Measurement of the Tau Dipole Moments at LEP

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(L3 Collaboration)

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Motivation

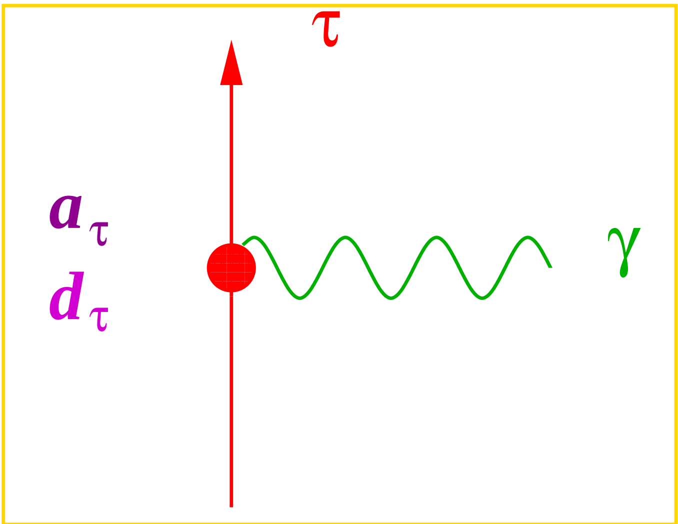
* Basic characteristics of the τ lepton

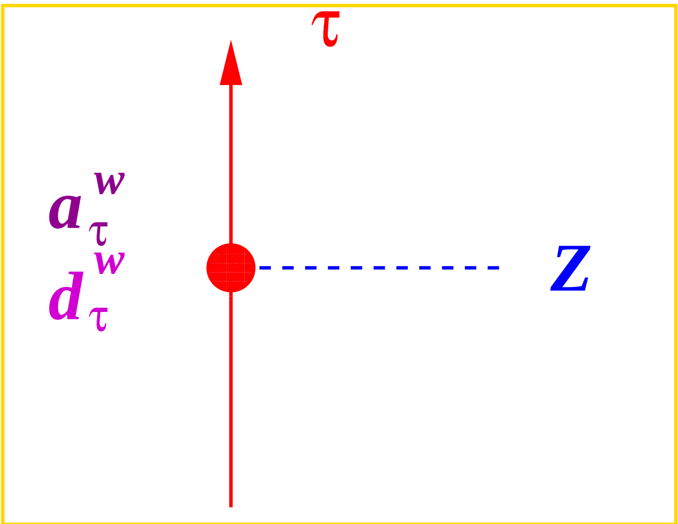
  $\rightarrow$ No measurement done
  ($\textit{spin precession technique}$??)

  $\rightarrow$ Substructure of the τ lepton

  $\rightarrow$ Lepton Universality

* At LEP energies both electromagnetic and weak moments of the τ lepton are accessible

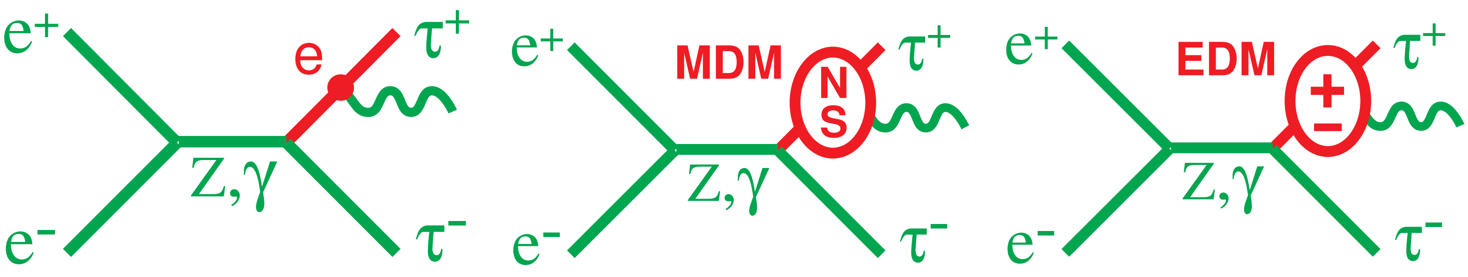




$Q^2 = 0$ (real photon) $\qquad Q^2 = m_Z^2$

* Nonzero values of d_τ or d_τ^w reveal new sources of CP violation

Electromagnetic Dipole Moments



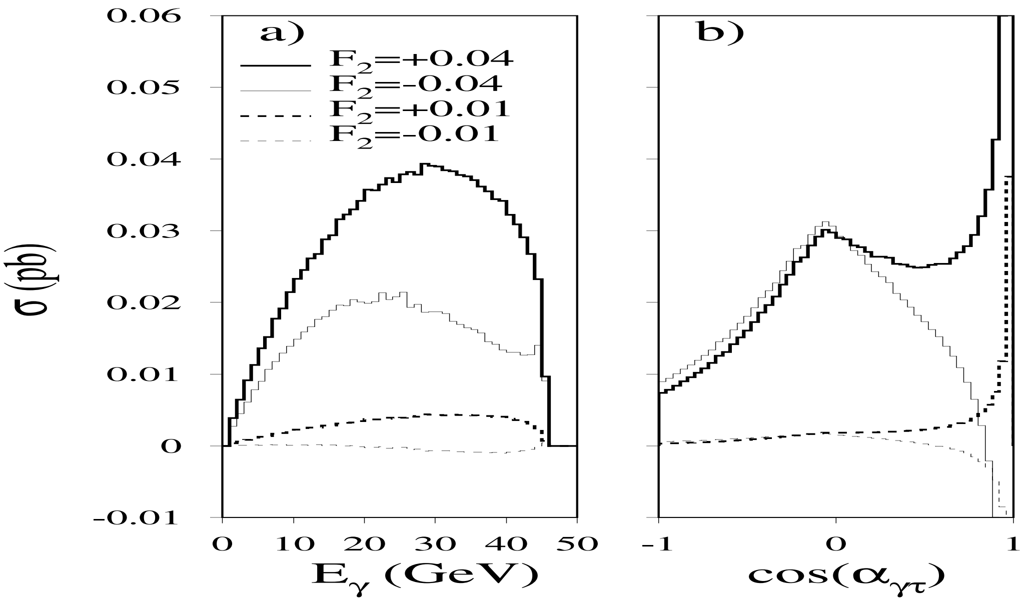
Electric charge, e
$e \equiv F_1(q^2\!=\!0)$

Anomalous Magnetic Dipole Moment, a_τ
$a_\tau \equiv F_2(q^2\!=\!0)$
$a_\tau^{\mathrm{SM}} = \alpha/2\pi + \ldots$
≈ 0.0012

Electric Dipole Moment, d_τ
$d_\tau \equiv eF_3(q^2\!=\!0)$
$d_\tau^{\mathrm{SM}} = 0$
$(\neq 0 \Rightarrow \not{T} \,\&\, \not{P})$

