CP violation in τ decay

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Workshop on YoungPyung, 2010
Belle Collaboration

Outline

1. CP violation in SM
   - Understanding of CP asymmetry
   - CP Mechanism
2. CP violation in τ decay
   - Ideas of CPV in τ
   - $\tau \to K\pi\nu$ decay
   - $\tau \to K\pi\pi\nu$ decay
3. status of $\tau \to K_S h \pi^0$
   - Motivation
   - Event selection
   - Invariant Mass distribution

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Origin of CP asymmetry

Electroweak and Yukawa coupling

$$\mathbf{V_{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

- Present known source of CP asymmetry is CKM matrix.
- CKM can be understood by Electroweak and Yukawa interaction of Higgs.
- Quark masses are not diagonalized in the flavor basis but diagonalized by unitary transformation. Then charged weak interaction are non-diagonal.
- 1 physical complex phase (η) bring the CP violation in quark sector.

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CP Mechanism

General CP observable

CP violation arises from the inference

$$A_{X\to Y} = e^{i\theta_1}|A_1|e^{i\delta_1} + e^{i\theta_2}|A_2|e^{i\delta_2}$$

$$A_{\overline{X}\to\overline{Y}} = e^{-i\theta_1}|A_1|e^{i\delta_1} + e^{-i\theta_2}|A_2|e^{i\delta_2}$$

θ_i : CP phase, δ_i : scattering phase (strong phase)

$$A_{CP} = \frac{|A_{X\to Y}|^2 - |A_{\overline{X}\to\overline{Y}}|^2}{|A_{X\to Y}|^2 + |A_{\overline{X}\to\overline{Y}}|^2} = \frac{-2|A_1||A_2|\sin(\theta_1-\theta_2)\sin(\delta_1-\delta_2)}{|A_1|^2+|A_2|^2}$$

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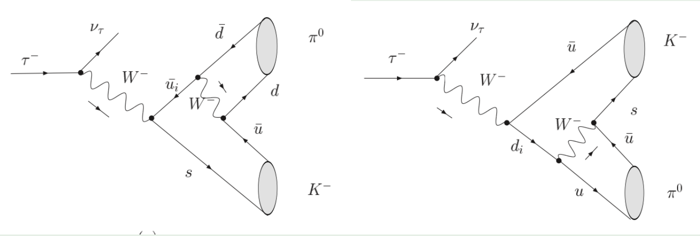
SM prediction of CP asymmetry in τ decays is too small to detect



Higher order contribution can only induce weak phase contribution (CKM)

$$A_{cp} = \frac{\Gamma(\tau \to K^+\pi^0\nu) - \Gamma(\tau \to K^-\pi^0\nu)}{\Gamma(\tau \to K^+\pi^0\nu) + \Gamma(\tau \to K^-\pi^0\nu)} \approx 2.3 \times 10^{-12}$$

what if we see the CP violation in τ decays ?

This indicates you found the new physics so called "beyond the SM"

Possible theory of CPV in τ decays

- R handed Vector Boson : L-R mixing
- Charged Higgs Doublet
- SUSY

In charged higgs model, higgs coupling is proportional to the mass difference of quarks. $\to \Delta S \neq 0$ decays is promising in τ CPV.

Experimental efforts

- Search for CP violation in $\tau \to K\pi\nu$ decays has been published by CLEO (2002).
- Same tryout is going on by τ group in BELLE

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introduction

Situation

- CLEO has obtained the branching fraction with 13.3 fb^{-1} data.
- CLEO defined CP observable and set the limit on it with simple guess on structure function.
- BELLE has finished the study on structure function with rather complicated.

Theory

Effective hamiltonian can be written by sum of SM and NP(new physics) term.

- $H_{eff} = H_{SM} + H_{NP}$
- $H_{SM} = \sin\theta_c \frac{G}{\sqrt{2}} \overline{\nu_\tau}\gamma_\mu(1-\gamma_5)\tau\bar{s}\gamma^\mu(1-\gamma_5)u + h.c$
- $H_{NP} = \sin\theta_c \frac{G}{\sqrt{2}} \eta_S \overline{\nu_\tau}(1+\gamma_5)\tau\bar{s}u + h.c$

in the case of $\tau \to K\pi\nu$, hadronic current decays into two pseudo-scalar meson, which can be expanded in terms of the independent momenta $(q_1 - q_2)^\mu$ and $Q^\mu = q_1^\mu + q_2^\mu$

- $J_\mu = \langle h_1(q_1)h_2(q_2)|\bar{u}\gamma_\mu s|0\rangle = (q_1 - q_2)^\nu T_{\nu\mu} F(Q^2) + Q_\mu F_s(Q^2)$

