High Q2 cross sections, EW and BSM at HERA

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DESY
on behalf of H1 and ZEUS collaborations

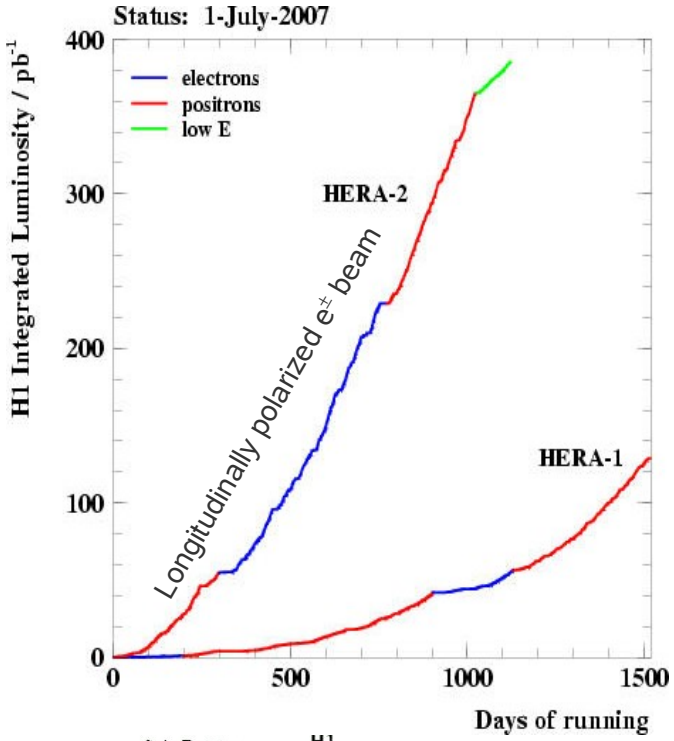
→ DIS at HERA
→ High Q^2 cross sections and electroweak physics
→ Physics beyond Standard Model
→ Summary

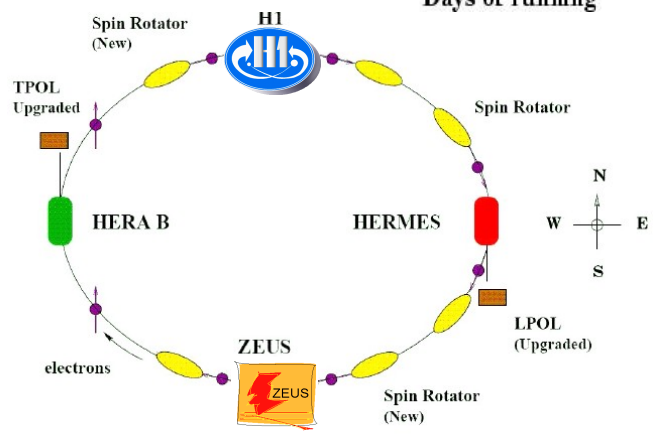
HERA

- $e^{\pm}$(27.5 GeV), p(820/920 GeV), $\sqrt{s}$ = 300/318 GeV
- Two large multipurpose detectors: H1 and ZEUS (asymmetric design)
- 1994-2000: HERA I data
  2003-07 HERA II data with longitudinal $e^{\pm}$ polarisation:

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$ ~30-40% at HERA

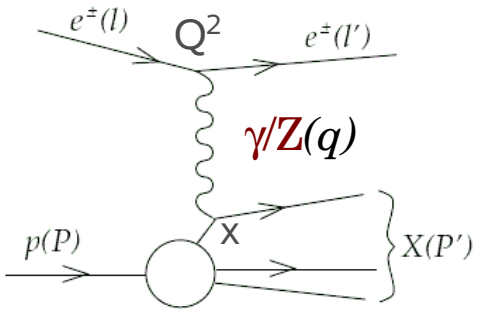
- ~1 fb^{-1} (H1+ZEUS) of luminosity delivered by HERA





Neutral current DIS cross section

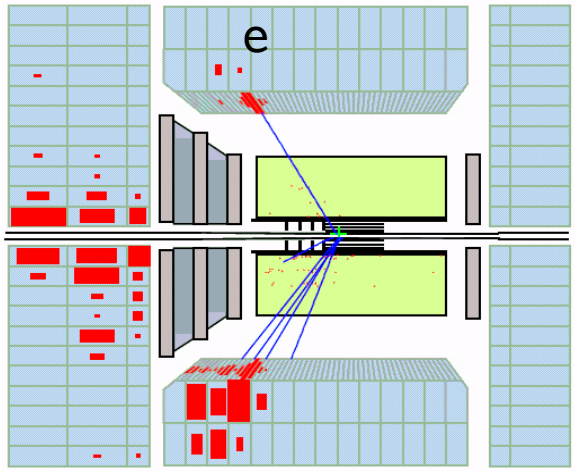
neutral current DIS cross section:



Q^2 - virtuality of exchange boson

x – Bjorken scaling variable

y - inleasticity



$$\frac{d^2\sigma_{NC}^{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2^{\pm} \mp Y_- x\tilde{F}_3^{\pm} - y^2\tilde{F}_L^{\pm}\right]$$

dominant contribution

important at high Q^2

sizable at high y

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

$$k = \frac{1}{4\sin^2\theta_w\cos^2\theta_w}\frac{Q^2}{Q^2+M_Z^2}$$

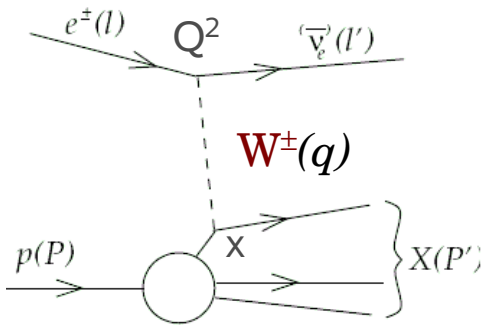
→ polarisation dependence due to γZ interference and Z terms:

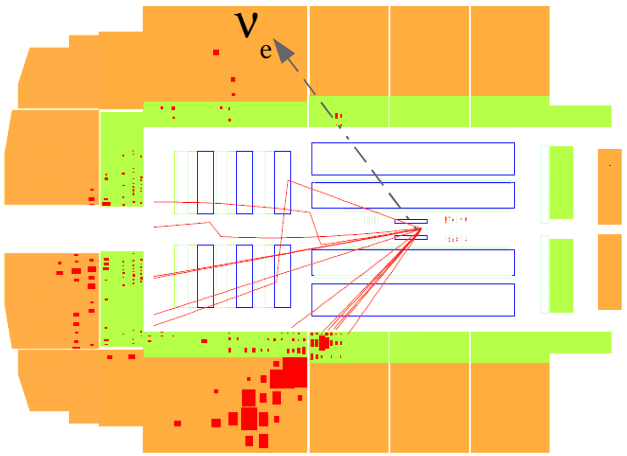
$$\tilde{F}_2^{\pm} = F_2 + k(-v_e \mp P_e a_e)F_2^{\gamma Z} + k^2\left(v_e^2 + a_e^2 \pm 2P_e v_e a_e\right)F_2^Z$$

$$x\tilde{F}_3^{\pm} = k(-a_e \mp P_e v_e)xF_3^{\gamma Z} + k^2\left(2v_e a_e \pm P_e(v_e^2 + a_e^2)\right)xF_3^Z$$

Charged current DIS cross section

charged current DIS cross section:





$$\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dx\,dQ^2} = (1 \pm P_e)\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \tilde{\sigma}_{CC}^{e^{\pm}p}$$

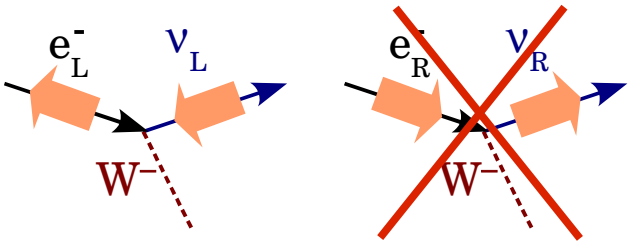
$\rightarrow$ linear polarisation dependence

