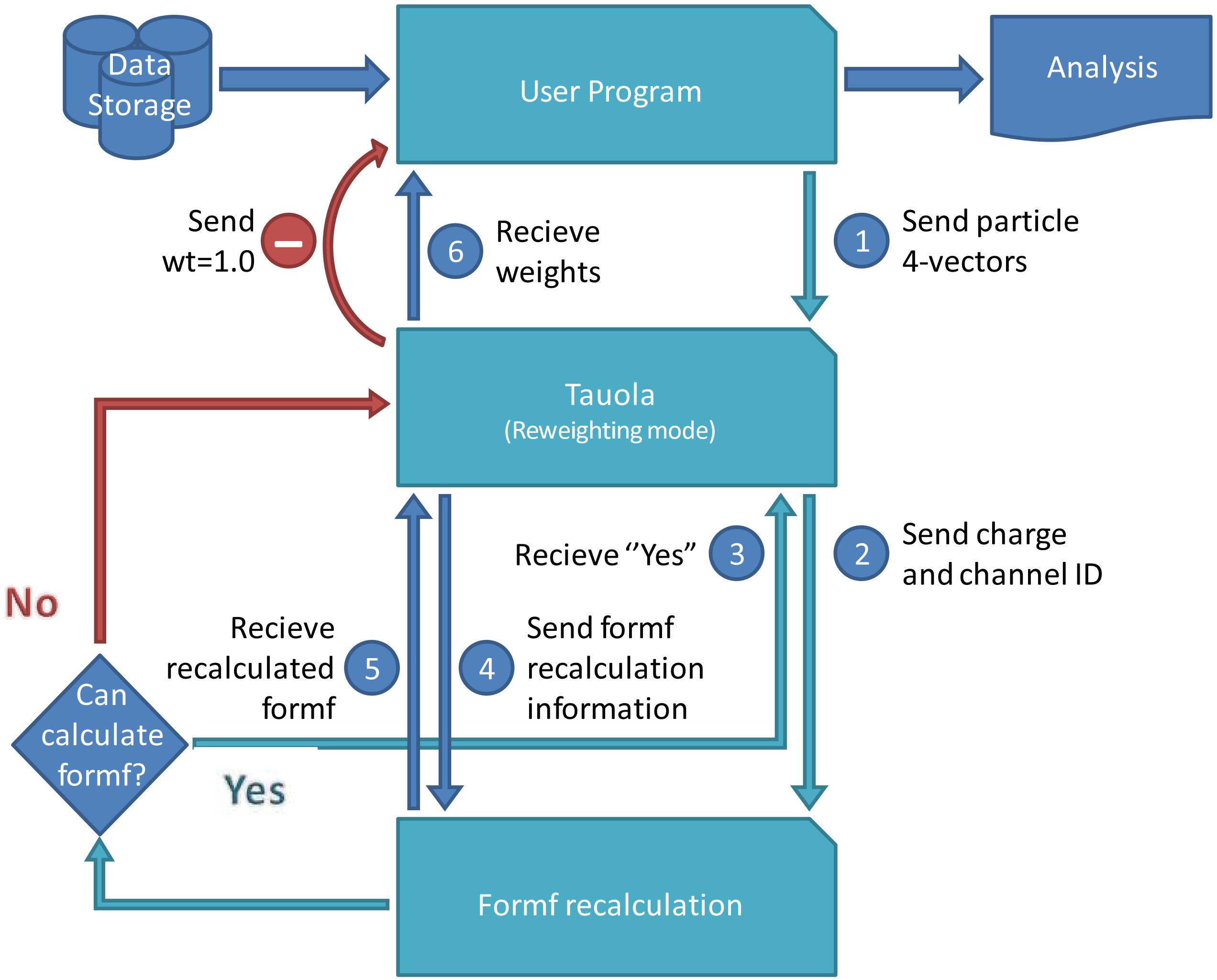


Figure 3: Flow chart for fifo communication. Verified to be compatible with Belle and BaBar software.

Summary – high energy and C++

- MC-TESTER released and documented.
- 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.
- New version of PHOTOS interface (C++/HepMC) released and documented.

Summary – low energy

- **TAUOLA**
- RChL currents installed. Cover 88 % of hadronic τ decay width. See talk of Pablo Roig for details.
- level of technical tests of installation: below 0.05 %
- TAUOLA with weights for alternative models and for use in fits to the data prepared as patch to Belle/BaBar software.
- **PHOTOS**
- Process dependent weights for Z W B decays available.
- Examples of thests for two body decays W, Z, H, B, γ^* and also $K \to \pi\pi l\nu$ and $K \to \pi\, l\nu$ available. (some still upon request).

