Introduction to PDF4LHC

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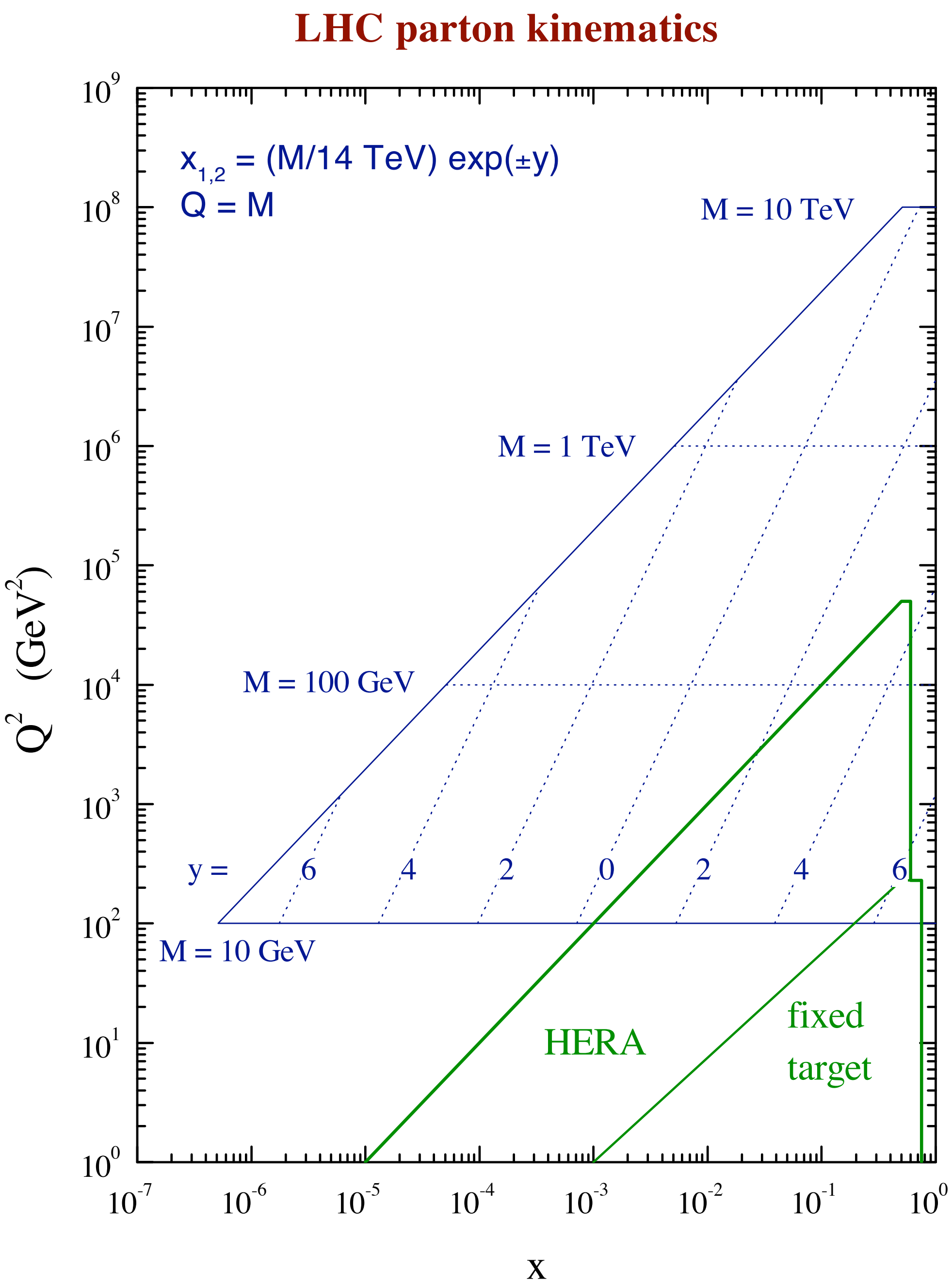
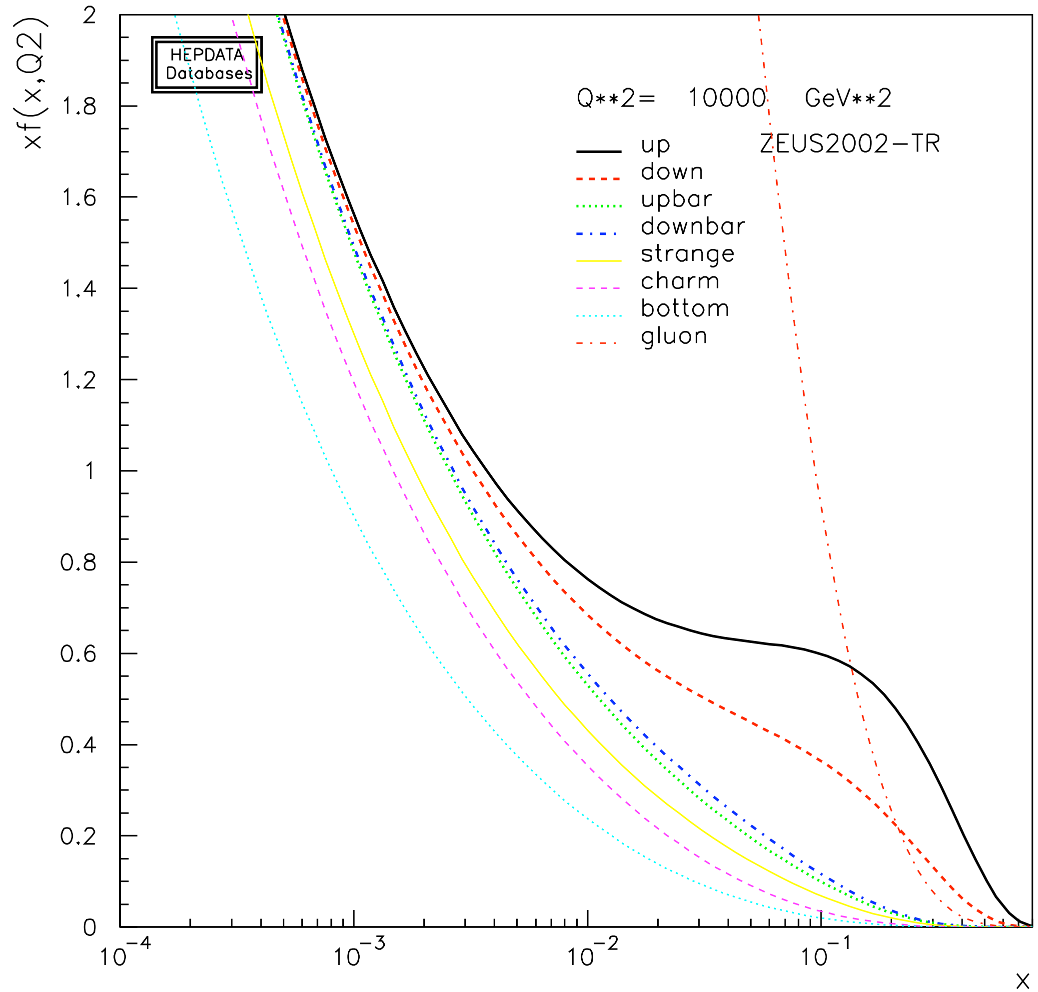
- Disclaimer & apologies
- Uncertainties
- Benchmark cross sections
- Heavy quarks
- Small x
- PDFs for MCs
- Underlying event

