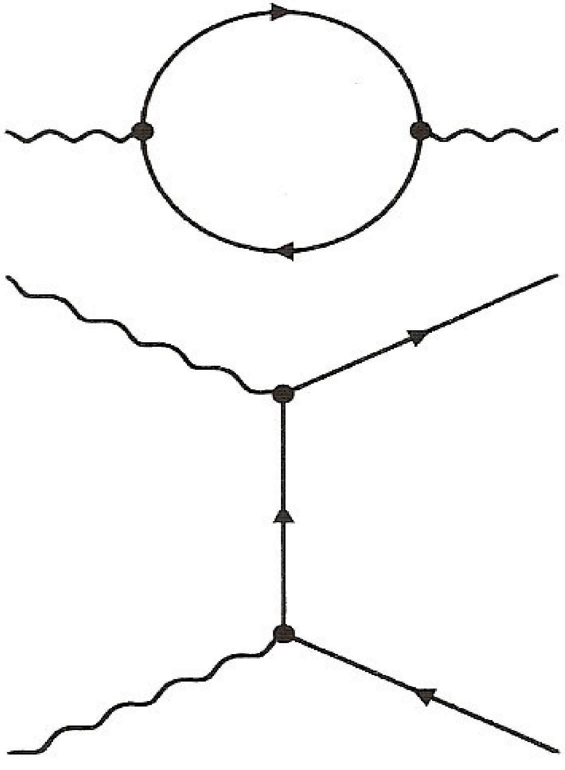
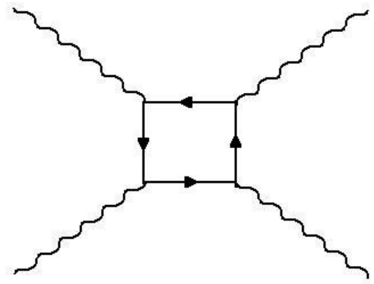
Measurement of the photon structure function with the L3 detector at LEP



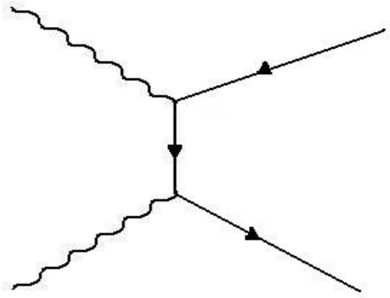
Philippe Mermod
SUBATECH, 31st May 2007

How can we observe photon-photon interactions ?

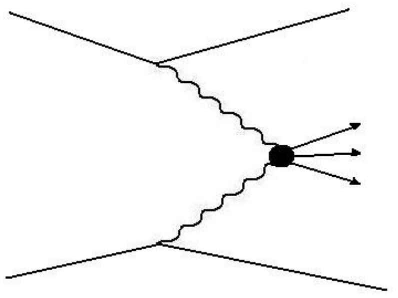
- 1930 (Hugues and Jauncey) attempt to measure **$\gamma\gamma \rightarrow \gamma\gamma$**
  $\rightarrow$ cross section far too small



- Cross section for production of charged pair is large enough to be measured, but a source of high-energy photons is needed



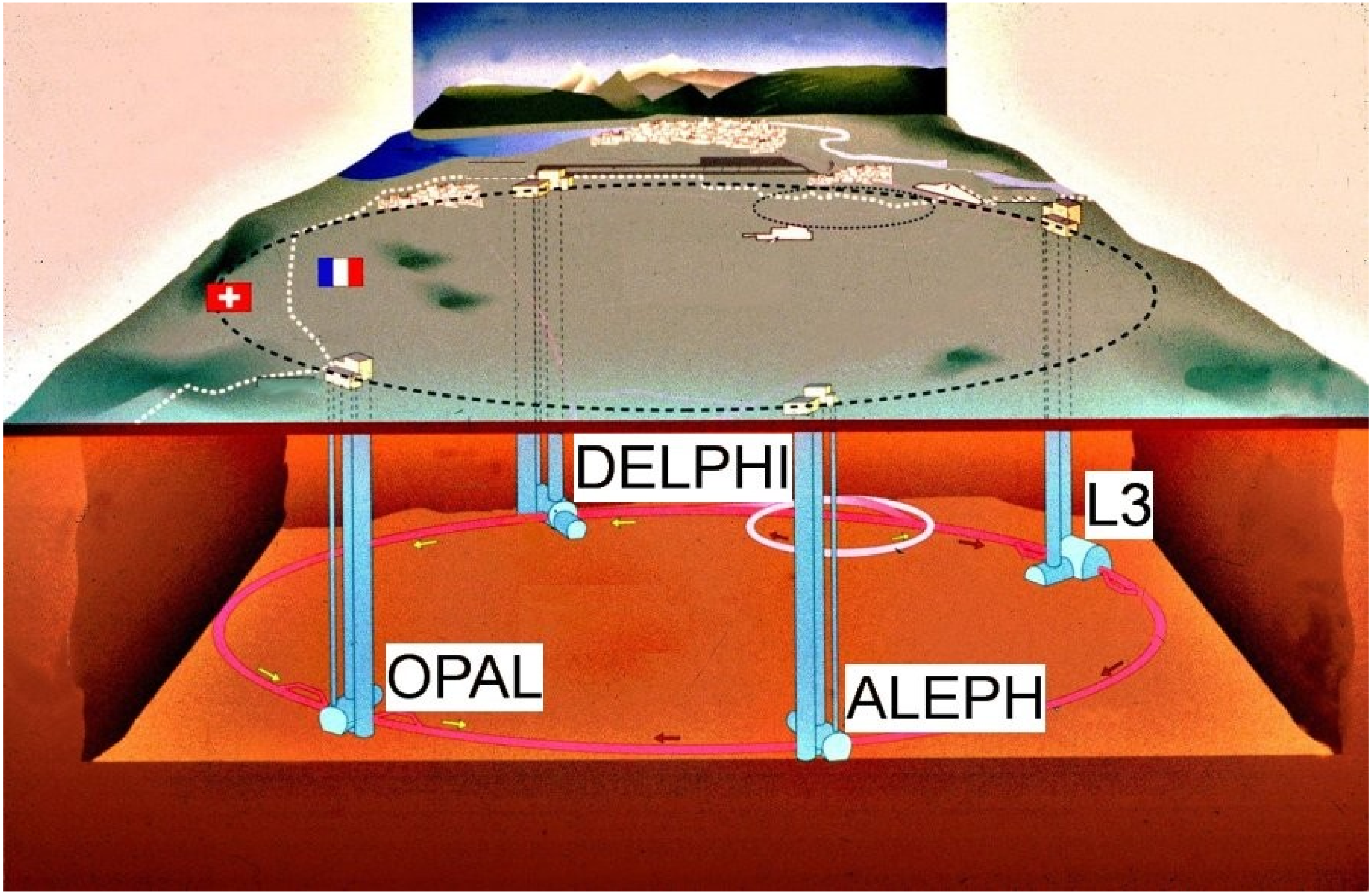
- Fermi (1924), Weiszäcker (1933) and Williams (1934) proposed to use charged particles as source of photons $\rightarrow$ **virtual photon beams**



