Measurement of the photon structure function $F_2^{\gamma}(x,Q^2)$ with the LUMI detector at L3

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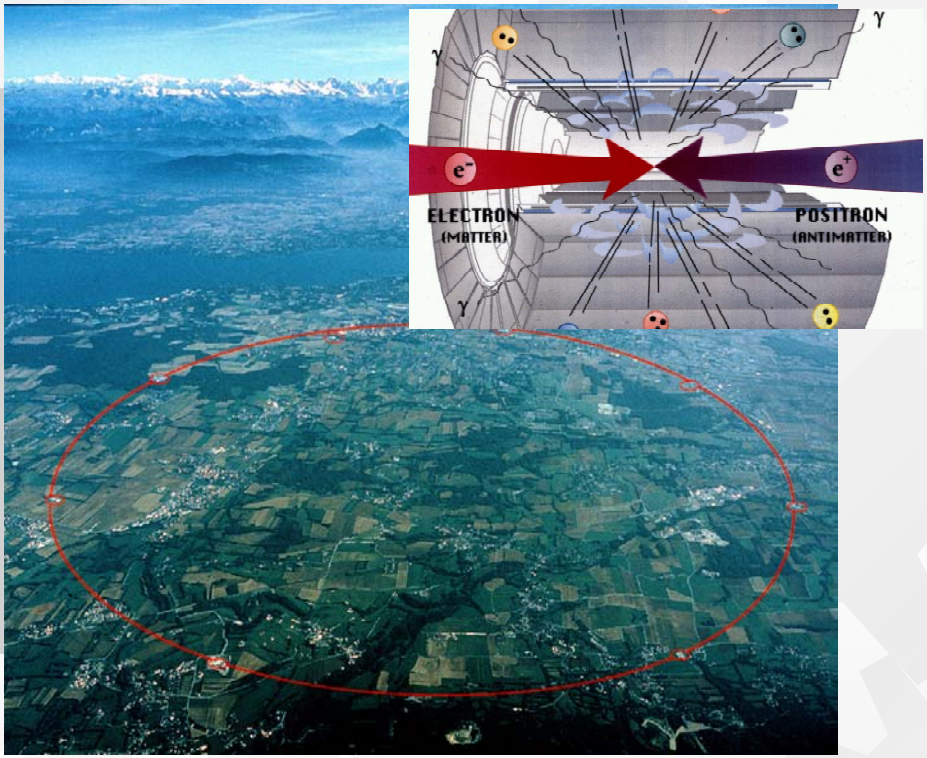
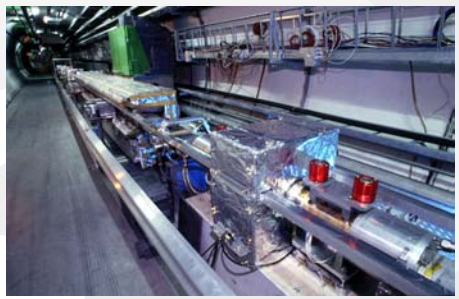
Topics of Discussion

- **Introduction:CERN, L3, LUMI**
- **Theoretical considerations**
- **Data analysis and results**
- **Summary**

