Electroweak physics at HERA

Rencontres de Moriond EW 2009,
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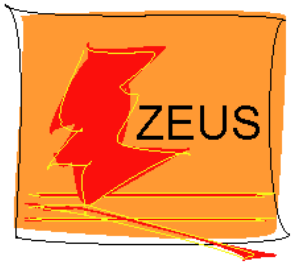


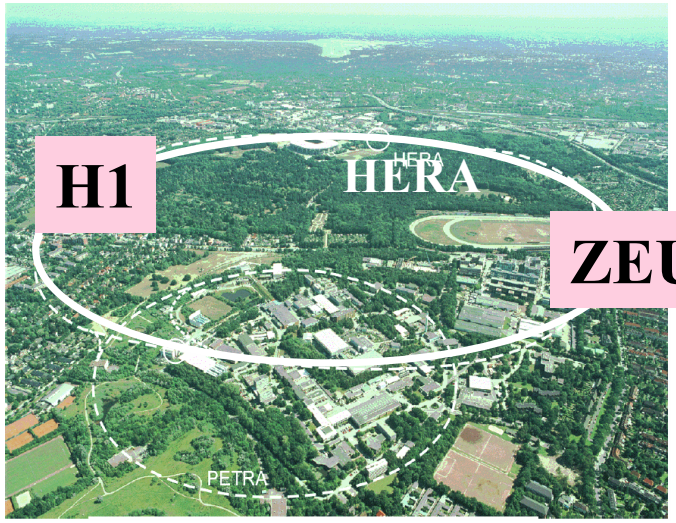
On behalf of the H1 and ZEUS collaborations

Contents

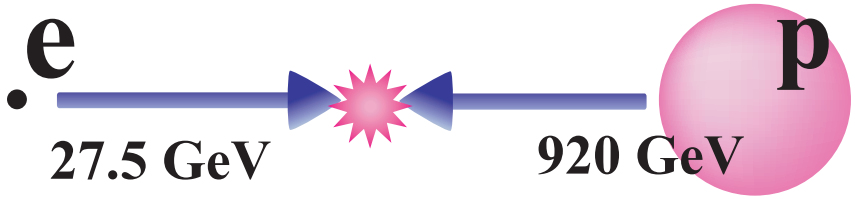
- DIS at HERA
- Neutral current
- Charged current
- Electroweak analysis
- Single W production

HERA

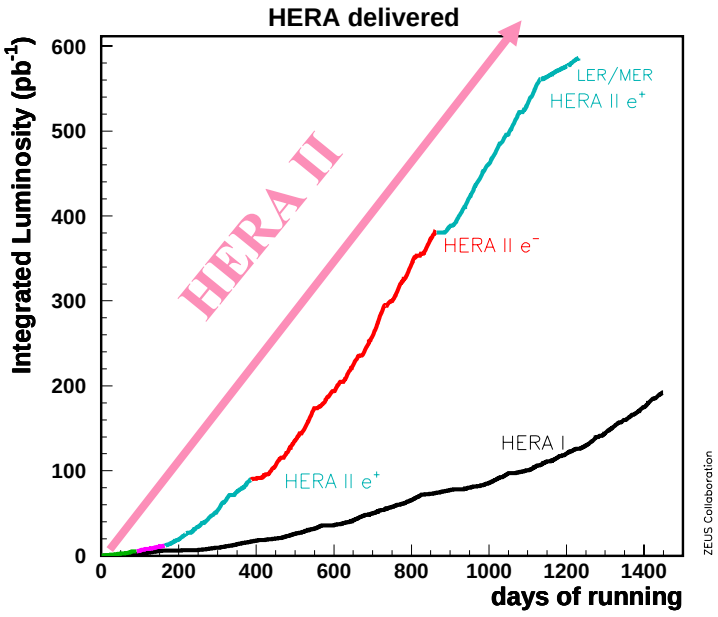
HERA is the unique electron proton collider in the world.



$$\sqrt{s} = 318 \ \ GeV$$



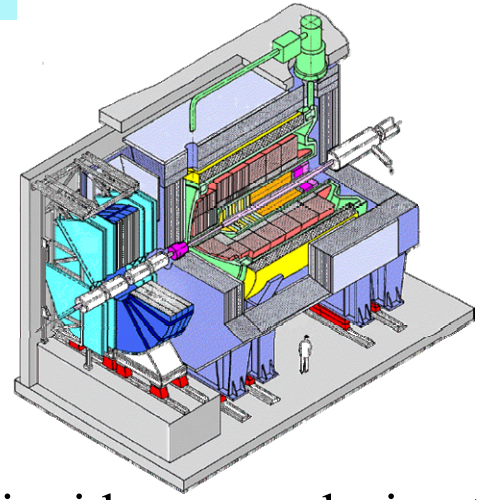
HERA's integrated luminosity



- At HERA II, after the luminosity upgrade,
  - Longitudinally polarized e^+/e^- beam was provided to H1 and ZEUS.
    - $P_e \sim 30 - 40\%$.
  - Ended operation on 30 June 07. About 0.5 fb^{-1} data were collected by each experiment.

