Study of the lowest tensor and scalar resonances in the $\tau \to \pi\pi\pi\nu_\tau$ decay

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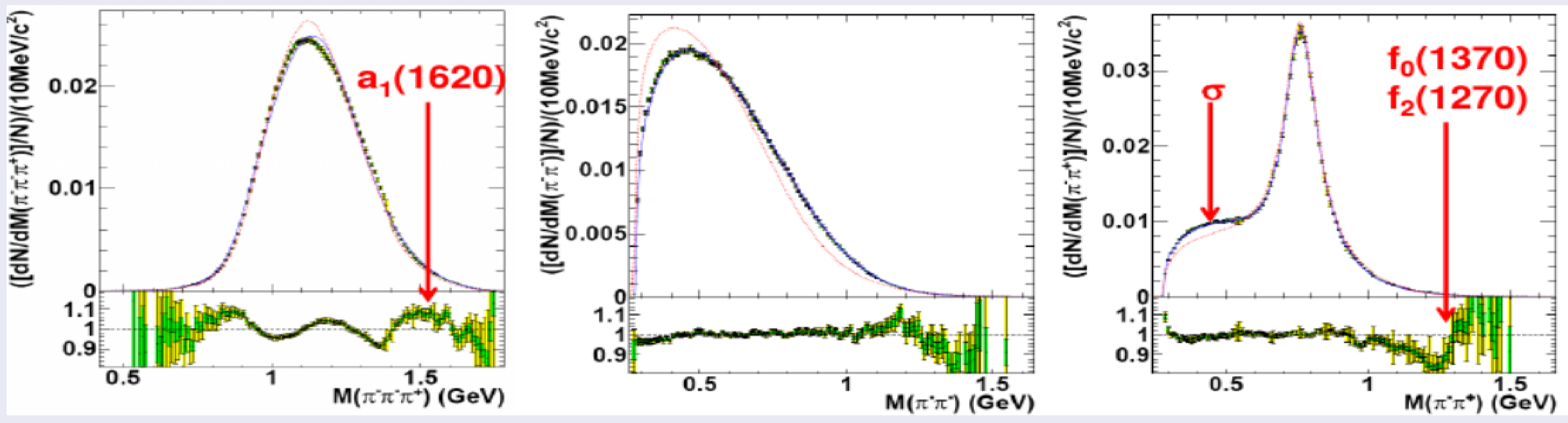
Introduction

Hadronic decay modes of τ-lepton gives information about the hadronization mechanism and resonance dynamics in the energy region, where the pQCD methods are not applied. In the last years substantial progress for the simulation of the process $\tau \to 3\pi\nu_\tau$ was achieved. The decay mode was chosen due to its relatively large branching ratio and already its non-trivial dynamics compare with the two-meson channel.



The progress [1] was related with a new parametrization of the hadronic current based on the Resonance Chiral Lagrangian and with the recent availability of the unfolded distributions from (preliminary) BaBar analysis for all invariant hadronic masses for the three-prong mode. However, 1) some points related with the scalars were not clarified; 2) tensor resonance contributions to the decay were not considered in the framework.

1. General description

- Lorenz invariant current

$$\langle (\pi(p_1)\pi(p_2))\pi^{\pm}(p_3)|\bar{d}\gamma^\alpha\gamma_5 u|0\rangle = H^{3\pi}_\mu(p_1,p_2,p_3) =$$
$$iP_T(q)^\alpha_{\ \mu}\left((p_1^\mu - p_3)^\mu \mathcal{F}_2(s_1,s_2,q^2) + (p_2^\mu - p_3)^\mu \mathcal{F}_1(s_1,s_2,q^2)\right)$$
$$+iq^\alpha \mathcal{F}_P(s_1,s_2,q^2), \quad F_2(s_1,s_2,q^2) = F_1(s_2,s_1,q^2)$$
$$s_i = (p_j - p_k)^2, \quad q^2 = (p_1+p_2+p_3)^2 \qquad (1)$$

- Amplitudes due to isospin symmetry relation [2]

$$H^{--+}_\mu(p_1,p_2,p_3) = H^{00-}_\mu(p_3,p_1,p_2) + H^{00-}_\mu(p_3,p_2,p_1) \qquad (2)$$

$$\mathcal{F}_1^{--+}(s_1,s_2,q^2) = \mathcal{F}_1^{00-}(s_3,s_2,q^2) - \mathcal{F}_1^{00-}(s_3,s_1,q^2) - \mathcal{F}_1^{00-}(s_1,s_3,q^2)$$

2. Theoretical model

Resonance Chiral Lagrangian with V, A resonanses [3]

