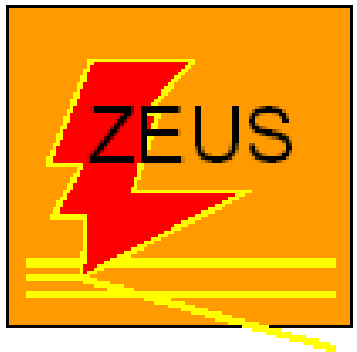
ZEUS EW Fit and Measurement of the CC Cross Section

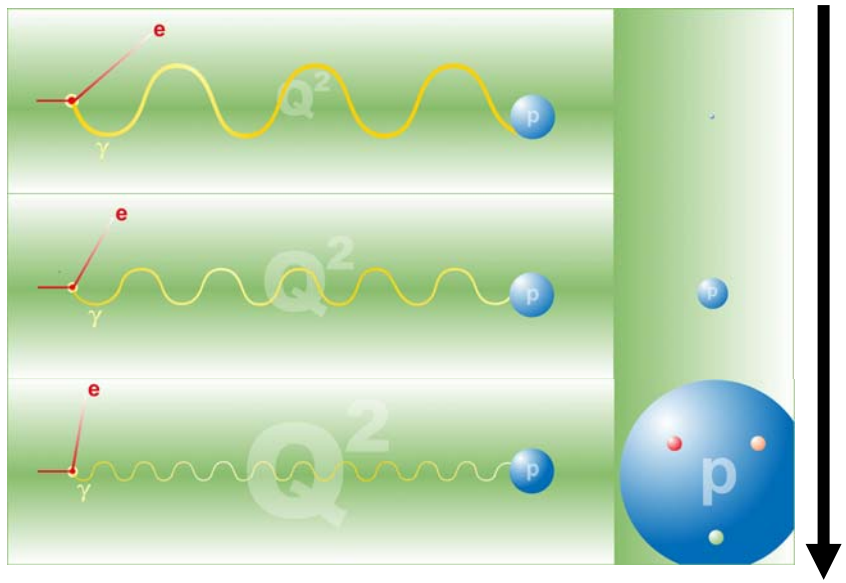
Kunihiro Nagano (KEK, Japan)



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 large

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

$Q^2_{MAX} = s$

At HERA: Ee=27.5 GeV, Ep=920 GeV

$\sqrt{s} = 320\ \text{GeV}$

$Q^2_{MAX} \approx 10^5\ GeV^2$

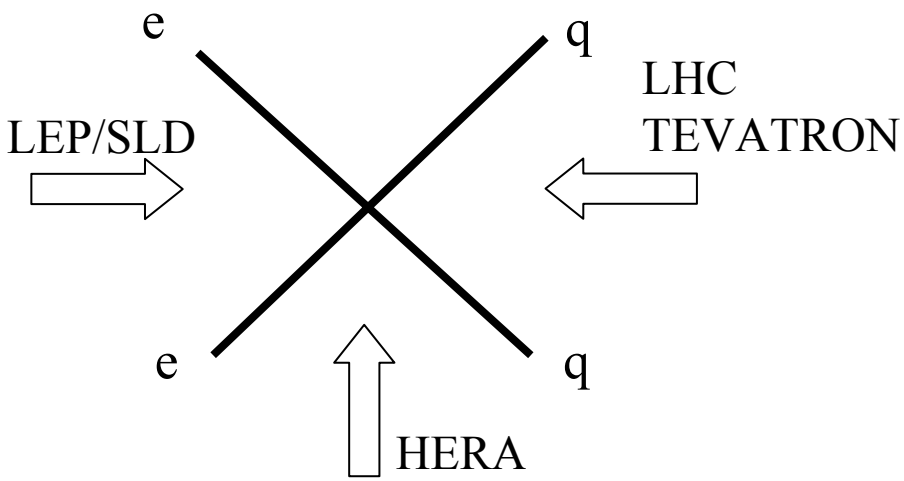
$\lambda_{MIN} \sim 1/1000\, r_{proton}$

(corresponds to ~50 TeV incident beam on fixed target)

ν -DIS: Weak @ $Q^2 \lesssim$ O(100) GeV^2

HERA: Electro-Weak @ $Q^2 \approx$ EW scale

Colliders at EW scale



► Tevatron / LHC

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

► HERA

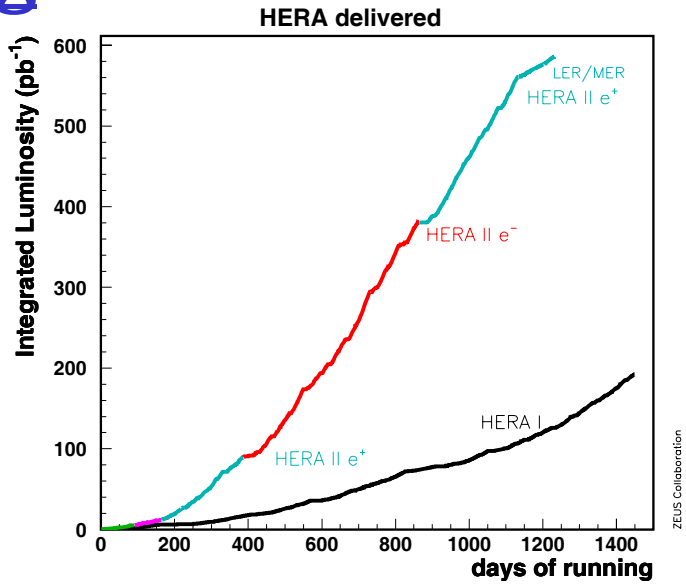
- Probe proton structure by t-channel exchange of gauge bosons
  -- At low Q^2: mainly by γ
  -- At high Q^2: γ/Z (NC) and W (CC)
- Investigate electron-quark elementary processes based on knowledge of proton structure (at low Q^2)

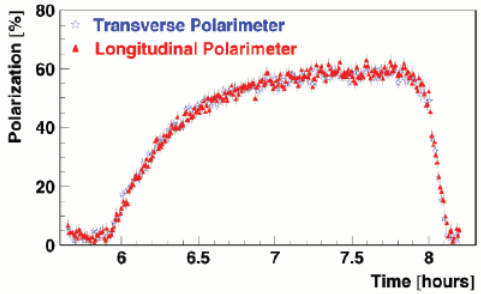
$$\sigma(ep) \propto \sum \sigma(eq) \otimes (pdf) \qquad EW \otimes QCD$$

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.

