Physics at high Q^2 at HERA

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On behalf of the
H1 and ZEUS collaborations

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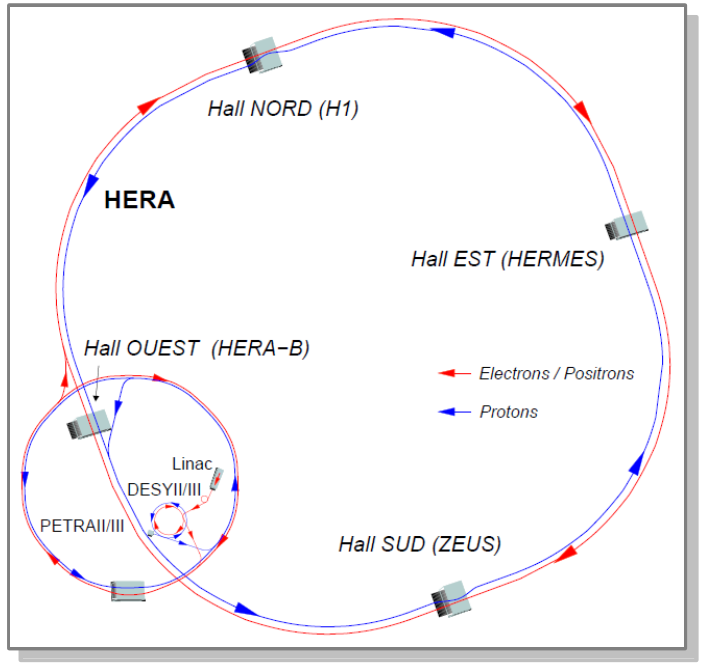
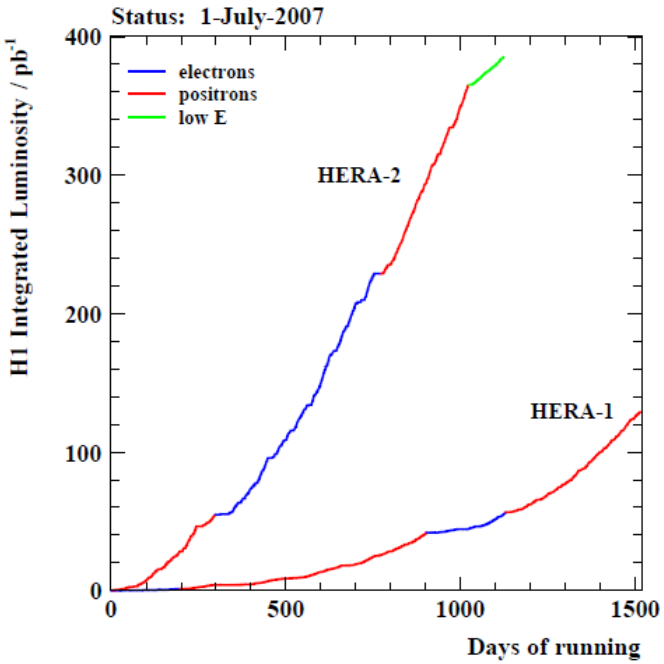
Outline:

- H1 and ZEUS at HERA
- Deep inelastic scattering
- Recent results on high Q^2 physics at HERA

HERA

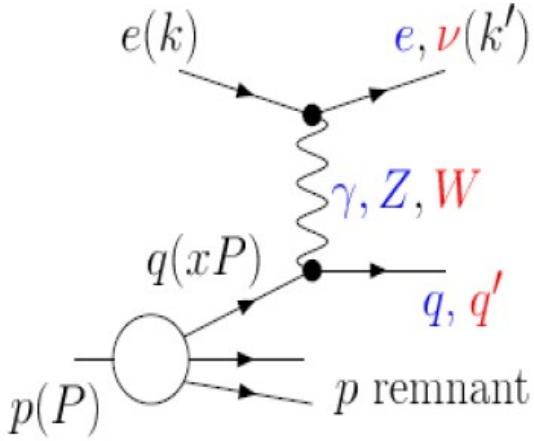
- The world most powerful electron microscope, located in Hamburg, Germany
- Two collider experiments at the ep interaction points
- Center-of-mass energy: 225-319 GeV
- HERA-II: longitudinal polarised electrons (positrons)





- Integrated luminosity of 0.5 fb^{-1} per experiment
- Studies of Electroweak physics, BSM, ...

