Dynamical Parton Distributions at NNLO

Pedro Jimenez-Delgado

PJD and E. Reya, *Phys. Rev.* **D79** (2009) 074023 (arXiv:0810.4274)

EPS-HEP 2009, Krakow 16 Jul 2009

technische universität dortmund

fakultät physik

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1. General framework

Standard ***FOPT*** *QCD* evolution: ***FFNS*** with $\mathbf{n_f = 3}$ $\quad (\mathbf{F^{HQ}_{2,L}}$ up to $\mathcal{O}(\alpha_s^2))$

Chi-square + ***Hessian*** method (experimental uncertainties):

$$\chi^2(\mathbf{p}) \equiv \sum_{i=1}^{N} \left(\frac{\text{data}(i) - \text{theory}(i,p)}{\text{error}(i)} \right)^2 , \qquad \mathbf{\Delta}\chi^2 = \chi^2 - \chi_0^2 \simeq \frac{1}{2} \sum_{i,j=1}^{d} \mathbf{H_{ij}}(\mathbf{a_i} - \mathbf{a_i^0})(\mathbf{a_j} - \mathbf{a_j^0}) \leq \mathbf{T^2}$$

with *tolerance parameter* $\mathbf{T^2 = T^2_{1\sigma} = \frac{\sqrt{2N}}{(1.65)^2}} \Rightarrow \mathbf{T \simeq 4.5}$

1178 *DIS* data points

- *FT* (SLAC,BCDMS,E665,NMC): $\mathbf{F_2^{p,n,d}}$
- *HERA* (H1,ZEUS): $\sigma^{\mathbf{r}} \leftrightarrow \mathbf{F^p_{2,L,3}}$

390 *Drell-Yan* data points E866: $\mathbf{\frac{d\sigma^{pp,pd}}{dM\, dx_F}}$

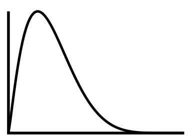
Inclusive jets and HQ production data not included (*GJR08*) for consistency

2. The dynamical approach

Idea: at low-enough Q^2 only "valence" partons would be "resolved"

$\longrightarrow$ structure at higher Q^2 appears ***radiatively*** (i.e. due to QCD ***dynamics***)

$$xf(x, Q_0^2) = N\, x^a (1-x)^b (1 + A\sqrt{x} + Bx)$$

DYNAMICAL:	***standard:***
$Q_0^2 < 1$ GeV^2 optimally ***determined***	$Q_0^2 = 2$ GeV^2 arbitrarily ***fixed***
Positive definite input distributions	Arbitrary fine tunning ($g < 0$!!)
$a > 0$ ***"valence"-like*** 	***Unrestricted*** parameters
Connection with NP models	Only measured region $Q^2 \geq Q_0^2$
QCD ***predictions*** for $x \leq 10^{-2}$	***Extrapolations*** to unmeasured region
More restrictive, less uncertainties	Less restrictive, ***smaller*** χ^2

3. The determination of $\alpha_s(M_Z^2)$

Only free parameter (besides masses) in *QCD*: acceptable agreement

However "dispersion" $>$ uncertainties: global fits (*DIS*) yield smaller values

Our results: $\left\{ \begin{array}{l} \textbf{\textit{dynamical}}: 0.1124 \pm 0.0020 \\ \text{standard}: 0.1158 \pm 0.0035 \end{array} \right.$

Indeed dynamical results (gluon) ***more constrained!***

Other NNLO determinations:

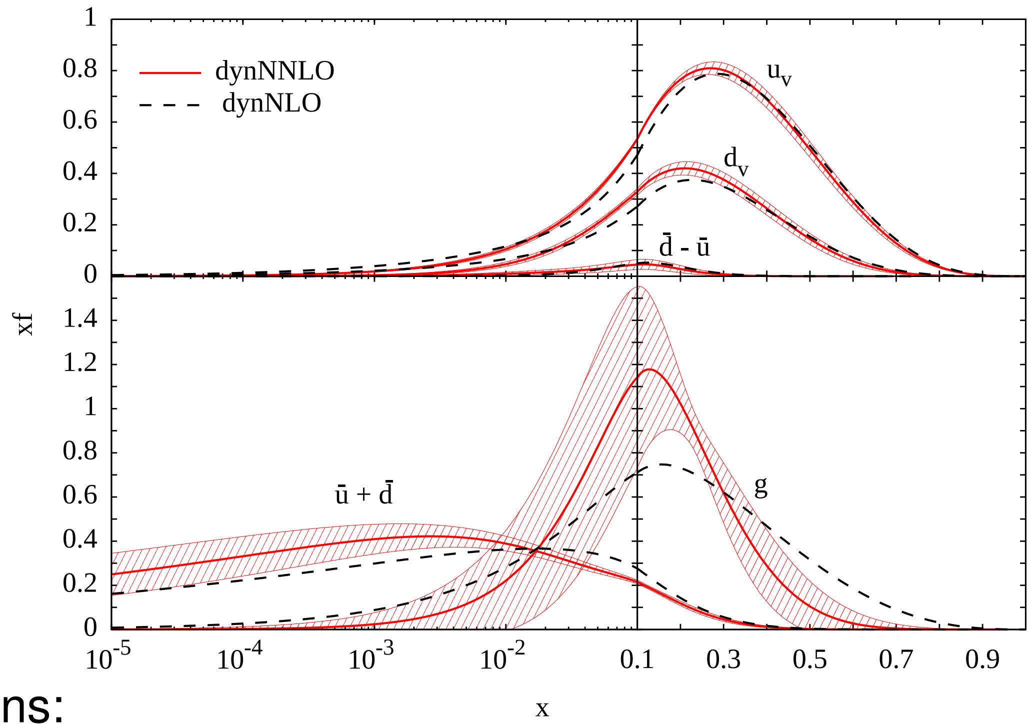
AMP (06)	0.1128 ± 0.0015
MSTW (08)	0.1171 ± 0.0014
ABKM (09)	0.1135 ± 0.0014

Errors scale with $\mathbf{T}$ + *Bayesian* treatments yield smaller estimates

4. Dynamical input distributions

Optimal determination:

$Q_o^2 = 0.55$ GeV^2



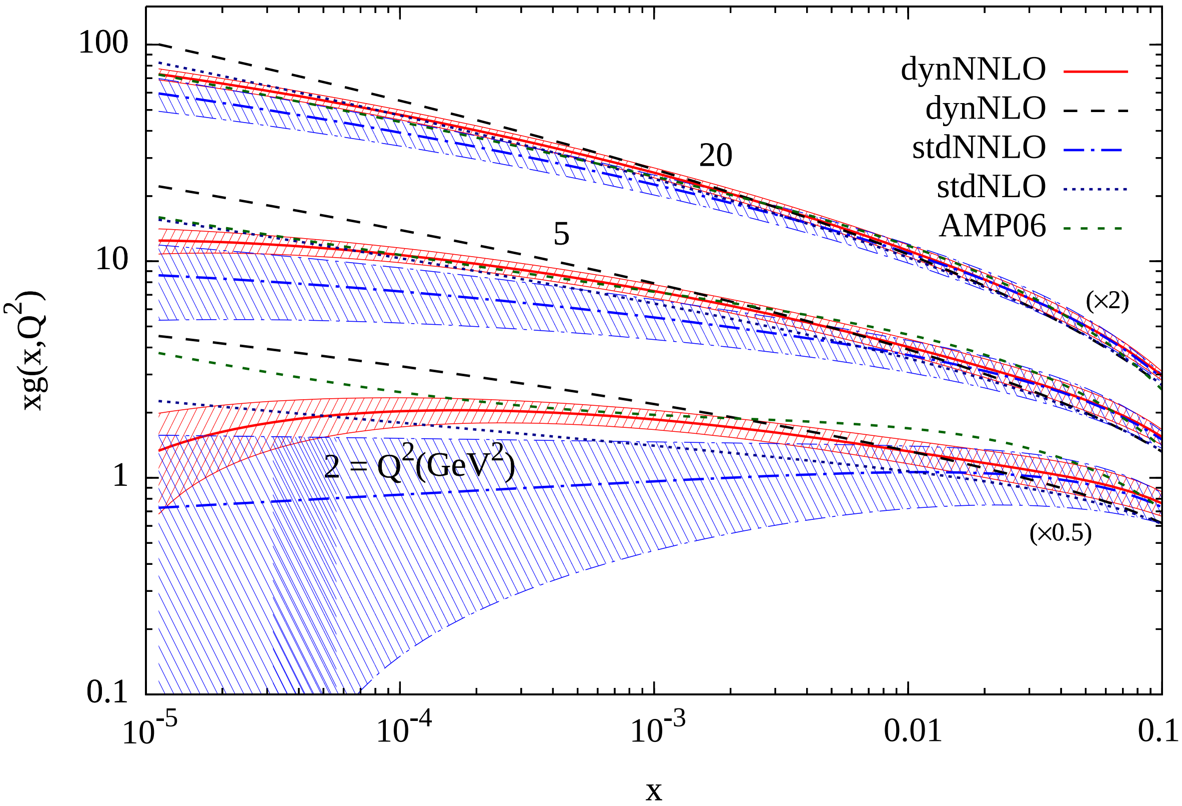
Similar quark distributions:

- Valence distributions enhanced around $x \simeq 0.1$ to 0.2
- Rather flat sea input in both cases (within $\simeq 1\sigma$)

Rather ***different input gluon!***

- Even more *valencelike* ($ag \simeq 1$ compared to $ag \simeq 0.5$ at NLO)
- Strongly enhanced around $x \simeq 0.1$

5. Dynamical vs standard: gluon distributions

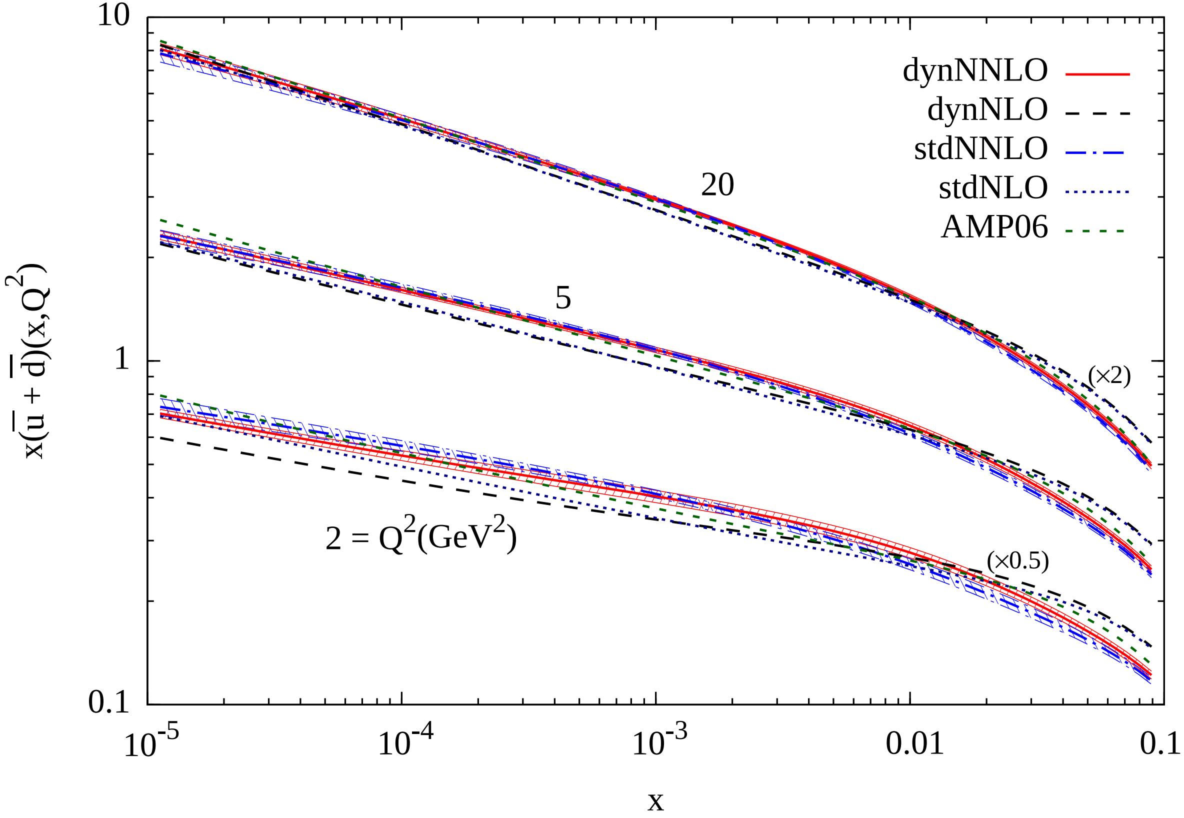


Uncertainties decrease as $\mathbf{Q^2}$ increase: ***pQCD evolution***

Valence-like input + ***larger evolution*** distance $\Rightarrow$ ***stronger constrained***

NNLO falls below NLO ($\mathbf{P_{gg}^{(2)}}$ *negative* and *more* singular.)

