xq_{sea} and xg at $10^{-4} < x < 10^{-1}$: HERA

What's new?

New HERA F_2 measurement
$\rightarrow$ New H1 and ZEUS NLO-QCD fits

1. improved precision: typically stat.< 1 %, syst.~ 3 %
   $\rightarrow$ full accounting of experimental systematic uncertainties is now mandatory.

   $\Rightarrow$ H1/ZEUS NLO-QCD fits take point-to-point correlations of experimental systematic uncertainties fully into account.

2. wide kinematic range covered in Q^2
   Remind: xg is extracted from the scaling violation:

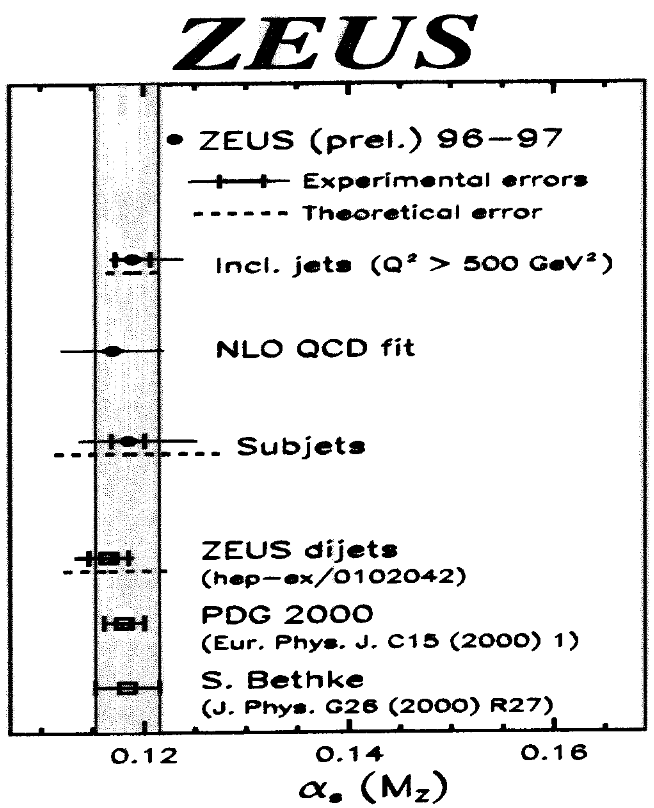
$$\begin{aligned} F_2 &\sim xq_{sea}, \\ \frac{dF_2}{d\ln Q^2} &\sim \alpha_s P_{qg} xg \end{aligned}$$

   $\rightarrow$ correlation between α_s and xg
   $\Rightarrow$ both α_s and xg were extracted simultaneously in H1/ZEUS NLO-QCD fits.

Well known problem in the past QCD fits

α_s determined from QCD fit tends to favour lower value
(e.g. BCDMS, PLB 274 (1992) 221: $\alpha_s = 0.113$)
$\rightarrow$ α_s was fixed to the world average in the fits.

Simultaneous extraction of α_s and xg

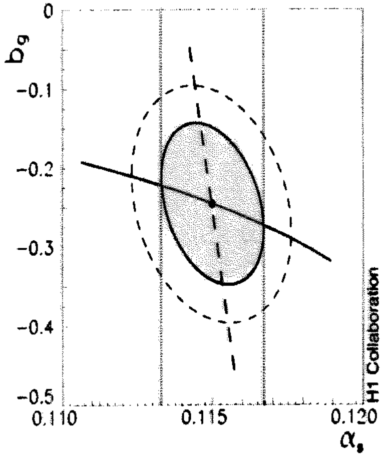


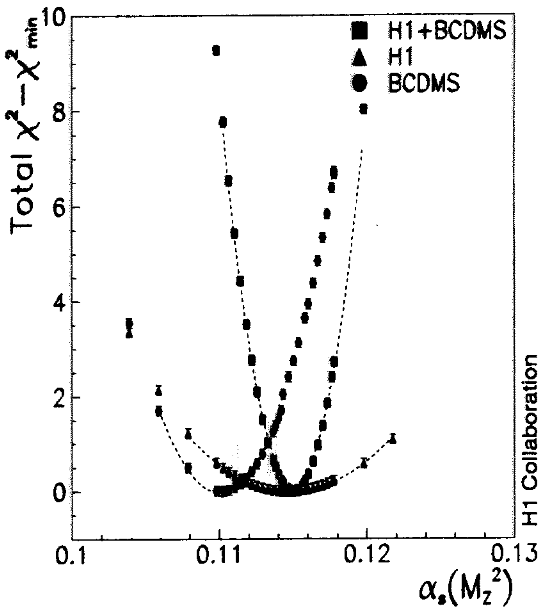
$$\alpha_s(M_Z^2) = 0.117 \pm 0.001(\text{stat.}) \pm 0.005(\text{syst.})$$

- Consistent with the world average.
- full accounting of correlated systematic errors
  $\Rightarrow$ no contradiction between α_s=0.120 as measured at LEP and as favoured by CDF jet cross-section.

correlation between α_s and xg

- $xg \sim x^{b_g}$ at low-x.

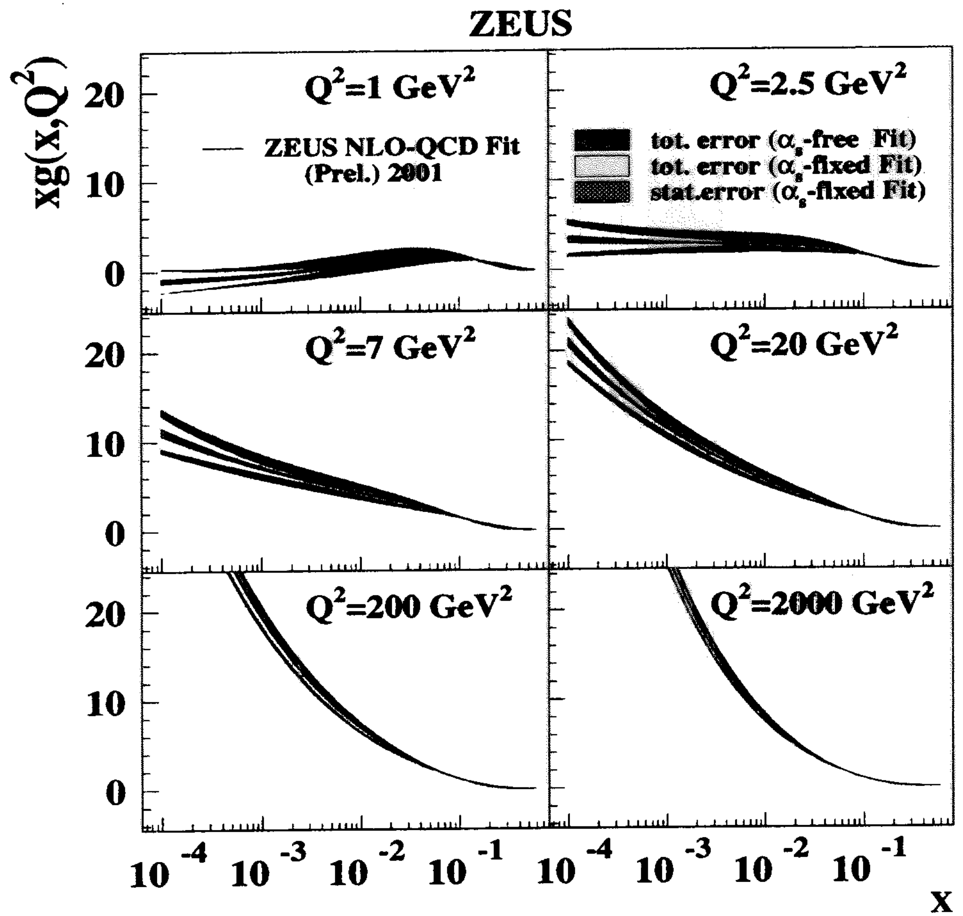


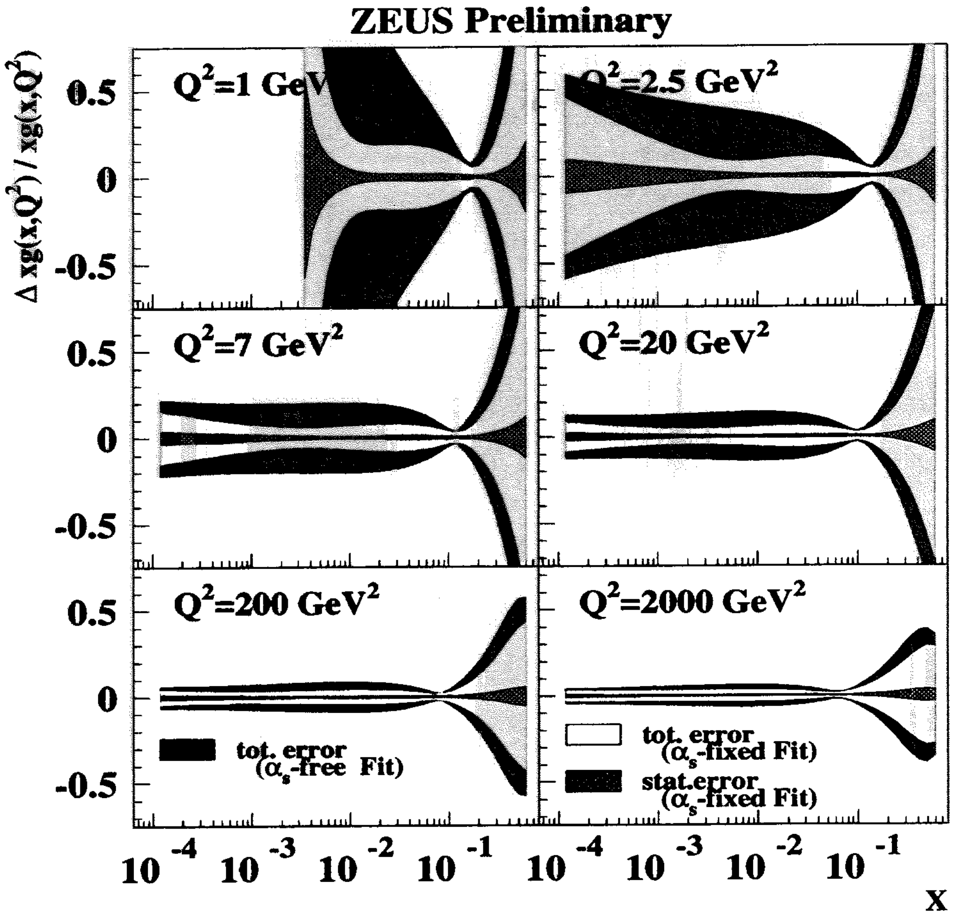


- A negative correlation between α_s and b_g which owes xg behaviour at low-x.
- Without HERA("BCDMS alone"),
  $\rightarrow$ b_g resulted in a positive value, i.e. valence like, with a small α_s

$\Rightarrow$ HERA provide xg at low-x and determine α_s!

