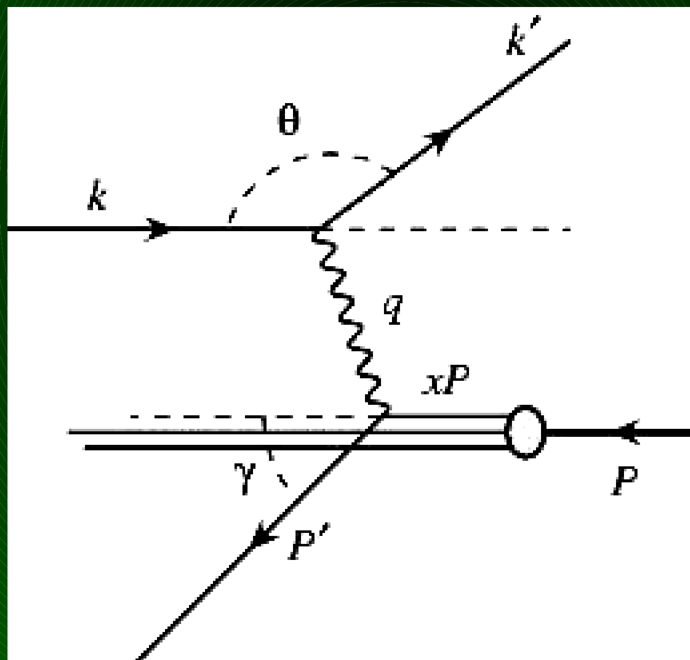
Proton Structure Measurements at High Q^2 and x

Katarzyna Wichmann, Hamburg University
on behalf of H1 and ZEUS Collaborations

- Introduction
- F_2 Measurements
- xF_3 & xG_3 Measurements
- CC Cross Section Measurements
- High-x Measurements
- DIS & Photoproduction Jet Data
- Future Measurements
- Summary&Outlook

Deep Inelastic Scattering @ HERA



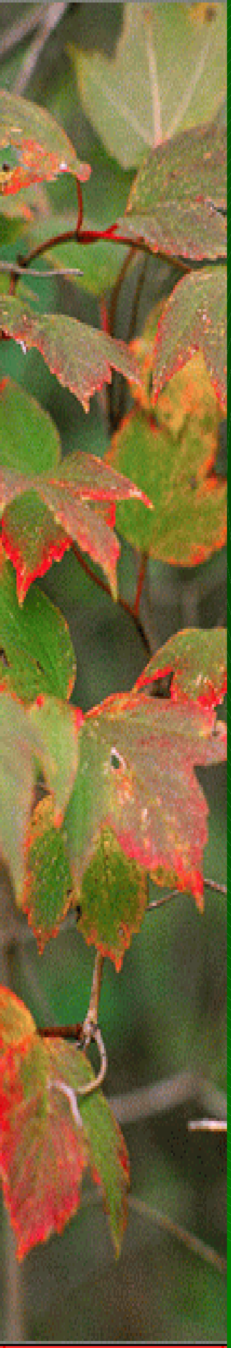
- Neutral Current – γ or Z^0 exchange
  - scattered electron in final state
- Charged Current – $W^\pm$ exchange
  - neutrino in final state

$$Q^2 = -q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2\,p\cdot q} \qquad y = \frac{p\cdot q}{p\cdot k}$$

$$s = (p+k)^2 \qquad Q^2 = x\cdot y\cdot s$$

- Q^2 – probing power
- x – Bjorken scaling variable
- y – inelasticity



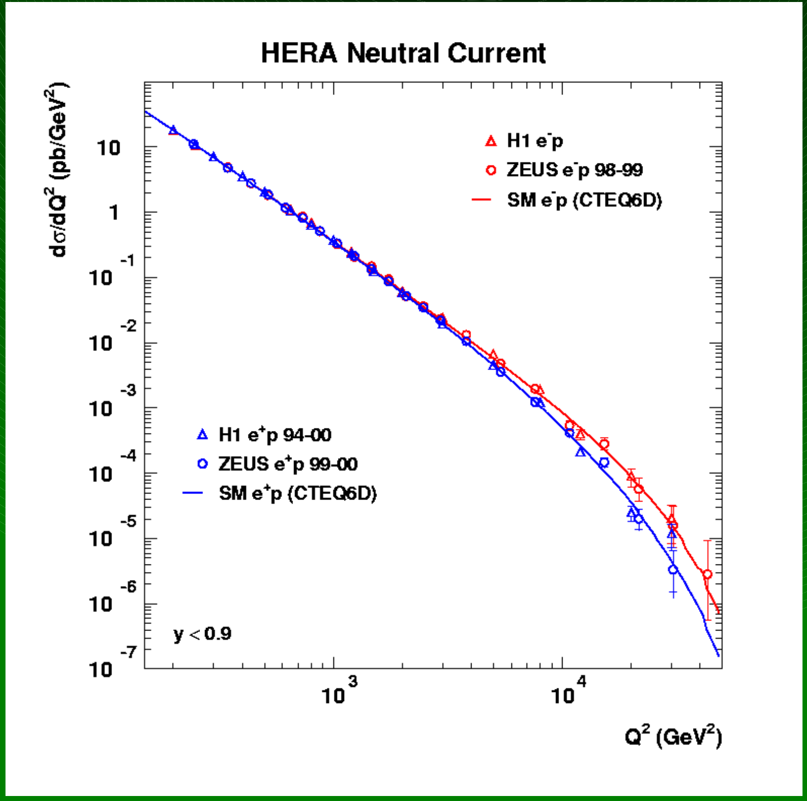
NC Cross Sections

- NC cross section

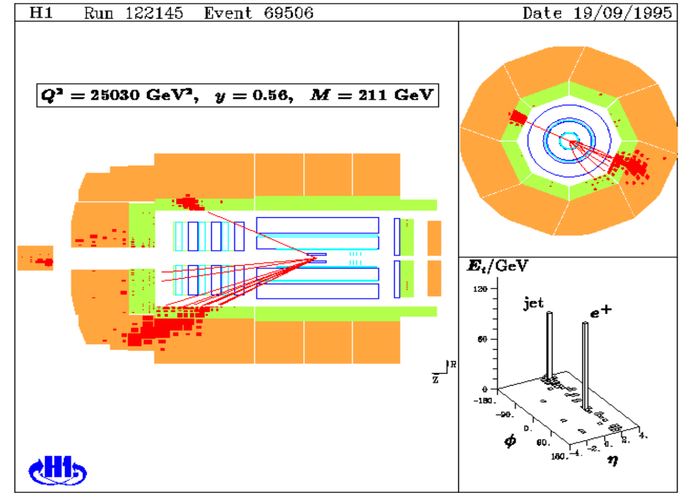
$$\frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left(F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right), \quad Y_\pm = 1 \pm (1-y)^2$$

$\tilde{\sigma}_{NC}(x,Q^2)$

- NC cross sections for e^+ and e^- differ for high Q^2 only



Candidate from NC sample



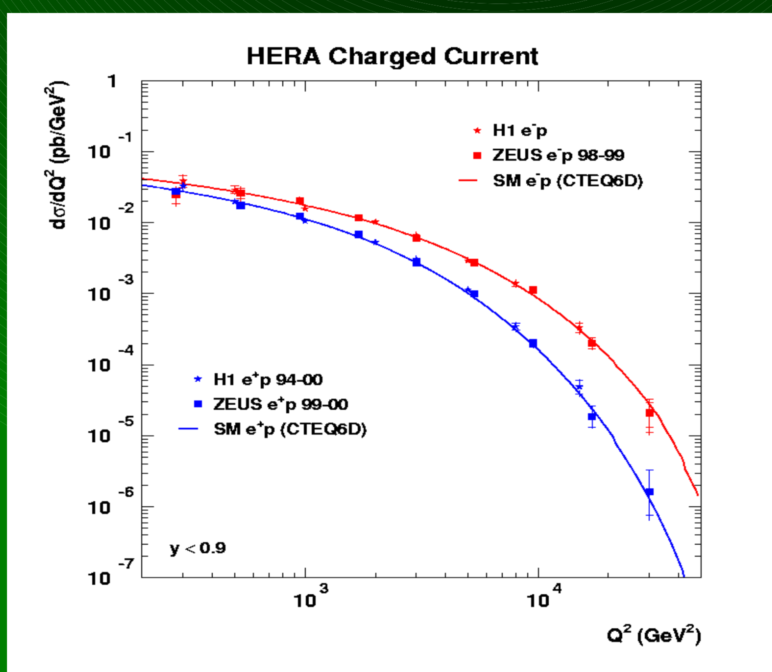
CC Cross Sections

- CC Cross sections different for e^+p and e^-p scattering:

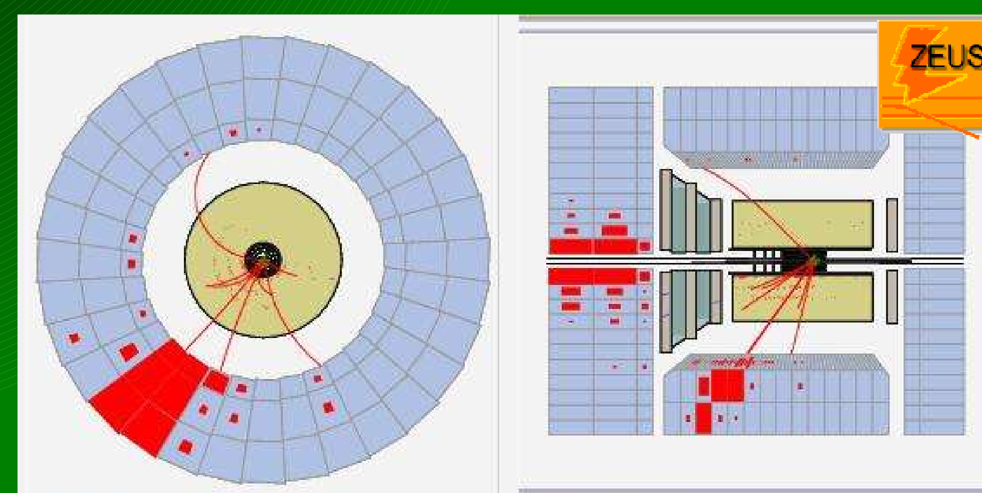
$$\frac{d^2\sigma^{CC}(e^{\pm}p)}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left(Y_+ F_2^{CC} - y^2 F_L^{CC} \mp Y_- xF_3^{CC}\right)$$

$$\tilde{\sigma}_{NC}(x,Q^2)$$

- electron/positron collisions probe different quark content of proton
- CC cross section suppressed compared to NC due to W mass



CC event in ZEUS detector



Structure Functions

- dominant contribution to cross sections: F_2

$$F_2 \propto \sum_q e_q^2 x(q+\bar{q})$$

- at high Q^2 xF_3 becomes significant

$$xF_3 \propto \sum_q x(q-\bar{q})$$

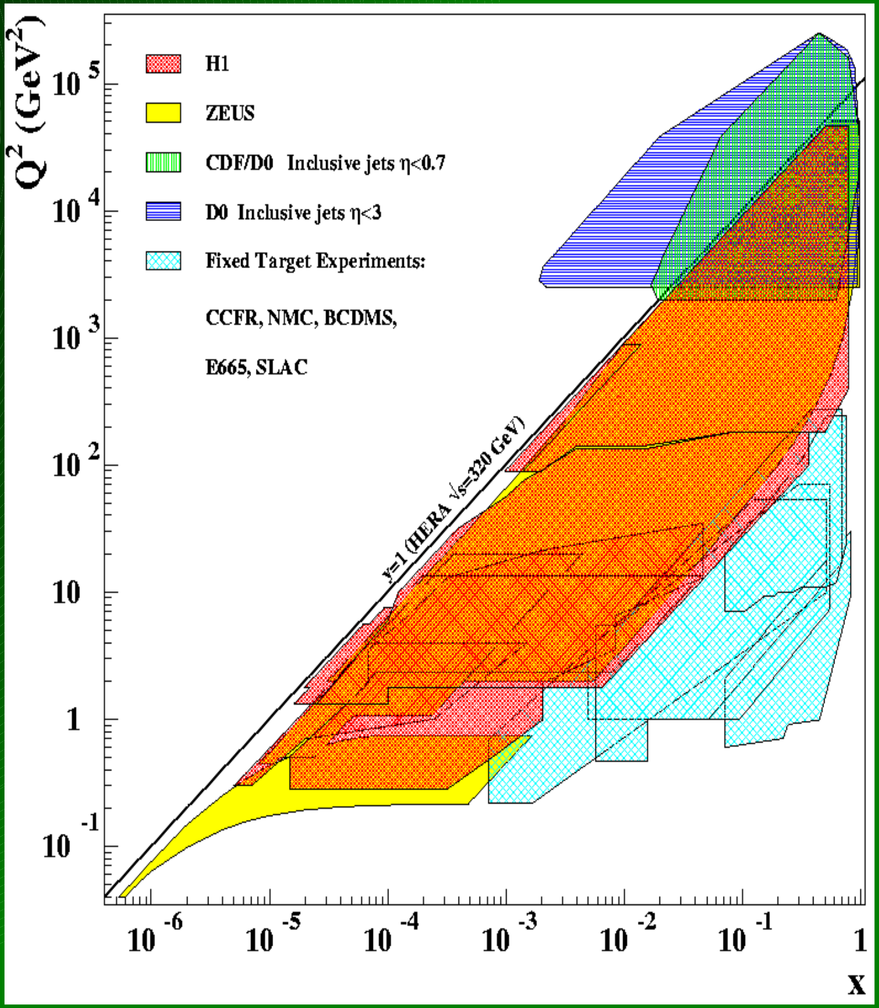
- F_L only significant at low Q^2 and high y

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

- HERA data allow study of sea and valence quarks
- gluons accessible via scaling violation and jet data

