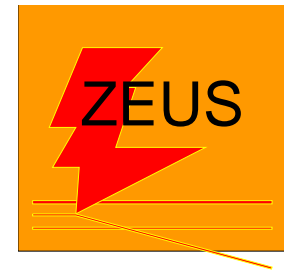


EW measurements with longitudinal polarised leptons in deep inelastic positron-proton scattering



Julian Rautenberg
on behalf of the
H1 and ZEUS Collaborations

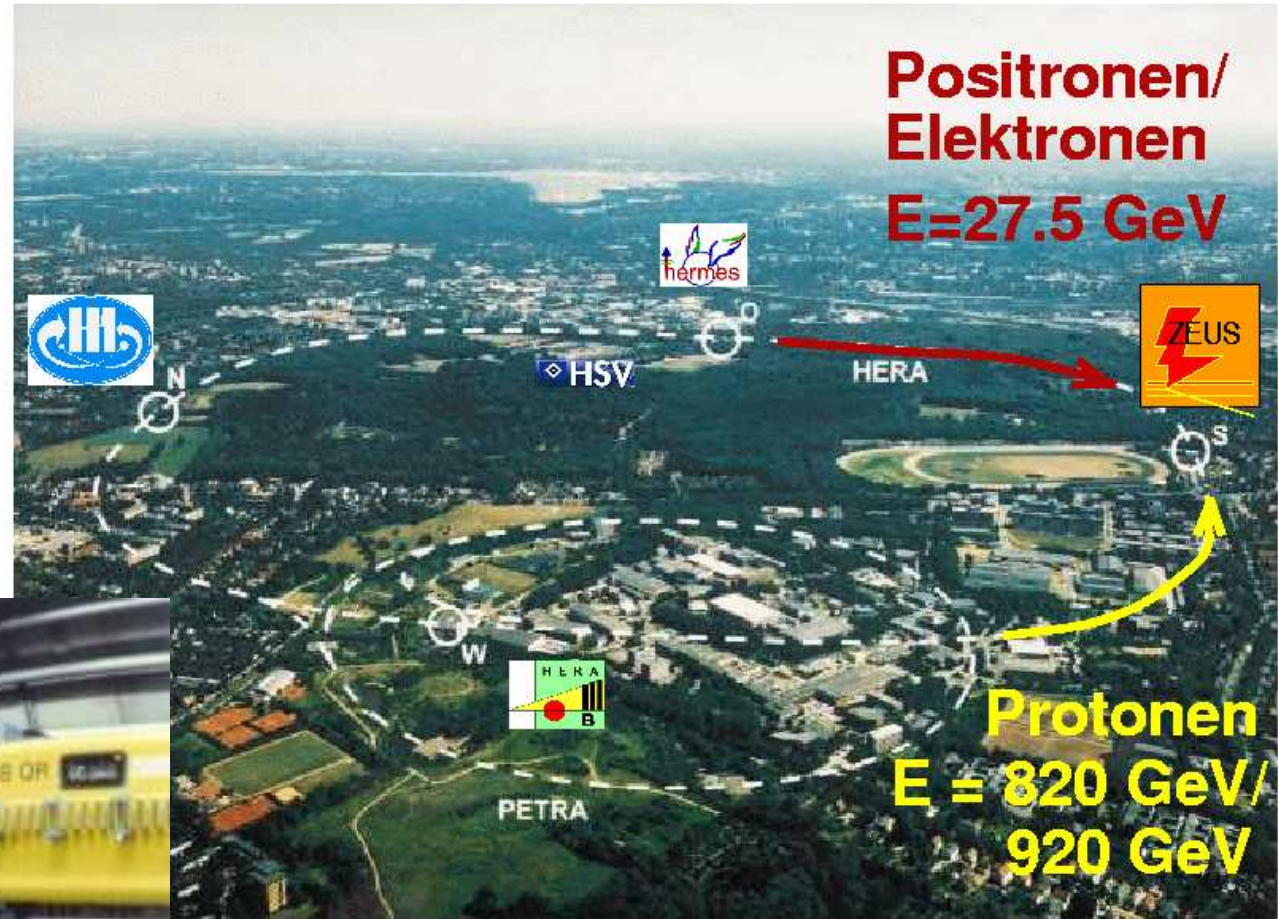
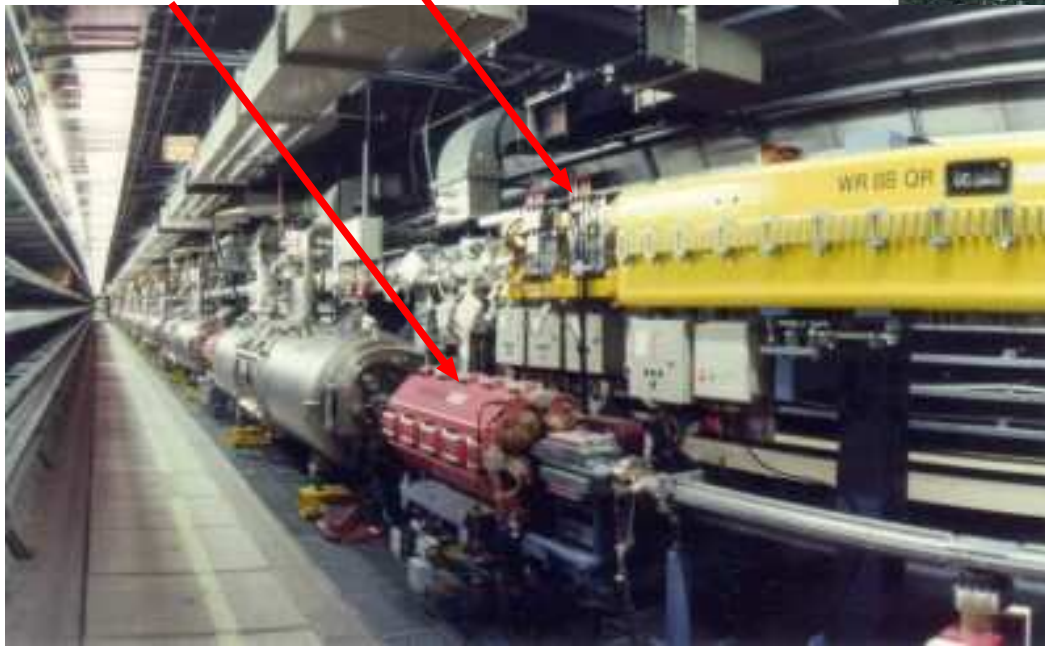


- Deep inelastic scattering at HERA I
- Polarisation at HERA II
- CC and NC Measurements

The Hadron-Elektron-Ringanlage (HERA)

World-wide unique
accelerator
at DESY, Hamburg

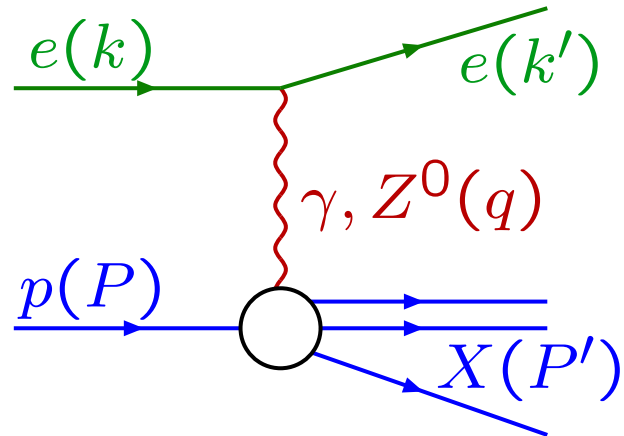
proton-ring
electron-ring



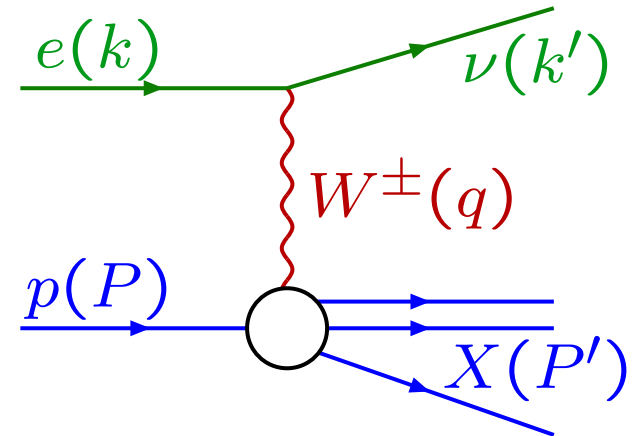
HERA-circumference: 6.3 km
Bunch-distance: 32m \approx 96 ns \approx 100 MHz

DIS at HERA

Neutral Current (NC)



Charged Current (CC)



Invariant kinematic quantities:

$$Q^2 = -q^2 = -(k - k')^2 \quad \text{negative four-momentum transfer squared}$$

$$x = \frac{Q^2}{2P \cdot q} \quad \text{In proton infinite-momentum frame: fraction of proton momentum}$$

$$y = \frac{P \cdot q}{P \cdot k} \quad \text{In proton rest-frame: energy-transfer}$$

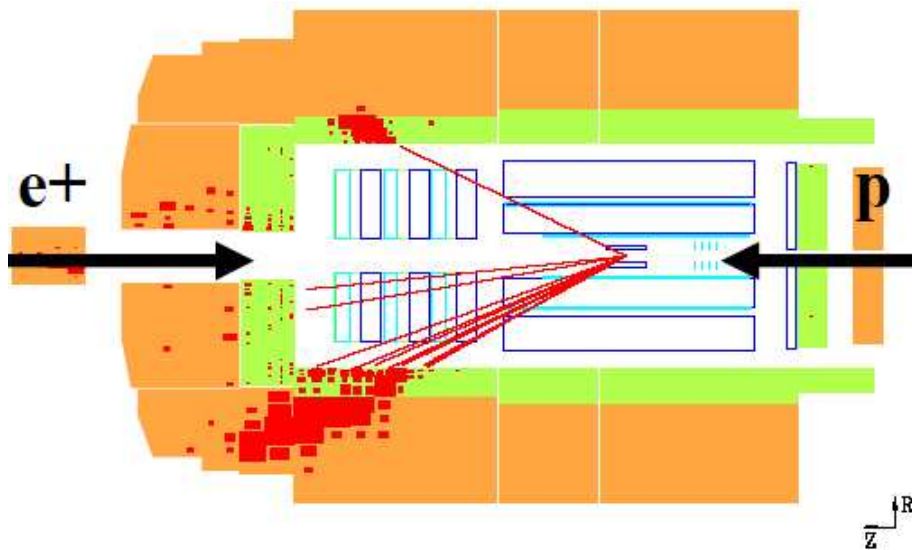
$$s = (k + P)^2 = \frac{Q^2}{xy} \quad \text{squared cms energy}$$

k, P fixed & 4-momentum conservation
 \Rightarrow 2 independent kinematic Quantities

