Total cross-section for real and virtual photons

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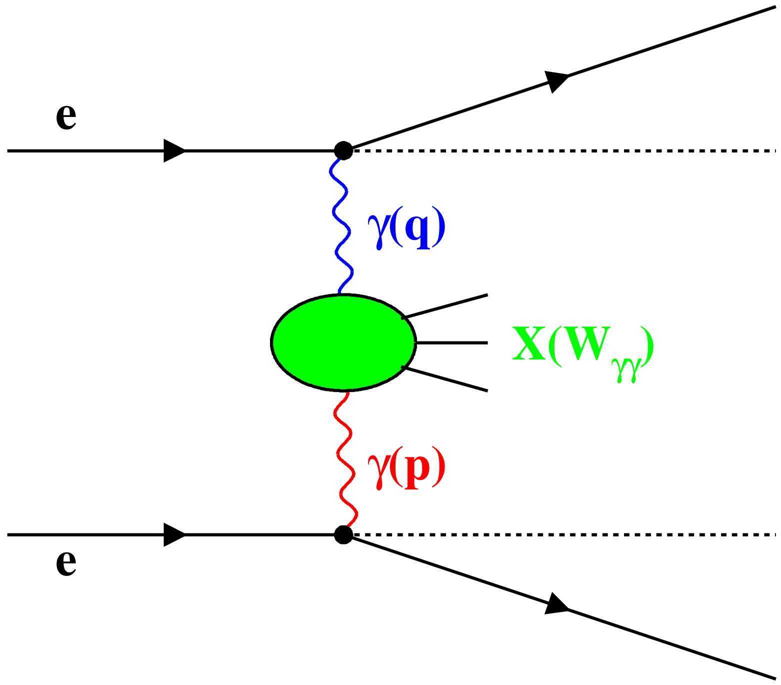
Outline

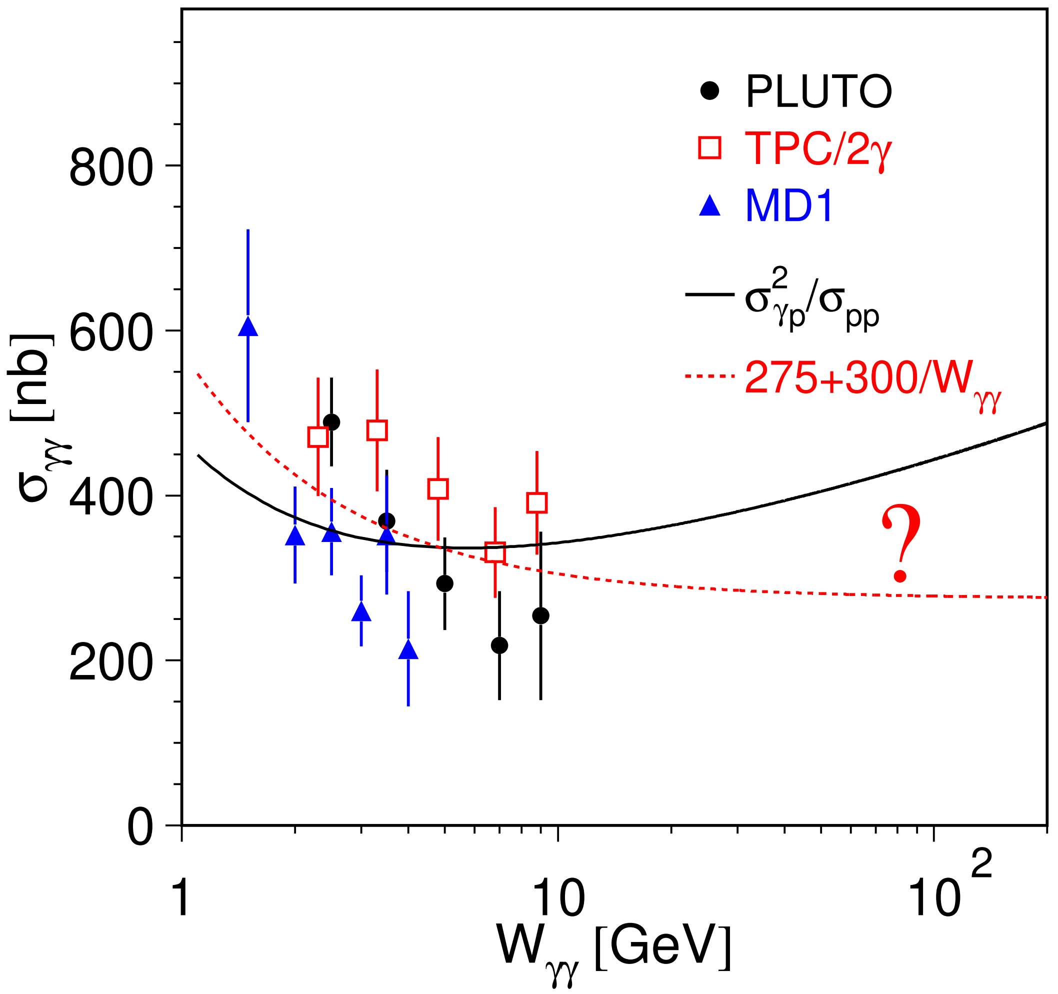
- Total $\gamma\gamma$ cross section (see also H.Vogt talk)
- Total $\gamma^*\gamma^*$ cross section

Motivation



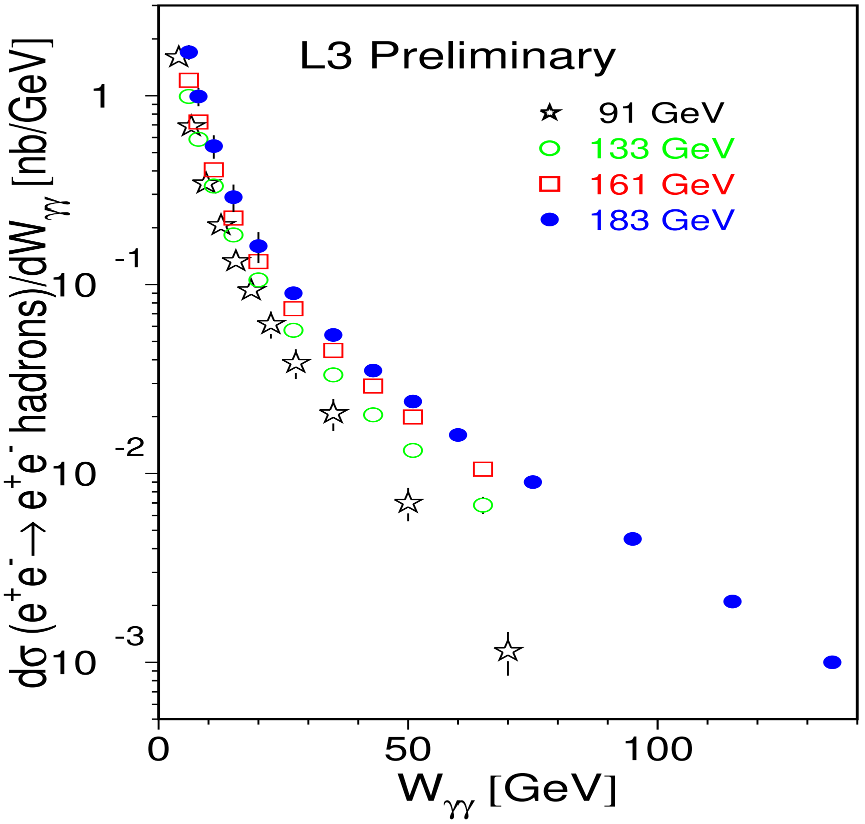
- High energy behaviour of two-photon collisions (non-perturbative domain, $Q^2 \simeq 0$)
- Perturbative QCD domain – high Q^2 photons, heavy flavour production

$\sigma_{\gamma\gamma}$, the measurements before LEP



- ❑ limited by beam energy ➜ $W_{\gamma\gamma} < 10 GeV$.
- ❑ Does $\sigma_{\gamma\gamma}$ increase at high energy ?
- ❑ At LEP, 5 GeV $< W_{\gamma\gamma} < 145 GeV$ is measured.

$d\sigma(e^+e^- \to e^+e^-$ hadrons $)$



✻ Effect of the $\gamma\gamma$ luminosity function

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

➜ $d\sigma_{ee}$ decreases with increasing $W_{\gamma\gamma}$.

