NLO Photon PDF

parametrization using ee and ep data

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A fit to:

- e^+e^- : $\gamma + \gamma* \rightarrow$ hadrons
- ep : $ep \rightarrow e +$ hadrons
- Dijet PHP at HERA: $\gamma + p \rightarrow$ j1 + j2 + hadrons

Gribov factorization

$$\sigma_{\gamma\gamma}(W^2) = \frac{\sigma^2_{\gamma p}(W^2)}{\sigma_{pp}(W^2)}$$

For low x ($x < 0.01$)

$$F_2^{\gamma}(x, Q^2) = F_2^{p}(x, Q^2)\frac{\sigma_{\gamma p}(W^2)}{\sigma_{pp}(W^2)}$$

$$F_2^{\gamma}/\alpha = 0.43 F_2^{p}$$

Comparison with other NLO parametrizations

Q_0^2 of the input PDFs $f_j^\gamma(x, Q_0^2)$
GRV: 0.25 GeV^2,
AFG: 0.5 GeV^2,
GRS: 0.3 GeV^2,
CJK: 0.77 GeV^2,
SAL: 2.0 GeV^2.

We use the proton input at low x ($x < 0.01$).

We take $m_c = 1.5\,\mathrm{GeV}$ and thus our $Q_0^2 = 2\,\mathrm{GeV}^2$ is below the charm threshold. We generate all heavy flavours (c, b, t) radiatively.

We go "backwards" (to lower Q^2) in our NLO evolution. There is a risk of getting unphysical results (as negative cross sections) — this is a signal for a bad initial parametrization. In practice we go down to 1.8 GeV^2 only.

Our input parametrization has free parameters in both point-like and hadronic parts.

Parametrization

$$f_q(x) = f_{\bar{q}}(x) = e_q^2 A^{\mathrm{PL}} \frac{x^2 + (1-x)^2}{1 - B^{\mathrm{PL}} \ln(1-x)} + f_q^{\mathrm{HAD}}(x)$$

$$f_u^{\mathrm{HAD}}(x) = f_d^{\mathrm{HAD}}(x) = A^{\mathrm{HAD}} x^{B^{\mathrm{HAD}}} (1-x)^{C^{\mathrm{HAD}}}$$

$$f_s^{\mathrm{HAD}}(x) = 0.3 f_d^{\mathrm{HAD}}(x)$$

$$f_G(x) = A_G^{\mathrm{HAD}} x^{B_G^{\mathrm{HAD}}} (1-x)^{C_G^{\mathrm{HAD}}}$$

As there are no data at $x \simeq 1$ we fix $C^{\mathrm{HAD}} = 1$ and $C_G^{\mathrm{HAD}} = 3$ as suggested by counting rules.

We have 6 free parameters.

In the DISγ scheme

$$\frac{1}{x}F_2 = \sum_q 2e_q^2 f_q^\gamma + \frac{\alpha_s}{2\pi} C_{F,2}^{(1)} \otimes \sum_q 2e_q^2 f_{q0}^\gamma + \langle e^2 \rangle \, C_{G,2} \otimes f_{G0}^\gamma$$

Terms in red are NLO and f_{q0}^γ are evolved at LO.

