Anomalous magnetic and electric dipole moments of the tau

(as measured by the L3 and OPAL experiments at LEP)

Lucas Taylor
Northeastern University, Boston

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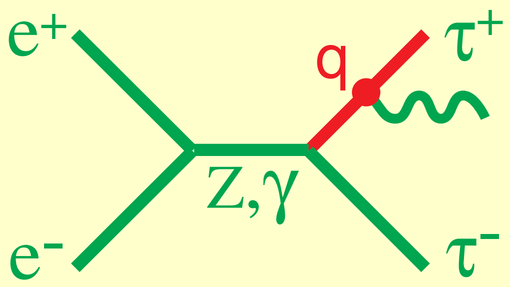
TAU 98, Santander

OPAL: CERN-EP / 98-33. Phys.Lett. B431:188-198, 1998. hep-ex/9803020
`http://www1.cern.ch/Opal/pubs/paper/html/pr233.html`

L3: CERN-EP / 98-45. Accepted by Phys. Lett. B. L3 preprint 144
`http://l3www.cern.ch/paper/publications.html`

Introduction

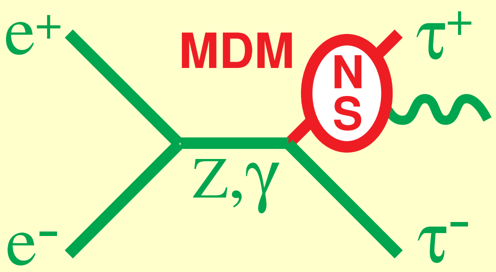


$$F_1(q^2)\gamma^\mu$$

$$\Downarrow$$

Electric charge, q_τ

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



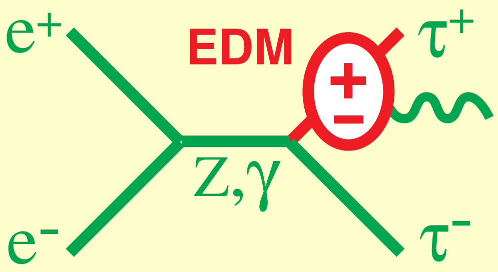
$$F_2(q^2)\frac{i}{2m_f}\sigma^{\mu\nu}q_\nu$$

$$\Downarrow$$

Anomalous Magnetic Dipole Moment, a_τ

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

$$a_\tau^{\rm SM} = \alpha/2\pi + \ldots \approx 0.0011$$



$$F_3(q^2)\sigma^{\mu\nu}\gamma^5 q_\nu$$

$$\Downarrow$$

Electric Dipole Moment, d_τ

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

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

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

Introduction

Motivated by the possibility of new physics, e.g.

- Compositeness
- Leptoquarks
- Novel mechanisms for Electroweak symmetry breaking...

Use generic ansatz to describe anomalous $\tau\tau\gamma$ couplings:

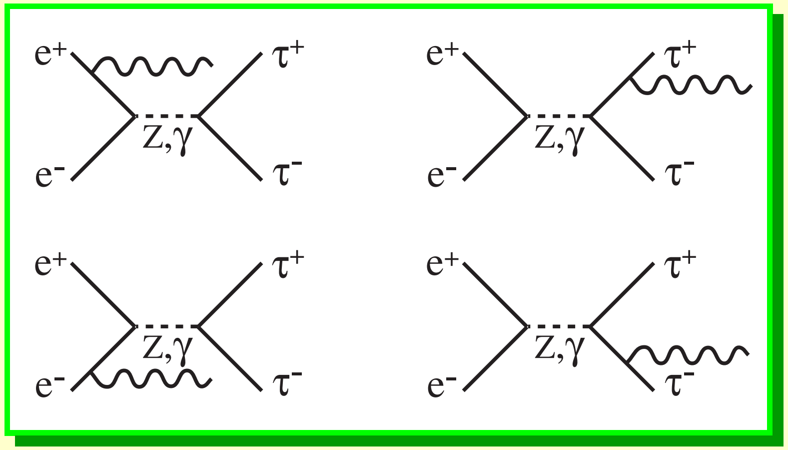
$$\boxed{\gamma^\mu \rightarrow F_1(q^2)\gamma^\mu + F_2(q^2)\frac{i}{2m_\ell}\sigma^{\mu\nu}q_\nu - F_3(q^2)\sigma^{\mu\nu}\gamma^5 q_\nu}$$

Calculations of $e^+e^- \rightarrow \tau^+\tau^-\gamma$
(with varying approximations):

"TTG" S. Gau, T. Paul, J. Swain, & L. Taylor, Nucl. Phys. **B 523**, 439, (1998).

