High-Q^2 NC and CC Cross sections at HERA and Proton Structure

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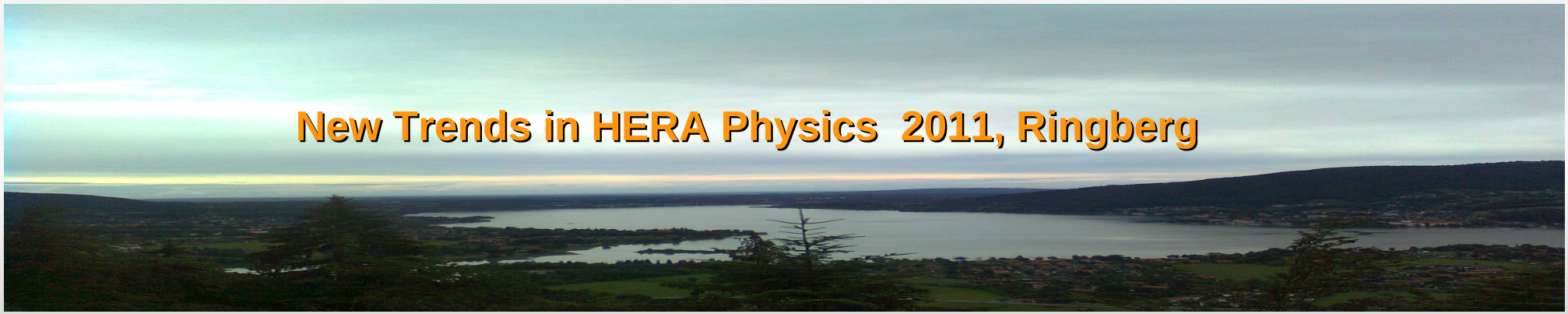
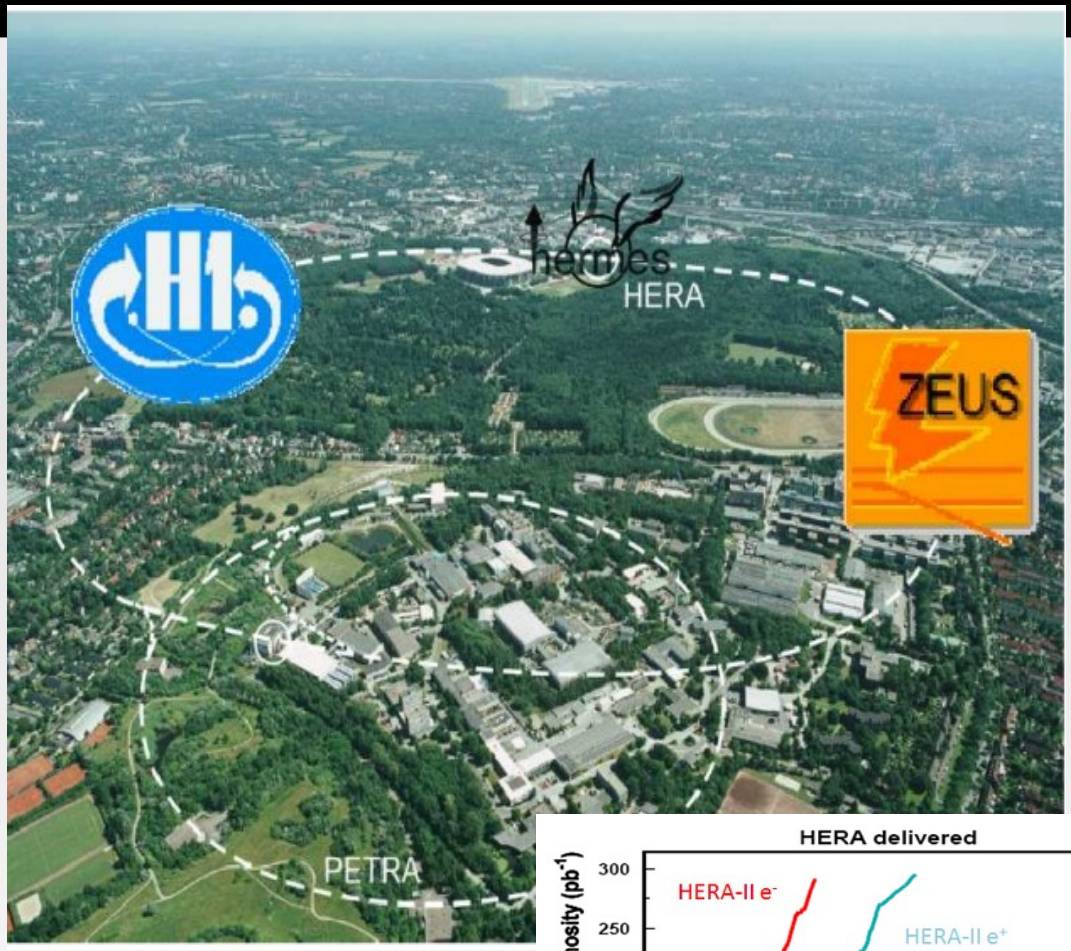
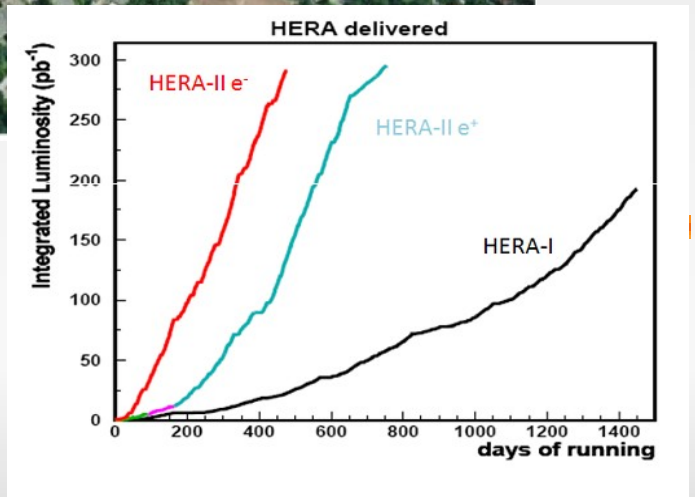
(On the behalf of H1 & ZEUS Collaborations)



HERA at DESY





HERA-II

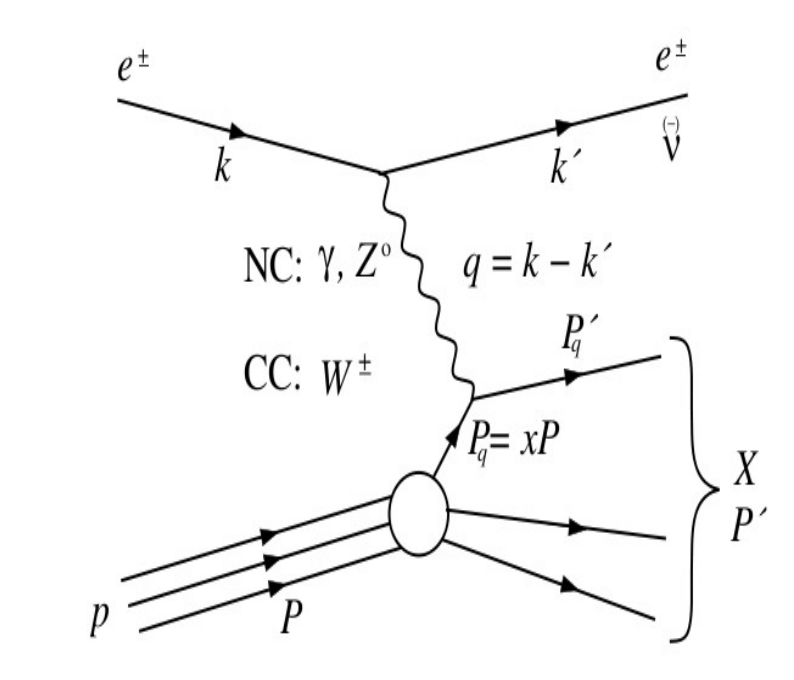
- *e* beam : 27.5 GeV
- *p* beam : 920 GeV
- Centre of mass E : 318 GeV
- H1 & Zeus : General Purpose Detectors

- HERA-II upgrade:
  Increased Luminosity
  Polarized Lepton Beam

(Mean Polaraization,
P_e ~ 30-40%)

Deep Inelastic Scattering (DIS)

(Charged Current & Neutral Current)



Neutral Current (NC)

γ , Z exchange : ep ---> eX

Charged Current (CC)

W± exchange : ep ---->νX

DIS Scaling Variables :-

- Q^2: Four momentum transfer (probing power)
  $Q^2 = -(k - k')^2 = -q^2$
- x : momentum fraction of struck quark)
  $x = Q^2 / 2\ k.p$
- y : inelasticity
  $y = p.q/p.k$
- s : centre of mass energy
  $s = (p+k)^2$
- related as
  $Q^2 = s\ .x.\ y$

Neutral Current Cross-sections

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

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

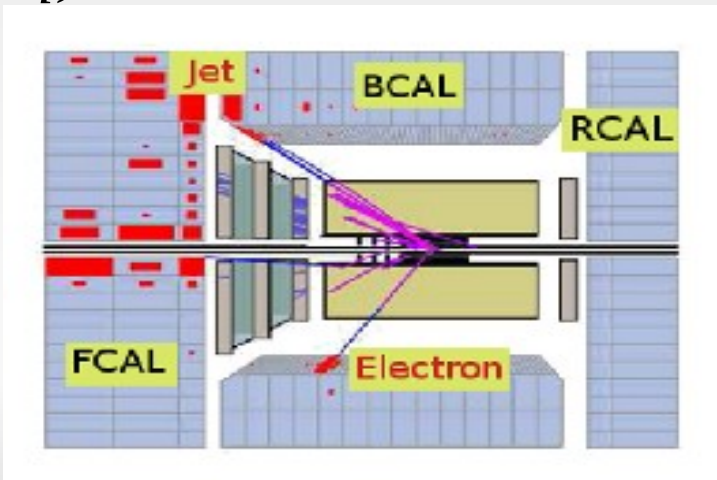
$$\Rightarrow \quad x\tilde{F}_3 = \kappa(-a_e \mp P_e v_e)xF_3^{\gamma Z} + \kappa^2(2v_e a_e \pm P_e(v_e^2 + a_e^2))xF_3^{Z})$$

where

$$\{F_2^{\gamma}, F_2^{\gamma Z}, F_2^{Z}\} = \sum \{e_q^2, 2e_q v_q, v_q^2 + a_q^2\}x(q + \bar{q})$$

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

- Dependence on P_e allows to study Assyemtry directly (A)
- e+p & e-p xsec difference allows to extract xF_3
- NC xsec linked to all quarks



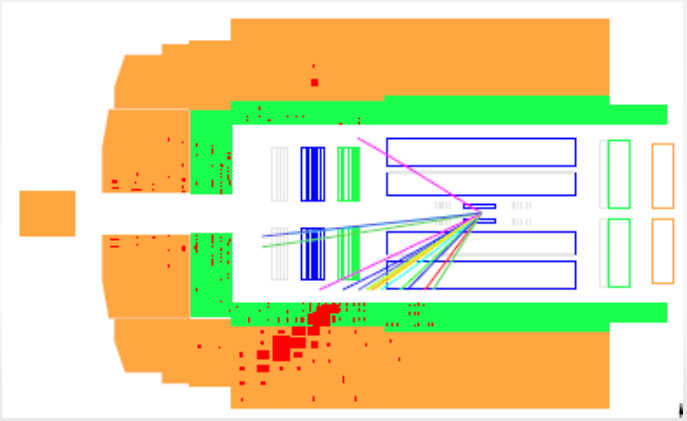
Charged Current Cross-sections

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

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

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

- W bosons interact with (right) left handed (anti-) particles only
- CC xsec depends on P_e
- CC xsec linked to valence quarks direclty

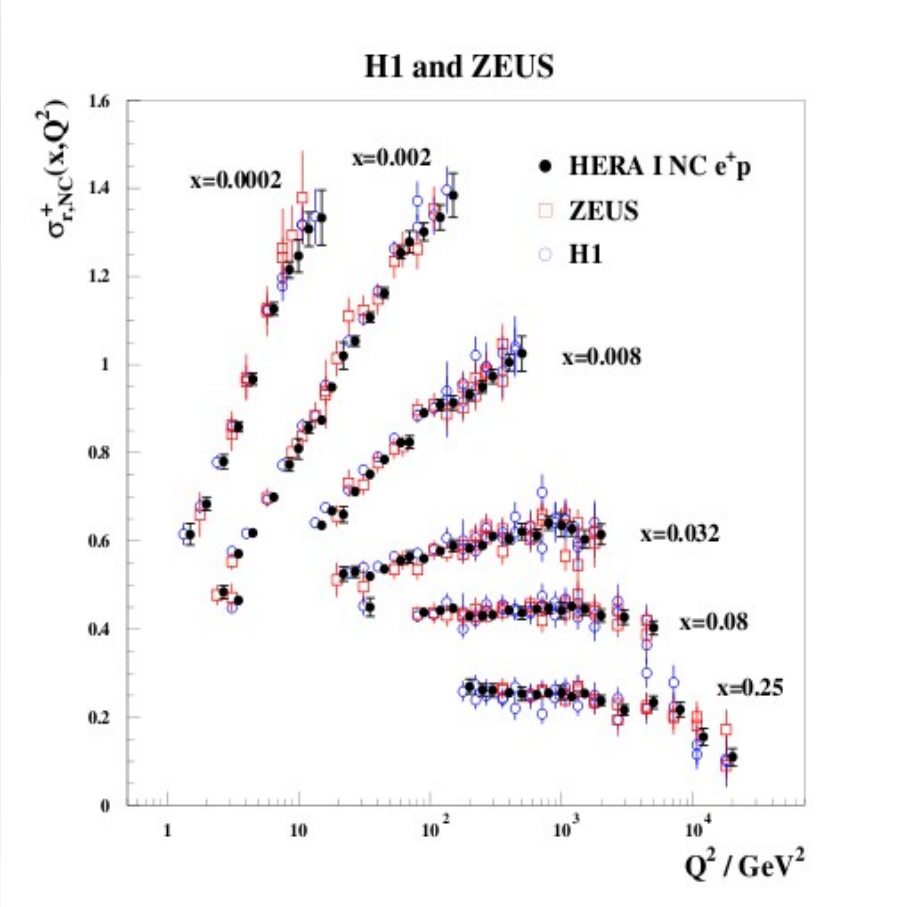


DIS & Proton Structure

HERA-1

- 1992-2000 efficiency runs
- e+p (~100 pb^{-1}) & e-p (15 pb^{-1}) data analysed by each experiment
- 6.10^{-7} – x – 0.65
- 0.045 – Q2 – 30000
- 0.005 – y – 0.95

