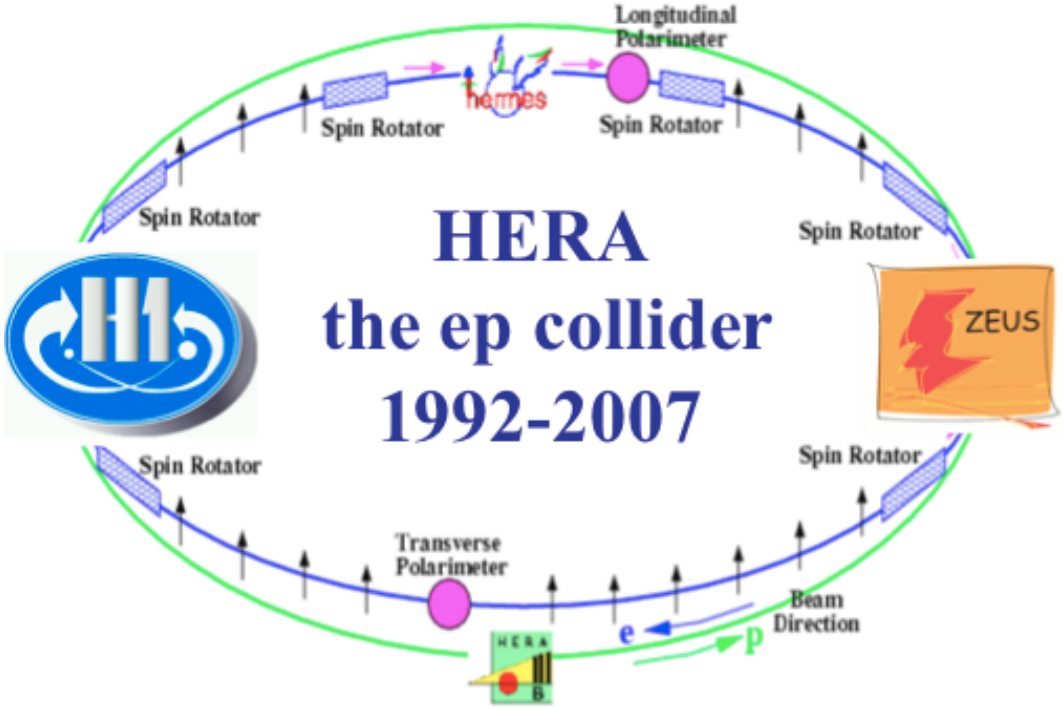
Proton structure and the HERAPDF2.0 parton densities

Halina Abramowicz, TAU/CERN
for the H1 and ZEUS Collaborations



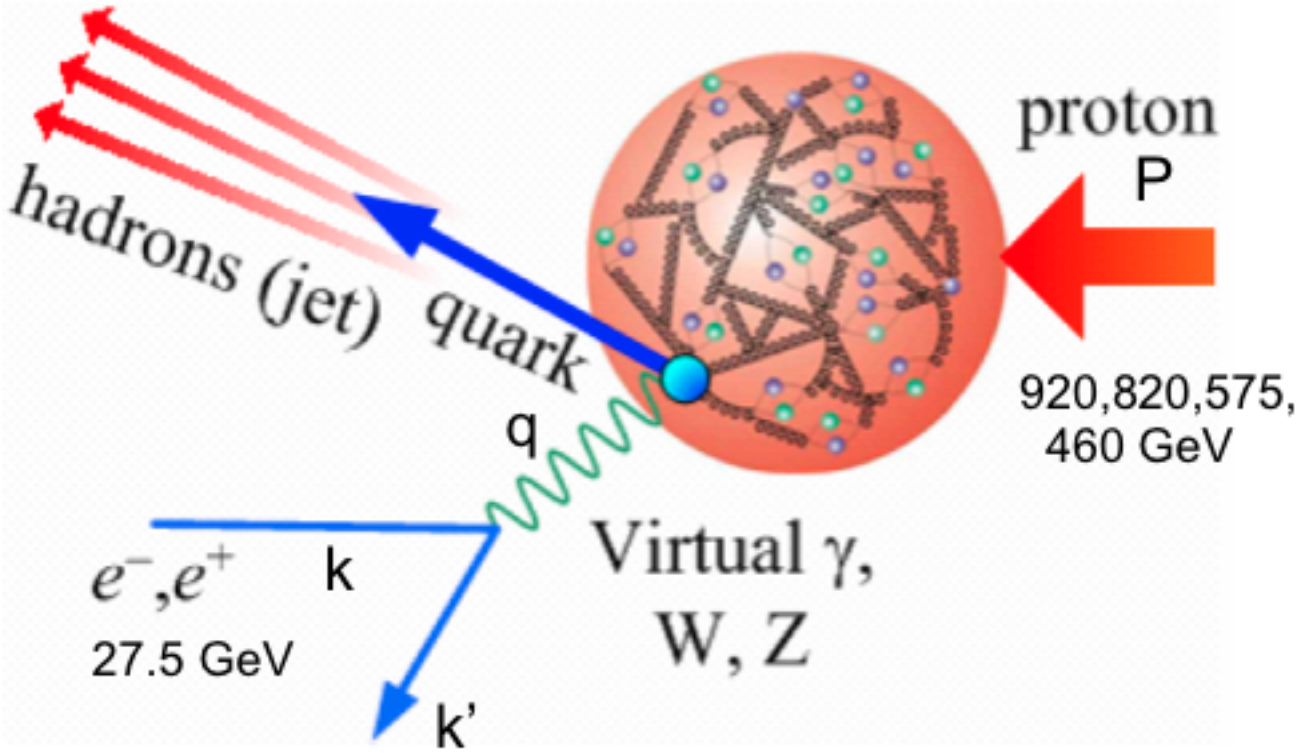
Completion of the HERA inclusive DIS cross section measurements:

1. NC at E_p=460, 575 GeV and model independent F_L measurements

2. NC measurements at highest $x \rightarrow 1$

3. Combination of all HERA I+II NC&CC inclusive measurements (HERAPDF2.0)

Deep Inelastic Scattering - DIS



$\mathbf{Q^2 = -q^2 = -(k-k')^2}$ virtuality of γ^*, Z^0, W

$\mathbf{x = Q^2/2(Pq)}$ Bjorken x

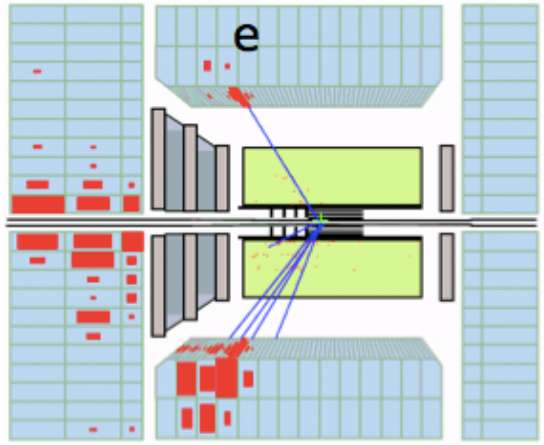
$\mathbf{y = (Pq)/(Pk)}$ inelasticity

$\mathbf{Q^2 = sxy}$ $s=(k+P)^2$

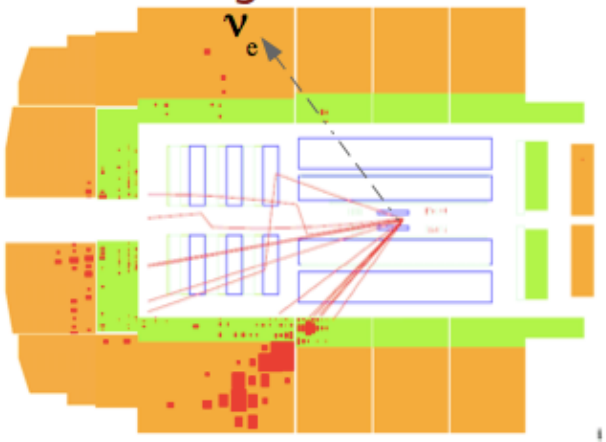
ep Scattering at HERA

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:

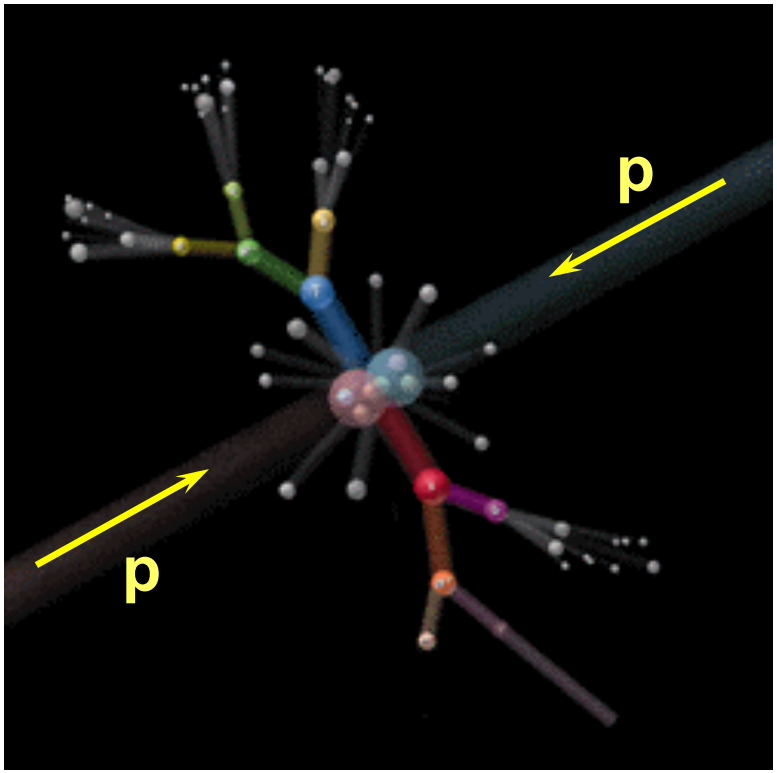
$$e^+ : \quad \tilde{\sigma}_{CC}^{e^+p} = x[\overline{u}+\overline{c}] + (1-y)^2 x[d+s]$$