CP violating contribution incorporates to s-wave form factors by substitution:

- $F_S(Q^2) \to \tilde{F}_S(Q^2) = F_S(Q^2) + \frac{\eta_S}{m_\tau} F_H(Q^2)$

Theory

So, the amplitude for this channel,

$$M = \sin\theta_C \frac{G}{\sqrt{2}} \overline{u}\gamma_\mu (1-\gamma_5) u[(q_1 - q_2)_\mu T^{\nu\mu} F + Q^\mu \tilde{F}_S]$$

The differential decay rate in hadronic rest frame,

$$\Gamma(\tau \to K\pi\nu_\tau) = M^2 d\Pi = \sum_X (L_X W_X) d\Pi$$

Where L_X and W_X, (for unpolarized τ)

	W_X	$\overline{L}_X$
B	$4(q_1)^2\lvert F\rvert^2$	$\frac{1}{3}(2+\frac{m^2}{Q^2}) - \frac{1}{6}(1-\frac{m_{tau}^2}{Q^2})(3\cos^2\psi - 1)(3\cos^2\beta - 1)$
SA	$Q^2\lvert F_S\rvert^2$	$\frac{m_\tau^2}{Q^2}$
SF	$4\sqrt{Q^2}\lvert q_1\rvert Im(F\tilde{F}_S^*)$	$-\frac{m_\tau}{Q^2}\cos\psi\cos\beta$
SG	$-4\sqrt{Q^2}\lvert q_1\rvert Re(F\tilde{F}_S^*)$	0

Observable

CP operation

$$d\Gamma_{\tau^-}(p_i, P, \eta_S) \to d\Gamma_{\tau^+}(-p_i, -P, \eta_S^*)$$

in order to get CP observable, subtract two the differential decay rates

CP observable

$$\Delta(p_i) = \frac{d\Gamma_{\tau^-}}{d\Pi}(p_i) - \frac{d\Gamma_{\tau^+}}{d\Pi}(-p_i)$$

$$\Sigma(p_i) = \frac{d\Gamma_{\tau^-}}{d\Pi}(p_i, \eta_S = 0) + \frac{d\Gamma_{\tau^+}}{d\Pi}(-p_i, \eta_S^* = 0)$$

CP observable

$$\xi^-(p_i) = \frac{\Delta(p_i)}{\Sigma(p_i)} = \frac{\overline{L}_{SF}\Delta W_{SF}}{\sum \overline{L}_X W_X}$$

by the way, CLEO defines somewhat different observable not including CP odd term in denominator

$$\xi^-(p_i) = \frac{\Delta(p_i)}{\Sigma(p_i)} = \frac{\overline{L}_{SF}\Delta W_{SF}}{\overline{L}_B W_B + \overline{L}_{SA} W_{SA}}$$

Observable

Averaged CP observable

The CP observable, ξ, can be integrated within particular range of momentum and Q^2.

$$\langle \xi^{\pm} \rangle = \int_{\Delta Q^2} \xi^{\pm} \frac{d\Gamma^{\pm}}{dQ^2 d\Omega} d\Omega dQ^2$$

Characteristic of CP observable

- dependent on momentum and hadron invariant mass
- sensitive to structure function (model dependence)
  $\rightarrow$ different from particular decay mode

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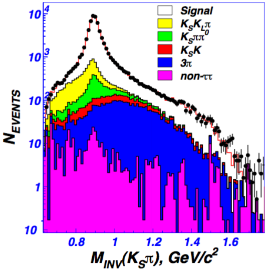
Hadron structure in $\tau \to K_S \pi \nu$

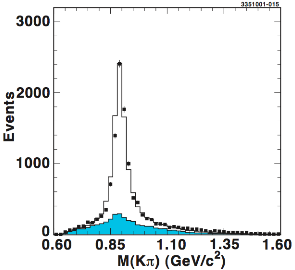
BELLE parametrization

- 2 solution for $K_0^*(800) + K^*(892) + K_0^*(1430)$
- 1 solution for $K_0^*(800) + K^*(892) + K^*(1410)$

CLEO parametrization

CLEO used $K^*(892) + K_0^*(1430)$





MC generation

TAUOLA is MC generator for τ decays which supports about 50 type of decays. For the decay $\tau \to K\pi\nu$, $F_S(Q^2)$ has been neglected
In order to study CPV with MC data, need another event generator
$\to$ Do we need to fix TAUOLA?

event generation

It is possible to weight the event for some momentum and mass range by:

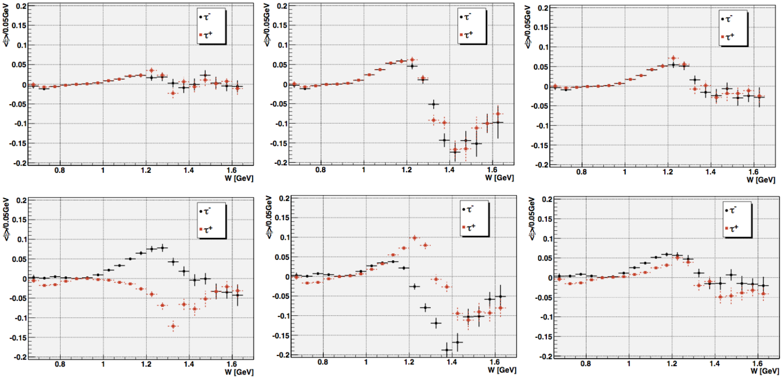
$$w = \frac{\sum(L_X W_X^{cp})}{\sum(L_X W_X^{tauola})}$$

W_X^{cp} is a function of η_S, s_1^2, s_2^2 and Q^2 so that don't need new generator.

This study has been done by Dr. Bischofberger and Prof. Hayashii (BELLE).

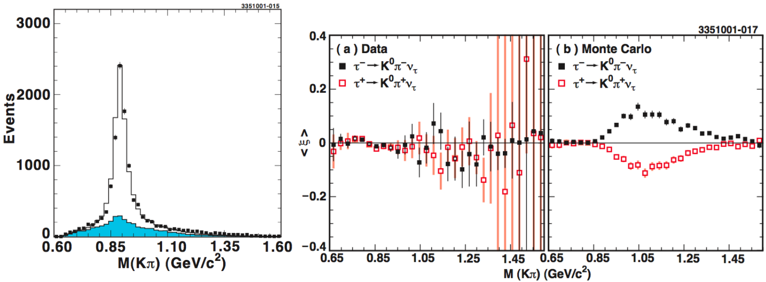
MC study

MC study for $< \xi >$ is done by using Belle parametrization result :



These result are obtained by assuming $Im(\eta_S) = 1$, maximal CP

CLEO result and comparison



- CLEO limits (90 % C.L) -0.172 $< \Lambda <$ 0.067 for 13.3 fb^{-1}
  Λ is equivalent to η_S but use different normalizatioin
- $F_S(Q^2)$ = 0 and $F_H = BW(K_0^*(1430)$

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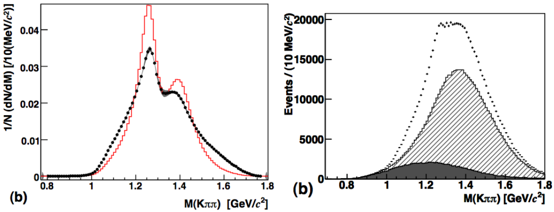
introduction

- No one has studied for 3 hadron case, because
  - No experimental information for the hadron structure for 3 hadron decay in τ sector
  - seems rather complicated to obtain observable
- Dr. Lee Myung Jae has finished the study of this channel. but background contributes too much.
  cause problem of systematics in sensitivity.
- with successful extraction by unfolding method, we can see $K_1(1270)$ and $K_1(1400)$ clearly



Theory

like as in $\tau \to K\pi\nu$ decay, H_{NP} added to H_{SM} but,

$$H_{NP} = \sin\theta_c \frac{G}{\sqrt{2}} \eta_S \overline{\nu_\tau}(1+\gamma_5)\tau\bar{s}u + \eta_P \overline{\nu_\tau}(1+\gamma_5)\tau\bar{s}\gamma_5 u + h.c$$

η_S is too small to contribute CP but η_P can contribute
Hadronic current is also different

$$J^\mu = \langle K(p_1)\pi(p_2)\pi(p_3)|\bar{s}\gamma^\mu(1-\gamma^5)u|0\rangle$$
$$= [F_1(p_1-p_3)_\nu + F_2(p_2-p_3)_\nu]T^{\mu\nu} + iF_3\epsilon^{\mu\nu\rho\sigma}p_{1\nu}p_{2\rho}p_{3\sigma} + F_4 Q^\mu$$

- F_1 and F_2 is due to $K_1(1270)$ and $K_1(1400)$ respectively.
- F_3 is the anomalous Wess-Zumino term.
- F_4 is scalar term, generally assumed to be negligible for this decay.