"B&R" J. Biebel and T. Riemann, Z. Phys. **C 76**, 53, (1997).

D. Zeppenfeld, unpublished.

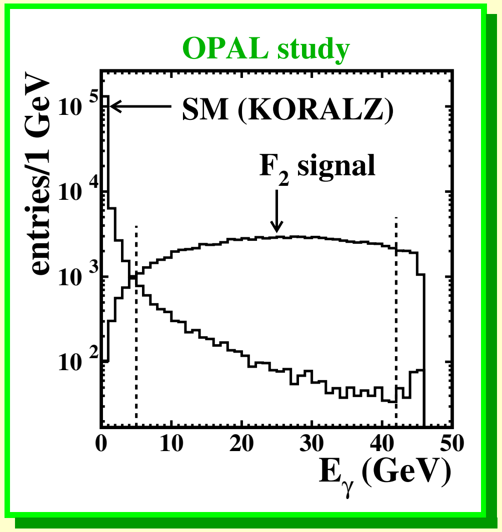


Modelling of $e^+e^- \to \tau^+\tau^-\gamma$

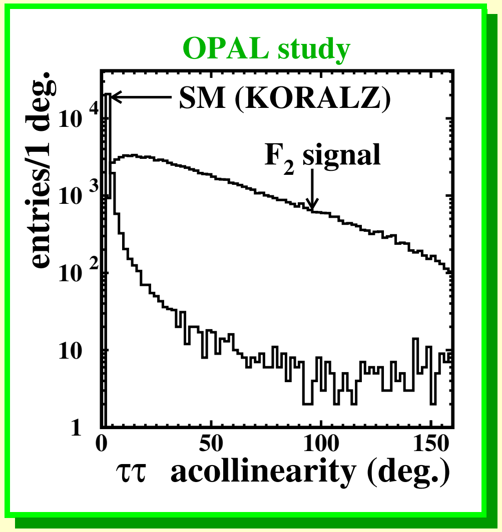
Anomalous values of F_2 or F_3 tend to:

- increase the rate of $\tau\tau\gamma$ events
- change the shapes of photon energy and angular spectra

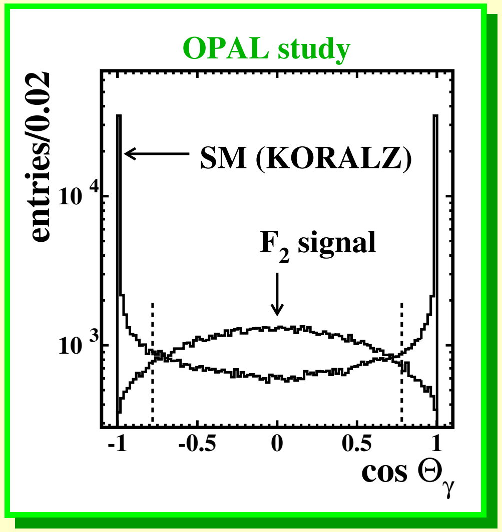
Enhancement at higher energy



Enhancement at larger opening angles



Enhancement in central region



(relative normalisations are arbitrary)

