Comparison of Resonance Chiral Lagrangian Currents to experimental data for $\tau^- \to \pi^+ \pi^- \pi^- \nu_\tau$

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in collaboration with

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

Trento, 12.04.2013

CONTENTS

TAUOLA

TAUOLA 2011(arXiv:1203.3955)

- Structure of the project, model etc.
- Main results
- 3 pion mode fit

TAUOLA 2013 : 3pion mode

- Model, inclusion of sigma meson
- Fit to BaBara preliminary data

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)*

1.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

Why we change TAUOLA?

- **All versions are based on VMD, i.e. 3 scalar modes BW(V1)*BW(V2) , reproduces LO ChPT limit**
- **3 scalar mode results are not able to reproduce experimental data**
- **2 scalar modes written analogous to 2π τ, i.e normalization not fixed**
  only vector FF , no scalar FF

TAUOLA 2011(arXiv:1203.3955)

- **Model Resonance Chiral Theory**
- **Technical tests:** semi-analytical result (Gauss integration) compared with linear interpolated spectrum
  ratio MC/semi-analytical of differential width
  comparison of analytical integration and MC for total width
- **First comparison with I. M. Nugent, SLAC-R-936, PhD Thesis**

Results for 3 pion modes

Three pseudoscalar modes:

$m_{\pi^\pm} = m_{\pi^0}$

$m_{K^\pm} = m_{K^0}$

$\tau^- \to (3\pi)^- \nu_\tau$; $\tau^- \to K^- \pi^- K^+ \nu_\tau$; $\tau^- \to K^0 \pi^- K^0 \nu_\tau$, $\tau^- \to K^- \pi^0 K^0 \nu_\tau$

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

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

FF: F_1 F_2 F_3 axial-vector, F_5 vector, $F_5(3\pi) = 0$ **, F_4 pseudoscalar**

General structure

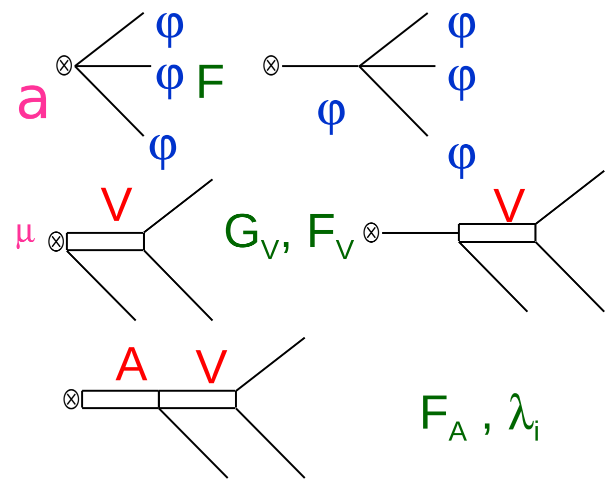
$$F_i = F_i^\chi + F_i^R + F_i^{RR}$$

$$F_4 \sim m_\pi^2 / q^2$$

χPT

RχT, 1R

RχT, 2R



No VV vertex for 3 pions

1 octet: F, F_V , G_V , λ_i (5, 3 for 3pi and Kkpi modes)

1 + 7 constants

$\tau^- \to \pi^0\pi^0\pi^-\nu_\tau$, $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$

arXiv:0911.4436

$$F_1^{\chi}(q^2, s_1, s_2) = -\frac{2\sqrt{2}}{3}$$

$$F_1^{R}(q^2, s_1, s_2) = \frac{\sqrt{2}\,F_V\,G_V}{3\,F^2}\left[\frac{3\,s_1}{s_1 - M_\rho^2 - iM_\rho\Gamma_\rho(s_1)} - \left(\frac{2G_V}{F_V} - 1\right)\left(\frac{2q^2 - 2s_1 - s_3}{s_1 - M_\rho^2 - iM_\rho\Gamma_\rho(s_1)} + \frac{s_3 - s_1}{s_2 - M_\rho^2 - iM_\rho\Gamma_\rho(s_2)}\right)\right],$$

$$F_1^{RR}(q^2, s_1, s_2) = \frac{4\,F_A\,G_V}{3\,F^2}\frac{q^2}{q^2 - M_A^2 - iM_A\Gamma_A(q^2)}\left[-(\lambda' + \lambda'')\frac{3\,s_1}{s_1 - M_\rho^2 - iM_\rho\Gamma_\rho(s_1)} + H\left(\frac{s_1}{q^2}, \frac{m_\pi^2}{q^2}\right)\frac{2q^2 + s_1 - s_3}{s_1 - M_\rho^2 - iM_\rho\Gamma_\rho(s_1)} + H\left(\frac{s_2}{q^2}, \frac{m_\pi^2}{q^2}\right)\frac{s_3 - s_1}{s_2 - M_\rho^2 - iM_\rho\Gamma_\rho(s_2)}\right],$$

Axial-vector

$$F_2(q^2, s_2, s_1) = F_1(q^2, s_1, s_2)$$

$$F_4^{\chi}(q^2, s_1, s_2) = \frac{2\sqrt{2}}{3}\frac{m_\pi^2[3(s_3 - m_\pi^2) - q^2(1 + 2\kappa R^{3\pi})]}{2q^2(q^2 - m_\pi^2)},$$

$$F_4^{R}(q^2, s_1, s_2) = -\frac{\sqrt{2}\,F_V\,G_V}{3\,F^2}\left[\alpha_2(q^2, s_2, s_1) + \alpha_2(q^2, s_1, s_2)\right]$$

$$\alpha_2(q^2, s_1, s_2) = \frac{3G_V}{F_V}\frac{s_1}{q^2}\frac{m_\pi^2}{q^2 - m_\pi^2}\frac{s_3 - s_2}{s_1 - M_\rho^2 - iM_\rho\Gamma_\rho(s_1)}$$

To include ρ'

$$\frac{1}{M_\rho^2 - q^2 - iM_\rho\Gamma_\rho(q^2)} \longrightarrow \frac{1}{1 + \beta_{\rho'}}\left[\frac{1}{M_\rho^2 - q^2 - iM_\rho\Gamma_\rho(q^2)} + \frac{\beta_{\rho'}}{M_{\rho'}^2 - q^2 - iM_{\rho'}\Gamma_{\rho'}(q^2)}\right]$$

$$\beta_{\rho'} = -F_{V'}G_{V'}/F^2$$

$$M_A,\ M_\rho,\ M_{\rho'},\ F_V,\ G_V,\ F_A,\ \beta_\rho,\ F \Rightarrow \Gamma_\rho(s),\ \Gamma_{\rho'}(s),\ \Gamma_A(s)$$

Three meson modes the widths of the resonances:

$$\Gamma_\rho(q^2) = \frac{M_\rho q^2}{96\pi F^2}\left[\sigma_\pi^3(q^2)\theta(q^2-4m_\pi^2) + \frac{1}{2}\sigma_K^3(q^2)\theta(q^2-4m_K^2)\right]$$

$$\Gamma_{\rho'}(q^2) = \Gamma_{\rho'}\,\frac{q^2}{M_{\rho'}^2}\,\frac{\sigma_\pi^3(q^2)}{\sigma_\pi^3(M_{\rho'}^2)}\,\theta(q^2-4m_\pi^2) \qquad \sigma_P(q^2) \equiv \sqrt{1-4m_P^2/q^2}$$

SU(2) limit

$m_{\pi^\pm} = m_{\pi^0}$

$m_{K^\pm} = m_{K^0}$

new-currents/RChL-currents/value_parameter.f

a_1 resonance:

$$\begin{aligned}\Gamma_{a_1}(q^2) &= 2\Gamma_{a_1}^{\pi}(q^2)\theta\left(q^2-9m_\pi^2\right)\\ &+ 2\Gamma_{a_1}^{K^\pm}(q^2)\theta\left(q^2-(m_\pi+2m_K)^2\right) + \Gamma_{a_1}^{K^0}(q^2)\theta\left(q^2-(m_\pi+2m_K)^2\right)\end{aligned}$$

$$\begin{aligned}\Gamma_{a_1}^{\pi,K}(q^2) &= \frac{-S}{192(2\pi)^3F_A^2F^2M_{a_1}}\left(\frac{M_{a_1}^2}{q^2}-1\right)^2\\ &\int dsdt\,(V_1^\mu F_1 + V_2^\mu F_2 + V_3^\mu F_3)^{\pi,K}\left((V_{1\mu}F_1 + V_{2\mu}F_2 + V_{3\mu}F_3)^{\pi,K}\right)^*\end{aligned}$$

$$V_i^\mu = c_i T^{\mu\nu}(p_j-p_k)_\nu, \quad i \neq j \neq k = 1,2,3$$

$$S = 1/n!$$

a1 width ($\Gamma_{a_1}(q^2)$) is tabulated to avoid problem with triple integration, linear interpolation

new-currents/RChL-currents/table/a1 ***new-currents/RChL-currents/wid_a1_fit.f***

