Electroweak physics at HERA

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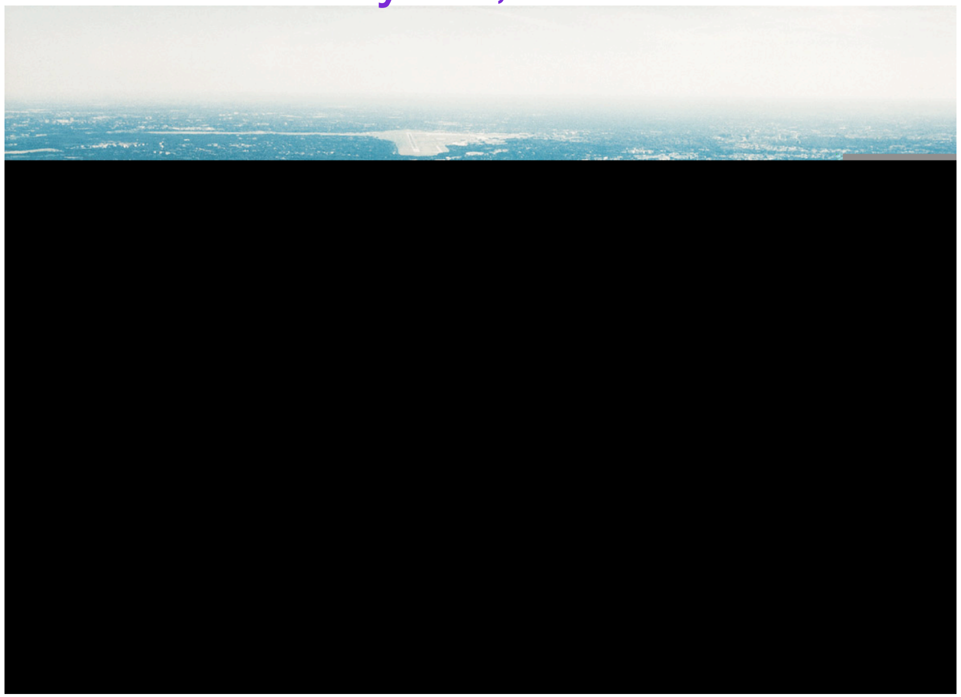
on behalf of the ZEUS and H1 collaborations
July 18, 2010



HERA ep collider (1992-2007)

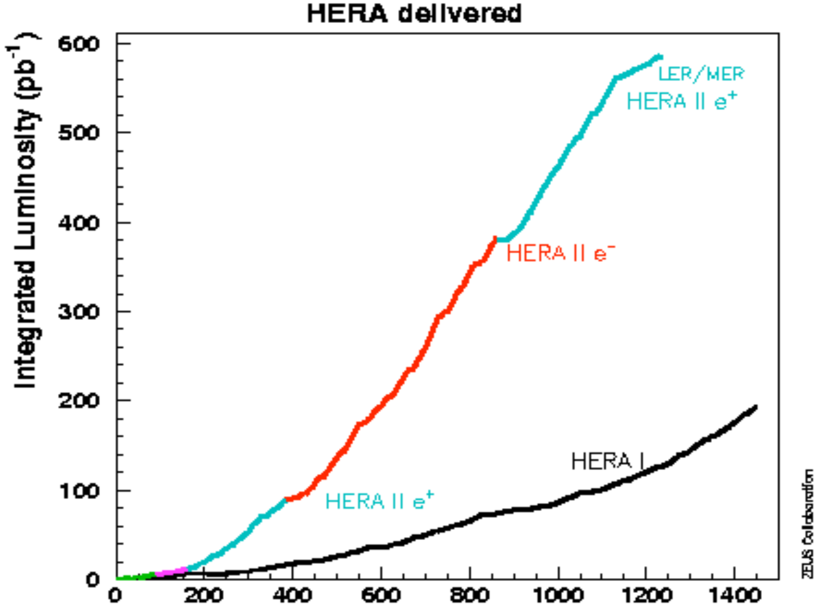
- $E_{e\pm}$ = 27.5 GeV
- 1992-2000 (HERA I) E_p = 820,920 GeV
- 2003-2007 (HERA II) E_p = 920 GeV $\sqrt{s} = 318\,GeV$

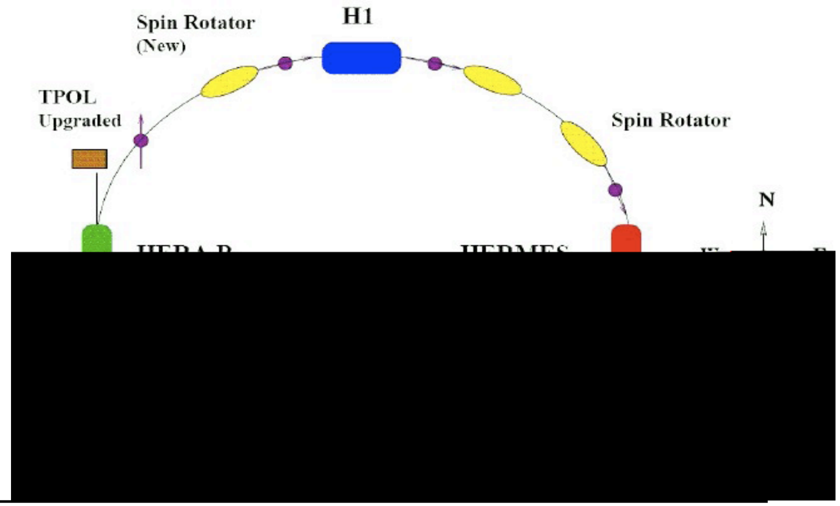
  - Increased luminosity
  - Longitudinal polarization of lepton beam

$$P_e = \frac{N_{RH} - N_{LH}}{N_{RH} + N_{LH}} \sim 30 - 40\%$$

- For colliding beam experiments:
  two large multipurpose detectors H1 and ZEUS

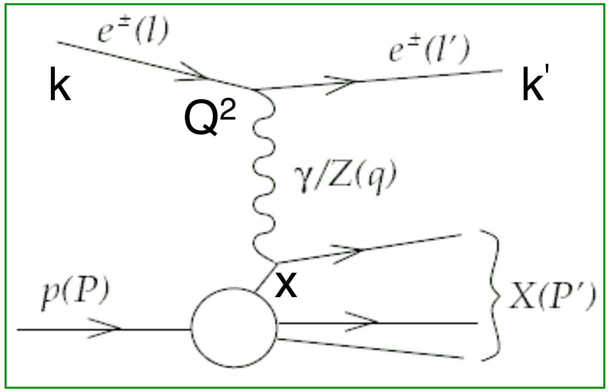
- ~0.5 fb^{-1} recorded luminosity for each experiment





Deep Inelastic Scattering (DIS)

Neutral Current (NC)

