

Precision DIS measurements at HERA



Burkard Reisert

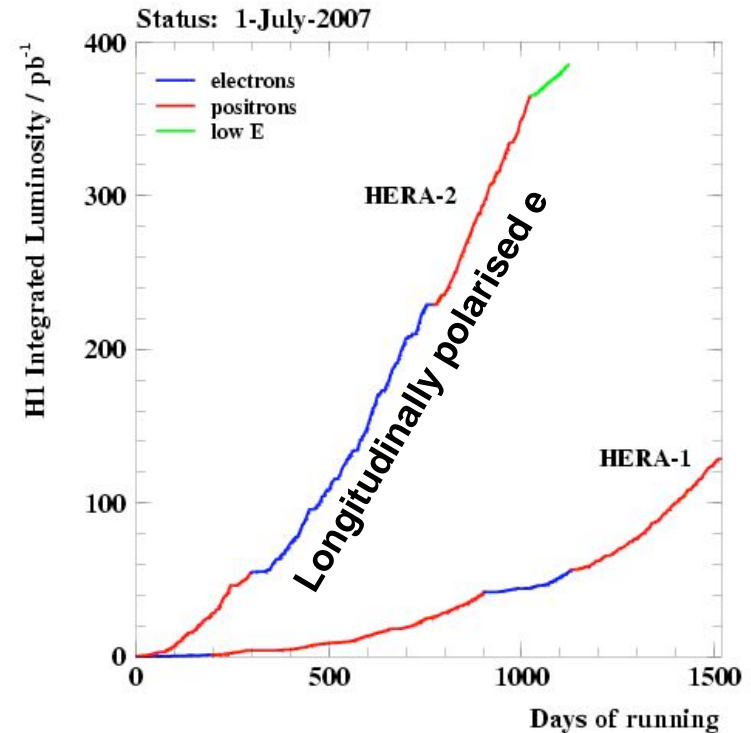
Max-Planck-Institut für Physik München
on behalf of the H1 and ZEUS Collaborations



New Measurements:

- Electro Weak Physics
- Longitudinal Structure Function
- Total γp Cross Section

HERA ep Collider: 1992-2007

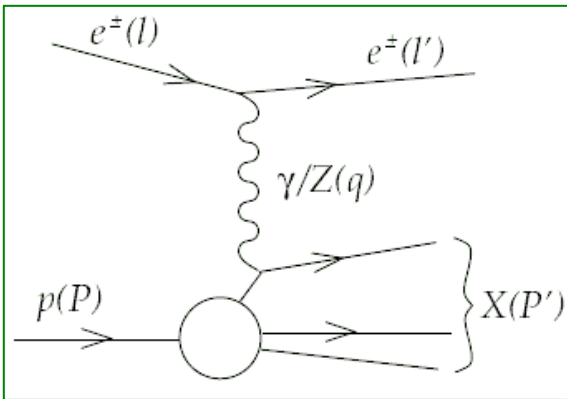


Two colliding beam experiments: H1 and ZEUS
 $\sim 0.5 \text{ fb}^{-1}$ collected pre experiment
 approximately same amount of collisions with
 electrons and positrons of
 Left- and right-handed polarisation

$E_e = 27.5 \text{ GeV}$, $E_p = 920 \text{ GeV}$
 dedicated low E_p runs
 $E_p = 460 \text{ GeV}, 575 \text{ GeV}$

Deep Inelastic Scattering (DIS)

Neutral Current (NC)



Boson virtuality

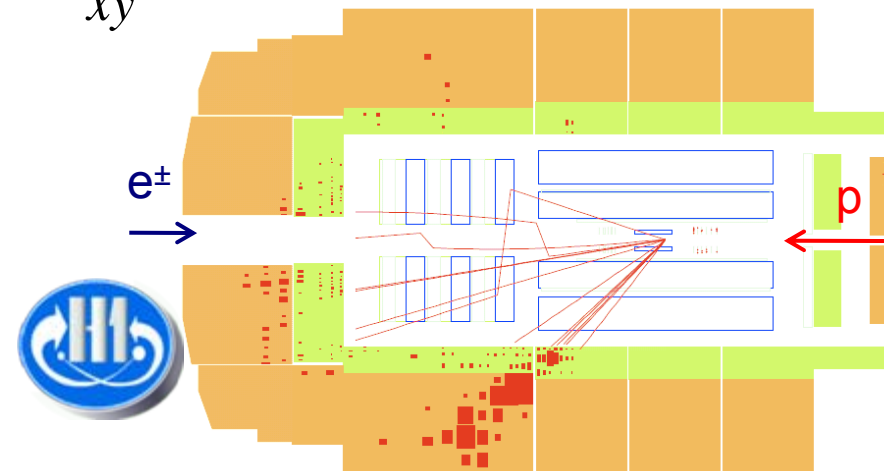
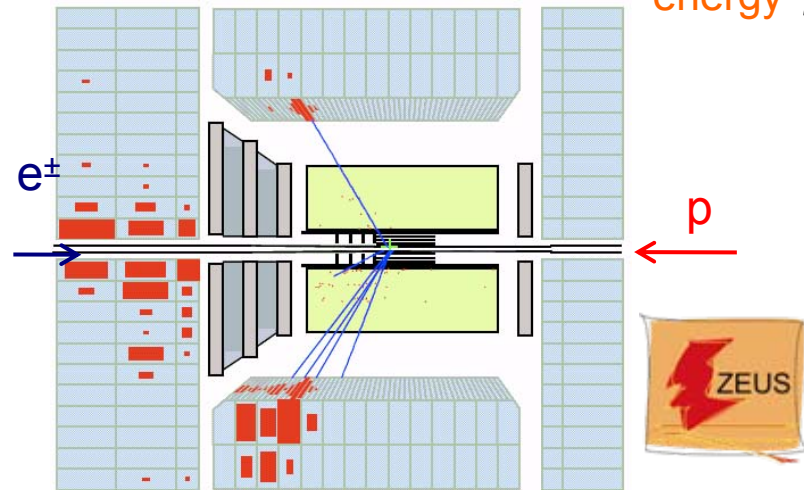
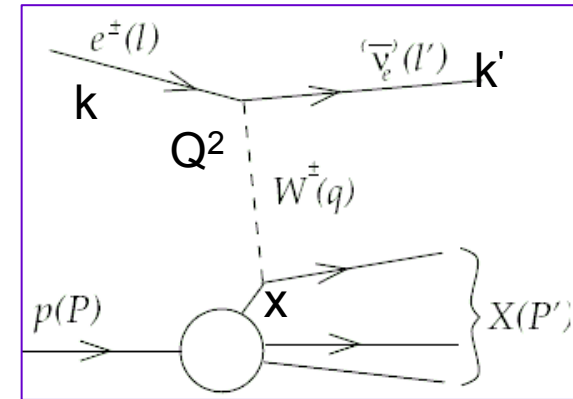
$$Q^2 = -q^2 = (k - k')^2$$

Bjorken x
$$x = \frac{Q^2}{2(Pq)}$$

Inelasticity
$$y = \frac{(Pq)}{(Pk)}$$

Centre-of-mass energy
$$s = (k + P)^2 = \frac{Q^2}{xy}$$

Charged Current (CC)



Neutral Current Cross Section

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[Y_+ \tilde{F}_2^\mp \mp Y_- x \tilde{F}_3^\pm - y^2 \tilde{F}_L^\pm \right] \quad Y_\pm = 1 \pm (1-y)^2$$

$$\kappa = \frac{1}{4 \sin^2 \theta_w \cos^2 \theta_w} \frac{Q^2}{Q^2 + M_Z^2}$$

Generalized structure functions:

$$\tilde{F}_2^\pm = F_2^\gamma + \kappa(-v_e \pm P_e a_e) F_2^{\gamma Z} + \kappa^2(v_e^2 + a_e^2 \pm 2P_e v_e a_e) F_2^Z$$

$$x \tilde{F}_3^\pm = \kappa(-a_e \mp P_e v_e) x F_3^{\gamma Z} + \kappa^2(2v_e a_e \pm P_e(v_e^2 + a_e^2)) x F_3^Z$$

$$\left[F_2^\gamma, F_2^{\gamma Z}, F_2^Z \right] = \sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2 \right] x(q + \bar{q})$$

$$\left[x F_3^{\gamma Z}, x F_3^Z \right] = \sum_q \left[e_q a_q, v_q a_q \right] 2x(q - \bar{q})$$

Charged Current Cross Section

$$\frac{d^2\sigma^{CC}(e^\pm p)}{dx dQ^2} = (1 \pm P_e) \frac{G_F^2}{4\pi x} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 \tilde{\sigma}_{CC}^{e^\pm p}$$