	HERA-I	HERA-II
e^-	~20 pb^{-1}	~200 pb^{-1}
e^+	~100 pb^{-1}	~200 pb^{-1}

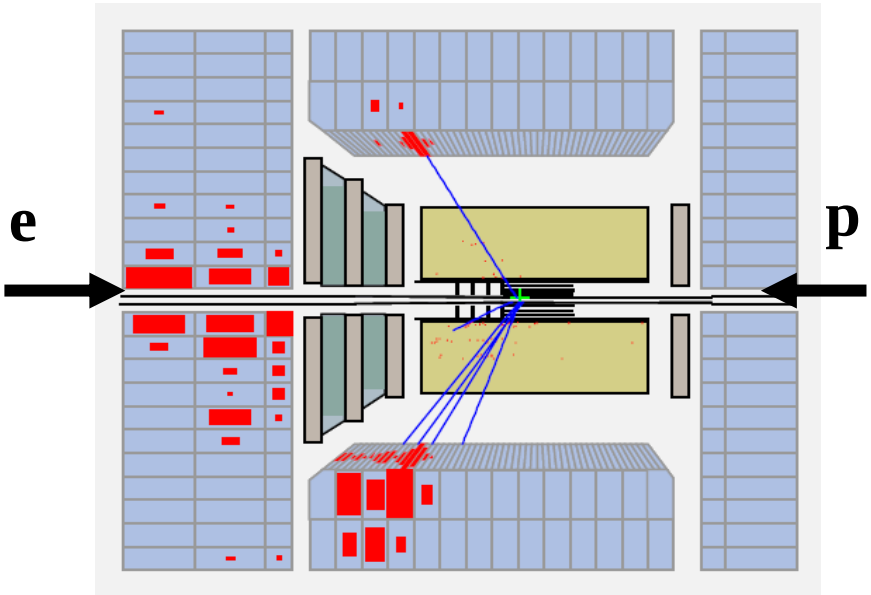
1 fb^{-1} collected by H1+ZEUS

- 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**

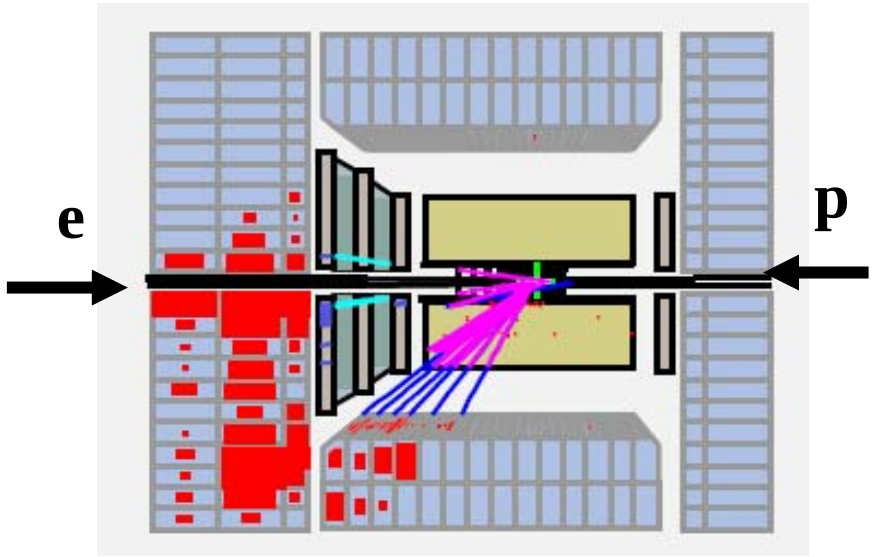
Year 2008: HERA results using full statistics etc are building up while LHC starts operation

