Total $\gamma\gamma$ cross section at LEP

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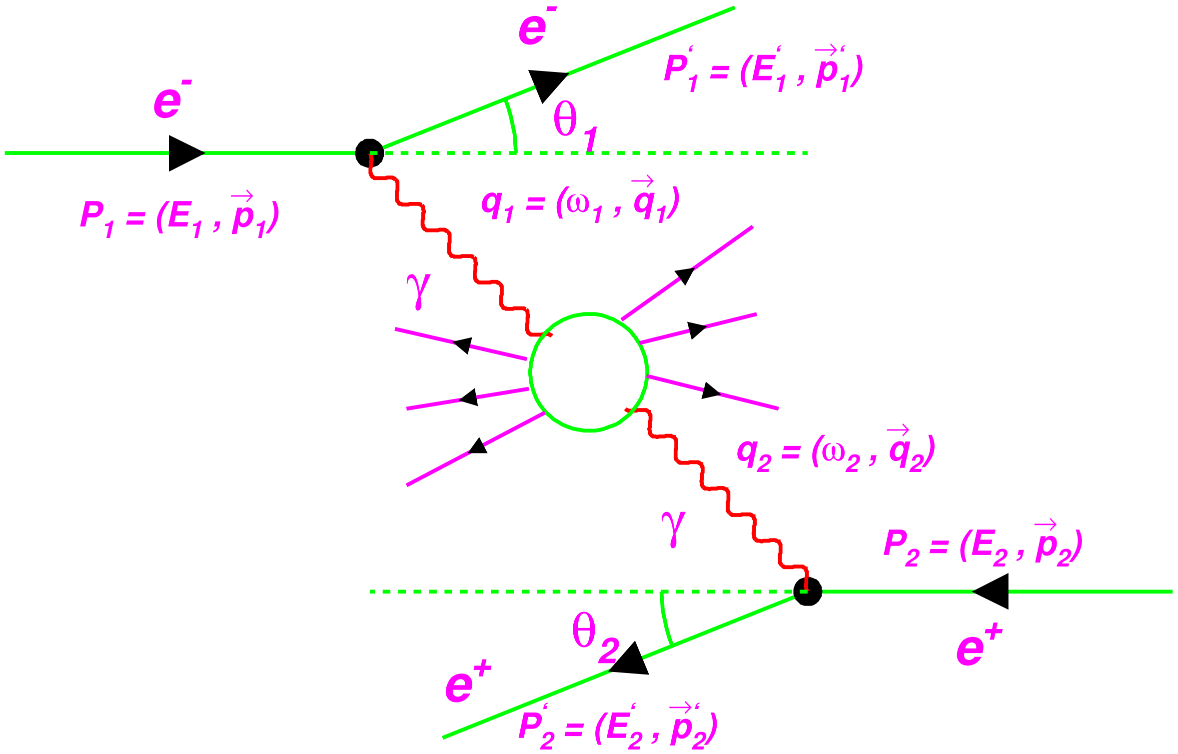
- ❑ $\gamma\gamma$ scattering
- ❑ Data and MC used
- ❑ Results and comparisons with theoretical models
- ❑ Single-particle inclusive cross section
- ❑ Conclusions

The $\gamma\gamma$ kinematic

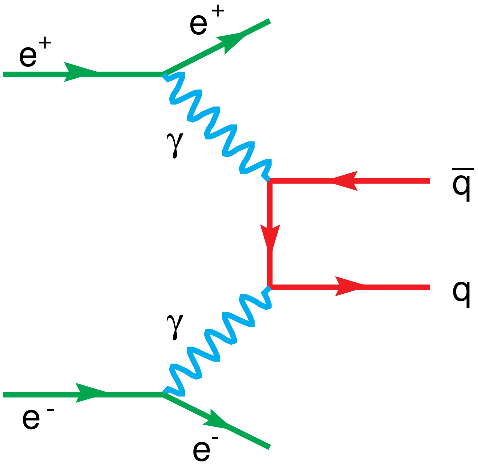


$$W_{\gamma\gamma}{}^2 = \left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p_i}\right)^2 = (q_1 + q_2)^2$$

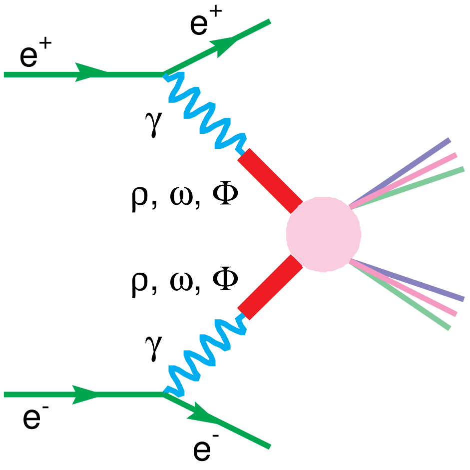
For each virtual photon:

$$Q^2 = -q^2 = 2\,E\,E'\,(1 - \cos\theta)$$

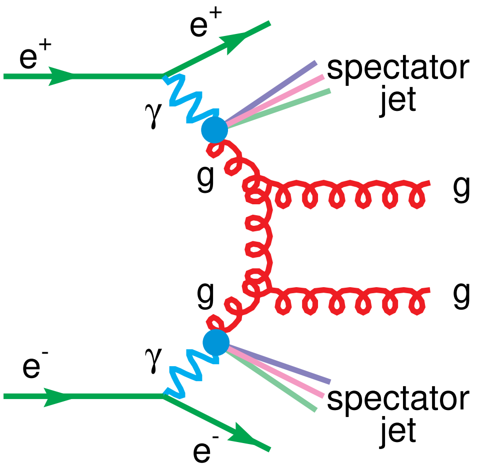
$\gamma\gamma \to hadrons$ processes



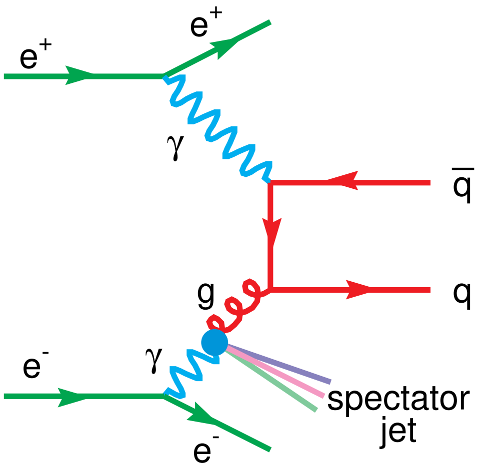
Direct



VDM



Double Resolved



Single Resolved

Data and MC used

- Data :

L3 :	91 GeV,	140. pb^{-1}
	130 - 140 GeV,	4.98 pb^{-1}
	161 GeV,	10.4 pb^{-1}
	183 GeV,	51.9 pb^{-1}
	189 GeV,	171.8 pb^{-1}
	192 - 202 GeV,	220.8 pb^{-1}

(Phys. Lett. B408, 450, 1997)

OPAL:	161 GeV,	9.9 pb^{-1}
	172 GeV,	10.0 pb^{-1}
	183 GeV,	54.4 pb^{-1}

(To be published in Eur. Phys. J. C)

- Monte Carlo :

  PHOJET: R. Engel and J. Ranft.

  (Phys. Rev. D54, 4246, 1996)

  PYTHIA: T. Sjöstrand

  (CPC 82, 74, 1994)

$\gamma\gamma \rightarrow hadrons$ event selection

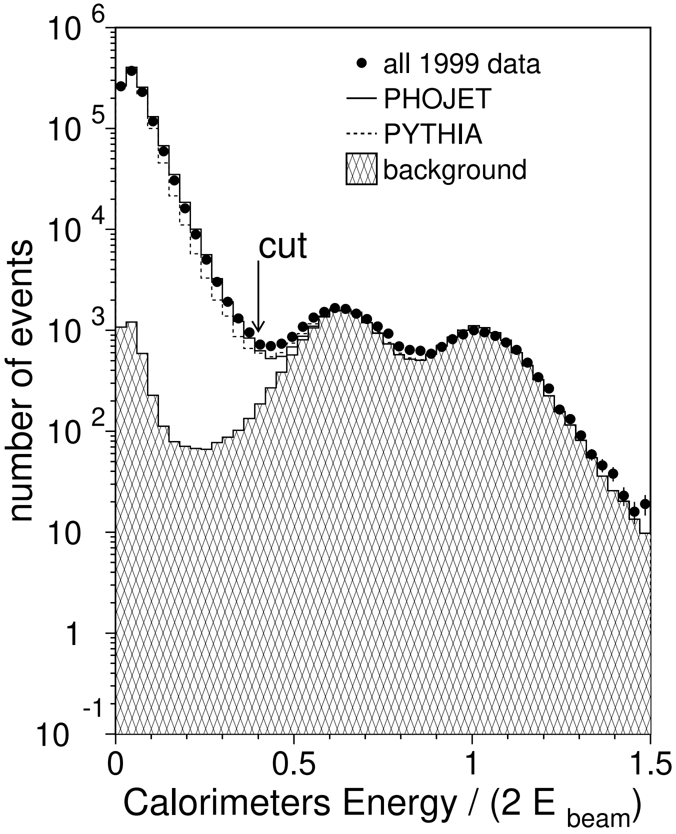
❑ L3 :

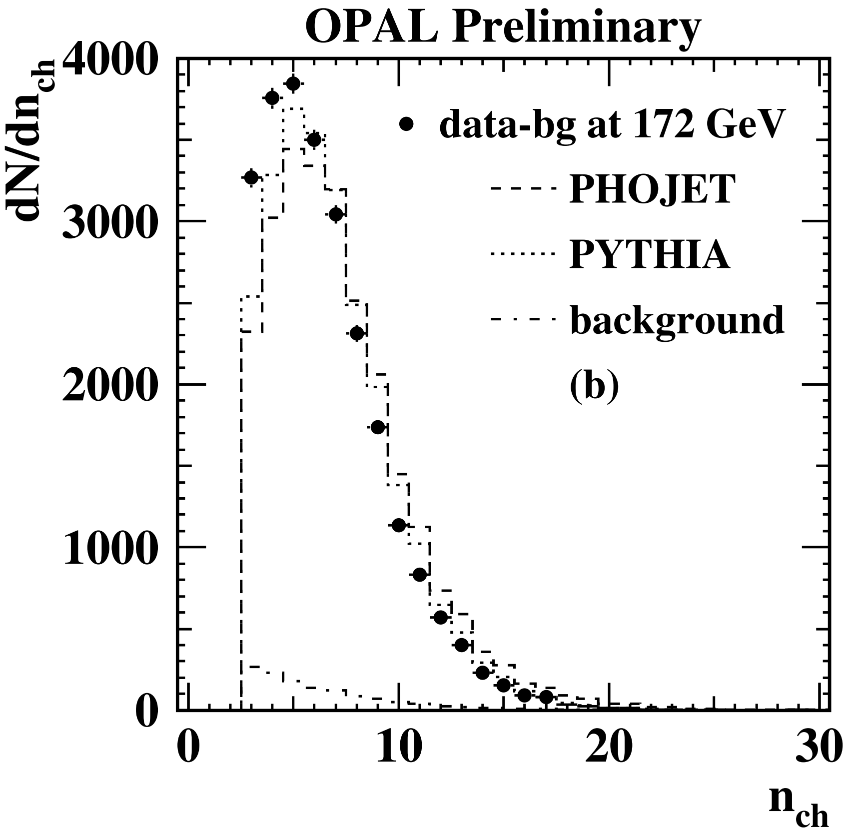
- → $\gamma\gamma$ events: $E_{tot} < .4\sqrt{s}$ and $E_{e.m} < 50 GeV$
- → no beam gas: $E_{e.m} > 500\, MeV$
- → hadronic events: at least 6 particles in the detector
- → antitag: less than 30 GeV in the luminosity monitor

