Photon Structure Function in $\gamma\gamma$ collisions at LEP

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- The hadronic Structure Function, F_2^{γ}
- Conclusions

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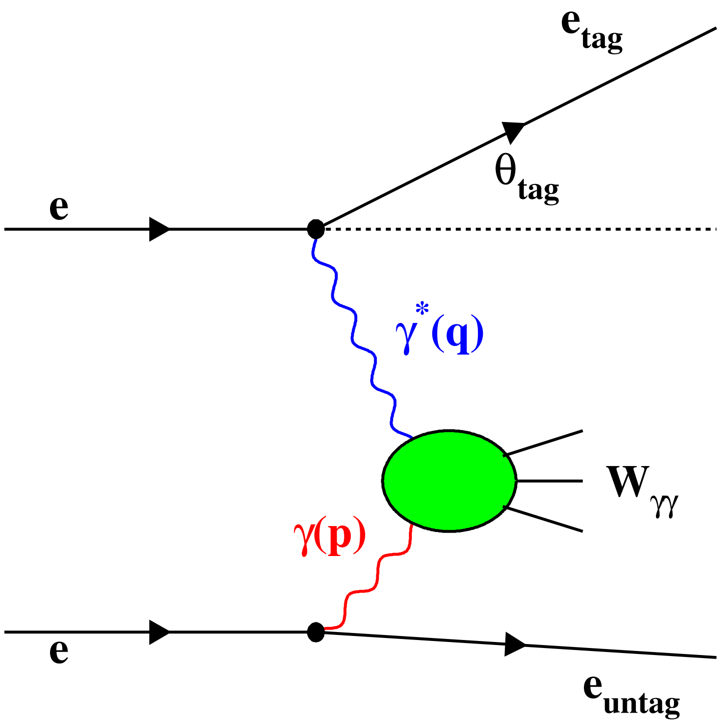
Introduction



Single Tag

probe γ^***:** $Q^2 = -q^2 > 0$

target γ**:** $P^2 = -p^2 \approx 0$

$$W_{\gamma\gamma}^2 = (q+p)^2$$

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

$$x = \frac{Q^2}{Q^2 + P^2 + W_{\gamma\gamma}^2} \quad , \quad y = 1 - \frac{E_{tag}}{E_{beam}} \cos^2 \frac{\theta_{tag}}{2} \ll 1$$

$$F_2^\gamma = 2xF_T^\gamma + F_L^\gamma \quad , \quad F_T^\gamma \sim \sigma_{TT} \quad , \quad F_L^\gamma \sim \sigma_{TL}$$

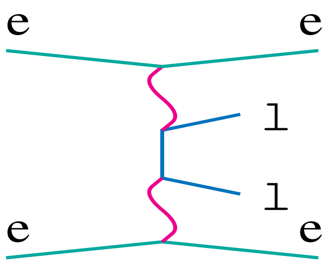
T=**transverse photon** ➡ **helicity** ± 1

L=**longitudinal photon** ➡ **helicity 0**

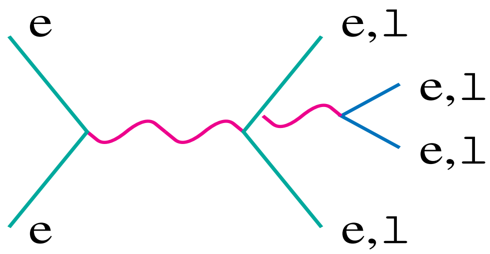
Since $y^2 \ll 1$ **only** F_2^γ **is measurable**

$F_{2,\mathrm{QED}}^{\gamma}$

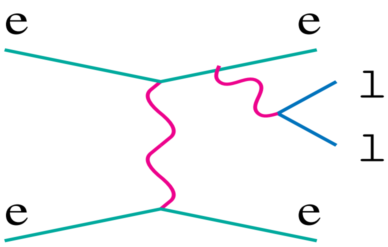
$e^+e^- \to e^+e^-\mu^+\mu^-$ ➡ **Leptonic Structure Function, $F_{2,\mathrm{QED}}^{\gamma}$**



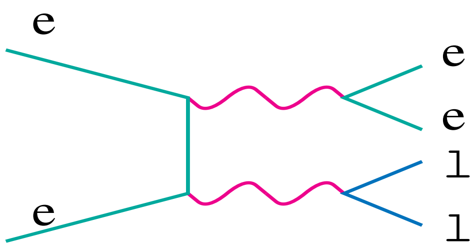
Multiperipheral



Annihilation



Bremsstrahlung

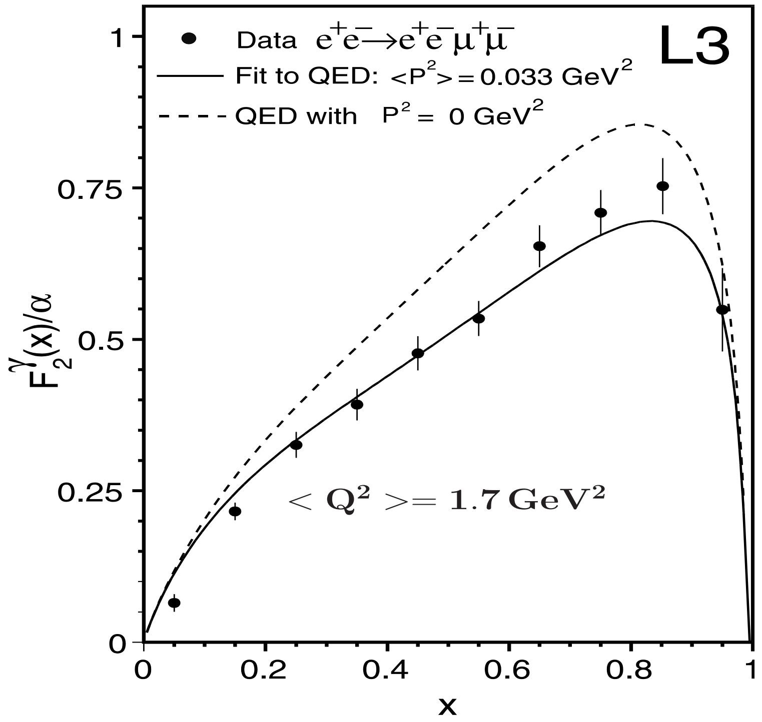


Conversion

Exp	Detector	$\mathcal{L}$	θ_{tag}	$\sqrt{s}$	Q^2	x	Ref
		pb^{-1}	mrad	GeV	GeV^2		
L3	Lumi Cal	93.7	25-68	91	1.4-7.6	0.-1.	[1]
OPAL	SW Cal.	67.4	28-55	91	1.5-7	0.-1.	[2]
	Forward	81.3	60-120	91	6-30	0.-1.	[2]
	Endcap	129.1	210-540	91	70-400	0.-1.	[2]