Measuring DIS Events at HERA

NC Event



CC Event



- Selection: presence of high energy scattered electron

$$E'_e > 10 \text{ GeV}$$

- Kinematics well reconstructed using electrons and/or hadrons

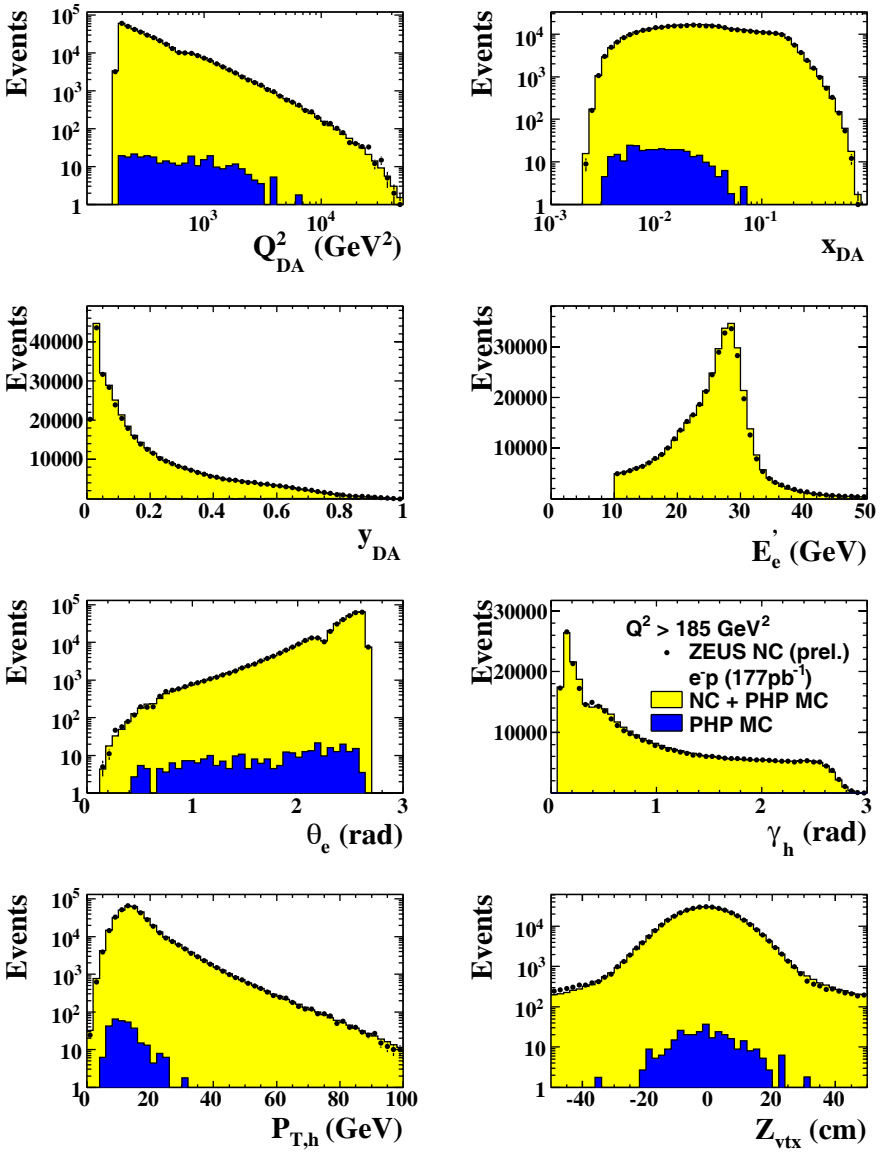
- Selection: presence of large missing transverse momentum: $P_{T,miss}$

$$P_{T,\,miss} > 12 \text{ GeV}$$

- Kinematics reconstructed using hadrons only

NC Events

ZEUS

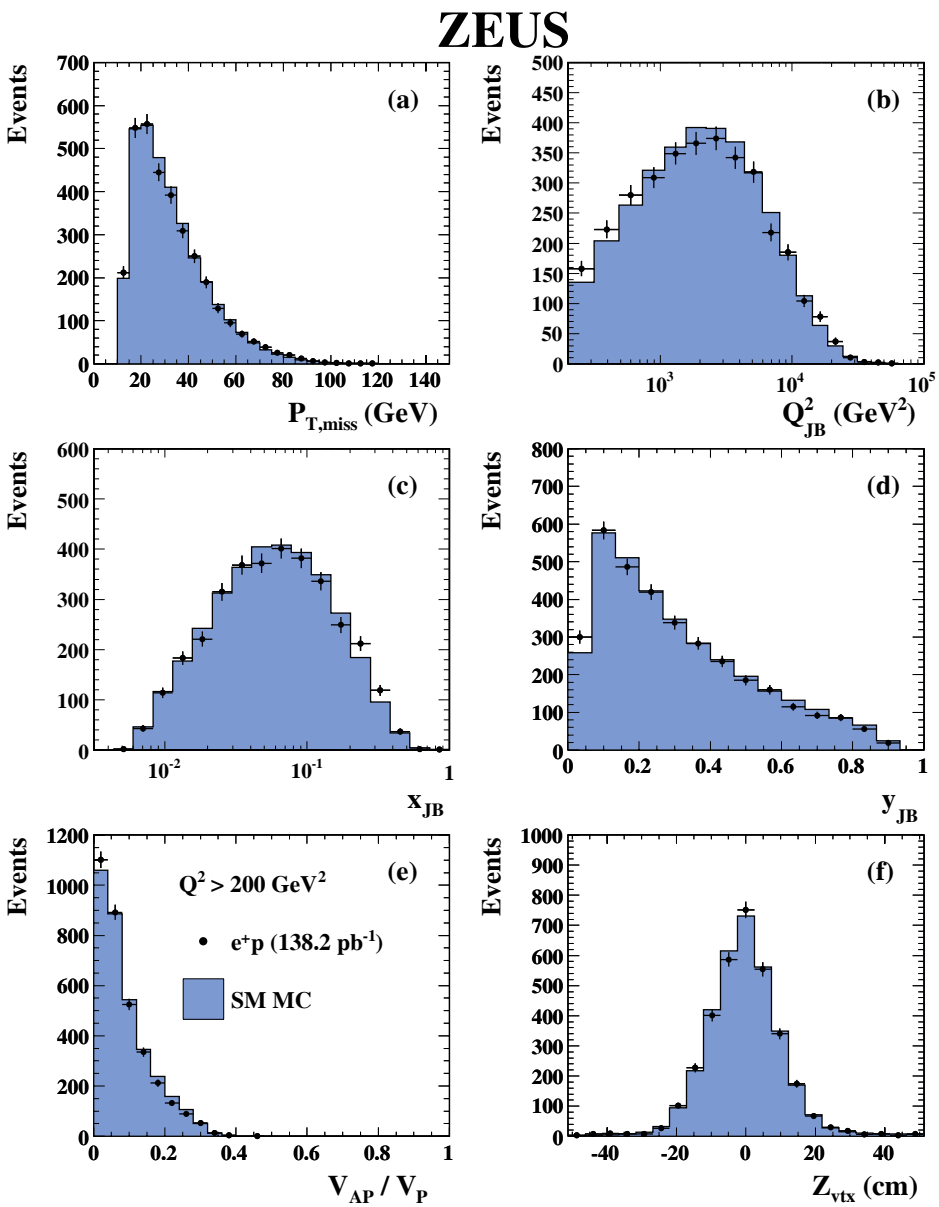


- Data set: 2005-2006 e-p
  Luminosity: 177 pb^{-1}
  (Updated @ DIS07)