Deep inelastic $\equiv Q^2 \gg 1 \text{ GeV}^2$, here $Q^2 \gtrsim 100 \text{ GeV}^2$

NC & CC DIS measurement: events

Neutral Current (NC)



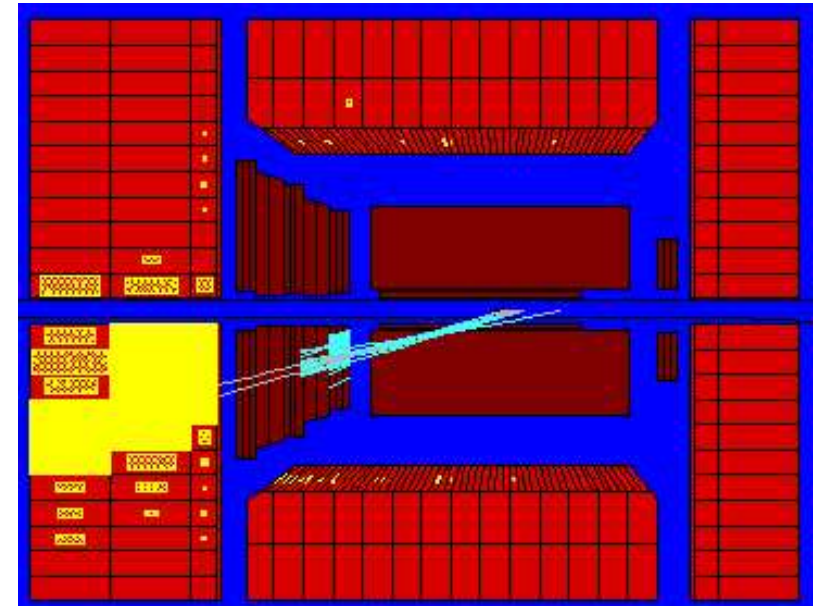
Signature:

- the DIS electron

Background-rejection:

- ep -collision vertex
- trans. (p_t) and long. ($E - p_z$) momentum conservation

Charged Current (CC)



Signature:

- ν undetected \Rightarrow trans. momentum

Background-rejection:

- ep -collision vertex
- sphericallity

Unpolarised inclusive cross sections

Neutral Current (NC)

Charged Current (CC)

EW propagator & coupling

$$\frac{d^2\sigma^{e\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times [Y_+ F_2^{\text{NC}} \mp Y_- x F_3^{\text{NC}} - y^2 F_L^{\text{NC}}]$$

$$F_2^{\text{NC}} = x \sum_{q=u\dots b} A_f [q + \bar{q}]$$

$$xF_3^{\text{NC}} = x \sum_{q=u\dots b} B_f [q - \bar{q}]$$

$$\tilde{\sigma} = \frac{xQ^4}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^{\text{NC}}}{dx dQ^2}$$

$$\frac{d^2\sigma^{e\pm p}}{dx dQ^2} = \frac{G_F^2}{4\pi x} \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \times [Y_+ F_2^{\text{CC}} \mp Y_- x F_3^{\text{CC}} - y^2 F_L^{\text{CC}}]$$

in CC F_i depend on lepton charge

$$F_{2,e^+}^{\text{CC}} = x [d + s + \bar{u} + \bar{c}]$$

$$xF_{3,e^+}^{\text{CC}} = x [d + s - (\bar{u} + \bar{c})]$$

$$\tilde{\sigma}^{e^+p} = x [\bar{u} + \bar{c} + (1-y)^2 (d+s)]$$

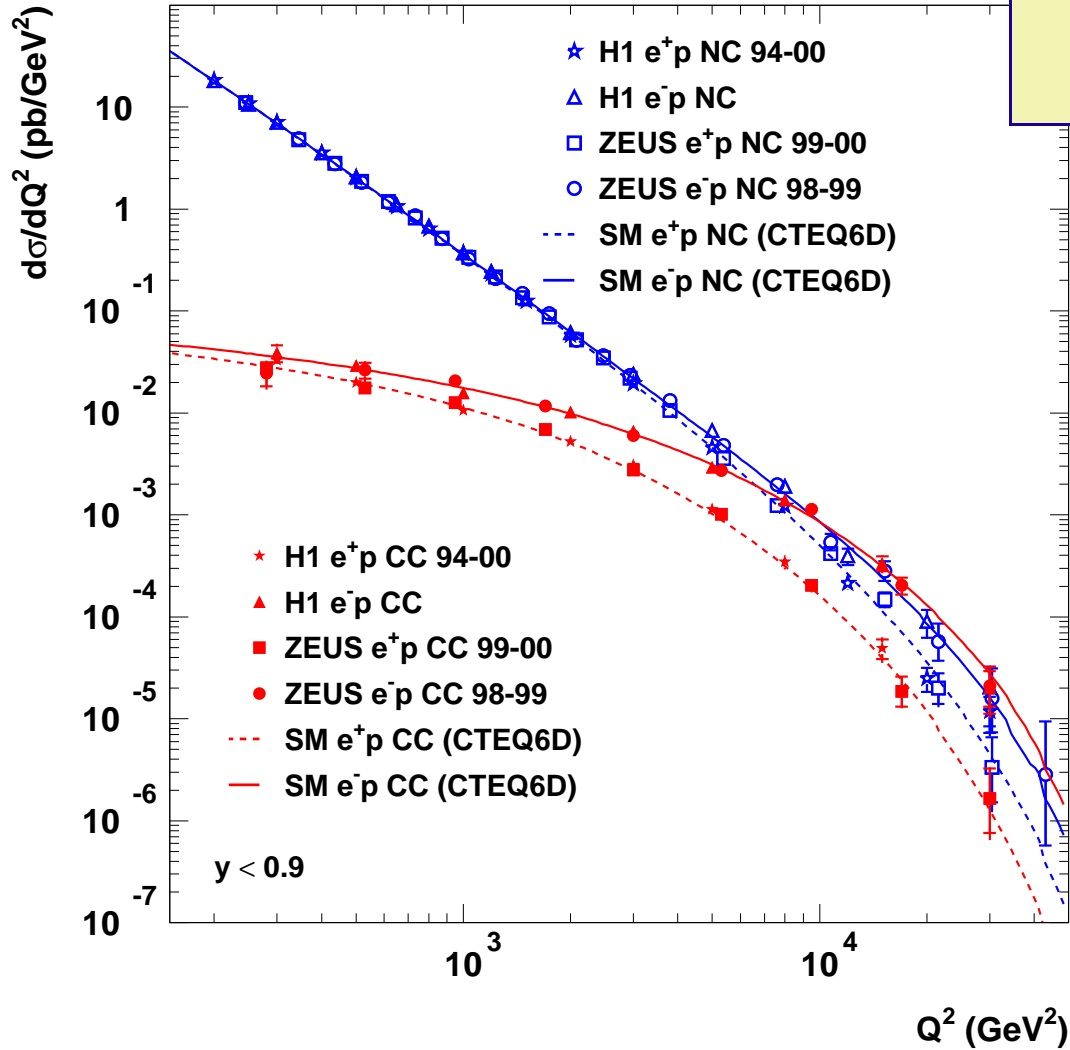
Helicity-factor:
 $Y_{\pm} = 1 \pm (1-y)^2$

F_2^{NC} parity conserving (EM)
 F_3^{NC} parity violating (weak)

