# CP violation in hadronic $\tau$ decays


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- Another possibility is to use a triple product in the angular distribution which does not need a strong phase

# CP violation

In the SM, $\tau$ decays through a virtual $W$ into $f + \nu_\tau$.

$$\mathcal{H}_{\rm eff}^{\rm SM} = \frac{G_F}{\sqrt{2}} \sin\theta_c\, \bar{\nu}_\tau \gamma_\mu (1-\gamma_5)\tau \quad \bar{s}\gamma^\mu(1-\gamma_5)u + \text{h.c.},$$

the hadronic matrix element $J^\mu \equiv \langle f|\bar{s}\gamma^\mu(1-\gamma^5)u|0\rangle$ has several form factors for different final states.

We need a different contribution to the effective Hamiltonian with different **weak phases**.

Moreover a different **strong phase** requires two different hadronic intermediate states, different hadronic operators.

# Literature

## Phenomenological analysis of CP violation in $\tau$ decays

1. G. Bonvicini *et al.* [CLEO Collaboration], "Search for CP Violation in $\tau- > K\pi\nu_\tau$ Decays," Phys. Rev. Lett. **88**, 111803 (2002) [arXiv:hep-ex/0111095].

2. A. Datta, K. Kiers, D. London, P. J. O'Donnell and A. Szynkman, "CP violation in hadronic tau decays," Phys. Rev. D **75** (2007) 074007 [Erratum-ibid. D **76** (2007) 079902] [arXiv:hep-ph/0610162].

3. K. Kiers, K. Little, A. Datta, D. London, M. Nagashima and A. Szynkman, "CP violation in $\tau- > K\pi\pi\nu_\tau$," Phys. Rev. D **78** (2008) 113008 [arXiv:0808.1707 [hep-ph]].

# Literature

4. D. Kimura, K. Y. Lee, T. Morozumi and K. Nakagawa, "CP violation of $\tau- > K\pi(\eta,\eta')\nu$ decays," arXiv:0808.0674 [hep-ph].

5. D. Kimura, K. Nakagawa, T. Morozumi and K. Y. Lee, "Direct CP Violation In Hadronic Tau Decays," Nucl. Phys. Proc. Suppl. **189** (2009) 84.

6. D. Delepine, "CP violation in semi-leptonic tau decays," AIP Conf. Proc. **917** (2007) 90 [arXiv:hep-ph/0702107].

## K pi pi nu

Assume an additional charged Higgs contribution.

$$\mathcal{H}_{\rm eff}^{\rm NP} = \frac{G_F}{\sqrt{2}} \sin\theta_c \left[\eta_S \bar{\nu}_\tau (1+\gamma_5)\tau\, \bar{s} u + \eta_P \bar{\nu}_\tau (1+\gamma_5)\tau\, \bar{s}\gamma_5 u\right]$$

NP effects incorporated in the SM scalar form factor:

$$B_4 \quad \to \quad \widetilde{B}_4 = B_4 + \frac{f_H}{m_\tau}\eta_P\,,$$

1. Rate asymmetry

$$A_{CP}^{(0)} = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}} \propto \frac{B_4 f_H \eta_P \sin(\delta_4 - \delta_H)\sin\phi_H}{2\Gamma}$$

but $B_4$ is small...rate asymmetry expected to be small...

# K pi pi nu

## 2. Modified rate asymmetry and triple product asymmetry

$$A_{CP}^{(i)} = \frac{1}{\Gamma + \overline{\Gamma}} \int \left( \frac{d\Gamma_i}{dQ^2\, ds_1\, ds_2} - \frac{d\overline{\Gamma}_i}{dQ^2\, ds_1\, ds_2} \right) dQ^2\, ds_1\, ds_2\,.$$