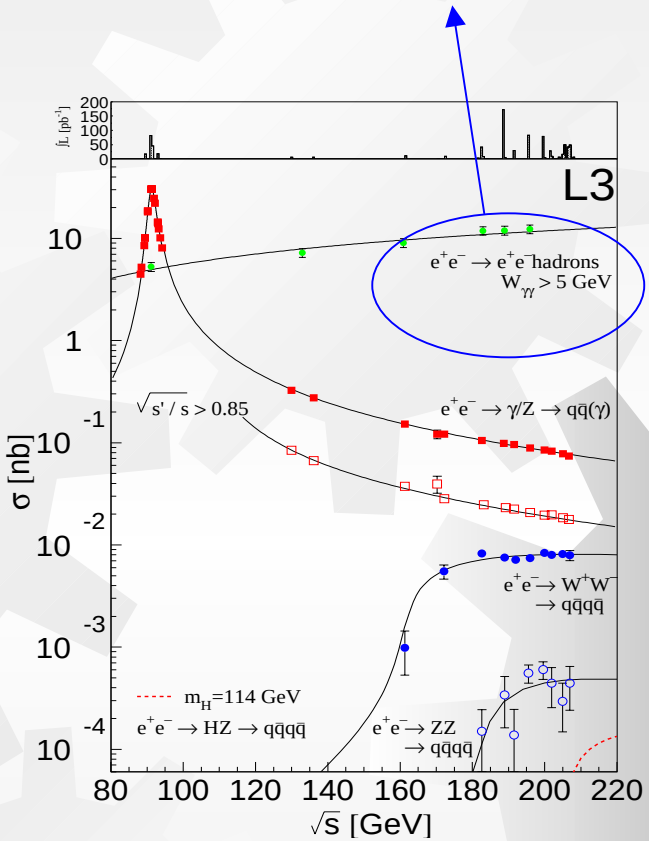
Introduction

LEP, CERN, Switzerland, France (future LHC)





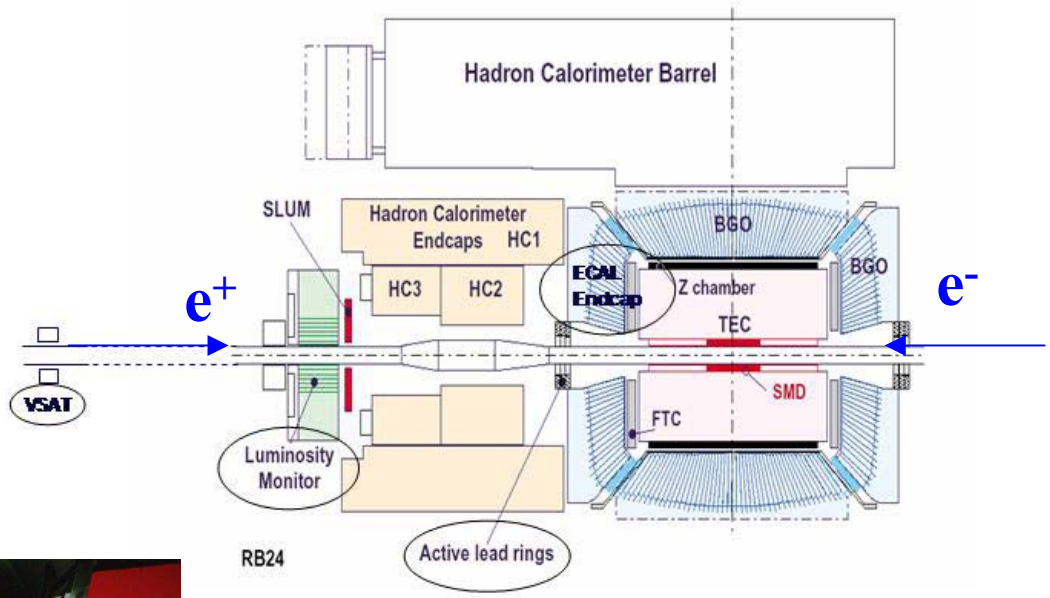
Two-photon reactions dominant

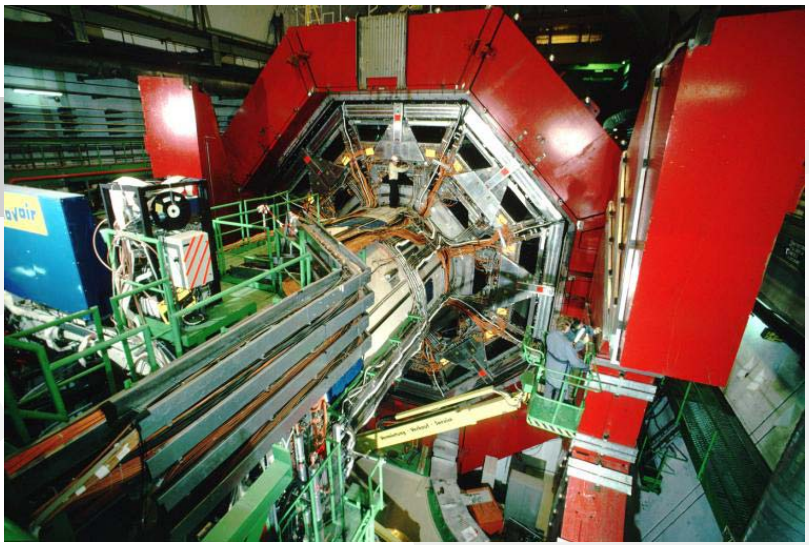


highest centre-of-mass energy :
207 GeV (Giga-electron Volts)

The L3 experiment

MAIN SUBSYSTEMS: central tracker (SMD, TEC) electromagnetic (ECAL), hadronic (HCAL) calorimeters, and muon chambers.