❑ OPAL :

- → $\gamma\gamma$ events: $E_{tot} < 45\, GeV$
- → no beam gas: $DCA < 3\, cm$ and net charge < 4
- → hadronic events: at least 2 tracks (with dE/dx not consistent with leptons)
- → antitag: less than 20 GeV in the luminosity monitor

cuts





➩ Good background suppression

From W_{vis} to $W_{\gamma\gamma}$

- subtraction of the background

- correct for detector acceptance: unfolding with Bayes (G. D'Agostini, NIM A362(1995) 487) for L3,
  with Guru (A. Höcker and V. Karvelishvili, NIM A372(1996) 469) for OPAL

⇨ importance of having MC which reproduce well the data

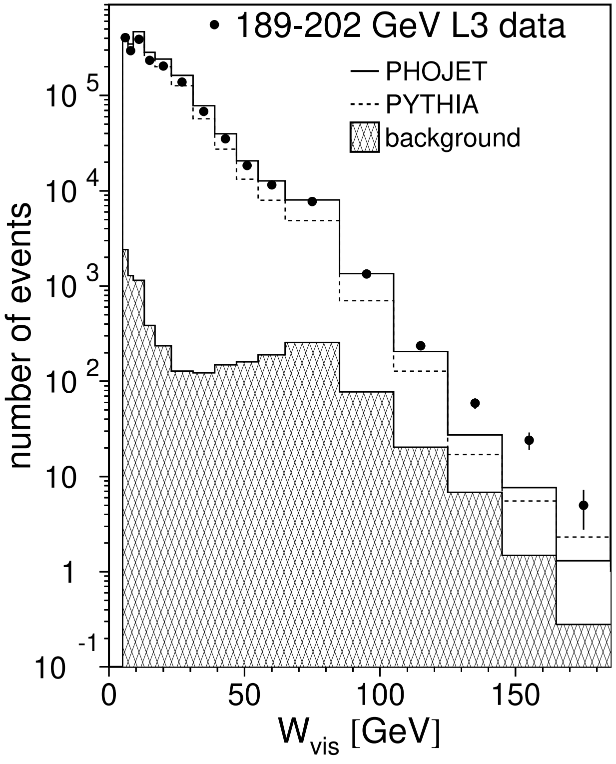
- $\sigma_{ee} \;=\; \mathcal{L}_{\gamma\gamma} \otimes \sigma_{\gamma\gamma}$

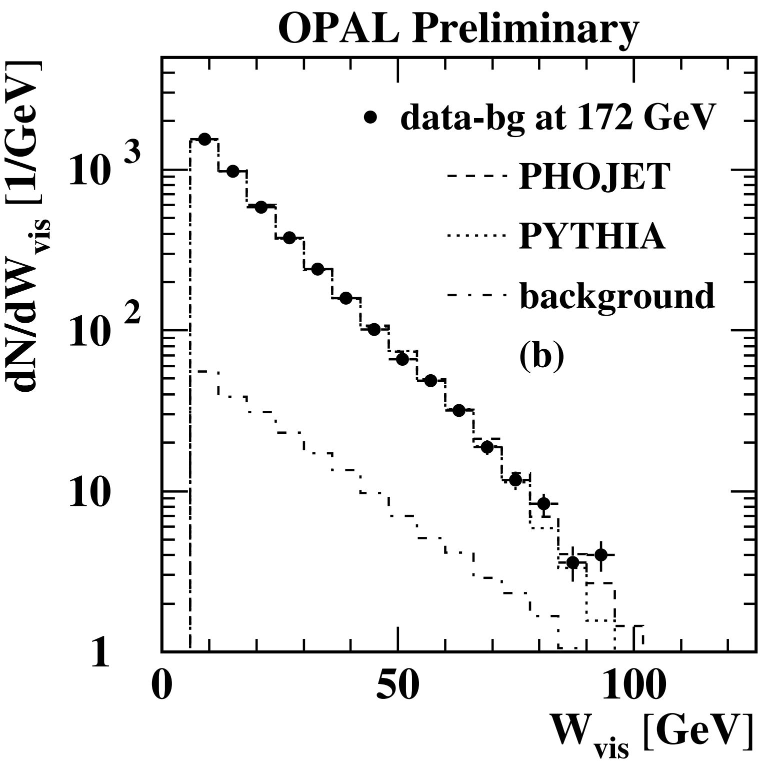
$$\frac{d\sigma_{ee}}{d(W^2_{\gamma\gamma}/s)} = \int \frac{dQ^2}{Q^2}\,\frac{dP^2}{P^2} \sum_{a,b=T,S} \mathcal{L}_{ab}\,\sigma^{\gamma\gamma}_{ab}(W_{\gamma\gamma}, P^2, Q^2)$$

$$\sigma^{\gamma\gamma}_{ab}(W_{\gamma\gamma}, P^2, Q^2) = F_a(Q^2) F_b(P^2)\, \sigma^{\gamma\gamma}_{ab}(W_{\gamma\gamma})$$

*T and S are Transverse and Scalar photon helicity indices.

