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Two- and three-meson decay modes of tau in TAUOLA

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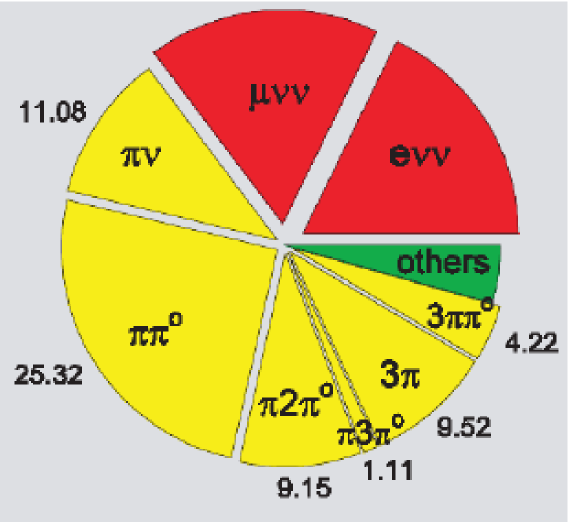
INP Cracow / KIPT Kharkov

Mini Workshop on Tau Physics. Mexico

τ - lepton physics



* τ mass and life time measurements

Mass 1776.86 ± 0.12 MeV : ***leptonic + hadronic decays***

* leptonic decay modes:

- muon-electron universality test

$$\left(\frac{g_\mu}{g_e}\right)^2_\tau = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$

$$\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0036 \pm 0.0020$$

BaBar PRL 105, 051602

Swagato' talk

- LFV search $\tau \to 3\mu$, $\tau \to \mu\gamma$

* hadronic decay modes Br ($\tau \to$ hadrons) = 64.8%

Precise measurements of hadronic decay modes = low + intermediate hadronic interaction

- hadronization mechanism and ChPT measurements
- Wess-Zumino anomaly
- measurement of resonance parameters
- Okuba-Zweig suppressed modes
- second class currents
- CKM matrix element measurements

$$\tau^- \to P^- \nu_\tau$$

* tau – muon universality

$$\left(\frac{g_\tau}{g_\mu}\right)_h^2 = \frac{\mathcal{B}(\tau \to h\nu_\tau)}{\mathcal{B}(h \to \mu\nu_\mu)} \frac{2m_h m_\mu^2 \tau_h}{(1+\delta_h) m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_h^2}{1 - m_h^2/m_\tau^2}\right)^2$$

$$\left(\frac{g_\tau}{g_\mu}\right)_{\pi(K)} = 0.9856 \pm 0.0057 \;\; (0.9827 \pm 0.0086)$$

BaBar PRL 105, 051602

0.9961 ± 0.0027 / 0.9860 ± 0.0070 HFLAV-Tau Spring 2017 Report

* $|V_{us}|$ measurement

CKM unitarity 0.2255 ± 0.0010

$$\mathcal{B}(\tau^- \to K^- \nu_\tau) = \frac{G_F^2 f_K^2 |V_{\rm us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar}\left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{\rm EW}$$

$$|V_{\rm us}| = 0.2193 \pm 0.0032$$

$\Delta \sim 2\sigma$

$$R_{K/\pi} = \frac{f_K^2 |V_{\rm us}|^2}{f_\pi^2 |V_{\rm ud}|^2} \frac{(1 - \frac{m_K^2}{m_\tau^2})^2}{(1 - \frac{m_\pi^2}{m_\tau^2})^2}$$

$$|V_{\rm us}| = 0.2255 \pm 0.0024$$

2P

~ 26 %

$\pi^-\pi^0, K^-K^0$: ρ(770), ρ(1450), ρ(1700), CVC (2 pion)

$K^-\pi^0, \overline{K^0}\pi^-$: *K*(892), K*(1410); F_K/F_π; m_s* (hep-ph/0605095)*; CP violation*

η-modes : $\eta\pi$ 2nd class current (not observed); (arXiv:1601.03989)
scalar resonance a_0(980), a_0(1450)
Kη *K*(1410)*

3P

~ 20 %

$\pi\pi\pi$: *a_1(1260) ρ(770), ρ(1450), σ(600) ….*
χPT study at threshold (L. Giranda, J. Stern, NP B 575, 285)

$KK\pi$: *K*(892), K*(1410), Weiss-Zumino anomaly, Okubo-Zweig – Iizuka (OZI) processes* $B(\tau^-\rightarrow\pi^-\phi\nu)$

$K\pi\pi$: *K_1(1270), K_1(1270),K*(892), K*(1410), ρ(770), ρ(1450), WZW, OZI, V_{us} , m_s , strange spectral function*

η-modes : *WZW + vector current, η-η' mixing V_{us} ,*

KKK : *WZW, OZI* $B(\tau^-\rightarrow K^-\phi\nu)$

>3P ~ 7 % $4\pi, 5\pi, K3\pi$

2P

~ 26 %

$\pi^-\pi^0, K^-K^0$

$K^-\pi^0, \overline{K^0}\pi^-$

η-modes

MODEL TEST AND PARAMETER DETERMINATION

3P

~ 20 %

$\pi\pi\pi$

$KK\pi$

$K\pi\pi$

η-modes

KKK

Hadronic decay modes:

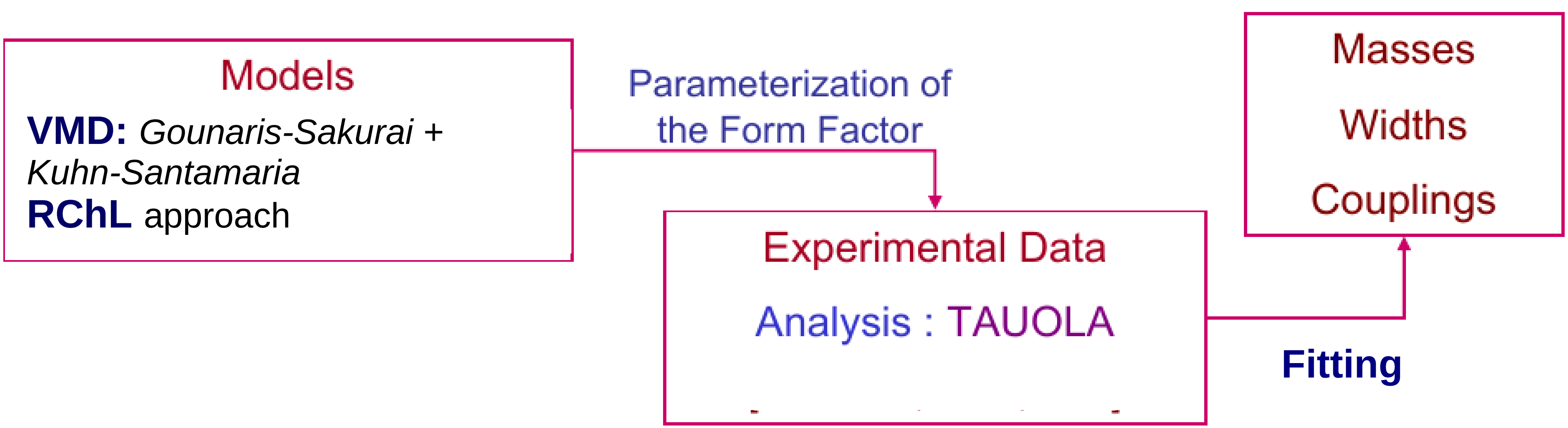
$$\mathcal{M}(\tau \to H\nu_\tau) = \frac{G_F}{\sqrt{2}} V_{CKM}\, \overline{u_{\nu_\tau}}\, \gamma^\mu (1-\gamma_5)\, u_\tau\, H_\mu$$

