Electroweak constraints from HERA

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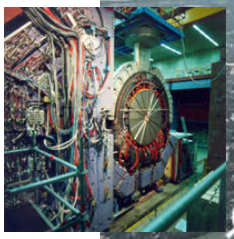
representing

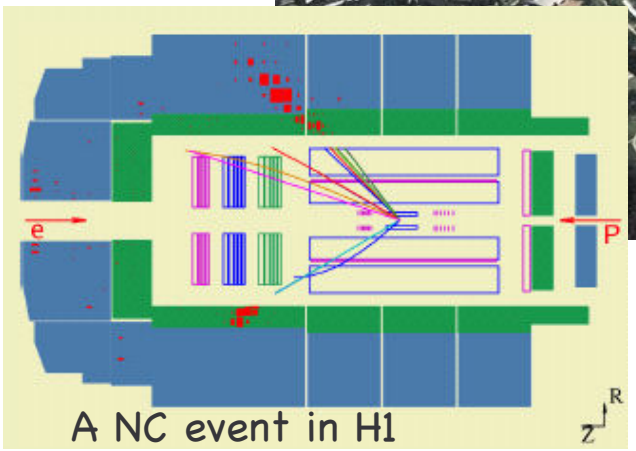
- o HERA, a QCD-EW machine
- o EW constraints from inclusive data
- o Search for new physics at high Q^2
- o Search for new physics in lepton+missing P_T events
- o Search for new physics in multilepton events

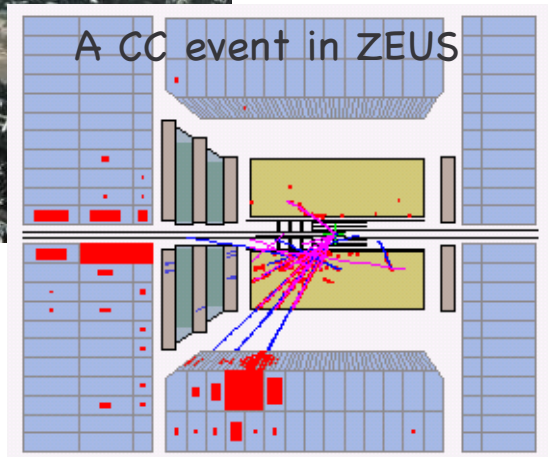
HERA, an ep collider

H1

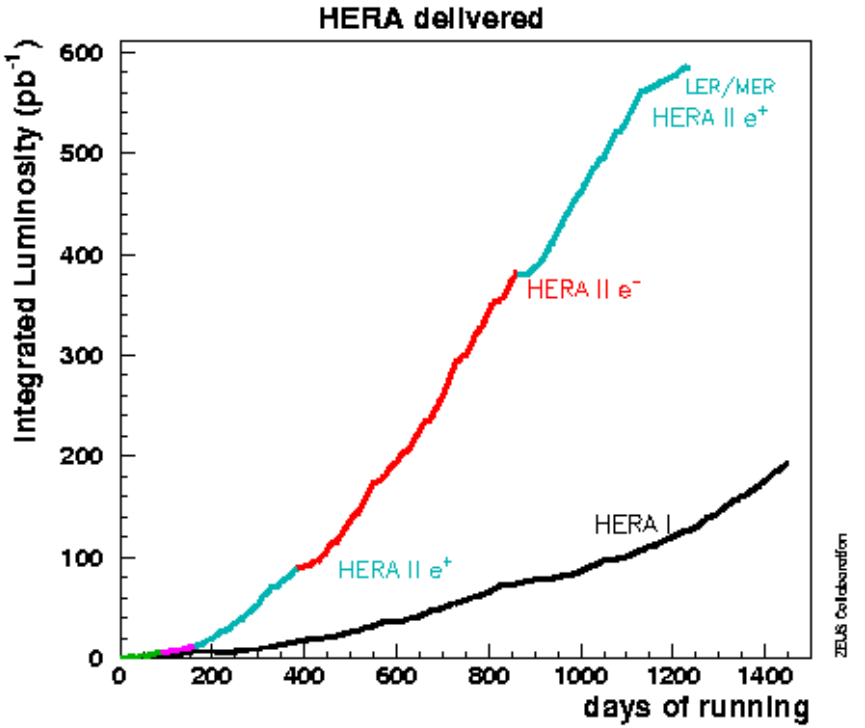


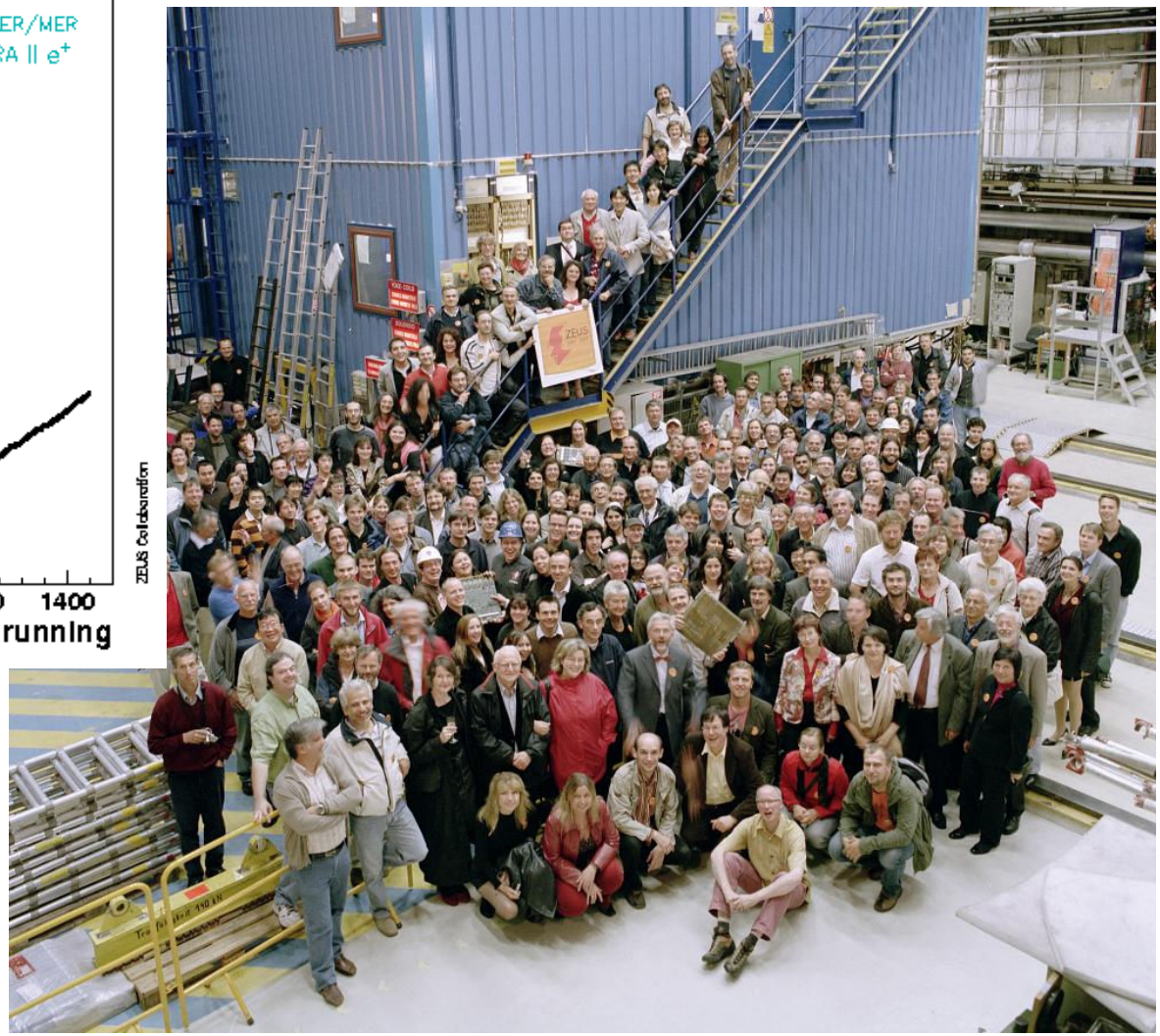
ZEUS





HERA luminosity





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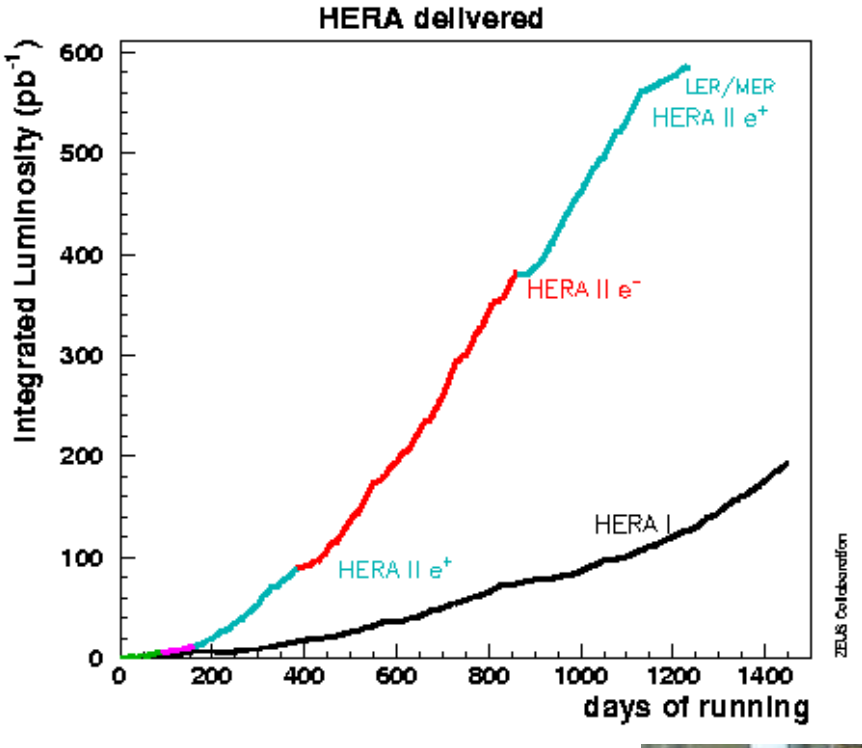
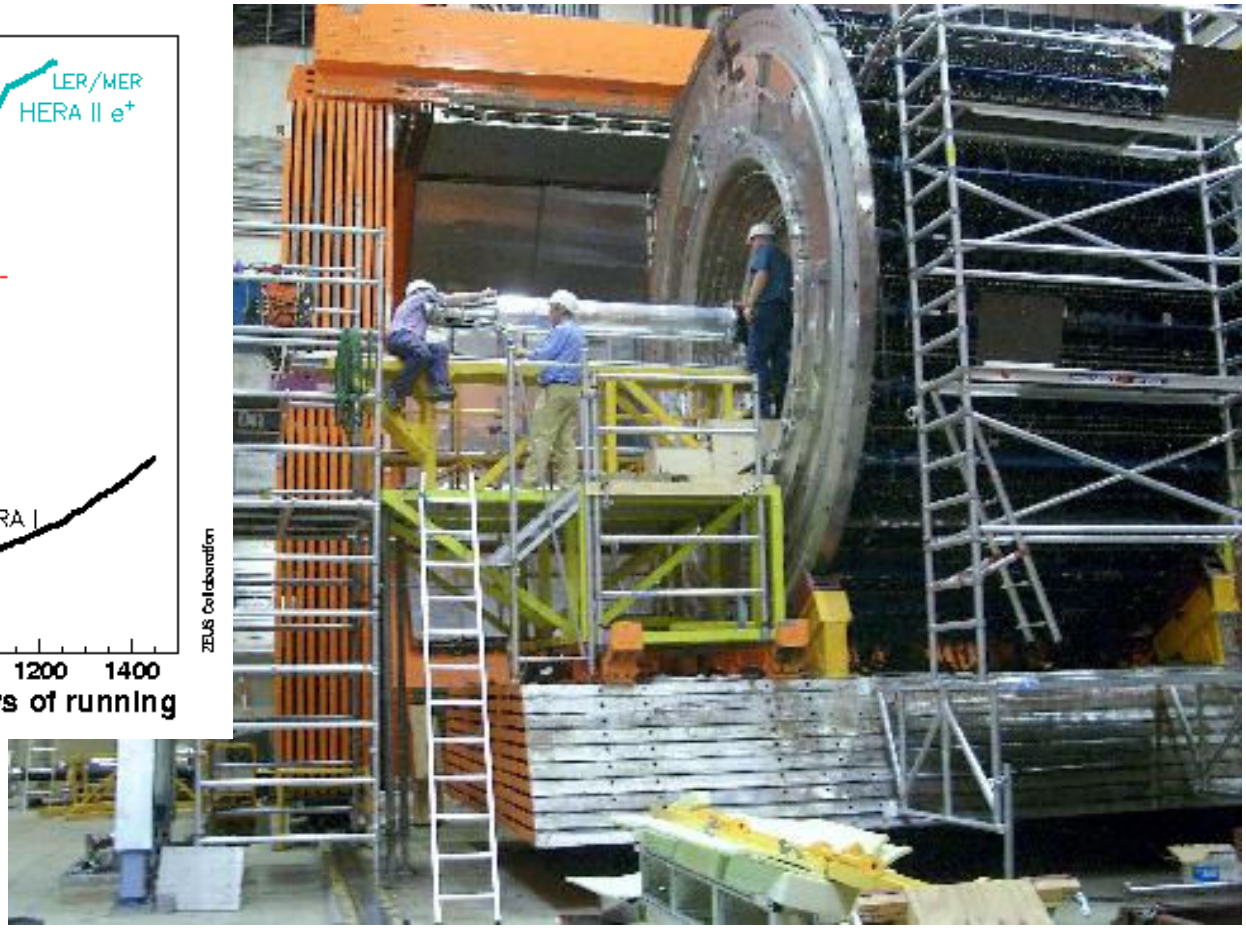
0.5 fb^{-1} per exp., 1 fb^{-1}
H1+ZEUS combined

