H1 NLO QCD Fits

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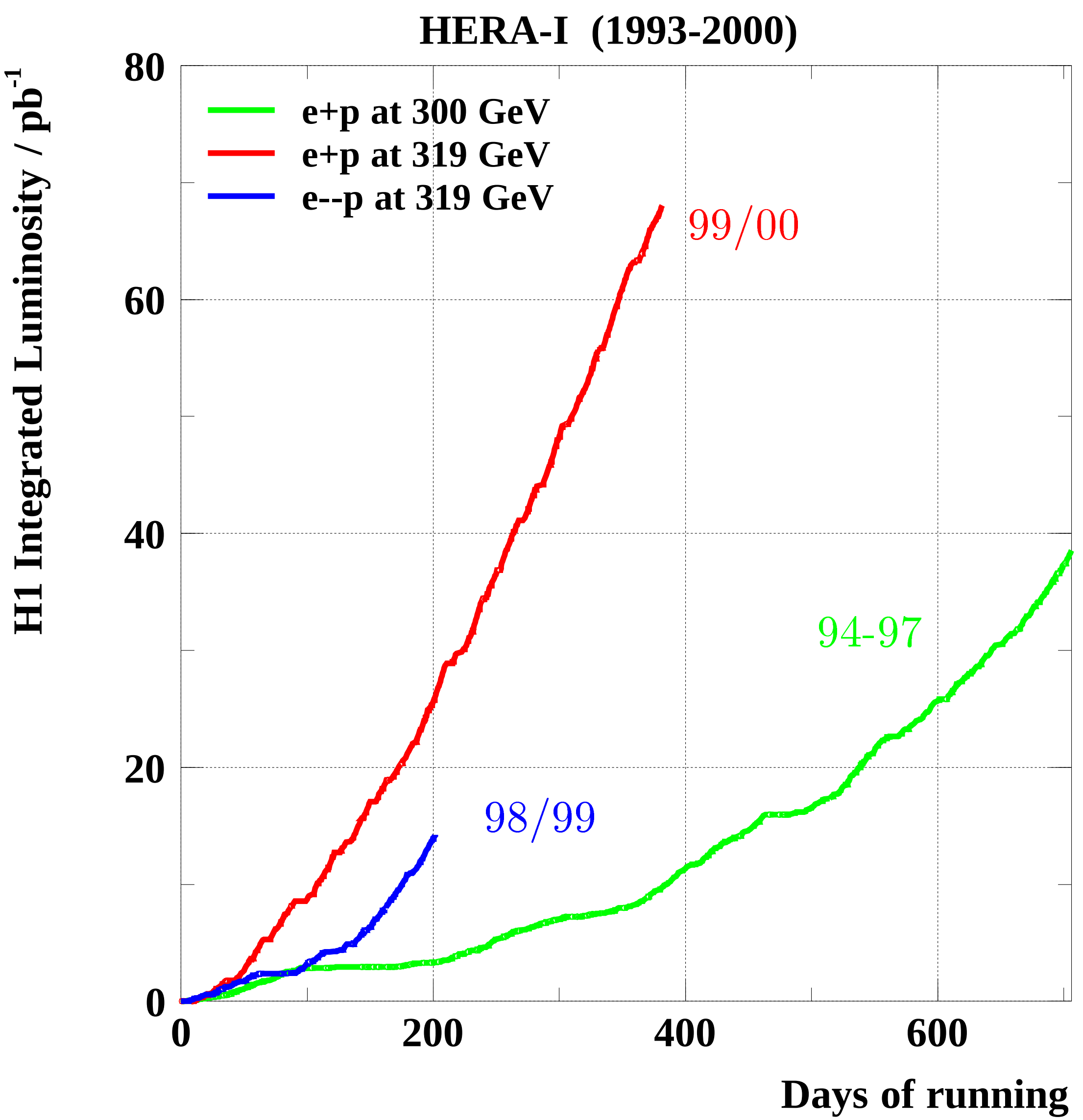
- **Data from HERA Run I**
- **Details of the H1 QCD Fit**
- **Gluon and $\boldsymbol{\alpha_s}$**
- u_V **and** d_V
- **Summary**

Data from HERA Run I



e^+p 1994-1997:

$E_e = 27.5$ GeV, $E_p = 820$ GeV

$\sqrt{s} = 300$ GeV

$\mathcal{L}_{H1} = 36.6$ pb^{-1}

e^-p 1998-1999:

$E_e = 27.5$ GeV, $E_p = 920$ GeV

$\sqrt{s} = 320$ GeV

$\mathcal{L}_{H1} = 16.4$ pb^{-1}

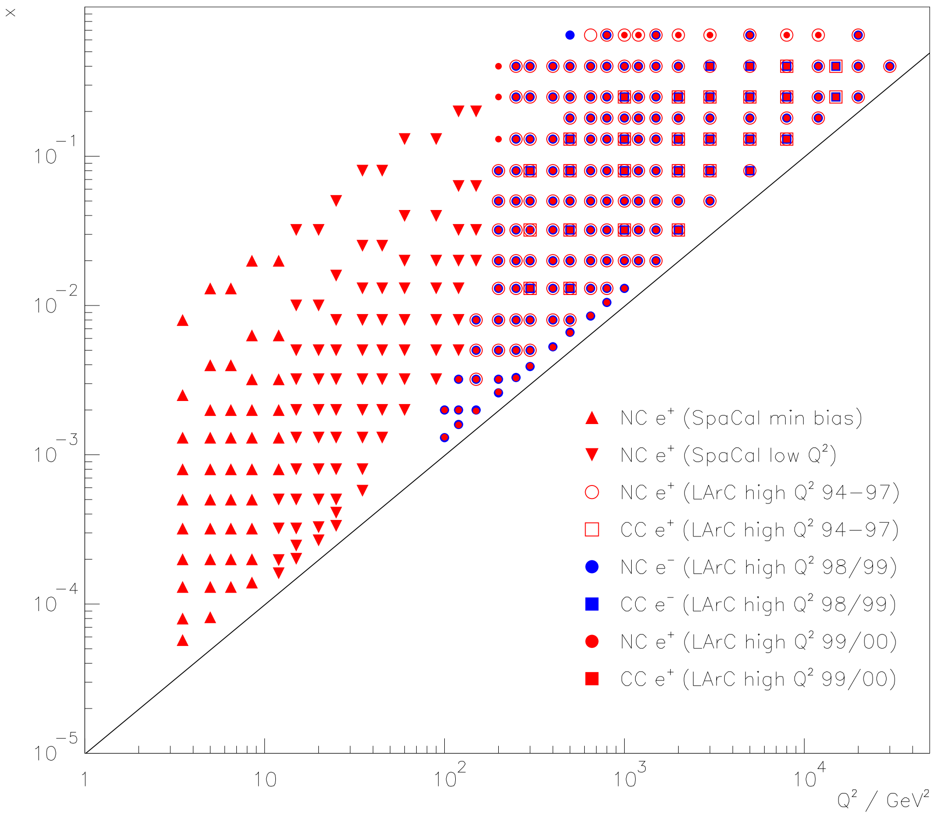
e^+p 1999-2000:

$E_e = 27.5$ GeV, $E_p = 920$ GeV

$\sqrt{s} = 320$ GeV

$\mathcal{L}_{H1} = 65$ pb^{-1}

H1 Inclusive Data Sets



H1 Low Q^2

$\mathbf{1.5 < Q^2 < 150}$ **Gev**^{2}

Eur. Phys. J. C21 (2001) 33-61 , 12/00

e^+p NC+CC 94-97

$\mathbf{150 < Q^2 < 30000}$ **Gev**^{2}

Eur. Phys. J. C13 (2000) 609-639 , 08/99

e^-p NC+CC 98/99:

$\mathbf{150 < Q^2 < 30000}$ **Gev**^{2}

Eur. Phys. J. C19 (2001) 269-288 , 12/00

soon to be published:

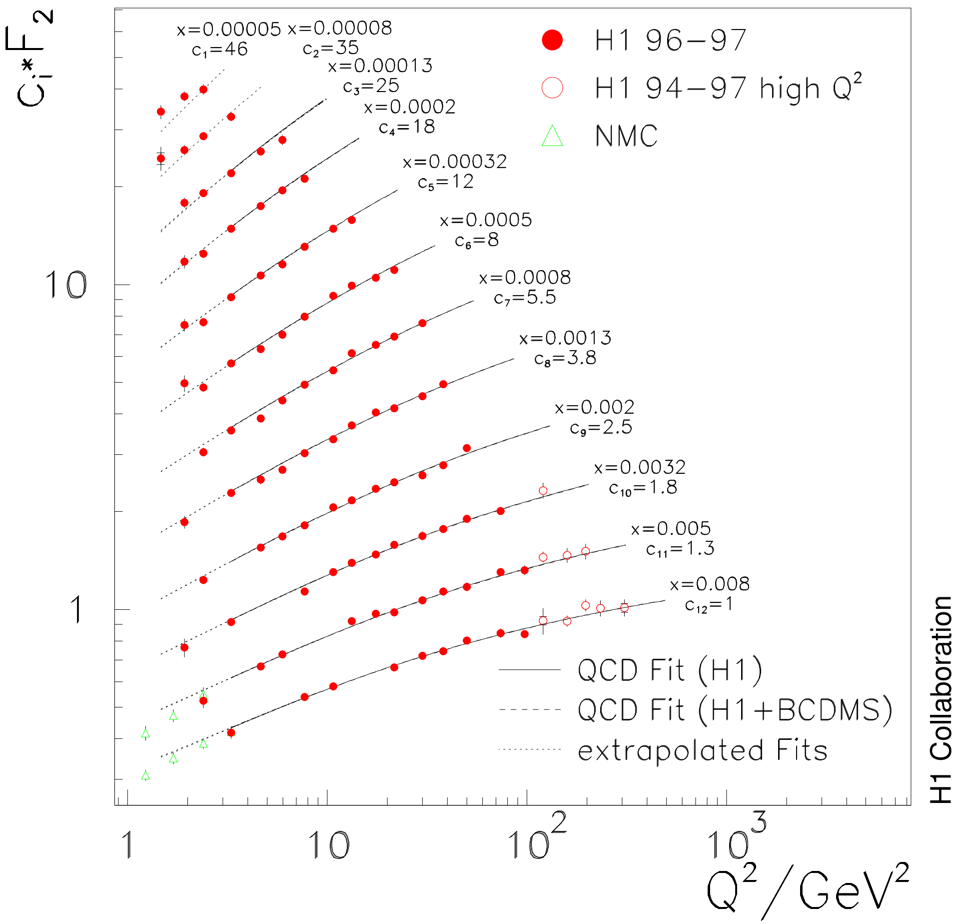
– e^+p NC+CC 1999/2000:

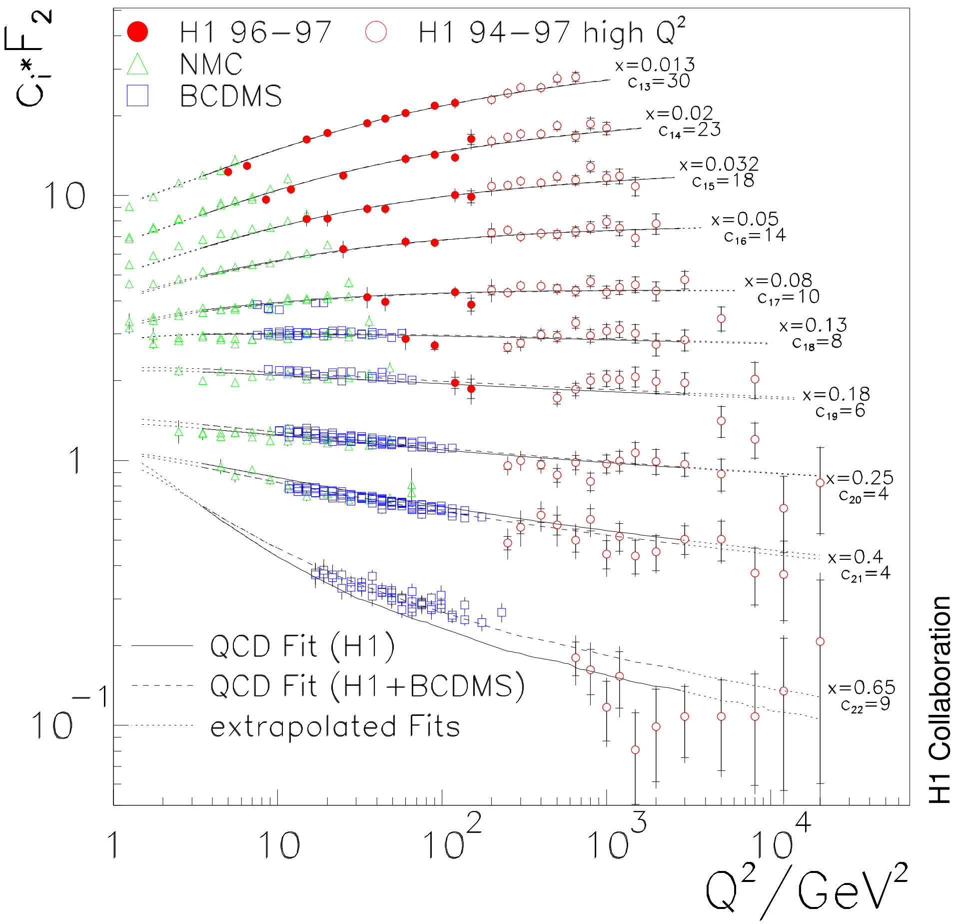
$\mathbf{150 < Q^2 < 30000}$ **Gev**^{2}

– high y extension e^-p, e^+p

$\mathbf{y = 0.75,\ 100 < Q^2 < 800}$ **Gev**^{2}

F_2 Measurement, Scaling Violations





H1 96-97 precision: stat. $\leq$ **1%**

syst. $\leq$ **3%**

scaling violations well described by the NLO QCD fit

Definition of χ^2

"Pascaud and Zomer" method, extended χ^2 (preprint LAL-95-05):

$$\chi^2 = \sum_k^{n_{exp}} \sum_i^{N_k} \frac{\left(\sigma_{k,i}^{exp} - \sigma_{k,i}^{th} \cdot (1 - n_k \delta_k^{norm} - \sum_j^{n_s(k)} s_{k,j}\, \delta_{k,i,j}^{syst})\right)^2}{{\delta_{k,i}^{sta}}^2 + {\delta_{k,i}^{unc}}^2}$$

$$+ \sum_k^{n_{exp}} n_k^2 + \sum_k^{n_{exp}} \sum_j^{n_{s(k)}} s_{j,k}^2$$

$\sigma_{k,i}^{exp}$:	measurement i of dataset k
$\sigma_{k,i}^{th}$:	prediction for data point i of dataset k
n_{exp}:	number of datasets
N_k:	number of data points in dataset k

$\delta_{k,i}^{sta}$:	statistical error
$\delta_{k,i}^{unc}$:	uncorrelated systematic error
$\delta_{k,i,j}^{sys}$:	correlated systematic error of source j
δ_k^{norm}:	uncertainty of dataset normalisation
n_k:	shift of normalisation
$s_{k,j}$:	shift of systematic of source j

data central values can be moved by shifts of n_k, $s_{k,j}$

shifts cost an additional penalty of n_k^2, $s_{k,j}^2$ to χ^2

n_k, $s_{k,j}$ are determined by the fit

correlation of systematic sources between datasets taken into account

Correlations between H1 Datasets

Normalisation of NC and CC datasets of the same data taking period

dataset	reaction	E_{el}	θ_{el}	E_{had}	Noise	BG	Vap	Asy
min bias	e^+p NC	E1	T1	H1	N1	B1	–	–
low Q^2	e^+p NC	E1	T1	H1	N1	B1	–	–
high Q^2 94-97	e^+p NC	E2	T2	H2	N1	B2	–	–
high Q^2 94-97	e^+p CC	–	–	H2	N1	B2	V1	–
high Q^2 98/99	e^-p NC	E2	T3	H2	N1	B2	–	A1
high Q^2 98/99	e^-p CC	–	–	H2	N1	B2	V2	–
high Q^2 99/00	e^+p NC	E2	T3	H2	N1	B2	–	A1
high Q^2 99/00	e^+p CC	–	–	H2	N1	B2	V2	–

e^-p high y extension identical to high98/99 e^-p NC

sources of systematic uncertainties:

E_{el}: electron energy calibartion
θ_{el}: polar angle of electron measurement
E_{had} : hadronic energy calibration
Noise: noise suppression algorithm

BG: background estimate by Monte Carlo
Vap: anti γp cut
Asy: background elimination by subtraction of the wrong charge lepton candidates

Error Bands

From the fit (using MINUIT) we obtain
– a set of parameters $p_1,\ p_2, \ldots,\ p_n$ characterising the input parton densities at starting scale
– a set of dataset normalisation factors and shifts due to correlated systematics
– information on the parameter errors
(χ^2 second derivative matrix, HESSE algorithm)

To obtain the error bands on PDFs, structure fuctions and cross sections for a given set of kinematic variables x, Q^2, y, s the fitted paramters are shifted under the constraint $\boldsymbol{\chi^2 = \chi^2_{min} + 1}$.

The error band will depend upon
– the paramterisation of the input parton densities
– Q_0^2 as this implicitly changes the parameterisation at Q^2
– the error band will depend upon the assumptions which enter the fit

$\mathcal{O}\ 10^5$ fits are performed where all essential ingredients to the fit are varied (α_s, m_c, m_b, $\ldots$)

H1 NLO QCD FIT

Strategy

- choose well defined scheme
  - NLO DGLAP evolution
  - Fixed Flavour Scheme $\Rightarrow$ massive c, b
  - in range $3.5\ \text{GeV}^2 < Q^2 < 3\,000\ \text{GeV}^2$

- Limit datasets to minimum: H1 + BCDMS p ($y > 0.3$)
  - proton data only $\Rightarrow$ avoid uncertainty of nuclear corrections
  - use well understood datasets only

- Limit input parton distributions to minimum
  - Gluon: g
  - "Valence quarks"
    $V = \frac{3}{4}\frac{1}{1+\epsilon}[(3+2\epsilon)u_V - 2d_V + (5+2\epsilon)(\bar{u}-\bar{d})]$
    $\xrightarrow{\bar{u}=\bar{d},\epsilon=0} \frac{3}{4}(3u_V - 2d_V); \quad \int V\mathrm{d}x = 3$ finite and predictable
  - "Sea quarks"
    $A = \frac{1}{4}\frac{1}{1+\epsilon}[\bar{u} - (u_V - 2d_V) - 5(\bar{u}-\bar{d}) + 2\epsilon(\bar{u}+\bar{d})]$
    $\xrightarrow{\bar{u}=\bar{d},\epsilon=0} \bar{u} - \frac{1}{4}(u_V - 2d_V)$