HERA Kinematic Range

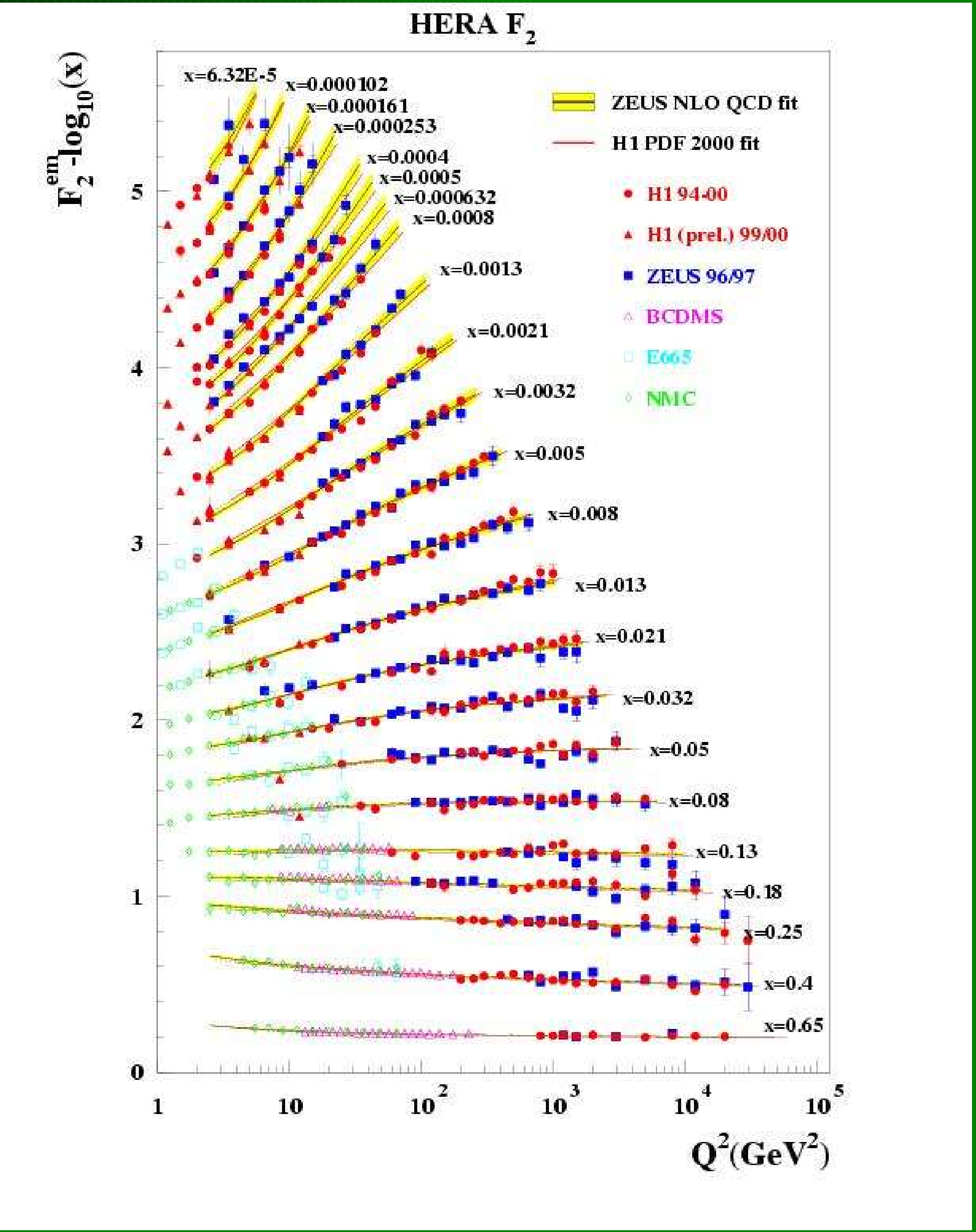
- HERA data overlap with fixed target at low Q^2 and high x
- fixed target measurements extended to higher Q^2 and y
- access to non-perturbative region ➟ low $Q^2<1$ GeV^2, see V. Lendermann's talk
- access to sea and valence quark densities
- gluon distributions at low x
- valence quarks at high x



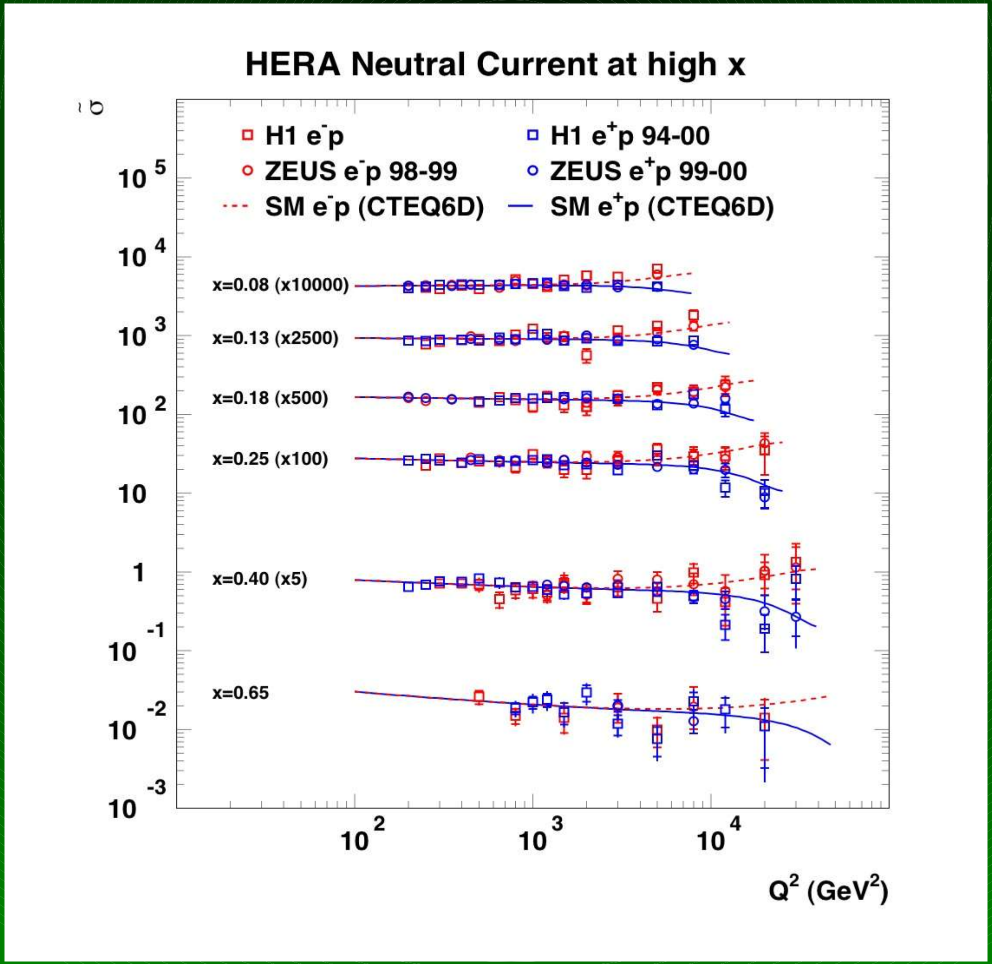
F_2 Measurements

$$F_2 \propto \sum_q e_q^2 x(q+\bar{q})$$

- sensitive to sum of q and qbar
- sensitive to gluon densities by QCD radiation
  - scaling violation
- measured with 2-3% precision
- for high $Q^2 > 1000$ GeV^2 statistical error dominates
- H1 and ZEUS results in agreement and well described by QCD



NC Cross Section Measurement



- at high Q^2 σ_{NC} differs significantly for e^+p and e^-p

  $$\sigma^{\pm}_{NC}(x,Q^2) \sim F_2 \mp f(y)xF_3$$

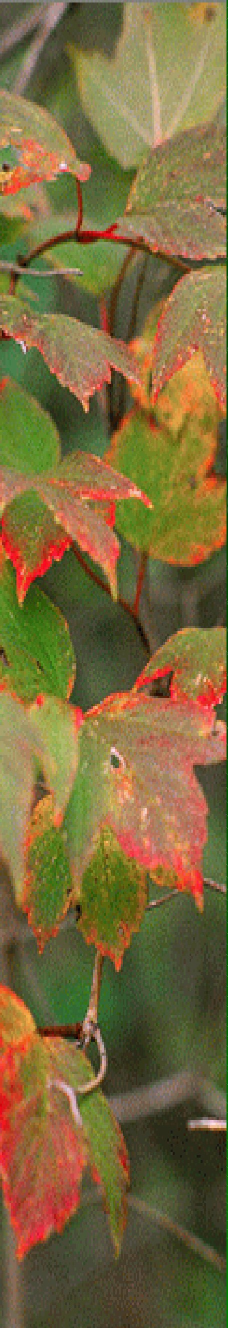
  - $\sigma^{e^-p}_{NC} - \sigma^{e^+p}_{NC} \sim xF_3$
- xF_3 comes from interference between γ and Z^0 and Z^0 exchange:

  $$xF_3 = xF_3^{\gamma Z} + Z\text{-exchange}$$

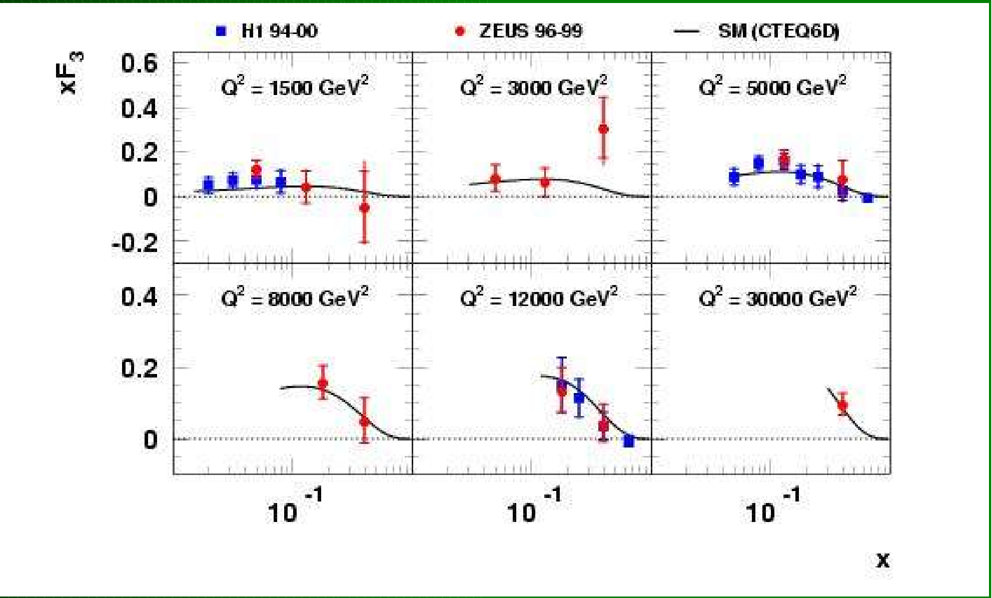
- constrains valence quark content of proton

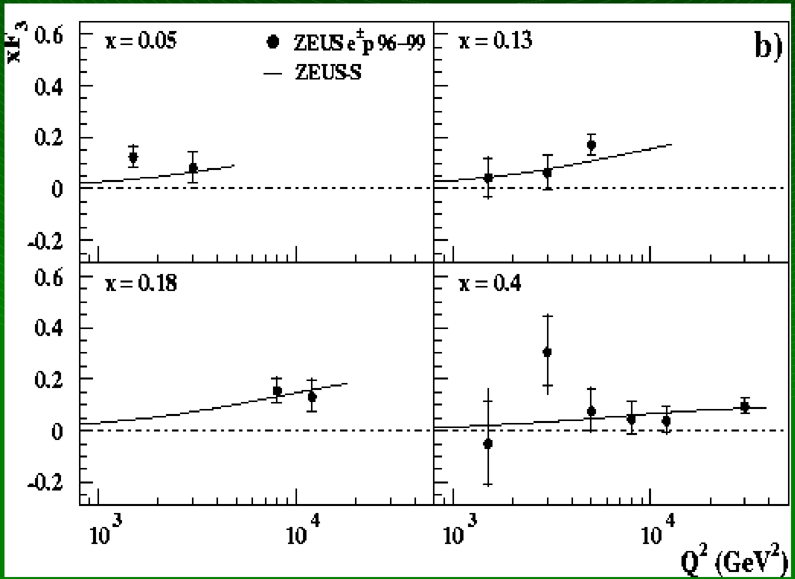
$$xF_3 \propto \sum_q x(q-\bar{q})$$

xF_3 Measurement



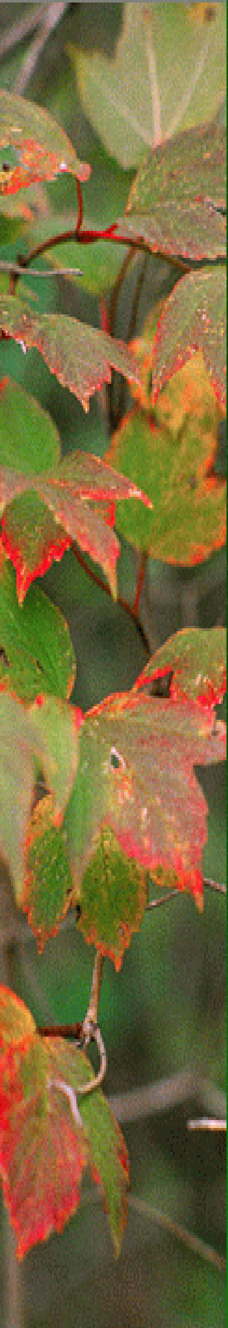
- $xF_3 \sim \Sigma\, x(q\text{-}qbar)$ positive
- H1 and ZEUS in agreement
- xF_3 measurements from HERA in agreement with global fit PDFs
- present measurement not very accurate and significant – better with HERA II data





- σ_{NC} small so high luminosity needed:
  - quark main uncertainty comes from statistics of e⁻p sample
  - HERA II has already ~7 times more luminosity
    - better measurements soon

xG_3 Measurement

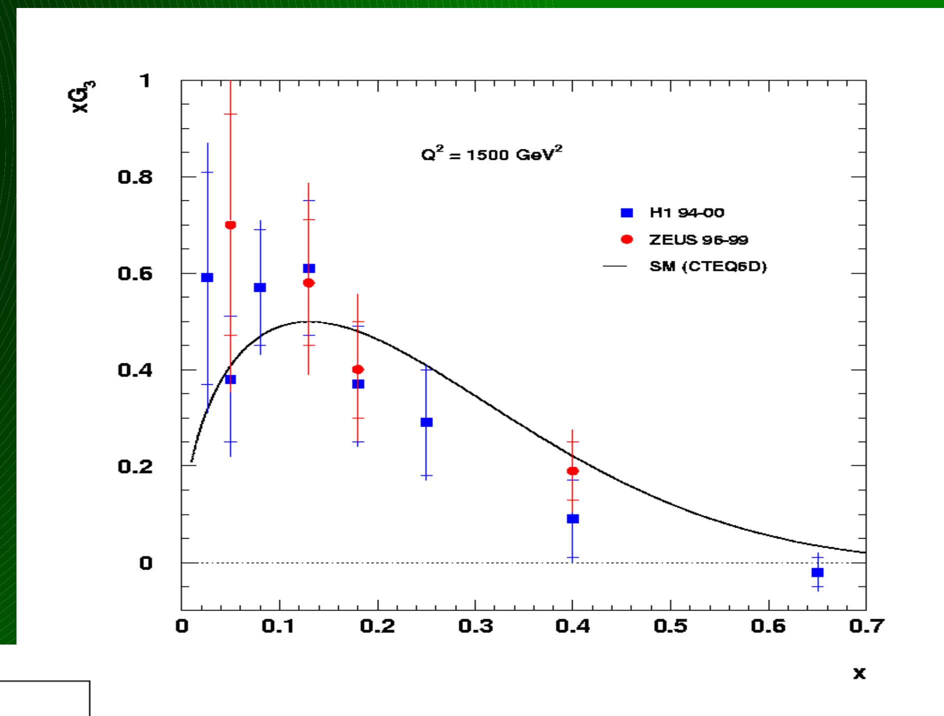


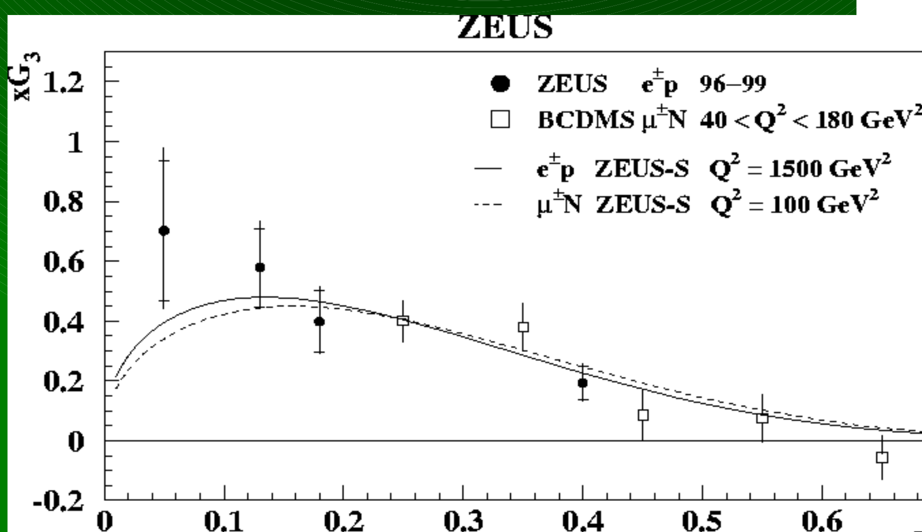
$$xF_3 = -a_e \chi_Z xG_3 + 2 v_e a_e \chi_Z^2 xH_3$$

pure Z exchange

γ-Z interference

- H_3 negligible compared to G_3 (v_e small)
- at fixed x weak Q^2 dependence
- H1 and ZEUS in agreement
- good agreement with theory

