Precision DIS measurements at HERA

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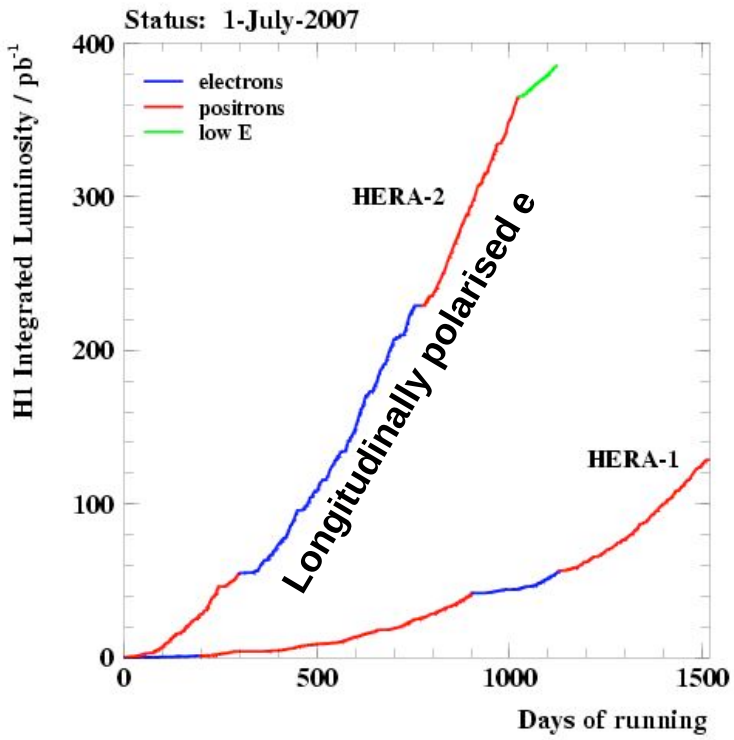
on behalf of the H1 and ZEUS Collaborations

New Measurements:

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

HERA *ep* Collider: 1992-2007



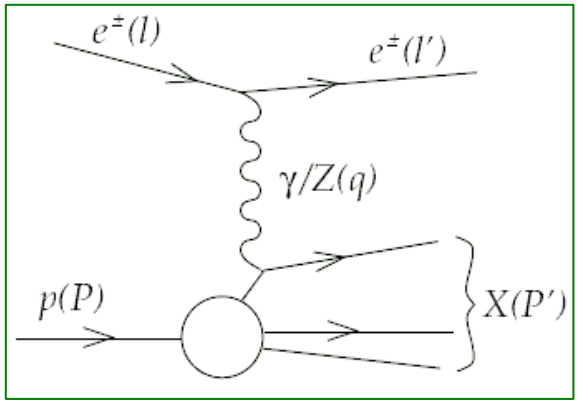
Two colliding beam experiments: H1 and ZEUS
~0.5 fb^{-1} collected pre experiment
approximately same amount of collisions with
electrons and positrons of
Left- and right-handed polarisation

E_e = 27.5GeV, E_p = 920 GeV

dedicated low Ep runs
Ep = 460GeV,575 GeV

Deep Inelastic Scattering (DIS)

Neutral Current (NC)



Boson virtuality

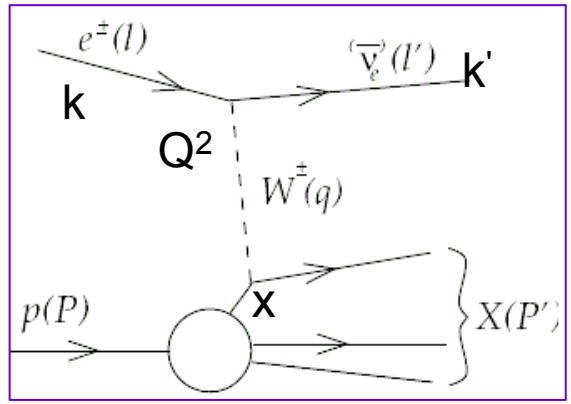
$$Q^2 = -q^2 = (k - k')^2$$

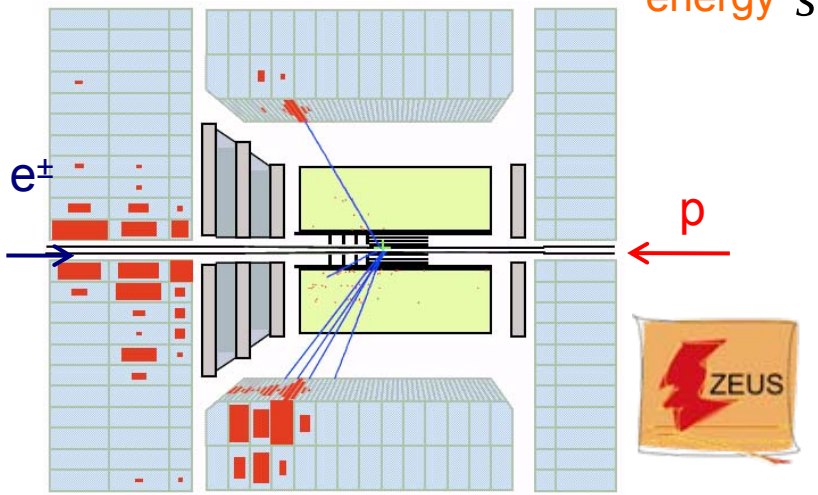
Bjorken x $\quad x = \dfrac{Q^2}{2(Pq)}$

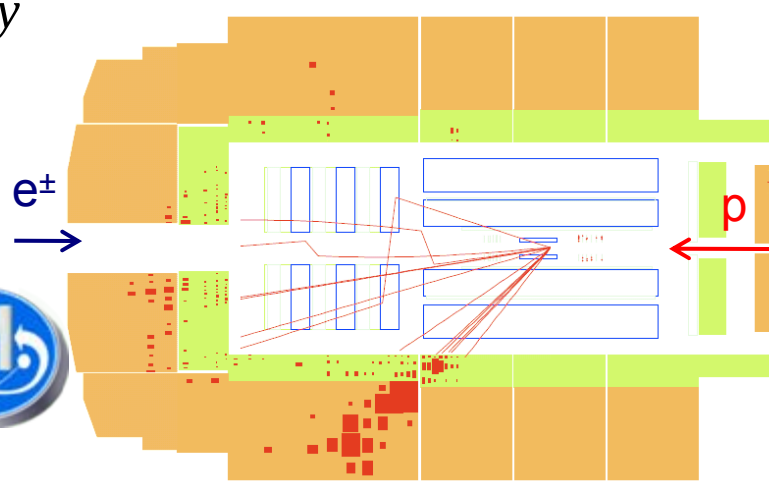
Inelasticity $\quad y = \dfrac{(Pq)}{(Pk)}$

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

Charged Current (CC)







Neutral Current Cross Section

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

$$Y_{\pm} = 1 \pm (1-y)^2$$

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

Generalized structure functions:

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

$$x\tilde{F}_3^{\pm} = \kappa(-a_e \mp P_e v_e)xF_3^{\gamma Z} + \kappa^2(2v_e a_e \pm P_e(v_e^2 + a_e^2))xF_3^{Z}$$

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

$$\left[xF_3^{\gamma Z}, xF_3^{Z}\right] = \sum_q \left[e_q a_q, v_q a_q\right] 2x(q-\bar{q})$$

Charged Current Cross Section

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

CC reduced cross section

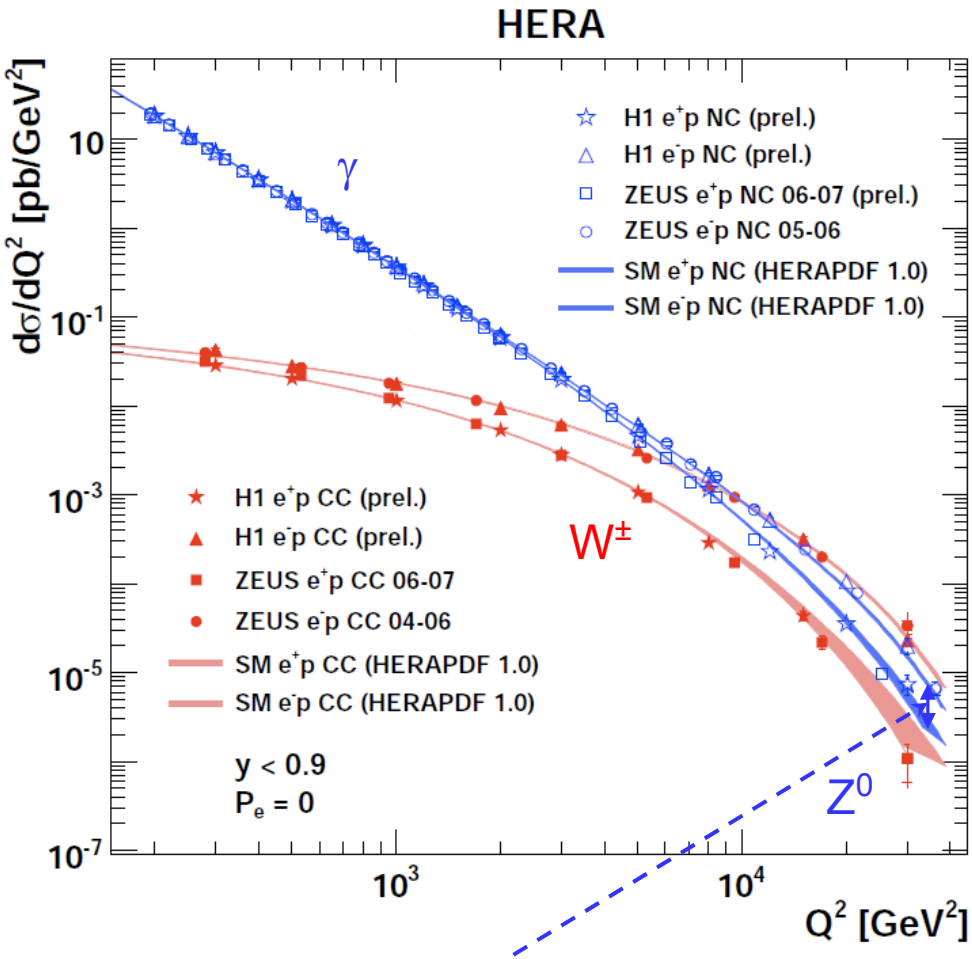
e^+/e^- sensitive to different quark densities:

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

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

CC gives sensitivity to different combinations of quarks as NC.

