PHYSICS AT HERA -I-

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New trends in High Energy Physics
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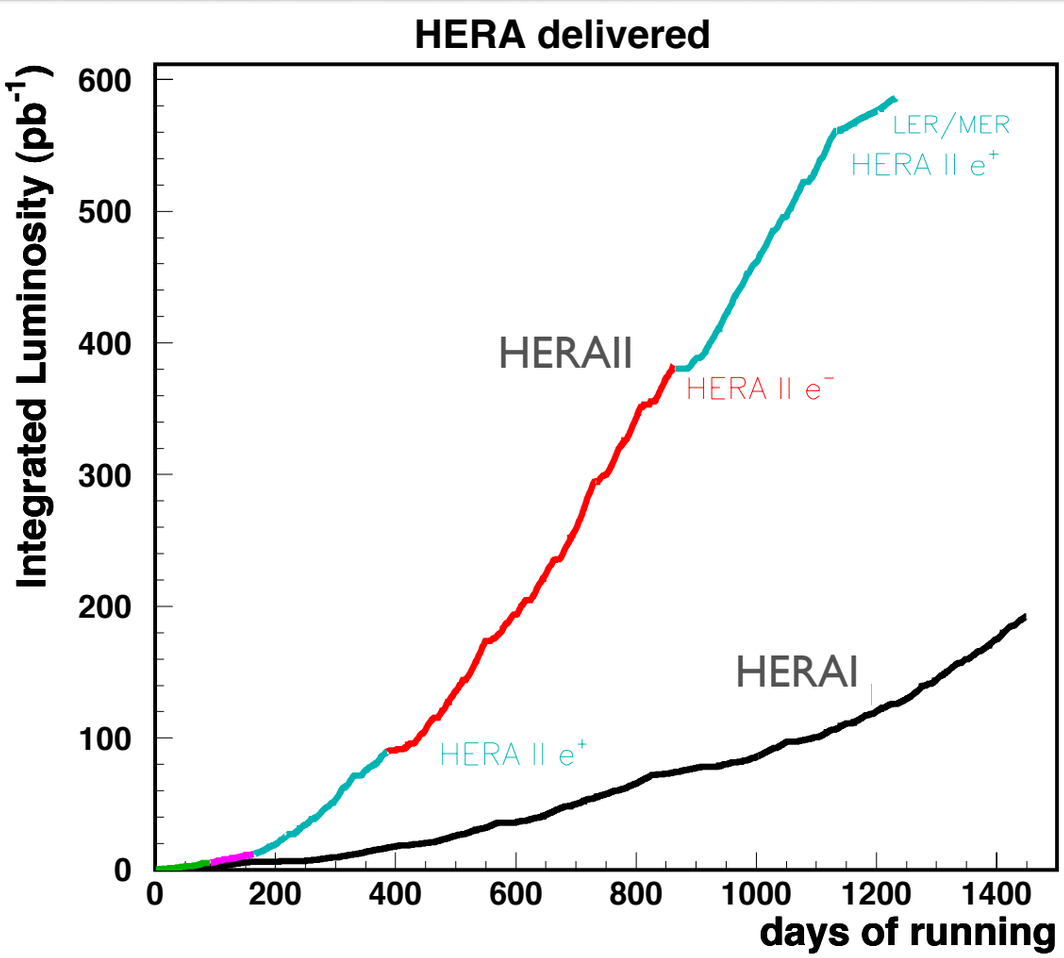
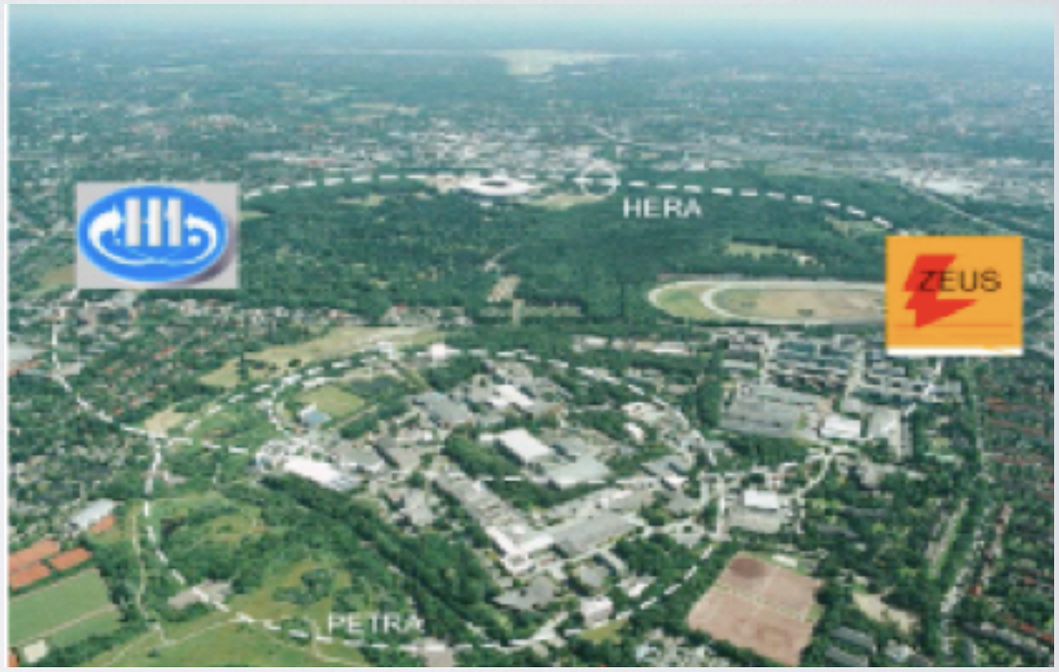
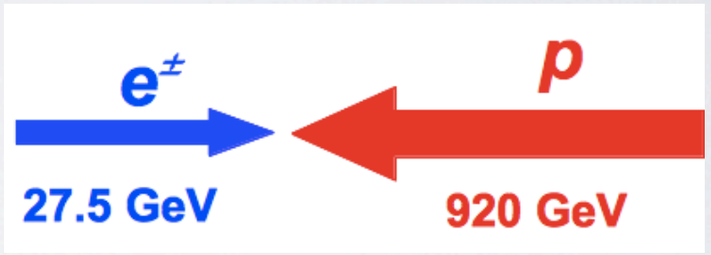
THE HERA COLLIDER

