Study of Photon Structure Functions at L3

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$\Rightarrow$ **Leptonic structure function :**

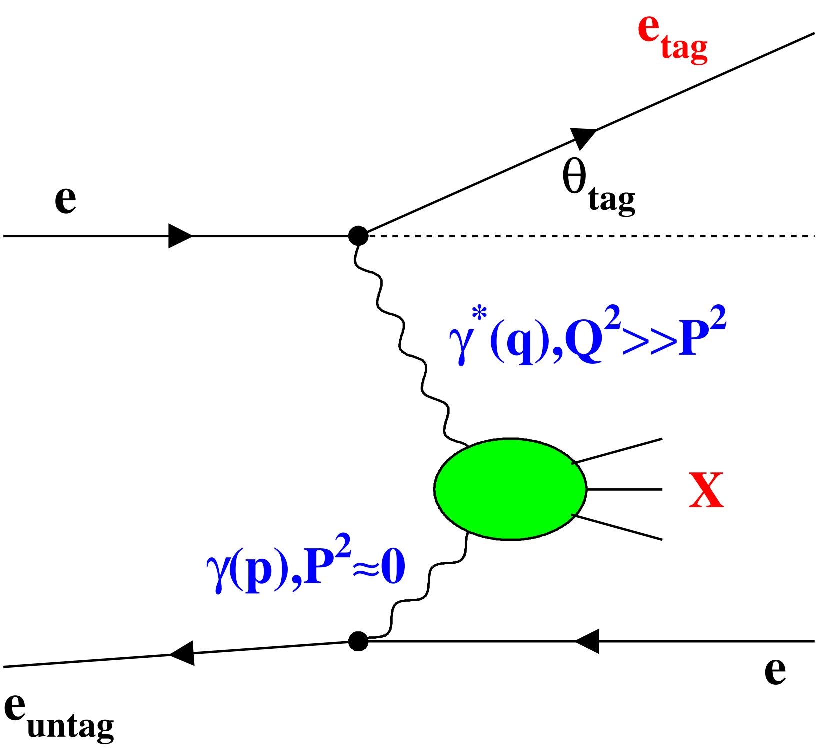
- x dependence
- Azimuthal Correlation $\rightarrow F_L^\gamma$

$\Rightarrow$ **Hadronic structure function :**

- x dependence $\rightarrow$ low $x \sim 10^{-2}$
- Q^2 evolution

DIS98, April 4-8 1998

Kinematics



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

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

$\Rightarrow$ Only F_2^γ is measurable since y^2 is small.

$\Rightarrow$ The effect of F_L^γ can be seen in azimuthal correlation of $e\gamma \longrightarrow el^+l^-$.

$F_{2,\mathrm{QED}}^{\gamma}$: Event Selection

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

  $\mathcal{L} = 94\mathrm{pb}^{-1}$, $\sqrt{s} \simeq 91\mathrm{GeV}$

- Event selection :

  ⇨ $E_{tag} > 35\mathrm{GeV}$
  ⇨ Only two opposite charged tracks
  ⇨ μ identification

- Monte Carlo :

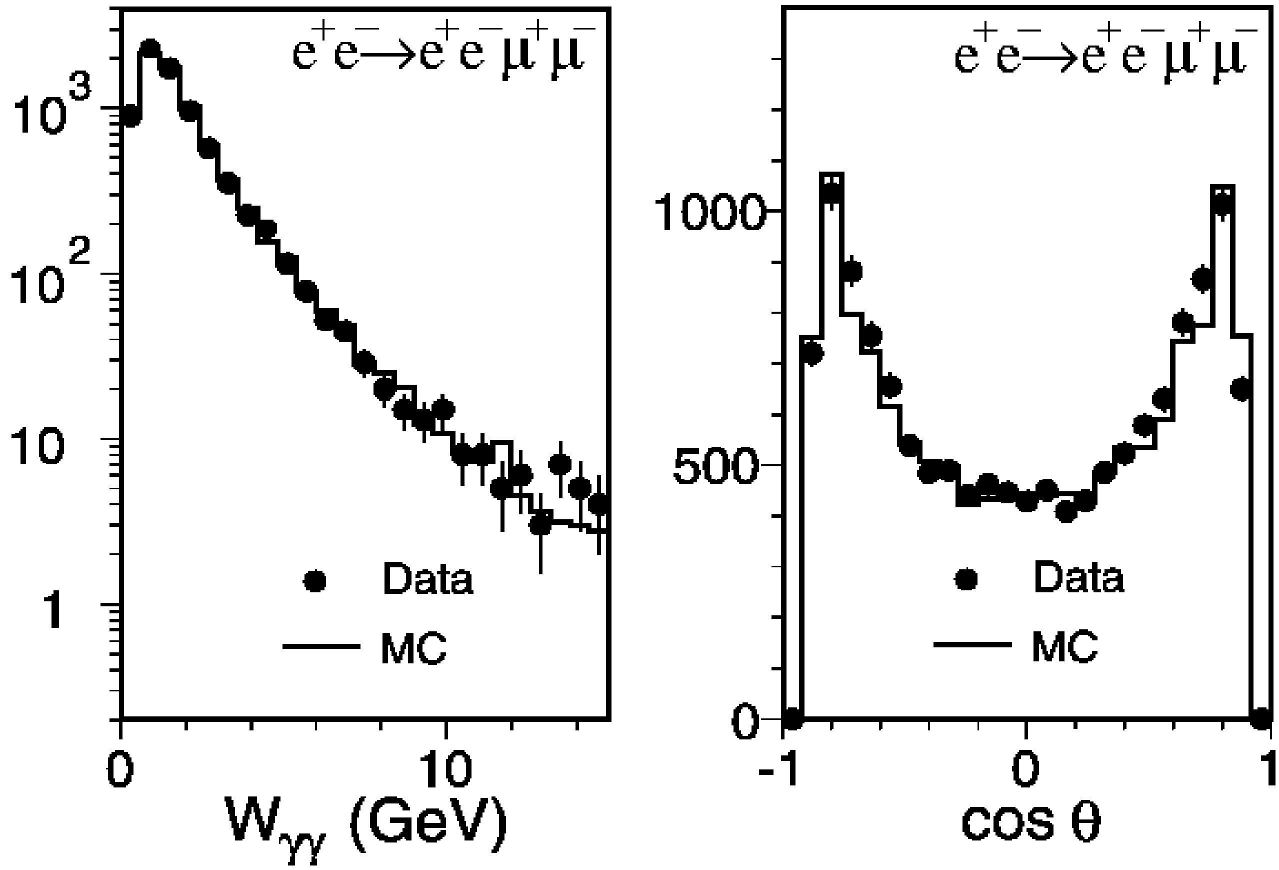
  Vermaseren : J. Vermaseren
  (Nucl. Phys. B229, 347)

