Electroweak constraints from HERA

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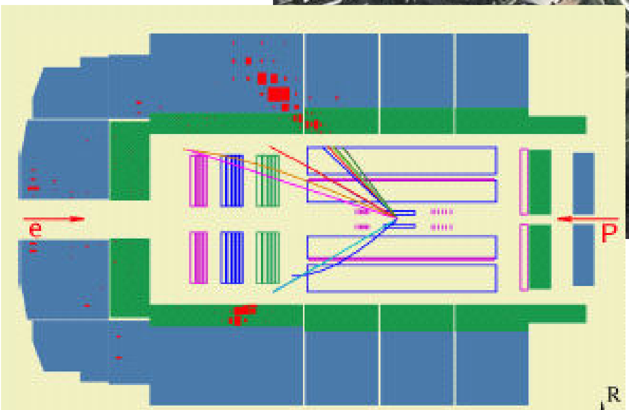
representing

- 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

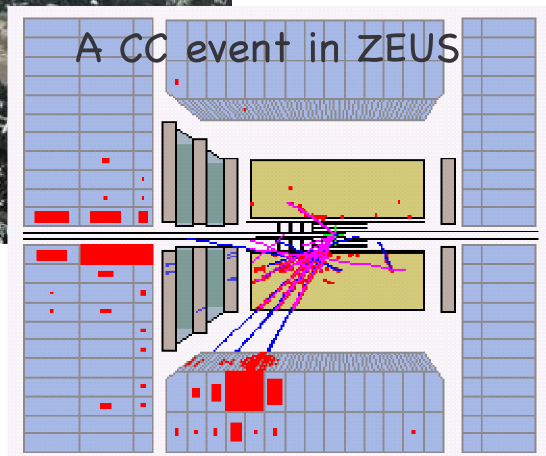
H1

ZEUS

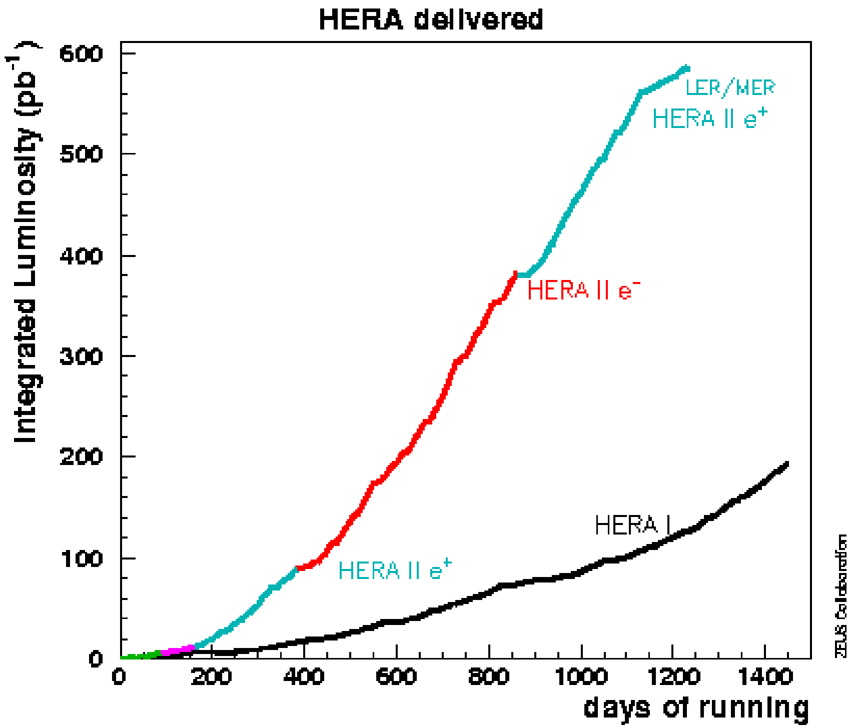


A NC event in H1

A CC event in ZEUS



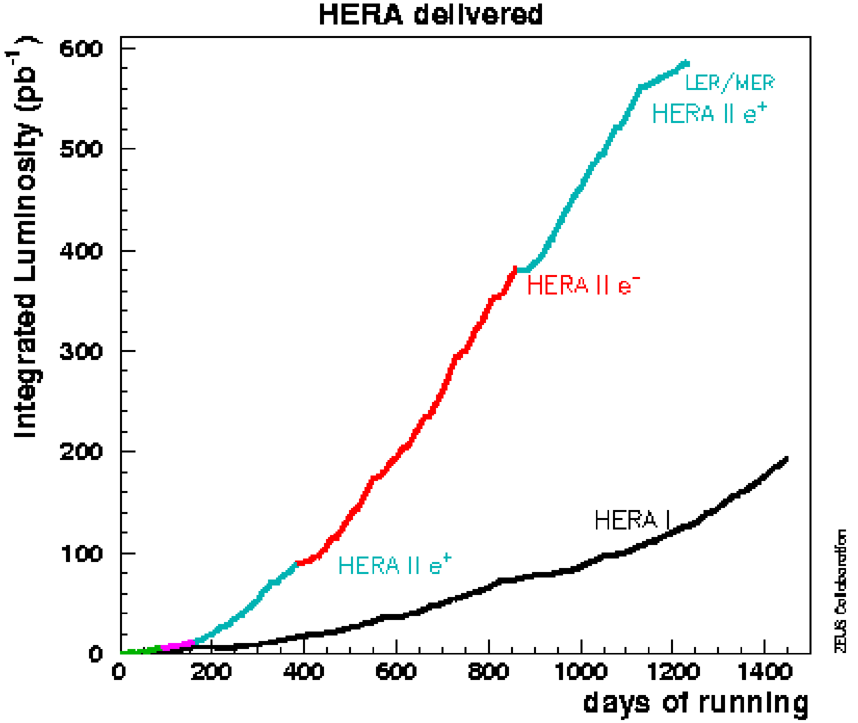
HERA luminosity

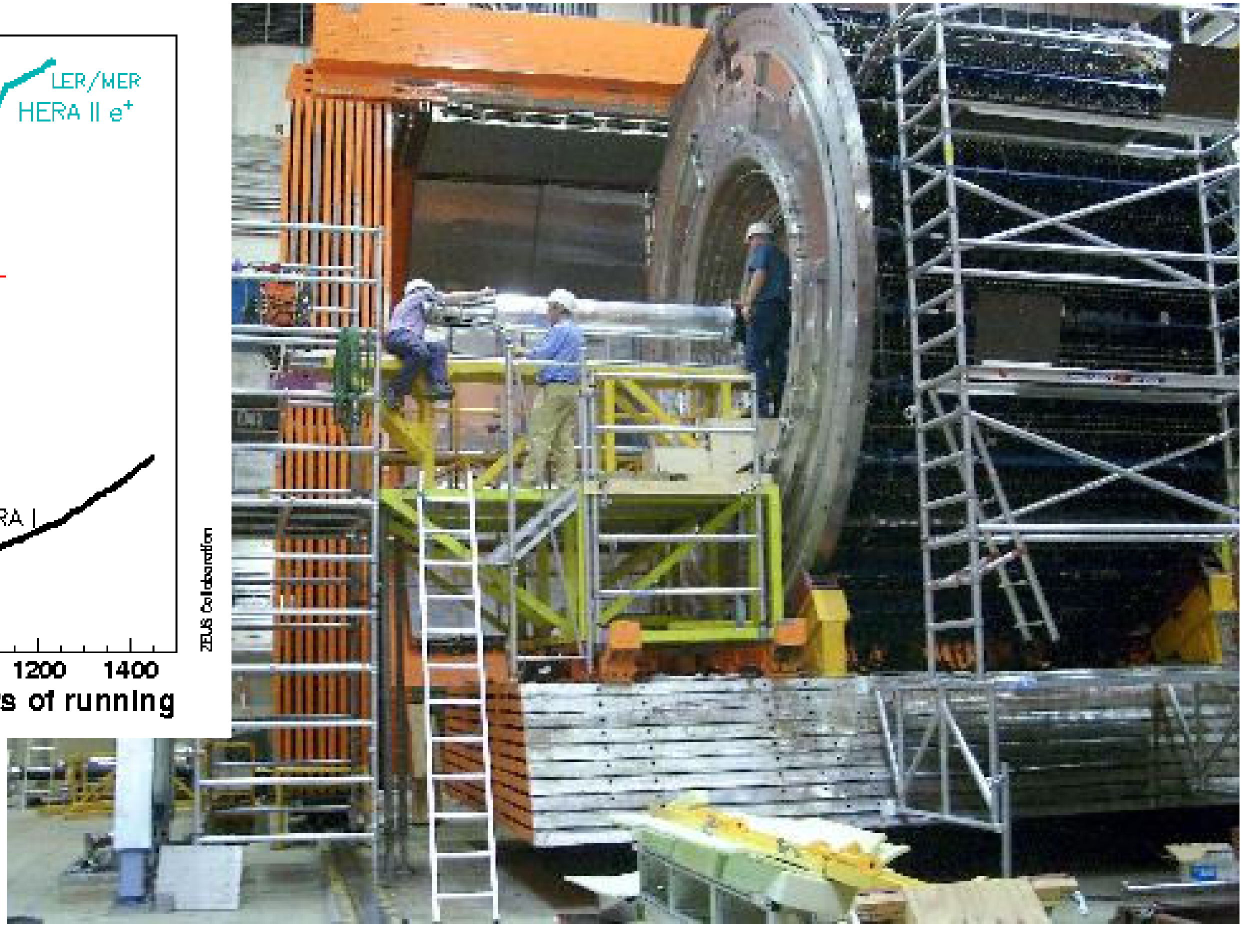


Last Fill 30/6/2007,

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

HERA luminosity



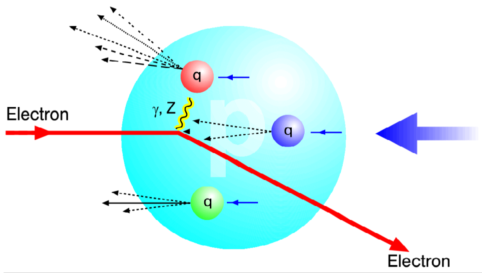


Last Fill 30/6/2007,

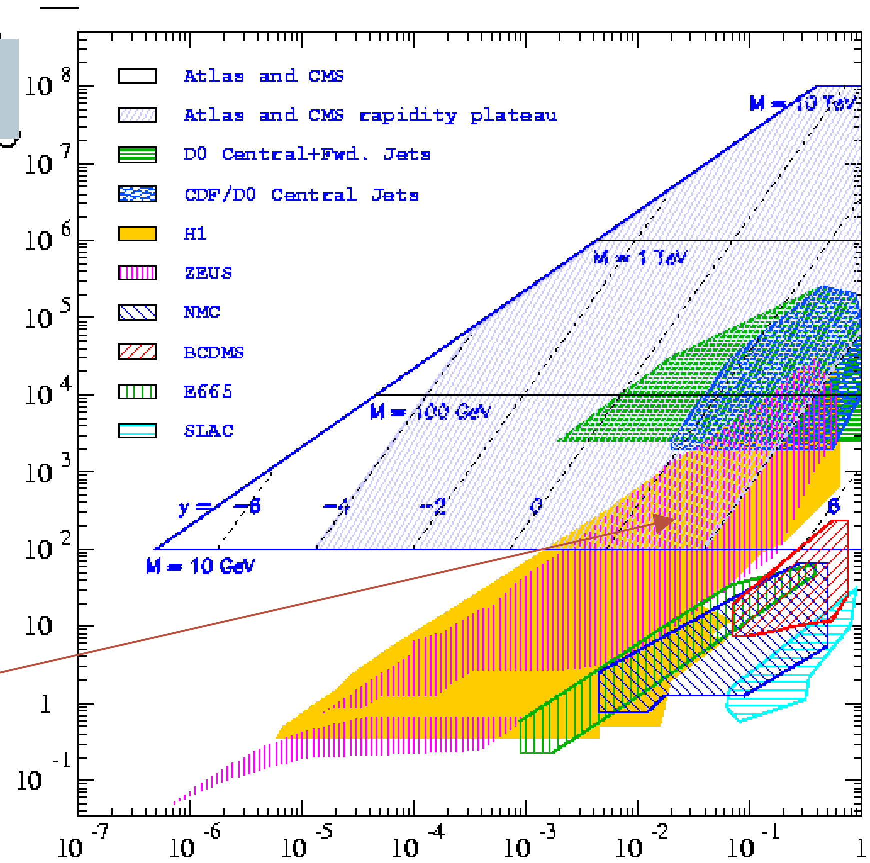
0.5 fb^{-1} per exp., 1 fb^{-1}
H1+ZEUS combined