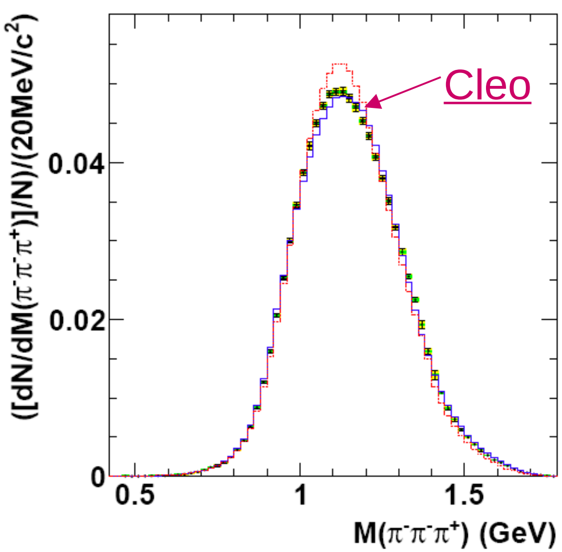
Fit of 3 pion available spectra from BaBar (May 2012)

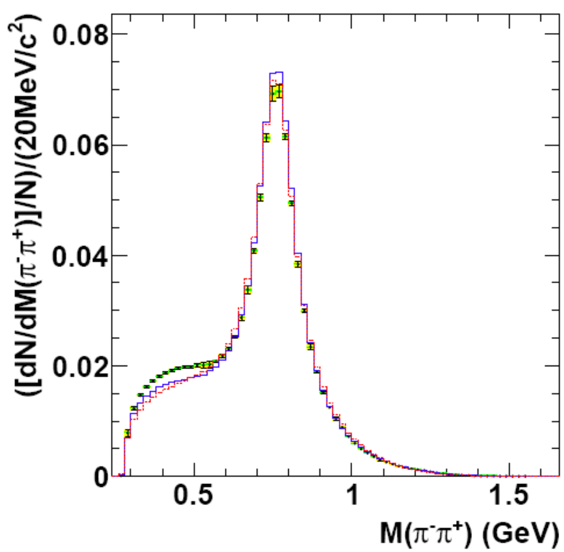
Fit Parameters							
	$M_{\rho'}$	$\Gamma_{\rho'}$	M_{a1}	F	F_V	F_A	$\beta_{\rho'}$
Min.	1.44	0.32	1.00	0.0920	0.12	0.10	-0.36
Max.	1.48	0.39	1.24	0.0924	0.24	0.20	-0.18
Default	1.453	0.40	1.12	0.0924	0.18	0.149	-0.25
Fit	1.4302	0.376061	1.21706	0.092318	0.121938	0.11291	-0.208811

χ^2= 2262.12
ndf=132

main contribution from low energy two pion inavariant mass region !!

20MeV bins, statist+system errors (SLAC-R-936)





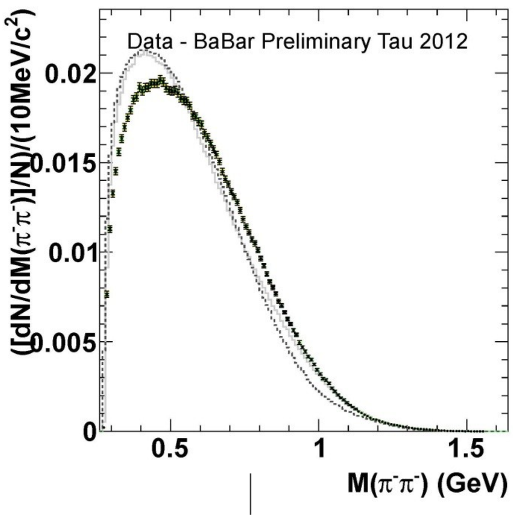
RChL is better than Tauola 1.05

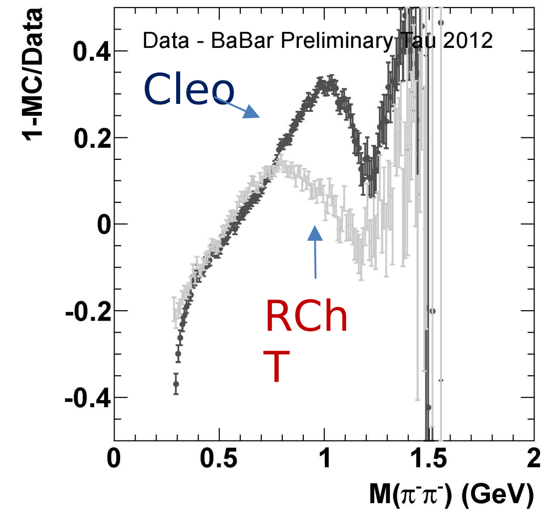
(Data -RChL) less 7% $\pi^+ \pi^- \pi^-$

(Data -RChL) less 12% $\pi^+ \pi^-$

TAU12: preliminary BaBar data I.M. Nugent arXiv:1301.7105

- 10 MeV/bin
- only statistical error
- $\pi^-\pi^-$ spectrum





To include sigma meson phenomenologically (Cleo)

$$F_1^{\mathrm{R}} \rightarrow F_1^{\mathrm{R}} + \frac{\sqrt{2}F_V G_V}{3F^2}\left[\alpha_\sigma BW_\sigma(s_1)F_\sigma(q^2,s_1) + \beta_\sigma BW_\sigma(s_2)F_\sigma(q^2,s_2)\right]$$

$$F_1^{\mathrm{RR}} \rightarrow F_1^{\mathrm{RR}} + \frac{4F_A G_V}{3F^2}\frac{q^2}{q^2 - M_{a_1}^2 - iM_{a_1}\Gamma_{a_1}(q^2)}\left[\gamma_\sigma BW_\sigma(s_1)F_\sigma(q^2,s_1) + \delta_\sigma BW_\sigma(s_2)F_\sigma(q^2,s_2)\right]$$

$$BW_\sigma(x) = \frac{m_\sigma^2}{m_\sigma^2 - x - im_\sigma\Gamma_\sigma(x)} \qquad \Gamma_\sigma(x) = \Gamma_\sigma\frac{\sigma_\pi(x)}{\sigma_\pi(m_\sigma^2)} \qquad F_\sigma(q^2,x) = \exp\left[\frac{-\lambda(q^2,x,m_\pi^2)R_\sigma^2}{8q^2}\right]$$

New fit parameters $\alpha_\sigma,\ \beta_\sigma,\ \gamma_\sigma,\ \delta_\sigma,\ R_\sigma$

Fit strategy

the a1 table:

$$\Gamma_{a_1}(q^2) = 2\Gamma^{\pi}_{a_1}(q^2)\theta\left(q^2 - 9m_\pi^2\right) + 2\Gamma^{K^\pm}_{a_1}(q^2)\theta\left(q^2-(m_\pi+2m_K)^2\right) + \Gamma^{K^0}_{a_1}(q^2)\theta\left(q^2-(m_\pi+2m_K)^2\right)$$

$$\Gamma^{\pi,K}_{a_1}(q^2) = \frac{S}{192(2\pi)^3 F_A^2 F^2 M_{a_1}}\left(\frac{M_{a_1}^2}{q^2}-1\right)^2 \int ds\,dt\,W_A^{\pi,K}$$

2dim Gauss integration

reruns during the fit procedure -> an hour for one fit point

Replace with ***exact 3pi part in several points + fixed table for KKpi part***

3pi spectrum is approximated

$$g(q^2) = \begin{cases} (q^2-9m_\pi^2)^3(a-b(q^2-9m_\pi^2)+c(q^2-9m_\pi^2)^2), & 9m_\pi^2 < q^2 < (m_\rho+m_\pi)^2 \\ q^2(d-e/q^2+f/q^4-g/q^6), & (m_\rho+m_\pi)^2 < q^2 < 3(m_\rho+m_\pi)^2 \\ h+2p\frac{q^2-3(m_\rho+m_\pi)^2}{(m_\rho+m_\pi)^2}, & 3(m_\rho+m_\pi)^2 < q^2 < m_\tau^2 \end{cases}$$

