# Photon Interactions at LEP and HERA

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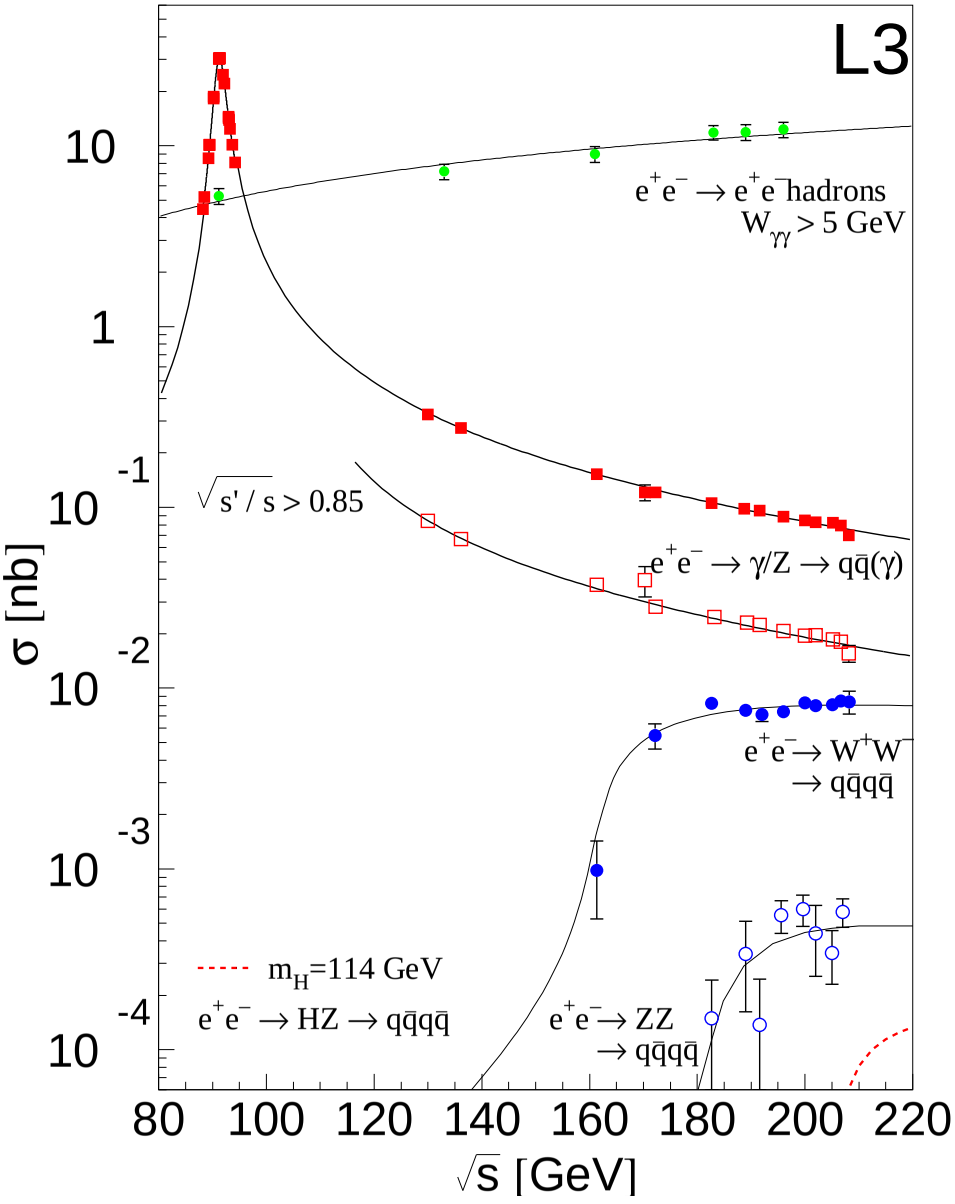
A very quick look to a large field of physics !!!!

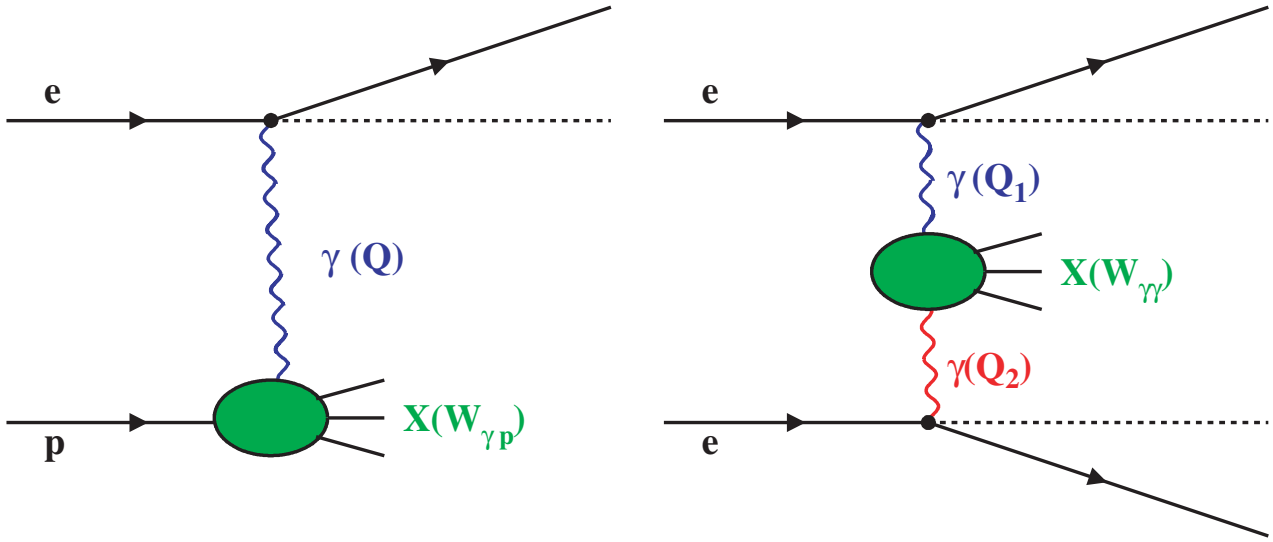
- The virtual photon interactions
- Photon structure
- Cross-sections vs $W_{\gamma\gamma}$ and $W_{\gamma p}$
- c and b production
- Test of BFKL dynamics
- Conclusions

# Hadron production at LEP




- Two-photon cross-section increases as $\ln^2 s$ ⇨ dominant at LEP
- We have only virtual photons !
  (Laser beams at TESLA?)