❑ Extract $\sigma_{\gamma\gamma}$ from $d\sigma_{ee}$

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

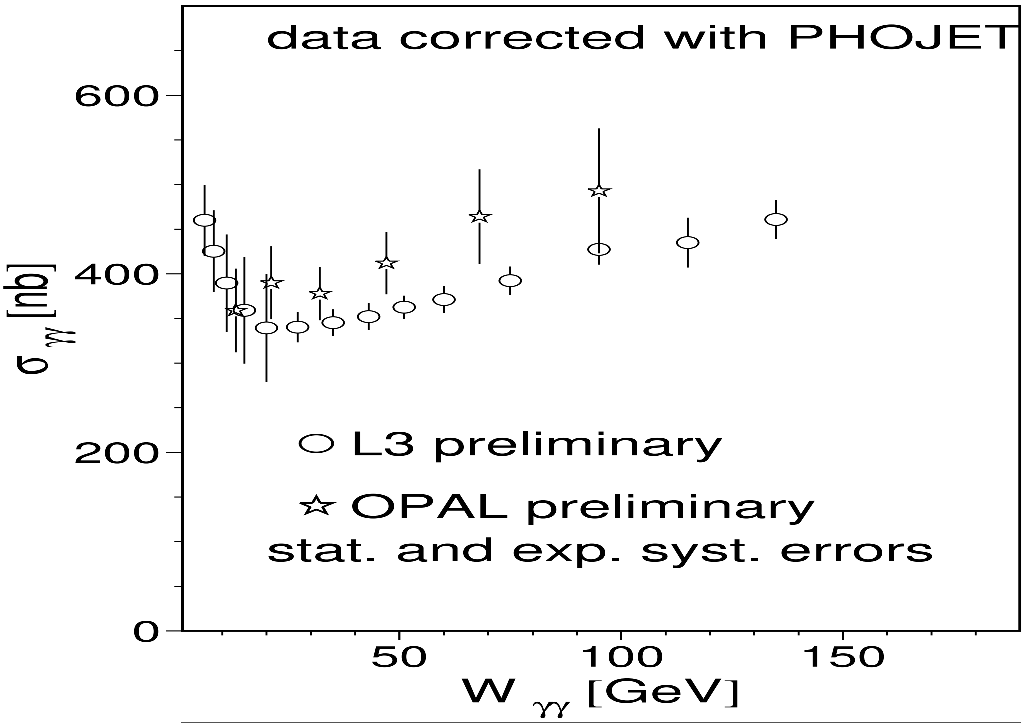
$$\sigma^{\gamma\gamma}_{ab}(W_{\gamma\gamma}, P^2, Q^2) = F_a(Q^2)F_b(P^2)\sigma^{\gamma\gamma}_{ab}(W_{\gamma\gamma})$$

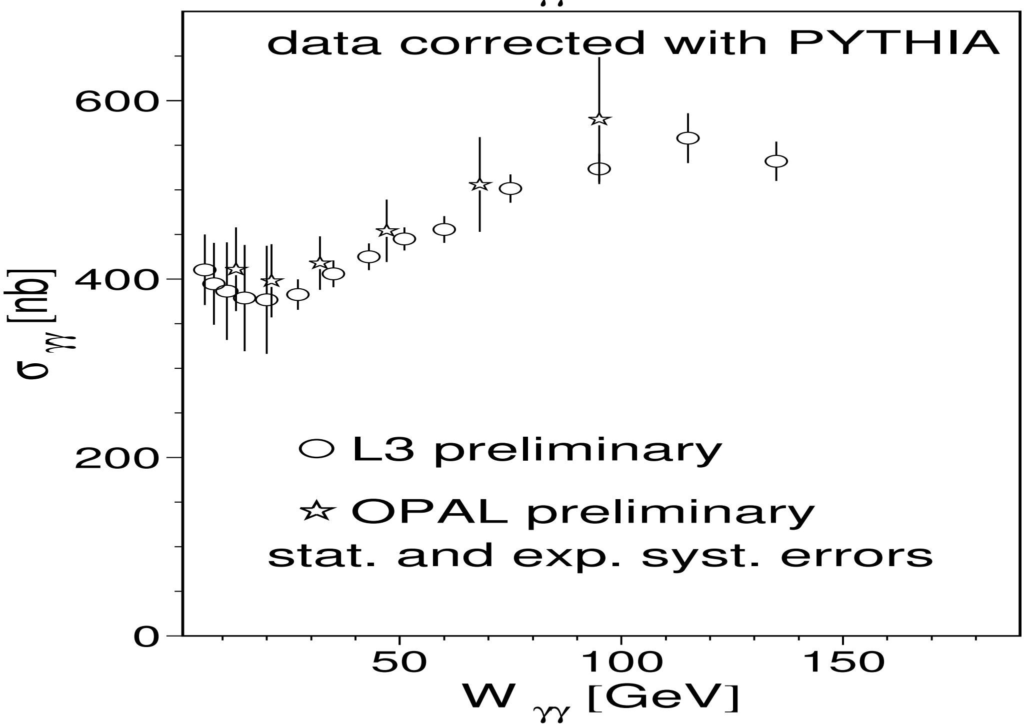
*T and S are Transverse and Scalar photon helicity indices.

➪ $\sigma^{\gamma\gamma}_{TT}$ is dominant.

➪ Remove the effect of $\mathcal{L}$ and $F(Q^2, P^2)$ ➜ $\sigma_{\gamma\gamma}(W_{\gamma\gamma})$