H1 and ZEUS detectors

H1

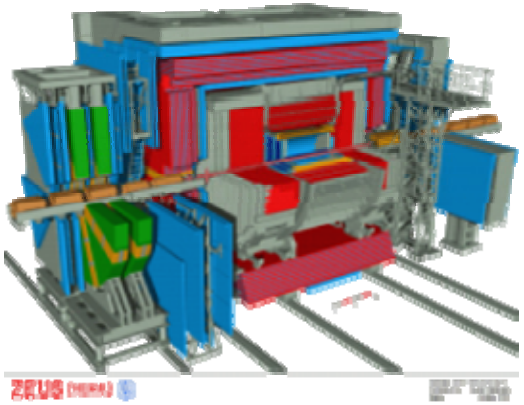


Liquid argon calorimeter.

$$\text{EM}: \frac{\sigma(E)}{E} = \frac{11\%}{\sqrt{E}} \oplus 1\%$$

$$\text{Had}: \frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} \oplus 2\%$$

ZEUS



Depleted uranium compensating calorimeter.

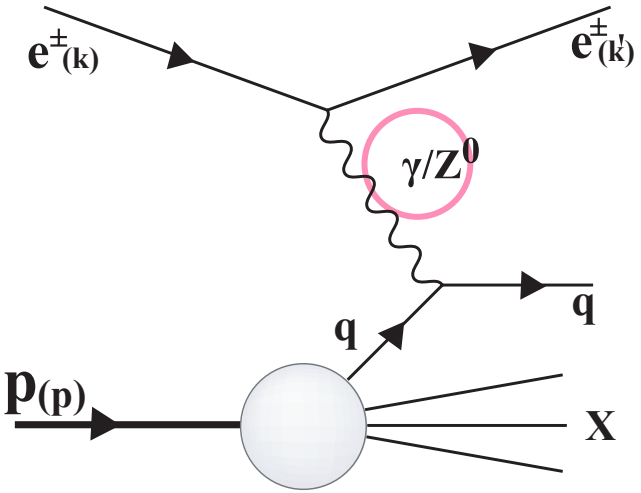
$$\text{EM}: \frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$$

$$\text{Had}: \frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$$

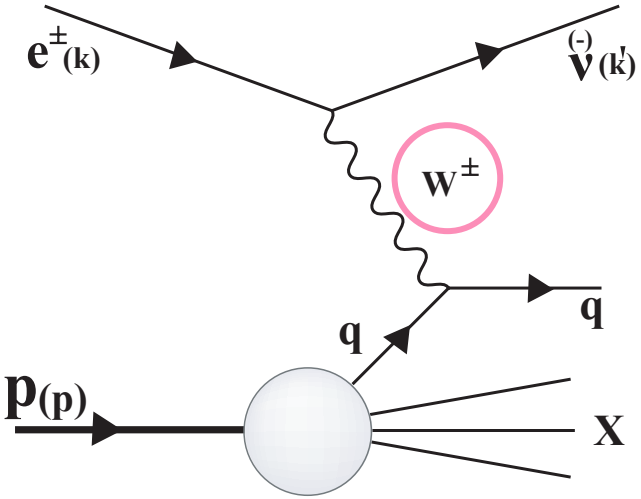
- General-purpose detectors for the particle detection, covering full solid angle.
  - Silicon vertex detector,
  - Central tracker,
  - Calorimeters,
  - Muon chambers.

Deep inelastic scattering at HERA

Neutral current $ep \to eX$



Charged current $ep \to \nu X$



◆Two processes, Neutral current (NC) and Charged current (NC),

–Neutral Current : Exchanges γ, Z^0 boson

–Charged Current : Exchanges **W** boson

Kinematic variables:

$Q^2 = -q^2 = -(k - k')^2$ Squared momentum transfer

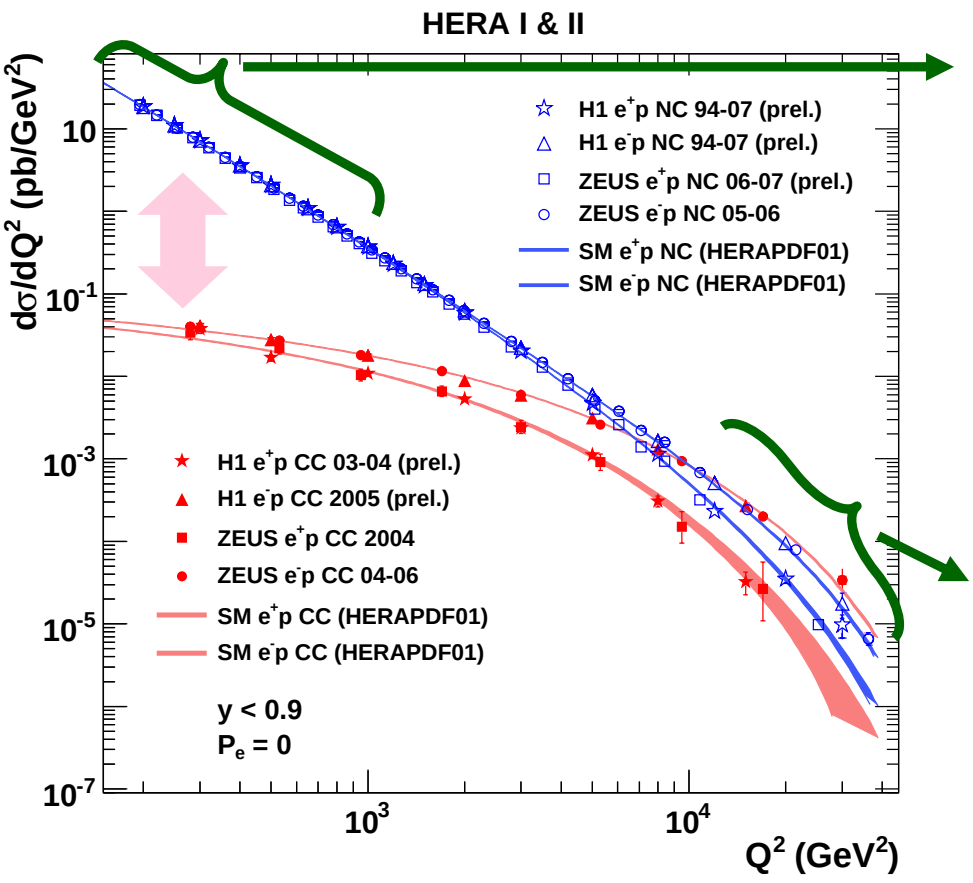
$Q^2 \sim 1/\lambda$, corresponds to spatial resolution at which the proton structure is probed and also it corresponds to the scale of the interaction between the electron and quark.

$x = \frac{Q^2}{2p \cdot q}$ Bjorken x,

Can be interpreted as the fraction of momentum carried by the struck parton.

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity

EW unification



◆NC cross section is much larger than CC cross section at lower Q^2, as NC is dominated by γ exchange.

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

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

◆However, as Q^2 approaches EW scale, i.e. $Q^2 \gtrsim M_W^2,\ M_Z^2,$ NC and CC cross sections become of the same order.

◆Unification of electromagnetic and weak forces are clearly visible.

Neutral Current cross section

NC cross section written with structure function

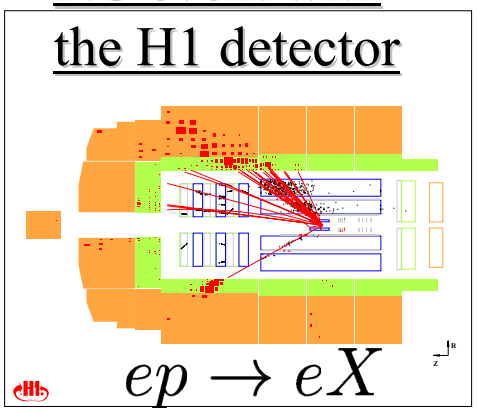
Parity violating structure function

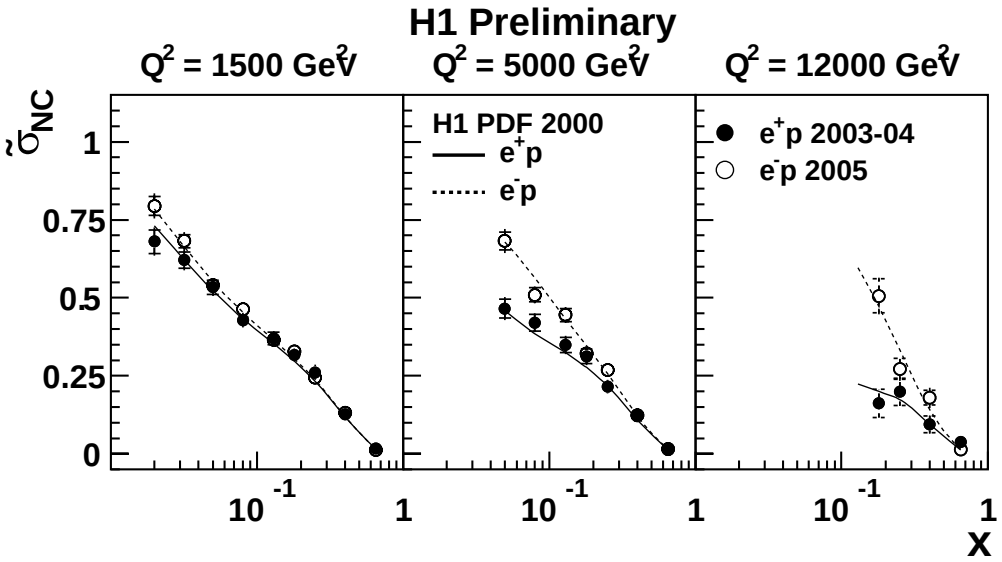
$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2)\right]$$

