PDFs from HERA experiments

Julian Rautenberg

Physikalisches Institut,

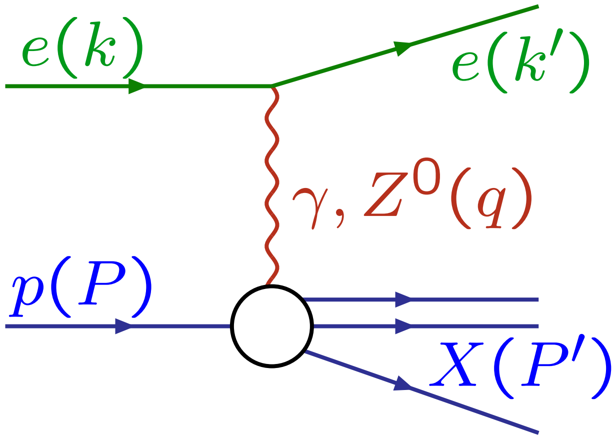
Universität Bonn

- Deep inelastic scattering at HERA
- From cross section measurements to PDFs
- PDF sets and recent developments
- HERA PDFs for LHC

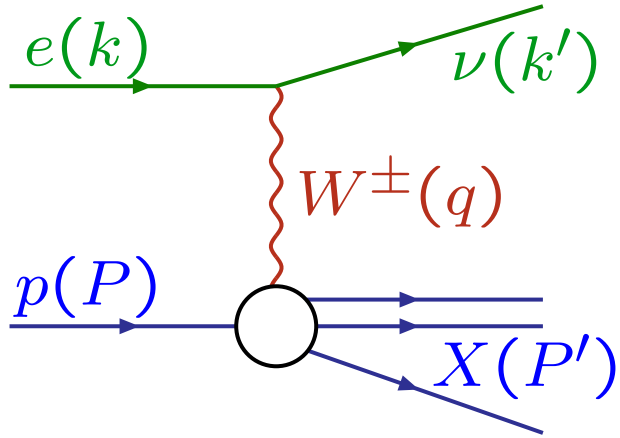
bmb+f - Förderschwerpunkt
ZEUS
Großgeräte der physikalischen Grundlagenforschung

Deep inelastic scattering at HERA

Neutral Current (NC)



Charged Current (CC)



Invariant kinematic quantities:

$Q^2 = -q^2 = -(k-k')^2$	negative four-momentum transfer squared
$x = \frac{Q^2}{2P\cdot q}$	In proton infinite-momentum frame: fraction of proton momentum
$y = \frac{P\cdot q}{P\cdot k}$	In proton rest-frame: energy-transfer
$s = (k+P)^2 = \frac{Q^2}{xy}$	squared cms energy

k, P fixed & 4-momentum conservation
$\Rightarrow$ 2 independent kinematic Quantities

Deep inelastic $\equiv Q^2 \gg 1\,$**GeV**^{2}**, here** $Q^2 \gtrsim 100\,$**GeV**^{2}

Unpolarized inclusive cross sections

Neutral Current (NC)

Charged Current (CC)

EW propagator & coupling

$$\frac{d^2\sigma^{e\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times \left[Y_+ F_2^{NC} \mp Y_- xF_3^{NC} - y^2 F_L^{NC}\right]$$

$$F_2^{NC} = x \sum_{q=u\ldots b} A_f\,[q+\bar{q}]$$

$$xF_3^{NC} = x \sum_{q=u\ldots b} B_f\,[q-\bar{q}]$$

$$\tilde{\sigma} = \frac{xQ^4}{2\pi\alpha^2 Y_+}\frac{d^2\sigma^{NC}}{dxdQ^2}$$

$$\frac{d^2\sigma^{e\pm p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \times \left[Y_+ F_2^{CC} \mp Y_- xF_3^{CC} - y^2 F_L^{CC}\right]$$

in CC F_i depend on lepton charge

$$F_{2,e^+}^{CC} = x\,[d+s+\bar{u}+\bar{c}]$$

$$xF_{3,e^+}^{CC} = x\,[d+s-(\bar{u}+\bar{c})]$$

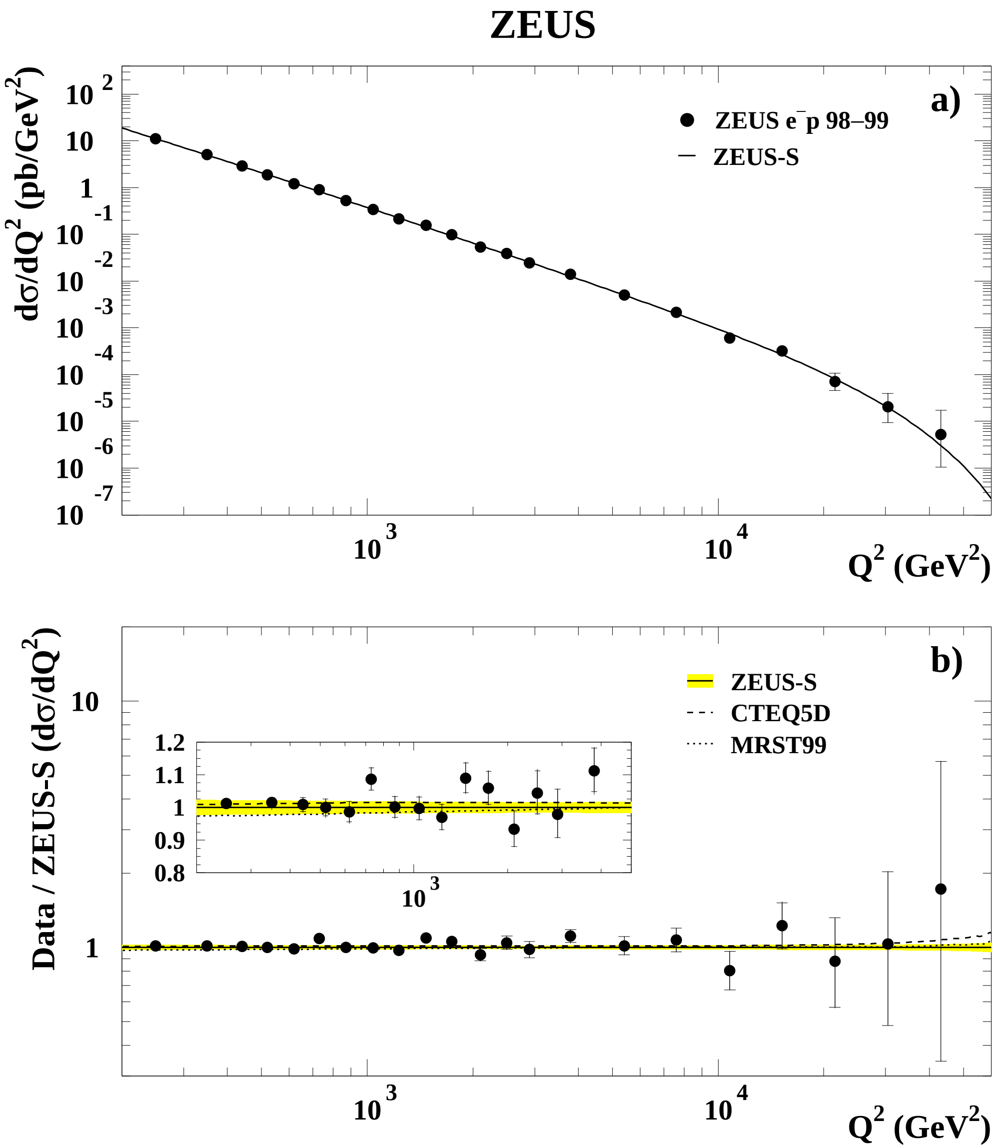
$$\tilde{\sigma}^{e^+p} = x\left[\bar{u}+\bar{c}+(1-y)^2(d+s)\right]$$

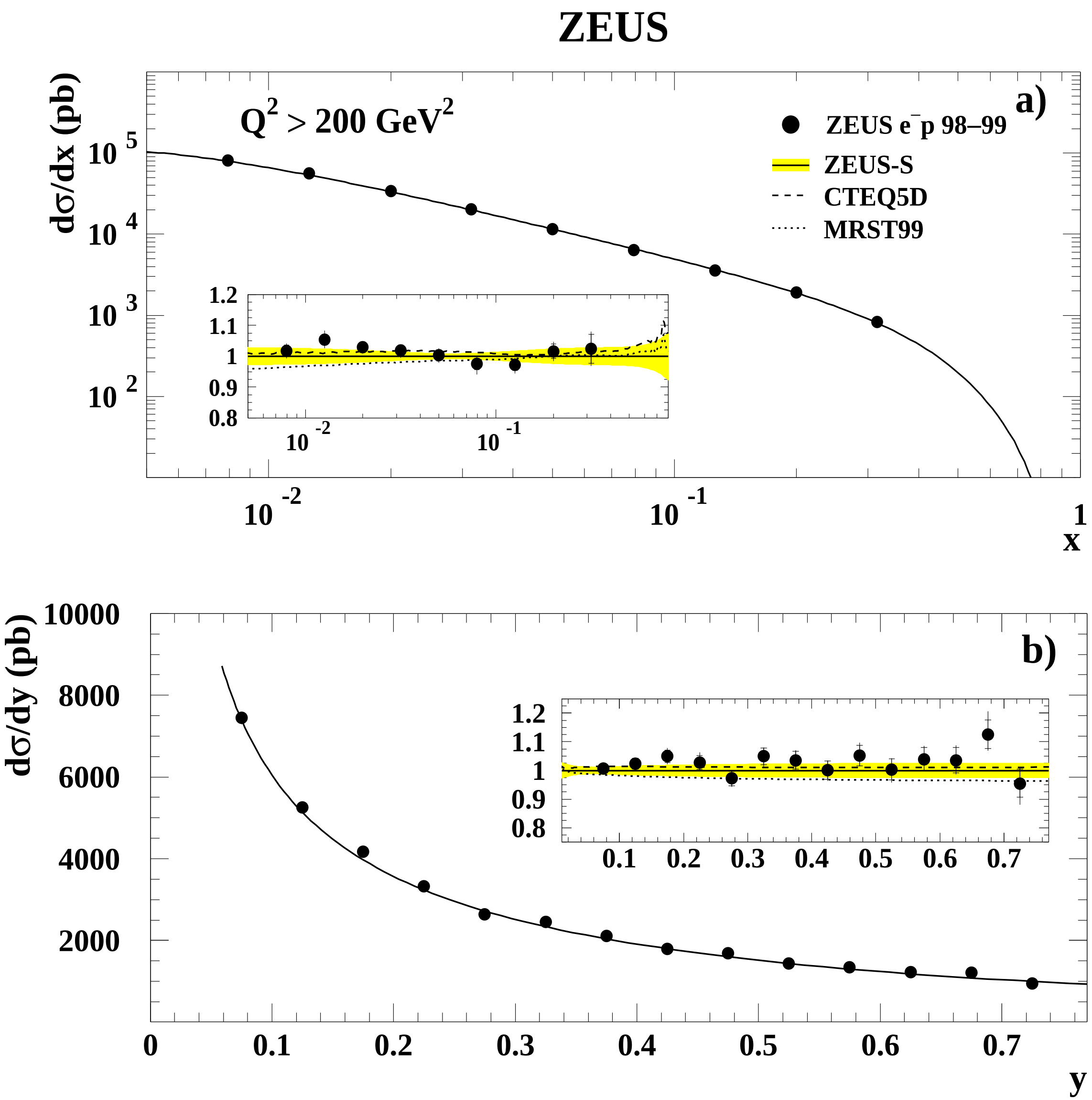
Helicity-factor:
$Y_\pm = 1 \pm (1-y)^2$

