CP violation in charm and tau at B-factories

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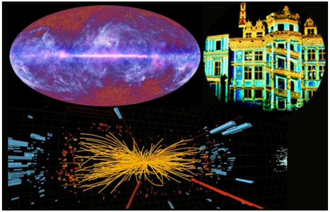
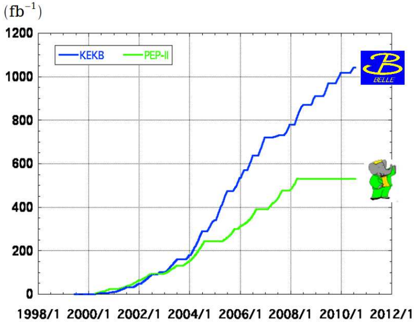


Outline:

1. Introduction
2. CPV in $D^+ \to K_S \pi^+$ at Belle
3. CPV in $\tau^- \to \pi^- K_S (\geq \pi^0) \nu_\tau$ at BABAR
4. CPV in $\tau^\pm \to K_S \pi^\pm \nu_\tau$ at Belle
5. Summary

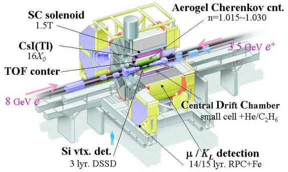
Integrated luminosity of B factories



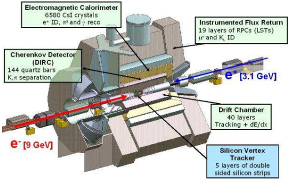
> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Belle Detector



BABAR detector



$$\sigma(b\bar{b}) = 1.1 \text{ nb} \quad N_{b\bar{b}} = 1.7 \times 10^9$$
$$\sigma(c\bar{c}) = 1.3 \text{ nb} \quad N_{c\bar{c}} = 2.0 \times 10^9$$
$$\sigma(\tau\tau) = 0.9 \text{ nb} \quad N_{\tau\tau} = 1.4 \times 10^9$$

B-factories are also charm- and τ-factories !

CP violation in charm

- In the SM CP violation is described by nonzero KM phase δ in CKM matrix
- So far CPV has been observed only in the B and K meson decays
- In charm sector of SM it is expected to be of the order of 0.1% or smaller
- Discovery of the large CP violation in charm would be sign for New Physics
- In general case there are three types of CP violation in D mesons: in decay (direct), in mixing, and in interference between decay with and without mixing. In charged $\mathrm{D}^{\pm}$ the only possible is direct CP violation.
- The CP asymmetry in the $\mathrm{D}^+ \to \mathrm{K_S}\pi^+$ decay:

$$\mathrm{A}_{\mathrm{CP}}^{\mathrm{D}^+\to\mathrm{K_S}\pi^+} \equiv \frac{\Gamma(\mathrm{D}^+ \to \mathrm{K_S}\pi^+) - \Gamma(\mathrm{D}^- \to \mathrm{K_S}\pi^-)}{\Gamma(\mathrm{D}^+ \to \mathrm{K_S}\pi^+) + \Gamma(\mathrm{D}^- \to \mathrm{K_S}\pi^-)} = \mathrm{A}_{\mathrm{CP}}^{\Delta\mathrm{C}} + \mathrm{A}_{\mathrm{CP}}^{\bar{\mathrm{K}}^0}$$

$\mathrm{A}_{\mathrm{CP}}^{\Delta\mathrm{C}} \approx 0$ is determined by the SM CF and DCS amplitudes
$\mathrm{A}_{\mathrm{CP}}^{\bar{\mathrm{K}}^0} = -0.332 \pm 0.006$ is induced by CP violation in $\mathrm{K}^0 - \bar{\mathrm{K}}^0$ mixing

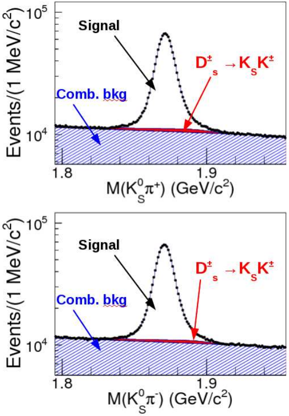
Nonzero $\mathrm{A}_{\mathrm{CP}}^{\Delta\mathrm{C}}$ would indicate the effects of New Physics.