Deep Inelastic Scattering (DIS)



DIS kinematics

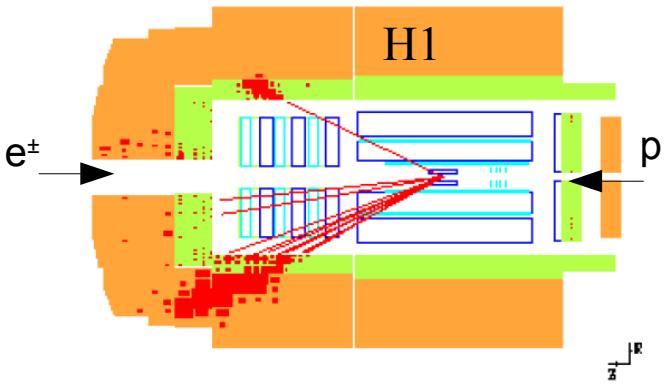
$$Q^2 = -q^2 = (k - k')^2, \qquad Q^2 \in [0, s]$$

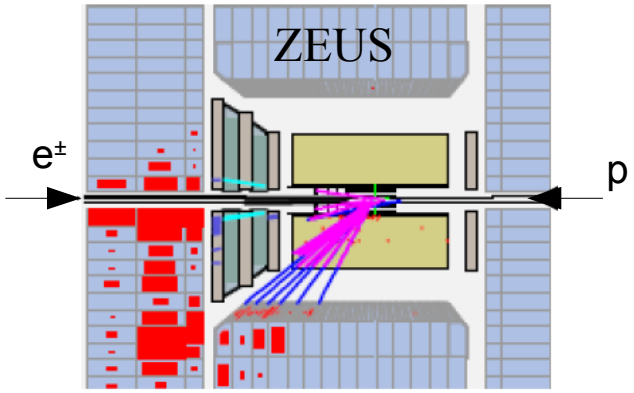
$$x = \frac{Q^2}{2P \cdot q}, \qquad x \in [0, 1]$$

$$y = \frac{q \cdot P}{k \cdot P}, \qquad y \in [0, 1]$$

- Q^2: virtuality of the exchanged boson
- x: momentum fraction carried by struck quark
- y: inelasticity

HERA covers a wide kinematic range, up to five orders in magnitude in log-scale of Q^2.





Example of neutral current (H1) and charged current (ZEUS) events.

Deep Inelastic Scattering: cross section

- DIS neutral current (NC) cross section is expressed using proton structure functions

$$\frac{\mathrm{d}^2\sigma^{\pm}_{\mathrm{NC}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{4\pi\alpha_s^2}{Q^4}\left[Y_+\tilde{F}_2 - y^2\tilde{F}_L \mp Y_- x\tilde{F}_3\right]$$

$Y_\pm = 1 \pm (1-y)^2$ helicity function

dominant contribution — sizable at high Y — important at high Q^2

⟹ Polarisation dependence due to γZ interference term

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

$$x\tilde{F}_3 = -(a_e - P_e v_e)\kappa_Z x F_3^{\gamma Z} + \left[2v_e a_e - P_e(v_e^2 + a_e^2)\kappa_Z^2 x F_3^Z\right]$$

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

- Charged current (CC) cross section

$$\frac{\mathrm{d}^2\sigma^{\pm}_{\mathrm{CC}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{Q^2 + M_W^2}\right]^2 \left[Y_+ F_2^{\pm\mathrm{CC}} - y^2 F_L^{\pm\mathrm{CC}} \mp Y_- x F_3^{\pm\mathrm{CC}}\right]$$

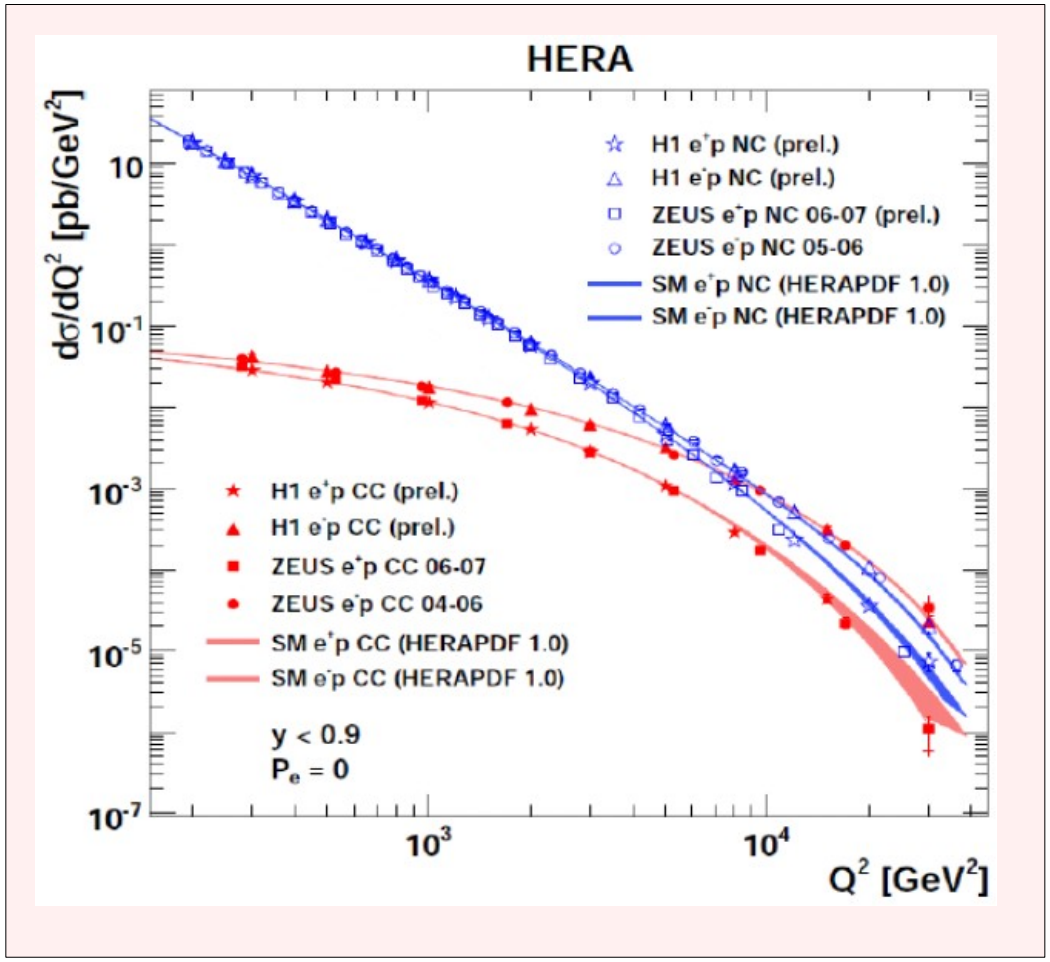
CC cross section for e^-, e^+ sensitive to different type of quark

