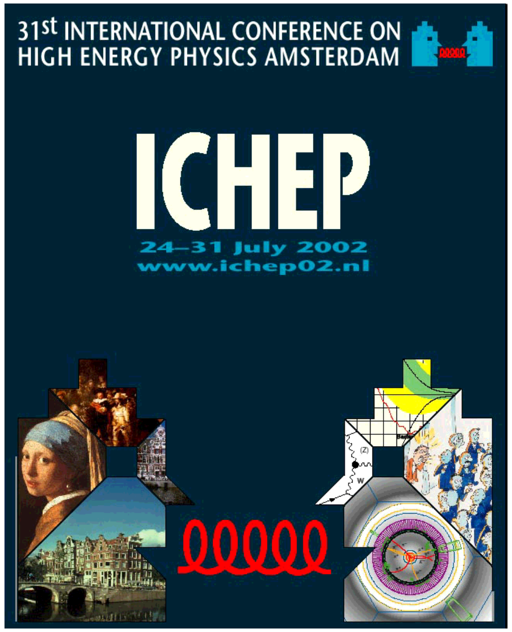
Photon and electron structure from e^+e^-



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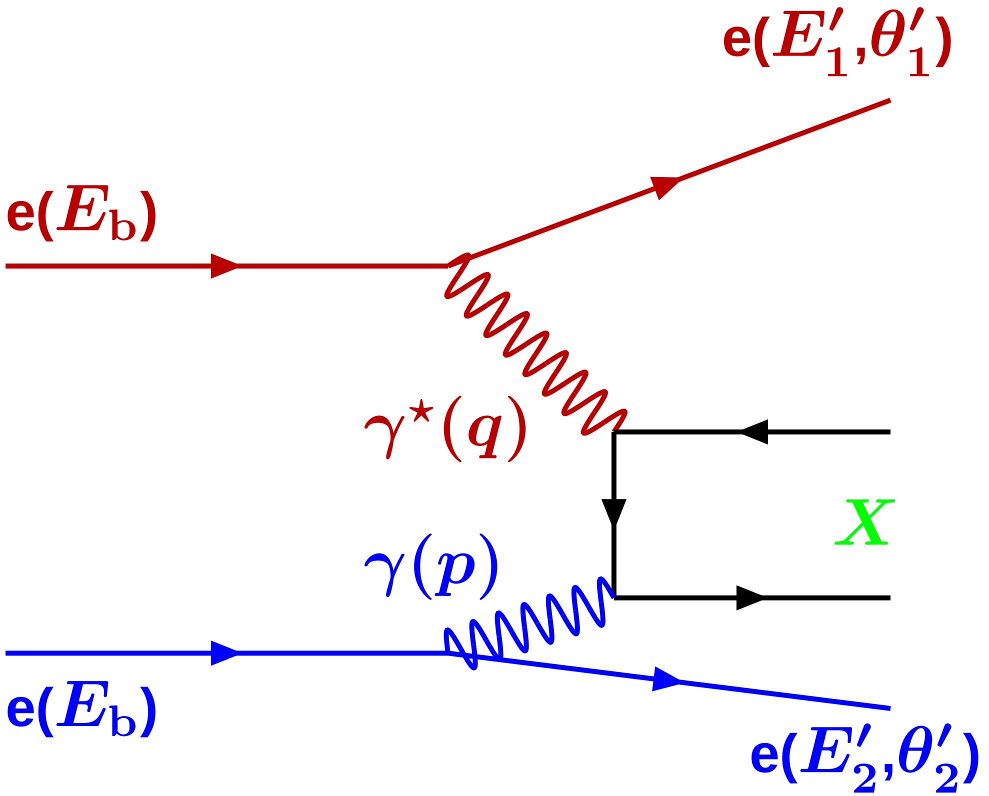
The list of abstracts covered in this talk

- Yes — F_2^γ from OPAL
- No — F_2^γ from ALEPH
- Yes — $F_{2,c}^\gamma$ from OPAL
- Yes — Electron structure function from DELPHI
- No — Electron structure function from OPAL
- Yes — α_s from fit to F_2^γ data from Albino et. al.

A glance at the new developments in 17 minutes

- **Introduction**
- **Experimental investigations**
  1) **News on F_2^γ**
  2) **News on $F_{2,c}^\gamma$**
  3) **What can we learn from the electron structure function?**
- **Theoretical interpretation**
  1) **The strong coupling constant α_s**
- **Where do we go from here?**
- **Conclusions and outlook**