CP violation in $D^+ \to K_S\pi^+$ at Belle

Use the data sample of $\int Ldt = 977\ \mathrm{fb}^{-1}$ collected by Belle

Events reconstruction

- K_S is formed from $\pi^+\pi^-$ with $0.4826 \le M_{\pi^+\pi^-} \le 0.5126\ \mathrm{GeV}/c^2$
- Common vertex fit(χ^2_D) of K_S and π^+ to form D^+ with $1.855 \le M_{K_S\pi^+} \le 1.885\ \mathrm{GeV}/c^2$, production vertex fit($\chi^2_P$) of D^+
- $p^{CMS}_{D^+} > 2.0,\ 2.5,\ 3.0\ \mathrm{GeV}/c^2$ for the data: below $\Upsilon(4S)$, at $\Upsilon(4S)$, $\Upsilon(5S)$ to remove D^+ mesons from B decays and comb. background



$$A_{rec}^{D^+\to K_S\pi^+} = \frac{N_{rec}^{D^+\to K_S\pi^+} - N_{rec}^{D^-\to K_S\pi^-}}{N_{rec}^{D^+\to K_S\pi^+} + N_{rec}^{D^-\to K_S\pi^-}}$$

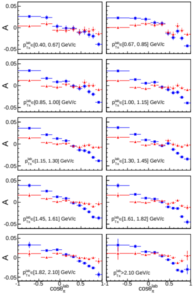
$A_{rec}^{D^+\to K_S\pi^+} = (-0.146 \pm 0.094)\%;\ N_{rec}^{D^+\to K_S\pi^+} + N_{rec}^{D^-\to K_S\pi^-} = (1738 \pm 2) \times 10^3$

$$A_{rec}^{D^+\to K_S\pi^+} = A_{CP}^{D^+\to K_S\pi^+} + A_{FB}^{D^+}(\cos\theta_{D^+}^{CMS}) + A_\epsilon^{\pi^+}(p_{T\pi^+}^{lab}, \cos\theta_{\pi^+}^{lab})$$

- $A_\epsilon^{\pi^+}$ - asymmetry between π^+ and π^- detection efficiencies
- $A_{FB}^{D^+}$ - forward-backward asymmetry (γ^*-Z^0 interference), odd function of $\cos\theta_{D^+}^{CMS}$

$D^+ \to K^-\pi^+\pi^+$ and $D^0 \to K^-\pi^+\pi^0$ samples are used to extract $A_\epsilon^{\pi^+}$

- $A_\epsilon^{\pi^+}$ in 10×10 bins of $(p_{T\pi^+}^{lab}, \cos\theta_{\pi^+}^{lab})$, $< A_\epsilon^{\pi^+} >= (+0.078 \pm 0.040)\%$ (red triangles)
- To apply $A_\epsilon^{\pi^+}$ correction each $D^\pm \to K_S\pi^\pm$ is weighted by $1 \mp A_\epsilon^{\pi^+}$ in 2D PS
- Correction for the asymmetry $A_D \sim 0.1\%$ due to the different interaction of K^0 and $\bar{K}^0$ with detector is applied weighting $D^\pm \to K_S\pi^\pm$ by $1 \mp A_D$ in bins of K_S phase space, finally $A_{rec}^{D^+\to K_S\pi^+_{corr}}$ is obtained



$$A_{CP}^{D^+\to K_S\pi^+} = (A_{rec}^{D^+\to K_S\pi^+_{corr}}(+\cos\theta_{D^+}^{CMS}) + A_{rec}^{D^+\to K_S\pi^+_{corr}}(-\cos\theta_{D^+}^{CMS})/2$$
$$A_{FB}^{D^+} = (A_{rec}^{D^+\to K_S\pi^+_{corr}}(+\cos\theta_{D^+}^{CMS}) - A_{rec}^{D^+\to K_S\pi^+_{corr}}(-\cos\theta_{D^+}^{CMS}))/2$$

B. R. Ko, E. Won, B. Golob, and P. Pakhlov, "Effect of nuclear interactions of neutral kaons on CP asymmetry measurements," Phys. Rev. D 84, 111501(R) (2011).