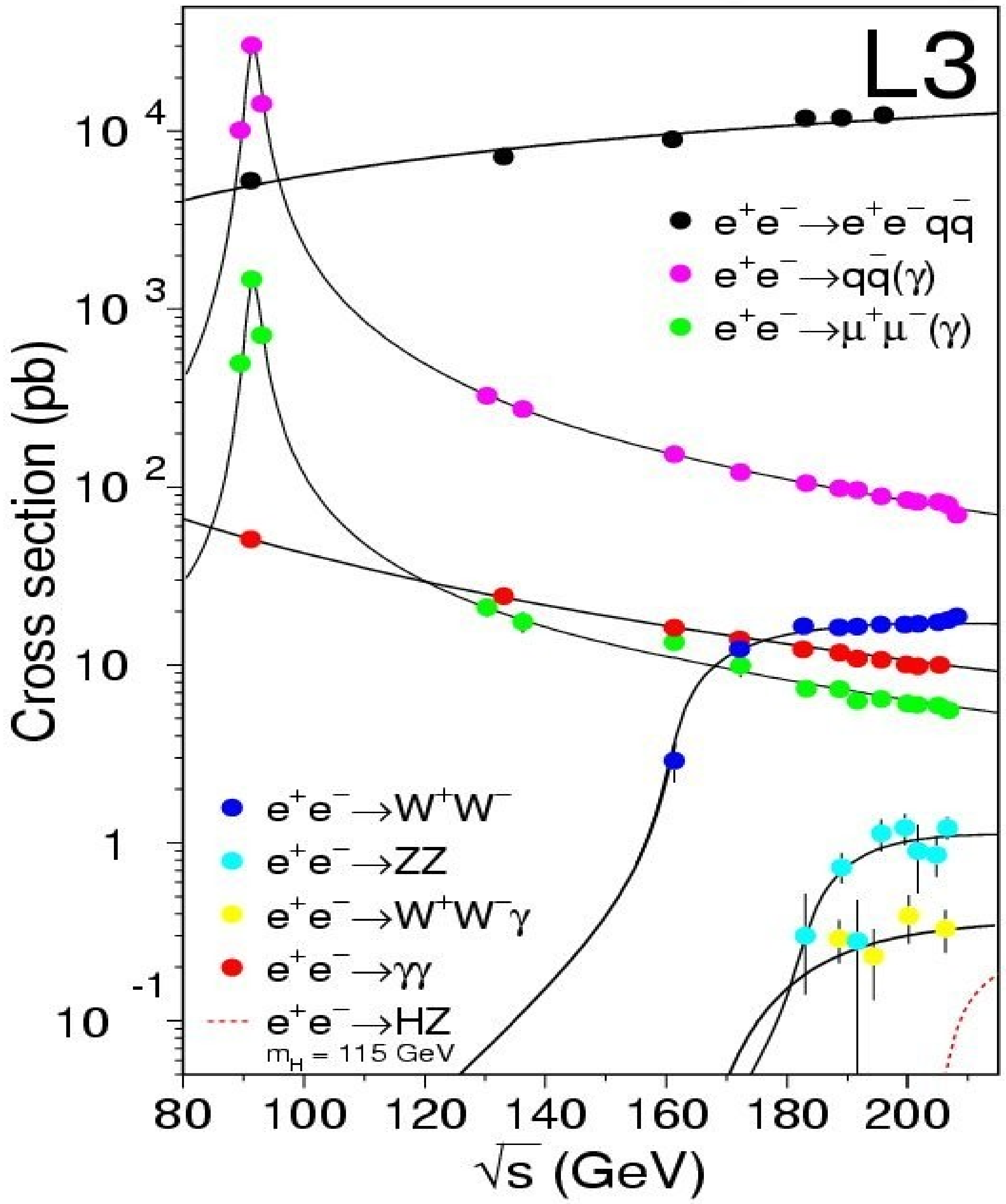
Experimental observations of two-photon reactions

- **1970** $e^+e^- \rightarrow e^+e^-e^+e^-$ VEPP-II (Novosibirsk)
- **1972** $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ Adone (Frascati)
- **1979** $e^+e^- \rightarrow e^+e^-\eta'$ SPEAR (SLAC)
- …
- **Nowadays** mostly high-energy e^+e^- colliders such as **LEP** and B-factories
- Some measurements at RHIC (ultra peripheral collisions), one at Tevatron

Large electron-positron collider (1989-2000)



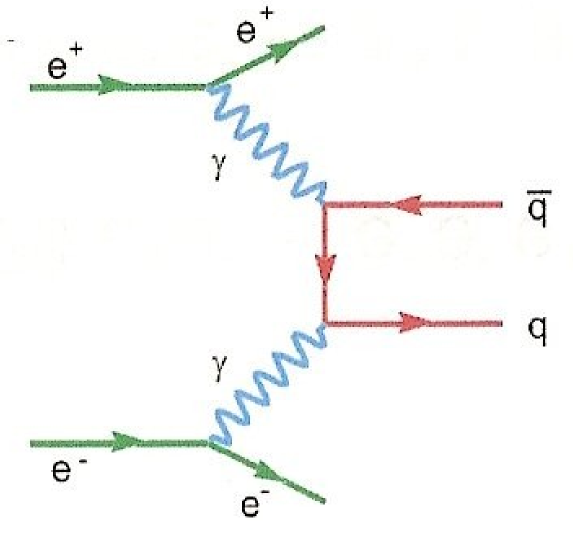
LEP physics



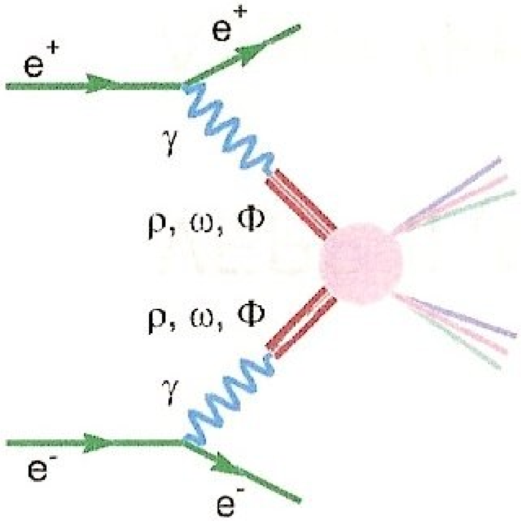
Two-photon cross section increases as $\sigma \sim \ln^3(\sqrt{s})$

- Background
- Physics topic in itself :
  - Study of the photon
  - QED and QCD
  - Resonances...

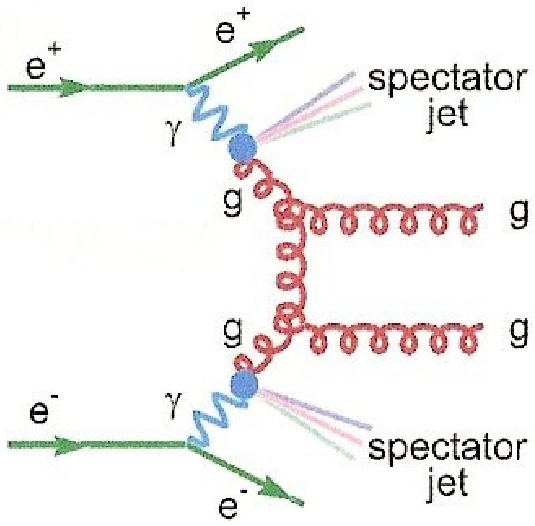
Two-photon physics



Direct

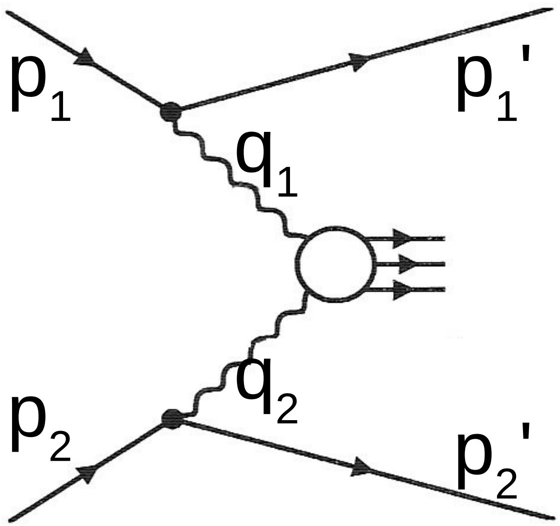


VDM



QCD resolved

Two-photon kinematics



Two-photon invariant mass **W** :

$W^2 = (q_1+q_2)^2$ $\quad W^2_{vis} = \sum_{vis} E_i^2 - p_i^2$ $\rightarrow$

Photon virtuality **Q^2** :

$Q_i^2 = -q_i^2 = 2E_iE_i'(1-\cos\theta_i)$

Variables **x and y** :

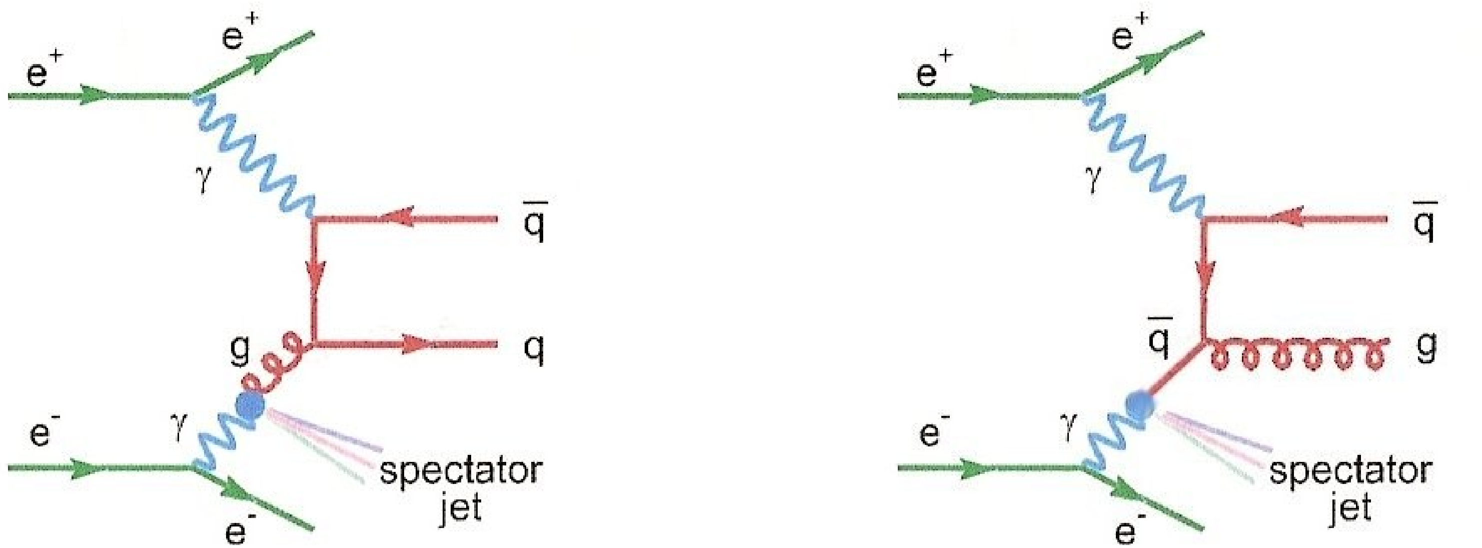
$x = Q_1^2/2q_1q_2 \quad y = q_1q_2/p_1q_2$

