τ lepton Monte Carlo, bremsstrahlung in decays – strategies for analysis.

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- **(1)** *Production and decay are separated perfectly: large lifetime.*

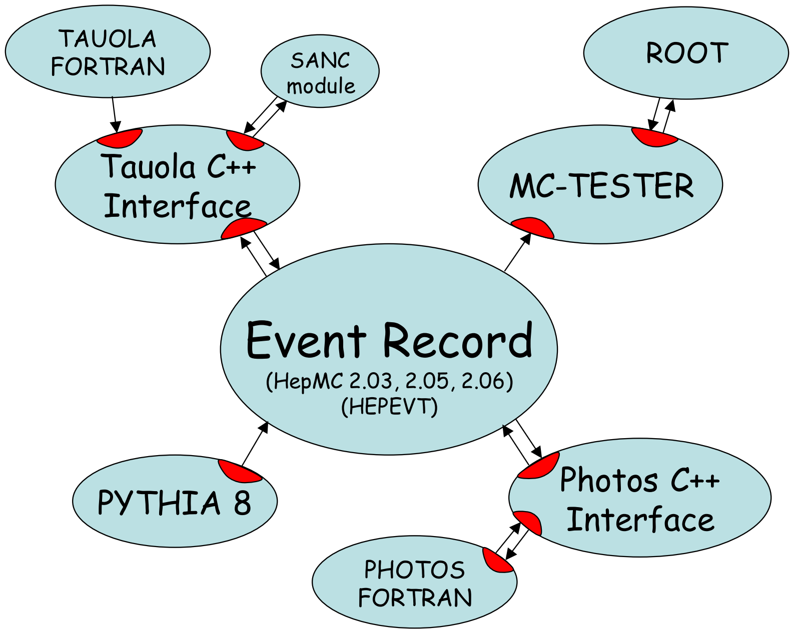
- **(2)** *from QCD point of view τ mass is intermediate. Decay M.E. has to be taken from models and low energy experiments data.*

- **(3)** *Fascinating laboratory for intermediate energy QCD, also well separated physics unit.*

- **(5)** How to prepare MC, theoretical constraints, fit algorithms, to get most from low energy data.

- **(6)** *Also: bremsstrahlung in decays.*

Simulation parts communicate through **event record:**



- Parts:

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

Necessary for precision:

- Phase space must be exact (will not be discussed here)
- Matrix element: hadronic current
- technical tests
- physics upgrades
- Fit strategies

General formalism for semileptonic decays

- Matrix element used in TAUOLA for semileptonic decay $J_{lept} \cdot J_{had}$. Valid down to 0.2 % precision level.