$K^0 - \bar{K}^0$ mixing CPV asymmetry in $D^+ \to K^0\pi^+$

- Neglecting by DCS $D^+ \to K^0\pi^+$ the SM $K^0 - \bar{K}^0$ mixing asymmetry should be calculated properly taking into account K_S detection efficiency as a function of K_S decay time.
- Correction factor 1.040 ± 0.005 was found to be applied to $A_{CP}^{\bar{K}^0} = -0.332 \pm 0.006$ to take into account the details of the Belle experiment:

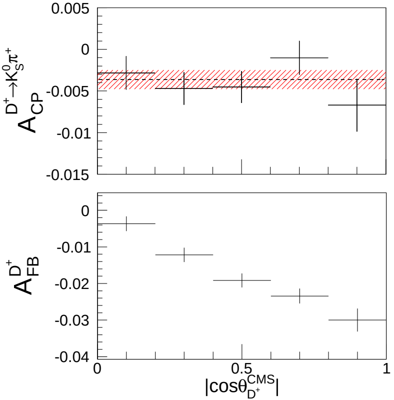
$$A_{CP}^{\bar{K}^0} = (-0.345 \pm 0.008)\%$$

Y. Grossman and Y. Nir, "CP Violation in $\tau \to \nu\pi K_S$ and $D \to \pi K_S$: The Importance of $K_S - K_L$ Interference," JHEP 1204, 002 (2012) [arXiv:1110.3790 [hep-ph]].

B. R. Ko and E. Won, "Evidence for CP Violation in the Decay $D^+ \to K^0_S \pi^+$,"
arXiv:1203.6409 [hep-ex], submitted to PRL

Source	$\sigma_{A_{CP}}$ (%)
$A_{\epsilon}^{\pi^+}$	0.064
Fitting	0.003
$\cos\theta^{CMS}_{D^+}$ binning	0.008
$A_{\mathcal{D}}$	0.016
Total	0.067

Experiment	$A_{CP}^{D^+\to K_S\pi^+}$ (%)
FOCUS	$-1.6\pm1.5\pm0.9$
CLEO	$-1.3\pm0.7\pm0.3$
BABAR	$-0.44\pm0.13\pm0.10$
Belle (3.2σ)	$-0.363\pm0.094\pm0.067$
New world average	-0.41 ± 0.09



This is the first evidence for CPV in charmed meson decays from a single experiment and a single decay mode !

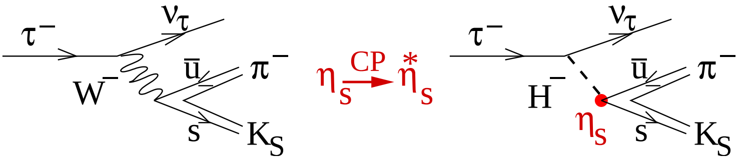
$$A_{CP}^{\Delta C} = A_{CP}^{D^+\to K_S\pi^+} - A_{CP}^{\bar{K}^0} = (-0.018 \pm 0.094 \pm 0.068)\%$$

So far no CPV has been found in the other charmed particle decay modes

Mode	A_{CP} (%)	Exp	Lum (fb^{-1})	Publication
$D^+ \to \phi\pi^+ / D_S^+ \to \phi\pi^+$	$+0.51 \pm 0.28 \pm 0.05$	Belle	955	PRL 108, 071801 (2012)
$D^+ \to \eta\pi^+$	$+1.74 \pm 1.13 \pm 0.19$	Belle	791	PRL 107, 221801 (2011)
$D^+ \to \eta'\pi^+$	$-0.12 \pm 1.12 \pm 0.17$	Belle	791	PRL 107, 221801 (2011)
$D^0 \to K_S\pi^0$	$-0.28 \pm 0.19 \pm 0.10$	Belle	791	PRL 106, 211801 (2011)
$D^0 \to K_S\eta$	$+0.54 \pm 0.51 \pm 0.16$	Belle	791	PRL 106, 211801 (2011)
$D^0 \to K_S\eta'$	$+0.98 \pm 0.67 \pm 0.14$	Belle	791	PRL 106, 211801 (2011)
$D^0 \to \pi^+\pi^-$	$+0.43 \pm 0.52 \pm 0.12$	Belle	540	Phys. Lett. B 670, 190 (2008)
$D^0 \to K^+K^-$	$-0.43 \pm 0.30 \pm 0.11$	Belle	540	Phys. Lett. B 670, 190 (2008)
$D_s^+ \to K_S\pi^+$	$+5.45 \pm 2.50 \pm 0.33$	Belle	673	PRL 104, 181602 (2010)
	$+0.6 \pm 2.0 \pm 0.3$	BABAR	469	preliminary
$D_s^+ \to K_S K^+$	$+0.12 \pm 0.36 \pm 0.22$	Belle	673	PRL 104, 181602 (2010)
	$-0.05 \pm 0.23 \pm 0.25$	BABAR	469	preliminary
$D^+ \to K_S K^+$	$-0.16 \pm 0.58 \pm 0.25$	Belle	673	PRL 104, 181602 (2010)
	$+0.13 \pm 0.36 \pm 0.25$	BABAR	469	preliminary
$D^\pm \to K^+K^-\pi^\pm$	$+0.35 \pm 0.30 \pm 0.15$	BABAR		preliminary

