Search for *CP*/*T*-violation in the tau sector at a superb τ factory

τ Electric Dipole Moment & similia

Eugenio Paoloni

on behalf
of the
Pisa group

Flavour In The Era Of The LHC

Outline

1. τ electric dipole moment
   - Motivation and present status
   - How to improve it in a significant way?
2. Lorentz structure of the τ decay vertex
3. T violation in τ decays
4. conclusions and plans

Motivation of the search

The electric dipole moment interaction

$$\mathcal{H}_i = ie\frac{F_\tau}{2m_\tau}\bar{\psi}\sigma^{\mu\nu}\gamma^5\psi F_{\mu\nu}$$

is the lowest dimension gauge invariant T odd operator that couple the photon (Z_0) with the τ current.
SM generates such interaction only at a very high order of the perturbative expansion (i.e. $F_\tau \ll 1$).
Possibility for the "New Physics" to stay on the stage.

PDG 2004 e, μ

$$d_e = (0.07 \pm 0.07) \times 10^{-26} e\,\mathrm{cm}$$
$$d_\mu = (3.7 \quad \pm 3.4) \times 10^{-19} e\,\mathrm{cm}$$

PDG 2004 τ

$$\Re(d_\tau) = (-0.22 \,\mathrm{to}\, 0.45) \times 10^{-16}\,\mathrm{cm}$$
$$\Im(d_\tau) = (-0.25 \,\mathrm{to}\, 0.01) \times 10^{-16}\,\mathrm{cm}$$

Belle measurement of the τ EDM (hep-ex/0210066)

Belle searched for *CP* violating effects in

$$e^+e^- \to \gamma^\star \to \tau^+\tau^-$$

analyzing $26.8 \cdot 10^6$ τ pairs. Sample composition:

	Yield	Purity (%)	Background mode (%)
$e\mu$	250,948	96.6 ± 0.1	$2\gamma \to \mu\mu(1.9)$, $\tau\tau \to e\pi(1.1)$.
$e\pi$	132,574	82.5 ± 0.1	$\tau\tau \to e\rho(6.0)$, $eK(5.4)$, $e\mu(3.1)$, $eK^*(1.3)$.
$\mu\pi$	123,520	80.6 ± 0.1	$\tau\tau \to \mu\rho(5.7)$, $\mu K(5.3)$, $\mu\mu(2.9)$, $2\gamma \to \mu\mu(2.0)$.
$e\rho$	240,501	92.4 ± 0.1	$\tau\tau \to e\pi\pi^0\pi^0(4.4)$, $eK^*(1.7)$.
$\mu\rho$	217,156	91.6 ± 0.1	$\tau\tau \to \mu\pi\pi^0\pi^0(4.2)$, $\mu K^*(1.6)$, $\pi\rho(1.0)$.
$\pi\rho$	110,414	77.7 ± 0.1	$\tau\tau \to \rho\rho(5.1)$, $K\rho(4.9)$, $\pi\pi\pi^0\pi^0(3.8)$, $\mu\rho(2.7)$.
$\rho\rho$	93,016	86.2 ± 0.1	$\tau\tau \to \rho\pi\pi^0\pi^0(8.0)$, $\rho K^*(3.1)$.
$\pi\pi$	28,348	70.0 ± 0.2	$\tau\tau \to \pi\rho(9.2)$, $\pi K(9.2)$, $\pi\mu(4.7)$, $\pi K^*(2.0)$.

Systematic $\sim$ statistical with only 25 millions τ-pairs

Belle measured T-odd correlations among the momenta of the decay products of the $\tau^+\tau^-$.

$$-0.22 < \Re(d_\tau) < 0.45 (10^{-16}\, e\, \mathrm{cm}) \quad 95\%\mathrm{C.L}$$

Table 2
Systematic errors for $Re(d_\tau)$ and $Im(d_\tau)$ in units of $10^{-16} e\,$cm.

