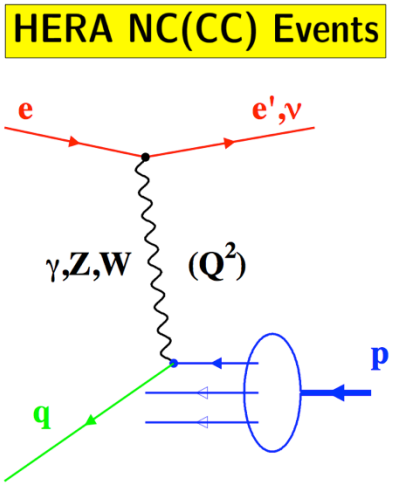
Recent HERA results on proton structure

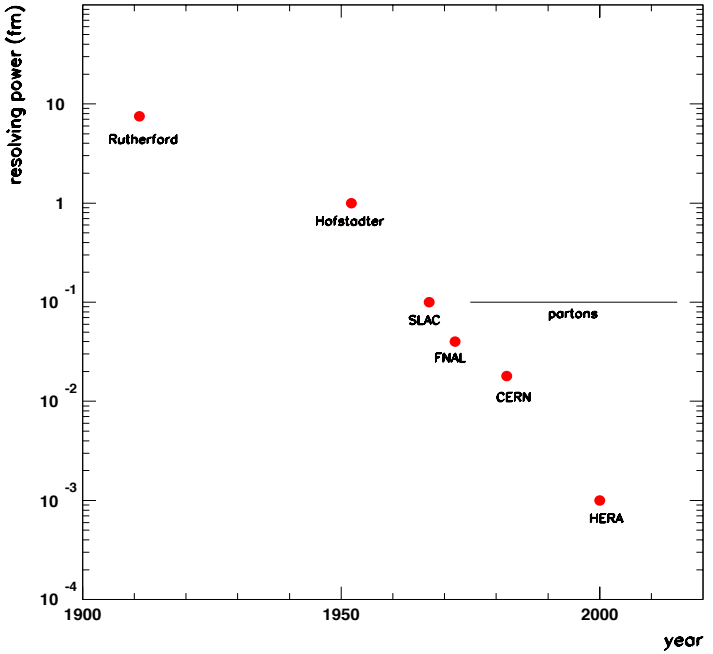
Aharon Levy, Tel Aviv University

On behalf of the H1 and ZEUS collaborations

Resolving Structure of Matter

HERA, e (27.5 GeV) p (920 GeV) collider to study the proton structure with a high resolving power. (~ 10^{-3} fm)





Kinematics:

$$Q^2 = -q^2 = -(k-k')^2$$

Boson virtuality

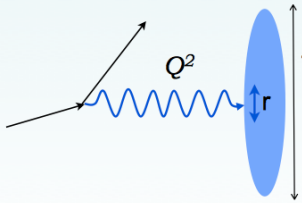
$$x = \frac{Q^2}{2p\cdot q}$$

Bjorken variable

$$y = \frac{p\cdot q}{p\cdot k}$$

Inelasticity

4-momentum transfer Q^2 defines distance scale r at which proton is probed

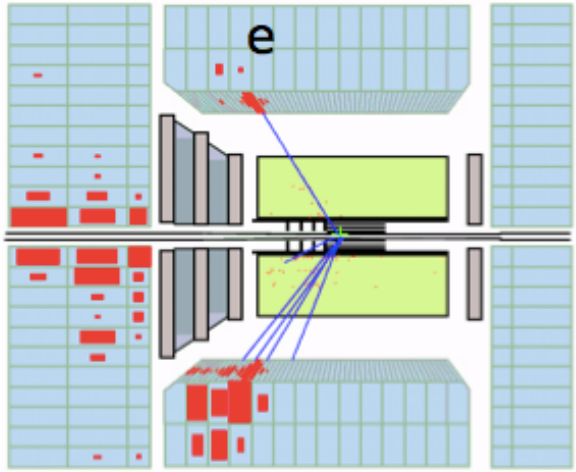


$r \approx \hbar c/Q = 0.2[fm]/Q[GeV]$

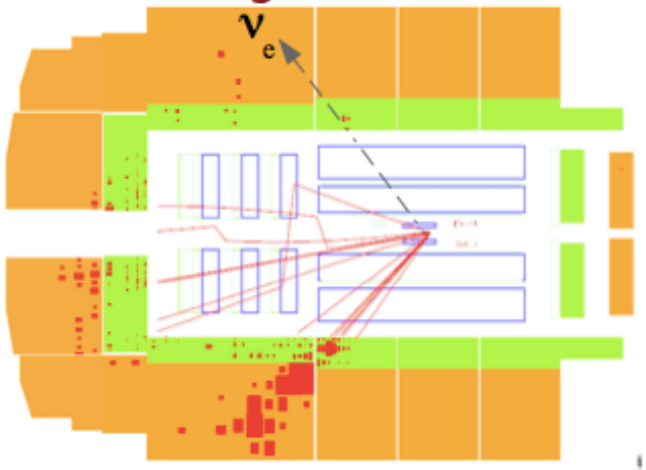
ep Scattering at HERA

DIS cross sections provide an access to parton distribution functions in proton:

Neutral Currents



Charged Currents



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

dominant contribution

important at high Q^2

sizable at high y

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

PDFs

LO: $F_2 \approx x\sum e^2_q(q+\bar{q})$ (in NLO $(\alpha_s\, g)$ appears)

$xF_3 \approx x\sum 2e_q a_q(q-\bar{q})$

In LO e^+/e^- charged current cross sections are sensitive to different quark densities:

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

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

Structure of talk

- **15 min talk → assume talk to experts**
- **Present only new recent results not shown so far**
- **Two new results:**

  measurement of F_L by H1 and ZEUS

  H1: $1.5 \le Q^2 \le 800$ GeV^2, ZEUS: $5 \le Q^2 \le 110$ GeV^2

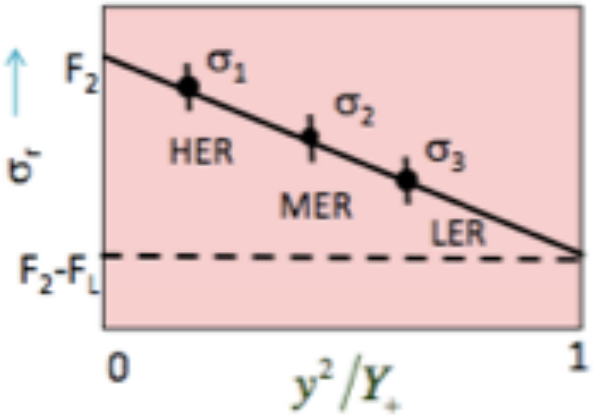
  measurement of inclusive cross section at high x (ZEUS), $725 \le Q^2 \le 15500$ GeV^2

How to measure F_L?