- Low Q2 data : sea & glouns
- High Q2 : valence quarks

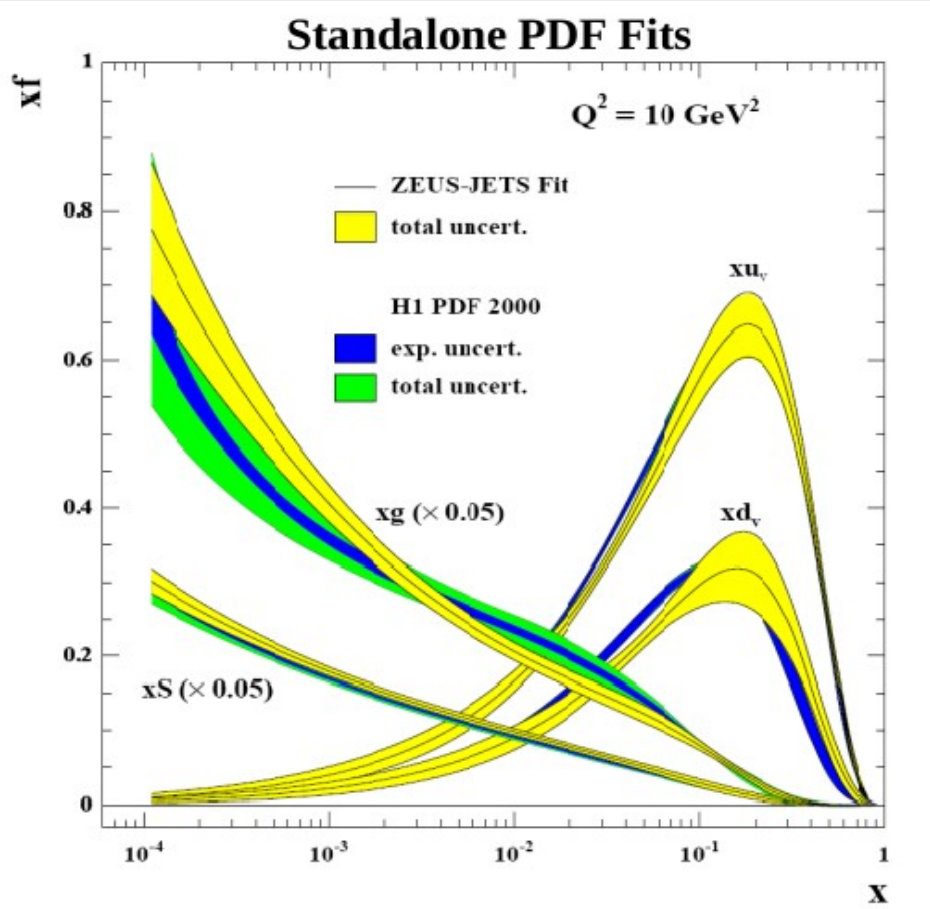


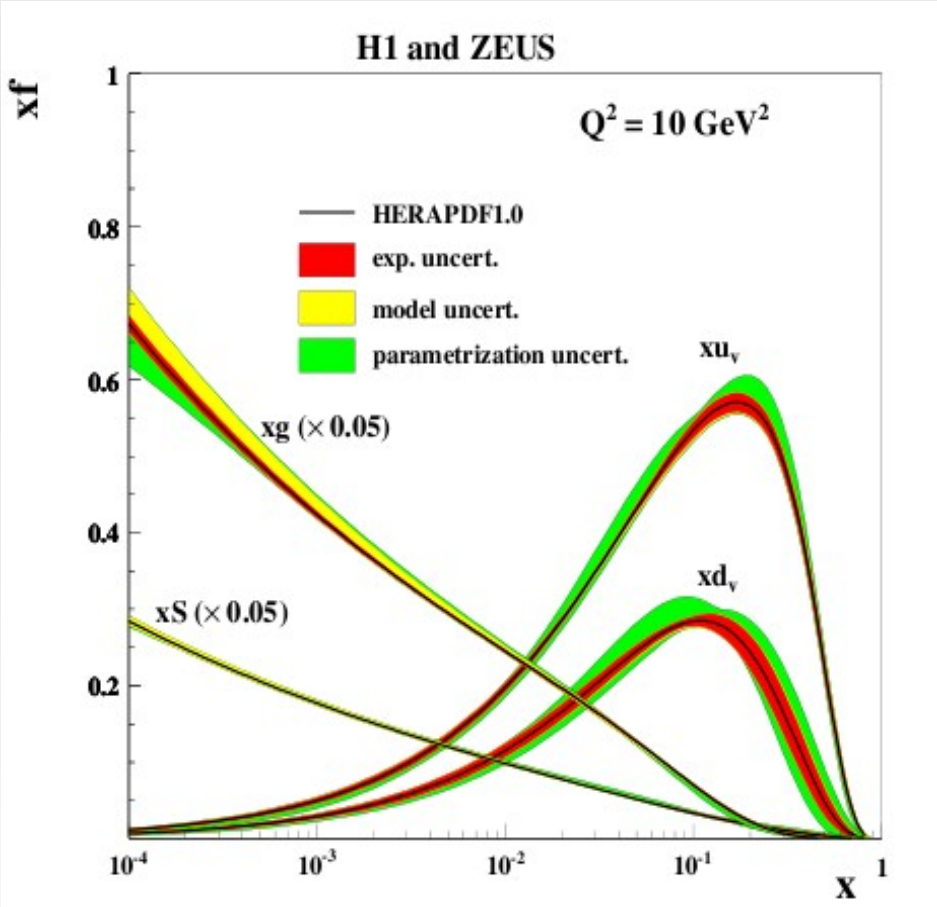
H1 & Zeus combination : More precise

Low – Q^2 : P.Kaur Slides

DIS & Proton Structure

HERAPDF1.0





More on HERAPDF's K.Lipka slides

- Cobination data : less uncertainities

DIS & Proton Structure

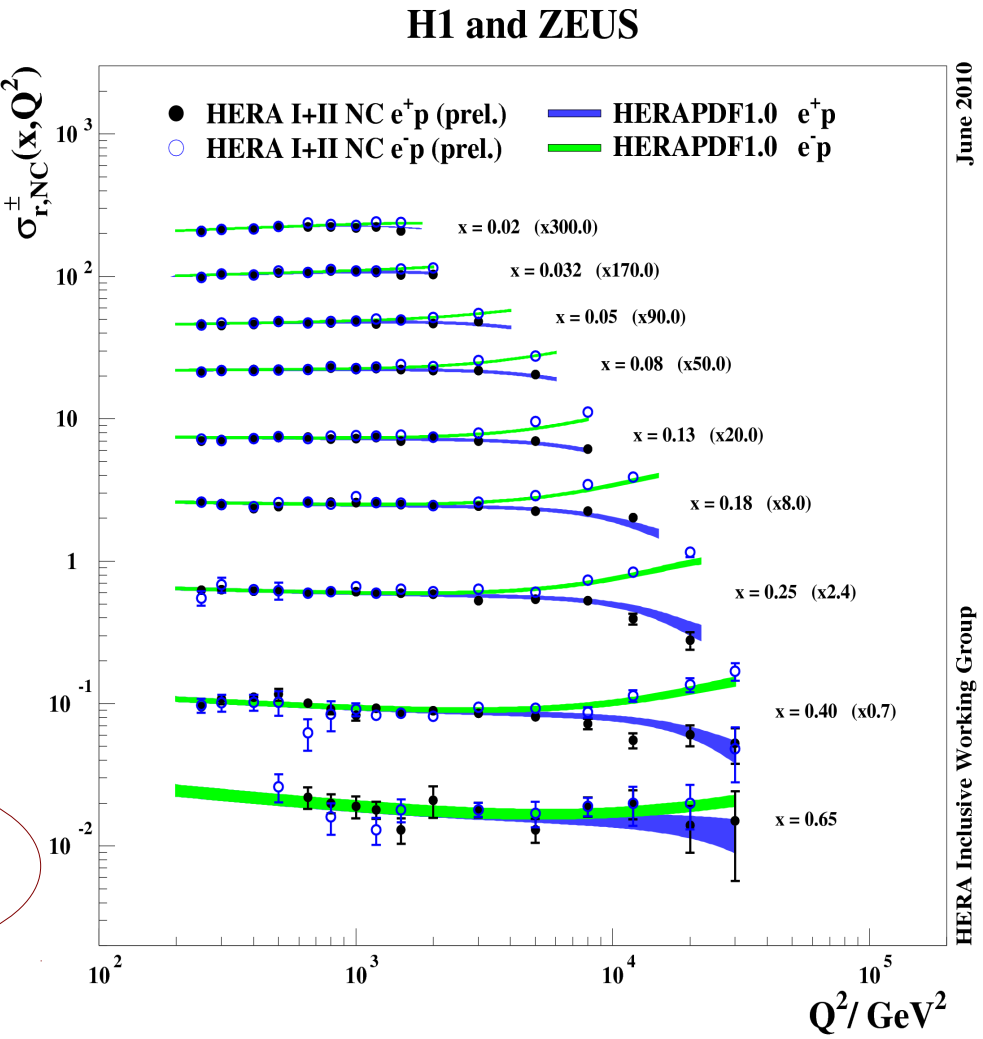
HERA-II

- 2004-2007 runs
- e-p (~170 pb-1) & e+p (135 pb-1) data analysed by each exp.
- Polarised e- & e+ beams ~ 30 – 40 %

=> MORE LUMInosity & POLarised beam

June 2010 : H1 – ZEUS combination (preliminary)

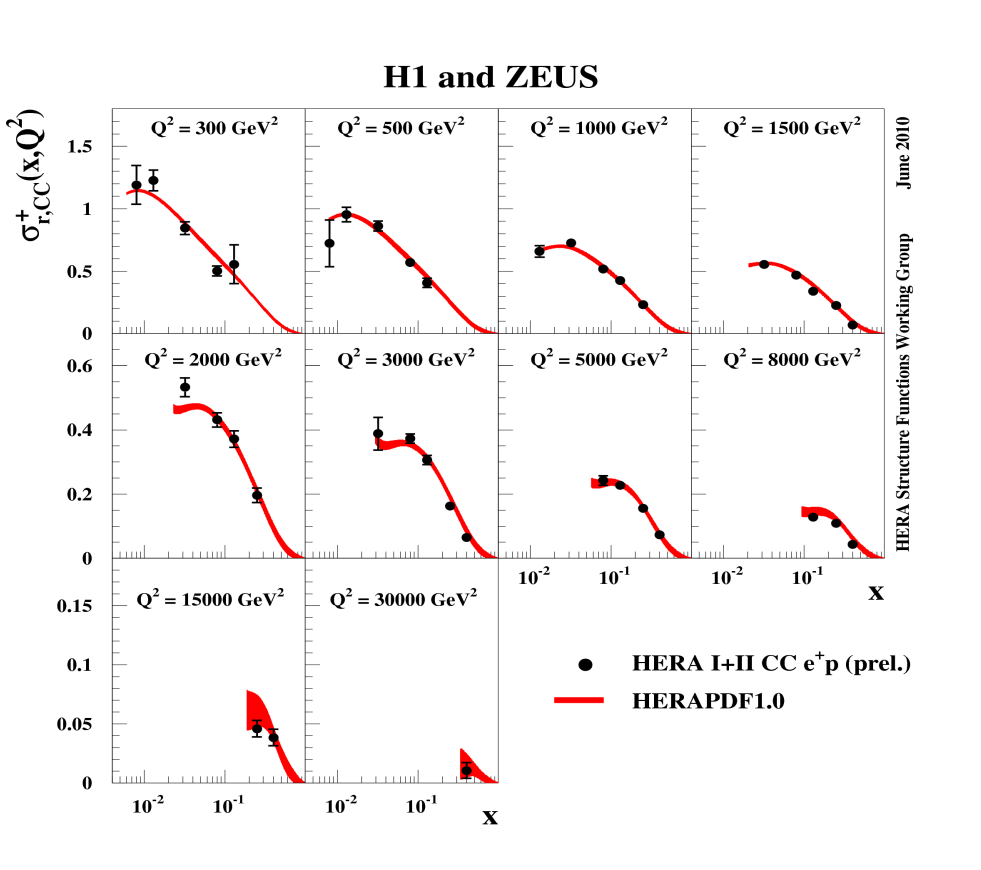
$$\sigma_{NC}^{e^{\pm}p} \propto [\, Y_+ \tilde{F}_2 \mp Y_- x \tilde{F}_3 \,]$$

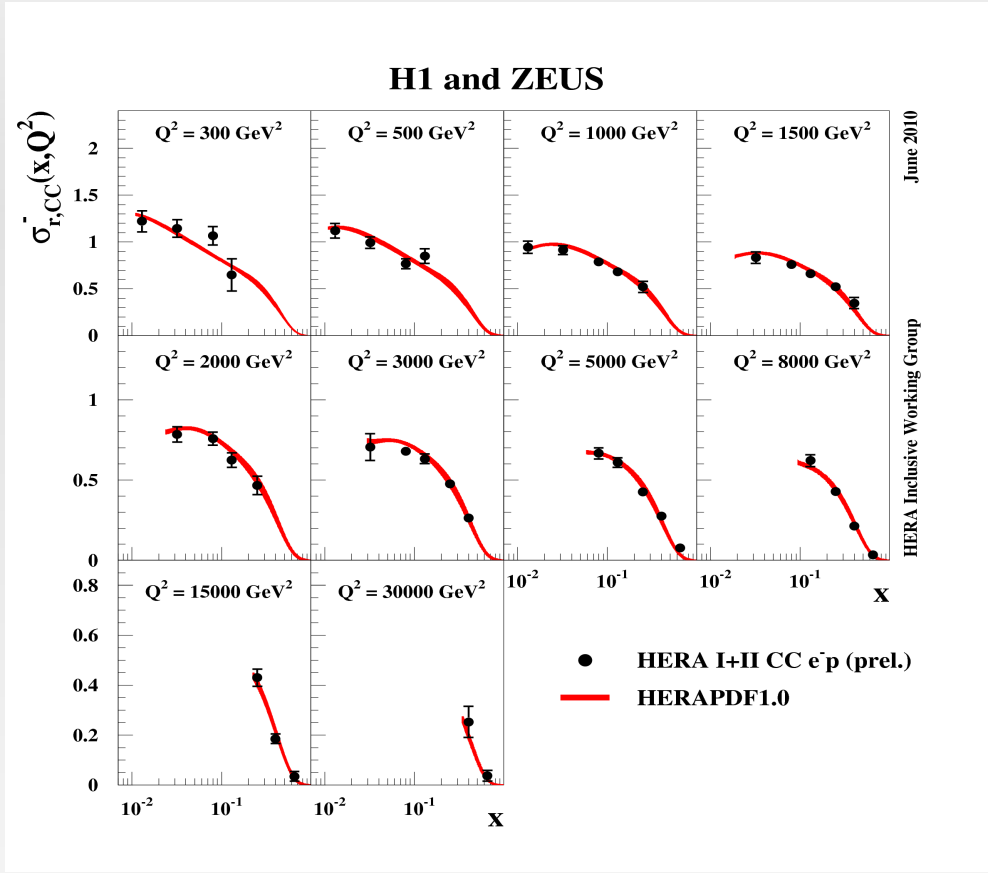


ZEUS e+p NC high-Q2 data II not included here

HERA-II High-Q2 data in hand

H1-prelim-10-141 & ZEUS-prel-10-017





$$\tilde{\sigma}^{e^- p}_{CC} \propto x\left[\left(u+c\right)\right]$$

$$\tilde{\sigma}^{e+p}_{CC} \propto x\left[\left(1-y\right)^2\left(d+s\right)\right]$$

CC data sensitive to the valence quarks direclty

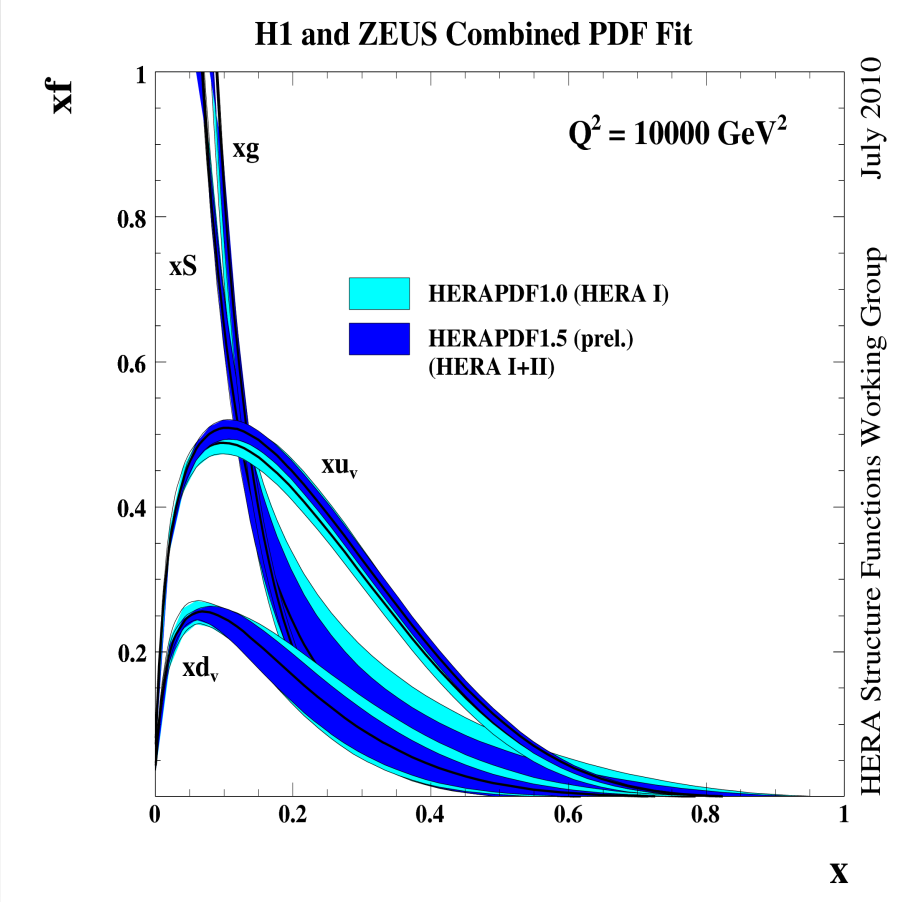
July 2010 : HERAPDF1.5

High -Q^2 CC & NC data

- Reduced Parametrisation uncertainties (whole of HERA I and HERA II high Q^2 data included in the fit)
- CC xsecs is a powerful probe to the flavor specific Parton Distribution Functions (PDFs)
- NC xsecs are sensitive to all flavors

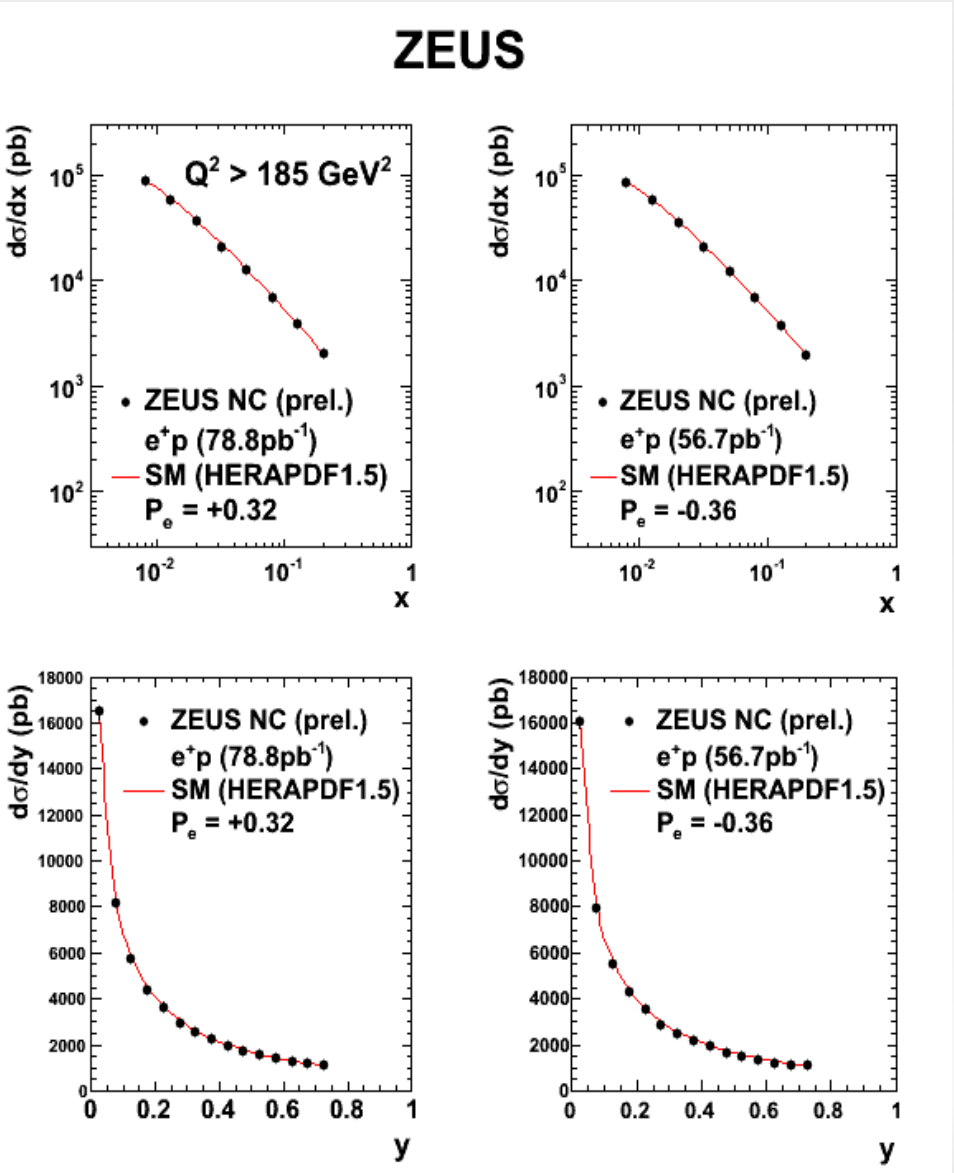
Not included:

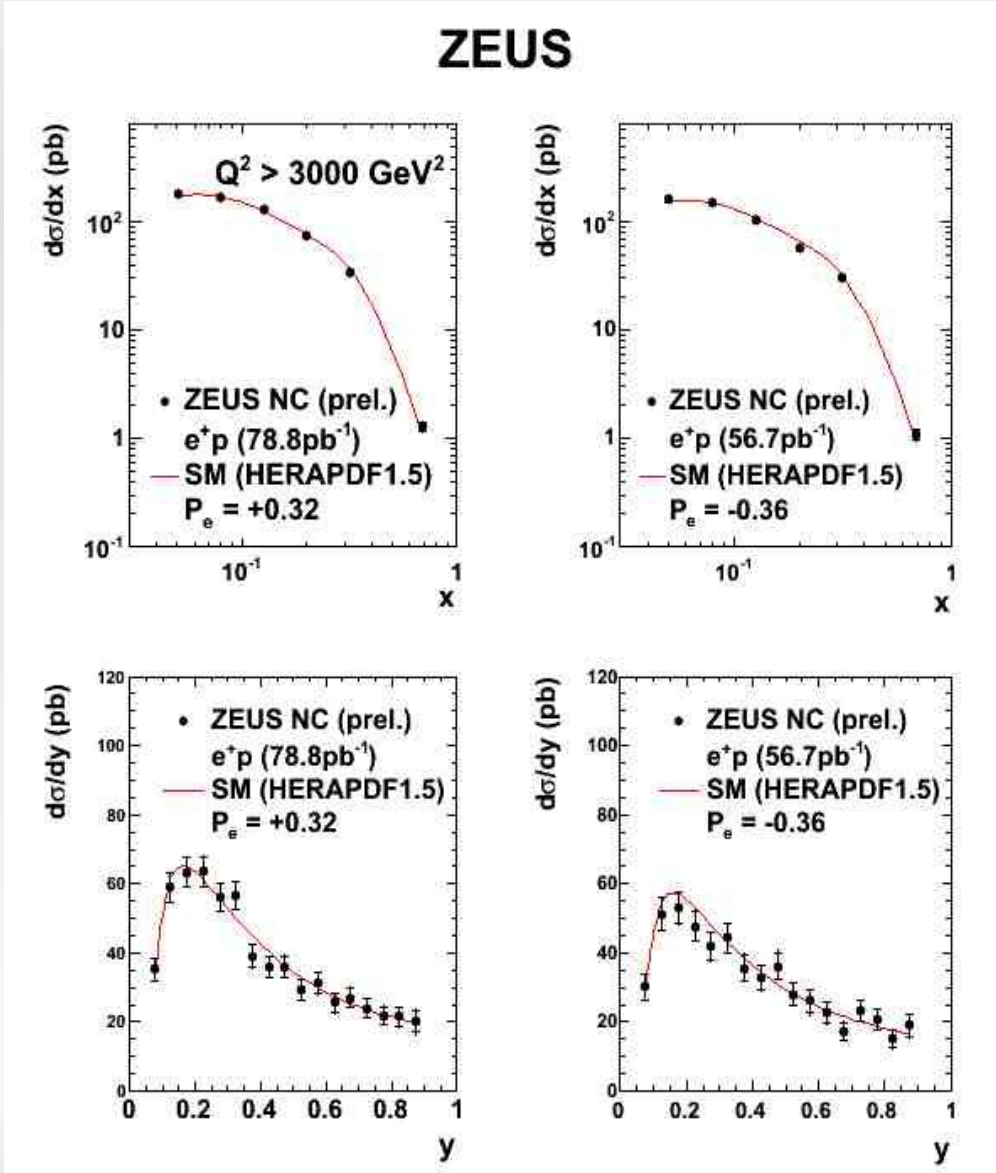
- Zeus e+p (135.5 pb^{-1}) NC Prelimimary ZEUS-prel-11-003



