Measurements of the Photon Structure Function at L3

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- Introduction: F_2^γ
- Results at Low and Medium Q^2
- High-Q^2 data, single and double tag
- Evolution with Q^2 and P^2
- Conclusions

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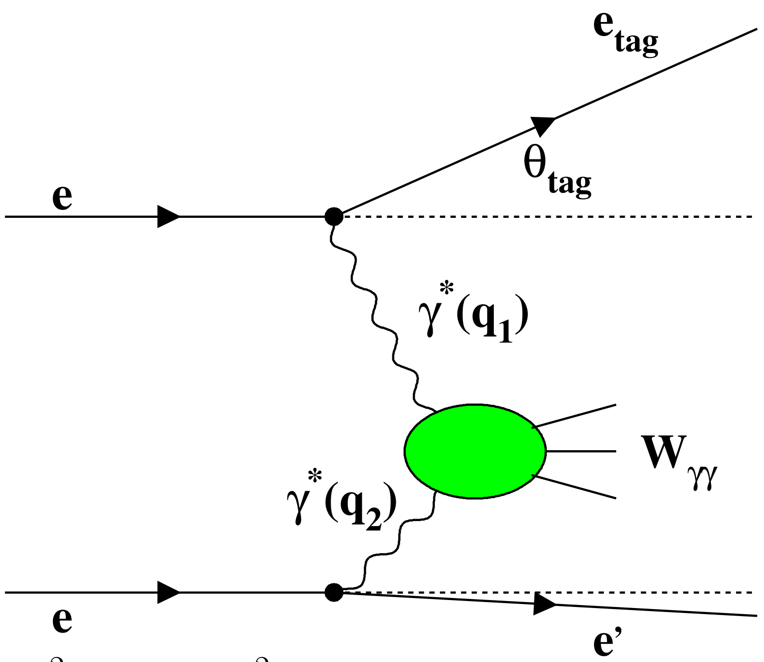
Introduction



Single Tag
probe γ^***:** $Q^2 = -q_1^2 > 0$
target γ**:** $P^2 = -q_2^2 \approx 0$

$$W_{\gamma\gamma}^2 = (q_1 + q_2)^2$$

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

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

$$F_2^\gamma = 2xF_T^\gamma + F_L^\gamma \sim (\sigma_{TT} + \sigma_{LT}) \quad , \quad F_L^\gamma \sim \sigma_{LT}$$

T=transverse photon ⇒ helicity ± 1
L=longitudinal photon ⇒ helicity 0

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

In Double Tag with $P^2 \ll Q^2$ one measures

$$F_{eff}^\gamma \sim (\sigma_{TT} + \sigma_{LT} + \sigma_{TL} + \sigma_{LL})$$

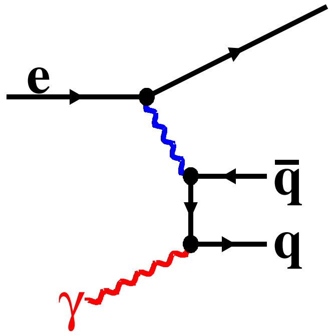
Measurement of $F_2^\gamma(\mathrm{x},Q^2)$ by L3

$$e^+e^- \longrightarrow e^+e^- \text{ hadrons} \Rightarrow F_2^\gamma$$

Traditional representation of subprocesses:

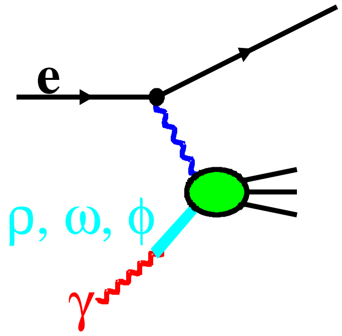
$$F_2^\gamma = F_2^{\mathrm{PL}} + F_2^{hadr}$$

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

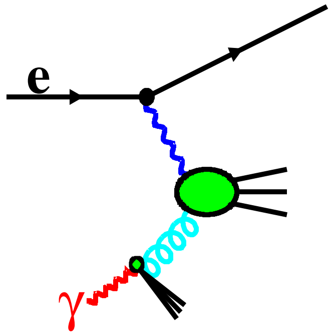


➜ **QPM + QCD evolution**

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



➜ **VDM, non-perturbative QCD**



➜ **Resolved** γ

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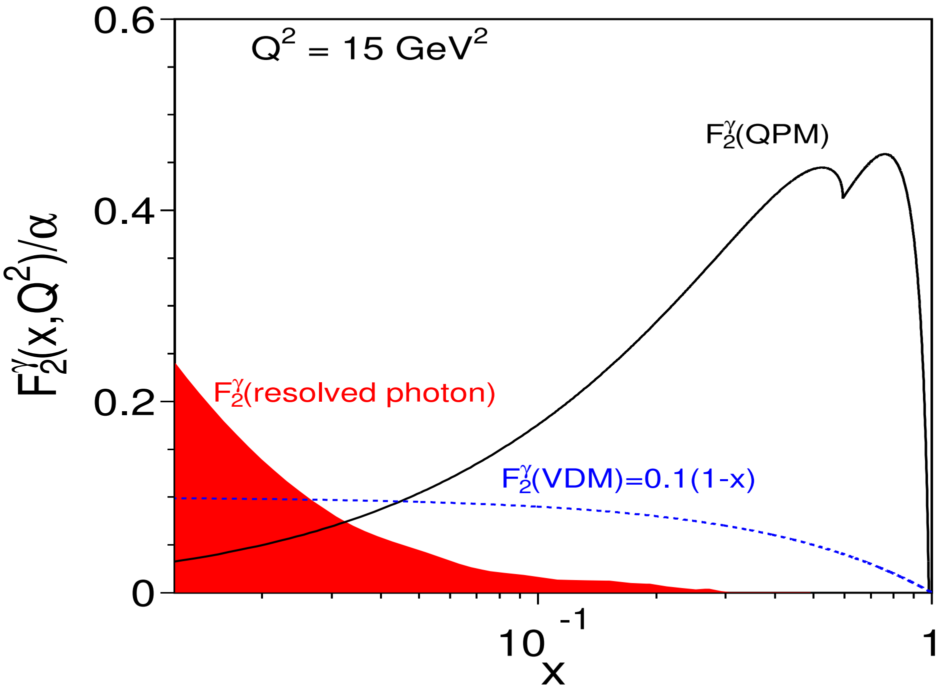
$F_2^\gamma(\mathrm{x},Q^2)$