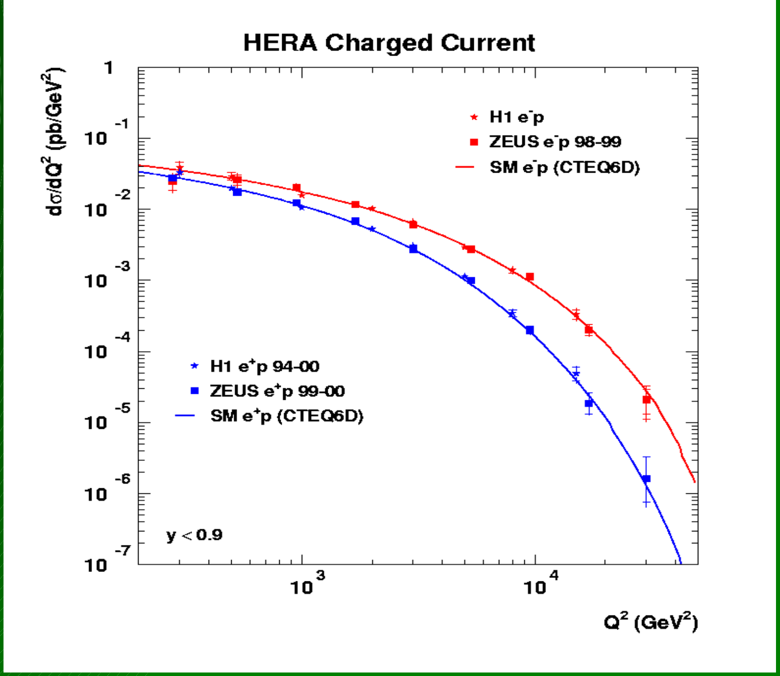




- difference in theory for DIS and μN small
- HERA data agree with BCDMS
- HERA extends measurement to x~0.05

CC Cross Section Measurements

- CC different for e^+ and e^-
  - $\sigma_{CC}^{e+p} \propto [\bar{u} + \bar{c} + (1-y)^2 (d+s)]$
    - sensitive to $d(x,Q^2)$
    - suppresed by helicity factor $(1-y^2)$
  - $\sigma_{CC}^{e-p} \propto [u + c + (1-y)^2 (\bar{d}+\bar{s})]$
    - sensitive to $u(x,Q^2)$



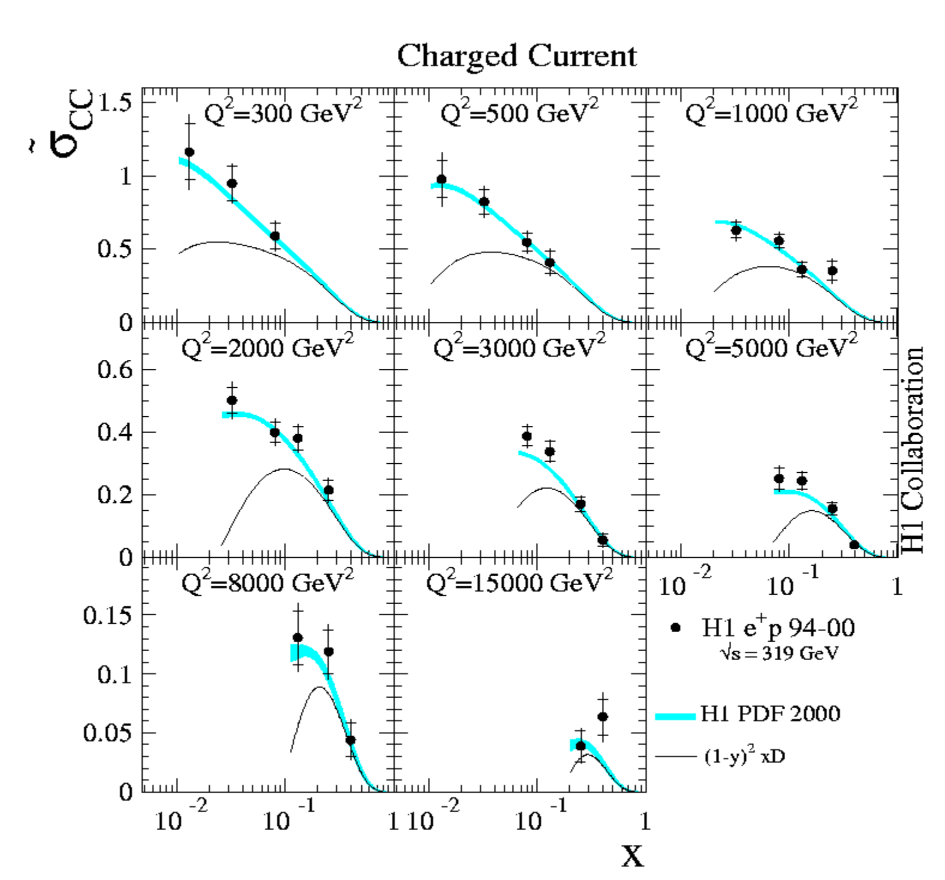
- CC provides flavor information

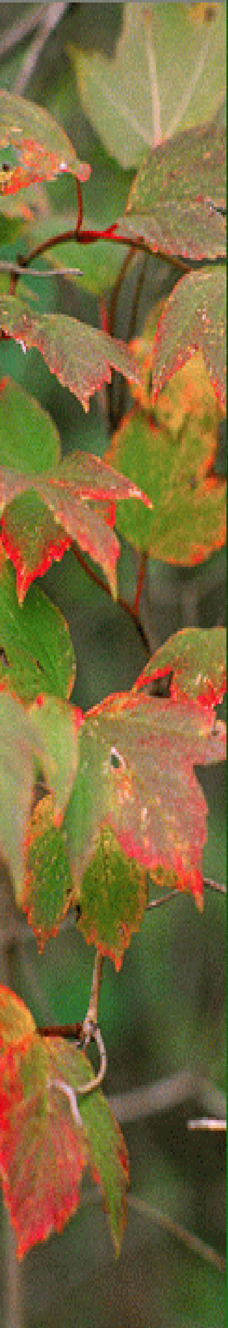
CC e^+p Cross Section Measurements

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

- $d(x,Q^2)$ poorly known ➟ CC e^+p data particularly valuable
- xd distribution dominates cross section at large x ➟

HERA data can be used to constrain d quark distribution in valence region





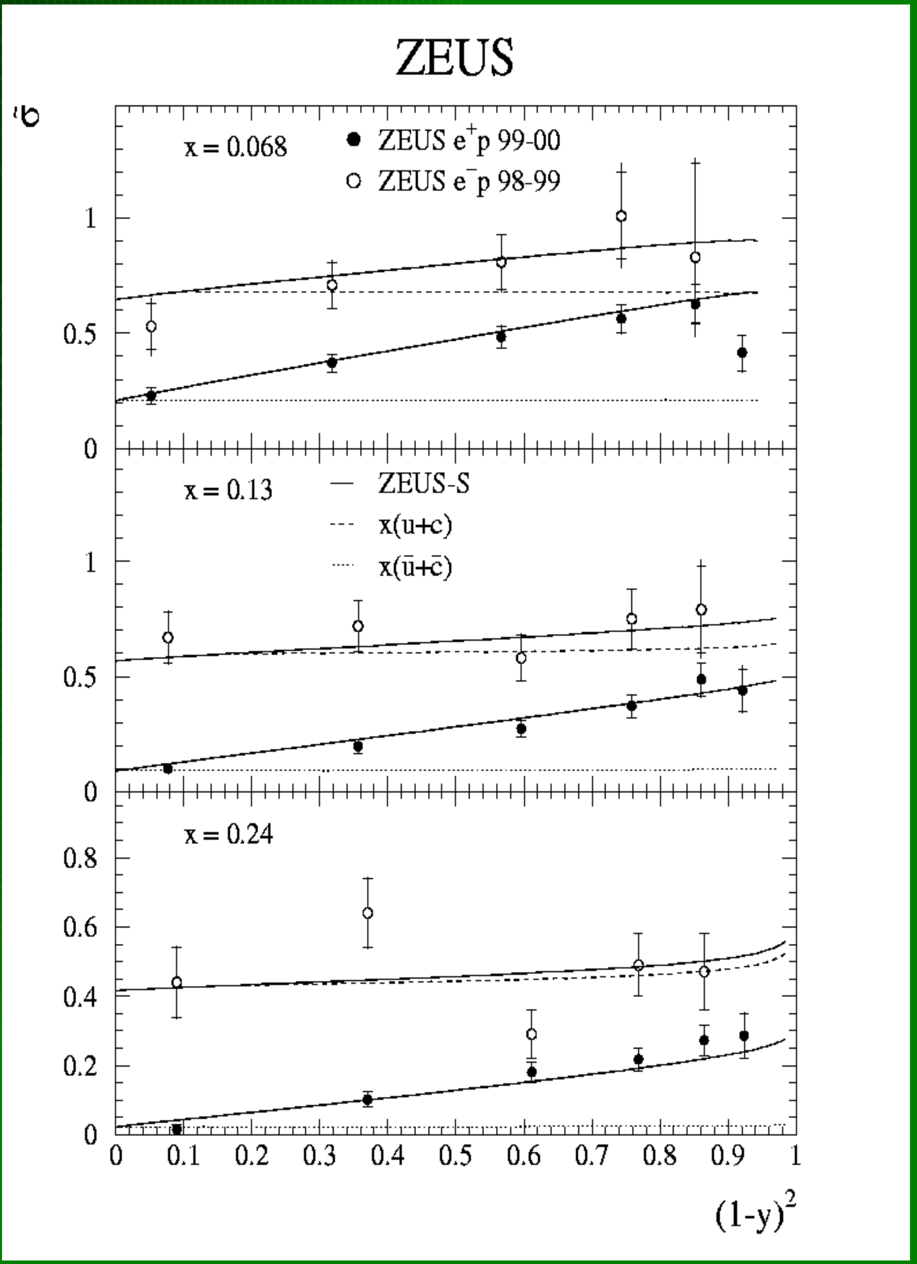
CC Cross Section Measurements

- reduced cross section plotted as a function of $(1\text{-}y)^2$

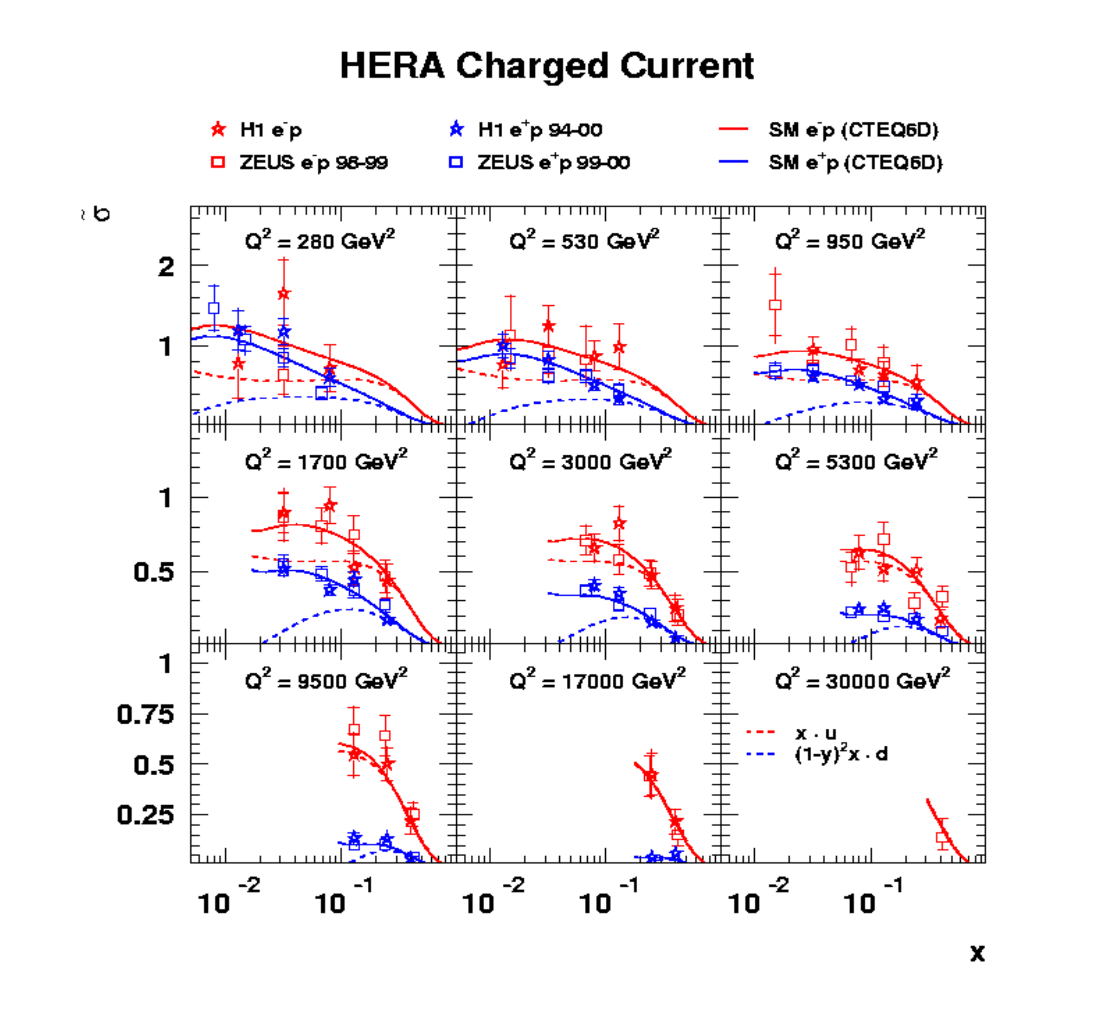
$$\sigma_{CC}^{e+p} \propto [\bar{u}+\bar{c}+(1-y)^2(d+s)]$$

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

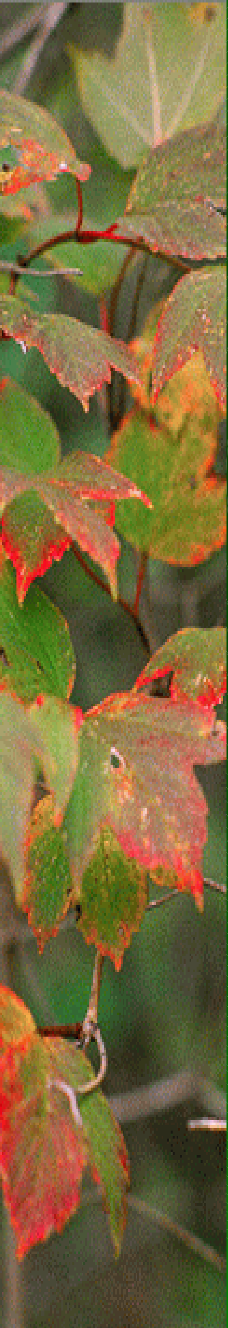
- for e^+p intercept gives (ubar+cbar) contribution and slope (d+s) contribution
- for e^-p intercept gives (u+c) contribution and slope (dbar+sbar) contribution
- at large x
  - e^+p sensitive to d_v
  - e^-p sensitive to u_v



