Structure Function Results from OPAL

8th International Workshop on Deep-Inelastic Scattering

DIS 2000

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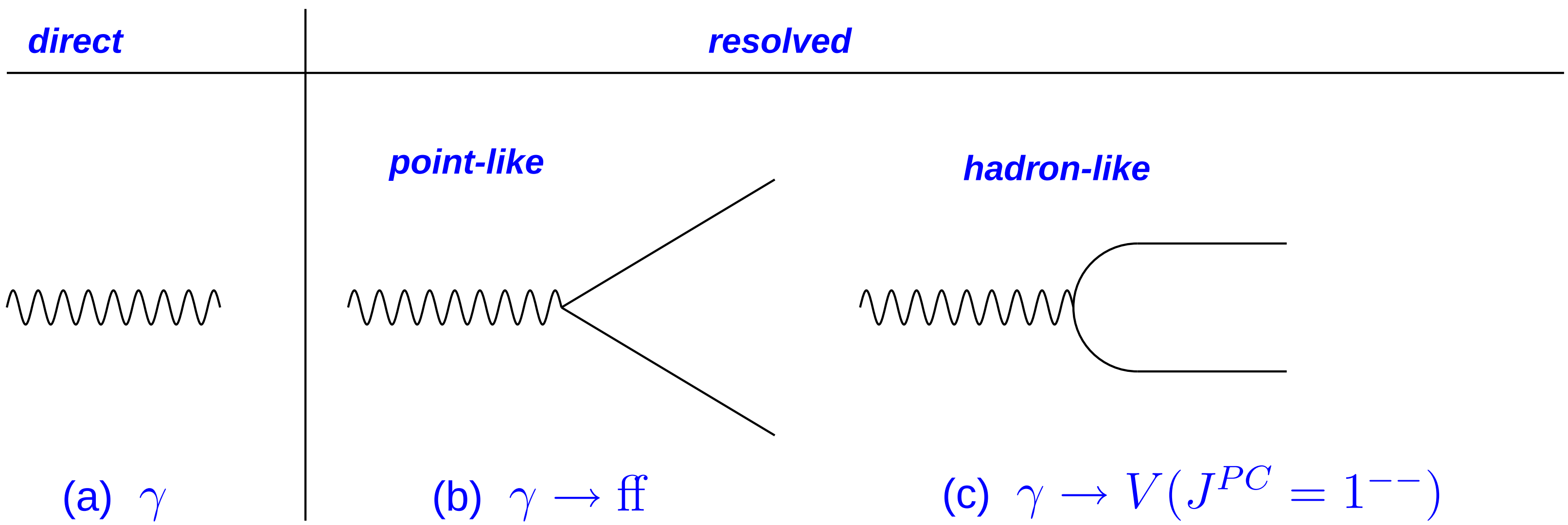
- Introduction

1. The charm structure function $F_{2,c}^{\gamma}$
2. New measurements of F_2^{γ}

- Conclusions

For the Collaboration

Why do we talk about Photon Structure?



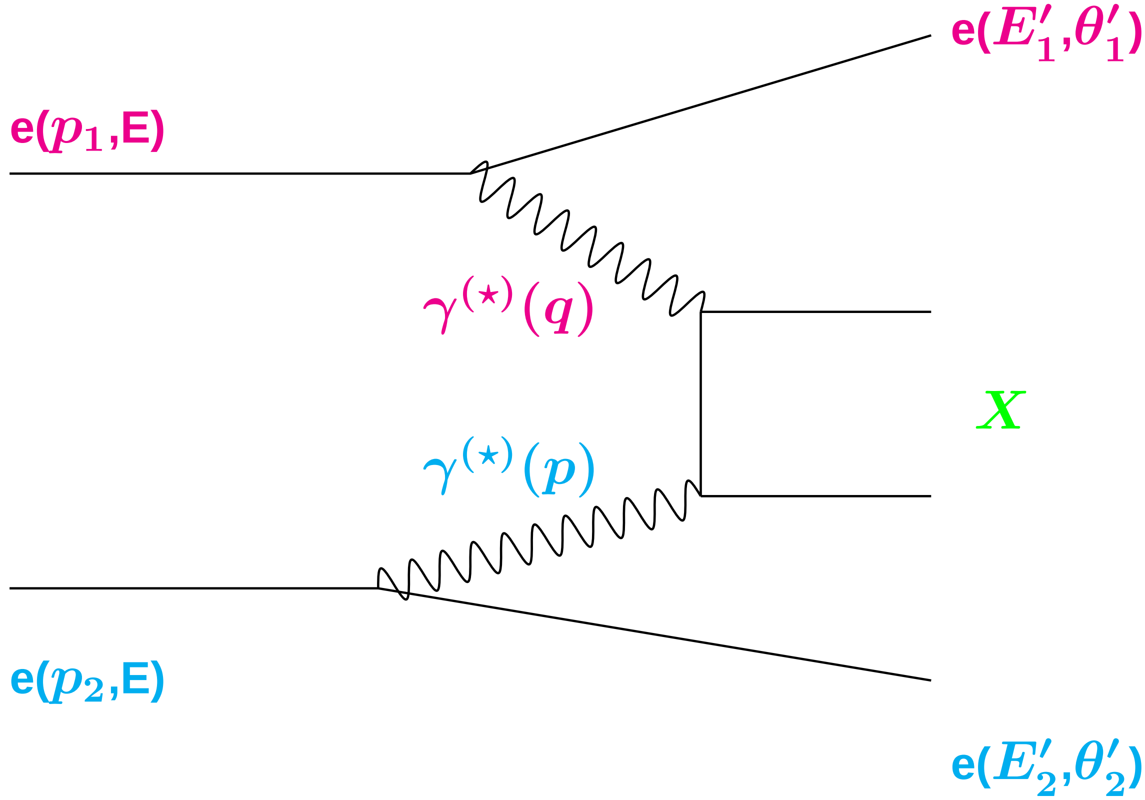
(a) γ (b) $\gamma \rightarrow \mathrm{f\bar{f}}$ (c) $\gamma \rightarrow V(J^{PC} = 1^{--})$

In (a) the whole photon interacts $\Rightarrow$ NO structure

The fluctuations (b,c) exist due to the uncertainty principle $\Rightarrow$ Photon 'Structure'

The typical lifetime of the fluctuations increases with the photon energy and decreases with the photon virtuality

The reaction e e → e e X



$$d^6\sigma = \frac{d^3p_1' d^3p_2'}{E_1' E_2'} \frac{\alpha^2}{16\pi^4 Q^2 P^2} \left[\frac{(q\cdot p)^2 - Q^2P^2}{(p_1\cdot p_2)^2 - m_e^2 m_e^2}\right]^{1/2}$$
$$\Big(4\rho_1^{++}\rho_2^{++}\sigma_{TT} + 2\rho_1^{++}\rho_2^{00}\sigma_{TL}$$
$$+2\rho_1^{00}\rho_2^{++}\sigma_{LT} + \rho_1^{00}\rho_2^{00}\sigma_{LL}+$$
$$2|\rho_1^{+-}\rho_2^{+-}|\tau_{TT}\cos 2\bar{\phi} - 8|\rho_1^{+0}\rho_2^{+0}|\tau_{TL}\cos\bar{\phi}\Big)$$

$$Q^2 = -q^2 = 2\,E\,E_1'\,(1-\cos\theta_1')$$

$$P^2 = -p^2 = 2\,E\,E_2'\,(1-\cos\theta_2')$$

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

The limit of deep inelastic electron-photon scattering

Using:

$$
\begin{aligned}
2xF_{\mathrm{T}}^{\gamma} &= \frac{Q^2}{4\pi^2\alpha}\,\sigma_{\mathrm{TT}}(x,Q^2)\\
F_{\mathrm{L}}^{\gamma} &= \frac{Q^2}{4\pi^2\alpha}\,\sigma_{\mathrm{LT}}(x,Q^2)\\
F_{2}^{\gamma} &= 2xF_{\mathrm{T}}^{\gamma} + F_{\mathrm{L}}^{\gamma}
\end{aligned}
$$