Introduction to deep-inelastic electron-photon scattering



$$Q^2 = -q^2 = 2\,E_\mathrm{b}\,E_1'\,(1-\cos\theta_1')$$
$$f_y = 1 + (1-y)^2$$

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

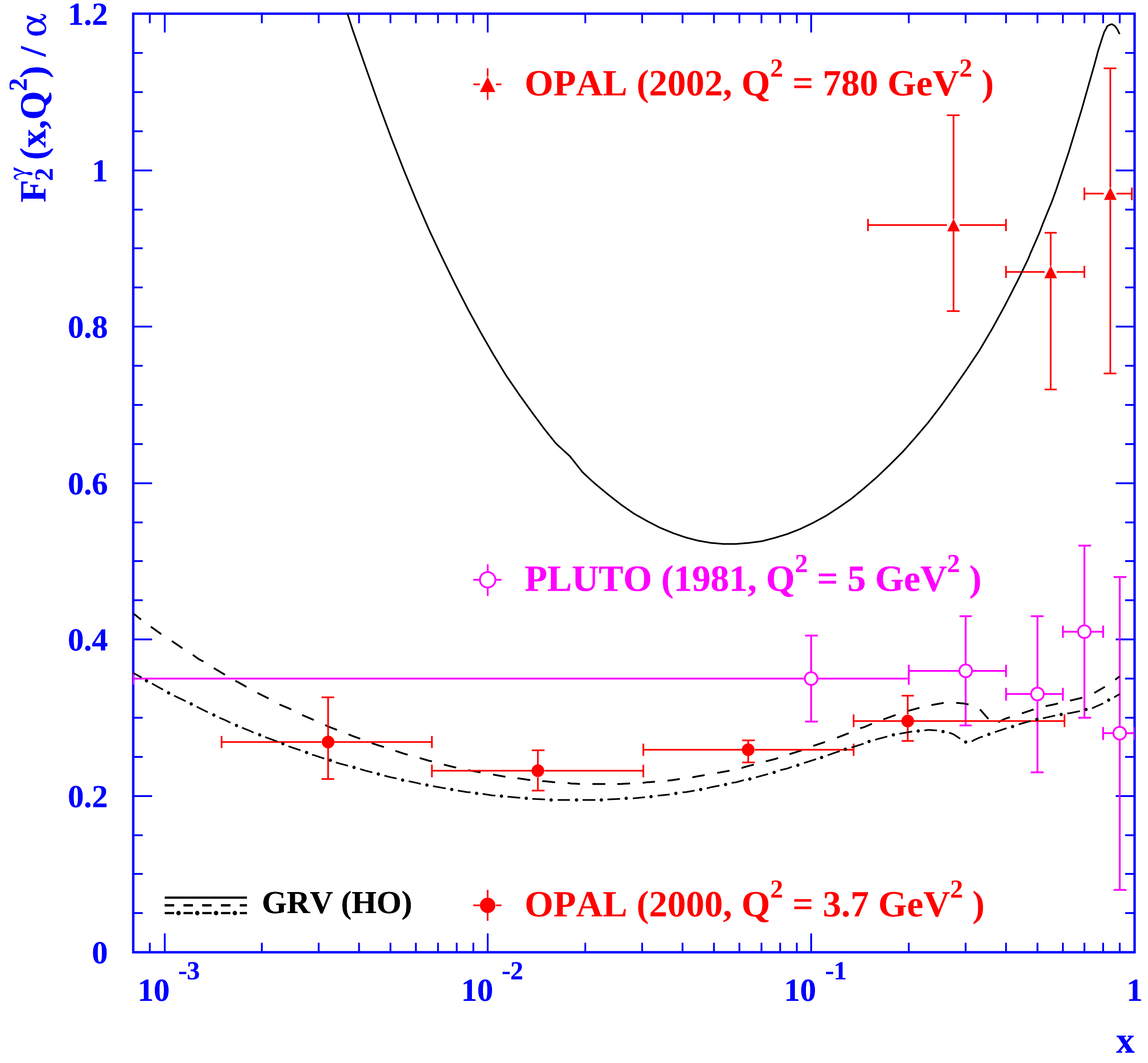
$$P^2 = -p^2 \ll Q^2$$
$$\frac{\mathrm{d}^2 N_\gamma^\mathrm{T}}{\mathrm{d}z\mathrm{d}P^2} = \frac{\alpha}{2\pi}\left[\frac{1+(1-z)^2}{z}\frac{1}{P^2} - \frac{2\,m_\mathrm{e}^2\,z}{P^4}\right]$$

$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P^2} \propto \frac{\mathrm{d}^2 N_\gamma^\mathrm{T}}{\mathrm{d}z\mathrm{d}P^2}\cdot\frac{2\pi\alpha^2}{x\,Q^4}\cdot f_y\cdot F_2^\gamma(x,Q^2)$$

The 'history' of photon structure function measurements

Date	Event
1973	Investigation of two-photon processes in QPM by Walsh and Zerwas
1977	The LO asymptotic behavior of $F_2^\gamma \propto 1/\alpha_s$ was discovered by Witten
1979	Calculation of NLO corrections by Bardeen and Buras
1981	The first measurement of F_2^γ by PLUTO
1986	The first extraction of Λ from F_2^γ data
1990	Start of F_2^γ measurements at TRISTAN
1994	Start of F_2^γ measurements at LEP
2002	The final LEP2 results start getting published
2002	NLO extraction of α_s based on a large set of data by Albino et. al
2011	First measurement of F_2^γ at a future Linear Collider

What a difference 21 years make



Kinematics

- About a factor 100 larger Q^2
- About a factor 100 smaller x

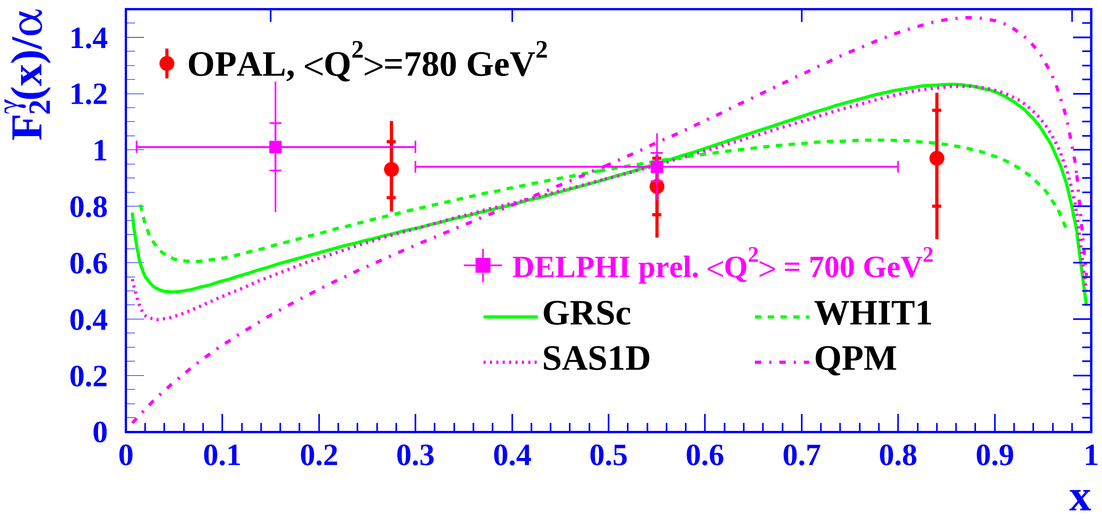
Analysis

- Multipurpose MC models
- Radiative corrections
- Sophisticated unfolding methods
- LEP combined effort
- About 50 measurements