CC Cross Section Measurements

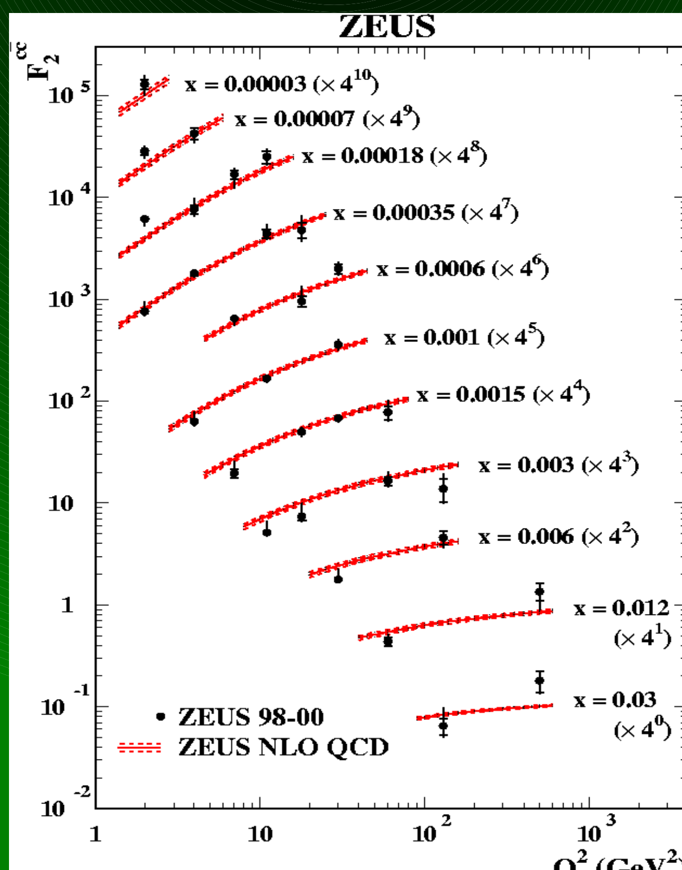


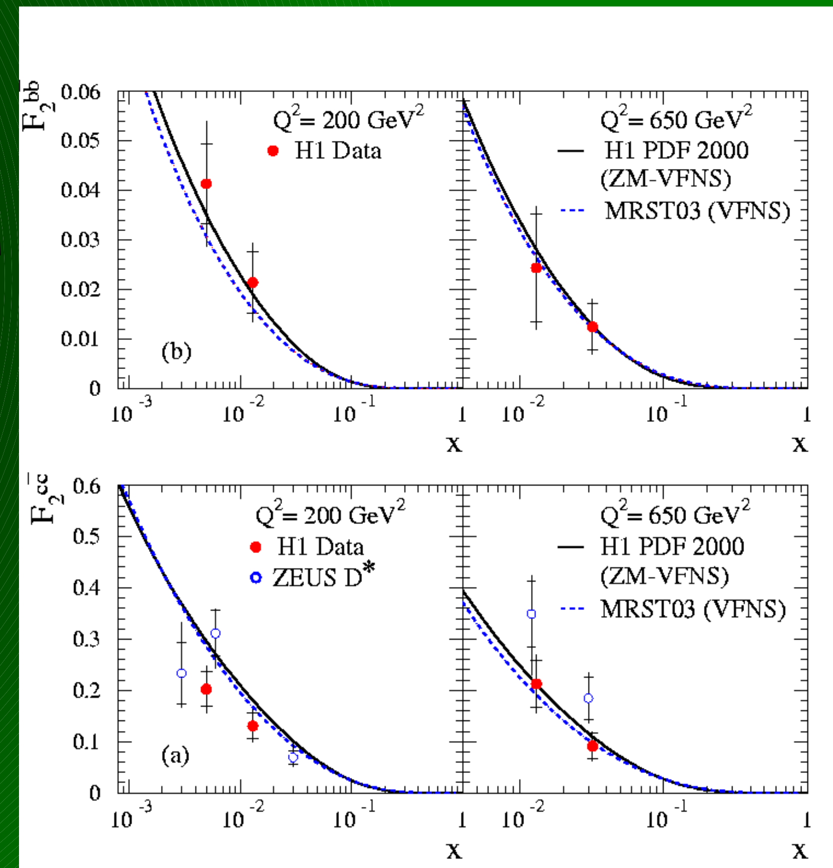
- H1 and ZEUS agree
- agreement with global PDFs
- at high x measurement of u_v and d_v densities



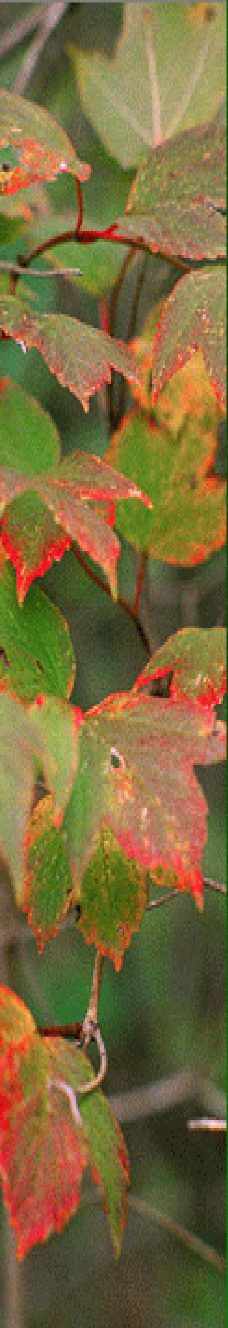
F_2^{cc} & F_2^{bb} Measurements

- F_2^{cc} and F_2^{bb} measured by H1 and ZEUS
- charm and beauty produced via BGF
  - directly sensitive to gluon parton densities





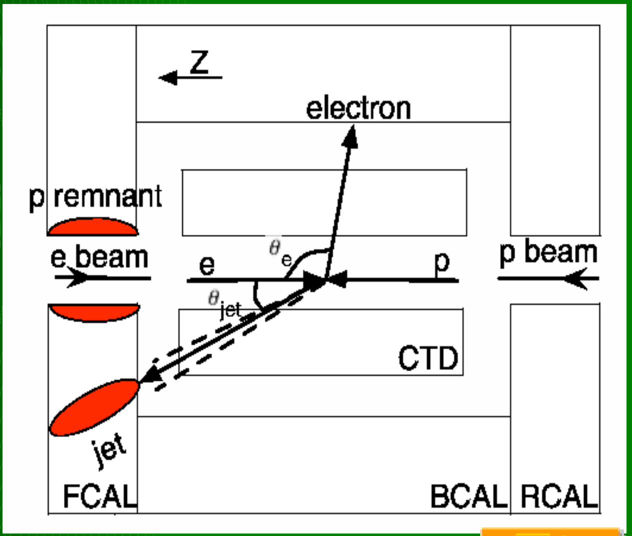
- measurements agree between experiments and with theoretical prediction
- could be used as additional constraint on gluon densities



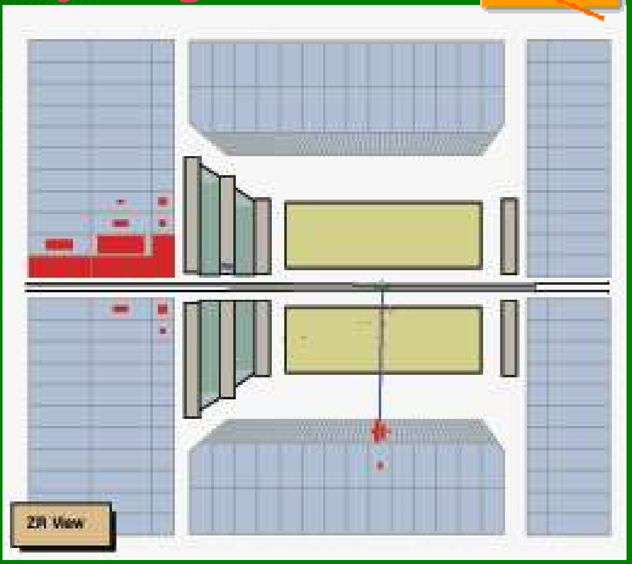
High x Measurement

- $x \to 1$ PDFs not confronted with experiment, highest x point so far: x=0.75
- NC DIS: higher x ➡ jet (from scattered quark) more forward in the detector
- jet not possible to measure anymore ➡ x = 0.65 (previous publication)
- measuring jet impossible ➡ counting number of events (integrated cross section) ➡ extending sensitivity to x=1
- Q^2 measured from electron, x from jet

1-jet high x event

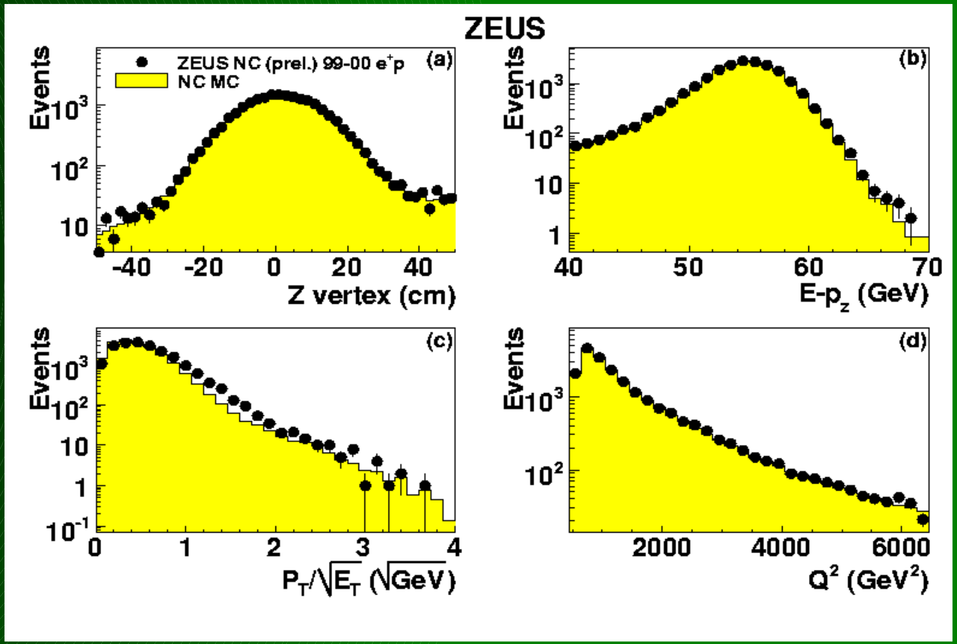


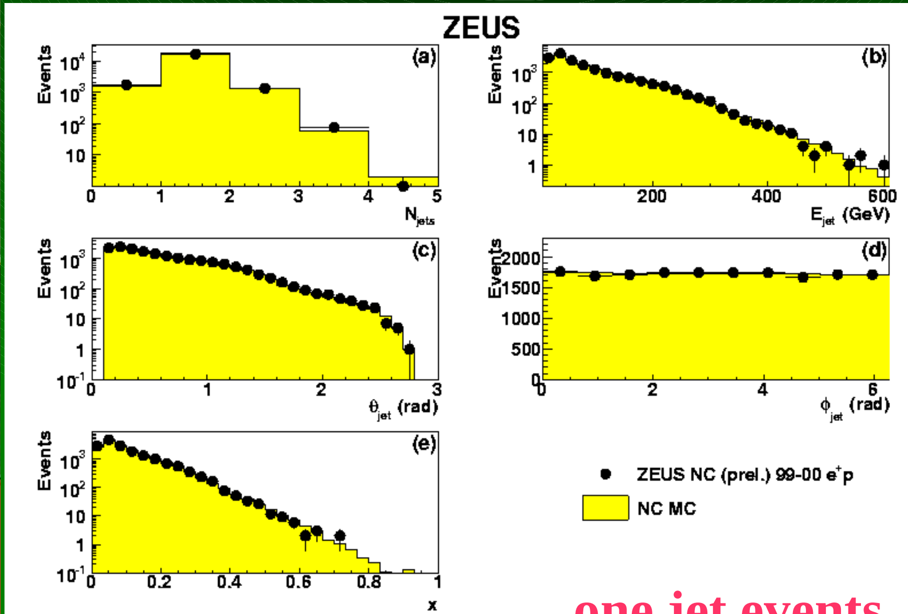
0-jet high x event



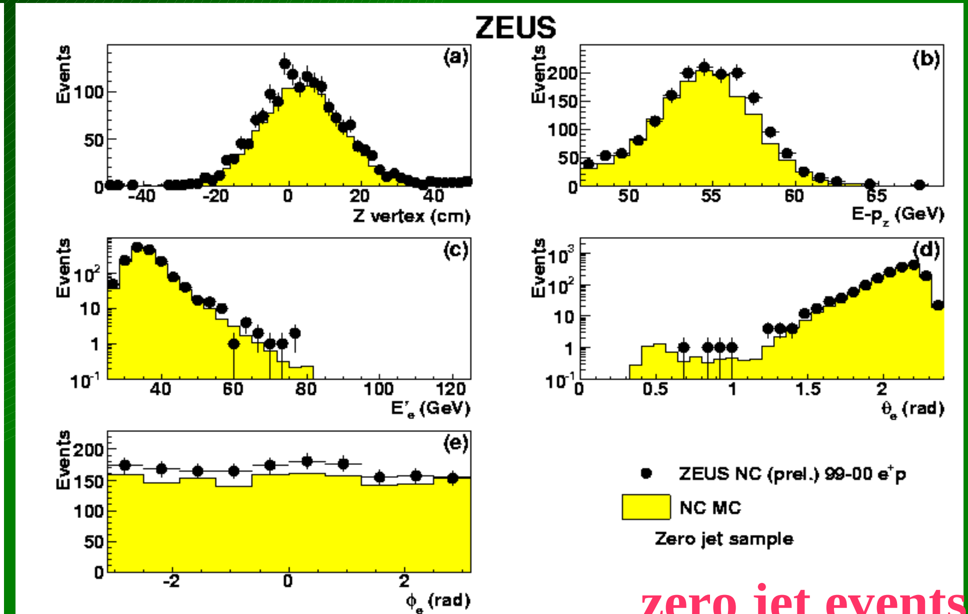
High x Measurement

- standard selection ensuring:
  - appropriate DIS event, $Q^2 = 576\ \mathrm{GeV}^2$
  - good jets with $E_T > 10$ GeV
  - background free and well reconstructed sample





