Tests of QED with multi-photonic final states

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OPAL Collaboration

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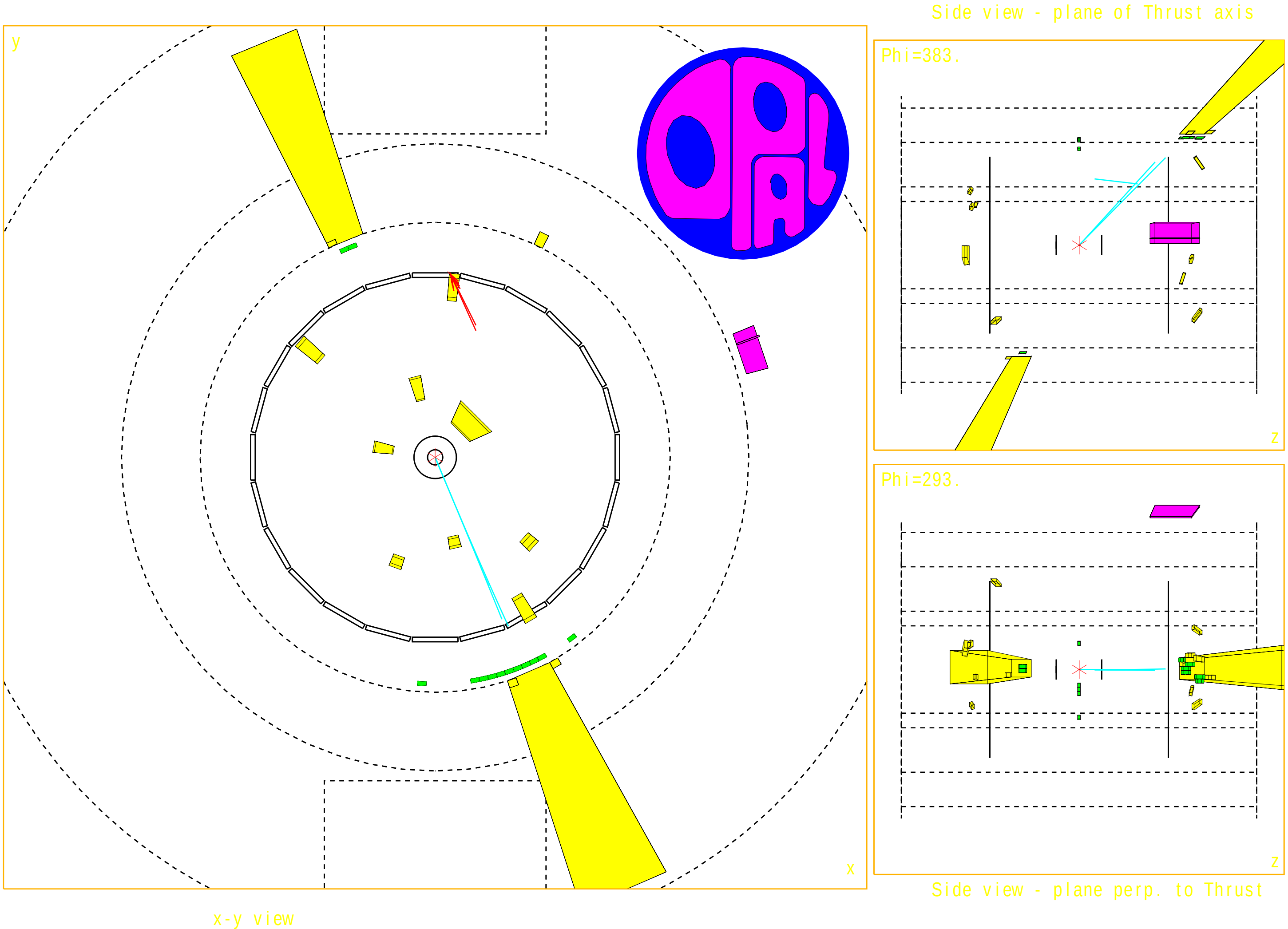
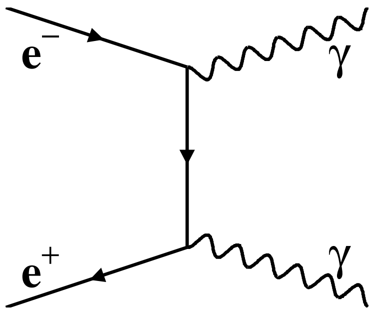
- selection
- corrections
- theory
- results
- resonance production