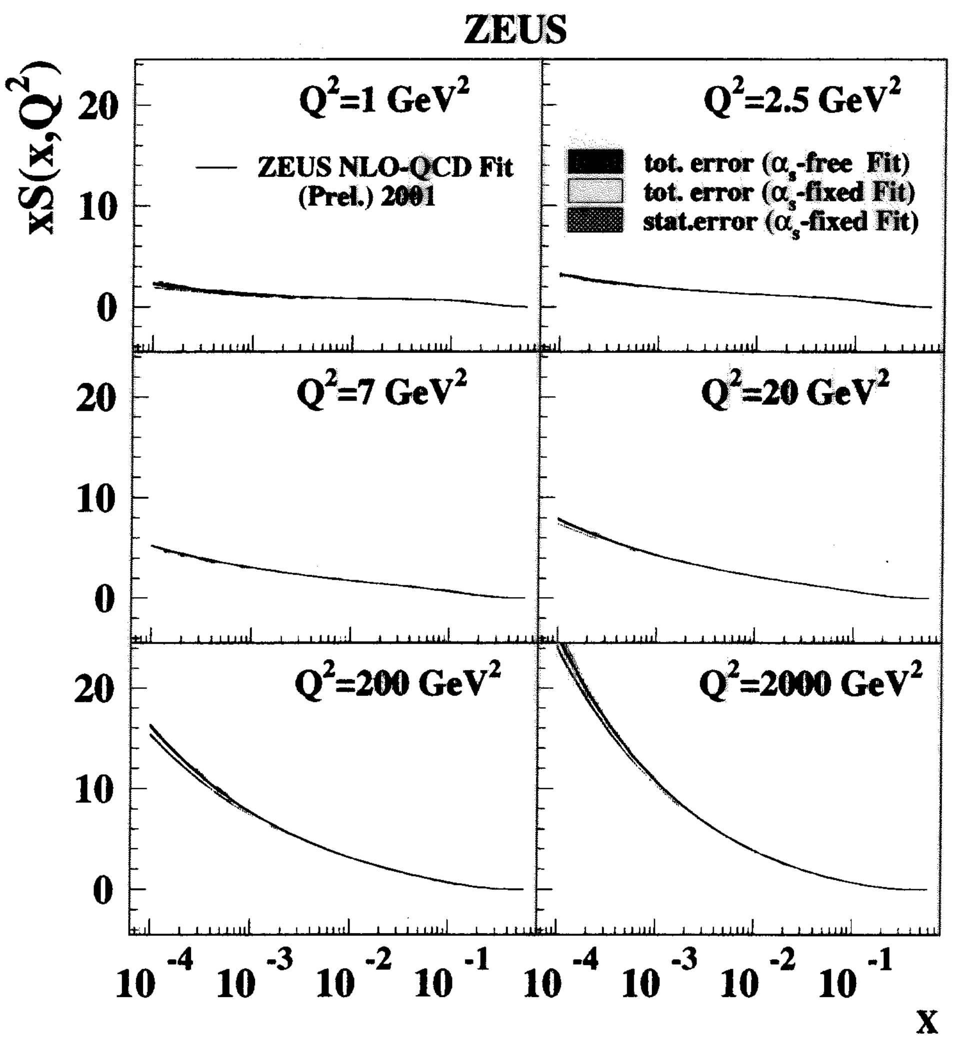
xg distribution

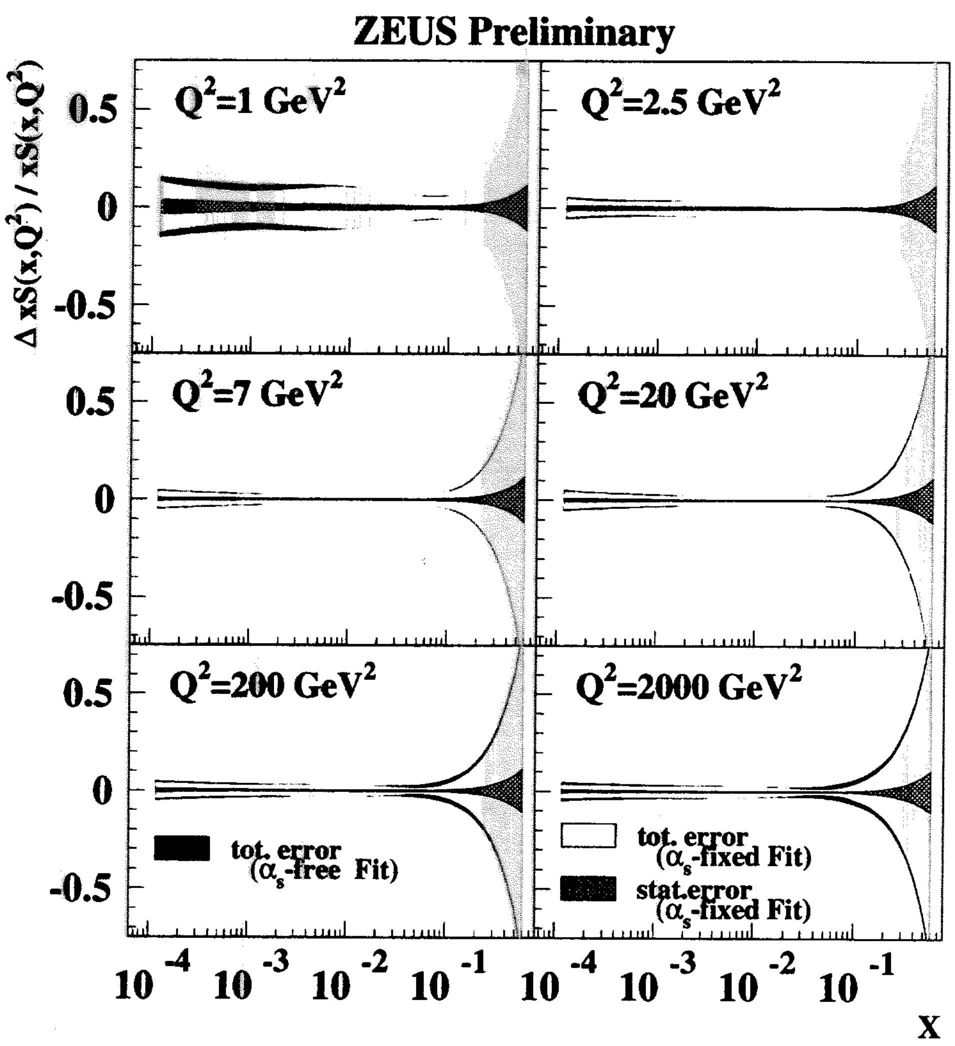




- Q^2 is great equaliser in DGLAP evolution: uncertainty is reduced as Q^2 evolves.
  $\Rightarrow$ important to check high-Q^2 at HERA-II with improved precision
- $10^{-3} < x < 10^{-1}$: well determined within $\lesssim 10\%$.
- $x \gtrsim 10^{-1}$: large uncertainty.$\Rightarrow$ no data constraint.(see later)