purely weak
 F_i^{CC} coupling independent

Inclusive HERA I measurements

HERA

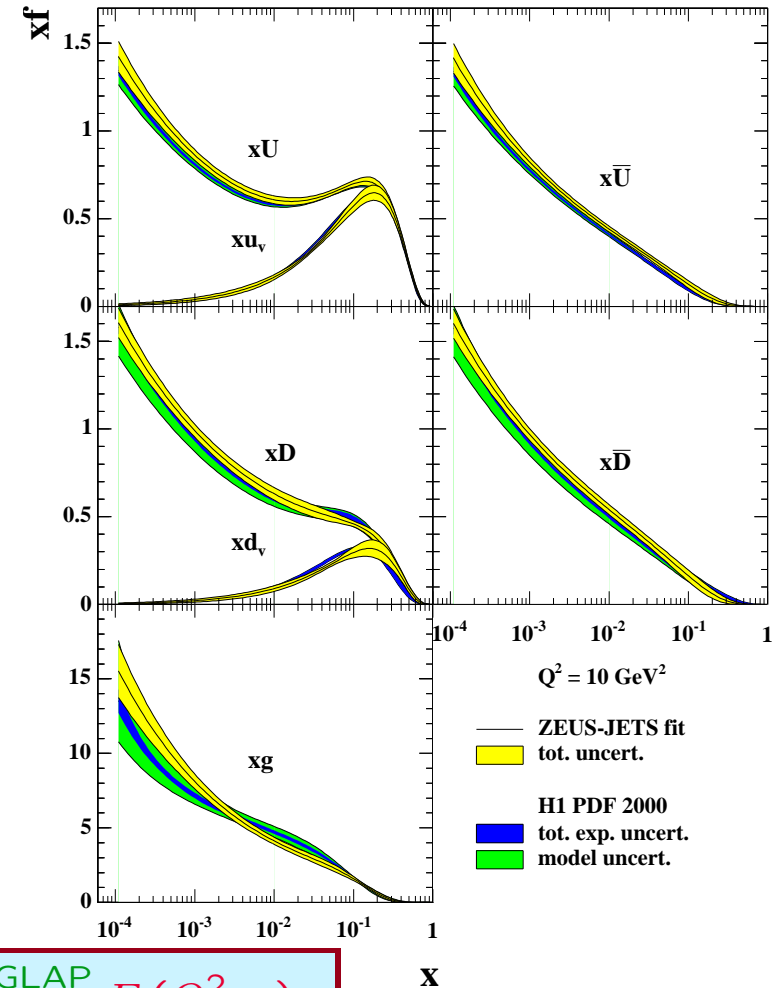


Electron ideal (EW) “probe” for F_i -measurements

⇒ Input for PDF extractions

⇒ Input for SM predictions

ZEUS



Confirmation of SM EW-sector
at scale up to $Q^2 \approx M_W^2$ & above

$$f_{Q_0^2}(x) \xrightarrow{\text{DGLAP}} F_i(Q^2, x)$$

⇒ Test of QCD

EW at HERA I: NC $x F_3$

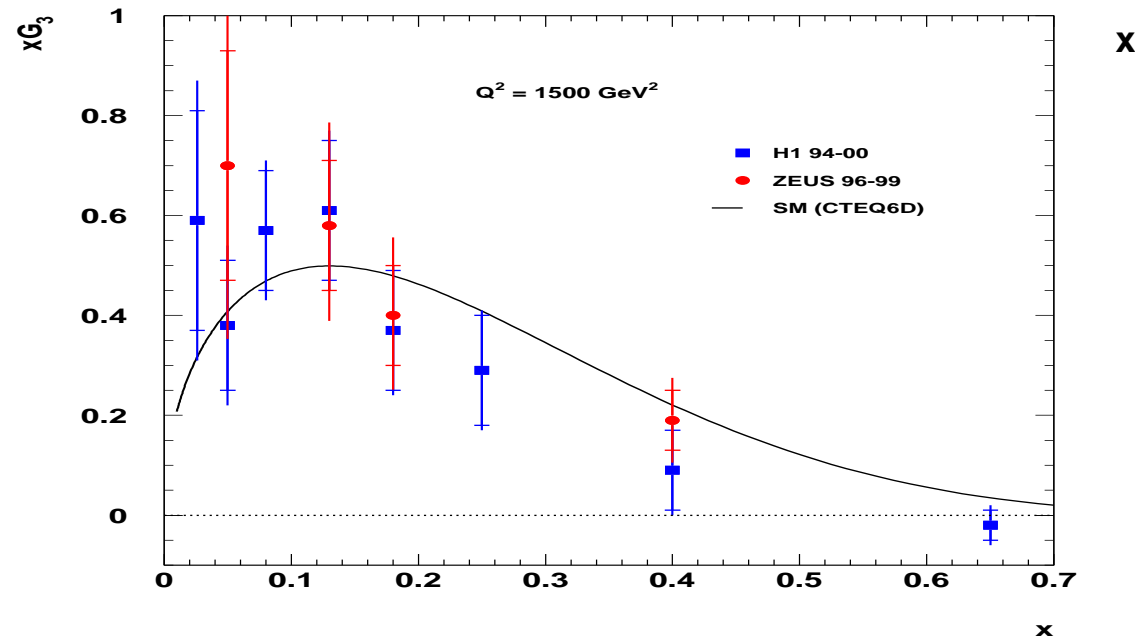
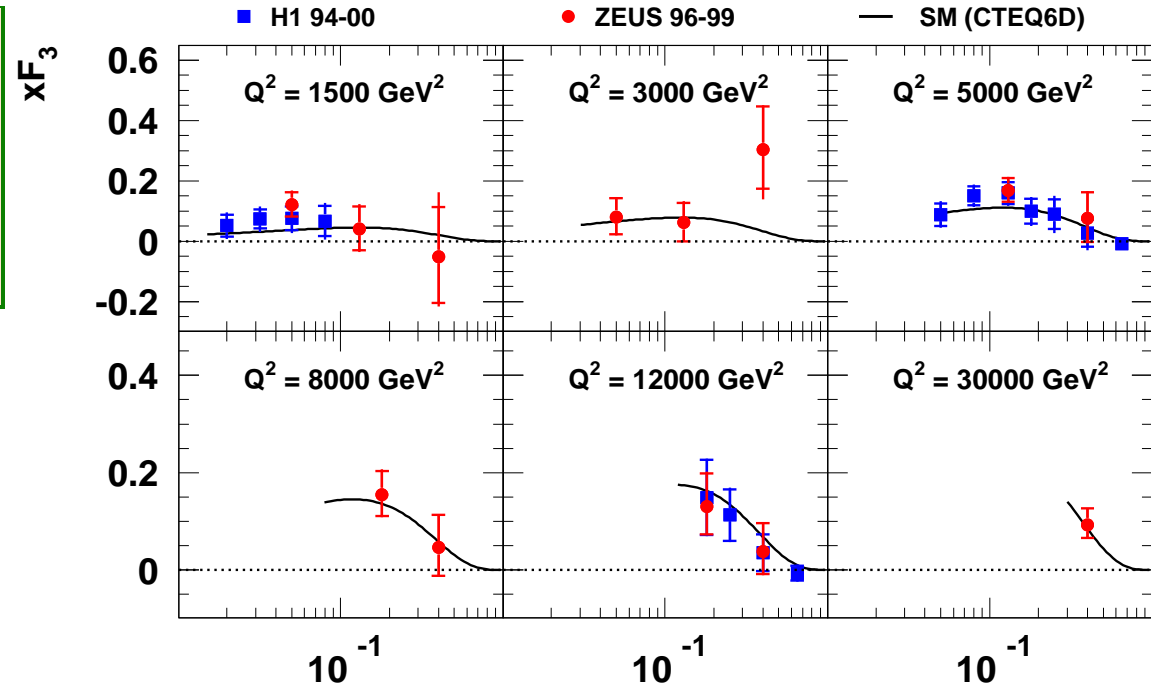
Parity violating $x F_3$:

- None-zero $x F_3$ measured at HERA
- Precision limited by low statistics of e^-p sample

composition of $x F_3$:

$$x F_3 = -a_e \chi_Z x G_3 + 2 a_e v_e \chi_Z^2 x H_3$$

- $x G_3$ stems from $\gamma-Z$ interference
- $x H_3$ arises from pure Z -exchange
- $\chi_Z = \kappa_W \cdot Q^2 / (M_Z^2 + Q^2)$
- $2 a_e v_e \chi_Z^2 x H_3$ negligible
- straight forward extract $x G_3$



EW at HERA I: NC $x F_3$

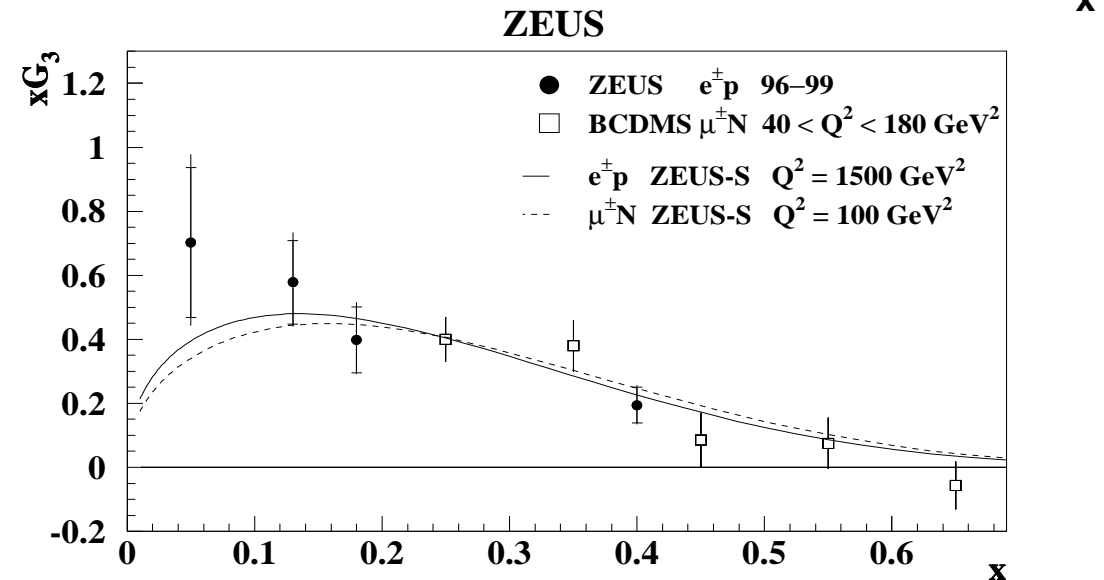
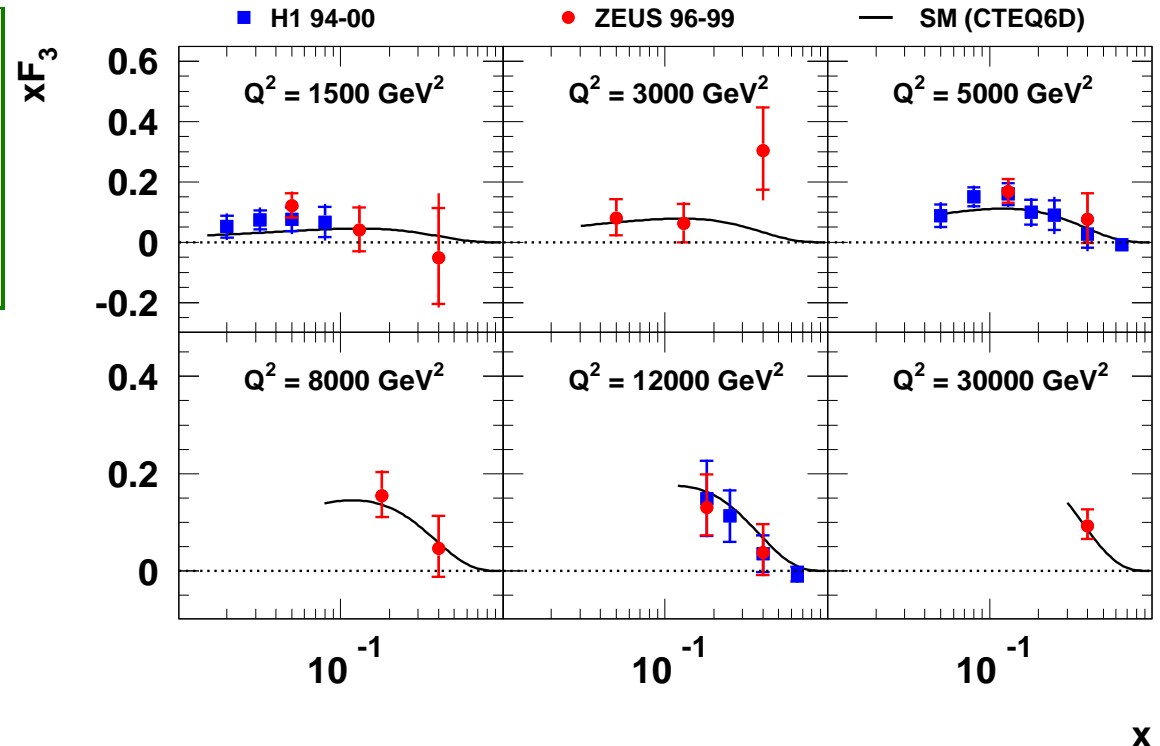
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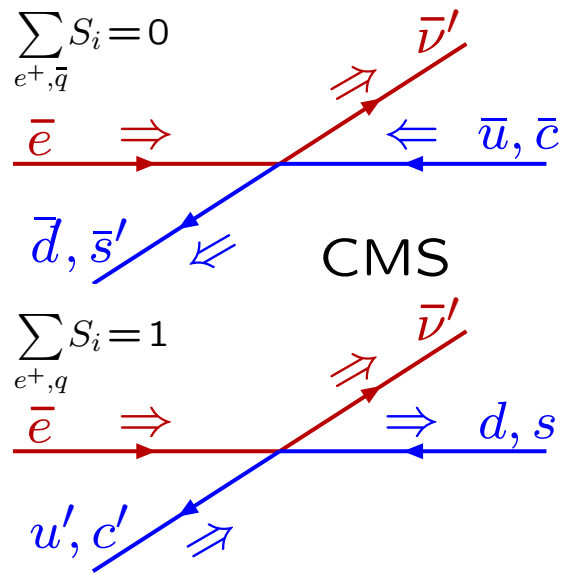
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- $2 a_e v_e \chi_Z^2 x H_3$ negligible
- straight forward extract $x G_3$
- compare to low Q^2 fixed-target BCDMS