Single-tag **:** $Q_1^2 = Q^2,\ Q_2^2 \approx 0$

$\rightarrow$ x can be interpreted as the momentum fraction of the struck parton

$W^2 = Q^2(1/x-1)$

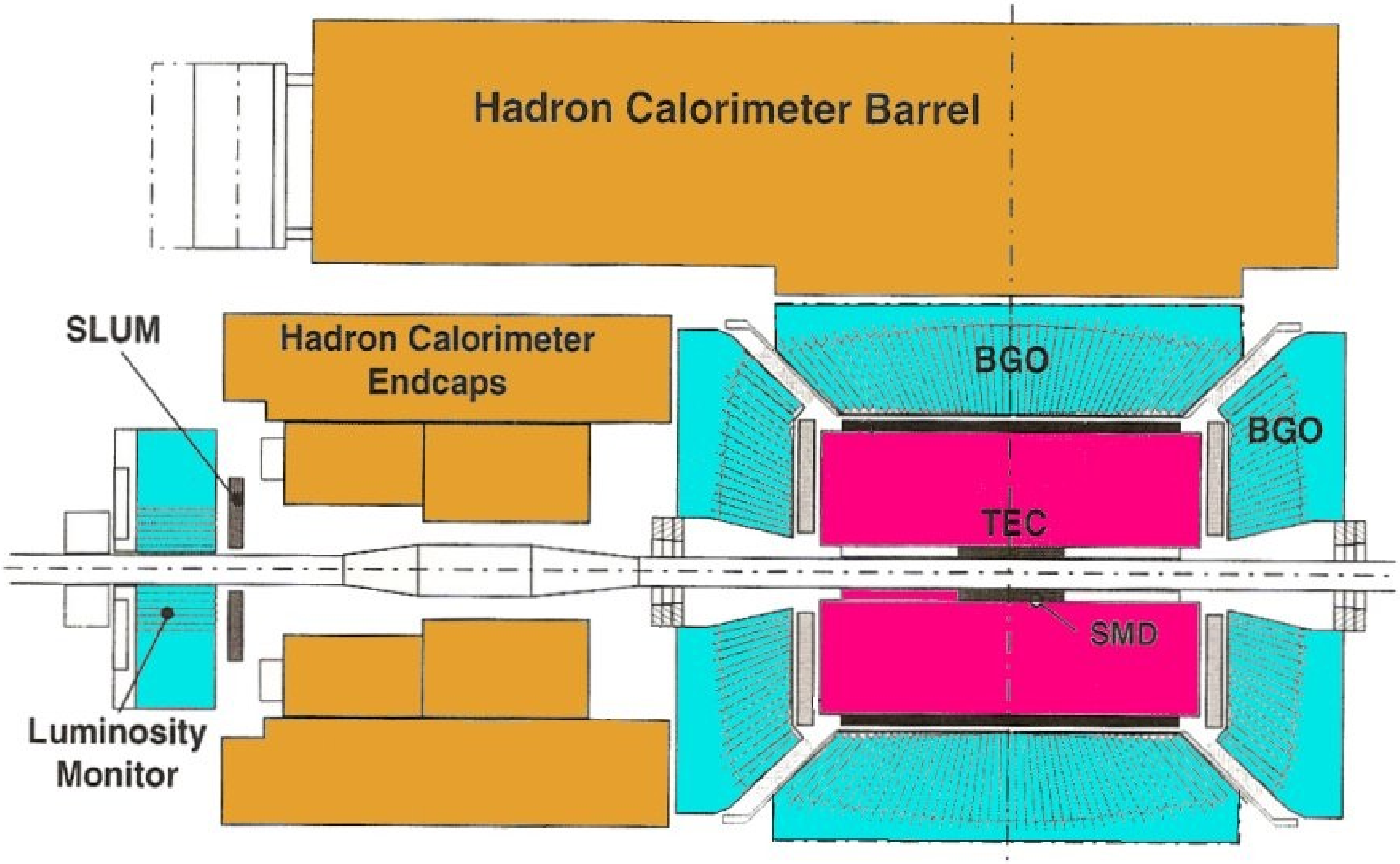
Single-tag : study the partonic content of the photon



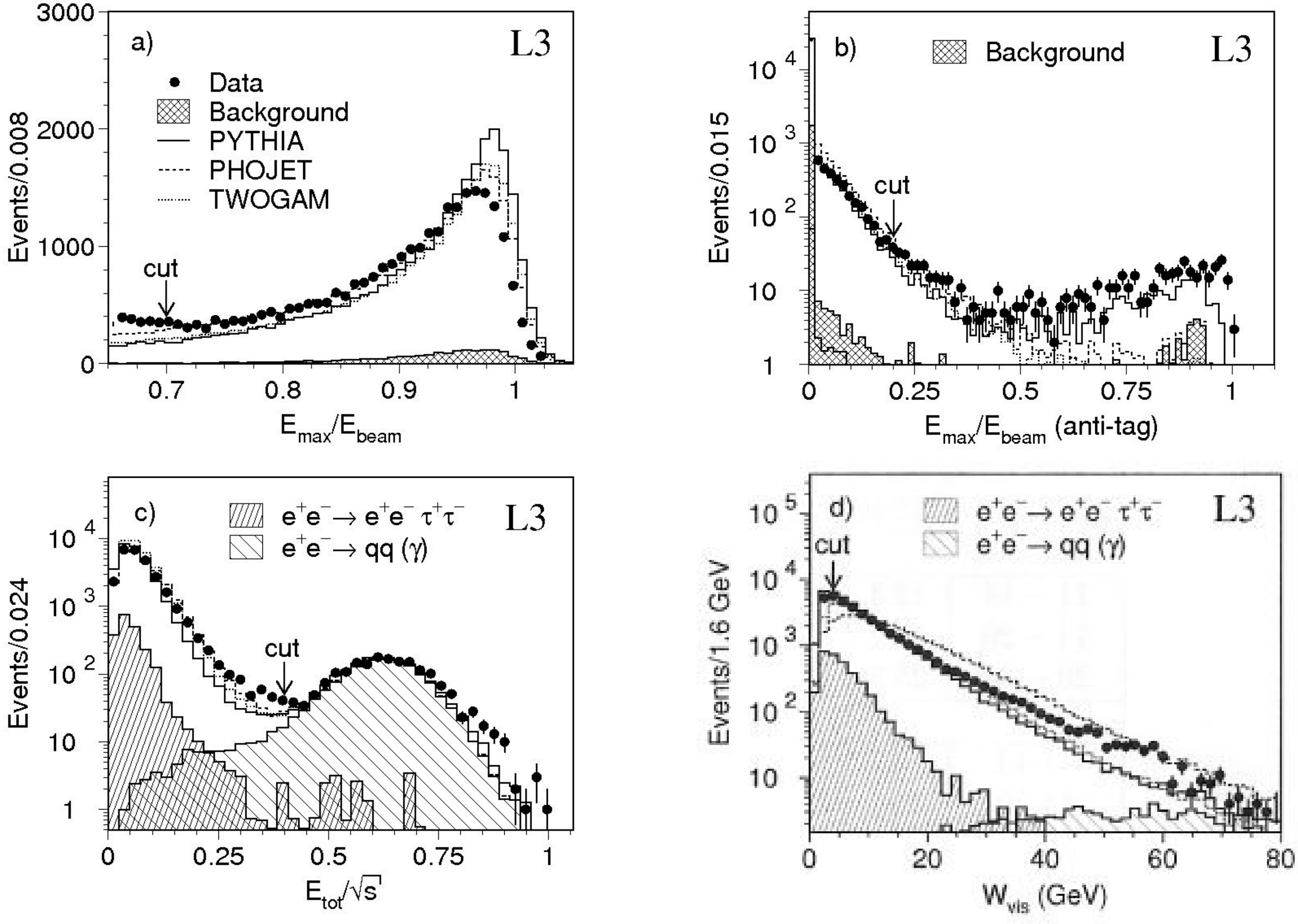
Analogy to deep inelastic scattering :

