IFIC (CSIC-UV), València

Monte Carlo generator TAUOLA: implementation Resonance Chiral Theory for two and three meson modes. Comparison with experimental data

O. Shekhovtsova

together with

I. Nugent, T. Przedzinski, P. Roig and Z. Was

QCD@Work, Lecce, 20 June 2012

CONTENTS

TAUOLA 2011 (arXiv:1202.3955)

- Structure of the project, model etc.
- Results for two and three meson currents
- Tests
- Numerical results and parameters of fits

First results of 3 pion fits to BaBar (Ian Nugent)

CONCLUSION

TAUOLA (Monte Carlo generator for tau decay modes)

Main references (manuals):

1. R. Decker, S.Jadach, M.Jezabek, J.H.Kuhn, Z. Was, Comput. Phys. Commun. 76 (1993) 361, ibid. 70 (1992) 69, ibid. 64 (1990) 275 ***CPC (reference) version***

2. P. Golonka, B. Kersevan ,T. Pierzchala, E. Richter-Was, Z. Was, M. Worek, Comput. Phys. Commun. 174 (2006) 818, hep-ph/0312240
3. J.H.Kuhn, Z. Was, Acta Phys. Polon. 39 (2008) 47 (5-pions), hep-ph/0602162
4. A. E. Bondar, S. I. Eidelman, A. I. Milstein, T. Pierzchala, N. I. Root, Z. Was and M. Worek (4 pions), Comput. Phys. Commun. 146 (2002) 139

The parametrization used by experimental collaboration (based on data 1997-1998):

1. Alain Weinstein : http://www.cithep.caltech.edu/~ajw/korb_doc.html#files *(cleo version)*
2. B. Bloch, private communications *(aleph version)*

Different intermediate states (because of different detector sensitivity), *e.g.*, $K\pi\pi$ *only* K^* *cleo* , K^*, ρ *aleph*

→ BaBar, Belle

Hadronic modes:

$\pi\nu_\tau$ $K\nu_\tau$ $2\pi\,\nu_\tau$ $2K\nu_\tau$ $K\pi\nu_\tau$ $3\pi\nu_\tau$ $KK\pi\nu_\tau$ $K\pi\pi\nu_\tau$ $2\pi\eta\nu_\tau$ $4\pi\nu_\tau$ $5\,\pi\nu_\tau$

88% hadronic width

CPC version

- **2 pseudoscalar modes written analogous to $2\pi\ \tau$**
  normalization not fixed (too small statics 1992),
  only vector FF , no scalar FF
- **3 pseudoscalar modes (CPC version)**
  3pion modes (BW(a1)*BW(ρ)) reproduces LO ChPT limit

KKpi modes:

- within CPC parametrization CLEO was not able to reproduce data
- CLEO parametrization: to adjust data added factors (hep-ex/0401005)

$$J^\mu = \left(q_1^\mu - q_3^\mu - Q^\mu \frac{Q(q_1-q_3)}{Q^2}\right) F_1(s_1,s_2,Q^2) + \left(q_2^\mu - q_3^\mu - Q^\mu \frac{Q(q_2-q_3)}{Q^2}\right) F_2(s_1,s_2,Q^2) + i\epsilon^{\mu\alpha\beta\gamma} q_{1\alpha} q_{2\beta} q_{3\gamma} F_3(s_1,s_2,Q^2)$$

$$F_1 = -\frac{\sqrt{2}}{3f_\pi}\mathrm{BW}_{a_1}(Q^2)\frac{\mathrm{BW}_\rho(s_2)+\beta_\rho \mathrm{BW}_{\rho'}(s_2)}{1+\beta_\rho},$$

$$F_2 = -\frac{\sqrt{2}}{3f_\pi}\cdot R_F \cdot \mathrm{BW}_{a_1}(Q^2)\cdot \mathrm{BW}_{K^*}(s_1),$$

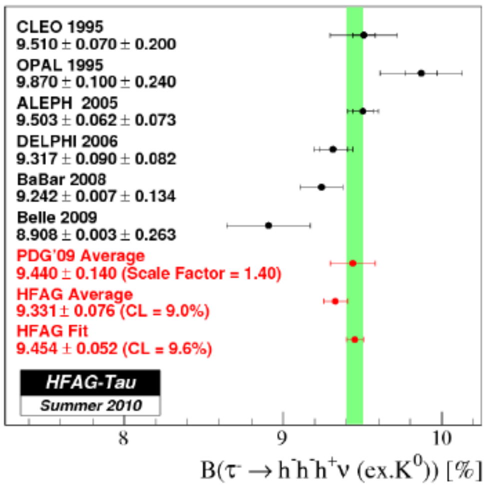
$$F_3 = -\frac{1}{2\sqrt{2}\pi^2 f_\pi^3}\cdot\sqrt{R_B}\cdot\frac{\mathrm{BW}_\omega(s_2)+\alpha \mathrm{BW}_{K^*}(s_1)}{1+\alpha} \cdot\frac{\mathrm{BW}_\rho(Q^2)+\lambda \mathrm{BW}_{\rho'}(Q^2)+\delta \mathrm{BW}_{\rho''}(Q^2)}{1+\lambda+\delta},$$

