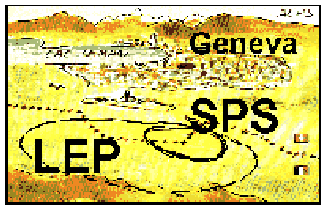
Two-Photon Physics at



Richard Nisius, CERN

DPG München, Gruppenvortrag 20.03.97

For the LEP Collaborations

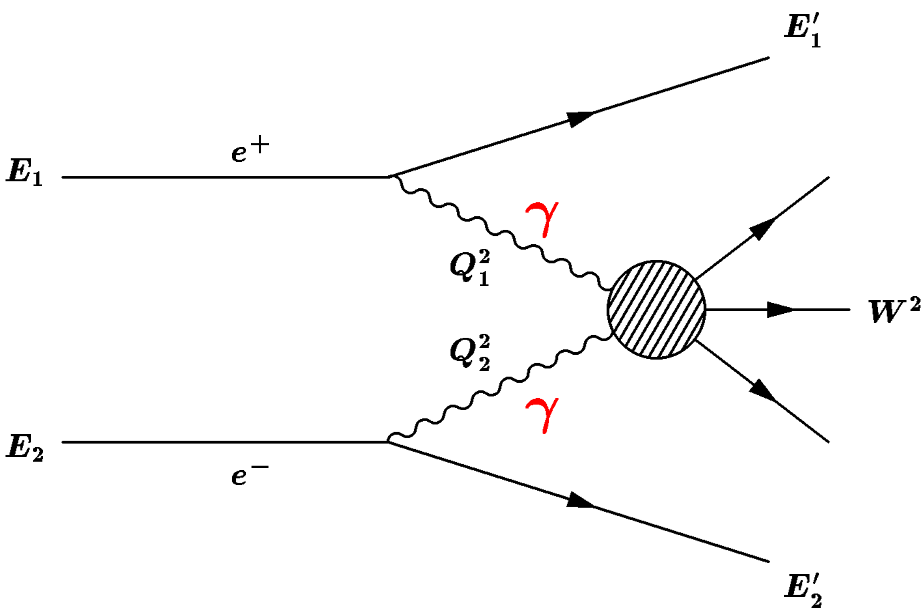
1. Photon-Photon scattering
   - Exclusive hadronic final states
   - Inclusive hadronic final states
2. Electron-Photon DIS
   - Lepton pairs and $F_{2,\mathrm{QED}}^{\gamma}$
   - The structure function $F_2^{\gamma}(x, Q^2)$

Analysis topics in Two-Photon events at LEP

	$\gamma\gamma$ scattering untagged events			$e\gamma$ scattering singly tagged events	
	exclusive hadronic f.s.	lepton pairs	$\gamma\gamma \longrightarrow$ hadrons	lepton pairs	$\gamma^{\star}\gamma \longrightarrow$ hadrons
A	$D^{*}(2010)^{\pm}$		hadron flow		
D			hadron flow		F_2^{γ} hadron flow
L	$K_S^0 K_S^0$, $\eta'(958)$ $a_2(1320)$, $f_2(1720)$? $\eta_c(1S)$, $\chi_{c2}(1P)$	$e\,\mu\,\tau$	$\sigma(W_{\gamma\gamma})$	e , μ $F_{2,QED}^{\gamma}$	
O			$\frac{d\sigma}{d\eta^{jet}}$ $\frac{d\sigma}{dE_T^{jet}}$	$e\,\mu\,\tau$ $F_{2,QED}^{\gamma}$	F_2^{γ} hadron flow

preliminary   published   presented

Photon–photon scattering



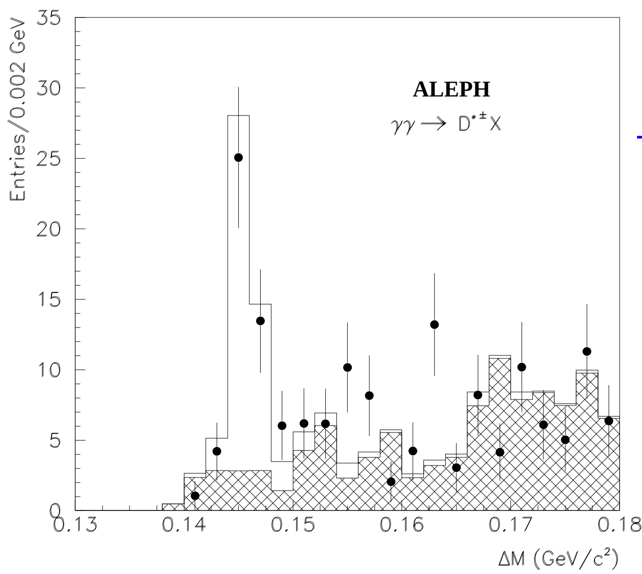
Exchange of two quasi-real photons (γ)

$$Q_i^2 = 2E_iE'_i(1-\cos\theta_i) \approx 0$$

$$W^2 = s_{\gamma\gamma} = \left(\sum_h E_h\right)^2 - \left(\sum_h \vec{p}_h\right)^2$$

At $\sqrt{s_{ee}} = 130\,\mathrm{GeV}$, for $W^2 > 4\,\mathrm{GeV}^2$ and $Q_i^2 < 1\,\mathrm{GeV}^2$:
$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- + \mathit{hadrons}) \approx 14\,nb \approx 40\cdot\sigma(\mathrm{e}^+\mathrm{e}^- \to (\gamma, \mathrm{Z}^0) \to \mathit{hadrons})$

$D^*(2010)^{\pm}$ production at LEP1



$M(D^{\star\pm}) - M(D^0)$

slow pion

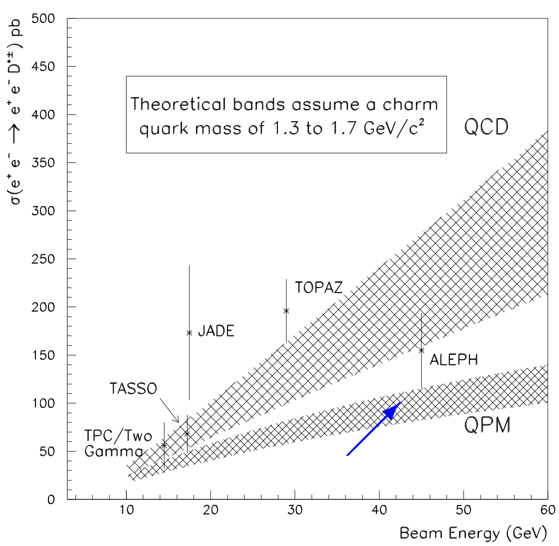
$$D^{\star +} \rightarrow D^0\,\pi^+$$

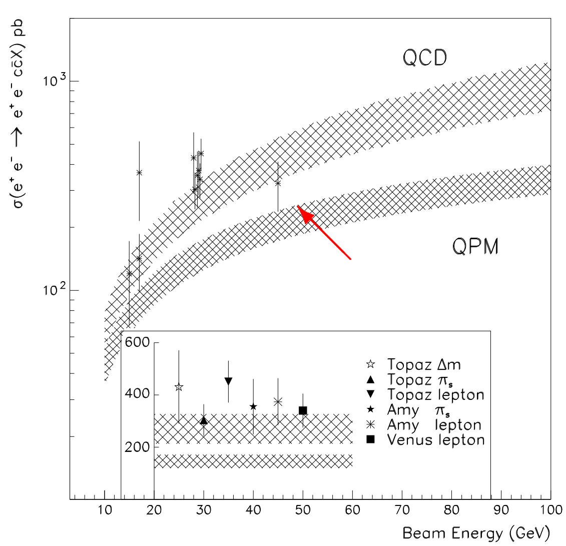
Decaymodes:

(1) $D^0 \rightarrow K^- \pi^+$

(2) $D^0 \rightarrow K^- \pi^+ \pi^0$

(3) $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$

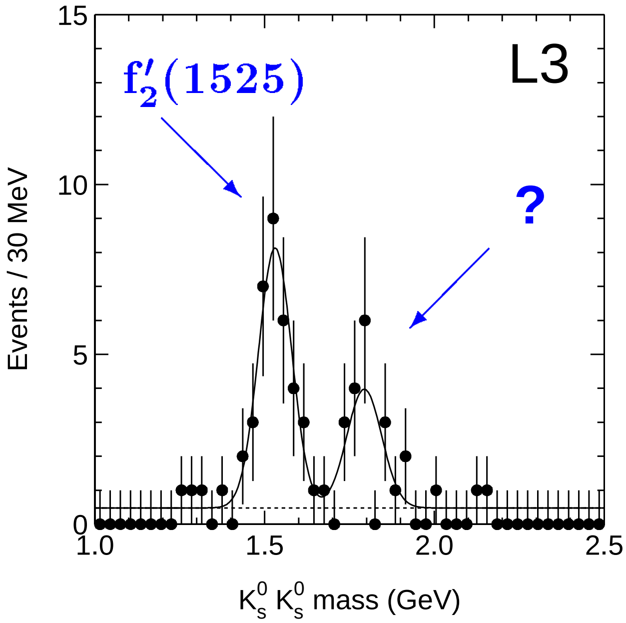


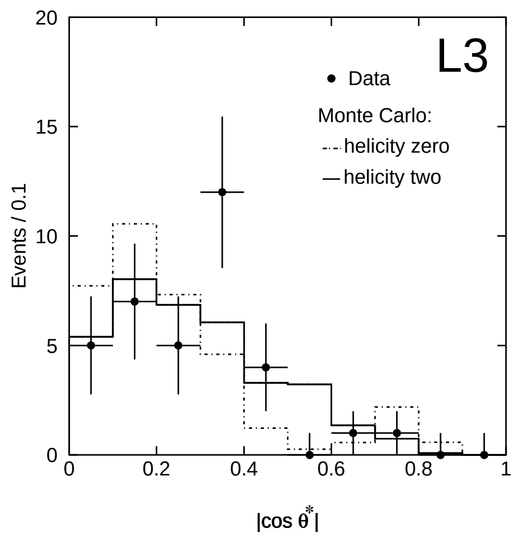


$$\sigma(e^+e^- \rightarrow e^+e^- D^{\star\pm}X) = 155 \pm 33 \pm 21\,\text{pb}$$

$$\Rightarrow\ \sigma(e^+e^- \rightarrow e^+e^- c\bar{c}X) = 326 \pm 87\,\text{pb}$$