Measure reduced cross sections

$$\sigma_r = F_2(x,Q^2) - (y^2/Y_+)F_L(x,Q^2)$$

at same x, Q^2 but different $y=Q^2/xs$ → vary s

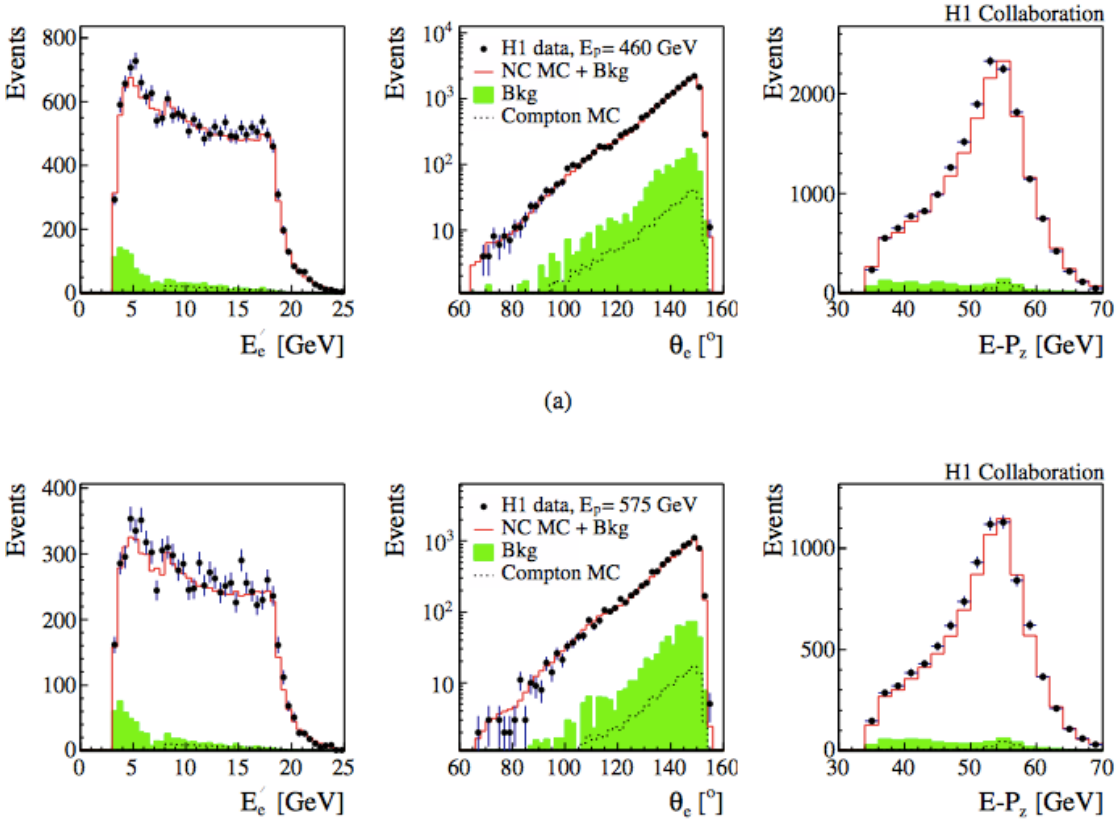


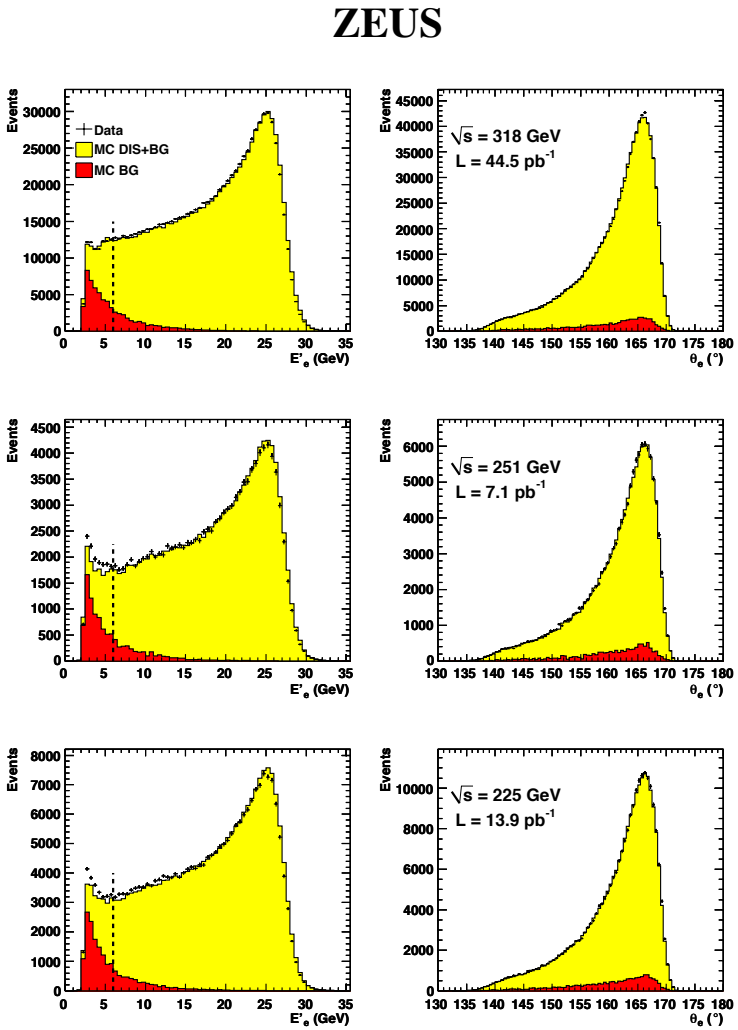
- Change proton beam energy to change s
- Large lever arm in y^2/Y_+
- Measurement at high y in LER

- **Intercept of the fit gives F_2**
- **Negative slope gives F_L**

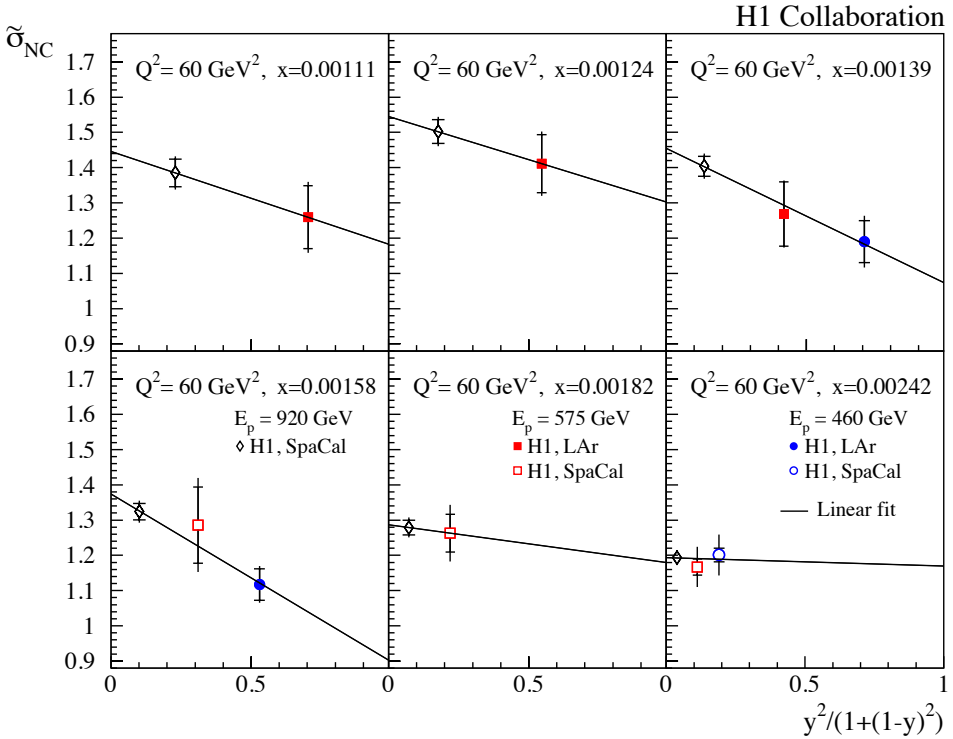
as $y = 1-E'_e/E_e(1-\cos\theta)$ → high y means low E'_e