$\Downarrow$

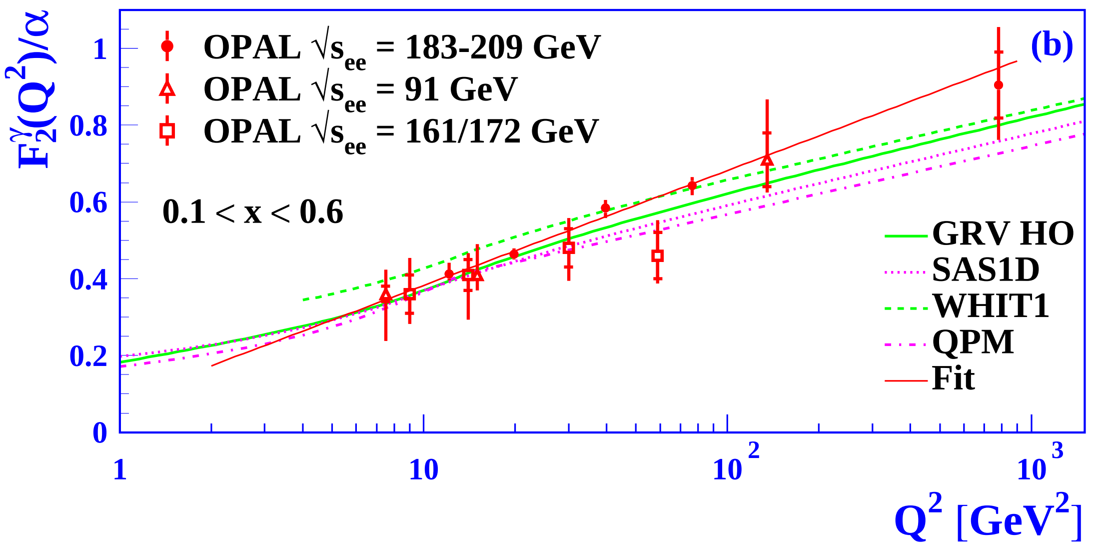
Significantly smaller errors

The measurement of F_2^γ at high Q^2



$F_2^\gamma(x)$ at high Q^2

- $F_2^\gamma(x)$ is very flat
- The measurements are statistics limited
- The QCD predictions are very QPM like



The evolution of F_2^γ with Q^2

- Big improvement in precision at medium Q^2
- Extension up to 780 GeV^2

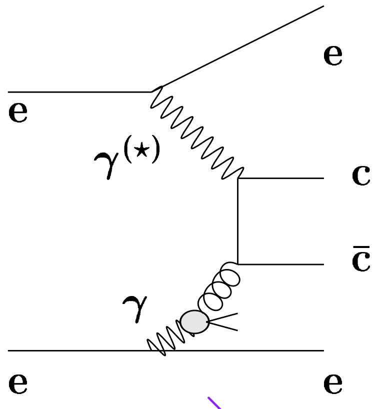
Needs Aleph and L3 to fight stat. error

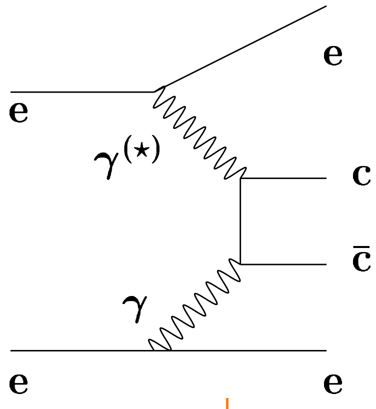
The $F_{2,c}^{\gamma}$ measurement

hadron-like:

depends on f_g^{γ}

dominates at low-x

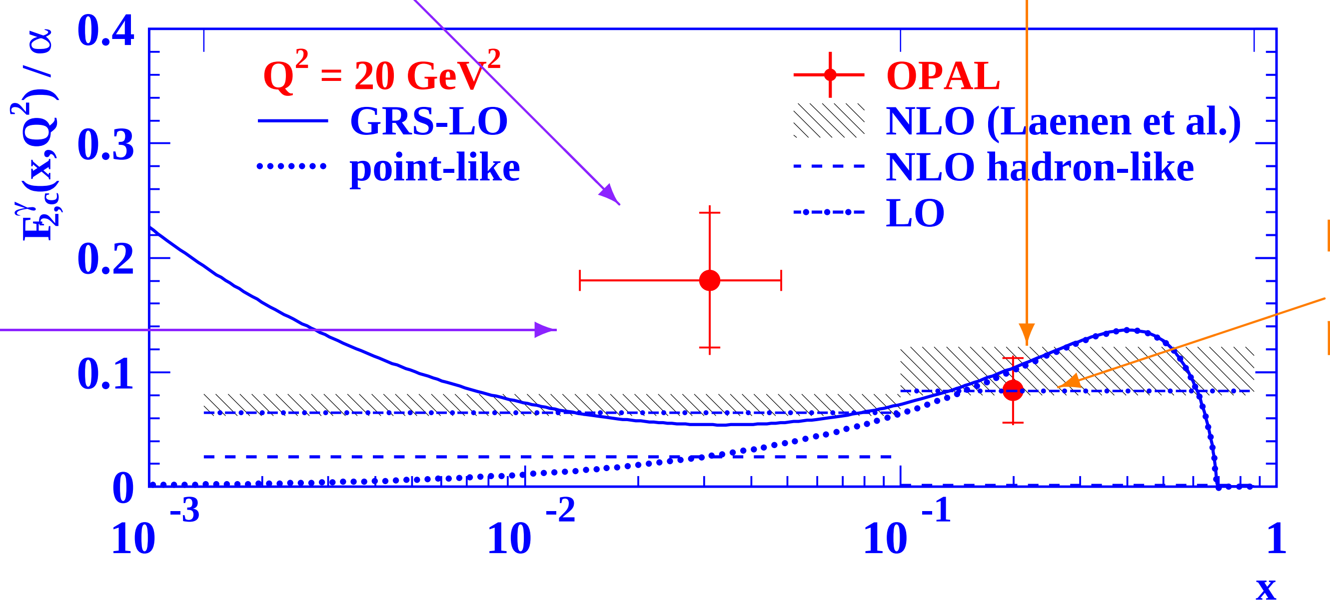




point-like:

pQCD prediction

dominates at high-x



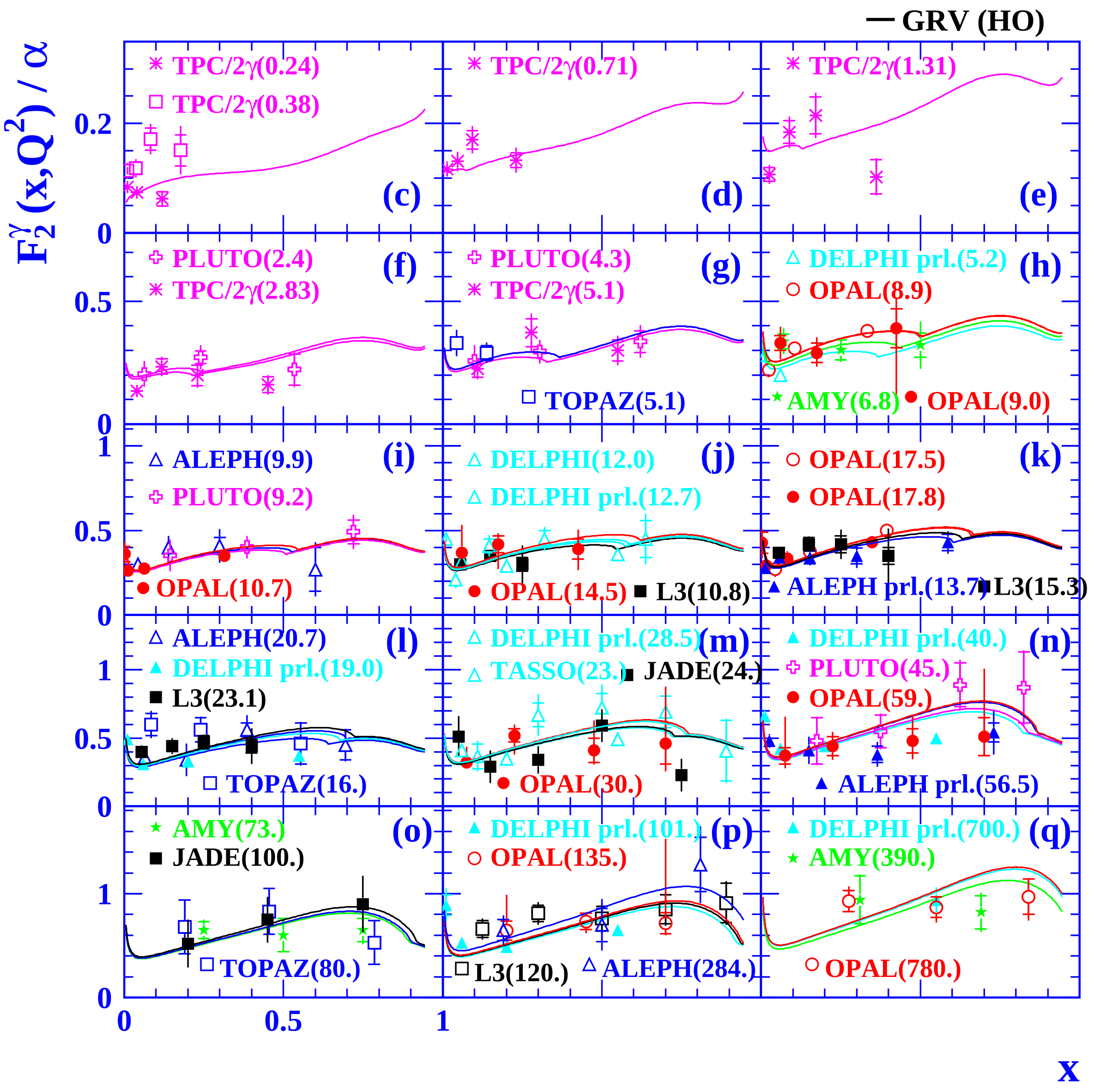
larger f_g^{γ} ?

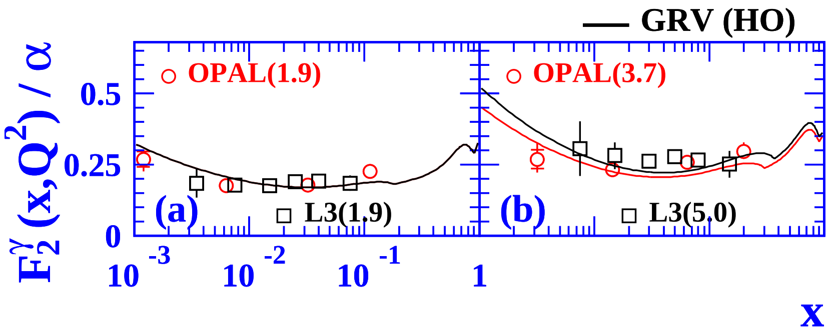
NLO = f(α_s,m_c)

perfectly fits

Needs Aleph, Delphi and L3 to confirm

The world data on F_2^γ





What have we got?