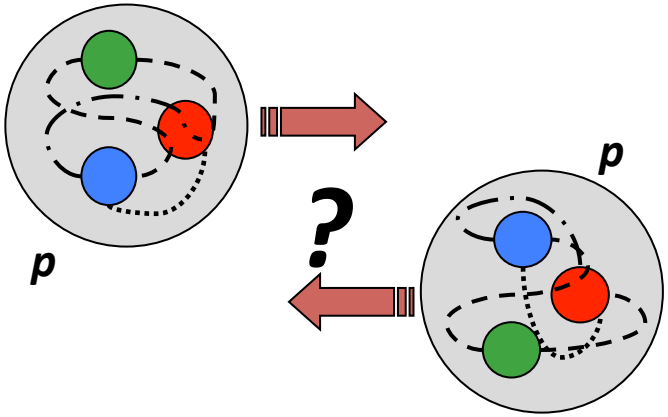
$$e^- : \quad \tilde{\sigma}_{CC}^{e^-p} = x[u+c] + (1-y)^2 x[\overline{d}+\overline{s}]$$

R. Plačakytė, Moriond QCD, 9-16 March

3

Hard pp interactions at LHC

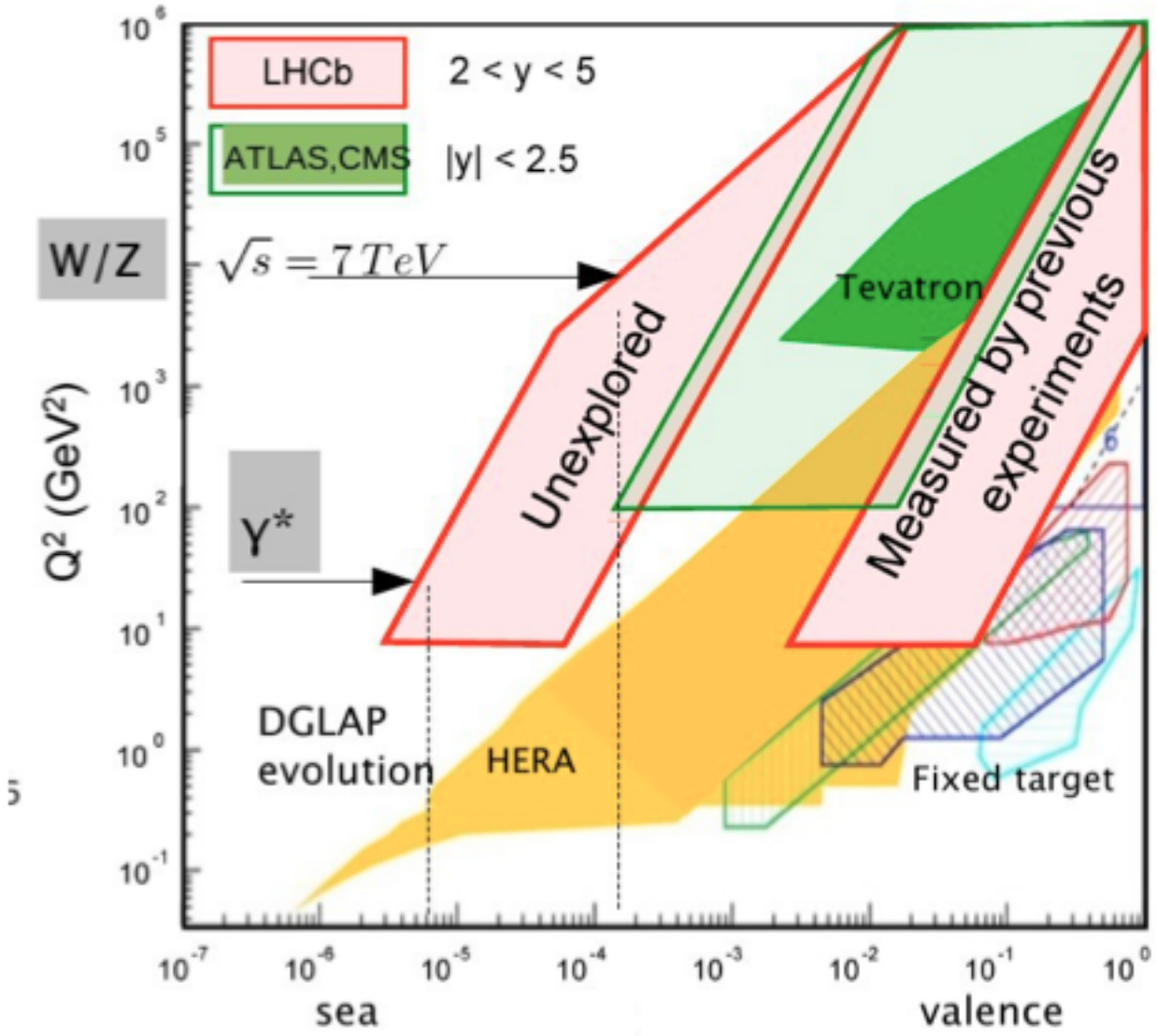




$$d\sigma_{pp} = \sum_{ab} \int_{x_1} \int_{x_2} dx_1 dx_2 f_p(x_1, \mu^2) f_p(x_2, \mu^2) d\hat{\sigma}_{ab}(x_1, x_2, \mu^2)$$

QCD factorization → parton distributions universal

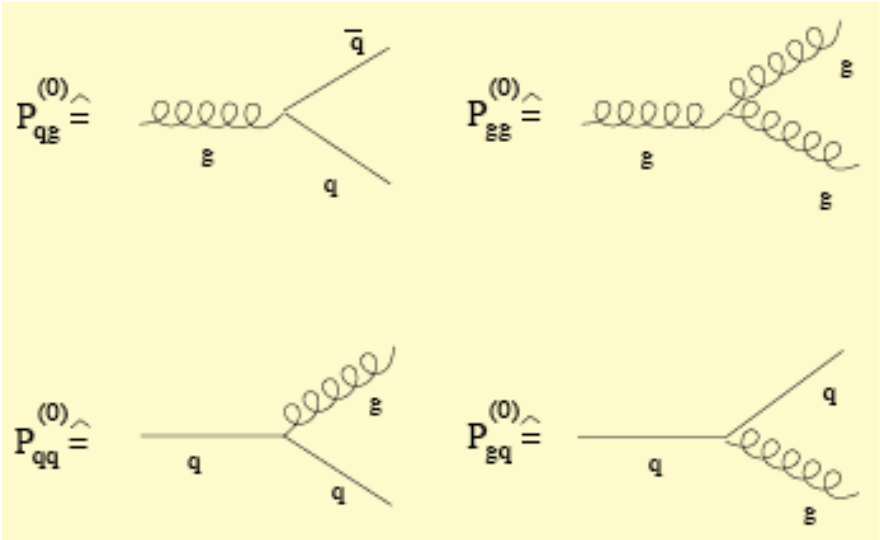
Phase space of measurements (partons) in x and Q^2



QCD evolution equations

Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equations

$$\frac{\partial}{\partial \ln Q^2}\begin{pmatrix} f_q(x,Q^2) \\ f_g(x,Q^2) \end{pmatrix} = \frac{\alpha_s(Q^2)}{2\pi}\begin{bmatrix} P_{qq} & P_{qg} \\ P_{gq} & P_{gg} \end{bmatrix} \otimes \begin{pmatrix} f_q \\ f_g \end{pmatrix}$$

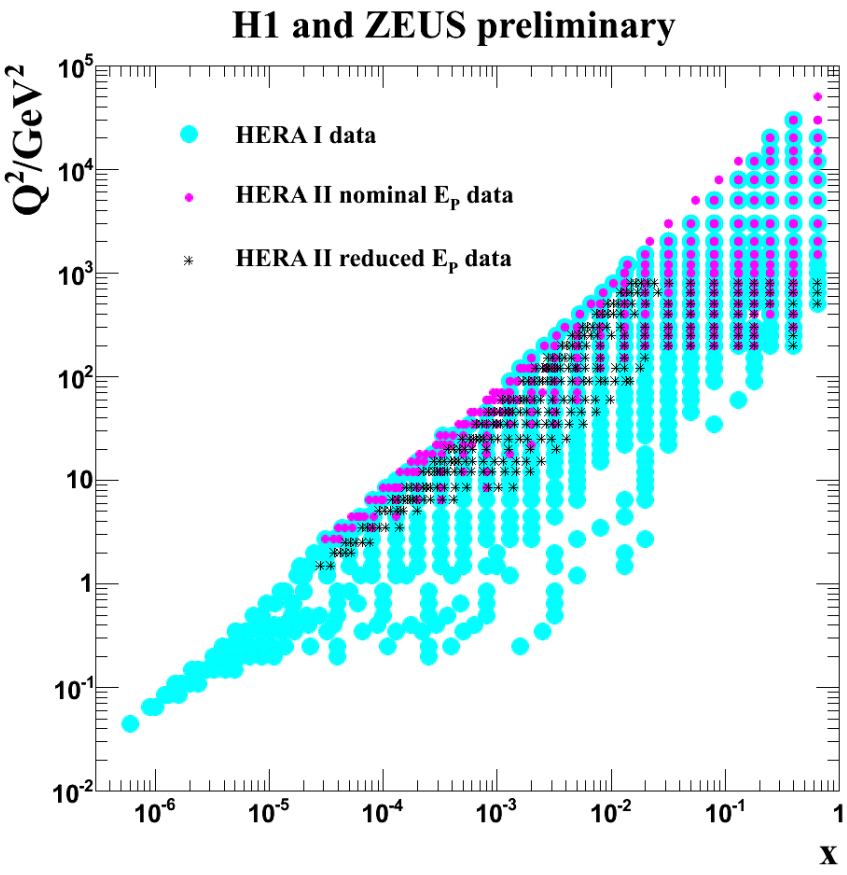


Combination of all H1 and ZEUS data sets, NC and CC

41 data sets from H1 and ZEUS (1 fb^{-1}): $0.045 \le Q^2 \le 50000$ GeV^2, $6\ 10^{-7} \le x \le 0.65$

21 data sets from HERA I (E_p=920 and 820 GeV) and

20 data sets from HERA II (12/4/4 sets for E_p= 920/575/460 GeV)



Combination of the H1 & ZEUS incl. unpolarized NC and CC data include expert knowledge in the treatment of the correlations between individual data sets.

