Studies of Proton Structure at HERA

I. Tsurin

on behalf of ZEUS and H1

- *Neutral current (NC)*
- *Charged current (CC)*
- *Structure functions F_2, xF_3, F_L*
- *Parton distribution functions (PDF)*
- *The strong coupling constant α_S*
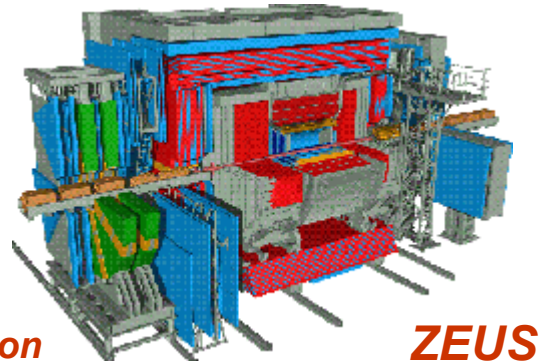- *New results on $F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$*

12th International QCD Conference
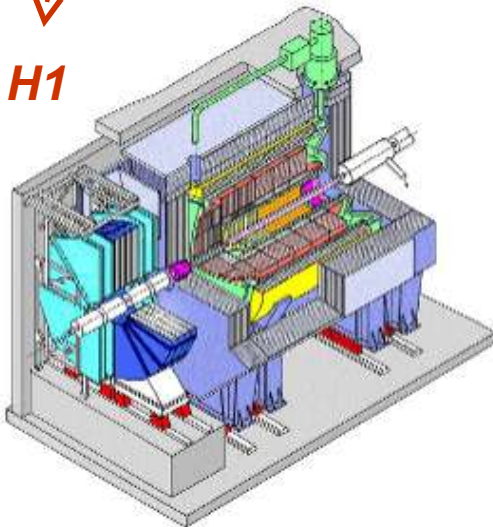**Montpellier July 4-9, 2005**

ep-Collider HERA

p-energy: 920 GeV
e-energy: 27.6 GeV

$$\sqrt{s} = 319\,\mathrm{GeV}$$
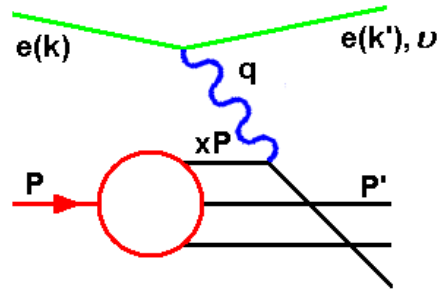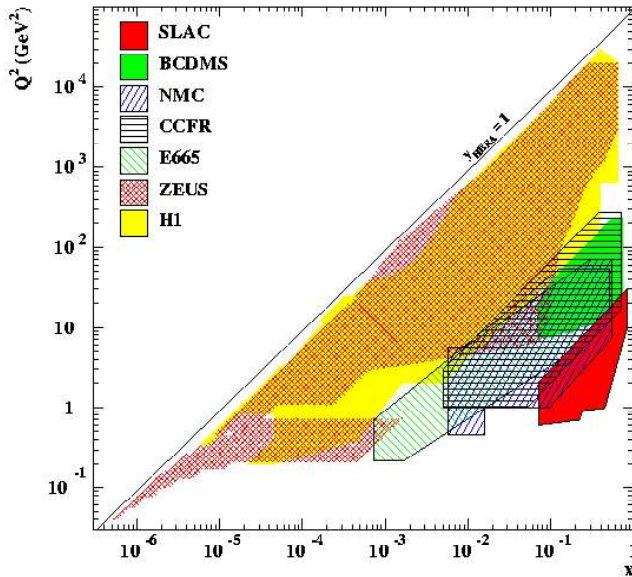
HERA II:
longitudinal e± beam polarisation

ZEUS

H1

Detectors instrumentation:

- *Liquid argon calorimeter (H1) and compensated uranium calorimeter (ZEUS)*
- *Tracking and vertex detectors*
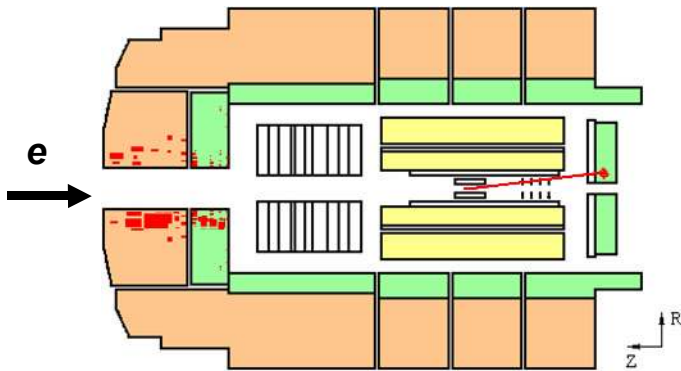- *Silicon micro-strip detectors*
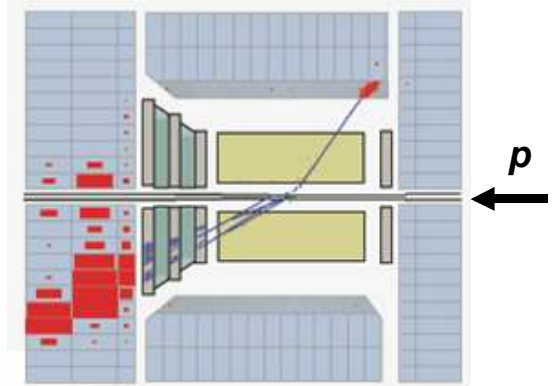- *Muon barrels and endcaps*