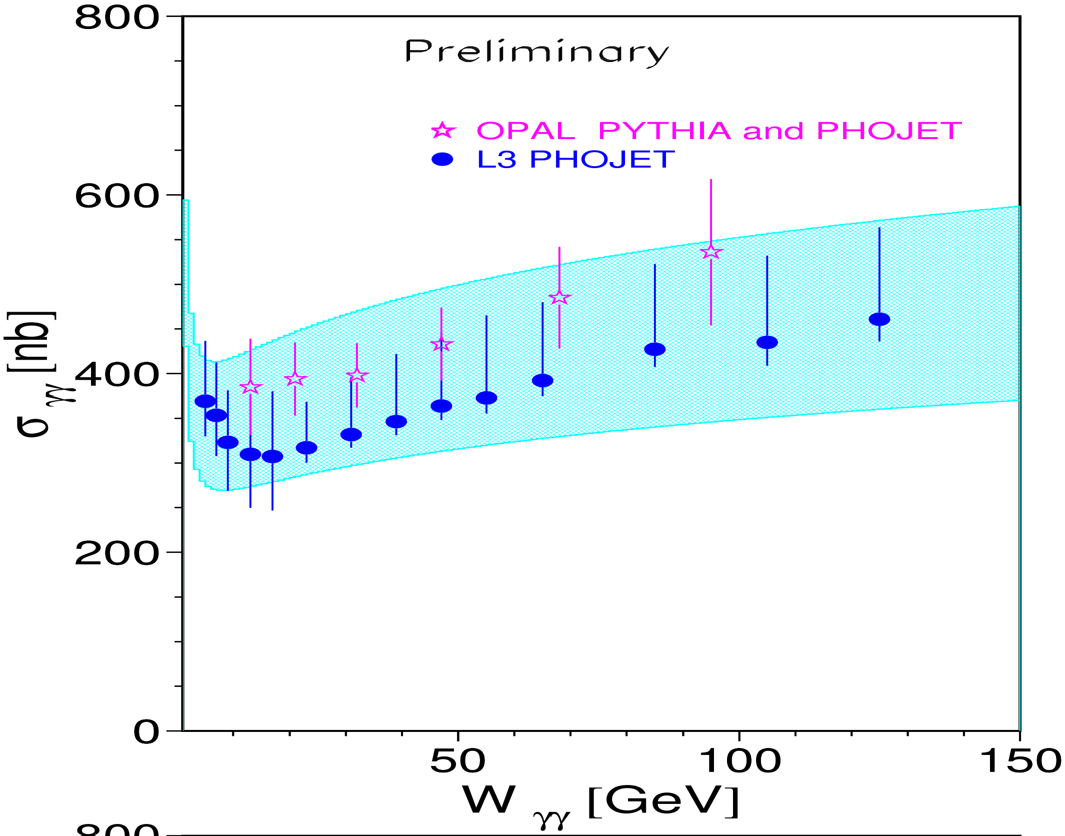
Results

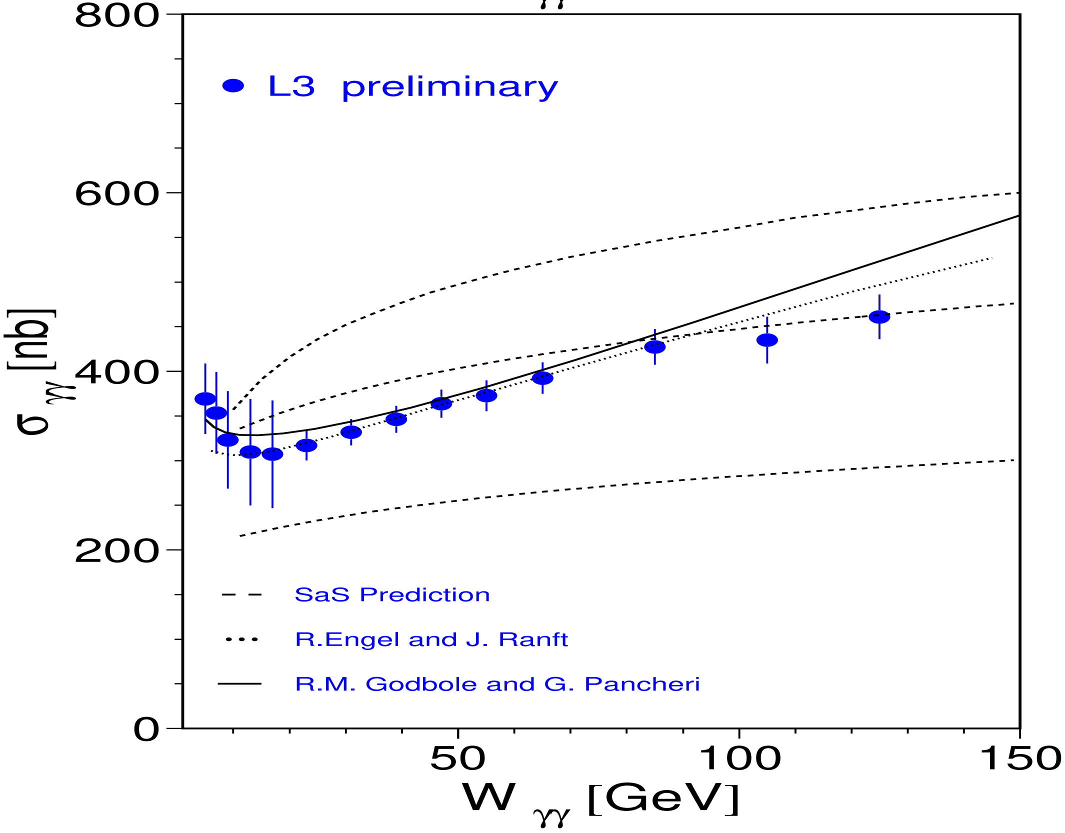




- The data show clear rising behaviour with increasing energy. ⇨ Independent of MC
- L3 and OPAL are compatible within errors.

Results


Preliminary
OPAL PYTHIA and PHOJET
L3 PHOJET
σγγ [nb]
W γγ [GeV]
0
200
400
600
800
50
100
150

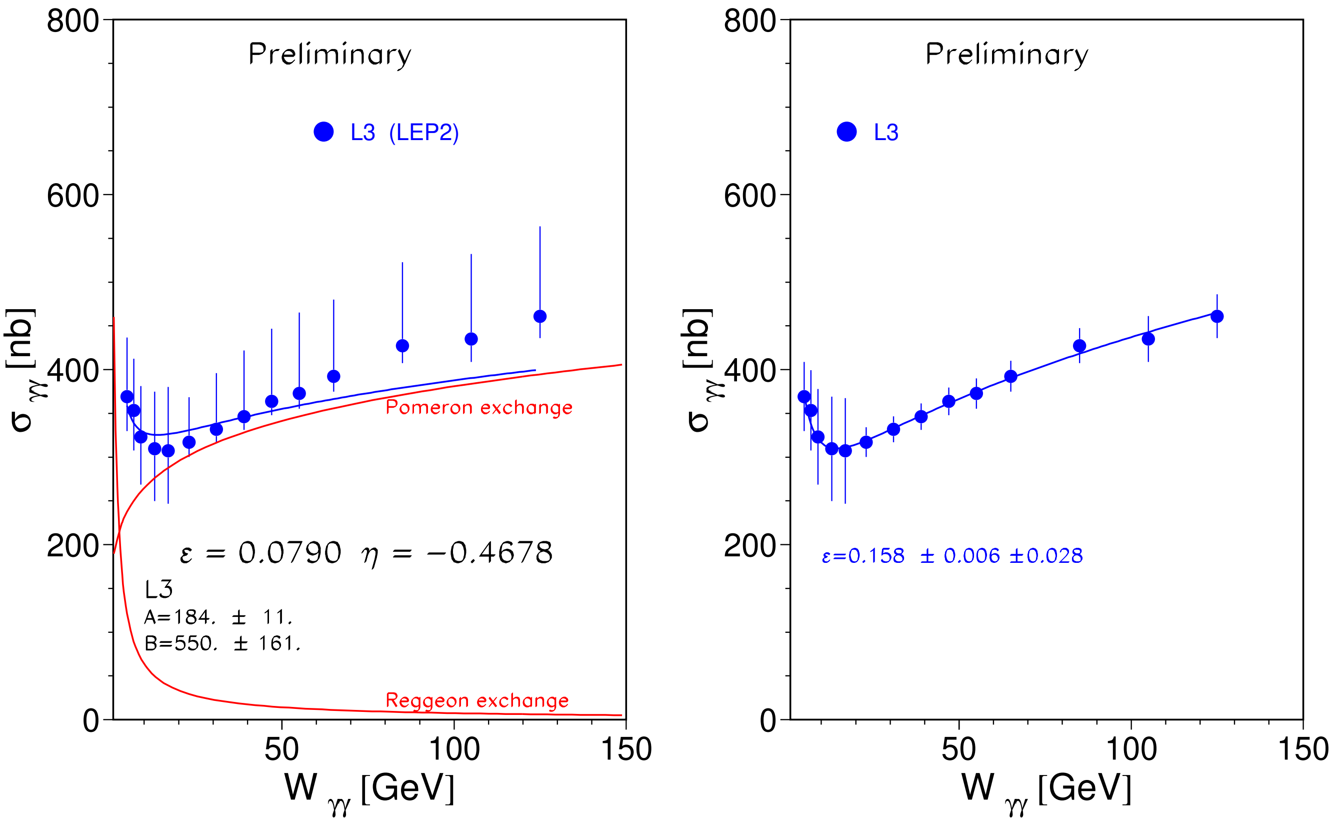

L3 preliminary
SaS Prediction
R.Engel and J. Ranft
R.M. Godbole and G. Pancheri
σγγ [nb]
W γγ [GeV]
0
200
400
600
800
50
100
150

DL fit

Fit with Donnachie and Landshoff parametrisation :
(Phys. Lett., B296, 227, 1992)

$$\sigma_{\gamma\gamma} = As^{\epsilon} + Bs^{\eta}, s = W_{\gamma\gamma}^2$$

Using the universal value of $\eta = -0.47$ (PDG96)



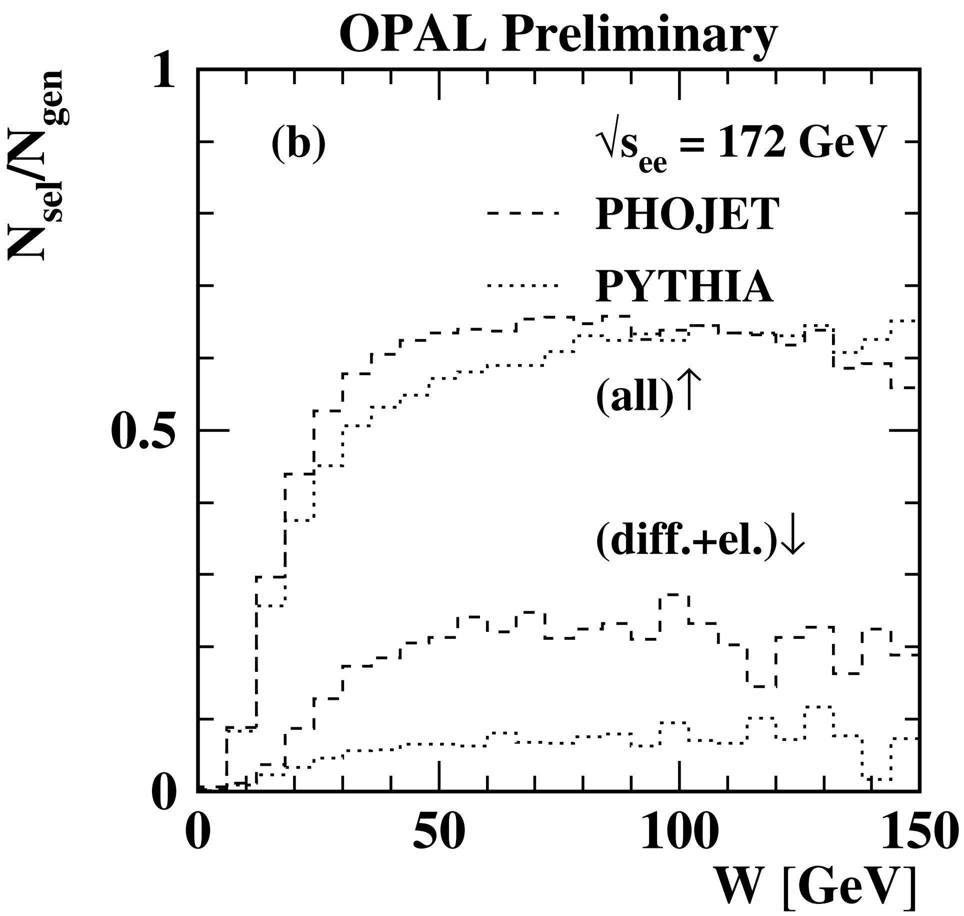
L3 : $\epsilon = 0.158 \pm 0.006$(stat.) ± 0.028(syst.)

