The photon PDF of the proton

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Present precision of PDFs (NNLO in α_s) implies that we should study the QED corrections (LO in α).

We show how the photon input PDF can be calculated with good accuracy, and used in DGLAP global analyses in which the photon is treated as an additional point-like parton.

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Evolution equations to LO in α and α_s

$$\frac{\partial q_i(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{qq}\otimes q_i + P_{qg}\otimes g\right) + $$

$$+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(\sum_i \frac{e_i^2}{C_F} P_{qq}\otimes q_i + \sum_i e_i^2 P_{q\gamma}\otimes \gamma\right)$$

$$\frac{\partial g(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left(\sum_i P_{gq}\otimes q_i + P_{gg}\otimes g\right)$$

$$\frac{\partial \gamma(x,Q^2)}{\partial \log Q^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{\gamma\gamma}\otimes \gamma + \sum_i e_i^2 P_{\gamma q}\otimes q_i\right)$$

but input for $\gamma(x,Q_0^2)$?

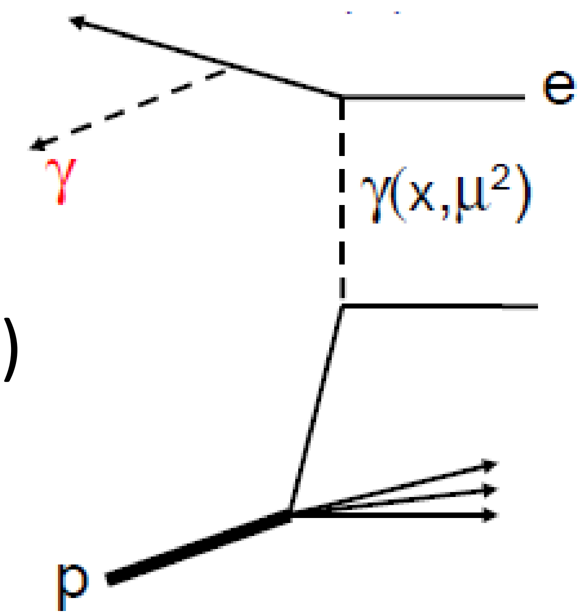
Existing determinations of $\gamma(x,Q_0^2)$

MRST(2004) – input given by emission from val. quark

$$\gamma^p(x,Q_0^2) = \frac{\alpha}{2\pi}\int\frac{dz}{z}\left[\frac{4}{9}\log\left(\frac{Q_0^2}{m_u^2}\right)u_0\left(\frac{x}{z}\right)+\frac{1}{9}\log\left(\frac{Q_0^2}{m_d^2}\right)d_0\left(\frac{x}{x}\right)\right]\frac{1+(1-z)^2}{z}$$

using current quark masses.

