Full angular spectrum analysis of tensor current contribution to $A_{cp}(\tau \to K_s \pi \nu_\tau)$.

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Abstract

Babar collaboration has reported an intriguing opposite sign in the integrated decay rate asymmetry $A_{cp}(\tau \to K_s\pi\nu_\tau)$ than that of SM prediction from the known K^0 - $\bar{K^0}$ mixing. Babar's result deviate from the SM prediction by about 2.7σ. If the result stands with higher precision in the future experiments, the observed sign anomaly in the $A_{cp}(\tau \to K_s\pi\nu_\tau)$ can most likely come only from a NP. In this work we present a full angular spectrum analysis on the contribution to $A_{cp}(\tau \to K_s\pi\nu_\tau)$ coming from the tensorial term. Assuming the real part of the NP tensorial coupling is negligible compare to its imaginary part and with $A_{cp}(\tau \to K_s\pi\nu_\tau)$ and $Br(\tau \to K_s\pi\nu_\tau)$ as data points to fit the imaginary part of the NP coupling, we have been able to fit the result within 1σ of the experimental values.

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1. INTRODUCTION

The study of CP violation in tau decays has always been of much interest for beyond the Standard Model studies in the past two decades. In SM, the only source of CP violation is the one phase in the Kobayashi Maskawa (KM) matrix. While the Kobayashi Maskawa ansatz for CP violation within the Standard Model [1] in the quark sector has been clearly verified by the plethora of data from the B factories, this is unable to account for the observed baryon asymmetry of the Universe. Hence, one needs to look for other sources of CP violation, including searches in the leptonic sector. Apart from the CP phases that may arise in the neutrino mixing matrix, the decays of the tau lepton may allow us to explore nonstandard CP-violating interactions. Various experimental groups have been involved in exploring CP violation in tau decays in the last decade or more. In 2002, the CLEO collaboration [2], and more recently the Belle Collaboration [3], studied the angular distribution of the decay products in $\tau \to K_s\pi\nu_\tau$ in search of CP violation; however, neither study revealed any CP asymmetry. The BABAR collaboration [4] for the first time reported a sign anomaly in the integrated decay rate asymmetry $A_{cp}(\tau \to K_s\pi\nu_\tau)$ of

$$A_{cp}^{Exp} = (-0.36 \pm 0.23 \pm 0.11)\%. \tag{1}$$

However for $\tau^\pm \to K_s^0\pi^\pm\nu_\tau \to [\pi\pi]_K^0\pi^\pm\nu_\tau$, Babar [4] has predicted the SM integrated decay-rate asymmetry to be

$$A_{cp}^{SM} = (0.33 \pm 0.01)\%. \tag{2}$$

In reference [5], comparing the rate asymmetries for decays to neutral kaons of the taus with that of D mesons, they have pointed out that since $\tau^+(\tau^-)$ decays initially to a $K^0(\bar{K^0})$ whereas $D^+(D^-)$ decays initially to $\bar{K^0}(K^0)$, the time-integrated decay-rate CP asymmetry (arising from oscillations of the neutral kaons) of τ decays must have a sign opposite to that of D decays. The observation of a CP asymmetry in τ decays to K_s having the same sign as that in D decays, and moreover of the same magnitude but opposite in sign to the SM expectation, implies that this asymmetry cannot be accounted for by the CP violation in $K^0\bar{K^0}$ mixing. Naively, one may expect that the simplest way to account for the observed anomaly would be to introduce a direct CP violation via a new CP violating charged scalar exchange. However, it turns out that the charged scalar type of exchange may contribute in the angular distributions, but its mixing with SM term in the integrated decay rate goes to zero. Now the next candidate of NP would be a new CP violating charged vector exchange, but CP violation from vector type NP will be observable only if both vector current and axial vector currents contribute to the same final states [6, 7]. Since in two pseudo scalar meson final states only vector current can contribute due to parity conservation of strong interaction, vector type of NP can contribute in general to CP violation in three or more pseudo scalar meson final states but not in two pseudo scalar meson final states such as $K_s\pi$. Now the only possibility left is tensor type of NP.