F_2^{NC} parity conserving (EM)
F_3^{NC} parity violating (weak)

purely weak
F_i^{CC} coupling independent

NC: Single differential cross sections





Excellent agreement with SM using ZEUS-S PDFs

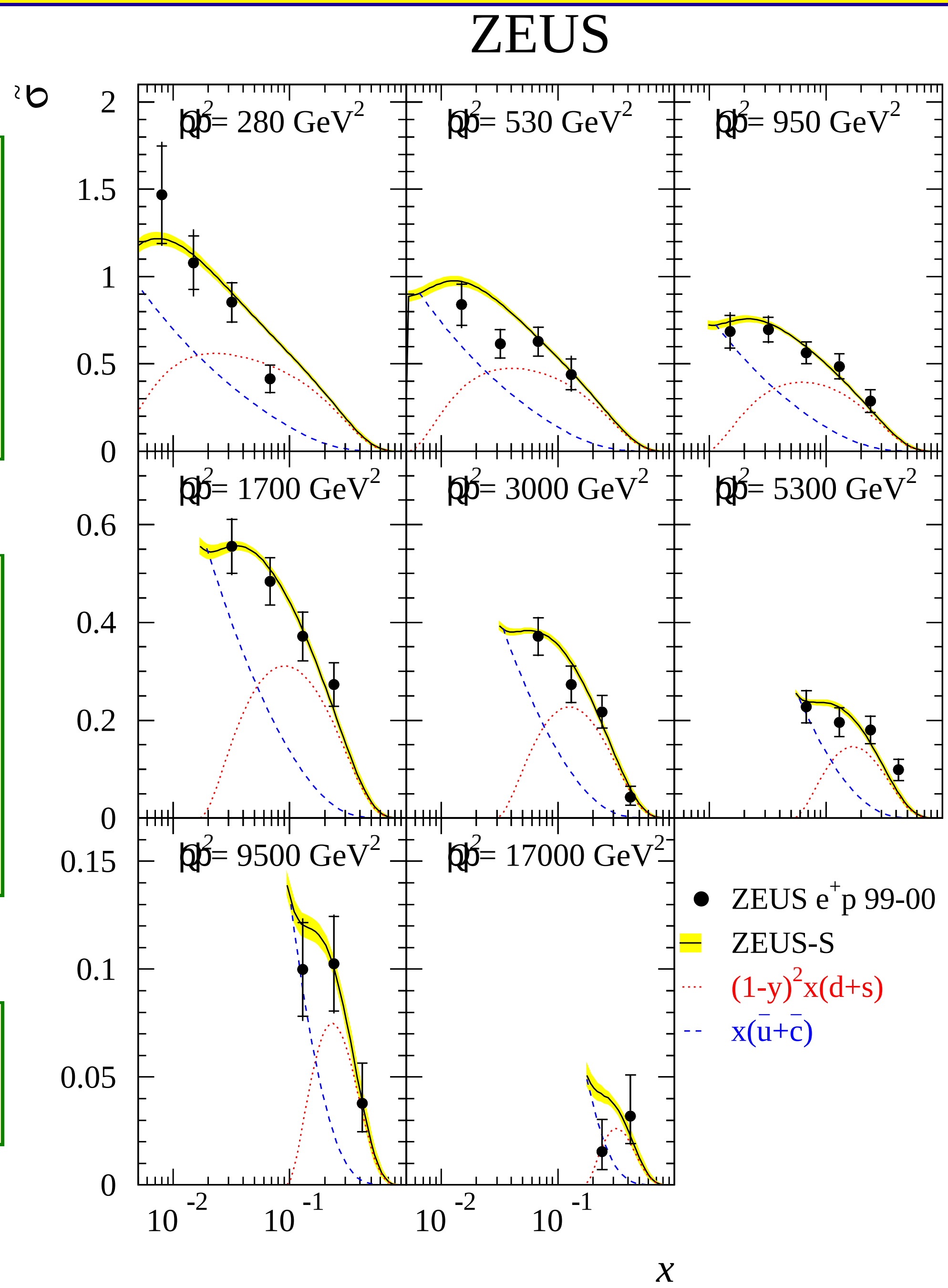
CC: reduced cross section $\tilde{\sigma}$

- Well described by ZEUS-S
- high-x: $d + s$ dominant
- low-x: $\bar{u} + \bar{c}$ dominant

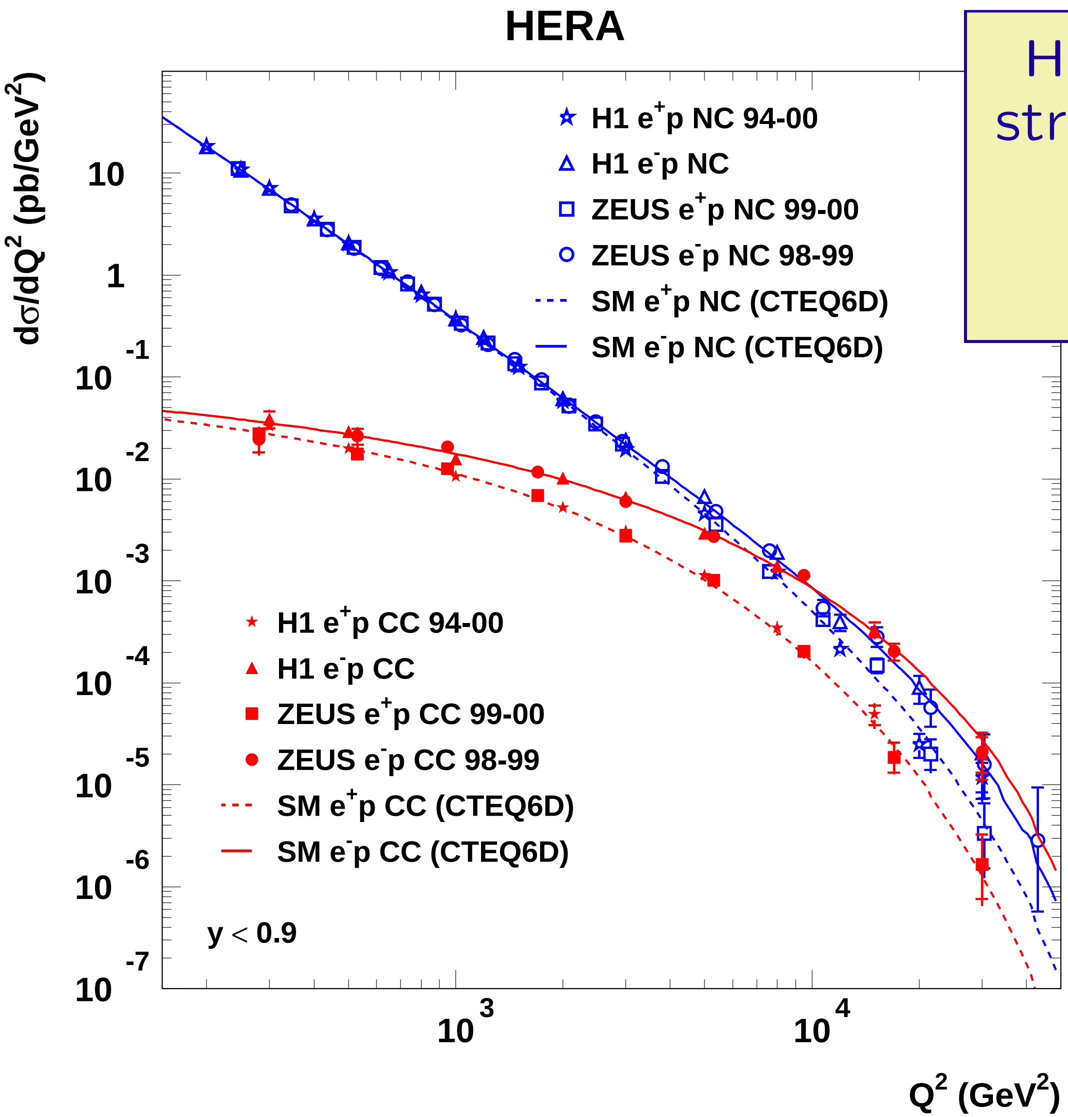
Down-type (anti-)quarks contribution suppressed by helicity:

$$\tilde{\sigma}^{e^+p} = x\left[\bar{u}+\bar{c}+(1-y)^2(d+s)\right]$$

Well described by SM with ZEUS-S



From Inclusive HERA I measurements to PDFs



HERA: Electron ideal (EW) "probe" for structure function $F_i(Q^2, x)$-measurements

$\Rightarrow$ Input for PDF $f_i(x)$ extractions

$\Rightarrow$ Input for SM predictions

$$f_{Q_0^2}(x) \xrightarrow{\text{DGLAP}} F_i(Q^2, x)$$

$\Rightarrow$ Test of QCD

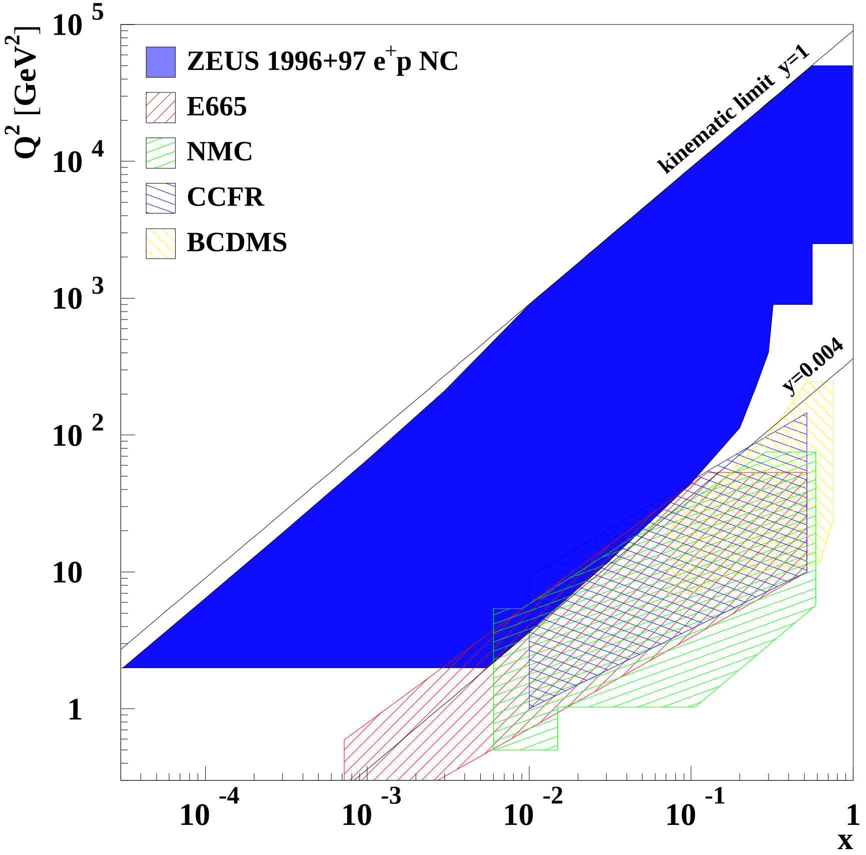
Note: $f_i(x)$ process independent while $F_i(Q^2, x)$ process dependent (f_i are factorization scheme dep.)

