High Q^2 Cross Sections and Electroweak Studies at HERA

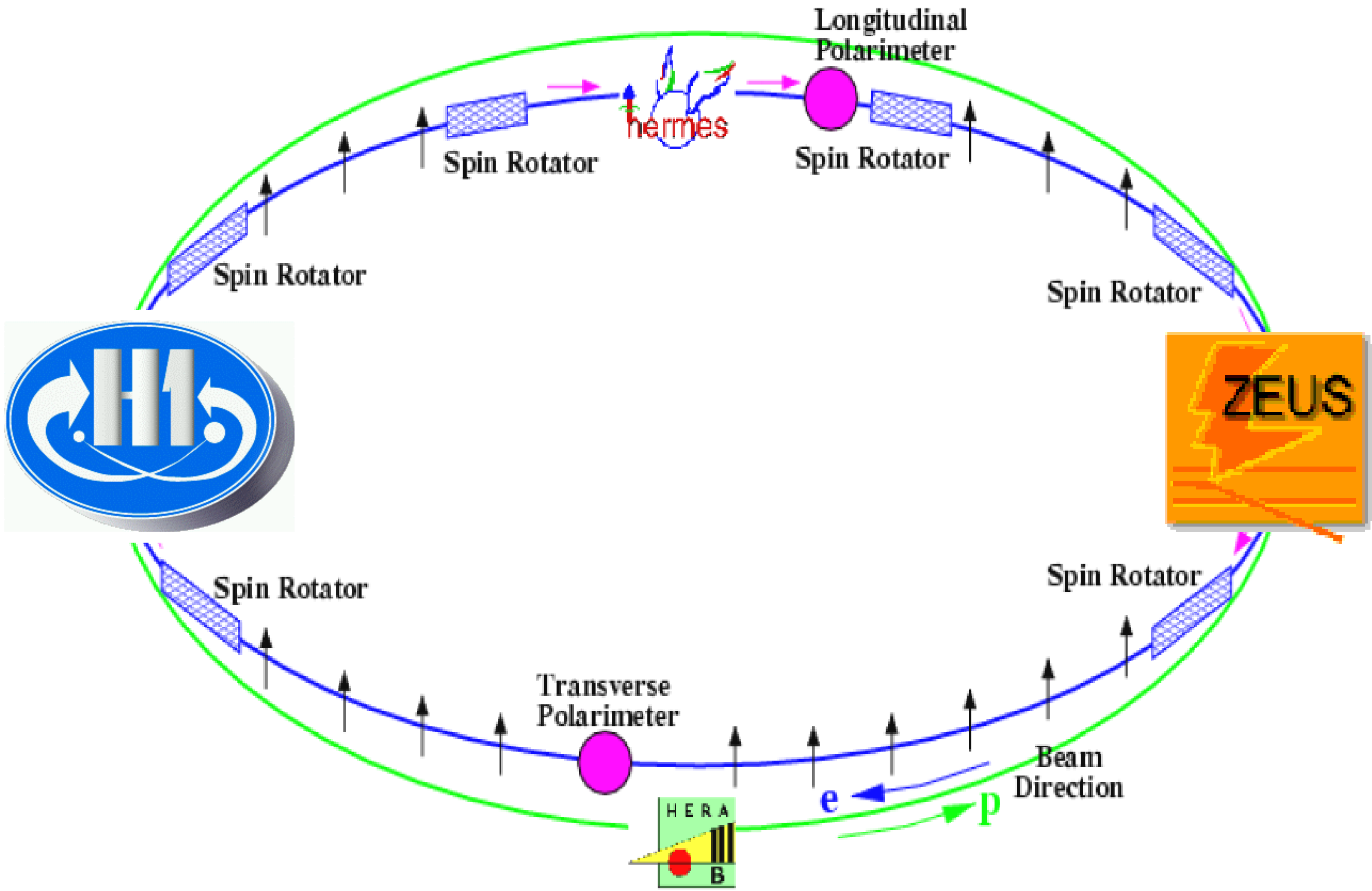
Lake Louis Winter Institute 2007

Steve Aplin
Deutsches Elektronen-Synchrotron

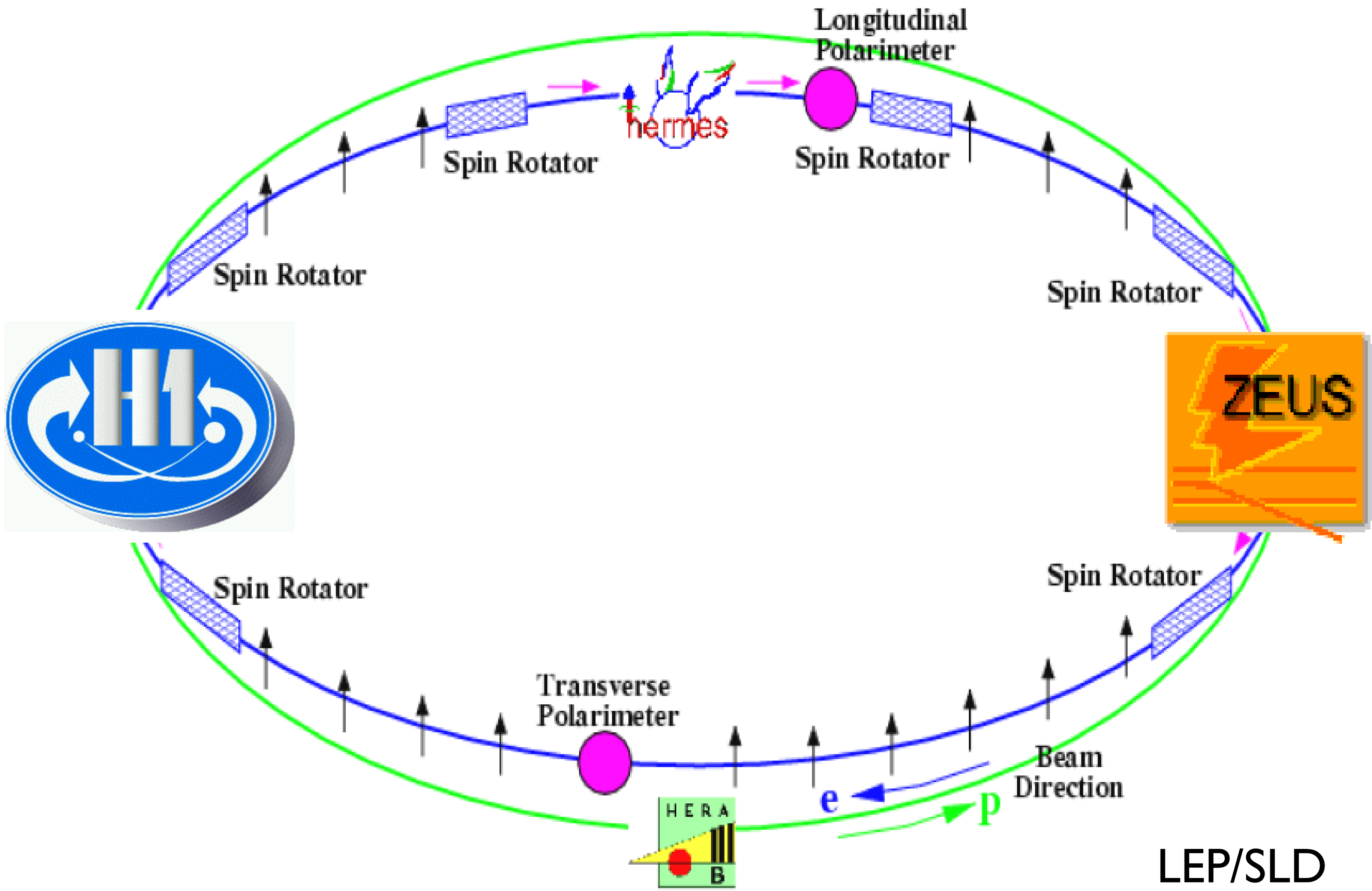
On behalf of the H1 and ZEUS collaborations

HERA

HERA


Longitudinal
Polarimeter
hermes
Spin Rotator
Spin Rotator
Spin Rotator
Spin Rotator
ZEUS
Spin Rotator
Spin Rotator
Transverse
Polarimeter
Beam
Direction
e
p
HERA
B

HERA



Longitudinal
Polarimeter
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ZEUS
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Direction
e
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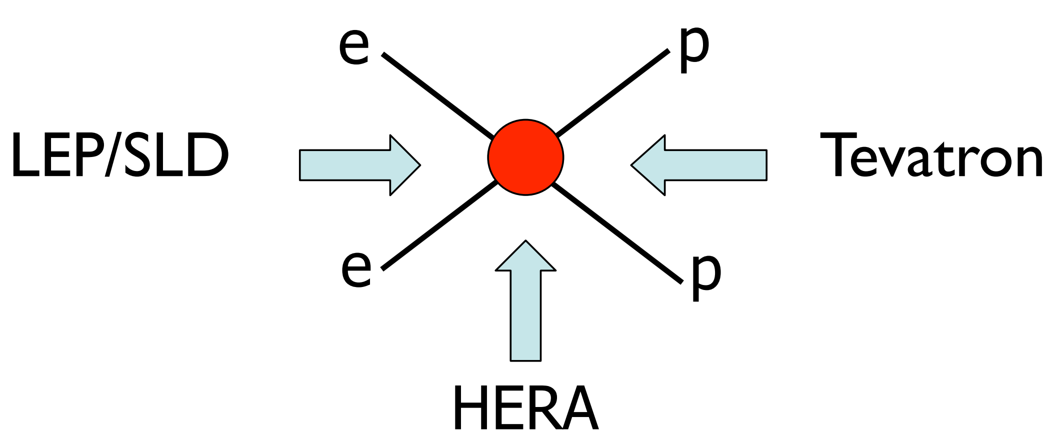
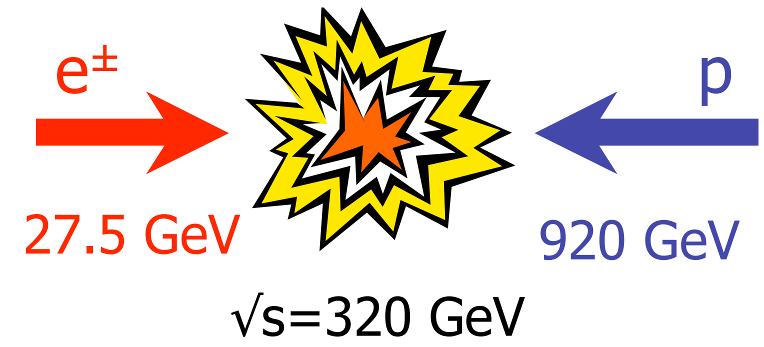
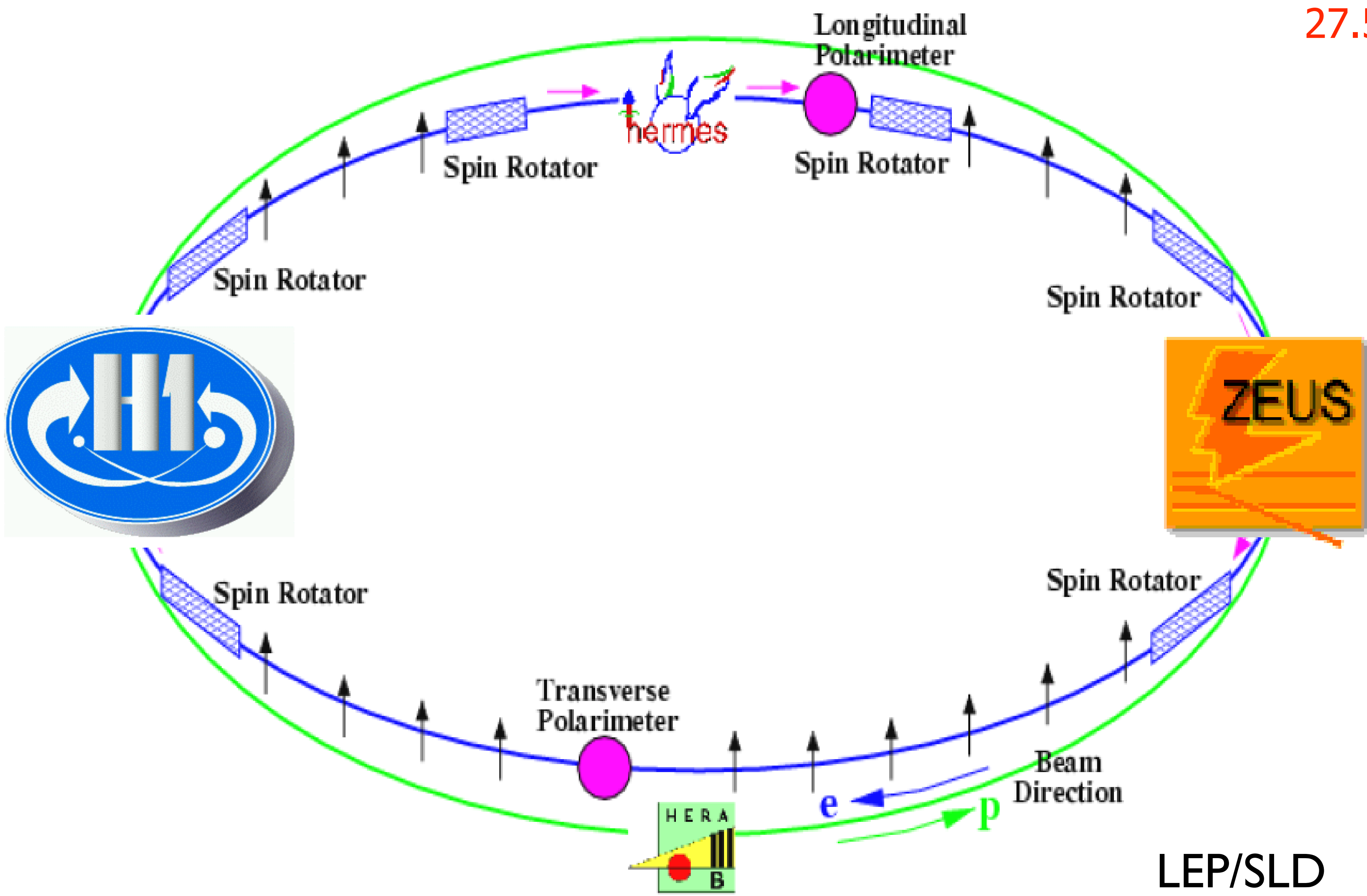
HERA
B



