QCD Photon Structure Functions at LEP

K. Freudenreich, ETH Zürich

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A. Finch (ALEPH),
the L3 two-photon group
and R. Nisius (OPAL)

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Outline

- Introduction
- Monte Carlo Deconvolution
- Fitting high Q^2 events to reduce the difference between $x_{generated}$ and $x_{reconstructed}$.
- Hadronic Structure Functions from single-tag events

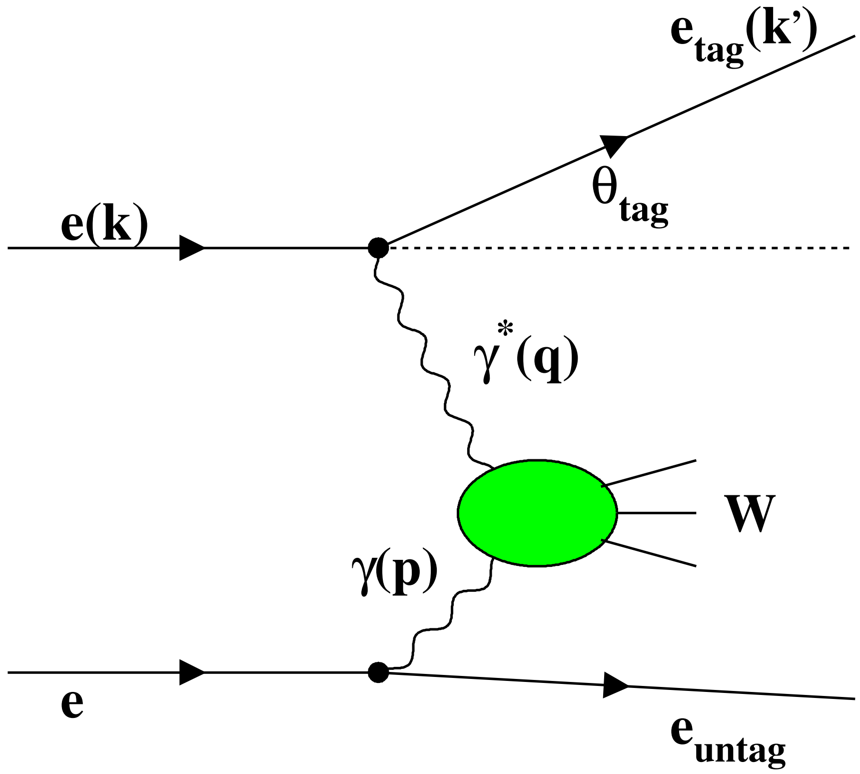
  New contributions from ALEPH, L3 and OPAL.

  DELPHI data unchanged since the 98 Lund meeting.

  – F_2^γ/α as a function of x
  – F_2^γ/α as a function of Q^2
- Conclusions

Introduction

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



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

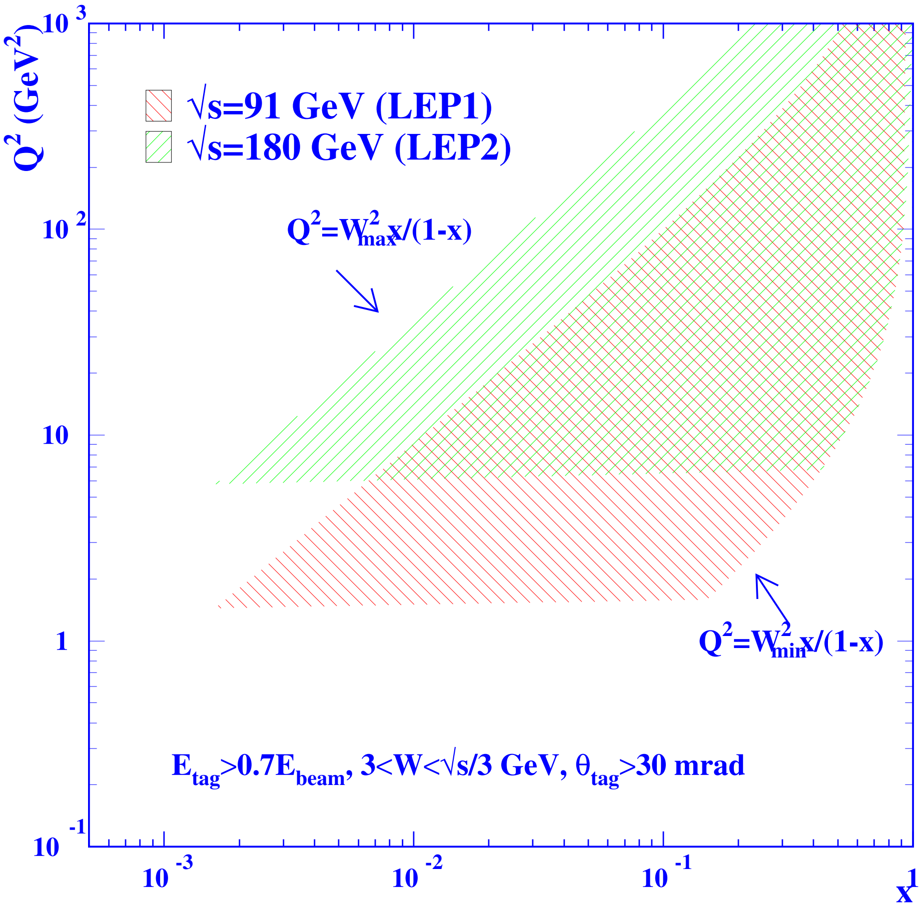
$W^2 = (q+p)^2 = (\Sigma_h\ E_h)^2 - (\Sigma_h\ \overrightarrow{p_h})^2$

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

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

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

Introduction



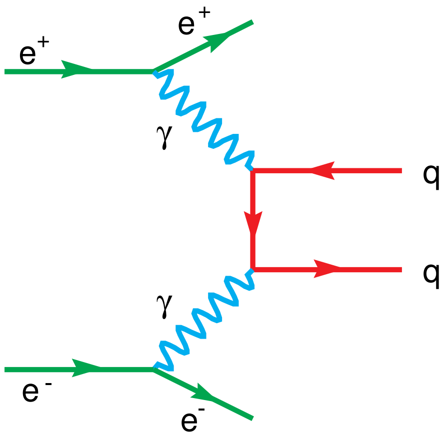
Kinematic range of published LEP data: */* new since ICHEP 98

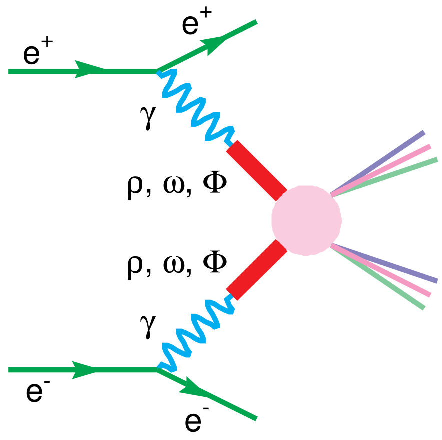
Expt.	$\sqrt{s}$	Θ_{tag}	Q^2 range	x
	[GeV]	[mrad]	[GeV^2]	
ALEPH *	91	65 - 150	6 - 3000	0.005 - 0.970
DELPHI	91	43 - 135	40 - 30	0.005 - 0.977
DELPHI	161,172,183,189	42 - 610	10 - 1000	0.01 - 0.8
L3	91	26 - 66	1.2 - 9	0.002 - 0.200
L3 *	91	200 - 600	40 - 500	0.05 - 0.98
L3 *	183	30 - 66	9 - 30	0.01 - 0.3
OPAL	91	27 - 55	1.1 - 6.6	0.0025 - 0.2
OPAL	161	33 - 55	11 - 41	0.02 - 0.6
OPAL	172	60 - 120	11 - 41	0.02 - 0.6

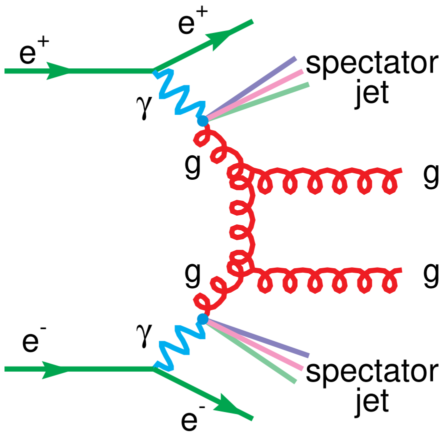
Introduction

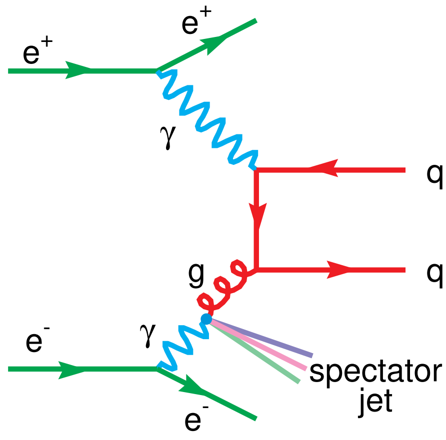
Graphs for the production of hadrons via the two-photon exchange:

QPM, direct **VDM**





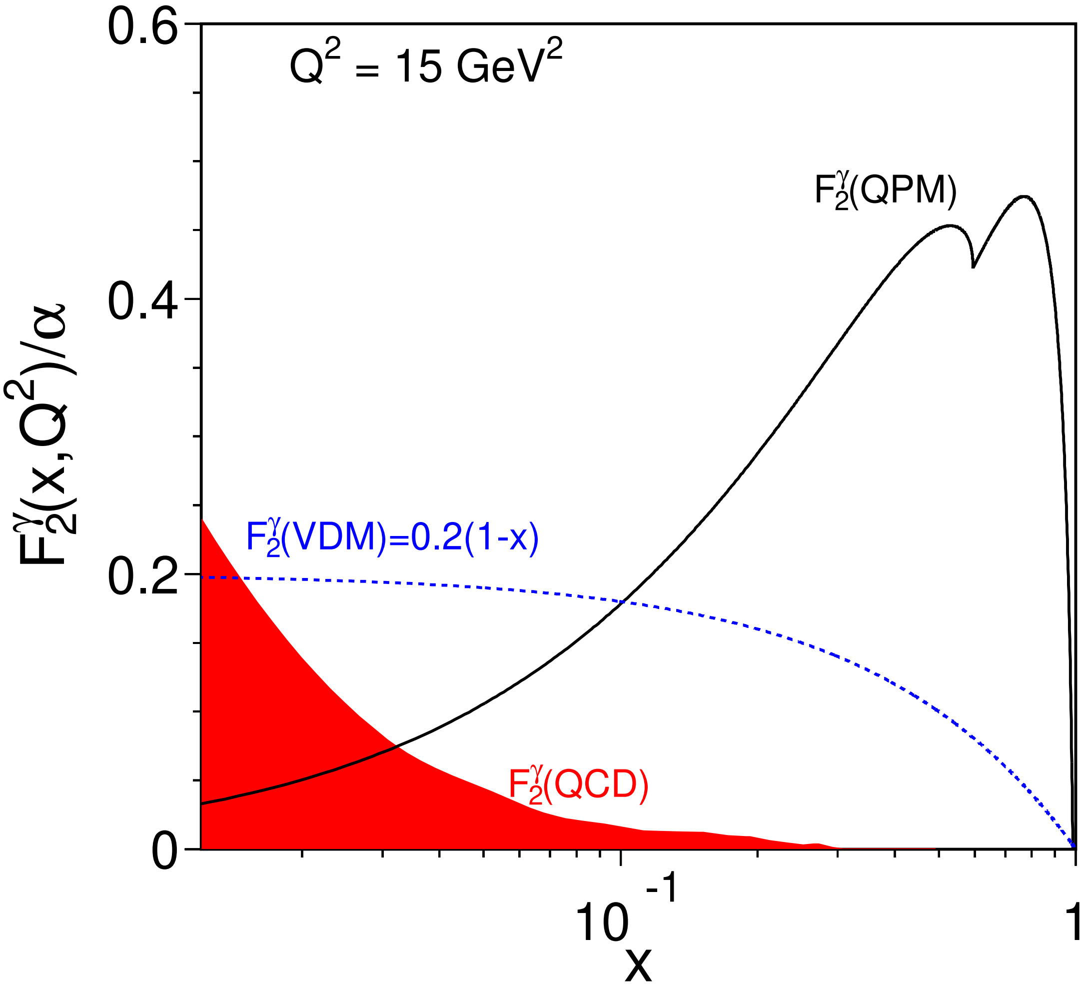




"double resolved" **"single resolved"**

Introduction

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



F_2^γ(QPM) dominates at large x (dip at $c\bar{c}$-threshold),
F_2^γ(VDM) is rather constant over the whole x-range,
F_2^γ(QCD) dominates at small x.

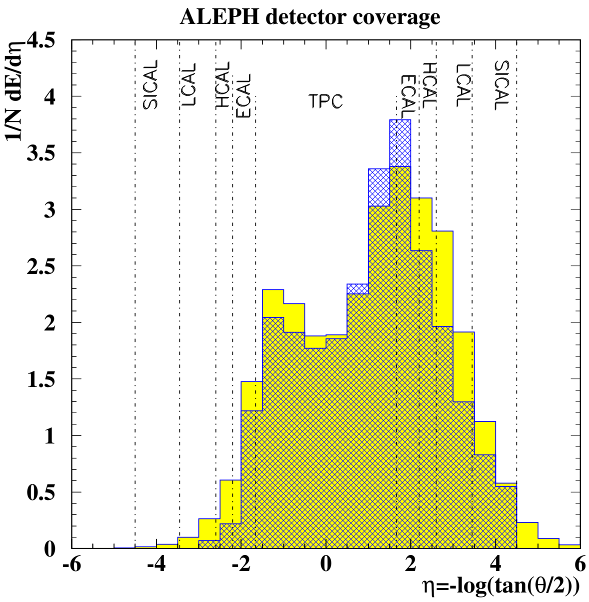
Monte Carlo Programs

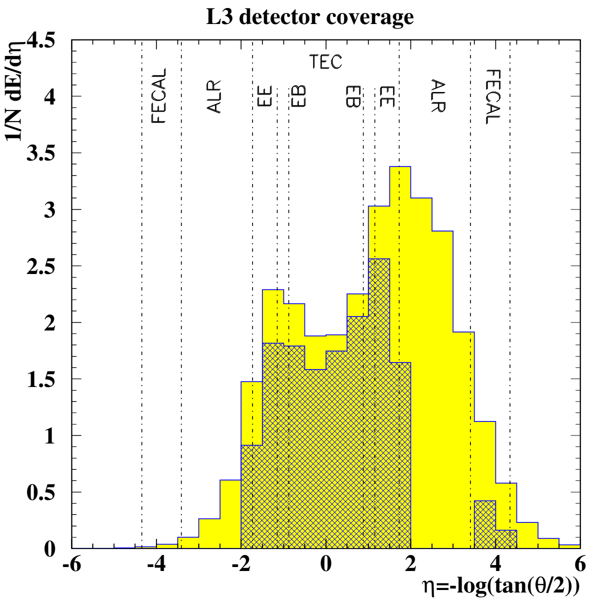
- $e^+e^- \longrightarrow e^+e^-$ **+ hadrons:**
  1. **TWOGAM, Nova, Olshevski and Todorov (1990)**
  2. **PHOJET, Engel and Ranft (1995, 1996)**
  3. **HERWIG, Marchesini et al. (1992)**
  4. **PYTHIA, Sjöstrand and Schuler (1994)**
  5. **JAMVG, Vermaseren et al. (1983)**
- $e^+e^- \longrightarrow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

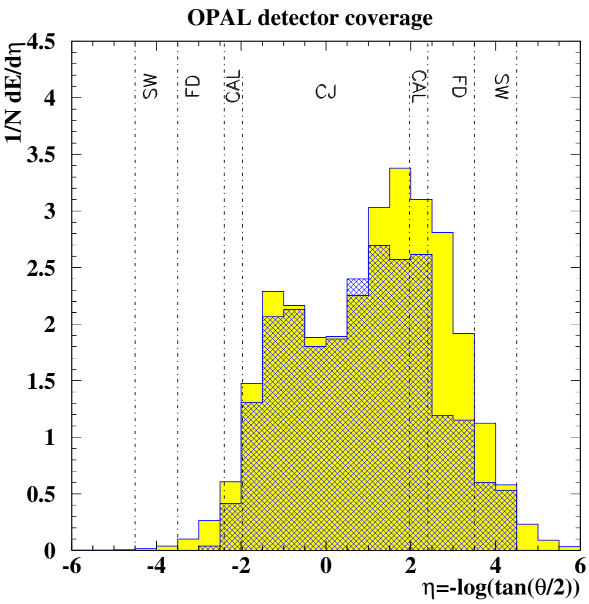
Programs 2,3 and 4 use inputs from γp and pp to evaluate the relative contributions of the diagrams.

Monte Carlo Acceptance

Hadronic energy flow in ALEPH, L3 and OPAL simulated with the HERWIG M.C. program







ALEPH	TPC	time projection chamber
	ECAL	el.mag. calorimeter
	HCAL	hadronic calorimeter
	LCAL	luminosity calorimeter
	SICAL	silicon tungsten calorimeter
L3	TEC	time extention chamber
	EE	endcap el.mag. calorimeter
	EB	barrel el.mag. calorimeter
	ALR	not used in this analysis
	FECAL	forward el.mag. calorimeter
OPAL	CJ	central jet chamber
	CAL	el.mag. / hadronic calorimeter
	FD	forward lead scintillator det.
	SW	silicon tungsten calorimeter

The detectors do not see the full energy flow, in particular in the forward region where the detector efficiency may not be perfect.