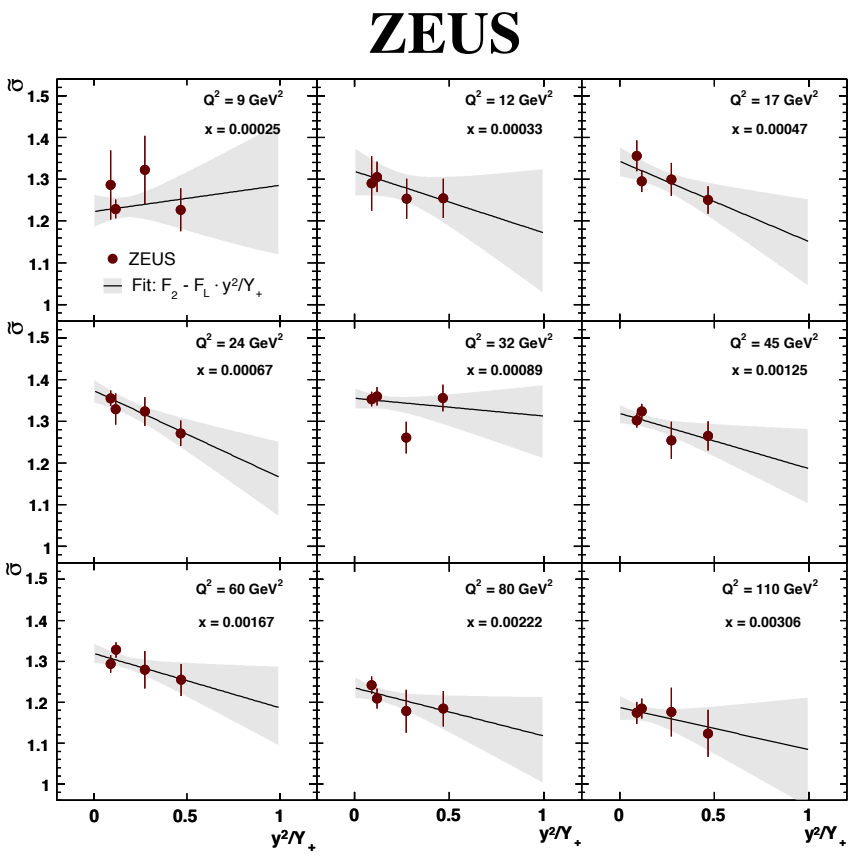
control plots



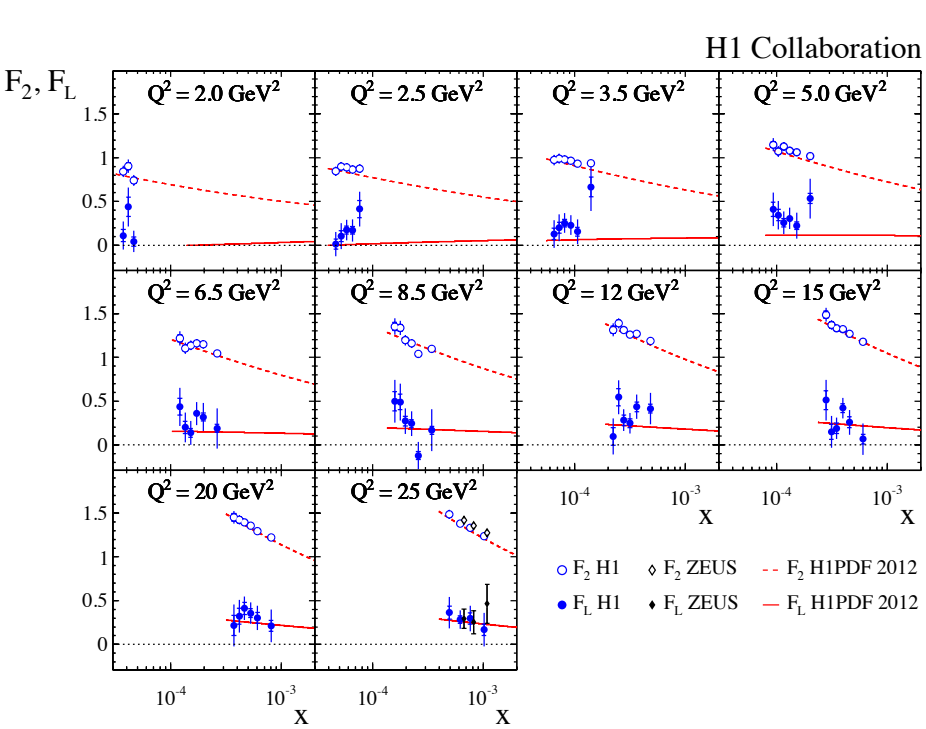


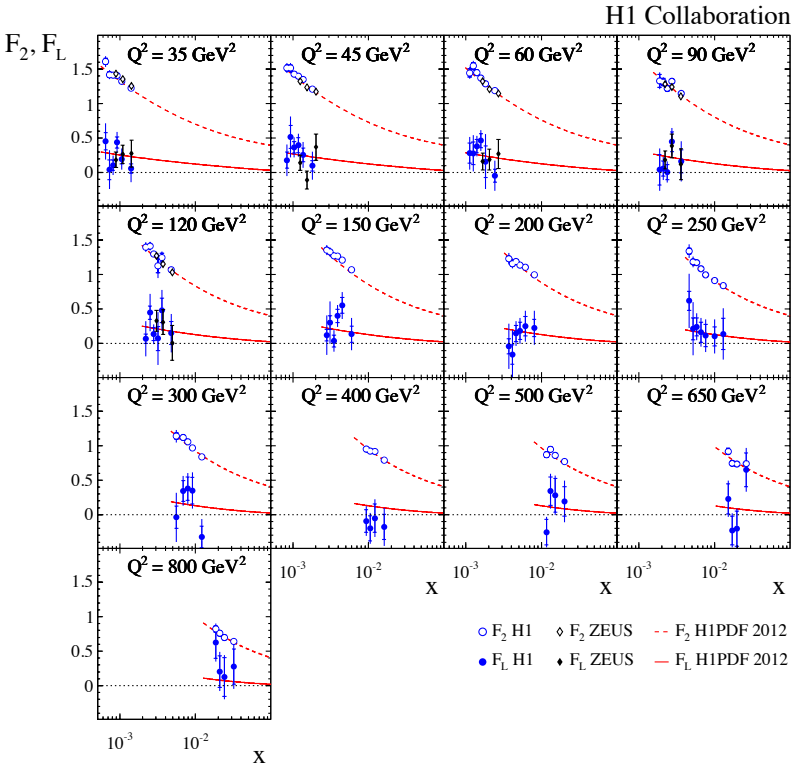
linear fits


H1 Collaboration
$\tilde{\sigma}_{NC}$
Q^2= 60 GeV^2, x=0.00111
Q^2= 60 GeV^2, x=0.00124
Q^2= 60 GeV^2, x=0.00139
Q^2= 60 GeV^2, x=0.00158
E_p = 920 GeV
H1, SpaCal
Q^2= 60 GeV^2, x=0.00182
E_p = 575 GeV
H1, LAr
H1, SpaCal
Q^2= 60 GeV^2, x=0.00242
E_p = 460 GeV
H1, LAr
H1, SpaCal
Linear fit
$y^2/(1+(1-y)^2)$

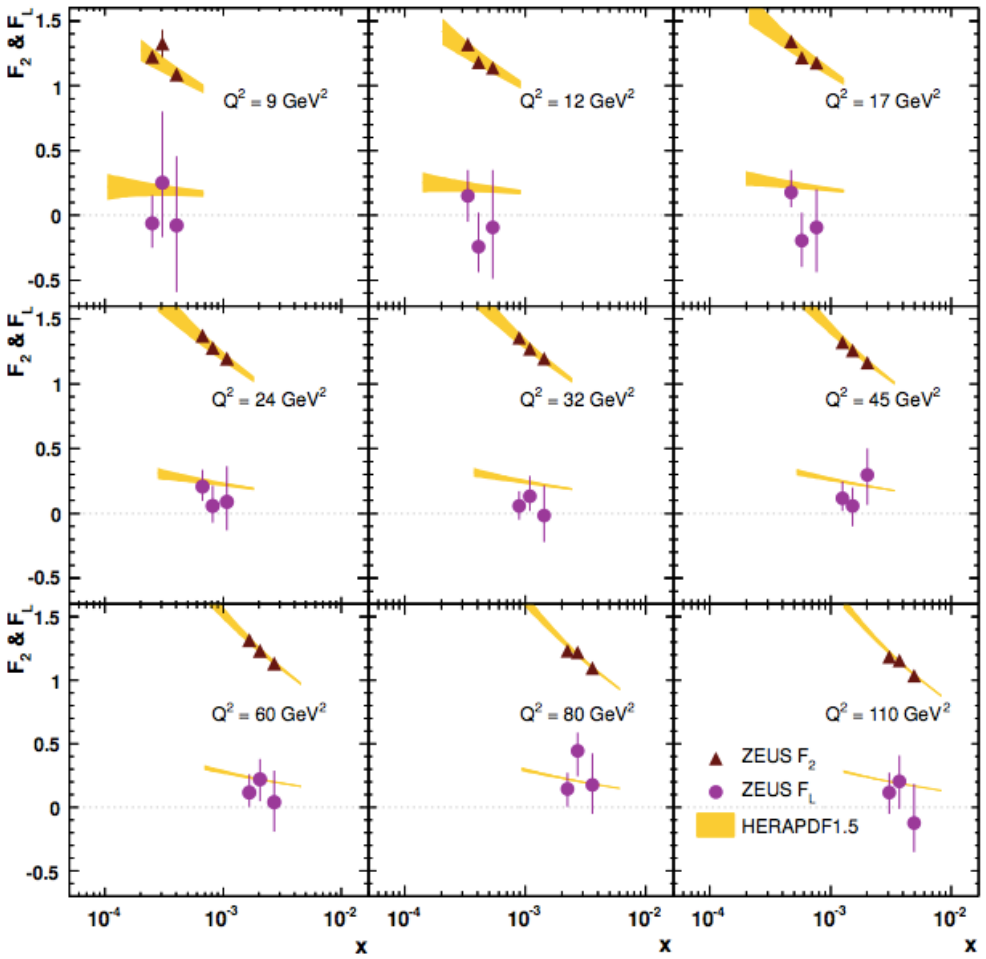

ZEUS
Q^2 = 9 GeV^2
x = 0.00025
ZEUS
Fit: $F_2 - F_L \cdot y^2/Y_+$
Q^2 = 12 GeV^2
x = 0.00033
Q^2 = 17 GeV^2
x = 0.00047
Q^2 = 24 GeV^2
x = 0.00067
Q^2 = 32 GeV^2
x = 0.00089
Q^2 = 45 GeV^2
x = 0.00125
Q^2 = 60 GeV^2
x = 0.00167
Q^2 = 80 GeV^2
x = 0.00222
Q^2 = 110 GeV^2
x = 0.00306
y^2/Y_+