HERA was an *ep* collider operating at a centre-of-mass energy of 318 GeV.
The lepton beam could be longitudinally polarised.
Two collider experiments: H1 and ZEUS.



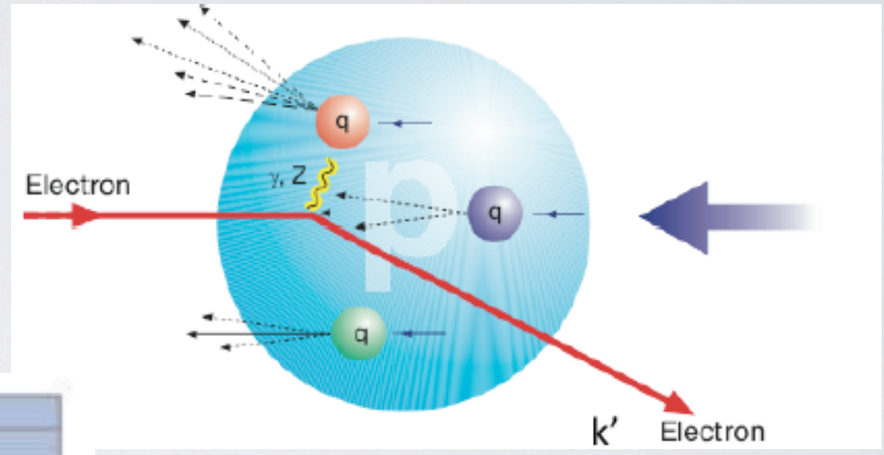


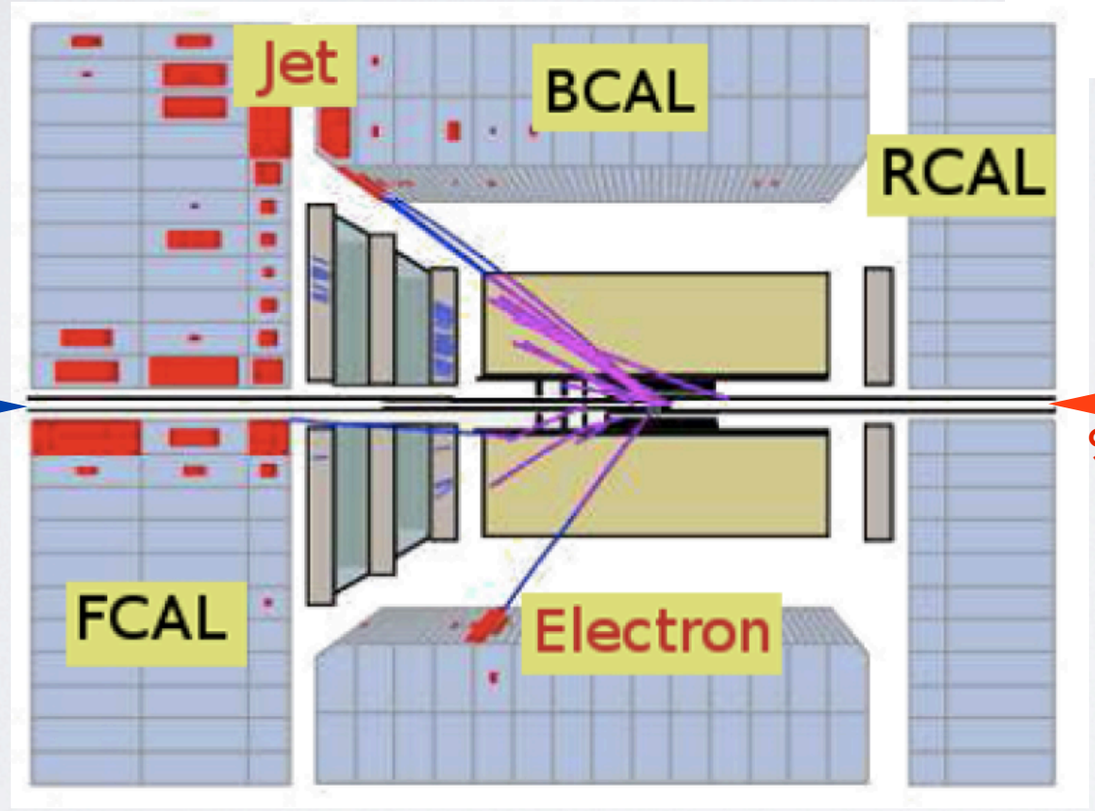


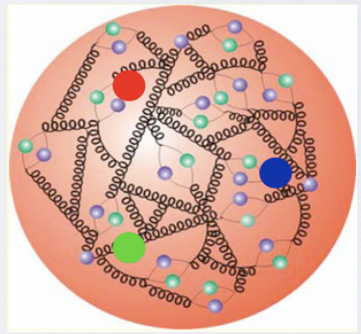
Data taking ended 4 years ago.
Total collected luminosity:
0.5 fb^{-1} per collider experiment.

THE **ZEUS AND H1** DETECTORS AT **HERA**

HERA: first and only electron-proton collider, super-microscope to investigate the structure of matter at a distance of 10^{-18} m



