Photon Structure Functions at LEP

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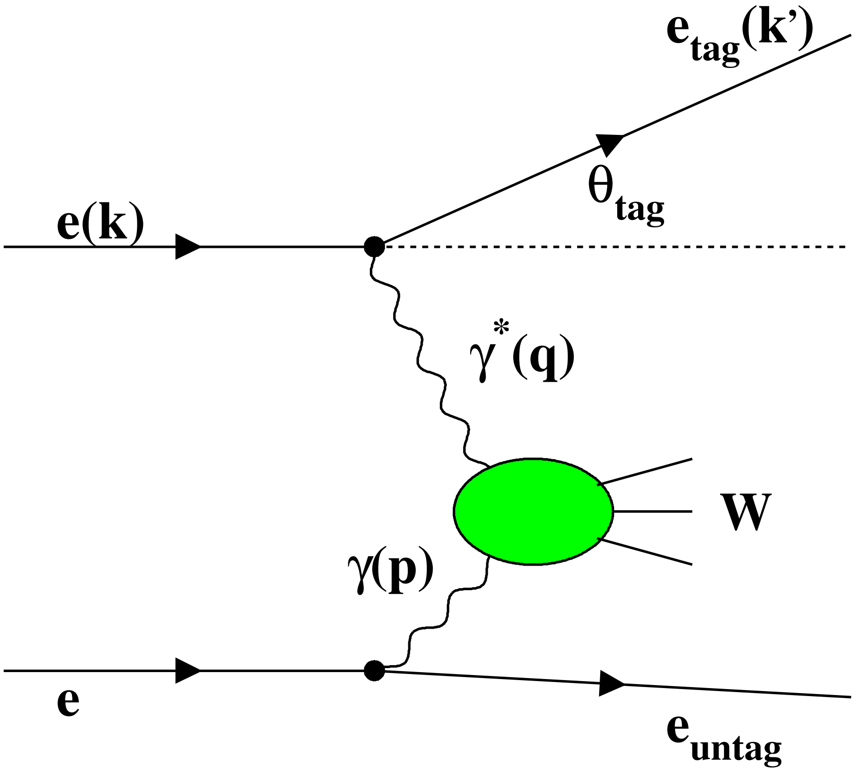
Outline

- Introduction
- Hadronic Structure Functions from single-tag events:
  Contributions to this conference from ALEPH (papers 898a + 898b), L3 (paper 525 + 1060) and OPAL (papers 398 + 399).
- Leptonic Structure Functions from single-tag events:
  Contributions to this conference from OPAL (papers 400 + 401) and L3 (paper 526).
- Conclusions

Introduction

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2\ F_L^\gamma(x,Q^2)]$$



Kinematics of the two-photon process:

$Q^2 = -q^2 = -(k-k')^2 = 2 \cdot E_{beam}E_{tag}(1 - cos\Theta_{tag})$

$P^2 = -p^2$, **not measured in single tag events**

$W^2 = (q+p)^2 = (\Sigma_h\, E_h)^2 - (\Sigma_h\, \vec{p_h})^2$

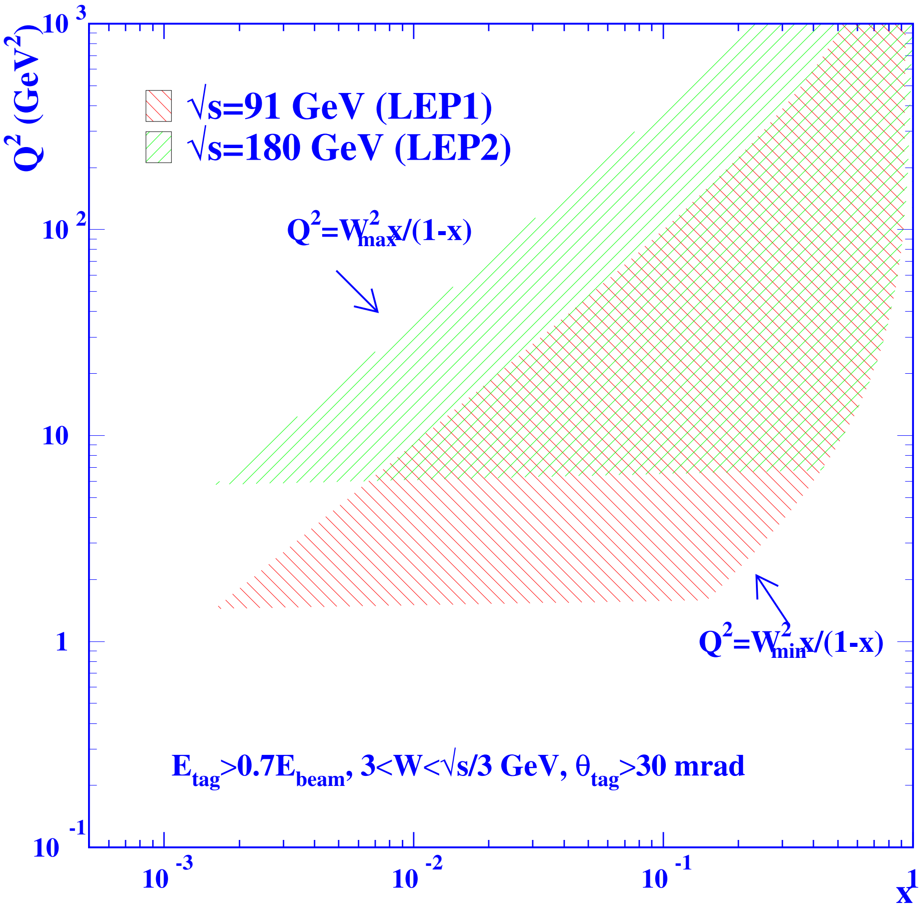
$x = \frac{-q^2}{2p \cdot q} = \frac{Q^2}{Q^2+P^2+W^2} \approx \frac{Q^2}{Q^2+W^2}$

$y = \frac{p \cdot q}{p \cdot k} = 1 - \frac{E_{tag}}{E_{beam}} cos^2(\frac{\theta_{tag}}{2}) \ll 1$

Because y^2 is very small $\Longrightarrow$ can neglect $F_L^\gamma(x,Q^2)$

Introduction

Kinematic region covered at LEP I and LEP II:



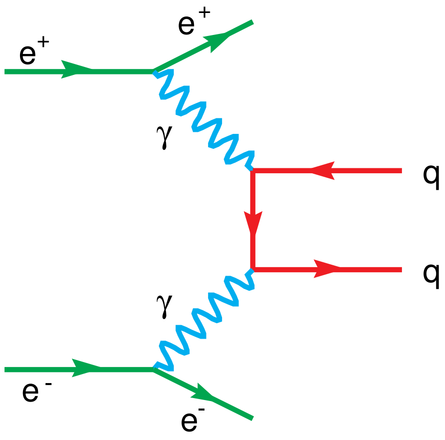
kinematic range of expts. (contributed papers)

Expt.	$\sqrt{s}$	Θ_{tag}	$< Q^2 >$	x
	GeV	rad.	GeV^2	
ALEPH	91	0.060 - 0.150	6 - 44	0.002 - 0.900
ALEPH	91	$>$ 0.318	50 - 2400	0.000 - 0.975
L3	91	0.026 - 0.066	1.2 - 9	0.002 - 0.200
L3	91	0.2 - 0.6	40 - 500	0.05 - 0.98
L3	183	0.030 - 0.066	9 - 30	0.01 - 0.3
OPAL	91	0.027 - 0.055	1.1 - 6.6	0.0025 - 0.2
OPAL	161	0.033 - 0.055	11 - 41	0.02 - 0.6
OPAL	172	0.060 - 0.120	11 - 41	0.02 - 0.6

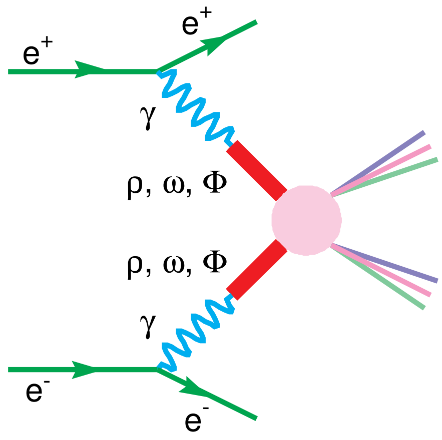
Hadronic Structure Functions

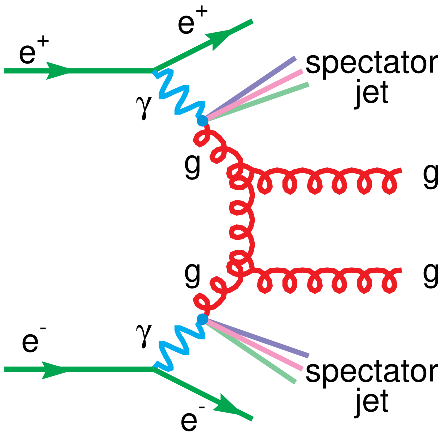
Graphs for the production of hadrons via the two-photon exchange:

QPM, direct

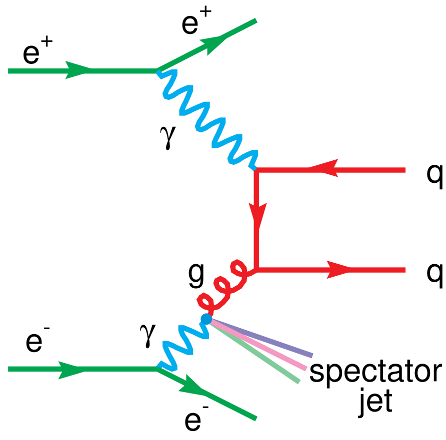


VDM





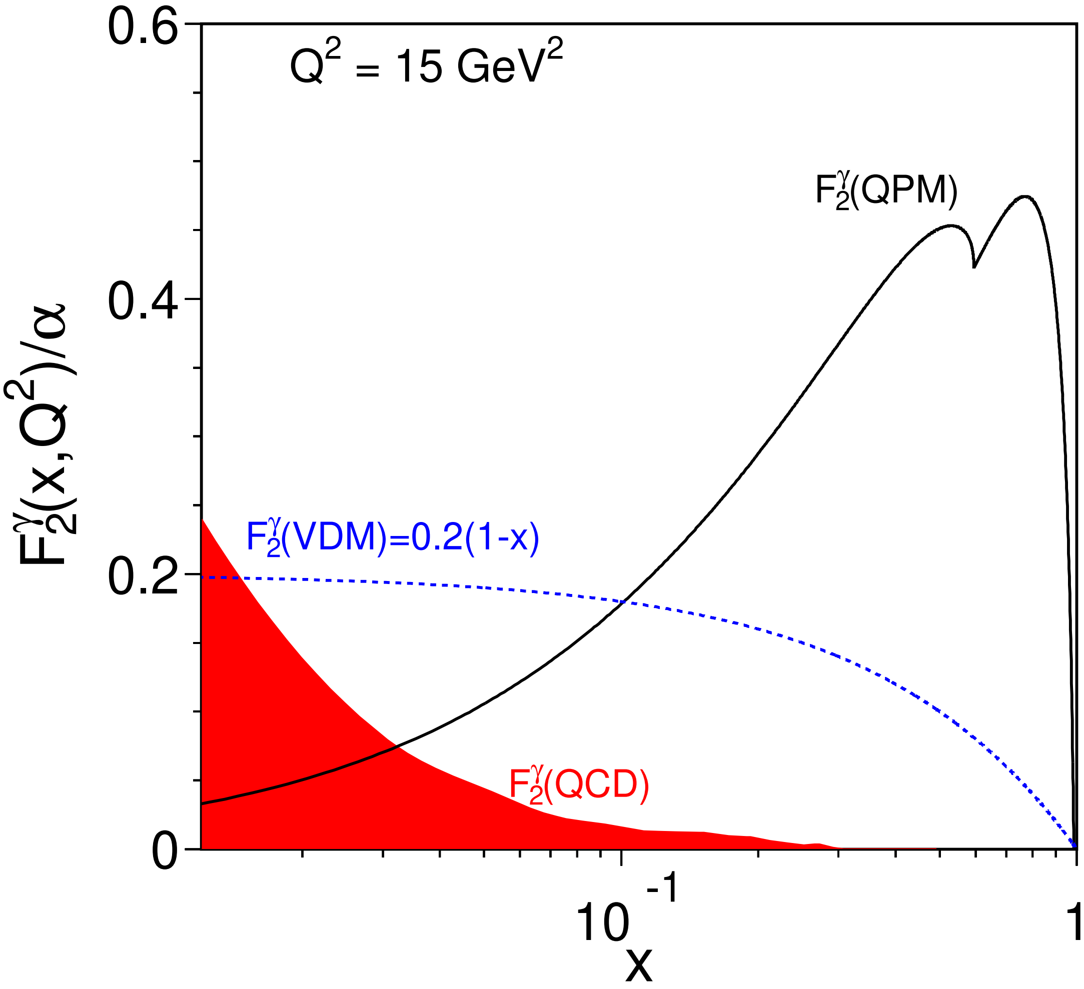
"double resolved"