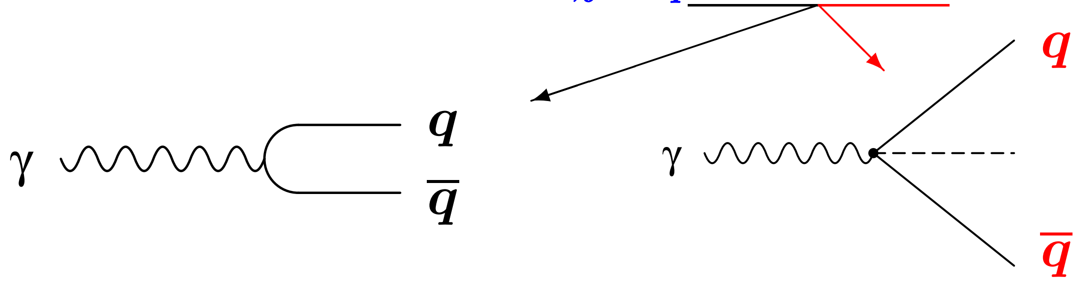
and the limit $(p\cdot q)^2 - Q^2P^2 \approx (p\cdot q)^2$ the cross section reduces to:

$$
\frac{\mathrm{d}^4\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P^2} = \frac{\mathrm{d}^2N_{\gamma}^{\mathrm{T}}}{\mathrm{d}z\mathrm{d}P^2}\cdot\frac{2\pi\alpha^2}{x\,Q^4}\cdot\left[1+(1-y)^2\right]\cdot \underbrace{\left[2xF_{\mathrm{T}}^{\gamma}(x,Q^2)+\frac{2(1-y)}{1+(1-y)^2}F_{\mathrm{L}}^{\gamma}(x,Q^2)\right]}_{\rightarrow F_2^{\gamma}\ \text{for}\ y\ll 1}
$$

with:
$$
\frac{\mathrm{d}^2N_{\gamma}^{\mathrm{T}}}{\mathrm{d}z\mathrm{d}P^2} = \frac{\alpha}{2\pi}\left[\frac{1+(1-z)^2}{z}\frac{1}{P^2} - \frac{2\,m_{\mathrm{e}}^2\,z}{P^4}\right]
$$

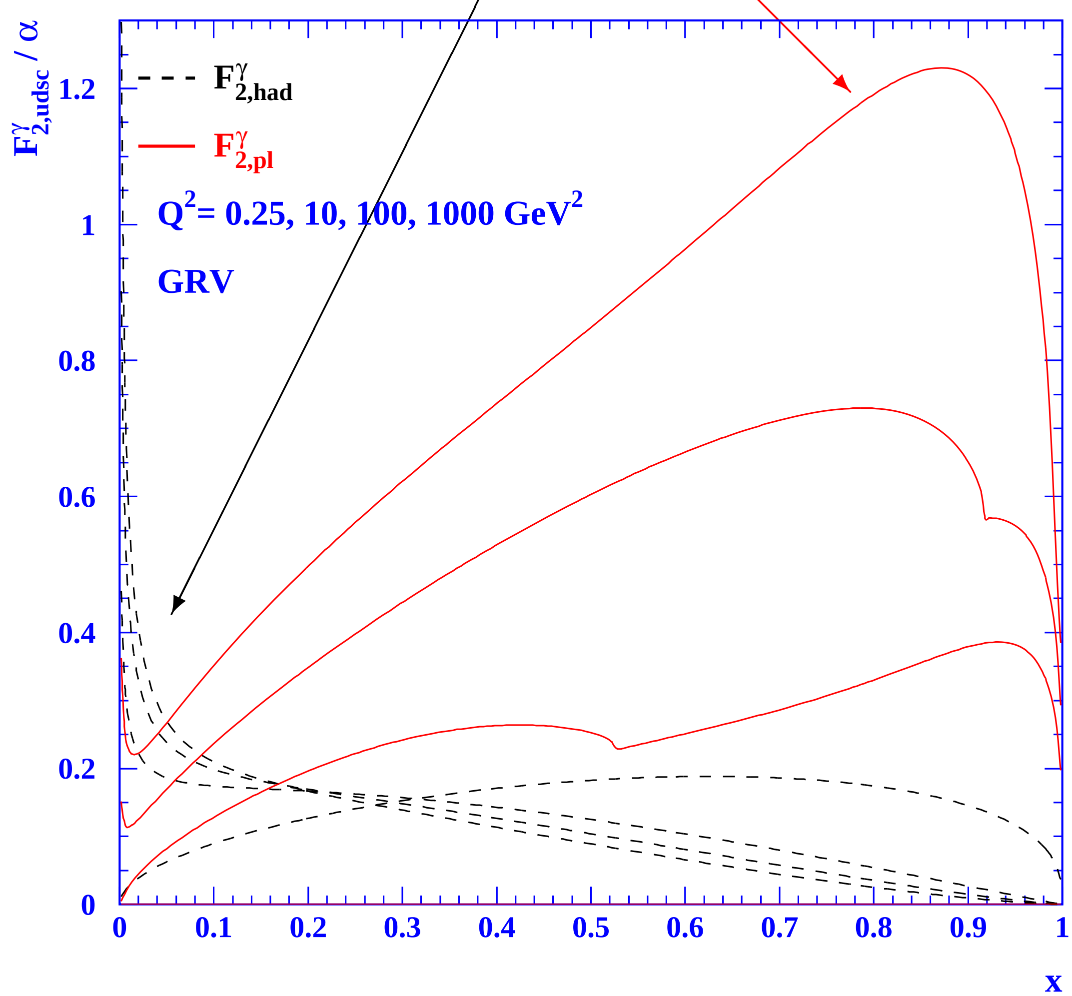
The contributions to $F_2^\gamma(x,Q^2)$