- Not only electron variables e.g. energy (Ee), scattering angle (θ_e) , but also angle of hadron system (γ_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



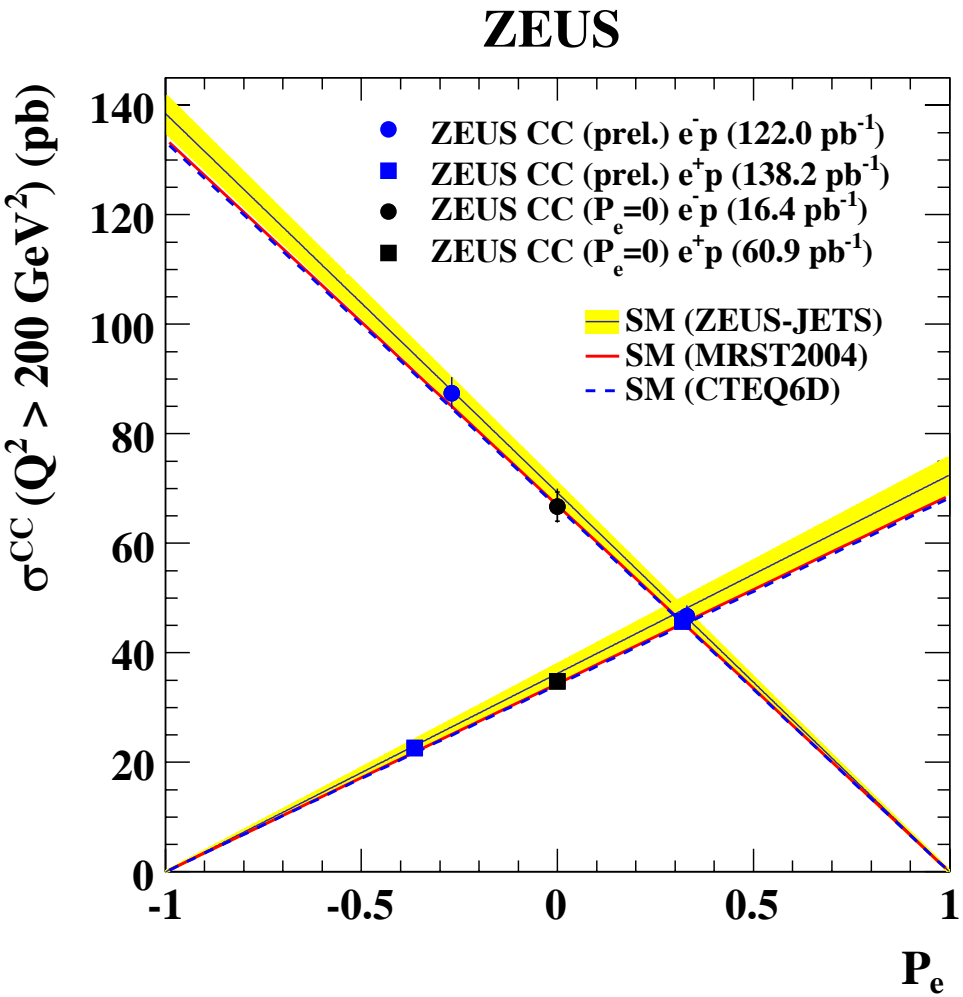
- Data set: 2006-2007 e+p
  Luminosity: 138 pb^{-1}
  (New result @ last summer)

- $P_{T,\,miss}$ and longitudinal hadronic energy ($E-P_Z$) etc. are well described.

- Shown are for data sets of both polarizations

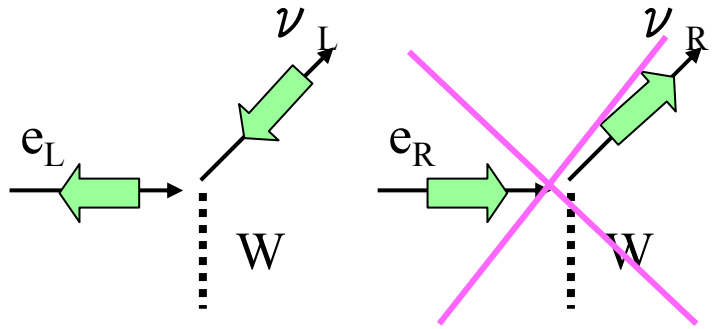
➔ Cross sections are measured separately for positively and negatively polarized beams (see next)

CC cross section vs. polarization



- "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+)
  ➔ $\sigma(\text{Pol}) = (1 \pm \text{Pol})\ \sigma(\text{Unpol})$