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

$$\tilde{\sigma}(e^{\pm}p) = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2}$$

NC event with the H1 detector





◆xF_3 term changes its sign with the incident positron and electron beam

◆ The e^-p cross section is larger than e^+p remarkably in high Q^2 region.

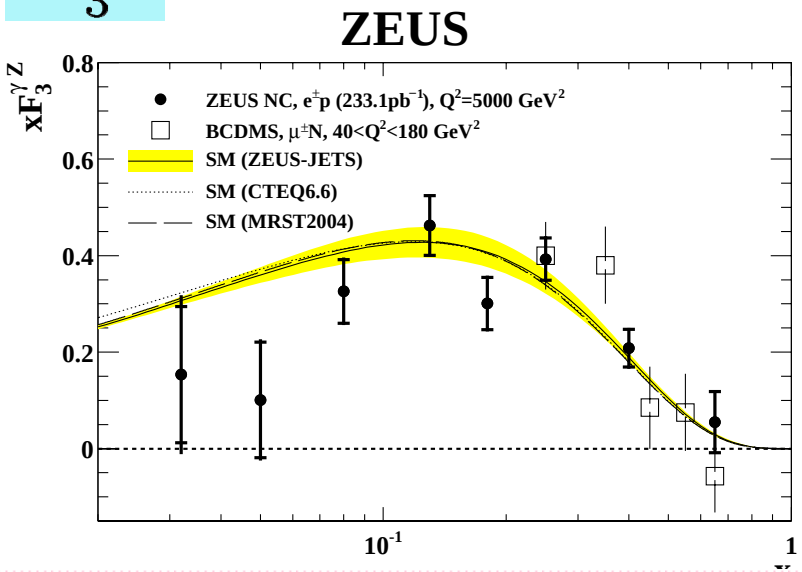
$xF_3(x,Q^2)$ determination

$$xF_3 \equiv -a_e \chi_z xF_3^{\gamma Z} + 2v_e a_e \chi_z^2 xF_3^Z \leftarrow \text{Contribution is very small.}$$

$$= \sum_i -a_e \chi_z \left[2e_i a_i\right] \times x(q_i - \bar{q}_i) \rightarrow \textbf{Valence quark PDFs}$$

$$, \chi_z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{\sin^2 2\theta_W}$$

$xF_3^{\gamma Z}$



To be published Eur.Phys C arXiv.0901.2385

Measurements at $1500<Q^2<30000$ GeV^2 were combined at $Q^2=5000$ GeV^2

◆A unique measurement of valence quark PDF is done at small x region

CC DIS with polarized lepton beam

CC cross section in Electroweak theory

Lepton beam polarization

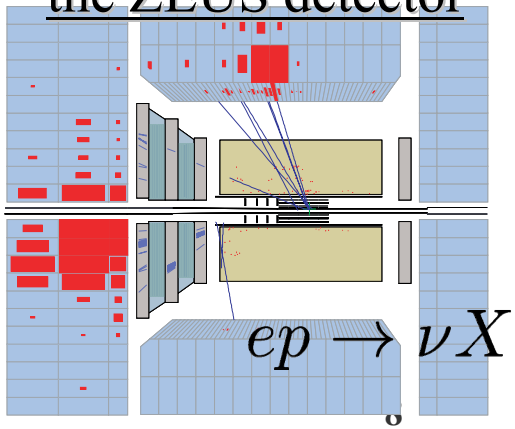
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

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

$$= \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \left[Y_+ F_2^{CC}(x,Q^2) \mp Y_- x F_3^{CC}(x,Q^2)\right]$$

◆ CC cross section depends linearly on polarization of incoming lepton as a consequence of chiral structure of weak interaction in the electroweak theory.