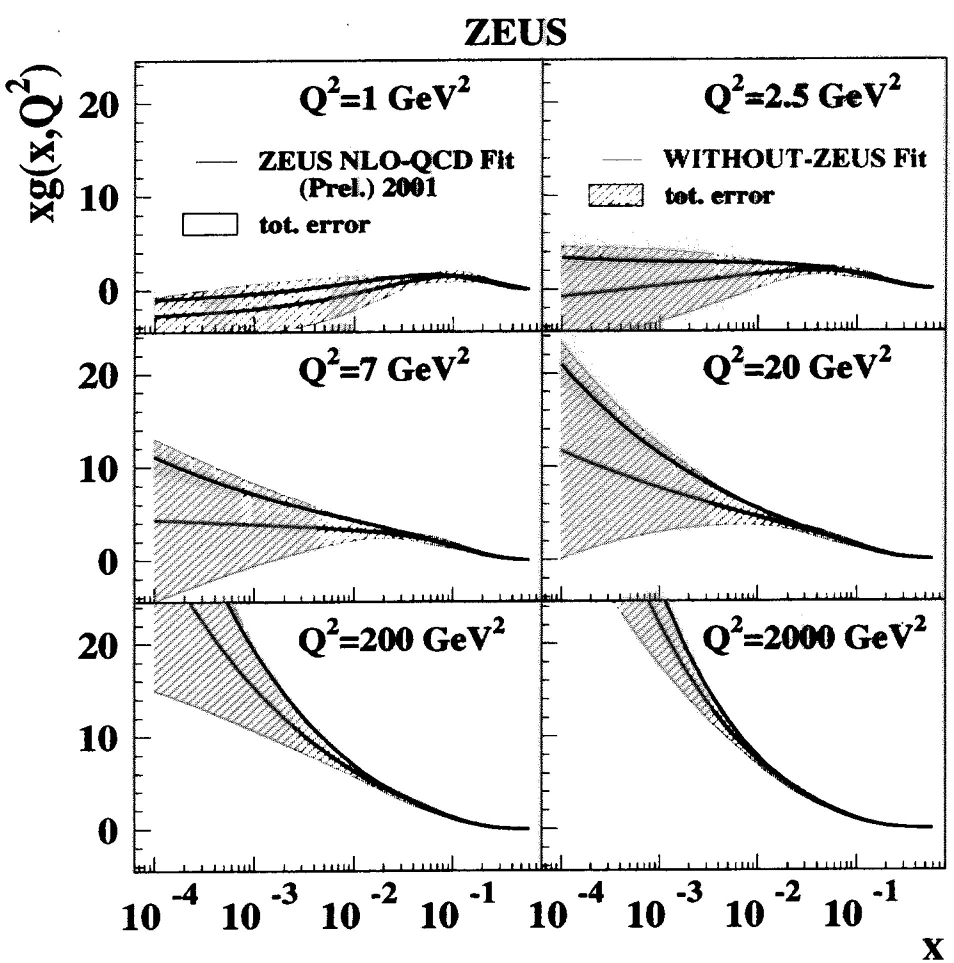
xq_{sea} distribution

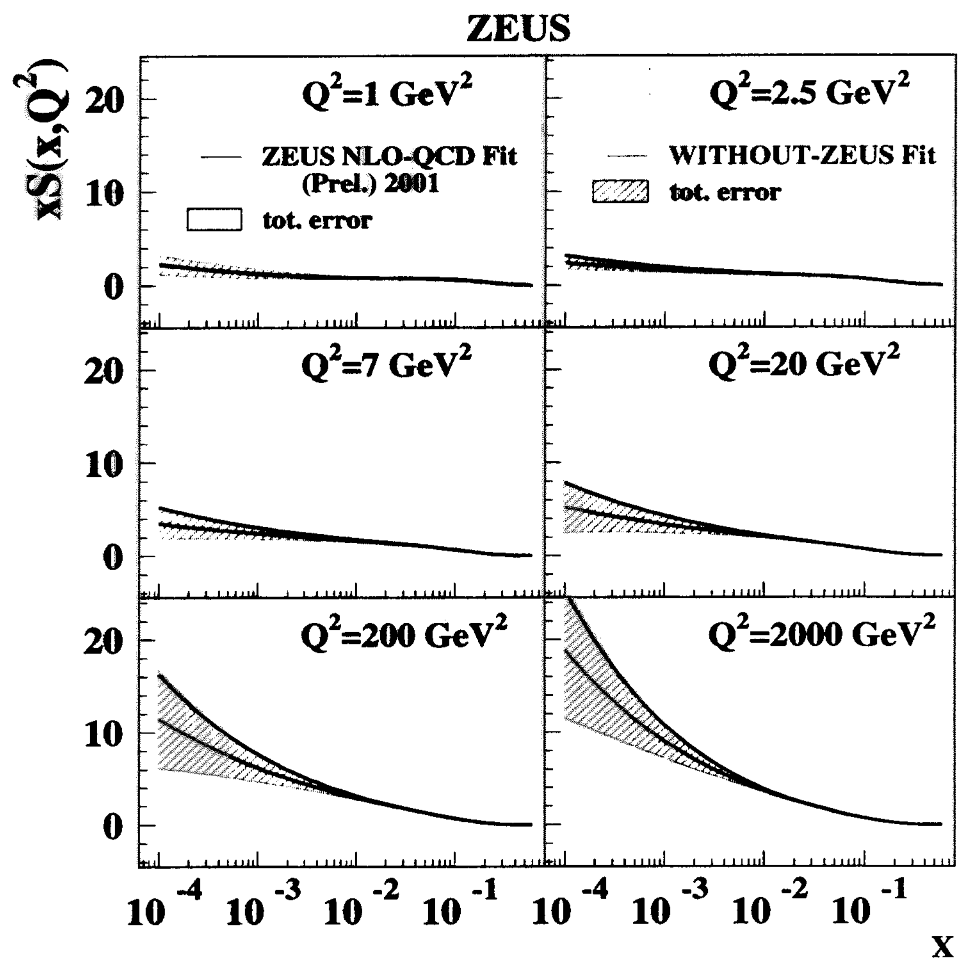




- uncertainty: typically $\lesssim$ 5%.

Sensitivity of HERA data to xg and xq_{sea}: without-HERA fit



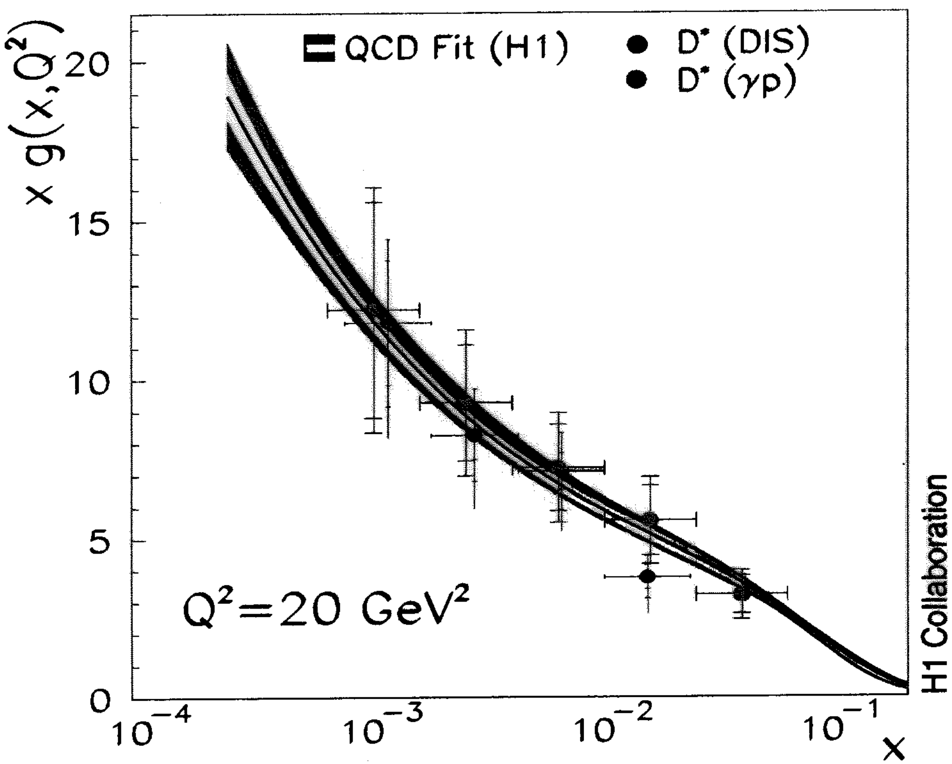


- Stronger rise than expected from fixed-target
  Remind: flat xg at low-x gives a small α_s e.g. BCDMS $\alpha_s = 0.113$.
- Much smaller uncertainties!

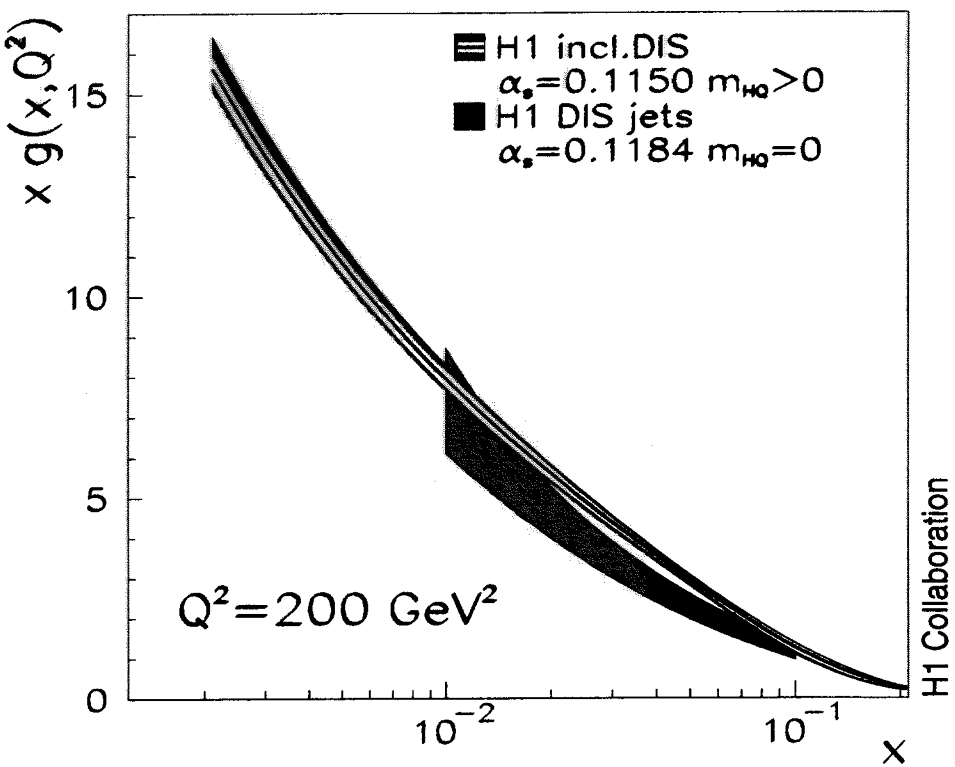
$\Rightarrow$ HERA determines xg and xq_{sea}.

xg cross checks

D^* in DIS and γP ($\gamma^{(*)}g \rightarrow cc$)



DIS jets ($\gamma^* g \rightarrow jj$)



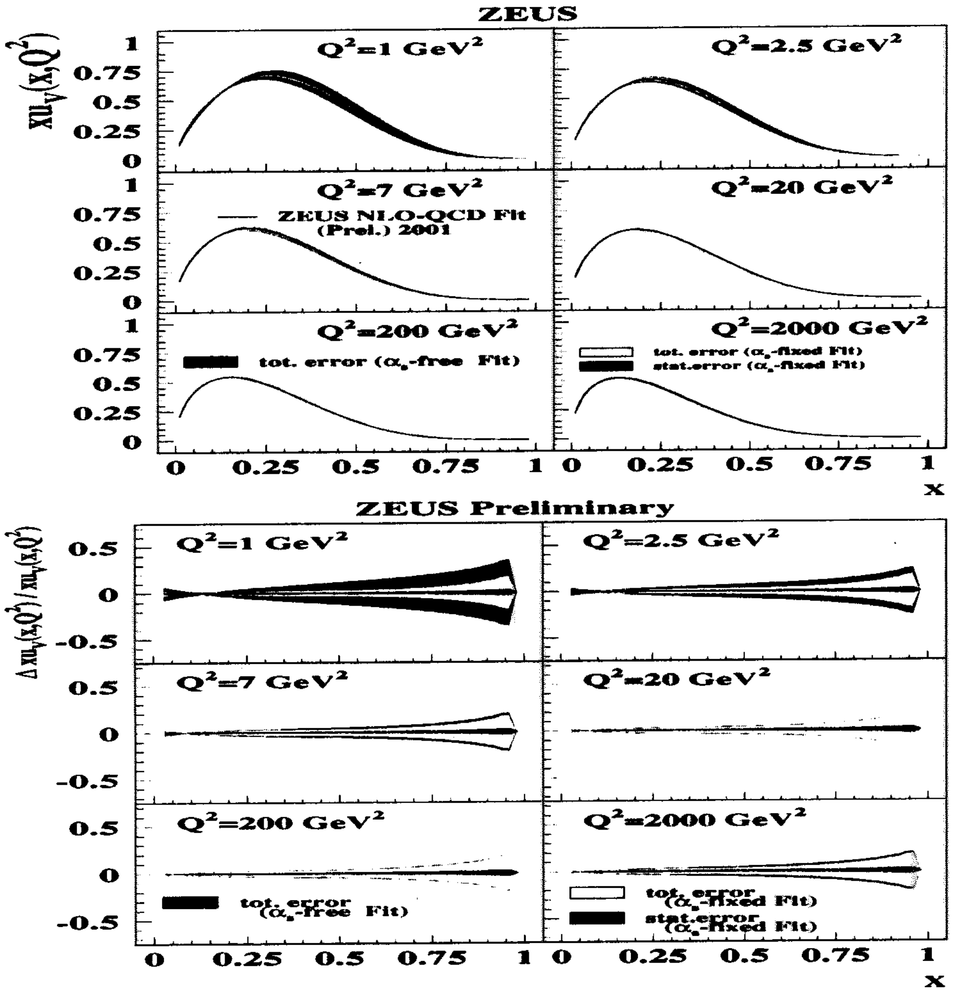
- xg from scaling violation is consistent with and is more precise than those obtained from D^* and DIS jets, i.e. exclusive processes.