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

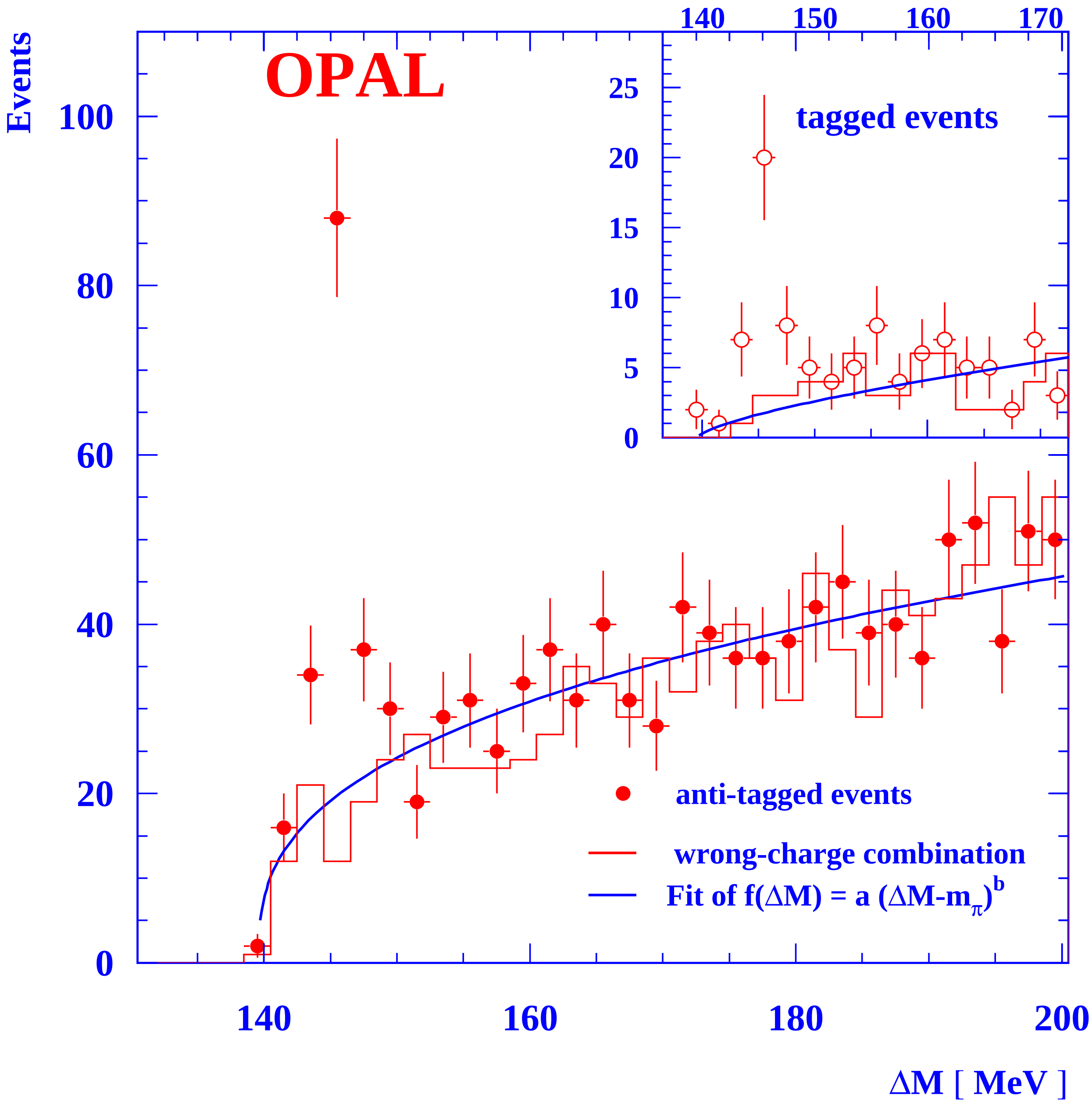


hadron-like, *non–perturbative* — e.g. VMD(ρ,ω,ϕ), low-x

point-like, *perturbative* — high-x

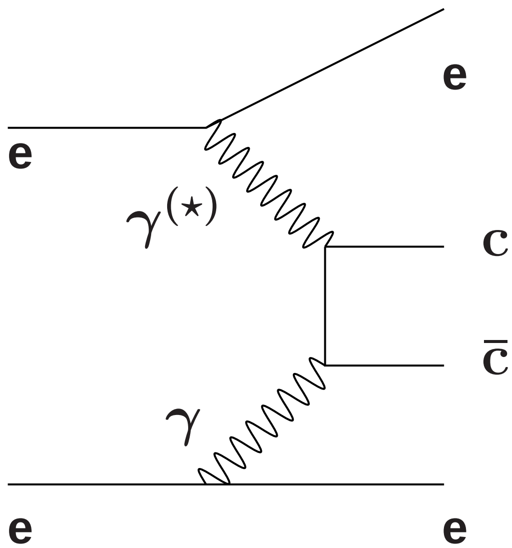


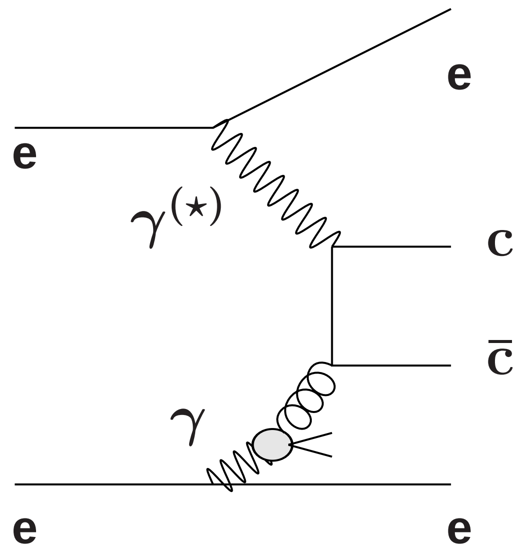
Charm production tagged by D*s



A clear signal in the $\Delta(M) = M(D^\star) - M(D^0)$ mass spectrum is seen for anti-tagged and tagged events

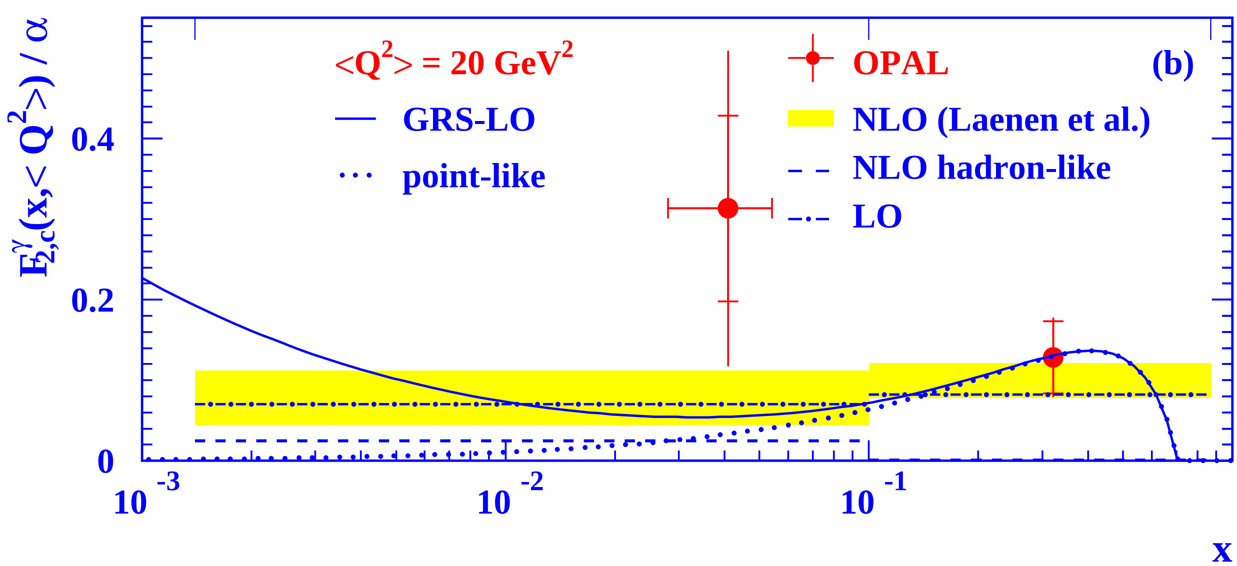
The first measurement of $F_{2,c}^{\gamma}$