Monte Carlo Programs :

1. **JAMVG, Vermaseren**
2. **DIAG36, Berends, Daverveldt and Kleiss**
3. **RADCOR, Berends, Daverveldt and Kleiss**



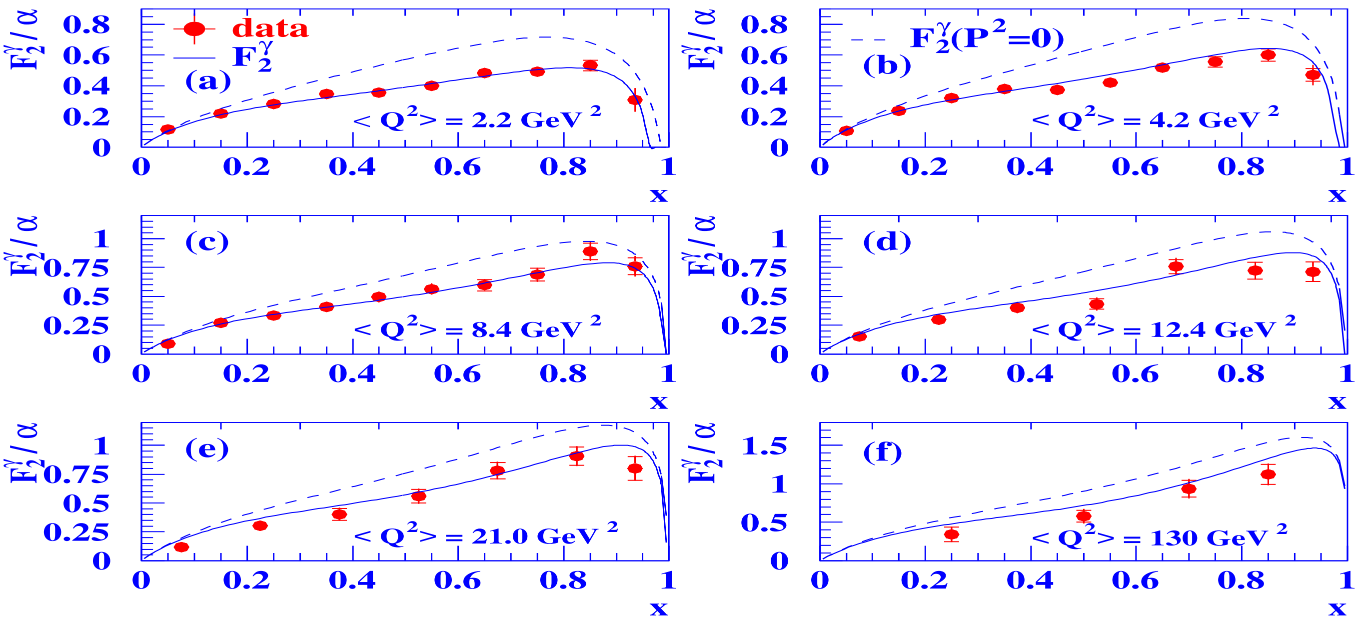
$< P^2 >= 0.033 \pm 0.005\,\mathrm{GeV}^2$

Non-zero target photon virtuality

$< P^2 >_{\mathrm{MC}} = 0.034\,\mathrm{GeV}^2$

incl. radiative corrections

OPAL

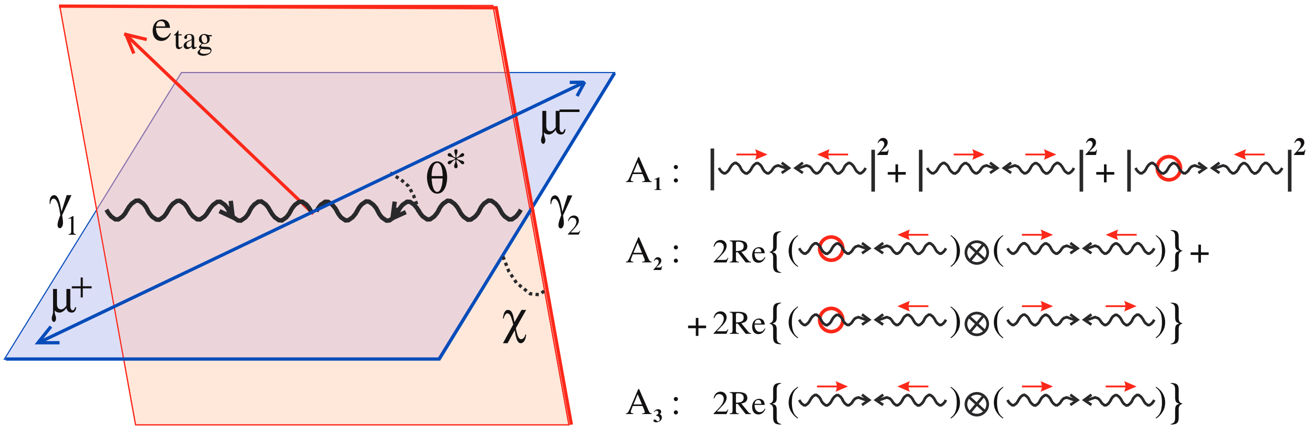


$< P^2 >= 0.05\ \mathrm{GeV}^2 \quad P(\chi^2) \sim 0.07 - 0.79$

Azimuthal Correlations

Study of the $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ cross section vs azimuthal angle χ

Provides information on the longitudinal component of the probe photon, $\gamma^*(q)$



Probe photon (left) Target photon (right)