ZEUS-prel-11-003

dσ/dx & dσ/dy for - & + P_e

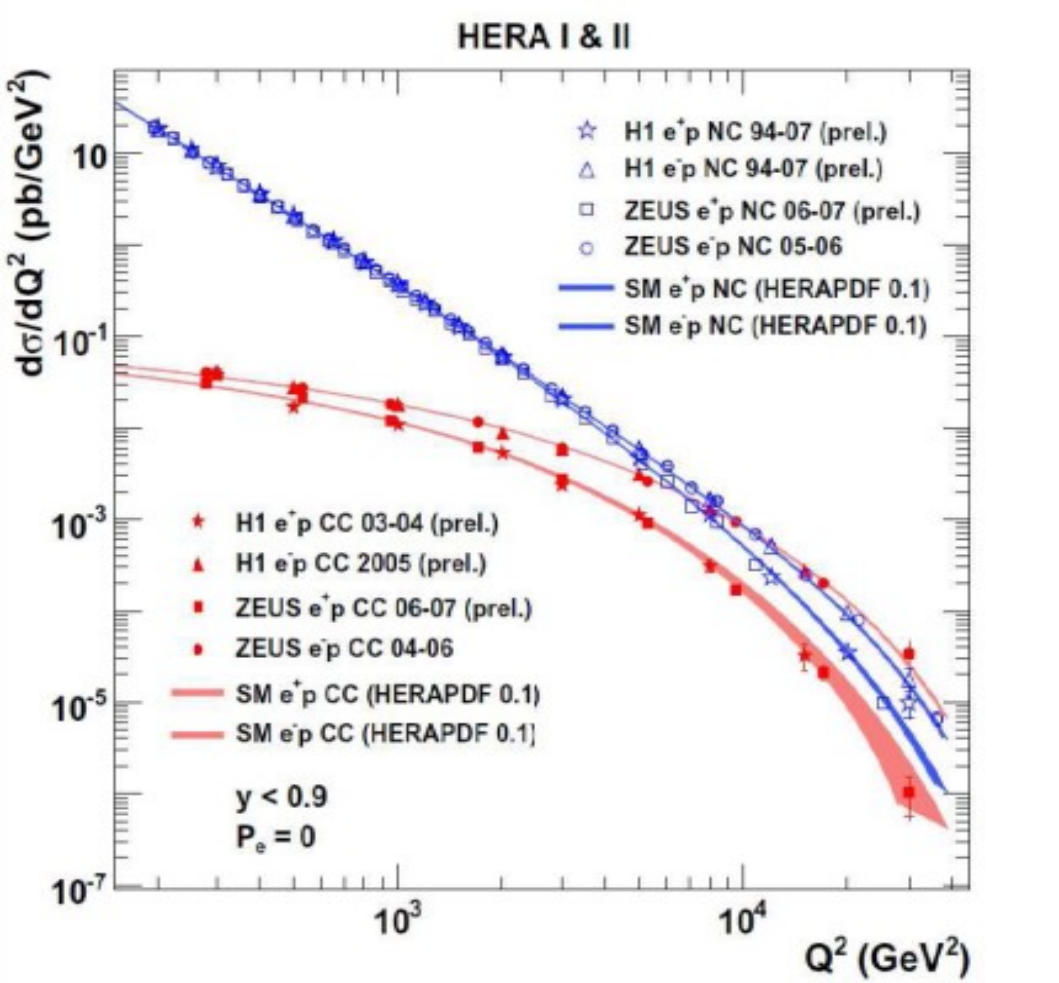




Completes the high-Q2 inclusive analysis

HERA @ Electroweak scale

NC & CC cross sections



⇐ **NC & CC Cross sections Comparable at $Q^2 \sim m_z^2, m_w^2$**

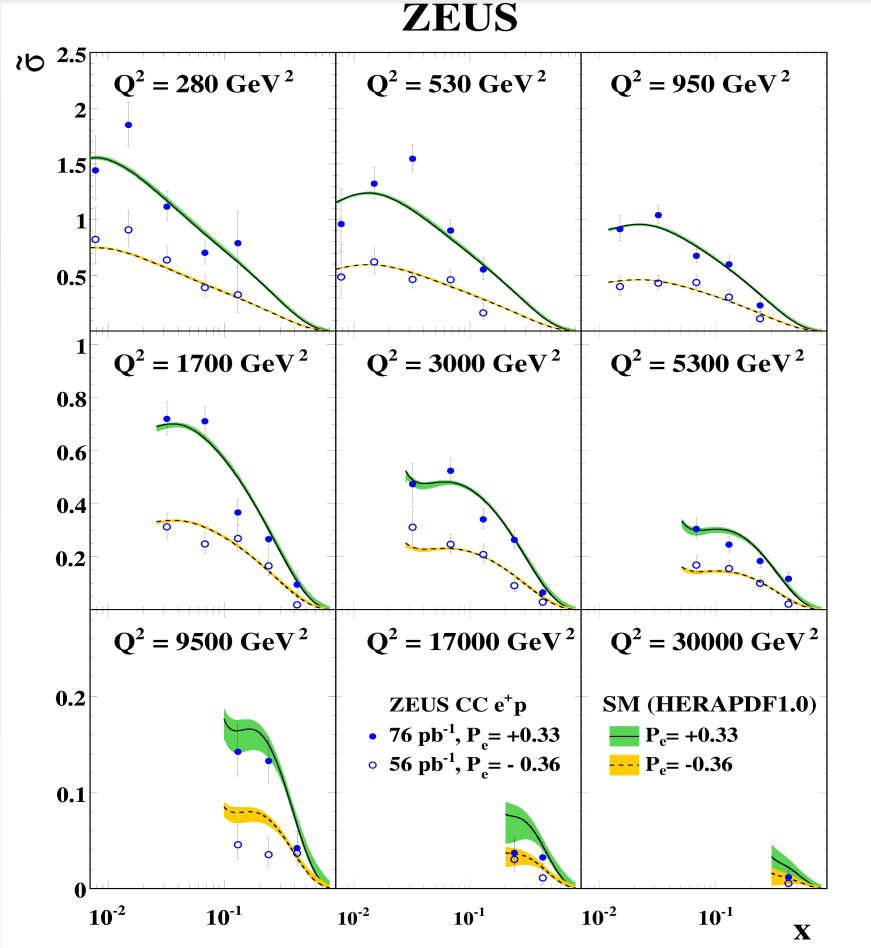
NC: $\frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$

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

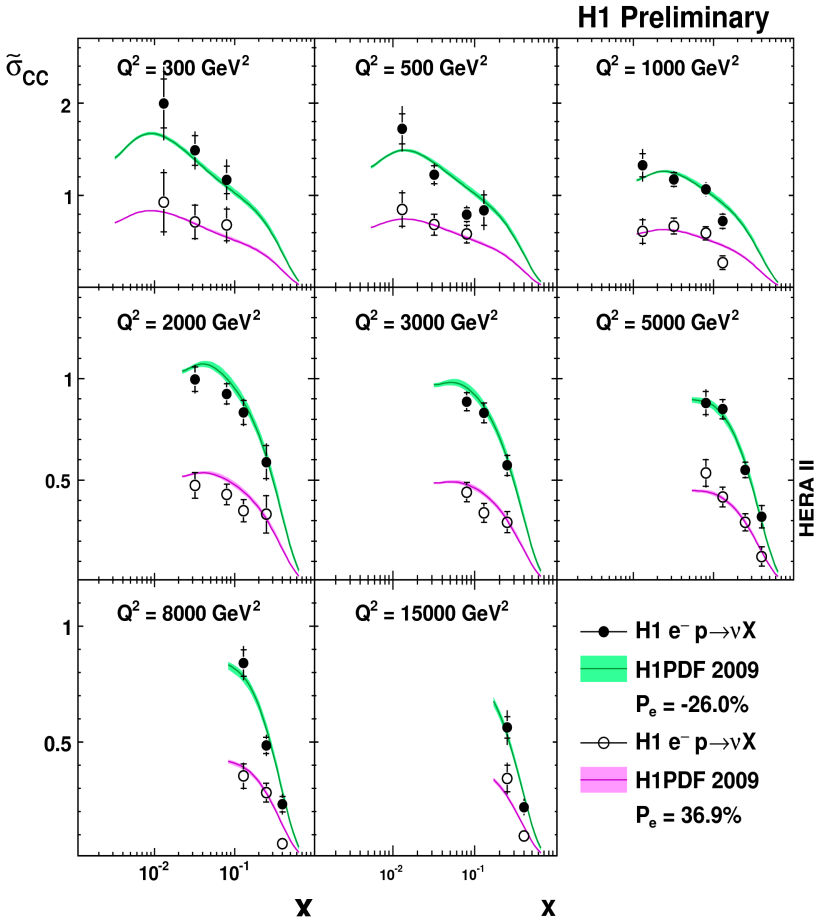
Electroweak Unification

CC Cross-Sections

Polarized lepton beam



$$\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2} \propto (1 \pm P_e)[\ldots]$$



- Effect of Polarization P_e clearly seen
- SM describes data well

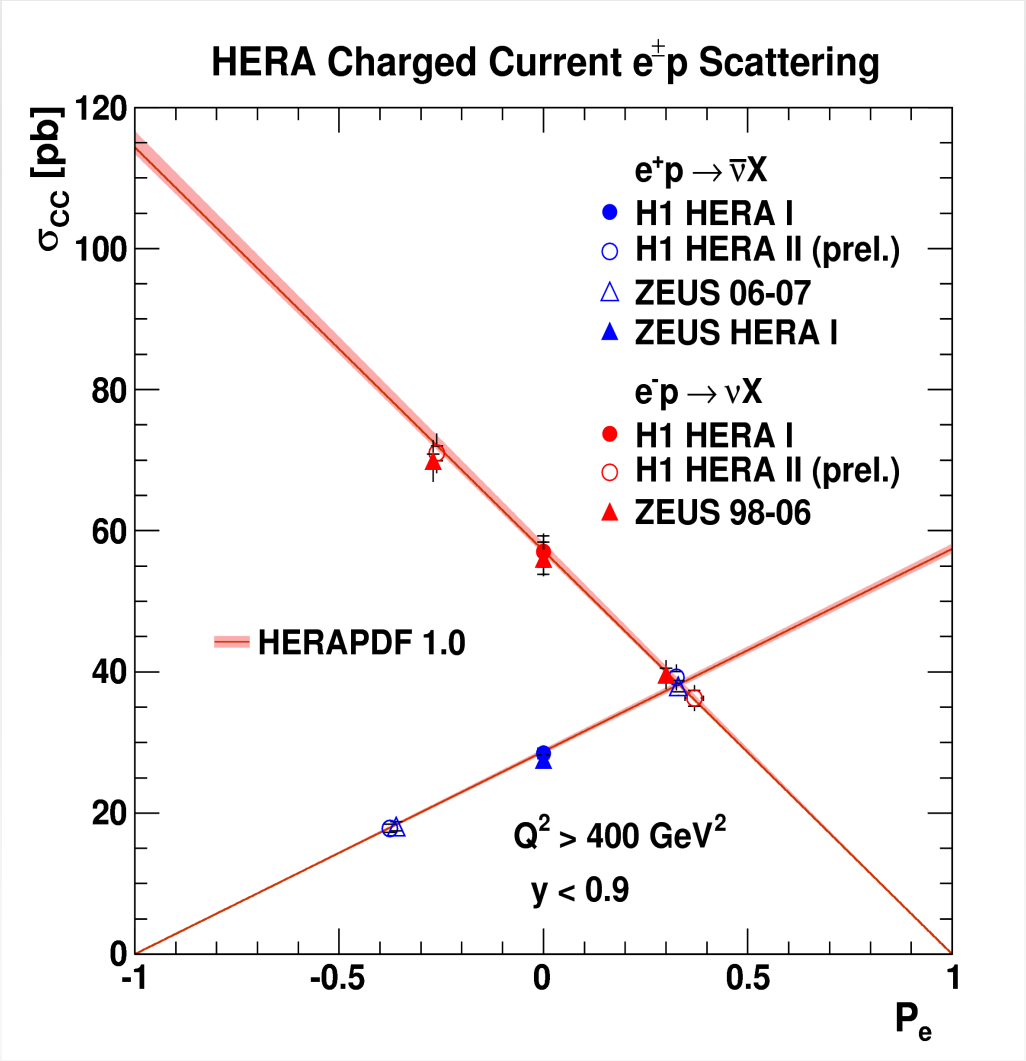
Charged Current Cross-Sections

Dependance on P_e

- Total CC xsec as a function of P_e
- Previous e^-p and e^+p results also shown
- Excellent test of EW theory SM describes data well

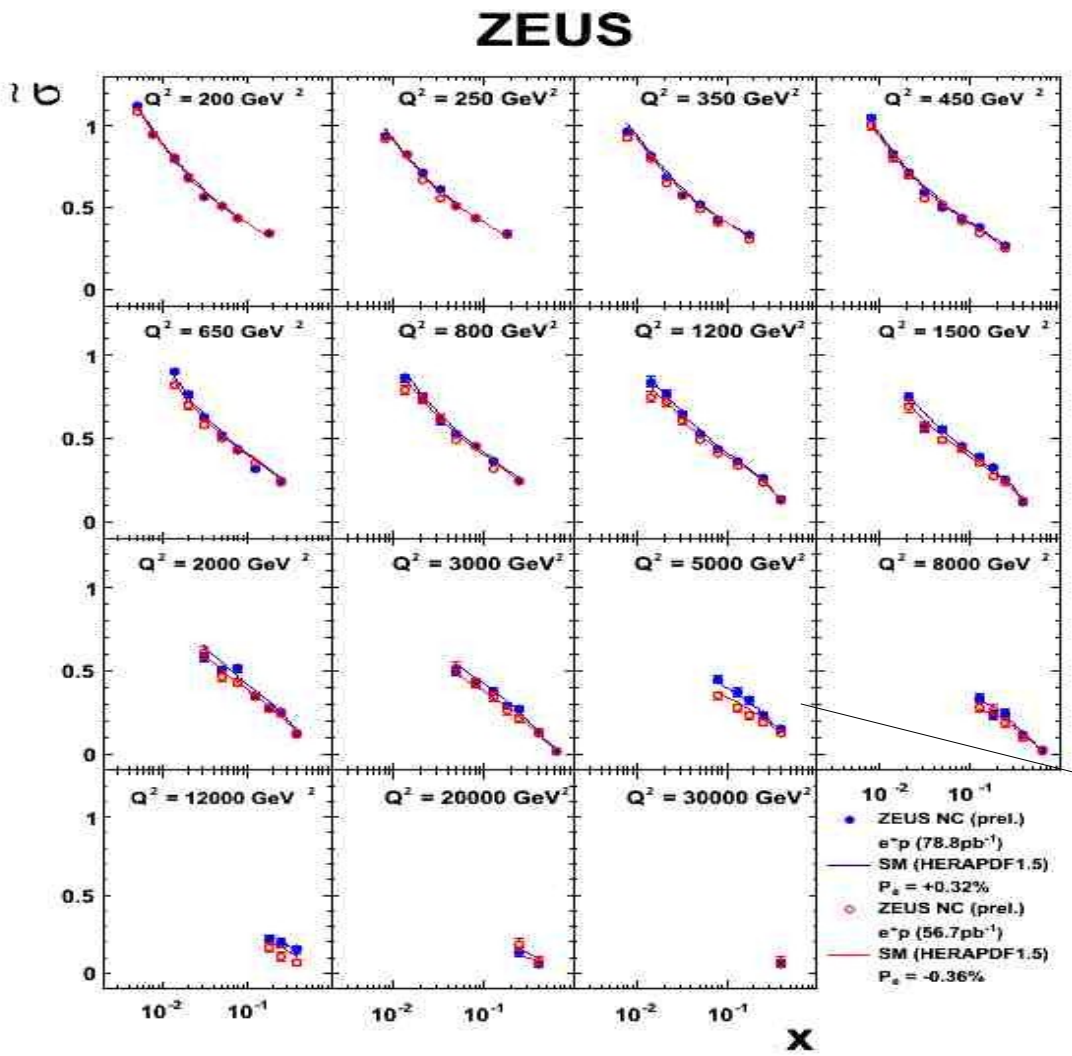
- CC e^+p total Cross section consistent with 0 for $P_e = -1$
- For CC e^-p, consistent with 0 for $P_e = 1$

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} \propto (1 \pm P_e)[\ldots]$$



NC ZEUS Cross-Sections

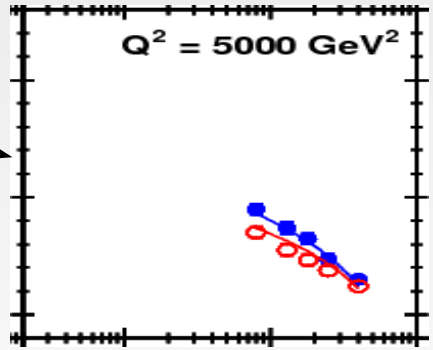
Polarised lepton beam



- +ve P_e e^+p NC 78.8 pb^{-1}
- -ve P_e e^+p NC 56.7 pb^{-1}

Effect small at low-Q^2

increases at high-Q^2



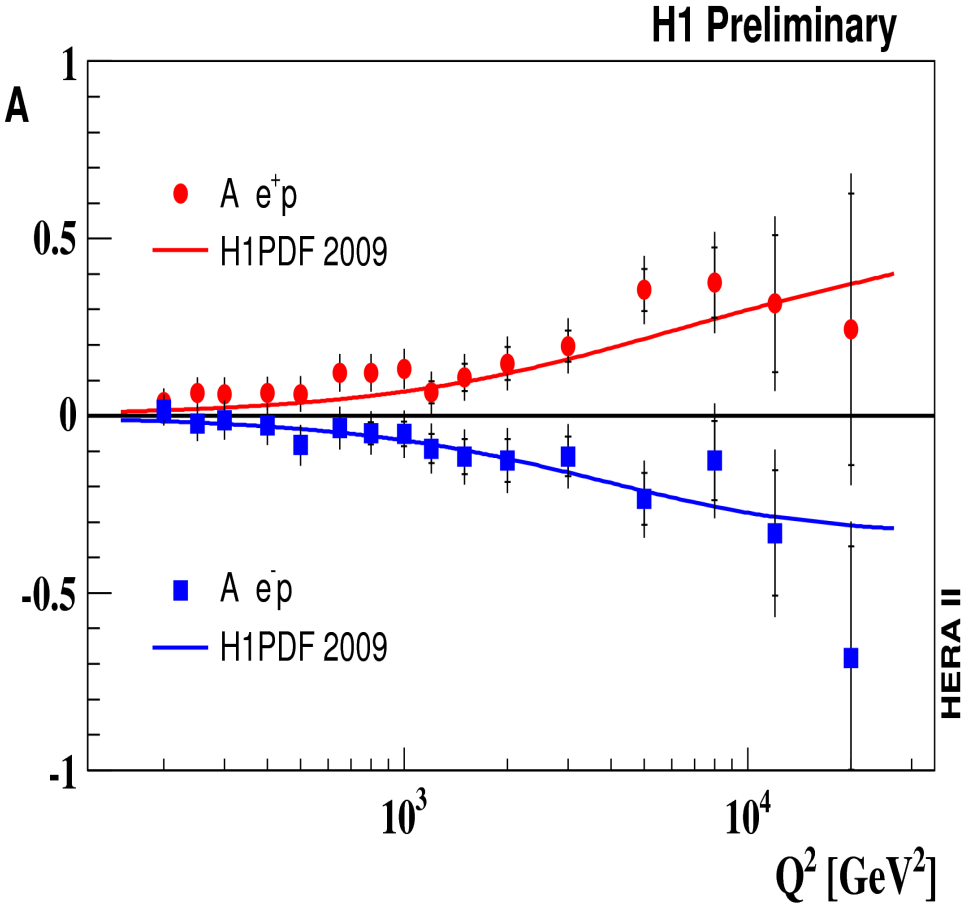
$$\tilde{F}_2 = F_2^{\gamma} + \kappa\left(-v_e + P_e a_e\right) F_2^{\gamma Z} + \kappa^2\left(v_e^2 + a_e^2 + P_e v_e a_e\right) F_2^{Z}$$

