# Combined QCD and Electro-Weak Fits at HERA


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**On behalf of**
**the H1 and ZEUS collaborations**


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**Contents**

# HERA is first and unique ep collider in the world!

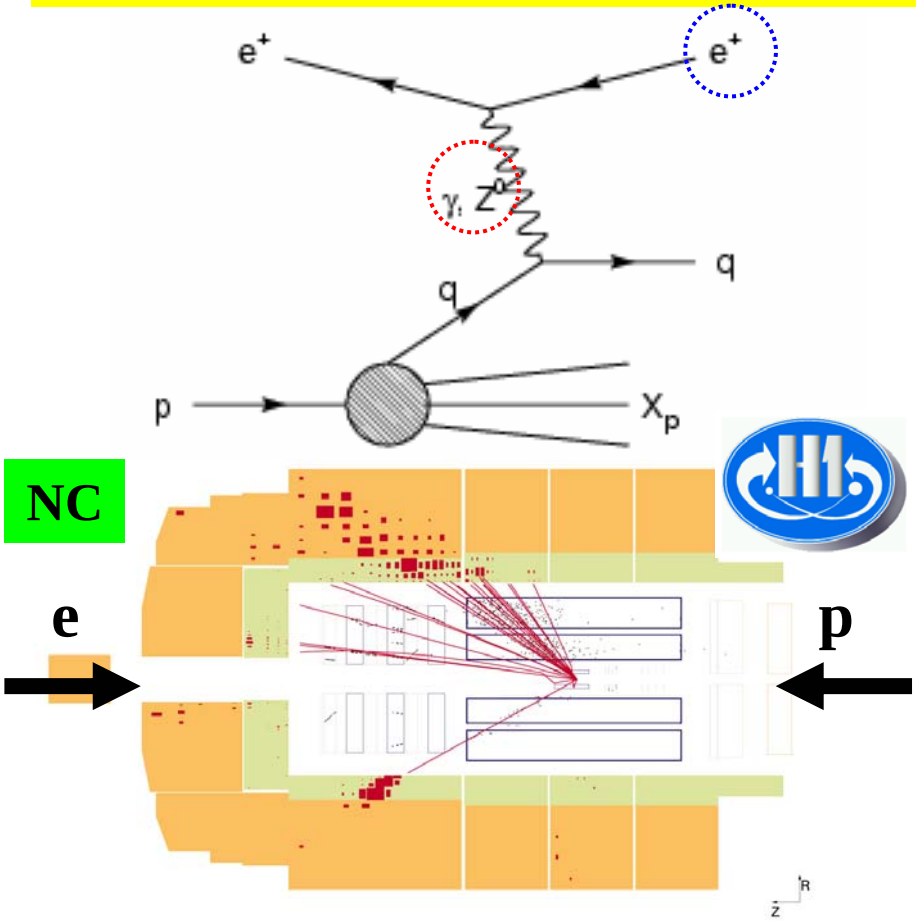
$$E_p = 920\text{GeV}, E_{e^\pm} = 27.5\text{GeV}, \sqrt{s} = 318\text{GeV}$$