6. Dynamical vs standard: sea distributions

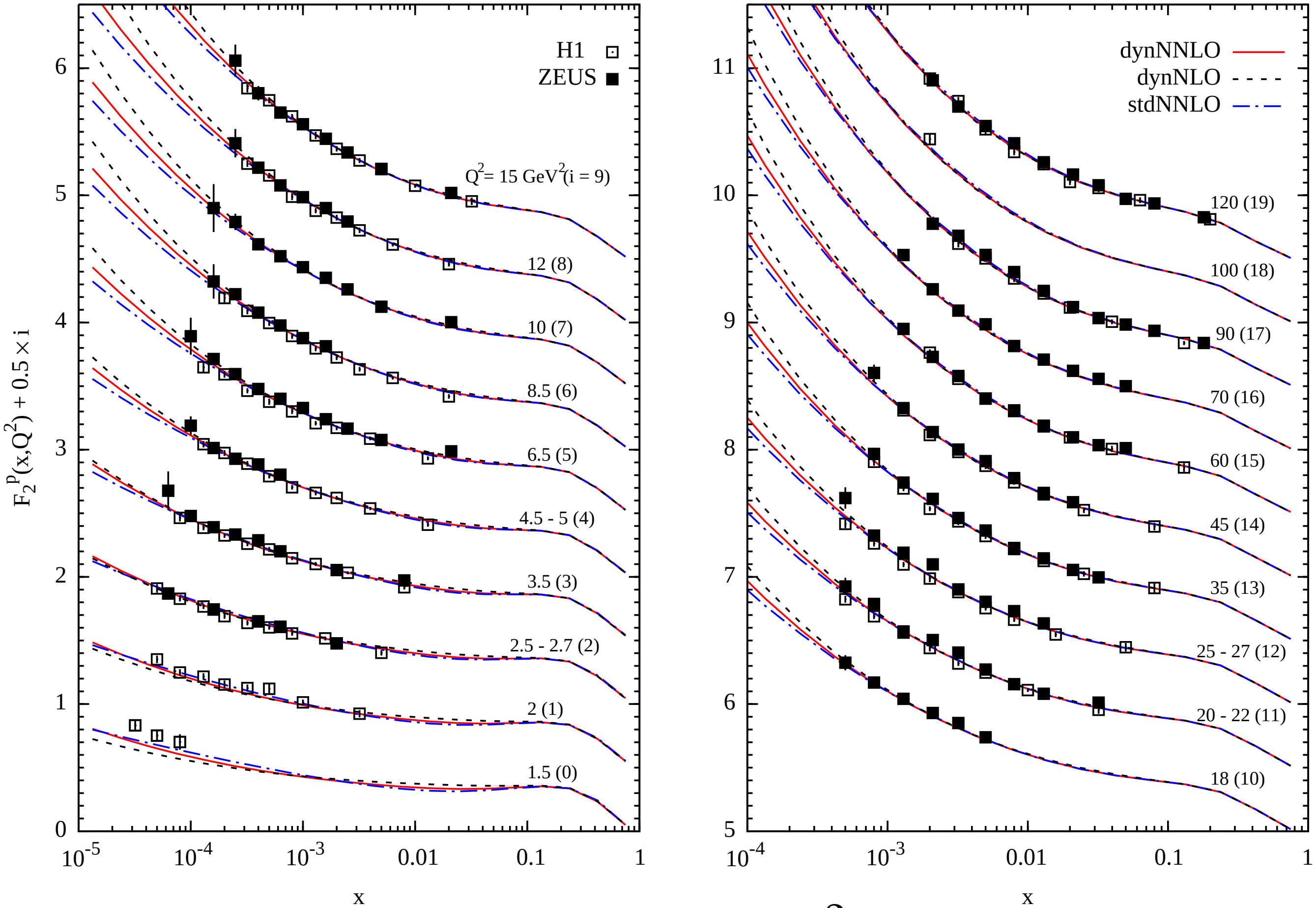


Less noticeable differences: all distributions quite ***similar***

Rather flat sea ($a_\Sigma \simeq 0.14$) $\Rightarrow$ marginally smaller errors than "standard"