OPAL : $\epsilon = 0.19 \pm 0.09$ (stat. + syst.)

PDG96 : $\epsilon = 0.079 \pm 0.001$

- ϵ is a factor of two bigger !

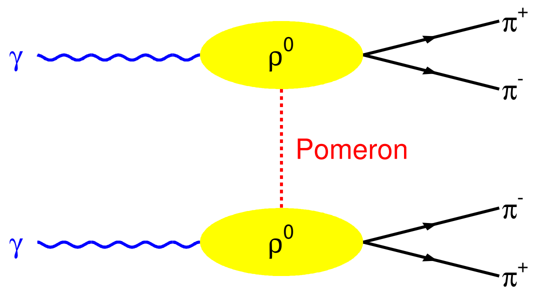
MC systematics
PYTHIA vs PHOJET



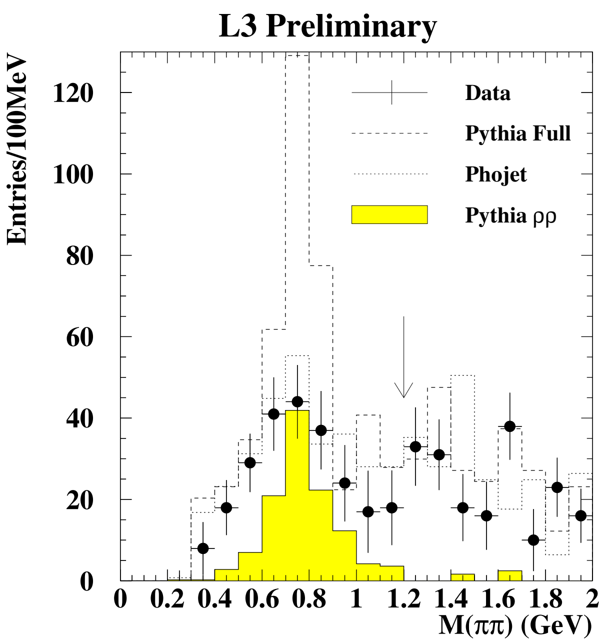
- Good modelling of the elastic and diffractive part ➩ is important

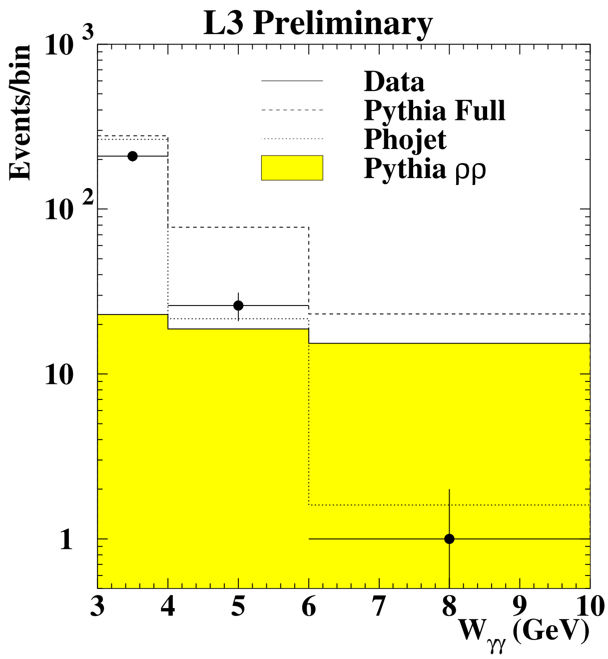
Contribution of $\rho^0 - \rho^0$ elastic scattering into $\pi\pi\pi\pi$ final state

$\gamma\gamma \rightarrow \rho^0\rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ at 183 GeV



➜ The cross-section is expected to remain large at high $W_{\gamma\gamma}$ because of the Pomeron exchange.



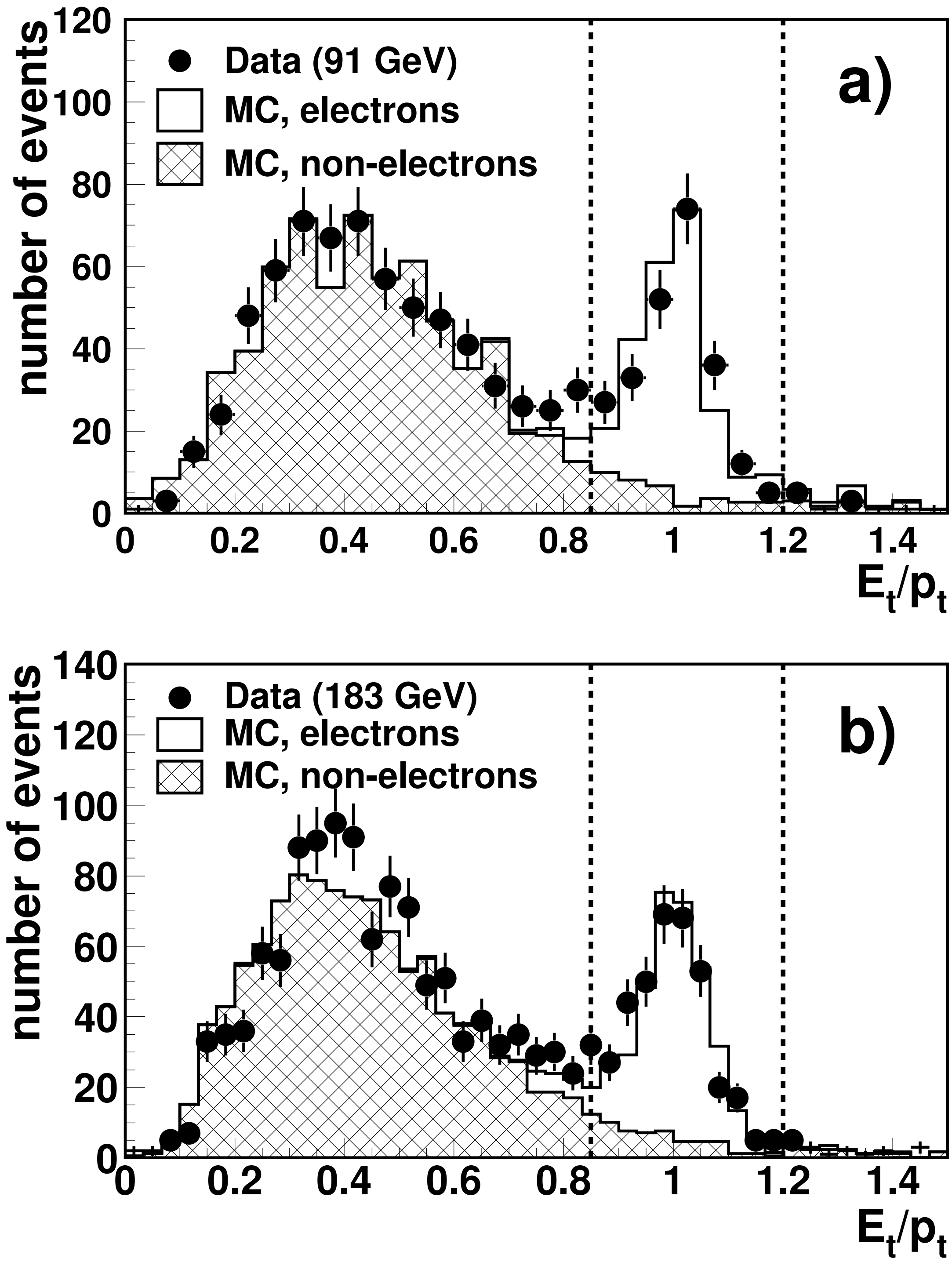


⇨ For $W_{\gamma\gamma} < 10$ GeV, the cross-section estimated by PYTHIA is too large.