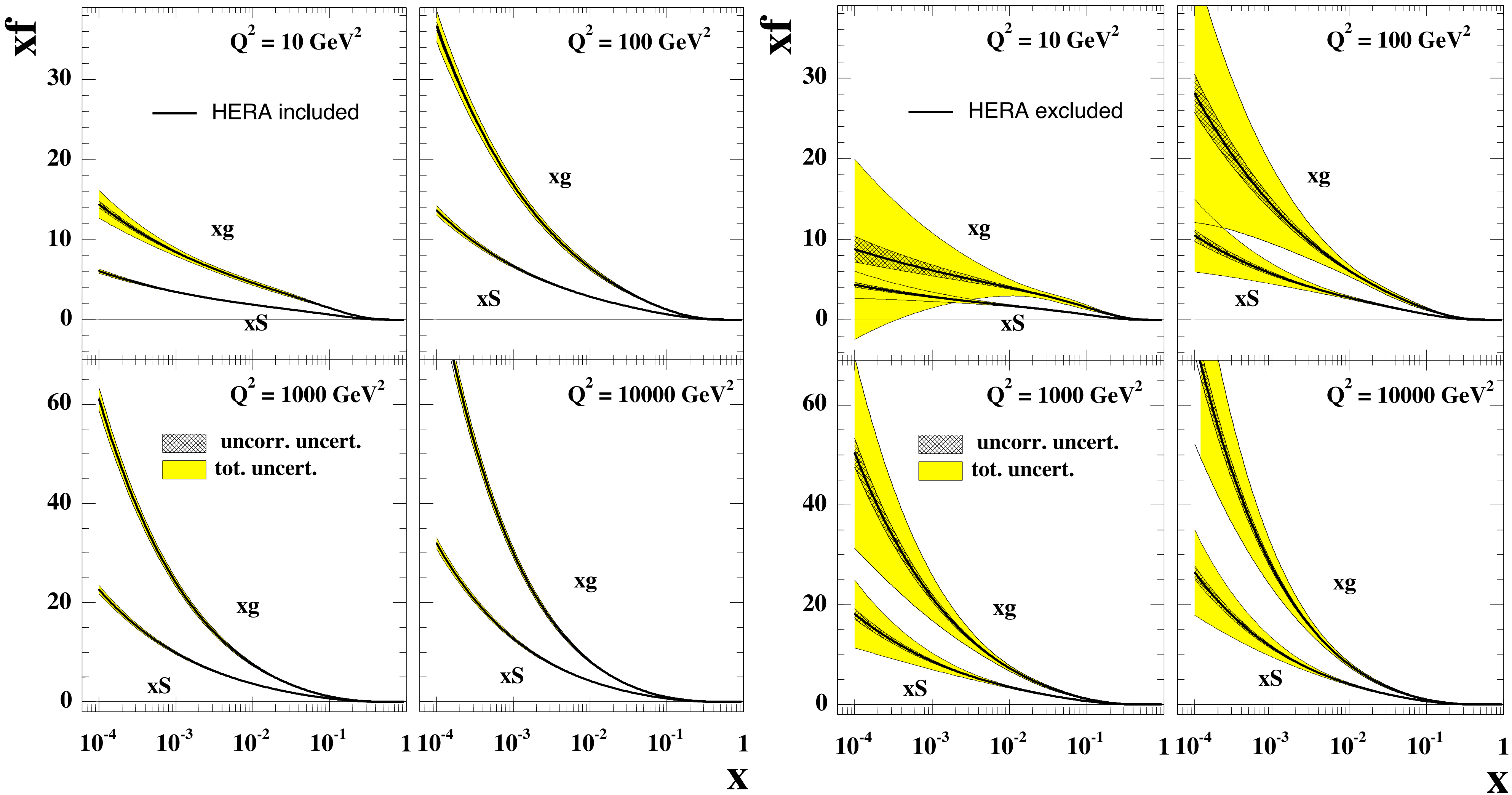
The LHC Region



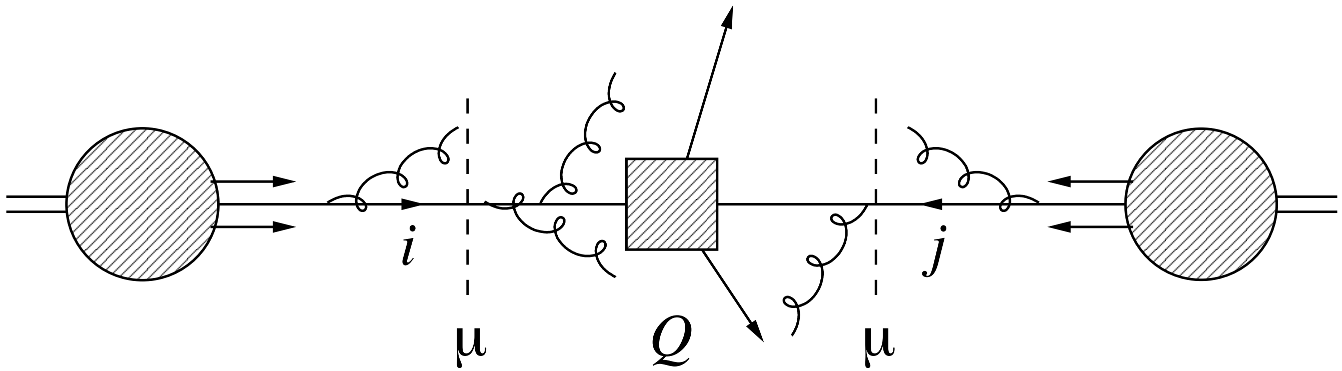


HERA Contribution

- ZEUS-S global fits with/out HERA data



PDFs for LHC



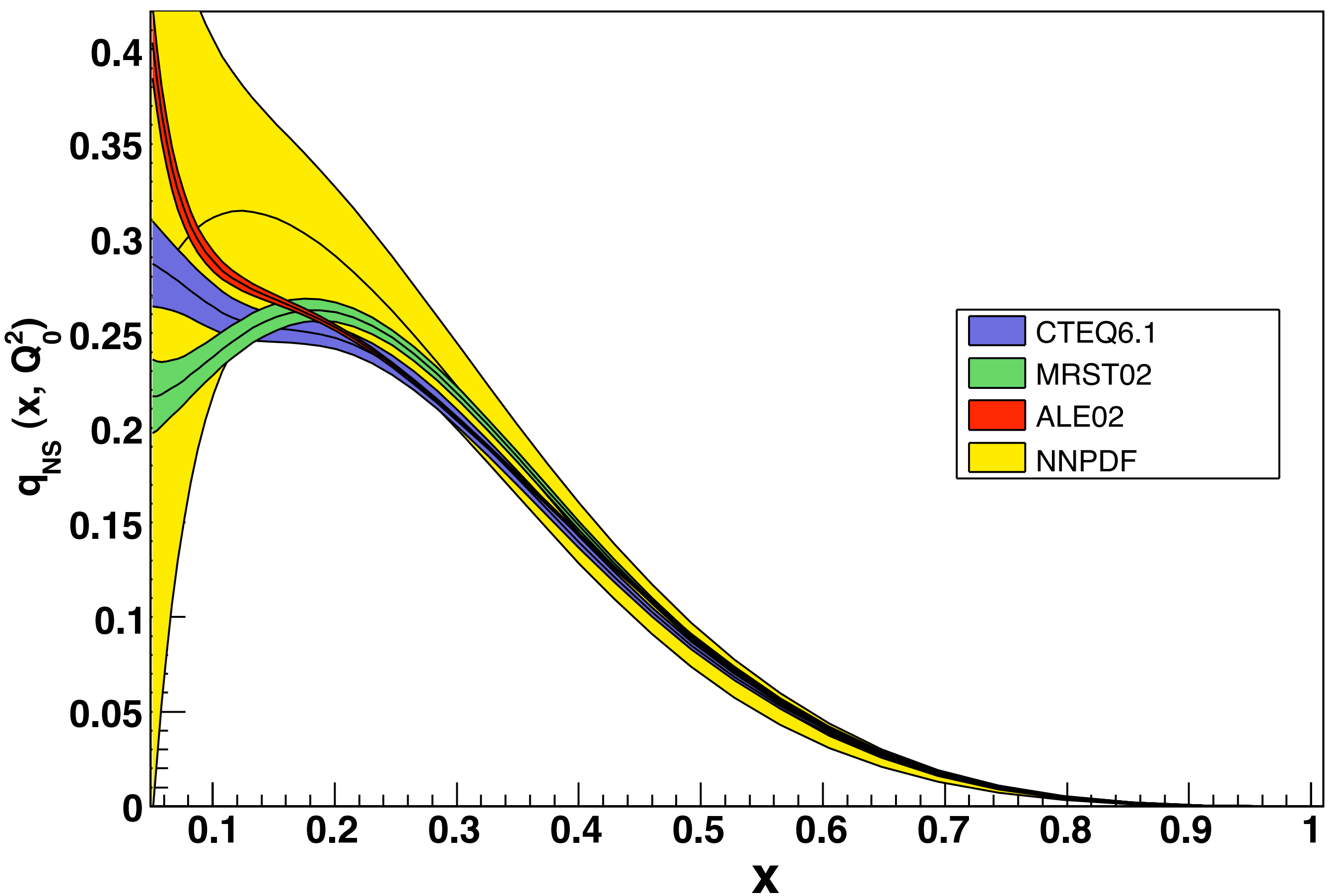
- Start from basic factorization theorem:

$$\sigma(S) = \sum_{i,j} \int dx_1 dx_2 D_i(x_1, \mu) D_j(x_2, \mu) \hat{\sigma}_{ij}(\hat{s} = x_1 x_2 S, \alpha_s(\mu), Q/\mu)$$

- Uncertainties come from several sources:
  - ➞ PDF fits, parametrization, evolution
  - ➞ Hard process scale dependence, higher orders, NP corrections
  - ➞ Power corrections: multiple interactions (underlying event)

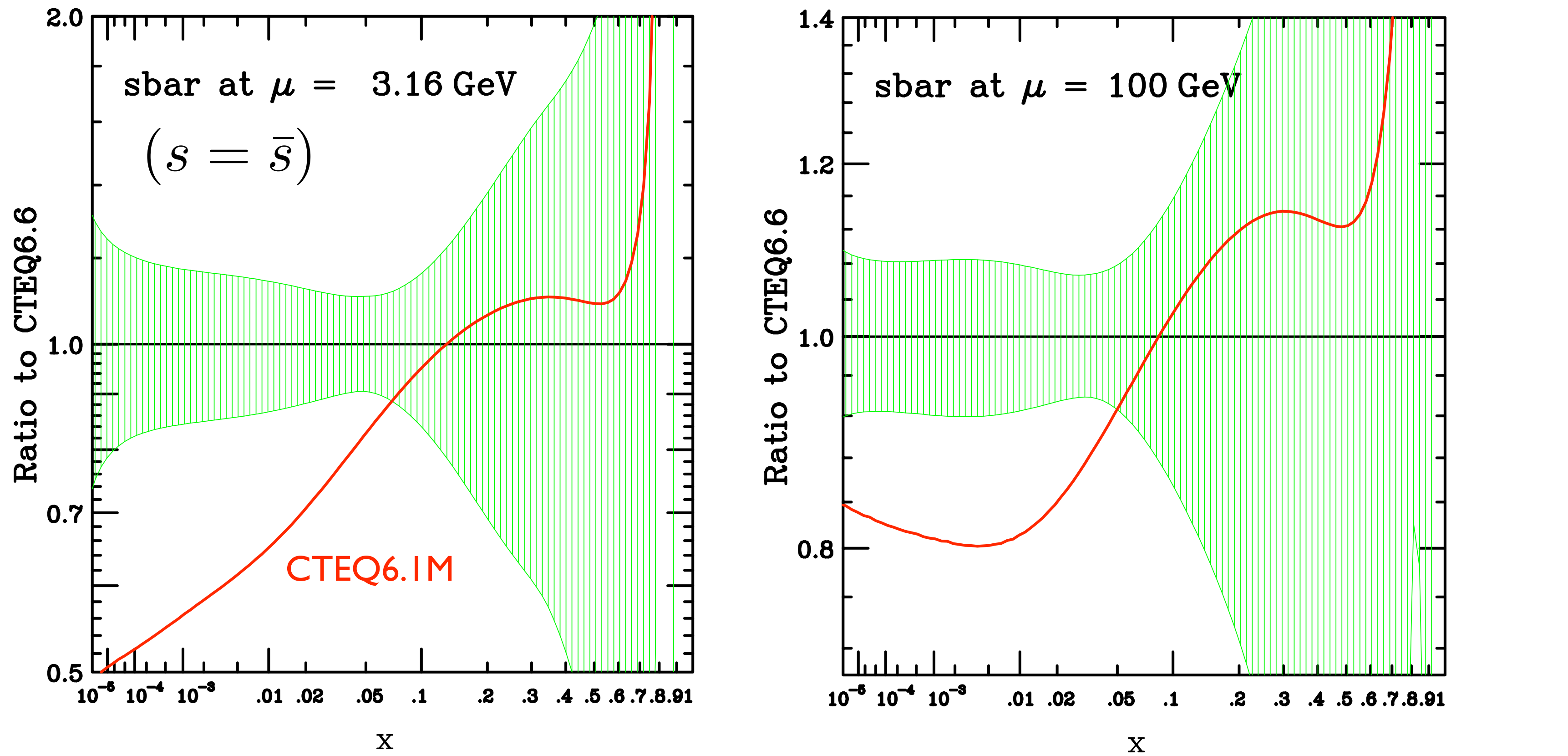
Parametrization Uncertainties

- Neural network approach doesn't constrain form of PDFs so much as fixed (Regge?) parametrizations



L Del Debbio et al., JHEP0703, 039

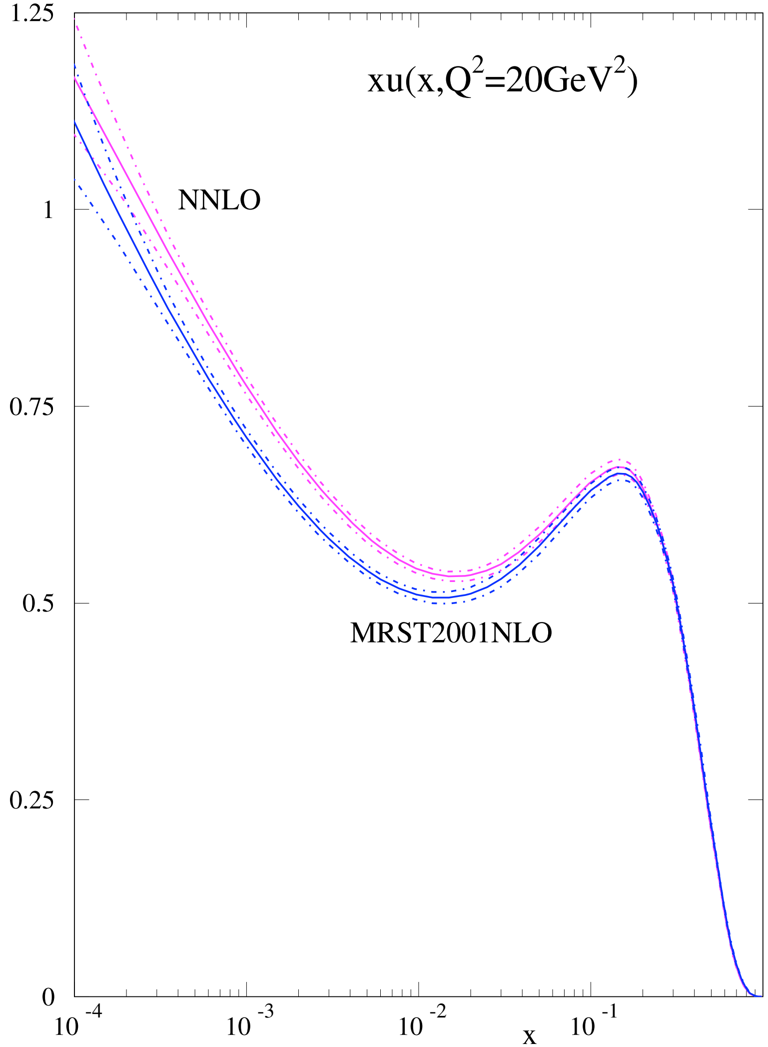
CTEQ6.6 Strange Quarks



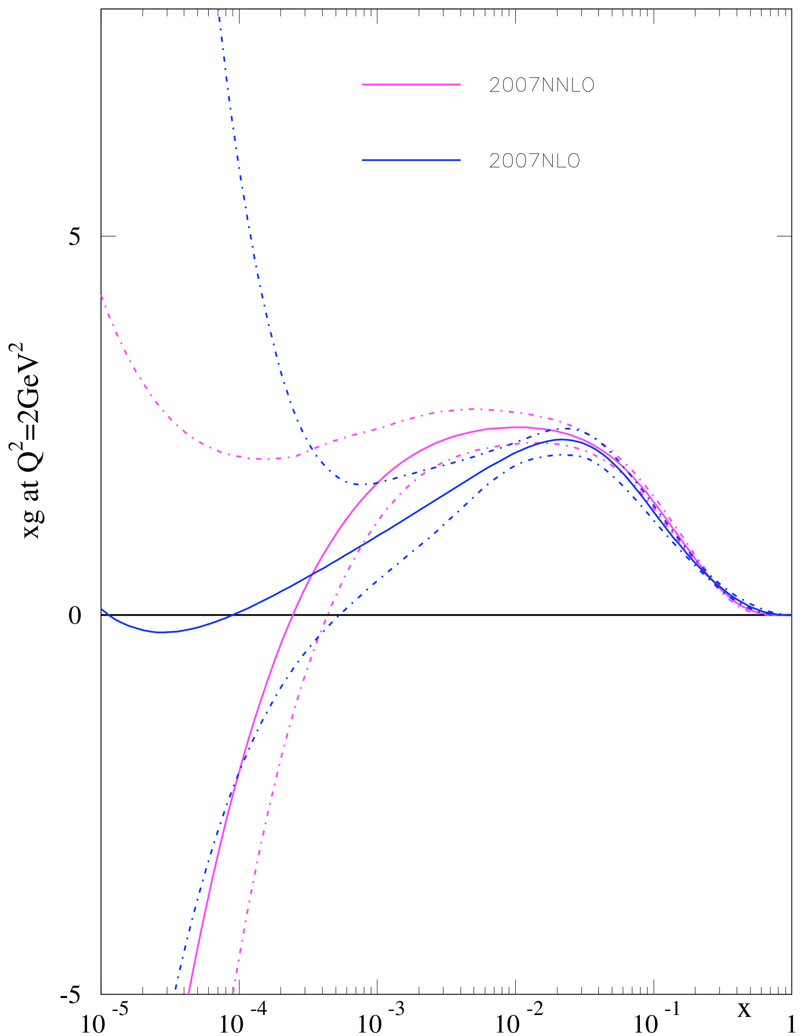
- Due to new data (NuTeV): $sW \to c$ in $\nu A \to \mu^+ \mu^- X$