e
p
LEP/SLD
Tevatron
e
p
HERA

HERA


e±
p
27.5 GeV
920 GeV
√s=320 GeV


Longitudinal Polarimeter
hermes
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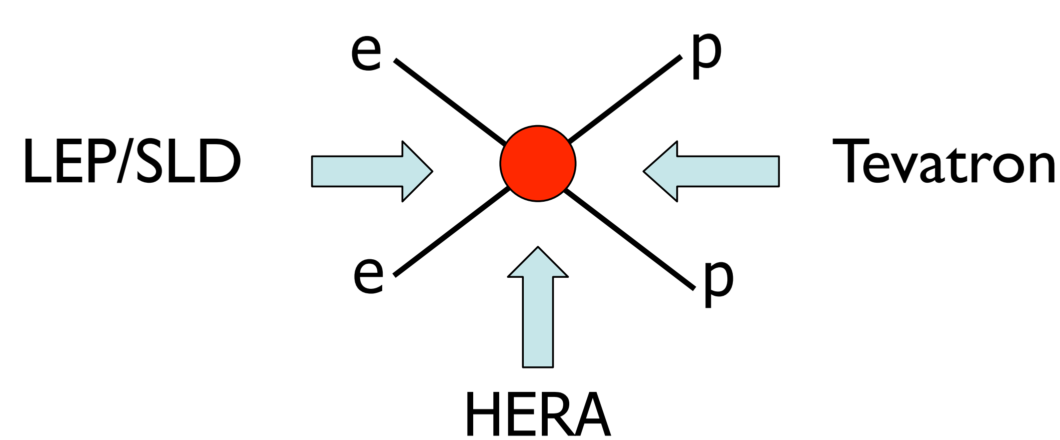
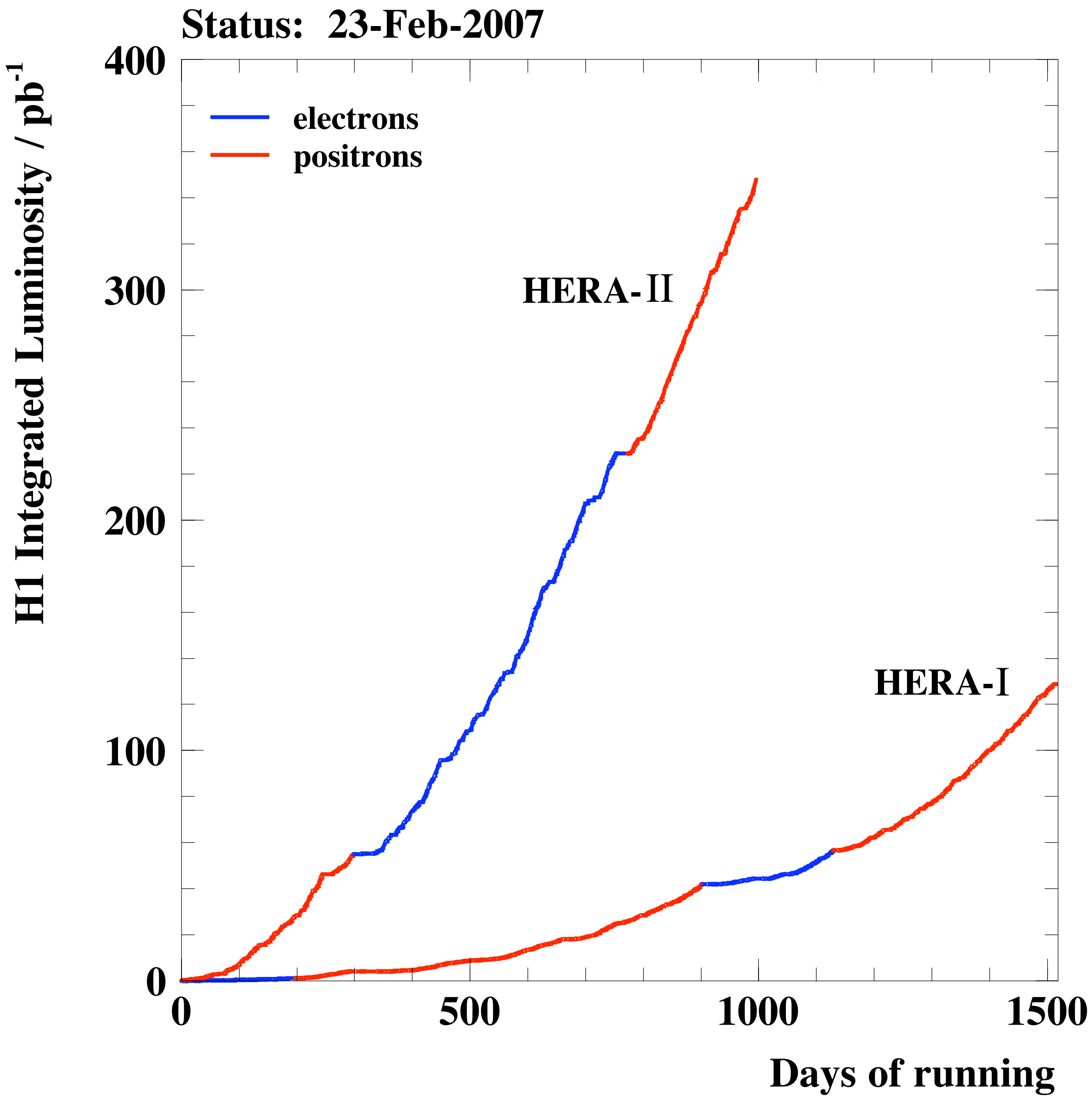
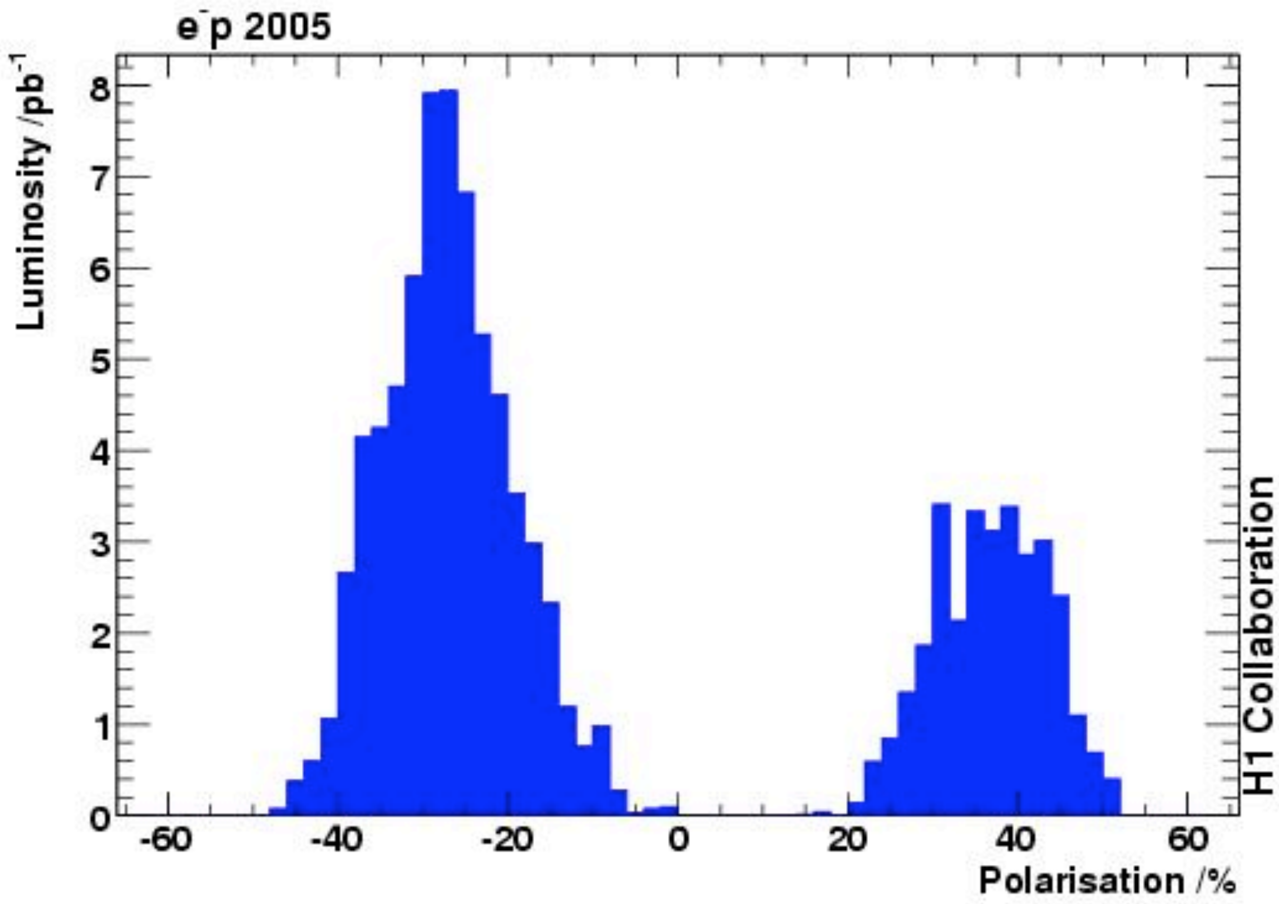
Transverse Polarimeter
HERA B
e
p
Beam Direction