  DIAG 36 : F.A. Berends, P.H. Daverveldt and R. Kleiss
  (Nucl. Phys. B253, 441)

  RADCOR : F.A. Berends, P.H. Daverveldt and R. Kleiss
  (Nucl. Phys. B253, 421)

$F_{2,\mathrm{QED}}^{\gamma}$: MC Comparison

- Select 7152 ± 85 events in $1.4 < Q^2 < 7.6\ \mathrm{GeV}^2$ after background subtraction.
- The background contamination is 1.8% from $\gamma^*\gamma \rightarrow \mathrm{e}^+\mathrm{e}^-$, $\tau^+\tau^-$ and $q\bar{q}$.



$\Rightarrow$ Consistent with Monte Carlo expectation.

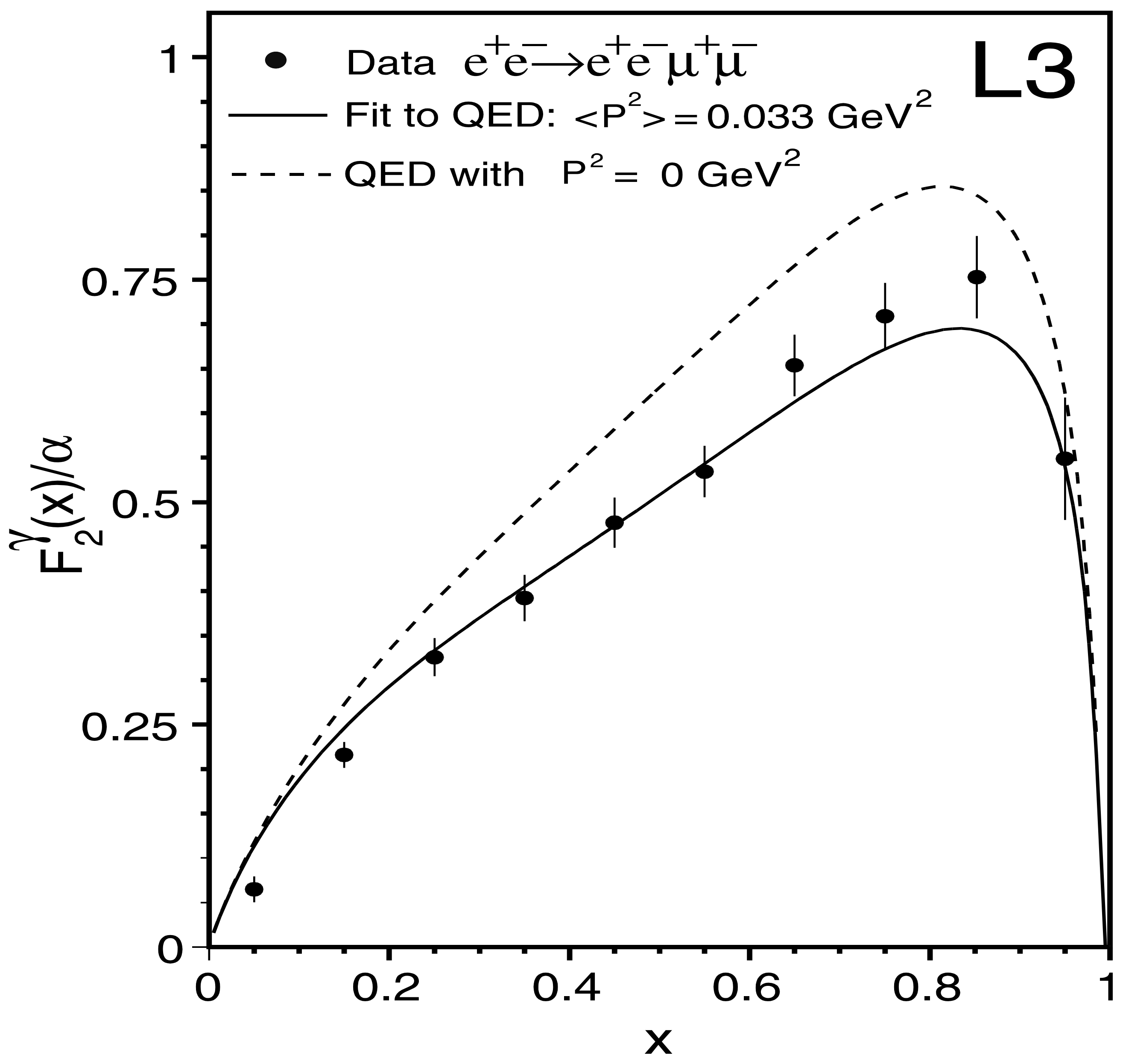
F_2^γ Extraction

$\Rightarrow$ **Neglecting y^2 terms :**

$$F_2^\gamma(x,Q^2) = \mathcal{W}(x,Q^2)\frac{d^2\sigma_{e\gamma\to e\mathrm{X}}}{dxdQ^2}$$