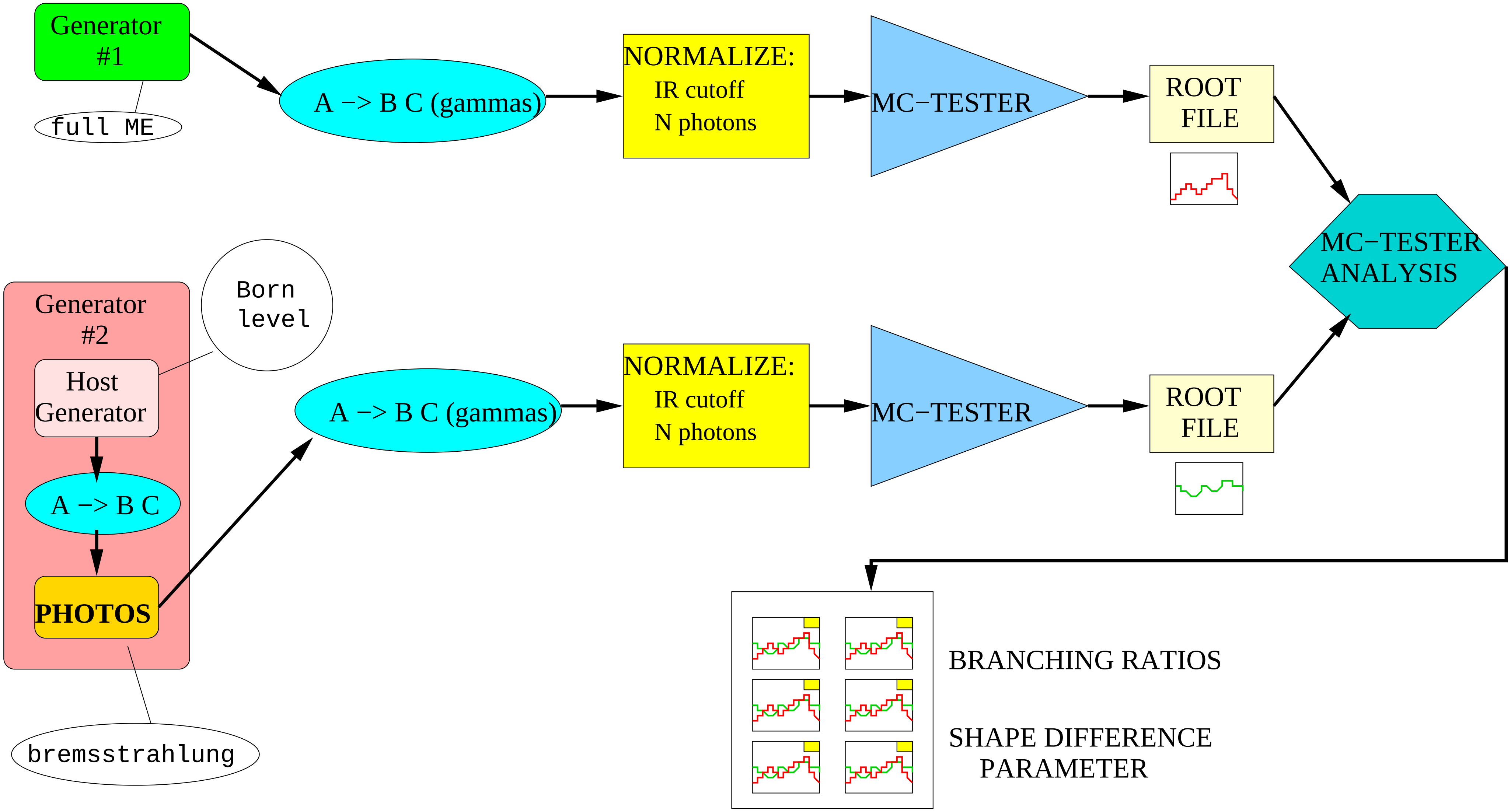
$$\tau(P,s) \to \nu_\tau(N) X$$
$$\mathcal{M} = \frac{G}{\sqrt{2}} \bar{u}(N)\gamma^\mu(v + a\gamma_5)u(P)J_\mu$$

- J_μ the current depends on the momenta of all hadrons

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

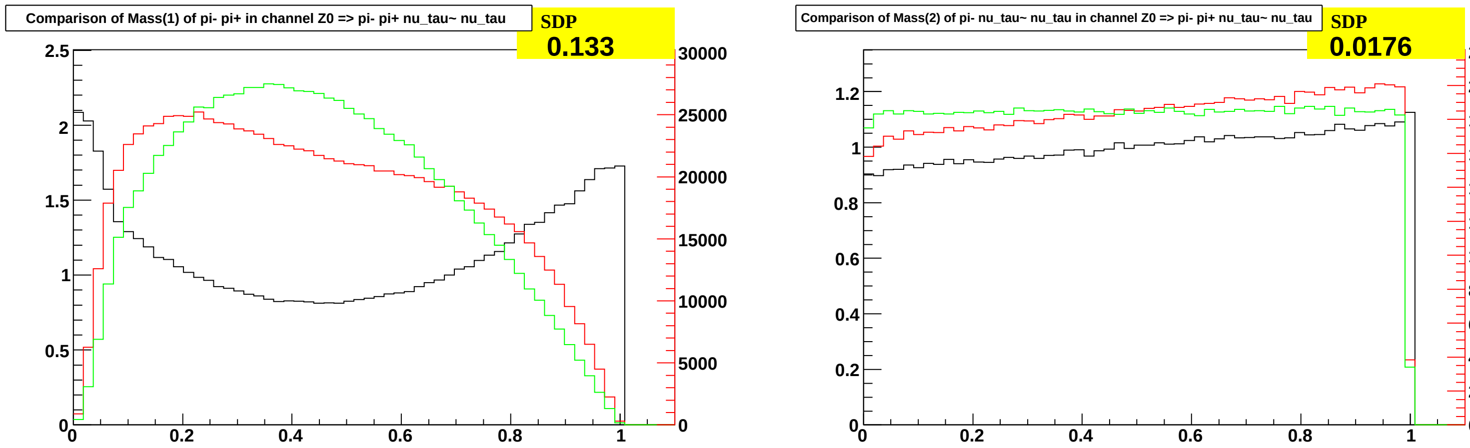
Tests!