# Virtual Photons




Hera

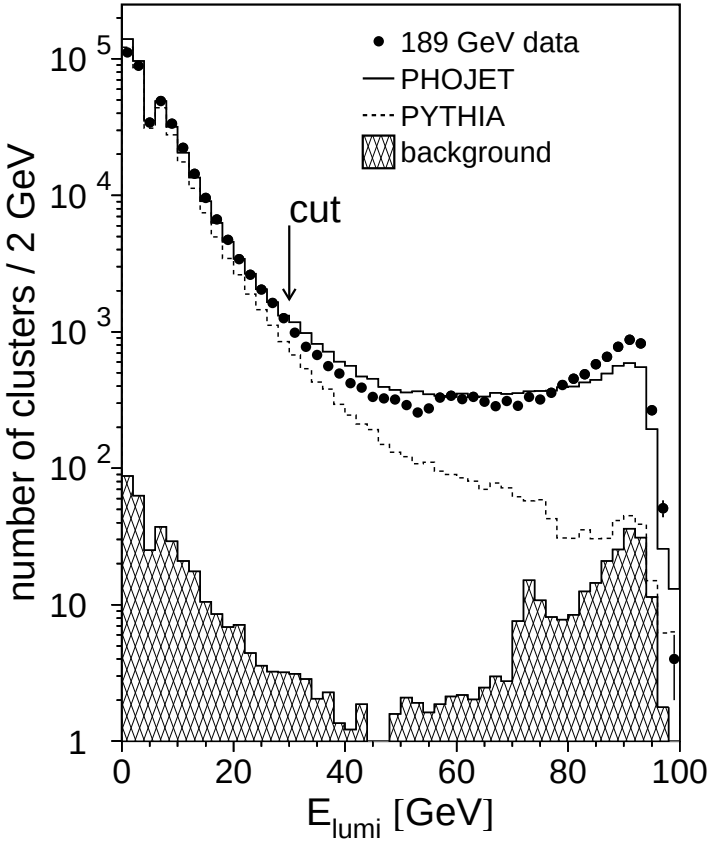
LEP

- $Q^2 \simeq 0$; Photoproduction
- $Q^2 >> 0$ DIS
- Composite target

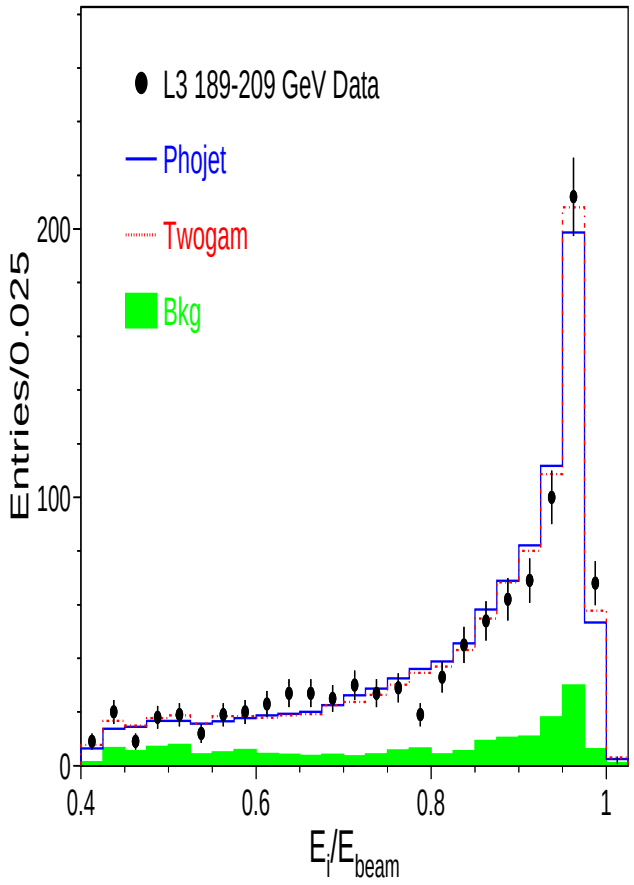
- $Q_1^2 \simeq Q_2^2 \simeq 0$ Untagged
- $Q_1^2 > Q_2^2 \simeq 0$ Single-tag
- $Q_1^2 \simeq Q_2^2 > 0$ Double-tag

# Two-photon : tagging scattered electron

anti-tag or single-tag



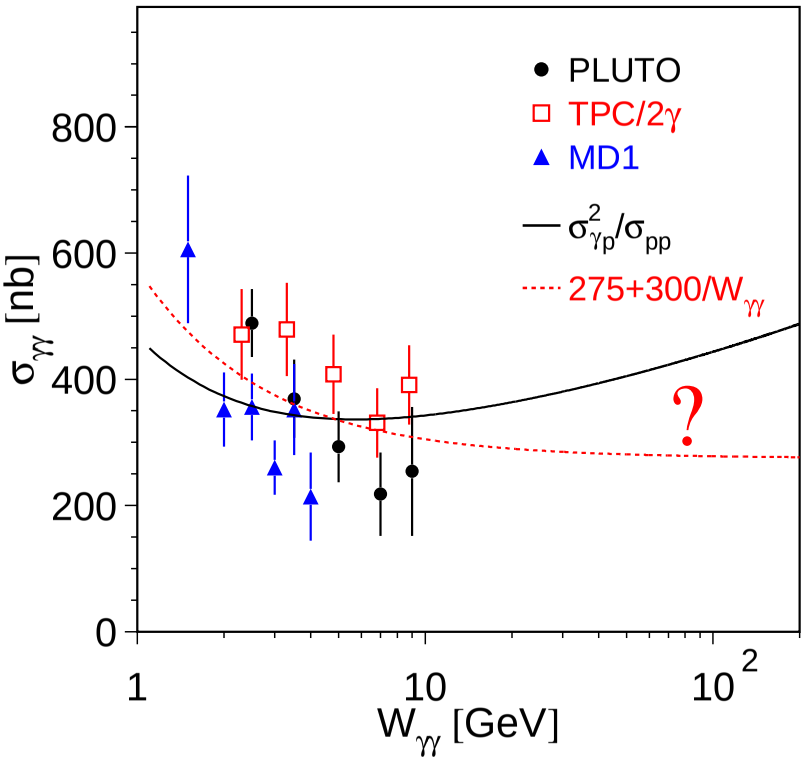

double-tag




Energy deposited in the small angle electromagnetic calorimeters.

