The Gluon Distribution xg and the Strong Coupling Constant α_s from Inclusive DIS data by H1

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- DIS cross section measurement at low Q^2
- Determination of $xg(x, Q^2)$
- Extraction of α_s

DIS 2001 Bologna
29.April 2001

H1 DATA
DESY 00-181
hep-ex 0012053

$12\,\mathrm{GeV}^2 < Q^2 < 150\,\mathrm{GeV}^2$ — 96 $7.4\,\mathrm{pb}^{-1}$, 97 $13.4\,\mathrm{pb}^{-1}$

$1.5\,\mathrm{GeV}^2 < Q^2 < 8.5\,\mathrm{GeV}^2$ — 97 $1.8\,\mathrm{pb}^{-1}$

$Y > 0.6$ — 96+97 $7.4\,\mathrm{pb}^{-1}$

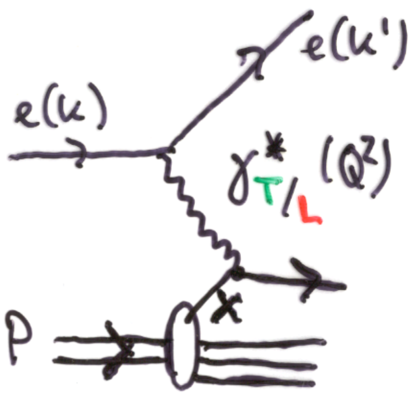
BORN DIS SCATTERING CROSS SECTION $Q^2 \ll M_Z^2$:

$$\frac{1}{\varkappa}\frac{d\sigma}{dx\,dQ^2} \equiv \tilde{\sigma}_R = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

$\tilde{\sigma}_R$: REDUCED CROSS-SECTION

$$Y_+ = 1 + (1-y)^2$$

$$\varkappa = \frac{2\pi\alpha^2}{Q^4 x} Y_+$$

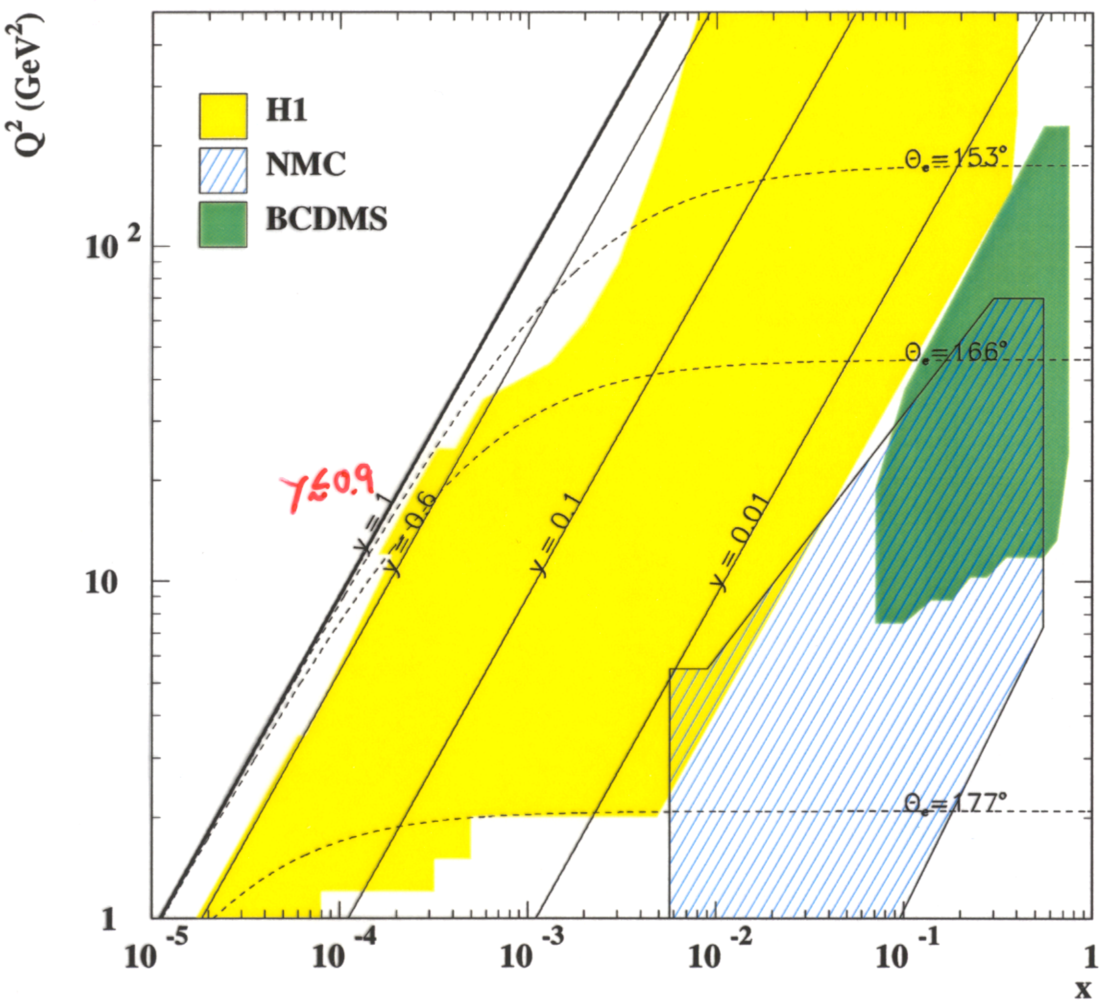


$F_L = \tilde{\sigma}_L$ ($H=0$, γ^*_L, k)

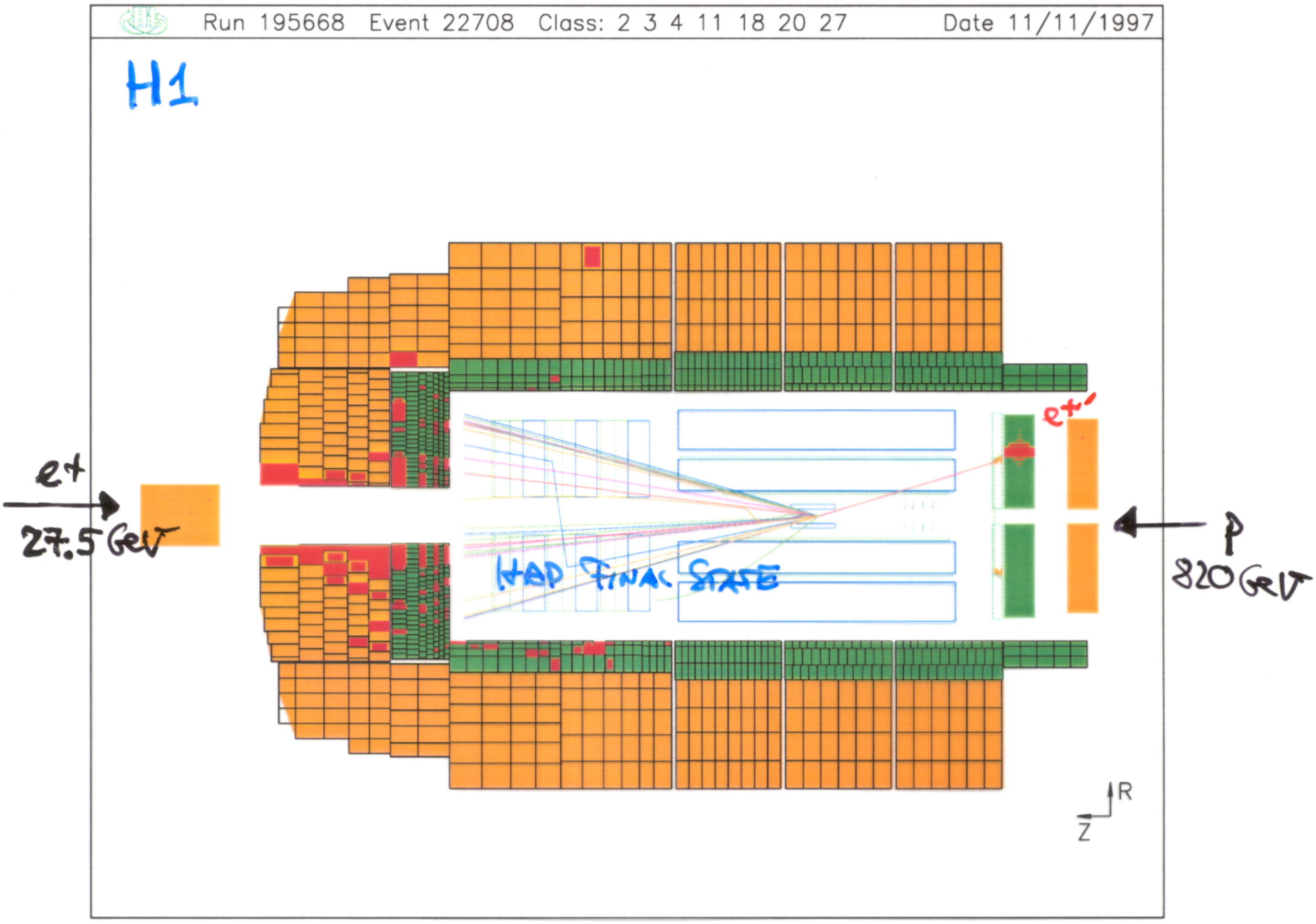
$F_2 = \tilde{\sigma}_T$ ($H=\pm 1$, γ^*_T, k) $+ \tilde{\sigma}_L$

$y < 0.6$: $\tilde{\sigma}_R \simeq F_2$

$1.5\,\mathrm{GeV}^2 < Q^2 < 150\,\mathrm{GeV}^2$

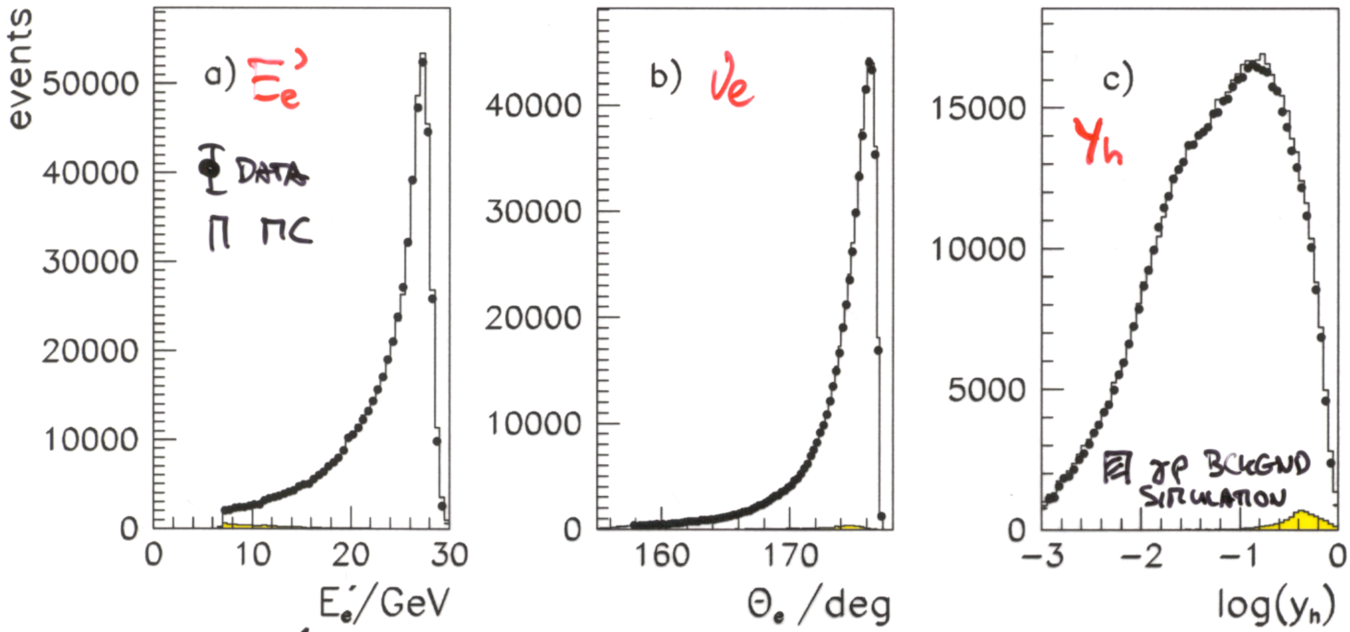


$3\times10^{-5} < x < 0.25$



OVERCONSTRAINED KINEMATICS:

REDUNDANT RECONSTRUCTION METHODS (e+, Σ...)