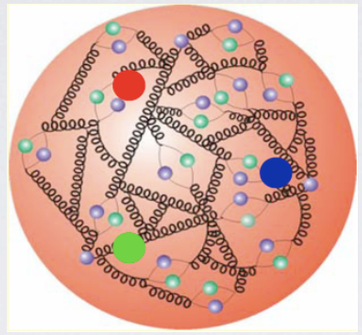


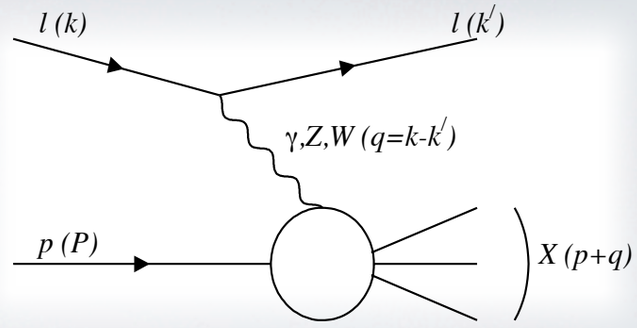


ZEUS and H1: multi-purpose detector designed to measure the products of the electron-proton collisions at HERA

PHYSICS AT HERA

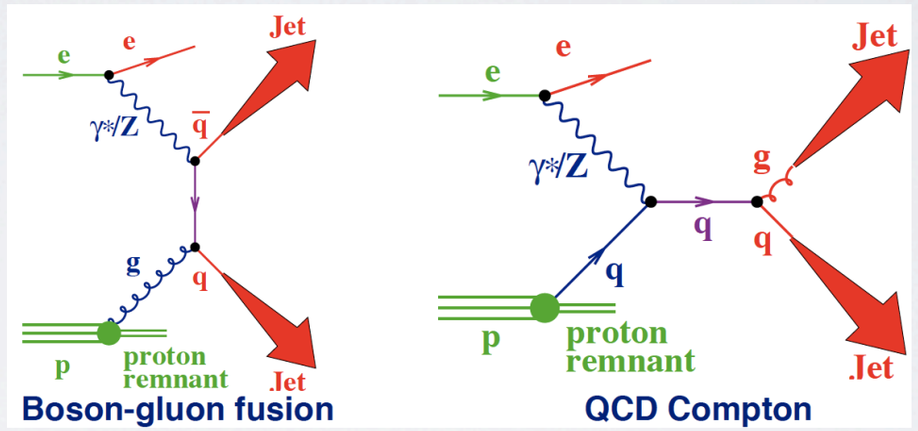
HERA and ep DIS:
- provide input to determine the structure of the proton

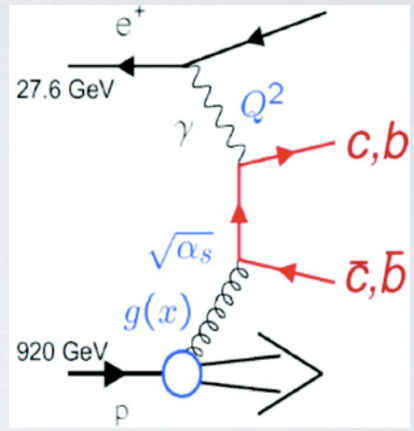




This talk

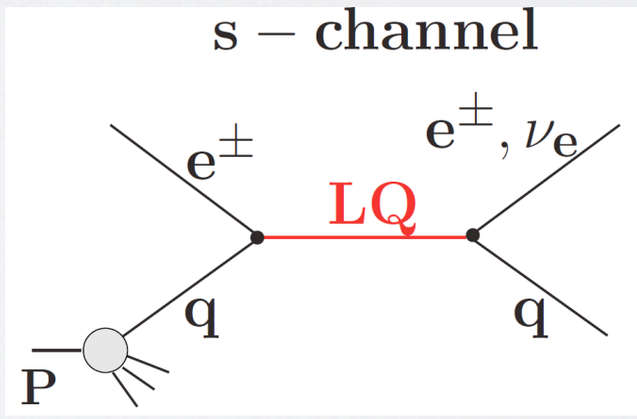
HERA as a QCD machine:
- jet production, measure α_s;
- heavy flavour production;
- diffraction.