Compare with data for electroprod^n of isolated photon: ep→eγX

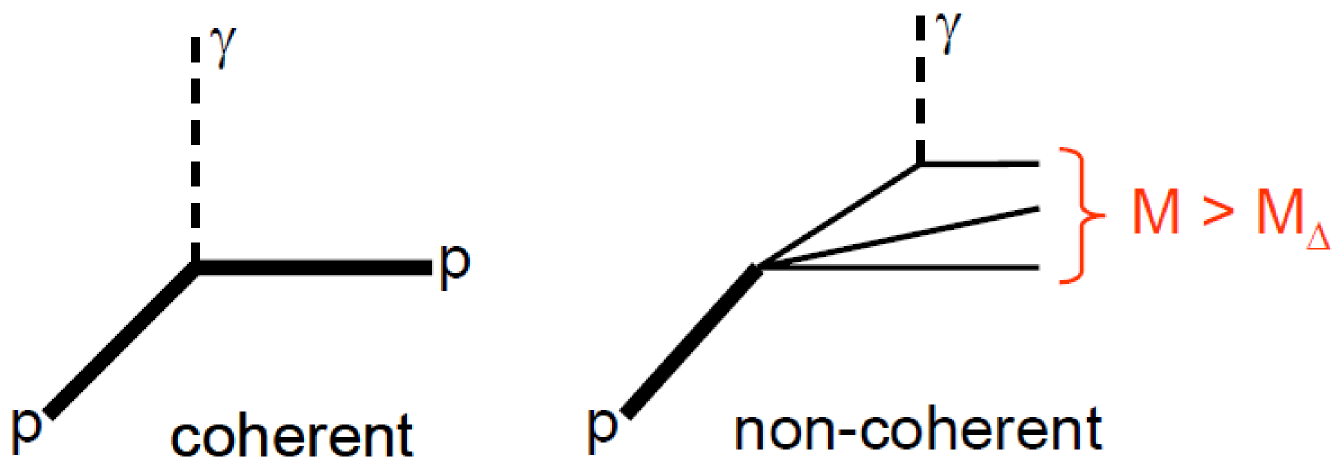


NNPDF(2013) freely parametrise $\gamma(x,Q_0^2)$ and attempt to determine it from LHC Drell-Yan data → large uncertainties.

CTEQ(prelim) use MRST form, but with arbitrary normalisation factor, $p_0(\gamma)$, fitted to ep→eγX data. Again large uncertainties.

Here we emphasize that the major part of $\gamma(x,Q_0^2)$ comes from coherent γ emission from proton which stays intact

(Previous analyses based on incoherent emission from quark)



$$\gamma(x,Q_0^2) = \gamma_{coh} + \gamma_{incoh}$$

major part--- well known to good accuracy

relatively small --- QED excit^{ns} of p – here we estimate it from quark viewpt. γ_{incoh} gives main uncertainty of $\gamma(x,Q^2)$

em form factor

$$\gamma_{\rm coh}(x,Q_0^2) = \frac{\alpha}{2\pi}\,\frac{[1+(1-x)^2]}{x}\int_0^{|t|<Q_0^2} dq_t^2\,\frac{q_t^2}{(q_t^2+x^2m_p^2)^2}F_1^2(t)$$