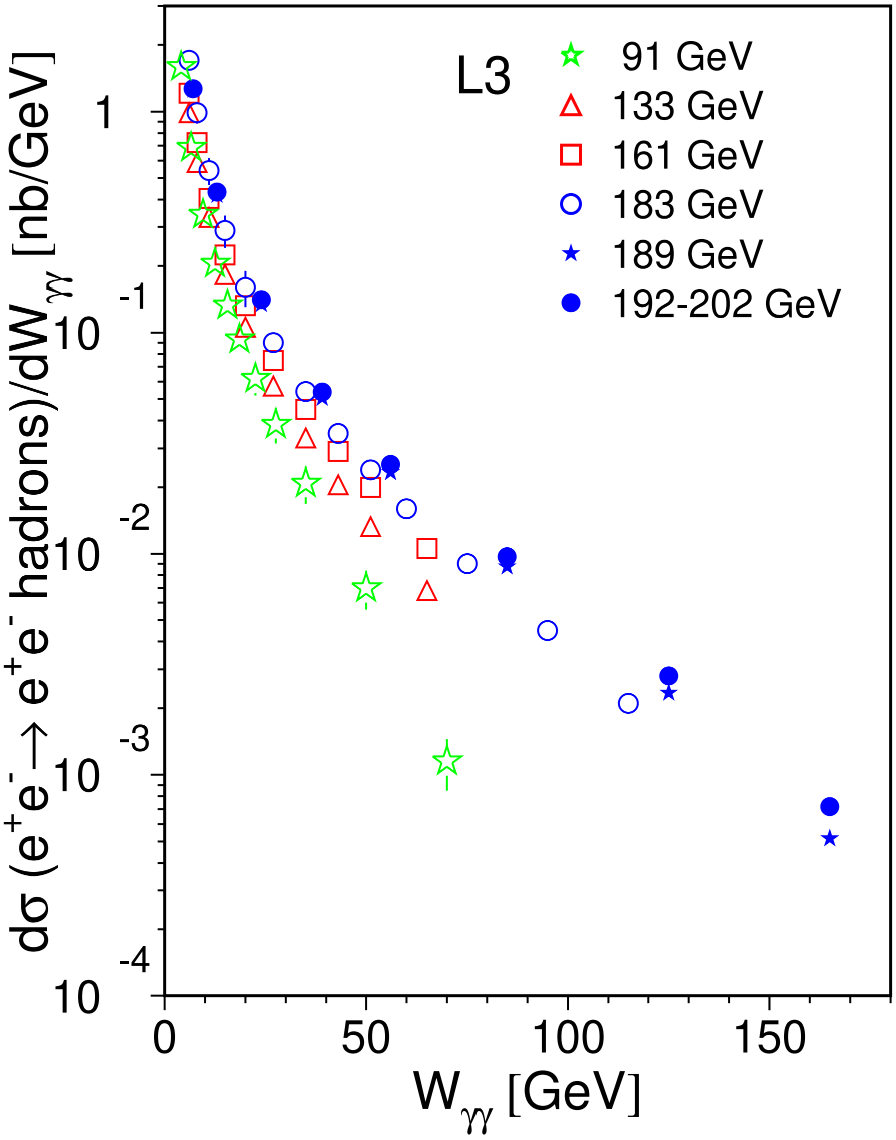
MC quality





MCs do not reproduce well the data for $W_{vis} > 100\,GeV$

Mass dependence

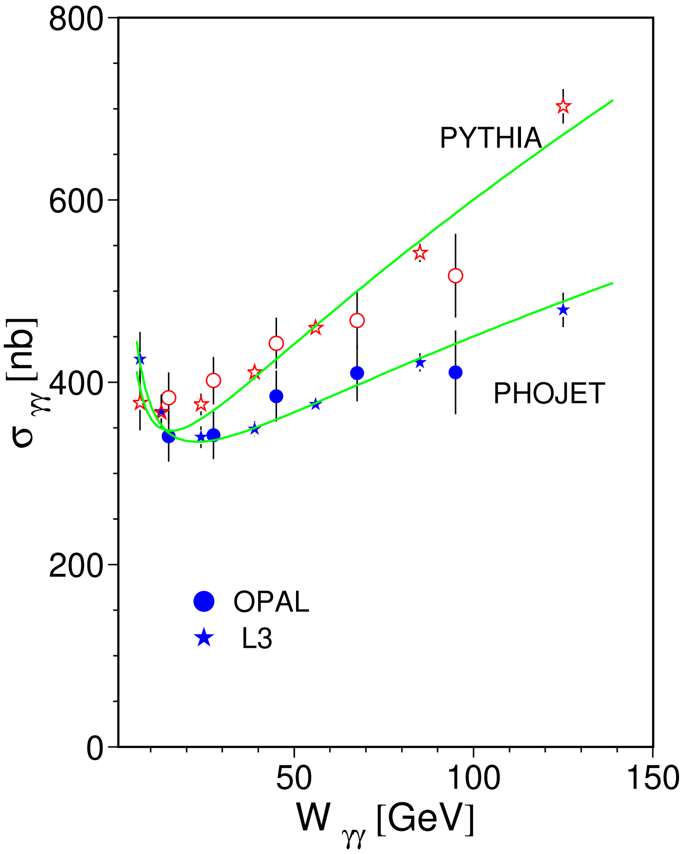


$d\sigma_{ee}$ increases with increasing beam energy

$d\sigma_{ee}$ decreases with increasing $\mathrm{W}_{\gamma\gamma}$

New data allow to reach higher $W_{\gamma\gamma}$

MC dependence

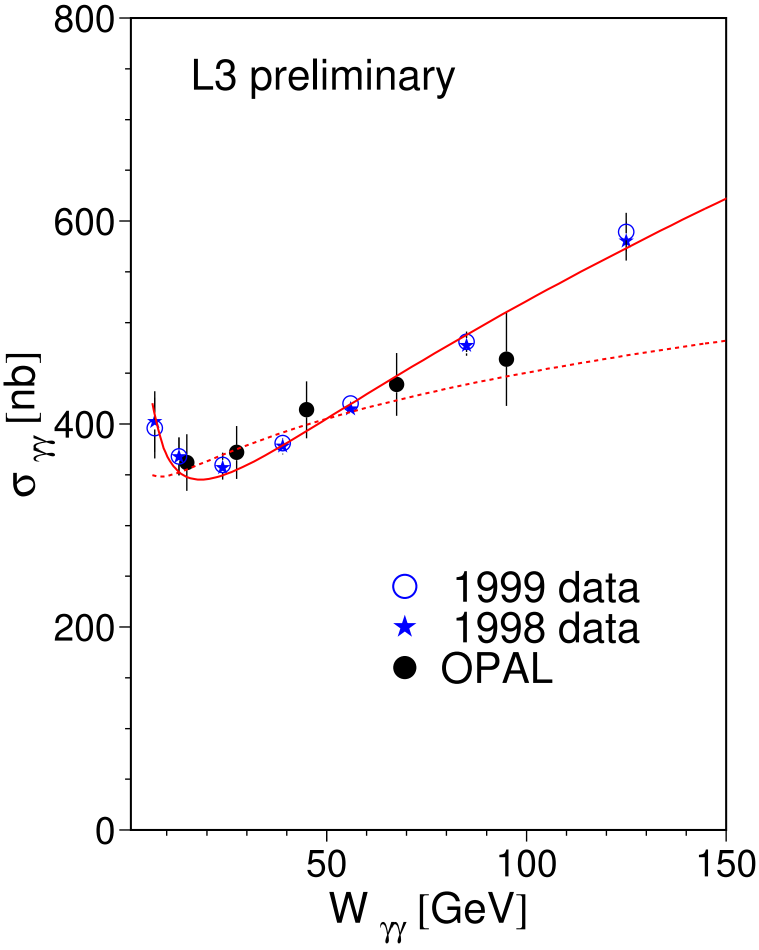


Statistic and detector related systematic errors only

- ❒ L3 and OPAL are compatible if the same generator is used.