Confirmation of SM EW-sector at scale up to $Q^2 \approx {M_W}^2$ & above

Test of PDF evolution
HERA: DGLAP works surprisingly well!

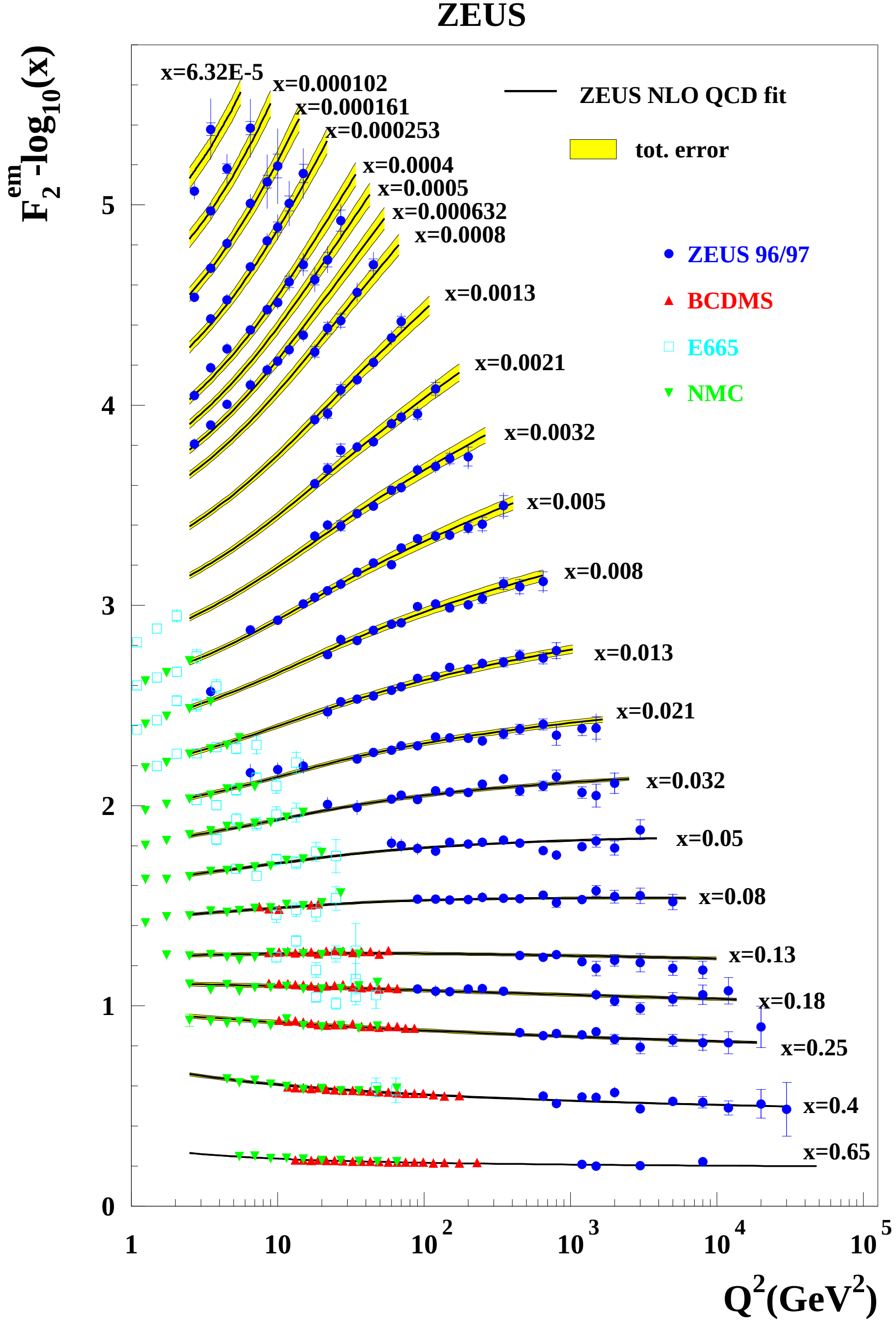
ZEUS-Standard QCD NLO-fit

Data-sets:	ZEUS NC 96-97, E665, NMC, CCFR, BCDMS
Cuts:	$Q^2 > 2.5$ GeV^2
	$W^2 > 20$ GeV^2
Kinematic range:	$6.3 \cdot 10^{-5} < x < 0.65$
	$2.5 < Q^2 < 30\,000$ GeV^2
DGLAP evolution:	QCDNUM
Factorization scheme:	$\overline{\text{MS}}$-scheme
Heavy flavor scheme:	TR-VFN
Parametrization:	$p_1 x^{p_2}(1-x)^{p_3}(1+p_5 x)$
Constraints:	sum-rules, etc.
Spilling functions:	NLO



PDF	p_1	p_2	p_3	p_5
xu_v	(1.69)	0.5	$4.00 \pm 0.01 \pm 0.08$	$5.04 \pm 0.09 \pm 0.64$
xd_v	(0.96)	0.5	$5.33 \pm 0.09 \pm 0.48$	$6.2 \pm 0.4 \pm 2.3$
xS	$0.603 \pm 0.007 \pm 0.048$	$-0.235 \pm 0.002 \pm 0.012$	$8.9 \pm 0.2 \pm 1.2$	$6.8 \pm 0.4 \pm 2.0$
xg	(1.77)	$-0.20 \pm 0.01 \pm 0.04$	$6.2 \pm 0.2 \pm 1.2$	0
$x\Delta$	$0.27 \pm 0.01 \pm 0.06$	0.5	(10.9)	0

ZEUS-S data comparison



Impacts

Fixed-target:

- quark distributions at high-x
- valence quark distributions
- flavor composition of sea

ZEUS:

- quark distributions at low-x
- gluon distribution

ZEUS-α_s:

$\alpha_s(M_Z) = 0.1166 \pm 0.0053$

ZEUS-JET fit

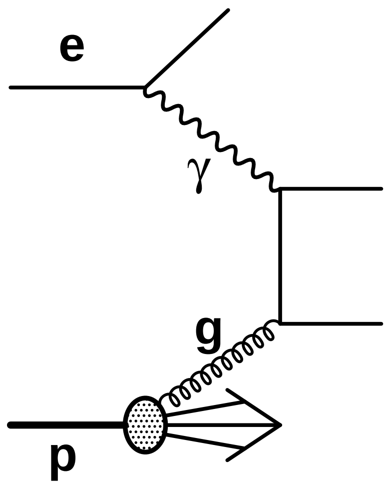
Use only ZEUS data:

- avoid tensions between data-sets spoiling χ^2
- better control over systematic uncertainties and their correlation
- avoid nuclear corrections

Use additional Jet-measurements:

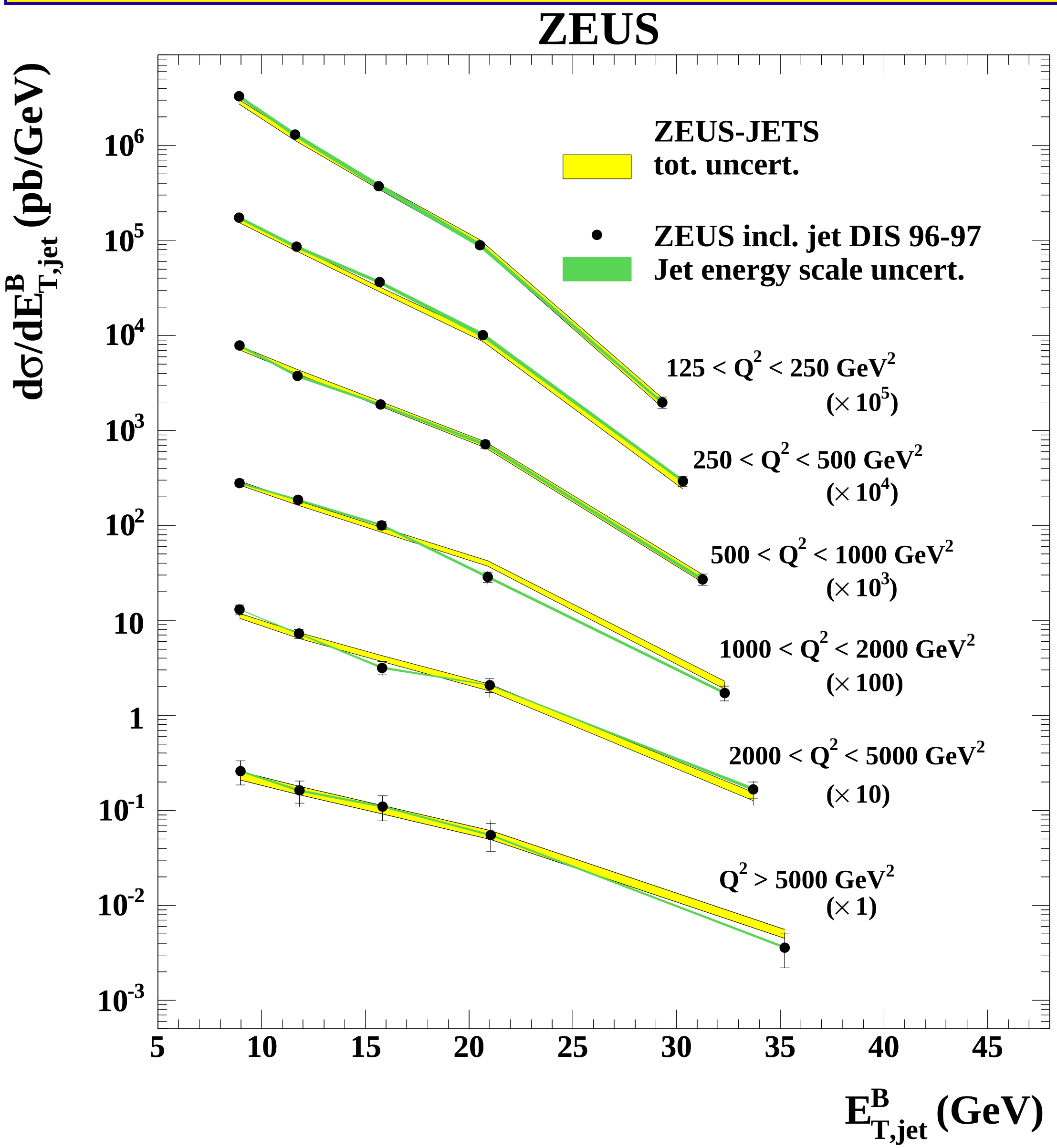
- Dominant process for dijet is BGF
- Jet cross section directly sensitive to gluons
- breaks high correlation between α_s and gluon PDF