Generic ansatz to describe anomalous $\tau\tau\gamma$ couplings:

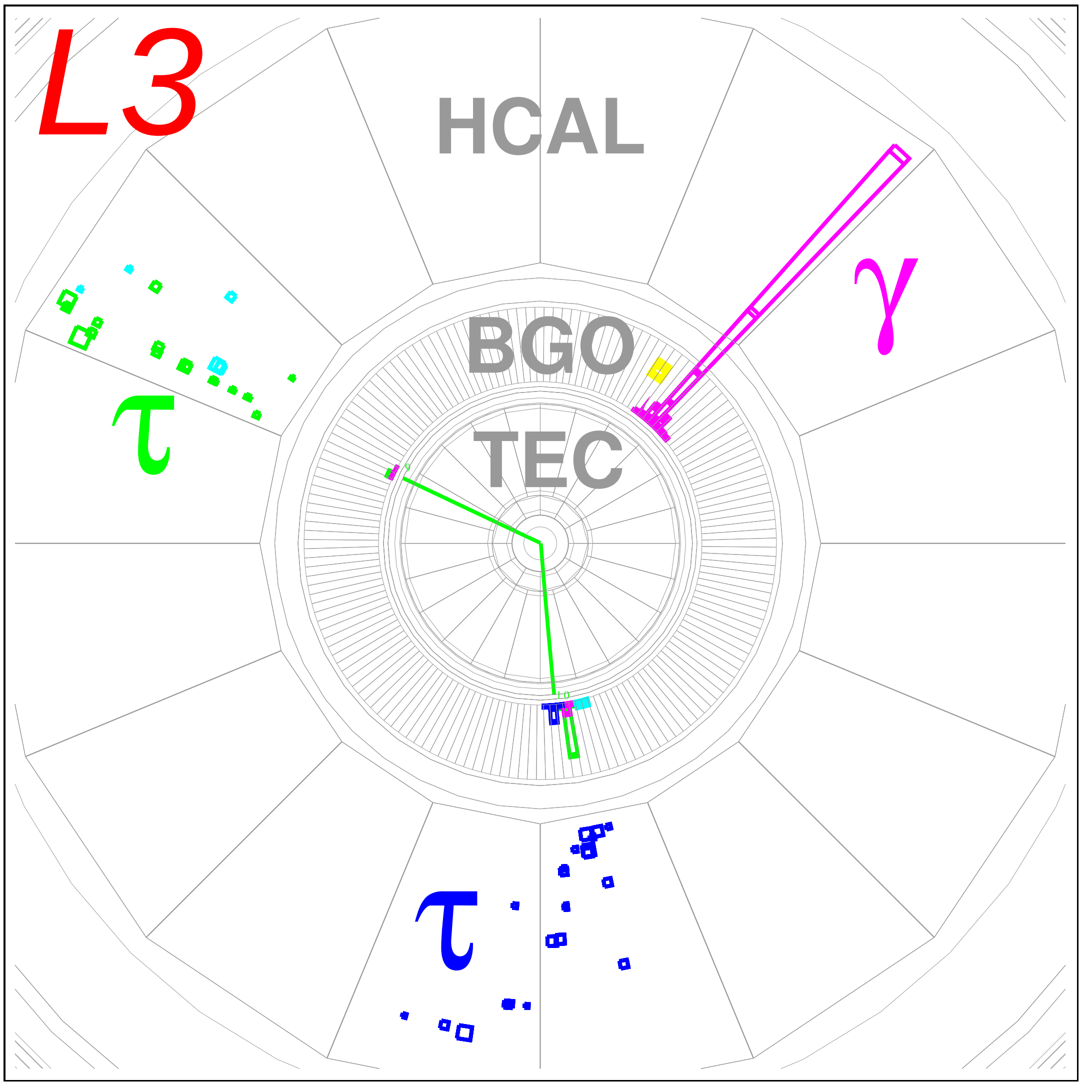
$$\boxed{\gamma^\mu \to F_1(q^2)\gamma^\mu + F_2(q^2)\frac{i}{2m_\ell}\sigma^{\mu\nu}q_\nu - F_3(q^2)\sigma^{\mu\nu}\gamma^5 q_\nu.}$$



Two independent calculations: analytical (B&R) and numerical (TTG)

(J. Biebel and T. Riemann, Z. Phys.C76,53,(1997), S. Gau et al., Nucl. Phys. B523,439,(1998))

Events $\mathrm{e\,e} \to \tau\tau\gamma$



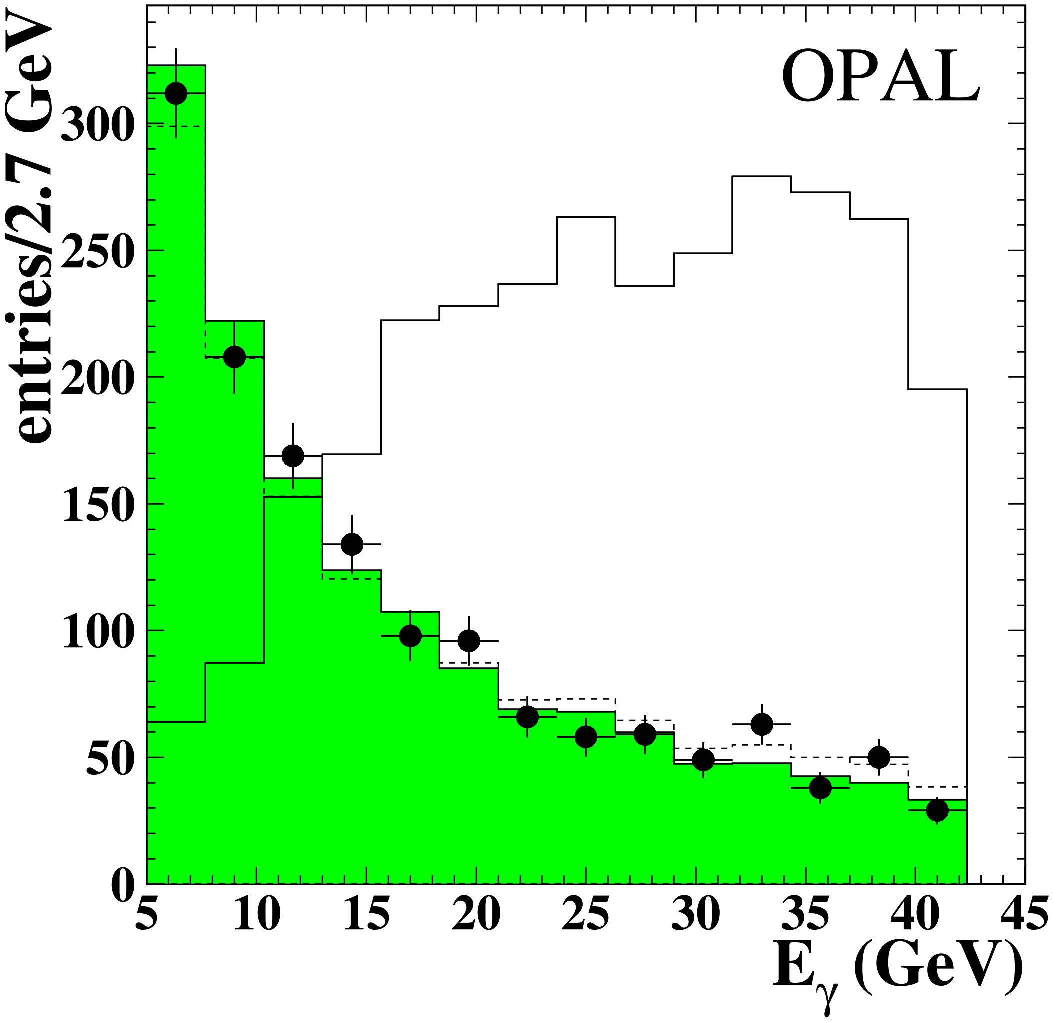
- use Z-peak data, $\int \mathcal{L} \approx 100 pb^{-1}$; corresponding to ≈ 150000 $\mathrm{e^+e^-} \to \tau^+\tau^-(\gamma)$ events

