Study of hadronic currents, preparation for fits and implementation into TAUOLA MC

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Outline

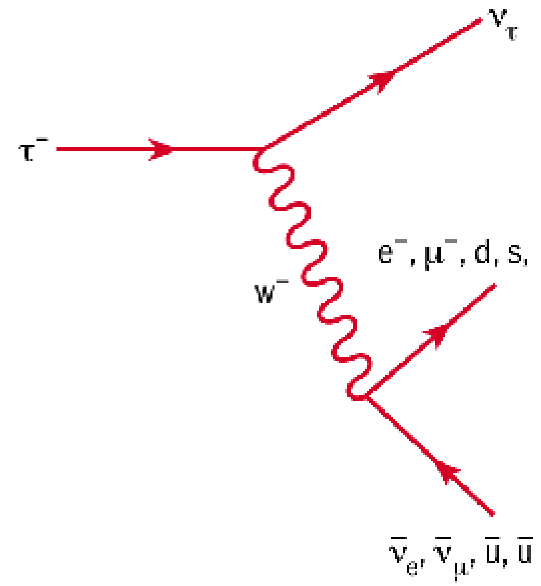
1. Introduction.
2. Hadronic current for τ decay into 3 hadrons
3. Model definition.
4. Investigation of numerical effects.
5. Preparation for fits to be performed by experiments.
6. Summary.

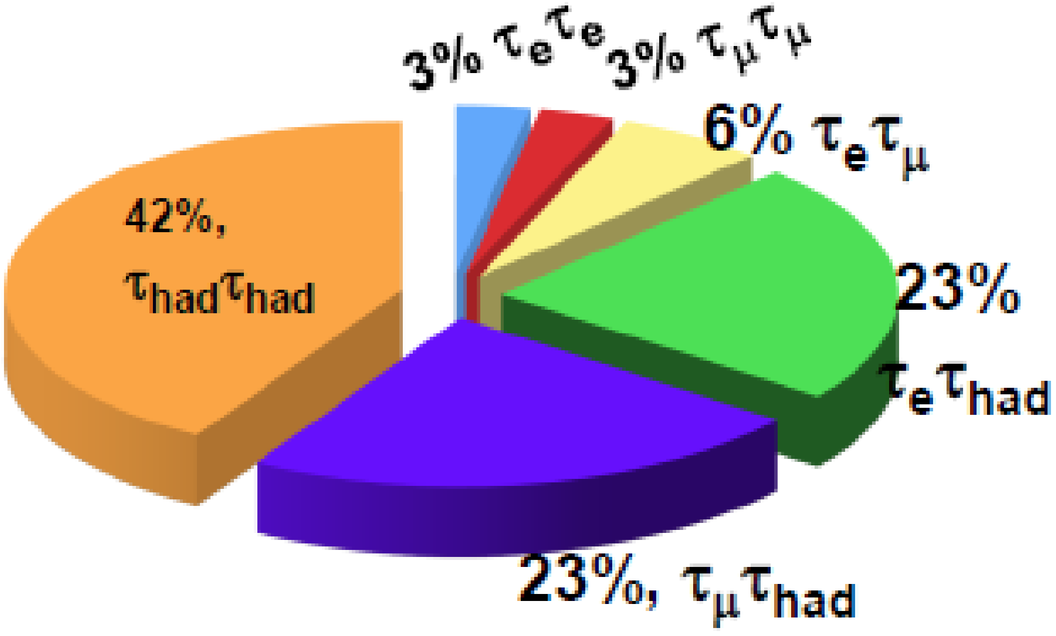
Introduction

TAUOLA – Monte Carlo generator for τ lepton decays

τ leptons give great opportunity to study medium energy QCD, where nothing really works.