- **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**

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F_2^γ : Data samples

Measurement	$\sqrt{s}$	θ_{tag}	Q^2	P^2	x	Ref
	GeV	mrad	GeV^2	GeV^2		
L3 Low Q^2	91	26-66	1.2-9	0.08	0.002-0.2	(1)
L3 Medium Q^2	183	30-66	9-30	0.08	0.01-0.3	(2)
L3 High Q^2 Single tag	91	200-600	40-500	0.014	0.05-0.98	Prel
L3 High Q^2 Double tag	91	200-600	40-500	1-8	0.05-0.98	Prel

(1) Phys. Lett. B436 (1998) 403
(2) Phys. Lett. B447 (1999) 147

Measurement	Events	Bckgd	Luminosity
			pb^{-1}
L3 Low Q^2	9928	355	140
L3 Medium Q^2	1694	71	52
L3 High Q^2 Single tag	496	40	120
L3 High Q^2 Double tag	43	< 2	120

Data samples

Measurement	E_{tag}	W_{vis}
	GeV	GeV
L3 Low Q^2	> 35	3-40
L3 Medium Q^2	> 70	> 3
L3 High Q^2 Single tag	> 14	> 3
L3 High Q^2 Double tag	> 14	> 3

Cuts

- The analyses also use cuts on p_t, antitag, number of charged particle tracks.
- The High-Q^2 analysis uses additional cuts on event rapidity and thrust direction.

W_{vis} Measurement

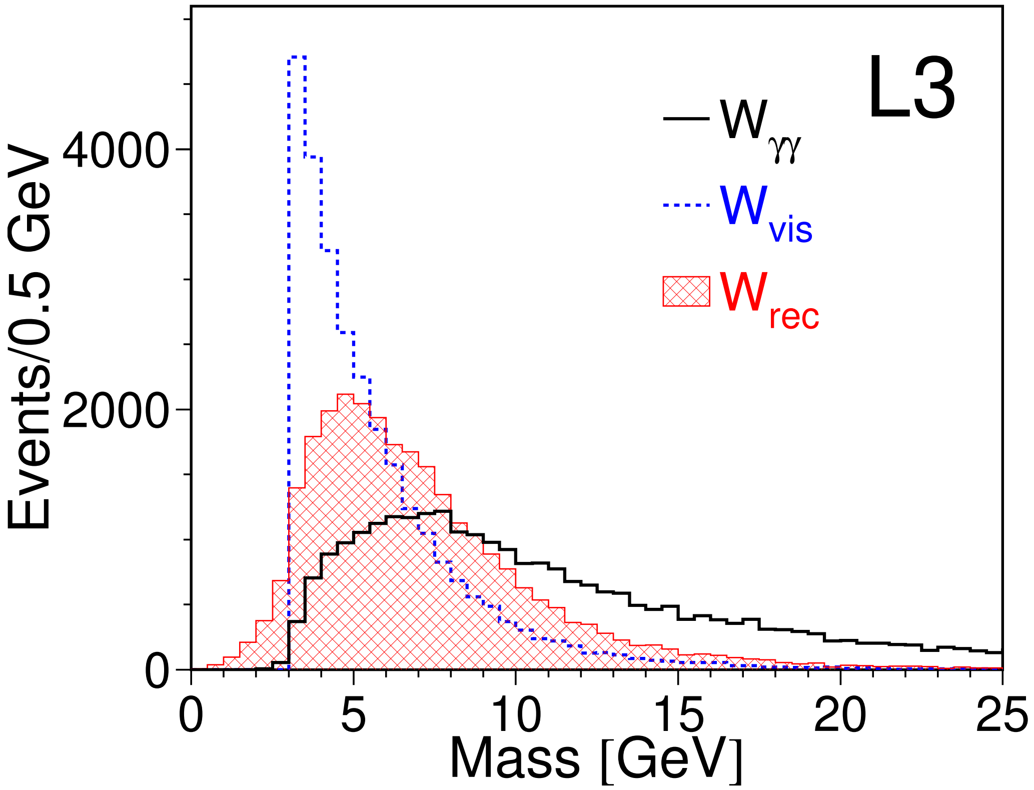
The hadronic final state is reconstructed from tracks and calorimetric clusters, but NOT completely due to detector acceptance: ➩ $W_{vis} < W_{\gamma\gamma}$ and $x_{vis} > x$.