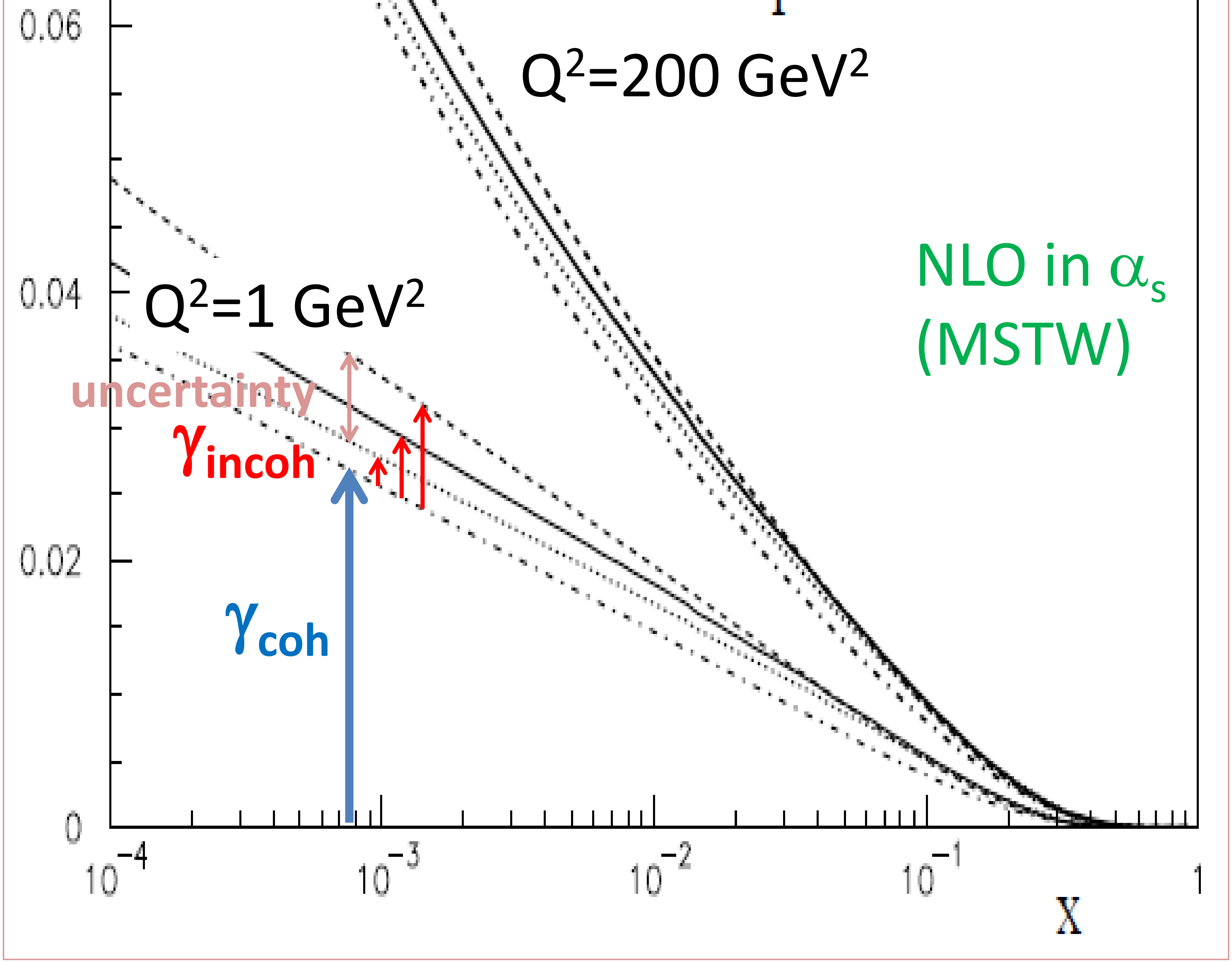
$$\gamma_{\rm incoh}(x,Q_0^2) = \frac{\alpha}{2\pi}\int_{|t_{\rm min}|}^{Q_0^2}\frac{dt}{t-m_q^2}\,\left(1-F_1^2(t)\right)\int_x^1\frac{dz}{z} \quad \times$$

$$\times \quad \left[\frac{4}{9}u_0(\frac{x}{z})+\frac{1}{9}d_0(\frac{x}{z})\right]\,\frac{1+(1-z)^2}{z}$$