EW at HERA I: helicity-structure in CC

W couples to
left-(right-)handed (anti-)particles

scattering off	Spin-sum in CMS	Helicity	constraint on scattering angle
$e^+\bar{q}$	R.H.+R.H.	zero	no preference (isotrop)
e^+q	R.H.+L.H.	one	dominantly forward



EW at HERA I: helicity-structure in CC

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$e^+\bar{q}$	R.H.+R.H.	zero	no preference (isotrop)
e^+q	R.H.+L.H.	one	dominantly forward

Down-type (anti-)quarks contribution suppressed by helicity:

$$\tilde{\sigma}^{e^-p} = x \left[u + c + (1-y)^2(\bar{d} + \bar{s}) \right]$$

$$\tilde{\sigma}^{e^+p} = x \left[\bar{u} + \bar{c} + (1-y)^2(d + s) \right]$$

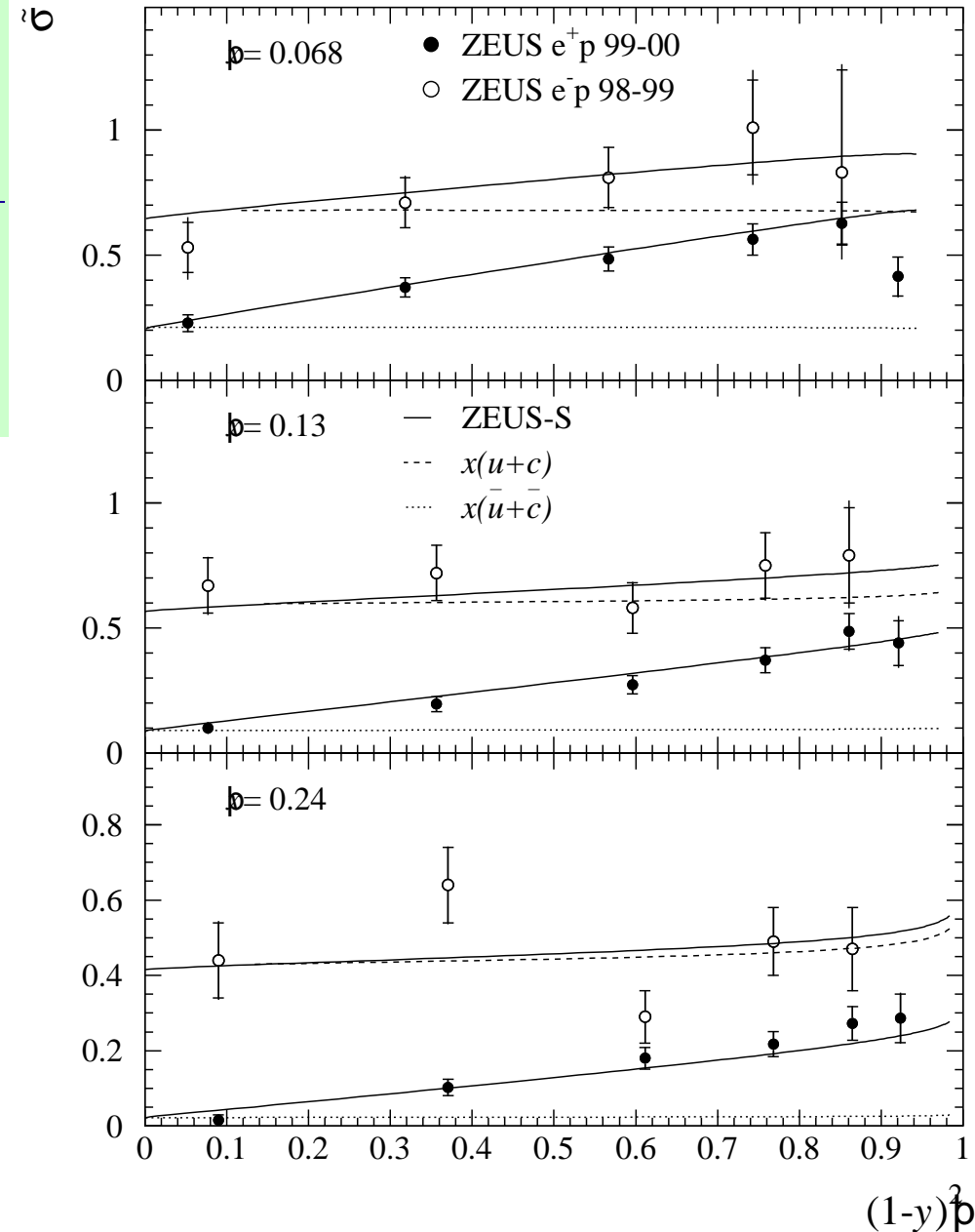
Helicity-structure of EW confirmed

Assuming $q_s = \bar{q}_s \Rightarrow$

$$\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p} = xu_v - (1-y)^2 xd_v$$