L3 explored several ideas to improve W_{vis} measurement:

- Use kinematics of the tagged electron and transverse momentum conservation*

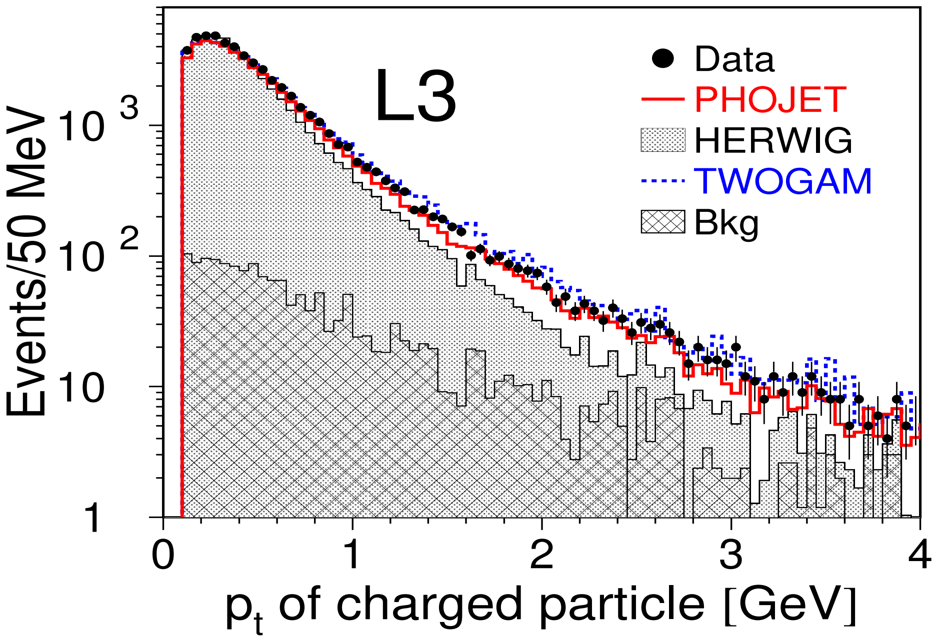
$$W_{rec}^2 \equiv (p_+^{e_{in}} - p_+^{e_{tag}})(\sum_i p_-^i) - |p_t^{e_{tag}}|^2, \text{ with } p_\pm \equiv E \pm p_z$$

* Physics at LEP2, CERN 96-01, Vol.2, 201 (Jaquet-Blondel).



➩ At low mass W_{rec} improves the measurement, but unfolding is still necessary.

MC Comparison at low Q^2

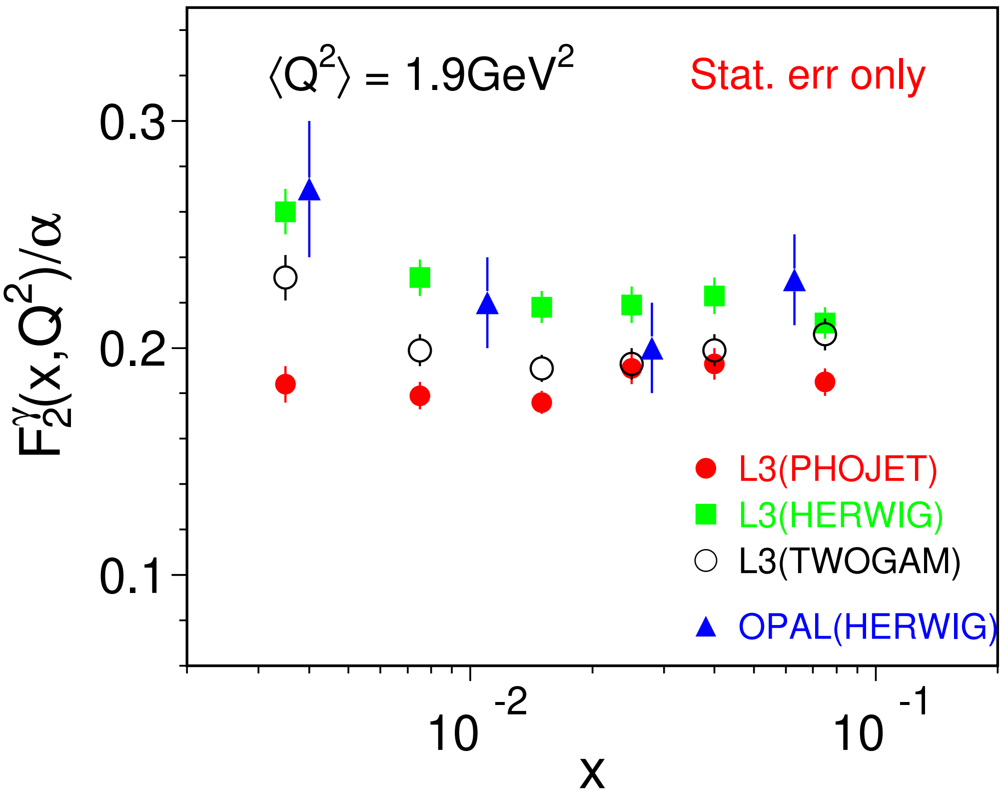


- p_t is defined wrt the beam direction.

- **PHOJET** and **TWOGAM** give an equally adequate description of the data. **HERWIG** fails.