- ❒ L3 and OPAL show the same rising behaviour with increasing energies.
  ⇨ Independent of MC
- ❒ The difference on absolute values goes up to $\sim 30\%$.
  ⇨ Due to the MC model dependence.

$\gamma\gamma$ total cross-section

Average of Pythia and Phojet
Statistic and detector related systematic errors only



Regge parametrisation $\sigma_{\gamma\gamma} = As^{\varepsilon} + Bs^{\eta}\ ,\ \ s = W^2_{\gamma\gamma}$

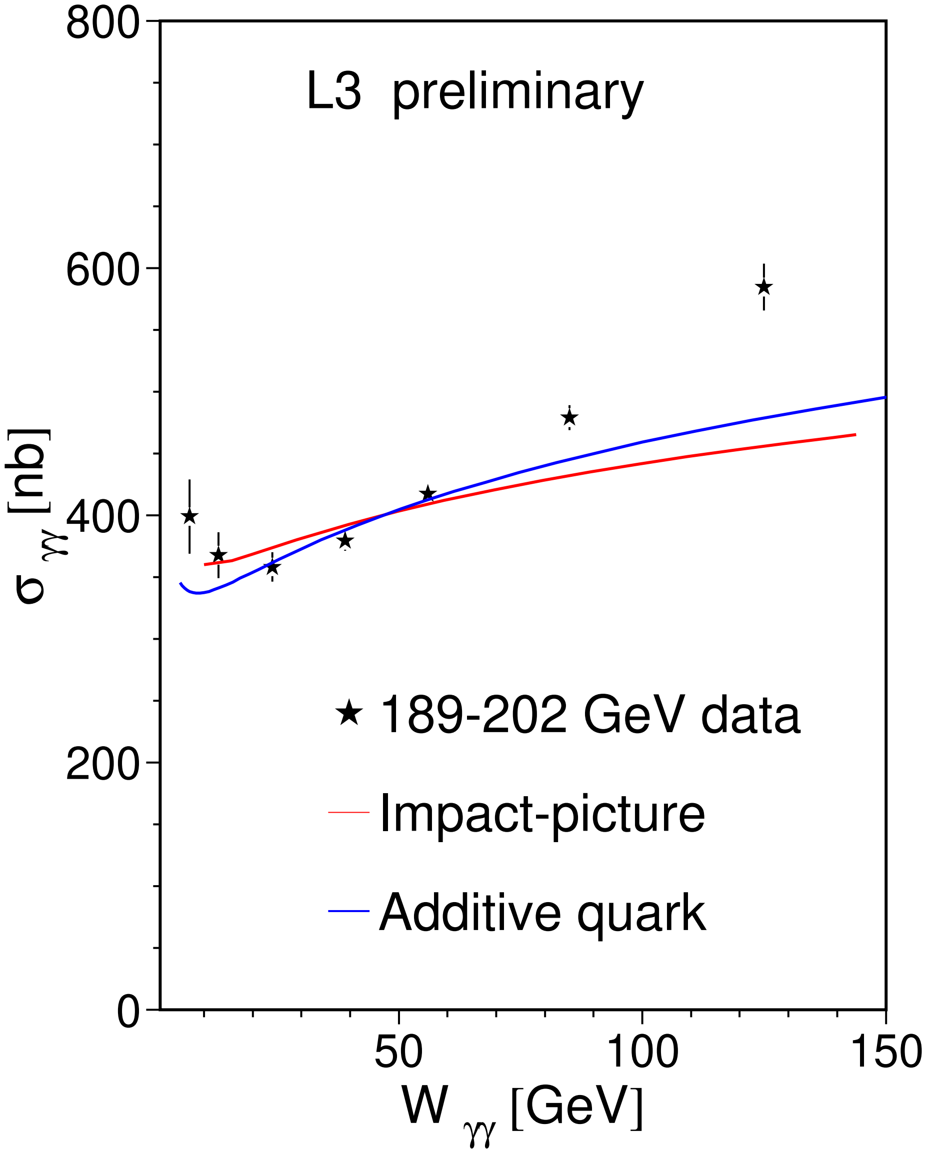
(A. Donnachie, P.V. Landshoff, Phys. Lett. B 296 (1992) 227)