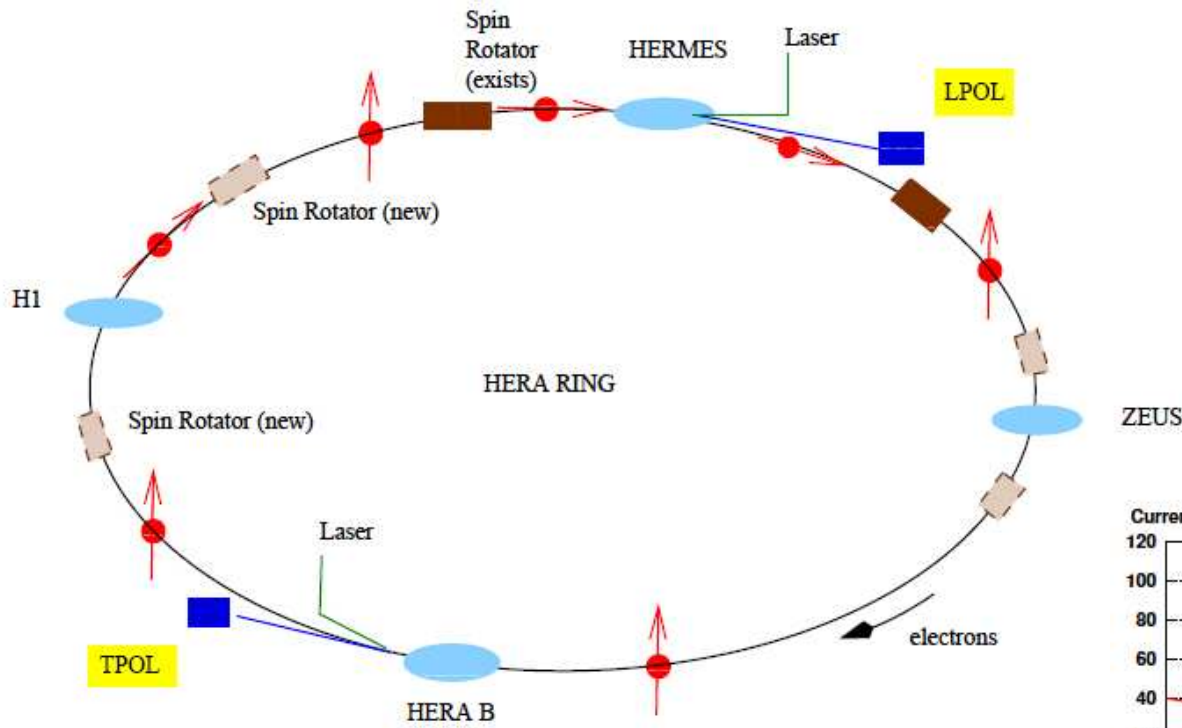
\Rightarrow access to valence PDFs

ZEUS



HERA II: longitudinally polarised leptons

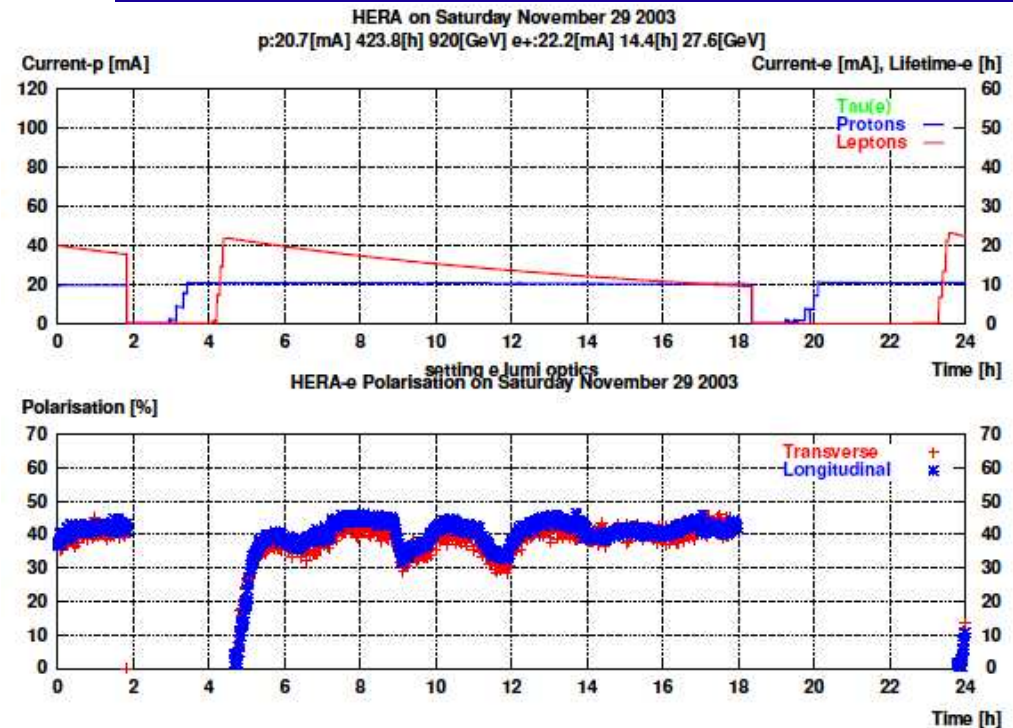
Longitudinal polarisation of lepton beam provides direct EW sensitivity



Sokolov-Terrov effect builds-up transverse polarisation
 Since 2002 spin-rotators also around H1 & ZEUS
 (before only Hermes)

Polarisation measured at HERMES (LPOL) & HERA-west (TPOL)

Polarisation builds-up fast and stable at up to $\approx 50\%$

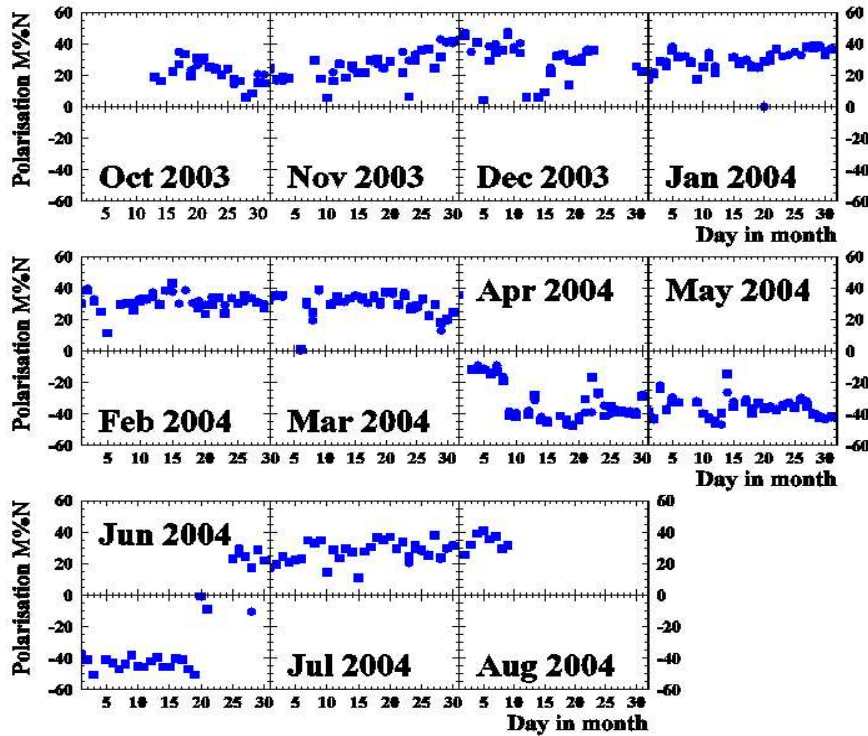


HERA II: e^+p 2003-04 data-taking period

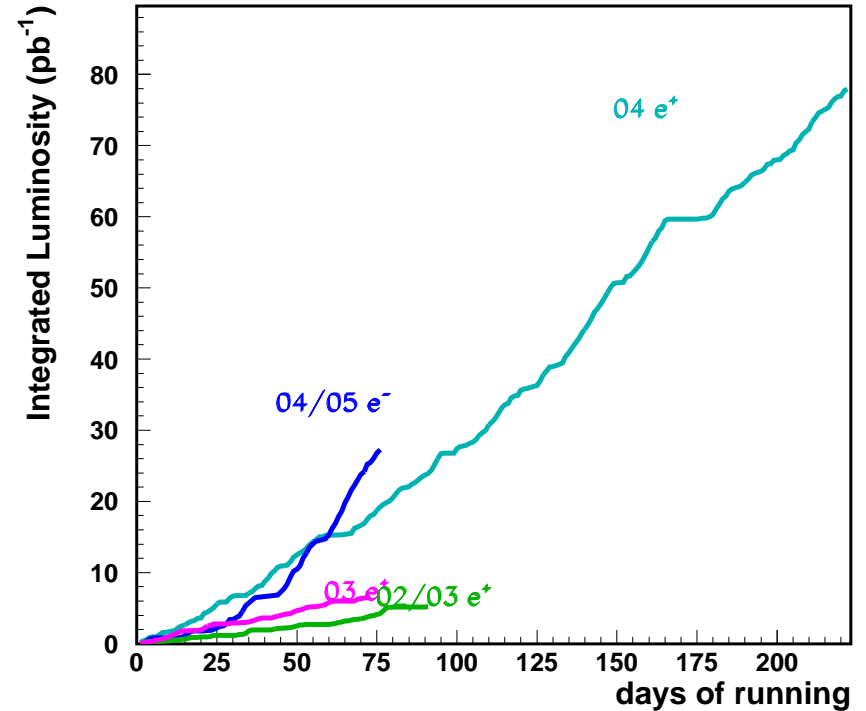
History of long. pol.: 20% — 50%

HERA delivered luminosity:

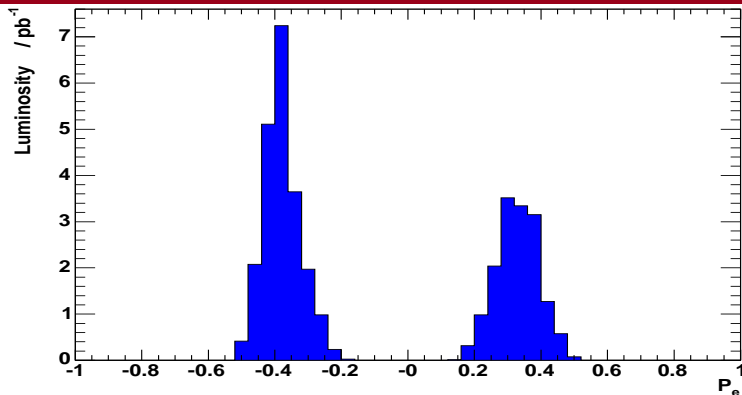
Average HERA polarisation





HERA delivered



Pol.-distribution of H1 luminosity



Cross-section data-sets:

	$\mathcal{L} / \text{pb}^{-1}$	P
	15.3	+33.0%
	21.7	-40.2%
	14.1	+31.8%
	16.4	-40.2%

Cross sections for polarised lepton beam

$$\text{CC: } \sigma_{CC}(P) = (1 + P) \cdot \sigma_{CC}(P = 0)$$

$$\text{NC: } \frac{d\sigma^{e^\pm p \rightarrow e^\pm X}}{dQ^2 dx} = \frac{2\pi\alpha^2}{xQ^4} \left[\sigma_0 + \sigma_i^\pm(\lambda) + \sigma_Z^\pm(\lambda) \right]$$

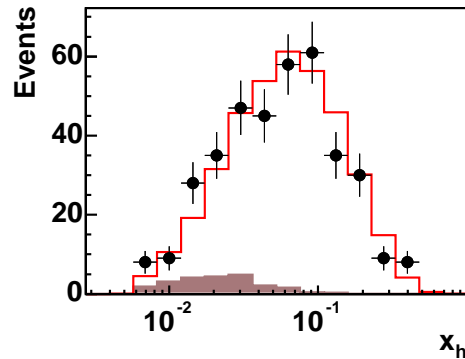
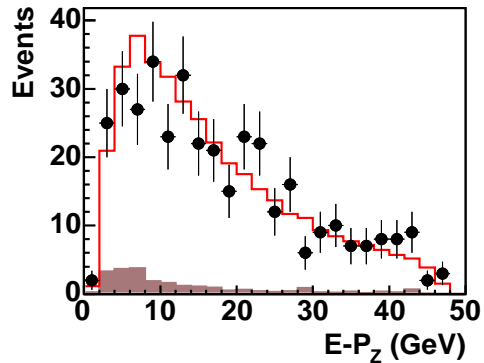
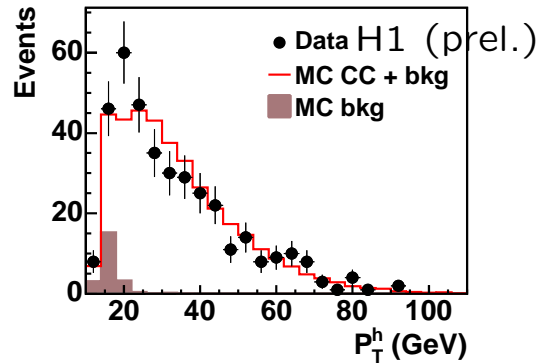
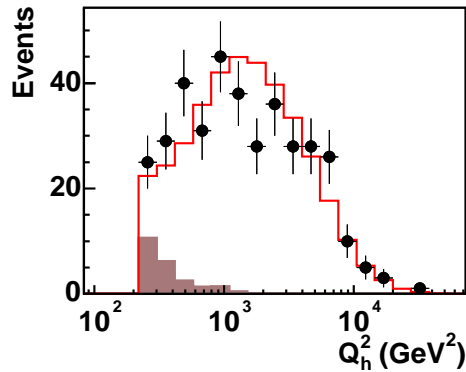
$$\begin{aligned} \sigma_0 &= Y_+ \hat{F}_2 \\ \sigma_i^\pm(\lambda) &= P_Z \left[Y_+ (-v \mp \lambda a) \hat{G}_2 + Y_+ (\pm a + \lambda v) x \hat{G}_3 \right] \\ \sigma_Z^\pm(\lambda) &= P_Z^2 \left[Y_+ (v^2 + a^2 \pm \lambda va) \hat{H}_2 + Y_- (\mp 2va - (v^2 + a^2)\lambda) x \hat{H}_3 \right] \end{aligned}$$

$$\begin{aligned} \hat{F}_2 &= x \sum_q (q + \bar{q}) \cdot q_q^2 \\ \hat{G}_2 &= x \sum_q (q + \bar{q}) \cdot 2v_q q_q \\ \hat{H}_2 &= x \sum_q (q + \bar{q}) \cdot (v_q^2 + a_q^2) \end{aligned}$$

$$\begin{aligned} x \hat{G}_3 &= 2x \sum_q (q - \bar{q}) \cdot a_q q_q \\ x \hat{H}_3 &= 2x \sum_q (q - \bar{q}) \cdot a_q v_q \end{aligned}$$

