INNOVACYJNA GOSPODARKA
NARODOWA STRATEGIA SPÓJNOŚCI
Dotacje na innowacje
Inwestujemy w waszą przyszłość
UNIA EUROPEJSKA
EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO
FNP
Fundacja na rzecz Nauki Polskiej

The tau decay in three pions in RChT.

Status of analysis

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in collaboration with

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

Frascati, 13.09.2013

$\tau^- \to \pi^0\pi^0\pi^-\nu_\tau$, $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ arXiv:0911.4436

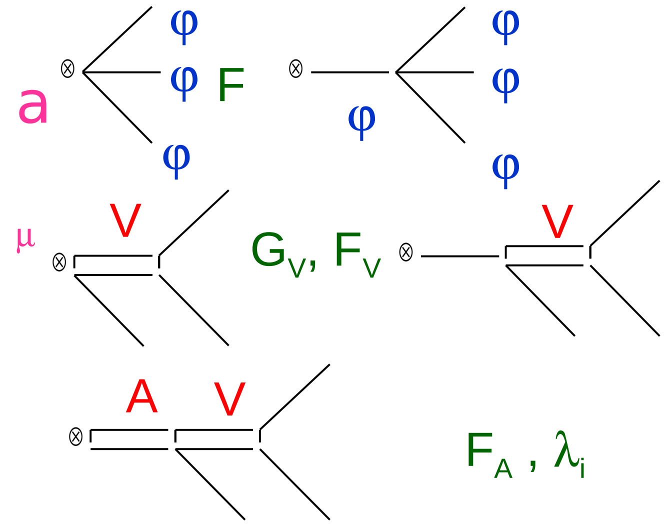
Axial-vector

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

χPT

RχT, 1R

RχT, 2R



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

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

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

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

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

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

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:

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

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

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

$$S = 1/n!$$

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***

TAUOLA update, main test done, results PRD Phys.Rev. D86 (2012) 113008

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

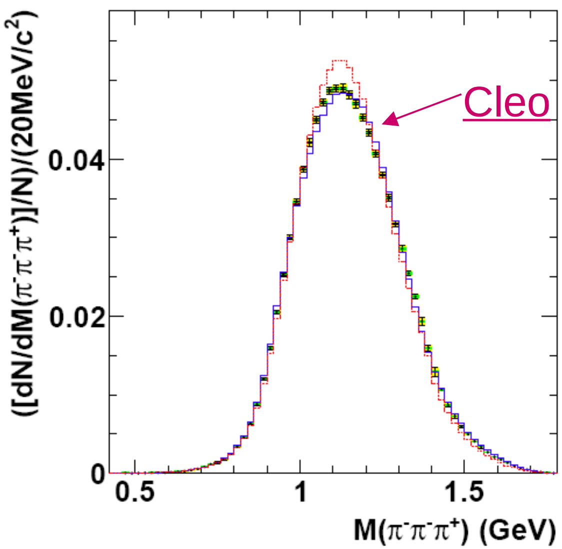
ndf=132

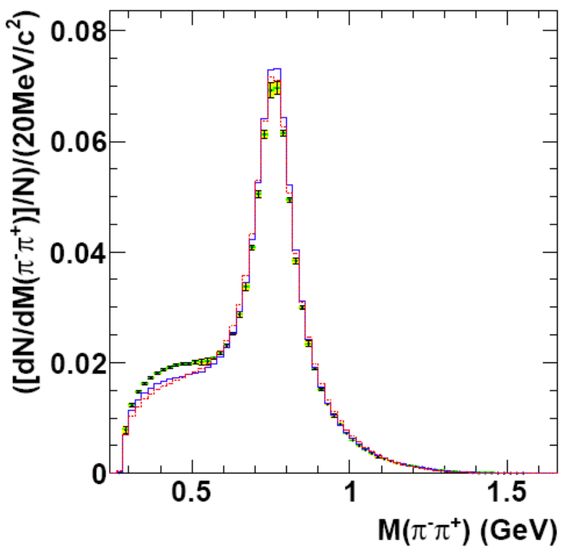
20MeV bins,

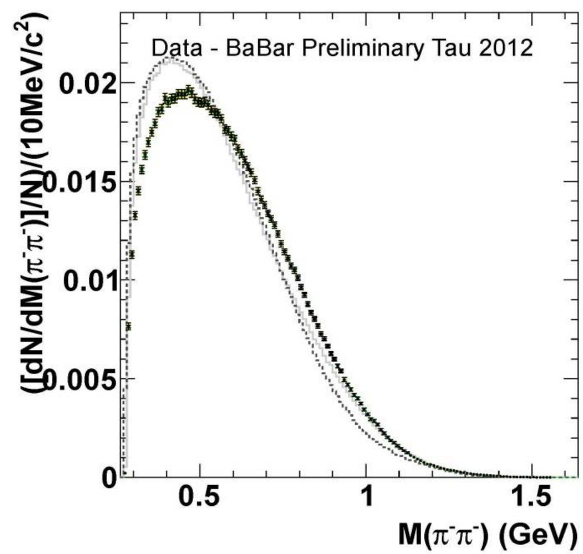
statist+system (SLAC-R-936)

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

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







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

2012: preliminary BaBar data I.M. Nugent arXiv:1301.7105

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

TAUOLA modification for 3 pion

1. FIXED BUG in F4 (essential for fit)

2. sigma meson added, phenomenologically (Cleo)

3. estimated Coulomb interaction

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

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

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

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

Coulomb interaction

$$\frac{d\Gamma}{dq^2 ds_1 ds_2} \to \frac{d\Gamma}{dq^2 ds_1 ds_2} \frac{2\alpha\pi/v_0(s_1)}{1-\exp\left[-2\alpha\pi/v_0(s_1)\right]} \frac{2\alpha\pi/v_0(s_2)}{1-\exp\left[-2\alpha\pi/v_0(s_2)\right]} \frac{2\alpha\pi/v_0(s_3)}{\exp\left[2\alpha\pi/v_0(s_3)\right]-1}$$

$$v_0(s) = 2\sigma_\pi(s)/(1+\sigma_\pi^2(s))$$

S-wave, as for e+e- pair, Landau et al, Relastivistic Quantum Theory

$\chi^2/ndf = 53043/401$ **without sigma, does not reproduce**

π0π0 π− prediction

$$F_1^{\mathrm{R}} \to F_1^{\mathrm{R}} + \frac{\sqrt{2}F_V G_V}{3F^2}\alpha_\sigma^0 BW_\sigma(s_3)F_\sigma(q^2,s_3)\,,$$

$$F_1^{\mathrm{RR}} \to F_1^{\mathrm{RR}} + \frac{4F_A G_V}{3F^2}\frac{q^2}{q^2-M_{a_1}^2-iM_{a_1}\Gamma_{a_1}(q^2)}\gamma_\sigma^0 BW_\sigma(s_3)F_\sigma(q^2,s_3)$$

π+π− π− $\alpha_\sigma = \beta_\sigma,\ \gamma_\sigma = \delta_\sigma$

$$\alpha_\sigma = 1.139486,\ \gamma_\sigma = 0.889769,\ R_\sigma = 0.000013,\ M_\sigma = 0.550 \quad \Gamma_\sigma = 0.700.$$