HERA luminosity



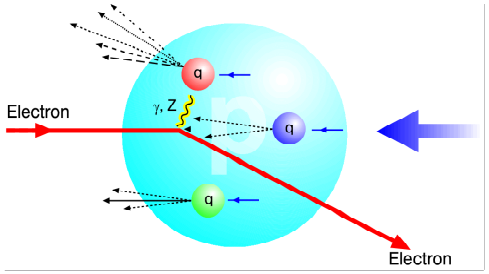


Last Fill 30/6/2007,

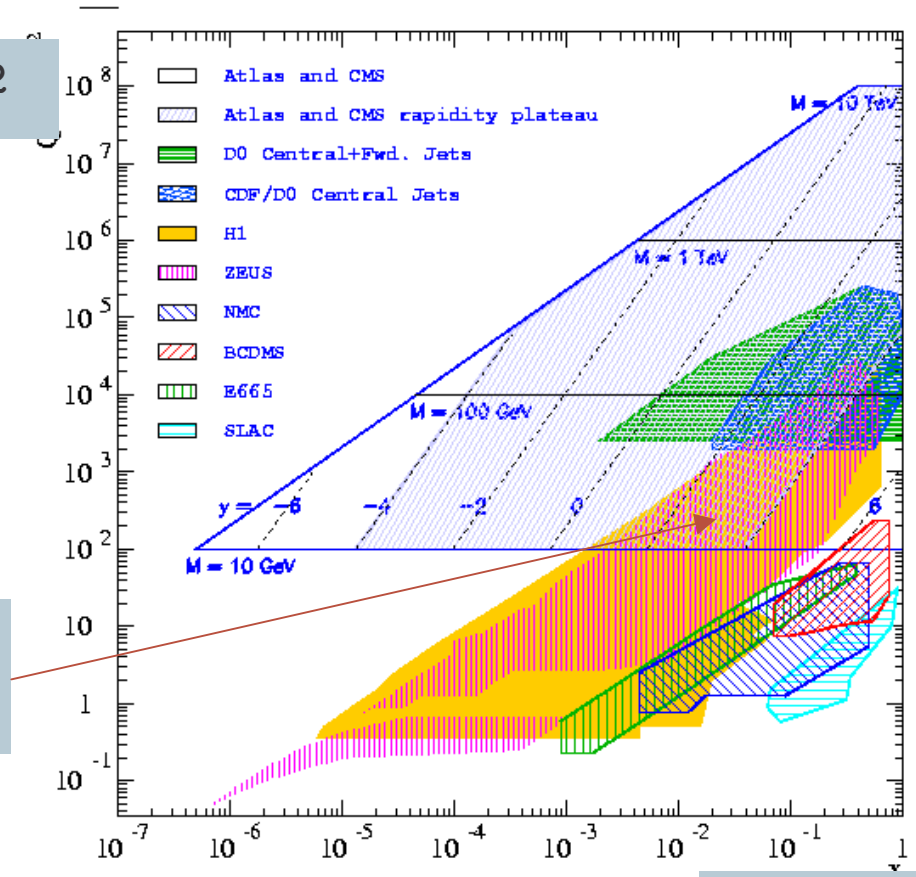
0.5 fb^{-1} per exp., 1 fb^{-1}
H1+ZEUS combined

HERA, for EW studies

Main goal of HERA: study the proton parton densities, i.e. make predictions for LHC



Q^2



xBjorken

But for $Q^2 \sim M^2_Z/M^2_W$ we can study EW interactions

this talk

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

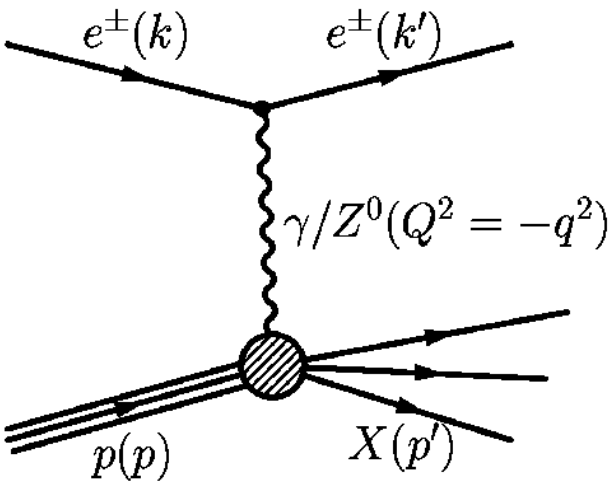
Geiser's talk

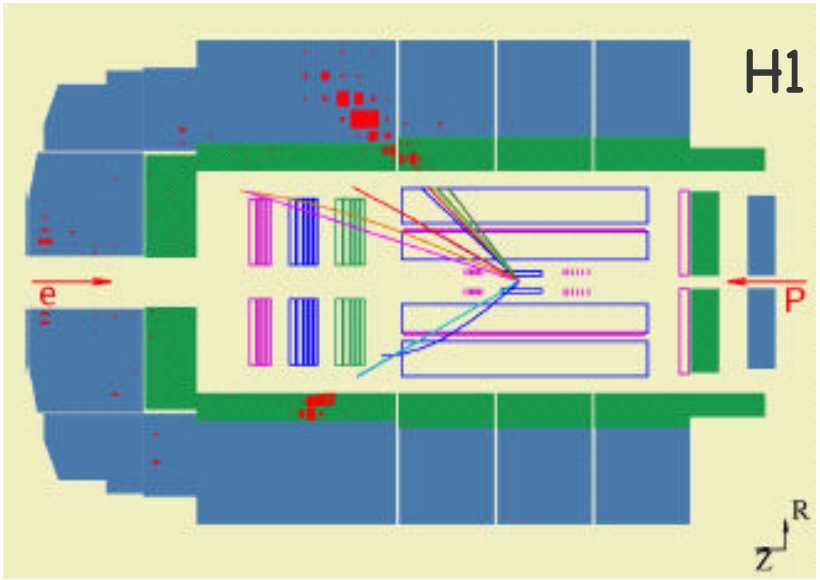
Chekelian's talk

Inclusive measurements

Neutral Current at high Q^2

$$\sigma(e^{\pm}) \propto Y_{+} F_2(e^{\pm}) \mp Y_{-} xF_3(e^{\pm})$$





$$F_2^{L,R} = \sum_q [xq(x,Q^2) + x\bar{q}(x,Q^2)] \cdot A_q^{L,R},$$

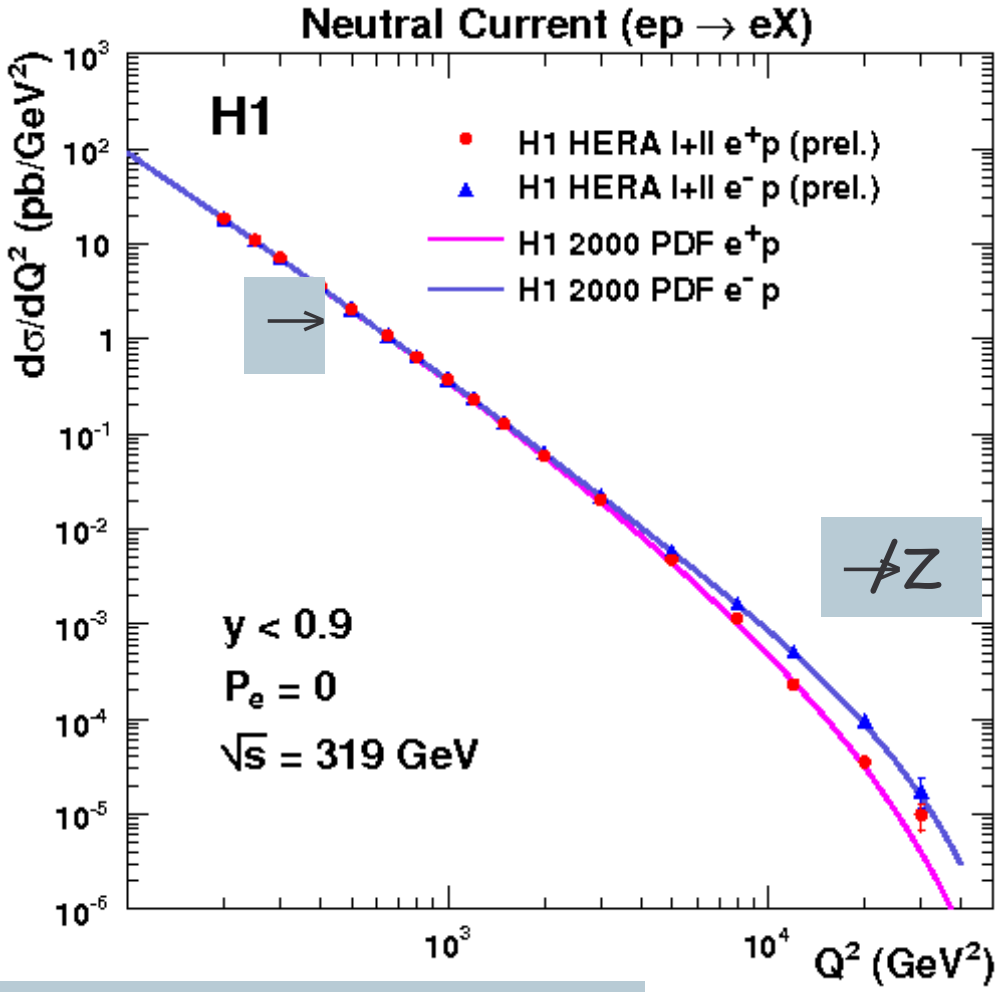
$$xF_3^{L,R} = \sum_q [xq(x,Q^2) - x\bar{q}(x,Q^2)] \cdot B_q^{L,R}.$$

→ ≠Z pure Z

$$A_q^{L,R} = Q_q^2 + 2Q_eQ_q(v_e \pm a_e)v_q\chi_Z + (v_e \pm a_e)^2(v_q^2 + a_q^2)(\chi_Z)^2,$$

$$B_q^{L,R} = \pm 2Q_eQ_q(v_e \pm a_e)a_q\chi_Z \pm 2(v_e \pm a_e)^2 v_q a_q (\chi_Z)^2,$$

Q^2 dependence in NC

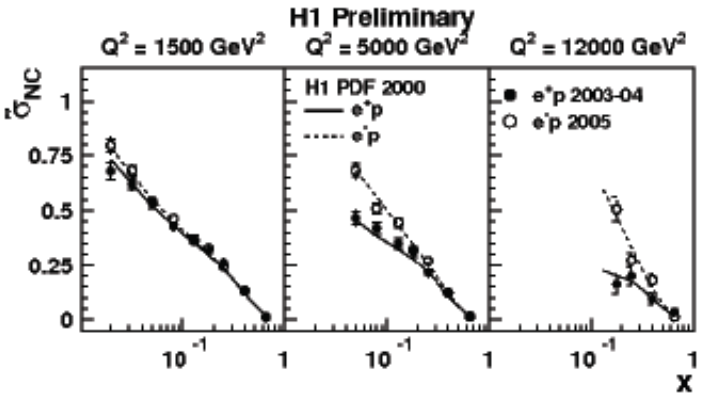


Contribution of interference and xF_3 only at very high Q^2

Good agreement with SM (EW+QCD) over 7 orders of magnitude

xF_3 and x-dependence in NC

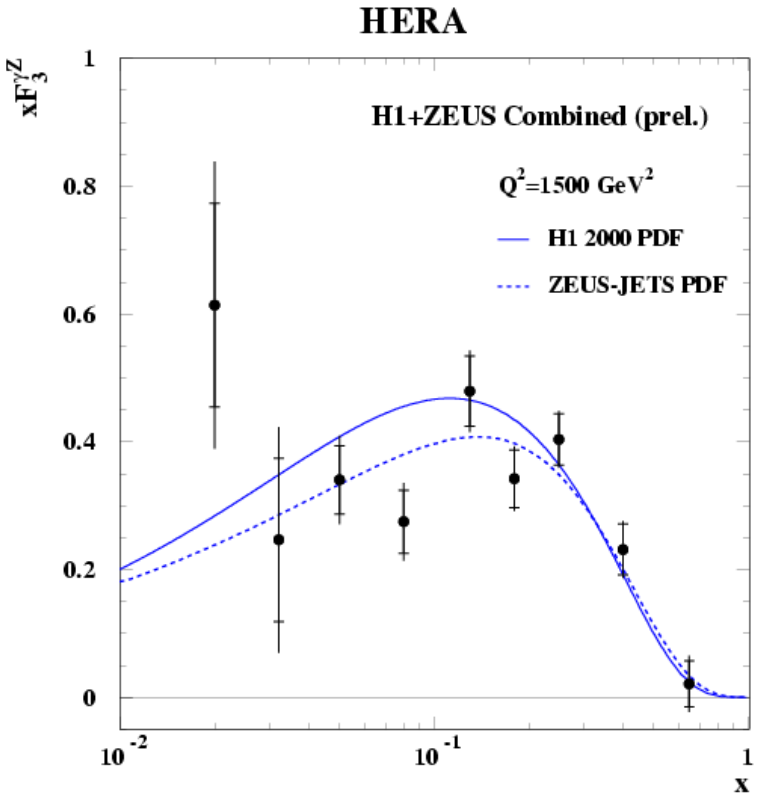
$$\sigma(e^{\pm}) \propto Y_+ F_2(e^{\pm}) \mp Y_- xF_3(e^{\pm})$$



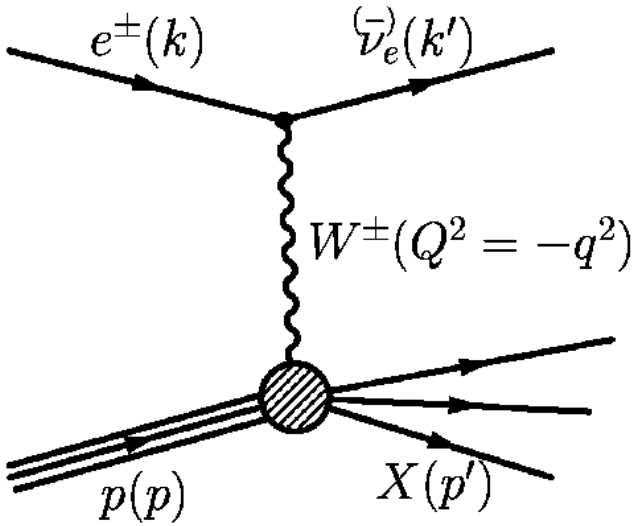
$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v + \Delta)$$

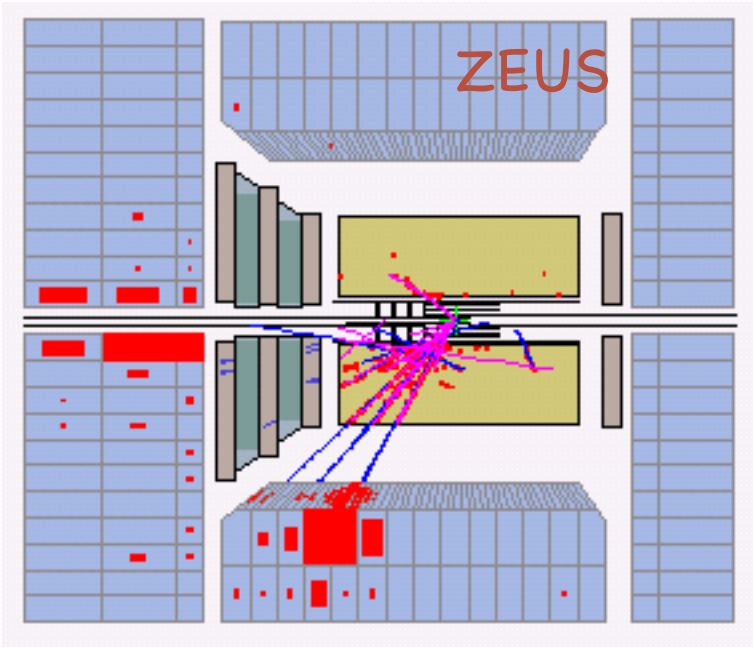
Gives a measure of the u and d valence at low x