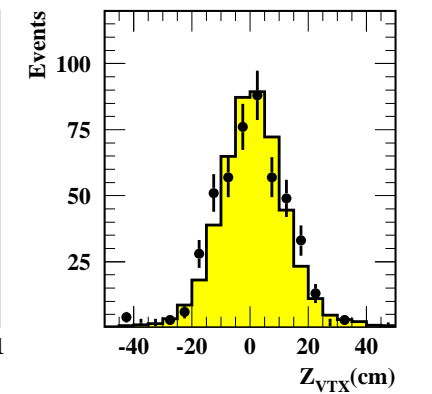
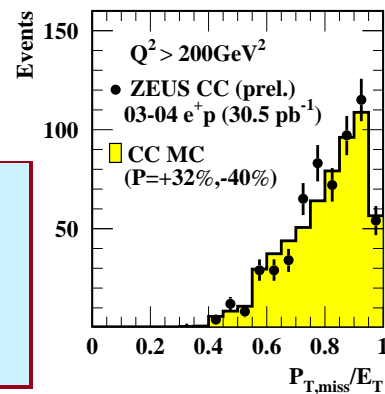
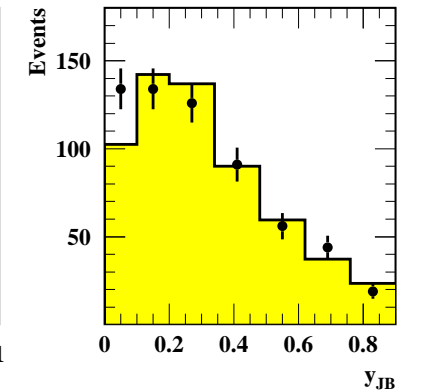
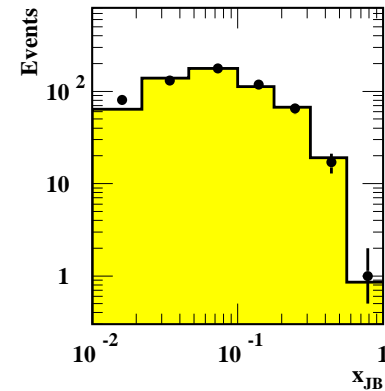
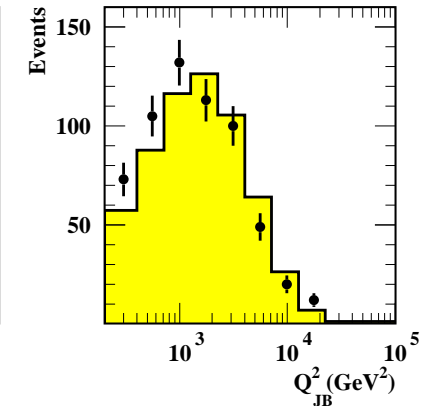
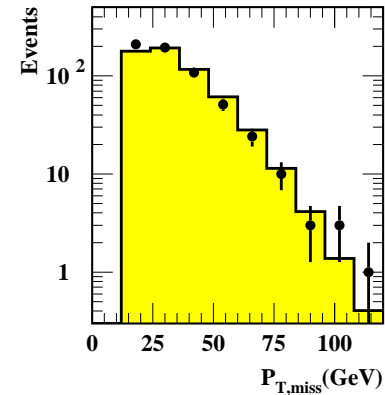
CC DIS measurement: control plots

L.H.



ZEUS

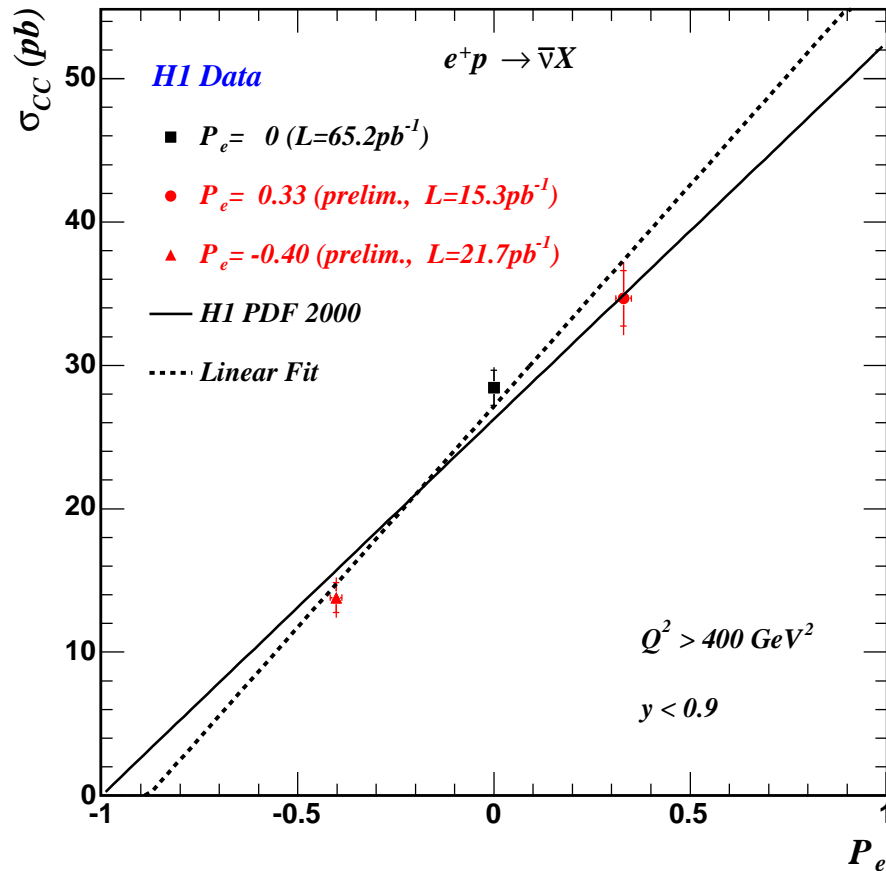
L.H.+R.H.



Kinematics reconstructed from
haronic final state (JB)

H1 / ZEUS Detectors are well understood
after major upgrade and performing well

H1 CC DIS measurement: cross section



Kinematic region: $Q^2 > 400 \text{ GeV}^2, y < 0.9$

$$\sigma_{CC}(P = +33 \pm 2) = 34.7 \pm 1.9(\text{stat.}) \pm 1.7(\text{syst.}) \text{ pb}$$

$$\sigma_{CC}(P = -40.2 \pm 1.5) = 13.8 \pm 1.0(\text{stat.}) \pm 1.0(\text{syst.}) \text{ pb}$$

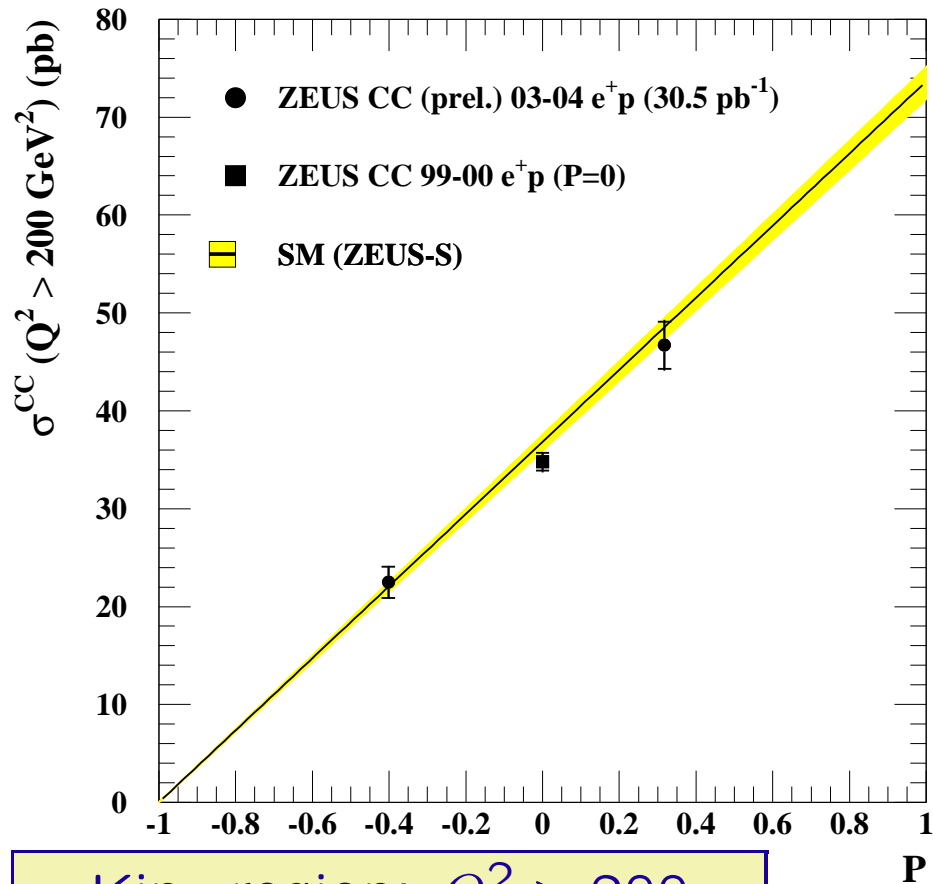
Since: $\sigma_{CC}(P) = (1 + P) \cdot \sigma_{CC}(P = 0) \Rightarrow$ linear fit to $\sigma_{CC}(P)$

$$\sigma_{CC}(P = -1) = -3.7 \pm 2.4(\text{stat.}) \pm 2.7(\text{syst.}) \text{ pb}$$