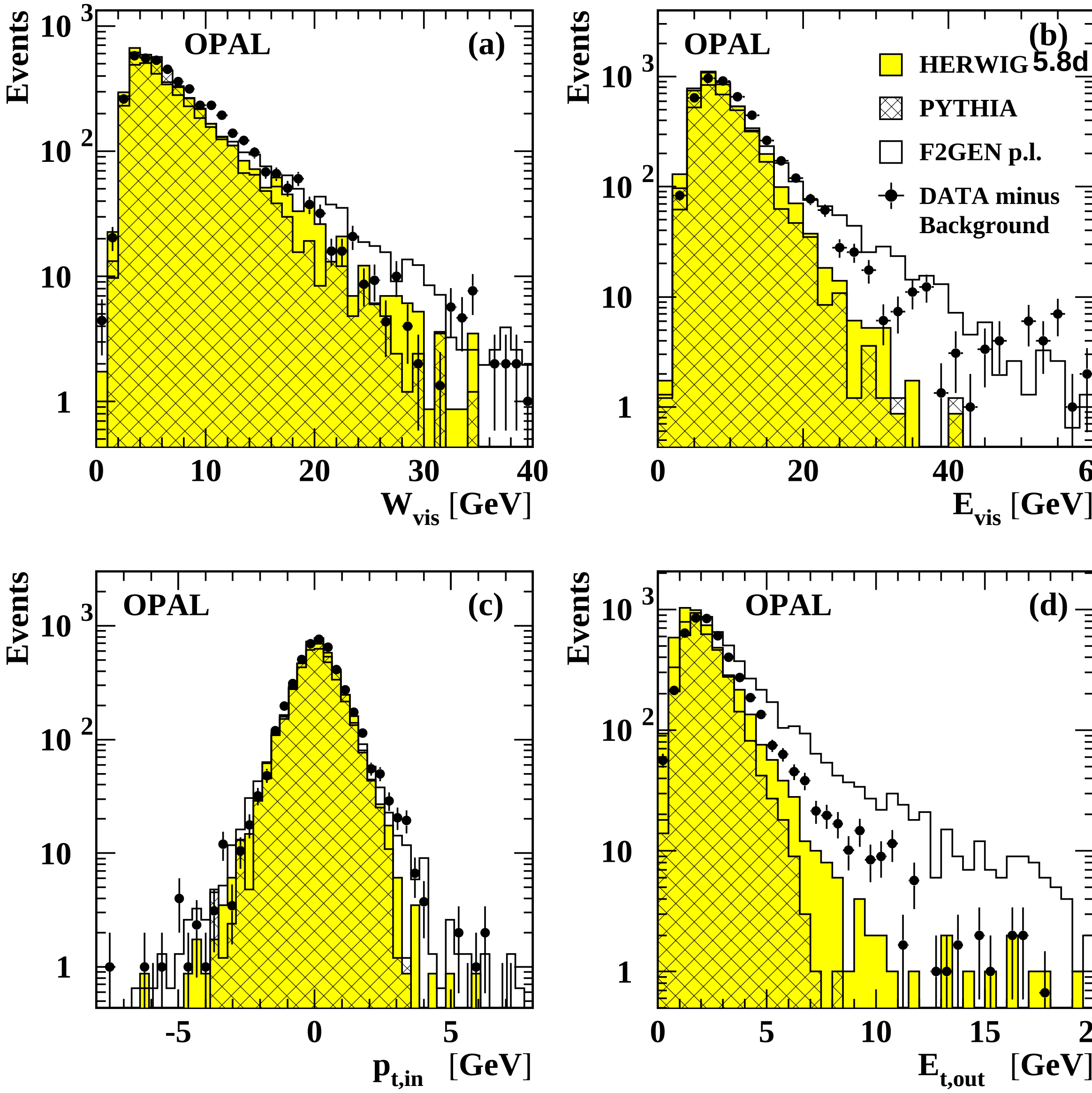


point-like, purely perturbative QCD prediction, dominates at **high-x**

hadron-like, depends on f_g^{γ}, dominates at **low-x**

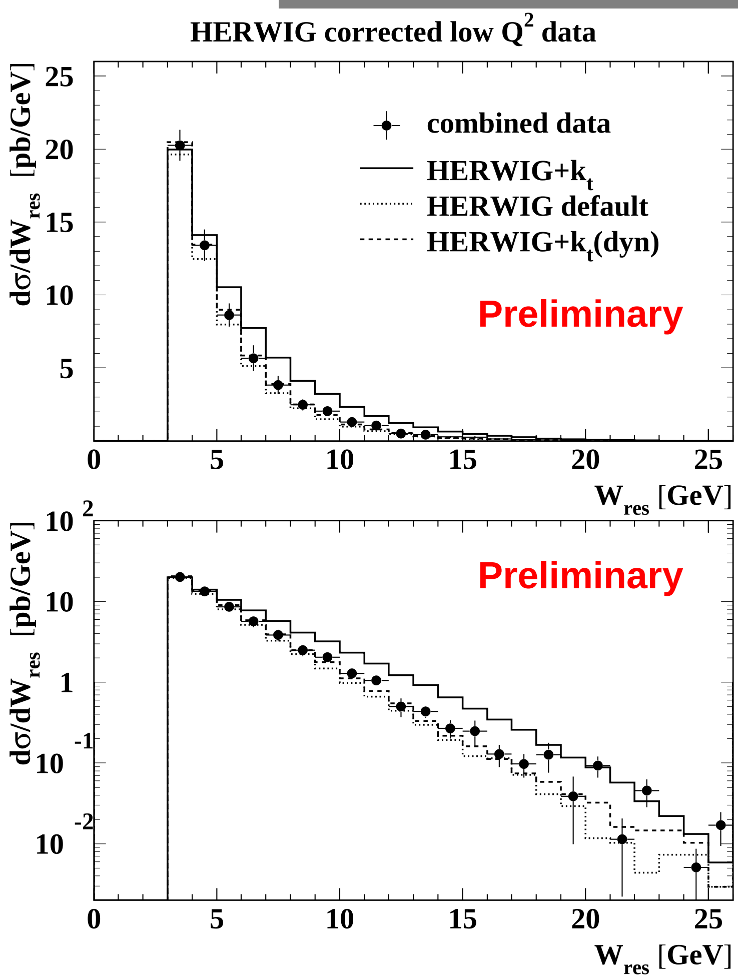


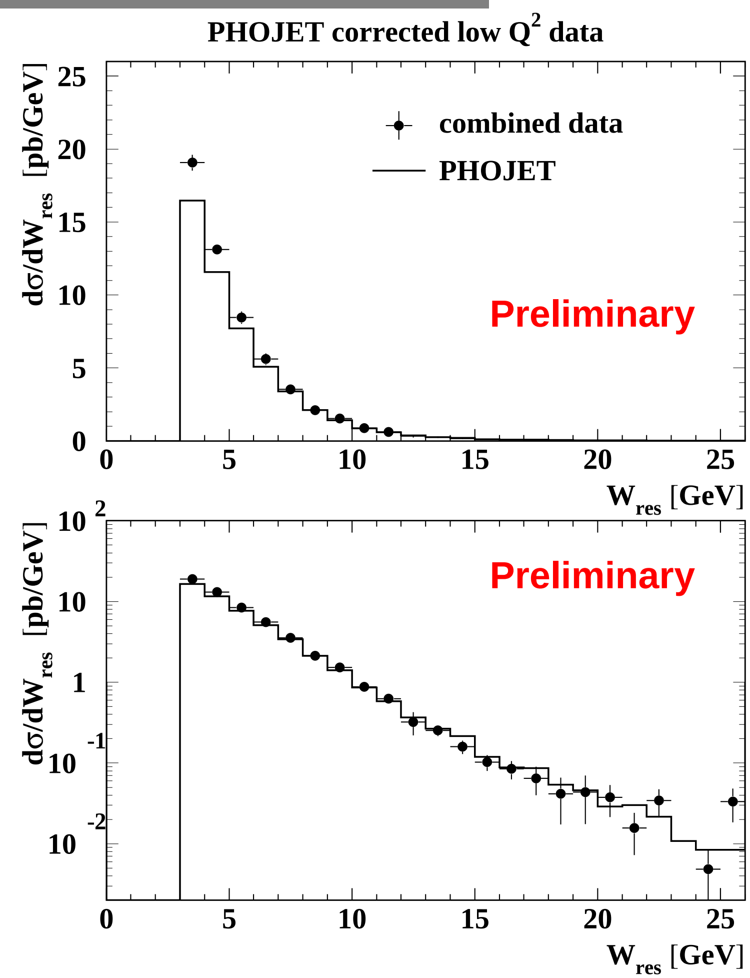
The description of the hadronic final state



There are significant differences between the data and the Monte Carlo predictions (OPAL ’96)

Comparison to LEP combined data





The combined data are a valuable input to constrain the Monte Carlo models (LEP Two-Photon WG '99)

Improvements on the OPAL analysis

OPAL 1996/97

1. HERWIG5.8d, PYTHIA5.718 and F2GEN
2. 1-dim unfolding
3. $\sqrt{s_{\mathrm{ee}}} = 91,\ 161,\ 172\,\mathrm{GeV}$ data.
4. generous variation of cuts

OPAL 2000

1. HERWIG5.9+k_{t} (dyn) and Phojet 1.05
2. 2-dim unfolding
3. $\sqrt{s_{\mathrm{ee}}} = 91,\ 183,\ 189\,\mathrm{GeV}$ data.
4. variation of cuts according to resolution
5. radiative corrections to F_2^{γ} (RADEG, Laenen et. al)

By these improvements a significant reduction of the systematic error has been achieved.

