PDFs & $\alpha_s(M_Z)$ from Inclusive and Jet Measurements in DIS @ HERA

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PANIC, Cambridge, MA, July 24-29, 2011

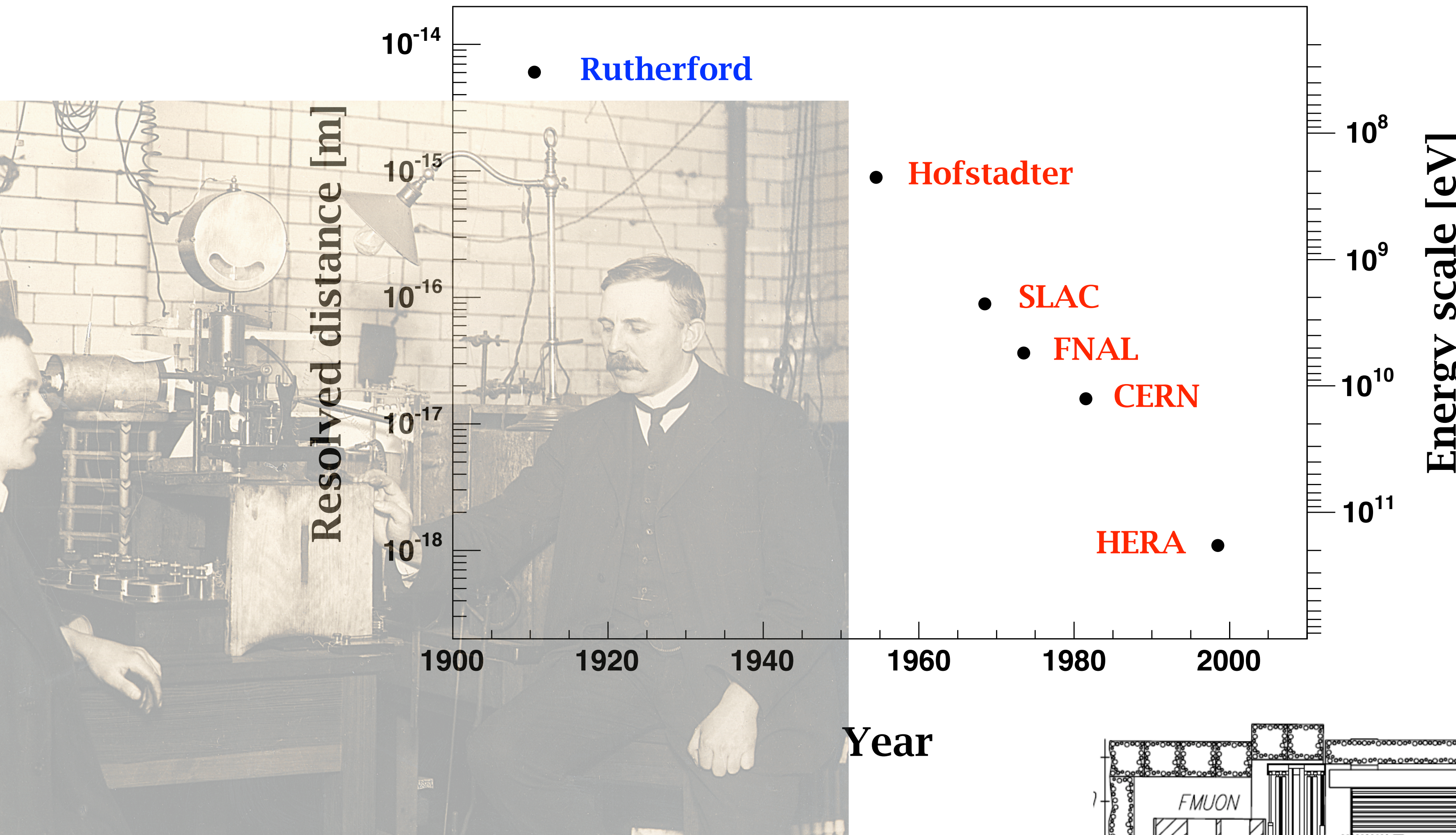
Rutherford Centennial & MIT Sesquicentennial

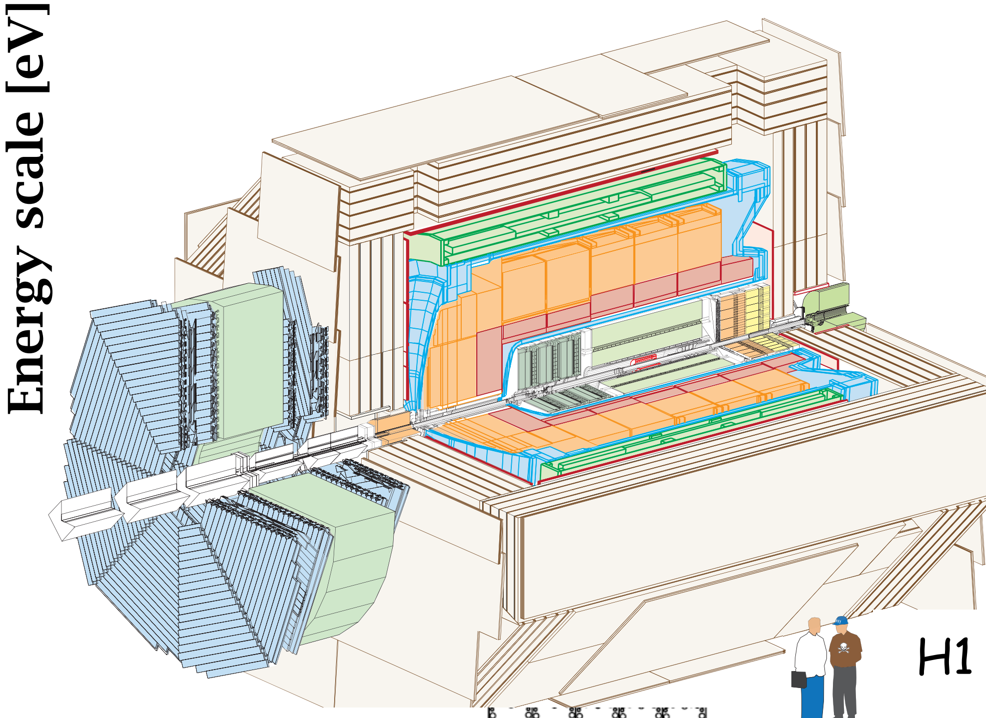
on behalf of the H1 and ZEUS collaborations

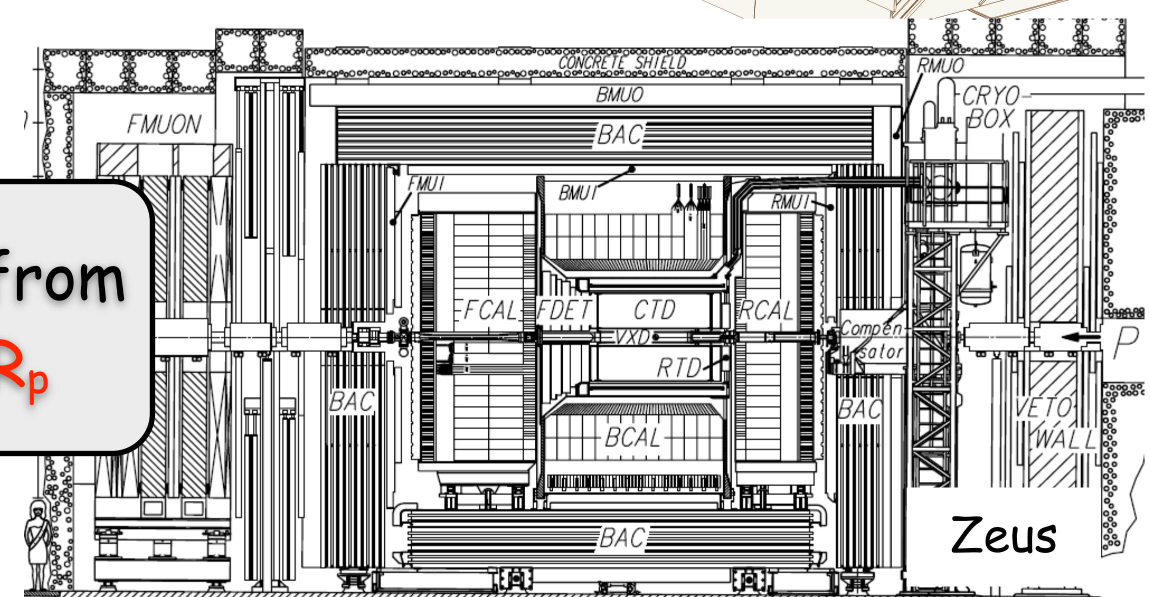
- introduction
- HERAPDFs
- data: inclusive & jet cross sections
- results

From Rutherford to HERA

Celebrating the Rutherford centennial



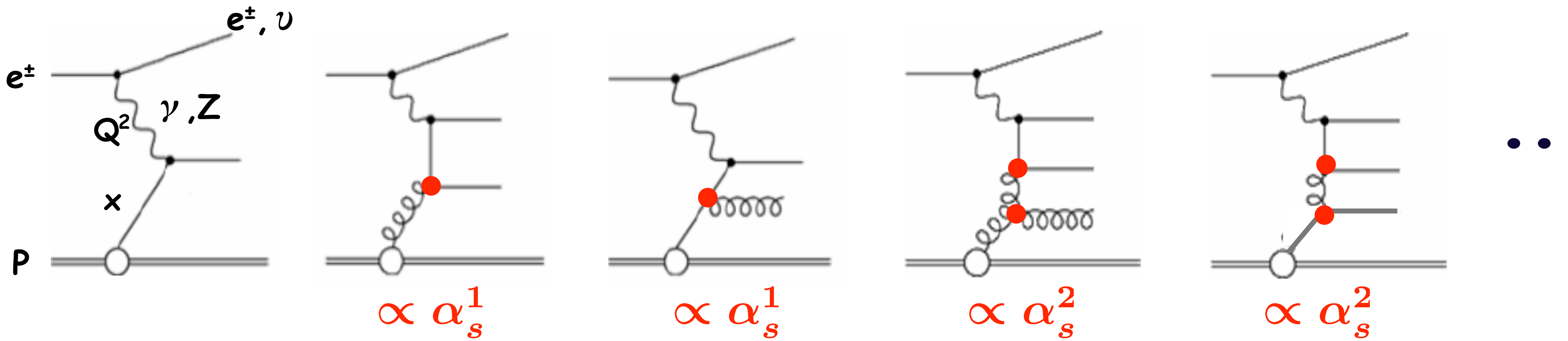




Resolution has increased from about 6 R_p to < 1/1000 R_p

HERA expts.

Physics of inclusive DIS & jets



in LO

inclusive DIS: $\sigma \propto q(x, \mu_f)$

jets in DIS in the Breit frame: $\sigma_{\mathrm{jet}} \propto \alpha_s(\mu_r)(c_g g(x, \mu_f) + c_q q(x, \mu_f))$

α_S and gluon are strongly correlated in fits to inclusive data alone, because sensitivity to the gluon only enters in NLO (scaling violations).

jet data are sensitive to α_S and gluon already in LO and together with inclusive data can reduce the strong correlation.

HERAPDFs

- idea: use only HERA data (combined H1 & ZEUS) in the PDF fits
  - precise data set with total uncertainties between 1-2% over most of the phase space
  - systematic correlated and uncorr. uncertainties well controlled, allowing for $\Delta\chi^2 = 1$ uncertainty criterion
  - $e^{\pm}p$ data only, i.e. no need for deuterium corrections and heavy target corrections
  - for central fit use parametrizations with minimum number of parameters
  - param. uncertainty ⇒ vary number of parameters (and parametrization) and Q_0^2, the starting scale of the parametrizations (default = 1.9 GeV^2)
  - model uncertainty ⇒ vary m_c, m_b, f_s, Q^2_{min} (defaults: 1.4 GeV, 4.75 GeV, 0.31, 3.5 GeV^2)

HERAPDF parametrizations I

- $x \cdot uv$, $x \cdot dv$, $x \cdot Ubar$, $x \cdot Dbar$ and $x \cdot g$ are parametrized according to:

$$xf(x, Q_0^2) = Ax^B (1-x)^C (1 + Dx + Ex^2 + \epsilon\sqrt{x})$$

- starting scale Q_0^2 = 1.9 GeV^2 (below m_c), NLO DGLAP evolution (RT-VFNS)
- constraints:
  - momentum sum rules, quark sum rules
  - $x \cdot sbar = f_s\, x \cdot Dbar$ strange sea is a fixed fraction f_s of Dbar at Q_0^2
  - $B_{Ubar} = B_{Dbar}$ and $Buv = Bdv$
  - Sea = $2x \cdot (Ubar+Dbar)$
  - Ubar = Dbar at x=0

- 10 free parameters are used up to HERAPDF1.5 fitting HERA-1 data:
  - B_g, C_g, B_{uv}, C_{uv}, C_{dv}, A_{Dbar}, B_{Dbar}, C_{Dbar}, C_{Ubar}, E_{uv}

- 14 free parameters are used for HERAPDF1.5f, HERAPDF1.6 fitting HERA-1 and HERA-2 data (more data require a more flexible parametrization):
  - $A'_g \cdot x^{B'g} \cdot (1-x)^{C'g}$ term for low-x gluon and $B_{uv} \neq B_{dv}$ to free low-x uv from dv

HERAPDF parametrizations II

$$xf(x,Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2+\epsilon\sqrt{x})$$

extended gluon parametrization: $Ag \cdot x^{Bg} \cdot (1-x)^{Cg} \cdot (1+Dx+Ex^2) - A'g \cdot x^{B'g} \cdot (1-x)^{Cg}$