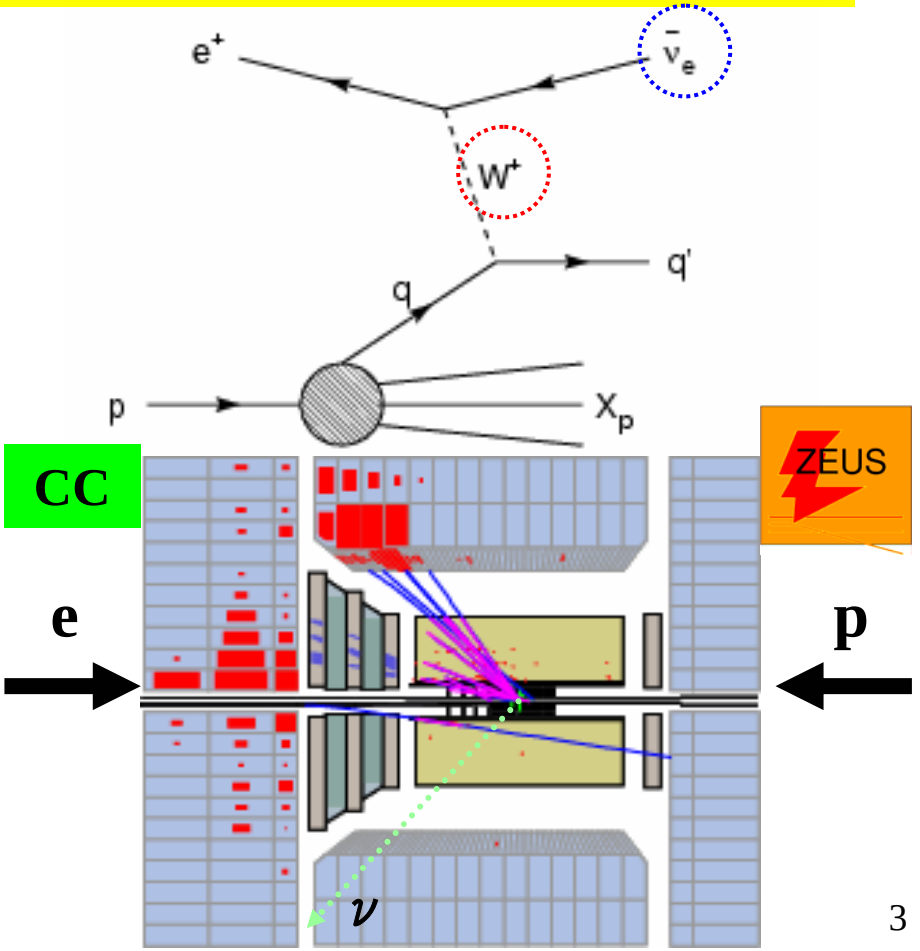

Two collider experiments, **H1** and **ZEUS**, will run until 30/Jul/2007

# Deep Inelastic Scattering at HERA

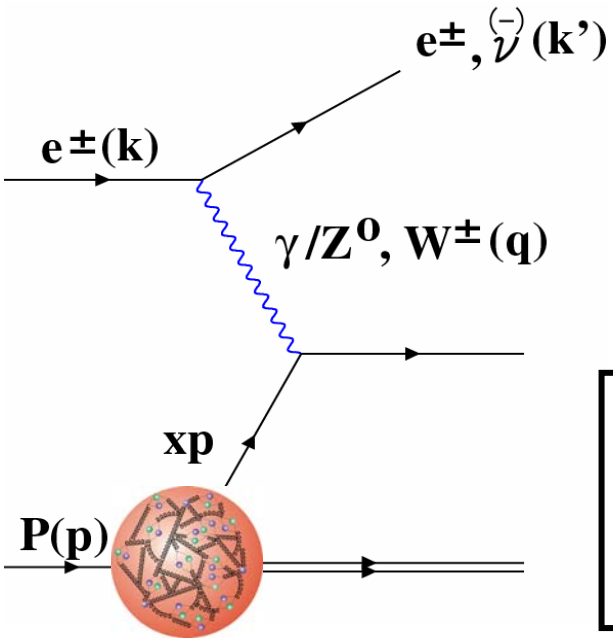
Owing to the large center-of-mass energy, the **electromagnetic** and **weak** interactions become of comparable strength at HERA

Therefore both Neutral Current (NC), mediated by $\gamma$ or $Z^0$, and Charged Current (CC), mediated by $W^{\pm}$, can occur



# DIS cross sections




$Q^2 = -q^2 = -(k - k')^2$ **Virtuality of exchanged boson**

$x = \frac{Q^2}{2p \cdot q}$ **momentum fraction of the struck quark**

$y = \frac{p \cdot q}{p \cdot k}$ **inelasticity**

electron is point-like, but proton is the confined state of partons → Proton is parameterized by **Structure Functions (SFs)**

**$\sigma_{ep}$=Coupling × Propagator × Kinematic Factor × SFs**

**SFs=coupling to boson × Parton Distribution Functions (PDFs)**

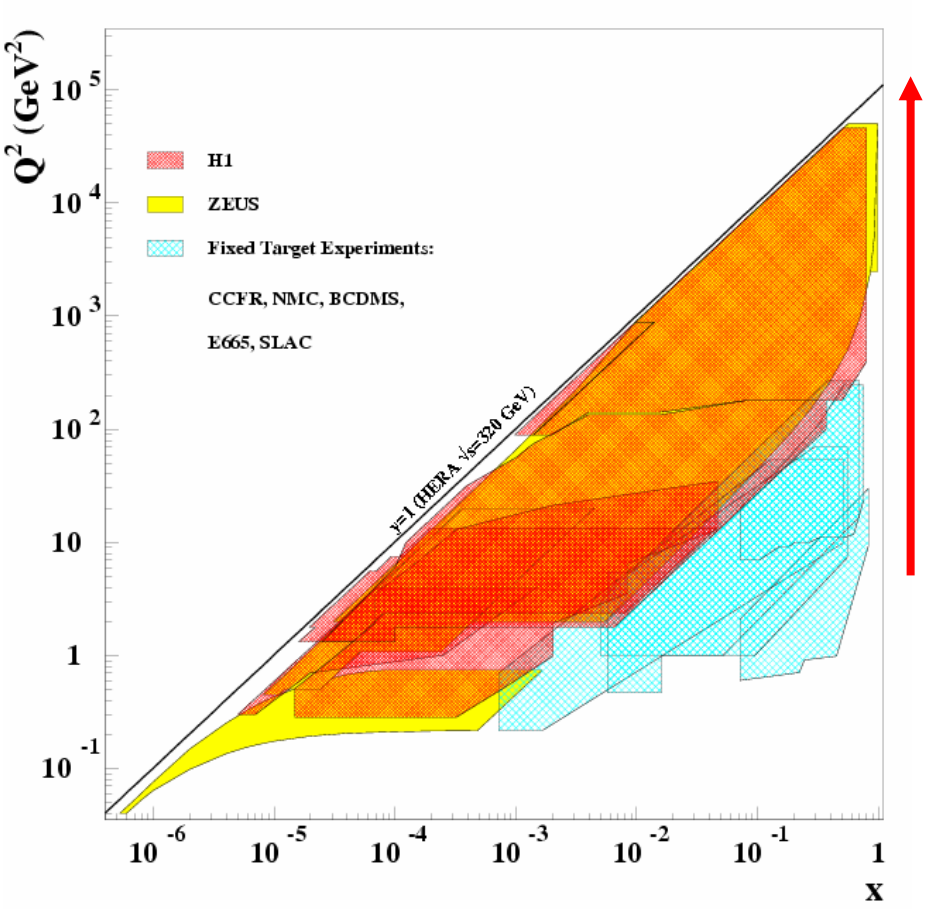
**DIS is a convoluted phenomenon for EW and QCD**

**Fit to the measured cross sections to study QCD and EW**

**→ See next slide**

# Combined QCD and EW Fits

**HERA kinematic plane**




**③ Based on own knowledge of PDFs, EW parameters can be extracted at high-$Q^2$**

**② Perturbative QCD can predict the $Q^2$ evolution of PDFs, DGLAP equation**

**① x-dependence of PDFs at initial scale, $Q^2_0$ are determined from fits to the measured cross sections at low $Q^2$**