Difference between approximation and exact result: **less than 5% $q^2 > 0.29\ \mathrm{GeV}^2$**
less than 1% $q^2 > 1.1\ \mathrm{GeV}^2$

No numerical consequence on the calculated current

Semi-analytical code (the same for q^2 3pion spectrum and 3pion part a1 width)

$$\Gamma_{a_1}^{\pi,K}(q^2) = \frac{S}{192(2\pi)^3 F_A^2 F^2 M_{a_1}} \left(\frac{M_{a_1}^2}{q^2} - 1\right)^2 \int dsdt W_A^{\pi,K} \qquad \int dsdt = \int_{4m_\pi^2}^{\left(\sqrt{q^2}-m_\pi\right)^2} ds \int_{t_-(s)}^{t_+(s)} dt$$

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

$$W_A = -(V_1^\mu F_1 + V_2^\mu F_2 + V_3^\mu F_3)(V_{1\mu} F_1 + V_{2\mu} F_2 + V_{3\mu} F_3)^*$$

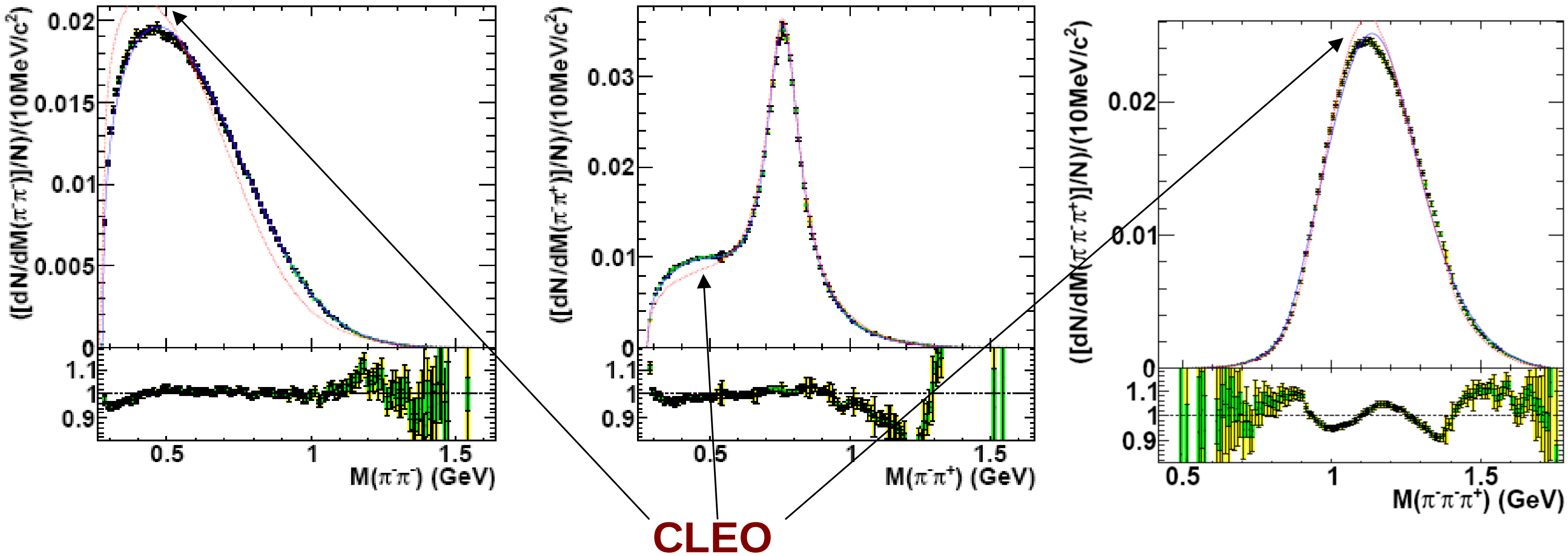
- A set of three histograms is generated using the aforementioned semi-analytic distributions.
- For each X for which `minuit` requests function value, an appropriate bin content is returned.
- Whenever `minuit` changes one of the parameters:

  `TAUOLA` is reinitialized with a new set of parameters;

  The function for approximation of a_1 width (mentioned above) is recalculated;

  A new set of histograms is generated.

BaBar data normalized $\Gamma = 2 \cdot 10^{-13}$ GeV



	M_ρ	$M_{\rho'}$	$G_{\rho'}$	M_{a1}	M_σ	G s	F	Fv	F_A	-B r'	α_σ	β_σ
Min	0.767	1.43	0.31	0.99	0.35	0.43	0.088	0.11	0.1	0.17		
Max	0.780	1.49	0.45	1.25	0.53	0.81	0.094	0.25	0.2	0.37		
Fit	0.772 (9)	1.43 (6)	0.45 (9)	1.11 (2)	0.47 (15)	0.61 (22)	0.090 (3)	0.170 (3)	0.141 (5)	0.28 (2)		

	α_σ	β_σ	$\gamma\sigma$	δ_σ	R s
Min	-10	-10	-10	-10	-10
Max	10	10	10	10	10
Fit	-3.1 (1.5)	1.3 (2.5)	1.3 (2.5)	0.5 (1.4)	0.02 (130)