e
p
LEP/SLD
Tevatron
e
p
HERA

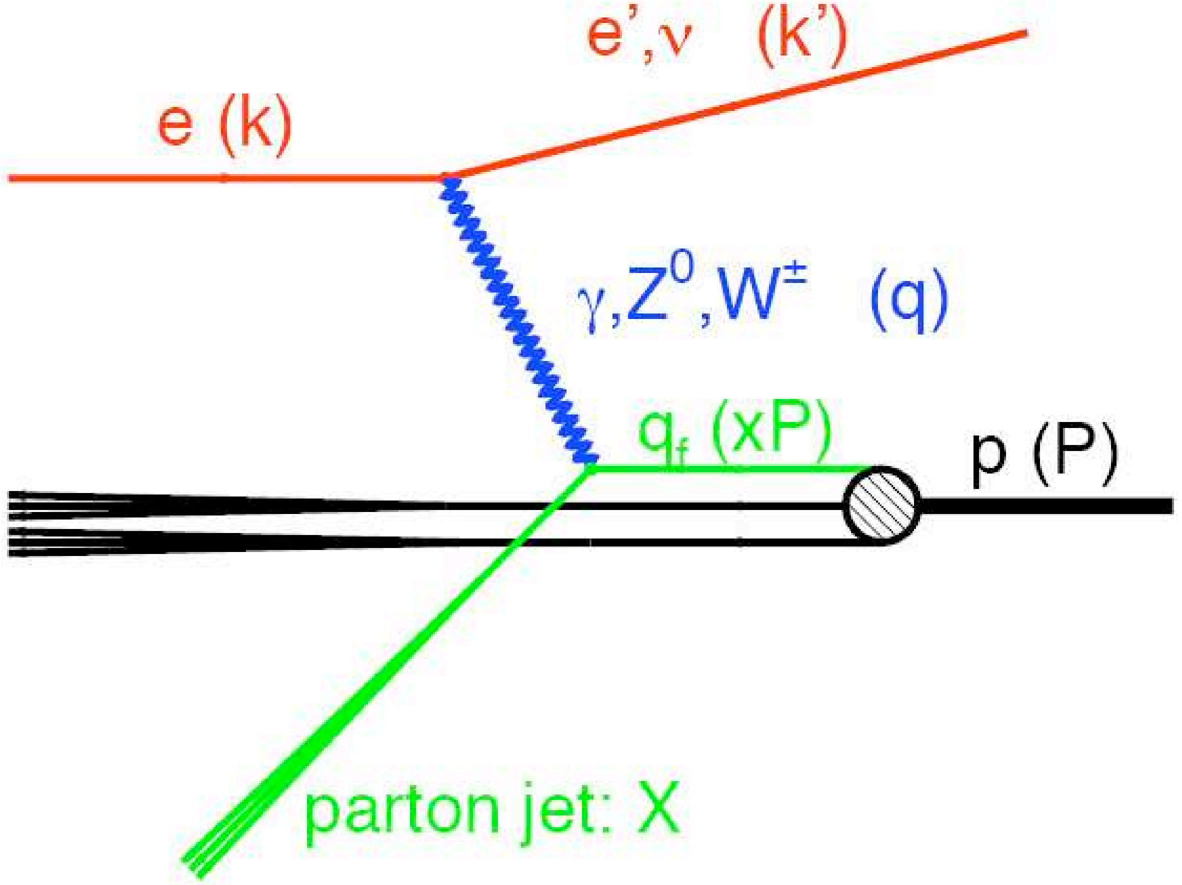
Luminosity and Polarisation



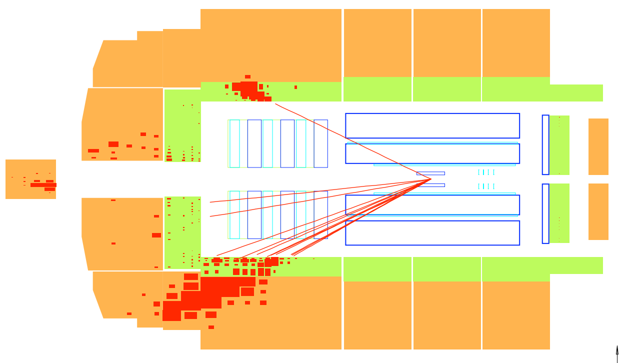


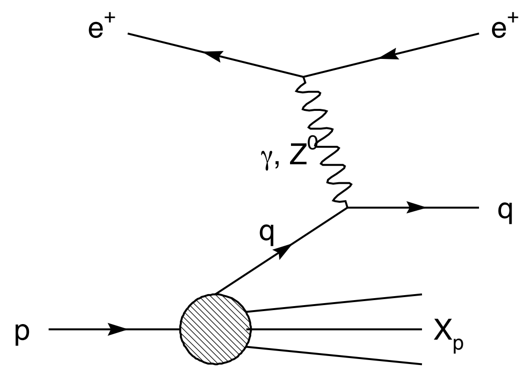
Deep Inelastic Scattering

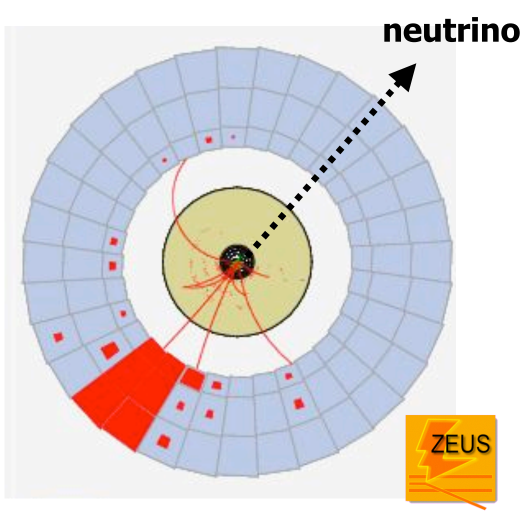
$$Q^2 = -q^2$$
$$x = Q^2 / 2(P \cdot q)$$
$$y = (P \cdot q)/(P \cdot k)$$
$$Q^2 = x\, y\, s$$