NNLO PDFs

- Small but significant changes from NLO, except for low-x gluon (see later)



MRST06



MSTW07

Parton-Parton Luminosities

- Define

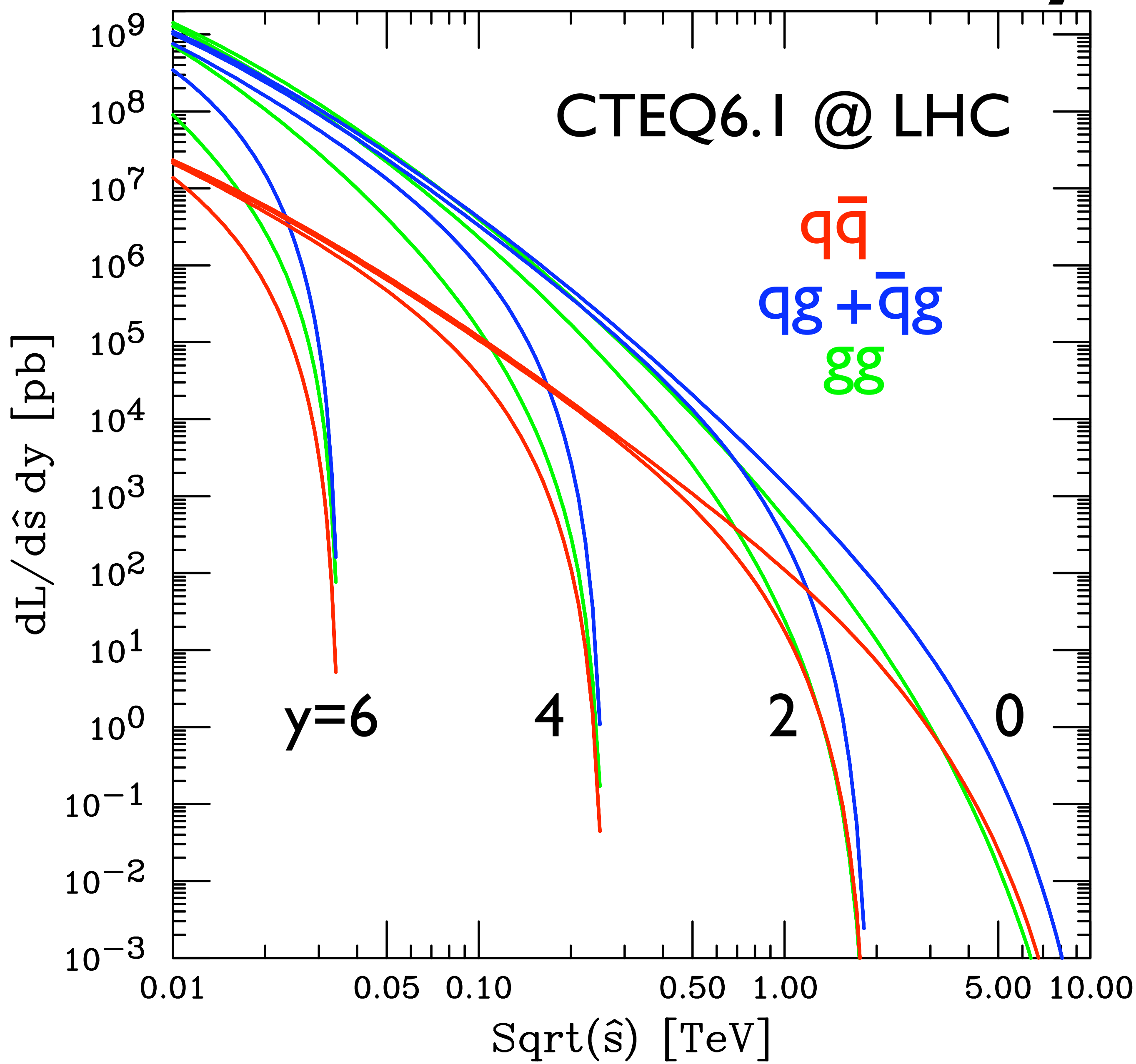
$$\frac{dL_{ij}}{d\hat{s}\,dy} = \frac{1}{S}\,\frac{1}{1+\delta_{ij}}\,\left[D_i(x_1,\mu)D_j(x_2,\mu) + (1 \leftrightarrow 2)\right]$$

- Then

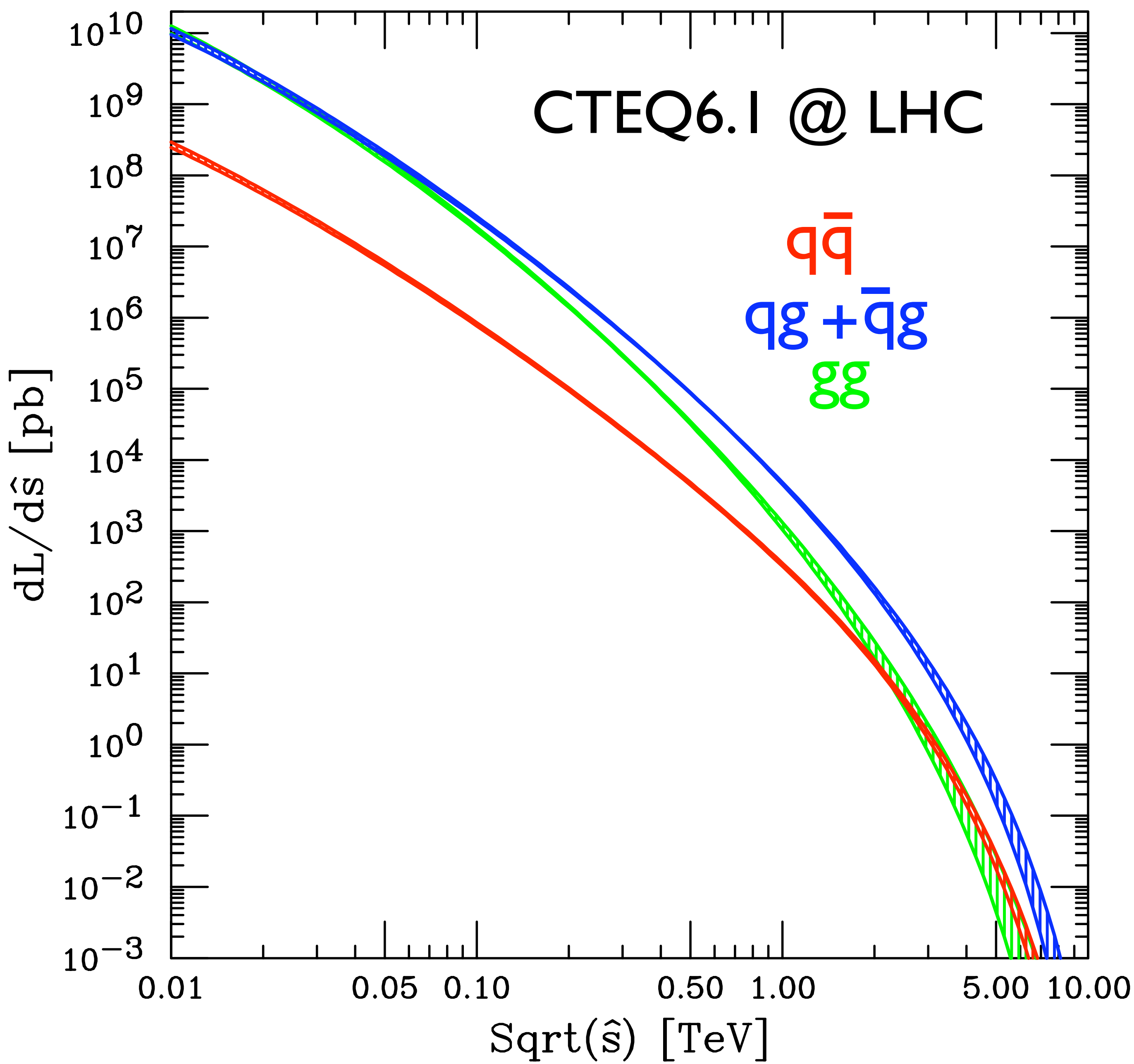
$$\sigma = \sum_{i,j} \int d\hat{s}\,dy \left(\frac{dL_{ij}}{d\hat{s}\,dy}\right) \hat{\sigma}_{ij}(\hat{s})$$

$$= \sum_{i,j} \int d\hat{s} \left(\frac{dL_{ij}}{d\hat{s}}\right) \hat{\sigma}_{ij}(\hat{s})$$