The last but one OPAL event

LEP closed for good on November 2nd, 2000, 8:00



$$e^+e^- \to \gamma\gamma(\gamma)$$



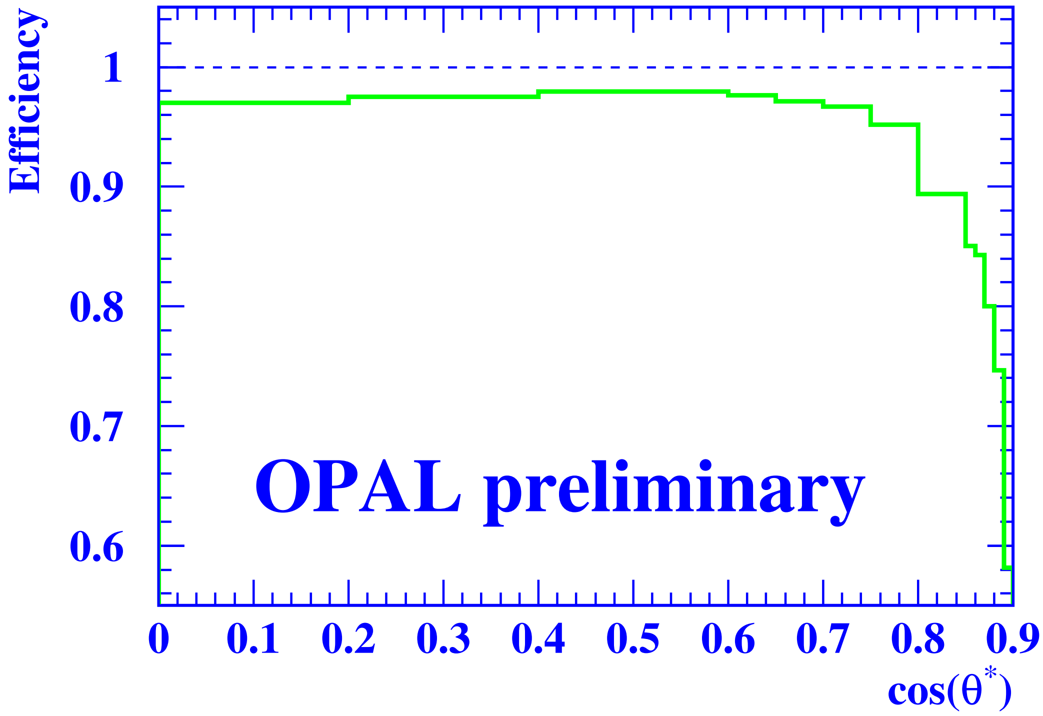
Selection

γ shower (almost) like electrons

total energy deposit in ECAL
no missing transverse momentum
small missing longitudinal momentum (escaping γ)

$\Rightarrow$ ~94% $e^+e^- \rightarrow e^+e^-$ ~6% $\gamma\gamma(\gamma)$

reduce background by factor $< 10^{-4}$
reject events with tracks
but keep converted photons
material/ detector depend
$\Rightarrow$ negligible background



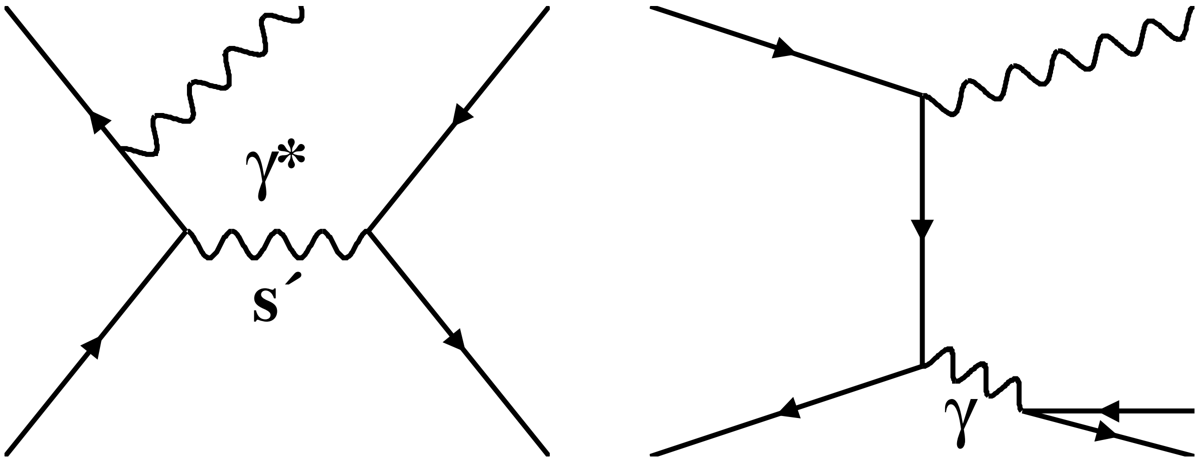
Conversions

distinguish conversion and single track (electron)

opening angle is small
$\longrightarrow$ 2 tracks visible mainly due to bending in $\boldsymbol{B}$ field
small $\boldsymbol{\theta} \longrightarrow$ small $\boldsymbol{p}_{\mathrm{t}} \longrightarrow$ small bending
$\longrightarrow$ only 1 track visible, badly reconstructed