- About 50 measurements
- Kinematical coverage:

  $6 \cdot 10^{-4} \leq x < 1$, and

  $1.9 \leq \langle Q^2 \rangle \leq 780\ \mathrm{GeV}^2$
- Consistency with large redundancy
- Quite different levels of sophistication

Needs very careful interpretation

Electron versus photon structure function

Electron structure: $F_2^{\mathrm{e}}(x_{\mathrm{e}} = zx)$

⊕ The electron energy is known
$\Rightarrow$ kinematics is better constrained
i. e. one can use the electron method

⊖ The folding of F_2^{γ} with the photon energy spectrum f_γ obscures the sensitivity to the photon structure

⊖ Large radiative corrections at low x_{e}

Photon structure: $F_2^{\gamma}(x)$

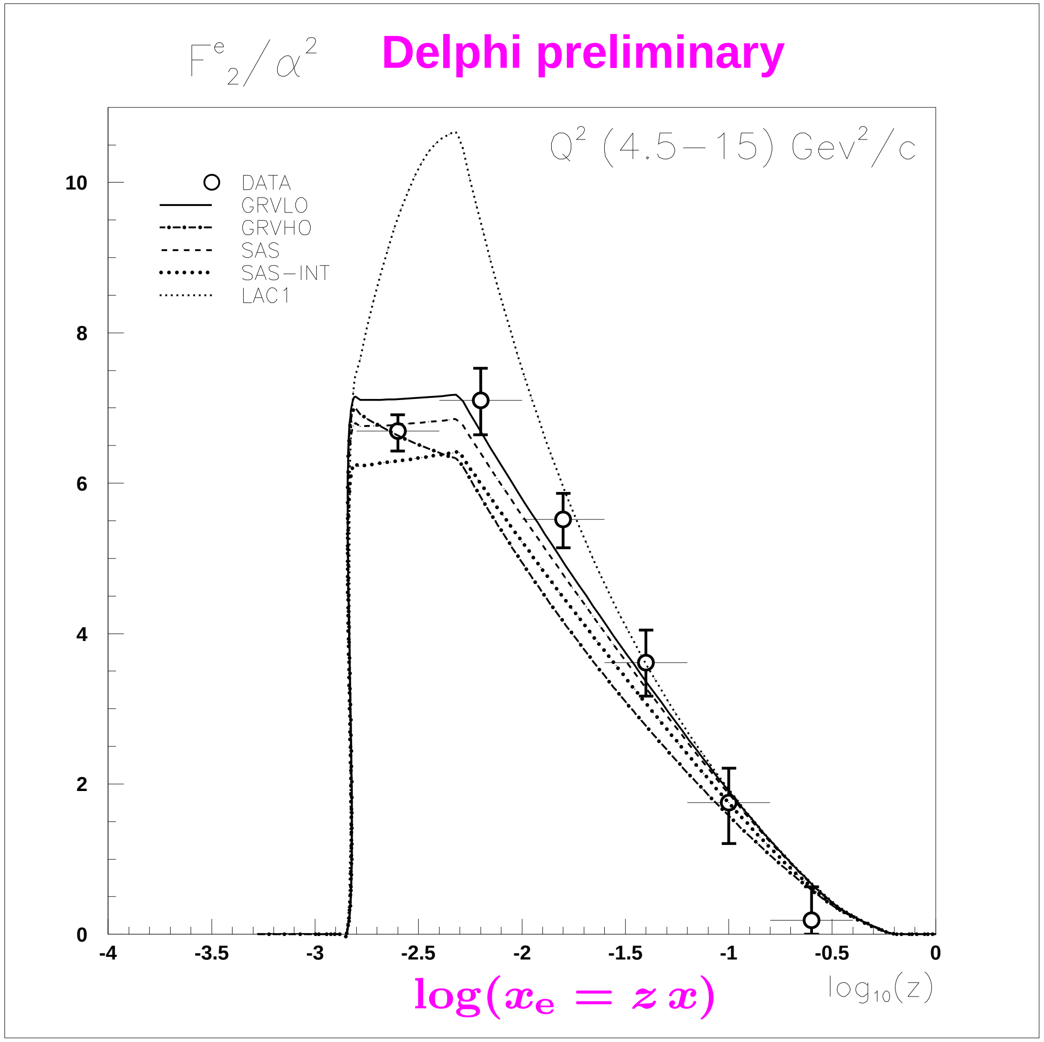
⊖ The photon energy is not known
$\Rightarrow$ x has to be obtained via W
using the hadronic final state

⊕ The photon structure is directly investigated as a function of x

⊕ Moderate radiative corrections

$$F_2^{\mathrm{e}}(x_{\mathrm{e}}, Q^2, P^2_{\mathrm{max}}) = \int_{x_{\mathrm{e}}}^{1} \mathrm{d}z \int_{P^2_{\mathrm{min}}}^{P^2_{\mathrm{max}}} \mathrm{d}P^2 f_\gamma(z, P^2) \cdot F_2^{\gamma}(x, Q^2, P^2)$$

The electron structure function from DELPHI



- First measurement of F_2^e
- About 3-20% precisions both statistical and systematic
- Steeply falling curve in $\log(x_e)$
- No radiative corrections and no bin-center corrections are applied
- LAC1 is disfavoured

How to get α_s from F_2^γ

Treatment of experimental data:

- Use correlation matrix if exists
- Treat sys. errors as uncorrelated
- Neglect P^2 effect and rad. cor.
- Symmetrise asymmetric errors
- Abandon TPC/2γ data

Assumptions made for the fits:

- Fixed flavour scheme, uds as active flavours
- Bethe-Heitler charm $m_c = 1.5 \pm 0.1\,\mathrm{GeV}$
- Perform DIS$_\gamma$ and $\overline{\mathrm{MS}}$ fits

  (1) p.l.: $Q_0^2 = \Lambda^2$, hadron-like $\equiv$ 0

  (2) full: $uds(Q_0^2) = Nx^\alpha(1-x)^\beta$, $g(Q_0^2) = 0$

(1) **Point-like fit:**

Use data with $(x > 0.45,\ Q^2 > 59\ \mathrm{GeV}^2)$ and fit α_s

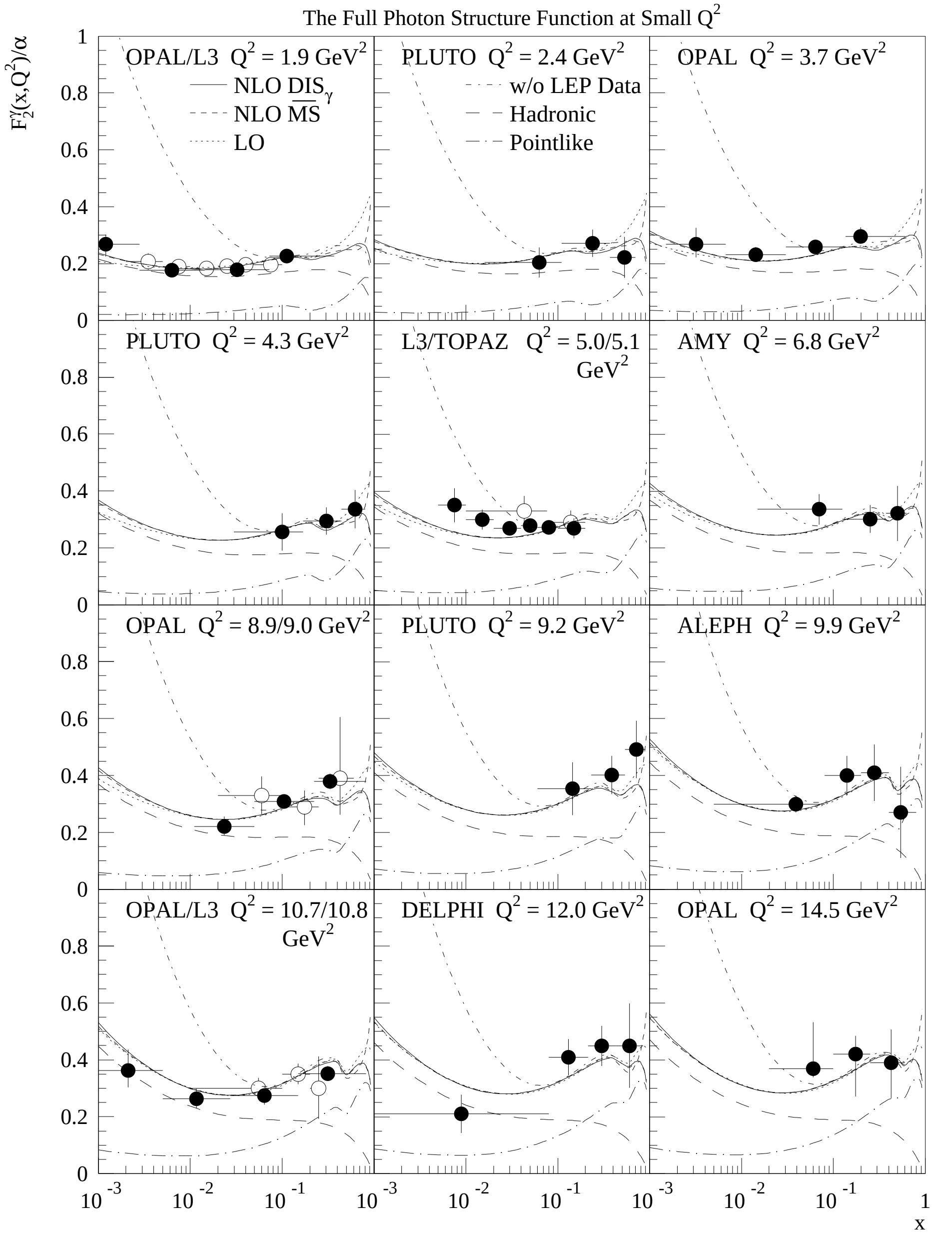
$$\alpha_s(M^2_{\mathrm{Z}^0}) = 0.1183\ \pm 0.0050\,\text{(exp.)}\,^{+\,0.0029}_{-\,0.0028}\ \text{(theor.)}$$