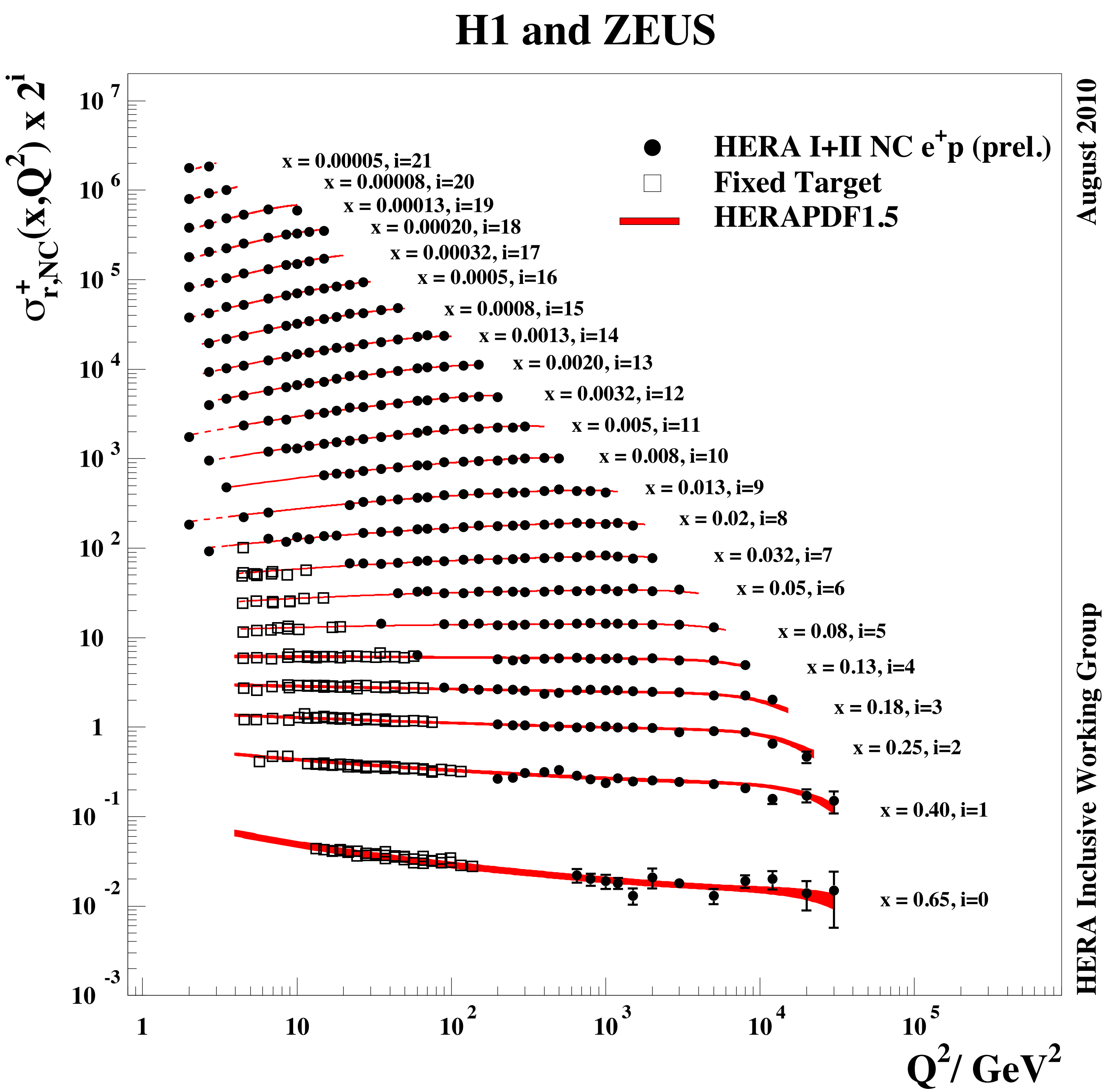
	A	B	C	D	E	ε
uv	Sum rule	free	free	free	free	var
dv	Sum rule	free	free	var	var	var
UBar	=(1-fs)ADbar	=BDbar	free	var	var	var
DBar	free	free	free	var	var	var
glue	Sum rule	free	free	var	var	var

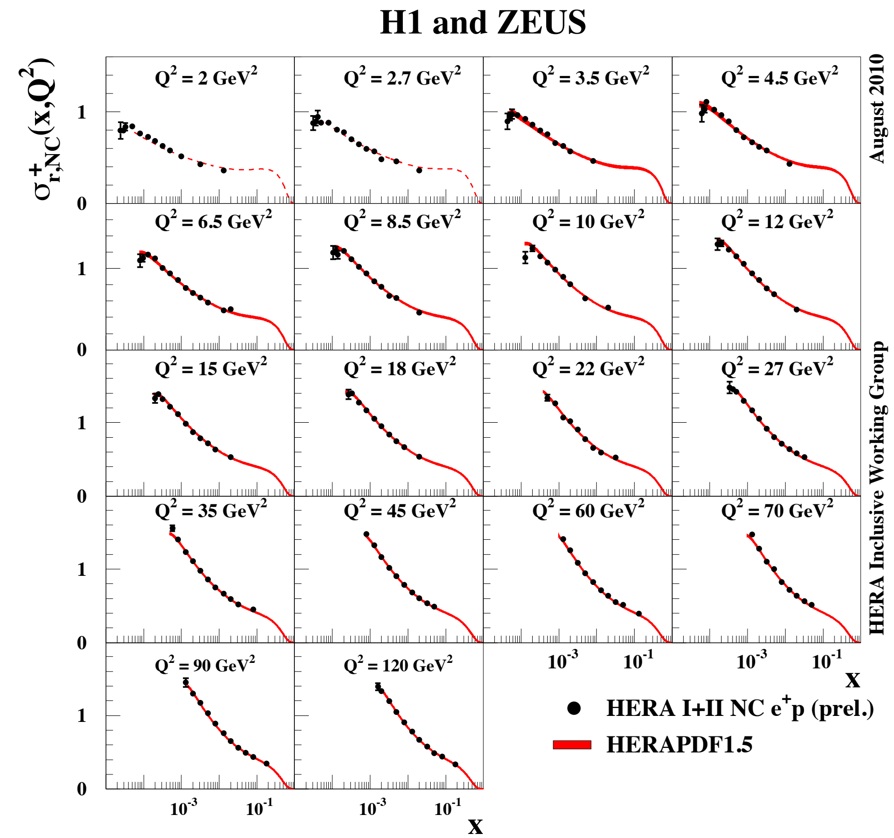
A'g	B'g
free	free

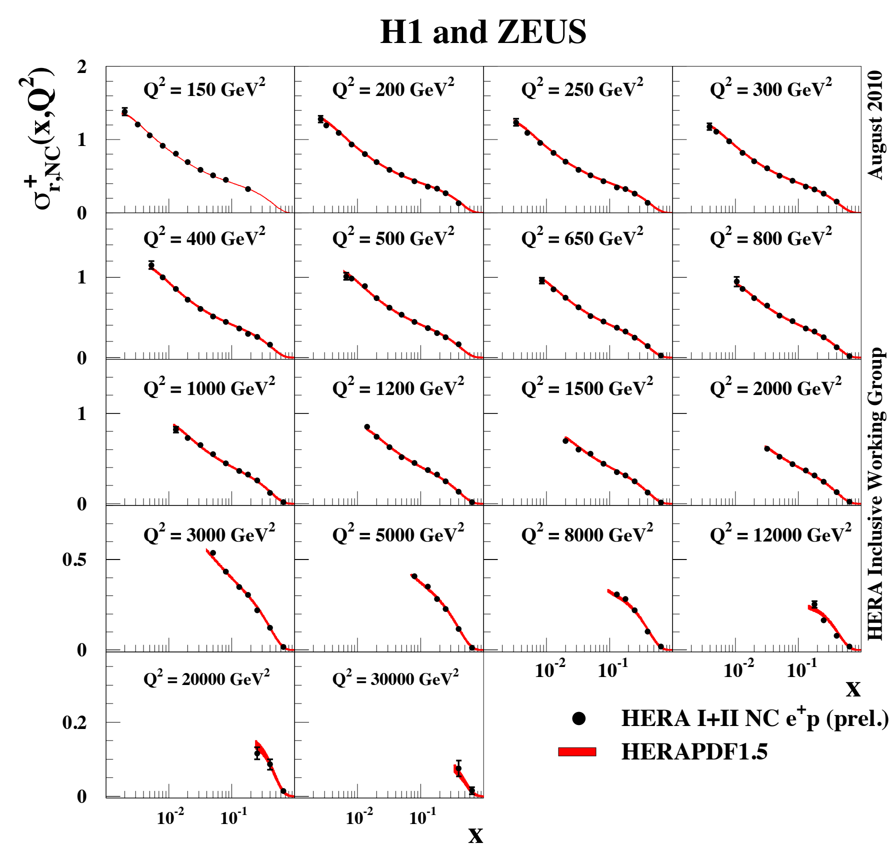
HERAPDF1.5f & HERAPDF1.6:
- additional parameters: Bdv, Duv, A'g, B'g
- estimate of parametrization uncertainty: indicated parametrization variations, Q_0^2
- estimate of model uncertainties: m_c, m_b, f_s, Q^2_{min} are varied

Incl. HERA NC e+p cross sections

- HERA PS: $0.045 < Q^2 < 3\cdot10^4$ GeV^2, $5\cdot10^{-5} < x < 0.65$
- combine H1 & ZEUS data

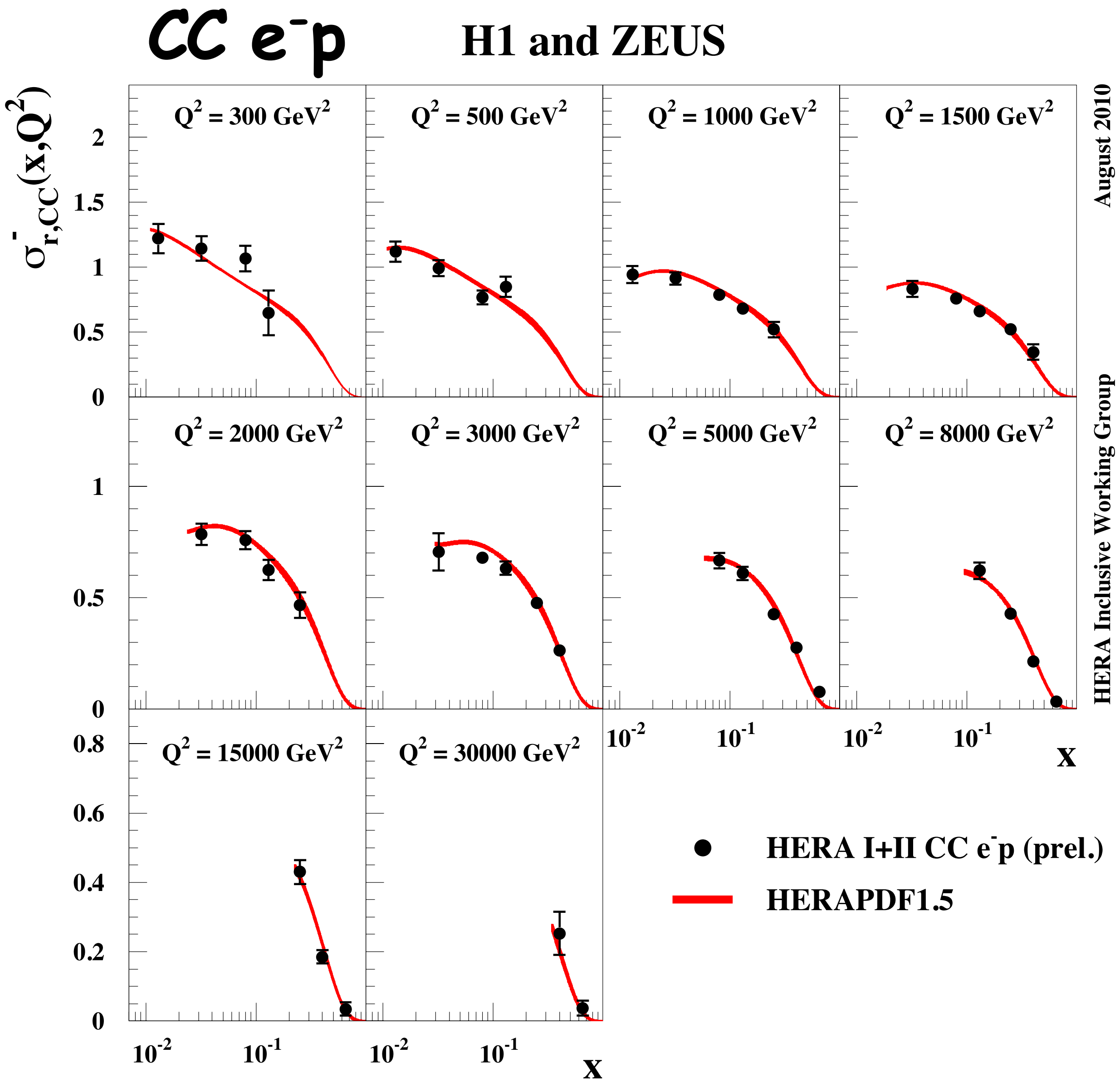


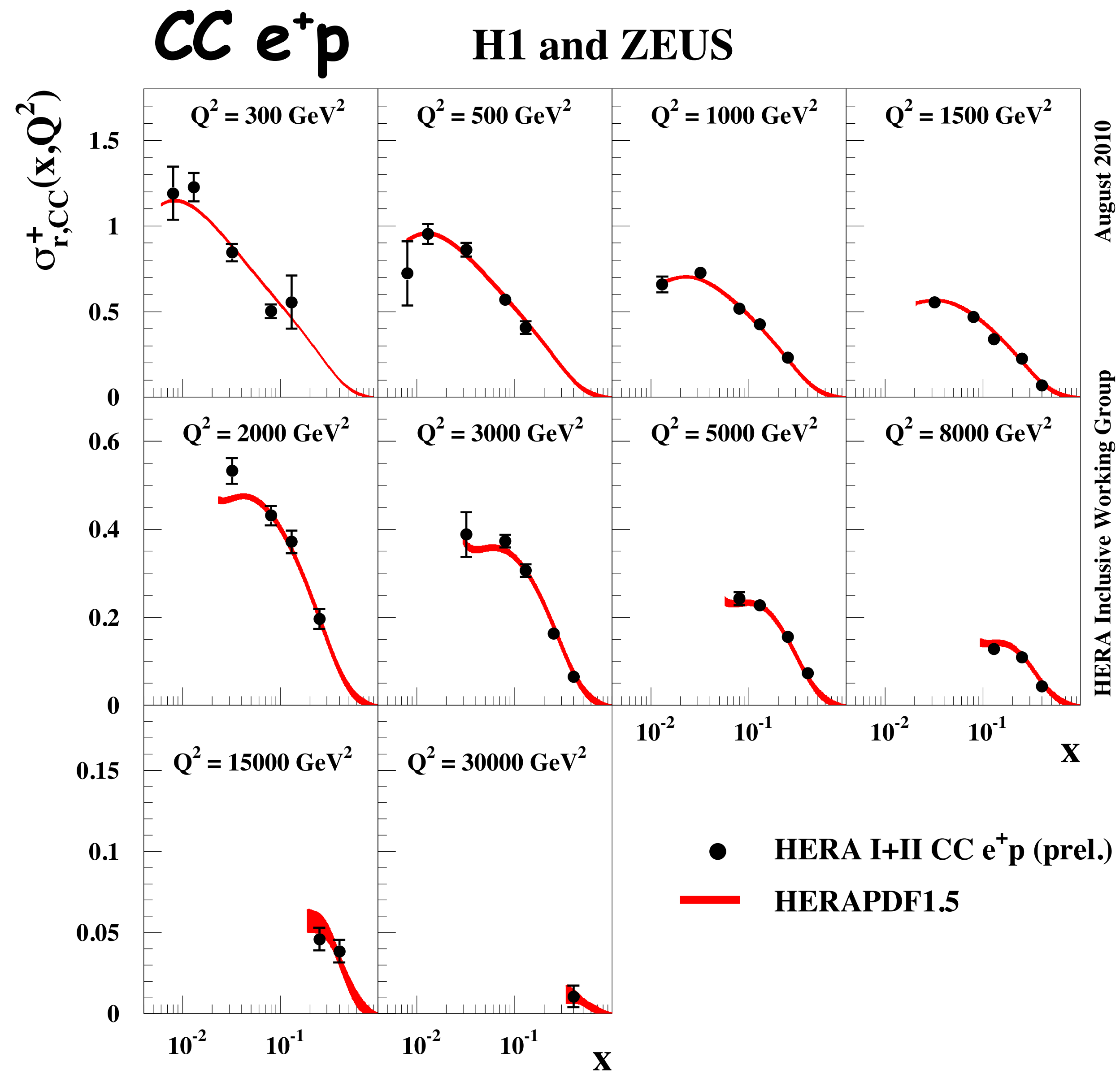




see talk by Rik Yoshida on combined (H1&ZEUS) NC and CC measurements, and H1 & ZEUS, JHEP 1001 109 (2010) + updates