- $\sigma_{\gamma\gamma^*}(x,Q^2) \approx 4\pi^2\alpha_{em}/Q^2 \cdot F_2^\gamma(x,Q^2)$
- $F_2^\gamma(x,Q^2) = x \sum e_i^2 q_i^\gamma(x,Q^2)$

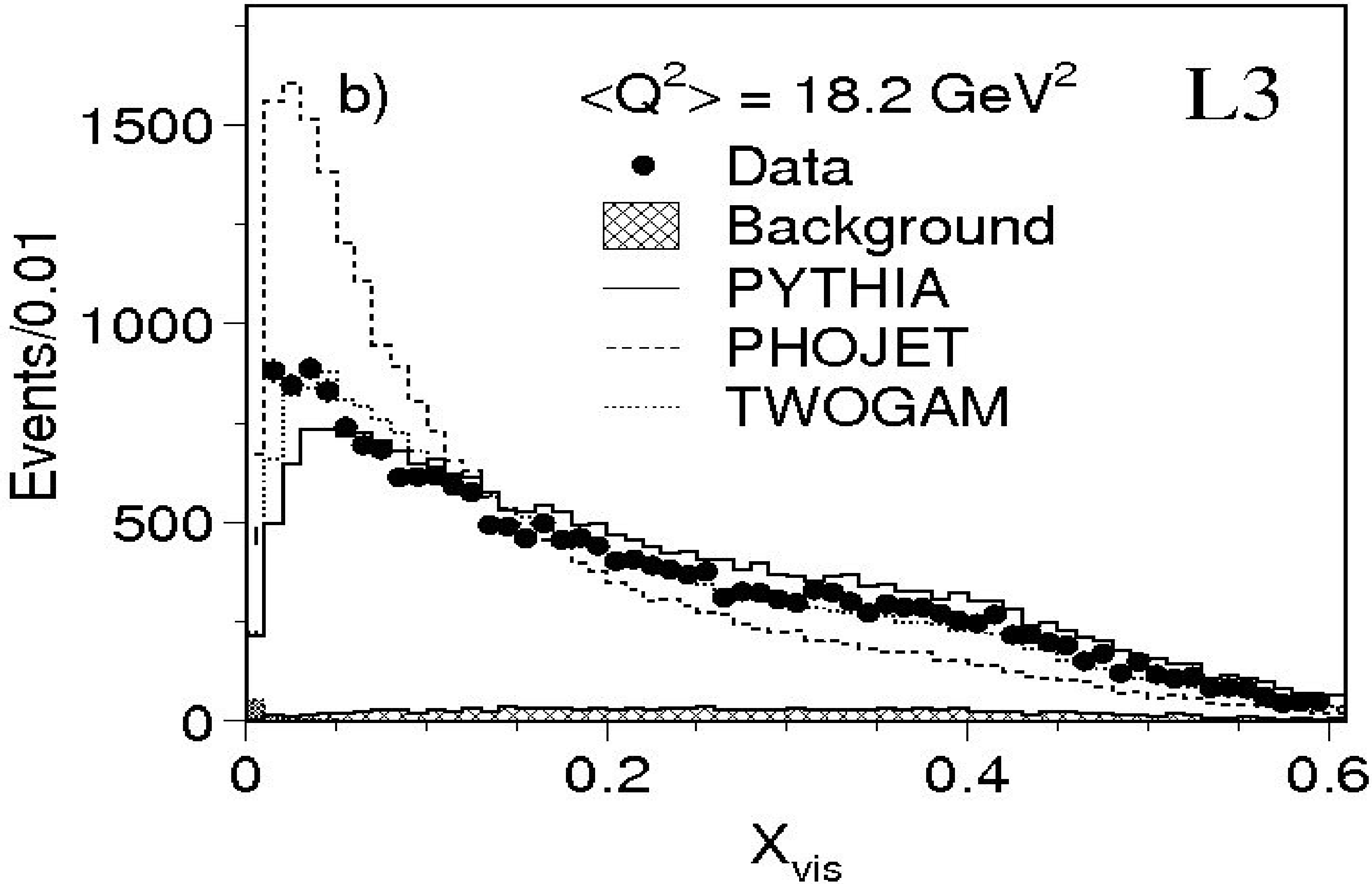
The L3 detector



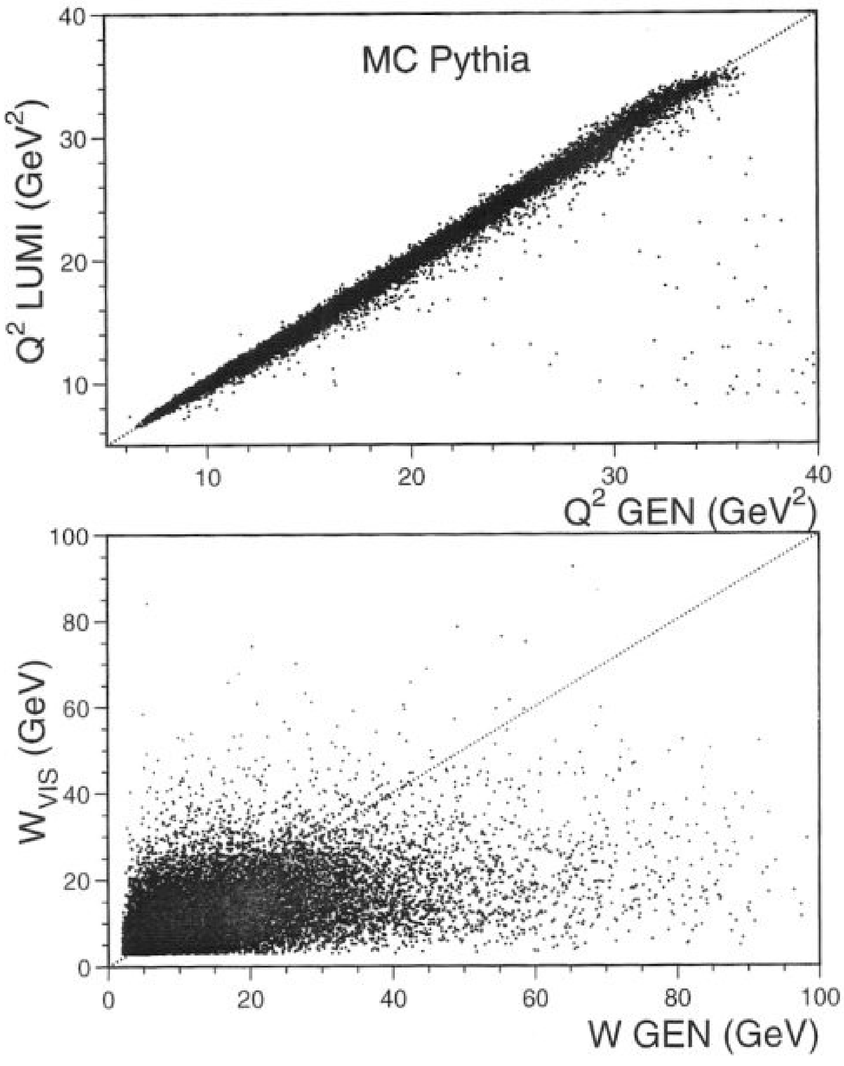
Event selection and MC

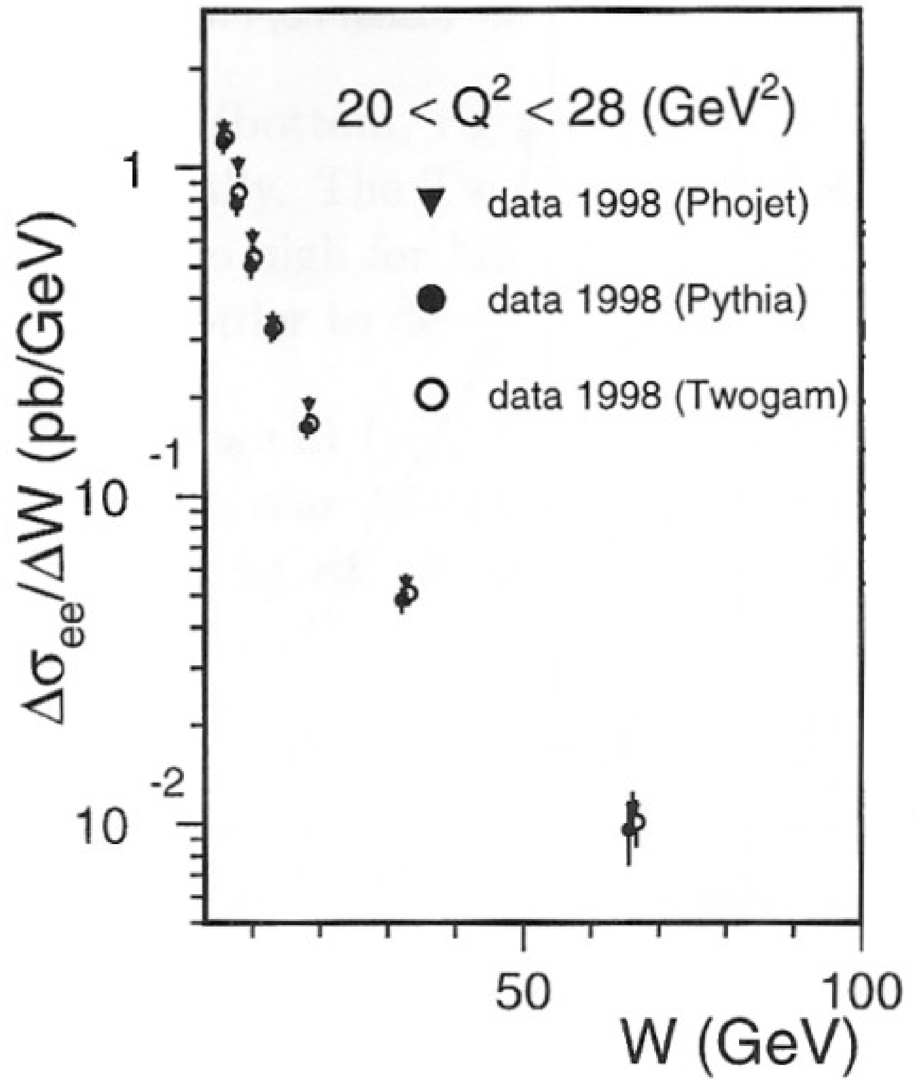


Event selection and MC