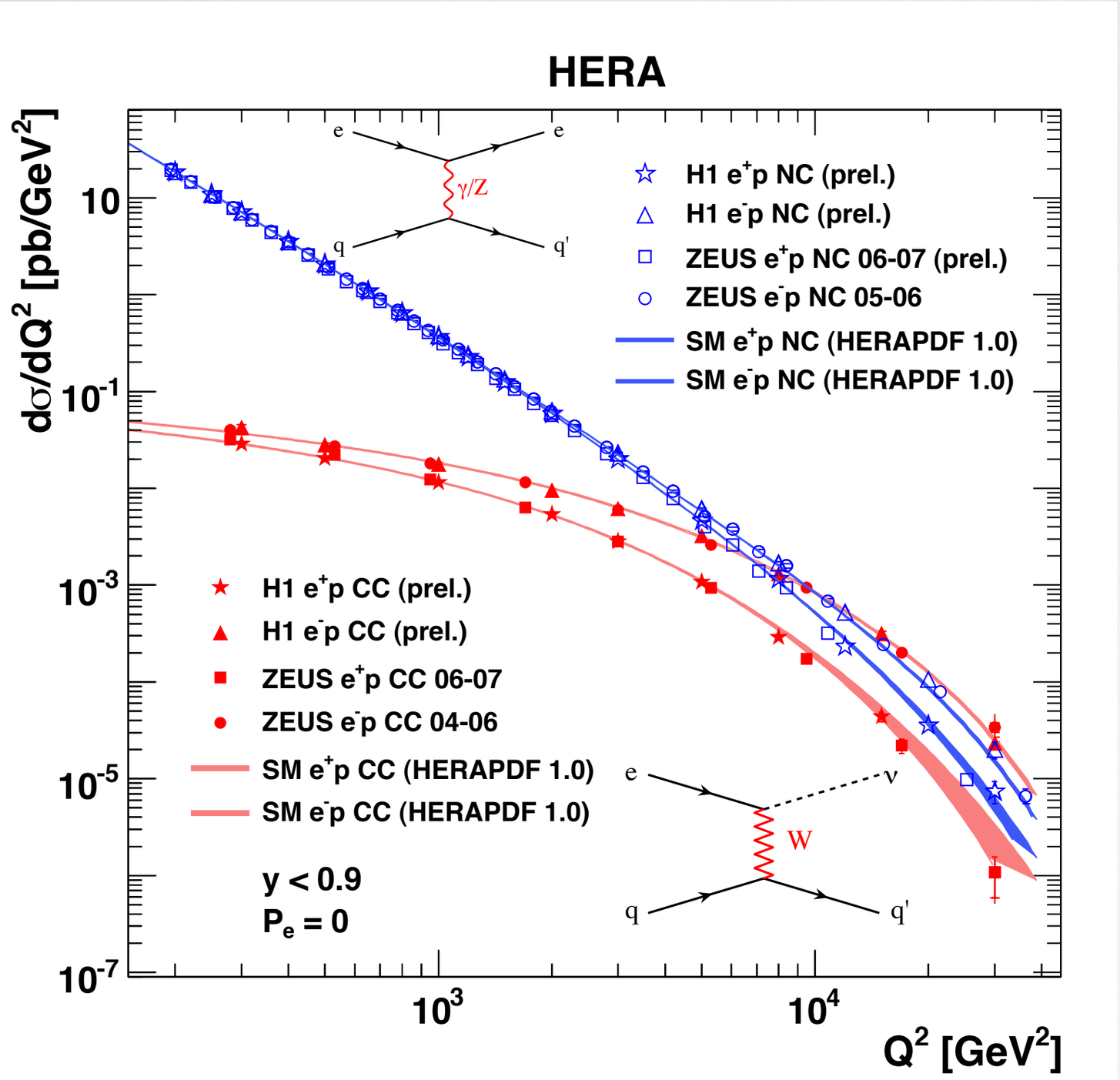


HERA as a discovery machine:
- investigate the EW frontier
- look for model-predicted (SUSY, Leptoquarks) and model-independent signatures.

Next talk



NEUTRAL AND CHARGED CURRENT CROSS SECTIONS



Cross section dominated by **photon exchange** at low Q^2

Electroweak unification at $Q^2 \sim 10000$ GeV^2 (M_Z^2)