CP violation in τ decays

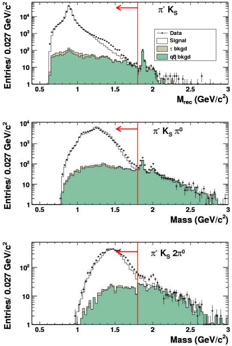
- CPV has not been observed in lepton decays
- It is strongly suppressed in the SM ($A^{CP}_{SM} \lesssim 10^{-12}$) and observation of large CPV in lepton sector would be clean sign of New Physics
- τ lepton provides unique possibility to search for CPV effects, as it is the only lepton decaying to hadrons, so that the associated strong phases allows us to visualize CPV in hadronic τ decays.
- In $\tau^- \to K_S \pi^- \nu_\tau$ there are two possible sources of CPV:
  - SM CPV in $K^0 - \bar{K}^0$ mixing, which appears in the time integrated decay-rate asymmetry
  - Effects of New Physics (MSSM, multi-Higgs-Doublet-Models), which can be detected through the deviation of the time integrated decay-rate asymmetry from the SM value as well as through the difference in $\tau^\pm$ decay angular distributions



CP violation in $\tau^- \to \pi^- K_S (\geq \pi^0) \nu_\tau$ at BABAR

J. P. Lees et al. [BABAR Collaboration], Phys. Rev. D 85 (2012) 031102 [arXiv:1109.1527 [hep-ex]]. Data sample of $\int L dt = 476\ fb^{-1}$ was analyzed

- $0.92 < \text{Thrust} < 0.99$ is calculated using all tracks and photon candidates, event is separated into two hemispheres: signal and tag
- Signal hemisphere: 1 $K_S \to \pi^+\pi^-$, 1 prompt track$^\pm$(not kaon$^\pm$) and $N_{\pi^0} \geq 0$; $M_{rec}(K_S \pi^\pm n\pi^0) < 1.8\ GeV/c^2$
- Tag hemisphere: 1 prompt track$^\mp$ identified as $e^\mp$ or $\mu^\mp$ with $P^{CMS} < 4\ GeV/c$
- To reject background from τ decays with fake K_S and $q\bar{q}$ $y(K_S) > 0.4$, $y(\tau) > 0.2$ likelihood ratio selections were applied



Source	Fractions (%)	
	e tag	μ tag
$\tau^\pm \to \pi^\pm K_S(\geq 0\pi^0)\nu_\tau$	78.7 ± 4.0	78.4 ± 4.0
$\tau^\pm \to K^\pm K_S(\geq 0\pi^0)\nu_\tau$	4.2 ± 0.3	4.1 ± 0.3
$\tau^\pm \to \pi^\pm K^0 \bar{K}^0 \nu_\tau$	15.7 ± 3.7	15.9 ± 3.7
other($q\bar{q}$, fake K_S)	1.40 ± 0.06	1.55 ± 0.07
All	199064	140602

$$A_{raw} = \frac{N(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - N(\tau^- \to \pi^- K_S \nu_\tau)}{N(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + N(\tau^- \to \pi^- K_S \nu_\tau)}$$

$$A_{raw}(e - tag) = (-0.32 \pm 0.23)\% \quad A_{raw}(\mu - tag) = (-0.05 \pm 0.27)\%$$

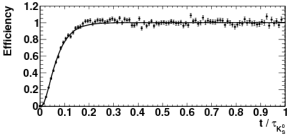
Selection criteria and charge-dependent detector effects induce a decay-rate asymmetry

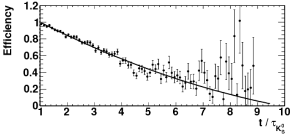
- Use $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ control sample, in which asymmetry from the SM and NP is suppressed. Measured asymmetry is consistent with zero, asymmetries measured in data and MC 3π samples agree within the experimental uncertainties $\sigma_\mathrm{A} = 0.12\%$ (e-tag) and $\sigma_\mathrm{A} = 0.08\%$ (μ-tag).
- Nuclear interaction effects (not included in detector simulation properly) for K^0 and $\bar{\mathrm{K}}^0$ are different, as a result additional decay rate asymmetry for the decays with $\mathrm{K_S}$ appears. Asymmetry correction is calculated on event-by-event basis using $\mathrm{P}^{\mathrm{LAB}}_{\mathrm{K_S}}$, $\theta^{\mathrm{LAB}}_{\mathrm{K_S}}$ and nuclear interaction cross sections: $\mathrm{A_{corr}} = (0.07 \pm 0.01)\%$.