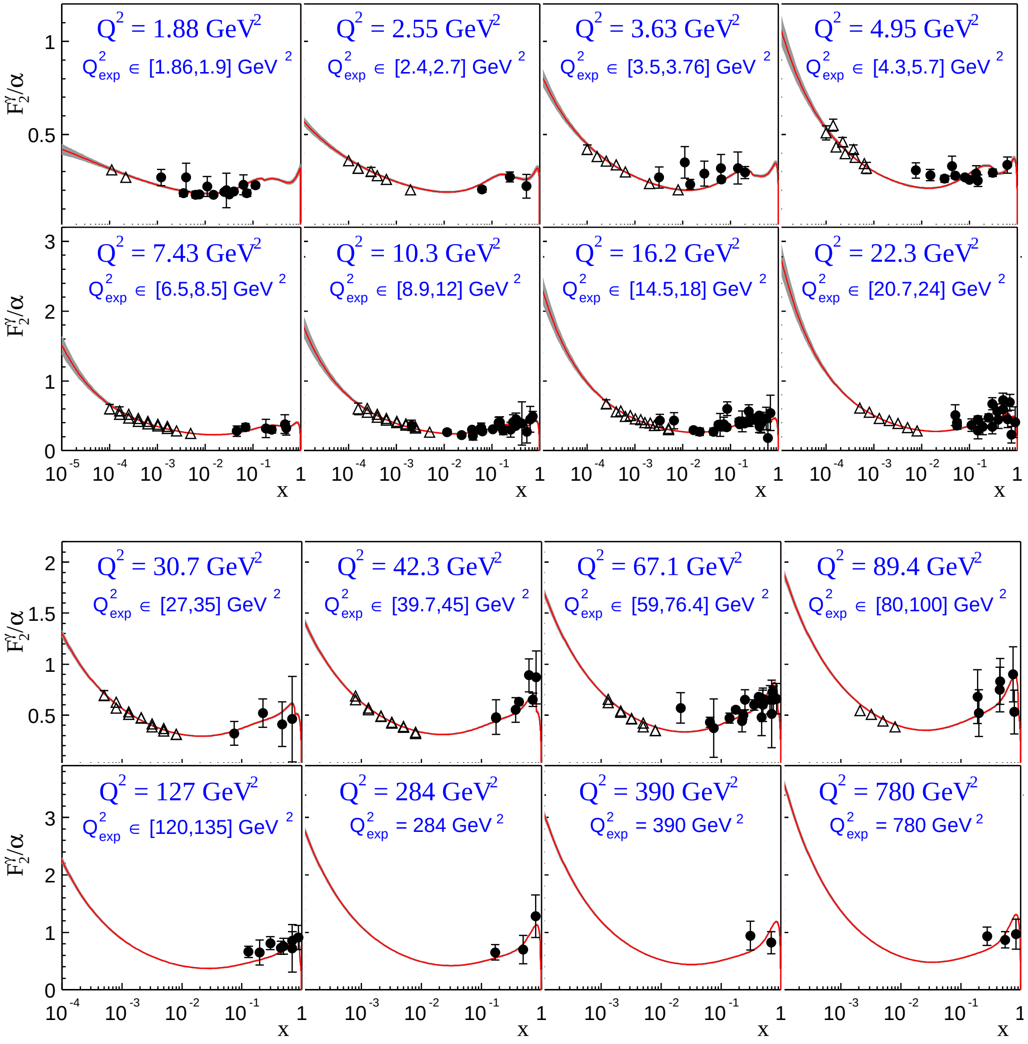
We use zero mass VFNS for the DGLAP evolution of heavy flavour PDFs.

For heavy quark contributions to F_2 we replace $f_h^\gamma \to \mathcal{S} f_h^\gamma$ and add to F_2 a Bethe-Heitler contribution, $(1-\mathcal{S})F_2^{\mathrm{B-H}}$.

The "weighting function" $\mathcal{S}$ is defined as

$$\mathcal{S} = \min\left(\ln \frac{\ln Q^2/\Lambda_4^2}{\ln m_h^2/\Lambda_4^2}, 1\right)$$

Results of the fit



We use the following data points:

164	F_2^γ from ee
122	F_2^p from ep
24	$\frac{d\sigma}{dE_\perp\, dx_\gamma^{\text{obs}}}$ from PHP dijets

Fit to 286 F_2 points gives
$\chi^2 = 297$, $\chi^2/\text{NDF} = 1.06$

Fit to 310 F_2 + dijets points gives
$\chi^2 = 496$, $\chi^2/\text{NDF} = 1.63$

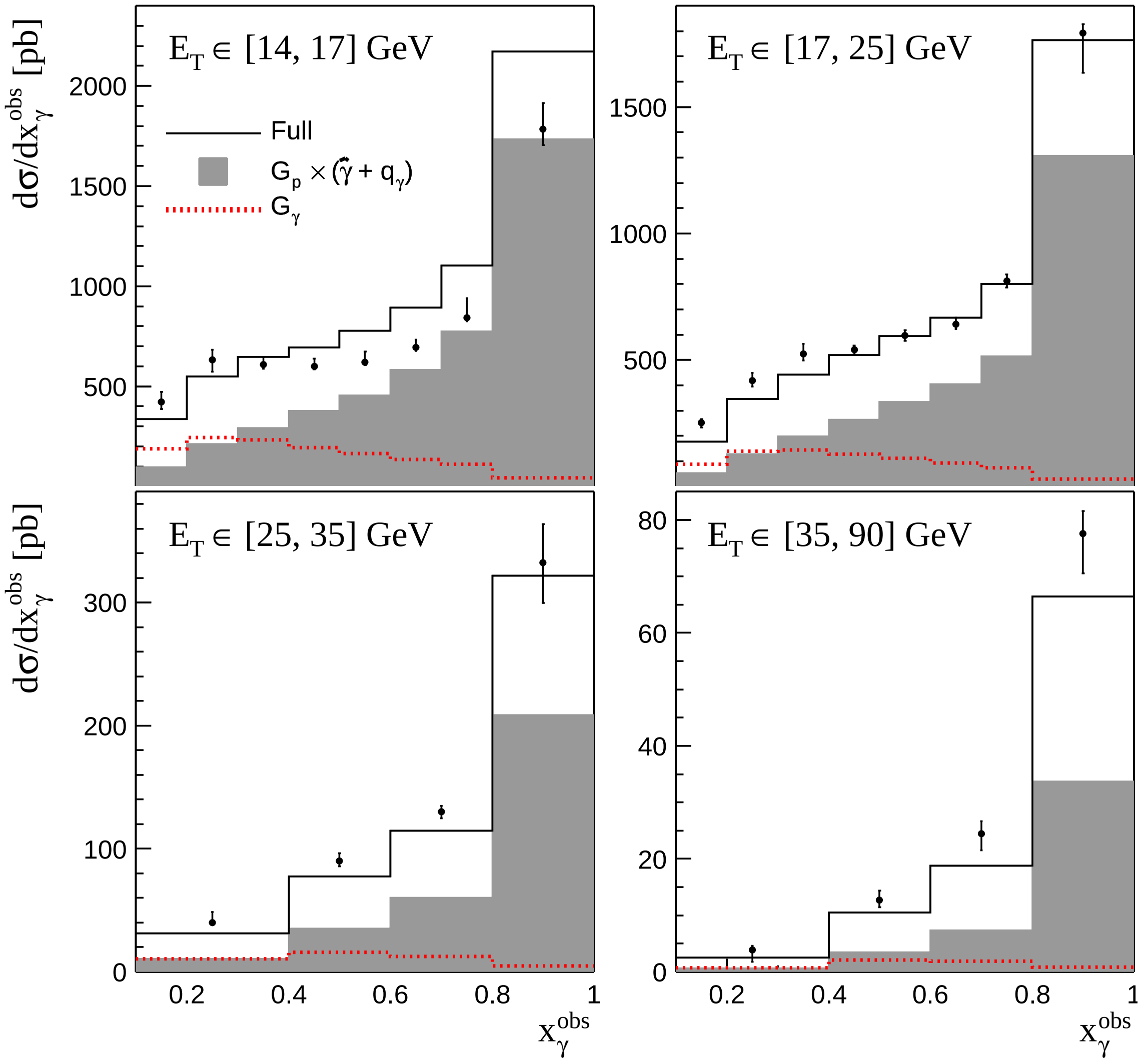
$\chi^2_{\text{dijets}} = 199$!!!

The curves in the plots are drawn at Q^2 given above the graph. The data points are within the Q^2_{exp} range.

Full dots — F_2^γ data

Triangles — F_2^p data

Di-jets PHP



$$\frac{d\sigma}{dx_\gamma^{obs}}[pb]$$

in 4 $E_\perp$(GeV) bins: $14 - 17$, $17 - 25$, $25 - 35$, $35 - 90$.