HERA, for EW studies

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



Q²



xBjorken

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

this talk

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

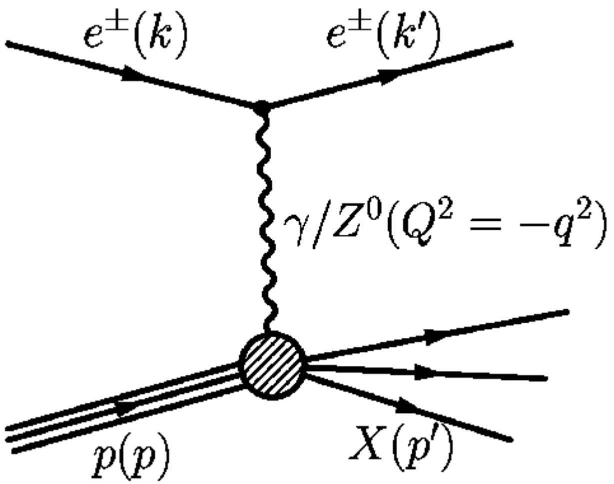
Geiser's talk

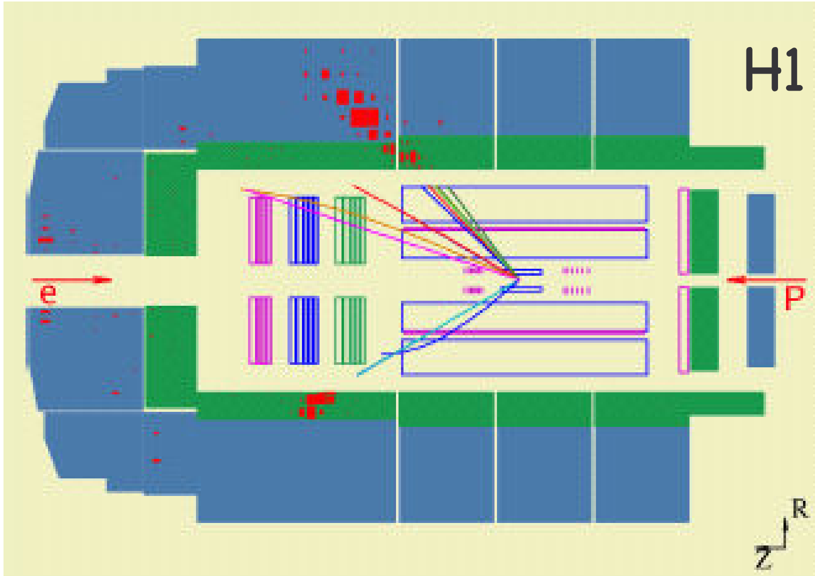
Chekelian's talk

Inclusive measurements

Neutral Current at high Q^2

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





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

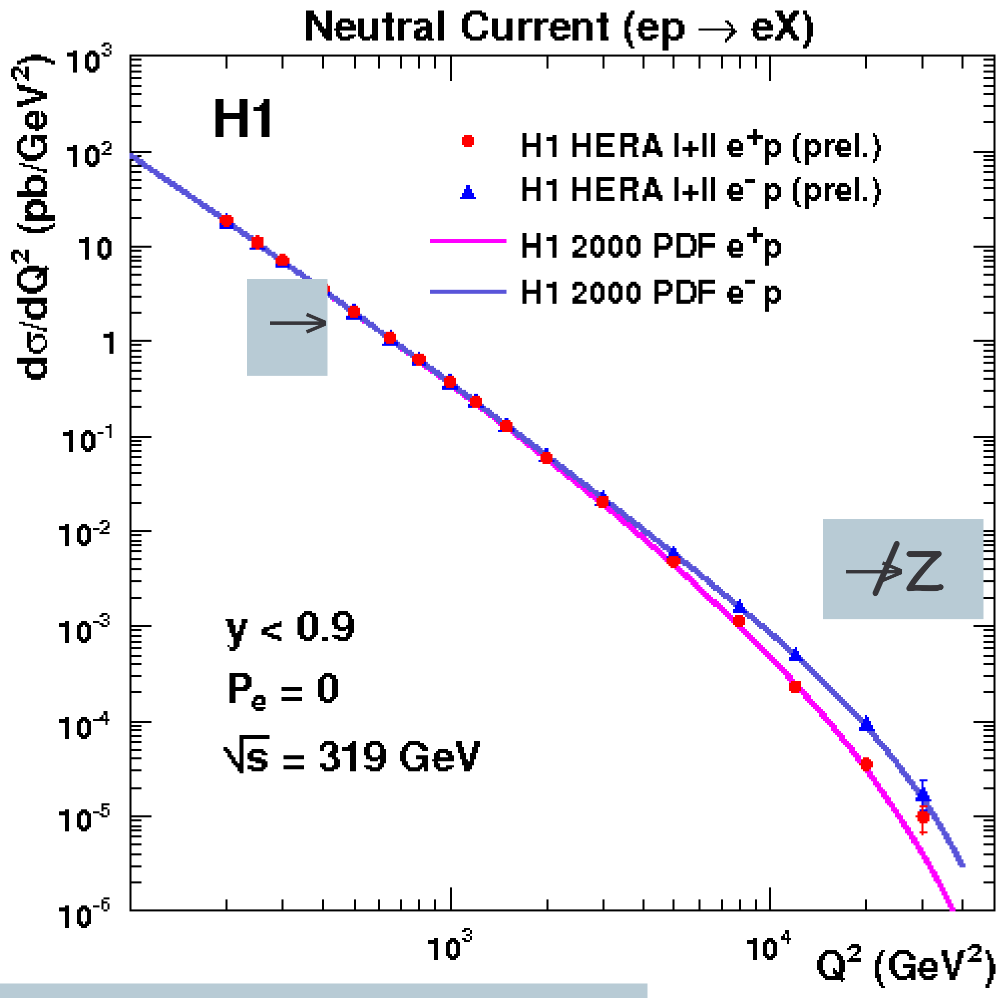
$$xF_3^{L,R} = \sum_q [xq(x,Q^2) - x\bar{q}(x,Q^2)] \cdot B_q^{L,R}.$$

→ $\quad$ $\not\to$Z $\quad$ 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

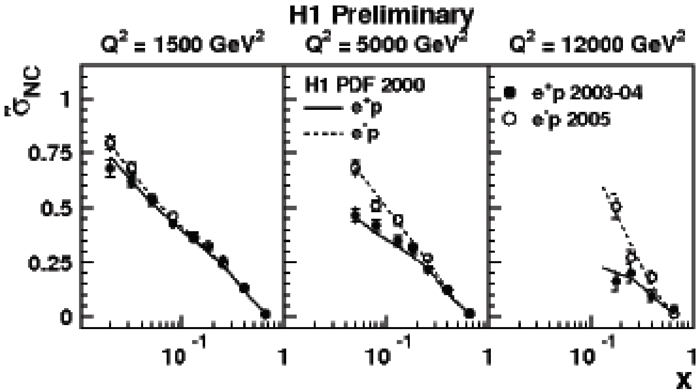


Contribution of interference and xF_3 only at very high Q^2

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

xF_3 and x-dependence in NC

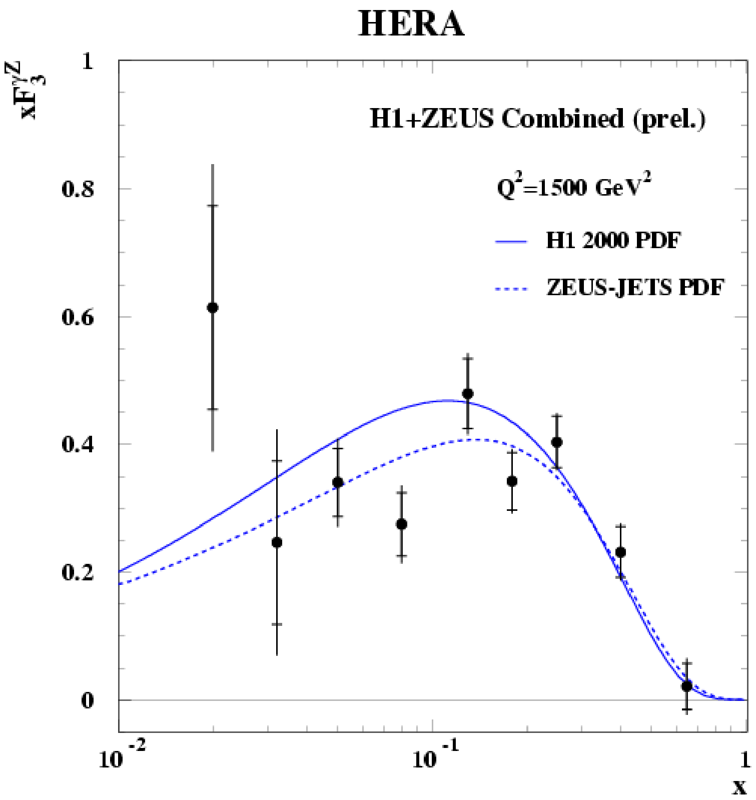
$$\sigma(e^{\pm}) \propto Y_{+}F_{2}(e^{\pm}) \mp Y_{-}xF_{3}(e^{\pm})$$



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

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

(LHC will measure it in W-production)



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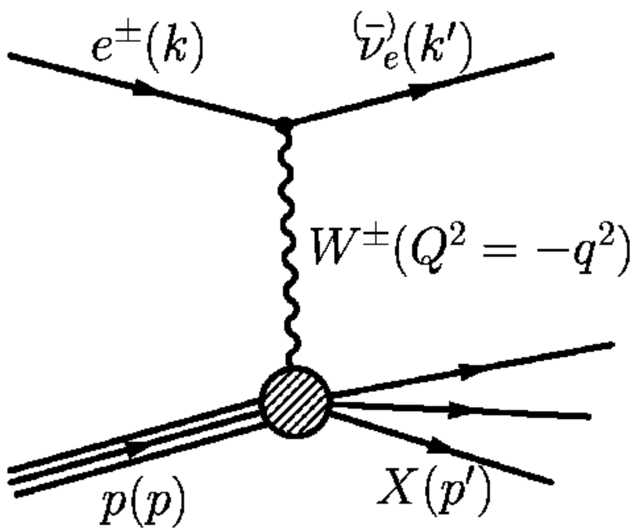
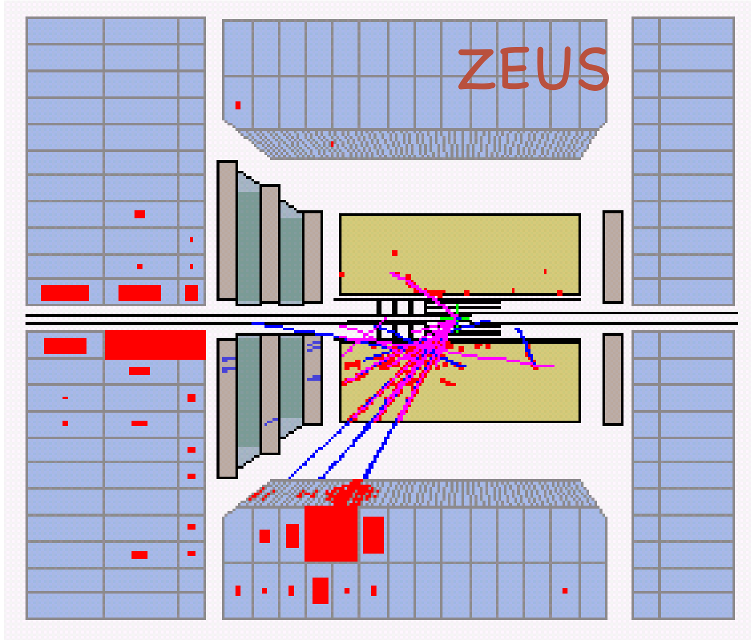
Charged Current at high Q^2



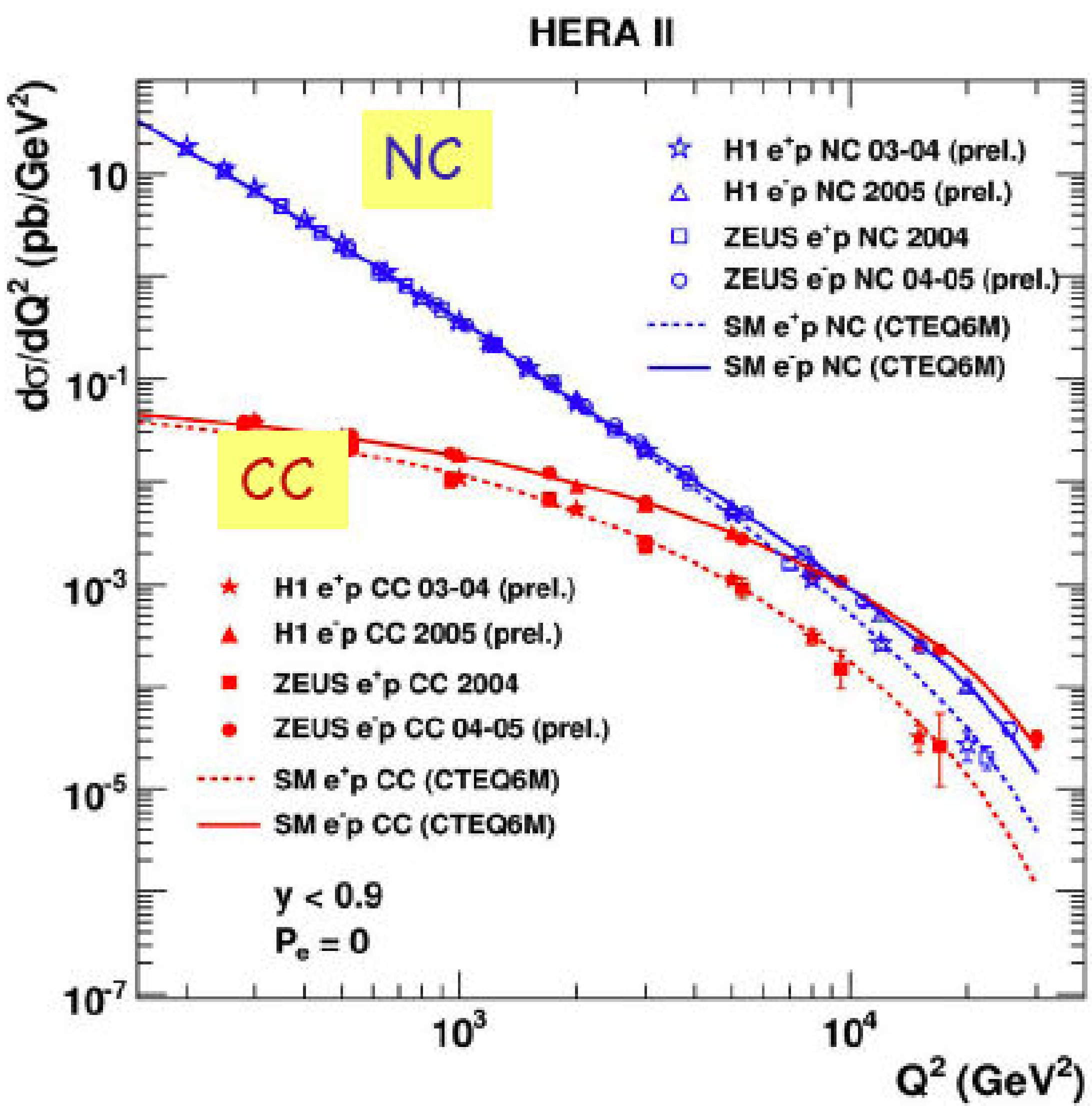


$$\frac{d\sigma^{e^+p}_{unpolCC}}{dQ^2dx} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}_i(Q^2,x) + (1-y)^2 d_i(Q^2,x)\right]$$