(LHC will measure it in W-production)



Charged Current at high Q^2



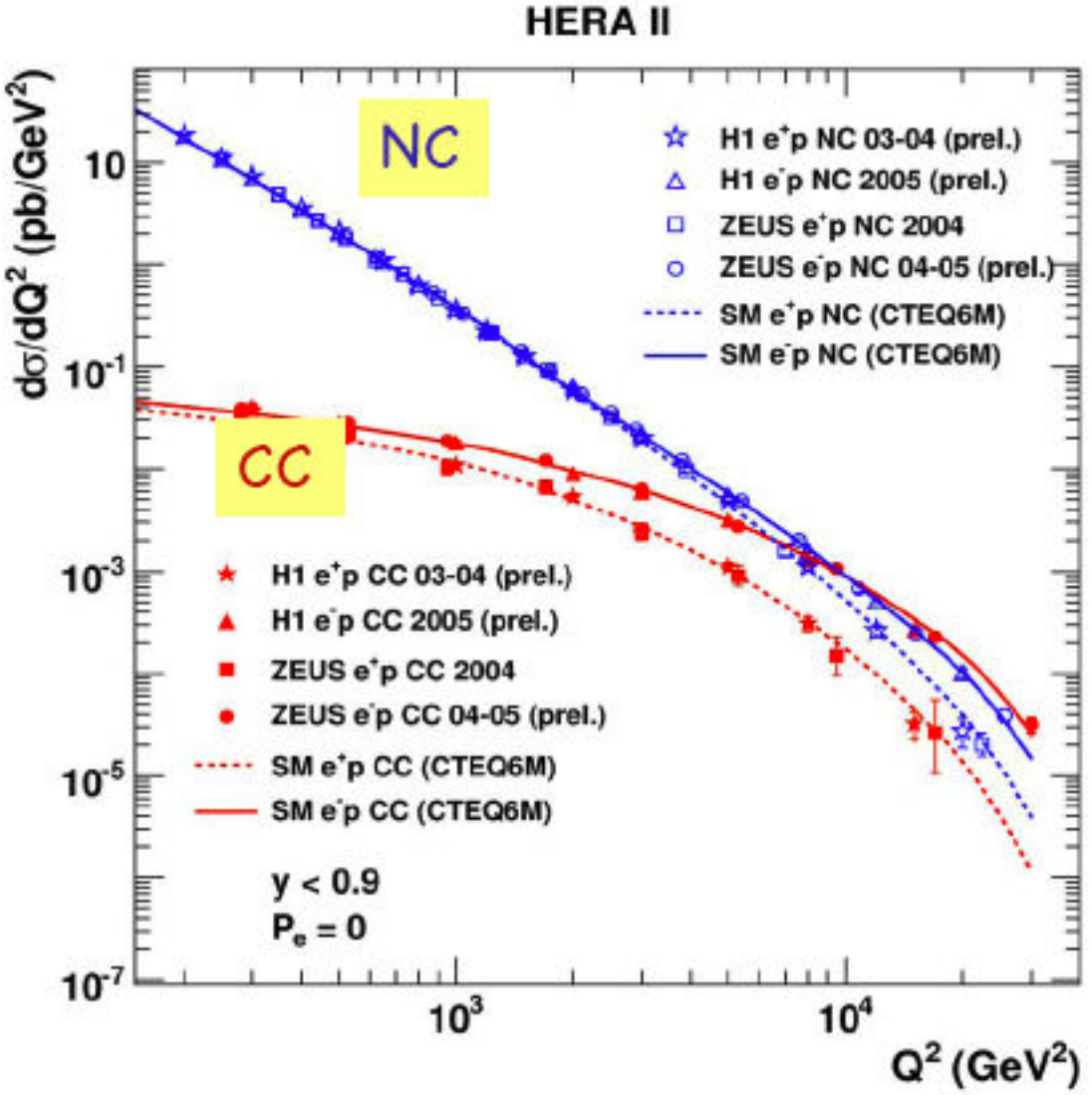


$$\frac{d\sigma^{e^+p}_{unpolCC}}{dQ^2dx} = \frac{G_F}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}_i(Q^2,x) + (1-y)^2 d_i(Q^2,x)\right]$$

$$\frac{d\sigma^{e^-p}_{unpolCC}}{dQ^2dx} = \frac{G_F}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[u_i(Q^2,x) + (1-y)^2 \bar{d}_i(Q^2,x)\right]$$

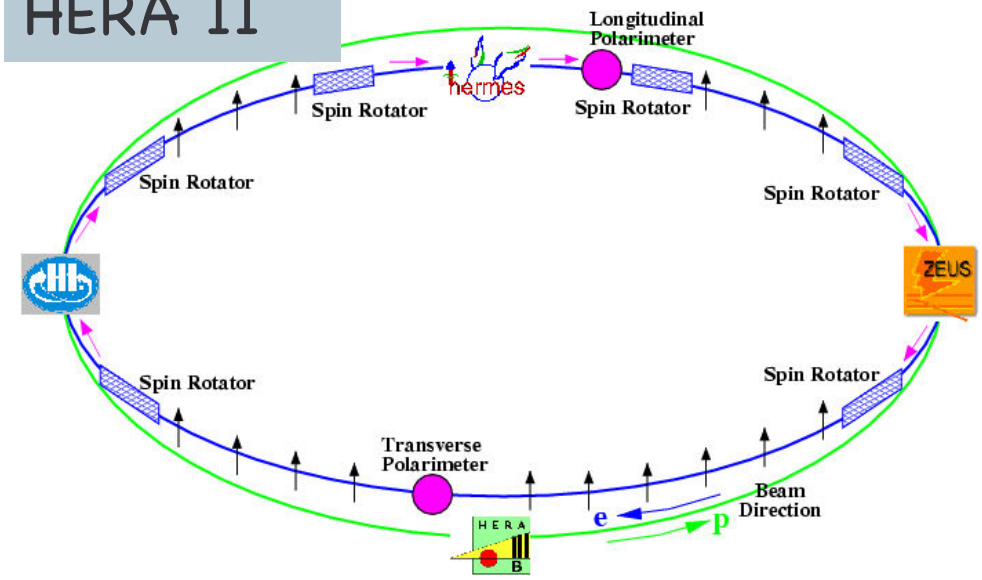
NC/CC at high Q^2

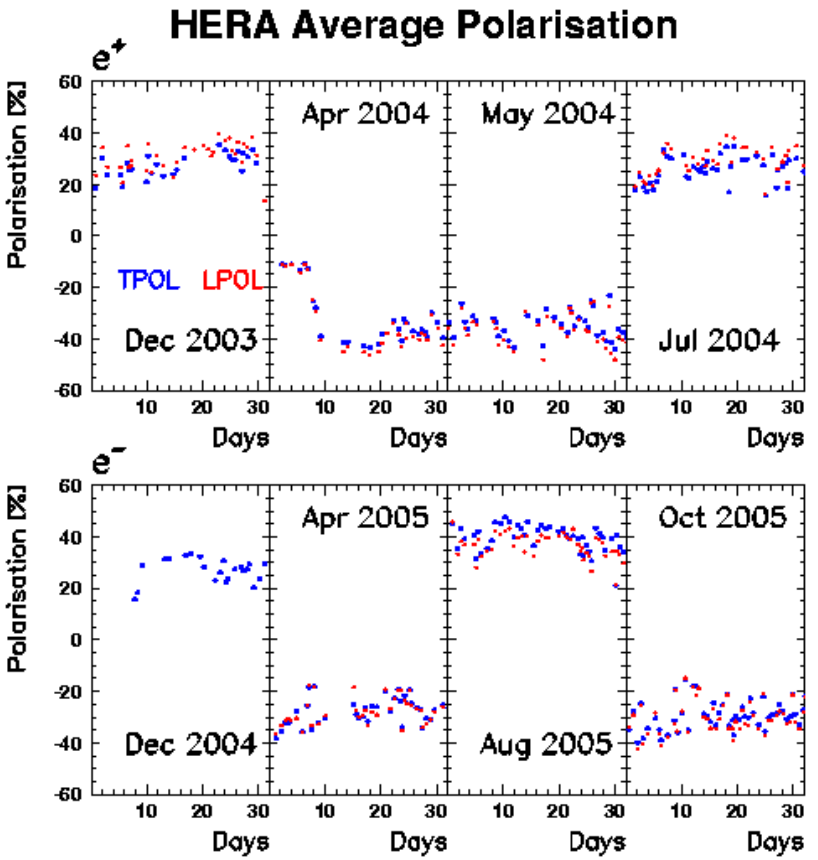
Textbook plot, the NC (EW) and CC interaction (pure weak) are of the same strength at the mass of the Z or W squared.



Polarized CC

HERA II



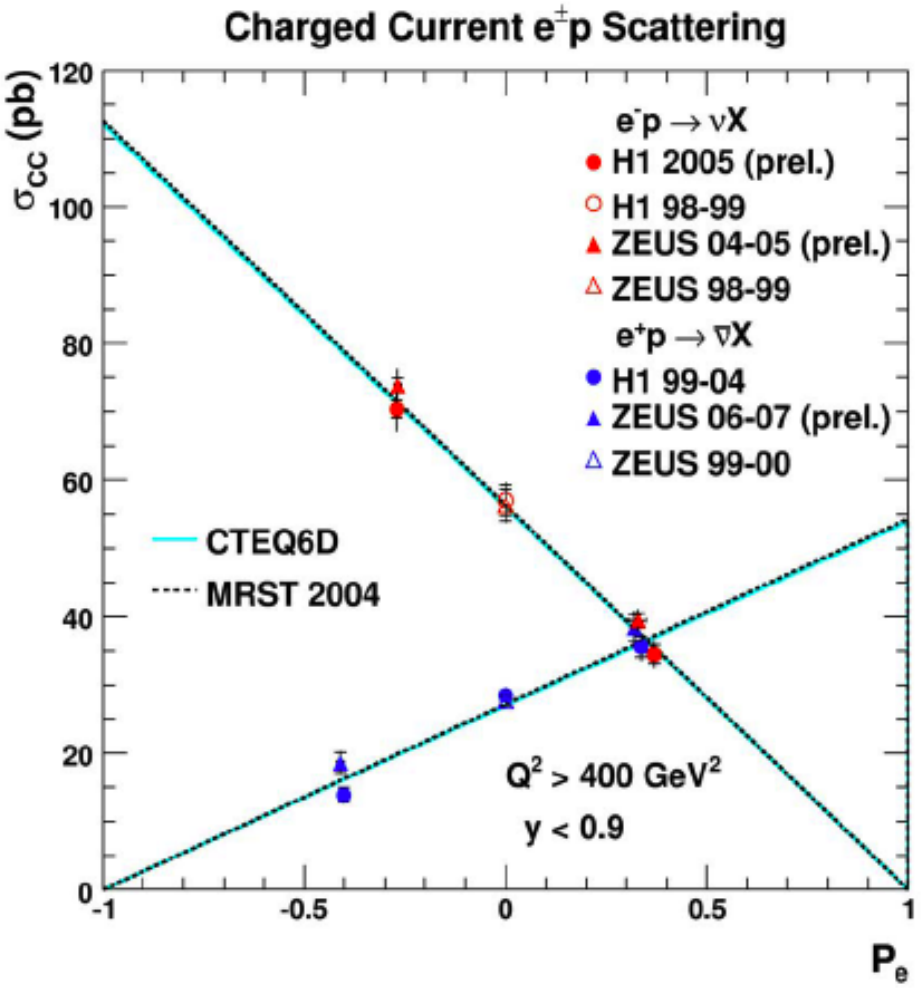


Lepton naturally transver. polarized (Sokolov-Ternov effect) with a build-up time of 30 minutes. Spin rotators to provide longitudinally polarized beams at the experiments.

Lepton polarization 30-40%, changed every 2-3 months, equal lumi for e^+, e^-, LH and RH. Polarization measured by three independent devices

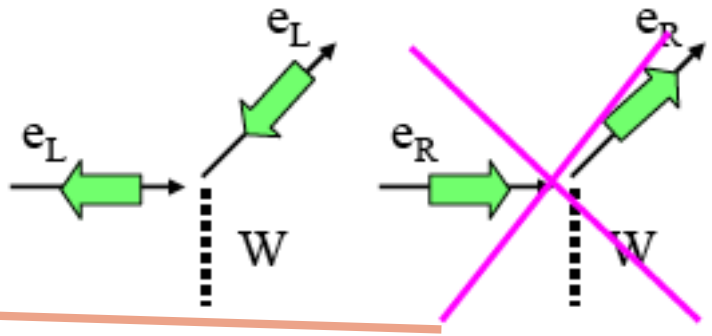
$$P = (N_R - N_L) / (N_R + N_L)$$

Polarized CC

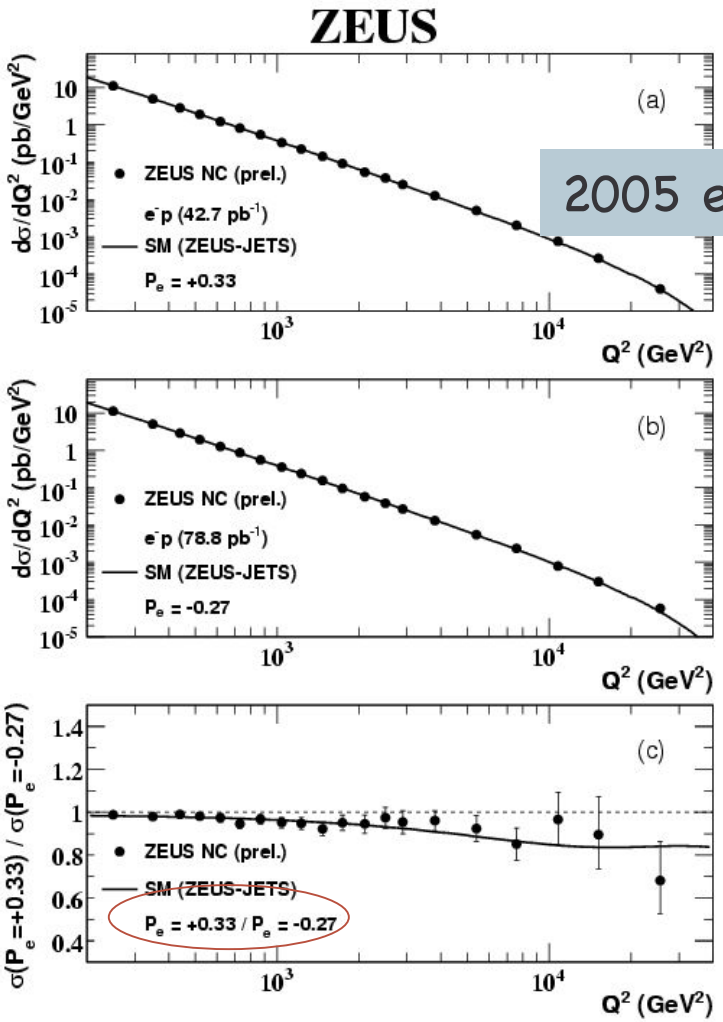


$$\sigma^{e\pm p}_{polCC}(Q^2, x) = \frac{1 \pm P_e}{2}\,\sigma^{e\pm p}_{LHCC}(Q^2, x)$$