$K_S^0\,K_S^0$ final states





$$\sigma(\gamma^\star\gamma^\star \to R) = 8\pi(2J_R + 1)\frac{\Gamma_{\gamma\gamma}(R)\Gamma(R)}{(W_{\gamma\gamma}^2 - m_R^2)^2 + m_R^2\Gamma^2(R)}$$

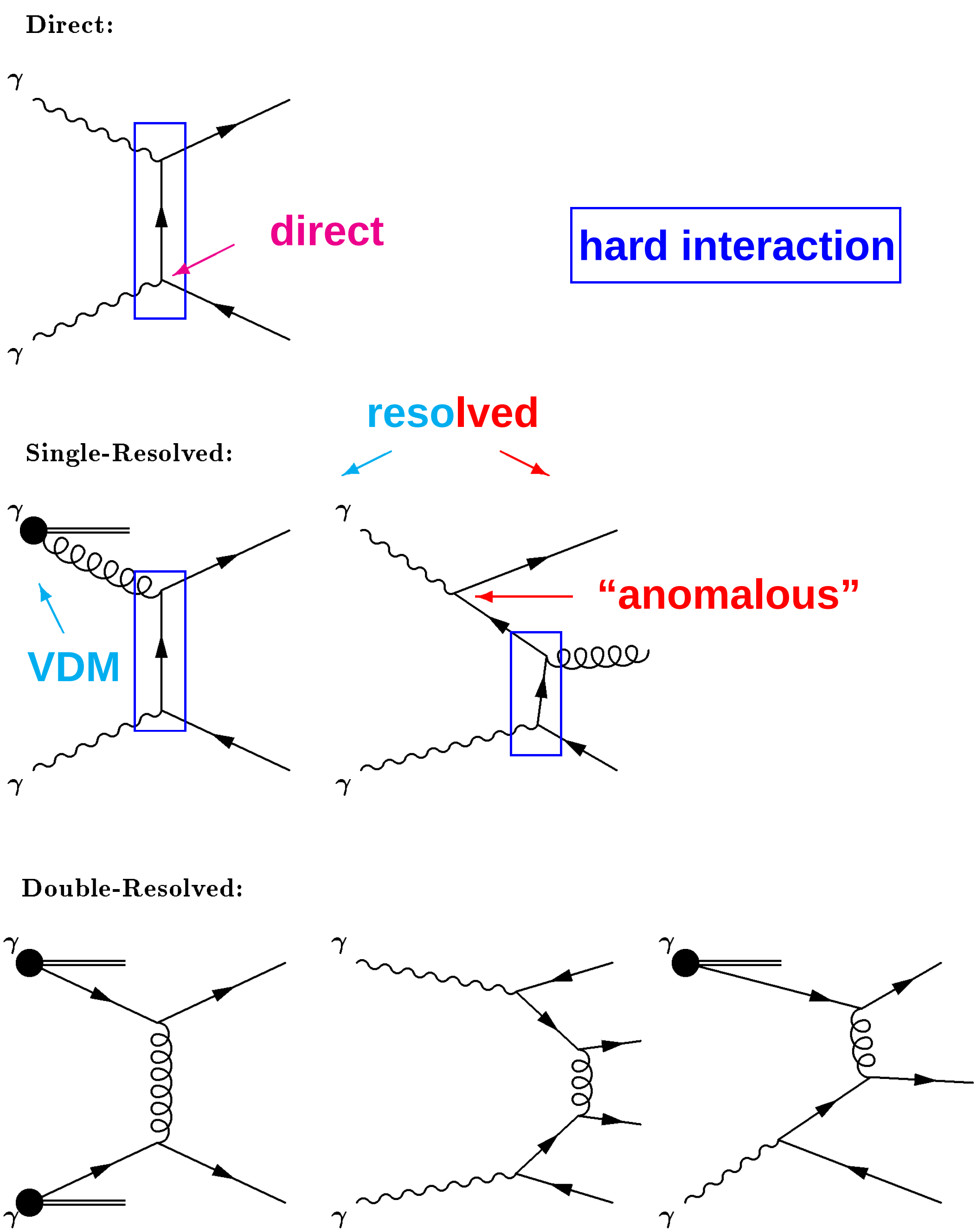
$$f_2'(1525) \to K_S^0\,K_S^0 \to \pi^+\pi^-\ \pi^+\pi^-$$

$f_2'(1525)$ signal of 31 ± 6 events for $\mathcal{L}_{int} = 114\text{pb}^{-1}$

$$\Gamma_{\gamma\gamma}(f_2')\cdot BR(f_2' \to K\,\overline{K}) = (0.093 \pm 0.018 \pm 0.022)\ keV$$

Probably pure helicity 2 state

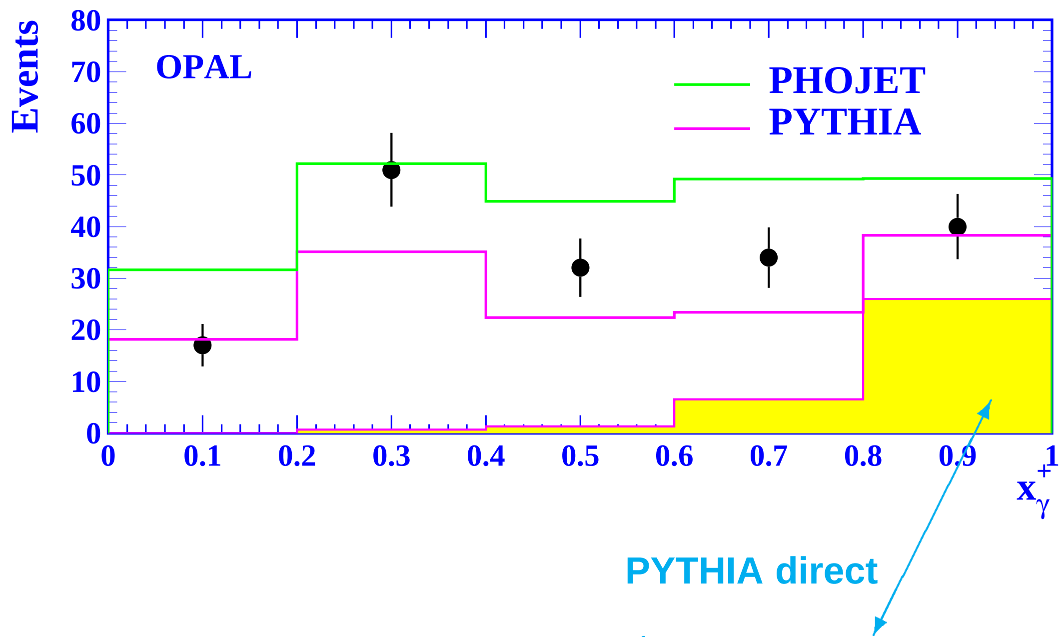
Leading order diagrams



The x_γ distribution for 2–jet events at $\sqrt{s_{ee}}$ = 131 GeV

x_γ is the fraction of the photon momentum participating in the hard interaction

$$x_\gamma = \max\left\{ \frac{\sum_{\rm jets}(E+p_z)}{\sum_{\rm hadrons}(E+p_z)}, \frac{\sum_{\rm jets}(E-p_z)}{\sum_{\rm hadrons}(E-p_z)} \right\}$$