Form Factor

$$H_\mu = \langle H | (\mathcal{V}_\mu - \mathcal{A}_\mu)\, e^{i\mathcal{L}_{QCD}} | 0 \rangle = \sum_i \underbrace{(\ldots\ldots\ldots)^i_\mu}_{\text{Lorentz structure}}\, \overbrace{F_i(q^2, \ldots)}^{\text{Form Factor}}$$

Lorentz structure

Determination of form factors:



TAUOLA (Monte Carlo generator for tau decay modes)

R. Decker, S.Jadach, M.Jezabek, J.H.Kuhn, Z. Was, Comp. Phys. Comm. 76 (1993) 361; ibid 70 (1992) 69, ibid 64 (1990) 275

1. leptonic decay modes: $\tau^-(P,s) \longrightarrow \nu_\tau(N) l^-(q_1)\bar{\nu}_l(q_2), \quad l = e, \mu$

$$\bar{\mathcal{M}} = \frac{G}{\sqrt{2}}\,\bar{u}(\nu_\tau;N)\gamma^\mu(v+\gamma_5 a)u(\tau^-;P)\ \bar{u}(l^-;q_1)\gamma_\mu(1-\gamma_5)u(\nu_{l^-};q_2)$$

(general str.) → $(v+\gamma_5 a)$ (V-A) SM str → $(1-\gamma_5)$

$$d\Gamma_l = \frac{1}{2M}\left(\frac{G}{\sqrt{2}}\right)^2 32(B + H_\mu s^\mu)d\mathrm{Lips}(P;q_1,q_2,N)$$

$$B = (v+a)^2(P\cdot q_1)(N\cdot q_2) + (v-a)^2(P\cdot q_2)(N\cdot q_1) - Mm(v^2-a^2)(q_1\cdot q_2)$$

2. semi-leptonic (hadronic) decay modes $\tau(P,s) \rightarrow \nu_\tau(N)X$

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

$$|\mathcal{M}|^2 = G^2\frac{v^2+a^2}{2}(\omega + H_\mu s^\mu)$$

$$\omega = P^\mu(\Pi_\mu - \gamma_{va}\Pi^5_\mu)$$

$$H_\mu = \frac{1}{M}(M^2\delta^\nu_\mu - P_\mu P^\nu)(\Pi^5_\nu - \gamma_{va}\Pi_\nu)$$

$$\Pi_\mu = 2[(J^*\cdot N)J_\mu + (J\cdot N)J^*_\mu - (J^*\cdot J)N_\mu]$$

$$\Pi^{5\mu} = 2\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma}J^*_\nu J_\rho N_\sigma$$

$$\gamma_{va} = -\frac{2va}{v^2+a^2}$$

TAUOLA (official)

Monte Carlo generator for tau decays

TAUOLA-BBB

CPC version

Comp. Phys. Comm. 76 (1993), 361

Aleph version

Cleo version

CPC + π^0 π^0 π^- Cleo
Phys Rev D61, 012002

RChL version

2 pi Belle FF

* *Belle MC = Cleo version for 3 pions + 2 pion own + others modes ??*

* *BaBar MC = CPC + new modes*

Phys.Rev. D61 (2000) 012002

Cleo (3pions) + RχT parametrizations

Models and parameterizations

Energy $2m_\pi$ – 2 GeV: low energy tail – χPT, then ….. models

$$F_i\left(q^2,\ldots.\right)$$

[Kühn, Wagner, 1984]

[Pich et al, 1989,1990]

[Kühn, Santamaría, 1990]

[Decker, Finkemeier, Kühn,

Mirkes, Was…,1990-2000]

Kühn & Santamaría model

Parameterization of 2P, 3P

VMD

TAUOLA

CPC, Cleo, Alepch

TAUOLA 2012 →

Phys.Rev. D86 (2012) 113008

RχT (chiral symmetry)

Large-N_C expansion

ruled by QCD

$2\pi\,\nu_\tau$ $2K\nu_\tau$ $K\pi\nu_\tau$ $3\pi\nu_\tau$ $KK\pi\nu_\tau$

Short overview: Theory

$$\mathcal{M}(\tau \to H\nu_\tau) = \frac{G_F}{\sqrt{2}} V_{CKM}\, \overline{u_{\nu_\tau}}\, \gamma^\mu (1-\gamma_5)\, u_\tau\, H_\mu$$

Form Factor

$$H_\mu = \left\langle H \middle| (\mathcal{V}_\mu - \mathcal{A}_\mu)\, e^{i\mathcal{L}_{QCD}} \middle| 0 \right\rangle = \sum_i \underbrace{(\ldots\ldots\ldots)^i_\mu}_{\text{Lorentz structure}} \overbrace{F_i(q^2, \ldots)}^{\text{Form Factor}}$$

Lorentz structure

* Two Lorentz structures for **2P**

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

* Four Lorentz structures for **3P**

$$H^\mu = N \quad \{T^\mu_\nu [c_1 (p_2 - p_3)^\nu F_1 + c_2 (p_3 - p_1)^\nu F_2 + c_3 (p_1 - p_2)^\nu F_3] + c_4 q^\mu F_4 - \frac{i}{4\pi^2 F^2} c_5 \epsilon^\mu_{\ \cdot\ \nu\rho\sigma} p_1^\nu p_2^\rho p_3^\sigma F_5\}$$

F_1, F_2, F_3 axial-vector, F_5 vector, F_4 pseudoscalar

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

Kühn & Santamaría Model

[Kühn, Santamaría, 1990]

KS:
- χPT $O(p^2)$ ✓
- Vector meson dominance
- Asymptotic behaviour ruled by QCD

χPT $O(p^4)$ ✗

$$BW_R = \frac{M_R^2}{M_R^2 - s - i\sqrt{s}\,\Gamma_R(s)}$$

$$F_V(s) = \frac{BW_\rho \left(\frac{1+\alpha\, BW_\omega}{1+\alpha}\right) + \beta\, BW_{\rho'} + \gamma\, BW_{\rho''} + \ldots}{1+\beta+\gamma+\ldots}$$

3P modes: Σ BW(res1)*BW(res2) LO χPT

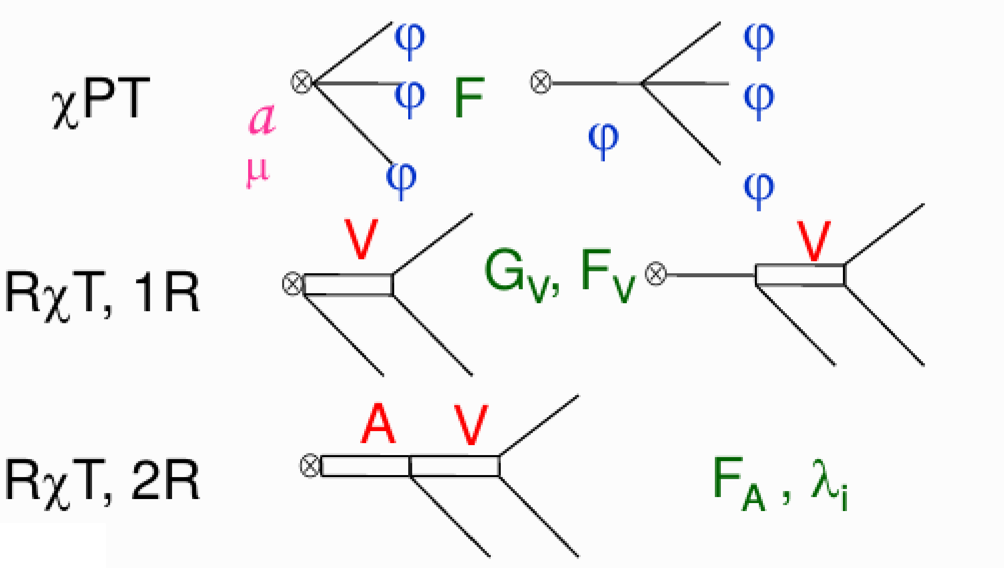
Resonance Chiral Theory
(Chiral Theory with the explicit inclusion of *resonances*)