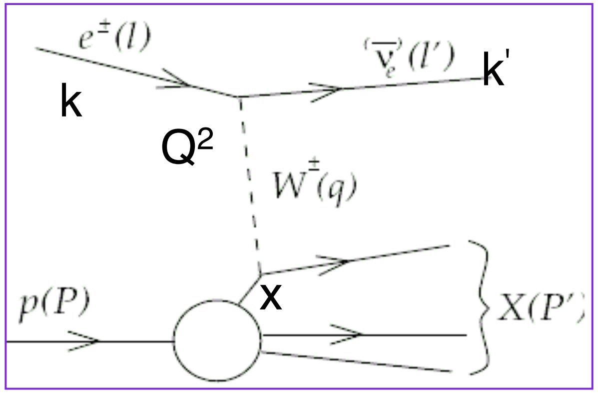


Boson virtuality

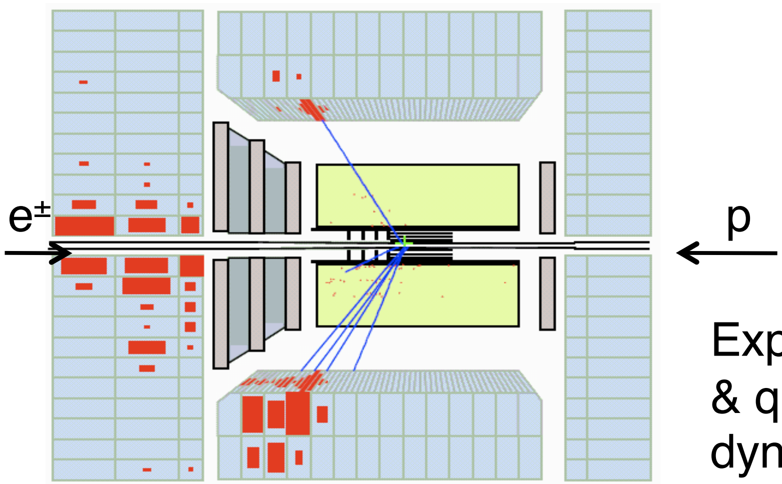
Bjorken x

inelasticity

Charged Current (CC)

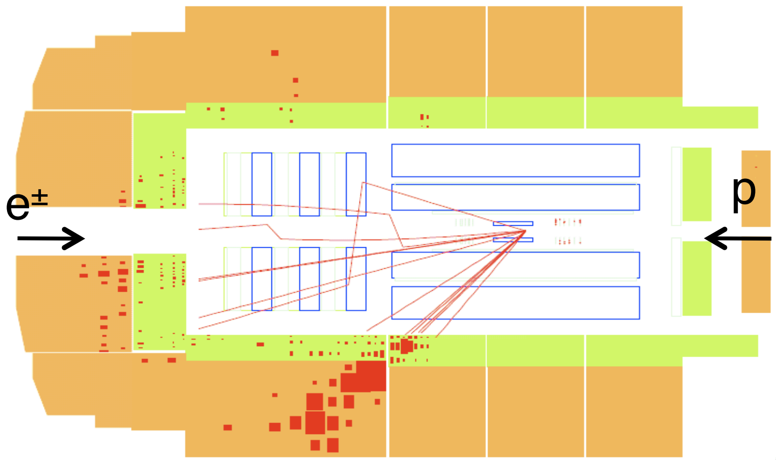


ZEUS



Explore proton structure
& quark-gluon interaction
dynamics

H1



NC cross section

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

dominant contribution

important at high Q^2

sizeable at high y

in QPM $\tilde{F}_L^{\pm} = 0$

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

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

generalized structure functions:

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

[redacted]

Polarization dependence due to γZ interference and Z terms with opposite signs for positron and electron

$$\left[F_2^{\gamma}, F_2^{\gamma Z}, F_2^Z\right] = \sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right] x(q + \bar{q})$$

F_2 functions are related to the sum of quark and anti-quarks

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = \sum_q \left[e_q a_q, v_q a_q\right] 2x(q - \bar{q})$$

xF_3 functions are related to difference bet. quark and anti-quarks
→ sensitivity to valence quarks

CC cross section

$$\frac{d^2\sigma^{CC}(e^{\pm}p)}{dx\,dQ^2} = (1 \pm P_e)\frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \tilde{\sigma}_{CC}^{e^{\pm}p}$$

CC reduced cross section

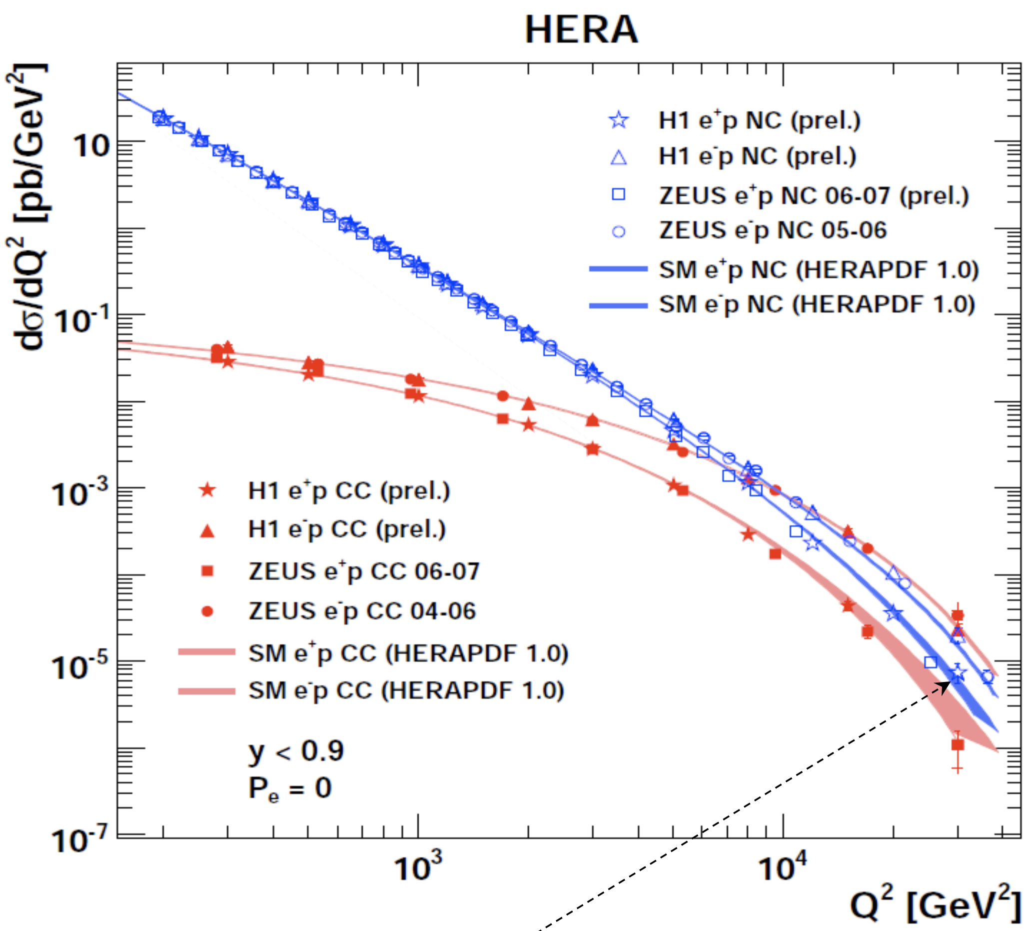
e^+/e^- sensitive to different quark densities:

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

in L.O:

CC gives sensitivity to different combinations of quarks as NC.