CC reduced cross section

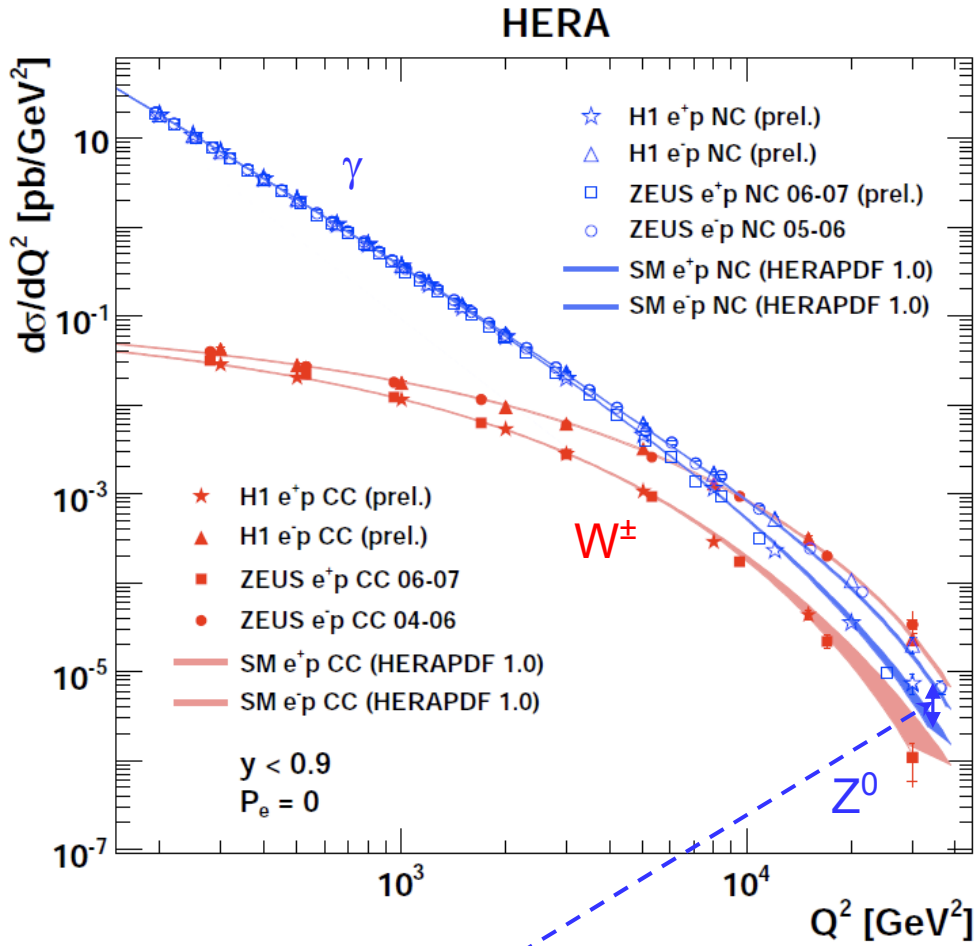
e^+/e^- sensitive to different quark densities:

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

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

CC gives sensitivity to different combinations of quarks as NC.

Electroweak Unification



difference in e⁺ and e⁻ for NC in high Q² region comes from contribution of Z exchange

$$\text{NC: } \frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$$

$$\text{CC: } \frac{d\sigma}{dQ^2} \sim \frac{1}{(Q^2 + M_W^2)^2}$$

EW component of SM:

NC and CC cross sections are similar at $Q^2 \approx M_Z^2, M_W^2$

Data compared with SM

(HERAPDF 1.0 → V. Radescu Track04)

Good agreement over full range

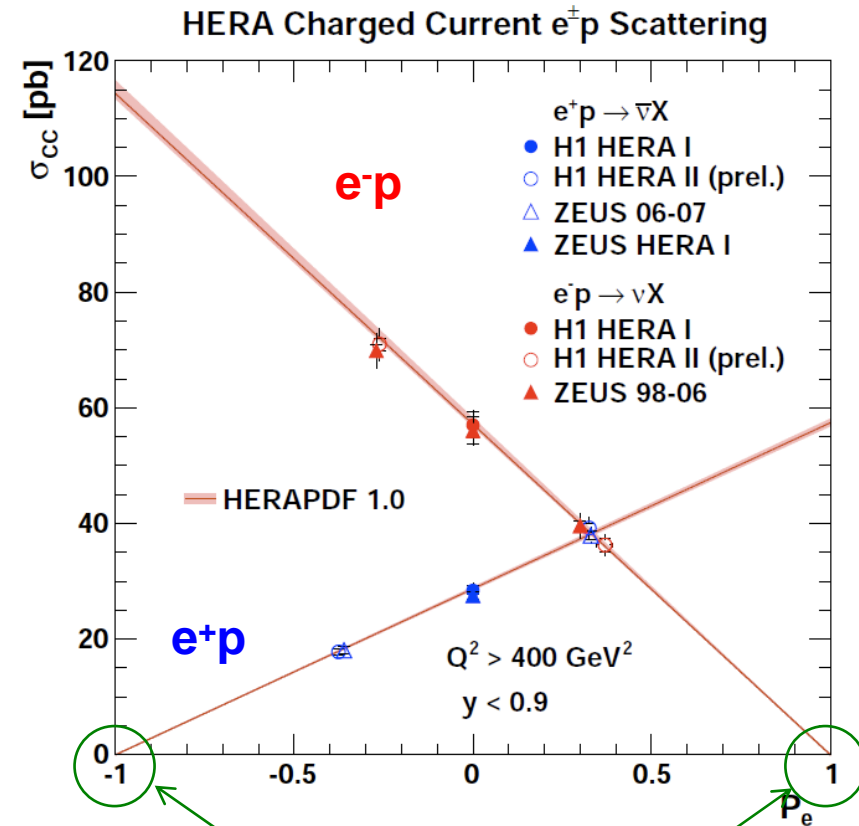
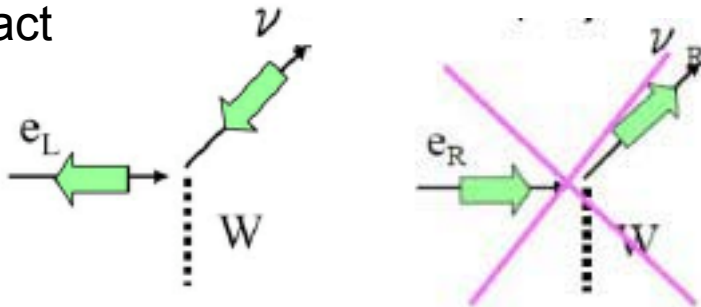
Total Charged Current Cross Section

Linear dependence of σ^{CC} on P_e

$$\sigma^{CC}(e^\pm p) = (1 \pm P_e)\sigma_{P_e=0}^{CC}(e^\pm p)$$

$$P_e = \frac{N_{RH} - N_{LH}}{N_{RH} + N_{LH}}$$

SM: weak CC interactions:
only left handed particles
(right handed anti-particles)
interact



SM: No right-handed weak currents

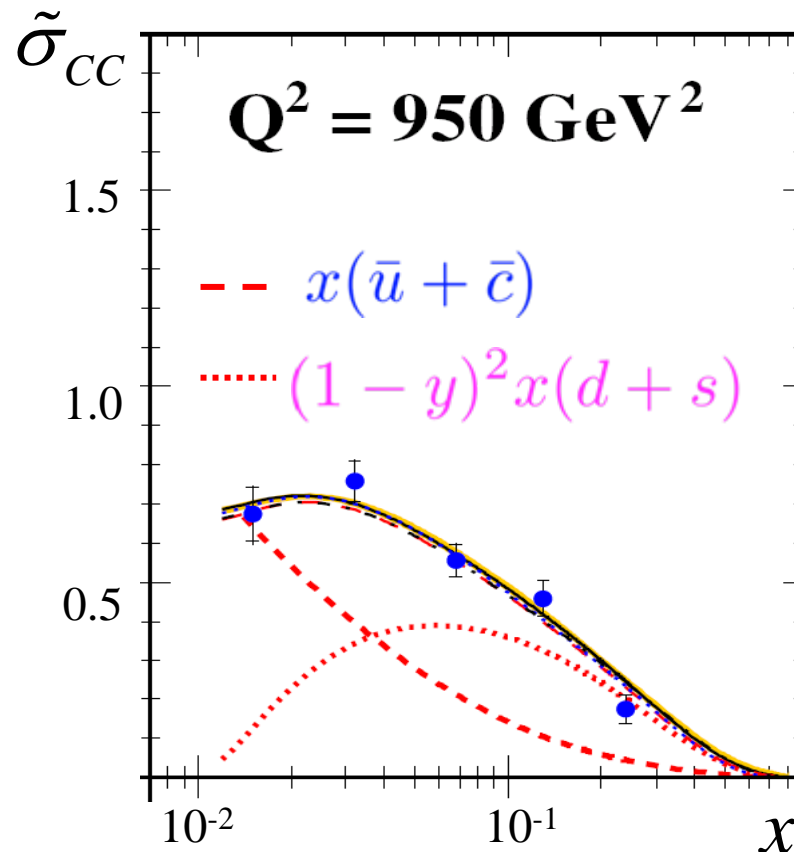
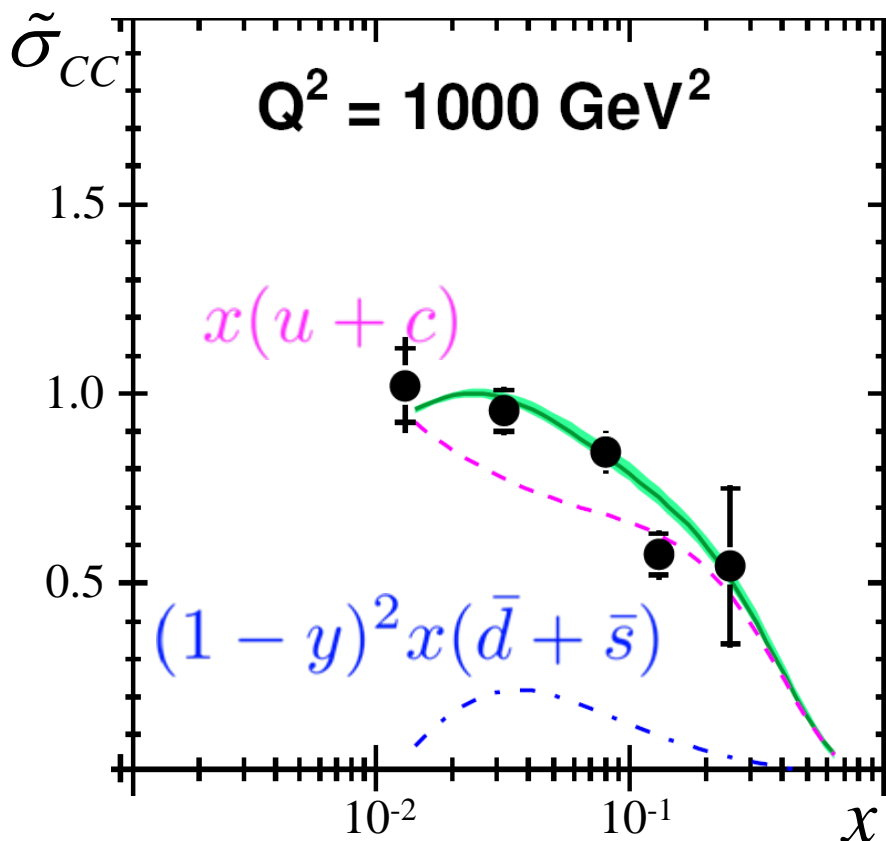
ZEUS and H1 in agreement with SM

