Why is Search for CP violation in τ decay so important?
why do we want longitudinally polarized e^- or $e^\pm$ beam(s)?

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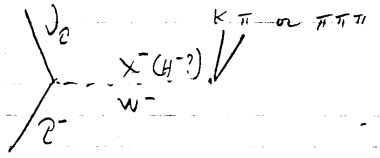
Why is search for CP violation in τ decay so important?

1. If CP violation is found in τ decay it implies the existance of a charged spin 0 particle (charged Higgs?) interfering with W exchange mechanism



2. If X^- exists, it implies that leptons participate fully in CP violations. CP violation is needed to have matter-antimatter asymmetry in the universe.
3. It will trigger a systematic study of X^- coupling to all other particles using semi-leptonic decay of hadrons

4 Neutrino Oscillation and existence of $X^{\pm}$.

Solar neutrino and atomospheric neutrino experiments

$\Longrightarrow$ neutrinos have mass

$\Longrightarrow$ origin of neutrino mass $\Rightarrow$ charged and neutral Higgs coupled to leptons.

5 Range of M_X

a. τ decay agrees with Standard model to 2 %

$$\frac{m_W^2}{m_X^2} < 0.02 \qquad \therefore \quad m_X \geq \frac{m_W}{\sqrt{0.02}} \sim 5.7\ \text{TeV}$$

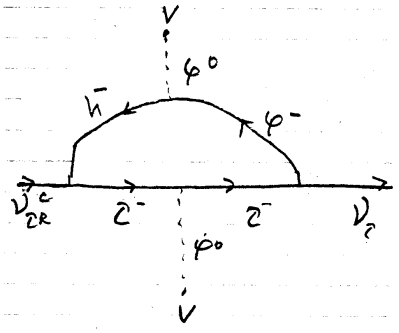
b. If CP violation in τ decay is about the same order of magnitude as $K_L \to 2\pi$ $|\epsilon| < 2.2\times10^{-3}$ then

$$m_X \sim \frac{m_W}{\sqrt{2.2\times10^{-3}}} = 1.7\ \text{TeV}$$

This is amazing, we can do 1.7 TeV physics using 4 Gev machine, if we can do 0.22 % experiment!

6 Some people insist that we should build 2 Tev machine to produce 1.7 Tev particle, rather than wasting time building a 4 Gev machine to do 1.7 Tev physics. If 1.7 Tev X particle is produced by 2 Tev machine there is no way we can measure the imaginary part of the coupling constant, whereas TCF can do this!

7 Maybe the τ neutrino mass is produced by



φ^0 neutral Higgs

φ^-, h^- } charged Higgs

V vac. exp. value of φ^0

This may explain 90 % of matter in the universe "Dark matter" that keeps the universe from expanding too fast.

3. Why do we want longitudinally polarized e^- or $e^\pm$ beam(s)?

1. We need polarization to see whether $\tau^- \to \nu_\tau + \bar{\nu}_\mu + \mu^-$ (YST 1995) violates CP.

$$\vec{W}_\tau \cdot (\vec{P}_\mu \times \vec{W}_\mu) \to \vec{W}_\tau \cdot (\vec{P}_\mu \times \vec{P}_e)$$

decay electron mom

No final state interaction ∴ we need T odd term

Can test T, TCP, CP for pure leptonic system
complex coupling constants for leptonic vertices.

2. For semileptonic decay of τ such as

$\tau \to K + \pi + \nu_\tau$ (YST 1996) (unpol + pol) Kühn + Mirkes 1996 (unpol)

wrong → 1998 Choi, Lee Song (pol), Choi Hagiwara, Tanabashi (1995) unpolarized.

$\tau^\pm \to \pi^\pm \pi^+ \pi^- + \nu_\tau$ (YST 1997) (unpol + pol)

we need $\vec{W}_\tau$ to obtain $\vec{W}_\tau \cdot \vec{P}_\pi$, $\vec{W}_\tau \cdot \vec{P}_K$ ← T even

$\vec{W}_\tau \cdot (\vec{P}_\pi \times \vec{P}_K)$ ← T odd

S wave, P wave, T violating phase

For τ^- decay

$$\cos(\delta_0 - \delta_1 + \delta_t)\left[c_0 \underbrace{\vec{P}_\tau \cdot (\overrightarrow{P_K - P_\pi})}_{\text{in Rest frame of } \vec{P}_K + \vec{P}_\pi} + c_1 \vec{W}_\tau \cdot \vec{P}_K + c_2 \vec{W}_\tau \cdot \vec{P}_\pi\right]$$

$$+ \sin(\delta_0 - \delta_1 + \delta_t)\, c_3\, \vec{W} \cdot (\vec{P}_K \times \vec{P}_\pi)$$

For τ^+ decay

$$\cos(\delta_0 - \delta_1 - \delta_t)\left[C_0 \vec{p}_\tau \cdot (\vec{p}_K - \vec{p}_\pi) - C_1 \vec{w}_\tau \cdot \vec{p}_K - C_2 \vec{w}_\tau \cdot \vec{p}_\pi \right]$$

$$+ \sin(\delta_0 - \delta_1 - \delta_t)\; C_3 \vec{w} \cdot (\vec{p}_K \times \vec{p}_\pi)$$

C_0, C_1, C_2 and C_3 are simple known functions. The objective is to obtain δ_t by comparing τ^- and τ^+ decays.