⇨ The measurement for $W_{\gamma\gamma} > 10$ GeV is difficult, but important.

Heavy flavour tagged by semi-leptonic decays:

Electron Identification



Lepton Selection

$$c \longrightarrow \mathrm{l}$$

$\mu^{\pm}$ Selection

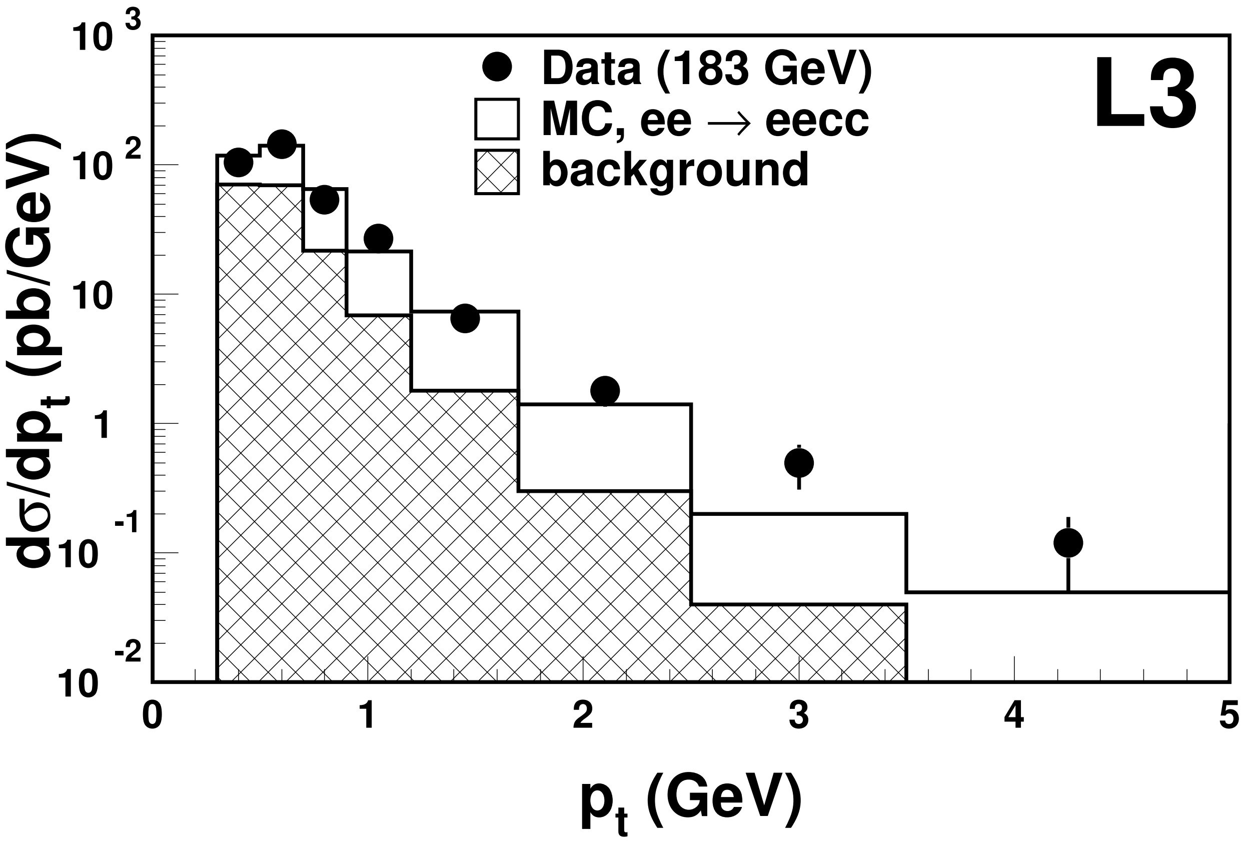
track in muon ch.
$|\cos\theta| < 0.90$
$P_{\mu} > 2$ GeV/c
$P_{\mu} < 0.2E_{beam}$

$e^{\pm}$ Selection

e.m. shower shape
$|\cos\theta| < 0.90$
$P_e > 0.6$ GeV
$\Delta\phi < 20$mrad
$0.85 < E_T/p_T < 1.2$

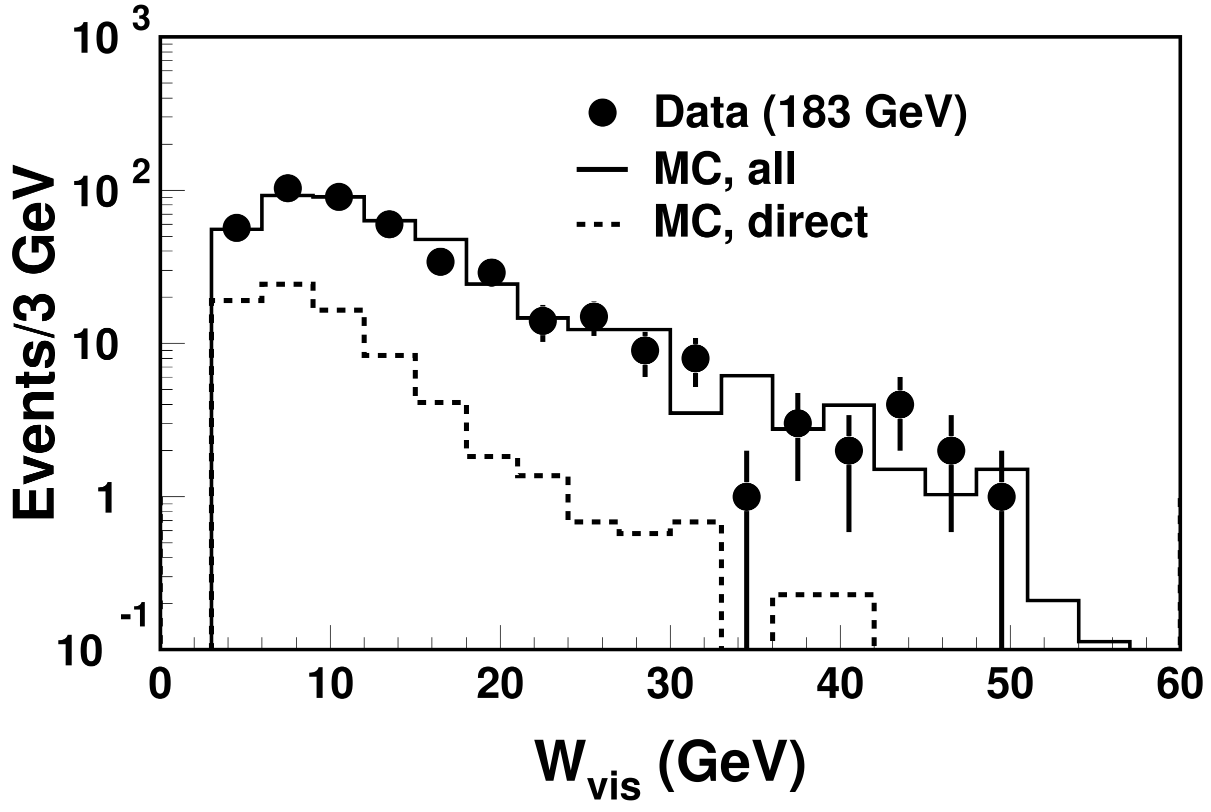
$\sqrt{s}$ GeV	$\mathcal{L}$ pb^{-1}	Hadrons # ev.	Electrons # ev.	Muons # ev.
91	80	93204	282	62
130 – 140	12	21045	82	-
161 – 172	21	44444	156	17
183	52	116760	433	52
189	176	399755	1586	208