F_2^γ : Modeling Dependence

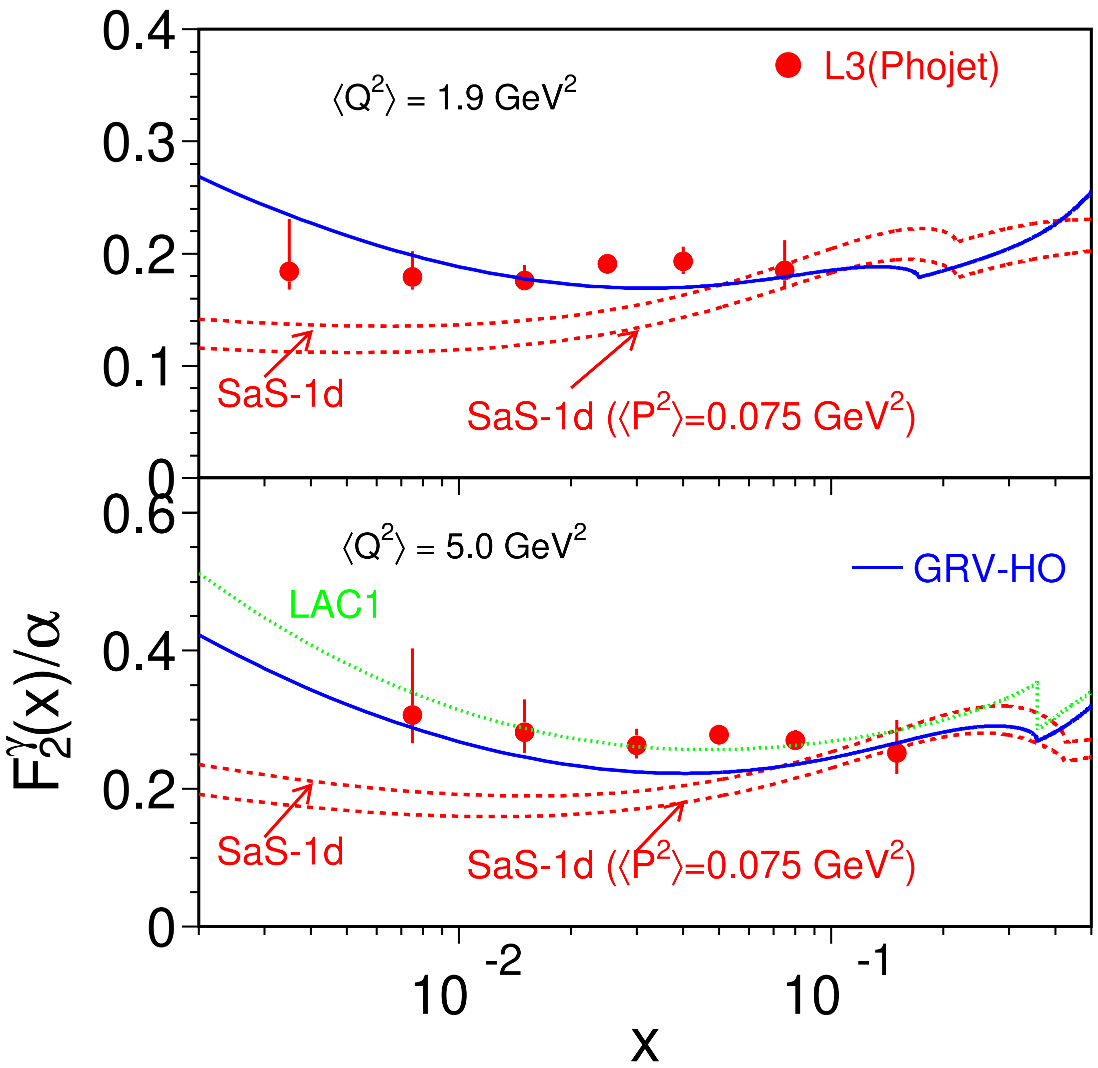
- Unfold the data: $x_i = \sum_i A_{ij} x_j^{rec}$;
  A_{ij} is specific for the Monte Carlo model.



- Good agreement between L3 and OPAL if the same model is used.
- At low x (high mass) → large differences between the different Monte Carlos lead to differences between the unfolded values of F_2^γ ($\sim 10 - 30\%$).