- Fairly standard rejection of:
  - hadron events
  - Bhabha & dimuon
  - two photon
  - cosmic ray's

	L3	OPAL
$\tau\tau\gamma$	1559	1429
background	6.7%	0.13%

OPAL fit of a_τ

- one dimensional fit to photon energy spectrum with a_τ free
- normalization fixed such that number of events agree in data and Monte Carlo



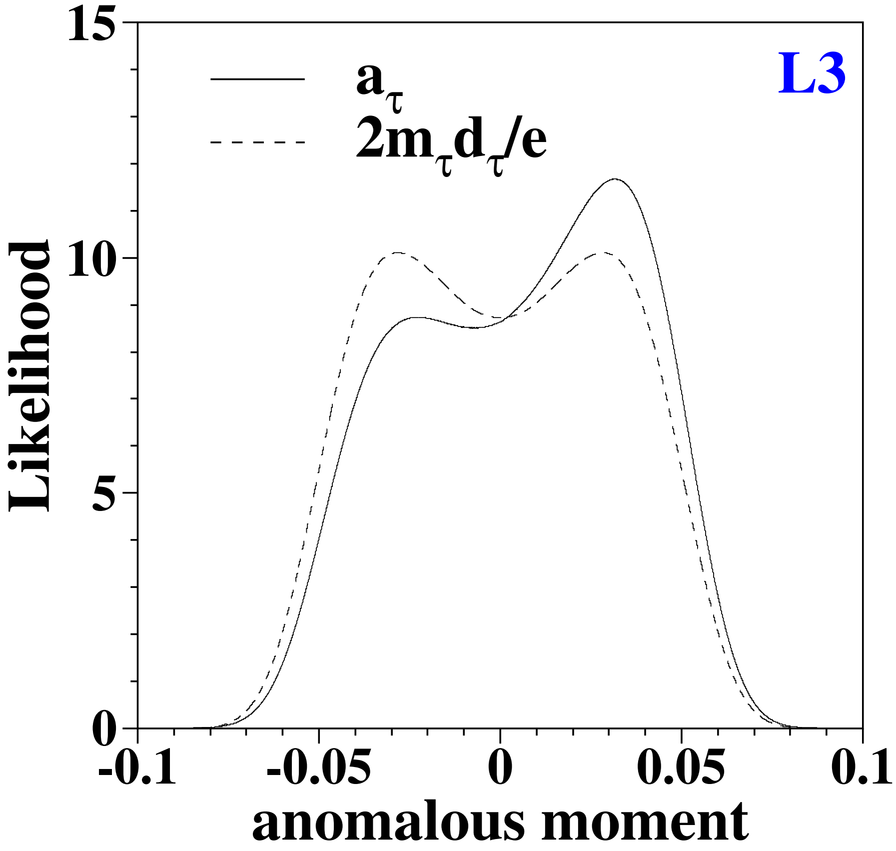
$$\boxed{-0.068 < a_\tau < 0.065 \text{ (95\% C.L.)}}$$

or, after substitution $| \ a_\tau \ | \rightarrow | \ \frac{2 \cdot m_\tau}{e} d_\tau \ |$