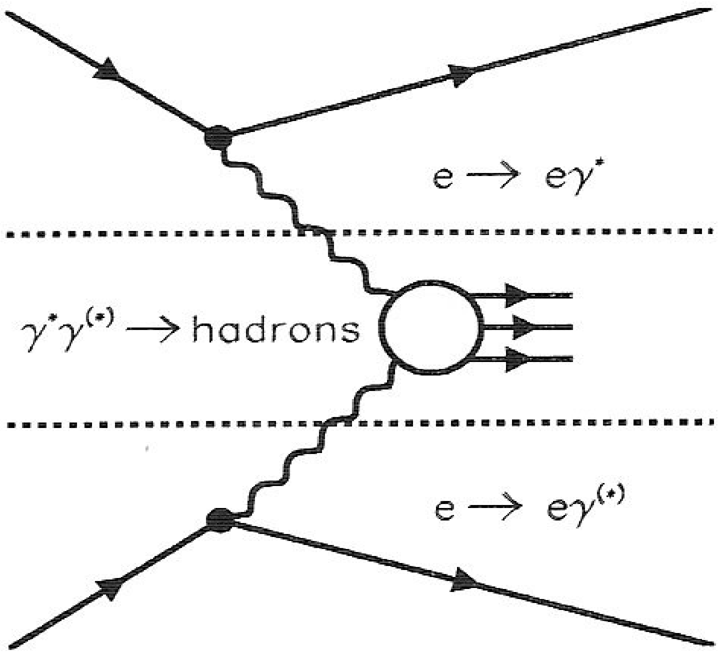


W (or x) distribution : unfolding





Physics at the level of $\gamma\gamma \rightarrow$ *hadrons*



Photon flux :

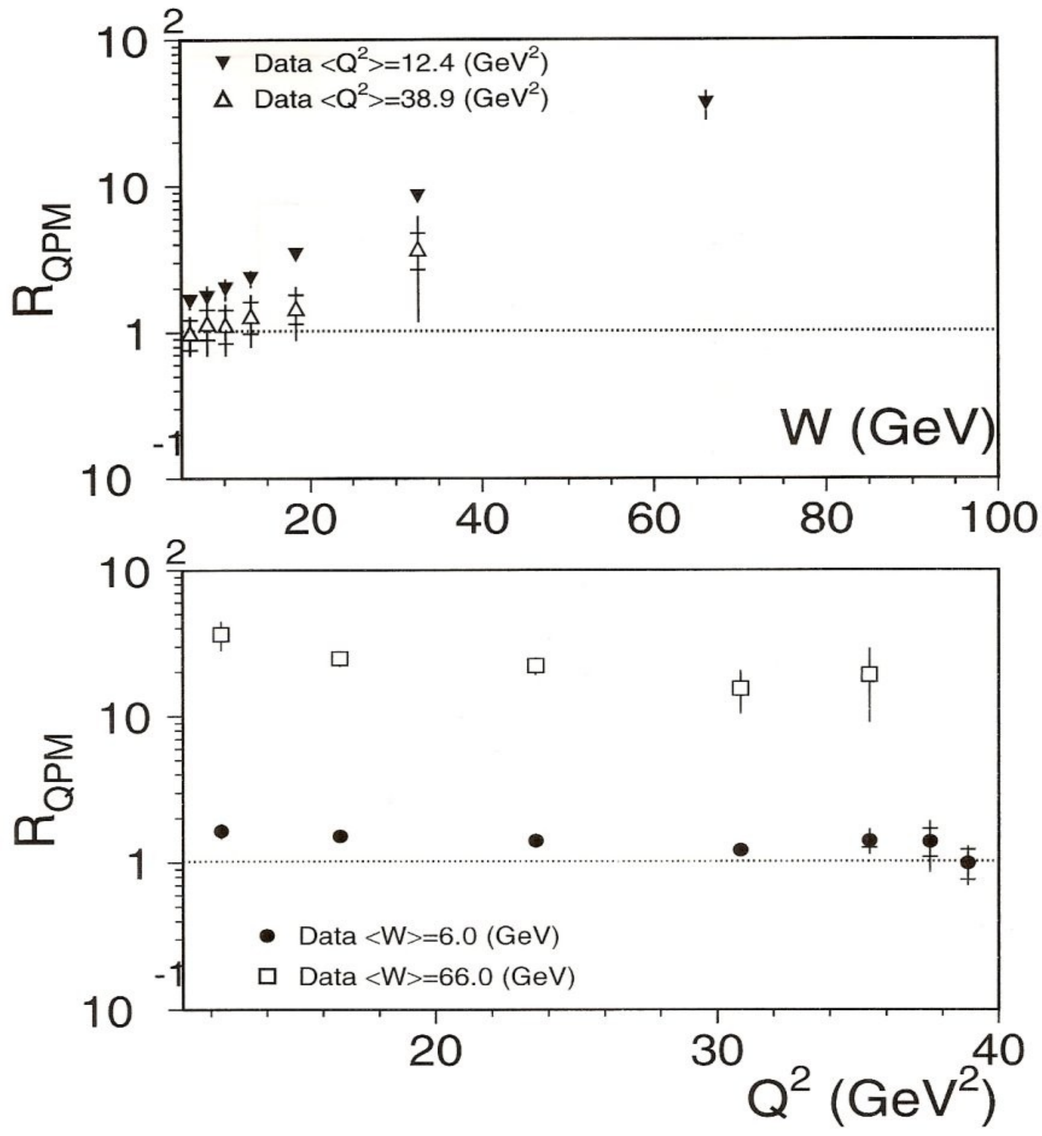
analytical program GALUGA

$$\sigma_{ee} = \int\left(L_{TT} F_{TT} \sigma_{TT} + \ldots\right) dQ^2 dW$$

Three approaches :