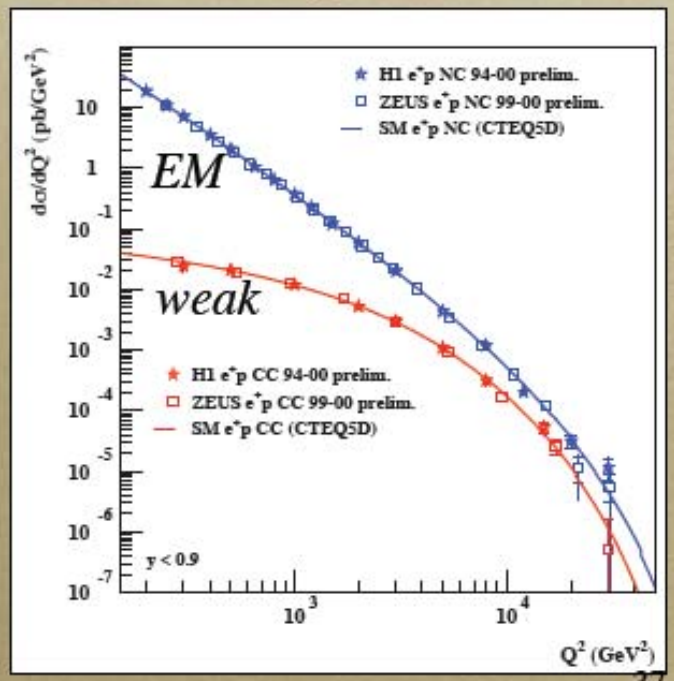


- Consistent with SM prediction of: σ(RH CC)=0
  (Error band from PDF uncertainty)

EW unification: a theorist's view

We are just about to achieve another layer of unification

HERA ep collider



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- *Unification of electromagnetic and weak forces*
- ⇒ *electroweak theory*
- *Long-term goal since '60s*
- *We are getting there!*
- *The main missing link: Higgs boson*

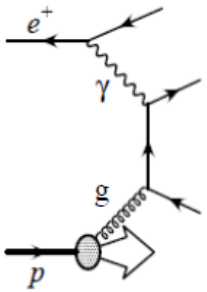
H.Murayama @ KEK TC 2007

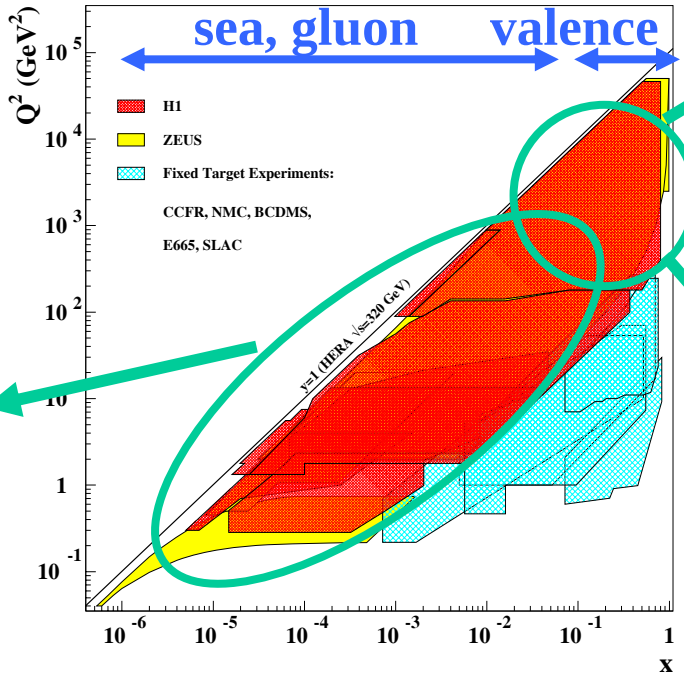
- NC and CC cross sections become similar at EW scale
  - ➔ "EW unification" (Remaining differences are mainly due to PDFs)

EW+QCD fit

◆ Jet process

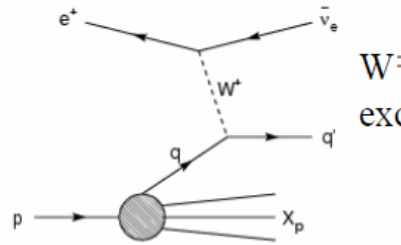
Directly sensitive to gluon density





S.Shimizu @ APS-DPDF06 + JPS06

◆ Charged current DIS (CC)

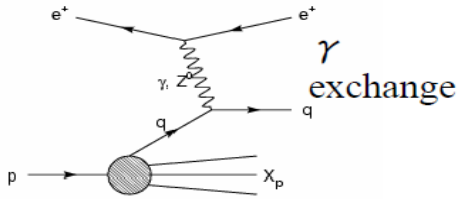


W± exchange

Charge selective interaction

e⁻ : u quark e⁺: d quark

◆ Neutral current DIS (NC)
At low Q^2



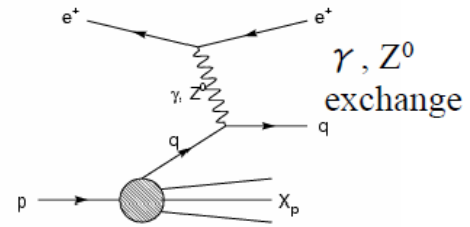
γ exchange

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

Sea + valence quark

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

◆ Neutral current DIS (NC)
At high Q^2



γ , Z^0 exchange

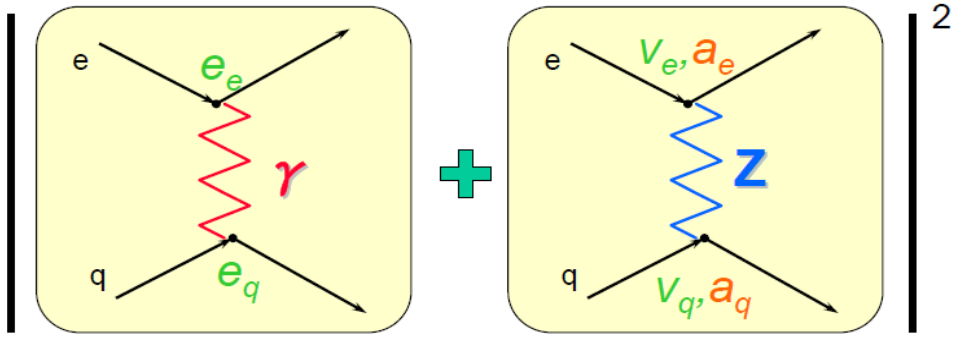
Z^0 introduces parity violation.