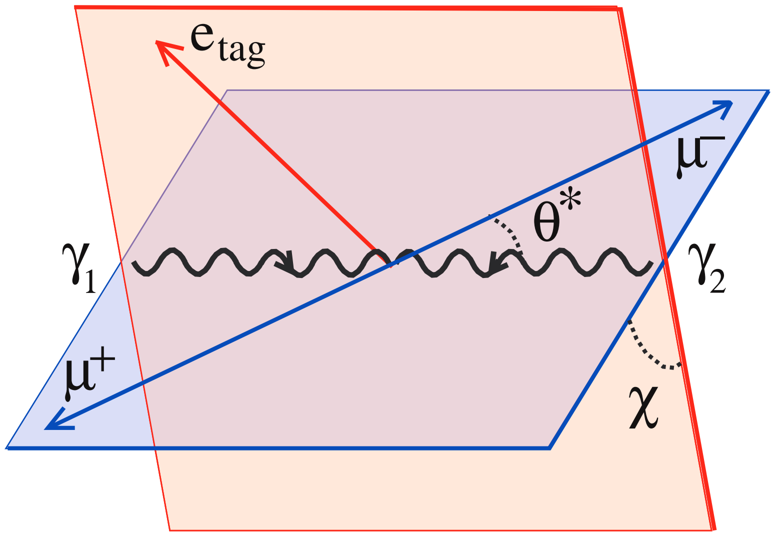
$\Rightarrow$ **$\mathcal{W}(x,Q^2)$ is calculated by Monte Carlo integration.**

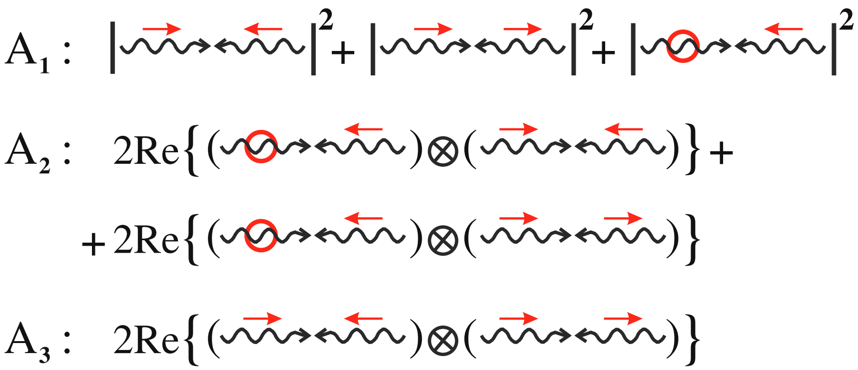
$F_{2,\mathrm{QED}}^{\gamma}$: x Dependence



⇒ Consistent with QED prediction with non-zero photon virtuality.

⇒ $\langle P^2 \rangle = 0.033 \pm 0.005$ GeV^2 agrees with MC including Radiative Corrections.
($\langle P^2 \rangle = 0.024$ GeV^2 predicted by MC without R.C.)