Another textbook plot, absence of right-handed charged current



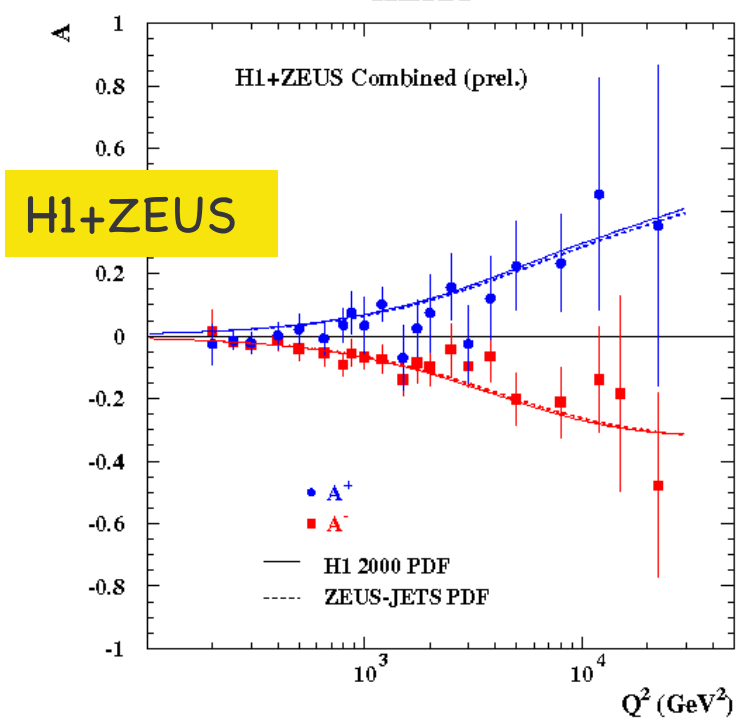
(Polarized NC at high Q^2)



2005 e^-p

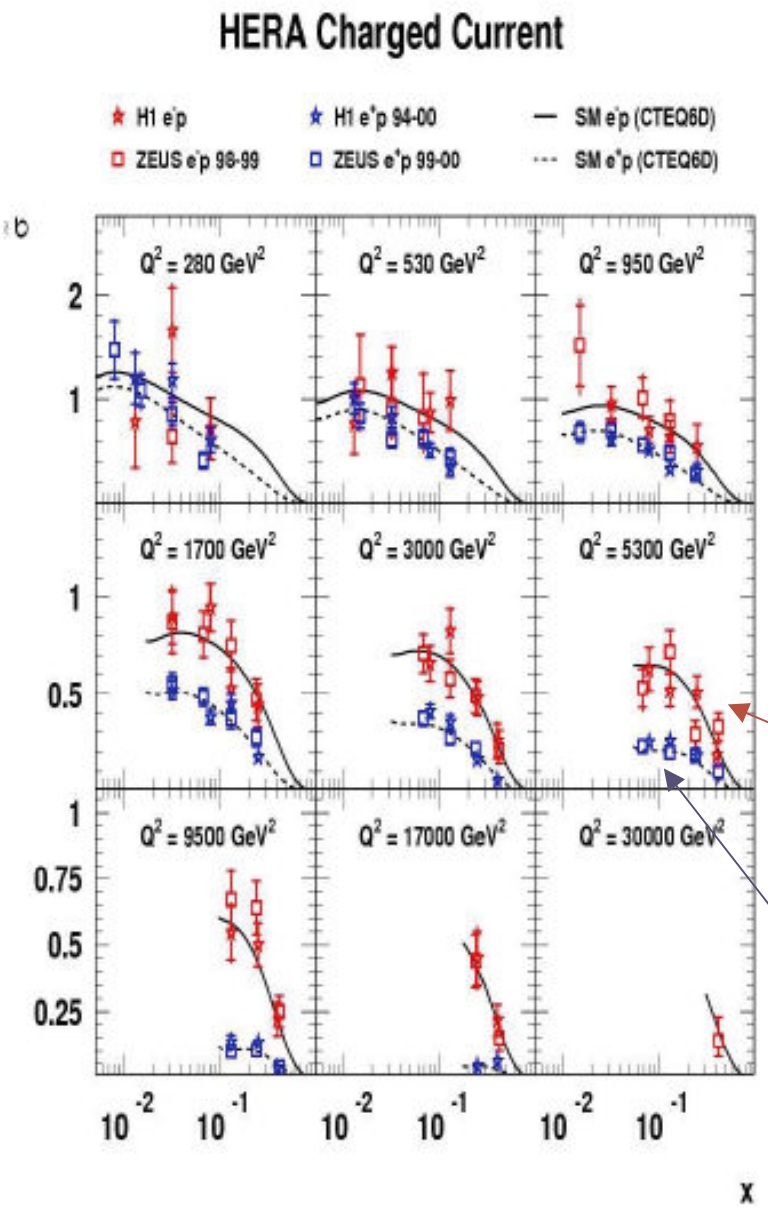
$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

H1+ZEUS



In NC the effect of P is small, but one can measure the asymmetry: parity-violating effect observed in NC at high Q^2 for the first time

Differential CC cross-sections

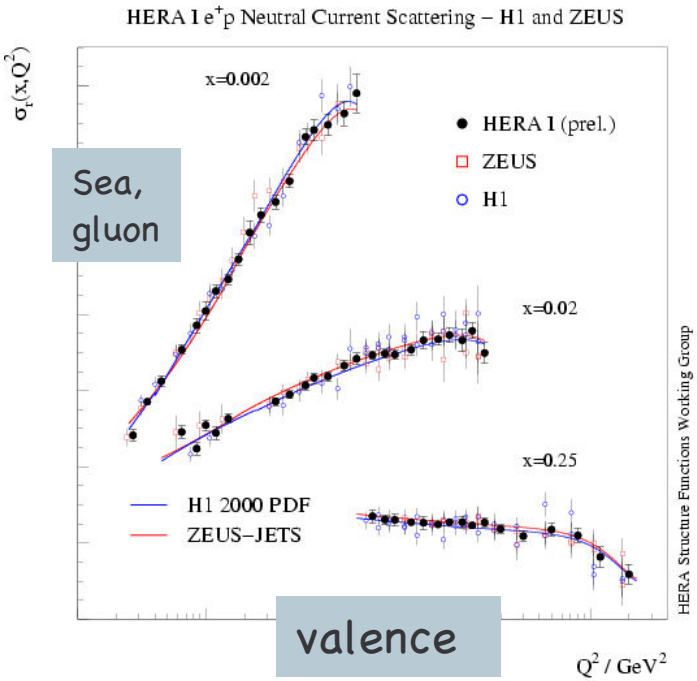


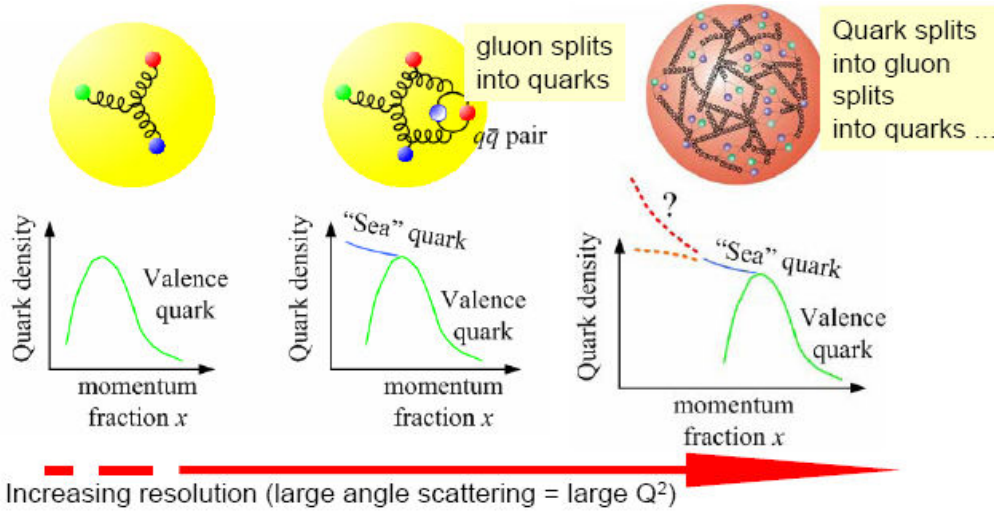
Differential CC cross sections can give information on the parton densities

u-dominated

d-dominated

Parton densities and QCD fits





$$F_2 = x\Sigma e_q^{\,2}(q+\bar{q})$$

- Measure F_2, ...
- Determine xu,xd,xS,xg from fits at a certain Q_0^2 and then evolve in Q^2 with QCD (DGLAP evolution equations)
- But at high Q^2 and with polarization, we can do more

Polarized QCD fits

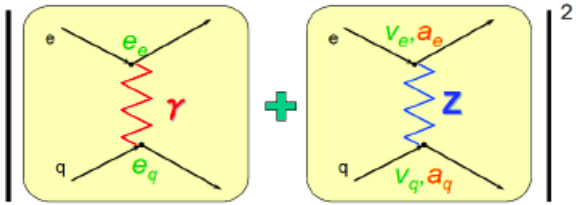
$$\sum_r(e^{\pm}p) = (Y_+F_2^0 \mp Y_\Sigma xF_3^{\,0}) \mp P(Y_\Sigma F_2^P \mp Y_- xF_3^P)$$

$$F_2^{0,P} = \sum_i A_i^{0,P}(Q^2)[xq_i(x,Q^2) + x\bar{q}(x,Q^2)]$$

$$xF_3^{0,P} = \sum_i B_i^{0,P}(Q^2)[xq_i(x,Q^2) \sum x\bar{q}(x,Q^2)]$$

Neutral current cross-section

Polarized structure functions



$$A^0(Q^2) = -e_i^2 - 2e_i v_i v_e P_Z + (v_e^2 + a_e^2)(v_i^2 + a_i^2)P_Z^2$$

$$B_i^0(Q^2) = -2e_i a_i a_e P_Z + 4a_i a_e v_i v_e P_Z^2$$

Unpolarized xF_3 determines the axial couplings

$$A_i^P(Q^2) = -2e_i v_i a_e P_Z - 2v_e a_e (v_i^2 + a_i^2)P_Z^2$$

$$B_i^P(Q^2) = -2e_i a_i v_e P_Z - 2v_i a_i (v_e^2 + a_e^2)P_Z^2$$

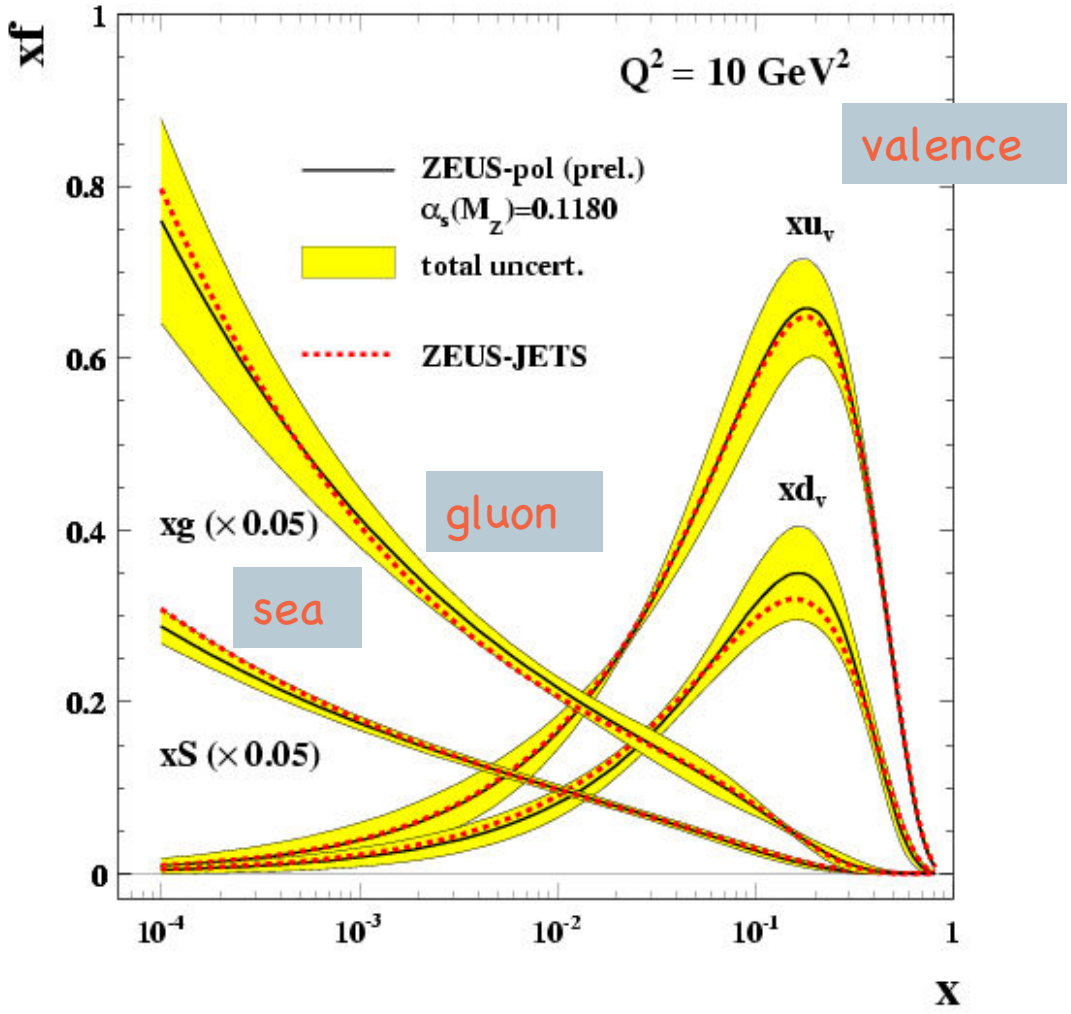
Polarized F_2 determines the vector couplings

