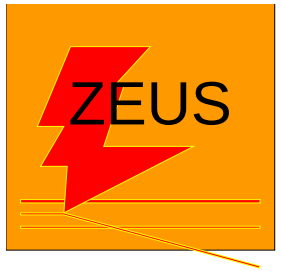
EW measurements with longitudinal polarised leptons in deep inelastic positron-proton scattering

Julian Rautenberg

on behalf of the

H1 and ZEUS Collaborations

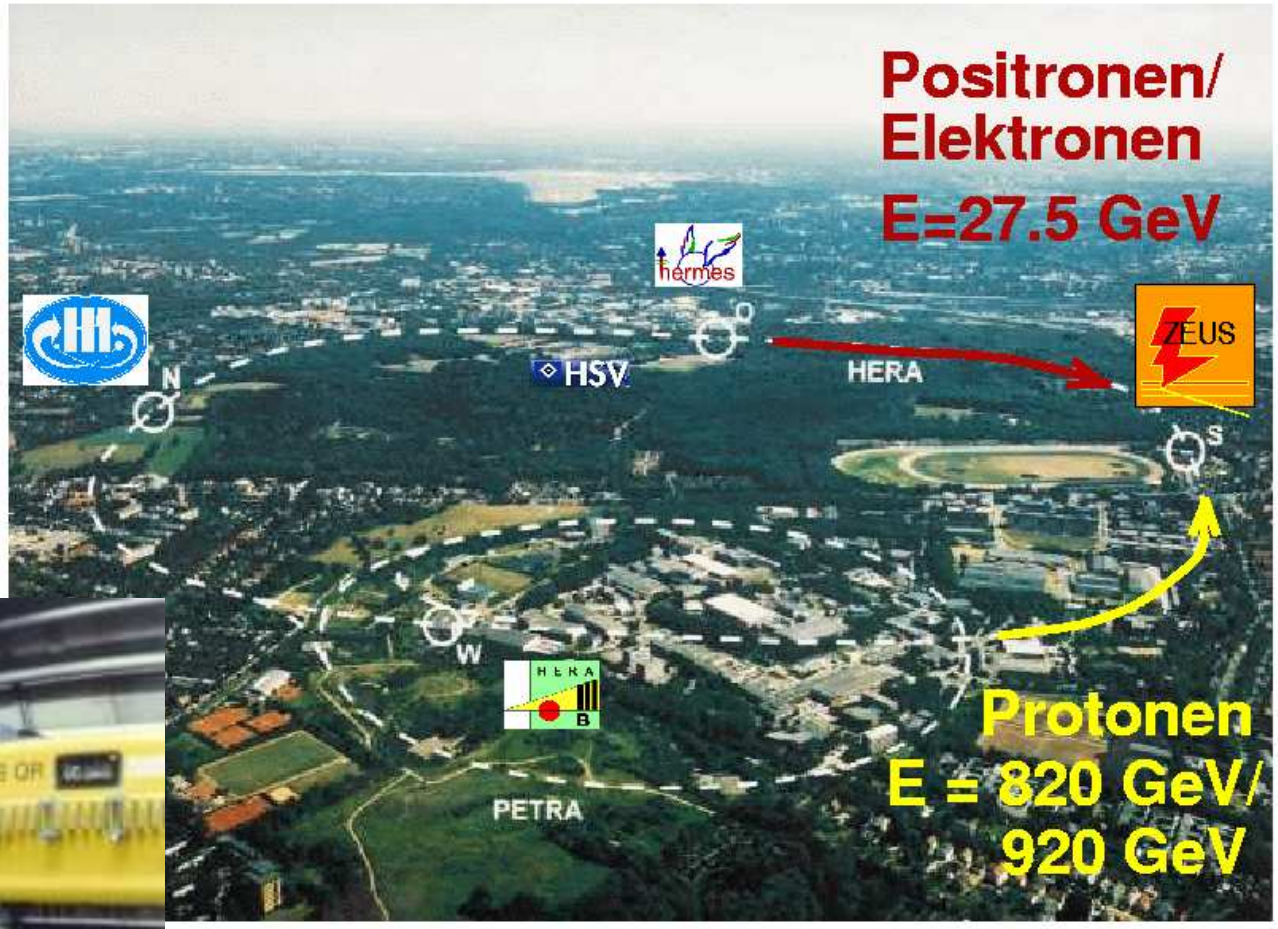


- Deep inelastic scattering at HERA I
- Polarisation at HERA II
- CC and NC Measurements

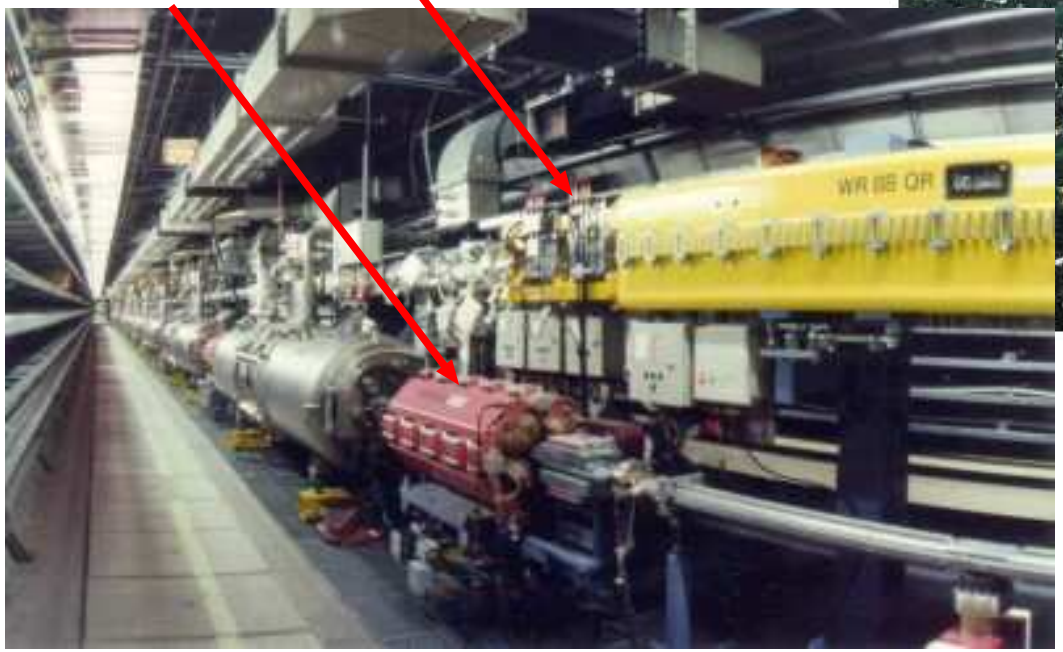
bmb+f - Förderschwerpunkt
ZEUS
Großgeräte der physikalischen Grundlagenforschung

The Hadron-Elektron-Ringanlage (HERA)

World-wide unique
accelerator
at DESY, Hamburg



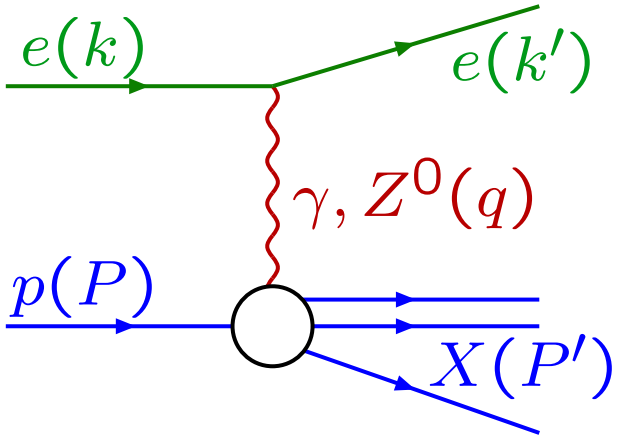
proton-ring
electron-ring



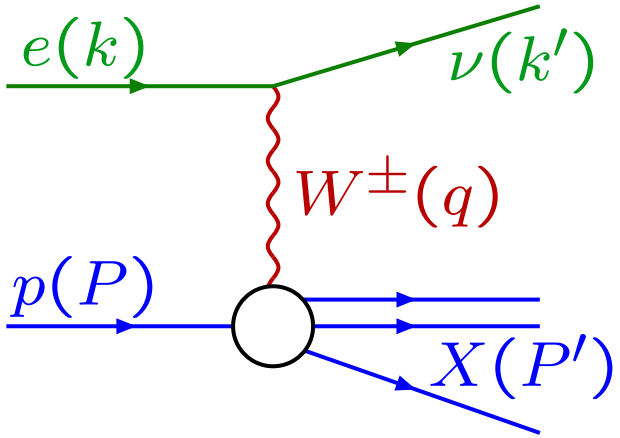
HERA-circumference: 6.3 km
Bunch-distance: 32m $\widehat{\approx}$ 96 ns $\widehat{\approx}$ 100 MHz

DIS at HERA

Neutral Current (NC)



Charged Current (CC)



Invariant kinematic quantities:

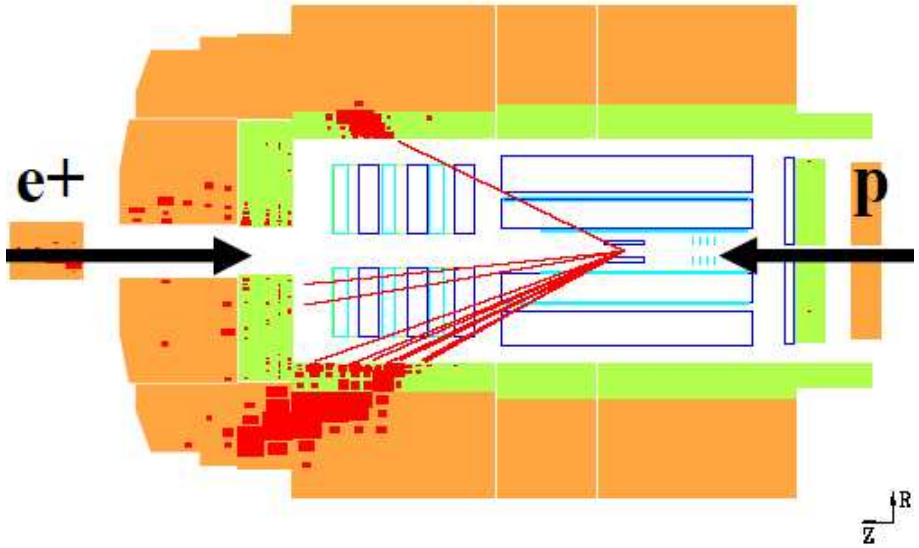
$Q^2 = -q^2 = -(k-k')^2$		negative four-momentum transfer squared
$x = \frac{Q^2}{2P\cdot q}$		In proton infinite-momentum frame: fraction of proton momentum
$y = \frac{P\cdot q}{P\cdot k}$		In proton rest-frame: energy-transfer
$s = (k+P)^2 = \frac{Q^2}{xy}$		squared cms energy