"single resolved"

Hadronic Structure Functions

Decomposition of F_2^γ/α into QPM, VDM and QCD at Q^2 = 15 GeV^2.



F_2^γ(QCD) contains the "singlet" part, F_2^γ(QPM) contains the "non-singlet" part

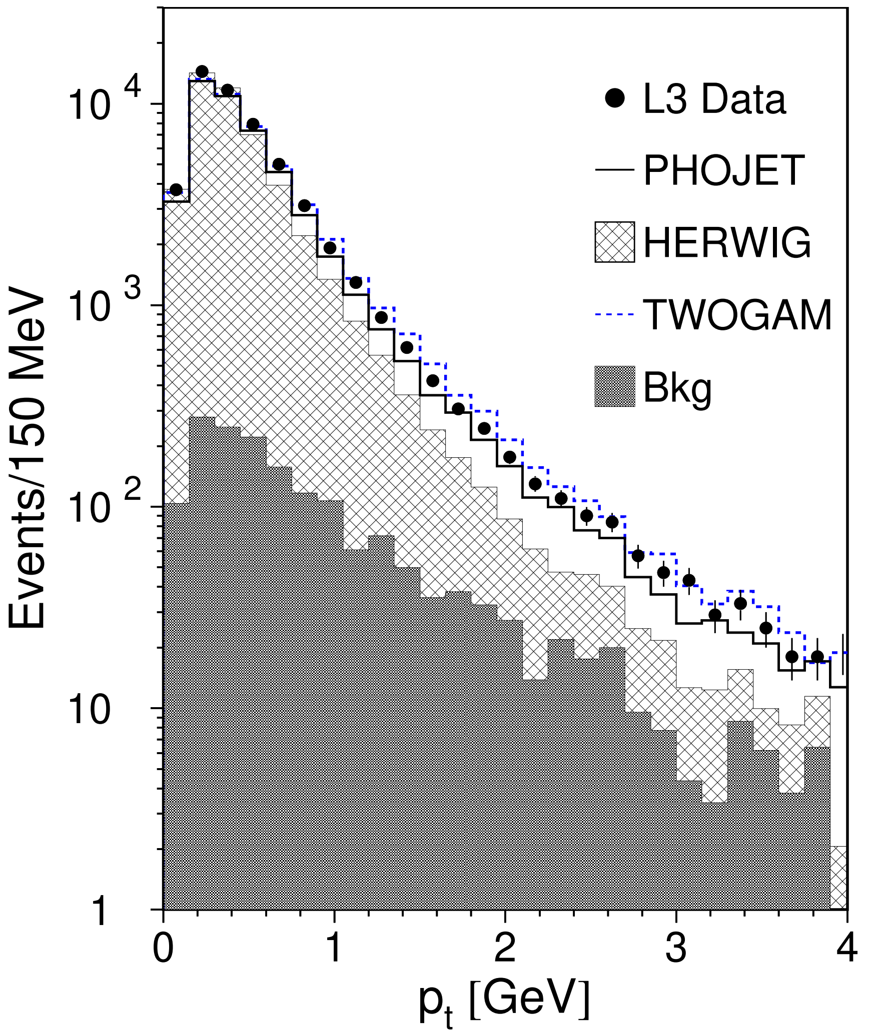
Hadronic Structure Functions

Monte Carlo Programs:

- $e^+e^- \to e^+e^-$ + hadrons:
  1. TWOGAM, Nova, Olshevski and Todorov (1990)
  2. PHOJET, Engel and Ranft (1995, 1996)
  3. HERWIG, Marchesini et al. (1992)
  4. PYTHIA, Sjöstrand and Schuler (1994)
- $e^+e^- \to e^+e^- + \tau^+\tau^-$ (background):
  - VEMASEREN, Vermaseren et al. (1979, 1983)
- $e^+e^- \to$ hadrons (background):
  - JETSET, Sjöstrand (1994)
- $e^+e^- \to \tau^+\tau^-$ (background):
  - KORALZ, Jadach, Ward and Was (1994)
- $e^+e^- \to W^+W^-$ (background):
  - KORALW, Skrzypek, Jadach, Placzek and Was (1996)

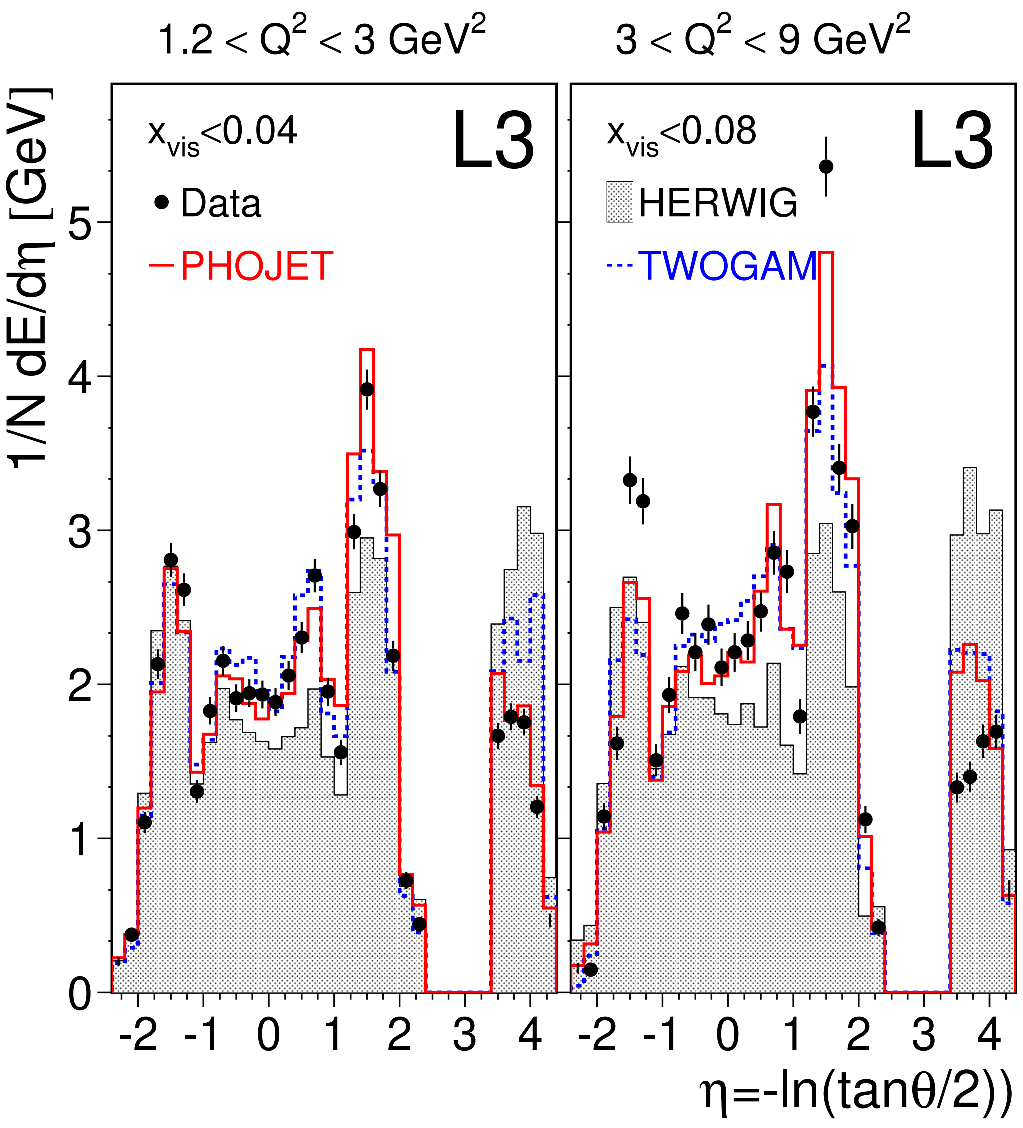
Programs 2,3 and 4 use inputs from γp and pp to evaluate the relative contributions of the diagrams.

Comparison of M.C. models to
the L3 data at $\sqrt{s}$ = 91 GeV
p_t distribution of charged tracks
in $1.2\ GeV^2 \leq Q^2 \leq 9\ GeV^2$:



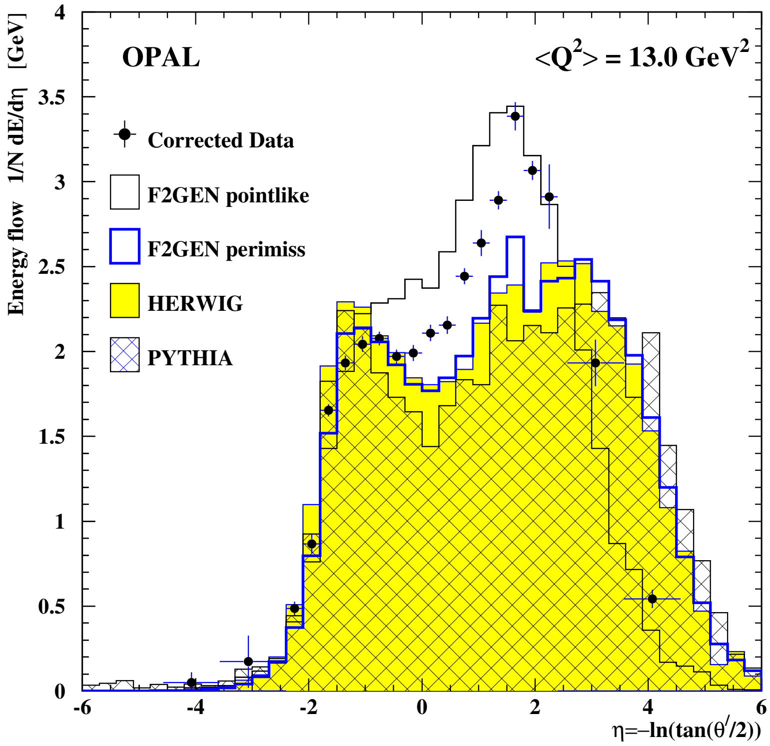
PHOJET (1.05C) and TWOGAM (1.71) do better than HERWIG (5.9).