→ precise, complete and easy in use

→ reduction of stat. and syst. uncertainties

1. HERA I data: JHEP 1001:109,2010 HERAPDF 1.0
2. HERA I and preliminary HERA II data HERAPDF 1.5

HERAverager (wiki-zeuthen.desy.de/HERAverager) is used for the cross section averaging, 162 corr. syst. sources are treated as multiplicative, the following χ^2 definition is used:

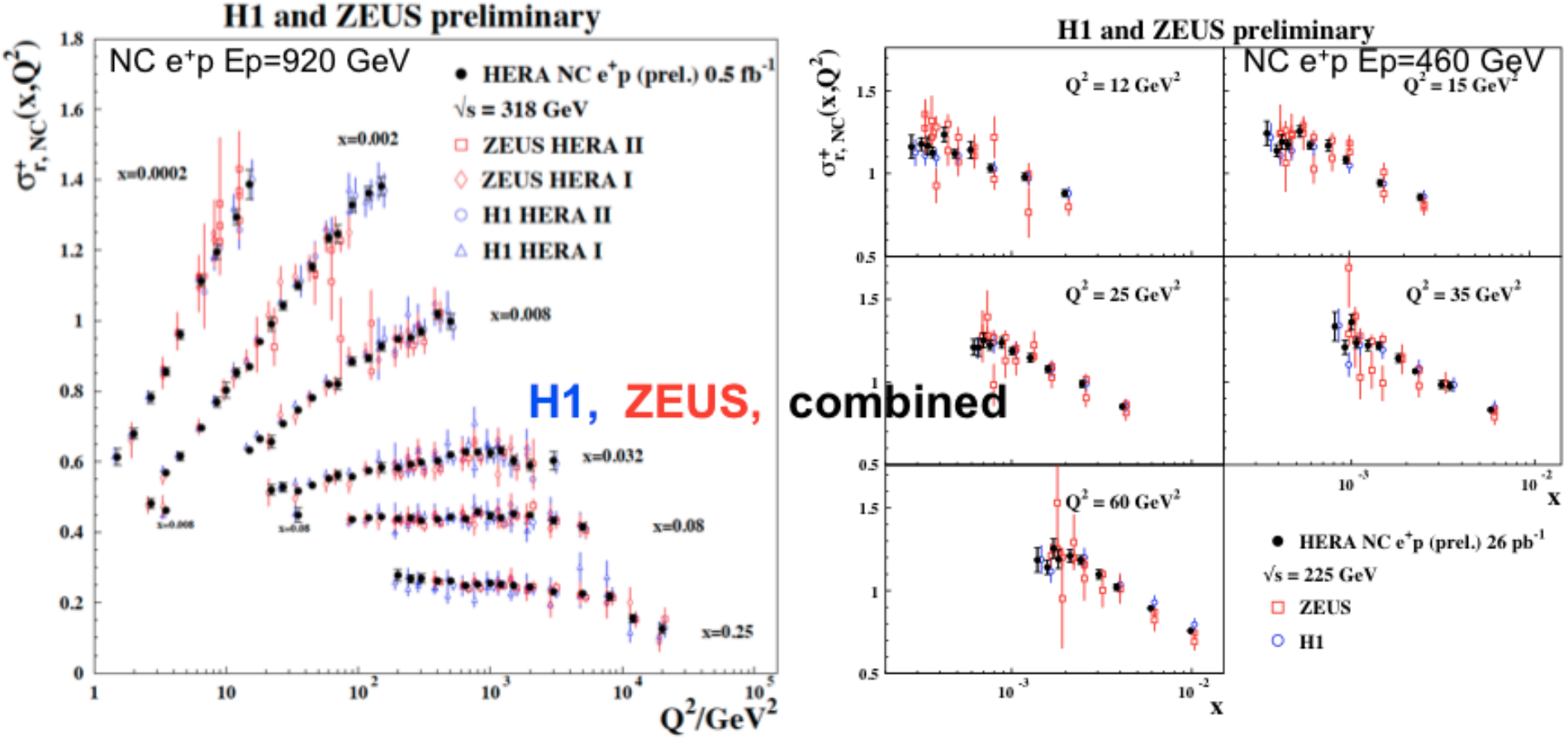
$$\chi^2_{\text{exp},ds}(\boldsymbol{m},\boldsymbol{b}) = \sum_{i,ds} + \sum_{j,b} = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\text{stat}}\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,\text{uncor}}\, m^i\right)^2} + \sum_j b_j^2$$

Three additional procedural errors

- multiplicative vs. additive
- correlation over all data sets of photoproduction bkg and hadronic energy scale uncertainties

Combination of all H1 and ZEUS, NC 920 and 460 GeV

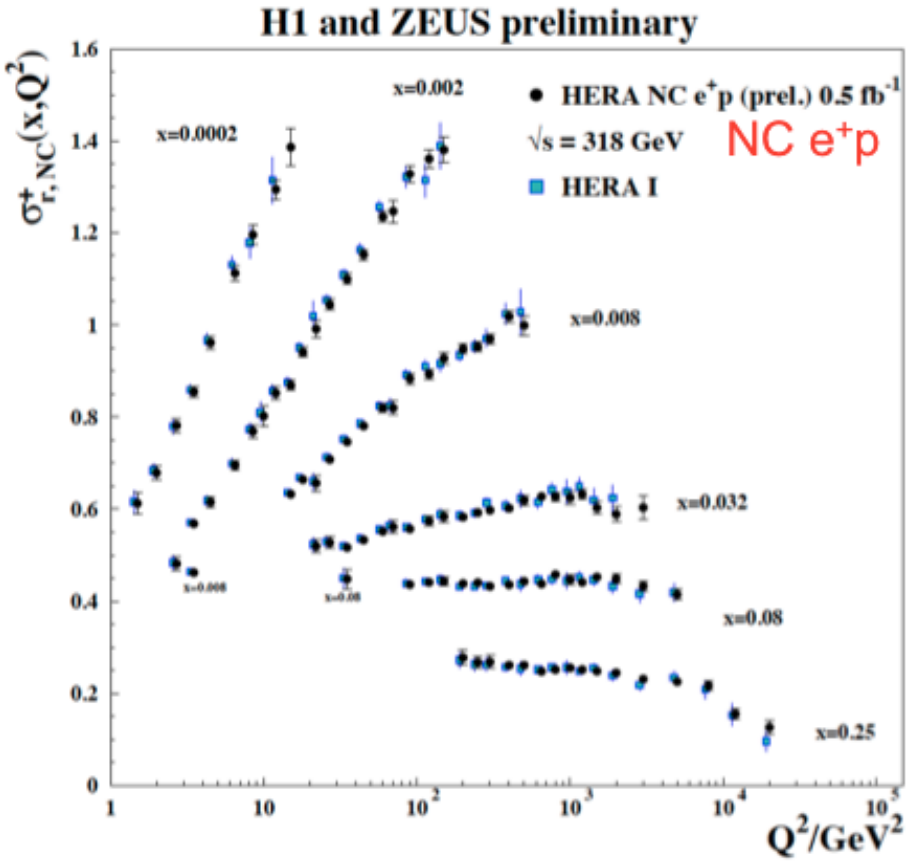
2927 cross sections are combined to 1307 points with 165 correlated systematic errors

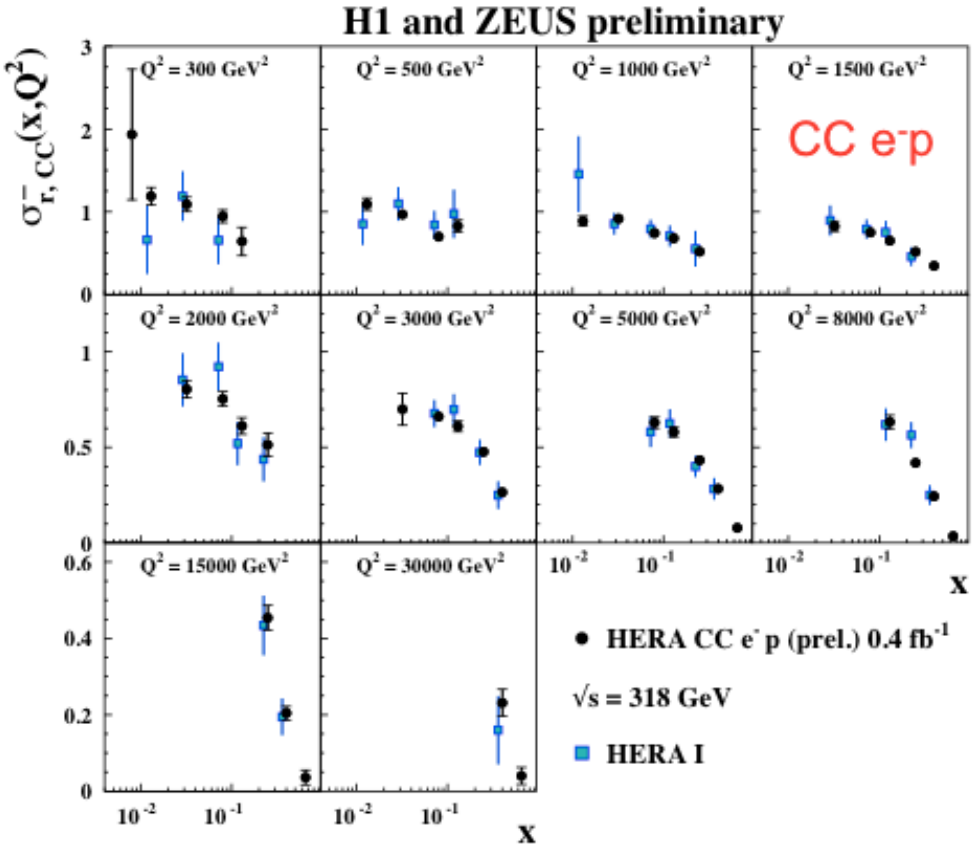


→ up to 6 measurements are combined into one averaged point

→ good consistency of the input data sets ($\chi^2/ndf = 1685/1620$)