2. EFFECTIVE HAMILTONIAN AND DECAY RATES.

With the assumption that all neutrinos are left handed, we propose the most general effective Hamiltonian containing all possible four fermion interaction operators that can contribute to $\tau \to K_s\pi\nu_\tau$ as given by:

$$H_{eff} = \frac{4G_F}{\sqrt{2}} V_{us}\Big[(\delta_{l3} + C^{\tau}_{V_1})\mathcal{O}^{\tau}_{V_1} + C^{\tau}_{V_2}\mathcal{O}^{l}_{V_2} + C^{\tau}_{S_1}\mathcal{O}^{\tau}_{S_1} + C^{\tau}_{S_2}\mathcal{O}^{\tau}_{S_2} + C^{\tau}_{T}\mathcal{O}^{\tau}_{T}\Big] + h.c \quad (1)$$

with the operators given by

$$\mathcal{O}^{\tau}_{V_1} = (\bar{s_L}\gamma^{\mu}u_L)(\bar{\nu_L}\gamma_{\mu}\tau_L) \quad (2)$$

$$\mathcal{O}^{\tau}_{V_2} = (\bar{s_R}\gamma^{\mu}u_R)(\bar{\nu_L}\gamma_{\mu}\tau_L) \quad (3)$$

$$\mathcal{O}^{\tau}_{S_1} = (\bar{s_R}u_L)(\bar{\nu_L}\tau_R) \quad (4)$$

$$\mathcal{O}^{\tau}_{S_2} = (\bar{s_L}u_R)(\bar{\nu_L}\tau_R) \quad (5)$$

$$\mathcal{O}^{\tau}_{T} = (\bar{s_L}\sigma^{\mu\nu}u_R)(\bar{\nu_L}\sigma_{\mu\nu}\tau_R) \quad (6)$$

Since we are concerned with CP violation in $\tau \to K_s\pi\nu_\tau$, we can set the $C^{\tau}_{V_1}$ and $C^{\tau}_{V_2}$ equal to zero for simplicity as these coefficients will not contribute in CP violation in two meson final states as argued earlier. And as we mentioned earlier and argued in a previous paper of ours [8] that in the integrated decay rate asymmetry the contribution from the charged scalars goes to zero, so the only terms left is the SM term and the tensor term.

2.1. Decay rate of $\tau \to K_s\pi\nu_\tau$ in SM.

In the SM the $\tau \to K_s\pi\nu_\tau$ decay rate can be expressed as:

$$d\Gamma_{SM}(\tau \to K\pi\nu) = \frac{1}{2m_\tau}\frac{G_F^2}{2}V_{us}^2\mathcal{L}_{\preceq\succeq}\mathcal{H}^{\preceq\succeq}dPS^{(3)} \quad (7)$$

where

$$\mathcal{L}_{\preceq\succeq} = [\bar{\nu}_\tau\gamma_\mu(1-\gamma_5)\tau]\,[\bar{\nu}_\tau\gamma_\nu(1-\gamma_5)\tau]^{\dagger} \quad (8)$$

and

$$\mathcal{H}^{\preceq\succeq} = \mathcal{J}^{\preceq}(\mathcal{J}^{\succeq})^{\dagger} \quad (9)$$

where

$$\mathcal{J}^{\preceq} = \langle K(q_1)\pi(q_2)|V^{\mu}(0)|0\rangle. \quad (10)$$

The hadronic current can be parametrized in terms of the vector and scalar form factors as:

$$\mathcal{J}^{\preceq} = F_V^{K\pi}(Q^2)(g^{\mu\nu} - \frac{Q^{\mu}Q\nu}{Q^2})(q_1-q_2)_\nu + \frac{(m_K^2 - m_\pi^2)}{s}F_S^{K\pi}Q^{\nu} \quad (11)$$

where $Q^{\mu} = (q_1+q_2)^{\mu}$ and in the hadronic rest frame the decay rate can be expressed as:

$$\frac{d\Gamma_{SM}(K\pi)}{ds} = \frac{G_F^2V_{us}^2m_\tau^3}{3\times 64\pi^3}\frac{1}{s^{\frac{3}{2}}}\left(1-\frac{s}{m_\tau^2}\right)^2\left(1+\frac{2s}{m_\tau^2}\right)\times P(s) \left\{P(s)^2\,|F_V|^2 + \frac{3(m_k^2-m_\pi^2)^2}{4s(1+\frac{2s}{m_\tau^2})}|F_S|^2\right\} \quad (12)$$

where

$$P(s) = |\vec{q_1}| = \frac{1}{2\sqrt{s}}\sqrt{[s-(m_k+m_\pi)^2]\,[s-(m_k-m_\pi)^2]} \quad (13)$$

is the momentum of the K in the $K\pi$ rest frame and s is the $K\pi$ invariant mass squared i.e $s = Q^2$. The vector form factor can be parameterized by $K^*(892)$,$K^*(1410)$ and $K^*(1680)$ meson amplitudes given as [9]:

$$F_V = \frac{1}{1+\beta+\chi}\Big[BW_{K^*(892)}(s) + \beta BW_{K^*(1410)}(s) + \chi BW_{K^*(1680)}(s) \quad (14)$$

where β and χ are the complex coefficients for the fractions of $K^*(1410)$ and $K^*(1680)$ resonances respectively and $BW_R(s)$ is a relativistic Breit-Wigner function for R = $K^*(892)$,$K^*(1410)$ and $K^*(1680)$ given as:

$$BW_R(s) = \frac{M_R^2}{s - M_R^2 + i\sqrt{s}\Gamma_R(s)} \quad (15)$$

and

$$\Gamma_R(s) = \Gamma_{0R}\frac{M_R^2}{s}\left(\frac{P(s)}{P(M_R^2)}\right)^{(2l+1)} \quad (16)$$

Here $\Gamma_R(s)$ is the s dependent total width of the resonance and $\Gamma_{0R}(s)$ is the resonance width at its peak and $l = 1$ for the vector states and $l = 0$ for the s-wave part. Similarly the scalar form factor F_S has $K_0^*(800)$ and $K_0^*(1430)$ contributions and is given as:

$$F_S = \kappa\frac{s}{M^2_{K_0^*(800)}}BW_{K_0^*(800)}(s) + \gamma\frac{s}{M^2_{K_0^*(1430)}}BW_{K_0^*(1430)}(s) \quad (17)$$

where κ and γ are the real constants that describe the fractional contributions from $K_0^*(800)$ and $K_0^*(1430)$ respectively. As reported by Belle [9], $K^*_{(892)}$ alone is not enough to describe the $K_s\pi$ mass spectrum. It is best explained for $K^*(892) + K^*(1410) + K^*(800)$ and $K^*(892) + K^*(1430) + K^*(800)$. We will use $K^*(892) + K^*(1410) + K^*(800)$ in this analysis which best fits the Belle mass spectrum.

2.2. Tensorial term.

We now include the contribution from the tensorial operator as it has been already pointed out earlier that scalar and the vectorial operators would not contribute to the integrated decay rate asymmetry and CPV. The key requirement in the relevant context of explaining the observed CPV in integrated $\tau \to K_s\pi\nu_\tau$ decay rate by the tensorial operator is that its coefficient C_T^l from Eqs (8) should be complex so that interference of the SM with this tensor amplitude gives the required CP phase. We have from Eqs (3) the effective Hamiltonian given as

$$\mathcal{H}^T_{eff} = \frac{4G_F}{\sqrt{2}}V_{us}C_T^{\tau}(\bar{s_L}\sigma^{\mu\nu}u_R)(\bar{\nu_L}\sigma_{\mu\nu}\tau_R) \quad (18)$$

where $\sigma^{\mu\nu} = \frac{i}{2}(\gamma^{\mu}\gamma^{\nu} - \gamma^{\nu}\gamma^{\mu})$ and the hadronic current can be expressed as

$$\langle K(q_1)\pi(q_2)|\bar{s}\sigma^{\mu\nu}u|0\rangle = i\frac{2F_T}{m_K+m_\pi}(q_1^{\mu}q_2^{\nu} - q_2^{\mu}q_1^{\nu}). \quad (19)$$

where F_T is the tensorial form factor and only tensor term can contribute due to parity conservation of strong interaction and pseudo-tensor term will not contribute. In a previous collaboration involving the author[8], we have argued that tensor type of NP may be able to explain the observed sign anomaly, however in that work we have assumed that the tensor form factors are constants, but it turns out that is not the case in general and so in this work we have been able to express the tensor form factors in terms of scalar and vector form factors using Dirac equations of motion.

We have from the equations of the motion:

$$\partial_\nu(\bar{u}_s\sigma^{\mu\nu}v_{\bar{u}}) = (m_s+m_u)\bar{u}_s\gamma^\mu v_{\bar{u}} + (i\partial_\mu\bar{u}_s)v_{\bar{u}} - \bar{u}_s(i\partial_\mu v_{\bar{u}}) \quad (20)$$

which gives

$$\begin{aligned} iQ_\nu\langle K(q_1)\pi(q_2)|\bar{u}_s\sigma^{\mu\nu}v_{\bar{u}}|0\rangle = \\ -\Big[-(m_s+m_u)\langle K(q_1)\pi(q_2)|\bar{u}_s\gamma^\mu v_{\bar{u}}|0\rangle \\ +\langle K(q_1)\pi(q_2)|\bar{u}_s v_{\bar{u}}|0\rangle M(q_1-q_2)^\mu\Big] \end{aligned} \quad (21)$$