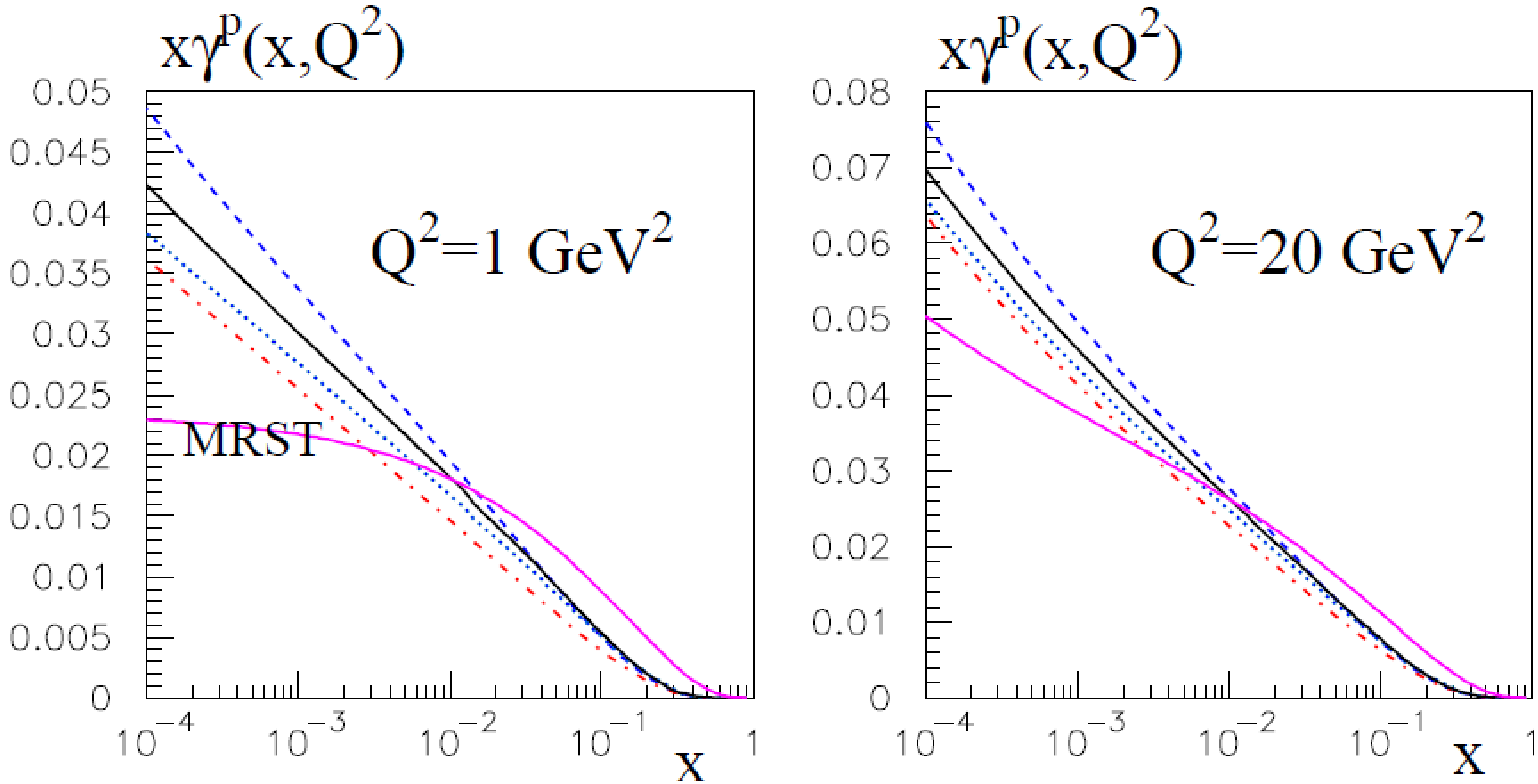
upper limit of $\gamma_{\rm incoh}$: use current q masses; for $Q<Q_0$ freeze u_0, d_0 at their values at Q_0.

lower limit of $\gamma_{\rm incoh}$: use constituent q masses; with non-rel $u_0=2\delta(x-1/3)$, $d_0=\delta(x-1/3)$