# Two-photon physics before LEP

$\sigma(\ \gamma\gamma \rightarrow hadrons)$ vs $W_{\gamma\gamma}$

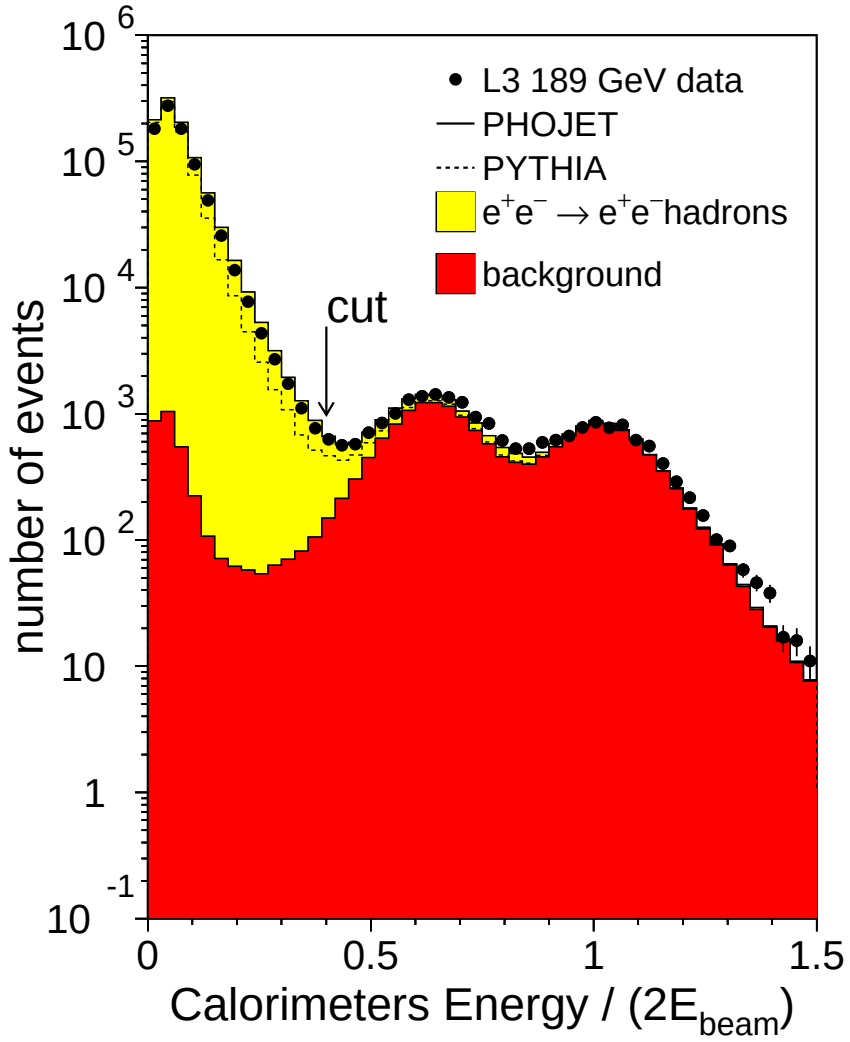



At low energies it is difficult to separate two-photon interactions from annihilation.

Main results were obtained for

- $F_2^\gamma$ (Single-tag events).
- Resonance formation.

# Event selection $e^+e^- \rightarrow e^+e^-$ *hadrons* at LEP




➪ Selection

$E_{tot} \leq 40\% \sqrt{s}$

$\#$ particles $\geq 6$

$W^2_{vis} = (\sum_i E_i)^2 - (\sum_i \vec{p}_i)^2 < W^2_{\gamma\gamma}$

➪ Main backgr. $(1 - 15\%)$:

$e^+e^- \rightarrow e^+e^-\tau^+\tau^-$

$e^+e^- \rightarrow hadrons$

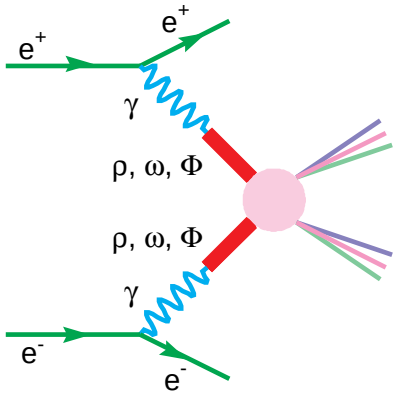
➪ Progress in Monte Carlo:

PYTHIA,PHOJET,TWOGAM

# Diagrams contributing to $\gamma\gamma$ interactions

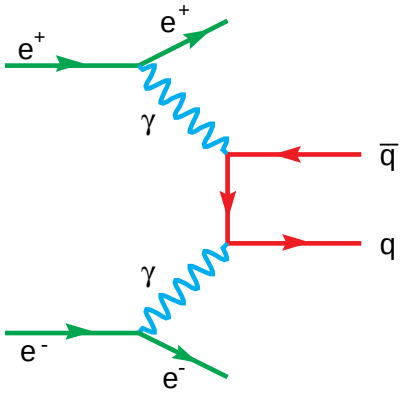
Monte Carlo models : VDM, LO QCD (DGLAP), pdf in the photon

SOFT:

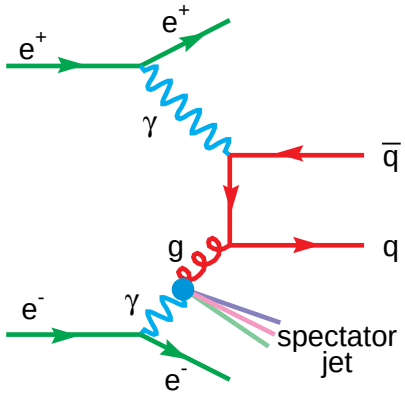



HARD:

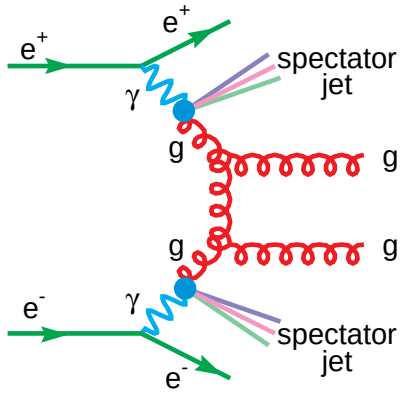
VDM




Direct (QED)