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

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

NC & CC DIS measurement: events

Neutral Current (NC)



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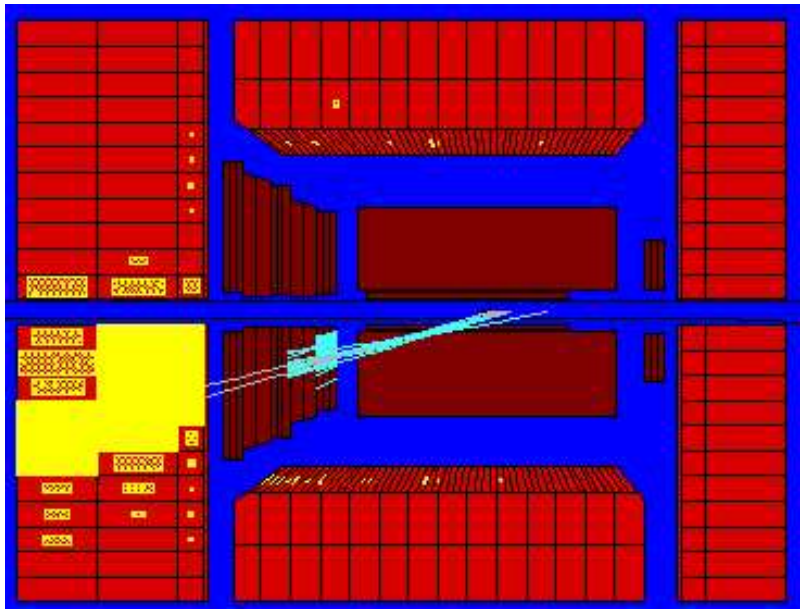


Signature:

- the DIS electron

Background-rejection:

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

Signature:

- ν undetected $\Rightarrow$ trans. momentum

Background-rejection:

- ep-collision vertex
- sphericallity

Unpolarised inclusive cross sections

Neutral Current (NC)

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

$$F_2^{\mathrm{NC}} = x \sum_{q=u\ldots b} A_f \left[q + \bar{q}\right]$$

$$xF_3^{\mathrm{NC}} = x \sum_{q=u\ldots b} B_f \left[q - \bar{q}\right]$$

$$\tilde{\sigma} = \frac{xQ^4}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^{\mathrm{NC}}}{dxdQ^2}$$

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

Charged Current (CC)

EW propagator & coupling

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

in CC F_i depend on lepton charge

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

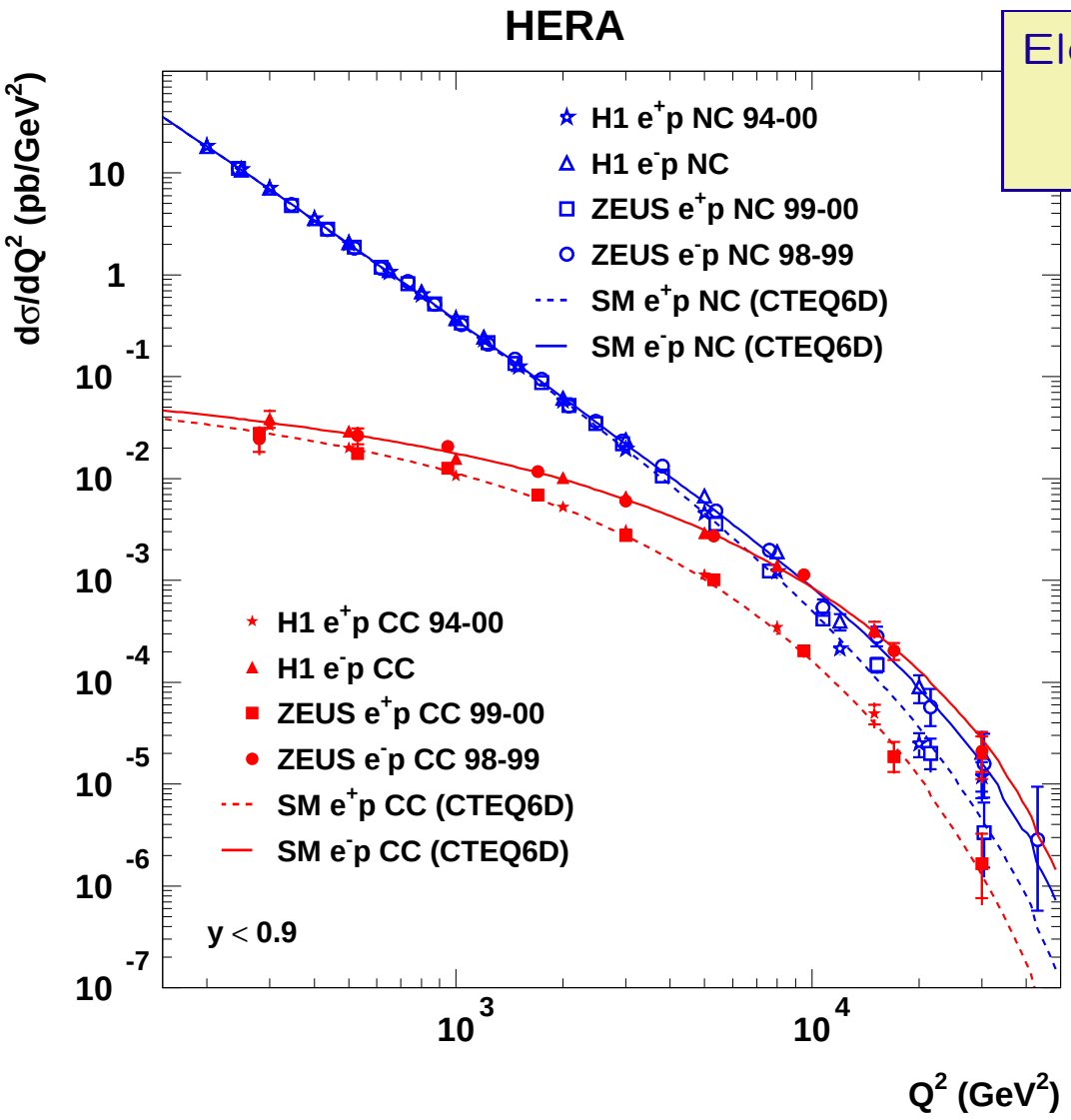
$$xF_{3,e^+}^{\mathrm{CC}} = x\left[d + s - (\bar{u} + \bar{c})\right]$$

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

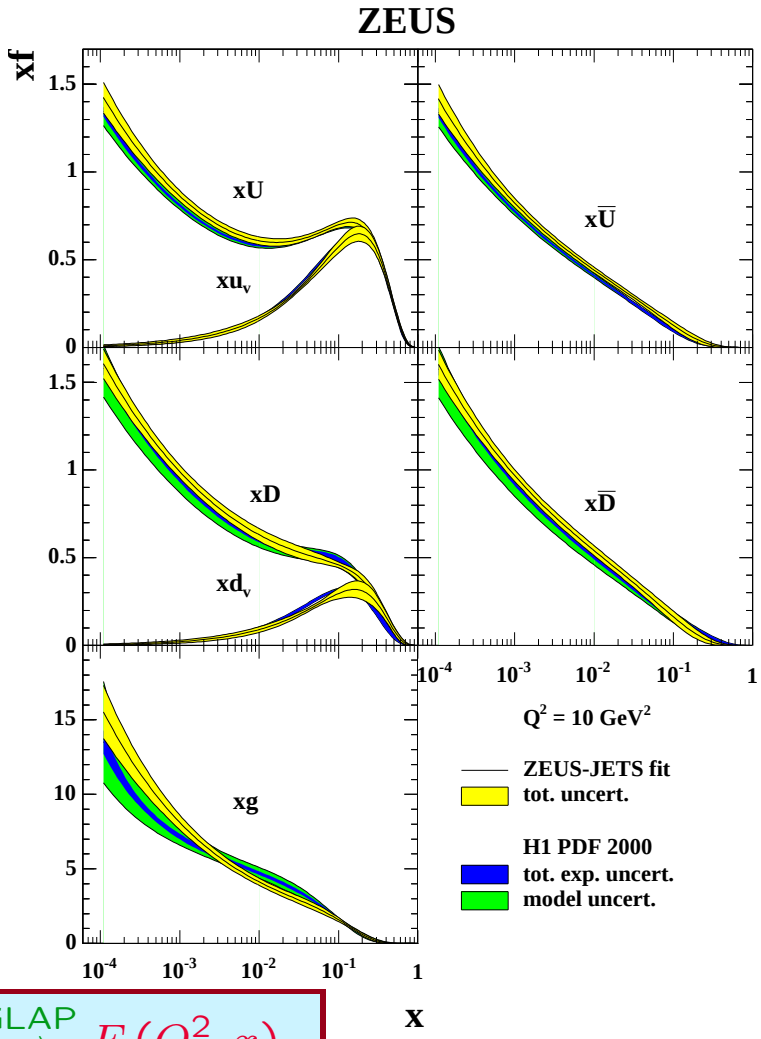
purely weak
F_i^{CC} coupling independent

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

Inclusive HERA I measurements



Electron ideal (EW) "probe" for F_i-measurements
$\Rightarrow$ Input for PDF extractions
$\Rightarrow$ Input for SM predictions