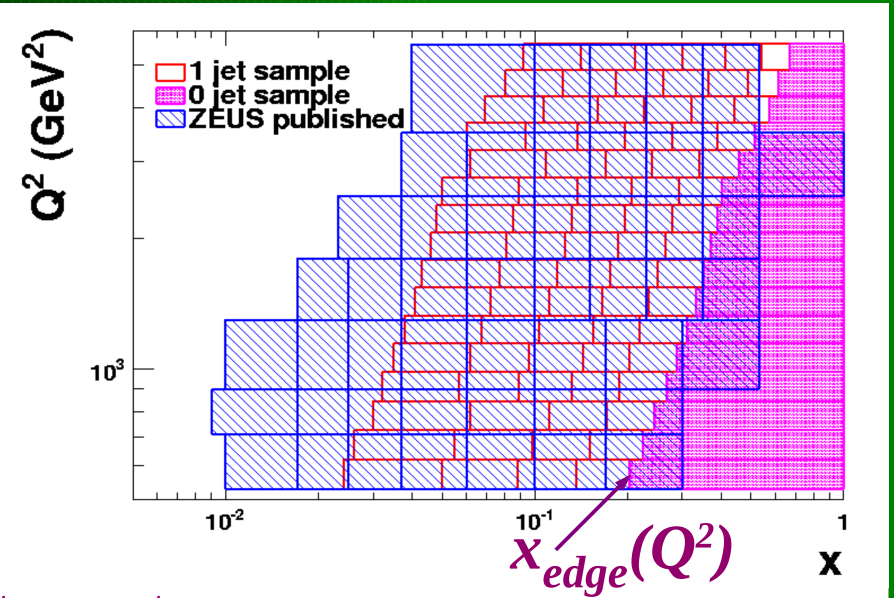
one jet events

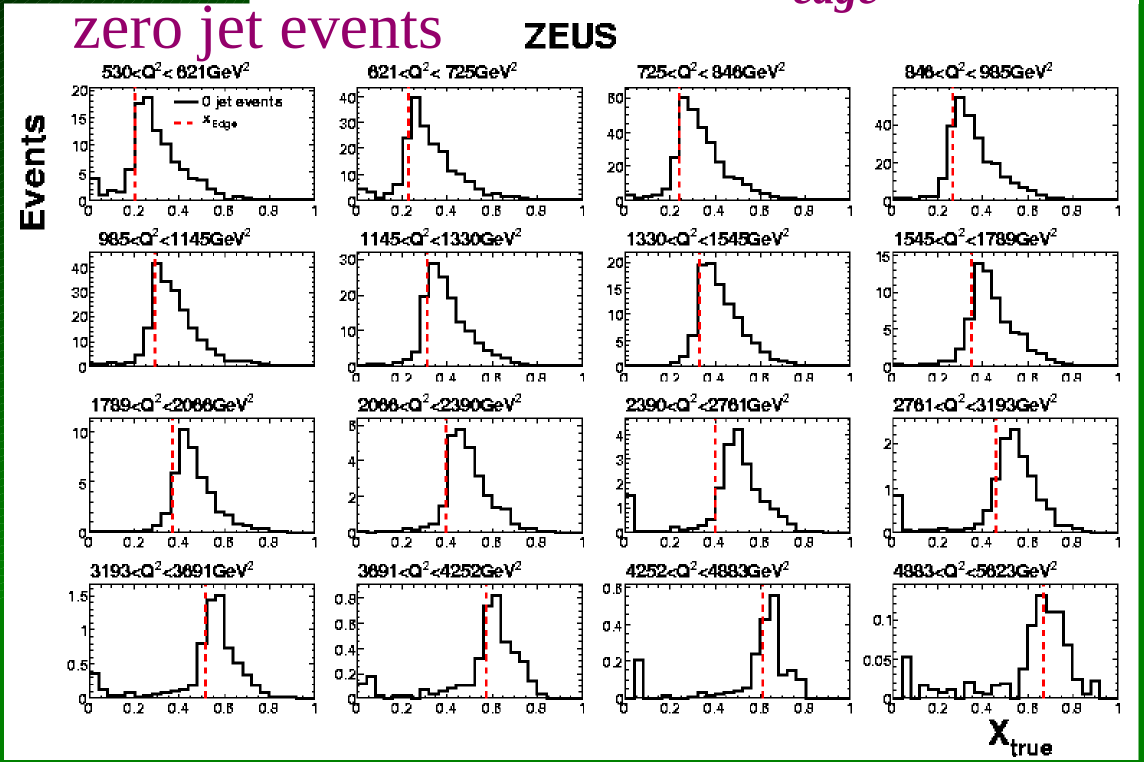


zero jet events

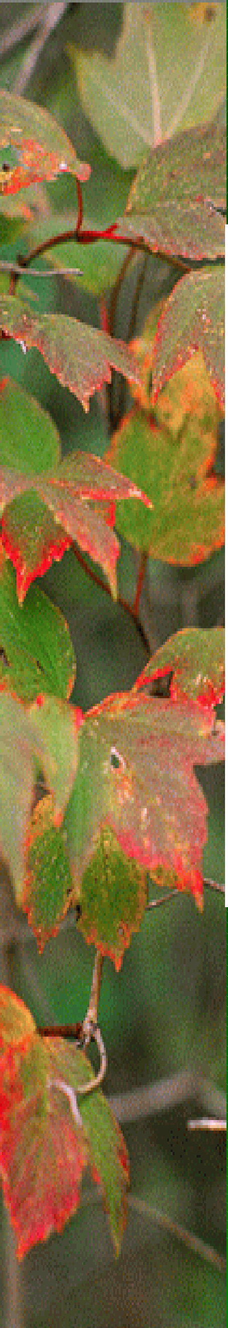
High x Measurement

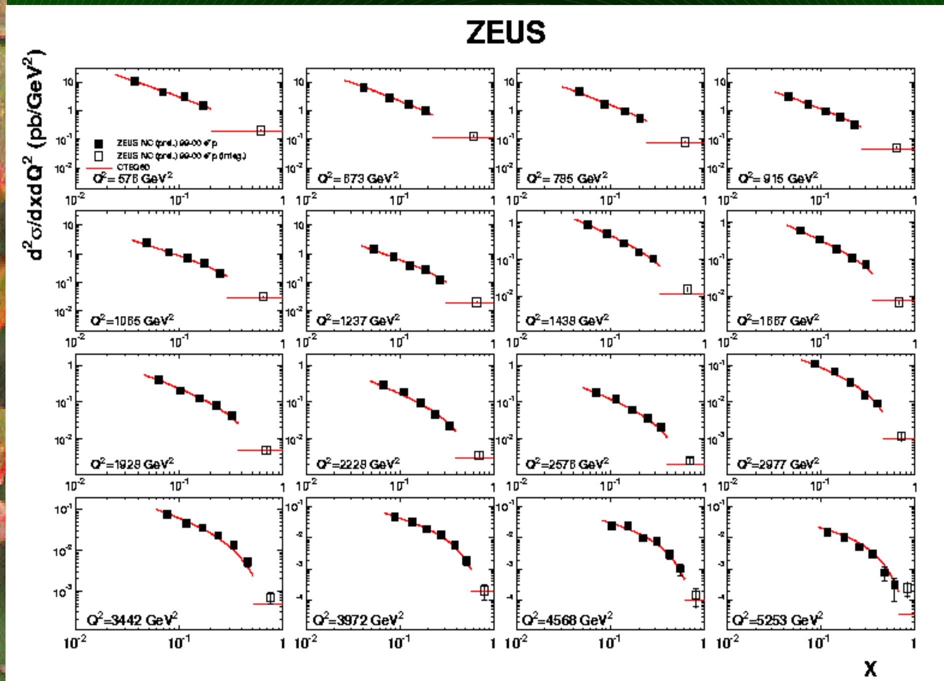
- compared to previous measurements:
  - more bins
  - better resolution
  - bins extend to x = 1
    - ➟ zero jet events
- x_{edge} depends on Q^2
- 0-jet events come from $x_{edge} < x < 1$
- high purity in highest x bins
  - comparable to mid-x



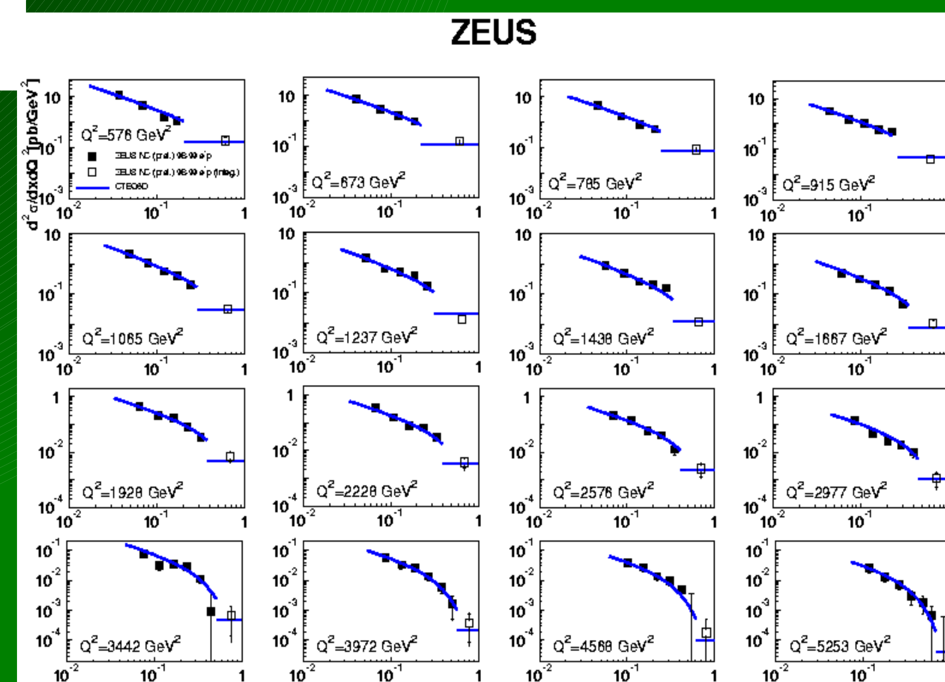


High x Measurement



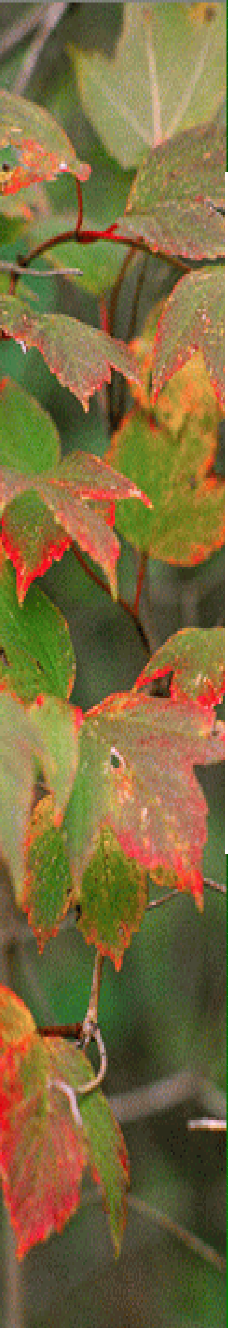


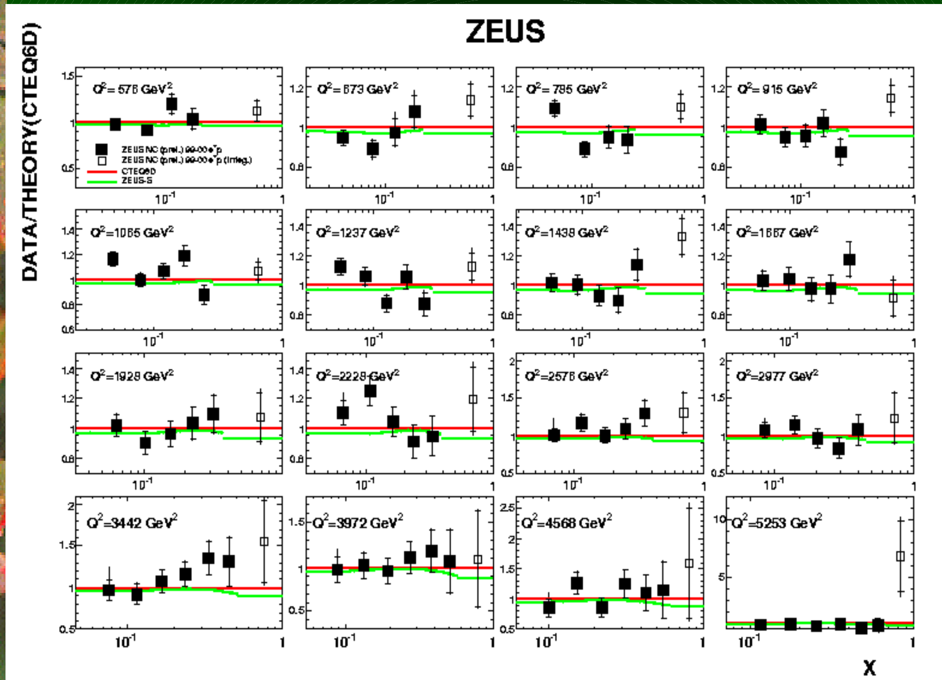
- measured Born level cross sections
- comparison with SM at NLO using CTEQ6D



- highest x points – integrated cross sections

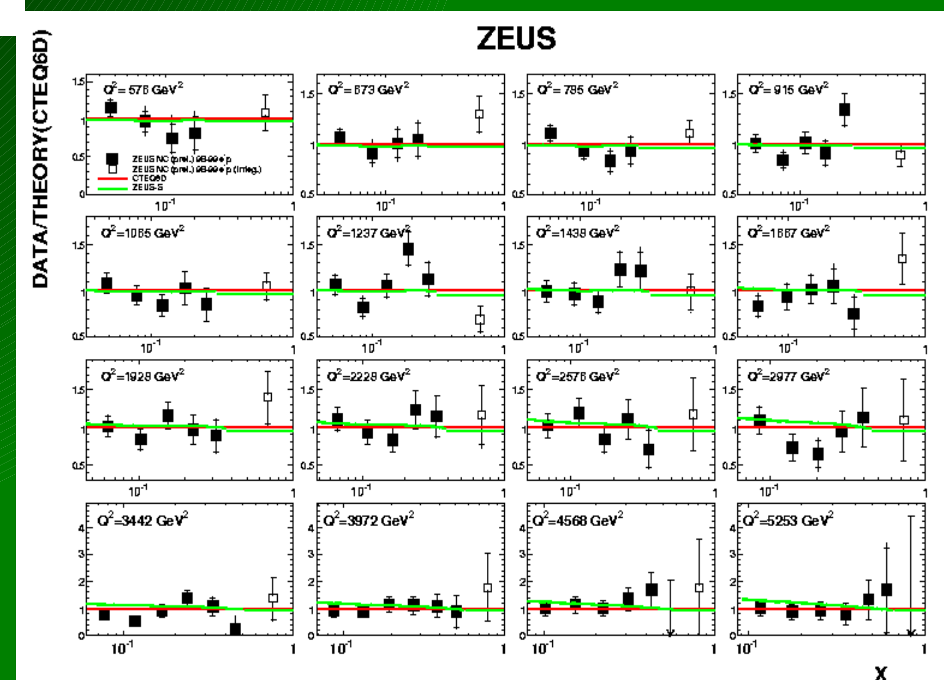
High x Measurement





- measured double differential cross sections generally agree well with
  - CTEQ6D PDFs
  - ZEUS-S PDFs
- for highest x bin data tend to lie above expectations

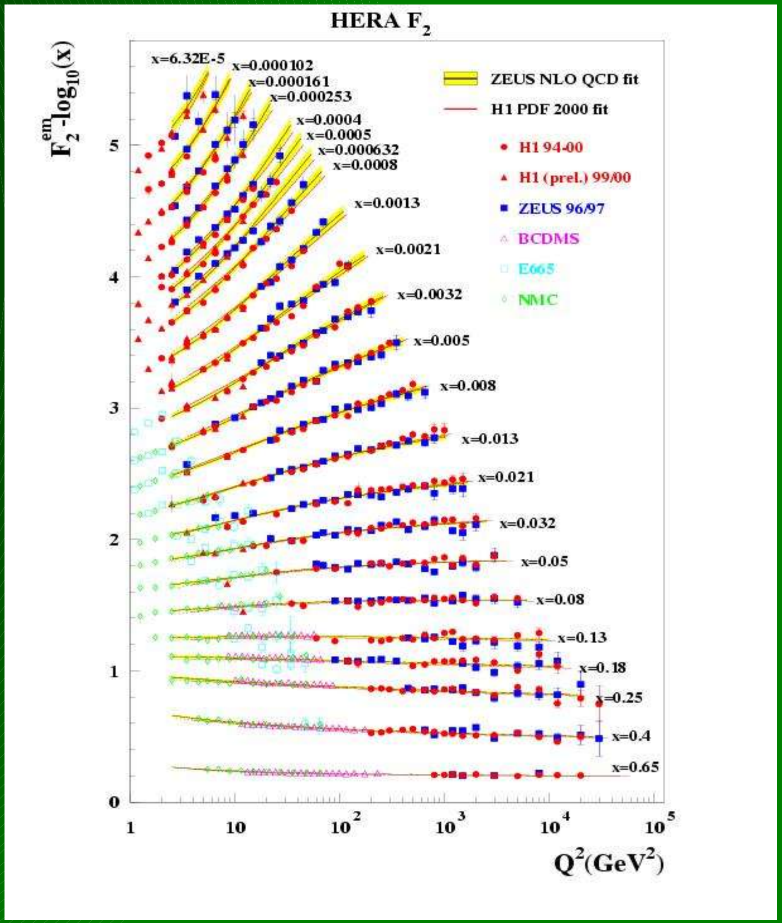
- expected impact on PDFs at highest x and also smaller x
  - now impacted modest
  - method developed, more data needed
  - might lead to change of parametrization