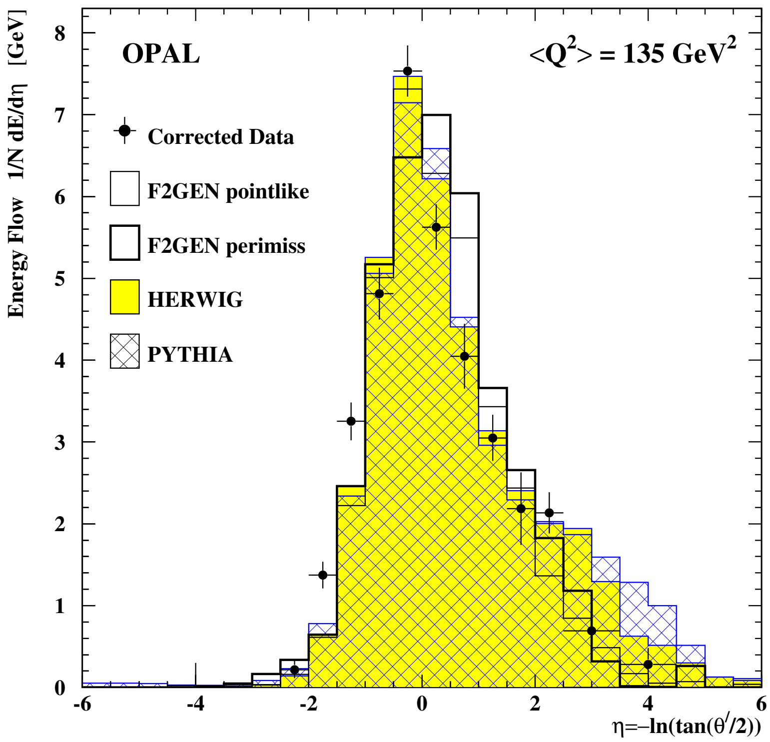
Comparison of M.C. models to the L3 data at $\sqrt{s}$ = 91 GeV: η distributions of all particles.



Again, TWOGAM and PHOJET do better than HERWIG.

η distributions for $< Q^2 >$ = 13 and 135 GeV^2 from OPAL:





Hadronic Structure Functions

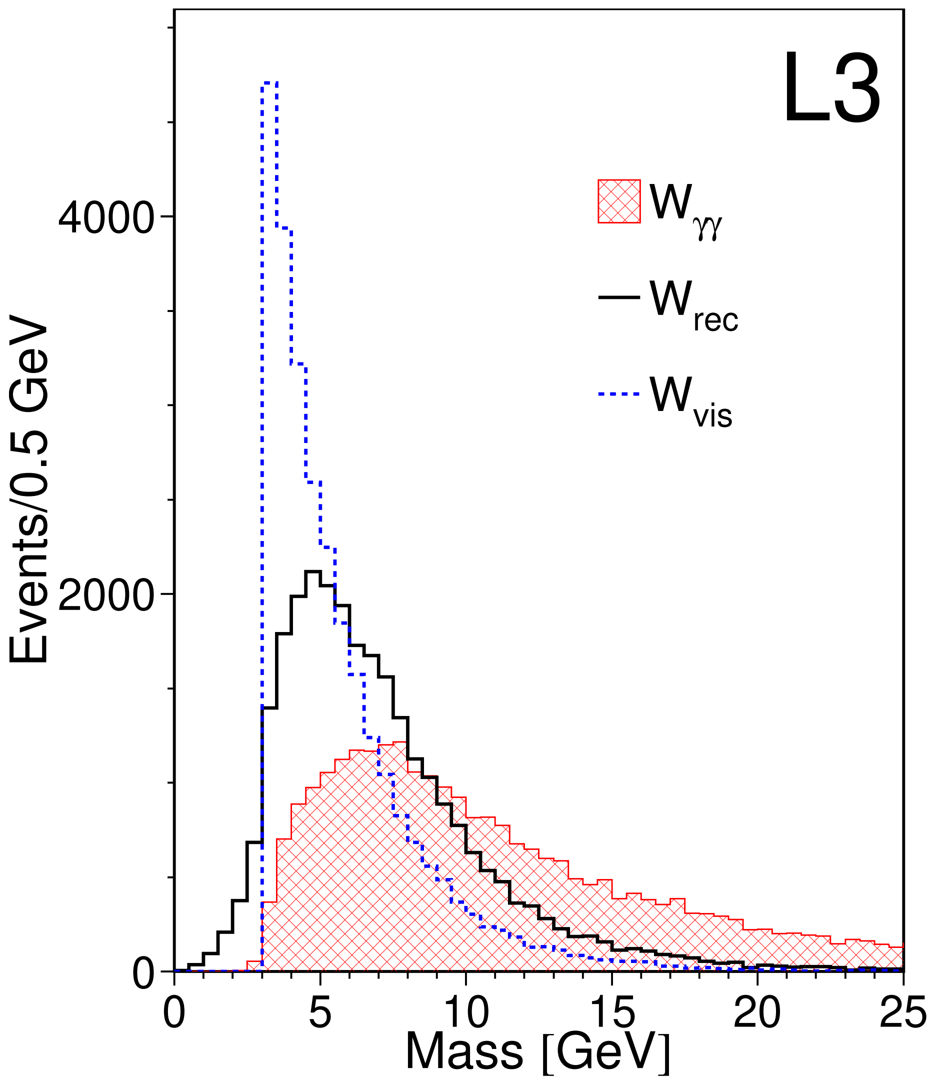
Because of detector effects:

$W_{vis} < W_{\gamma\gamma}$ **and** $x_{vis} > x$. **Improve** W_{vis}

by using transverse momentum conservation:

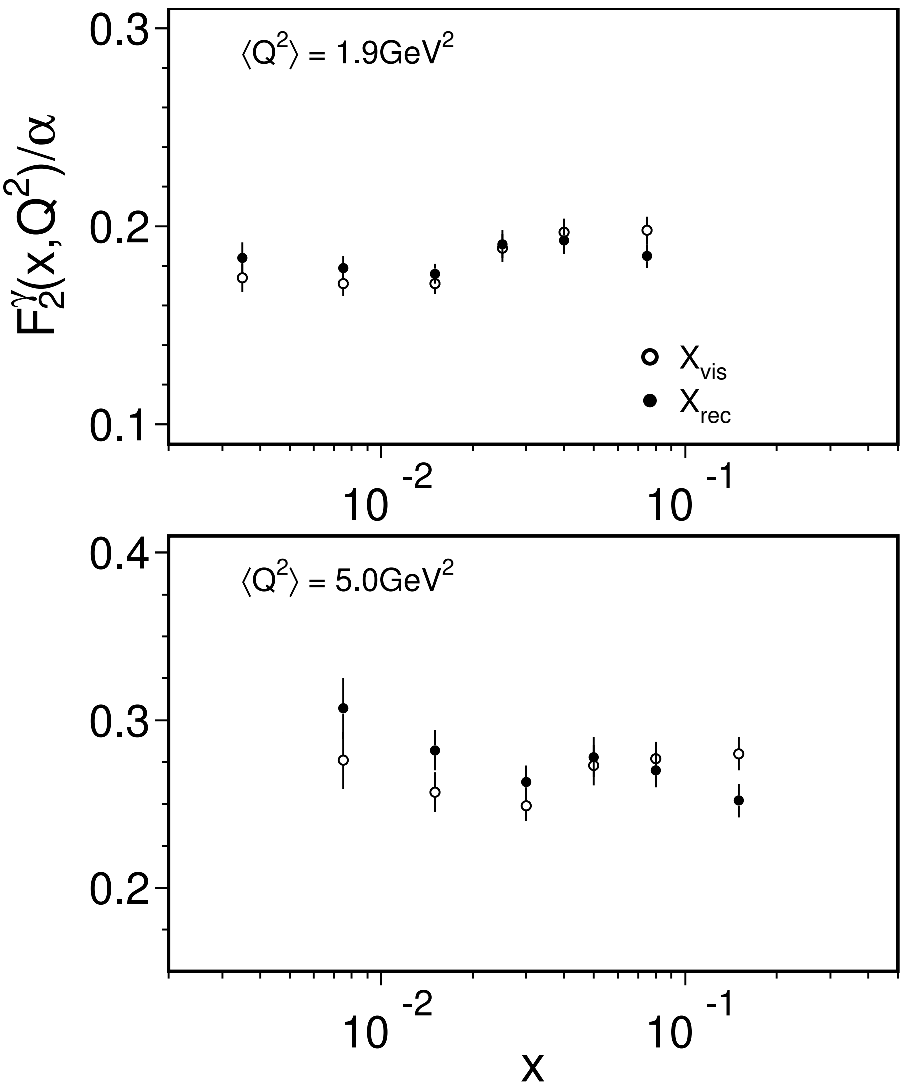
$W_{rec}^2 = (p_+^{e_{in}} - p_+^{e_{tag}})(\Sigma_i\, p_-^i) - |p_t^{e_{tag}}|^2$

with $p_\pm = E \pm p_z$



Hadronic Structure Functions

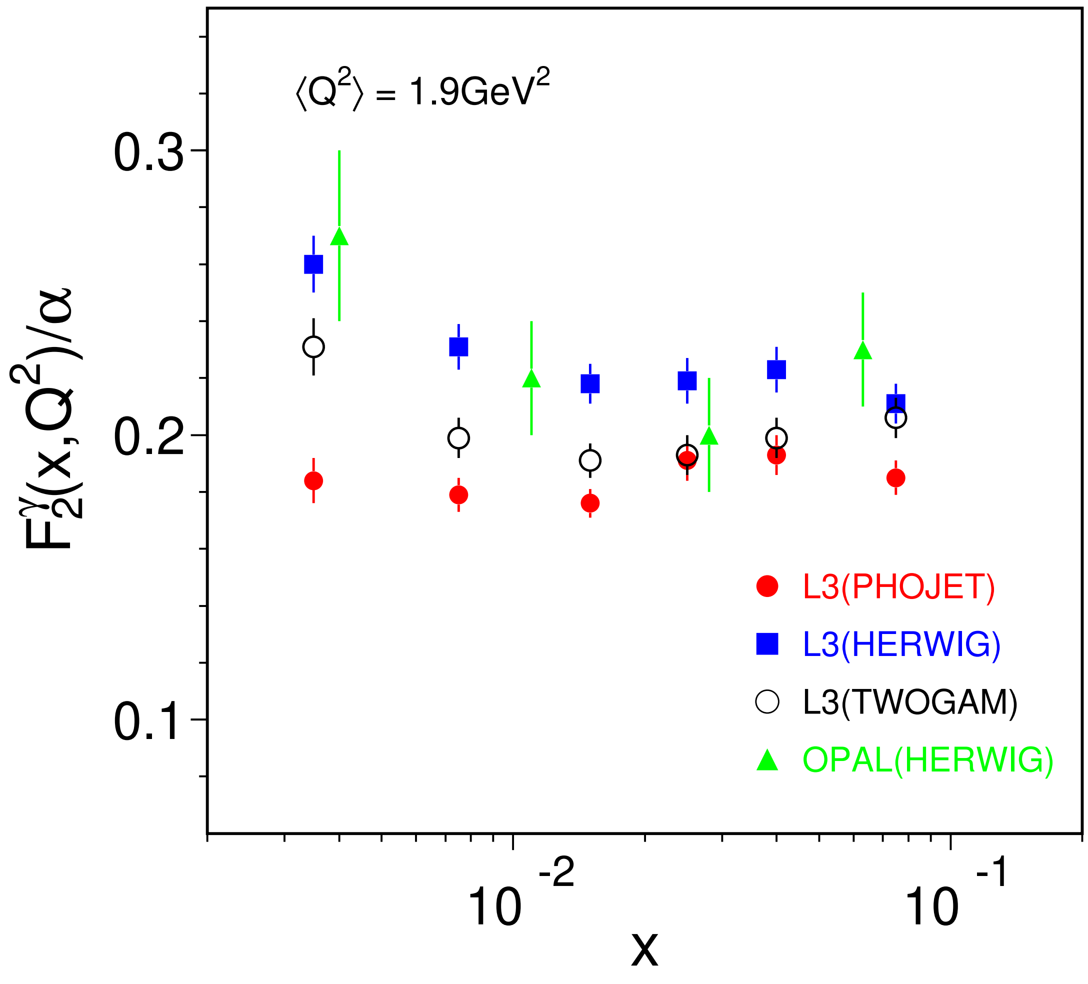
Using x_{vis} and x_{rec} for the unfolding of the L3 data (with the help of PHOJET) at $\sqrt{s}$ = 91 GeV.