Parton densities and Z-couplings fitted at the same time

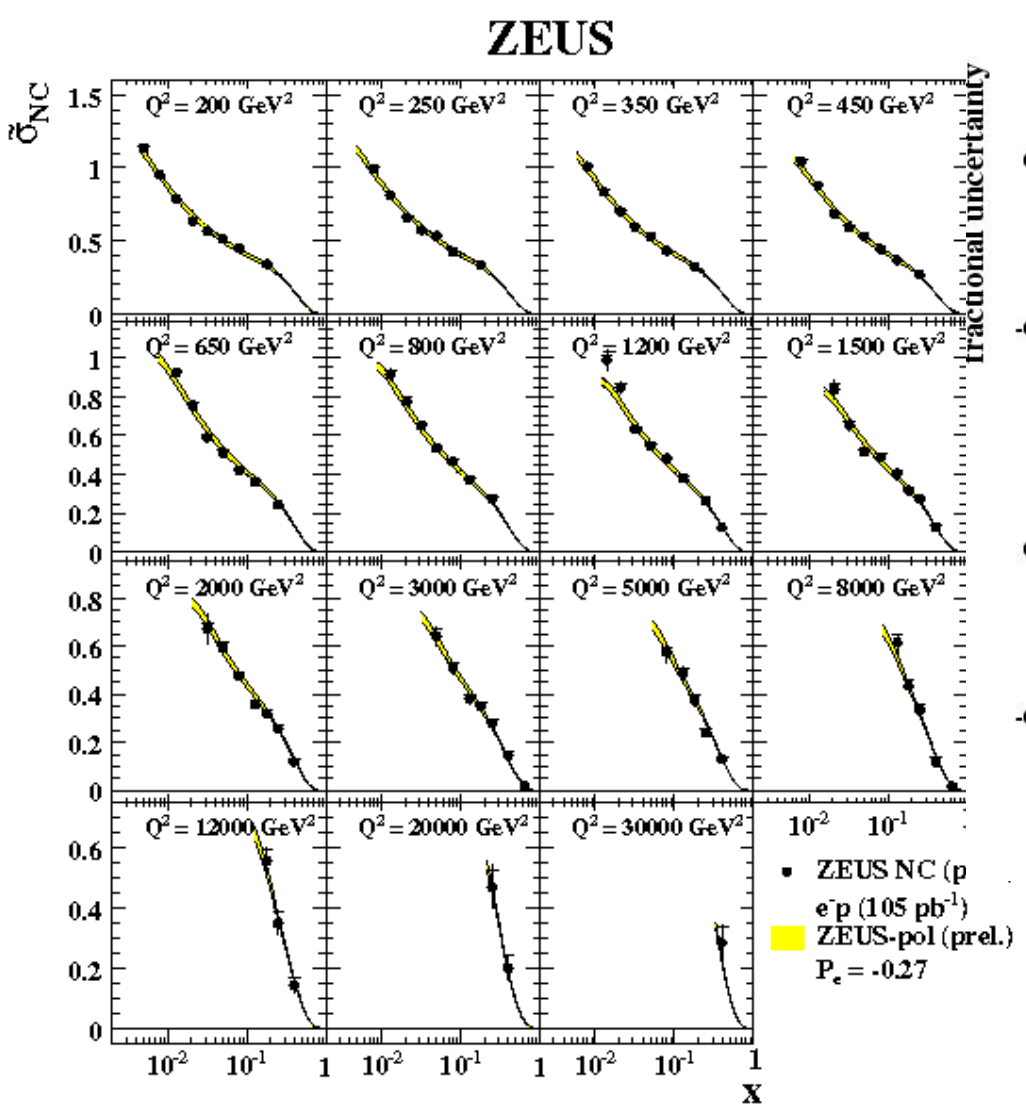
Polarized QCD fits

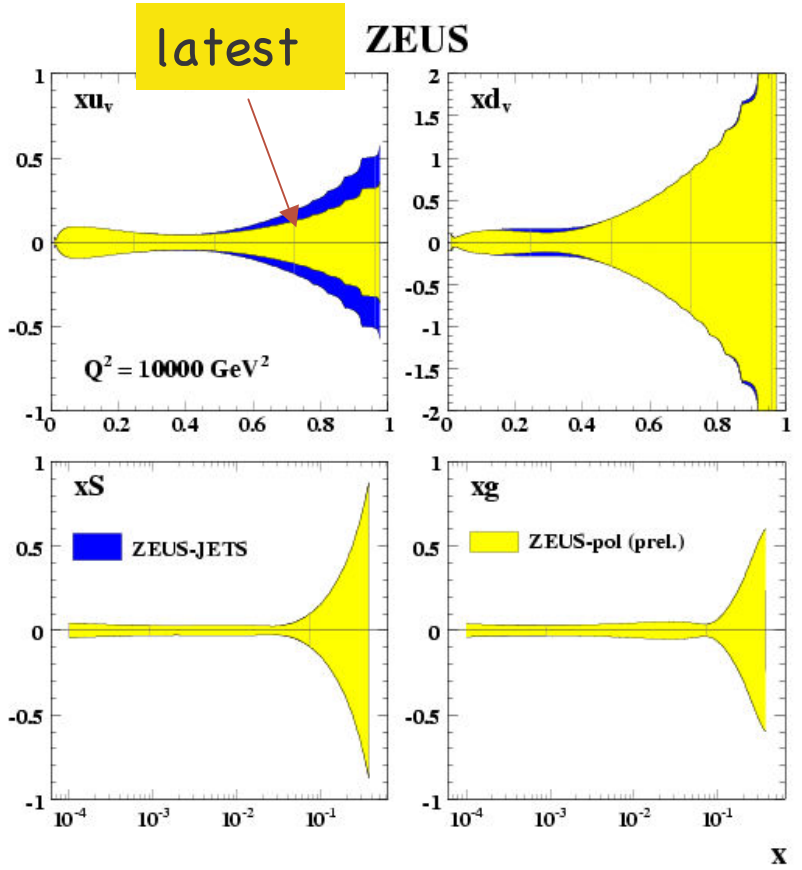
ZEUS-Pol fit:

- o fit ZEUS data only
- o low-x gluon and sea constrained by F_2 data
- o u,d separation by CC
- o EW parameters by NC at high Q^2



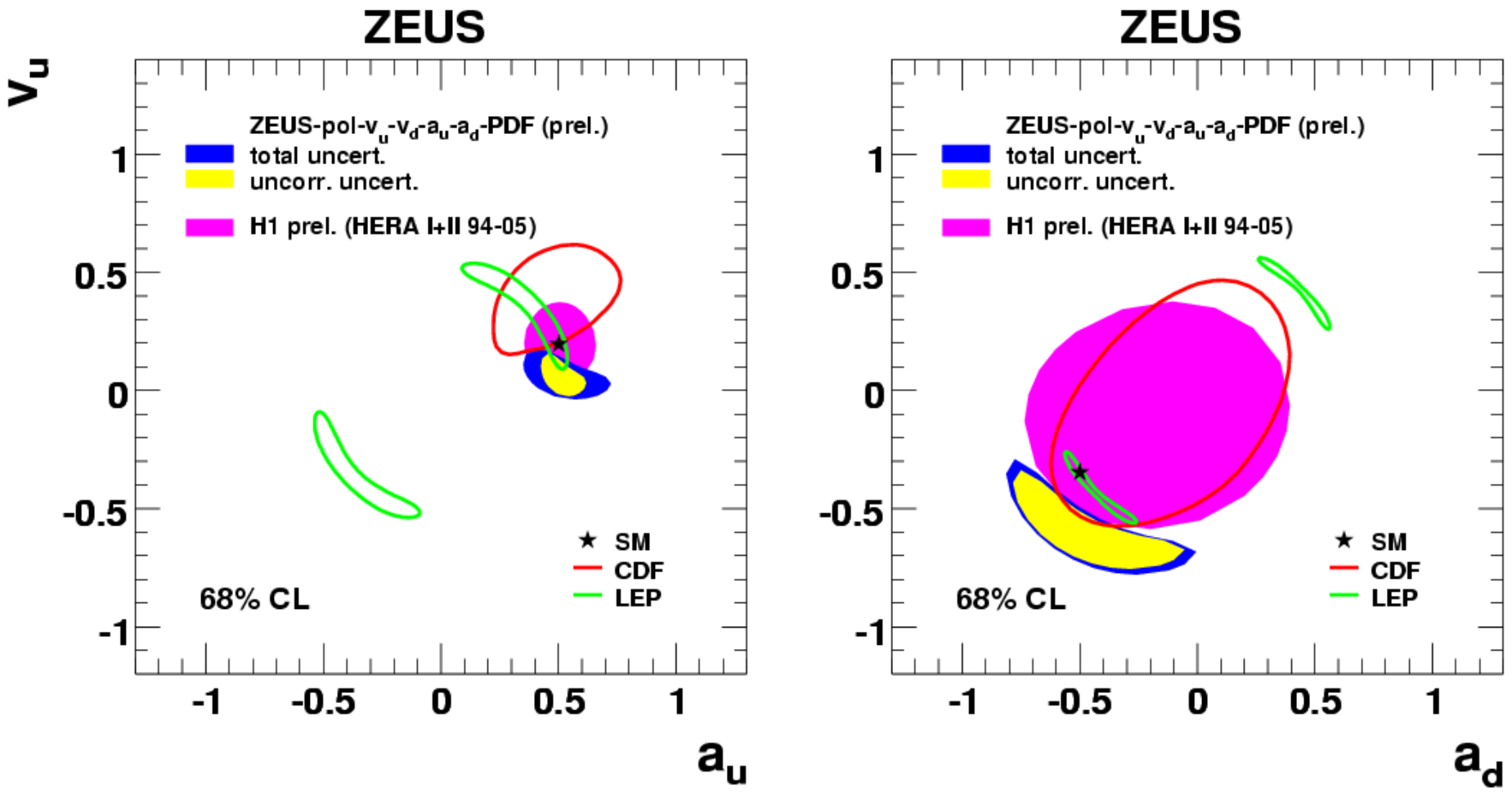
Polarized QCD fits





u-valence more and more constrained at HERA

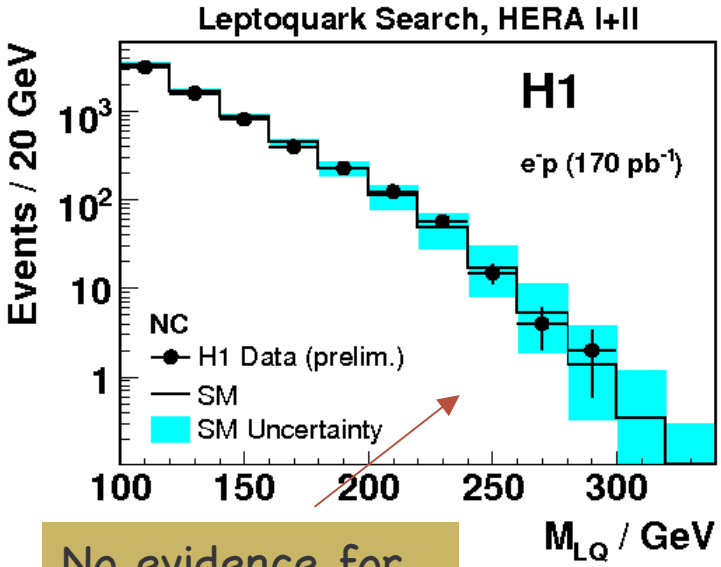
Polarized QCD fits



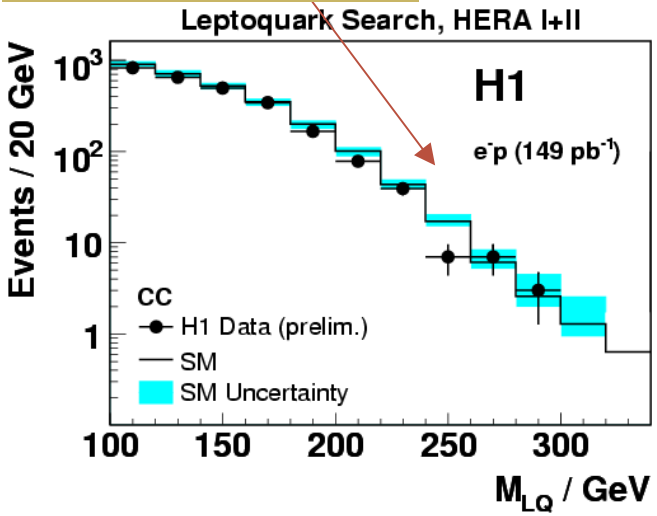
Vector and axial couplings for u- and d- quarks determined with competitive precision, in agreement with SM