- reproduces NLO χPT
- appropriate high enegy form-factor behaviour
- $\mathcal{F}_i = \mathcal{F}_i^{RR} + \mathcal{F}_i^{R} + \mathcal{F}_i^{\chi PT}$

The first comparison (only V,A) to the Belle data [4] requires S, *added by "hand"* as

$$\mathcal{F}_1^{R} \to \mathcal{F}_1^{R} + \left(\alpha_\sigma BW_\sigma(s_1)F_\sigma(q^2,s_1) + \beta_\sigma BW_\sigma(s_2)F_\sigma(q^2,s_2)\right) \qquad (3)$$
$$\mathcal{F}_1^{RR} \to \mathcal{F}_1^{RR} + \frac{q^2}{\Pi_{a_1}(q^2)}\left(\gamma_\sigma BW_\sigma(s_1)F_\sigma(q^2,s_1) + \delta_\sigma BW_\sigma(s_2)F_\sigma(q^2,s_2)\right)$$
$$F_\sigma(q^2,s) = \exp\left[-\frac{\lambda(q^2,s,m_\pi^2R^2)}{8q^2}\right], \quad BW_\sigma = BW(L=0)$$

Fitted to the BaBar preliminary data above, $\chi^2/n.d.f. = 910/410$ (8-times imrovement), the low energy part of spectra reproduced, $\alpha \simeq -\beta$, $\gamma \simeq 2\delta$, $R = 1.86$. *The form-factors (3) do not obey (2)*

2.1 Scalar mesons

The relevant resonance Lagrangian

$$\Delta\mathcal{L}_S = c_d\langle S u_\mu u^\mu\rangle + c_m\langle S\chi_+\rangle, \quad \Delta\mathcal{L}_{AS} = \lambda_1^{AS}\langle\{\nabla_\mu S, A^{\mu\nu}\}u_\nu\rangle$$

that results in

$$\mathcal{F}_1(s_1,s_2,q^2)^{\pi^0\pi^0\pi^-} = \frac{2}{3}\mathcal{F}^a_{S\pi}(q^2)\mathcal{G}_{\sigma\pi\pi}(s_3) \qquad (4)$$
$$\mathcal{F}_1(s_1,s_2,q^2)^{\pi^-\pi^-\pi^+} = -\frac{2}{3}\mathcal{F}^a_{S\pi}(q^2)\left(2\mathcal{G}_{S\pi\pi}(s_1) - \mathcal{G}_{\sigma\pi\pi}(s_2)\right)$$

obey (2), where

$$\mathcal{F}^a_{S\pi}(q^2) = \frac{2c_d}{F} - \frac{\sqrt{2}F_A\lambda_1^{AS}}{F}\frac{q^2}{M_A^2-q^2}, \quad \mathcal{G}_{\sigma\pi\pi}(s) = \frac{\sqrt{2}c_d}{F}\frac{(s-2m_\pi^2)}{M_\sigma^2-s}$$

Incorporating the width and σ - $f_0(980)$ splitting

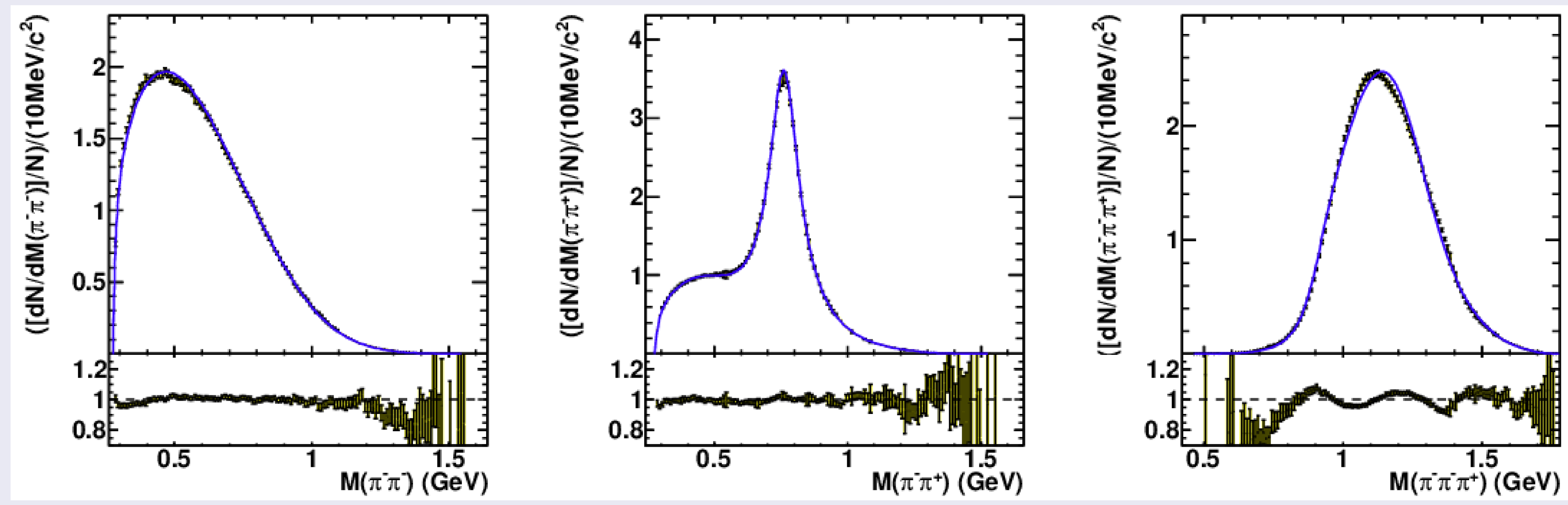
$$\frac{1}{M_S^2-s} \to \frac{\sin^2\phi_S}{M_{f_0}^2 - s - iM_{f_0}\Gamma_{f_0}} + \frac{\cos^2\phi_S}{M_\sigma^2 - s - c_\sigma s^k\overline{B}_0(s,m_\pi^2,m_\pi^2)} \qquad (5)$$