$$\boxed{| \ d_\tau \ | < 3.7 \cdot 10^{-16} e \cdot cm}$$

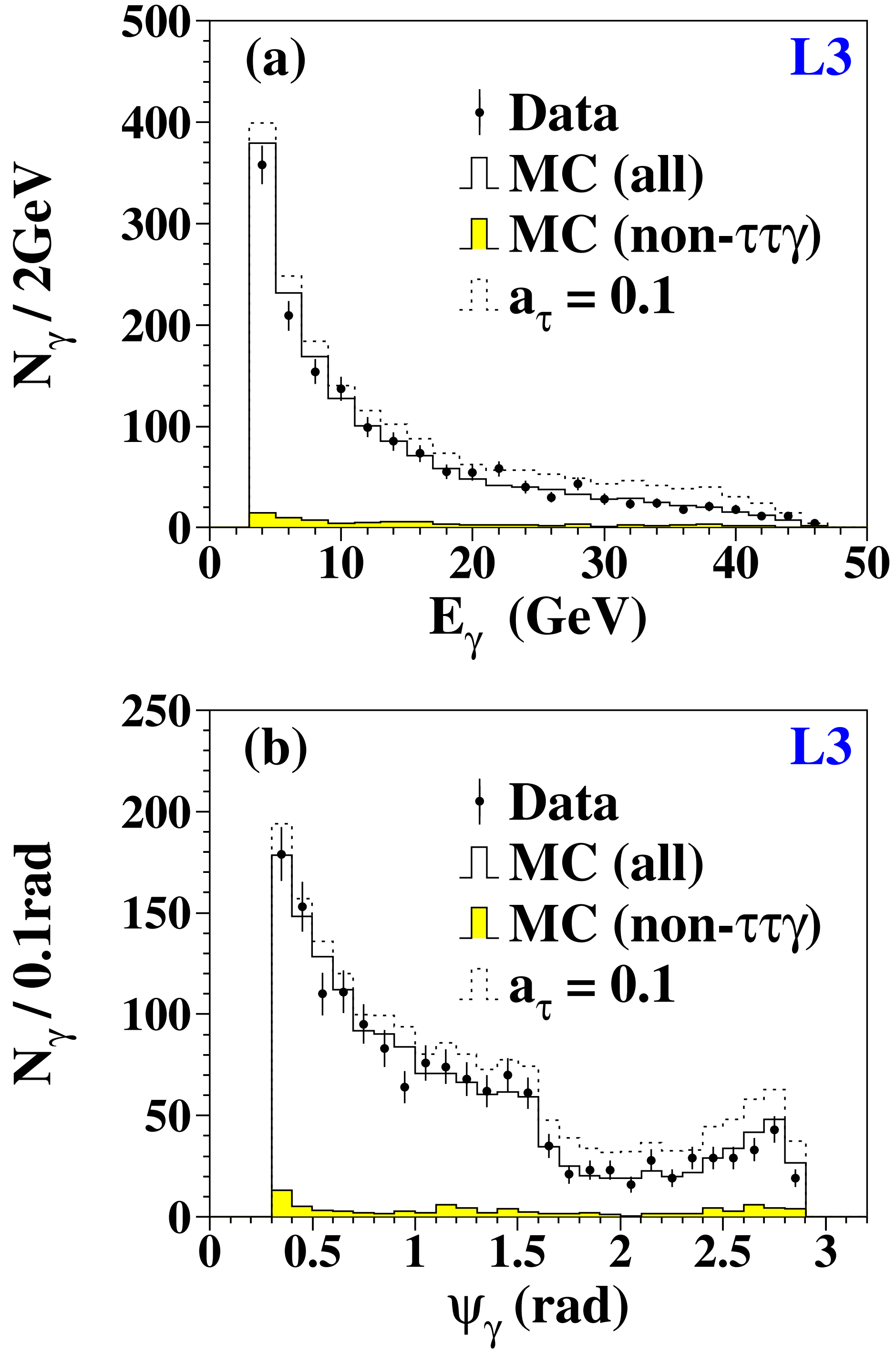
L3 fits for a_τ and d_τ

- two dimensional fit to photon energy vs. angle beetween γ and closest τ
- normalization fixed by $\int \mathcal{L}$
- Fit for a_τ assumes $d_\tau = 0$ and vice-versa



- $\mathcal{L}(a_\tau)$ is asymmetric due to inclusion of linear (interference) terms in a_τ
- $\mathcal{L}(d_\tau)$ is exactly symmetric (linear term $\equiv 0$

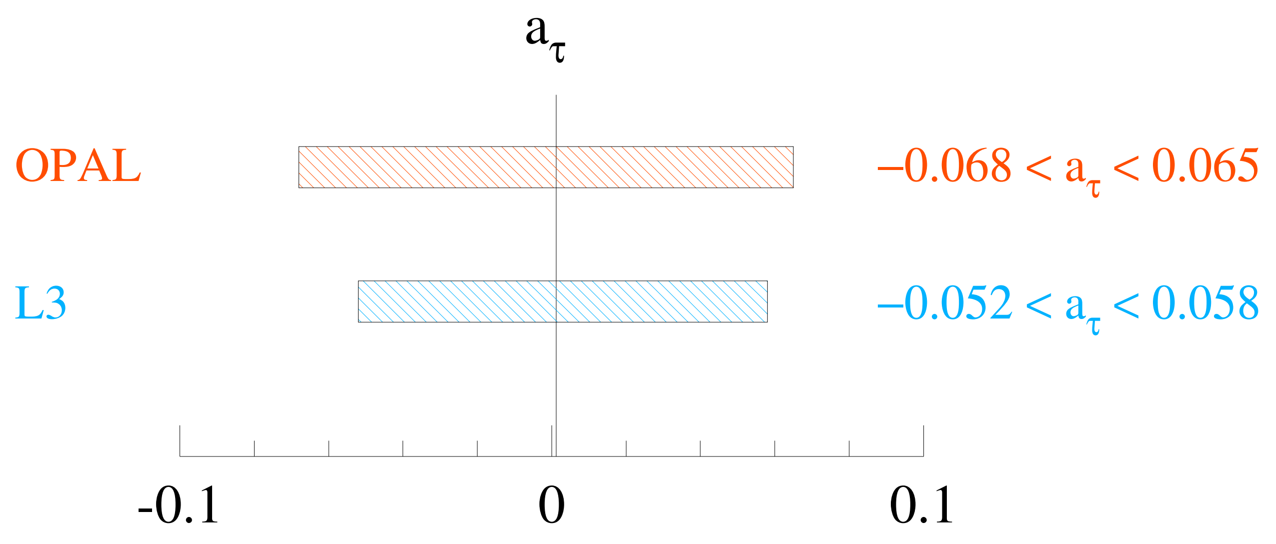
L3 fits for a_τ and d_τ

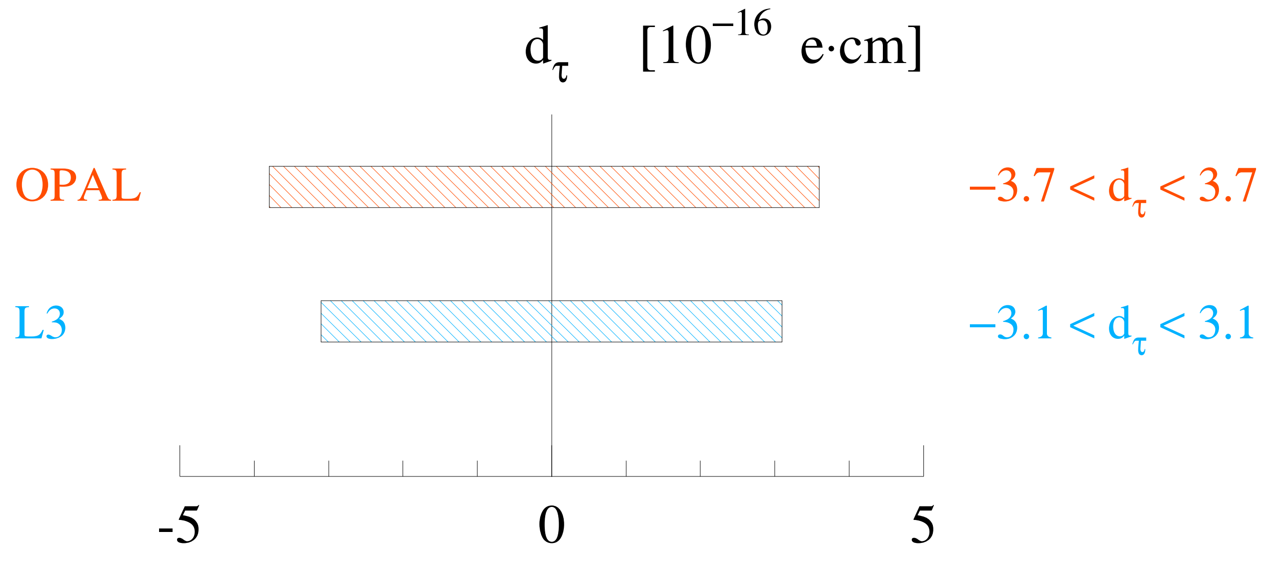


$$a_\tau = 0.004 \pm 0.027 \pm 0.023 \text{ (68\% C.L.)}$$

$$d_\tau = 0.0 \pm 1.5 \pm 1.3 \cdot 10^{-16} ecm$$

Summary on a_τ and d_τ





all limits at 95% C. L.