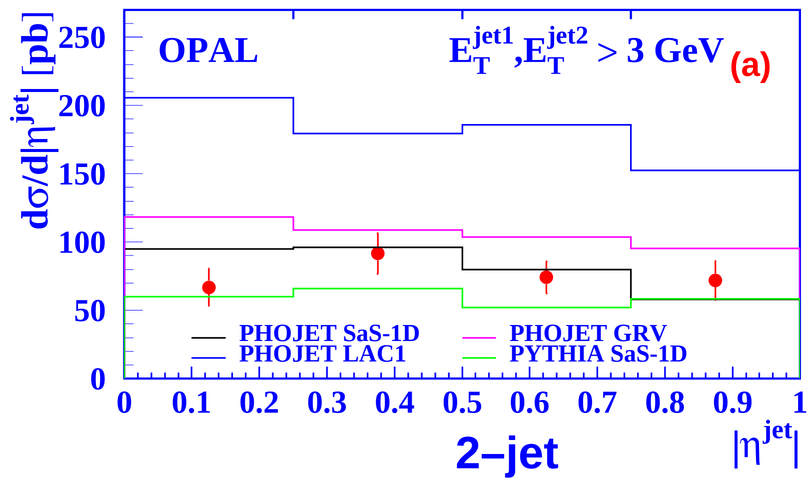


Direct events : $x_\gamma \equiv 1$ no remnant jet

Resolved events : $x_\gamma < 1$ remnant jets possible

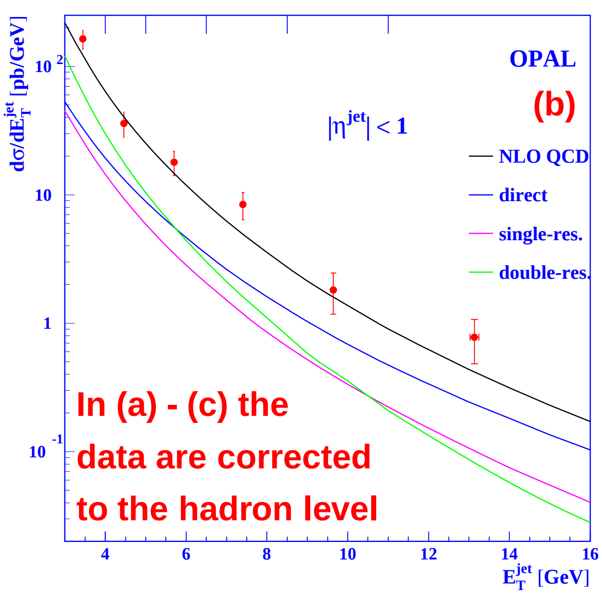
The inclusive jet cross-sections at $\sqrt{s_{ee}} = 133\,\mathrm{GeV}$

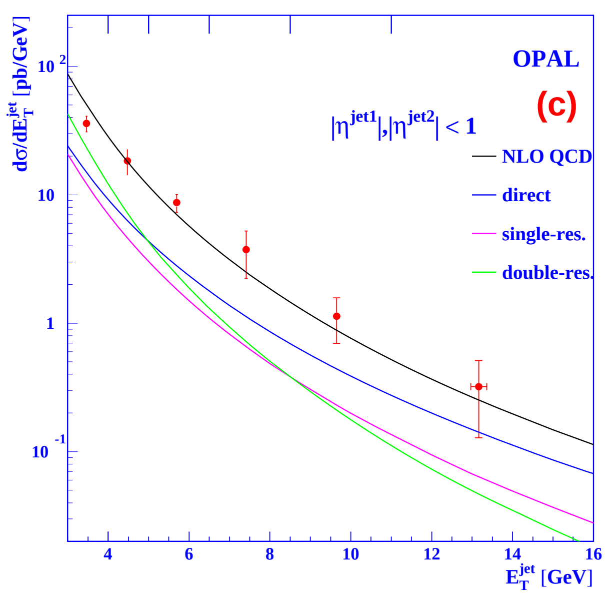
$\frac{d\sigma}{d\eta^{jet}}$ compared to *Monte Carlo models*



2–jet

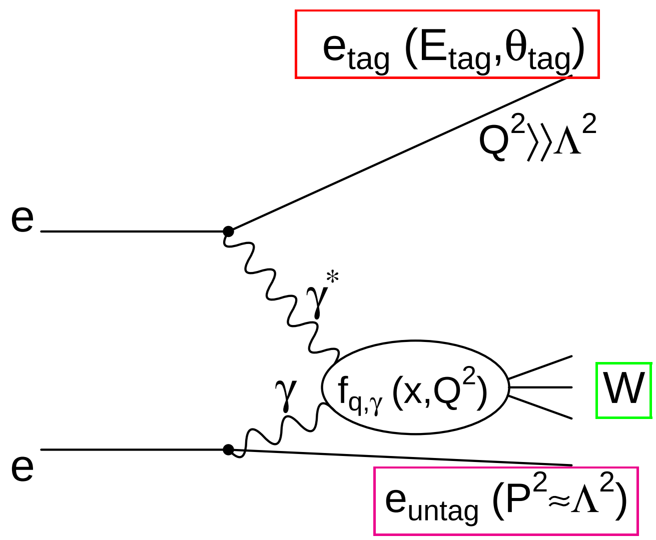
$\frac{d\sigma}{dE_T^{jet}}$ compared to *NLO Calculations*





1–jet ⟷ **2–jet**

Electron-Photon Scattering



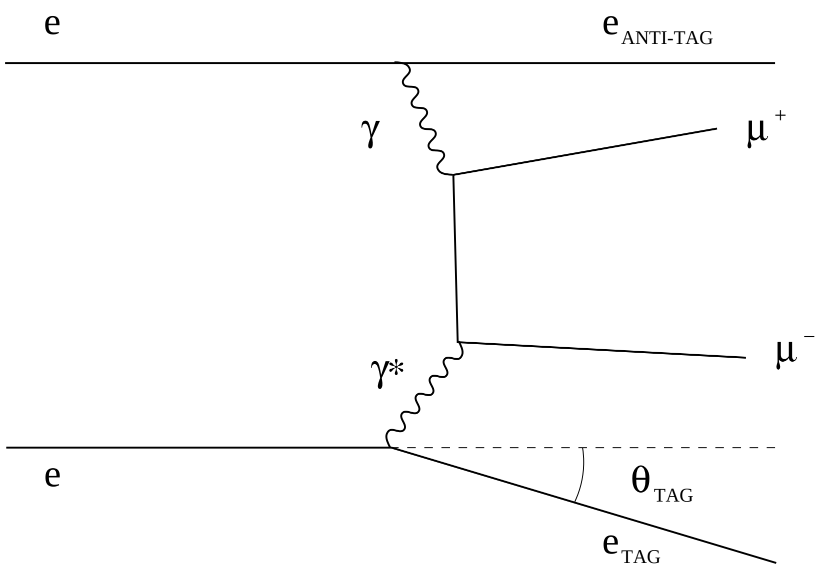
$$\frac{d^2\sigma_{e\gamma\to eX}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\cdot \left[\left(1+(1-y)^2\right) F_2^\gamma(x,Q^2) - \underbrace{y^2 F_L^\gamma(x,Q^2)}_{\to 0}\right]$$

$$Q^2 = 2\,E_\mathrm{b}\,E_\mathrm{tag}\,(1-\cos\theta_\mathrm{tag}) \gg P^2$$

$$x = \frac{Q^2}{Q^2+W^2+P^2}$$

$$y = 1-\frac{E_\mathrm{tag}}{E_\mathrm{b}}\cos^2\left(\frac{\theta_\mathrm{tag}}{2}\right) \ll 1$$

The production of lepton pairs



$$\frac{d^2\sigma_{e\gamma\to e\mu^+\mu^-}}{dx\,dQ^2} =$$

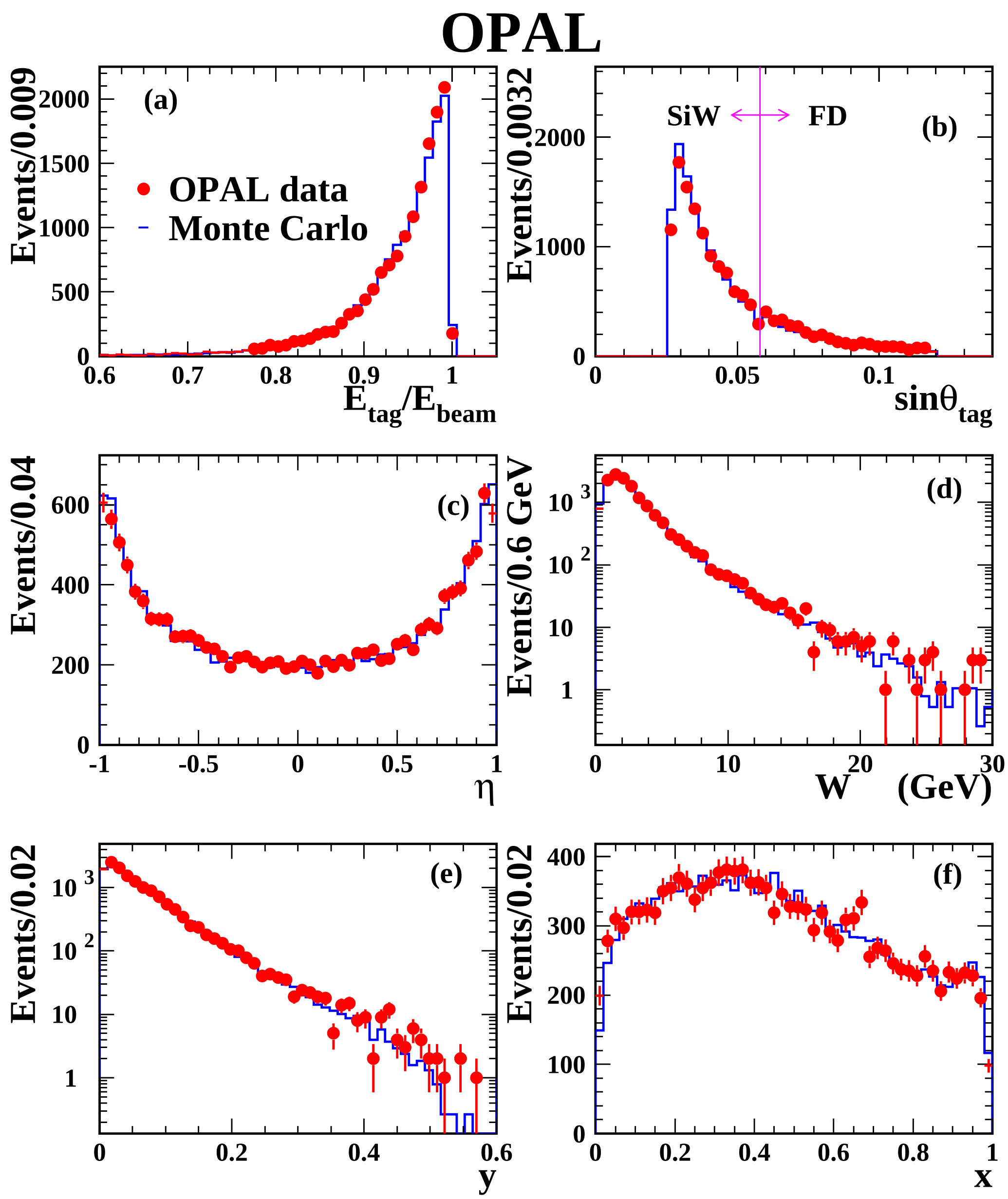
$$\frac{2\pi\alpha^2}{x\,Q^4}\left[\left(1+(1-y)^2\right)F^{\gamma}_{2,\mathrm{QED}} - y^2 F^{\gamma}_{\mathrm{L},\mathrm{QED}}\right]$$