BINWISE CROSS-SECT.

$$\frac{d^2\sigma^{\square}}{dx\,dQ^2} = \frac{N^{REC} - N^{BG}}{\mathcal{L}} \frac{\Delta_{BC}}{\epsilon Acc} \frac{1}{1+\delta_{RAD}}$$

PRECISION:

STAT < 1%

SYST: $\mathcal{L}$ ~ 1.5%

δE ~ 0.3–2.7%

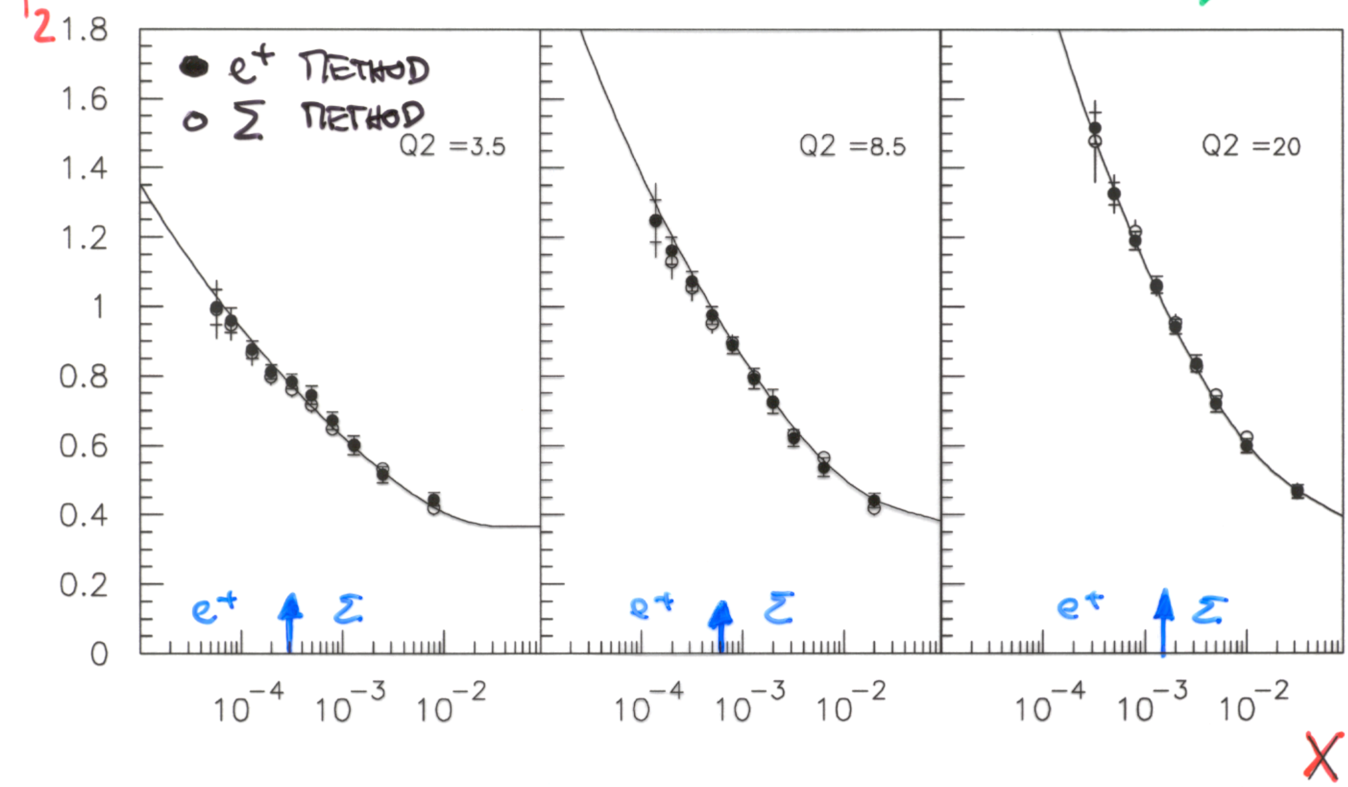
$\delta\theta$ ~ 0.3 mrad

E_{had} ~ 2%

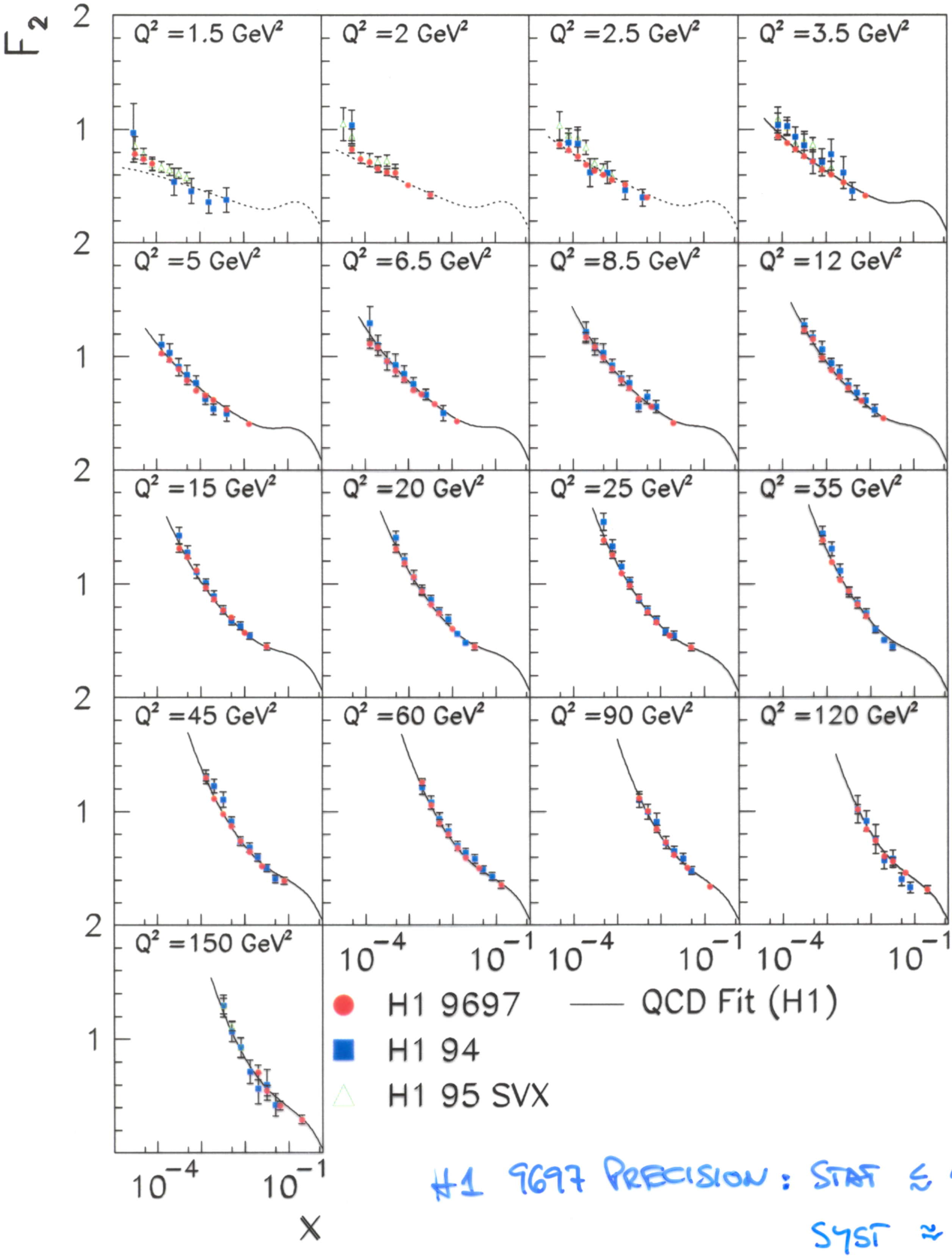
ε ~ 0.5–2%

UNFOLD

KINEMATIC RECONSTRUCTION METHODS AGREE IN FULL RANGE OF Y: DETECTOR CALIBRATION ✓



COMPARISON H1 DATASETS

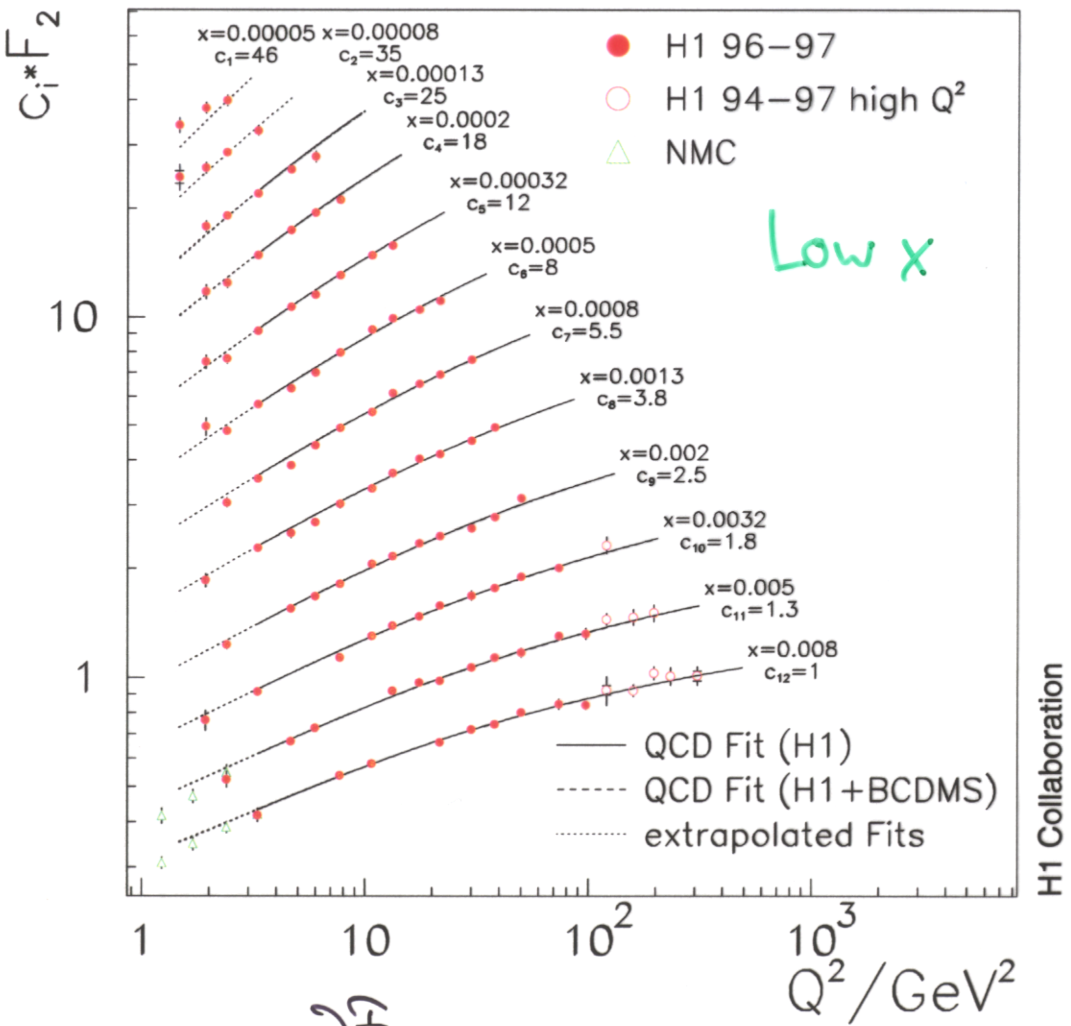


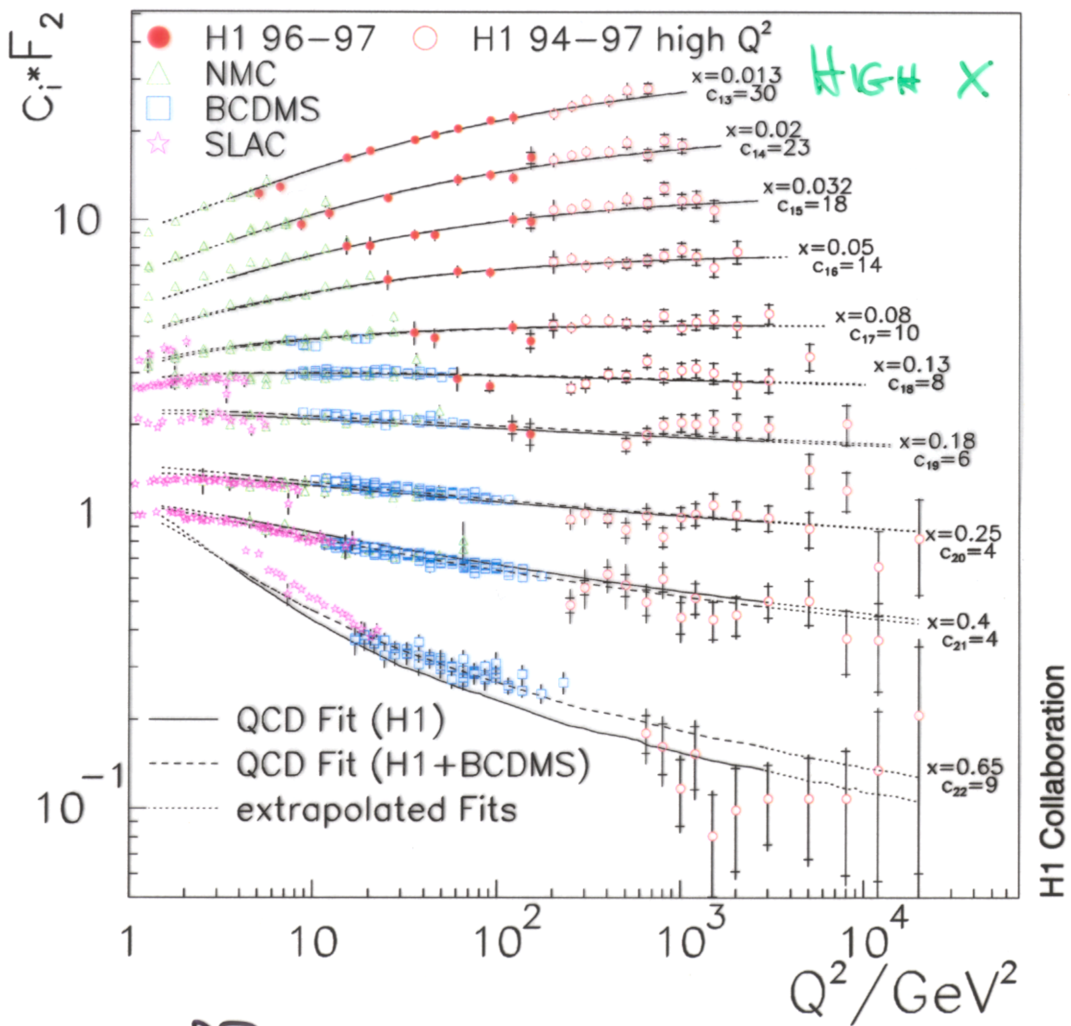
H1 9697 PRECISION : STAT $\lesssim 1\%$

SYST $\approx 3\%$

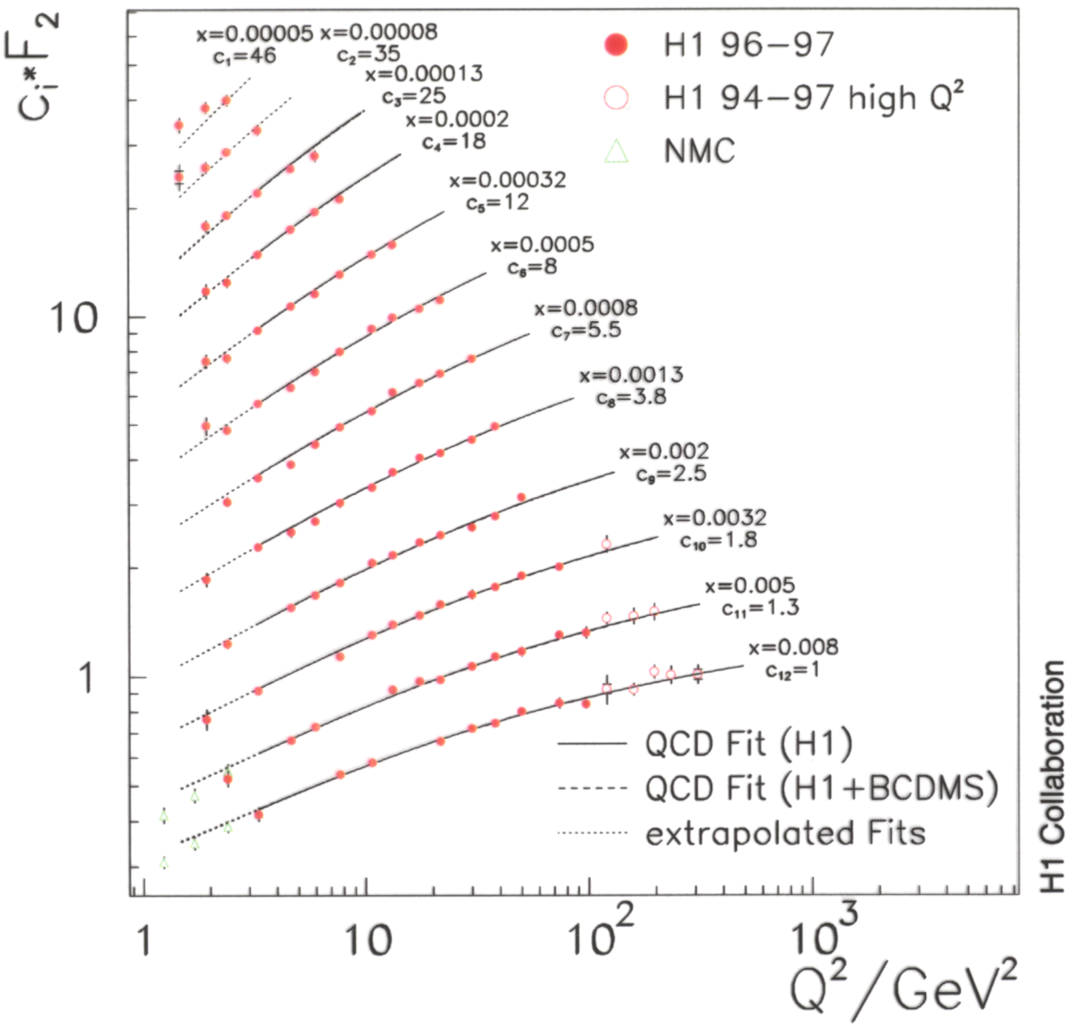
$$\frac{\partial}{\partial \log Q^2}\begin{pmatrix}\Sigma\\ g\end{pmatrix} = \frac{\alpha_s}{2\pi}\begin{pmatrix}P_{qq} & n_f P_{qg}\\ P_{gq} & P_{gg}\end{pmatrix}\begin{pmatrix}\Sigma\\ g\end{pmatrix}$$

$$\frac{\partial}{\partial \log Q^2}\, q_{NS} = \frac{\alpha_s}{2\pi}\, P_{qq} \otimes q_{NS}$$

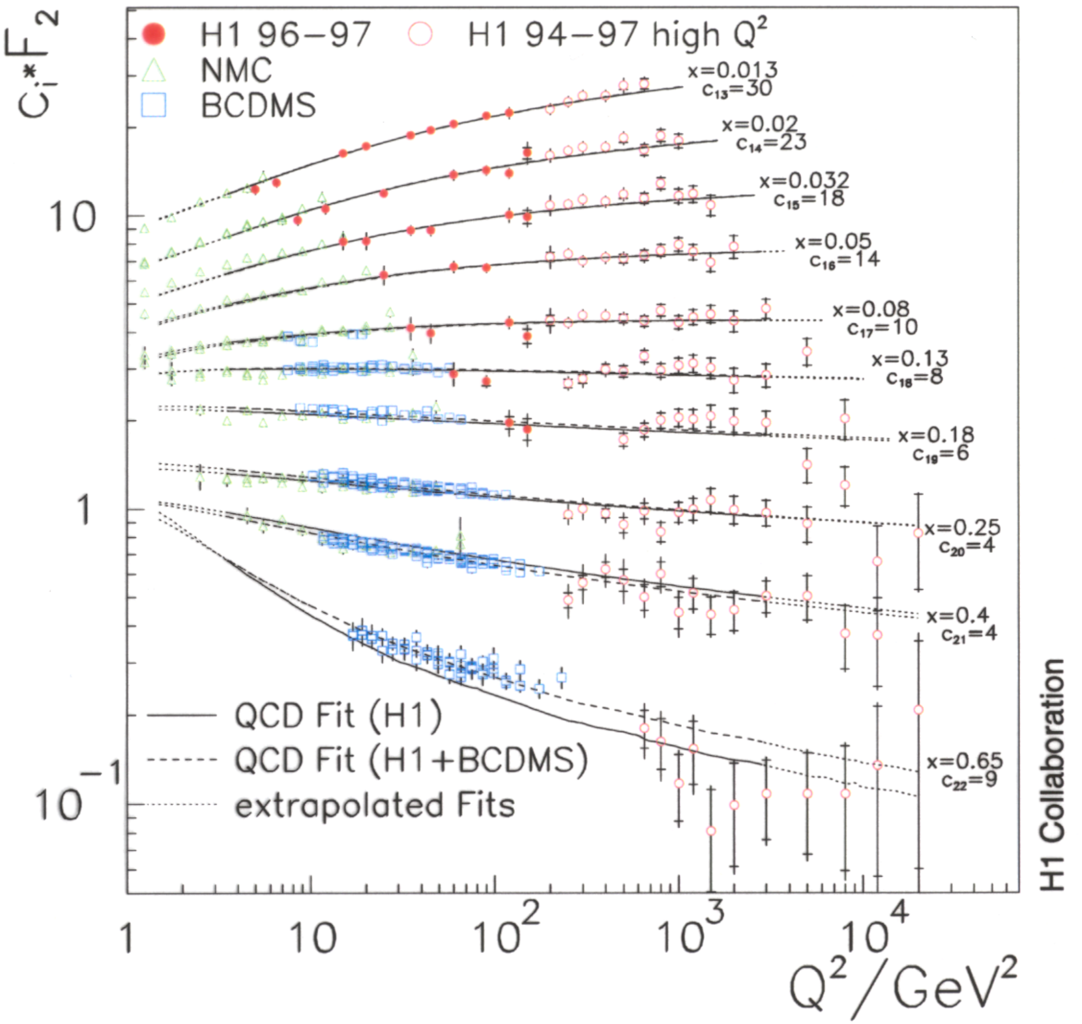




$$\frac{\partial F_2}{\partial \log Q^2} \sim \alpha_s\, x g \qquad\qquad \frac{\partial F_2}{\partial \log Q^2} \sim \alpha_s\, F_2$$



$c_i * F_2$
x=0.00005 c_1=46
x=0.00008 c_2=35
x=0.00013 c_3=25
x=0.0002 c_4=18
x=0.00032 c_5=12