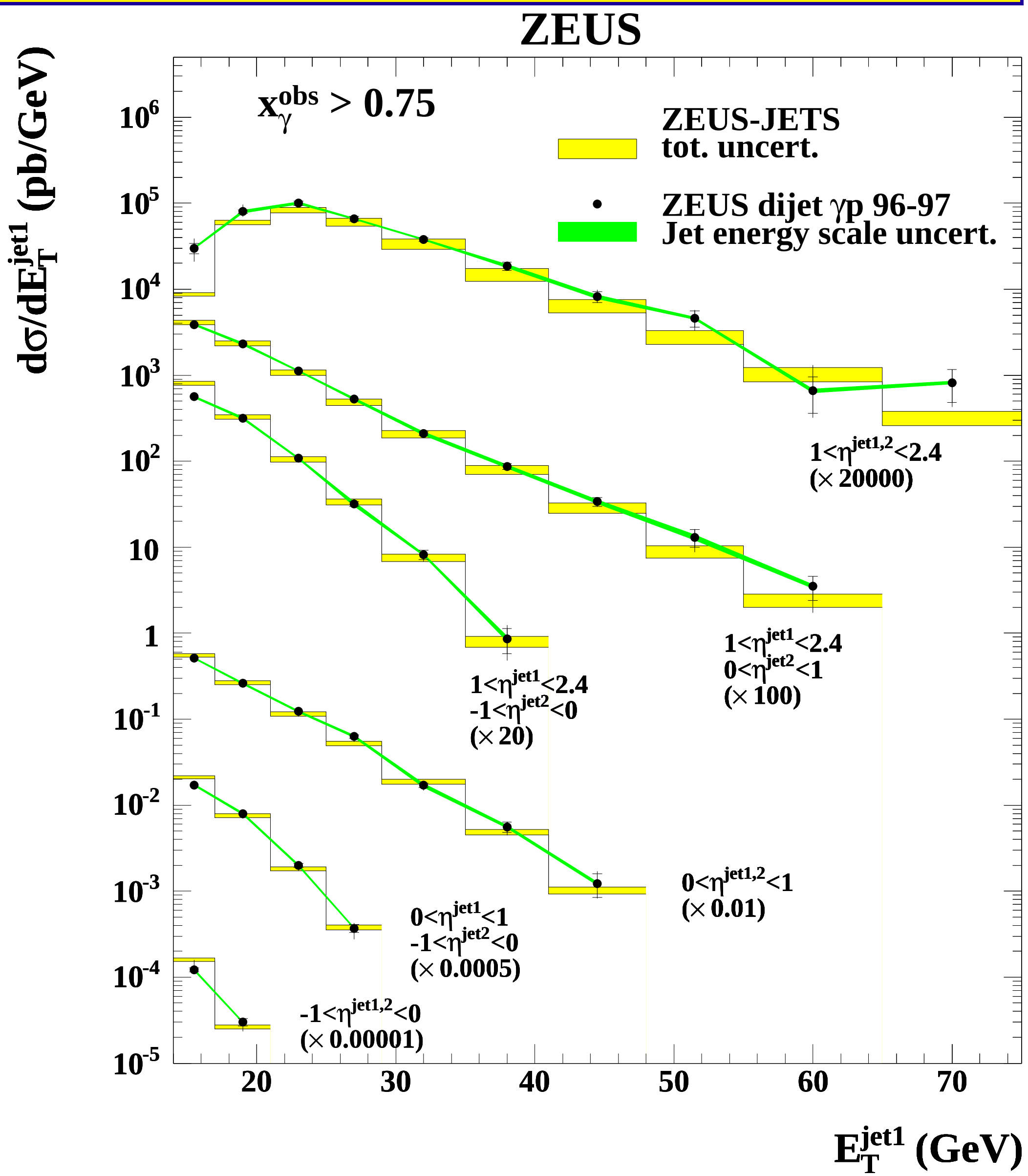
ZEUS Data Set	N_{data}
NC e+p 96-97	242
CC e+p 94-97	29
NC e-p 98-99	92
CC e-p 98-99	26
NC e+p 99-00	90
CC e+p 99-00	30
DIS jets e+p 96-97	30
γp two-jets e+p 96-97	38
χ^2/data-points	470/577



PDF	p_1	p_2	p_3	p_4
xu_v	$(3.1 \pm 0.7 \pm 1.2)$	$0.64 \pm 0.05 \pm 0.08$	$4.06 \pm 0.18 \pm 0.24$	$2.3 \pm 1.1 \pm 1.0$
xd_v	$(1.7 \pm 0.3 \pm 0.5$	$0.63 \pm 0.05 \pm 0.08$	$4.8 \pm 0.7 \pm 1.0$	$2.6 \pm 2.2 \pm 2.3$
xS	$0.72 \pm 0.03 \pm 0.10$	$-0.217 \pm 0.005 \pm 0.020$	$7.0 \pm 0.8 \pm 2.0$	0
xg	$(0.9 \pm 0.1 \pm 0.3)$	$-0.28 \pm 0.02 \pm 0.04$	$10.2 \pm 0.7 \pm 2.1$	$16 \pm 4 \pm 10$