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

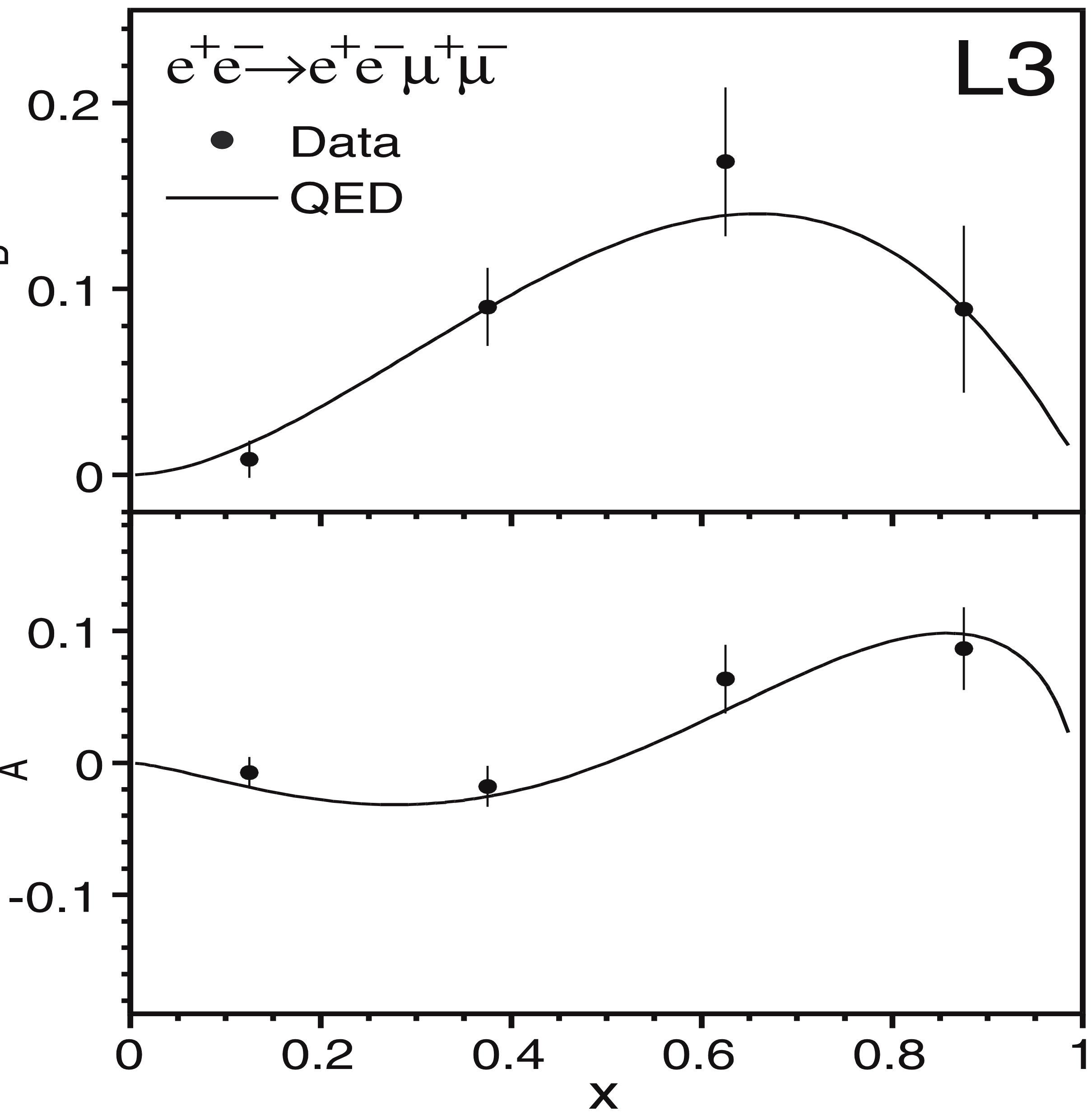
$$z = \cos\theta^*$$

$A_1 \propto F_2^\gamma \Rightarrow$ **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 seen ➔ $F_L^\gamma \neq 0$

⇒ Consistent with QED prediction.

$F_{2,\mathrm{QCD}}^{\gamma}$: Event Selection

- $\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}\textit{hadrons}$

  $\mathcal{L} = 140\mathrm{pb}^{-1}$, $\sqrt{s} \simeq 91\mathrm{GeV}$

- Event selection :

  ⇨ $E_{tag} > 35$ GeV
  ⇨ Number of charged tracks > 2
  ⇨ $3 < W_{vis} < 40$ GeV^2
  ⇨ $p_t^{out} < 5$ GeV
  $p_t^{bal} = |\vec{p_t}^{in} + \vec{p_t}^{tag}| < 5$ GeV

- Monte Carlo :

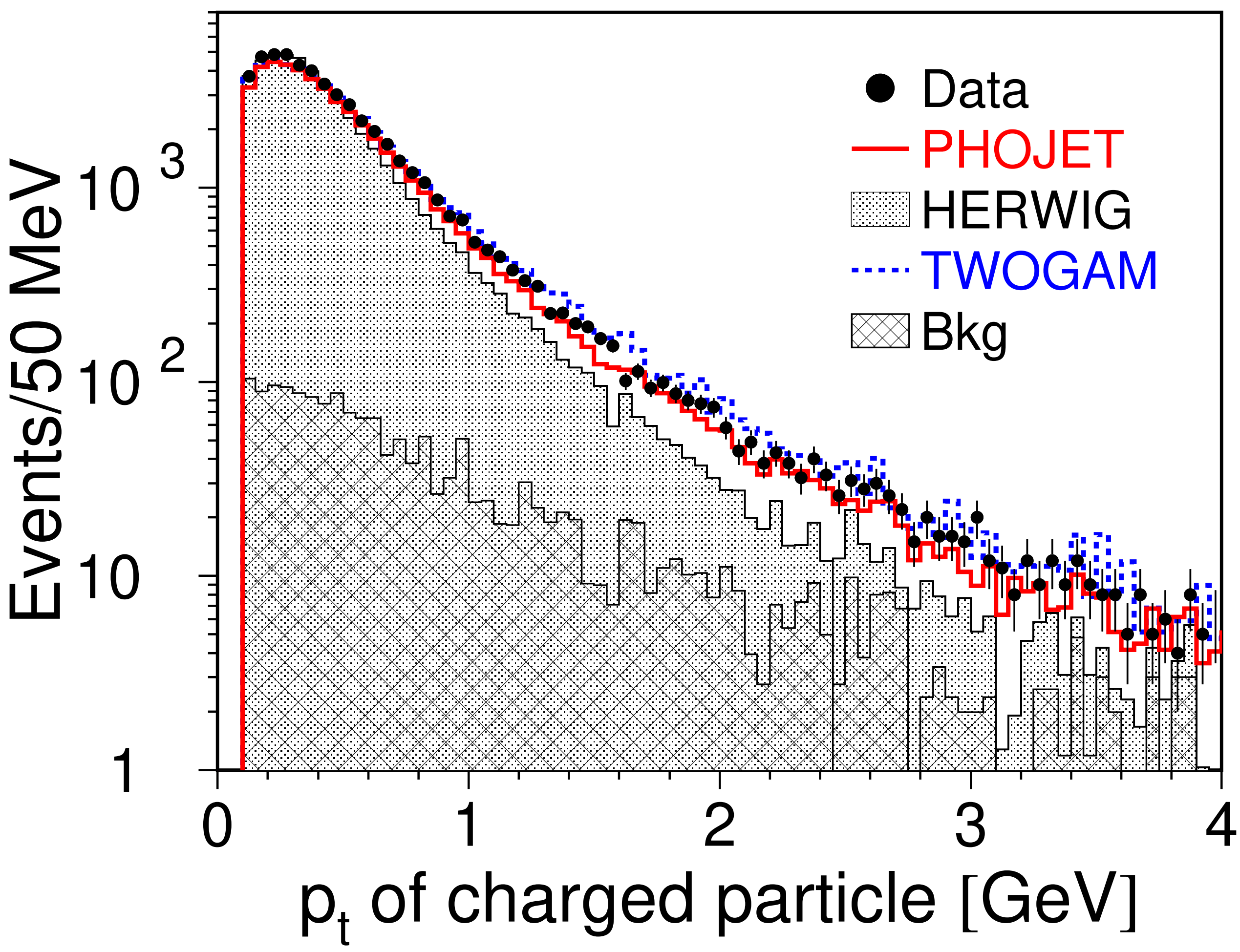
  PHOJET: R. Engel and J. Ranft.
  (Phys. Rev. D54, 4246)