NNLO generally above NLO

7. Small-x *DIS* data

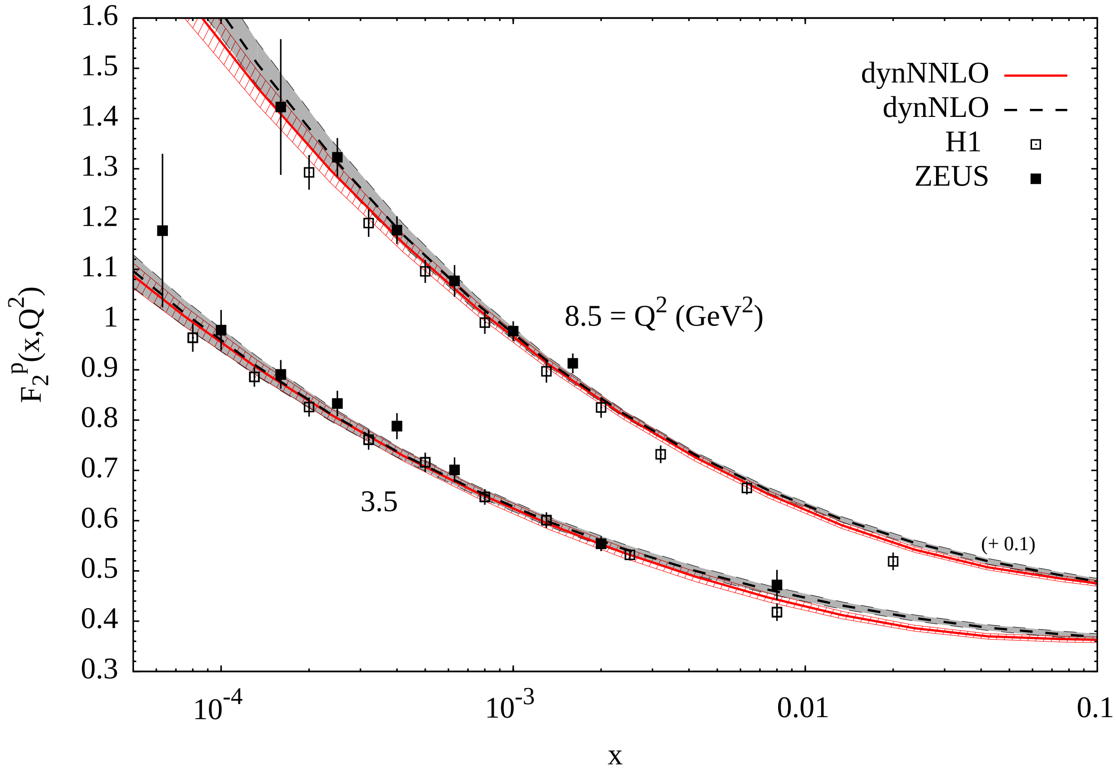


Dynamical: *QCD* ***predictions*** for $\mathbf{x} \leq 10^{-2}$; $\chi^2_{\text{DIS}} = 0.90$

Standard: ***Fine tunned*** at $\mathbf{Q_o^2 = 2}$ GeV^2; $\chi^2_{\text{DIS}} = 0.87$