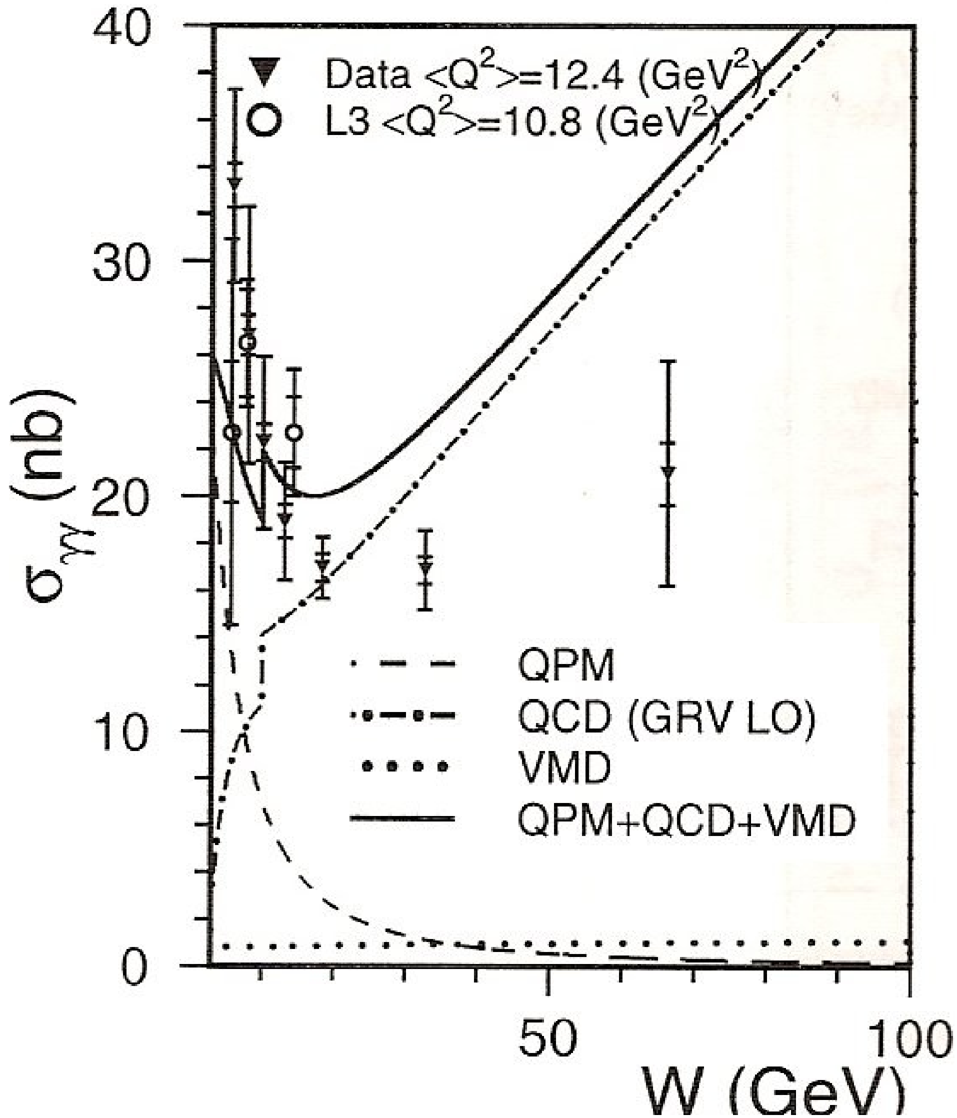
- Ratio to QED processes ($e^+e^- \rightarrow e^+e^- \mu^+\mu^-$)
- Luminosity funct. $\rightarrow \sigma_{\gamma\gamma}(Q^2,W)$
- Direct extraction of $F_2^\gamma(Q^2,x)$