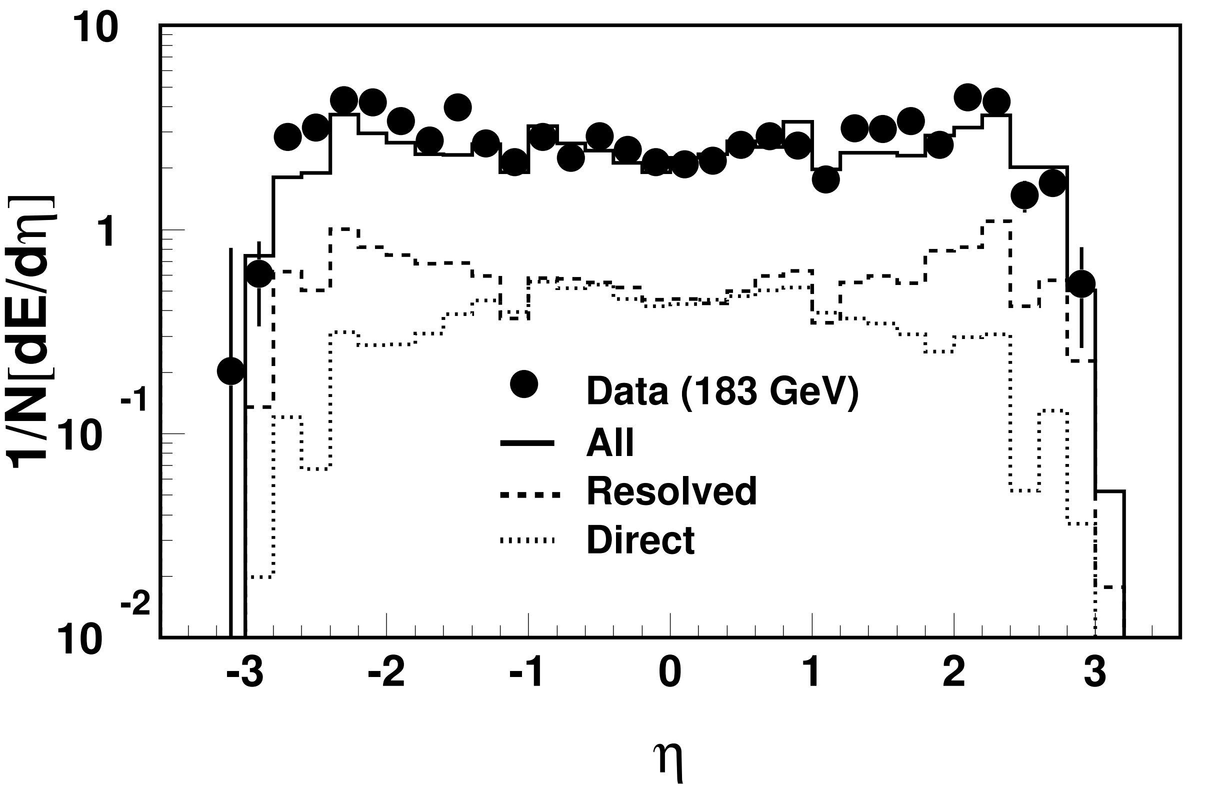
Inclusive lepton production



- p_t spectrum is well described by PYTHIA
- direct process produces, in average, more energetic leptons than resolved one
- fraction of charm events is increasing with p_t of lepton