Incl. HERA CC e±p cross sections

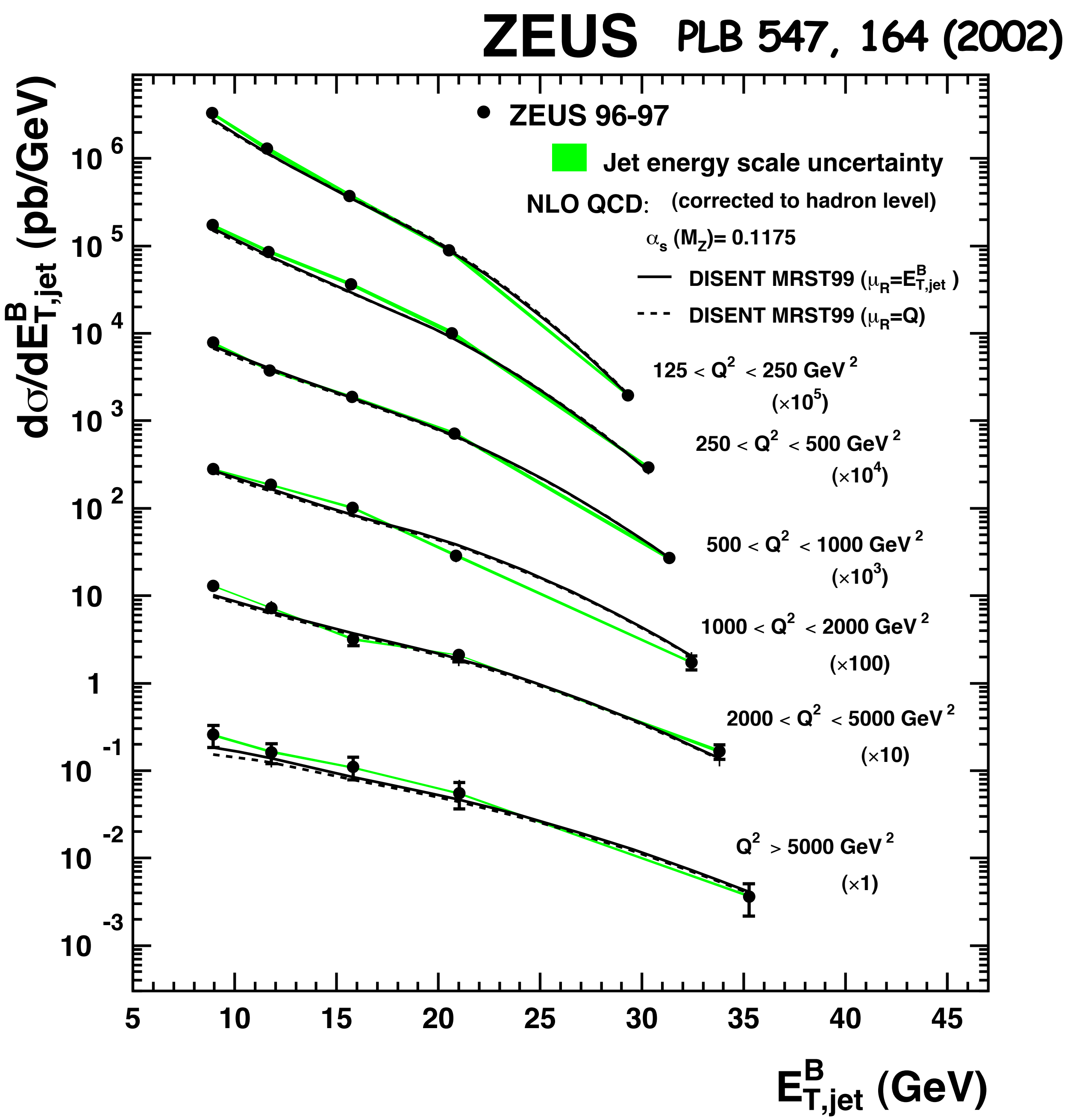


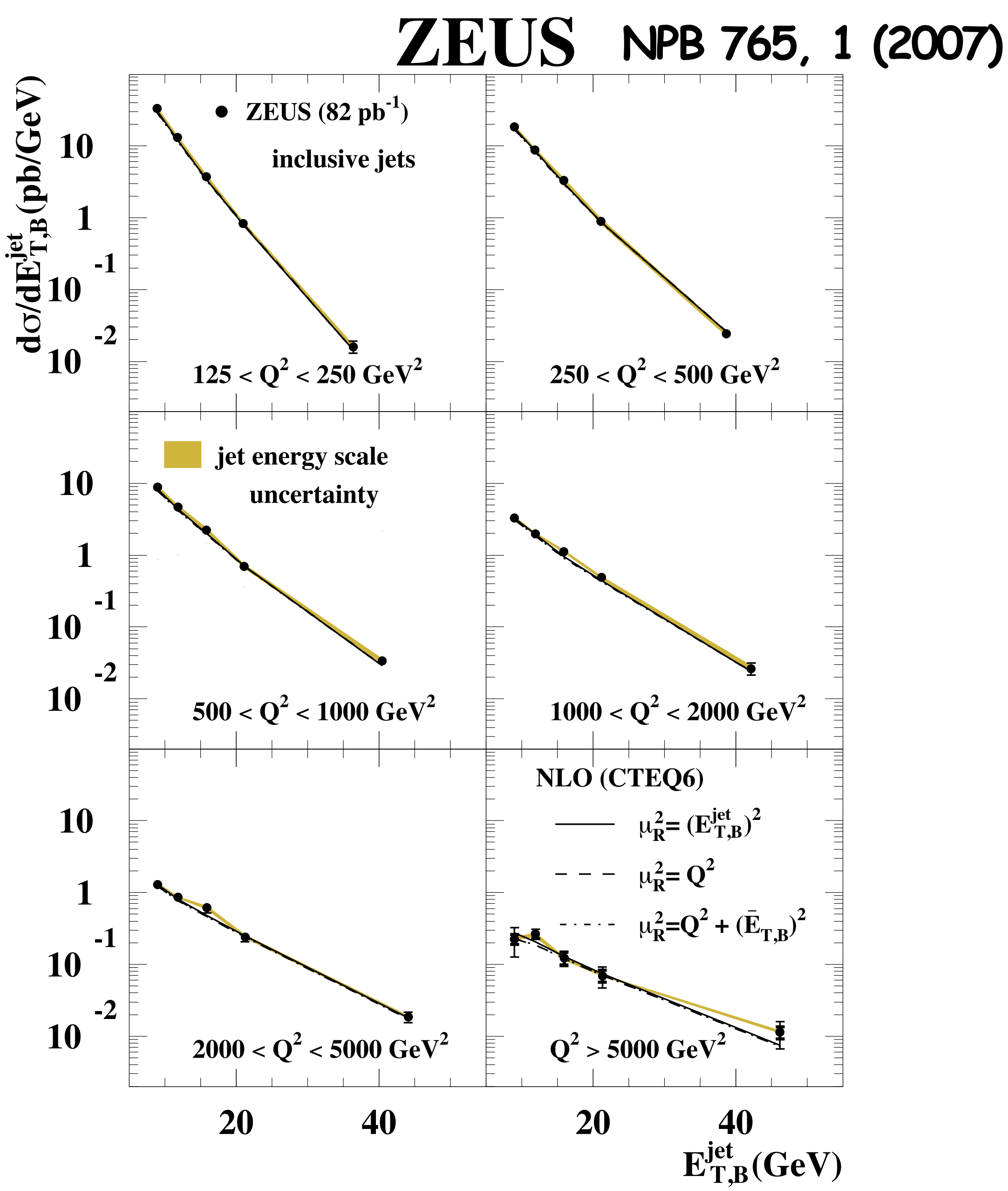


$$\frac{d^2\sigma^-_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[u + c + (1-y)^2(\bar{d}+\bar{s})\right]$$

$$\frac{d^2\sigma^+_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[\bar{u} + \bar{c} + (1-y)^2(d + s)\right]$$

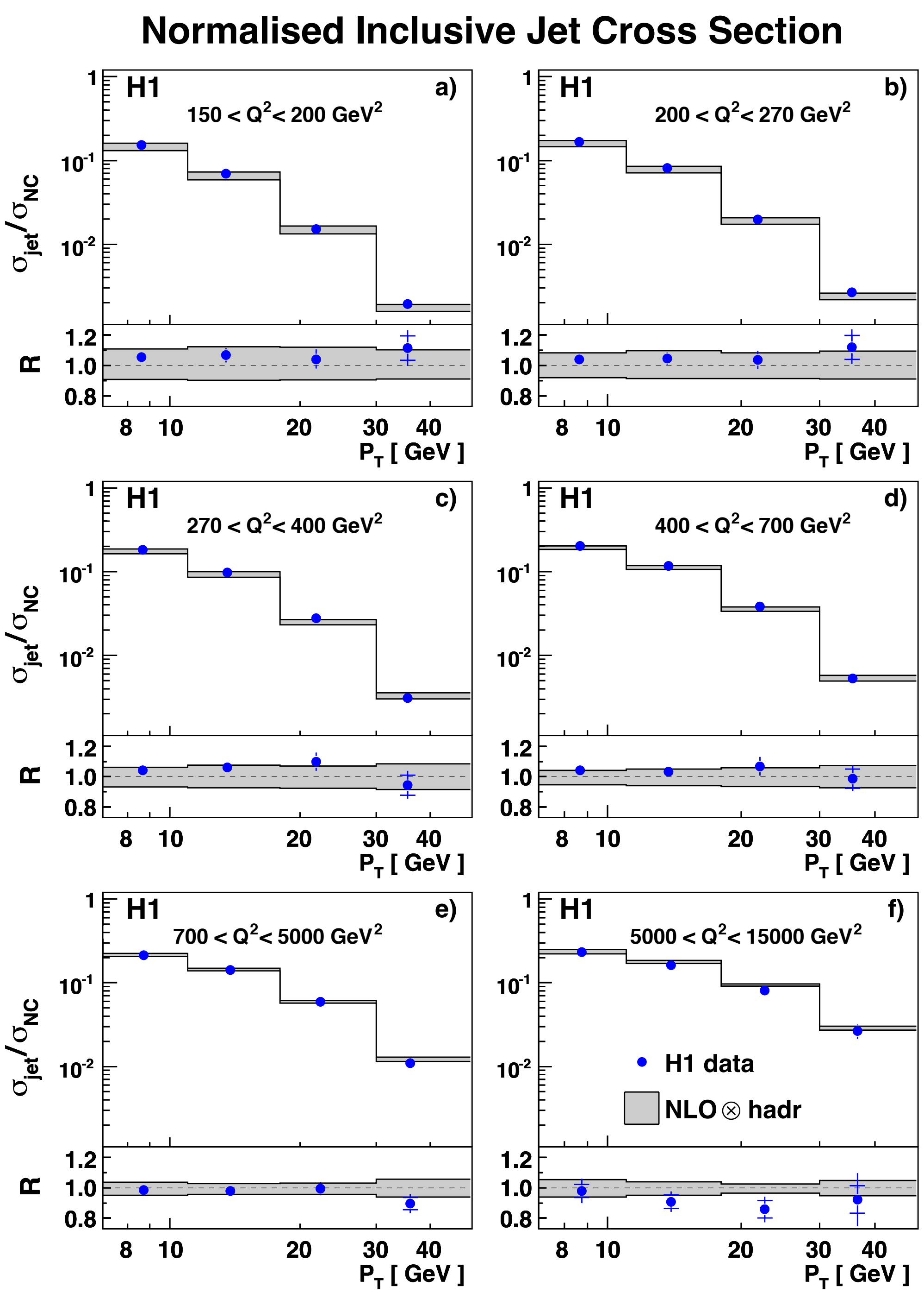
Incl. jet cross sections (ZEUS)



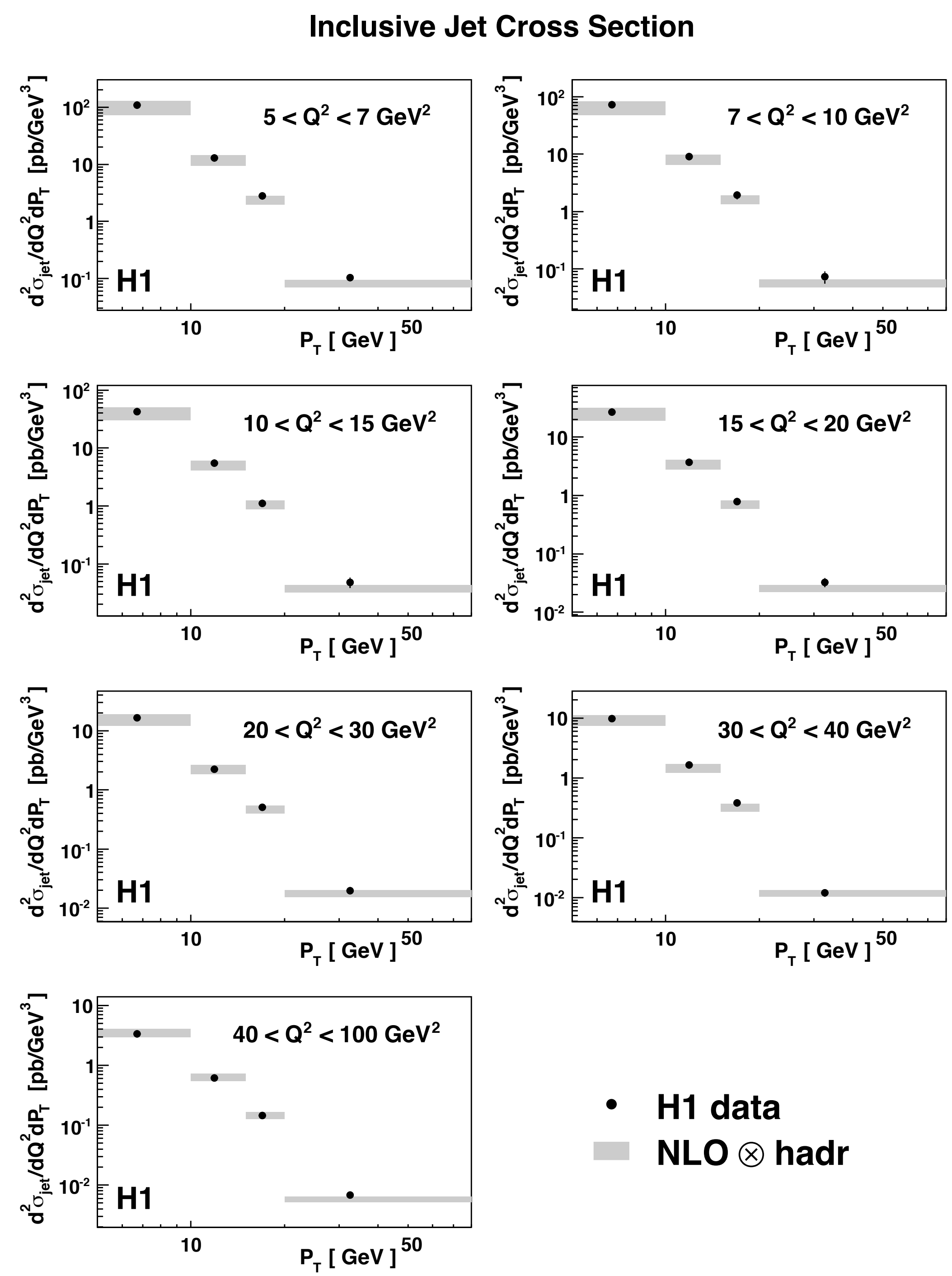


exp. uncertainty for inclusive jets at high Q^2: ~ 15% uncorrelated, 4% correlated