The difference between the two distributions is used in evaluating the systematic errors.

Hadronic Structure Functions

Unfolding F_2^γ/α with different Monte Carlo programs ($\sqrt{s}$ = 91 GeV).
L3 data points contain statistical errors only.
The OPAL data have been obtained with the HERWIG program.



OPAL and L3 agree if they use the same M.C. model. But HERWIG (5.9) does not reproduce the experimental distributions.

Hadronic Structure Functions

QCD predictions for comparison with the data:

- **GRV-LO/HO, Glück, Reya and Vogt (1992)**
  evolution starts at a low value of Q_0^2 (= 0.25 GeV^2)

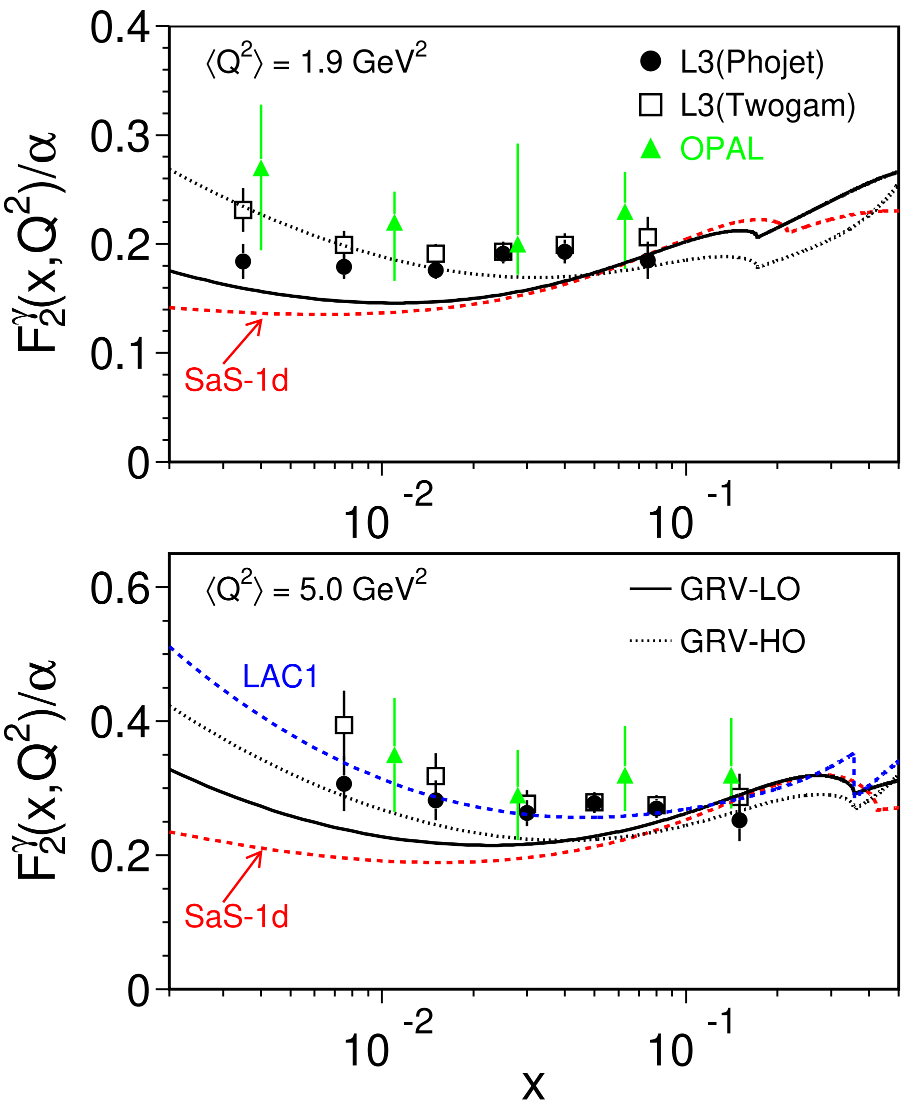
- **SaS-1d, Schuler and Sjöstrand (1995, 1996)**
  evolution starts at a low value of Q_0^2 (= 0.36 GeV^2)

- **LAC, Abramovicz, Charchula and Levy (1991)**
  evolution starts at a high value of Q_0^2 (= 4 GeV^2)

Taking into account the target photon virtuality ($p^2 > 0$) reduces the predictions.

Hadronic Structure Functions

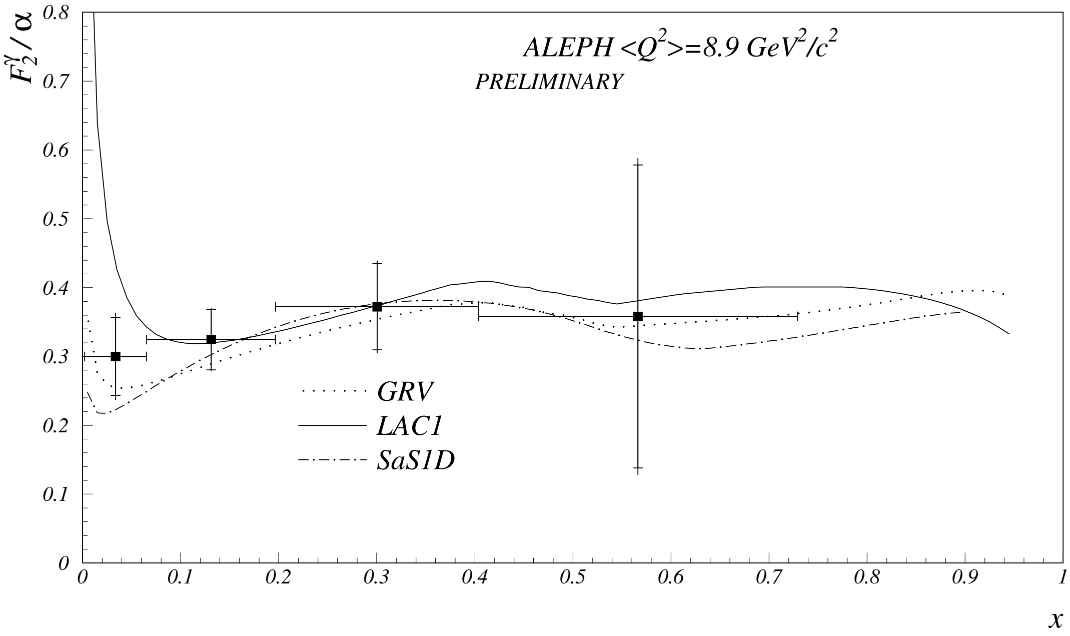
Comparison of the measured F_2^γ/α at $\sqrt{s}$ = 91 GeV from L3 and OPAL at low values of Q^2:

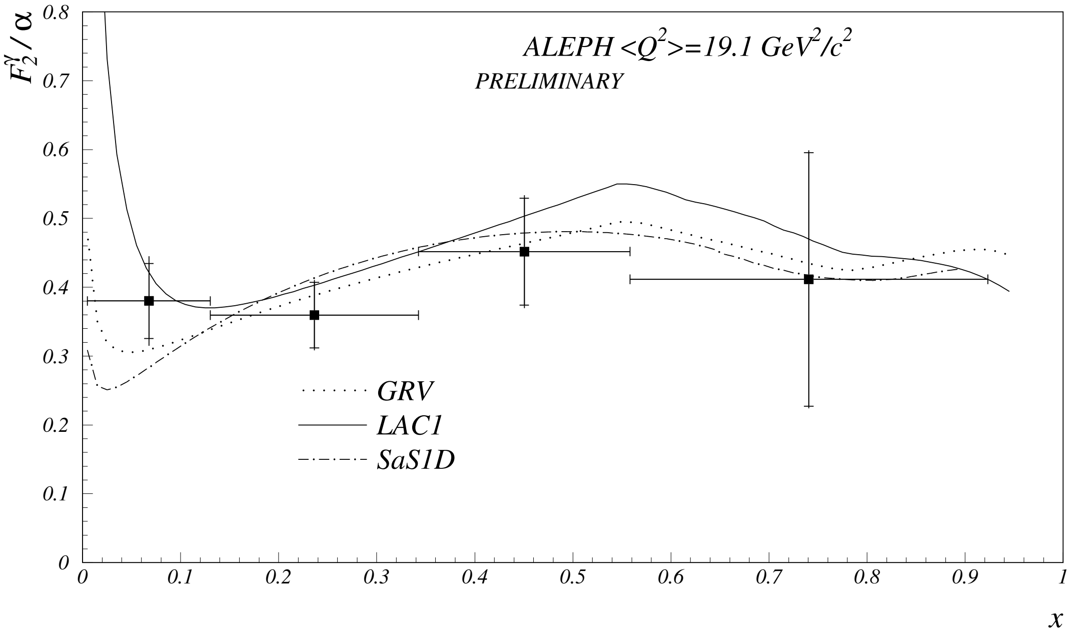


F_2^γ/α starts rising at low values of x. There, GRV-HO fits the experimental data both from OPAL and L3 better than GRV-LO.