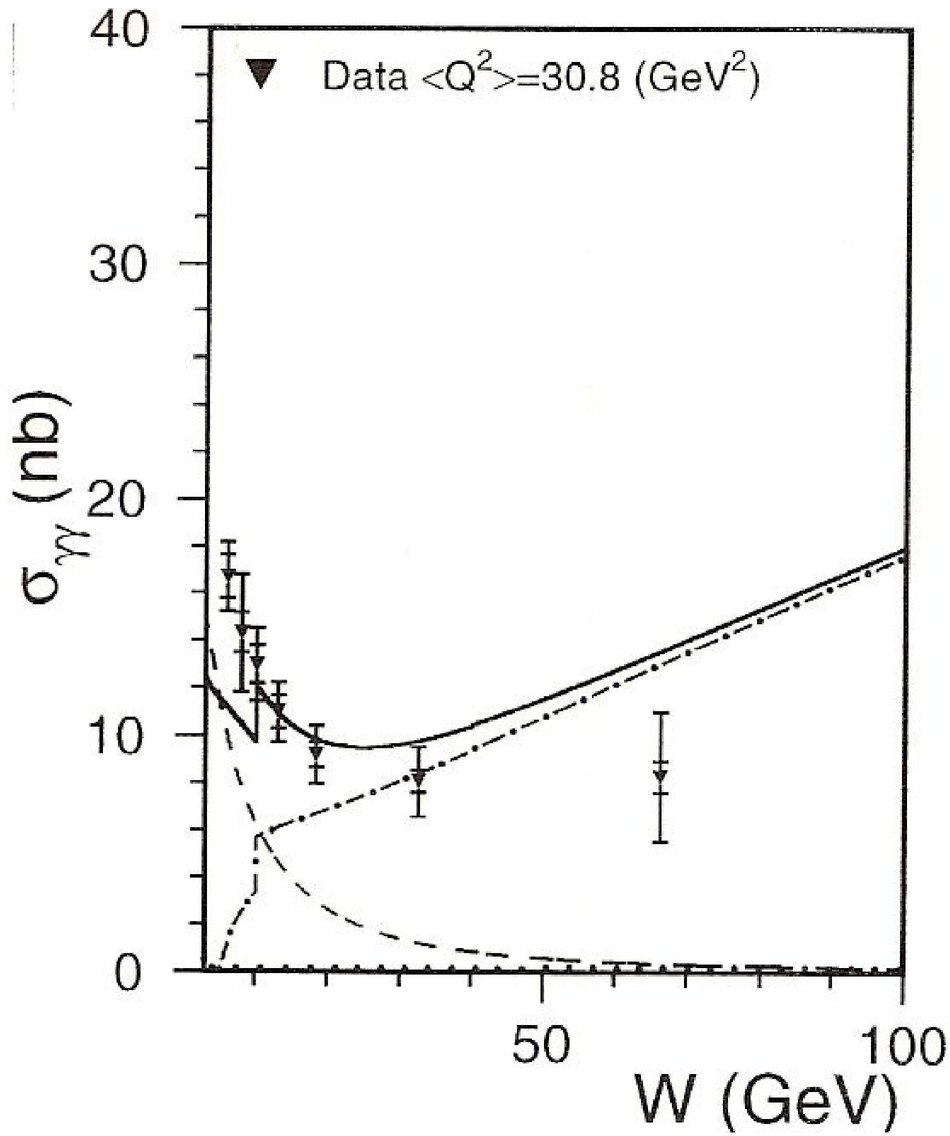
Ratio to QED processes



The photon behaves as a point-like particle for high Q^2 and low W

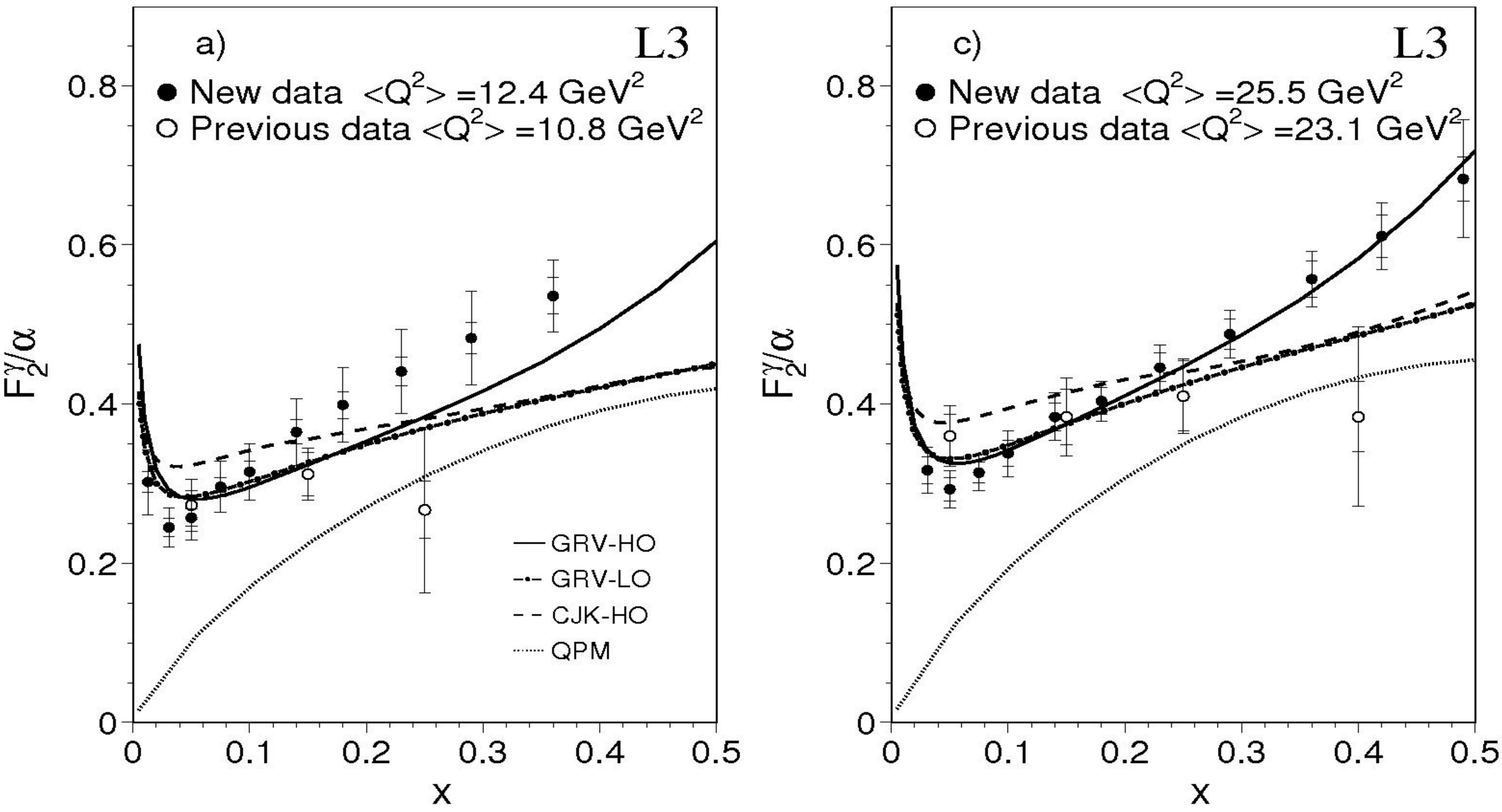
γγ→hadrons cross section



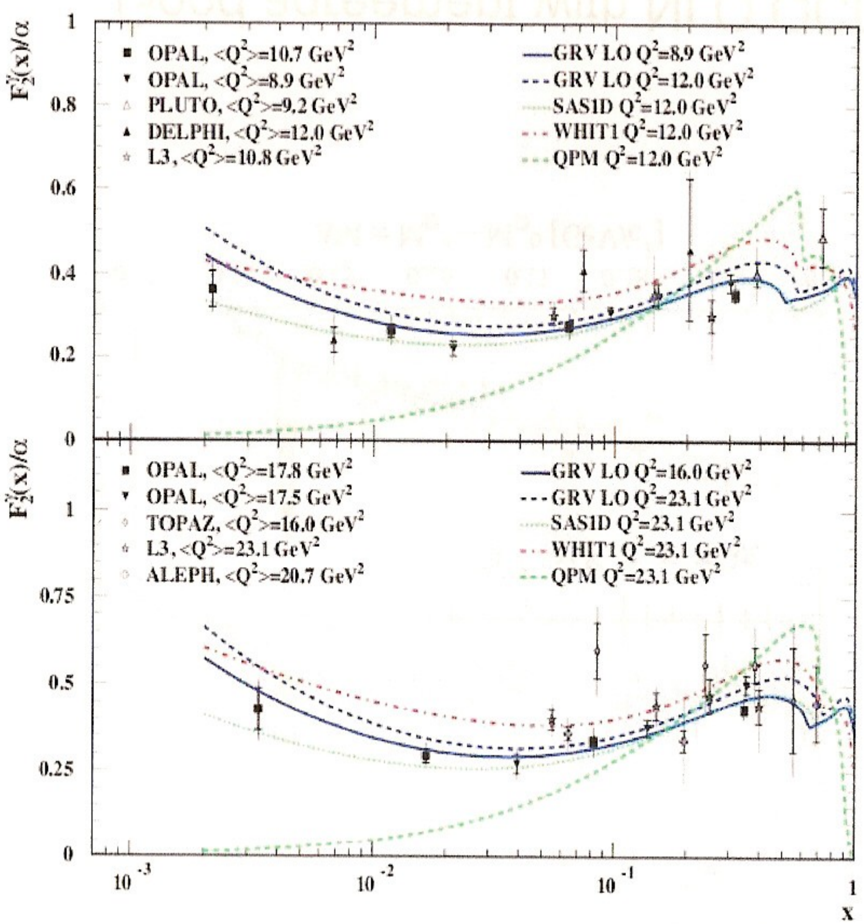


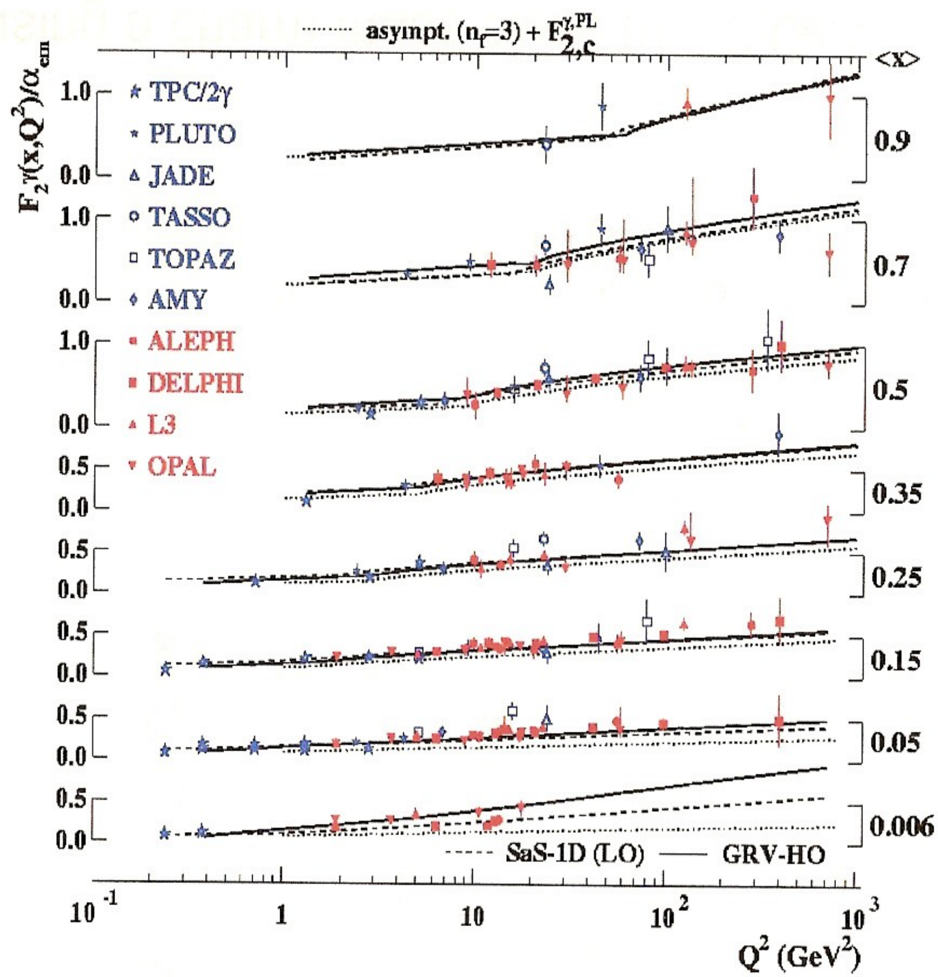
Photon structure function F_2^γ

L3 Coll., Phys. Lett. B 622, 249 (2005)