Electroweak Unification



difference in e^+ and e^- for NC in high Q^2 region comes from contribution of Z exchange

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

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

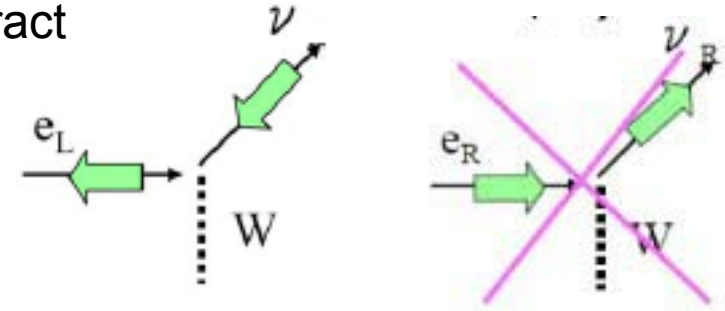
Total Charged Current Cross Section

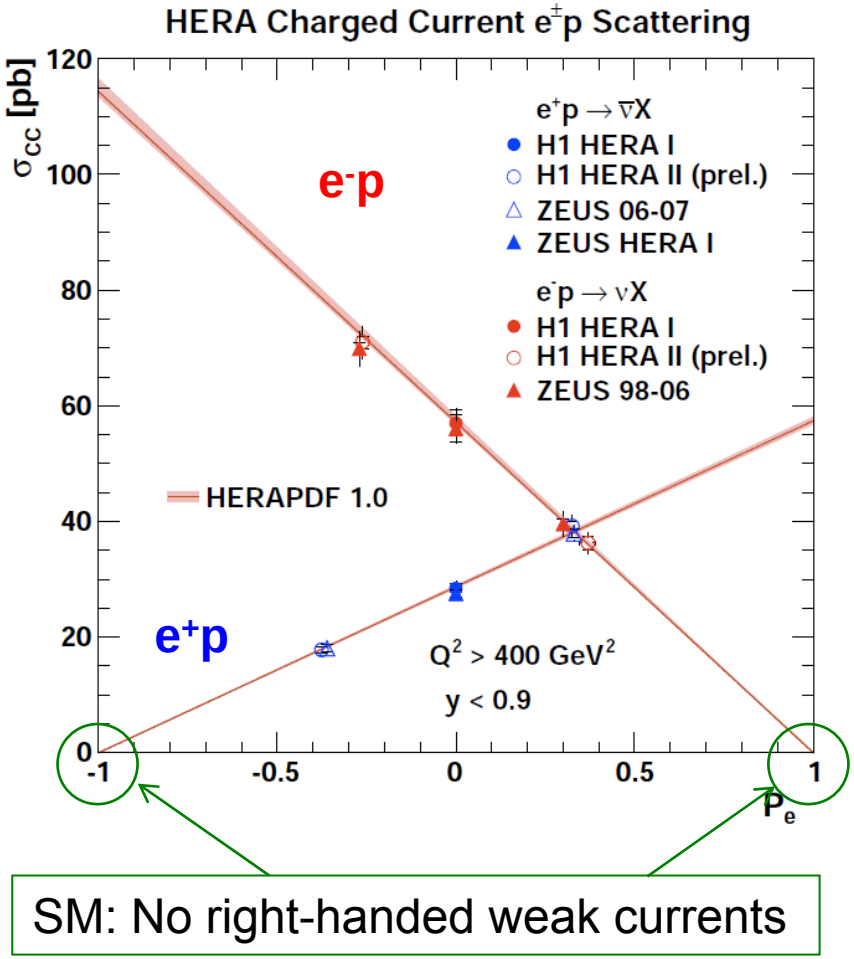
Linear dependence of σ^{CC} on P_e

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

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

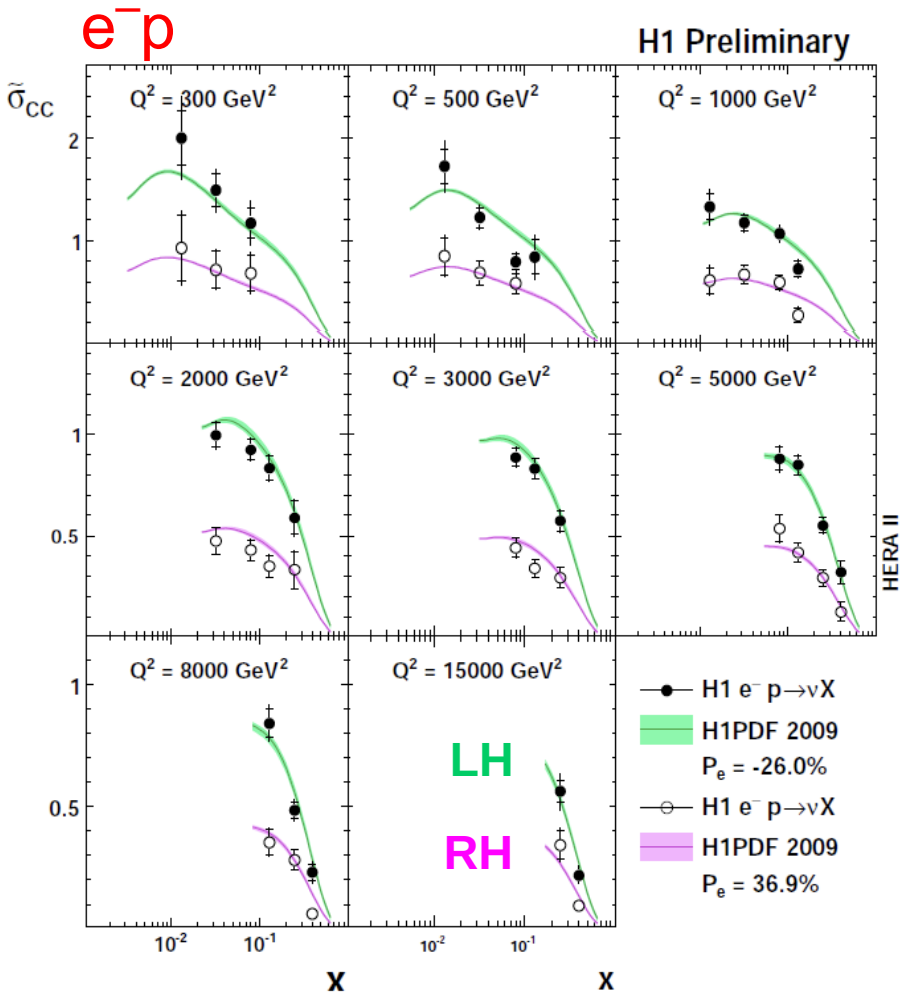
SM: weak CC interactions:
only left handed particles
(right handed anti-particles)
interact