Summary – low energy

- **Grain of salt.**
- We assume that Lorentz invariance will not need to be reconsidered at any step of our project.
- With respect to the separation of matrix element into leptonic and hadronic part, we assume that electroweak corrections will not affect such separation beyond precision level of several permille at most, question of an overall normalization factor for all hadronic channel, is of no practical importance for Monte Carlo.
- We assume that isospin symmetry should be a good guiding principle. We assume that it should hold more accurately for distributions than for amplitude phases, but we do not expect large effects.
- Some of the effective couplings can be predicted by considering the asymptotic behaviour of Green functions and form factors both in the effective theory ($R\chi T$) and in the operator product expansion of QCD. However, these predictions are affected by different sources of errors, most importantly the model dependence on the realization of the large-N_C limit of QCD (mainly the choice of the resonance spectra, but not only). Special care should be taken when relating different channels, especially if the statistics

in both of them is very different and in one decay channel only a subset of resonance parameters is used. One should not forget that the (formal or not) integration of heavy degrees of freedom out affects the values of the parameters in the remaining lower-energy theory. Results for the individual modes should be analyzed consequently.

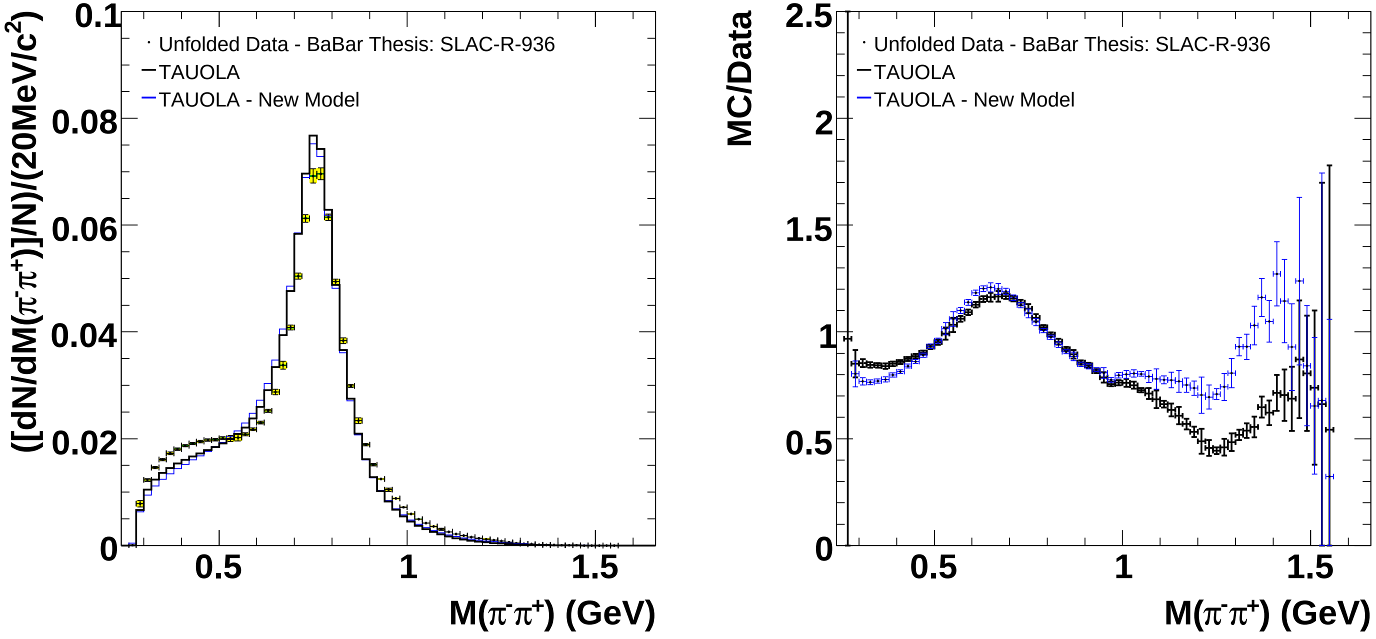
- Our effective couplings and interactions are based on the low-energy effective field theory of QCD (χPT), whose results are reproduced at NLO in the corresponding limit by $R\chi T$. Although the latter being formally sound, there is model dependence in any realization of the large-N_C limit of QCD for mesons and, moreover, we are introducing the contribution of excited resonances only at a phenomenological level, a feature that can be improved in the future. We may need to explore the limits of such approach and take feed back from experiments.