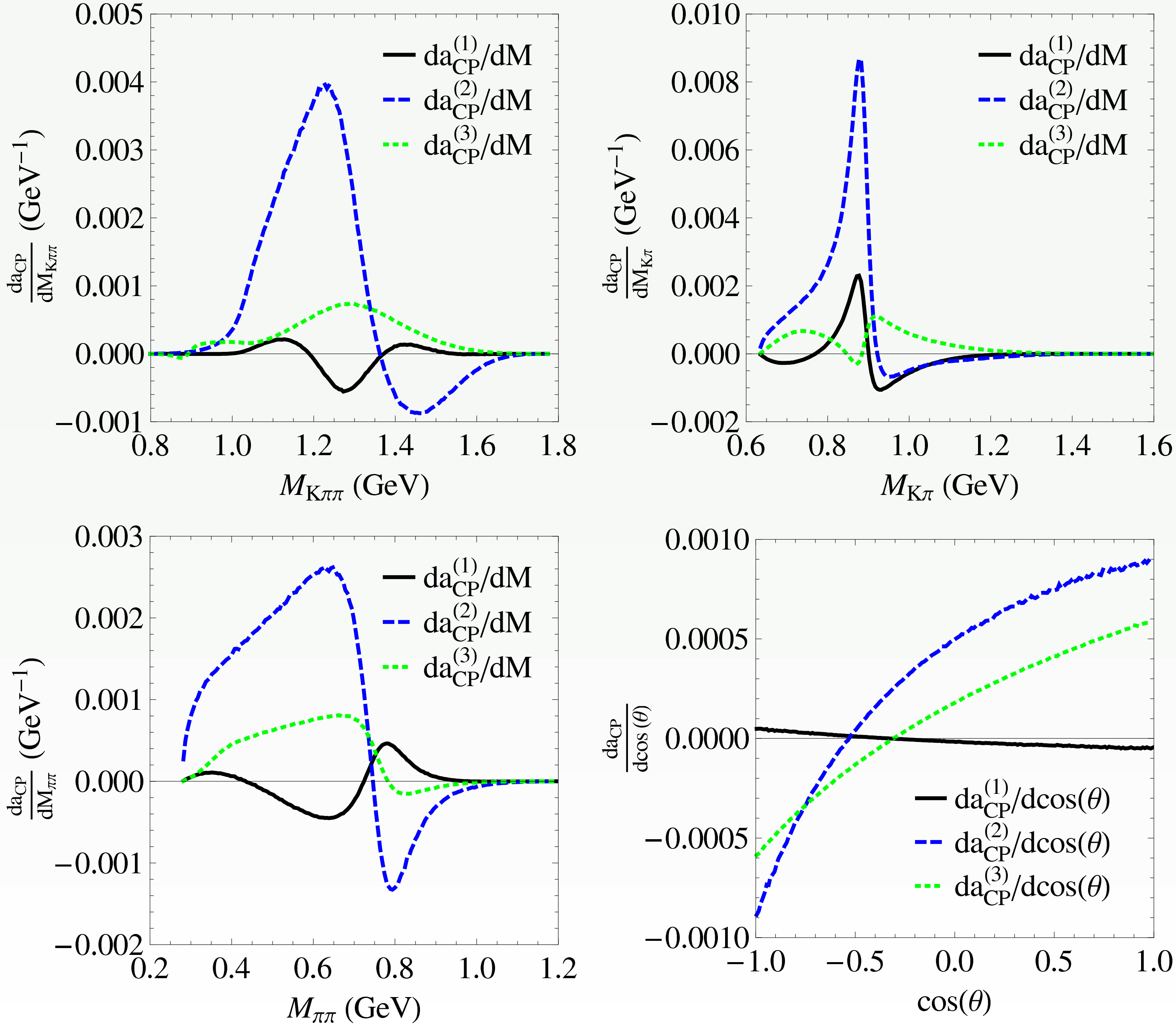
with

$$\frac{d\Gamma_1}{dQ^2\, ds_1\, ds_2} = A(Q^2)\left[\langle \overline{K}_3 \rangle \mathrm{Re}\big(B_1 B_3^*\big) - \langle \overline{K}_2 \rangle \mathrm{Re}\big(B_2 B_4^*\big)\right],$$

$$\frac{d\Gamma_2}{dQ^2\, ds_1\, ds_2} = A(Q^2)\left[\langle \overline{K}_3 \rangle \mathrm{Re}\big(B_2 B_3^*\big) + \langle \overline{K}_2 \rangle \mathrm{Re}\big(B_1 B_4^*\big)\right],$$

$$\frac{d\Gamma_3}{dQ^2\, ds_1\, ds_2} = A(Q^2)\left[\langle \overline{K}_3 \rangle \mathrm{Im}\big(B_1 B_2^*\big) + \langle \overline{K}_2 \rangle \mathrm{Im}\big(B_3 B_4^*\big)\right],$$