Comparison of TTG and B&R calculations

TTG is more complete than B&R

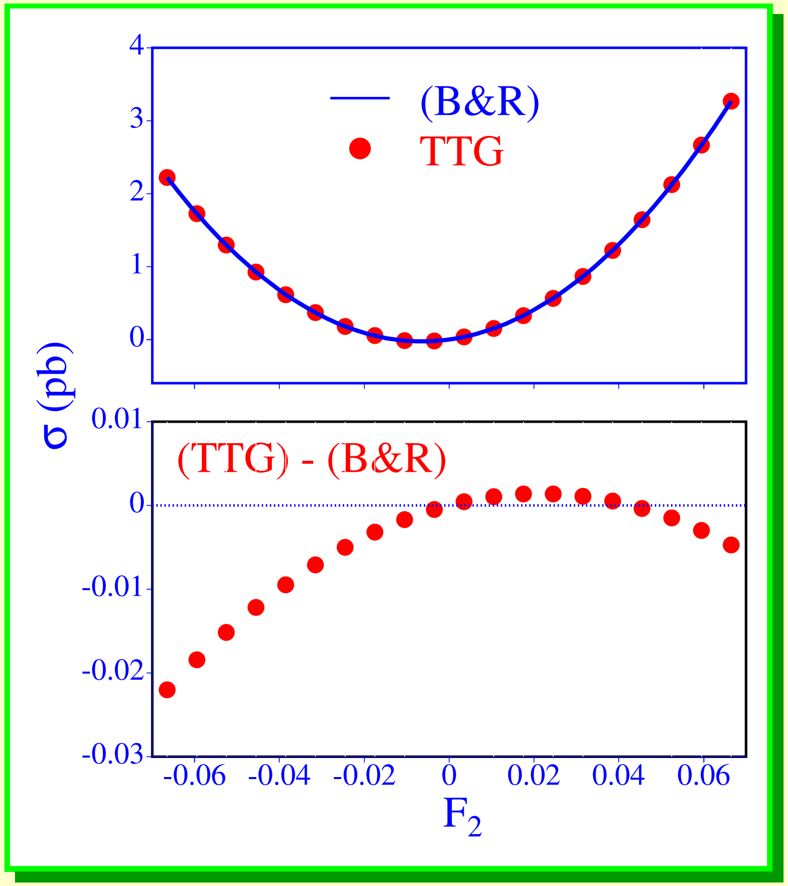
$\Rightarrow$ to make a fair comparison we ignore terms in TTG describing:

- anomalous contributions to the ISR and FSR interference
- γ exchange
- $\gamma - Z$ interference

TTG and B&R calculations agree very well (for the same assumptions)

Asymmetry caused by interference terms linear in F_2 (between final-state SM radiation and final-state anomalous radiation)

Anomalous contributions to the $e^+e^- \to \tau^+\tau^-\gamma$ cross-section



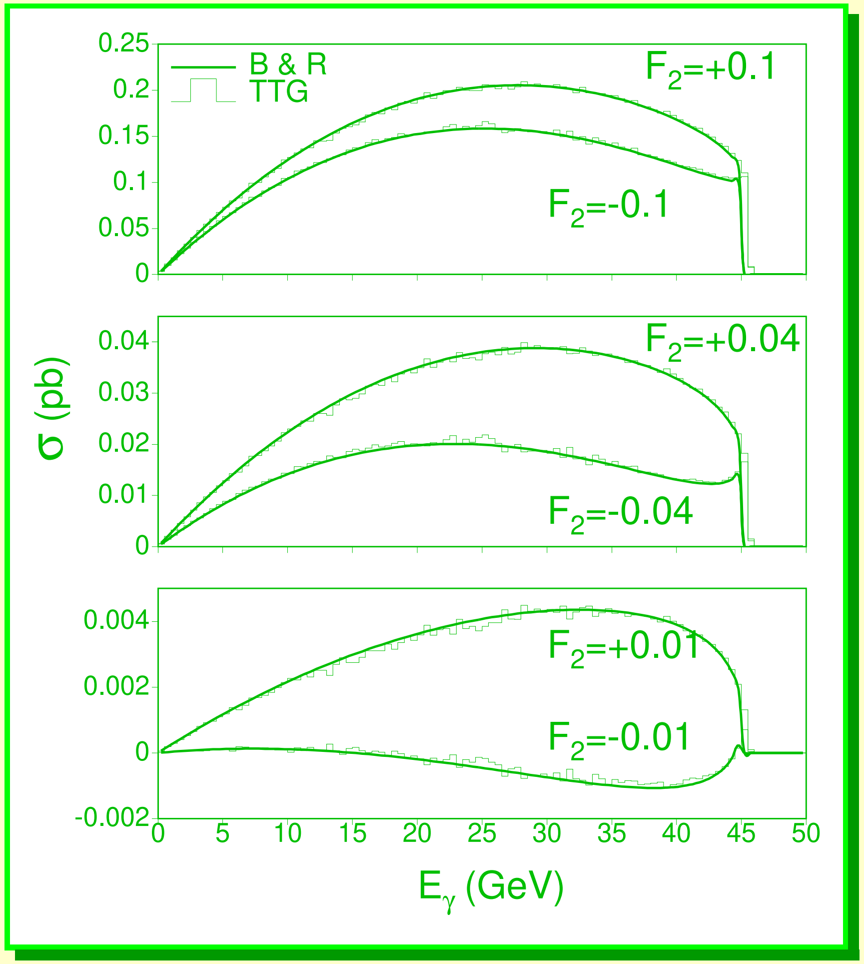
Comparison of TTG and B&R calculations

Compare anomalous contributions to the cross-section as a function of photon energy and F_2