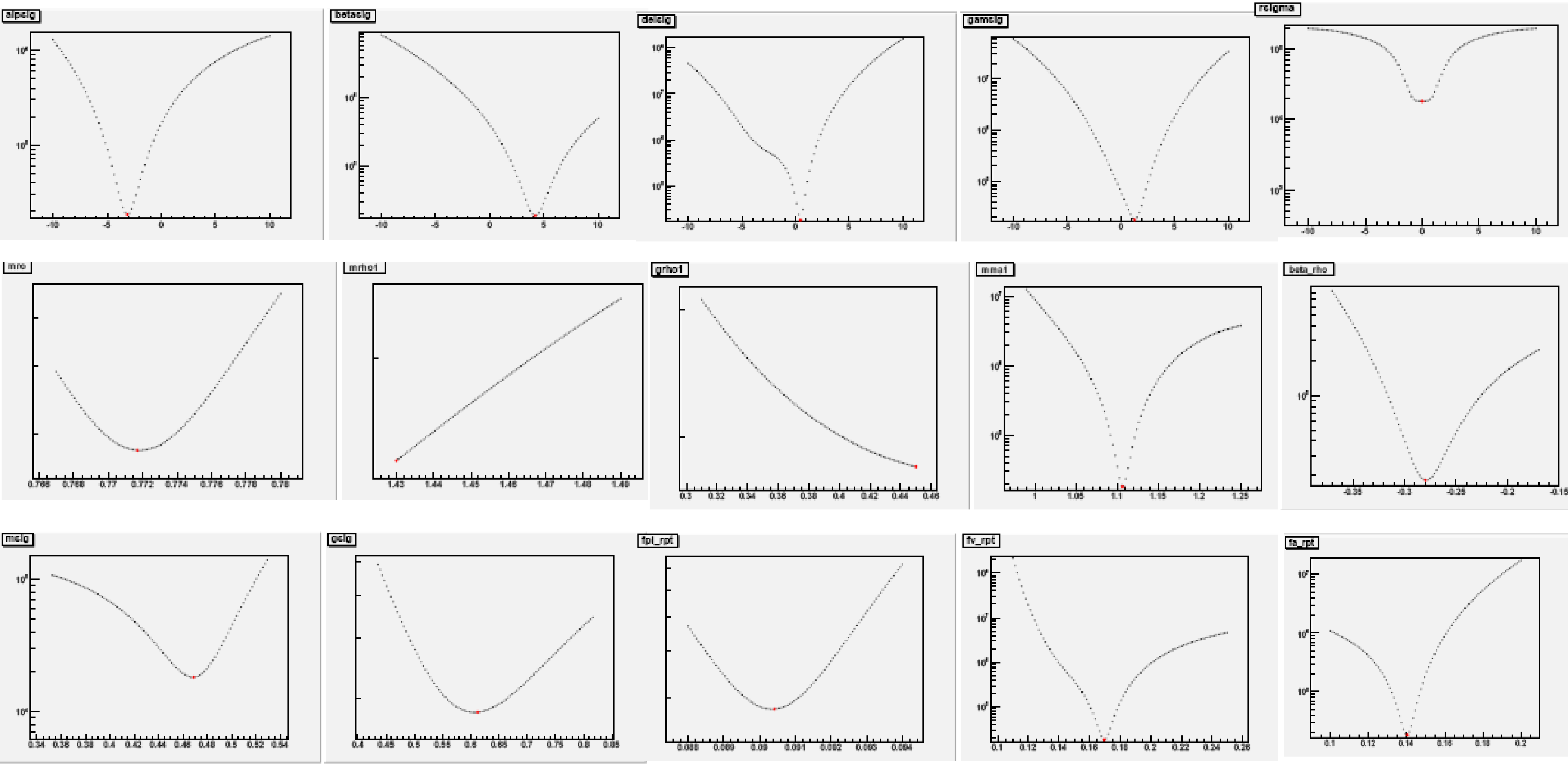
χ^2/ndf = 18645/401 stat

χ^2 /ndf = 2749/401 stat+syst

$$\Gamma_{\tau\to\pi^-\pi^-\pi^+\nu} = 2.006 \cdot 10^{-13}$$

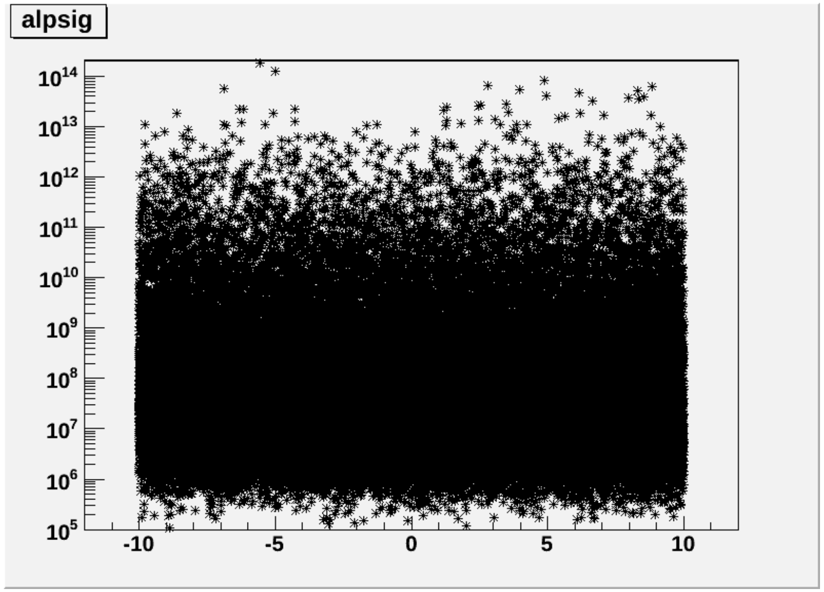
Non convergent MINUIT ->

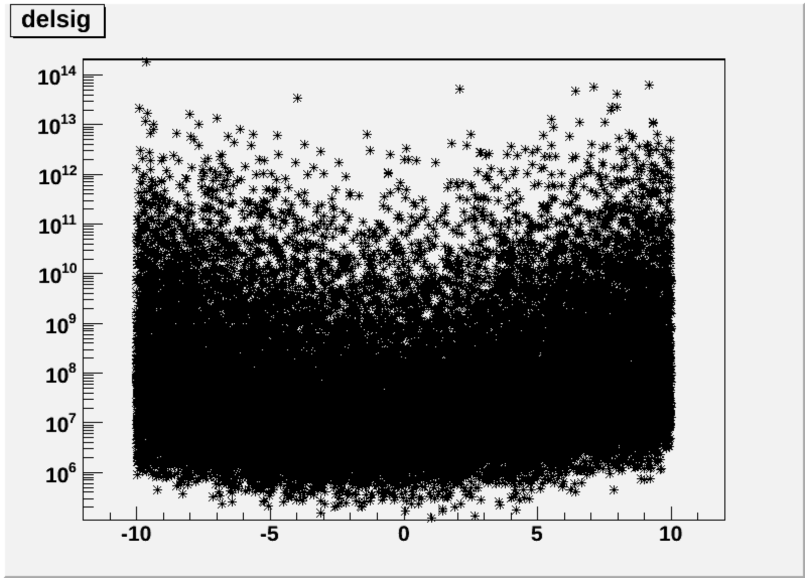
- to check whether it is minimum
- to increase the precision of integration (UNDER WORK)



Some parameters to fix, some to shrink the region, some to expand the region

Scanning of parameters (1e5 points) rsigma = 0. :



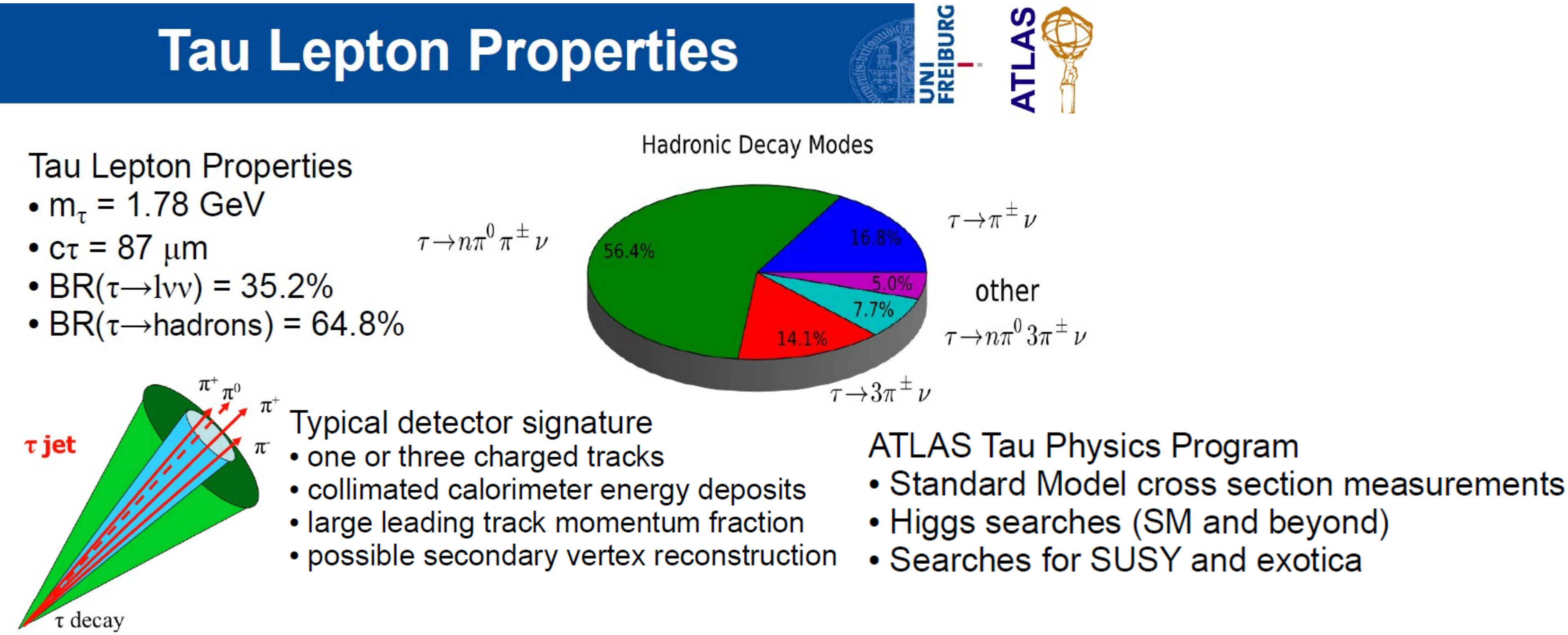


no conclusion

(-10;10) -> (-5;5)

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



τ is used a tag
dynamics is not studied
however

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

2 pion + 3 pion mode fit: BaBar, Belle data

Conclusion

• strategy for fitting of 3 pseudoscalar unfolded distribution is prepared

• **agreement with 1 dim BaBar spectra**

(inclusion of sigma meson)

for $\pi^+ \pi^- \pi^- \nu_\tau$ mode

WORK IN PROGRESS

• $\pi^+ \pi^- \pi^- \nu_\tau$: effect of sigma meson on a1 width; Coulom interaction of pions

• **Two dimension distributions for $\pi^+ \pi^- \pi^- \nu_\tau$**

•**Two pion mode**

• **Prediction for $\pi^- \pi^0 \pi^0 \nu_\tau$**

• **KKpi modes** ***C++ coding***

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. Publication Phys.Rev. D86 (2012) 113008 by: O. Shekhovtsova, T. Przedzinski, P. Roig, Z. Was
2. tar ball (nov 14, 2011) : for corresponding TAUOLA upgrade; svn tag inside.
3. We were strugling for satisfactory fit to the exprimental data, see TAU12 coference talk by O. Shekhovtsova, I. M. Nugent, T. Przedzinski, P. Roig, Z. Was but our calculations require refinements.
4. Numerical results for the actual version, with estimation of agreement with the data, see talks (references 105-107 of our main paper).
5. **First agreement: ...** , Comparison of Resonance Chiral Lagrangian Currents to Experimental Data for tau to pi-pi^-pi^+ nu_tau by O. Shekhovtsova, I. M. Nugent, T. Przedzinski, P. Roig, Z. Was to appear soon.
6. **In future,** new version of the tar ball
7. **In future,** A patch to improve tauolapp for 2 and 3 pi final states.