Quark Antiquark Decomposition

Data of the entire HERA II data sets (LH and RH, corrected to $P_e=0$)

H1 Preliminary

ZEUS



H1 + ZEUS Cross Section Combinations → talk by Voica Radescu



Neutral Current: xF_3

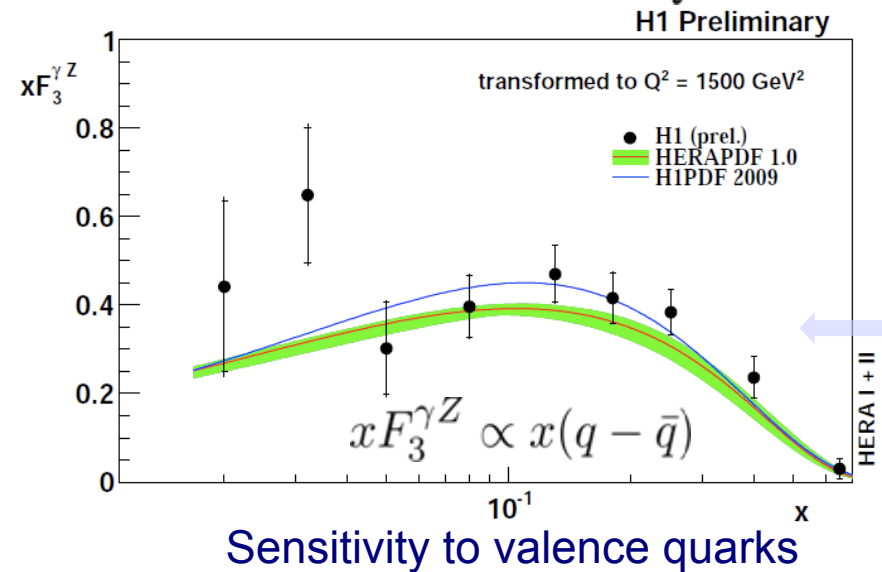
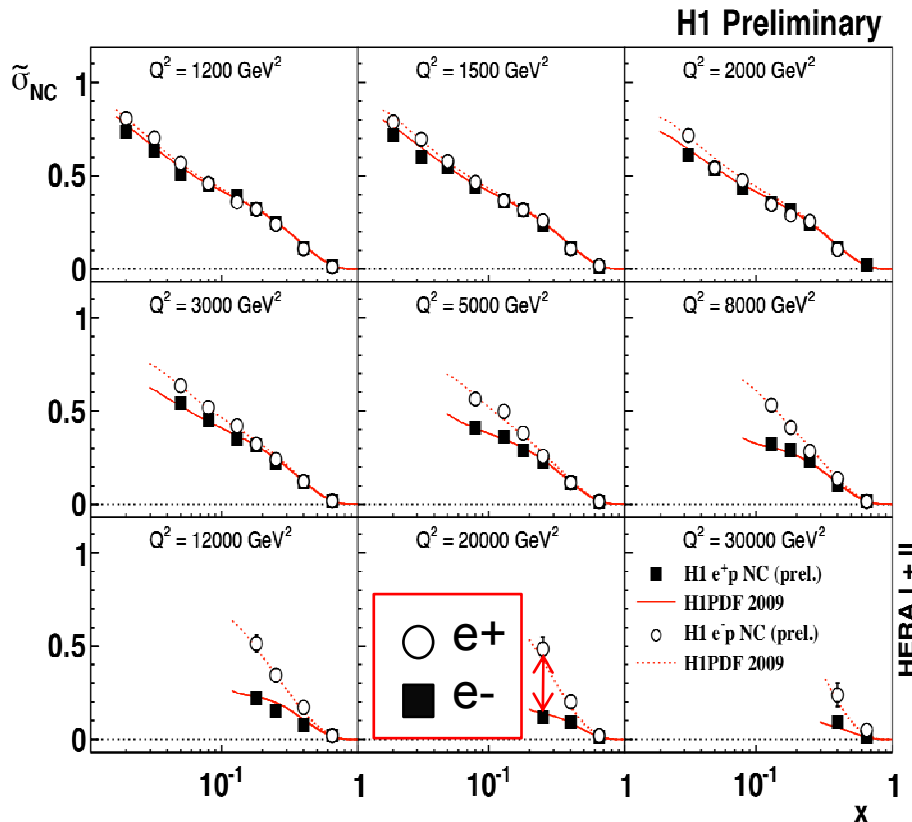
NC cross section:

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{NC}(e^{\pm}p)}{dx dQ^2} \frac{xQ^4}{2\pi\alpha^2 Y_{\pm}} = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3 - \frac{y^2}{Y_+} \tilde{F}_L$$

$$\Rightarrow x\tilde{F}_3 = \frac{Y_+}{2Y_-} [\tilde{\sigma}^- - \tilde{\sigma}^+]$$

dominant contribution to $x\tilde{F}_3$:

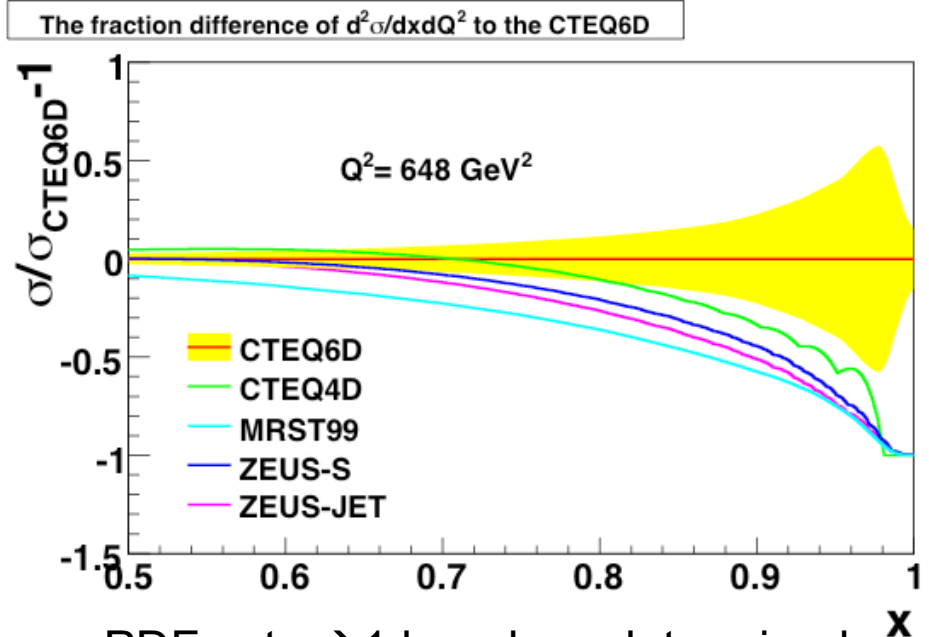
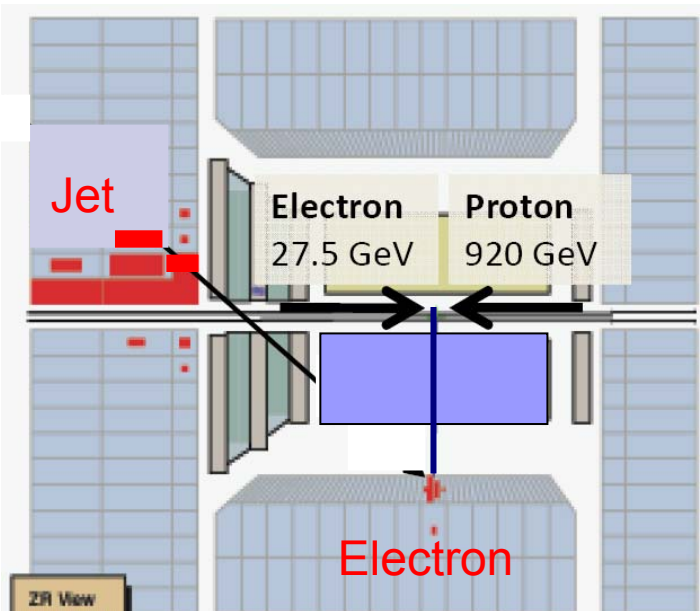
$$xF_3^{\gamma Z} \simeq x\tilde{F}_3 \frac{(Q^2 + M_Z^2)}{\alpha^2 \kappa Q^2}$$



more on NC & CC polarization effects
 \rightarrow see talk by V. Chekelian

NC at High x: Motivation

H1 and ZEUS have measured
 NC cross sections up to $x_{\max}=0.65$
 (Fixed Target experiments e.g. BCDMS $x_{\max}=0.75$)