CC event with the ZEUS detector

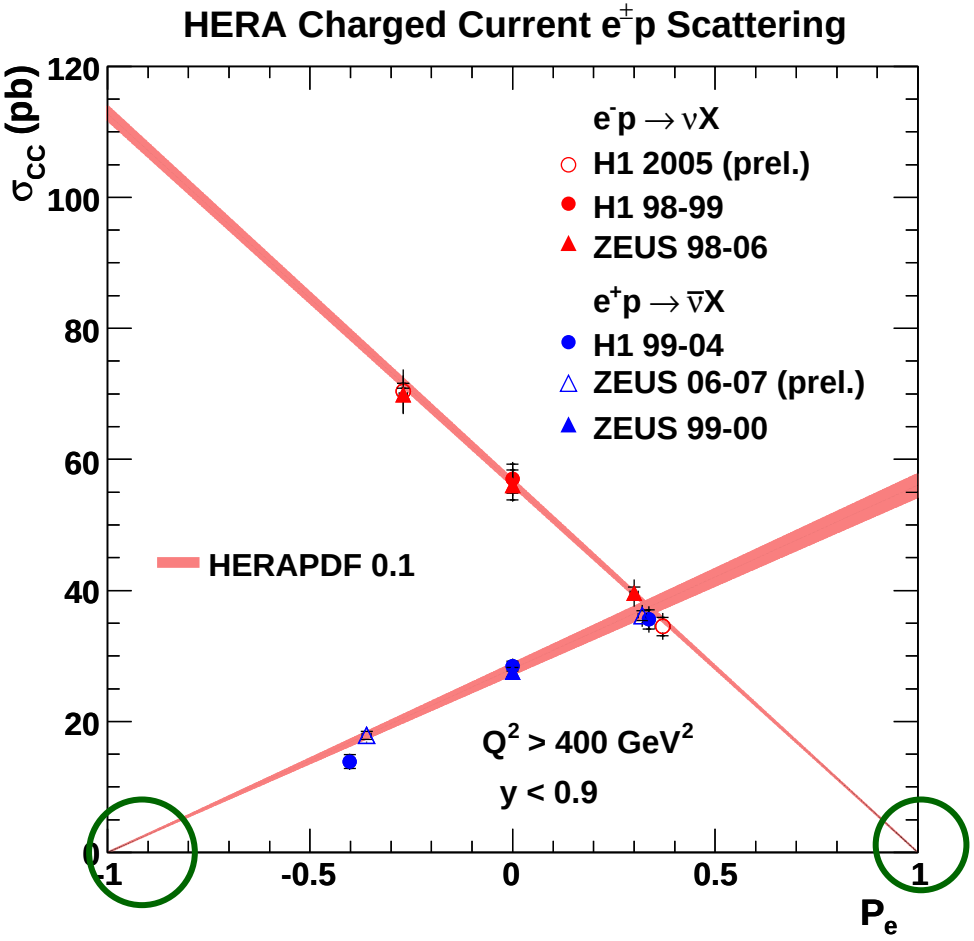


Structure function

Sensitive to each quark flavor

$$F_2,\ xF_3 = \begin{cases} 2x\left[u(x,Q^2) + c(x,Q^2) \pm \bar{d}(x,Q^2) \pm \bar{s}(x,Q^2)\right] & (e^- p) \\ 2x\left[d(x,Q^2) + s(x,Q^2) \pm \bar{u}(x,Q^2) \pm \bar{c}(x,Q^2)\right] & (e^+ p) \end{cases}$$

Polarized CC total cross section



◆ Data clearly shows a linear dependence of CC cross section on polarization, demonstrating the V-A chiral structure of week current.

◆No CC which couples to right handed chirality.

◆Lower limit on mass of W_R is,

$$W_R > 208.\ GeV$$

(H1 collaboration, Phys.Lett B634 173,2006)

NC DIS with polarized lepton beam

Parity is also violated in NC but through the γ-Z interference and Z exchange.