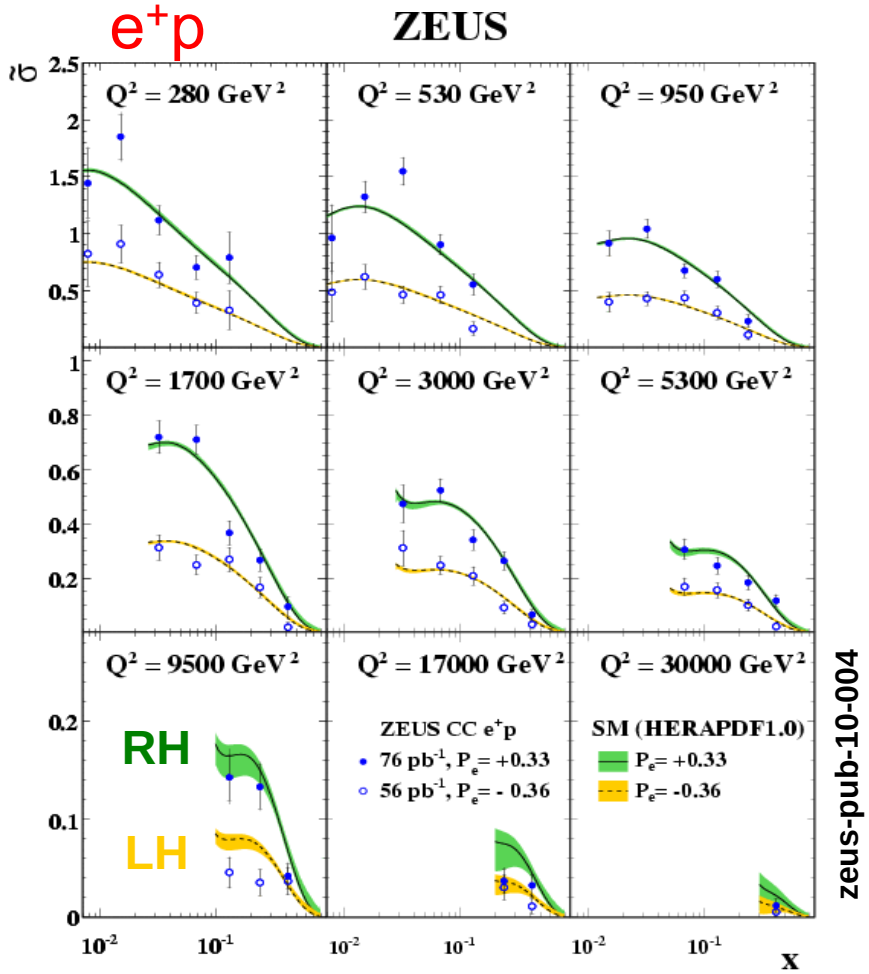




ZEUS and H1 in agreement with SM

Polarised CC Cross Sections



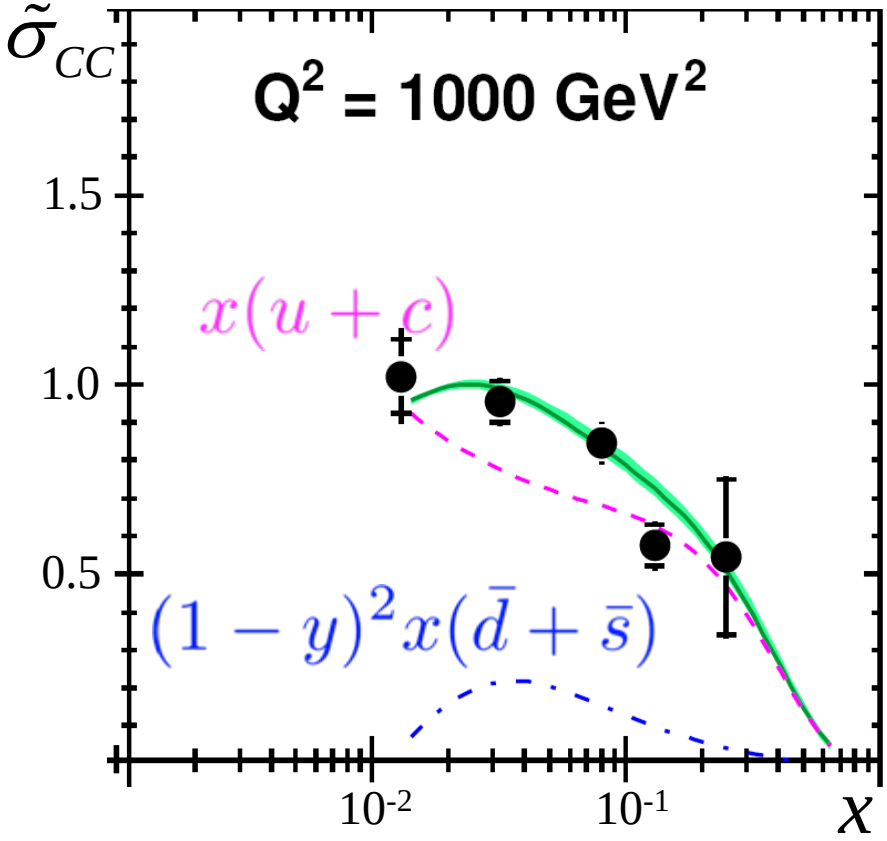


Predictions of SM give good description of data

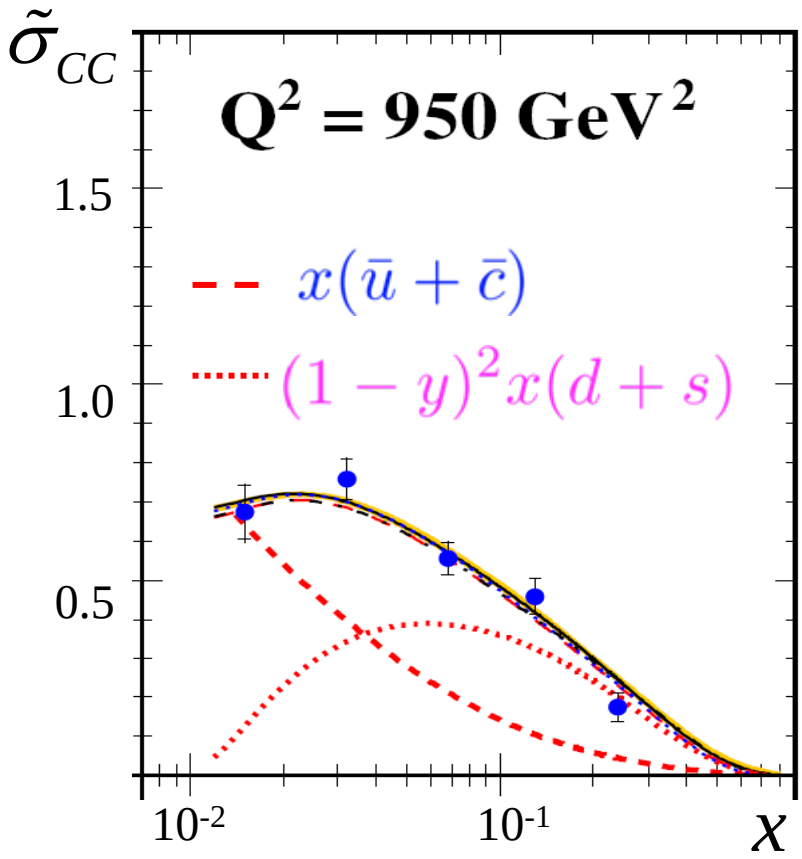
Quark Antiquark Decomposition

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

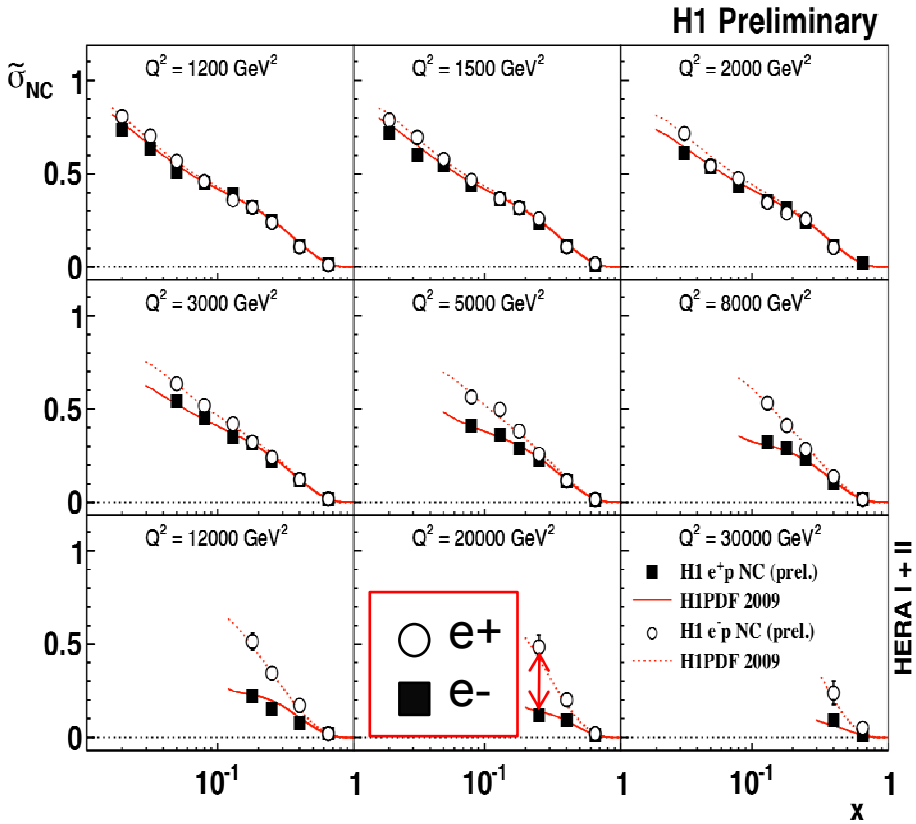
Neutral Current: xF_3

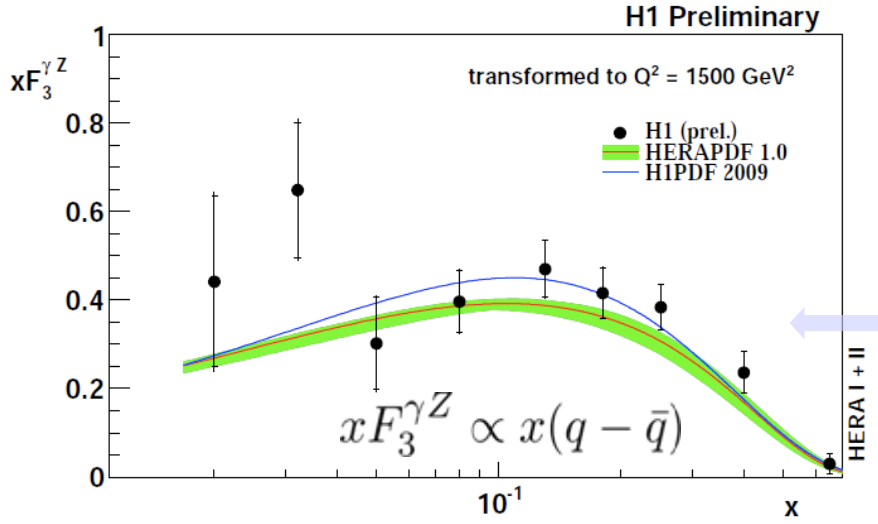
NC cross section:

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

dominant contribution to xF_3:

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



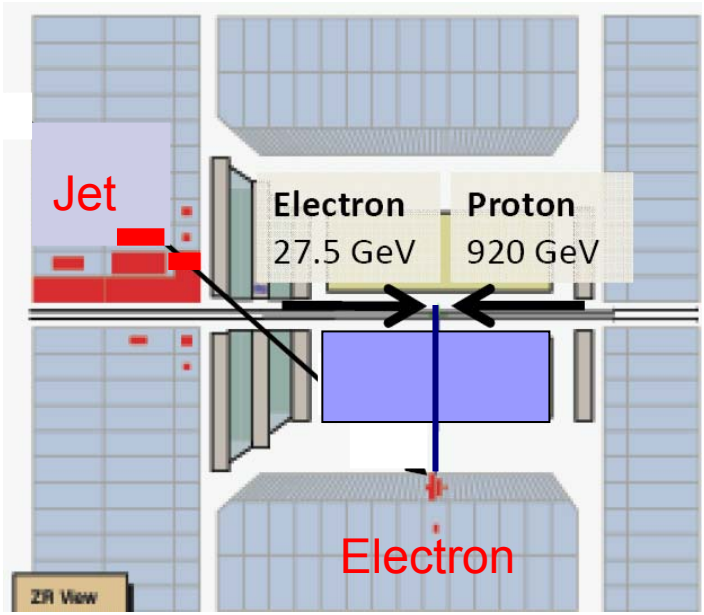


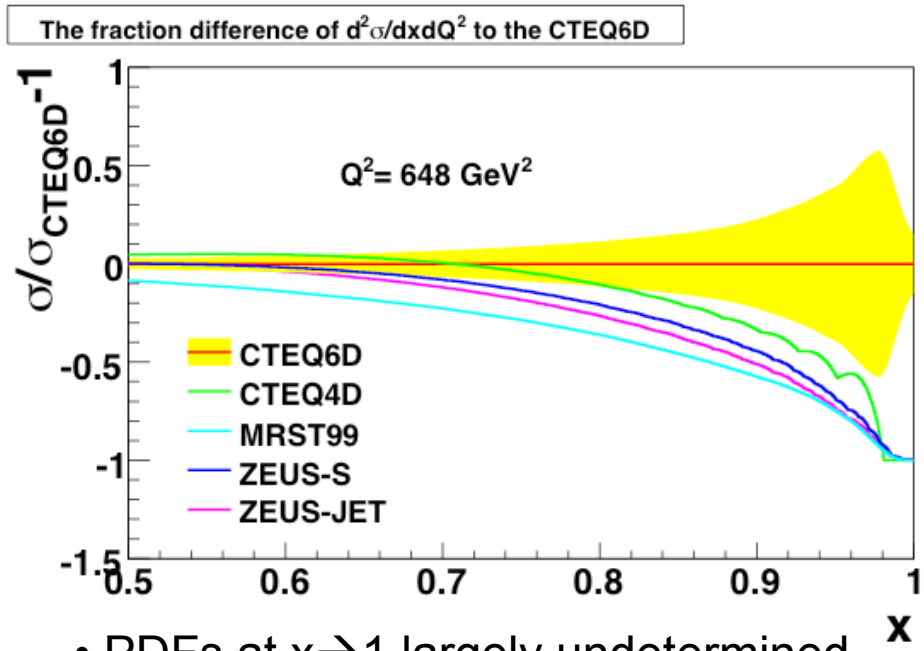
Sensitivity to valence quarks

more on NC & CC polarization effects
→ 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)

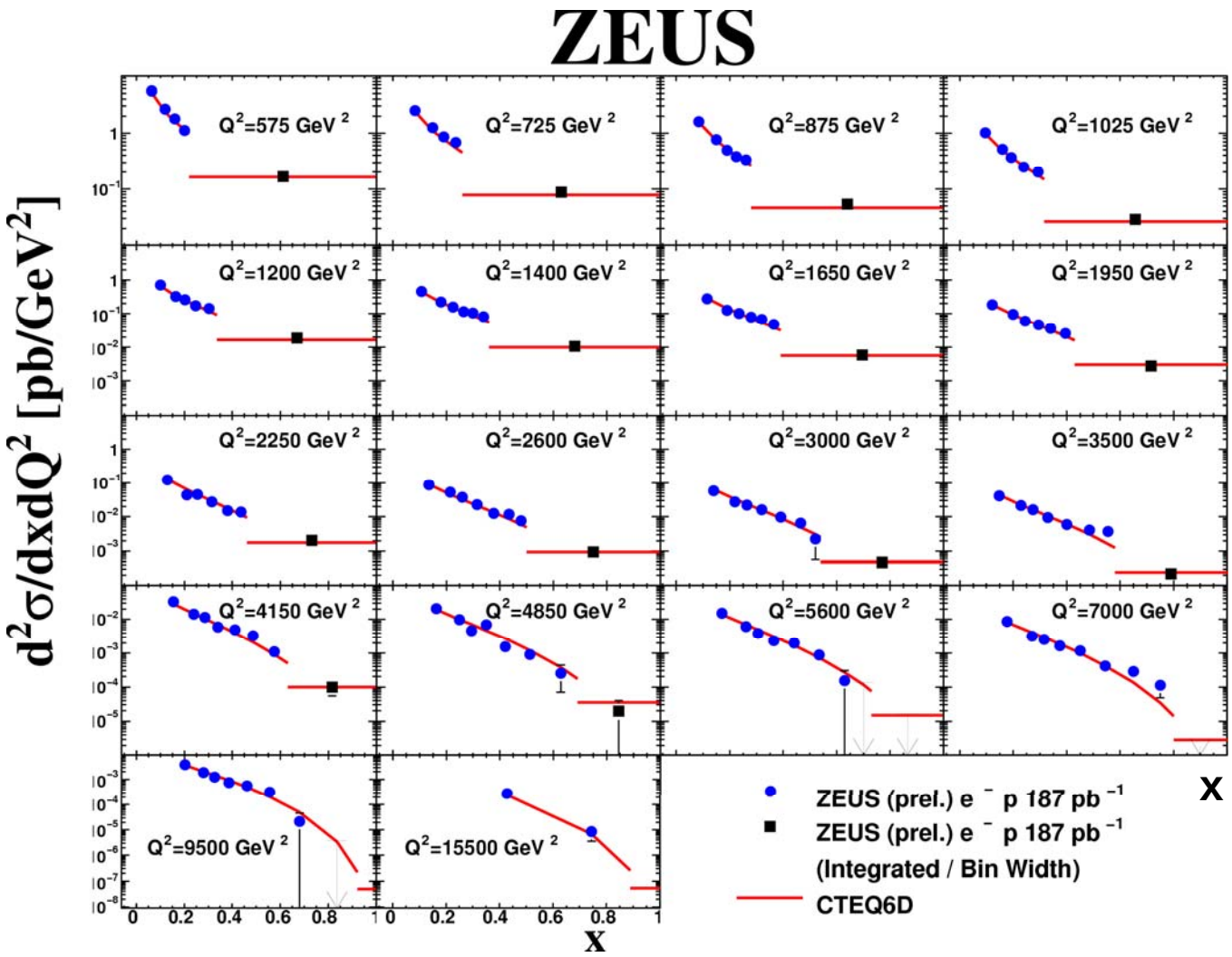




- PDFs at x→1 largely undetermined
- Variations between various PDFs sets larger than uncertainty estimates

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

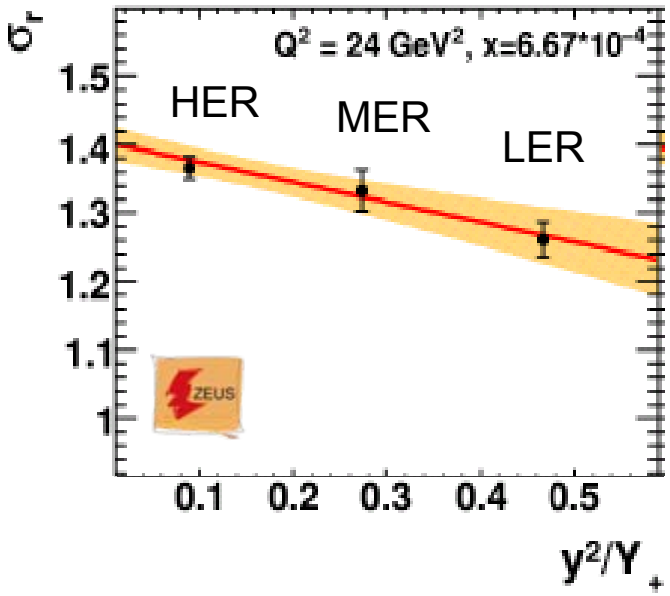
NC at High x: Results



Measurement of FL

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

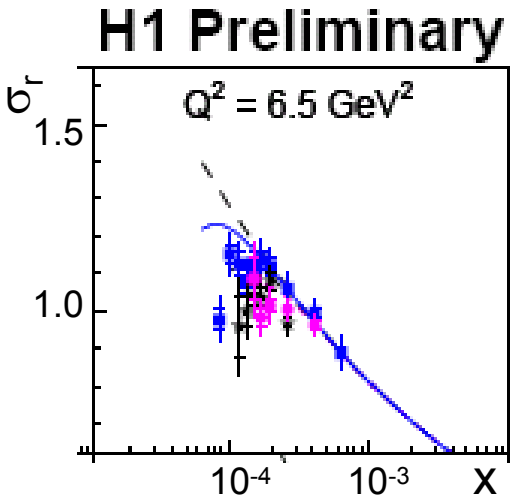
at same *x* and Q^2 but different $y = Q^2/x \cdot s$ → vary s