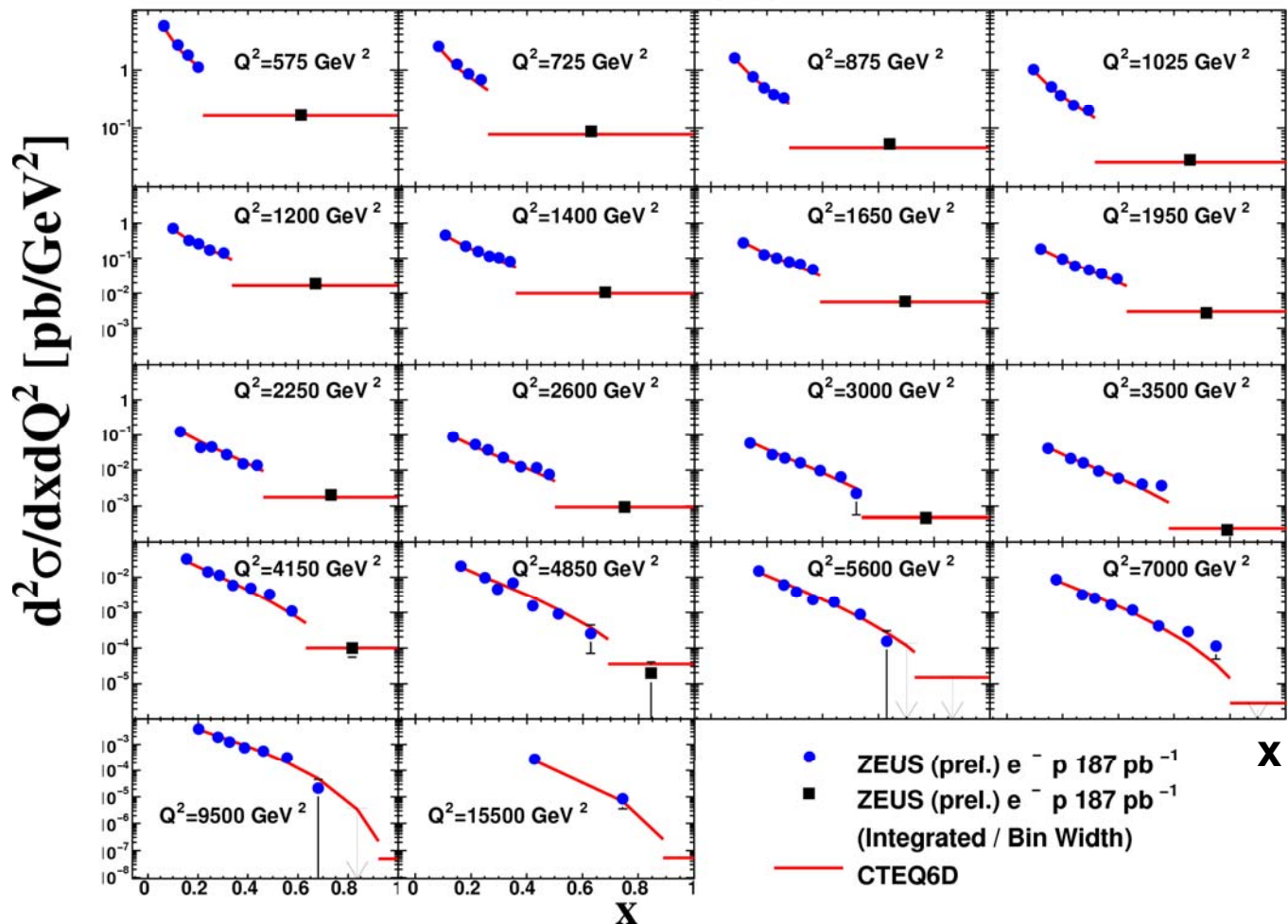


- PDFs at $x \rightarrow 1$ largely undetermined
- Variations between various PDFs sets larger than uncertainty estimates

We cannot measure $x > x_{\text{limit}}$, however we know $x_{\text{limit}} < x < 1$
 → High x constraint by integrated cross section

NC at High x: Results

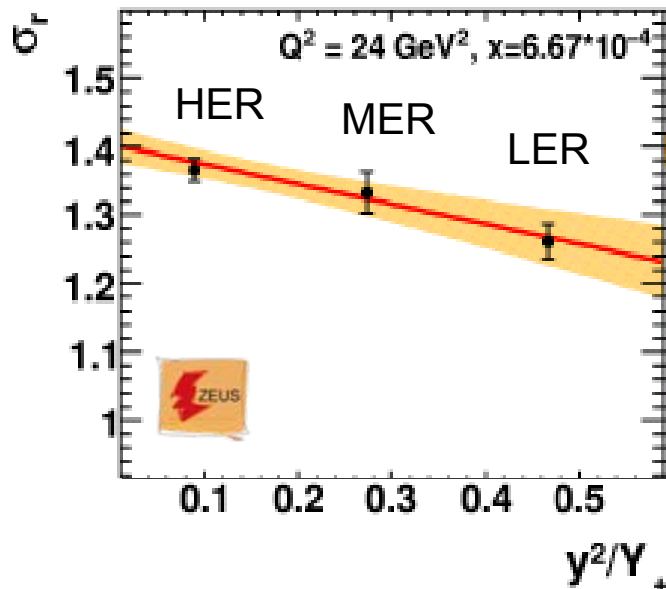
ZEUS



Measurement of FL

Measure cross sections at same x and Q^2 but different $y = Q^2/x \cdot s \rightarrow$ vary s

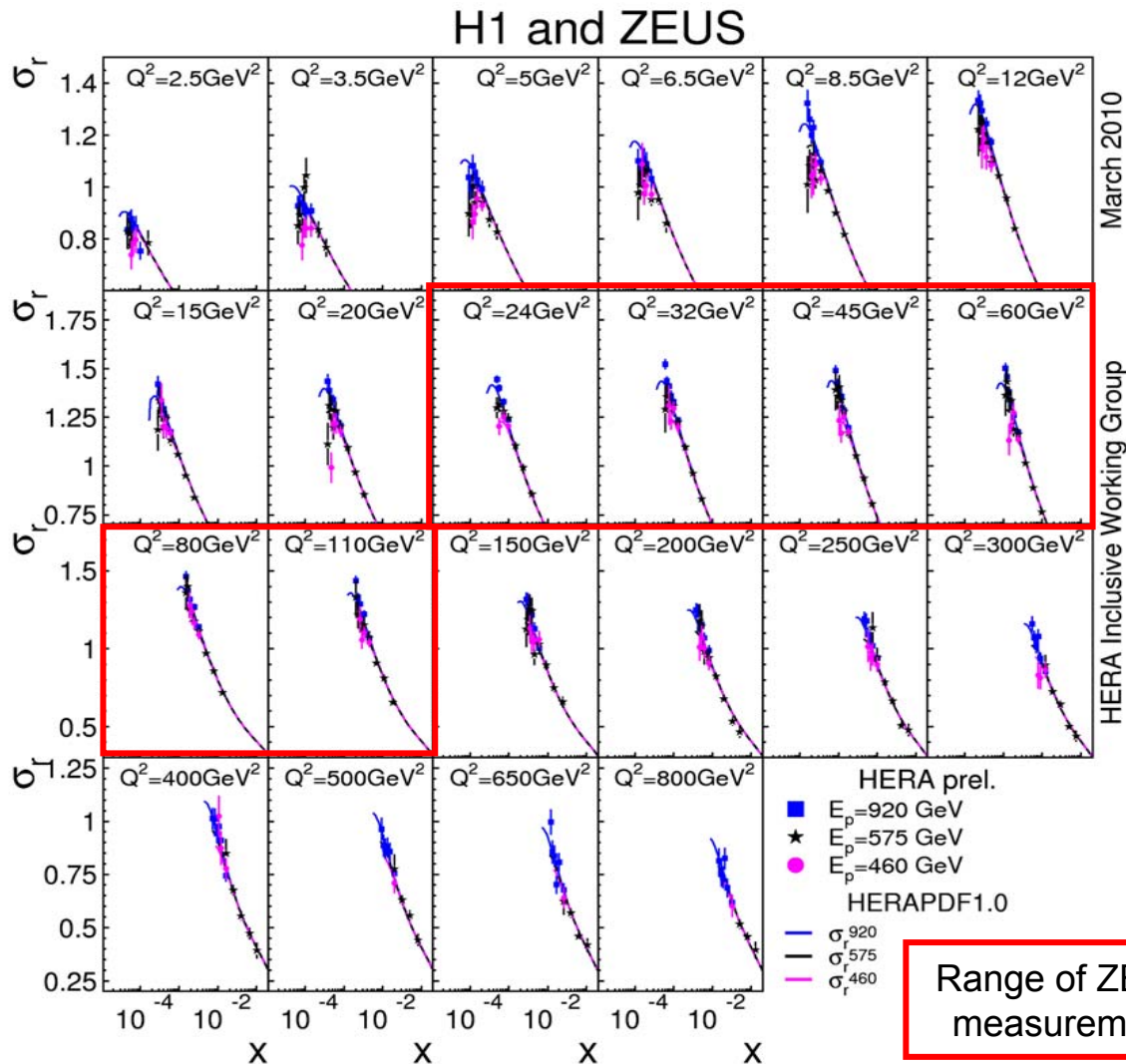
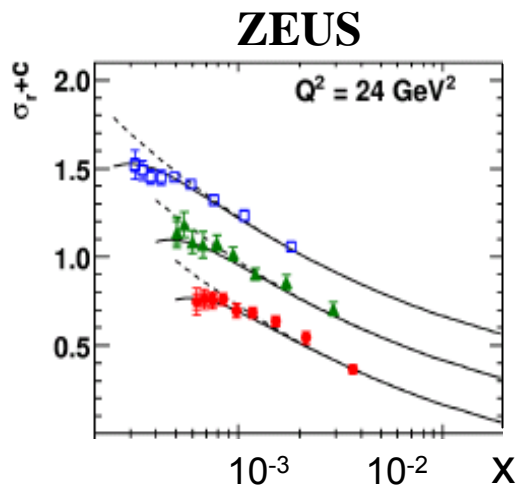
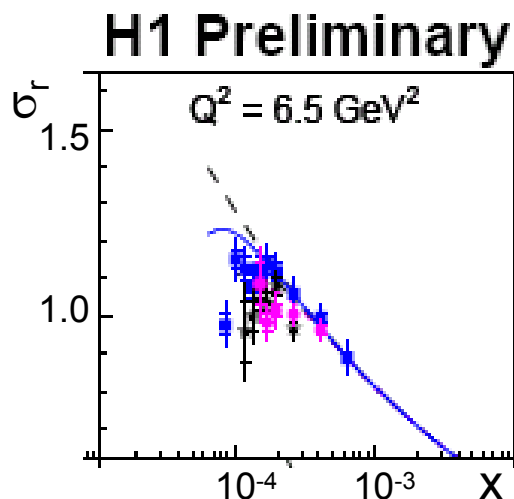
$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$