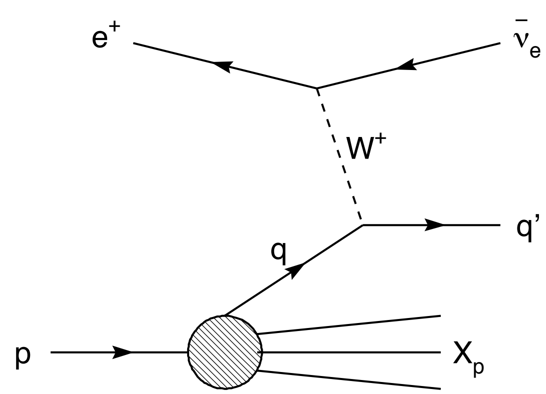


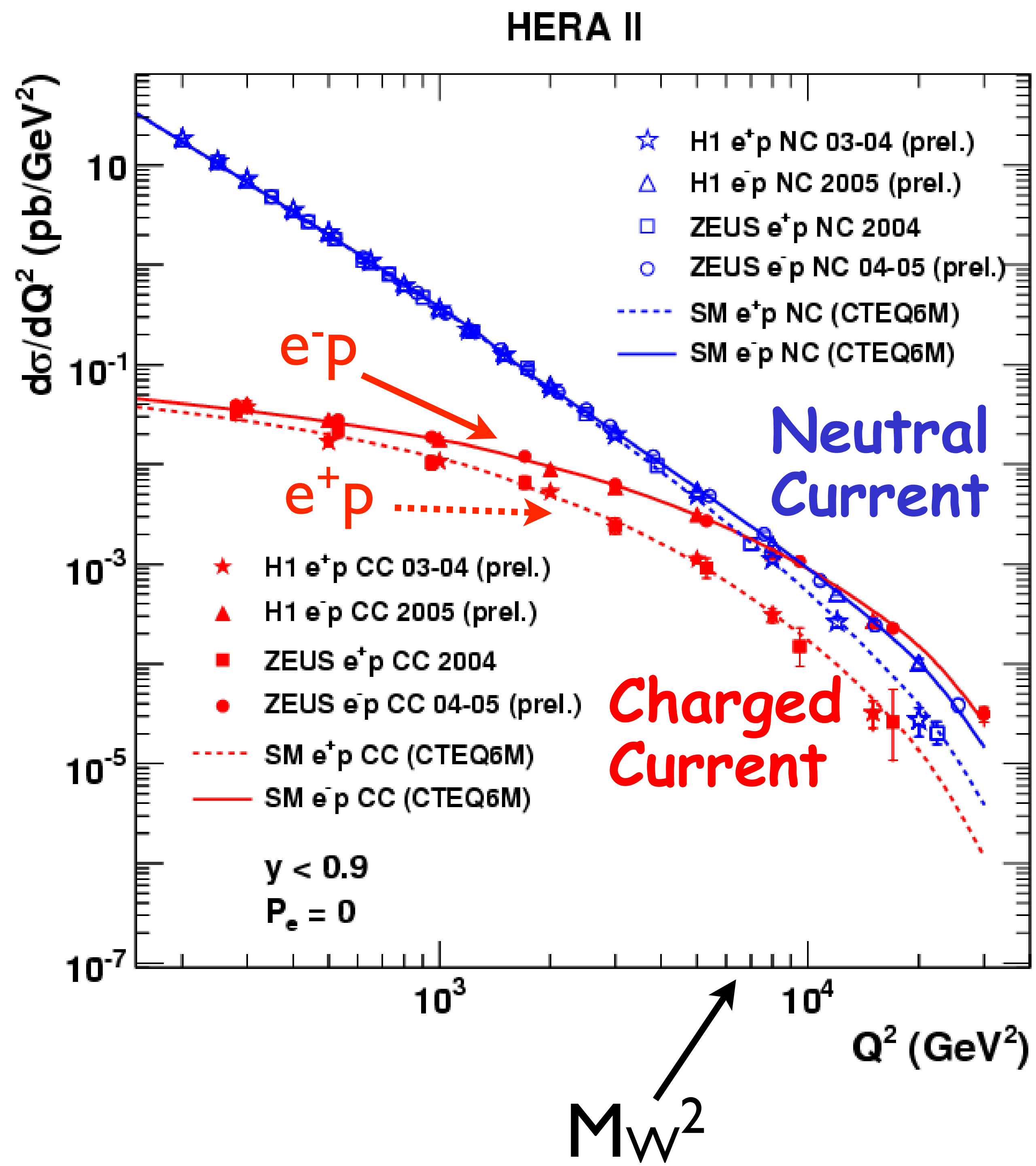
Neutral and Charged Currents







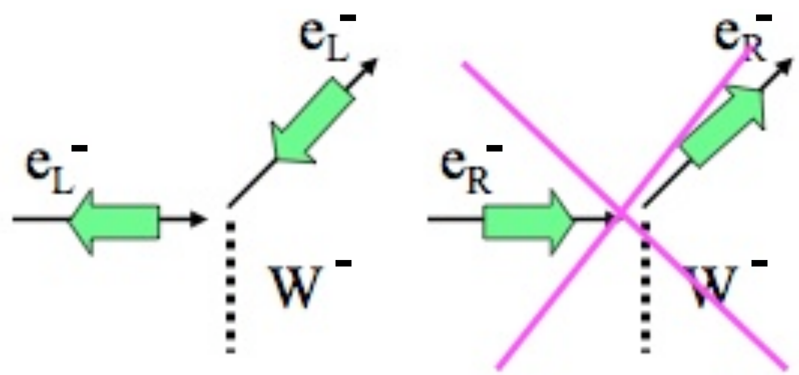




Charged Current Cross Section vs P_e

Standard Model weak interaction left-handed

– only LH particles (RH anti-particles) interact

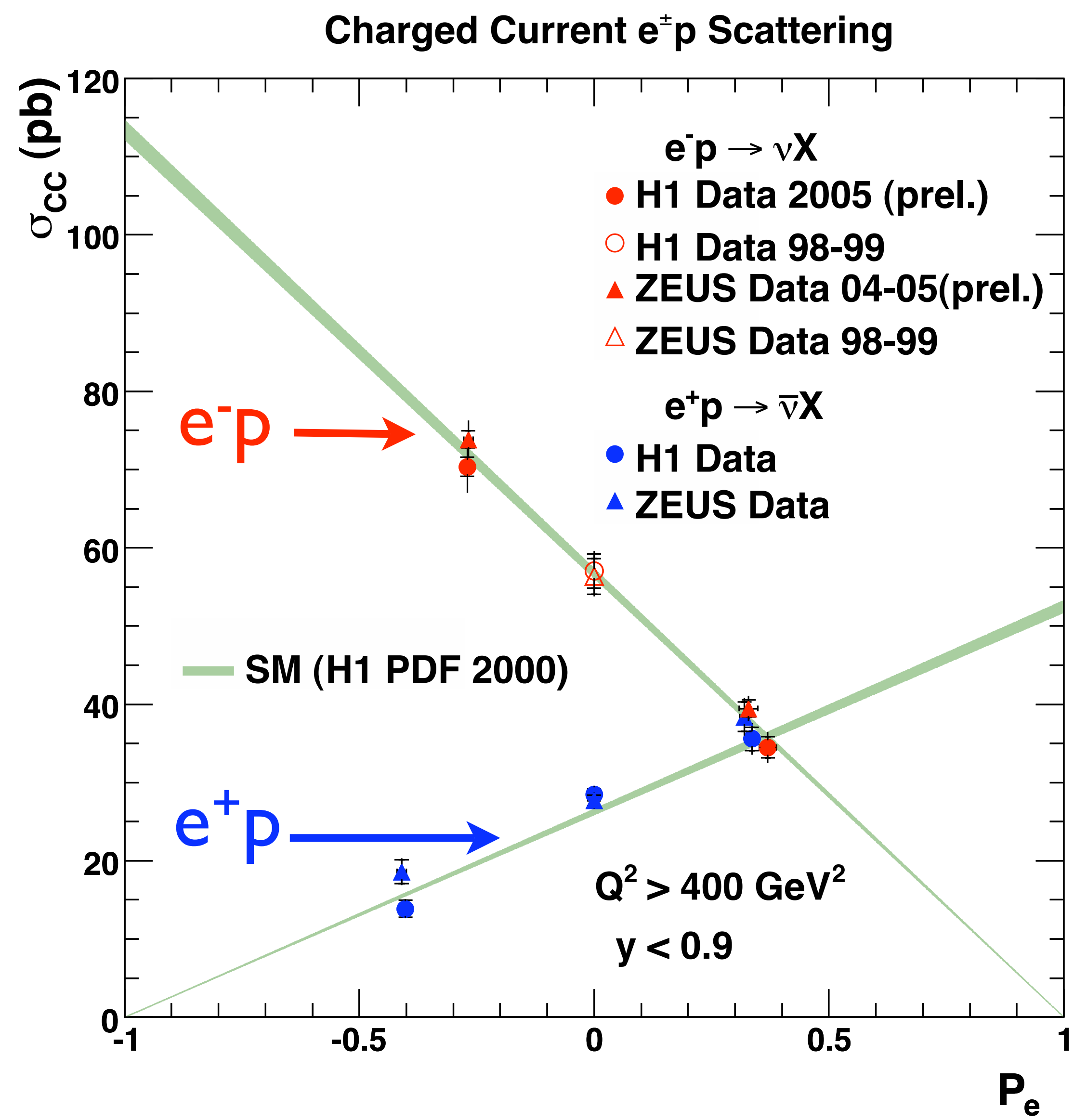


Polarisation is asymmetry of the helicity states

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

CC cross section modified by P_e:

$$\sigma_{CC}^{e^\pm p}(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^{e^\pm p}(P_e = 0)$$



- Measurement shows the expected linear dependence on P_e
- Extrapolation to $P_{e-} = +1$, $P_{e+} = -1$ absence of RH charged currents
- *$M(W_R) \gtrsim 200$ GeV @ 95% CL*

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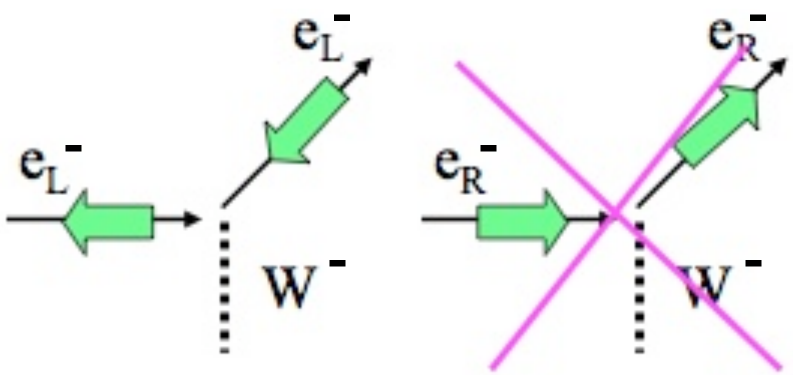

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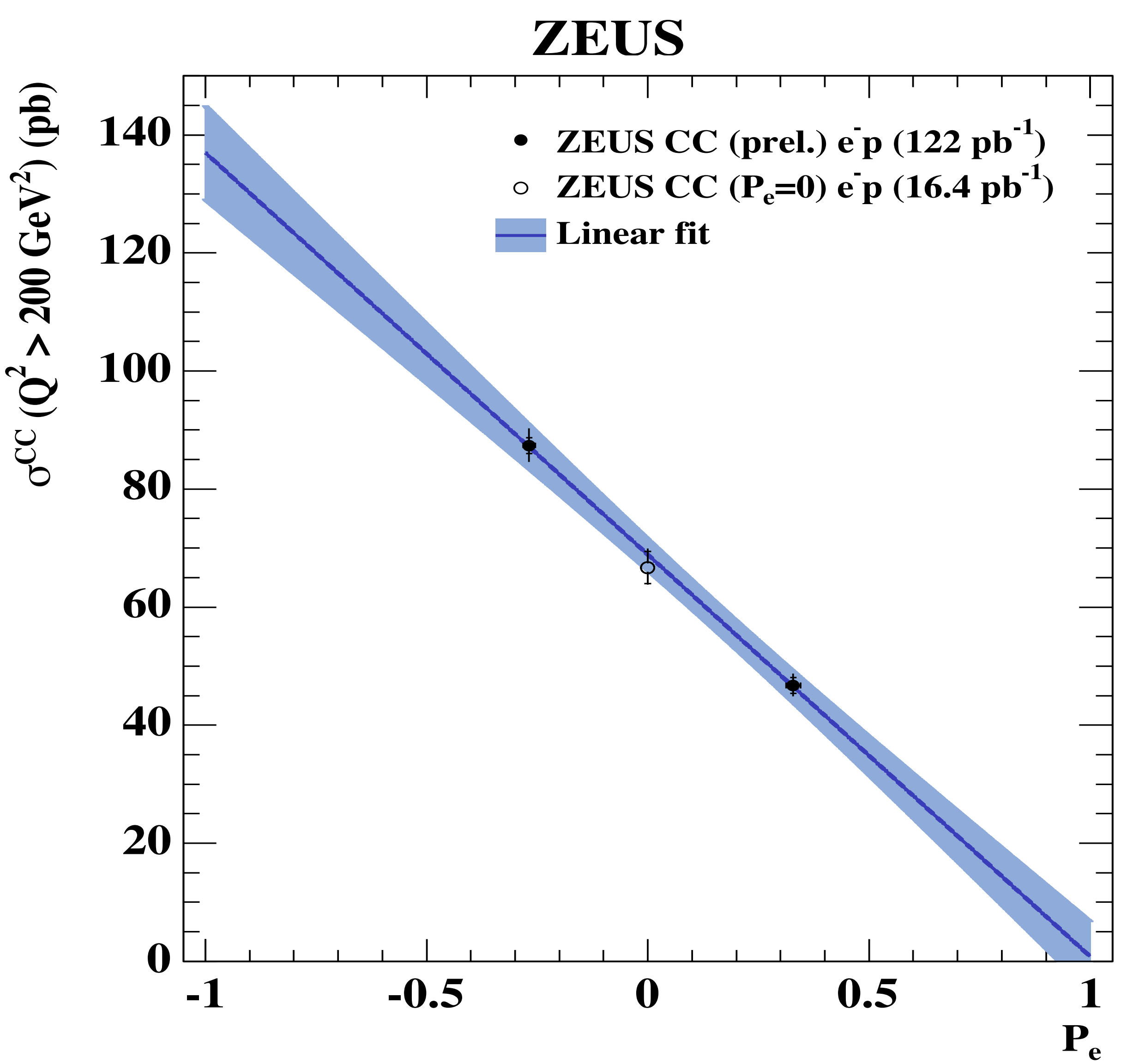

Neutral Current Cross Section

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left[F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right] \qquad Y_\pm = 1 \pm (1-y)^2$$

Dominant contribution (F_2)

Sizeable only at high y (F_L)

Contribution only important at high Q^2 (xF_3)

$$F_2 = F_2^{em} + \frac{Q^2}{Q^2+M_Z^2} F_2^{\gamma Z} + \left[\frac{Q^2}{Q^2+M_Z^2}\right]^2 F_2^Z \propto \sum_{q=u...b} (q+\bar{q})$$

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Contribution only important at high Q^2 (xF_3)

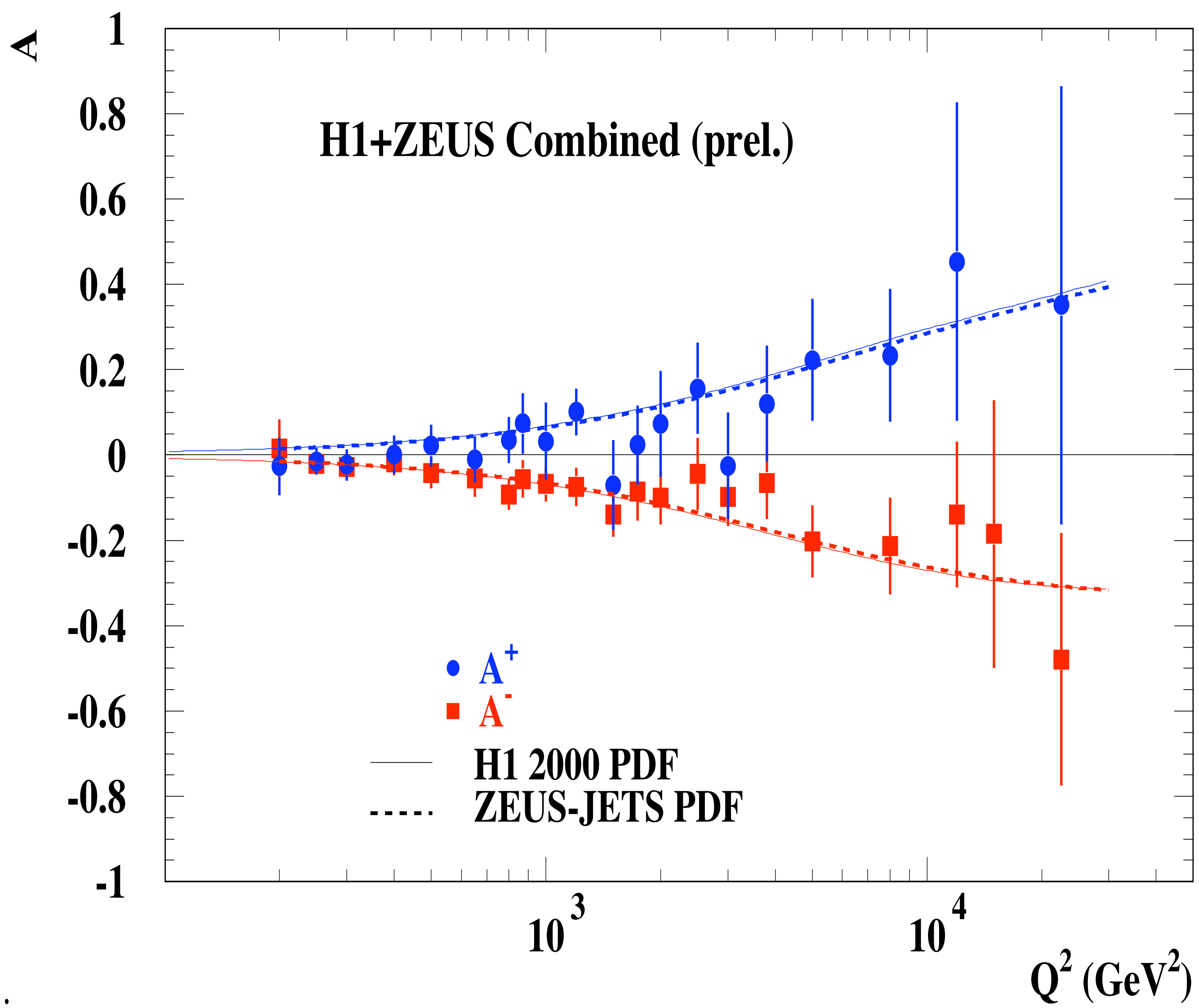
$$\begin{aligned}(F_2, F_2^{\gamma Z}, F_2^Z) &= x\sum(e_q^2, 2e_q v_q, v_q^2 + a_q^2)(q+\bar{q}) \\ (xF_3^{\gamma Z}, xF_3^Z) &= 2x\sum(e_q a_q, v_q a_q)(q-\bar{q})\end{aligned}$$