- Different solutions have been advocated for taking unitarity properties (via the propagator widths) into account. In particular, there is no consensus that the exponentiation of the real part of the resonance width is always the best solution. This point must be investigated further, especially in light of precision fits to high-statistics data.

Summary – low energy

- At the same time, the seeming violation of these principles may be a consequence of some experimental problems. That is why such discussion requires simultaneous participation of theorists and experimental physicists in the proper computer environment.
- We are at the end of achieving technical milestone and we need clarification of experimental user requirements on program and documentation.
- We can do it simultaneously with checks on numerical stability, platform/compiler dependence, issues.
- Particularly important is to define social scheme on how to select (make available for user) fit parameters.

Summary – low energy



(a) A

(b) B

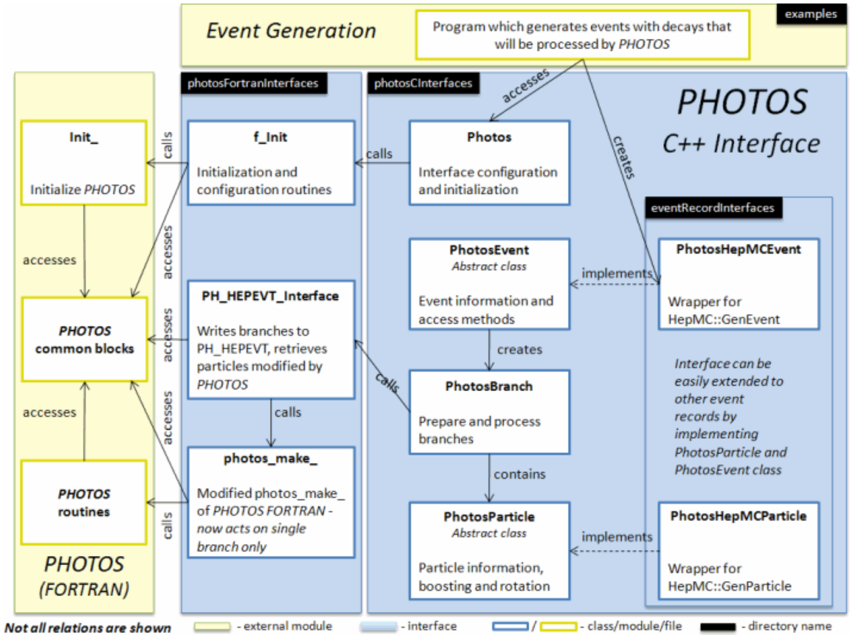
Figure 4: Invariant mass distribution of the $\pi^+\pi^-$ pair in $\tau \to \pi^+\pi^-\pi^-\nu$ decay. Histogram is from our model, the unfolded BaBar data are taken from PhD thesis of Ian Nugent. The plot on the left hand side corresponds to the differential decay distribution, and the one on the right hand side to plot ratios between Monte Carlo results and data. Clearly the ris plento of room for common work.

Presentation

- PHOTOS (by E.Barberio, B. van Eijk, Z. W., P.Golonka) is used to simulate the effect of radiatiative corrections in decays, since 1989.
- many citations from experiments $\longrightarrow$ responsability
- Full events combining complicated tree structure of production and subsequent decays are fed into PHOTOS, usually with the help of HEPEVT event record of F77
- PHOTOS version for HepMC event record used in C++ applications is ready for tests now.
- At every event decay branching, PHOTOS intervene. With certain probability extra photon may be added and kinematics of other particles adjusted.