Direct vs Resolved

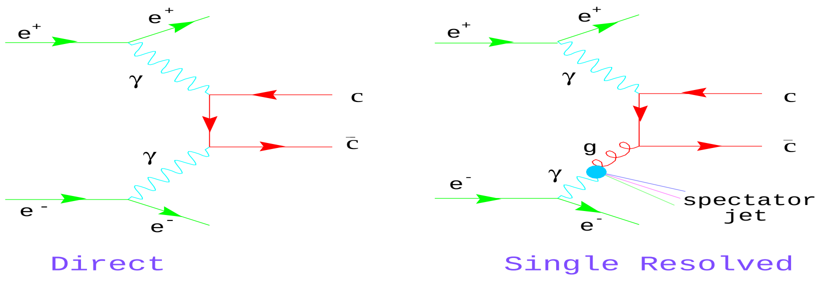


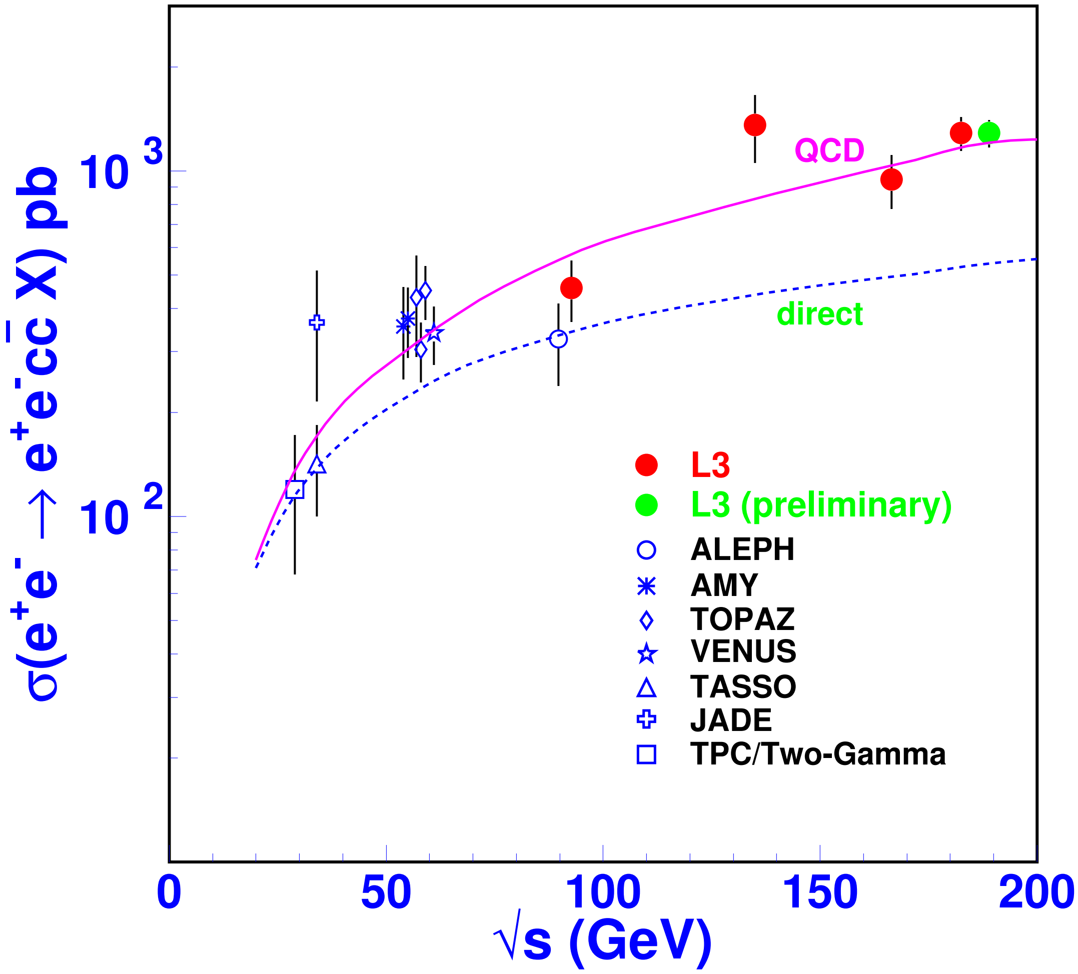


- resolved processes are needed to describe the data

Charm production in $\gamma\gamma$ collisions

L3: CERN-EP/98-185, to appear in Phys. Lett. B



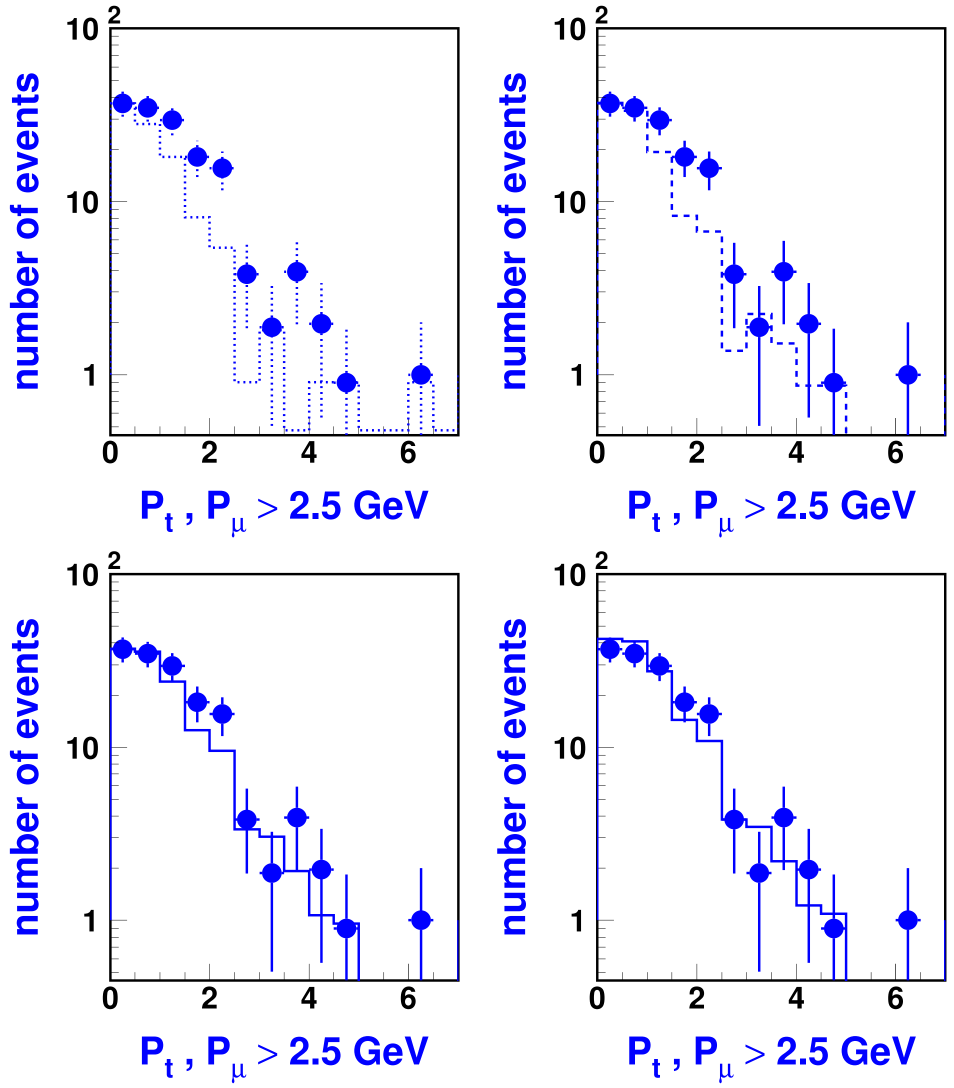


- clear evidence of gluon content of photon
- Charm could be a candidate to contribute to the faster rise of $\sigma_{\gamma\gamma}$

Beauty production in $\gamma\gamma$ collisions

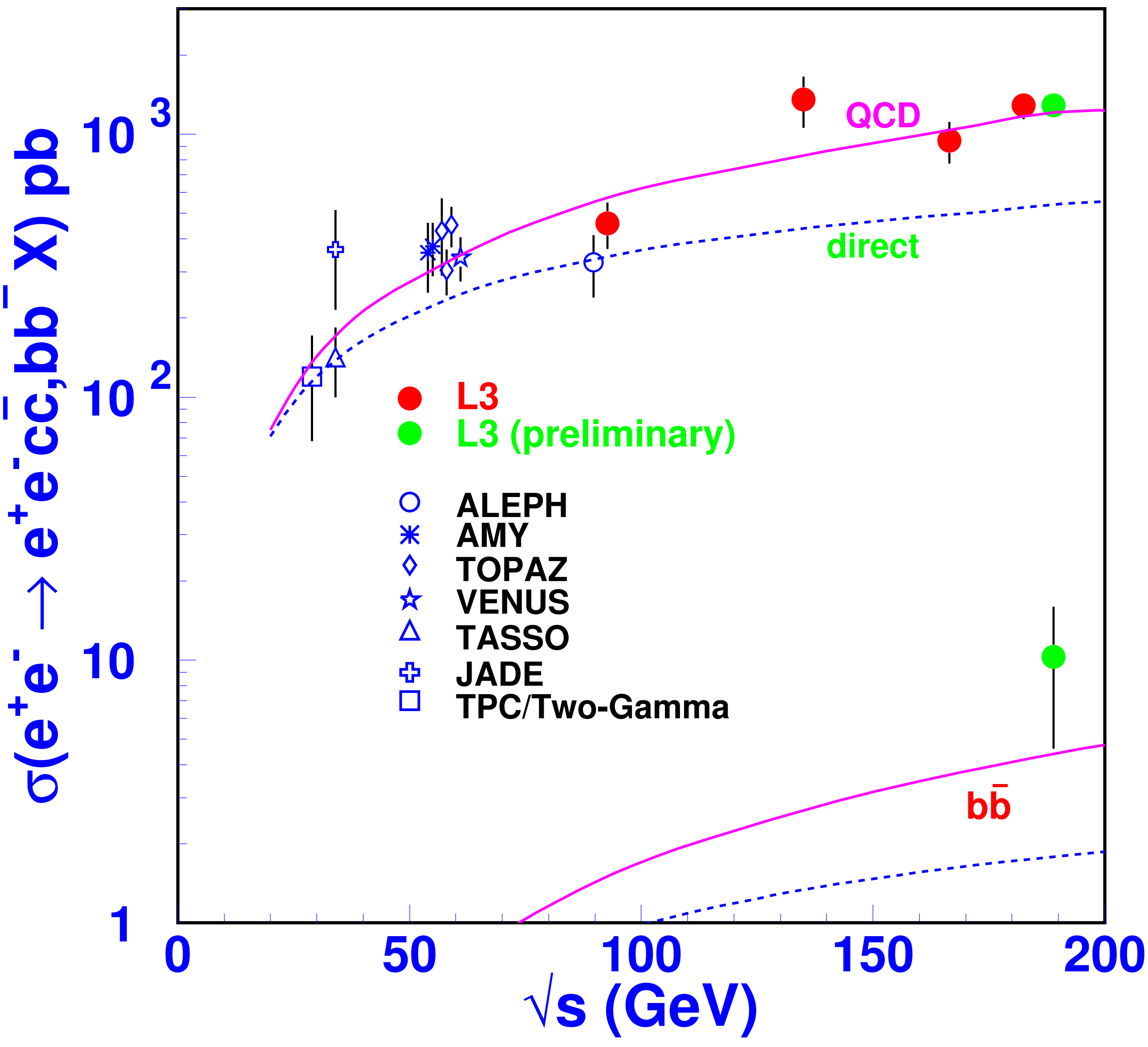
High momentum, high transverse momentum muons

$$P_\mu > 2.5 \text{ GeV}, \; P^\mu_{tj} > 1.5 \text{ GeV}$$
$$N^\mu_{ev} = 49, \epsilon_b = 0.01, \pi_b = 0.34$$



L3 PRELIMINARY:
$$\sigma_{bb} = 10.3 \text{ pb} \pm 4.6 \text{ (stat.)} \pm 3.3 \text{ (syst.)}$$

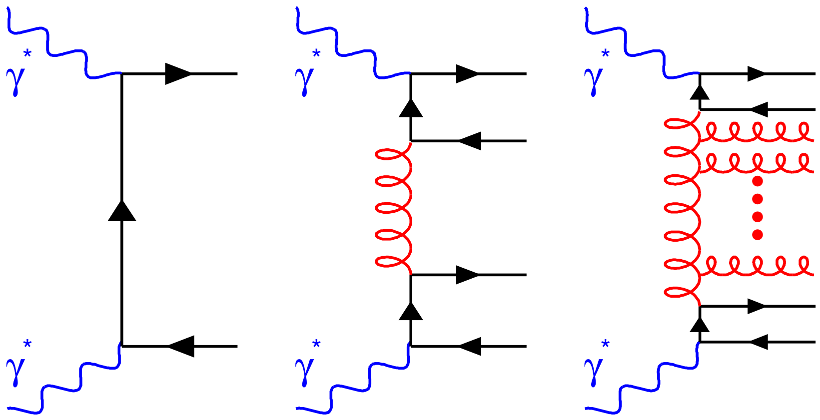
Charm and beauty in $\gamma\gamma$ collisions



$b\bar{b}$ in $\gamma\gamma$ collisions seems within reach

- theory prediction from M.Drees,M.Krämer,J.Zunft and P.M.Zerwas,Phys. Lett. B306 (1993) 371) ; $m_c = 1.3$ GeV, $m_b = 5.0$ GeV.

$\gamma^*\gamma^*$ collisions



- J. Bartels et al. (Phys. Lett. B389 742, 1996) and S.J. Brodsky et al. (Phys. Rev. D56 6957, 1997) point out the BFKL Pomeron can be investigated in $\gamma^*\gamma^*$ collisions.