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

valence quark

- Rich variety of ZEUS data sensitive to various PDFs
  - -- Advantage: Eliminates uncertainty in heavy target correction (ν Fe, ν 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



$$\frac{d^2\sigma_{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\{1+(1-y)^2\}F_2 \mp \{1-(1-y)^2\}xF_3\right]$$

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

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

- **EW structure functions in QPM**

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

ZEUS EW+QCD Analysis

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

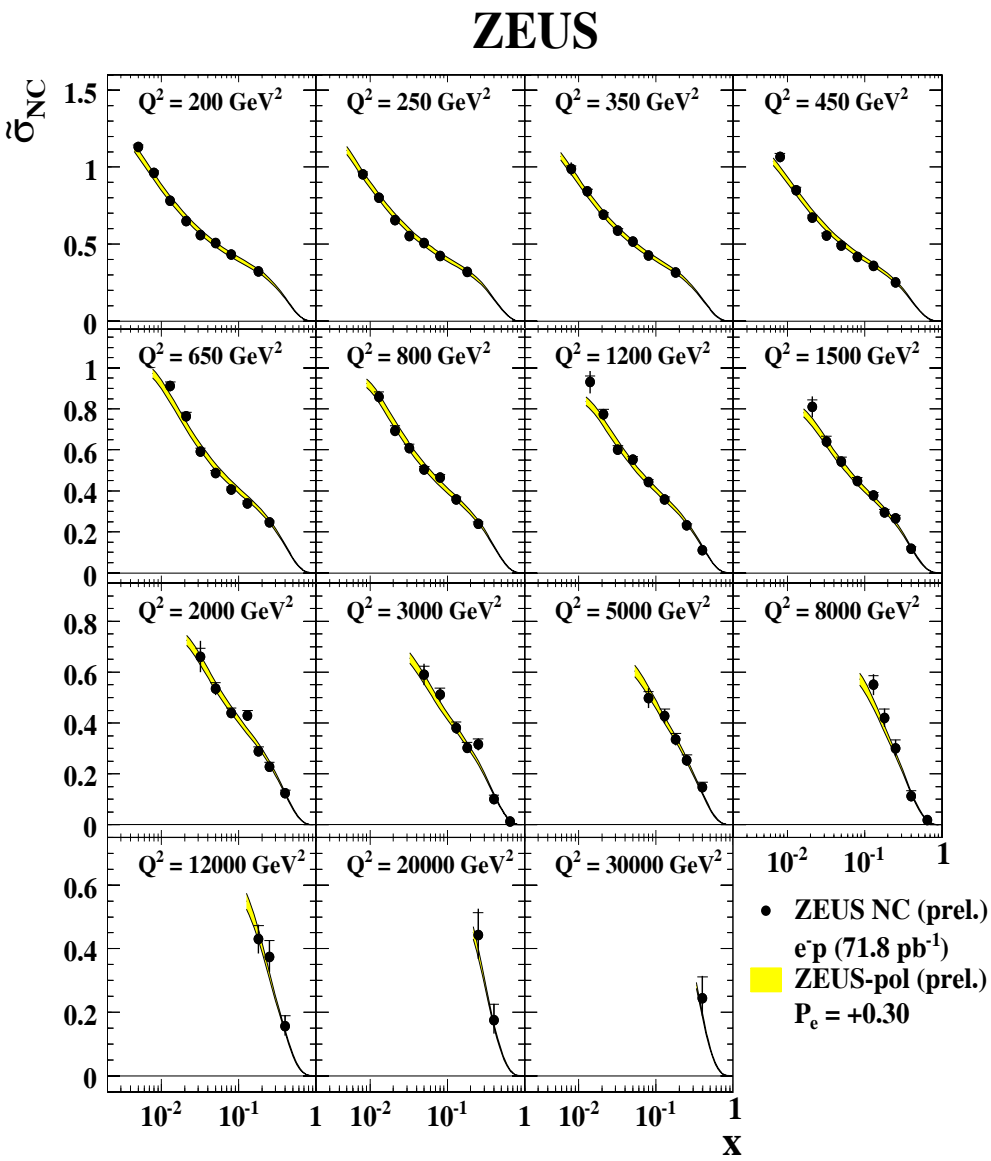
- **Updates: ① HERA-II NC e^- p : 121 pb^{-1} → 177 pb^{-1}**
  ② q-Z couplings: 2 parameter determination → 4 parameters

→ "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
  - -- $Q_0^2 = 7\ GeV^2$
  - -- Form: $xf(x) = Ax^b(1-x)^c(1+dx)$
  - -- xu_V, xd_V, xS, xg, $x\Delta$ (=$x\bar{d}$ - $x\bar{u}$)
- Constraints
  - -- Momentum and number sum rules
  - -- Equal behavior of uv and dv at low x: $b(u_V) = b(d_V)$
  - -- Δ : set as consistent with Gottfried sum rule and Drell Yan (CCFR)