	e tag	μ tag
Detector and sel. bias (3π)	0.12%	0.08%
Background subtraction	0.05%	0.06%
$\mathrm{K}^0/\bar{\mathrm{K}}^0$ interaction	0.01%	0.01%
Total uncertainty	0.13%	0.10%
Corrected asymmetry	$(-0.39 \pm 0.23 \pm 0.13)\%$	$(-0.12 \pm 0.27 \pm 0.10)\%$

Combined asymmetry: $\mathrm{A}(\text{e and } \mu \text{ tags}) = (-0.27 \pm 0.18 \pm 0.08)\%$

- Measured asymmetry A includes contributions coming from $\tau^- \to K^- K_S \nu_\tau$ and $\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$, so that:
  $A = \frac{f_{signal} A_{signal} + f_{KK_S} A_{KK_S} + f_{\pi K^0 \bar{K}^0} A_{\pi K^0 \bar{K}^0}}{f_{signal} + f_{KK_S} + f_{\pi K^0 \bar{K}^0}}$
- Taking into account SM expectations, $A_{KK_S} = -A_{signal}$ and $A_{\pi K^0 \bar{K}^0} = 0$:
  $A = \left(\frac{f_{signal} - f_{K\ K_S}}{f_{signal} + f_{K\ K_S} + f_{\pi K^0 \bar{K}^0}} \right) A_{signal}$
- CPV asymmetry induced by $K^0 - \bar{K}^0$ mixing was properly evaluated taking into account K_S detection efficiency as a function of decay time:
  $A_{CP}^{K^0} = (+0.36 \pm 0.01)\%$ (compare with
  $A_{CP}^{\bar{K}^0} = (-0.345 \pm 0.008)\%$ for $D^+ \to K^0 \pi^+$)





Y. Grossman and Y. Nir, "CP Violation in $\tau \to \nu \pi K_S$ and $D \to \pi K_S$: The Importance of $K_S - K_L$ Interference," JHEP 1204, 002 (2012) [arXiv:1110.3790 [hep-ph]].

$A_{signal} = (-0.36 \pm 0.23 \pm 0.11)\%$
was measured to be 2.8σ from the SM expectation
$A_{CP}^{K^0} = (+0.36 \pm 0.01)\%$

CP violation in $\tau^\pm \to K_S\pi^\pm\nu_\tau$ at Belle

The $K_S\pi^-$ hadronic current is parametrized by vector ($F_V(Q^2)$) and scalar ($F_S(Q^2)$) form factor:

$$J^\mu = \langle K_S(q_1)\pi^-(q_2)|\bar{s}\gamma^\mu u|0\rangle = F_V(Q^2)\left(g^{\mu\nu} - \frac{Q^\mu Q^\nu}{Q^2}\right)(q_1 - q_2)_\nu + F_S(Q^2)Q^\mu$$

Effect of CP violating scalar boson exchange diagram can be introduced by replacing the SM scalar form factor:

$$F_S(Q^2) \to \tilde{F}_S(Q^2) = F_S(Q^2) + \frac{\eta_S}{m_\tau}F_H(Q^2),\ F_H = \langle K_S(q_1)\pi^-(q_2)|\bar{s}u|0\rangle,\ d\Gamma_{\tau^-}(\eta_S) \stackrel{CP}{\to} d\Gamma_{\tau^+}(\eta_S^*)$$

$\tau^- \to K_S\pi^-\nu_\tau$ differential decay width:

$$\frac{d\Gamma}{dQ^2 d\cos\beta d\cos\theta} = (A(Q^2) - B(Q^2)(3\cos^2\beta - 1)(3\cos^2\psi - 1))|F_V(Q^2)|^2 + M_\tau^2|F_S|^2 +$$

$$+C(Q^2)\cos\beta\cos\psi \mathrm{Re}(F_V \tilde{F}_S^*(\eta_S))$$

- β - angle between $\vec{q}_1$ and direction to CMS frame in the $K_S\pi$ rest frame
- ψ - angle between $\vec{P}_\tau$ and direction to CMS frame in the $K_S\pi$ rest frame
- θ- angle between $\vec{P}_\tau$ in CMS and momentum of $K_S\pi$ system in τ rest frame (correlated with ψ)

To extract CPV term the following observable is defined in bin "i" of Q^2 ($d\omega = dQ^2 d\cos\theta d\cos\beta$):