Unfolding Procedure

Because of detector effects:

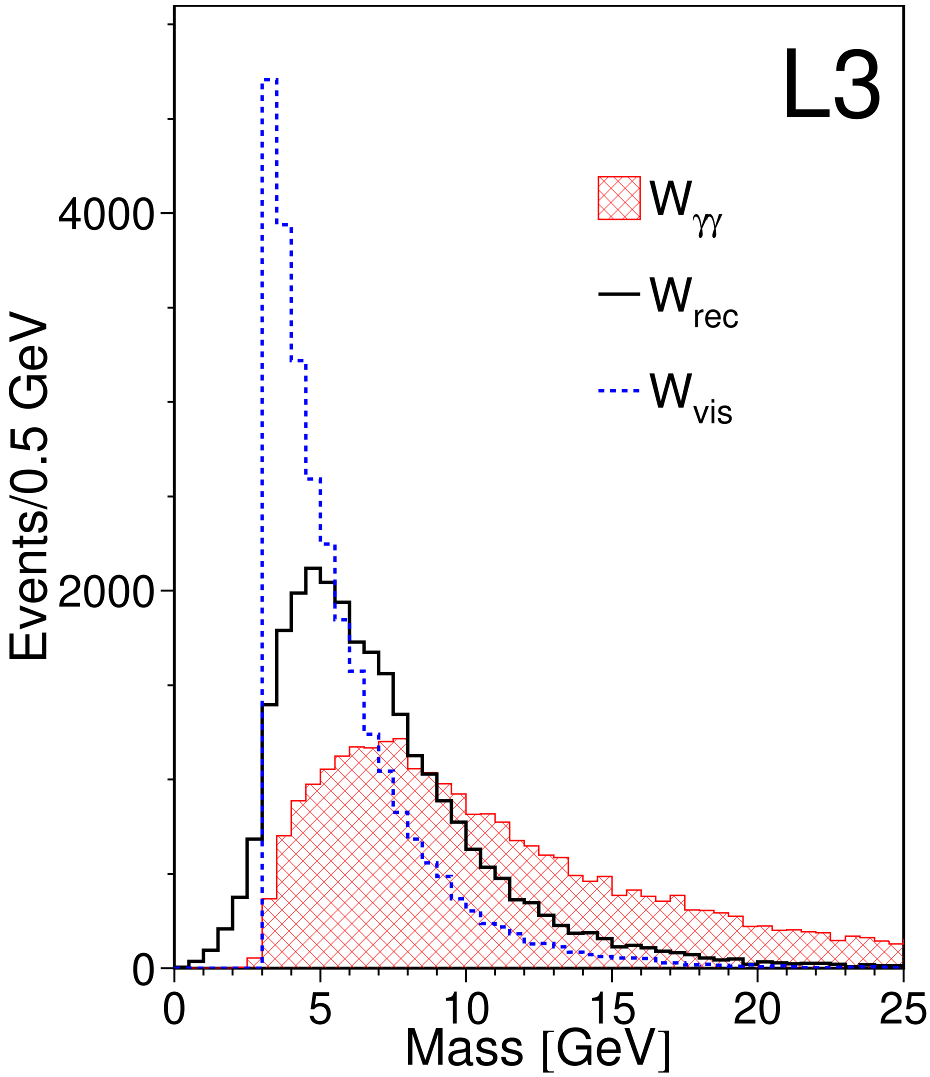
$W_{vis} < W_{\gamma\gamma}$ **and** $x_{vis} > x$.

Improve W_{vis}

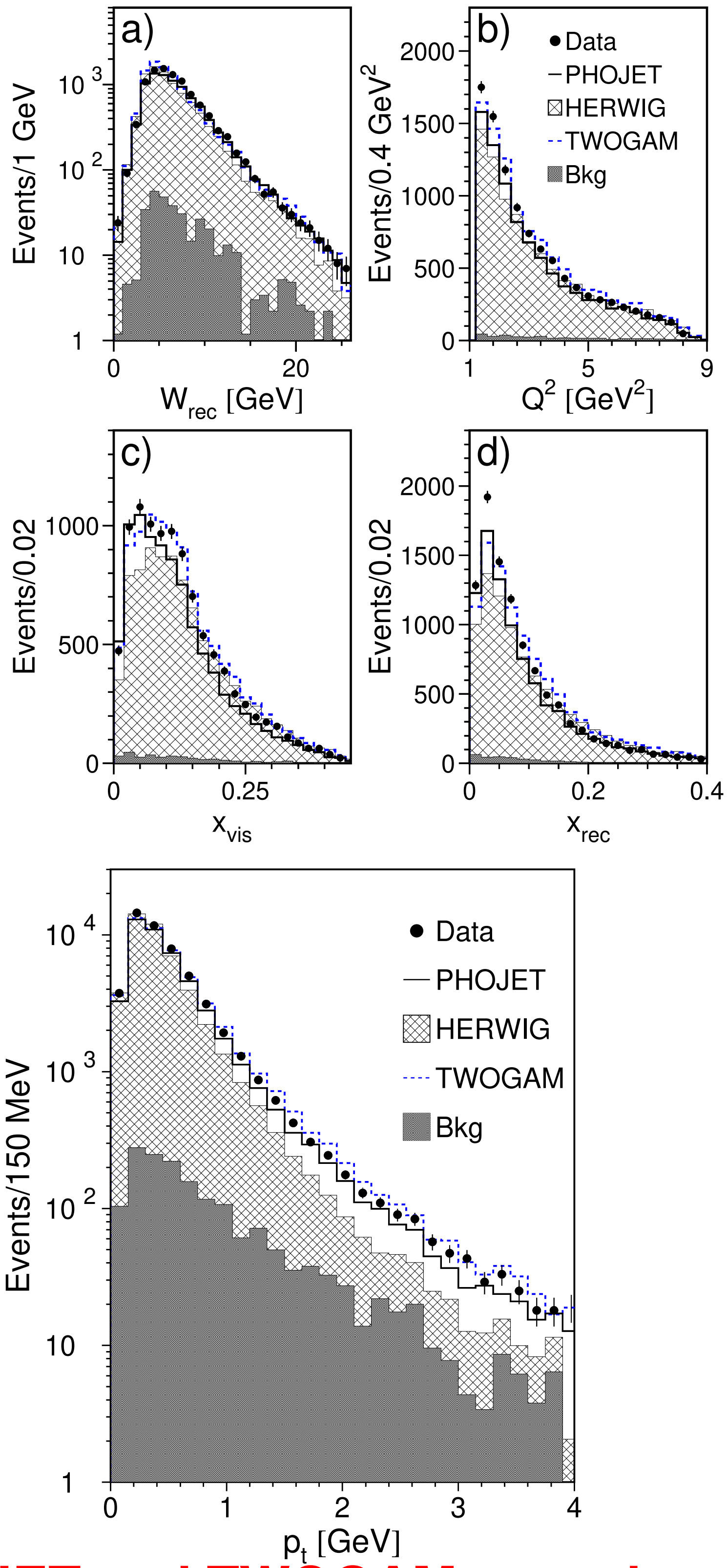
by using transverse momentum conservation:

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

with $p_\pm = E \pm p_z$



Comparison Monte Carlo $\Longleftrightarrow$ Data L3



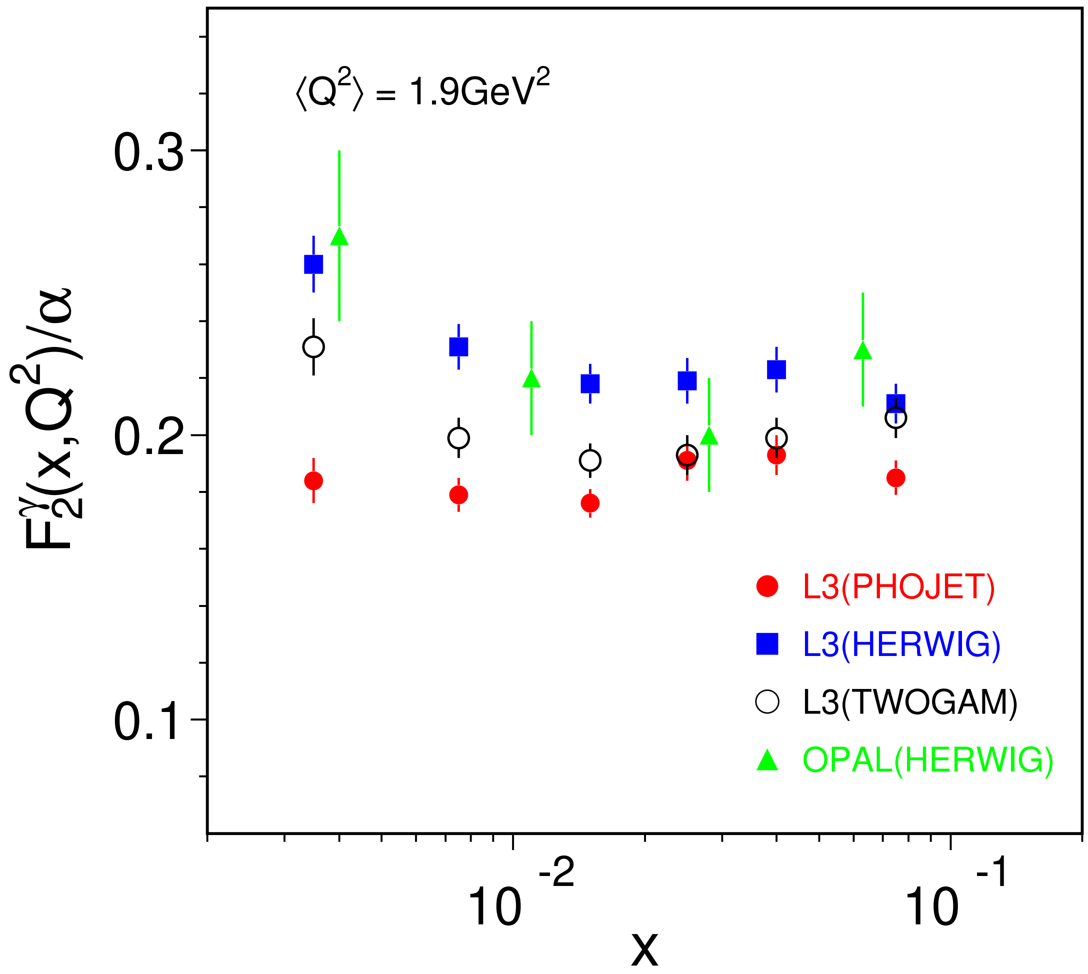
For L3 PHOJET and TWOGAM reproduce the data better than HERWIG.

Unfolding Procedure

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.

Kinematic Fitting (prl.)

For high Q^2 events, kinematic fitting improves the resolution and yields better agreement between measured and generated values.

L3 minimizes (120 pb^{-1} of data at 89 - 92 GeV):

$$\chi^2 = \Sigma_{i,j=1}^{3} V_{i,j}^{-1} \Delta p_i \Delta p_j + \Sigma_{k=1}^{3} W_k C_k^2$$

with

$$\Delta p_1 = E - \Sigma_l E_l^h$$
$$\Delta p_2 = p_z - \Sigma_l p_{z,l}^h$$
$$\Delta p_3 = p_{in} - \Sigma_l p_{in,l}^h$$

$(E, \vec{p})$ is the four-momentum vector of the hadronic system,
p_{in} is its transverse momentum in the scattering plane.

The constraints C_k are:

$$C_1 = E^- + E^+ + E - 2E_{beam} + 2RC = 0$$
$$C_2 = p_z^- + p_z^+ + p_z = 0$$
$$C_3 = p_{in}^- + p_{in}^+ + p_{in} = 0$$

The fit yields an improved value of

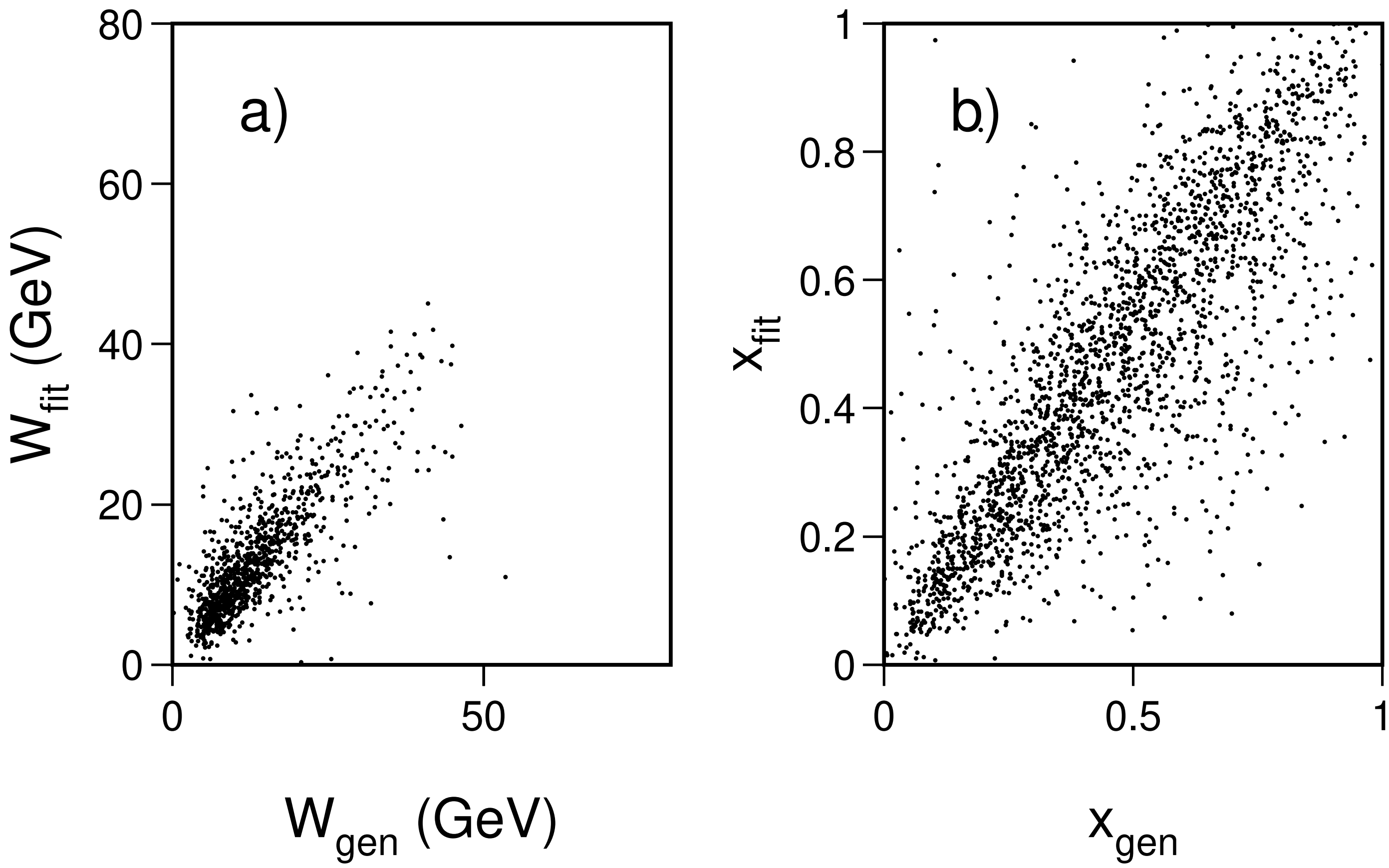
$$W_{fit}^2 = E^2 - p_{in}^2 - p_{out}^2 - p_z^2$$

and thus

$$x_{fit}$$

Kinematic Fitting (prl.)

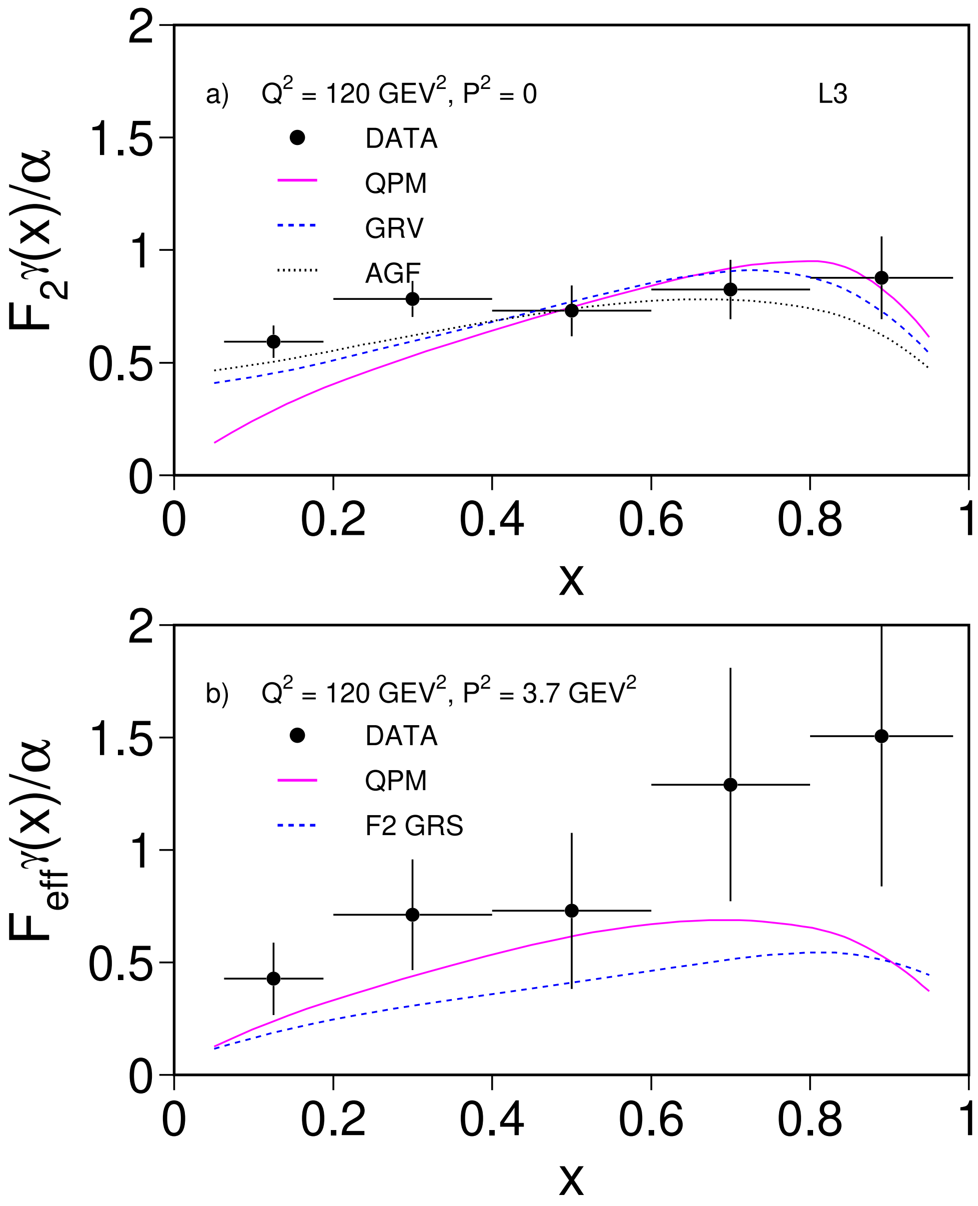
a) Correlation between the generated value of $W_{\gamma\gamma}$ and the value obtained after the kinematical fit (JAMVG Monte Carlo).