Comparison of all HERAI and HERAI+II data sets, NC and CC

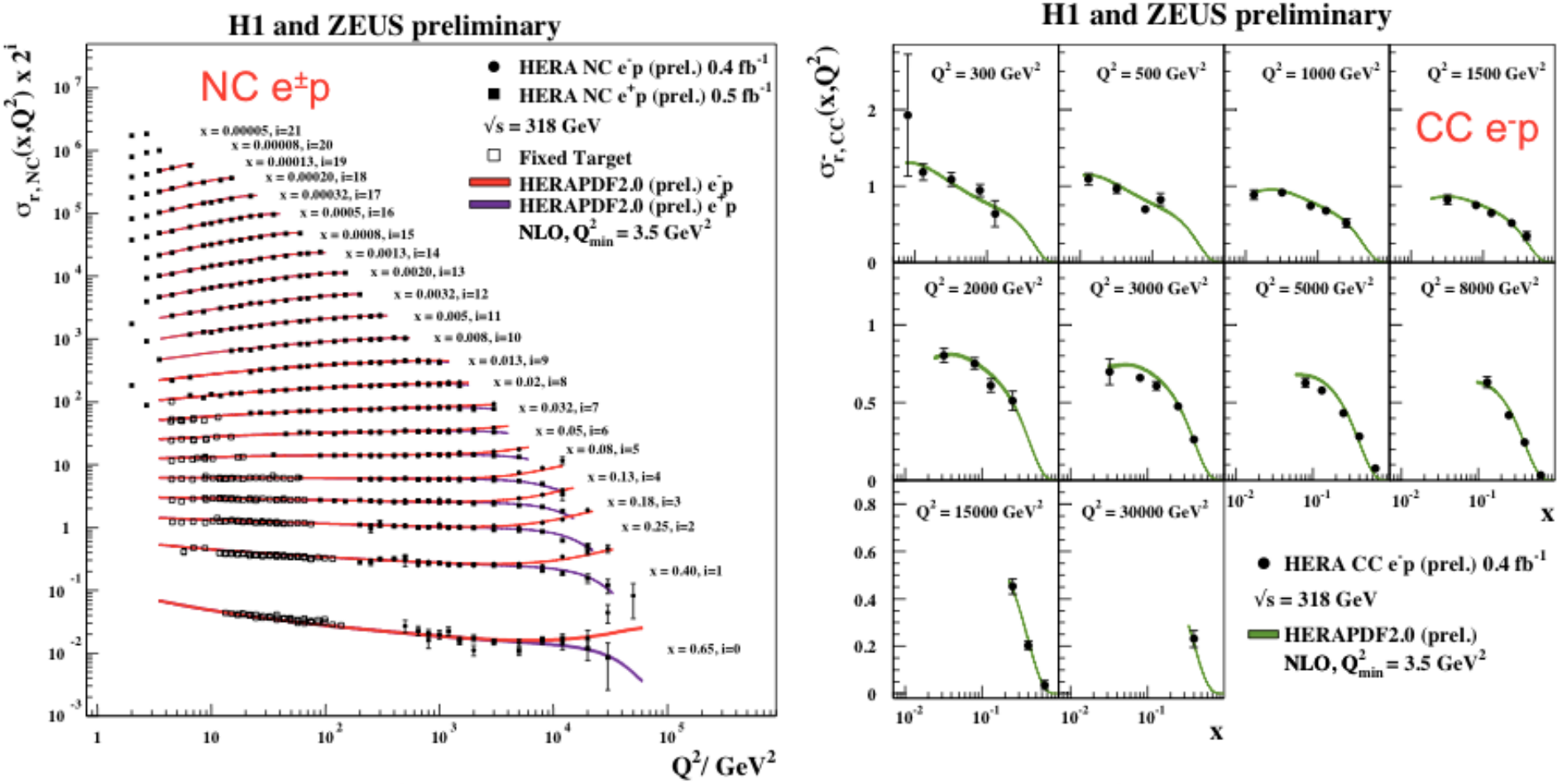




→ significant improvements in precision at high Q^2 (especially for e^-p NC&CC) and at high y:
about 1% precision in the best measured regions

HERAI+II data sets → HERAPDF2.0

$e^{\pm}p$ NC&CC (E_p=920 GeV), $e^{+}p$ NC (E_p = 820, 575, 460 GeV), corresponding to 1 fb^{-1}
→ 165 correlated syst. err.; $0.045 \le Q^2 \le 50000$ GeV^2, $6\ 10^{-7} \le x \le 0.65$



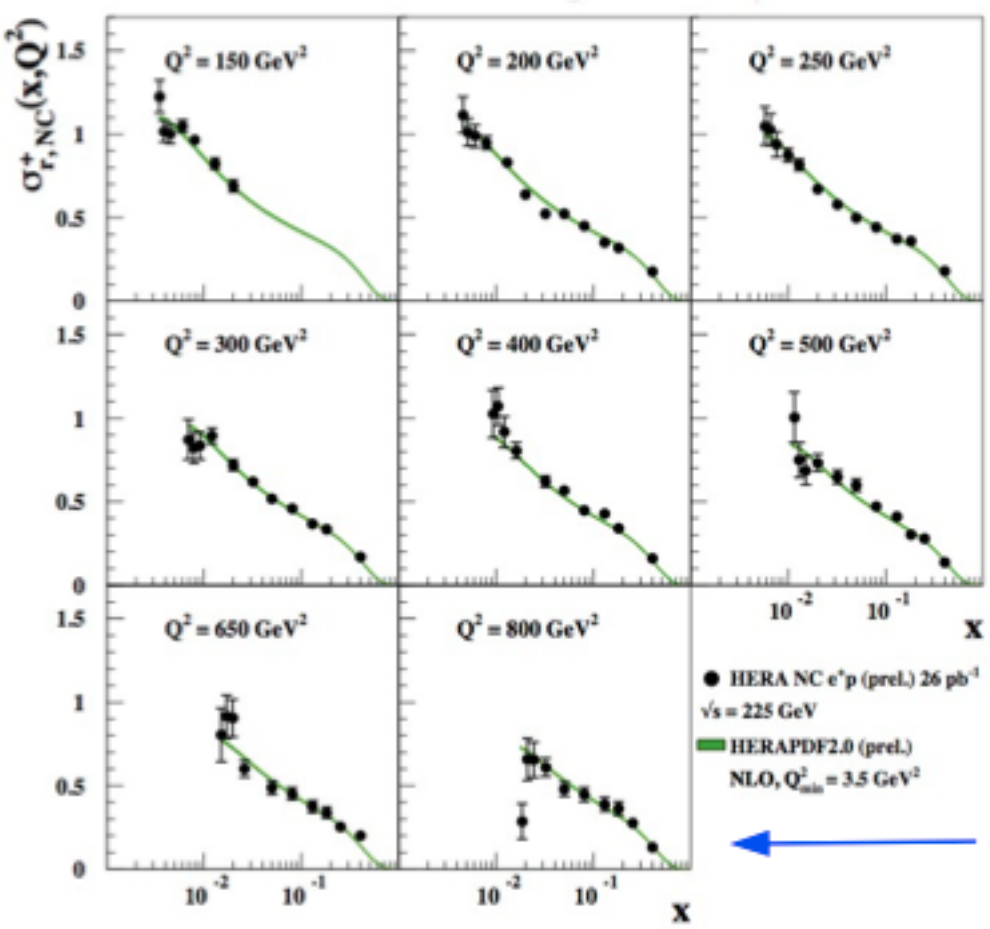
Global fits of parton distributions
Use HERAI+II data only – HERAPDF2.0

- Postulate x dependence of all partons at some Q_0^2
- Solve DGLAP evolution equations for these initial conditions
- Calculate appropriate physical quantities which have been measured (cross sections)
- Compare data and expectations
- Iterate till good agreement is achieved

- Which order of perturbative expansion (splitting functions) is adequate ???
- How to treat heavy quark contributions at low/high Q^2
- What functional form to assume for the x-dependence
- Where in Q_0^2 to start the fit

Neutral Current

$$\frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2 \mp Y_-xF_3 - y^2F_L\right]$$



Proton structure functions

$$F_2 = x\sum e_q^2[q(x) + \bar{q}(x)]$$

- Dominant
- Sensitive to sea quarks

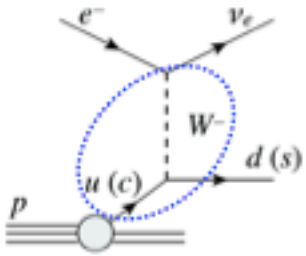
$$xF_3 = x\sum 2e_q a_q[q(x) - \bar{q}(x)]$$

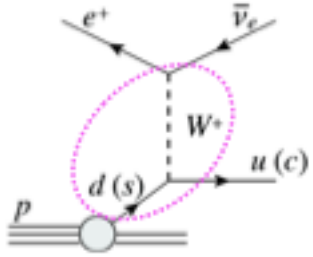
- Sensitive to valence distributions
- Essential at high Q^2