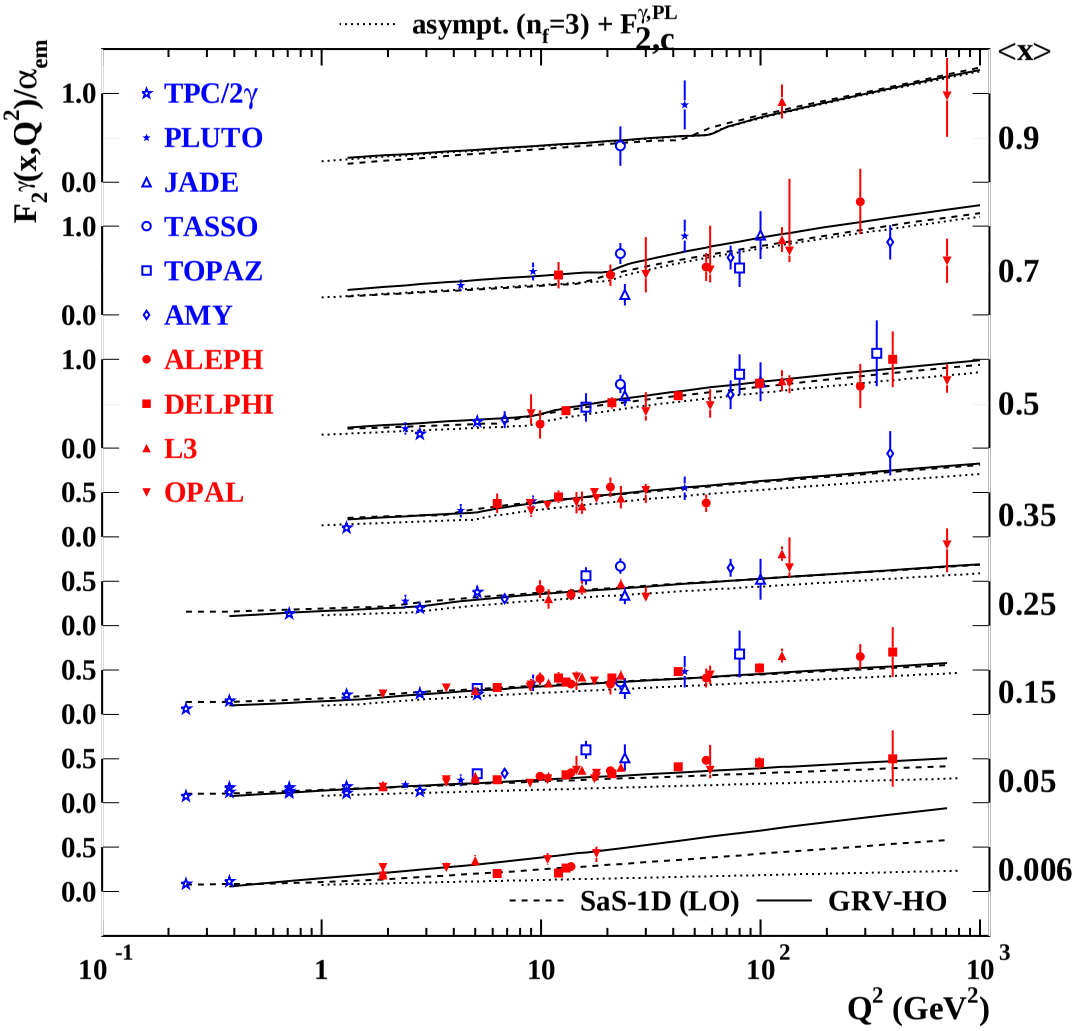

Single Resolved




Double Resolved

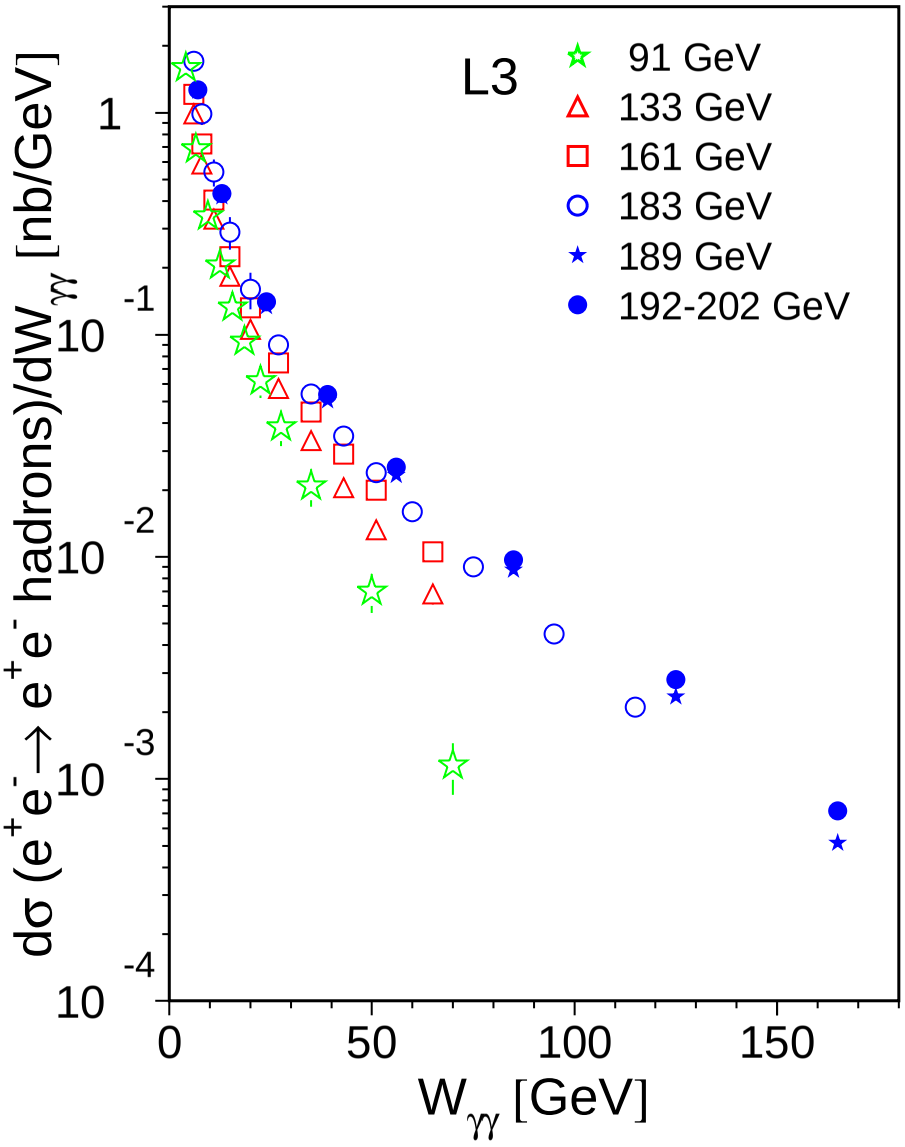
# Single-tag cross-sections ⇨ $F_2^\gamma$