b) correlation between the generated value of x and the value obtained after the kinematical fit (JAMVG Monte Carlo).

Kinematic Fitting (prl.)

a) The structure function F_2^γ for real photons at $Q^2 = 120$ GeV^2.

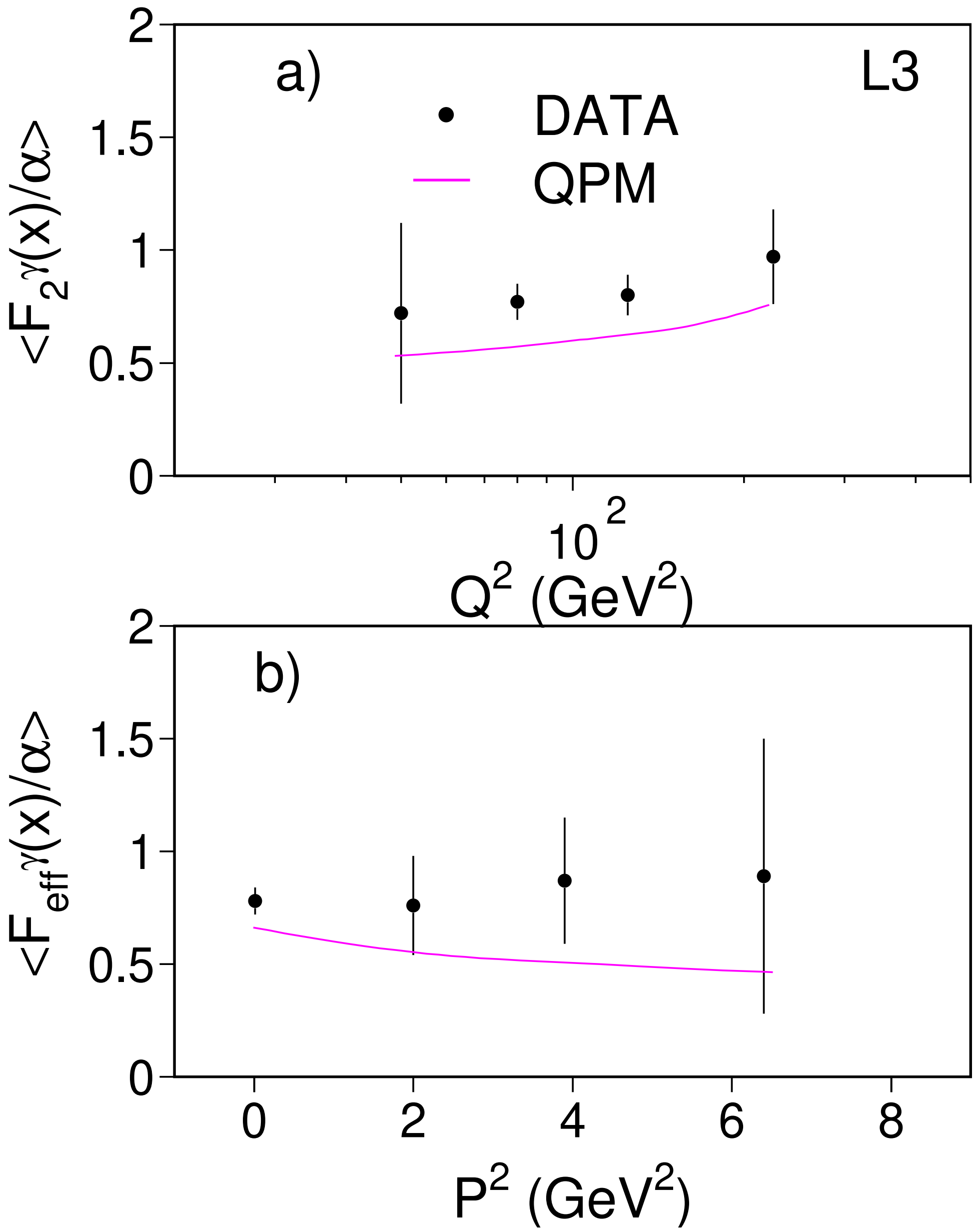


b) F_{eff}^γ for virtual photons at $Q^2 = 120$ GeV^2 and $P^2 = 3.7$ GeV^2, compared to the QPM and GRS calculation with:

$$F_{eff}^\gamma = \frac{Q^2}{4\pi^2\alpha}(\sigma_{TT} + \sigma_{LT} + \sigma_{TL})$$

Kinematic Fitting (prl.)

a) Dependence of F_2^γ averaged over x=0.05-0.98 for single-tag data, compared to QPM (full line);



b) Dependence of F_{eff} averaged over x=0.05-0.98 vs. P^2 for double-tag data at $Q^2 = 120$ GeV^2, compared to QPM predictions (full line).

Parametrizations

QCD parametrizations used 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)

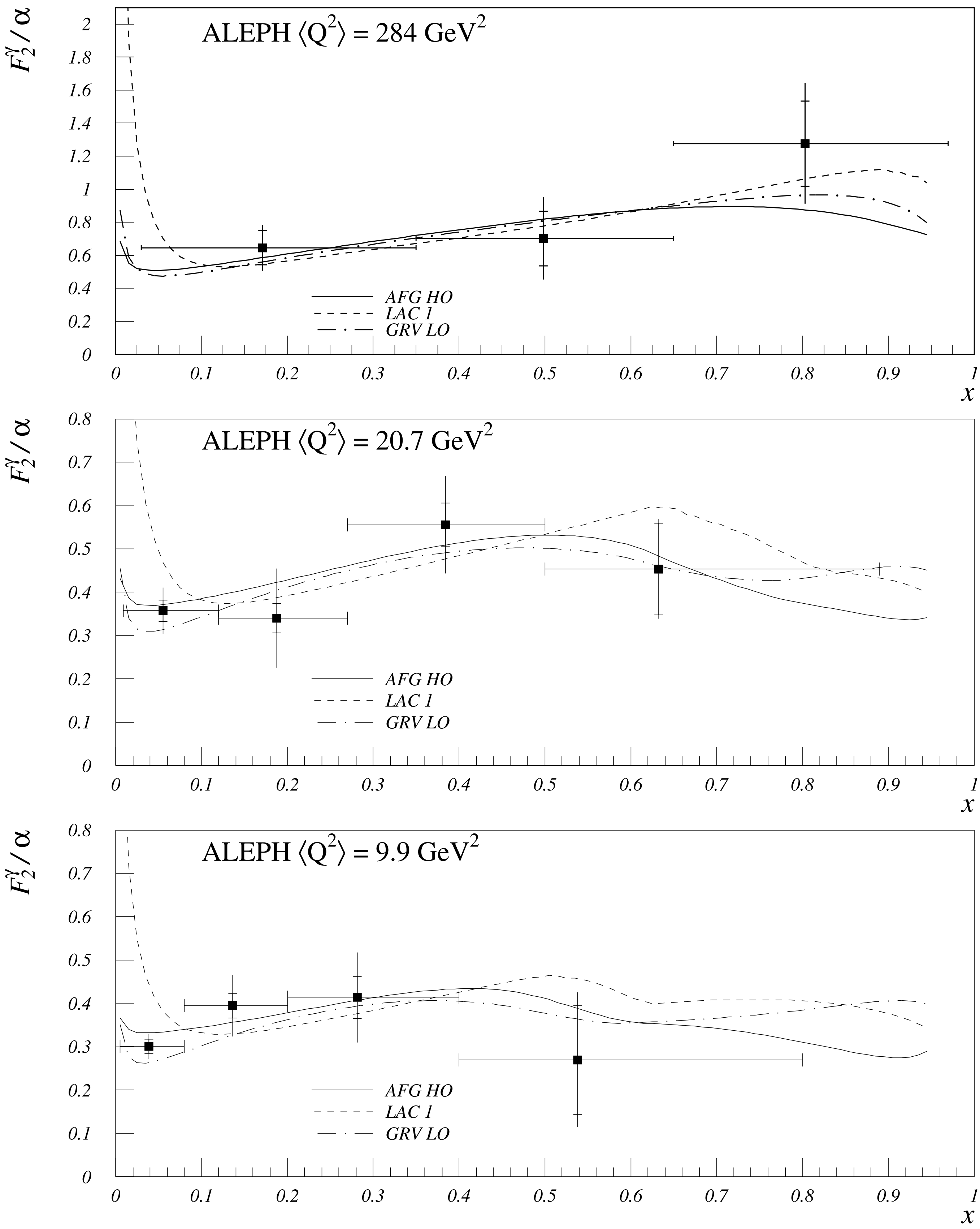
- **SaS-1d, Schuler and Sjöstrand (1995, 1996)**
  evolution starts at a low value of Q_0^2 (= 0.36 GeV^2)