x=0.0005 c_6=8
x=0.0008 c_7=5.5
x=0.0013 c_8=3.8
x=0.002 c_9=2.5
x=0.0032 c_{10}=1.8
x=0.005 c_{11}=1.3
x=0.008 c_{12}=1
H1 96−97
H1 94−97 high Q^2
NMC
QCD Fit (H1)
QCD Fit (H1+BCDMS)
extrapolated Fits
H1 Collaboration
1
10
10^2
10^3
Q^2/GeV^2



$c_i * F_2$
H1 96−97
H1 94−97 high Q^2
NMC
BCDMS
x=0.013 c_{13}=30
x=0.02 c_{14}=23
x=0.032 c_{15}=18
x=0.05 c_{16}=14
x=0.08 c_{17}=10
x=0.13 c_{18}=8
x=0.18 c_{19}=6
x=0.25 c_{20}=4
x=0.4 c_{21}=4
x=0.65 c_{22}=9
QCD Fit (H1)
QCD Fit (H1+BCDMS)
extrapolated Fits
H1 Collaboration
1
10
10^2
10^3
10^4
10^{-1}
Q^2/GeV^2

WE FIT PROTON TARGET DATA ONLY (NO d): 2+1 PARAMETRIZATIONS

"VALENCE QUARKS" $V = \frac{3}{4} \cdot \frac{1}{1+\epsilon}[(3+2\epsilon)u_V - 2d_V + (5+2\epsilon)(\overline{u}-\overline{d})] \xrightarrow{\overline{u}=\overline{d},\epsilon=0} \frac{3}{4}(3u_v - 2d_v)$ $\int V dx$ FINITE

"SEA QUARKS" + GLUON $A = \frac{1}{4} \cdot \frac{1}{1+\epsilon}[4\overline{u} - (u_V - 2d_V) - 5(\overline{u}-\overline{d}) + 2\epsilon(\overline{u}+\overline{d})] \xrightarrow{\overline{u}=\overline{d},\epsilon=0} \overline{u} - \frac{1}{4}(u_v - 2d_v)$ $\int A dx = \infty$

EXTERNAL CONSTRAINTS: $s + \overline{s} = (\frac{1}{2}+\epsilon)\cdot(\overline{u}+\overline{d})$ $\epsilon = -0.08$ NuTeV