HERA I+II unpolarized DIS cross section

At low Q^2: $\sigma_{NC}(e^+p) \approx \sigma_{NC}(e^-p)$ due to photon exchange. Charged current events are suppresed by massive W-boson

At high Q^2,
$\sigma_{CC}(e^-p) > \sigma_{CC}(e^+p)$, due to W^- (W^+) exchange which couple to up (down) type quark.

Diffence of NC cross section for electron and positron due to interference γ – Z boson.



HERA data allow a visualization of the "unification" of the electromagnetic and weak interactions at W-Z scale.

$xF_3^{\gamma Z}$ – interference of γ and Z-boson

The expression for $xF_3(x,Q^2)$ is related to the reduced NC cross sections

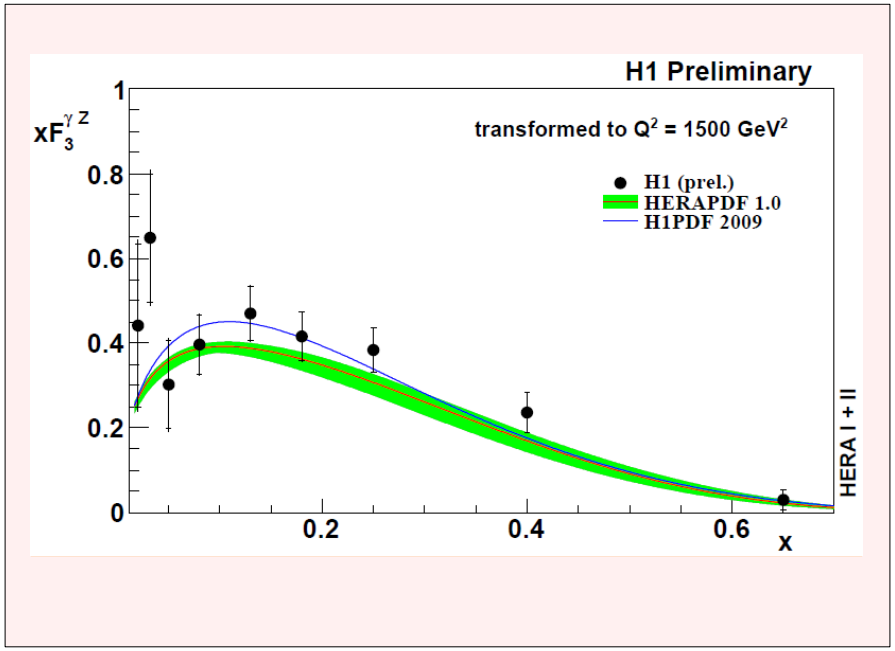
$$x\tilde{F}_3^{\pm}(x,Q^2) = -a_l P_Z x F_3^{\gamma Z}(x) + 2a_l v_l P_Z^2 x F_3^Z(x)$$

$$P_Z = \frac{Q^2}{Q^2 + M_Z^2}\frac{1}{\sin(2\theta_W)}$$

a, v: axial & vector coupling of the lepton

dominant contribution to $xF_3(x,Q^2)$ arises from the γ – Z interference term: $xF_3^{\gamma Z}$