Electroweak unification



difference in e⁺ and e⁻ for NC in high Q² region comes from contribution of Z exchange

NC: $\frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$

CC: $\frac{d\sigma}{dQ^2} \sim \frac{1}{(Q^2 + M_W^2)^2}$

EW component of SM:
NC and CC cross sections become similar at $Q^2 \approx M_Z^2, M_W^2$

Data compared with with SM (HERAPDF 1.0) → described later

Good agreement over full range

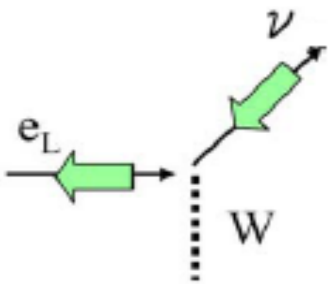
Total CC cross sections for e^+p & e^-p as function of polarization

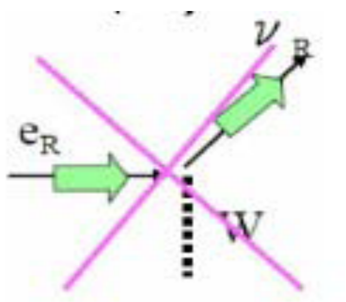
Linear dependence of σ^{CC} on P_e

$$\sigma^{CC}(e^{\pm}p) = (1 \pm P_e)\sigma^{CC}_{P_e=0}(e^{\pm}p)$$

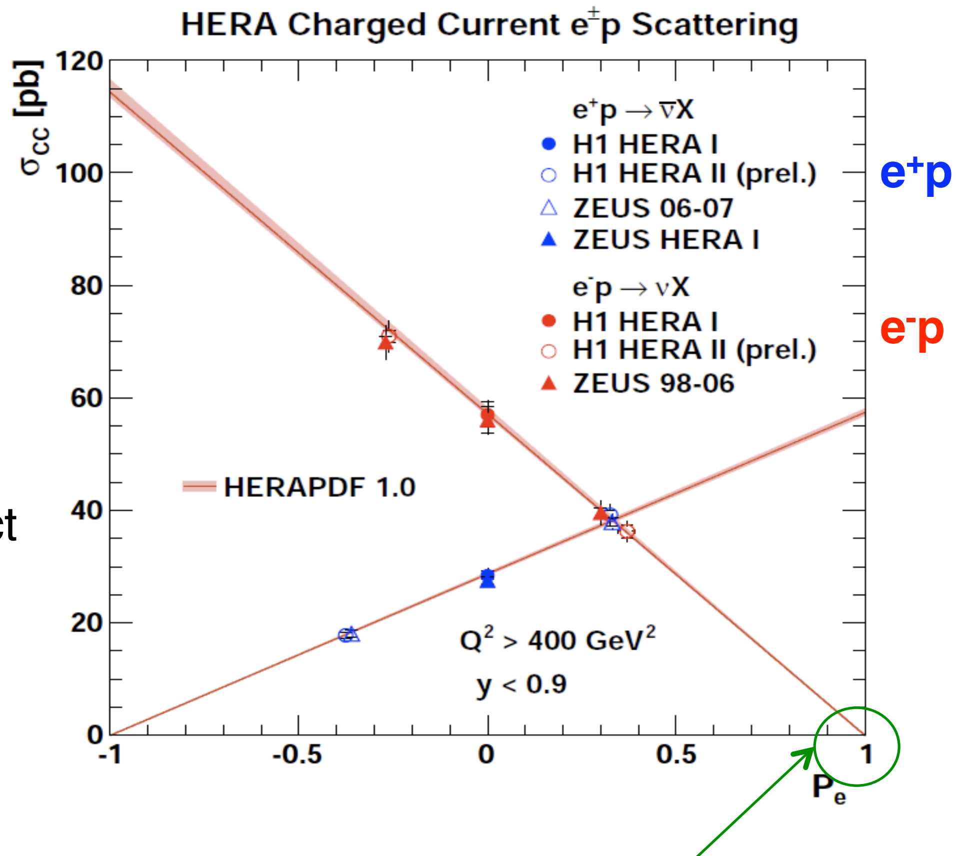
$$P_e = \frac{N_{RH} - N_{LH}}{N_{RH} + N_{LH}}$$

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





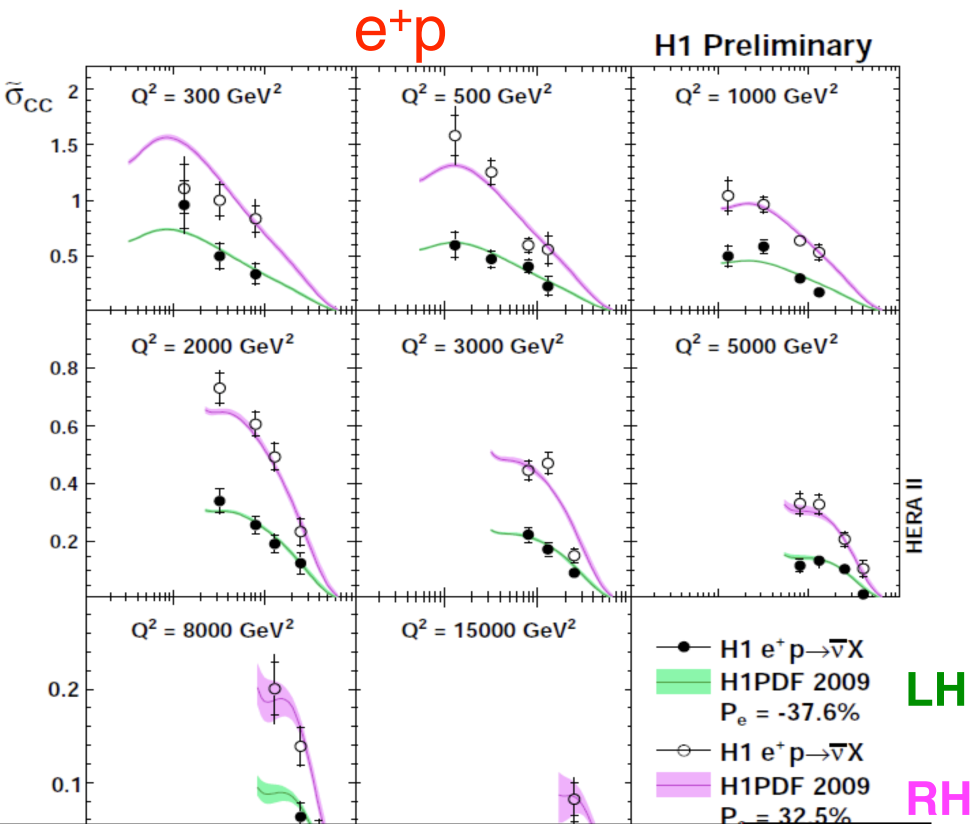
ZEUS and H1 in agreement with SM



Absence of right-handed weak current in SM

Polarized CC reduced cross section measurements

double differential CC reduced cross sections as a function of x in Q^2 bins



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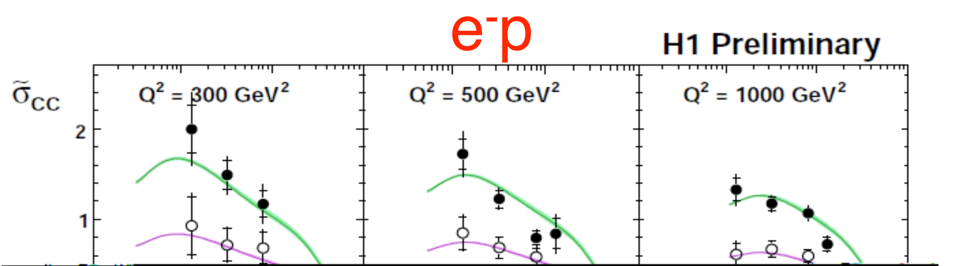