Tagging: Luminosity Monitor (LUMI), Very Small Angle Tagger (VSAT), Active Lead Rings (ALR), Electromagnetic Calorimeter endcaps

The photon

- QED: Photon mediator.

  Photon structureless: direct/bare photon
- Heisenberg uncertainty principle: $\Delta E \cdot \Delta t > 1$

  Photon violates conservation of energy: $\gamma \to f\bar{f}$

  f or $\bar{f}$ interacts => parton content resolved, photon reveals its structure.

  Photon extended object=> charged fermions+gluons
- Dual nature of photon: direct or resolved
- One possible description: Photon Structure Function

The different appearances of the photon

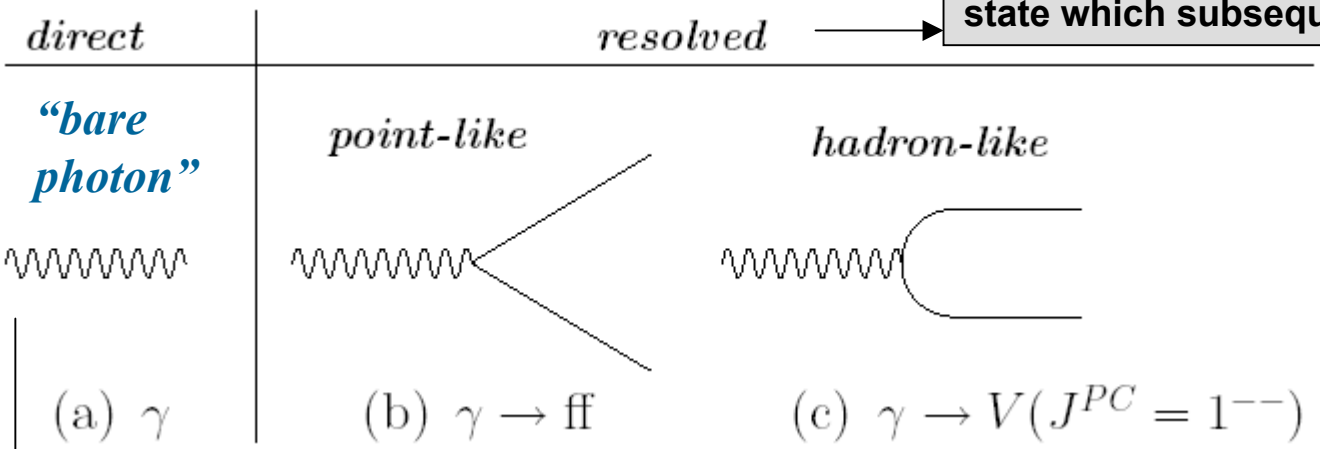
Photon: QED-photon couples to fermions (quarks & leptons)

Lepton pair production => process can be calculated in QED

Quark pair production => QCD corrections

Photon interactions receive several contributions:

photon fluctuates into a hadronic state which subsequently interacts



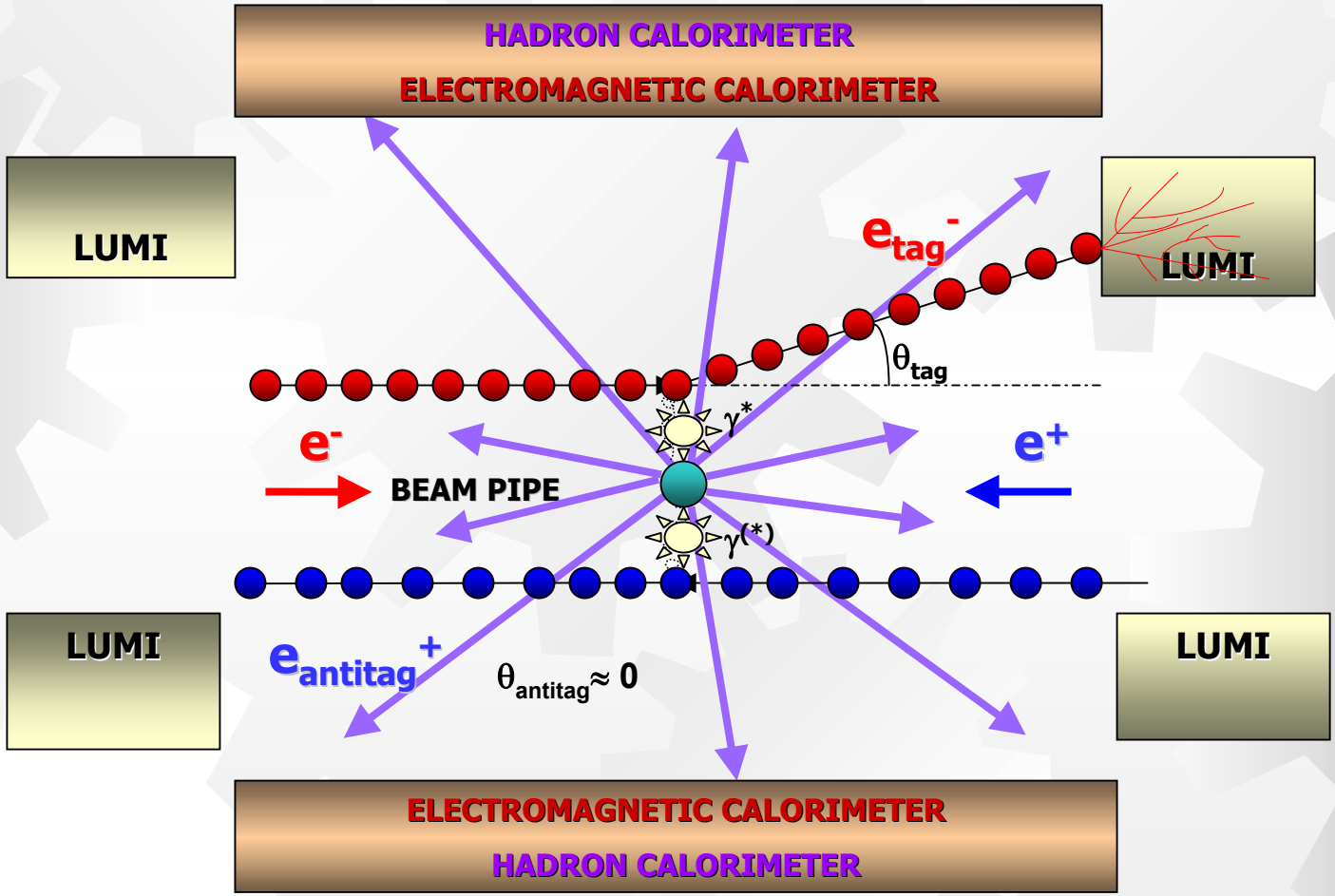
Does not reveal a structure

The QED structure functions can only be used for the analysis of leptonic final states.

For hadronic final states the leading order QED diagrams are not sufficient and QCD corrections are important.

$e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^-$ + hadrons deep-inelastic scattering reaction

θ_{tag} >> 0 → electron observed inside the detector
$\theta_{antitag} \approx 0$ → other electron undetected →"single-tag"



Photon Structure Function

$F_2^\gamma(x,Q^2)$ ~ probability that the probe photon with virtuality Q^2 sees a parton (quark or gluon) with momentum fraction x inside the target quasi-real photon.

$$\frac{d\sigma_{e(k)\gamma^*(q)\to e_{tag}(k')X}(x,Q^2)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2F_L^\gamma(x,Q^2)]$$

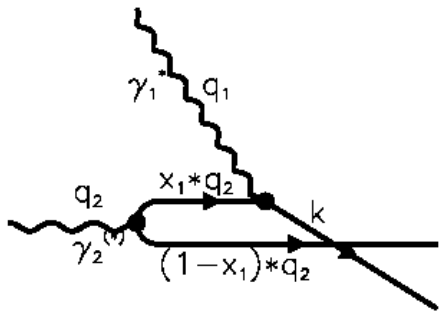
$$y = (p\cdot q)/(p\cdot K) \approx 1-\left(E_{tag}/E_{beam}\right)\cdot\cos^2(\theta_{tag}),\ y\approx 0$$

$$q_i = (E_{\gamma_i^*}, \vec{p}_{\gamma_i^*}),\ (i=1,2)$$

$$q_i^{\,2} = E_{\gamma_i^*}^{\,2} - \vec{p}_{\gamma_i^*}^{\,2}$$

$$-q_1^2 = Q_1^2 \equiv Q^2 > 0$$

$$-q_2^2 = Q_2^2 \cong 0$$



mass squared of the outgoing interacting fermion:

$$k^2 = (xq_2+q_1)^2 = q_1^2 + 2xq_1\cdot q_2 \cong 0$$

$$\Rightarrow\ x = -\frac{q_1^2}{2q_1\cdot q_2} = \frac{Q^2}{2q_1\cdot q_2}$$

Single-tag variables:

$$Q^2 = -q^2 \approx 2E_{tag}E_{beam}(1-\cos\theta_{tag})$$

$$x = Q^2/(Q^2+W^2+P^2) = Q^2/2(p\cdot q)$$

$$W^2 = (q_1+q_2)^2 = (E_{\gamma^*}+E_\gamma)^2 - (\vec{q}+\vec{p})^2$$

$$q_1 = (E_{\gamma^*}, q),\ q_2 = (E_\gamma, p)$$

For single tagged events: P

$$x = \frac{Q^2}{Q^2+W^2}$$

The Bjorken variable x tells us what fraction of the photon four momentum was carried by the particle which participated to the interaction: the target photon itself or a parton (quark or gluon) inside the photon.

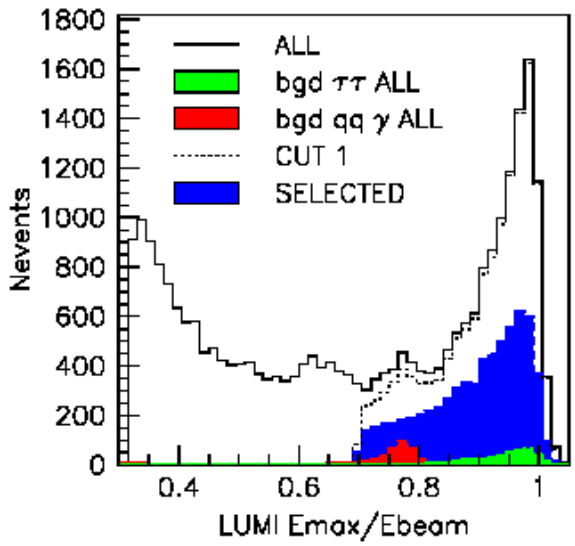
Analysis Method

1) Selection
2) Split x and Q^2 in several bins
3) Unfolding
   energy of the target photon is not known
⇒ Correction with MC
   (Pythia, Phojet, Twogam)
4) Calculate measured cross section:

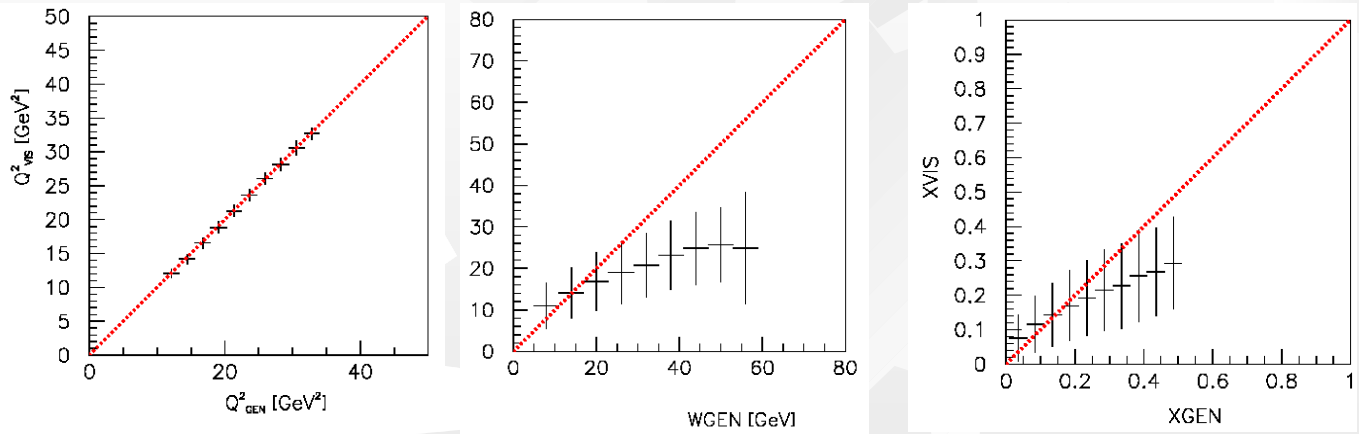
$$\frac{N_{unfolded} - N_{background}}{L \cdot acceptance \cdot trigger\ efficiency}$$

