Measurement of the Tau Dipole Moments at LEP

Pablo García–Abia

University of Basel

(L3 Collaboration)

- Motivation
- Electric and Anomalous Magnetic Dipole Moments
- Weak Dipole Moments
- Conclusions

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Motivation

* $\ast$ Substructure of the τ lepton
* $\ast$ Lepton universality
* $\ast$ Search for <u>new sources</u> of CP violation:

$$\not{C}\not{P} \text{ in } \mathrm{Z} \to \mathrm{f\bar{f}} \implies \text{new physics beyond SM}$$

$\ast$ $\mathrm{Z} \to \tau^+\tau^-(\gamma)$:

(1) $\not{C}\not{P}$ extensions of SM $\to$ $d_f \sim m_f$

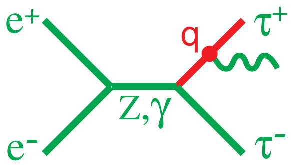
(2) Sensitivity to Spin Correlations of the final state fermions: τ decays

$\not{C}\not{P}$ couplings in $\mathrm{e^+e^-} \to \tau^+\tau^-(\gamma)$ parametrized as

$\boxed{\text{dipole form factors}}$

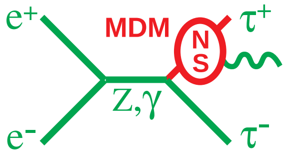
$Q^2 = 0 \to$ electric and anomalous magnetic *$\tau\gamma$ vertex*

$Q^2 = m_{\mathrm{Z}}^2 \to$ weak electric and anomalous magnetic *$\mathrm{Z}\tau\tau$ vertex*



