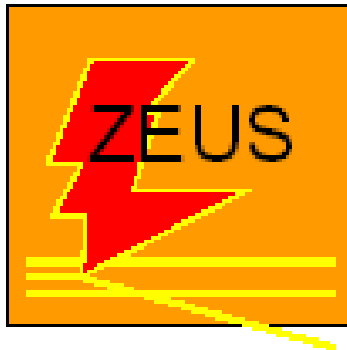


# **ZEUS EW Fit and Measurement of the CC Cross Section**

**Kunihiro Nagano (KEK, Japan)**

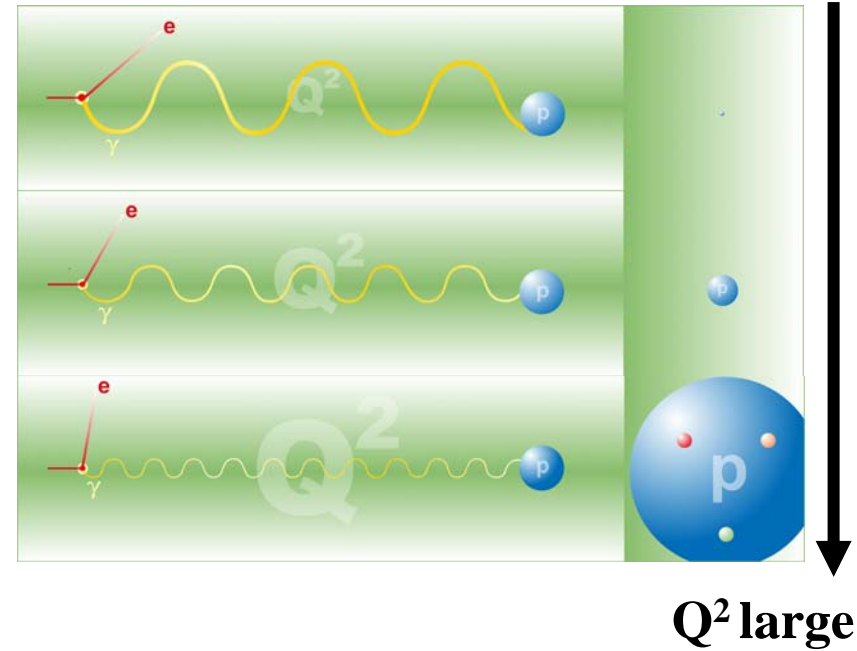


**On behalf of  
the ZEUS collaboration**

**XVI International Workshop on Deep-Inelastic Scattering  
and Related Subjects (DIS08)**

**7-11 April 2008, University College London, UK**

# HERA : the world's only ep collider



$Q^2$  corresponds to:

the scale (wavelength) to probe the proton  $\lambda \sim 1/\sqrt{Q^2}$

the scale of the elementary interaction between e and quark

$$Q_{MAX}^2 = s \quad \text{At HERA: } E_e=27.5 \text{ GeV}, E_p=920 \text{ GeV} \quad Q_{MAX}^2 \approx 10^5 \text{ GeV}^2$$

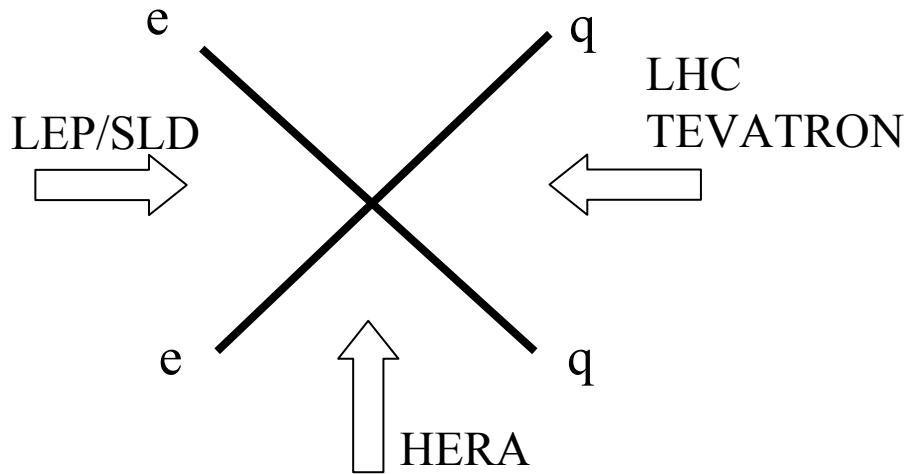
$$\sqrt{s} = 320 \text{ GeV} \quad \lambda_{MIN} \sim 1/1000 r_{proton}$$

**$\nu$ -DIS: Weak @  $Q^2 \lesssim \text{O}(100) \text{ GeV}^2$**

**HERA: Electro-Weak @  $Q^2 \approx \text{EW scale}$**

(corresponds to  $\sim 50 \text{ TeV}$   
incident beam on fixed target)

# Colliders at EW scale



## ► Tevatron / LHC

- Search for new symmetries and particles.
- Proton structures are “necessary inputs”

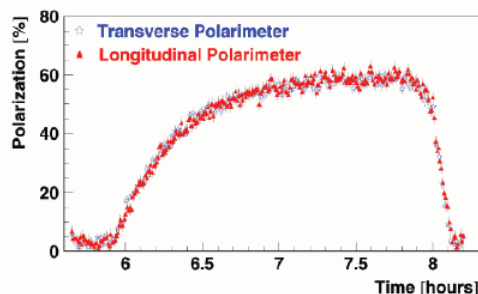
## ► HERA

- Probe proton structure by t-channel exchange of gauge bosons
  - At low  $Q^2$ : mainly by  $\gamma$
  - At high  $Q^2$ :  $\gamma/Z$  (NC) and  $W$  (CC)
- Investigate electron-quark elementary processes based on knowledge of proton structure (at low  $Q^2$ )

$$\sigma(ep) \propto \sum_{EW \otimes QCD} \sigma(eq) \otimes (pdf) \quad \text{A “SM” study!}$$

# HERA Running

- ▶ HERA-I : Until year 2000
  - Unpolarized  $e^+$  and  $e^-$  beams
- ▶ HERA-II : from year 2002 to Mar/2007
  - High luminosity to allow more statistical sensitivity for large  $Q^2$
  - Longitudinally polarized  $e^+$  and  $e^-$  beams to allow direct sensitivity to EW