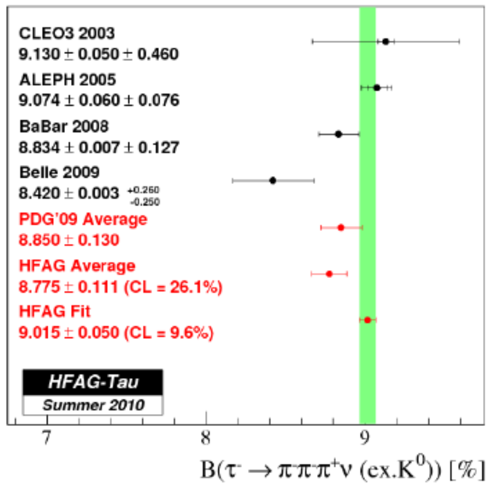
$$R_B = 3.23 \pm 0.26$$

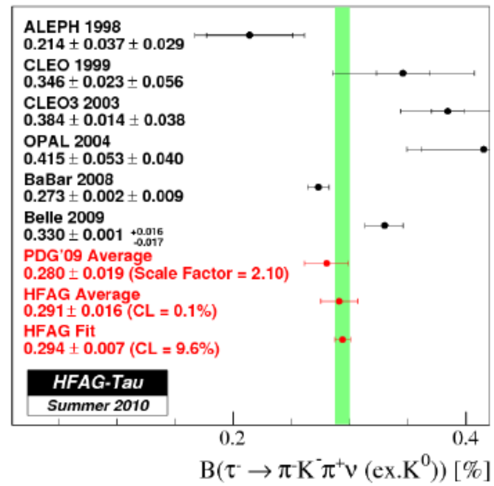
Main problem: almost no published spectra to update Monte Carlo
Private codes inside of collaborations

BaBar/Belle comparison for 3 meson modes

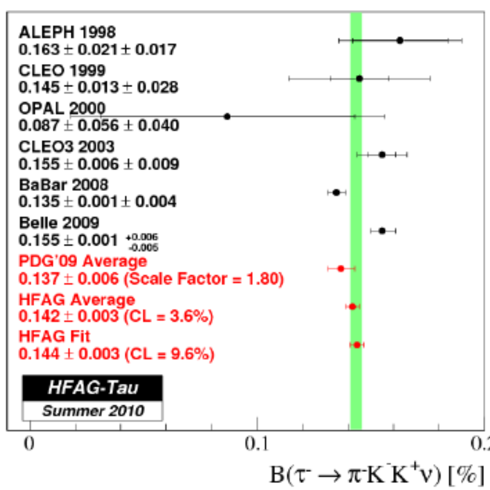
Ian Nugent (BaBar) for Workshop tau lepton decays: hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow

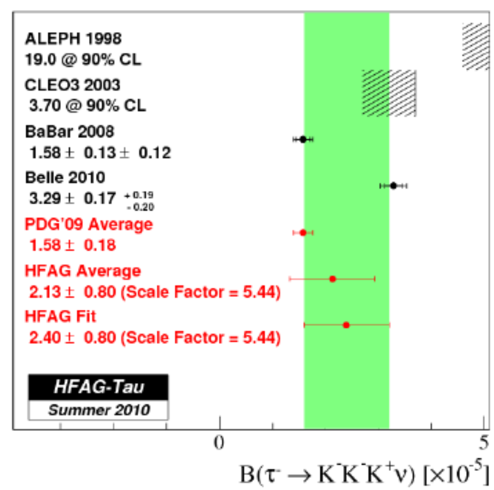






PRL100, 011801 (2008)



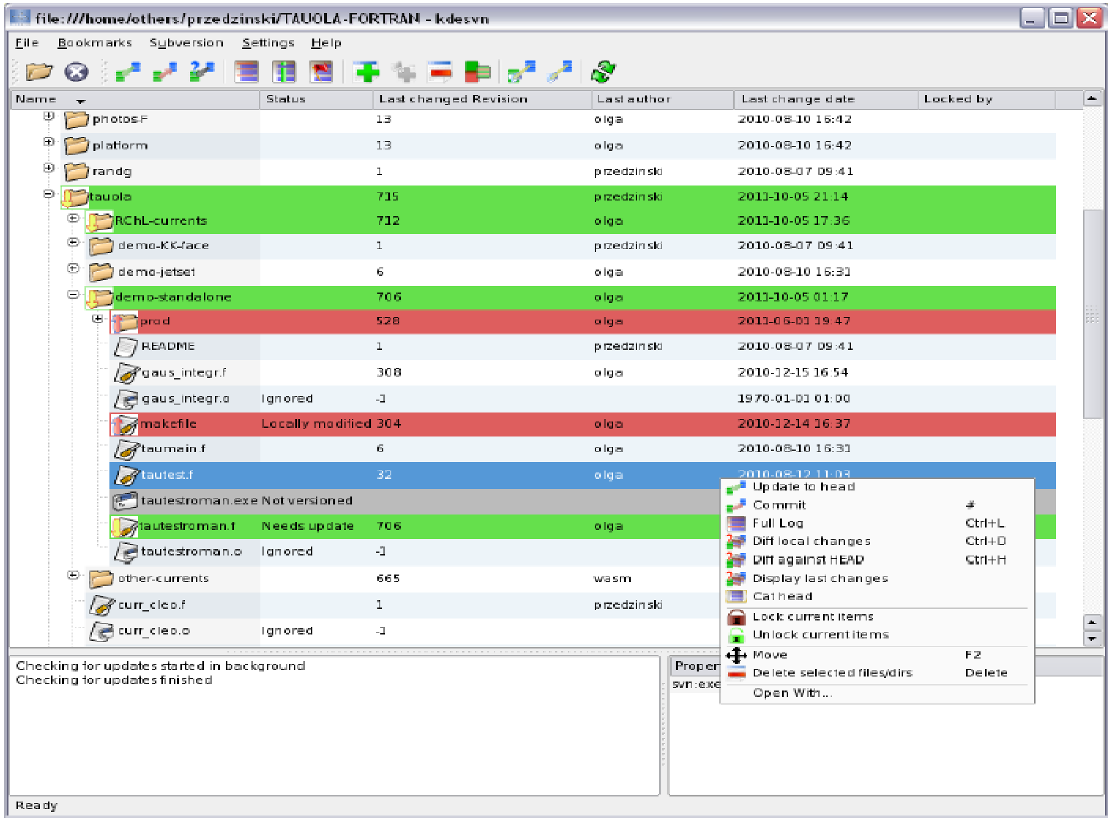


Only 3 pion mode result within errors

TAUOLA 2011 - 2012

Code management

- SVN revision control system
  - displaying recent changes
  - branching different approaches
  - tagging milestones and stable revisions
  - when bug is found – "blame" to check who and when
  - GUI: kdesvn