Results of numerical tests:

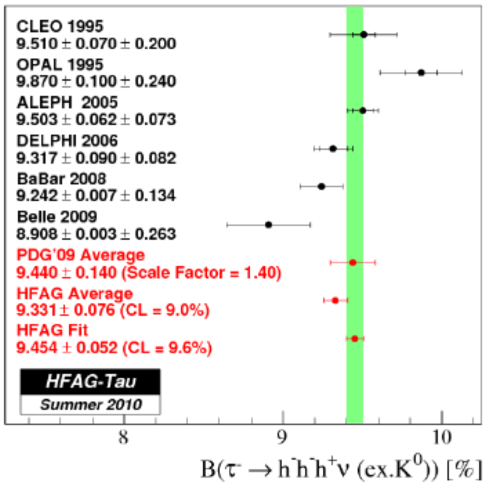
MC-TESTER: TAUOLA cleo vs. TAUOLA new currents	PS/PDF	rootfiles
Channels 4,5,7,22,14,15,16	PS PDF	first second
Tests in old style (90's): comparison with analytical calc.		
	PS PDF	tgz (restr.)
tau -> pi- pi0 nu	PS PDF	tgz (restr.)
tau -> K- pi0 nu	PS PDF	tgz (restr.)
tau -> pi- K0 nu	PS PDF	tgz (restr.)
tau -> K- K0 nu	PS PDF	TeX
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

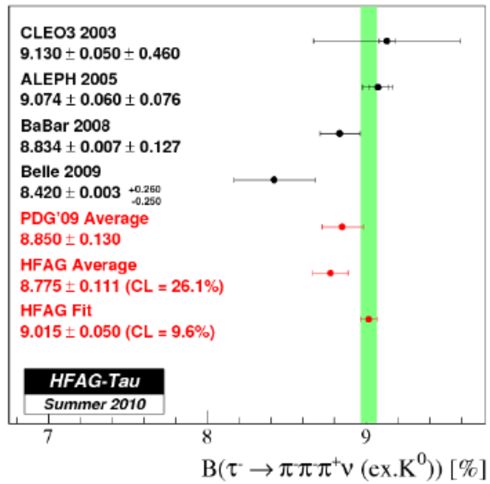
We expect matrix element to evolve even after our paper is finished. This page is the place to check on the progress. Eventually new co-authors and contribution from data analysis will be added here or link to such works will be added.

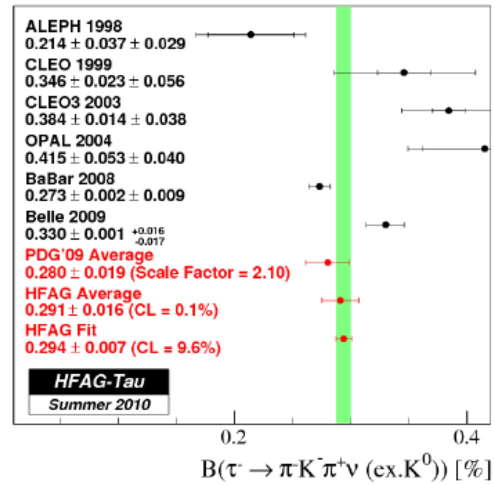
BACK UP

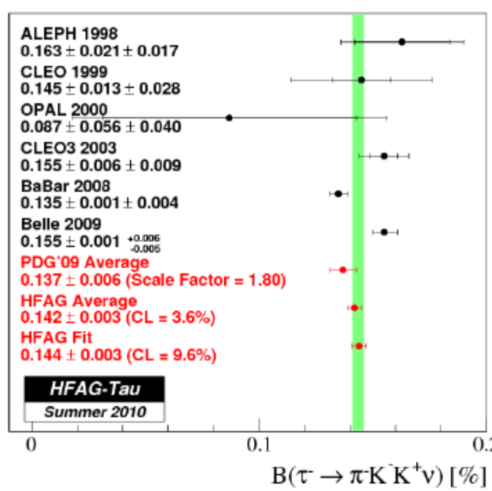
BaBar/Belle comparison for 3 meson modes

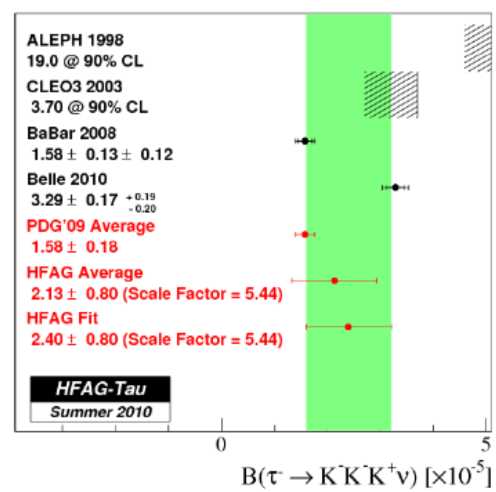
Ian Nugent (BaBar) for Workshop tau lepton decays: hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow











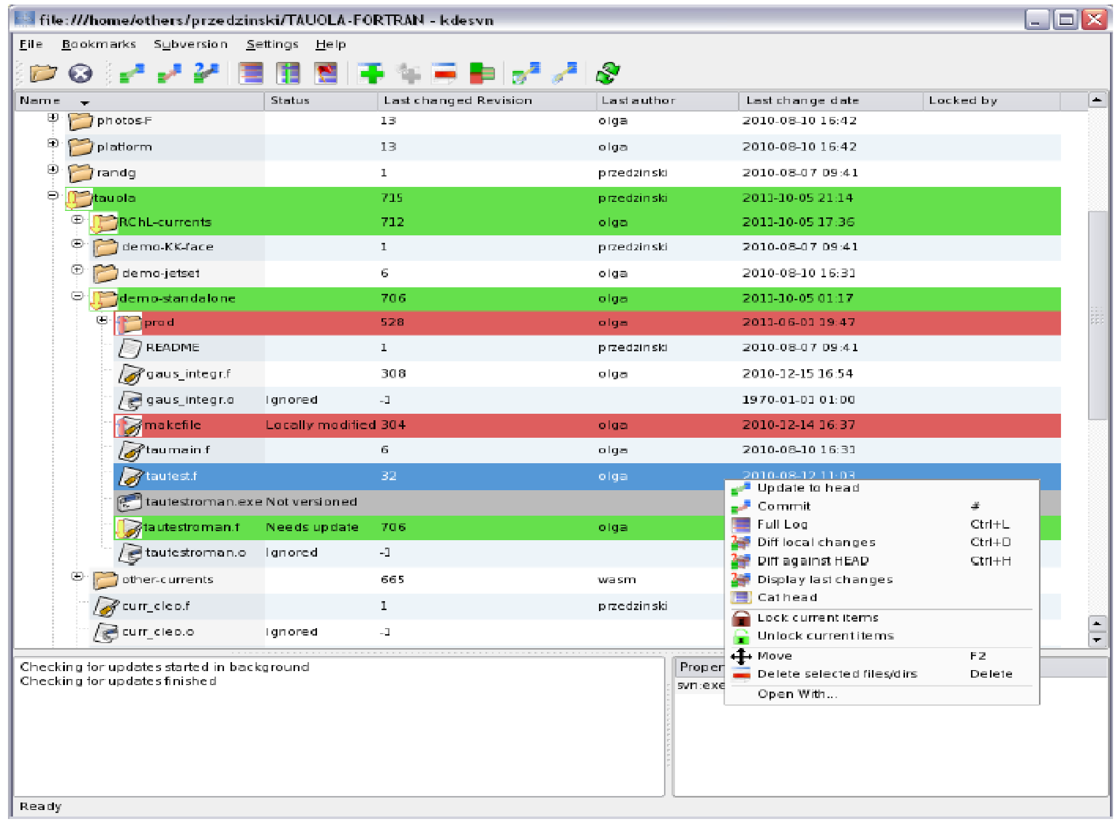
PRL100, 011801 (2008)