- Change proton beam energy to change cms energy
 - $E_p = 920 \text{ GeV}$, High Energy Run (HER)
 - $E_p = 575 \text{ GeV}$, Medium Energy Run (MER):
 - $E_p = 460 \text{ GeV}$, Low Energy Run
- Large lever arm in y^2/Y_+
- Measure at high y in LER

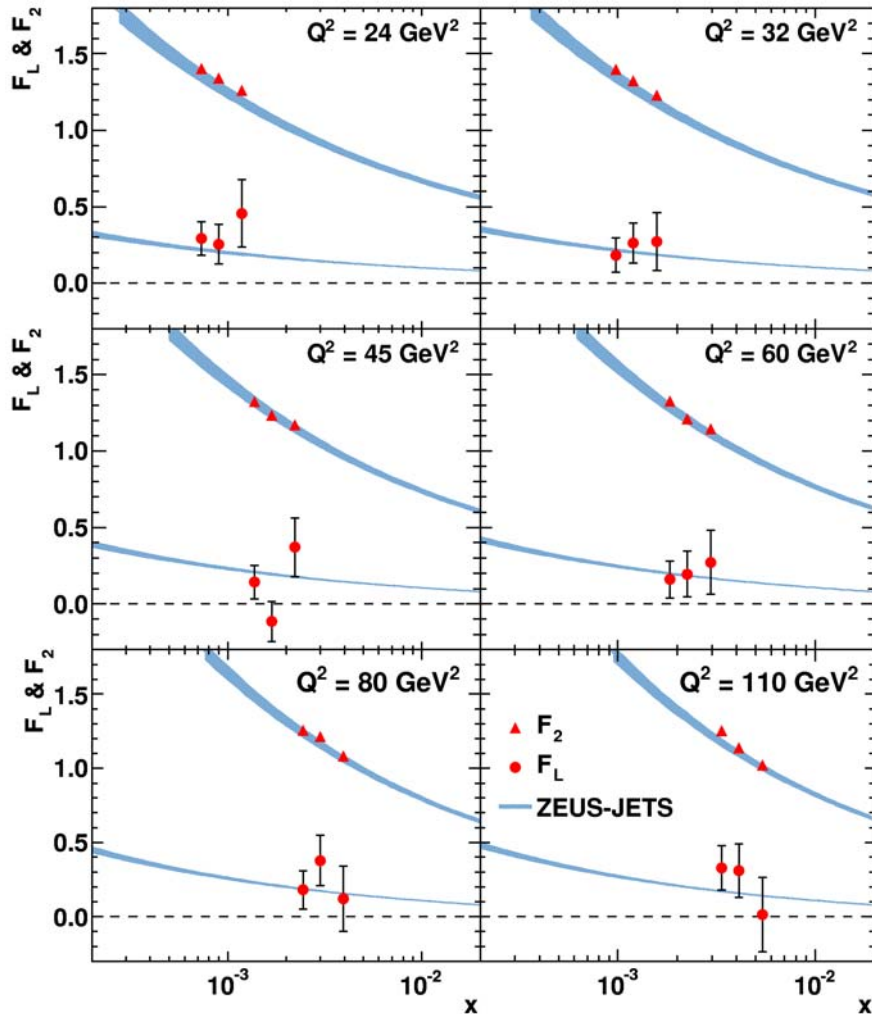
- Extended measurement to high y region
 $y = 1 - E'_e/E_e(1 - \cos\theta) \rightarrow$ high y means low E'_e