≈ No evidence for new physics beyond the Standard Model ≈

(no indication for CP violation)

Weak Dipole Moments

effective Lagrangian ansatz:

$$\mathcal{L}_{eff} = -\frac{i}{2} \cdot \frac{eF_3^w}{2m_\tau} \bar{\psi} \sigma^{\mu\nu} \gamma_5 \psi Z_{\mu\nu} + \frac{1}{2} \cdot \frac{eF_2^w}{2m_\tau} \bar{\psi} \sigma^{\mu\nu} \psi Z_{\mu\nu}$$

$a_\tau^w \equiv F_2^w$ (Weak anomalous magnetic dipole moment)

$d_\tau^w \equiv \frac{eF_3^w}{2m_\tau}$ (Weak electric dipole moment)

Standard Model:

$$a_\tau^w = -(2.10 + 0.61i) \times 10^{-6}$$

$$d_\tau^w \sim 3 \times 10^{-37} e \cdot cm$$

several extensions of SM predict via 1–loop effects larger values of a_τ^w and d_τ^w, e. g.:

composite models:	a_τ^w up to 10^{-3}
lepto-quarks:	$d_\tau^w \approx 2 \times 10^{-19}\ e \cdot cm$

method of the measurement

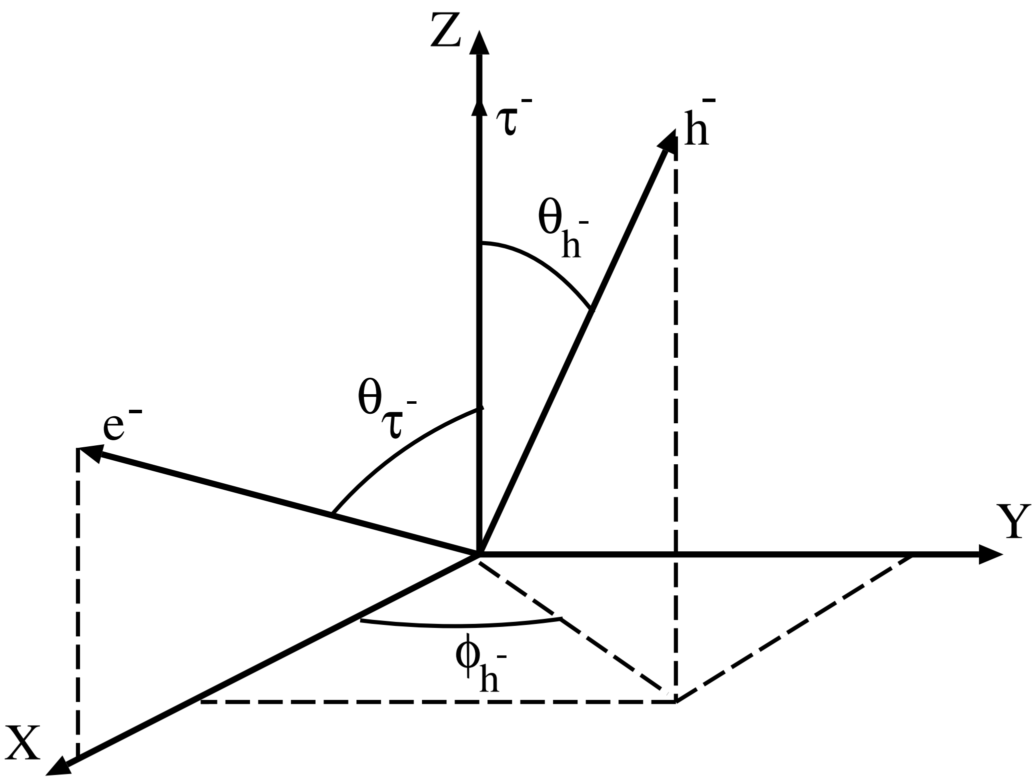
Weak dipole moments are accessible from the τ polarisation in $Z \to \tau\tau$:

$$\frac{d\sigma}{d\Omega_{\tau^-}} = \frac{d\sigma^0}{d\Omega_{\tau^-}} + \frac{d\sigma^{Spin}}{d\Omega_{\tau^-}} + \frac{d\sigma^{Spin-Spin}}{d\Omega_{\tau^-}}$$

Use exclusive hadronic τ decays: $\tau^- \to h^- \nu_\tau$

$$\frac{d\sigma^{Spin}(\tau^+\tau^-)}{d(\cos\theta_{\tau^-})d\phi_{h^\pm}} = C \cdot [\mp X_+ \cos\phi_{h^\pm} + (Y_- \mp Y_+)\sin\phi_{h^\pm}]$$