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: $F_V G_V = f_\pi^2$, $F_V^2 - F_A^2 = f_\pi^2$, $F_V^2 M_V^2 = F_A^2 M_A^2$

General structure for 3P modes

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



TAUOLA 2017

2P and 3P modes

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

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

* KS FF from CPC

$$F_\pi^{(I=1)}(q^2) = \frac{1}{1+\beta+\gamma+\cdots}\left(BW_\rho + \beta\, BW_{\rho'} + \gamma\, BW_{\rho''} + \cdots\right) \qquad BW_\rho = \frac{M_\rho^2}{(M_\rho^2 - q^2) - i\sqrt{q^2}\Gamma_\rho(q^2)}$$

* GS

$$F_\pi(s) = \frac{1}{1+\beta+\gamma}(\mathrm{BW}_\rho + \beta\cdot\mathrm{BW}_{\rho'} + \gamma\cdot\mathrm{BW}_{\rho''}) \qquad \mathrm{BW}_i^{\mathrm{GS}} = \frac{M_i^2 + d\cdot M_i\Gamma_i(s)}{(M_i^2 - s) + f(s) - i\sqrt{s}\Gamma_i(s)}$$

* RChL Eur.Phys.J.C27 (2003) 587 (rho, rho')

$$F_\pi(s) = \frac{1 + \sum_i \frac{F_{V_i} G_{V_i}}{f^2}\frac{q^2}{M_{V_i}^2 - q^2}}{1 + \left(1 + \sum_i \frac{2G_{V_i}^2}{f^2}\frac{q^2}{M_{V_i}^2 - q^2}\right)\frac{2q^2}{f^2}\left[B_{22}^{r,(\pi)} + \frac{1}{2}B_{22}^{r,(K)}\right]}$$

* dispersive integral + modified high energy RChL

$$F_V^\pi(s) = \exp\left[\alpha_1\, s + \frac{\alpha_2}{2}\, s^2 + \frac{s^3}{\pi}\int_{s_{\rm thr}}^{\infty} ds' \,\frac{\delta_1^1(s')}{(s')^3(s' - s - i\epsilon)}\right]$$

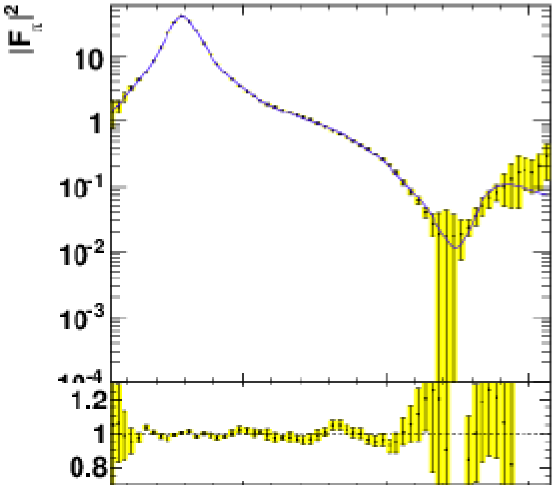
low energy

$$F_V^\pi(s) = \frac{M_\rho^2 + (\alpha' e^{i\phi'} + \alpha'' e^{i\phi''})\, s}{M_\rho^2\left[1 + \frac{s}{96\pi^2 F_\pi^2}\left(A_\pi(s) + \frac{1}{2}A_K(s)\right)\right] - s} - \frac{\alpha' e^{i\phi'}\, s}{M_{\rho'}^2\left[1 + s\, C_{\rho'} A_\pi(s)\right] - s} - \frac{\alpha'' e^{i\phi''}\, s}{M_{\rho''}^2\left[1 + s\, C_{\rho''} A_\pi(s)\right] - s}$$