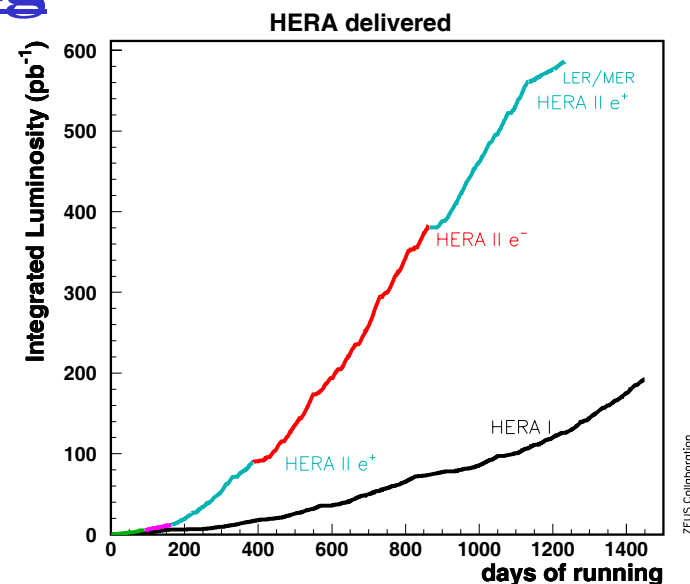


- Transverse Pol due to Sokolov-Ternov effects
- Change transverse pol. to longitudinal pol.

- ▶ Low Energy Run : Mar – June 2007

- A special run with low proton beam energy (460, 575 GeV) to measure “ $F_L$ ” structure function → See this afternoon session

**Year 2008: HERA results using full statistics etc are building up while LHC starts operation**

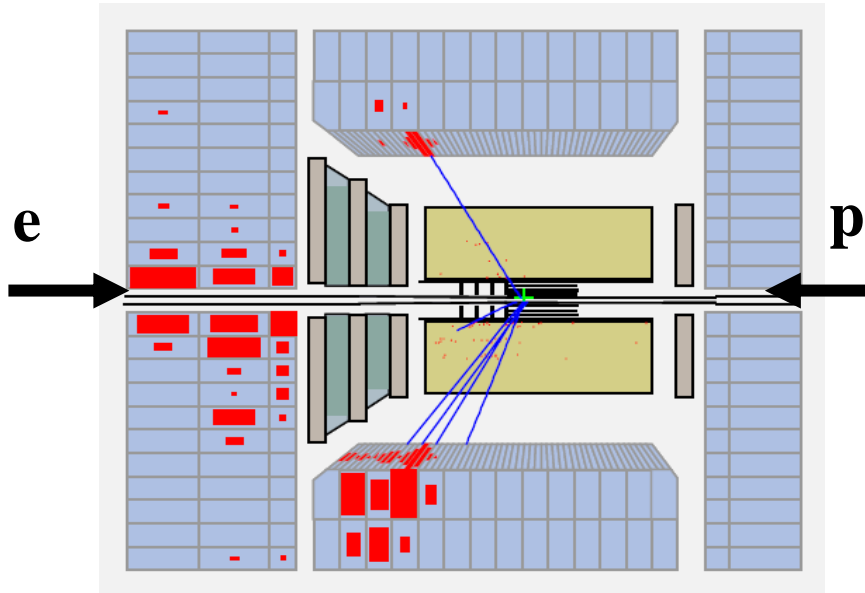


	HERA-I	HERA-II
$e^-$	$\sim 20 \text{ pb}^{-1}$	$\sim 200 \text{ pb}^{-1}$
$e^+$	$\sim 100 \text{ pb}^{-1}$	$\sim 200 \text{ pb}^{-1}$

**1  $\text{fb}^{-1}$  collected by H1+ZEUS**

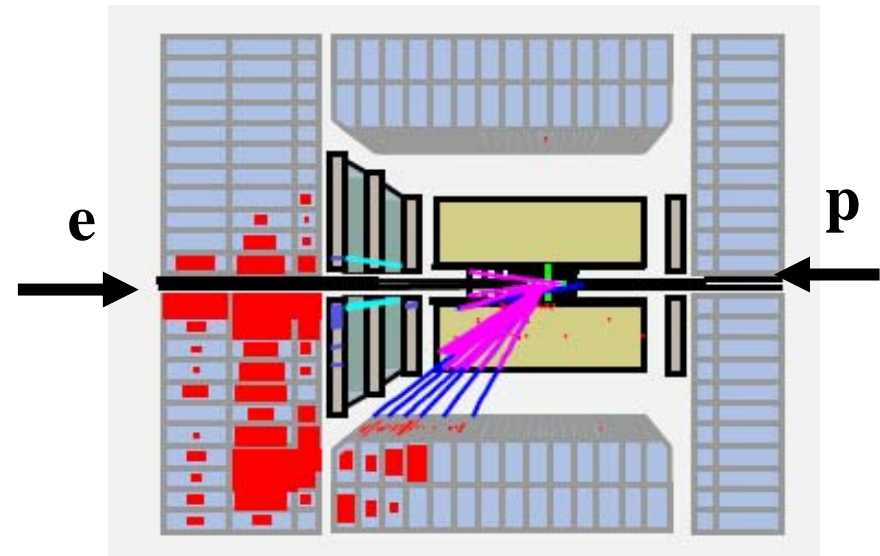
# Measuring DIS Events at HERA

**NC Event**



- Selection: presence of high energy scattered electron  
 $E'_e > 10 \text{ GeV}$
- Kinematics well reconstructed using electrons and/or hadrons