$\Rightarrow$ Prospect: $\Delta(xg) = 3\%$ at HERA-II

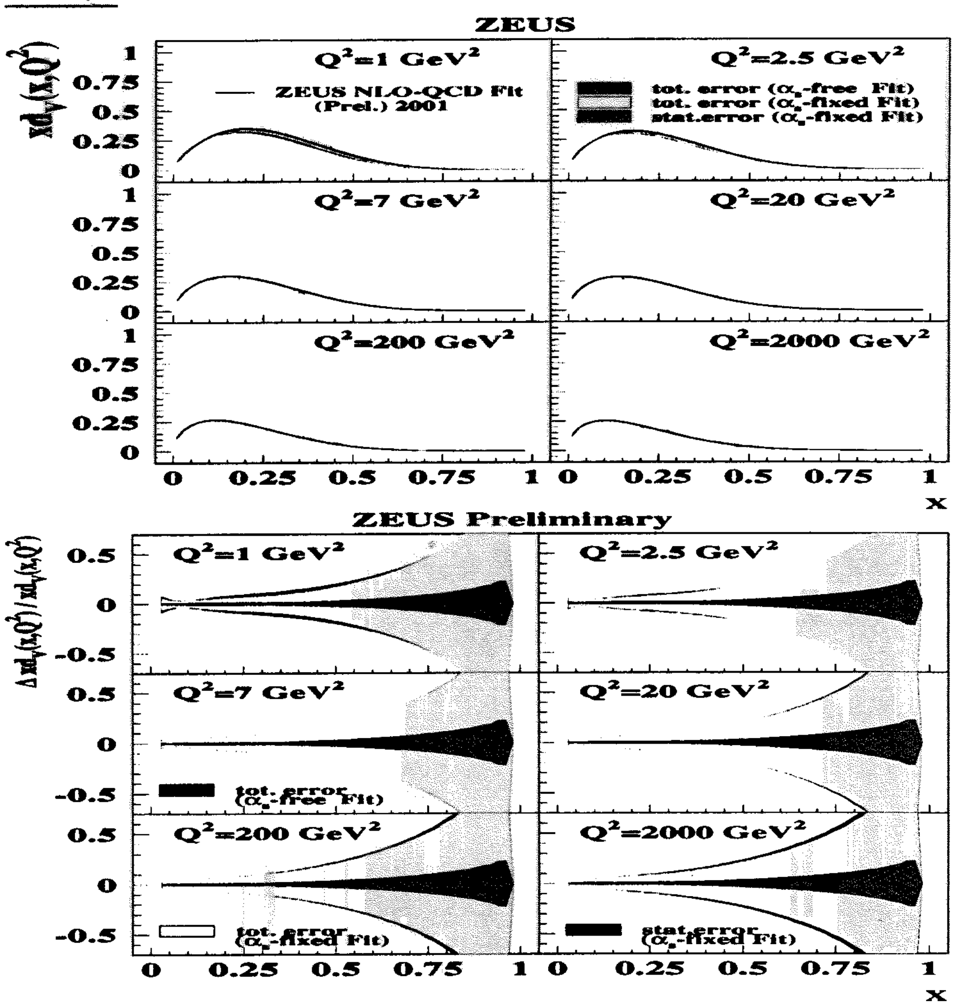
$\Rightarrow$ HERA-II: $\mathcal{L} = 1$ fb^{-1} in 2001 – 2005 with upgraded detectors (newly installed Silicon VTX detector will help c-tag)

large-x: valence distributions

xu_V



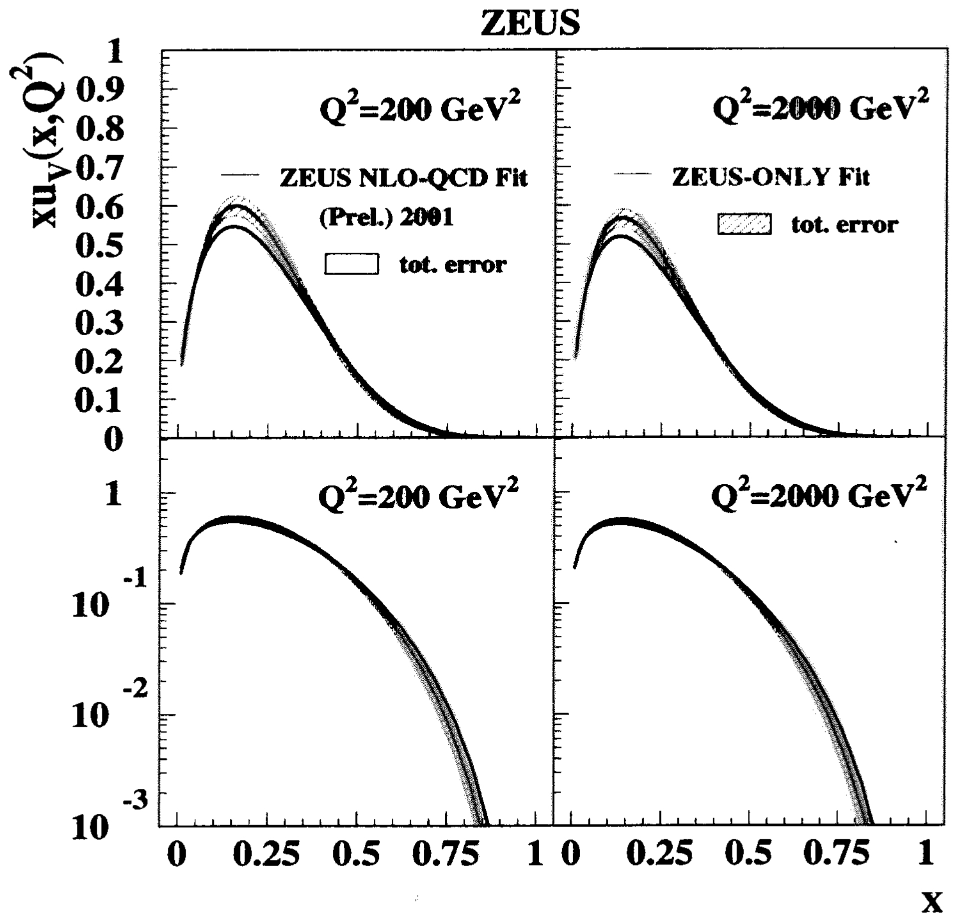
xd_V

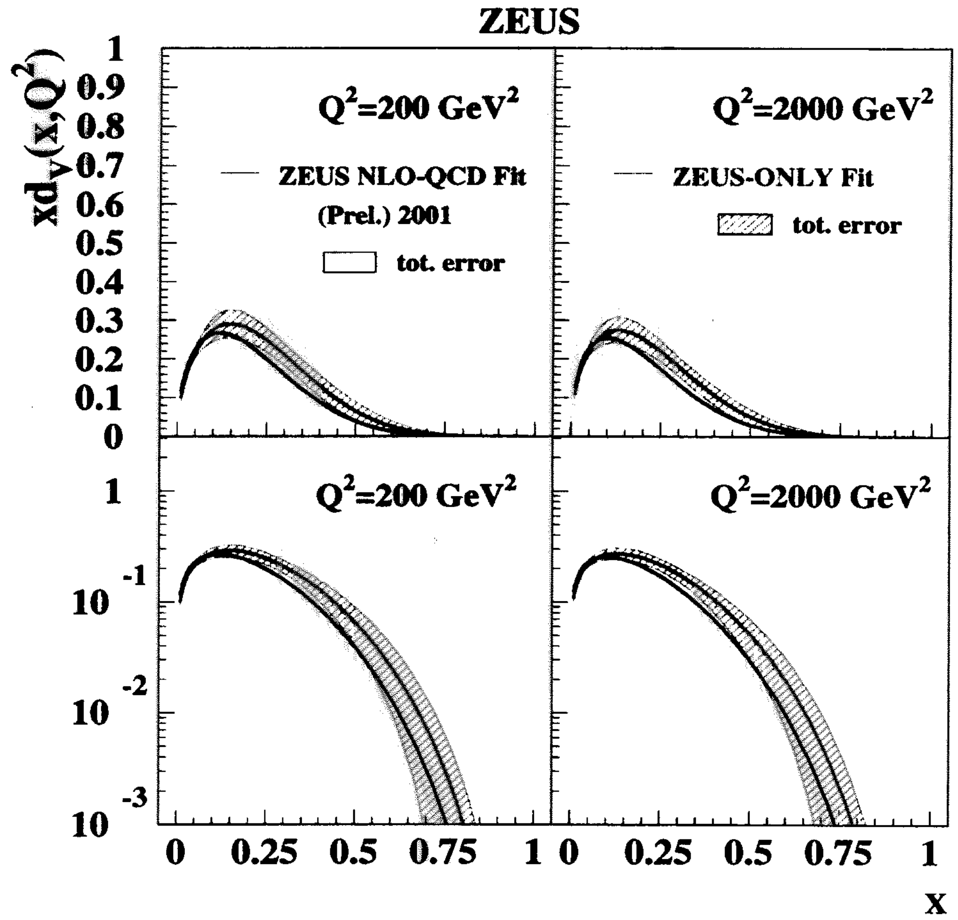


- xu_V: well determined within about 5% up to very large $x \sim 0.6$.
- xd_V: large error band compared to that of xU_V.

  Remind: $F_2^p \propto x(4u+d)$, $F_2^D \sim (F_2^p + F_2^n)/2 \propto x(u+d)$

ZEUS-ONLY fit [xu_V and xd_V]

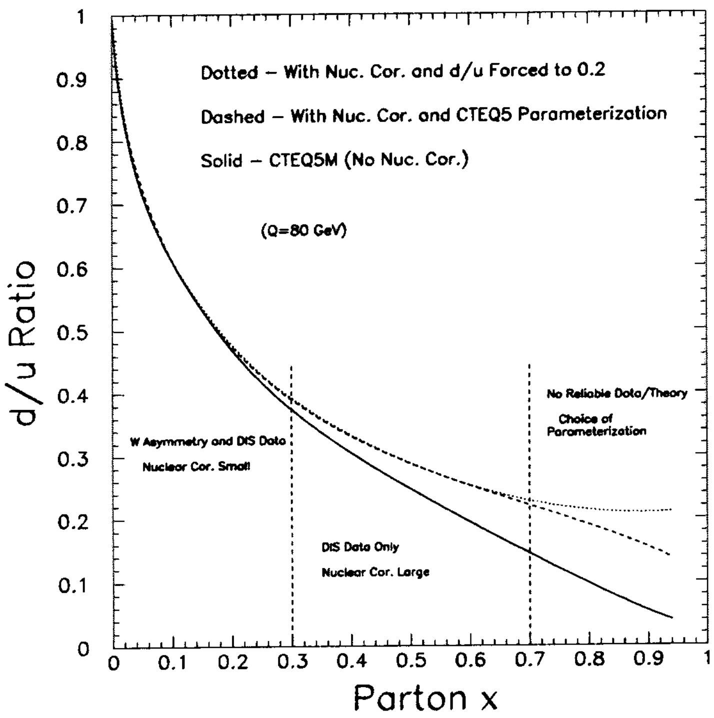




- HERA data gave valences with a reasonable precision.
- ZEUS-ONLY fit prefers a shift of xd_V toward higher-x.