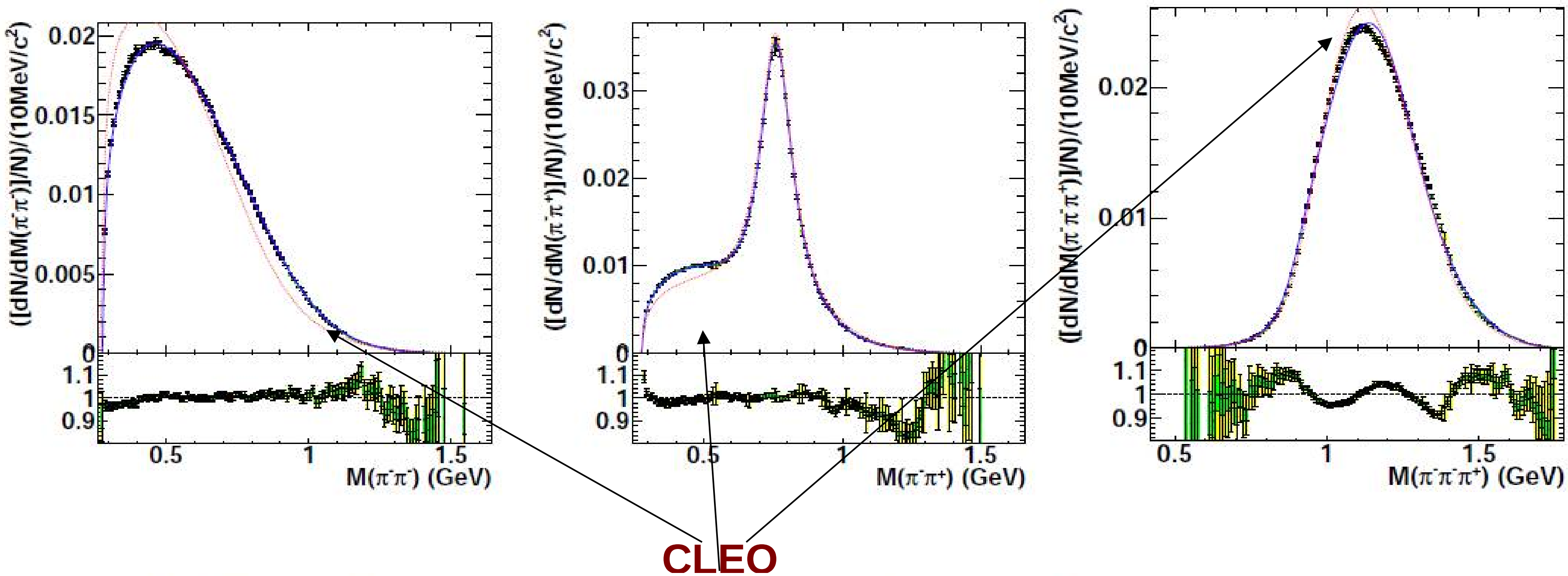
$$\alpha_\sigma^0 = \alpha_\sigma \cdot Scaling_{factor}^\gamma$$

CLEO (↑ $Scaling_{factor}^\gamma$)

$$Scaling_{factor}^\gamma = 2.1/3.35 = 0.63$$

$$\Gamma = (2.1440 \pm 0.02\%)\cdot 10^{-13}$$

2.1% higher than the PDG value



	M_ρ [8]	$M_{\rho'}$	$\Gamma_{\rho'}$	M_{a_1}	M_σ	Γ_σ	F	F_V
Min	0.767	1.35	0.30	0.99	0.400	0.400	0.088	0.11
Max	0.780	1.50	0.50	1.25	0.550	0.700	0.094	0.25
Fit	0.771849	1.350000	0.448379	1.091865	0.487512	0.700000	0.091337	0.168652

	F_A	$\beta_{\rho'}$	α_σ	β_σ	γ_σ	δ_σ	R_σ
Min	0.1	-0.37	-10.	-10.	-10.	-10.	-10.
Max	0.2	-0.17	10.	10.	10.	10.	10.
Fit	0.131425	-0.318551	-8.795938	9.763701	1.264263	0.656762	1.866913

χ^2/ndf = 6658/401 stat

χ^2/ndf = 889/401 stat+syst

$$\Gamma_{\tau^- \to \pi^-\pi^-\pi^+\nu_\tau} = 2.0001 \cdot 10^{-13}\ \mathrm{GeV}$$

Fit strategy

the a1 table:

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

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

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 GeV^2**
less than 1% q^2> 1.1 GeV^2

No numerical consequence on the calculated current

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

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

$$\int dsdt = \int_{4m_\pi^2}^{\left(\sqrt{q^2}-m_\pi\right)^2} ds \int_{t_-(s)}^{t_+(s)} dt$$

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

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

- 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.