Incl. jet cross sections (H1)



EPJC 65, 363 (2010)



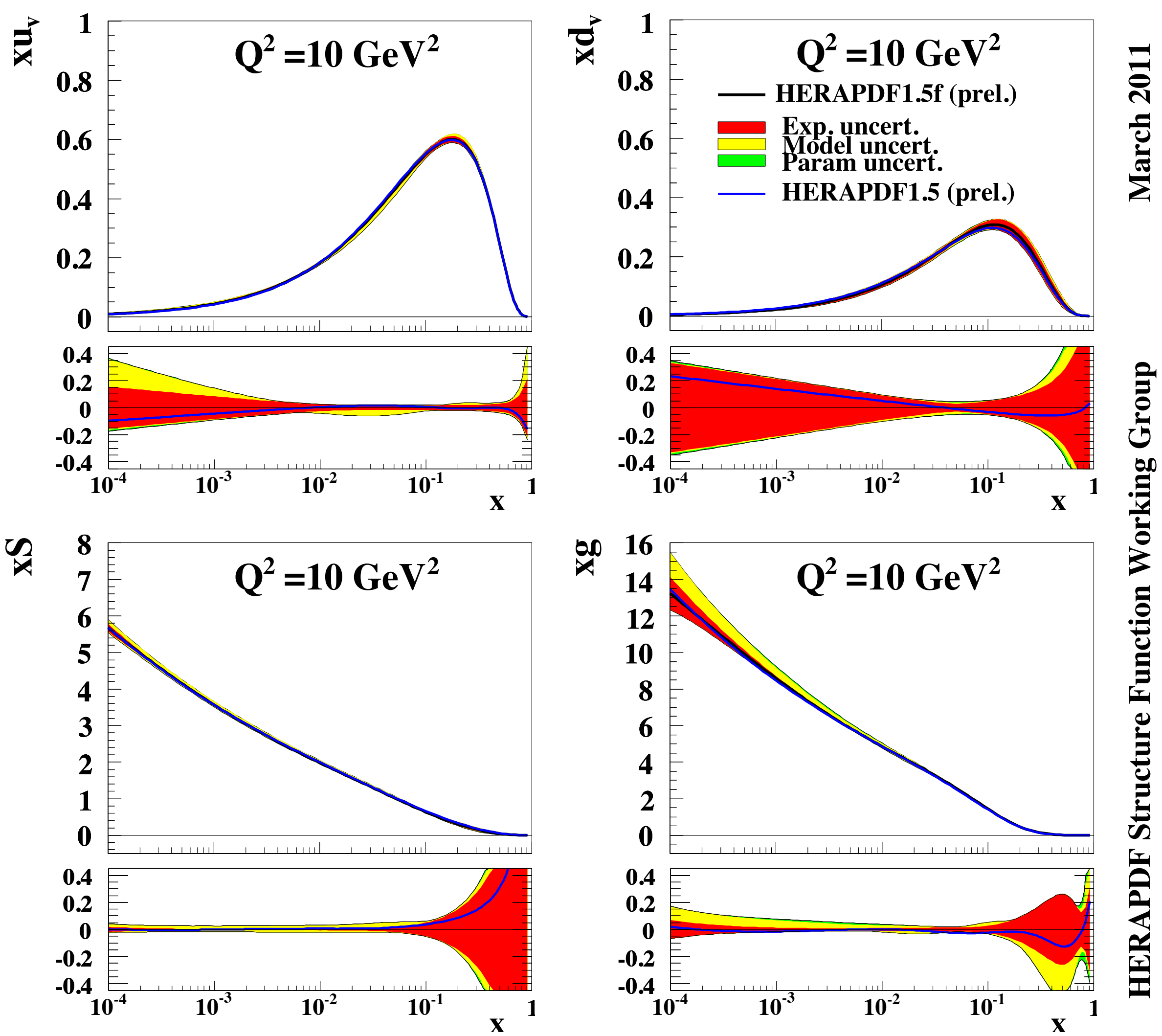
EPJC 67, 1 (2010)

exp. uncertainty for normalized inclusive jets at high Q^2: ~ 6% uncorrelated, 3% correlated

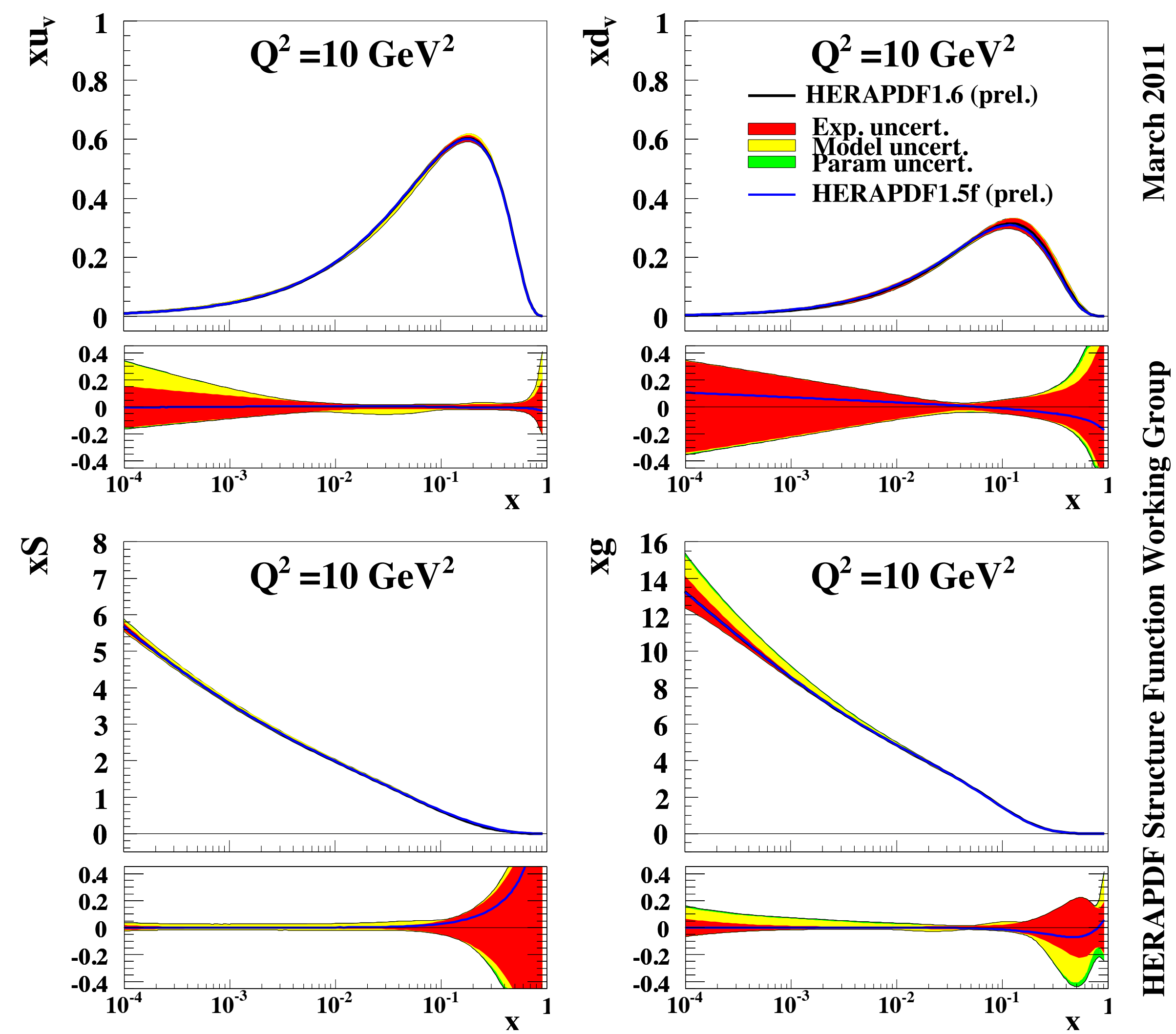
for inclusive jets at low Q^2: ~ 9% uncorrelated, 8% correlated

HERAPDF1.5f (no jets) vs HERAPDF1.6 (+jets)