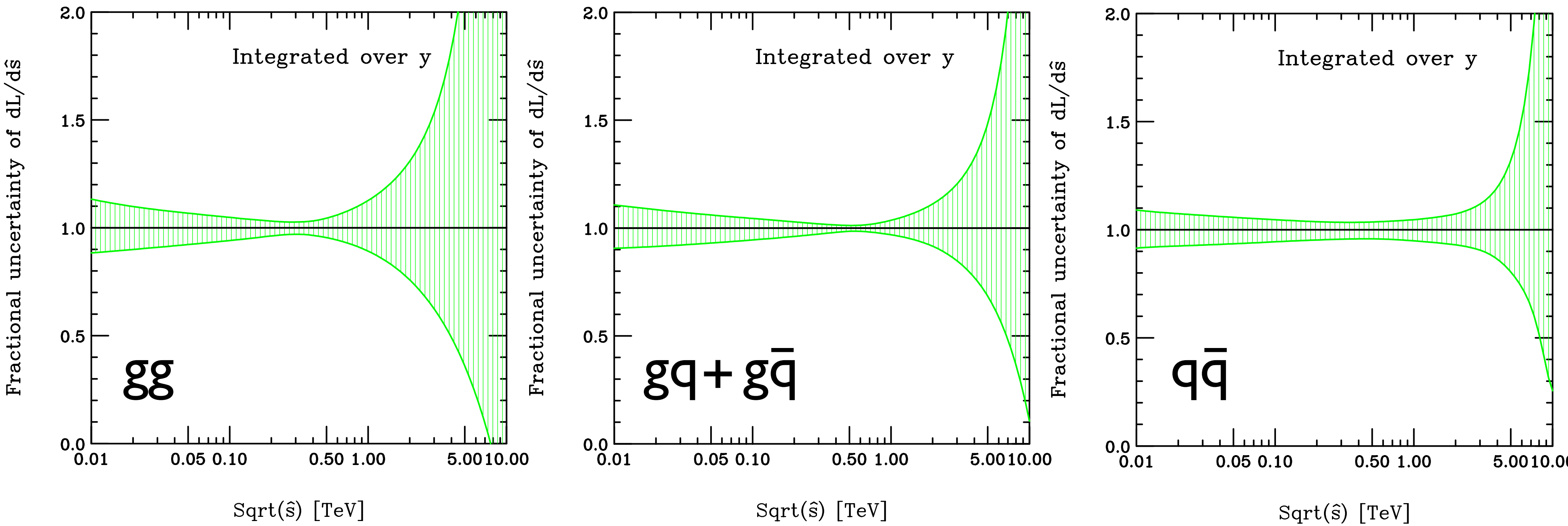
Luminosities vs y



Luminosity Uncertainties

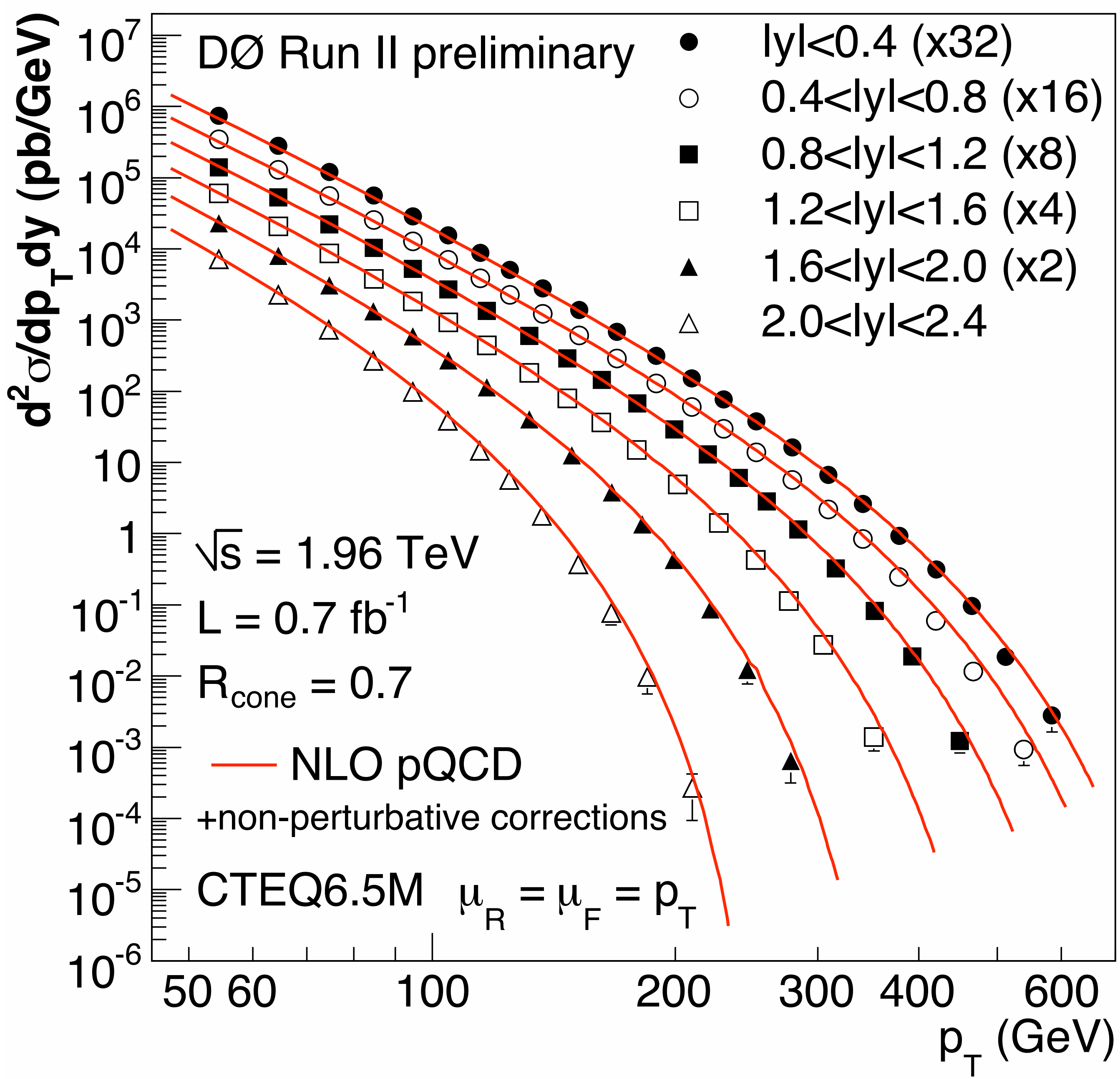


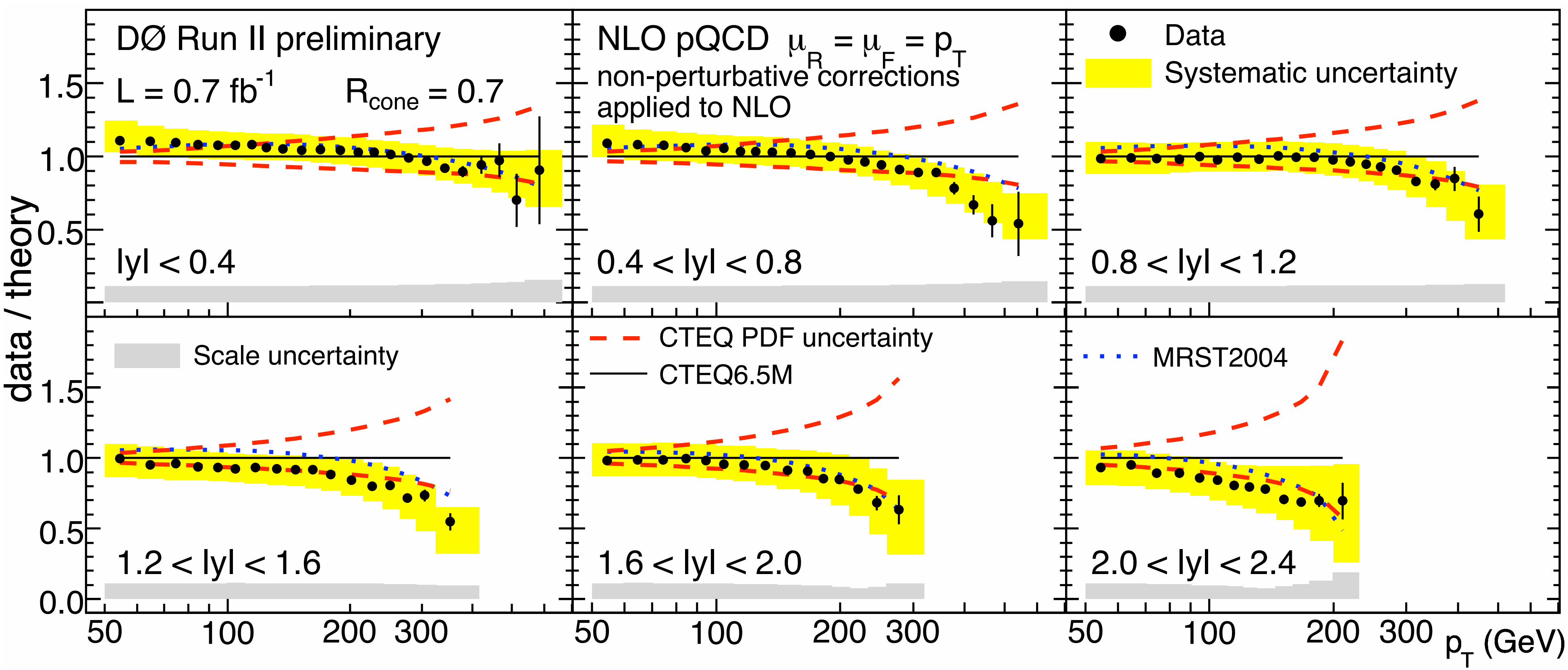
Relative Luminosity Uncertainties



CTEQ6.1 @ LHC

Tevatron Jet Production





- High p_T now at lower limit of CTEQ band!
- Good agreement with MRST

Vector Boson Production

Table 5: LHC W and Z cross sections for decay via the lepton mode, for various PDFs

PDF Set	$\sigma(W^+).B(W^+ \to l^+\nu_l)$	$\sigma(W^-).B(W^- \to l^-\bar{\nu}_l)$	$\sigma(Z).B(Z \to l^+l^-)$
ZEUS-S no HERA	10.63 ± 1.73 nb	7.80 ± 1.18 nb	1.69 ± 0.23 nb
ZEUS-S	12.07 ± 0.41 nb	8.76 ± 0.30 nb	1.89 ± 0.06 nb
CTEQ6.1	11.66 ± 0.56 nb	8.58 ± 0.43 nb	1.92 ± 0.08 nb
MRST01	11.72 ± 0.23 nb	8.72 ± 0.16 nb	1.96 ± 0.03 nb

- "Standard candles": $\delta\sigma/\sigma < 5\%$
- Extra uncertainties due to cuts?