F_2^γ : low Q^2

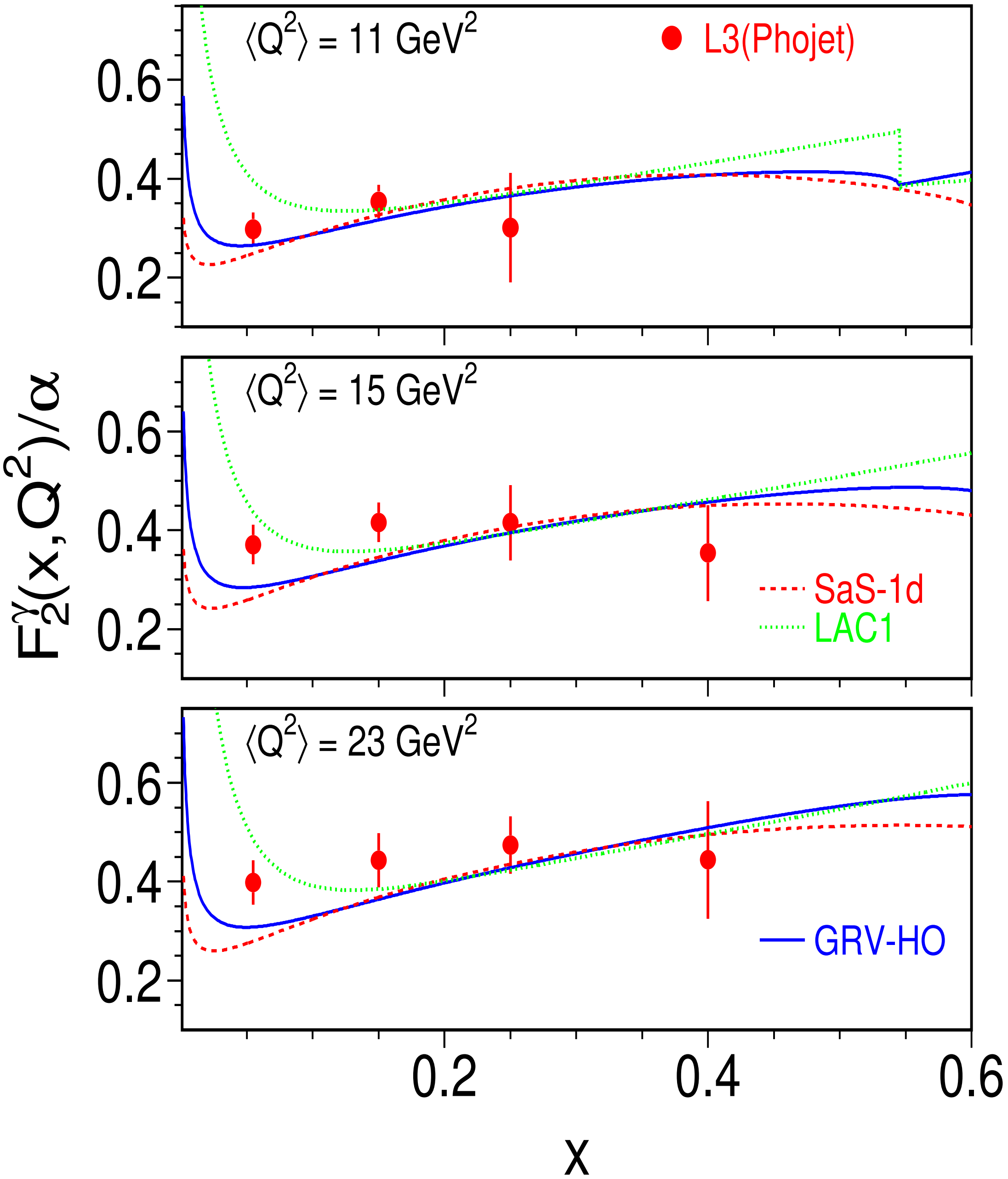
❑ Low Q^2 ➜ access to low x



- **SaS-1d** lies **below the data**.
- **GRV-HO** gives a good description at 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 unknown 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**

High-Q^2 analysis

- **Kinematic fitting (2C- or 3C-fit) improves the resolution and the agreement between measured and generated values.**

  Minimize:

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

$$\Delta p_1 \equiv E - \sum_l E_l^h$$

$$\Delta p_2 \equiv p_z - \sum_l p_{z,l}^h$$

$$\Delta p_3 \equiv p_{in} - \sum_l p_{in,l}^h$$

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

Constraints:

$$C_1 = E^- + E^+ + E - 2E_{beam} + 2RC = 0$$

$$C_2 = p_z^- + p_z^+ + p_z = 0$$

$$C_3 = p_{in}^- + p_{in}^+ + p_{in} = 0$$

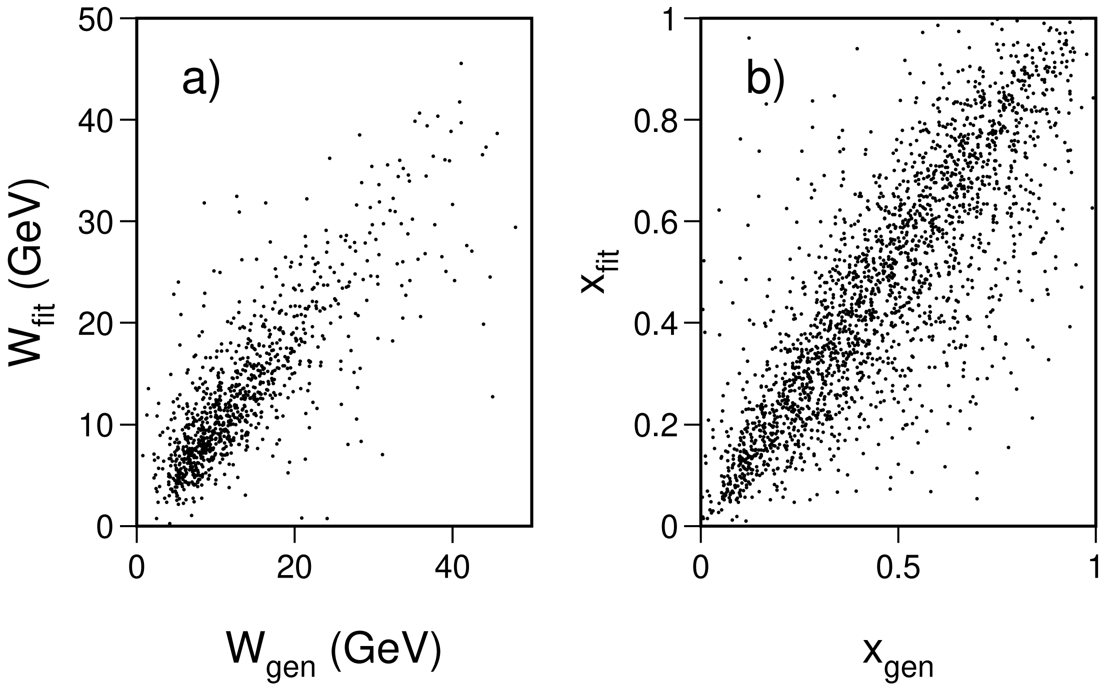
RC is an estimate of the average radiative correction. For Single Tag combine C_1, C_2: $E^+ = -p_z^+$ and $p_{in}^+ = 0$. The mean values of $C_1 - C_3$ are adjusted to zero by an overall scale factor for the hadronic energy. The fit allows a calculation of

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

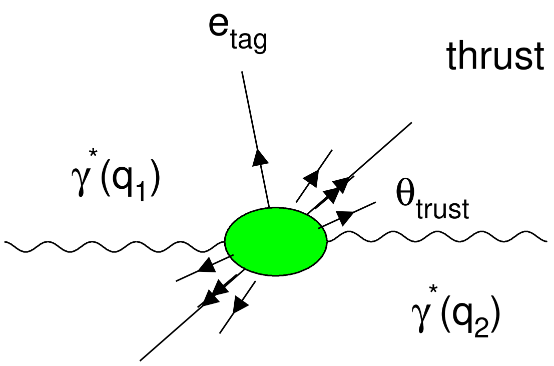
and the momentum of the target photon.

High-Q^2: W_{fit} and x_{fit}

- JAMVG Monte Carlo at $\sqrt{s} = 91$ GeV, $< Q^2 >= 120$ GeV^2, $P^2 = 0$.