e.g. $X_+ = X_+(Re(a_\tau^w), \theta_{\tau^-})$

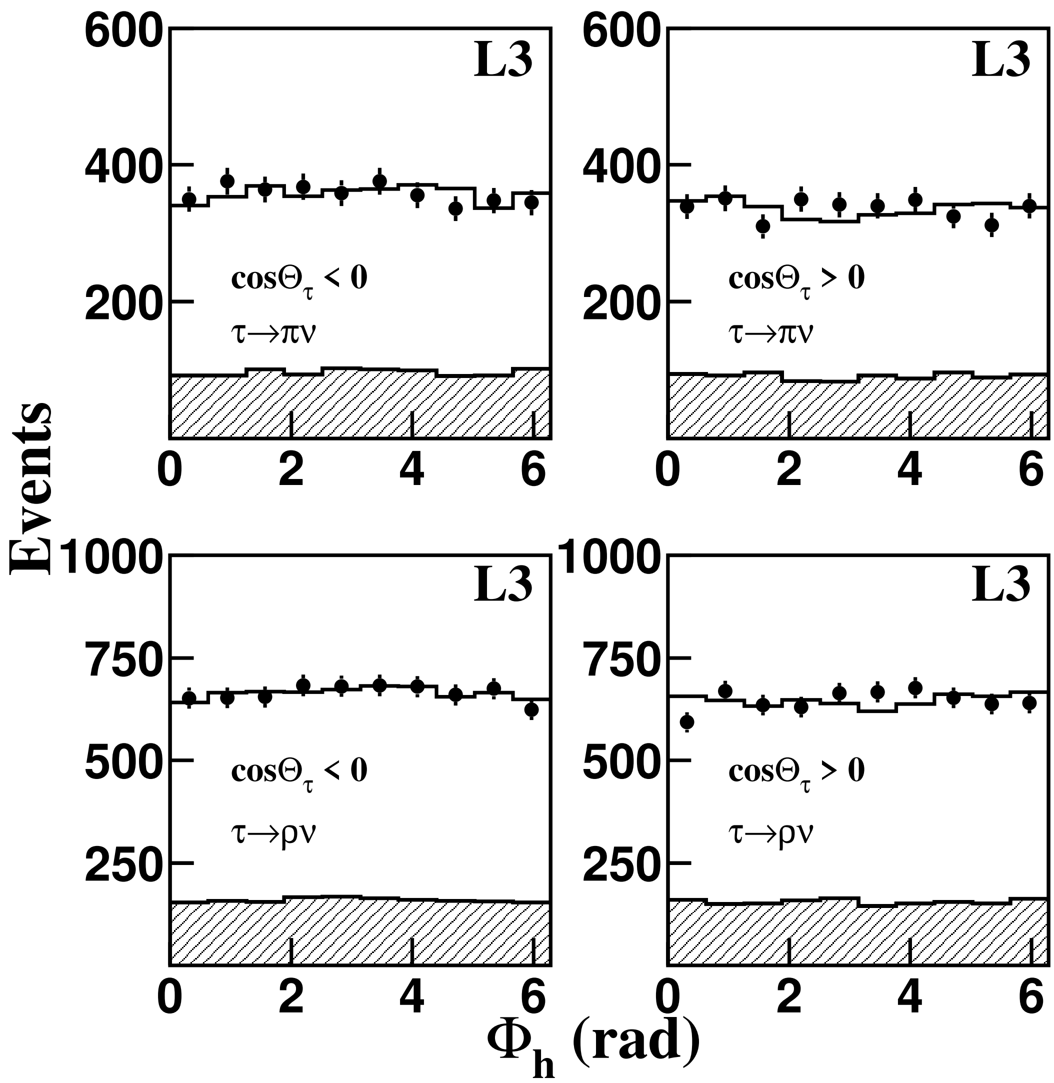


τ direction of flight needed - only for hadronic decays accessible

L3 Results

using $\tau \to \rho\nu$ and $\tau \to \pi\nu$ decays,

Data 1991-95 :$\approx$ 9000 events



The first direct measurement of a_τ^w:

$$Re(a_\tau^w) = (0.0 \pm 1.6 \pm 2.3) \times 10^{-3}$$

$$Im(a_\tau^w) = (-1.0 \pm 3.6 \pm 4.3) \times 10^{-3}$$

$$Re(d_\tau^w) = (-0.44 \pm 0.88 \pm 1.33) \times 10^{-17} e \cdot cm$$

inclusive measurement of d_τ^w

Use all τ decay modes,

$$e^+e^- \to \tau^+\tau^- \to A\,B + n\nu$$

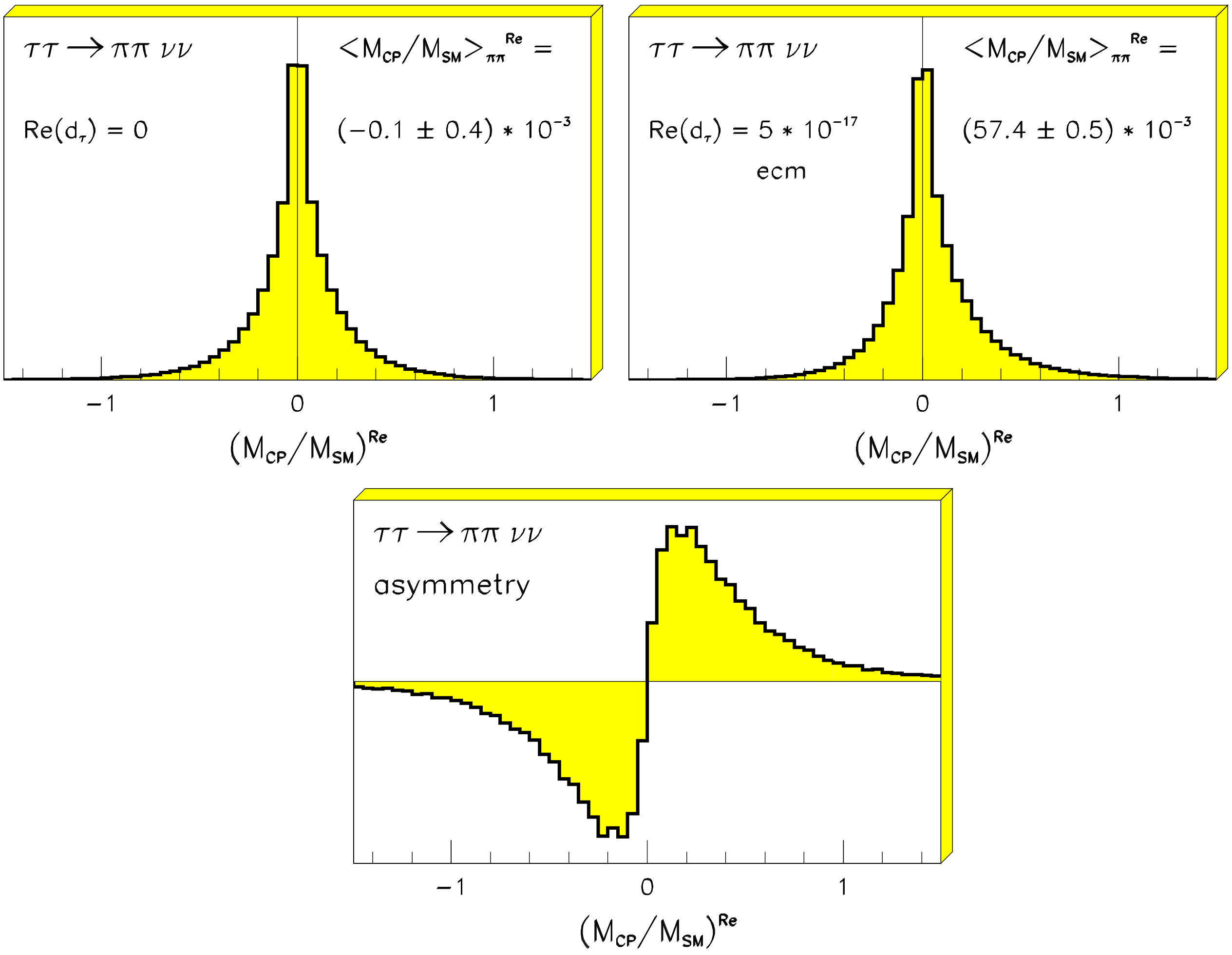
and describe with the ansatz:

$$d\sigma \propto |T_{SM} + T_{CP}|^2 = |T_{SM}|^2 + 2Re(T_{SM}^* T_{CP}) + |T_{CP}|^2$$

$$2Re(T_{SM}^* T_{CP}) = Re(d_\tau^w)\mathcal{M}_{CP}^{Re} + Im(d_\tau^w)\mathcal{M}_{CP}^{Im}$$