distinction possible mainly in central region

low s' Bhabhas $\quad (\sqrt{s'} \equiv M(\gamma^*) \geq 1$ MeV$)$



virtual decay

real (on shell) conversion

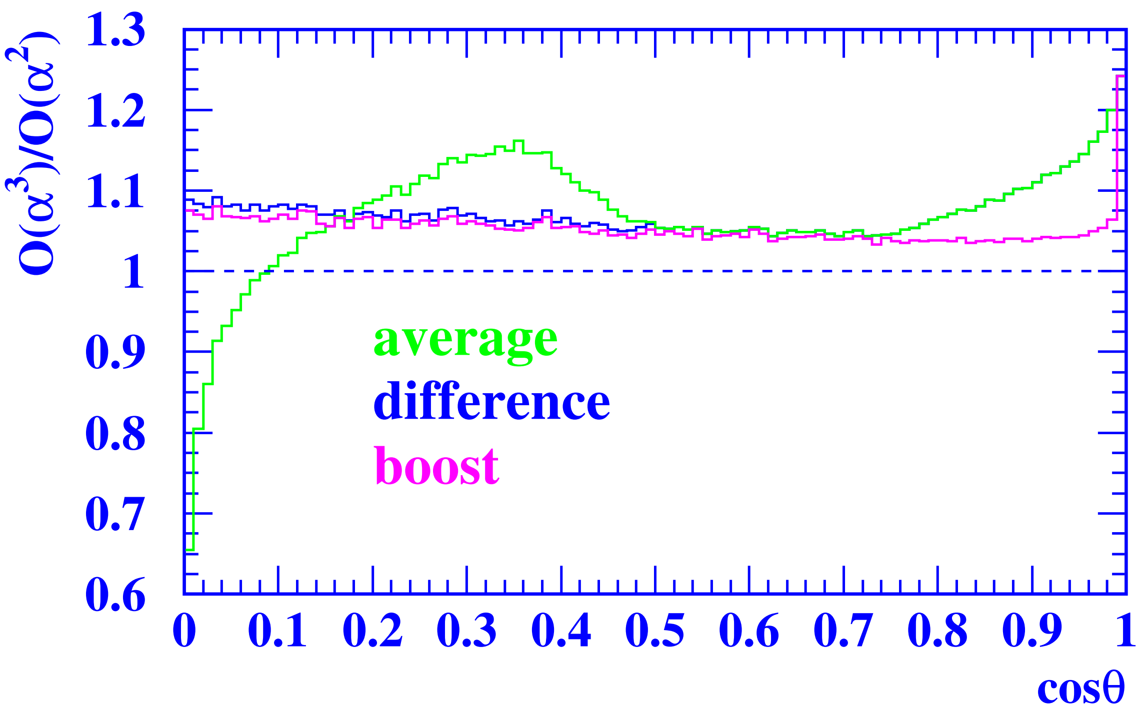
need 1 detector layer to distinguish

Radiative corrections

models for LO i.e. $|\cos\theta_1| = |\cos\theta_2| \equiv \cos\theta$

measured: $|\cos\theta_1| \neq |\cos\theta_2|$ what is $\cos\theta$?

minimize rad. correction $\mathcal{O}(\alpha^3)/\mathcal{O}(\alpha^2)$ by good choice



calculated from 2 highest energy photons:

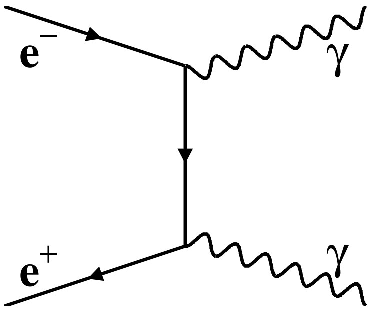
average: $\cos\theta' = (|\cos\theta_1| + |\cos\theta_2|)/2$

difference: $\cos\theta'' = (|\cos\theta_1 - \cos\theta_2|)/2$

boost: $\cos\theta^* = |\sin\frac{\theta_1-\theta_2}{2}|/\sin\frac{\theta_1+\theta_2}{2}$ (adopted)

acception of events with one high energy γ escaping
$\Rightarrow$ corrections of 20-30 % using $\cos\theta^*$
reject events with large missing longitudinal momentum

Process
in lowest order



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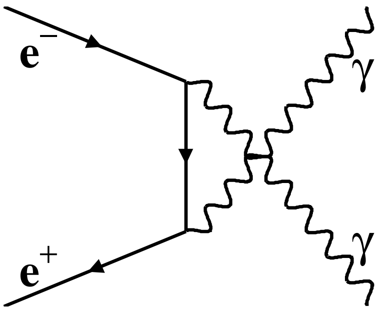
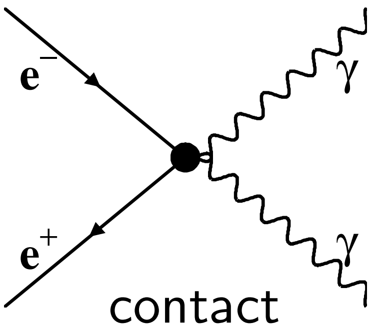