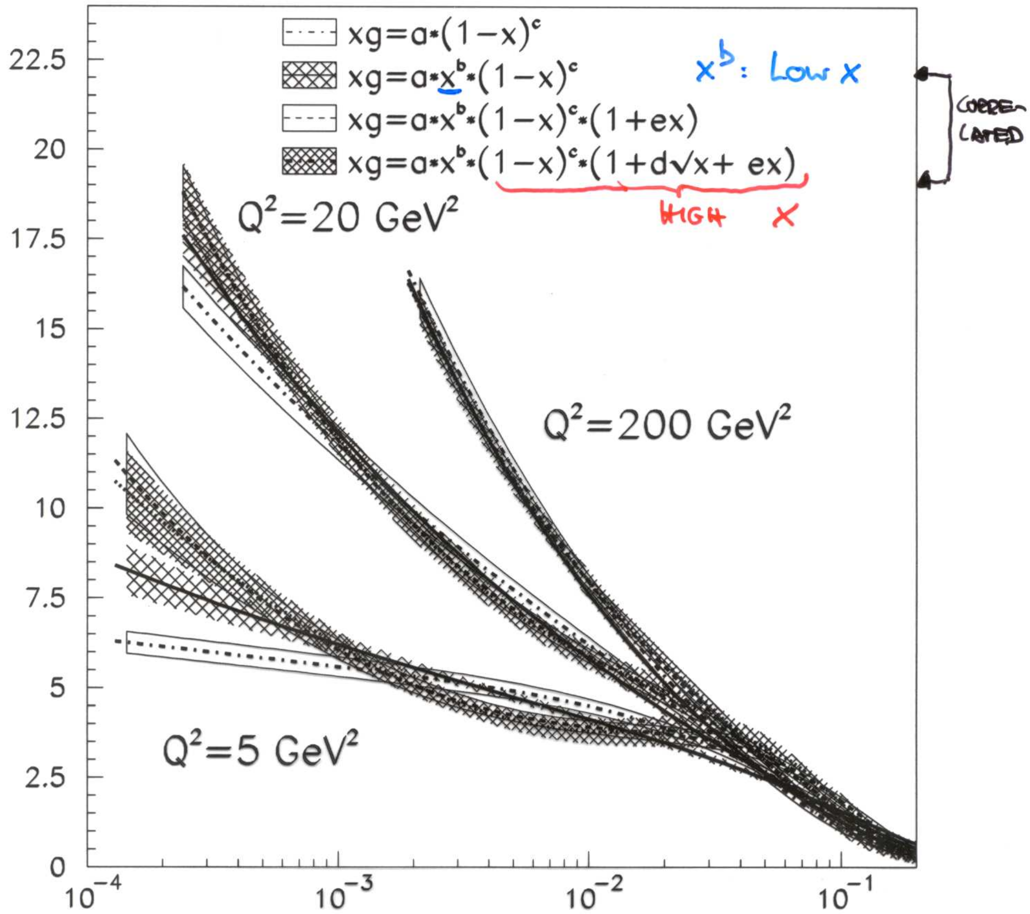
- External constraints:

strange content	$s+\bar{s} = (\frac{1}{2}+\epsilon)(\bar{u}+\bar{d})$	$\epsilon = -0.08$ NuTeV
$\bar{u}-\bar{d}$ asymmetry	$\delta = \int_0^1(\bar{u}-\bar{d})\mathrm{d}x$	$\delta = -0.118 \pm 0.011$ NuSea
quark counting	$\int_0^1 V\mathrm{d}x = 3 + \delta\frac{3}{4}\frac{5+2\epsilon}{1+\epsilon}$	take ϵ, δ into account
momentum sum	$\int_0^1(\Sigma + xg)\mathrm{d}x = 1$	

- Parameterisation:
  general form: $xpdf(x) = Ax^B(1-x)^C(1+a\sqrt{x}+bx+cx^{3/2}+dx^2)$

DGLAP DOES NOT PREDICT THE X-DEPENDENCE:

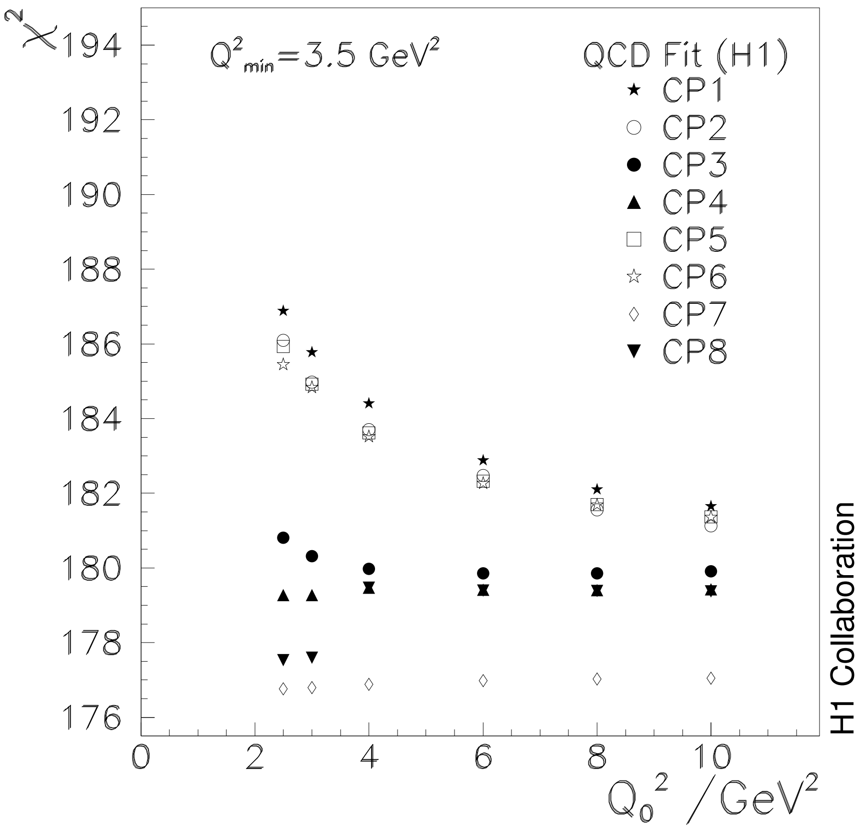
STUDY PARAMETRIZATION BIAS

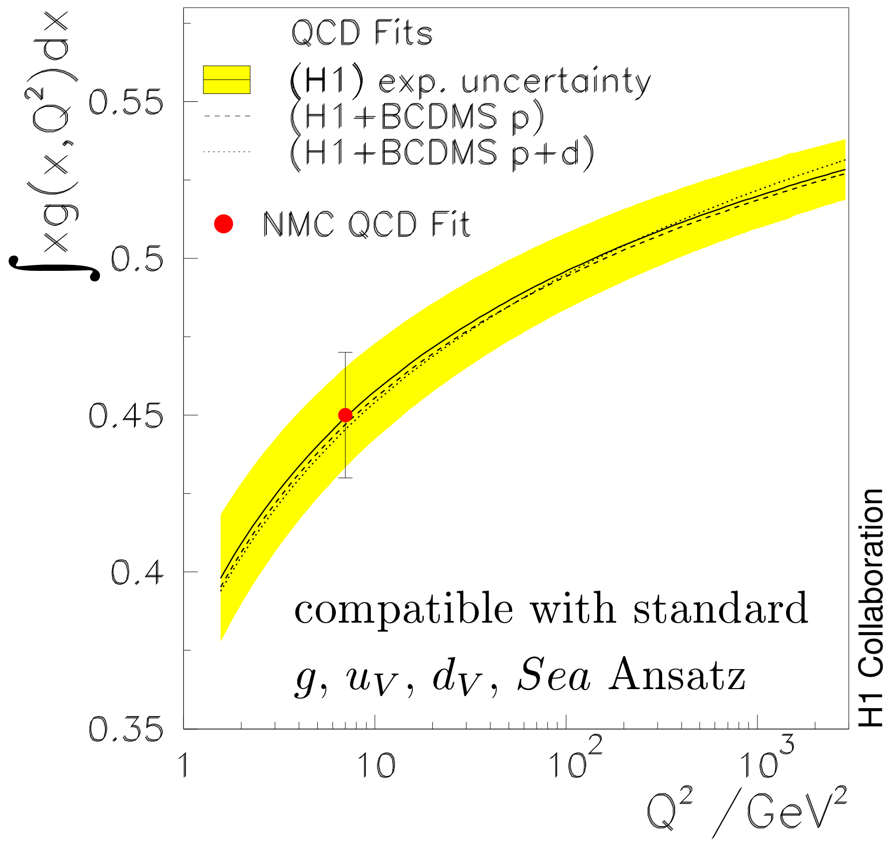


FIT 'PHILOSOPHY':