**Such a unique study, the simultaneous determination on PDFs and EW parameters, is only possible at HERA!**

# Extraction of PDFs for both experiments

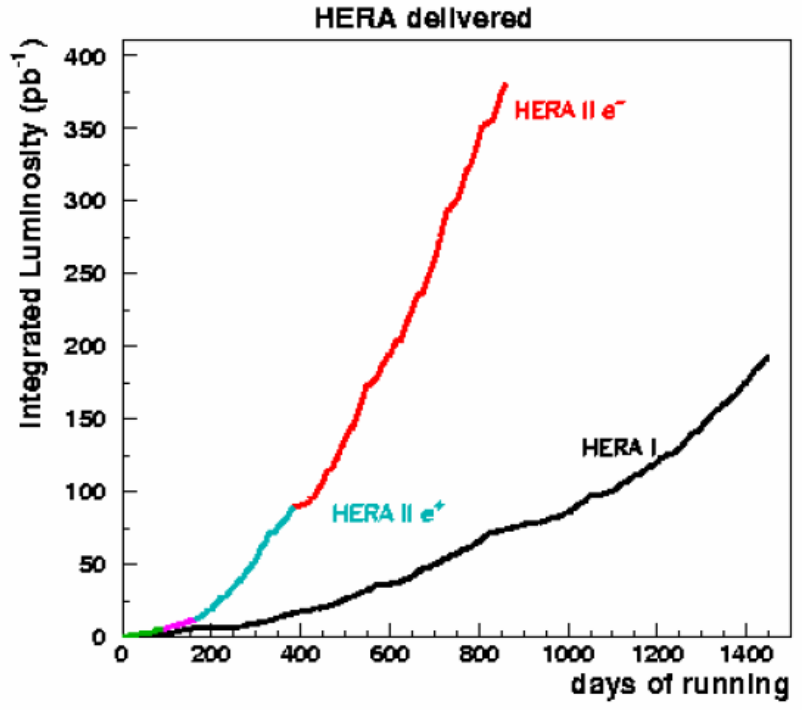
- Both experiments fit only to their own data
  - to handle the systematic errors within single experiment
  - to eliminate the uncertainty from heavy-target correction
- DGLAP evolution equations were performed in $\overline{\mathbf{MS}}$ renormalization scheme

| | **H1 PDF 2000** | **ZEUS-JETs** |
|---|---|---|
| Data-sets | HERA-I $F_2$ + Unpol. high$Q^2$ NC+CC | HERA-I $F_2$ + Unpol. high$Q^2$ NC+CC<br>HERA-I DIS inclu.Jet + PhP di-Jets |
| PDFs parameterization | $xg, xU, xD, x\overline{U}, x\overline{D}$ are parameterised at $Q_0^2$=4GeV$^2$ | $u_v, d_v, Sea, gluon, x\Delta(= x\overline{d} - x\overline{u})$ are parameterised at $Q_0^2$=7GeV$^2$ |
| Treatment of correlated systematic uncertainties | evaluated using Hessian method | evaluated using OFFSET method |

# HERA-II

Since Autumn 2003, HERA-II started with two upgrade :

- Large luminosity → more sensitivity at high-$Q^2$
- Polarized e beams → direct sensitivity on EW




| | HERA-I | HERA-II |
|---|---|---|
| $e^+$ | ~100pb$^{-1}$ | ~20pb$^{-1}$@$P_e$=+33%<br>~20pb$^{-1}$@$P_e$=-40% |
| $e^-$ | ~20pb$^{-1}$ | ~40pb$^{-1}$@$P_e$=+35%<br>~80pb$^{-1}$@$P_e$=-27% |

Recently, H1 and ZEUS collaborations measured polarized ep CC/NC DIS cross sections in HERA-II! ← See talks from **Alex** & **Vladimir**

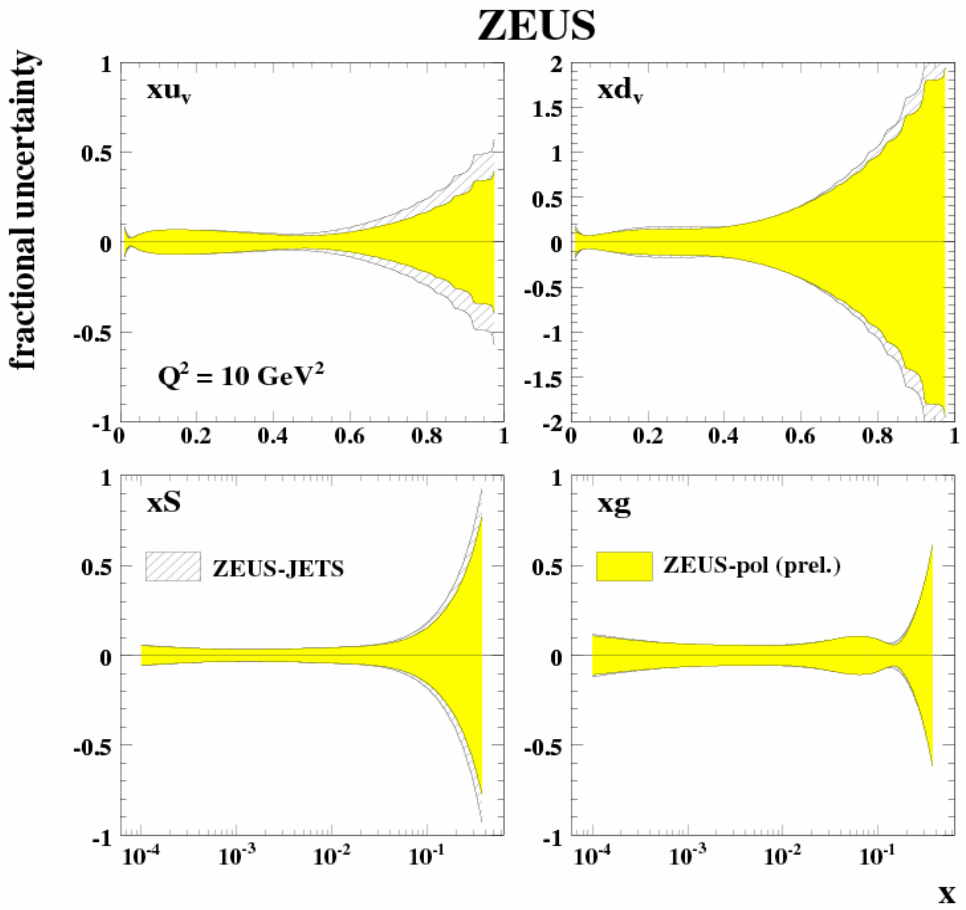
# Fit including HERA-II data

ZEUS performed the first fit including HERA-II data

**"ZEUS-POL"** (prel.)

Much statistics at high-$Q^2$ with polarized e

- Better constrain on PDFs at high-x
- Improved sensitivity to EW parameters




**Impact on PDFs :**

The precisions of the high-x PDFs are improved, particularly for the u-valence PDF, and it can be expected from :