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

- **AFG-HO, Aurenche, Fontannaz and Guillet (1994)**

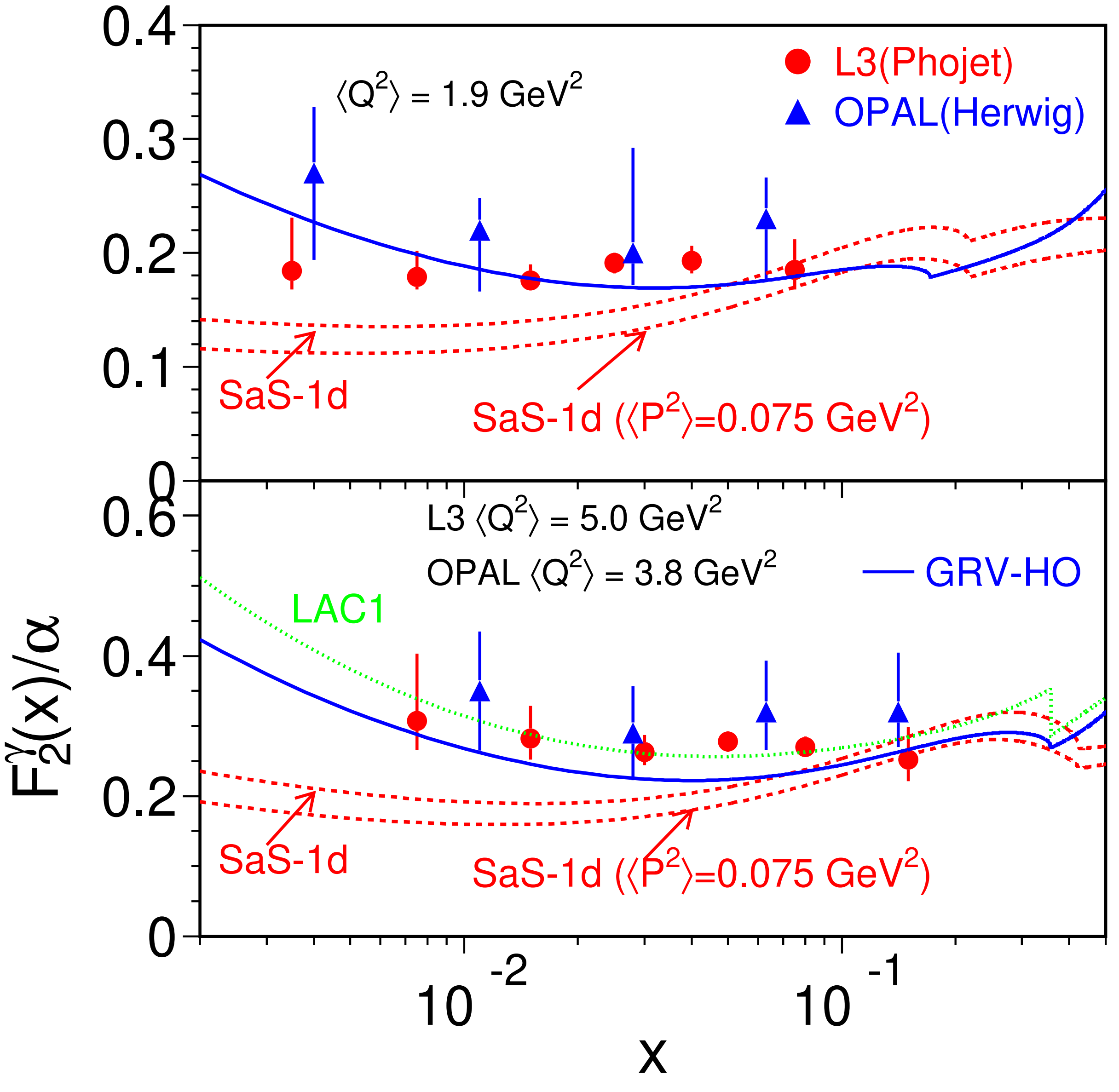
Taking into account the target photon virtuality ($P^2 > 0$) reduces the predictions.

F_2^γ/α form ALEPH



F_2^γ/α at low Q^2

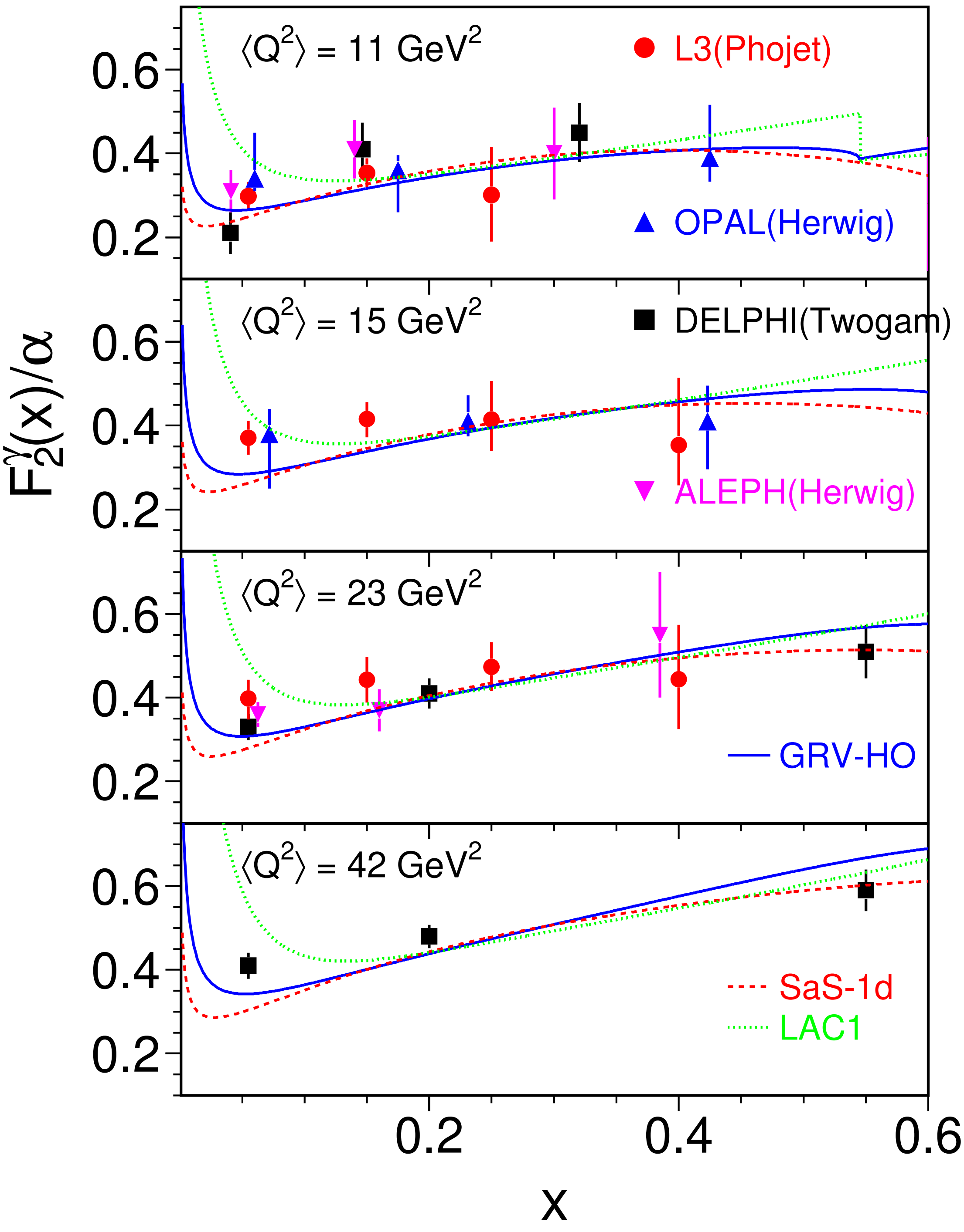
Comparison of the measured F_2^γ/α at $\sqrt{s}$ = 91 GeV from L3 and OPAL at low values of Q^2:



In the lowest Q^2 bin GRV-HO fits the experimental data both from OPAL and L3 best. In the second Q^2 bin both GRV-HO and LAC1 agree with the data.