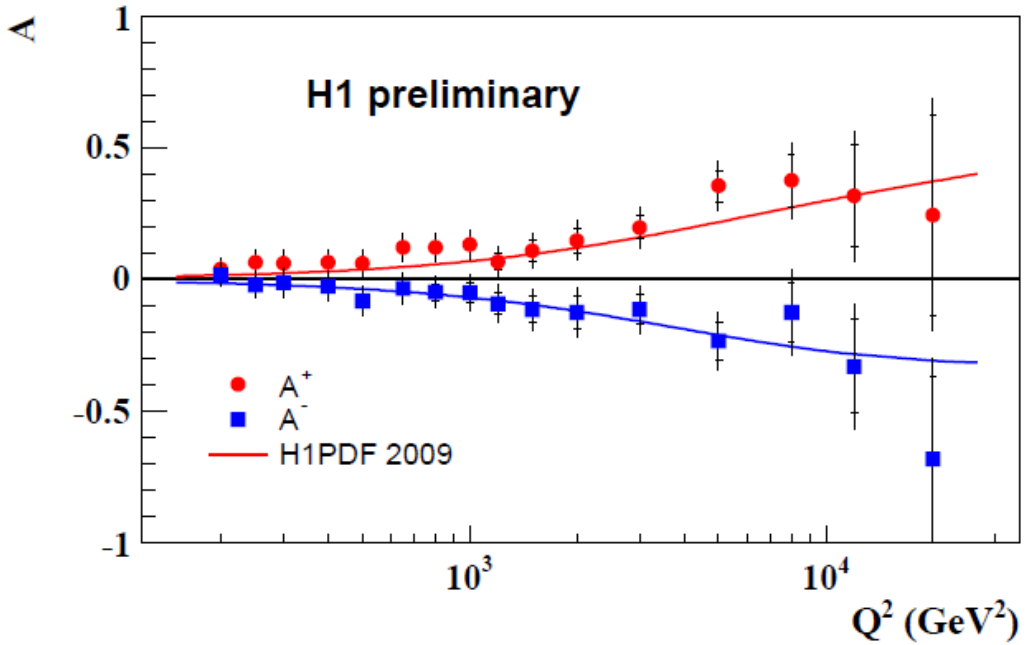
$xF_3^{\gamma Z}$: little dependence on Q^2 → transformation to one Q^2 value.

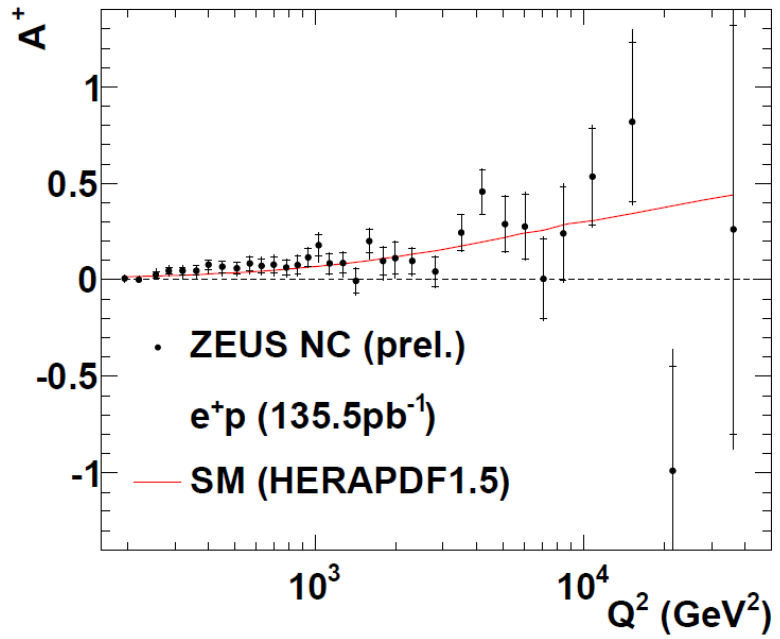


Neutral current polarisation asymmetry

Polarization asymmetry $$A = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}.$$

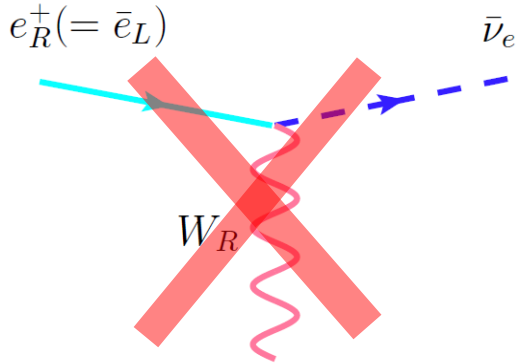
At high Q^2, the difference between A values for e^+p and e^-p interaction becomes important due to the Z-boson exchange.