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

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

EW at HERA I: NC xF_3

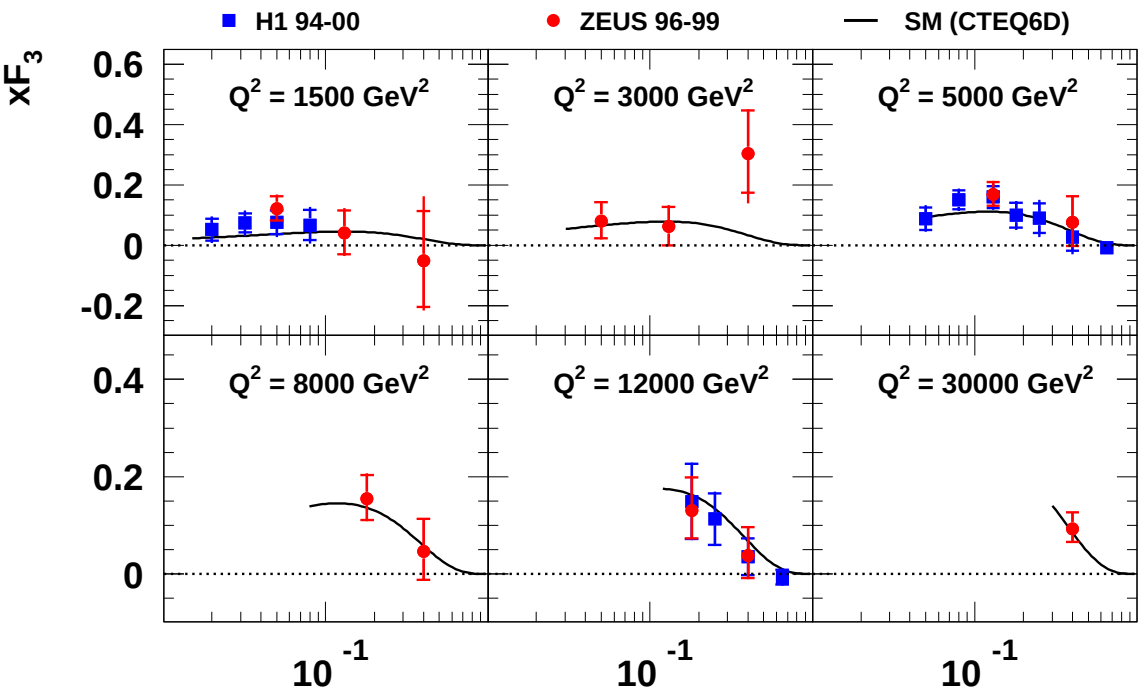
Parity violating xF_3:

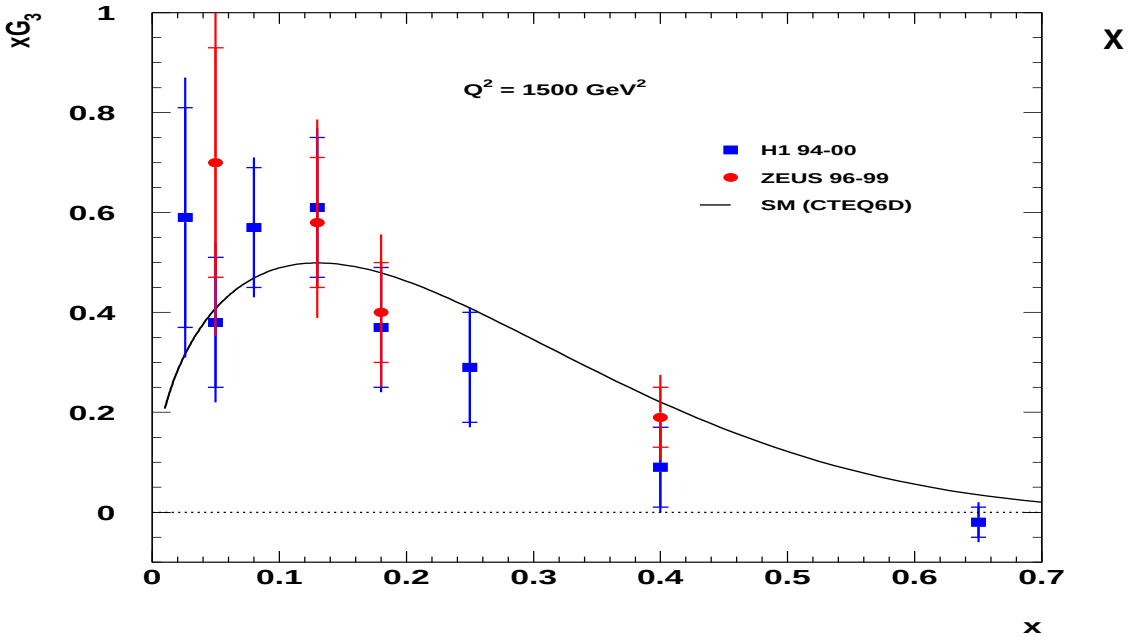
- None-zero xF_3 measured at HERA
- Precision limited by low statistics of e^-p sample

composition of xF_3:

$$xF_3 = -a_e \chi_Z xG_3 + 2a_e v_e \chi_Z^2 xH_3$$

- xG_3 stems from $\gamma - Z$ interference
- xH_3 arises from pure Z-exchange
- $\chi_Z = \kappa_W \cdot Q^2/(M_Z^2 + Q^2)$
- $2a_e v_e \chi_Z^2 xH_3$ negligible
- straight forward extract xG_3





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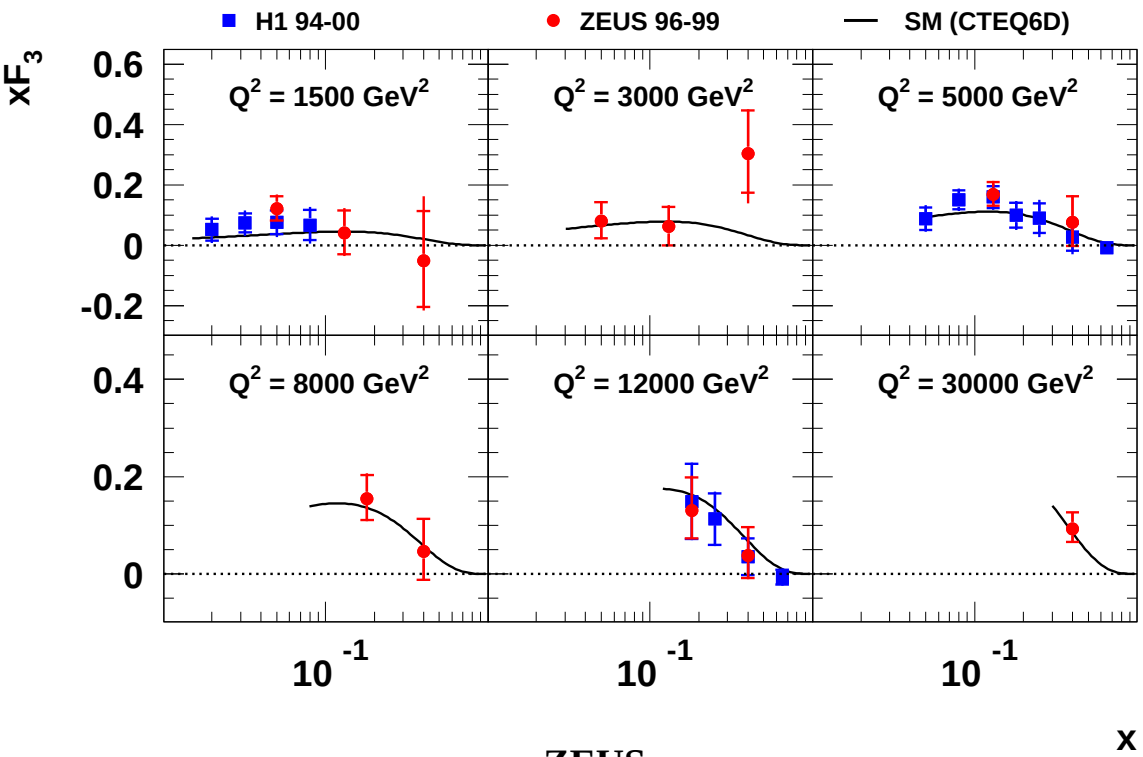

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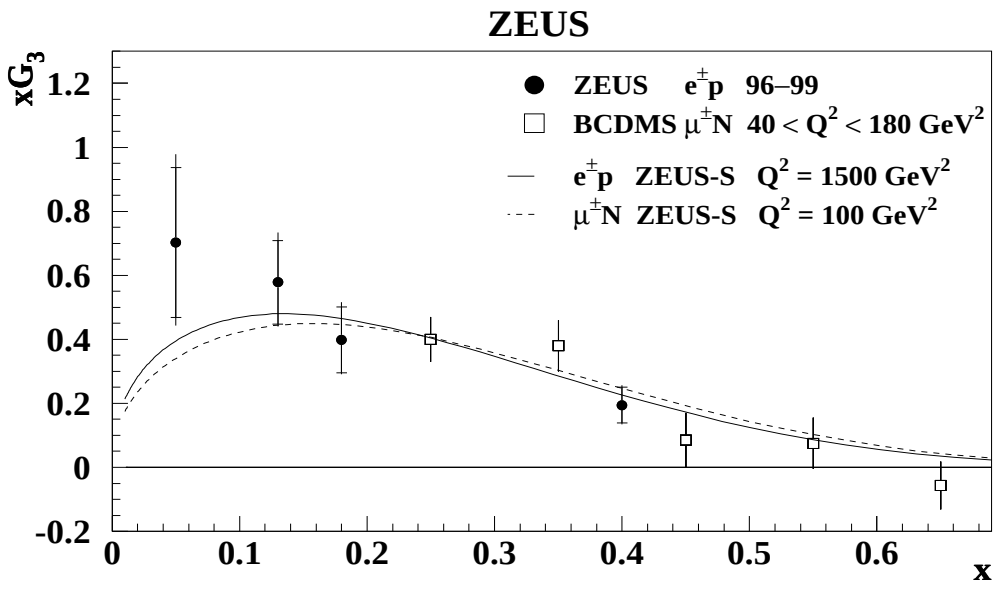
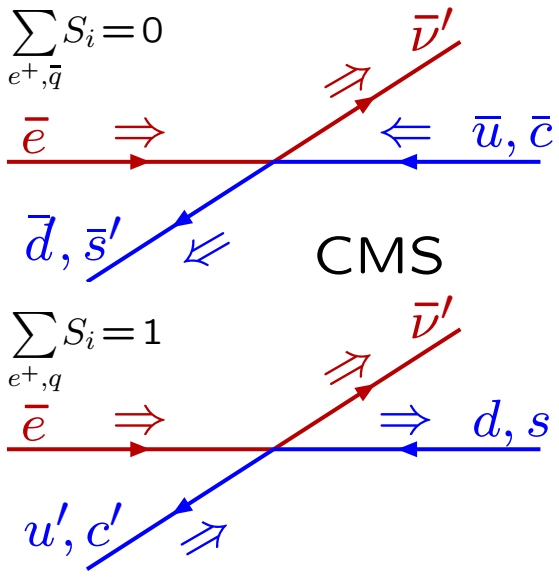
- straight forward extract xG_3
- compare to low Q^2 fixed-target BCDMS