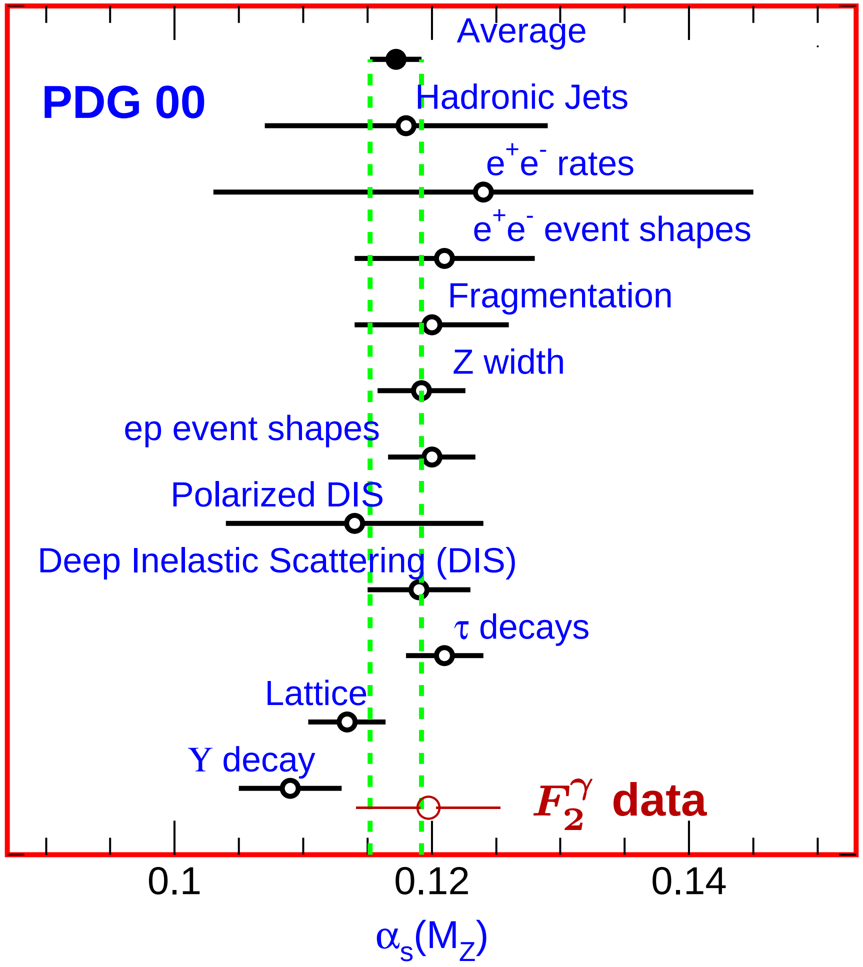
(2) **Full fit:**

Use all data, 5 parameter fit for $(N,\ \alpha,\ \beta,\ \alpha_s,\ Q_0^2)$

$$\alpha_s(M^2_{\mathrm{Z}^0}) = 0.1198\ \pm 0.0028\,\text{(exp.)}\,^{+\,0.0034}_{-\,0.0046}\ \text{(theo.)}$$