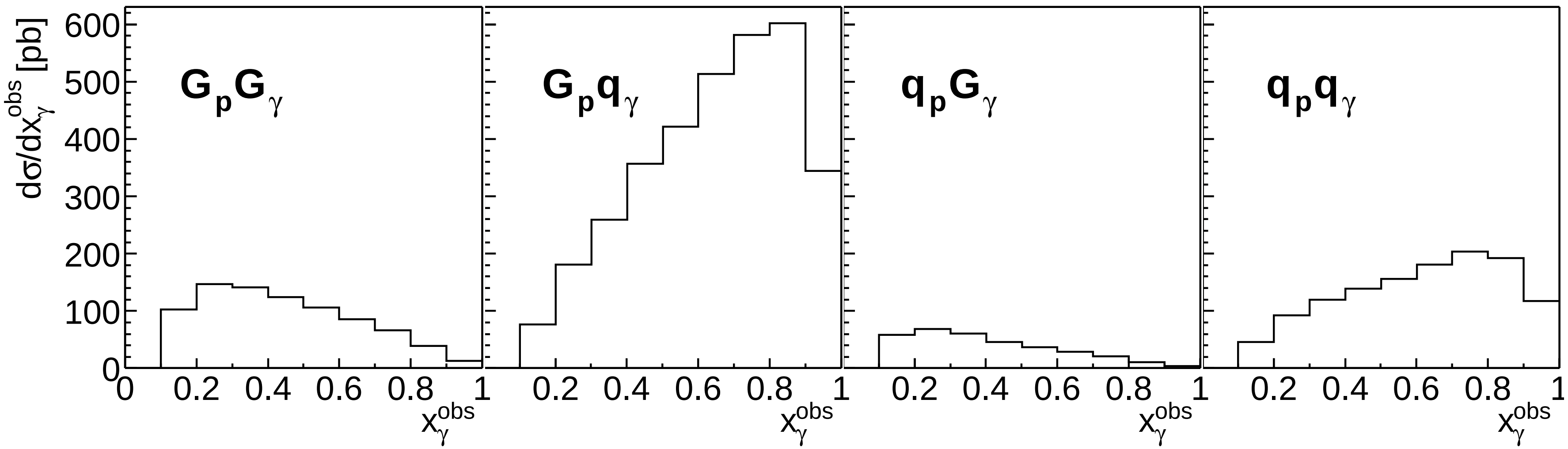
24 dijet PHP points measured by ZEUS

Eur. Phys. J. C23 (2002) 615

$\chi^2_{\text{dijets}} = 199$

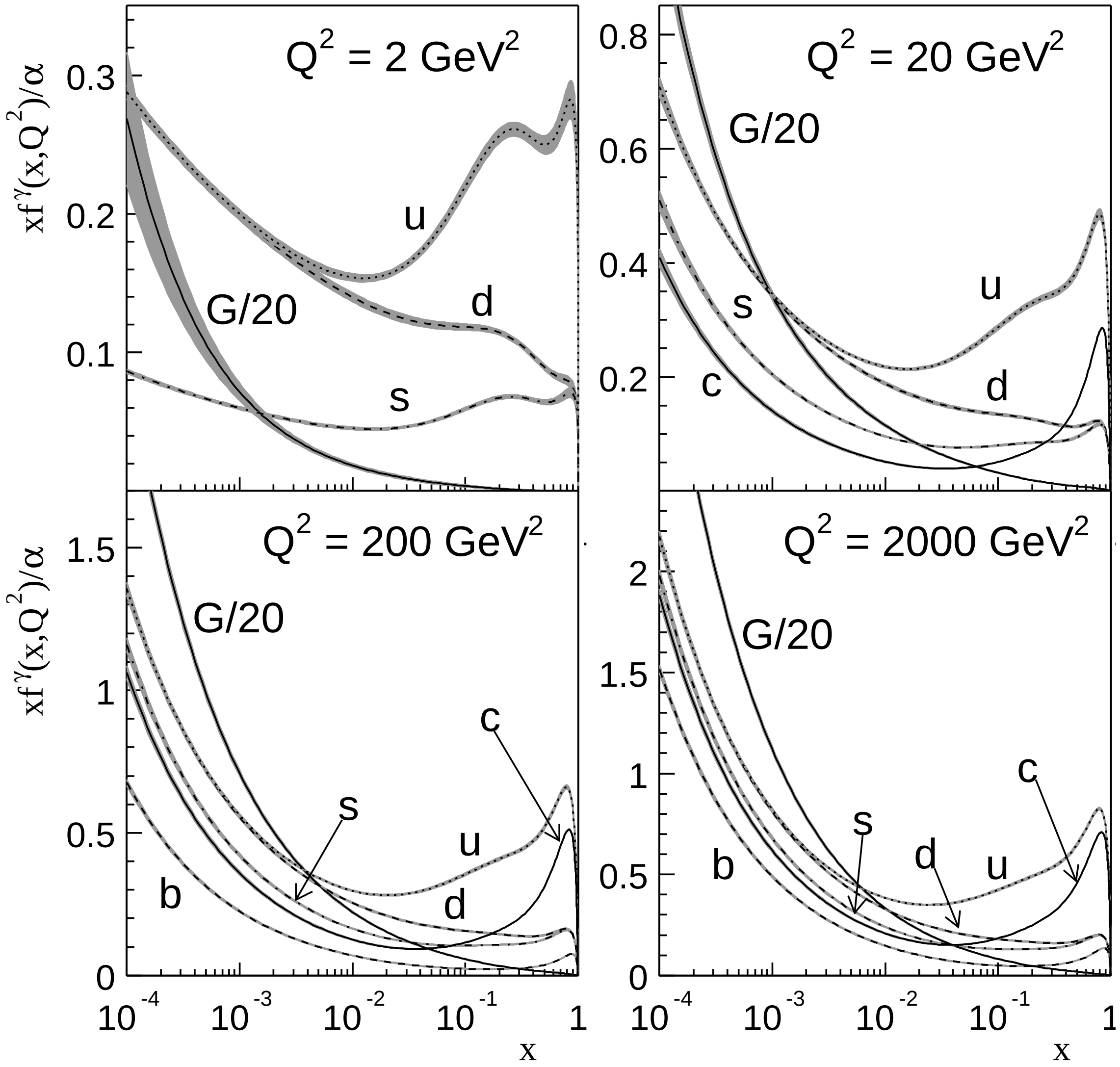
The histograms are calculated using the Frixione code with SAL photon and ZEUS-TR proton.