Polarisation Asymmetry in Neutral Current Cross Section

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

$$A^{\pm} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2} \propto a_e v_q$$

- $\delta A = A^{+} - A^{-}$, only significant at high Q^2
- probability for $\delta A = 0$ at $Q^2 > 5000\ GeV^2$ is $3.1 x 10^{-3}$
- Clear evidence of Parity Violation in NC interactions at distances $< 10^{-18} m$



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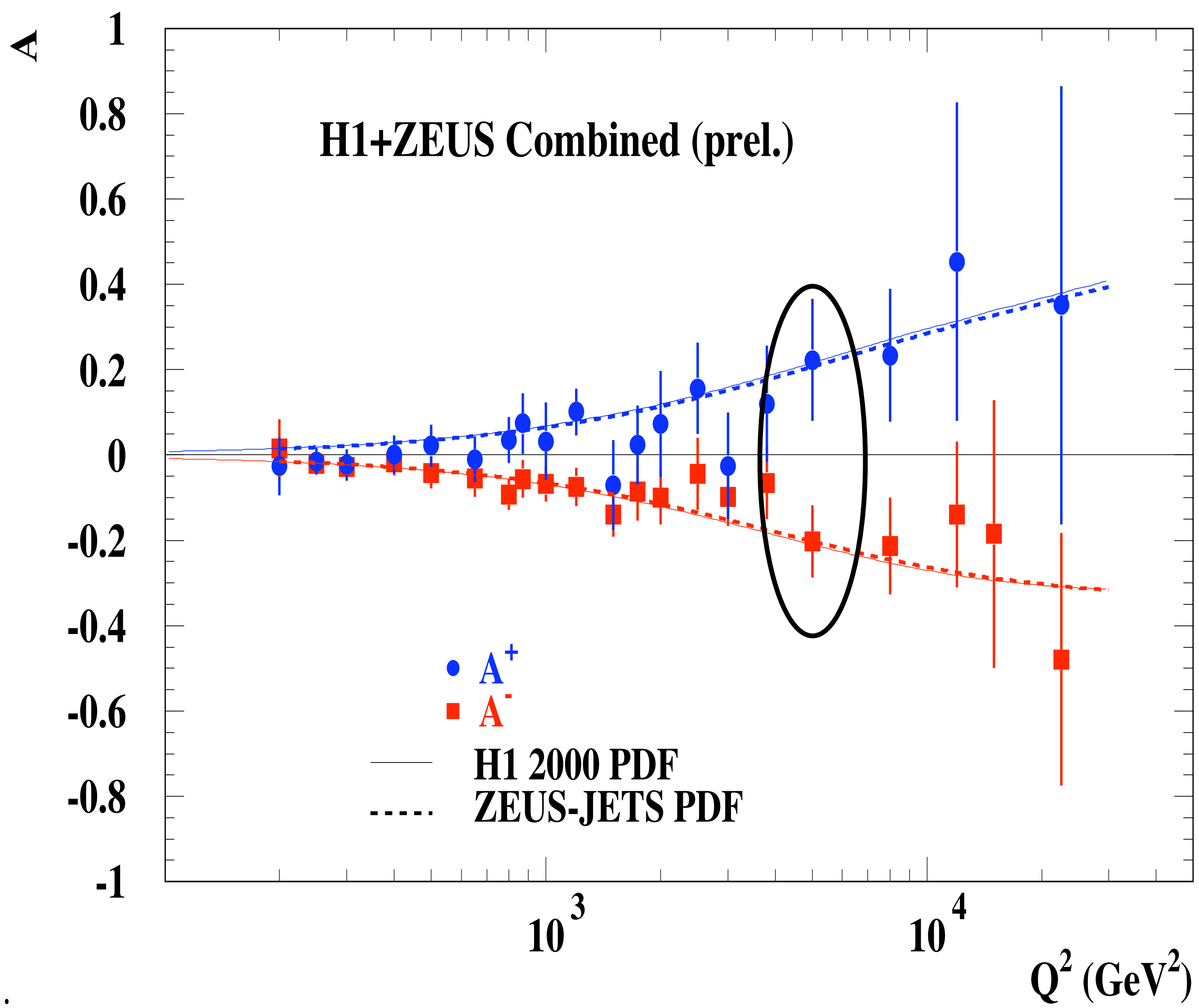
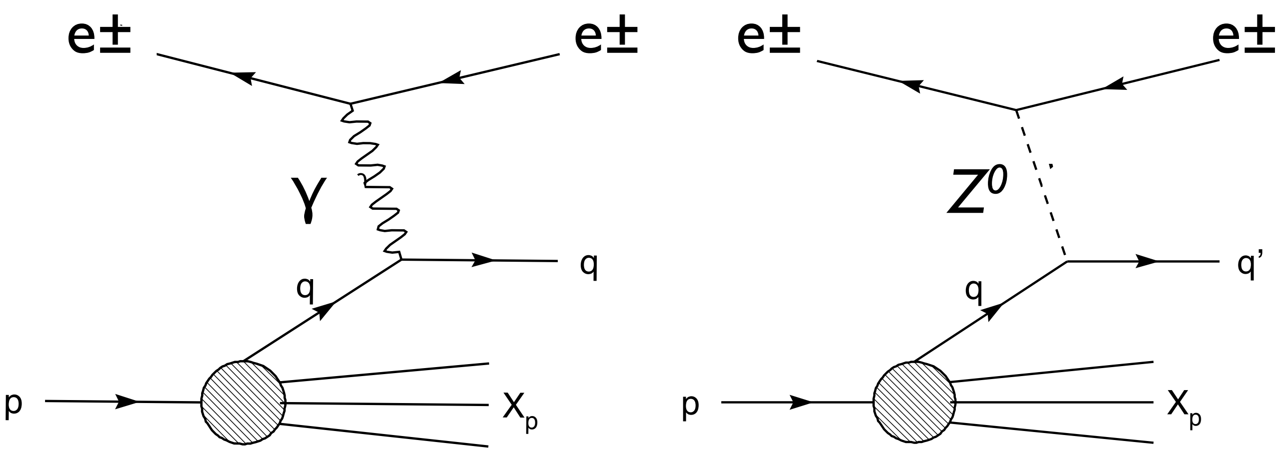
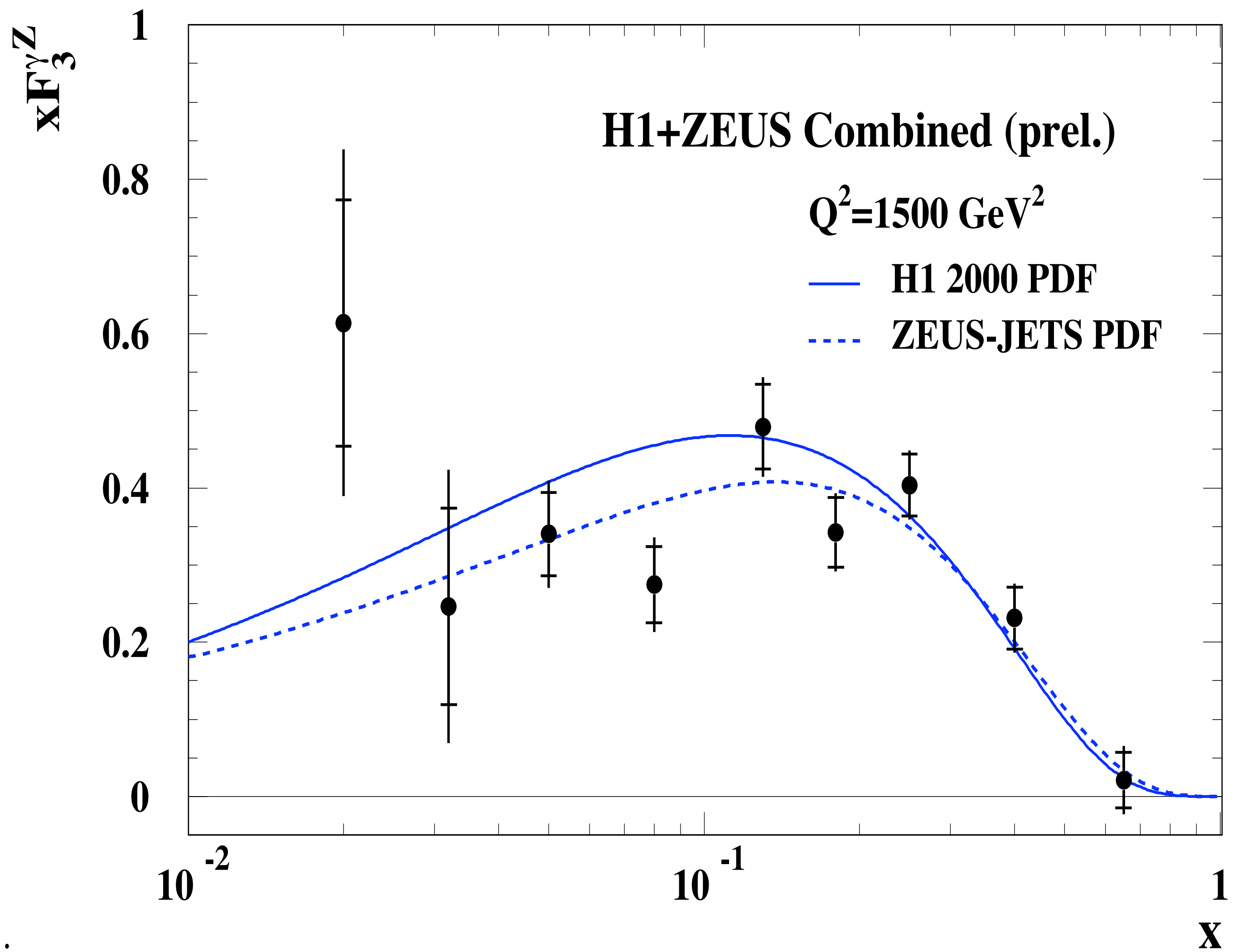