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

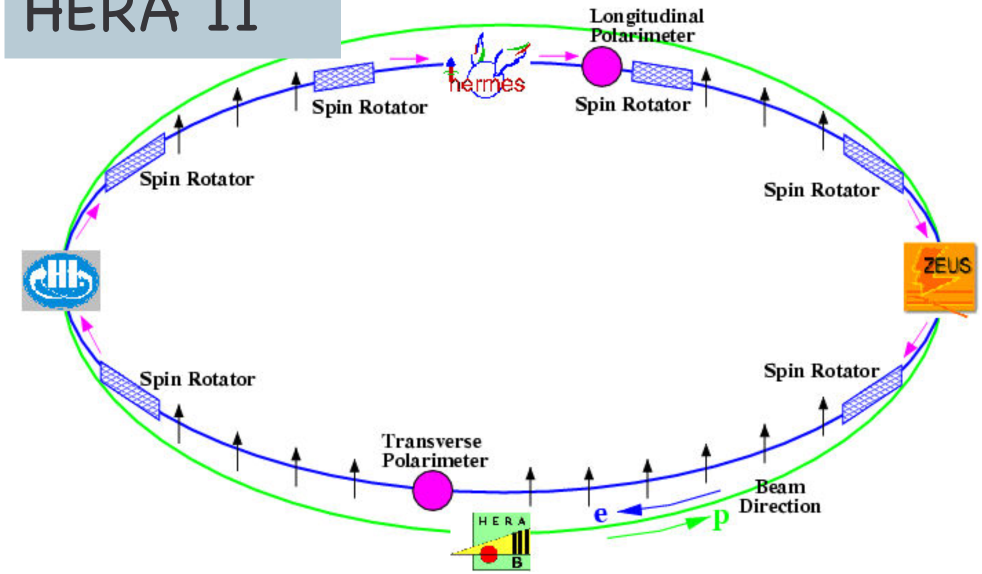
NC/CC at high Q^2

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



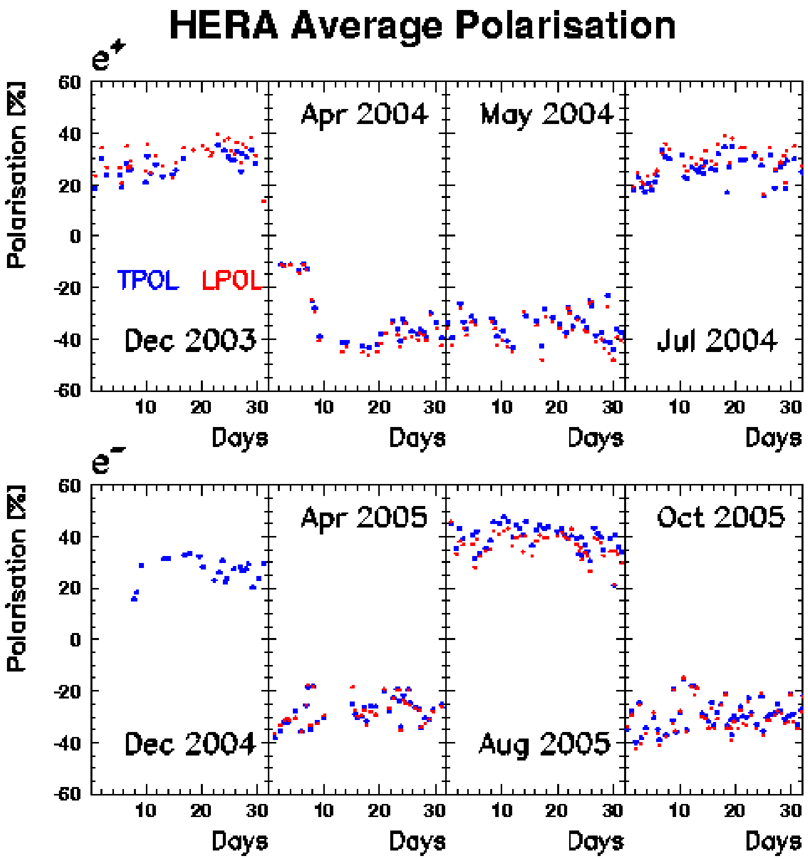
Polarized CC

HERA II



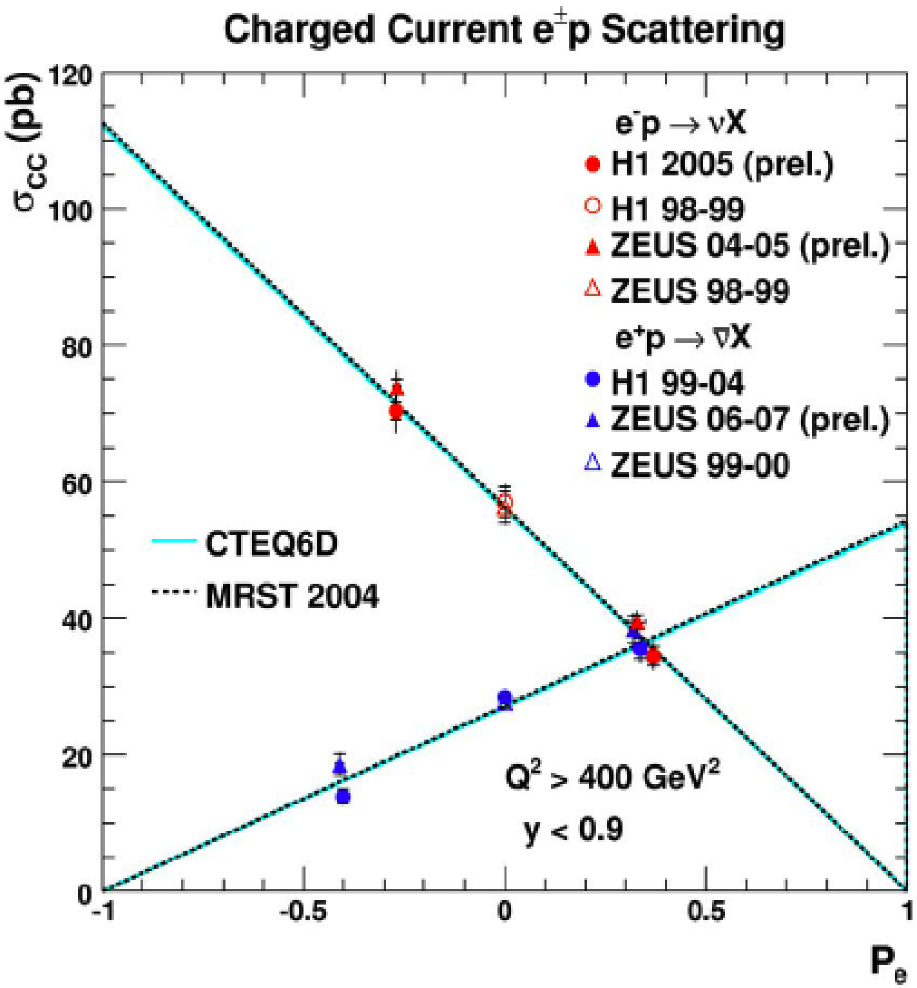
Lepton naturally transver. polarized (Sokolov-Ternov effect) with a build-up time of 30 minutes. Spin rotators to provide longitudinally polarized beams at the experiments.

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



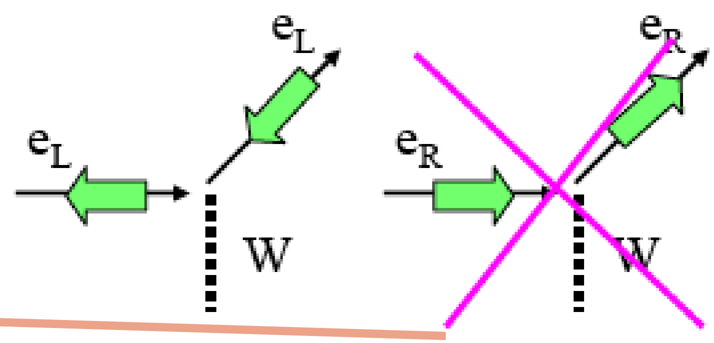
$$P = (N_R - N_L) / (N_R + N_L)$$

Polarized CC

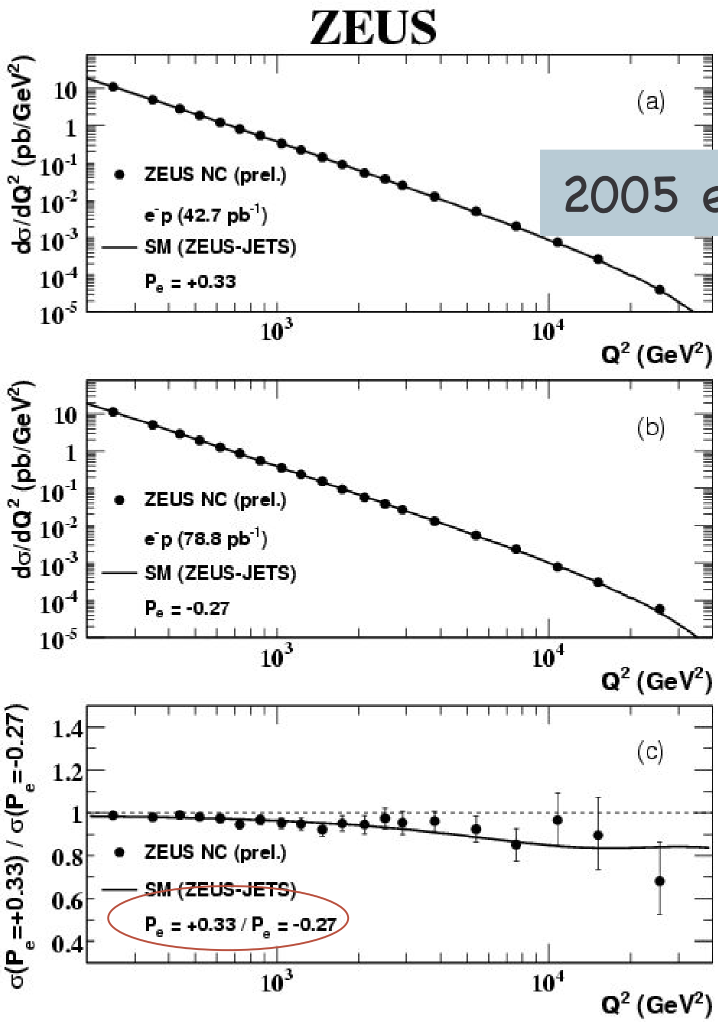


$$\sigma^{e\pm p}_{polCC}(Q^2,x) = \frac{1 \pm P_e}{2}\sigma^{e\pm p}_{LHCC}(Q^2,x)$$

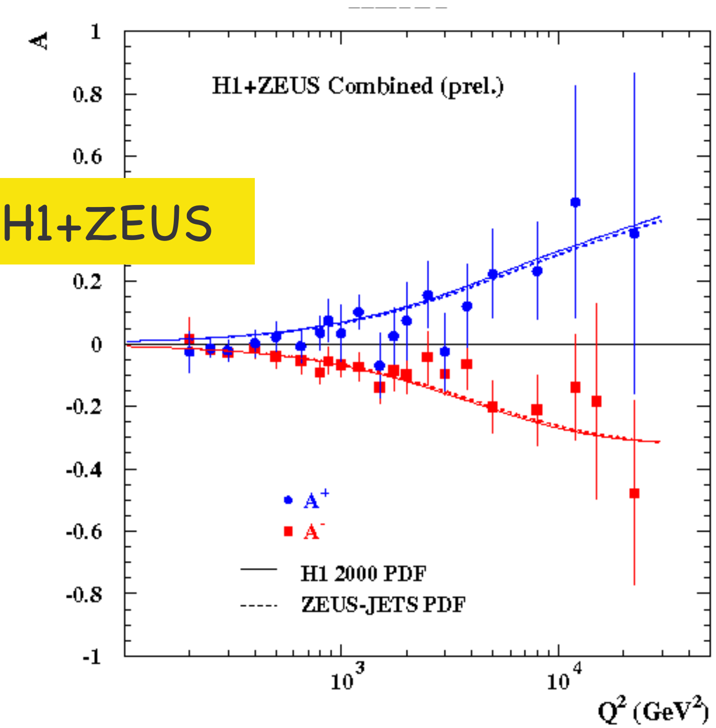
Another textbook plot, absence of right-handed charged current



(Polarized NC at high Q^2)