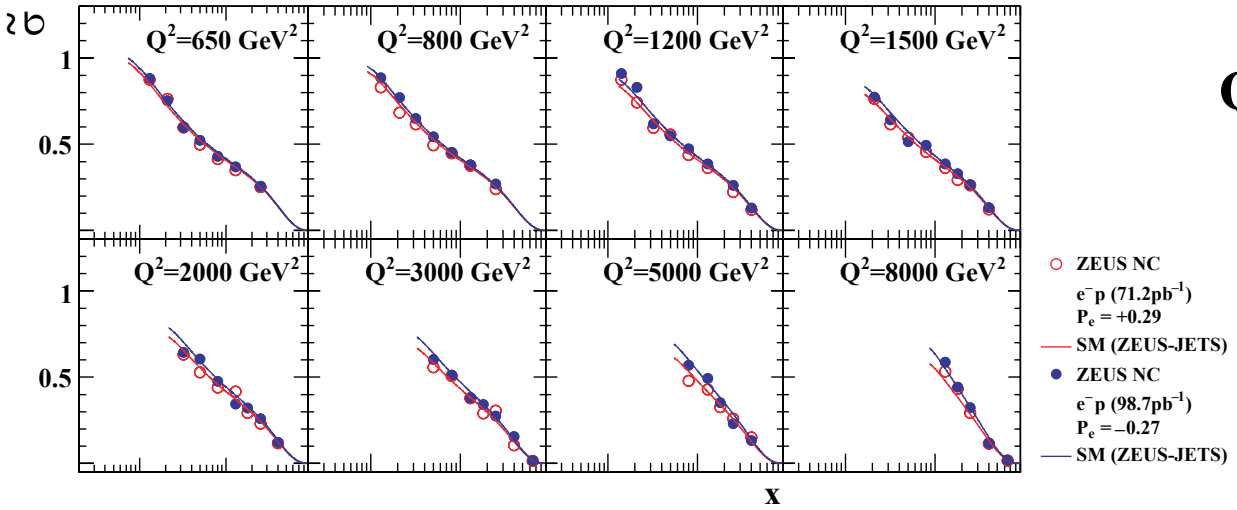
$$\frac{d\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2(x,Q^2) \mp Y_-xF_3(x,Q^2)\right]$$

$$\frac{d^2\sigma(e^-p)}{dxdQ^2}$$

$$F_2 \simeq \sum_i \left[e_i^2 + P_e(2\chi_Z a_e e_i v_i)\right] \times x(q_i + \bar{q}_i)$$

Quark-anti quark PDFs

ZEUS

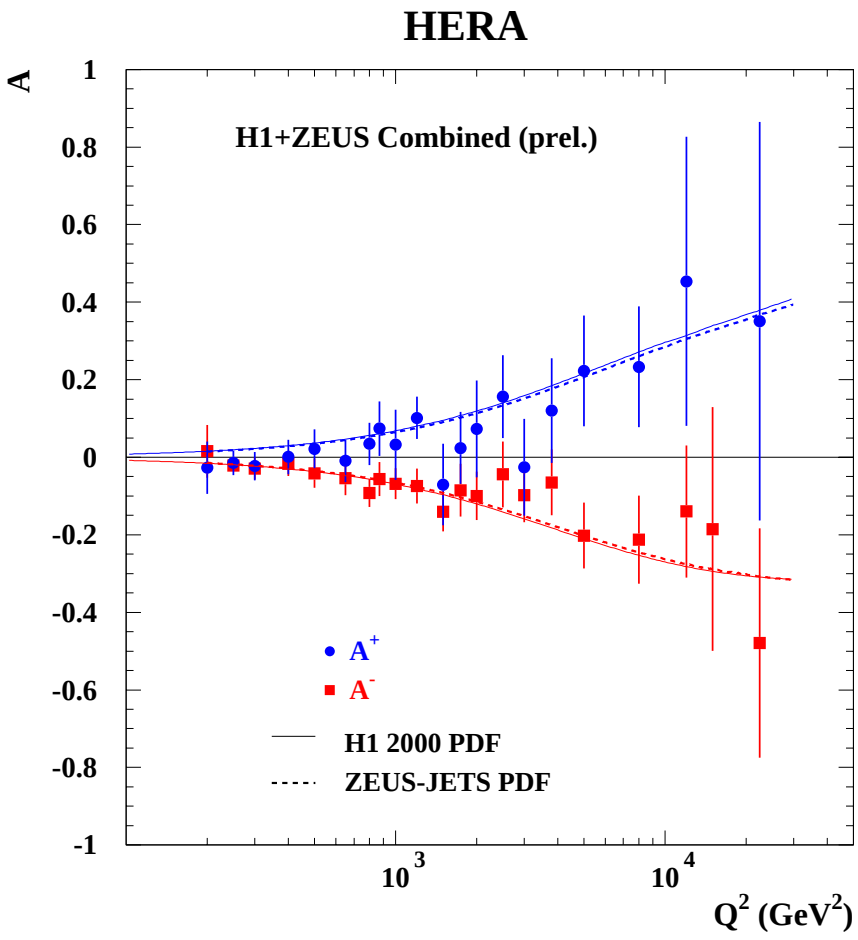


◆NC cross section become different for negative and positive P_e in high Q^2 region.

◆However this effect is small.

NC DIS with polarized lepton beam

Therefore the asymmetry is defined to show P_e dependence of NC cross section.