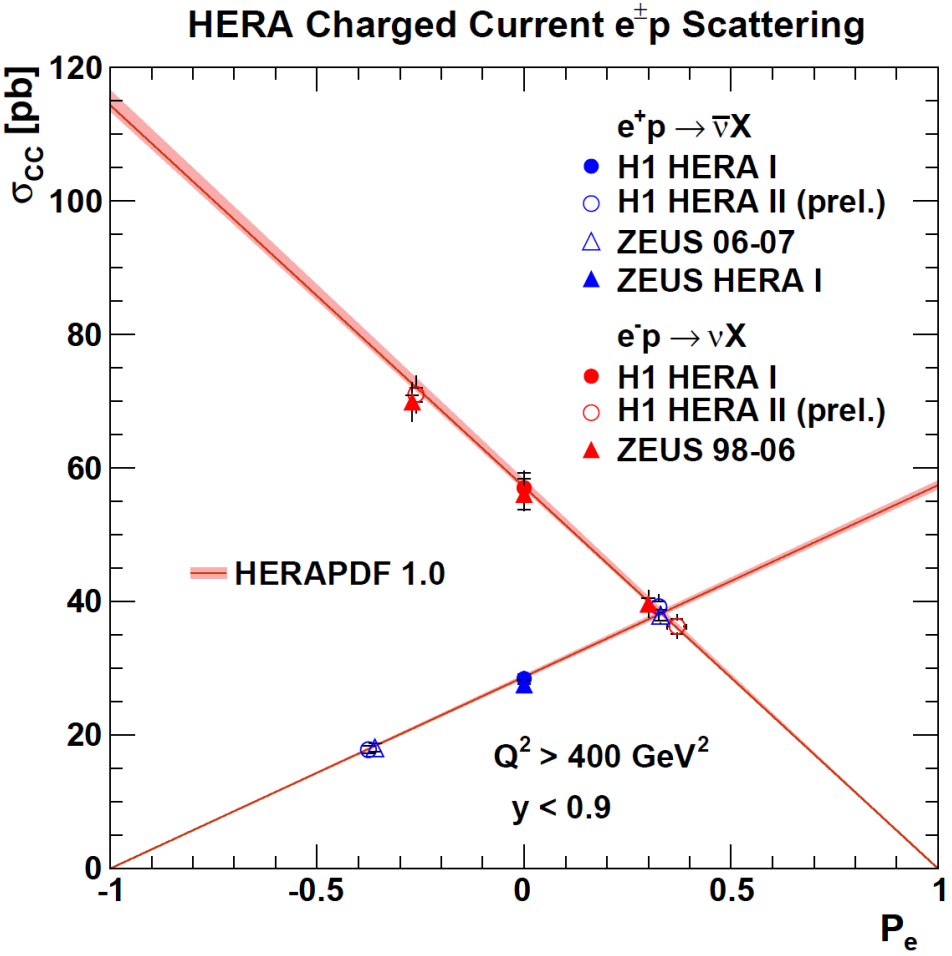




Charged current total cross section

- Charged current interaction affect only left-handed particles
- Cross section varies linearly in function of polarisation

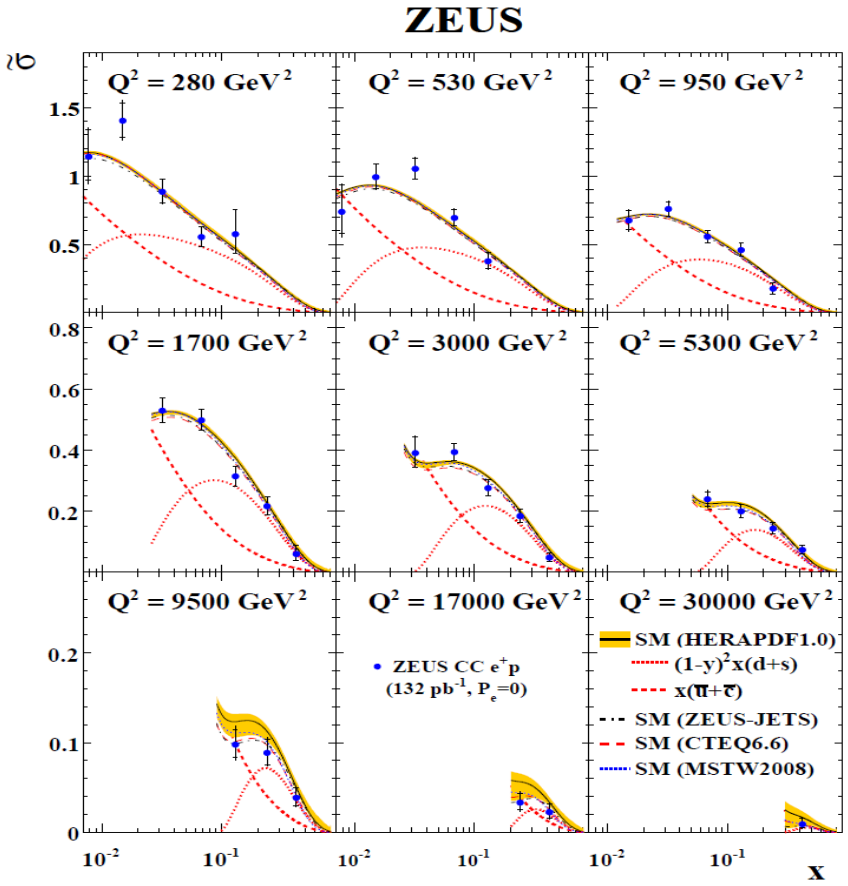




- Good agreement with SM prediction.
- Difference at P_e = -1 will be used to constrant M_{WR}.
  (M_{WR} > 198 GeV from final ZEUS result.)