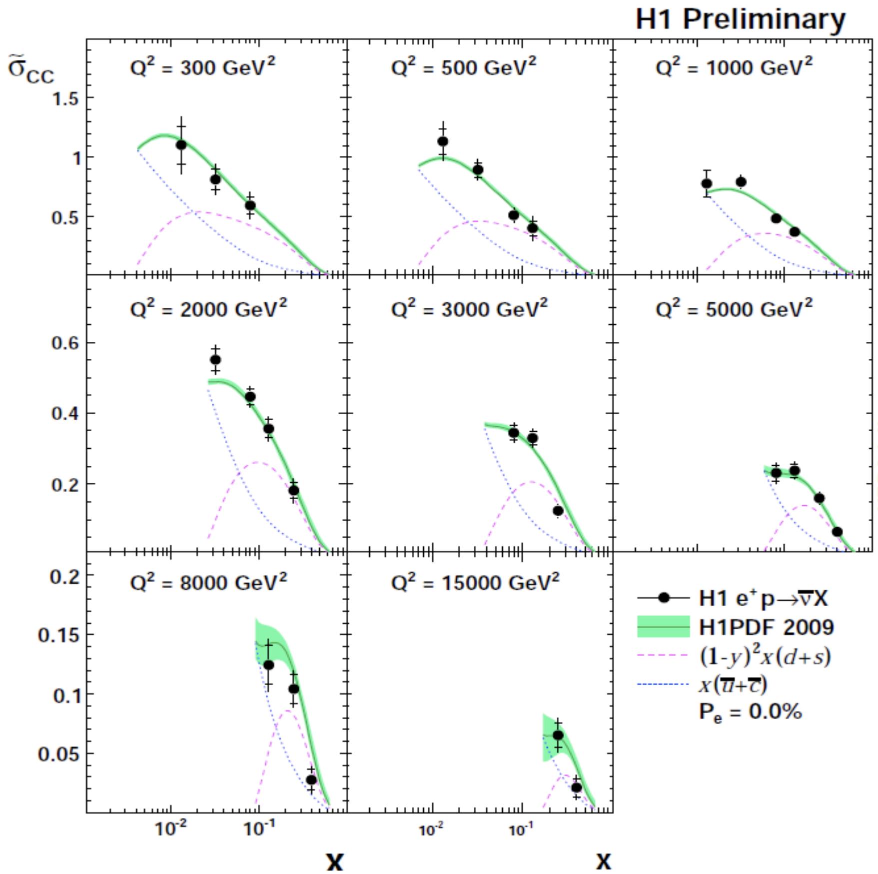
[redacted]

Data points shown sep. for + and - polarizations

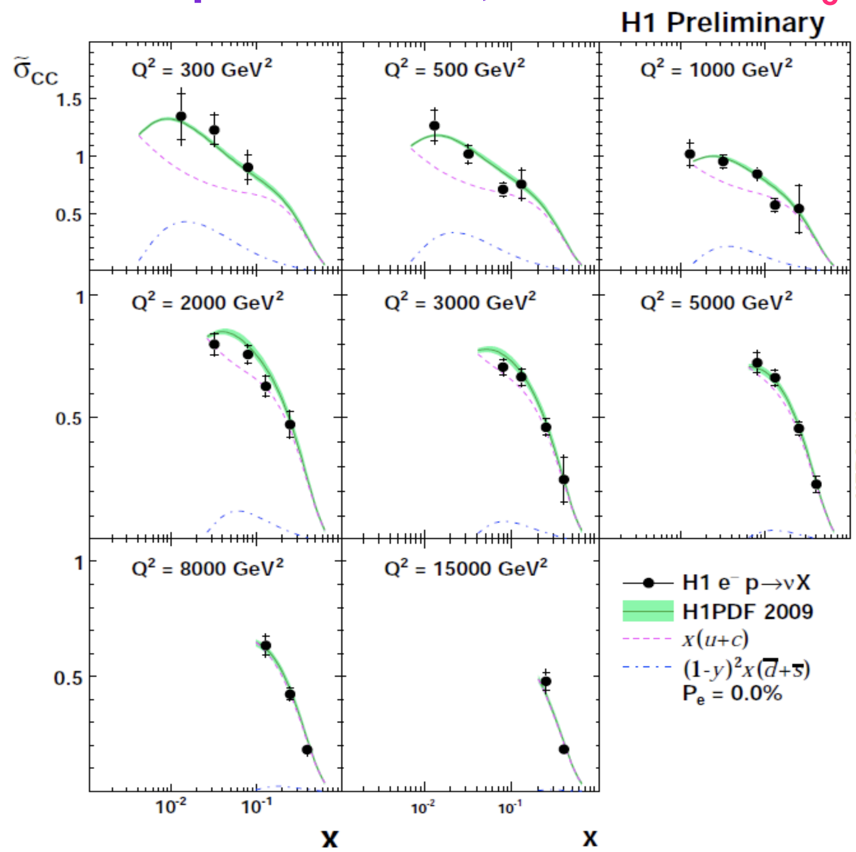
Predictions of SM give good description of data

CC reduced cross section measurements

Data points shown for entire data set (both + and – polarizations, corrected to P_e=0)



e^+p



e^-p

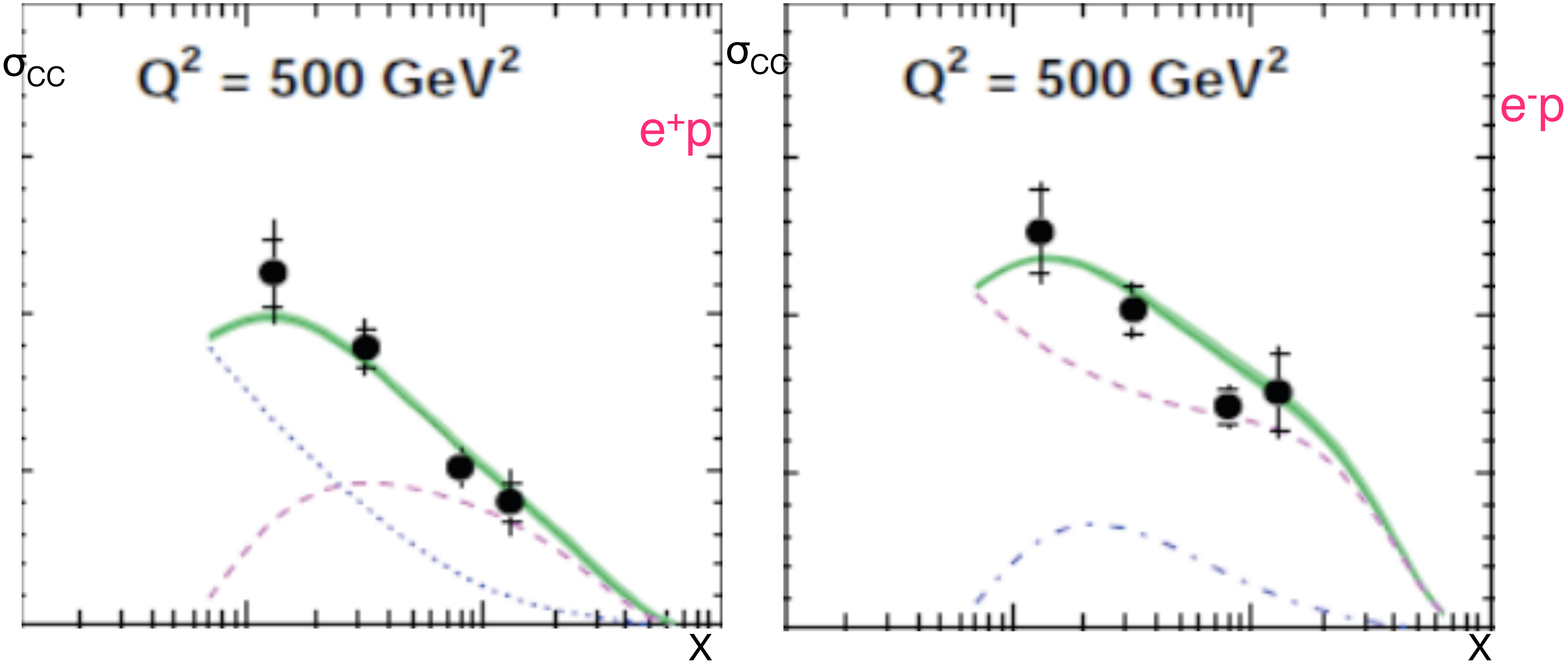
$(1-y)^2x(d+s)$ $\quad x(\bar{u}+\bar{c})$ $\quad (1-y)^2x(\bar{d}+\bar{s})$ $\quad x(u+c)$