Hadronic Structure Functions

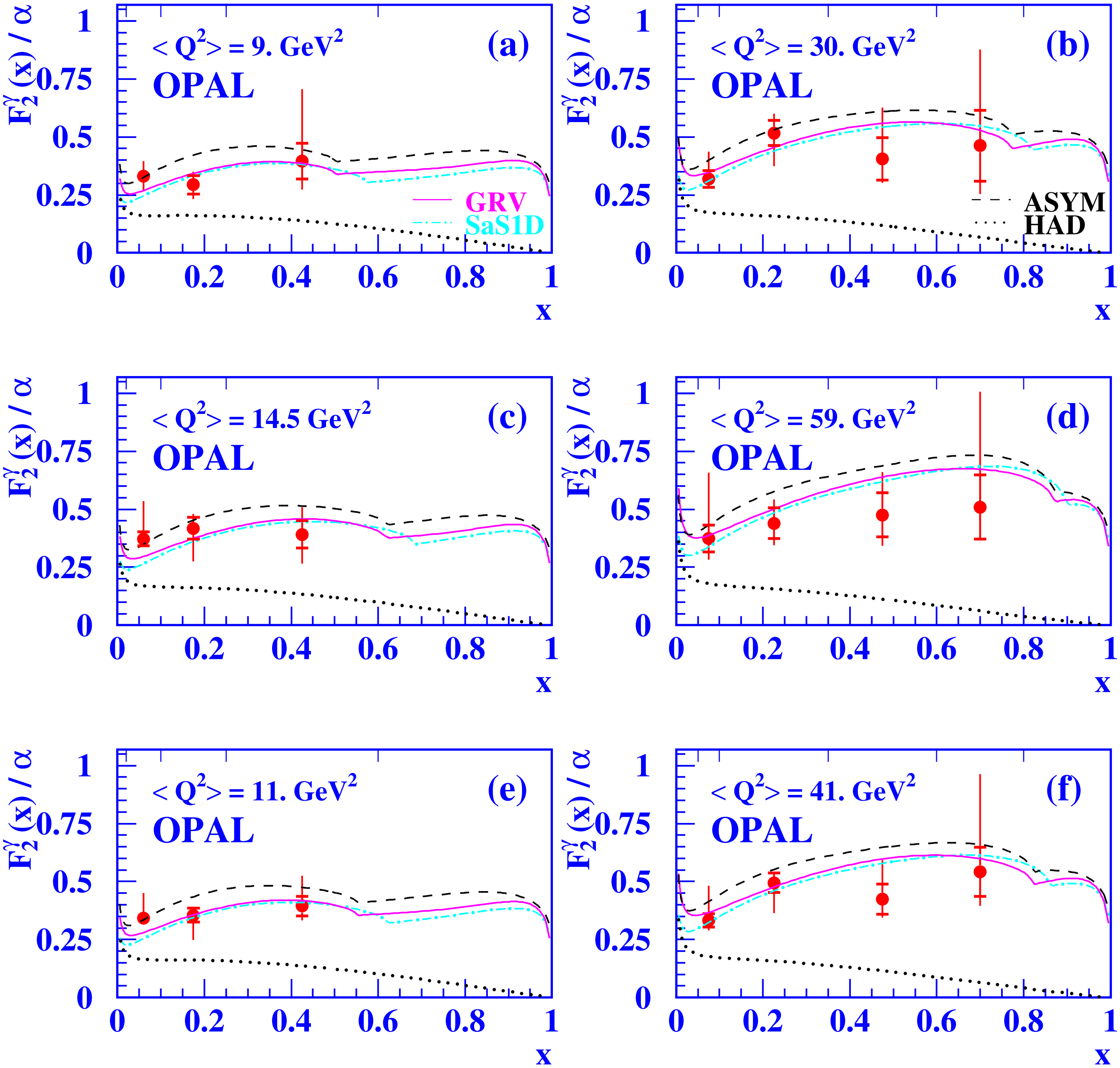
F_2^γ/α measured by ALEPH at $\sqrt{s}$ = 91 GeV at low values of Q^2:





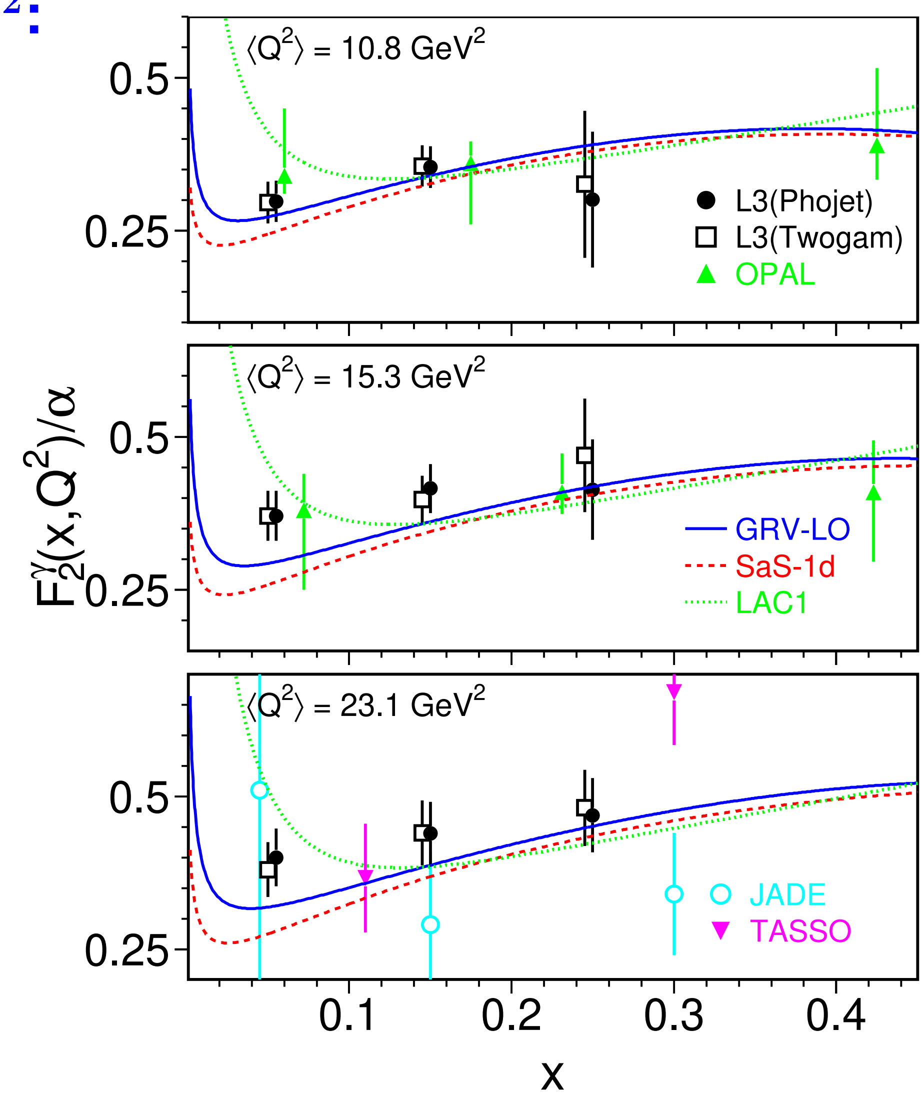
Hadronic Structure Functions

F_2^γ/α from OPAL at LEP2 energies:



Hadronic Structure Functions

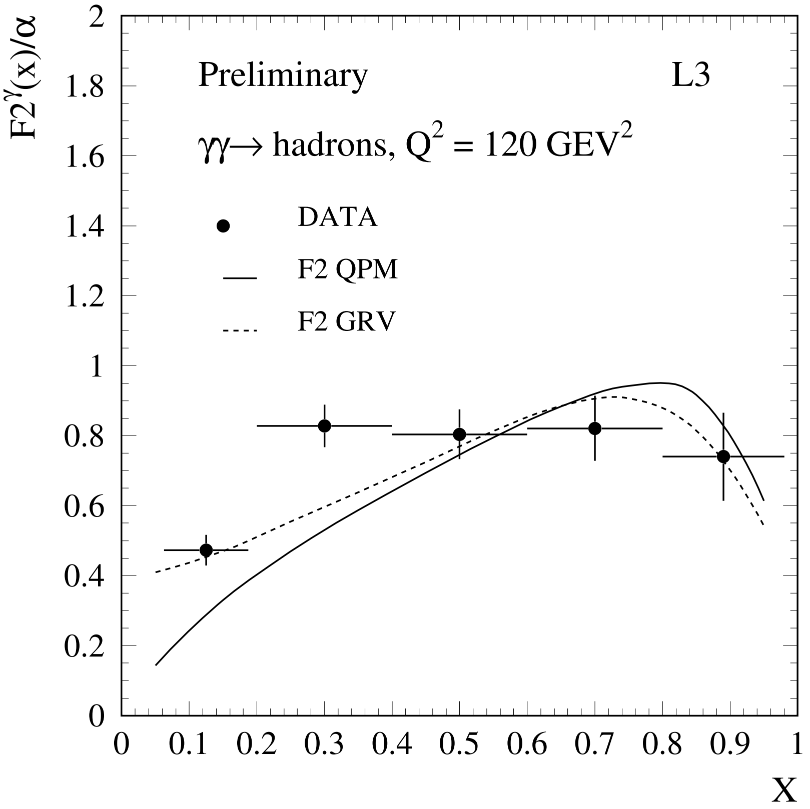
Comparison of the measured F_2^γ/α at LEP2 energies from L3 , OPAL, JADE and TASSO at medium values of Q^2:



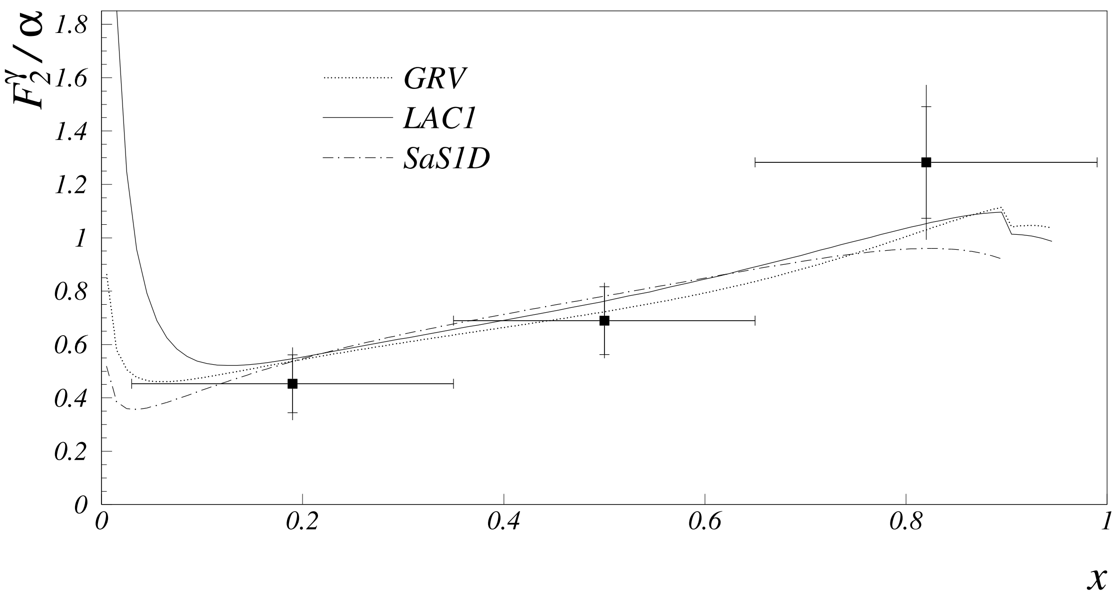
LEP data improve F_2^γ/α with respect to PETRA.

Hadronic Structure Functions

F_2^γ/α from L3 at $< Q^2 >$ = 120 GeV^2 ($\sqrt{s}$ = 91 GeV).