Charged current reduced cross section

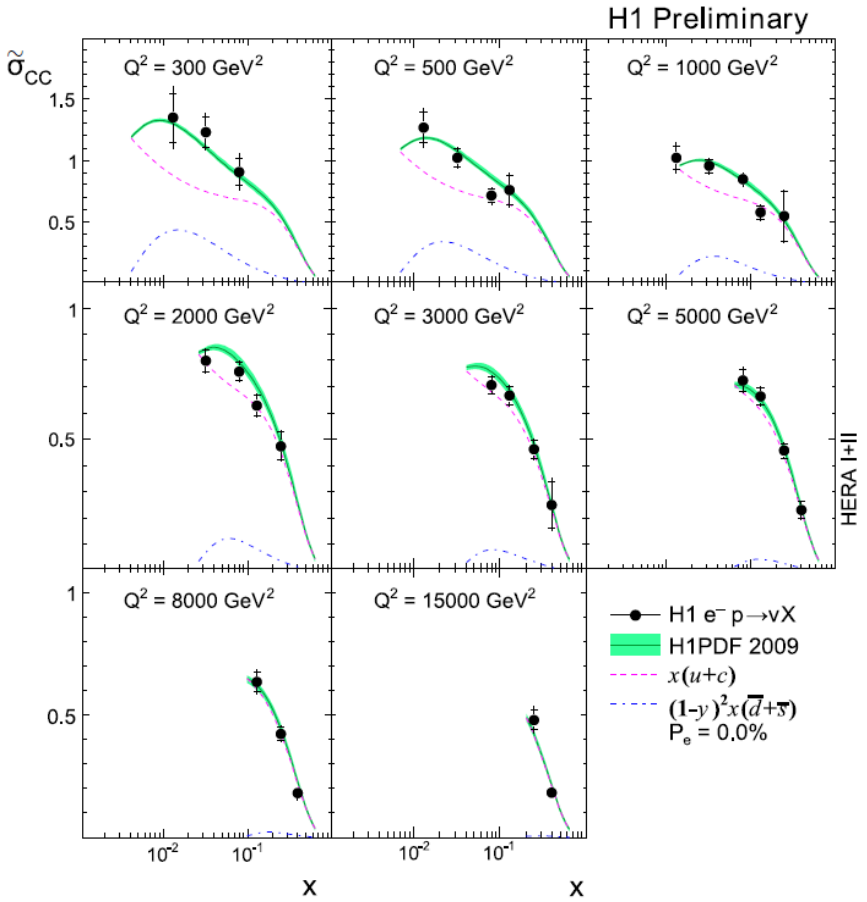
positron



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

- PDF of d-quark dominates e^+p cross section at high x

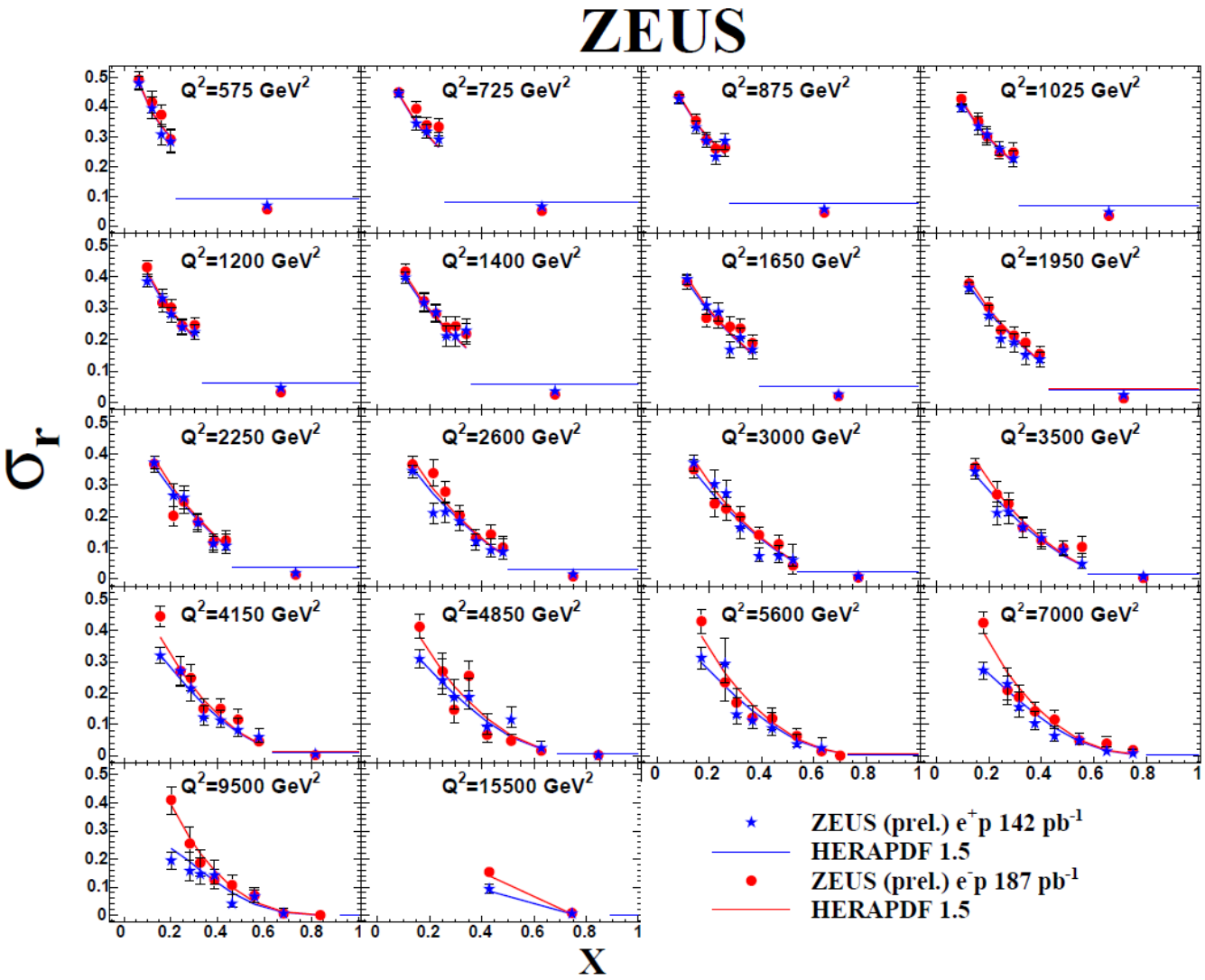
electron



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