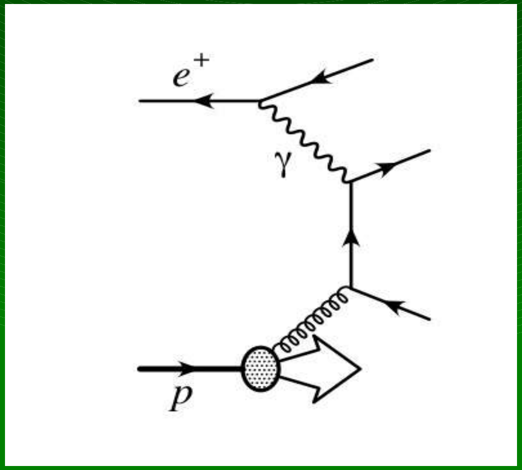


Jet Data in Global Fits: NEW

- ***inclusive DIS*** measurements contribute only ***indirectly*** to ***gluon*** distribution, via ***higher-order terms***

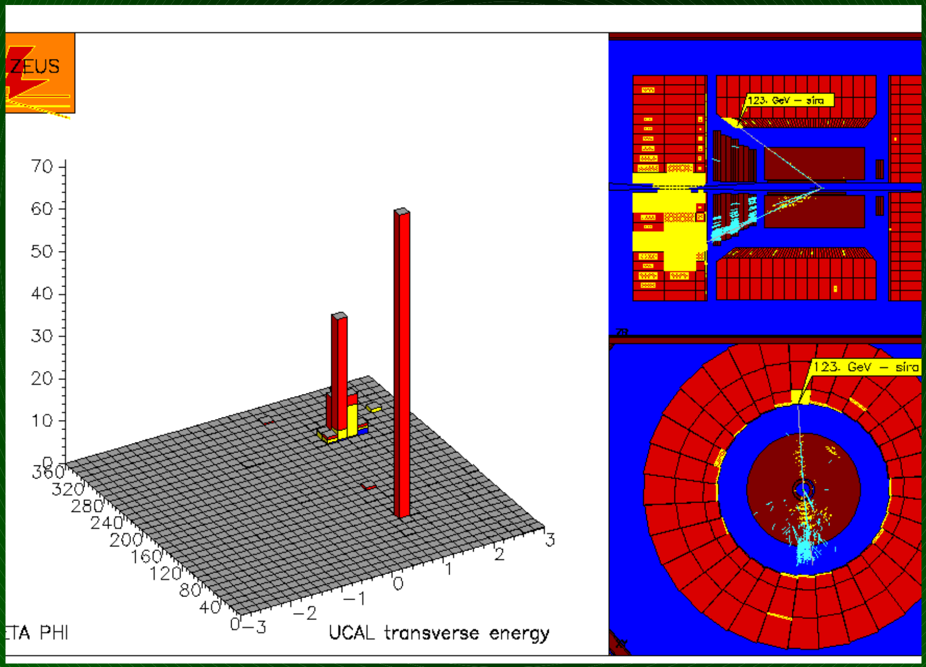
- ***jet cross section*** measurements sensitive ***directly to α_s and gluon*** (BGF, QCD Compton)
  - ***small*** experimental and theoretical ***uncertainties***





- enough sensitivity to determine proton PDFs within a single experiment

Jet Data in Global Fits: NEW

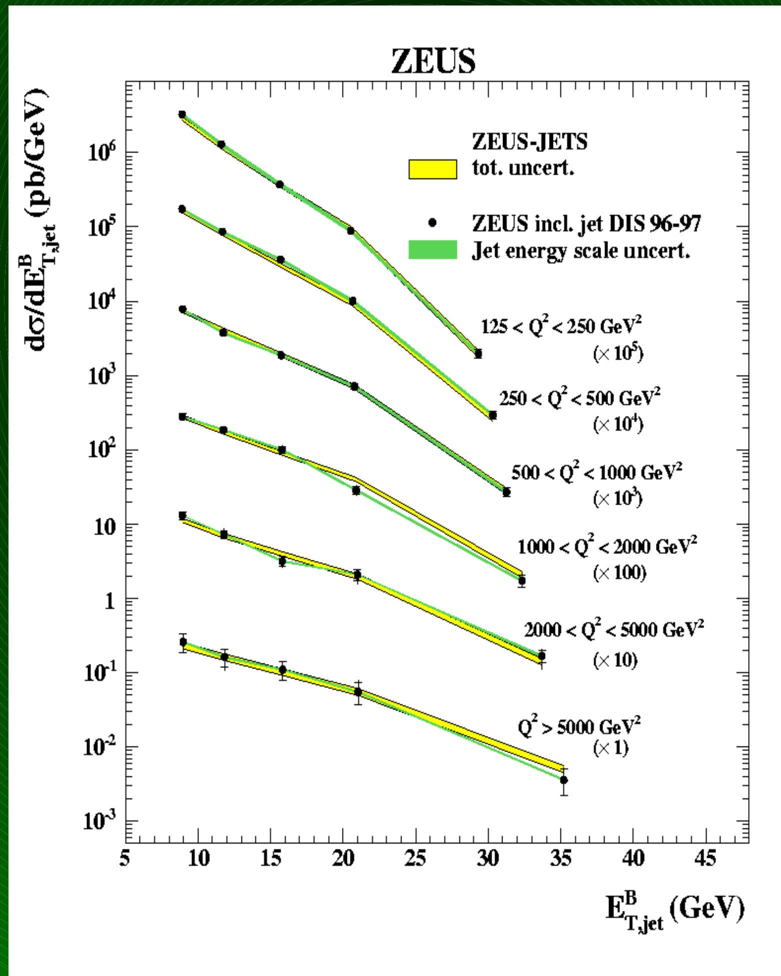


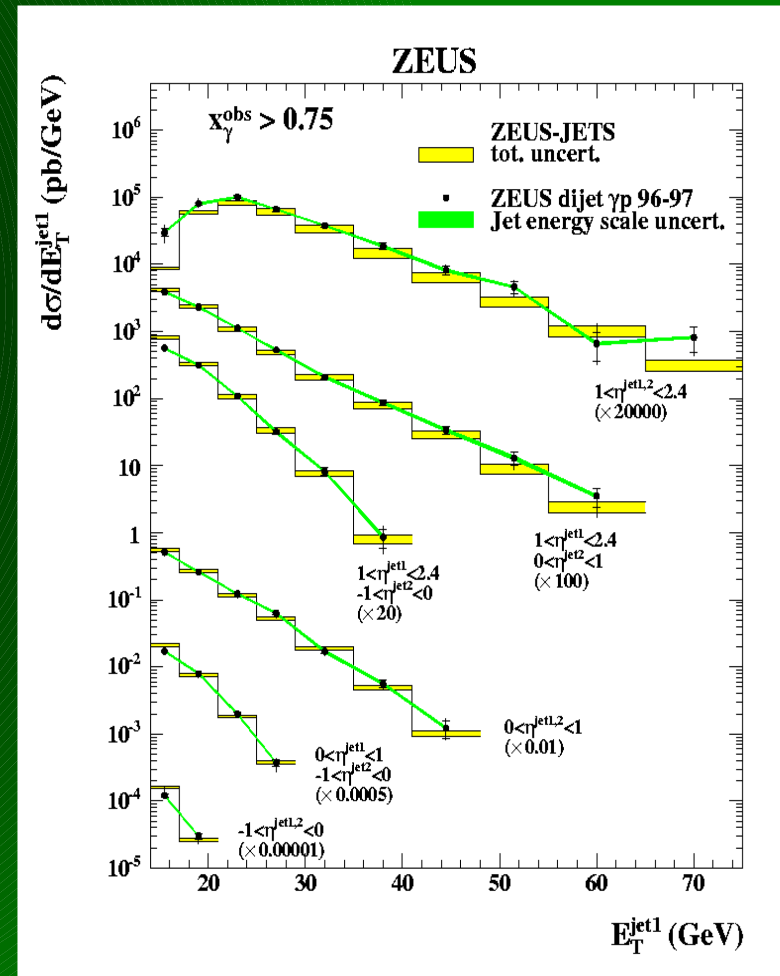
- **HERA jet data:**
  - very precise
  - sensitive to gluon, eg BGF
  - well understood correlations between points
  - small uncertainty on jet energy scale

- jet data never before rigorously included in global fits
- calculations done using a grid of weights from pQCD predictions (theory program) and then interpolating

➟ see details in A. Cooper-Sarkar's talk!

DIS & Photoproduction Jet Data



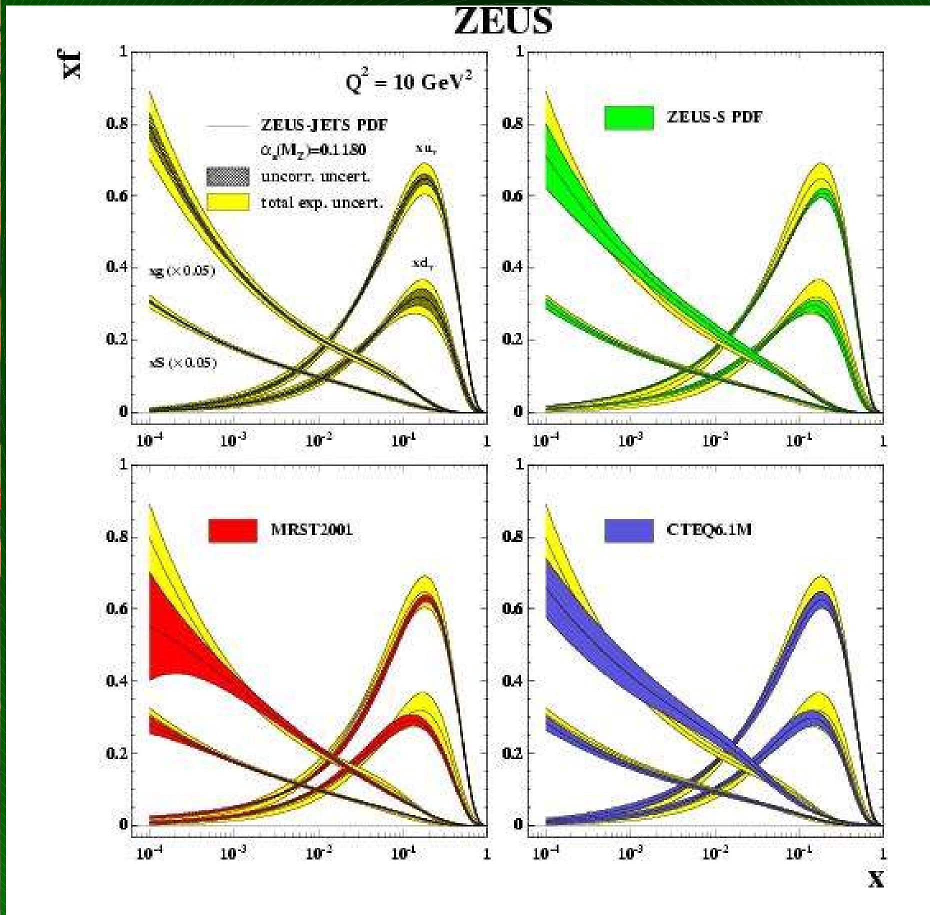


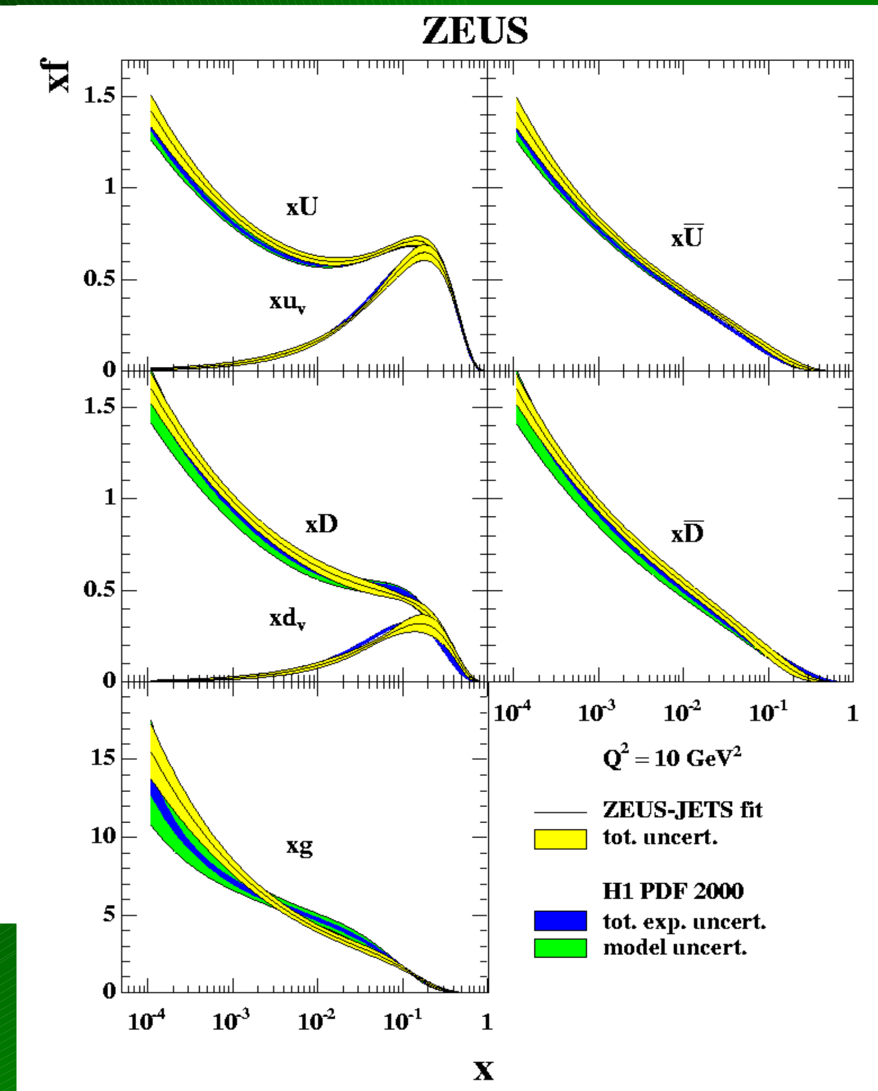
- DIS jet data used in global fit
- good agreement with ZEUS-JETS PDFs

two very different processes combined

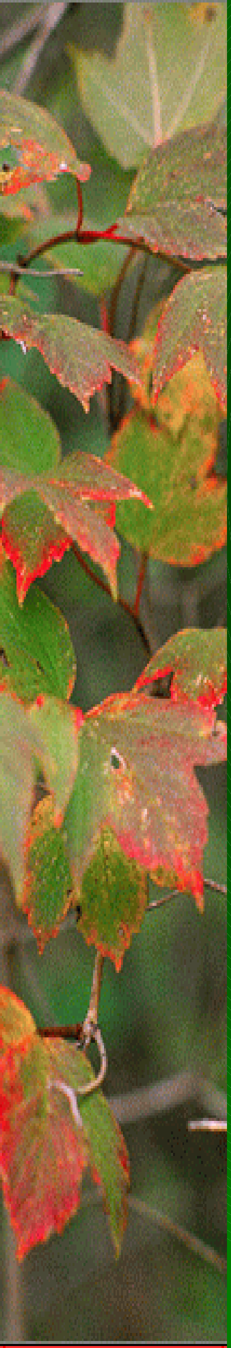
- photoproduction jet data used in global fit
- good agreement with ZEUS-JETS PDFs