Theory

Similarly to the previous work,

$$F_4 \to \overline{F}_4 = F_4 + \frac{F_H}{m_\tau}\eta_P$$

where pseudo-scalar form factor, F_H, has been defined :

$$F_H = \langle K(p_1)\pi(p_2)\pi(p_3)|\bar{s}\gamma^5 u|0\rangle$$

observables in $\tau \to K\pi\pi\nu$ decay

3 kind of observable for 3 hadron decay. (general)

- Rate asymmetry
  The difference between the rate for the process and that for the associated anti-process
  In principle, same observable as for $\tau \to K\pi$.
- Polarization-dependent Rate asymmetry
  Integrate decay rate for particular kinematic angle by weighting
- Triple-product Rate Asymmetry

each asymmetry observable is proportional to $|F_H| Im(\eta_P)$.

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Motivation

- Branching fraction measurement (latest result from ALEPH,1998)
- Hadron Structure Function of 3 hadron in τ decays.
- Study of Wess-Zumino anomaly term.
- CP violation (for $K_S \pi \pi^0 \nu$ decay)

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Event selection

- Tauskim
- $2 \leq$ Ntrk ≤ 4 , (at least 2 track from primary vertex)
- $20^\circ \leq \mathcal{M}_{missing} \leq 175^\circ$
- Thrust > 0.9
- $E_{ECL} < 9.0$ GeV
- Event topology : 1-3
- Charge Sum = 0
- Particle ID LR cut : eid > 0.8 , muid > 0.8 , k/$\pi > 0.7$
- K_S^0 : zdist $<$ 2cm, 1.5cm $<$ flight length $<$ 40cm
- π^0 : -6 $<$ Sgg $<$ 5
- $E_\gamma < 0.3$ GeV

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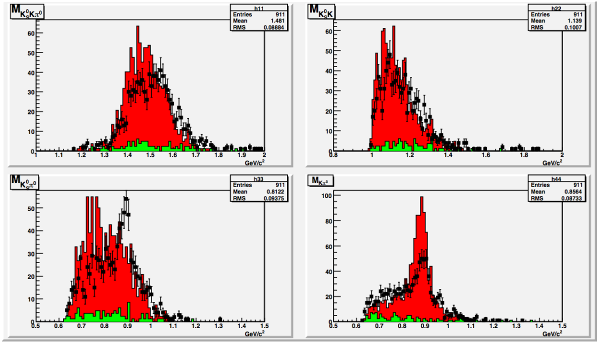
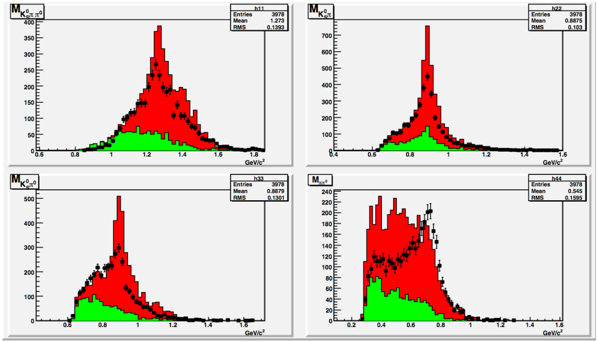
Mass distribution for $\tau \to K_s K \pi^0 \nu$



- Statistics : 67.7 fb^{-1}
- Vector current ($K^*(892)$ and $\rho(770)$) is seen
- expected background : 16.2 %
  $\tau \to K_S K$: 5.6 %, $\tau \to K_S \pi \pi^0$: 7.6%, other τ decays : 3.0%

Mass distribution for $\tau \to K_s \pi \pi^0 \nu$



- Statistics : 67.7 fb^{-1}
- Vector current ($K^*(892)$ and $\rho(770)$) is seen
- expected background : 34.6%
  $\tau \to K_S K \pi^0$: 6.2 %, $\tau \to K_S \pi$: 7.4%, $\tau \to K_S K_S \pi$: 5.8%, $\tau \to \pi \pi^0$: 5 %, other τ decays : 10.0%

Summary

- CP violation in τ decay is a definite sign of New Physics
- CLEO has published limits for $\tau \to K^0 \pi \nu$ and $\tau \to \pi \pi^0 \nu$ from an analysis of data corresponding to 13.3fb^{-1} and set the limit of CP violation by optimized CP observable $\langle \xi \rangle$
- τ group in Belle has been studying CP violation with the same method carried out by CLEO.
- Not only for $\tau \to K \pi \nu$ but also for $\tau \to K \pi \pi \nu$ decay, CP observable can be studied by similar method.
- Before studying CP violation in τ decay, one should understand the structure of the decay.
- Too much background affects $\tau \to K \pi \pi \nu$ decay so that $\tau \to K_S \pi \pi^0 \nu$ decay can be another option to be studied
- Study of $\tau \to K_S \pi (K) \pi^0 \nu$ channel is on going.
  preliminary result of branching fraction will be obtained soon.

Thank you !

For Further Reading I

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