Fundamental input for the **determination of the proton structure.**

Deviation from Standard Model prediction sensitive to beyond the SM processes

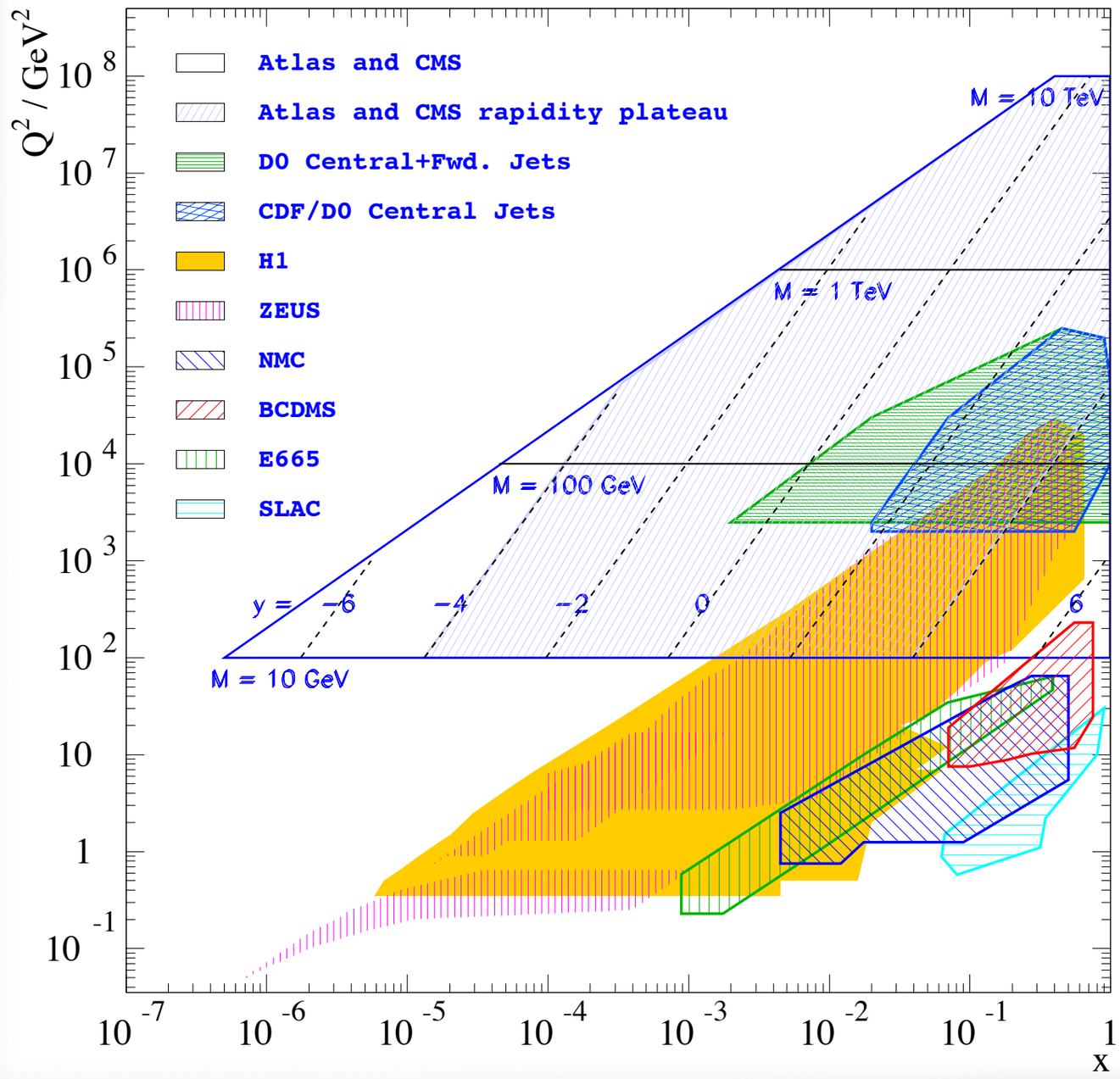
HERA, TEVATRON AND THE LHC

- Q^2 : hardness of the interaction, ~ E_T^2 at the TeVatron
- x : fraction of the proton momentum involved in the interaction.

At the LHC Q^2 and x correspond to the mass and the rapidity of the products:

$$Q^2 = M^2$$

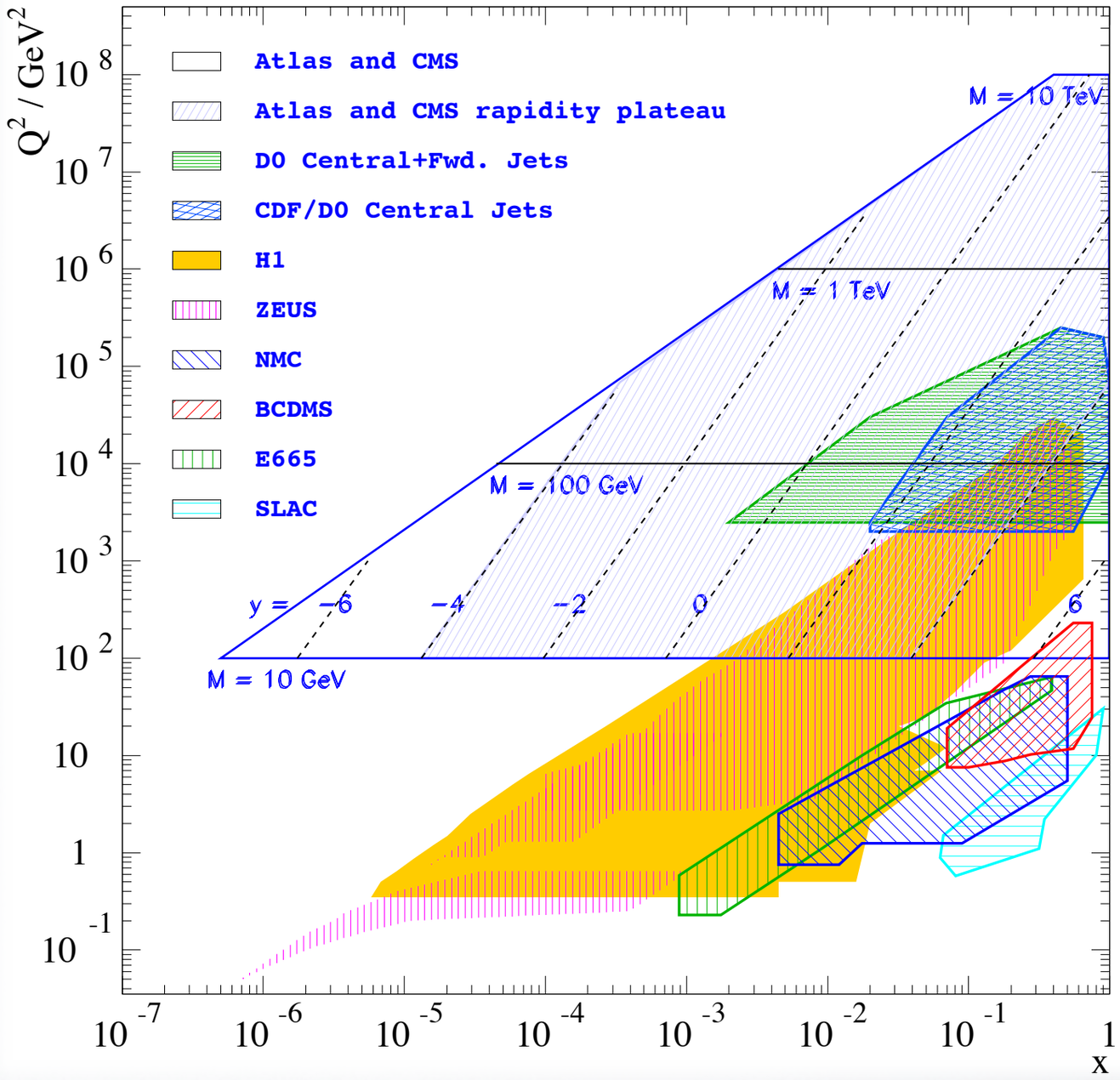
$$x = \frac{M}{14TeV} e^{-y}$$



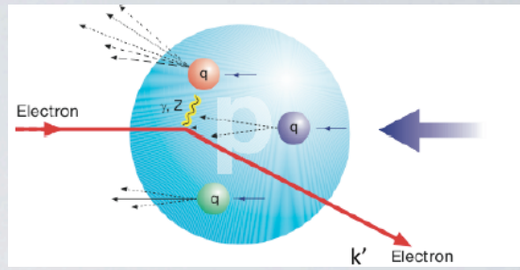
HERA, TEVATRON AND THE LHC

- The evolution in Q^2 is driven by the DGLAP equations, given the x-dependence, the PDF can be determined at any Q^2

- Using the HERA data, precise predictions for the production of particles of mass M~100 GeV in the central rapidity region can be obtained.



THE STRUCTURE OF THE PROTON



The NC *ep* cross section can be expressed in terms of the structure functions F_2, F_3, F_L:

$$\frac{d^2\sigma^{e^\pm p}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2(x,Q^2) \mp Y_-xF_3(x,Q^2) - y^2F_L(x,Q^2)\right] \quad \text{where } Y_\pm = 1 \pm (1-y)^2$$

point-like

structure functions

The structure functions are related to the proton parton distribution functions:

$$F_2 \sim x(q+\bar{q}) \qquad F_3 \sim x(q-\bar{q}) \qquad F_L \sim x\alpha_s g$$

The ep CC cross section is sensitive to the quark charges:

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

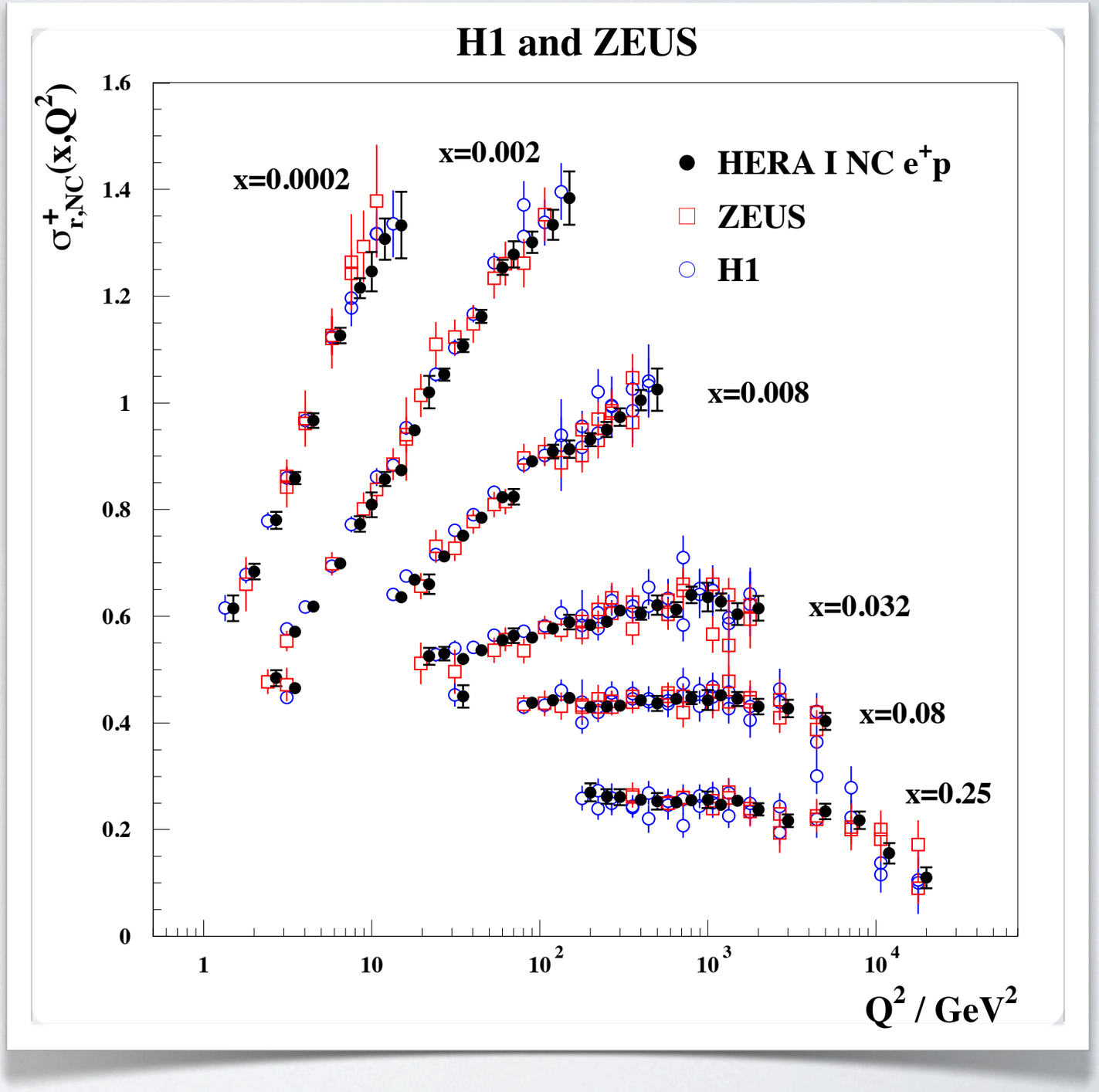
THE F_2 STRUCTURE FUNCTION

$$F_2 \sim x(q + \bar{q})$$

The data of H1 and ZEUS are being combined in order to achieve the best possible precision.