xF_3 Structure Function Neutral Current



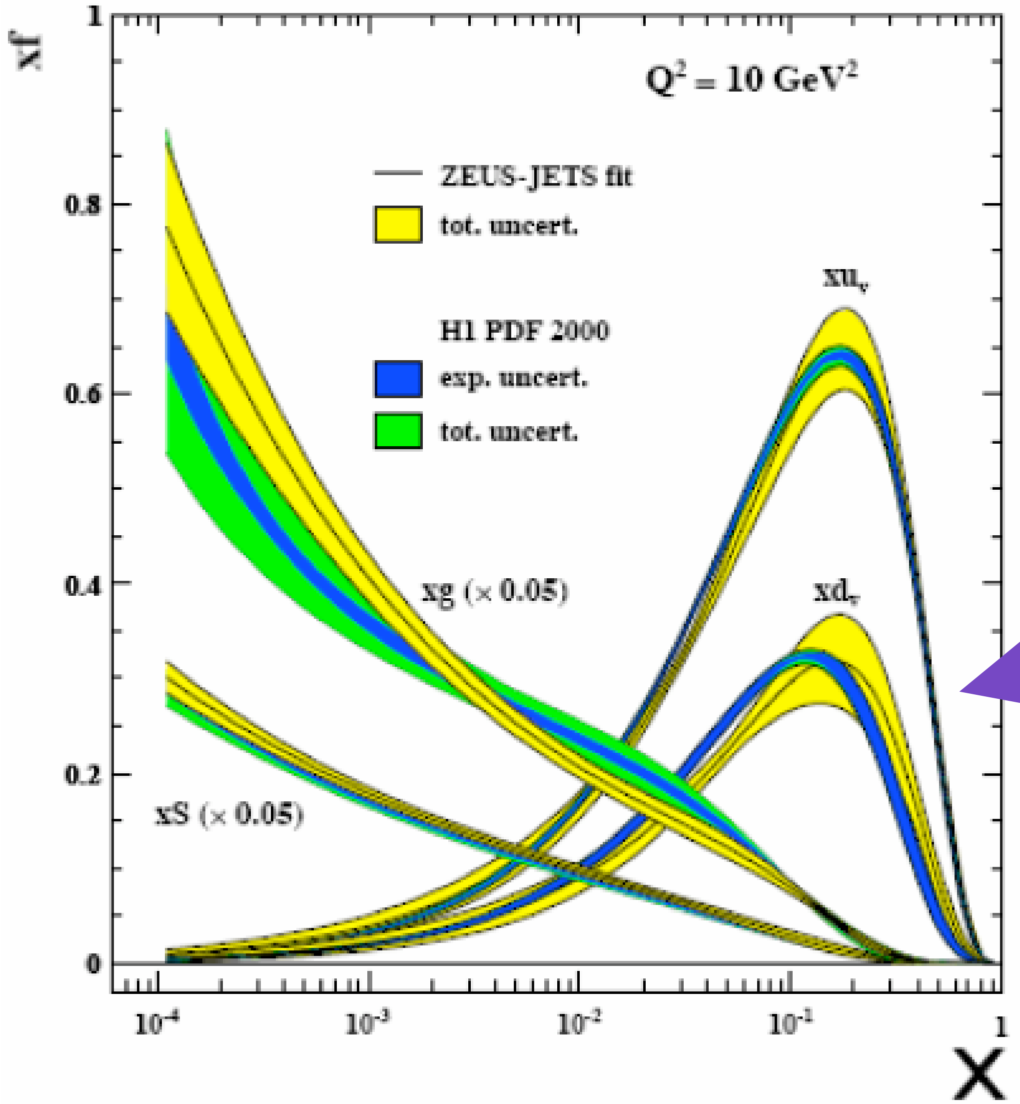
$$xF_3^{\gamma Z} \propto \tilde{\sigma}^- - \tilde{\sigma}^+ \simeq \frac{x}{3}(2u_v + d_v)$$

- γZ^0 interference term flips sign when $e^+ \rightarrow e^-$
- Constrains x dependence of the valence quarks

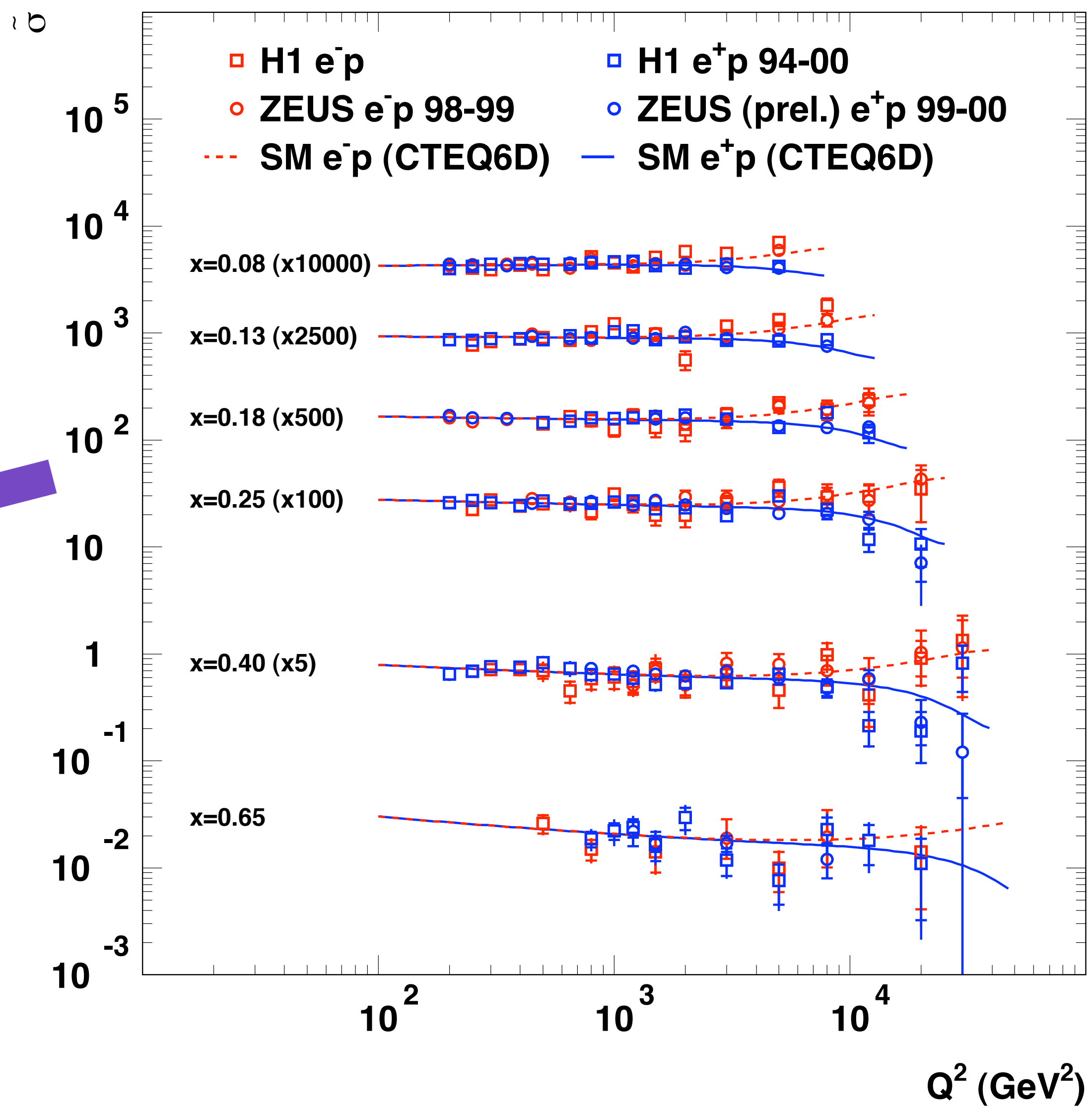


Extraction of Parton Density Functions

(From HERA I Data)