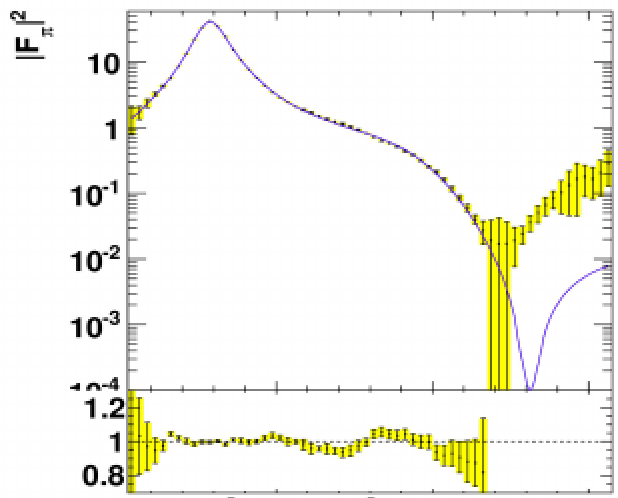
high energy

→ $K^- K^0$

Belle parametrization

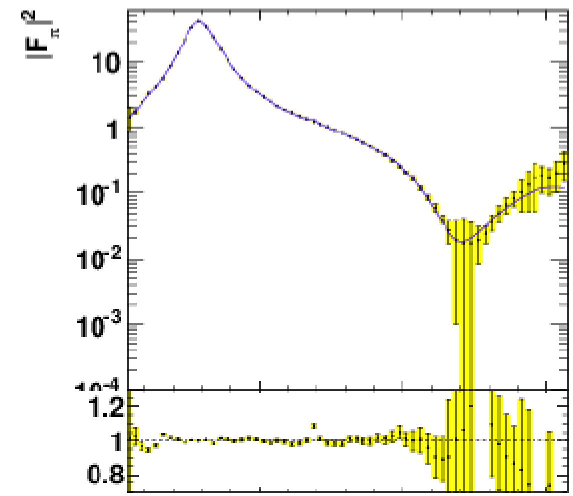


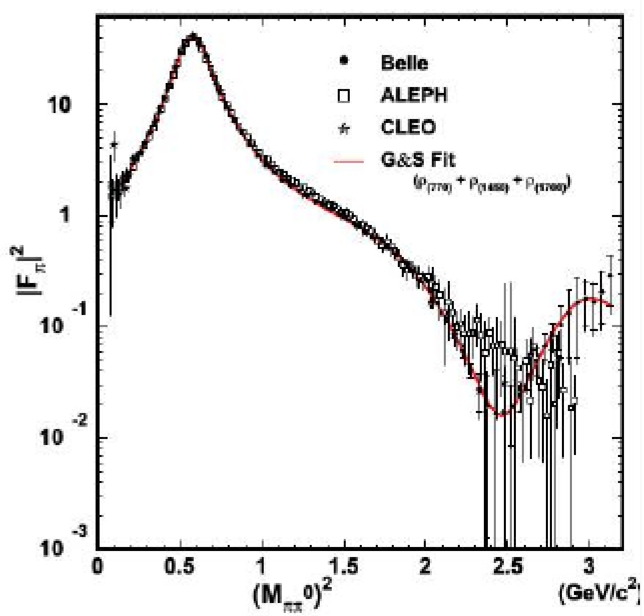
RChL parametrization



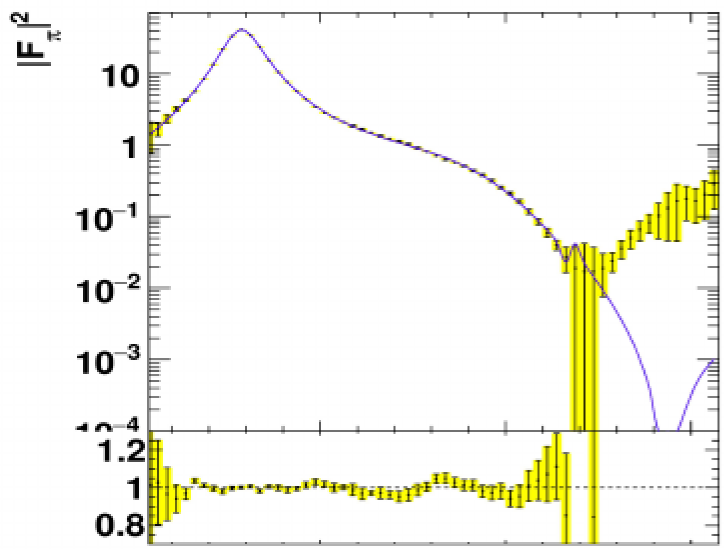
rho + rho'

dispersive integral





Phys Rev D 78 (2008) 072006



rho + rho' +rho''

arXiv:1506.08390

K pion mode $\tau^- \to (K\pi)^- \nu_\tau$

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

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

Vector FF (K*, K*′):

1. Exponention of FSI

M.Jamin, A. Pich, J. Portoles, Phys. Lett B 664(2008) 78

$$F^V_{K\pi}(s) = \left(\frac{M^2_{K^*} + s\gamma_{K\pi}}{M^2_{K^*} - s - iM_{K^*}\Gamma_{K^*}(s)} - \frac{s\gamma_{K\pi}}{M^2_{K^{*\prime}} - s - iM_{K^{*\prime}}\Gamma_{K^{*\prime}}(s)}\right) \exp\left\{\frac{-s}{128\pi^2 F^2}\left[ReA_{K\pi}(s) + ReA_{K\eta}(s)\right]\right\}.$$

different treatment of FSI

2. simplified version of *D.R. Boito, R.Escribano, M. Jamin, Eur. Phys. J C59(2009)821*

′Gounaris-Sakurai′

$$\widetilde{F}^{K\pi}_+(s) \equiv F^{K\pi}_+(s)/F^{K\pi}_+(0)$$

$$\widetilde{F}^{K\pi}_+(s) = \frac{m^2_{K^*} - \kappa_{K^*}\widetilde{H}_{K\pi}(0) + \gamma s}{D(m_{K^*}, \gamma_{K^*})} - \frac{\gamma s}{D(m_{K^{*\prime}}, \gamma_{K^{*\prime}})}$$

$$D(m_n, \gamma_n) \equiv m^2_n - s - \kappa_n \mathrm{Re}\widetilde{H}_{K\pi}(s) - i\, m_n \gamma_n(s)$$

Scalar FF

The private code of M. Jamin, Boito, Escribano, Jamin, EPJ C 59, 821

Dispersion relations on Mushkhelishvili-Omnes approach (Emilie’ talk)

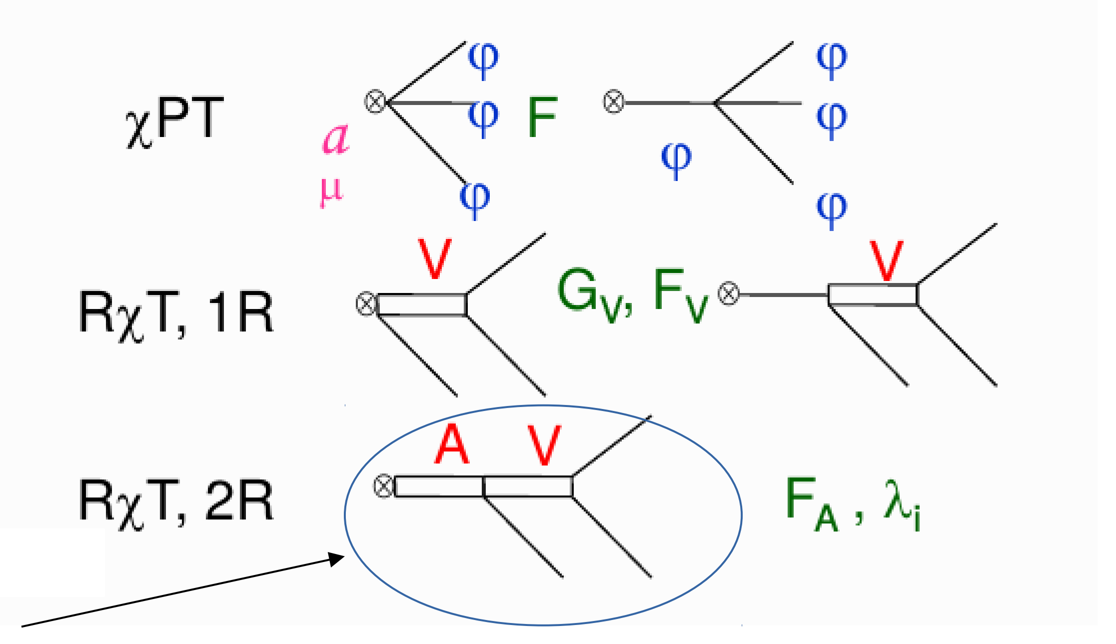
Three meson decay modes

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

Form factors

KS: Σ BW(res1)*BW(res2)
Axial-vector part res = $a_1(1260)$

RχT:
A = $a_1(1260)$



KS (VMD)

Cleo parametrization

$\tau^- \rightarrow \pi^0 \pi^0 \pi^- \nu_\tau$ D. Asner et al., Phys.Rev. D61 (2000) 012002,hep-ex/9902022

Dalitz plots distributions

a1(1200) →

		Significance	Branching fraction (%)	$\lvert\beta\rvert$	phase φ/π
$\rho\pi$	S-wave	–	68.11	1.00	0.0
$\rho(1450)\pi$	S-wave	1.4σ	0.30 ± 0.64	0.12 ± 0.09	0.99 ± 0.25
$\rho\pi$	D-wave	5.0σ	0.36 ± 0.17	0.37 ± 0.09	-0.15 ± 0.10
$\rho(1450)\pi$	D-wave	3.1σ	0.43 ± 0.28	0.87 ± 0.29	0.53 ± 0.16
$f_2(1270)\pi$	P-wave	4.2σ	0.14 ± 0.06	0.71 ± 0.16	0.56 ± 0.10
$f_0(600)\pi$	P-wave	8.2σ	16.18 ± 3.85	2.10 ± 0.27	0.23 ± 0.03
$f_0(1370)\pi$	P-wave	5.4σ	4.29 ± 2.29	0.77 ± 0.14	-0.54 ± 0.06

$$B_Y^L(s_i) = \frac{m_{0Y}^2}{(m_{0Y}^2 - s_i) - i m_{0Y} \Gamma^{Y,L}(s_i)}$$

$$\Gamma^{Y,L}(s_i) = \Gamma_0^Y \left(\frac{k_i'}{k_0'}\right)^{2L+1} \frac{m_{0Y}}{\sqrt{s_i}}$$

* fitted the beta constants + a1 mass and width

* other parameters fixed to PDG, sigma mass = 860 MeV and width = 880 MeV

* Dalitz distributions (Zbigniew' Talk)