Both TTG and B&R show that interference is significant especially for small values of F_2

(curves for $F_2 > 0$ and $F_2 < 0$ are significantly different)

Simplified TTG and B&R agree to $\sim 1\%$ for a wide range of E_γ and F_2

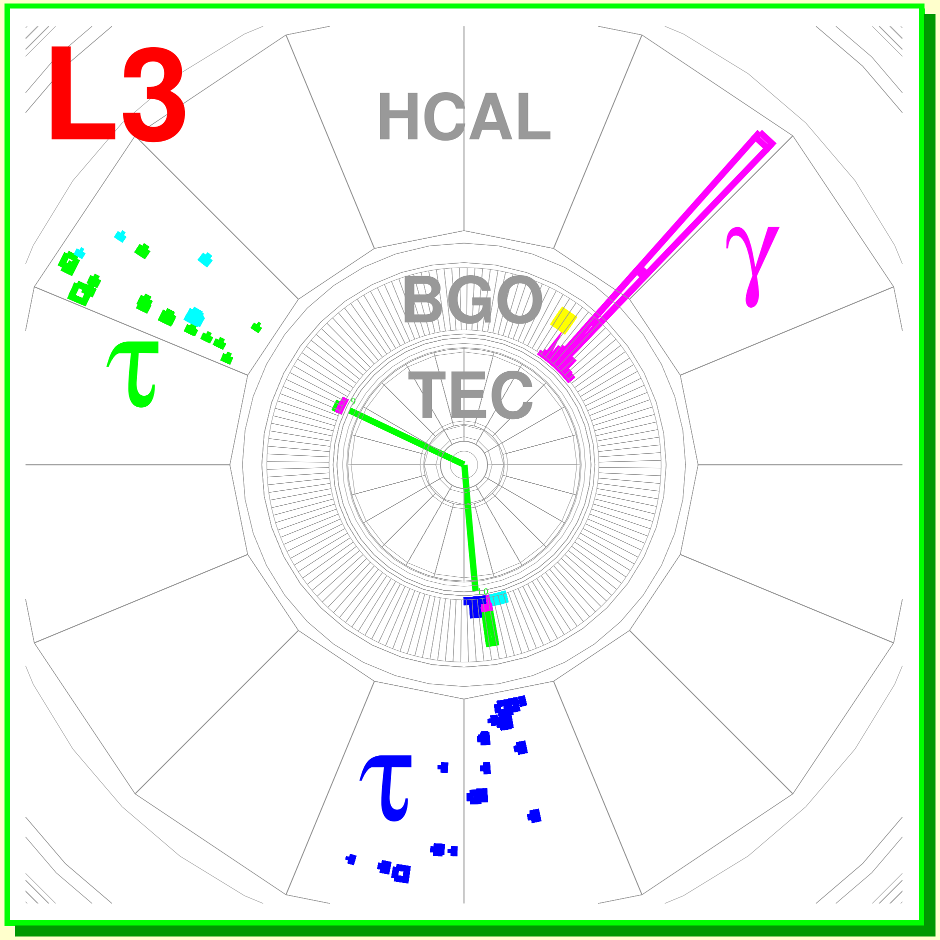


Inclusion of all terms in TTG only changes result by $\sim 1\%$ (compared to B&R)
$\Rightarrow$ both TTG and B&R are adequate for LEP data

Event selection

- Use on-peak data ($\int \mathcal{L} \approx \mathbf{100}\, \boldsymbol{pb^{-1}}$)
- Fairly standard rejection of:
  - hadron events
  - Bhabha
  - dimuon
  - two-photon
  - cosmic ray muons
- Take special care in the rejection of (pathological) radiative Bhabhas and dimuons

	L3	OPAL
$\tau\tau\gamma$ events	1559	1429
Background	**6.7%**	**0.13%**



Determination of F_2 and F_3

Both L3 and OPAL use large $e^+e^- \to \tau^+\tau^-(\gamma)$ MC samples based on:

- KORALZ to describe SM process: $e^+e^- \to \tau^+\tau^-(\gamma)$
- PHOTOS for SM ISR and FSR
- TAUOLA to describe tau decays
- Realistic detector simulation based on GEANT