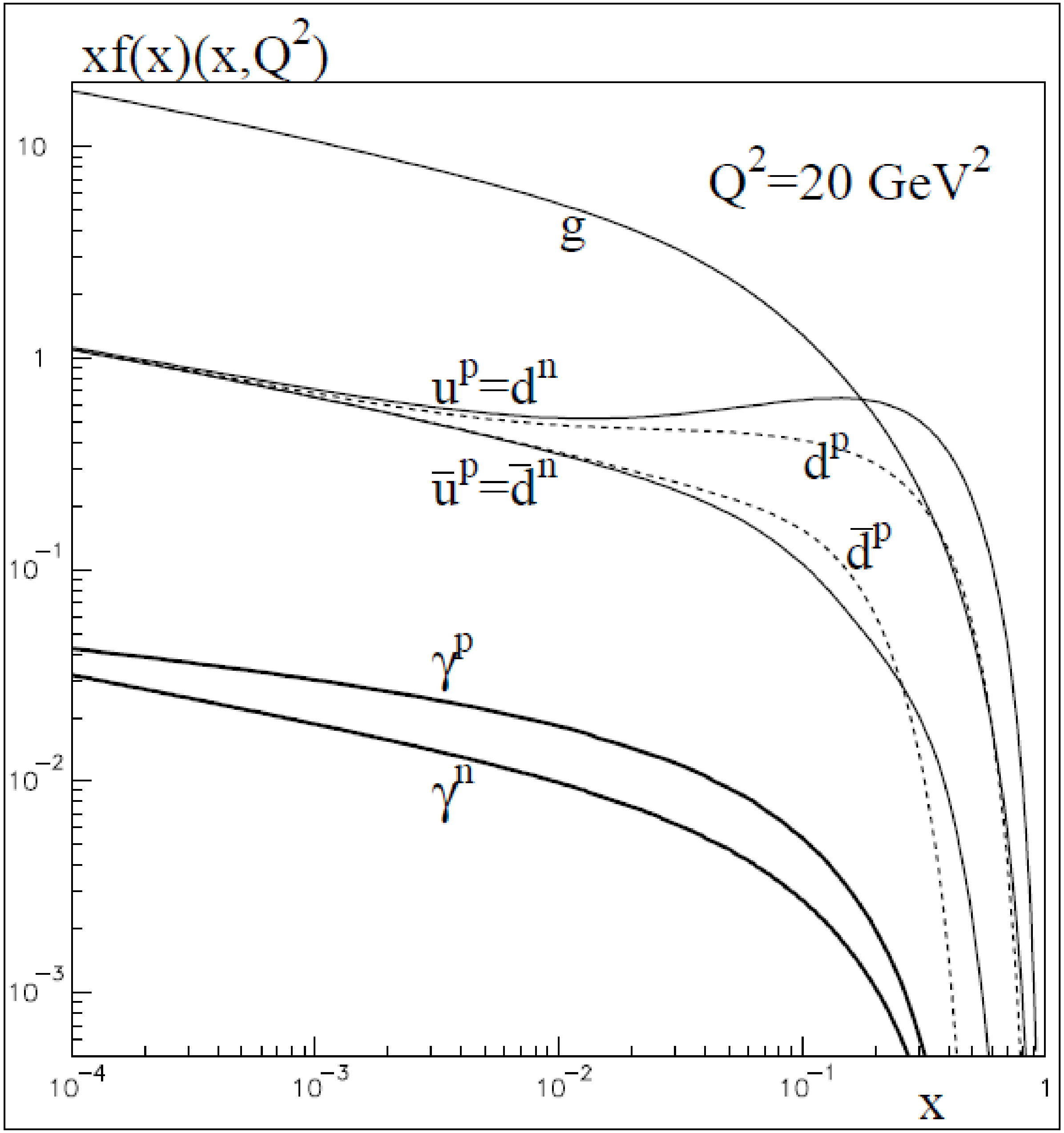
also take a, physics-motivated, linear interpol^n of 2 limits


0.06
0.04
0.02
0
Q²=200 GeV²
Q²=1 GeV²
NLO in αs
(MSTW)
uncertainty
γincoh
γcoh
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
X

Comparison with MRST(2004)



Note MRST is based solely on γ_{incoh}, whereas here it comes mainly from γ_{coh}. MRST should have been suppressed by t_{min} and by $1-F_1^2$ --- so, at large x, where $|t_{min}|$ is large, MRST exceeds the present input.



Comparison of γ^p, γ^n PDFs with the other PDFs.

There will be a small breaking of isospin symmetry, $u^p \neq d^n$, coming from $P_{q\gamma}$ in the evolution eq. for quarks.