MC-TESTER to test PHOTOS/TAUOLA



Part of techinical tests, also for tests of user installation

1. MC-TESTER: published in CPC
2. Web page: http://mc-tester.web.cern.ch/MC-TESTER/



(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.

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`
π^-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`*
$K^-\pi^0K^0$	$2.769 \cdot 10^{-15} \pm 0.04\%$	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 currents, preprint IFJPAN-IV-2011-6, UAB-FT/695

- 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.

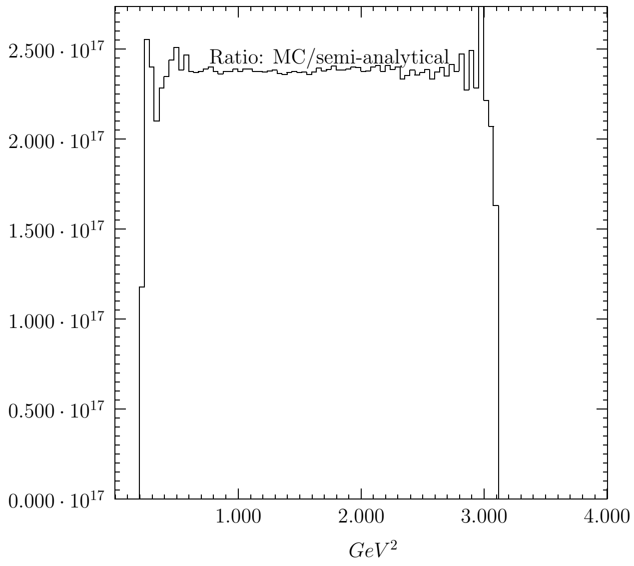


Figure 3: First attempt for comparison of Monte Carlo result with numerical calculation for spectrum of hadronic system invariant mass sqared. Ratio of the two is shown. Statistical sample of 2.5M evts was used and semi-realistic initialization as explained in the section. Reasonable agreement between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