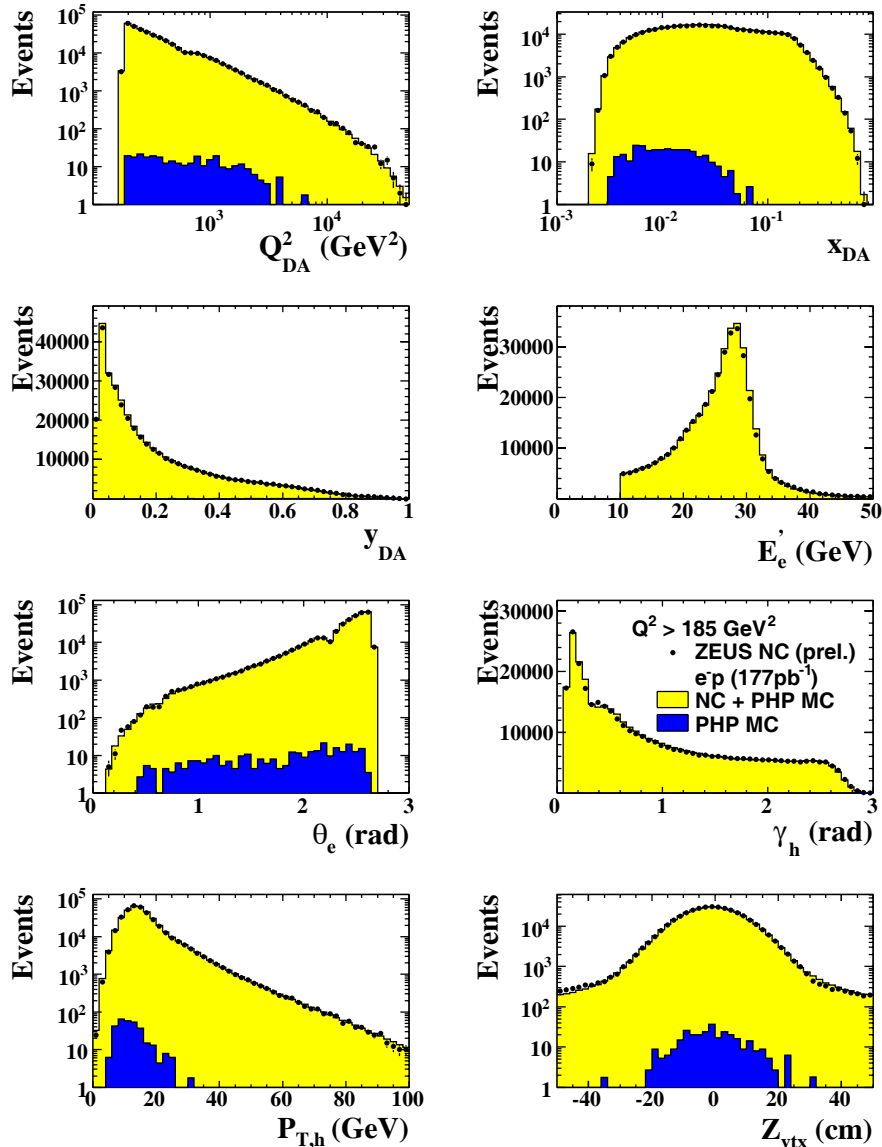
**CC Event**



- Selection: presence of large missing transverse momentum:  $P_{T, \text{miss}}$   
 $P_{T, \text{miss}} > 12 \text{ GeV}$
- Kinematics reconstructed using hadrons only

# NC Events

## ZEUS



- Data set: 2005-2006 e-p  
Luminosity: 177 pb<sup>-1</sup>  
(Updated @ DIS07)

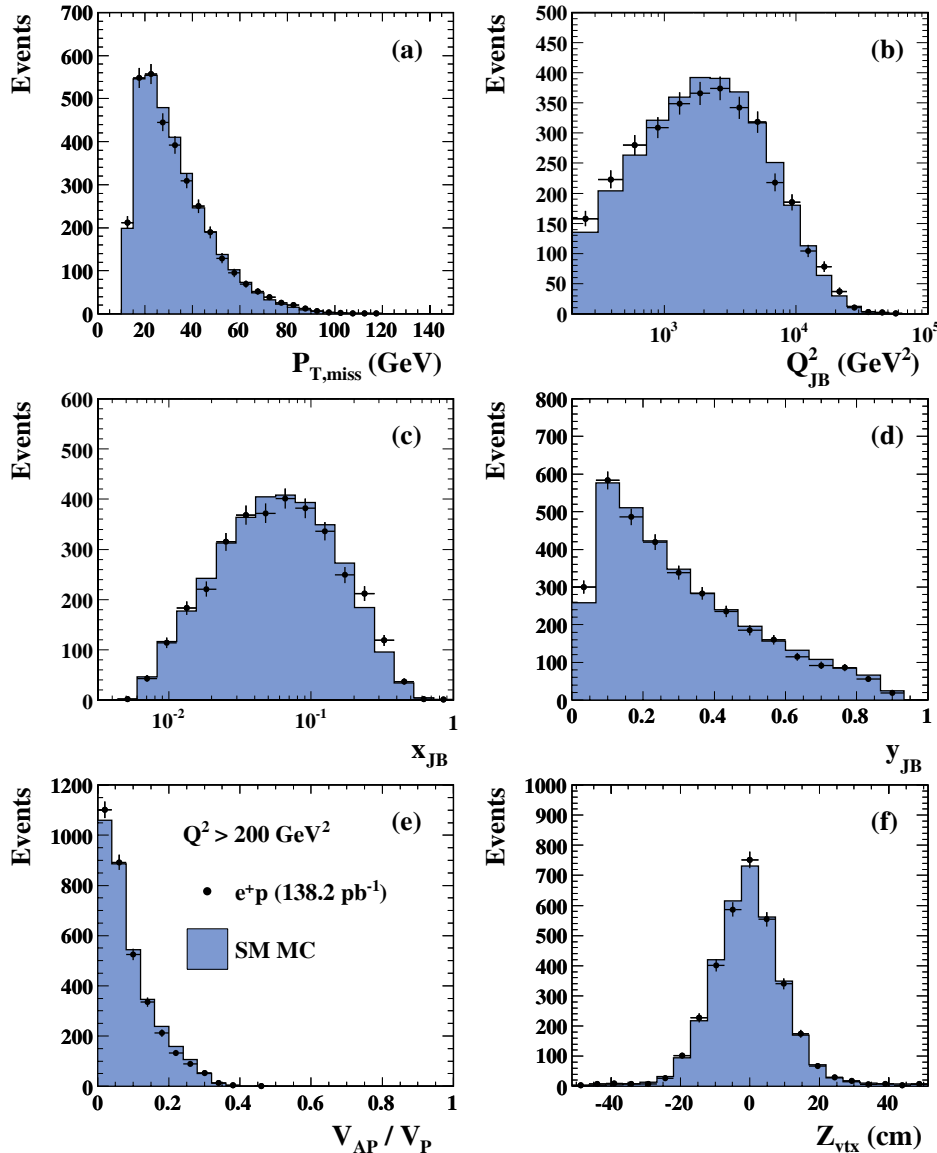
- Not only electron variables e.g. energy ( $E_e$ ), scattering angle ( $\theta_e$ ), but also angle of hadron system ( $\gamma_h$ ), transverse momentum of hadron system ( $P_{T,h}$ ) is confirmed to be understood in NC events