$$\sigma_{NC} \propto 4u + d$$

$$\sigma_{CC} \propto u$$

How is on EW parameters?

See next slides.

# Extraction of $M_W$ in space-like region

CC cross section

$$\frac{d^2\sigma_{CC}(e^{\pm}p)}{dx\,dQ^2} \propto G_F^2 \times \frac{M_W^4}{(Q^2+M_W^2)^2}$$

$G_F \Leftrightarrow$ normalization

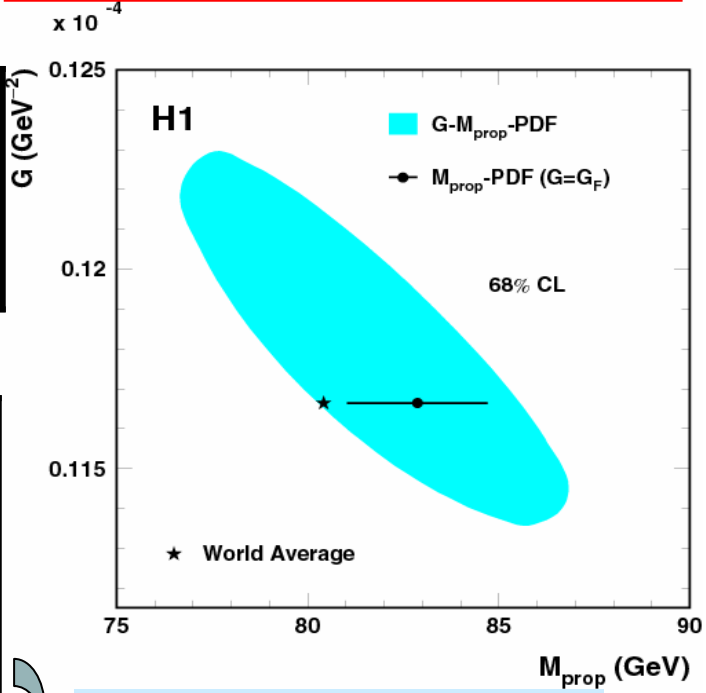
$M_W \Leftrightarrow Q^2$ dependence

① $G_F$-$M_W$-PDFs free

| | $M_W$(GeV) | $G_F$(GeV$^{-2}$) |
|---|---|---|
| ZEUS-POL | 82.8±1.5(stat) ±1.3(sys) | (1.127±0.013(stat) ±0.014(sys))×10$^{-5}$ |

② $M_W$-PDFs free

| | $M_W$ (GeV) |
|---|---|
| ZEUS(HERA-I) | 78.9±2.0(stat) ±1.8(sys) ±2.0(PDF) |
| H1(HERA-I) | 82.87±1.82(stat) ±0.25(sys) |
| ZEUS-POL | 79.1±0.77(stat) ±0.99(sys) |




Improved by HERA-II high-statistics data

**$G_F$ is consistent with one obtained from the muon lifetime measurement, and it demonstrates the universality of the CC interaction over a large range of $Q^2$**

**Complementary and consistent with Tevatron/LEP time-like one**

# Polarized NC cross section

$$\frac{d^2\sigma^{NC}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[(Y_+ F_2^0 \mp Y_- xF_3^0) + P_e(Y_+ F_2^p \mp xF_3^p\right]$$

**($F_L$ is ignored)**

Unpolarized SFs

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

Polarized SFs

$$F_2^0 = \sum_i x(q_i + \overline{q_i}) \bullet (e_i^2 - 2e_i v_i v_e P_z + (v_e^2 + a_e^2)(v_i^2 + a_i^2)P_Z^2)$$

$$xF_3^0 = \sum_i x(q_i - \overline{q_i}) \bullet (-2e_i a_i a_e P_z + 4a_i v_i v_e a_e P_Z^2)$$

$$F_2^p = \sum_i x(q_i + \overline{q_i}) \bullet (2e_i a_e v_i P_z - 2a_e v_e (v_i^2 + a_i^2)P_Z^2)$$

$$xF_3^p = \sum_i x(q_i - \overline{q_i}) \bullet (2e_i a_i v_e P_z - 2a_i v_i (v_e^2 + a_e^2)P_Z^2)$$