$Re(d_\tau)$	$e\mu$	$e\pi$	$\mu\pi$	$e\rho$	$\mu\rho$	$\pi\rho$	$\rho\rho$	$\pi\pi$
Mismatch of distribution	0.80	0.58	0.70	0.11	0.15	0.21	0.16	0.06
Charge asymmetry	0.00	0.01	0.01	0.01	0.01	0.01	-	-
Background variation	0.43	0.12	0.07	0.07	0.08	0.03	0.04	0.05
Momentum reconstruction	0.16	0.09	0.24	0.04	0.06	0.06	0.04	0.45
Detector alignment	0.02	0.02	0.01	0.00	0.01	0.01	0.02	0.03
Radiative effects	0.09	0.04	0.02	0.01	0.01	0.02	0.00	0.16
Total	0.93	0.60	0.74	0.14	0.18	0.22	0.17	0.48

Little space for improvements...

τ EDM with polarized e^+e^- beams (Phys. Rev. D51 5996)

Ananthanarayan & Rindani proposed in 1995 a very clever method:

- use an e^- beam with tunable longitudinal polarization P

$$e^-(p_-) + e^+(p_+) \to \gamma^\star \to \tau^+ + \tau^-$$

$$\tau^- \to H_A(q_-) + \nu_\tau \quad \tau^+ \to H_B(q_+) + \bar{\nu}_\tau$$

- under CP:

$$\mathbf{p}_+ \leftrightarrow -\mathbf{p}_- \quad \mathbf{q}_+ \leftrightarrow -\mathbf{q}_-$$

- measure the mean value of the CP odd observables:

$$O_1 = \hat{\mathbf{p}}_+ \cdot (\mathbf{q}_+ \times \mathbf{q}_-) \propto \Re(d_\tau) \quad O_2 = \hat{\mathbf{p}}_+ \cdot (\mathbf{q}_+ + \mathbf{q}_-) \propto \Im(d_\tau)$$

- compare $\langle O_i \rangle$ measured with opposite polarizations

$$\Re(d_\tau) \propto \langle O_1 \rangle_P - \langle O_1 \rangle_{-P}$$

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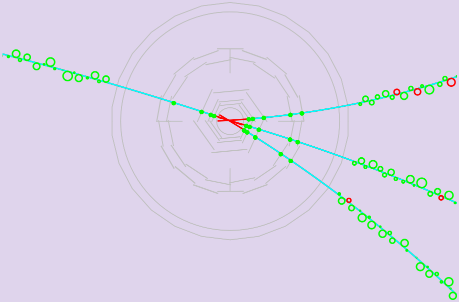
Experimental approach

BABAR $e^+e^- \to \tau^+\tau^- \to 3+1$



Event selection

- Low multiplicity
- Missing momentum
- Missing energy
- Particle id.

Select only

$$\tau \to \pi\nu \quad \tau \to \rho\nu$$

Observable

- identify the positive and the negative track

$$O_1 = |\mathbf{p}_\perp^+| \, |\mathbf{p}_\perp^-| \sin(\phi_+ - \phi_-)$$

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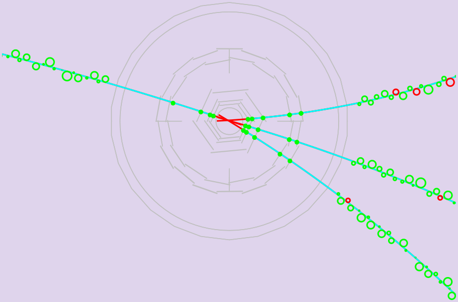

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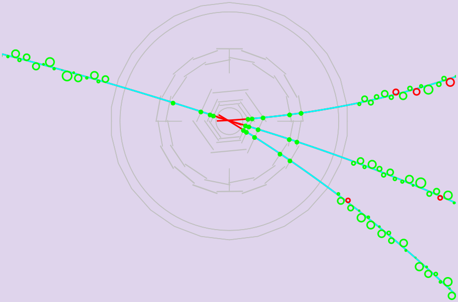

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Sensitivities ($10^7 \tau -$ pairs)