- SEEK MINIMAL AMOUNT OF PARAMETERS + DATASETS
- SEEK STABILITY WRT Q_0^2 VARIATION
- SEEK χ^2 SATURATION

Choice of Parametric Form

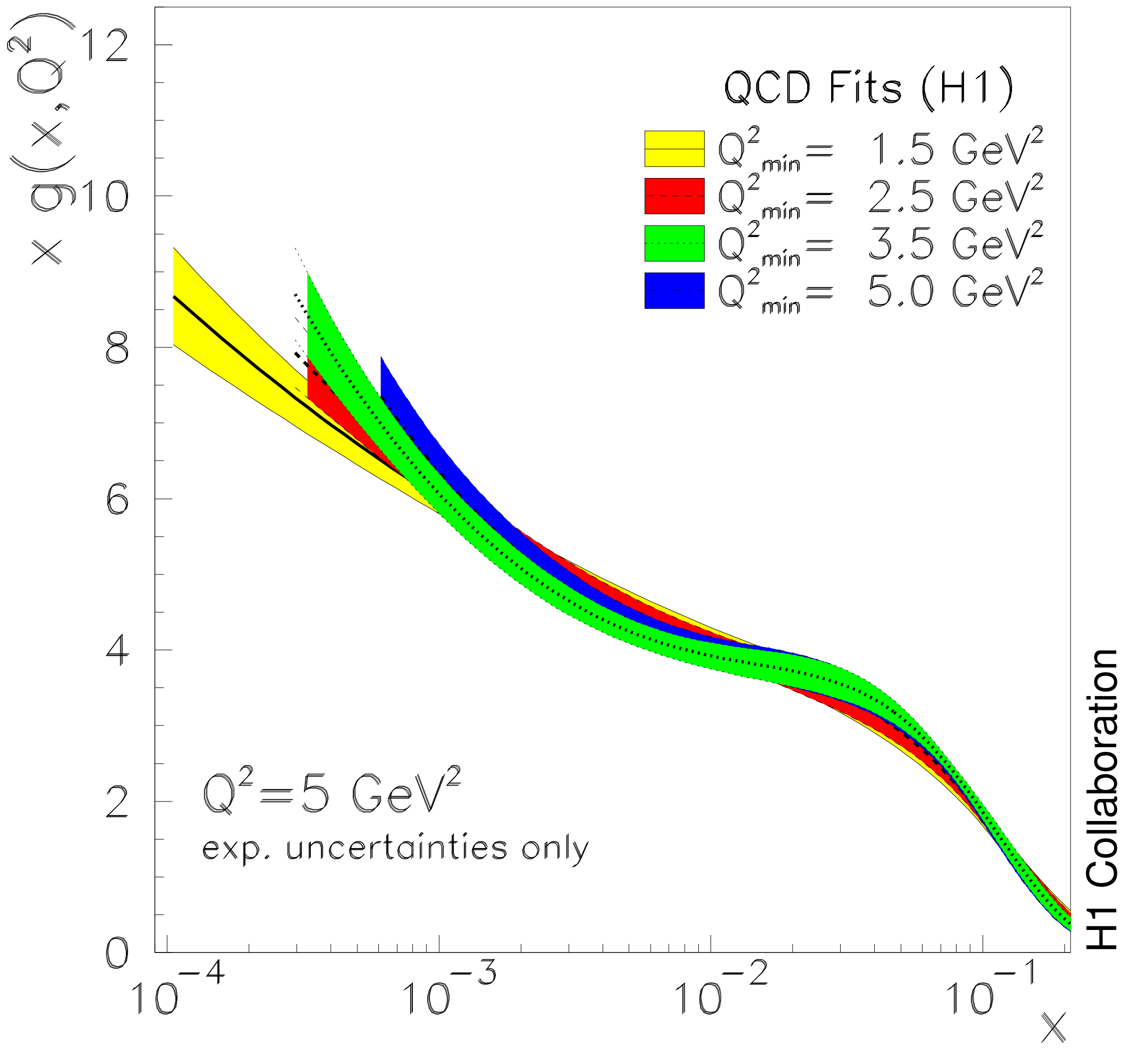




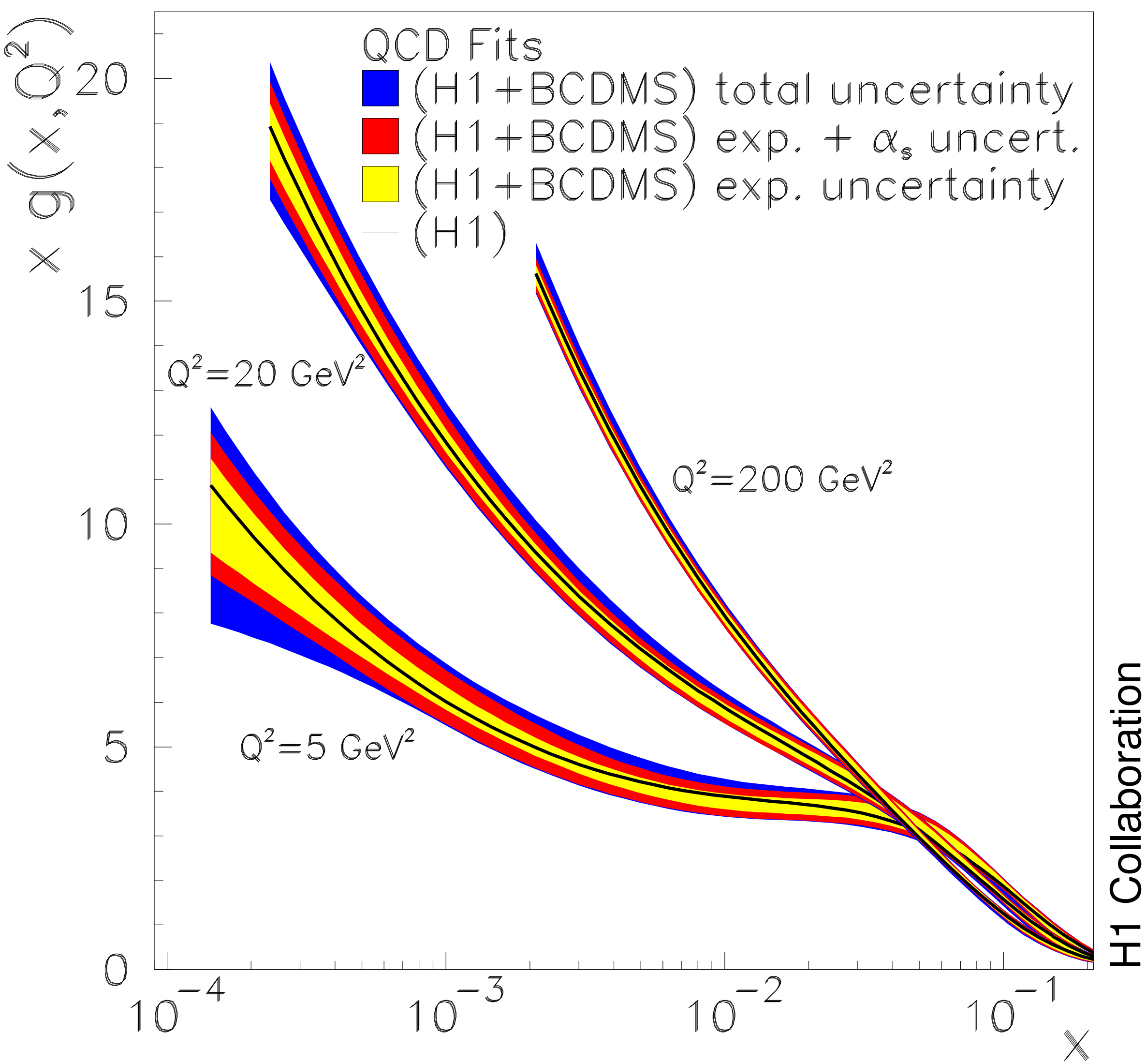
Fit 'Philosophy':

- seek minimal amount of datasets
- seek stability w.r.t. Q_0^2 variation
- seek χ^2 plateau

Gluon: Variation of Q^2_{min}



Gluon from the H1 QCD Analysis

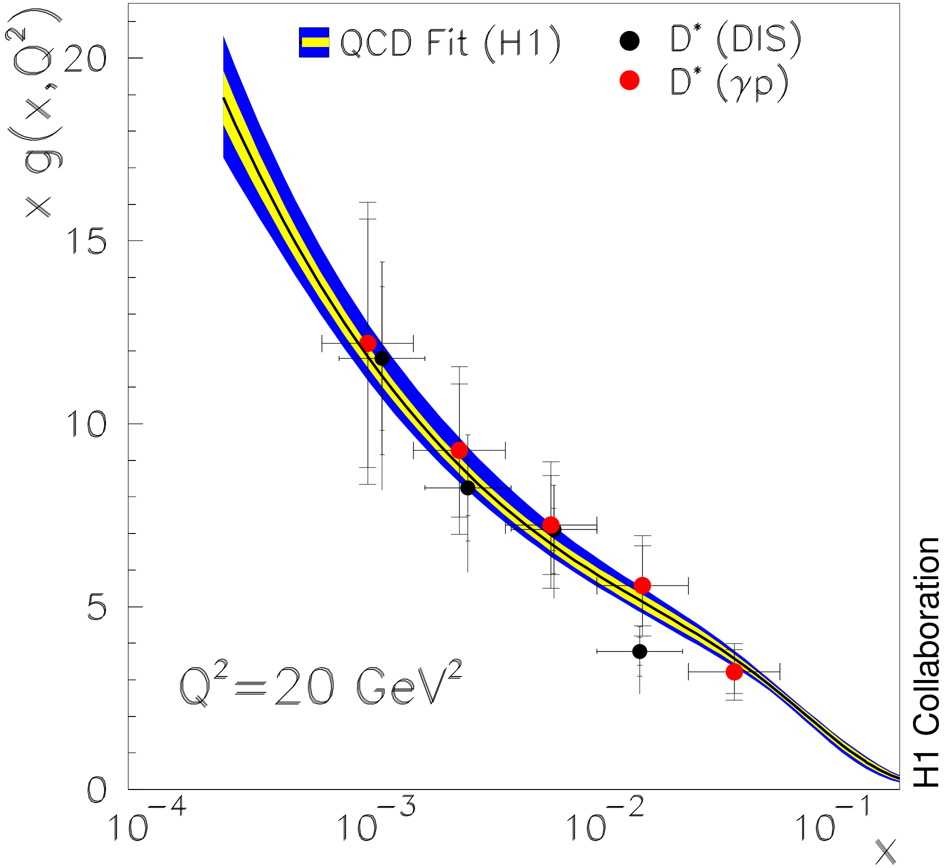


Errors are shown separately for exp. only, exp $+\alpha_s$ uncertainty, and total uncertainty which includes various checks on theoretical assumptions (“model error”)