Electric charge, q_τ

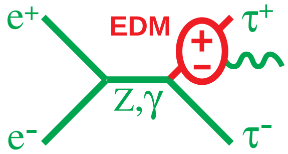
$$q_\tau \equiv F_1(q^2\!=\!0)$$



Anomalous Magnetic Dipole Moment, a_τ

$$a_\tau \equiv F_2(q^2\!=\!0)$$

$$a_\tau^{\mathrm{SM}} = \alpha/2\pi + \ldots \approx 0.0012$$



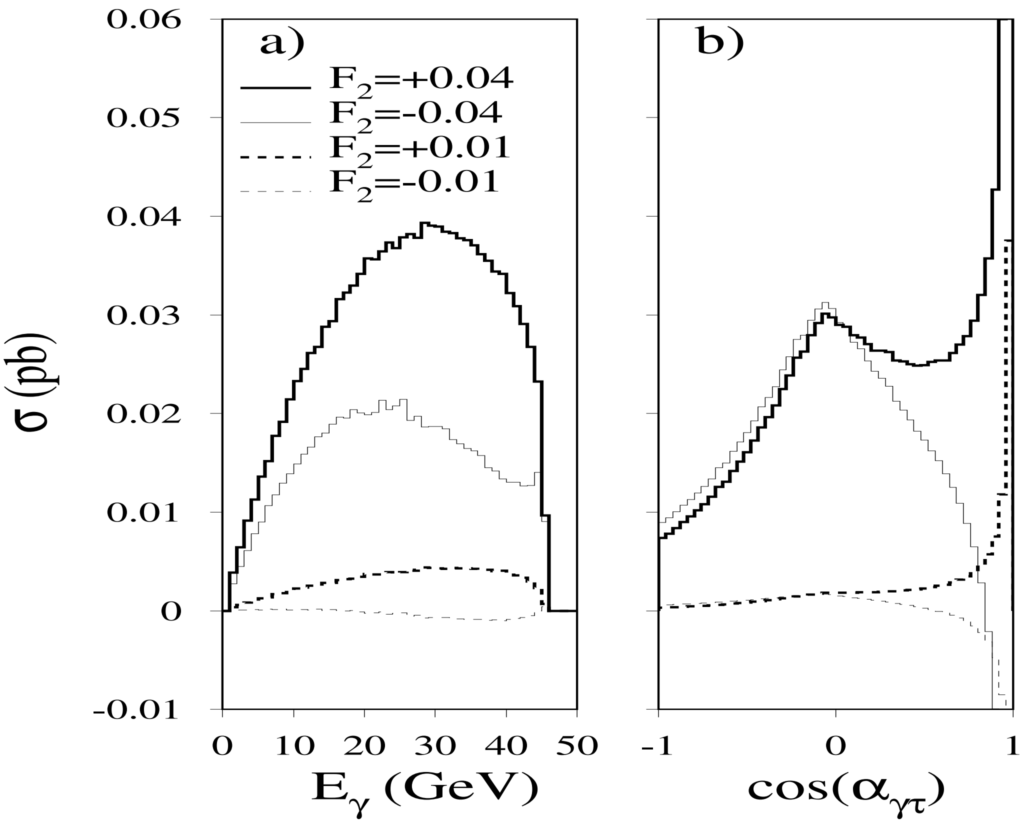
Electric Dipole Moment, d_τ

$$d_\tau \equiv eF_3(q^2\!=\!0)$$