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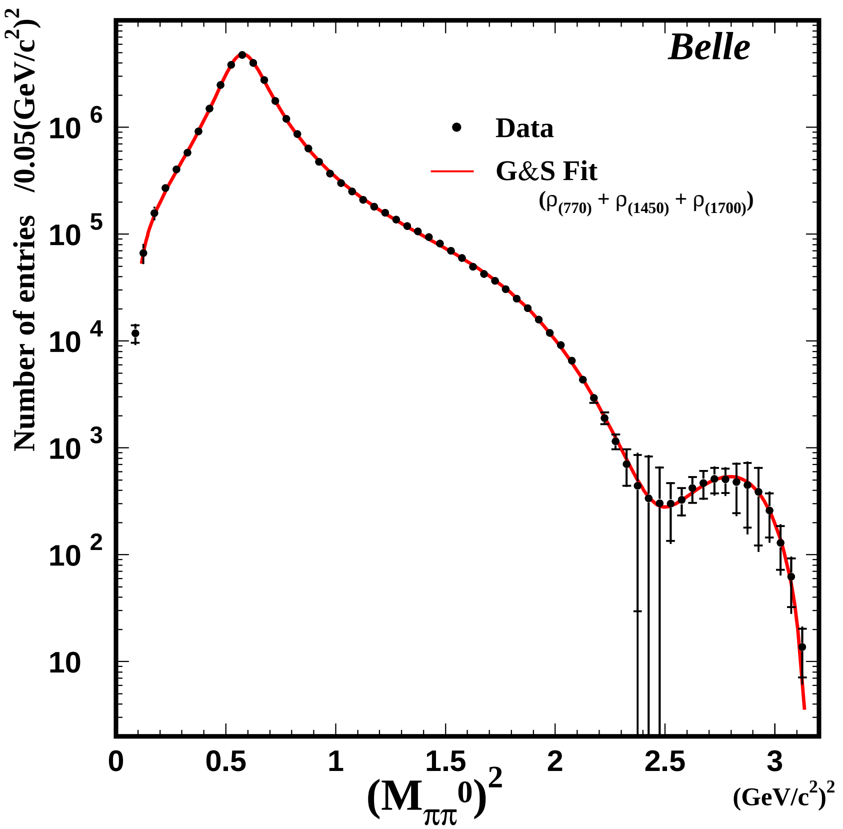
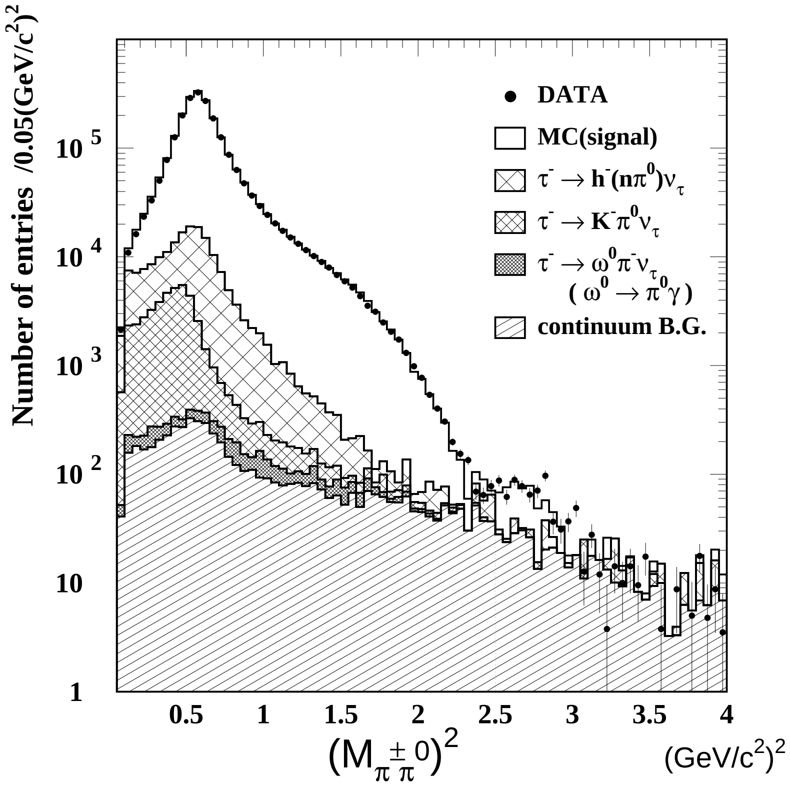
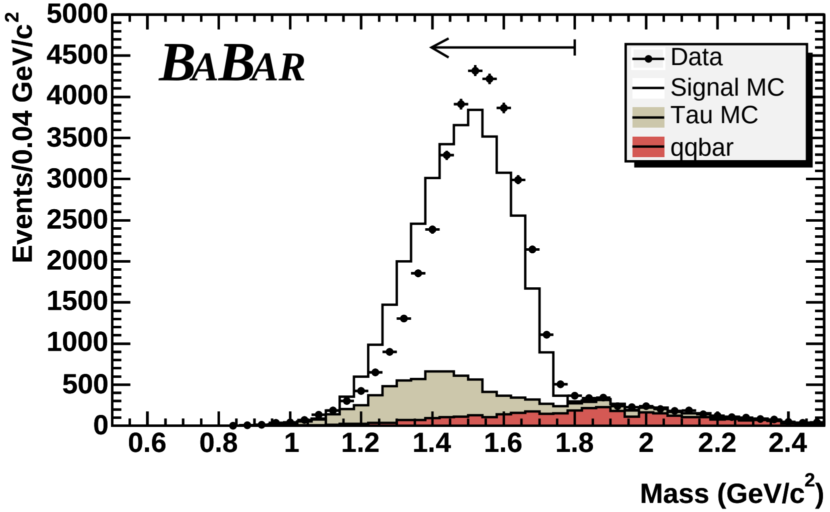
- Example from our web page: ratio of Monte Carlo obtained $\frac{d\Gamma}{dQ^2}$ and semi analytical formula is given on or web page for every channel.
- Perfect technical agreement.
- Physics precision is not as good, also $\frac{d\Gamma}{dQ^2}$ represents an input to the model parametrization.
- Differential 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)).