$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{e^{\pm}p}(P_R) - \sigma^{e^{\pm}p}(P_L)}{\sigma^{e^{\pm}p}(P_R) + \sigma^{e^{\pm}p}(P_L)}$$

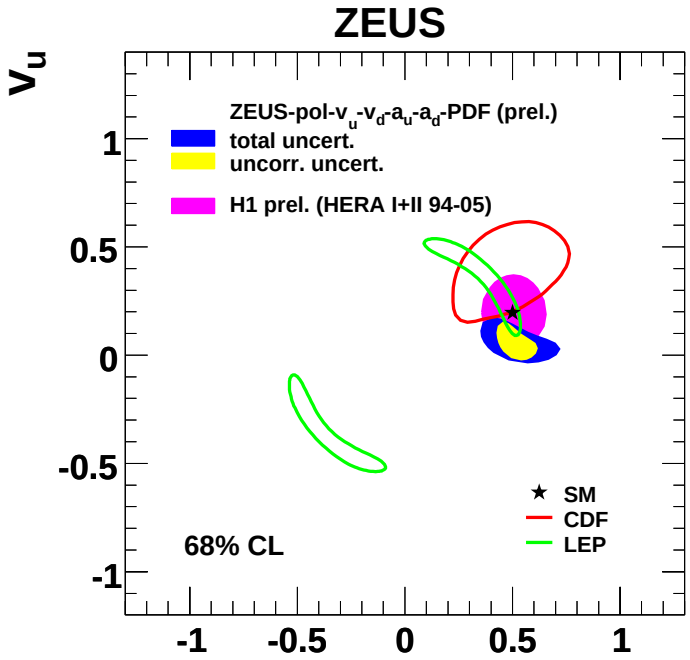
◆Asymmetry is a direct quantity to access the size of the parity violation,

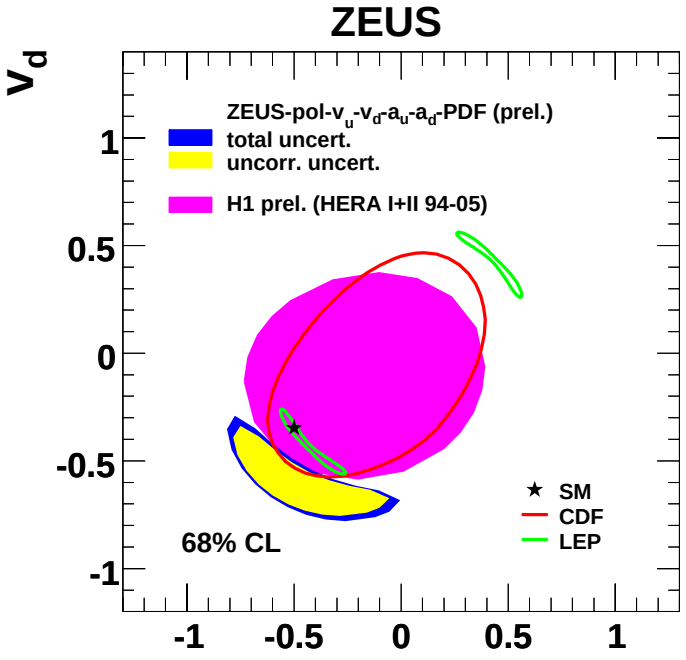
$$A^{\pm} \simeq \chi_Z a_e \frac{2\mathbf{v_i}}{e_i}$$

◆ Data shows the deviation of A from zero.

◆Thus, parity violation in ep NC DIS at very small distances is demonstrated at scales down to 10^{-18} m.

Determination of quark couplings to Z





From NC cross section,

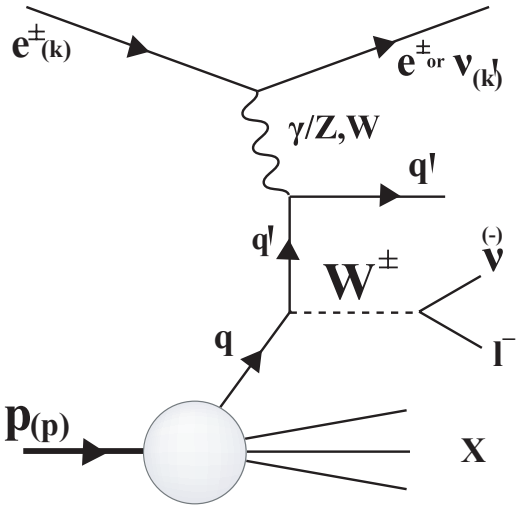
$$F_2 \sim \sum_i x(q_i + \bar{q}_i) \times (e_i^2 + 2P_e \chi_Z a_e e_i \mathbf{v_i})$$ Polarized data → vector coupling

$$xF_3 \sim \sum_i x(q_i - \bar{q}_i) \times (-2\chi_Z a_e e_i \mathbf{a_i})$$ Unpolarized data → axial-vector.