Deeply Inelastic Scattering

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

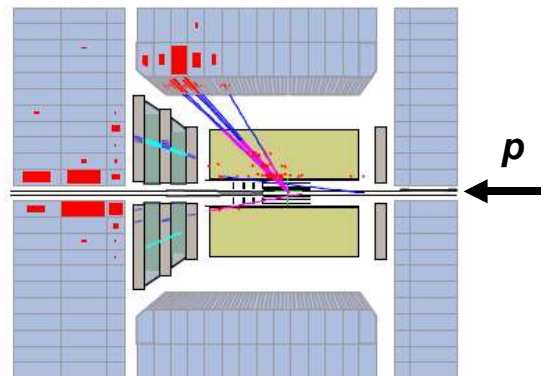$$y = \frac{P \cdot (k-k')}{k}; \quad x = \frac{Q^2}{s\,y}$$

high x, low Q² NC event

low Q² NC event

high Q² NC event

CC event

H1

ZEUS

NC and CC Cross-sections

NC cross-section (γZ, $*^0$):

$$\frac{\partial^2 \sigma_{NC}(x,Q^2)}{\partial x\, \partial Q^2} = \frac{2\pi a_s^2}{x \cdot Q^4} \tilde{\sigma}_{NC}$$
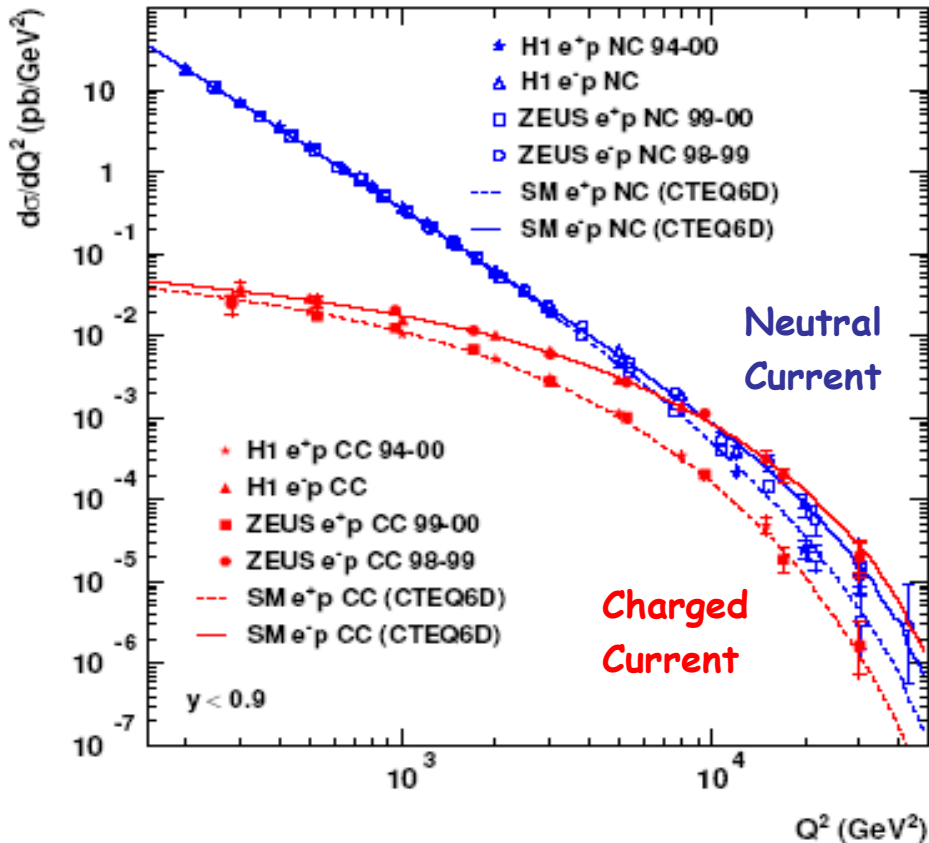
CC cross-section ($W^{\pm}$):

$$\frac{\partial^2 \sigma_{CC}(x,Q^2)}{\partial x\, \partial Q^2} = \frac{G^2}{2\pi} \cdot \frac{M_W^2}{Q^2 + M_W^2} \tilde{\sigma}_{CC}$$
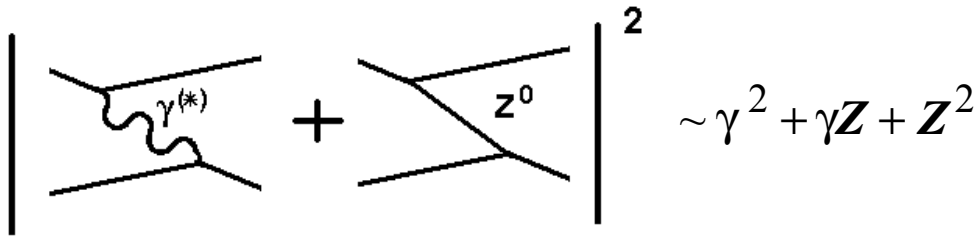
Reduced cross sections:

$$\tilde{\sigma}_{NC}^{\pm}(x,Q^2) = \left[Y_+ F_2 - y^2 F_L \mp Y_- xF_3 \right]$$

$$\tilde{\sigma}_{CC}^{\pm}(x,Q^2) = \left[Y_+ W_2 - y^2 W_L \mp Y_- xW_3 \right]$$