- 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.



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.

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.

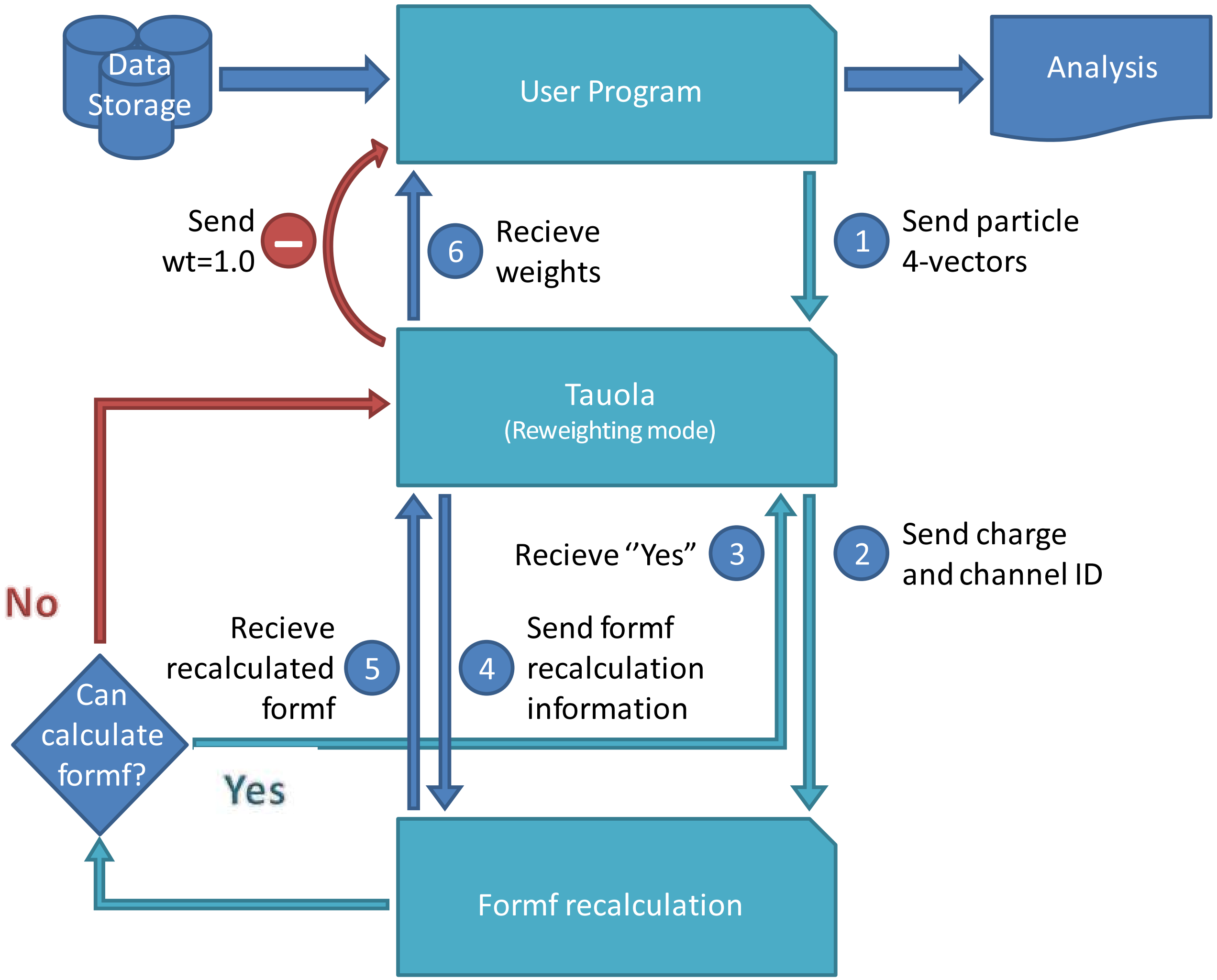


Figure 2: Flow chart for fifo communication. Verified to be compatible with Belle and BaBar software.