  HERWIG: G. Marchesini et al.
  (CPC 67, 465)

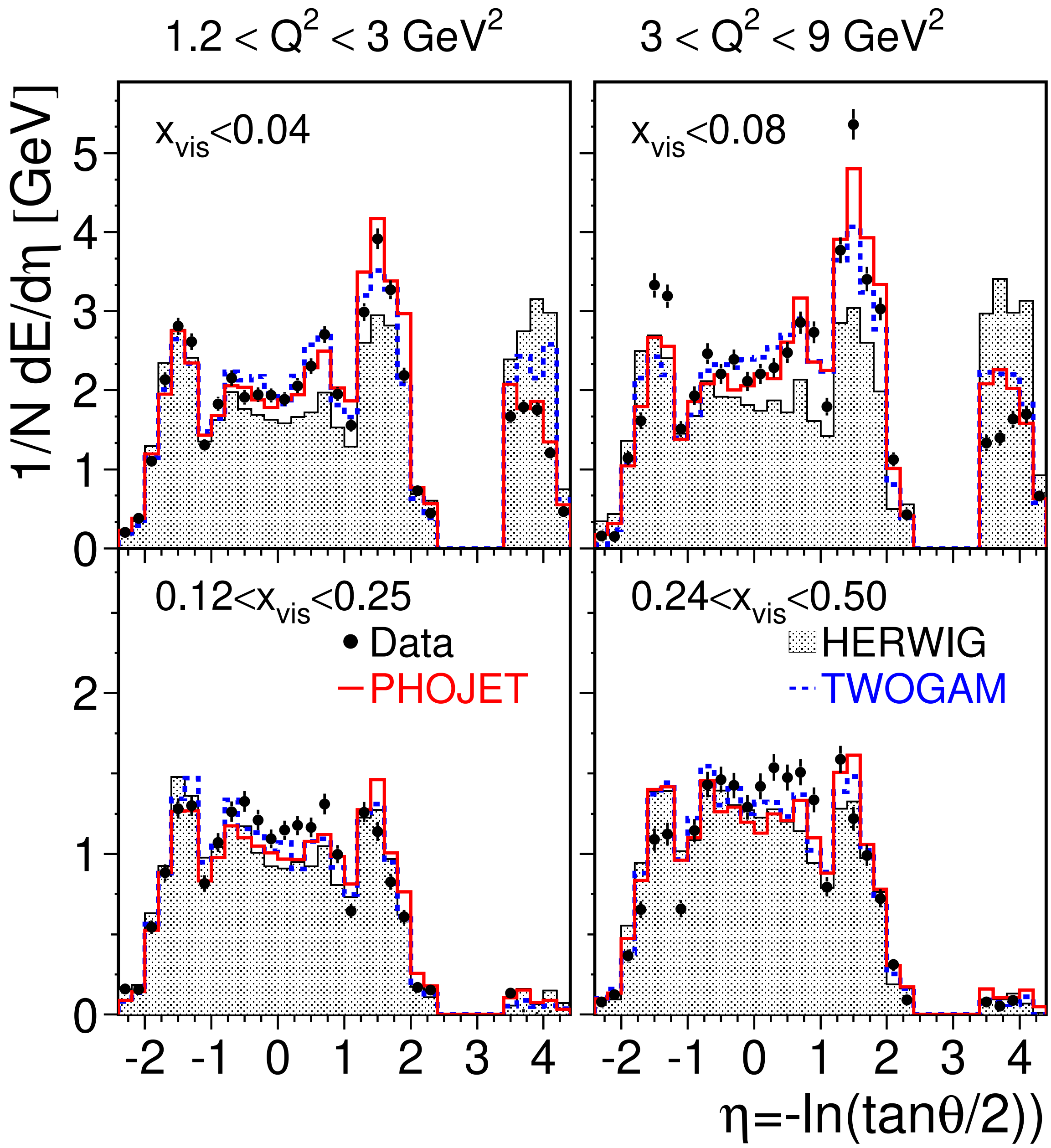
  TWOGAM: S. Nova, A. Olshevski and T. Todorov
  (DELPHI Note 90-35)

- **Select 9928 events in $1.2 < Q^2 < 9.0$ GeV^2**

Q^2(GeV)	selected	$\gamma^*\gamma \to \tau^+\tau^-$	$Z \to q\bar{q}$
1.2 - 3.0	5772	117.1	35.4
3.0 - 9.0	4156	119.1	84.0