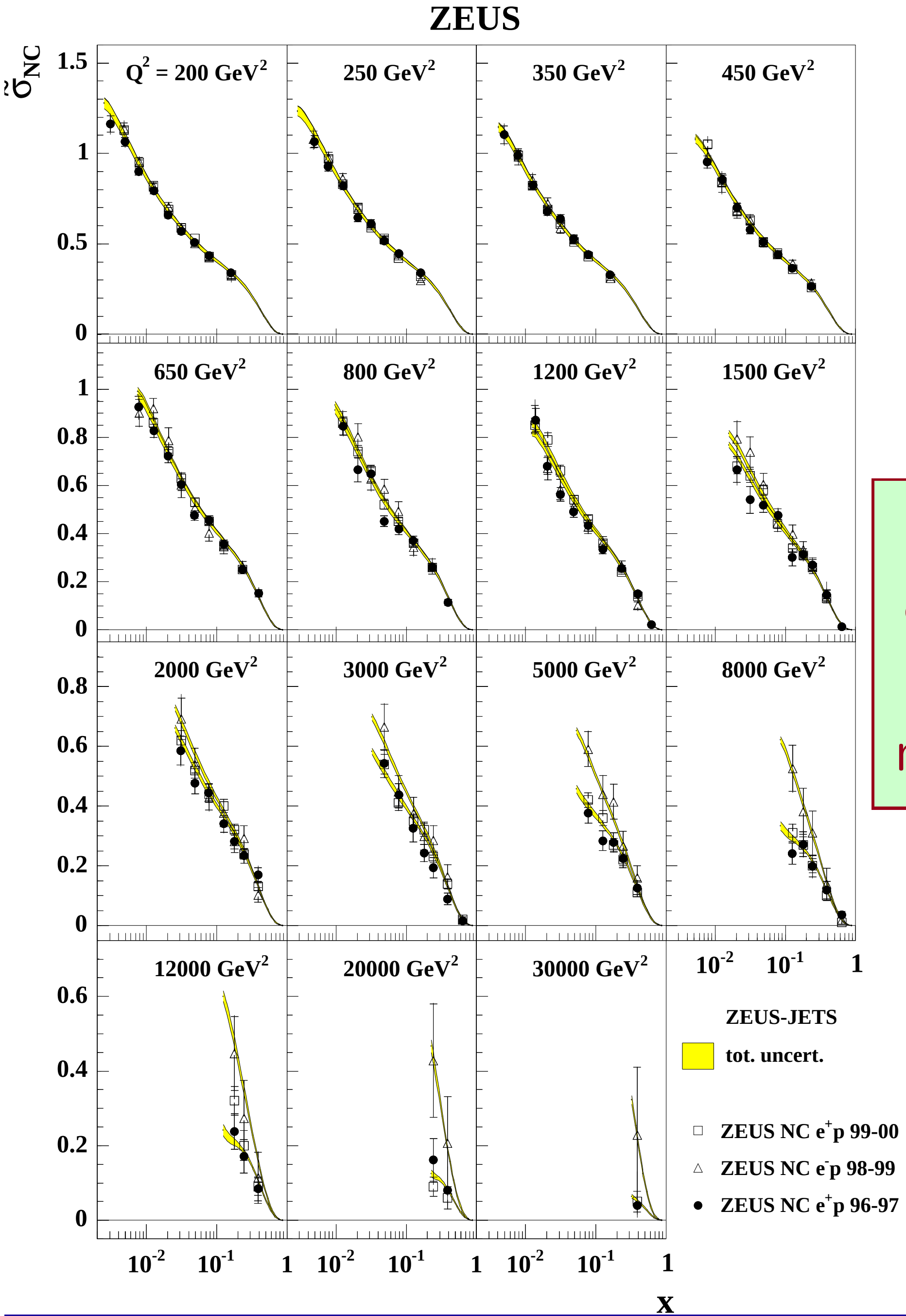
ZEUS-JET fit: Jet-Input



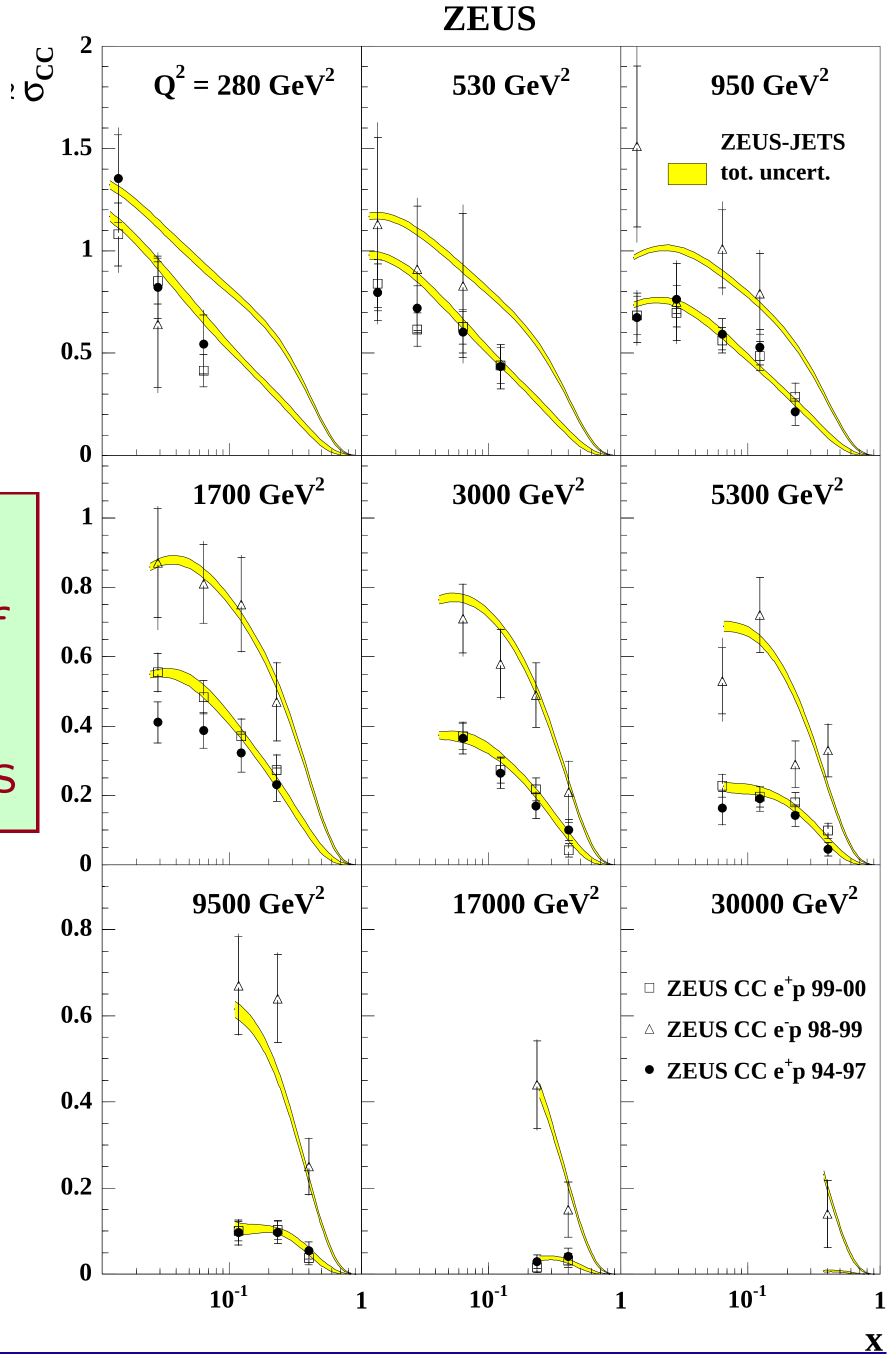


Jet cross section via BGF directly sensitive to gluons

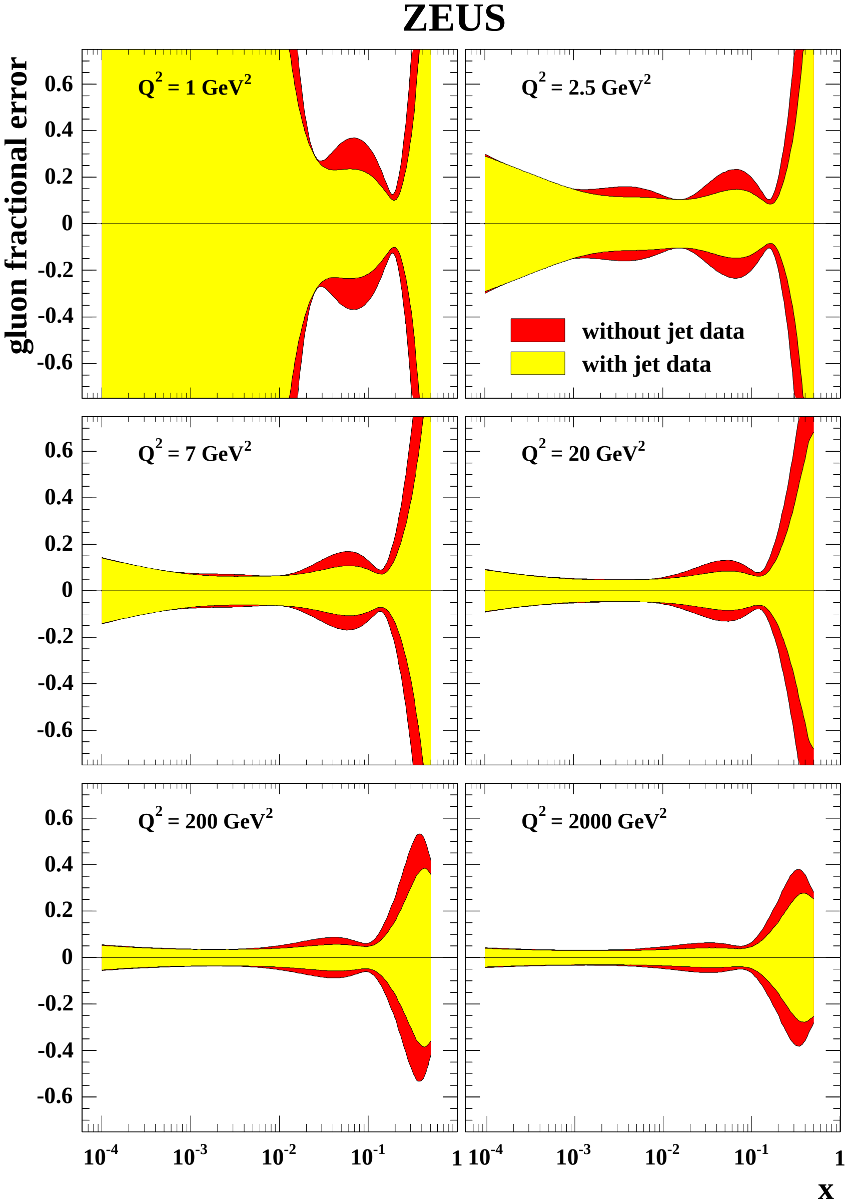
ZEUS-JET fit: Data comparison

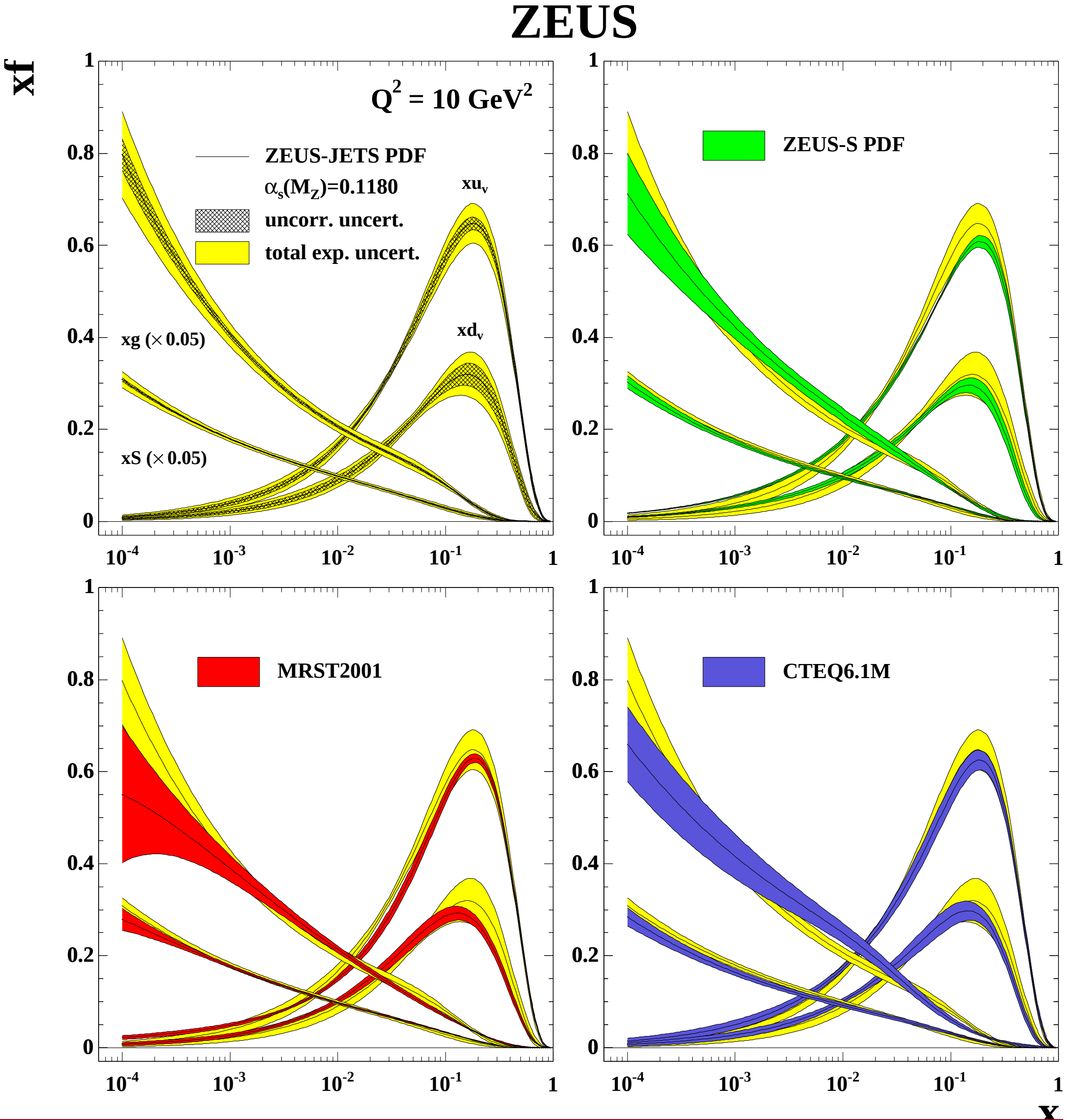


Very good description of cross section measurements



ZEUS-JET fit: Improvements

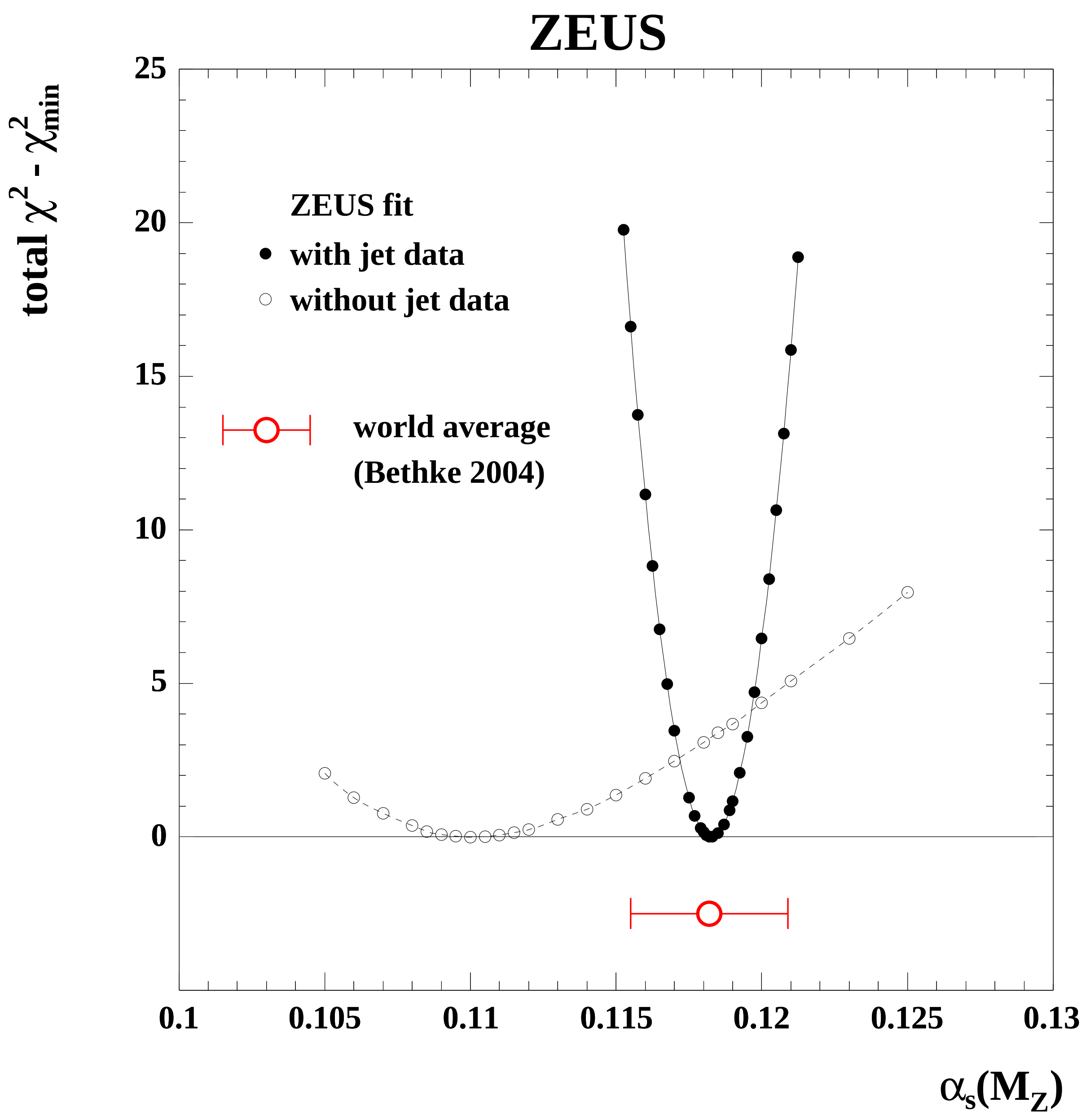