Which is important for:

➔ CC where hadronic energy measurement is crucial

# CC Events

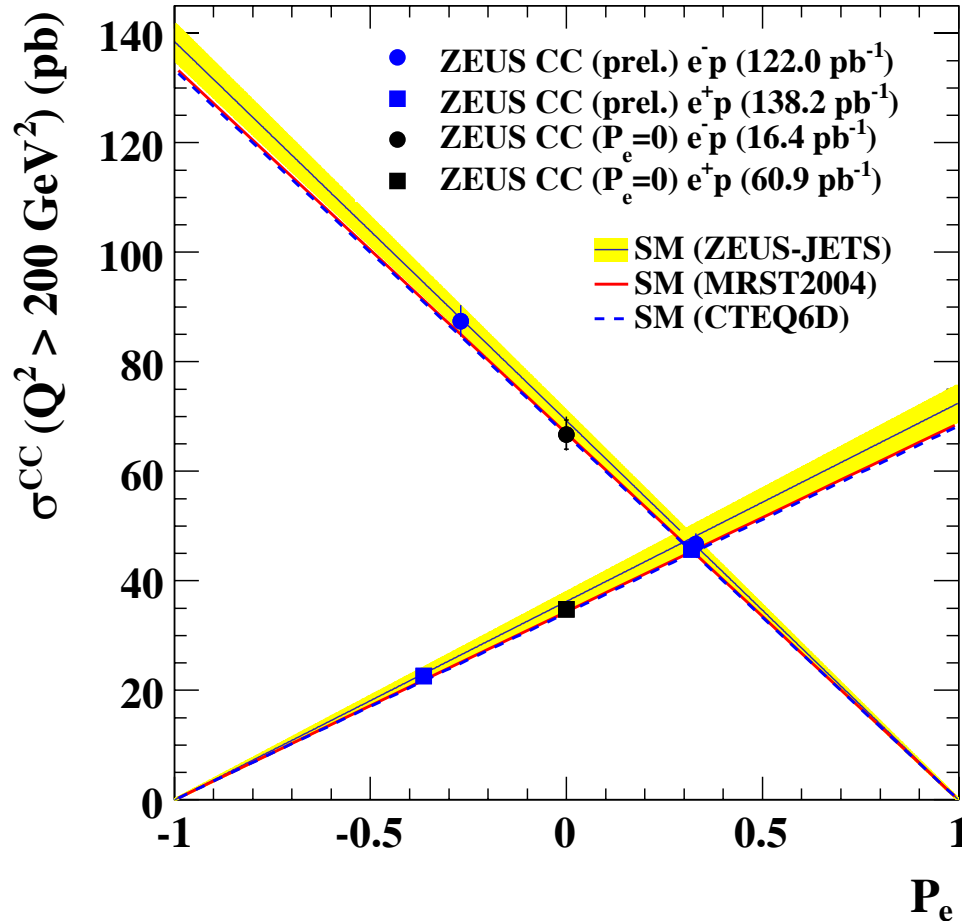
## ZEUS



- Data set: 2006-2007  $e^+p$   
Luminosity: 138  $\text{pb}^{-1}$   
**(New result @ last summer)**
  - $P_{T,miss}$  and longitudinal hadronic energy ( $E-P_Z$ ) etc. are well described.
  - Shown are for data sets of both polarizations
- ➔ Cross sections are measured separately for positively and negatively polarized beams (see next)

# CC cross section vs. polarization

## ZEUS



## ● “Pure” Weak

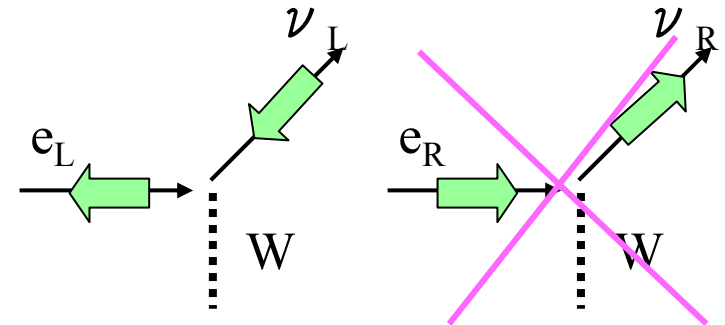
→ Chiral structure of weak int. is directly visible as a function of Polarization

## ● Weak = “100% parity violated”

→ Zero cross section

@ Pol=1 (-1) for  $e^-$  ( $e^+$ )

→  $\sigma(\text{Pol}) = (1 \pm \text{Pol}) \sigma(\text{Unpol})$



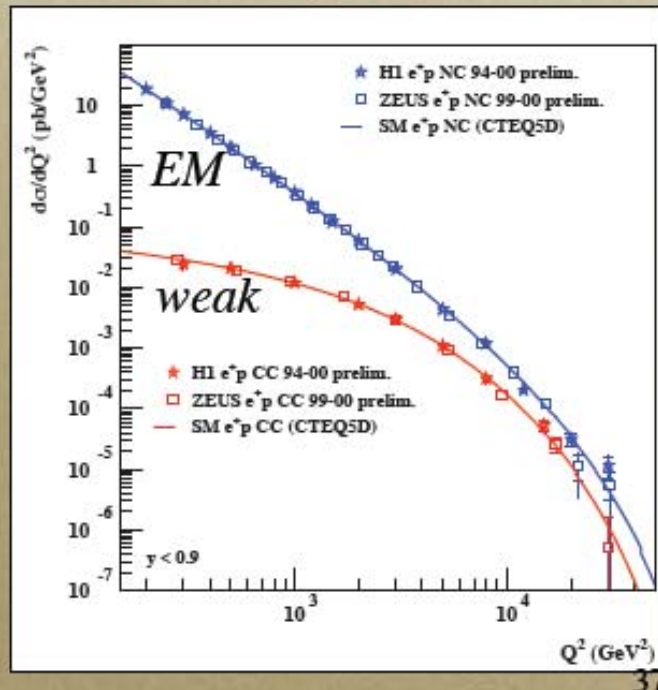
- Consistent with SM prediction of:  $\sigma(\text{RH CC})=0$   
(Error band from PDF uncertainty)