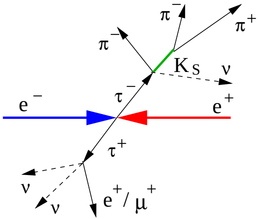
$$A_i^{CP} = \frac{\int_i \cos\beta\cos\psi\left(\frac{d\Gamma_{\tau^-}}{\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right)d\omega}{\frac{1}{2}\int_i\left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right)d\omega} \simeq \langle\cos\beta\cos\psi\rangle^i_{\tau^-} - \langle\cos\beta\cos\psi\rangle^i_{\tau^+}$$

M. Bischofberger et al., Phys. Rev. Lett. 107 (2011) 131801
($\Upsilon(3,4,5s)$+off resonance data with $\int \mathrm{Ldt} = 699\ \mathrm{fb}^{-1}$)

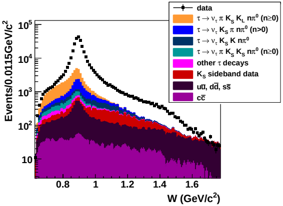
Selections

- Event is separated into two hemispheres in CMS, Thrust>0.9
- Signal side: $\mathcal{P}_{\mathrm{K}/\pi} = \frac{\mathcal{L}_\pi}{\mathcal{L}_\pi + \mathcal{L}_\mathrm{K}} > 0.7$, $\mathrm{L}(\mathrm{K_S}) > 2$ cm, $0.485 \leq \mathrm{M} \leq 0.511\ \mathrm{GeV/c^2}$, no additional γ with $\mathrm{E}_\gamma > 0.15$ GeV
- Tag side: 1 prong (e, μ or $\pi(\mathrm{n} \geq 0)\pi^0$) $\mathrm{N}_\gamma(\mathrm{E}_\gamma > 0.1\ \mathrm{GeV}) < 5$

$$\mathrm{N}(\tau^- \to \mathrm{K_S}\pi^-\nu_\tau) = (162.0 \pm 0.4) \times 10^3,$$
$$\mathrm{N}(\tau^+ \to \mathrm{K_S}\pi^+\nu_\tau) = (162.2 \pm 0.4) \times 10^3$$



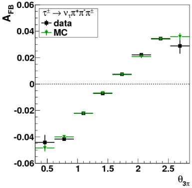
BG source	fraction
$\mathrm{K_S K_L}\pi^\pm$	$(9.5 \pm 3.2)\%$
$\mathrm{K_S}\pi^\pm\pi^0$	$(3.7 \pm 1.2)\%$
$\mathrm{K_S K}^\pm$	$(1.7 \pm 0.2)\%$
$\pi^\pm\pi^+\pi^-$	$(1.79 \pm 0.03)\%$
other τ	$(2.0 \pm 0.5)\%$
$\mathrm{q\bar{q}}$	$(3.4 \pm 1.0)\%$
Total	$(22.1 \pm 3.6)\%$

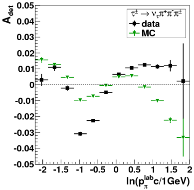


To avoid possible bias, the CPV search is performed as a blind analysis

Corrections

- Sources of artificial CPV are studied with $\tau^\pm \to \pi^\pm\pi^+\pi^-\nu$ events, associated corrections were applied in event-by-event basis:
- FB asymmetry ($\gamma - Z^0$ interference), was tabulated as a function of $\theta_{3\pi}^{LAB}$
- Asymmetry induced by detector (differencies between π^+ and π^- eff.) was tabulated as a function of (P^{LAB}, θ^{LAB})
- The effect of these correction on A_i^{CP} was found to be small ($O(10^{-3})$-FB, $O(10^{-4})$-detector) since A_i^{CP} depends on the angles relative to the $\vec{P}_\tau$





$$A_i^{CP} = \frac{\langle \cos\beta \cos\psi \rangle^i_{\tau^-}}{1 - f^-_{b,i}} - \frac{\langle \cos\beta \cos\psi \rangle^i_{\tau^+}}{1 - f^+_{b,i}}$$

$\sqrt{Q^2}$ (GeV/c^2)	Corrected and BG subtr. A^{CP} (10^{-3})
$0.625 - 0.890$	$7.9 \pm 3.0 \pm 2.8$
$0.890 - 1.110$	$1.8 \pm 2.1 \pm 1.4$
$1.110 - 1.420$	$-4.6 \pm 7.2 \pm 1.7$
$1.420 - 1.775$	$-2.3 \pm 19.1 \pm 5.5$