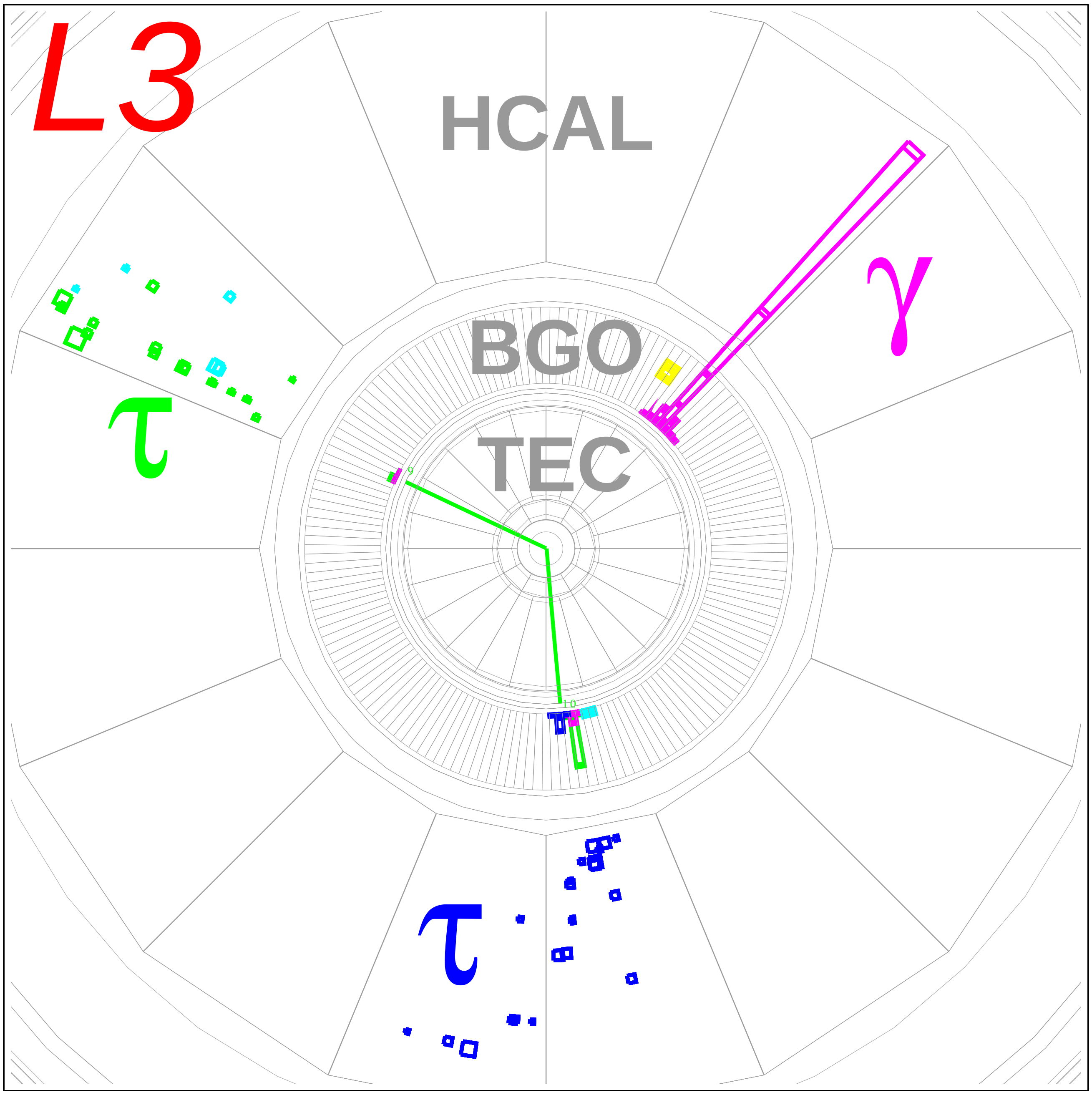
$$d_\tau^{\mathrm{SM}} = 0$$

$$(\neq 0 \Rightarrow \not{T}\ \&\ \not{P})$$

Anomalous couplings enhance production of photons with high energy and large opening angle



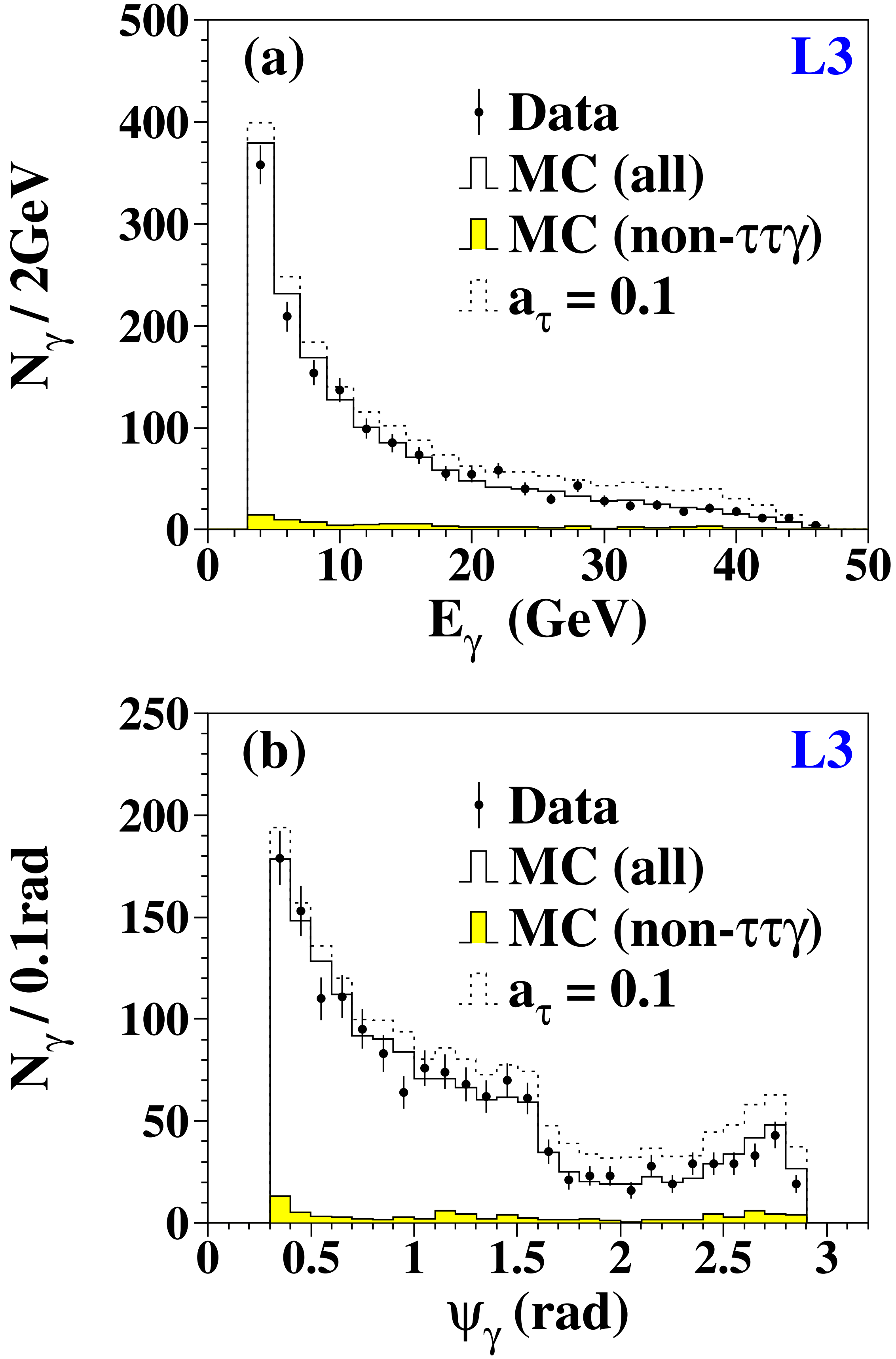
Two independent calculations: analytical (Riemann) and numerical (TTG)