Where we define $\langle K(q_1)\pi(q_2)|\bar{s}u|0\rangle = F_0$ with M an adjustable parameter and now contracting Eqs (13) from section 2.1 with Q_μ we get $F_0 = +\frac{(m_K^2-m_\pi^2)}{(m_s-m_u)}F_S$ where $Q_\nu = (q_1+q_2)_\nu$. Our justification in going from Eqs (20) to Eqs(21) is that since strong force is mass independent, the corrections to replacing the quark four momentum with respective meson four momentum would be same to both s and u quarks and so it would be a common factor (M) and all other factors absorbed into the form factors. Now using Eqs (13,21) and the F_0 given above, after few algebraic manipulations we can express the tensor form factor F_T in terms of scalar form factor F_S and vector form factor F_V by comparing the coefficients of Q^μ and $(q_1-q_2)^\mu$ from LHS and RHS of Eqs(23), details can be found in the appendix, which gives

$$F_T^a = \frac{(m_s+m_u)(m_K+m_\pi)}{s}[-F_V+F_S] \quad (22)$$

and

$$F_T^b = -\frac{(m_s+m_u)(m_K+m_\pi)}{s}[F_V - \frac{(m_K^2-m_\pi^2)}{(m_s^2-m_u^2)}MF_S] \quad (23)$$

We fix M such that $F_T^b = F_T^a$, from the forms of F_T^a and F_T^b, if we require $M = \frac{(m_s^2-m_u^2)}{(m_K^2-m_\pi^2)}$, then clearly $F_T^b = F_T^a$. This value of M seems to be a reasonable measure of Quark-Hadron duality violation in these kind of reactions, where in the Quark-Hadron duality limit, M $\to$ 1.[1] See Figure 1 for the plot of $|F_T^a|$ as a function of hadronic invariant mass squared.

[1] The reason why we neglected a correction factor, similar to M, when replacing total quark momentum (q_1+q_2) with total hadron momentum (Q) in the LHS of Eqs (21) is because it goes through K^* resonances, a QCD bound state, where most of the energy momentum of the resonance is expected to be carried by the quarks (as only soft gloun exchange between u and s quarks are expected to dominate due to larger $\alpha_s(Q^2)$ at low Q^2).

2.3. *Including the contribution from the tensor term to the $\tau\to K_s\pi\nu_\tau$ decay rate.*

When tensorial term is included, the total decay rate is given by

$$d\Gamma = (\frac{d\Gamma_{SM}}{ds} + \frac{d\Gamma_{MIX}}{ds} + \frac{d\Gamma_T}{ds})ds \quad (24)$$

where the $\frac{d\Gamma_{SM}}{ds}$ is given in the Eqs.(14) and the full angular dependence of the other two terms can be expressed as:

$$\begin{aligned} \frac{d\Gamma_{MIX}}{ds\frac{d\cos\beta}{2}\frac{d\alpha}{2\pi}} &= -\frac{G_F^2V_{us}^2m_\tau^2}{\pi^3(m_k+m_\pi)2s^{\frac{1}{2}}}(1-\frac{s}{m_\tau^2})^2P^2 \\ &\{-P\times Re(F_V^\dagger F_TC_T) + Re(F_S^\dagger F_TC_T) \\ &\times[\frac{m_k^2-m_\pi^2}{2\sqrt{s}}]\times(\sin\beta\cos\alpha\sin\psi+\cos\beta\cos\psi)\} \end{aligned} \quad (25)$$

and

$$\begin{aligned} \frac{d\Gamma_T}{ds\frac{d\cos\beta}{2}\frac{d\alpha}{2\pi}} &= \frac{G_F^2V_{us}^2m_\tau^3|F_T|^2}{(m_k+m_\pi)^2\pi^3 2s^{\frac{1}{2}}}(1-\frac{s}{m_\tau^2})^2P^2 \\ &\Bigg\{\frac{P}{2}+\frac{3}{2}(s-m_k^2-m_\pi^2)\frac{(m_k^2-m_\pi^2)}{s^{3/2}} \\ &\times(\sin\beta\cos\alpha\sin\psi+\cos\beta\cos\psi) - (1-\frac{s}{m_\tau^2})\frac{P}{2} \\ &\times(\sin\beta\cos\alpha\sin\psi+\cos\beta\cos\psi)^2\Bigg\} \end{aligned} \quad (26)$$