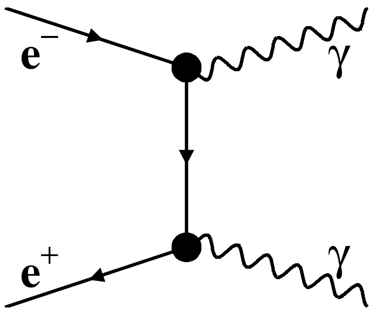
QED

+ new physics

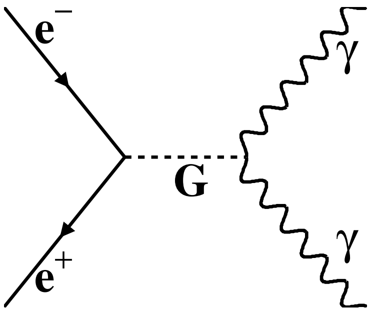


contact interaction

or

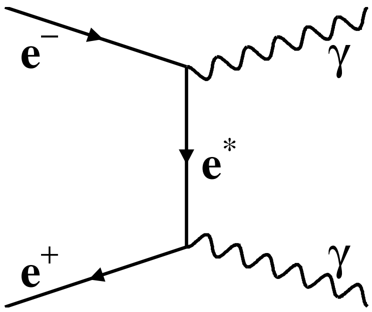


anomalous couplings



graviton

or



excited electron

explicit models

Differential cross-section

Lowest order: $$\left(\frac{d\sigma}{d\Omega}\right)_{\mathbf{Born}} = \frac{\alpha^2}{s}\,\frac{1+\cos^2\theta}{1-\cos^2\theta}$$

divergent for $\cos\theta \longrightarrow 1$ in relativistic limit

if electron mass is taken into account $\longrightarrow$ finite

$\mathcal{O}(\alpha^3)$: $$\frac{d^5\sigma}{d\theta_1 d\phi_1 d\theta_2 d\phi_2 dE_3}$$

computed by Monte Carlo

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Cut-off parameter

add short range exponential term to coulomb field

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_\pm} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathbf{Born}} \pm \frac{\alpha^2 s}{2\Lambda_\pm^4}(1+\cos^2\theta)$$

Effective Lagrangian theory

dim 6: $$\mathcal{L}_6 = i\bar{\Psi}\gamma_\mu(\mathrm{D}_\nu\Psi)(gF^{\mu\nu} + g\tilde{F}^{\mu\nu})$$

gives the same xsn as Λ_+: $$g^2 \equiv \frac{4\pi}{\Lambda^4} = \frac{2\pi\alpha}{\Lambda_+^4}$$

dimension 7 and 8 give equivalent results:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda'} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathbf{Born}} + \frac{s^2}{32\pi}\frac{1}{\Lambda'^6}$$

Explicit Models

Graviton exchange

gravitons couple to energy-momentum tensor (not mass)
coupling is small but particle type is no problem

Idea: gravitons propagate in n+3+1 dimensions
$M_{\mathrm{Pl}} = 10^{19}$GeV explained by $M_{\mathrm{Pl}}^2 = R^n M_{\mathrm{D}}^{n+2}$
with M_{D} of $\mathcal{O}(10^{2-3}$GeV), R: radius of n dim.

gravitons have momentum in extra dimensions
$\Rightarrow$ effective mass spectrum
HUGE number of Kaluza Klein excitation modes

$\longrightarrow$ deviation of cross-section with
$\alpha\pi M_{\mathrm{D}}^4 \sim \Lambda_{\pm}^4$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{G}} \simeq \left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_{\pm}}$$