Very important in measurements of hard processes e.g. Higgs boson parameters





Hadronic current for τ decay into 3 scalars

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

$$J^{\mu} = N\{T_{v}^{\mu}[c_1(p_2 - p_3)^{v}F_1 + c_2(p_3 - p_1)^{v}F_2 + c_3(p_1 - p_2)^{v}F_3] + c_4 q^{\mu}F_4 - \frac{i}{4\pi^2 f_{\pi}^2} c_5 \epsilon^{\mu}{}_{\nu\rho\sigma} p_1^{v} p_2^{\rho} p_3^{\sigma} F_5\}$$

Model definition

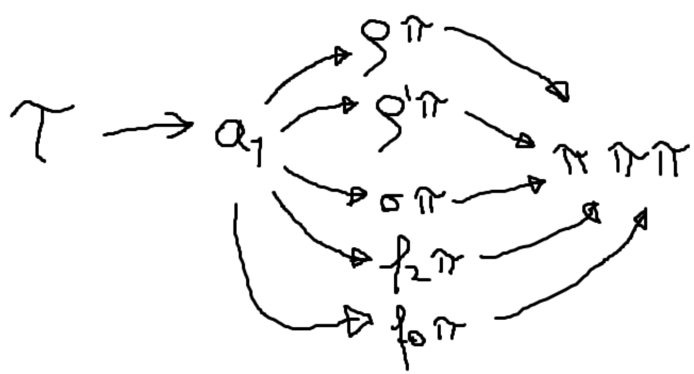
Resonance Chiral Lagrangian models (variants 2012 and 2013)

•Both masses and coupling constants were fitted
•Well founded from theoretical side
•Fitted to 1-dimentional BaBar data

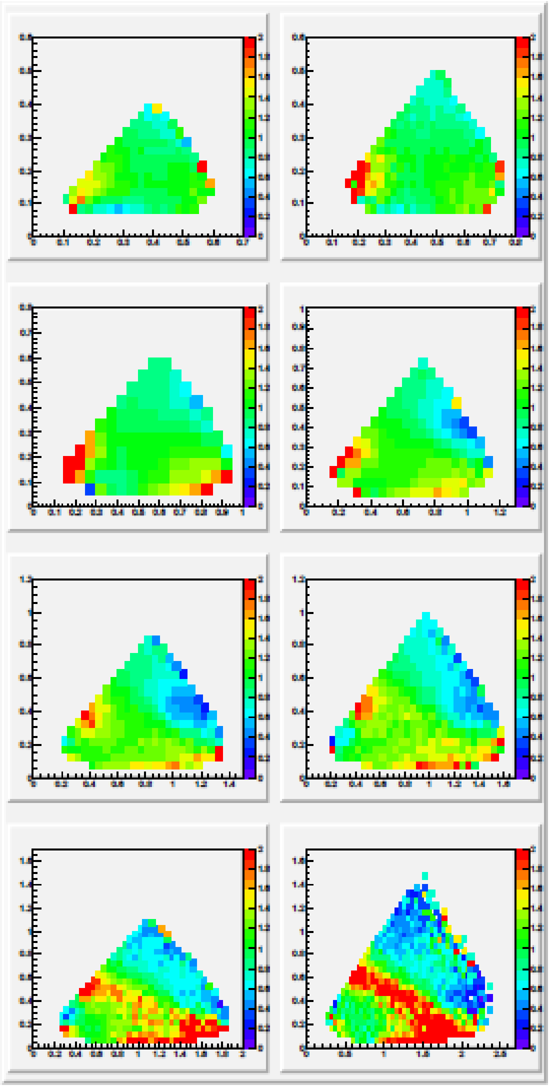
$$\tau \to a1\ \nu_\tau \to \rho\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to a1\ \nu_\tau \to \rho'\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to a1\ \nu_\tau \to \sigma\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to \sigma\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to \rho\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to \rho'\ \pi\ \nu_\tau \to \pi\ \pi\ \pi\ \nu_\tau$$
$$\tau \to \pi\ \pi\ \pi\ \nu_\tau$$

CLEO Model (1999)

•Only coupling constants were fitted, masses and widths taken from PDG/theory
•Fitted to three dimensional distributions from CLEO
• Similar but simpler model was used in BaBar

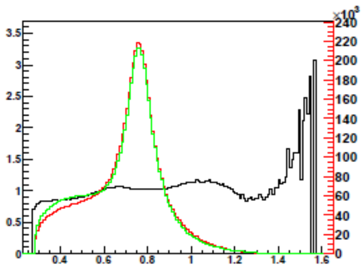


Investigation of numerical effects
- output distributions
- input distr. for fits

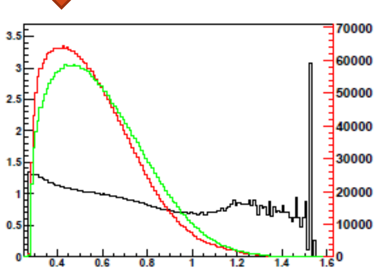


On the right, plots of ratios of Dalitz plots in S_1, S_2 variables in RChL model to CLEO modeling. Consecutive plots correspond to slices in Q^2; respectively for 0.36-0.81, 0.81-1.0,1.0-1.21, 1.21-1.44, 1.44-1.69, 1.69-1.96, 1.96-2.25, 2.25-3.24 GeV^2.