QUARK COUNTING $\int_0^1 V\, dx = 3 + \delta \cdot \frac{3}{4} \cdot \frac{5+2\epsilon}{1+\epsilon}$ $\leftarrow \delta = \int_0^1 (\overline{u}-\overline{d}) dx$ $\delta = -0.118 \pm 0.011$ NuSea

MOMENTUM CONSERVATION $\int_0^1 (\Sigma + xg)\, dx = 1$

GENERALIZED PAR'N ANSATZ:

@ INPUT SCALE Q_0^2

$$\left.\begin{array}{l} A(x,Q_0^2) \\ V(x,Q_0^2) \\ xg(x,Q_0^2) \end{array}\right\} \; xq(x) = a_q x^{b_q}(1-x)^{c_q}[1 + d_q\sqrt{x} + e_q x + f_q x^2]$$

$\chi^2(a, \ldots, f)$

FULL ERROR TREATMENT:

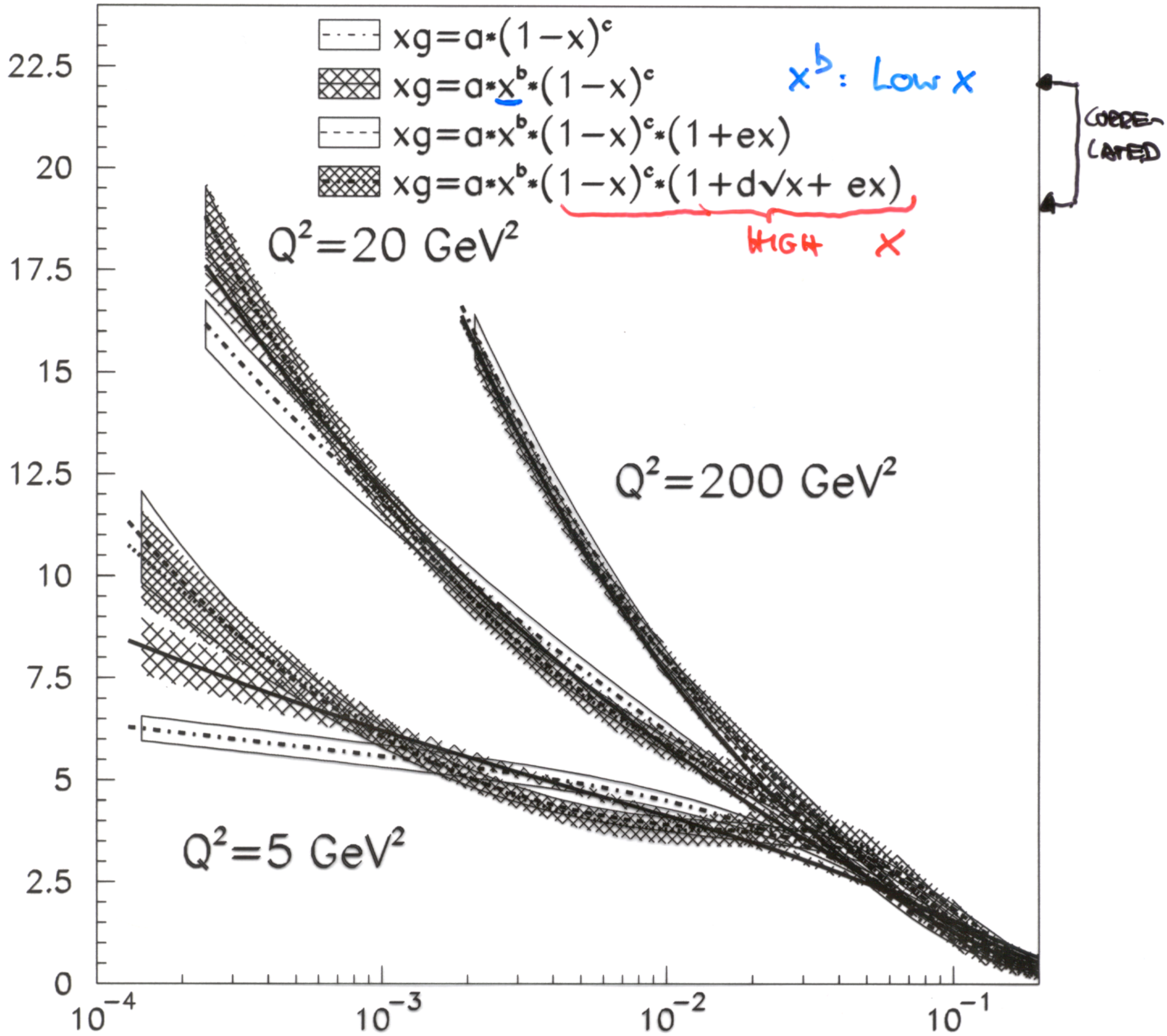
CROSS SECTION: EXP, THY — NORM — CORR. SYST. ERRORS — PENALTY

$$\chi^2 = \sum_k^{n_{exp}} \sum_i^{n_p(k)} \frac{[\sigma_{r,i}{}^{exp} - \sigma_{r,i}{}^{th} \times (1 - \nu_k \delta_k^{norm} - \Sigma_\lambda^{n_s(k)} s_{\lambda,k}\delta_{i\lambda}^{syst})]}{\delta_{i,sta}^2 + \delta_{i,unc}^2} + \sum_k \nu_k^2 + \sum_k \sum_\lambda (s_\lambda^{exp})^2$$

k: DATA SETS; i: DATA POINTS; UNCORR. ERRORS; $s_{\lambda,k}$: DETERMINED IN THE FIT

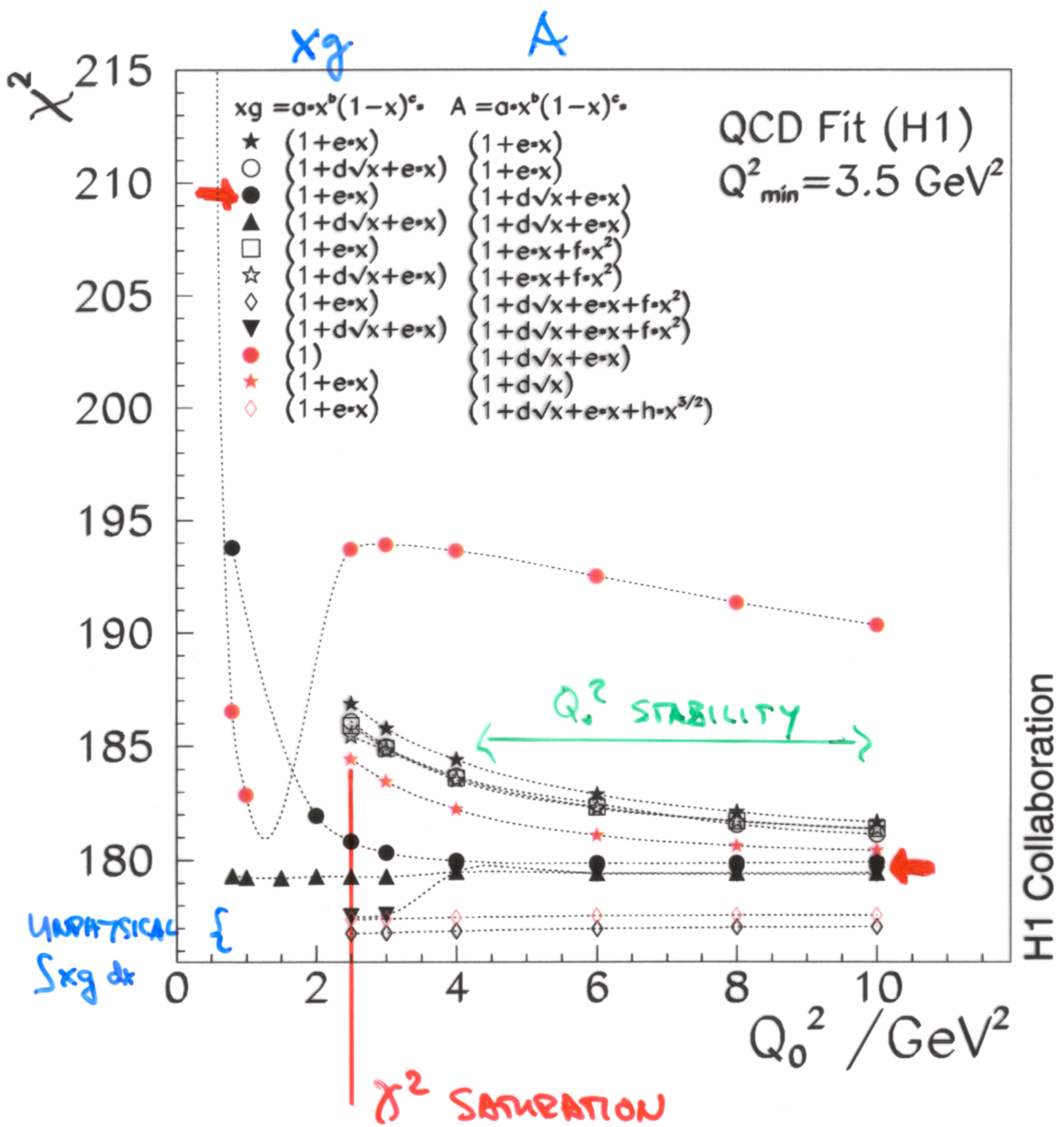
DGLAP DOES NOT PREDICT THE X-DEPENDENCE:

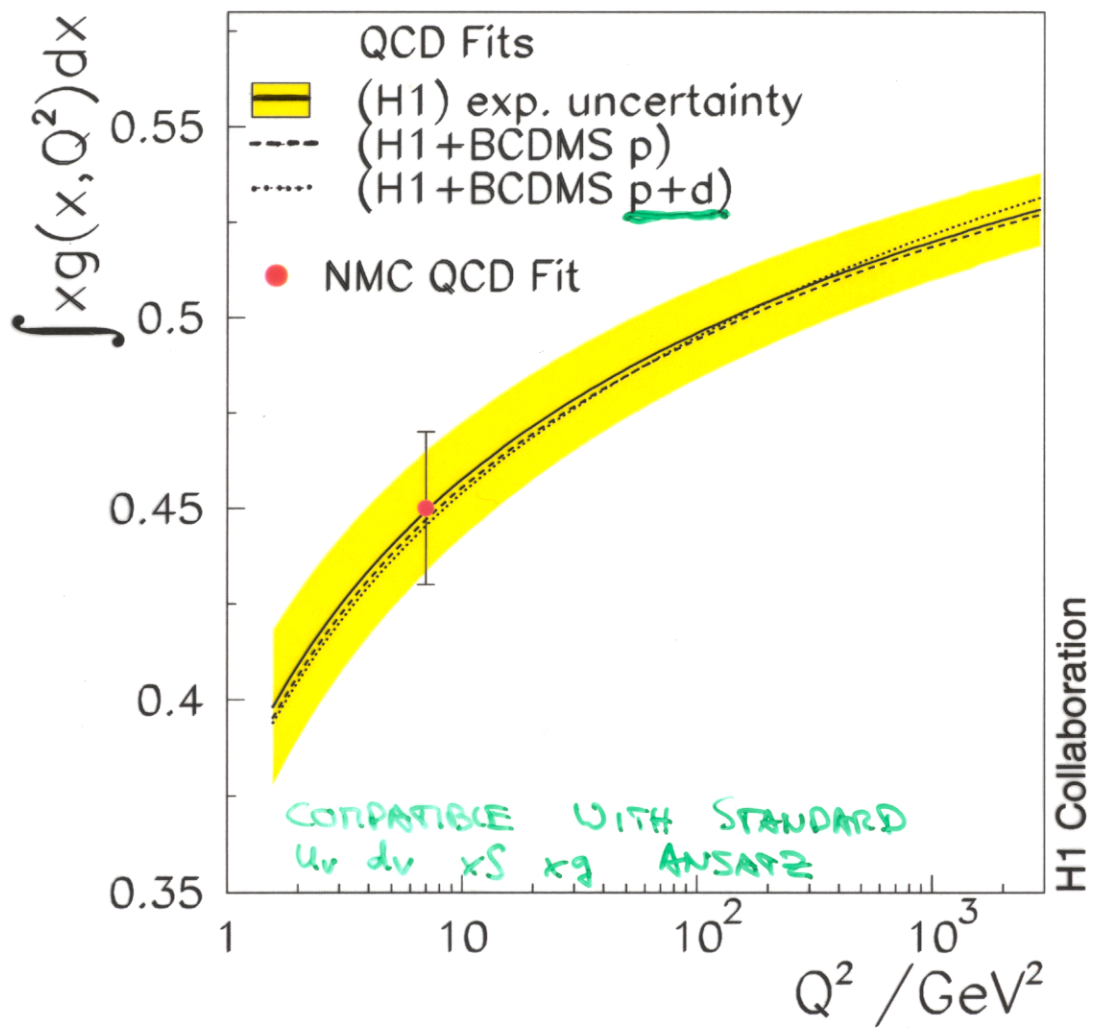
STUDY PARAMETRIZATION BIAS



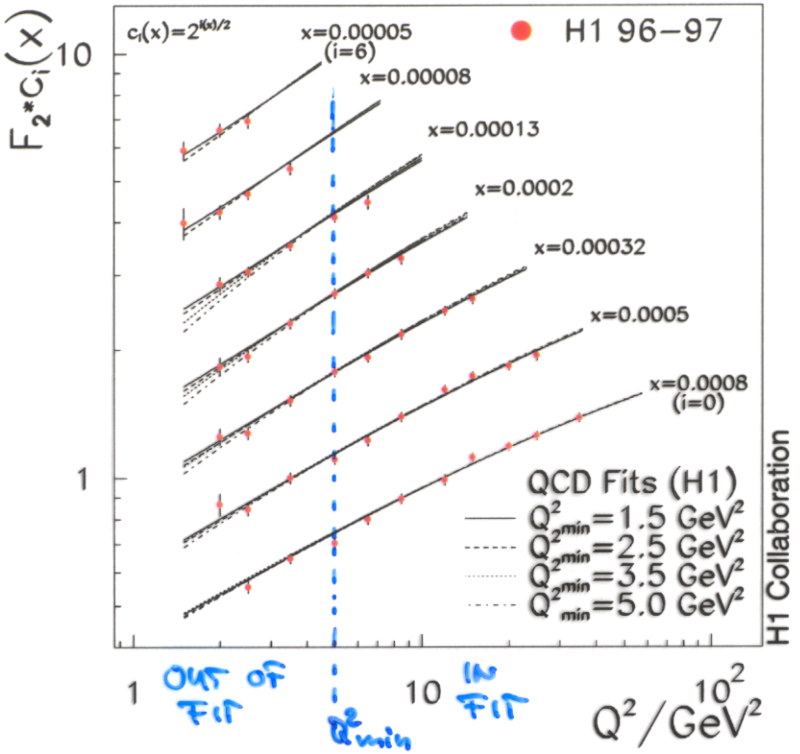
FIT 'PHILOSOPHY':

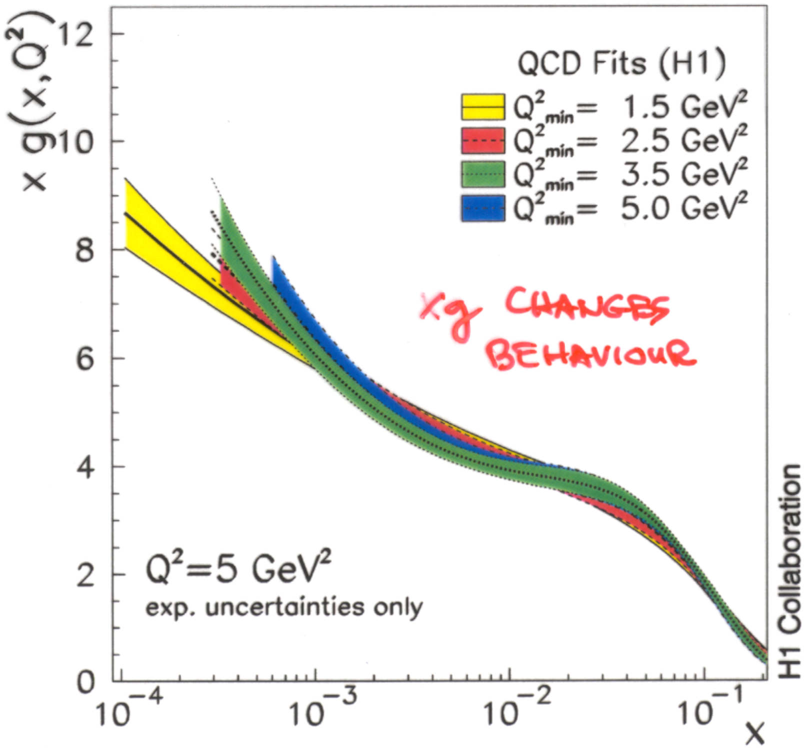
- SEEK MINIMAL AMOUNT OF PARAMETERS + DATASETS
- SEEK STABILITY WRT Q_0^2 VARIATION
- SEEK χ^2 SATURATION

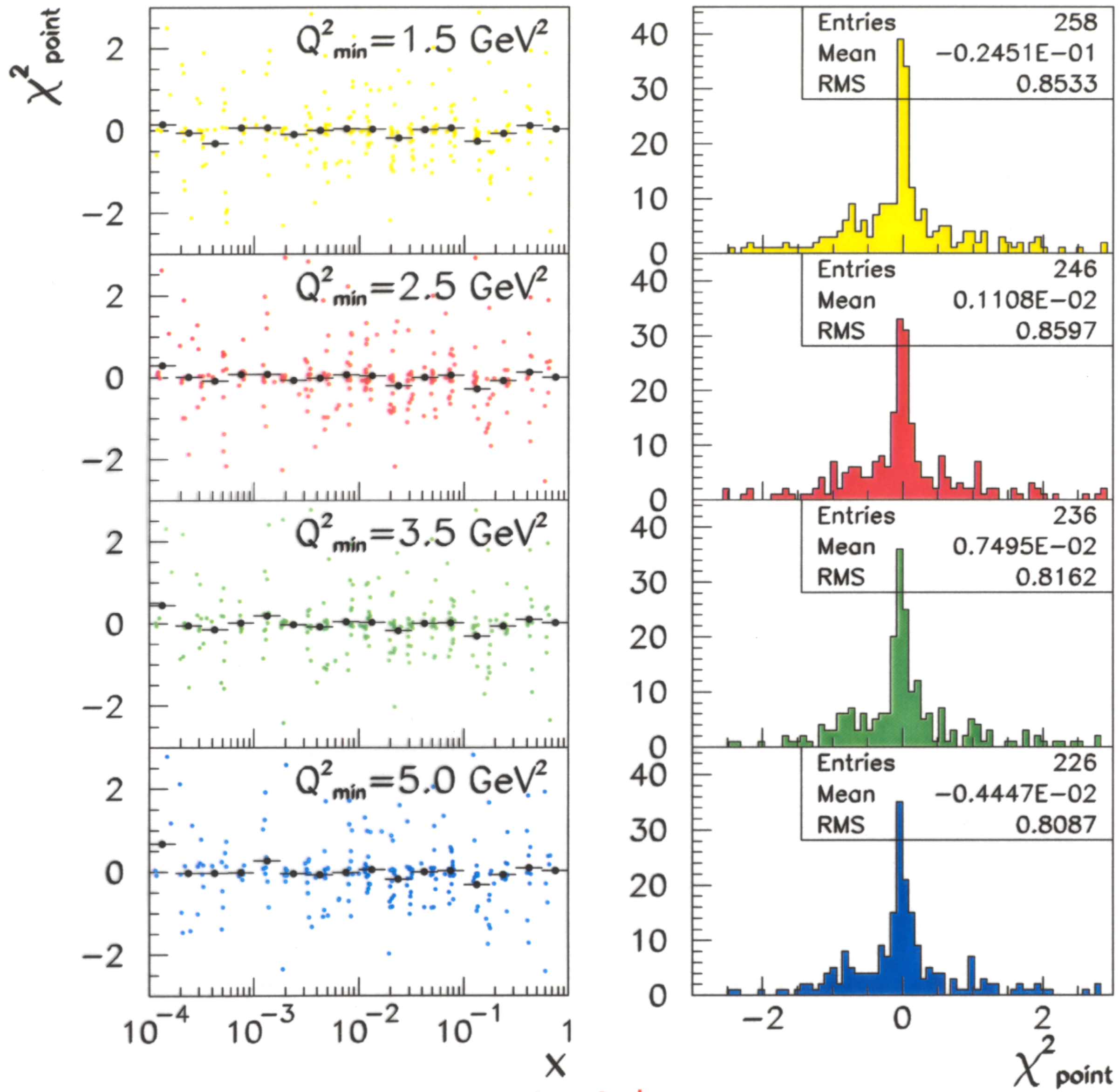

xg A
χ^2
xg =a·x^b(1−x)^c· A =a·x^b(1−x)^c·
(1+e·x) (1+e·x)
(1+d√x+e·x) (1+e·x)
(1+e·x) (1+d√x+e·x)
(1+d√x+e·x) (1+d√x+e·x)
(1+e·x) (1+e·x+f·x²)
(1+d√x+e·x) (1+e·x+f·x²)
(1+e·x) (1+d√x+e·x+f·x²)
(1+d√x+e·x) (1+d√x+e·x+f·x²)
(1) (1+d√x+e·x)
(1+e·x) (1+d√x)
(1+e·x) (1+d√x+e·x+h·x^3/2)
QCD Fit (H1)
Q^2_{min}=3.5 GeV²
Q₀² STABILITY
UNPHYSICAL ∫xg dx
χ^2 SATURATION
Q_0^2 /GeV²
H1 Collaboration


QCD Fits
(H1) exp. uncertainty
(H1+BCDMS p)
(H1+BCDMS p+d)
NMC QCD Fit
$\int xg(x,Q^2)dx$
COMPATIBLE WITH STANDARD
u_v d_v xS xg ANSATZ
Q^2 /GeV²
H1 Collaboration