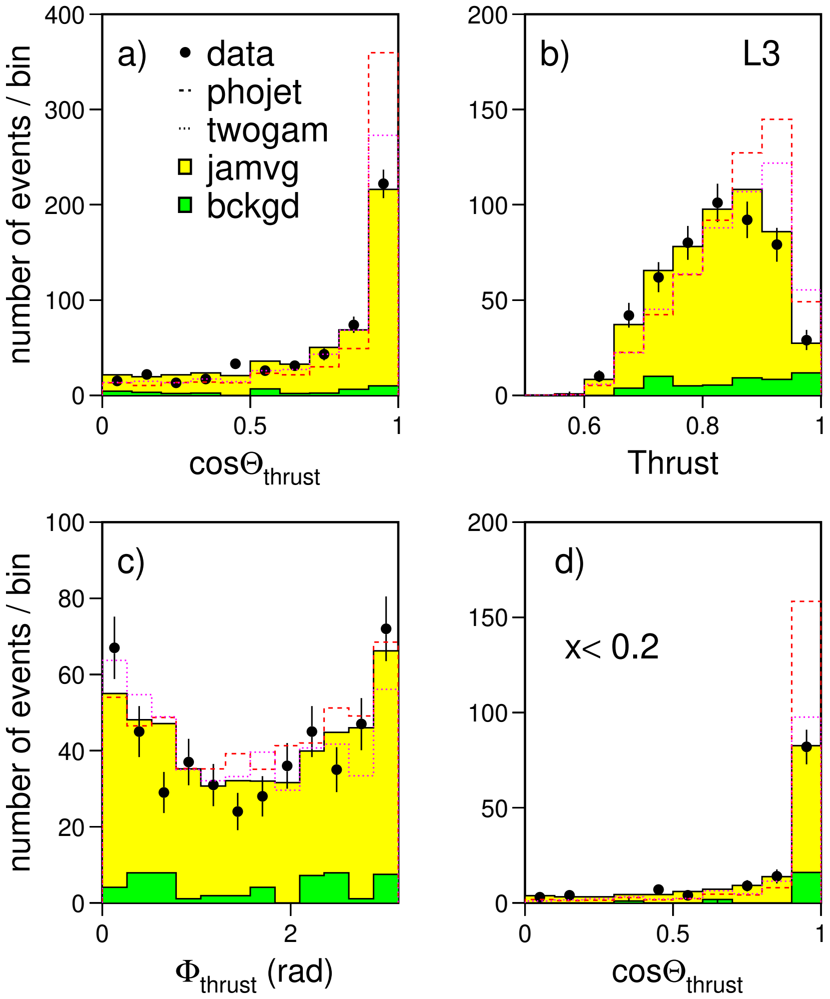


- ⇨ On average the relations are linear.
- ⇨ This simplifies the task of unfolding. It involves little extrapolation from low fitted to high $W_{\gamma\gamma}$.
- ⇨ PHOJET and TWOGAM produce similar correlations.
- Transformation to $\gamma\gamma$ CM can be made.



High-Q^2: Thrust in $\gamma^*\gamma^*$ CM

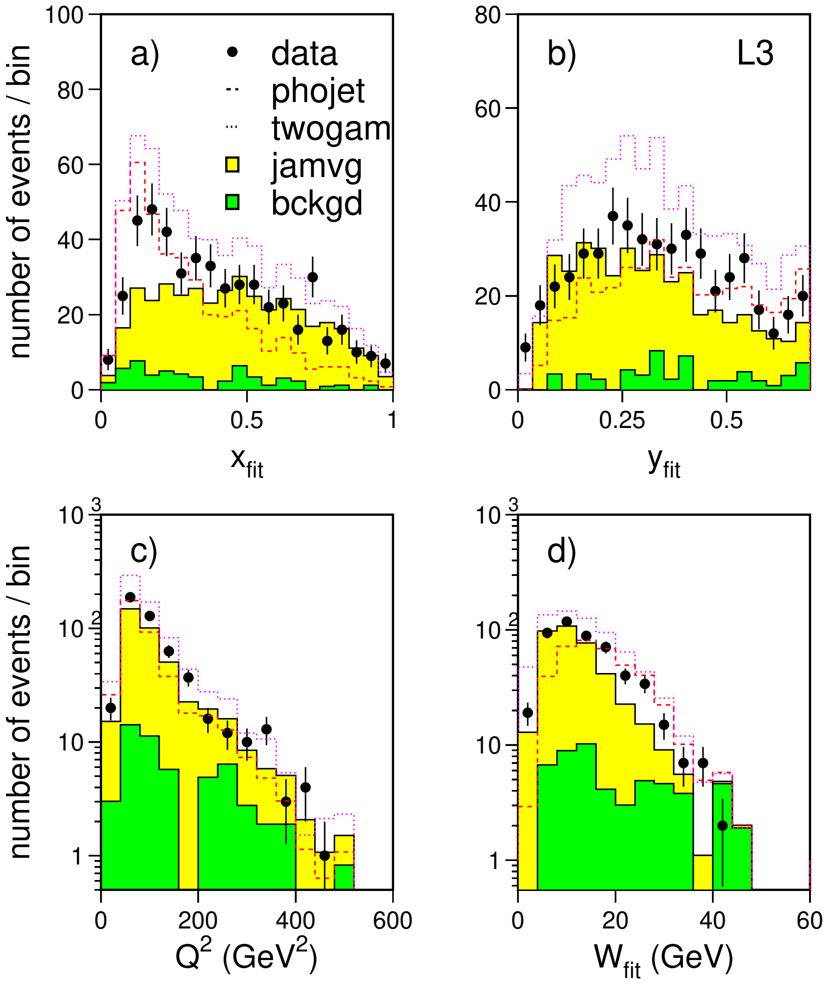
- $< Q^2 >= 120$ **GeV**^{2}, $P^2 = 0$



- **MC distributions normalized to data-background.**
- **Thrust is well described by JAMVG. In PHOJET and TWOGAM the particles are more aligned along the thrust axis than in the data.**
- **No sign of a forward-peaking diffraction contribution, even not at $x < 0.2$.**
- **Azimuthal distribution is well reproduced by all generators.**