d/u at large-x

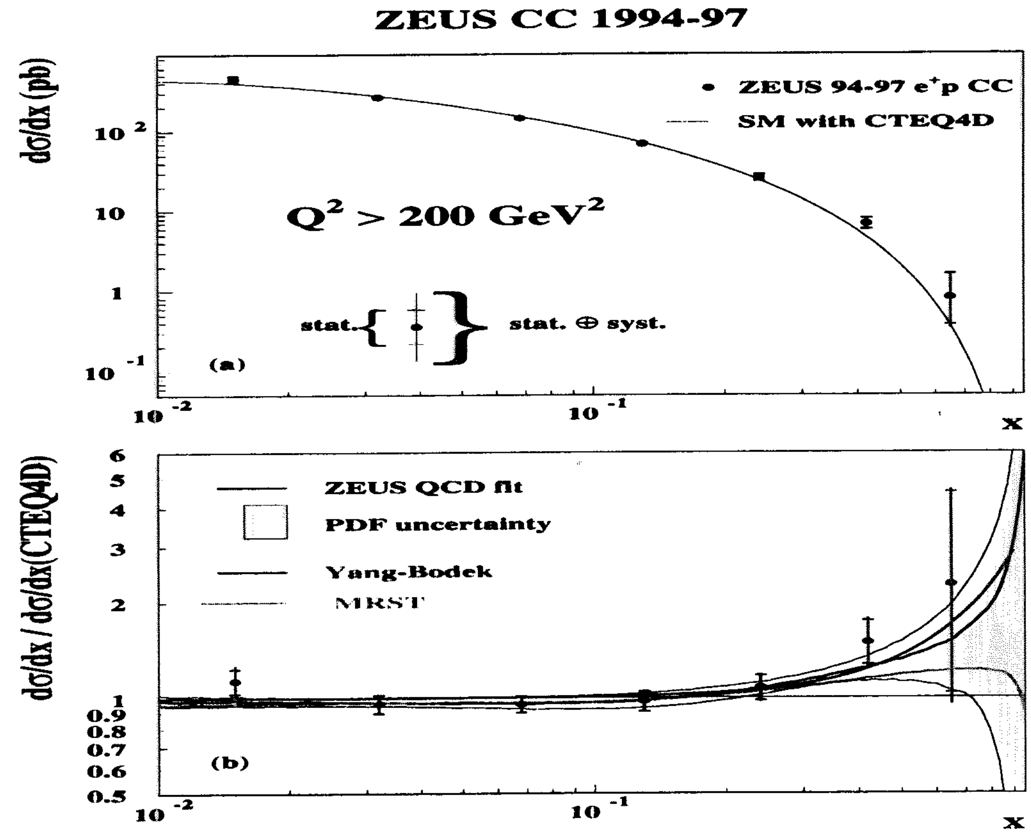
d/u uncertainty



(CTEQ, PLB 476 (2000) 291)

- F_2^D: uncertainty in D correction

ZEUS $e^+p\, d\sigma/dx$



- Yang-Bodek (= a reanalysis of NMC $F_2{}^D$) increase d-quark.($d/u \to 0.2$ at $x \to 1$).

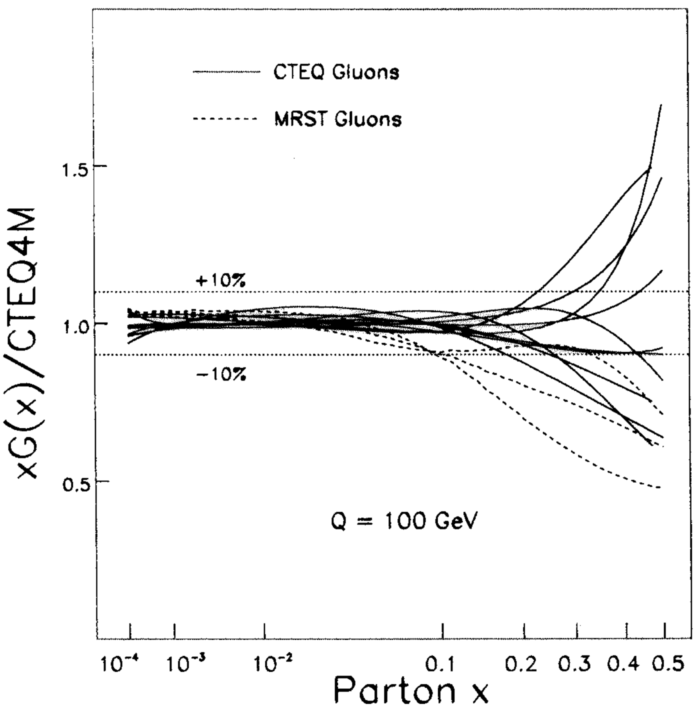
$\Rightarrow$ Prospect: PDFs will be determined only from HERA I & II data which are free from nuclear correction, target-mass, higher-twist uncertainties etc.

xg at large-x

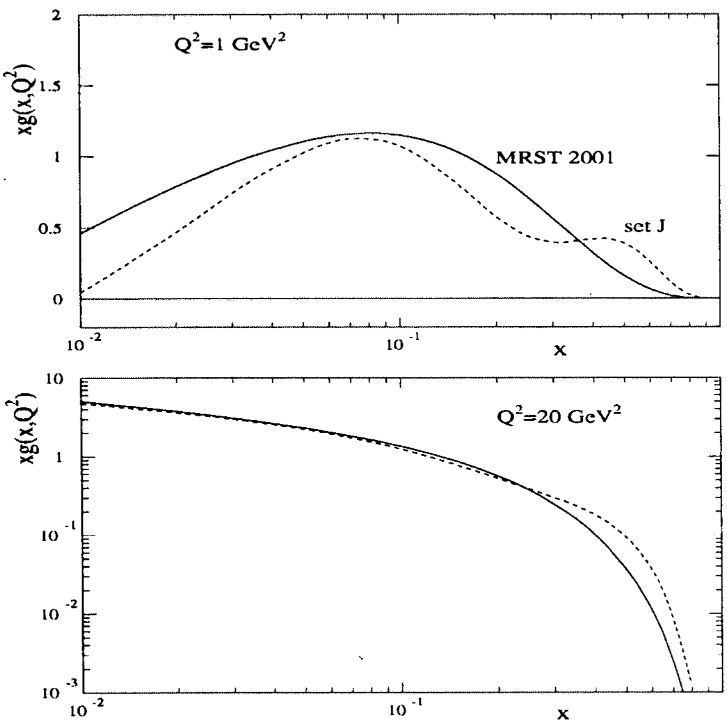
No "good" data !

- prompt-γ ($pp \to \gamma X$):
  there is a clear discrepancy between data and QCD
  $\to$ cannot be used in the fit

Not sufficient, even though TEVATRON jet data are used



(CTEQ, PLB 476 (2000) 291)



(MRST, "MRST 2001" hep-ph/0110215)

A common homework to all QCD fitters

$\Rightarrow$ Prospect: high statistics sample from TEVATRON Run-II

$\Rightarrow$ Needed: theoretical better understanding of $\sigma(p\bar{p} \to jX)$

Heavy-quark PDFs

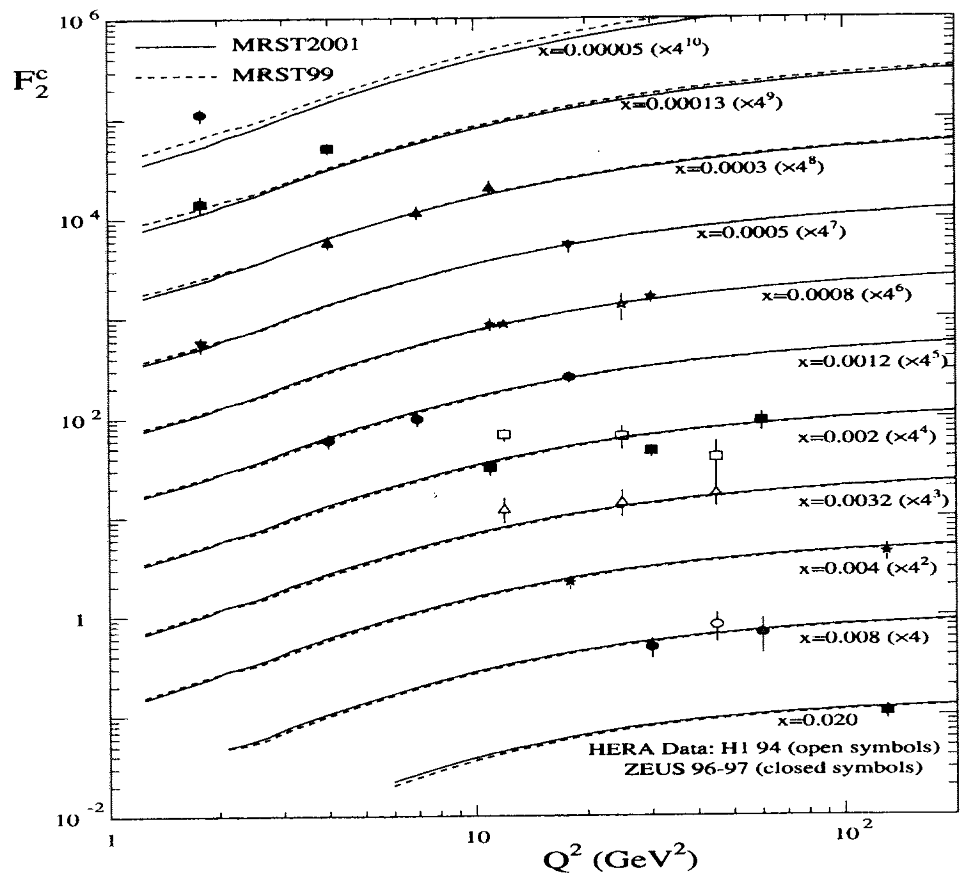
Theoretical improvements

Two conventional approaches:

- fixed flavour number scheme (FFN)
  - calculate the BGF process to HQs ($\gamma^* g \to c\bar{c}$) correctly up to NLO.
    - ∗ only light quarks(u,d,s) are active
    - ∗ correct at threshold: $Q^2 \sim m_c^2$.
  - but does not take ln Q^2/m_c^2 terms
- zero-mass variable flavour number scheme (ZM-VFN)
  - re-sums ln Q^2/m_c^2 terms into heavy-quark PDFs which obey the usual DGLAP evolution.
    - ∗ HQs are active(c,b) at scales beyond threshold.
  - but cannot be right at $Q^2 \sim m_c^2$.

⇒ Improved schemes: RT-VFN, ACOT.

F_2^c, *extrapolated* from D^*

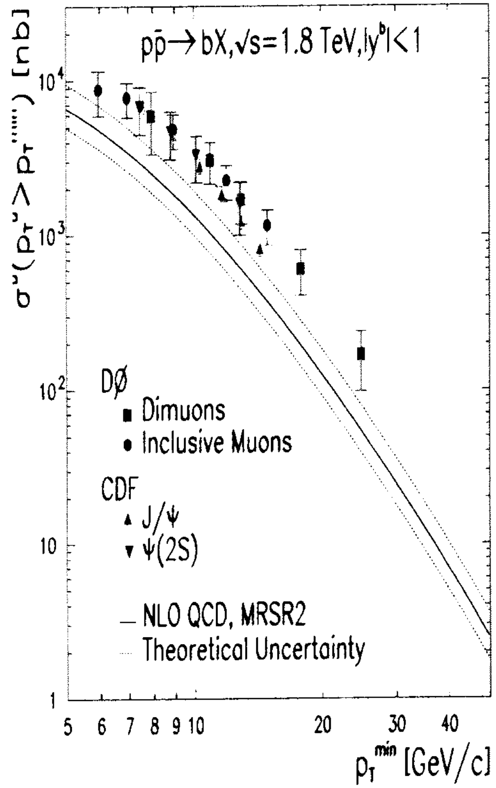


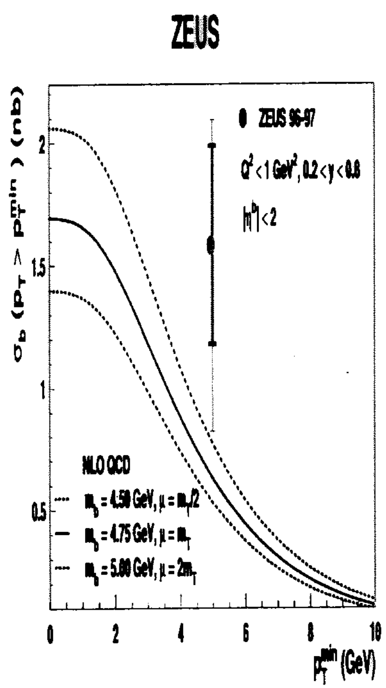
- MRST2001(RT-VFN) agrees well with data within the current limited statistics.