ZEUS-JETS Parton Densities



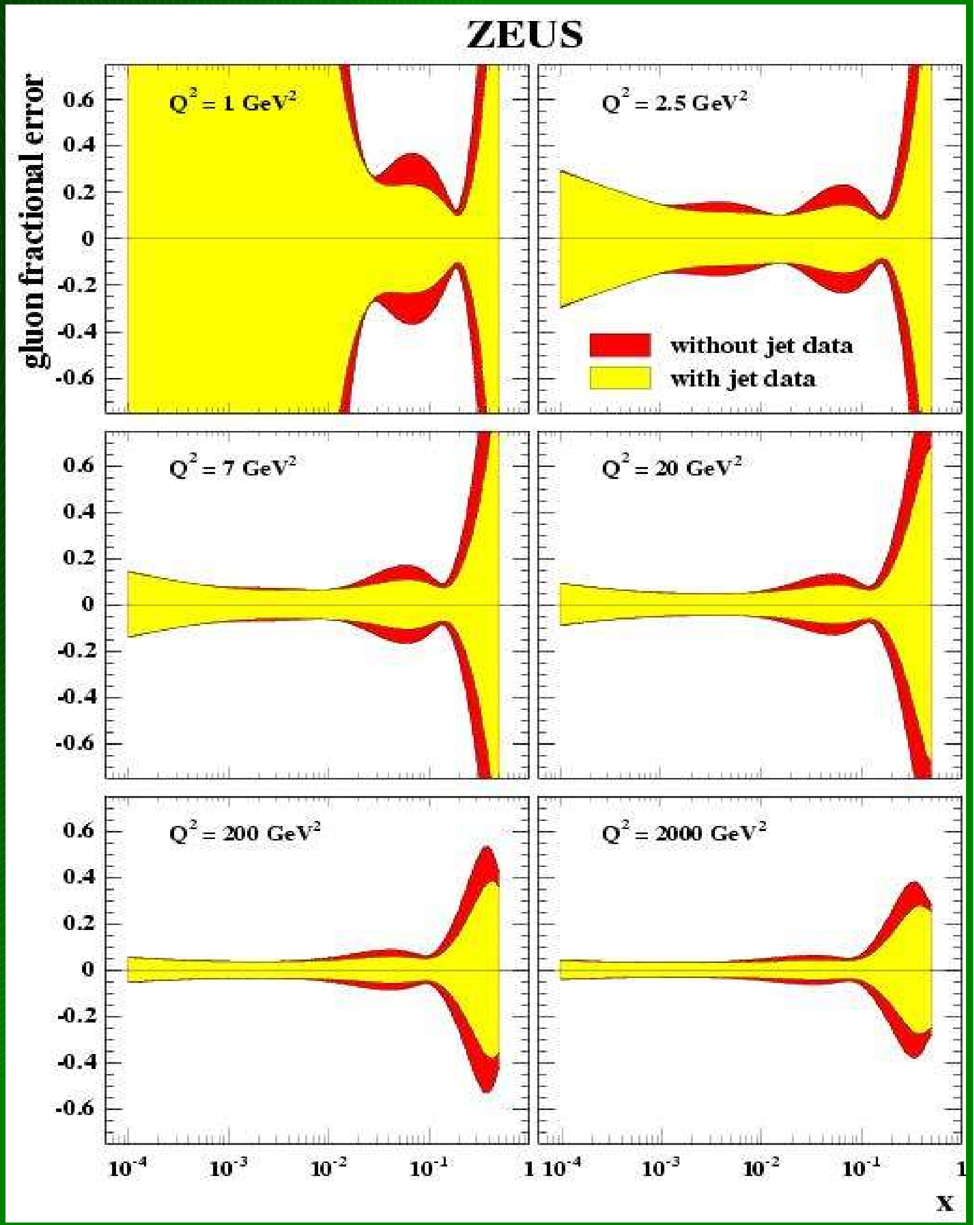


- HERA PDFs consistent with MRST and CTEQ
- H1 and ZEUS fits consistent despite different fit approach

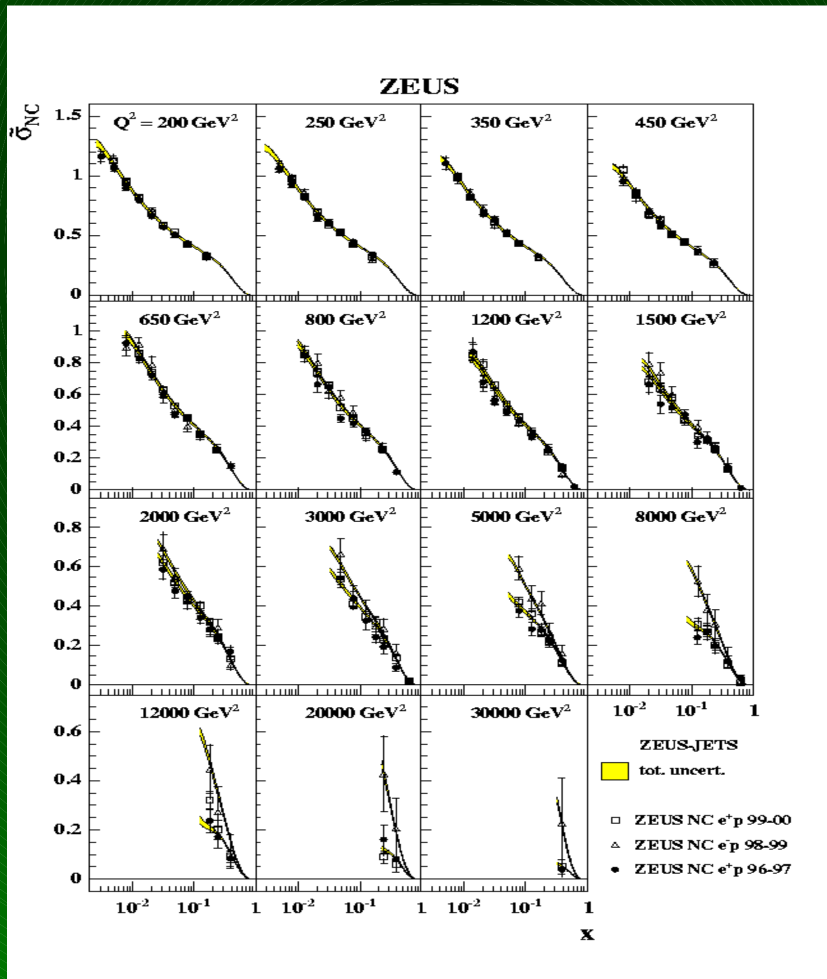


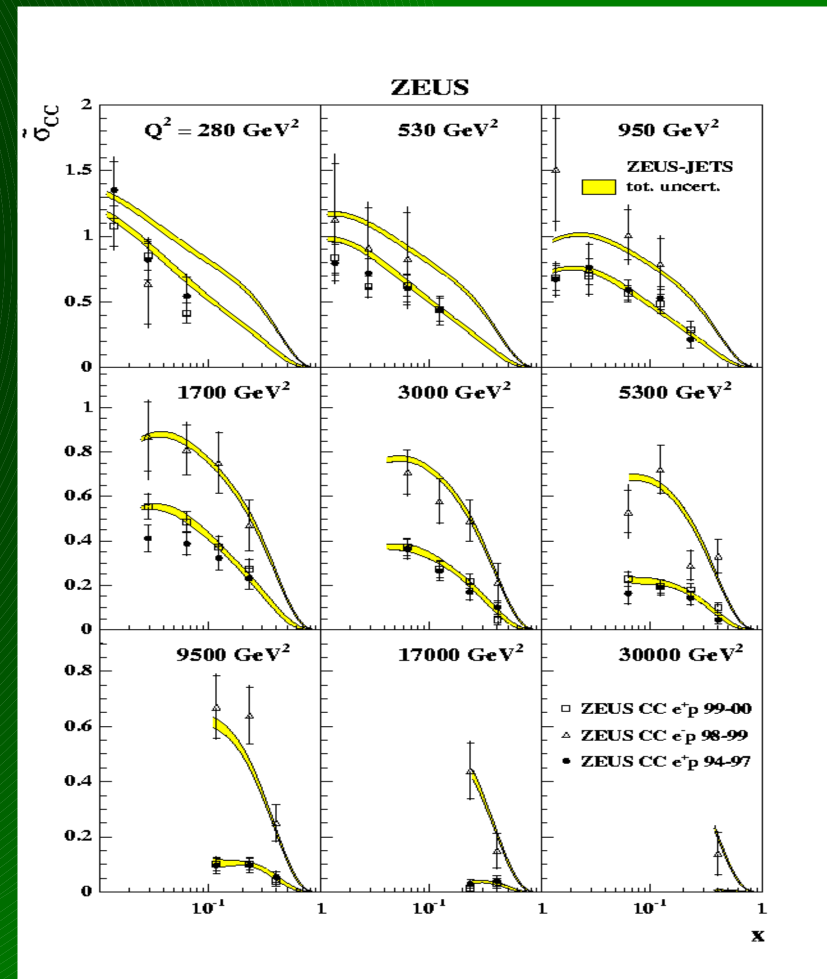
ZEUS-JETS Parton Densities

- only in ZEUS-JETS PDFs jets were included in rigorous way
- first time jet data from HERA included
- jet data has significant impact on gluon uncertainty for mid and high-x PDFs



NC & CC High Q^2 Cross Sections

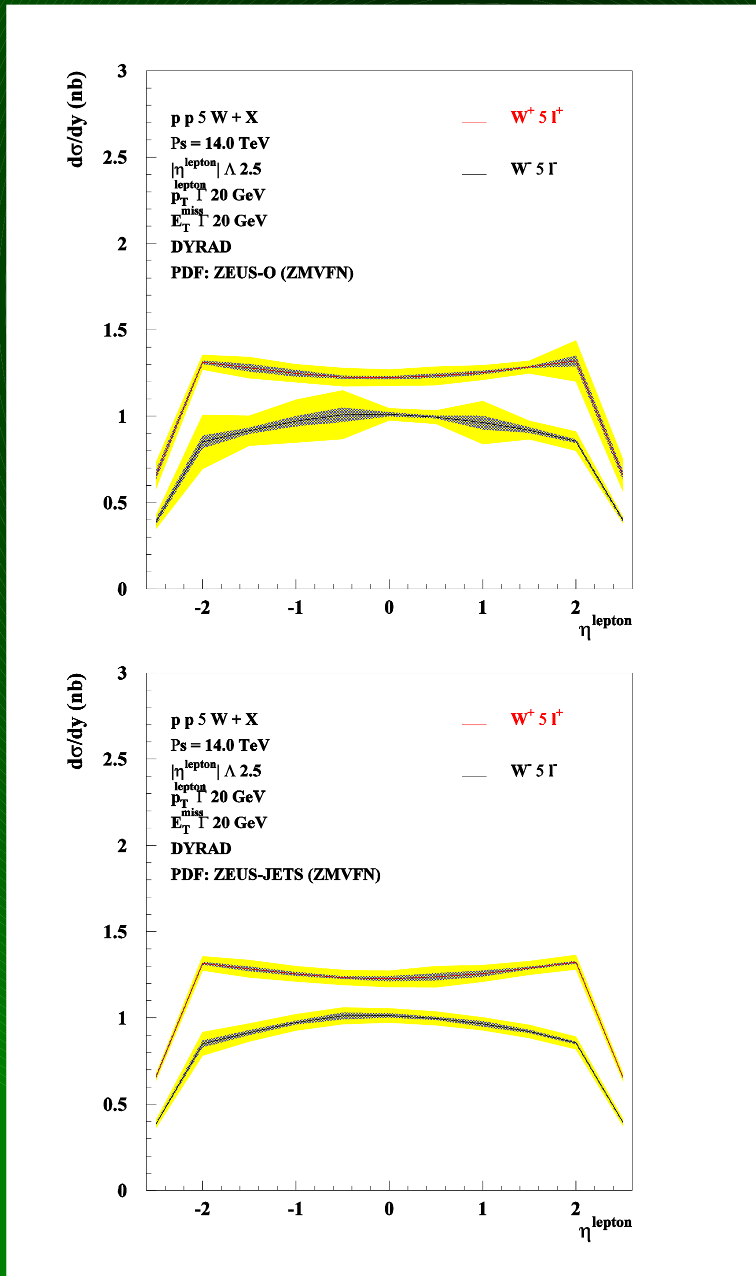




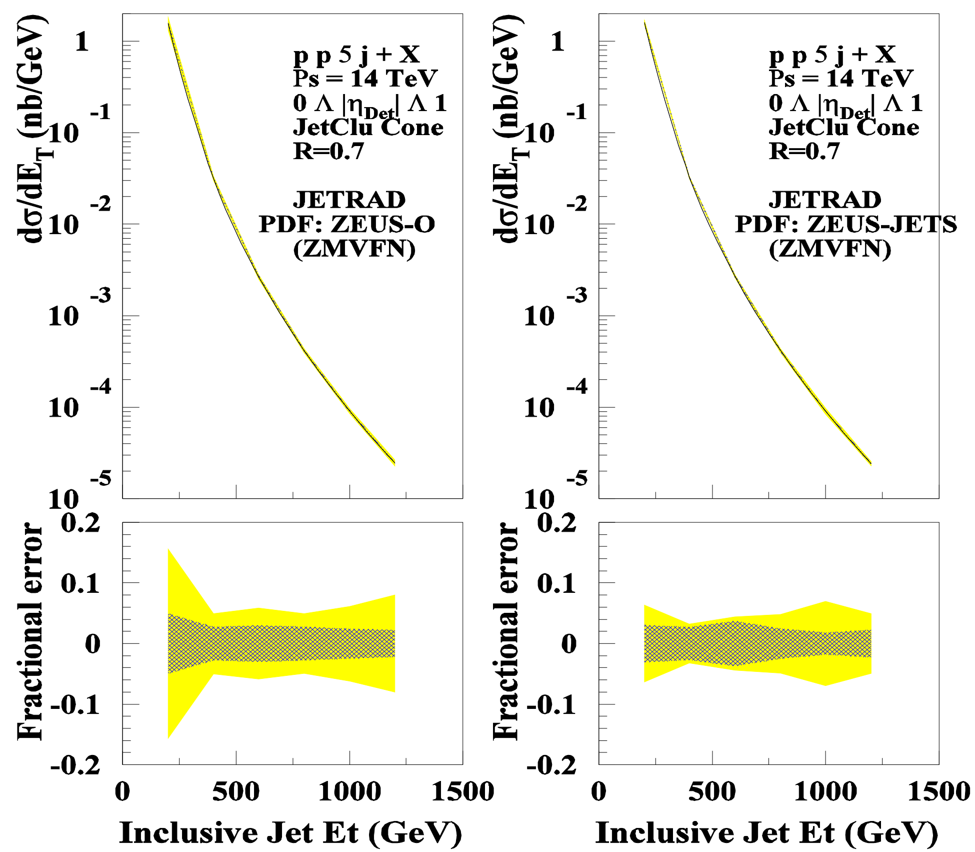
- NC and CC cross sections compared to ZEUS-JETS PDFs
- good agreement between data and prediction with ZEUS-JETS