H1 – F_2 – F_L


H1 Collaboration
F_2, F_L
$Q^2 = 2.0$ GeV^2
$Q^2 = 2.5$ GeV^2
$Q^2 = 3.5$ GeV^2
$Q^2 = 5.0$ GeV^2
$Q^2 = 6.5$ GeV^2
$Q^2 = 8.5$ GeV^2
$Q^2 = 12$ GeV^2
$Q^2 = 15$ GeV^2
$Q^2 = 20$ GeV^2
$Q^2 = 25$ GeV^2
x
F_2 H1
F_2 ZEUS
F_2 H1PDF 2012
F_L H1
F_L ZEUS
F_L H1PDF 2012


H1 Collaboration
F_2, F_L
$Q^2 = 35$ GeV^2
$Q^2 = 45$ GeV^2
$Q^2 = 60$ GeV^2
$Q^2 = 90$ GeV^2
$Q^2 = 120$ GeV^2
$Q^2 = 150$ GeV^2
$Q^2 = 200$ GeV^2
$Q^2 = 250$ GeV^2
$Q^2 = 300$ GeV^2
$Q^2 = 400$ GeV^2
$Q^2 = 500$ GeV^2
$Q^2 = 650$ GeV^2
$Q^2 = 800$ GeV^2
x
F_2 H1
F_2 ZEUS
F_2 H1PDF 2012
F_L H1
F_L ZEUS
F_L H1PDF 2012

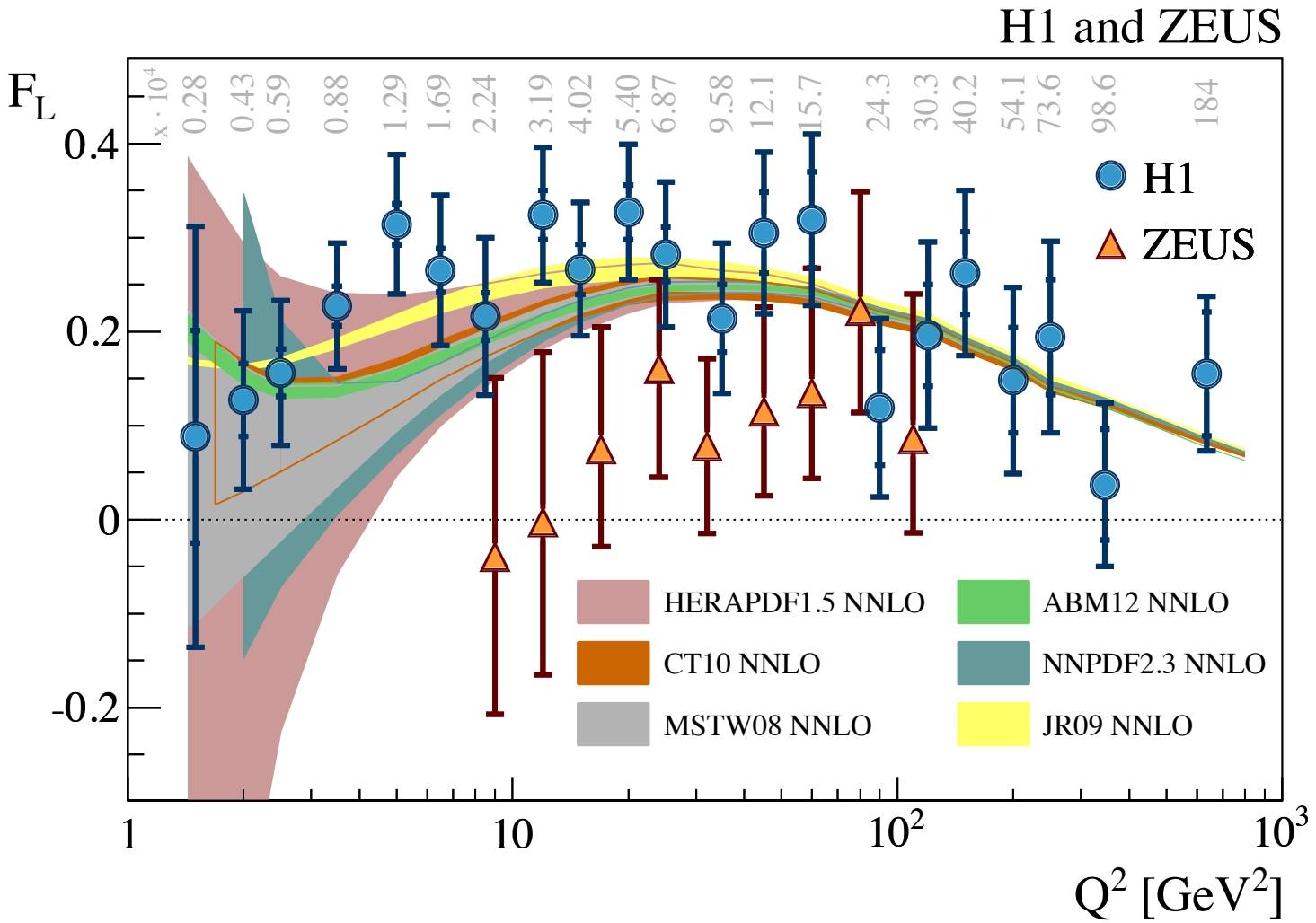
ZEUS – F_2 - F_L


F2 & FL
Q2 = 9 GeV2
Q2 = 12 GeV2
Q2 = 17 GeV2
Q2 = 24 GeV2
Q2 = 32 GeV2
Q2 = 45 GeV2
Q2 = 60 GeV2
Q2 = 80 GeV2
Q2 = 110 GeV2
ZEUS F2
ZEUS FL
HERAPDF1.5
x

H1 – ZEUS, FL

H1: DESY 13-211
Eur. Phys. J. C

ZEUS
Phys. Lett. B.



Conclusion F_L

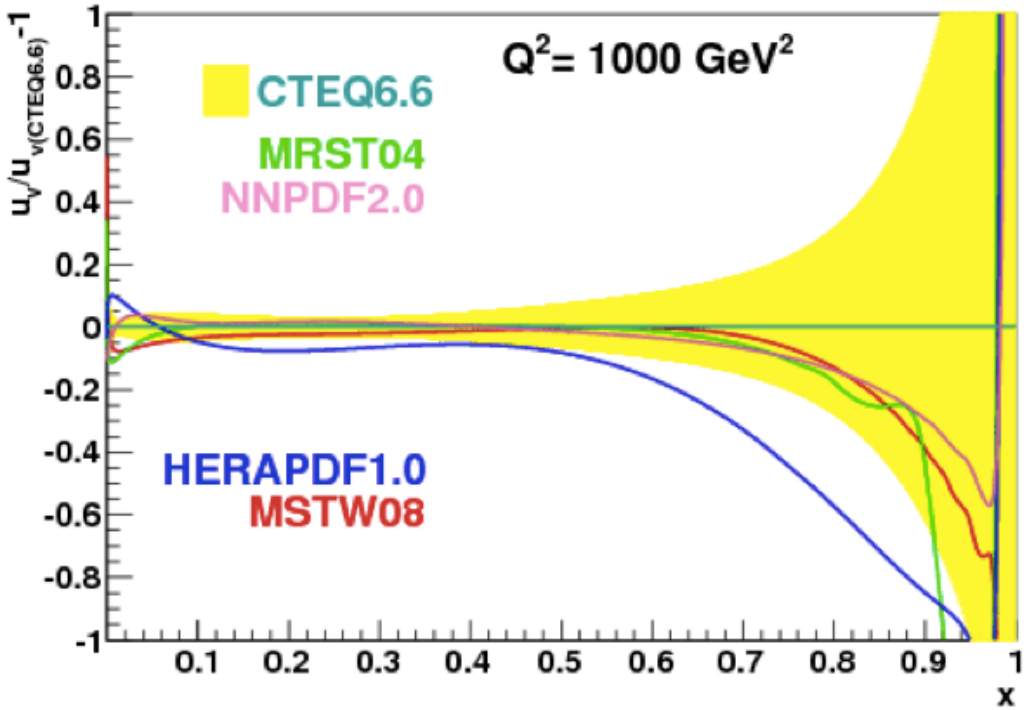
Final measurements of F_L being published by HERA.