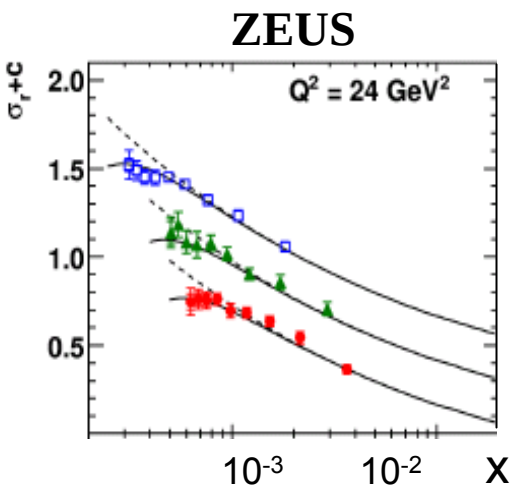


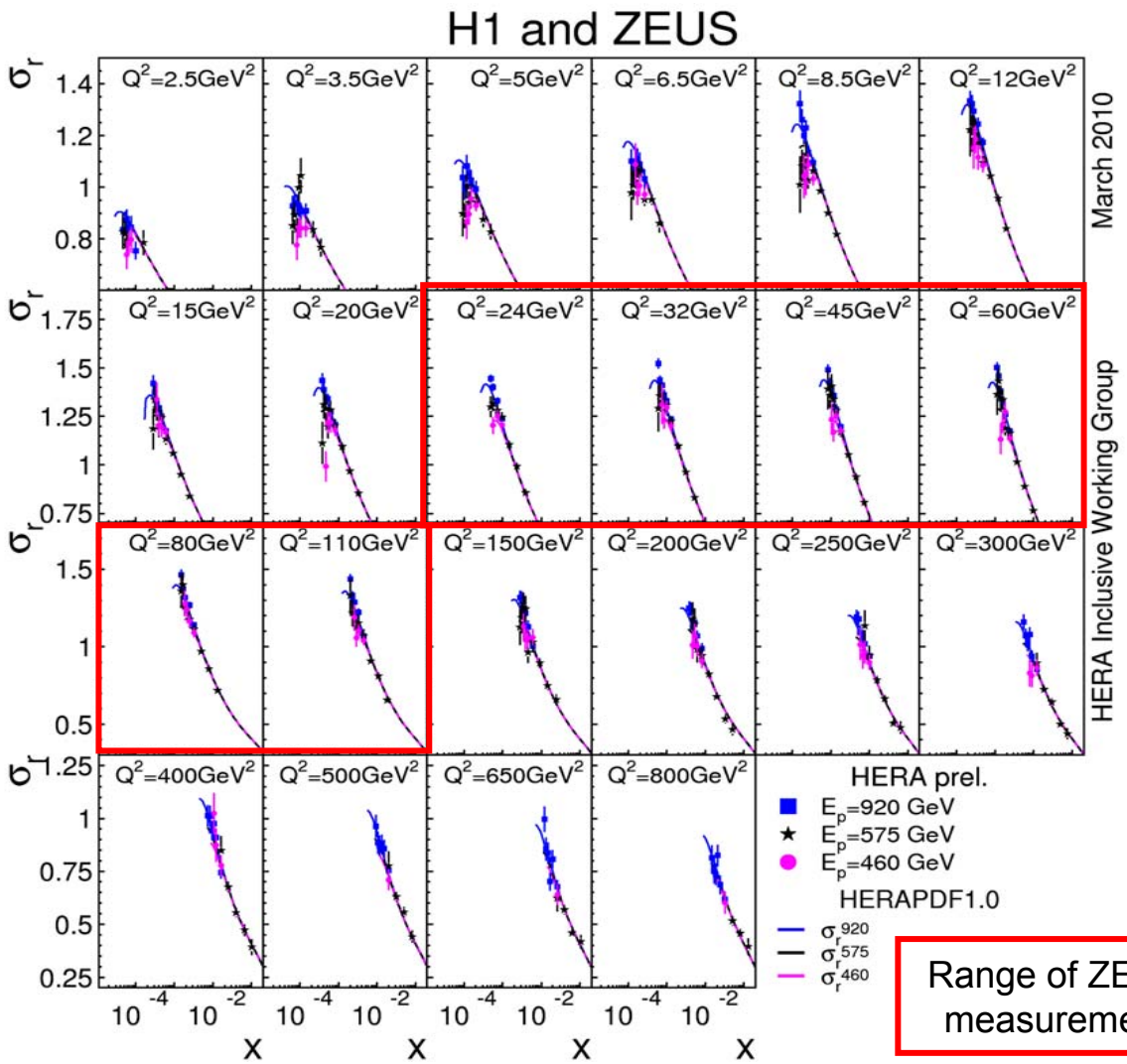
- Change proton beam energy to change cms energy
  - E_p = 920 GeV, High Energy Run (HER)
  - E_p = 575 GeV, Medium Energy Run (MER):
  - E_p = 460 GeV, Low Energy Run
- Large lever arm in y^2/Y_+
- Measure at high *y* in LER