$$F^{\gamma}_{2,\mathrm{QED}}(x, Q^2, P^2 = 0)/\alpha \approx$$

$$\frac{x}{\pi}\left[1 - 2x(1-x)\ln\frac{Q^2(1-x)}{x m_\mu^2} - 1 + 8x(1-x)\right]$$

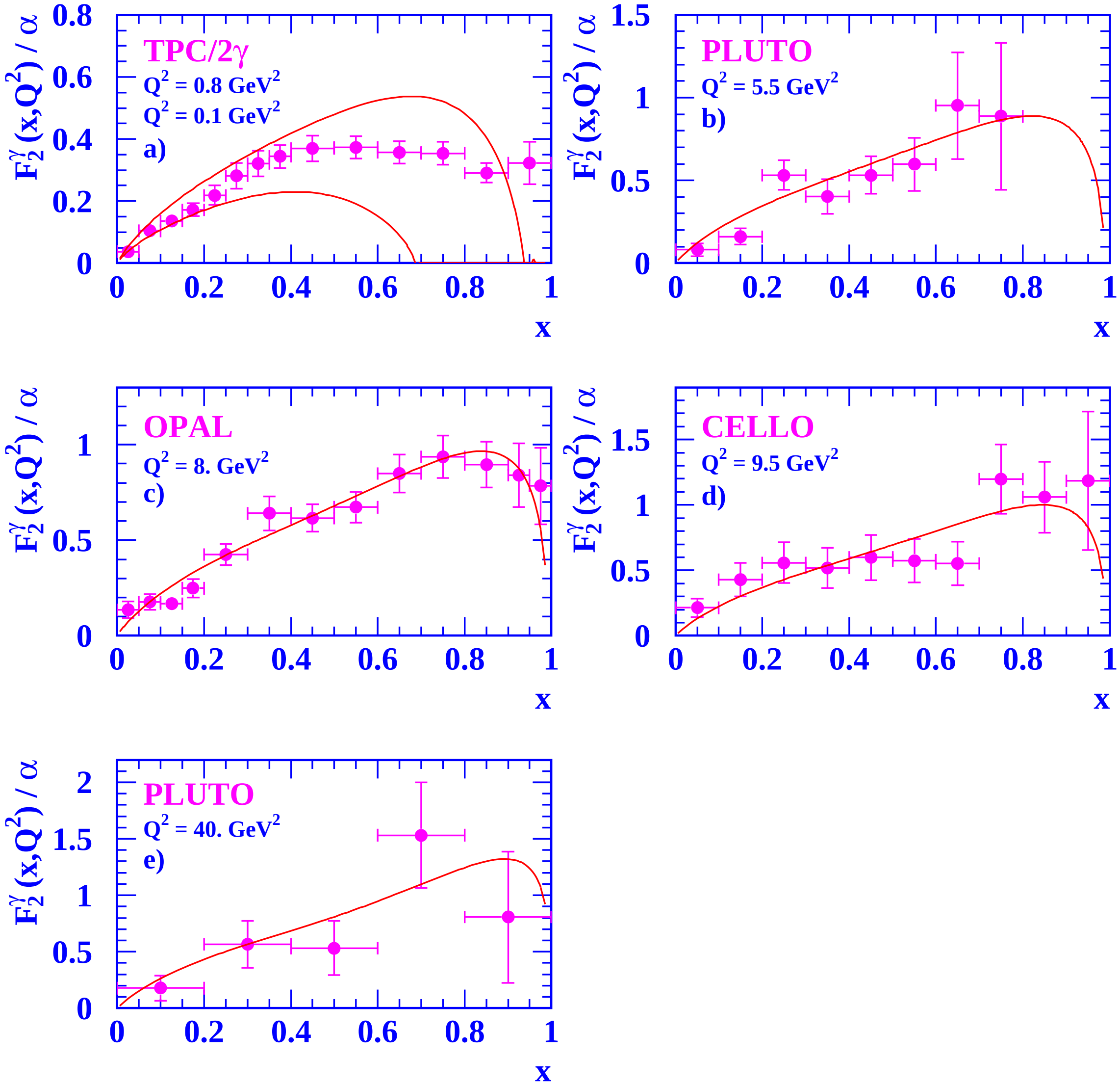
$$F^{\gamma}_{\mathrm{L},\mathrm{QED}}(x, Q^2, P^2 = 0)/\alpha \approx \frac{4}{\pi}x^2(1-x)$$

Some check distributions

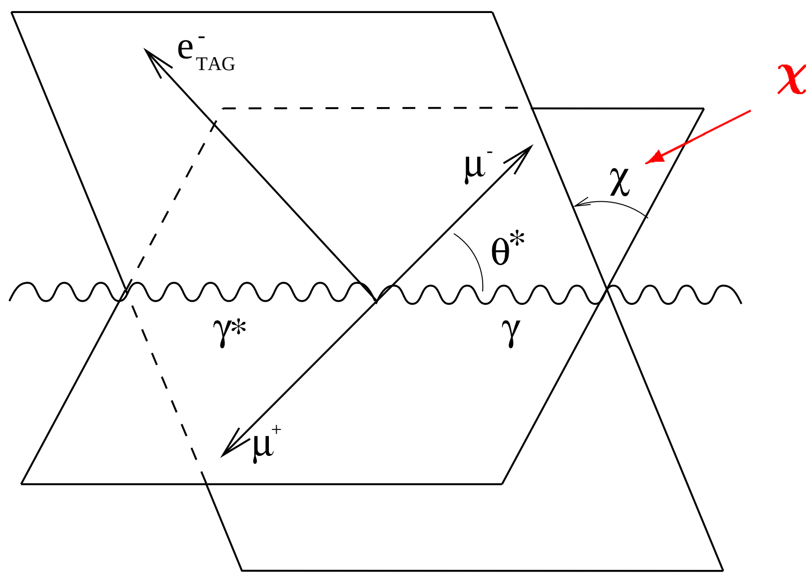


The data is well described by the QED Monte Carlo

The world data on $F_{2,\mathrm{QED}}^{\gamma}$ compared to QED



Azimuthal Correlations

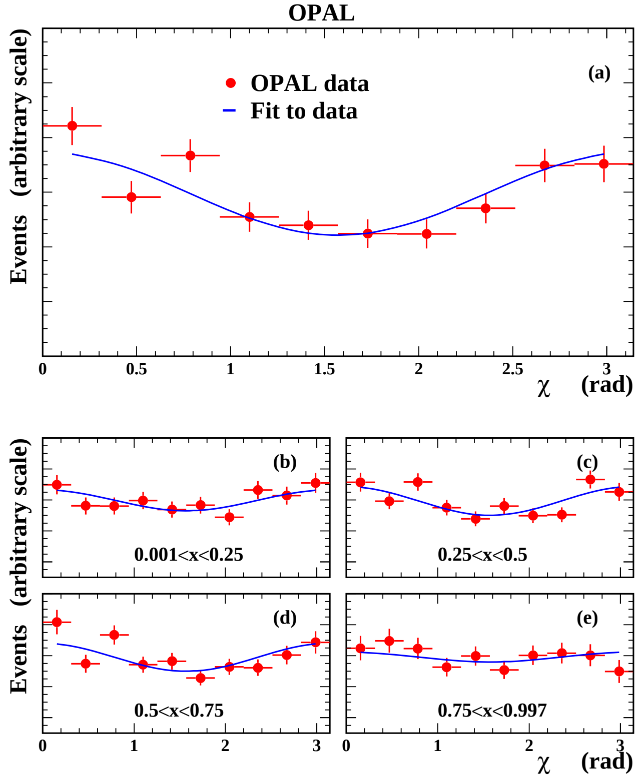


$$\frac{d\sigma(e\gamma \to e\mu^+\mu^-)}{dx\,dy\,d\chi/2\pi} \simeq \frac{2\pi\alpha^2}{Q^2}\left(\frac{1+(1-y)^2}{xy}\right)\cdot F_2^\gamma \cdot \left(1+\frac{1}{2}\epsilon(F_B^\gamma/F_2^\gamma)\cdot\cos 2\chi\right)$$