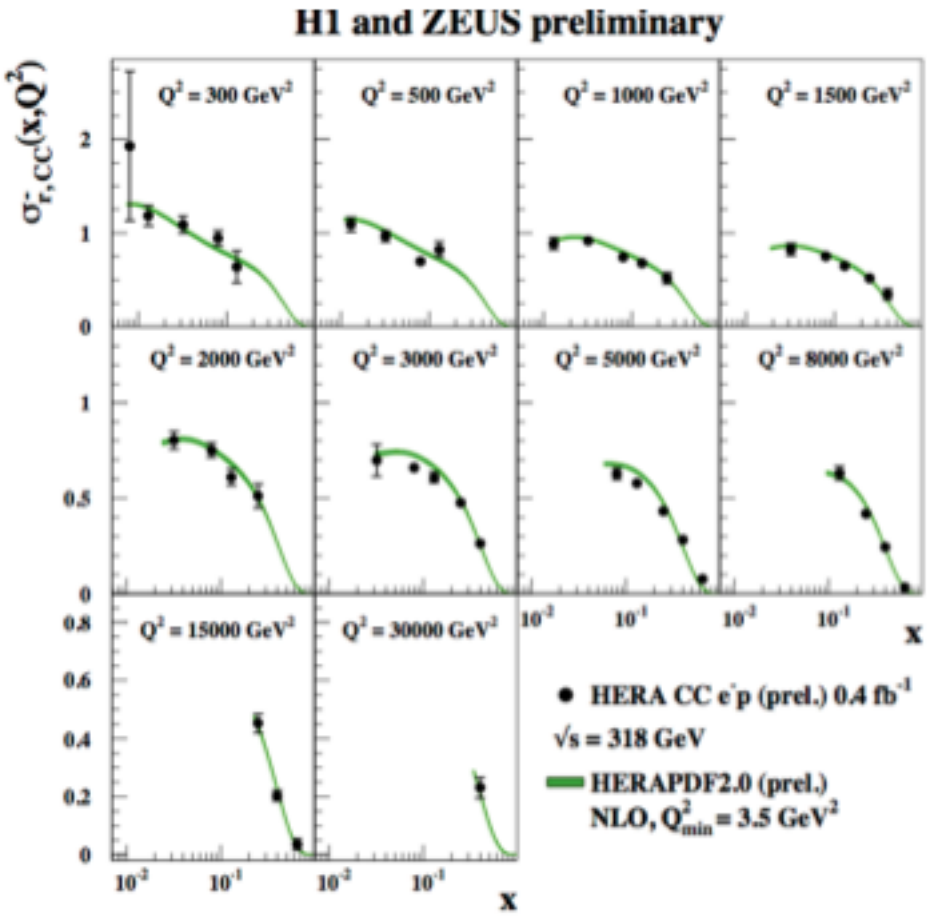
$$F_L \sim \alpha_S \times g$$

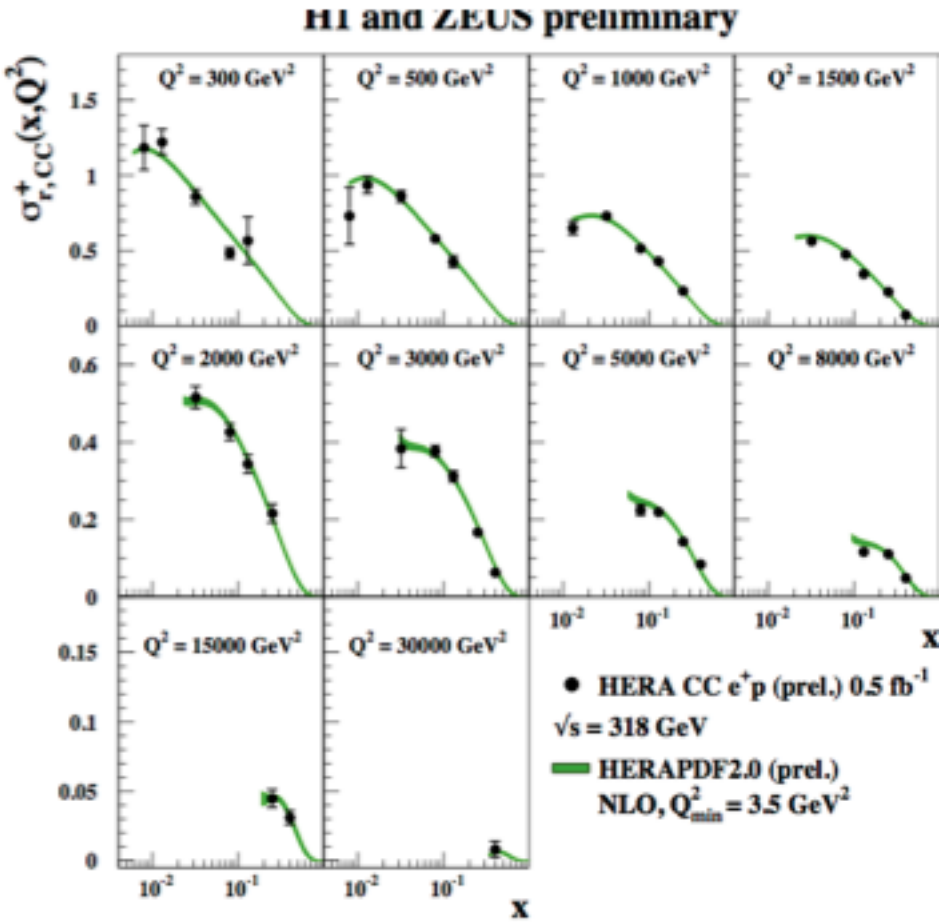
- Sensitive to gluon
- Essential at high y

Charge Current: flavor decomposition









Global QCD fits

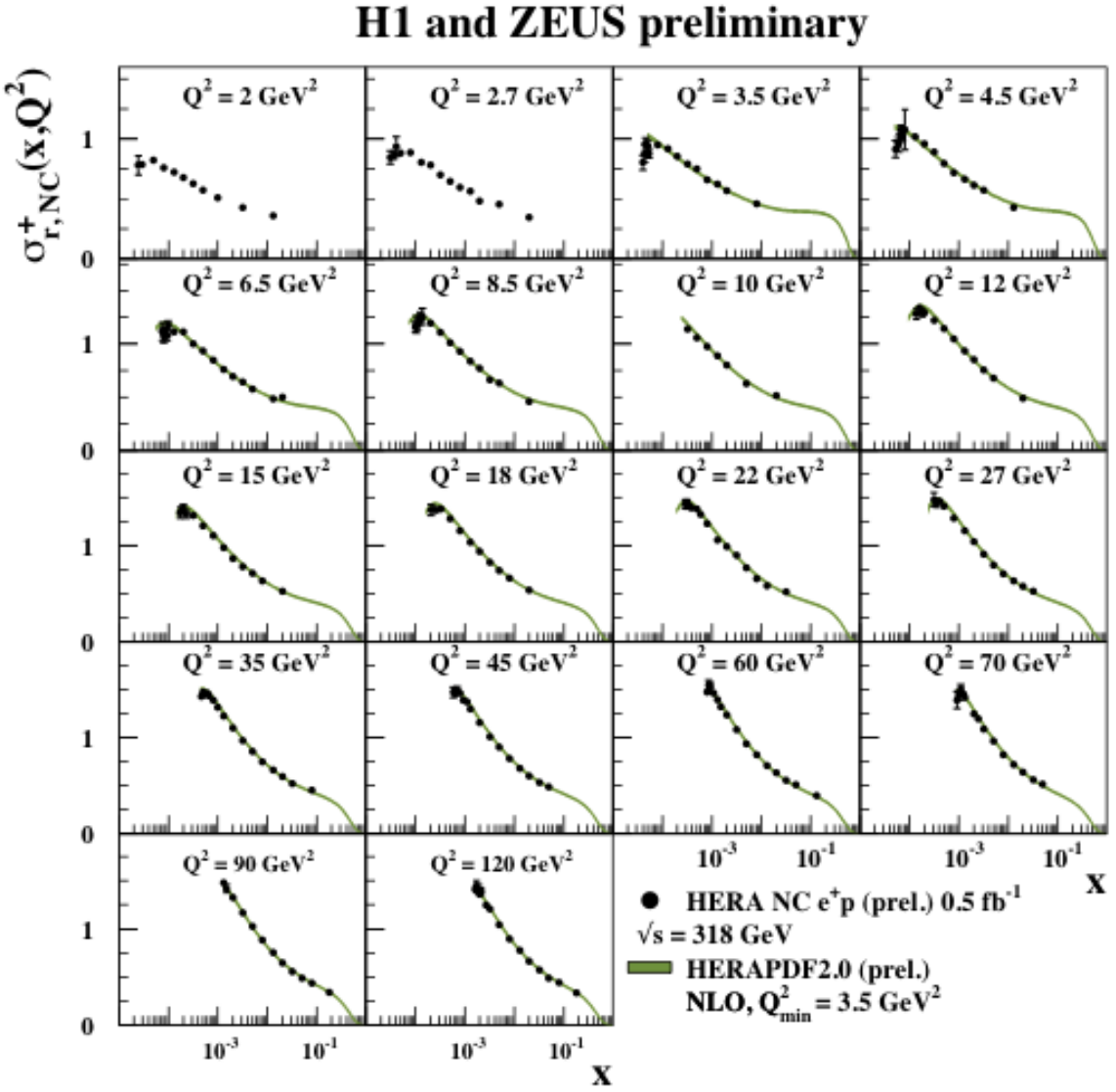
Input parameters of the fit (Q^2_0=1.9 GeV^2)

$$xg,\ xu_v,\ xd_v,\ x\bar{U} = x\bar{u},\ x\bar{D} = x\bar{d} + x\bar{s}$$
$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

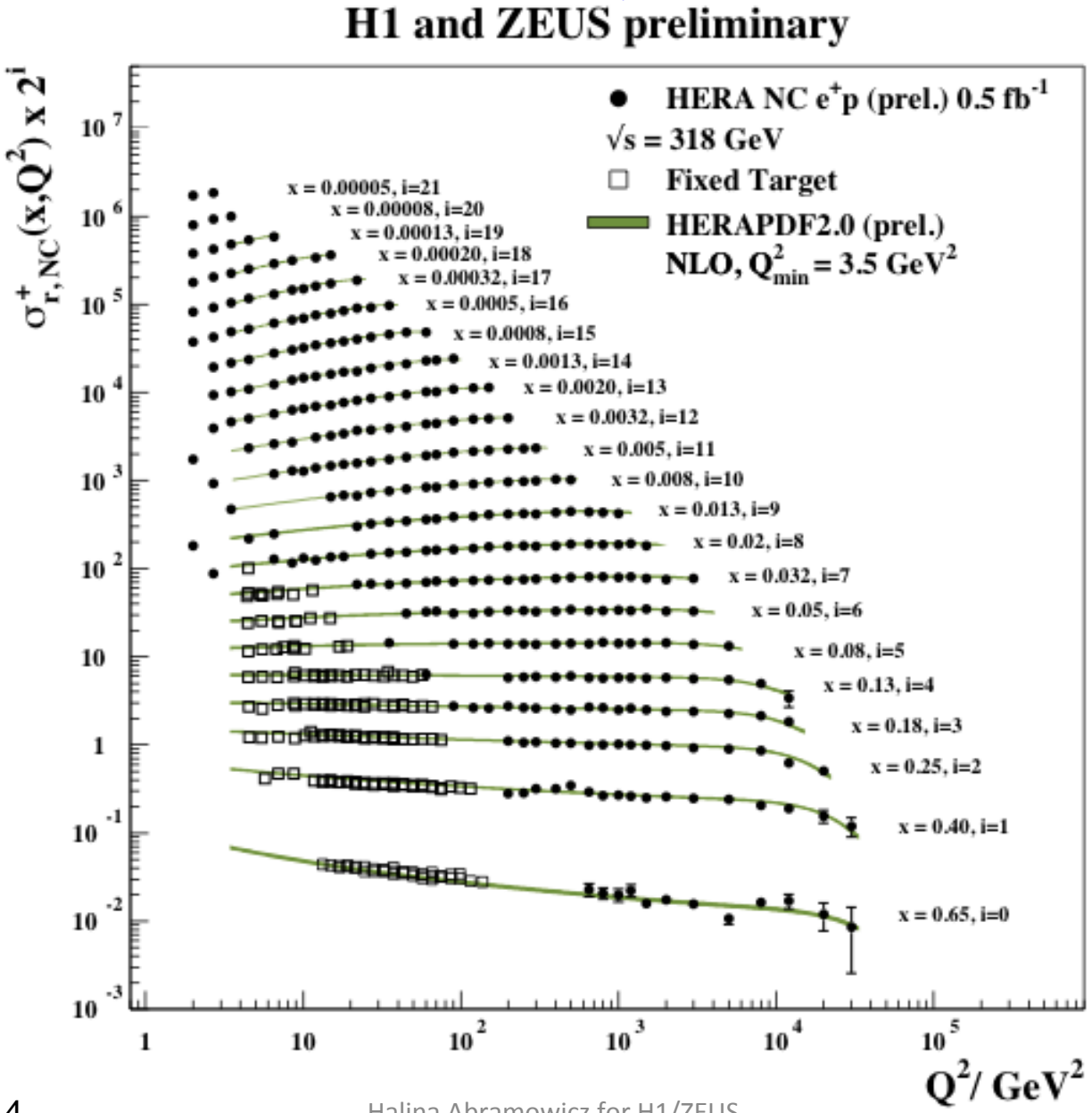
In addition

- M_c^{opt} – mass of the charm quark (best χ^2 to F^2_c)
- M_b^{opt} - mass of the bottom quark
- f_s – suppression of strange quarks (neutrino and ATLAS)
- Q^2_{min} – for determination of χ^2 (3.5 GeV^2, 10 GeV^2)
- $\alpha_s(M_Z^2)$ = 0.118
- Momentum sum rule
- Flavour conservation