◆Electroweak parameters and PDFs can be determined simultaneously.

HERA gives the best determination of u-quark coupling to Z^0 boson.

Single W production



Event topology $ep \rightarrow e(\nu_e)\, W X$

$W \rightarrow l \nu_l$

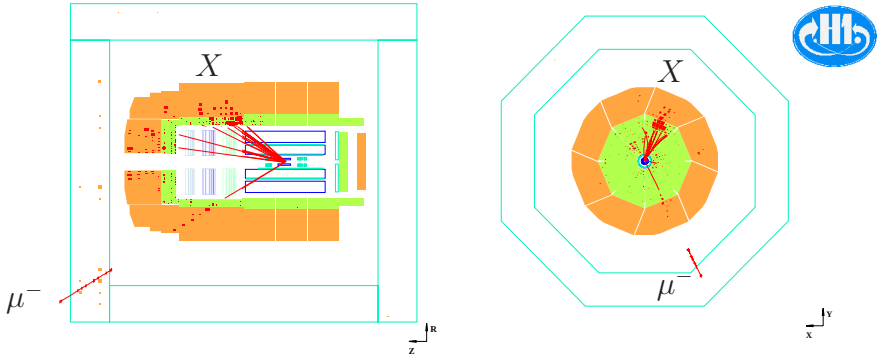
large missing Et

The single W production at HERA is interesting and predicted by SM with small cross section.

Dominant production is from the quark line.

An $ep \rightarrow \mu^- X$ events candidate detected by H1

arXiv: 0901.0488 [hep-ex]



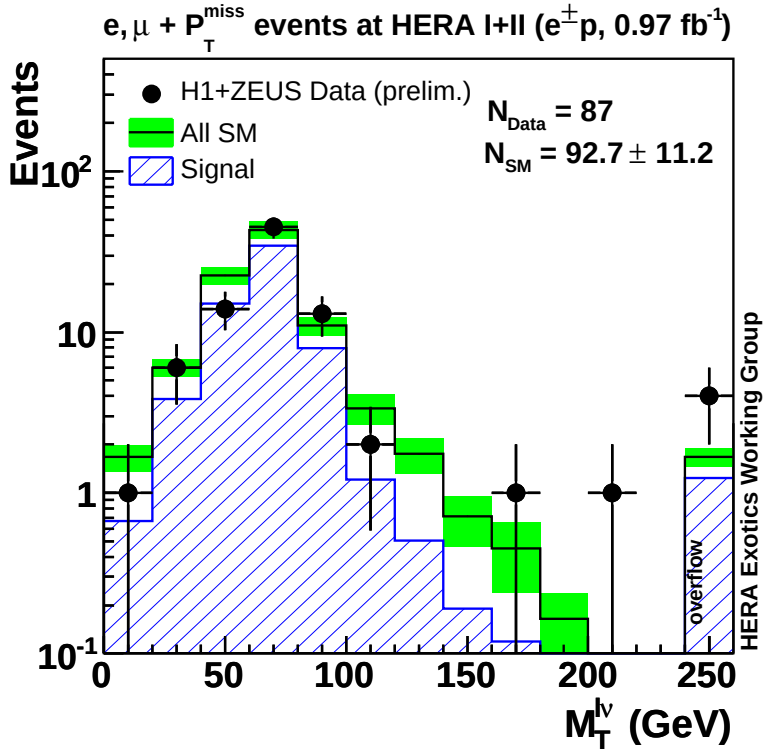
Run 473929 Event 107593

Experimental signatures are leptonic decays of W boson, that is, one high Pt lepton + a large missing Et.

- $P_{T,l} > 10GeV$
- Missing$E_T > 12GeV$
- $\Delta\phi_{l-X}$

Cross section for single W production

The transverse mass of lepton-neutrino



◆ The data are dominated by W production and contribution from other SM processes is low.

◆ Cross section for single W production is extracted.

$$\text{H1} \quad : \quad \sigma_W = 1.14 \pm 0.25(stat) \pm 0.14(syst) \text{ pb}, \quad \sigma_W^{SM} = 1.27 \pm 0.19 \text{ pb}$$

$$\text{ZEUS} : \quad \sigma_W = 0.89^{+0.25}_{-0.22}(stat) \pm 0.10(syst) \text{ pb}, \quad \sigma_W^{SM} = 1.2 \pm 0.18 \text{ pb}$$

●Combined H1 and ZEUS cross section measurement analysis isongoing !!

Summary

- Electroweak interactions are tested by measurements of DIS at HERA precisely.

  - Electroweak unification
  - Observation of Parity violation
  - Quark couplings to Z boson are measured.
  - Cross section of the single W boson production.

- These results are well described by Standard Model.