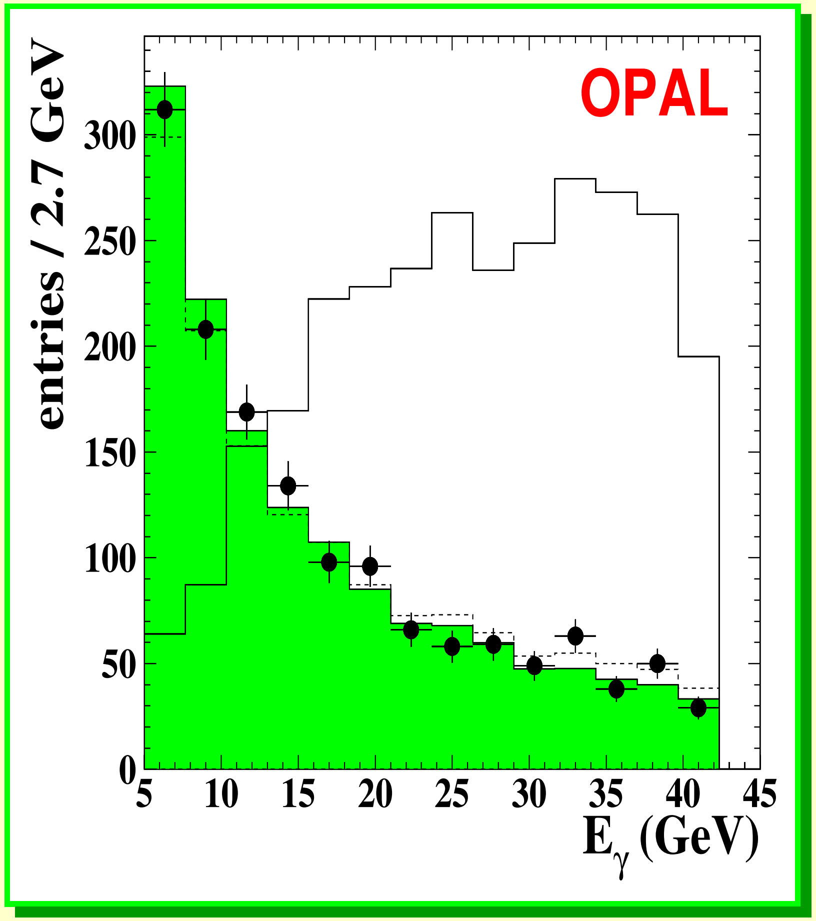
Fully simulated SM events are then reweighted as a function of F_2 (F_3):

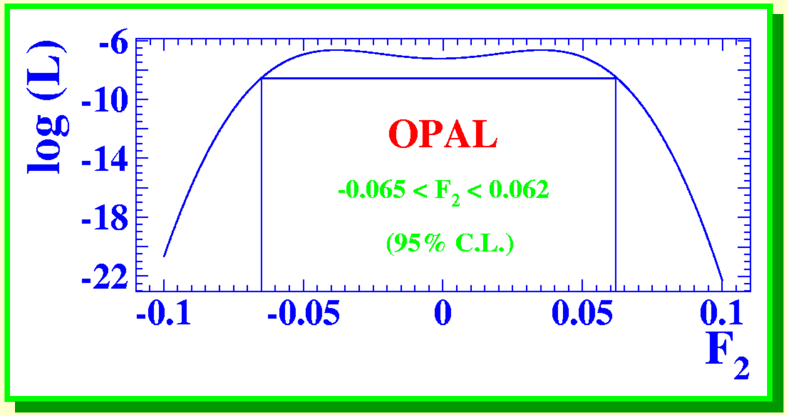
L3: uses TTG prediction relative to SM and does event-by-event reweighting based on the 4-vectors of the τ^+, τ^-, and γ
($\Rightarrow$ all F_2 dependences of acceptance, efficiency, etc. are included)

OPAL: uses energy spectrum reweighted according to Zeppenfeld with additional correction from B&R to allow for interference

OPAL fit for F_2 (and inference of F_3)

- 1-dimensional fit to photon energy spectrum with F_2 free
- Normalisation fixed such that number of $\tau\tau\gamma$ events agree in data and MC