$F_{2,\mathrm{QCD}}^{\gamma}$: Energy Flow



⇒ **PHOJET and TWOGAM show reasonable agreement with the data.**

⇒ **HERWIG disagrees badly for small x.**

W_{vis} Measurement

- Due to detector acceptance and efficiency

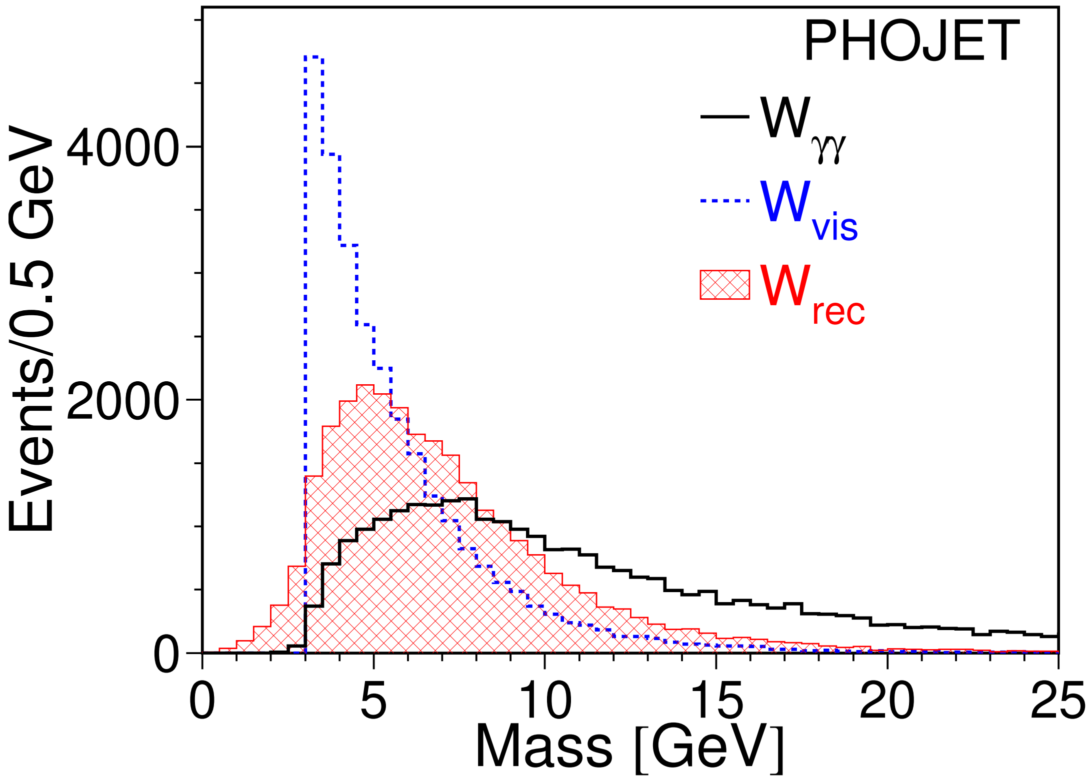
  $\Rightarrow W_{vis} < W_{\gamma\gamma}$ → Unfolding

- Improve $W_{vis} \Rightarrow$ Use kinematics of e_{tag}

$$W^2_{rec} \equiv (p^{e_{in}}_{+} - p^{e_{tag}}_{+})(\sum_i p^i_{-}) - |p^{e_{tag}}_t|^2$$

$$p_{\pm} \equiv E \pm p_z$$

* Physics at LEP2, CERN 96-01, Vol.2, 201.