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** to be discussed later ...
- 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

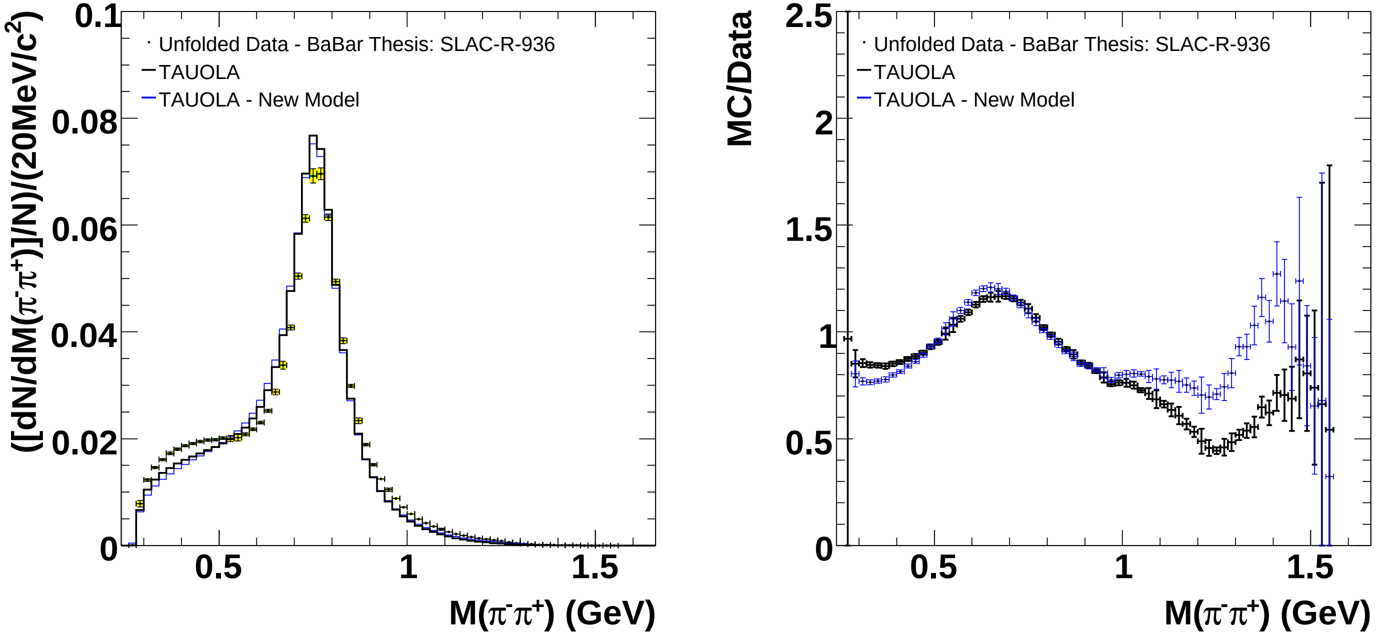
- How to share responsability and work between phenomenologists, MC authors, experimental physicists.
- Technical precision, hadronic current adaptation, new model construction, algorithm design. Fits to data, background subtraction
- Can we perform any better?

TAUOLA hadronic currents are clear plug ins, but ...

- Pretabulation necessary for unitarity constraints on $\frac{d\Gamma}{dQ^2}$ double/triple gaussian integration.
- I/O and software compatibility between currents from different authors.
- Fits to data: documentation required for collaboration members. who have other worries, expertise to keep.
- Isospin relations and codes for currents for e^+e^- and $e^+e^-\gamma$