An hard photon ($Q_1 >> 0$) explores the parton content of the other ($Q_2 \simeq 0$)




- Large range of $Q^2$ and $x = \frac{Q^2}{Q^2+W^2_{\gamma\gamma}}$
- Positive scaling violation for all $x$
  ⇨ $\gamma \to q\bar{q}$ (QED).
- Parametrisations before LEP (82 points)
- At present 220 points, not yet all data !

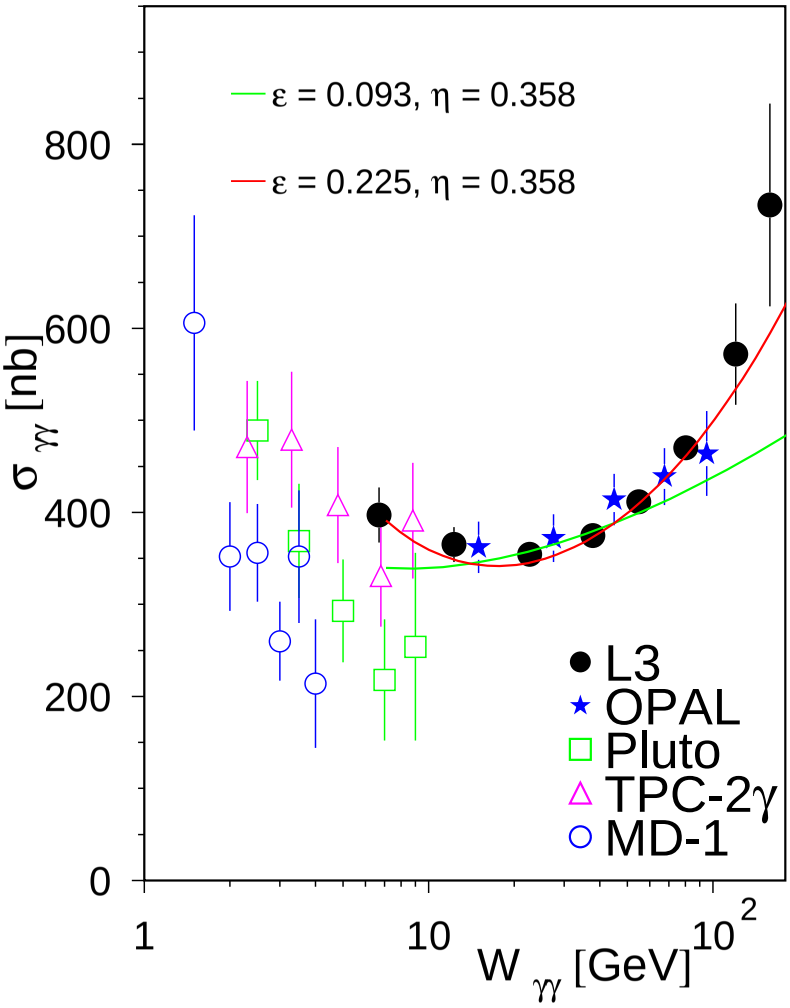
# Cross-section $e^+e^- \rightarrow e^+e^-$ *hadrons*




- Rapid decrease with $W_{\gamma\gamma}$ due to $L_{\gamma\gamma}$
- Increase with beam energy
- A problem :unfolding from $W_{vis}$ to $W_{\gamma\gamma}$ requires very good Monte Carlo models.
  ⇨ Dominant systematic error!

# $\sigma(\ \gamma\gamma \rightarrow hadrons)$ vs $W_{\gamma\gamma}$

Taking out $L_{\gamma\gamma}$ (QED) and exptrapolating to $Q^2 = 0$




Regge parameterization (Reggeon + Pomeron):

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

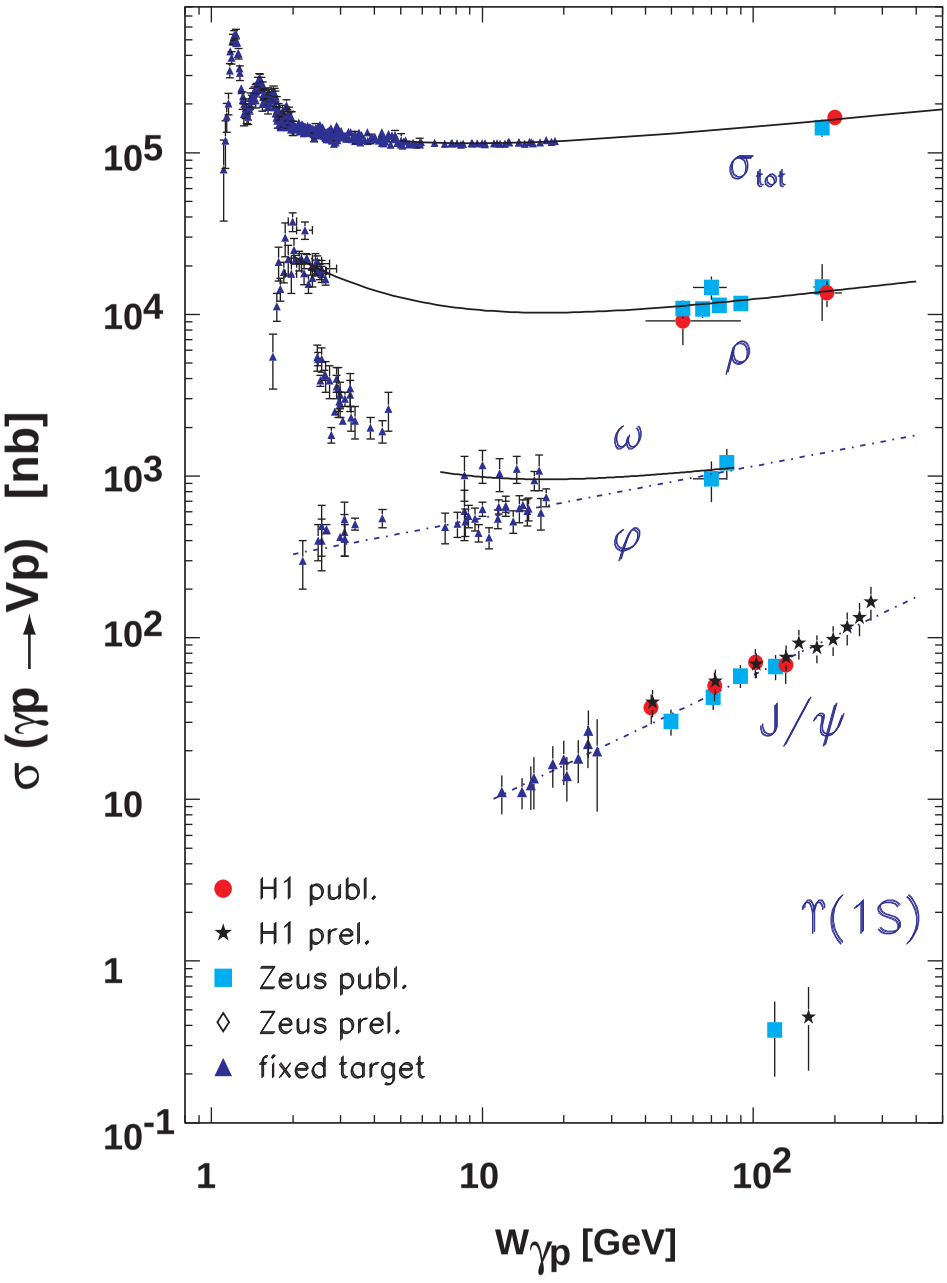
If photons behave like hadrons, $\varepsilon$ and $\eta$ are *Universal* and constrained by hadron–hadron and $\gamma p$ data (PDG 2000):