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

Neutral Current Cross-Sections

Assymetry : A+

- H1prelim-09-042



⇐ **Difference in LH & RH lepton beam Cross sections**

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

A^+ measurement

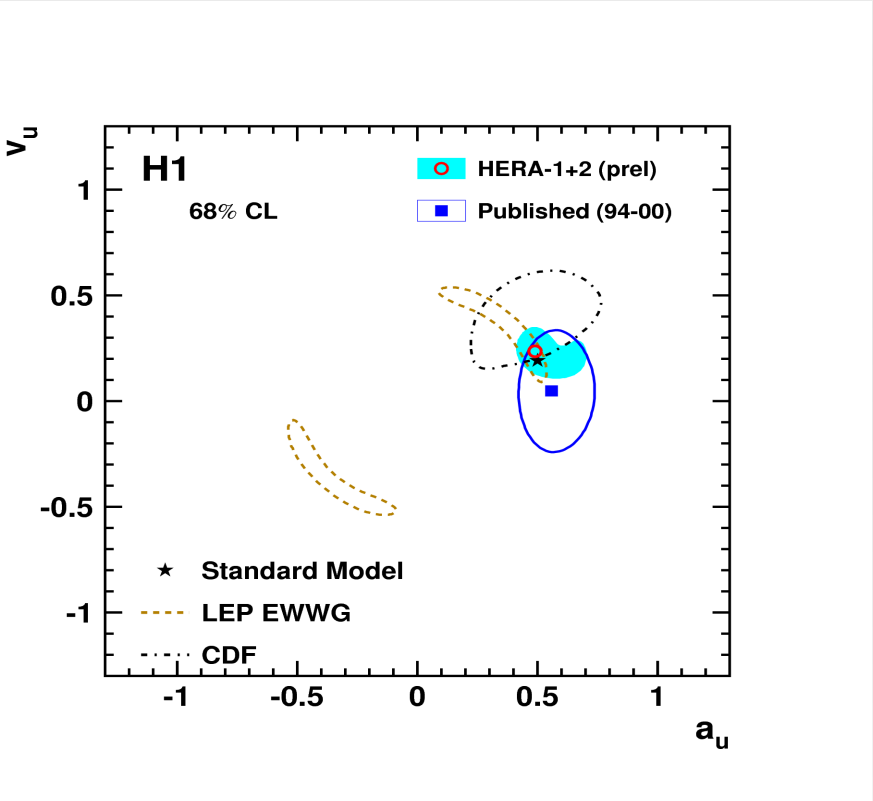
A^+ sensitive to $a_e v_e$

A^+ increases at high-Q^2

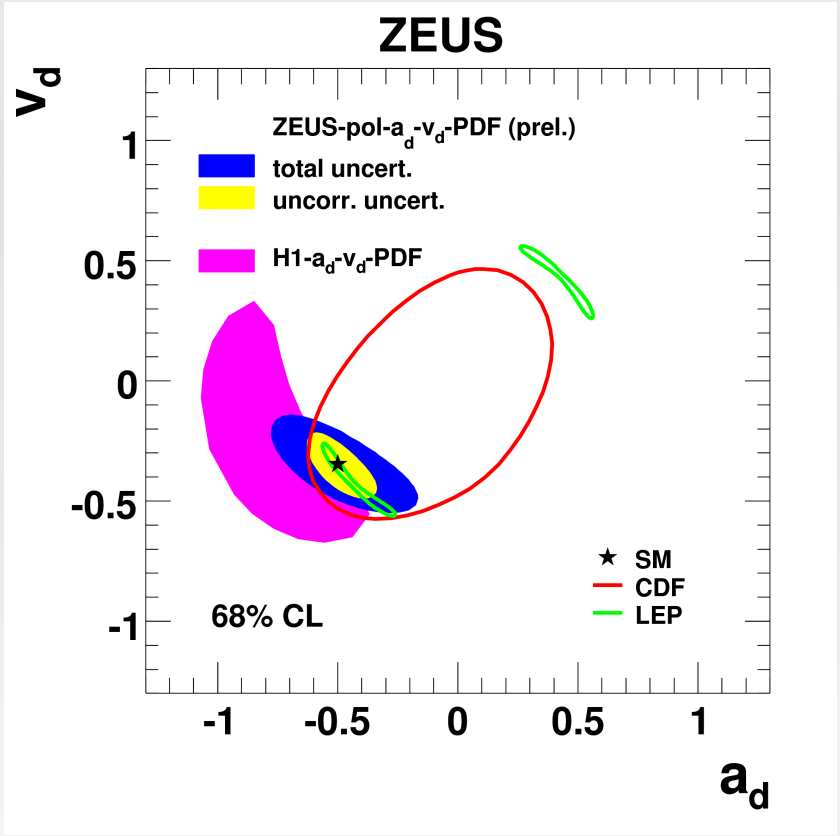
Neutral Current Cross-Sections

Coupling constants

H1prelim-10-042



ZEUS-prel-06-003



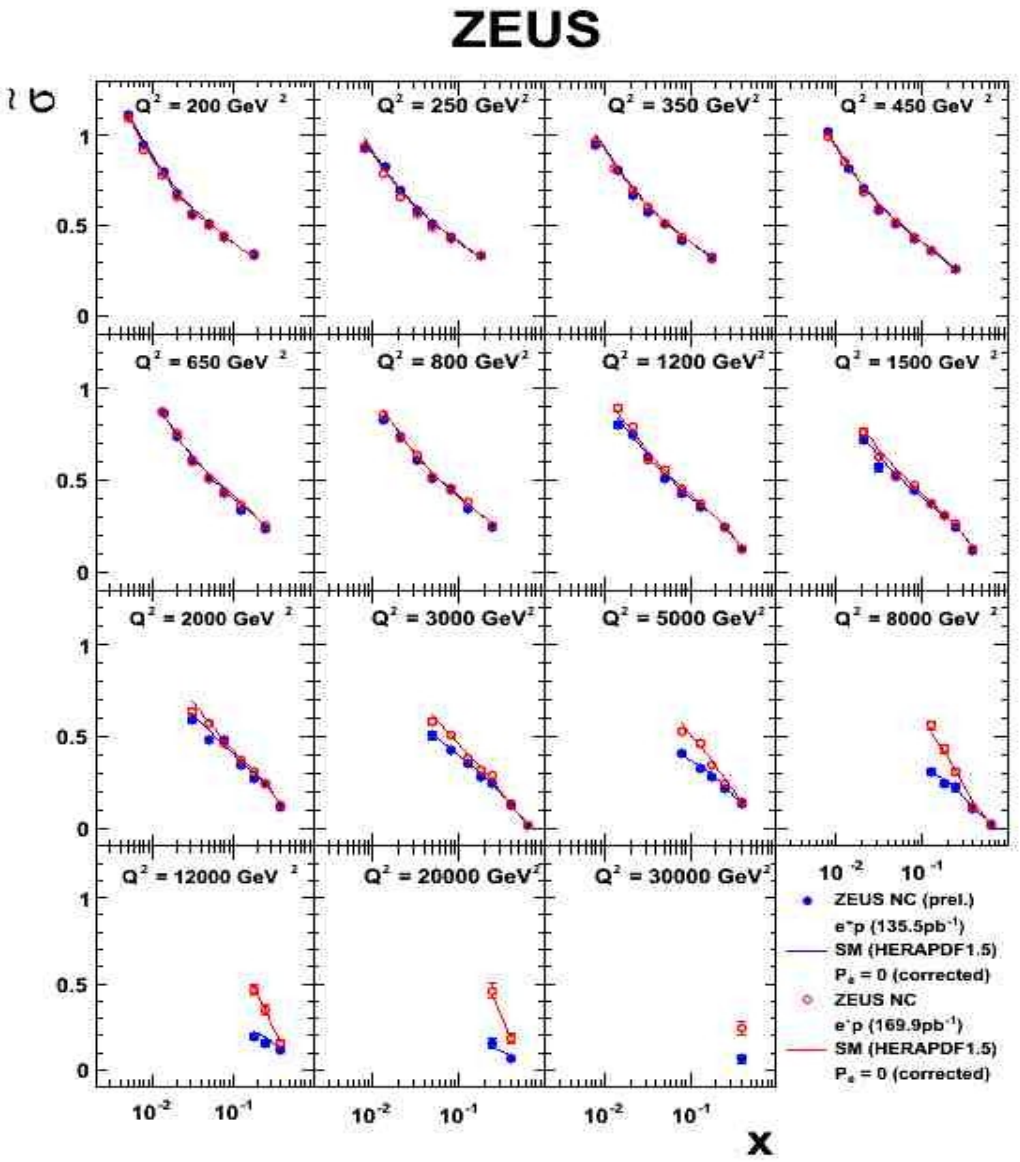
All H1 DIS NC & CC data (including polarized beams)

- 68 % CL on Ew neutral coupling of u (d) on Z
- Compared to SM values
- & to LEP & CDF results

ZEUS DIS NC & CC data e-p data (both polarizations) ~120 pb^{-1}

Neutral Current Cross-Sections

xF3 extraction - I



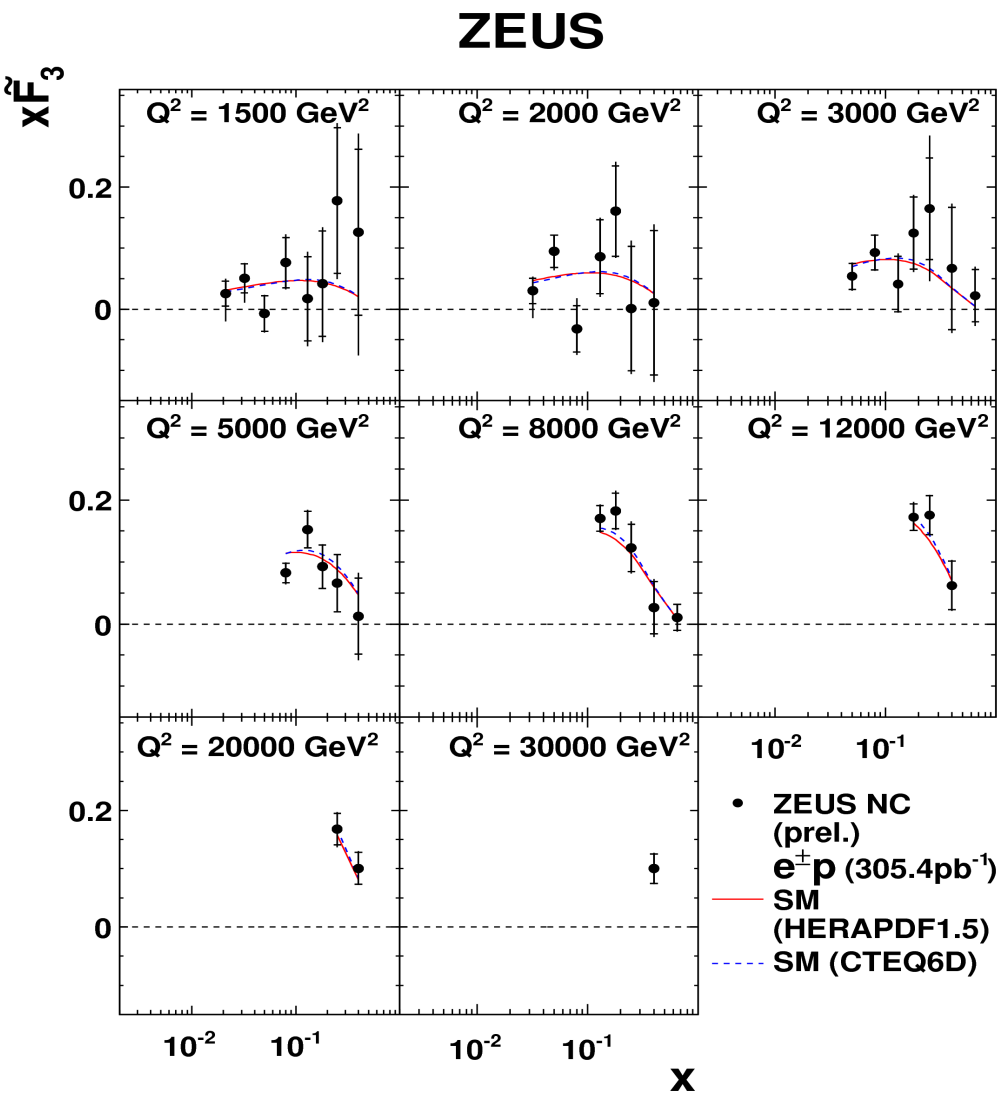
- e^+p NC high-Q^2 135.5 pb^{-1}
- e^-p NC high-Q^2 169.9 pb^{-1}

$$\tilde{\sigma}^{e^- p} - \tilde{\sigma}^{e^+ p} = \frac{Y_-}{Y_+} 2x\tilde{F}_3$$

Difference in Cross sections visible at high-Q2

Neutral Current Cross-Sections

xF3 extraction - II



- (Difference in e+p and e-p Cross sections gives a direct handle on xF3 Structure Function)

$$\tilde{\sigma}^{e^- p} - \tilde{\sigma}^{e^+ p} = \frac{Y_-}{Y_+} 2x\tilde{F}_3$$

Difference in Cross sections visible at high-Q2

High-Q^2 HERA II Analysis
A short database

HERA-II

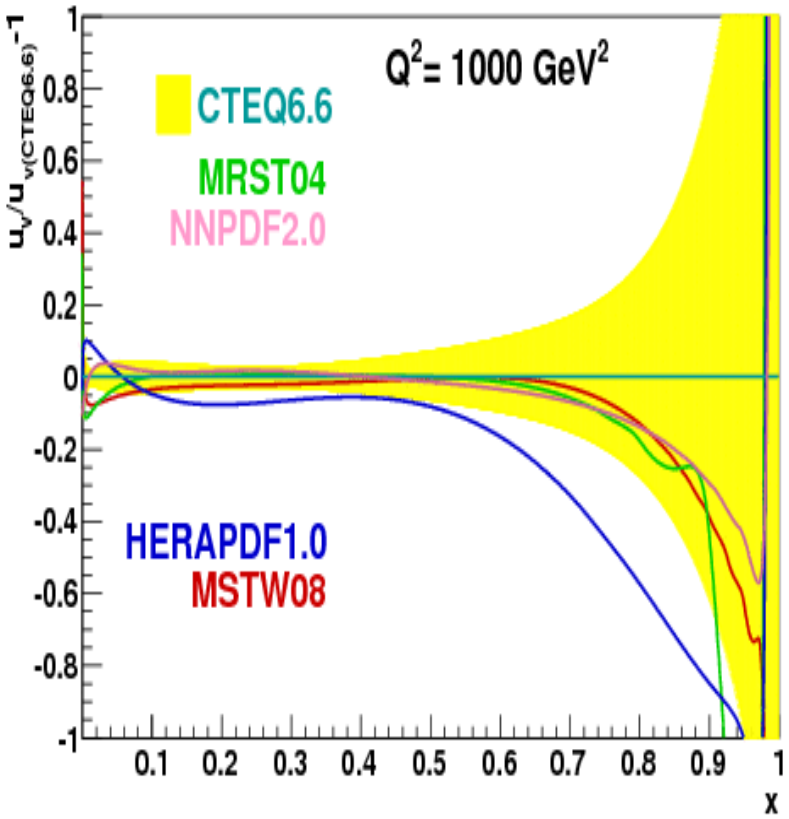
- HERA II (~200 pb^{-1} e-p & ~150 pb^{-1}) data analysed

- H1 results :
  NC e-p & e+p : H1prelim-09-042
  CC e-p & e+p : H1prelim-09-043
- ZEUS results
  NC e-p : EPJC-62-2009-625
  CC e-p : EPJC-61-2009-223
  CC e+p : EPJC-70-2010-953
  NC e+p : ZEUS-prel-11-003
- H1 & ZEUS combination : H1prelim-10-141 & ZEUS-prel-10-017
- HERAPDF1.5 & High-Q2 data

No deviations from SM seen

Neutral Current high-x Cross-Sections

Motivation



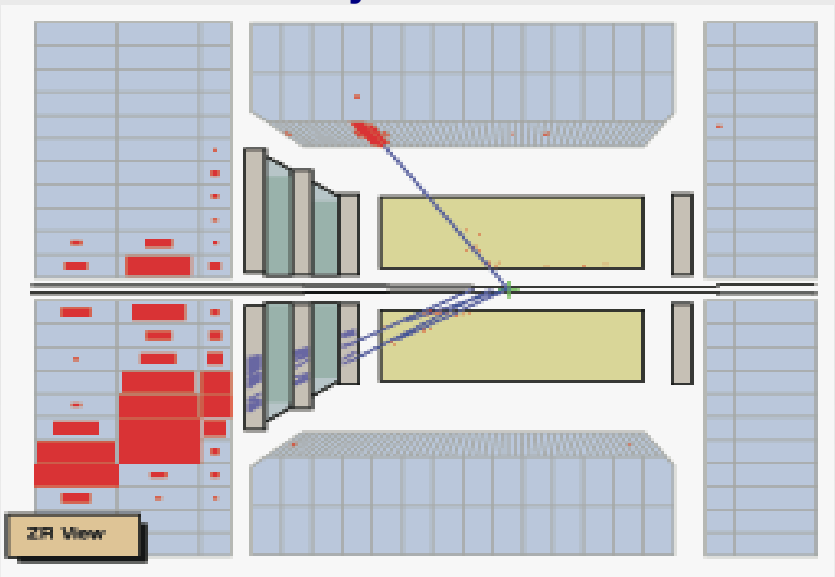
- Proton PDFs poorly determined at high-x
- Variations larger than uncertainty estimates
- Is measurement from HERA to constraint PDFs at high-x possible?

- Large x Physics relevant to understand LHC physics (eg. For high mass searches at the LHC)

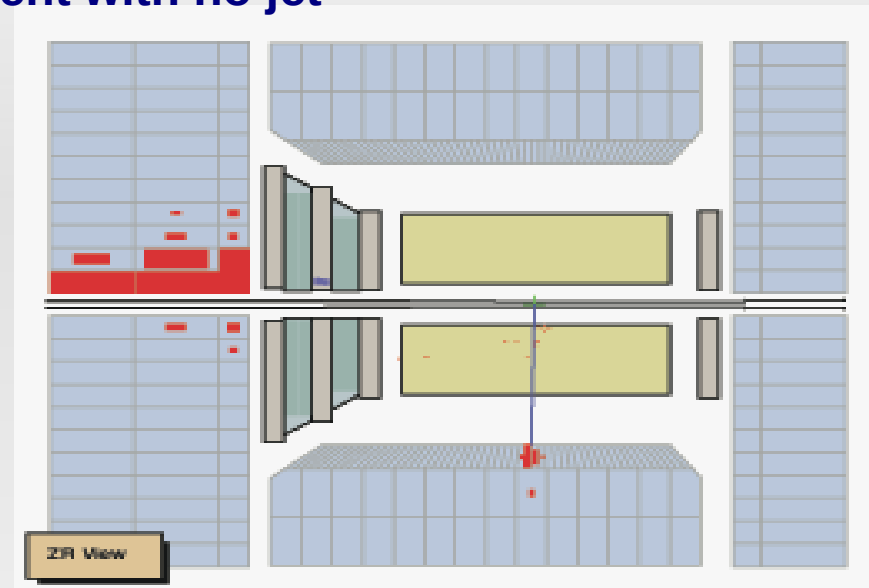
Neutral Current high-x Cross-Sections

Event Topology

Event with a jet



Event with no jet

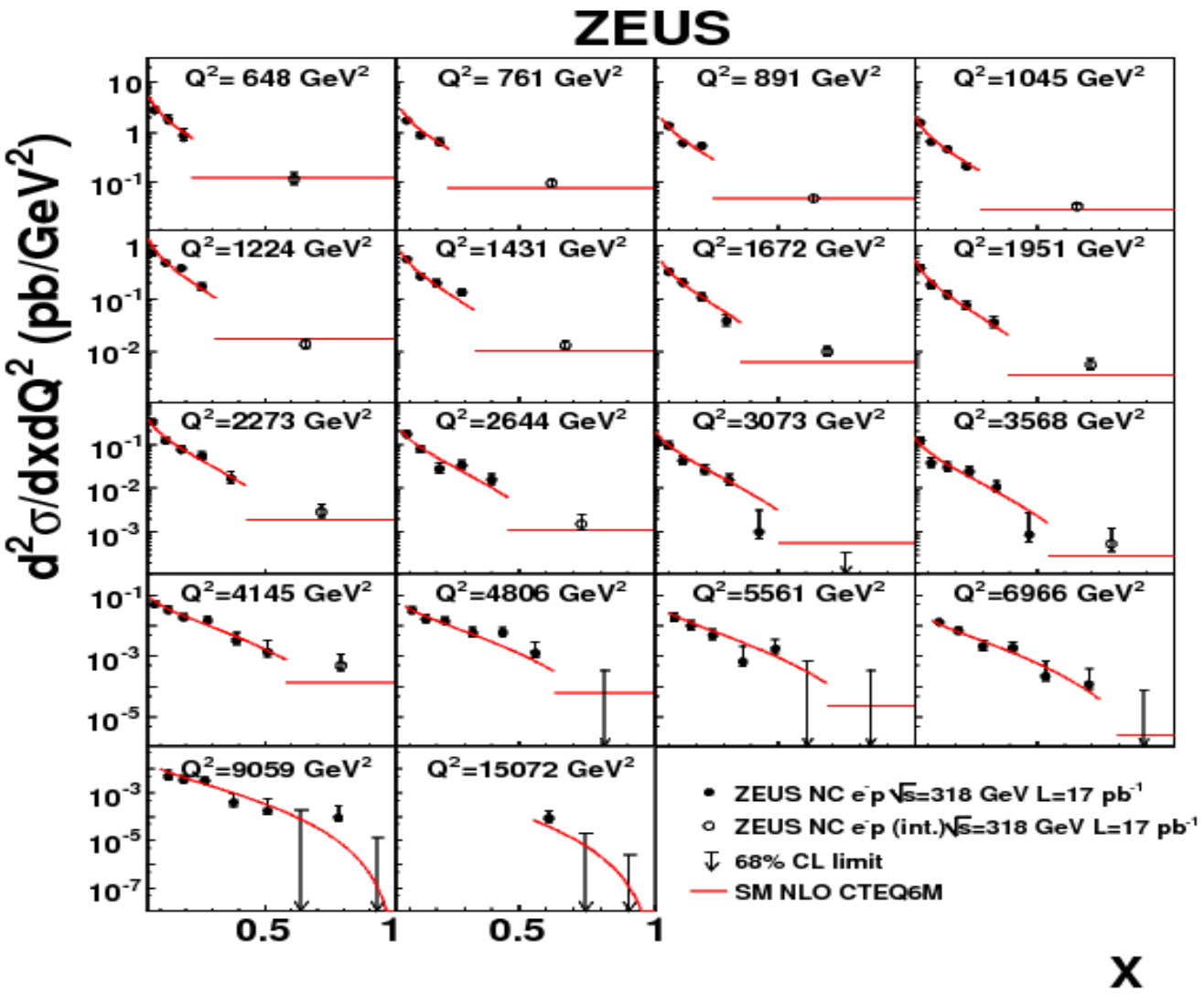


- Jet definition : E_T of jet > 10 GeV & θ_{jet} > 0.11 rad
- x reconstructed using jet information for x < xlimit

- No jet in final State
- x can not be reconstructed but these events have x > xlimit
- Constraint high-x by integration in x.