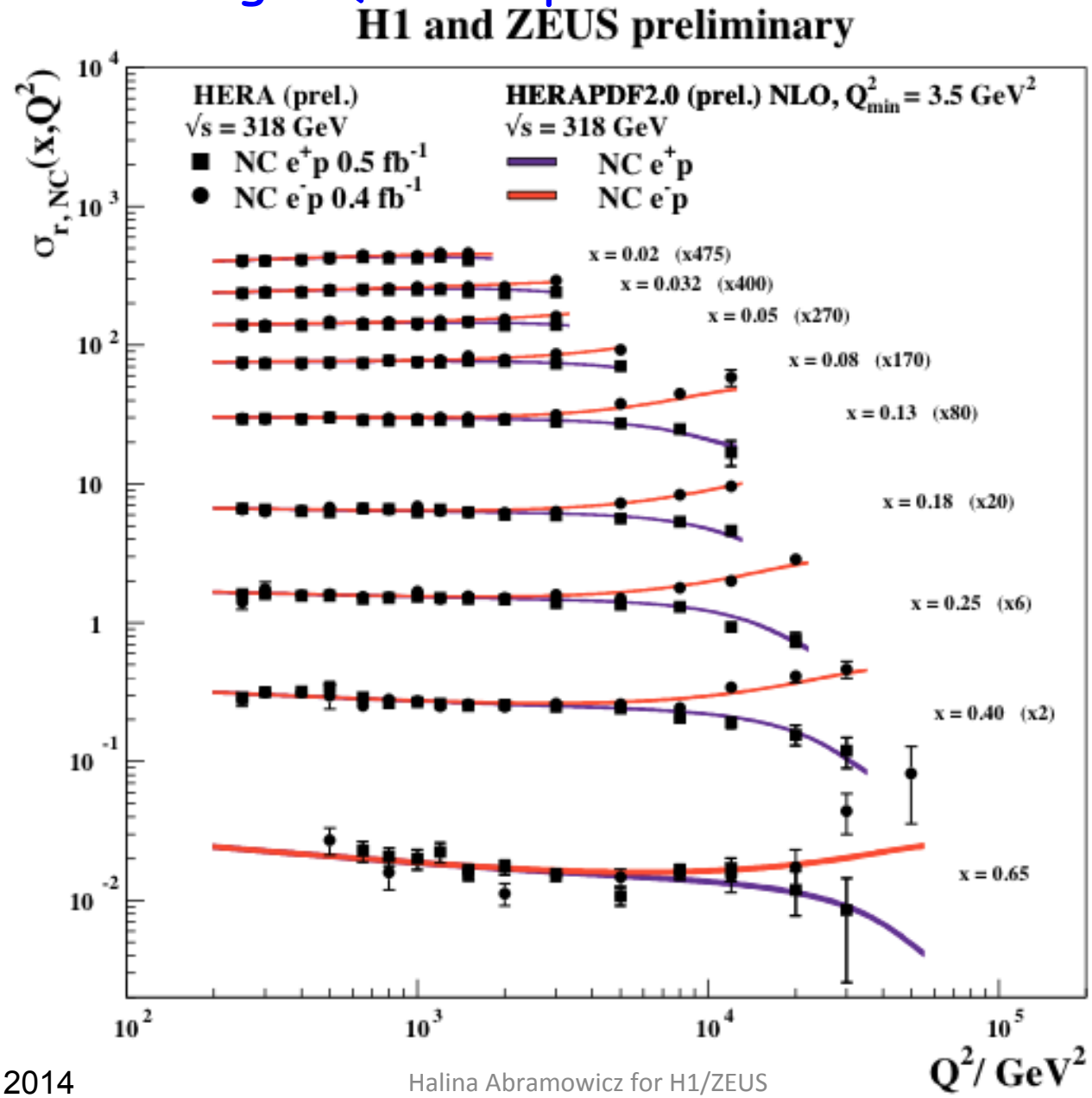
Low Q^2 e+p data HERAI+II



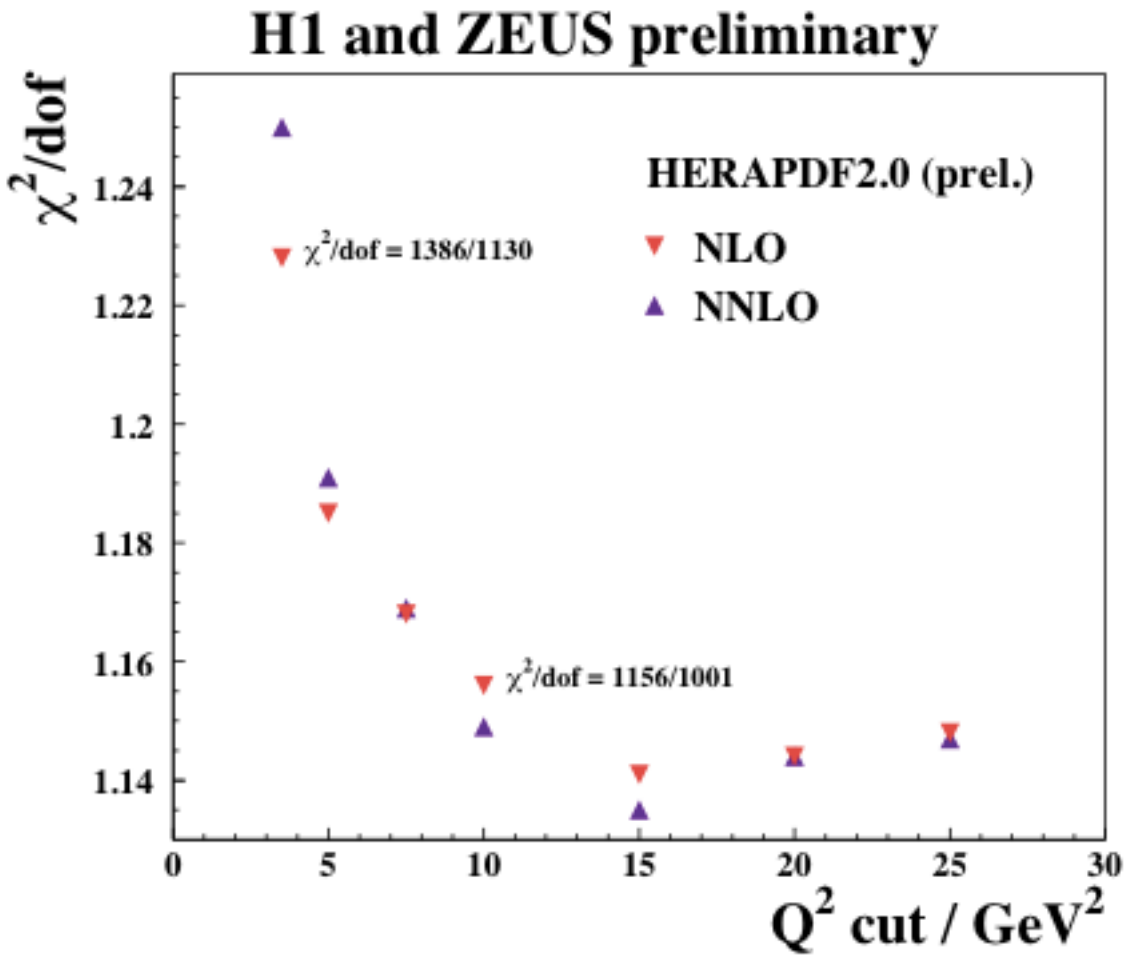
Scaling violations e+p data HERAI+II



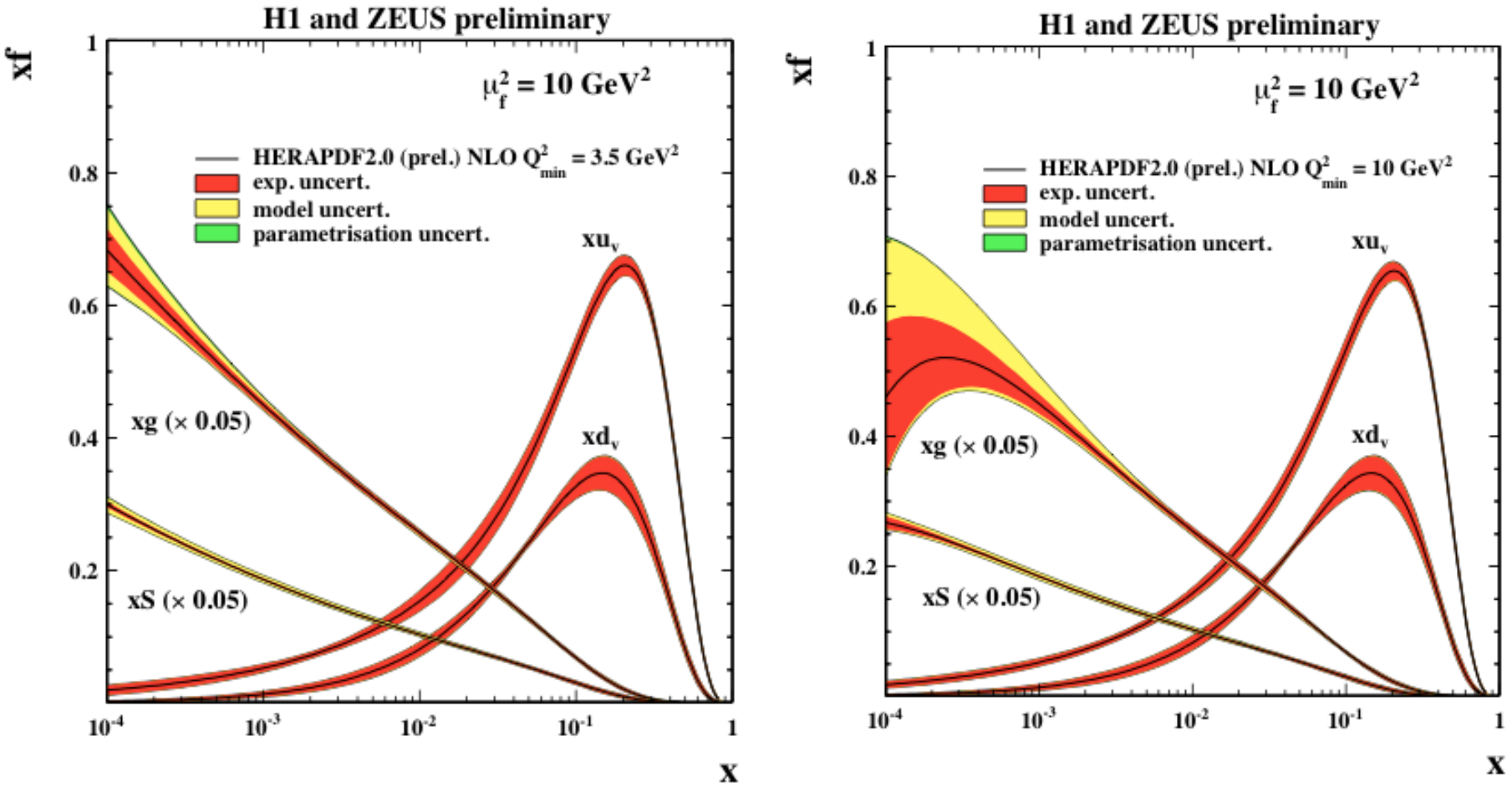
Large Q^2 e+/e-p data HERAI+II