Higher-twist relevant at small $\mathbf{Q^2}$

8. Typical uncertainty bands

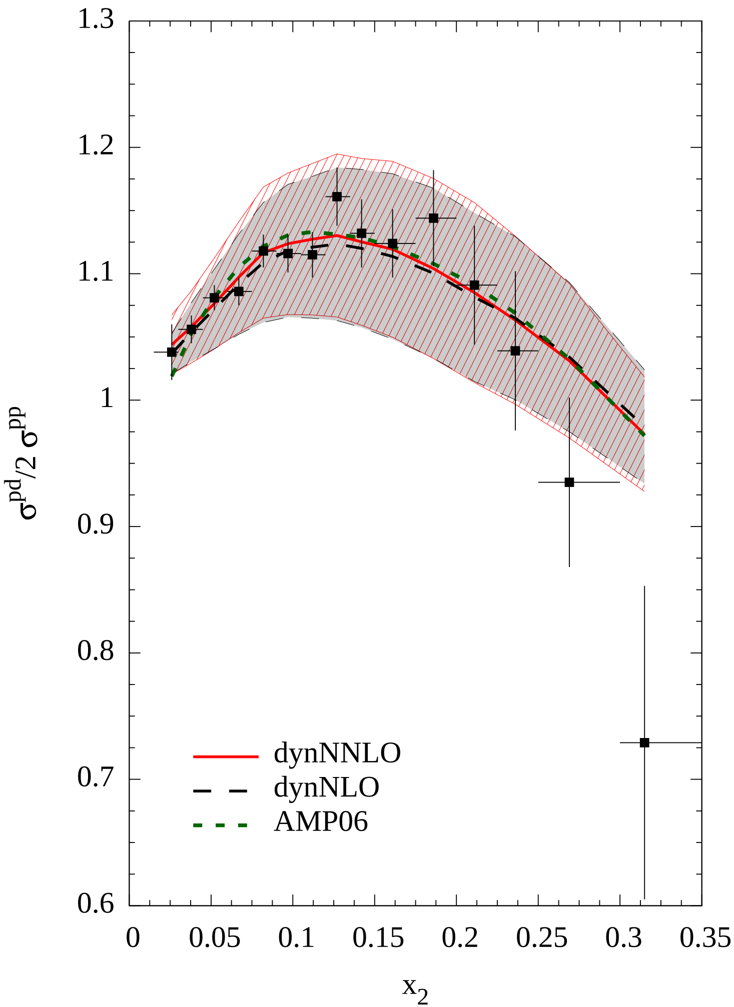


NNLO corrections at the "few percent" ($\chi^2_{\rm NNLO} \simeq \mathbf{0.9}\chi^2_{\rm NLO}$) with somewhat (not much) reduced uncertainty bands

$\longrightarrow$ NNLO effects ***small to be distinguished*** by the (*DIS*) data

Other effects (*QED*, factorization schemes, higher-twist . . .) comparable

9. The Drell-Yan asymmetry



Closely related to the *DY-asymmetry*:

$$\mathbf{A}_{\mathrm{DY}} = \frac{\sigma^{\mathrm{pp}} - \sigma^{\mathrm{pn}}}{\sigma^{\mathrm{pp}} + \sigma^{\mathrm{pn}}}$$

DY data instrumental in fixing $\bar{\mathbf{d}} - \bar{\mathbf{u}}$

Experimentally $\mathbf{x_1} > \mathbf{x_2} \longleftrightarrow$ dominated by beam quark + target antiquark

NNLO effects even smaller

“standard” results very similar

10. *DIS* "reduced" cross-section

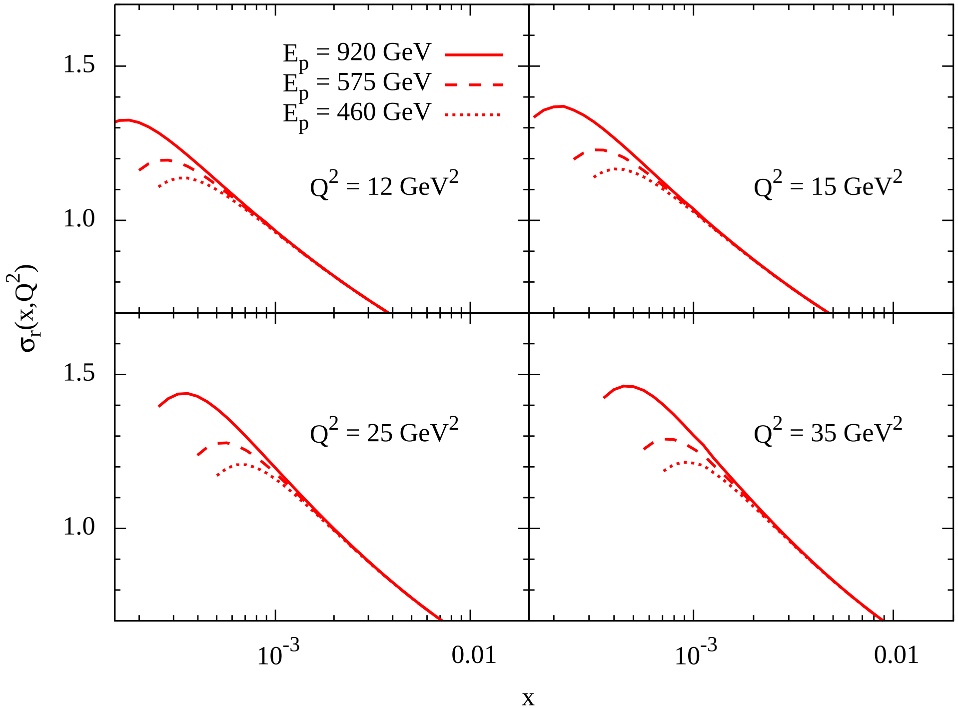
$$\sigma_r^{\mathrm{NC}} \equiv \left(\frac{2\pi\alpha^2}{xyQ^2}Y_+\right)^{-1}\frac{d^2\sigma^{\mathrm{NC}}}{dx\,dy} = F_2^{\mathrm{NC}} - \frac{y^2}{Y_+}F_L^{\mathrm{NC}} \mp \frac{Y_-}{Y_+}xF_3^{\mathrm{NC}}$$