Neutral Current high-x Cross-Sections

HERA – I Cross Sections

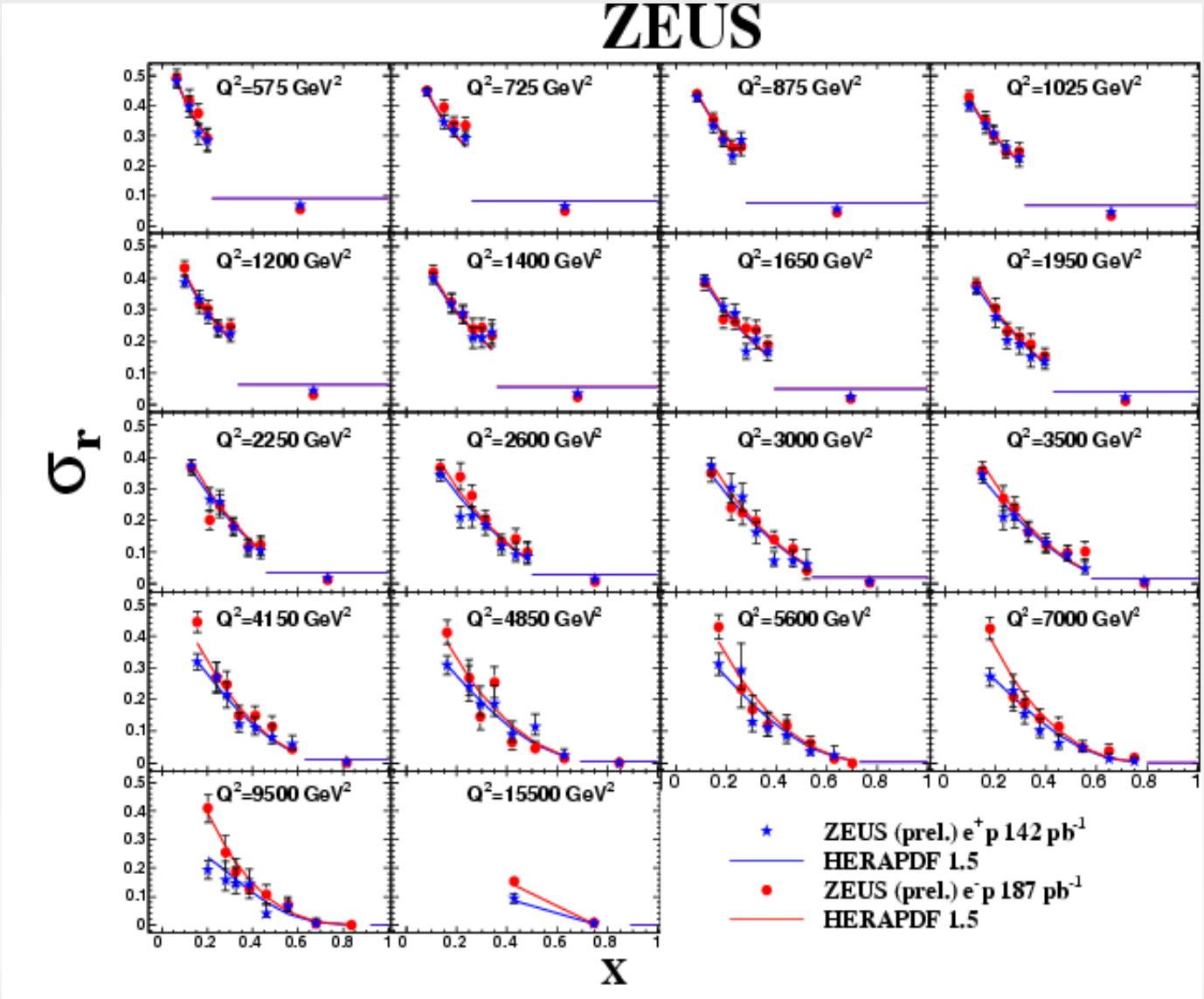


Published 2006

- Zeus 17 pb-1 (HERA I)
- Solid Circles : x from jets
- Open Circles : no jet reconstructed
- Integrated Cross secion in x calculated
- compared to CTEQ6M

Neutral Current high-x Cross-Sections

HERA 11 Reduced Cross sections



ZEUS-prel-11-004

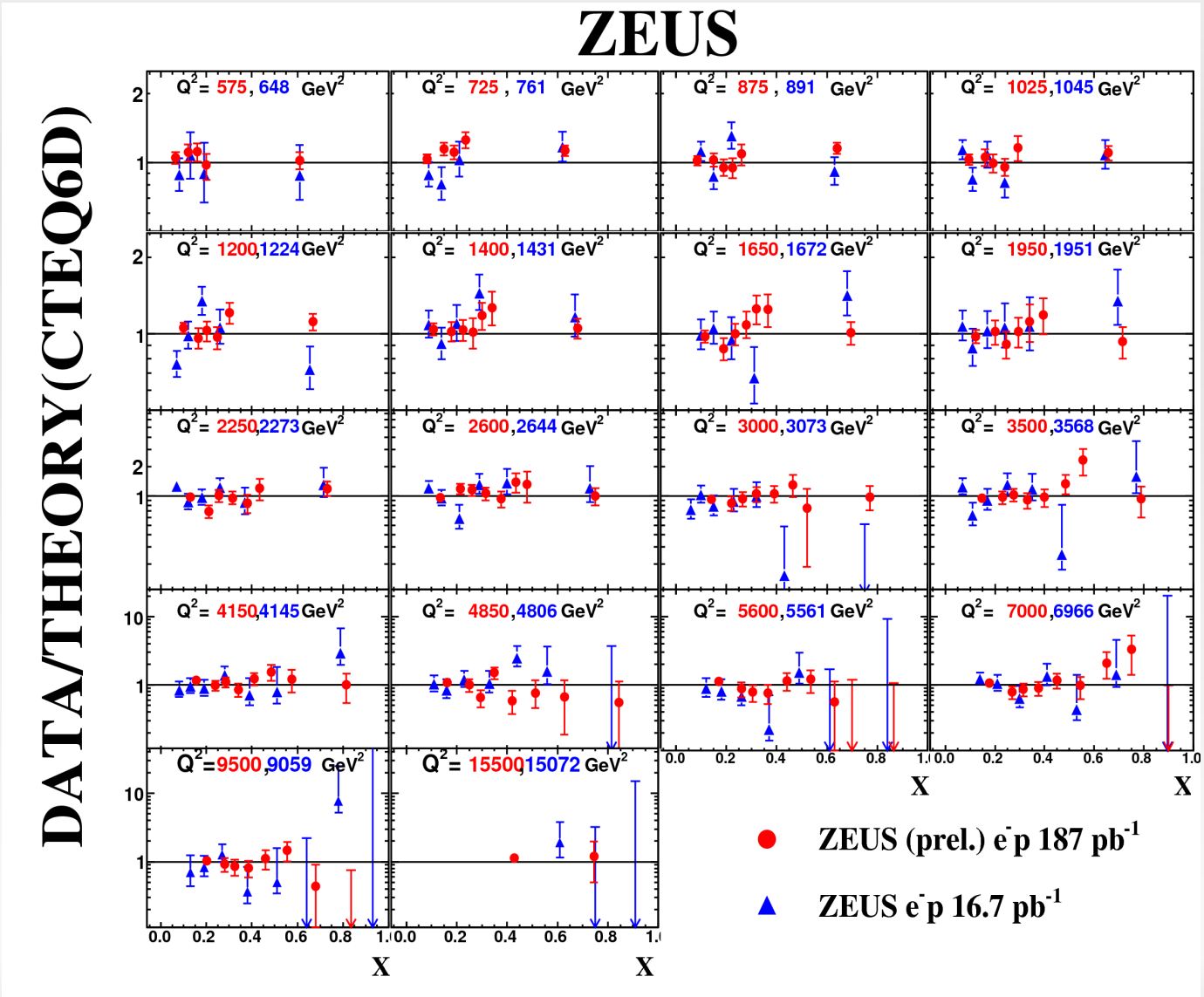
- **Solid stars : e+p NC high-x**
- **Circles : e-p high-x NC ZEUS (prel) data**
- **Commpared to HERAPDF**
- **In Good Agreement with SM expectations**

- **xF_3 Clearly visible at high-Q^2**

Completes high – x HERA II analysis

Neutral Current high-x Cross-Sections

HERA I- II Cross Sections



- e-p HERA-I : 16.7 pb^{-1}
- e-p HERA – II : 187 pb^{-1}
- ~ 10 times LUMI
- More bins
- dd bins span higher-x

SM agrees ..... BSM @ HERA ?

Contact Interactions : eqeq (DESY-II-114)

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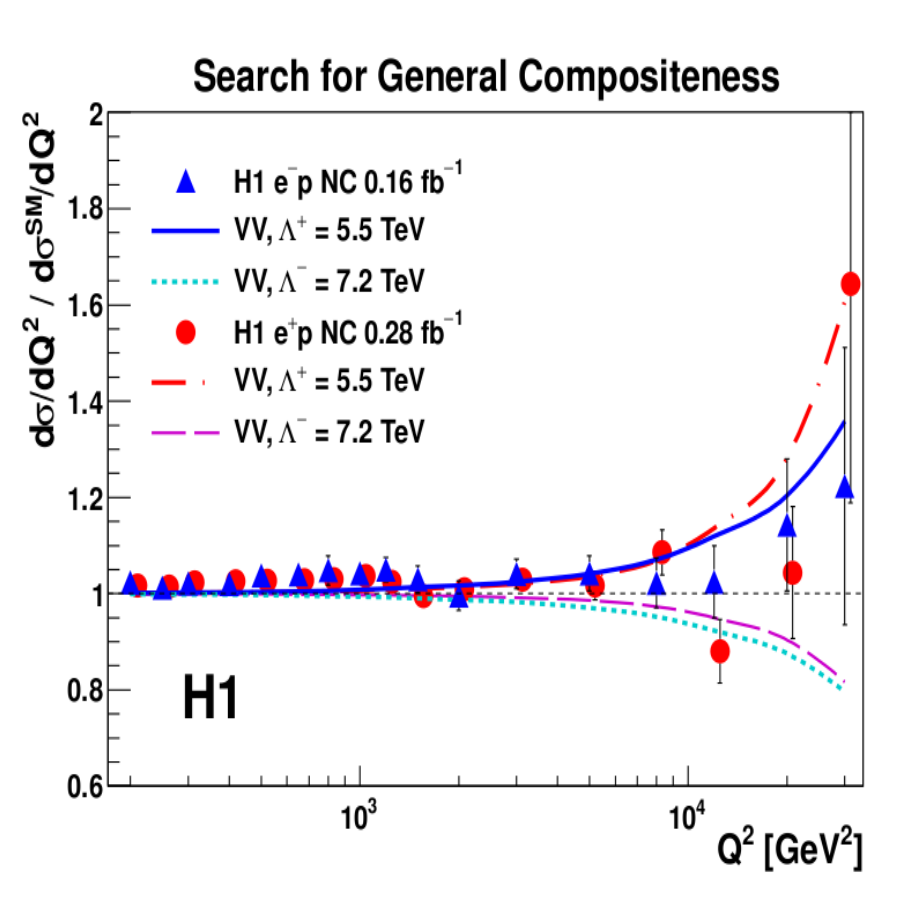
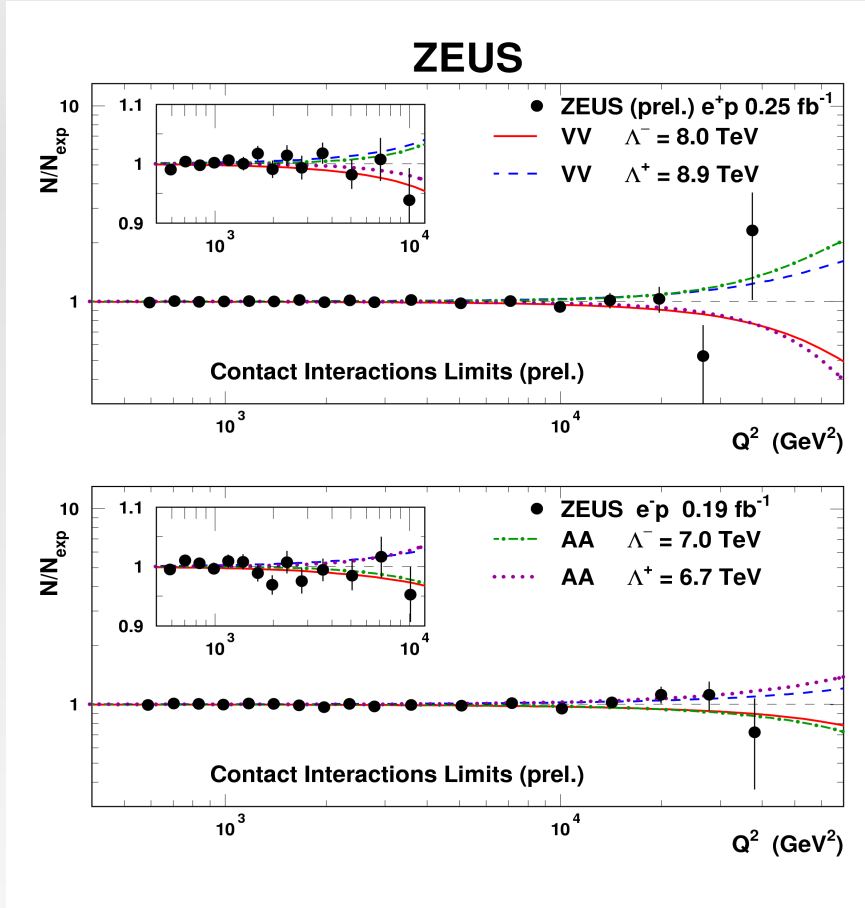
ZEUS-prel-09-013





- VV compositeness scale model
- Both signs of chiral cofficients considered

More on limits : See backup

SM agrees ..... BSM @ HERA ?

Heavy Leptoquarks (DESY-II-123)

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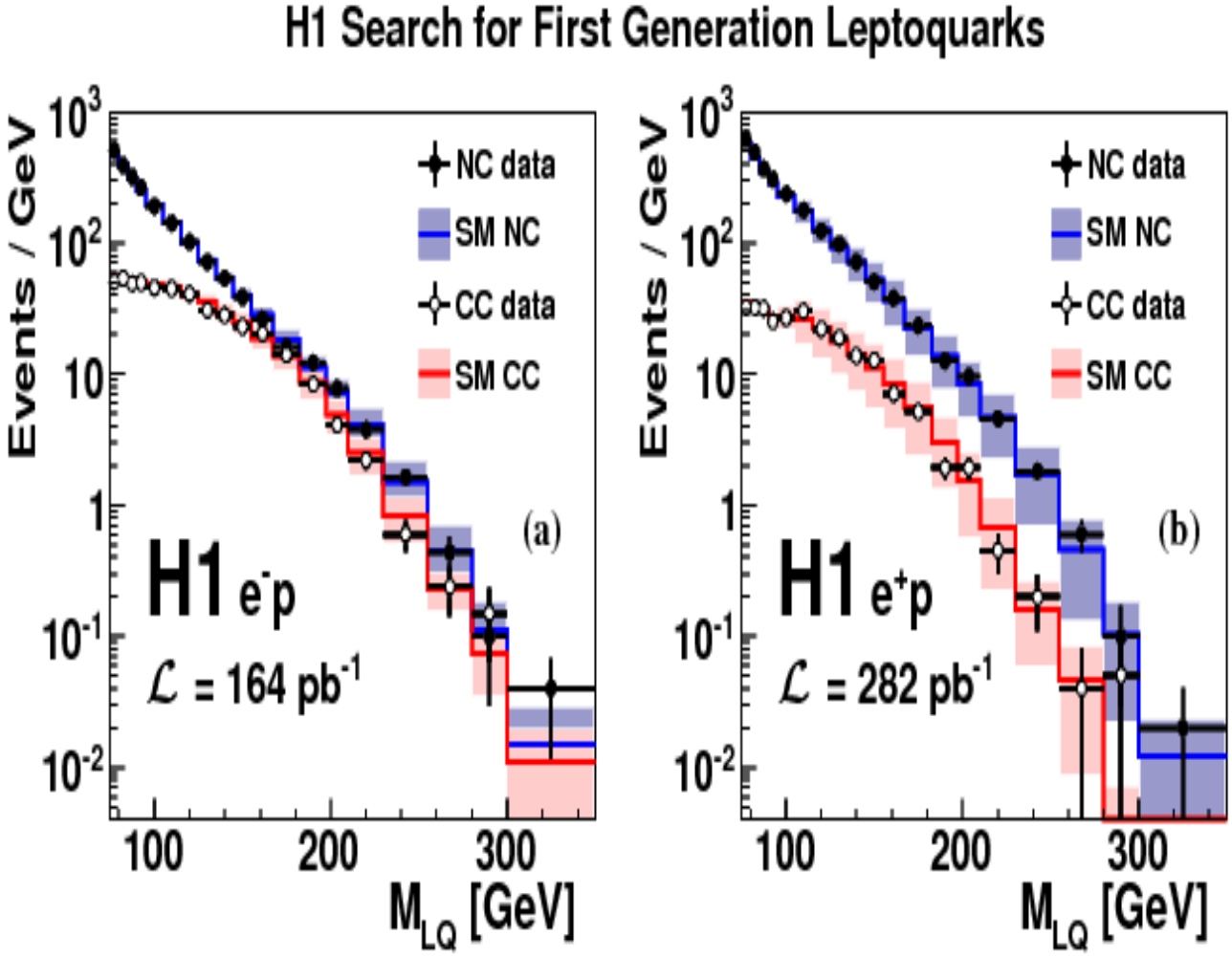

- **NC HERA (H1) :**
- **CC HERA (H1) :**
- **No deviations from SM**
- **~450 pb^{-1} data used**

- **Limits placed for $\lambda = 0.3$, $M_{lq} <= 800$ GeV discarded for 1st generation LQ**

More on limits & ZEUS results see backup

SM agrees ..... BSM @ HERA ?