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

Combined low E_p Cross Sections

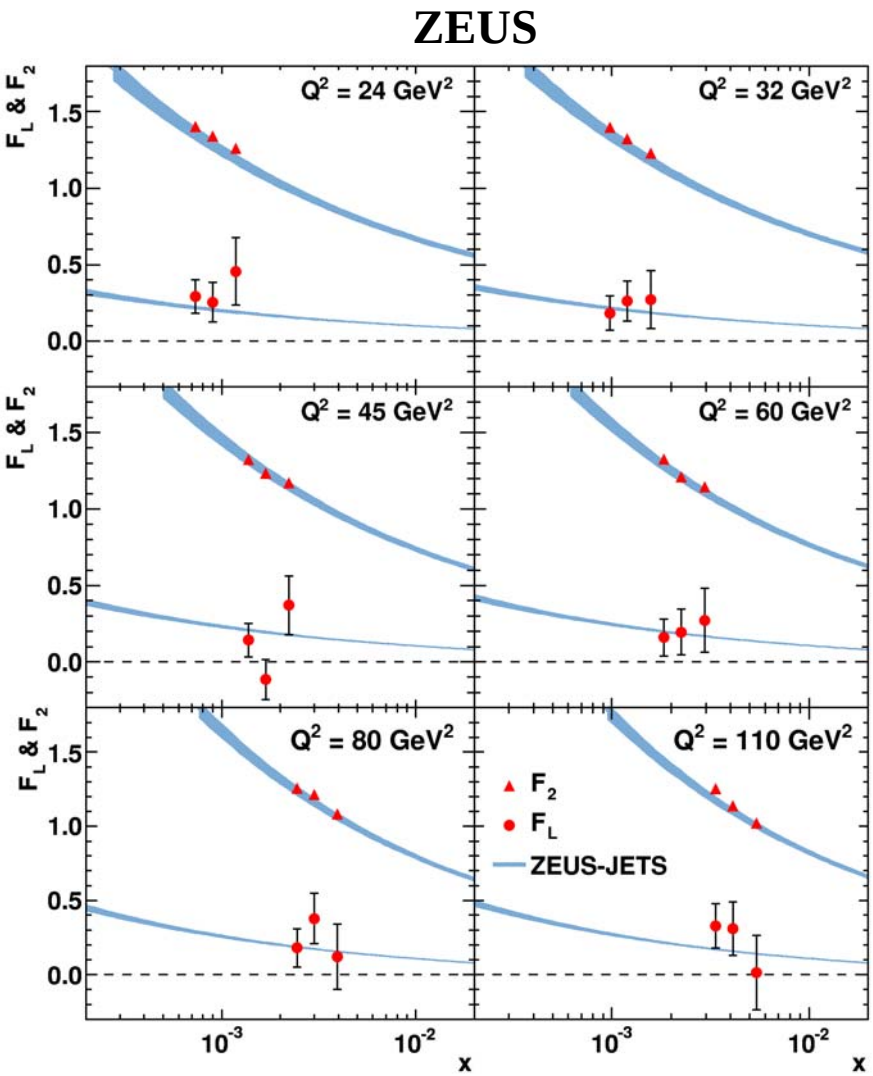






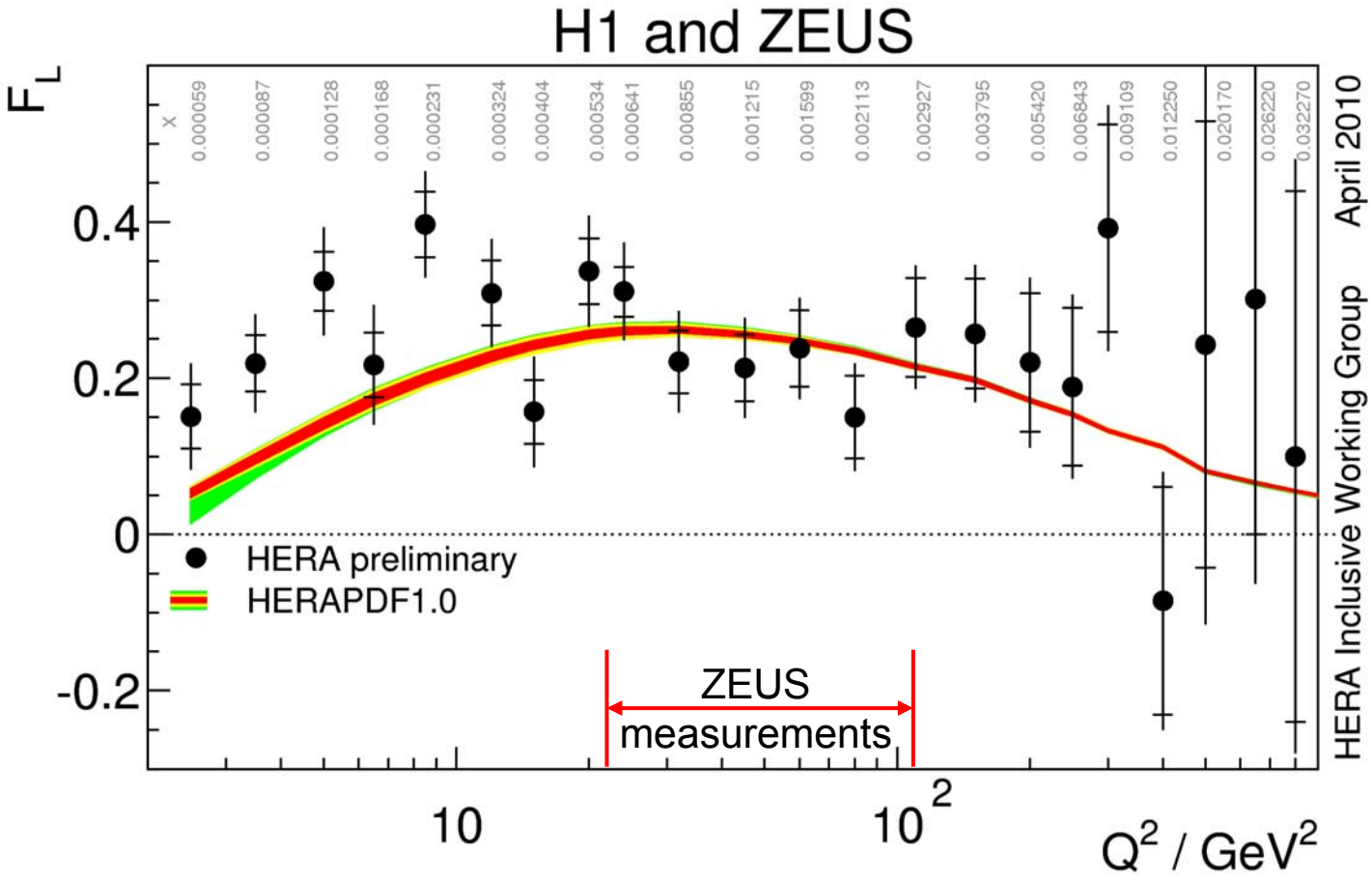
Range of ZEUS measurement

Extracted F_L and F_2



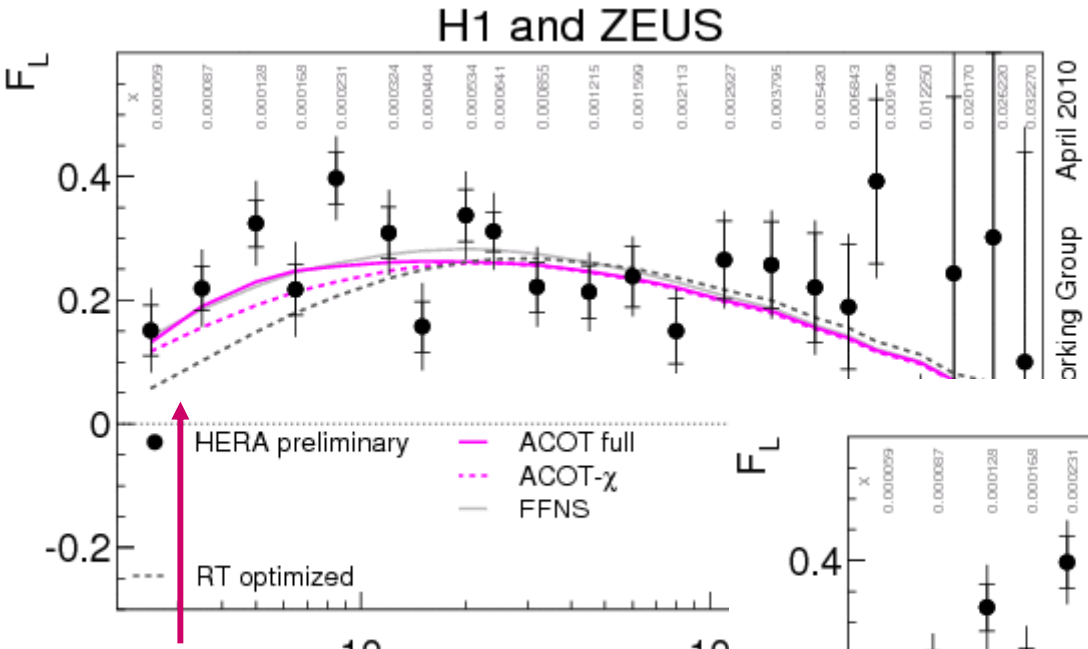
- First F_2 measurement without assumptions on F_L
- Data support a non-zero F_L
- Predictions for F_2 and F_L are consistent with data

H1 + ZEUS Combined F_L

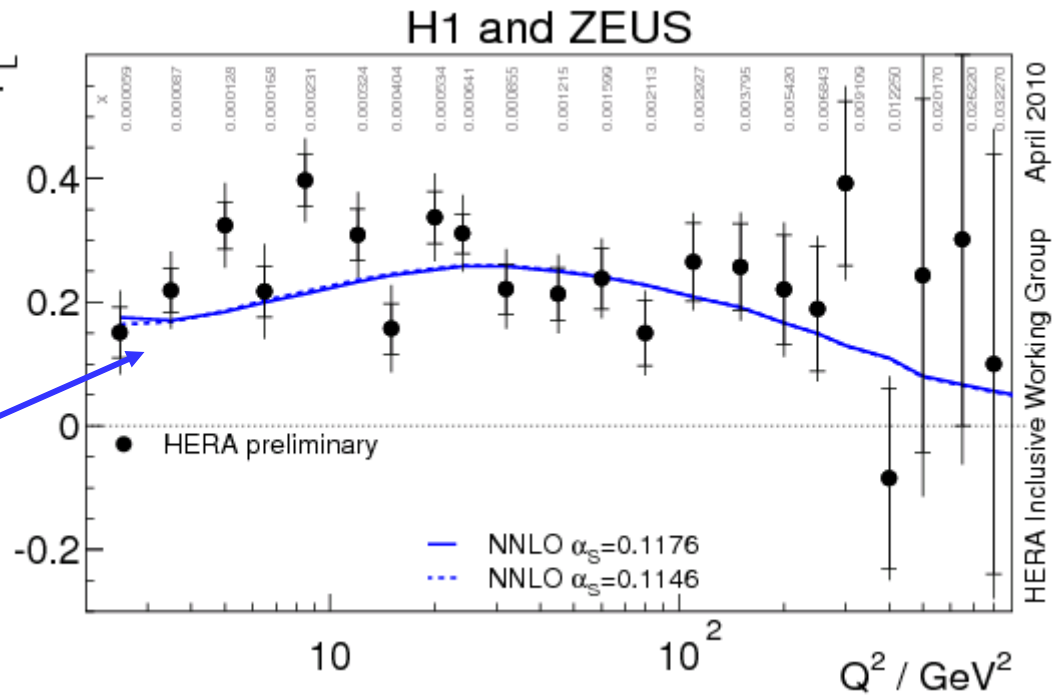


Good agreement between data and predictions for $Q^2>10$ GeV^2.
F_L at low Q^2 above prediction using HERAPDF1.0