HERA I

Neutral Current

$$\left| \underset{\gamma^{(*)}}{} + \underset{Z^0}{} \right|^2 \quad \sim \gamma^2 + \gamma Z + Z^2$$
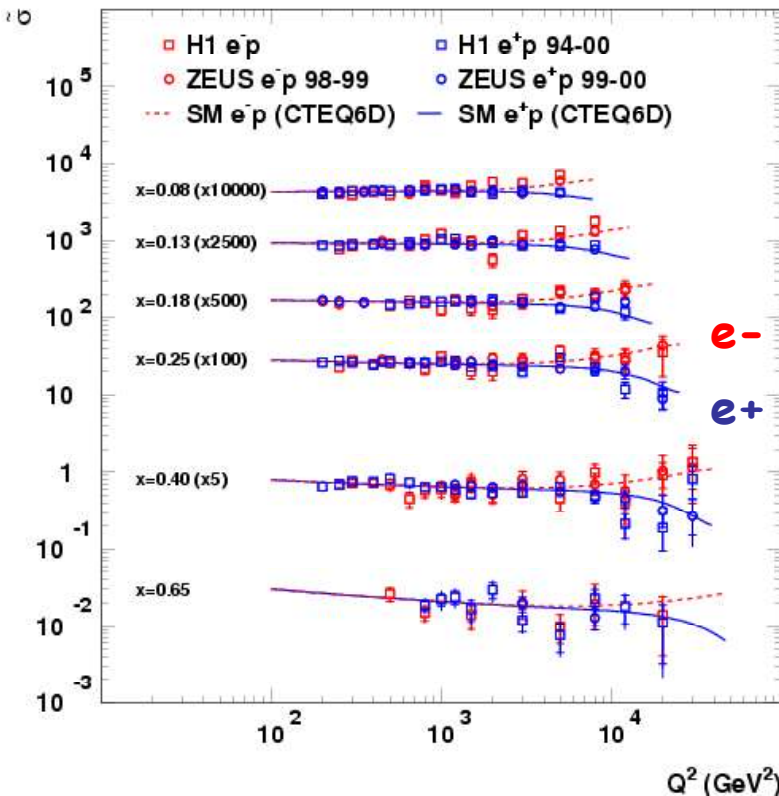
QPM $(F_L=0)$: $\quad \tilde{\sigma}^{\pm}_{NC}(x,Q^2) \sim F_2 \mp f(y)xF_3$

$$F_2(x,Q^2) = x \sum e_q^2 (q + \bar{q})$$

$$xF_3^{\gamma Z}(x,Q^2) = 2x \sum e_q a_q (q - \bar{q})$$

HERA Neutral Current at high x

Z exchange increases electron proton cross section and reduces positron proton cross section at large Q^2

HERA I:

$$L(e^- p) \approx 15\, pb^{-1}$$

$$L(e^+ p) \approx 110\, pb^{-1}$$

Z⁰ Contribution at High Q²

$$xF_3^{\gamma Z} = \frac{1}{3} x[2(U - \bar{U}) + (D - \bar{D})]$$
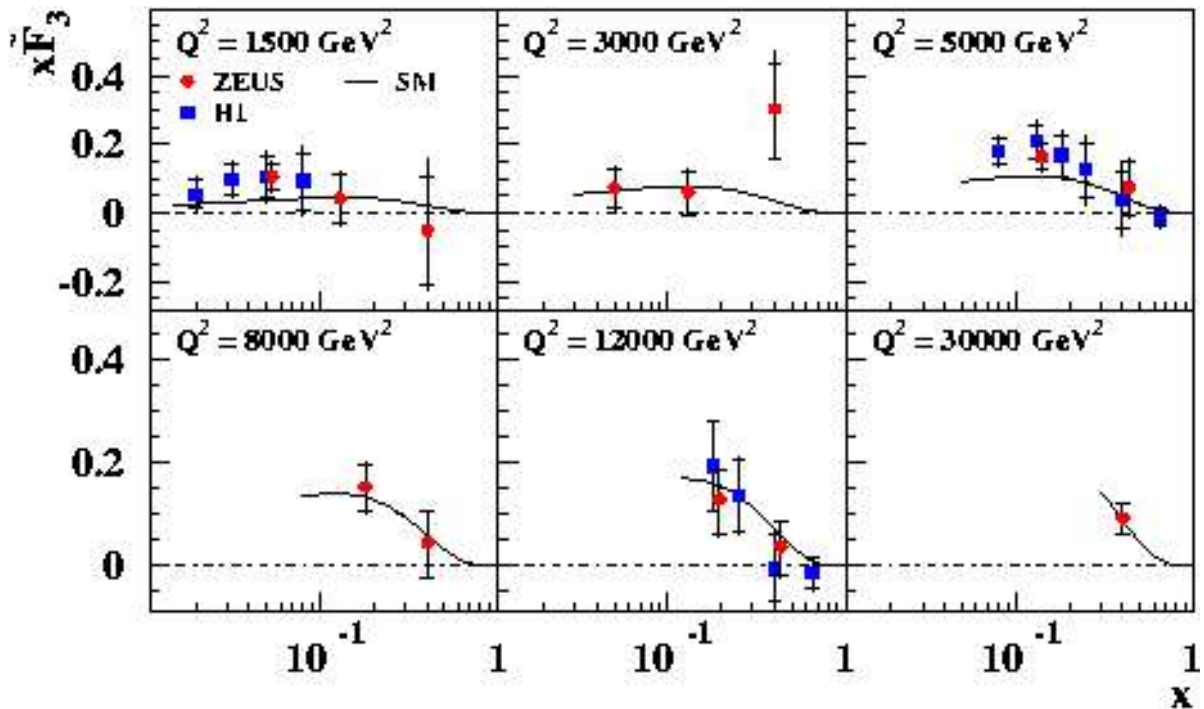
$$U = u + c; \quad D = d + s$$