$\frac{1}{2}\epsilon = \frac{(1-y)}{1+(1-y)^2} \approx 1, \quad F_B^\gamma = F_L^\gamma = \frac{4\alpha}{\pi}x^2(1-x)$ **(in LO)**

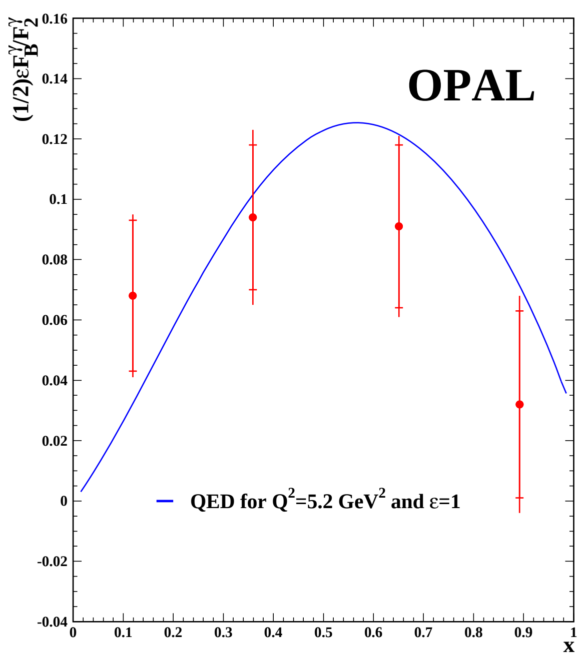
The measurement of F_B^γ / F_2^γ

arbitrary scales



χ

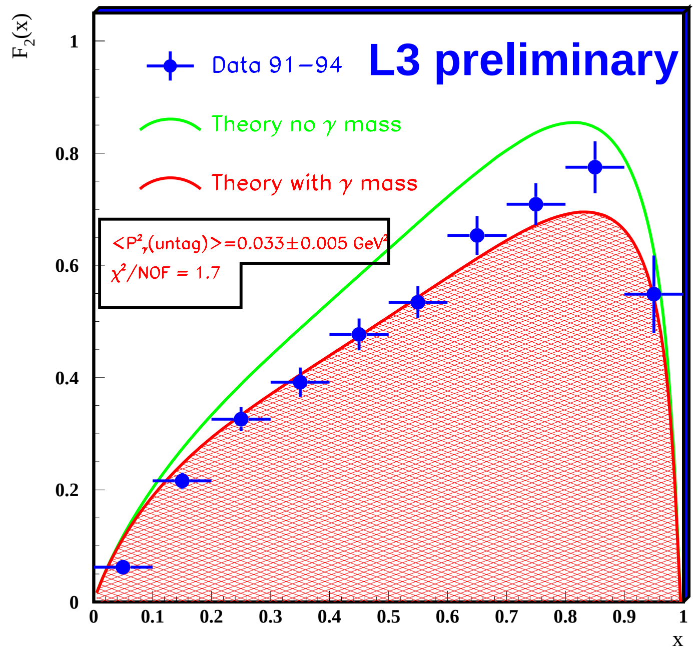
$\frac{1}{2}\epsilon(F_B^\gamma/F_2^\gamma)$



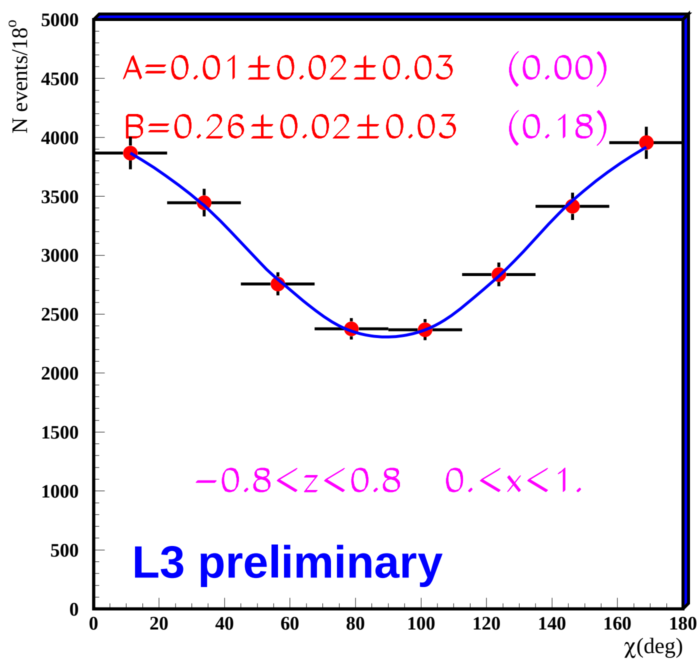
x

Results on μ- pairs in tagged events

eμμ - $F_2(x)$



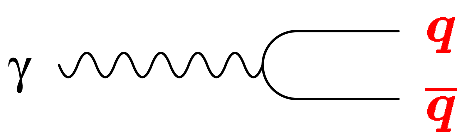
eμμ - dσ/dχ

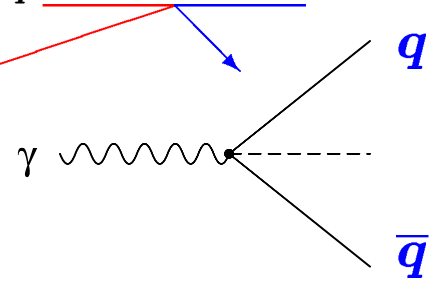


$$\frac{dN}{d\chi} \sim 1 + A\cos(\chi) + B\cos(2\chi)$$

The contributions to $F_2^\gamma(x, Q^2)$

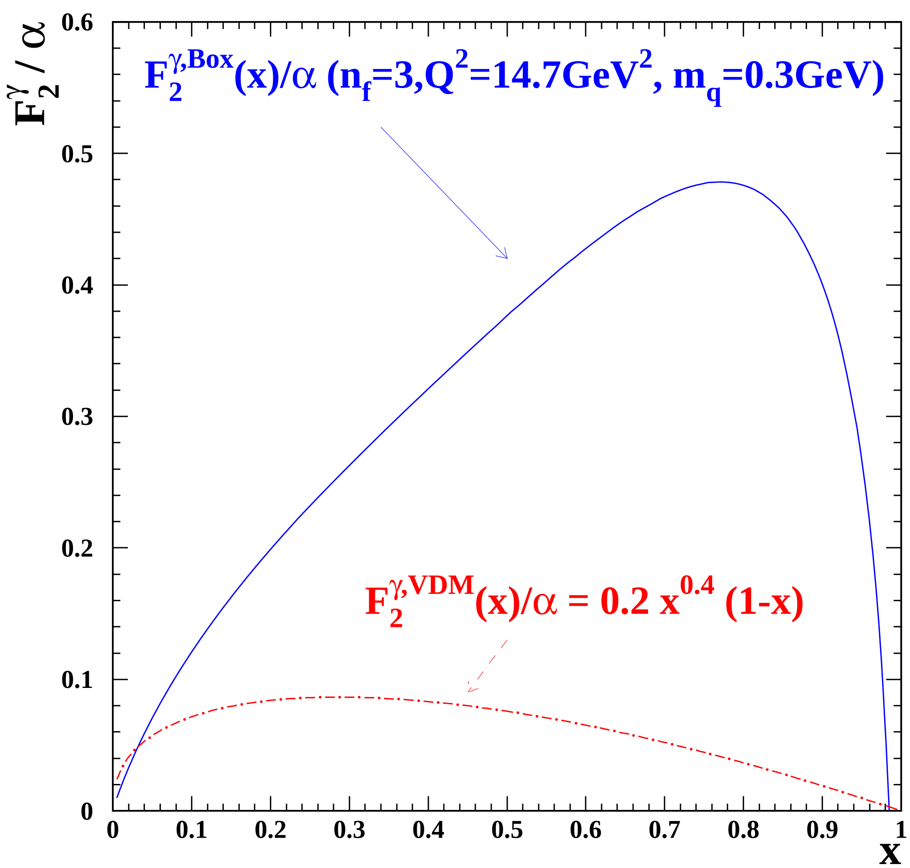
$$F_2^\gamma(x, Q^2) = x \sum_{c,f} e_q^2 \, f_{q,\gamma}(x, Q^2)$$