# EW unification: a theorist's view

We are just about to achieve  
another layer of unification

*HERA ep collider*



○ Unification of  
electromagnetic and  
weak forces

⇒ *electroweak theory*

○ Long-term goal since  
'60s

○ *We are getting there!*

○ The main missing link:  
*Higgs boson*

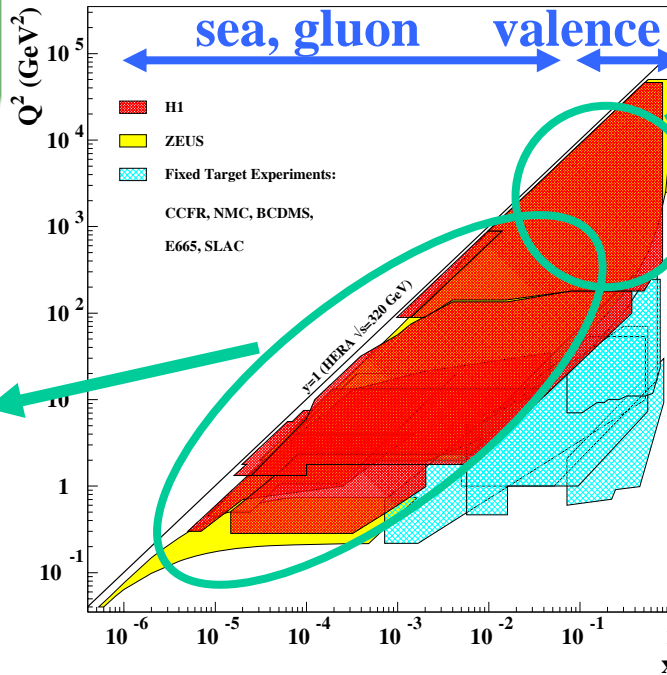
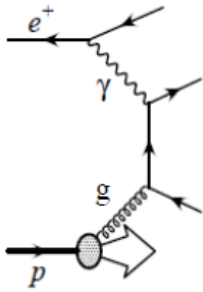
H.Murayama @ KEK TC 2007

- NC and CC cross sections become similar at EW scale  
→ “EW unification” (Remaining differences are mainly due to PDFs)

# EW+QCD fit

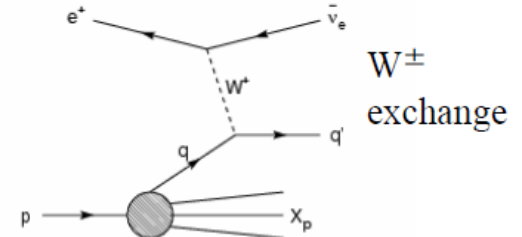
## ♦ Jet process

Directly sensitive to **gluon density**



S.Shimizu @ APS-DPDF06 + JPS06

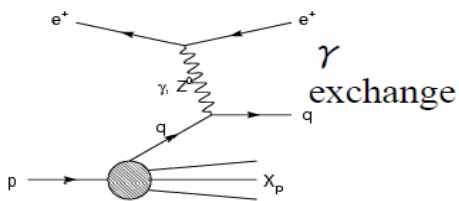
## ♦ Charged current DIS (CC)



Charge selective interaction

$e^- : u \text{ quark}$   $e^+ : d \text{ quark}$

## ♦ Neutral current DIS (NC) At low $Q^2$

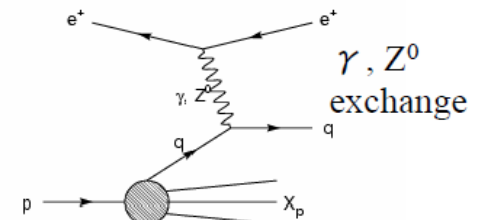


$$\gamma \rightarrow F_2 \propto \sum x(q + \bar{q})$$

**Sea + valence quark**

$$\frac{\partial F_2}{\partial \ln Q^2} \propto xg \quad \text{gluon}$$

## ♦ Neutral current DIS (NC) At high $Q^2$



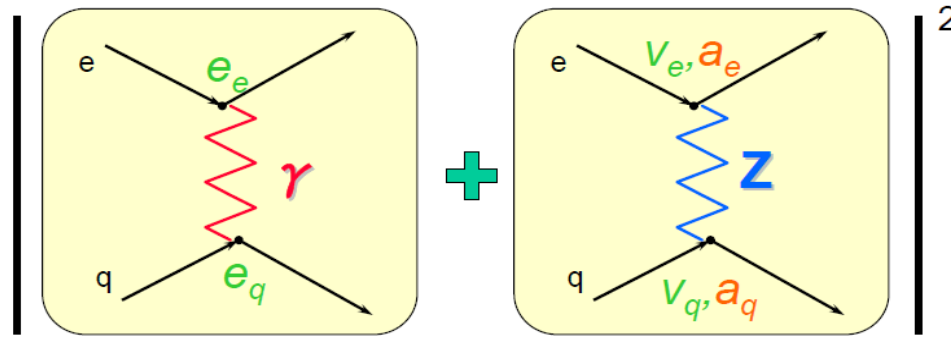
$Z^0$  introduces parity violation.

$$\rightarrow xF_3 \propto \sum x(q - \bar{q})$$

**valence quark**

- Rich variety of ZEUS data sensitive to various PDFs
  - Advantage: Eliminates uncertainty in heavy target correction ( $\nu \text{ Fe}$ ,  $\nu \text{ D}$ )
- A fit to data from a single experiment
  - Advantage: Handling of systematic errors is straightforward
- A fit to determine both PDF and EW parameters
  - Advantage: correlation automatically taken into account