→ 11 PDF parameters + 4 EW parameters

Data Set



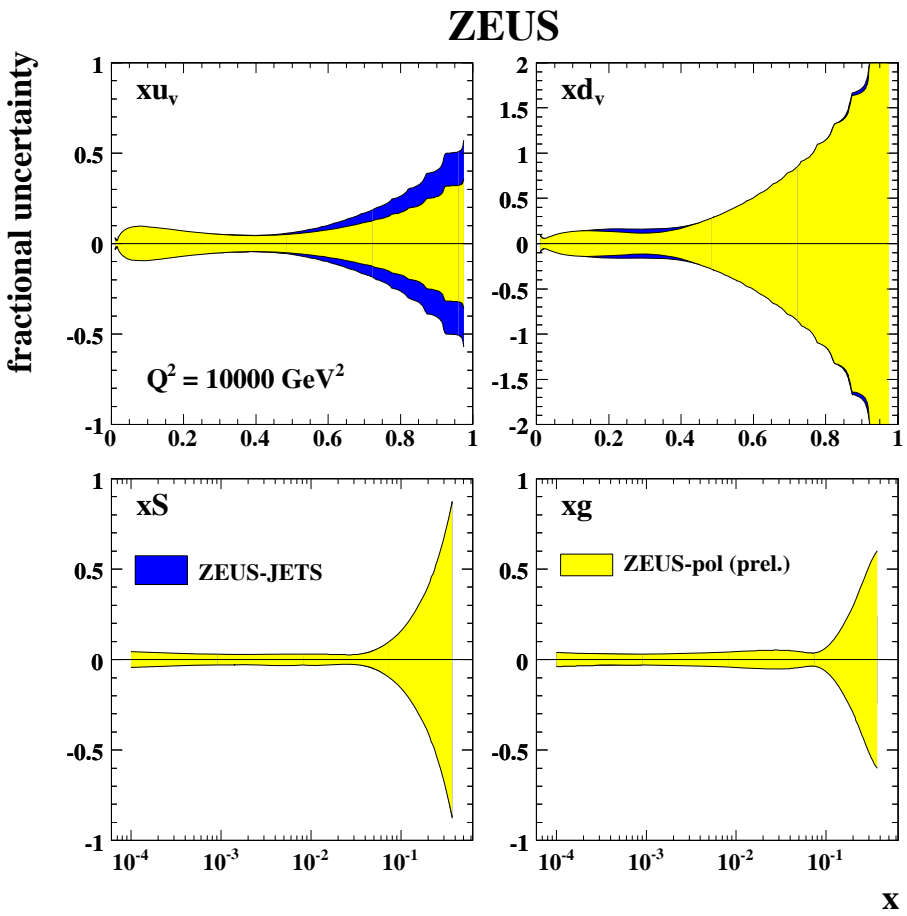
- HERA I
  - -- NC low Q^2: 96/97
  - -- NC high Q^2: e+ 99/00
    e- 98/99
  - -- CC high Q^2: e+ 99/00
    e- 98/99
  - -- PHP di-jets
  - -- DIS inclusive jet
- HERA-II
  - -- Pol. NC high Q^2: e- 05/06
  - -- Pol. CC high Q^2: e- 05/06