F_2^γ/α at medium Q^2

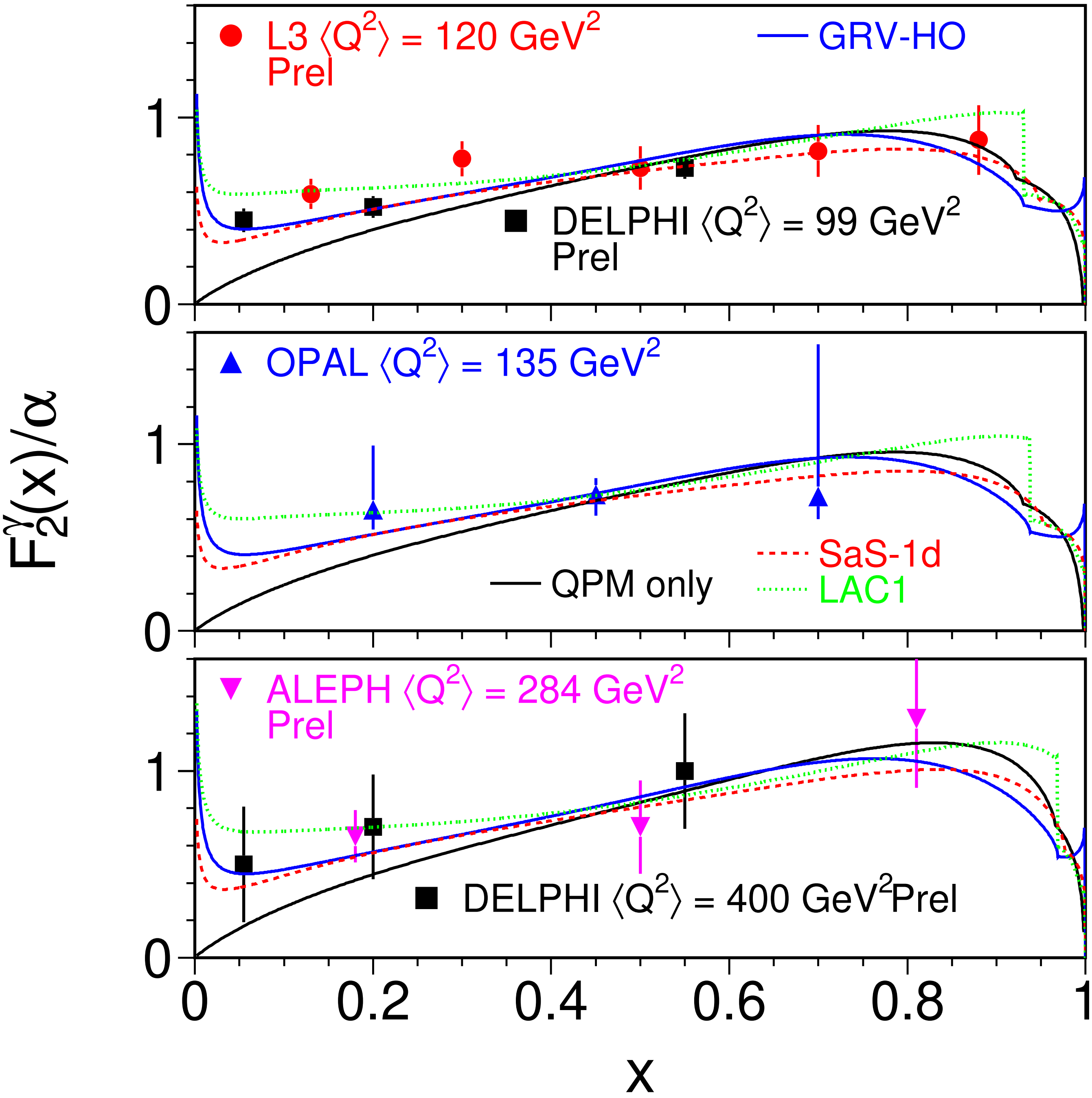
F_2^γ/α from LEP at medium values of Q^2:



At $x < 0.1$ GRV-HO and LAC1 enclose the data.
At $x > 0.1$ there is good agreement. Agreement less good if $P^2 \neq 0$ in the parametrizations.