Isospin transformation to get $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$

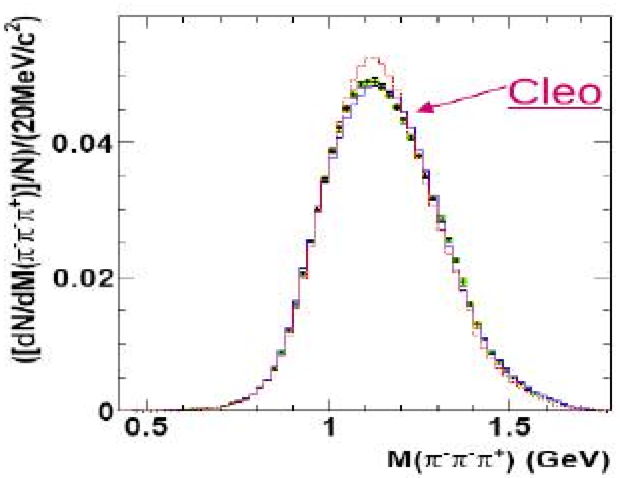
RχT parametrization

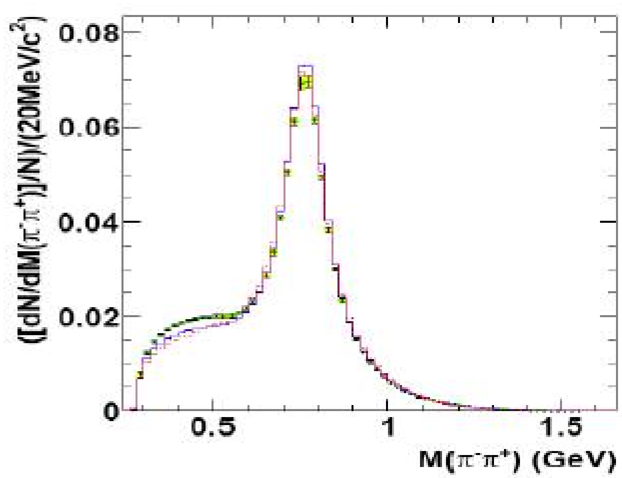
$$F_1^{\chi}(q^2, s_1, s_2) = -\frac{2\sqrt{2}}{3}\,,$$

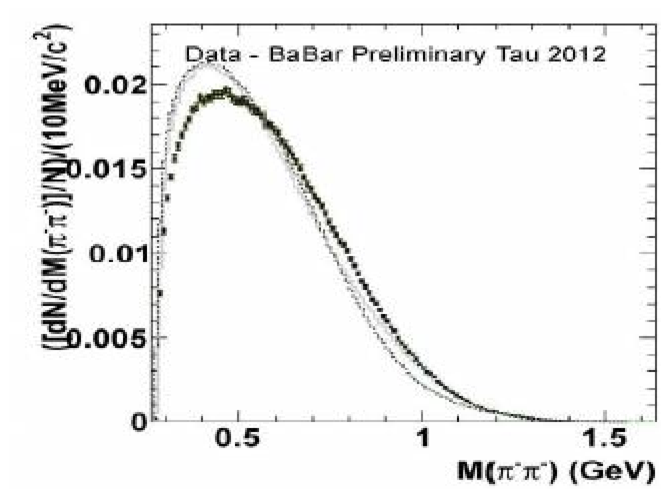
$$F_2(Q^2, s_2, s_1) = - F_1(Q^2, s_1, s_2)$$

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

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







Tauola 2013 : inclusion of sigma meson

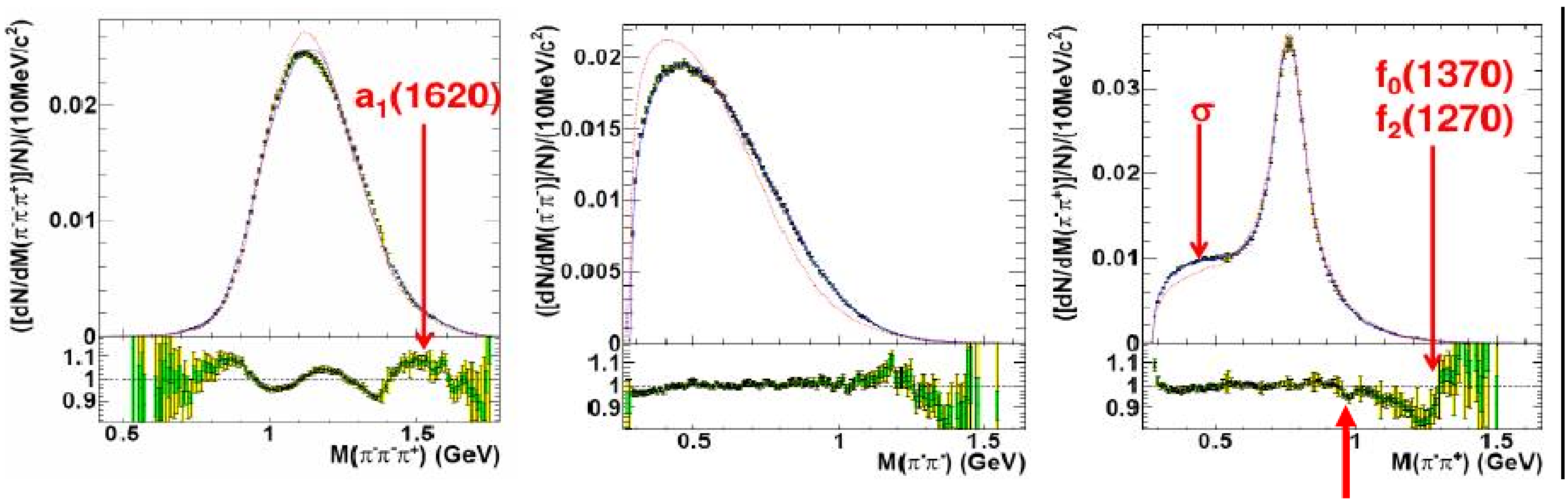
Tauola 2013 : inclusion of sigma meson

$\pi^- \pi^- \pi^+$

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

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

Phys. Rev. D 88, 093012 (2013)



* alpha, beta are related for χPT - correct inclusion based on χPT structure
* inclusion tensor resonances in RχT framework

J.J Sanz Cillero, O.S.

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

CLEO parametrization

$$F_5^V = -\frac{1}{2\sqrt{2}\pi^2 F^3}\sqrt{R_B}\,\frac{BW_\omega + \alpha BW_{K^*}}{1+\alpha}\,\frac{BW_\rho + \lambda BW_{\rho'} + \delta BW_{\rho''}}{1+\lambda+\delta}$$