P	c_{AB} (GeV^2)	$\sqrt{\langle O_1^2 \rangle}$ (GeV^2)	$\lvert \delta \, \mathrm{Re} d_\tau^\gamma \rvert$ (e cm)
		(a)	
0.00	-1.58×10^{-5}	1.78	5.71×10^{-15}
-0.62	-8.19×10^{-1}	1.78	1.10×10^{-17}
$+0.62$	8.15×10^{-1}	1.78	1.11×10^{-17}
-0.71	-9.37×10^{-1}	1.78	9.65×10^{-18}
$+0.71$	9.33×10^{-1}	1.78	9.67×10^{-18}
-1.00	-1.32	1.78	6.86×10^{-18}
$+1.00$	1.31	1.78	6.86×10^{-18}
		(b)	
0.00	-3.91×10^{-4}	1.66	1.57×10^{-14}
-0.62	-6.36×10^{-1}	1.66	9.63×10^{-18}
$+0.62$	6.35×10^{-1}	1.66	9.64×10^{-18}
-0.71	-7.29×10^{-1}	1.66	8.41×10^{-18}
$+0.71$	7.27×10^{-1}	1.66	8.42×10^{-18}
-1.00	-1.03	1.66	5.98×10^{-18}
$+1.00$	1.02	1.66	5.98×10^{-18}
		(c)	
0.00	-7.03×10^{-5}	1.51	5.76×10^{-14}
-0.62	-3.63×10^{-1}	1.51	1.12×10^{-17}
$+0.62$	3.62×10^{-1}	1.51	1.12×10^{-17}
-0.71	-4.15×10^{-1}	1.51	9.77×10^{-18}
$+0.71$	4.15×10^{-1}	1.51	9.77×10^{-18}
-1.00	-5.85×10^{-1}	1.51	6.93×10^{-18}

P-weighted Sensitivities ($10^7 \tau$ − pairs)

	c_{AB} (GeV^2)	$\sqrt{\langle O_1^2 \rangle}$ (GeV^2) (a)	$\lvert \delta\, \mathrm{Re} d_\tau^\gamma \rvert$ (e cm)
$\pi\pi$	1.72×10^3	3.46	2.61×10^{-19}
$\pi\rho$	1.34×10^3	2.38	1.68×10^{-19}
$\rho\rho$	7.62×10^2	1.48	1.33×10^{-19}
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$$c_{AB} \cdot \Re(d_\tau) = \frac{e}{\sqrt{s}} \left[\langle O_1 \rangle_P - \langle O_1 \rangle_{-P} \right]$$

- Most systematic effects should cancels in $\langle O_1 \rangle_P - \langle O_1 \rangle_{-P}$
- With a sample in excess of $10^{10} \tau$ pairs it seems possible to enter in the very high precision realm $d_\tau \sim 10^{-20} e\,\mathrm{cm}$

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Requirements

- A very high luminosity e^+e^- machine with polarizable beams.
- A preliminary study to ascertain to robustness of the observables with respect to systematic effects.
- A dedicated system to measure the beam polarization?
- A tracking system with efficiency as uniform as possible in azimuthal and polar angle ...and very well aligned to reduce biases on reconstructed momenta.
- An hermetic detector to better reject backgrounds and cross-feeds.
- A Monte Carlo generator able to take into account spin correlations
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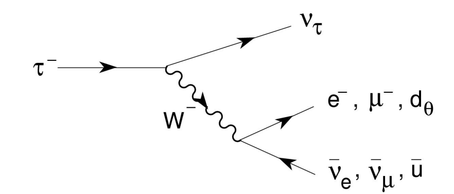
τ leptonic decays: what we believe

- Standard Model V-A structure only:



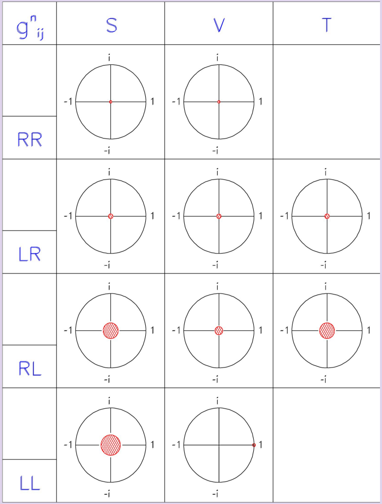
$$\mathcal{L}_{cc} = \frac{g}{2\sqrt{2}} W_\mu^\dagger \sum_l \bar{\nu}_l \gamma^\mu (1-\gamma_5) l + \text{h.c.},$$

- no contributions from other 4-Fermion contact interactions:

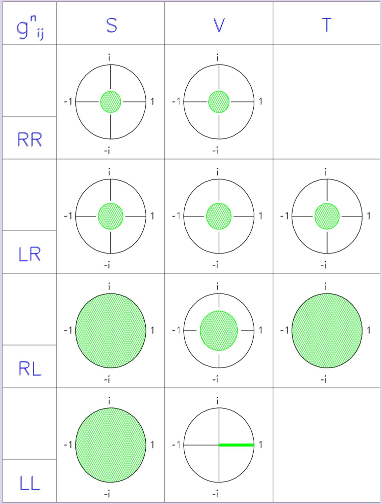
$$\mathcal{H} = 4 \frac{G_{l'l}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{\epsilon\omega} \left[\overline{l'_\epsilon} \Gamma^n (\nu_{l'})_\sigma\right] \left[\overline{(\nu_l)_\lambda} \Gamma_n l_\omega\right],$$

Leptonic decays: what we know

μ



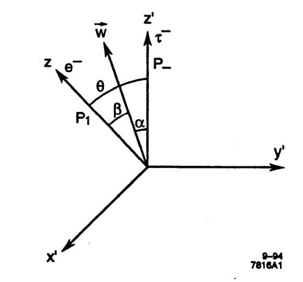
τ

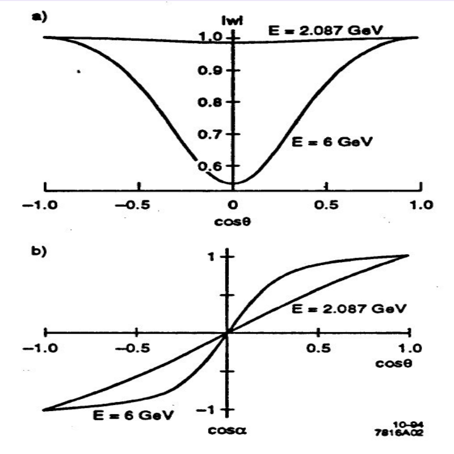


T violation in τ decays (Yung Su Tsai)

e^+e^- polarization allows the search for CP/T violation in τ decays. The τ pairs produced with polarized beams have a significant spin polarization along the beam line.

Reference Frame

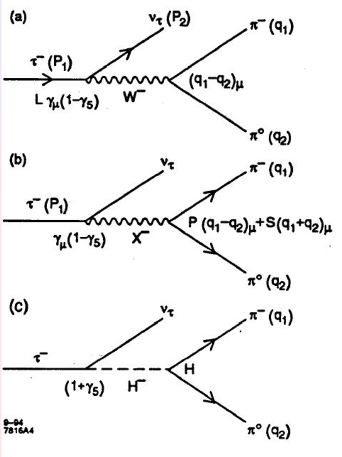




T odd observables in τ decays (Yung Su Tsai)

One can search for *CP* violation in the decay:

$$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$$



Observable

T odd:

$$\mathbf{w} \cdot (\mathbf{q_1} \times \mathbf{q_2})$$

or *CPT* violation in $\tau \rightarrow \pi\nu$

Observable

CPT odd:

$$\mathbf{w} \cdot \mathbf{q}_\pi$$

Conclusions

- τ Electric dipole moment at a superb τ factory looks very interesting (if not exciting!)
- I plan to ascertain the robustness of the Ananthanarayan & Rindani observables against systematic effects and report at the next meeting
- *CP* violation in τ decays needs some theoretical effort: what are the less irrelevant operators involved? What is the estimated size of the effect?