Quark radius

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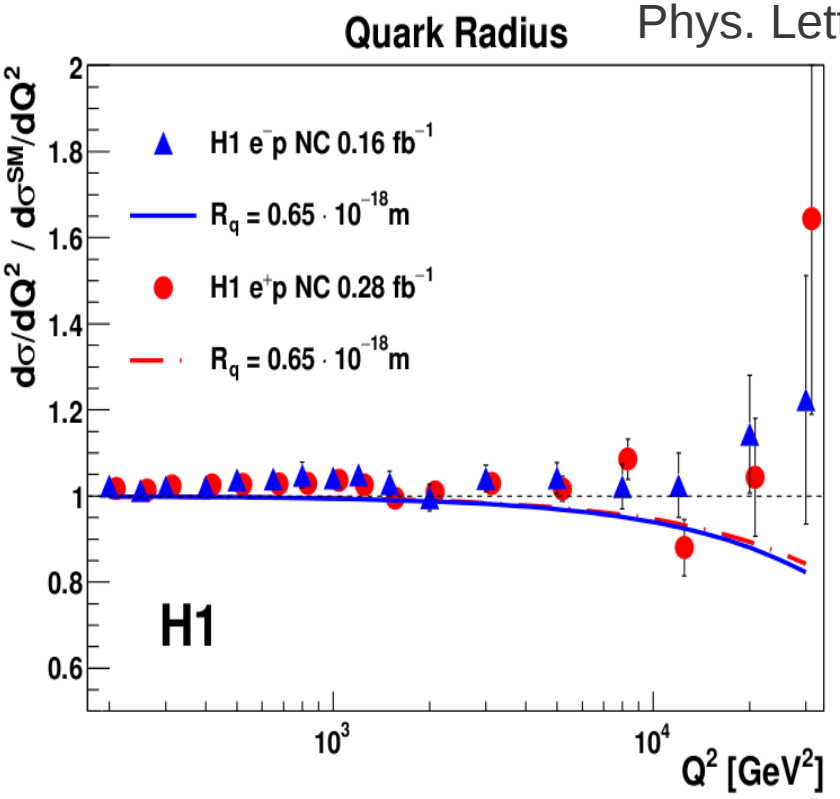
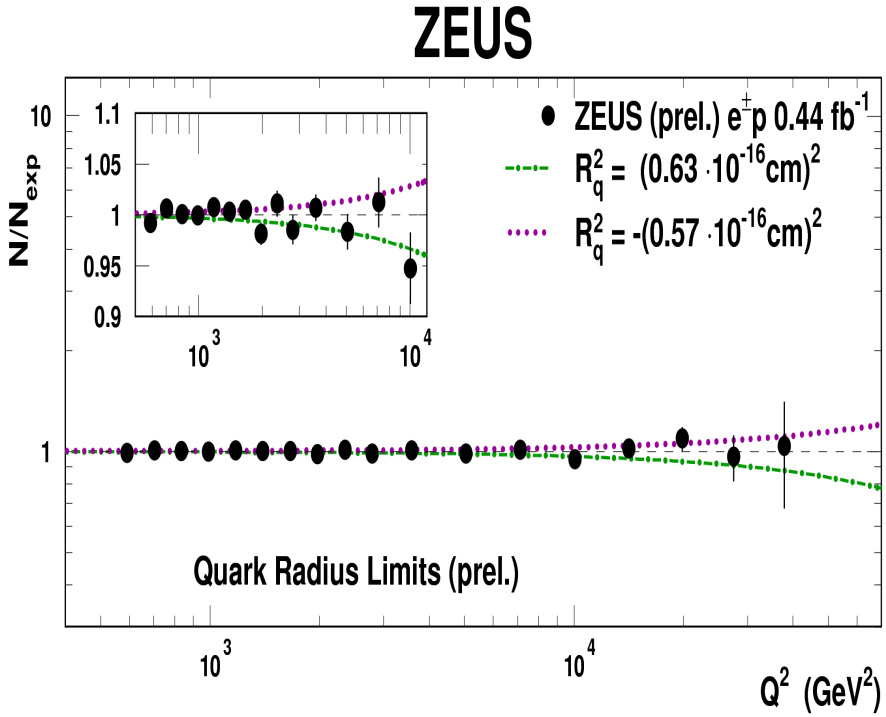


ZEUS-prel-09-013



- $R_q < 0.65 \cdot 10^{-18}$ m

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

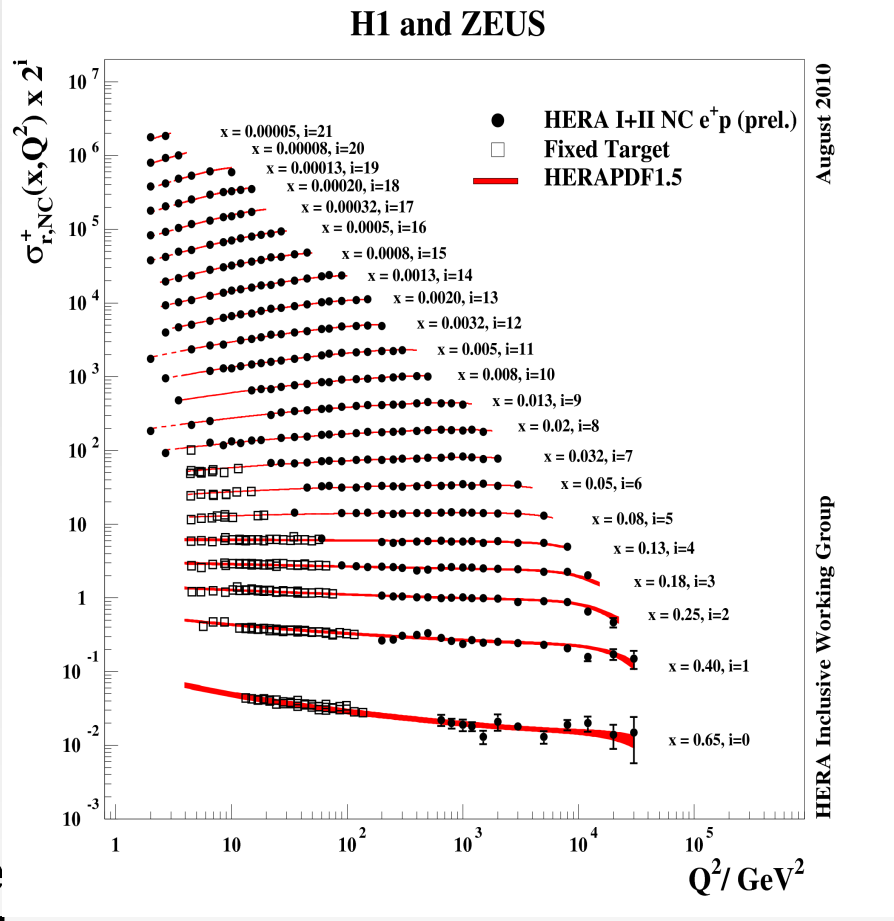
Destructive for SM expectations

- $R_q < 0.63 \cdot 10^{-18}$ m

Summary

HERA-II

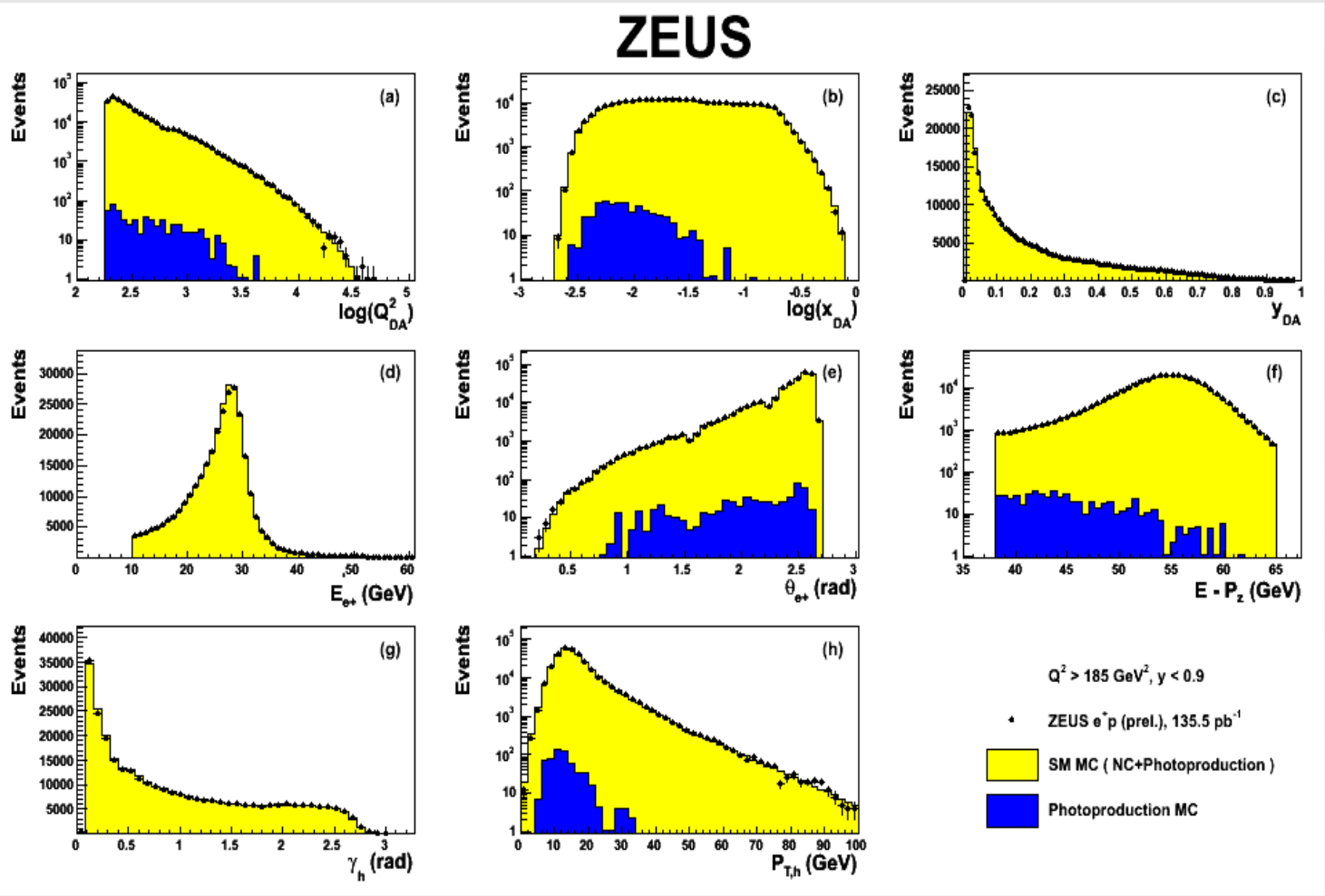
- HERA II Inclusive high -Q2 results almost finished
  (some of the data sets still preliminary)
- HERA II ZEUS high-x analysis close to complete
  (NC e-p & e+p high-x results almost final)
- EW theory tested well in both NC and CC sectors



- Results will constrain the uncertainities in the Unpolarised NC cross sections to be included
  NC high-x Cross sections will help constrain the PDFs at high-x.

New : high-Q2 Neutral Current Cross-Sections

Control Plots

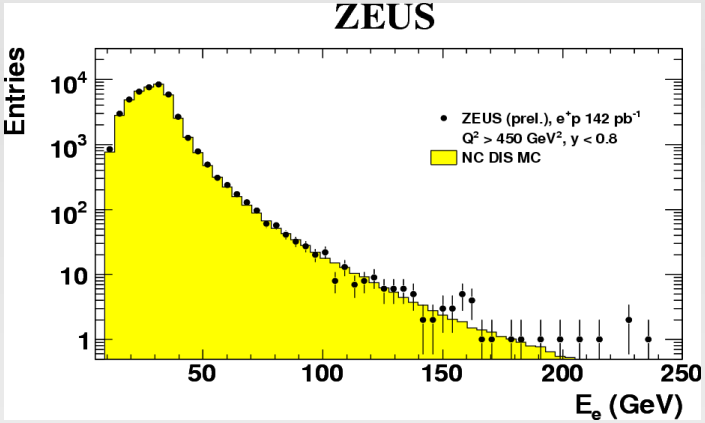


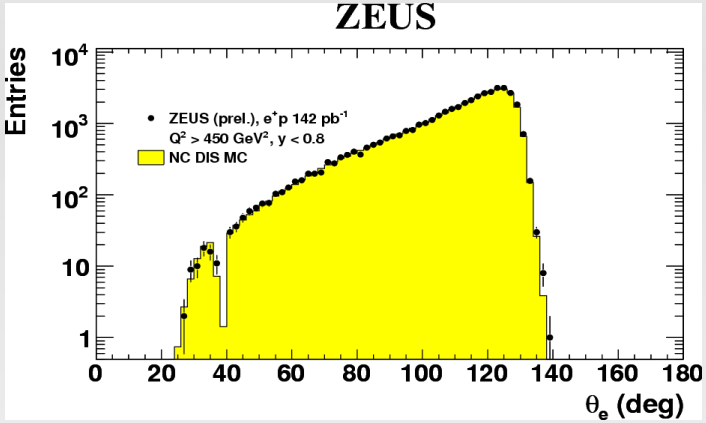
- e^+p NC 135.5 pb^{-1}
- ZEUS-prel-11-003
- Pe = +32%
  L = 78.8%
- Pe = -36%
  L = 56.7%

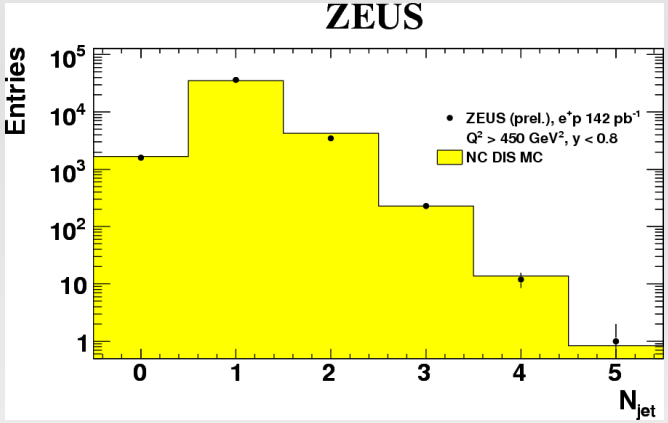
- Kinematic Range
  Q2 > 185 GeV2
  y < 0.9
- Data well described

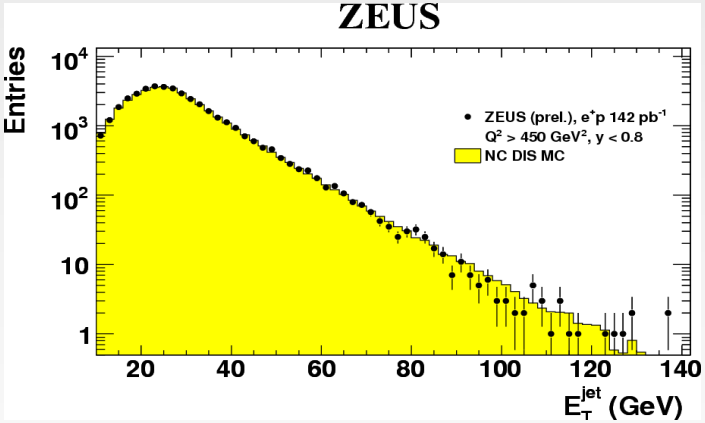
New : high-x Neutral Current Cross-Sections

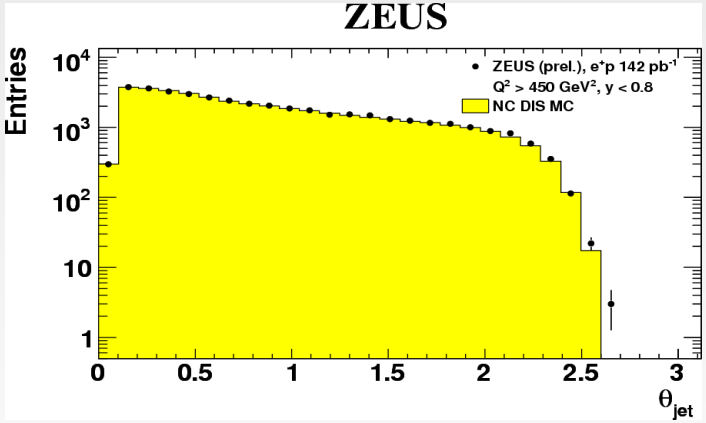
Control Plots I









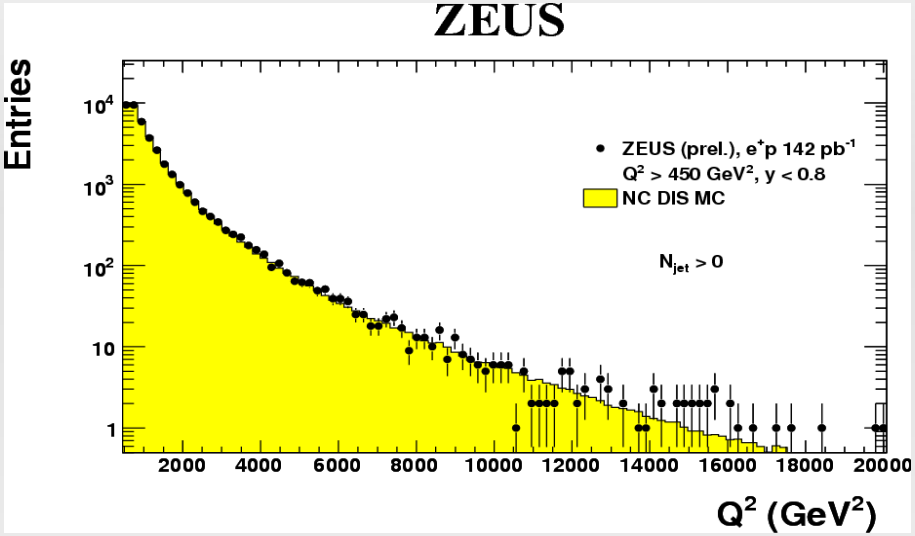


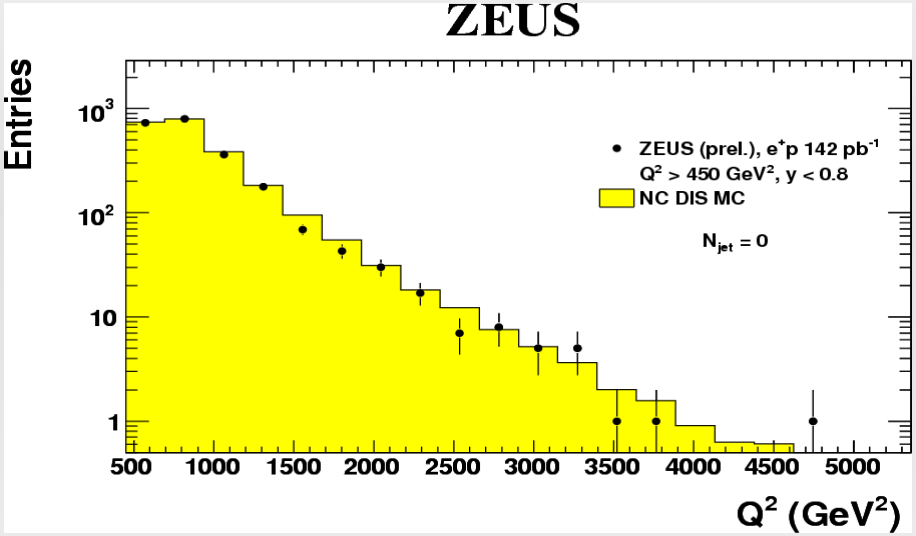
- e^+p NC 142 pb^{-1}
- ZEUS-prel-11-004

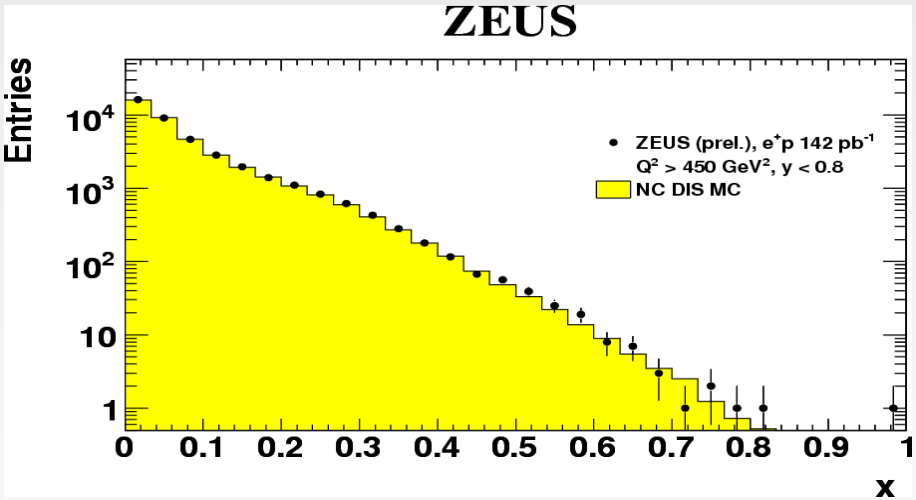
- kinematic Range
  Q2 > 450 GeV2
  y<0.8
- Data well described