$\phi_S = 8^\circ$ and the two-point subtracted Feyman integral

$$\overline{B}_0(s,m_\pi^2,m_\pi^2) = \frac{1}{16\pi^2}\left[2 - \rho(s)\ln\left|\frac{\rho(s)+1}{1-\rho(s)}\right| + i\pi\rho(s)\theta(s-4m_\pi^2)\right]$$

2.2 Preliminary numerical results

Fit to the preliminary BaBar data: f_0 parameters fixed to their PDG values, the σ-propagator: BW_σ or (5)



The fit slightly prefers BW_σ, the study is in progress.

2.3 Tensor mesons

The relevant resonance Lagrangian

$$\Delta\mathcal{L}_T = g_T\langle T_{\mu\nu}\{u^\mu,u^\nu\}\rangle, \quad \Delta\mathcal{L}_{AT} = \lambda_1^{AT}\langle\{T_{\mu\nu},A^{\nu\alpha}\}h^\mu_\alpha\rangle \qquad (6)$$

$\Delta\mathcal{L}_T$ is in [5] (neglecting a part contributes to the local term), $\Delta\mathcal{L}_{AT}$ the most general tensor Lagrangian. The calculated form factors $\mathcal{F}_1(s_1,s_2,q^2)^{\pi^-\pi^-\pi^+}$ and $\mathcal{F}_1(s_1,s_2,q^2)^{\pi^-\pi^-\pi^+}$ obey (2).

- *Comparison with the VMD current.* The allowed Lorentz structure

$$\langle f_2(k,\epsilon)\pi^-(p)|\bar{d}\gamma^\alpha\gamma_5 u|0\rangle = i\epsilon^*_{\mu\nu}P_T(q)^{\alpha\rho}p^\nu\left(g^\mu_\rho\mathcal{F}^a_{T\pi}(q^2) + p_\rho p^\mu\mathcal{G}^a_{T\pi}(q^2)\right)$$

where the form factors (in $m_\pi \to 0$)

$$\mathcal{F}^a_{T\pi}(q^2) = -\frac{8g_T}{F} + \frac{4\sqrt{2}F_A\lambda_1^{AT}}{F}\frac{(qp)}{M_A^2-q^2}, \quad \mathcal{G}^a_{T\pi}(q^2) = -\frac{4\sqrt{2}F_A\lambda_1^{AT}}{F}\frac{1}{M_A^2-q^2}$$

To reproduce the Cleo result $\mathcal{G}^a_{T\pi}(q^2) = 0$.

3. Summary and plans

- isospin symmetrical form factors for $\tau \to \pi\pi\pi\nu_\tau$
- scalar resonance contributions: adding $f_0(980)$, inclusion of the real part of the pion loops to σ propagator
- tensor resonance contribution: the current within expanded Resonance Chiral approach, generalization of the VMD result
- preliminary fit to the BaBar preliminary data (*not tensor yet*)

⋆⋆ *study of the real part loop influence on the σ propagator (N/D parametrization), precise study of tensor form factors technical part: numerical tests and estimation of parameter errors using the BaBar*

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