Combined low E_p Cross Sections



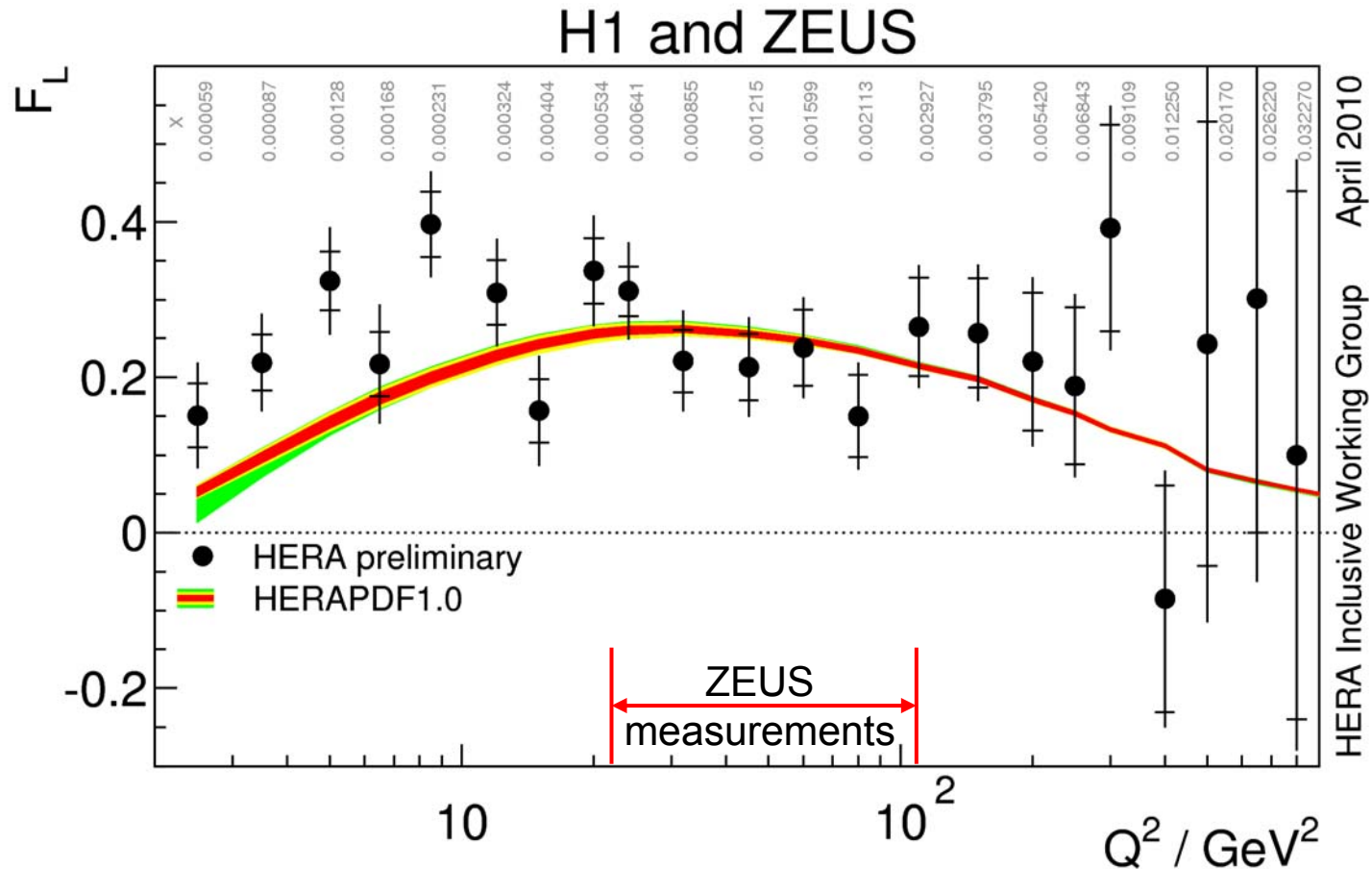
Extracted F_L and F_2

ZEUS



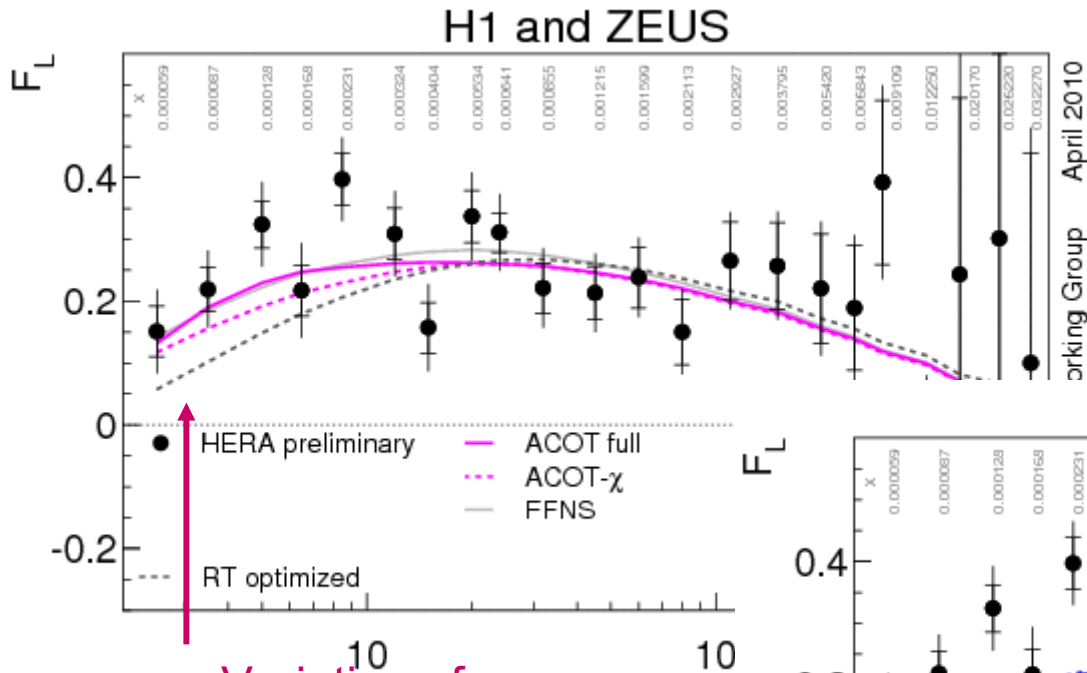
- First F_2 measurement without assumptions on F_L
- Data support a non-zero F_L
- Predictions for F_2 and F_L are consistent with data

H1 + ZEUS Combined F_L



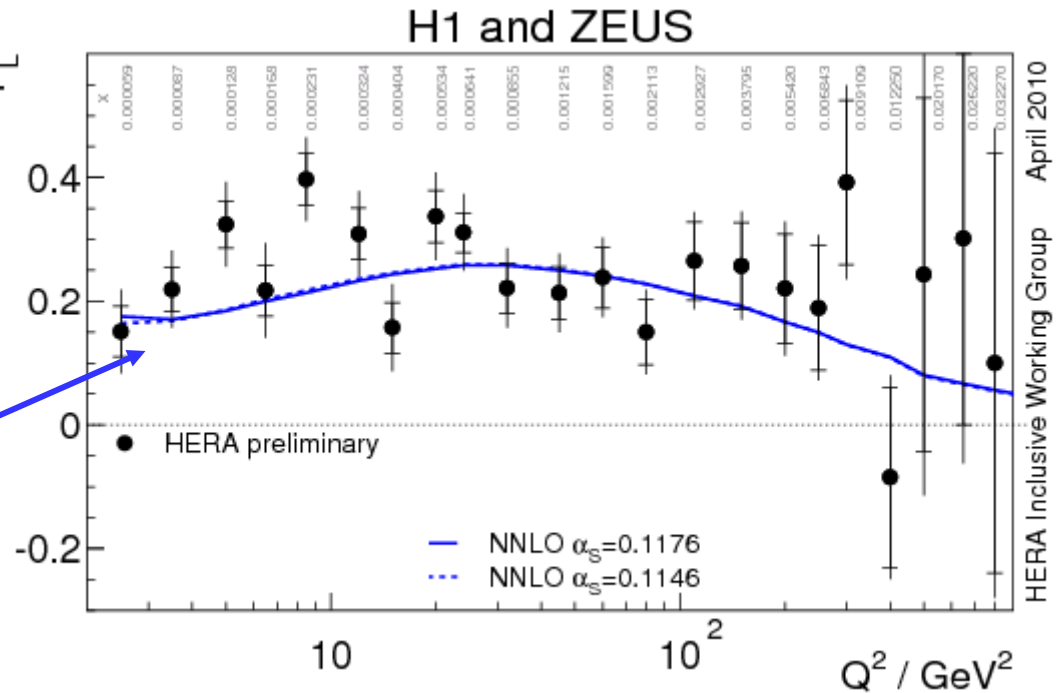
Good agreement between data and predictions for $Q^2 > 10 \text{ GeV}^2$.
 F_L at low Q^2 above prediction using HERAPDF1.0

Variants of Predictions for F_L



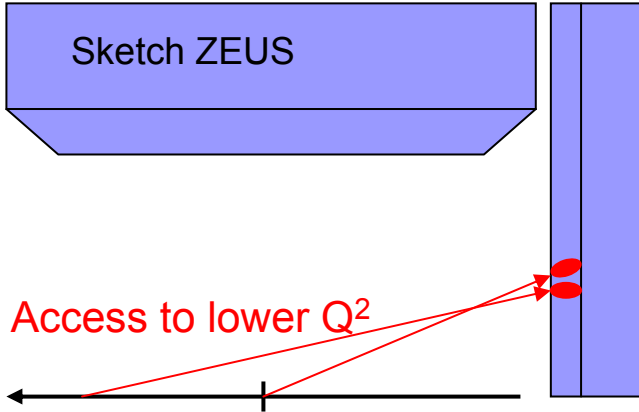
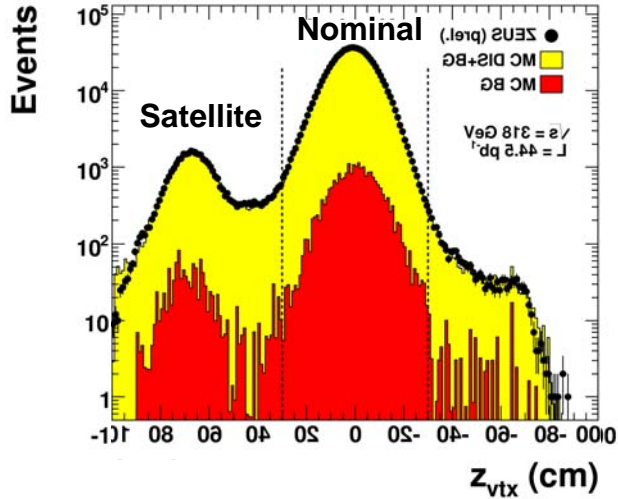
Variation of heavy flavour treatment