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

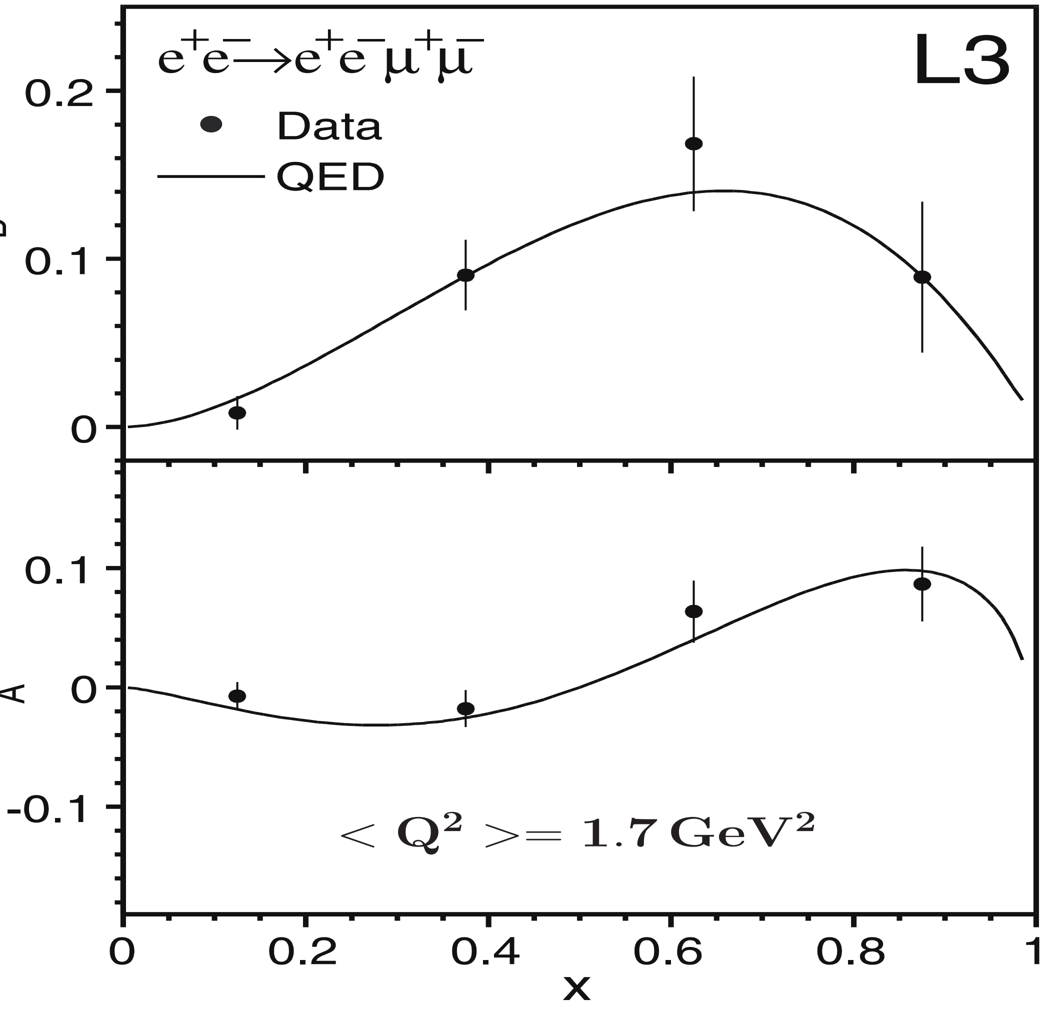
$$z = \cos\theta^*$$

$A_1 \propto F_2^\gamma \Rightarrow$ **Sum of all photon helicity states**

$A_2 \propto F_A^\gamma \Rightarrow$ **Interference of longitudinal-transverse photons**

$A_3 \propto F_B^\gamma \Rightarrow$ **Interference of two transverse photons**

F_A^γ and F_B^γ



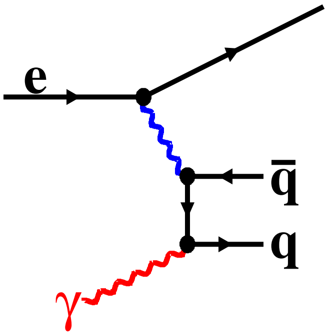
- Non-zero F_A^γ is measured → $F_L^\gamma \neq 0$
- Consistent with QED prediction.

$F_2^\gamma(\mathrm{x},Q^2)$

$\mathrm{e}^+\mathrm{e}^- \longrightarrow \mathrm{e}^+\mathrm{e}^-$ hadrons ➡ F_2^γ

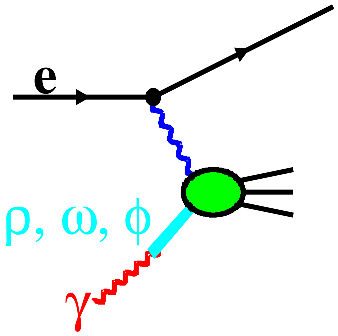
$$F_2^\gamma = F_2^{\mathrm{PL}} + F_2^{hadr}$$