Variants of Predictions for F_L

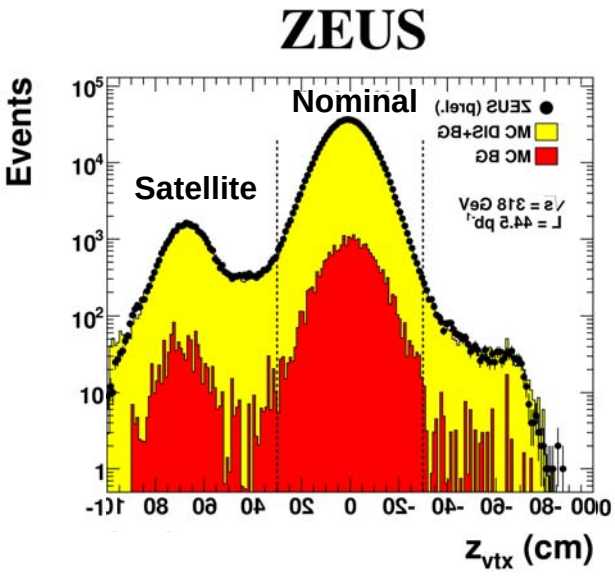


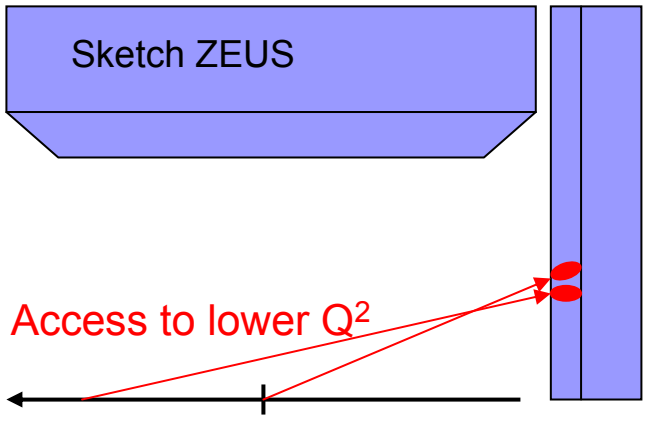
Variation of heavy flavour treatment

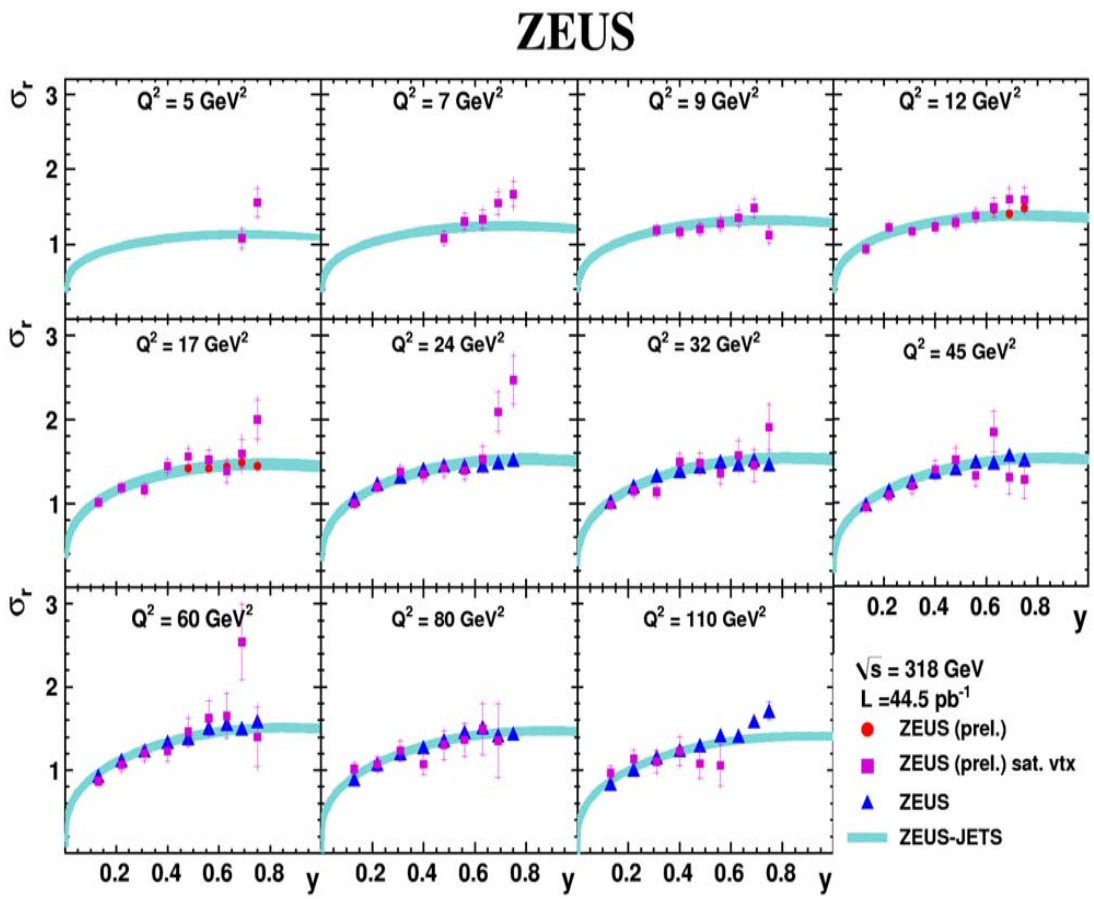


Higher Order calculation

Extension of σ @ high y to low Q^2

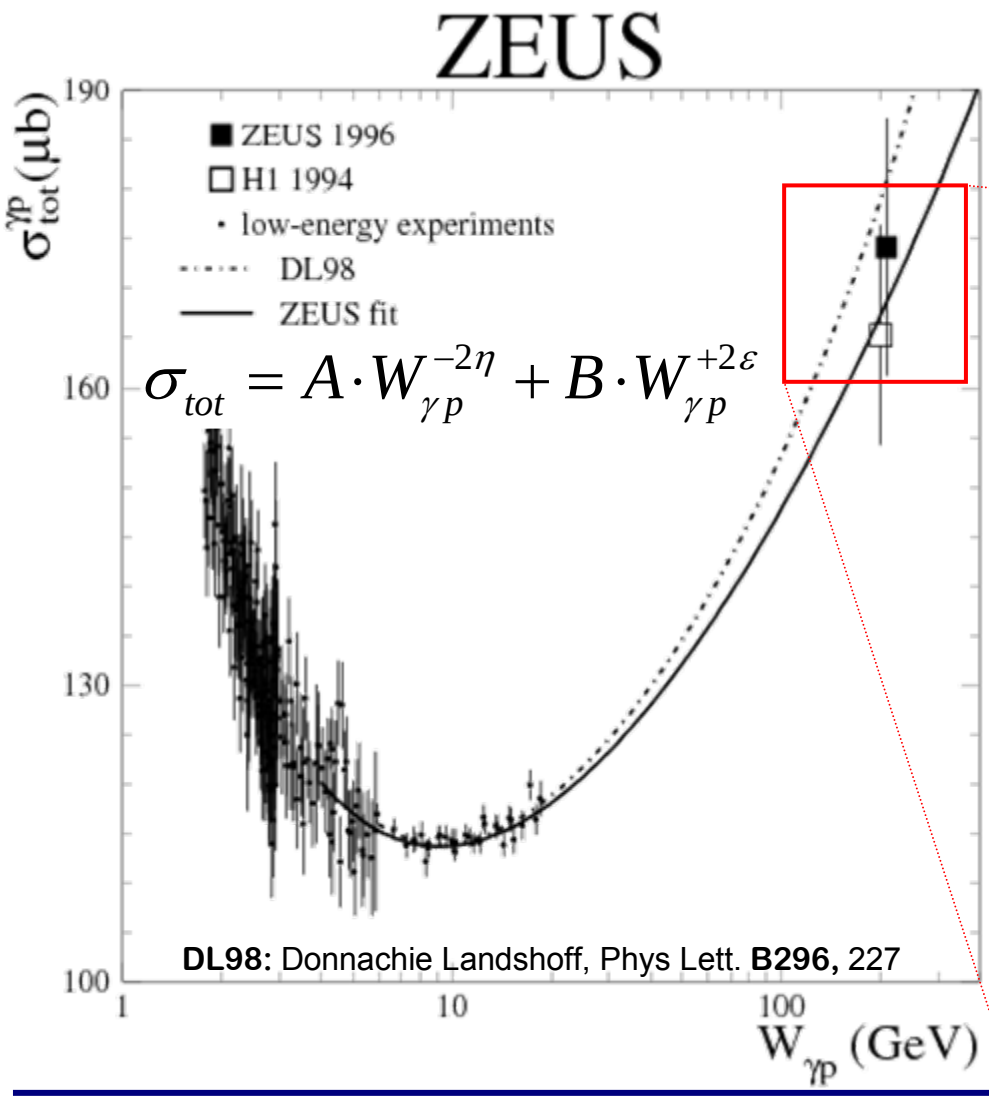






Data agree well with previous ZEUS measurements
Increase overlap with H1 at low Q^2

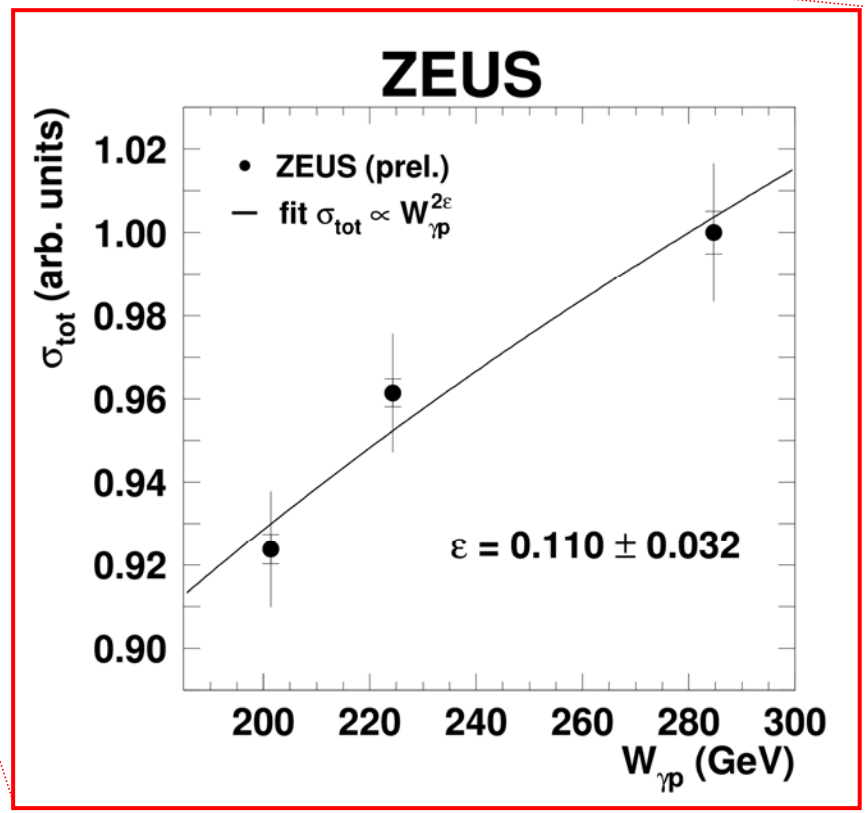
Total Photon-Proton Cross Section



DL98: Donnachie Landshoff, Phys Lett. **B296,** 227

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 Q2, 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 Q2
  H1prelim-09-044
- Combined low Ep cross section and FL extraction
  H1prelim-10-043