In SM,

Axial coupling : $a = T^3$

Vector coupling : $v = T^3 - 2e\sin^2\theta_W$

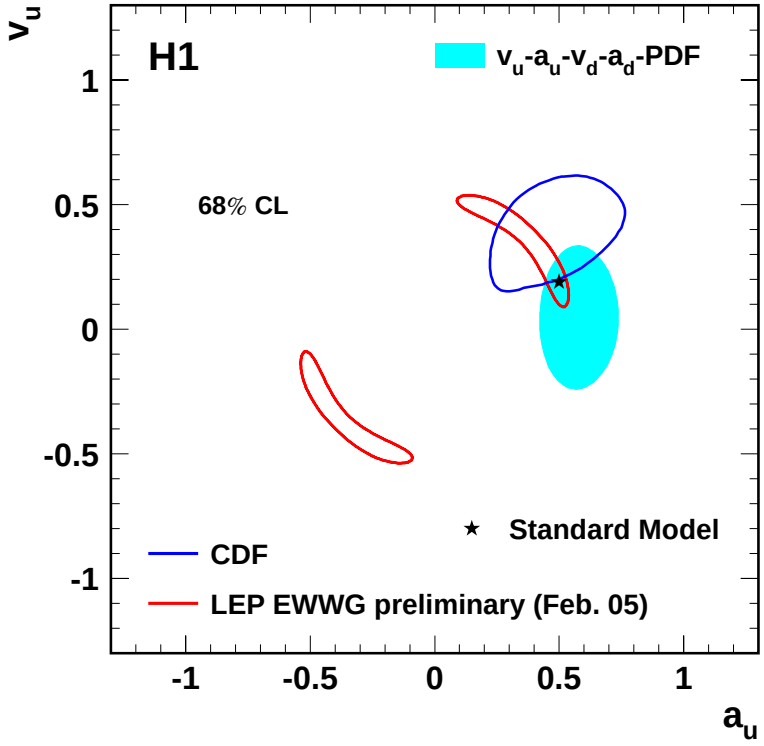
**$v_e \sim 0.04$, $P_Z >> P_Z^2$**

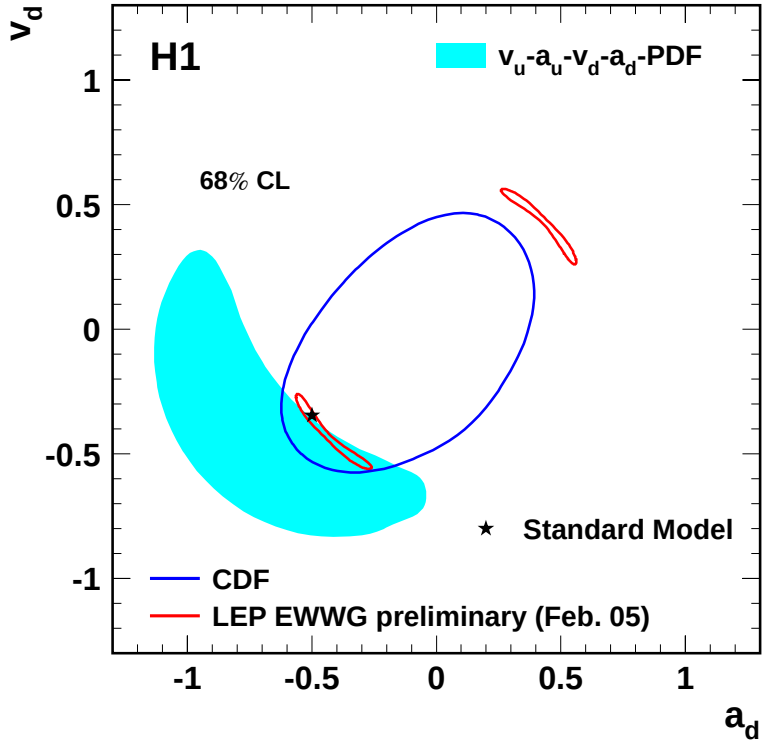
**$xF_3^0$ is sensitive to $a_i$**

**$F_2^p$ is sensitive to $v_i$**

# Extraction of quark couplings to Z only using unpolarized data

**In HERA, the light quarks dominate the cross sections, so such measurements are complementary to LEP and CDF results**



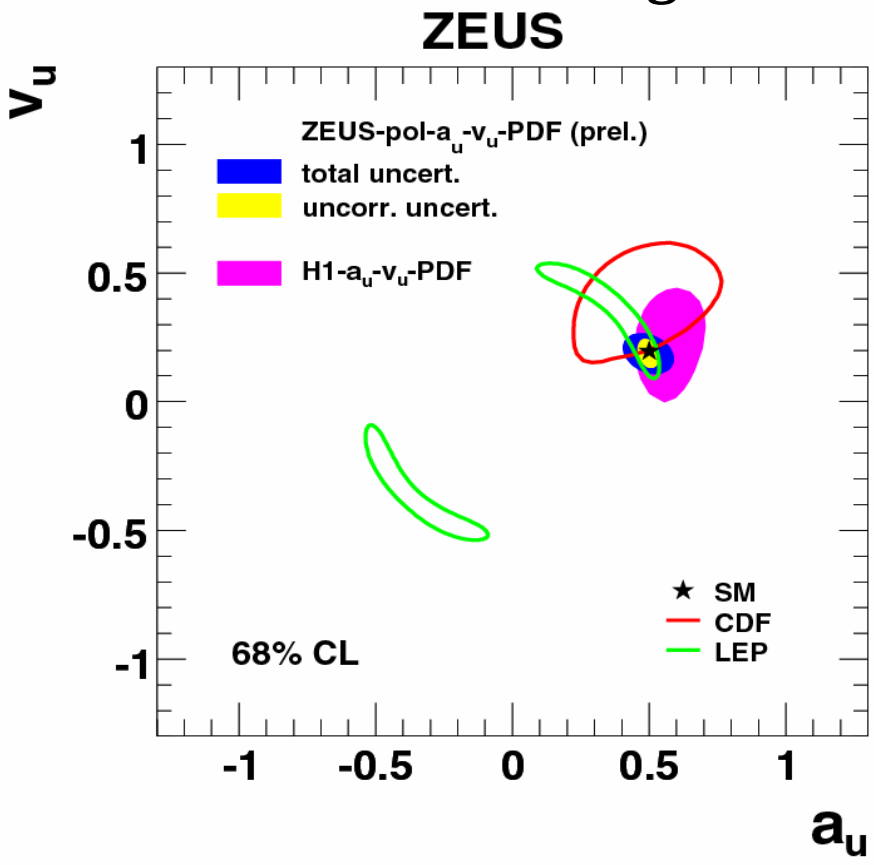



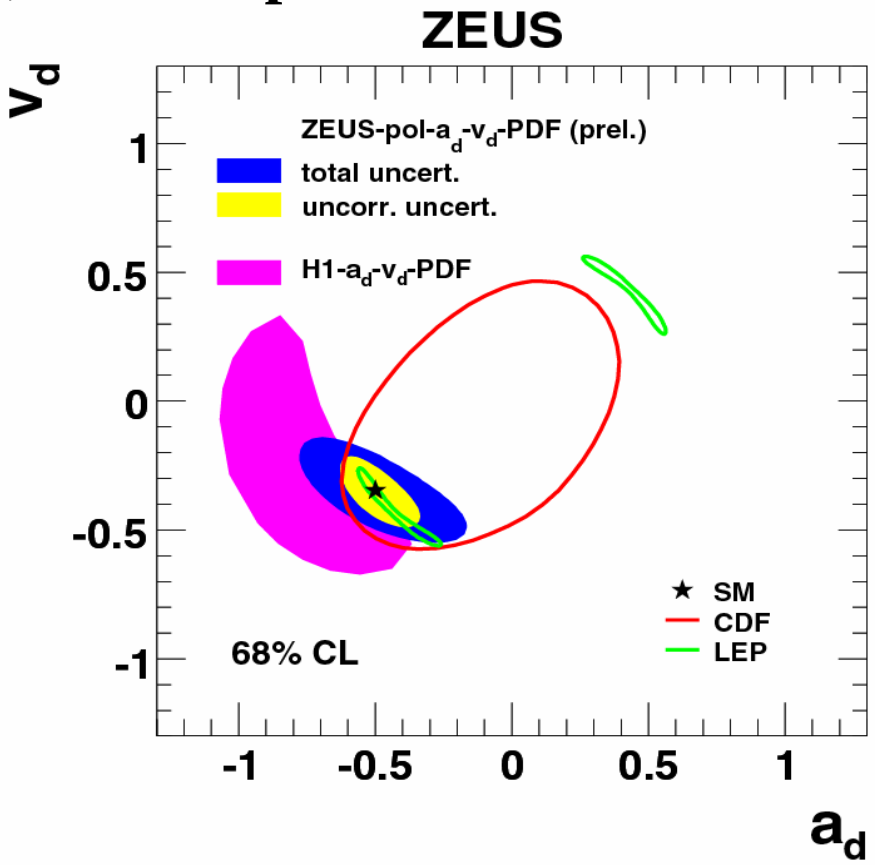