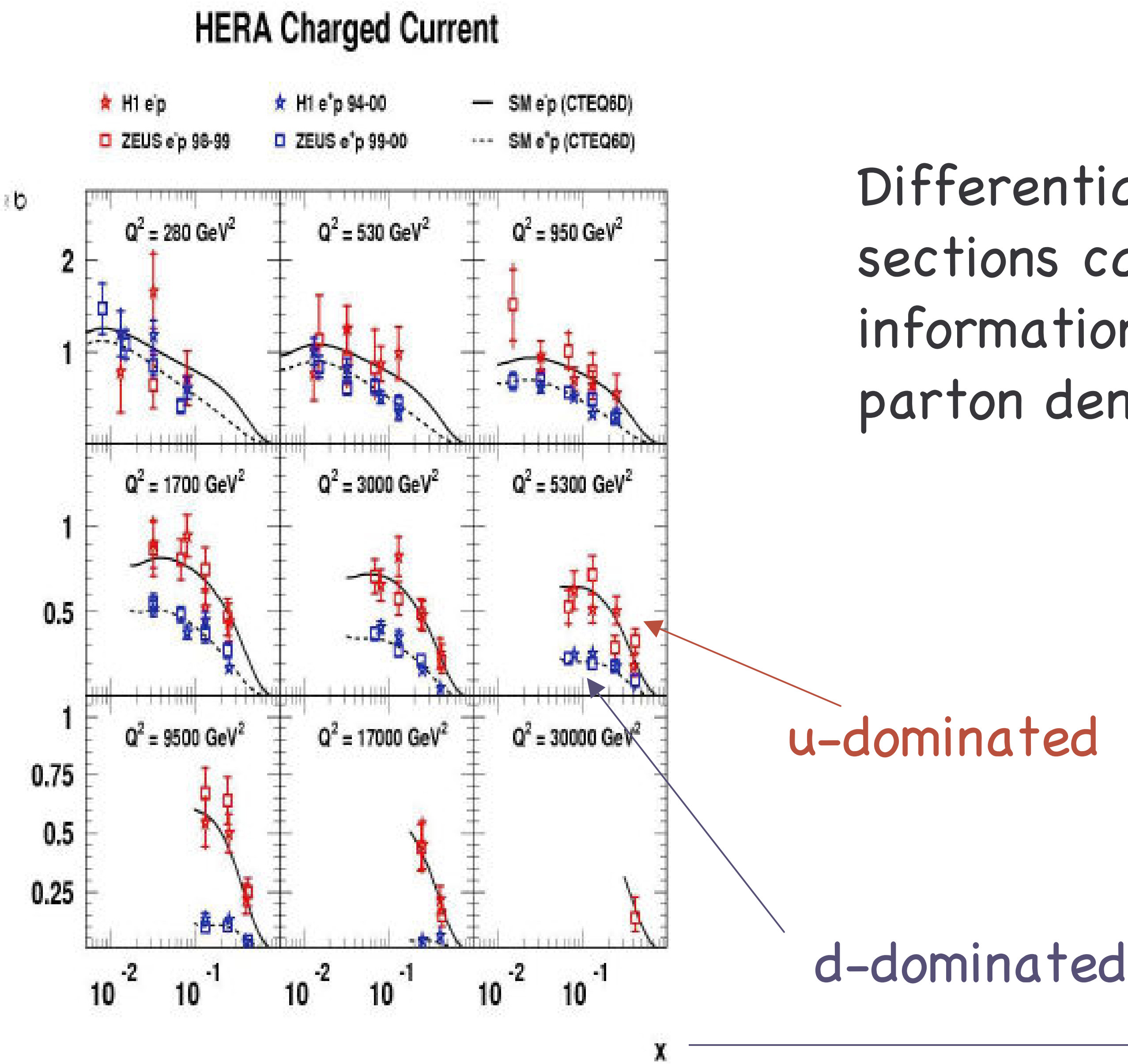


$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$



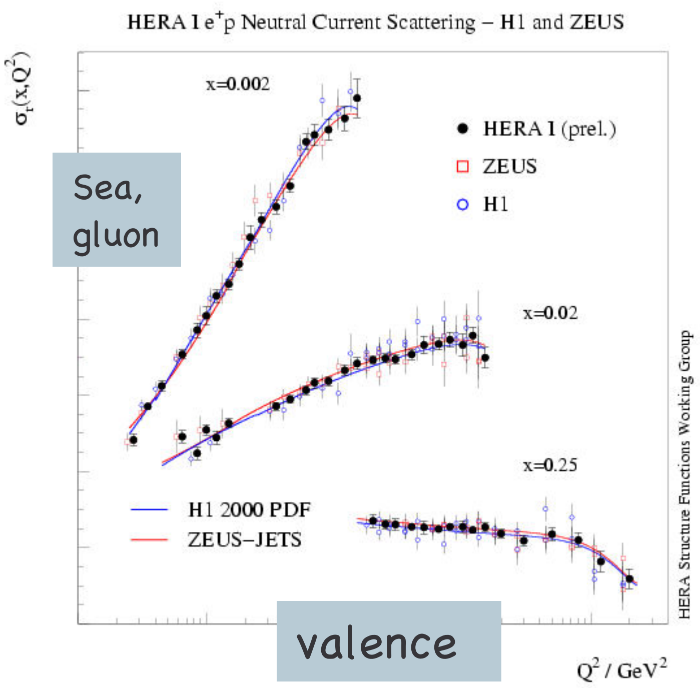
In NC the effect of P is small, but one can measure the asymmetry: parity-violating effect observed in NC at high Q^2 for the first time

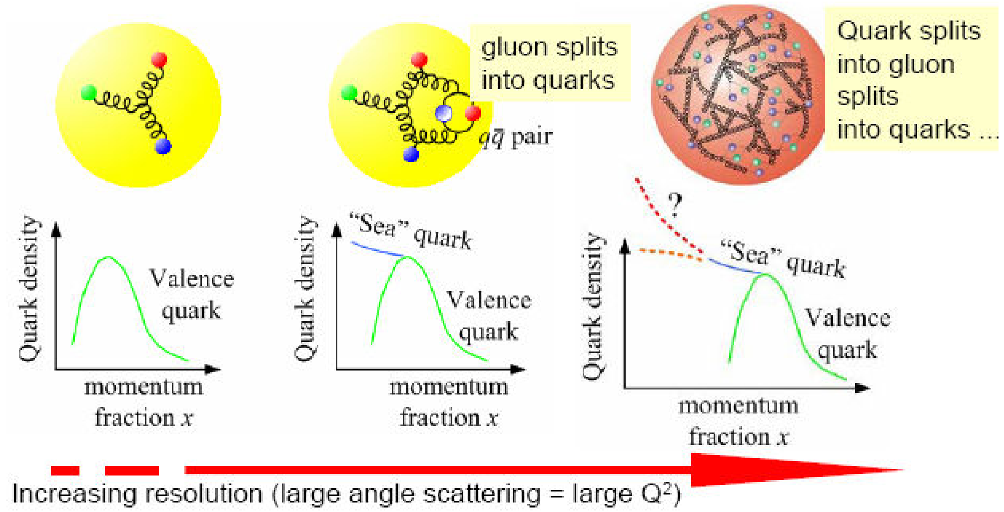
Differential CC cross-sections



Differential CC cross sections can give information on the parton densities

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

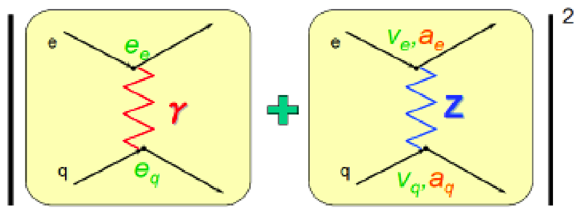
$$\Sigma_r(e^{\pm}p) = (Y_+F_2^0 \mp Y_{\Sigma}xF_3{}^0) \mp P(Y_{\Sigma}F_2^P \mp Y_-xF_3^P)$$

Neutral current cross-section

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

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

Polarized structure functions



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

$$B_i^0(Q^2) = -2e_ia_ia_eP_Z + 4a_ia_ev_iv_eP_Z^2$$

Unpolarized xF_3 determines the axial couplings

$$A_i^P(Q^2) = -2e_iv_ia_eP_Z - 2v_ea_e(v_i^2 + a_i^2)P_Z^2$$

$$B_i^P(Q^2) = -2e_ia_iv_eP_Z - 2v_ia_i(v_e^2 + a_e^2)P_Z^2$$

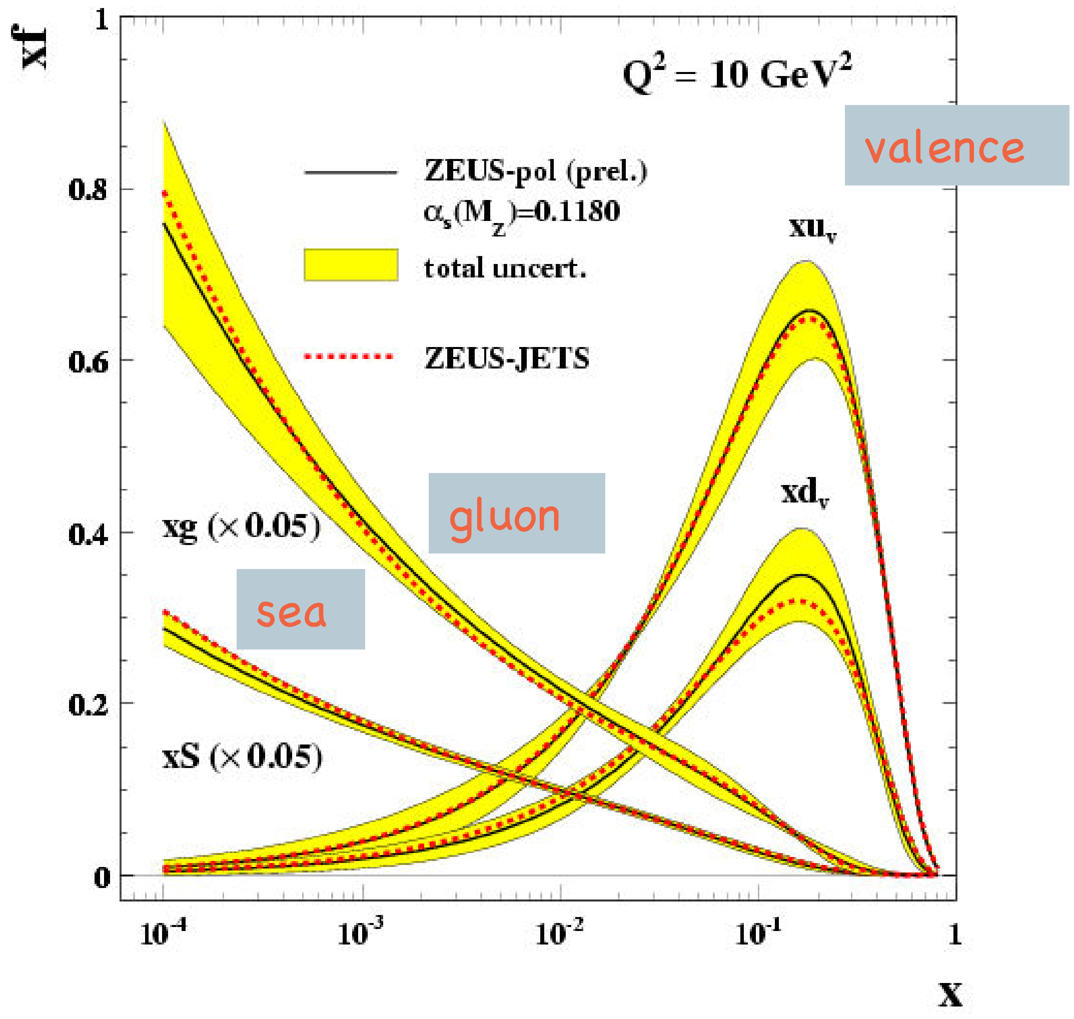
Polarized F_2 determines the vector couplings