Higher Order calculation

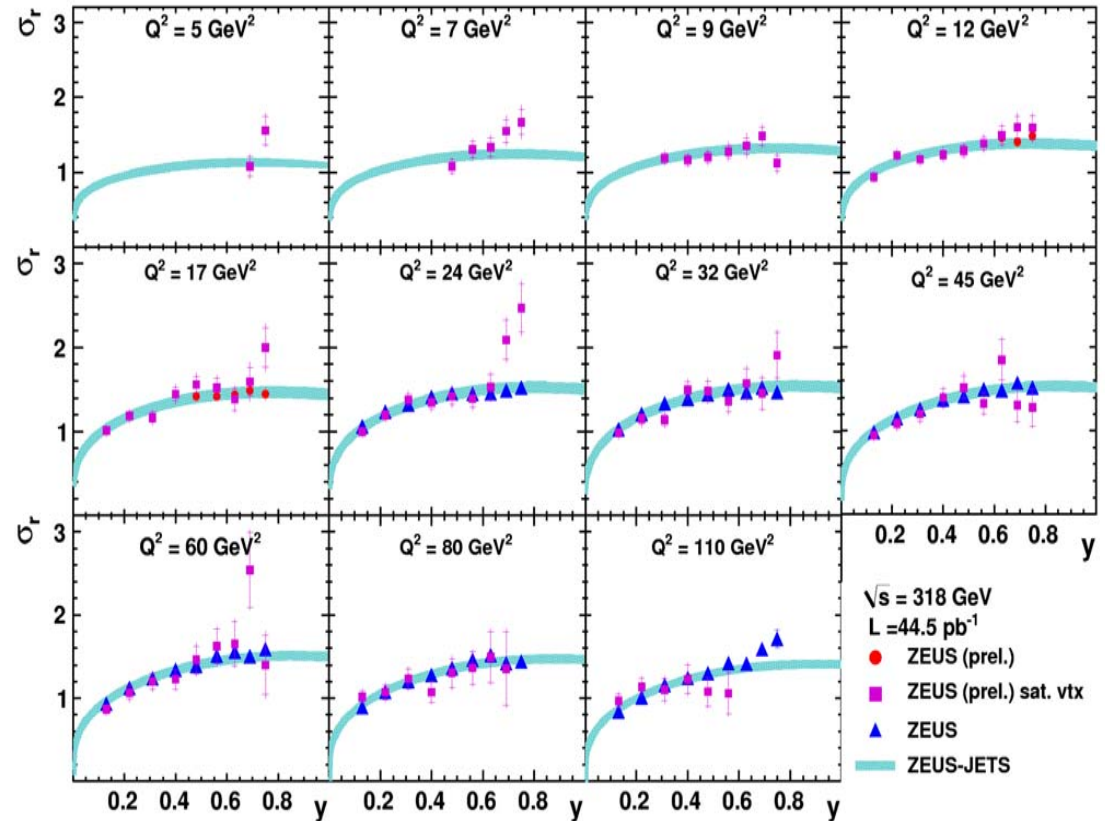


Extension of σ @ high y to low Q^2

ZEUS



ZEUS

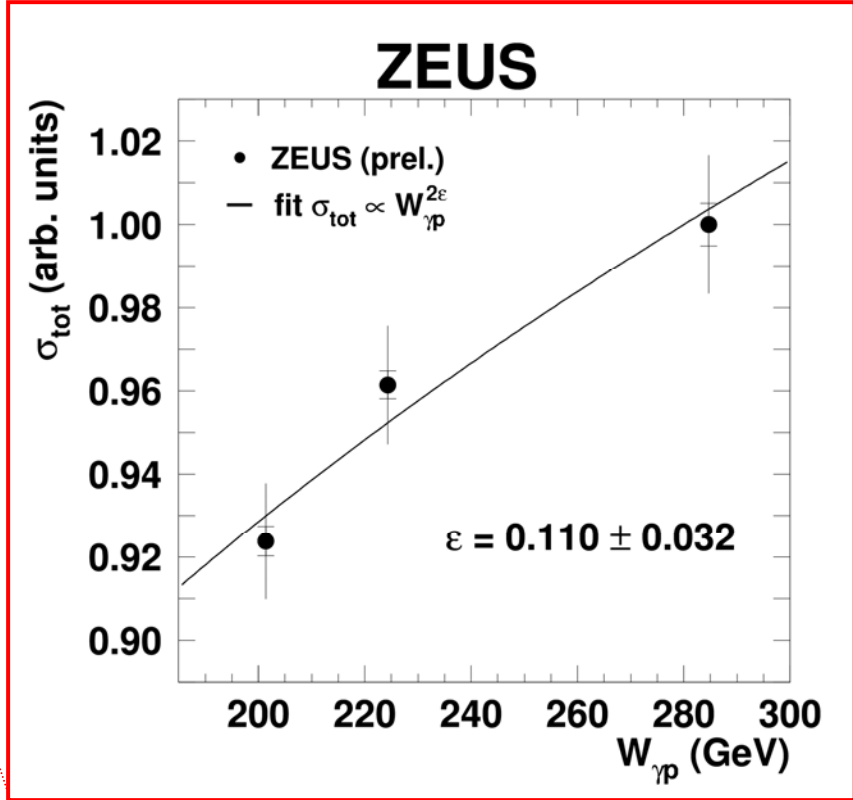
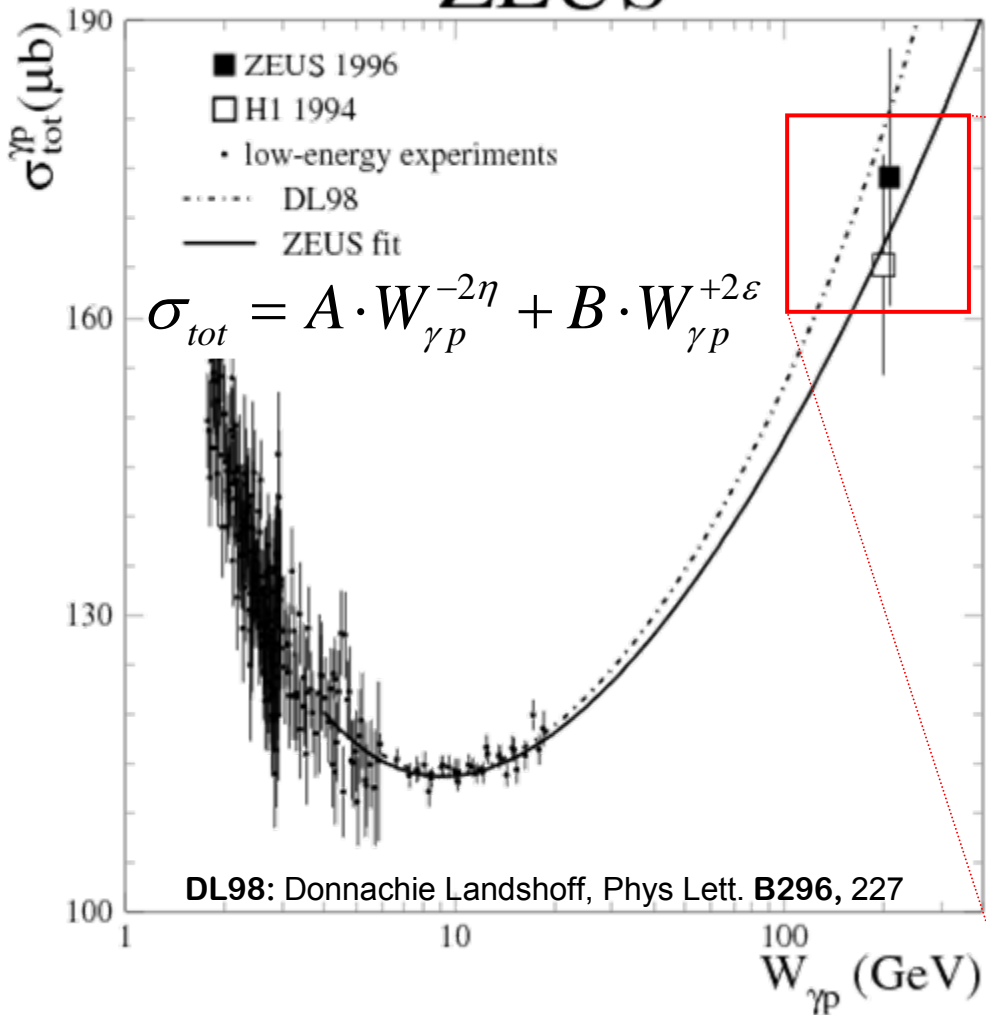


Data agree well with previous ZEUS measurements
 Increase overlap with H1 at low Q^2

Total Photon-Proton Cross Section

ZEUS

Measurements at 3 proton energies
Slope with $W_{\gamma p}$ locally extracted



Summary

- HERA delivered a wealth of ep DIS data
- H1 and ZEUS measurements reach their ultimate precision
- HERA is a unique place to study
the structure of the proton



Results to Cover



- NC e-p: DESY-08-202
- CC e-p: DESY-08-177
- CC e+p: ZEUS-pub-10-004
- NC e-p high x
ZEUS-prel-10-007
- H1+ZEUS comb F2cc:
ZEUS-prel-09-015
→ Comb. + QCD Fit of F2cc
Massimo Corradi, track 04
- FL: DESY-09-046
- extension to low Q^2 , high y
ZEUS-prel-10-006
- Total Cross Section
ZEUS-prel-10-011
- NC at medium Q^2 : DESY-09-005
- low Q^2 , low x : DESY-08-171
- Polarized CC: H1prelim-09-043
- Polarized NC: H1prelim-09-042
→ V. Chekelian, track 02
- Comb. inclusive cross sections
DESY-09-158
→ combination and QCD analysis
V. Radescu, track 04
- FL extended Q^2
H1prelim-09-044
- Combined low E_p cross section
and FL extraction
H1prelim-10-043