OPAL data are compatible with PDG values:
$\eta = 0.34$ and $\epsilon = 0.095$

A fit of L3 data with η fixed to 0.34 gives:

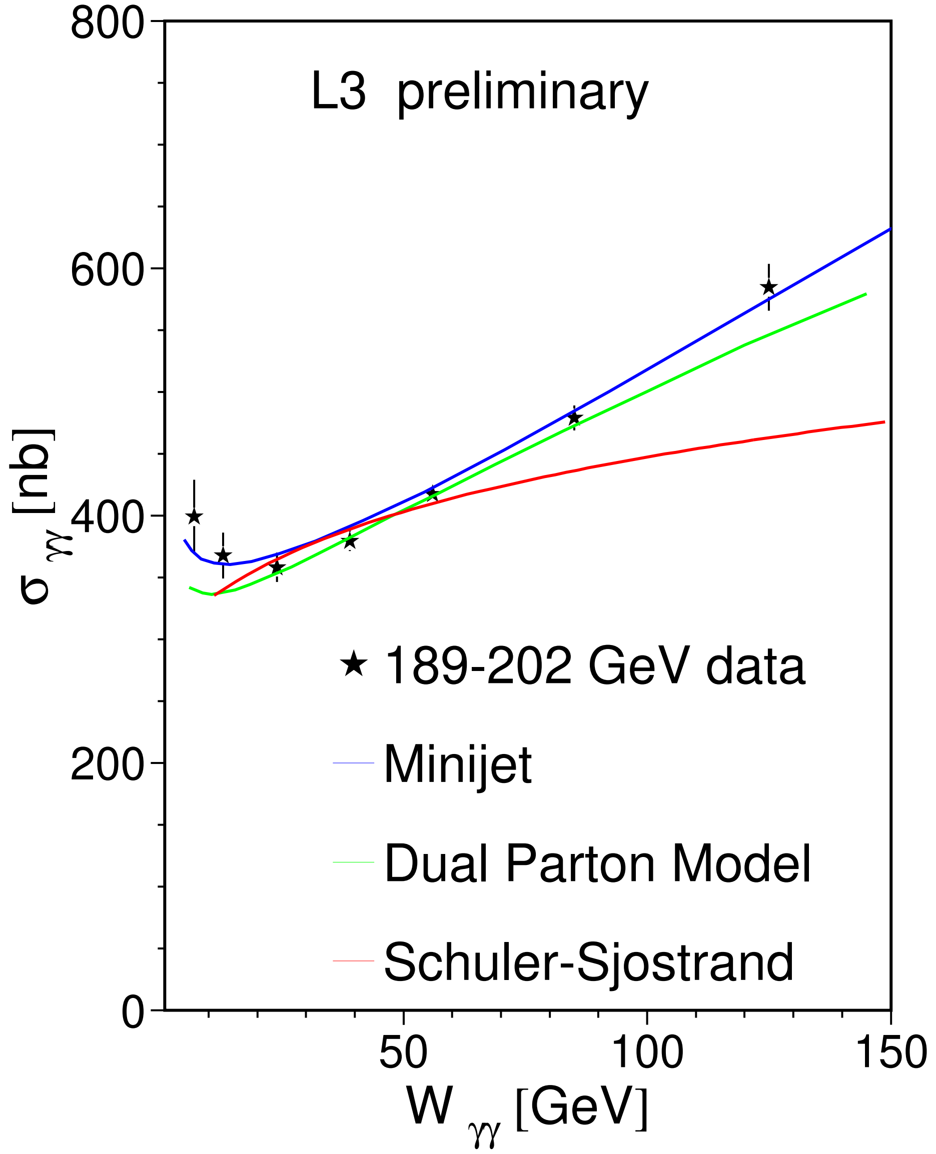
$\epsilon = 0.095$ (fixed)	χ^2/d.o.f. $=$ 165/12
$\epsilon = 0.263 \pm 0.014$ (free)	χ^2/d.o.f. $=$ 16/11