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



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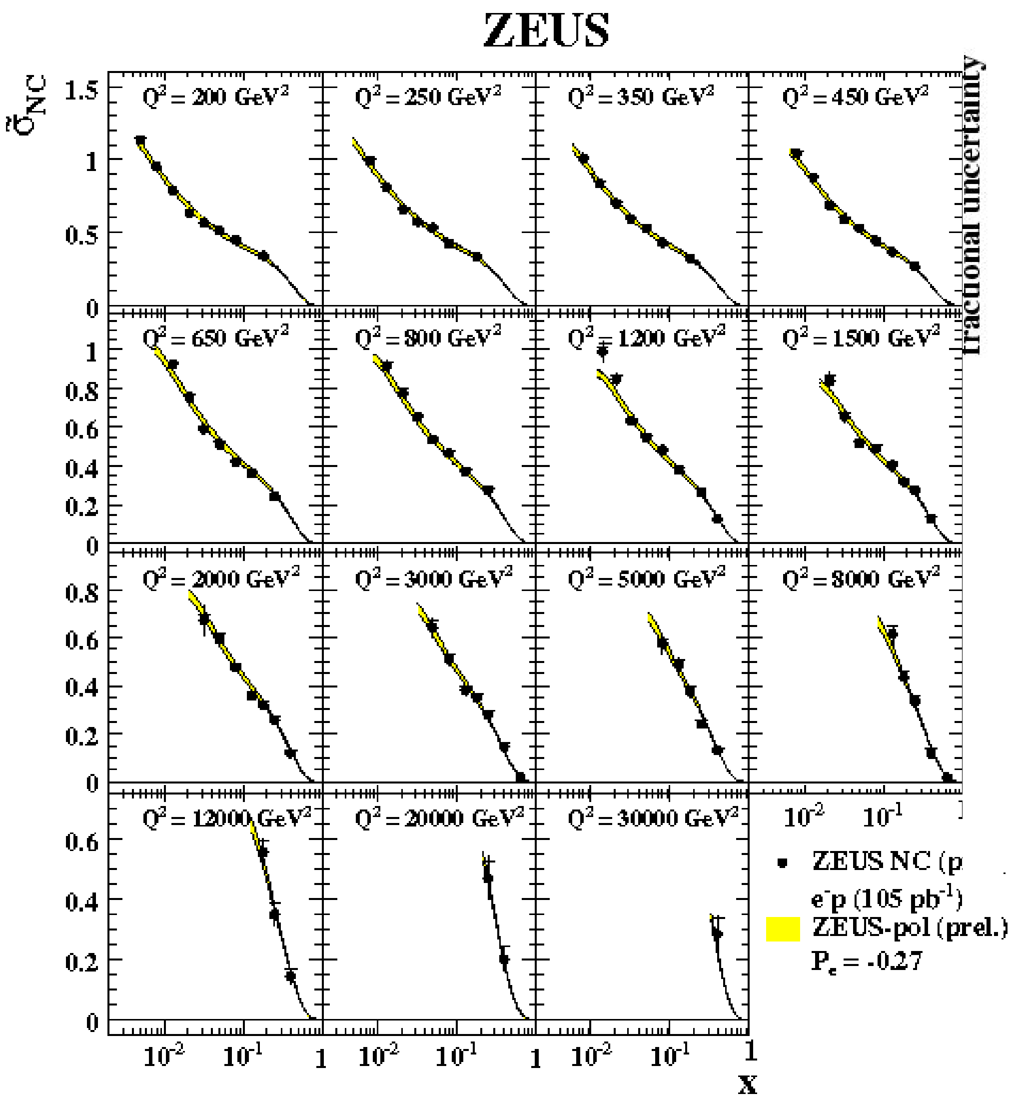
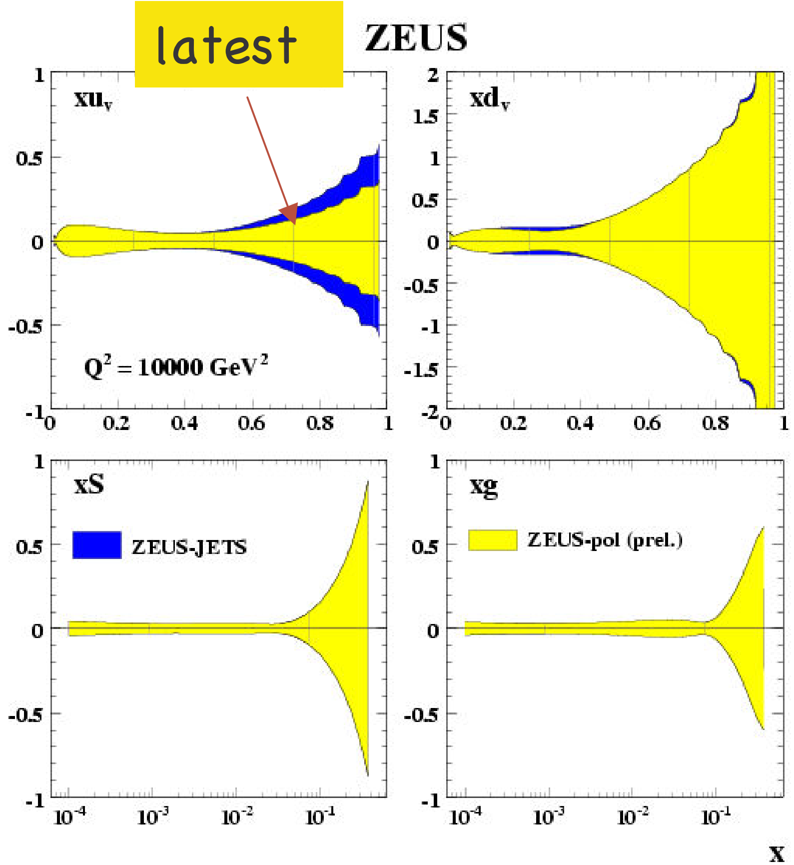
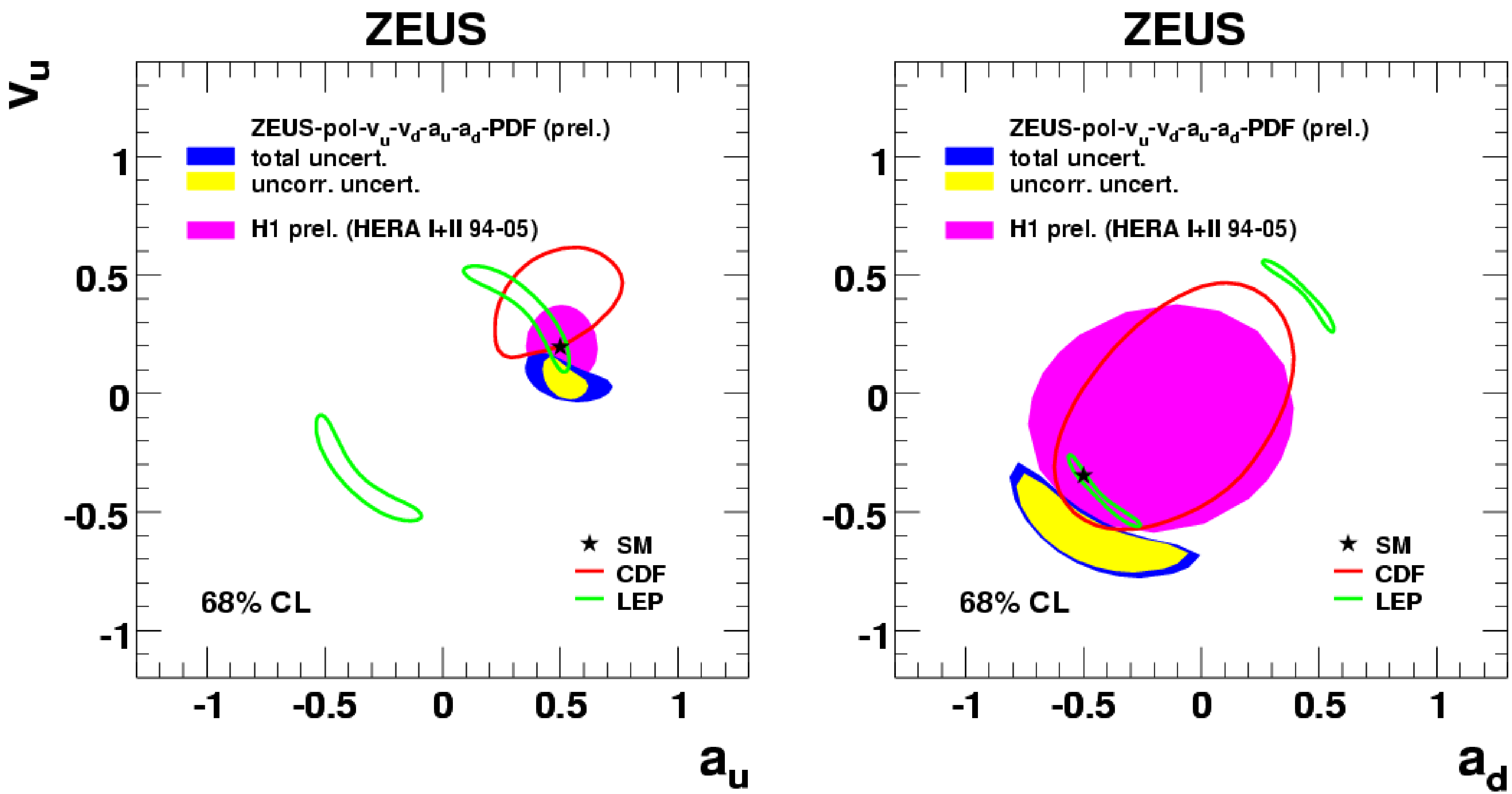
Polarized QCD fits





u-valence more and more constrained at HERA

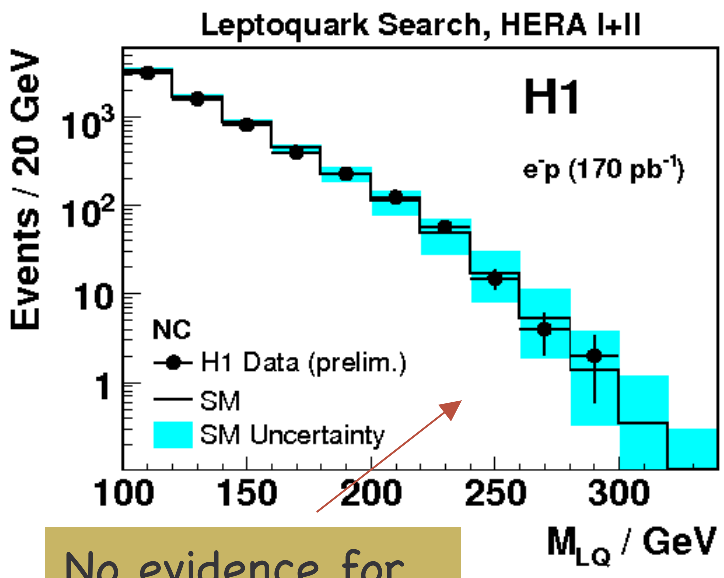
Polarized QCD fits

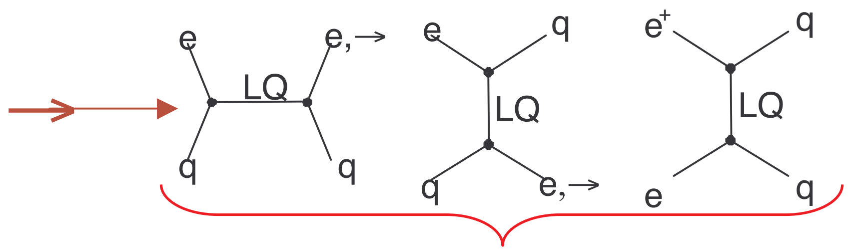


Vector and axial couplings for u- and d- quarks determined with competitive precision, in agreement with SM

Search for new physics in EW processes

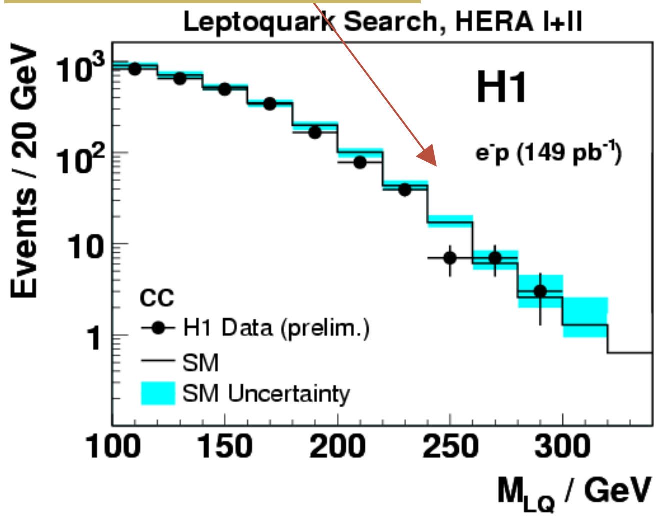
Search for Leptoquarks

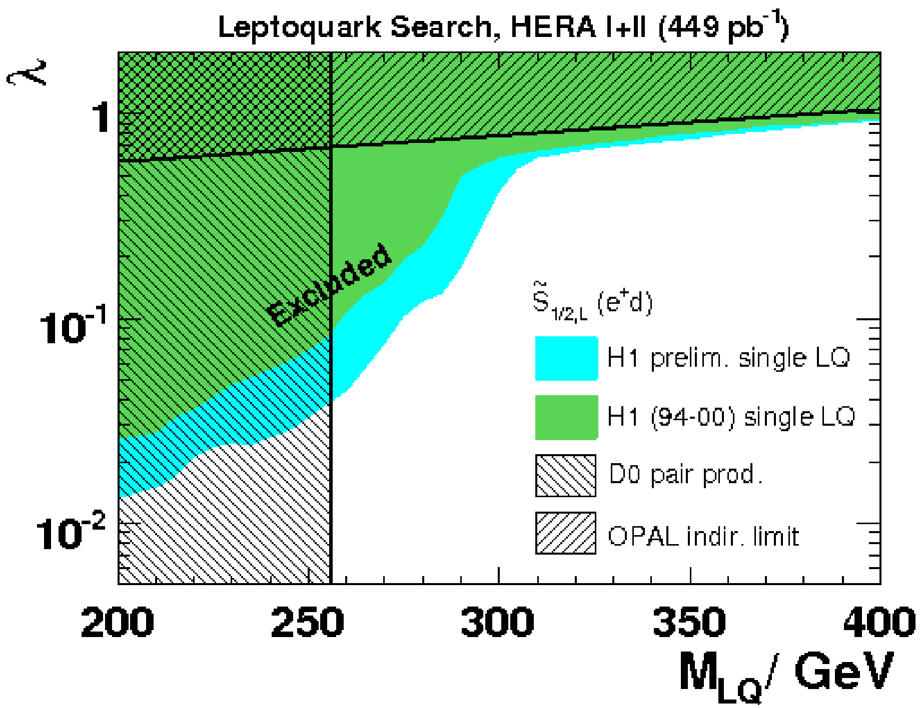




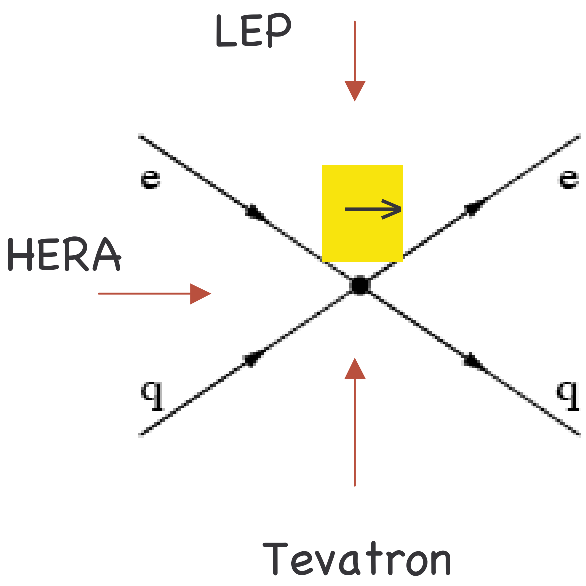
All HERA II data analyzed by H1, ex. For one LQ type:

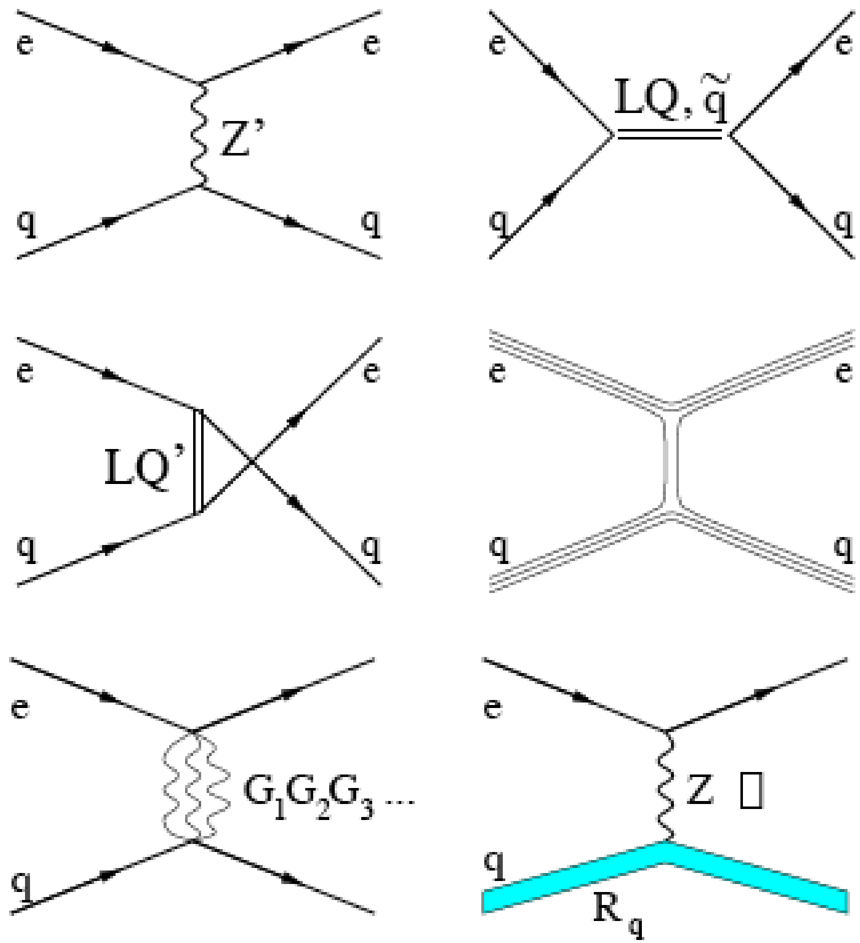
No evidence for a mass peak





Search for Contact Interactions

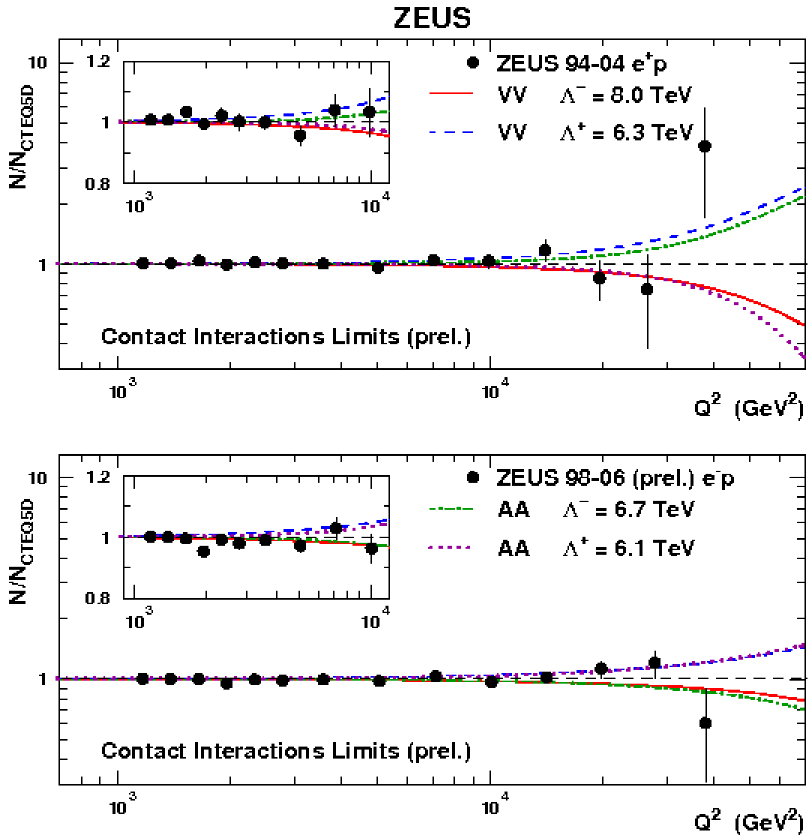


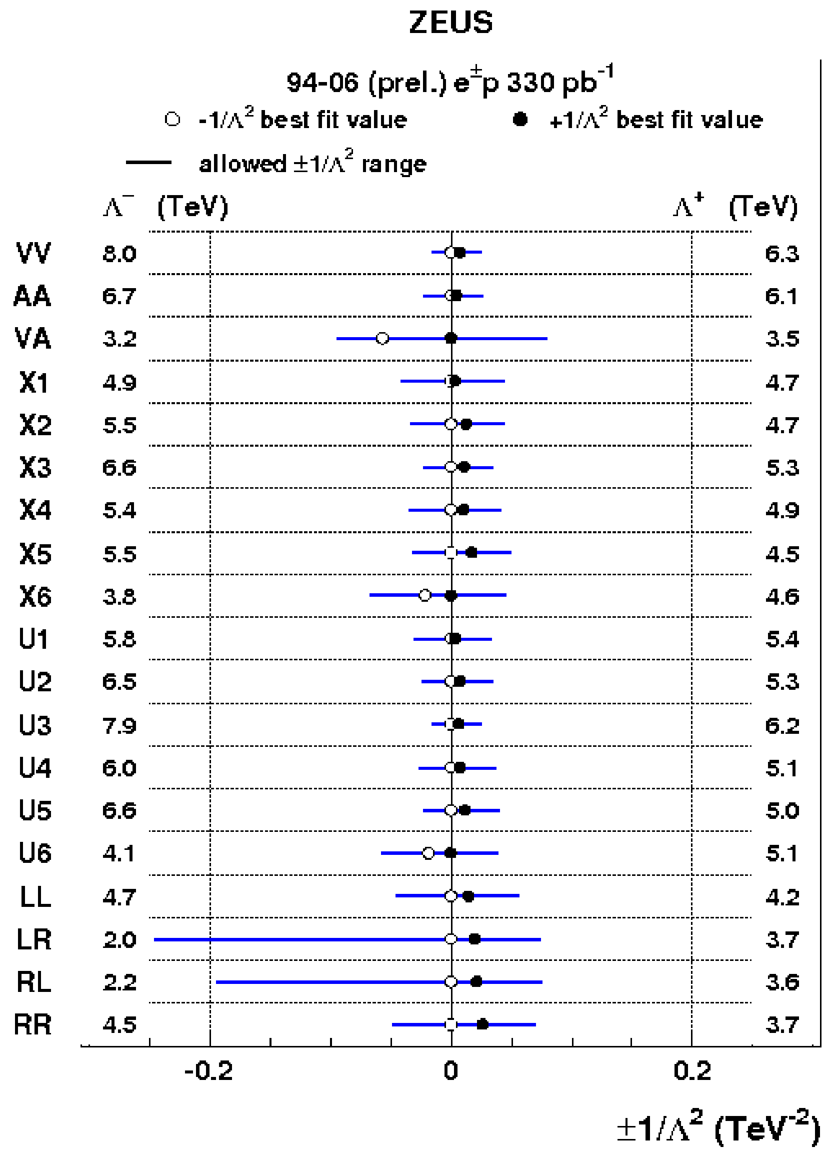


The $d\sigma/dQ^2$ at high Q^2 could show signs of new physics at scales $\rightarrow$ greater than $\sqrt{s}$

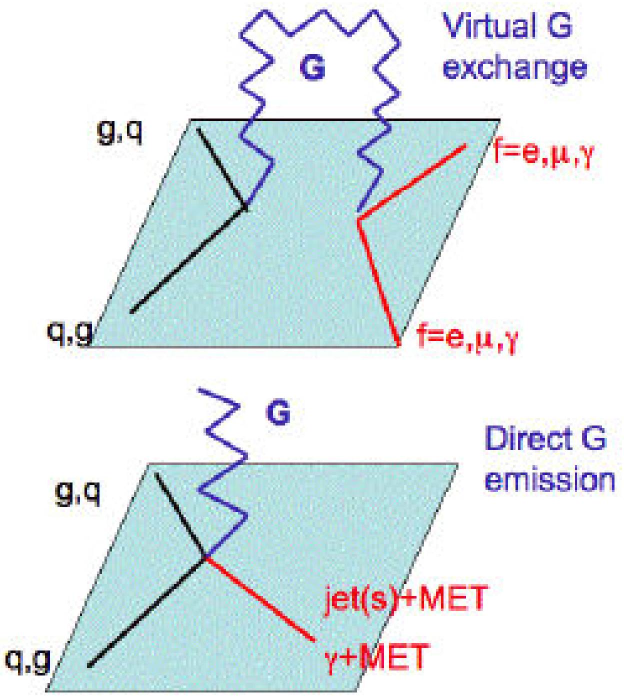
Contact Interactions

Example for the VV, AA interactions:



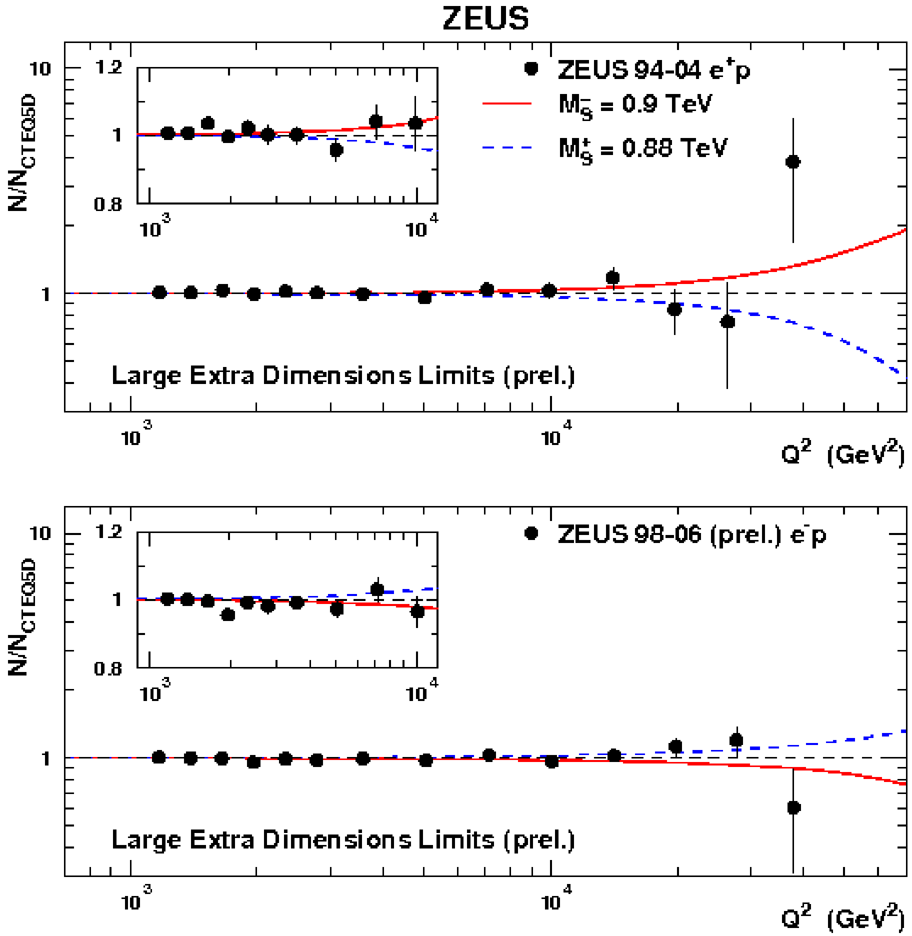


Extra dimensions



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

If R=O(10μm) → $M_s \sim$ TeV



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

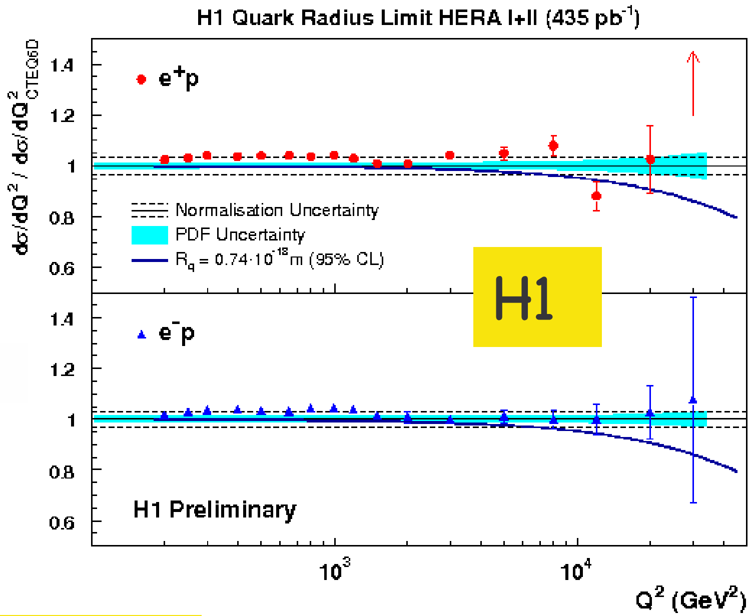
At 95% CL

Quark radius

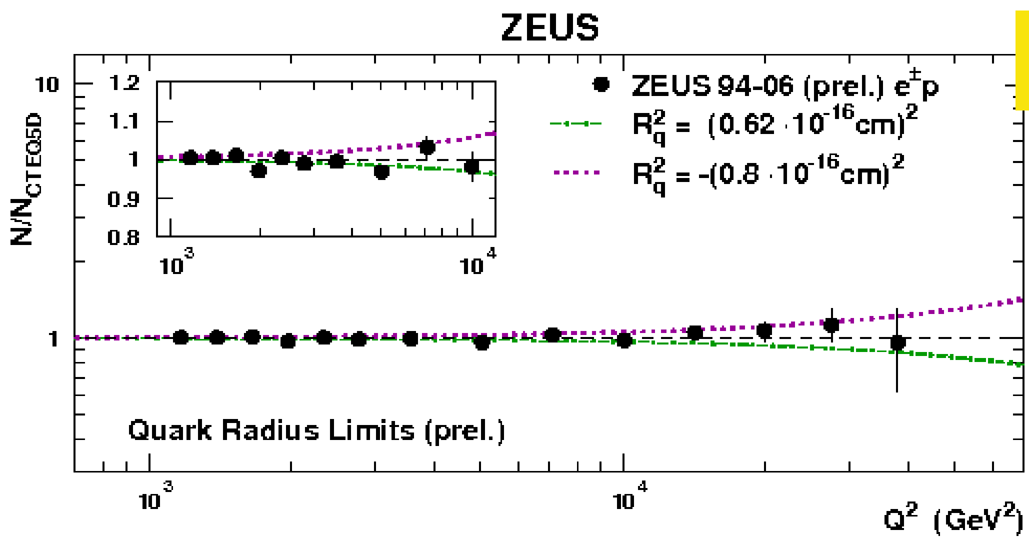
Can be determined as a form factor, assume electron pointlike:

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

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



H1

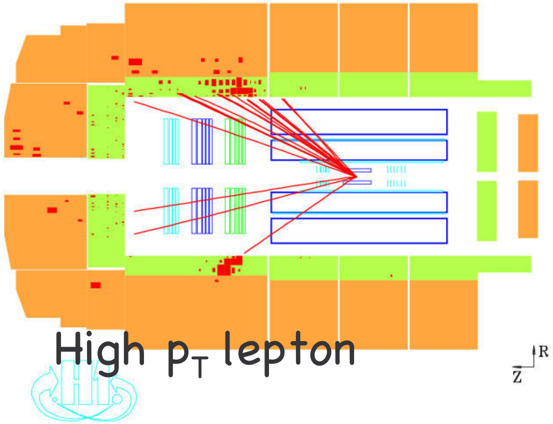


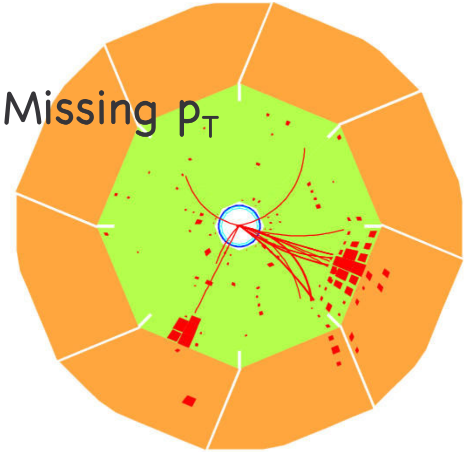
ZEUS

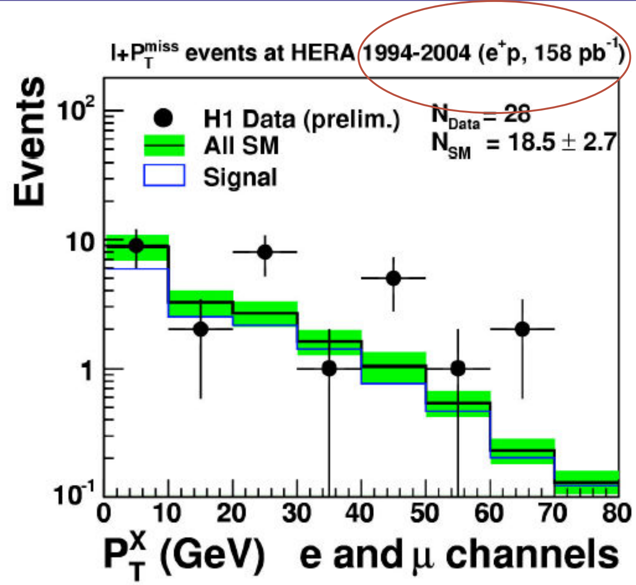
$$R_q < 0.62 \cdot 10^{-16}\ \text{cm}$$

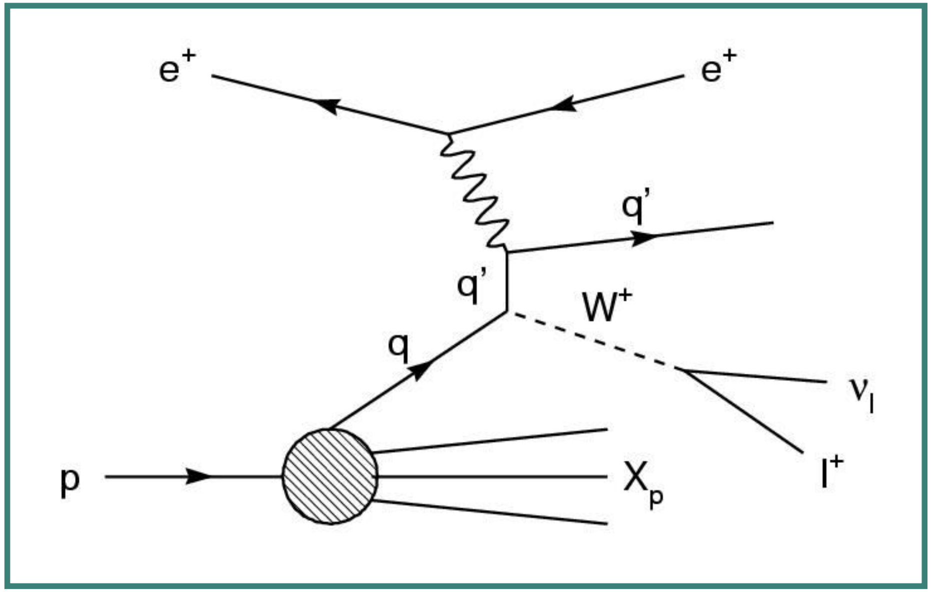
Most stringent limit today

Search for new physics in W-like events







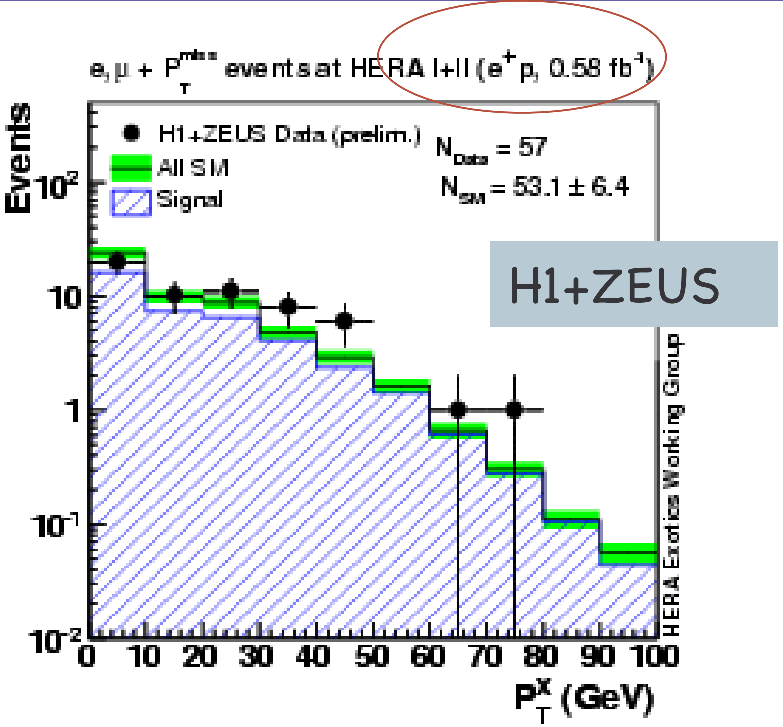


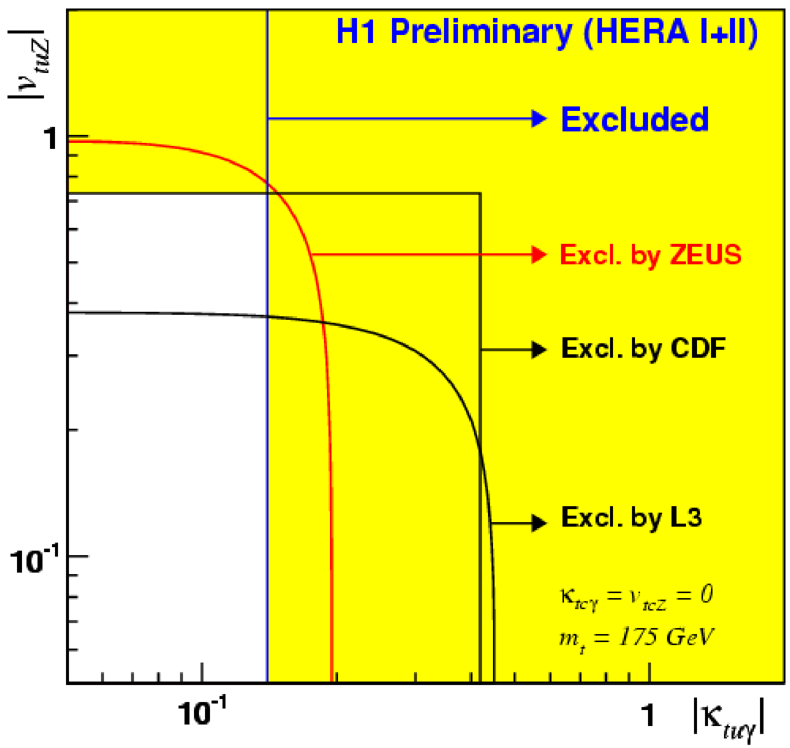
New physics at H1?

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

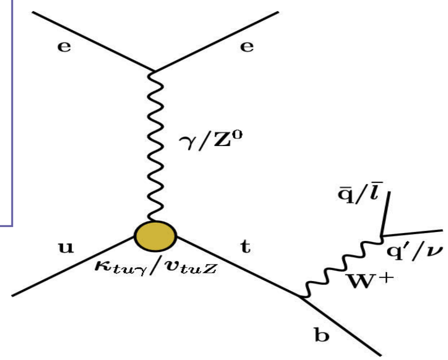
Due to W production in the SM

Search for new physics in W-like events



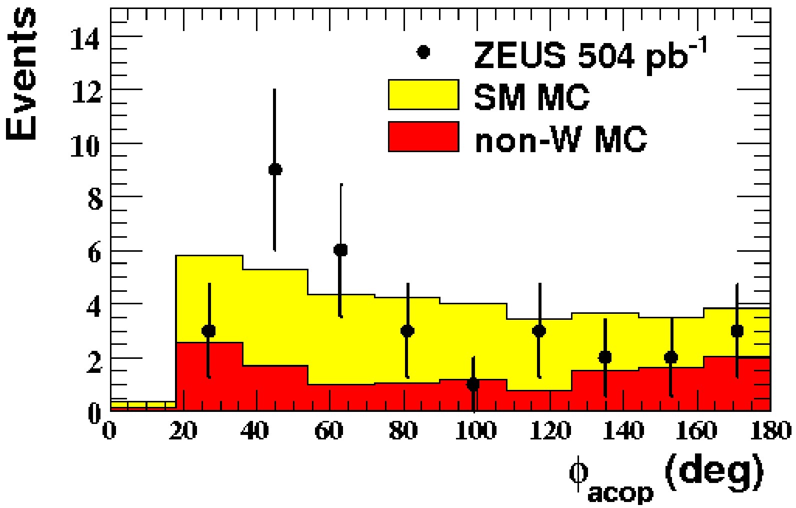


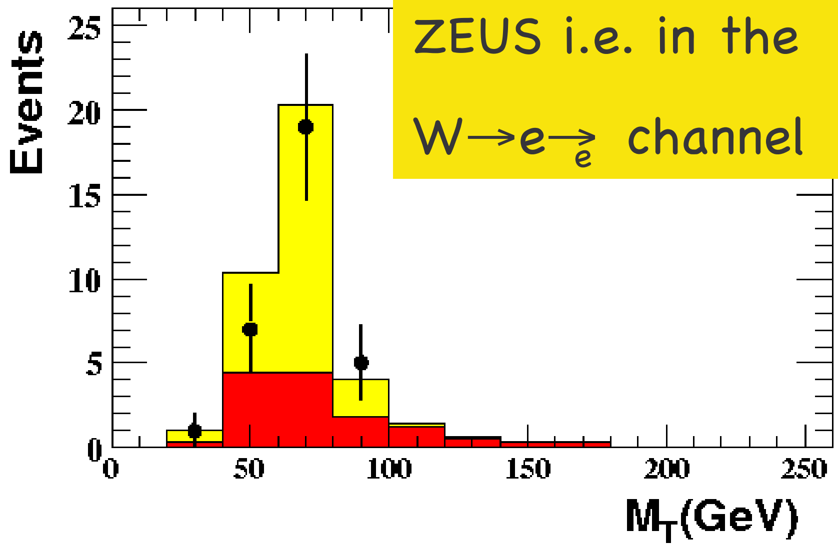
P_T^X > 25 GeV		e+μ Data/SM	
H1	0.29 fb^{-1}	17/7.1±0.9	(2.9σ)
ZEUS	0.29 fb^{-1}	6/7.5±1.1	
H1+ZEUS	0.58 fb^{-1}	23/14.6±1.9	(1.8σ)