5) $F_2^{\gamma}(x,Q^2)$ obtained using analytically calculated differential cross section (program Galuga)

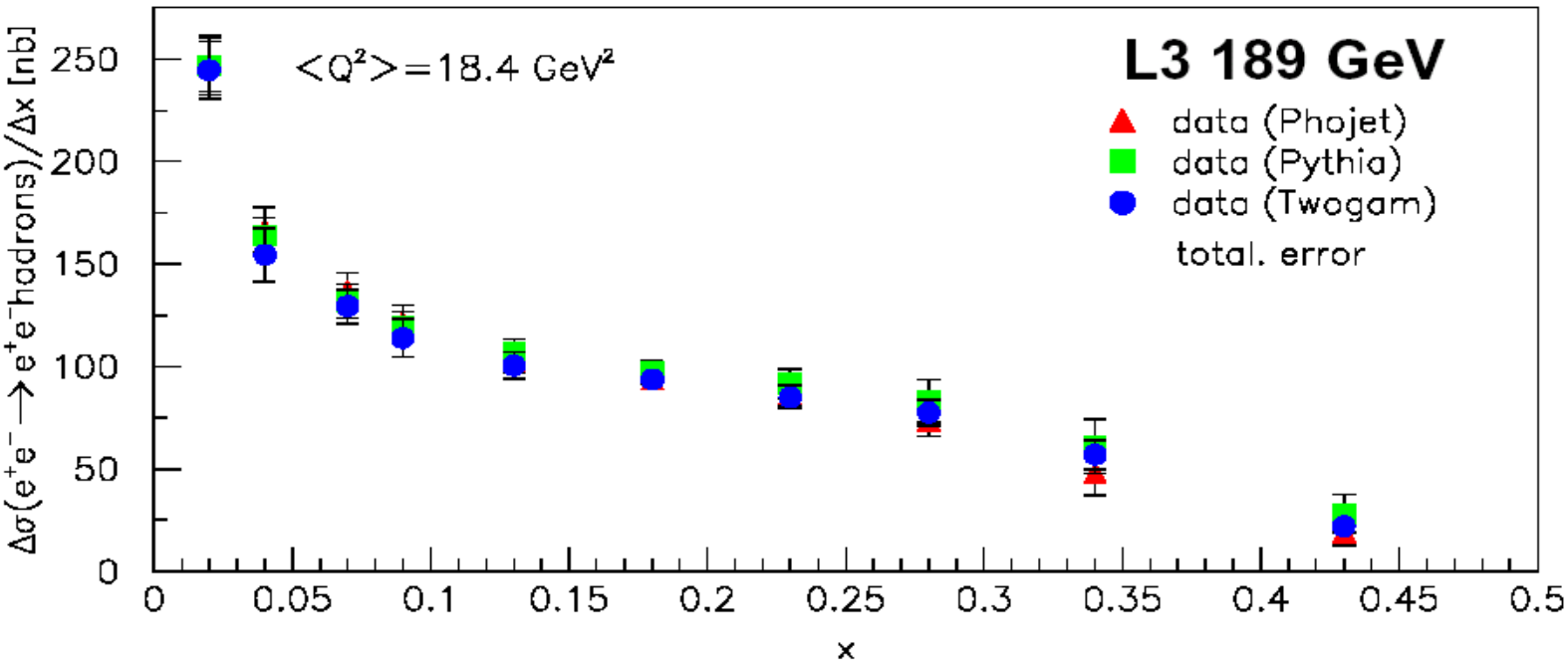
Example: selection 1998



Correlations between the generated and measured Q^2, x, W; MC: Phojet



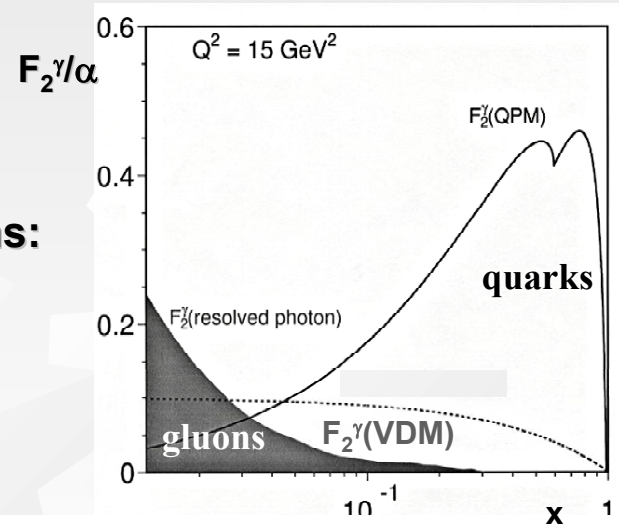
x dependence of $\Delta\sigma/\Delta x$, YEAR 1998