Wess-Zumino

$$\sqrt{R_B} = 1$$

Analysis of data

$$\sqrt{R_B} = 1.80 \pm 0.53$$

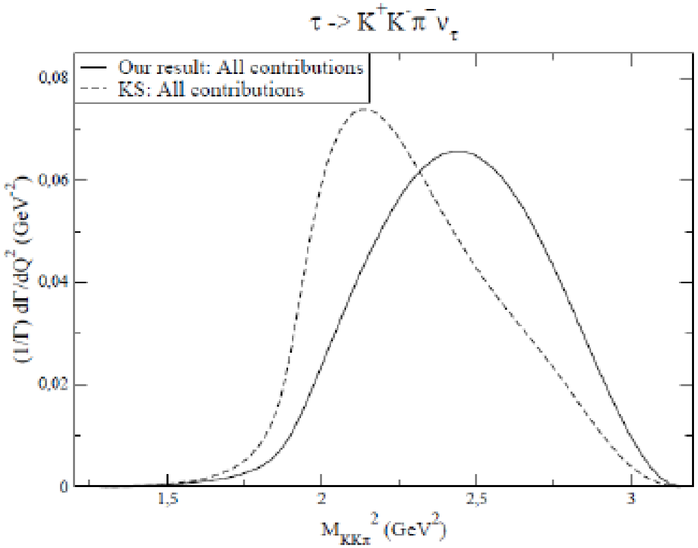
RχT parametrization

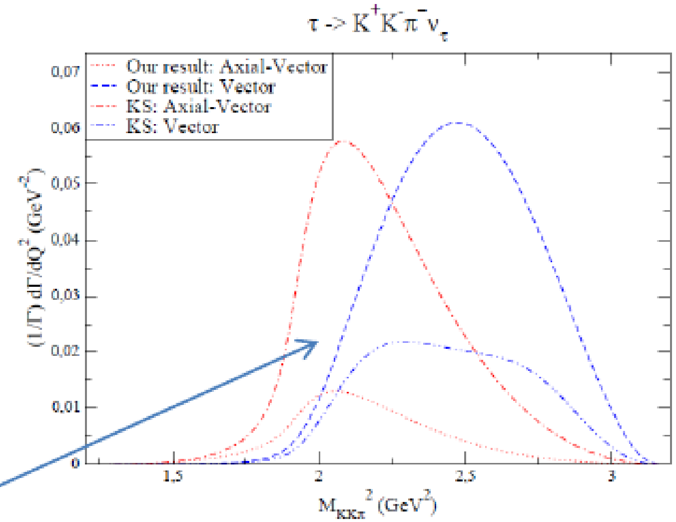
$$F_1^{\mathrm{RR}}(q^2,s_2,s_1) = \frac{2}{3}\frac{F_A G_V}{F^2}\frac{q^2}{M_A^2 - q^2 - iM_A\Gamma_A(q^2)}\left[\frac{B^{\mathrm{RR}}(q^2,s_1,s_3,s_2,m_K^2,m_K^2,m_\pi^2)}{M_\rho^2 - s_2 - iM_\rho\Gamma_\rho(s_2)} + \frac{A^{\mathrm{RR}}(q^2,s_1,s_3,m_K^2,m_K^2,m_\pi^2)}{M_{K^*}^2 - s_1 - iM_{K^*}\Gamma_{K^*}(s_1)}\right].$$

$$F_5^{\mathrm{RR}}(q^2,s_2,s_1) = -16\sqrt{2}\pi^2 F_V\, G_V\,\frac{1}{M_\rho^2 - q^2 - iM_\rho\Gamma_\rho(q^2)}\left[\frac{C^{\mathrm{RR}}(q^2,s_1,m_K^2)}{M_{K^*}^2 - s_1 - iM_{K^*}\Gamma_{K^*}(s_1)} + C^{\mathrm{RR}}(q^2,s_2,m_\pi^2)\left(\sin^2\theta_V\frac{1+\sqrt{2}\cot\theta_V}{M_\omega^2 - s_2 - iM_\omega\Gamma_\omega} + \cos^2\theta_V\frac{1-\sqrt{2}\tan\theta_V}{M_\phi^2 - s_2 - iM_\phi\Gamma_\phi}\right)\right],$$

→ **OZI**

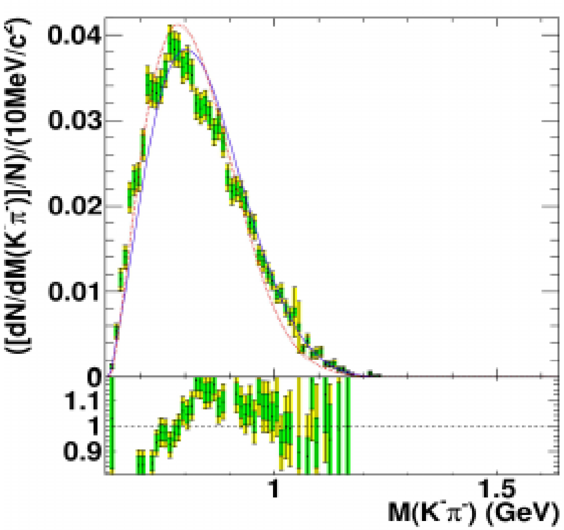
CPC and TAUOLA 2011 (*arXiv:0911.2640*):