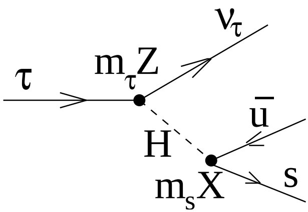
From the A_i^{CP} the CPV parameter $Im(\eta_S)$ can be extracted:

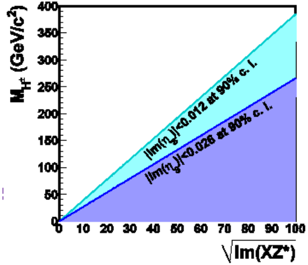
$$A_i^{CP} \simeq Im(\eta_S)\frac{N_s}{n_i}\int_i C(Q^2)\frac{Im(FF_H^*)}{m_\tau}dQ^2 \equiv c_i Im(\eta_S)$$

Use several parametrizations of F_V and F_S from our previous study of $M_{K_S\pi}$ spectrum and floating relative phase ($\phi_S = 0°...360°$):

$$|Im(\eta_S)| < (0.012 - 0.026) \text{ at } 90\% \text{ CL}$$

Theoretical predictions for $Im(\eta_S)$ in MHDM:





$$\eta_S \simeq \frac{m_\tau m_s}{M_{H^\pm}^2}X^*Z \quad |Im(XZ^*)| < 0.15\frac{M_{H^\pm}^2}{1\,GeV^2/c^4} \quad (|Im(\eta_S)| < 0.026)$$

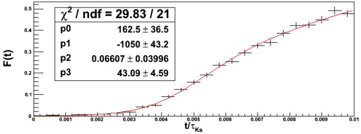
Summary

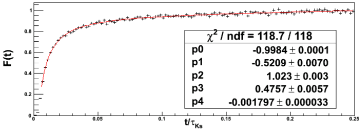
- B-factories collected the world largest data sample with charmed particle and τ lepton decays, which opened a new era in precise studies of CPV in charm and tau.
- Evidence (3.2σ) for CPV in $D^+ \to K_S\pi^+$ has been observed at Belle with a 977 fb^{-1} data sample. CP asymmetry is measured to be $A_{CP} = (-0.363 \pm 0.094 \pm 0.067)\%$, which is the first evidence for CPV in charmed meson decays from a single experiment and a single decay mode. CP asymmetry due to the change of charm is consistent with zero, $A_{CP}^{\Delta C} = (-0.018 \pm 0.094 \pm 0.068)\%$.
- Search for CP violation in $\tau^- \to \pi^- K_S(\geq \pi^0)\nu_\tau$ was done by BABAR with a 476 fb^{-1} data sample. The decay-rate asymmetry $(-0.36 \pm 0.23 \pm 0.11)\%$ is measured for the first time and differs from the SM prediction $(0.36 \pm 0.01)\%$ by 2.8σ.
- Search for CP violation in $\tau^- \to K_S\pi^-\nu_\tau$ analyzing angular distributions was performed at Belle. Upper limits for CPV parameter are in range $|\mathrm{Im}(\eta_S)| < 0.026$ at 90% CL or better, depending on the parametrizations of the $F_V(Q^2)$ and $F_S(Q^2)$. Improve previous (CLEO) limits by 1 order of magnitude.
- Further improvements in the sensitivity to the CPV asymmetry in τ decays require the detailed study of the hadronic form factors as well as incorporation of the spin-spin correlations in $\tau\tau$ events.

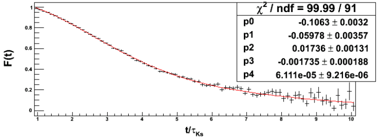
I. I. Bigi, "Probing CP Violation in $\tau^- \to \nu(K\pi/K2\pi/3K/K3\pi)^-$ Decays," arXiv:1204.5817 [hep-ph].

Backup slides

Y. Grossman and Y. Nir, "CP Violation in $\tau \to \nu\pi K_S$ and $D \to \pi K_S$: The Importance of $K_S - K_L$ Interference," JHEP 1204, 002 (2012) [arXiv:1110.3790 [hep-ph]]





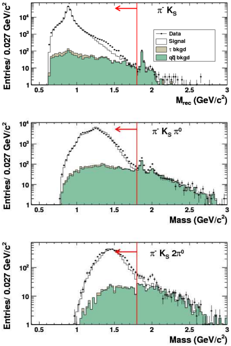


Correction factor 1.040 ± 0.005

CP violation in $\tau^- \to \pi^- K_S (\geq \pi^0) \nu_\tau$ at BABAR

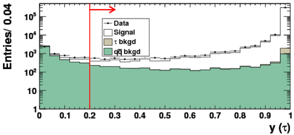
J. P. Lees et al. [BABAR Collaboration], Phys. Rev. D 85 (2012) 031102 [arXiv:1109.1527 [hep-ex]]. Data sample of $\int L dt = 476\ \mathrm{fb}^{-1}$ was analyzed