- PDF of u-quark dominates e^-p cross section

Neutral current reduced cross section



NC measurement at high x (up to 1)

x reconstruction relies on jets force jets to balance pT of electron yields better x resolution.

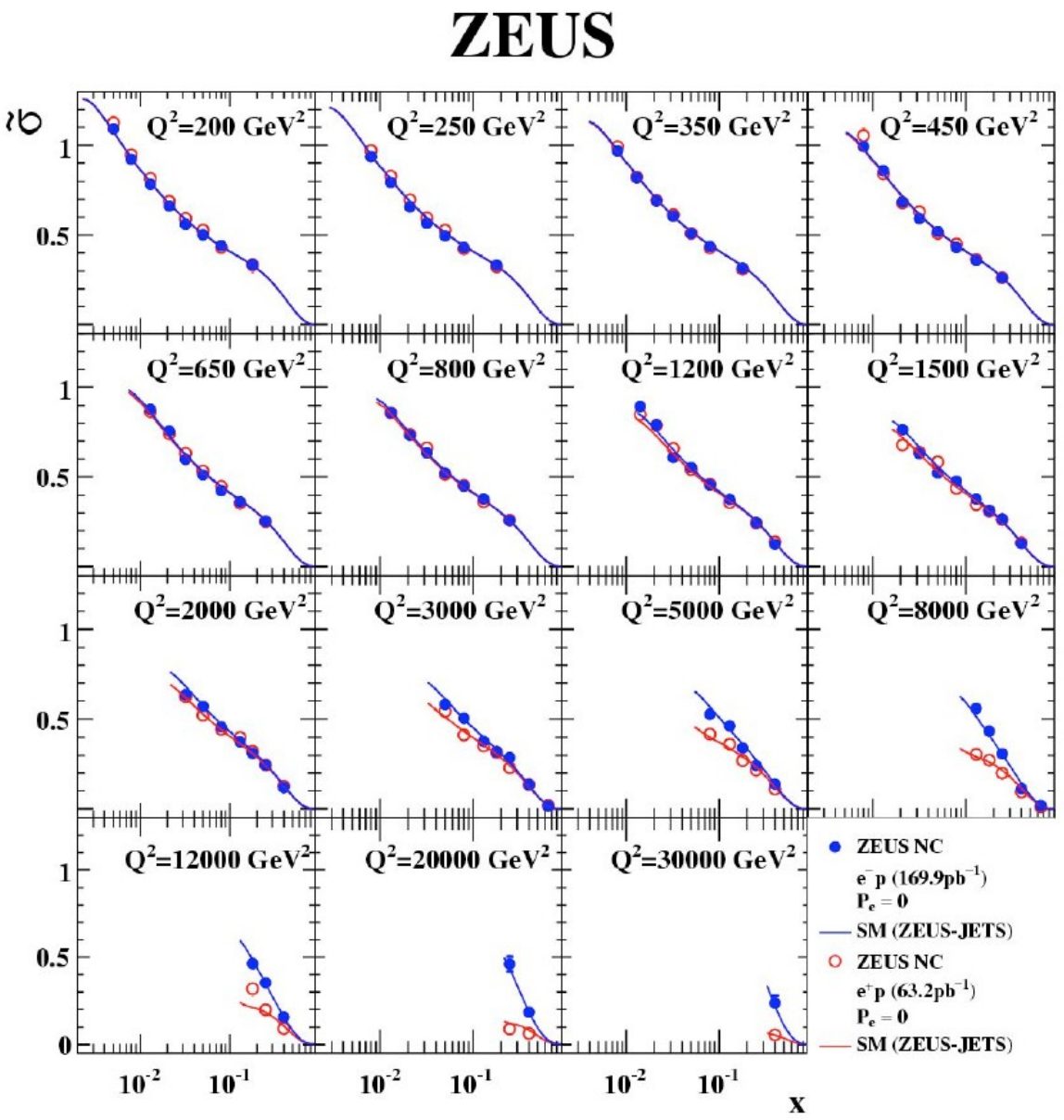
New method allows access to the very high x region not accessible so far at HERA.