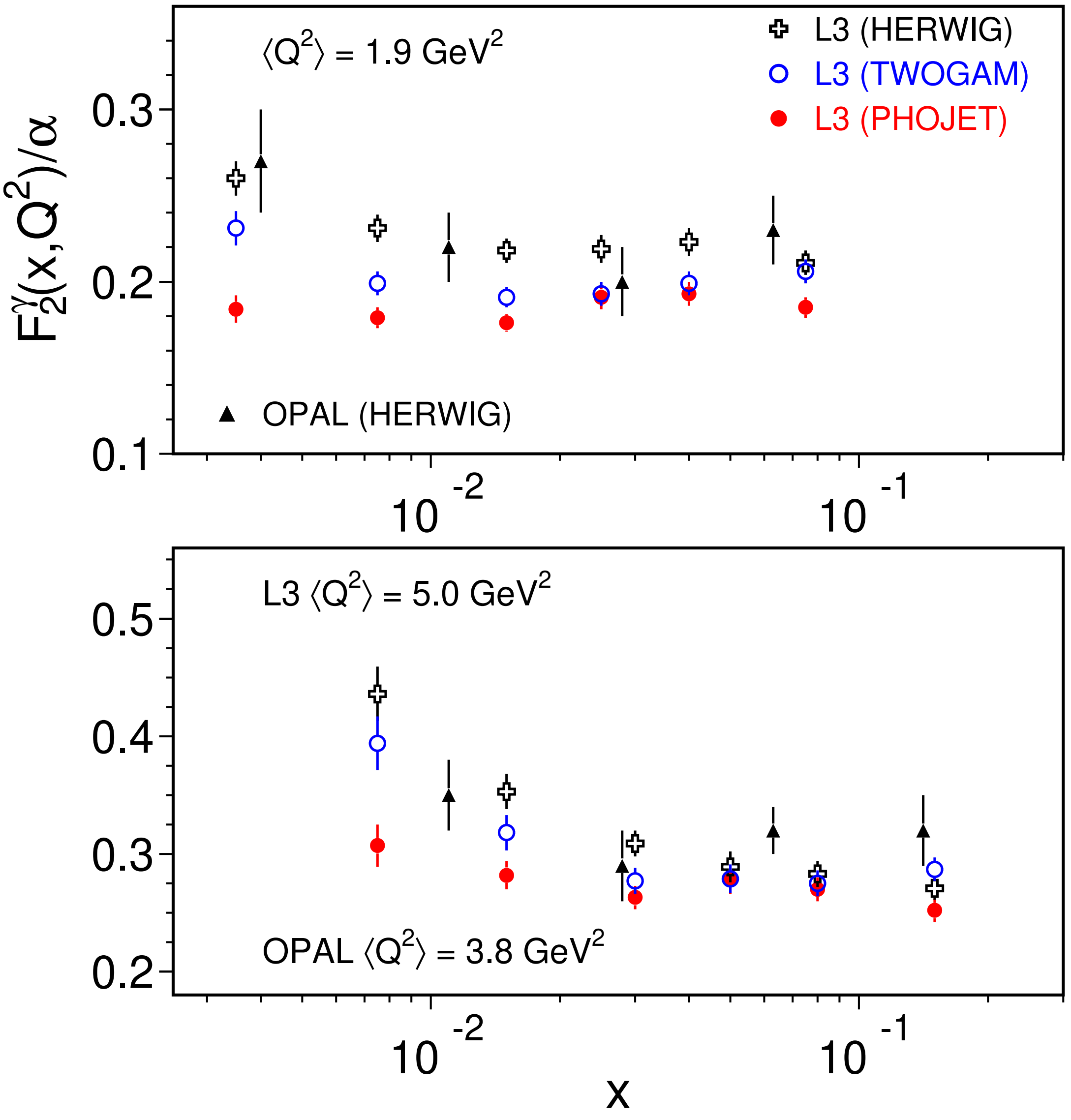
- $x_{rec} \rightarrow x$

  $\Rightarrow$ Unfolding by Prof. D'Agostini's program.

  * NIM, A372, 469.

$F_{2,\mathrm{QCD}}^{\gamma}$: Modelling Dependence

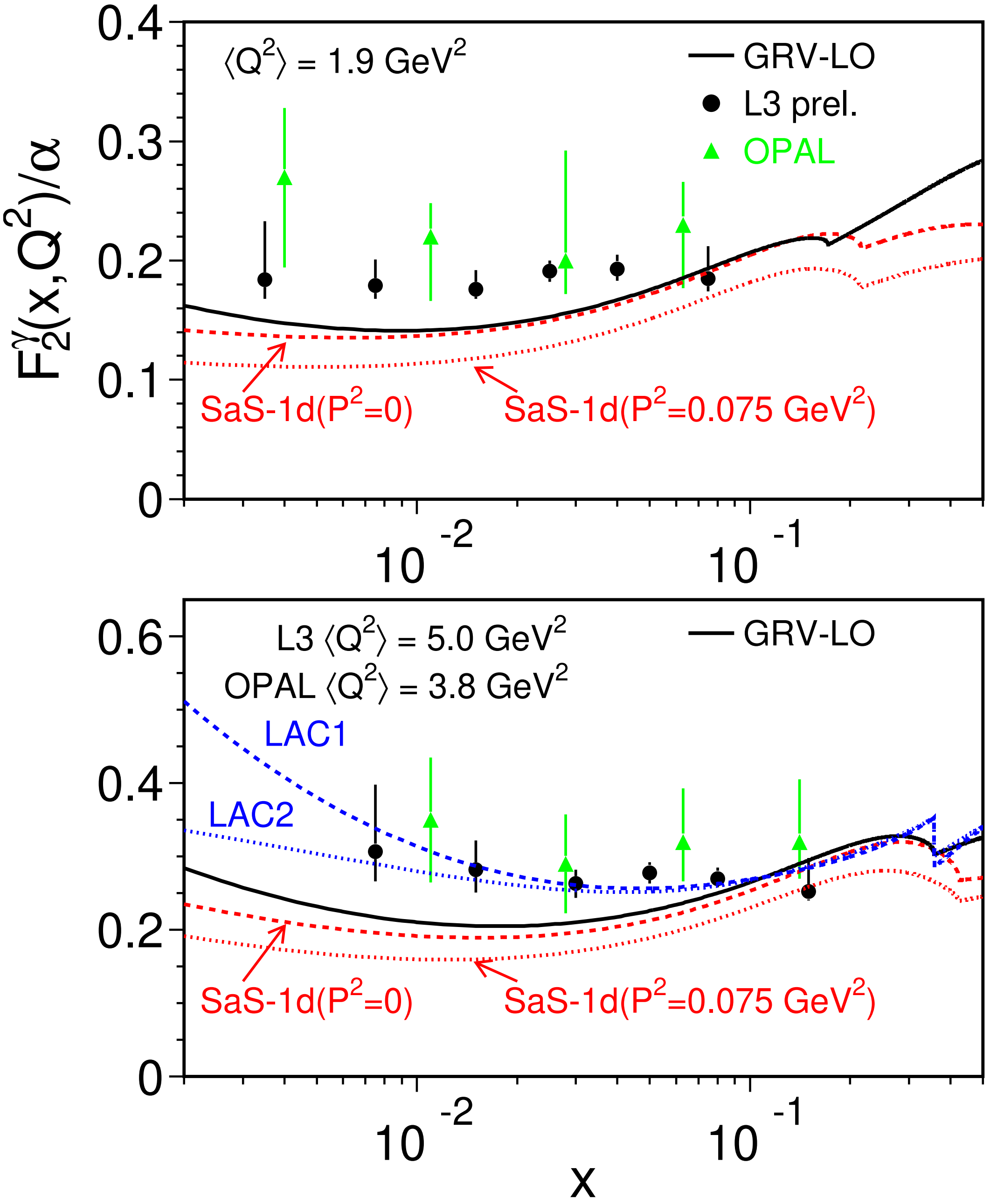
- **Data are unfolded with different Monte Carlos**