Some words about unfolding

The Principle:

$$g^{\rm det}(\vec{u}_{\rm vis}) = \int A(\vec{u}_{\rm vis}, \vec{u})\, f^{\rm part}(\vec{u})\, {\rm d}\vec{u} + B(\vec{u}_{\rm vis})$$

1. **1-dimensional case:**
   $g^{\rm det}(\vec{u}_{\rm vis}) = g^{\rm det}(x_{\rm vis}),\ \ x_{\rm vis} = f(E_{\rm tag}, \theta_{\rm tag}, W_{\rm vis})$ and $f^{\rm part}(\vec{u}) = f^{\rm part}(x)$ which is related to F_2^{γ}. The distribution of background events is denoted $B(\vec{u}_{\rm vis})$.

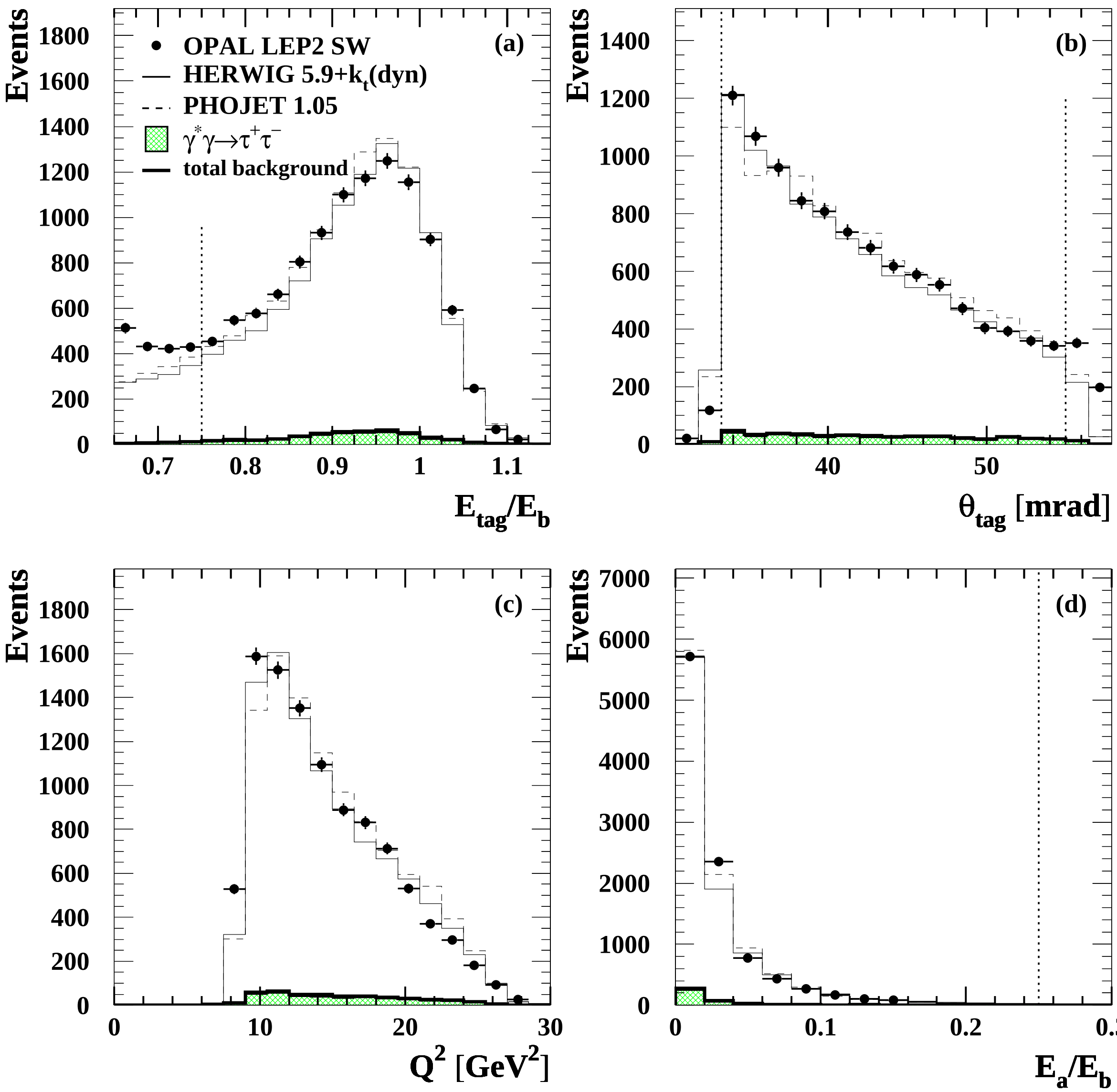
2. The correlation matrix $A(\vec{u}_{\rm vis}, \vec{u})$ has to be obtained from the Monte Carlo Models $\Rightarrow$ Model Dependence, and one has to consider all reasonable models $\Rightarrow$ individual choices.

3. The unfolding result should be independent of the $f^{\rm part}(x) \propto F_2^{\gamma}$ used in the Monte Carlo. This is not true if F_2^{γ} and the $\gamma^{\star}\,\gamma$ fragmentation do not factorise.

4. **2-dimensional case:**
   Take a second variable $v = E_{\rm t,out}, E_{\rm for}, \ldots$. Now the result should be independent of the joint input distribution function $f^{\rm part}(x, v)$, and only the transformation $A(x_{\rm vis}, v_{\rm vis}, x, v)$ as predicted by the Monte Carlo model matters, which now also depends on the transformation of v.