- F_2^{PL} : **dominant at large** x

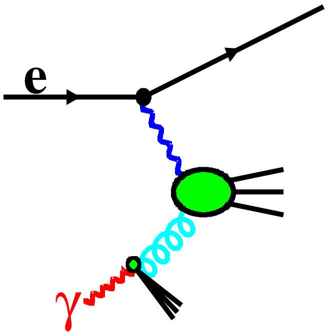


➜ **QPM**

- F_2^{hadr} : **dominant at small** x

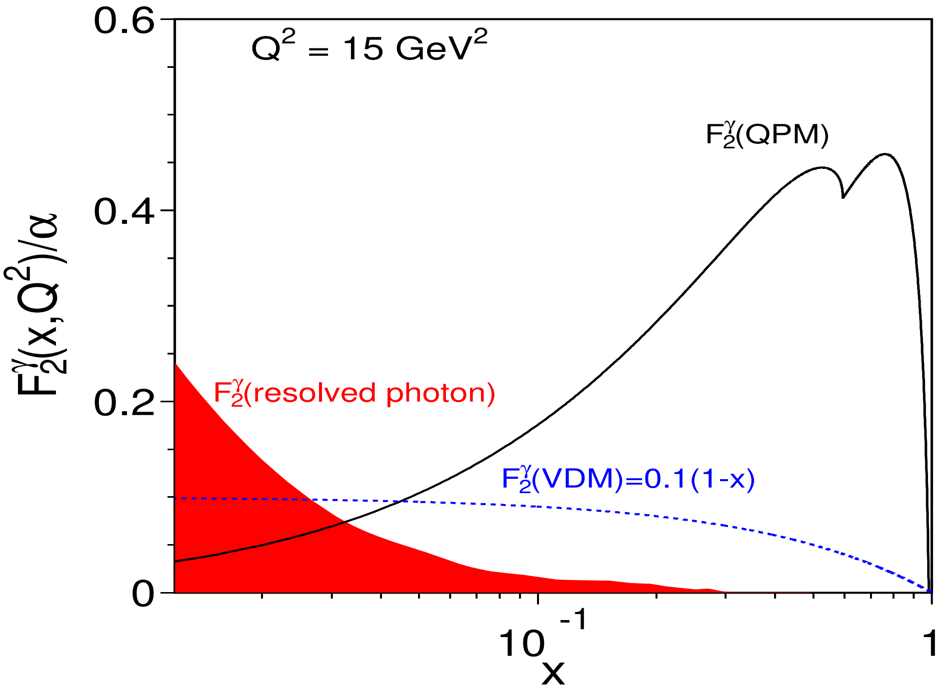


➜ **VDM, non-perturbative QCD**



➜ **Resolved** γ, **perturbative QCD**

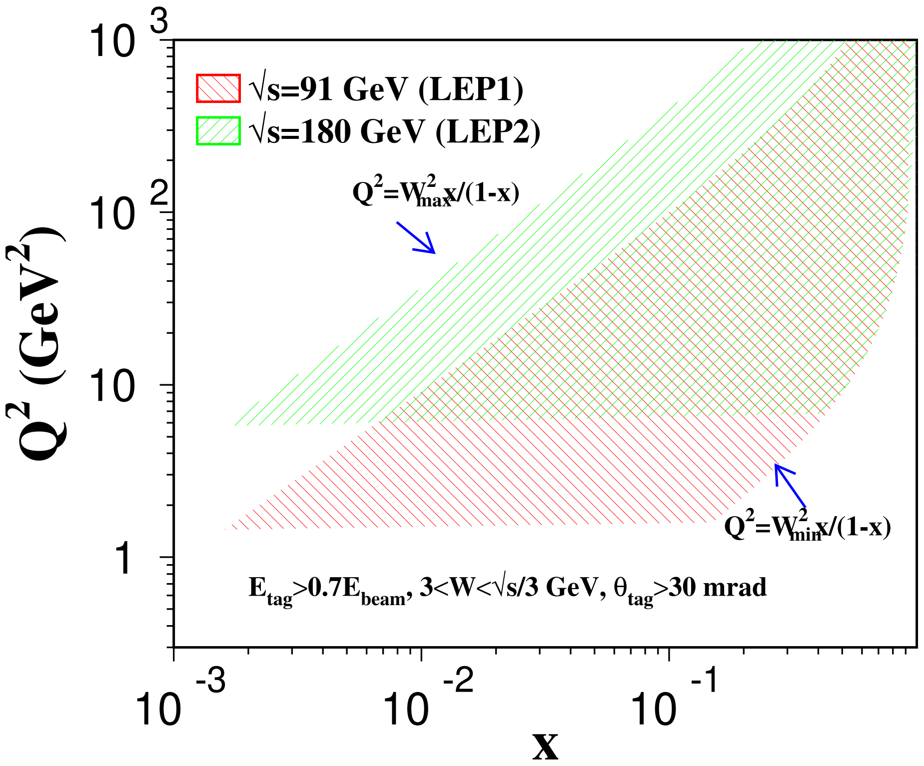
$F_2^\gamma(\mathrm{x},Q^2)$



- At high x ➜ Quark constituents are dominant
- At low x ➜ Gluon constituents are dominant
- F_2^γ is not predictable when VDM and resolved becomes important

F_2^γ parametrisations evolved from different Q_0^2:

- **GRV-LO/HO**, Glück, Reya and Vogt (1992) Q_0^2=0.25 GeV^2
- **SaS-1d**, Schuler and Sjöstrand (1995, 1996) Q_0^2=0.36 GeV^2
- **LAC**, Abramovicz, Charchula and Levy (1991) Q_0^2= 4 GeV^2



Exp	$\sqrt{s}$	θ_{tag}	Q^2	x	Ref
	GeV	mrad	GeV^2		
L3	91	26-66	1.2-9	0.002-0.2	[3]
L3	91	200-600	40-500	0.05-0.98	Prel
L3	183	30-66	9-30	0.01-0.3	[4]
OPAL	91	27-55	1.1-6.6	0.0025-0.2	[5]
OPAL	161,172	33-120	6-100	0.02-0.6	[6]
ALEPH	91	60-150	6-44	0.0027-0.9	Prel
ALEPH	91	> 318	50-2400	0.-0.975	Prel
DELPHI	91	43-135	40-30	0.005-0.977	[7]
DELPHI	161,172,183,188	42-610	10-1000	0.01-0.8	Prel