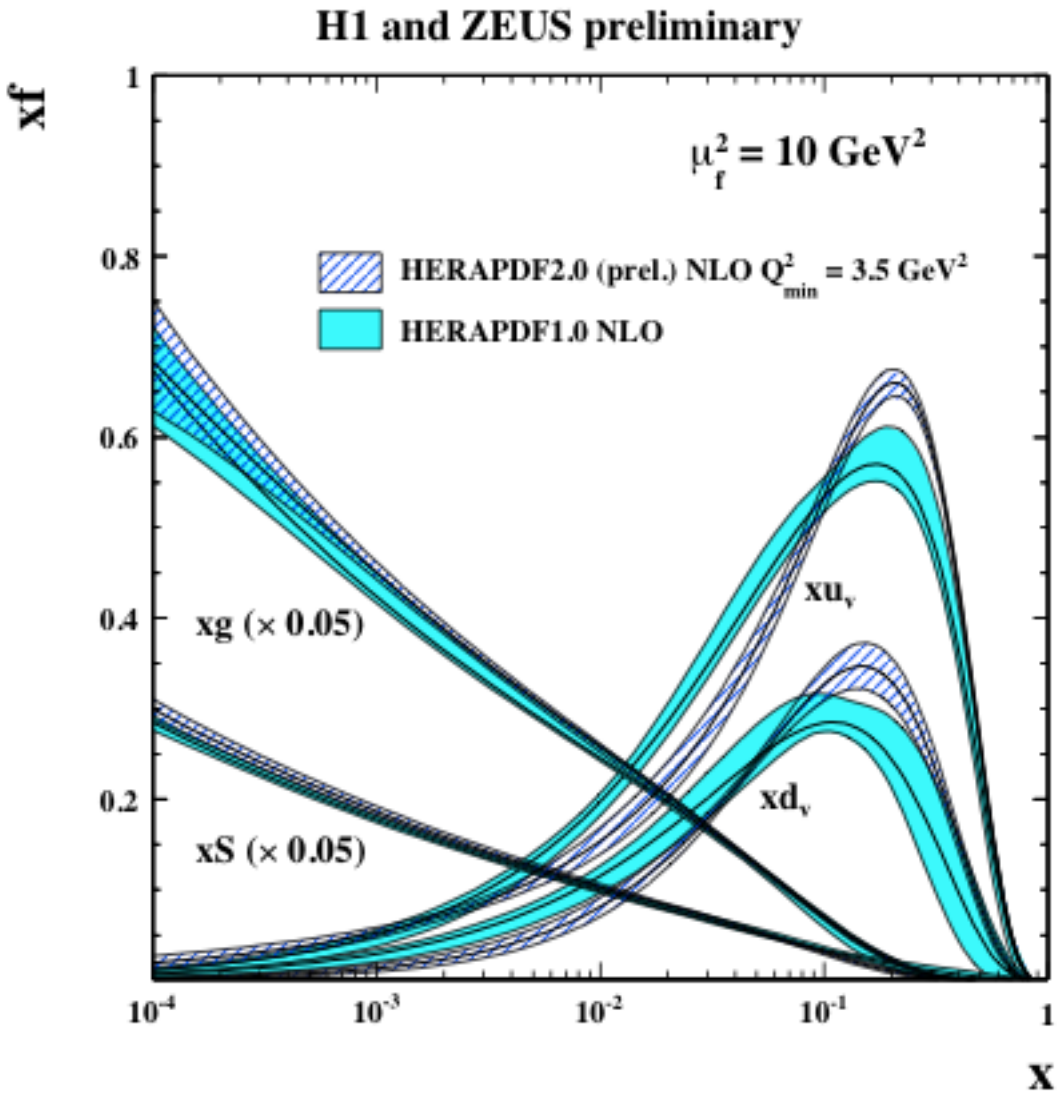
First signs that DGLAP cannot be abused



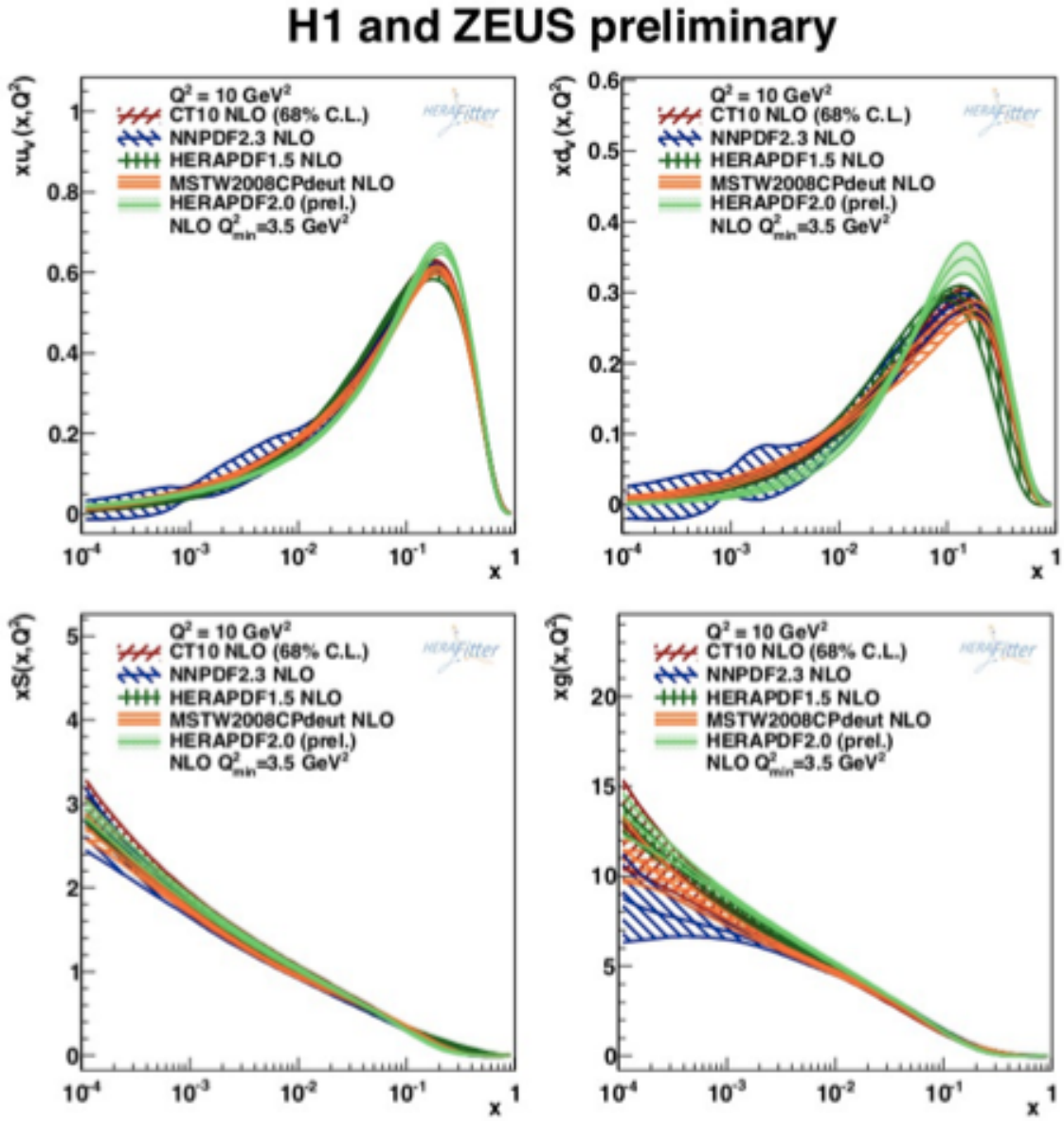
Price to pay for constraining partons only above 10 GeV^2



Changes with respect to HERAPDF1.0 (HERAI)