F_3 estimated by making substitution:

$$|eF_2/2m_\tau| \longrightarrow |eF_3|$$

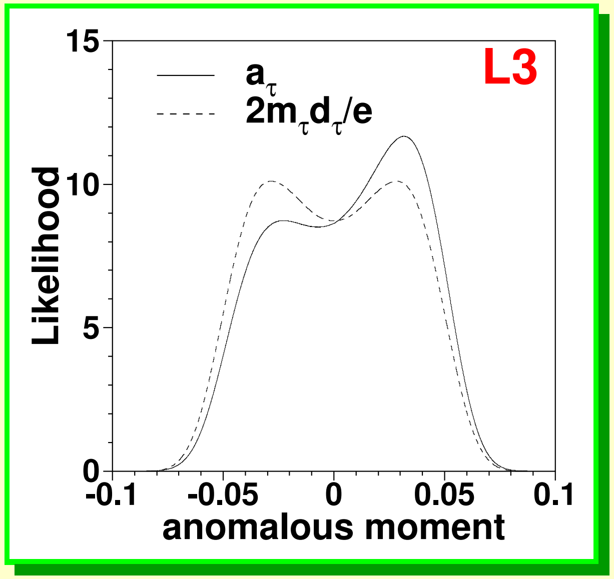
L3 fits for F_2 and F_3

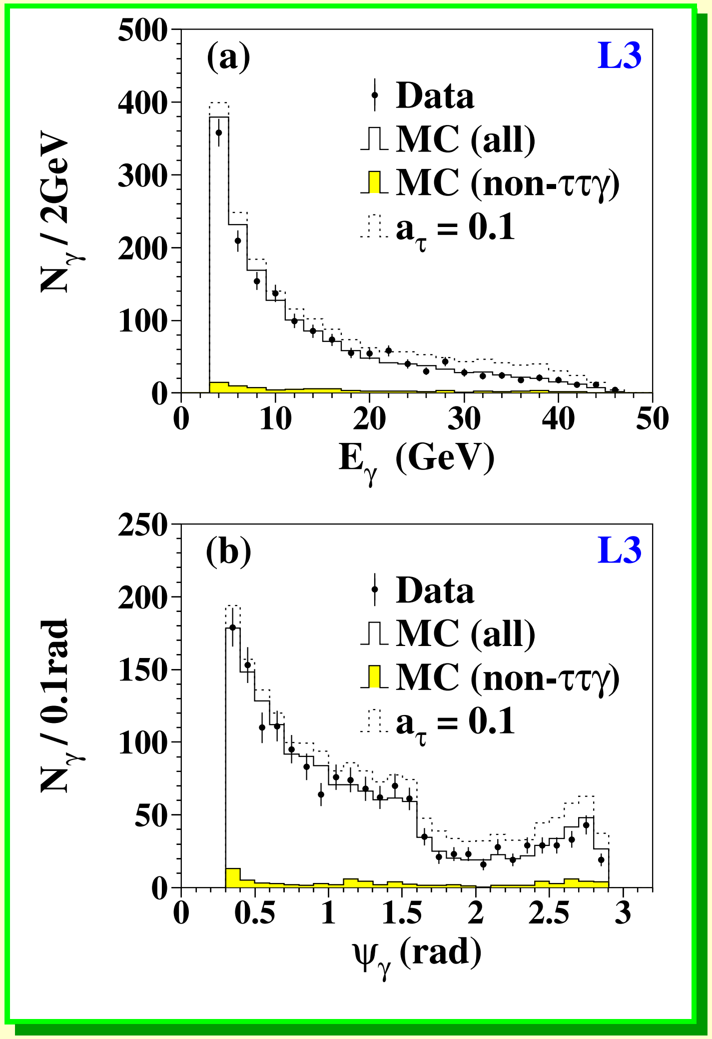
- 2-dimensional fits to: (γ energy) *vs.* (angle between γ and closest τ)
- Normalisation fixed by $\int \mathcal{L} \Rightarrow$ measure

  $\sigma(Z \to \tau\tau(\gamma)) = 1472 \pm 6 \pm 20\,\mathrm{pb}$

  (agrees with SM (ZFITTER): $1479\,\mathrm{pb}$)

- Fit for F_2 conservatively assumes $F_3 = 0$ and vice-versa





- $\mathcal{L}(F_2)$ is asymmetric due to interference
- $\mathcal{L}(F_3)$ exactly symmetric (linear term $\equiv 0$)