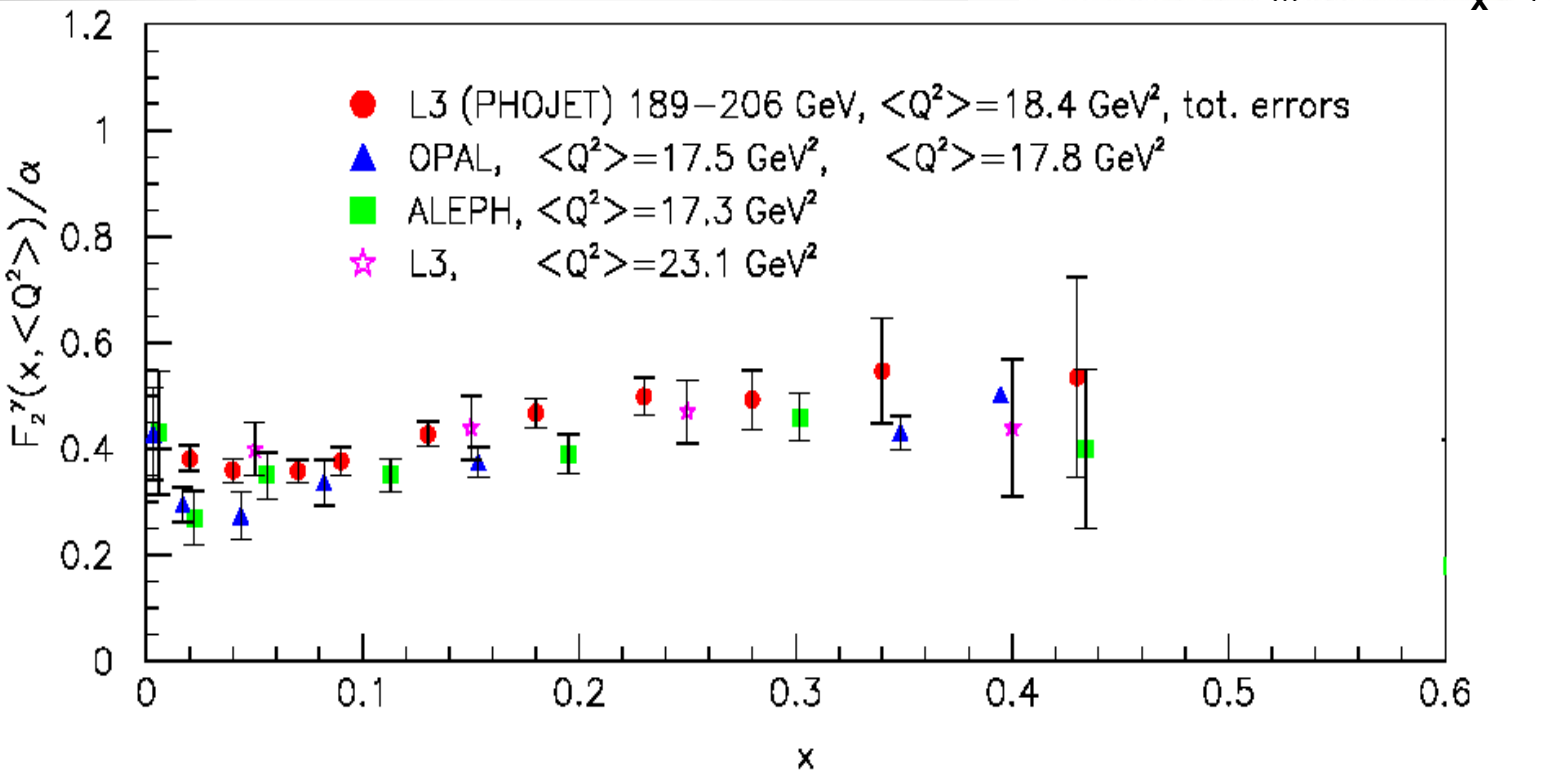
Evolution of F_2^γ with x

$F_2^\gamma(x,Q^2)$ vs x with the different contributions:

VDM, QCD, QPM



Preliminary results:

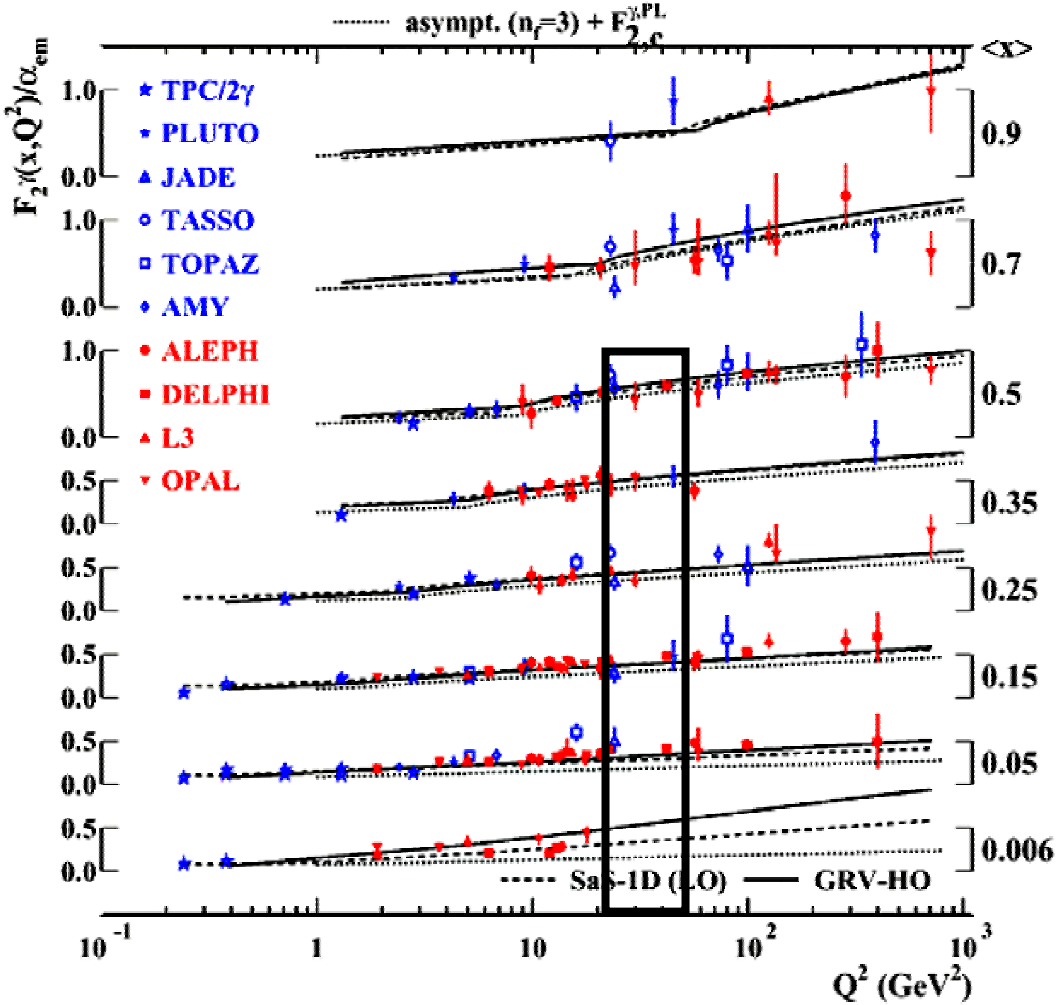


Q^2 evolution of F_2^γ

Expected LUMI-L3 results

add data points to the low x region!

High statistics! Test of QCD and QED.



Summary

- Photon is not just a simple structureless object. It's more than that! It can fluctuate into other states (resolved photon, QCD corrections). The photon can be regarded as an object with an internal structure consisting of charged fermions and gluons.
- Photon structure function analyzed for

  $e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^-$ + hadrons
- Results obtained at LEP/ L3 (using LUMI for tagging the scattered electron) provides the highest statistics ever obtained (highest c.m. energy).

Thank you! ☺