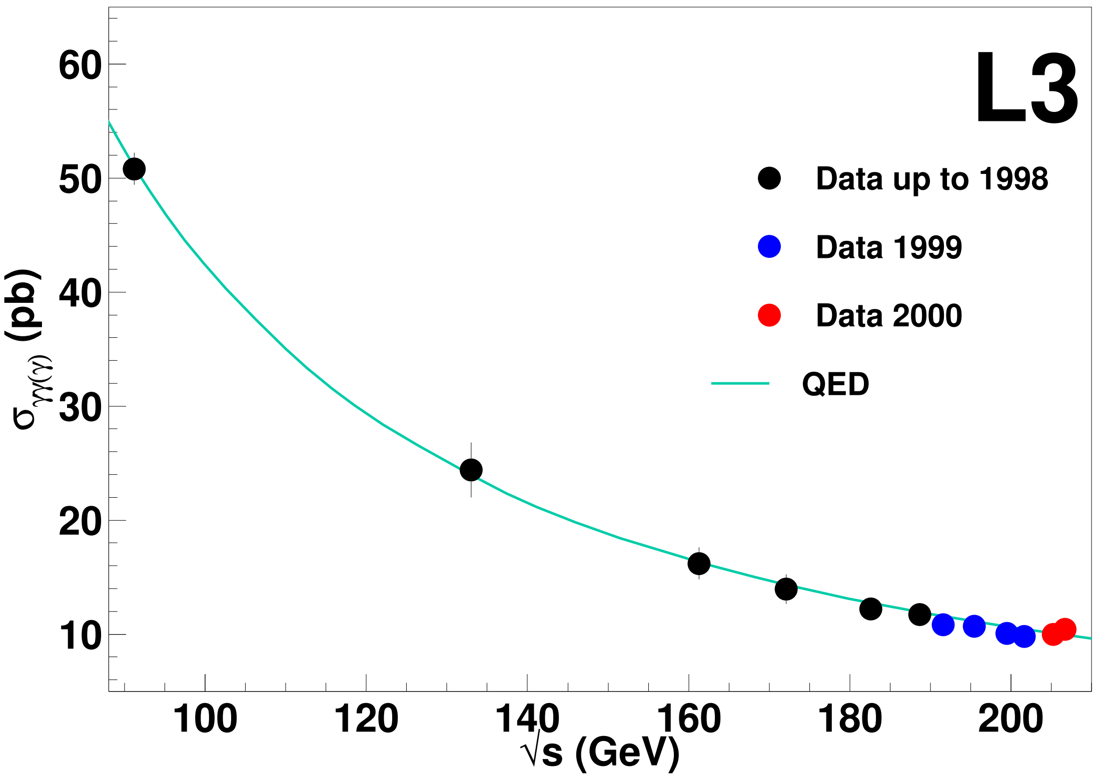
Excited electron exchange

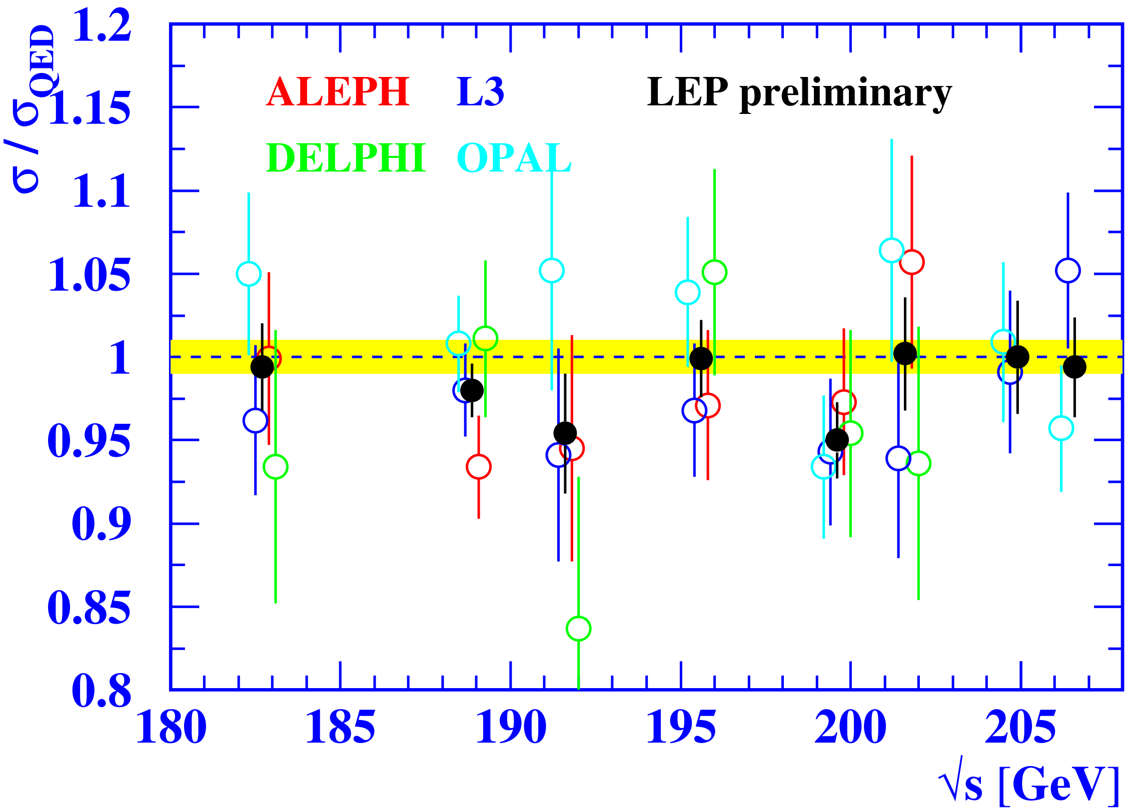
depends on e* mass and ee*γ coupling

for large masses

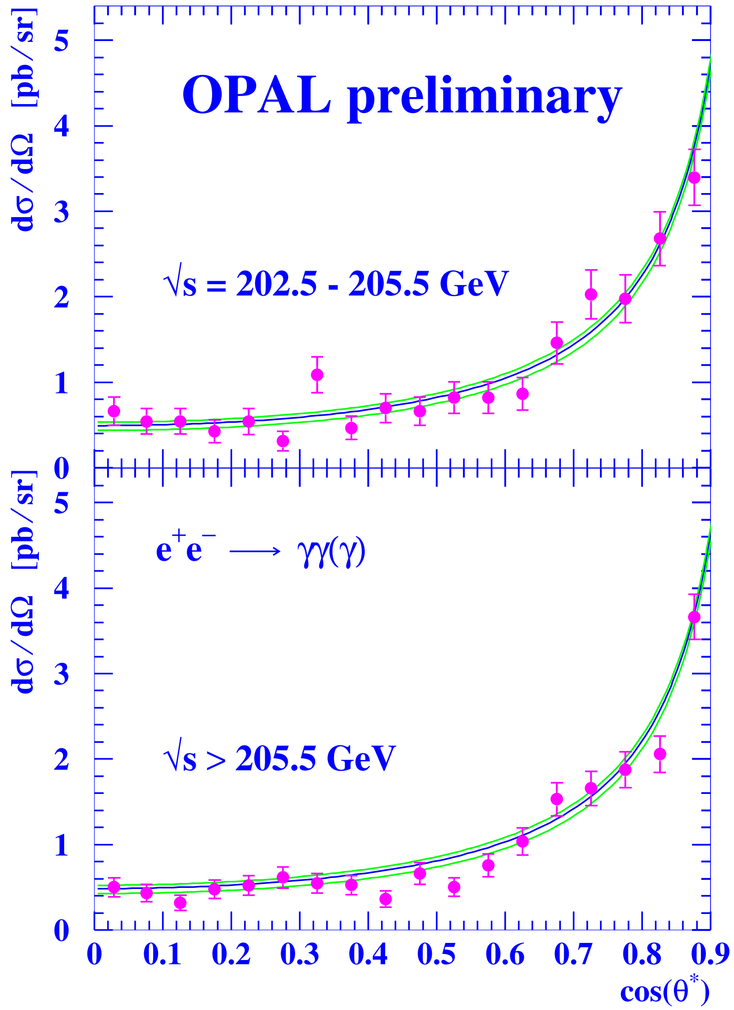
$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{e}^*} \simeq \left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_{\pm}}$$