Where the P is same as in Eqs (15)and the angles α, β are same as defined in Figure 1 of reference [10] and ψ is defined as the angle between direction of flight of the lab frame and the direction of flight of τ as seen from the hadronic rest frame. We now integrate over the $\cos\beta$ from -1 to +1 and α from 0 to 2π, and require that $Re(C_T^\tau) << Im(C_T^\tau)$ to avoid too large NP contribution to $Br(\tau\to K_s\pi\nu_\tau)$ which has been measured with much more accurately then $A_{cp}(\tau\to K_s\pi\nu_\tau)$, so then we can approximately take $Re(C_T^\tau)\approx 0$ and we are left with only one parameter $Im(C_T^\tau)$ to fit. We can now use the $A_{cp}(\tau\to K_s\pi\nu_\tau)$ and $Br(\tau\to K_s\pi\nu_\tau)$ as data points to fit the $Im(C_T^\tau)$ parameter. In a previous collaboration involving the author [8], we have shown in the Eqs (44) of that reference that the CPV coming from the $K-\bar{K}$ mixing and the direct CPV in $A_{cp}(\tau\to K_s\pi\nu_\tau)$ can be separated as

$$A_{cp}(\tau\to K_s\pi\nu_\tau) = \frac{A_{cp}^K + A_{cp}^\tau}{1+A_{cp}^K A_{cp}^\tau} \quad (27)$$

and also we have

$$Br(\tau\to K_s\pi\nu_\tau) = \frac{(\Gamma^{\tau^+}+\Gamma^{\tau^-})}{2}\tau_\tau \quad (28)$$

where A_{cp}^K is the CPV coming from the $K-\bar{K}$ mixing and A_{cp}^τ is the direct CP violation coming from NP particle mediated CPV at lepton and/or quark vertices and τ_τ is the τ lifetime.

Since both A^K_{cp} and A^τ_{cp} are expected to be small, we can savely ignore terms involving the product of the two. And also since $Re(C^\tau_T) \approx 0$ and the sign of the complex part is opposite in Γ^{τ^+} relative to the Γ^{τ^-}, the branching fraction receives no contribution from the SM and Tensorial mixing part.

3. RESULTS

With taking the approximation of $A^k_{pc}A^\tau_{cp} \approx 0$ we can express Eqs (29,30) as:

$$A_{cp}(\tau \to K_s\pi\nu_\tau) = A^K_{cp} + A^\tau_{cp} \quad (1)$$

and

$$Br(\tau \to K_s\pi\nu_\tau) = \frac{(\Gamma^{\tau^+} + \Gamma^{\tau^-})}{2}\tau_\tau = (\Gamma_{SM} + \Gamma_T)\tau_\tau \quad (2)$$

where A^k_{cp} is the known SM CPV from the $K - \bar{K}^0$ mixing, Γ_{SM} is the SM decay rate corresponding to fitted form factors from Belle[9], Γ_T is the tensorial decay rate we gets from integration of Eqs (28) and τ_τ is the life time of τ lepton. From Eqs (31,32) and using F^a_T from Eqs (24) the best fitted value of the complex parameter $Im(C^\tau_T)$ to the two data points gives at $\chi^2 \approx 4.5$:

$$Im(C^\tau_T) = -0.071, \quad (3)$$

which gives

$$Br(\tau \to K_0\pi\nu_\tau)^{(Th)} = 2Br(\tau \to K_s\pi\nu_\tau)^{(Th)} = (0.756 \pm 0.085)\% \quad (4)$$

and

$$A^{\tau(Th)}_{cp} = (-0.703 \pm 0.54)\% \quad (5)$$

whereas the experimental values of these observables are given as

$$A^{(Exp-SM)}_{cp} = A^{\tau(Exp)}_{cp} - (A^k_{cp})^{SM} = (-0.69 \pm 0.26)\%, \quad (6)$$

and

$$Br(\tau \to K_0\pi\nu_\tau)^{(Exp)} = 2Br(\tau \to K_s\pi\nu_\tau)^{(Exp)} = (0.84 \pm 0.04)\%. \quad (7)$$

Comparing Eqs (35,36) and Eqs (34,37) we see that the theoretical predicted values fit with the experimental values within 1σ. In Figure 1 we have shown the plots of $|F^a_T|$ as a function of $S(K\pi)$ where $S(K\pi)$ is the hadronic invariant mass squared.