New : high-x Neutral Current Cross-Sections

Control Plots II



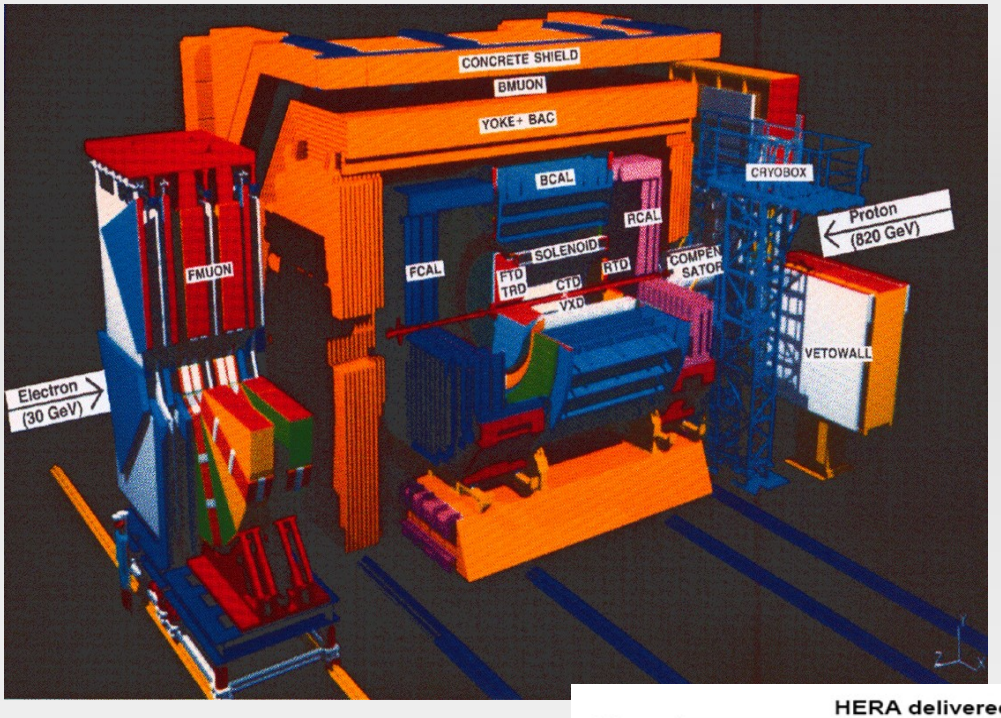


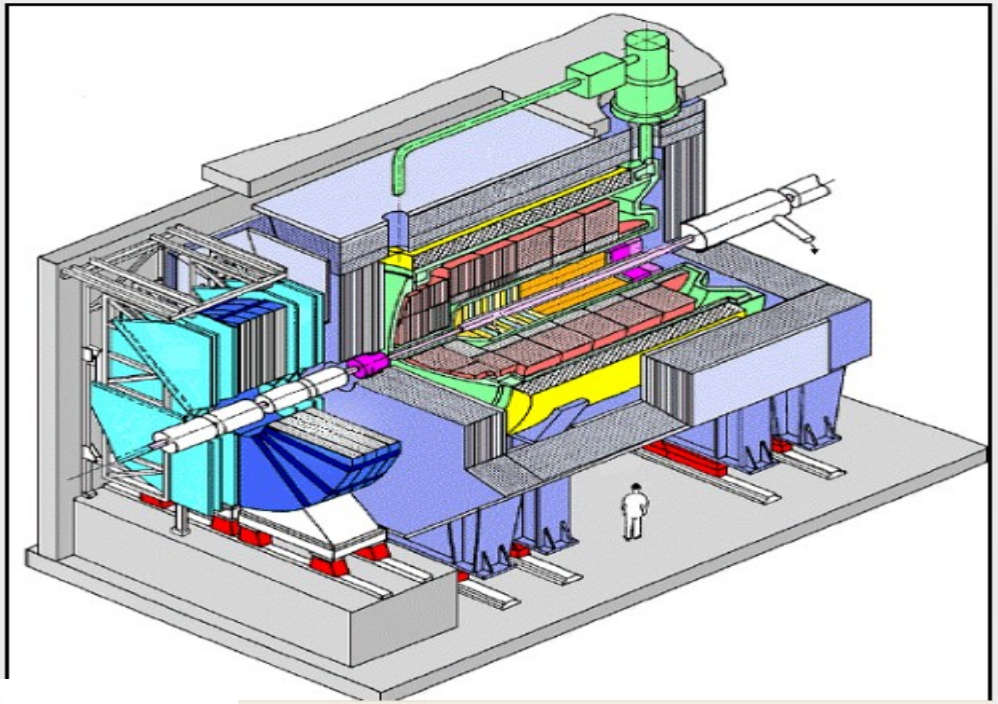


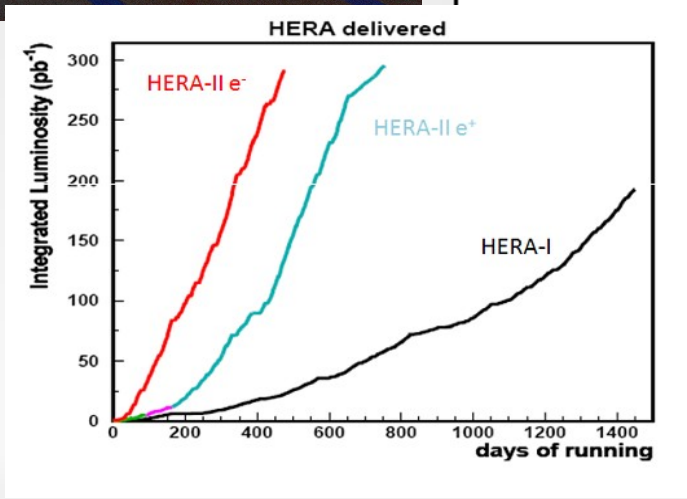
- e^+p NC 142 pb^{-1}
- ZEUS-prel-11-004

- kinematic Range
  Q2 > 450 GeV2
- Data well described

H1 & Zeus at HERA

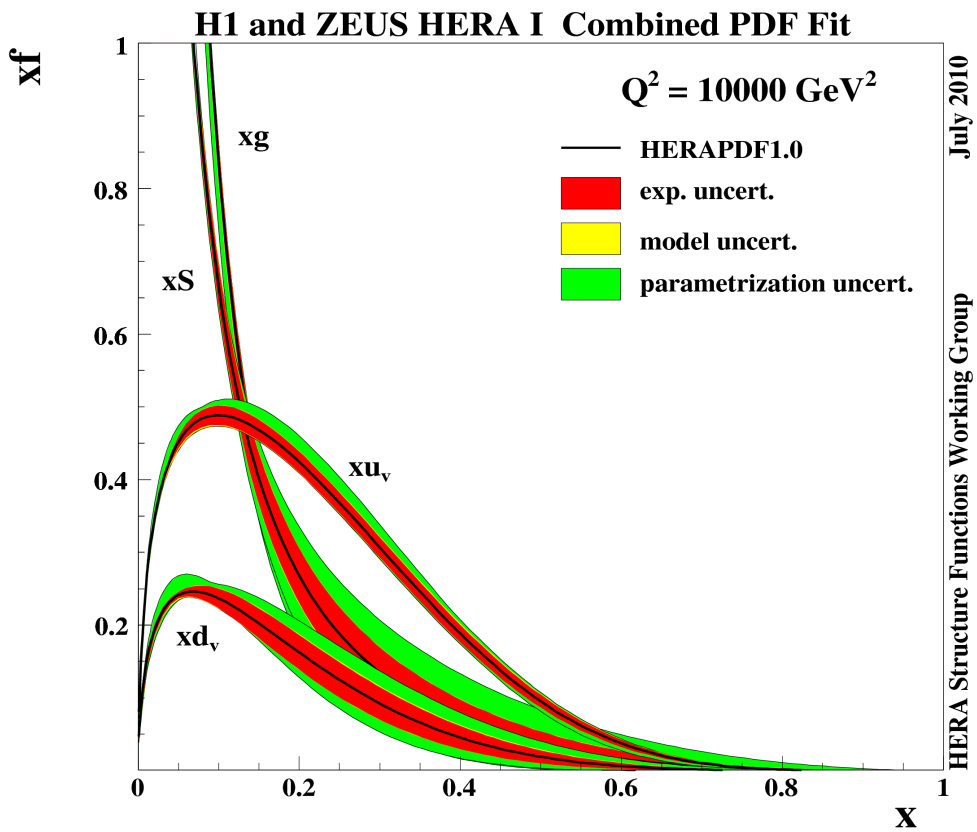


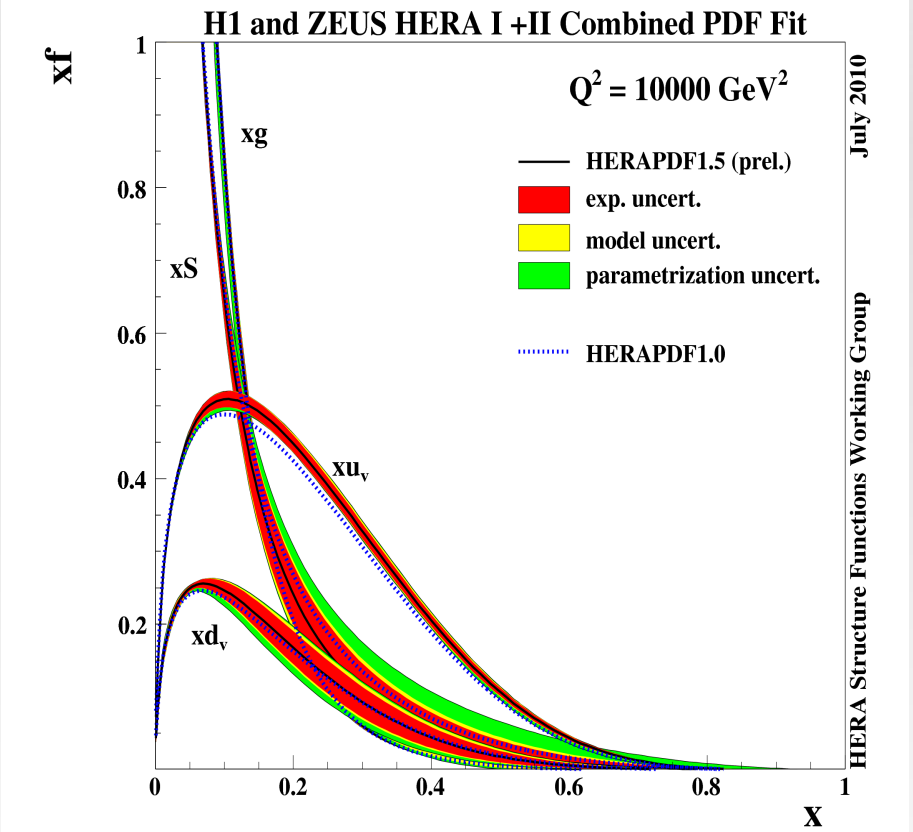




DIS & Proton Structure

HERAPDF1.5





- Most precise Zeus e-p (135.5 pb-1) NC will help better contraints

Charged Current Cross-Sections

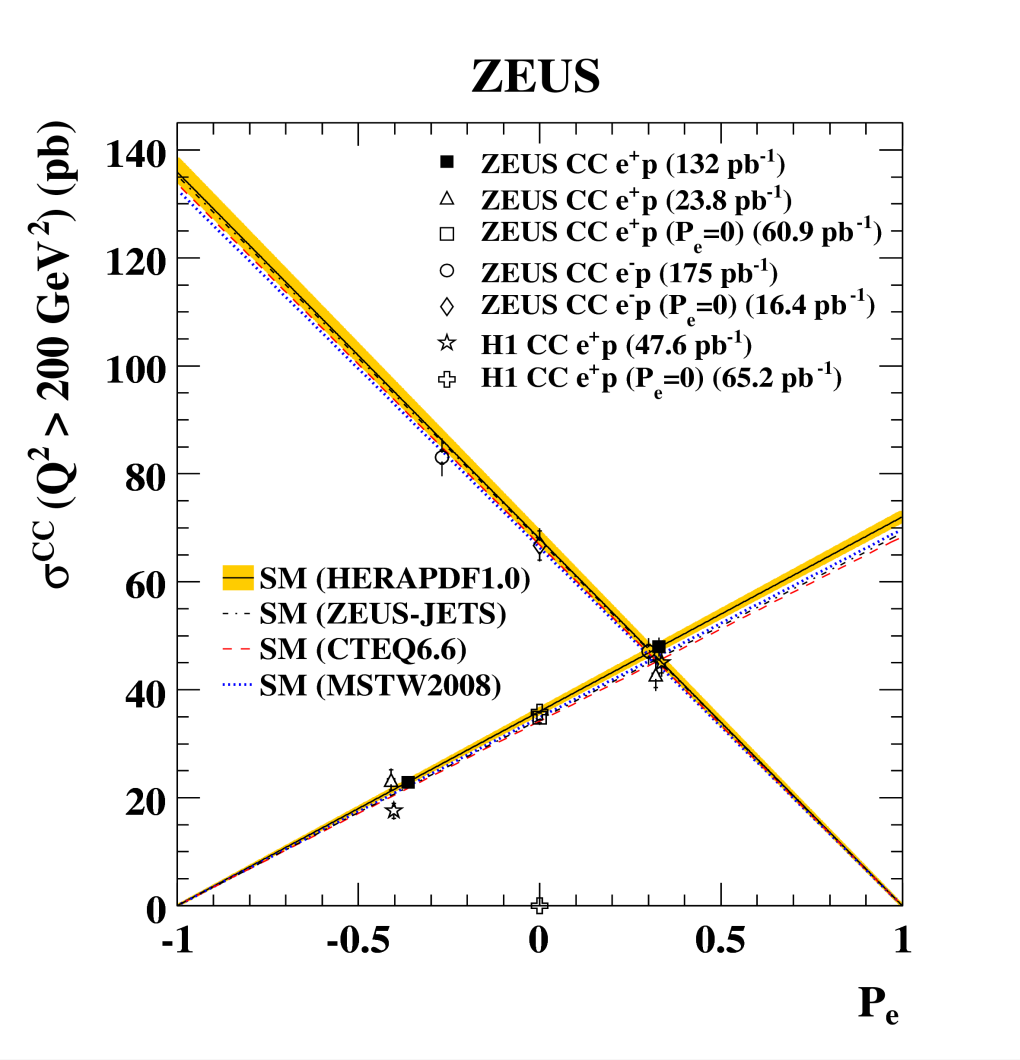
Eur. Phys. J.C. (2010) 70 : 945-963

- Total CC xsec as a function of P_e
- Previous e^-p and e^+p results also shown
- Excellent test of EW theory
- SM describes data well

- CC e^+p total Cross section consistent with 0 for $P_e = -1$
- For CC e^-p, consistent with 0 for $P_e = 1$