$\varepsilon = 0.093 \pm 0.002$ soft Pomeron

Best fit $\varepsilon = 0.225 \pm 0.021$ ($\gamma \rightarrow q\bar{q}$ ➪ hard Pomeron)

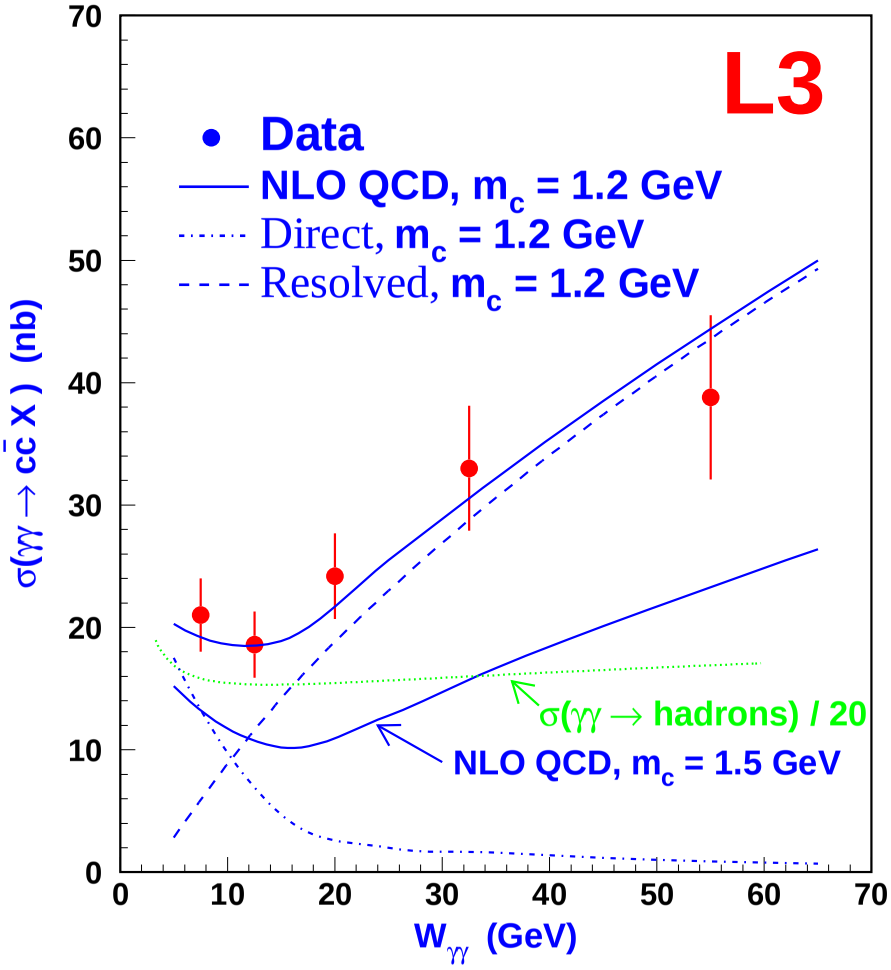
# Hera : Vector Meson production

From soft processes to perturbative QCD,
by varying the scales $Q^2, t, m_V$.