H1 covers large kinematic range in Q^2, (1.5 – 800 GeV^2); good tracking & EM calorimetry in the rear direction, go to smaller electron energies.

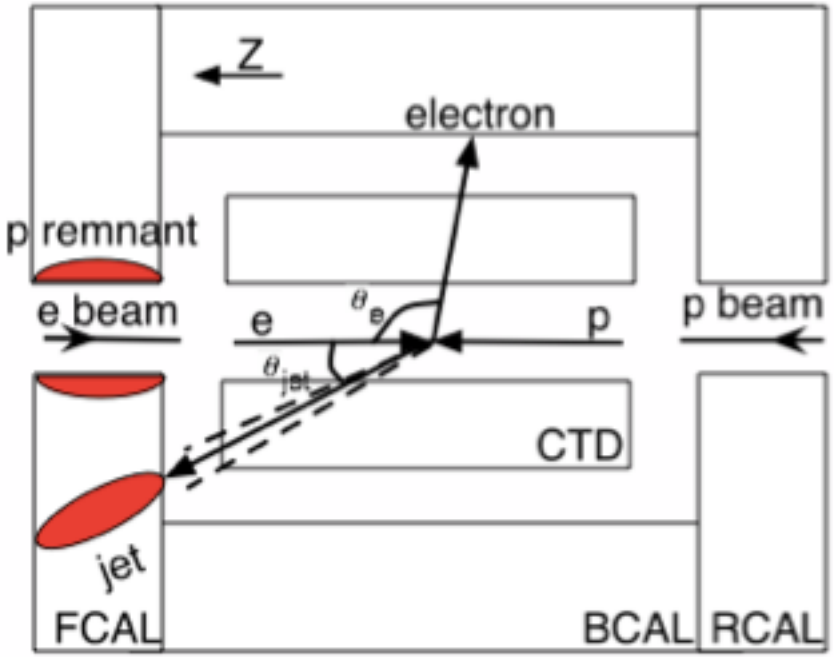
At low Q^2, very large uncertainties in the theoretical predictions.

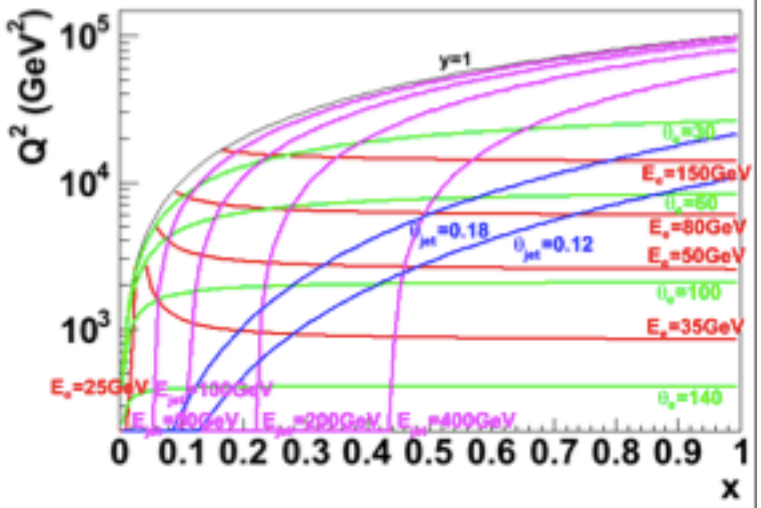
High x - Motivation

The PDF's are poorly determined at high-x. Sizeable differences despite the fact that all fitters use the same parametrization $xq \propto (1-x)^{\eta}$. Is it possible to check this ?