High Q^2: $x_{fit}, y_{fit}, Q^2, W_{fit}$

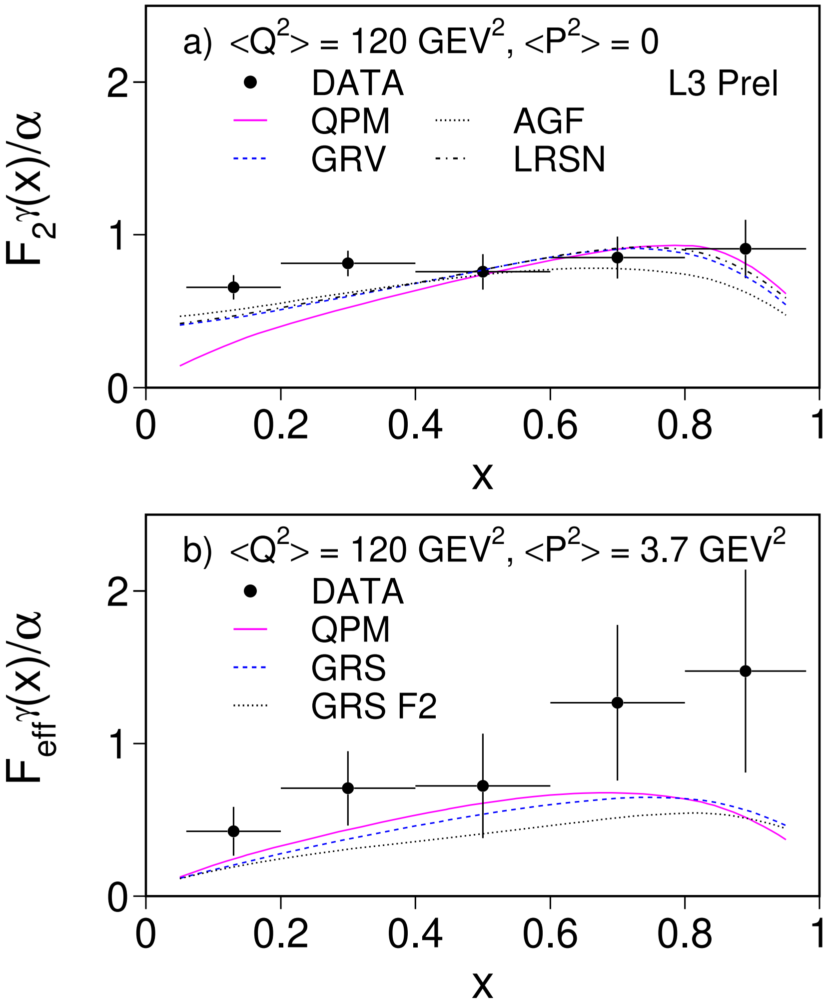
- $<Q^2>= 120$ **GeV**^{2}, $P^2 = 0$



- **MC distributions normalized to the integrated luminosity of the data.**
- **For $x > 0.5$ and $y < 0.4$ the JAMVG describes the data well.**
- **At lower x and larger y the data agrees roughly with PHOJET.**

F_2^γ : high Q^2

❑ F_2^γ versus x



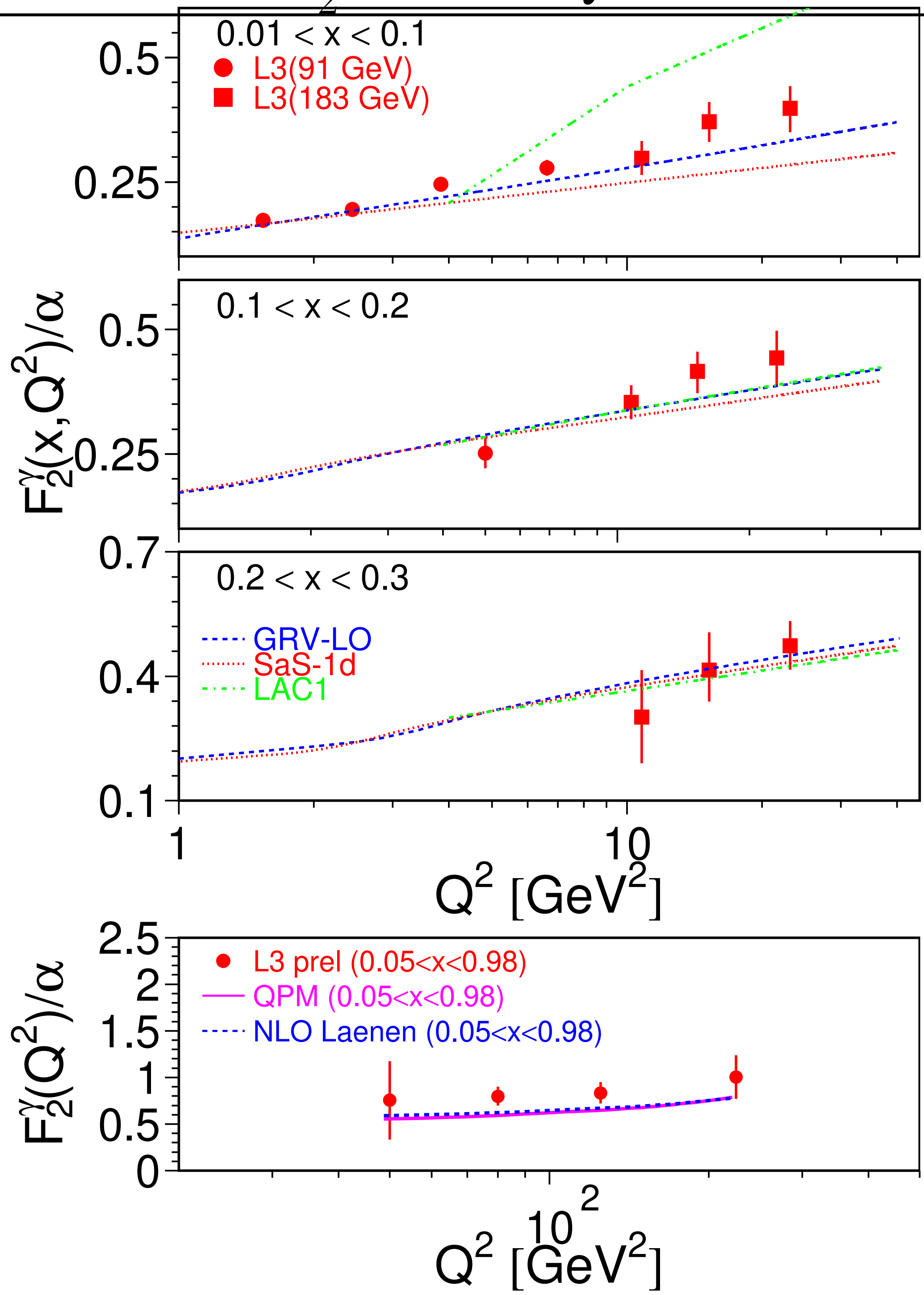
➩ **QPM (with light- and charm quark masses 0.325 and 1.6 GeV) describes the F_2^γ data for $x > 0.5$.**