Prospect: systematic and precise check at HERA-II

However, b ?

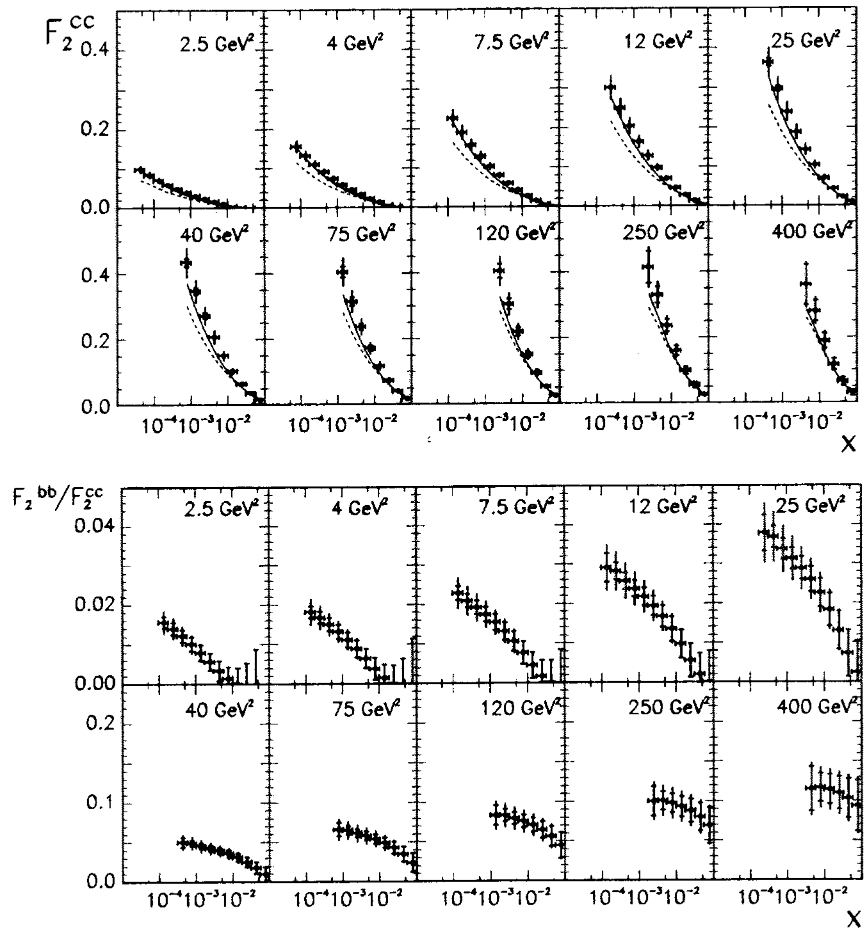
Open-b at "hadron colliders"($p\overline{p}$,γp)





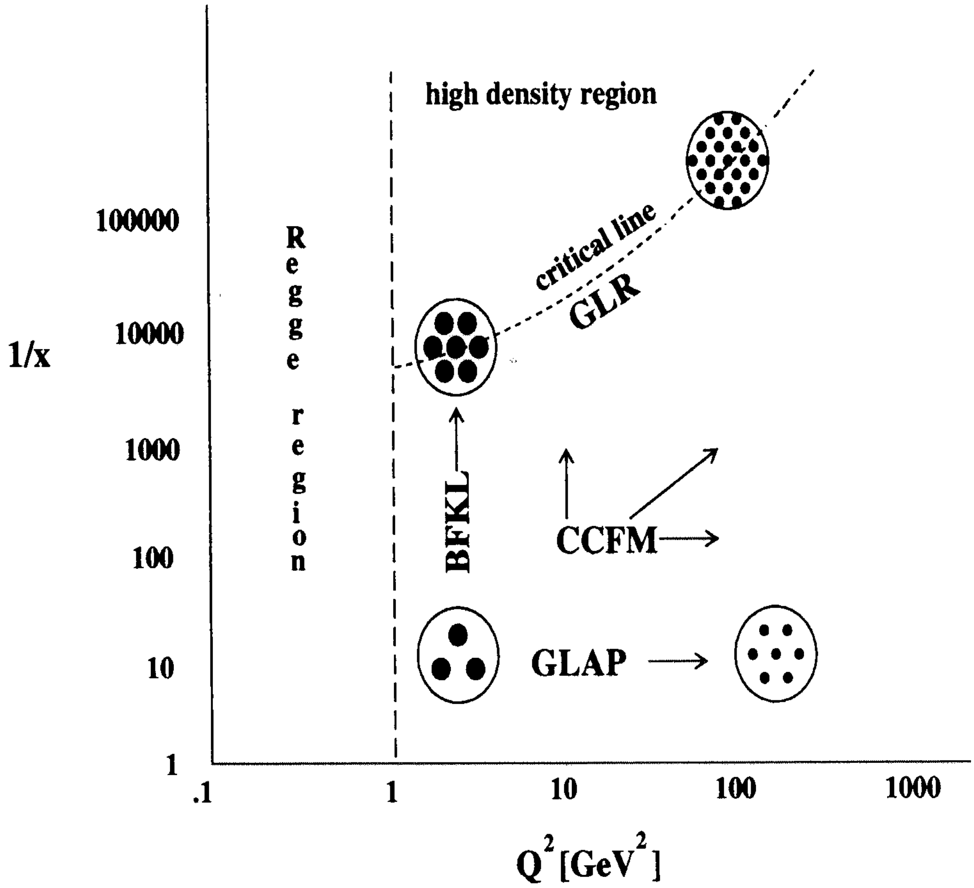
- Open-b cross-section is larger than NLO-QCD prediction both at TEVATRON($p\overline{p}$) and HERA(γP).

$F_2^{b\overline{b}}$ at HERA-II



Prospect: systematic and precise check at HERA-II

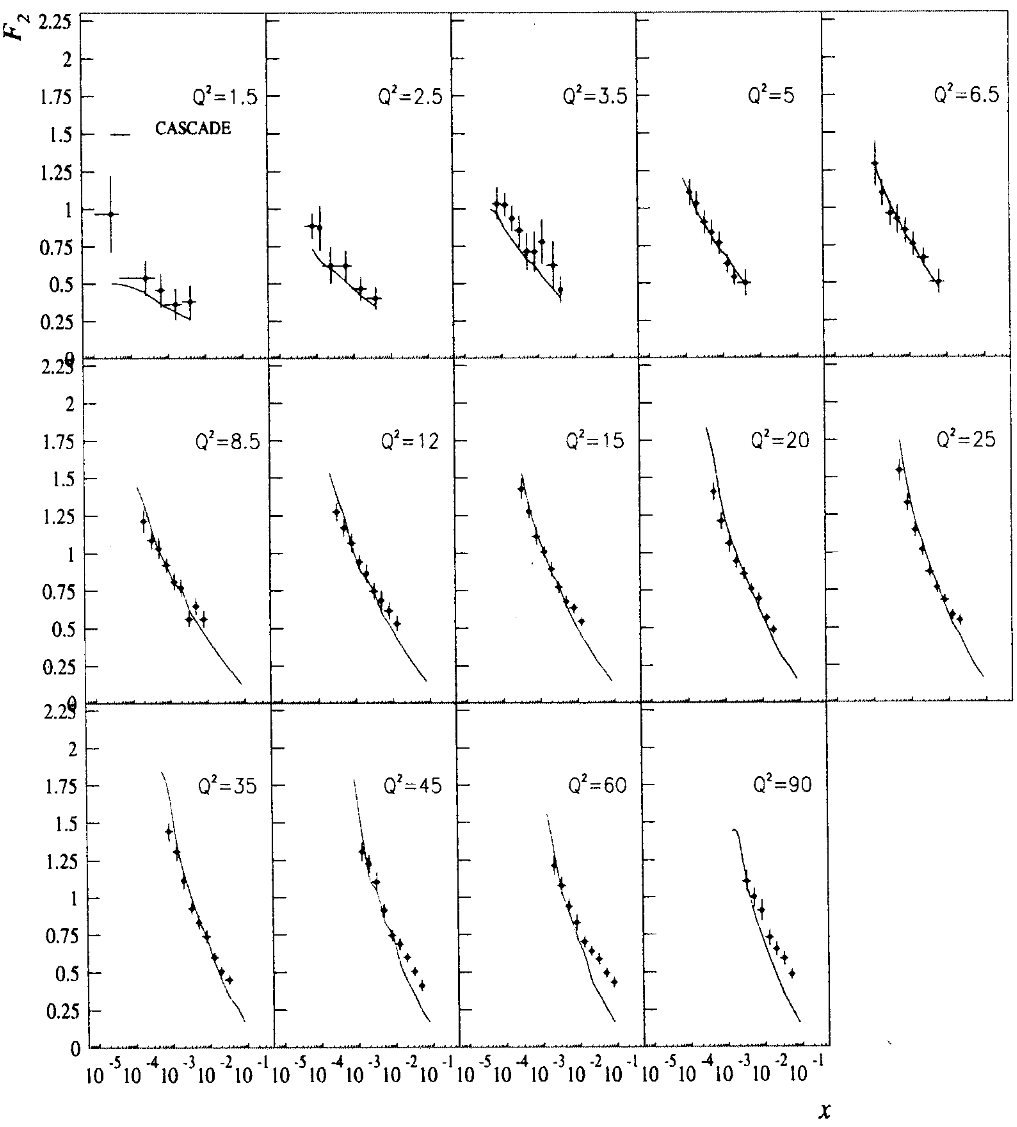
Other evolutions



- Remind: DGLAP ln Q^2 re-summation.
- BFKL: $\ln(1/x)$ re-summation
  - predicts $xg(x, Q^2) \sim x^{-\lambda}$
  - theoretical work still needed for NLO
    $\rightarrow$ LO/NLO seems to give a large corr.
- CCFM: a unified eq. for DGLAP/BFKL
  - gluon-emission: angular ordered.
    (DGLAP: k_T ordered, BFKL: x ordered.)
  - gives also a good description of F_2 at low-x
    (H. Jung and G.P. Salam, Eur.Phys.J C 19 (2001) 351)