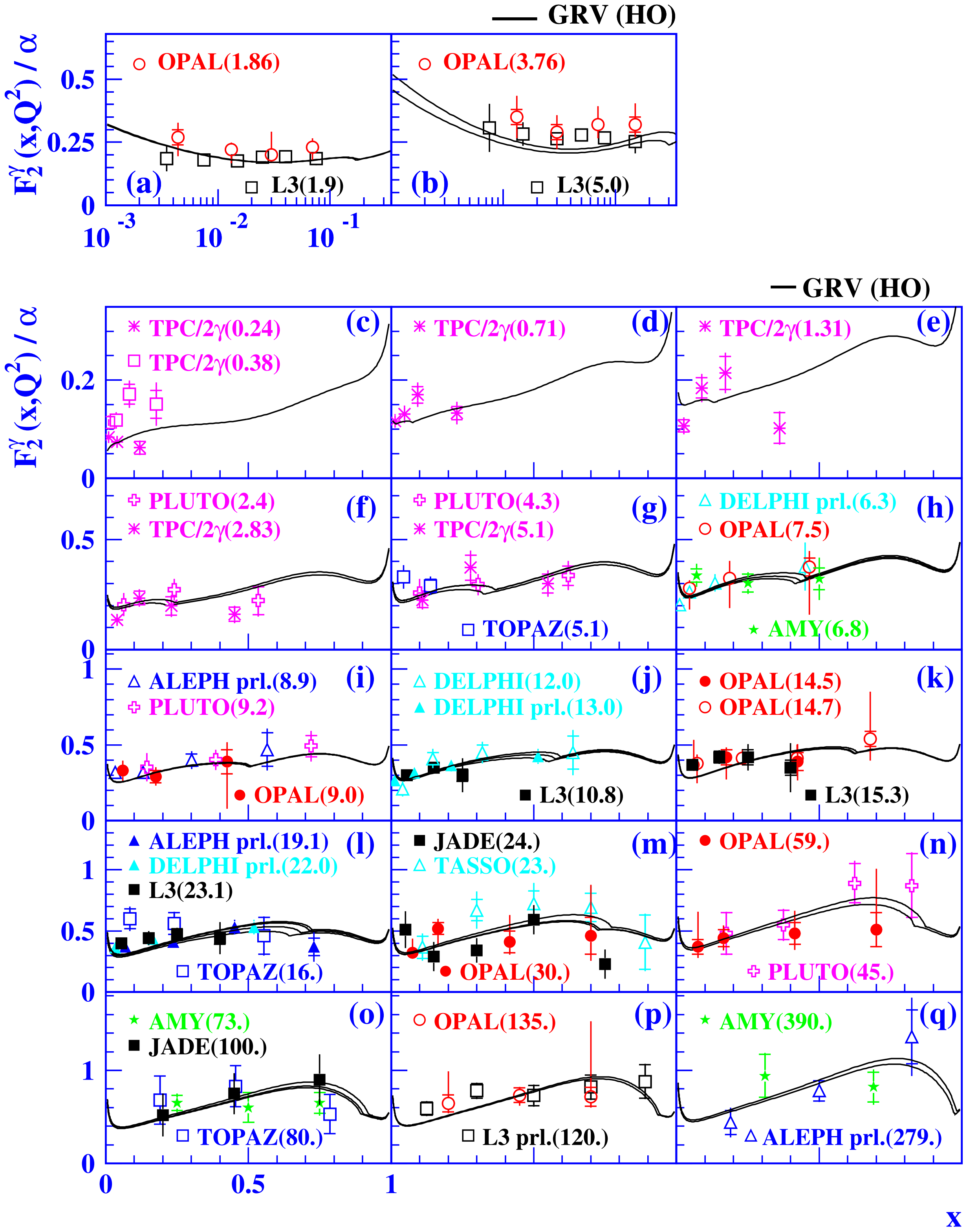
F_2^γ/α at high Q^2

F_2^γ/α at 99 GeV^2 $< Q^2 <$ 400 GeV^2



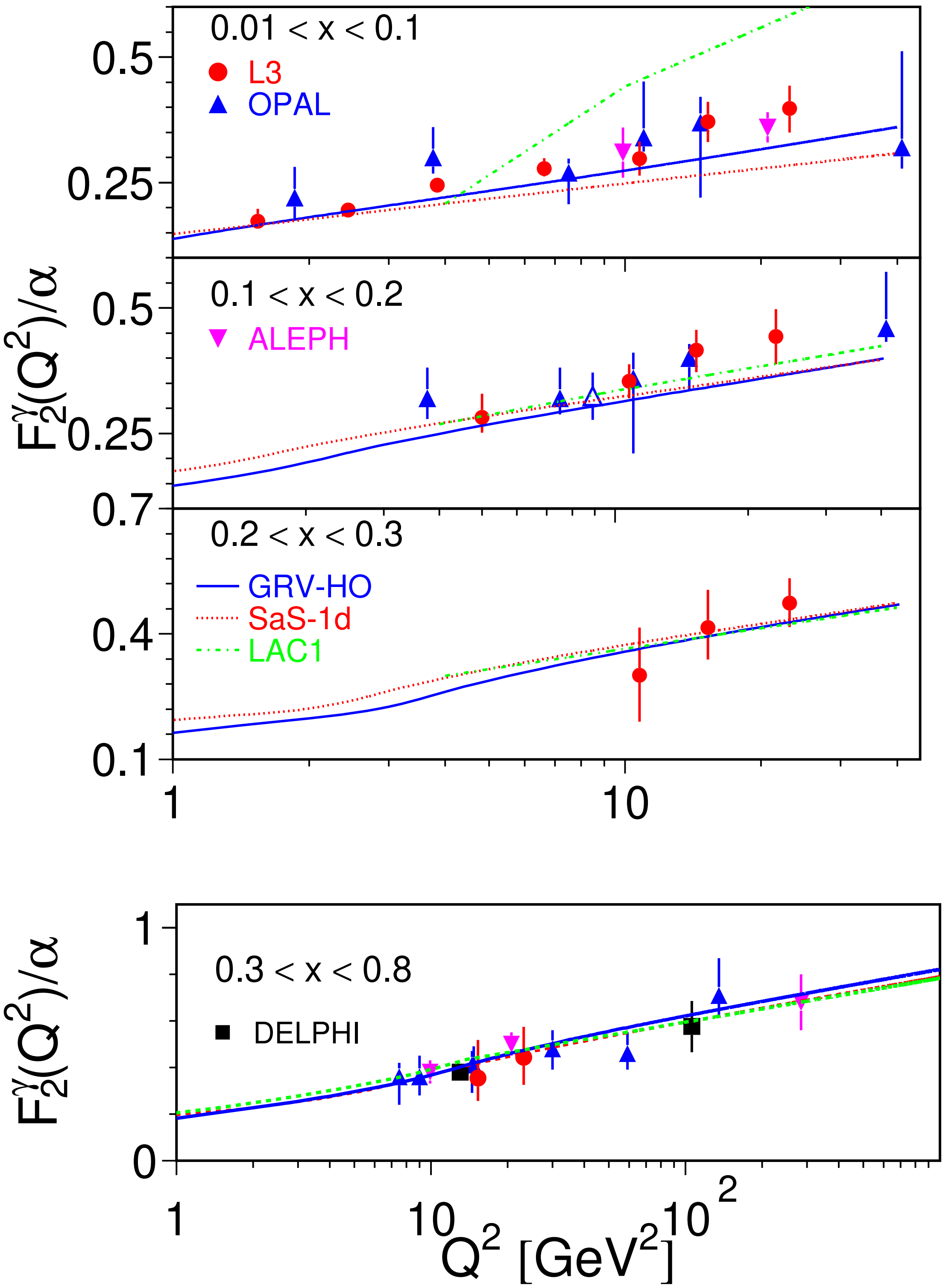
QPM alone **is insufficient to describe the data at low x $\Longrightarrow$ need resolved contributions.**

World data on F_2^γ/α



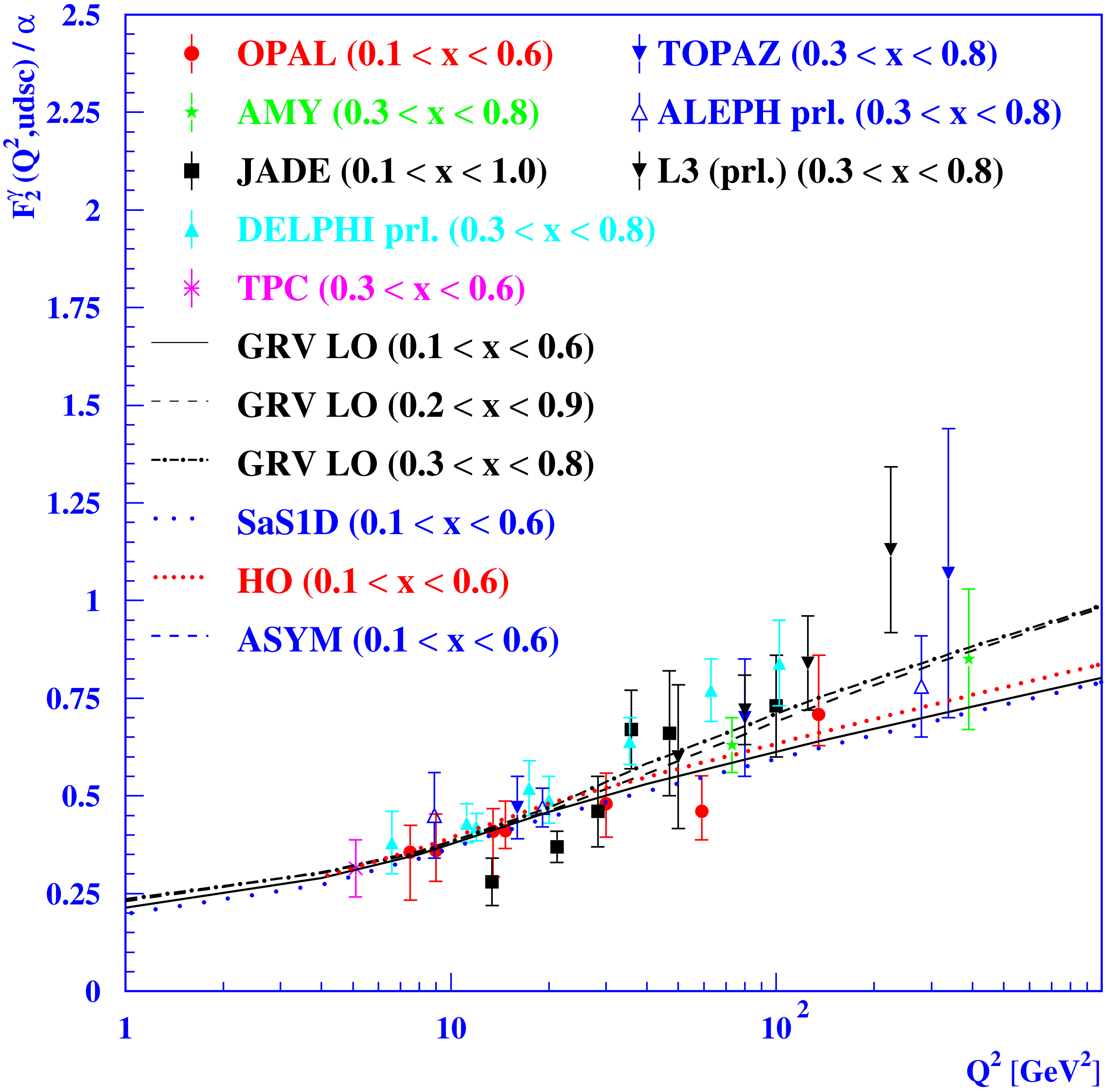
F_2^γ/α versus Q^2

The measured F_2^γ/α from LEP versus Q^2:



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

World data of F_2^γ/α versus Q^2



Conclusions

LEP data cover a large range in x and Q^2, viz. $0.002 < x < 0.98$ and $1GeV^2 < Q^2 < 3000GeV^2$

- **At low Q^2, the higher order GRV parametrization is preferred for $x < 0.05$.**
- **At high Q^2, the agreement of the parametrizations with the data gets better.**
- **The observed Q^2-dependence is compatible with QCD.**
- **An improvement of the M. C. generators is desirable.**
  $\Longrightarrow$ Conclusions of the LEP working group on 2-photon physics: The results of the different experiments are mostly closer than the sizable differences found between data and models.

LEP has improved the measurement of the photon structure functions significantly.
Dear theoretical friends: Please redo your parametrizations, especially at low x and high Q^2.