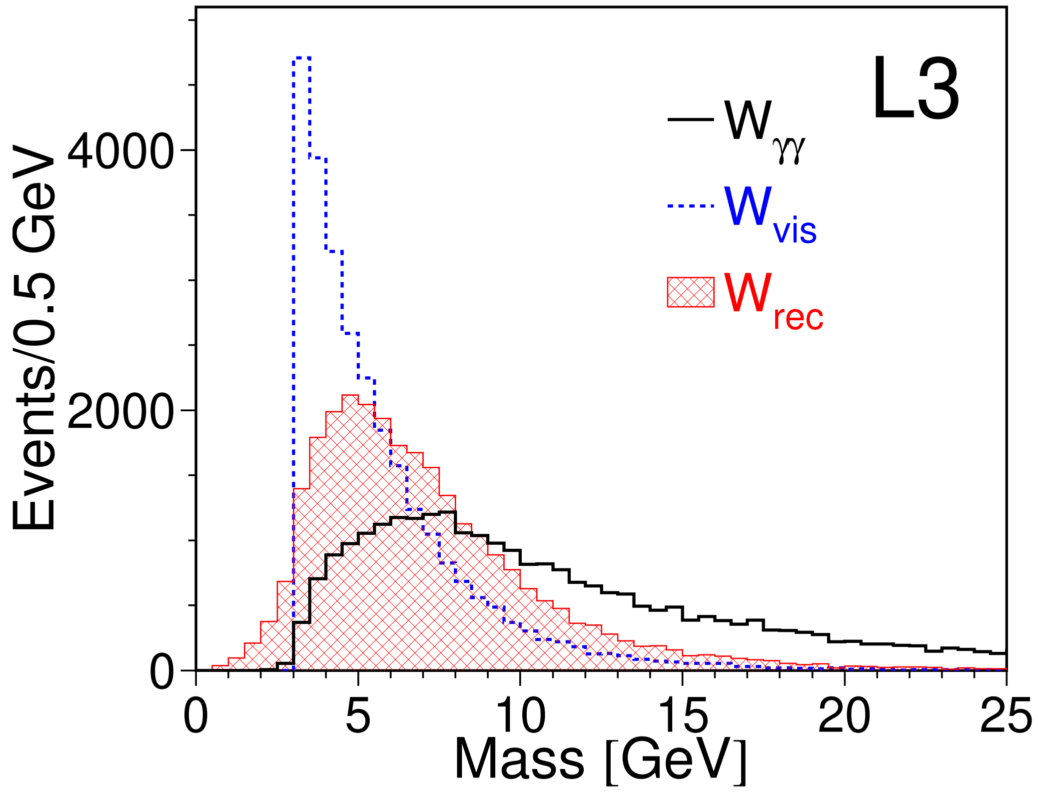
W_{vis} Measurement

The hadronic final state is NOT fully reconstructed due to detector acceptance

- W_{vis} ➔ reconstructed from tracks and calorimetric clusters

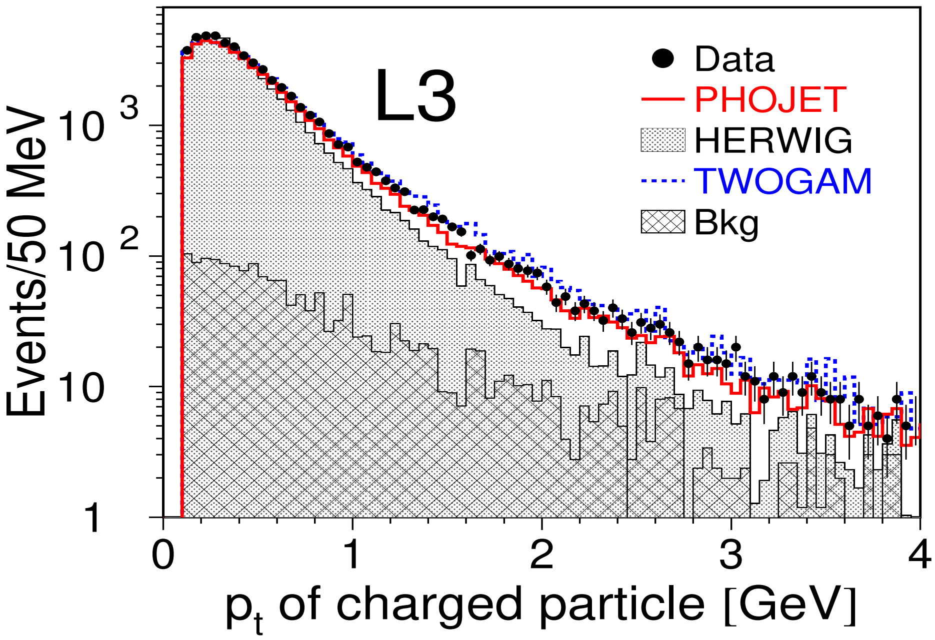
- W_{rec} ➔ use the kinematics of the tagged electron $\Rightarrow$ transverse momentum conservation