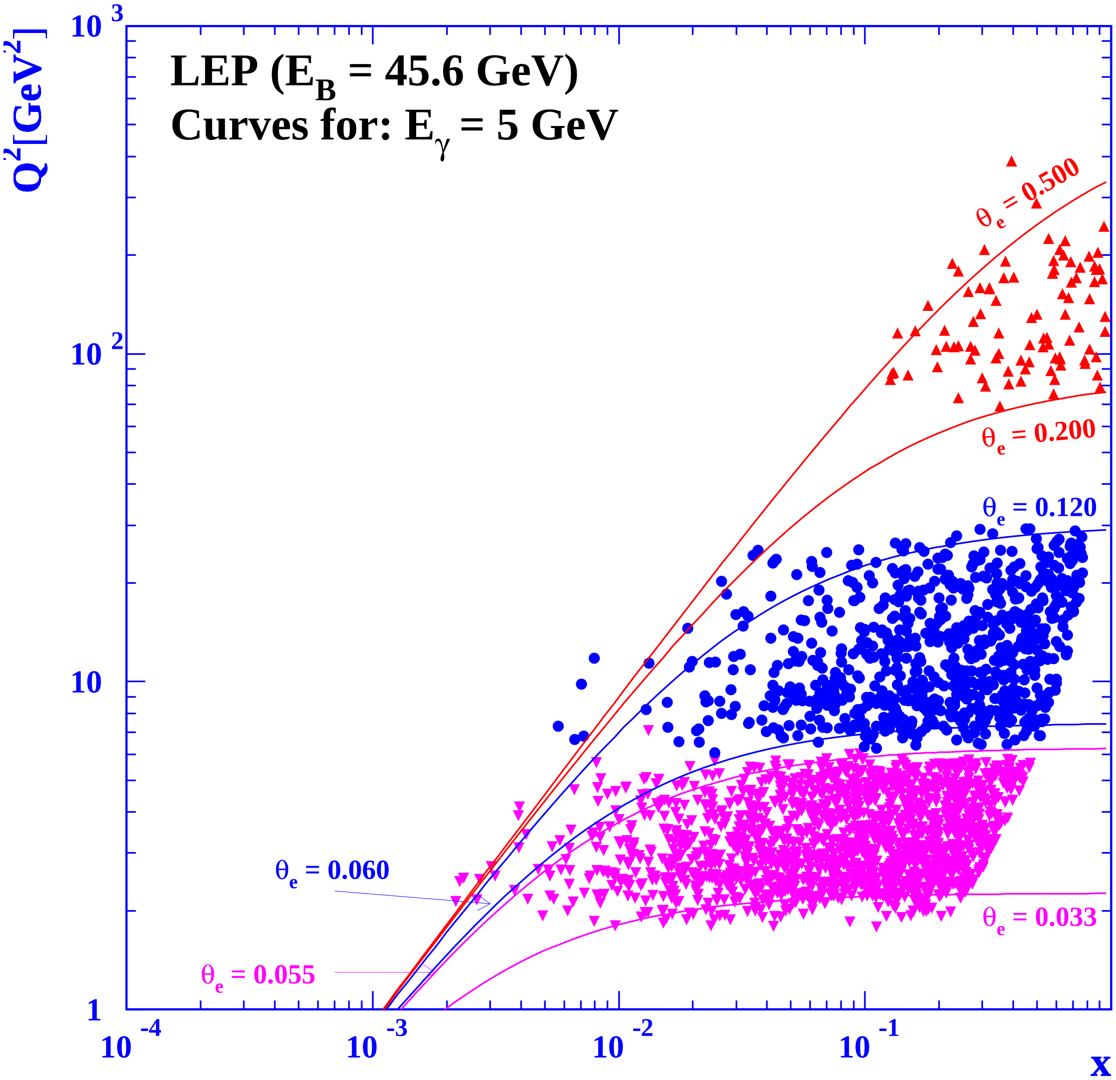


hadronic, VDM, p_T = “small” pointlike, p_T = “large”

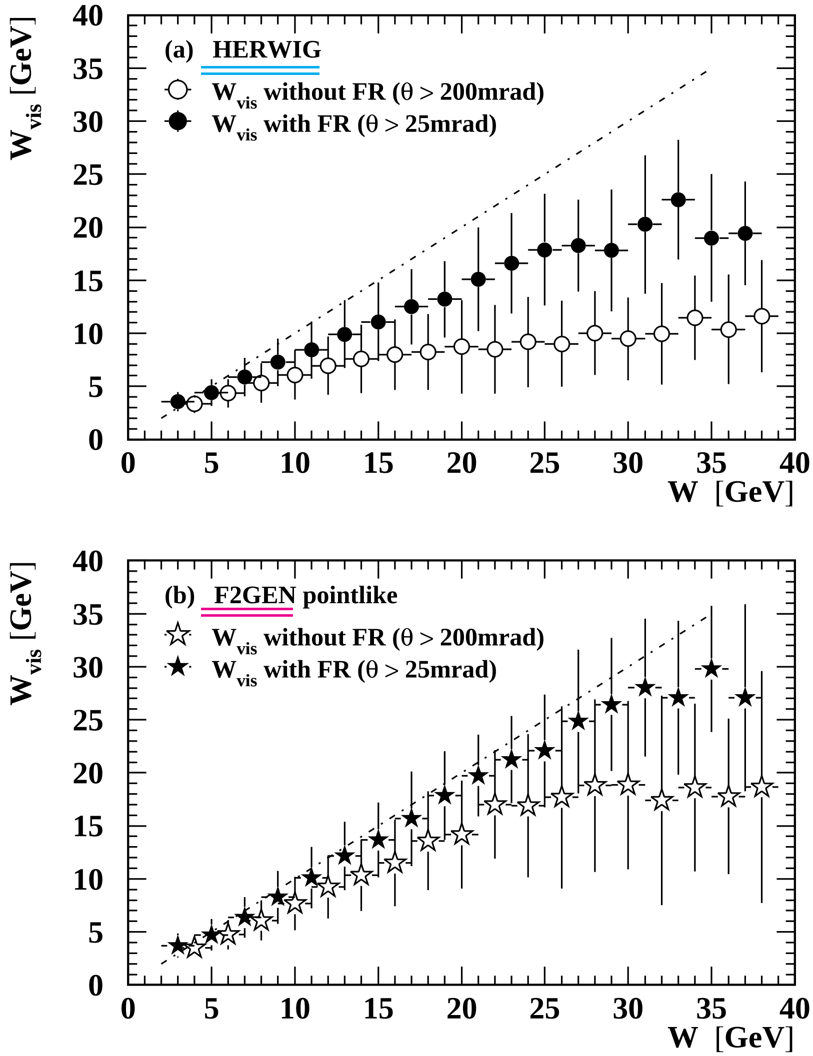
ρ, ω, ϕ, *non–perturbative* *perturbative*