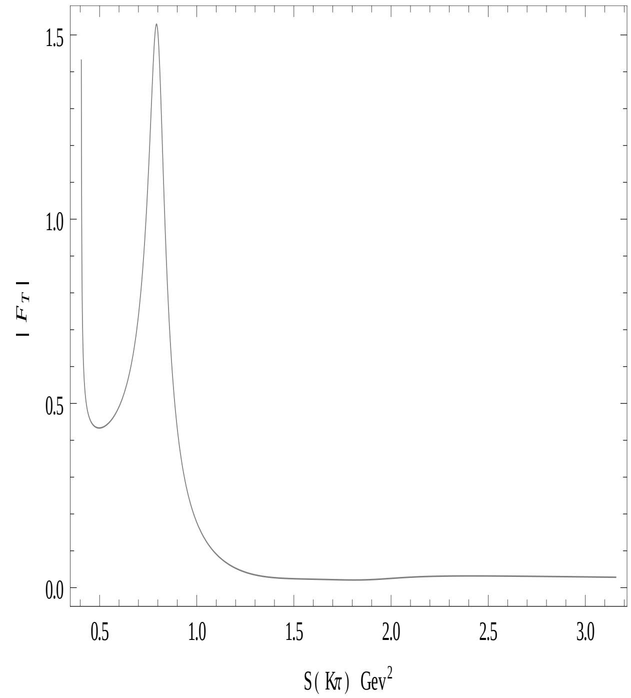

FIGURE 1: This figure shows the plots of $|F^a_T|$ as a function of $S(K\pi)$ where $S(K\pi)$ is the hadronic invariant mass squared.

4. FUTURE PROSPECTS

In what follows, we will assume the direction of the τ has been measured and so we can set $\psi \to 0$ in Eqs (25) and Eqs (26). Then, since all the terms which depend on α goes to zero, we can integrate out in α also. Now then the angular dependence of the mixing term is given as:

$$\frac{d\Gamma_{MIX}}{ds\frac{d\cos\beta}{2}\frac{d\alpha}{2\pi}} = -\frac{G_F^2 V_{us}^2 m_\tau^2}{\pi^3(m_k + m_\pi)2s^{\frac{1}{2}}}(1 - \frac{s}{m_\tau^2})^2 P^2 \{-P \times Re(F_V^\dagger F_T C_T) + Re(F_S^\dagger F_T C_T) \times [\frac{m_k^2 - m_\pi^2}{2\sqrt{s}}] \times (\cos\beta)\}. \quad (1)$$

It is clear from Eqs (25) and Eqs (1) that the mixing of the vector form factor(F_V) with the tensor form factor(F_T) has no dependence on any of the angles, all angular dependence cancels, and so CP violation coming from the interference of the vector part of SM current and the New Tensor current will show up in angular integrated decay rate as we found in the previous section. And also from Eqs (25) and Eqs (1) we notice that the CP violation coming from the interference of the scalar part of the SM current and the New Tensor current will not contribute to angular integrated CP violation and decay rate, but it can contribute in the angular distribution spectrum. The simplest way to extract the angular dependence, especially in the case of linear dependence ones like in Eqs (1), is by weighted integrals. We will use $\cos\beta$ as weight multiplying the differential rate and then integrate out in $d\cos\beta/2$ given as:

$$\frac{d}{ds}\left[\langle\frac{\Gamma_{MIX}\times\cos\beta}{d\cos\beta/2}\rangle - \langle\frac{\bar{\Gamma}_{MIX}\times\cos\beta}{d\cos\beta/2}\rangle\right] = -\frac{G_F^2|V_{us}|^2 m_\tau^2(m_k - m_\pi)}{6\pi^3} Im[C_T](1 - \frac{s}{m_\tau^2})^2\frac{P^2}{s} Im[F_s^\dagger F_T], \quad (2)$$

then by normalizing Eqs (2) by $\frac{1}{2}(\frac{d\Gamma}{ds} + \frac{d\bar{\Gamma}}{ds})$ we have

$$\langle A\cos\beta\rangle_{CP}(S) = \frac{\frac{d}{ds}[\langle \frac{\Gamma_{MIX}\times\cos\beta}{d\cos\beta/2}\rangle - \langle \frac{\bar{\Gamma}_{MIX}\times\cos\beta}{d\cos\beta/2}\rangle]}{\frac{1}{2}(\frac{d\Gamma}{ds} + \frac{d\bar{\Gamma}}{ds})}. \quad (3)$$

In Figure 2 we have shown the plot of $\langle A_{CP}\cos\beta\rangle$ as a function of $S(K_s\pi)$ using $Im(C_T)$ from Eqs (3)