Total cross-section





Angular distribution



— QED — 95%CL fit interval

systematic errors:

efficiency	1.0 – 2.5%
luminosity	0.2 – 0.5%
theory	$<$ 1.0%

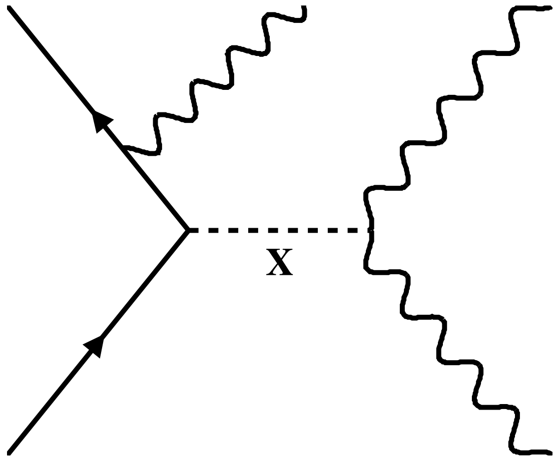
					M_D	
[GeV]	Λ_+	Λ_-	Λ'	M_{e^*}	$\lambda=+1$	$\lambda=-1$
ALEPH[1]	319	317	705	331	810	820
DELPHI[1]	330	320	–	311	822	848
L3[2]	378	327	703†	319	840	950
OPAL[2]	344	325	763	354	833	887

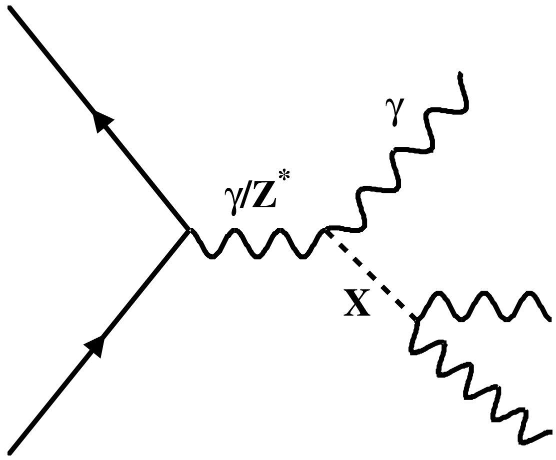
[1] 202 GeV; [2] 209 GeV

† not updated

Resonance production

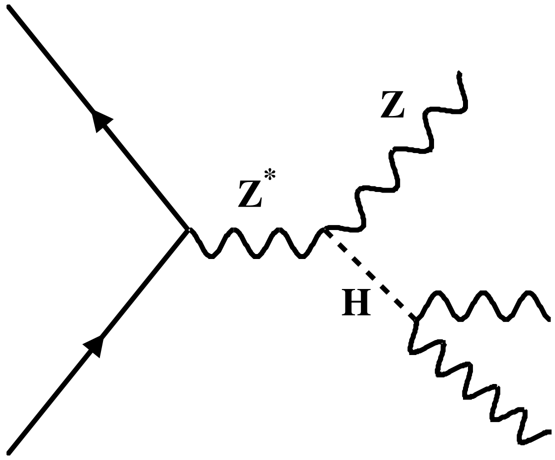
$$e^+e^- \longrightarrow \gamma X \qquad X \longrightarrow \gamma\gamma$$