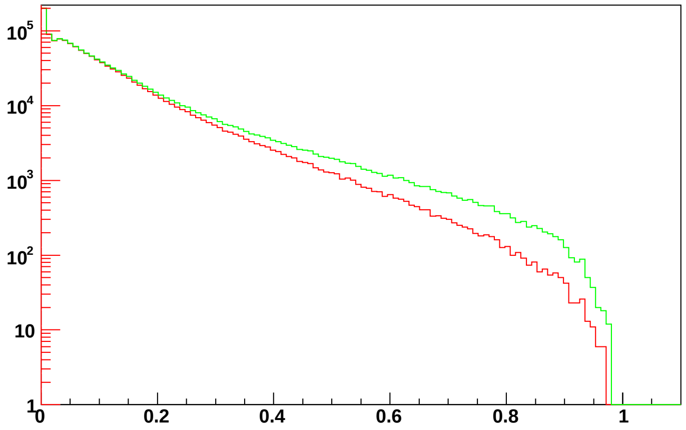
Main References

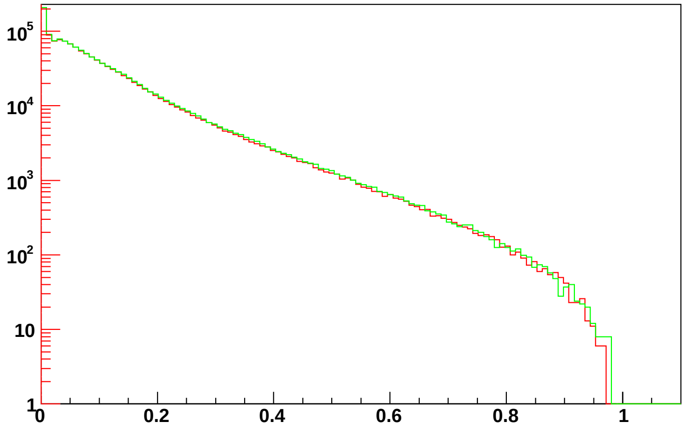
- E. Barberio, B. van Eijk and Z. Was, Comput. Phys. Commun. **66**, 115 (1991): single emission
- E. Barberio and Z. Was, Comput. Phys. Commun. **79**, 291 (1994). double emission introduced, tests with second order matrix elements
- P. Golonka and Z. Was, EPJC 45 (2006) 97 multiple photon emisson introduced, tests with precioson second order exponentiation MC.
- P. Golonka and Z. Was, EPJC 50 (2007) 53 complete matrix element for Z decay, and further tests
- G. Nanava, Z. Was, Eur.Phys.J.C51:569-583,2007, best description of phase space
- G. Nanava, Z. Was, Q. Xu, arXiv:0906.4052. EPJC complete matrix element for W decay
- N. Davidson, T. Przedzinski, Z. Was, IFJPAN-IV-2010-6, Web-page for C++ version: http://www.ph.unimelb.edu.au/˜ndavidson/photos/doxygen/index.html HepMC interface
- Z. Was, Q. Xu, $Kl3$ decays: at work.



- Bremsstrahlung of decays must be taken into account.
- Factorization, matrix elements: scalar QED, RChT.
- Phase space, convenience of use.
- New options: No brem in particular channel etc.
- Better than in FORTRAN access to decaying particle frame. Installation of process dependent matrix elements: Z, W, B decays.
- Documentation: N. Davidson, G. Nanava, T. Przedzinski, E. Richter-Was, and Z. Was, hep-ph/1002.0543
- Web page www.ph.unimelb.edu.au/˜ndavidson/photos/doxygen/index.html is regurarly updated. Tar ball is available from that web page.
- Next release planned for January.

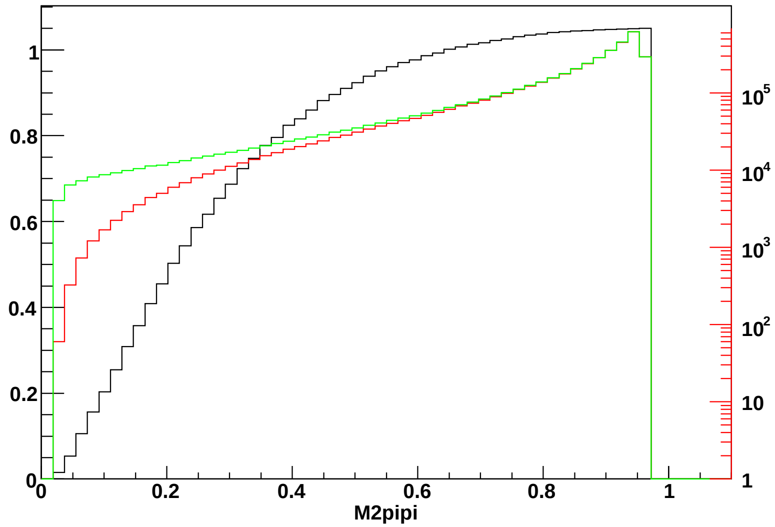
PHOTOS numerical tests Z decay





- 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.

PHOTOS numerical tests low energy



- Emissions from many lines. Interference weight $\longrightarrow$ 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 $K \longrightarrow l\nu\pi$ 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 $\gamma^* \longrightarrow \pi^+\pi^-(\gamma)$. It is of interest by itself and as building block of amplitudes for many decays.