HERA high x high Q^2

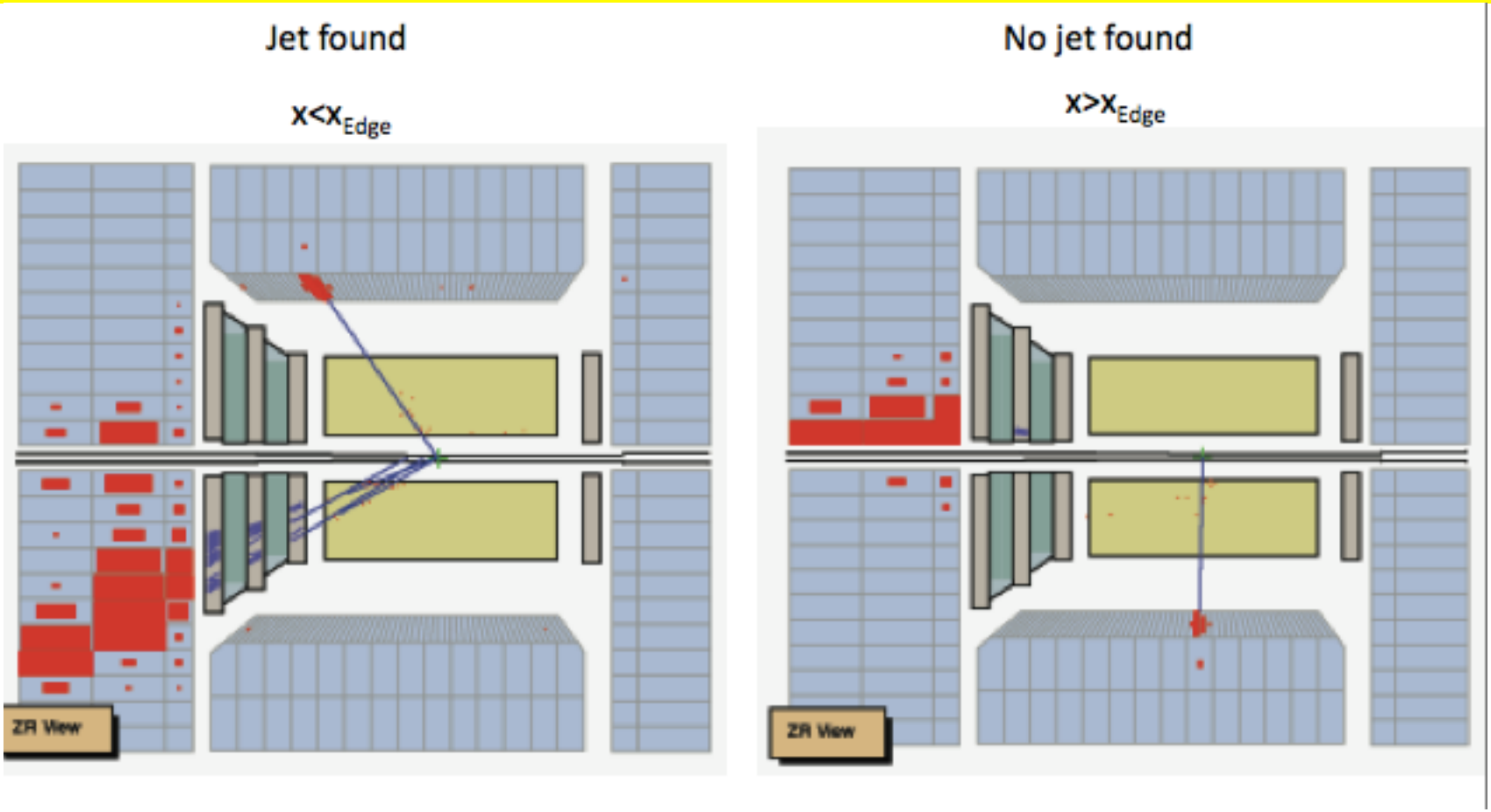




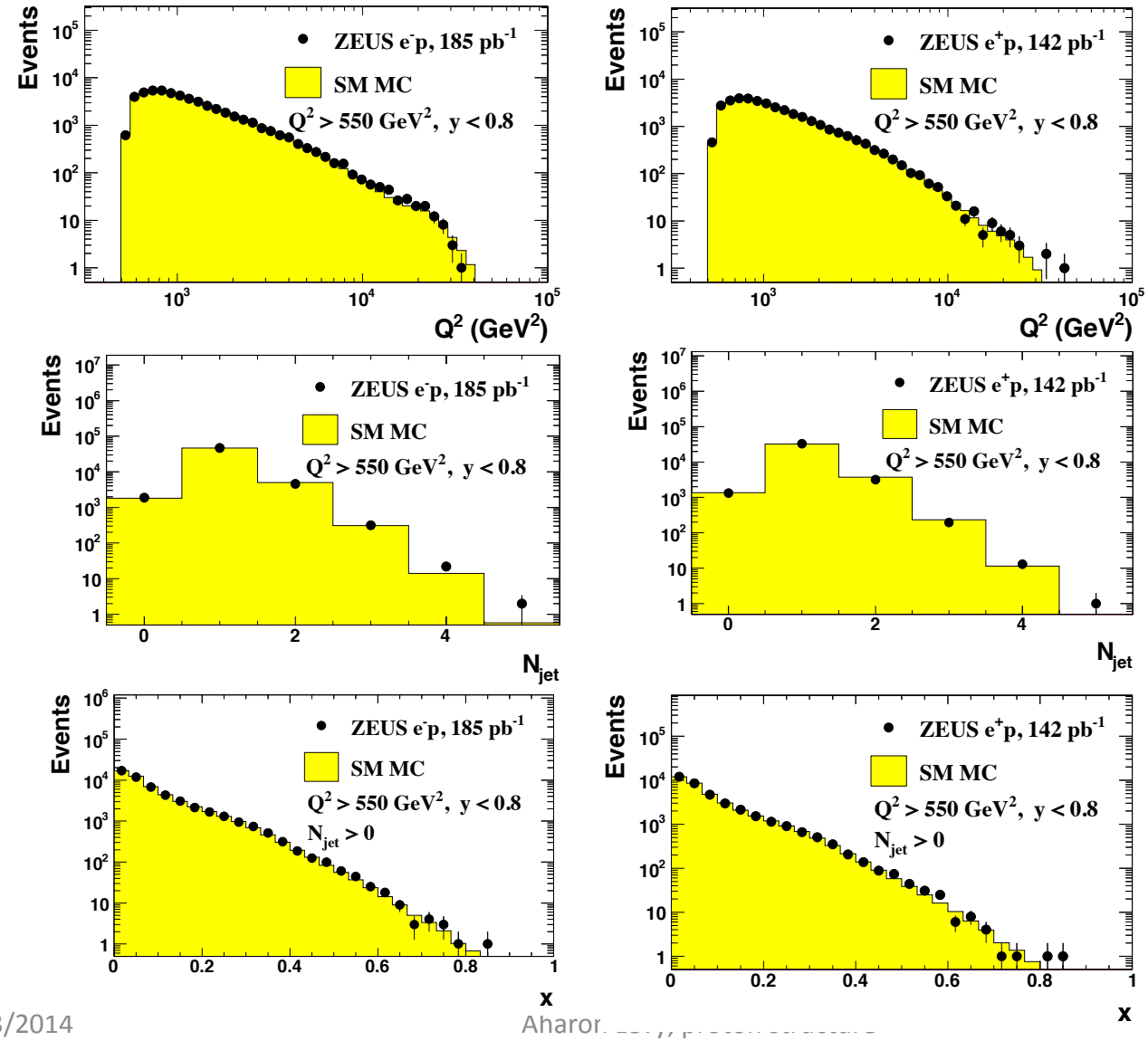
- At high Q^2, scattered electron seen with ≈100% acceptance
- For not too high x, measure x from jet: $\frac{d^2\sigma}{dxdQ^2}$
- For $x>x_{Edge}$, measure $\int_{x_{Edge}}^{1} \frac{d^2\sigma}{dxdQ^2} dx$