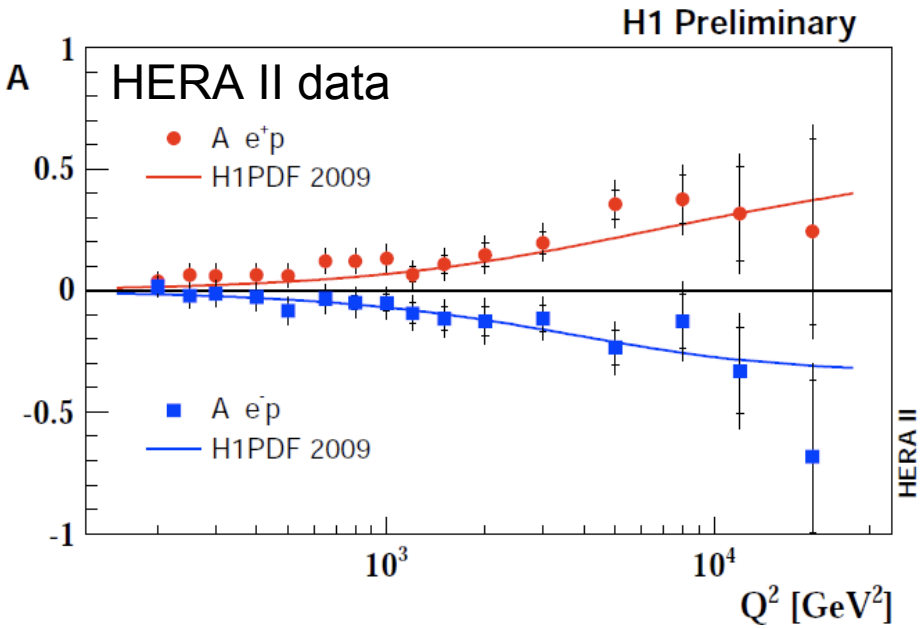
Backup

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:

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

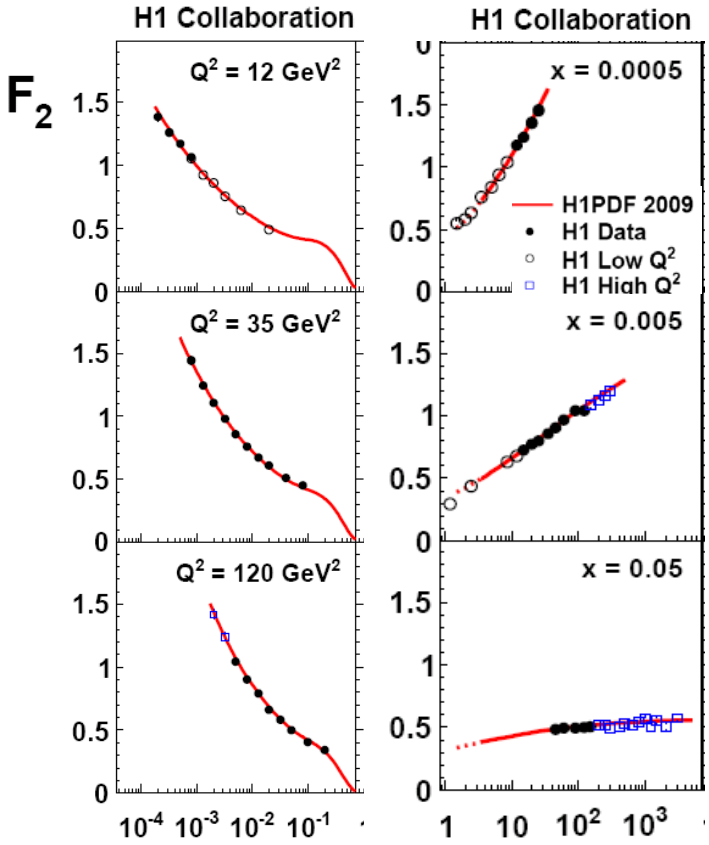
At LO: $F_2^{\gamma Z} = x\sum_q 2e_q v_q (q + \bar{q})$

Data well described by SM

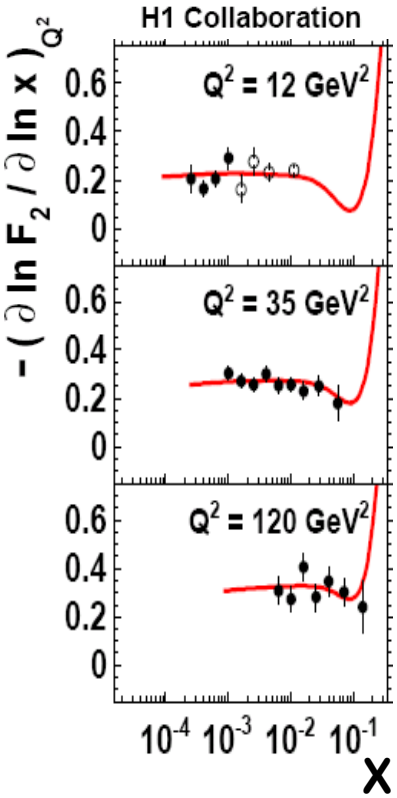
F_2 at medium Q^2

New measurement (L = 22pb^{-1}, 2000) combined with published results (96/97)

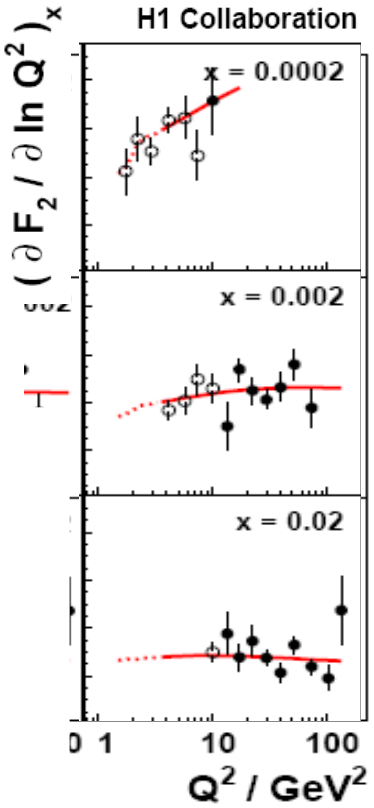
$s_r \sim F_2$ ($12 < Q^2 < 150\text{GeV}^2$, $y<0.6$) impressive accuracy 1.3 - 2%



Steep rise described by QCD

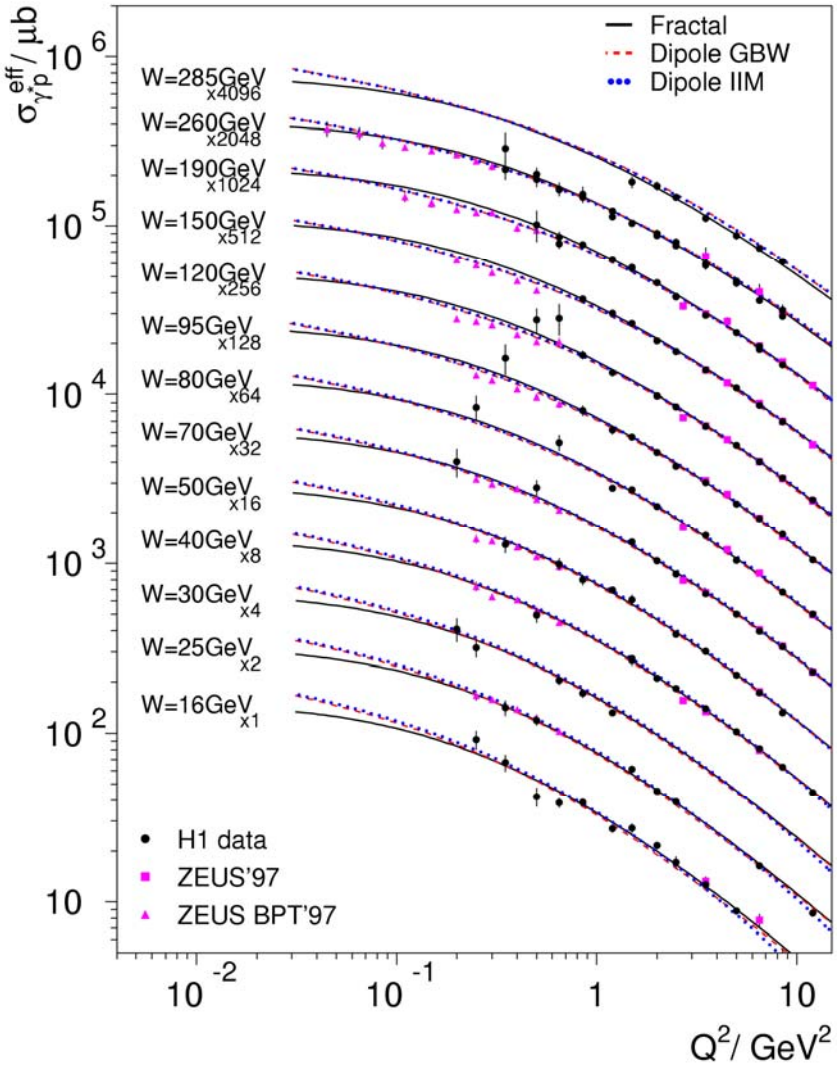


Rise compatible with $F_2 \propto x^{-\lambda}$



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 $Q^2 \sim 1\text{GeV}^2$