Evolution equations to LO in α and α_s

$$\frac{\partial q_i(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{qq}\otimes q_i + P_{qg}\otimes g\right) +$$

$$+\frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(\sum_i \frac{e_i^2}{C_F} P_{qq}\otimes q_i + \sum_i e_i^2 P_{q\gamma}\otimes\gamma\right)$$

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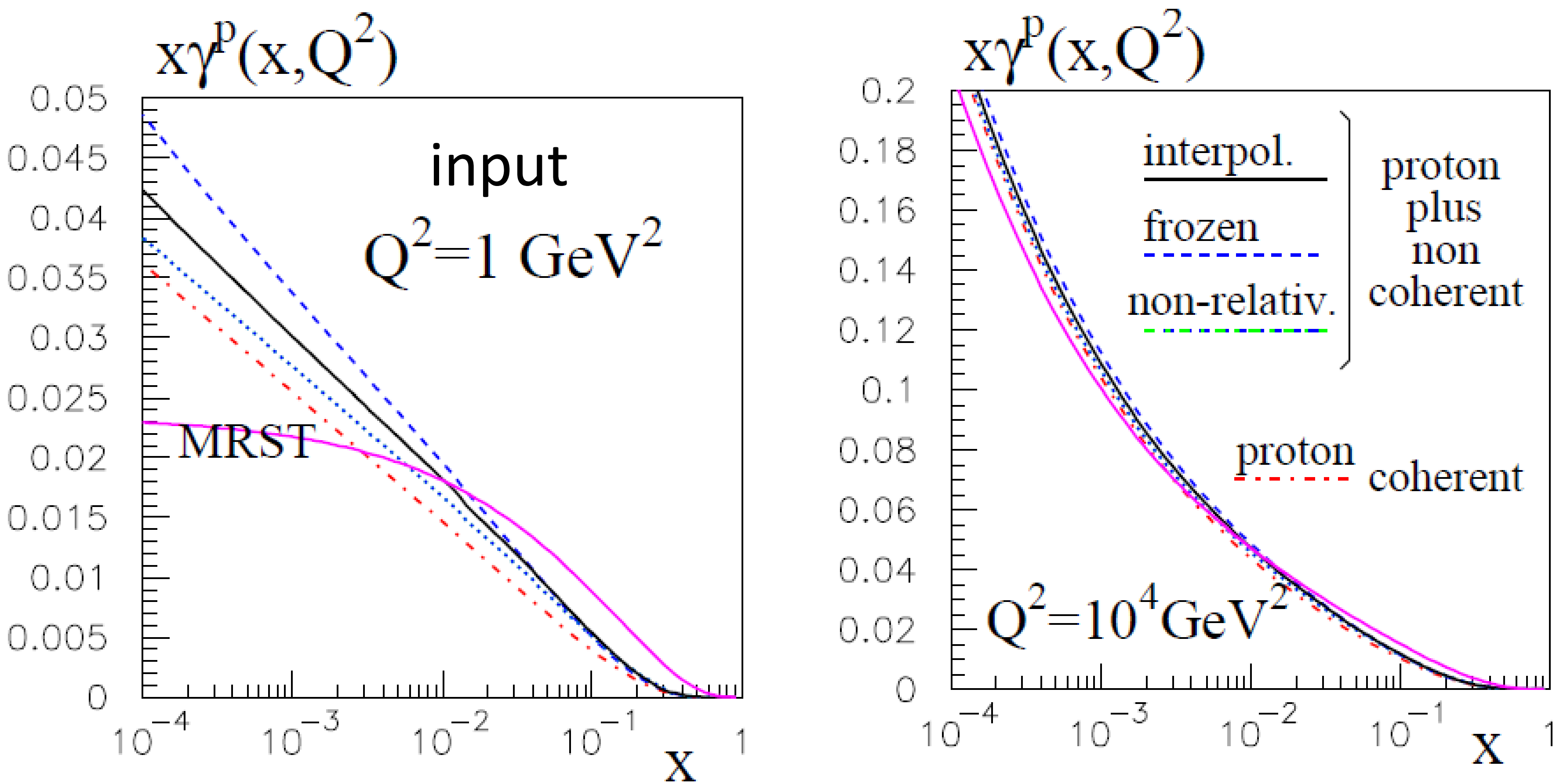
$$\frac{\partial \gamma(x,Q^2)}{\partial \log Q^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{\gamma\gamma}\otimes\gamma + \sum_i e_i^2 P_{\gamma q}\otimes q_i\right)$$

At large Q^2 the behaviour of $\gamma^p(x,Q^2)$ becomes stable and relatively insensitive to the form taken for the input.