Allen Caldwell EPS13 14

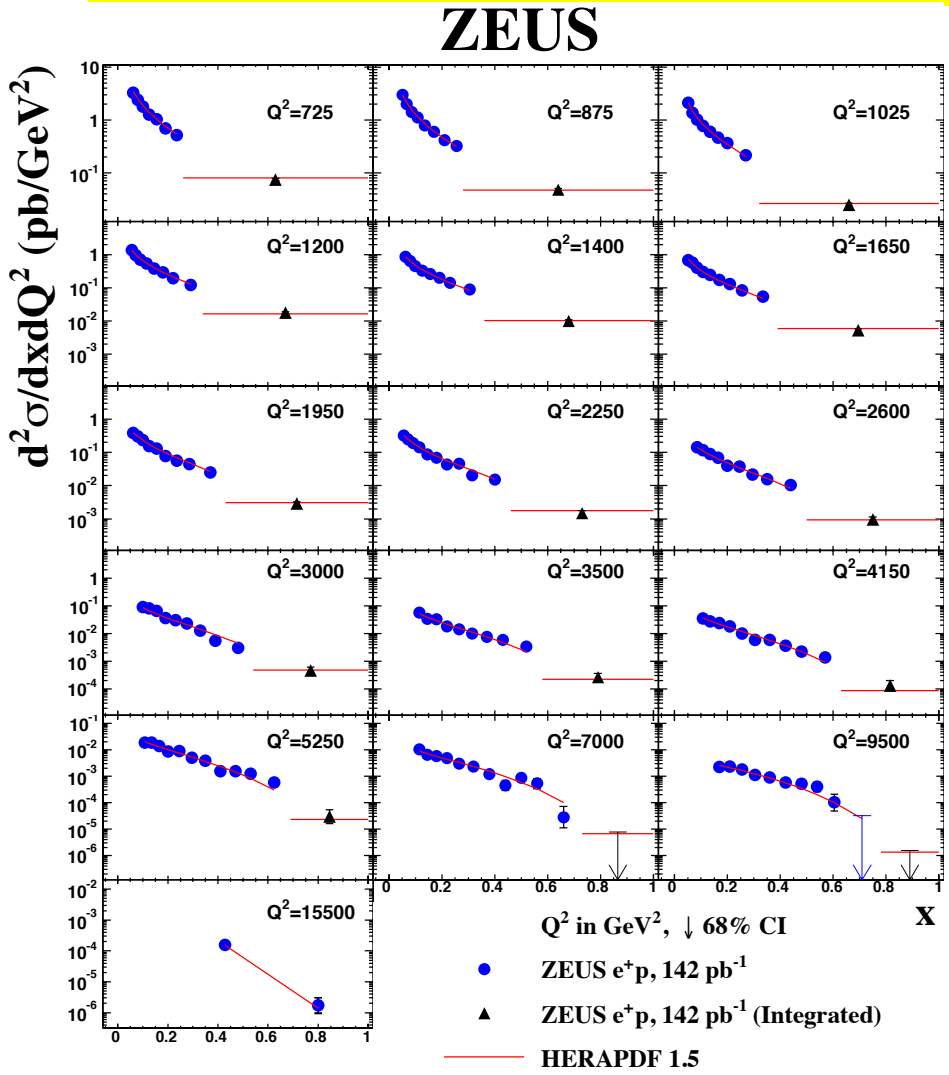
1-jet, 0-jet

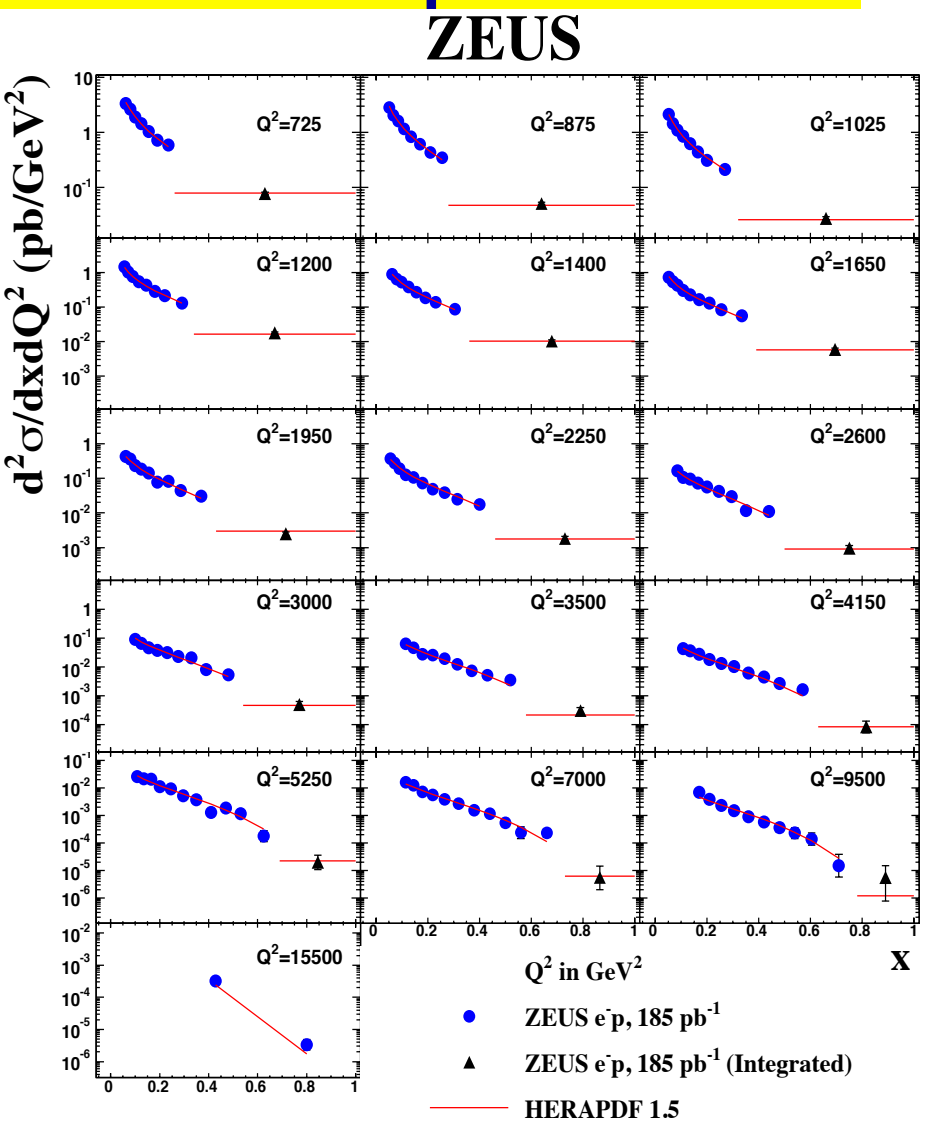


Control plots

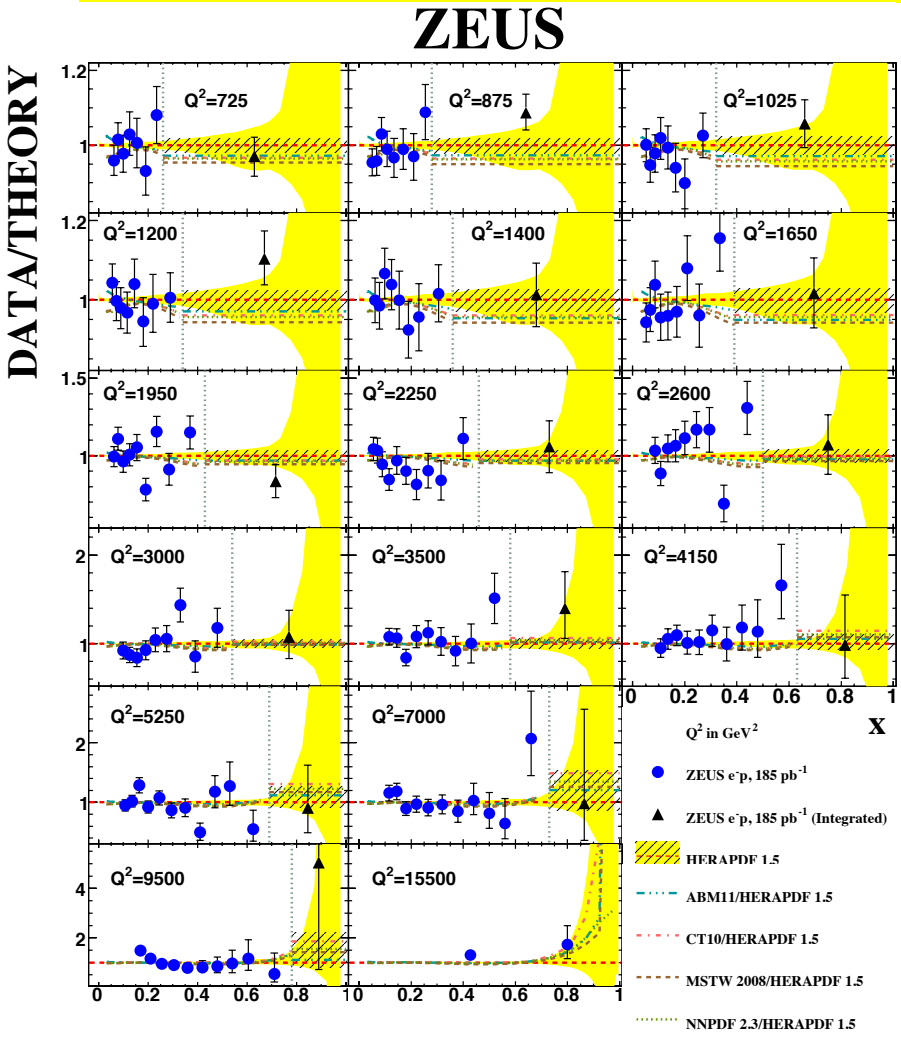


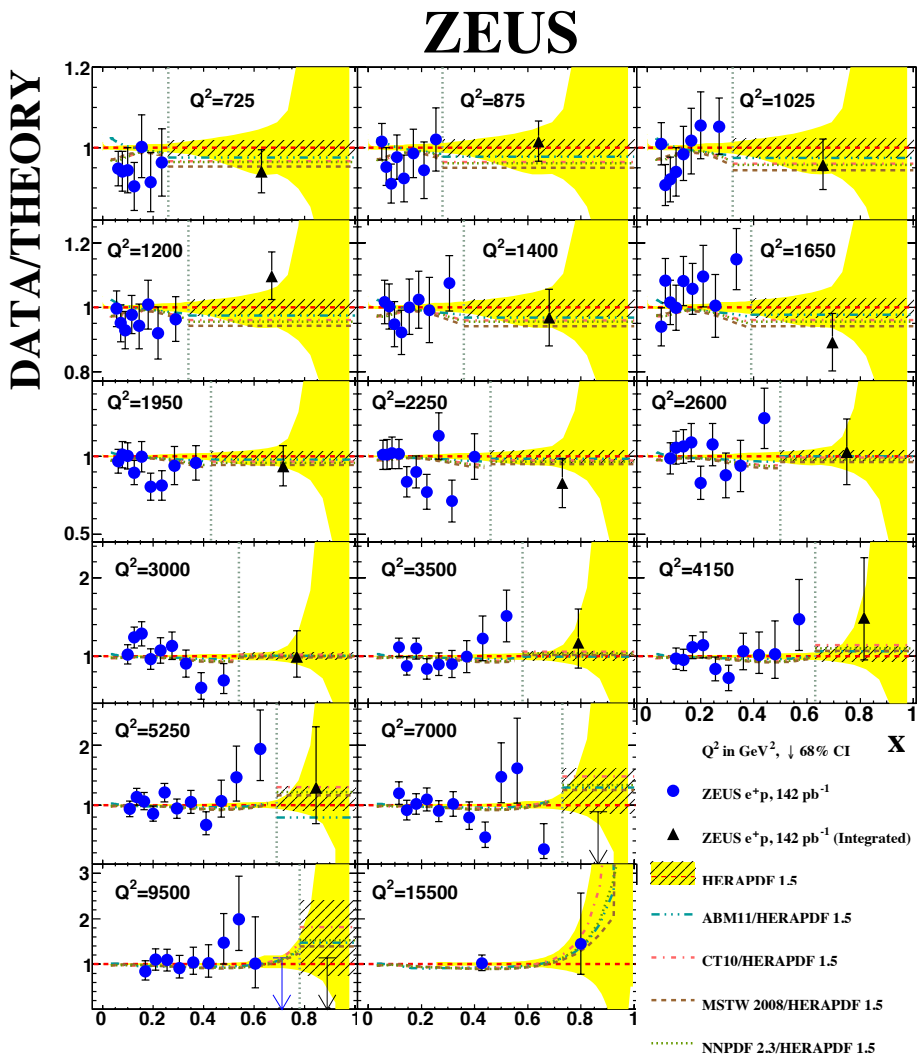
NC cross section $e^{\pm}p$





Data/Theory NC $e^{\pm}p$



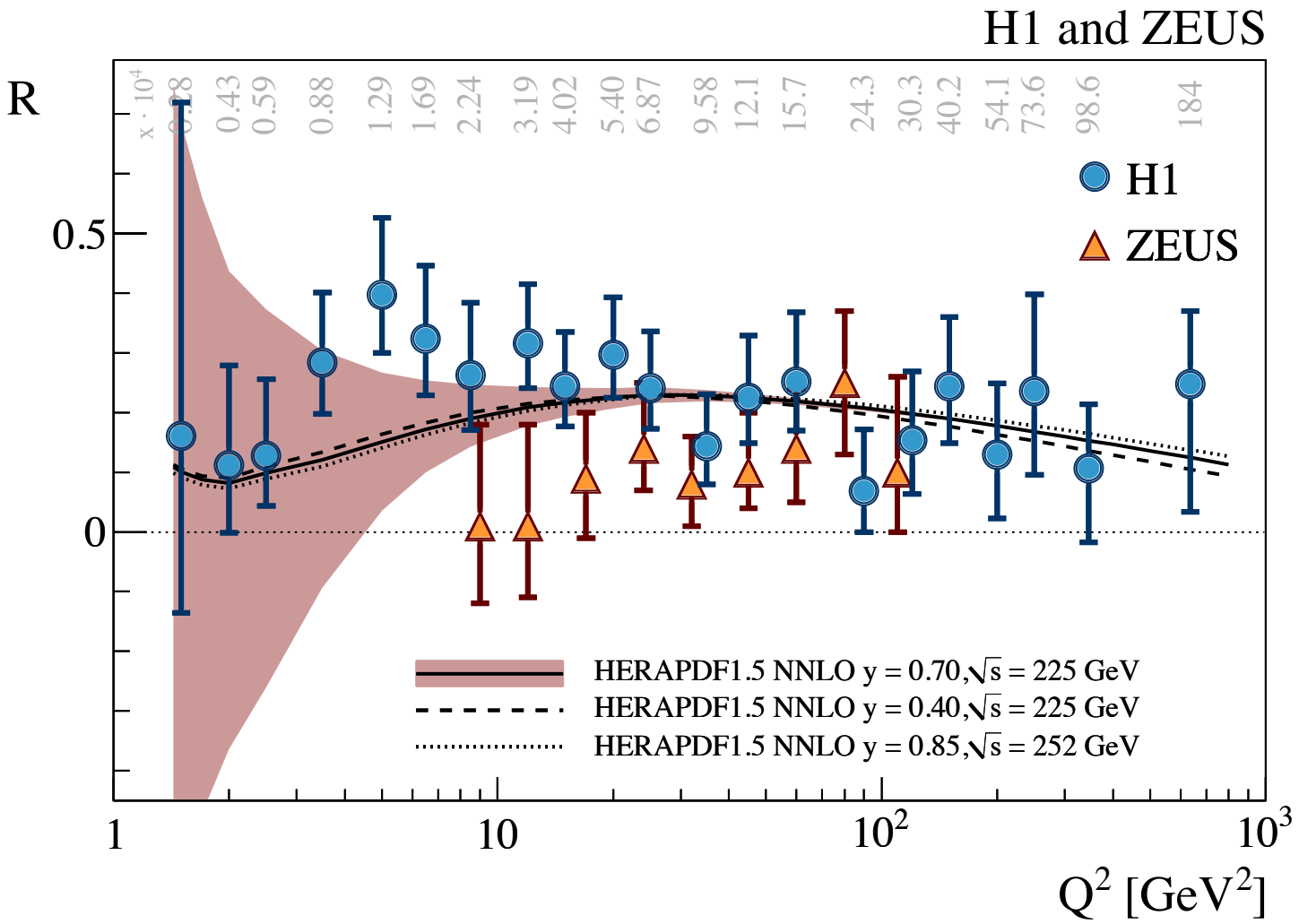


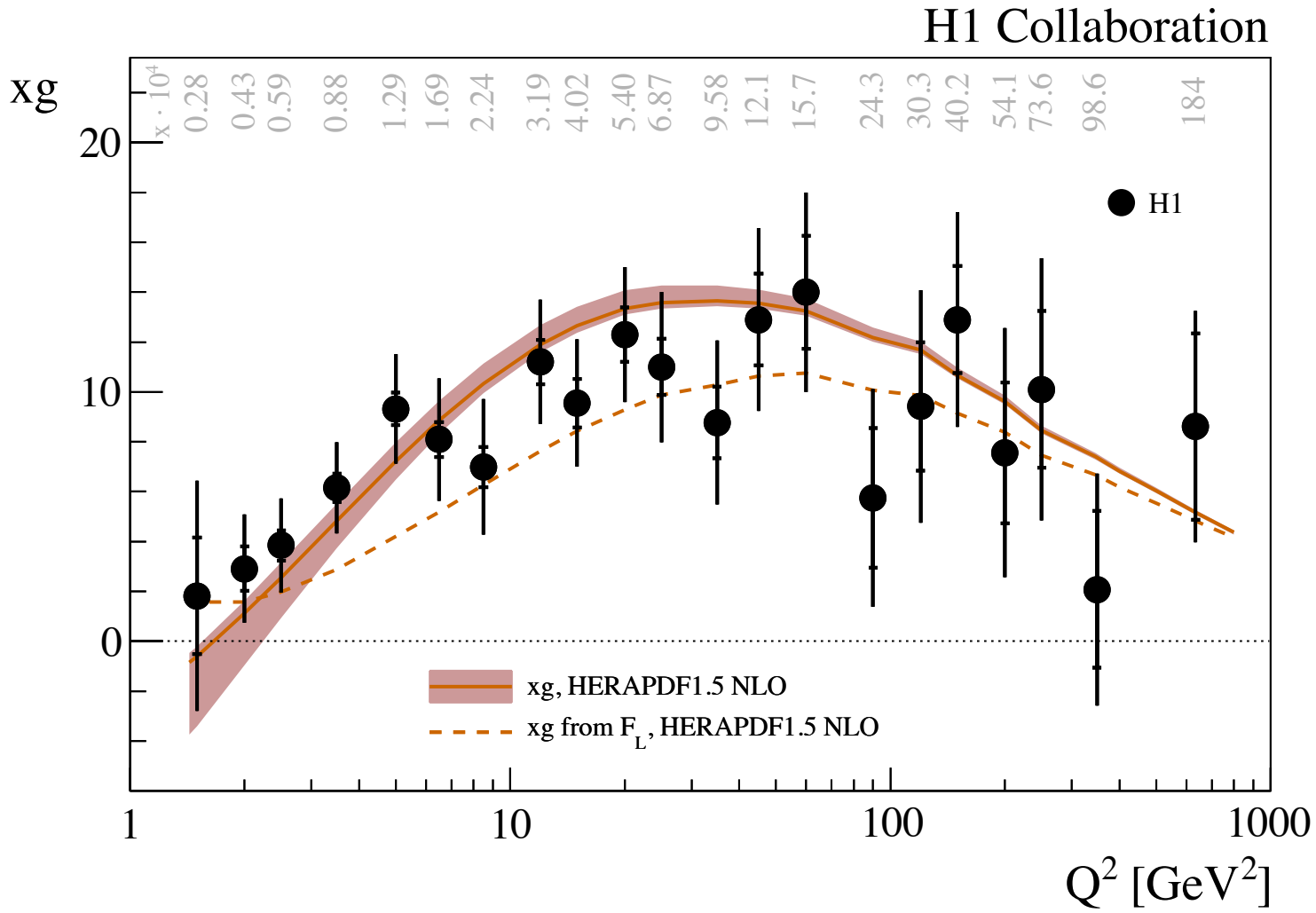
Conclusions high x

Measured $e^{\pm}p$ NC DIS cross sections at $Q^2>725$ GeV^2 up to $x\cong 1$.

Fine binning in x, extension of kinematic coverage up to $x\cong 1$ make data important input to fits constraining the PDFs in the valence-quark domain.

Backups


H1 and ZEUS
R
0.5
0
$x \cdot 10^4$
0.28
0.43
0.59
0.88
1.29
1.69
2.24
3.19
4.02
5.40
6.87
9.58
12.1
15.7
24.3
30.3
40.2
54.1
73.6
98.6
184
H1
ZEUS
HERAPDF1.5 NNLO y = 0.70, $\sqrt{s}$ = 225 GeV
HERAPDF1.5 NNLO y = 0.40, $\sqrt{s}$ = 225 GeV
HERAPDF1.5 NNLO y = 0.85, $\sqrt{s}$ = 252 GeV
1
10
10^2
10^3
Q^2 [GeV^2]


H1 Collaboration
xg
$x \cdot 10^4$
0.28
0.43
0.59
0.88
1.29
1.69
2.24
3.19
4.02
5.40
6.87
9.58
12.1
15.7
24.3
30.3
40.2
54.1
73.6
98.6
184
20
10
0
H1
xg, HERAPDF1.5 NLO
xg from F_L, HERAPDF1.5 NLO
1
10
100
1000
Q^2 [GeV^2]