$$u = u_v + u_{sea}; \quad \bar{u} = u_{sea}; \quad c = \bar{c};$$

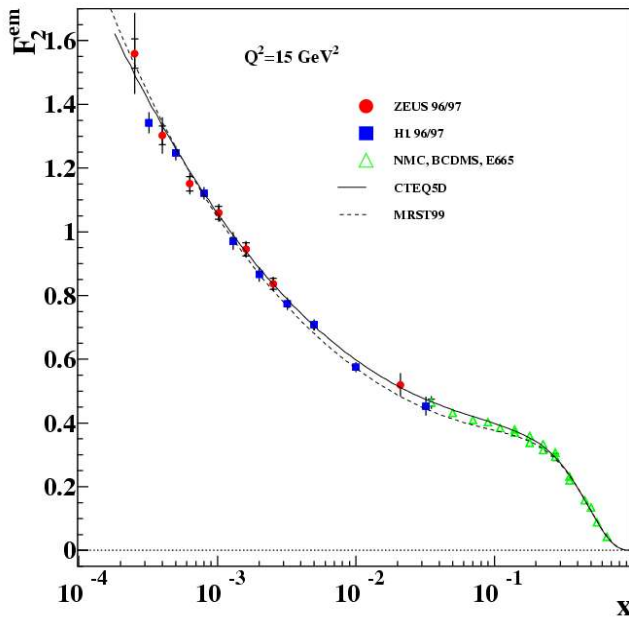$$d = d_v + d_{sea}; \quad \bar{d} = d_{sea}; \quad s = \bar{s};$$

$$x F_3^{\gamma Z} \sim 2x\,u_v + xd_v$$

Measurements of xF₃ provide a constraint on u, d valence quark densities at large x

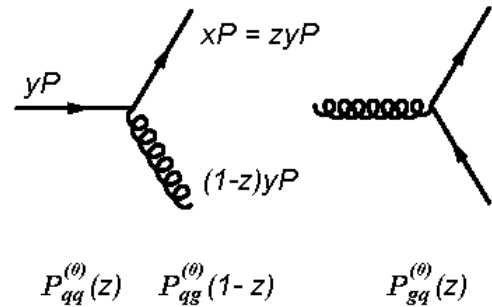$$xF_3 \sim \sigma_{NC}^{e^- p} - \sigma_{NC}^{e^+ p}$$
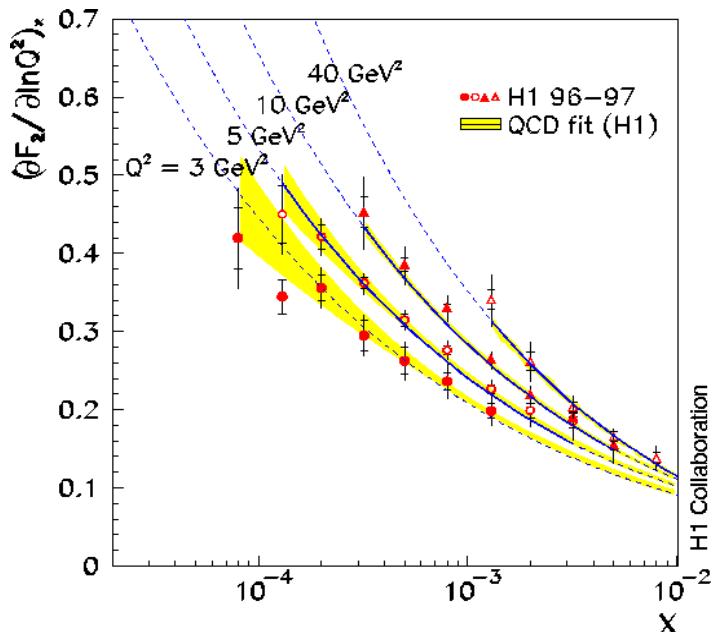
Proton Structure at Low *x*

$Q^2 = 15\ \mathrm{GeV^2}$

- ZEUS 96/97
- H1 96/97
- NMC, BCDMS, E665
- CTEQ5D
- MRST99

Steep rise towards low x driven by:

- *sea quark densities*
- *gluon densities*

$xP = zyP$

yP

$(1-z)yP$

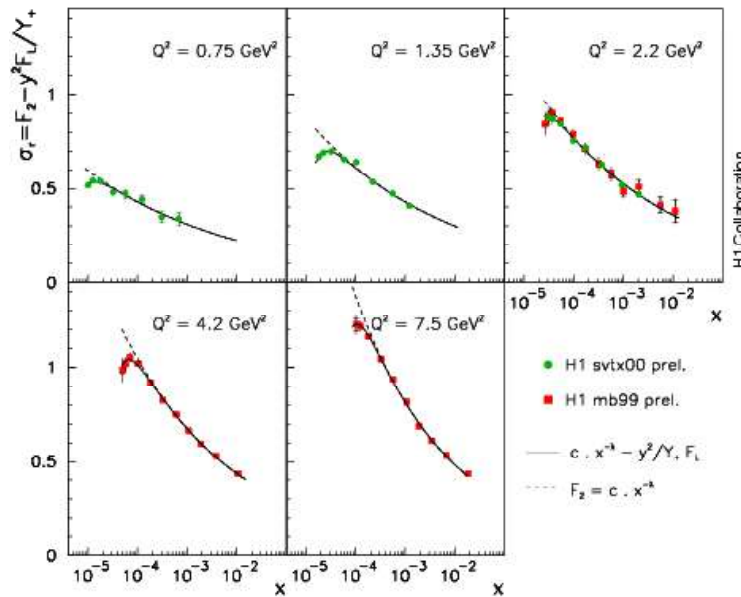$P_{qq}^{(\theta)}(z)$ $\quad P_{qg}^{(\theta)}(1-z)$ $\quad\quad P_{gq}^{(\theta)}(z)$