➩ **The QCD calculations by GRV-HO, AGF lie somewhat below the data for $x < 0.4$.**

➩ **For virtual photons the F2 calculated by GRS is supplemented with longitudinal photon contributions from the QPM to allow comparison with the data.**

➩ **The Structure function for virtual photons is somewhat high wrt QPM and GRS.**

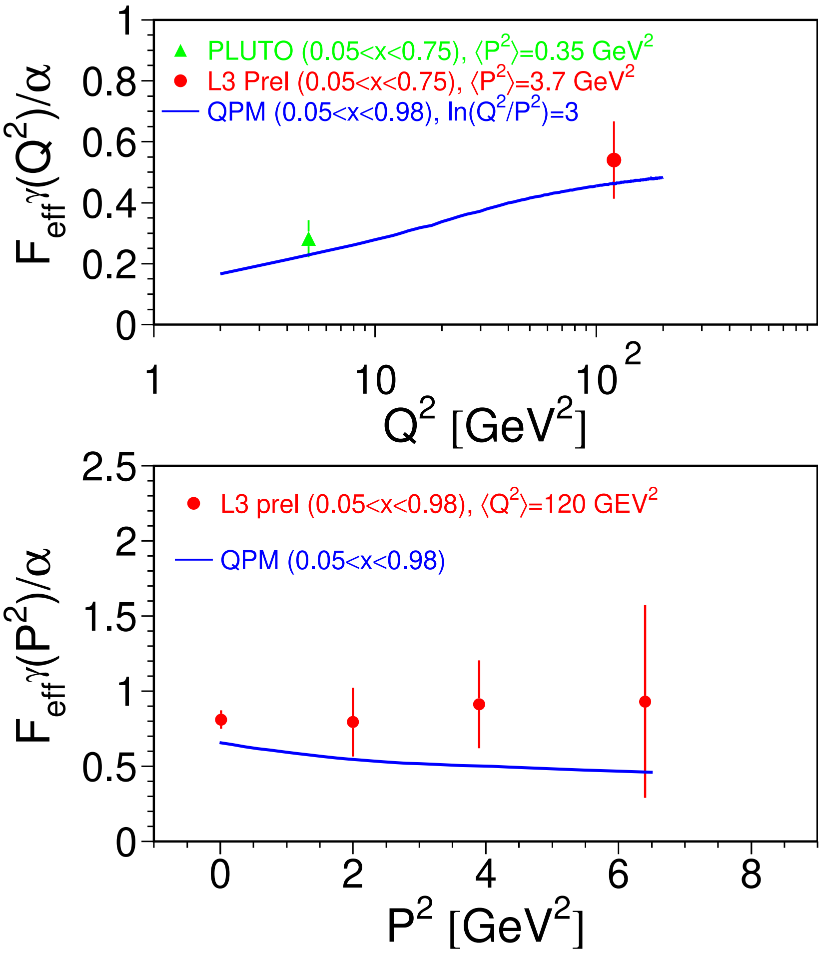
F_2^γ versus Q^2



⇨ **LAC1 disagrees with the data in the low x bin**

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

F_{eff}^{γ} versus Q^2 and versus P^2



- The Q^2 evolution for F_{eff}^{γ} agrees with the QPM prediction for $\ln(Q^2/P^2) = 3$.
- The P^2 evolution for F_{eff}^{γ} agrees with the QPM prediction.
- The data lie somewhat above the predictions.

Conclusions

- The W_{vis} measurement is improved by using kinematical constraints. Kinematic fitting leads to an improved description of $\gamma^*\gamma^*$ collision parameters.

- Hadronic Photon Structure Function, F_2^γ for $1\,\mathrm{GeV}^2 < Q^2 < 500\,\mathrm{GeV}^2$ and $0.002 < x < 1$ at L3

  - Low Q^2 and medium Q^2:
    - GRV-HO reproduces the data well, but too low for $x < 0.1$.
  - High Q^2:
    - At low x Perturbative theory including resolved processes is somewhat lower than the data
    - No sign of diffraction seen, even for $x < 0.2$
  - Q^2 evolution of F_2^γ and F_{eff}^γ agrees with QCD