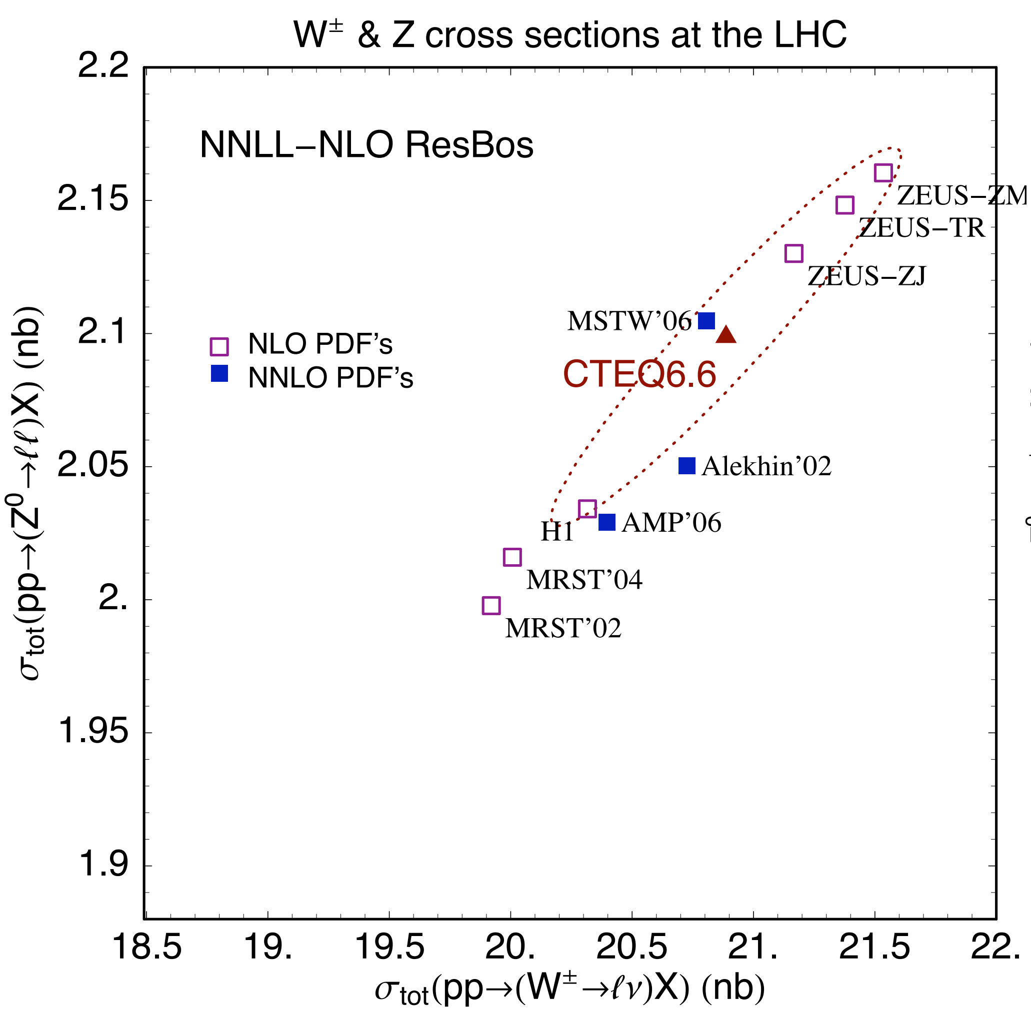
Cross Section Uncertainties

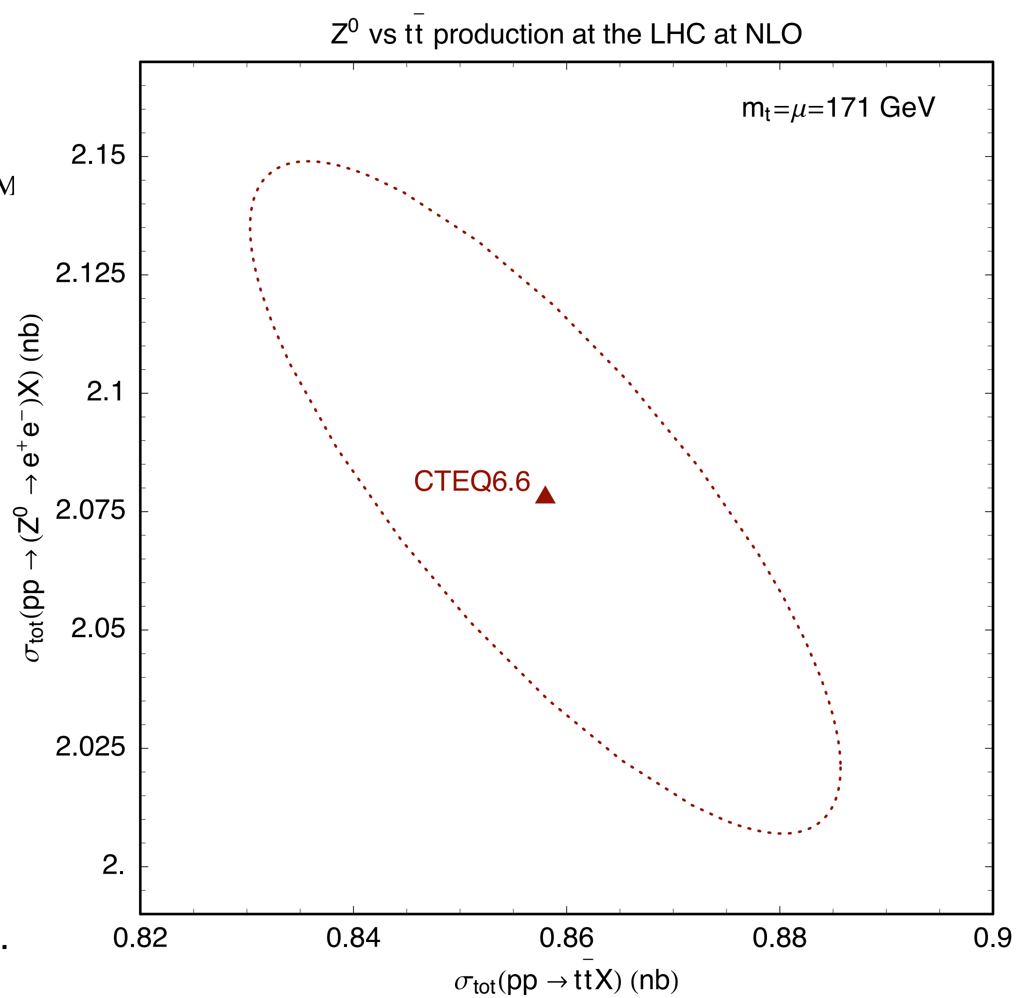
$\sqrt{s}$ (TeV)	Scattering process	$\sigma, \Delta\sigma$ (pb)	Correlation $\cos\varphi$ with Z^0 (Tev2)	$W^\pm$(Tev2)	Z^0 (LHC)	$W^\pm$ (LHC)
1.96	$p\bar{p} \to (Z^0 \to \ell^+\ell^-)X$	241(8)	1	**0.987**	0.23	0.33
	$p\bar{p} \to (W^\pm \to \ell\nu_\ell)X$	2560(40)	**0.987**	1	0.27	0.37
	$p\bar{p} \to t\bar{t}X$	7.2(5)	-0.03	-0.09	-0.52	-0.52
14	$pp \to (Z^0 \to \ell^+\ell^-)X$	2080(70)	0.23	0.27	1	**0.956**
	$pp \to (W^\pm \to \ell\nu)X$	20880(740)	0.33	0.37	**0.956**	1
	$pp \to (W^+ \to \ell^+\nu_\ell)X$	12070(410)	0.32	0.36	**0.928**	**0.988**
	$pp \to (W^- \to \ell^-\bar{\nu}_\ell)X$	8810(330)	0.33	0.38	**0.960**	**0.981**
	$pp \to t\bar{t}X$	860(30)	-0.14	-0.13	**-0.80**	**-0.74**

CTEQ6.6, arXiv:0802.0007

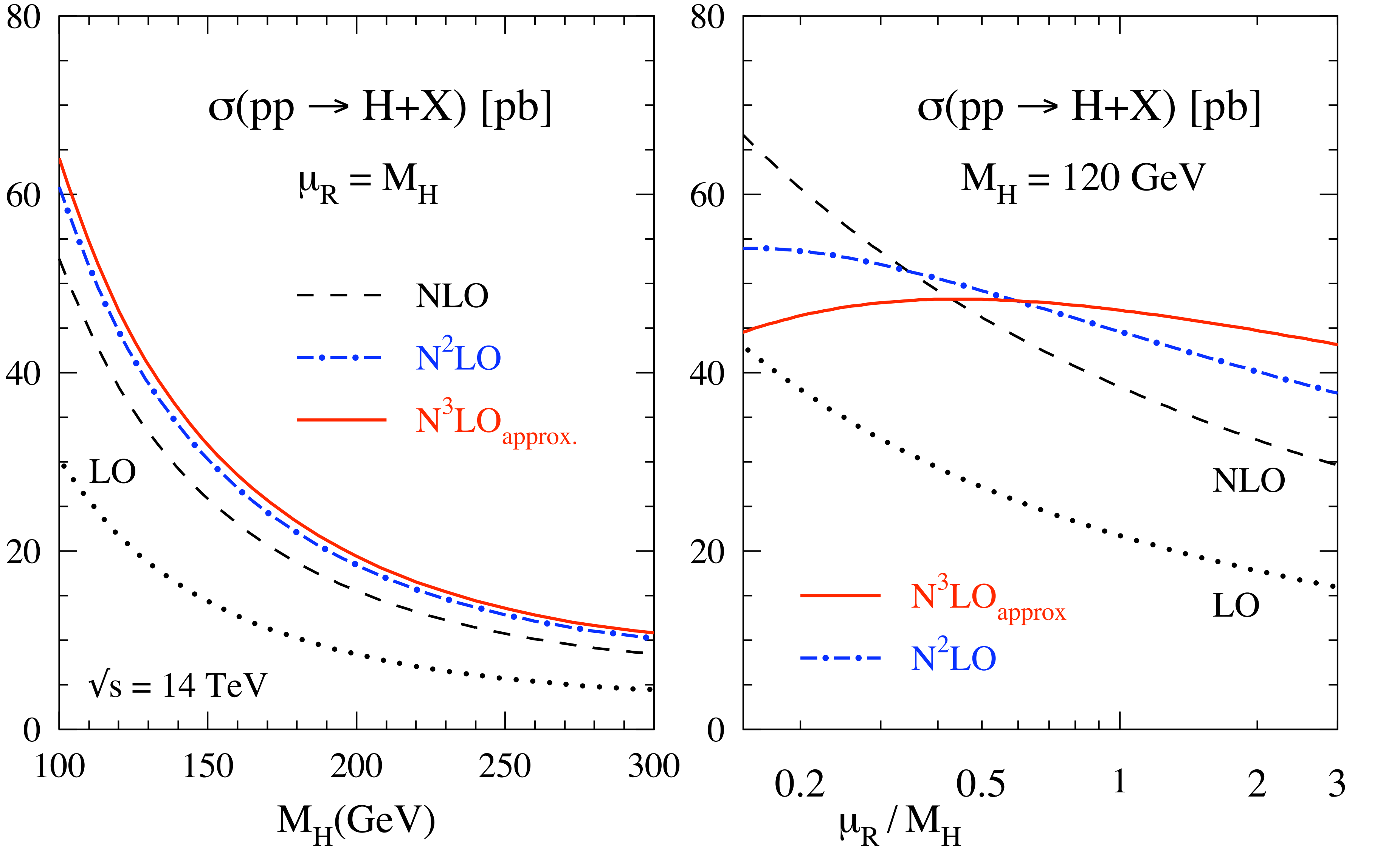
- Note strong anticorrelation between $t\bar{t}$ and W,Z at LHC, not present at Tevatron

Cross Section Correlations





Higgs Cross Section



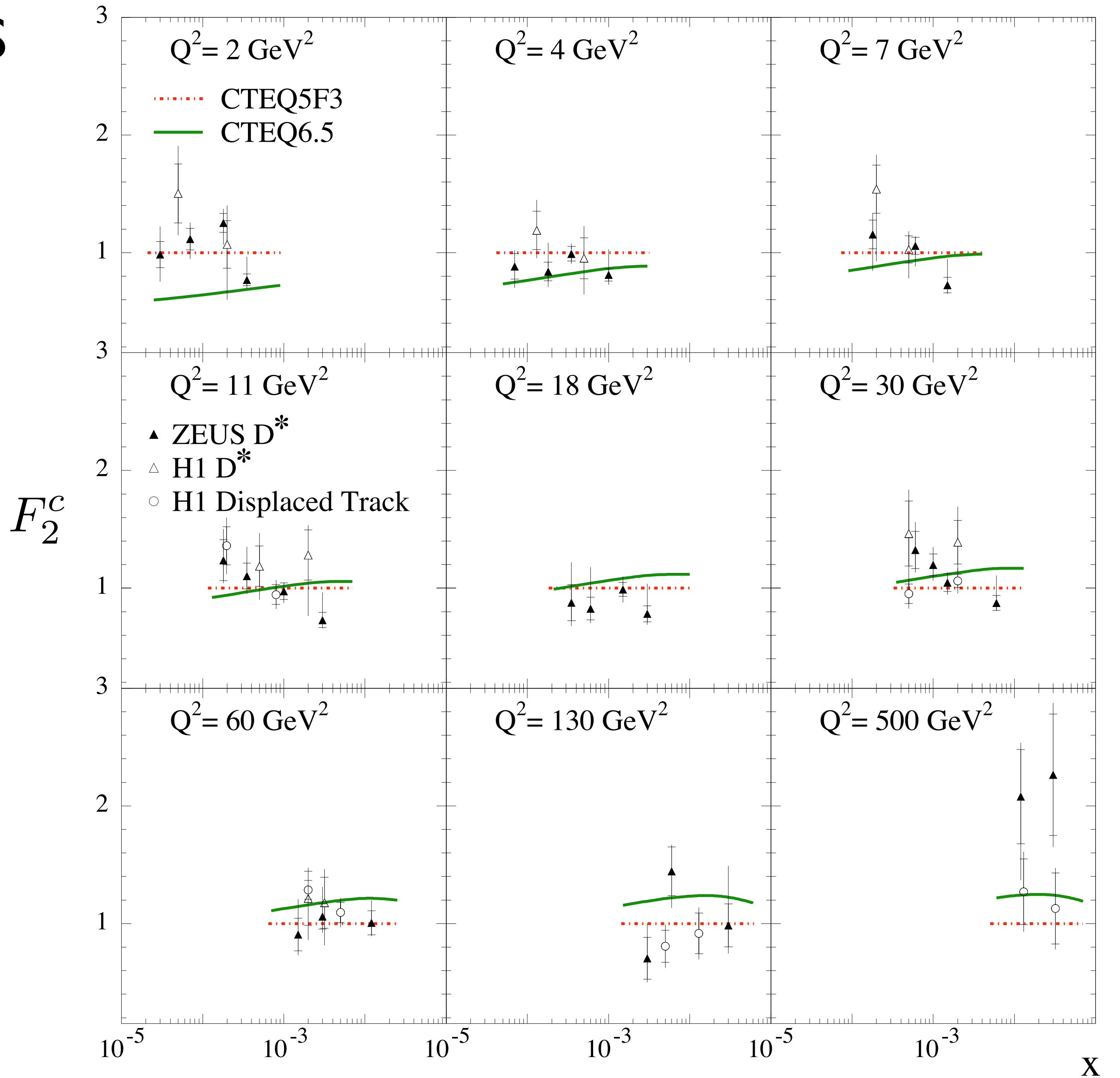
S. Moch and A. Vogt, Phys. Lett. B631 (2005) 48

Heavy Quarks

- Complicated multi-scale problem: Λ_{QCD}, m_q, Q
  - → Fixed flavour-number scheme (FFNS): heavy quarks only in hard process, misses $\ln^n(Q/m_q)$
  - → Variable flavour-number schemes (VFNS): massless in evolution, matched at $Q^2 = m_q^2$