Normalization (BaBar data) $\Gamma = 2 \cdot 10^{-13}$ GeV

PDG value without $\tau^- \to \pi^- \bar{K}^0 \nu_\tau$ $\Gamma = 2.04 \cdot 10^{-13}$ GeV

After fit $\Gamma_{\tau^- \to \pi^- \pi^- \pi^+ \nu_\tau} = 2.0001 \cdot 10^{-13}$ GeV

χ^2 calculated with/without the BaBar correlation matrix

RESULTS of FIT. TESTS.

PARAMETER NAME	with matrix MINIMUM	without matrix minimum
$ alpsig$	-8.795938	-9.575605
$ betasig$	9.763701	9.843028
$ gamsig$	1.264263	0.992978
$ delsig$	0.656762	0.937268
$ rsigma$	-1.866913	-1.901675
$ mro$	0.771849	0.772582
$ mrho1$	1.350000	1.350002
$ grho1$	0.448379	0.421663
$ mma1$	1.091865	1.091777
$ msig$	0.487512	0.469322
$ gsig$	0.700000	0.689697
$ fpi_rpt$	0.091337	0.091300
$ fv_rpt$	0.168652	0.167656
$ fa_rpt$	0.131426	0.129935
$ beta_rho$	-0.318546	-0.322381
	χ^2/ndf = 10625/401	χ^2/ndf = 6658/401

ESSENTIAL CHANGES FOR SIGMA VALUES

Correlation matrix

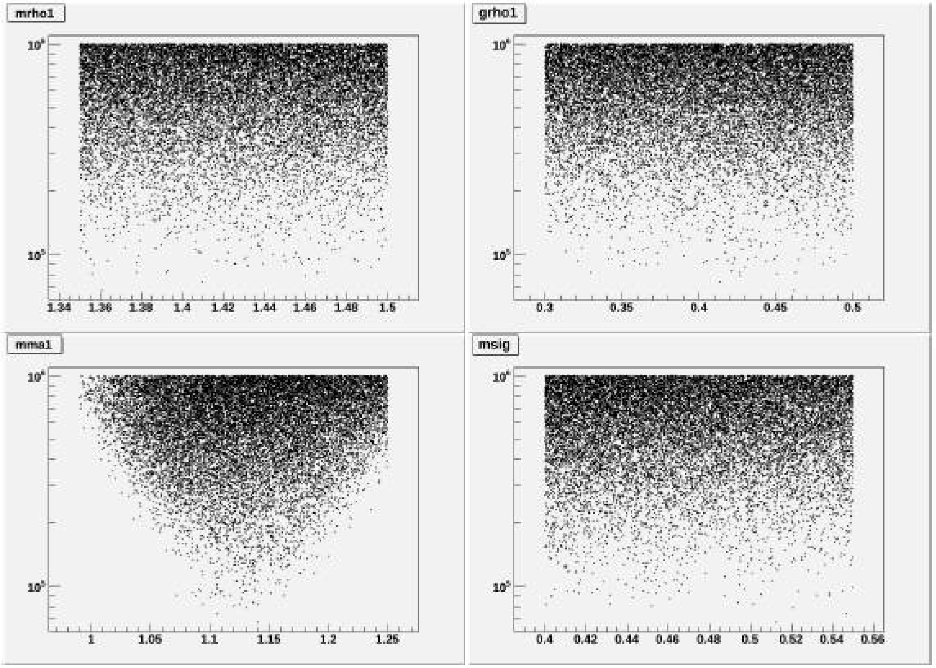
	α_σ	β_σ	γ_σ	δ_σ	R_σ	M_ρ	$M_{\rho'}$	$\Gamma_{\rho'}$	M_{a_1}	M_σ	Γ_σ	F_π	F_V	F_A	β_ρ
α_σ	1	0.60	0.36	-0.29	-0.41	-0.69	0.46	0.68	-0.77	-0.09	0.02	0.78	0.76	0.52	-0.78
β_σ	0.60	1	0.44	-0.39	-0.42	-0.75	0.55	0.79	-0.89	-0.16	0.04	0.89	0.88	0.58	-0.88
γ_σ	0.36	0.44	1	-0.56	-0.22	-0.59	0.16	0.37	-0.47	-0.28	0.00	0.49	0.45	0.30	-0.45
δ_σ	-0.29	-0.39	-0.56	1	0.46	0.46	-0.24	-0.42	0.49	0.01	0.01	-0.49	-0.47	-0.31	0.47
R_σ	-0.41	-0.42	-0.22	0.46	1	0.42	-0.33	-0.56	0.62	0.34	0.02	-0.53	-0.56	-0.42	0.48
M_ρ	-0.69	-0.75	-0.59	0.46	0.42	1	-0.27	-0.64	0.79	0.29	-0.02	-0.83	-0.74	-0.48	0.75
$M_{\rho'}$	0.46	0.55	0.16	-0.24	-0.33	-0.27	1	0.67	-0.61	-0.13	0.03	0.61	0.66	0.37	-0.65
$\Gamma_{\rho'}$	0.68	0.79	0.37	-0.42	-0.56	-0.64	0.67	1	-0.88	-0.24	0.03	0.86	0.88	0.57	-0.88
M_{a_1}	-0.77	-0.89	-0.47	0.49	0.62	0.79	-0.61	-0.88	1	0.28	-0.03	-0.96	-0.97	-0.62	0.95
M_σ	-0.09	-0.16	-0.28	0.01	0.34	0.29	-0.13	-0.24	0.28	1	-0.02	-0.30	-0.29	-0.20	0.30
Γ_σ	0.02	0.04	0.00	0.01	0.02	-0.02	0.03	0.03	-0.03	-0.02	1	0.03	0.03	0.03	-0.04
F_π	0.78	0.89	0.49	-0.49	-0.53	-0.83	0.61	0.86	-0.96	-0.30	0.03	1	0.95	0.55	-0.97
F_V	0.76	0.88	0.45	-0.47	-0.56	-0.74	0.66	0.88	-0.97	-0.29	0.03	0.95	1	0.63	-0.96
F_A	0.52	0.58	0.30	-0.31	-0.42	-0.48	0.37	0.57	-0.62	-0.20	0.03	0.55	0.63	1	-0.56
β_ρ	-0.78	-0.88	-0.45	0.47	0.48	0.75	-0.65	-0.88	0.95	0.30	-0.04	-0.97	-0.96	-0.56	1