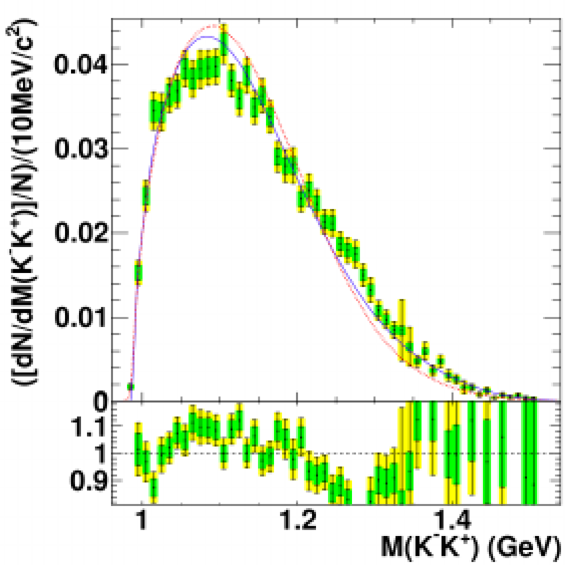


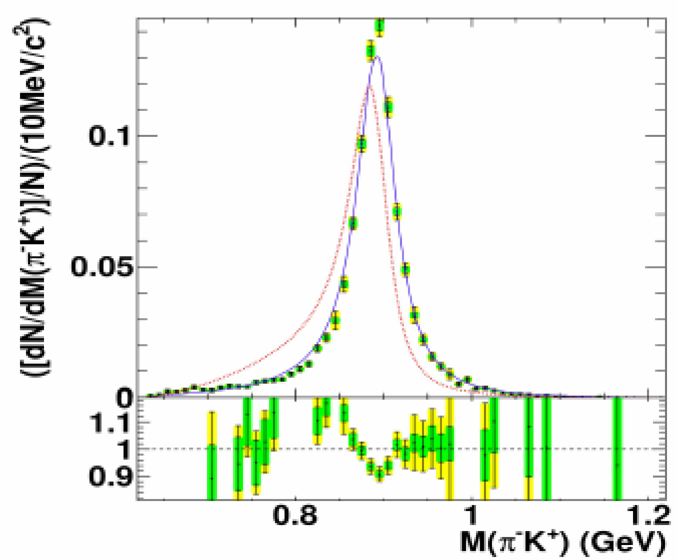


Sizable vector contribution in RChT

$\tau^- \to K^+ K^- \pi^- \nu$

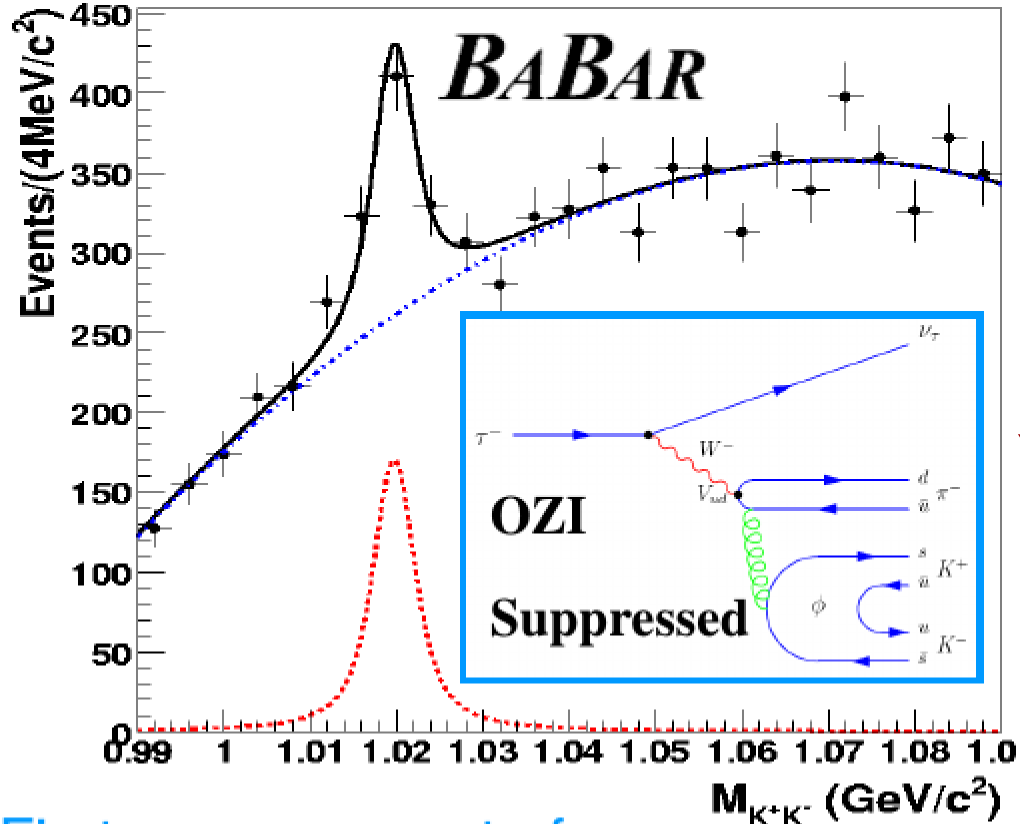






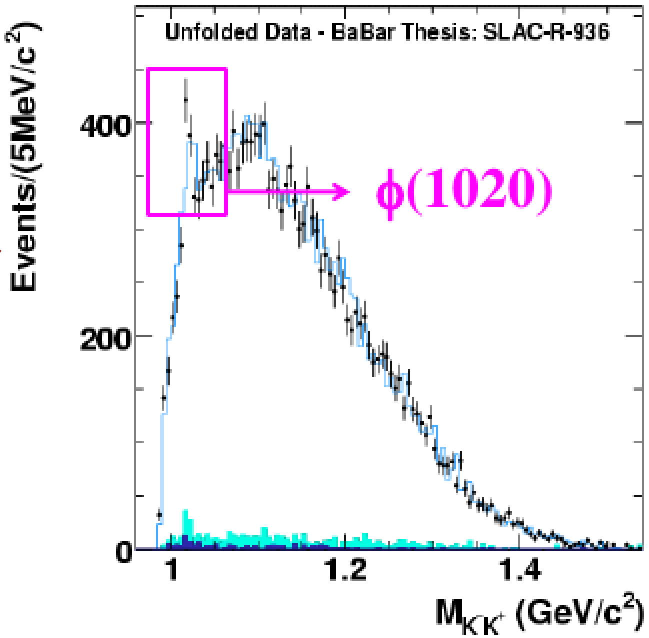
Also K*(1400), ρ(1450)

Blue – RChL Red – Cleo



I. Nugent (BaBar Colaboration)

Tau Workshop, Cracow, 2013



First measurement of:

$B(\tau^- \to \pi^- \phi \nu) = (3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$

Significance: 5.7σ

RχT TAUOLA (default) ideal mixing angle **no OZI contribution**

Not in TAUOLA

Also $K^- \pi^0 K^0 \nu_\tau$

No yet Kππ and KKK modes with RχT

TAUOLA CPC

TAUOLA 2012

Phys.Rev. D86 (2012) 113008

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

Checks of implementation and numerical stability (Zbigniew' talk)

TAUOLA 2013

Phys. Rev. D 88, 093012 (2013)

Phenomenological inclusion of sigma 3pions,

K*(1400), ρ(1450) for K K π

Belle 2 pion FF

DIPSWITCH PARAMETERS

new-currents/RChL-currents/value_parameter.f

Model choice

DIPSWITCH	MODE
FFVEC	PIPI0, KPI, KK0
FFKPIVEC	KPI
FFKKVEC	KK0
FFKPISCAL	KPI
FF3PISCAL	PIPIPI
FF3PIRHOPR	PIPIPI
FFKKPIRHOPR	KKPI,KK0PI0
FFKKPIKPR	KKPI, KK0PI0

Numerical values of model parameters

What is new/future ?

* tauola -bbb project (Zbigniew' and Kuba' talks)

* inclusion of $\pi\eta$ (second class current), $K\eta$ and $\eta\pi\pi$ modes
  FF within dispersion relation (Emilie' talk)

Second class current: not observed yet, suppressed within SM: $m_u \neq m_d$, viol G-inv

D. Gomez Dumm, P. Roig, PRD 86, 076009

$BR_V \cdot 10^5$	$BR_S \cdot 10^5$	$BR \cdot 10^5$	Reference
0.26(2)	$0.72^{+0.46}$	0.98(51)	Breit-Wigner [$a_0(980)$]
0.26(2)			
0.26(2)			
0.26(2)			
0.26(2)			
0.26(2)	1.41(9)	1.67(9)	3 coupled channels

Location of TAUOLA with new hadronic currents, 200 decay channels, which can be manipulated by user:

https://twiki.cern.ch/twiki/bin/view/FCC/Tauola

$BR^{BaBar}_{exp} < 9.9 \cdot 10^{-5}$ 95%CL

2)

$^{-5}$ 90%CL

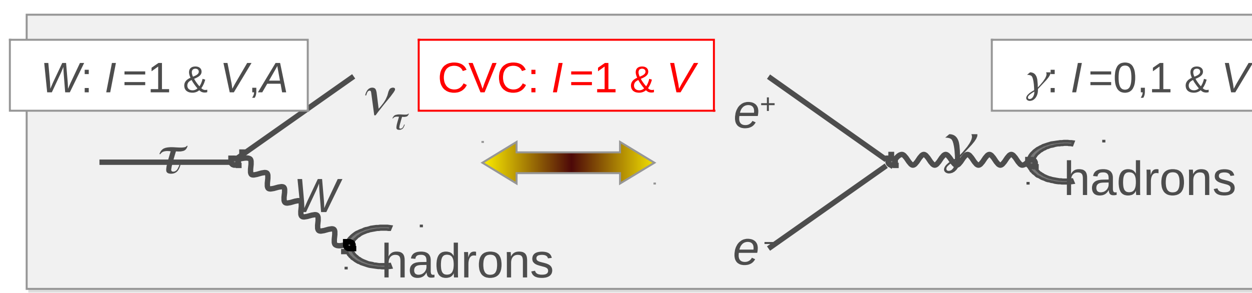
374 (2009))

Check of CVC $\eta\pi\pi$

$\mathcal{B}(\tau \to \nu\pi^0\pi^-\eta) = (0.160 \pm 0.009)\%$

$\mathcal{B}(\tau \to \nu\pi^0\pi^-\eta) = (0.162 \pm 0.008)\%$

R. Waldi (BaBar, e+e-), ICHEP 2016



$\mathcal{B}(\tau \to \nu\pi^0\pi^-\eta) = (0.139 \pm 0.010)\%$ [PDG14]