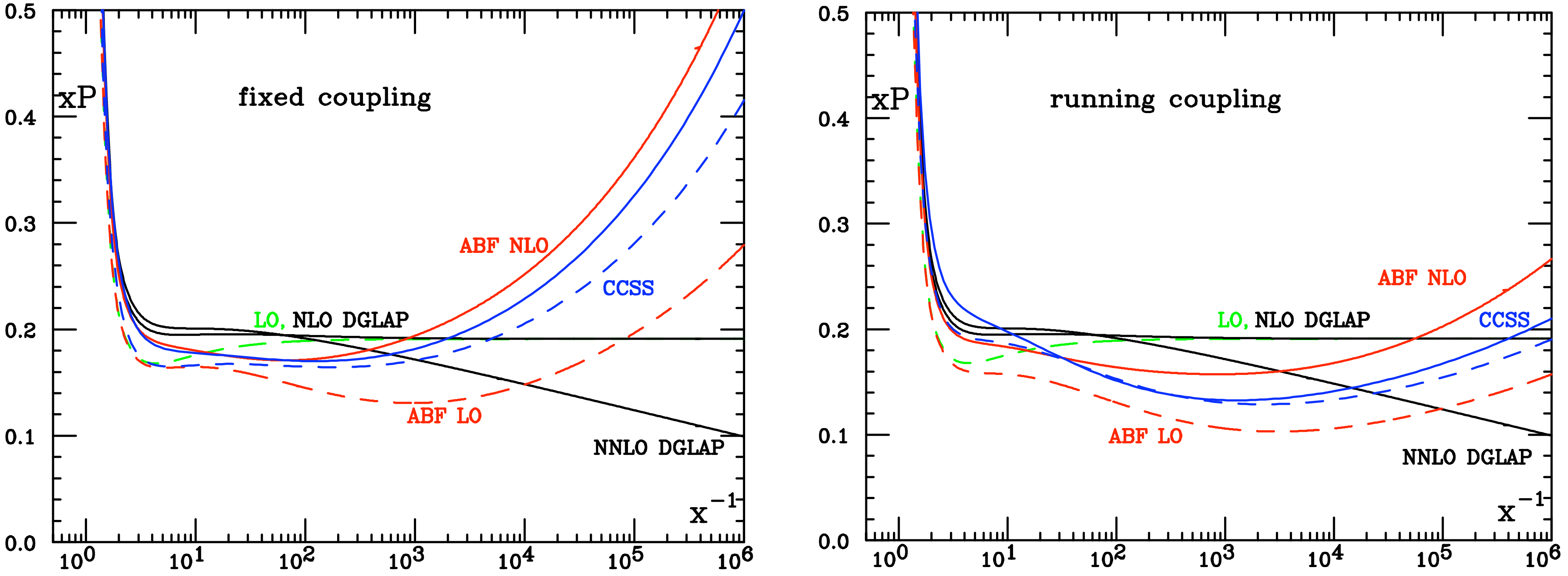
$$
\begin{aligned}
l_i^{(N_f+1)} &= l_i^{(N_f)} + \alpha_s^2\, A_{qq,h}^{NS,(2)} \otimes l_i^{(N_f)} \\
g^{(N_f+1)} &= g^{(N_f)} + \alpha_s^2\, [A_{gq,h}^{S,(2)} \otimes q_S^{(N_f)} + A_{gg,h}^{S,(2)} \otimes g^{(N_f)}] \\
(h+\bar{h})^{(N_f+1)} &= \alpha_s^2\, [A_{hq}^{S,(2)} \otimes q_S^{(N_f)} + A_{hg}^{S,(2)} \otimes g^{(N_f)}]
\end{aligned}
$$

- In practice FFNS not bad, even at $Q^2 \gg m_c^2$



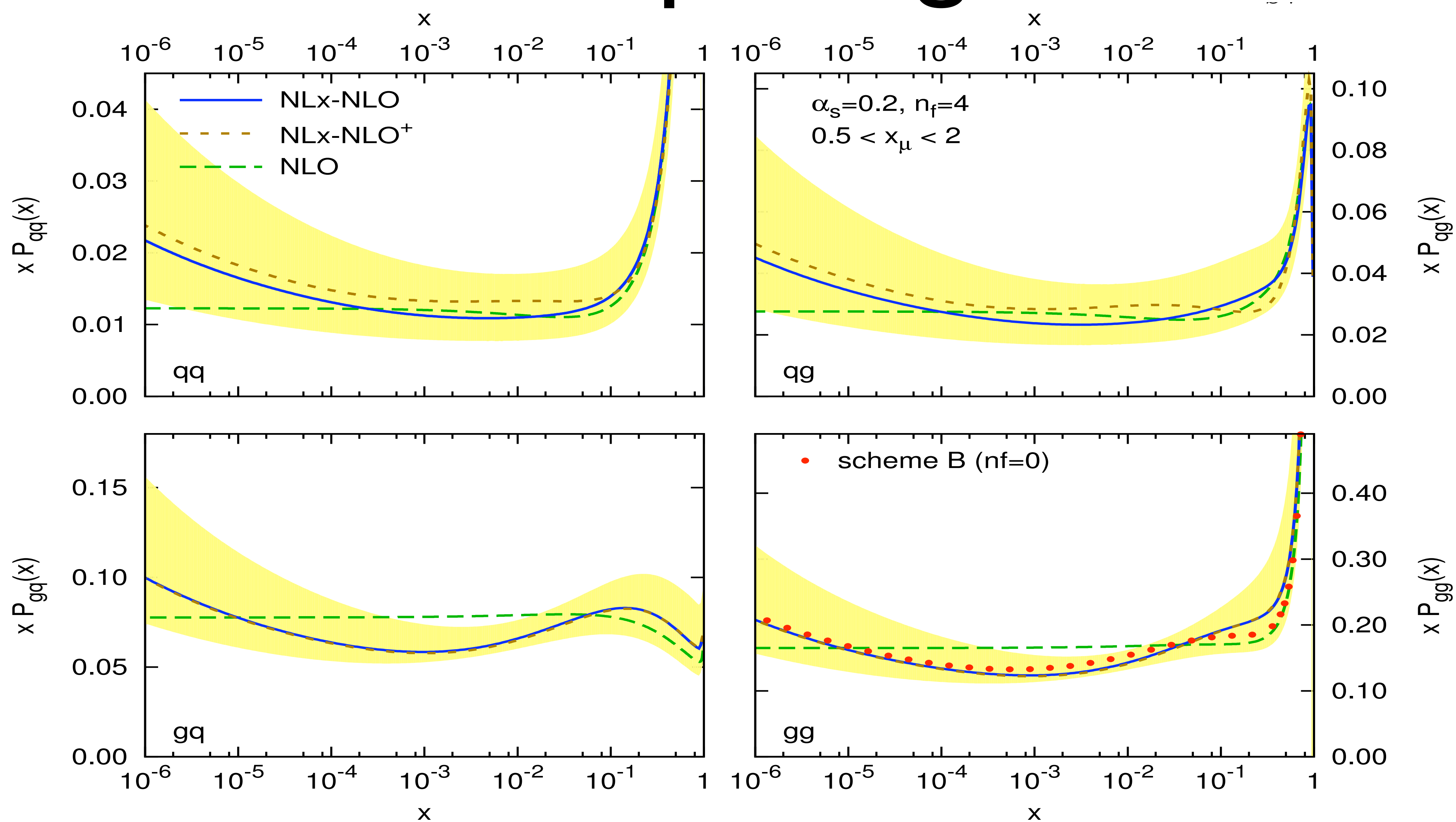
Small x Resummation

- Gluon splitting function: results are converging



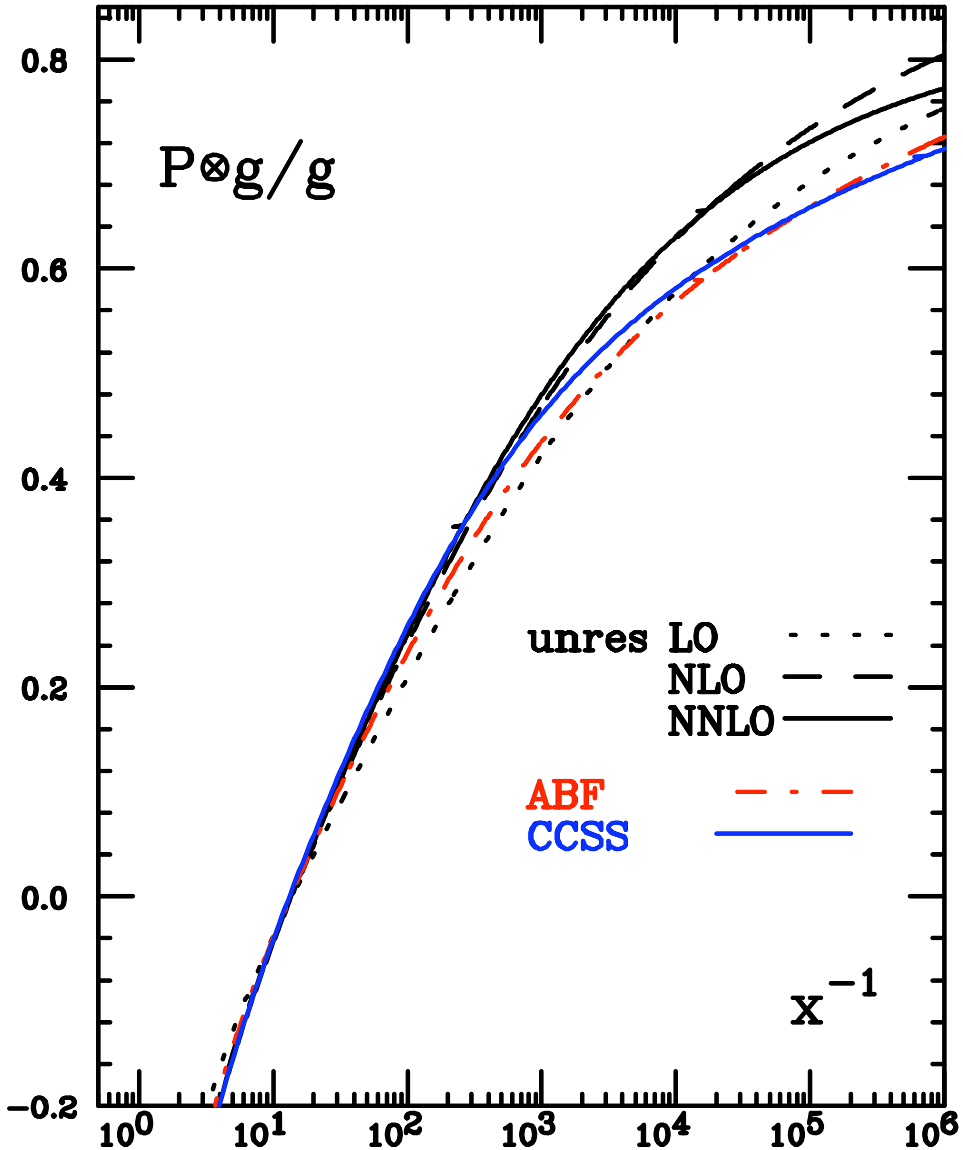
ABF: Altarelli, Ball, Forte
CCSS: Ciafaloni, Colferai, Salam, Stasto
[also Thorne & White]