HERA Neutral Current at high x

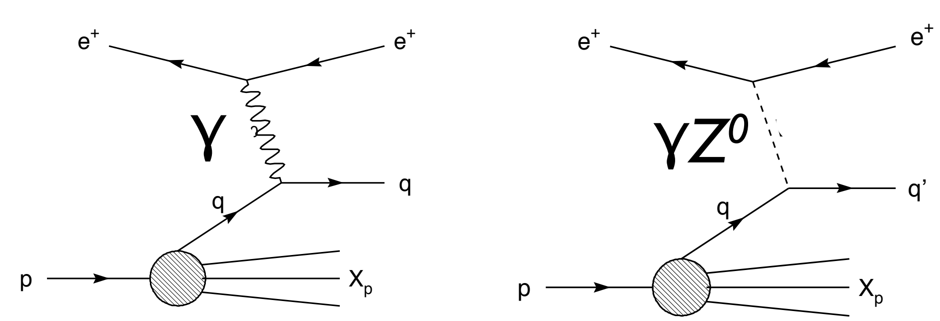


Low x sea, gluons constrained by F_2 at low Q^2

high x u,d valance quarks constrained by high Q^2

NC and CC cross sections

medium x gluon constrained by jet data



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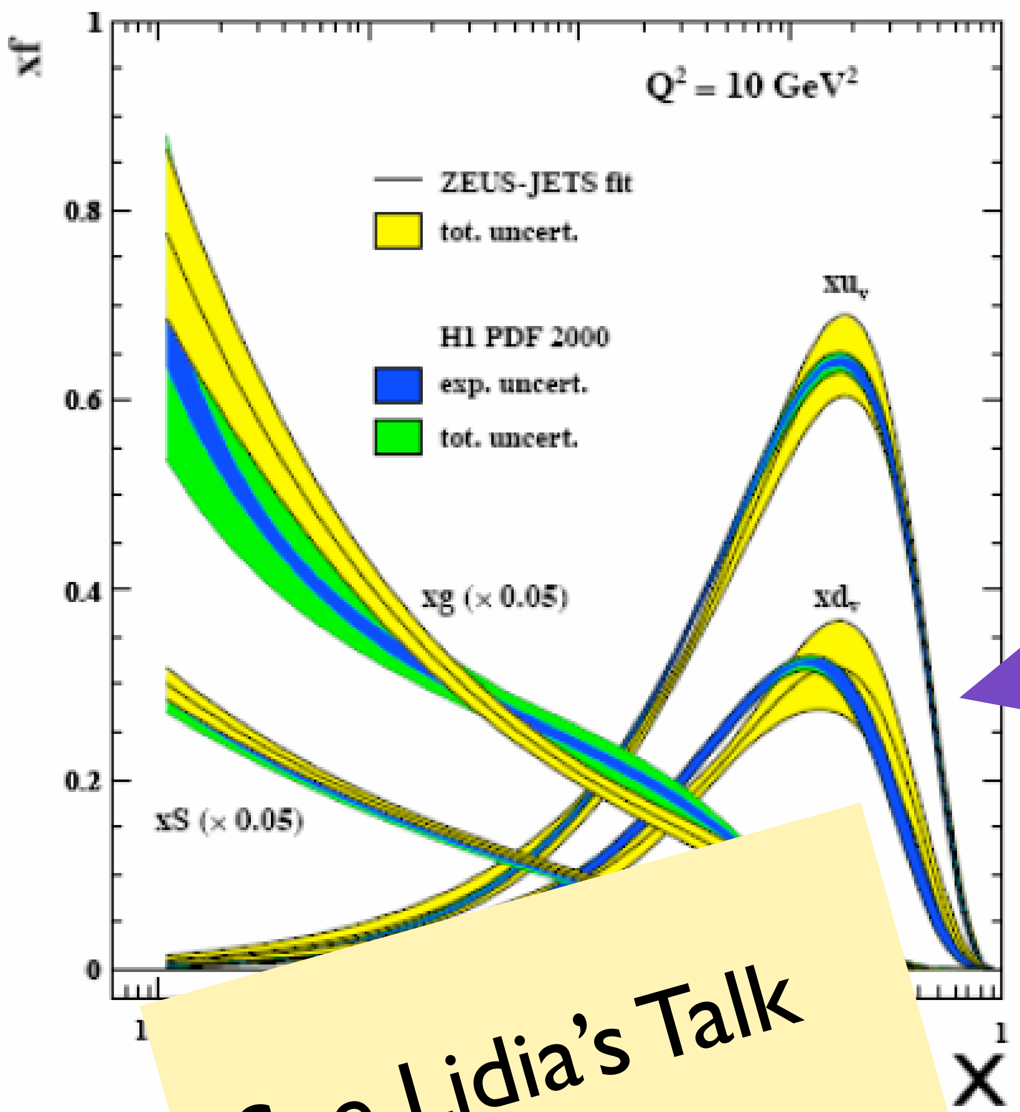
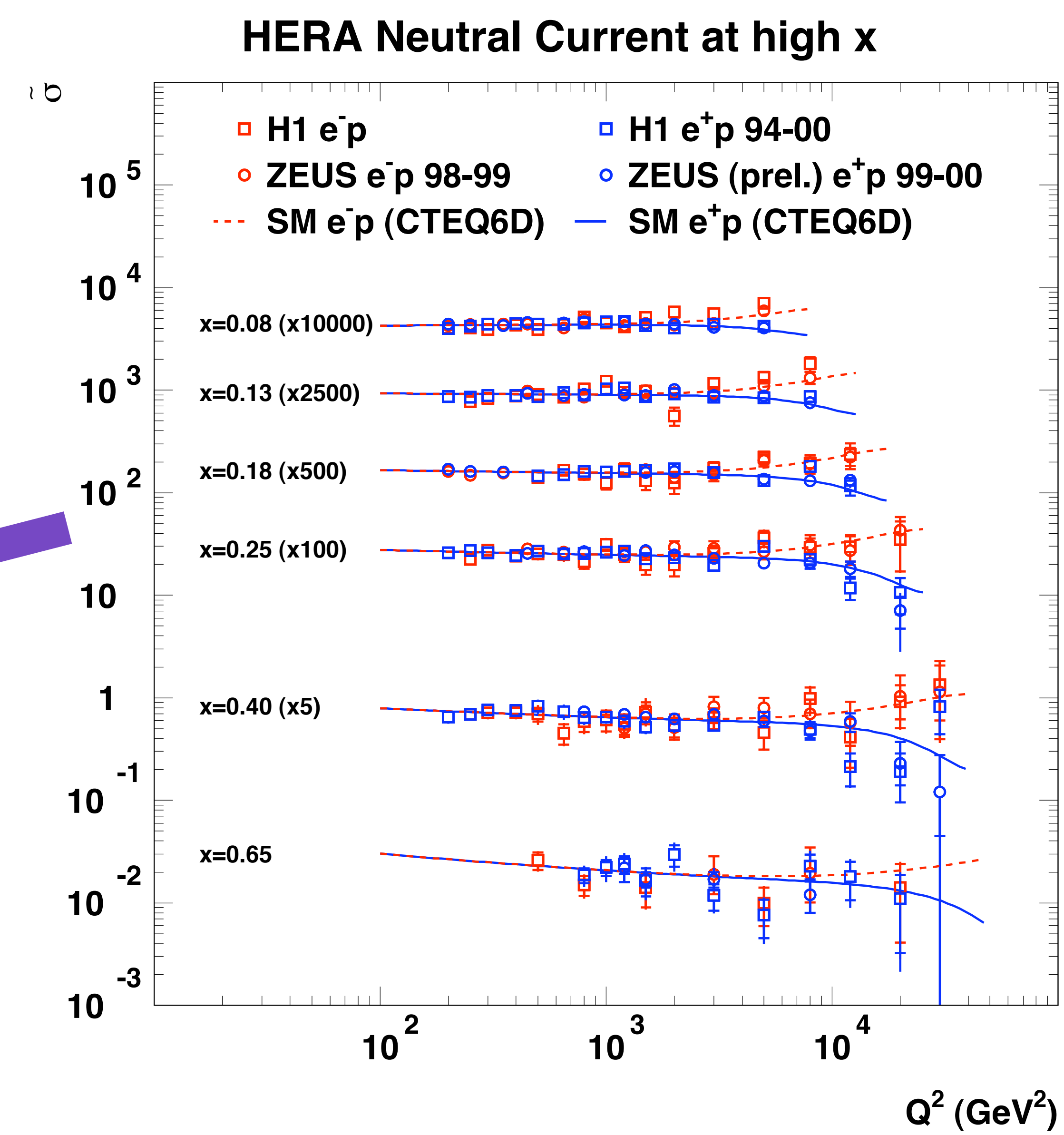
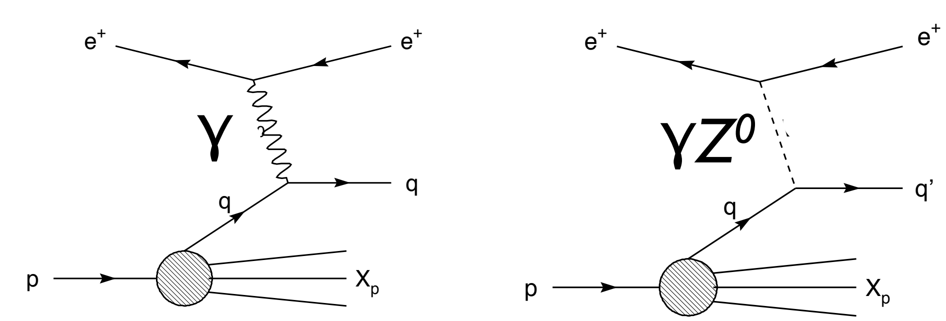


See Lidia's Talk





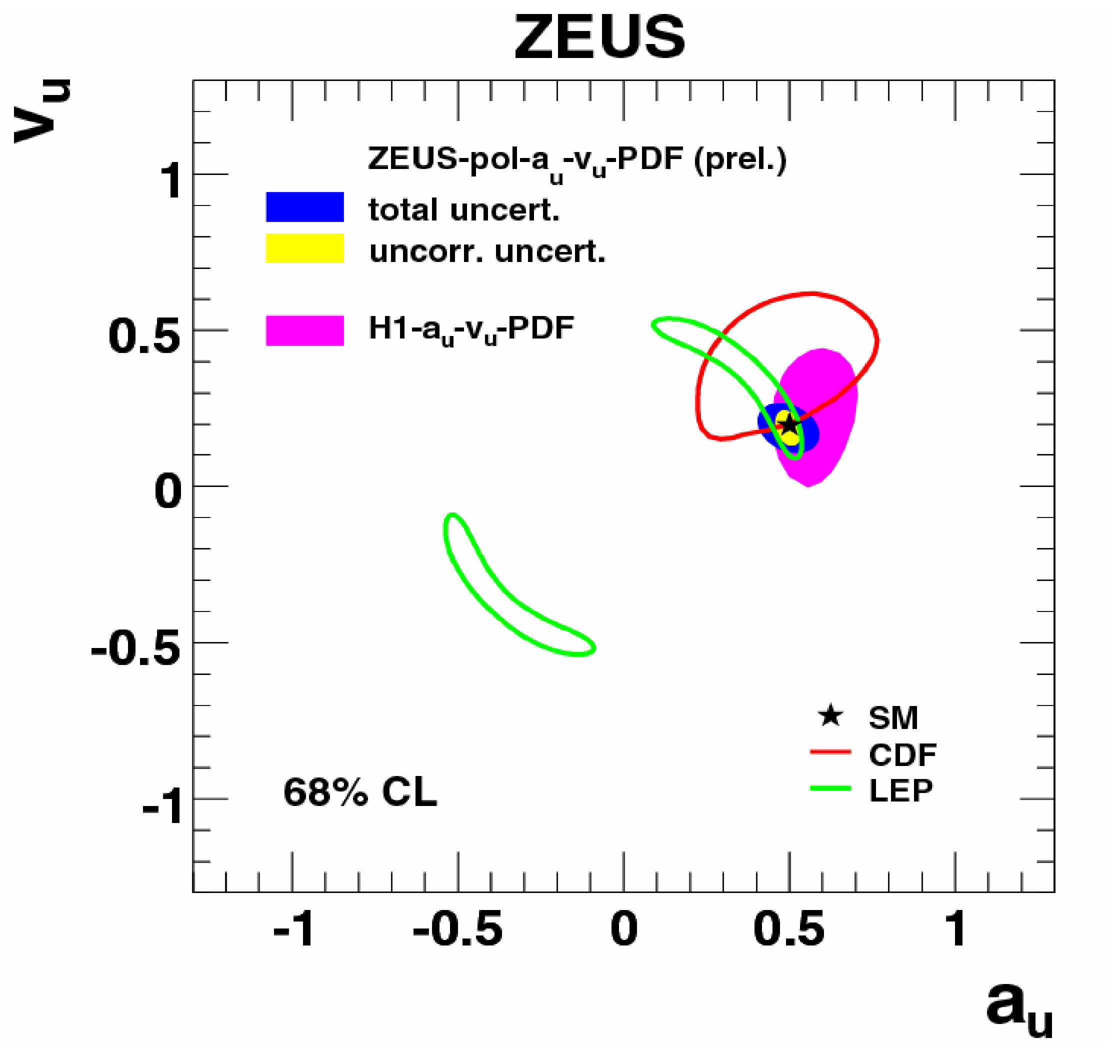
Low x s[illegible]strained by F_2 at low Q^2

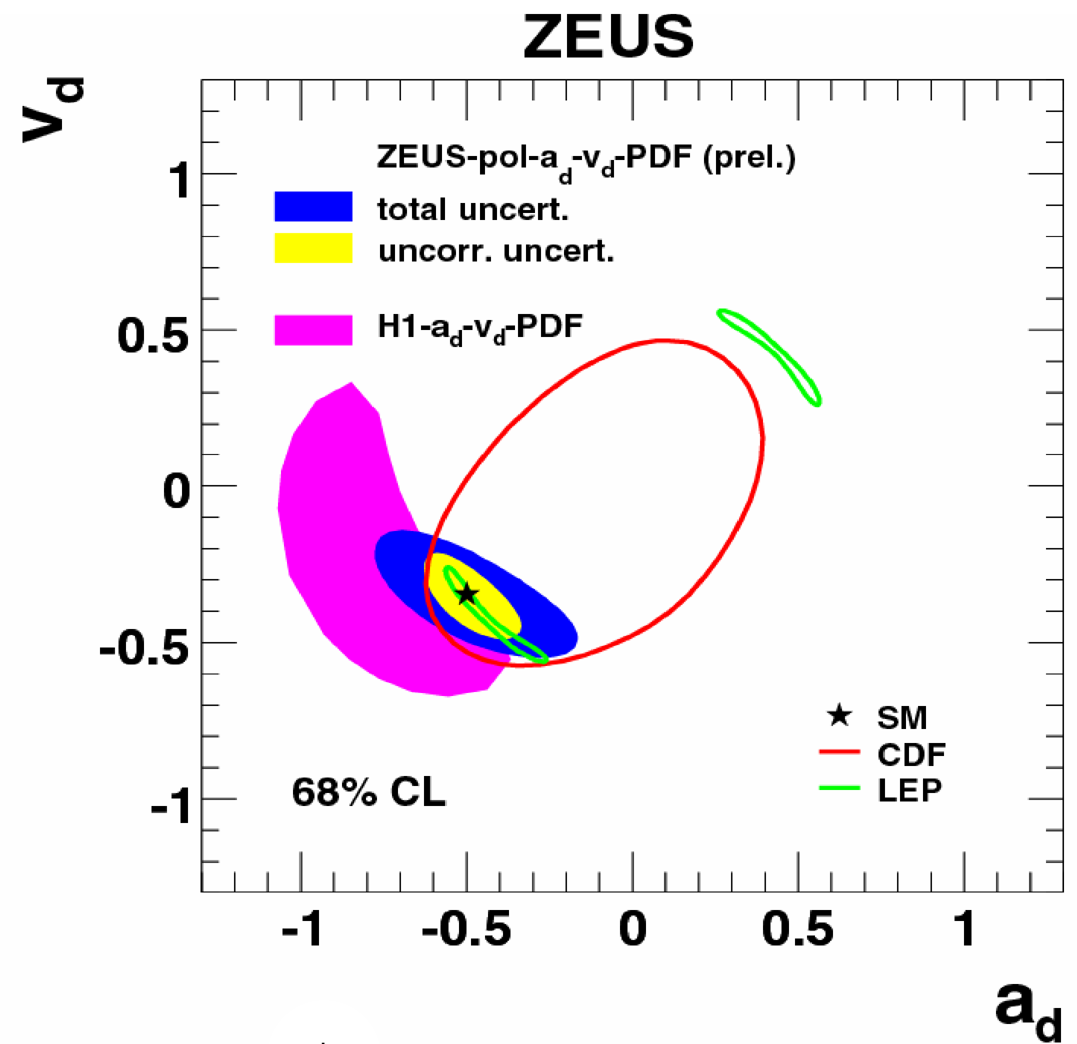
high x u,d valance quarks constrained by high Q^2