Z. Was, T. Przedzinski, O.Shekhovtsova ifj.edu.pl

http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm

Resonance chiral lagrangian currents and tau decay Monte Carlo

Progam is managed by: T. Przedzinski, O. Shekhovtsova, Z. Was

1. Paper (mar 18 2012) by: O. Shekhovtsova, T. Przedzinski, P. Roig, Z. Was
2. tar ball (nov 14, 2011) : for corresponding TAUOLA upgrade; svn tag inside.
3. -------------------------
4. **In future**, Next paper:
   (i) technical aspects simple, (ii) scalar form-factors, (iii) further updates on physics, possibly because of the first systematic results from comparisons with the data.
5. **In future,** new version of the tar ball
6. **In future,** Numerical results for the new version,
   hopefully with estimation of agreement with the data.

Results of numerical tests:

MC-TESTER: TAUOLA cleo vs. TAUOLA new currents	PS/PDF	rootfiles
Channels 4,5,7,22,14,15,16	PS PDF	first second
Tests in old style (90's): comparison with analytical calc.		
tau -> pi- pi0 nu	PS PDF	tgz (restr.)
tau -> K- pi0 nu	PS PDF	tgz (restr.)
tau -> pi- K0 nu	PS PDF	tgz (restr.)
tau -> K- K0 nu	PS PDF	tgz (restr.)
tau -> pi- pi- pi+ nu	PS PDF	TeX
tau -> pi0 pi0 pi- nu	PS PDF	TeX
tau -> K- pi- K+ nu	PS PDF	TeX
tau -> K0 pi- K0 nu	PS PDF	TeX
tau -> K- pi0 K0 nu	PS PDF	TeX
Technical tests, style of 90's too, MC analytical calc. Channel pi0 pi0 pi-		
F1=1, other formfactors zero, mpi=mpi0=aver	PS PDF	TeX
F1 physical, other formfactors zero, mpi=mpi0=aver	PS PDF	TeX
F1 F2 physical, other formfactors zero, mpi=mpi0=aver	PS PDF	TeX
All formfactors physical, mpi=mpi0=aver	PS PDF	TeX
ME reweighting, results of tests	PS/PDF	rootfiles
Cleo to RChL	PS PDF	first second
RChL to cleo	PS PDF	first second

We expect matrix element to evolve even after our paper is finished. This page is the place to check on the progress. Eventually new co-authors and contribution from data analysis will be added here or link to such works will be added.

Last update: 18 Mar 2012 by Z. Was

Structure of *new-currents/RChL-currents*

Added to \tauola *cleo* version

- codes for currents
  - frho_pi.f pipi0 mode
  - fkk0.f kk0 mode
  - fkpipl.f kpi modes
  - f3pi_rcht.f 3 pion modes
  - fkkpi.f KKpi modes
  - fkk0pi0.f KK0pi0 mode
- library of functions used in the currents
  - funct_rpt.f Width of resonances etc
- code for a1 width as function of qq
  - /tabler/a1/da1wid_tot_rho1_gauss.f
  - wid_a1_fit.f linear interpolation
- numerical values of fit parameters, dipswitches
  - value_parameter.f
- tests of MC results (for separate modes)
  /cross-check/check_analyticity_and_numer_integr

Every directory with own README

Two meson modes: $\tau^- \to \pi^- \pi^0 \nu_\tau$; $\tau^- \to (K\pi)^- \nu_\tau$; $\tau^- \to K^- K^0 \nu_\tau$

$$J^\mu = N\left[(p_1 - p_2)^\mu F^V(s) + (p_1 + p_2)^\mu F^S(s)\right]$$

$$s = (p_1 + p_2)^2$$

$$N^{\pi^-\pi^0} = 1,\ N^{K^-K^0} = \frac{1}{\sqrt{2}},\ N^{\pi^-\bar{K}^0} = \frac{1}{\sqrt{2}},\ N^{\pi^0 K^-} = \frac{1}{2}$$

TAUOLA 2011: only vector FF

Three meson modes: $\tau^- \to (3\pi)^- \nu_\tau$; $\tau^- \to K^-\pi^-K^+ \nu_\tau$; $\tau^- \to K^0\pi^- K^0 \nu_\tau$; $\tau^- \to K^-\pi^0K^0 \nu_\tau$

$$J^\mu = N\left\{T_\nu^\mu\left[c_1(p_2-p_3)^\nu F_1 + c_2(p_3-p_1)^\nu F_2 + c_3(p_1-p_2)^\nu F_3\right] + c_4 q^\nu F_4 - \frac{i}{4\pi^2 F^2} c_5 \varepsilon^{\mu\nu\rho\sigma} p_{1\nu} p_{2\rho} p_{3\sigma} F_5\right\}$$

Decay mode (p_1, p_2, p_3)	c_1	c_2	c_3	c_4	c_5
$\pi^-\pi^-\pi^+$	1	- 1	0	1	0
$\pi^0\pi^0\pi^-$	1	- 1	0	1	0
$K^-\pi^-K^+$	1	- 1	0	0	1
$K^0\pi^-\bar{K}^0$	1	- 1	0	0	1
$K^-\pi^0K^0$	0	1	- 1	0	- 1

$$N = \begin{cases} \cos\theta_{Cabibo}/F, & 2n\ kaons \\ \sin\theta_{Cabibo}/F, & 2n+1\ kaons \end{cases}$$

$$T_\mu^\nu = g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}, \quad q^\mu = p_1^\mu + p_2^\mu + p_3^\mu$$