Resummed Splitting Functions

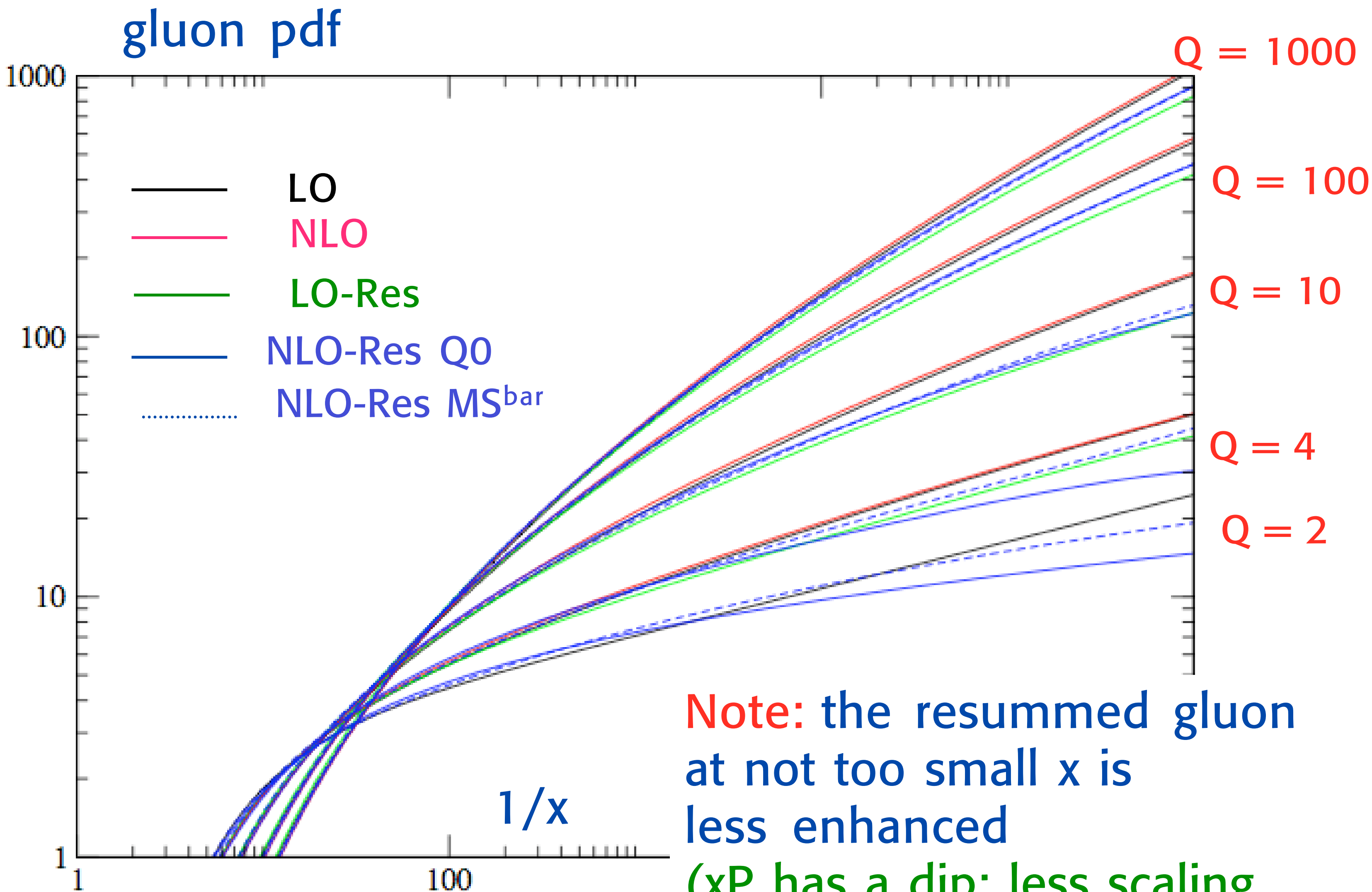


M Ciafaloni, RADCOR07

Convolution with gluon



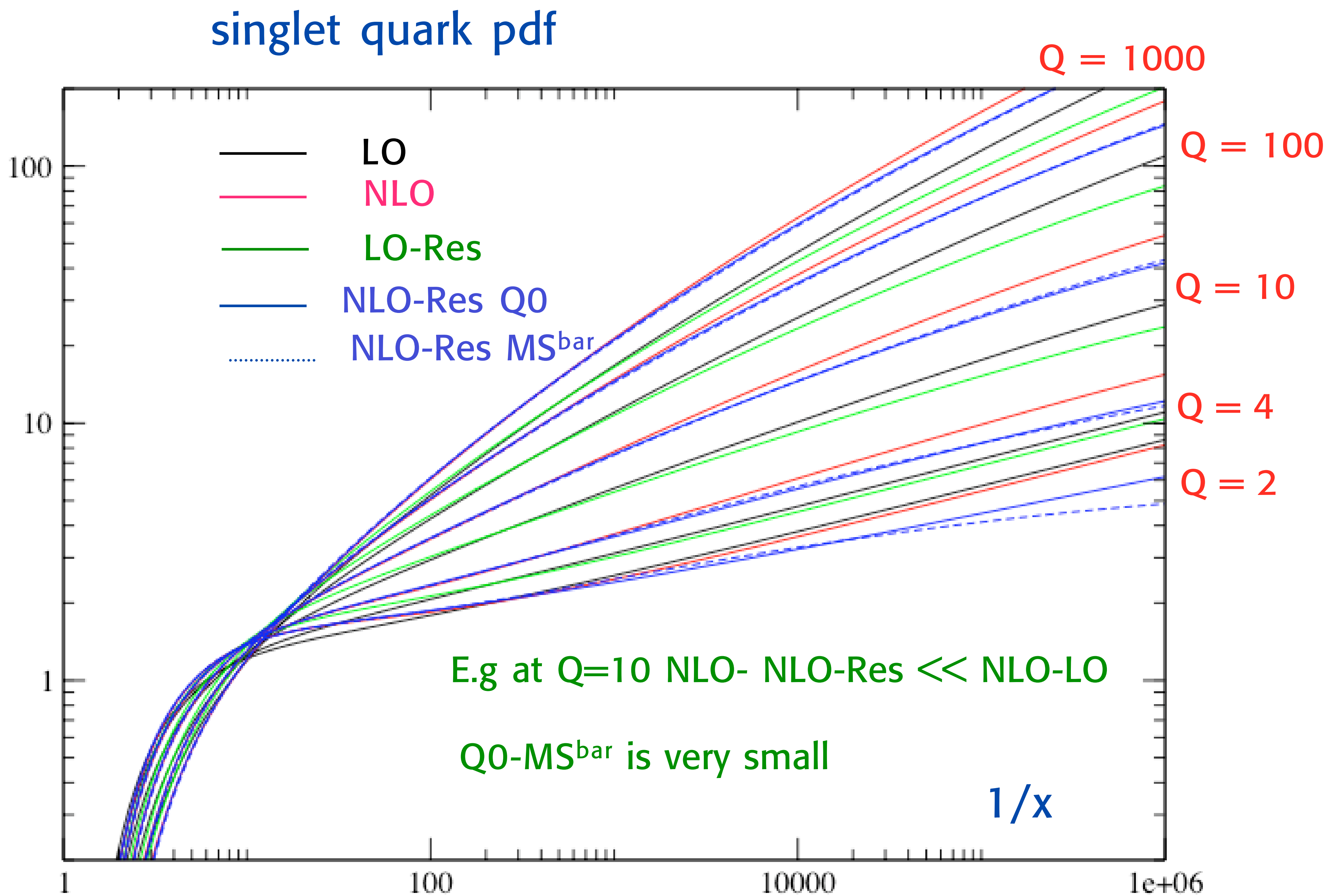
Evolution of Gluon PDF



Note: the resummed gluon at not too small x is less enhanced (xP has a dip: less scaling violations)

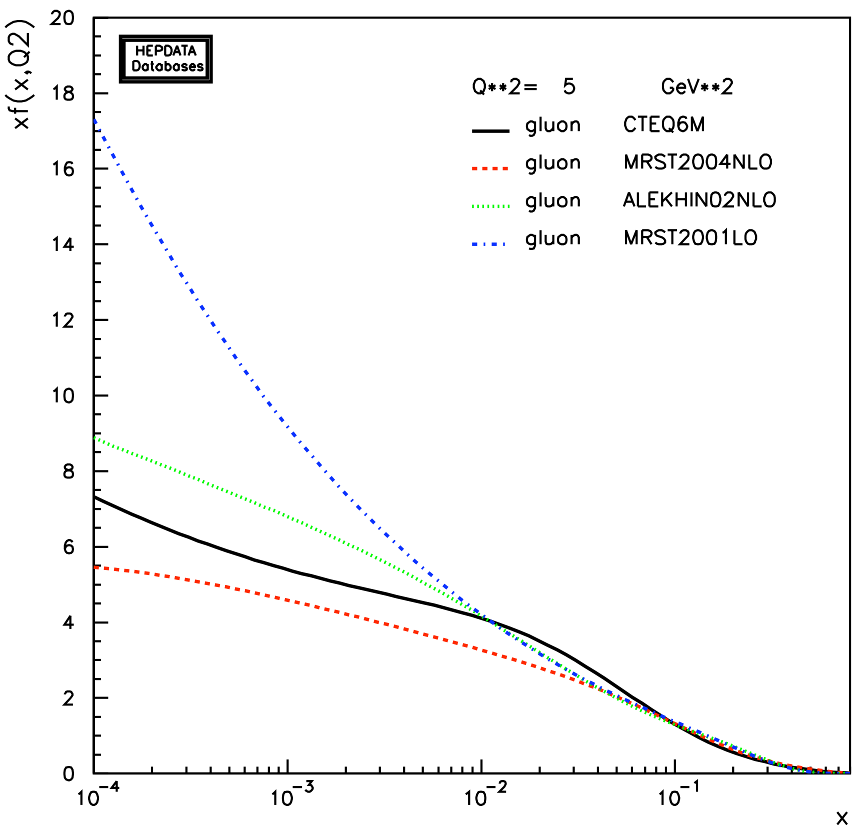
G Altarelli, RADCOR2007

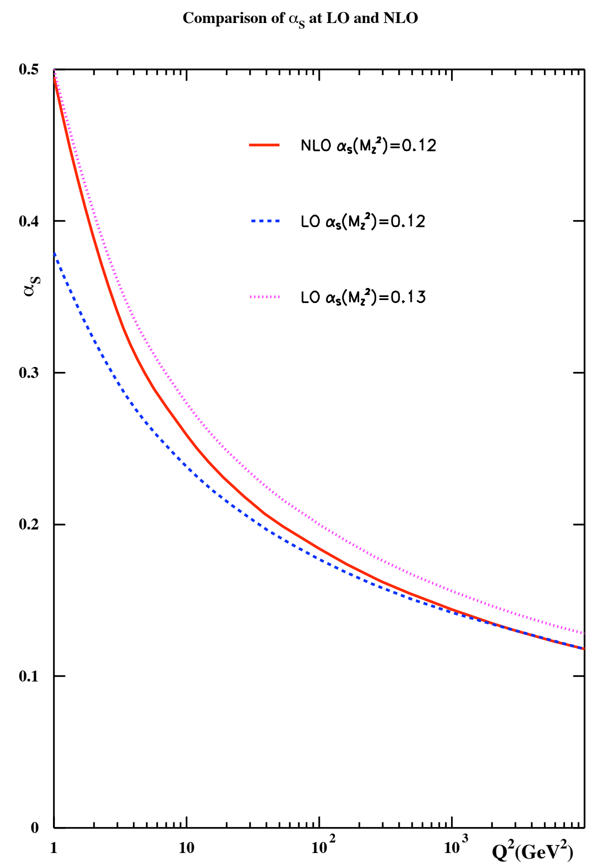
Evolution of Singlet Quark



PDFs for LO MCs

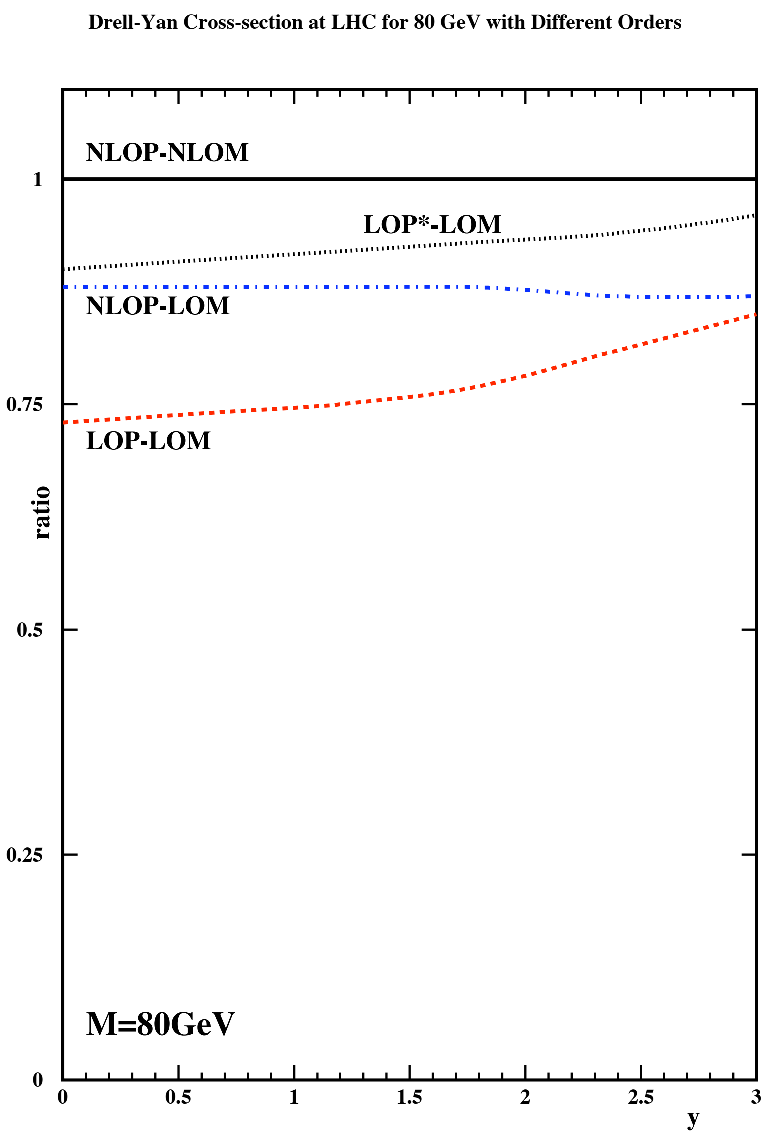
- Lack of NLO ⇒large LO gluon
- Fast evolution at low Q^2 ⇒large α_s
- Proposal: use NLO α_s , no mom. cons'n
  ⇒Good fits, close to NLO





A Sherstnev & RS Thorne arXiv:0711.2473

LO* PDFs

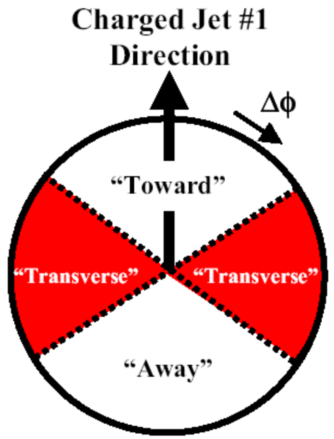


$$pp \longrightarrow jj$$

pdf type	matrix element	σ (μb)	K-factor
NLO	NLO	183.2	
LO	LO	149.8	1.22
NLO	LO	115.7	1.58
LO*	LO	177.5	1.03