$$\frac{\partial F_2}{\partial \log Q^2} \sim \alpha_s (F_2 \otimes P_{qq} + g \otimes P_{gq}) \approx \alpha_s \cdot g \otimes P_{gq}$$

$\delta F_2 / \delta(\ln Q^2)$ at low x reflects the gluon momentum distributions.

40 GeV²
10 GeV²
5 GeV²
$Q^2 = 3\ \mathrm{GeV^2}$

- H1 96–97
- QCD fit (H1)

H1 Collaboration

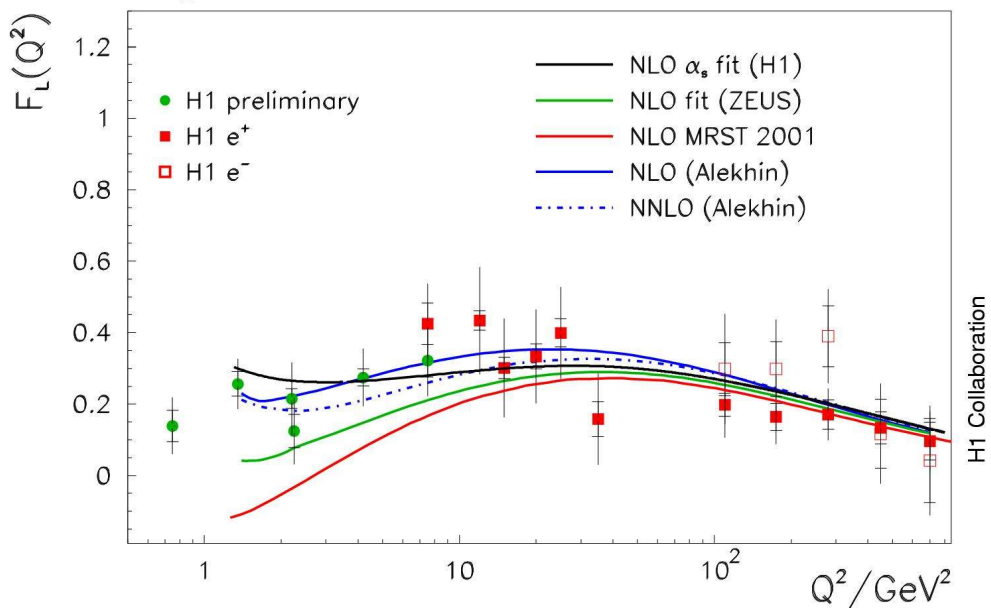**at low x gluon density dominates !**

Structure Function F_L

Decreasing of the NC cross section at low x (high y) is due to F_L

Extrapolation:
$$F_2(Q^2) = c \cdot x^{-\lambda}$$

$$\tilde{\sigma}_{NC}(Q^2) = F_2(Q^2) - \frac{y^2}{Y_+} F_L(Q^2)$$

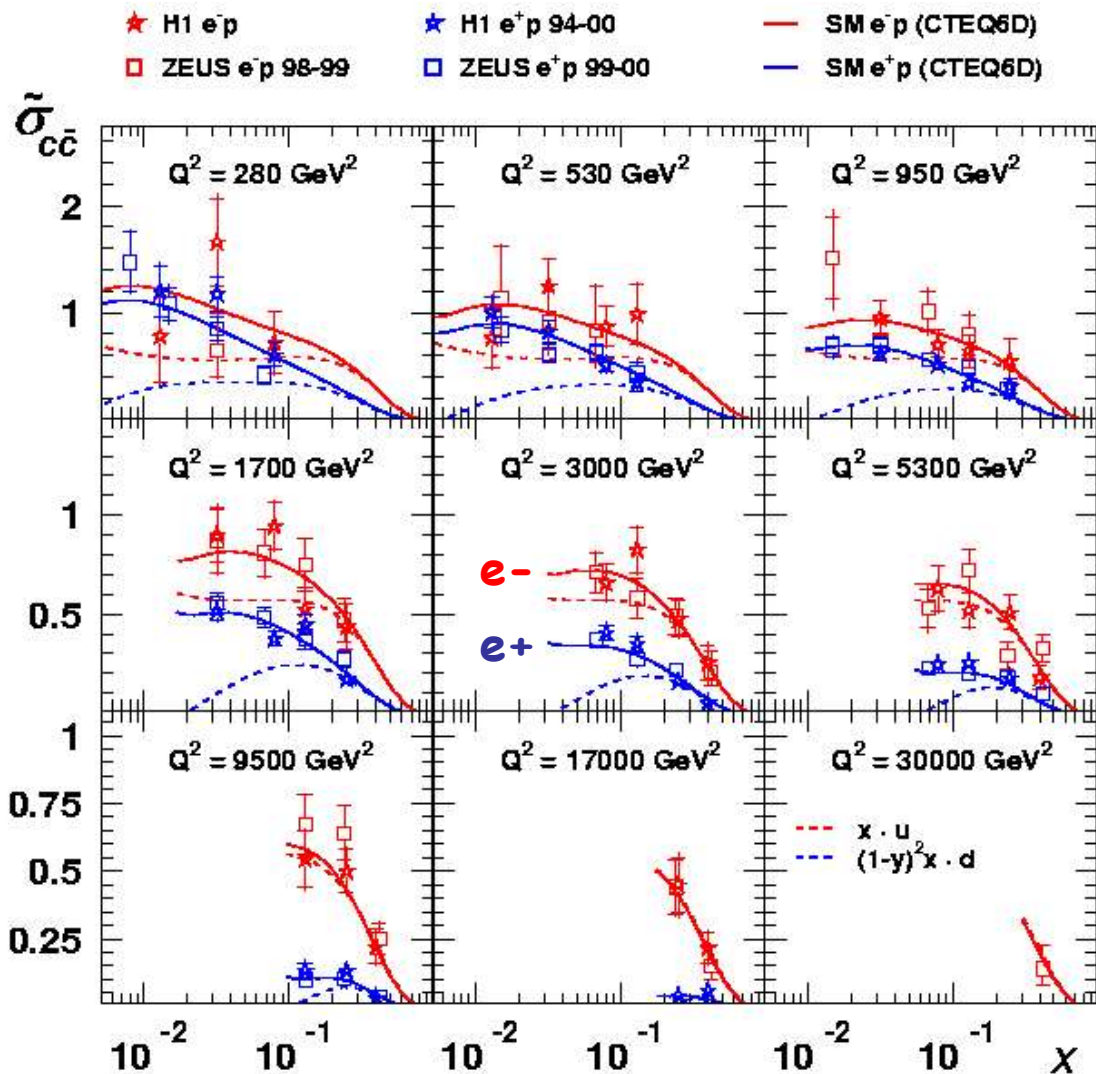F_L extraction from H1 data

Charged Current

$$\tilde{\sigma}^{+}_{CC} \sim x\overline{U} + (1-y)^2 \, xD$$

$$\tilde{\sigma}^{-}_{CC} \sim xU + (1-y)^2 \, x\overline{D}$$

CC processes provide flavor information

at high x: $\tilde{\sigma}^{+}_{CC} \sim xd_v; \quad \tilde{\sigma}^{-}_{CC} \sim xu_v$
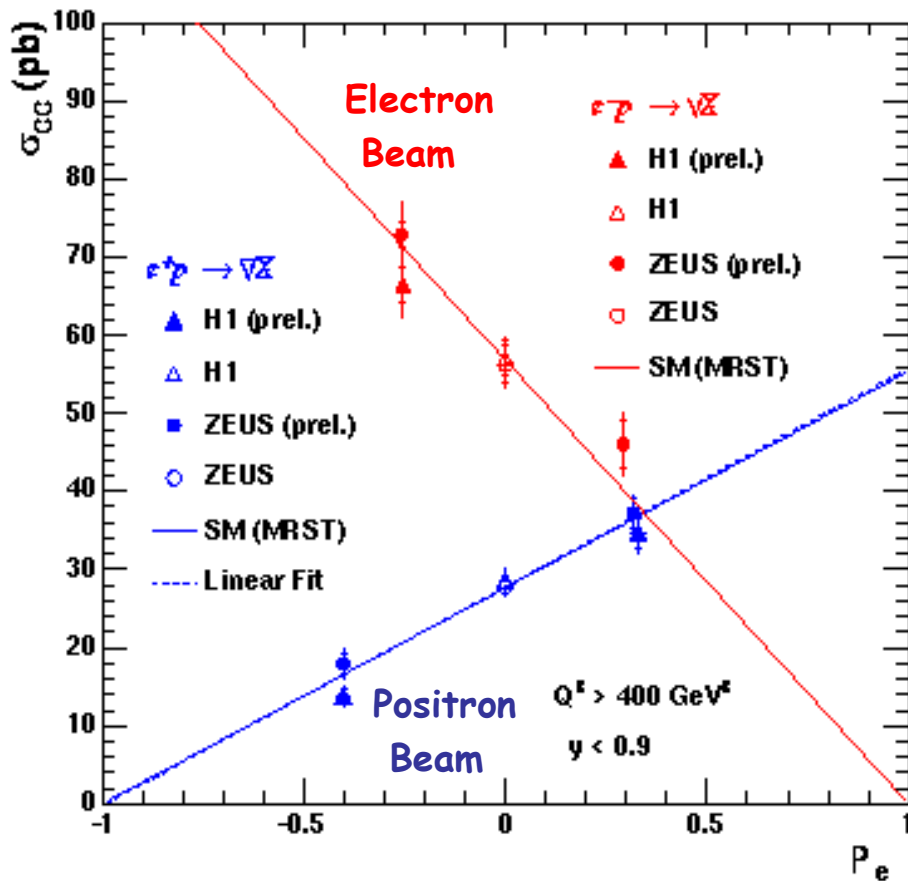
measurements of u_v and d_v densities