Cross checks and systematic errors

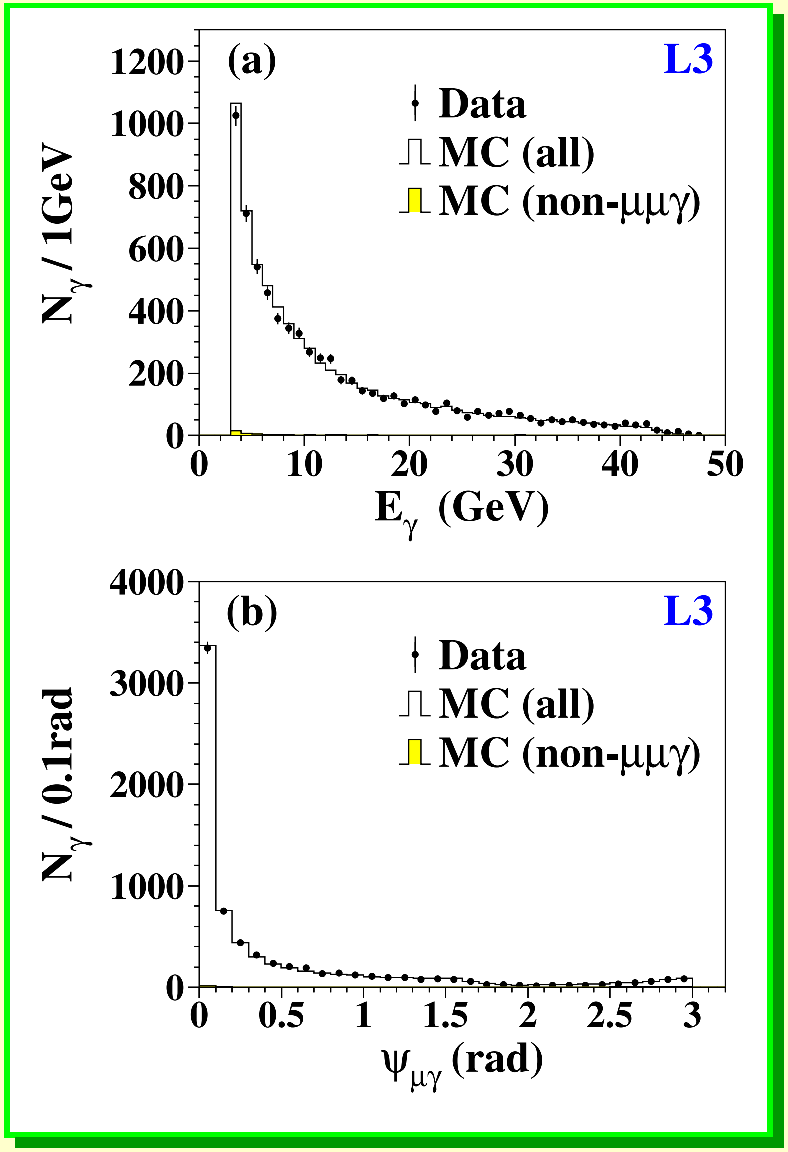
Many cross-checks of analyses, e.g.

L3 study of: $e^+e^- \rightarrow \mu^+\mu^-\gamma$

(no anomalous effects for this process within the sensitivity of LEP)

$\Rightarrow$ excellent experimental check of:

- Photon selection criteria
- Photon reconstruction efficiency
- Photon energy scale and resolution
- Standard Model radiation as described by KORALZ/PHOTOS