The phase space at $\sqrt{s_{ee}} = M_{Z^0}$



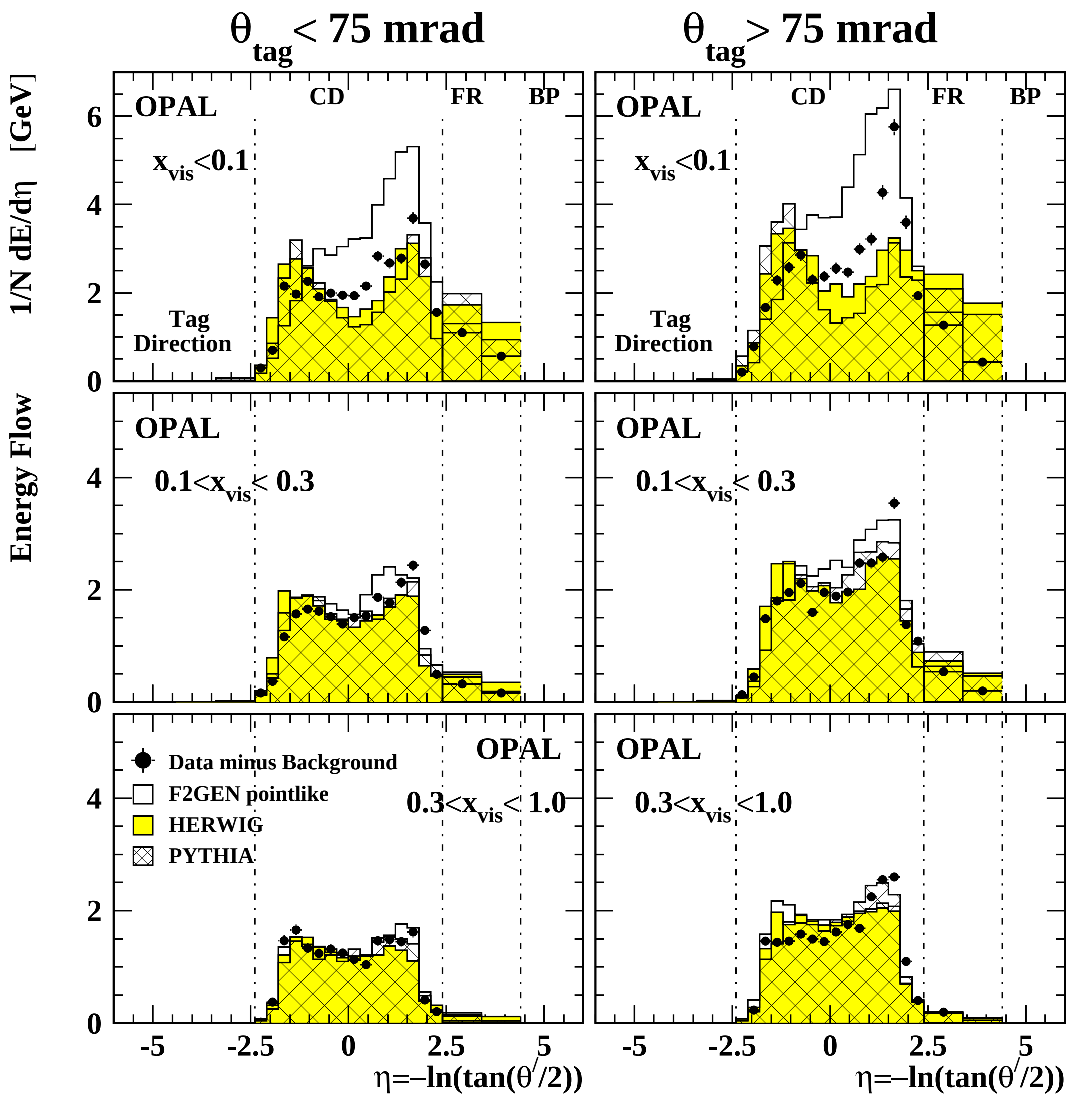
The W – W_{vis} correlation



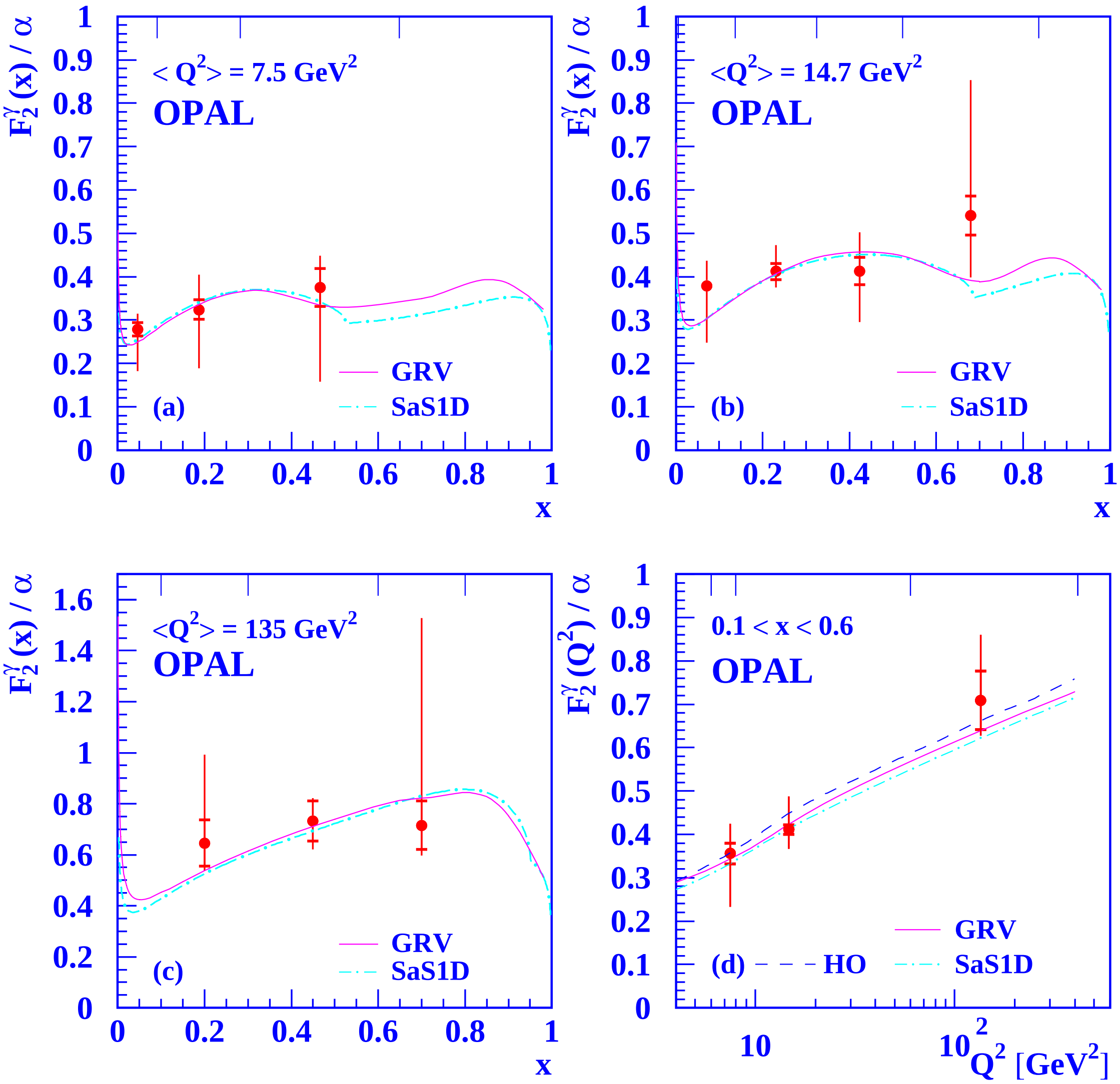
The correlation based on F2GEN is much stronger

The inclusion of the Forward Region significantly improves the correlation

The energy flow for $\sqrt{s_{ee}} = M_{Z^0}$



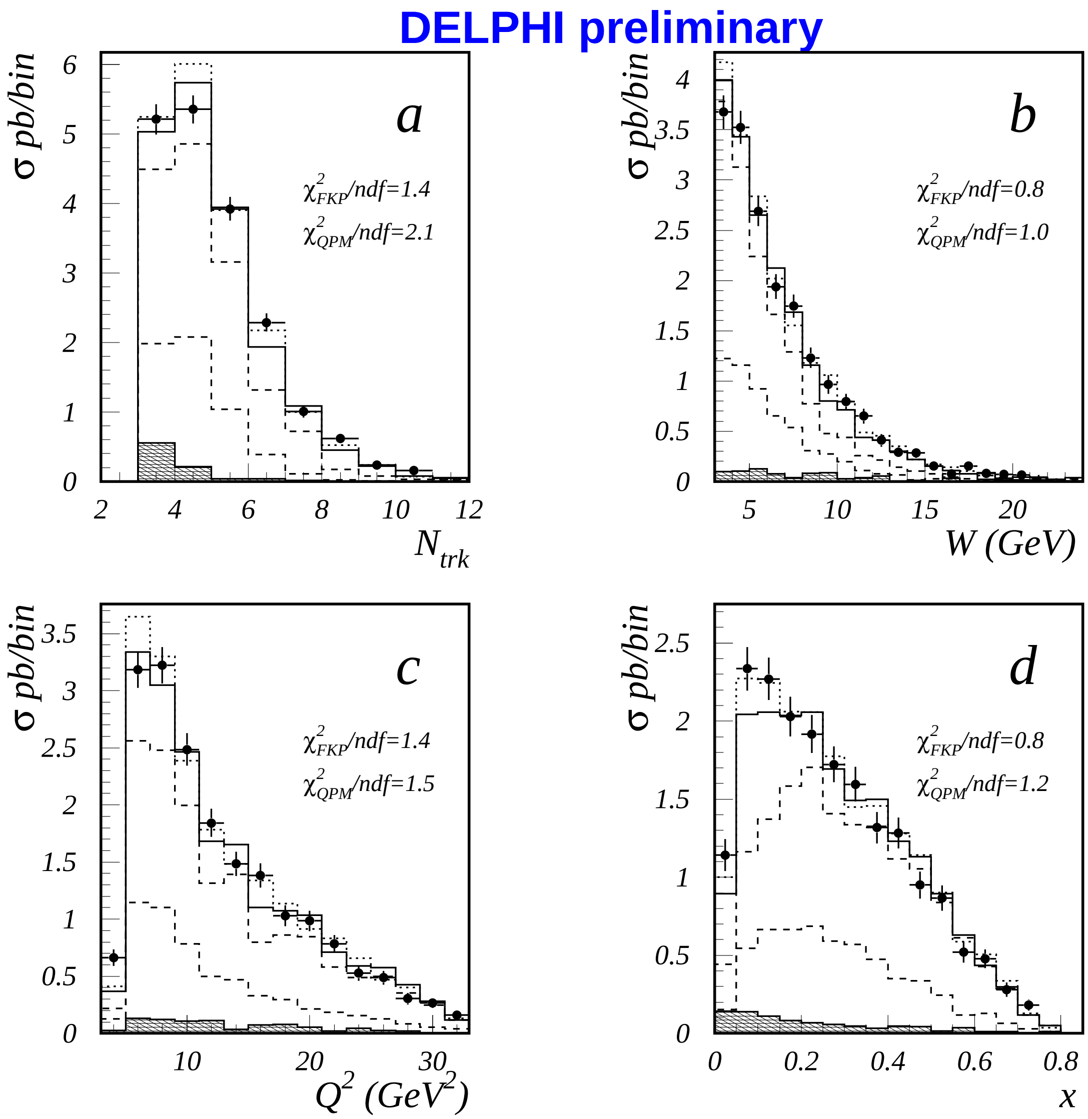
OPAL results on $F_2^\gamma(x, Q^2)$ at $\sqrt{s_{ee}} = M_{Z^0}$



$$F_2^\gamma(Q^2)/\alpha = (0.08\,^{+0.13}_{-0.18}) + (0.13\,^{+0.06}_{-0.04})\ \ln Q^2$$