  ⇨ BFKL diagram is predicted to be dominant at high Q^2 and high $W_{\gamma^*\gamma^*}$.
  ⇨ two virtual photons ➜ double-tagged events

- In Leading order approximation :

$$\sigma_{\gamma^*\gamma^*} = \sigma_0 (\frac{s}{s_0})^{\alpha_P - 1} \simeq \sigma_0 (\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}})^{\alpha_P - 1}$$

$$s_0 = \frac{\sqrt{Q_1^2 Q_2^2}}{y_1 y_2}; \quad \alpha_P - 1 = 4 \ln 2 \frac{N_c \alpha_s}{\pi}$$

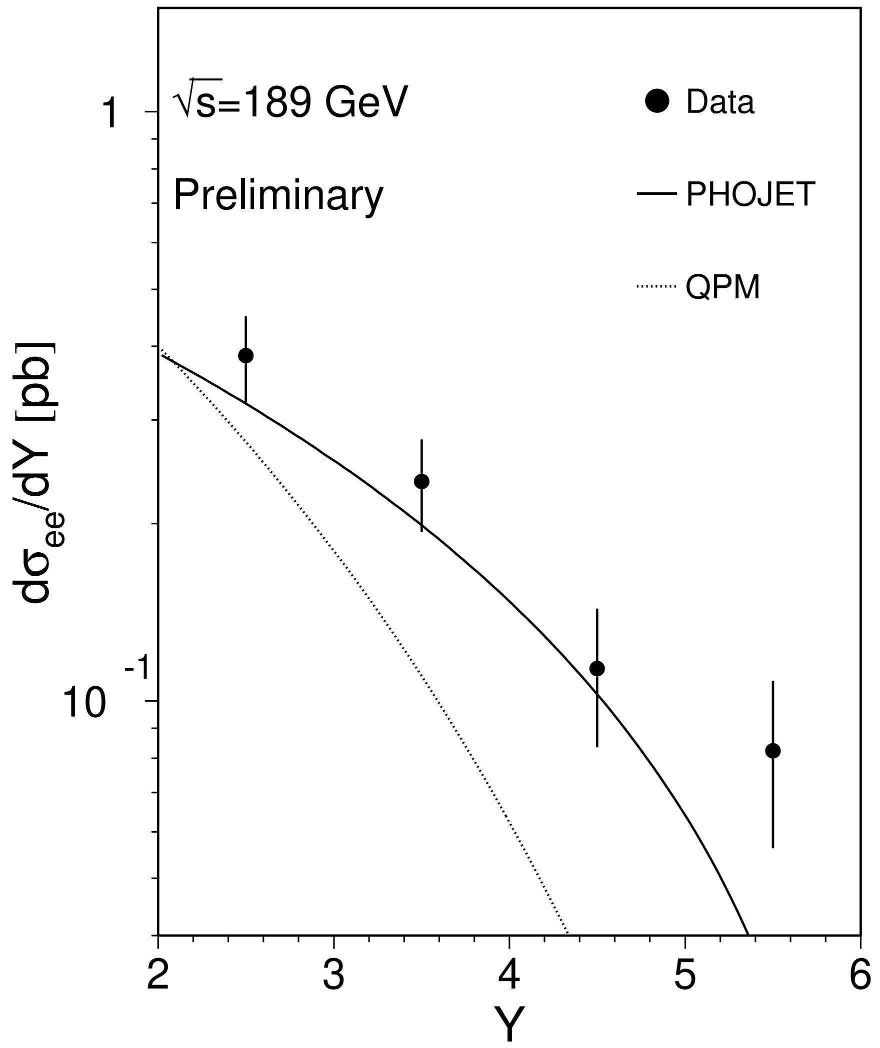
$$Y = \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}}); \quad < Q_1^2 > \approx < Q_2^2 >$$

- Using $N_c = 3$, $\alpha_s = 0.2$ ➜ $\alpha_P - 1 \simeq 0.53 > 0.079$

Double tag events

	91 GeV	183 GeV	189 GeV
Luminosity	140. pb^{-1}	52. pb^{-1}	176. pb^{-1}
$< Q^2 >$	3.5 GeV^2	14. GeV^2	14.5 GeV^2
Events	137	34	108
Bkg	12	4	14

The backgrounds come from $e^+e^- \to e^+e^-\tau^+\tau^-$ and single tagged events.

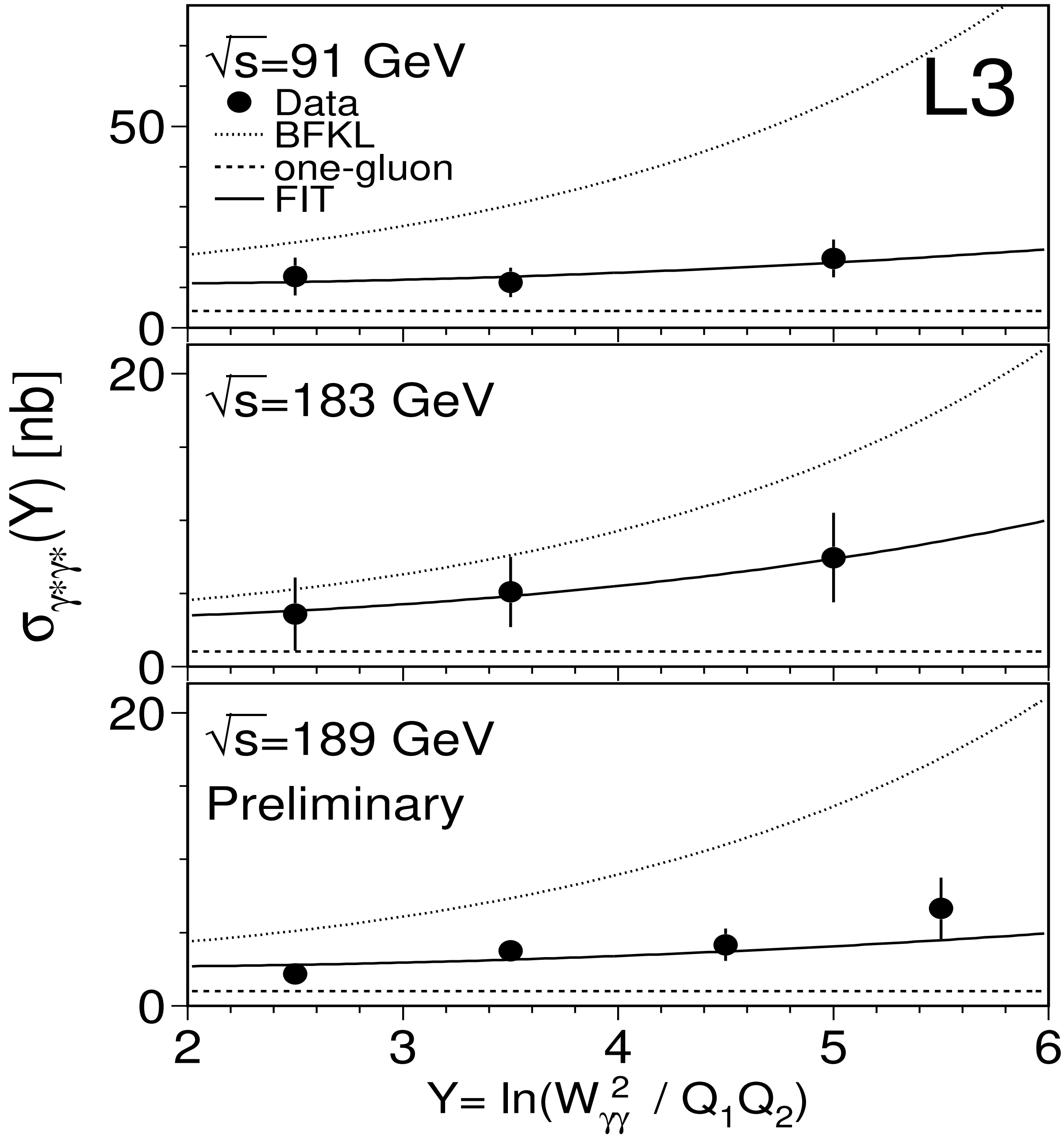


QPM ➩ is **insufficient** to describe the data

PHOJET ➩ is **almost sufficient** to describe the data

$\sigma_{\gamma^*\gamma^*}$

L3: CERN-EP/98-205, to appear in Phys. Lett. B



$$\alpha_P - 1 = 0.28 \pm 0.05 \quad \text{at} \sqrt{s} \simeq \quad 91 \text{ GeV}$$
$$\alpha_P - 1 = 0.40 \pm 0.07 \quad \text{at} \sqrt{s} \simeq 183 \text{ GeV}$$
$$\alpha_P - 1 = 0.29 \pm 0.03 \quad \text{at} \sqrt{s} \simeq 189 \text{ GeV}$$

⇨ **BFKL is not favoured**

⇨ **the data provide a stuff to fit (fix) 'soft + hard' mixture**

Conclusion

- Total cross section

  - $\sigma_{\gamma\gamma}$ increases at high energies – L3 and OPAL, independent of used MC
  - fitted Pomeron slope value, $\epsilon = 0.16 \pm 0.03$ is larger than PDG value ➜ as expected by QCD
  - The dominant uncertainty is the modelling dependence
  - Heavy flavour production in agreement with QCD prediction, ➜ $\gamma g \rightarrow c\bar{c}$ is important
  - Virtual photons cross section at LEP has been measured by L3. Fitted Pomeron slope value is $\epsilon = 0.29 \pm 0.03$ for $< Q^2 > = 15$ GeV^2, inconsistent with BFKL (0.53) prediction

- The data of different channels are very important to understand the transition between soft and hard domains