DEPENDENCE ON Q^2_{min}

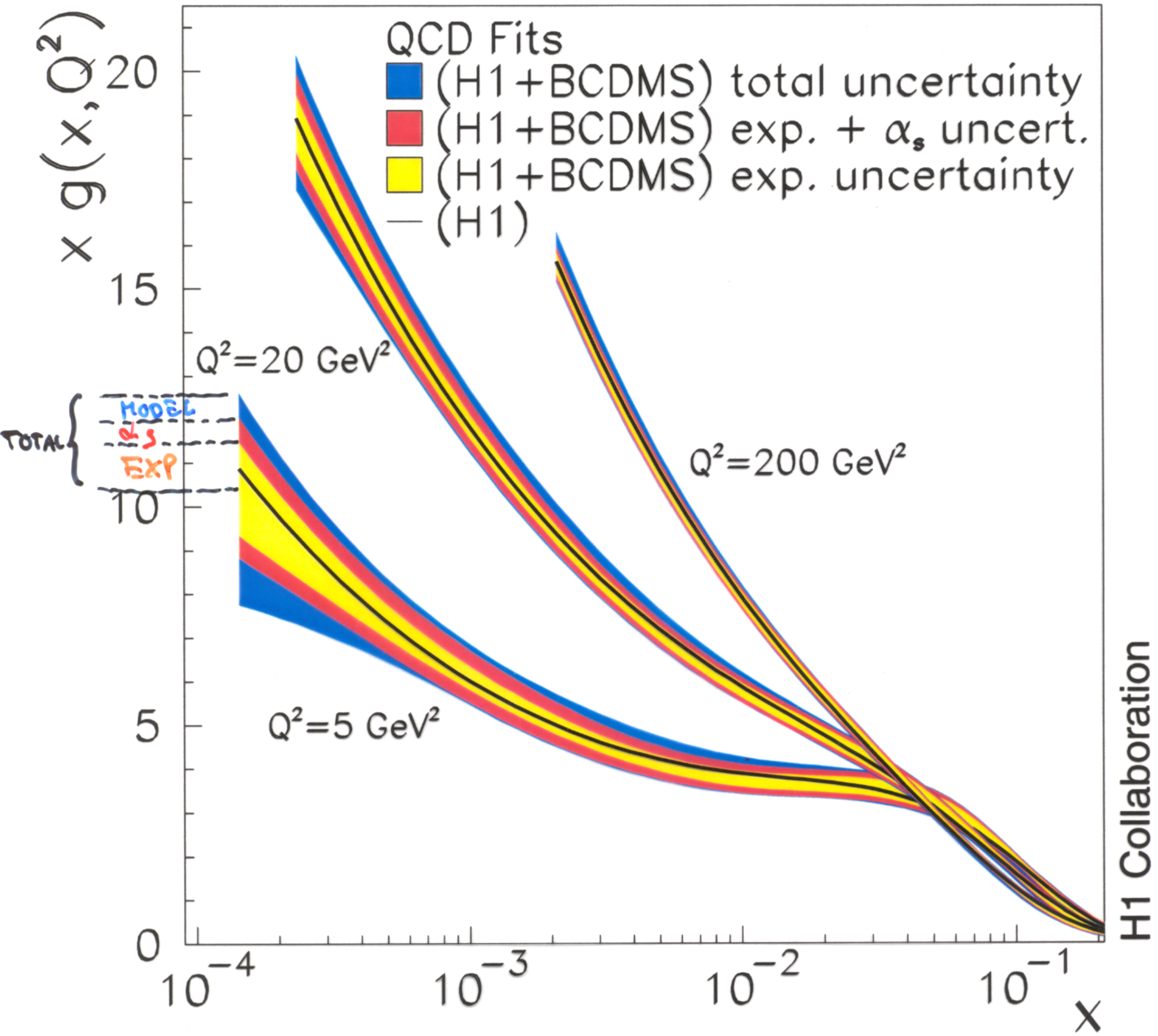






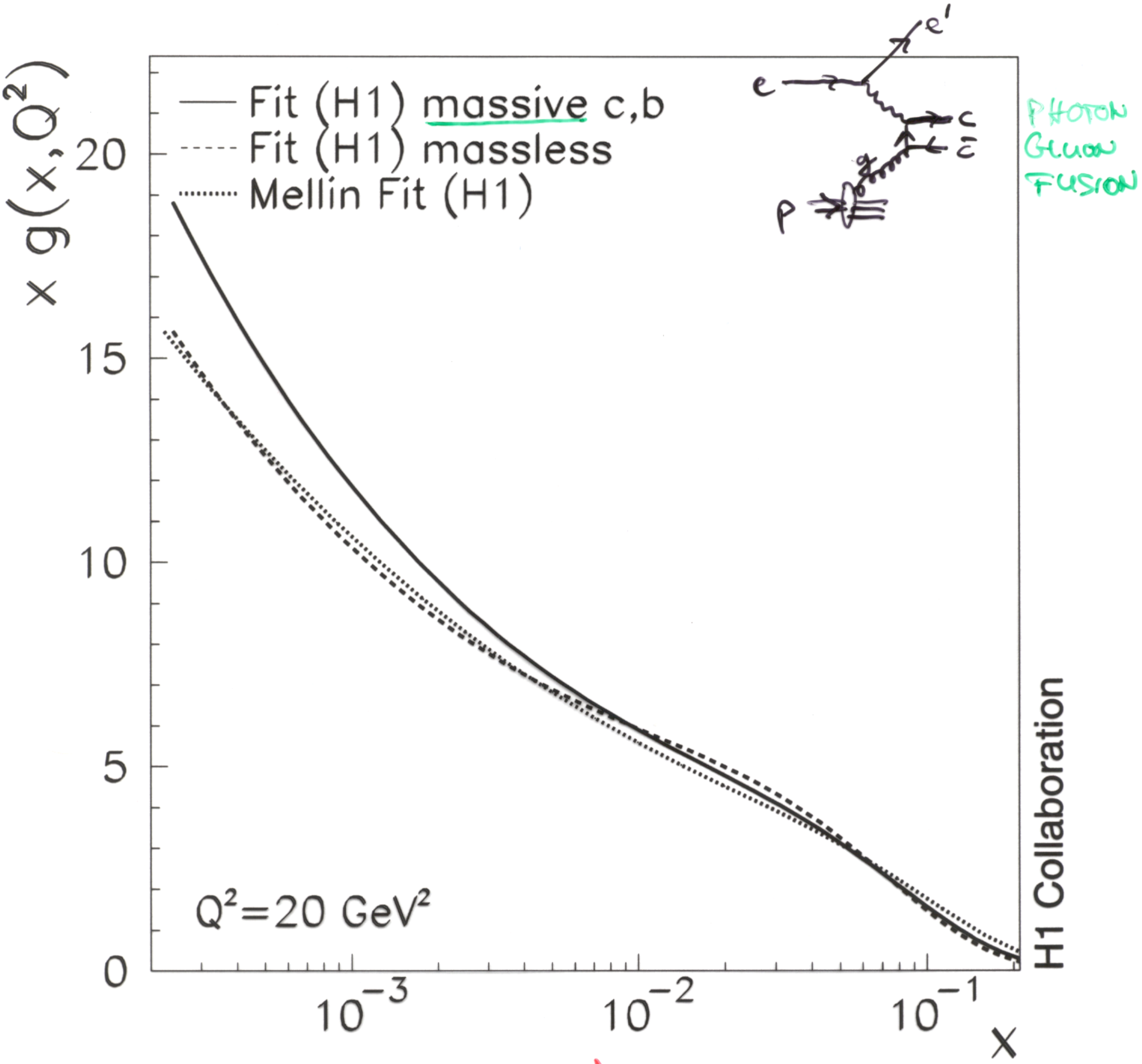
NO LOCAL LOW Q^2 / LOW x DEVIATIONS FOUND

Gluon from the H1 QCD Analyses

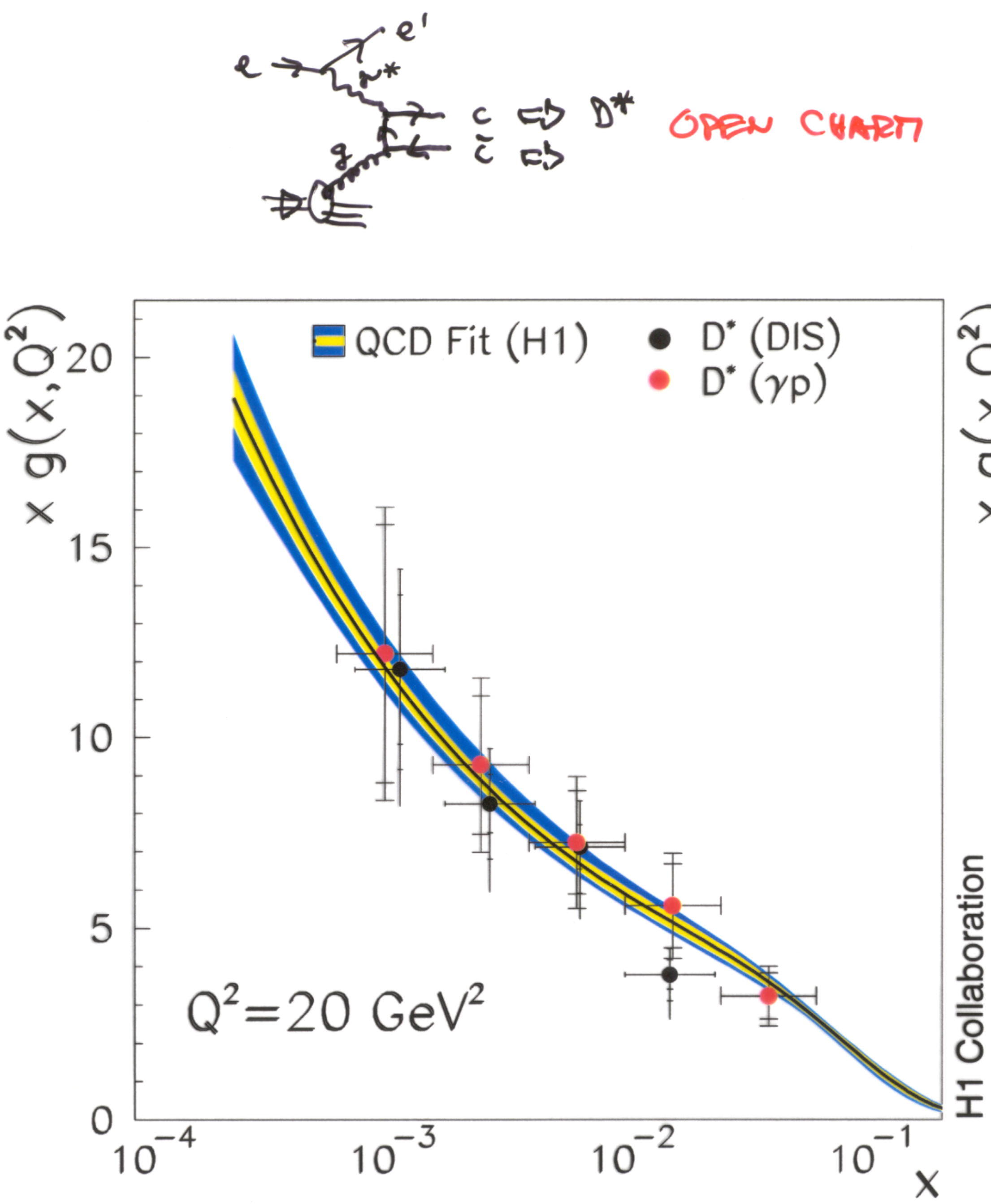


- First gluon extraction from H1 data alone!
- Gluon derived from H1 and H1+BCDMS data ($e^{+/-}p$) agree

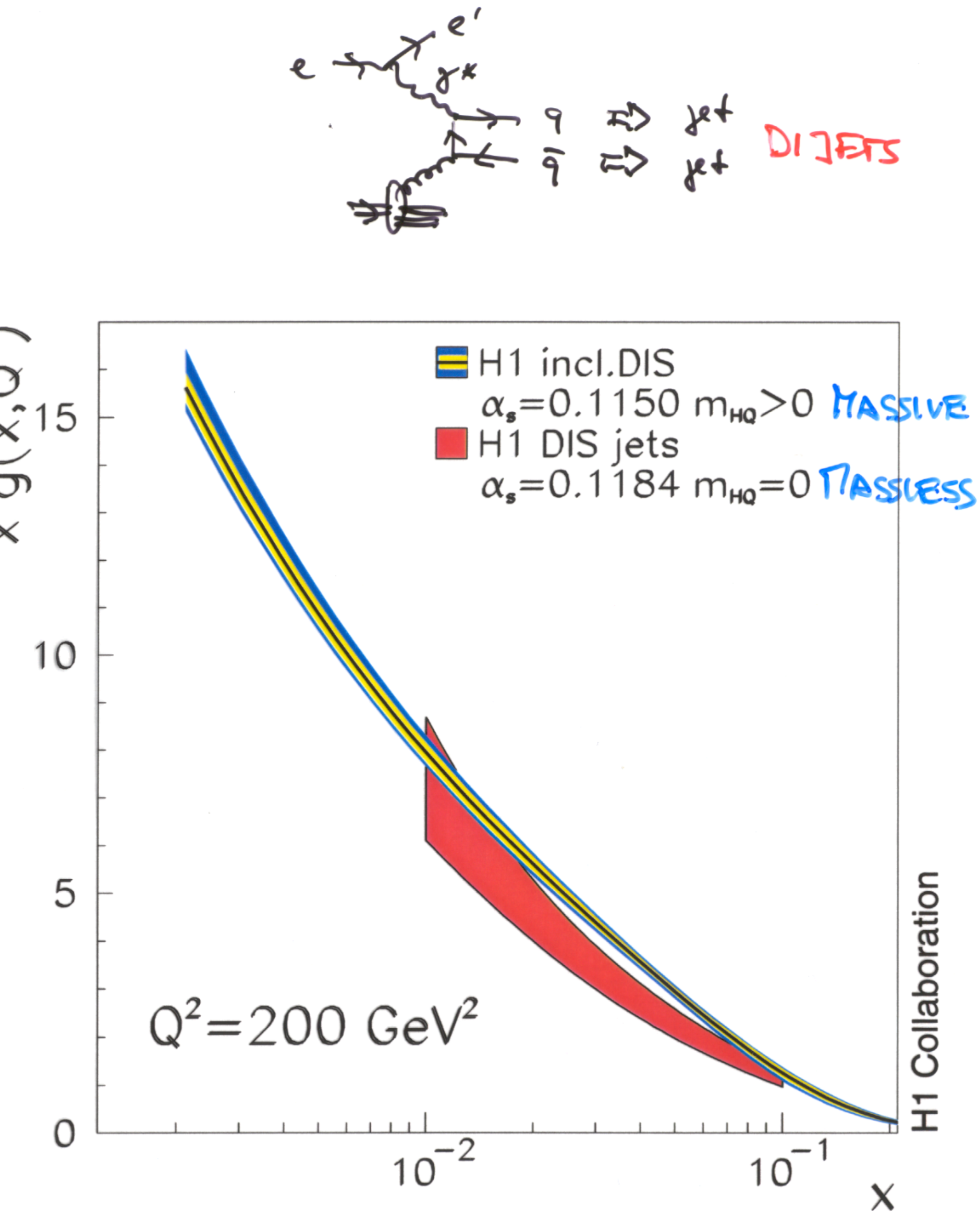
GLUON DEPENDS ON CHARM (& BOTTOM) TREATMENT