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



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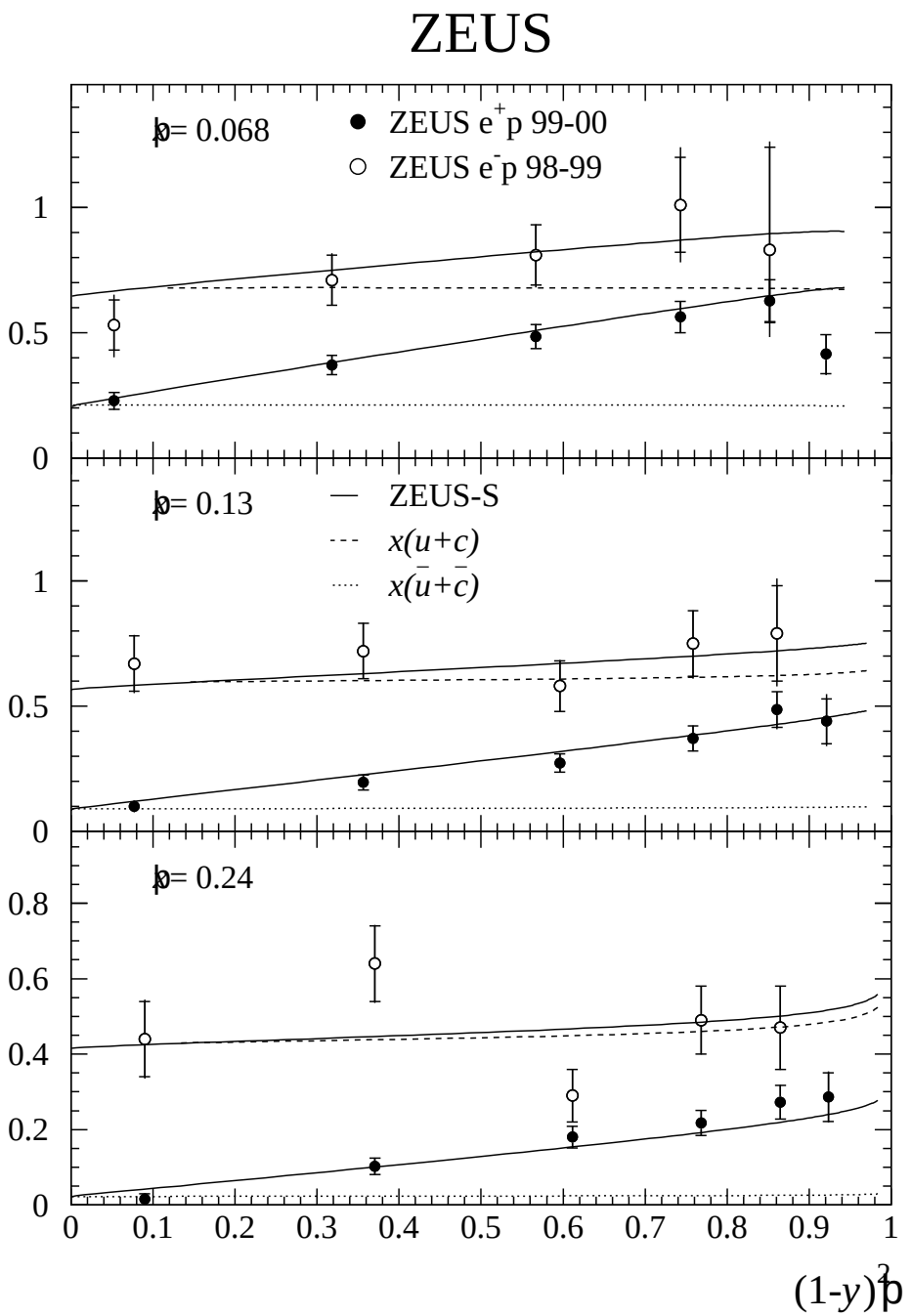
Down-type (anti-)quarks contribution suppressed by helicity:

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

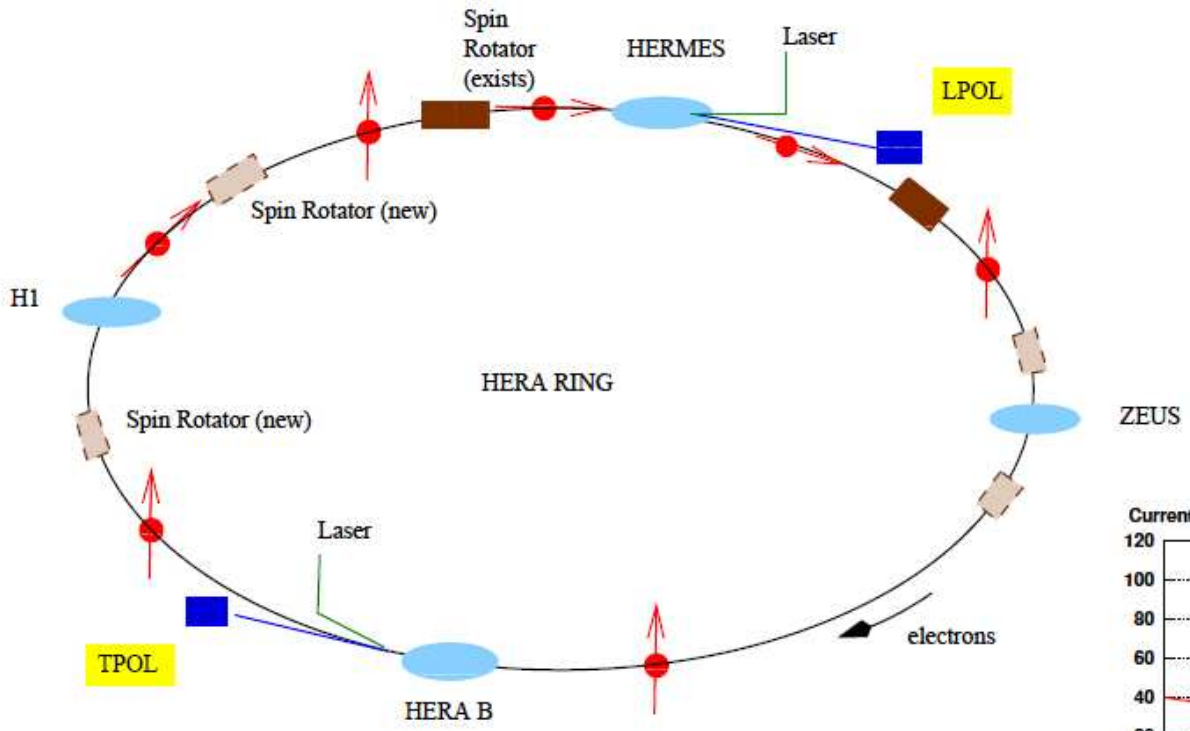
Helicity-structure of EW confirmed

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



HERA II: longitudinally polarised leptons

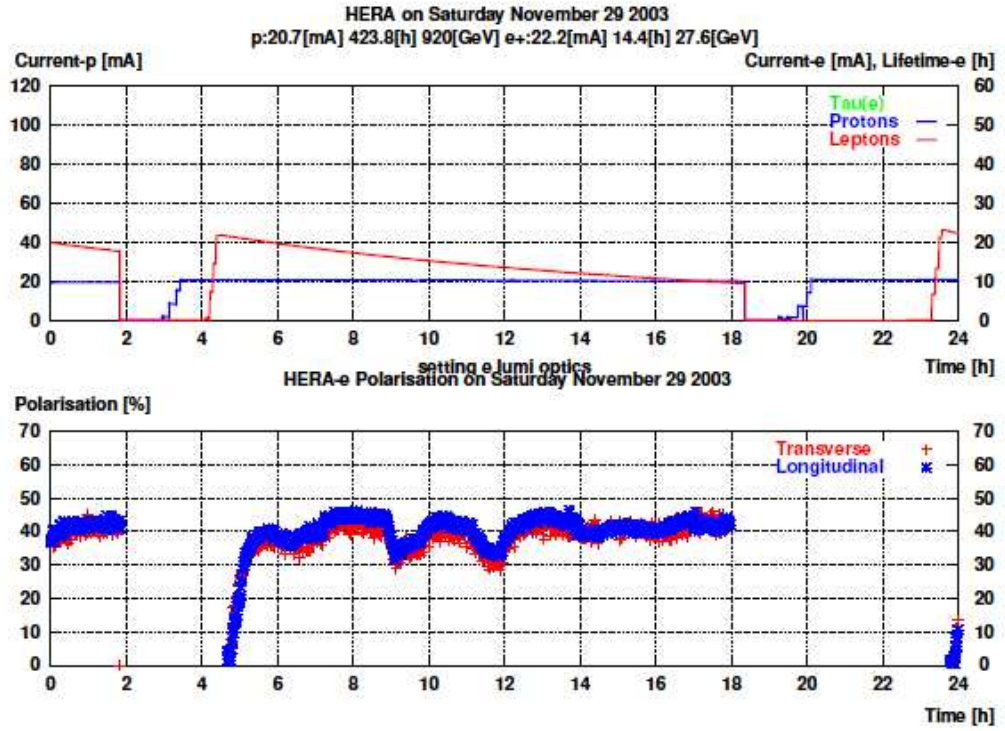
Longitudinal polarisation of lepton beam provides direct EW sensitivity