Sizeable improvement

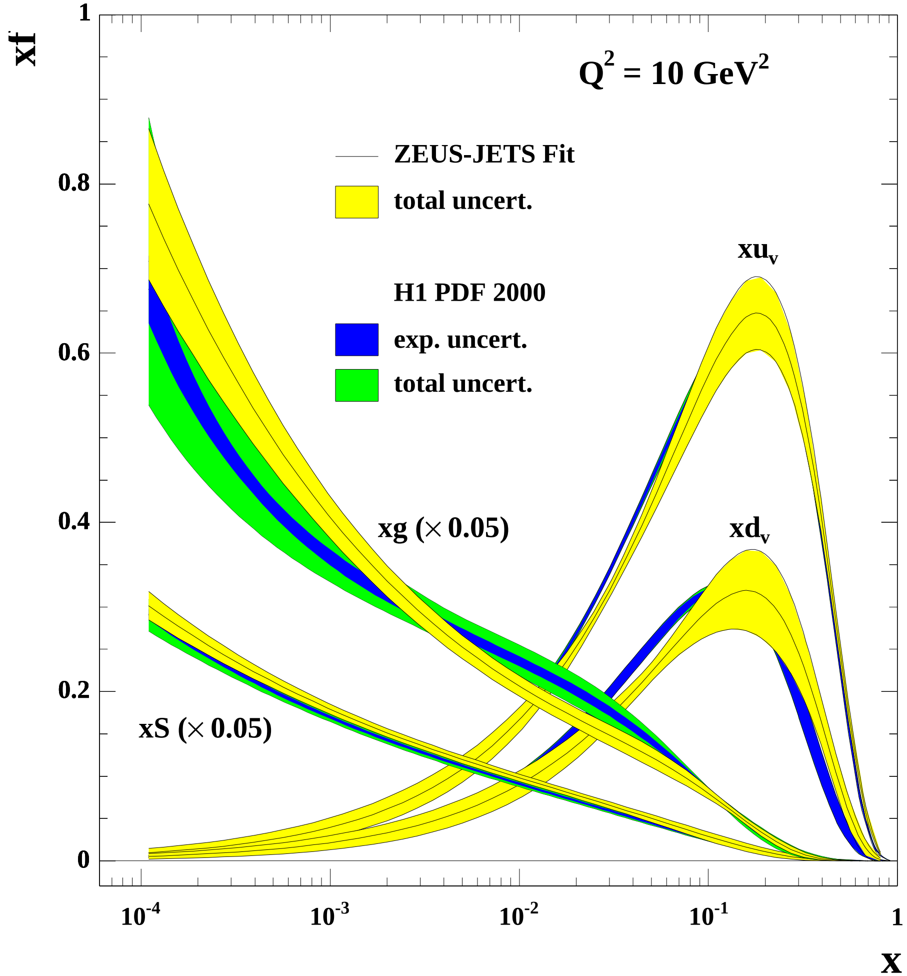
Compatible with other global analysis though only ZEUS data!

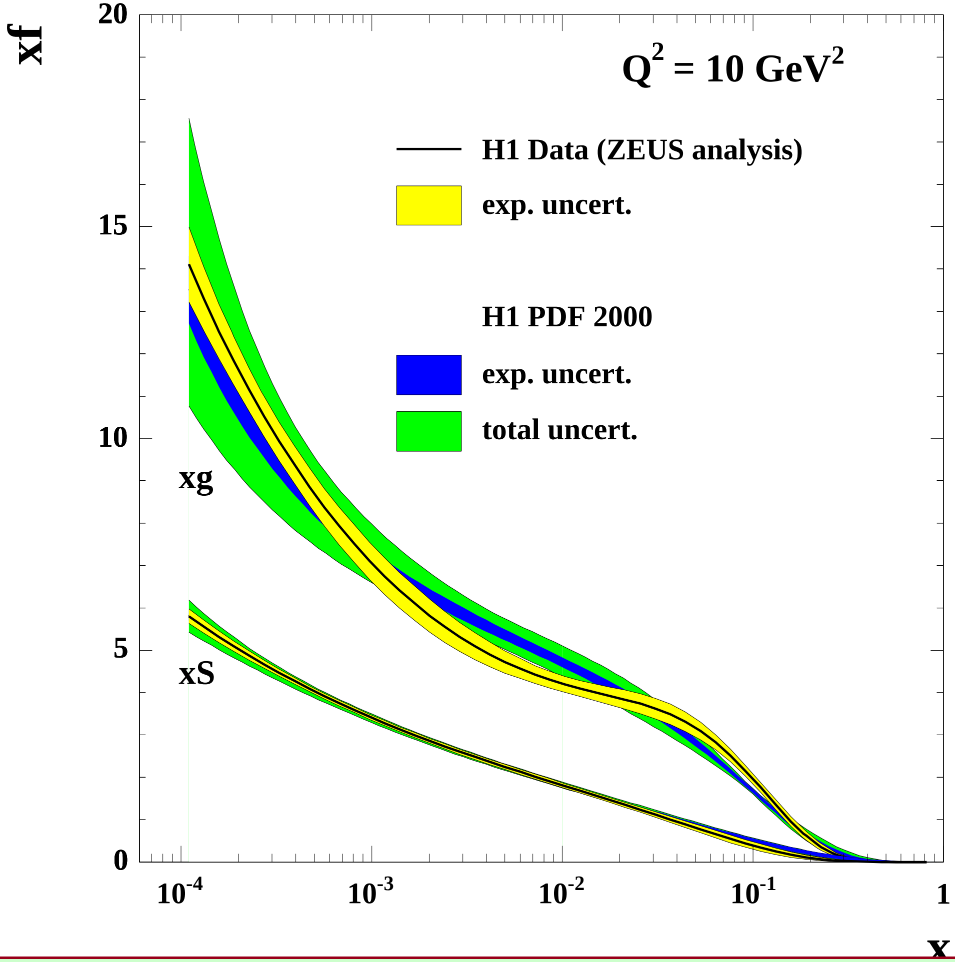
ZEUS-JET-α_s fit



- Jet data break correlation between gluon-PDF and α_s
- Fit with α_s as additional 12th parameter
- Gluon PDF uncertainty increases only slightly
- Very precise α_s determination from HERA data alone!