MASSIVE (m_c = 1.4 GeV) CHARM TREATMENT USED



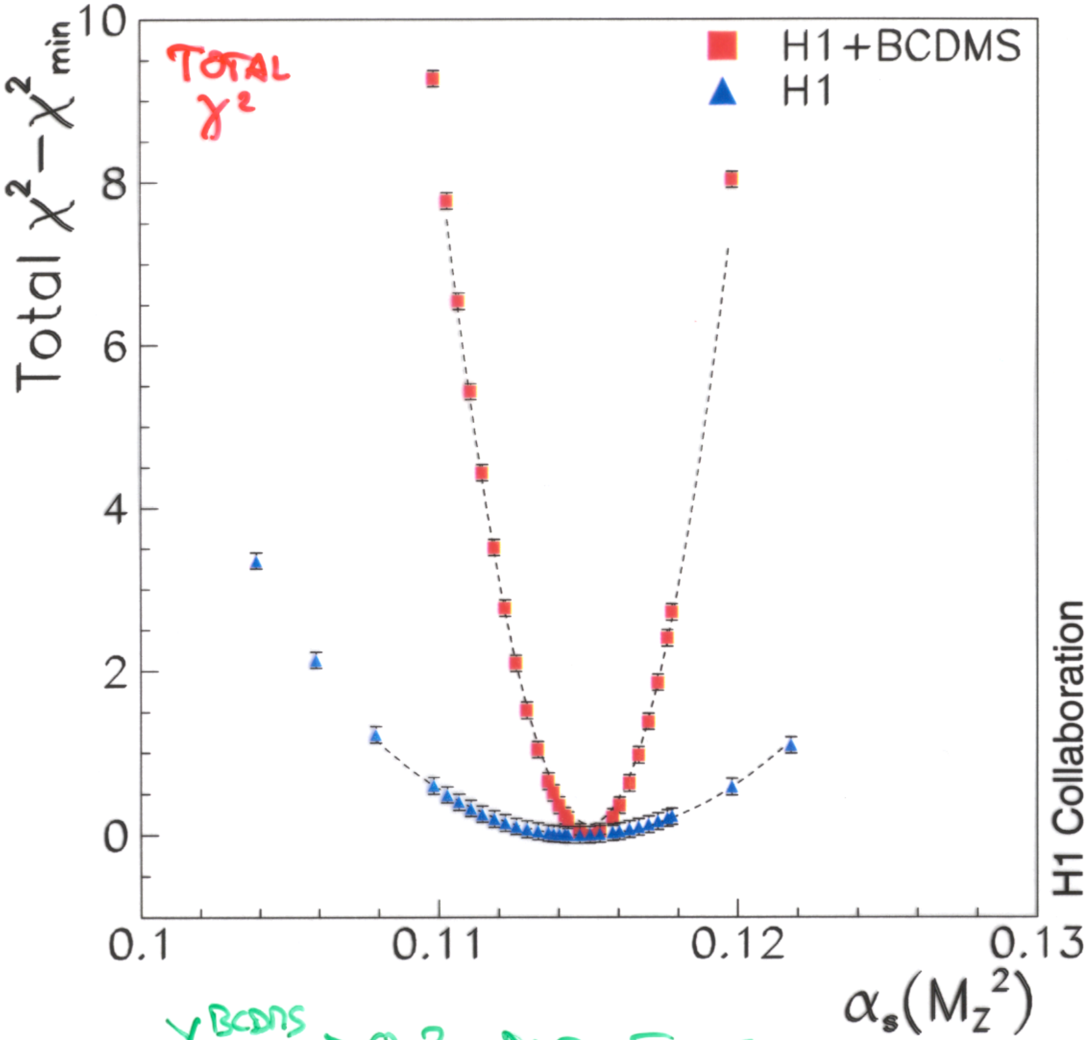
e
e'
c ⇒ D*
c̄ ⇒
g
OPEN CHARM
QCD Fit (H1)
D* (DIS)
D* (γp)
x g(x,Q²)
Q²=20 GeV²
x
H1 Collaboration

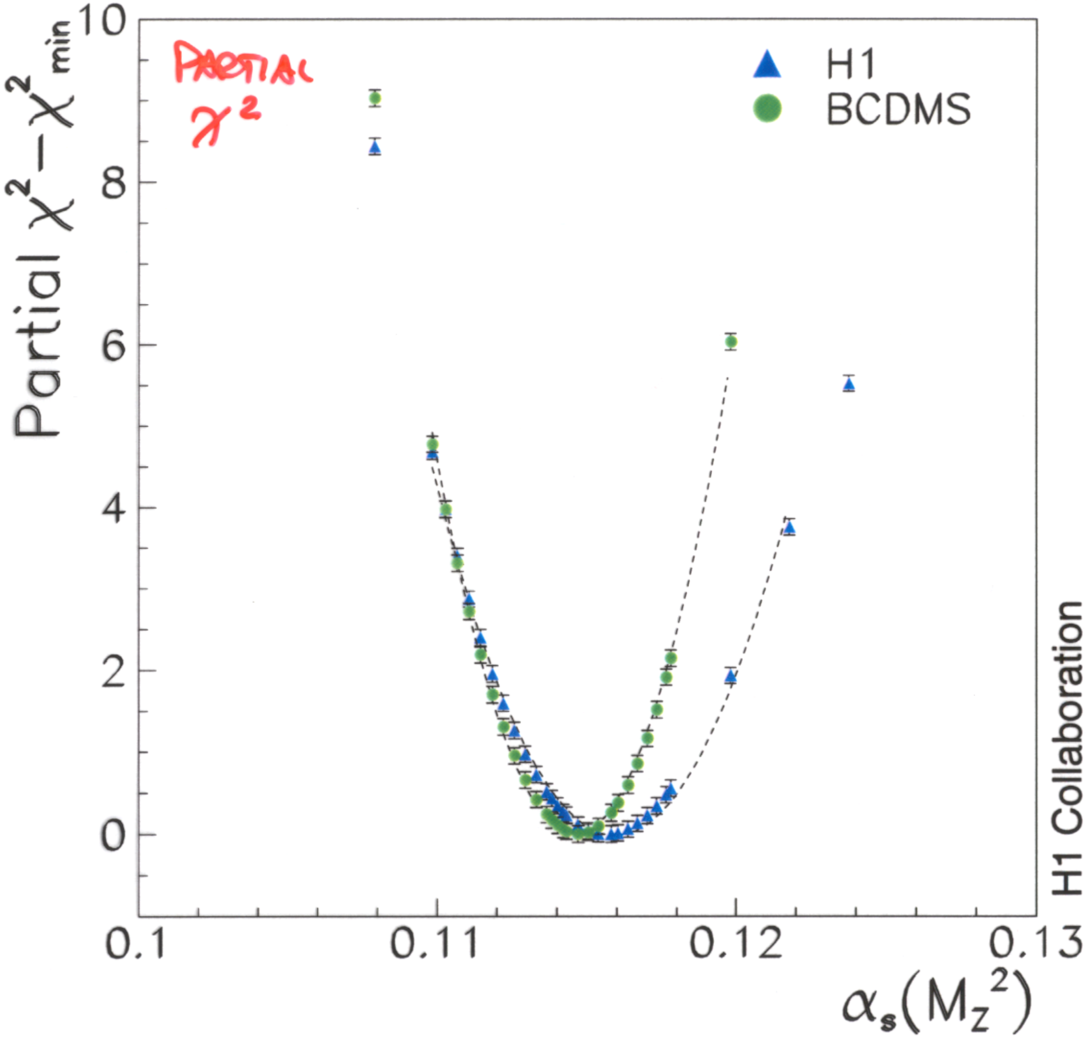


e
e'
γ*
q ⇒ jet
q̄ ⇒ jet
DIJETS
H1 incl.DIS
αs=0.1150 mHQ>0 MASSIVE
H1 DIS jets
αs=0.1184 mHQ=0 MASSLESS
x g(x,Q²)
Q²=200 GeV²
x
H1 Collaboration

α_s – Sensitivity:

We scanned parameter space
(Q_0^2, Q^2_{min}, α_s, data sets, syst. error treatment...)
$\gtrsim 10^5$ fits

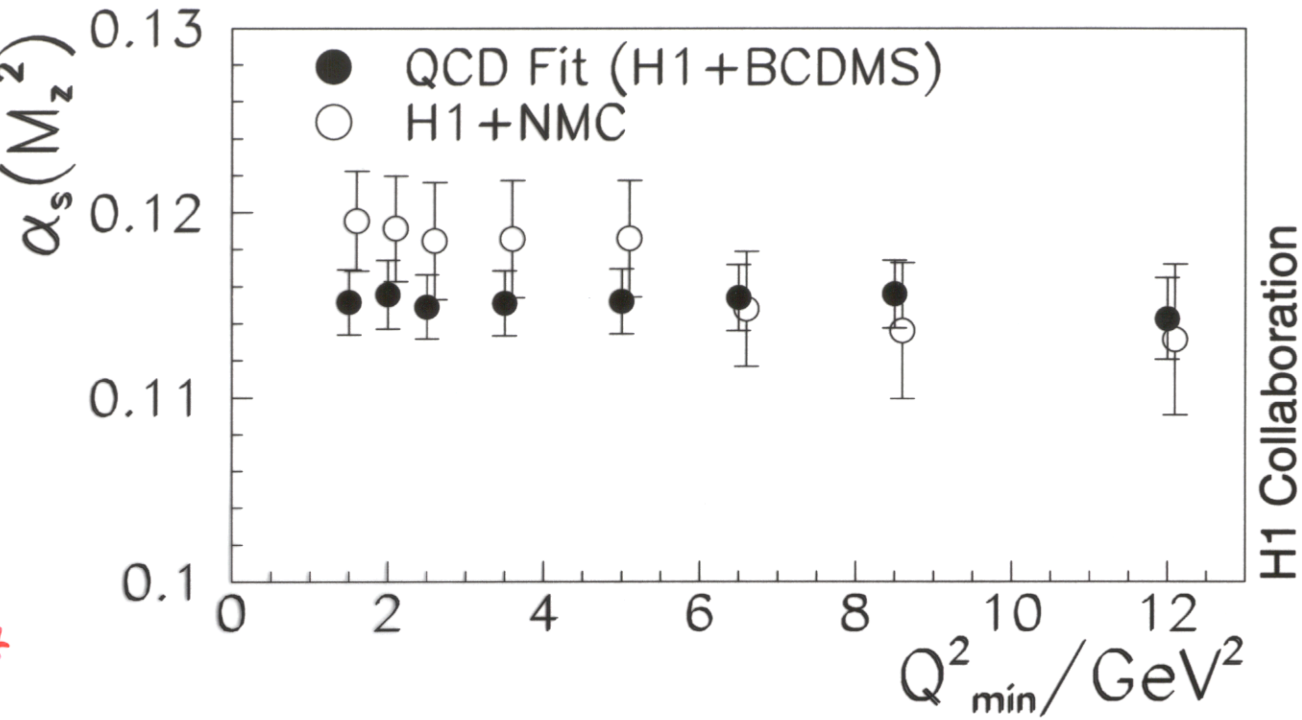




$y_\mu^{BCDMS} > 0.3$ due to systematics
SLAC discrepancy

α_s CROSS CHECK RESULTS:

- H1 ALONE 0.115 ± 0.005 (EXP)
- H1 + NMC ($Q^2 > 6.5\,GeV^2$) 0.116 ± 0.003 →
- H1 + BCDMS (p) 0.115 ± 0.0017
- H1 + BCDMS (p+d) 0.1158 ± 0.0016
- H1 + BCDMS (p) $m_{HQ} = 0$ 0.1153 ± 0.0017



COMPARISON TO RECENT DETERMINATIONS FROM INCLUSIVE DIS:

ALEKHIN	hep-ph 0011002	0.1165 ± 0.0017 (STAT + SYST) $^{+0.0026}_{-0.0034}$ (THY)	ALL $e^{+/-}p$ DIS, HIGHER TWIST, SYSTEMATICS
SANTIAGO YNDURAIN	hep-ph 0102247	0.1166 ± 0.0013 (EXP + HT)	F_2, xF_3, NNLO MOMENTS
KATAEV et al	hep-ph 9910378	0.118 ± 0.002 (STAT) ± 0.005 (SYST) ± 0.003 (THY)	NNLO xF_3

	ZEUS	H1
α_s	0.1172 prelim.	0.1150
errors:	$\pm$ 0.0008(stat) $\pm$ 0.0054(syst)	$\pm$ 0.0017 (exp) $^{+0.0009}_{-0.0005}$ (model)
sum:	0.0055	0.0020
scales:	?	$\approx$ 0.005

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 $\overline{u} - \overline{d}$	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