CC with Polarised e± Beams

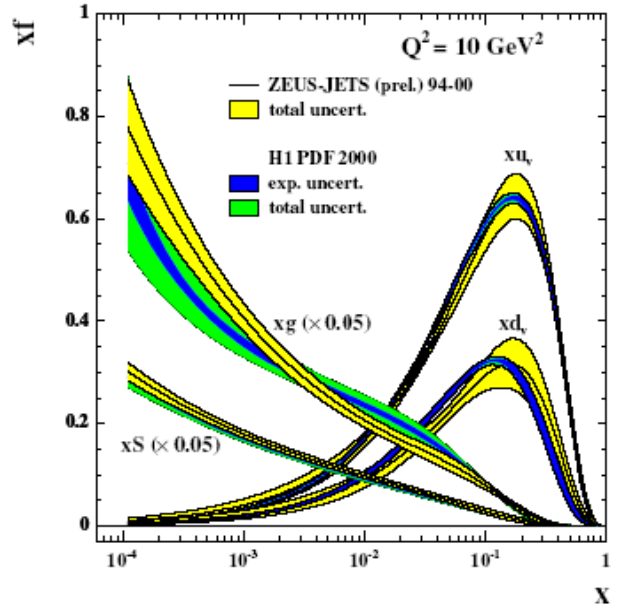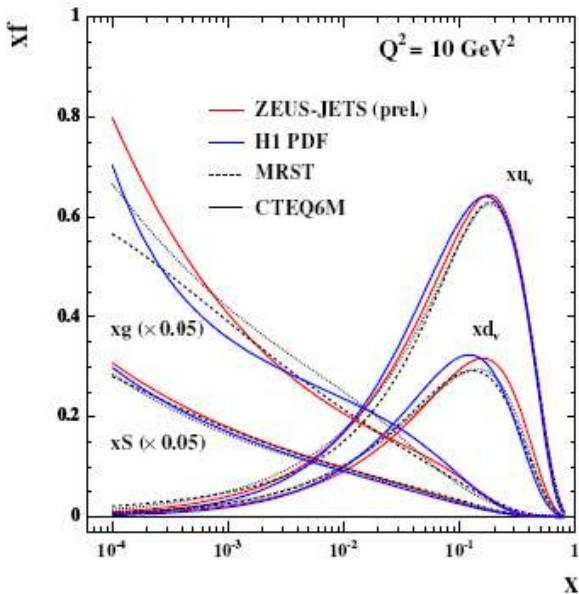$$\sigma_{CC}^{e^+p}(p) = (1+p) \cdot \sigma_{CC}^{e^+p}(p=0)$$

$$\sigma_{CC}^{e^-p}(p) = (1-p) \cdot \sigma_{CC}^{e^-p}(p=0)$$

Linear dependence of CC cross section on the longitudinal polarisation of the electron and positron beams
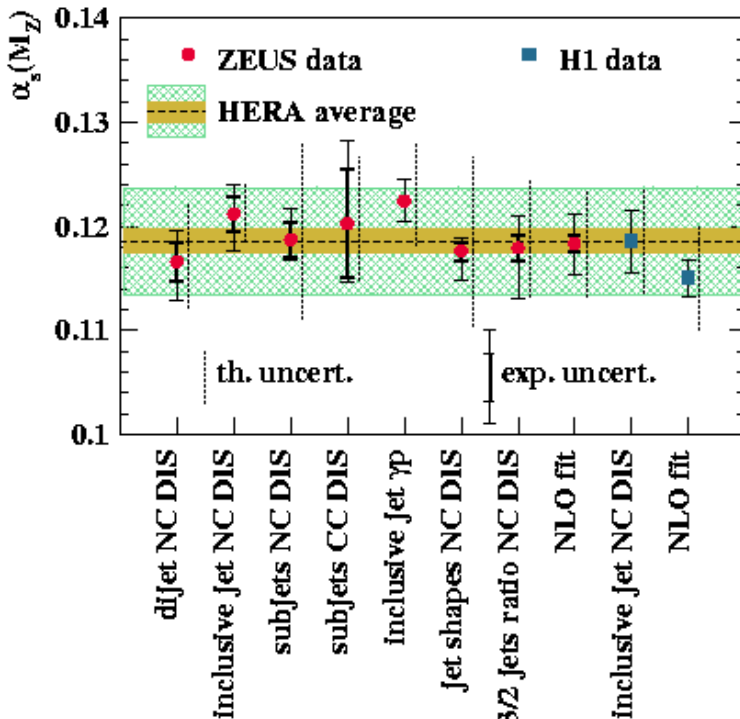
HERA II