In SM weak interaction acts only on left-handed particles (right-handed anti-particles)

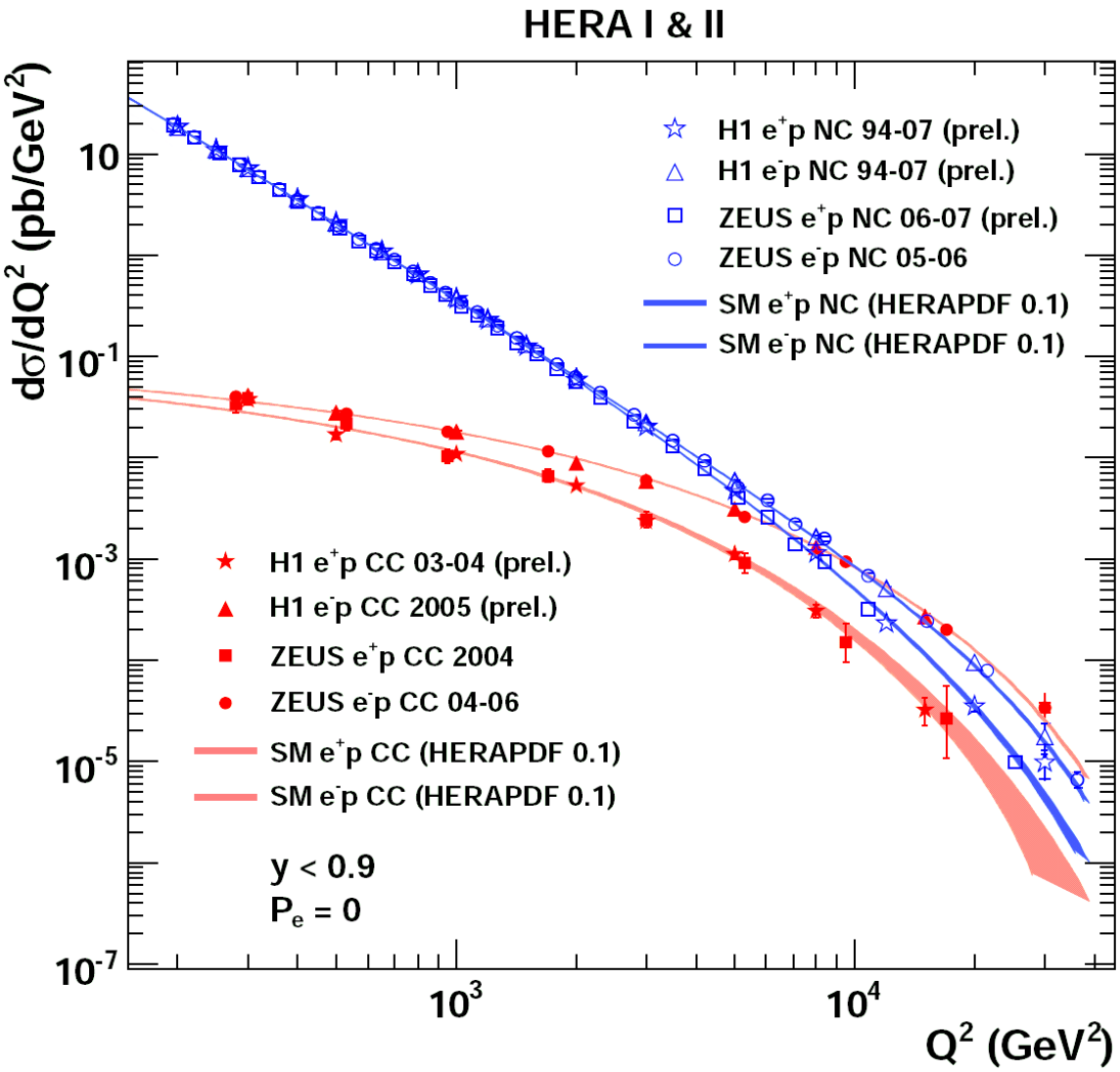
e^+/e^- sensitive to different quark densities:

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

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



Charged and neutral currents at HERA



neutral (γ/Z)
charged ($W^{\pm}$)
currents cross sections
at $Q^2 \gtrsim M^2_{Z/W}$ scale
get similar:

EW unification

good agreement with
SM (HERAPDF 0.1)

Neutral currents at HERA

- the charge dependent polarisation asymmetries in neutral currents – direct measure of EW effects

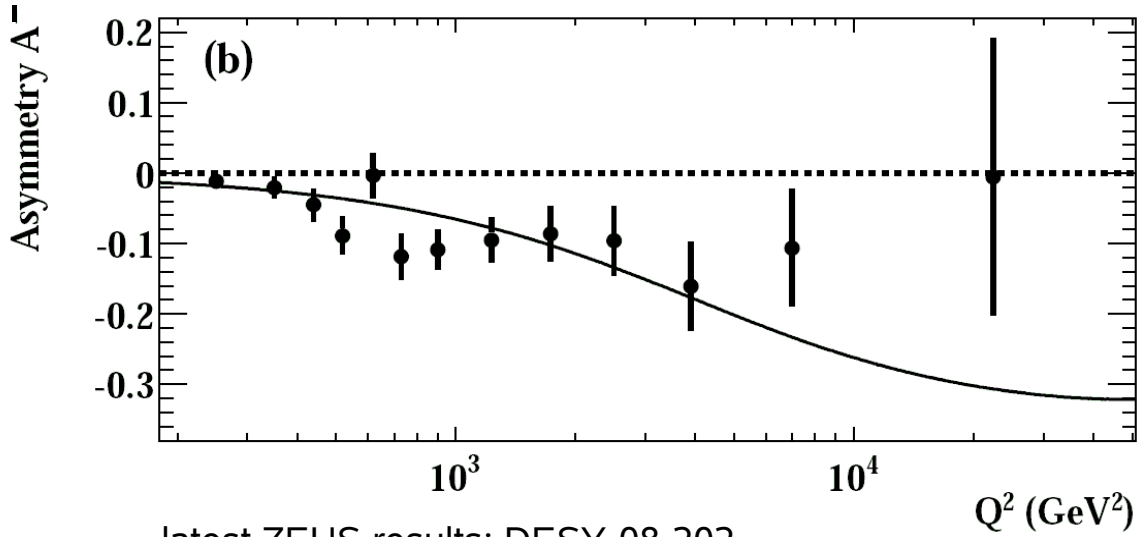
neglecting Z term generalised structure function F_2 is expressed:

$$\tilde{F}_2^{\pm} \approx F_2 + k(-v_e \mp P_e a_e) F_2^{\gamma Z}$$

at LO: $F_2^{\gamma Z} = x \sum 2 e_q v_q (q + \overline{q})$

polarisation asymmetry A is proportional to $a_e v_q$ combination:

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

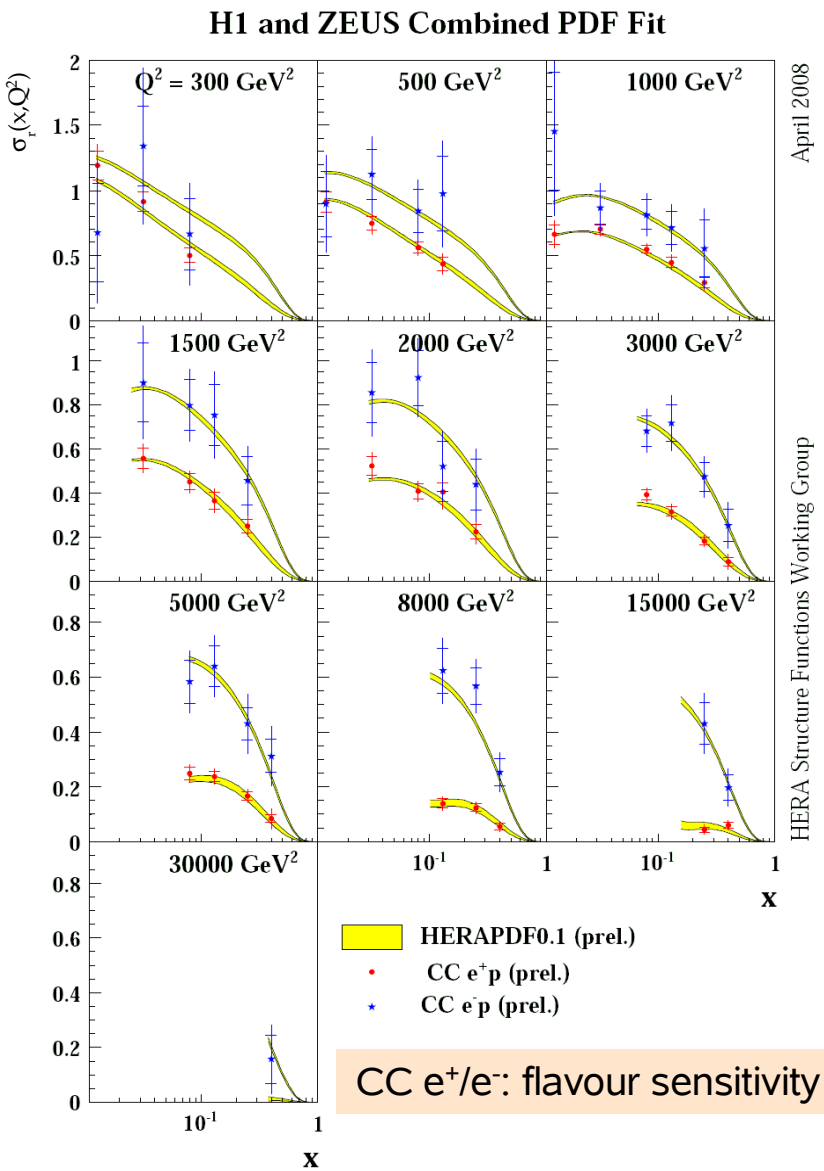


latest ZEUS results: DESY-08-202

and directly measures the parity violation

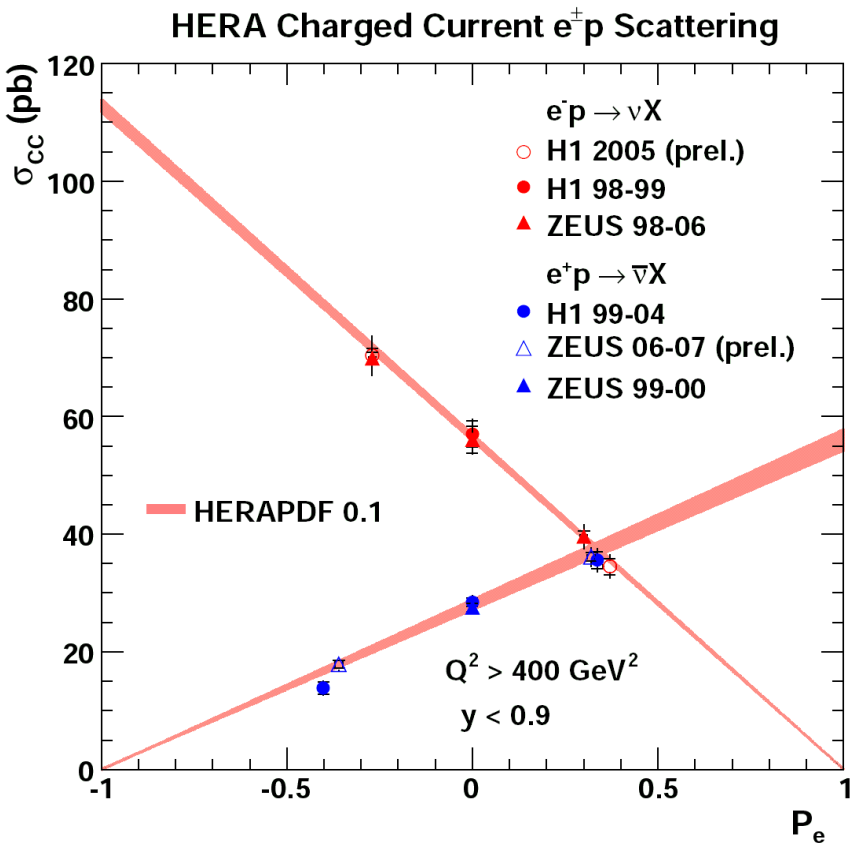
→ to be updated with all HERA II data

Charged currents at HERA



CC e^+/e^-: flavour sensitivity

SM weak interactions: only left-handed particles interact (right-handed currents forbidden)



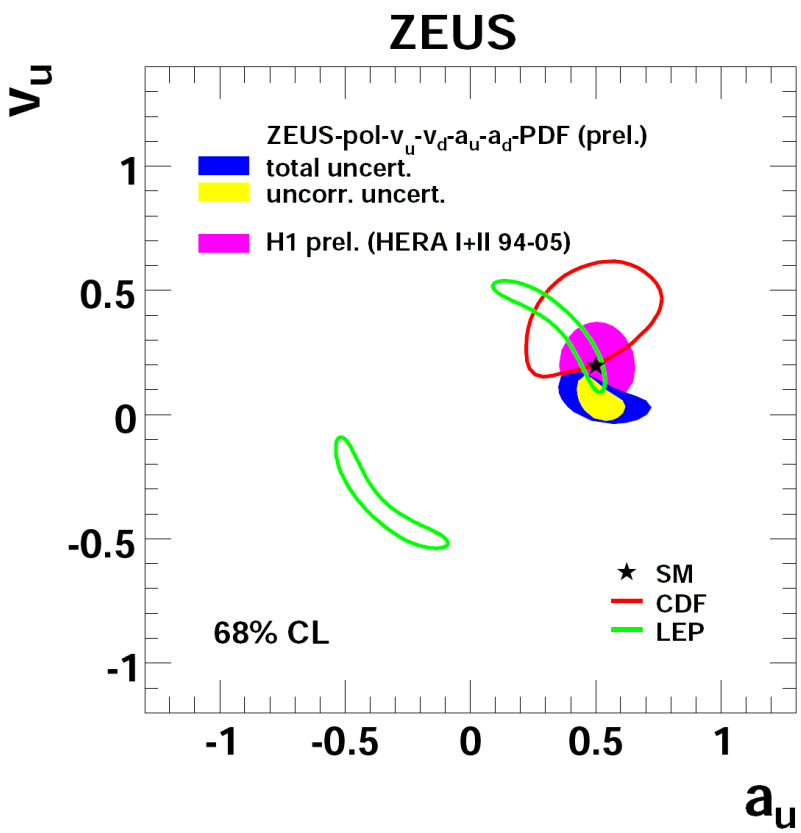
HERA results are consistent with SM

Combined QCD & EW fit

- weak couplings a_u,a_d,v_u,v_d of light quarks to Z boson can be extracted from DIS data with combined QCD-EW fit
  - γZ interference and Z exchange in neutral currents
  - charged currents for u-, d-quark separation

- preliminary results with part of polarised HERA II data bring additional sensitivity, especially on v_q

HERA results are competitive to LEP and Tevatron



Searches in inclusive DIS

Model-based searches:

- quark radius
- leptoquarks
- squarks in R-parity violating SUSY
- single top
- excited fermions
- magnetic monopoles

Search for new physics in rare excl. processes

Model-independent searches:

- isolated leptons with large missing P_T
- multi leptons at high P_T
- general search

Quark form factor

- Possible new interactions between e and q can modify DIS cross section at high Q^2 via virtual effects

- Fermion substructure can be detected measuring the spatial distribution of charge radius:

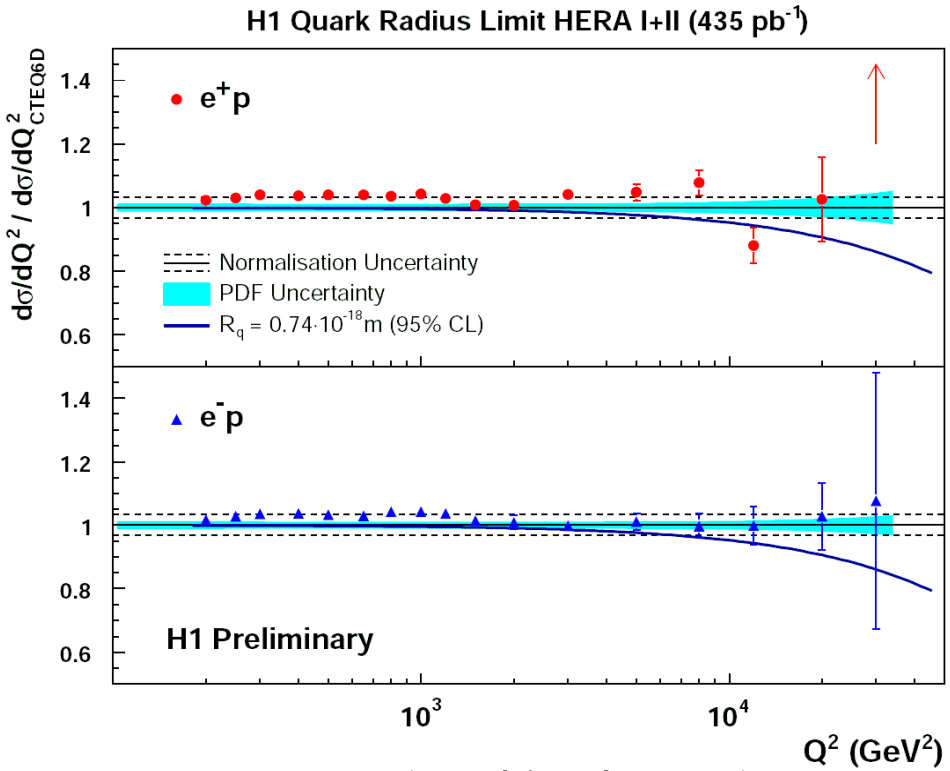
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2)$$

where $f(Q^2) = 1 - \frac{\langle r^2 \rangle}{6} Q^2$

- R is the root-mean-square radius of the electroweak charge of the e/q

- reduces SM cross section at high momentum transfer

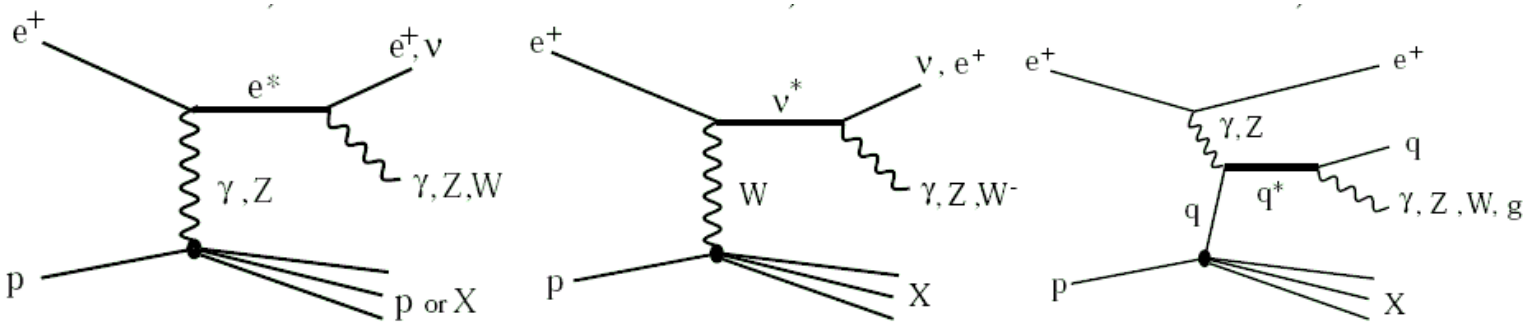
- assuming:
  $f_e = 1$, R_q can be constrained
  $f_e = f_q$, common limit on fermion sizes



ZEUS (combined 94-06):
$R_q < 0.62 \cdot 10^{-18}$ m
H1 (94-07, all HERA data):
$R_q < 0.74 \cdot 10^{-18}$ m

Excited states of first generation fermions

- Models with composite quarks and leptons can explain the three-family structure and mass hierarchy of fermions
  - these models predict existence of excited states of leptons and quarks



excited e* excited ν* excited q*

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda}\bar{F}^*_R\sigma^{\mu\nu}\left[g f\frac{\tau^a}{2}W^a_{\mu\nu} + g' f'\frac{Y}{2}B_{\mu\nu} + g_s f_s\frac{\lambda^a}{2}G^a_{\mu\nu}\right]F_L + h.c.$$

compositeness scale

couplings associated to SU(2)xU(1)xSU(3)

e*→ eγ, e*→ eZ, e*→ νW
ν*→ νγ, ν*→ νZ, ν*→ eW
q*→ qγ, q*→ qZ, q*→ qW

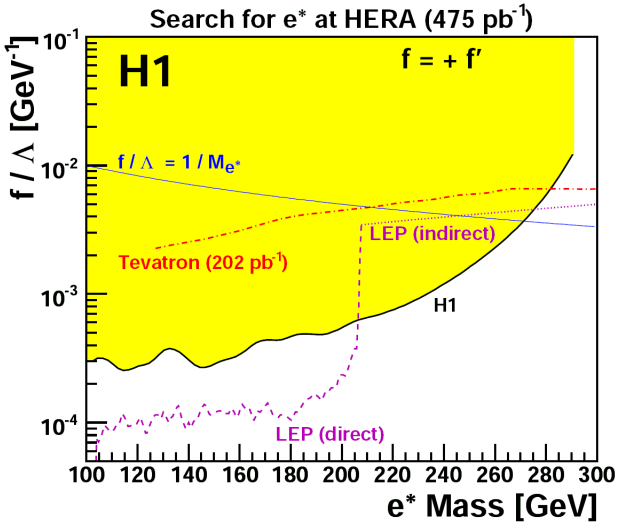
decay channels with hadronic and leptonic decays considered

→ H1: full HERA $e^{\pm}p$ data (~0.5 fb^{-1}) used for searches

Excited states of first generation fermions

→ no indication of signal found, mass exclusion limits on f/Λ derived
- shown for f=+f' (f=-f' also derived for ν*)

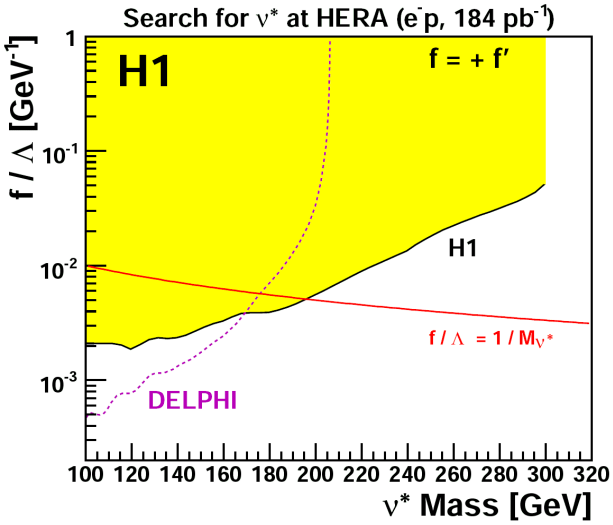
excited e*



for f=+f' and $f/\Lambda = 1/M_{e^*}$

M_{e^*} < 272 GeV excluded

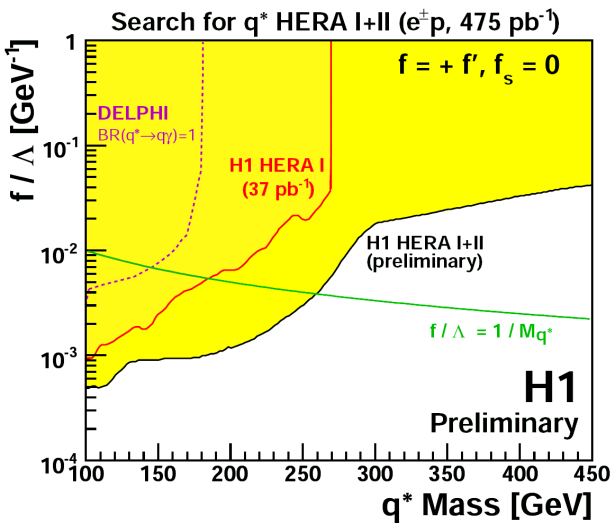
excited ν*



for f=+f' and $f/\Lambda = 1/M_{\nu^*}$

M_{ν^*} < 196 GeV excluded

excited q*



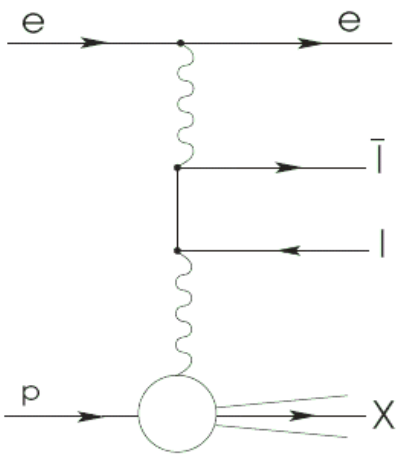
for f=+f', f_s=0, $f/\Lambda = 1/M_{q^*}$