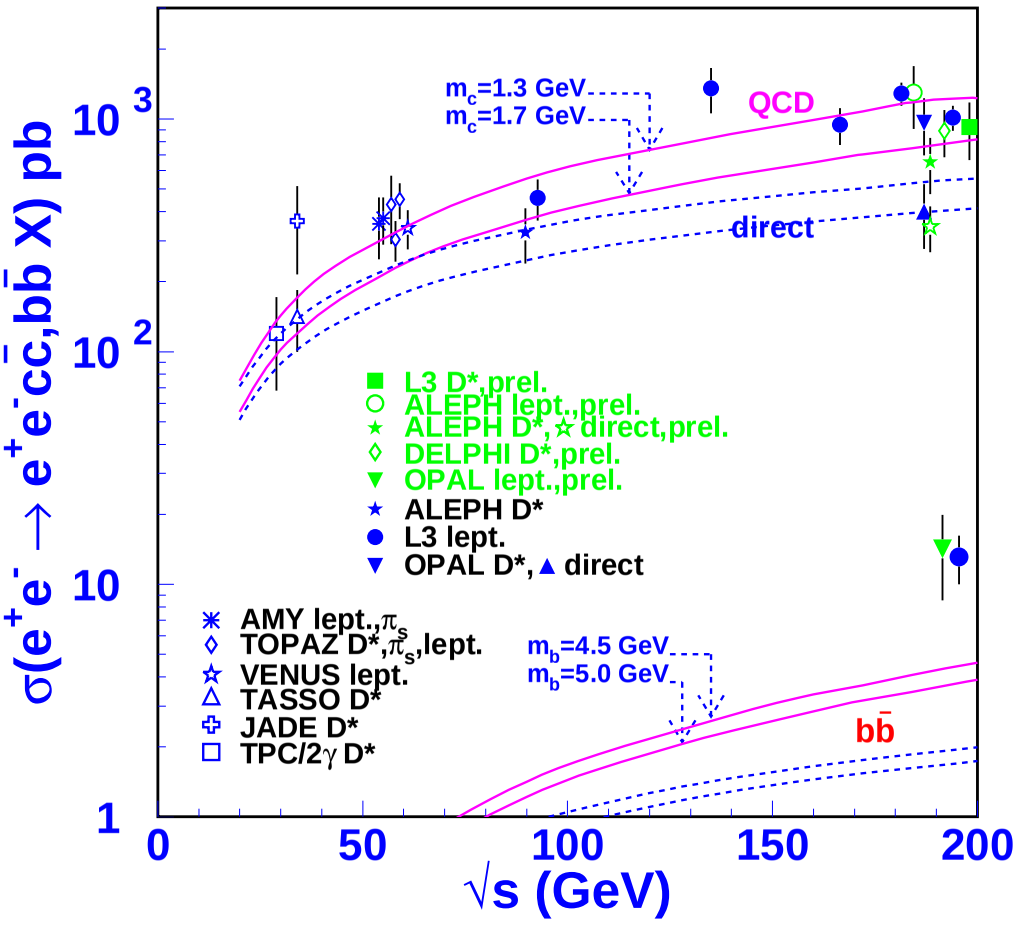

- $\varepsilon \simeq 0.1$ photoproduction and light mesons
- $\varepsilon \simeq 0.4$ $J/\psi$

# $\sigma(\ \gamma\gamma \rightarrow c\bar{c}X)$ vs $W_{\gamma\gamma}$




- Steeper rise with energy : $\varepsilon = 0.40 \pm 0.08$
- Data agree with NLO calculations
  $m_c = 1.2$ GeV
  S.Frixione et al. J.Phys.G 26(2000)723.
- Direct ($\gamma\gamma \rightarrow q\bar{q}$) decreases
  Resolved ($\gamma g \rightarrow q\bar{q}$) increases

# $c\bar{c}$ and $b\bar{b}$ production

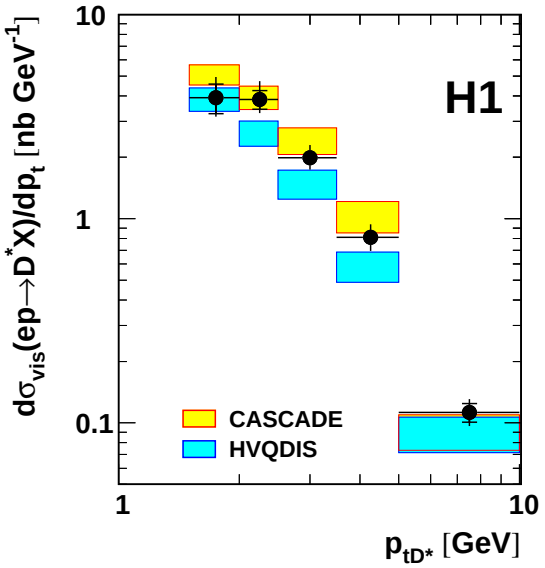


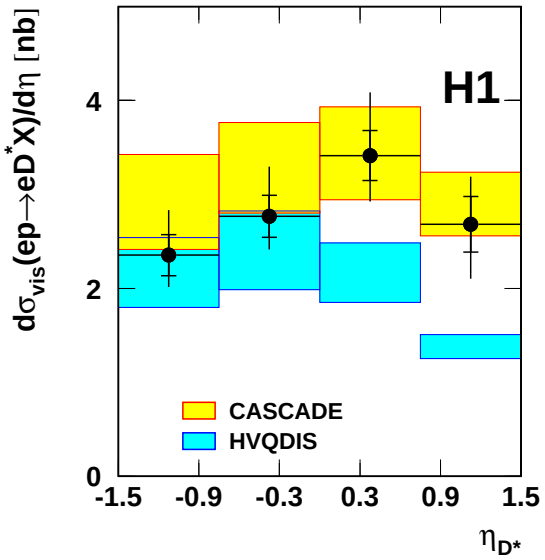

- Cross-section rises from $c\bar{c}$ threshold.
- Direct ($\gamma\gamma \to c\bar{c}$) is not sufficient.
  ⇨ Need $\gamma g \to c\bar{c}$

## $b\bar{b}$ a challenge for the theory

- 4 st.dev higher than predictions.
- Excess at HERA by about a factor 3.
  Warning : are H1 and Zeus compatible?