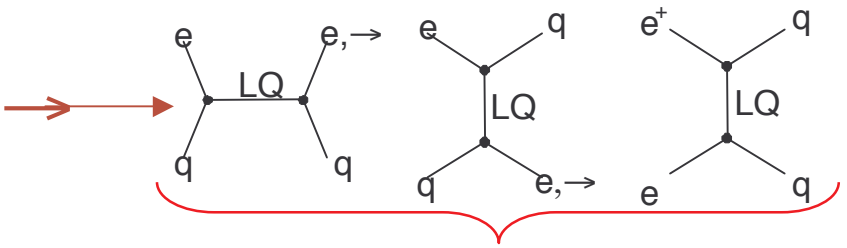
Search for new physics in EW processes

Search for Leptoquarks

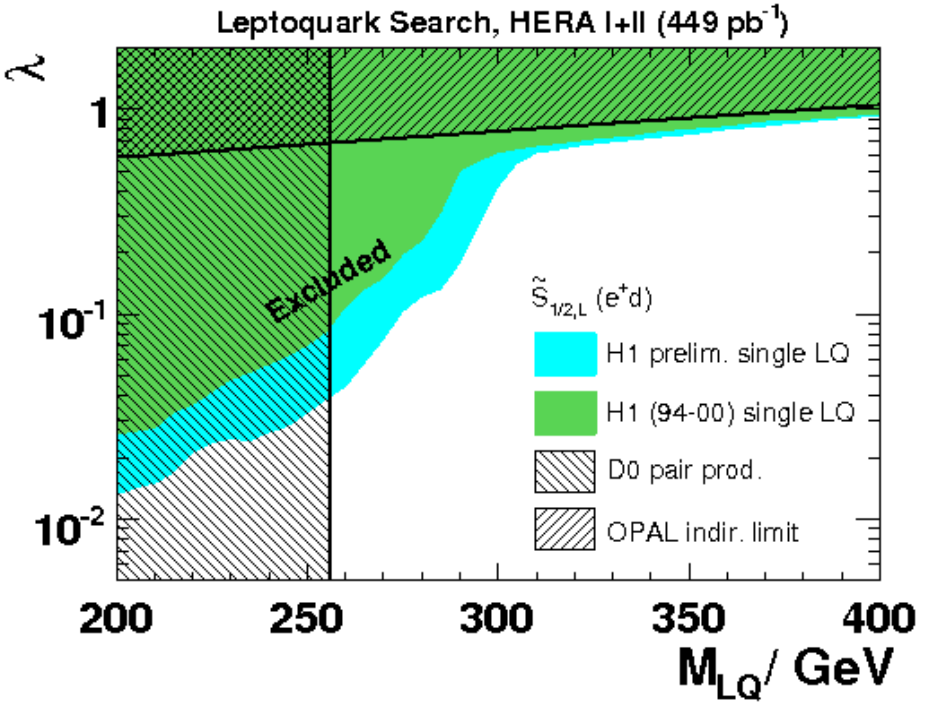


No evidence for a mass peak

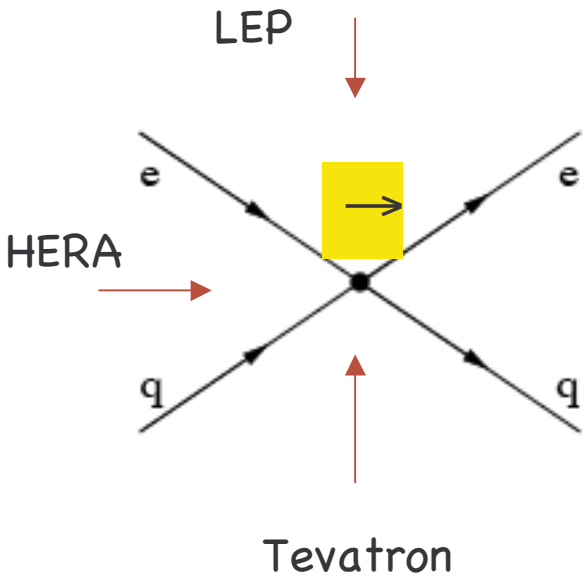


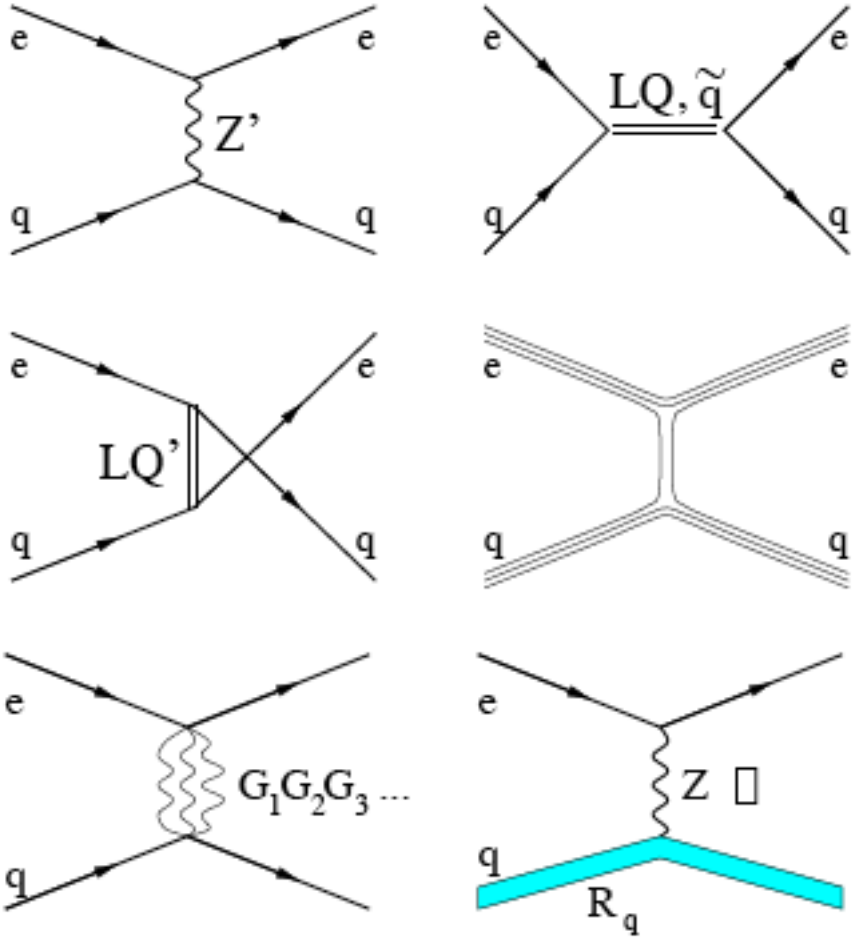


All HERA II data analyzed by H1, ex. For one LQ type:



Search for Contact Interactions

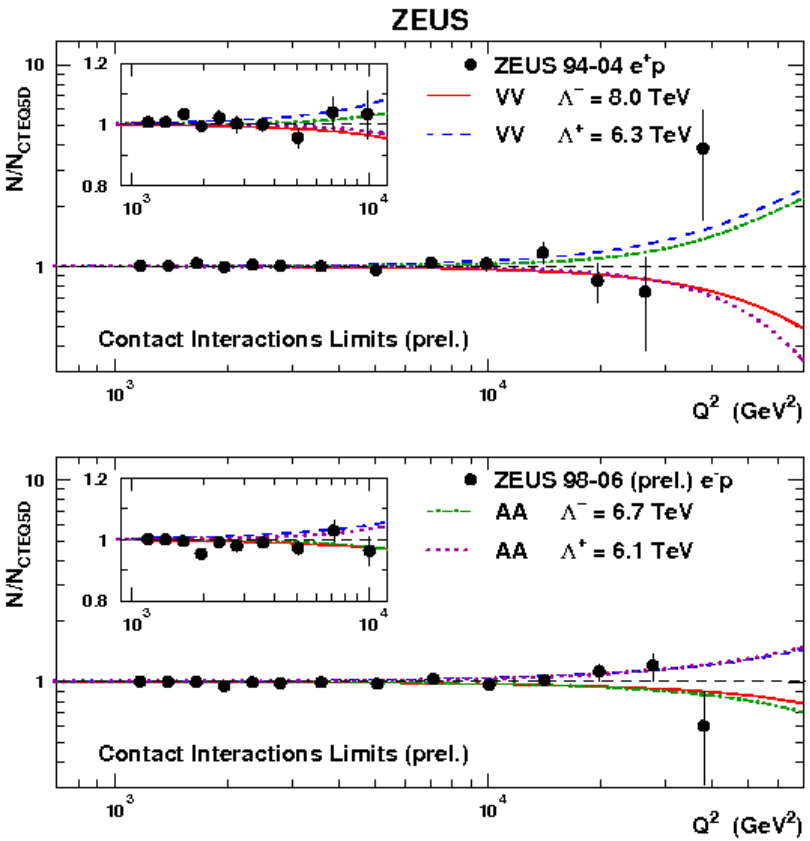


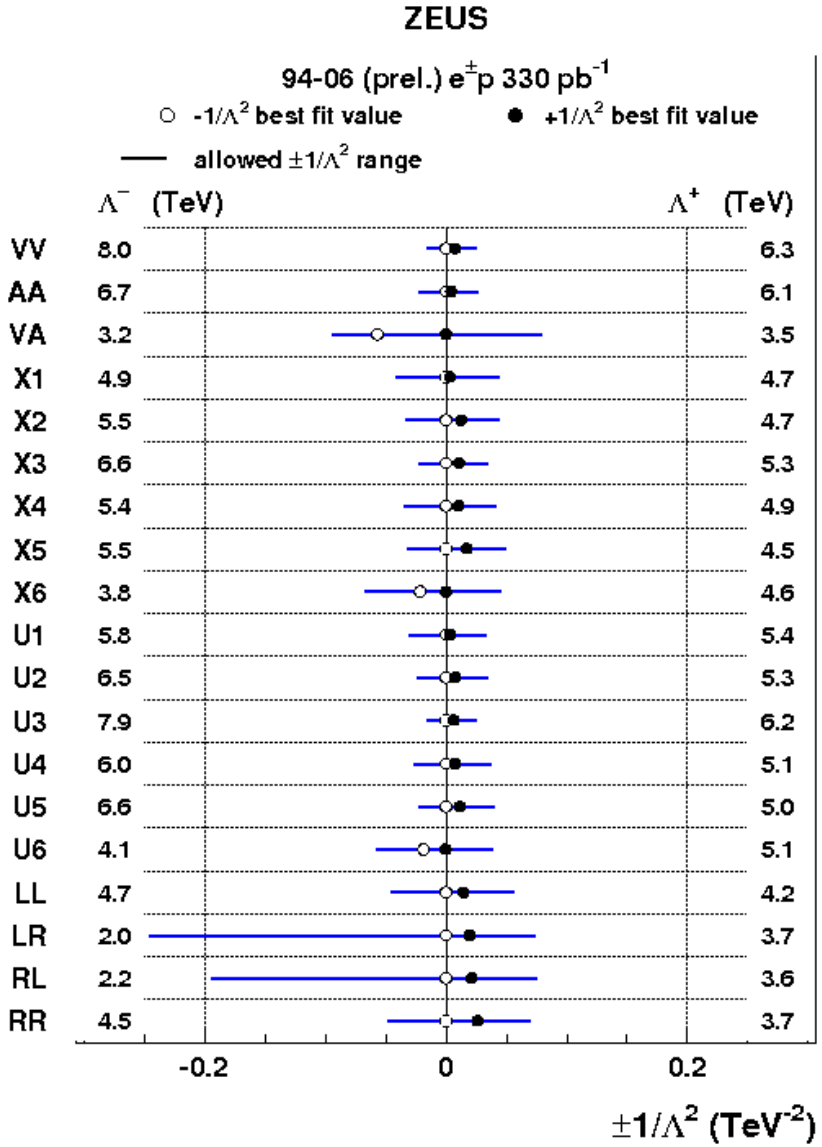


The $d\sigma/dQ^2$ at high Q^2 could show signs of new physics at scales → greater than $\sqrt{s}$

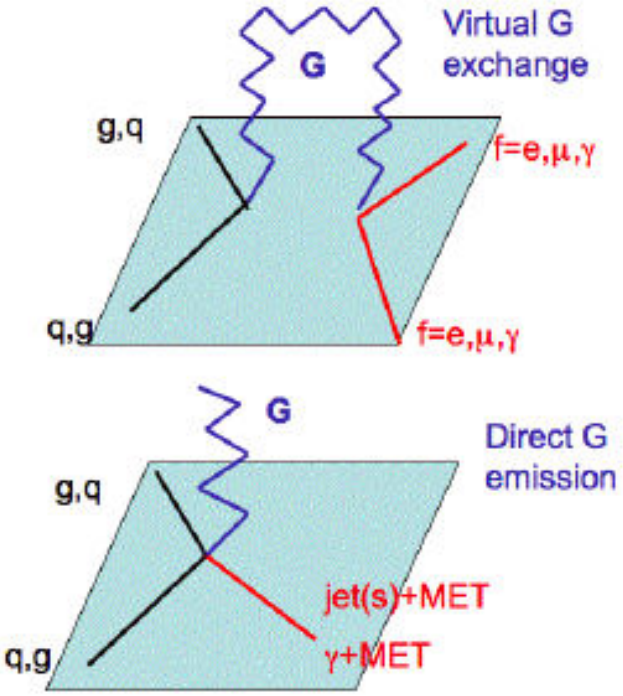
Contact Interactions

Example for the VV, AA interactions:



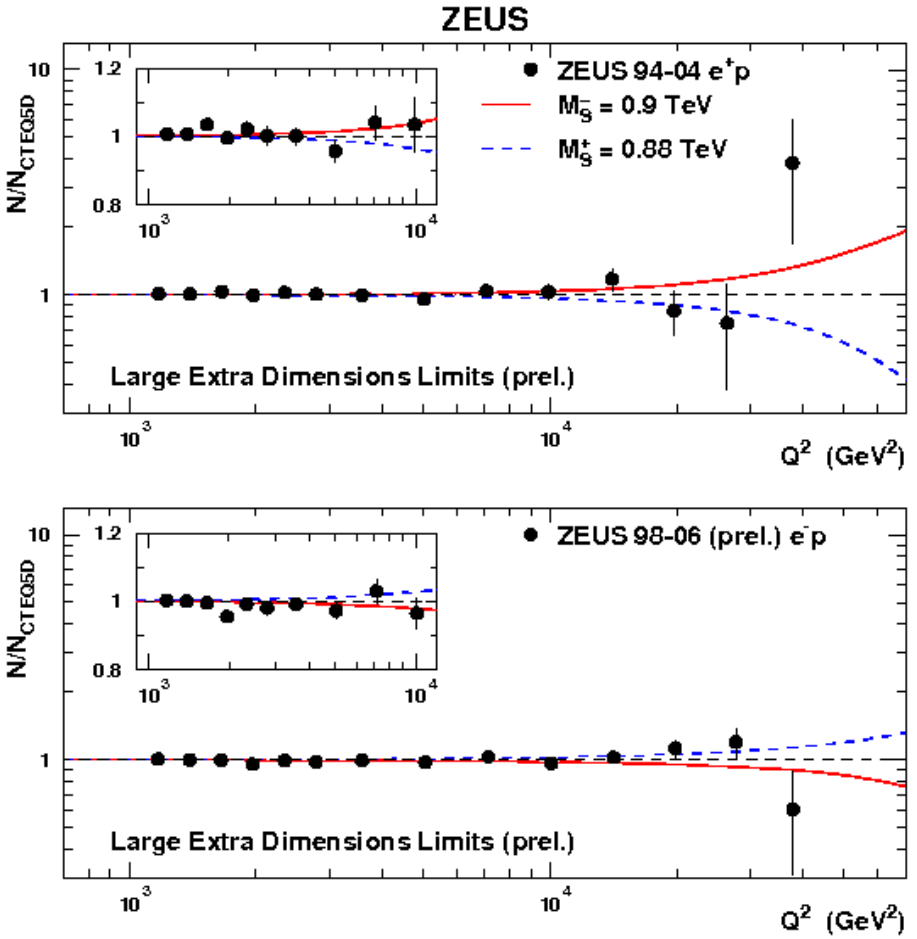


Extra dimensions



$M^2_{Pl} \sim R^n M_S^{2+n}$

If $R = O(10\mu m) \rightarrow M_S \sim$ TeV



$M_S^- > 0.9$ TeV, $M_S^+ > 0.88$ TeV

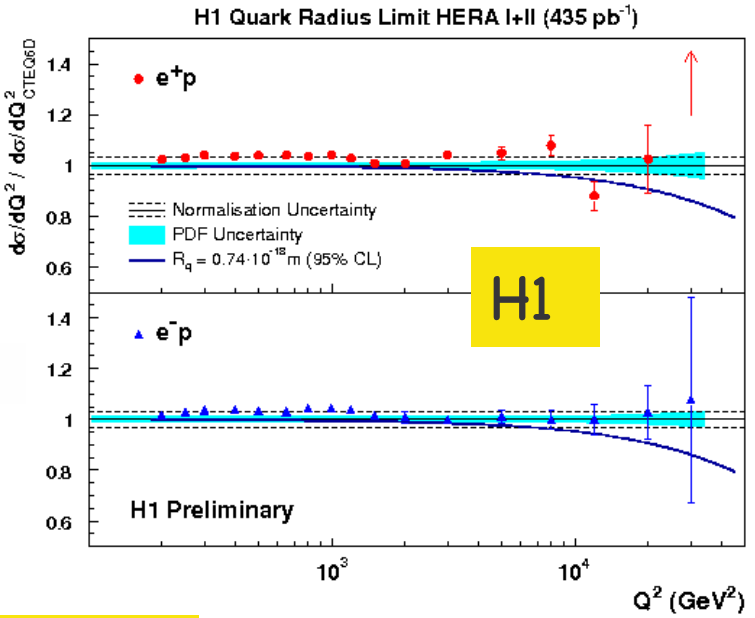
At 95% CL

Quark radius

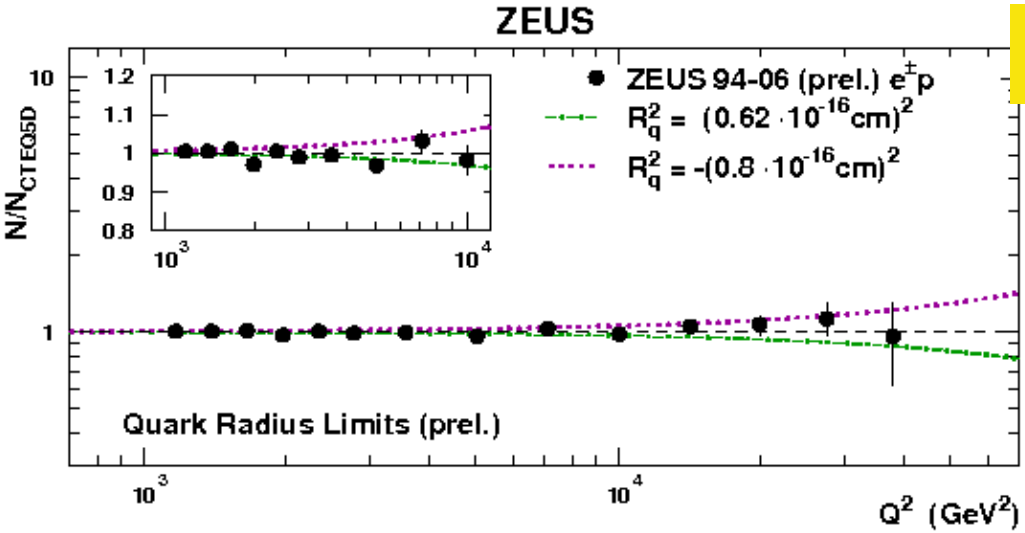
Can be determined as a form factor, assume electron pointlike:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2\right]^2 \cdot \left[1 - \frac{R_e^2}{6} Q^2\right]^2$$