M_{q^*} < 259 GeV excluded

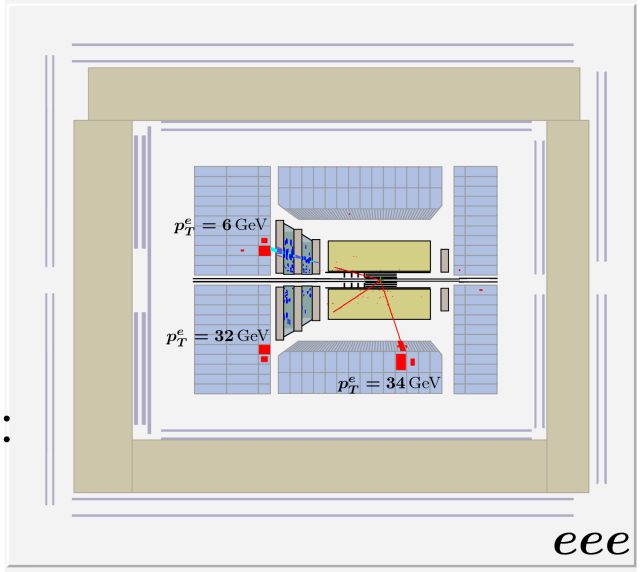
→ e*,ν* results are complementary to LEP and Tevatron,
q* results has better sensibility (at low M_{q^*})

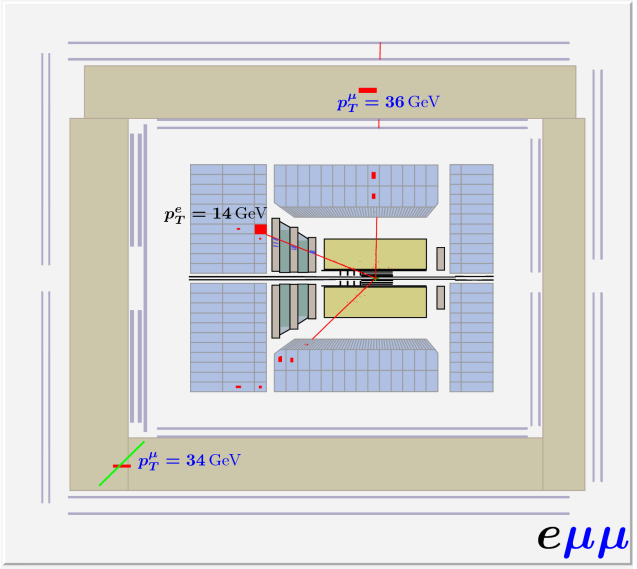
Events with multi leptons and high P_T

- in Standard Model events with multi leptons are produced in photon-photon interactions ($\gamma\gamma \to l^+l^-$)
  - at large invariant masses deviations from SM may indicate new physics



- considered final state topologies:
  ee, eee, eμ, μμ. eμμ
- full HERA data (~1 fb^{-1}) considered by H1 and ZEUS
- the combination of H1 and ZEUS multi-electron analyses is ongoing (next slide)



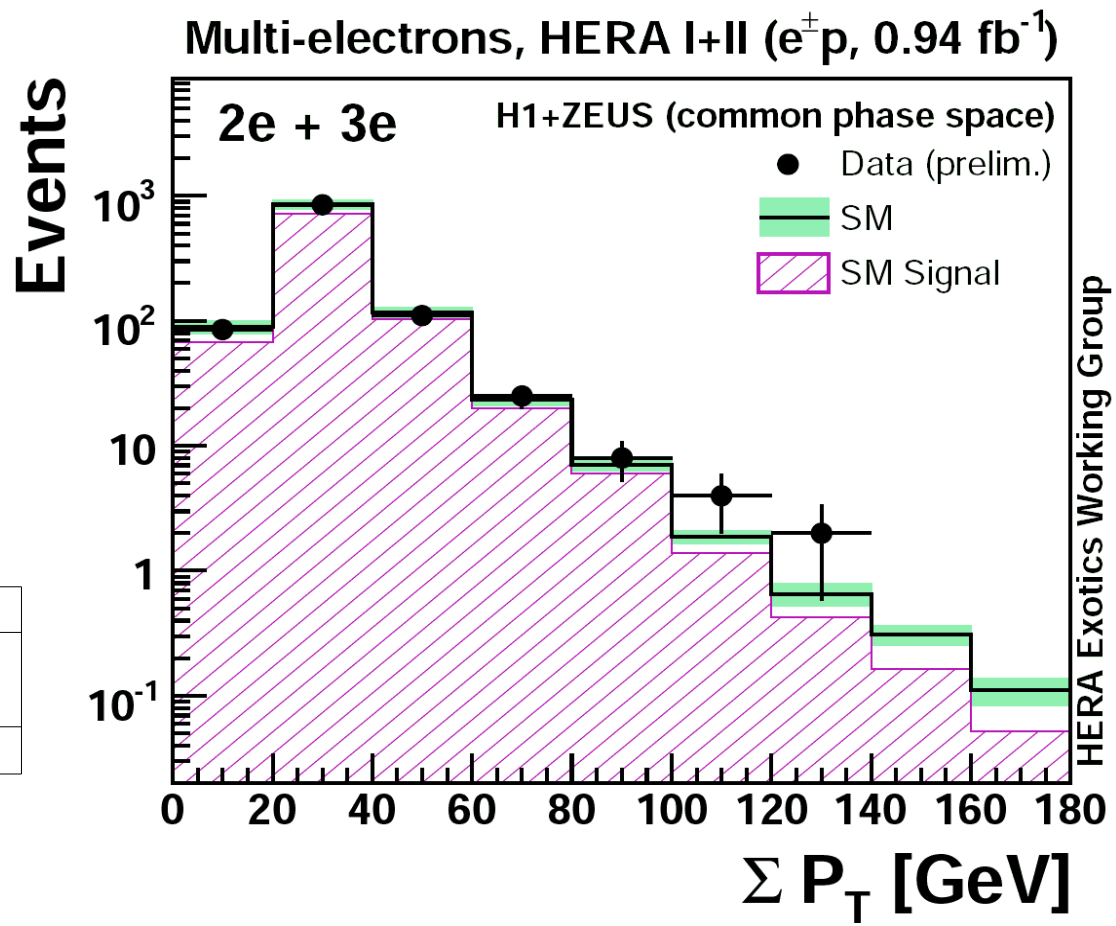


Events with multi leptons and high P_T

→ H1 and ZEUS combined results in the common phase space (~0.94 fb^{-1})

sensitivity to new physics – 'hardness' scale (ΣP_T)

in agreement with SM expectations



for ΣP_T>100 GeV:

	# 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

more events observed in e^+p

General Search

→ Model independent search for deviations from Standard Model predictions

→ full HERA $e^{\pm}p$ data (~0.5 fb^{-1}): final result by H1

27 different final states

final state configurations considered

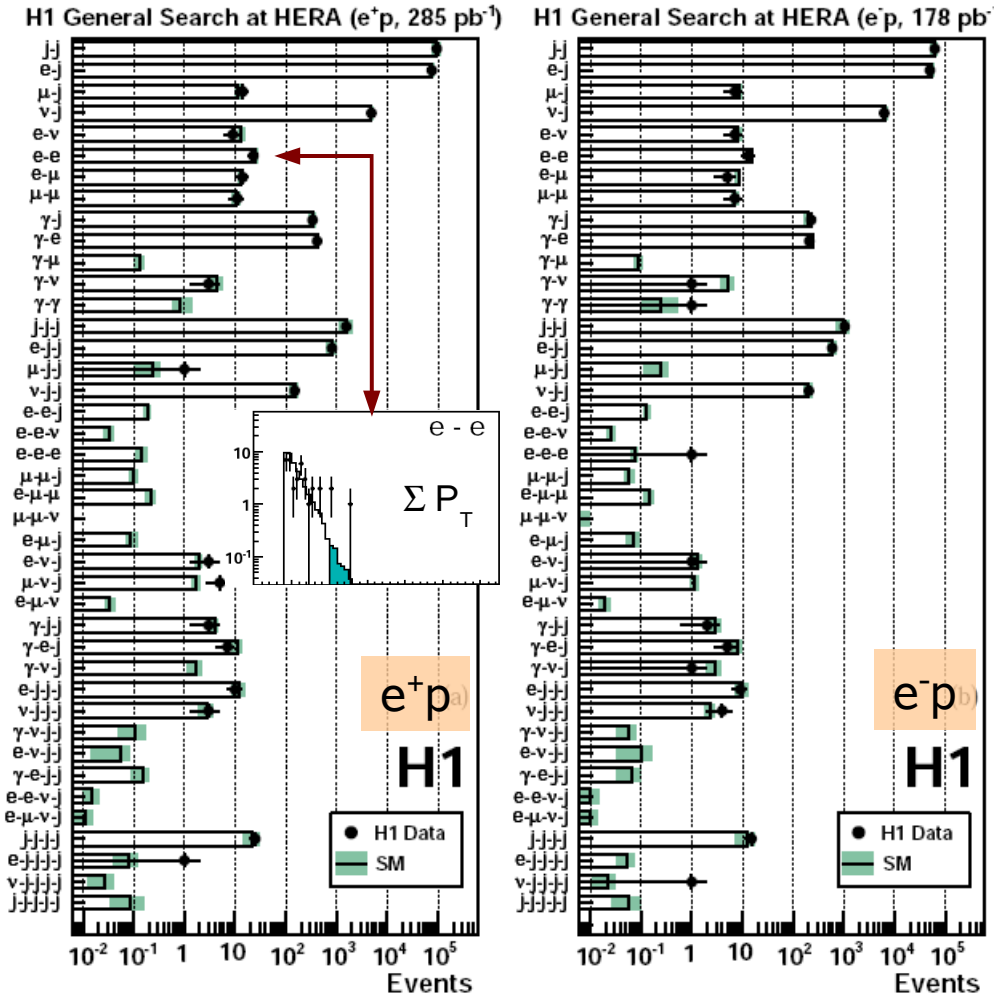
e, μ, jets (j), γ, ν

– at least 2 particles with P_T > 20 GeV

→ deviations searched in ΣP_T, M_{all} with dedicated algorithm

good agreement with SM

high P_T phenomena well understood at HERA



Summary

→ a result of successful HERA operation

~1 fb^{-1} of collected data by H1 and ZEUS experiments together

shown latest results of:

→ high precision measurements:

high Q^2 NC/CC cross sections, QCD+EW fits

→ physics beyond SM:

- quark charge radius, excited fermions, multi-leptons at high P_T and general search

- no large deviations from SM observed

→ not all HERA results covered in this presentation

→ combinations of H1 and ZEUS results are ongoing

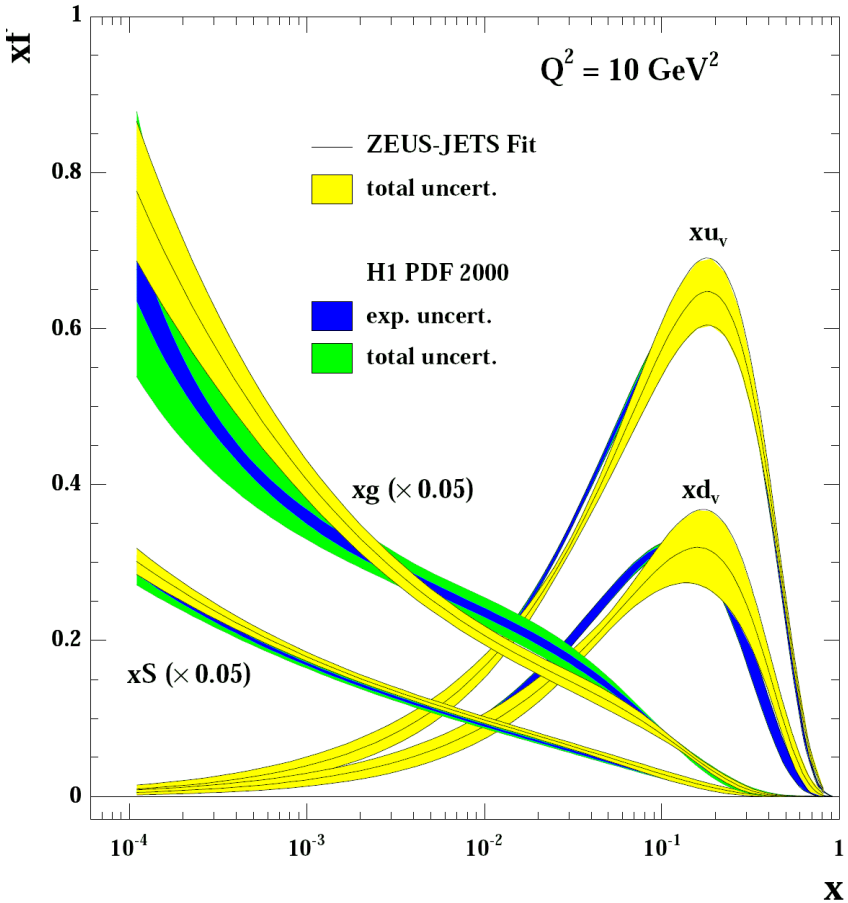
Backup slides

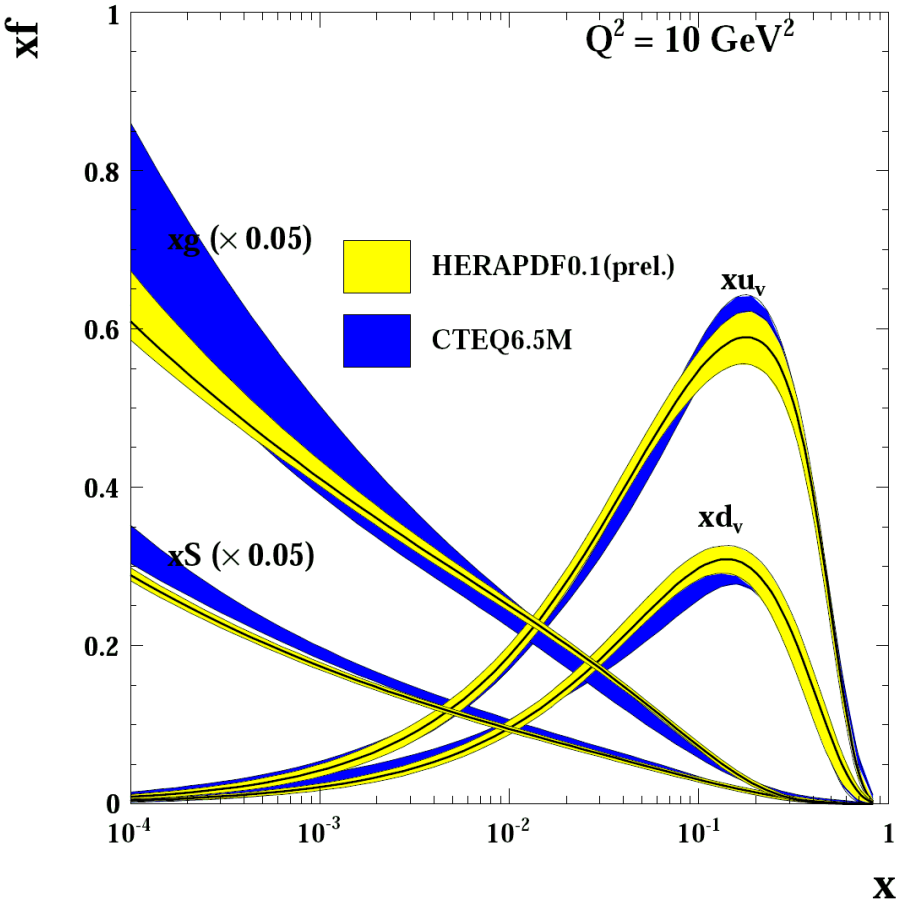
Common QCD fit on HERA combined data

- HERA data alone can be used for PDF fit **HERAPDF 0.1**
  low x $\rightarrow$ sea and gluon PDF
  high Q^2 $\rightarrow$ valence PDF