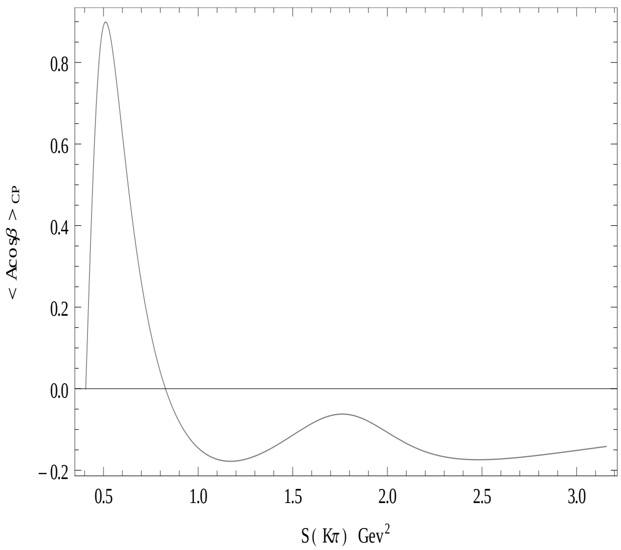

FIGURE 2: This figure shows the plots of $\langle A\cos\beta\rangle_{CP}(S)$ as a function of $S(K\pi)$ where $S(K\pi)$ is the hadronic invariant mass squared and $Im(C_T)$ is taken from Eqs (3).

Now by integrating in the $S(K\pi)$ in the range $((m_k+m_\pi)^2, m_\tau^2)$ we have:

$$\int_{(m_k+m_\pi)^2}^{m_\tau^2} (\langle A\cos\beta\rangle_{CP}(S))dS = -0.127. \quad (4)$$

If the observed anomaly in the A_{CP} is due to a new tensor interaction, then from the above equation we can expect quite large CP violation to be observed in the angular weighted CP asymmetry in the $\tau \to K_s\pi\nu_\tau$ decay mode in future experimental searches. As we can see from Figure 2, CP violation from new tensor interaction will show up most dramatically in the low hadronic invariant mass square($S(K_S\pi)$) region.

5. CONCLUSIONS

Babar collaboration has reported an intriguing opposite sign in the integrated decay rate asymmetry $A_{cp}(\tau \to K_s\pi\nu_\tau)$ than that of SM prediction from the known K^0 - $\bar{K}^0$ mixing. Babar's result deviates from the SM prediction by about 2.7σ. In this work we have presented an improved analysis of our previous work on the contributions coming from tensorial current to this observable. Assuming the real part of the NP coupling is negligible compare to its imaginary part, the best fitted value of the parameter $Im(C_T^\tau)$ to the two data points $A_{cp}(\tau \to K_s\pi\nu_\tau)$ and $B_r(\tau \to K_0\pi\nu_\tau)$ is given by $Im(C_T^\tau) = -0.071$ which gives $A_{cp}^{Th} = (-0.703 \pm 0.51) \times 10^{-2}$ compare to the experimental minus SM value of $A_{cp}^{(Exp-SM)} = (A_{cp}^{Exp} - A_{cp}^{SM}) = (-0.69 \pm 0.26) \times 10^{-2}$. And similarly we have $Br(\tau \to K_0\pi\nu_\tau)^{(Th)} = (0.756 \pm 0.084) \times 10^{-2}$ comapre to the $Br(\tau \to K_0\pi\nu_\tau)^{(Exp)} = (0.84 \pm 0.04) \times 10^{-2}$. As we can see the theoretical predictions fit with the experimental results within 1σ for both observables. If the observed anomaly in the A_{CP} is due to a new tensor interaction, then, according to Eqs (4), we can expect quite large CP violation to be observed in the angular weighted CP asymmetry in the $\tau \to K_s\pi\nu_\tau$ decay mode in future experimental searches.

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APPENDICES

F. EXPRESSING F_T IN TERMS OF F_V AND F_S USING EQUATIONS OF MOTION.

We have from the equations of the motion:

$$\partial_\nu(\bar{u}_s\sigma^{\mu\nu}v_{\bar{u}}) = (m_s+m_u)\bar{u}_s\gamma^\mu v_{\bar{u}} + (i\partial_\mu\bar{u}_s)v_{\bar{u}} - \bar{u}_s(i\partial_\mu v_{\bar{u}}) \quad (1)$$

which gives

$$\begin{aligned} &iQ_\nu\langle K(q_1)\pi(q_2)|\bar{u}_s\sigma^{\mu\nu}v_{\bar{u}}|0\rangle = \\ &-[-(m_s+m_u)\langle K(q_1)\pi(q_2)|\bar{u}_s\gamma^\mu v_{\bar{u}}|0\rangle \\ &+\langle K(q_1)\pi(q_2)|\bar{u}_s v_{\bar{u}}|0\rangle M(q_1-q_2)^\mu] \end{aligned} \quad (2)$$