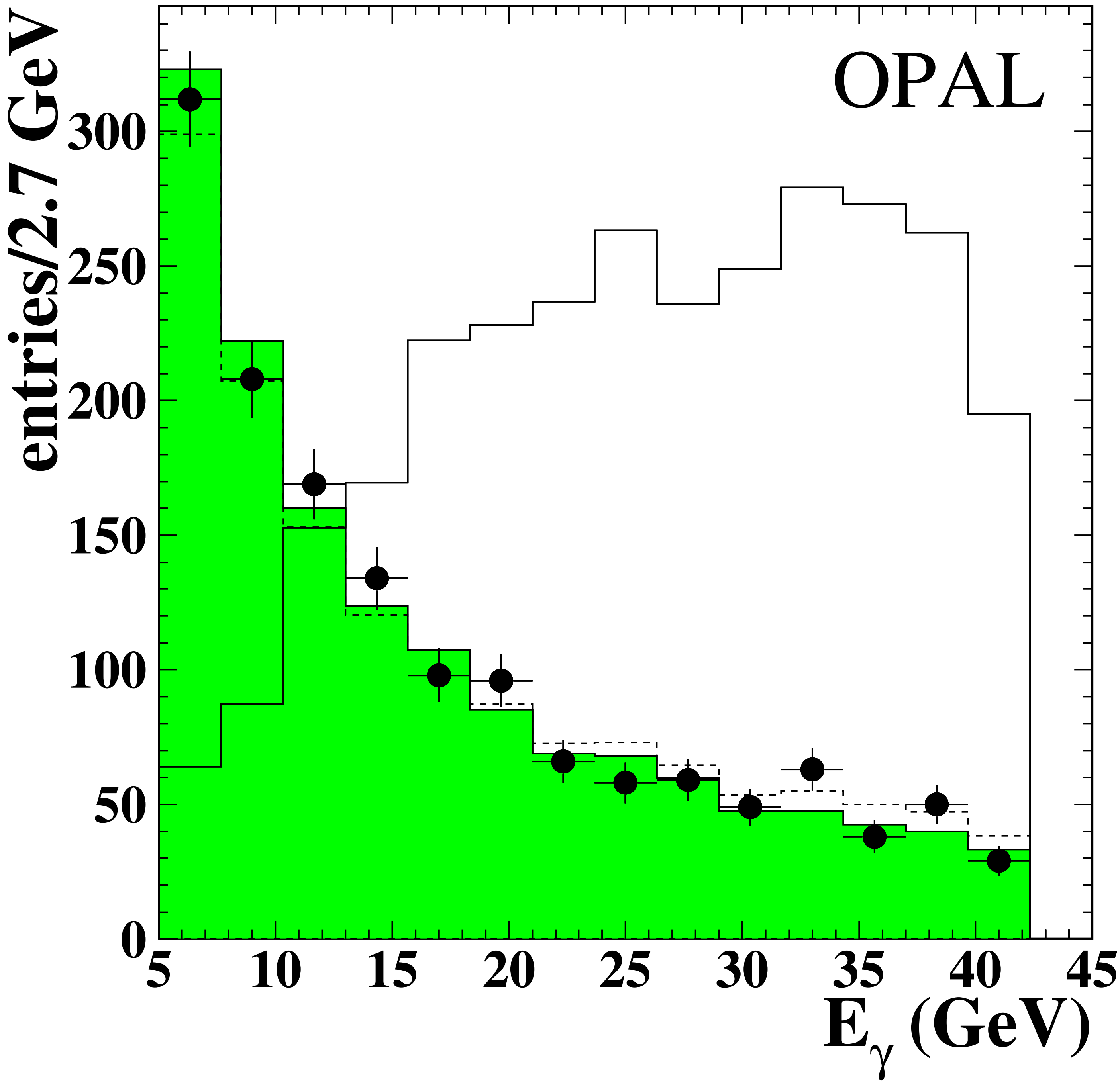
L3 and OPAL, about 1500 events each.