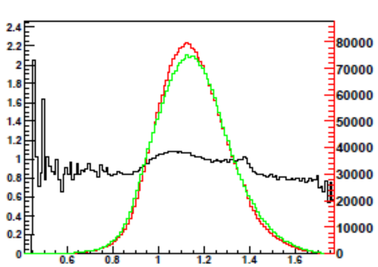
Input: RChL style CLEO style



Mass of π -π+



Mass of π -π -



Mass of π -π -π+

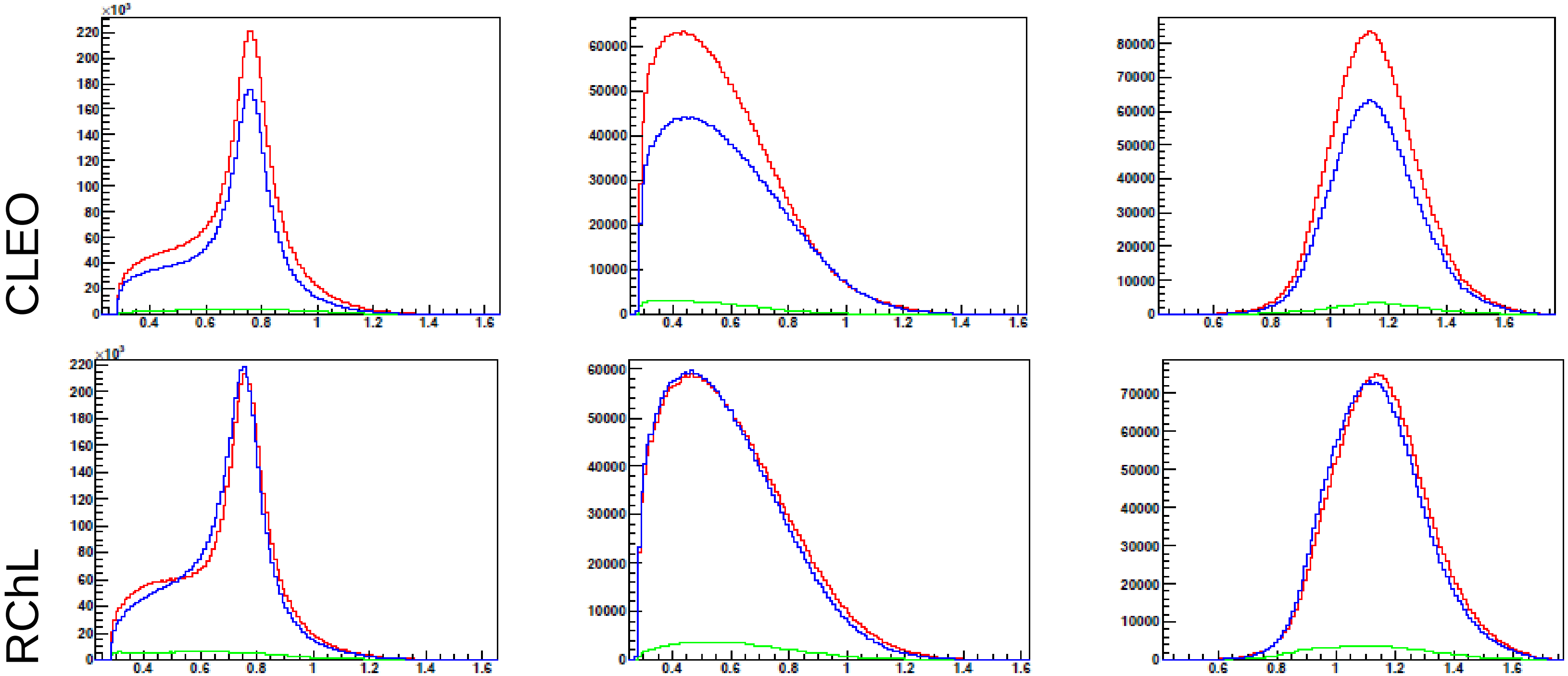
Investigation of numerical effects (computing)
- analysis of interference using weighted events

Looking at hadronic current only in context of output distributions does not give full understanding of the process. We could model them using polynomial but that would not teach us anything about physics. It is important to understand underlying physics and interplay of different parts of hadronic current.