Summary

- Success of HERA operation are shown in many precision measurements.
- Recents results from study of deep inelastic scattering
  - Electroweak unification is confirmed by neutral and charged current cross section at high Q^2.
  - Polarisation asymmetry in both NC and CC interaction.
  - Interference of γ to Z-boson was measured via structure function $xF_3^{\gamma Z}$.
  - CC data are compatible with the absent right handed currents
- Many results from HERA are still coming in the next few years including H1-ZEUS combinations.

Extra slides

Unpolarised reduced NC cross section



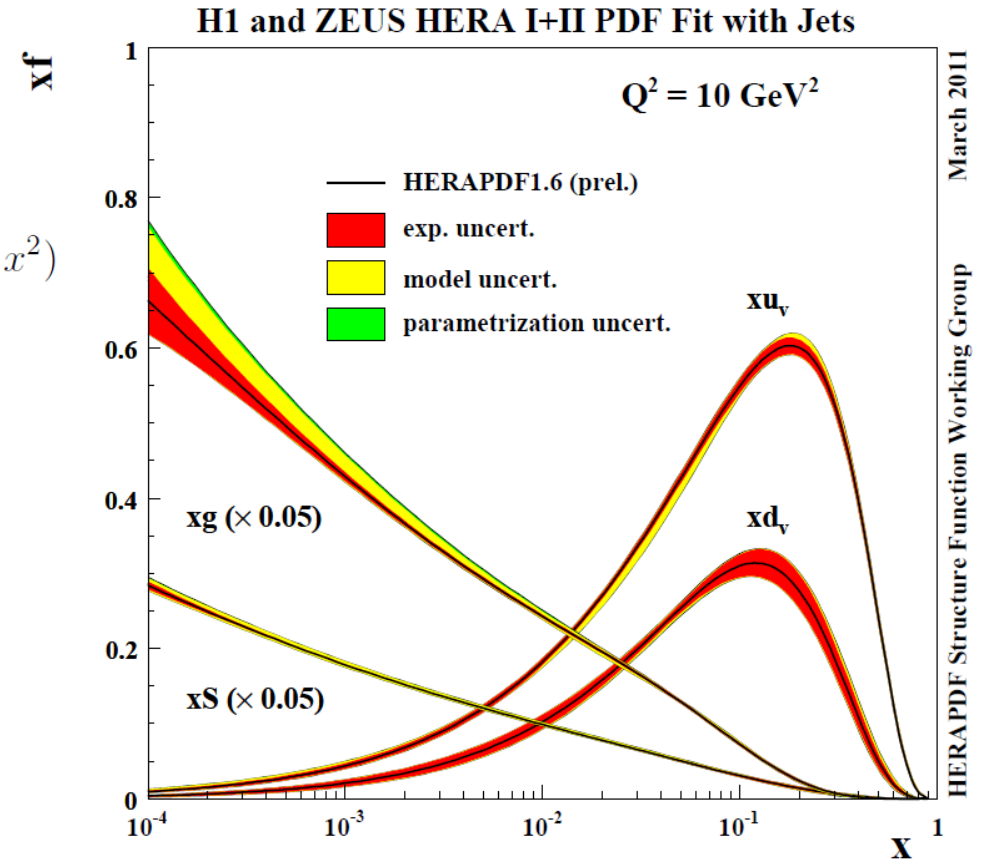
Separation of e^+p and e^-p cross sections at high Q^2 due to γZ interference term.

Visible difference in the e^+p and e^-p cross sections is well described by the SM predictions

HERAPDF 1.6 with jets

HERAPDF 1.6 parametrisation

$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g} \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1 + D_{u_v} x + E_{u_v} x^2) \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}} \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} \cdot (1-x)^{C_{\bar{U}}} \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} \cdot (1-x)^{C_{\bar{D}}}
\end{aligned}
$$



Parton density functions for HERAPDF1.6 as a function of x for $Q^2 = 10$ GeV^2. The central value (solid line) is shown together with the experimental, model and parametrisation uncertainties represented by the red, yellow and green shaded bands, respectively.