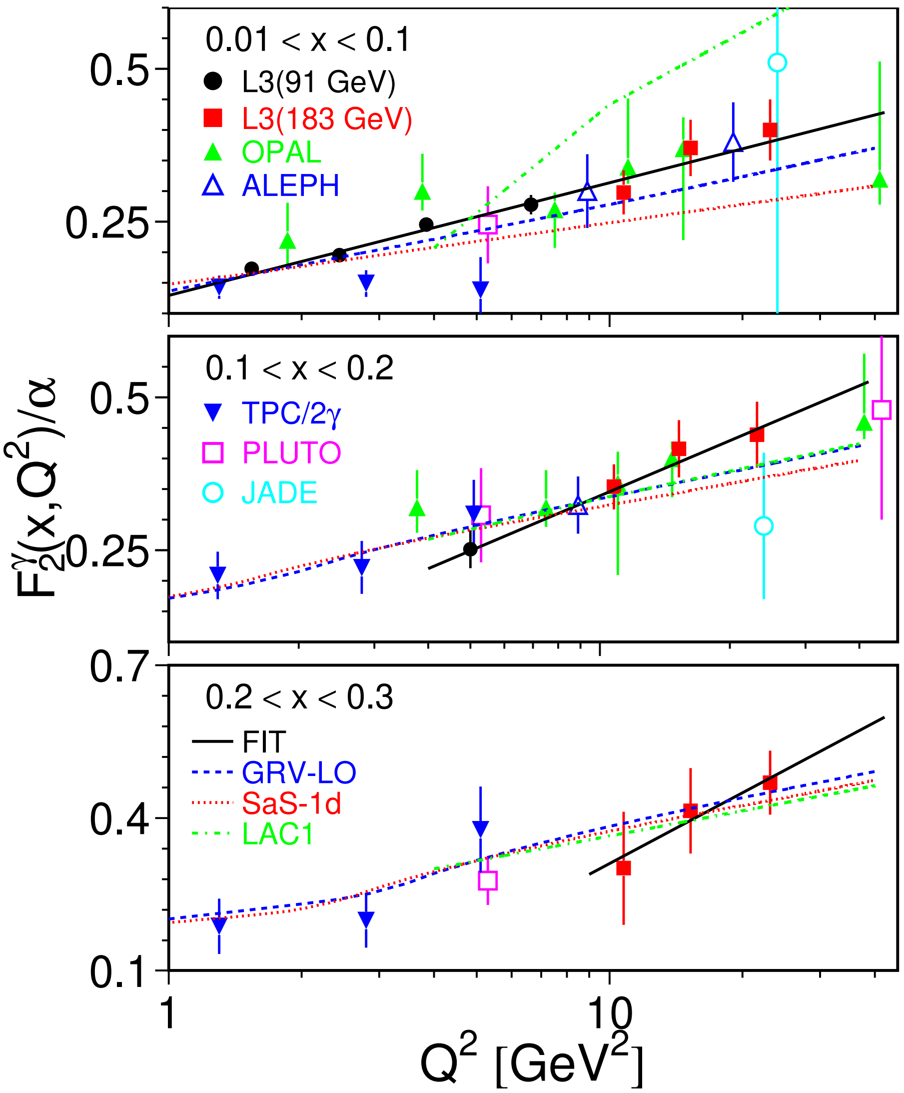


F_2^γ/α from ALEPH at $< Q^2 >$ = 279 GeV^2 ($\sqrt{s}$ = 91 GeV).



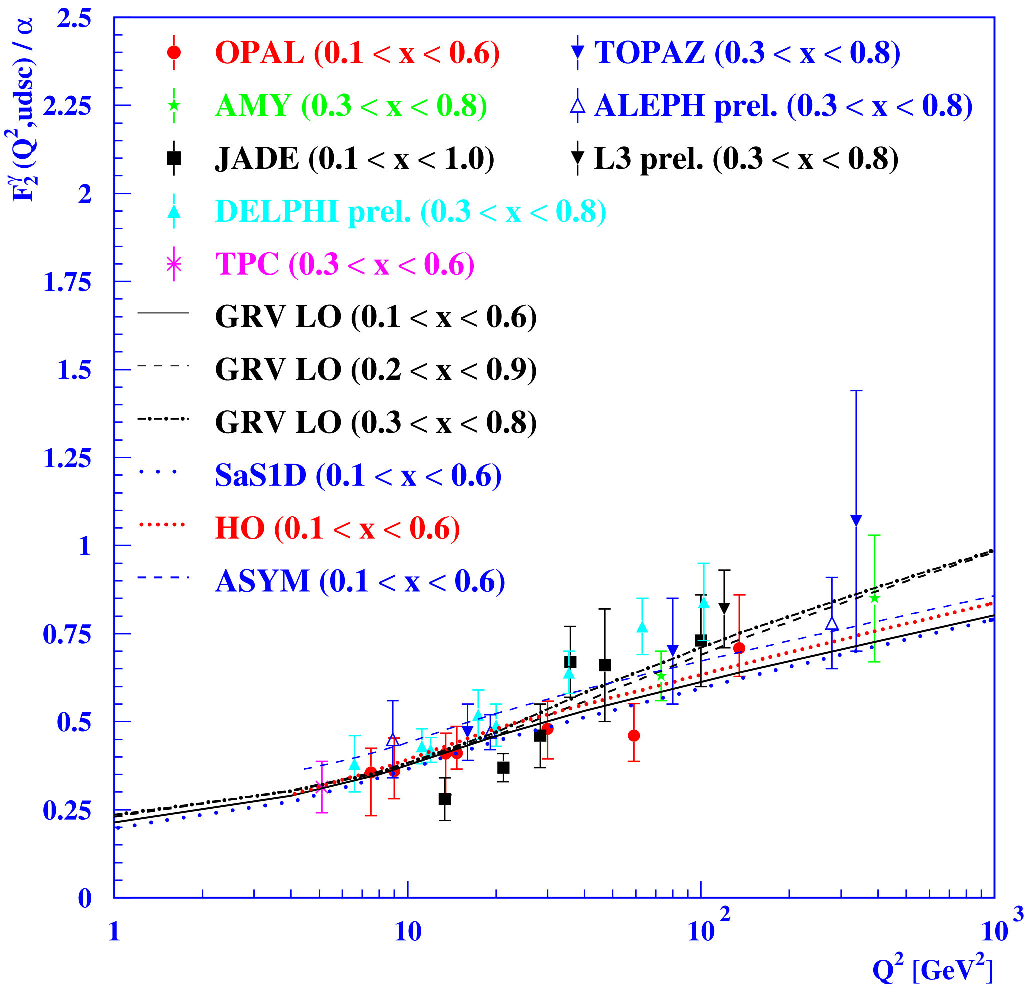
Hadronic Structure Functions

The measured F_2^γ/α from L3 at 91 GeV, at 183 GeV, OPAL, ALEPH, TPC/2γ, PLUTO and JADE versus Q^2:



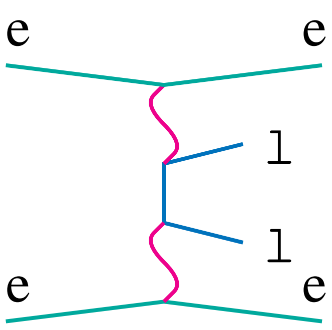
LAC1 disagrees with the data in the low x bin.
The Q^2-dependence is compatible with QCD.

The measured F_2^γ/α from ALEPH, AMY, DELPHI, JADE, L3, OPAL, TOPAZ and TPC versus Q^2:

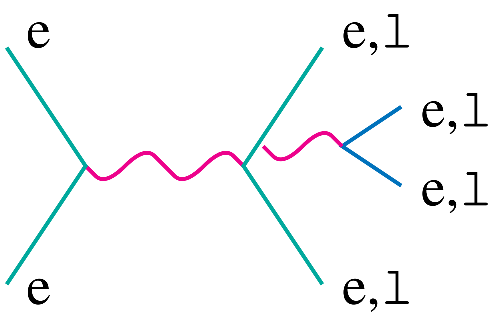


Leptonic Structure Functions

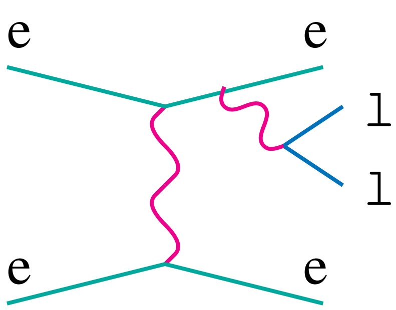
The reaction $e^+e^- \to e^+e^-l^+l^-$, where l can be any lepton, arises from $O(\alpha^4)$ QED processes:



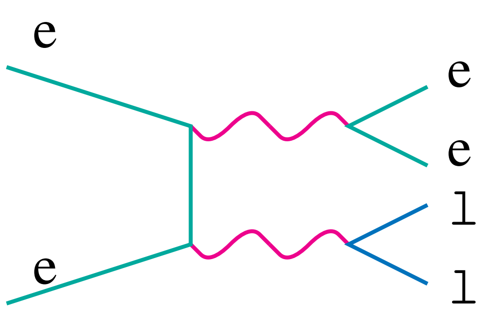
Multiperipheral



Annihilation



Bremsstrahlung



Conversion

The multiperipheral diagram is dominant

Leptonic Structure Functions

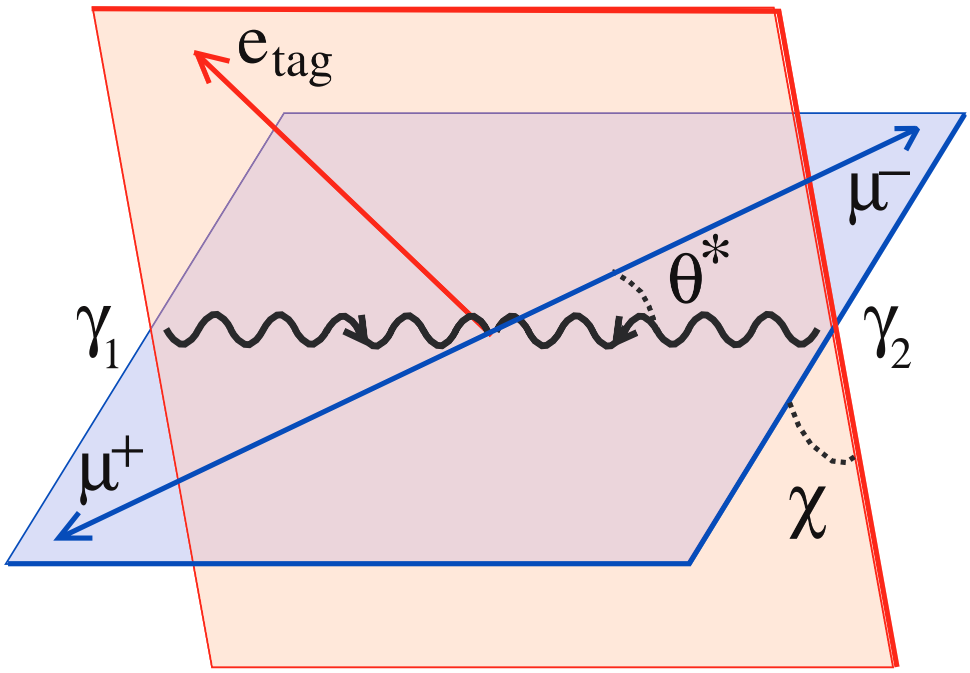
Since $F_L^\gamma(x,Q^2)$ is multiplied by the small factor y^2, $\Longrightarrow$ very difficult to obtain it from a cross-section measurement.

The azimuthal correlations of leptons in the $\gamma\gamma$ c.m. system are sensitive to the photon helicity amplitudes and thus to $F_L^\gamma(x,Q^2)$

For this purpose, L3 and OPAL studied the single tag process in:

$$e^+e^- \rightarrow e^+e^- \mu^+\mu^-$$

Definition of polar and azimuthal angles of the μ^- in the $\gamma\gamma$ c.m. system.