H1 and ZEUS HERA I+II 14 parameter PDF Fit no jets



H1 and ZEUS HERA I+II PDF Fit with jets



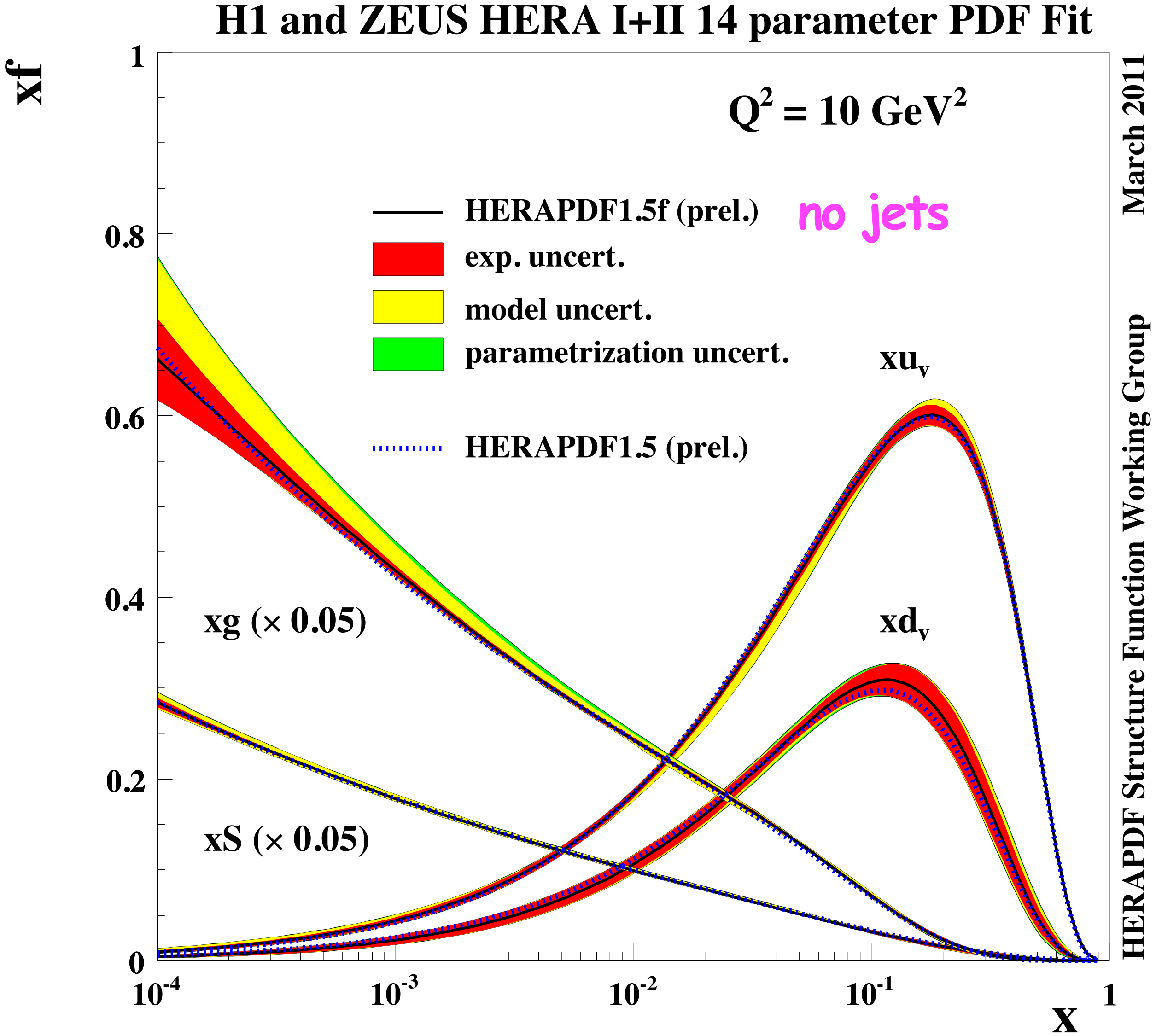
fixed $\alpha_S(M_Z) = 0.1176$

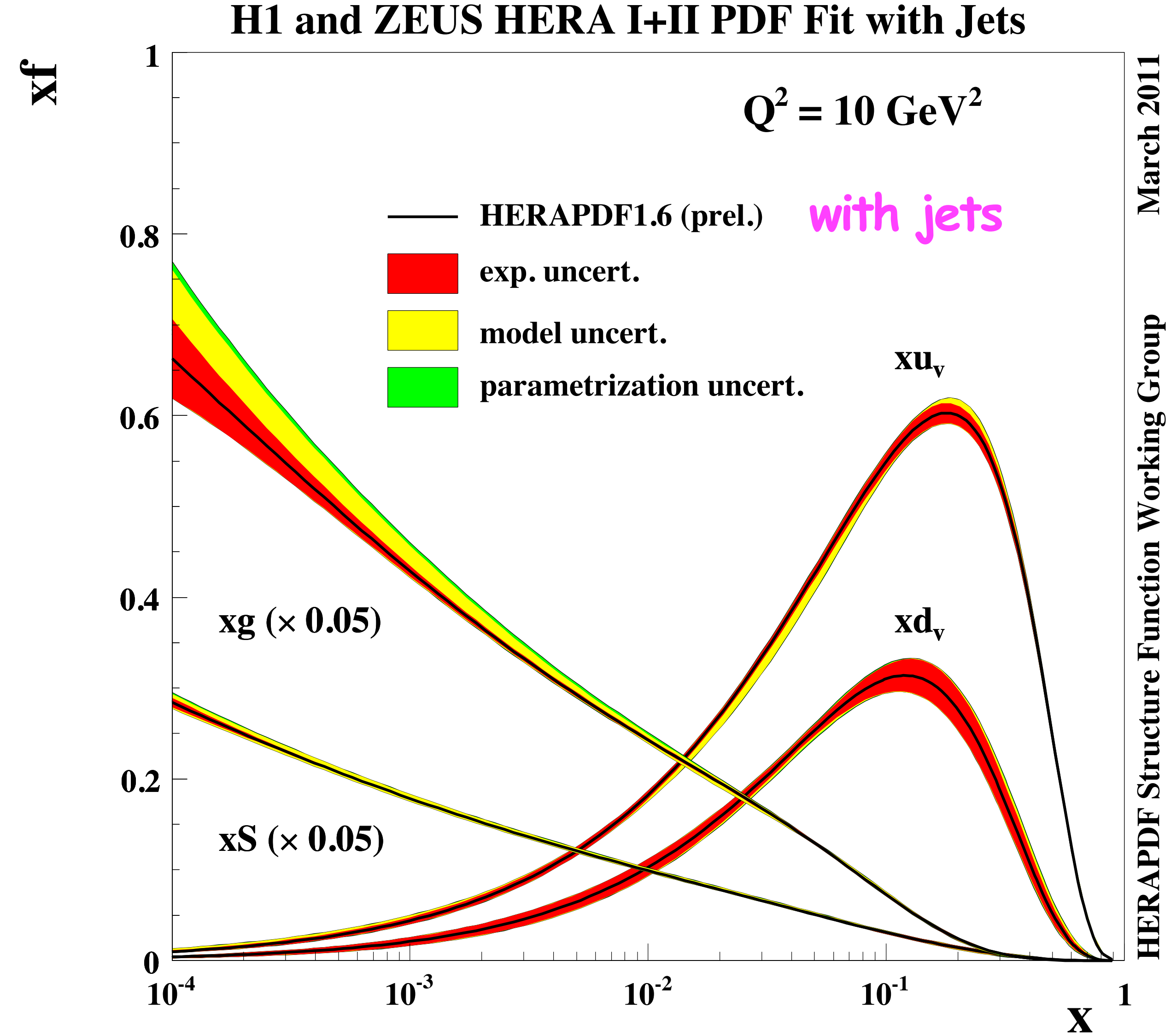
➡ adding jet data results in almost no differences, besides a softer high-x Sea and a marginal reduction in the high-x gluon uncertainty

H1prelim-11-034
ZEUS-prel-11-001

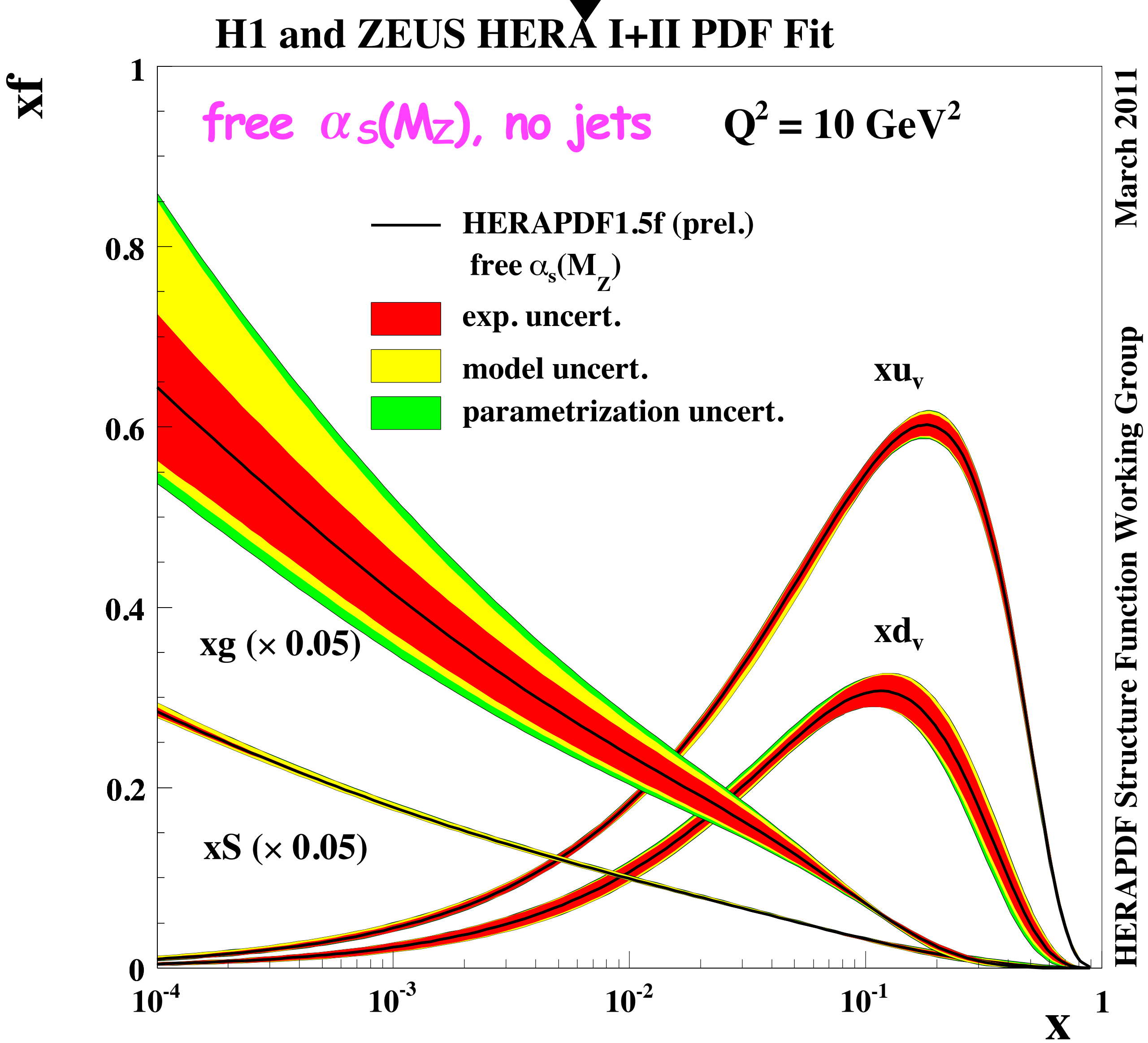
HERAPDF1.5f (no jets) vs HERAPDF1.6 (+jets)

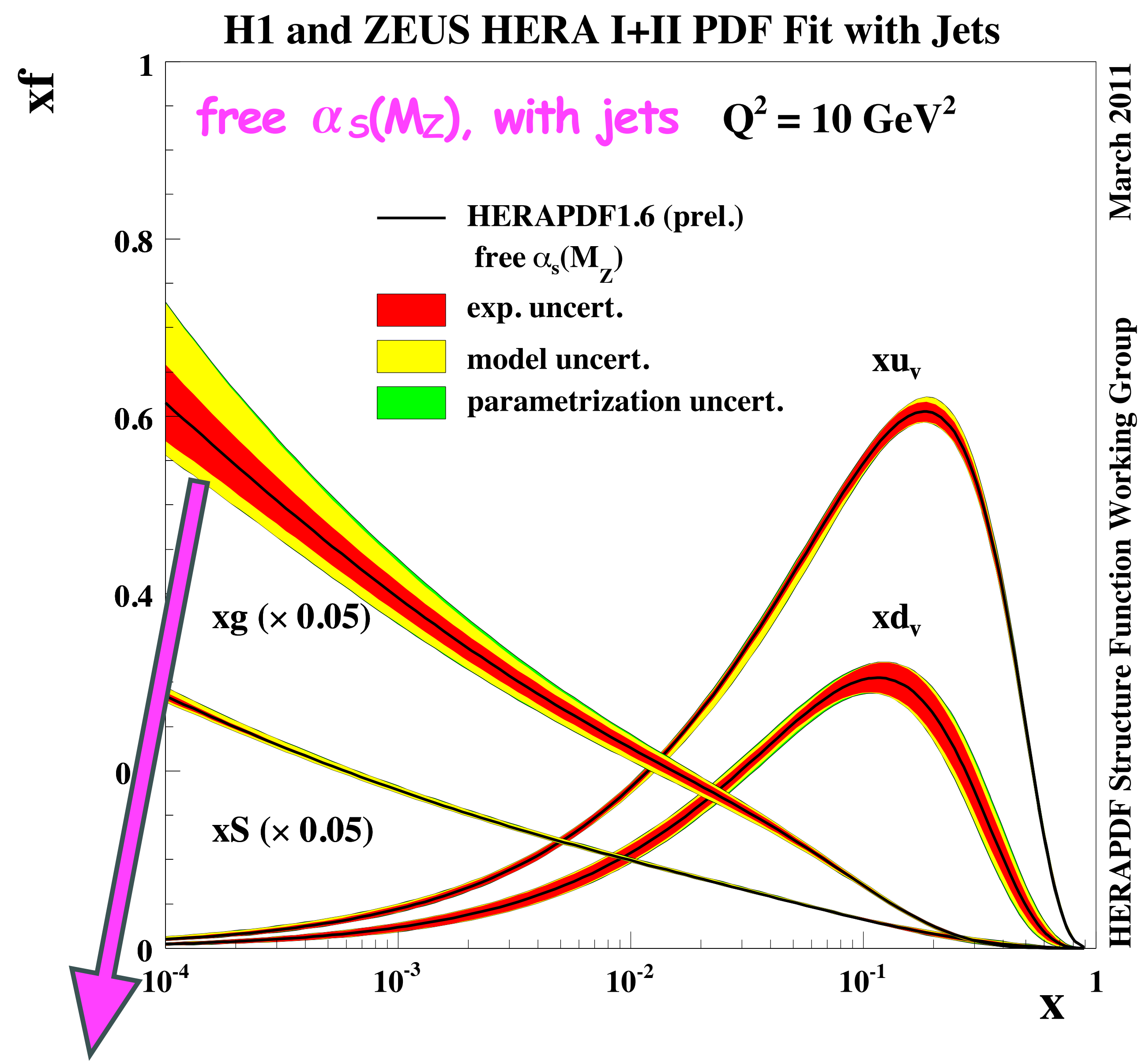
fixed $\alpha_S(M_Z) = 0.1176$





HERAPDF1.5f (no jets) vs HERAPDF1.6 (+jets)

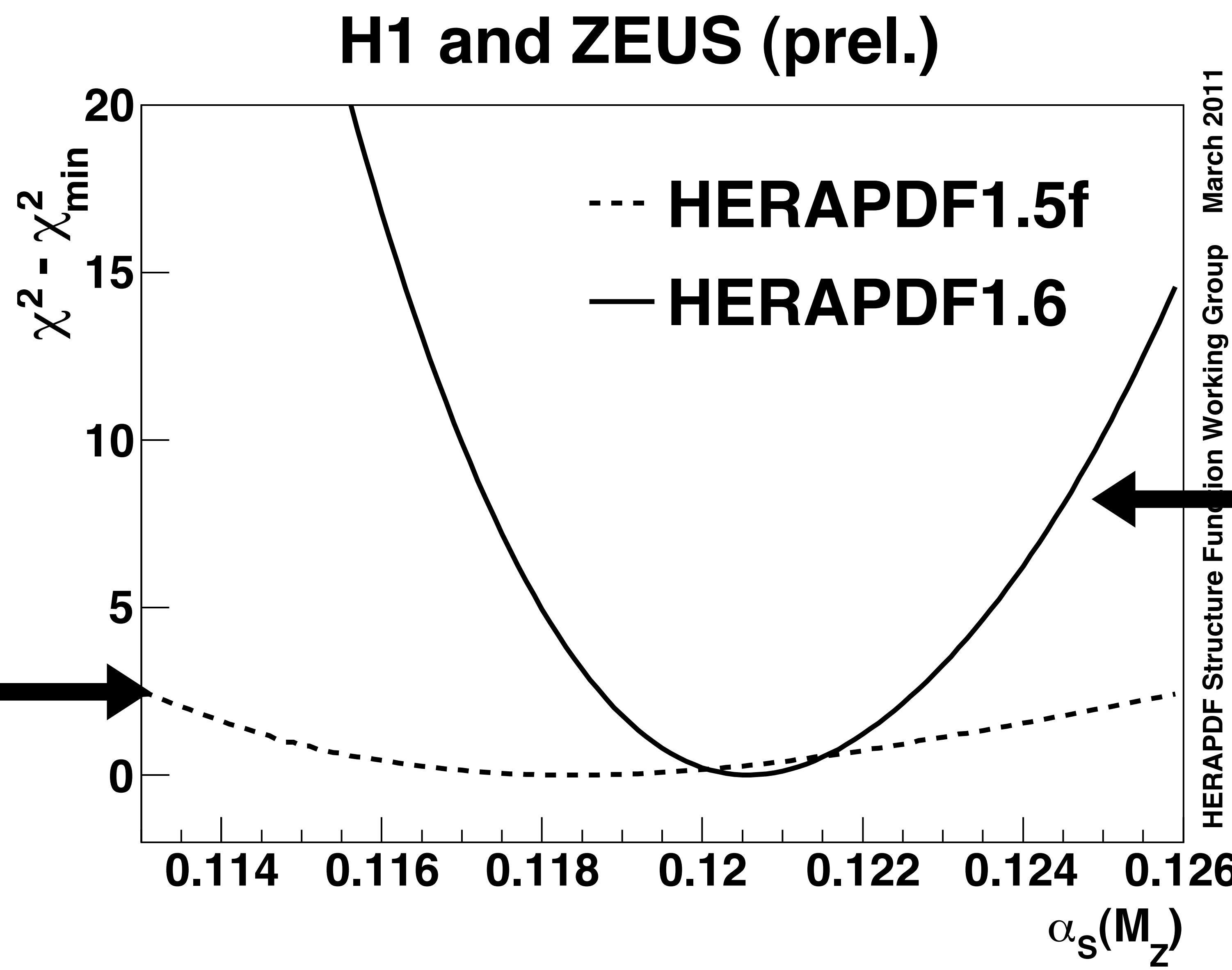




adding jet data dramatically decreases the low-x gluon uncertainty, not only the exp. but also the model and parametrization uncertainties

HERAPDF1.5f & 1.6 and $\alpha_s(M_Z)$ scan

inclusive DIS data only



inclusive DIS + jets data

➡ adding jet data successfully reduces the correlation of α_s and the gluon

$\alpha_s(M_Z)$ from incl. DIS & jets in DIS

$$\alpha_s(M_Z) = 0.1202 \pm 0.0013(\mathrm{exp}) \pm 0.0007(\mathrm{model/param}) \pm 0.0012(\mathrm{hadronization})\ ^{+0.0045}_{-0.0036}(\mathrm{scale})$$

$$\alpha_s(M_Z) = 0.1202 \pm 0.0019(\mathrm{exp/model/param/hadronization})\ ^{+0.0045}_{-0.0036}(\mathrm{scale})$$