Backup



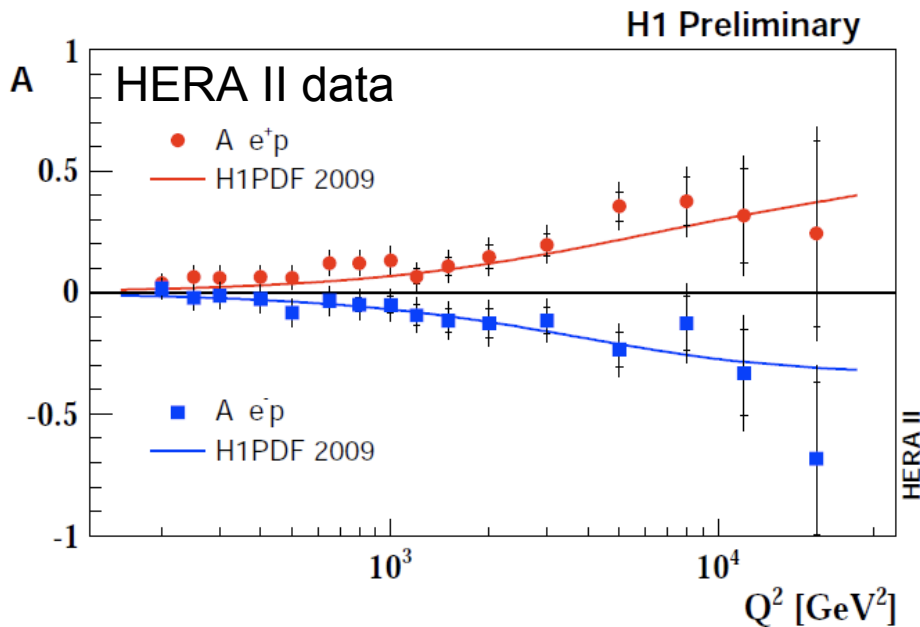


Polarized NC measurements

The charge dependent polarization asymmetries in neutral currents
→ direct measure of EW effects

Polarization asymmetries (A) sensitive to ratio of γZ interference term to F_2
A is proportional to $a_e v_q$ combination

$$A_{\pm} = \frac{2}{P_R - P_L} \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp \kappa a_e \frac{F_2^{\gamma Z}}{F_2}$$



neglecting Z term, the generalized structure function F_2 is expressed:

$$\tilde{F}_2^{\pm} \approx F_2^{\gamma} + \kappa(-v_e \pm P_e a_e) F_2^{\gamma Z}$$

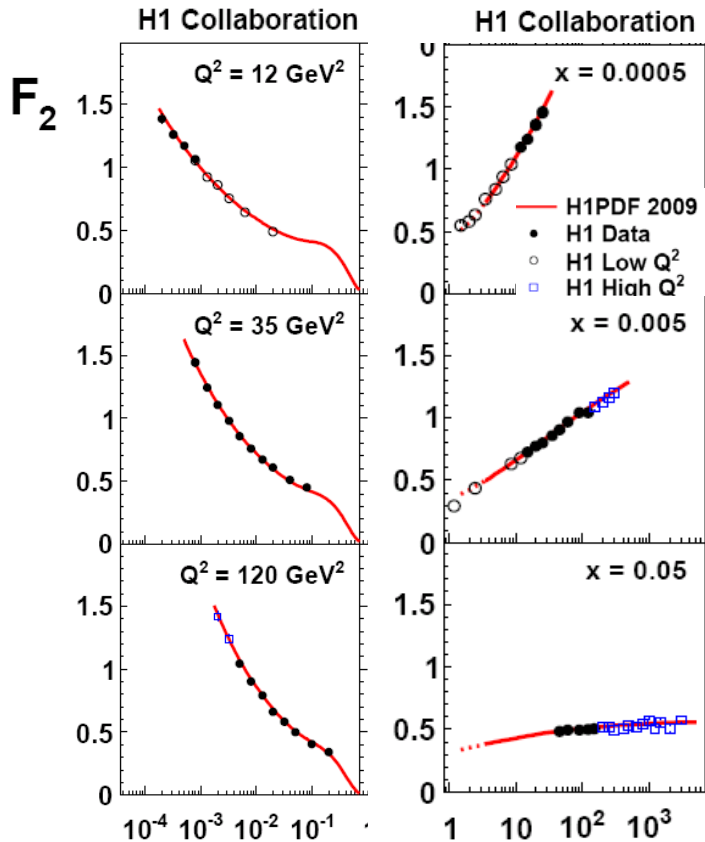
At LO: $F_2^{\gamma Z} = x \sum_q 2e_q v_q (q + \bar{q})$

Data well described by SM

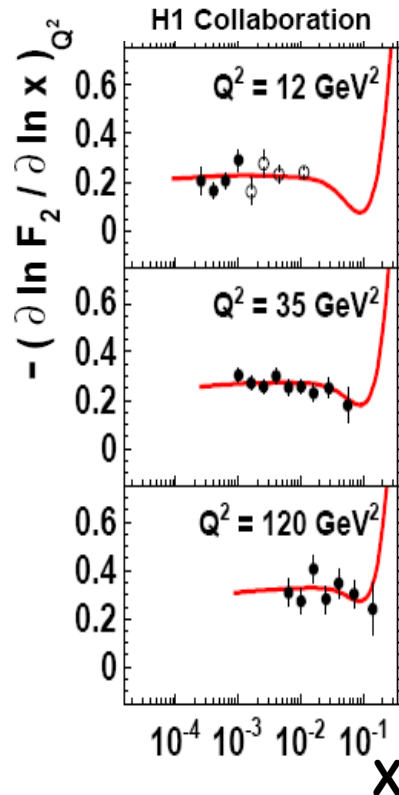


F_2 at medium Q^2

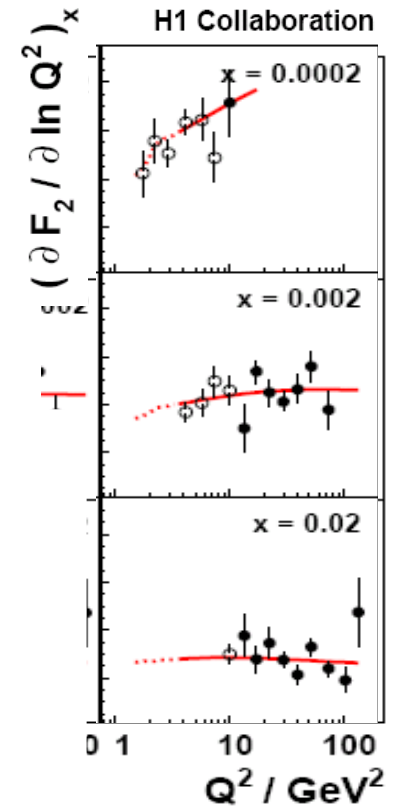
New measurement ($L = 22\text{pb}^{-1}$, 2000) combined with published results (96/97)
 $s_r \sim F_2$ ($12 < Q^2 < 150\text{GeV}^2$, $y < 0.6$) impressive accuracy 1.3 - 2%



Steep rise described by QCD



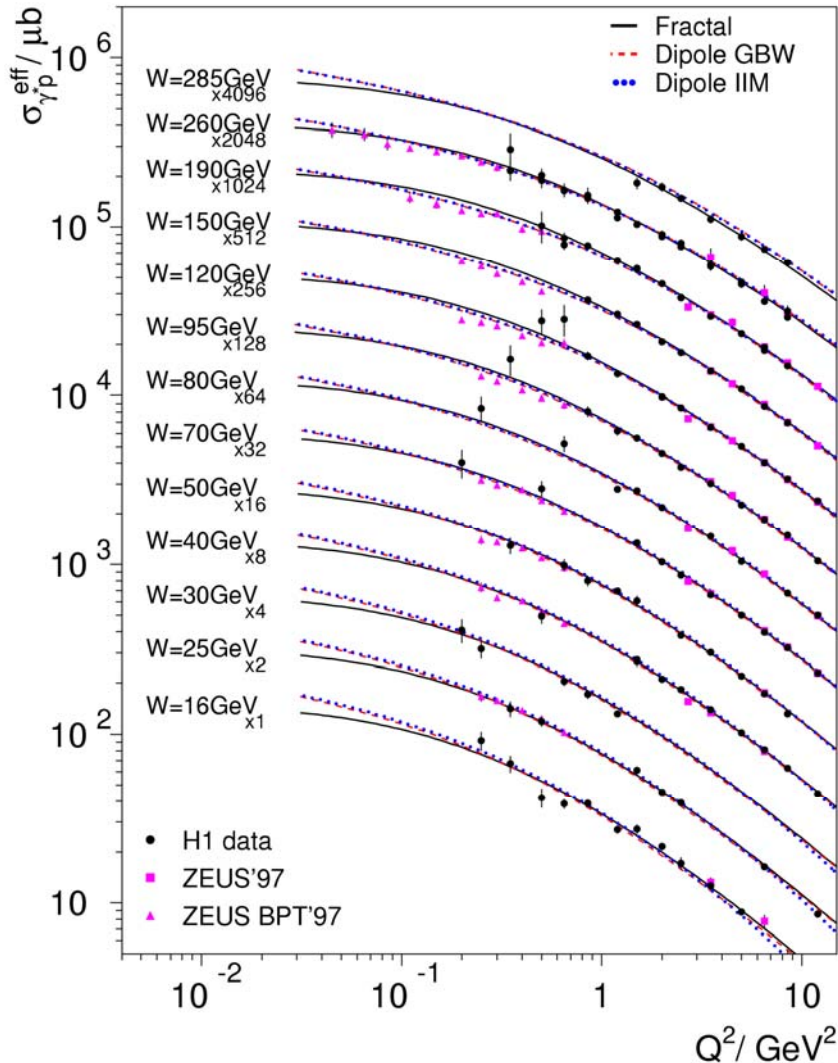
Rise compatible with $F_2 \propto x^{-\lambda}$



Effect of Gluon dynamics well described by fit



NC Measurement at low Q^2



- Measurement presented as effective γ^*p cross section
- precision of combined measurements better than 2%

- Smooth transition from perturbative to non-perturbative regime at $Q^2 \sim 1 \text{ GeV}^2$