Usually dominated by F_2^γ

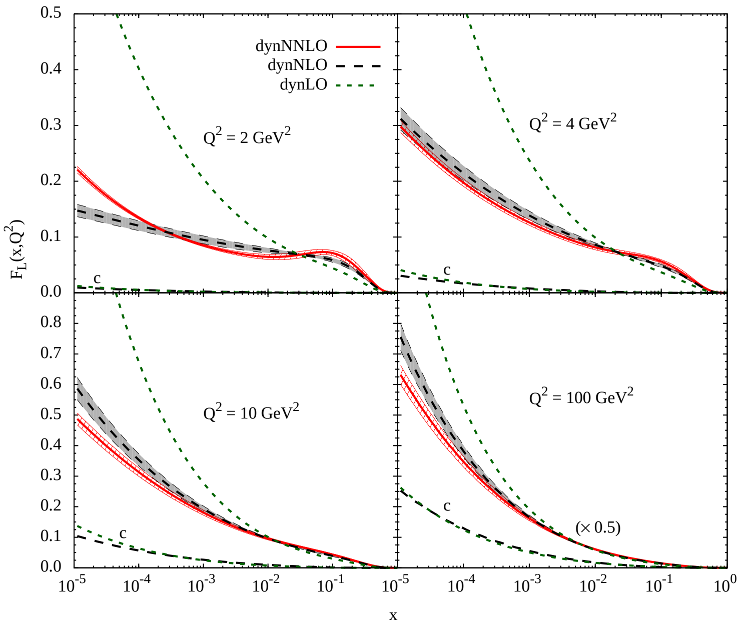
$$y = \frac{Q^2}{s}\frac{1}{x}$$

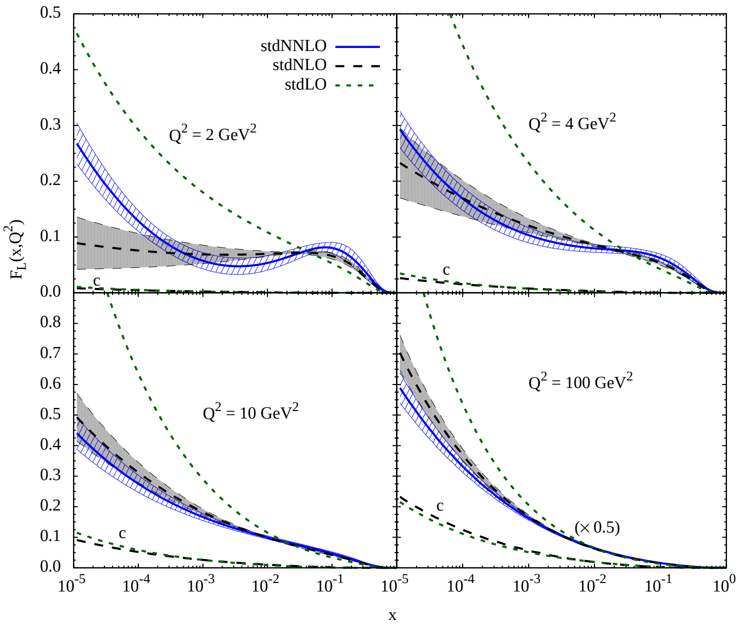
For fixed Q^2 (and s)
F_L relevant with increasing y
$\Rightarrow$ ***turnover*** at small x