Our justification in going from Eqs (1) to Eqs (2) is that since strong force is mass independent, the corrections in replacing the quark four momentum with respective meson four momentum would be same to both s and u quarks and so it would be a common factor (M) and all other factors absorbed into the form factors. So then we have

$$\begin{aligned} &-Q_\nu\frac{2F_T}{m_K+m_\pi}(q_1^\mu q_2^\nu - q_2^\mu q_1^\nu) = \\ &-[-(m_s+m_u)\langle K(q_1)\pi(q_2)|\bar{s}\gamma^\mu u|0\rangle + MF_0(q_1-q_2)^\mu] \end{aligned} \quad (3)$$

with $\langle K(q_1)\pi(q_2)|\bar{u}_s v_{\bar{u}}|0\rangle = F_0$ where M is an adjustable parameter and $Q_\nu = (q_1+q_2)_\nu$.[2] Using $\langle K(q_1)\pi(q_2)|\bar{u}_s\gamma^\mu v_{\bar{u}}|0\rangle = F_V^{K\pi}(Q^2)(g^{\mu\nu} - \frac{Q^\mu Q_\nu}{Q^2})(q_1-q_2)_\nu + \frac{(m_K^2-m_\pi^2)}{s}F_S^{K\pi}Q^{\nu 3}$ and con-

[2]For $\langle K(q_1)\pi(q_2)|\bar{u}_u v_s|0\rangle$ we have $F_0 = -\frac{(m_K^2-m_\pi^2)}{(m_s-m_u)}F_S$ but that minus sign is compensated by a negative sign in second term in RHS of Eqs (20)(charge conjugated one).

[3]This is intuitively understood as $\langle K(q_1)\pi(q_2)||K^*(892);K^*(1430)_0\rangle\langle K^*(892); K^*(1430)_0|a_s^\dagger b_{\bar{u}}^\dagger\bar{u}_s\gamma^\mu v_{\bar{u}}|0\rangle$, where the negative sign from the antiparticle wave function under parity transformation is canceled by the negative sign under parity transformation for the antiparticle creation operator, hence the current as a whole, which behaves like a vector under parity.

tracting it with Q_ν gives $F_0 = +\frac{(m_K^2-m_\pi^2)}{(m_s-m_u)}F_S$, and using the identity $Q\cdot q_2 q_1^\mu - Q\cdot q_1 q_2^\mu = \frac{(Q\cdot q_1+Q\cdot q_2)(q_1-q_2)^\mu-(Q\cdot q_1-Q\cdot q_2)Q^\mu}{2}$ we have

$$\begin{aligned}
\frac{F_T}{m_K+m_\pi}&[(Q\cdot q_1+Q\cdot q_2)(q_1-q_2)^\mu-(Q\cdot q_1-Q\cdot q_2)Q^\mu] = \\
&[-(m_s+m_u)F_V+\frac{(m_K^2-m_\pi^2)}{(m_s-m_u)}MF_S](q_1-q_2)^\mu \\
&-\Big[-(m_s+m_u)(m_K^2-m_\pi^2)/Q^2F_V \\
&+(m_s+m_u)(m_K^2-m_\pi^2)/Q^2F_S\Big]\,Q^\mu \qquad (4)
\end{aligned}$$

where $Q\cdot q_1 = \frac{Q^2+m_K^2-m_\pi^2}{2}$ and $Q\cdot q_2 = \frac{Q^2+m_\pi^2-m_K^2}{2}$; then comparing the coeffecients of $(q_1+q_2)^\mu$ and $(q_1-q_2)^\mu$ from the LHS and RHS of Eqs(41) we have,

$$F_T^a = \frac{(m_s+m_u)(m_K+m_\pi)}{s}[-F_V+F_S] \qquad (5)$$

and

$$F_T^b = -\frac{(m_s+m_u)(m_K+m_\pi)}{s}[F_V-\frac{(m_K^2-m_\pi^2)}{(m_s^2-m_u^2)}MF_S] \qquad (6)$$

Now to fix M we contract Eqs (4) by Q_μ, then the LHS gives zero and the RHS gives $M=\frac{(m_s^2-m_u^2)}{(m_K^2-m_\pi^2)}$, which when put in F_T^b, shows that $F_T^a = F_T^b$. Contracting Eqs (4) with $(q_2-q_1)_\mu$ will give,using $M=\frac{(m_s^2-m_u^2)}{(m_K^2-m_\pi^2)}$, F_T same as F_T^a in Eqs (42).

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