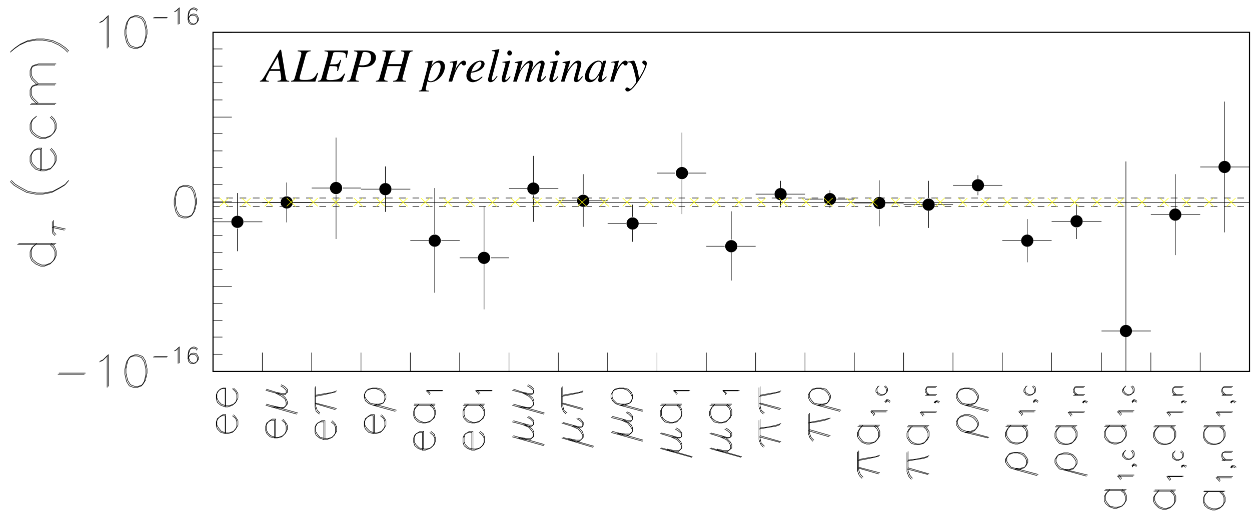
CP–odd observables:

$$\mathcal{O}^{\rm Re} = \frac{\mathcal{M}_{\rm CP}^{\rm Re}}{\mathcal{M}_{\rm SM}} \quad , \quad \mathcal{O}^{\rm Im} = \frac{\mathcal{M}_{\rm CP}^{\rm Im}}{\mathcal{M}_{\rm SM}}$$



ALEPH Results (*)

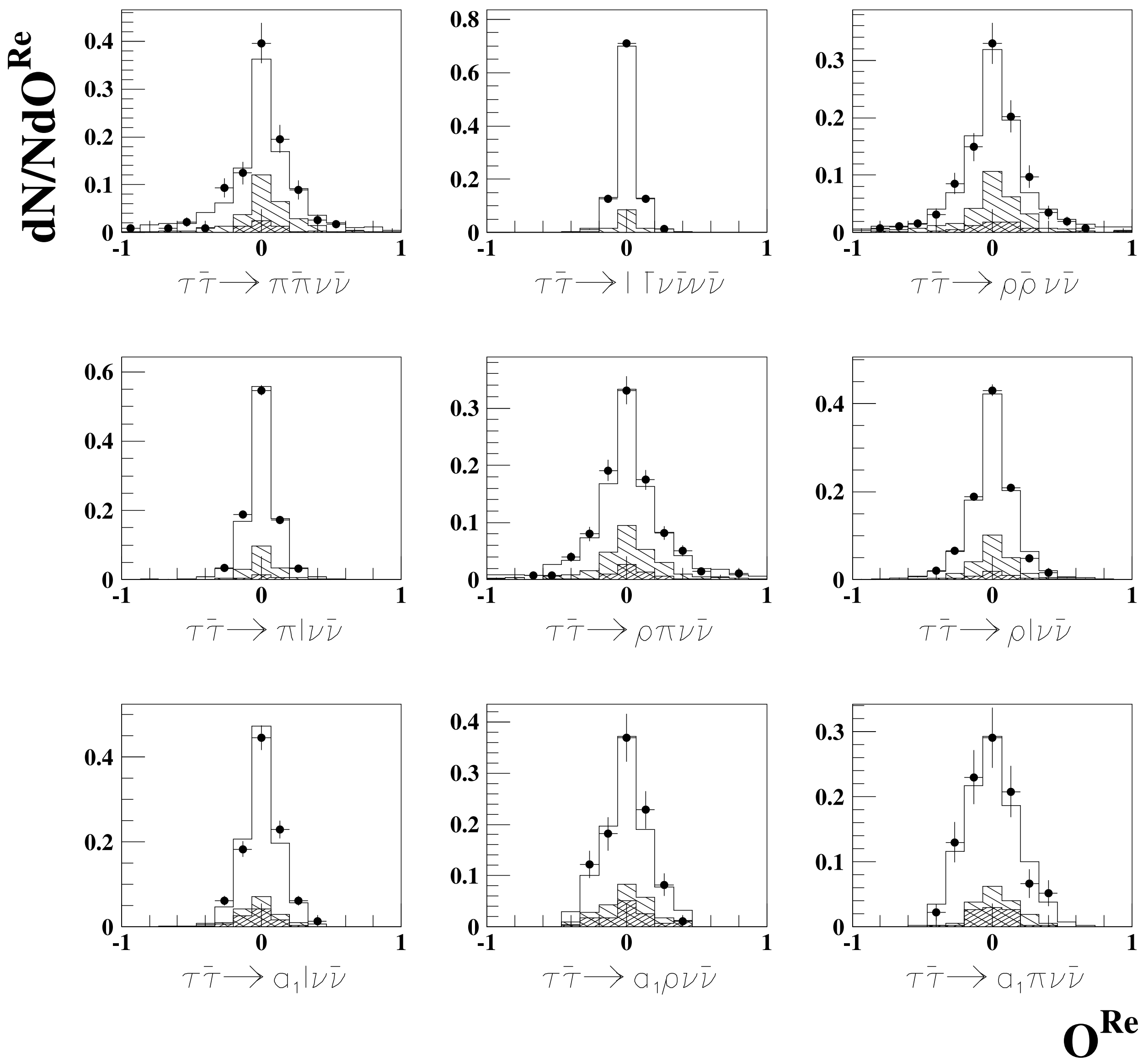
Data 1990-95 83000 events



$$Re(d_\tau^w) = (-0.29 \pm 2.59 \pm 0.88) \times 10^{-18}\, e \cdot cm$$

DELPHI Results (*)