CCFM

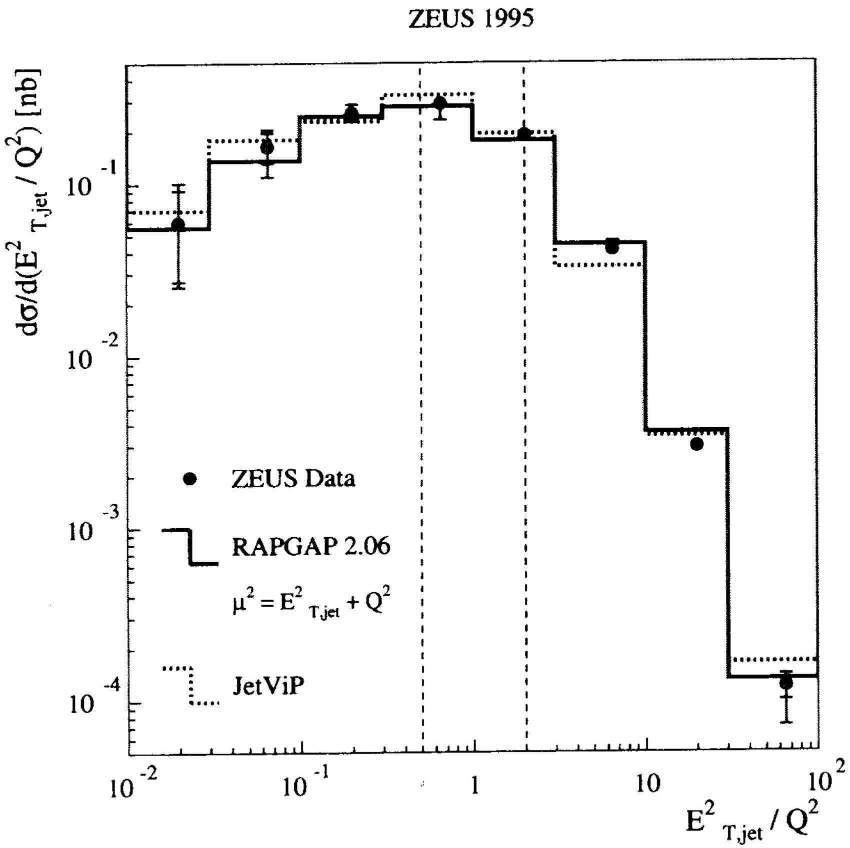
A theoretical improvement: backward evol. for MC programme etc. (H. Jung and G.P. Salam, Eur.Phys.J C 19 (2001) 351)



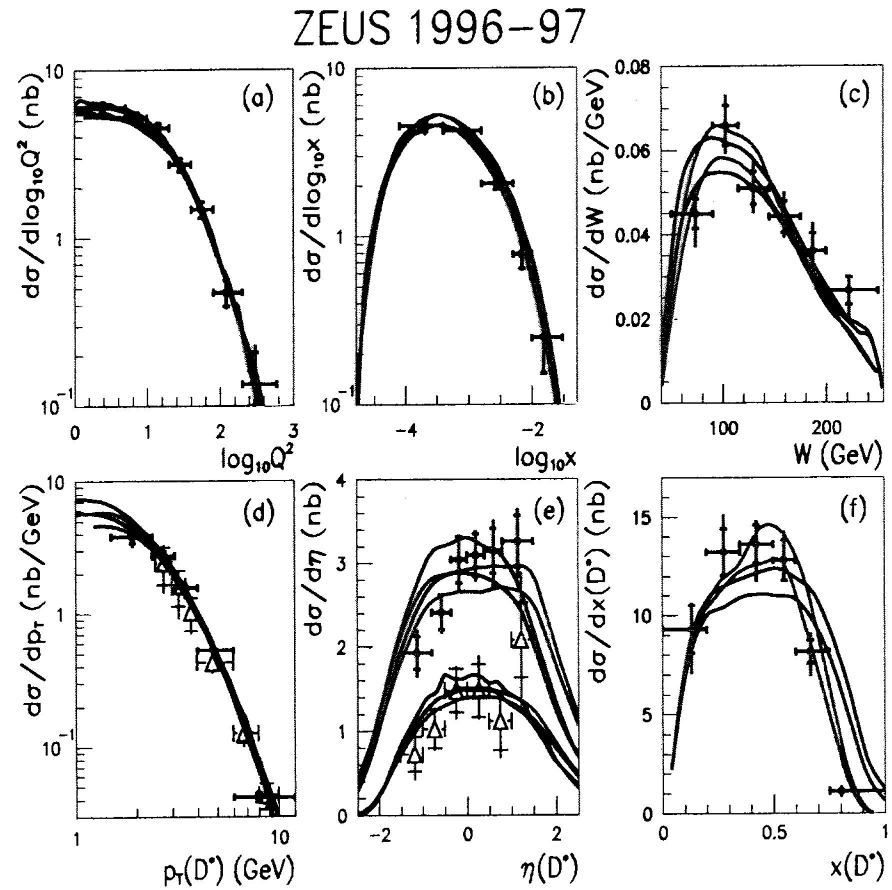
- CCFM does a good job also.(at low-x)
  $\rightarrow$ (but need more theory improvements for BFKL/CCFM)

Hunting BFKL,CCFM...

Forward jet in DIS (PLB 474(2000) 1-2,223)



D^* in DIS (EPJ,C12(2000) 1,35)

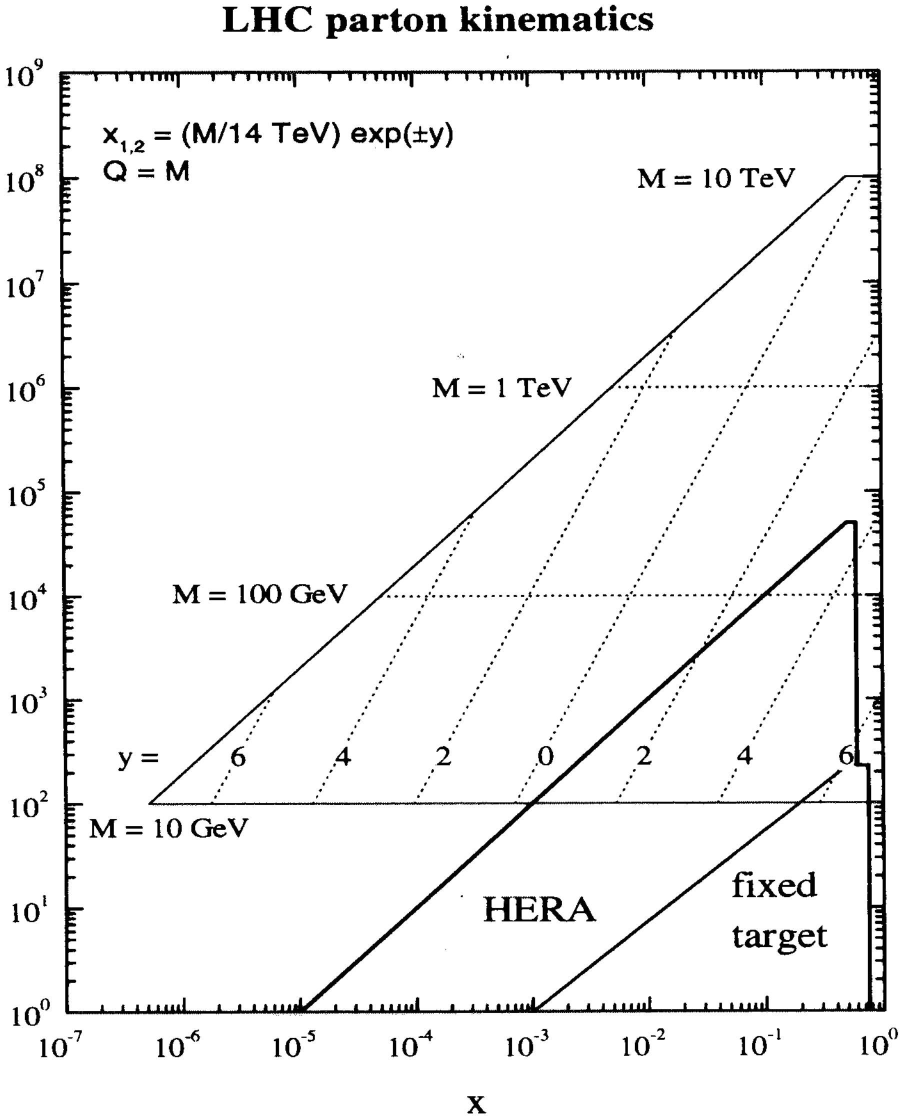


- No clear indication of the need for BFKL, CCFM.
- Though theory improvements are needed, BFKL/CCFM do a so-so good job:
  → DGLAP may not the sole winner at HERA... (dipole-model etc. → hot topic)

PDFs: issues, progress, prospects [my answers]

1. Uncertainties
   - almost established how to take fully into the correlated systematic errors account.
   - further discussion.
2. Gluon PDF and α_s
   - correlation understood, resulted in a consistent α_s
3. PDFs at large-x
   - d/u: $\rightarrow$ HERA-II CC e^+p
   - xg: $\rightarrow$ TEVATRON RUN-II.
4. Heavy-quark PDFs
   - Theoretical improvements in mass treatment.
   - HERA-II: big prospect.
5. NNLO and $\ln(1/x)$ re-summations
   - NNLO almost ready.(MRST2001)
   - No indication for need of $\ln(1/x)$ re-summations at HERA