Impact for LHC

- NLO cross sections for jets and W for LHC

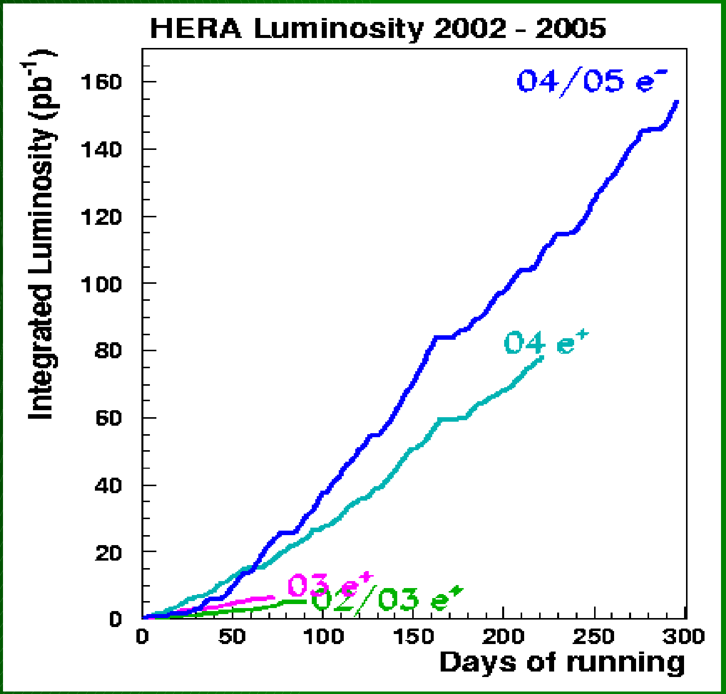


K. Nagano



Future Measurements

- HERAII collecting data
  - e^+p and e^-p scattering
  - polarized electron beams
- already ~7 times more luminosity for electron sample then HERAI



- better results & fits expected with high luminosity
- first CC & NC results from HERAII

➡ see J. Meyer's talk

Summary

- HERA provides many measurements giving access to proton parton densities
  - F_2 measurements constrain sum of q and $qbar$, and gluon densities
  - xF_3 measurements at high x sensitive to valence quark content of proton
  - CC cross sections at high x allow measurement of u_v and d_v densities
  - high-x DIS NC cross sections expected to have impact on highest-x and lower-x PDFs
  - DIS and photoproduction jet data improve uncertainty of mid and high-x gluon distributions
- HERAII luminosity ➠ more precise measurements

HERA II Prospects

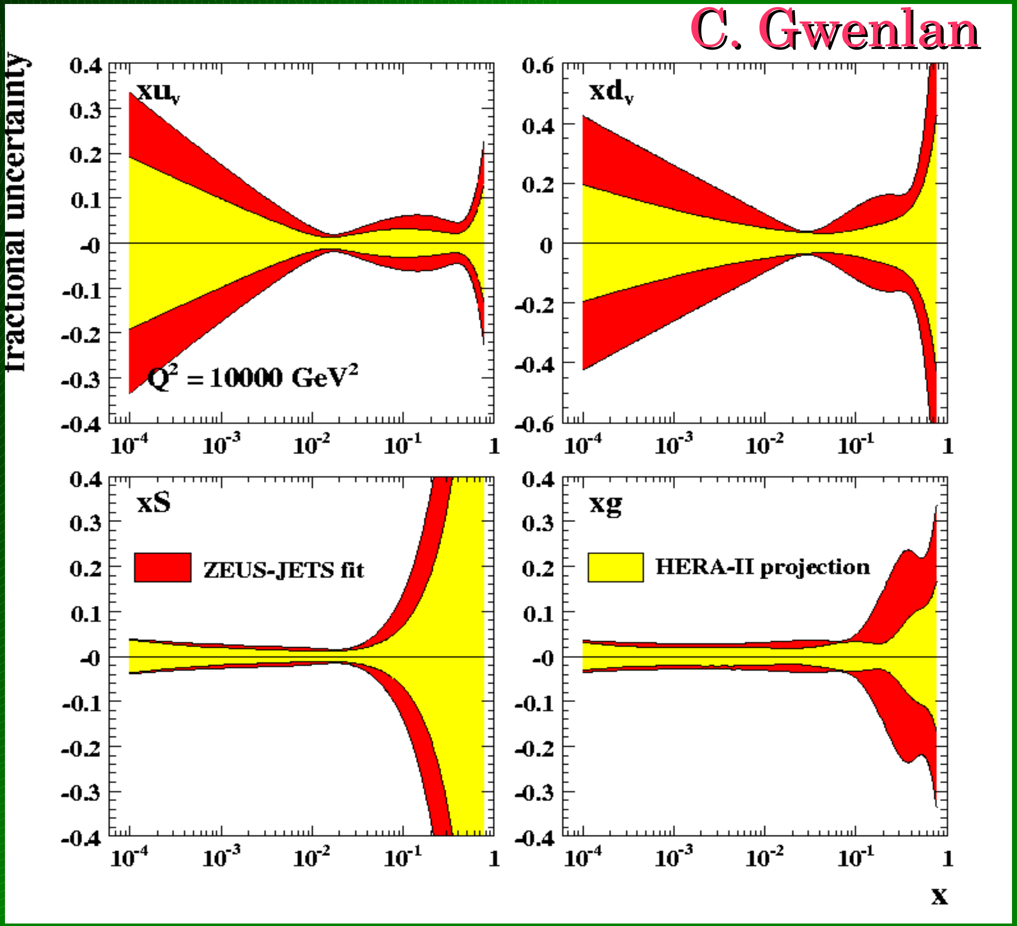
- PDFs measurements from HERA I
  - inclusive DIS NC&CC cross section statistically limited
  - jet cross sections statistically limited at high E_T and high Q^2
  - jets measured only in certain kinematic regions NOT optimized for sensitivity to gluon

- HERA II present scenario:
  - 700 pb^{-1} equally split between e^+ and e^- until mid-2007
  - 350 pb^{-1} for NC & CC e^+/e^- scattering
  - ongoing ZEUS study on optimizing dijet phtoproduction measurement (C. Targett-Adams)

⇒ HERA II PDFs

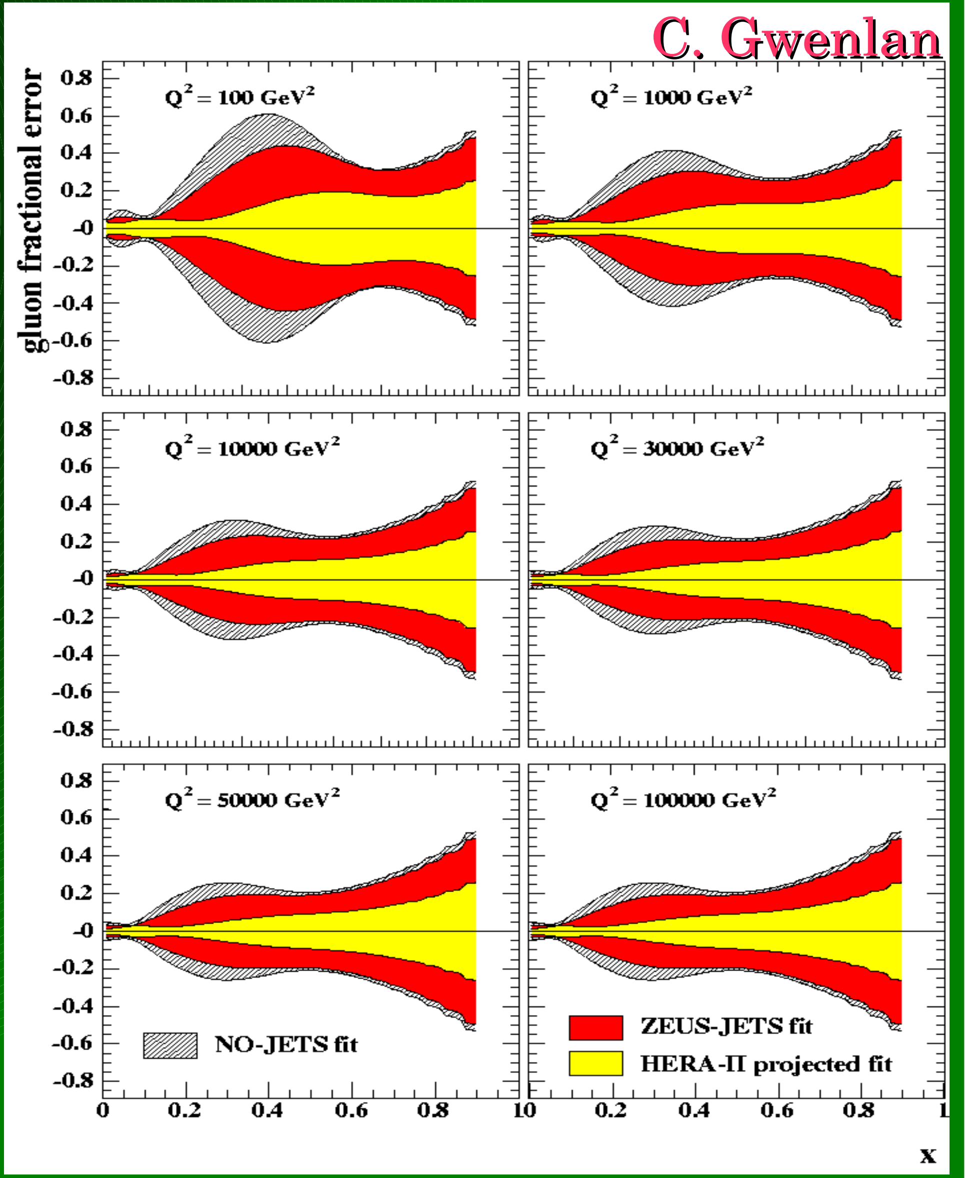
HERA II Projected Fits

- statistically limited data sets
  - statistical uncertainty scaled from present to 700 pb^{-1}
  - systematic uncertainty taken from present data
- optimized jet cross sections
  - include simulated data points from NLO QCD
  - statistical uncertainty calculated for 500 pb^{-1}
  - no systematic uncertainties included



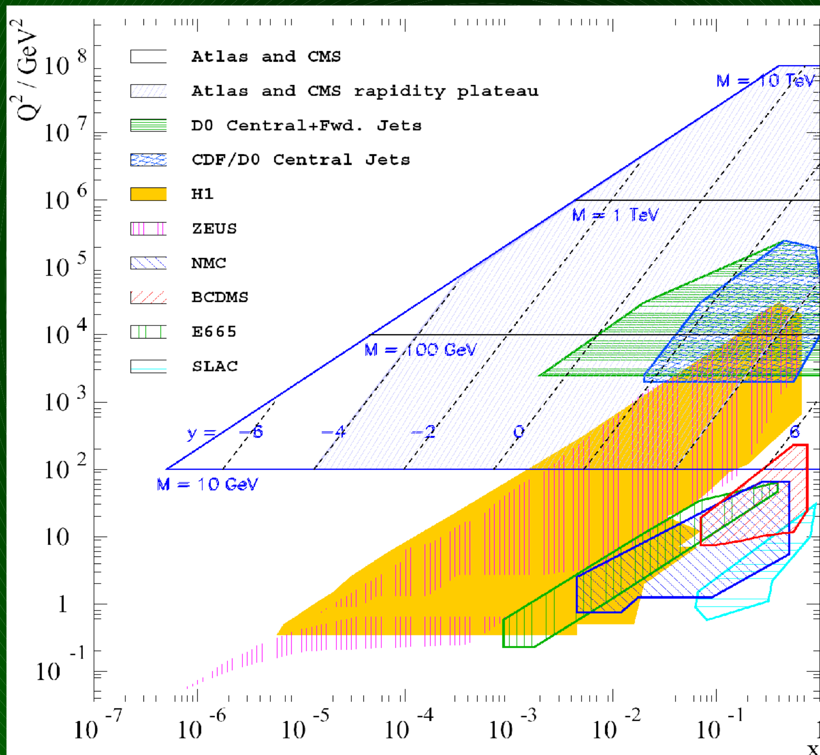
HERA II Projected Fits

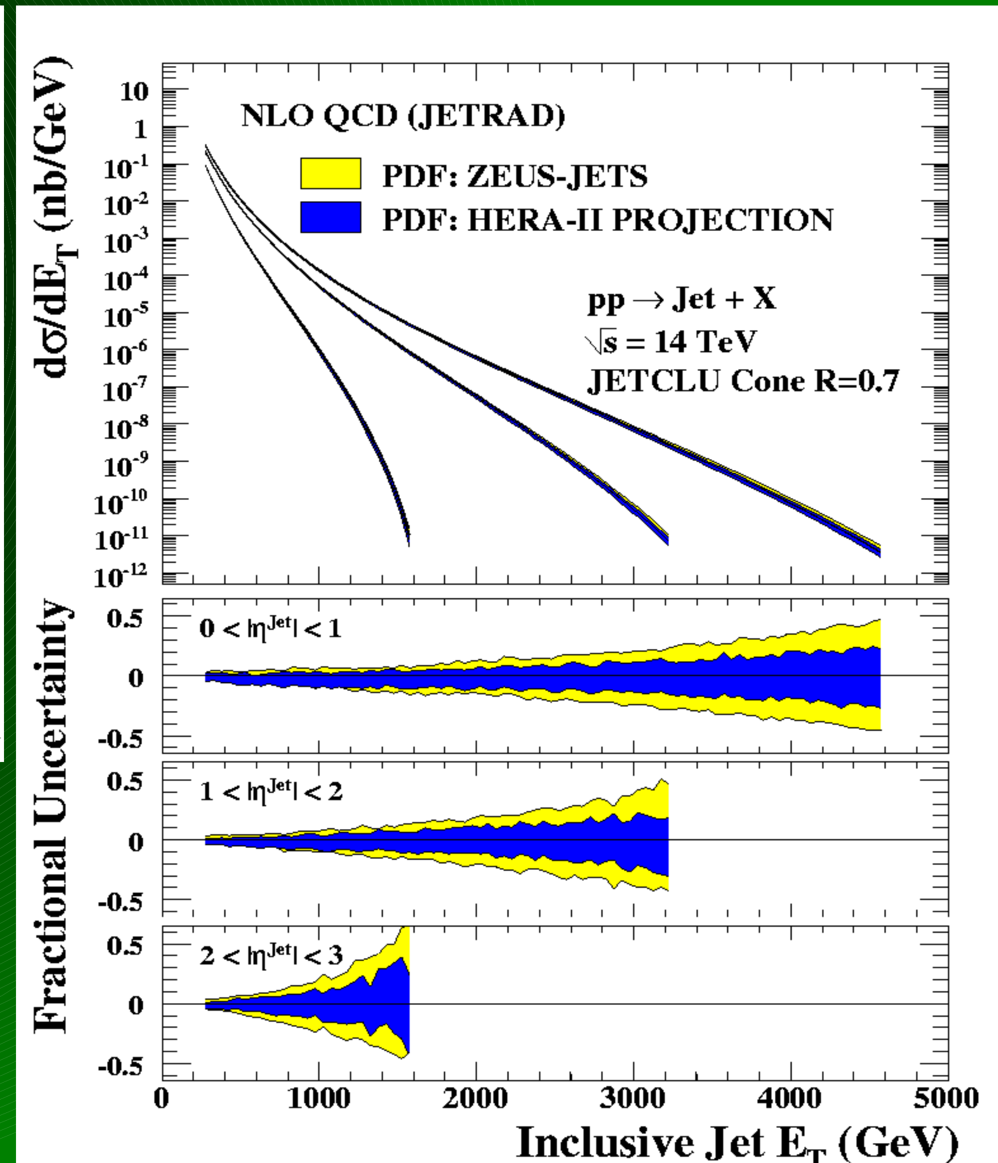
- uncertainties on valence quarks significantly reduced over whole x range
- uncertainties on sea quarks significantly reduced at high x
  - most significant improvement from increased statistics of HERA II
- uncertainties on gluon significantly reduced at mid-to-high-x gluon
  - most significant improvement from optimized cross sections



➡ for details see C. Gwenlan's DIS05 talk

HERA II Kinematic Plane





- HERA covers regions in x also relevant for LHC
- high pt jets, new particles etc depend strongly on high-x partons – improvement to LHC cross sections after HERA II
- see details in hep-ph/0509220