- **Comparable precision to that from the Tevatron**
- **Remove LEP ambiguities**

# Extraction of quark couplings to Z with polarized data

**HERA-II data can improve both couplings.**

**axial-vector : high-statistics, vector : polarized beams**




**Clearly, Polarized data improves the vector couplings.**

**HERA-II data makes a significant impact on the quark couplings**

# SM formalism

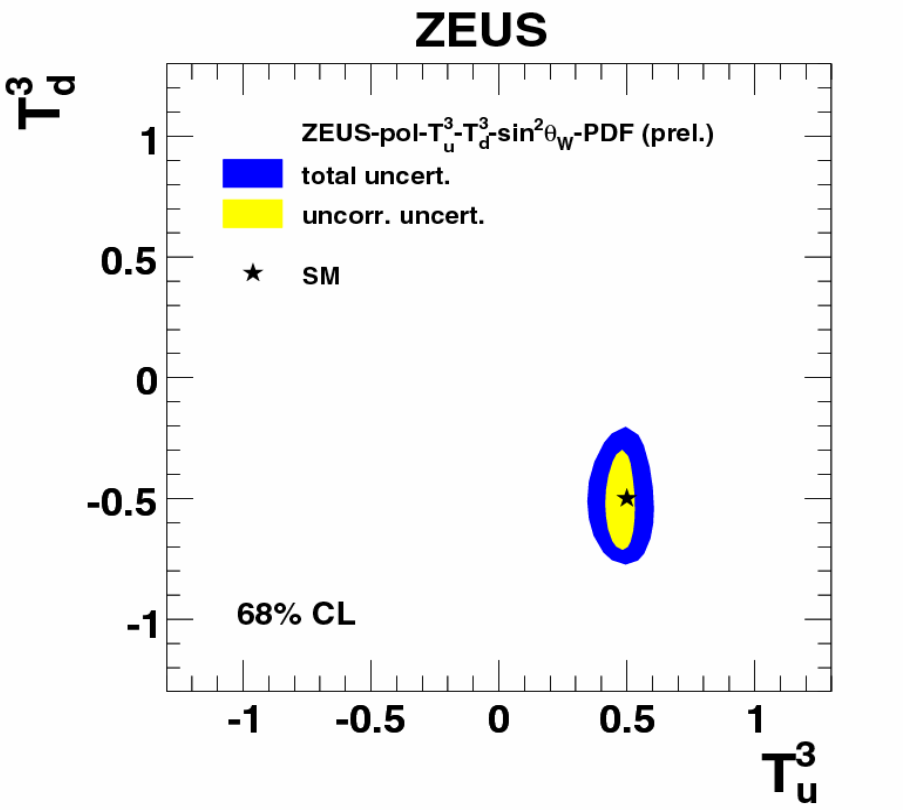
$$a_q = T_q^3$$
$$v_q = T_q^3 - 2e_q \sin^2\theta_W$$

The values of $T_u^3$, $T_d^3$ and $\sin^2\theta_W$ were freed with PDFs parameters.