FF: F_1, F_2, F_3 axial-vector, F_5 vector, F_4 pseudoscalar → **RχT** , Pablo Roig talk

arXiv:1202.3955

http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm

Numerical benchmarks of formfactor implementation:

1. a1 width is tabulated to avoid problem with triple integration:

   Cross check with linear interpolation

2. Check of every channel: **/cross-check/check_analyticity_and_numer_integr**

   semi-analytical result (Gauss integration): comparison with linear interpolated spectrum

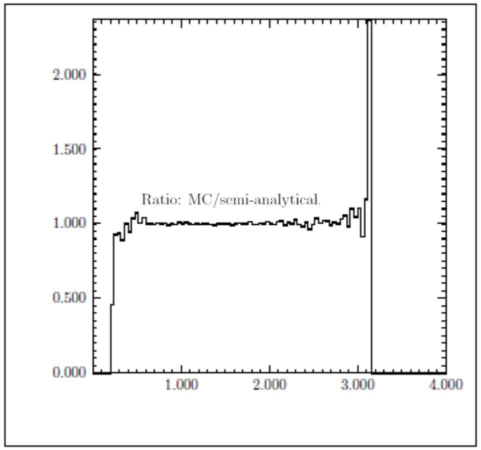
   ratio MC/semi-analytical of differential width (qq)

   comparison of analytical integration and MC for total width

   2 pion, 2 Kaon with physical mass of pions, Kaons

   others $m_\pi = (m_{\pi^0} + 2 \cdot m_{\pi^+})/3$ $m_K = (m_{K^0} + m_{K^+})/2$

An example: three pions ($\tau \to \pi^-\pi^-\pi^+\nu_\tau$):



- $F_1 = F$, $F_{others} = 0$ to check phase space
- F_1 = physical, $F_{others} = 0$
- F_{all} = physical

linear interpolation ~ 0.1% for whole spectrum except for ends

MC (6e6): (2.1013±0.016%)·10^{-13}GeV; semi-analyt(2.1007±0.02% %)·10^{-13}GeV

Comparison of semi-analytical integration and MC

3 pseudoscalars

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{ud}|^2}{128(2\pi)^5 M_\tau F^2}\left(\frac{M_\tau^2}{q^2}-1\right)^2 \int dsdt\left[W_{SA}+\frac{1}{3}\left(1+2\frac{q^2}{M_\tau^2}\right)(W_A+W_B)\right]$$

$$W_B = \frac{1}{64\pi^4 F^4}\left[stu+(m_{K,\pi}^2-m_\pi^2)(q^2-m_{K,\pi}^2)s+m_{K,\pi}^2(2m_\pi^2-q^2)q^2-m_{K,\pi}^2 m_\pi^4\right]|F_5|^2\,,$$

$$W_{SA} = q^2|F_4|^2\,. \qquad W_A = -(V_1^\mu F_1+V_2^\mu F_2+V_3^\mu F_3)(V_{1\mu}F_1+V_{2\mu}F_2+V_{3\mu}F_3)^*\,,$$

$$\int dsdt = \int_{4m_{K,\pi}^2}^{\left(\sqrt{q^2}-m_\pi\right)^2} ds \int_{t_-(s)}^{t_+(s)} dt \qquad t_\pm(s) = \frac{1}{4s}\left\{(q^2-m_\pi^2)^2-\left[\lambda^{1/2}(q^2,s,m_\pi^2)\mp\lambda^{1/2}(m_{K,\pi}^2,m_{K,\pi}^2,s)\right]^2\right\}$$

Two pions

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{ud}|^2 m_\tau^3}{384\pi^3}\left(1-\frac{q^2}{m_\tau^2}\right)^2 \lambda\left(1,\frac{m_{\pi^+}^2}{q^2},\frac{m_{\pi^0}^2}{q^2}\right)|F_\pi|^2$$

Channel	Analytical , GeV^{-1}	Monte Carlo , GeV^{-1}
pipi0	$(5.2431 \pm 0.02\%) \cdot 10^{-15}$	$(5.2441 \pm 0.005\%) \cdot 10^{-15}$
KK0	$(2.0863 \pm 0.02\%) \cdot 10^{-15}$	$(2.0864 \pm 0.005\%) \cdot 10^{-15}$
Kpi0	$(2.5193 \pm 0.02\%) \cdot 10^{-14}$	$(2.5197 \pm 0.008\%) \cdot 10^{-14}$
pipipi	$(2.1007 \pm 0.02\%) \cdot 10^{-13}$	$(2.1013 \pm 0.016\%) \cdot 10^{-13}$
K-pi-K+	$(3.7379 \pm 0.024\%) \cdot 10^{-15}$	$(3.7383 \pm 0.02\%) \cdot 10^{-15}$
K0pi-K0	$(3.7385 \pm 0.024\%) \cdot 10^{-15}$	$(3.7383 \pm 0.02\%) \cdot 10^{-15}$
Kpi0K0	$(2.7370 \pm 0.02\%) \cdot 10^{-15}$	$(2.7367 \pm 0.02\%) \cdot 10^{-15}$