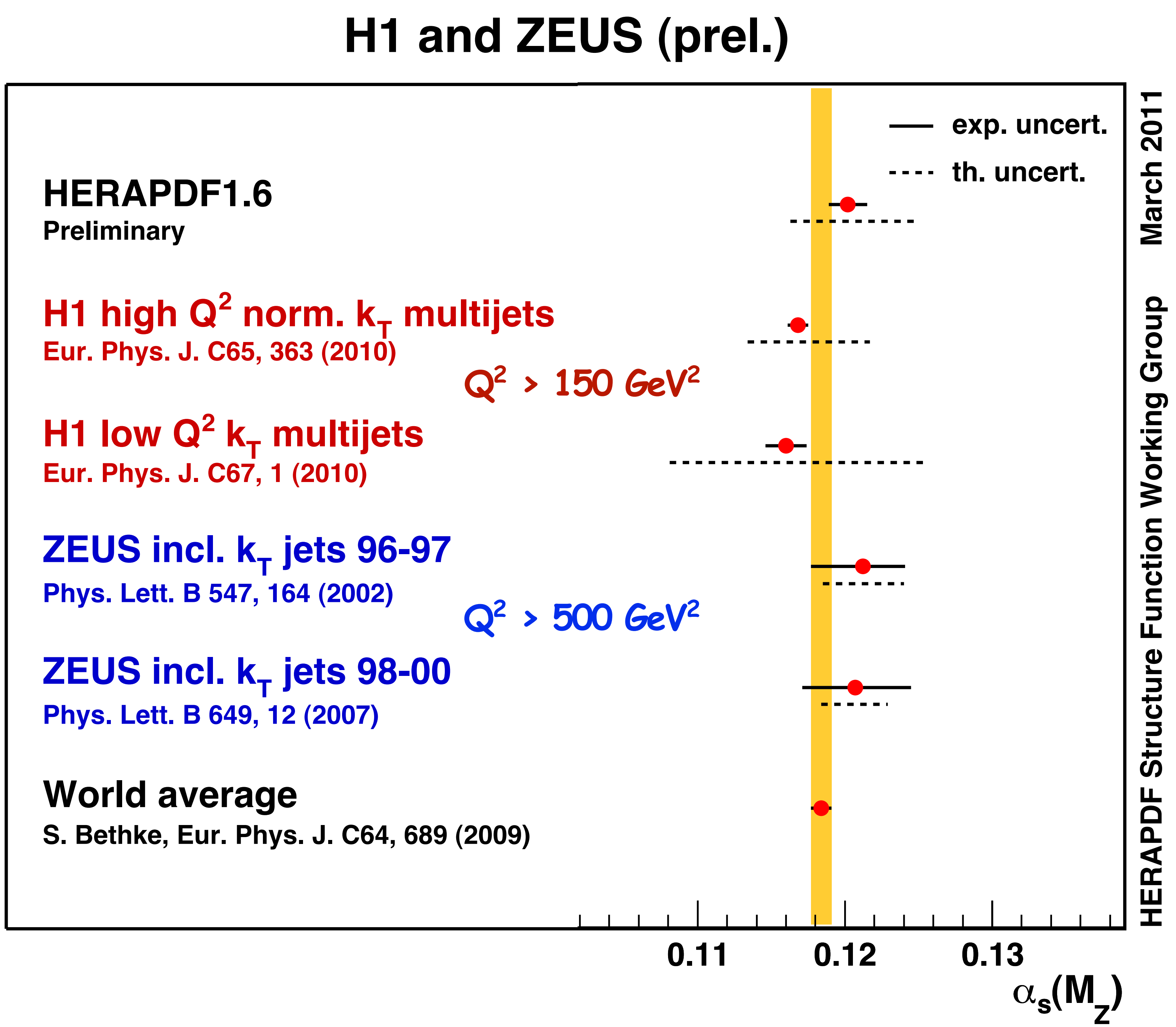
scale uncertainty from variation of renormalization & factorization scale by a factor of $\frac{1}{2}$ and 2

HERAPDF1.6 $\alpha_S(M_Z)$=0.1176	χ^2	N_{data}
all data	811.5	780
inclusive data	730.2	674
jet data	81.3	106

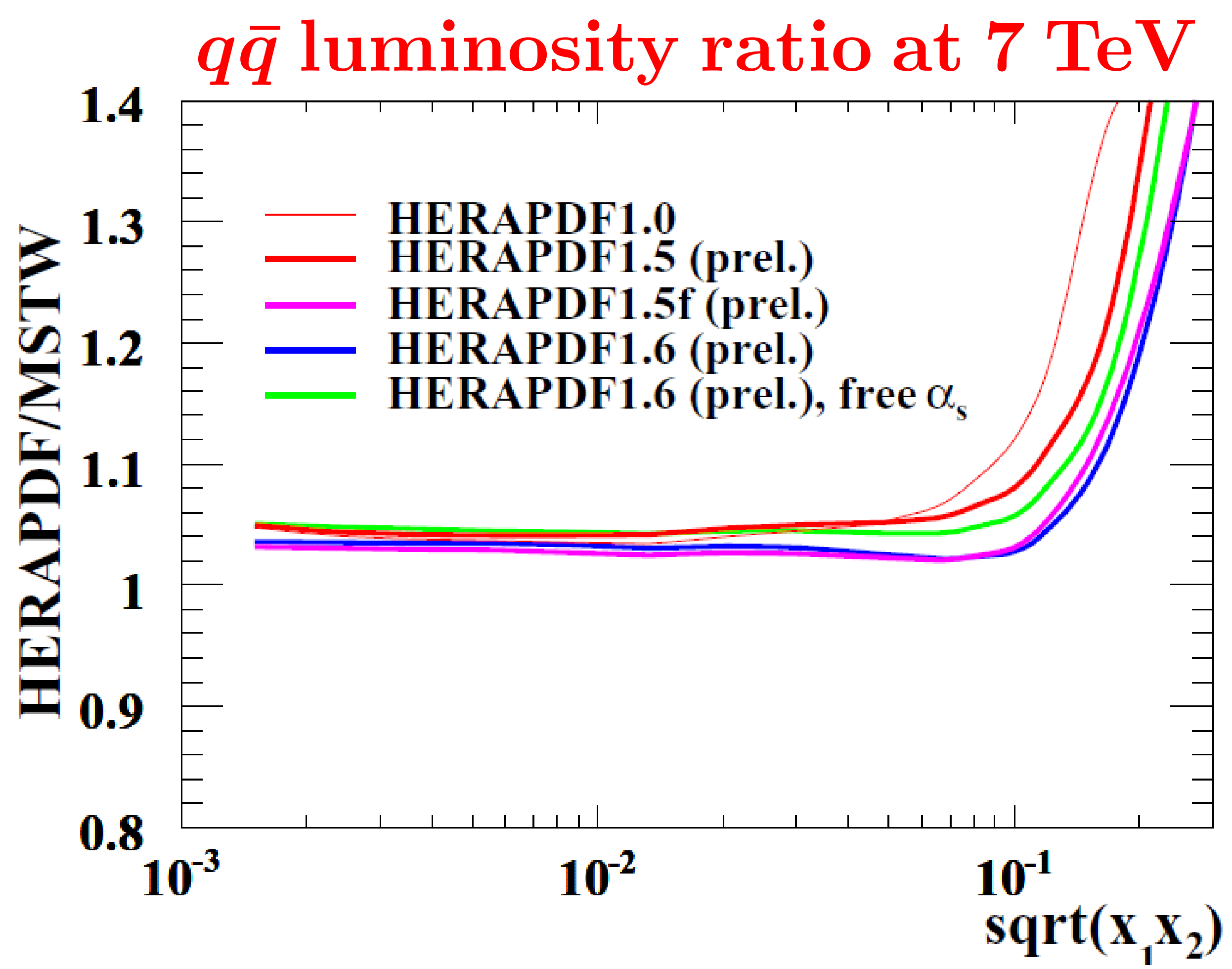
HERAPDF1.6 $\alpha_S(M_Z)$ free	χ^2	N_{data}
all data	807.6	780
inclusive data	730.0	674
jet data	77.6	106

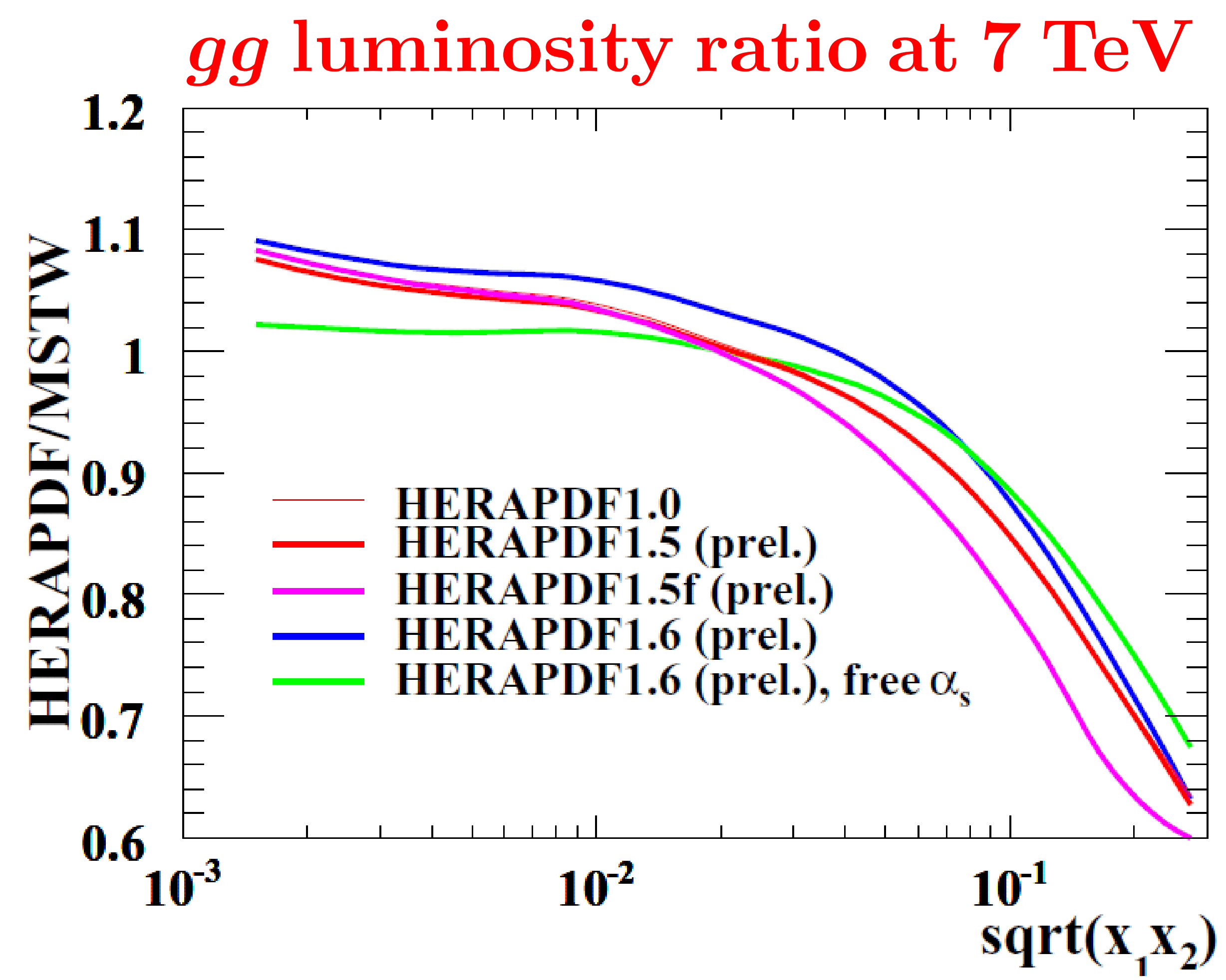
$\alpha_s(M_Z)$ summary

- for HERAPDF1.6 the PDF uncertainty is part of the exp. uncertainty
- for the H1 and ZEUS results from jets only, it is part of the theory uncertainty



LHC parton lumis: HERAPDFs/MSTW2008





from HERAPDF1.5f (no jets) to HERAPDF1.6 (+jets) "no" difference,

HERAPDF1.6 (+jets & free α_S) leads to a small increase at high-x

from HERAPDF1.5f (no jets) to HERAPDF1.6 (+jets) increases the gluon, particularly at high-x,

HERAPDF1.6 (+jets & free α_S) leads in addition to a decrease at low-x

Summary

- An NLO QCD fit with simultaneous determination of the PDFs & $\alpha_S(M_Z)$ was performed using HERA data only.
- Combined H1 and ZEUS inclusive DIS cross sections together with inclusive jet cross sections from H1 and ZEUS are used.
- Including jet data in the fit and letting $\alpha_S(M_Z)$ free
  - dramatically reduces the correlation between the gluon PDF and $\alpha_S(M_Z)$ compared to fits without jets
  - the precision of the gluon PDF is improved and an accurate and unbiased determination of $\alpha_S(M_Z)$ is achieved, with a value consistent with the world average.

HERA Combined results

HERA results

H1 home page

ZEUS home page

HERAPDF table

https://www.desy.de/h1zeus/combined_results/herapdftable/

NAME	NC and CC DIS	NC, lower E(p_beam)	Jets	Charm	Docu	Grids	Data comparison	Date
HERAPDF1.7 NLO	HERAI + partial HERAII	H1+ZEUS	H1 and ZEUS(1)	H1+ZEUS	Figures	N.A.		June 2011
HERAPDF1.6 NLO	HERAI + partial HERAII	---	H1 and ZEUS(1)	---	Writeup and figures	N.A.		March 2011
HERAPDF1.5 NNLO	HERAI + partial HERAII	---	---	---	Figures	LHAPDF beta 5.8.6		March 2011
HERAPDF1.5 NLO	HERAI + partial HERAII	---	---	---	Figures	LHAPDF beta 5.8.6		July 2010
Charm mass scan	HERAI	---	---	H1+ZEUS	Writeup and figures	---		August 2010
HERAPDF1.0 NNLO	HERAI	---	---	---	ICHEP2010 writeup and figures	Docu for LHAPDF		April 2010
	HERAI	H1+ZEUS	---	---	Writeup and figures	N.A.		April 2010
	HERAI	---	---	H1+ZEUS	DIS2010 writeup and figures	N.A.		April 2010
HERAPDF1.0 NLO PUBLISHED	HERAI	---	---	---	Paper HERAPDF1.0 page	LHAPDF	Benchmarking HERAPDF1.0	Nov. 2009

(1) H1 jets data: 1 and 2 , ZEUS jets data: 1 and 2 .