Strong correlation, >0.95 $M_{a_1}, F_\pi, F_V, \beta_{\rho'}$

Also correlated β_σ and $\Gamma_{\rho'}$

- Test 1 (random scanning)

a sample 210K random points



- Test 2: with parameters of fit generated 8 MC samples of 20Mevents → fitted again

Parameter name	Value used for generation	Fit results	
		Mean	Variance
α_σ	-8.795938	-8.868953	0.234678
β_σ	9.763701	9.723322	0.194560
γ_σ	1.264263	1.217747	0.075296
δ_σ	0.656762	0.655876	0.128600
R_σ	-1.866913	-1.852253	0.083545
M_ρ	0.771849	0.771837	0.000141
$M_{\rho'}$	1.350000	1.358949	0.010310
$\Gamma_{\rho'}$	0.448379	0.451351	0.006315
M_{a_1}	1.091865	1.090961	0.000770
M_σ	0.487512	0.486787	0.005740
Γ_σ	0.700000	0.699481	0.001322
F_π	0.091337	0.091356	0.000046
F_V	0.168652	0.168637	0.000126
F_A	0.131426	0.131545	0.000214
β_ρ	-0.318546	-0.318571	0.001729

Conclusion

- strategy for fitting of 3 pseudoscalar unfolded distribution is prepared

- Coulomb interaction

- description of data improved(**inclusion of sigma meson)**

- prediction for $\pi^- \pi^0 \pi^0 \ \nu_\tau$

Work in progress on study of systematics

Plans/perspectives

- **Two dimension distributions for $\pi^+ \pi^- \pi^- \ \nu_\tau$**
- **Two pion mode**
- **KKpi modes**

C++ coding

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

Z. Was homepage | O. Shekhovtsova e.mail: Olga.Shekhovtsova (at) lnf.infn.it | T. Przedzinski homepage

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.