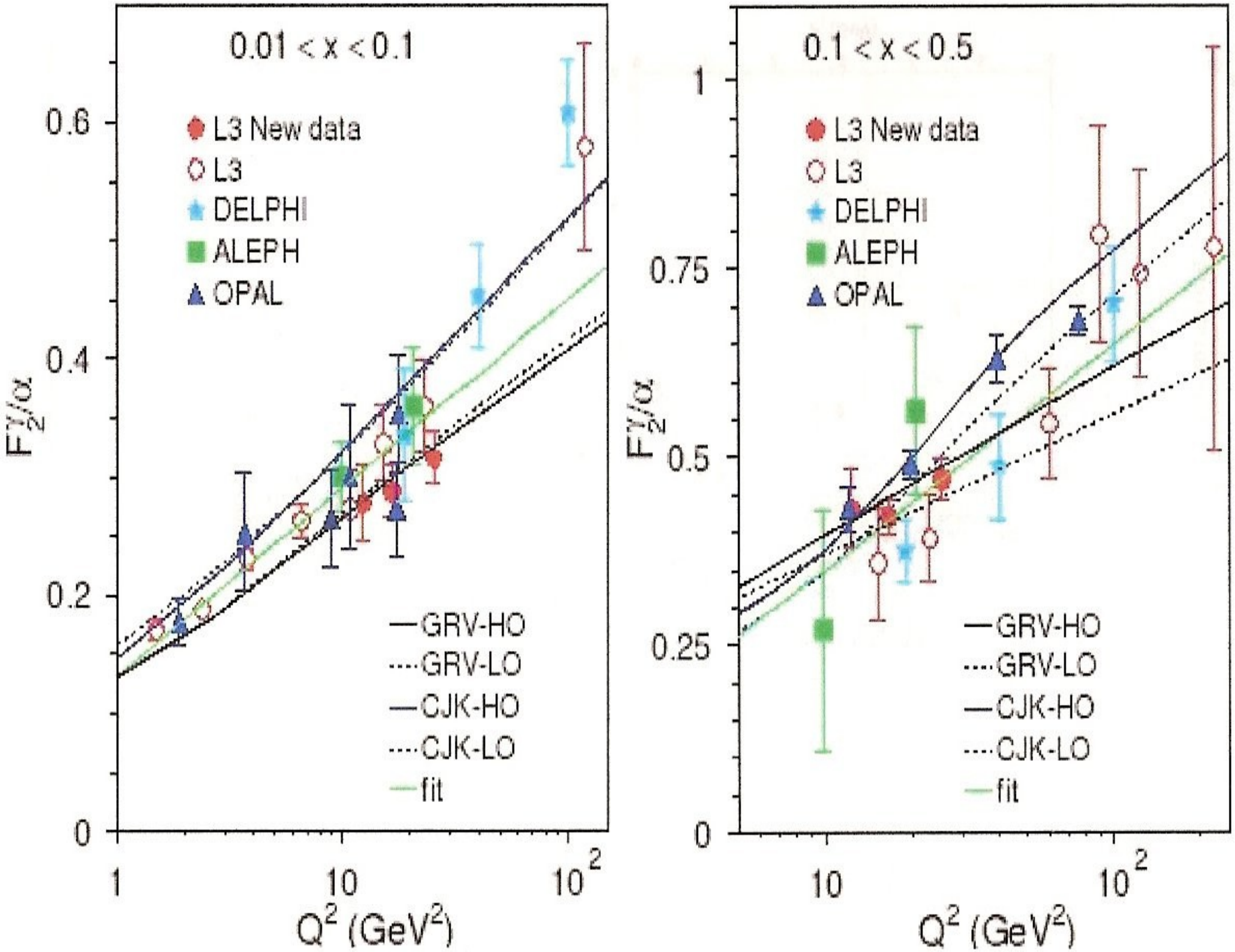
Experimental determination of F_2^γ





Overall agreement with QCD predictions

Experimental determination of F_2^γ



The Q^2 range is not large enough to constrain the input parton density functions $q_i(x,Q^2)$

Conclusions on the photon structure measurement

- F_2^γ is measured at LEP with the L3 detector in center-of-mass energies $189 \leq \sqrt{s} \leq 209$ GeV with $11 \leq Q^2 \leq 34$ GeV^2, $0.006 \leq x \leq 0.556$
- The data at high Q^2 are consistent with predictions from direct processes
- At small x (high W) we observe an increasing contribution from resolved processes, revealing the gluonic content of the photon
- The data are better reproduced by the higher-order parton density functions of GRV

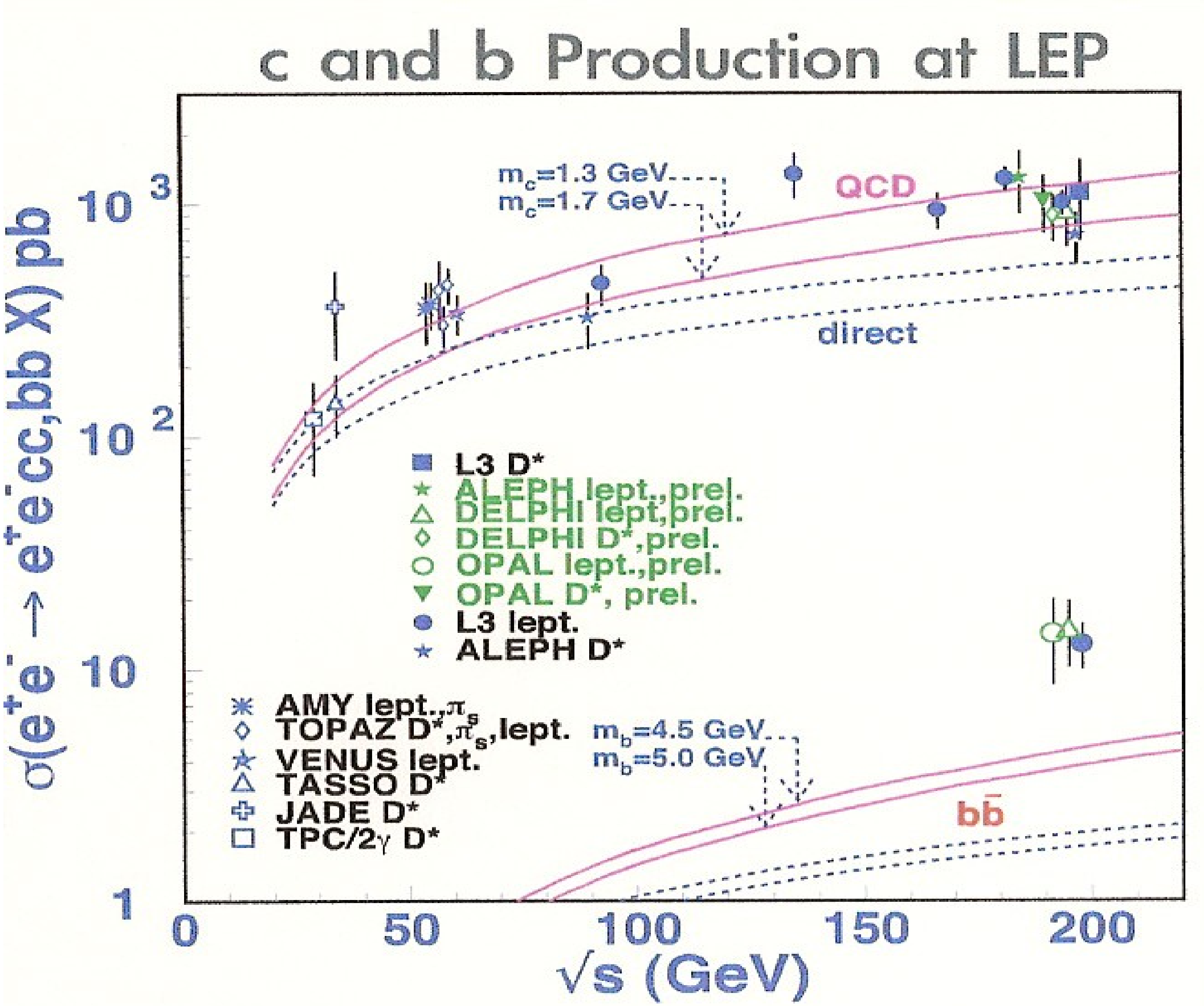
Remarks and outlook

- Systematic uncertainties dominate, due to the poor measurement of W and the insufficient MC description
  - > No real need for better statistics in our Q^2 range

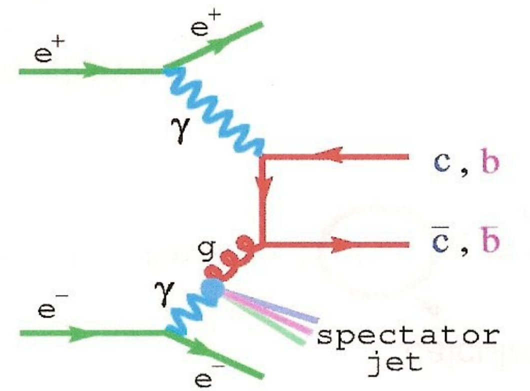
On the other hand :

- Data at higher Q^2
- Exclusive production (resonances, exotics...)
- Heavy flavour production **(next slide)**
  - **> need higher energies → LHC, ILC (final slide)**

Inclusive charm and beauty



- Charm OK
- Resolved component clearly needed



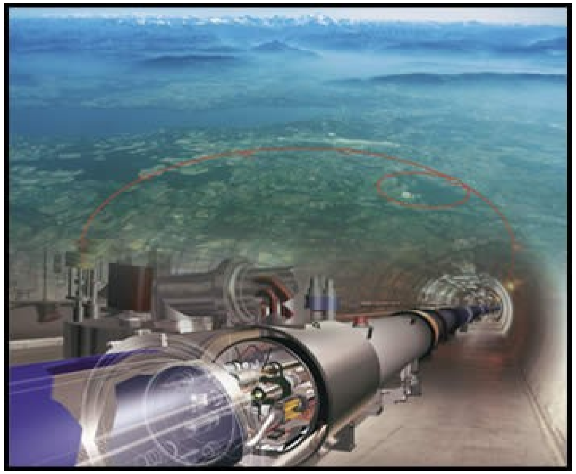
- Beauty in excess by a factor 3

The future of two-photon physics

- **LHC (2008)**

  proton-proton

  14 TeV



- **ILC (2015)**

  electron-positron

  500 GeV