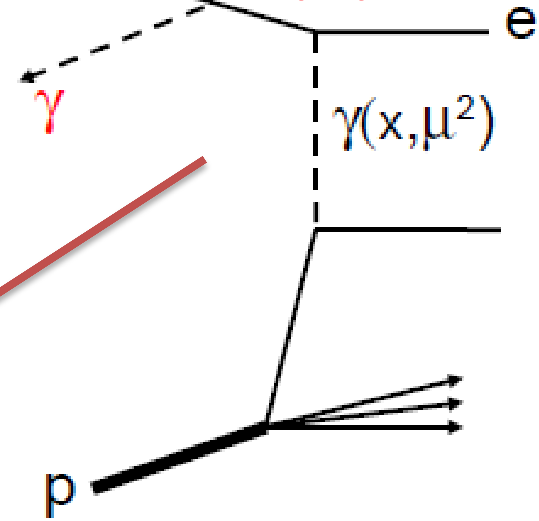
The evolution $d\gamma^p/d\log Q^2$ is driven by $P_{\gamma q} \times q$ and the quark PDFs are well determined



Expt[al] probe of photon PDF: ep → eγX data

Photons observed in direction of incoming e are mediated by eγ → eγ, **diag.(A)** --- so data at high negative rapidity, η^γ, at angles close to e beam, are driven by photon PDF.

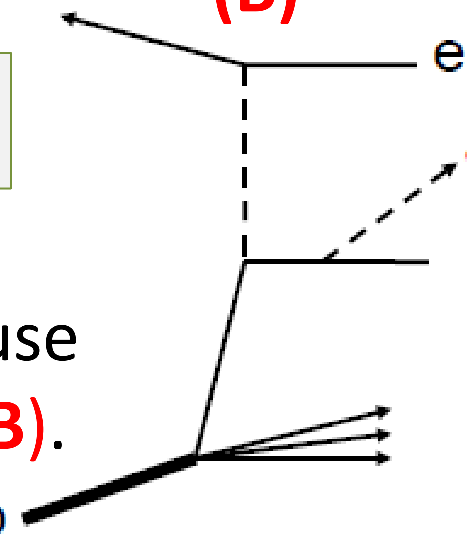
(A)



η^γ range	$d\sigma/d\eta^\gamma$ (pb)	
	ZEUS	(A)
$-0.7 - -0.3$	17.4 ± 1.1	16.4
$-0.3 - 0.1$	13.0 ± 0.9	7.7
$0.1 - 0.5$	10.7 ± 1.0	2.7
$0.5 - 0.9$	8.7 ± 1.3	0.8

+/-20% scale uncertainty

(B)



The discrepancy as η^γ increases is because then emission is mainly from q's, **diag (B)**.

Conclusions We determine the input γ PDF. The uncertainty is relatively small, since the major part, γ^p_{coh}, of the distrib^n (which is produced by the coherent emission of the photon from a proton that remains intact) is well known.

Compare with other determinations

Group	input photon PDF	data
MRST 2004	model for $\gamma^p_{\rm incoh}$	predict $ep \to e\gamma X$
NNPDF 2013	freely parametrised	fit to LHC D-Yan
CTEQ prelim.	parametrise with $p_0(\gamma)$	fit to $ep \to e\gamma X$
this work	calc. $\gamma^p_{\rm coh}$ (dominates) + model for $\gamma^p_{\rm incoh}$	predict $ep \to e\gamma X$