(Kpi0 – Kpi0K0): $m_{\pi^\pm} = m_{\pi^0}$, $m_{K^\pm} = m_{K^0}$

Numerical results

Channel	Width, [GeV]		
	PDG	Equal masses	Phase space with masses
$\pi^-\pi^0$	$(5.778 \pm 0.35\%) \cdot 10^{-13}$	$(5.2283 \pm 0.005\%) \cdot 10^{-13}$	$(5.2441 \pm 0.005\%) \cdot 10^{-13}$
$\pi^0 K^-$	$(9.72 \pm 3.5\%) \cdot 10^{-15}$	$(8.3981 \pm 0.005\%) \cdot 10^{-15}$	$(8.5810 \pm 0.005\%) \cdot 10^{-15}$
$\pi^- \bar{K}^0$	$(1.9 \pm 5\%) \cdot 10^{-14}$	$(1.6798 \pm 0.006\%) \cdot 10^{-14}$	$(1.6512 \pm 0.006\%) \cdot 10^{-14}$
$K^- K^0$	$(3.60 \pm 10\%) \cdot 10^{-15}$	$(2.0864 \pm 0.007\%) \cdot 10^{-15}$	$(2.0864 \pm 0.007\%) \cdot 10^{-15}$
$\pi^-\pi^-\pi^+$	$(2.11 \pm 0.8\%) \cdot 10^{-13}$	$(2.1013 \pm 0.016\%) \cdot 10^{-13}$	$(2.0800 \pm 0.017\%) \cdot 10^{-13}$
$\pi^0\pi^0\pi^-$	$(2.10 \pm 1.2\%) \cdot 10^{-13}$	$(2.1013 \pm 0.016\%) \cdot 10^{-13}$	$(2.1256 \pm 0.017\%) \cdot 10^{-13}$
$K^-\pi^- K^+$	$(3.17 \pm 4\%) \cdot 10^{-15}$	$(3.7379 \pm 0.024\%) \cdot 10^{-15}$	$(3.8460 \pm 0.024\%) \cdot 10^{-15}$
$K^0\pi^-\bar{K}^0$	$(3.9 \pm 24\%) \cdot 10^{-15}$	$(3.7385 \pm 0.024\%) \cdot 10^{-15}$	$(3.5917 \pm 0.024\%) \cdot 10^{-15}$
$K^-\pi^0 K^0$	$(3.60 \pm 12.6\%) \cdot 10^{-15}$	$(2.7367 \pm 0.025\%) \cdot 10^{-15}$	$(2.7711 \pm 0.024\%) \cdot 10^{-15}$

only ρ

with ρ' (parameters from pion mode) $(2.6502 \pm 0.008\%) \cdot 10^{-15}$ GeV

FSI effects

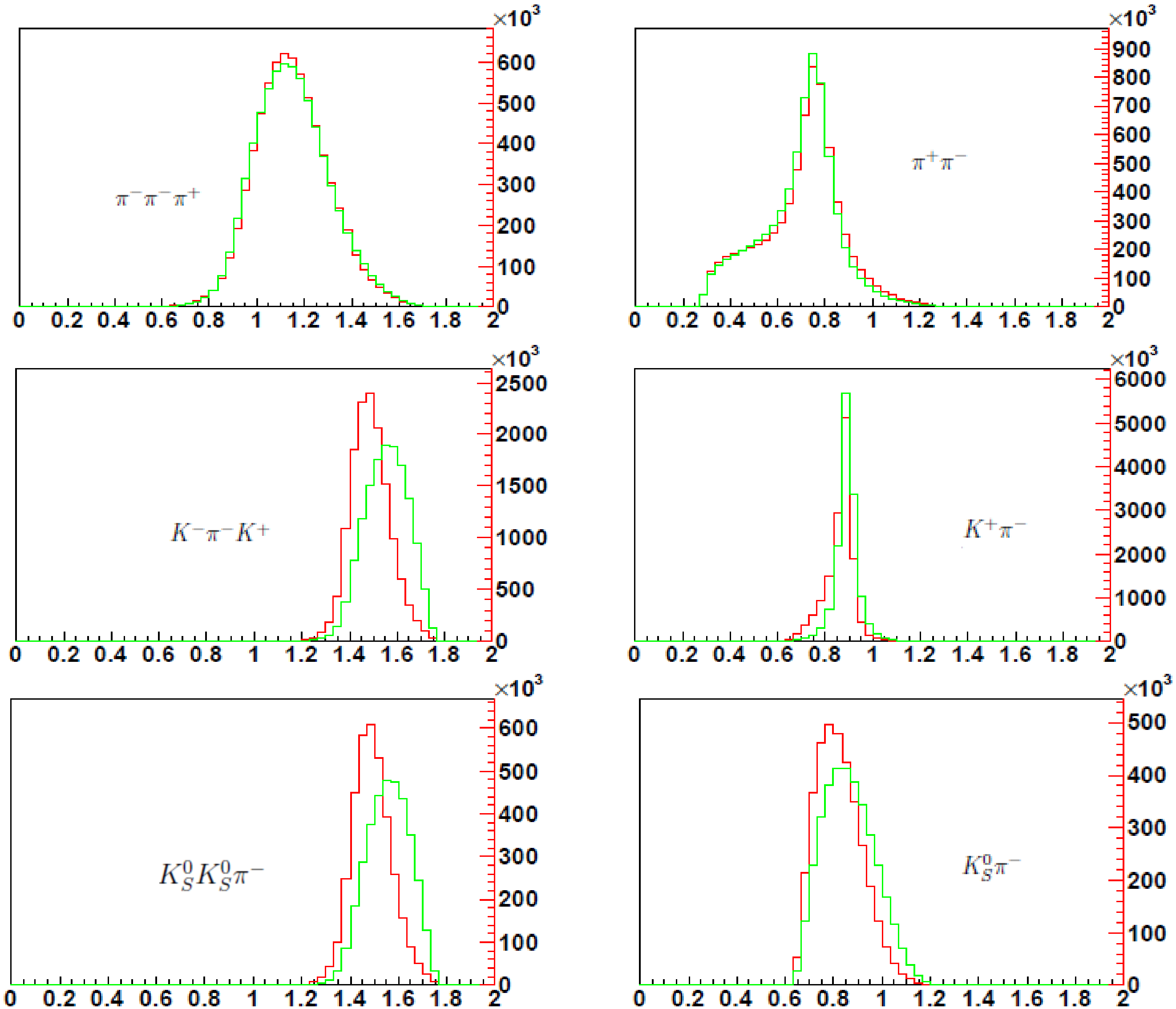
No.	Channel	Width [GeV]	Width [GeV]
1.	$\pi^-\pi^0$	$5.2441 \cdot 10^{-13} \pm 0.005\%$	$4.0642 \cdot 10^{-13} \pm 0.005\%$
2.	$\pi^0 K^-$	$8.5810 \cdot 10^{-15} \pm 0.005\%$	$7.4275 \cdot 10^{-15} \pm 0.005\%$
3.	$\pi^-\bar{K}^0$	$1.6512 \cdot 10^{-14} \pm 0.006\%$	$1.4276 \cdot 10^{-14} \pm 0.006\%$
4.	$K^- K^0$	$2.0864 \cdot 10^{-15} \pm 0.007\%$	$1.2201 \cdot 10^{-15} \pm 0.007\%$