Note: $\sin^2\theta_W$ is also present in $P_Z$, thus providing an extra constraint

| | ZEUS-POL-$T_u^3$-$T_d^3$-$\sin^2\theta_W$ |
|---|---|
| $T_u^3$ | $0.47 \pm 0.05 \pm 0.13$ |
| $T_d^3$ | $-0.55 \pm 0.18 \pm 0.35$ |
| $\sin^2\theta_W$ | $0.231 \pm 0.024 \pm 0.070$ |

**Consistent with their SM values**



# Summary

**The simultaneous determination on PDFs and EW parameters can be made at HERA.**

**HERA-II data, large luminosity with polarized electron beams, reduced high-x PDFs uncertainties, and significantly improved the EW parameters.**

# Outlook

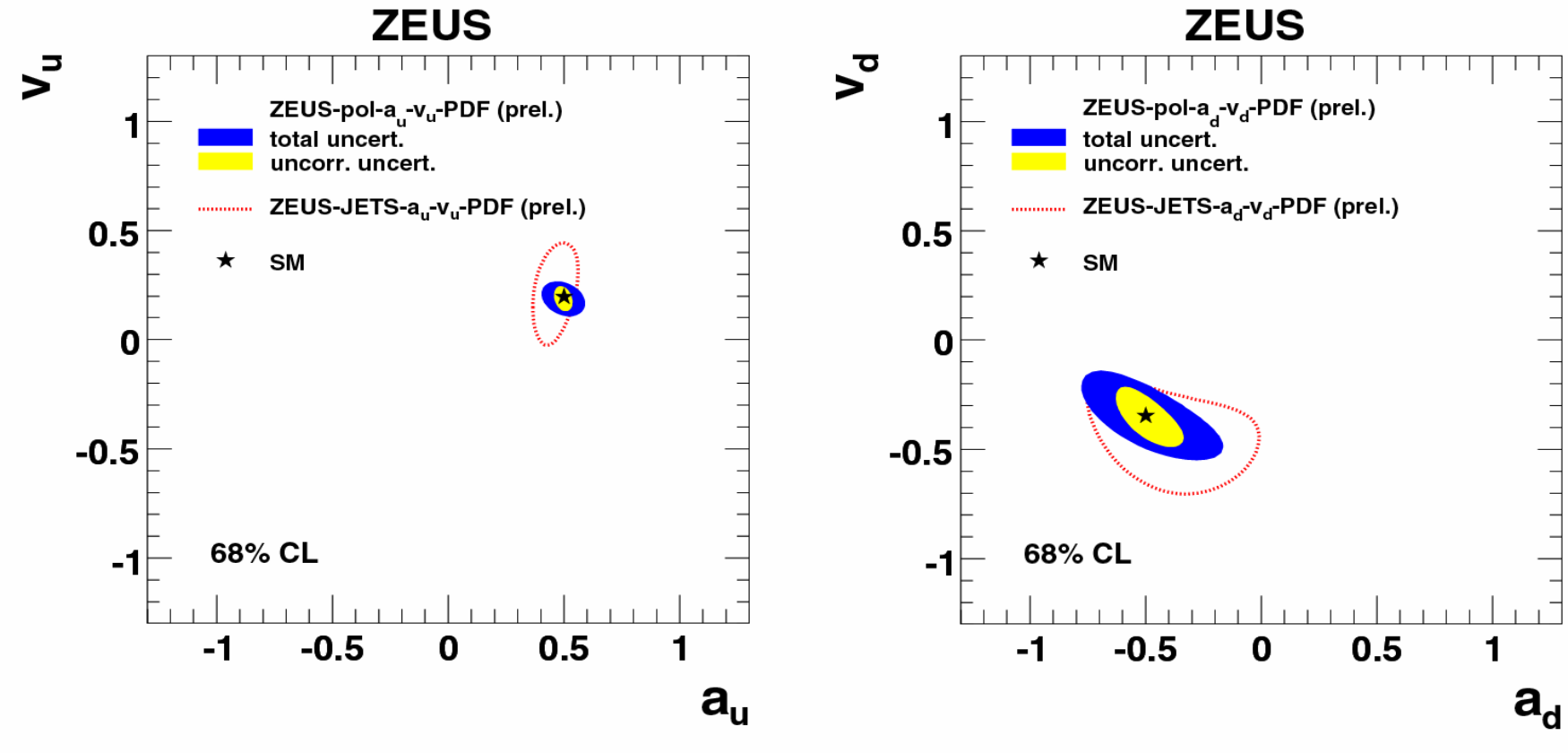
**HERA will run until 30/June/2007 to collect polarized positron data.**

**Further precise measurements will come soon!**

# Backup slides

# $a_u$-$v_u$ and $a_d$-$v_d$

Two of the vector and axial vector couplings for u and d quarks are freed with PDFs parameters.