Consistent with no R.H. W-exchange

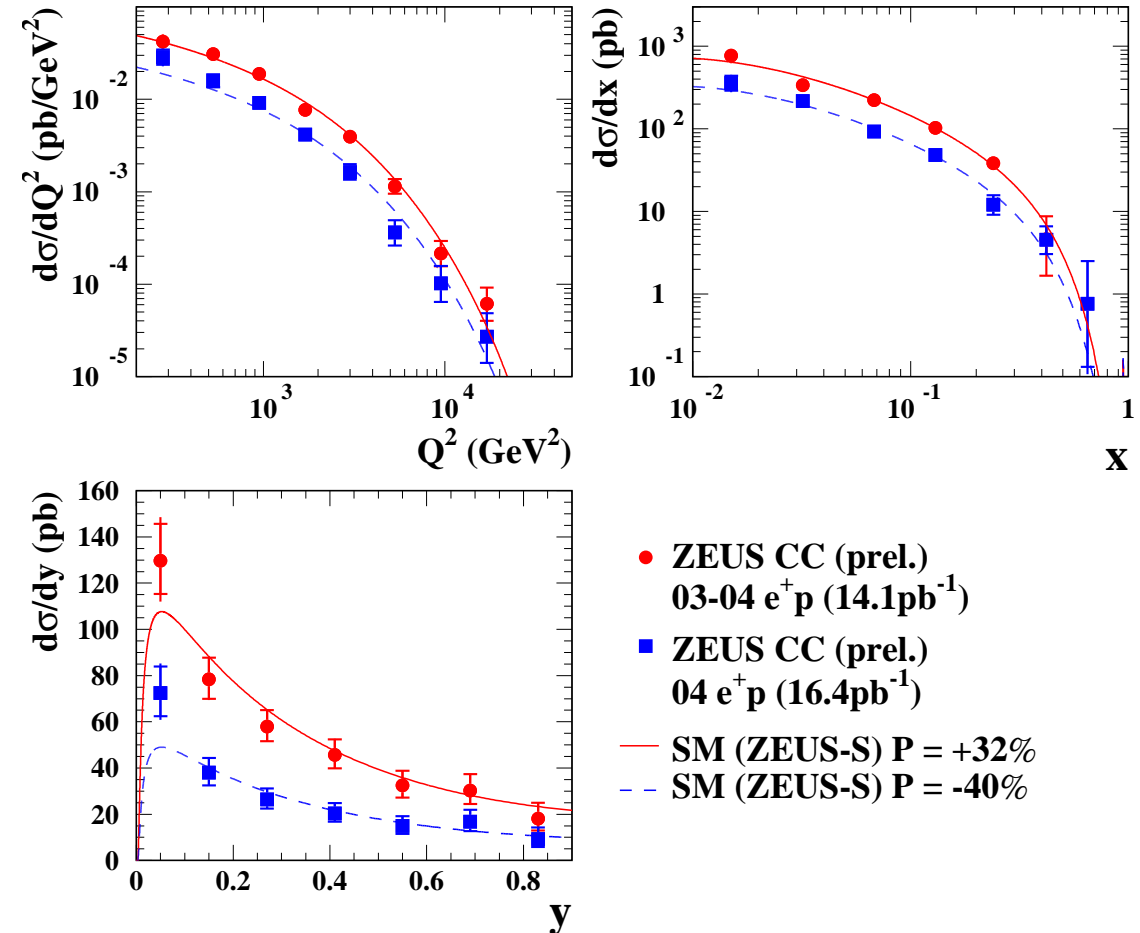
ZEUS CC DIS measurement: cross section

ZEUS



Kin. region: $Q^2 > 200$

ZEUS



$$\sigma_{CC}(P = +31.8 \pm 0.9) = 46.7 \pm 2.4(\text{stat.}) \pm 1.0(\text{syst.}) \pm 2.3(\text{lumi.}) \text{ pb}$$

$$\sigma_{CC}(P = -40.2 \pm 1.1) = 22.5 \pm 1.6(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.1(\text{lumi.}) \text{ pb}$$

Consistent with SM using ZEUS-S (no R.H. W-exchange)

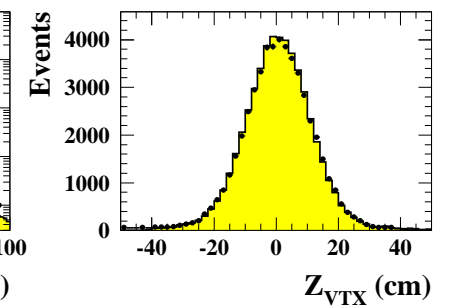
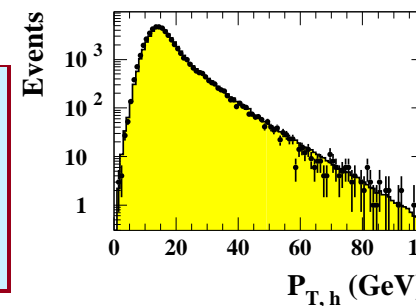
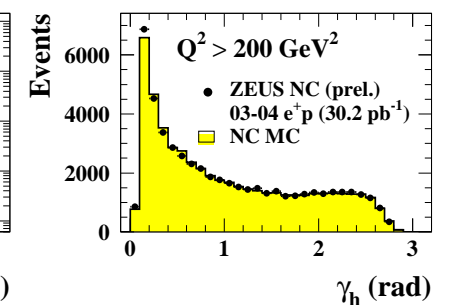
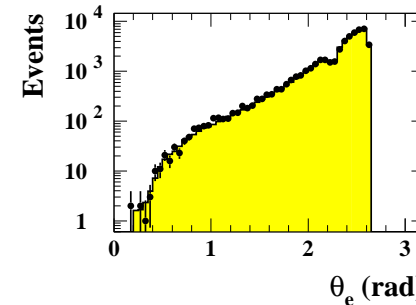
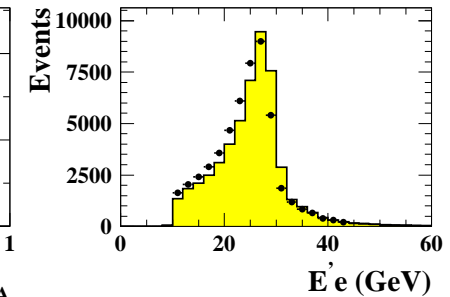
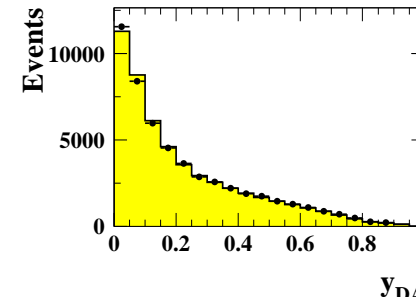
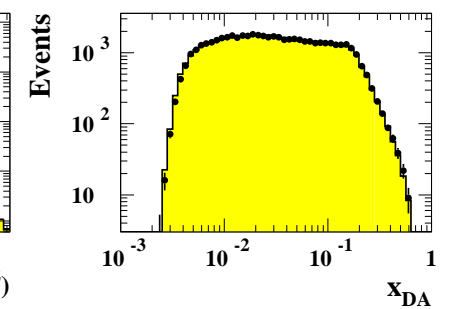
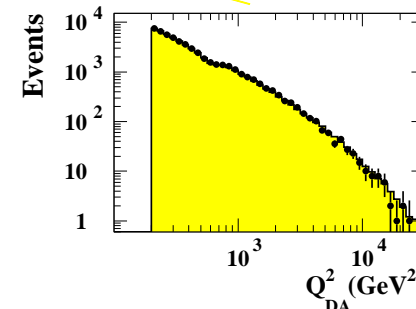
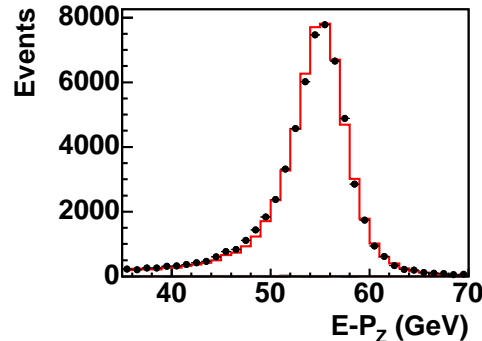
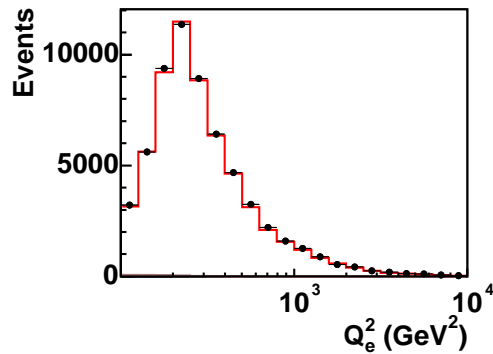
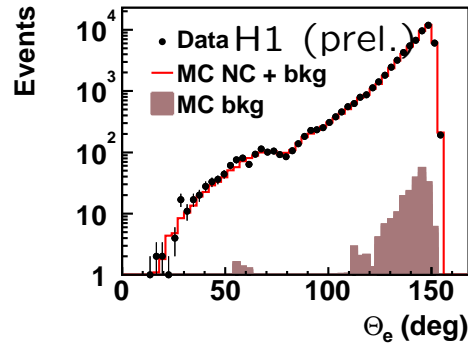
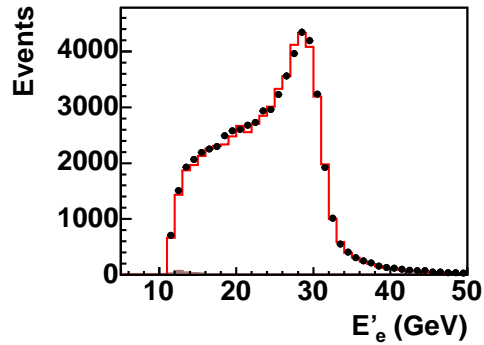
NC DIS measurement: control plots

L.H.