- Limit placed on M_{W_R}, consistent with other experiments

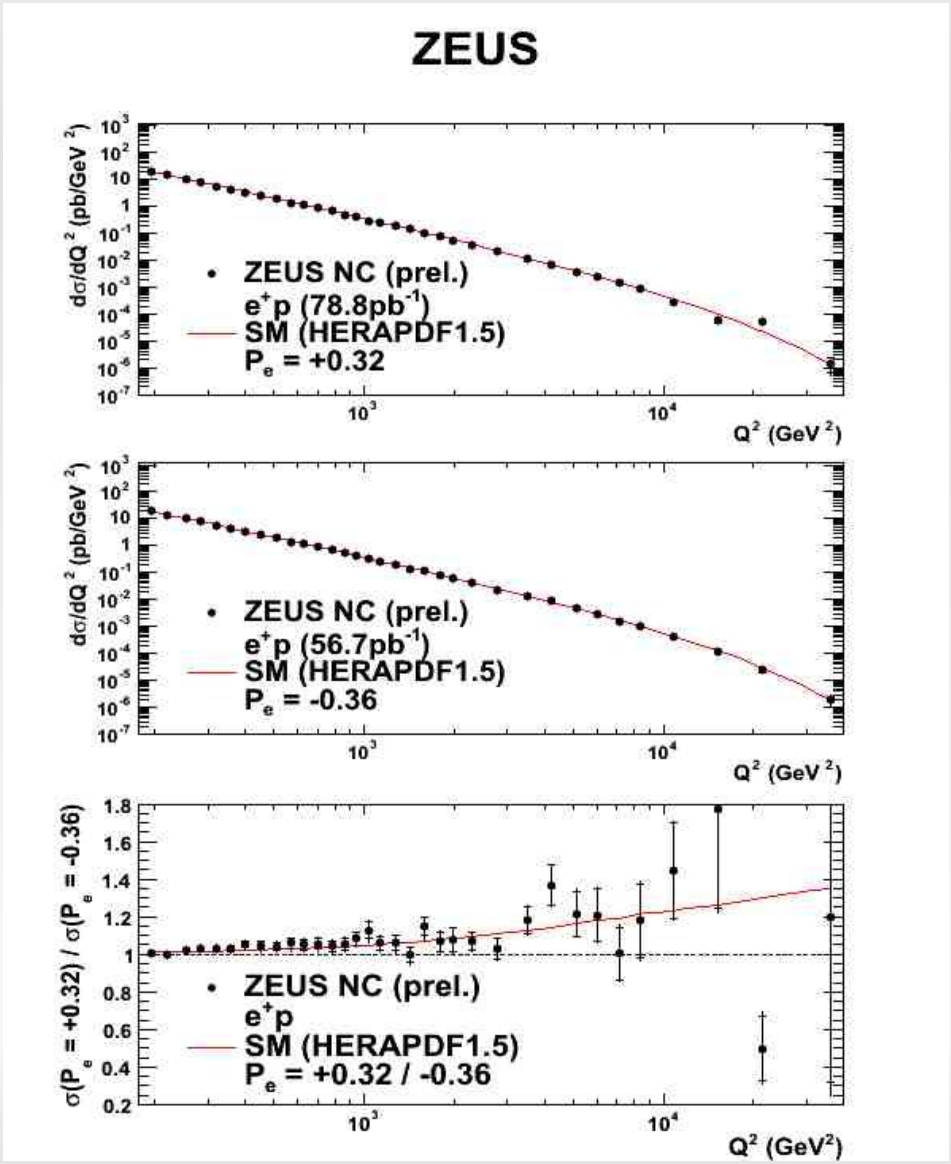
  $M_{W_R} > 198$ GeV at 95% CL



New : Neutral Current Cross-Sections

Zeus-prel-11-003

- e^+p NC 135.5 pb^{-1}



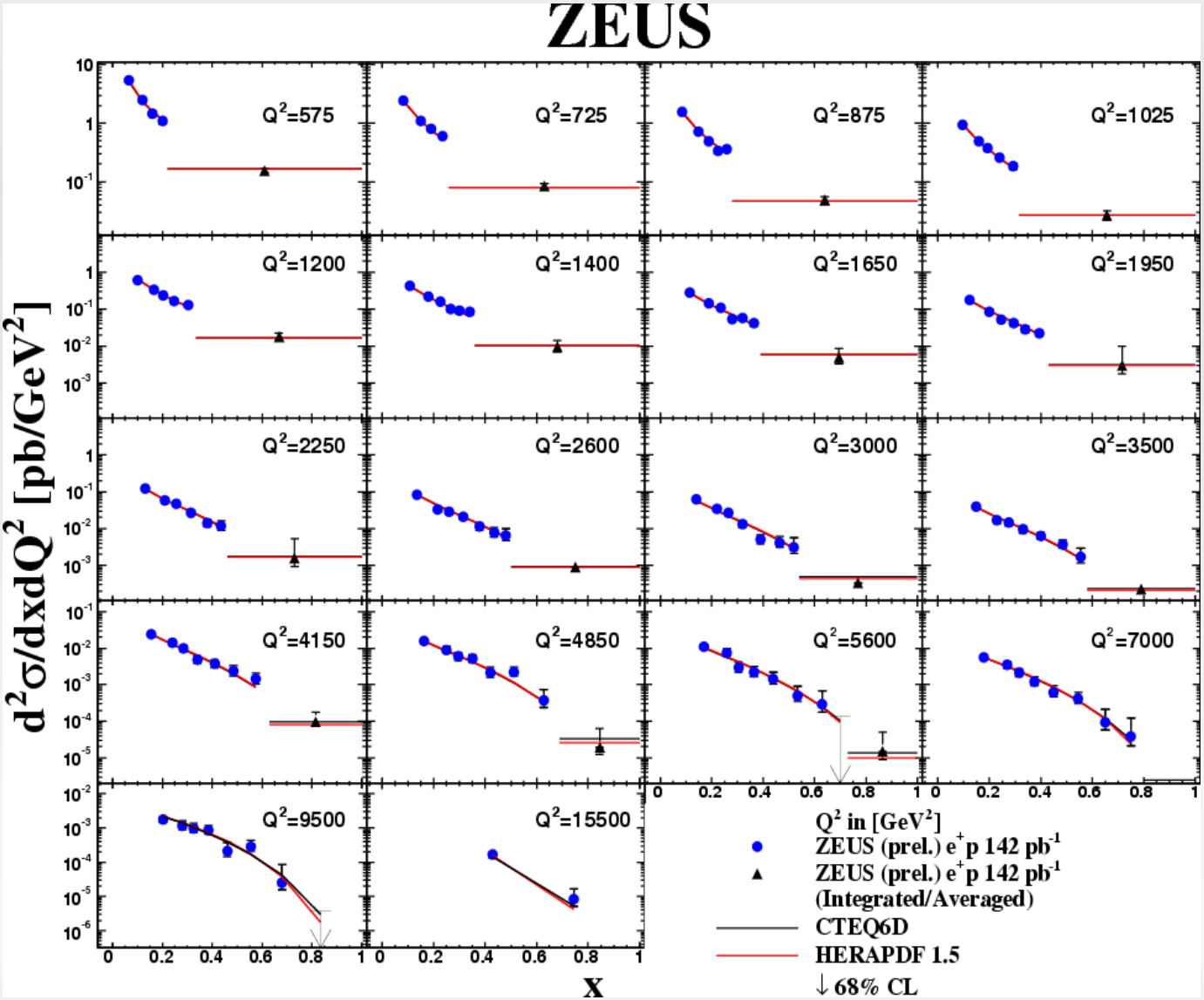
⇐ **e+p NC RH polarised e beam**

⇐ **e-p NC LH polarised e beam**

⇐ **Difference in LH & RH beam Clearly visible**

Neutral Current high-x Cross-Sections

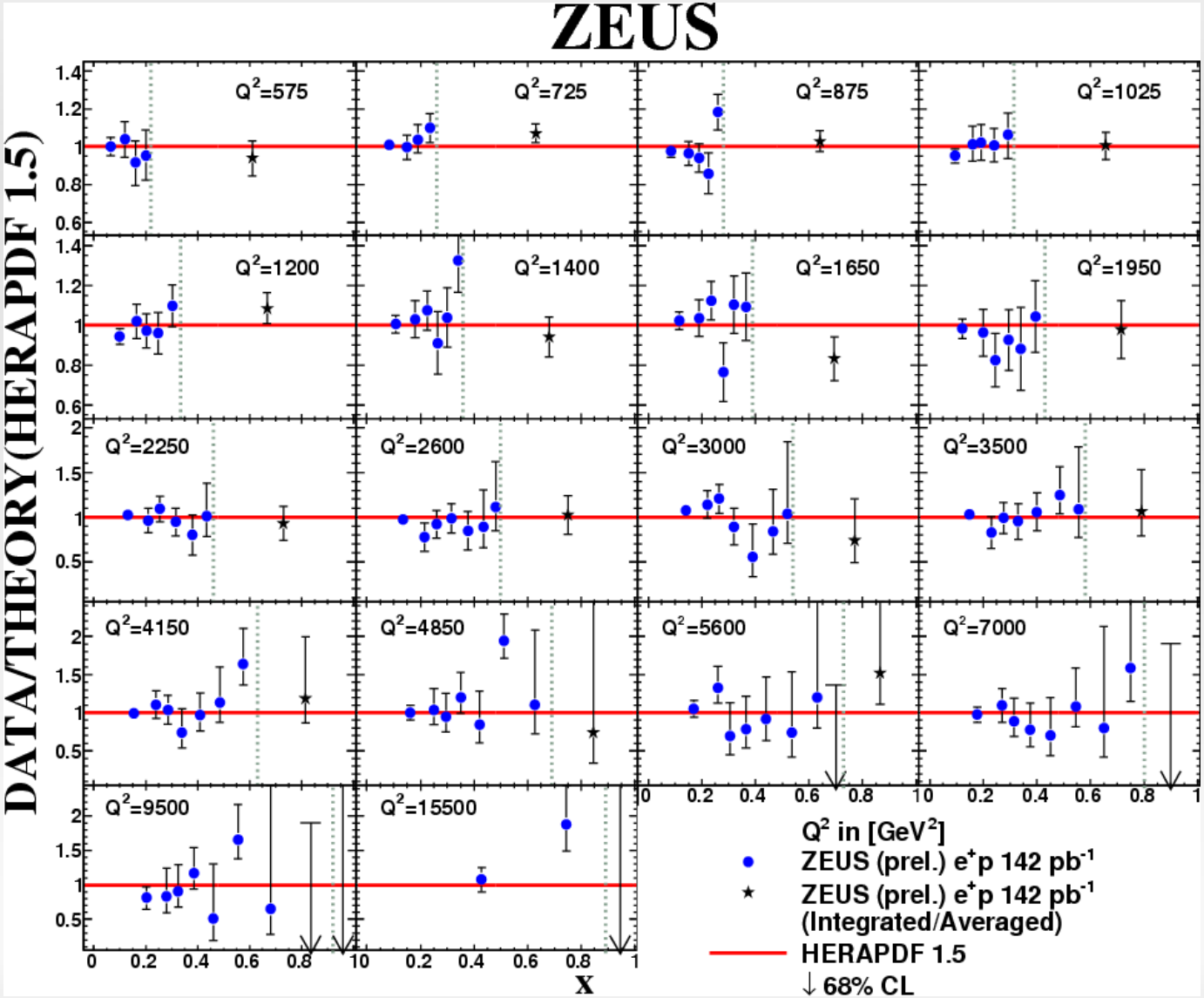
Cross Sections



- **Solid Circles** : x from jets
- **Black Triangles : no jet reconstructed**
- **Integrated Cross secion in x calculated**
- **Compared to HERAPDF & CTEQ6D**

New : Neutral Current high-x Cross-Sections

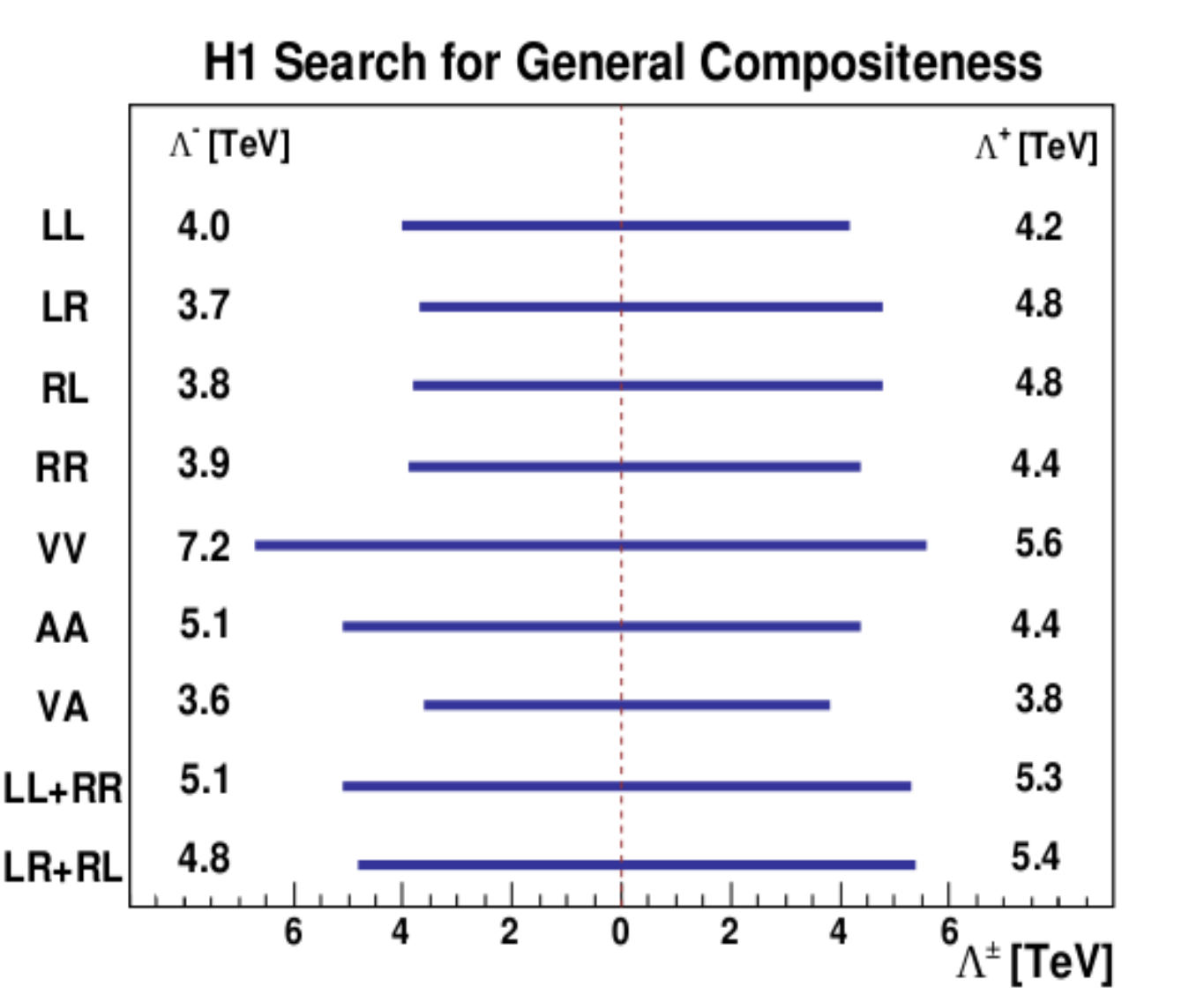
Comparison to theory



- **Solid Circles** : x from jets
- **Black Stars : no jet reconstructed**
- **Commpared to HERAPDF**
- **In Good Agreement with SM expectations**

SM agrees ..... BSM @ HERA ?

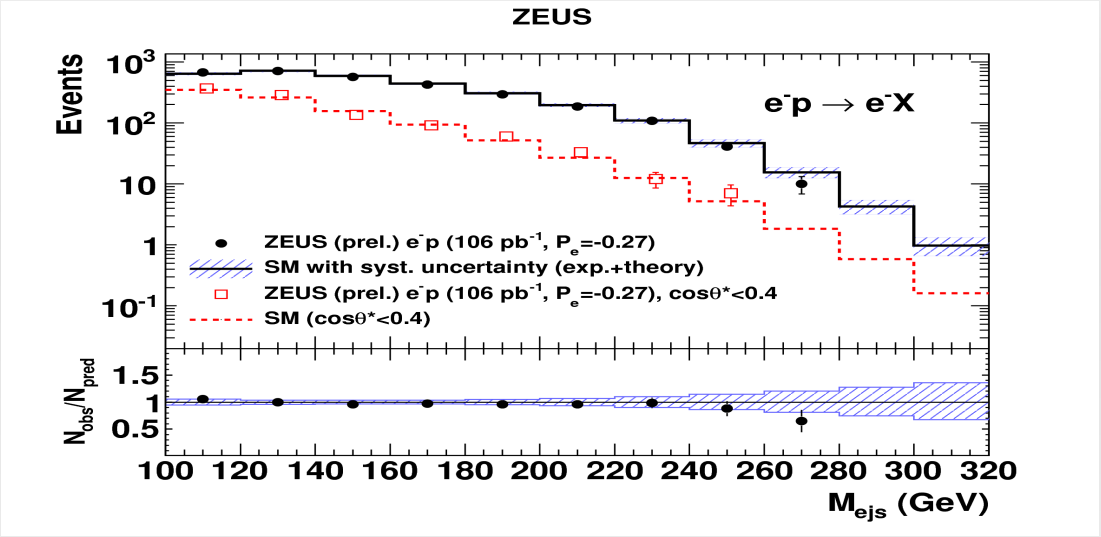
Contact Interactions : eeqq (DESY-11-114)

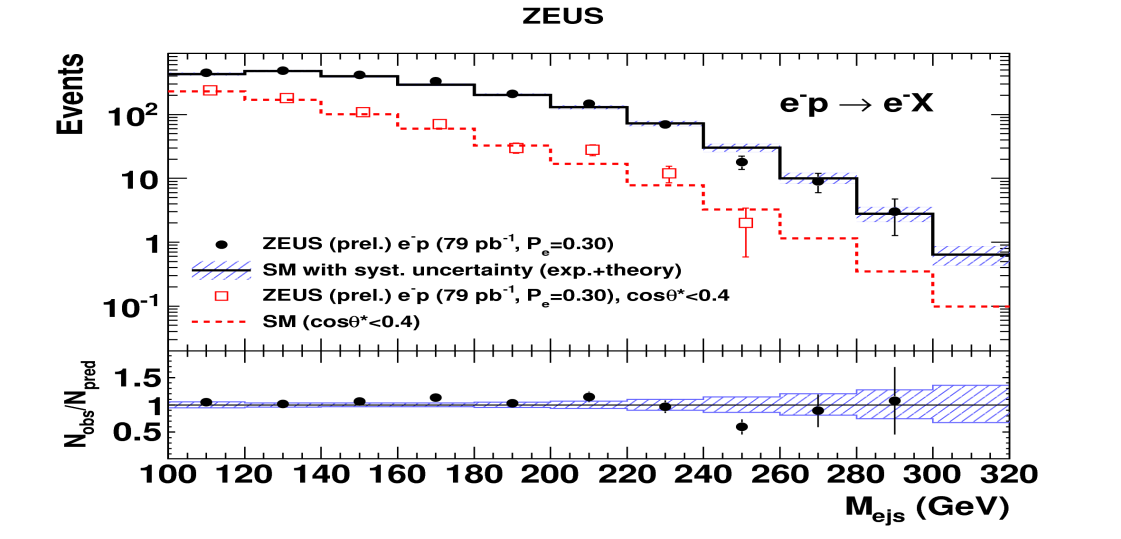


- Full HERA for H1 taken
- Both signs of chiral cofficients considered
- Lower limits on compositeness scale for various chiral models with 95 % CL

SM agrees ..... BSM @ HERA ?

Heavy Leptoquarks (ZEUS-prel-11-008)

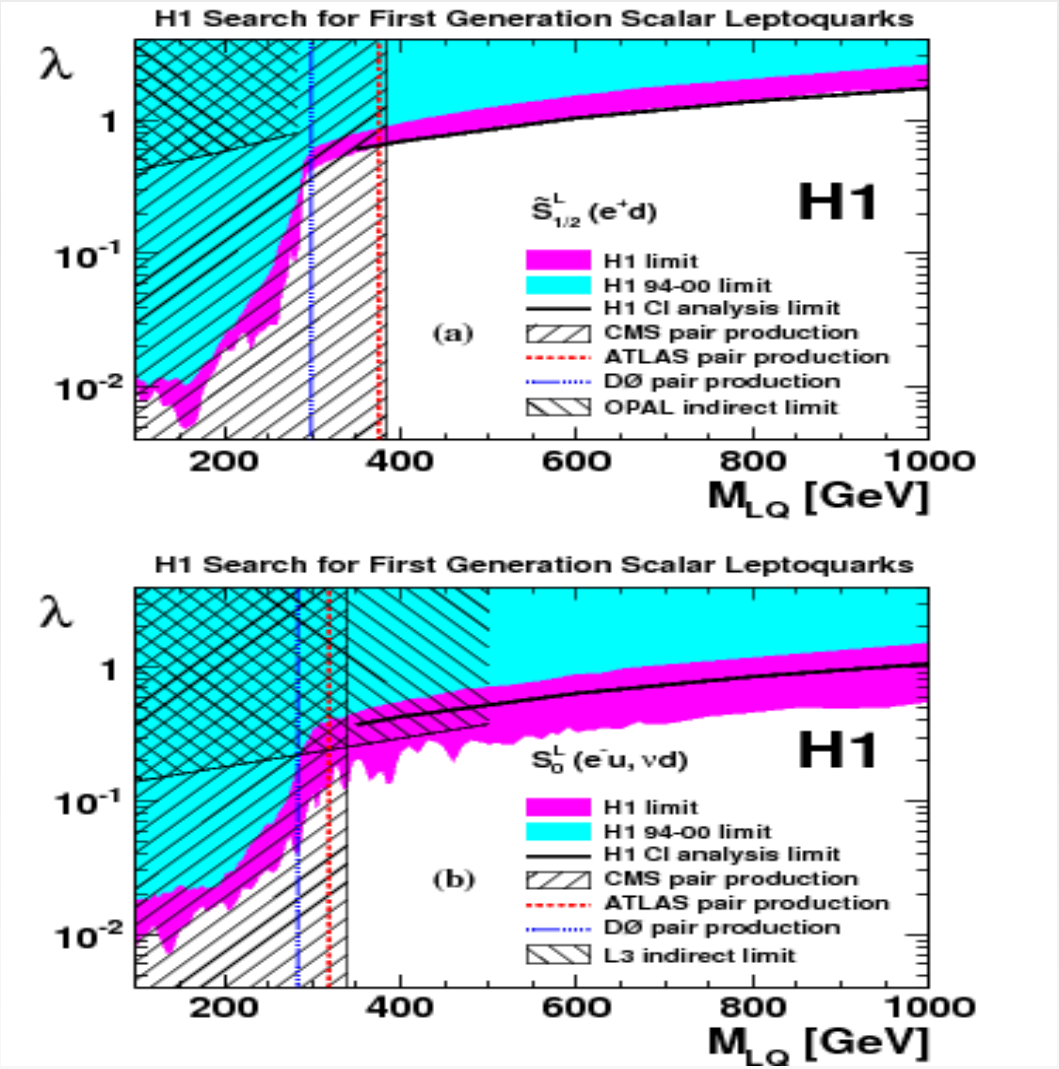




More on limits see backup

SM agrees ..... BSM @ HERA ?

Heavy Leptoquarks Limits (DESY-11-123)

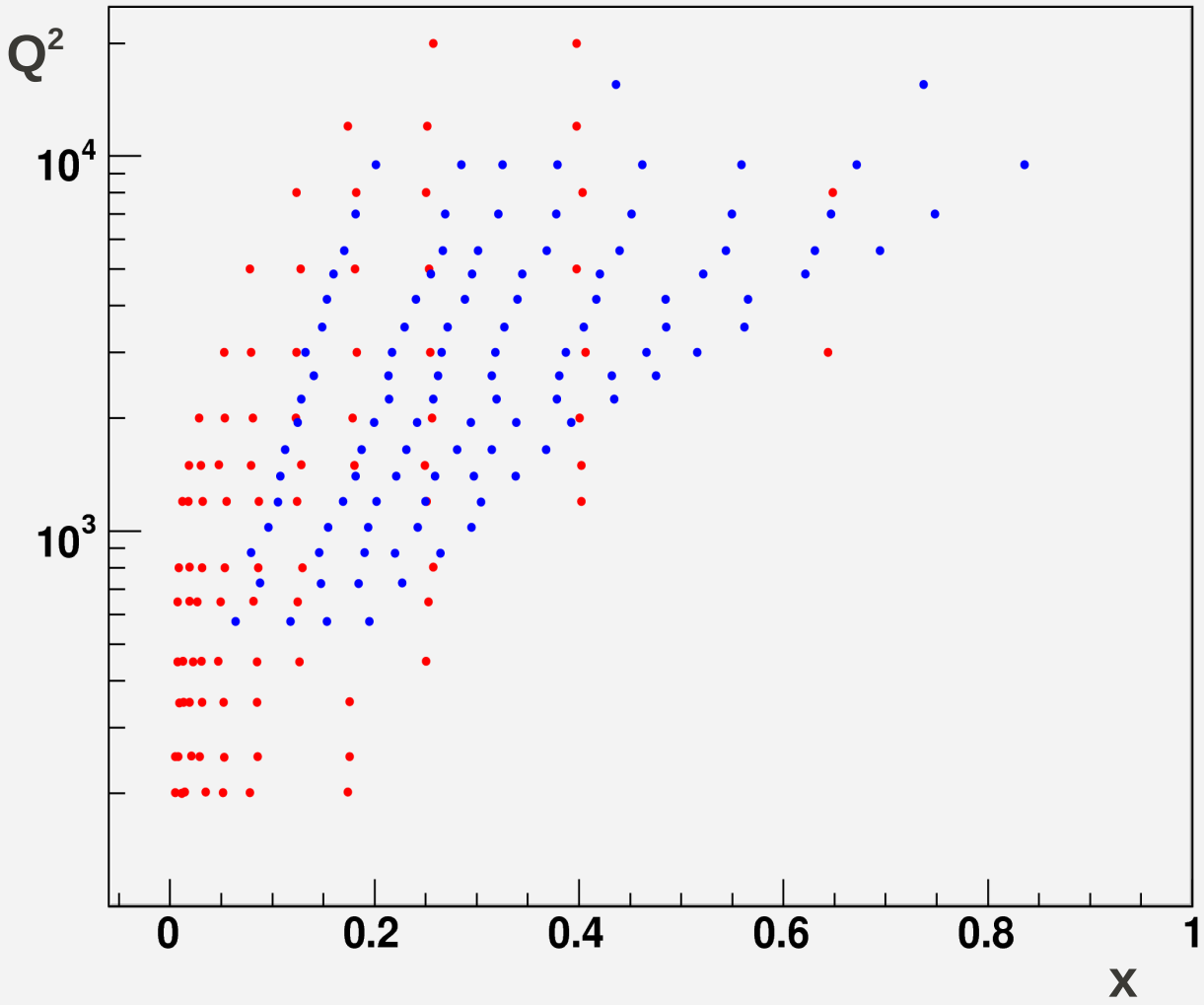


- **NC HERA (H1) :**
- **CC HERA (H1) :**
- **No deviations from SM**
- **~450 pb-1 data used**

- **Limits placed for $\lambda = 0.3$, $M_{lq} <= 800$ discarded for 1st generation LQ**

Neutral Current high-x Cross-Sections

Binning Comparison



- High-x dd bins
- High Q2 dd bins

- More bins at High Q2 & x where PDFs are falling steeply