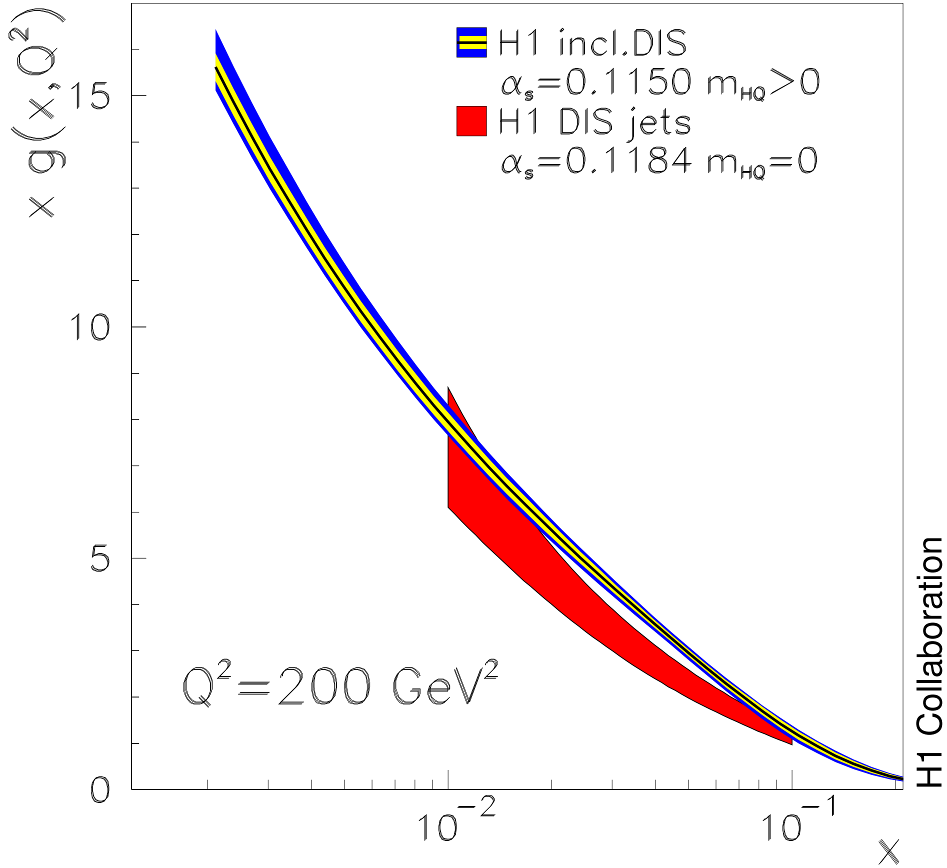
Compared with “H1 data alone”

Gluon Comparison

D^* in DIS and γp ($\gamma g \to c\bar{c}$)

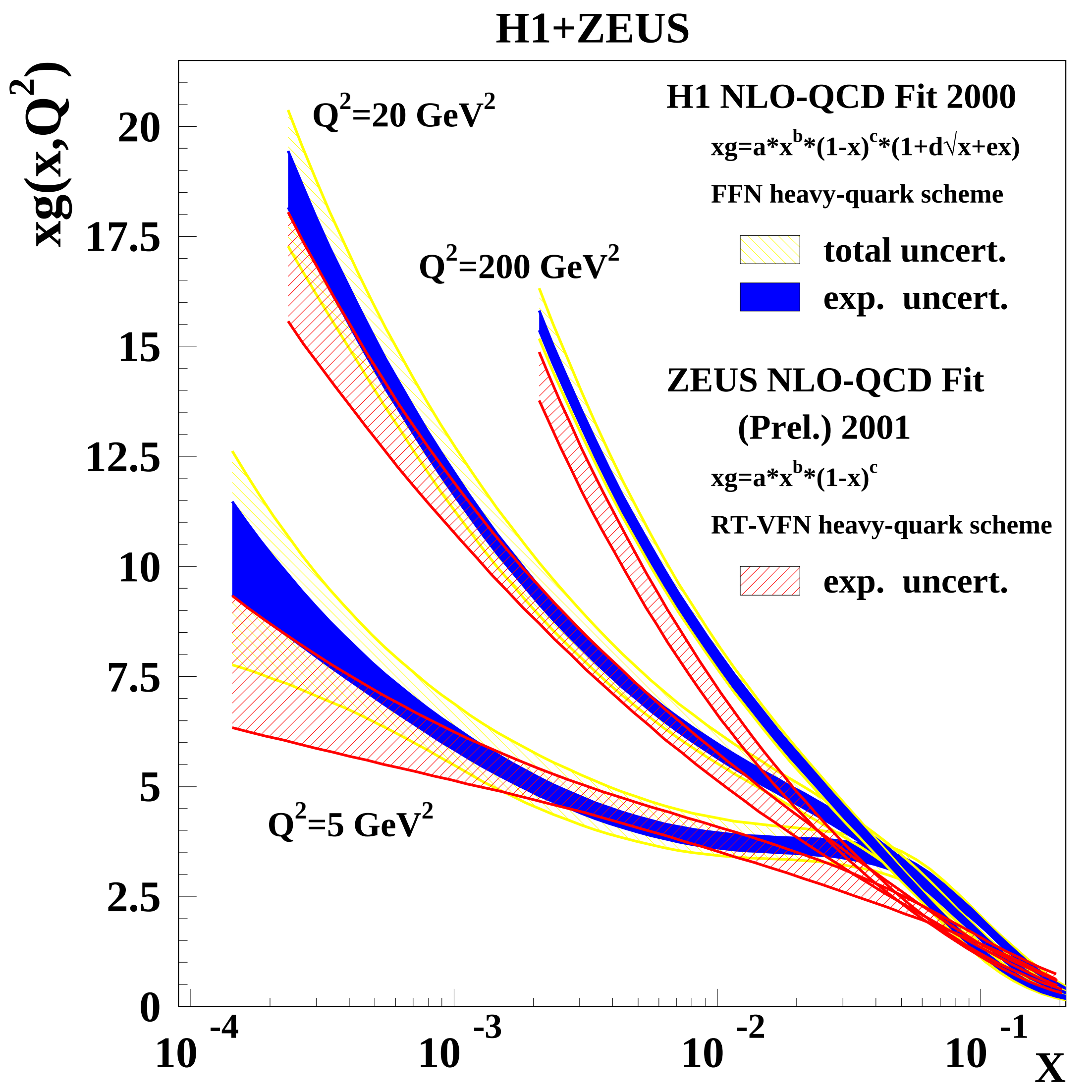


DI JETS in DIS ($\gamma g \to jet\ jet$)