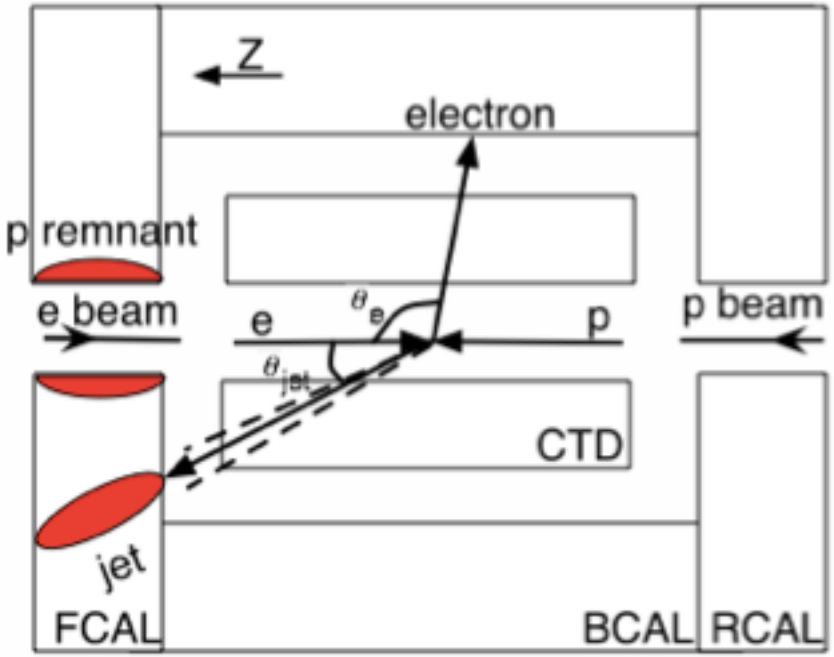
Comparison to other popular PDFs

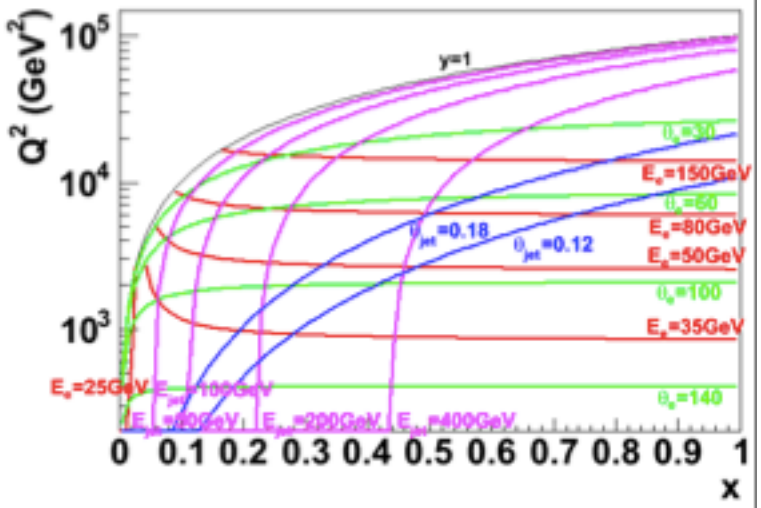


Conclusions

- Combination of all H1 and ZEUS DIS cross section measurements
- Preliminary version of QCD fits – HERAPDFII – strong constraints on high-x quark PDFs
- Anymore surprises? – maybe, high-x integrated cross sections not used yet in the fits

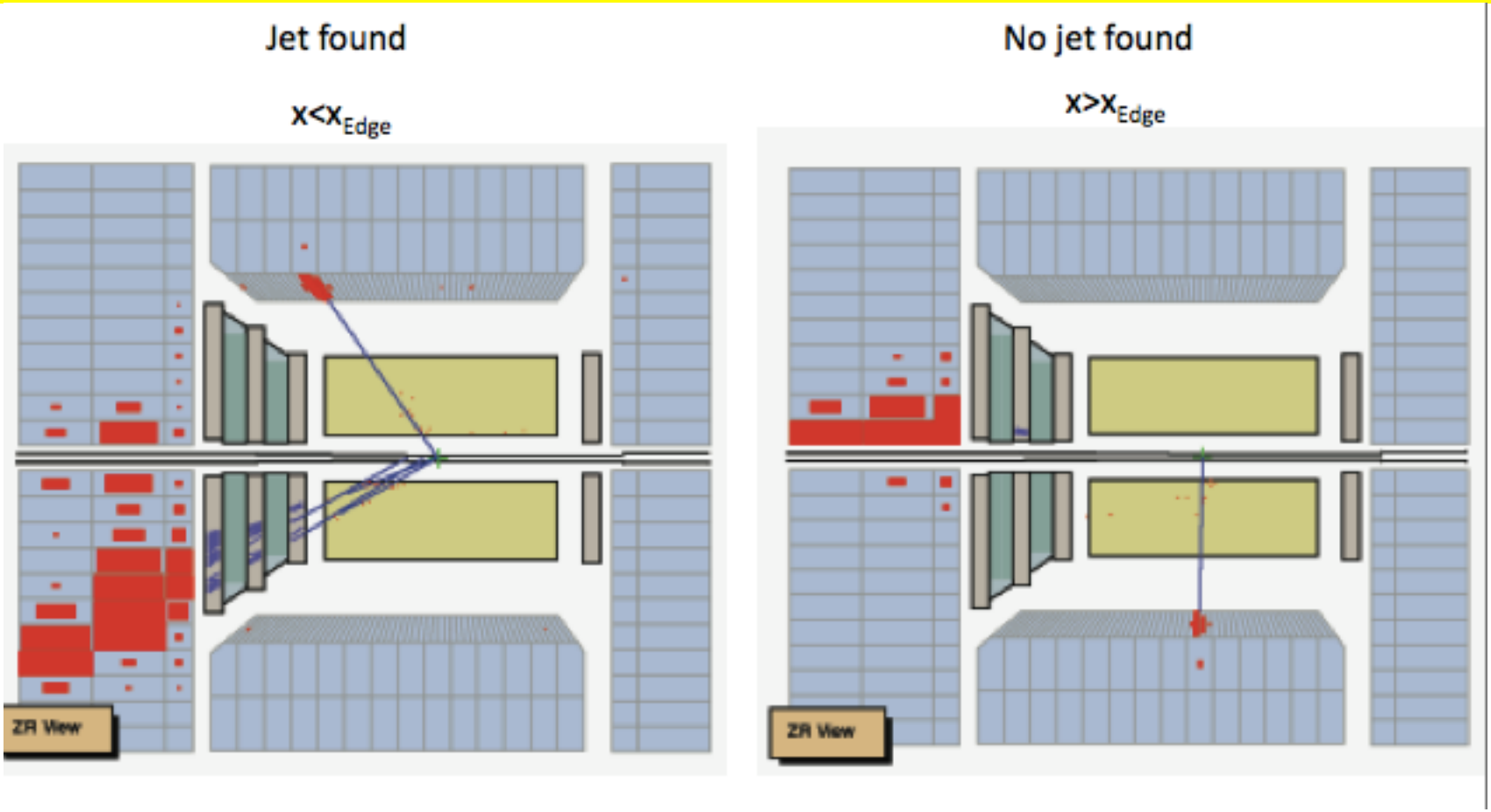
HERA high x high Q^2





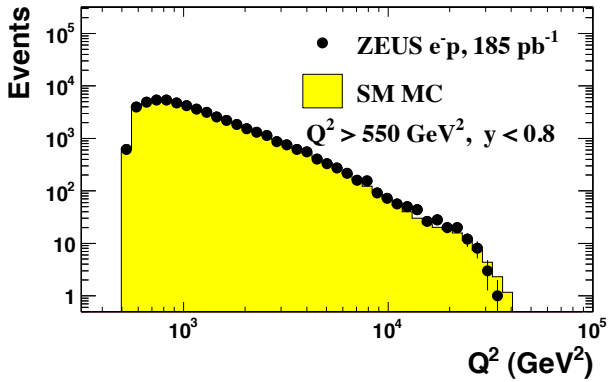
- At high Q^2, scattered electron seen with ≈100% acceptance
- For not too high x, measure x from jet: $\frac{d^2\sigma}{dxdQ^2}$
- For $x>x_{Edge}$, measure $\int_{x_{Edge}}^{1} \frac{d^2\sigma}{dxdQ^2} dx$

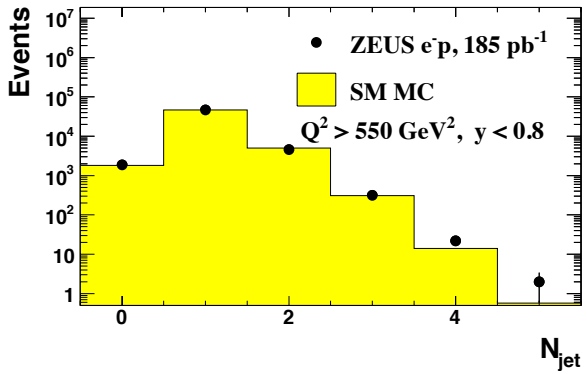
1-jet, 0-jet

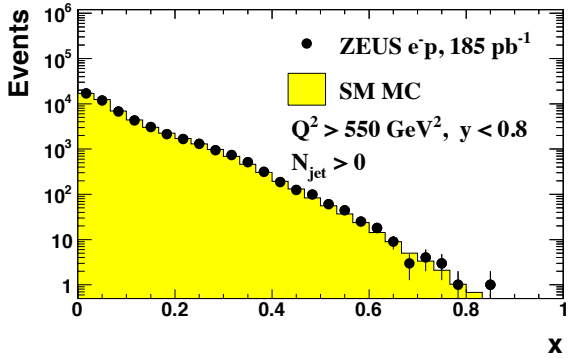


Control plots

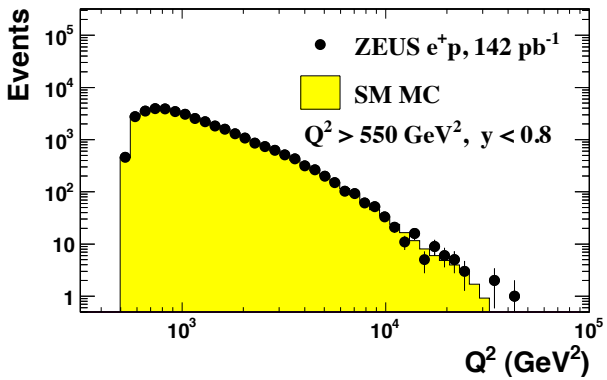
e^-p

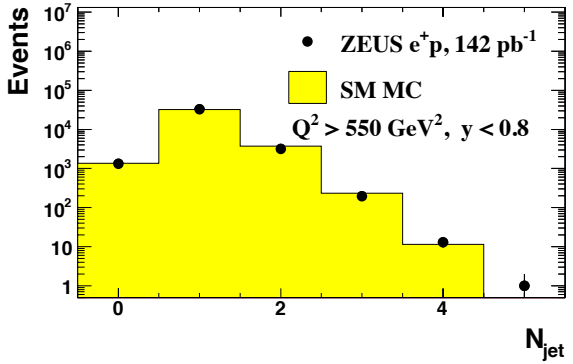


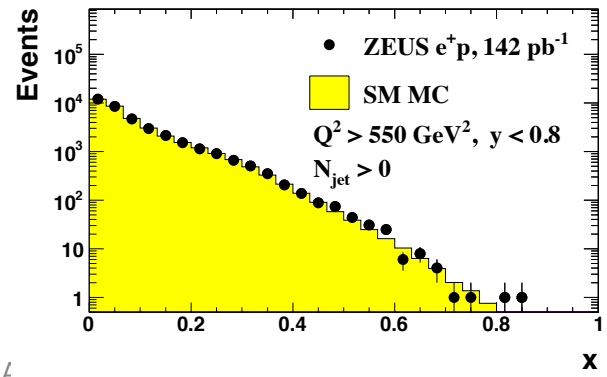




e^+p







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