# K pi pi nu


$da^{(1)}_{CP}/dM$
$da^{(2)}_{CP}/dM$
$da^{(3)}_{CP}/dM$
$\frac{da_{CP}}{dM_{K\pi\pi}}$ (GeV$^{-1}$)
$M_{K\pi\pi}$ (GeV)
$\frac{da_{CP}}{dM_{K\pi}}$ (GeV$^{-1}$)
$M_{K\pi}$ (GeV)
$\frac{da_{CP}}{dM_{\pi\pi}}$ (GeV$^{-1}$)
$M_{\pi\pi}$ (GeV)
$da^{(1)}_{CP}/d\cos(\theta)$
$da^{(2)}_{CP}/d\cos(\theta)$
$da^{(3)}_{CP}/d\cos(\theta)$
$\frac{da_{CP}}{d\cos(\theta)}$
$\cos(\theta)$

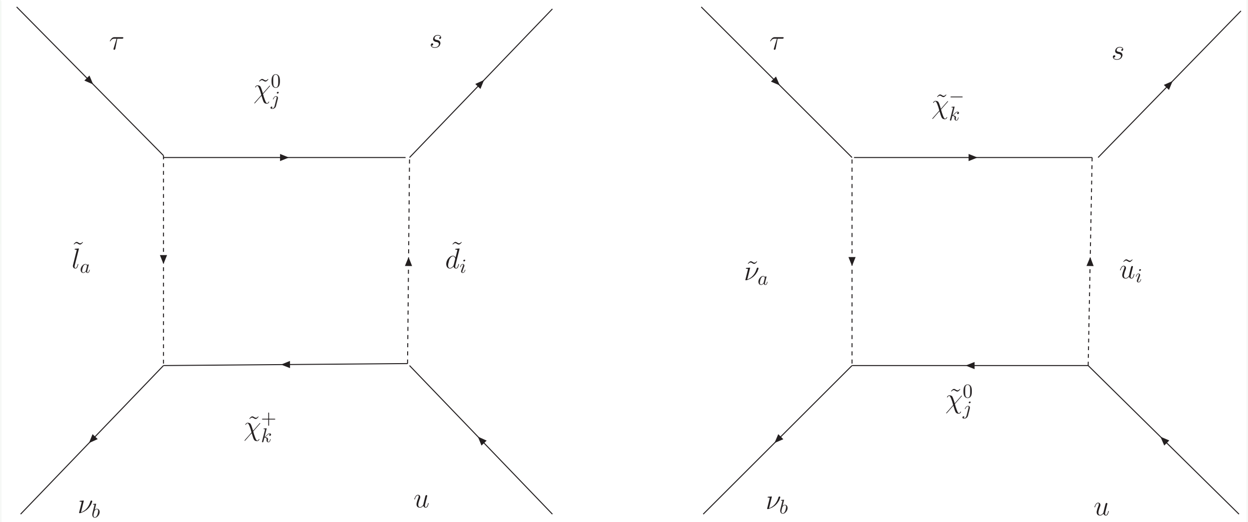
where the $A_{CP}^{(i)}$ are obtained from $a_{CP}^{(i)}$ multiplying it by $f_H \mathrm{Im}(\eta_P)$.

Taking $\eta_P \simeq 1$ and phases $O(1)$, we get $f_H \mathrm{Im}(\eta_P) \simeq 10$.

$\Longrightarrow$ CP asymmetries visible with

"large" non-standard Higgs couplings...

# Tree vs. Loop




Example

Estimate : $C^{SUSY}_{scal}/C^{SM} \sim \dfrac{g^4 y_\tau (\delta^d_{LR})_{32} V^{CKM}_{13}}{16\pi^2 G_F M^2_{SUSY} V^{CKM}_{12}}$

$$\sim 10^{-5} (\delta^d_{LR})_{32} \tan\beta \frac{M_W^2}{M^2_{SUSY}} \leq 10^{-6}$$