consistent gluon from inclusive analysis, open charm and dijets

Gluon from H1 and ZEUS

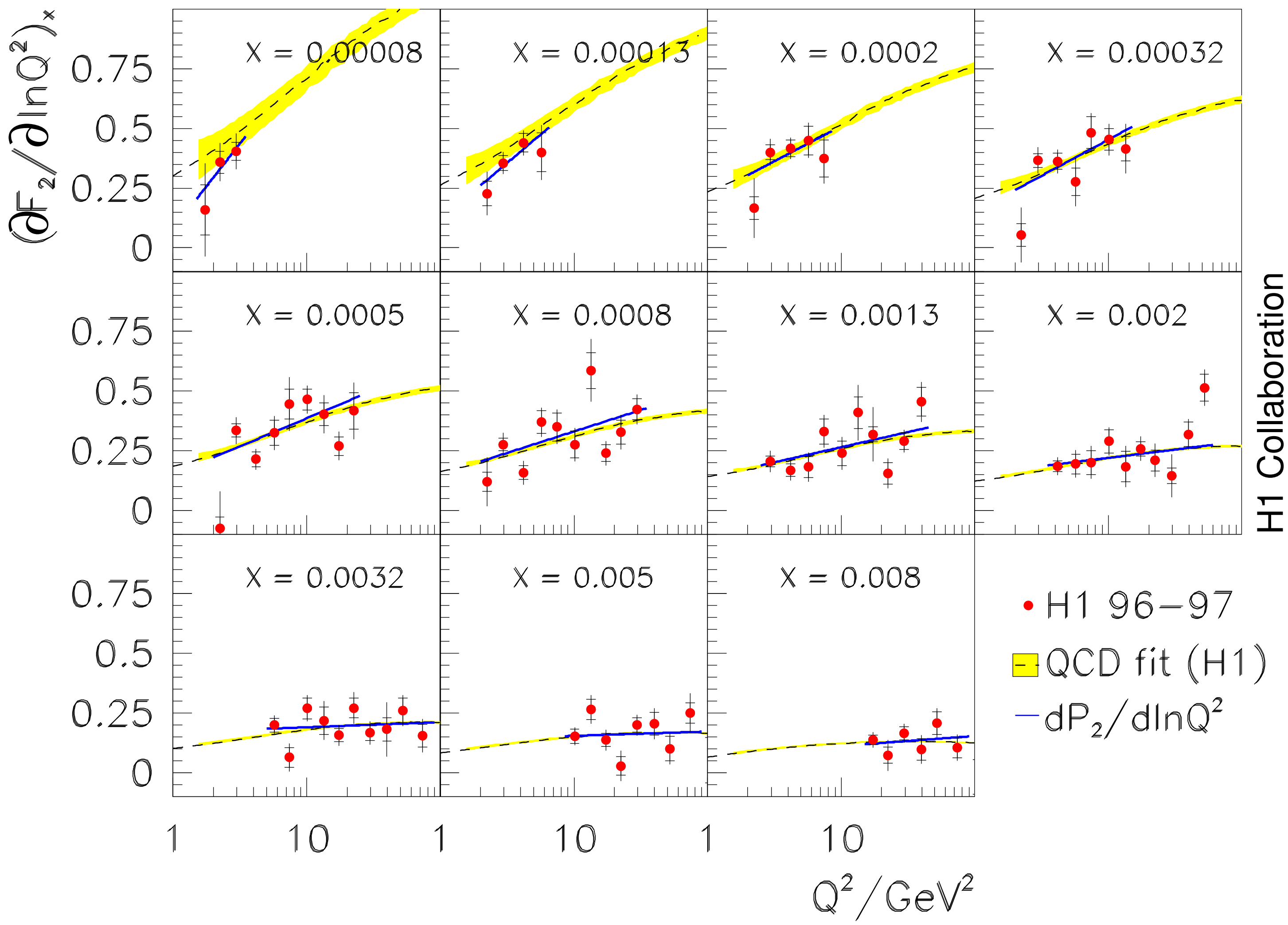


H1 Fit Quality: Derivative $(\partial F_2/\partial \ln Q^2)_x$

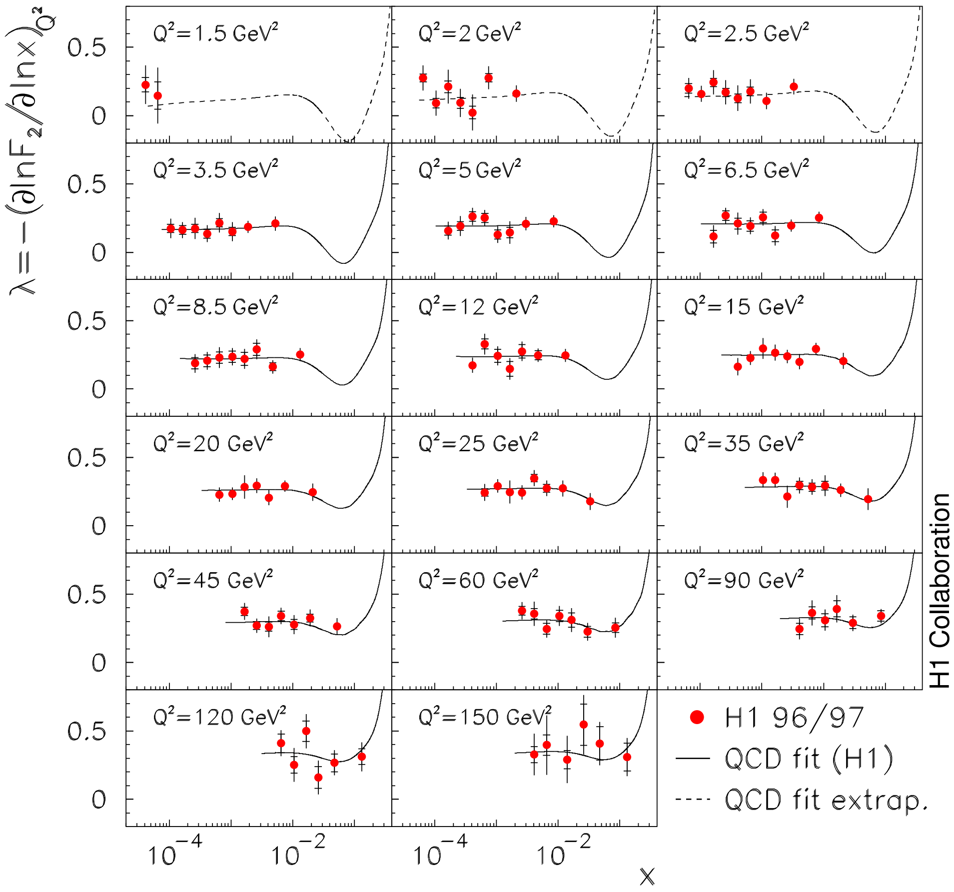
Sensitive to

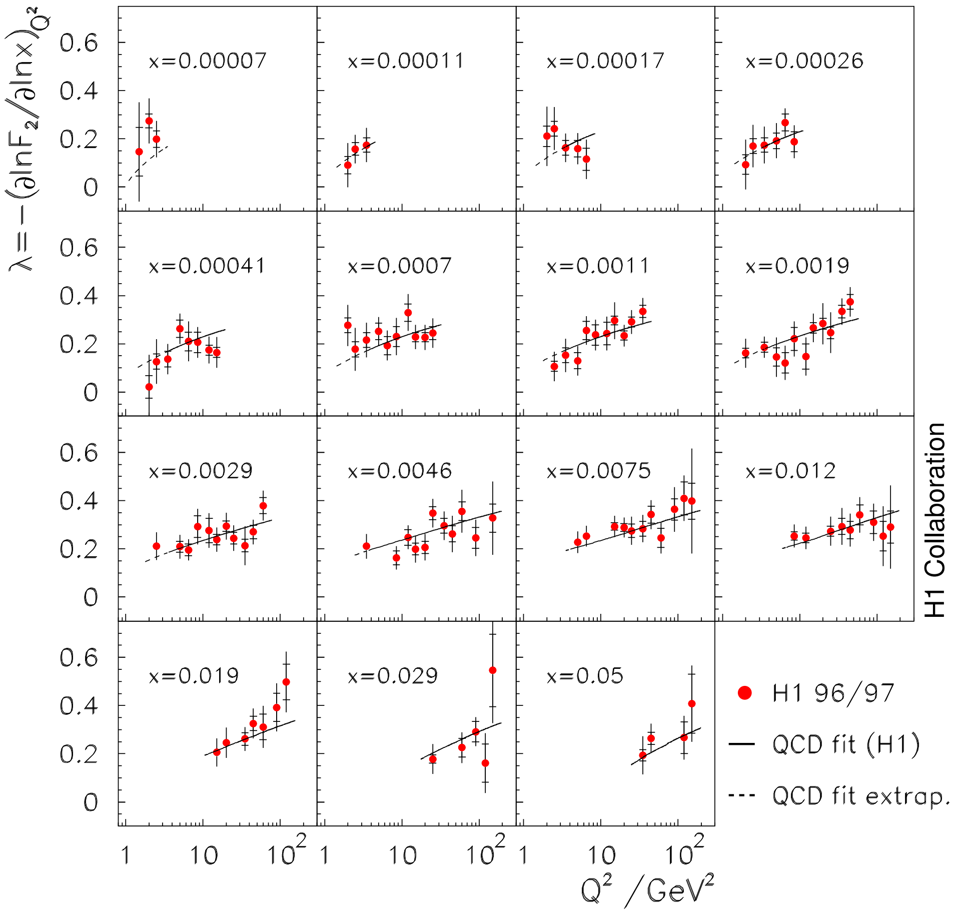
$\boldsymbol{\alpha_s \cdot xg}$

NLO QCD fit in good agreement with data



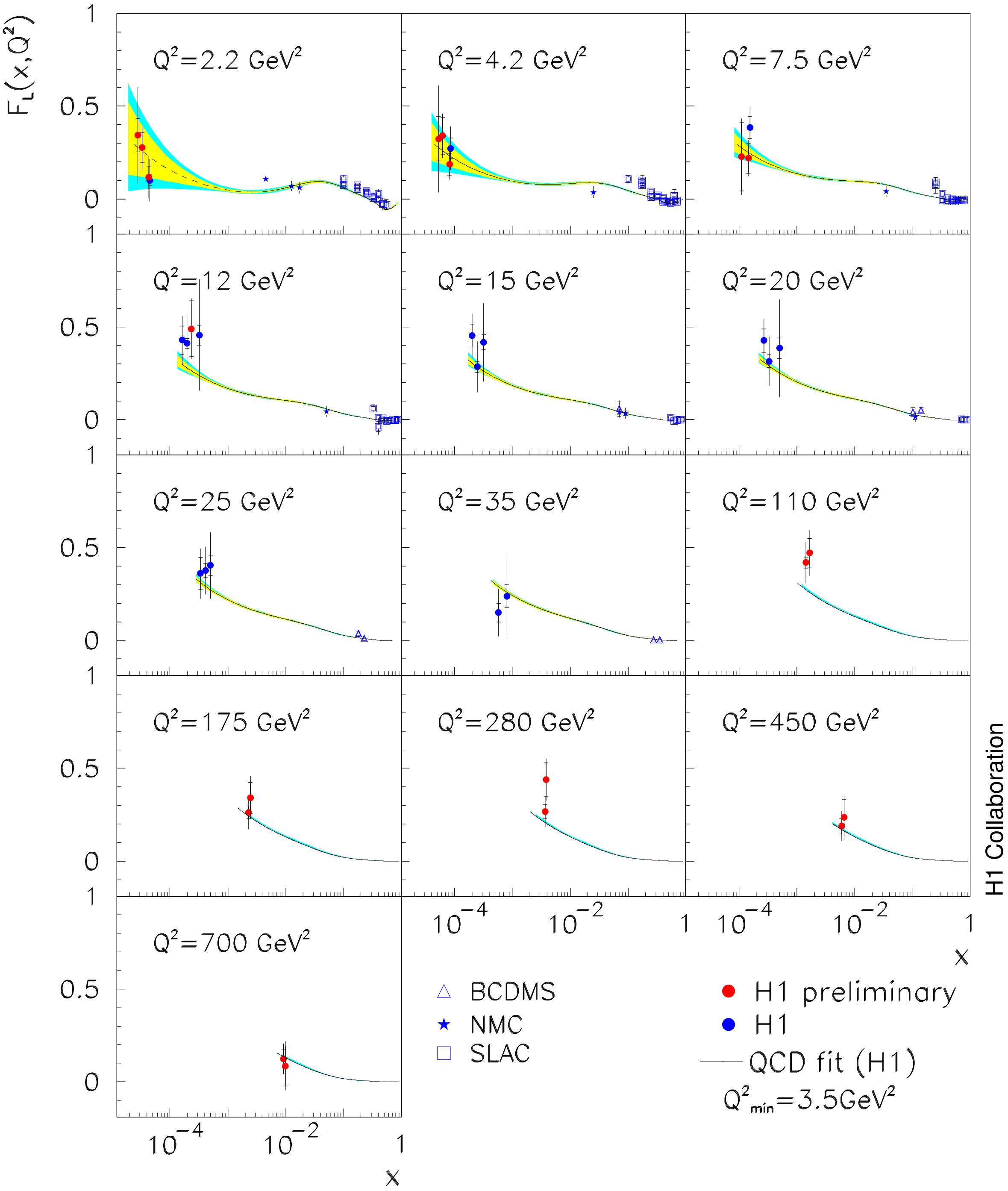
H1 Fit Quality: derivative $(\partial \ln F_2 / \partial \ln x)_{Q^2}$