From T even part :

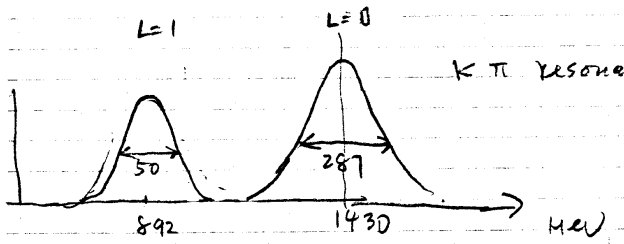
$$\cos(\delta_0 - \delta_1 + \delta_t) - \cos(\delta_0 - \delta_1 - \delta_t) = -2 \sin(\delta_0 - \delta_1) \sin\delta$$

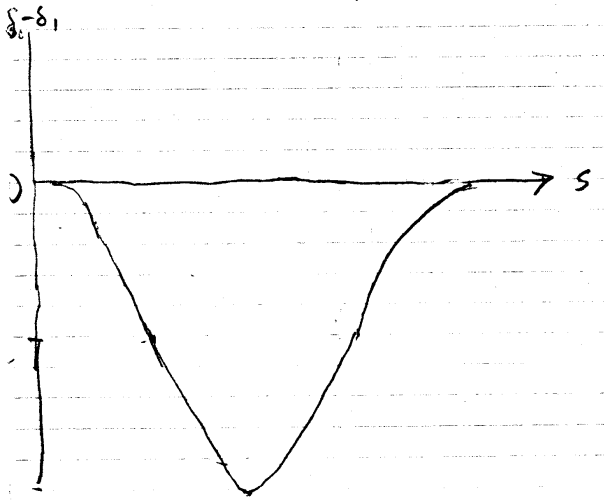
From T odd part :

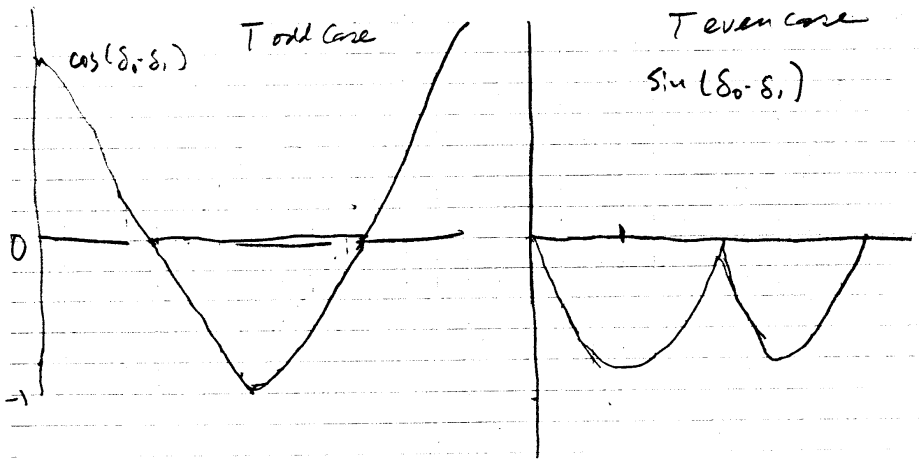
$$\sin(\delta_0 - \delta_1 + \delta_t) - \sin(\delta_0 - \delta_1 - \delta_t) = 2 \cos(\delta_0 - \delta_1) \sin\delta_t$$

δ_0, δ_1 and δ_t are all functions of $(p_K + p_\pi)^2 = s$

δ_0 and δ_1 vary rapidly but δ_t not expected to vary much


L=1
L=0
K π resonances
50
287
892
1430
MeV


$\delta_0 - \delta_1$
s
0
-1


T odd Case
$\cos(\delta_0 - \delta_1)$
T even case
$\sin(\delta_0 - \delta_1)$
0
-1

Characteristics of τ polarization in τcf and B factory
MST, Phys. Rev 51D, 3172 (1995)

τcf 99% s wave production 1% d wave

B factory 75% s wave production 25% d wave

If cp is conserved in the production

$\vec{W}_{\tau^-} = \vec{W}_{\tau^+} \equiv \vec{W}_\tau$ parallel to e^- or e^+ if s wave

$= \left| \frac{W_{e^-} + W_{e^+}}{1 + W_{e^-} \cdot W_{e^+}} \right| \hat{e}_z$ ← beam direction

From $\vec{W}_\tau \cdot \vec{P}_\pi$ term to obtain δ_t

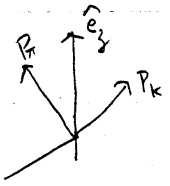
compare : $(\vec{P}_\pi)_z$ distributions from τ^+ and τ^-.

Difference indicates ~~cp~~.

Check the result with reversed $\vec{W}_\tau$.

Similarly for $\vec{W}_\tau \cdot \vec{P}_K$ term

$\vec{W}_\tau \cdot (\vec{P}_K \times \vec{P}_\pi) = \vec{P}_K \cdot (\vec{P}_\pi \times \hat{e}_z) |W_\tau|$



$= P_{Ky} P_{\pi x} |W_\tau|$

plot $P_{Ky} P_{\pi x}$ distribution from τ^+ and τ^- decay
difference is ~~cp~~.

τ/charm Factory (Pol.) vers B Factory (unpol.) for CPV in τ

cross section	factor	of	6
Pol.	"	"	5
			30

If B factory can do 0.8 % exp.

τ charm can do $\frac{0.8}{\sqrt{30}}$ % $= 1.4 \times 10^{-3}$ experiment.