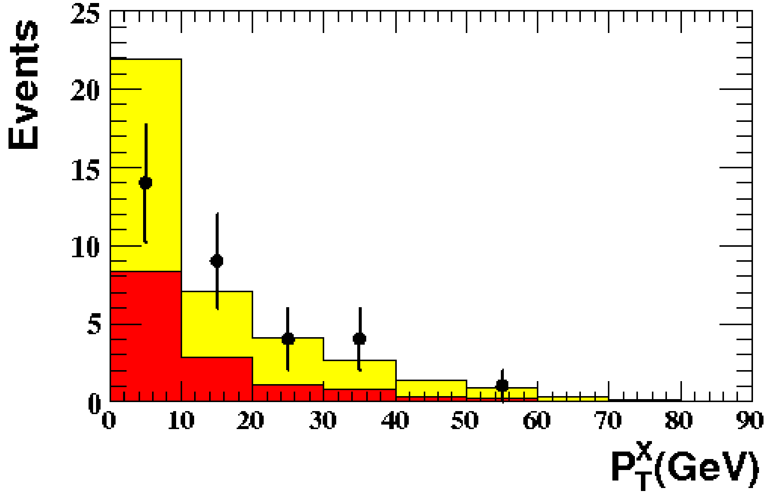
Limit on single top production due to an anomalous FCNC coupling

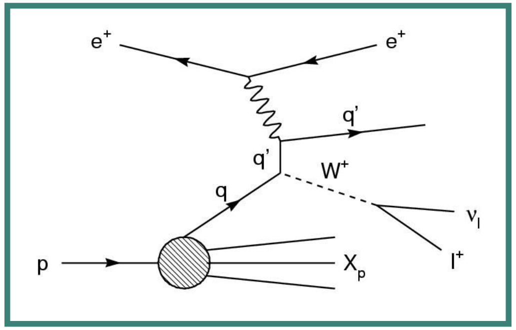
Measurement of W cross-section





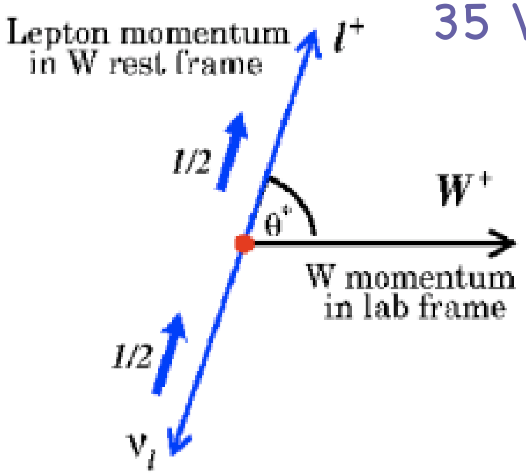
ZEUS i.e. in the $W \to e \nu_e$ channel





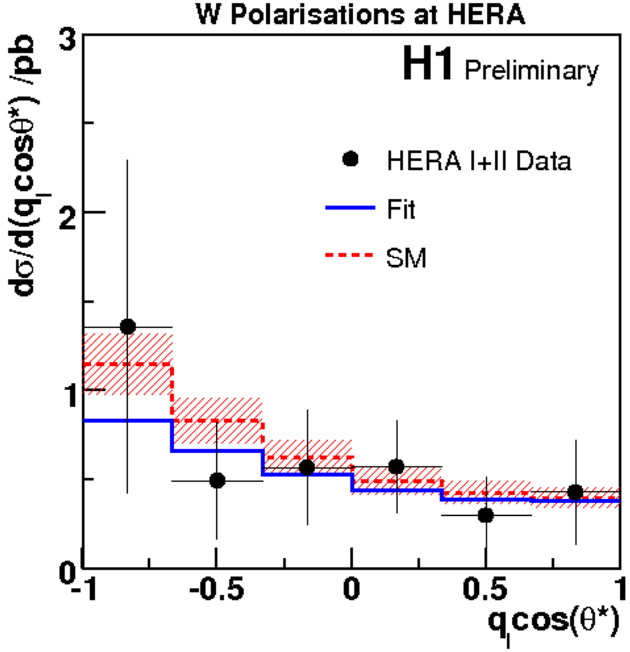
$\sigma(ep \to lWX) = 0.89_{-0.22}^{+0.25}$(stat.) ± 0.10 (syst.) pb ; σ(SM)=1.2 pb

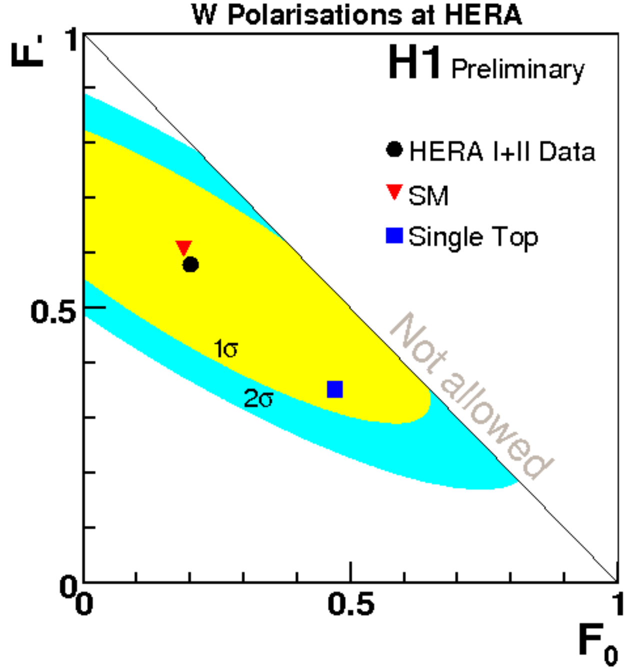
Measurement of W polarization



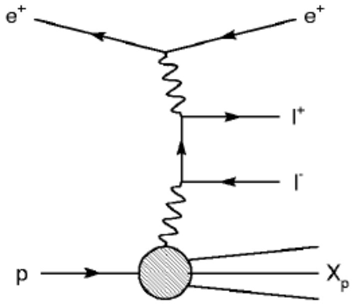
35 W-events at H1, study the angular distributions

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



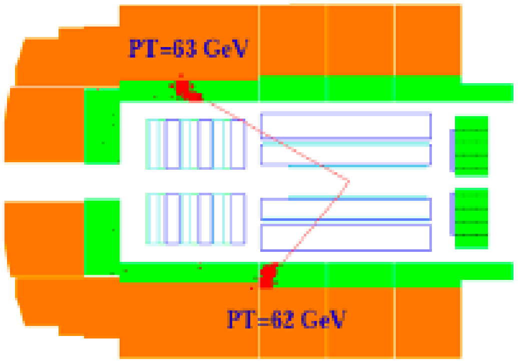


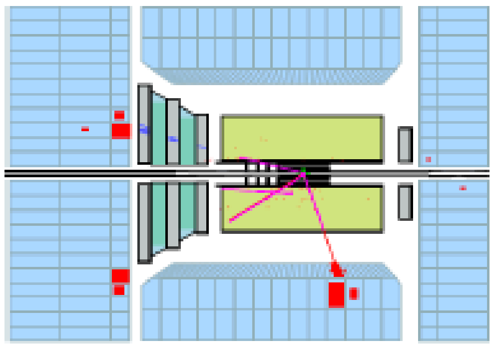
Search for new physics in BH-like events

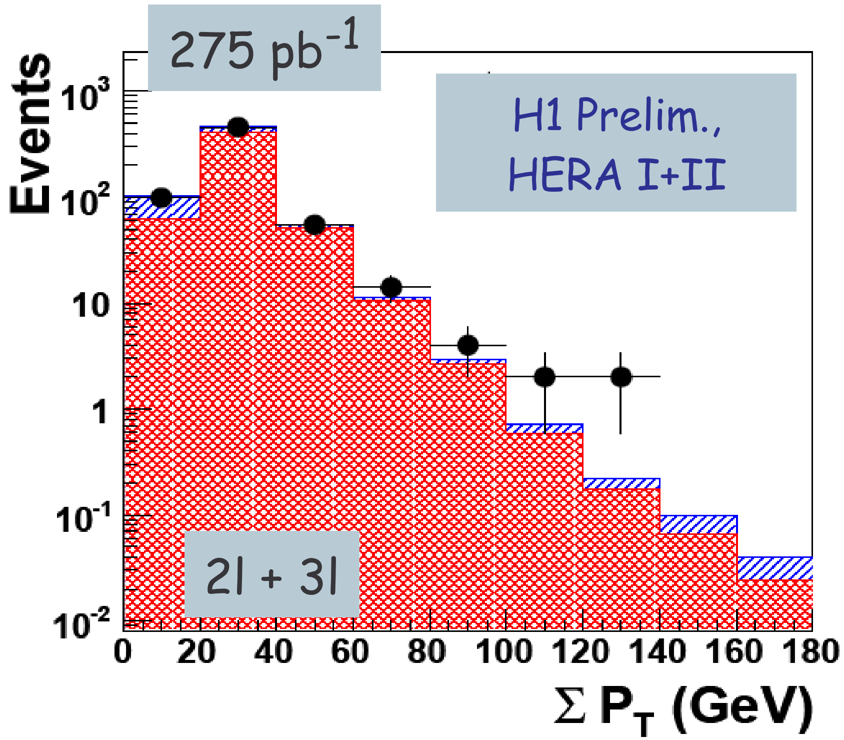


Bethe-Heitler

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







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

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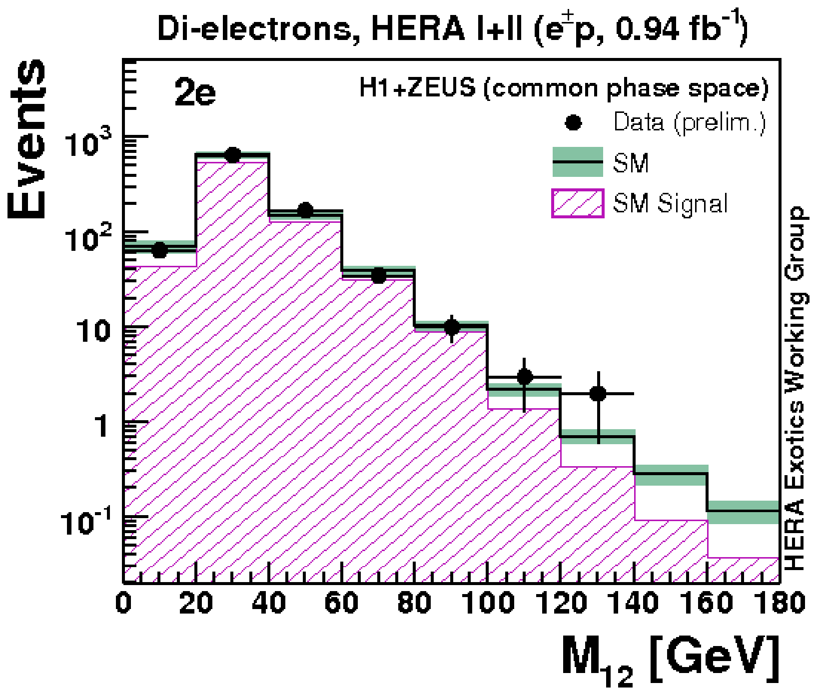
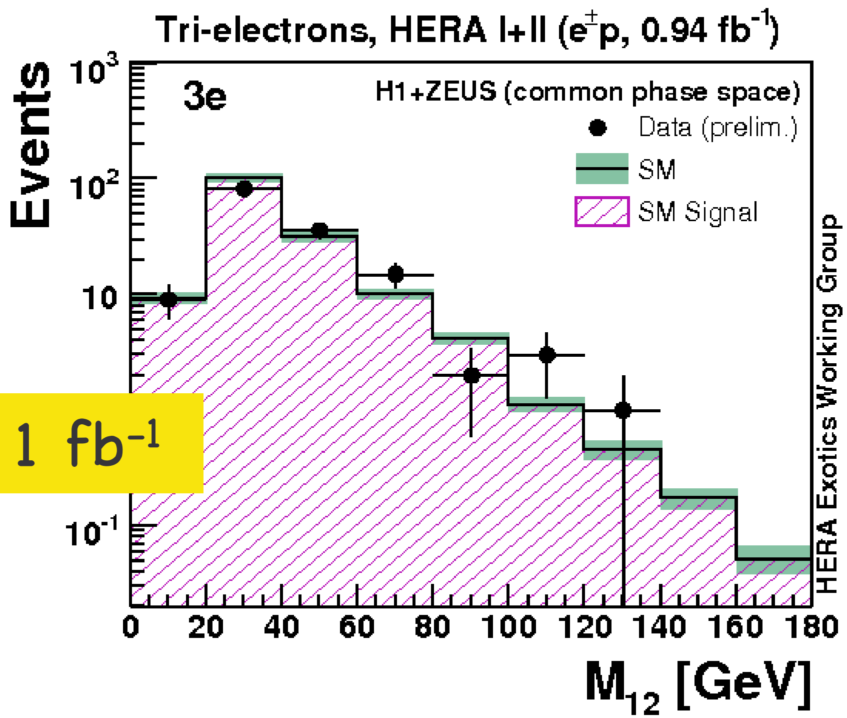
Search for new physics in BH-like events

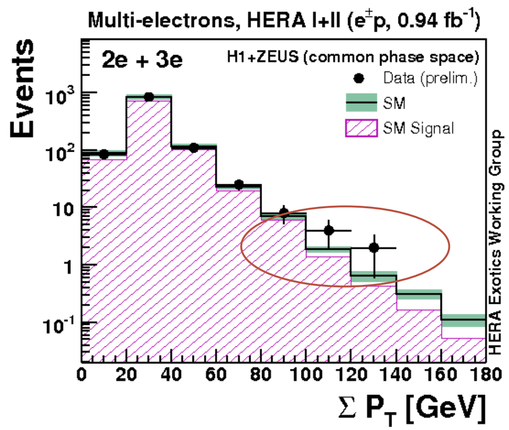




1 fb^{-1}

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

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