NLO QCD fit describes derivatives well

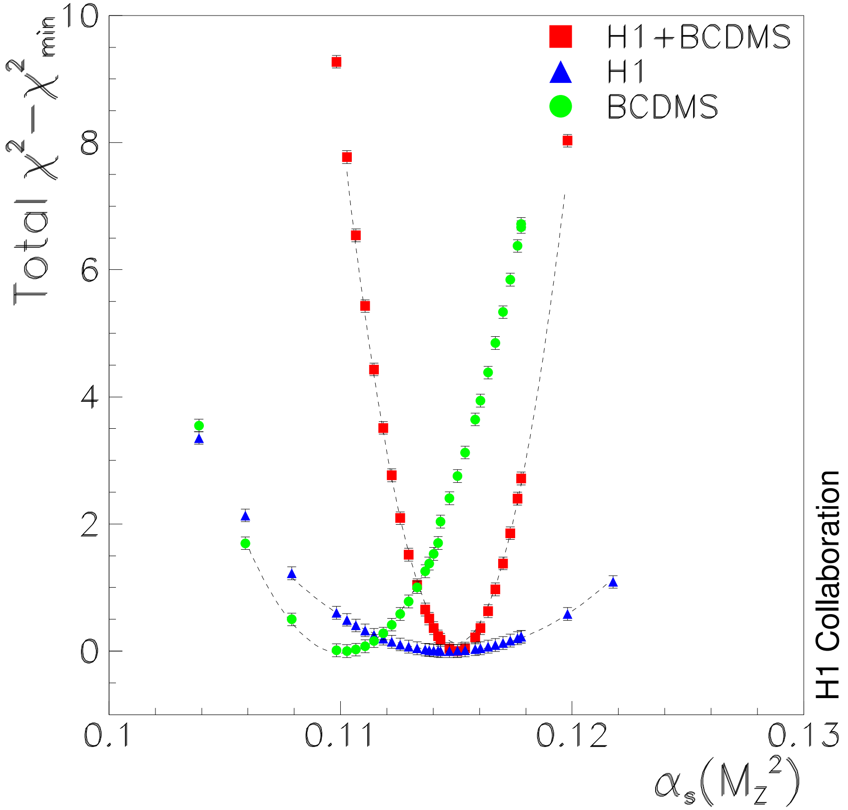
Longitudinal Structure Function F_L



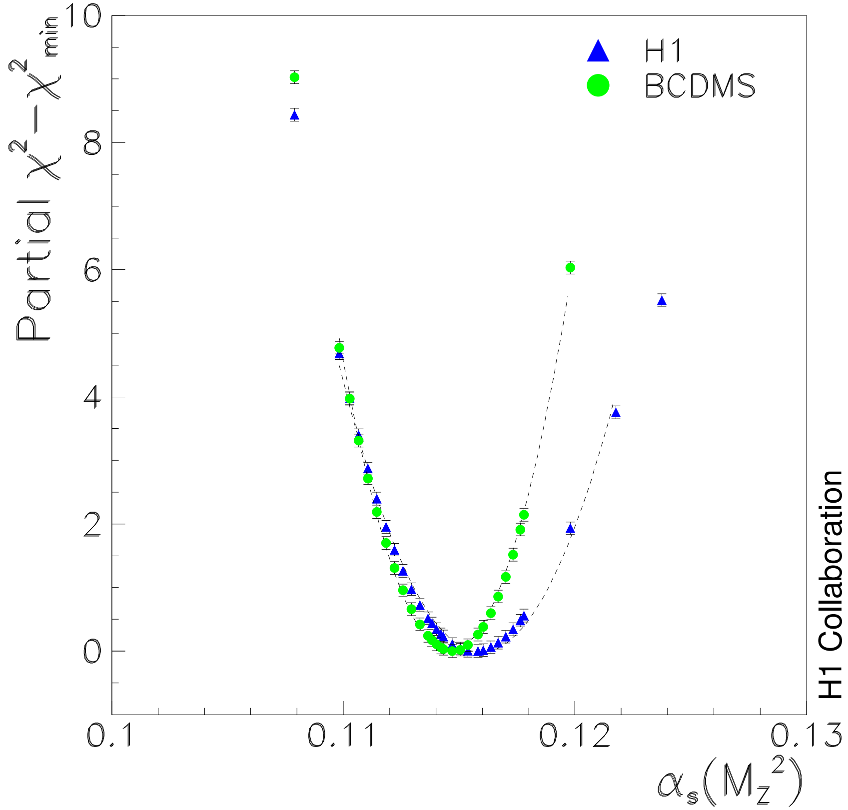
QCD fit ($y < 0.35$) fit gives consistent description

Combination of H1 + BCDMS p

Total χ^2



Partial χ^2



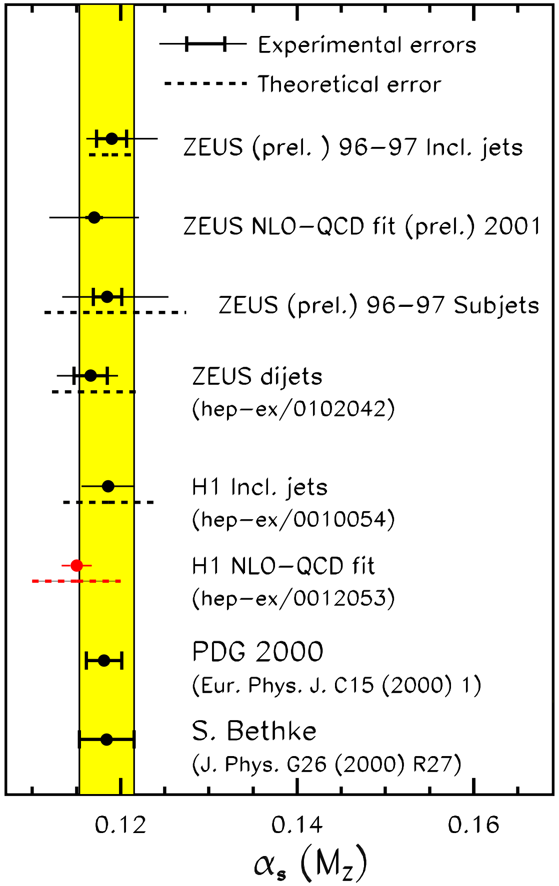
HERA data provide xg at small x

BCDMS constraint large x

compatible minima of partial χ^2's

Measurement of α_s

$$\text{Result: } \boldsymbol{\alpha_s(M_Z) = 0.1150 \pm 0.0017\ (\text{exp})^{+0.0009}_{-0.0005}\ (\text{model})}$$