Compare to

$e^+e^- \longrightarrow ZH$



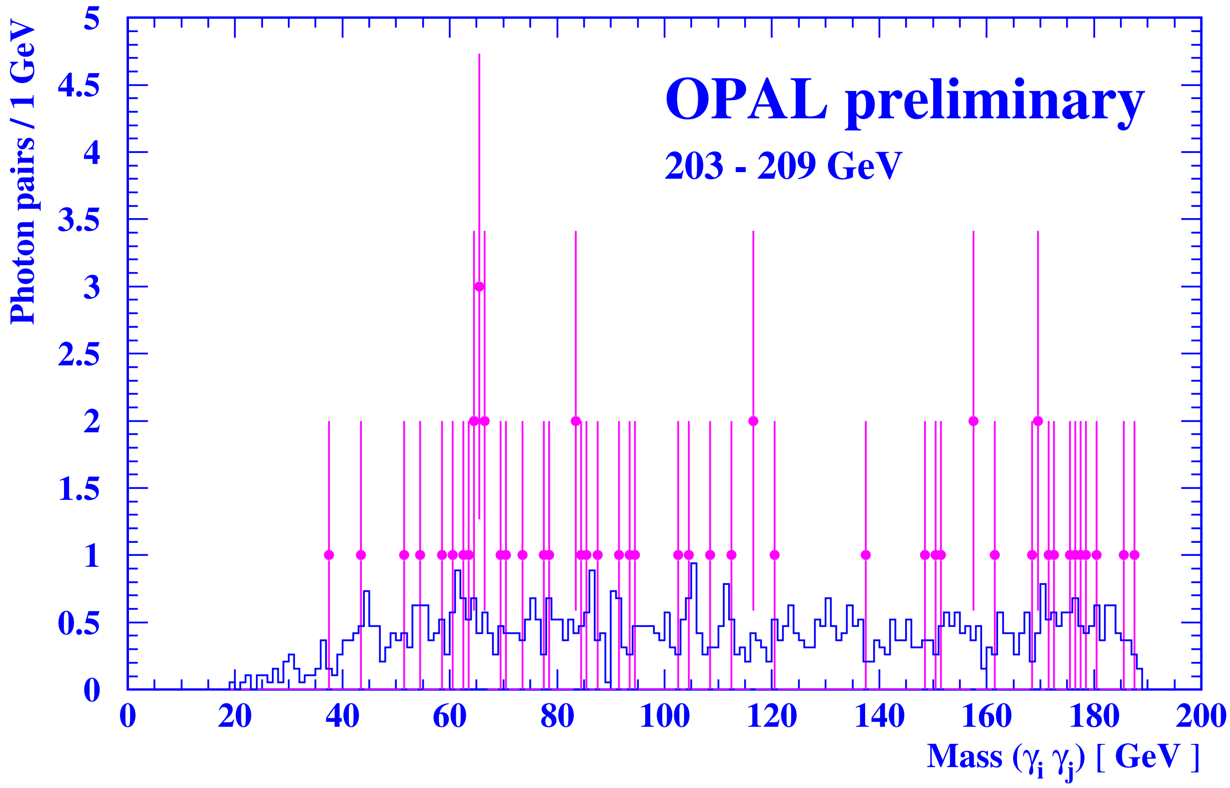
for Higgs $\longrightarrow \gamma\gamma$ search :

kinematic limit higher than for $e^+e^- \longrightarrow ZH$

SM coupling too small, study anomalous couplings

$\gamma\gamma\gamma$ events

3 combinations for mass pairing



planar events

$\longrightarrow$ use 3 body kinematics to calculate energies

spatial resolution better than energy resolution

$\longrightarrow$ good mass resolution (< 1 GeV)

some fluctuations

but no significant resonance observed

Anomalous Couplings

SM: $H\gamma\gamma$ couplings only via loop

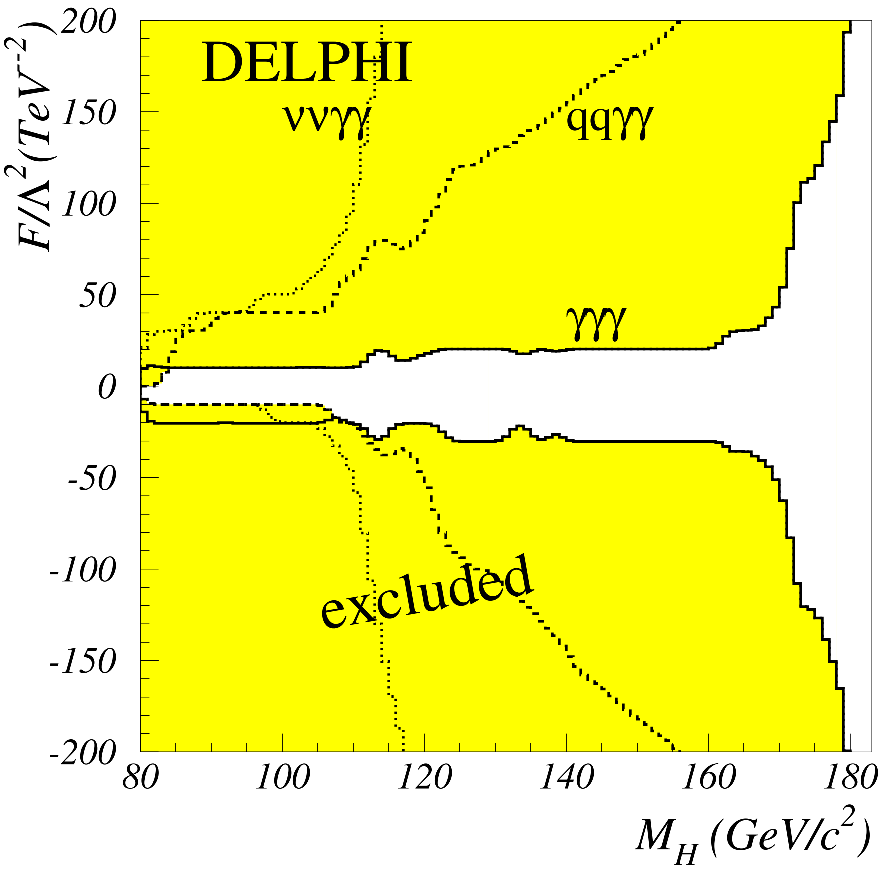
anomalous couplings from dim 6 Lagrangian:

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{H}\gamma\gamma} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n$$

$$= -\frac{g M_W}{\Lambda^2} \frac{\sin^2\theta_W}{2} (f_{BB} + f_{WW} - f_{BW}) H A_{\mu\nu} A^{\mu\nu}$$

no $Z\gamma$ self interactions $\longrightarrow$ strong constraints on f_{BW}

assumption: $f_{BW} = 0$; $f_{BB} = f_{WW} \equiv F$

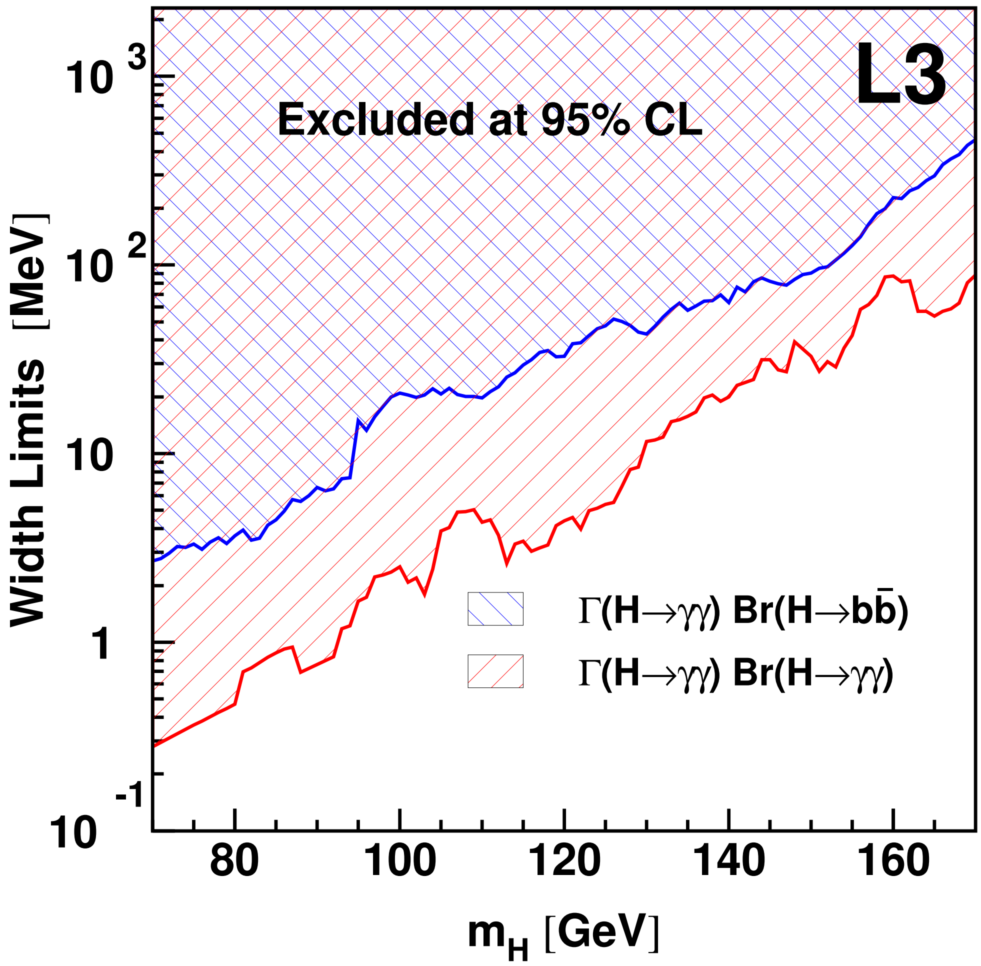


Width $\Gamma(H \to \gamma\gamma)$

SM: $\Gamma(H \to \gamma\gamma) \simeq 10^{-3}\Gamma_H$,
with $\Gamma_H < 10$MeV (for $M_H \leq 2 \times M_W$)

$\Gamma(H \to \gamma\gamma)$

$$= \frac{\alpha \sin^2 \theta_W}{4} M_W^2 M_H^3 \left| \frac{f_{BB} + f_{WW} - f_{BW}}{\Lambda^2} + \text{SM} \right|^2$$



Conclusion

$\mathbf{e^+e^-} \longrightarrow \gamma\gamma(\gamma)$ provides high precision data

simple process with interesting and
wide-ranging physics potential

even at LEPII energies pure QED
clean selection, negl. background, high efficiency
$\longrightarrow$ small systematic errors

deviations from processes beyond the SM

effective models:

$\mathbf{\Lambda_\pm > 320 - 370}$ GeV

$\mathbf{\Lambda' \ > 700 - 760}$ GeV

explicit models:

$\mathrm{M}_{\mathbf{e^*}} \mathbf{> 320 - 350}$ GeV

$\mathrm{M}_{\mathbf{D}} \mathbf{> 810 - 950}$ GeV

possible resonance production

search for fermiophobic Higgs and
anomalous couplings complementary to
$\mathbf{e^+e^-} \longrightarrow$ ZH and $\mathbf{e^+e^-} \longrightarrow \gamma$H with H $\longrightarrow \mathbf{b\bar{b}}$