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 kasztan@ifj.edu.pl

Added to \tauola *cleo* version ***new-currents/RChL-currents***

- 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

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

Every directories with own README

Resonance Chiral Theory
(Chiral Theory with the explicit inclusion of *resonances*)

G.Ecker et al., Nucl. Phys B321(1989)311

1. **The resonance fields** ($V_{\mu\nu}$, $A_{\mu\nu}$ *antisymmetric tensor field*) is added by explicit way , based on ChPT
2. Reproduces NLO prediction of ChPT (at least)
3. Theoretical results for **2πτ, 2K τ, Kπτ, 3πτ, KKπτ** → **self consistent results for TAUOLA**
4. Correct high energy behaviour of form factors: $F_V G_V = f_\pi^2$, $F_V^2 - F_A^2 = f_\pi^2$, $F_V^2 M_V^2 = F_A^2 M_A^2$

****

Finite numbers of parameters (one octet: f_π , F_V, G_V, F_A)

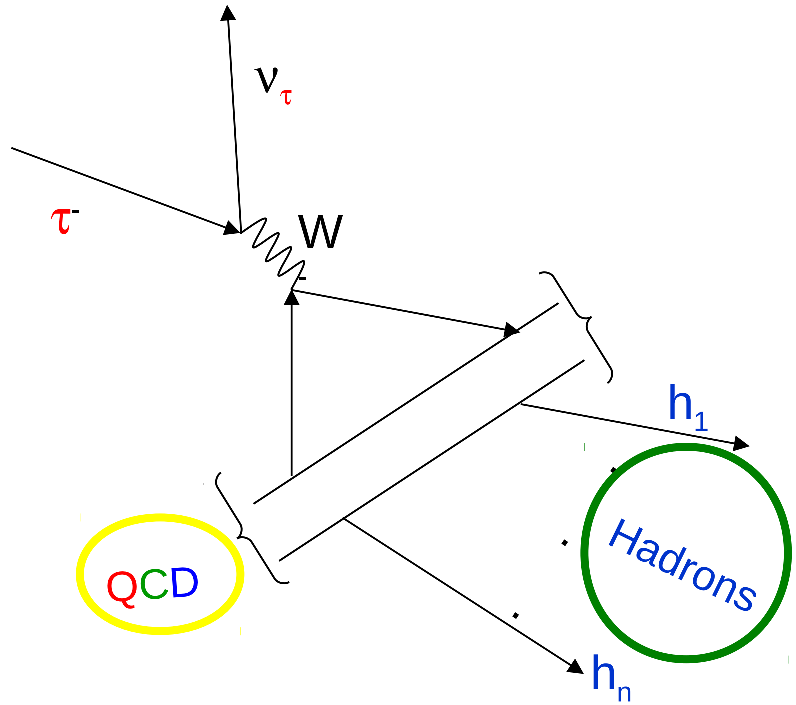
2πτ, 2K τ, Kπτ, 3πτ, KKπτ **88% of tau hadronic width**

Currents in RChT in TAUOLA2011

Hadronic decay mode of τ

$$\tau(P) \to X \nu_\tau(N)$$

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} \bar{u}(N) \gamma^\mu (1-\gamma_5) u(P) J_\mu$$



J_μ=<Hadrons|(V-A)$_\mu$ $e^{iS_{QCD}}$|0>=

Σ_i(Lorentz Structure)^i $F_i(Q^2,s_j)$

3 pseudoscalars: 3 Lorentz independent structure
2 pseudoscalars: 2 Lorentz independent structure (vector; scalar)

TAUOLA: hadronic currents   tauola.f
Form factors new-currents/RChL-currents

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

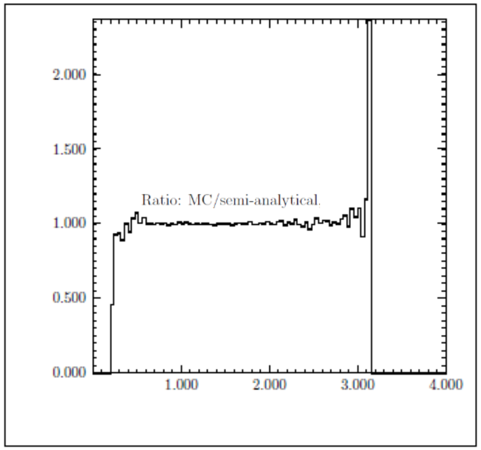
   ratio MC/semi-analytical of differential width (qq)

   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, F_{others} = 0 to check phase space

physical, F_{others} = 0

- F_{all} = physical

rpolation ~ 0.1% for whole spectrum except for ends

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

Comparison of semi-analytical integration and MC

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

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

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

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

Two pions

¿ ¿ ¿ lline V rSub { size 8 { ital ud } } rline rSup { size 8 { 2 } } m rSub { size 8 { τ } } rSup { size 8 { 3 } } {384π rSup { size 8 { 3 } } }

¿ left (1 - { {q rSup { size 8 { 2 } } } over {m rSub { size 8 { τ } } rSup { size 8 { 2 } } } } right) rSup { size 8 { 2 } } λ left (1, { {m rSub { size 8 {π rSup { size 6 { + } } } } rSup { 2 } } over { size 12 {q rSup { 2 } } } } size 12 {,} { {m rSub {π rSup { size 6 { 0 } } } rSup { 2 } } over { size 12 {q rSup { 2 } } } } right) lline size 12 {F rSub { π } } rline rSup { 2 } ¿ ¿ ¿ ¿ ¿ G_F ¿ ¿ $\frac{d\Gamma}{dq^2}$ = ¿ ¿ ¿

Channel	Analytical , GeV^{-1}	Monte Carlo , GeV^{-1}
pipi0	$(5.2431\pm0.02\%)\cdot10^{-15}$	$(5.2441\pm0.005\%)\cdot10^{-15}$
KK0	$(2.0863\pm0.02\%)\cdot10^{-15}$	$(2.0864\pm0.005\%)\cdot10^{-15}$
Kpi0	$(2.5193\pm0.02\%)\cdot10^{-14}$	$(2.5197\pm0.008\%)\cdot10^{-14}$
pipipi	$(2.1007\pm0.02\%)\cdot10^{-13}$	$(2.1013\pm0.016\%)\cdot10^{-13}$
K-pi-K+	$(3.7379\pm0.024\%)\cdot10^{-15}$	$(3.7383\pm0.02\%)\cdot10^{-15}$
K0pi-K0	$(3.7385\pm0.024\%)\cdot10^{-15}$	$(3.7383\pm0.02\%)\cdot10^{-15}$
Kpi0K0	$(2.7370\pm0.02\%)\cdot10^{-15}$	$(2.7367\pm0.02\%)\cdot10^{-15}$

$m_{\pi^\pm} = m_{\pi^0}$

$m_{K^\pm} = m_{K^0}$

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	$(3.60 \pm 10\%) \cdot 10^{-15}$	$(2.0864 \pm 0.007\%) \cdot 10^{-15}$	$(2.0864 \pm 0.007\%) \cdot 10^{-15}$
$\pi^-\pi^-\pi^+$	$(2.11 \pm 0.8\%) \cdot 10^{-13}$	$(2.1013 \pm 0.016\%) \cdot 10^{-13}$	$(2.0800 \pm 0.017\%) \cdot 10^{-13}$
$\pi^0\pi^0\pi^-$	$(2.10 \pm 1.2\%) \cdot 10^{-13}$	$(2.1013 \pm 0.016\%) \cdot 10^{-13}$	$(2.1256 \pm 0.017\%) \cdot 10^{-13}$
$K^-\pi^-K^+$	$(3.17 \pm 4\%) \cdot 10^{-15}$	$(3.7379 \pm 0.024\%) \cdot 10^{-15}$	$(3.8460 \pm 0.024\%) \cdot 10^{-15}$
$K^0\pi^-\bar{K}^0$	$(3.9 \pm 24\%) \cdot 10^{-15}$	$(3.7385 \pm 0.024\%) \cdot 10^{-15}$	$(3.5917 \pm 0.024\%) \cdot 10^{-15}$
$K^-\pi^0K^0$	$(3.60 \pm 12.6\%) \cdot 10^{-15}$	$(2.7367 \pm 0.025\%) \cdot 10^{-15}$	$(2.7711 \pm 0.024\%) \cdot 10^{-15}$

only ρ

with ρ' (parameters from pion mode)