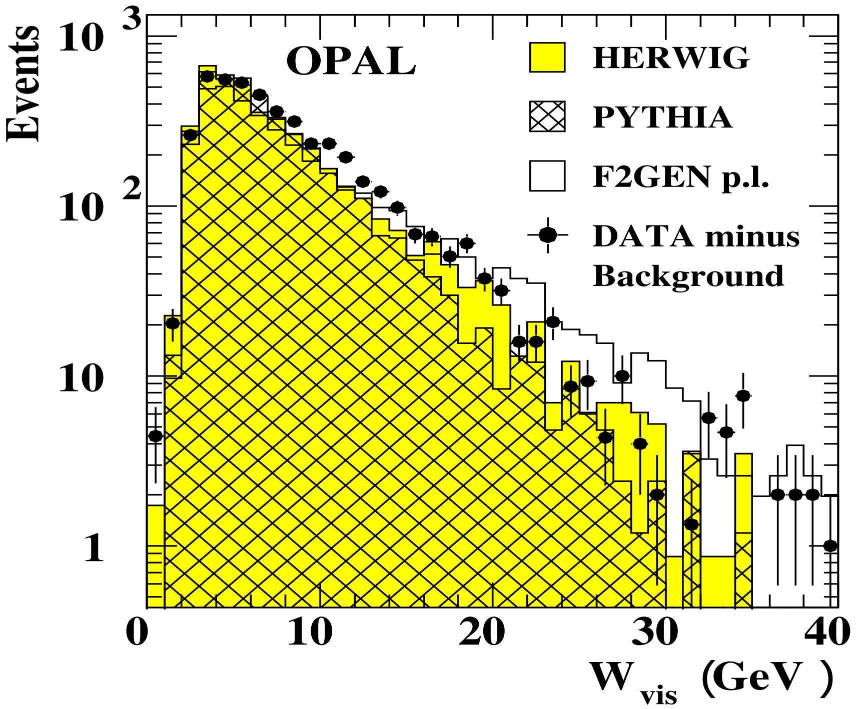
- Use Unfolding to get x from x_{rec}



Good Modelling of the Monte Carlo is needed

F_2^γ : MC comparison

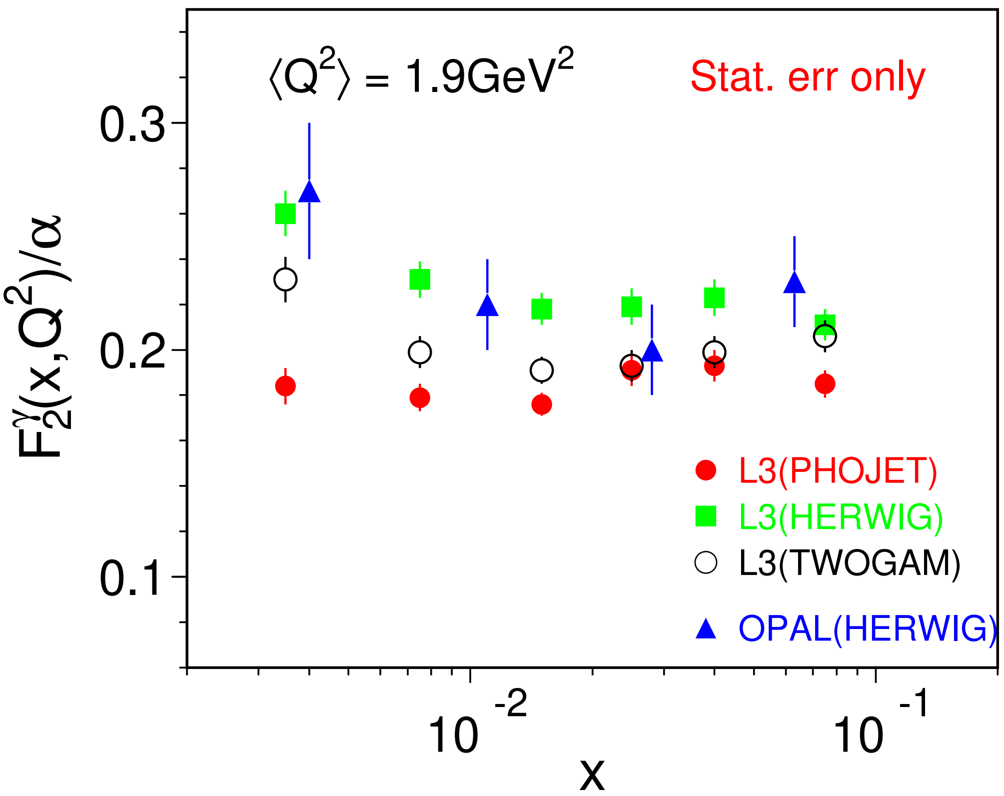




L3	PHOJET	TWOGAM	HERWIG
OPAL	HERWIG	PYTHIA	F2GEN
DELPHI	TWOGAM	F2MC	
ALEPH	HERWIG	QPM+VDM	

F_2^γ : Modelling Dependence

❑ Unfold the data with different Monte Carlos

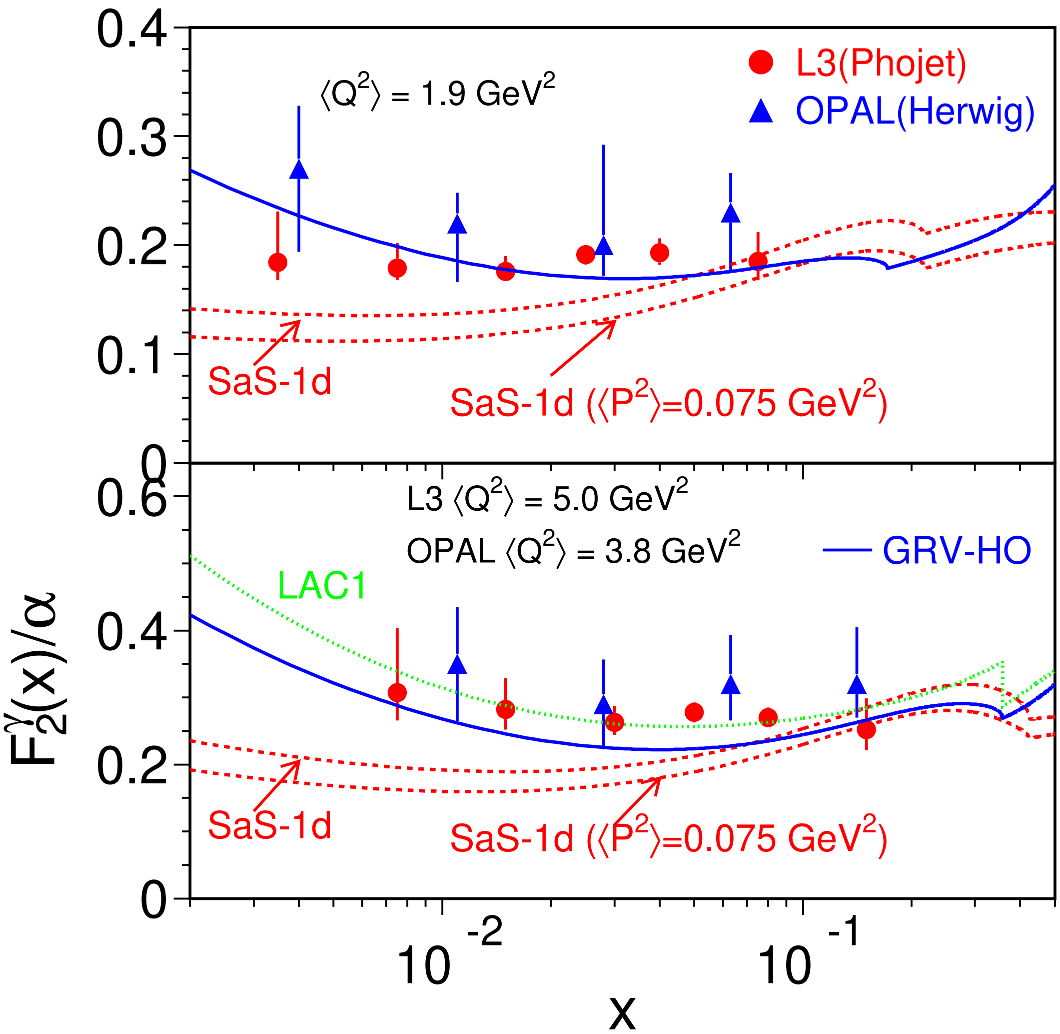


⇨ L3 and OPAL agree if they use the same MC

⇨ At low x ➔ large discrepancies between the different MC ($\sim 10 - 30\%$)