Sokolov-Termov effect builts-up transverse polarisation

Since 2002 spin-rotators also around H1 & ZEUS

(before only Hermes)

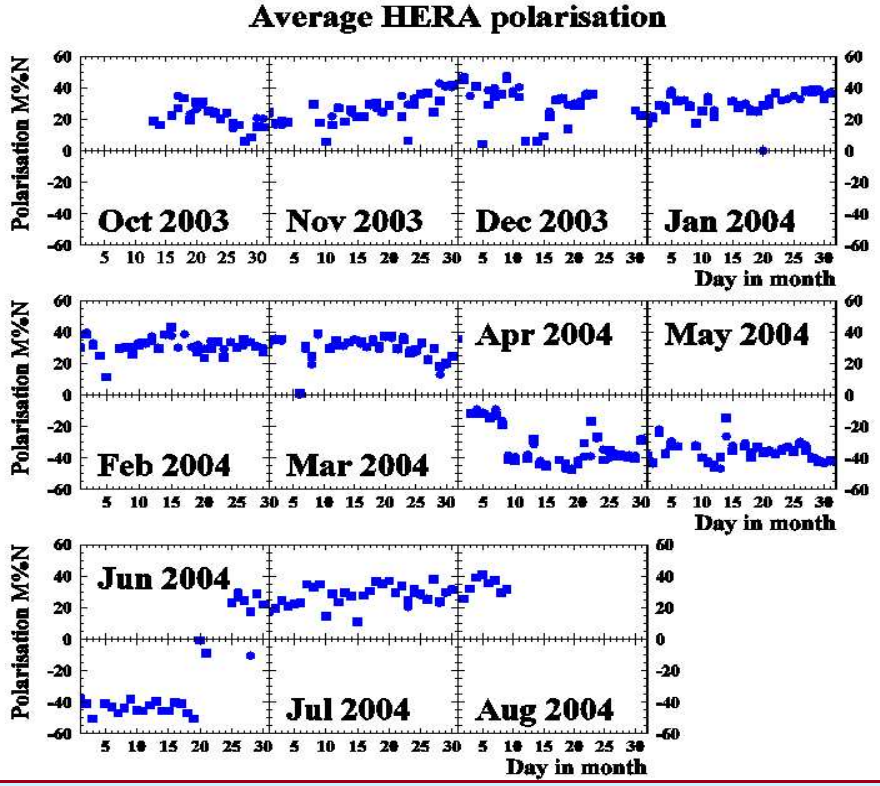


Polarisation measured at HERMES (LPOL) & HERA-west (TPOL)

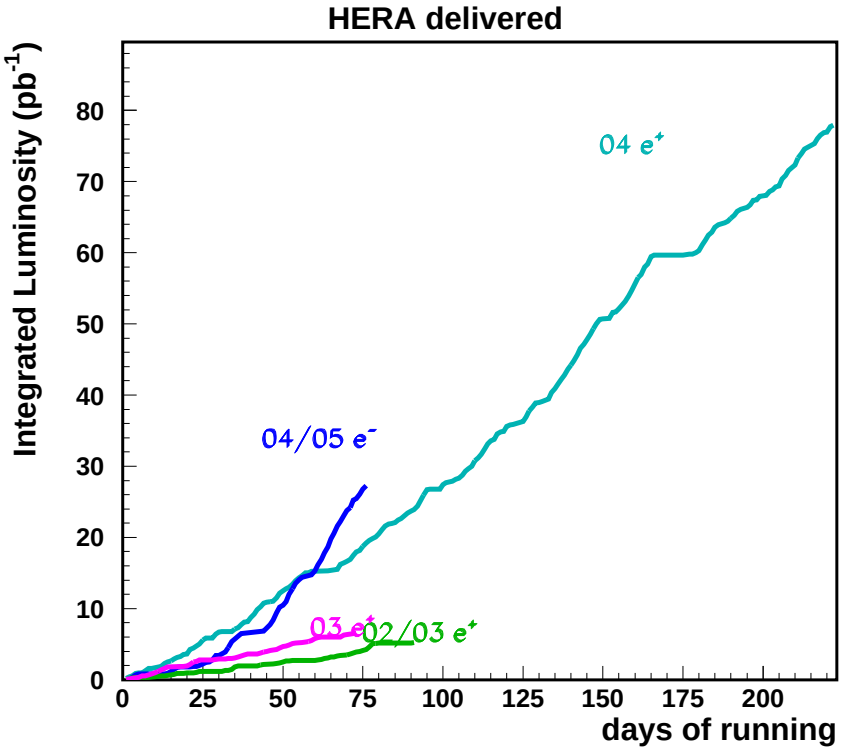
Polarisation builts-up fast and stable at up to $\simeq 50\%$

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

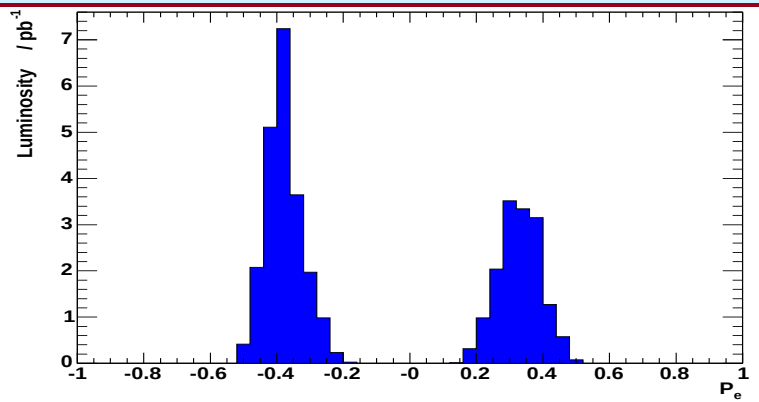
History of long. pol.: 20% — 50%



HERA delivered luminosity:



Pol.-distribution of H1 luminosity



Cross-section data-sets:

	$\mathcal{L}/\,\mathrm{pb}^{-1}$	P
H1	15.3	+33.0%
	21.7	-40.2%
ZEUS	14.1	+31.8%
	16.4	-40.2%

Cross sections for polarised lepton beam

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

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

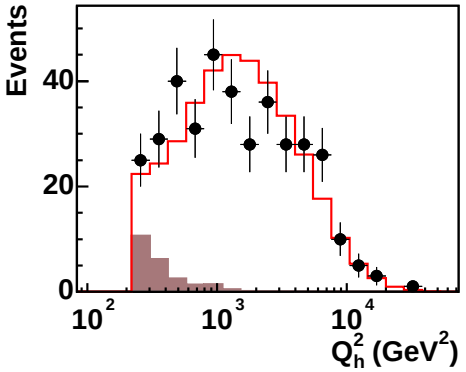
$$\begin{aligned}
\sigma_0 &= Y_+\hat{F}_2 \\
\sigma_i^\pm(\lambda) &= P_Z\left[Y_+(-v\mp\lambda a)\hat{G}_2 + Y_+(\pm a+\lambda v)x\hat{G}_3\right] \\
\sigma_Z^\pm(\lambda) &= P_Z^2\left[Y_+(v^2+a^2\pm\lambda va)\hat{H}_2 + Y_-(\mp 2va-(v^2+a^2)\lambda)x\hat{H}_3\right]
\end{aligned}$$

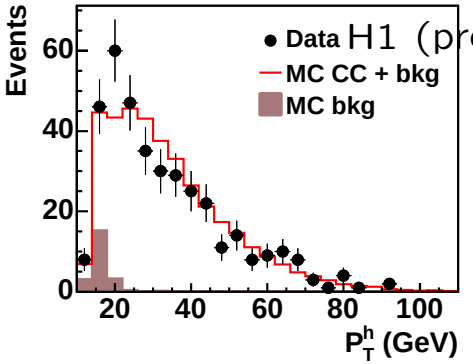
$$\begin{aligned}
\hat{F}_2 &= x\sum_q (q+\bar{q})\cdot q_q^2 \\
\hat{G}_2 &= x\sum_q (q+\bar{q})\cdot 2v_q q_q \\
\hat{H}_2 &= x\sum_q (q+\bar{q})\cdot ({v_q}^2+{a_q}^2)
\end{aligned}$$

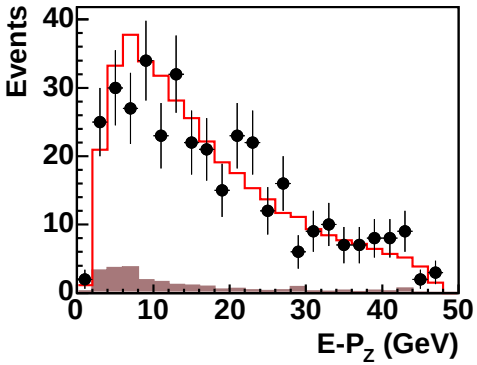
$$\begin{aligned}
x\hat{G}_3 &= 2x\sum_q (q-\bar{q})\cdot a_q q_q \\
x\hat{H}_3 &= 2x\sum_q (q-\bar{q})\cdot a_q v_q
\end{aligned}$$

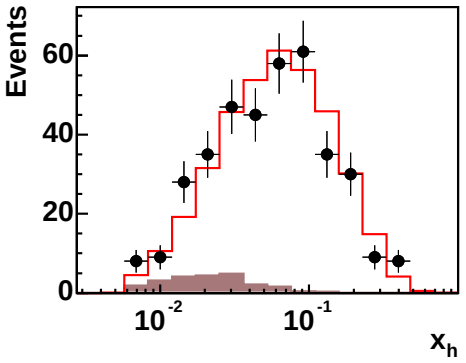
CC DIS measurement: control plots

L.H.