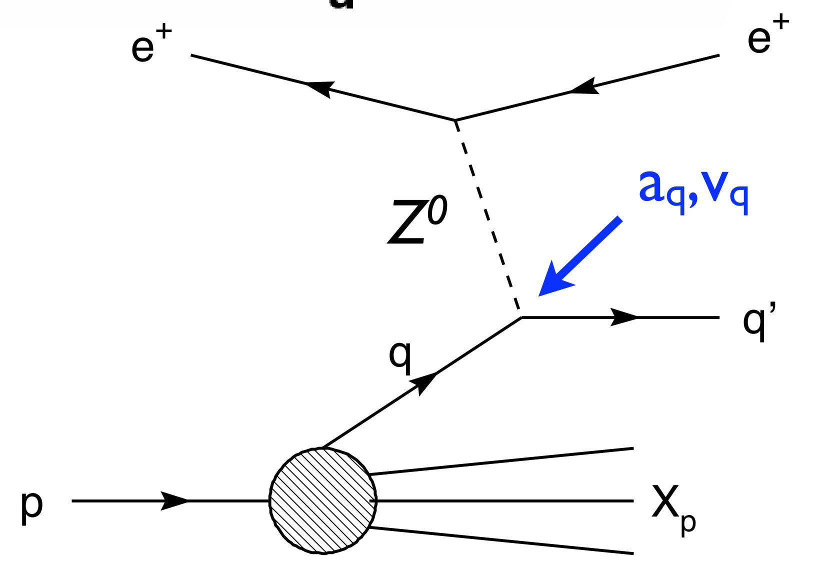
NC and CC cross sections

medium x gluon constrained by jet data

Fits of Electroweak Parameters







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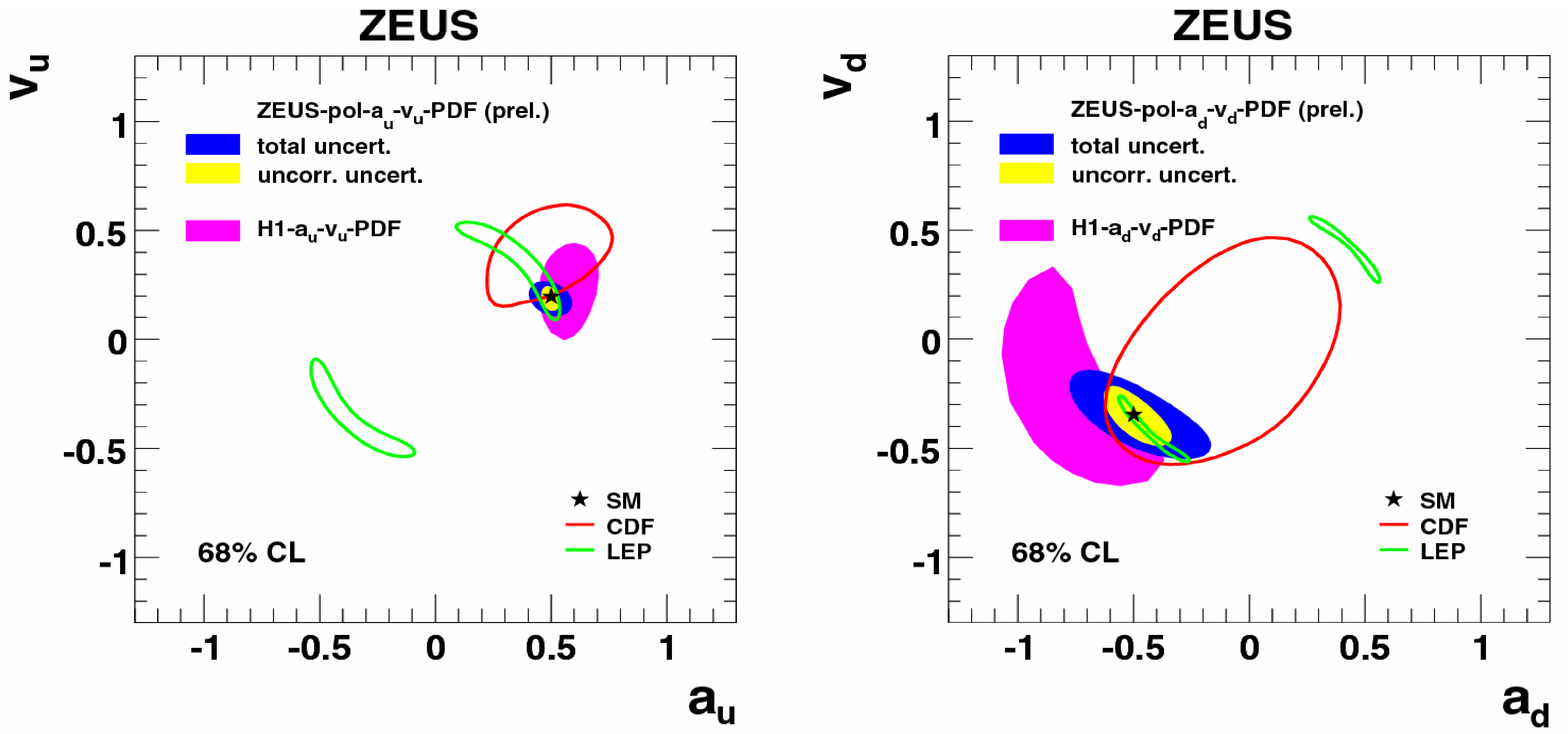

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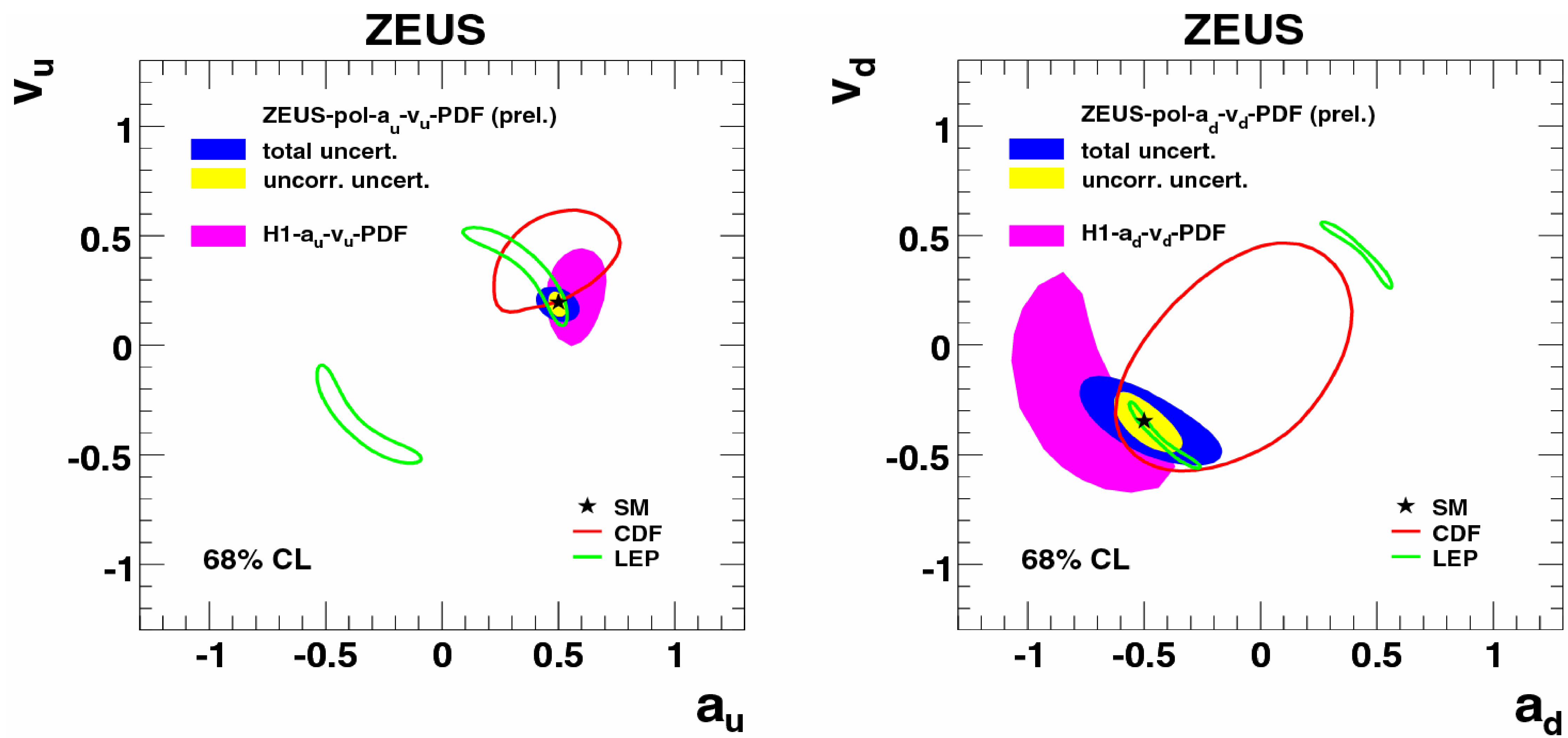

- Sensitivity to a_q, v_q couplings of the light quarks to Z^0 allows for a combined QCD-EW
- H1 performs fit using unpolarised HERA I data
- ZEUS provides preliminary results including HERA II data, with its polarisation giving improved sensitivity to v_q

Summary

- DIS at HERA provides the possibility for testing the Standard Model and the measurement of electroweak parameters over a broad range of phase space
- The large sample of $e^{\pm}p$ data has allowed for the determination of the structure functions xF_3 and $xF_3^{\gamma Z}$, further increasing knowledge of the proton at lower x
- New longitudinal polarised lepton data has been able to demonstrate
  - the absence of RH Charged Currents
  - clear evidence of parity violation in Neutral Current interactions
  - improvement on the combined QCD+EW fit using HERA I data, especially for the light quark weak couplings to the Z^0
- Still more data to analyse, and yet more still to come, increasing reach and precision

Polarised NC and CC cross Section Formulas

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dxdQ^2}\frac{Q^4x}{2\pi\alpha^2Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+}x\tilde{F}_3^{\pm} - \frac{y^2}{Y_+}\tilde{F}_L^{\pm}$$

$$\begin{aligned}\tilde{F}_2^{\pm} &= F_2 + k(-v_e \mp Pa_e)F_2^{\gamma Z} + k^2(v_e^2 + a_e^2 \pm 2Pv_ea_e)F_2^Z \\ x\tilde{F}_3^{\pm} &= k(-a_e \mp Pv_e)xF_3^{\gamma Z} + k^2(2v_ea_e \pm P(v_e^2 + a_e^2))xF_3^Z\end{aligned}$$

$$\tilde{\sigma}^- - \tilde{\sigma}^+ = 2\frac{Y_-}{Y_+}(-a_e \cdot kxF_3^{\gamma Z} + 2v_ea_e \cdot k^2xF_3^Z)$$

$$-2kY_-a_exF_3^{\gamma Z}/Y_+$$

$$F_2 = \sum_{q=u...b} \left(e_q^2 - 2e_q v_q v_e P_Z + (v_e^2 + a_e^2)(v_q^2 + a_q^2) P_Z^2 \right) \cdot x(q + \overline{q})$$

$$xF_3 = \sum_{q=u...b} (-2e_q a_q a_e P_Z + 4a_q v_q v_e a_e P_Z^2) \cdot x(q - \overline{q})$$

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

Remember that $P_Z >> P_Z^2$ and $v_e \sim 0.04$

➔ xF_3 γ-Z^0 interference term is largest

➔ Expect axial coupling of u-quark to be best constrained

Improvements to Parton Density Functions

(From HERA II Data)

- ZEUS performed a new fit incorporating HERA II $e^- p$ data
- further improved on the previous HERA I fit especially for u_v (d_v) at large x