FSI **No FSI**

$14\% - 32\%$

FFVEC = 1 (FSI), 0 (no FSI)

Comparison between CLEO and TAUOLA2011



TAUOLA2011

CLEO

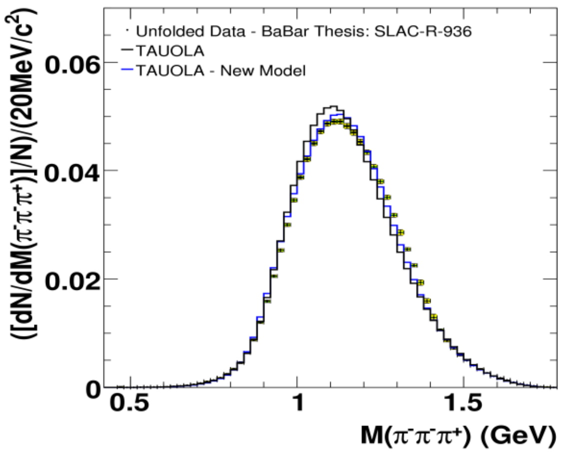
$$\tau \rightarrow \pi^-\pi^-\pi^+\nu_\tau$$

$$\tau \rightarrow K^-\pi^-K^+\nu_\tau$$

$$\tau \rightarrow K^0\pi^-\bar{K}^0\nu_\tau$$

http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm

$$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$$



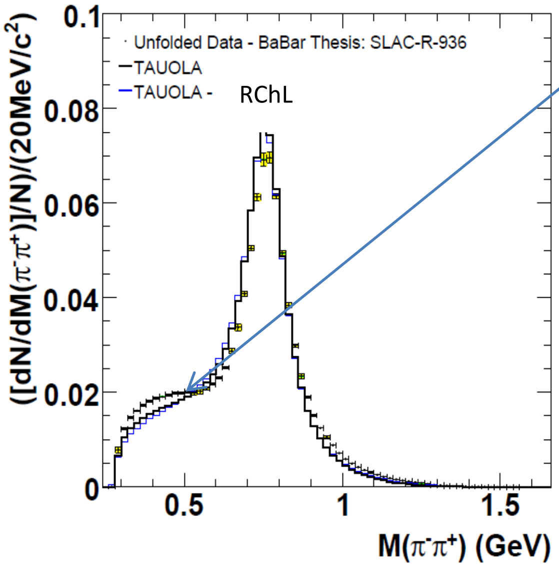
BABAR data: *Ian M. Nugent, (Victoria U.) . SLAC-R-936, Dec16, 2009. Ph.D. Thesis (Advisor: Dr. J. Michael Roney)*

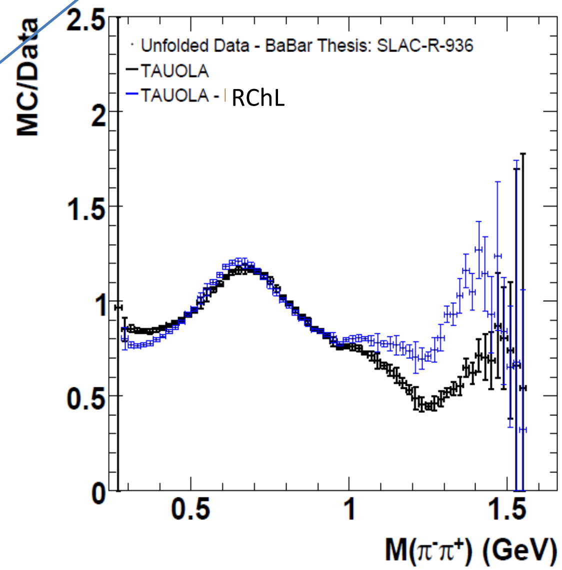
Low energy region is not described well by both models CPC (LO ChT) RChT (NLO ChT)

?sigma meson?

TAUOLA 2012

Talk of Pablo Roig





Fit of 3 pion available spectra from BaBar
an exercise done Ian Nugent

(Aachen University, Alexander von Humboldt Foundation)

Presented at Workshop tau lepton decays:
hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow

Fit Parameters							
	$M_{\rho'}$	$\Gamma_{\rho'}$	M_{a1}	F	F_V	F_A	$\beta_{\rho'}$
Min.	1.44	0.32	1.00	0.0920	0.12	0.10	-0.36
Max.	1.48	0.39	1.24	0.0924	0.24	0.20	-0.18
Default	1.453	0.40	1.12	0.0924	0.18	0.149	-0.25
Fit	1.4302	0.376061	1.21706	0.092318	0.121938	0.11291	-0.208811