$(2.6502 \pm 0.008\%) \cdot 10^{-15}$ GeV

Diff PDG 2-17%

FSI effects

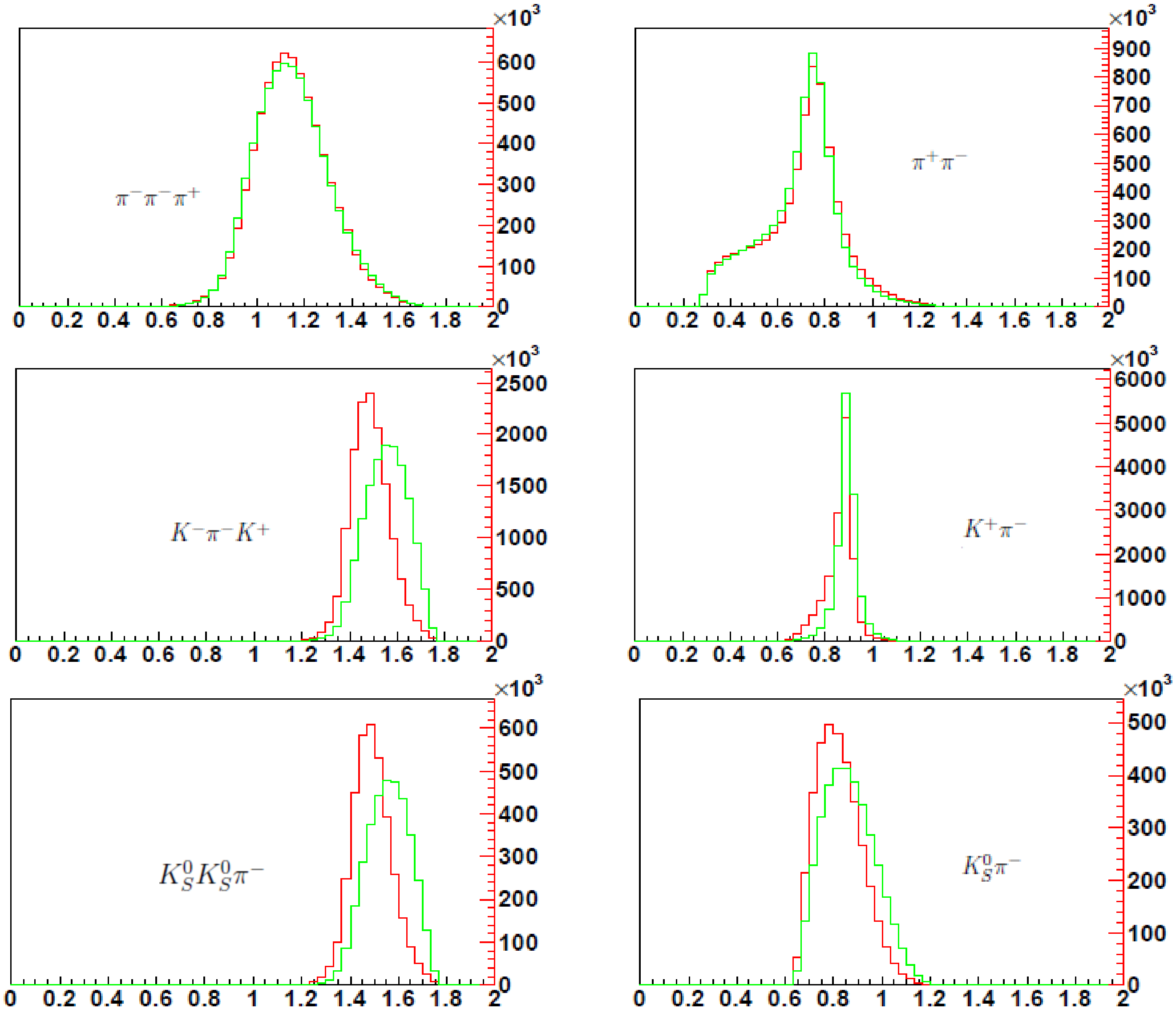
No.	Channel	Width [GeV]	Width [GeV]
1.	$\pi^-\pi^0$	$5.2441 \cdot 10^{-13} \pm 0.005\%$	$4.0642 \cdot 10^{-13} \pm 0.005\%$
2.	$\pi^0 K^-$	$8.5810 \cdot 10^{-15} \pm 0.005\%$	$7.4275 \cdot 10^{-15} \pm 0.005\%$
3.	$\pi^-\bar{K}^0$	$1.6512 \cdot 10^{-14} \pm 0.006\%$	$1.4276 \cdot 10^{-14} \pm 0.006\%$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

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

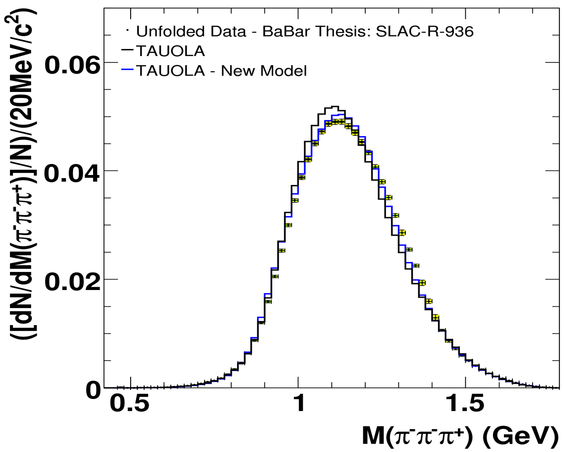
$\tau \rightarrow K^-\pi^-K^+\nu_\tau$

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

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

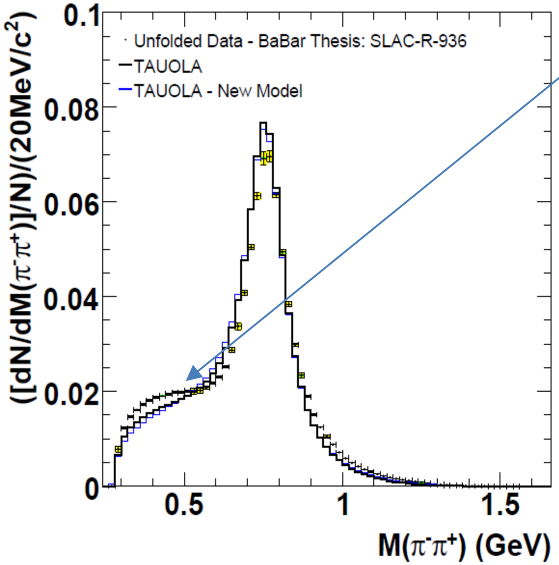
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$