without that I can not imagine how to get precision better than few %

Summary – low energy



(a) A

(b) B

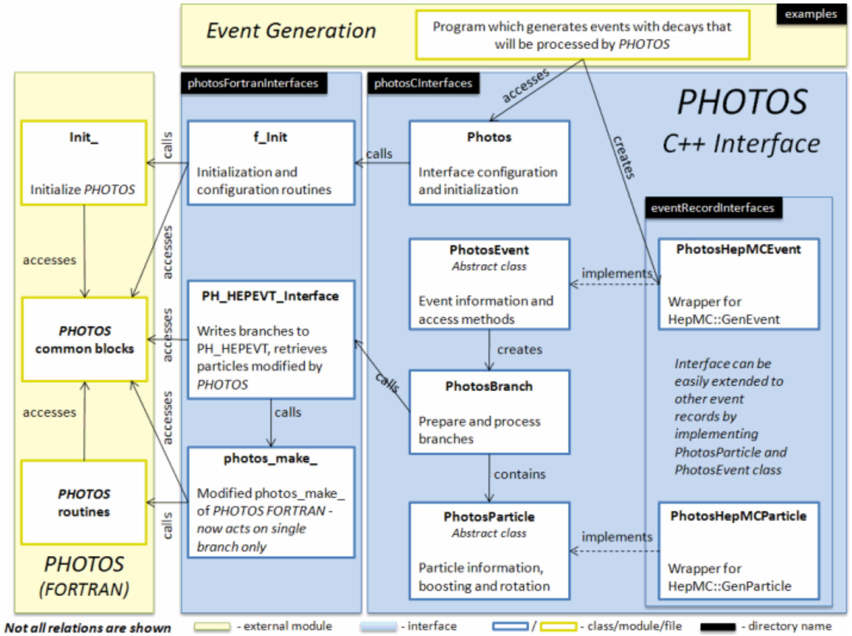
Figure 3: Invariant mass distribution of the $\pi^+\pi^-$ pair in $\tau \rightarrow \pi^+\pi^-\pi^-\nu$ decay. Histogram is from our model, the unfolded BaBar data are taken from PhD thesis of Ian Nugent. The plot on the left hand side corresponds to the differential decay distribution, and the one on the right hand side to plot ratios between Monte Carlo results and data. Clearly the ris plento of room for common work.

Presentation

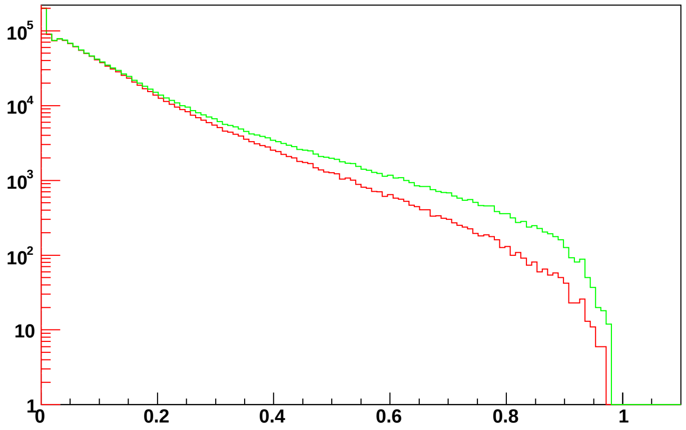
- PHOTOS (by E.Barberio, B. van Eijk, Z. W., P.Golonka) is used to simulate the effect of radiatiative corrections in decays, since 1989.
- many citations from experiments $\longrightarrow$ responsability
- Events of complicated tree structure of production and subsequent decays are fed into PHOTOS,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

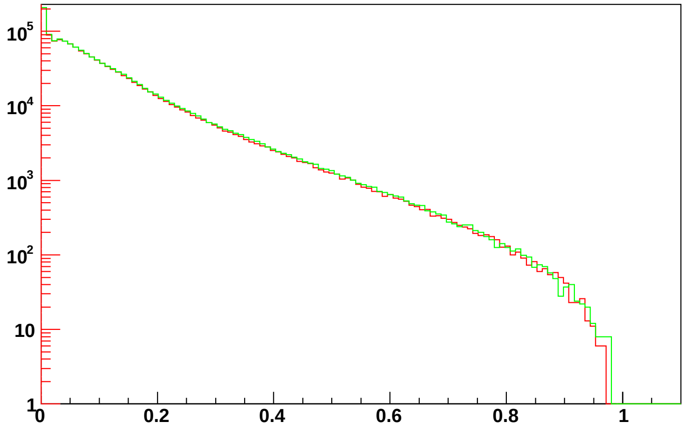
Main References

- 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.