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

➔ HERA-II data more to come

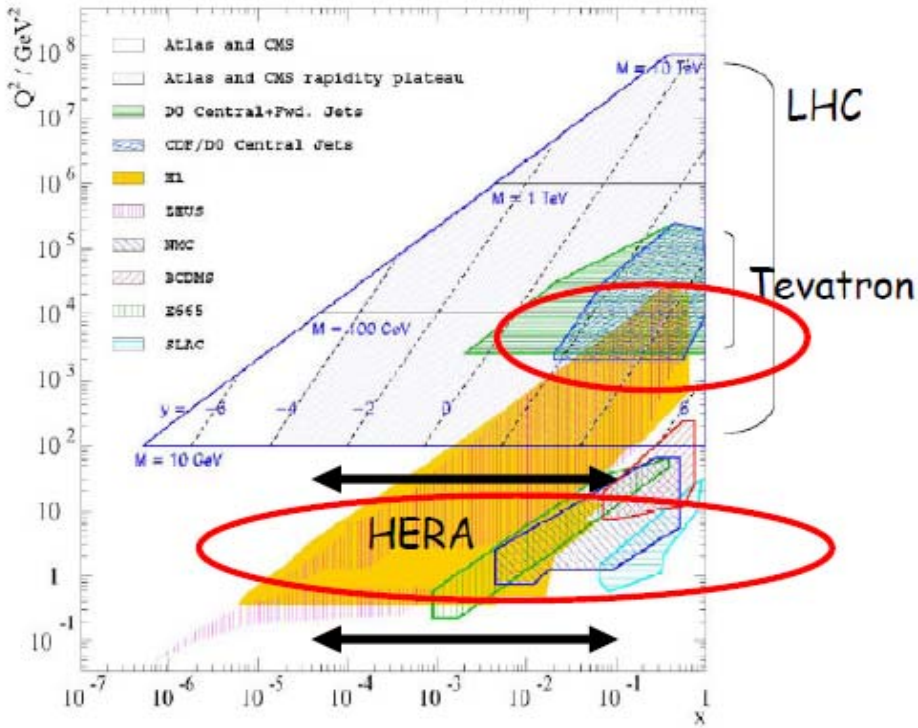
Extracted PDFs

- Fit with all EW parameters set to SM

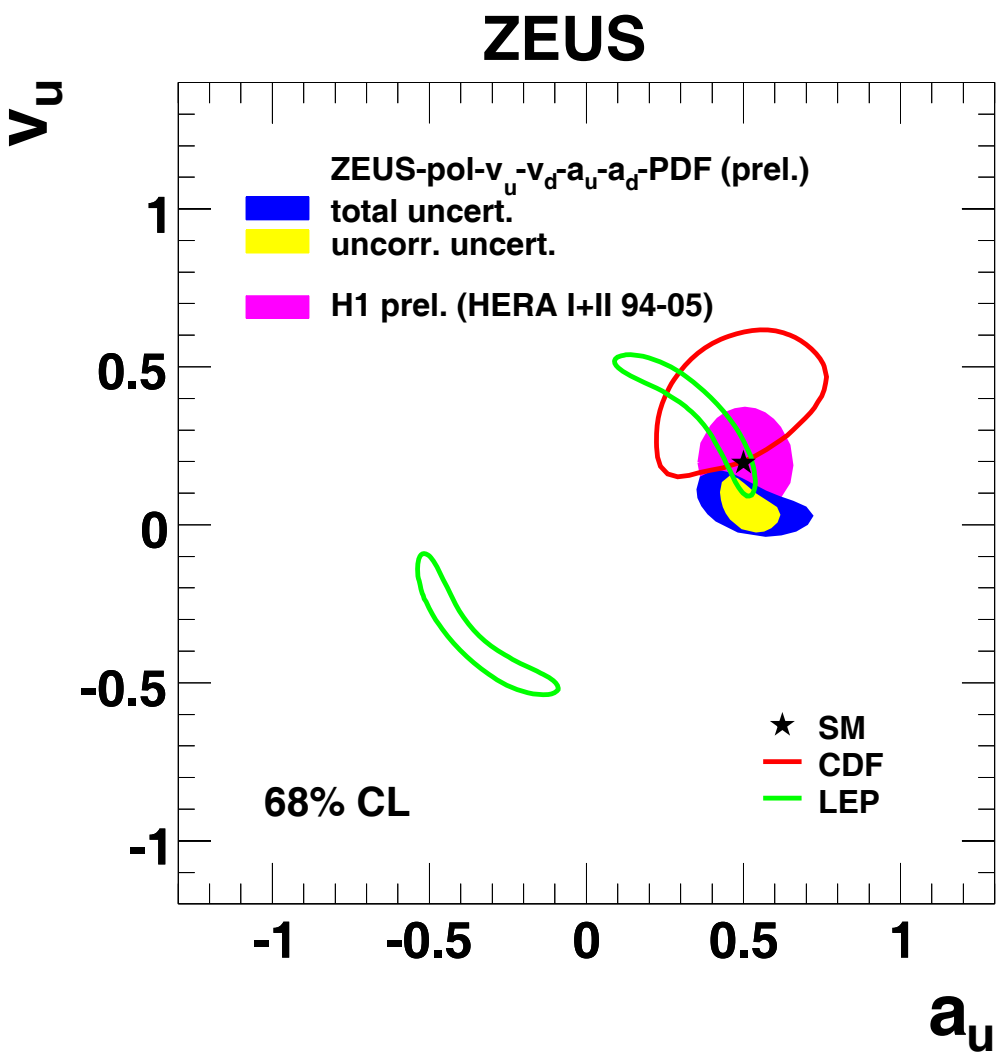


➔ u_V uncertainty is reduced as high Q^2 NC is sensitive to u @ large x

➔ improvement holds up to at large Q^2 (10000 GeV^2 plotted)

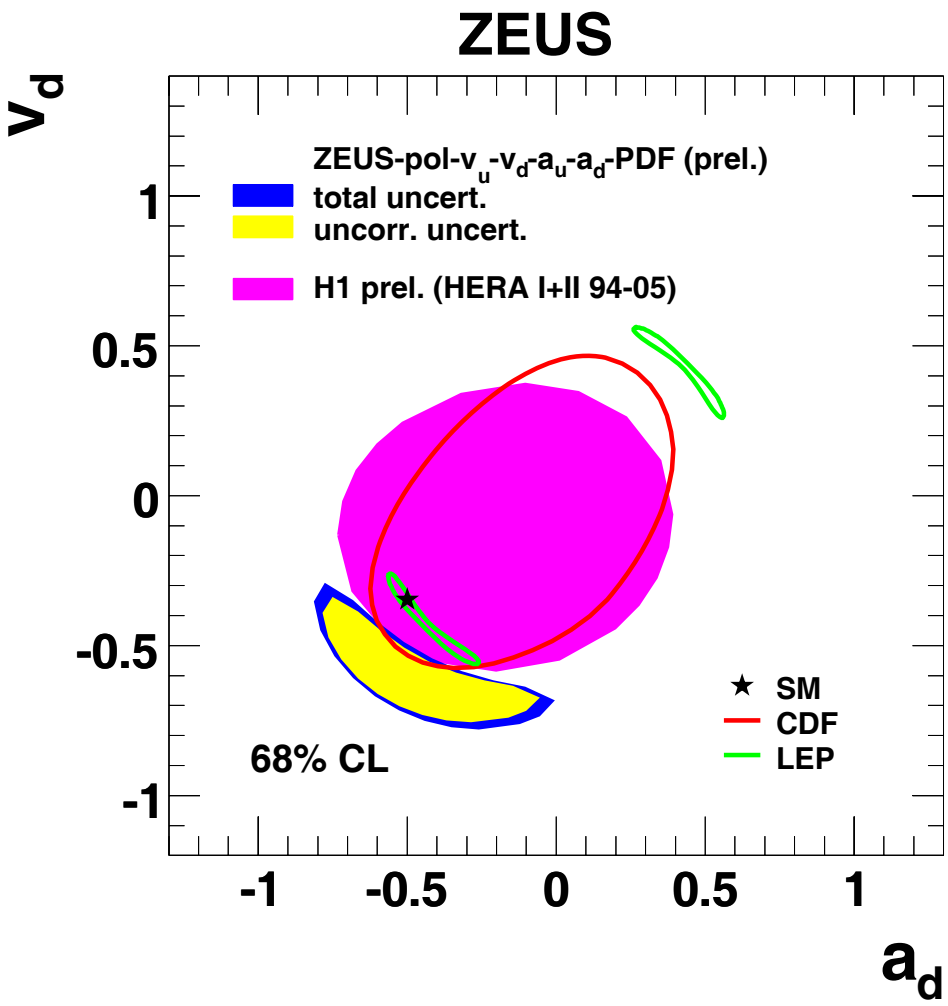


u-Z couplings extraction



- 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