F_L ***positive***



11. The perturbative stability of F_L



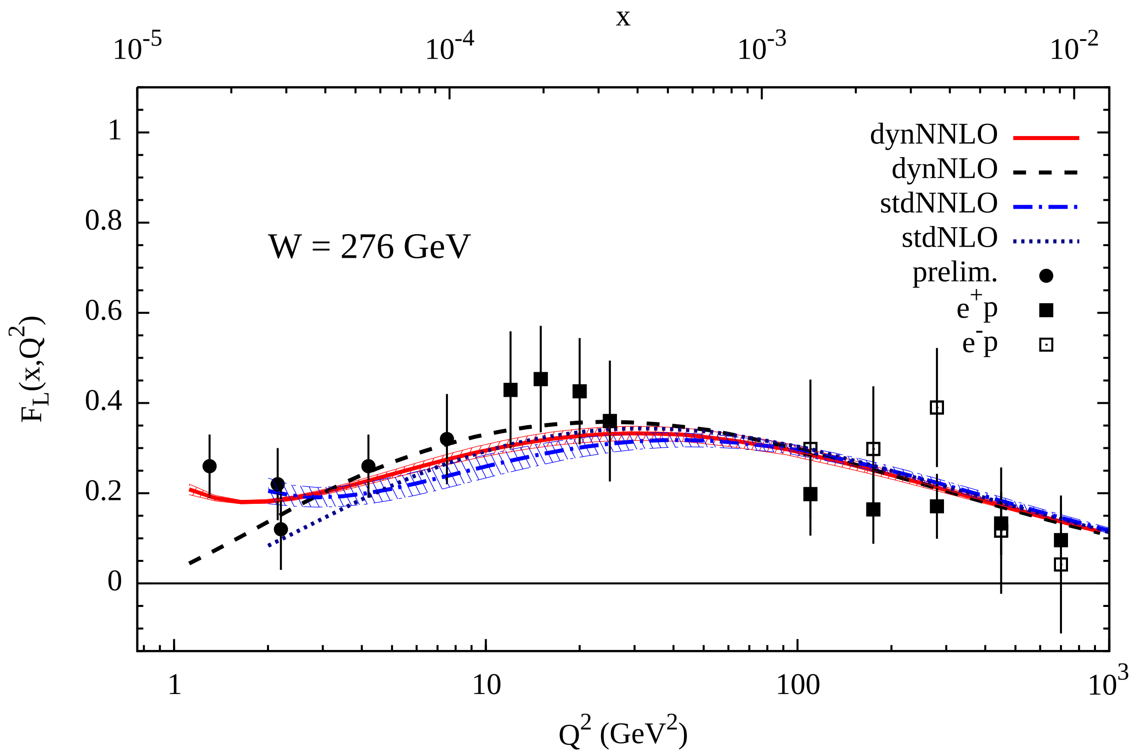


Quark and gluon contributions “compensate” in the error bars

dynamical: perturbatively stable already at $Q^2 \gtrsim 3$ GeV^2 $\rightarrow$ NNLO effects?

standard: no clear differences due to the larger uncertainty bands

12. Comparison with existing data



Gluon dominated in the small-x region

Positive and in complete ***agreement*** with measurements

Dynamical predictions more tightly constrained

Higher-twist effects may contribute for $Q^2 \leq 2$ GeV^2

Outlook

Dynamical PDFs (. . . , *GRV98*, *GJR08*) extended to ***NNLO***

Dynamical approach: more ***predictive*** and ***smaller uncertainties***

NNLO predictions stable and in agreement with data ($\chi^2_{\rm NNLO} \simeq \mathbf{0.9}\chi^2_{\rm NLO}$)

Small effects: NNLO/NLO usually not distinguishable (by data)

Positive distributions (gluon) and cross-sections ($\mathbf{F_L}$) ***possible***

Dynamical predictions for $\mathbf{F_L}$ stable and in agreement with all data

Consistent determination (together with the distributions) of $\alpha_s(M_Z^2)$

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