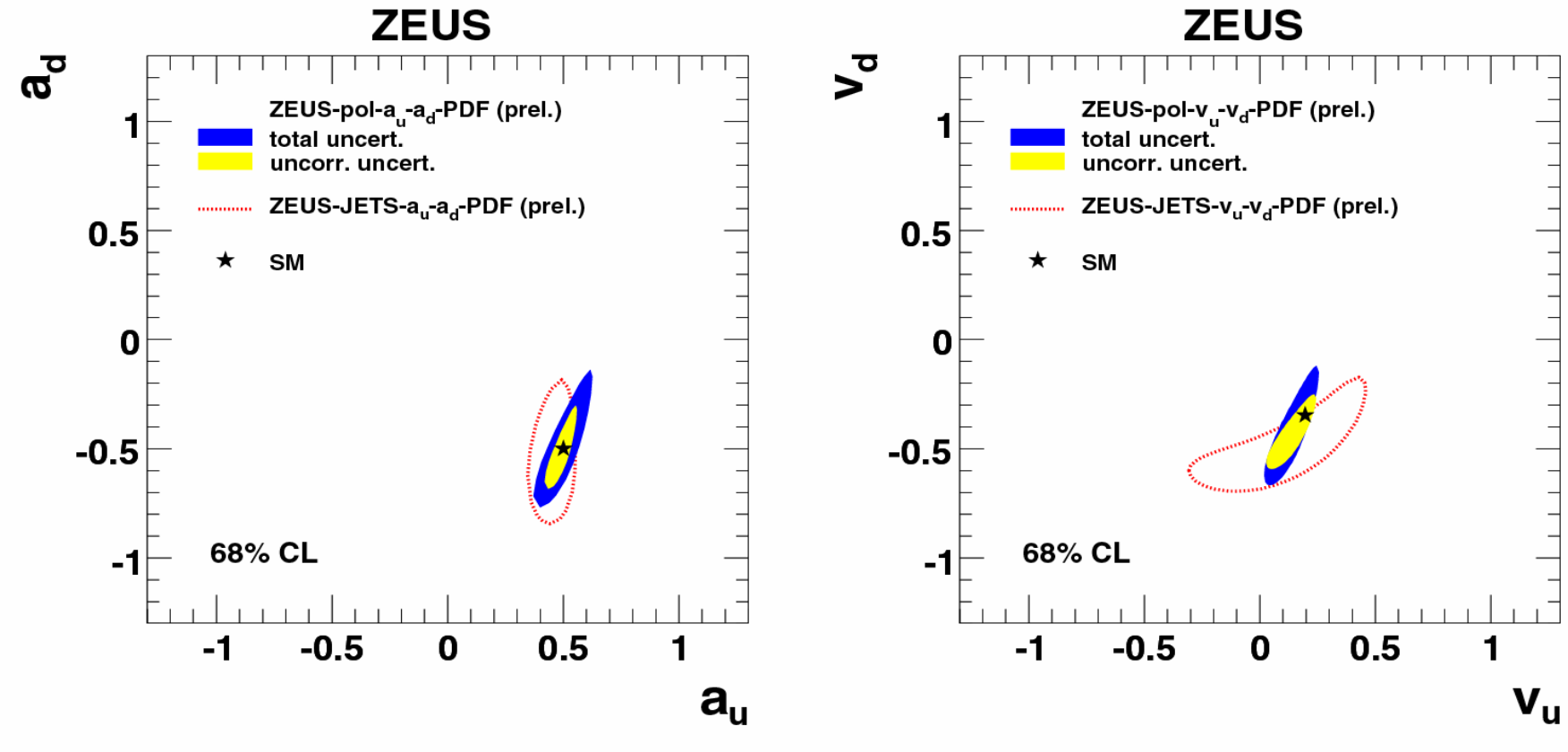



**Clearly, Polarized data improves the vector couplings**

# $a_u$-$a_d$ and $v_u$-$v_d$

LEP and CDF access information on $a_i^2+v_i^2$

But, HERA access information on $a_u$ and $a_d$ from $xF_3^0$, and on $v_u$ and $u_d$ from $F_2^P \rightarrow$ stronger correlations between a flavor




**Improvement is evident**

# Extension of SM formalism

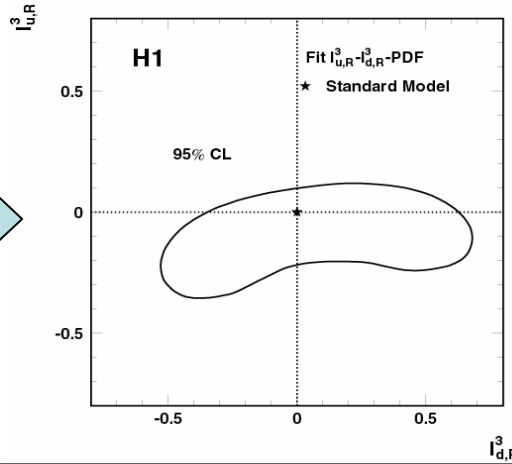
$$a_q = T^3_{q,L} + T^3_{q,R}$$
$$v_q = T^3_{q,L} - T^3_{q,R} - 2e_q \sin^2\theta_W$$

The extension to include right-handed isospin.

The left-handed couplings $T_{q,L}{}^3$ were fixed to SM values but the right handed couplings were freed.

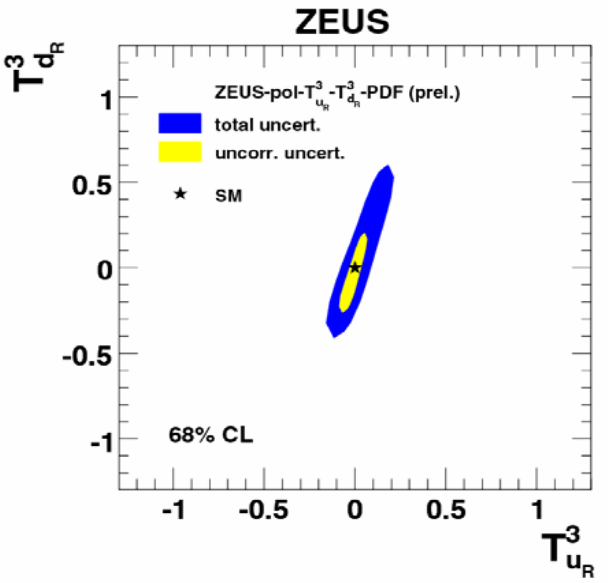
$\sin^2\theta_W$ was also freed in a further fit

**HERA-I**




| | ZEUS-POL-$T_{u,R}{}^3$-$T_{d,R}{}^3$ |
|---|---|
| $T_{u,R}{}^3$ | -0.04±0.06±0.13 |
| $T_{u,L}{}^3$ | -0.14±0.18±0.33 |
| | ZEUS-POL-$T_{u,R}{}^3$-$T_{d,R}{}^3$-$\sin^2\theta_W$ |
| $T_{u,R}{}^3$ | -0.07±0.07±0.07 |
| $T_{u,L}{}^3$ | -0.26±0.19±0.19 |
| $\sin^2\theta_W$ | -0.238±0.011±0.023 |

**HERA-II**




**Consistent with their SM values**