# $D^*$ production in DIS at Hera



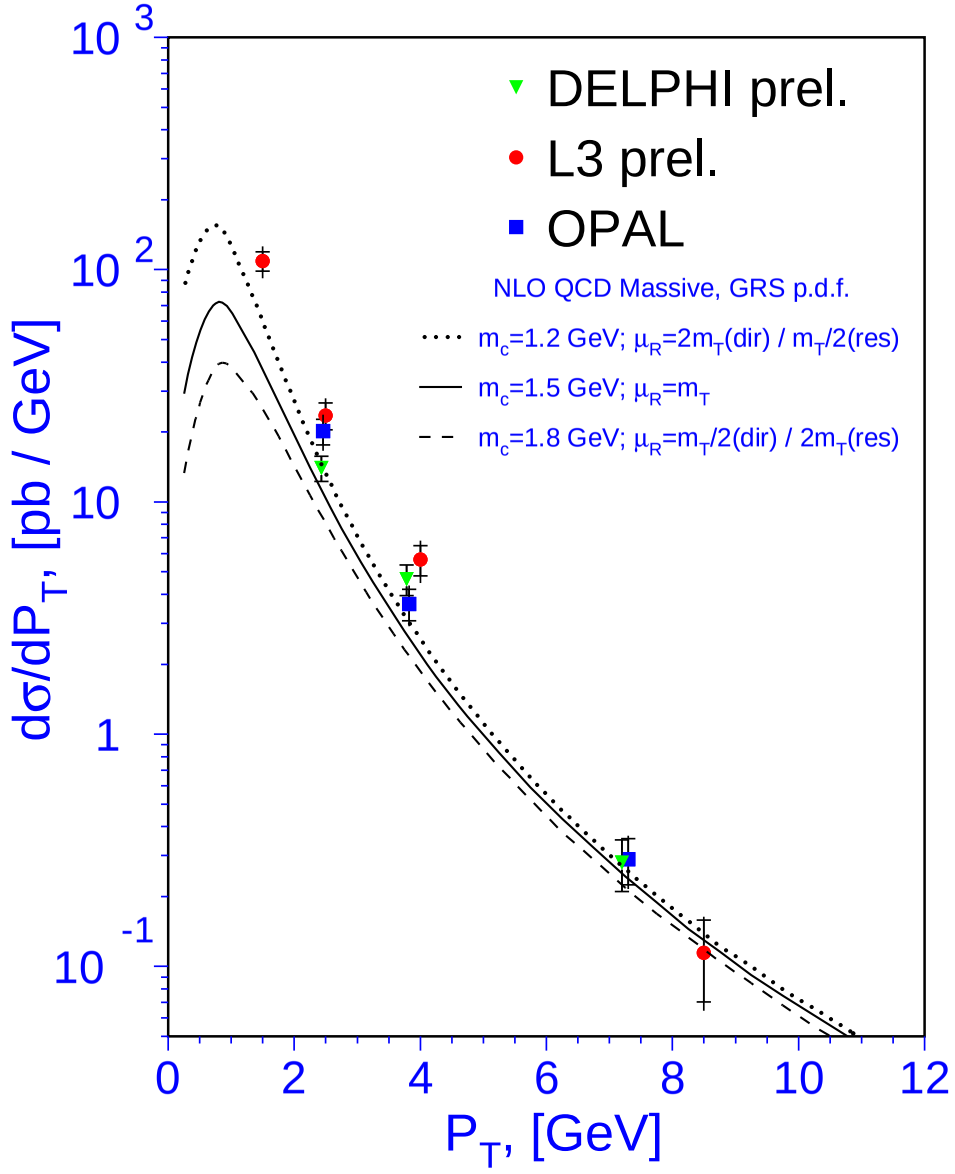




## Different treatement of gluon singularities

- HVQDIS=NLO+DGLAP
- bands $1.3 < m_c < 1.5$
- CASCADE = Catani Ciafaloni Fiorani Marchesini model

It can be a solution also for other problems!

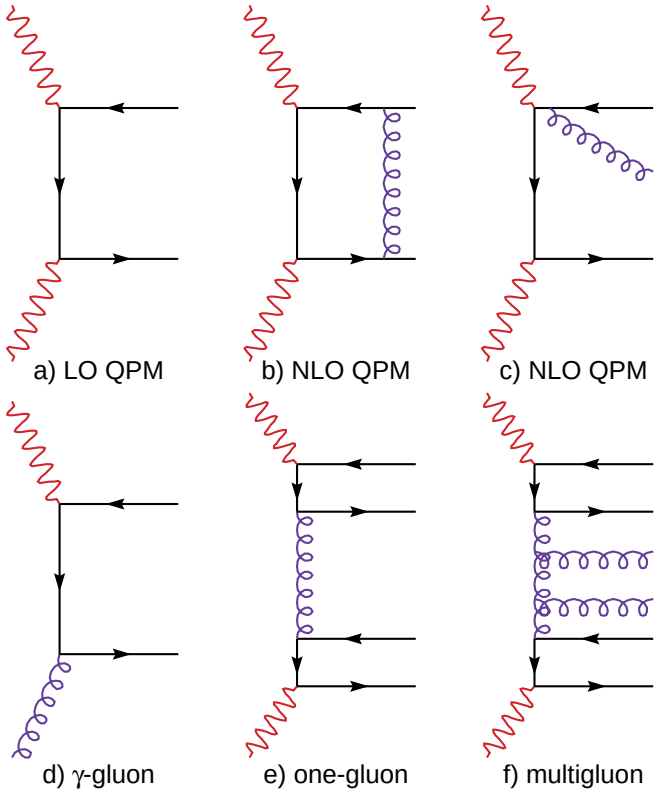
# $D^*$ production in Two-photon



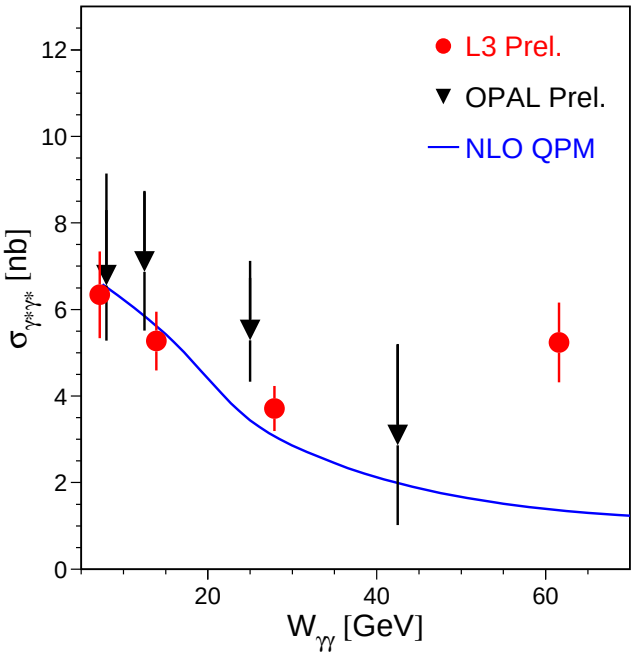

NLO QCD : S.Frixione, M. Krämer and E. Laenen Nucl. Phys. B571(2000)169

# BFKL dynamics

Double-tag: $Q_1^2 \simeq Q_2^2 >> 0$




$< Q^2 > = 16$ GeV$^2$




- For $W_{\gamma\gamma} < 40$ GeV NLO QPM
- Excess for $W_{\gamma\gamma} > 40$ GeV : Resolved photon or BFKL dynamics.

# Conclusions

- Diverse and accurate measurements of the photon interactions are performed at LEP and Hera.
  They are the basis for understanding QCD not only in the perturbative sector, but also in the field of non-perturbative, diffractive phenomena.

- A large amount of LEP and Hera data have still to be analysed, it would be unwise to leave them unexploited.

- This work is vital for LHC and future projects (TESLA,...)

# Inclusive $\pi^0$