$\gamma\gamma$ total cross-section



C. Bourrely, J. Soffer, T.T. Wu, CERN-TH/99-76
P. Desgrolard, M. Griffon, E. Martynov, E. Predazzi, HEP-PH/9811393

$\gamma\gamma$ total cross-section



R.M. Godbole, A. Grau, G. Pancheri, Nucl. Phys. B 82 (2000) 246

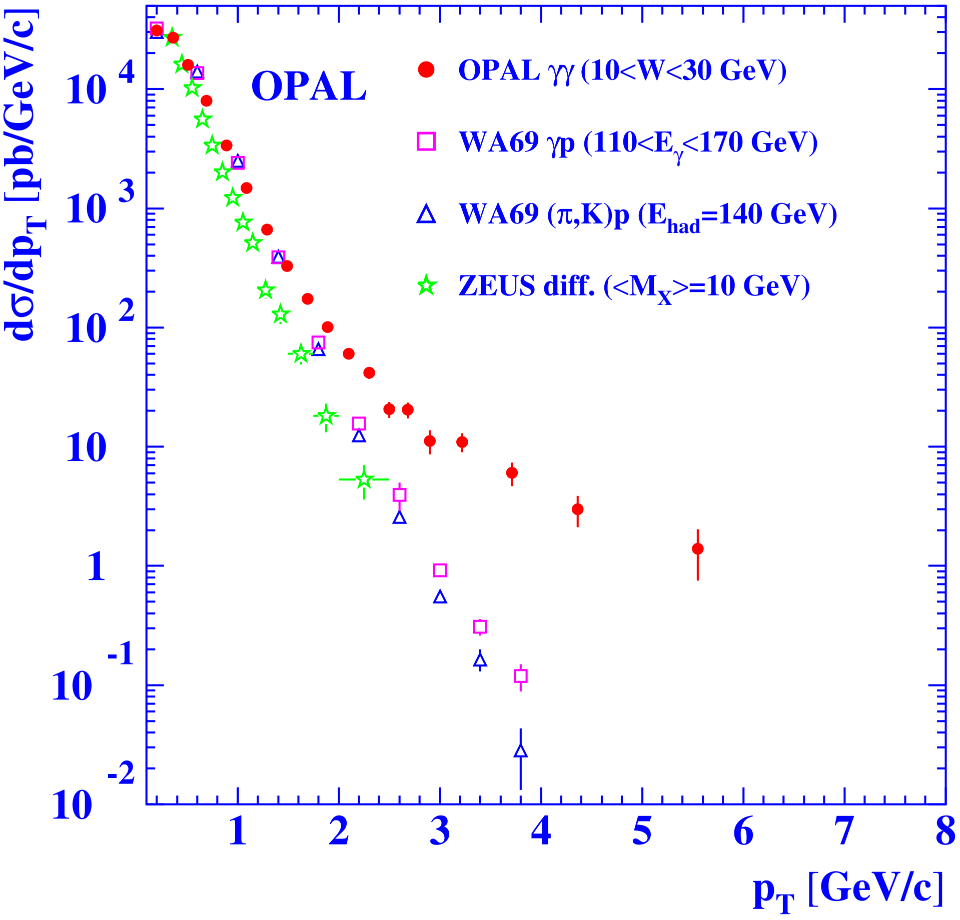
R. Engel, private communication

G.A. Schuler, T. Sjöstrand, Z. Phys. C 73 (1997) 677

$\frac{d\sigma}{dp_T}(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\pi^\pm + X)$

$W_{\gamma\gamma} > 10\,GeV$ and $|\eta| < 1.5$

(Eur. Phys. J. C6, 253, 1999)