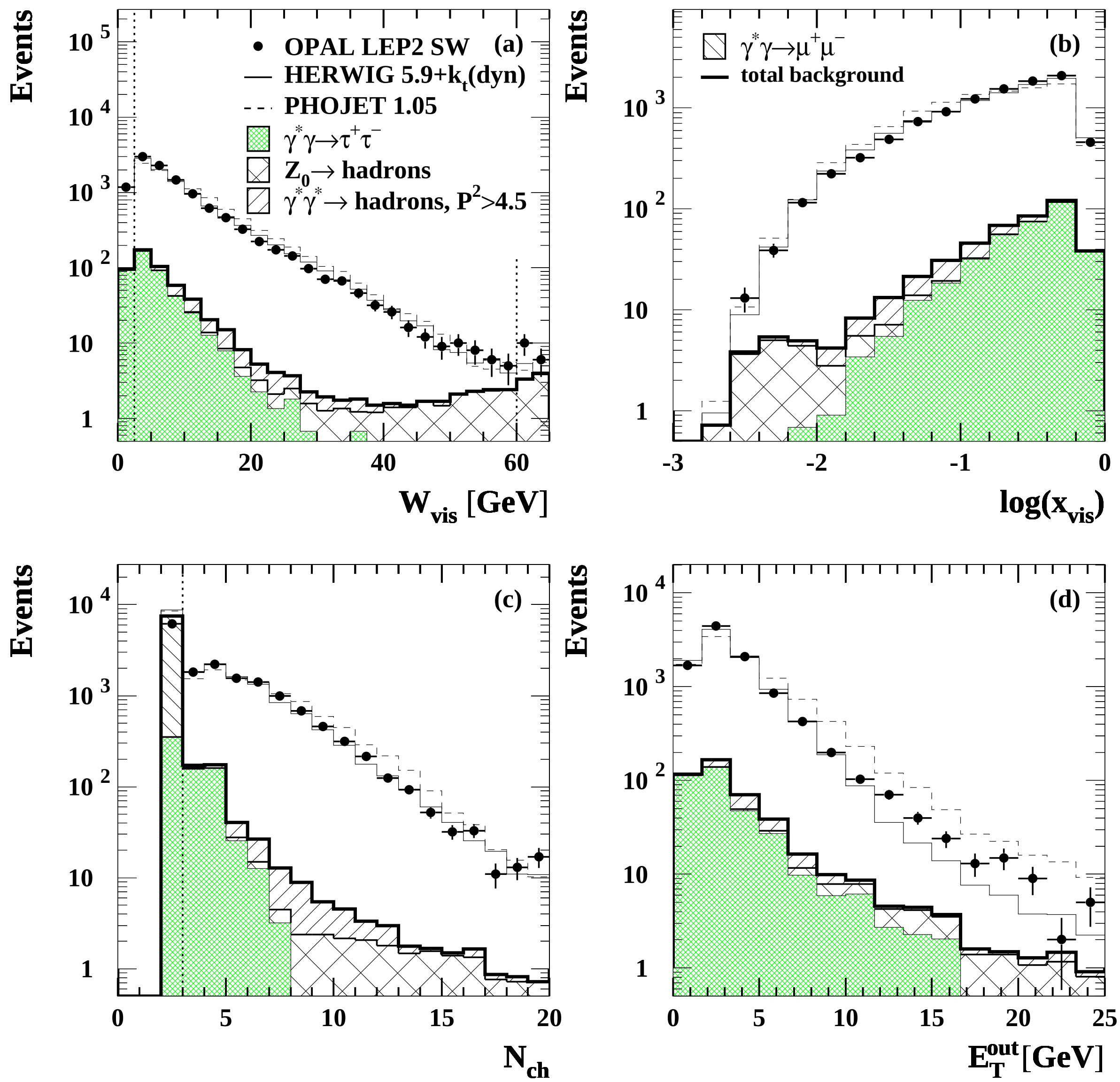
5. **N-dimensional case:**
   Take as many variables as you wish. Now the result should be independent of the joint input distribution function of all variables, and only the transformation matrix matters.
   Only possible for infinite statistics.

Description of electron quantities



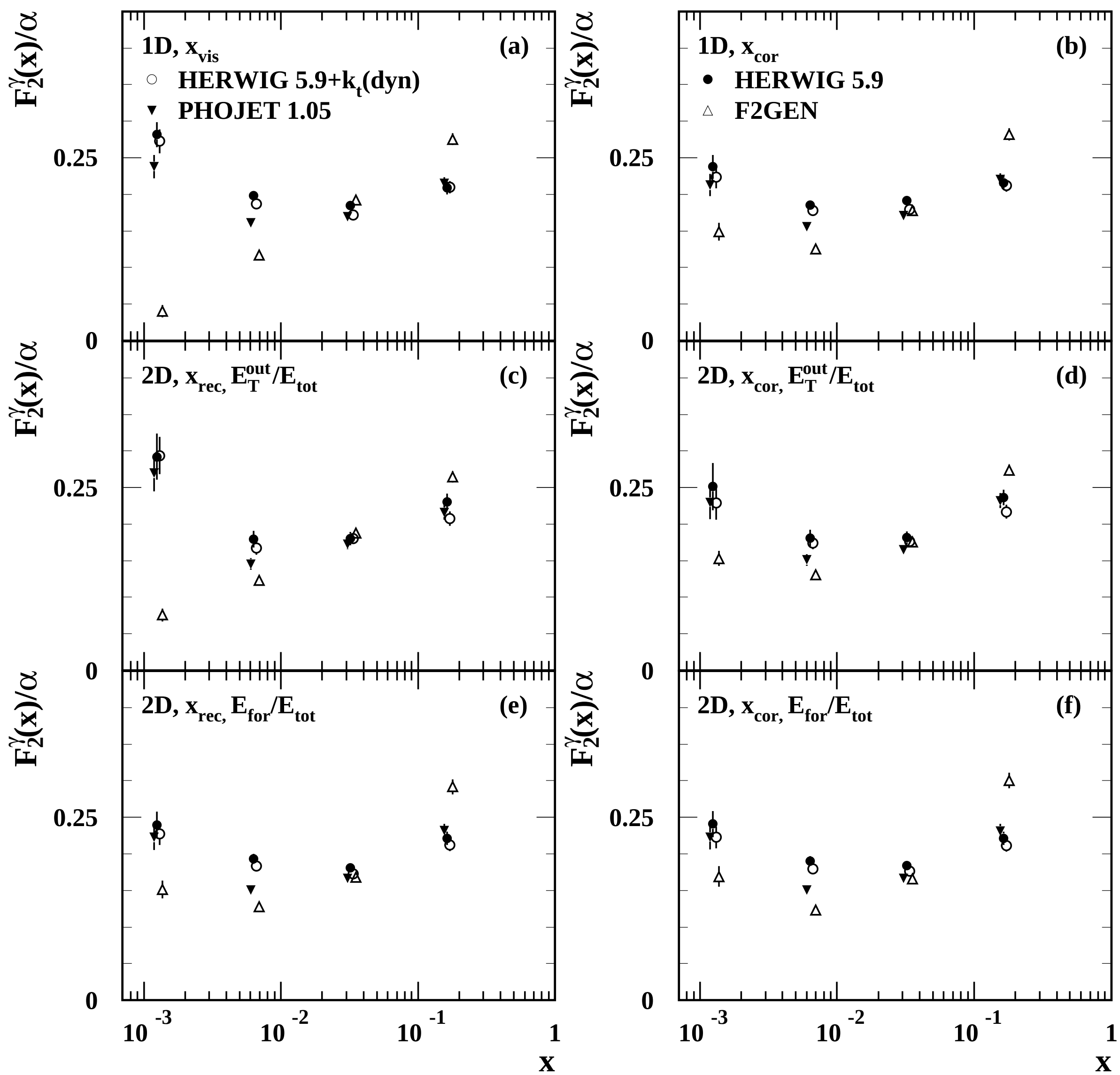
A satisfactory description is seen within the selected phase space.