Last update: 18 Mar 2012 by Z. Was

IFJ PAN, Cracow, Poland, 15-22 September 2013,

SECOND WORKSHOP: tau lepton decays:

hadronic currents from data of Belle and BaBar, new physics signatures at LHC, bremsstrahlung in decays of tau leptons and other particles or resonances.

- Purpose and main informations
- Program: Indico
- Preliminary program and up to date list of participants
- Accommodation in Cracow
- How to get to Cracow
- How to reach IFJ PAN

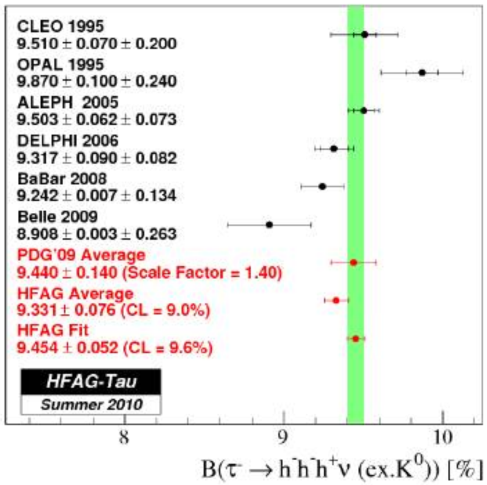
In weeks just after and before our meeting other, of compatible topics, events take place in Cracow:

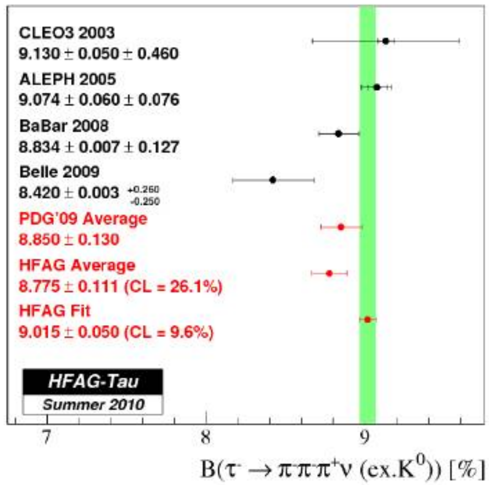
- LHCPhenoNet Summer School 7-12 September 2013
- ILD Meeting 24-26 September 2013

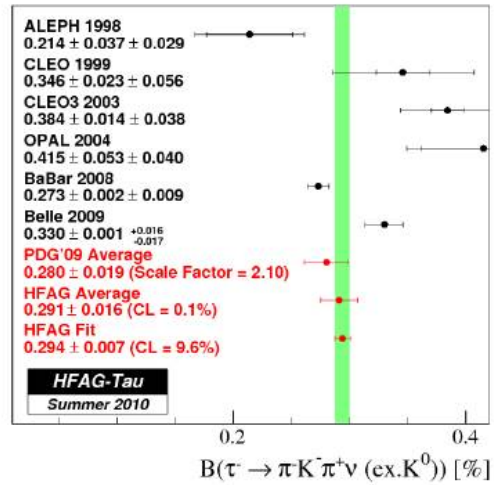
BACK UP

BaBar/Belle comparison for 3 meson modes

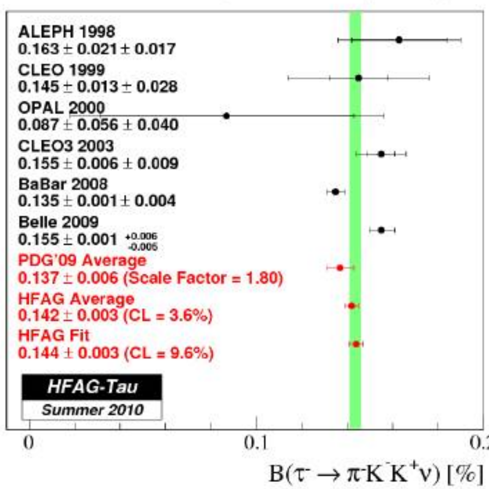
Ian Nugent (BaBar) for Workshop tau lepton decays: hadronic currents from Belle Babar data and LHC signatures, 14-19 May 2012 IFJ, Cracow