Low background

Good E_γ and θ_γ resolutions



(a)
L3
Data
MC (all)
MC (non-ττγ)
a_τ = 0.1
N_γ / 2GeV
E_γ (GeV)
0
100
200
300
400
500
0
10
20
30
40
50
(b)
L3
Data
MC (all)
MC (non-ττγ)
a_τ = 0.1
N_γ / 0.1rad
ψ_γ (rad)
0
50
100
150
200
250
0
0.5
1
1.5
2
2.5
3


OPAL
entries/2.7 GeV
0
50
100
150
200
250
300
5
10
15
20
25
30
35
40
45
E_γ (GeV)

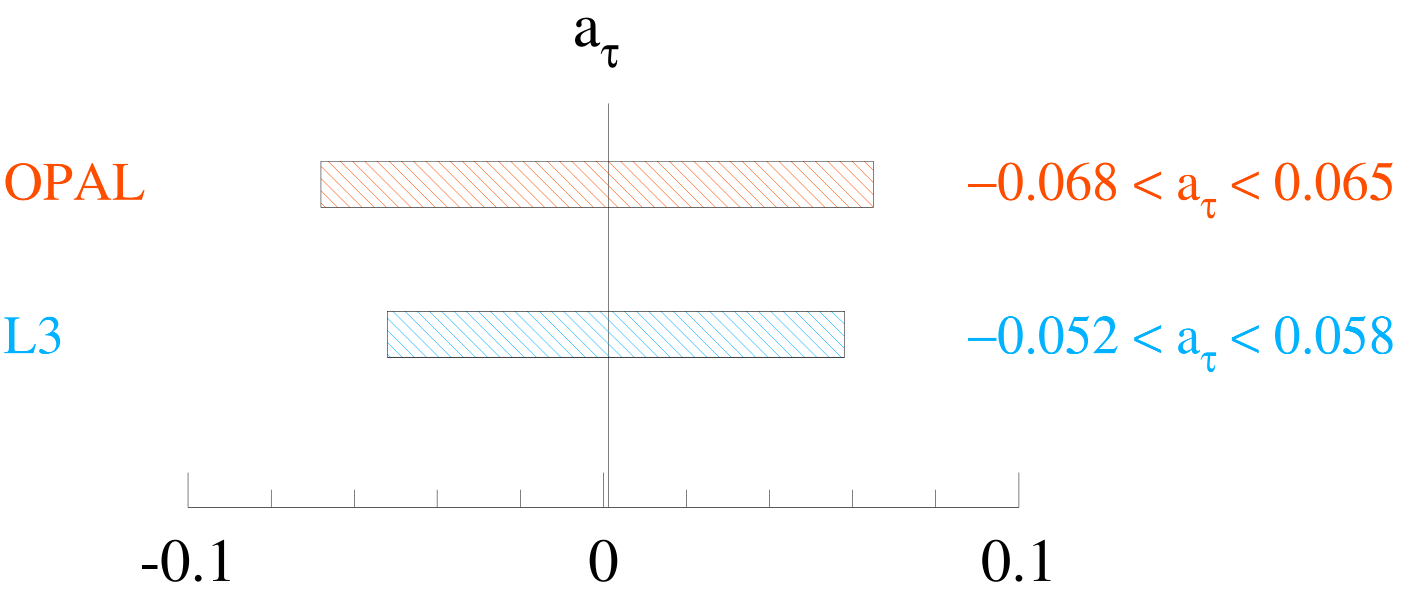
Systematic Errors

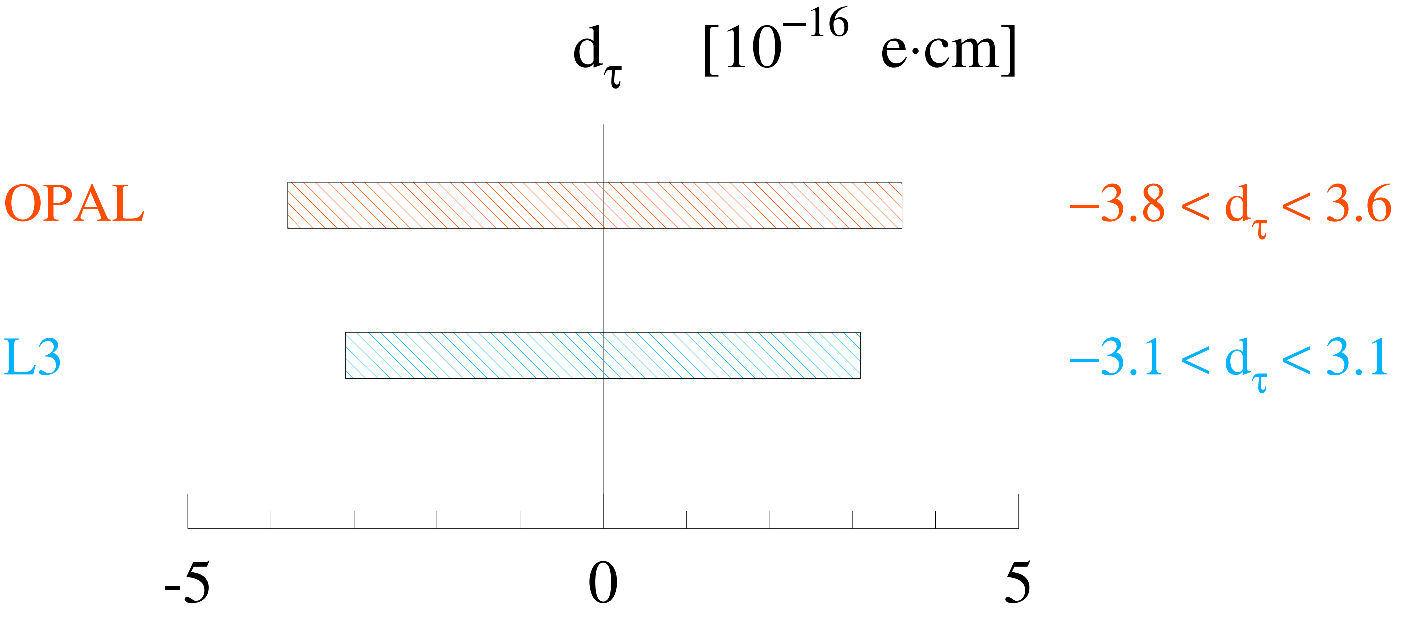
- normalisation of the $\tau\tau\gamma$ sample
- event selection cuts and γ reconstruction

- modelling of the process $e^+e^- \rightarrow \tau^+\tau^-\gamma$
- multiple photon radiation

$\approx$ at the level of the statistical error $\approx$

Results on Electric Dipole Moments





$\approx$ <u>No deviation from SM observed</u> $\approx$

(no indication for CP violation)

Weak dipole moment d_τ^w $\rightarrow$ form factor at $Q^2 = m_Z^2$

$$\mathrm{e}^+\mathrm{e}^- \rightarrow \tau^+\tau^- \rightarrow A\,B + n\nu$$

CP–odd observables:

$$\langle \mathcal{O}^{\mathrm{Re}} \rangle_{AB} = \frac{m_Z}{e} \cdot c_{AB} \cdot \mathrm{Re}\,(d_\tau^w)$$

$$\langle \mathcal{O}^{\mathrm{Im}} \rangle_{AB} = \frac{m_Z}{e} \cdot f_{AB} \cdot \mathrm{Im}\,(d_\tau^w)$$