HERA combined PDFs



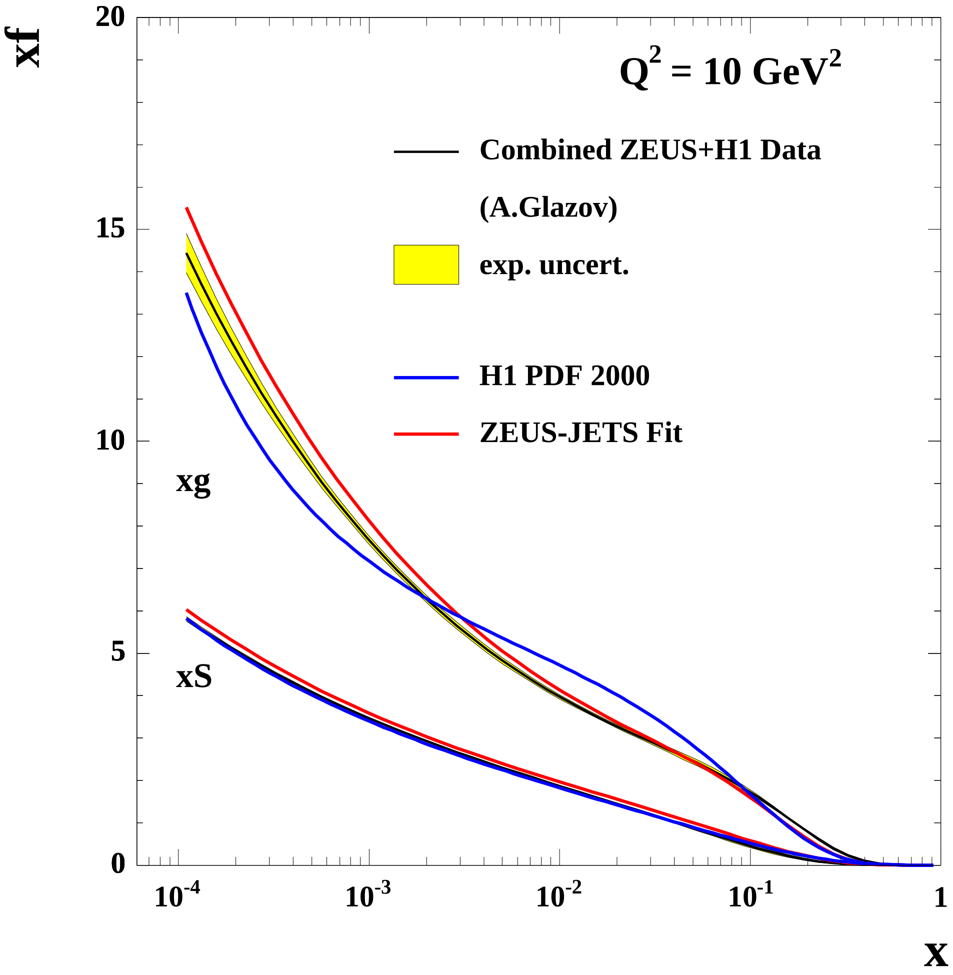


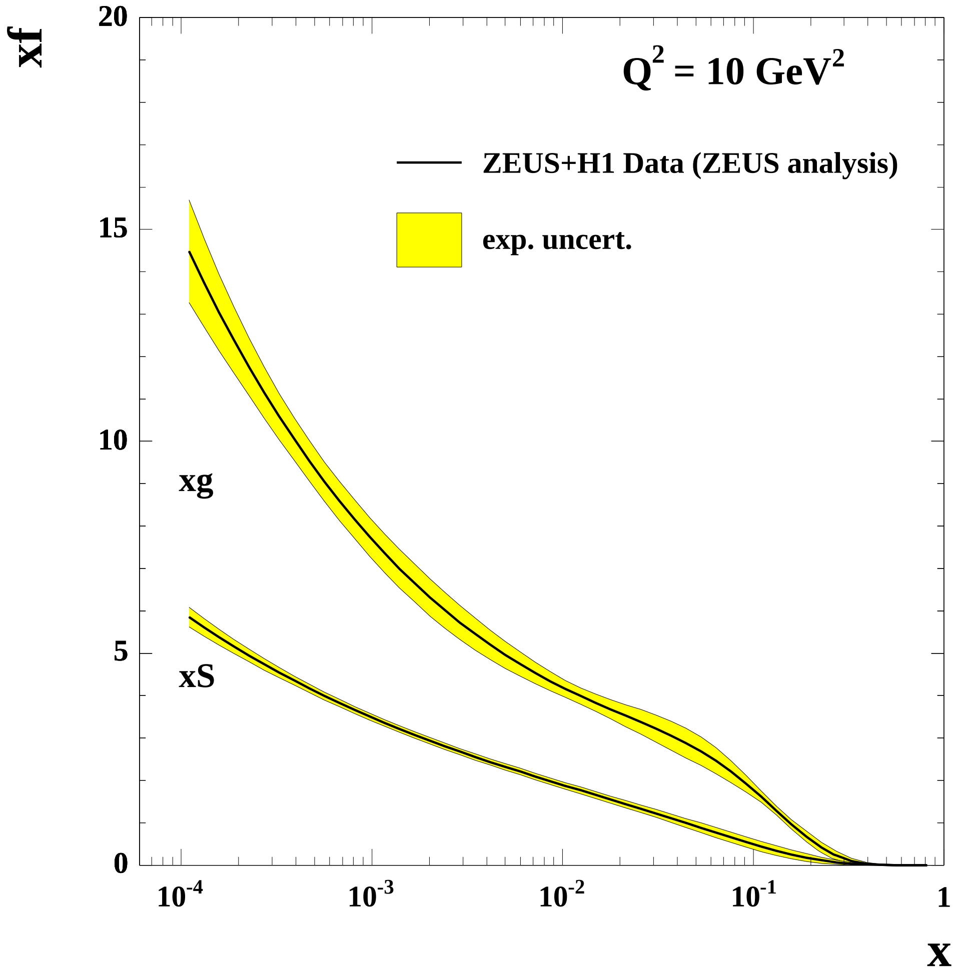
Goal: more precise HERA PDFs

But:

- Differences in Model
- Differences in Data
- Estimation of uncertainties

HERA combined PDFs

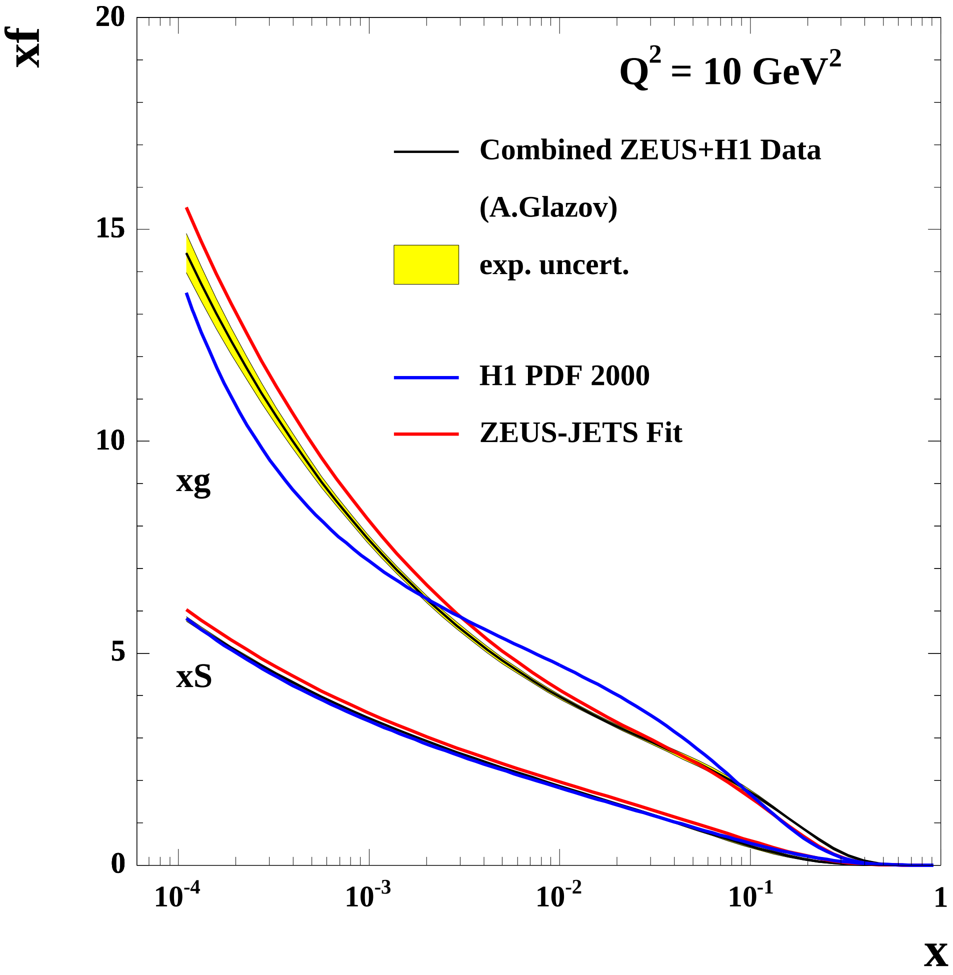


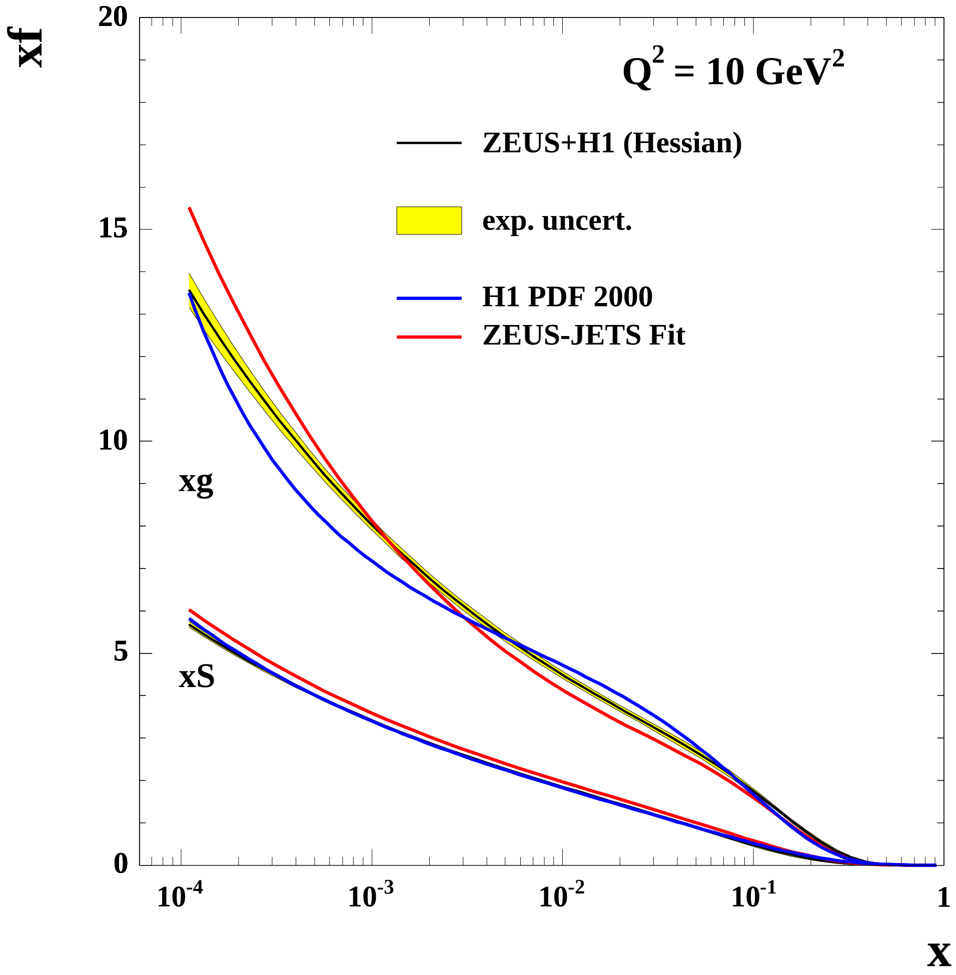


- Average cross sections and then fit or
- Fit to H1 & ZEUS data

Improvement in uncertainty of $\times 2$ due correlations of syst.?