$$R_q < 0.74 \cdot 10^{-16}\ \text{cm}$$



H1

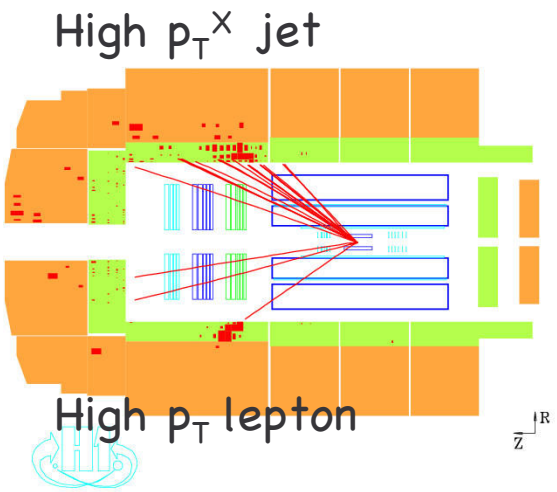


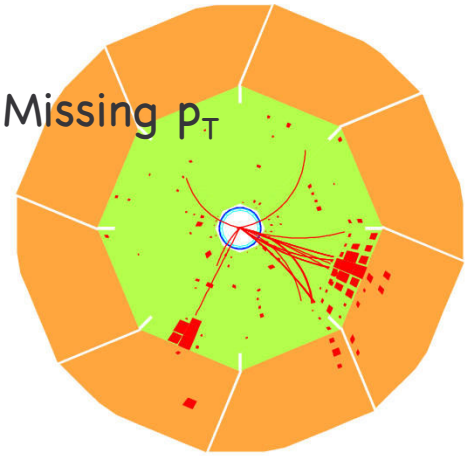
ZEUS

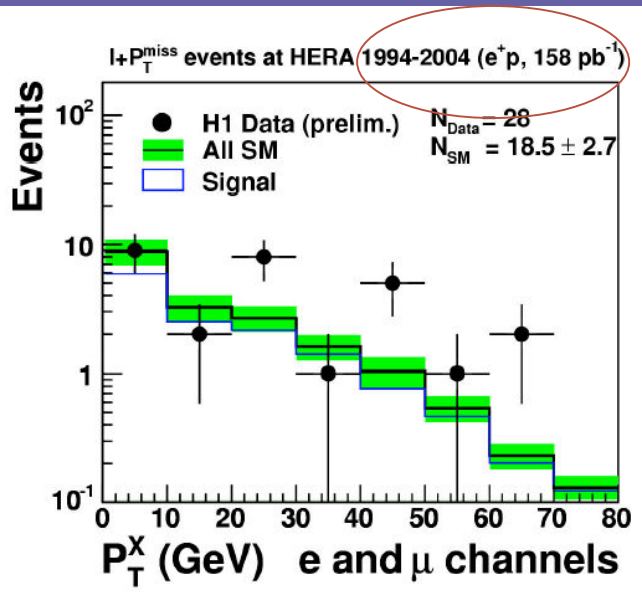
$$R_q < 0.62 \cdot 10^{-16}\ \text{cm}$$

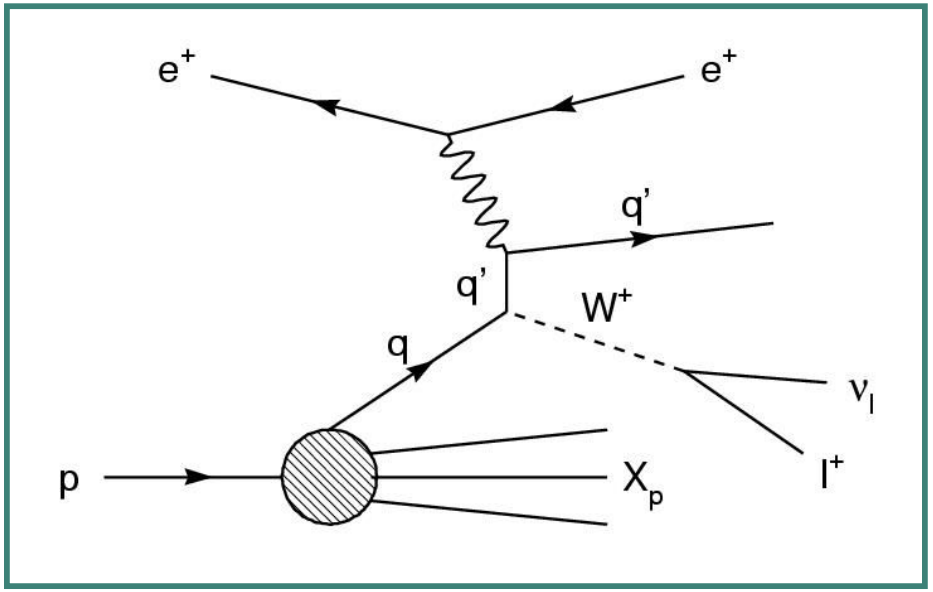
Most stringent limit today

Search for new physics in W-like events







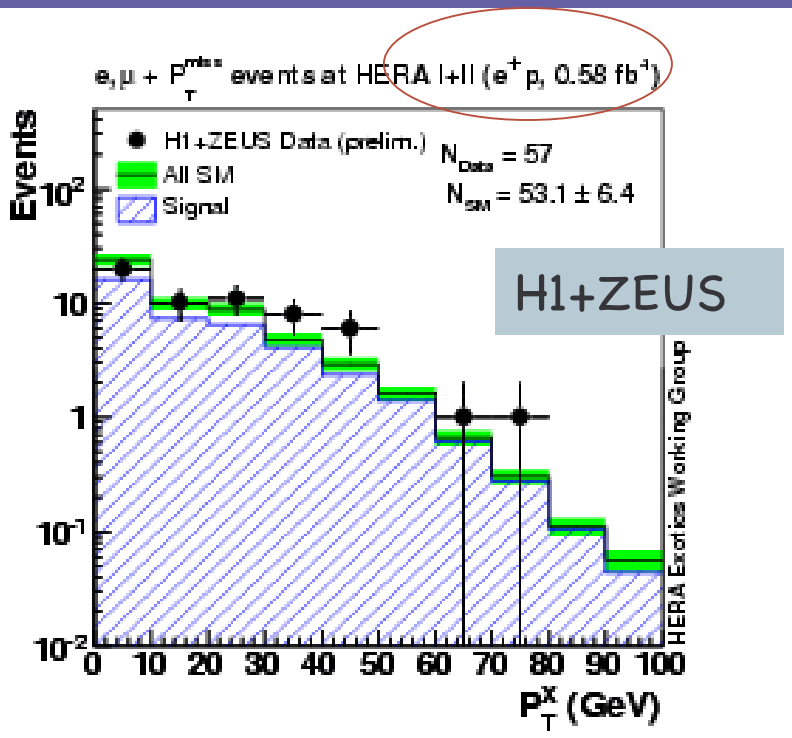


New physics at H1?

Seen only in e^+p, not seen by ZEUS

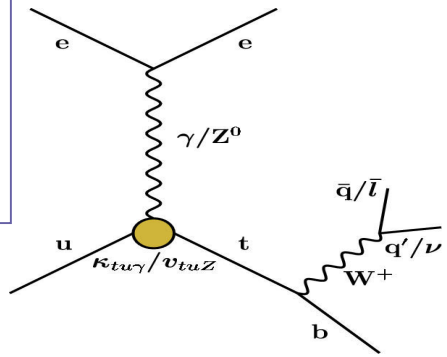
Due to W production in the SM

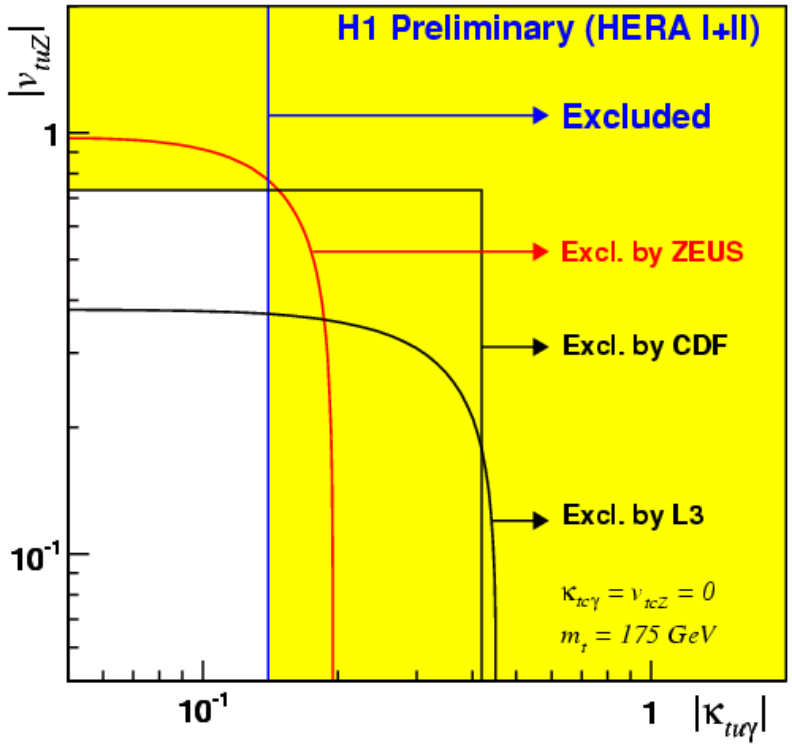
Search for new physics in W-like events



H1+ZEUS

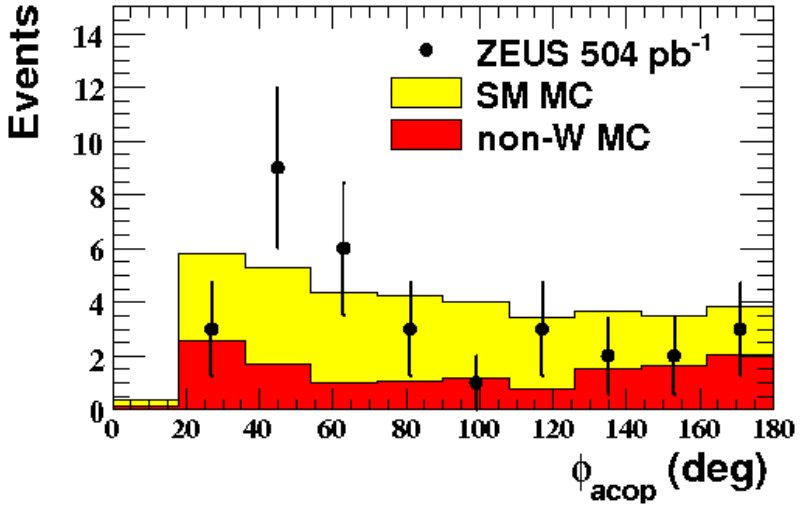
P_T^X > 25 GeV		e+μ Data/SM	
H1	0.29 fb^{-1}	17/7.1±0.9	(2.9σ)
ZEUS	0.29 fb^{-1}	6/7.5±1.1	
H1+ZEUS	0.58 fb^{-1}	23/14.6±1.9	(1.8σ)