Optimal observables:

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

$\mathcal{M}$ $\rightarrow$ τ flight and spin directions required.

$$\boxed{\langle \mathcal{O} \rangle \neq 0 \Longrightarrow \text{CP violation}}$$

ALEPH, DELPHI and OPAL

$\approx$ Optimal Variables $\approx$

L3 method

Azimuthal asymmetries specially defined to be sensitive to the transverse polarisation of each single τ

This method allows to measure both d_τ^w and a_τ^w:

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

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

Experiment	Data	#decays	Decay channels
ALEPH$^{(*)}$	1990–95	83 000	e, μ, π, ρ, a_1
DELPHI$^{(*)}$	1992–95	22 000	e, μ, π, ρ, a_1 (3pr)
OPAL	1991–95	70 000	e, μ, π, ρ, a_1 (3pr)
L3	1991–95	9 000	π, ρ

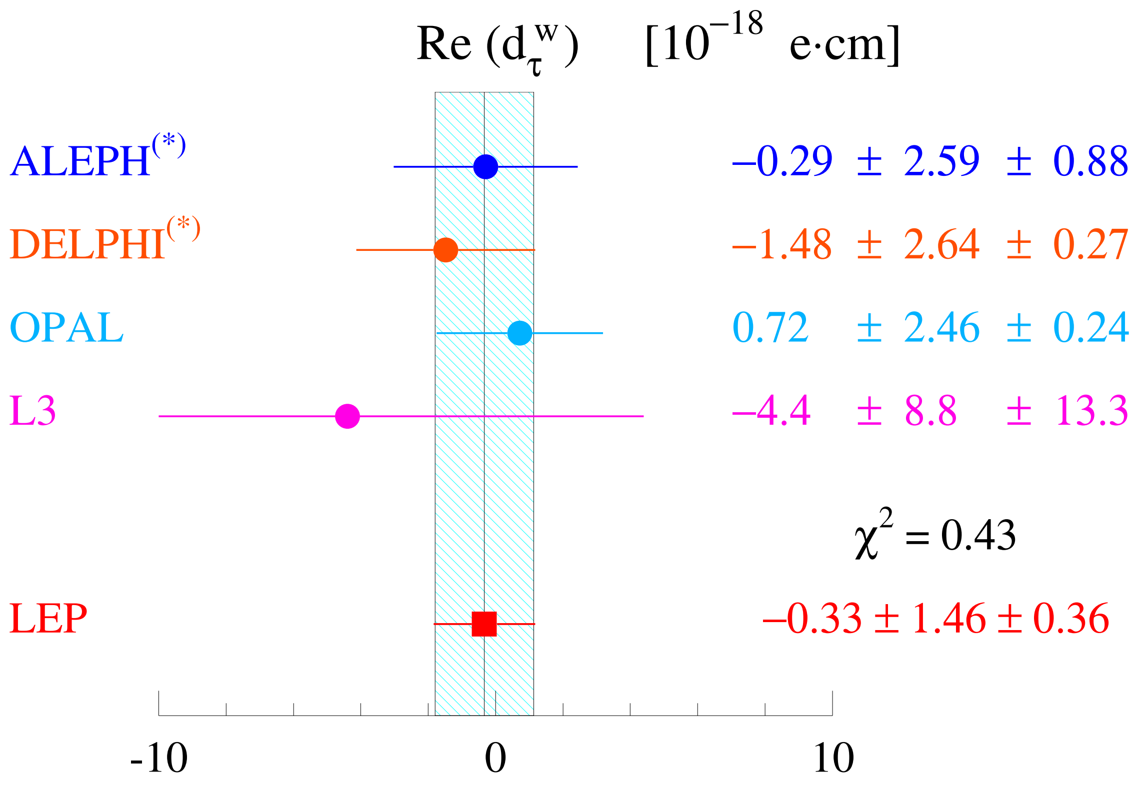
Main systematic effects:

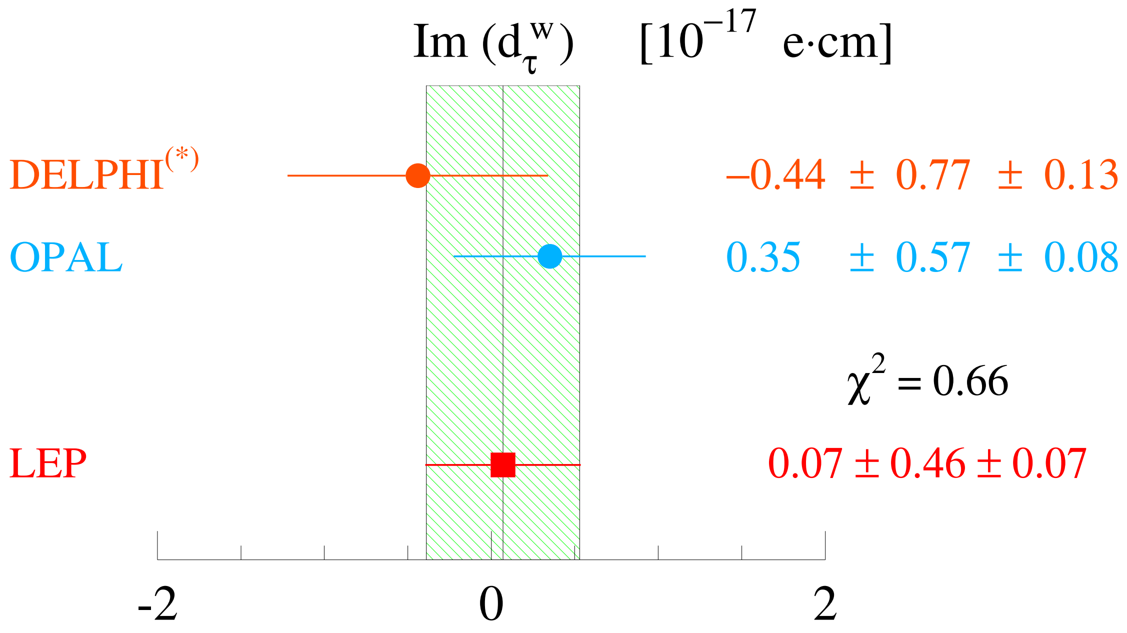
- ⋆ alignement and homogeneity of the detectors
- ⋆ CP invariance of the detectors

  Checked at the level of $\sim 10^{-19}\ e{\cdot}\mathrm{cm}$

  by artificially destroying the Spin Correlations (event by event)

Results on Weak Dipole Moments





≈ No deviation from SM observed ≈

(no indication for CP violation)

From full data samples at LEP $\rightarrow$ CP tests

$\approx$ No indication of CP violation in $Z \rightarrow \tau\tau(\gamma)$ $\approx$

Limits set at 95% CL on:

$*$ weak dipole moments:

$$\begin{aligned}
(\ -3.3 < \ \mathrm{Re}\,(d^w_\tau) \ &< 2.7\ ) \times 10^{-18} \quad e \cdot cm \\
(\ -0.9 < \ \mathrm{Im}\,(d^w_\tau) \ &< 1.0\ ) \times 10^{-17} \quad e \cdot cm \\
|d^w_\tau| \ &< 0.7 \ \ \times 10^{-17} \quad e \cdot cm
\end{aligned}$$

$$\text{From } \Gamma_{\tau\tau}\ (*) \quad \longrightarrow \quad |d^w_\tau| \quad \lesssim \ 10^{-17} \quad e \cdot cm$$

$$\begin{aligned}
\mathrm{Re}\,(a^w_\tau) &= (\quad 0.0 \pm 1.6 \pm 2.3\ ) \times 10^{-3} \\
\mathrm{Im}\,(a^w_\tau) &= (\ -1.0 \pm 3.6 \pm 4.3\ ) \times 10^{-3}
\end{aligned}$$

$*$ electric and anomalous magnetic dipole moments:

$$\begin{aligned}
-0.05 < \ a_\tau \ < 0.05 \\
(\ -3 < \ d_\tau \ < 3\ ) \times 10^{-16} \quad e \cdot cm
\end{aligned}$$