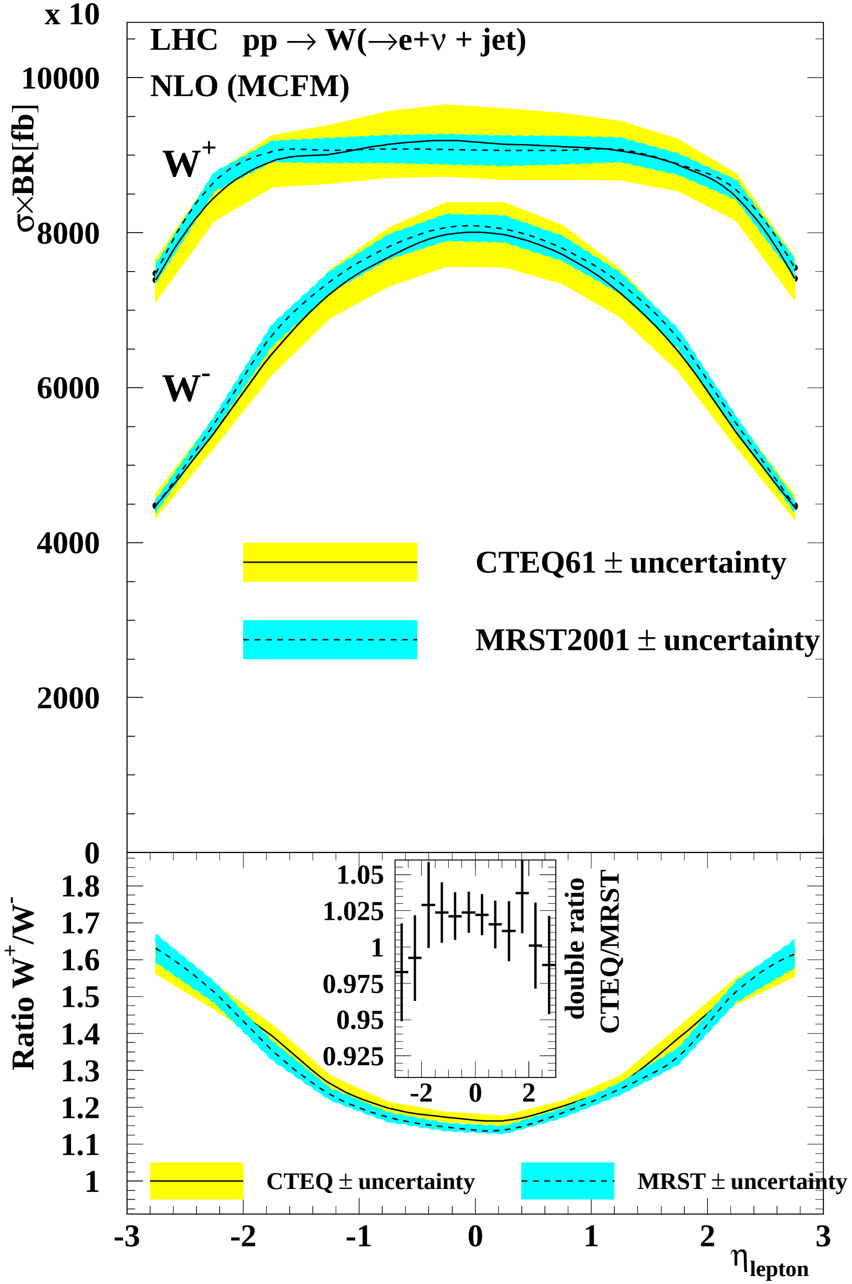
HERA combined PDFs





Main difference is uncertainty method

HERA PDFs for LHC

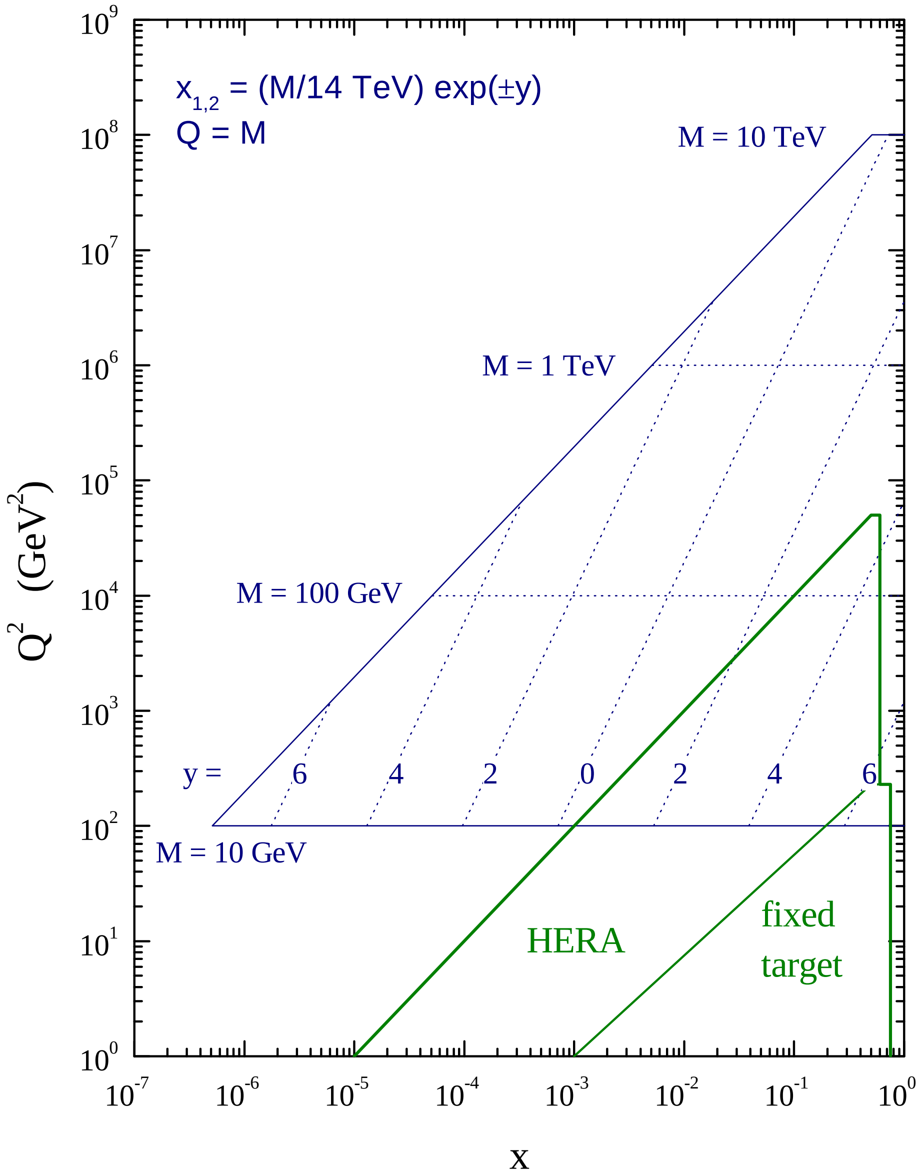


- Uncertainties from PDFs e.g. for W/Z-productions are dominant $\simeq 5\%$
- Crucial for lumi-measurement use
- But restricted overlap in kinematic plane between LHC & HERA

Surprises when extrapolating?

- DGLAP sufficient?
- small x?
- (N)NLO?
- Non-linear effects?
- Saturation?

HERA PDFs for LHC



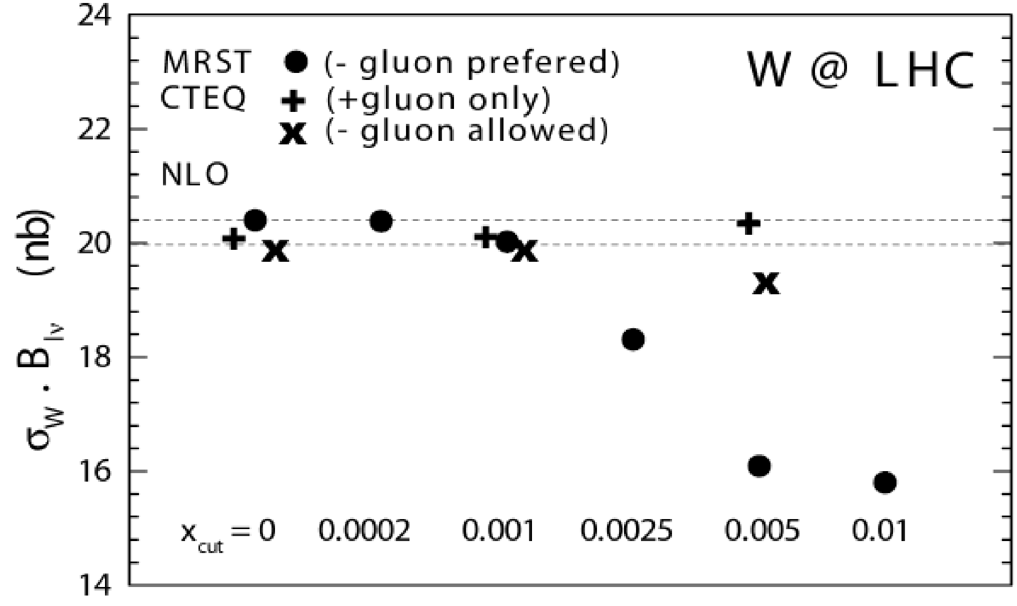
- Uncertainties from PDFs e.g. for W/Z-productions are dominant $\simeq 5\%$
- Crucial for lumi-measuremnt use
- But restricted overlap in kinematic plane between LHC & HERA

Surprises when extrapolating?

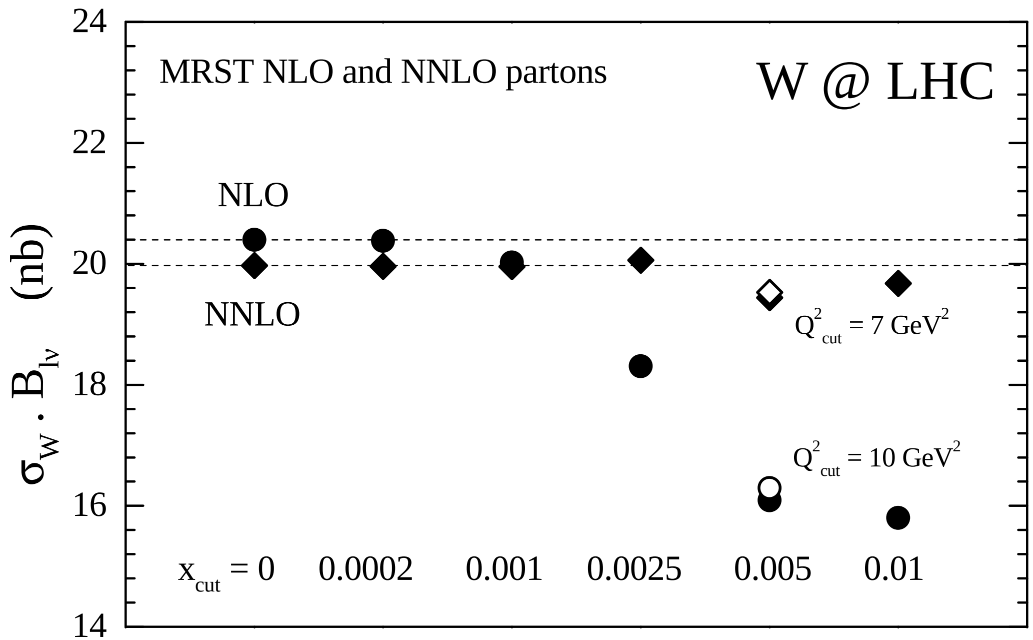
- DGLAP sufficient?
- small x?
- (N)NLO?
- Non-linear effects?
- Saturation?

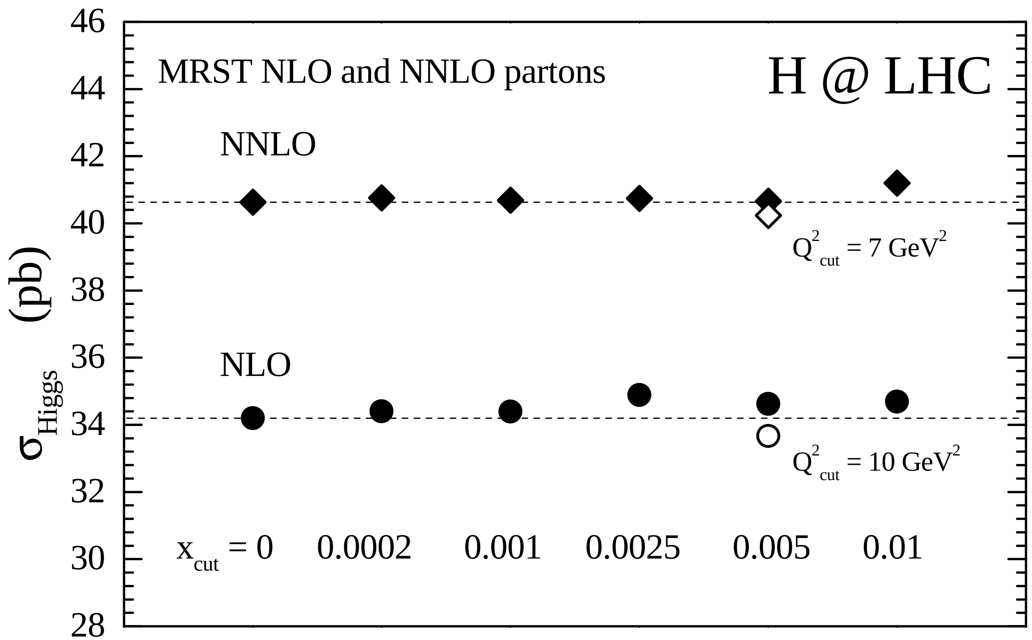
At LHC x_i is measured with M and rapidity

HERA PDFs for LHC



- MRST (CTEQ) studied stability vs lower x-cut of data-input
- Big effect at LHC
- But more stable at NNLO and for positive gluon only





Summary

HERA delivers precise cross section measurements
probing the structure of the proton
as input for PDF determinations

PDF determination is improving in
theory, phenomenology and experiment

A lot of HERA II lumi will yield
much improved precise PDFs