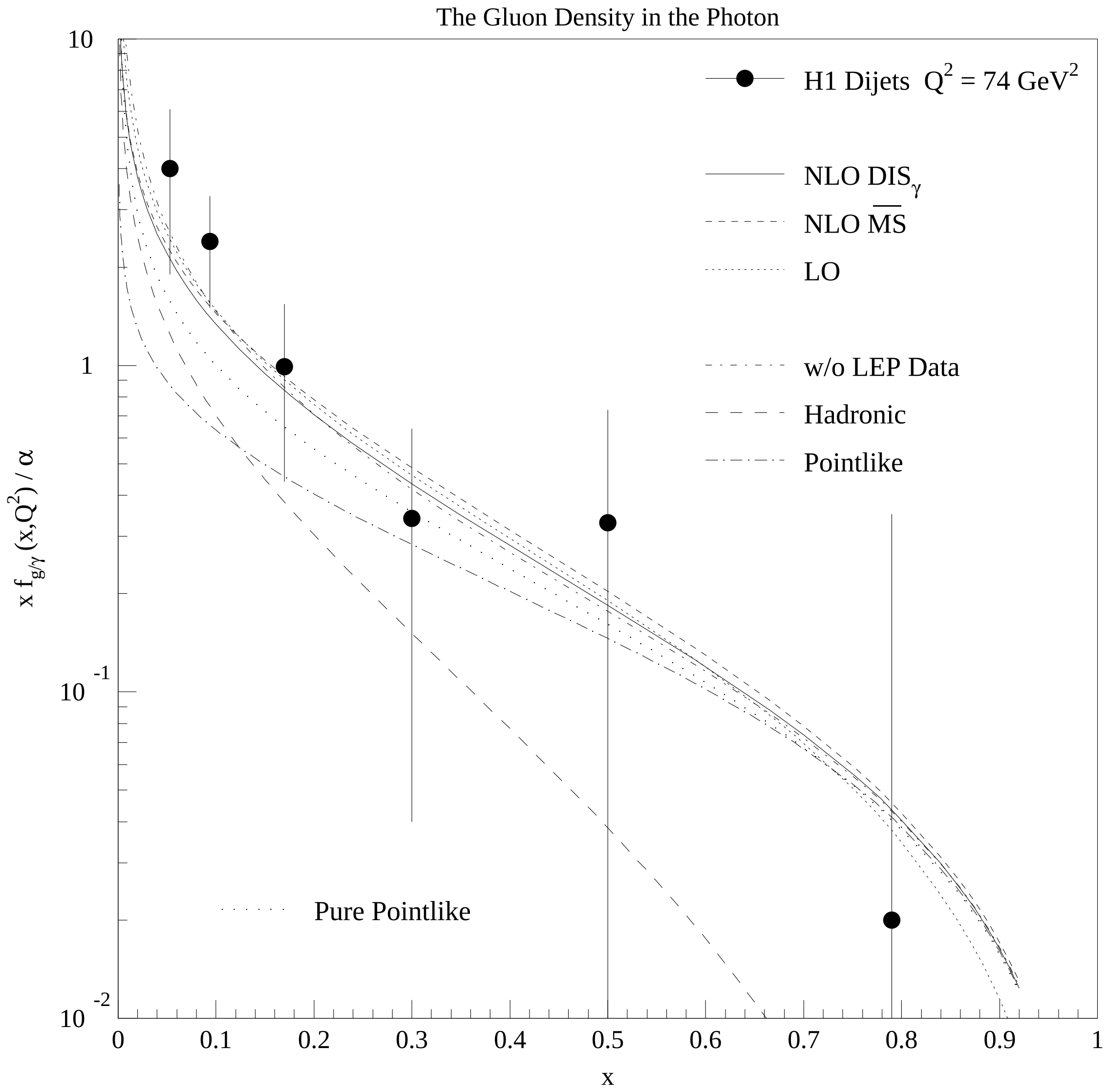
The α_s from F_2^γ data





$$\alpha_s(M^2_{Z^0}) = 0.1198 \pm 0.0054$$

Comparison of $f_{g/\gamma}$ from F_2^γ with the HERA result

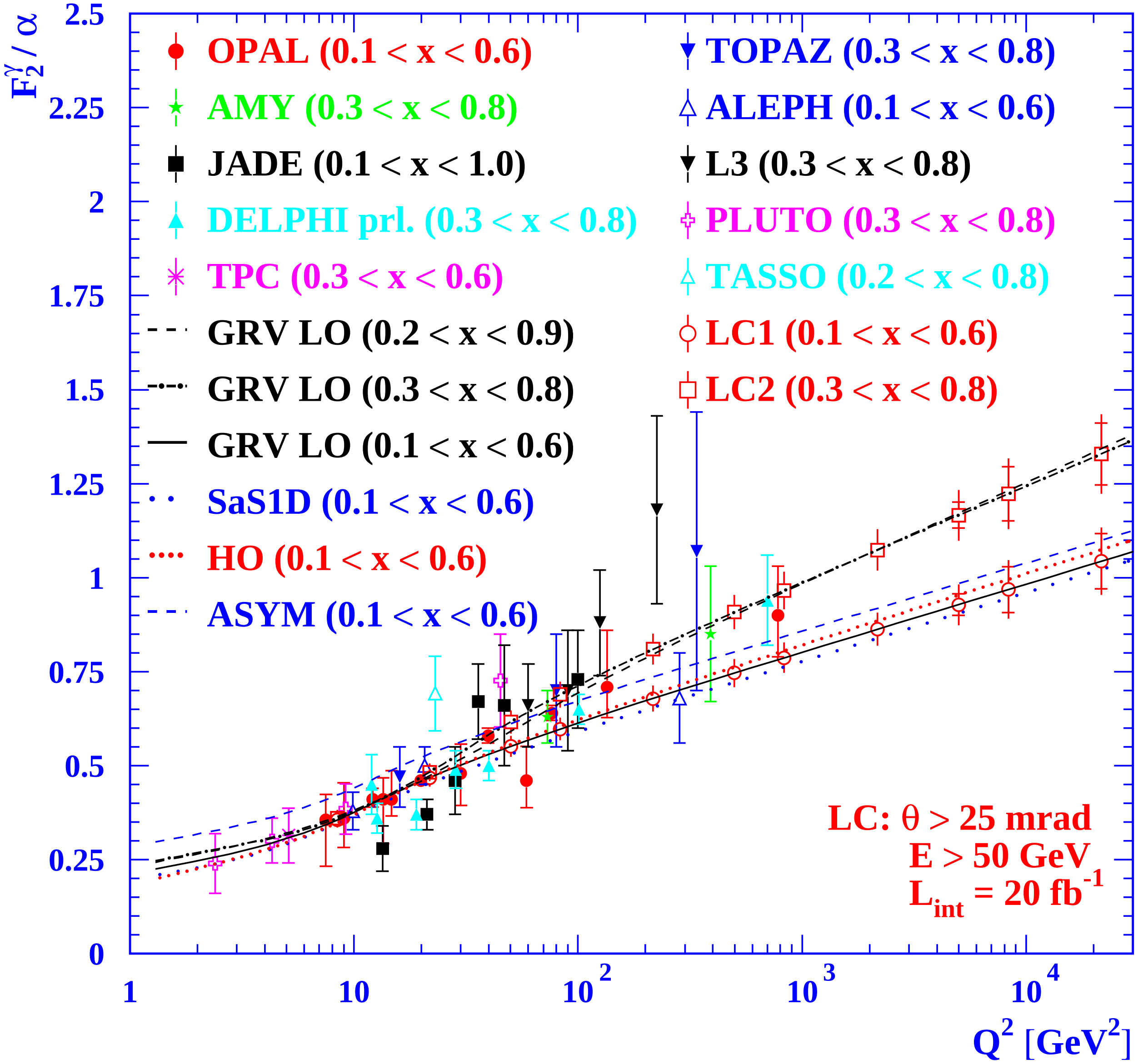


Consistency check

- **Gluon from fit to F_2^γ data is at the low end of the H1 result**
- **Both the point-like and the hadron-like components from the full fit are needed to describe the data**
- **The pure point-like result shows the interplay between a longer evolution and non-vanishing PDFs at the starting scale**

Include HERA data in the fit

The future of F_2^γ measurements



Two x-ranges studied

LC2: $0.3 < x < 0.8$

LC1: $0.1 < x < 0.6$

The Linear Collider will play an important role in testing this pQCD prediction, since

$\Delta\alpha_s(M^2_{Z^0})$**theo.** $\rightarrow \mathcal{O}(0.002)$

Conclusions and ...

1. The photon structure has now been investigated up to factorization scales of about 1000 GeV^2, and the errors of the measurements have continuously been reduced.
2. The investigation of the electron structure function serves as a valuable cross-check, but does not give more insight into the photon structure.
3. The first NLO extraction of α_s based on LEP2 data has been performed. The quoted precision of the result is compatible with other determinations. It is very desirable to also include the HERA data into the fit.
4. ...

Outlook

Have you recently seen some really high luminosity F_2^γ data?

No, not recently!

May be they are just around that corner, but ... I am sure, as Time Evolves Sooner or Later they will Arrive.