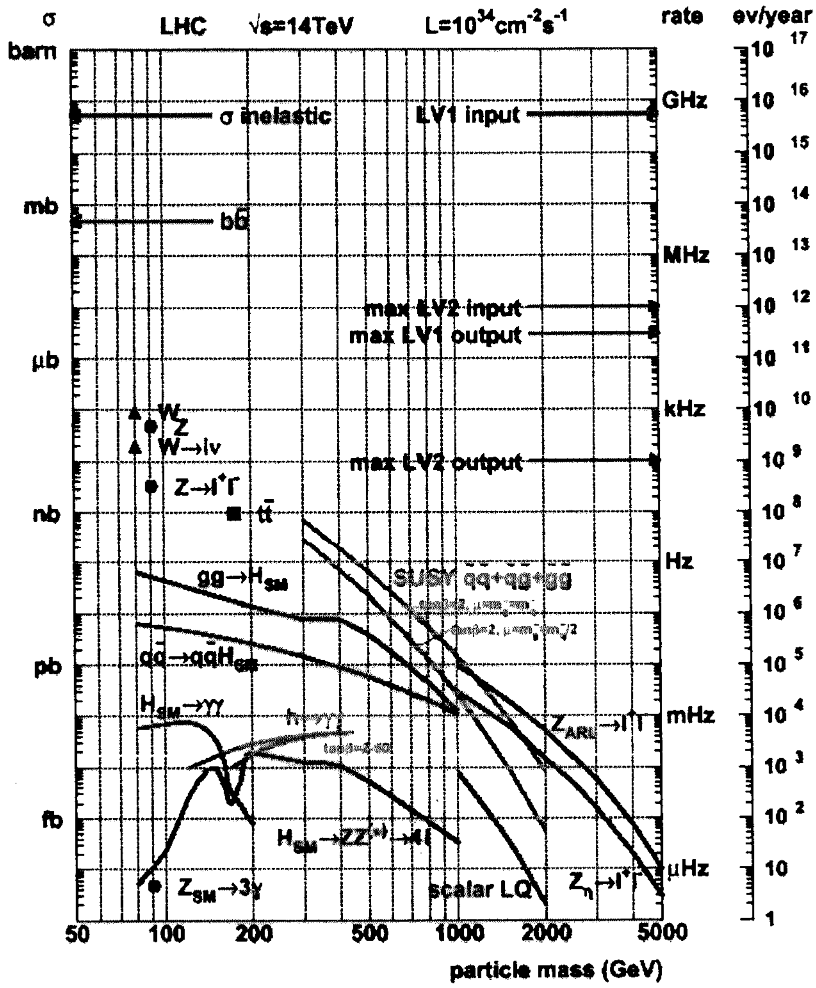
LHC parton kinematics



1. M : 100GeV $\sim$ 1TeV at $|y| < 2.5$
   $\Rightarrow$ Q^2 : $10^4 \sim 10^6$ GeV^2
   x : $10^{-4} \sim 10^{-1}$
2. high $M \gtrsim 1$ TeV or large $|y| \gtrsim 3$
   $\Rightarrow$ large $x \gtrsim 10^{-1}$
3. small $x \lesssim 10^{-5}$: (very forward, maybe difficult)
   - $\ln(1/x)$ resummation (BFKL,CCFM) ?
   - saturation?

Kinematics [1]: $10^{-4} \lesssim x \lesssim 10^{-1}$

Cross sections at LHC

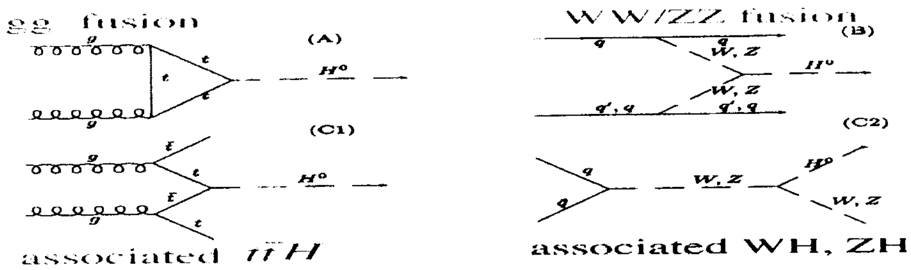


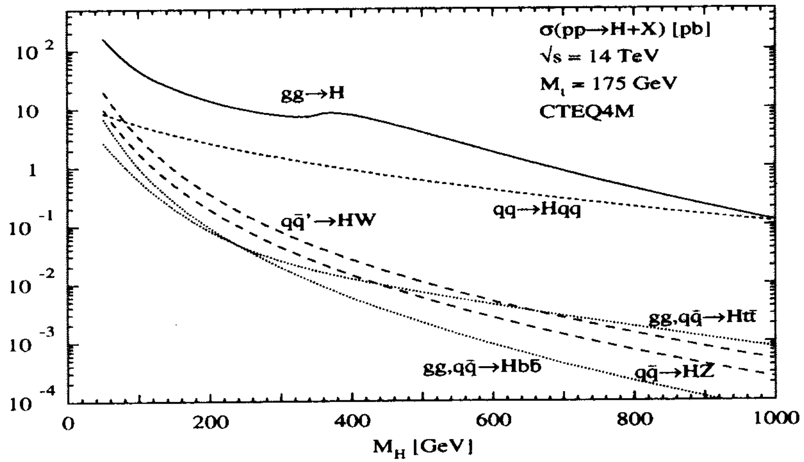
- Precision physics with SM gauge-bosons and top-quark
  Scale: $Q^2 \sim 10^4 (M_Z^2, M_W^2, M_t^2)$
  - $\sigma(W,Z)$ is a candidate of $\mathcal{L}$ monitor: $\Leftarrow$ sea quarks
  - "t-factory"($gg \to t\bar{t}$): $\Leftarrow$ gluon
    $\Rightarrow \Delta m_t \sim 1\%$ possible.
- SM Higgs search
  - $gg \to H$ dominates: $\Leftarrow$ gluon

$\Rightarrow$ gluon and sea at large Q^2 : $10^4 \sim 10^6$ GeV^2 are needed.

Kinematics [2]: large $x \gtrsim 10^{-1}$

Heavy SM Higgs

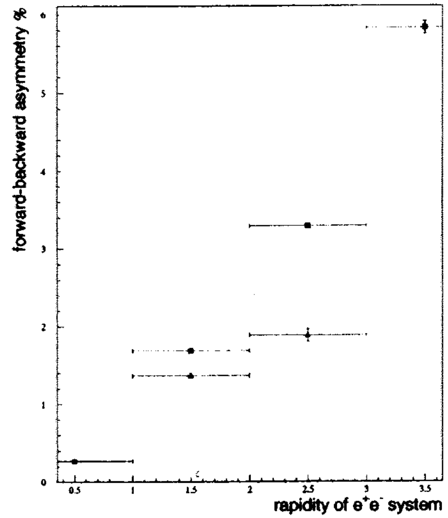




WW/ZZ fusion important for large M_H

- σ becomes large thanks to:
  - valence quarks $>$ gluons at large-x: $\Rightarrow$ difference in "slopes" between of $\sigma(gg \to H)$ and $\sigma(qq \to Hqq)$.
- experimental advantage: large p_T ($\sim M_W/2$) forward jets due to recoiled quarks

Drell-Yan prod. of l^+l^-: $\mathcal{A}_{FB}(M_Z^2)$



$\mathcal{A}_{FB}$: initial $q(\bar{q})$-direction should be known.

$\rightarrow$ require large rapidity of lepton pair $y(l^+l^-)$, i.e. $x_1 >> x_2$ of partons

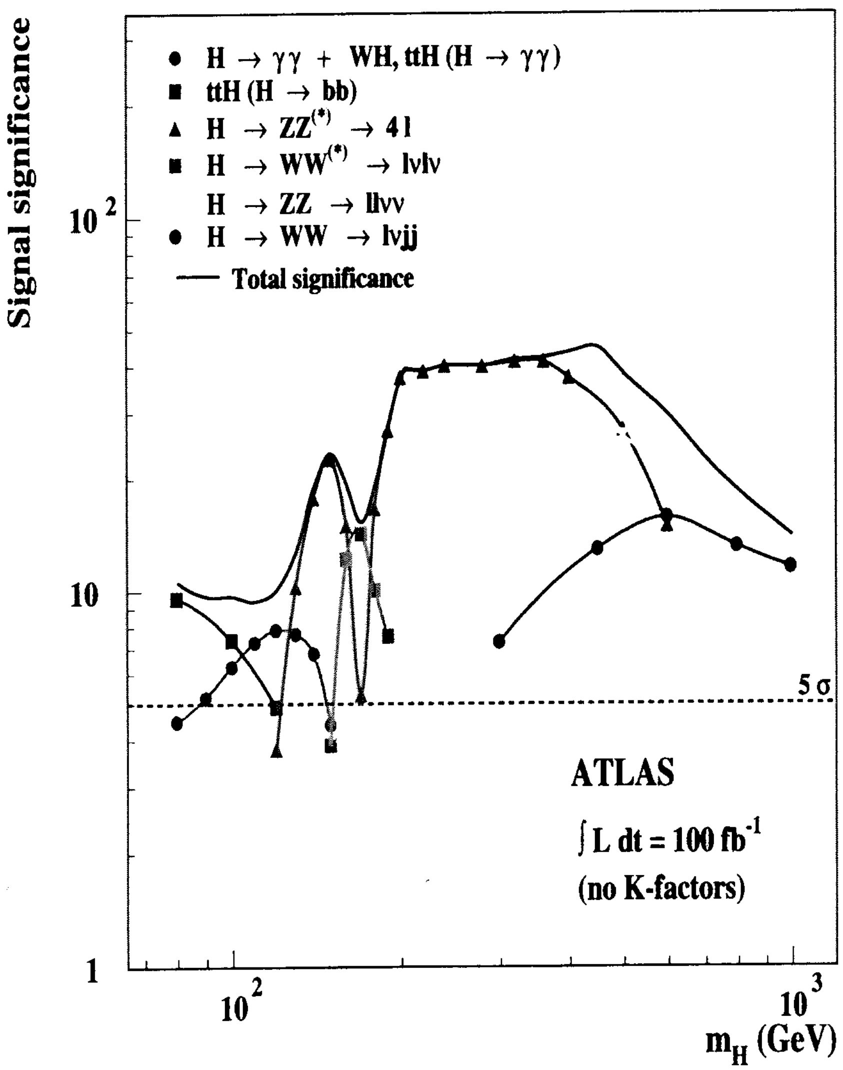
$\rightarrow$ larger x parton should be quark

$\rightarrow$ A_{FB} signed according to sign of $y(l^+l^-)$

$\Rightarrow$ determination of $\sin^2\theta_W < 2 \times 10^{-4}$ (stat only) is feasible (comparable/better than LEP)

...if PDFs at high-x are well constrained.

Heavy-quark PDFs: low-mass SM Higgs search



Due to huge amount of QCD backgrounds:
→ high-p_T leptons, γ give clear signals
→ distinctive decay modes $(WW, ZZ, \gamma\gamma)$
are the most promising.

- $M_H \gtrsim 2M_Z$:
  $H \to ZZ \to 4l$, gold plated
- $100 \lesssim M_H \lesssim 2M_Z$:
  $H \to ZZ^{(*)}$, $H \to WW^{(*)}$ $H \to \gamma\gamma$
- $M_H \lesssim 100$: mainly decays into $b\bar{b}$
  – $gg \to t\bar{t}H$

Also, $gg \to b\bar{b}H$ is important in the MSSM scenario with $\tan\beta >> 1$ (coupling to b becomes large)

⇒ Big question on heavy-quark PDFs.

Summary

- gluon and sea-quark PDFs at $10^{-4} < x < 10^{-1}$
  - well constrained by HERA data
    - new precise F_2 data + new error treatment
    - correlation between α_s and xg understood

  are needed at high $Q^2 > 10^4$ GeV^2
  - DGLAP "smears" uncertainty as Q^2 evolves
  - HERA high-Q^2 OK but with limited statistics
    $\rightarrow$ HERA-II at high-Q^2!

- PDFs at large-x
  - valence quarks: u well constrained, but d not so much.
    $\rightarrow$ HERA-II CC e^+
  - gluon high-x: no "good" data, maybe TEVATRON jets.

- heavy-quark PDFs
  - Theory improvement: RT-VFN, ACOT schemes.
  - HERA $F_2^{c\bar{c}}$ OK but with limited statistics
  - open-b problem at hadron colliders

  $\rightarrow F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at HERA-II.

Outlook

see next slide $\Rightarrow$

Outlook: EW unification → EW symmetry breaking