H1 prelim-08-045
ZEUS prelim-08-003

$\rightarrow$ impressive precision achieved
$\rightarrow$ important input for LHC





General contact interactions (CI)

- Possible new interactions between e and q can modify DIS cross section at high Q^2 via virtual effects
- Four fermion eeqq contact interactions
  → convenient method to investigate these interferences
- Effective Lagrangian for neutral current vector like contact interactions:

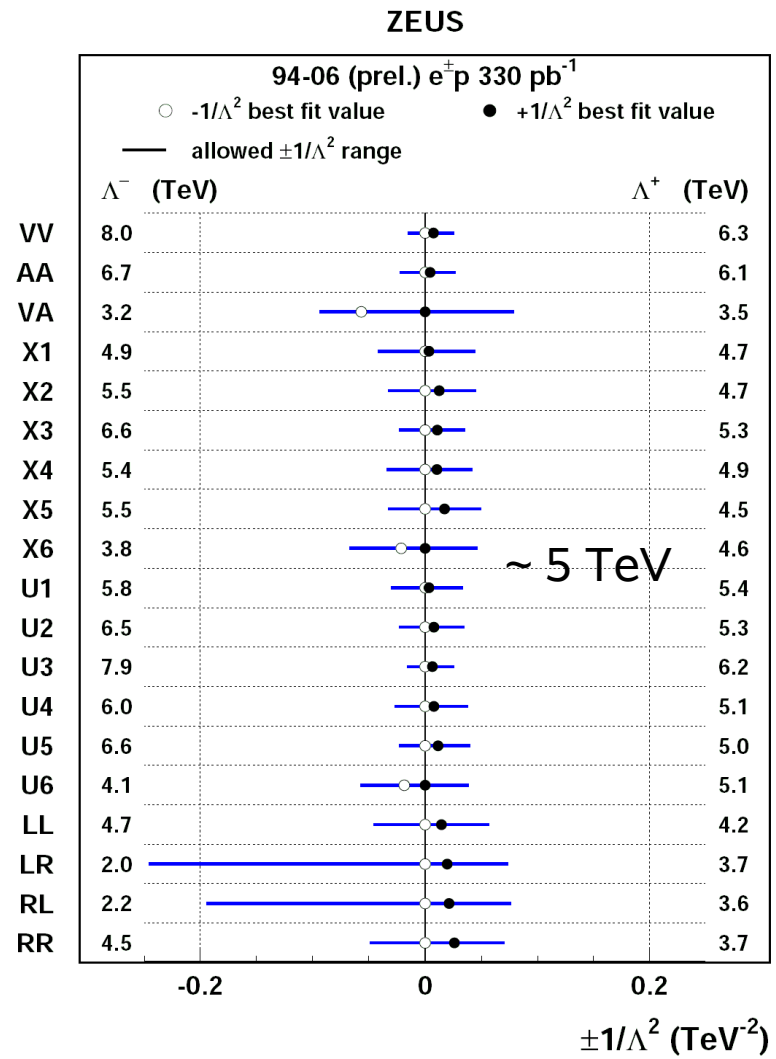
  (scalar and tensor CI are constrained beyond HERA sensitivity)

$$\mathcal{L}_{CI} = \sum_{\substack{i,j=L,R \\ q=u,d,s,c,b}} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

couplings: $\eta_{ij}^{eq} = \epsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2}$

Λ – compositeness scale

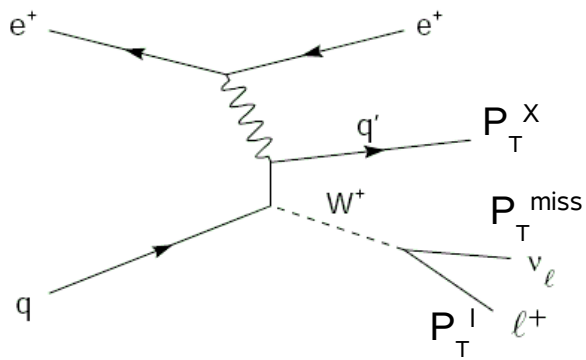
- Limits comparable with those derived at LEP and TEVATRON



Events with isolated leptons and missing P_T

- Rare topology events with high energy isolated lepton and missing transverse momentum may be a sign for new physics
  - in SM: real W production $ep \to eW^{\pm}X$ with leptonic decay $W^{\pm} \to l\,\nu_l$

example of W production:



→ previously an excess in e and μ has been reported by H1 collaboration (not observed by ZEUS)

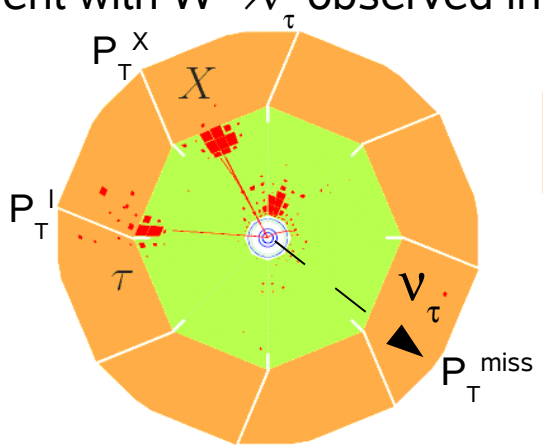
P_T^X (hadronic transverse momentum)>25 GeV

→ now full HERA statistics are exploited by both experiments (2 x 0.5 fb^{-1})

consistent with SM

→ the production cross section of W boson measured

event with $W \to \nu_\tau$ observed in H1:

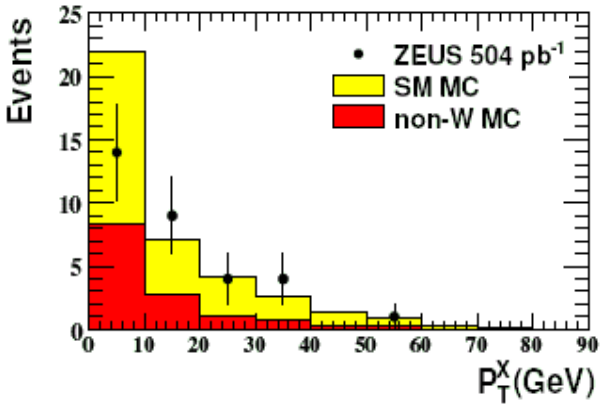


DESY-08-170
DESY-08-089

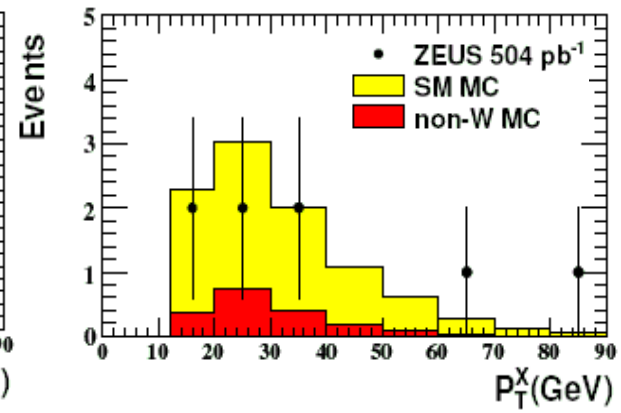
SM:	1.27±0.19 pb
H1:	$1.14 \pm 0.25_{stat} \pm 0.14_{syst}$ pb
ZEUS:	$0.89 \pm^{0.25}_{0.22\,stat} \pm 0.10_{syst}$ pb