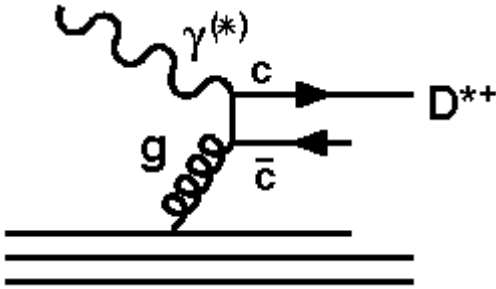# Parton Distribution Functions and α_S

Determination of PDFs by H1 and ZEUS using NC and CC events measurements only

Strong coupling constant α_S as measured from jet rates and from jets and NLO QCD fits to structure functions.
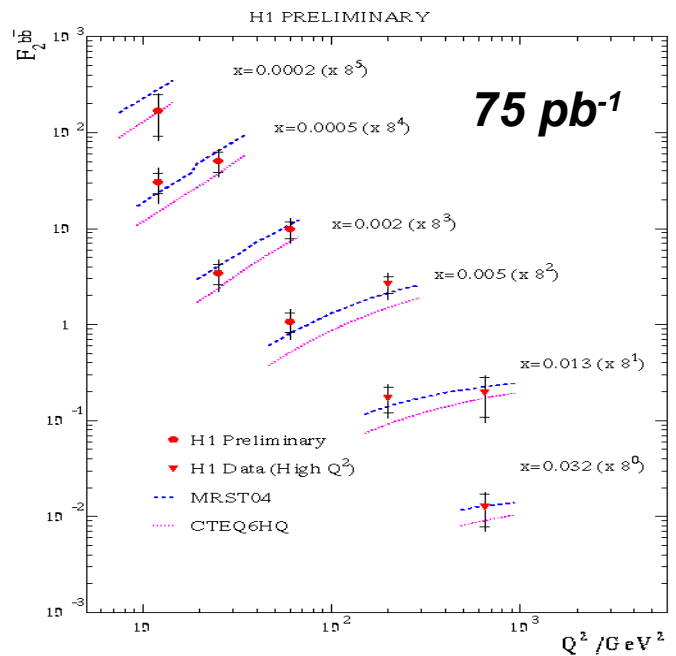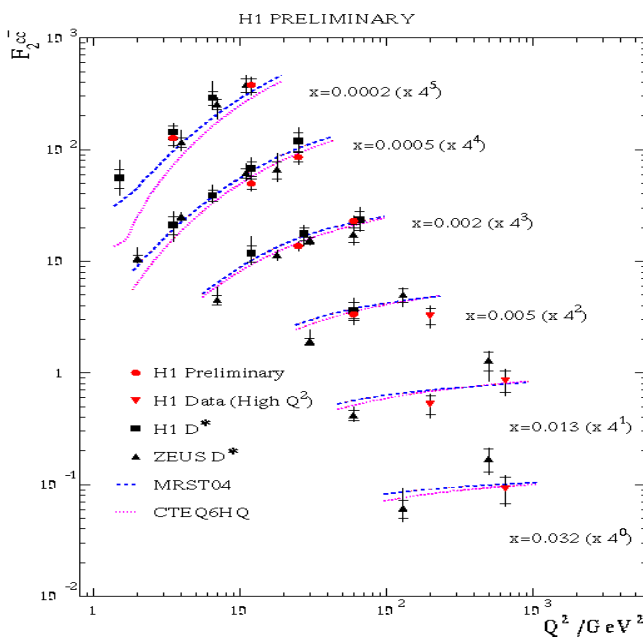
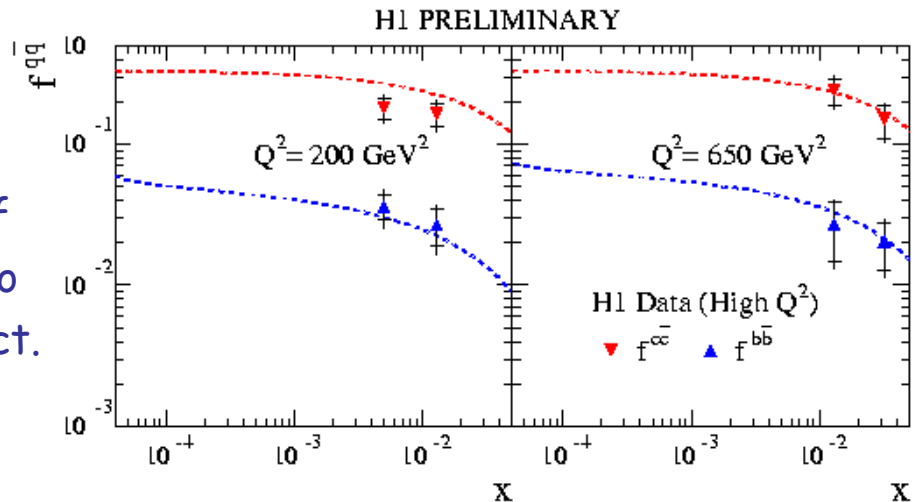# Contribution from Heavy Quarks

Classical method: reconstruct D*

New measurement: a c-quark lifetime tagging using the silicon detectors.

The first measurement of $F_2^{b\bar{b}}$

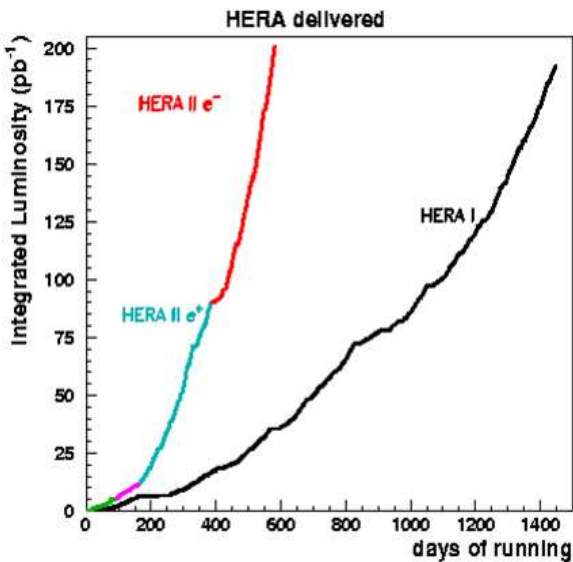
$$f^{q\bar{q}} = F_2^{q\bar{q}} / F_2$$

The contribution of c and b quarks up to 30% and 3% respect.

Outlook

H1 and ZEUS collect data with high luminosity and e± polarized beams.

Physics of HERA II has begun.

More statistics will lead to higher precision in structure analyses.

Acknowledgments

- *H1 Collaboration*

- *ZEUS Collaboration*

- *DESY directorate*