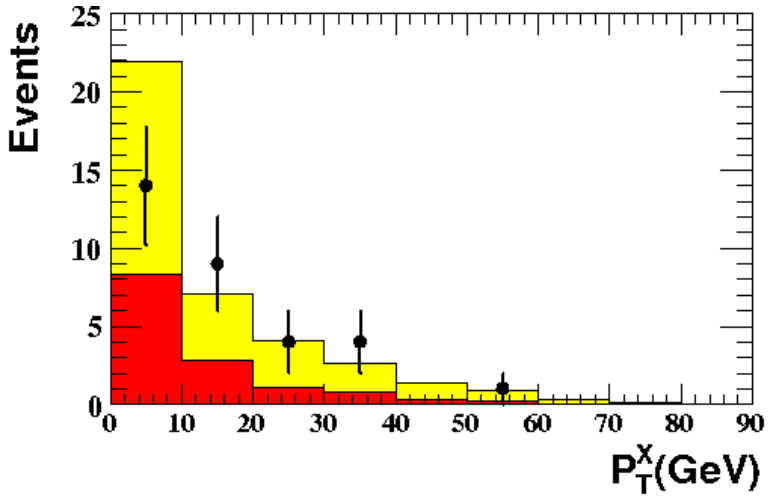


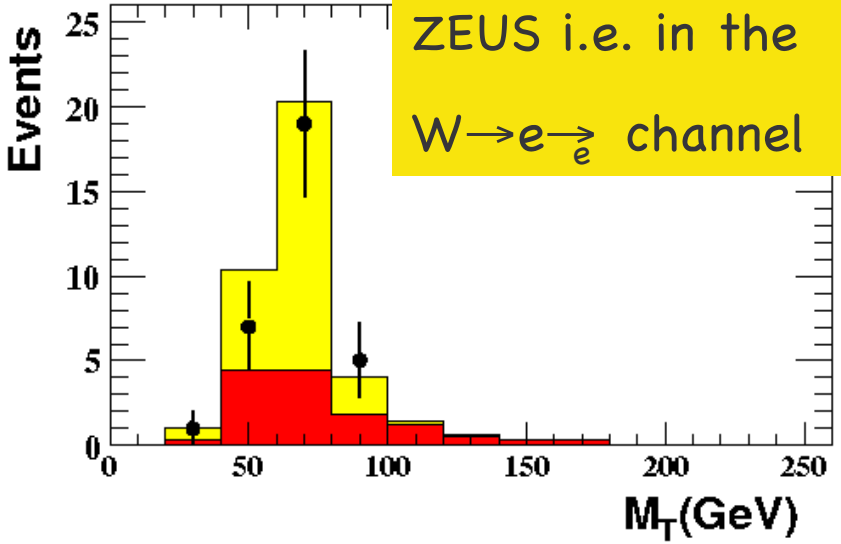


Limit on single top production due to an anomalous FCNC coupling

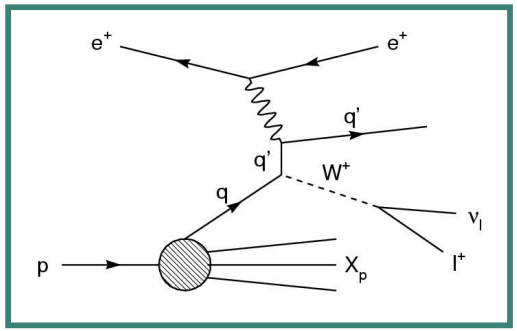
Measurement of W cross-section





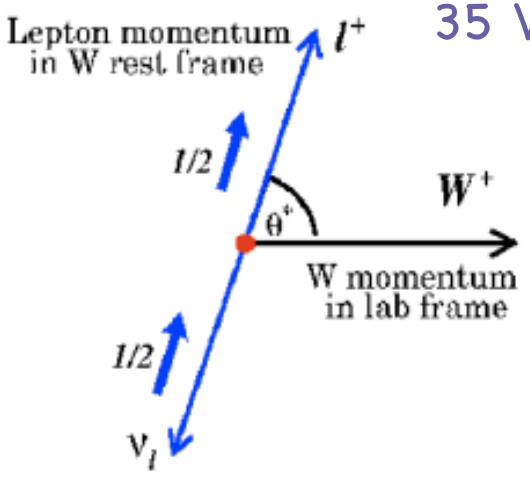


ZEUS i.e. in the $W \to e \to_{e}$ channel



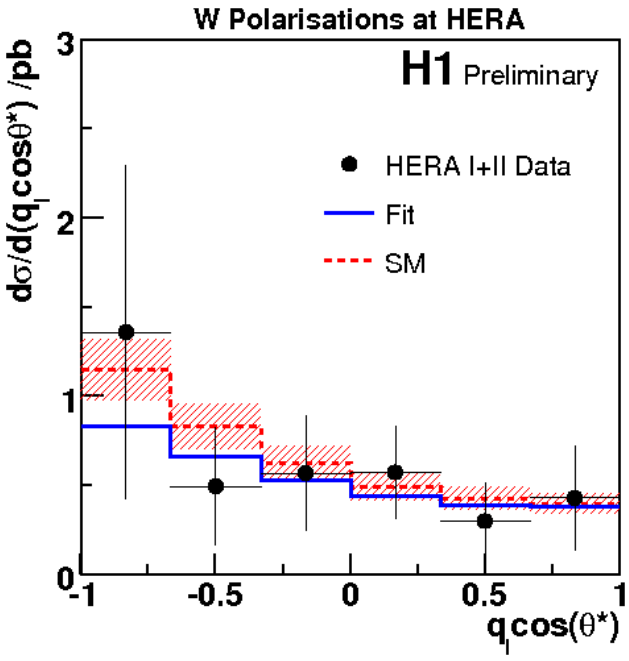
$\sigma(ep \to lWX) = 0.89^{+0.25}_{-0.22}$(stat.) ± 0.10 (syst.) pb ; σ(SM)=1.2 pb

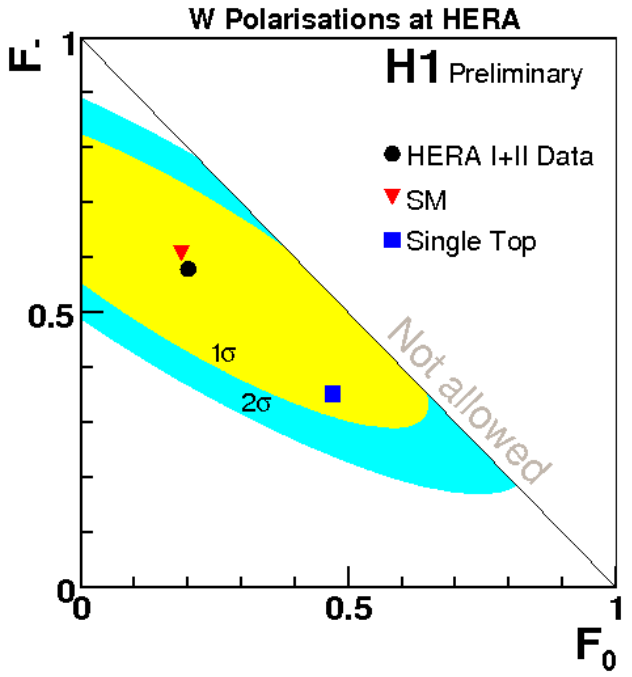
Measurement of W polarization



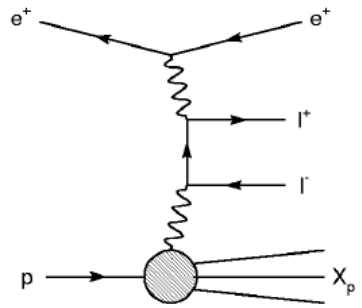
35 W-events at H1, study the angular distributions

$$\frac{dN}{d\cos\theta^*} \propto (1 - F_- - F_0) \cdot \frac{3}{8}(1 + \cos\theta^*)^2 + F_0 \cdot \frac{3}{4}(1 - \cos^2\theta^*) + F_- \cdot \frac{3}{8}(1 - \cos\theta^*)^2 .$$

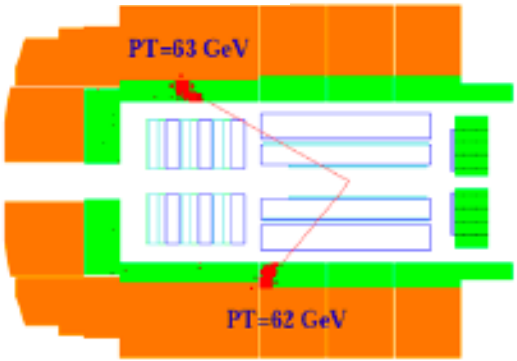


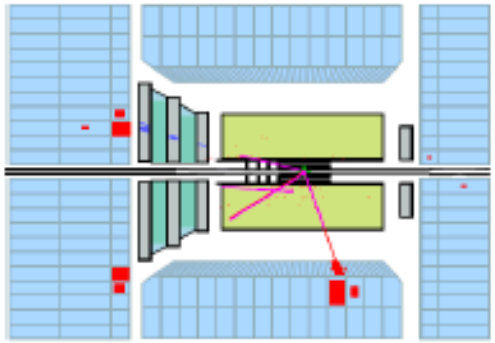


Search for new physics in BH-like events

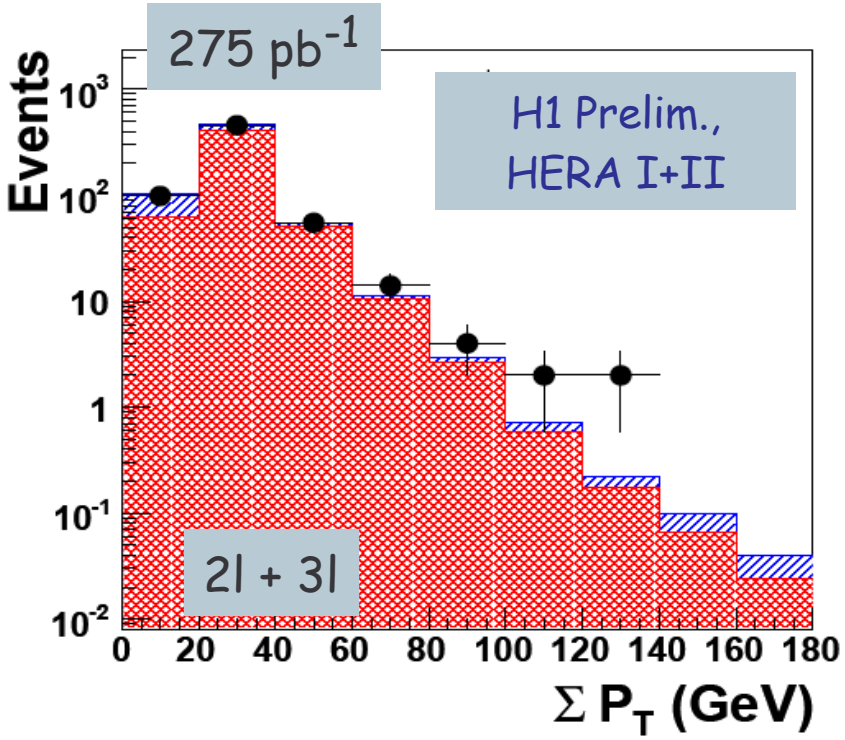


Bethe-Heitler



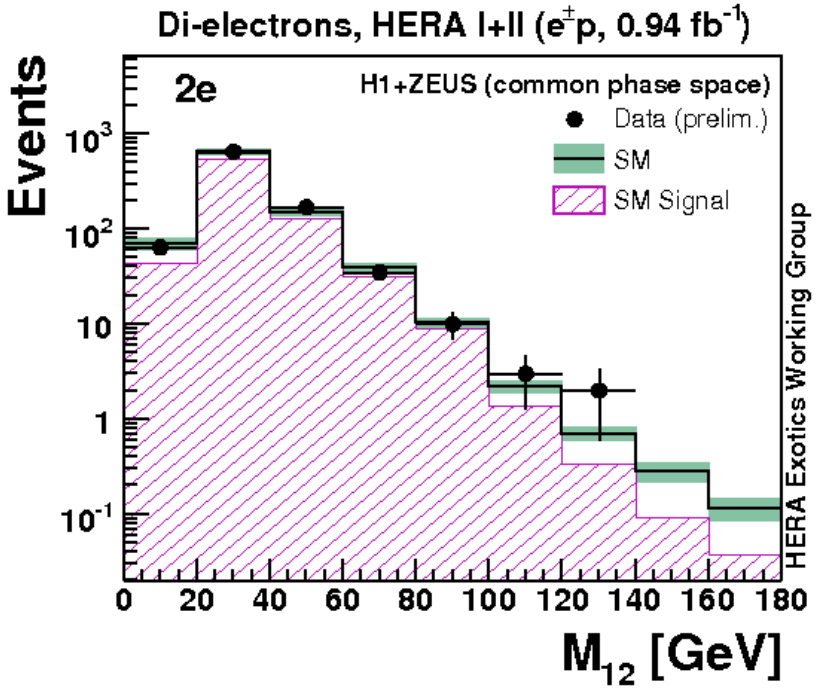


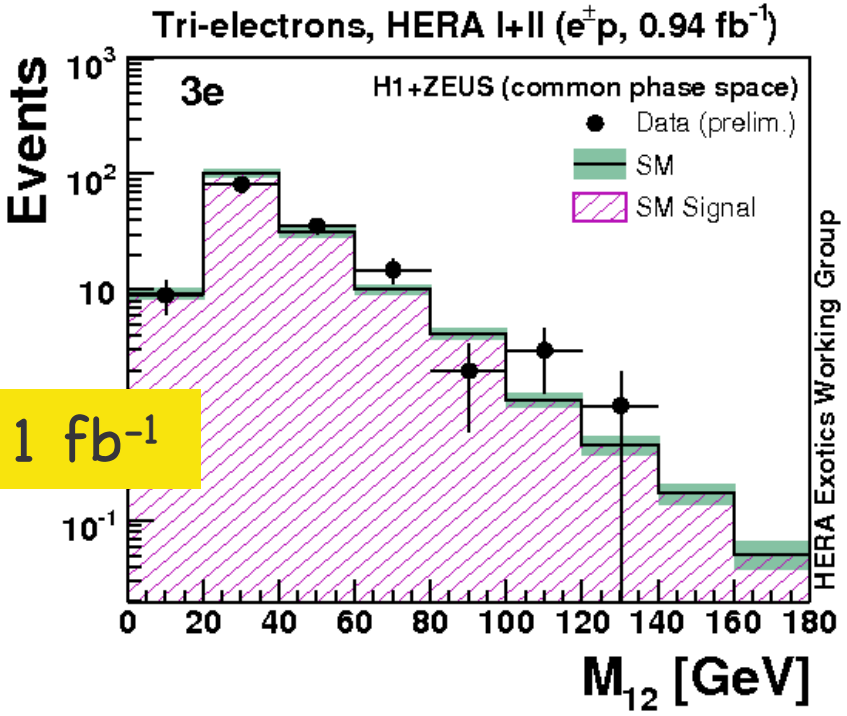
Again excess was observed by H1 in the 2e, 3e channel in e^+p.



Look for 2e, 3e in whole statistics H1+ZEUS

Search for new physics in BH-like events

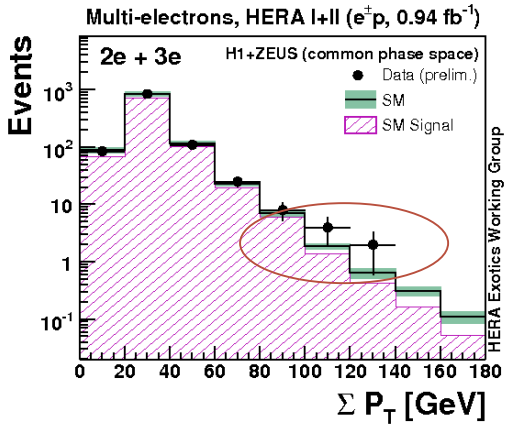




1 fb^{-1}

$$\Sigma P_T > 100 \text{ GeV}$$

Data sample	Data	SM
e^+p (0.56 fb^{-1})	5	1.82 ± 0.21
e^-p (0.38 fb^{-1})	1	1.19 ± 0.14
$e^{\pm}p$ (0.94 fb^{-1})	6	3.00 ± 0.34



Marginal excess, in general agreement with SM

Conclusions

o HERA completing analysis of inclusive data in CC and NC at high Q^2 with the polarized HERA II data.

o Legacy of HERA will be a reanalysis of all HERAI+II, combined data from H1+ZEUS.

o More precise determination of EW parameters and stringent limits on the quark radius will follow from this.

Thank you for your attention