F_2^γ : low Q^2

❑ Low Q^2 ➜ access to low x



⇨ **SaS-1d lies below the data**

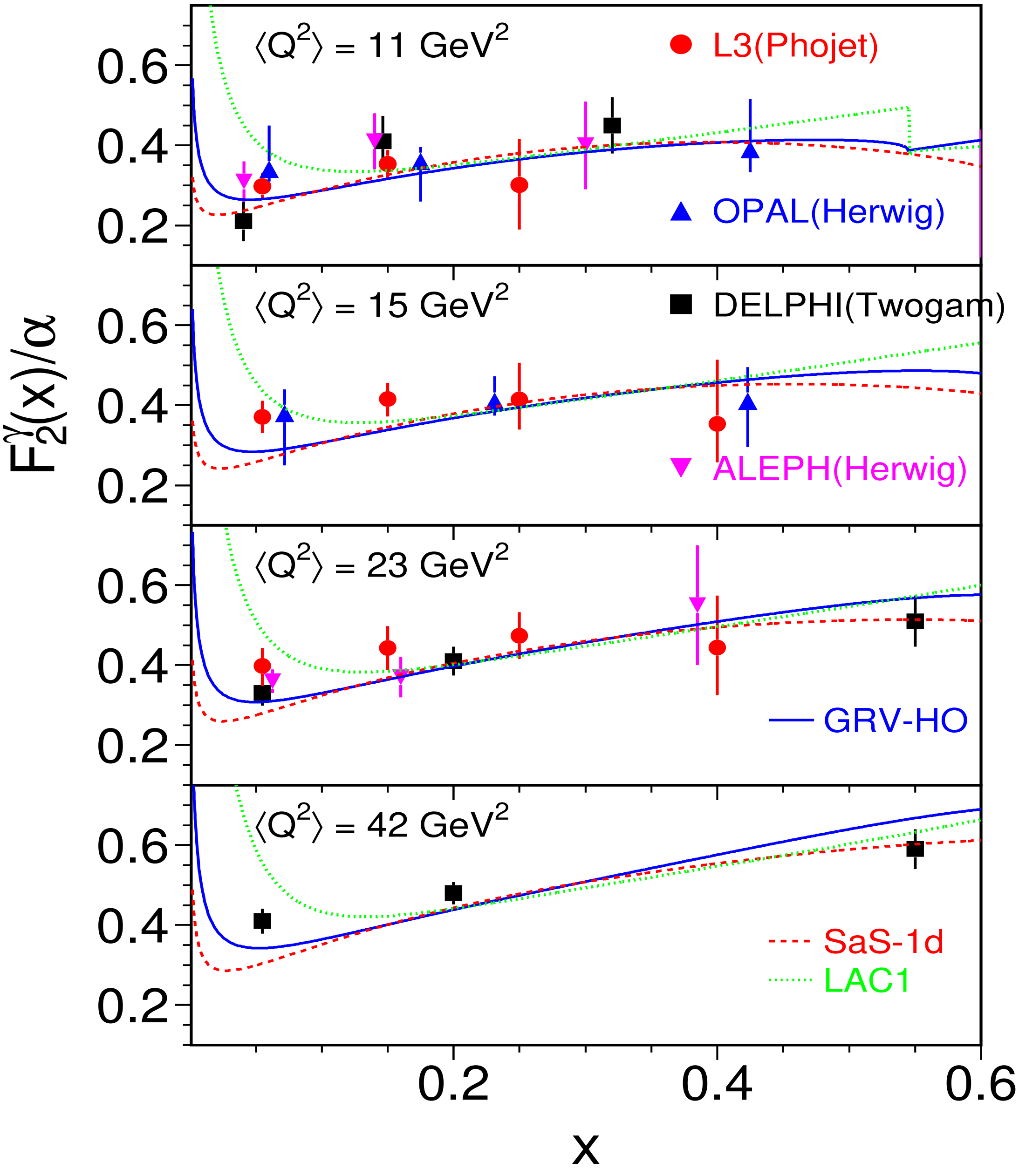
⇨ **GRV-HO describes better the low x**

⇨ **LAC1 agrees with the data at $Q^2 = 5\,\mathrm{GeV}^2$**

⇨ **The effect of $< P^2 > \neq 0$ decreases SaS-1d by $\sim 15\%$ ➜ Since $< P^2 >$ depends on the unkown mixture F_2^{PL} and F_2^{hadr} no correction is applied to the data**