Blue and magenta dashed lines show the contributions of the PDF combinations

Sensitivity to different combinations of quarks than in NC

CC reduced cross section measurements

Data points shown for entire data set (both + and – polarizations, corrected to P_e=0)

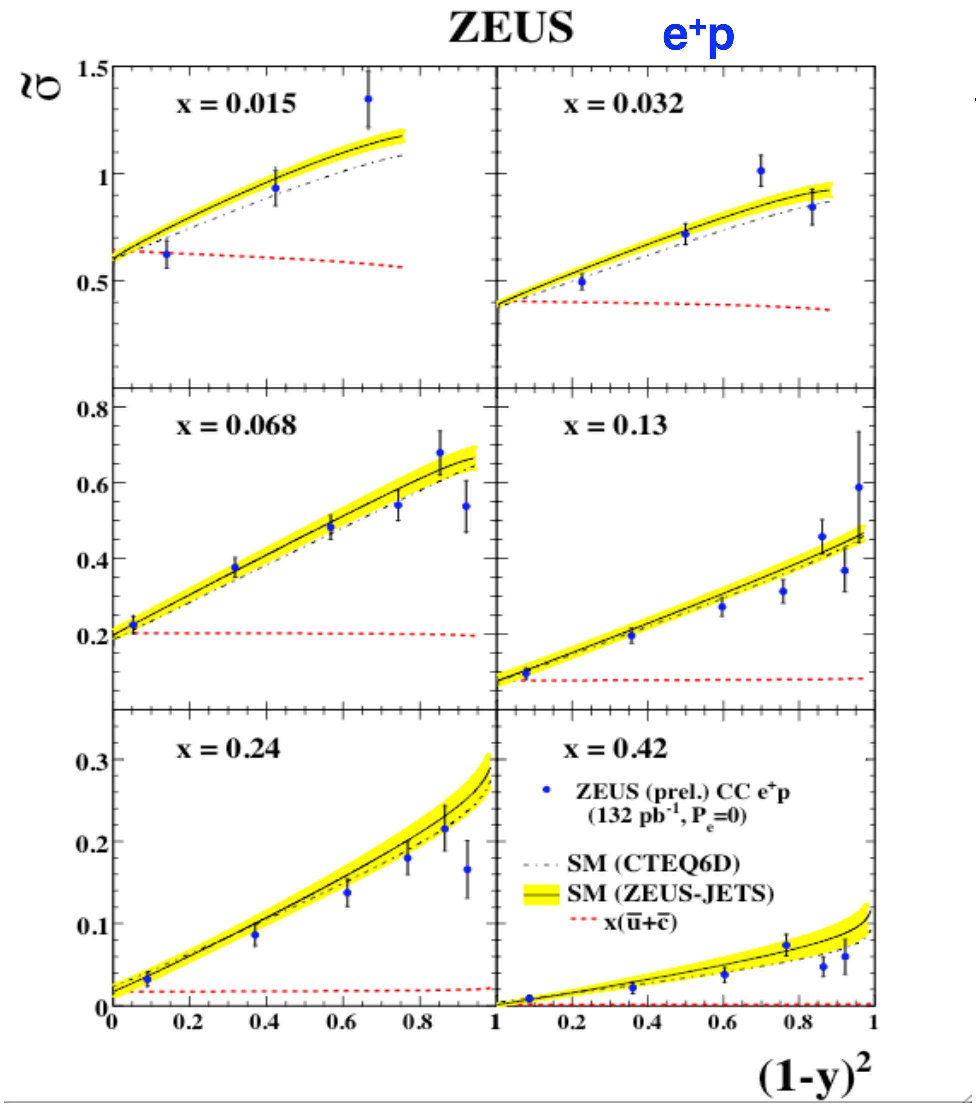


$(1-y)^2 x(d+s)$ $x(\bar{u}+\bar{c})$ $(1-y)^2 x(\bar{d}+\bar{s})$ $x(u+c)$

Blue and magenta dashed lines show the contributions of the PDF combinations

Sensitivity to different combinations of quarks than in NC

Unpolarized CC measurements



→ different way to look at sensitivity to these diff. quark species

Unpolarized reduced CC e^+p cross section in bins of x as a function of $(1-y)^2$
→ Helicity structure of CC

At leading order in QCD:

intercept

slope

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

Data are well described by SM calculations

- ZEUS-JETS fit
- global fits CTEQ6

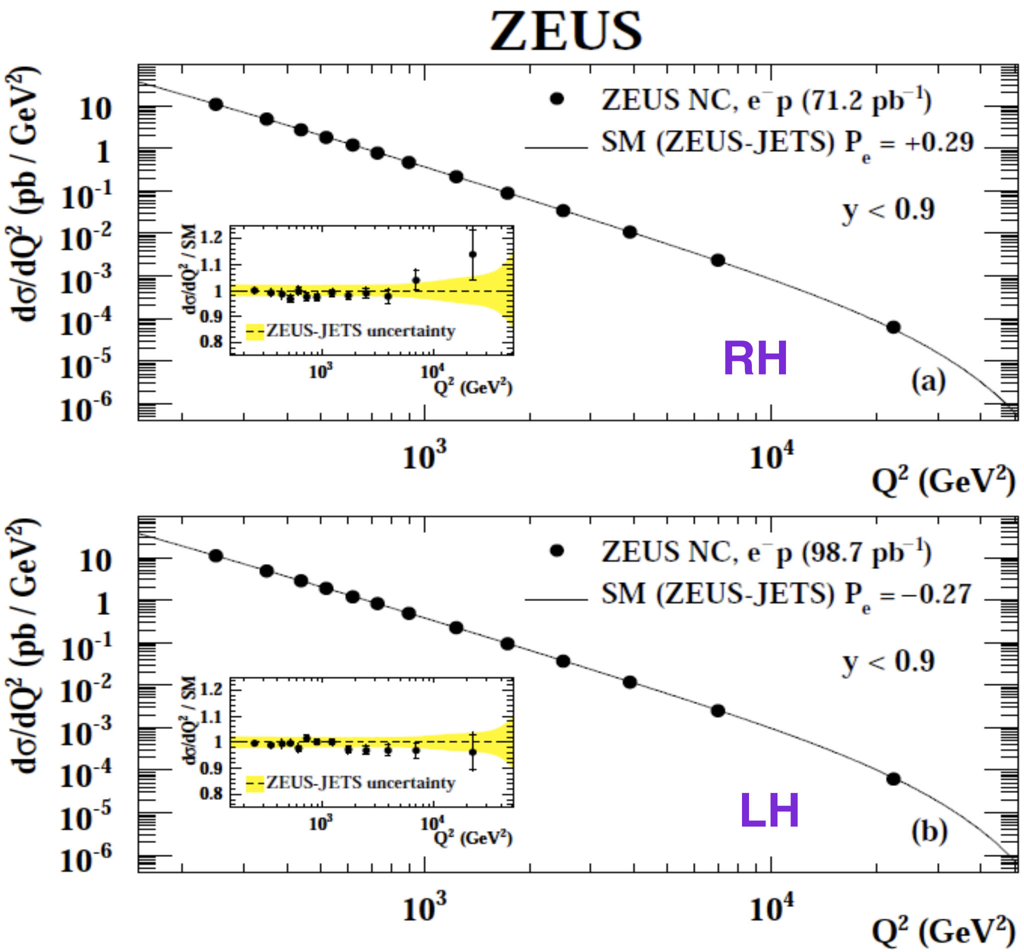
Polarized NC measurements

Single differential cross sections vs. Q^2 for polarized e^-p

Data well described by SM

Sensitivity to polarization asymmetries

→ compare these directly (next slide)

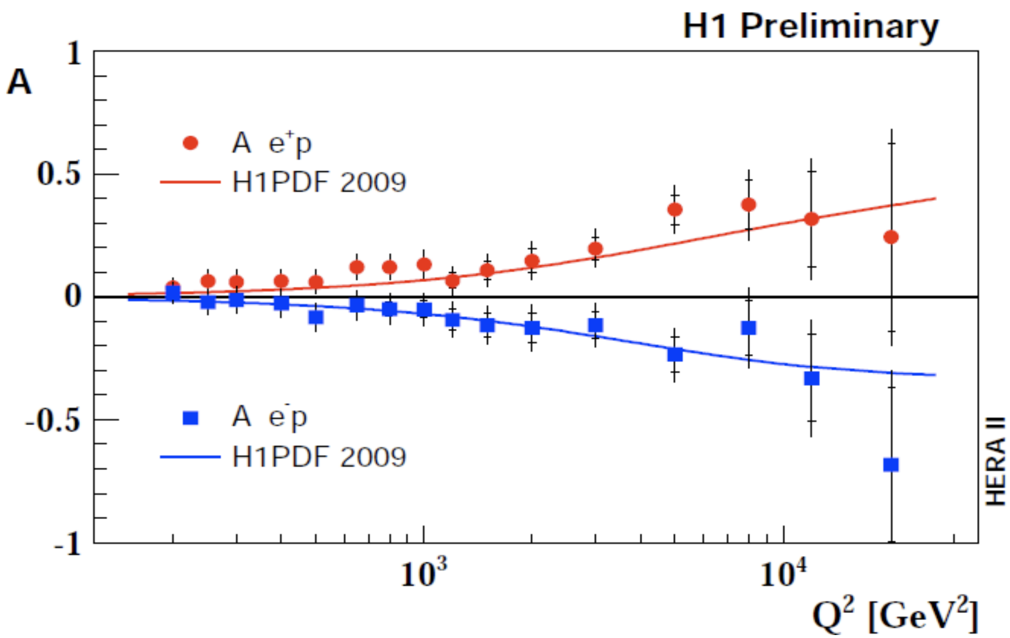


Polarized NC measurements Asymmetry

The charge dependent polarization asymmetries in neutral currents
→ direct measure of EW effects

Polarization asymmetries (A) sensitive to ratio of γZ interference term to F_2
A is proportional to $a_e v_q$ combination

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



HERA II data

low Q^2→ contribution from Z negligible
cross sections overlap
high Q^2→ Z becomes important, A increases

Data well described by SM

recall: neglecting Z term,
generalized structure function F_2 is expressed:

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

At LO: $F_2^{\gamma Z} = x \sum_q 2 e_q v_q (q + \bar{q})$

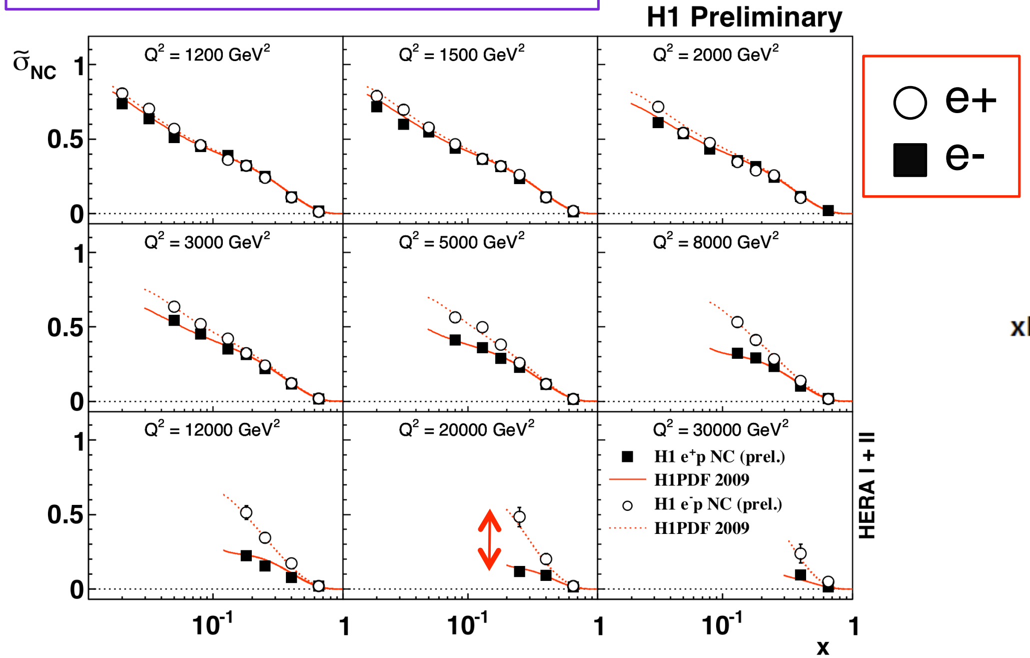
xF_3 measurements in NC

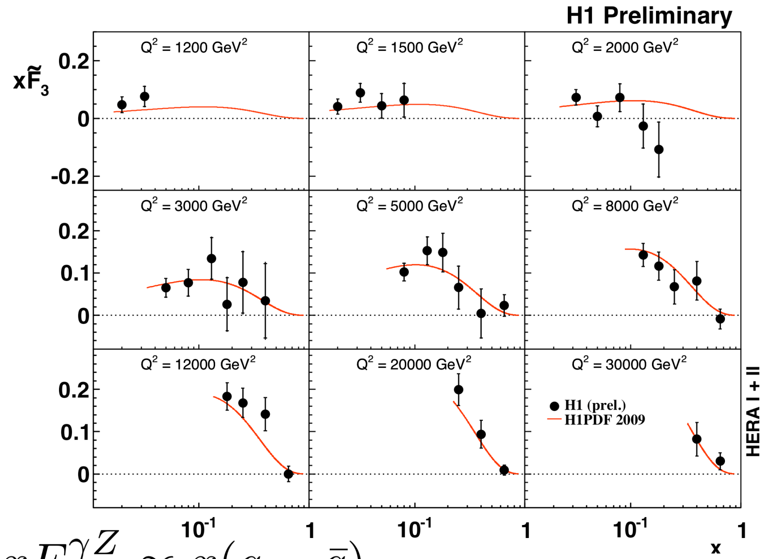
recall: NC cross section:

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{NC}(e^{\pm}p)}{dxdQ^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} = \tilde{F}_2 \mp \frac{Y_-}{Y_+}x\tilde{F}_3 - \frac{y^2}{Y_+}\tilde{F}_L$$

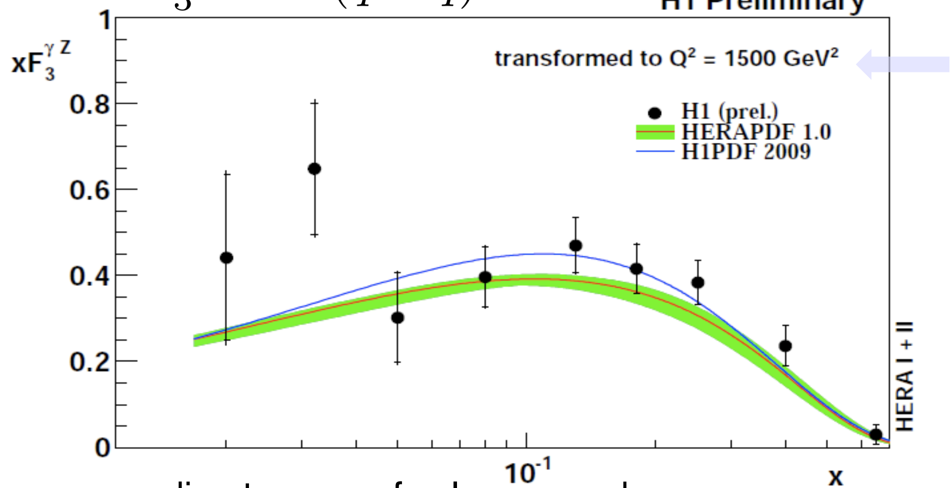
$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left[\tilde{\sigma}^- - \tilde{\sigma}^+\right]$$

comparing reduced xsec for e- and e+ can extract xF_3





$$xF_3^{\gamma Z} \propto x(q - \bar{q})$$



direct meas. of valence quarks

dominant contribution to xF_3: $xF_3^{\gamma Z} \simeq x\tilde{F}_3 \frac{(Q^2 + M_Z^2)}{\alpha^2 \kappa Q^2}$

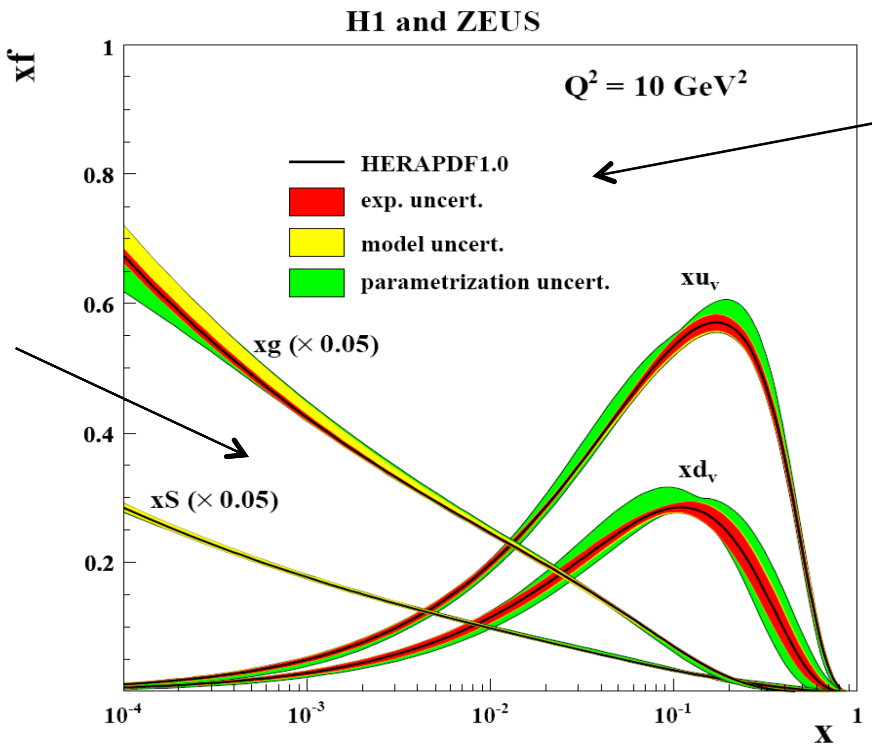
HERAPDF 1.0 fit

Seen several ways that HERA is sensitive to pdfs.

to extract best knowledge of PDFs: QCD fit using all of H1 + ZEUS combined data from HERA 1

→New set of parton distributions HERAPDF1.0

Parton distributions unfolded in NLO QCD fit using the HERA $e^{\pm}p$ data only



Experimental, model, and parameterization uncertainties are shown separately

Gluon and sea distributions scaled down by a factor of 20

Using all HERA I data →
- improved precision, especially for the gluon distribution
- compatible with global fits

For the QCD fits with the aim of the extraction of the PDFs, the quark coupling was fixed to SM values

can also do a fit where couplings are constrained from data → next slide

JHEP 1001:109,2010 / arXiv:0911.0884 [hep-ex]

Combined QCD + EW fit results

Simultaneous EW+PDF analysis of NC and CC data

Now have precise enough data
→ can precisely fit the axial and vector coupling to u and d quarks