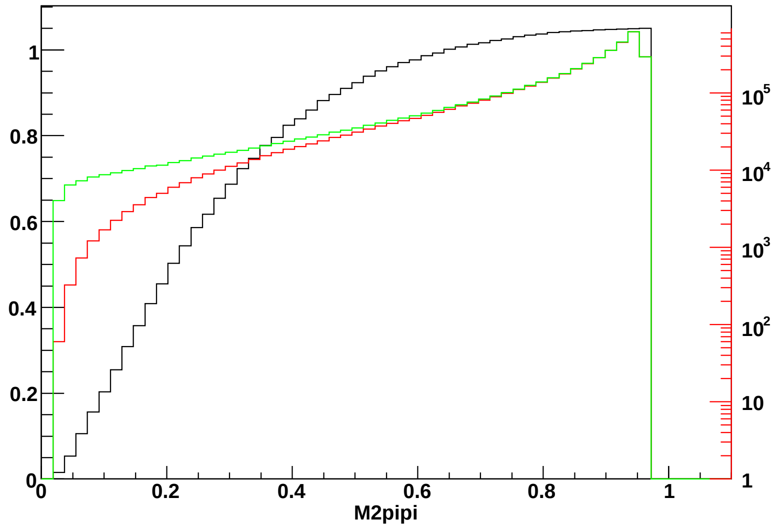
- Bremsstrahlung of decays must be taken into account.
- Factorization, matrix elements: scalar QED, RChT.
- Phase space, convenience of use.
- New options: No brem in particular channel etc.
- Better than in FORTRAN access to decaying particle frame. Installation of process dependent matrix elements: 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.





- 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.

PHOTOS numerical tests low energy

Bremsstrahlung in K(l3) decays http://hibiscus.if.uj.edu.pl/~przedzinski/Kl3/

Z. Was homepage | Quingjun Xu hompege

WEBPAGE AND PHYSICS AT WORK

PHOTOS Monte Carlo tests for Bremsstrahlung in K(l3) decays.
Authors: Qingjun Xu, Z. Was

Special version of PHOTOS MC was prepared. New options useful for tests were prepared. The following versions are used for the comparisons listed below

1. "Standard PHOTOS" denotes **F77** version 2.15, or **C++** version 3.0
2. For "standard phase-space" no modification in phase space generation are introduced.
3. For "exact phase space" single generation channel is used. Comparison with "standard phase-space" helps to establish numerical precision for standard phase space generation, and is of more technical nature. This comparison is important for evaluating of systematic errors eg. for multibremmstarhlung algorithm.
4. "M.E. of V. Cirigiano" means that instead of M.E. obtained from scalar QED M.E. from paper *V. Cirigliano et al. JHEP 0811 (2008) 006* is used.
5. For PDF we're using logarithmic scale, while for PS linear scale is used.

Results of numerical tests:

Standard photos vs matrix element	PS/PDF	rootfiles
K0 -> pi e nu_e	PS PDF	first second
K0 -> pi mu nu_mu	PS PDF	first second
K- -> pi0 e nu_e	PS PDF	first second
K- -> pi0 mu nu_mu	PS PDF	first second
Matrix element standard phasespace vs exact phasespace		
K0 -> pi e nu_e	PS PDF	first second
K0 -> pi mu nu_mu	PS PDF	first second
Standard photos vs exact phasespace matrix element of V. Cirigliano et al.		
K0 -> pi e nu_e	PS PDF	first second
K0 -> pi mu nu_mu	PS PDF	first second
Exact phasespace: matrix element of V. Cirigliano et al. vs matrix element		
K0 -> pi e nu_e	PS PDF	first second
K0 -> pi mu nu_mu	PS PDF	first second

These results are suplementing future paper by Qingjun Xu and Zbigniew Was.
Results of matrix element from V. Cirigliano et al. may be improperly implemented. We would expect matrix element from V. Cirigliano et al. to be closer to Standard photos than to Matrix element of scalar QED. At present it look to be apart from both of them. We must understand what is going on.

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Figure 4: Web page for Kl3 tests. Is it really of interest?