Leptonic Structure Functions

In the single-tag configuration, neglecting the longitudinal component of the target photon, the cross section contains three terms:

$$\frac{d^4\sigma}{dx\,dy\,dz\,d\chi} = \frac{2\pi\alpha^2}{Q^2}\frac{1+(1-y)^2}{xy}\left[A_1(x,z)+A_2(x,z)\cdot\cos\chi+A_3(x)\cdot\cos 2\chi\right]$$

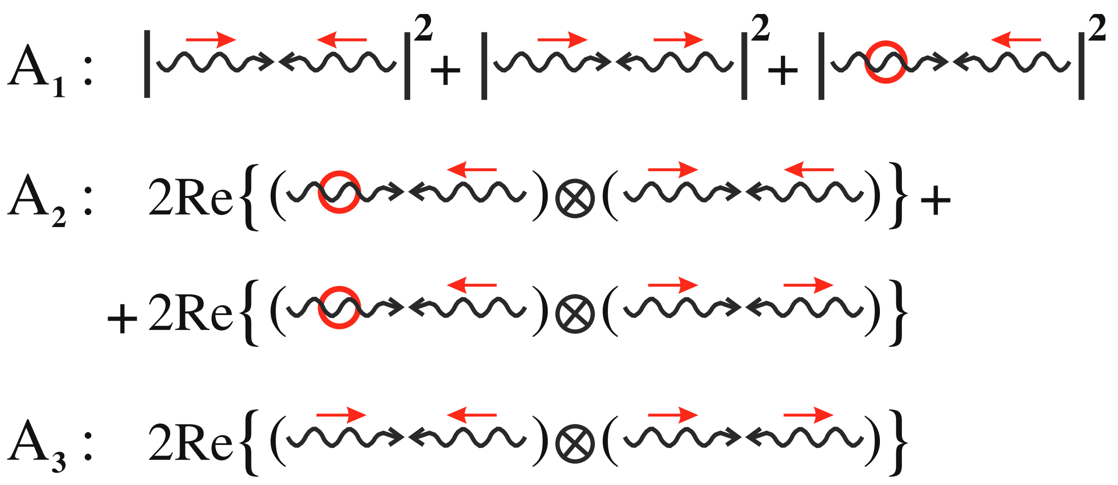
A_1, A_2 and A_3 are related to three differential structure functions $\tilde{F}^{\gamma}_{T,L,A,B}$:

$$A_1 \;=\; \widetilde{F}^{\gamma}_2(x,z) = 2x\widetilde{F}^{\gamma}_T(x,z) + \widetilde{F}^{\gamma}_L(x)$$

$A_2 \;=\; -\widetilde{F}^{\gamma}_A(x,z)$ (int. term is $\propto \sqrt{F^{\gamma}_L(x,Q^2)}$)

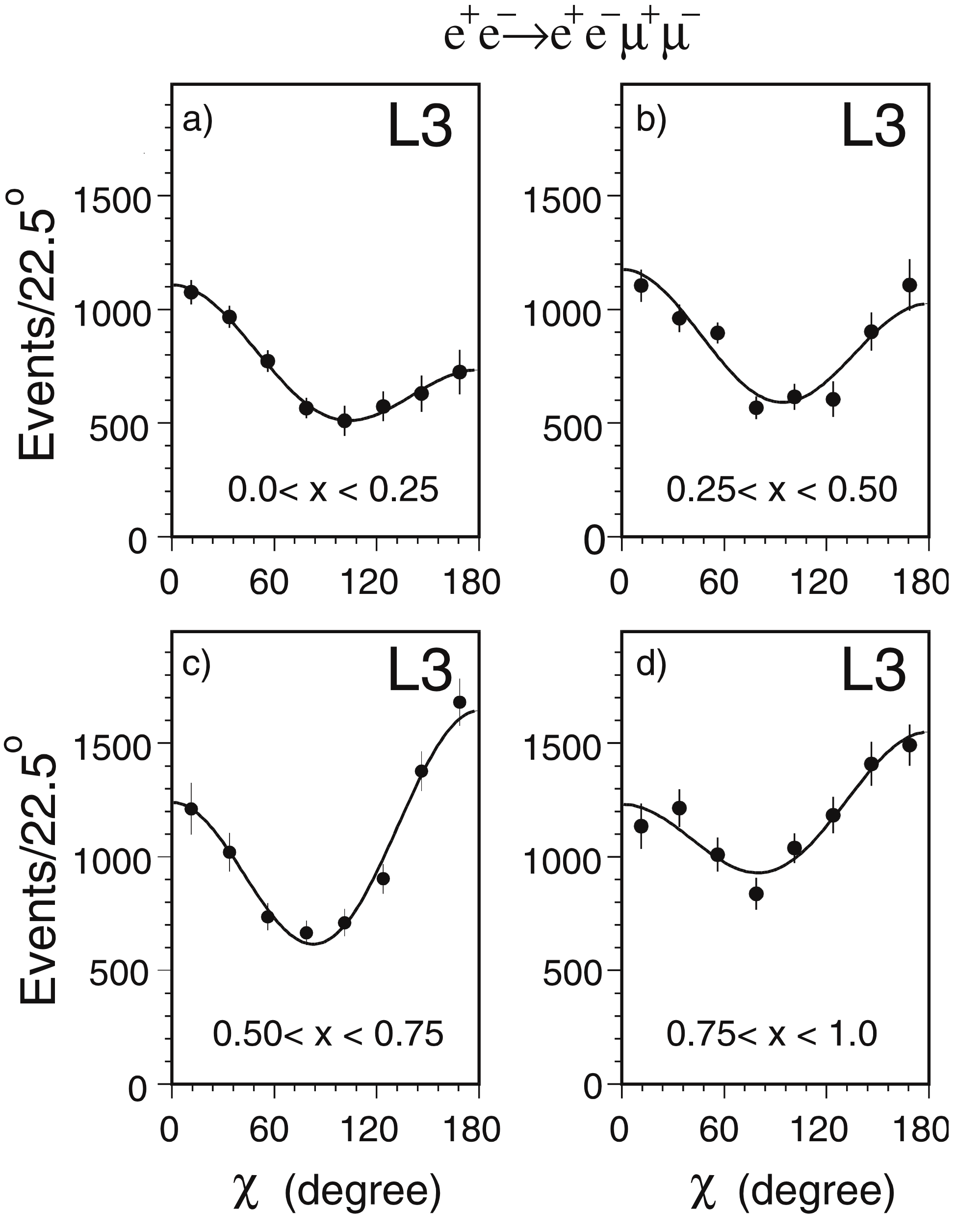
$A_3 \;=\; \frac{1}{2}\widetilde{F}^{\gamma}_B(x)$ (interference term)

with $F^{\gamma}_{T,L,A,B} = \int_{-1}^{1}\int_{0}^{2\pi}\frac{d\chi\,d\eta}{2\pi}\tilde{F}^{\gamma}_{T,L,A,B}$ and $z = cos\Theta^*$