F_2^γ : medium Q^2

❑ F_2^γ versus x

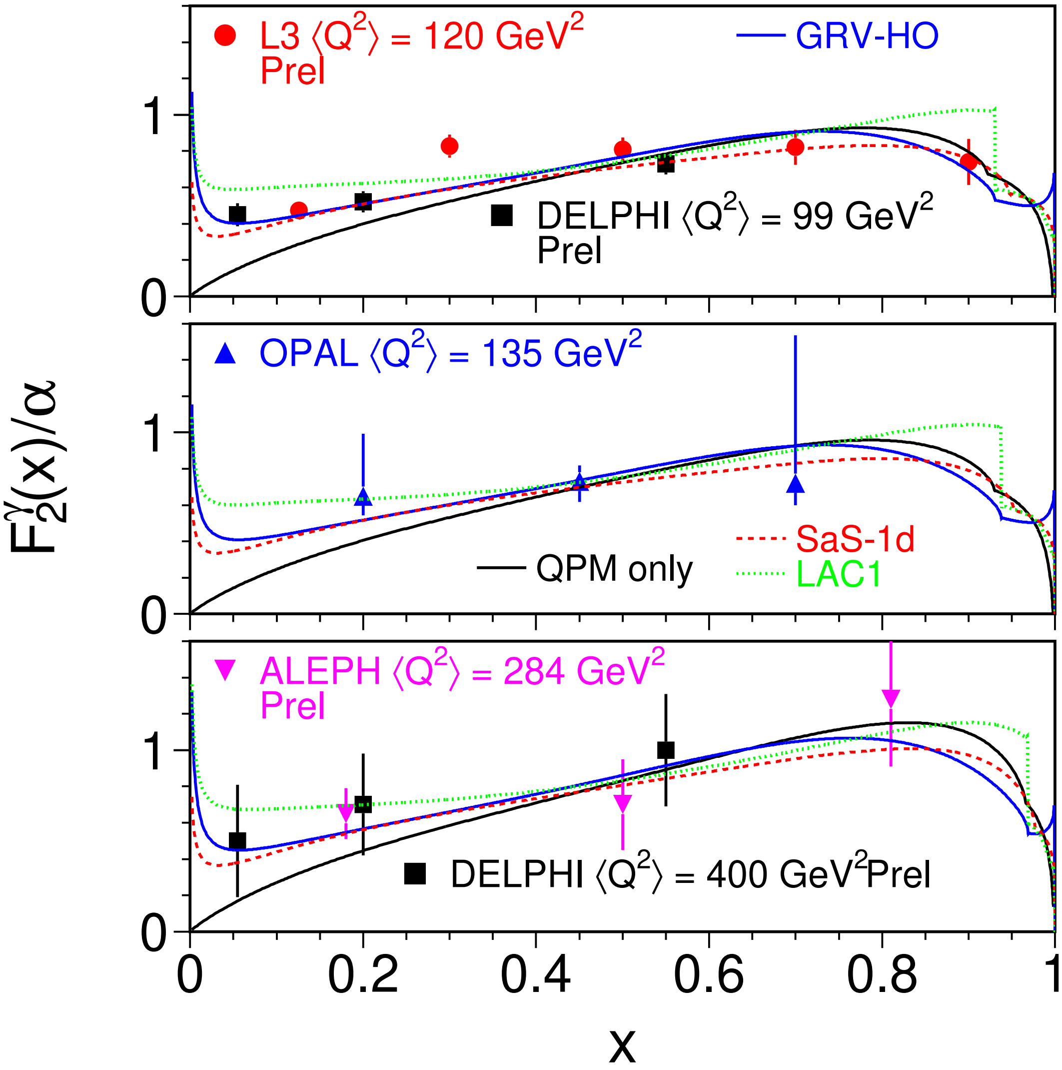


⇨ $x > 0.1$ ➔ good agreement

⇨ $x < 0.1$ ➔ data lie between LAC1 and GRV

F_2^γ : high Q^2

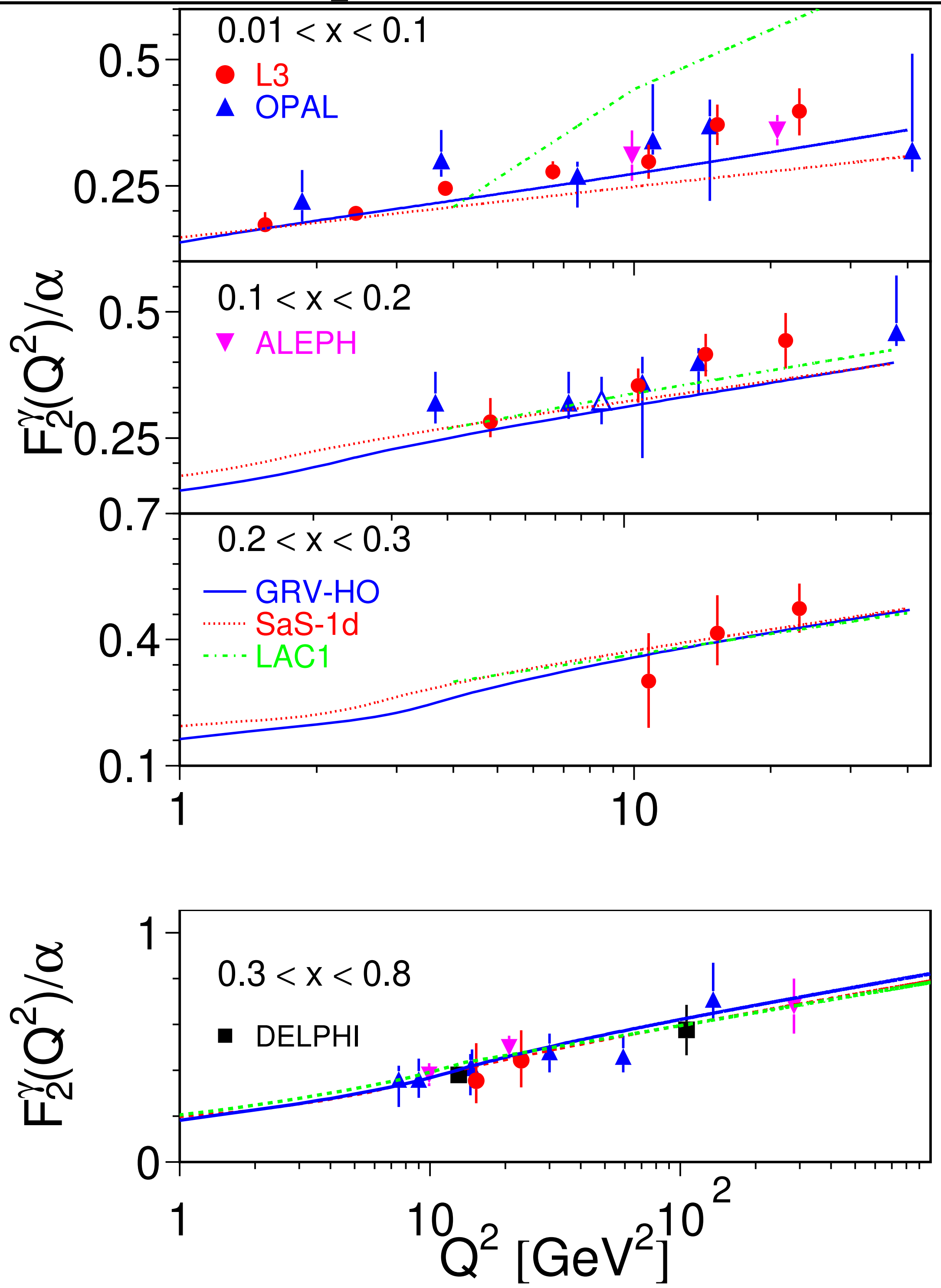
❑ F_2^γ versus x



⇨ **QPM** model **only** is **not enough** to describe the data **for** $x < 0.3$ ➜ **need resolved processes**

⇨ **Better agreement** of the parametrisations with **data** at high Q^2

F_2^γ versus Q^2



⇨ LAC1 disagrees with the data in the low x bin

⇨ The Q^2 evolution agrees with is the QCD prediction

Conclusions

- **Leptonic Photon Structure Function, $F_{2,\mathrm{QED}}^{\gamma}$:**
  - **Non-zero target photon virtuality** $< P^2 > \neq 0$
  - $F_{2,\mathrm{QED}}^{\gamma}$ **in agreement with QED**
  - $F_L^{\gamma} \neq 0$

- **Hadronic Photon Structure Function, F_2^{γ} :**

  $1\,\mathrm{GeV}^2 < Q^2 < 2400\,\mathrm{GeV}^2$ **and** $0.002 < x < 1$ **at LEP**

  - **Low Q^2 and medium Q^2:**
    - $x < 0.1$ ➔ **no satisfactory parametrisation of** F_2^{γ}
      $x > 0.1$ ➔ **agreement with data is better**
  - **Large Q^2:**
    - **QPM only is not enough at low** x
    - **Perturbative theory including resolved processes seems O.K.**
  - Q^2 **evolution of** F_2^{γ} **agrees with QCD**

- **LEP data are useful as input for new parametrisations of** F_2^{γ}

- **Improvements on the MC modelling are welcome**

References

[1] Phys. Lett. B438 (1998) 363
[2] CERN-EP/99-010, Submitted to Eur. Phys. Jounal C
[3] Phys. Lett. B436 (1998) 403
[4] Phys. Lett. B447 (1999) 147
[5] Phys. Lett. B412 (1997) 225
[6] Phys. Lett. B411 (1997) 387
Zeit. fur Physik C74 (1997) 33
[7] Zeit. Phys C69 (1996) 223