# Light quark couplings to Z



$$\frac{d^2\sigma_{e^+p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[ \{1 + (1 - y)^2\} F_2 \mp \{1 - (1 - y)^2\} x F_3 \right]$$

$$\begin{aligned} \tilde{F}_2 &= F_2^\gamma - (v_e \pm P_e a_e) \chi_Z F_2^{\gamma Z} + ((v_e^2 + a_e^2) \pm P_e 2v_e a_e) \chi_Z^2 F_2^Z \\ \tilde{F}_3 &= - (a_e \pm P_e v_e) \chi_Z F_3^{\gamma Z} + ((2v_e a_e \pm P_e (v_e^2 + a_e^2)) \chi_Z^2 F_3^Z \end{aligned}$$

## ● EW structure functions in QPM

Unpol:  $\sigma(e^+) - \sigma(e^-) \rightarrow F_3^{\gamma Z}$   
 Pol:  $\sigma(P_e \rightarrow) - \sigma(P_e \leftarrow) \rightarrow F_2^{\gamma Z}$   
 $\Downarrow$   
 Unpol:  $\sigma(e^+) - \sigma(e^-) \rightarrow a_f$   
 Pol:  $\sigma(P_e \rightarrow) - \sigma(P_e \leftarrow) \rightarrow v_f$

$$\begin{aligned} F_2^{\gamma Z} &= 2e_f v_f \Sigma_i x [q_f + \overline{q_f}] \\ F_2^Z &= (v_f^2 + a_f^2) \Sigma_i x [q_f + \overline{q_f}] \\ F_3^{\gamma Z} &= 2e_f a_f \Sigma_i x [q_f - \overline{q_f}] \\ F_3^Z &= 2v_f a_f \Sigma_i x [q_f - \overline{q_f}] \end{aligned}$$

# ZEUS EW+QCD Analysis

- ZEUS first EW+QCD fit including HERA-II → Shown @ DIS06

- Updates: ① HERA-II NC  $e^- p$  :  $121 \text{ pb}^{-1} \rightarrow 177 \text{ pb}^{-1}$

- ② q-Z couplings: 2 parameter determination → 4 parameters

→ “ZEUS-JETS” QCD-fit with q-Z couplings free

- DGLAP evolution @ NLO

- Heavy quarks treated in variable flavor-number scheme of Thorne, Roberts

- PDFs parameterization

  - $Q_0^2 = 7 \text{ GeV}^2$

  - Form:  $xf(x) = Ax^b(1-x)^c(1+\underline{dx})$

  - $xu_V, xd_V, xS, xg, x\Delta (=x\bar{d} - xu)$

- Constraints

  - Momentum and number sum rules

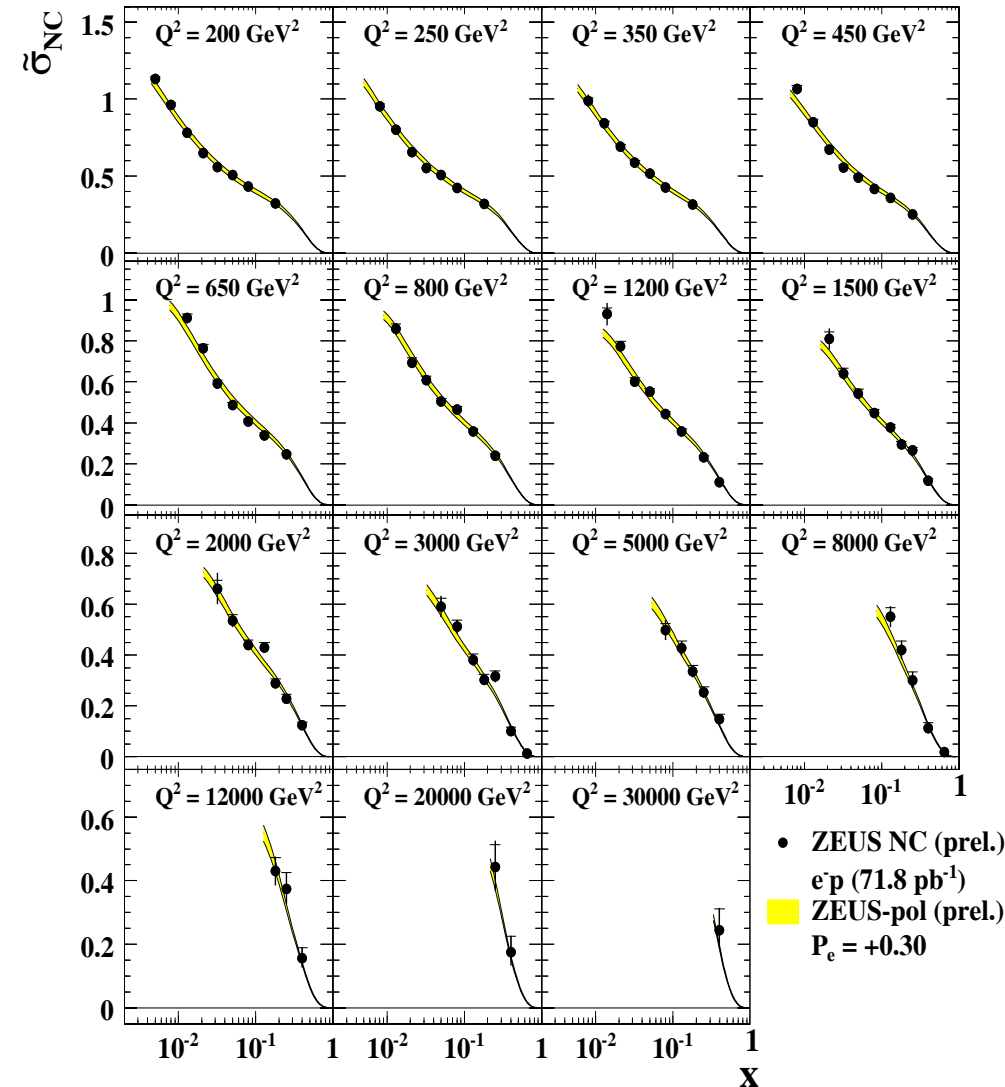
  - Equal behavior of  $u_V$  and  $d_V$  at low  $x$ :  $b(u_V) = b(d_V)$

  - $\Delta$  : set as consistent with Gottfried sum rule and Drell Yan (CCFR)