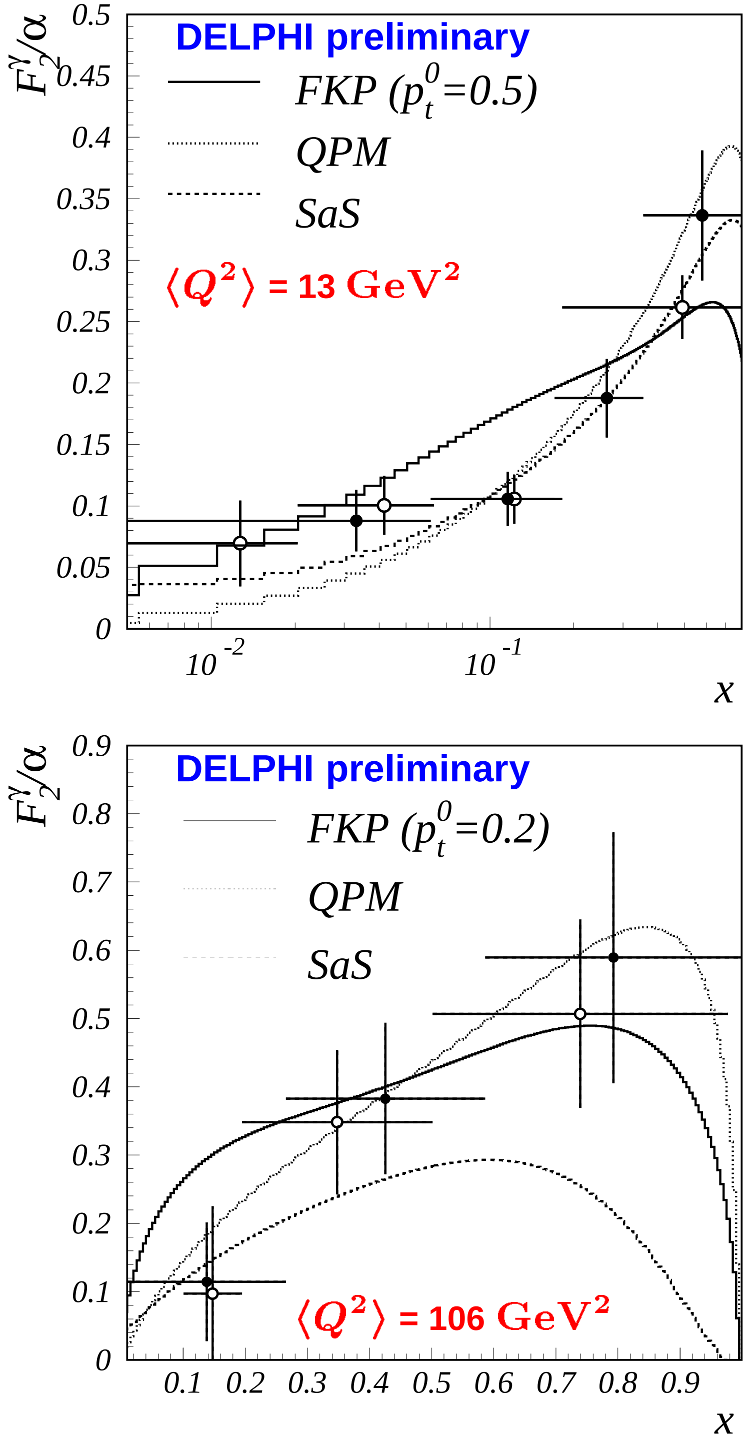
$\chi^2/\mathrm{dof} = 0.05 \quad Corr = -0.95$

The DELPHI approach to F_2^γ

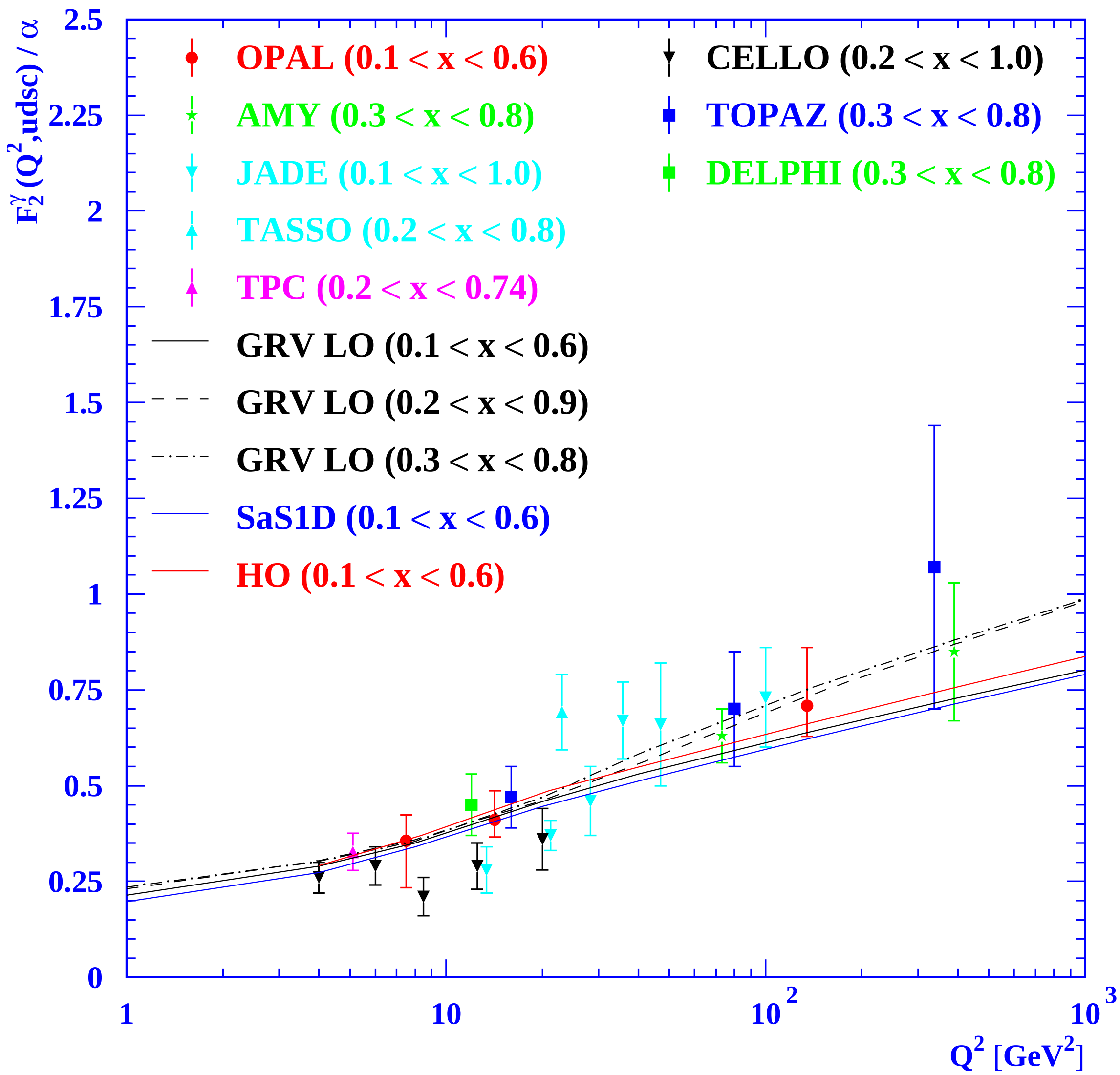


dots	DELPHI data
solid	QPM + GVDM + RPC
dottet	FKP + GVDM + RPC
upper dash	GVDM + QPM
lower dash	GVDM
hatched	background

Results on F_2^γ ('pointlike')



$\mathrm{d}F_2^\gamma/\mathrm{d}\ln Q^2$ for n_f = 4 = (udsc)



Conclusions

Two-Photon physics is a very active field at LEP with good prospects for LEP2

- **Photon-Photon scattering**
  1. A number of resonances have been measured.
  2. The flow of hadronic energy has been compared to Monte Carlo models.
  3. NLO calculations of jet production agree nicely with the data.

- **Electron-Photon DIS**
  1. There is in good agreement with QED predictions and the measured $F_{2,\mathrm{QED}}^{\gamma}$ structure function and the ratio $F_{\mathrm{B}}^{\gamma}/F_{2}^{\gamma}$.
  2. The F_{2}^{γ} structure function was measured for $7.5 < \langle Q^2 \rangle < 135\ \mathrm{GeV}^2$. The systematic errors have a large contribution from the imperfect description of the hadronic final state by the QCD inspired Monte Carlo models.

and . . .

Outlook

What can we expect from LEP on Two-Photon physics in the future

- Photon-Photon scattering
  1. More resonances (see list).
  2. Jet production for the direct component alone.
  3. Determination of the gluon content of the photon in jet production.
  4. . . .
- Electron-Photon DIS
  1. P^2 dependence of $F^{\gamma}_{2,\mathrm{QED}}$.
  2. Azimuthal correlations in hadronic final states.
  3. F_2^{γ} for 20 $< Q^2 <$ 1000 GeV^2.
  4. Double tag events.
  5. . . .

The LEP2 programme has just started