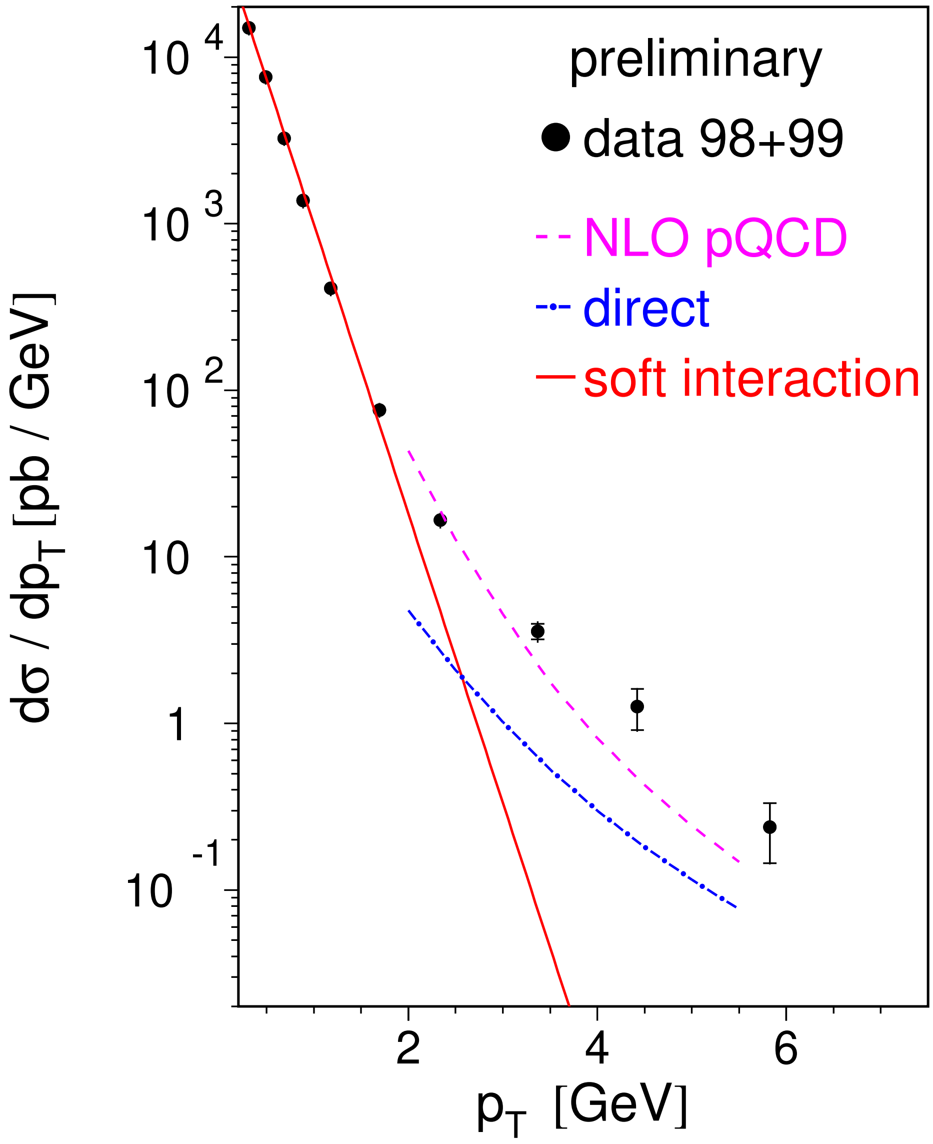


At low p_T: $\gamma\gamma$ behaves like soft hadron-hadron and photon-hadron collisions

At high p_T: QED and hard QCD processes become dominant in $\gamma\gamma$

$\frac{d\sigma}{dp_T}(e^+e^- \to e^+e^-\pi^0 + X)$

$W_{\gamma\gamma} > 5\,GeV$ and $|\eta| < 0.5$



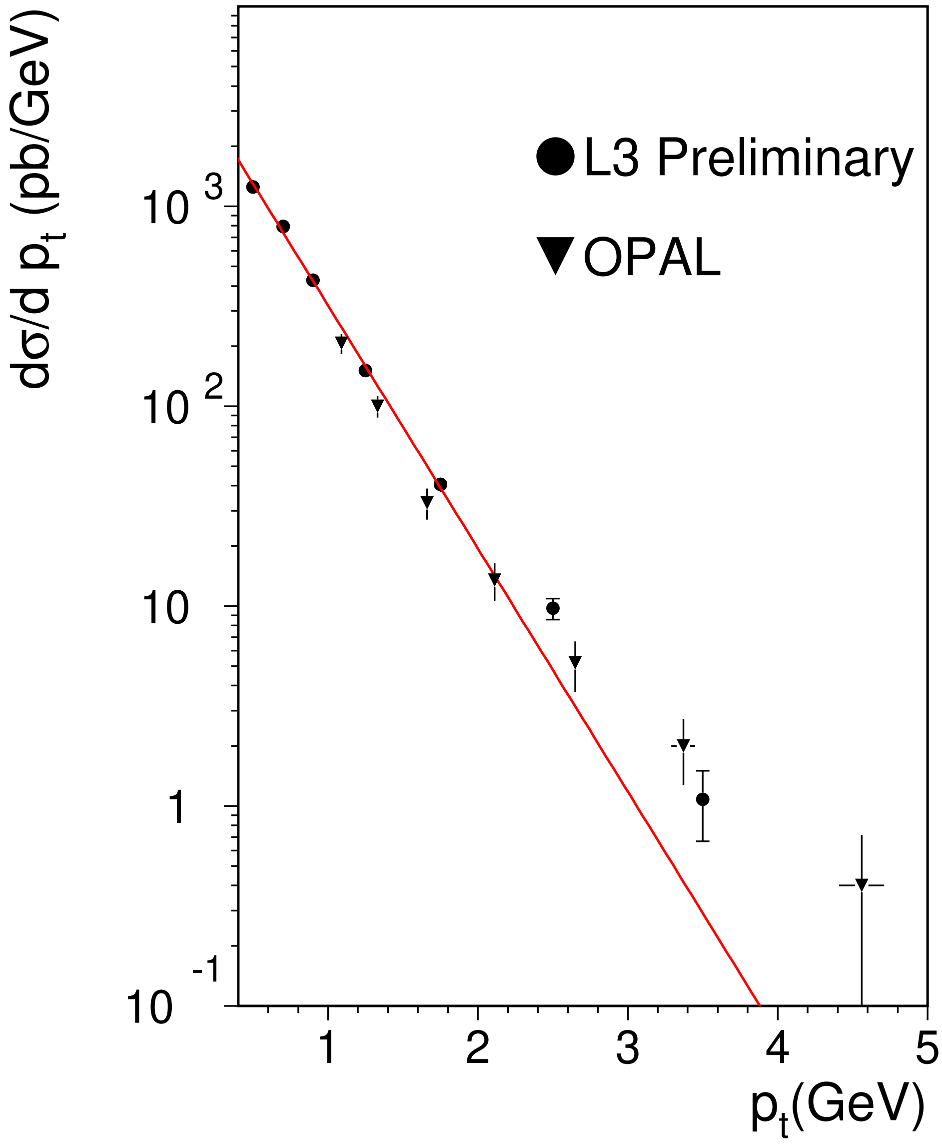
Same behaviour as $\pi^{\pm}$

Exponential fit : $< p_T > = 250 \pm 25\,MeV$

NLO pQCD: J. Binnewies, B.A. Kniehl and G. Kramer, Phys. Rev. D56(1996)6110

$\frac{d\sigma}{dp_T}(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- K^0_s + X)$

$W_{\gamma\gamma} > 10\,GeV$ and $|\eta| < 1.5$



Exponential fit: $< p_T > = 357 \pm 8\,MeV$

increases with the particle mass as expected

Hard QCD contribution obvious for $p_T > 2\,GeV$

Conclusions

- ❑ L3 and OPAL measurements of total and single-particle inclusive cross-sections are consistent.
- ❑ Major systematic errors come from MC simulation.
- ❑ PDG Regge parametrisations and simple hadron-like behaviour not favoured by data

⇨ need for MC improvements and solid theoretical predictions.