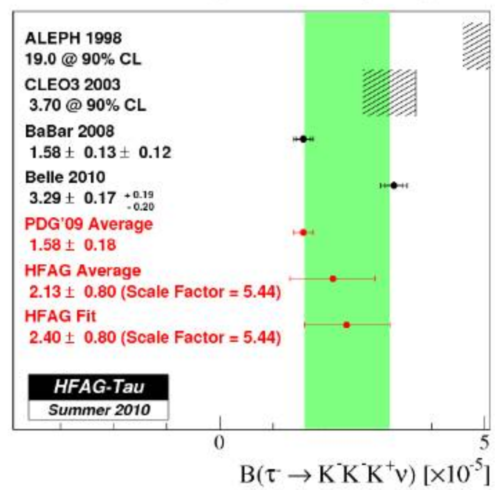






PRL100, 011801 (2008)



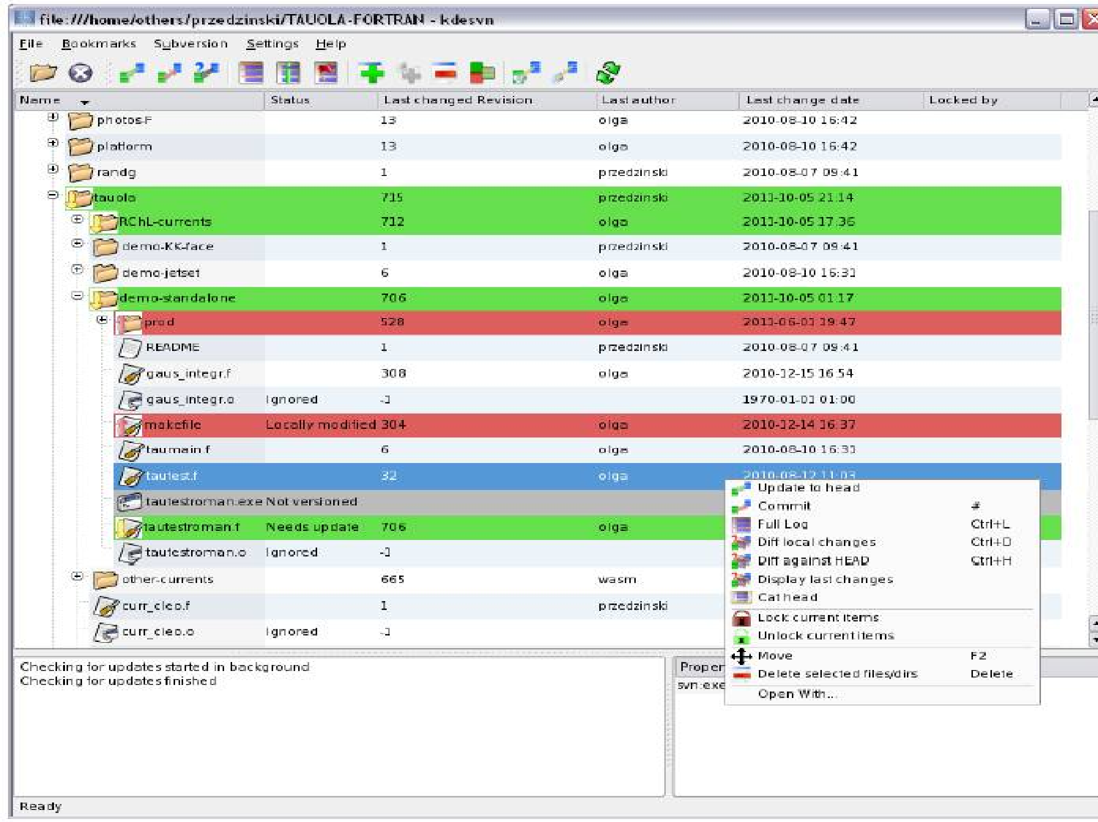


Only 3 pion mode result within errors

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)