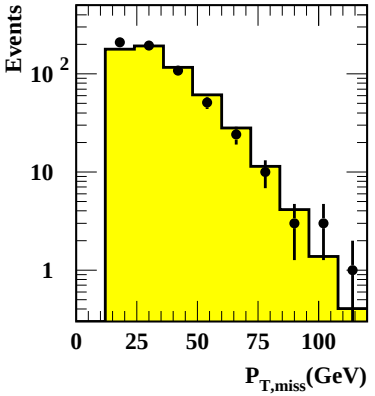


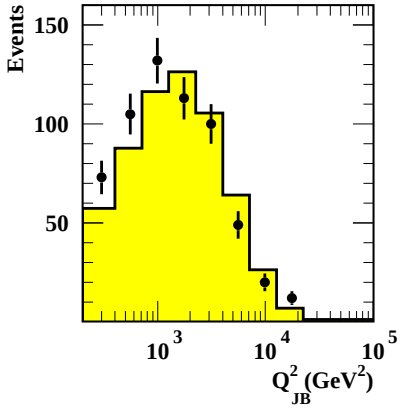


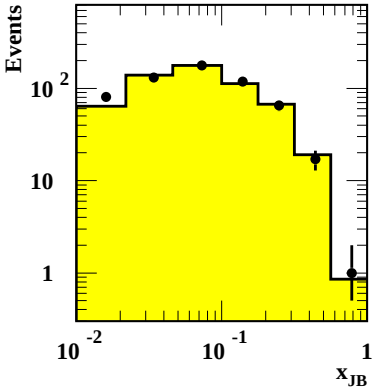


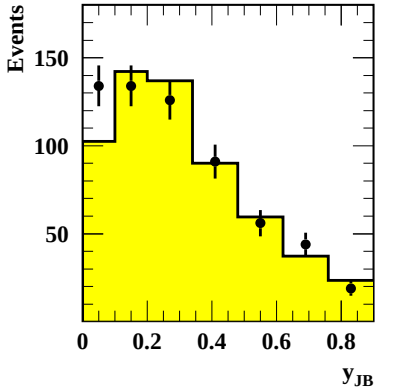
ZEUS

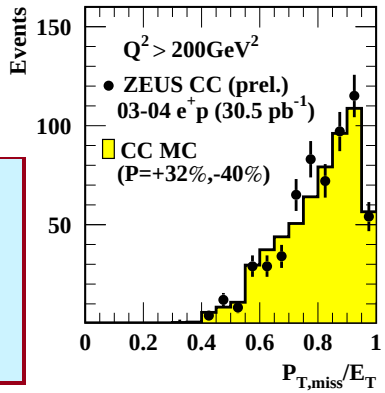
L.H.+R.H.

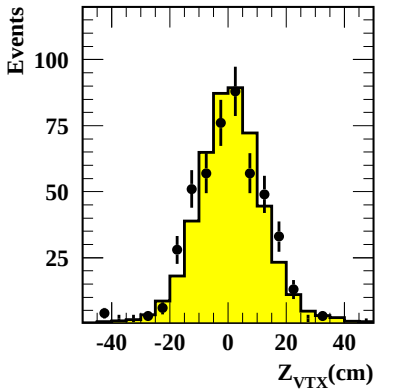








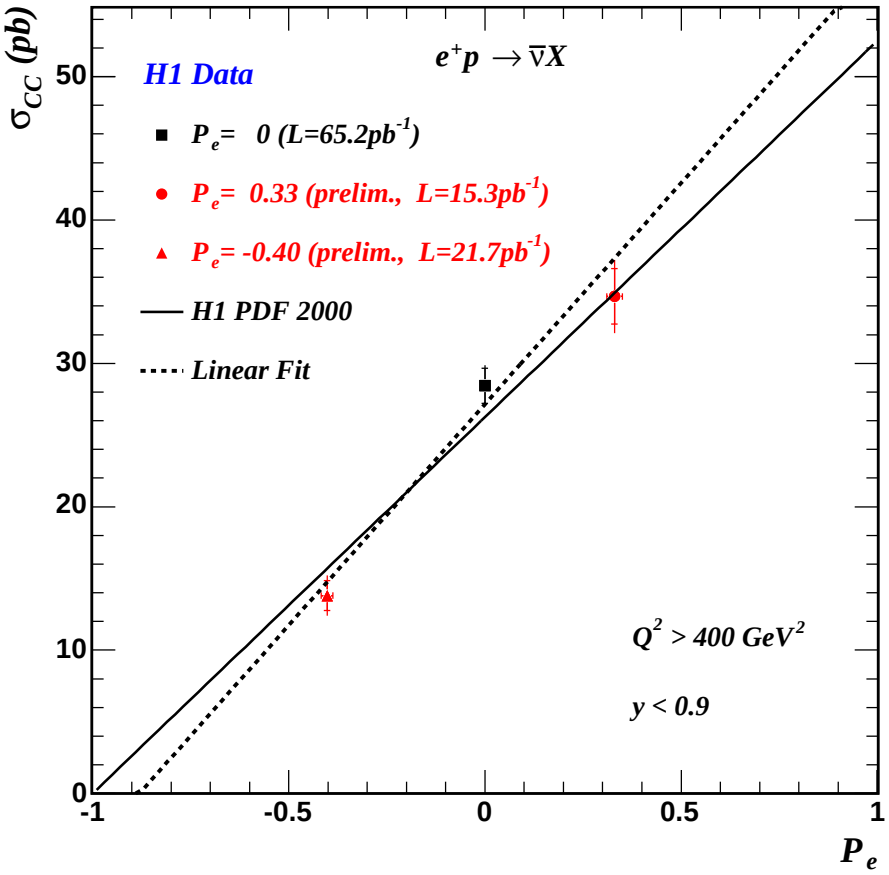




Kinematics reconstructed from haronic final state (JB)

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

H1 CC DIS measurement: cross section



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

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

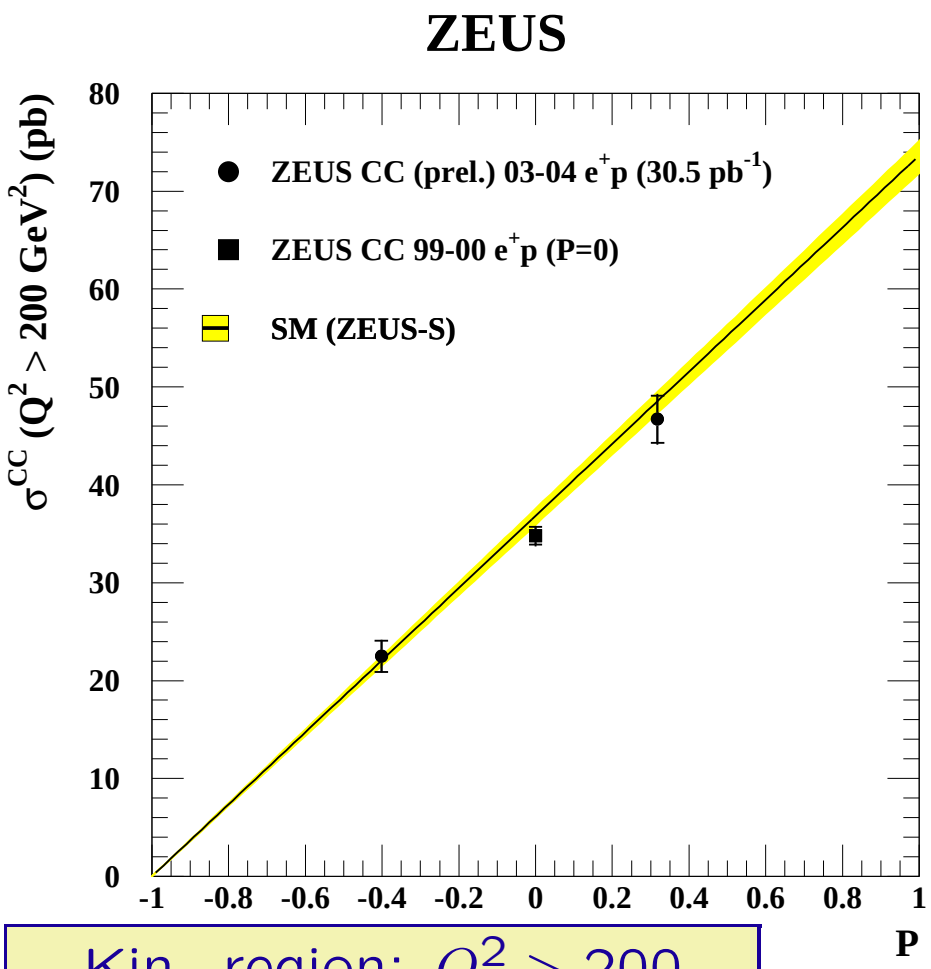
$$\sigma_{CC}(P = -40.2 \pm 1.5) =$$
$$13.8 \pm 1.0(\mathrm{stat.}) \pm 1.0(\mathrm{syst.})\ \mathrm{pb}$$