Dijet PHP sensitivity to f_G^γ and f_G^p



Typical contributions of different parton types to $d\sigma/dx_\gamma^{\text{obs}}$ for $E_\perp \in [14, 17]$ GeV.

Dijet PHP is dominated by the contribution of gluons in the proton and the region most sensitive to gluons in the photon is suppressed by kinematic constraints.

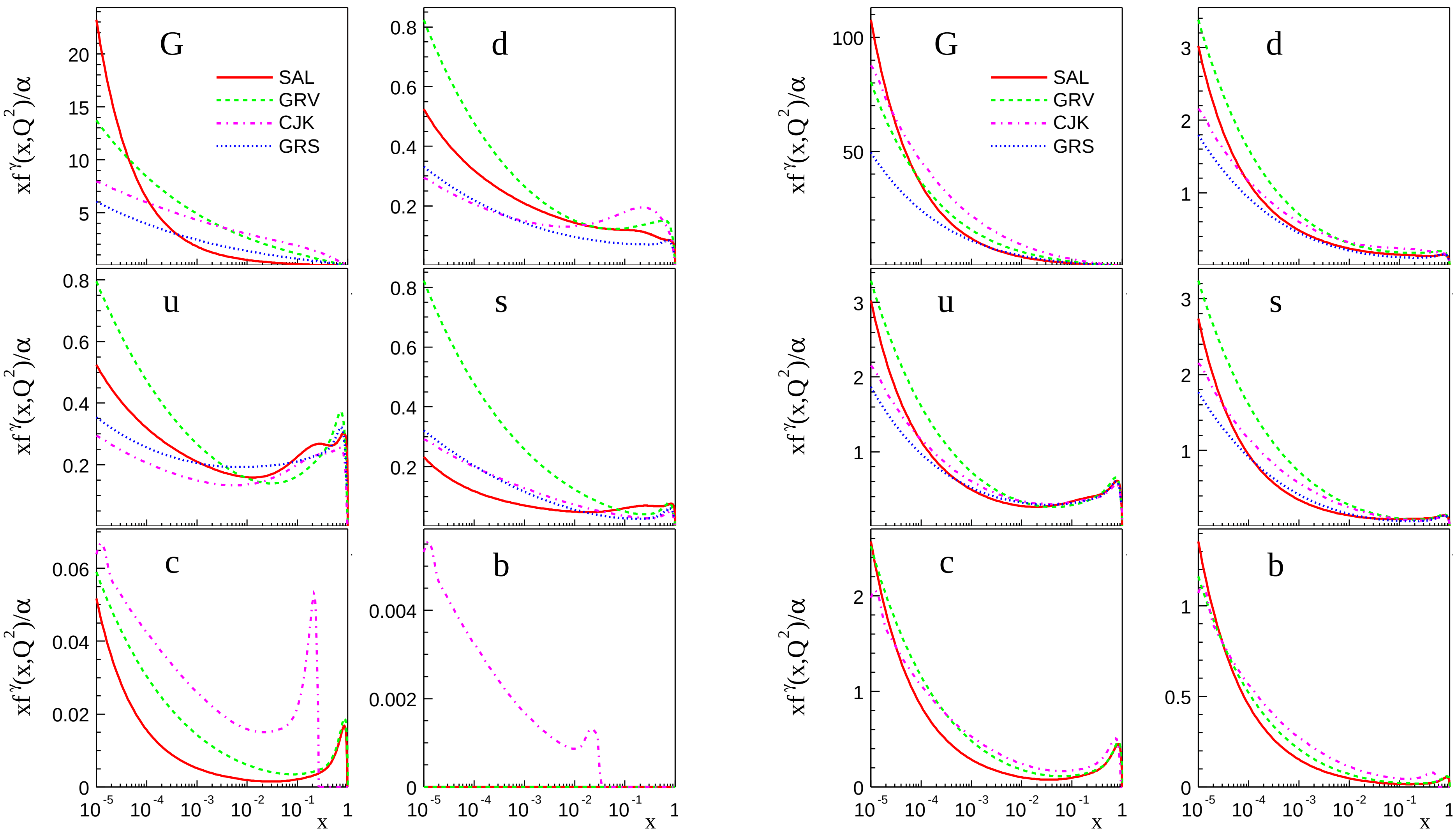


SAL PDFs

The bands mark the fit uncertainty.

Comparison to Other NLO DISγ Parametrizations

$Q^2 = 2.5$ GeV^2 $Q^2 = 100$ GeV^2



Summary & Conclusions

- A new NLO parameterization of the photon PDFs
- F_2^γ, low-x F_2^p and dijet PHP data used in the fit.
- A good description of the F_2 data.
- The dijet data are much more sensitive to the gluons in the proton than in the photon.
- The obtained PDFs fulfil the Frankfurt-Gurvich sum rule which was not imposed in the fit.

Heavy quarks in F_2

$$\frac{1}{x}F_2 = \sum_{q=d,u,s} e_q^2 \, \mathcal{F}_{2q} + \sum_{h=c,b,t} e_h^2 \, \Theta(W - 2m_h) \, \mathcal{H}_{2h}$$

$$\mathcal{F}_{2q} = 2C_{F,2} \otimes f_q^\gamma(Q^2) + C_{G,2} \otimes f_G^\gamma(Q^2)$$

All $f_k^\gamma(Q^2)$ given by ZM-VFNS DGLAP evolution with # flavours: $m_q^2 < Q^2$.

Heavy quarks — two limits of Q^2:

$$\mathcal{H}_{2h}(x, Q^2) = \begin{cases} 2f_h^{\mathrm{BH}}(x,Q^2) & \text{for } Q^2 \lesssim m_h^2 \quad \text{(Bethe-Heitler } \gamma^*\gamma \to h\bar{h}\text{)} \\ \mathcal{F}_{2h}(x,Q^2) & \text{for } Q^2 \to \infty \quad (m_h \text{ neglected)} \end{cases}$$

At intermediate Q^2 we use a phenomenological formula
= a weighted sum of both contributions.

The weights are constructed to avoid double counting and to get proper limits at low and high Q^2.

In this sum:

- f_h^γ multiplied by $\mathcal{S}(m_h^2, Q^2)$ and

  f_h^{BH} multiplied by $\left[1 - \mathcal{S}(m_h^2, Q^2)\right]$

$$\mathcal{S}(m_h^2, Q^2) = \min\left(\ln \frac{\ln Q^2/\Lambda_4^2}{\ln m_h^2/\Lambda_4^2}, 1\right) \in [0,1]$$

- coefficient functions $C_{F,2}$ and $C_{G,2}$ (calculated for $m_h = 0$) multiplied by

$$\frac{f_h^{\mathrm{BH}}(x, Q^2)|_{\text{leading twist}}}{f_h^{\mathrm{BH}}(x, Q^2 \to \infty)} \in [0,1]$$

The Bethe-Heitler contribution reads

$$\begin{aligned} f_h^{\mathrm{BH}}(x, Q^2) &= 3e_h^2 \frac{\alpha_{\mathrm{em}}}{2\pi} \Big\{ \left[x^2 + (1-x)^2 + 4x(1-3x)\frac{m_h^2}{Q^2} - 8x^2 \frac{m_h^4}{Q^4}\right] \ln \frac{\left(1+\sqrt{1-\beta}\right)^2}{\beta} \\ &\quad + \left[8x(1-x) - 1 - 4x(1-x)\frac{m_h^2}{Q^2}\right]\sqrt{1-\beta}\Big\} \end{aligned}$$

where $\beta = \dfrac{4m_h^2 x}{Q^2(1-x)} = \dfrac{4m_h^2}{W^2}$.