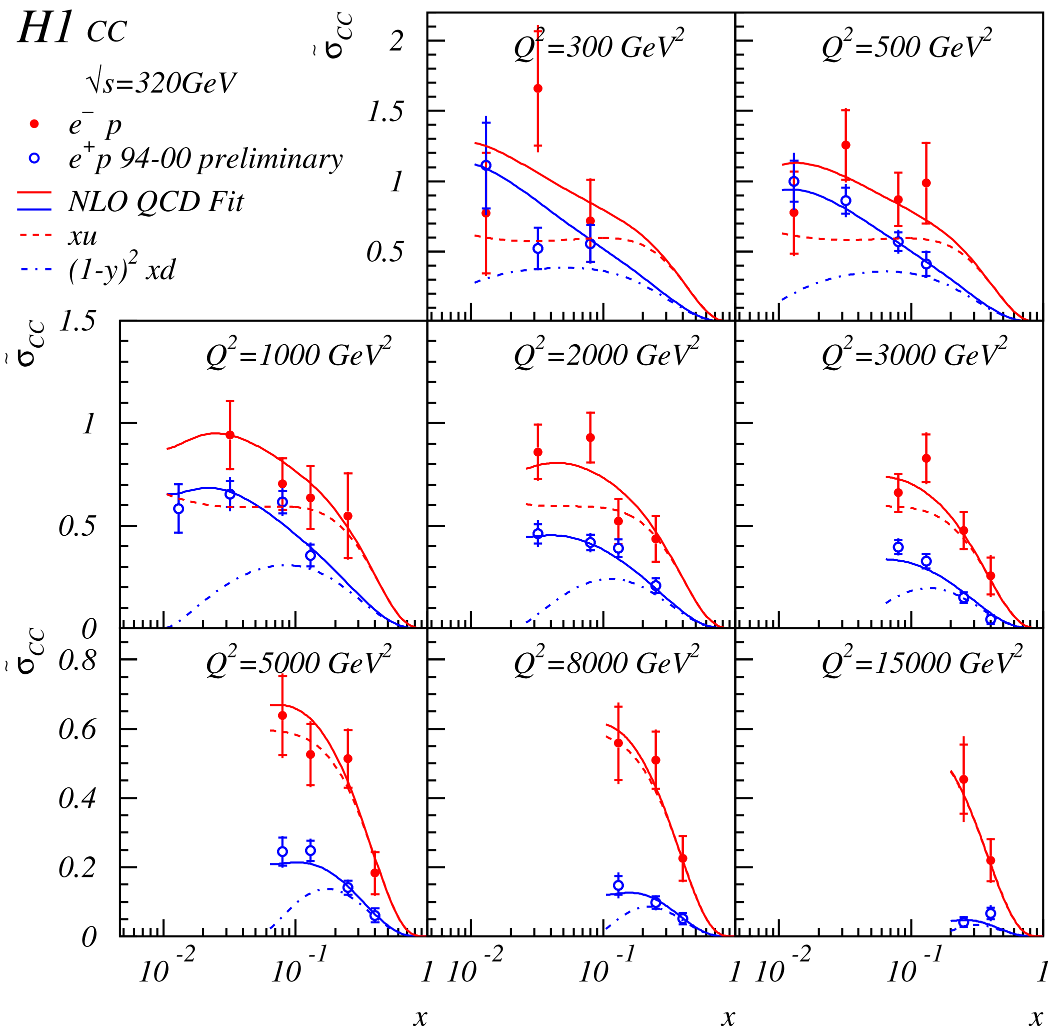


analysis uncertainty	$+\delta\,\alpha_s$	$-\delta\,\alpha_s$
$Q^2_{min} = 2$ GeV^2		0.00002
$Q^2_{min} = 5$ GeV^2	0.00016	
parameterisations	0.00011	
$Q^2_0 = 2.5$ GeV^2	0.00023	
$Q^2_0 = 6$ GeV^2		0.00018
$y_e < 0.35$	0.00013	
$x < 0.6$	0.00033	
$y_\mu > 0.4$	0.00025	
$x > 5 \cdot 10^{-4}$	0.00051	
uncertainty of $\bar{u} - \bar{d}$	0.00005	0.00005
strange quark contribution $\epsilon = 0$	0.00010	
$m_c + 0.1$ GeV	0.00047	
$m_c - 0.1$ GeV		0.00044
$m_b + 0.2$ GeV	0.00007	
$m_b - 0.2$ GeV		0.00007
total uncertainty	0.00088	0.00048

renormalisation/factorisation scale uncertainties ≈ 0.005 not included

	$\mu_r = 0.25$	$\mu_r = 1$	$\mu_r = 4$
$\mu_f = 0.25$	-0.0038	-0.0001	+0.0043
$\mu_f = 1$	-0.0055	——-	+0.0047
$\mu_f = 4$	——-	+0.0005	+0.0063

CC Cross Sections e^+p vs. e^-p



$$\frac{d^2\sigma_{CC}}{dx\, dQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W{}^2}{M_W{}^2+Q^2}\right)^2 \cdot \tilde{\sigma}_{CC}^{e^\pm p}$$

$$\tilde{\sigma}_{CC}^{e^-p}|_{LO} = (u+c) + (1-y)^2(\bar{d}+\bar{s})$$

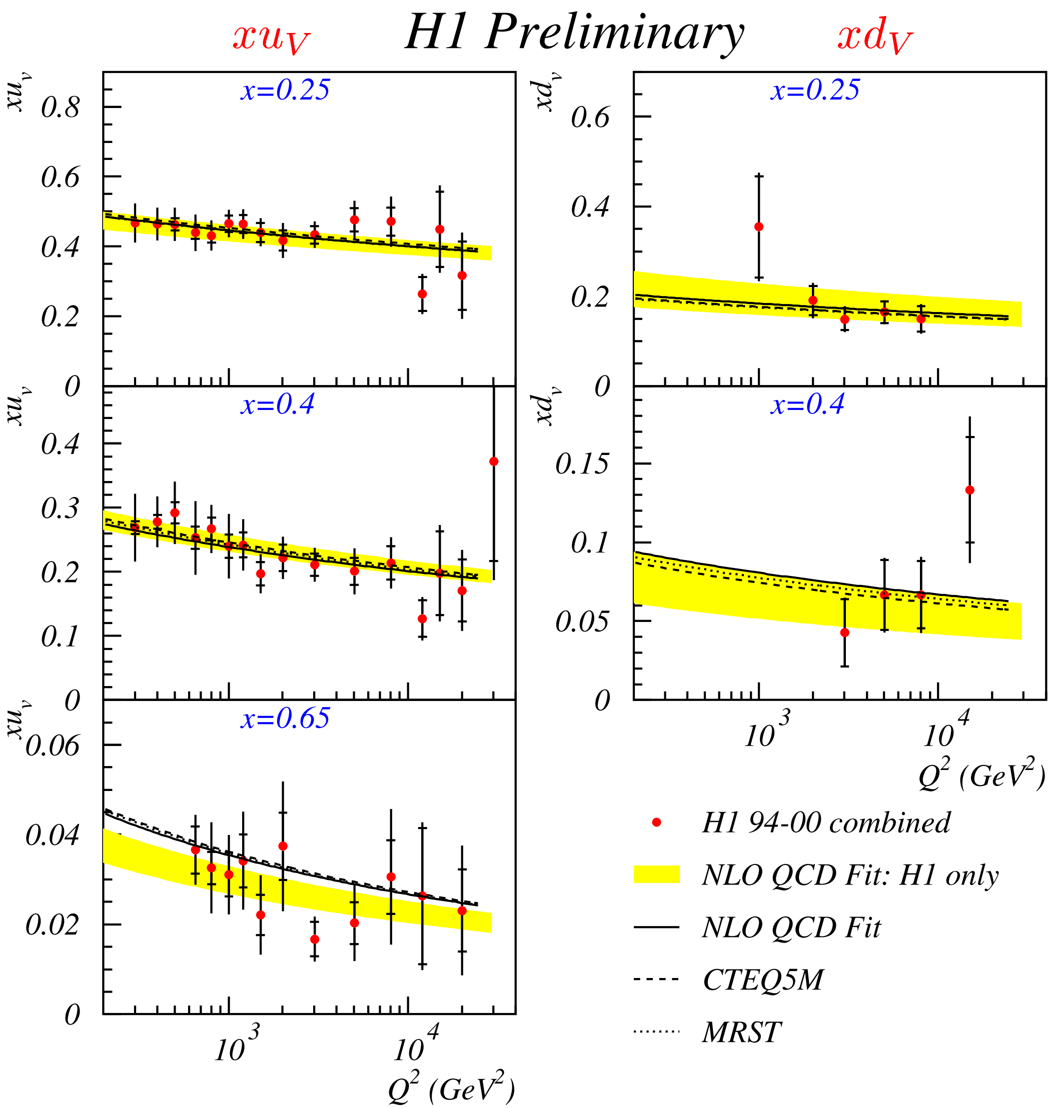
$$\tilde{\sigma}_{CC}^{e^+p}|_{LO} = (\bar{u}+\bar{c}) + (1-y)^2(d+s)$$

at large x:

e^- CC probes u_V

e^+ CC probes d_V

Valence Quark Flavour Decomposition at high x



Obtain $\boldsymbol{xu_V}$ and $\boldsymbol{xd_V}$
from $\tilde{\boldsymbol{\sigma}}^{e^{\pm}p}_{NC}$ and $\tilde{\boldsymbol{\sigma}}^{e^{\pm}p}_{CC}$
via local extraction method:

$$\boldsymbol{xq_V(x,Q^2) = \sigma_{meas} \cdot \left(\frac{xq_V}{\sigma}\right)_{\mathbf{fit}}}$$

only if $\boldsymbol{\left(\frac{\sigma(xq_V)}{\sigma}\right)_{\mathbf{fit}} > 0.7}$,
allmost model independent

$\boldsymbol{xu_V}$, $\boldsymbol{xd_V}$ consitent with
NLO QCD Fit

Summary

list of controversial topics

- systematic errors and normalisation fitted
  $\Rightarrow$ central values shifted full use of experimental information

- minimum amount of datasets included

$$\begin{array}{ccc} \text{H1} + \text{BCDMS p} & \leftrightarrow & \text{global data}(d,\ Fe) \\ \text{proton data only} & & \text{nuclear corrections} \end{array}$$

- χ^2 criterion: H1 + BCDMS p: $\Delta\chi = 1$

- experimental errors on α_s
  (ZEUS much larger)