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

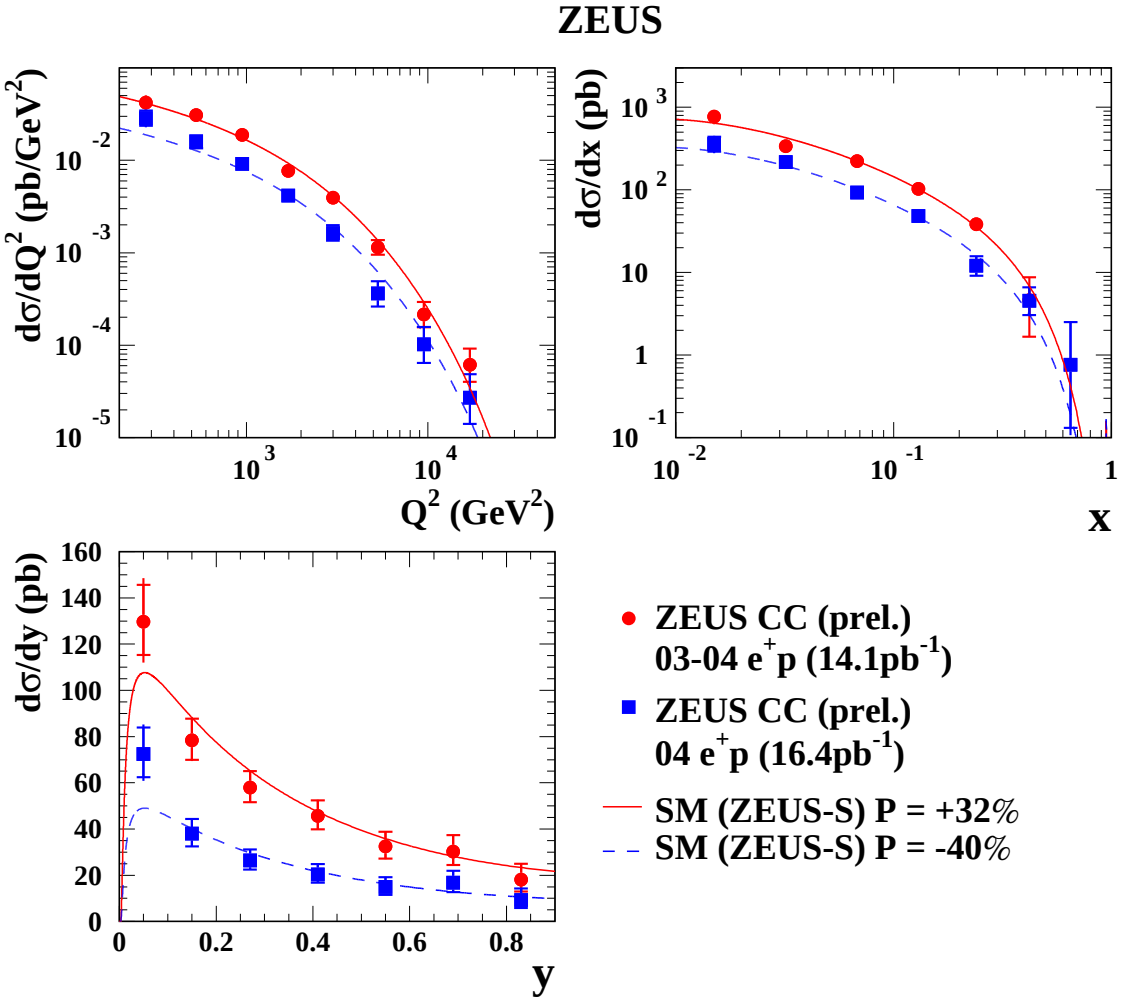
$\sigma_{CC}(P=-1) = -3.7 \pm 2.4(\mathrm{stat.}) \pm 2.7(\mathrm{syst.})\ \mathrm{pb}$

Consistent with no R.H. W-exchange

ZEUS CC DIS measurement: cross section



Kin. region: $Q^2 > 200$



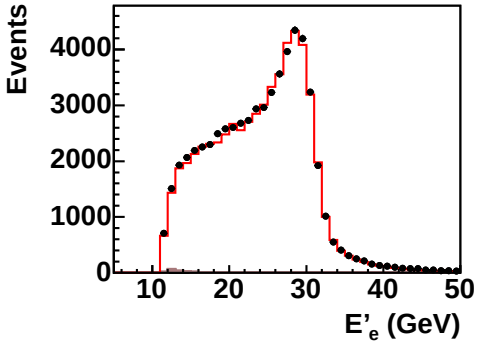
$$\sigma_{CC}(P = +31.8 \pm 0.9) = 46.7 \pm 2.4(\text{stat.}) \pm 1.0(\text{syst.}) \pm 2.3(\text{lumi.})\ \text{pb}$$

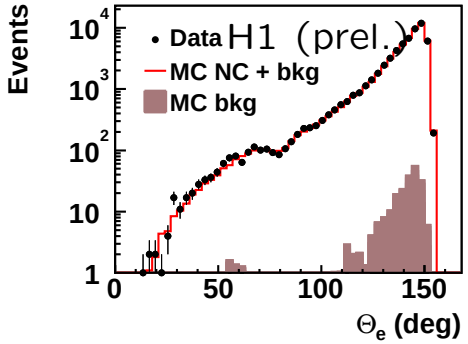
$$\sigma_{CC}(P = -40.2 \pm 1.1) = 22.5 \pm 1.6(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.1(\text{lumi.})\ \text{pb}$$

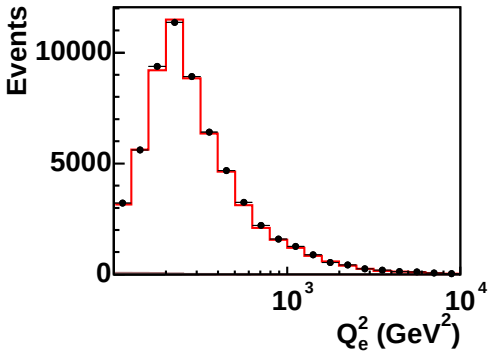
Consistent with SM using ZEUS-S (no R.H. W-exchange)

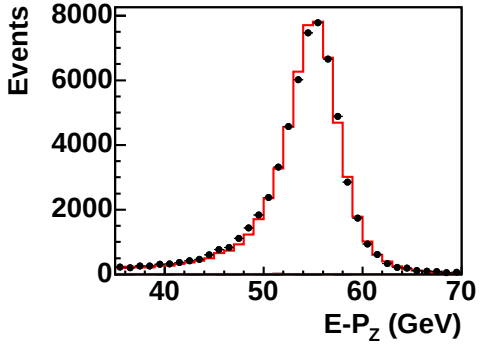
NC DIS measurement: control plots

L.H.





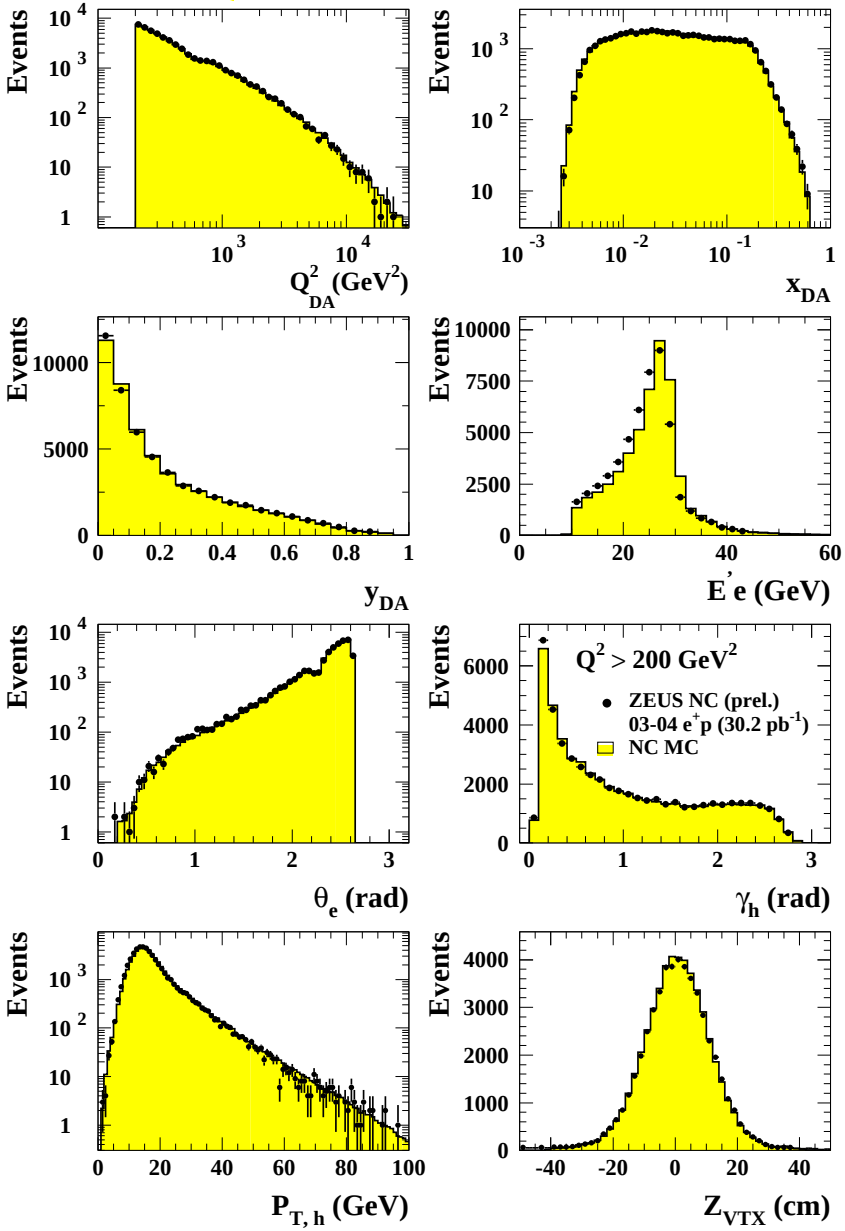




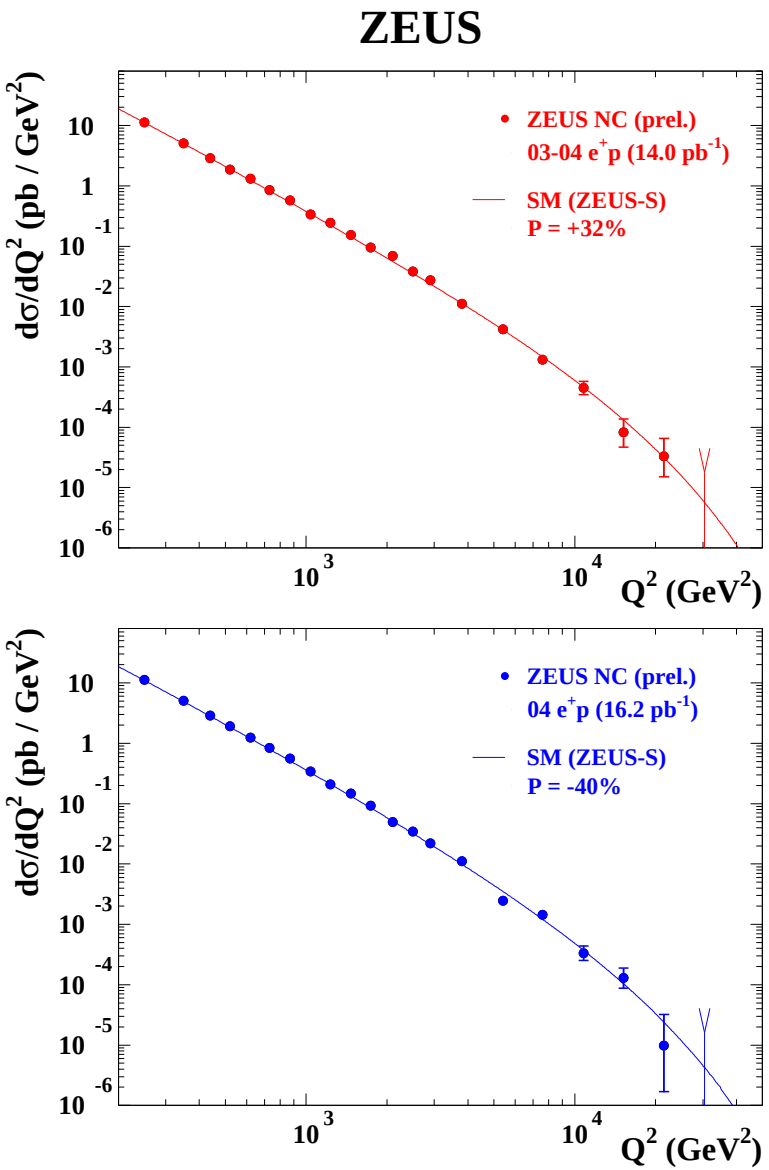
Kinematics reconstructed from electron and hadronic final state

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

ZEUS L.H.+R.H.