Description of hadronic variables



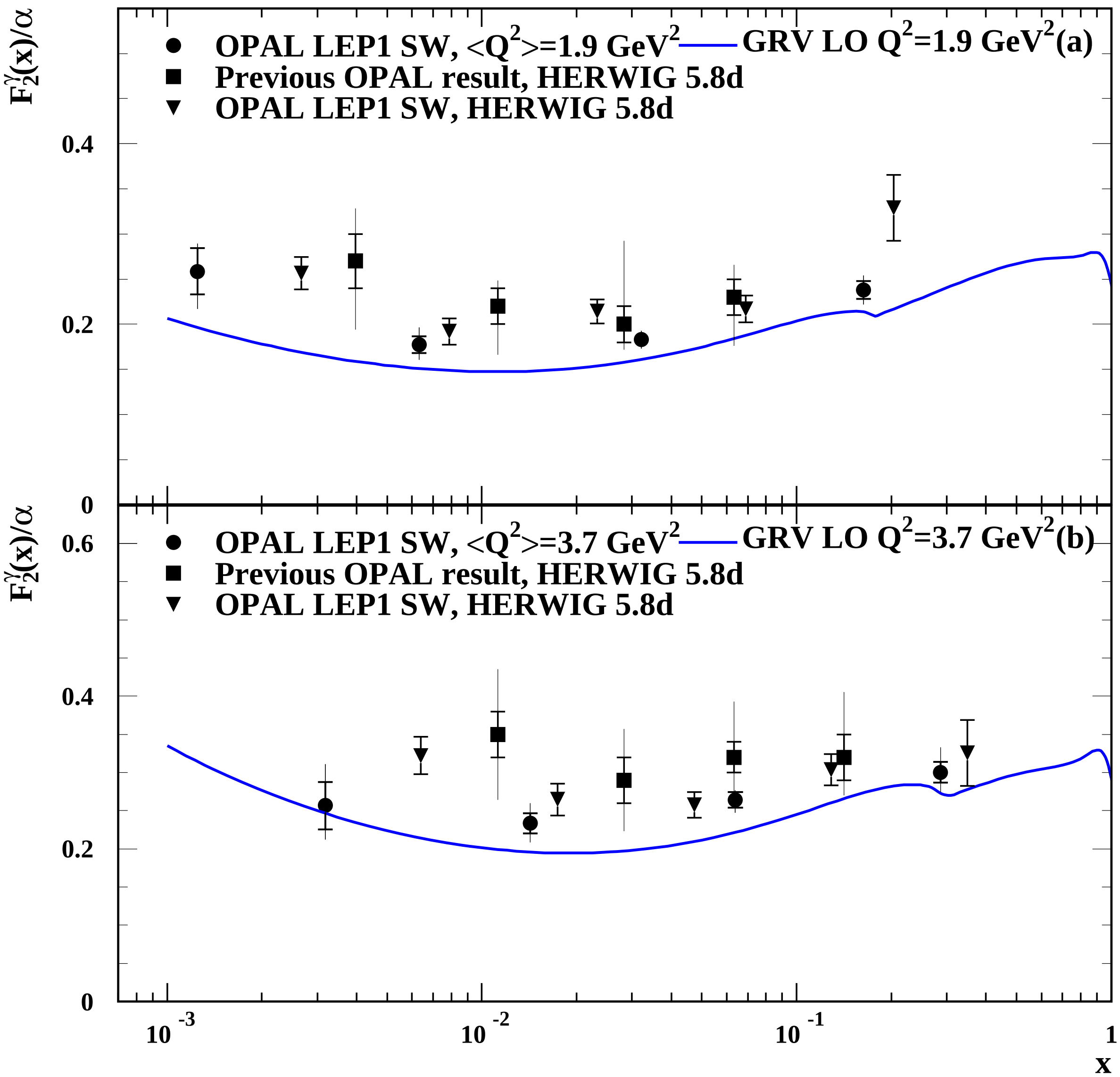
Significant differences are seen.

1-dim versus 2-dim unfolding



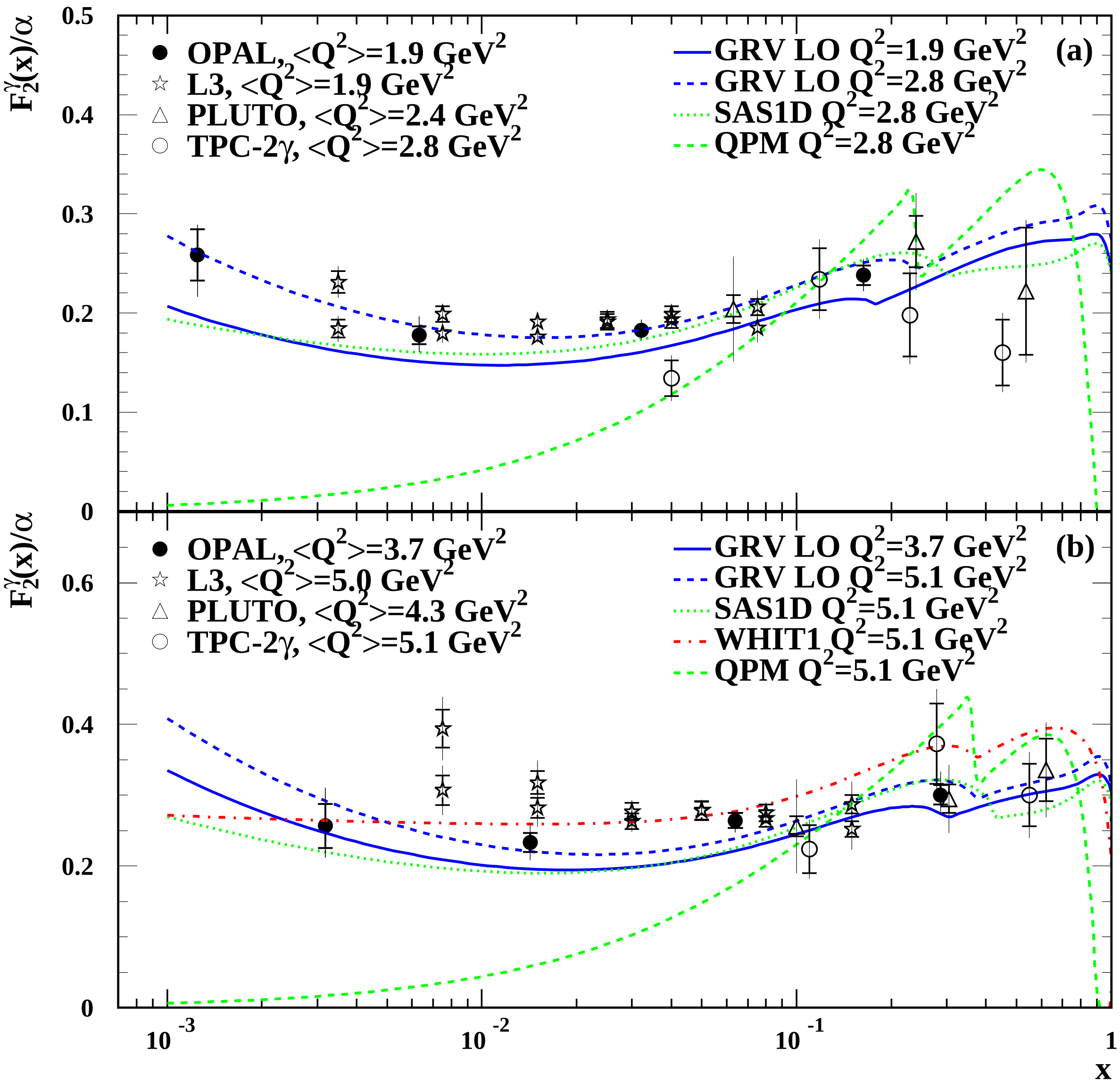
A significant better stability with respect to different modelling of the hadronic final state is achieved by 2-dim unfolding.