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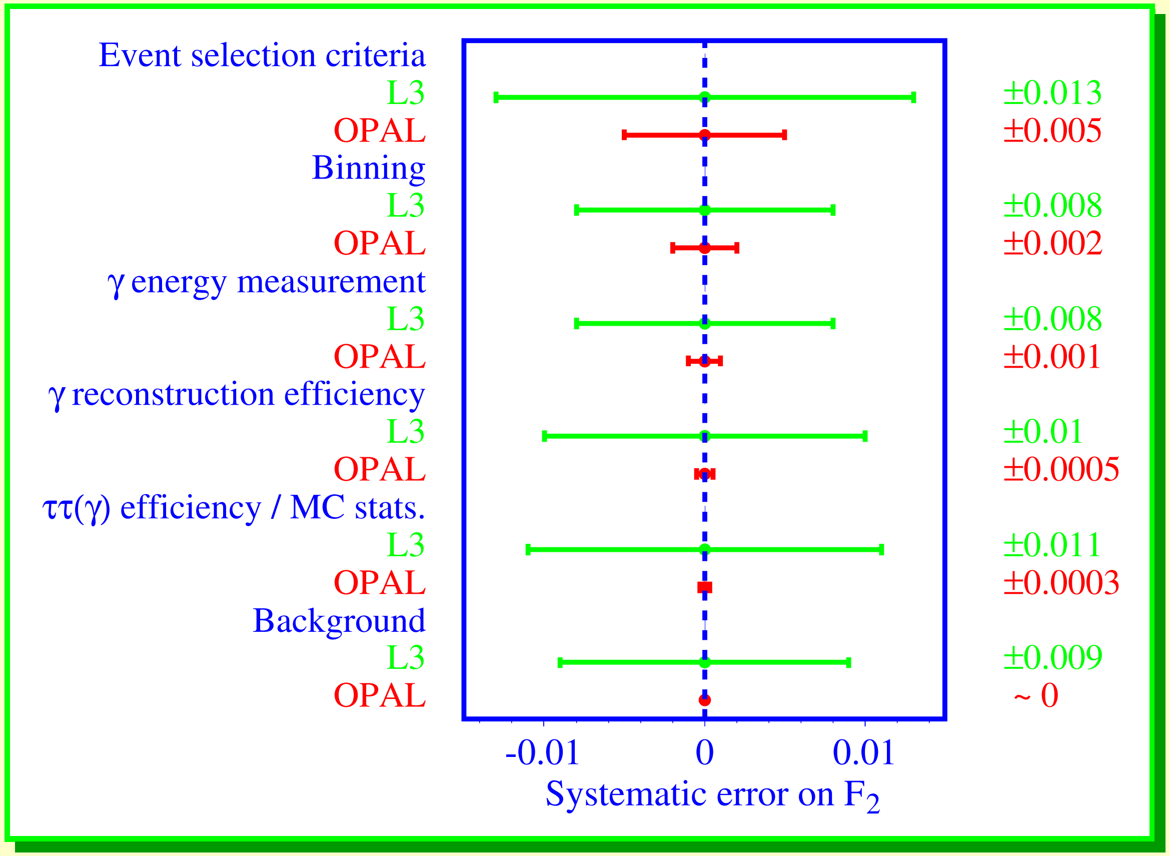
Cross checks and systematic errors

Main systematic errors of L3 and OPAL $\tau\tau\gamma$ analyses



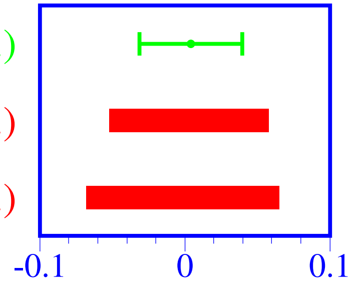
L3 checks and finds negligible systematic effects from:

- SM description of $\tau\tau\gamma$ (checked with $\mu\mu\gamma$)
- Residual differences between TTG and B&R calculations
- Effects of multiple photon radiation

Summary

First measurements of the tau anomalous magnetic and electric dipole moments

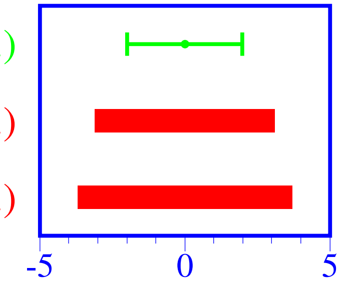
τ anomalous magnetic dipole moment, F_2



L3 (68% C.L.)	$0.004 \pm 0.027 \pm 0.023$
L3 (95% C.L.)	$-0.052 < F_2 < 0.058$
OPAL (95% C.L.)	$-0.068 < F_2 < 0.065$

$$F_2(0)^{\mathrm{SM}} = \alpha/2\pi + \ldots \approx 0.0011$$

τ anomalous electric dipole moment, eF_3 ($*10^{-16}$ e cm)



L3 (68% C.L.)	$0.0 \pm 1.5 \pm 1.3$
L3 (95% C.L.)	$\lvert eF_3 \rvert < 3.1$
OPAL (95% C.L.)	$\lvert eF_3 \rvert < 3.7$

$$F_3(0)^{\mathrm{SM}} = 0$$

Still no evidence for new physics beyond the Standard Model