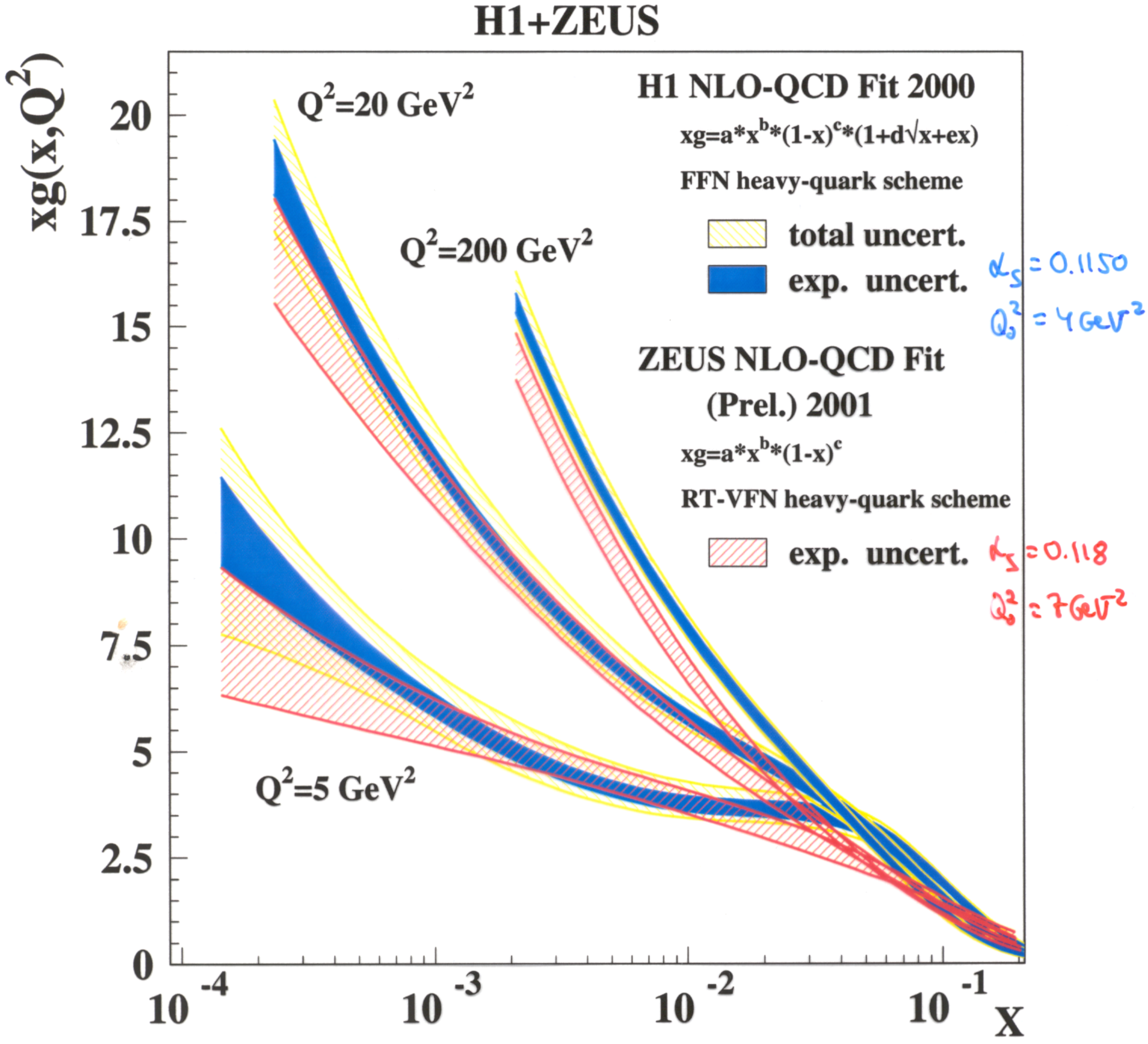
SCALE UNCERTAINTY

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

FACT. SCALE

RENORMALIZATION SCALE

Comparison H1 + ZEUS QCD Analyses

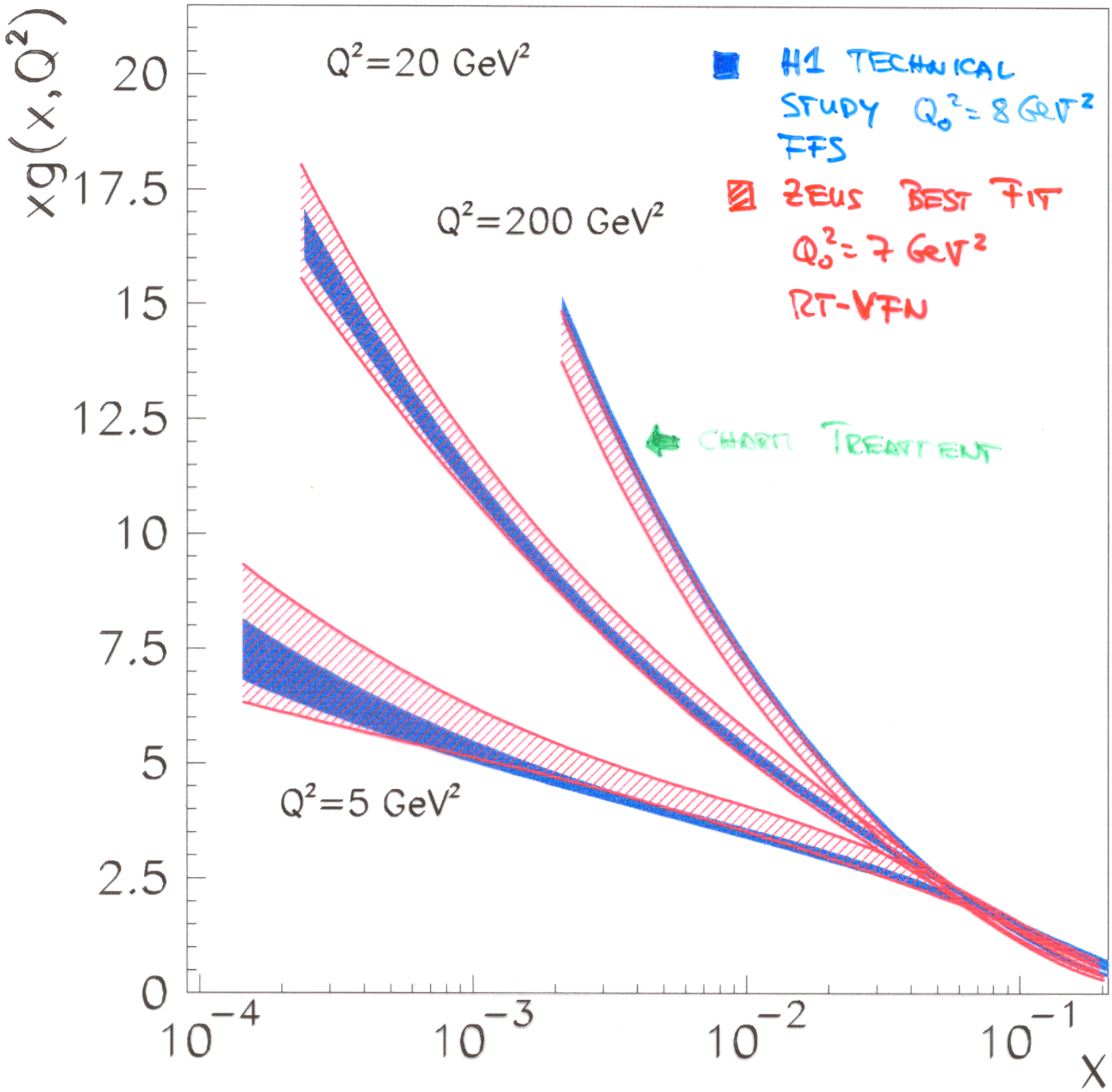


Differing Model Assumptions

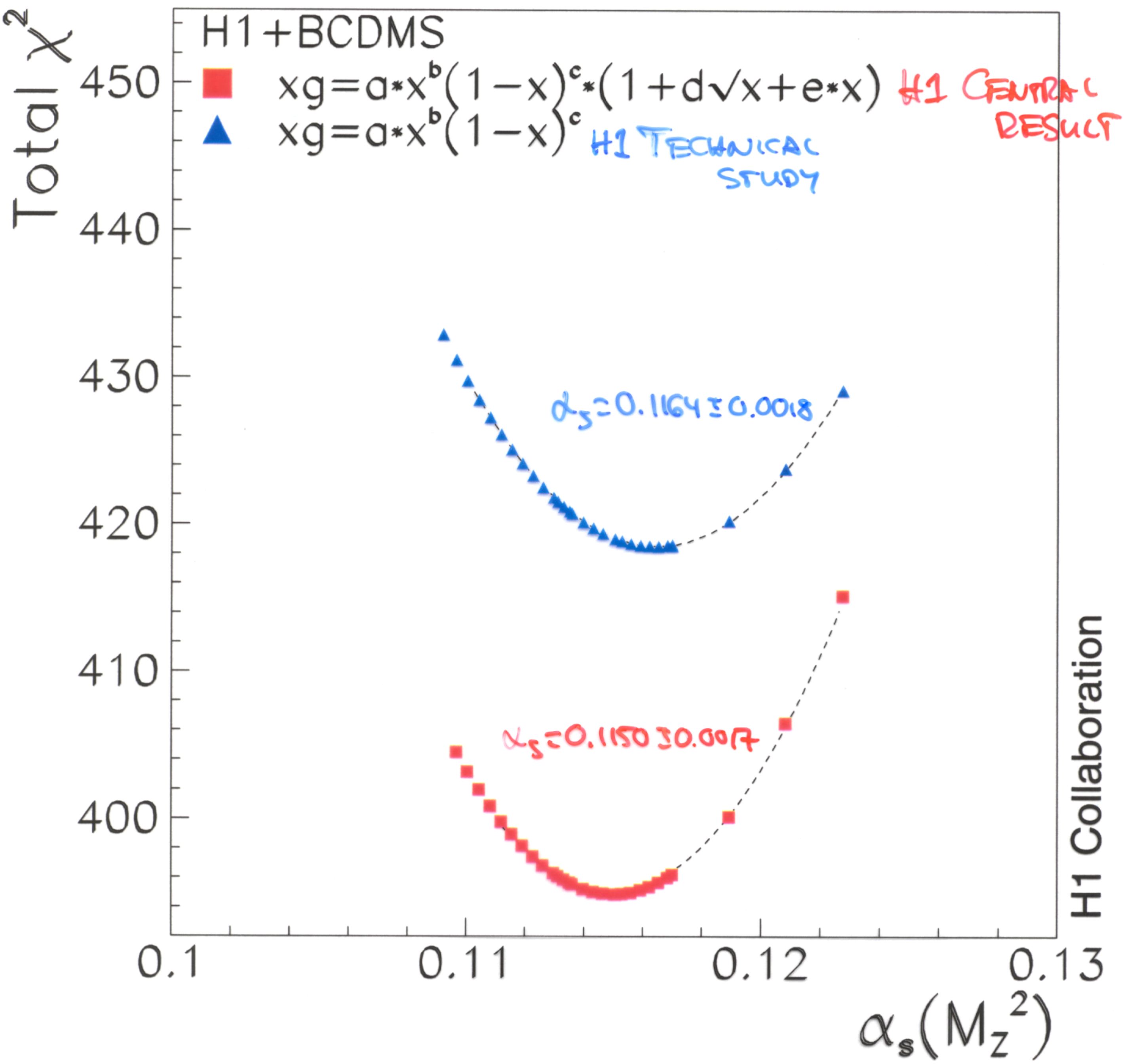
- Parametrization
- α_s, Q_0^2
- HQ Treatment...

H1 TECHNICAL CROSSCHECK:

STUDY WITH 3PARAMETER GLUON, FORCED $\alpha_s = 0.118$



AGREEMENT OF CENTRAL VALUES



3 PARAMETER GLUON ANSATZ DISFAVOURED

Summary

- Precision Measurement of the DIS cross section $ep \to eX$ at low Q^2 by H1 $\sigma_{stat} \leq 1\%,\ \sigma_{syst} \approx 3\%$

  Extension to low ($y \approx 0.003$) and high ($y \approx 0.9$) inelasticities

- NLO DGLAP QCD Fits to H1 (xg) and H1+BCDMS (α_s, xg) proton target data are successful

  Full experimental knowledge used for error propagation

- precision determination of the gluon distribution xg

  3-5% uncertaintly at low x, $Q^2 =$ 20 GeV^2

  xg from scaling violations consistent with xg from D*,Di-jets

- determination of α_s with high experimental precision

  $$\alpha_s^{NLO}(M_Z^2) = 0.1150\ \pm 0.0017\ (exp)^{+0.0009}_{-0.0005}\ (model) \pm 0.005\ (scales)$$

  dominating uncertainty: renormalization scale dependence $\leadsto$ NNLO