Comparison with old OPAL results



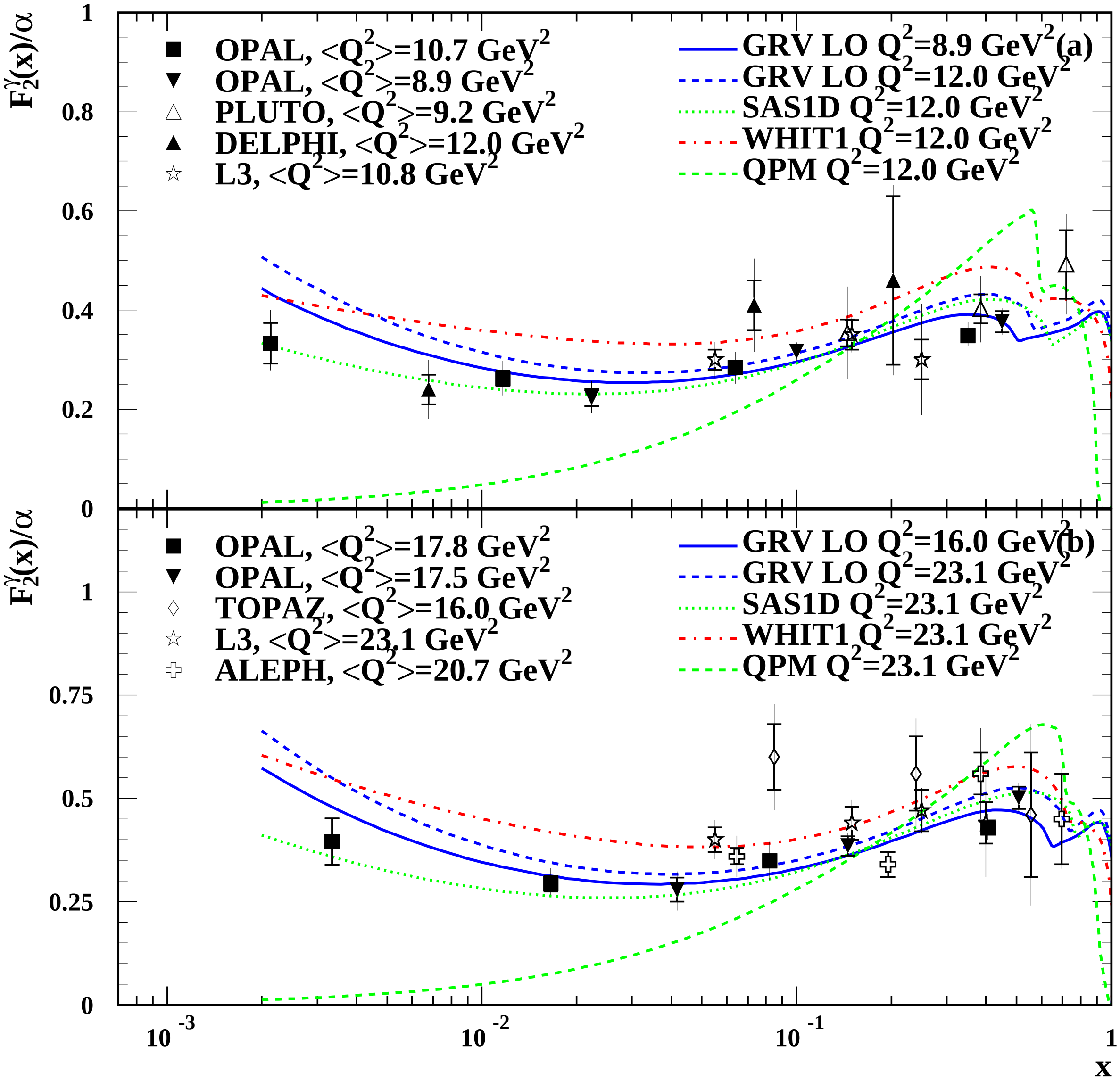
When the same MC model is used, the new results are consistent with the old ones, but with reduced errors. Using the improved MC models leads to a lower measured F_2^γ.

New measurements at low Q^2 and x



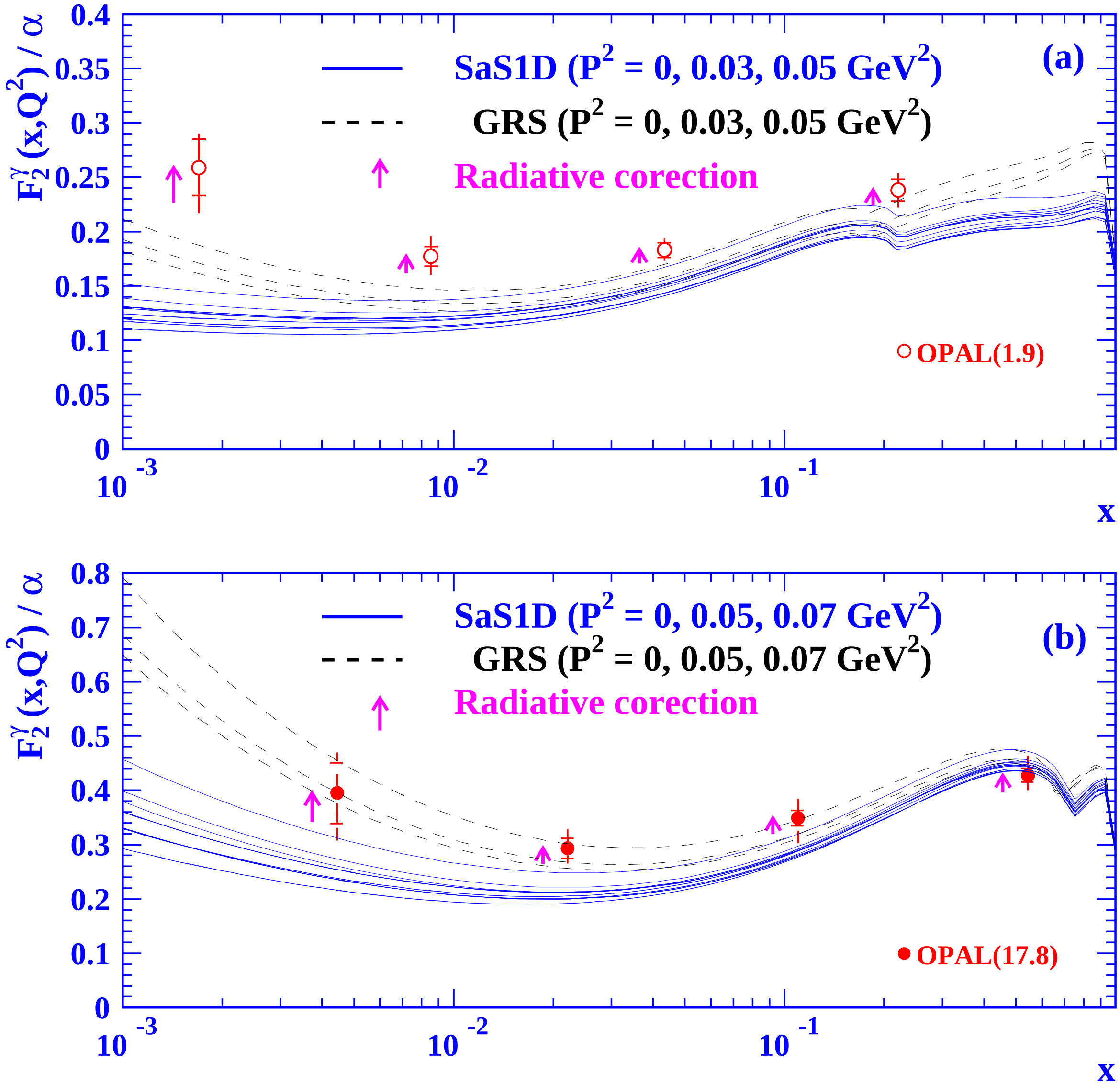
GRV(LO) and SaS1D are somewhat low, and the data has not been corrected for the P^2 effect.

New measurements at larger Q^2



Also at higher Q^2 the errors could be significantly reduced.

Radiative corrections and P^2 effect



The radiative corrections are x dependent and 'known'

$\Rightarrow$ *apply correction*.

The P^2 distribution of the data is unknown and the P^2 suppression is theoretically uncertain $\Rightarrow$ *do not correct*.

Conclusions

1. The first measurement of $F_{2,c}^{\gamma}$ has been made. For large x the NLO calculation perfectly agrees with the data. At low-x the data suggest a hadron-like component also for charm quarks, although in this region the model dependence is rather large.
2. The measurement of the hadronic structure function F_2^{γ} has been updated by OPAL. New Monte Carlo models and improved unfolding procedures lead to significantly smaller systematic errors.

Outlook

1. We need massive matrix elements implemented in the MC's and more data to improve on $F_{2,c}^{\gamma}$.
2. Monte Carlo models should still be improved and 2-dim unfolding is only a work-around.

Slides: http://home.cern.ch/nisius

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