Too sophisticated current of many resonances/parameters is not good, compromise with quality/dimensionality of available data needed. Complexity due to unitarity (s-dependent widths) may be alrorithmicaly perilous too.

In order to check interplay of hadronic current internals we used **re-weighting method**.

Investigation of numerical effects (step before fiting) - analysis of interference using weighted events



Current	Absolute width	1D distributions	3D distributions	Absolute width differential
$\pi^0\pi^0\pi^-$ CLEO	75.1% 4.4% 20.5%	75.1% 4.4% 20.8%	75.1% 4.4% 22.4%	75.1% 4.4% 22.7%
$\pi^-\pi^-\pi^+$ CLEO	75.3% 4.3% 20.4%	75.3% 4.3% 20.7%	75.3% 4.3% 22.3%	75.3% 4.3% 22.6%
$\pi^-\pi^-\pi^+$ CLEO isospin intricate	74% 5.8% 20.2%	74% 5.8% 20.2%	74% 5.8% 20.6%	74% 5.8% 20.7%
$\pi^-\pi^-\pi^+$ RChL	97.5% 6.5% 4%	97.5% 6.5% 11%	97.5% 6.5% 18.2%	97.5% 6.5% 18.5%
$\pi^0\pi^0\pi^-$ RChL	94% 1.3% 4.7%	94% 1.3% 7.4%	94% 1.3% 9.5%	94% 1.3% 10%

Investigation of numerical effects (numerical aspects) - analysis of interference using weighted events

Only after thorough investigation of a theoretical model one may perform fits to experimental data in an educated way.

From previous slide one can see that for fitting of RChL model one should use 3-dimentional distributions, otherwise some physics will be left out of control.

On the other hand, with CLEO modeling close to current parameterization we should control physics, but at the same time we know that σ parameters are not consistent with our current knowledge of this state.

Preparation for fits

Current environments for 2 kinds of fitting procedure:

1. Fits with help of semi analytical distributions
   a) Good for error calculation, easy control of derivatives with respect to parameters
   b) Difficult to implement cuts
   c) Sometimes laborious to obtain, and CPU costly, numerical speed-ups (tabulation) needed
2. Fits using re-weighted events
   a) Opposite as in (a) (b) of previous case
   b) In principle does not depend on details of the model
   c) May be CPU costly as well, uncontrollable number of iterations if dependence on model parameters is not understood

Preparation for fits
- re-weighting method

- Re-weighting is used as a way to obtain fitted distributions without analytical calculation: weights modify histograms changes.They are then used to fit with tools like Minuit2.

- When using re-weighting method, bulding of fitted distributions is done same way as in experiment.

- Main flaws of this method are CPU consumption (dependent on number of model parameters), and requirement of manual optimization of iterative steps. Difficulties for calculation of correlation matrices due to statistical fluctuations.

Preparation for fits - semi-analytical fit

- In this approach we need to prepare analytic function for fitting algorithm directly for coded hadronic current. That means building proper **structure function** and integrating it within bins of fitted histogram. Structure functions are build from components of hadronic tensor which is tensor product of hadronic current with itself.

- Main flaws:
  - Structure functions inconvenient for numerical integration, change of variables may not guarantee stability
  - Require substantial effort to build, code and test
  - Some models have too convoluted structure to use this method effectively without simplifications like linearization or partial unitarity constraints.
  - CPU consumption dependent on functional form of fitted model.

Summary

- Different modelings of τ decay into three pions were studied and compared.
- Issues of different models were pointed out.
- Desired experimental distributions were discussed.
- Two different computing approaches to fitting were studied and prepared for simple cases, but are still developed/optimized.

I hope my work one day may be helpful for high precision confrontation of data with models…

Thank you for your attention !