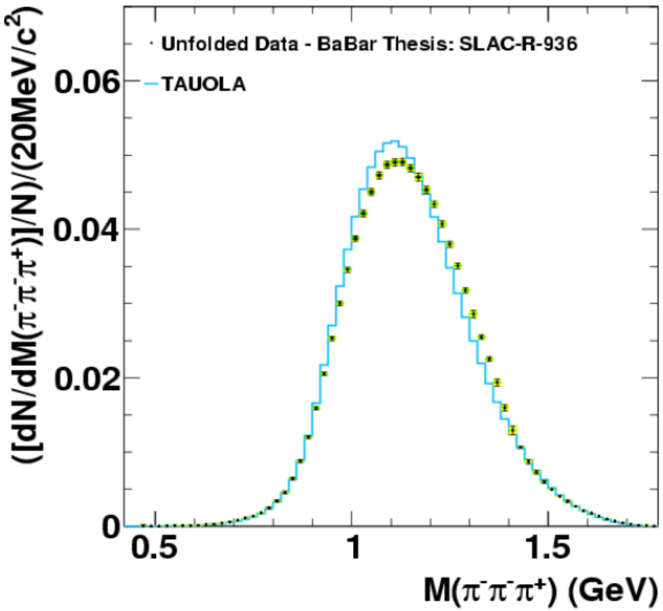
χ^2= 2262.12

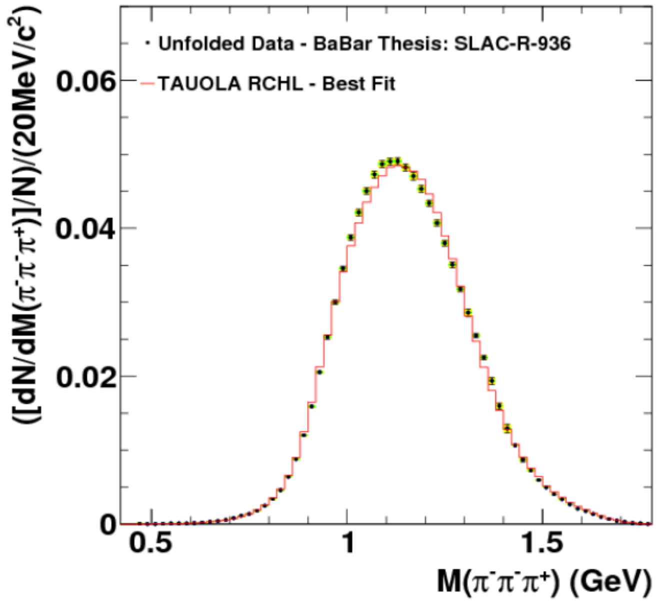
ndf=132

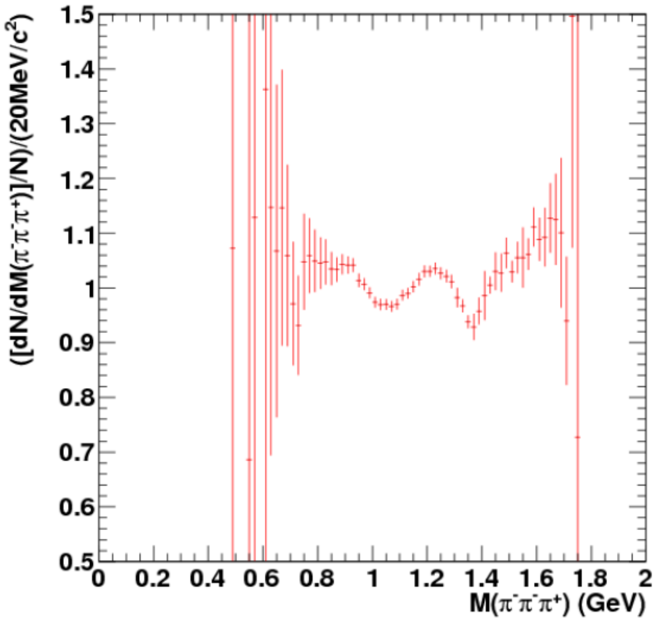
Note:

- The fit is a work in progress – not necessarily the minimum
- Reliable errors estimates are not available yet

$\pi^- \pi^- \pi^+$ invariant mass





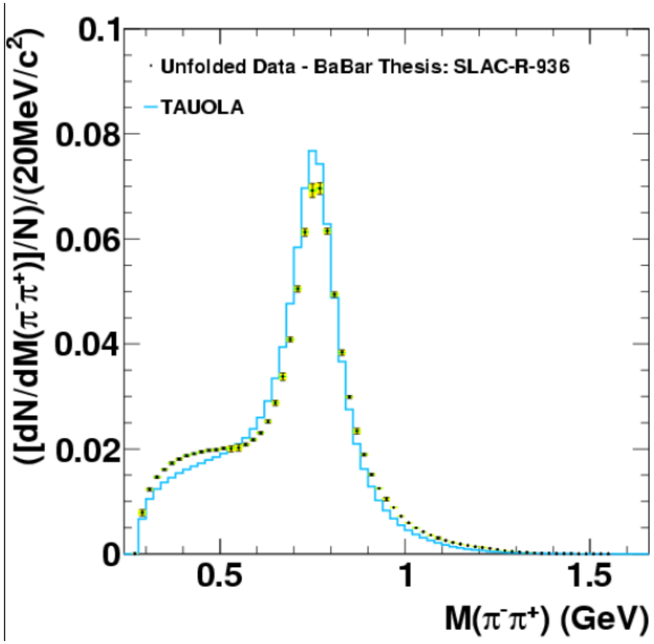


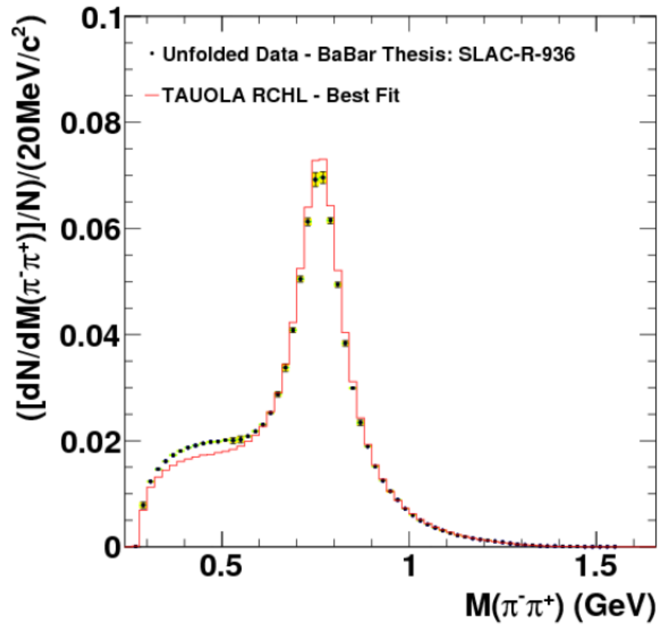
For the $\pi^- \pi^- \pi^+$ invariant mass:

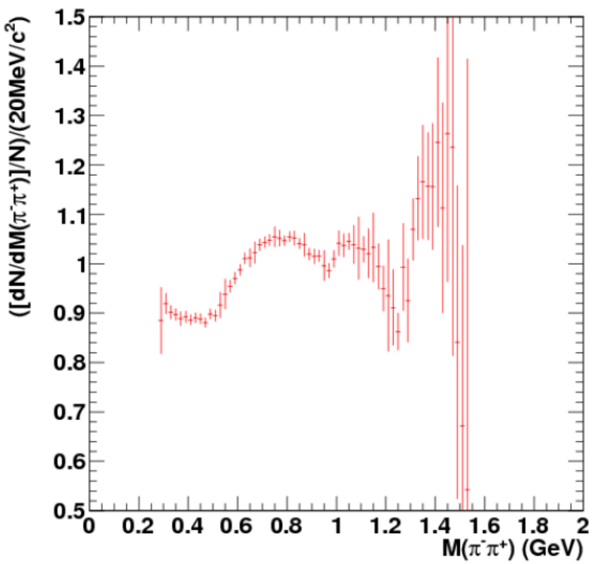
- RCHL Current is in better agreement then Tauola 1.05
- $a_1(1260)$ mass is lower but there is still some disagreement (FSR?)

(Data- MC (RChL)) is less than 7 %

$\pi^-\pi^+$ invariant mass







For the $\pi^-\pi^+$ invariant mass:

- RCHL Current is in better agreement then Tauola 1.05
- Disagreement is visible in the low mass region

(Data- MC (RChL)) is less than 12 %

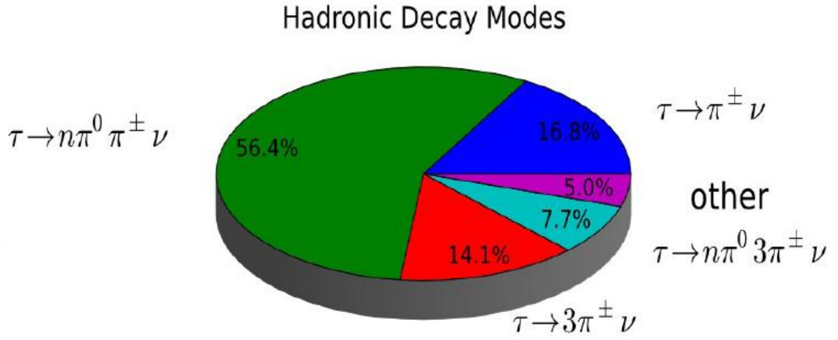
Application for LHC

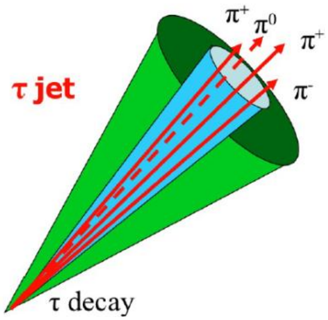
Martin Flechl (ATLAS) for Workshop tau lepton decays: hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow

Tau Lepton Properties

UNI FREIBURG ATLAS

Tau Lepton Properties
- m_τ = 1.78 GeV
- $c\tau$ = 87 μm
- BR($\tau \to l\nu\nu$) = 35.2%
- BR($\tau \to$hadrons) = 64.8%





Typical detector signature
- one or three charged tracks
- collimated calorimeter energy deposits
- large leading track momentum fraction
- possible secondary vertex reconstruction

ATLAS Tau Physics Program
- Standard Model cross section measurements
- Higgs searches (SM and beyond)
- Searches for SUSY and exotica

τ is used a tag
dynamics is not studied
however

its knowledge is important for
Higgs polarization measurement
agreement MC/data

CONCLUSION

- released version, *http://annapurna.ifj.edu.pl/~wasm/RChL/RChL.htm*
- done under SVN code manager
- **$2\pi\tau$, $2K\ \tau$, $K\pi\tau$, $3\pi\tau$, $KK\pi\tau$** **88% of tau hadronic width**
- first comparison / fit

TAUOLA2012

- common work with experimentalists (I. Nugent, D. Epifanov) → fit of parameters
- higher energy resonances in 3 pseudoscalar modes
- scalar FF in Kpi mode, FSI for 2 pseudoscalar modes (*TALK OF P.ROIG*)
- sigma meson in 3 pseudoscalar modes
- 4 pion modes in RChT to get 97% hadronic width, G.Ecker, R. Unterdorfer, Eur.Phys. JC24 (2002) 535
- other channels: pi eta, k eta etc

Common work: theory + experiment

Workshop tau lepton decays:
hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow

TAU12, Nagoya, 17-21 September, 2012

BACK UP

DIPSWITCH PARAMETERS

new-currents/RChL-currents/value_parameter.f

DIPSWITCH	VALUE	MEANING	MODE
FFVEC	0, 1*	FSI OFF, ON*	PIPI0, KPI, KK0
FFKPIVEC	0, 1*	FSI GS, EXPON	KPI
FFKKVEC	0*,1	RHOPR OFF*,ON	KK0

* default value

Input: parameters from fit etc.