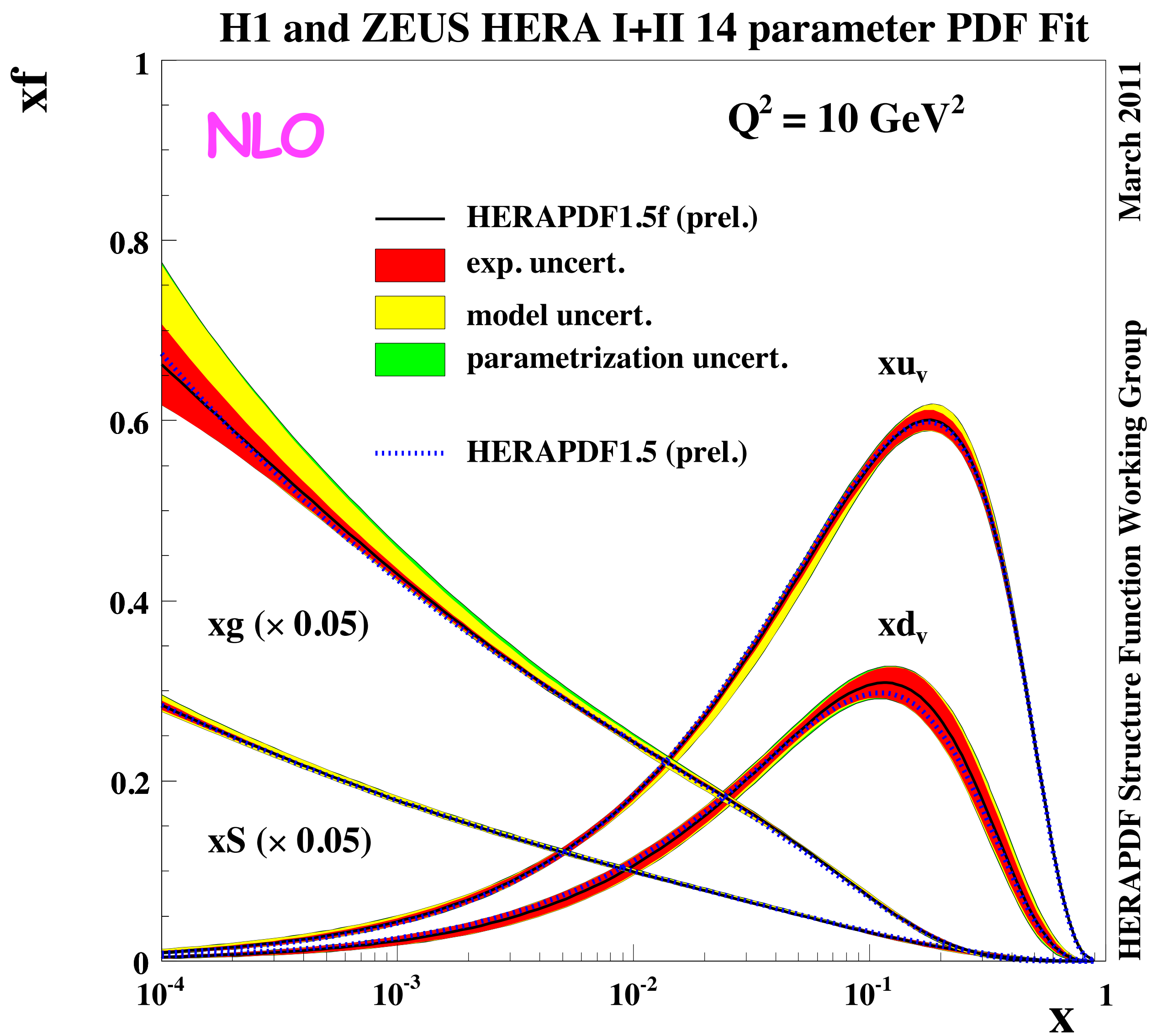
More information on the results can be obtained from the contact persons and/or from the H1 and ZEUS management.

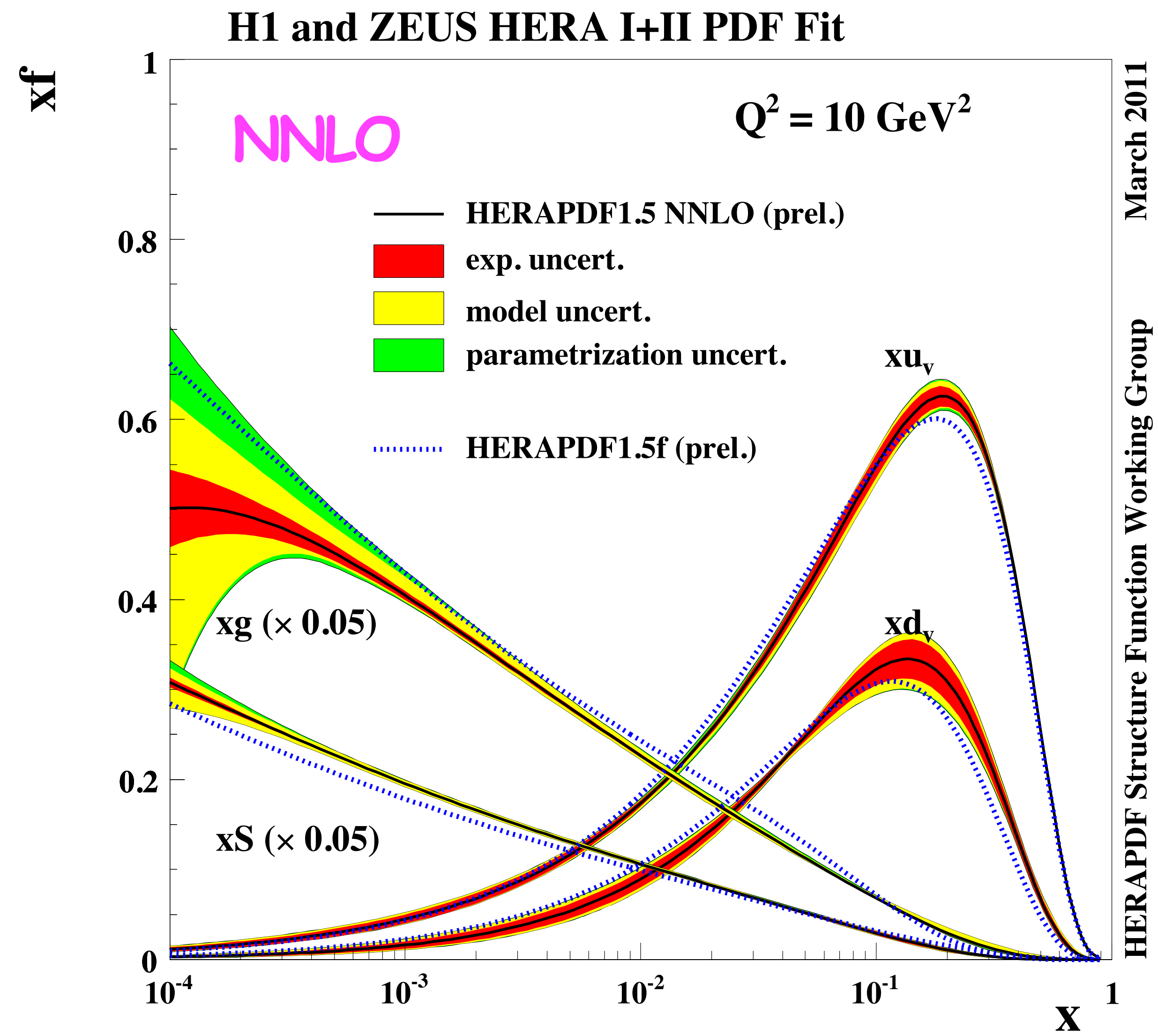
Last modified: Wed Jul 13 16:32:06 CEST 2011

Extras

HERAPDF1.5 NLO & NNLO

fixed $\alpha_S(M_Z) = 0.1176$



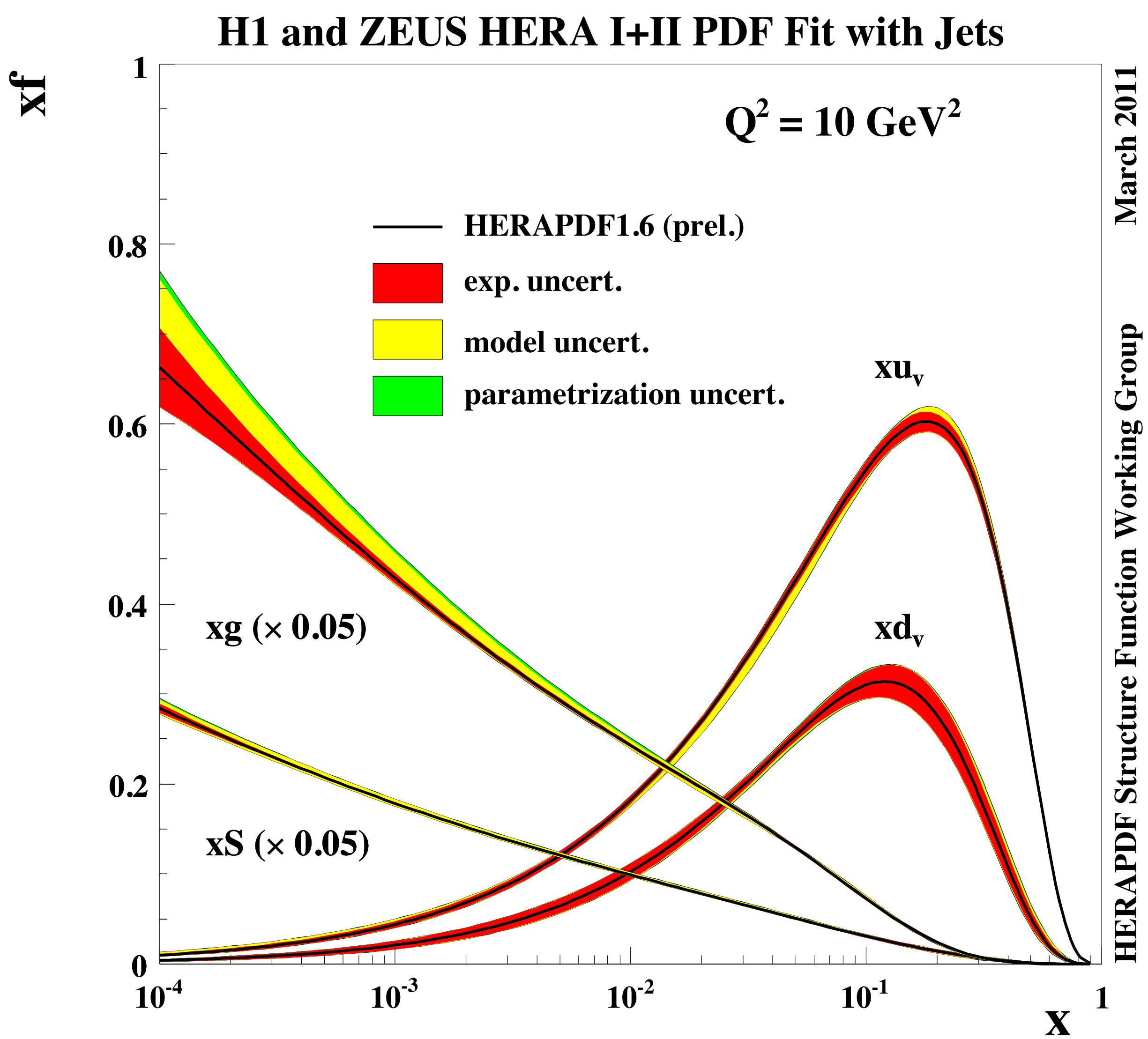


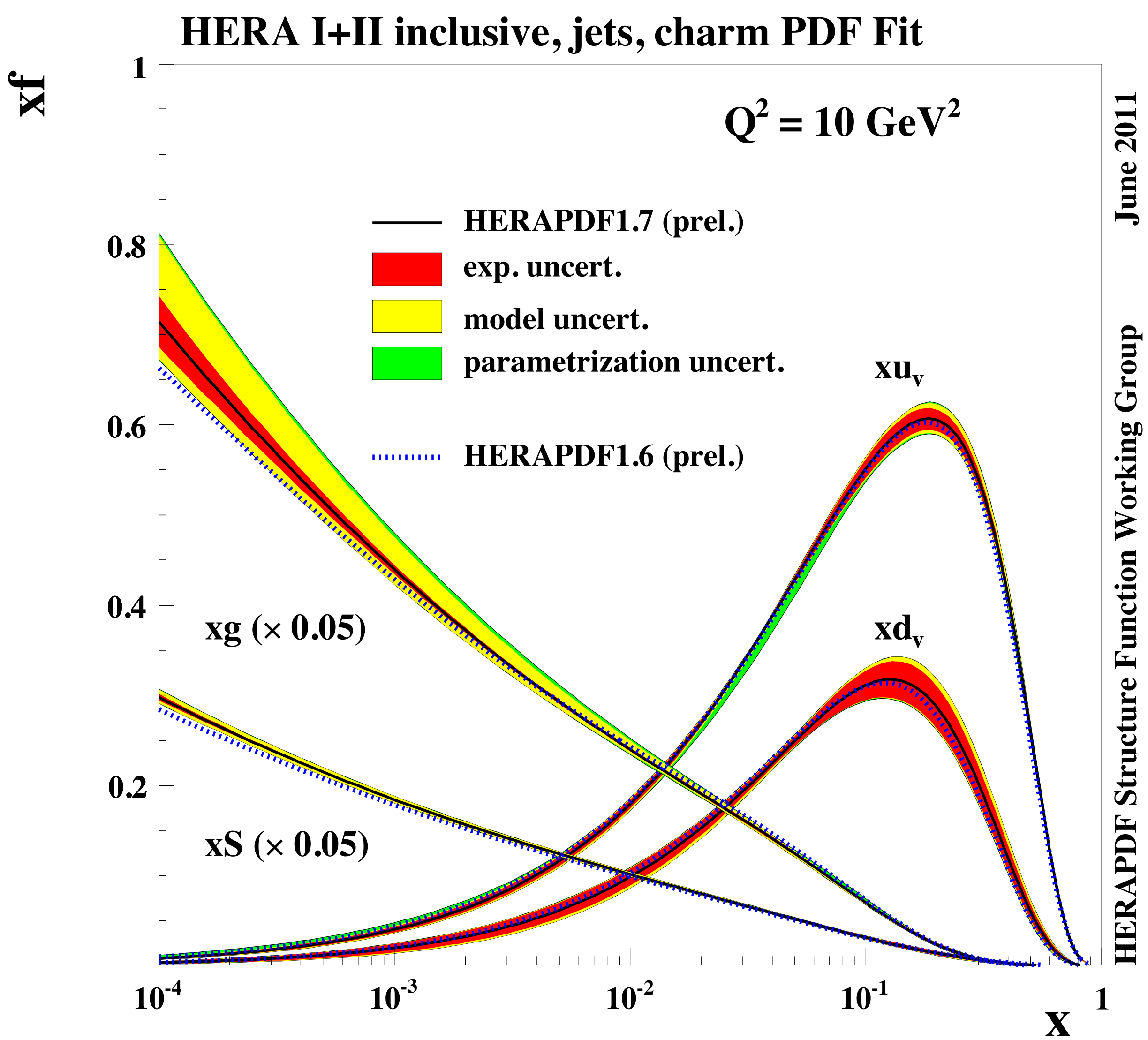
in NNLO:
- larger gluon uncertainty at low-x
- softer (more valence-like) gluon
- slightly steeper Sea at low-x
- small shift in valence to high-x