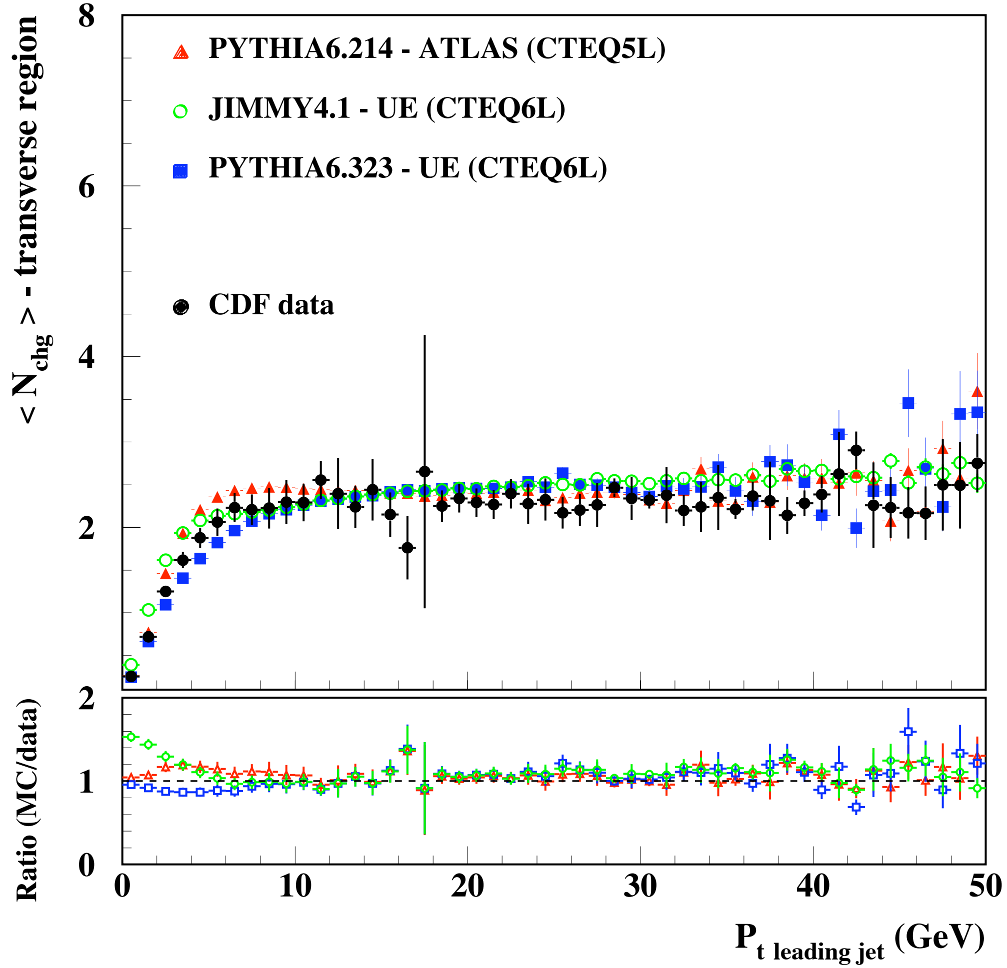
$$pp \longrightarrow H$$

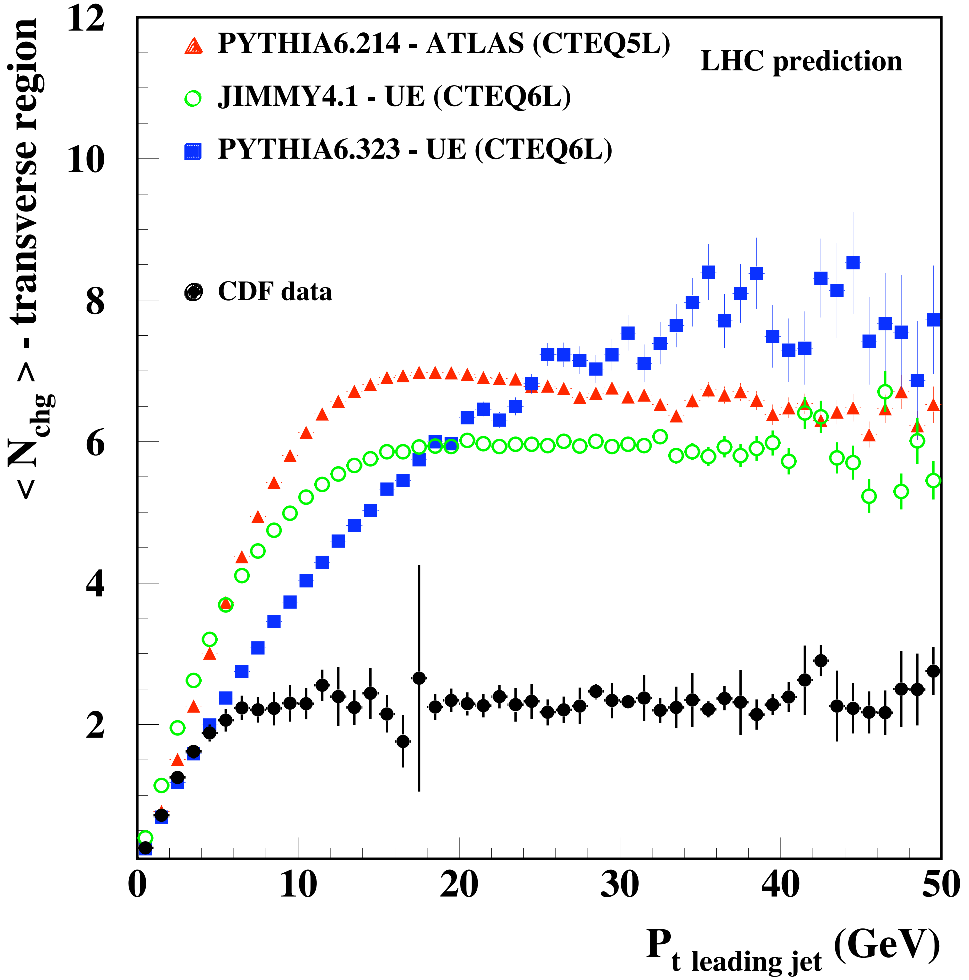
pdf type	matrix element	σ (pb)	K-factor
NLO	NLO	38.0	
LO	LO	22.4	1.70
NLO	LO	20.3	1.87
LO*	LO	32.4	1.17



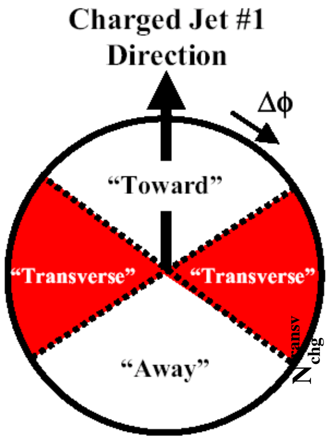
Underlying Event

- Small-x PDFs important for multiple interactions
- Really need multi-parton distributions

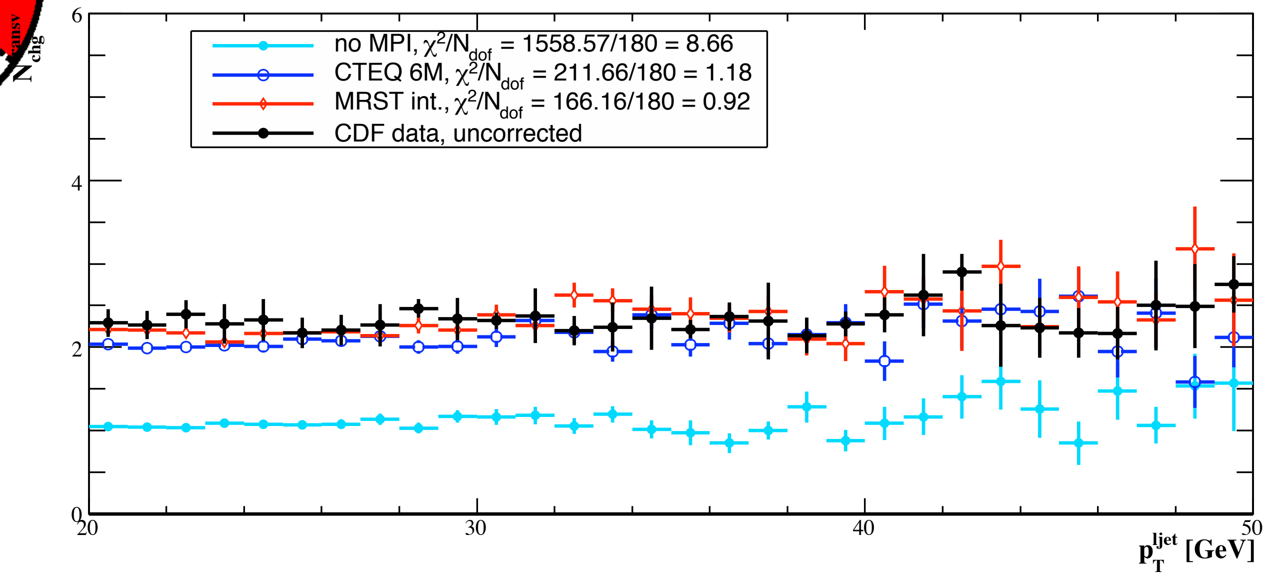




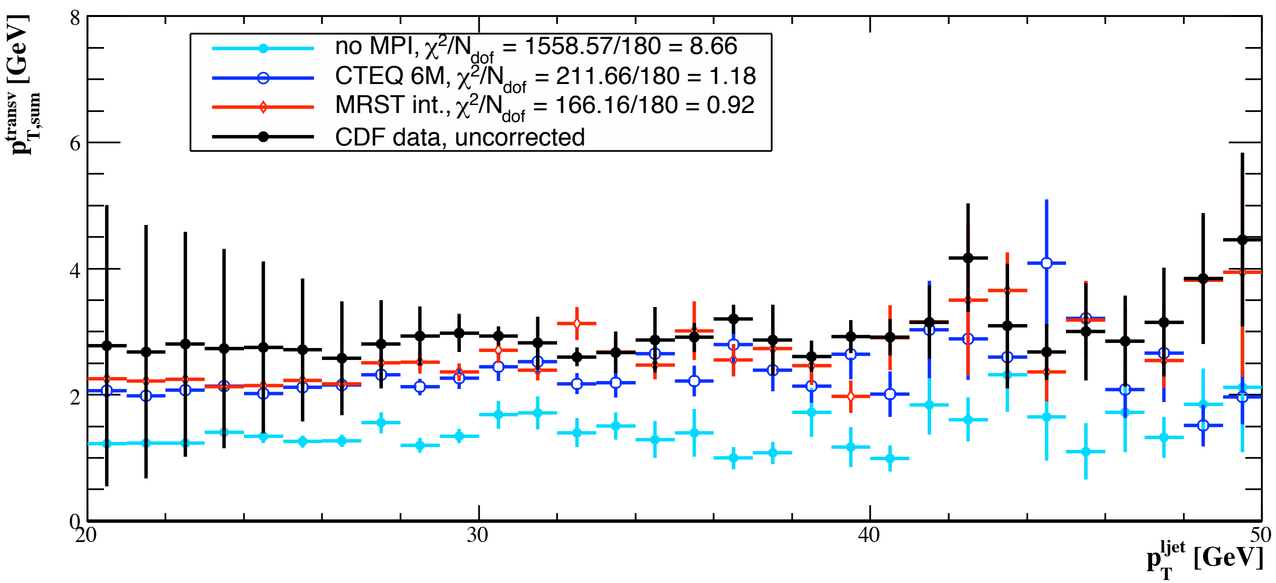
Herwig++ UE



Charged Jet #1 Direction
Δφ
"Toward"
"Transverse"
"Transverse"
"Away"



no MPI, χ²/N_dof = 1558.57/180 = 8.66
CTEQ 6M, χ²/N_dof = 211.66/180 = 1.18
MRST int., χ²/N_dof = 166.16/180 = 0.92
CDF data, uncorrected
N_chg^transv
p_T^ljet [GeV]



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CTEQ 6M, χ²/N_dof = 211.66/180 = 1.18
MRST int., χ²/N_dof = 166.16/180 = 0.92
CDF data, uncorrected
p_T,sum^transv [GeV]
p_T^ljet [GeV]

Conclusions/Summary

- Uncertainties: theoretical important
- Benchmark cross sections: can we improve? Cuts??
- Heavy quarks: crucial for new physics. Uncertainty?
- Small x: theory converged?
- PDFs for MCs: new developments
- Underlying event: multiPDFs?
- Apologies again: spin, diffractive, unintegrated,...