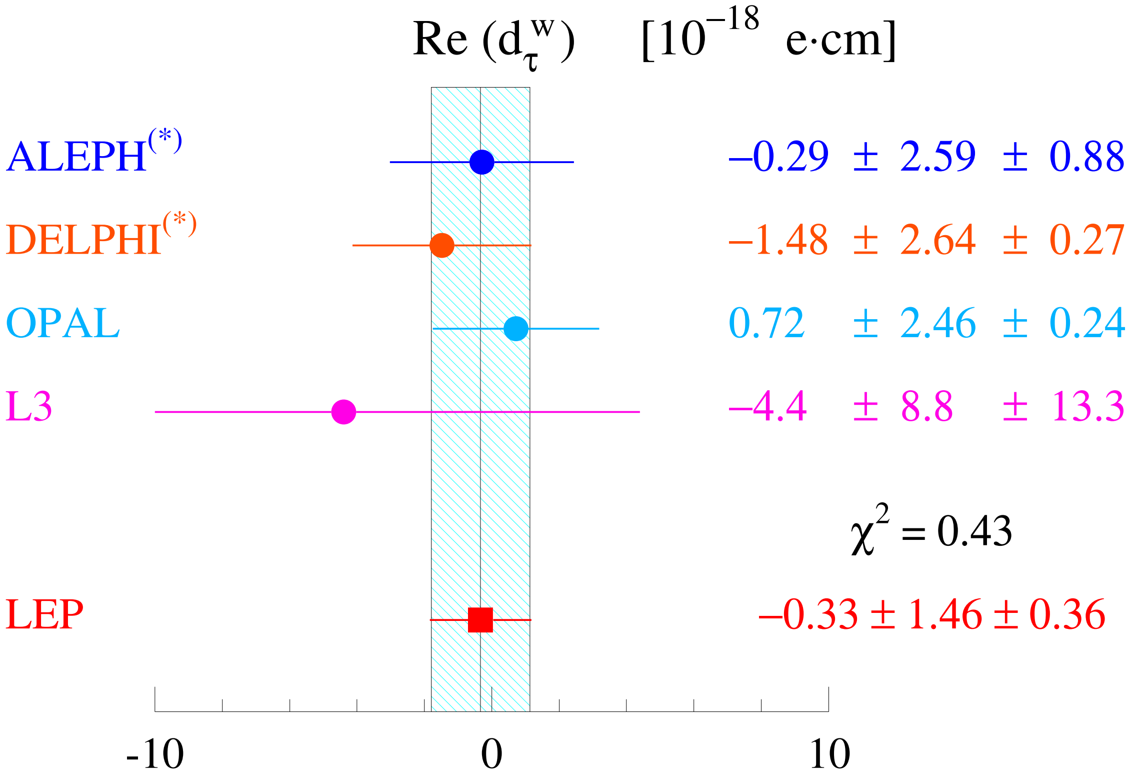
Data 1992-95 22000 events

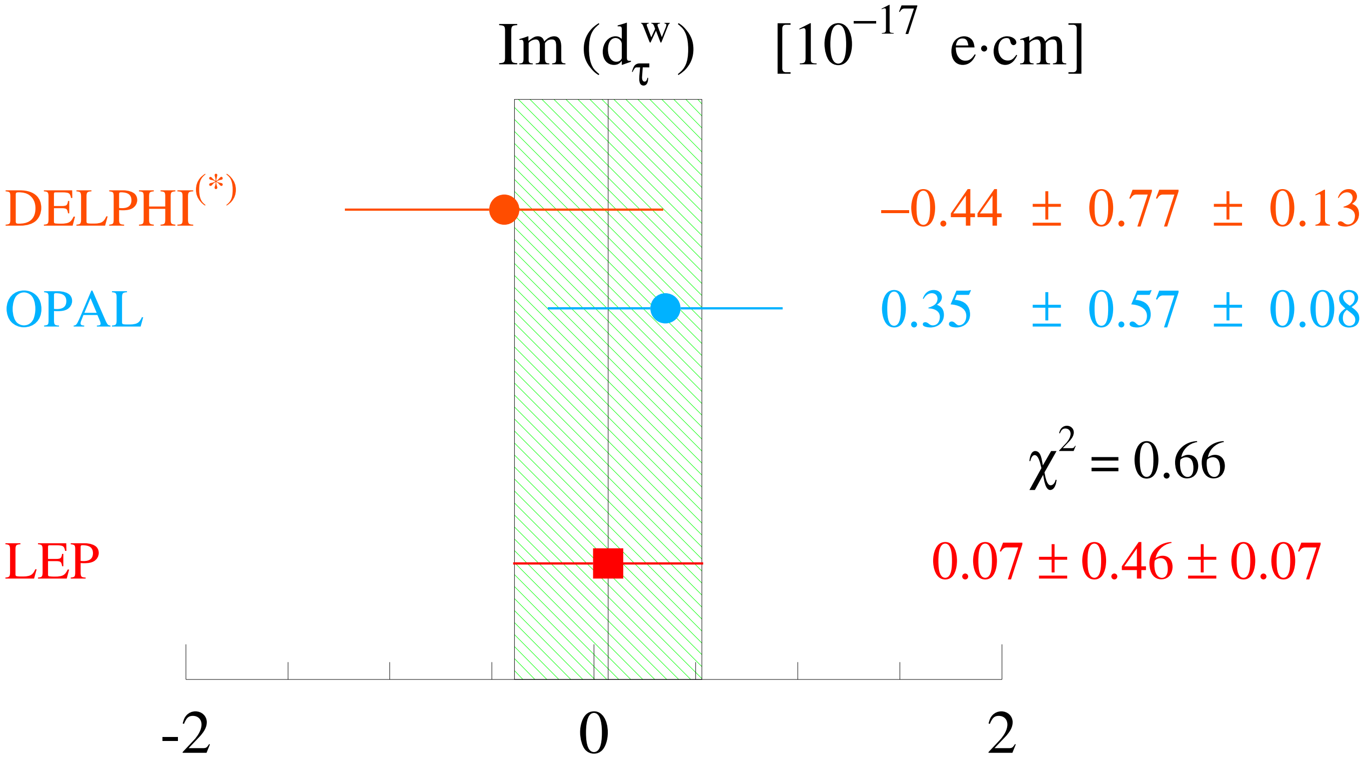


$$Re(d_\tau^w) = (-1.48 \pm 2.64 \pm 0.27) \times 10^{-18}\, e \cdot cm$$

$$Im(d_\tau^w) = (-0.44 \pm 0.77 \pm 0.13) \times 10^{-17}\, e \cdot cm$$

LEP Results


Re (d_τ^w) $[10^{-18}$ e·cm]
ALEPH(*)
DELPHI(*)
OPAL
L3
LEP
$-0.29 \pm 2.59 \pm 0.88$
$-1.48 \pm 2.64 \pm 0.27$
$0.72 \pm 2.46 \pm 0.24$
$-4.4 \pm 8.8 \pm 13.3$
$\chi^2 = 0.43$
$-0.33 \pm 1.46 \pm 0.36$
-10
0
10


Im (d_τ^w) $[10^{-17}$ e·cm]
DELPHI(*)
OPAL
LEP
$-0.44 \pm 0.77 \pm 0.13$
$0.35 \pm 0.57 \pm 0.08$
$\chi^2 = 0.66$
$0.07 \pm 0.46 \pm 0.07$
-2
0
2

Summary

* Electromagnetic and weak dipole moments of the τ lepton have been measured at LEP

* The precision is not sufficient to probe the Standard Model

* It just approaches the size of effects which are predicted by models with give the maximum values for $\mid a_\tau^w \mid$ and $\mid d_\tau^w \mid$

* No hints for physics beyond the Standard Model