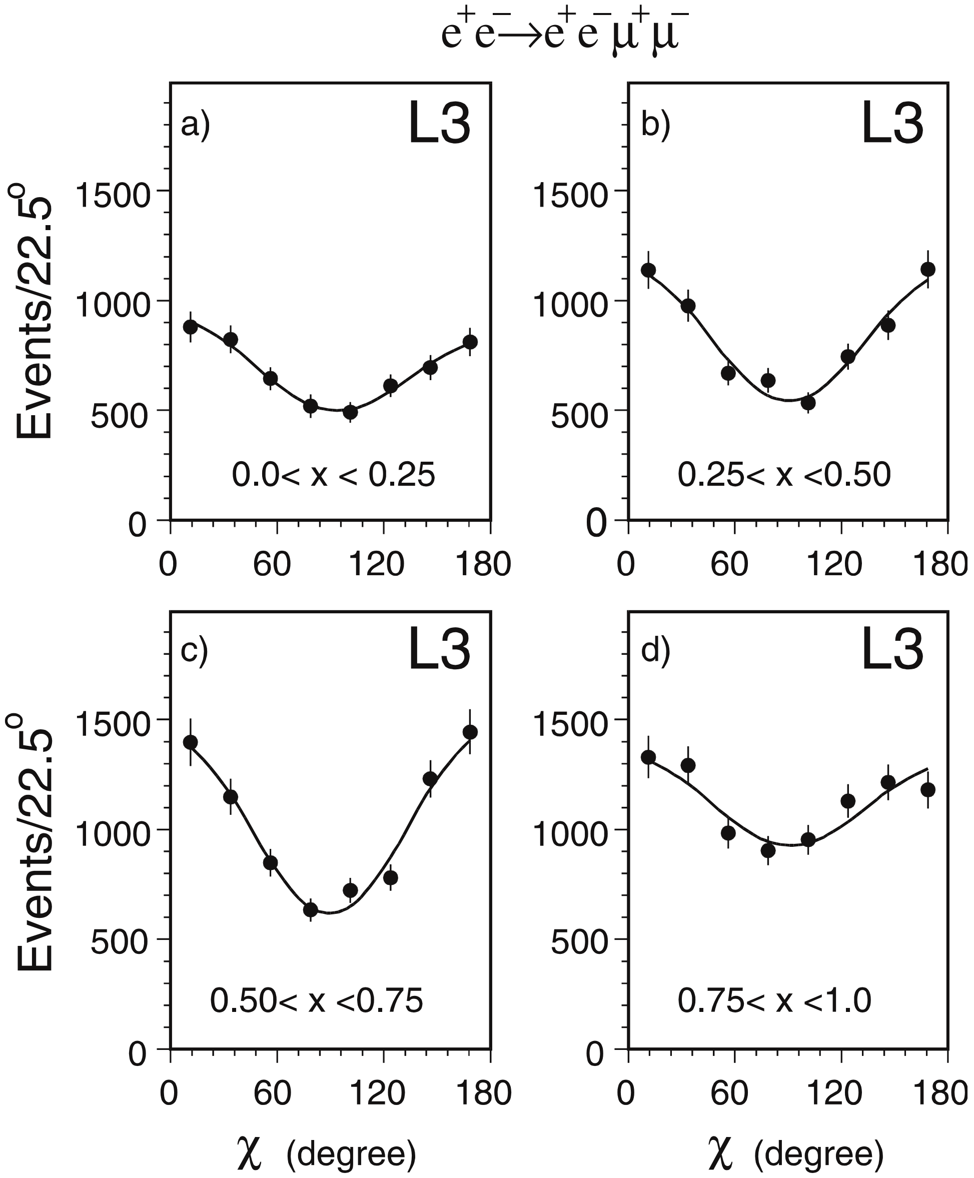


probe photon $\rightarrow\leftarrow$ target photon

Leptonic Structure Functions

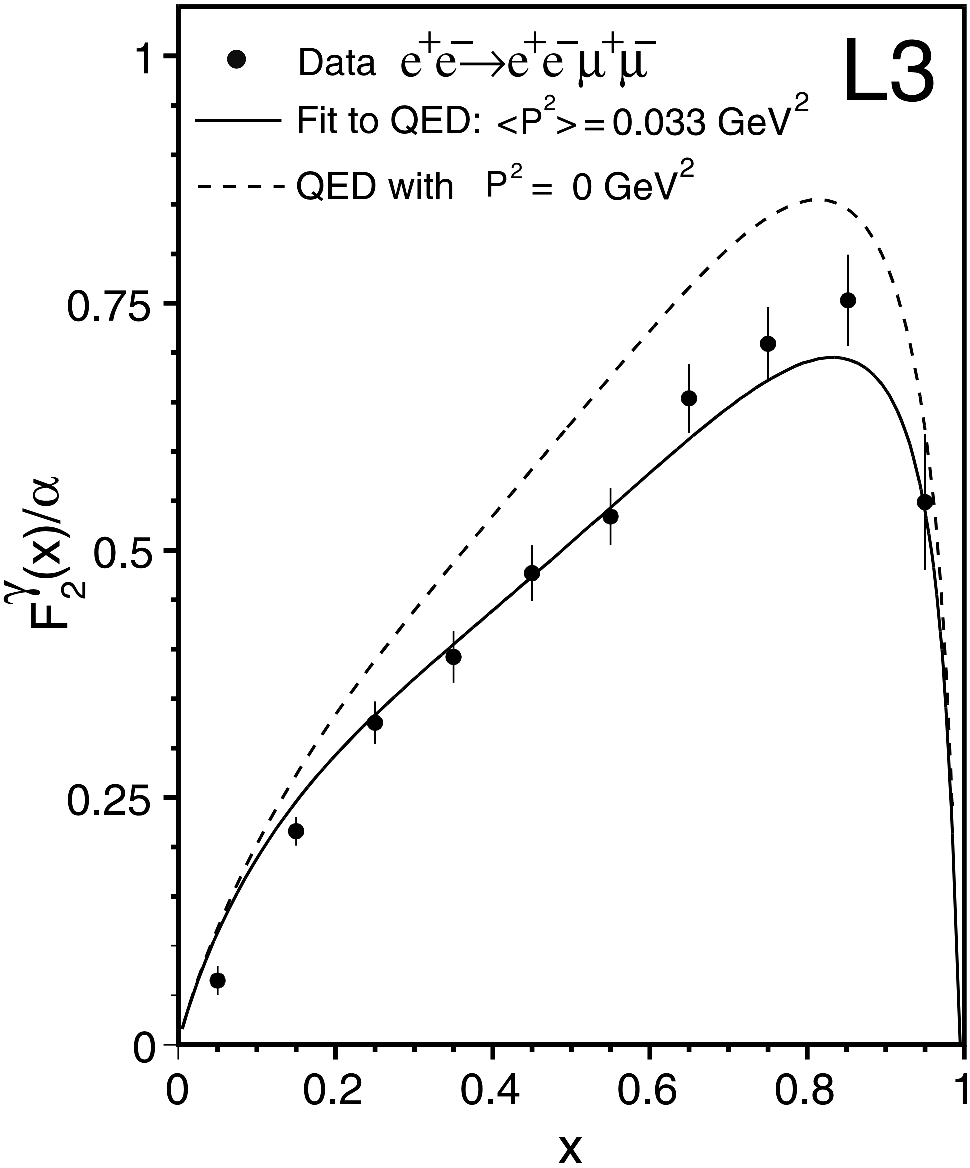


Leptonic Structure Functions



Leptonic Structure Functions

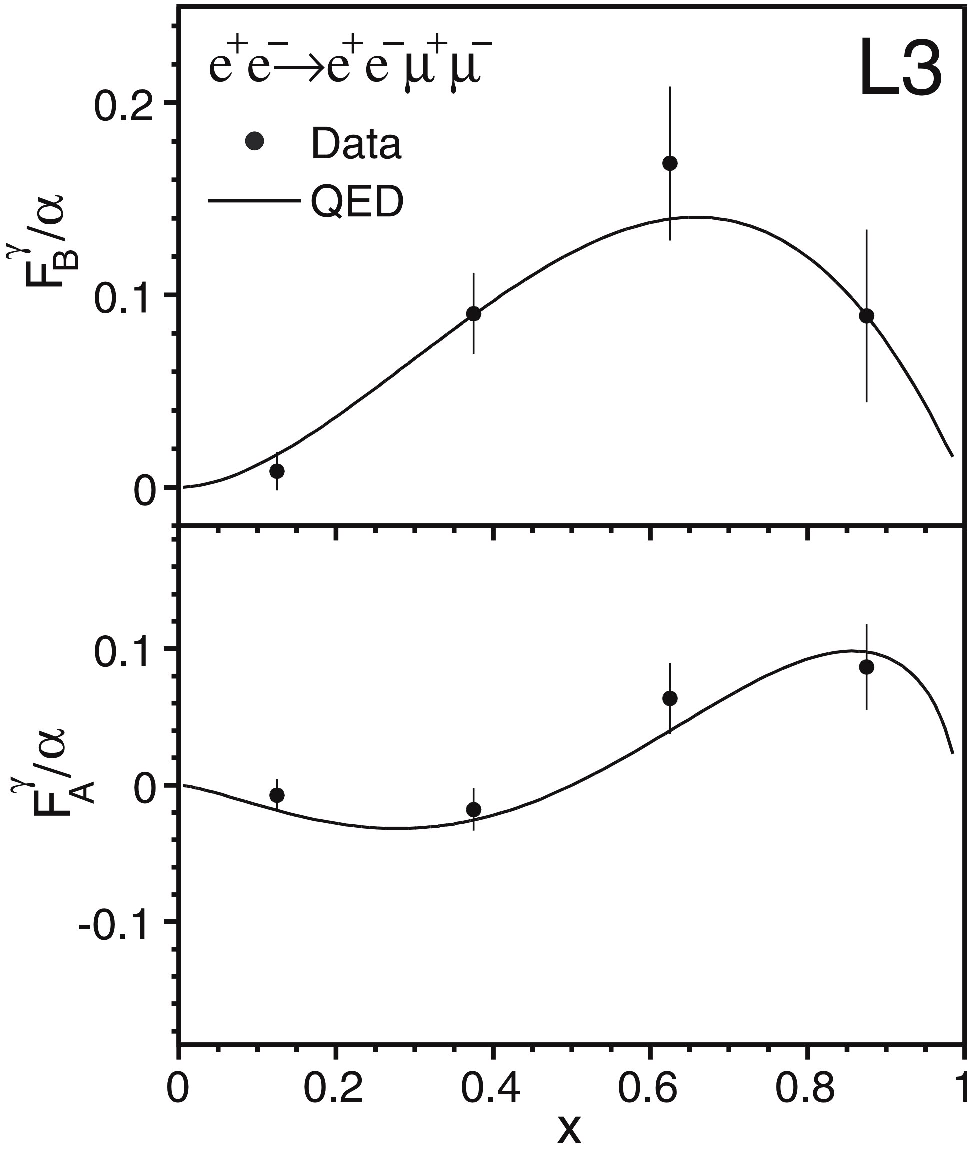
Determination of the leptonic structure function F_2^γ in the range 1.4 GeV$^2 \leq Q^2 \leq 7.6$ GeV^2 (at $\sqrt{s}$ = 91 GeV). Only statistical errors are given.



The so called virtuality ($P^2 = -p^2$) is found to be non-zero and agrees with the QED prediction. Without radiative corrections $< P^2 >$ is found to be about 2 st. dev. lower.

Leptonic Structure Functions

Measurement of the leptonic structure functions F_B^γ and F_A^γ in the Q^2 range 1.4 GeV$^2 < Q^2 < 7.6$ GeV^2 (at $\sqrt{s}$ = 91 GeV).

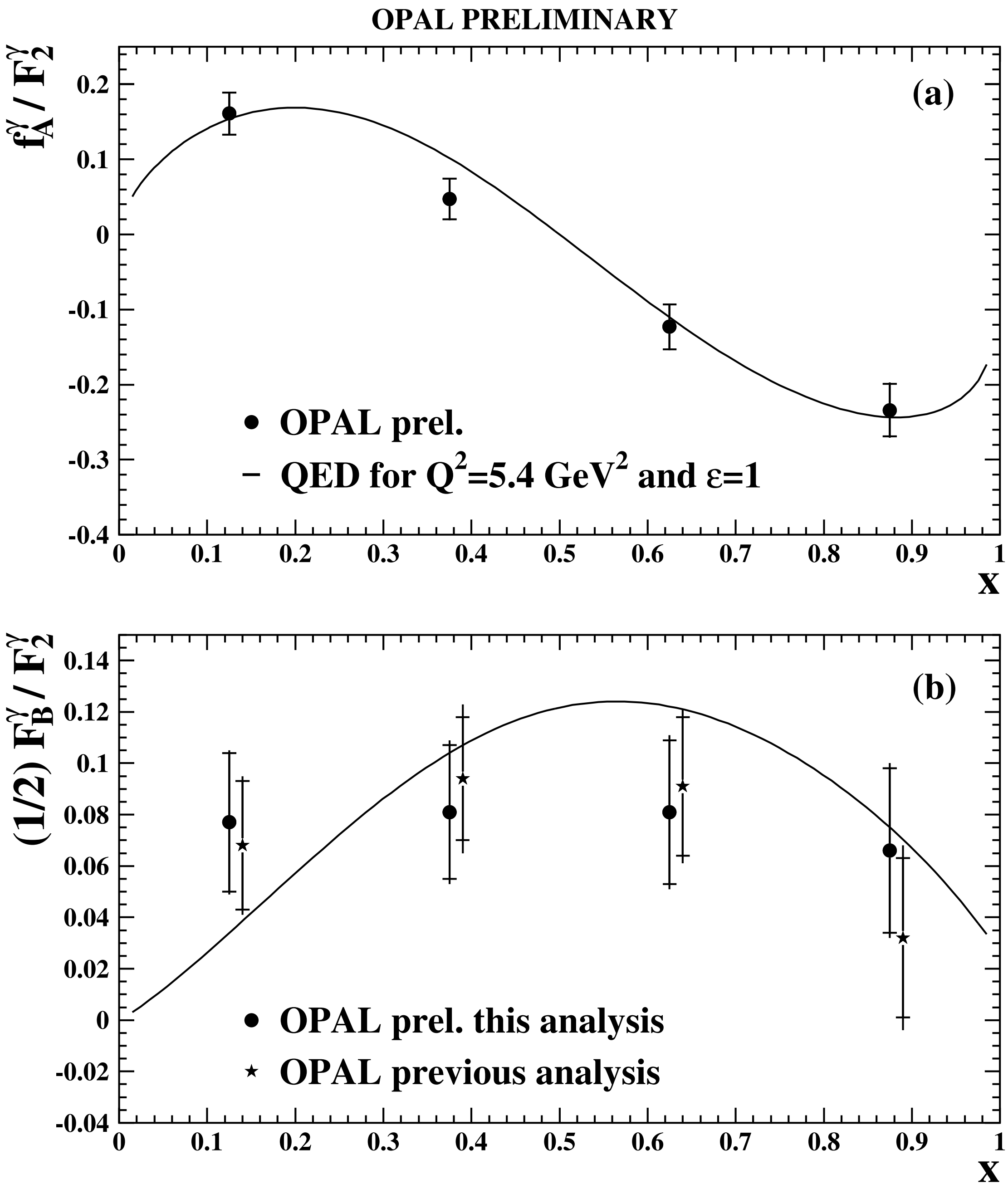


Both F_B^γ and F_A^γ are not zero.

Good agreement with QED

Leptonic Structure Functions

The leptonic structure functions F_A^γ and F_B^γ from OPAL:



Good agreement with QED as well

Conclusions

Conclusions on the leptonic structure functions:

- The data reproduce the QED predictions well:
  1. Virtuality of the target photon is important.
  2. Initial radiation effects are needed.
  3. The existence of $F_L^\gamma(x, Q^2)$ established via the interference term in azimuthal angular distributions.

Conclusions on the hadronic structure functions:

- The higher order GRV parametrization is preferred for $x < 0.05$.
- The observed Q^2-dependence is compatible with QCD. The LAC1 parametrization is ruled out at small x.
- An improvement of the M. C. generators is desirable.

LEP has improved the measurement of the photon structure functions significantly and will do so even more in the future.