CONCLUSIONS

* **TAUOLA 2 P and 3 P**

tauola -bbb

Location of TAUOLA with new hadronic currents, 200 decay channels, which can be manipulated by user:
https://twiki.cern.ch/twiki/bin/view/FCC/Tauola

Rχ T version

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

BACK SLIDES

2P

~ 26 %

$\pi^-\pi^0, K^-K^0$: *Belle ()*

$K^-\pi^0, \overline{K^0}\pi^-$: *Belle (), BaBar ()*

η-modes : $\pi\eta$ not observed yet,
Kη

3P

~ 20 %

$\pi\pi\pi$: *BaBar, Belle*

$KK\pi$: *BaBar, Belle*

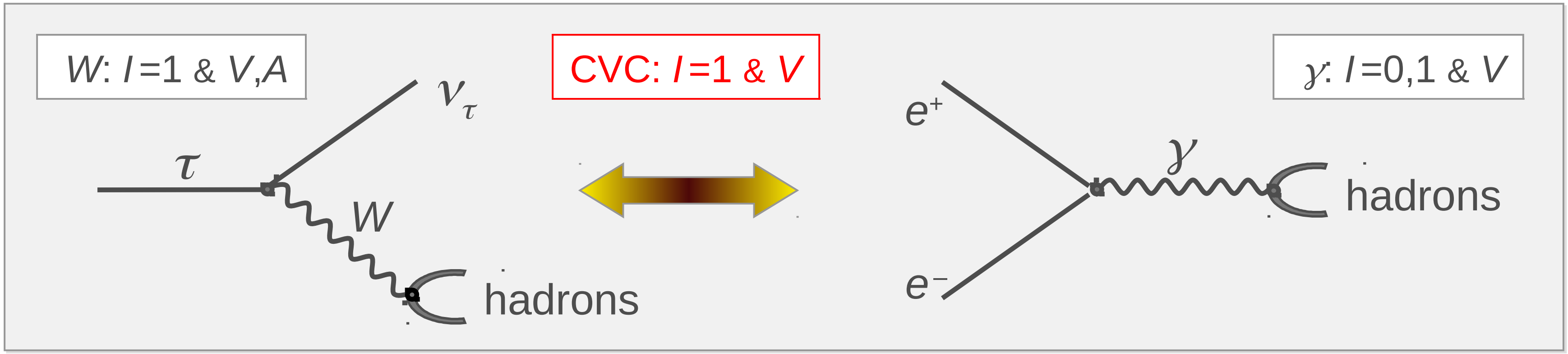
$K\pi\pi$

η-modes : *BaBar, Belle*

KKK : *BaBar, ???Belle???*

>3P ~ 7 % $4\pi, 5\pi, K3\pi$

Check of CVC



2 π , 4 π , ππη

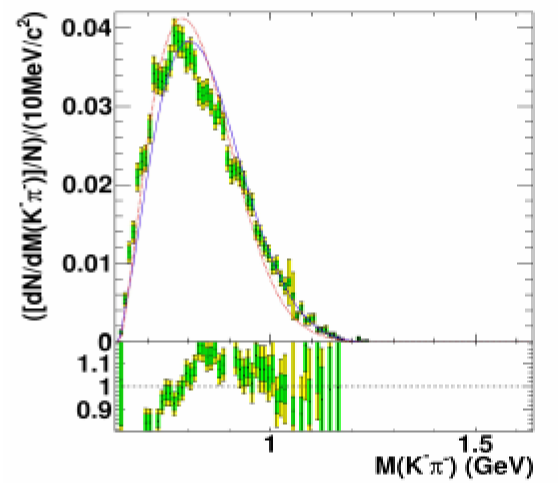
R. Waldi (BaBar) ICHEP

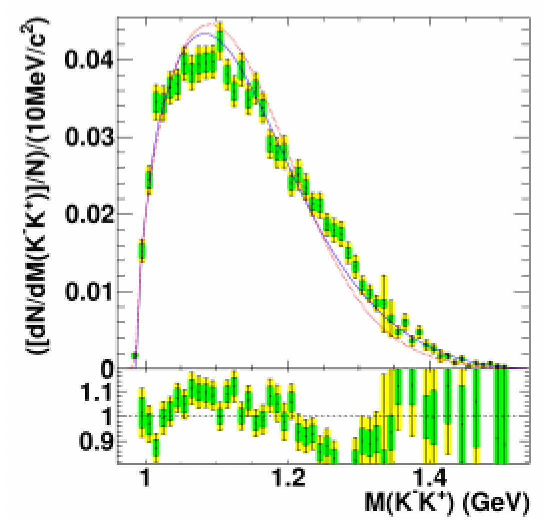
$\mathcal{B}(\tau \to \nu\pi^0\pi^-\eta) = (0.160 \pm 0.009)\%$ **2016**

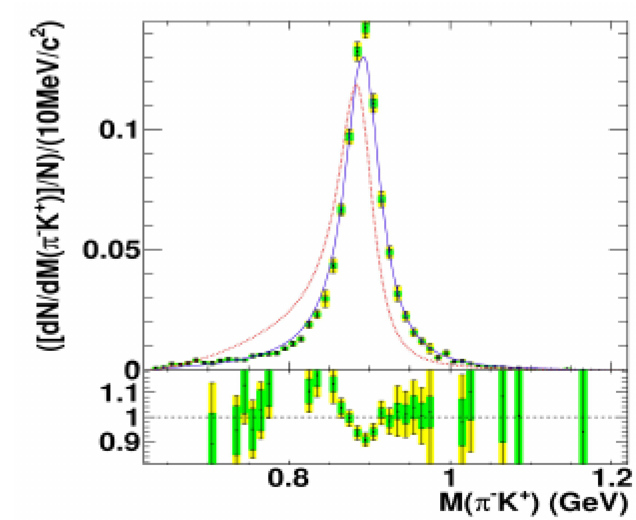
$\mathcal{B}(\tau \to \nu\pi^0\pi^-\eta) = (0.162 \pm 0.008)\%$ **2007 + 2016**

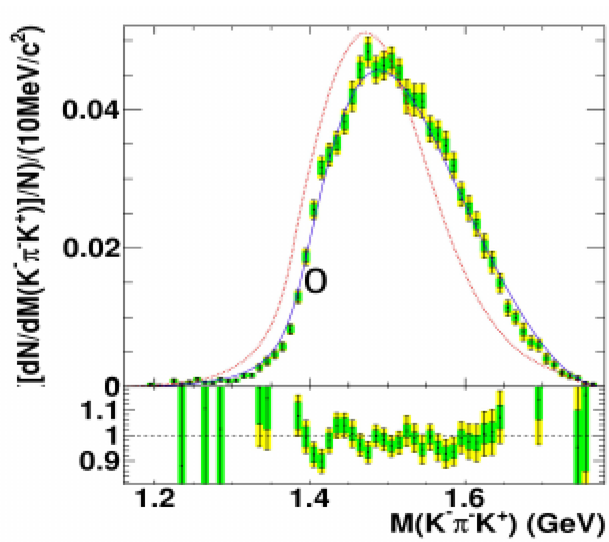
$\tau^- \to K^+ K^- \pi^- \nu$

Preliminary fitting results to BaBar preliminary data









Blue – RChL Red – Cleo

some parameters on their limits …

* generalization of 3 pion fit strategy

* in contrary to 3 pion case, no discussion of experimental systematic errors yet

* *the a1 width table corresponds to 3pion parameter values, not re-tabulated*