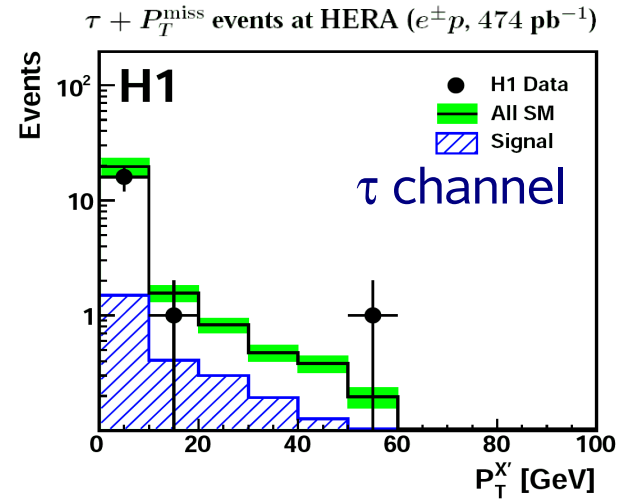
Events with isolated leptons and missing P_T

e channel



μ channel

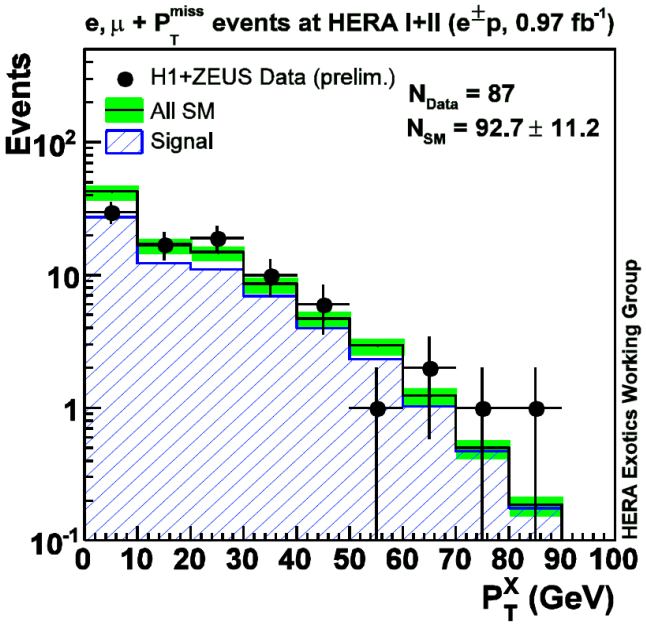




DESY-08-170
ZEUS pub-08-005

H1 e,μ +P_t^{miss}: 2.4σ excess of events in e^+p
not confirmed by ZEUS

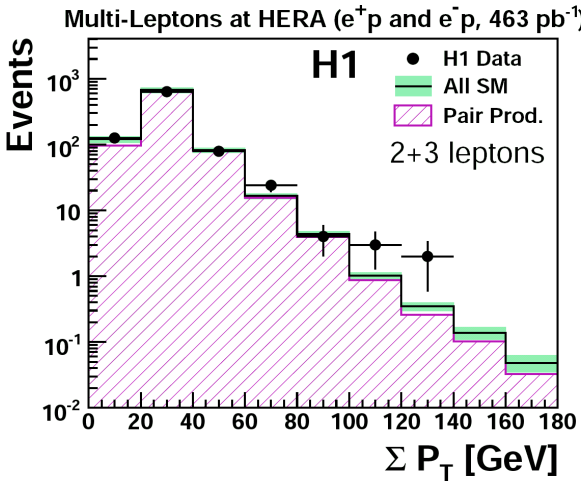
combinations of H1 and ZEUS results are ongoing



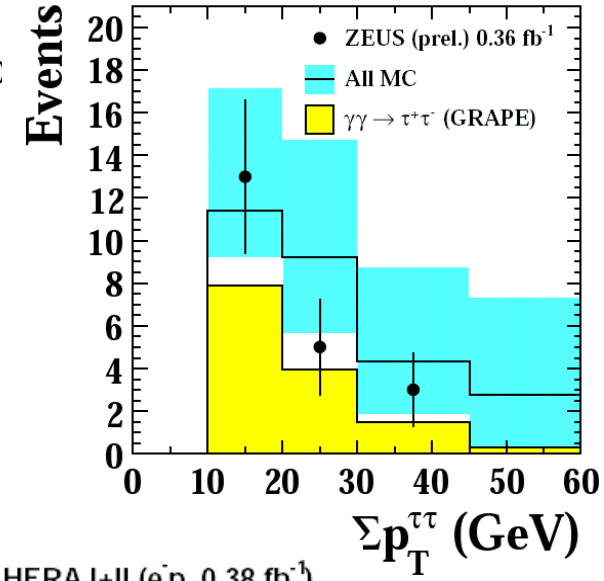
Events with multi leptons and high P_T

sensitivity to new physics – 'hardness' scale (ΣP_T)

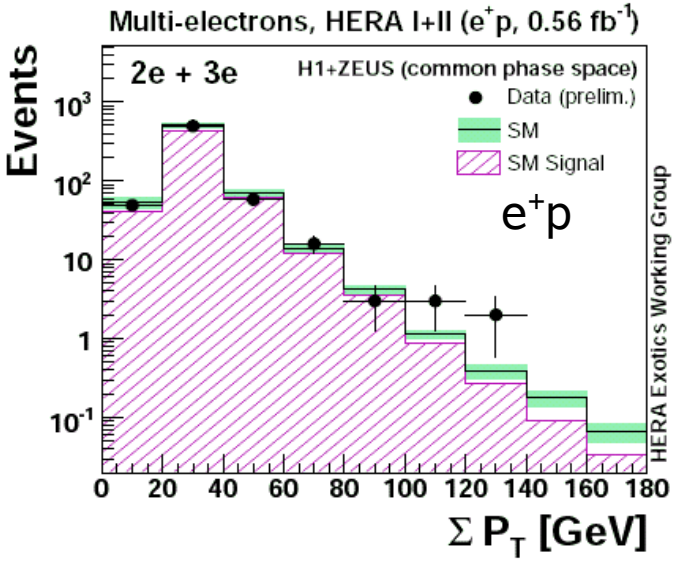
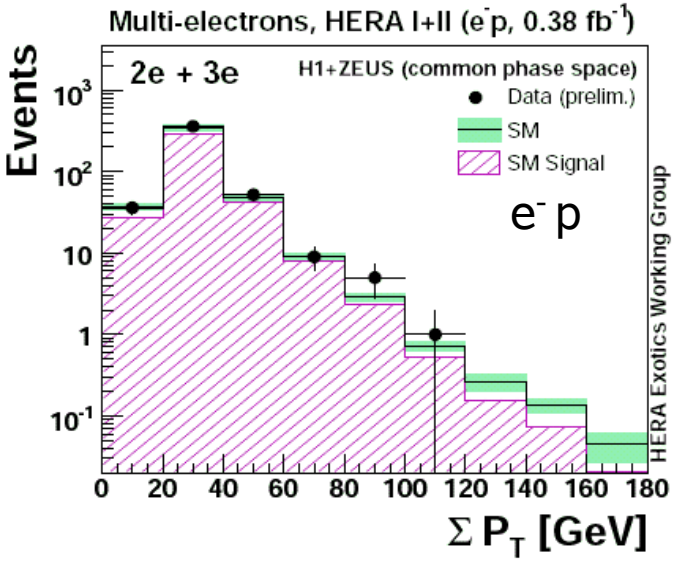
in agreement with SM expectations



latest ZEUS (HERAII) results



for ΣP_T>100 GeV (0.94 fb^{-1}):

data = 6 (5 in e^+p)

SM = 3.00±0.34 (1.82 in e^+p)