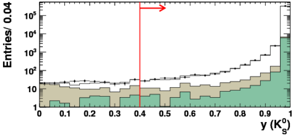
- $0.92 < \mathrm{Thrust} < 0.99$ is calculated using all tracks and photon candidates
- Event is separated into two hemispheres: signal and tag
- K_S candidate is reconstructed from $K_S \to \pi^+\pi^-$ with $0.488\ \mathrm{GeV}/c^2 < M_{\pi^+\pi^-} < 0.508\ \mathrm{GeV}/c^2$, $R(\mathrm{IP}, \pi^+\pi^-\text{-vertex}) > 3\sigma_r$
- For the prompt track: $|dr| < 1.5$ cm, $|dz| < 2.5$ cm, $P_\perp > 0.1$ GeV/c
- For π^0 candidate: $E_{LAB\gamma} > 30$ MeV, $0.115\ \mathrm{GeV}/c^2 < M_{\gamma\gamma} < 0.150\ \mathrm{GeV}/c^2$
- Signal hemisphere: 1 K_S, 1 prompt track$^\pm$(not kaon$^\pm$) and $N_{\pi^0} \geq 0$
- Tag hemisphere: 1 prompt track$^\mp$ identified as $e^\mp$ or $\mu^\mp$ with $P^{CMS} < 4$ GeV/c
- $M_{rec}(K_S \pi^\pm n\pi^0) < 1.8\ \mathrm{GeV}/c^2$



Impact of $M_{rec}(K_S \pi^\pm n\pi^0)$ MC/data discrepancy on asymmetry is small and included in systematic uncertainty

- To reject $q\bar{q}$ background $y(\tau)$ likelihood ratio is used (5 parameters: visible energy, thrust value, $P_{\perp}^{TOT}$, number of neutral clusters in signal and tag regions): $y(\tau) > 0.2$
- To suppress background from τ decays with fake K_S $y(K_S)$ is used (4 parameters: $R(IP,\pi^+\pi^-\text{-vertex})$, $M_{\pi^+\pi^-}$, $P_{K_S}^{LAB}$, $\theta_{K_S}^{rmLAB}$): $y(K_S) > 0.4$





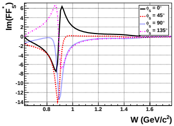
Source	Fractions (%)	
	e tag	μ tag
$\tau^\pm \to \pi^\pm K_S(\geq 0\pi^0)\nu_\tau$	78.7 ± 4.0	78.4 ± 4.0
$\tau^\pm \to K^\pm K_S(\geq 0\pi^0)\nu_\tau$	4.2 ± 0.3	4.1 ± 0.3
$\tau^\pm \to \pi^\pm K^0 \bar{K}^0 \nu_\tau$	15.7 ± 3.7	15.9 ± 3.7
other($q\bar{q}$, fake K_S)	1.40 ± 0.06	1.55 ± 0.07
All	199064	140602

Data/MC correction to the $q\bar{q}$ and fake K_S background evaluation from the study of the data at $y(\tau) < 0.1$ and $y(K_S) < 0.1$

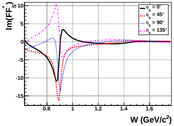
$$A_{raw} = \frac{N(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - N(\tau^- \to \pi^- K_S \nu_\tau)}{N(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + N(\tau^- \to \pi^- K_S \nu_\tau)}$$

$$A_{raw}(e - tag) = (-0.32 \pm 0.23)\% \quad A_{raw}(\mu - tag) = (-0.05 \pm 0.27)\%$$

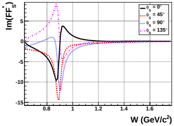
Belle CPV assymetry in $\tau^{\pm} \to K_S \pi^{\pm} \nu_\tau$



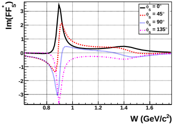
$K_0^*(800) + K^*(892) + K_0^*(1430)$ (solution 1)



$K_0^*(800) + K^*(892) + K_0^*(1430)$ (solution 2)



$K_0^*(800) + K^*(892) + K^*(1410)$



$K_0^*(800) + K^*(892) + K^*(1680)$