→ 11 PDF parameters + 4 EW parameters

# Data Set

## ZEUS



## ● HERA I

- NC low  $Q^2$ : 96/97
- NC high  $Q^2$ :  $e^+$  99/00  
 $e^-$  98/99
- CC high  $Q^2$ :  $e^+$  99/00  
 $e^-$  98/99
- PHP di-jets
- DIS inclusive jet

## ● HERA-II

- Pol. NC high  $Q^2$ :  $e^-$  05/06
- Pol. CC high  $Q^2$ :  $e^-$  05/06

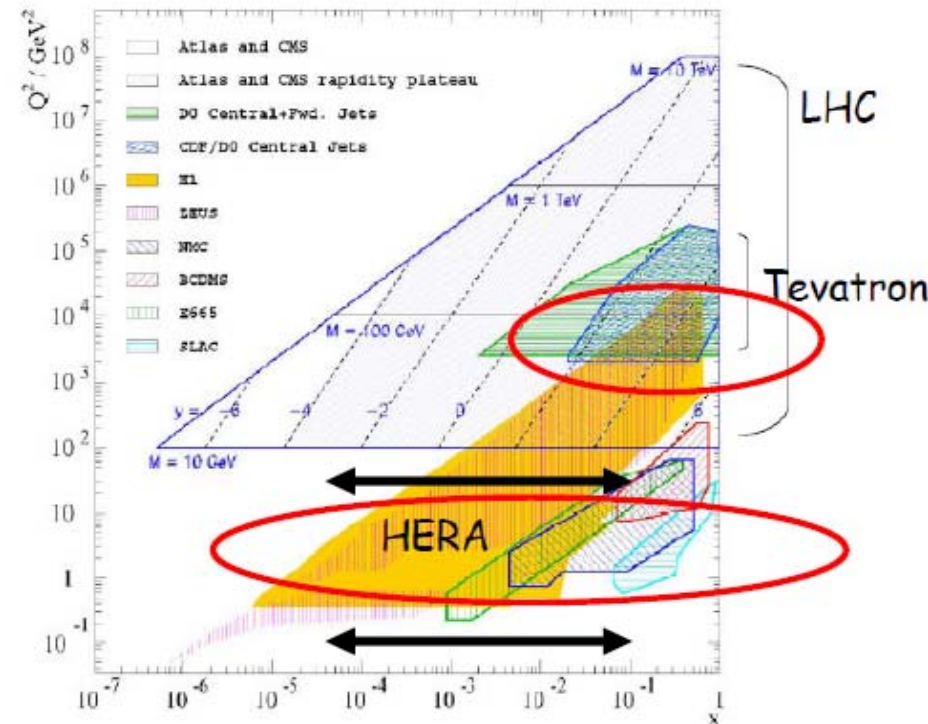
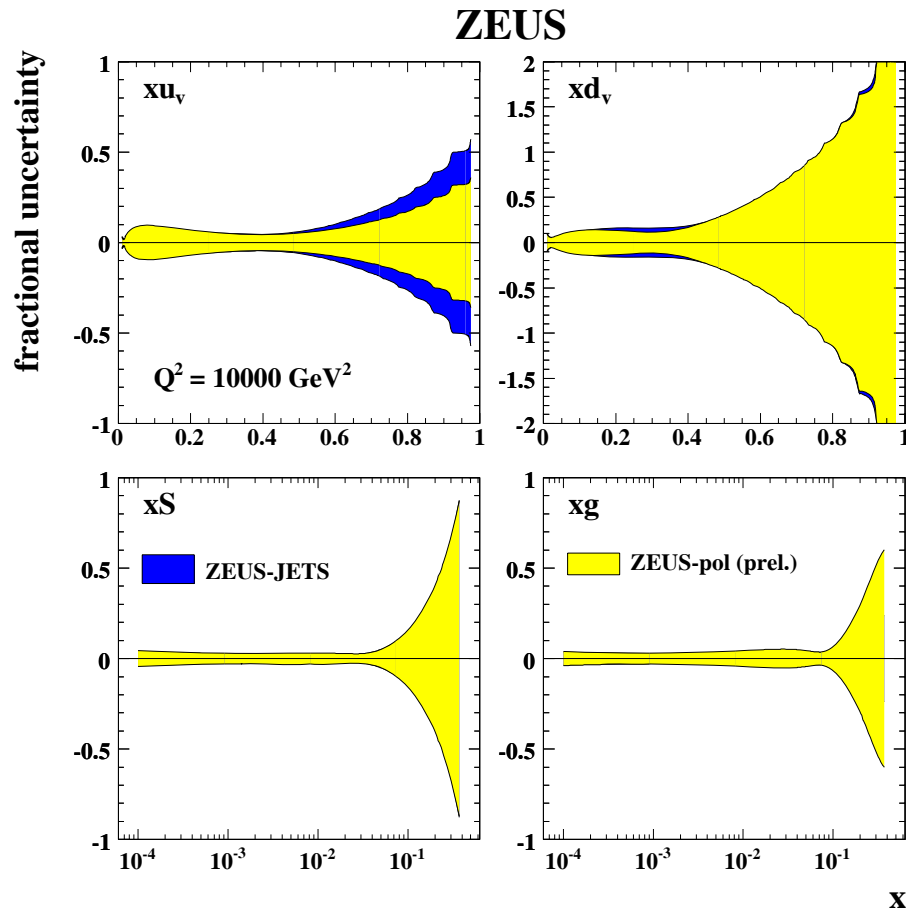
➔ Fit gives a nice description to all of these wide variety of data sets