NNLO does not provide a better fit than NLO at low-x and Q2

HERAPDF1.6 & 1.7

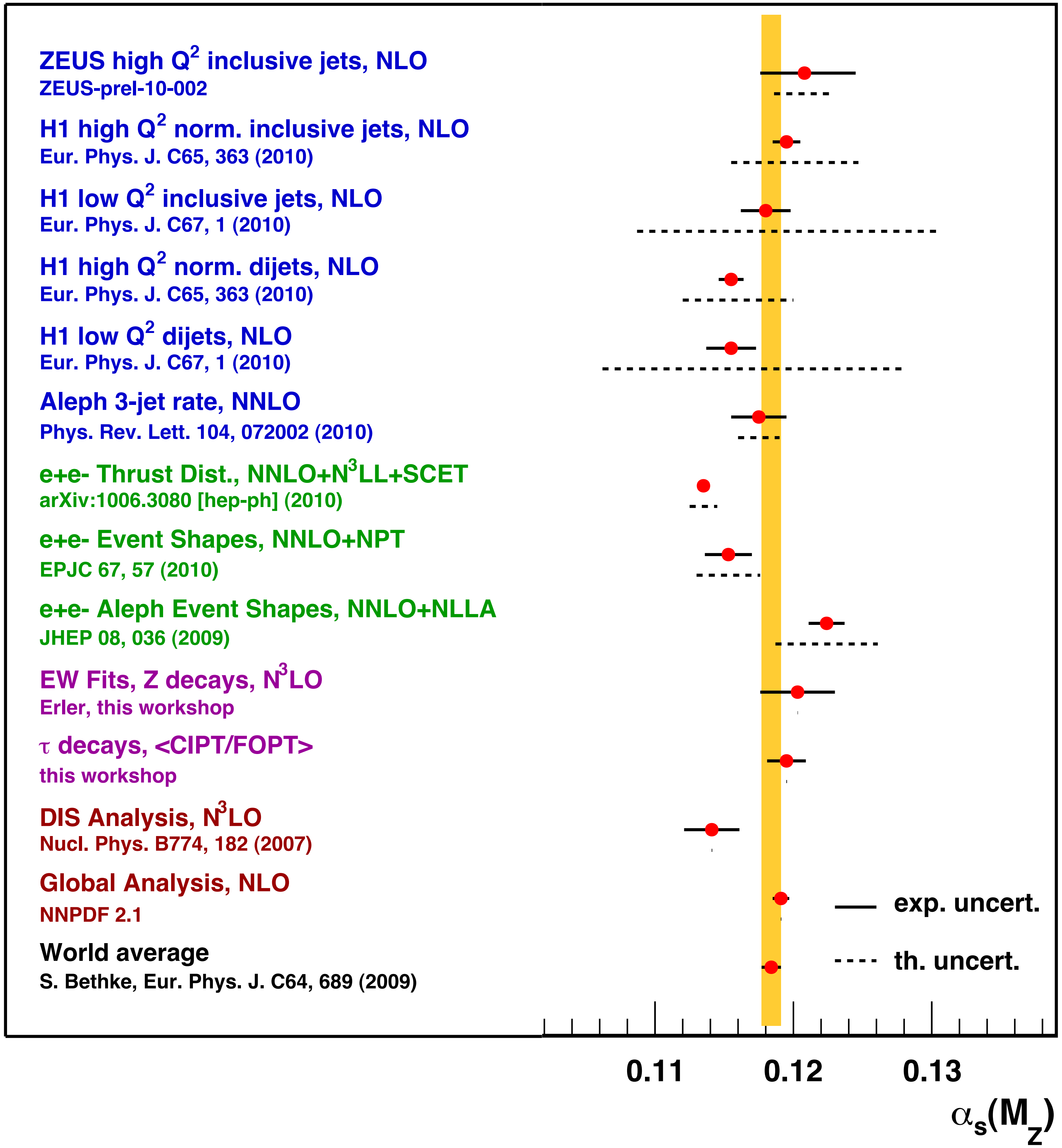
HERAPDF1.7 has fixed $\alpha_S(M_Z)$ = 0.1190 & includes additional low energy & charm data





$\alpha_S(M_Z)$ from different processes

$\alpha_S(M_Z)$ values shown in discussion session at α_S-workshop at MPI Munich in February '11



What is measured in inclusive DIS ?

➢ Neutral Current: $e^{\pm} p \to e^{\pm} X$

$$\frac{d^2\sigma^{e^\pm p}}{dxdQ^2} \propto \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2) - y^2 F_L(x,Q^2)\right] \quad Y_\pm \equiv 1 \pm (1-y)^2$$

QPM:

$$F_2(x,Q^2) \propto x\sum_f q_f(x,Q^2) + \bar{q}_f(x,Q^2)$$

Dominant contribution

$$xF_3(x,Q^2) \propto x\sum_f q_f(x,Q^2) - \bar{q}_f(x,Q^2)$$

Z/γ interference

QCD:

$$F_L(x,Q^2) \propto x\alpha_s g(x,Q^2)$$

Directly sensitive to the gluon & α_s

➢ Charged Current: $e^{\pm} p \to \nu X$

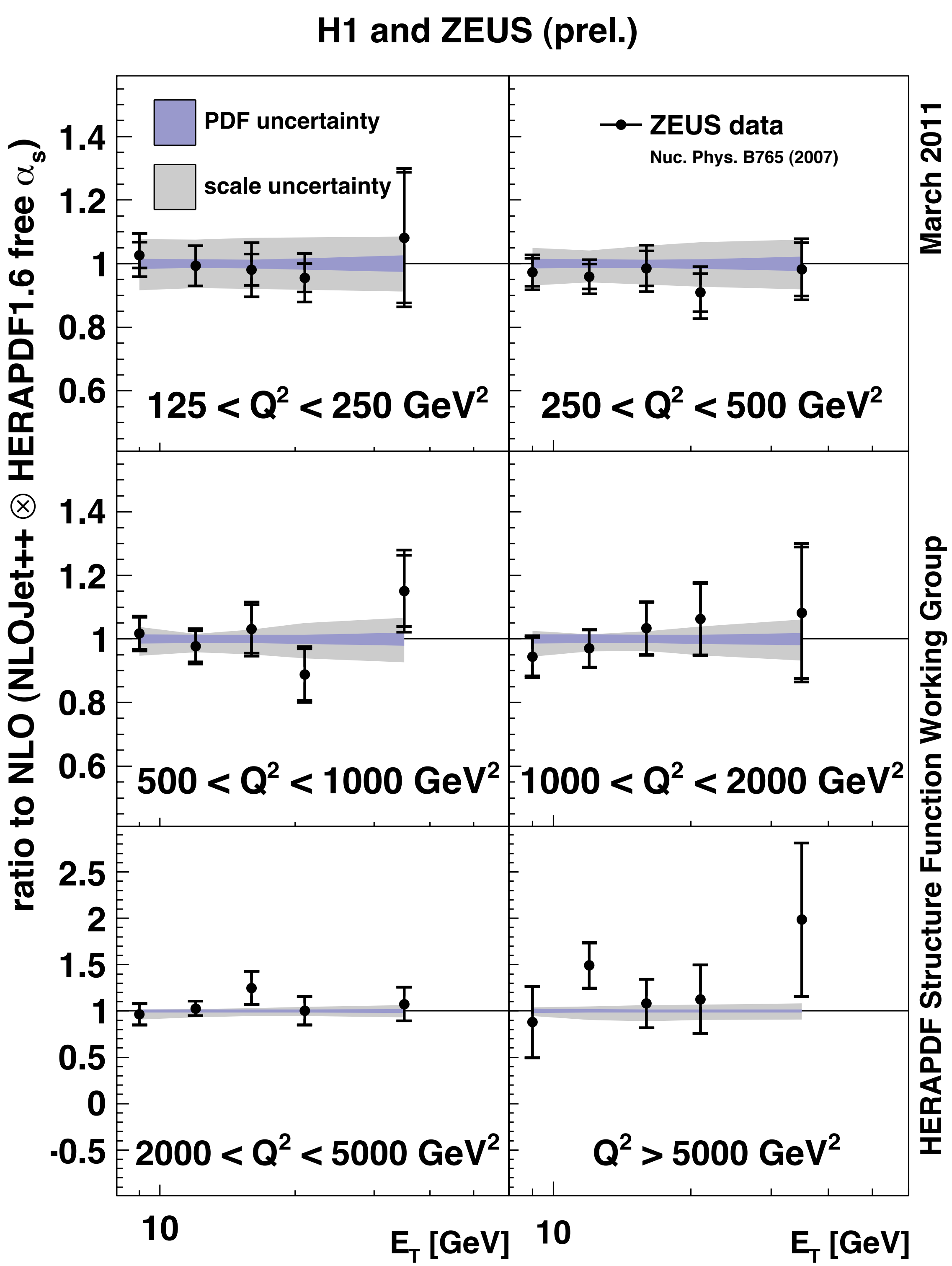
$$\sigma_{CC}^{e^+p} \propto x\{(\bar{u}+\bar{c}) + (1-y)^2(d+s)\}$$

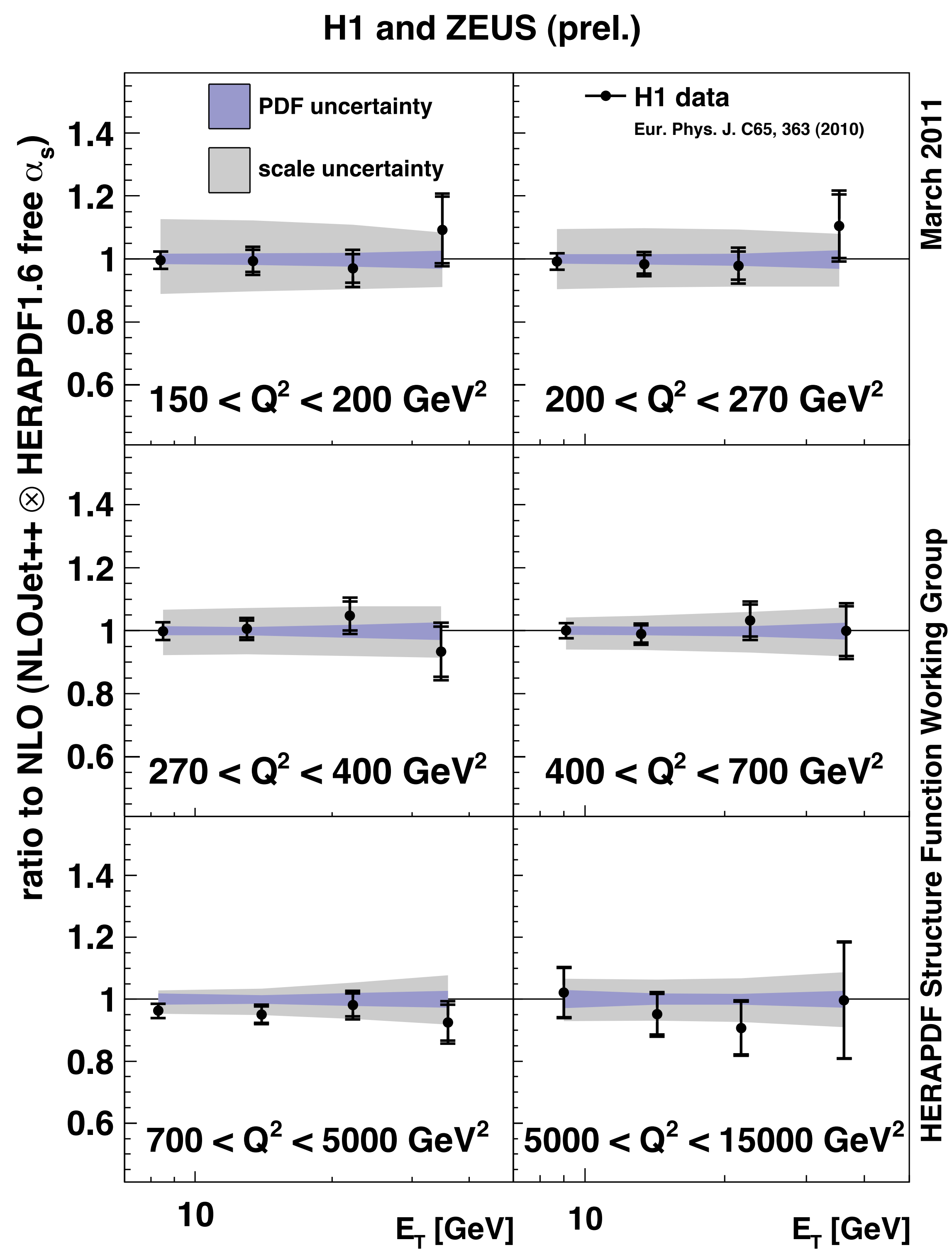
sensitive to mainly d-valence quarks at high x

$$\sigma_{CC}^{e^-p} \propto x\{(u+c) + (1-y)^2(\bar{d}+\bar{s})\}$$

sensitive to mainly u-valence quarks at high x

HERAPDF1.6 and DIS jets





excellent description of the jet data sets used, shown here for 2 out of 4

systematic error sources for jets

Source of correlated uncertainty	Correlation fraction	Data set
H1 LAr electron energy scale (99-07)	25%	[4]
H1 LAr electron angle (99-07)	100%	[4]
H1 Jet energy scale (99-07)	50%	[4]
H1 Luminosity (99-00)	100%	[5]
H1 Spacal electron energy scale (99-00)	50%	[5]
H1 Spacal electron angle (99-00)	50%	[5]
H1 Jet energy scale (99-00)	50%	[5]
H1 low Q^2 jet measurement model dependence	50%	[5]
ZEUS luminosity measurement (96-97)	100%	[6]
ZEUS jet energy scale (96-97)	100%	[6]
ZEUS luminosity measurement (98-00)	100%	[7]
ZEUS jet energy scale (98-00)	100%	[7]
Theoretical luminosity measurement uncertainty	100%	[4], [5], [6], [7]

model uncertainties

Model parameter	Standard value	Lower Limit	Upper Limit
Strange fraction f_s	0.31	0.23	0.38
Charm mass m_c [GeV]	1.4	1.35	1.65
Beauty mass m_b [GeV]	4.75	4.3	5.0
Minimum Q^2 [GeV^2]	3.5	2.5	5.0

+ hadronization uncertainty for jets is included in the model uncertainty