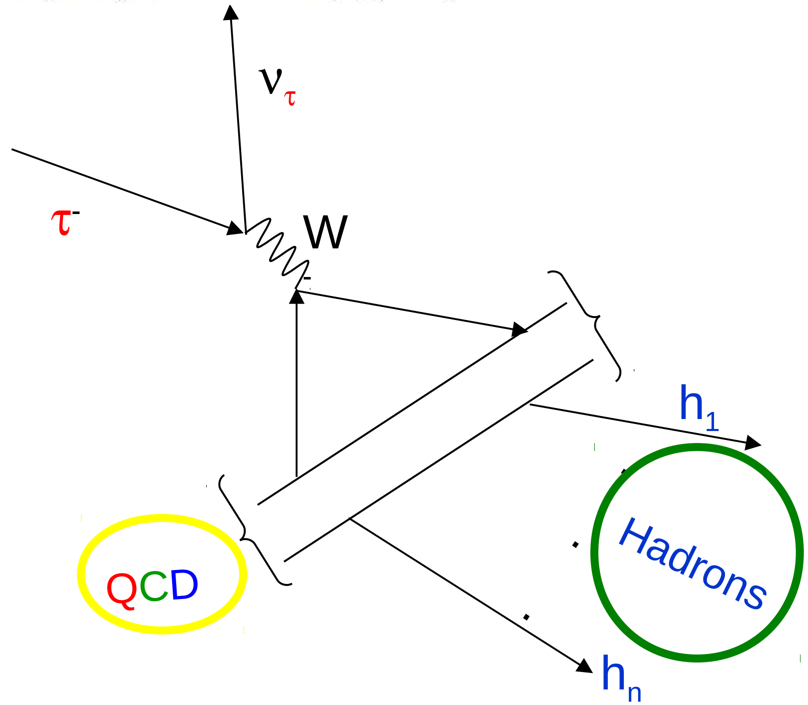
2πτ, 2K τ, Kπτ, 3πτ, KKπτ **88% of tau hadronic width**

Currents in RChT in TAUOLA2011

Hadronic decay mode of τ

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

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



$J_\mu = \langle Hadrons|(V-A)_\mu\, e^{iS_{QCD}}|0\rangle =$

$\Sigma_i(\text{Lorentz Structure})^i\, F_i(Q^2, s_j)$

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

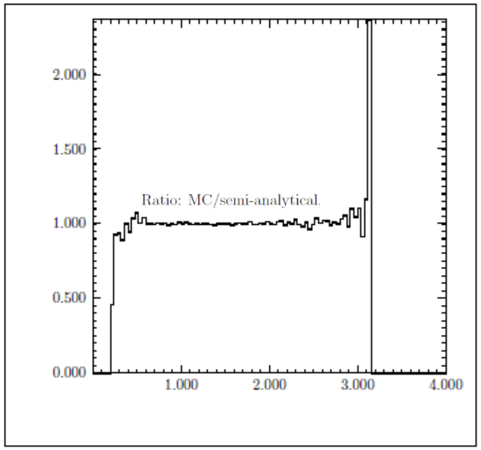
   ratio MC/semi-analytical of differential width (qq)

   comparison of analytical integration and MC for total width

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

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

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

terpolation ~ 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 pseudosca

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

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

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

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

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	$(5.2431\pm0.02\%)\cdot10^{-15}$	$(5.2441\pm0.005\%)\cdot10^{-15}$
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+	$(3.7379\pm0.024\%)\cdot10^{-15}$	$(3.7383\pm0.02\%)\cdot10^{-15}$

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

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

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)

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

2012: preliminary BaBar data I.M. Nugent arXiv:1301.7105

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

TAUOLA modification for 3 pion

1. FIXED BUG in F4 (essential for fit)

2. sigma meson added, phenomenologically (Cleo)

3. estimated Coulomb interaction

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

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

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

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