➔ HERA-II data more to come

# Extracted PDFs

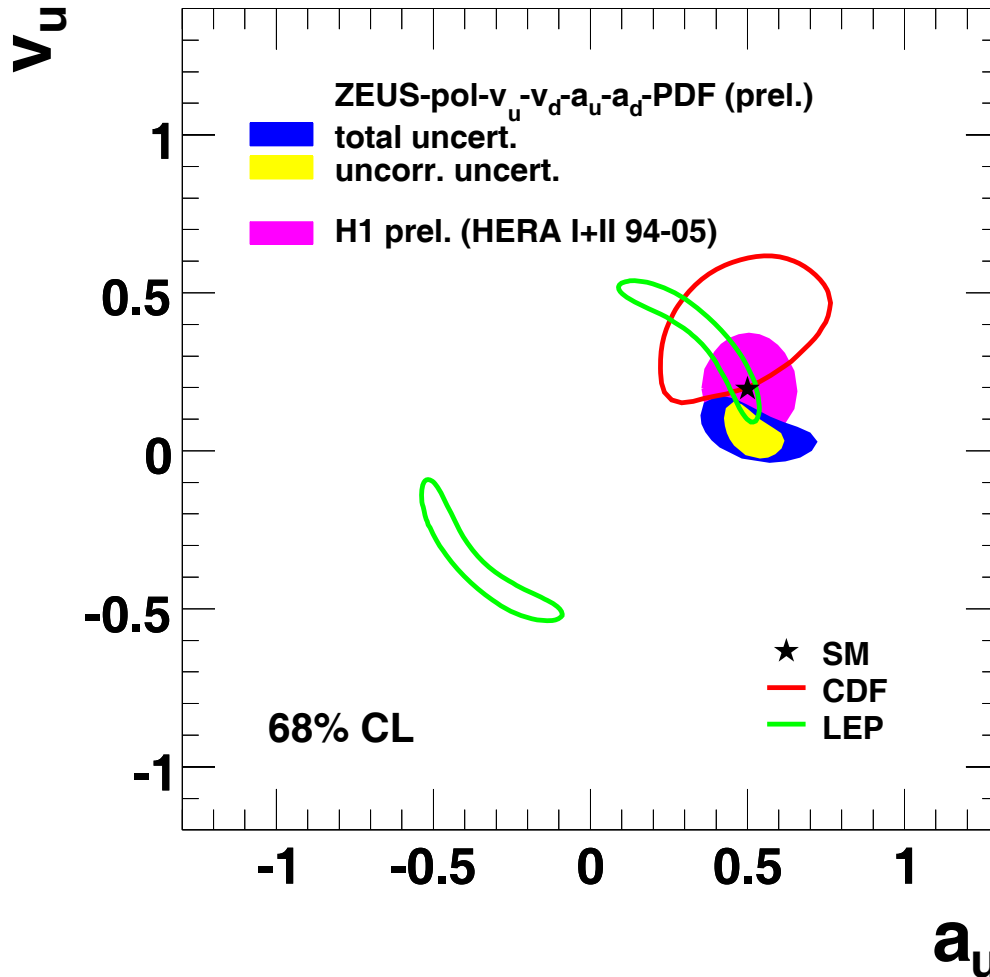
- Fit with all EW parameters set to SM

- ➔  $u_V$  uncertainty is reduced as high  $Q^2$   
NC is sensitive to  $u$  @ large  $x$
- ➔ improvement holds up to  
at large  $Q^2$  (10000  $\text{GeV}^2$  plotted)



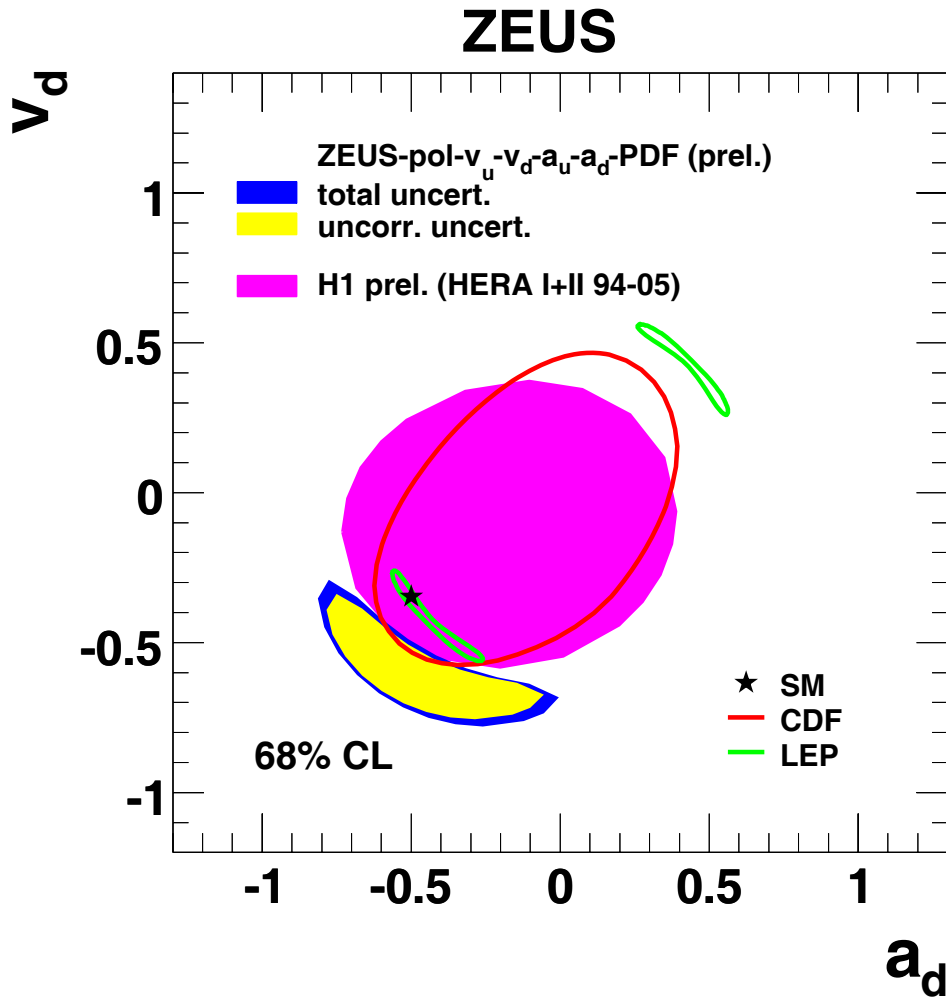
# u-Z couplings extraction

## ZEUS



- HERA limits are competitive with other experiments
- Resolved LEP ambiguity

# d-Z couplings extraction



- HERA limits are competitive with other experiments

- Resolved LEP ambiguity

➔ Larger uncertainties are due to lower sensitivity of NC to d than to u (Charge squared)



# Summary

- HERA has provided the most precise measurements of inclusive structure function significantly improving our knowledge of proton structure
- Based on this precise understanding of the proton structure, HERA data can now be used to determine the fundamental parameters of EW interactions with large statistics
  - Direct sensitivity to right-handed CC
  - Best determination of NC couplings of light quarks
- “Legacy results” using full statistics will come soon