ZEUS

L.H.+R.H.

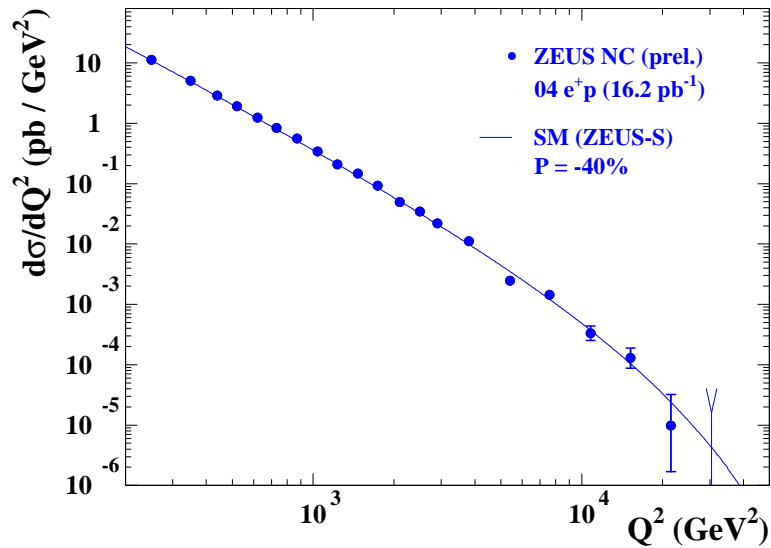
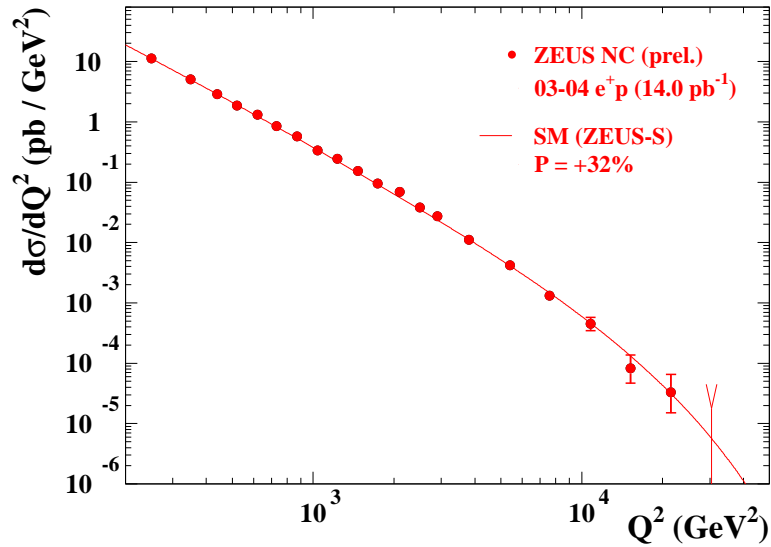


Kinematics reconstructed from electron and hadronic final state

H1 / ZEUS Detectors are well understood after major upgrade and performing well

ZEUS NC DIS measurement: cross section

ZEUS

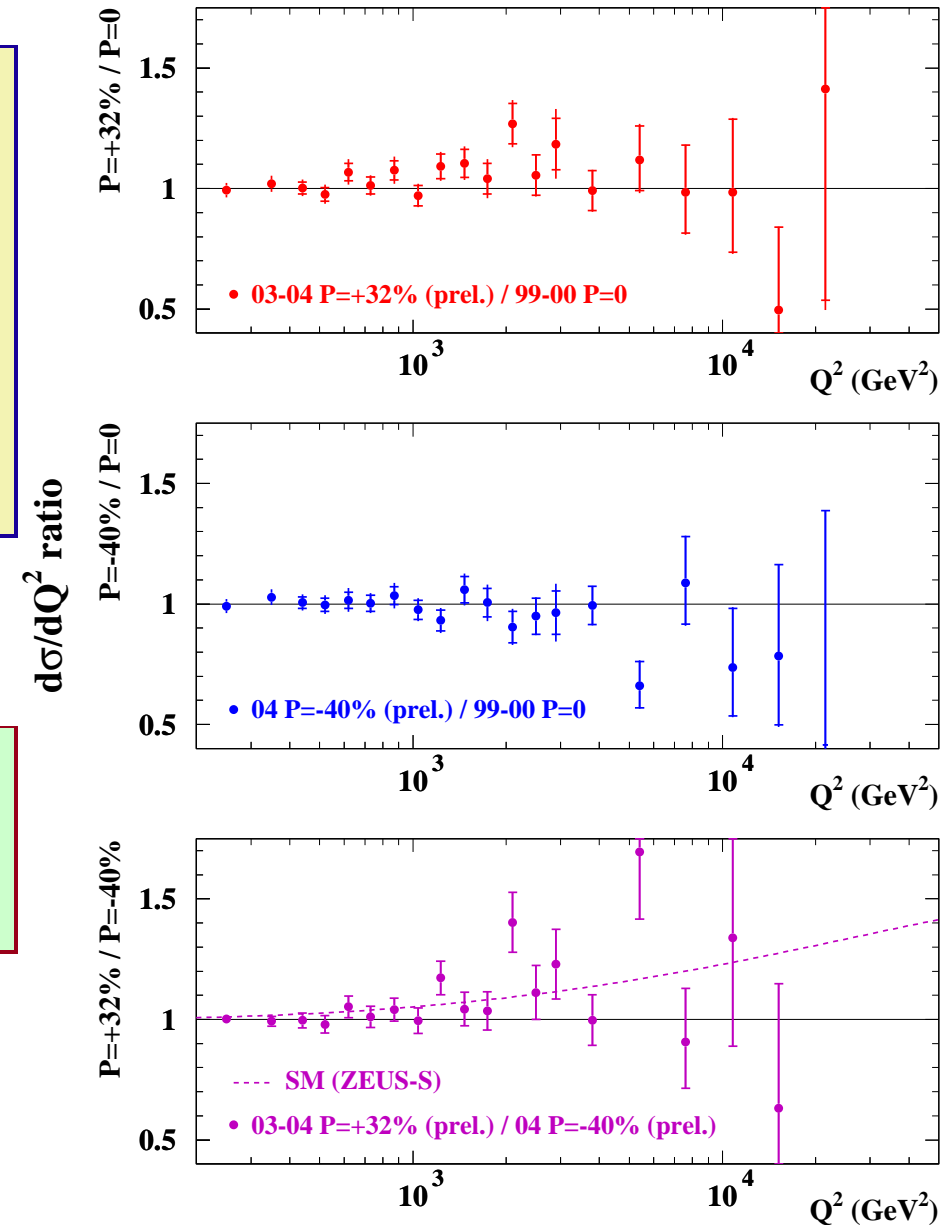


Consistent
with SM

NC much less
polarisation-
dependent

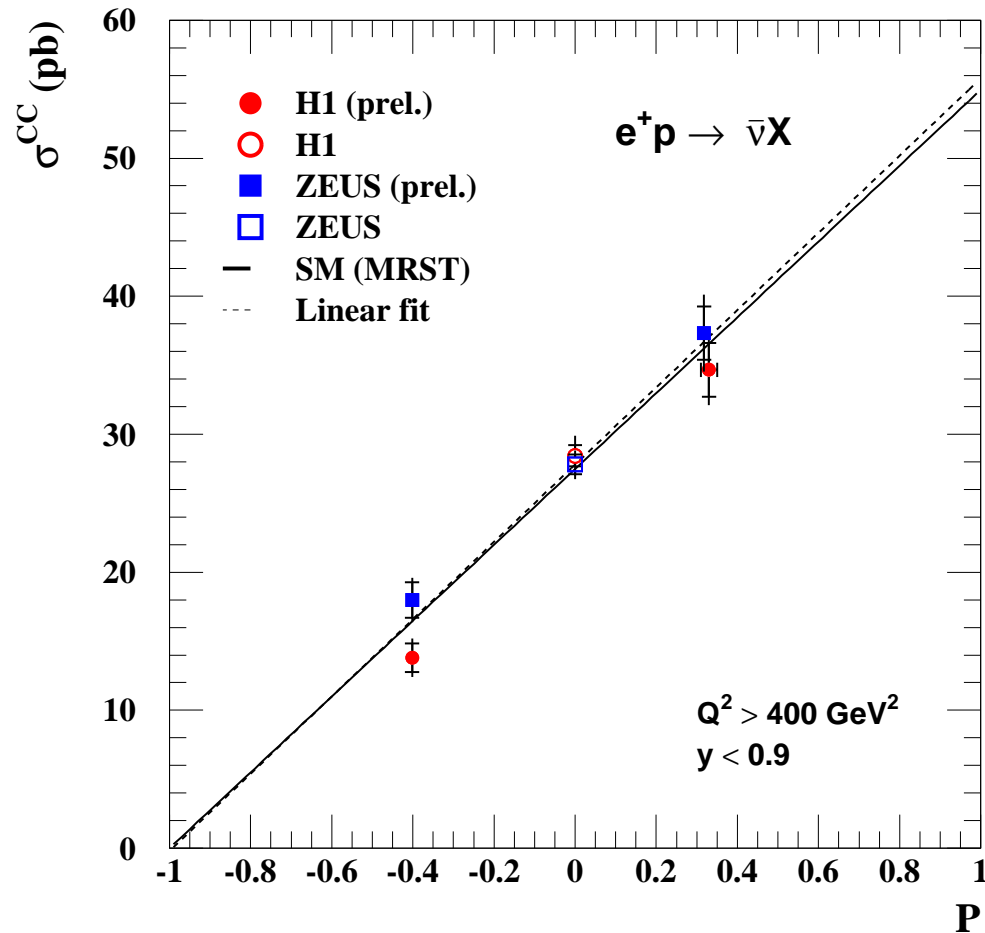
NC challenge
for HERA II

ZEUS



Summary & Outlook

HERA II



- Both H1 & ZEUS:
- performing well after upgrade
 - measured e^+p CC cross section with long. polarised e^+

Longitudinal lepton beam at HERA II starts to be a success !

EW sector of SM confirmed

Right now HERA runs e^-
 Total HERA I e^- luminosity exceeded
 New data coming to complete EW text-book plot