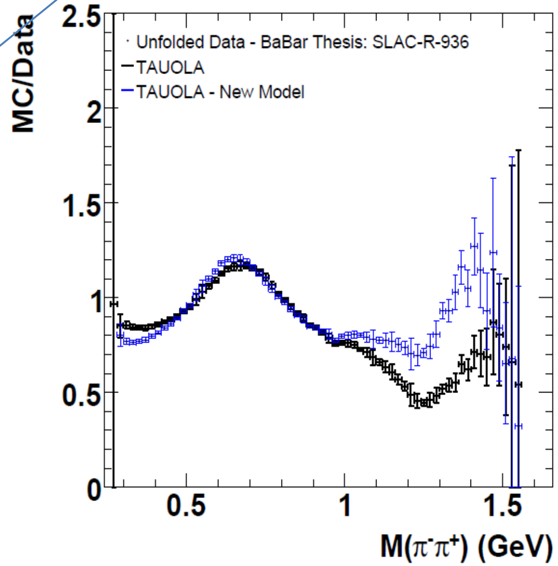
BABAR data: *Ian M. Nugent talk*



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

Isoscalar contribution sigma meson

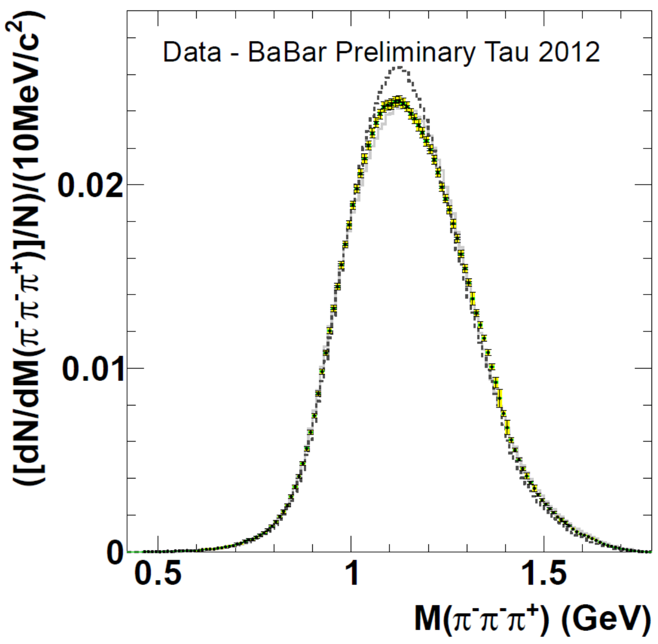


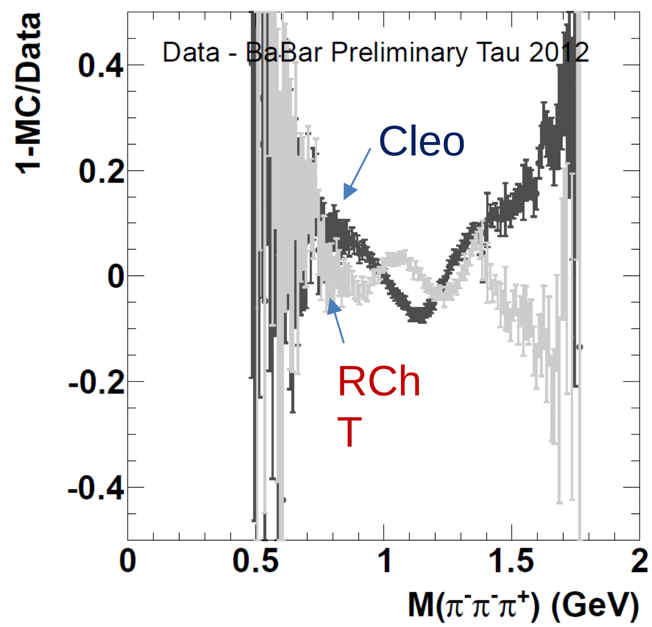


work in progress

TAUOLA 2012

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



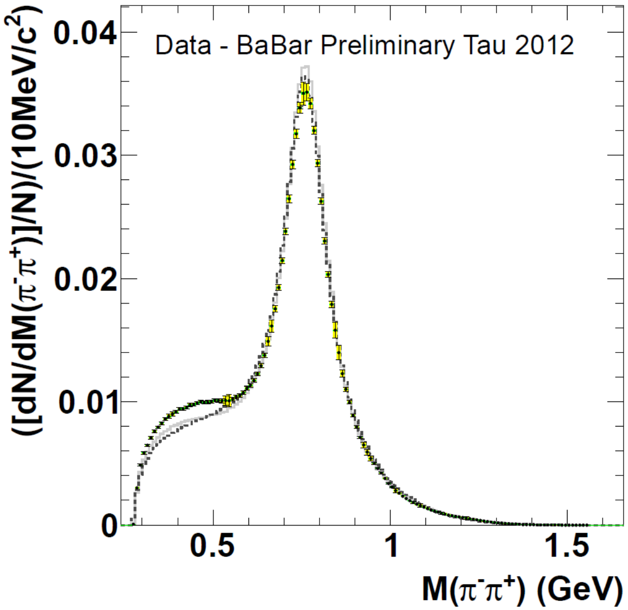


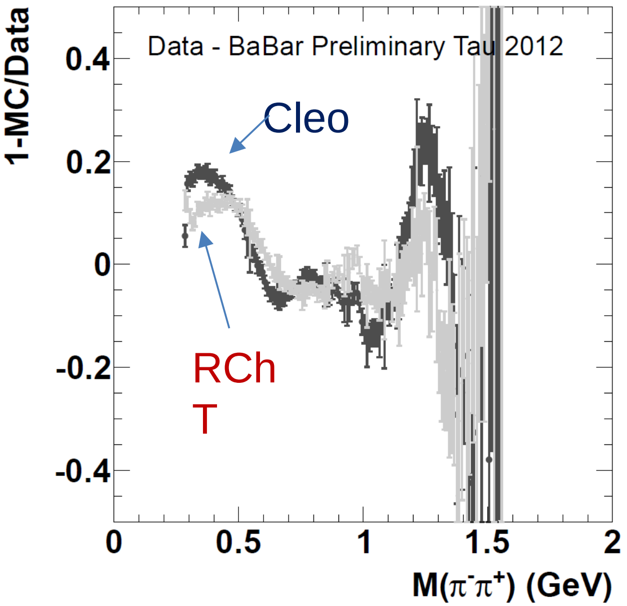
(Data- MC (RChL)) is less than 7 %

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?)

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

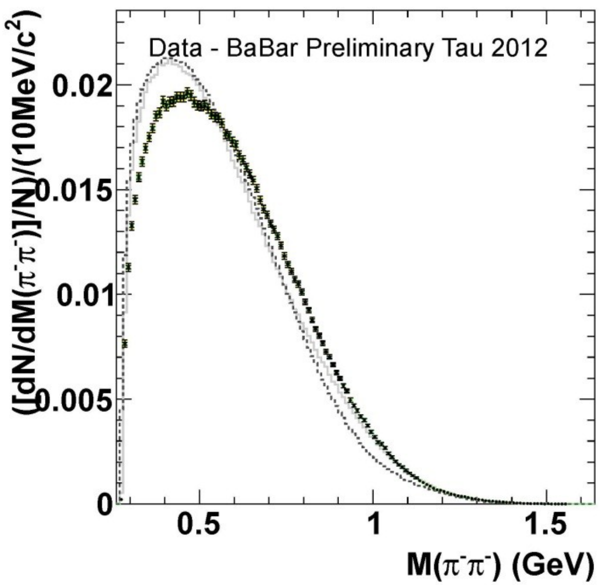


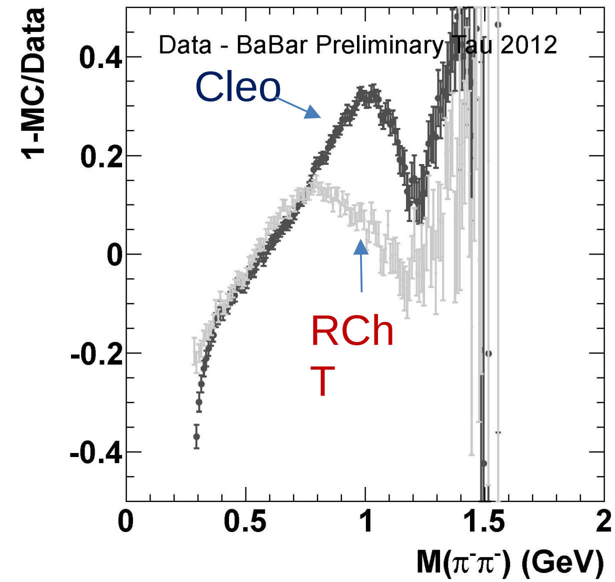


For the $\pi^-\pi^+$ invariant mass:

- 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 %





Mass invariant spectrum does not contain any resonance
i.e. confirms that the chiral contribution in the low energy sector is included correct

WORK IN PROGRESS

Reweighting calculation J. Zaremba

http://annapurna.ifj.edu.pl/~jzaremba/

Non convergent MINUIT ->

- to check whether it is minimum
- to increase the precision of integration (UNDER WORK)

Red point is the χ^2 for the result of the fit.