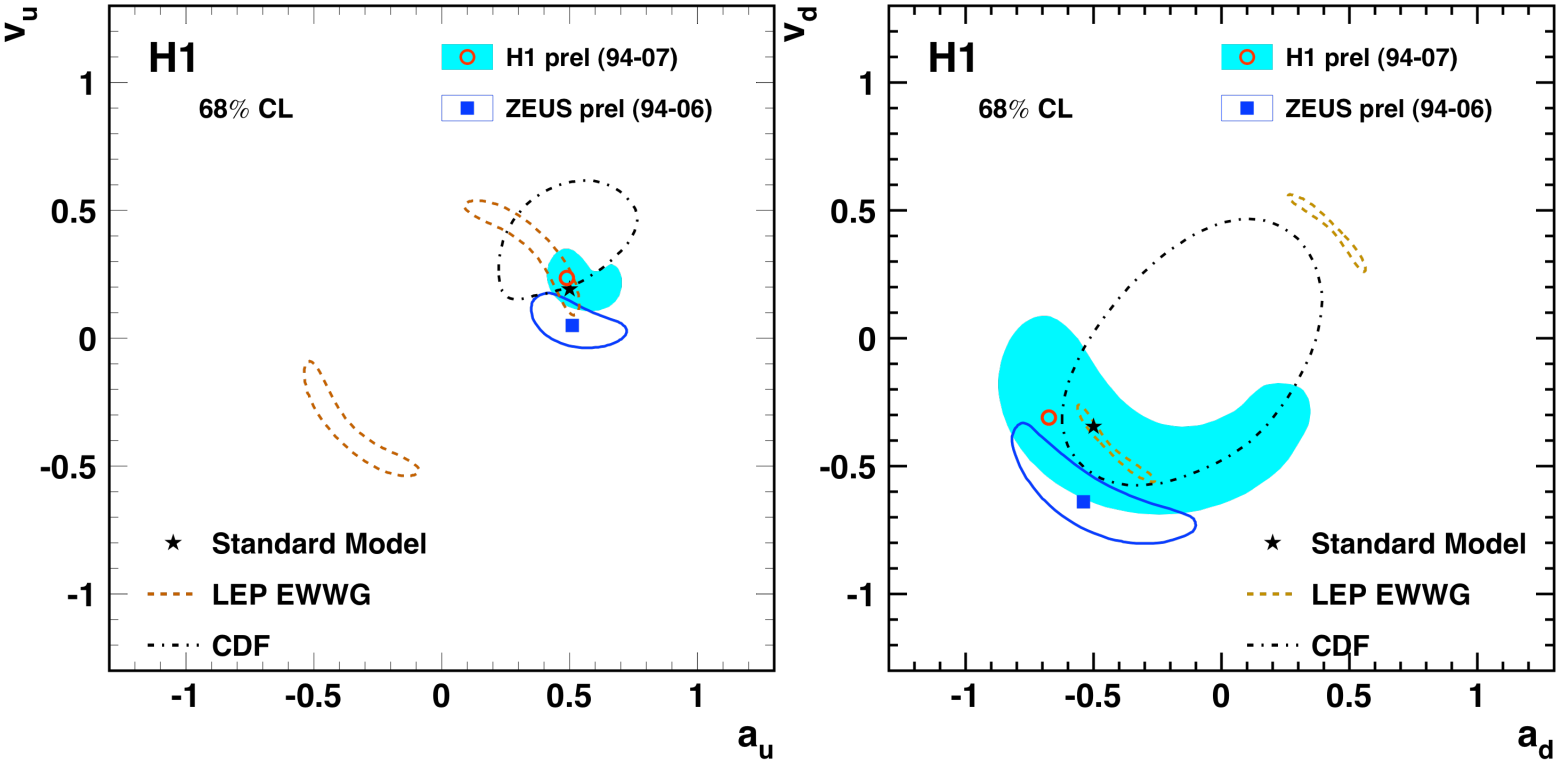
allowed parameter space:

combined HERA I & II

previous pub. HERA I

u-quark

d-quark



LEP

CDF

precision at HERA can solve ambiguity in LEP fit

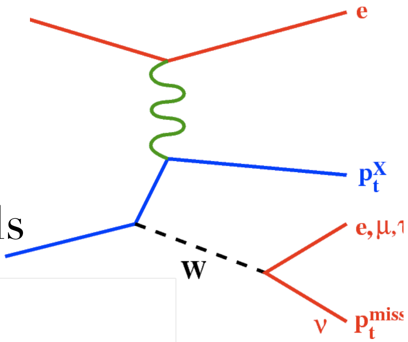
HERA II improves precision, esp. for u-quark

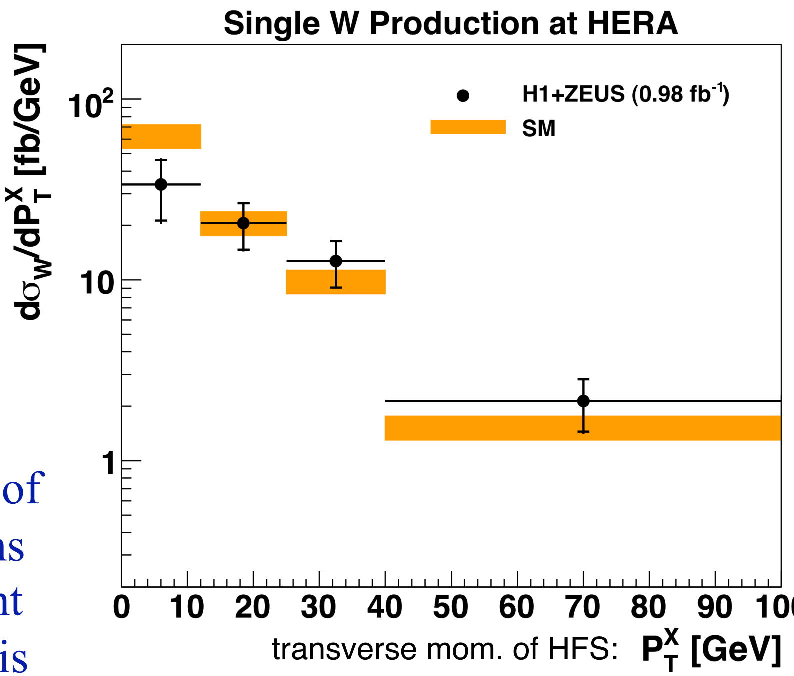
Weak couplings v_q much improved as expected

SM is ★ HERA data is consistent

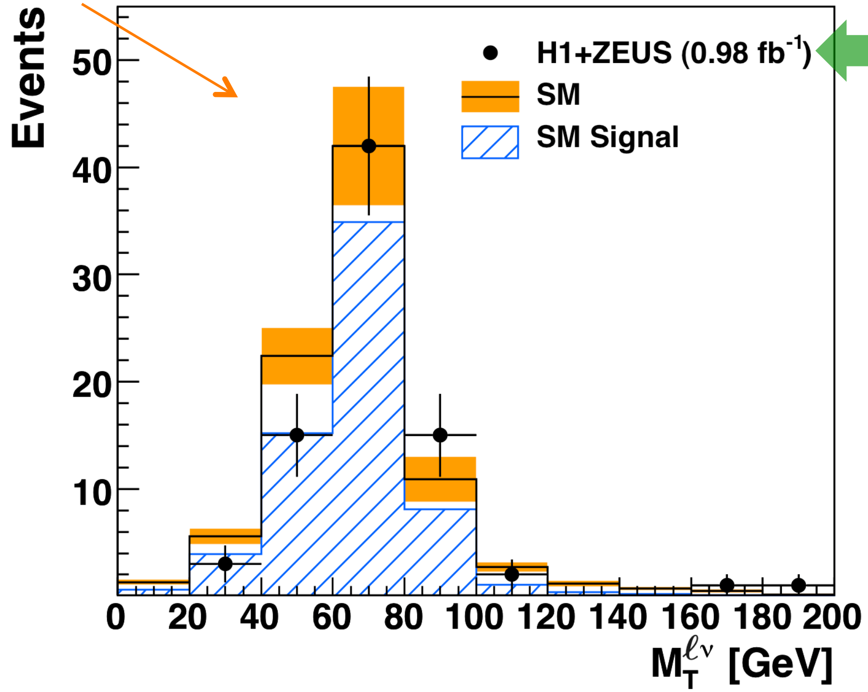
Direct W production

- ℓ=e,μ and ν with high P_T
- complete HERA data, ~1 fb^{-1}
- combine W cross sections
  electron and muon channels





81 data events
SM prediction: 87.8 ± 11.0



The production of single W bosons with subsequent leptonic decay is the main signal contribution to the SM expectation

total single W cross section
$\sigma = 1.06 \pm 0.16 \pm 0.07$ pb

SM prediction
$\sigma = 1.26 \pm 0.19$ pb

Jacobian peak as expected from single W prod, all kinematic dists. show good agreement w/ SM

Summary

- NC and CC cross sections measured at high Q^2 for HERA I & HERA II
  - polarized and unpolarized
  - 1st combined results for the two experiments: ZEUS and H1
- extracted a set of PDFs: HERAPDF1.0
  - using combined H1 and ZEUS HERA I data
- EW fits to extract axial and vector couplings of quarks
- EW effects at HERA are well described by SM