⇒ **Use the value from PHOJET.**

⇒ **Take a discrepancy between PHOJET and TWOGAM as systematic error.**

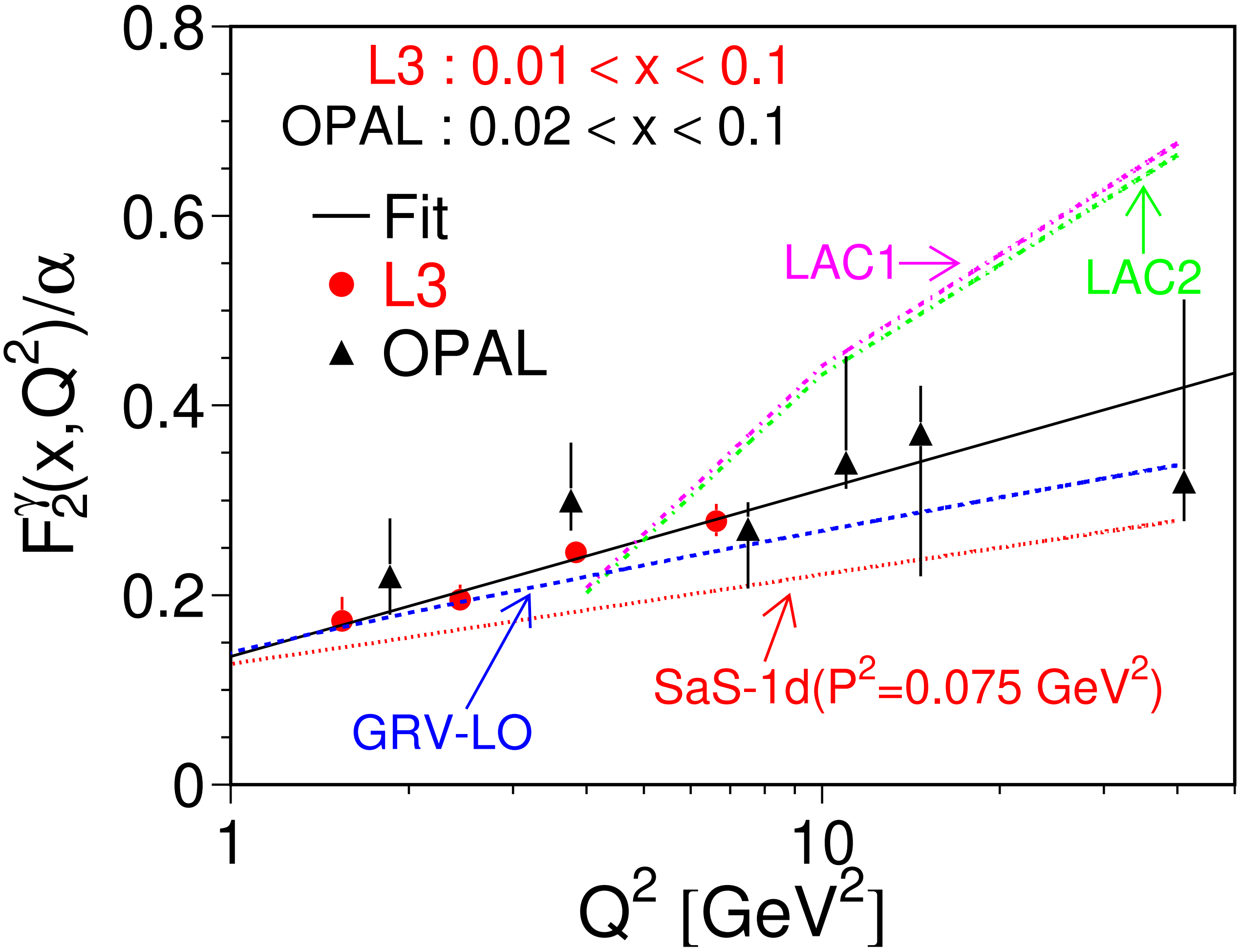
$F_{2,\mathrm{QCD}}^{\gamma}$: x dependence



⇒ **The dominant error is Modelling dependence**

⇒ **LAC is favoured at $Q^2 = 5\ \mathrm{GeV}^2$ ➜ Check Q^2 evolution**

- Four Q^2 bins in $0.01 < x < 0.1$
- Fit with $a + b \times \ln(Q^2/\mathrm{GeV}^2)$



$\Rightarrow$ $a = 0.135 \pm 0.006^{+0.029}_{-0.008}$, $b = 0.076 \pm 0.006^{+0.008}_{-0.018}$

$\Rightarrow$ $F^{\gamma}_2(Q^2) \propto \ln Q^2$

$\Rightarrow$ The slope predicted by LAC is too large.

Summary and Conclusions

- Leptonic structure function :

  $\Rightarrow$ $F_{2,\mathrm{QED}}^{\gamma}$ is measured in $1.4 < Q^2 < 7.6$ GeV^2.
  Clear non-zero photon virtuality effect in x dependence.

  $\Rightarrow$ First measurement of F_A and F_B.
  F_L^{γ} effect seen in Azimuthal correlation.

  $\Rightarrow$ Good agreement with QED.

- Hadronic structure function :

  $\Rightarrow$ $F_{2,\mathrm{QCD}}^{\gamma}$ is measured at $0.002 < x < 0.1$ ($Q^2 = 1.9\mathrm{GeV}^2$) and $0.005 < x < 0.2$ ($Q^2 = 5.0\mathrm{GeV}^2$).

  $\Rightarrow$ The $\ln Q^2$ evolution consistent with QCD.

$*$ The results are preliminary.