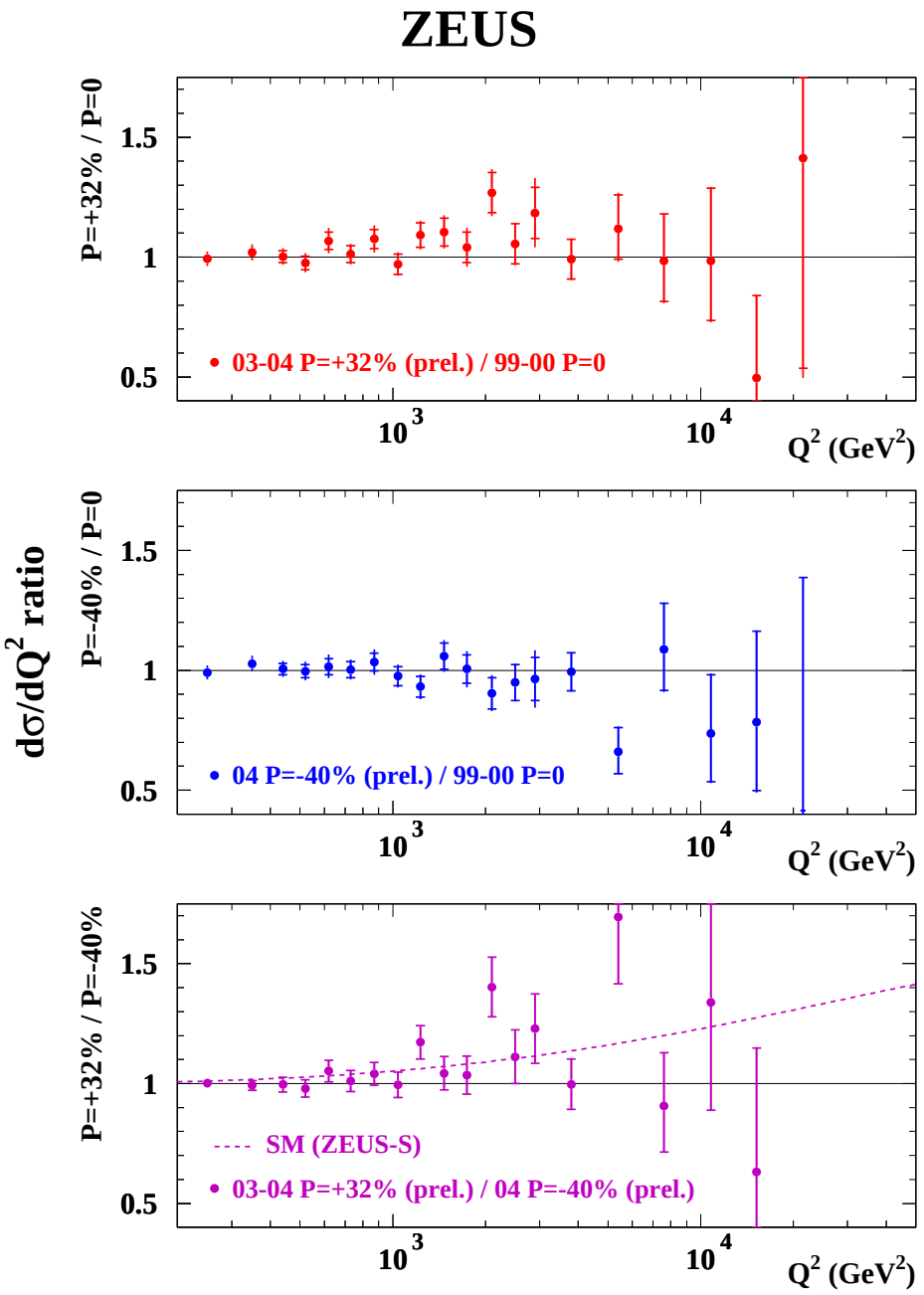
ZEUS NC DIS measurement: cross section



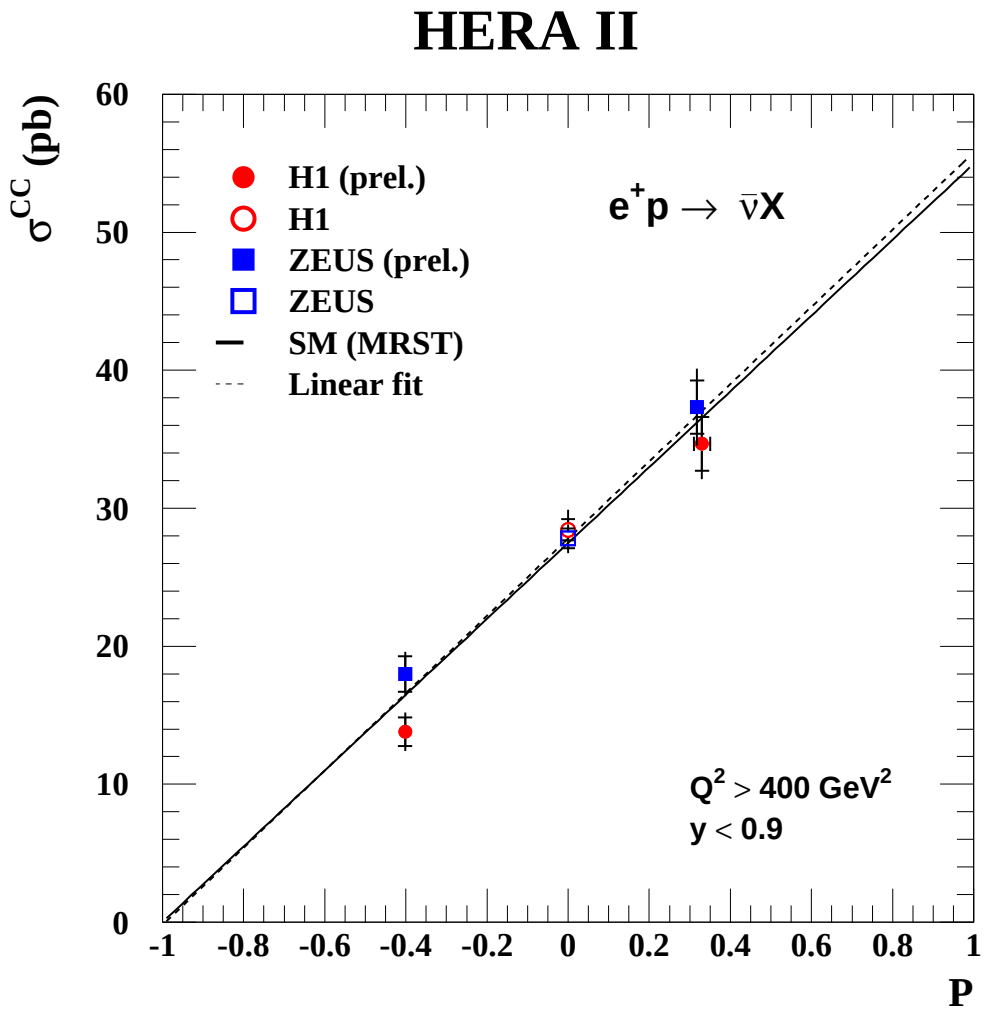
Consistent with SM

NC much less polarisation-dependent

NC challange for HERA II



Summary & Outlook

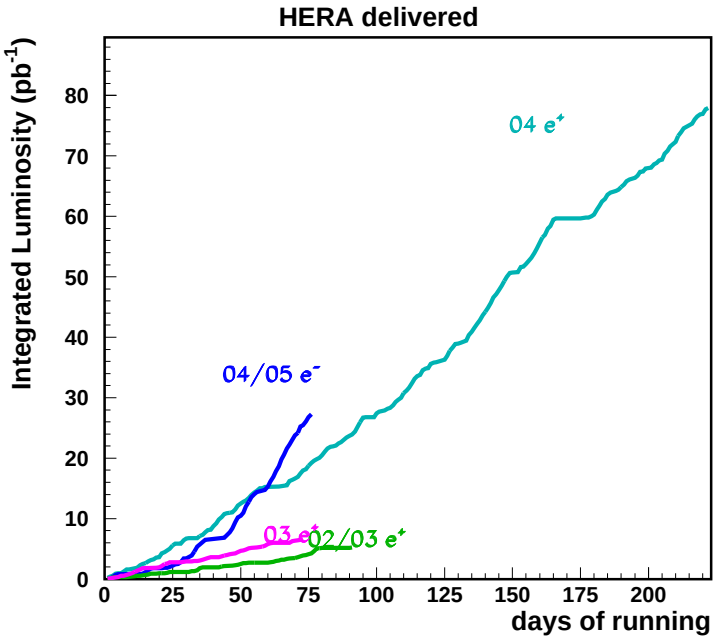


Both H1 & ZEUS:

- 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