From F_2: valence and sea quarks, gluons from scaling violations

$$\frac{\partial F_2(x, Q^2)}{\partial \ln Q^2} = \alpha_s(Q^2) x g(x, Q^2)$$



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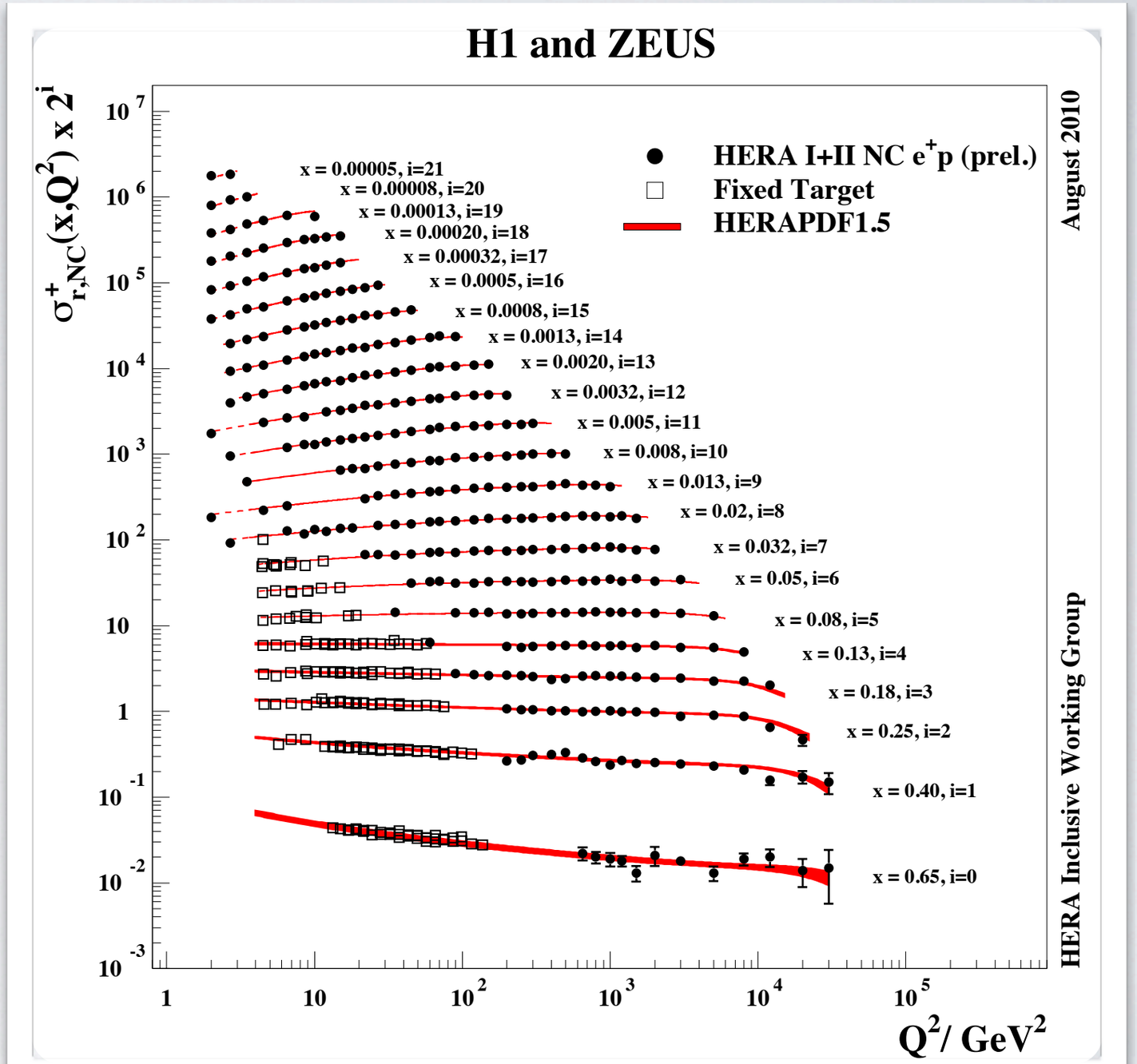
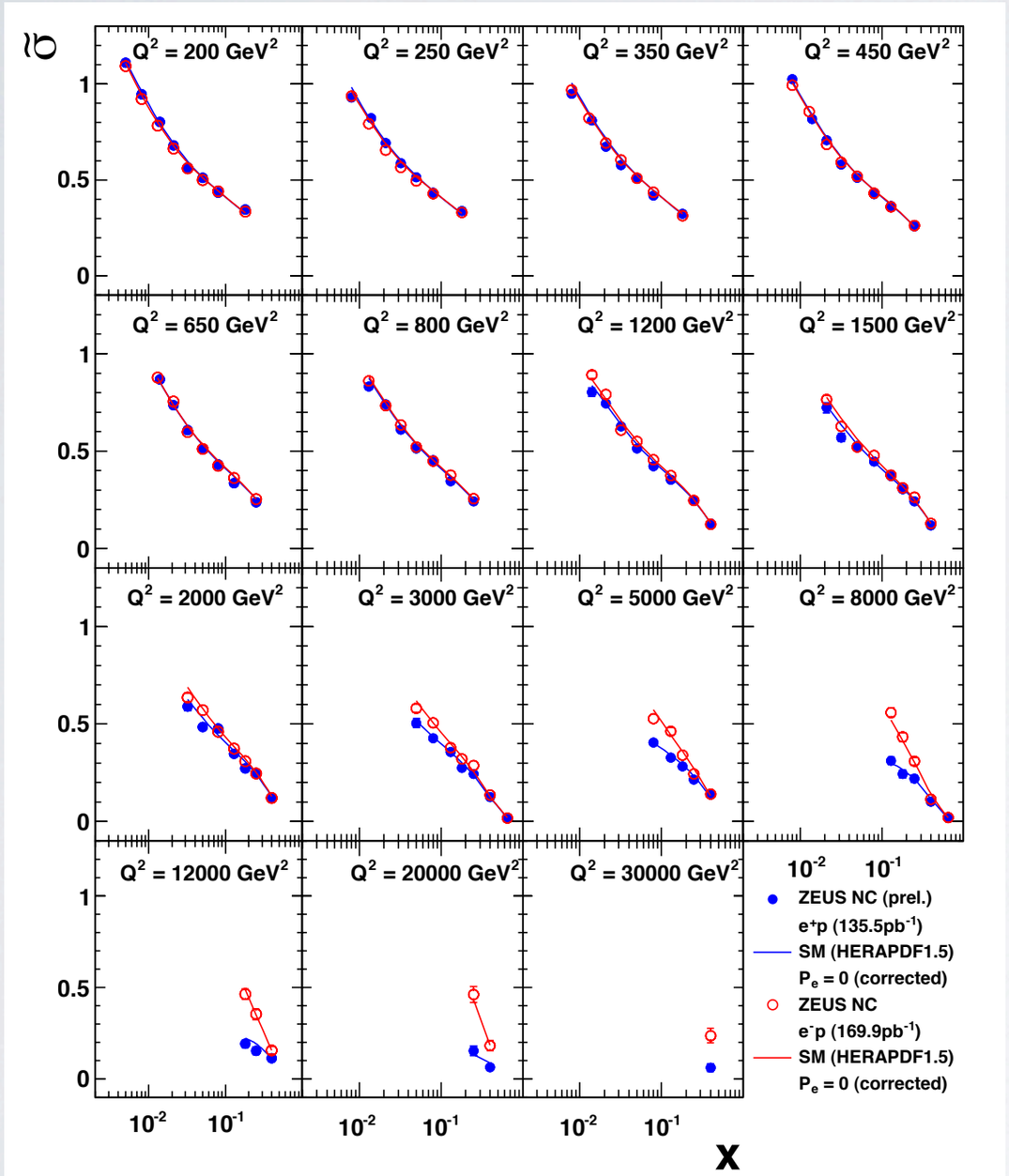
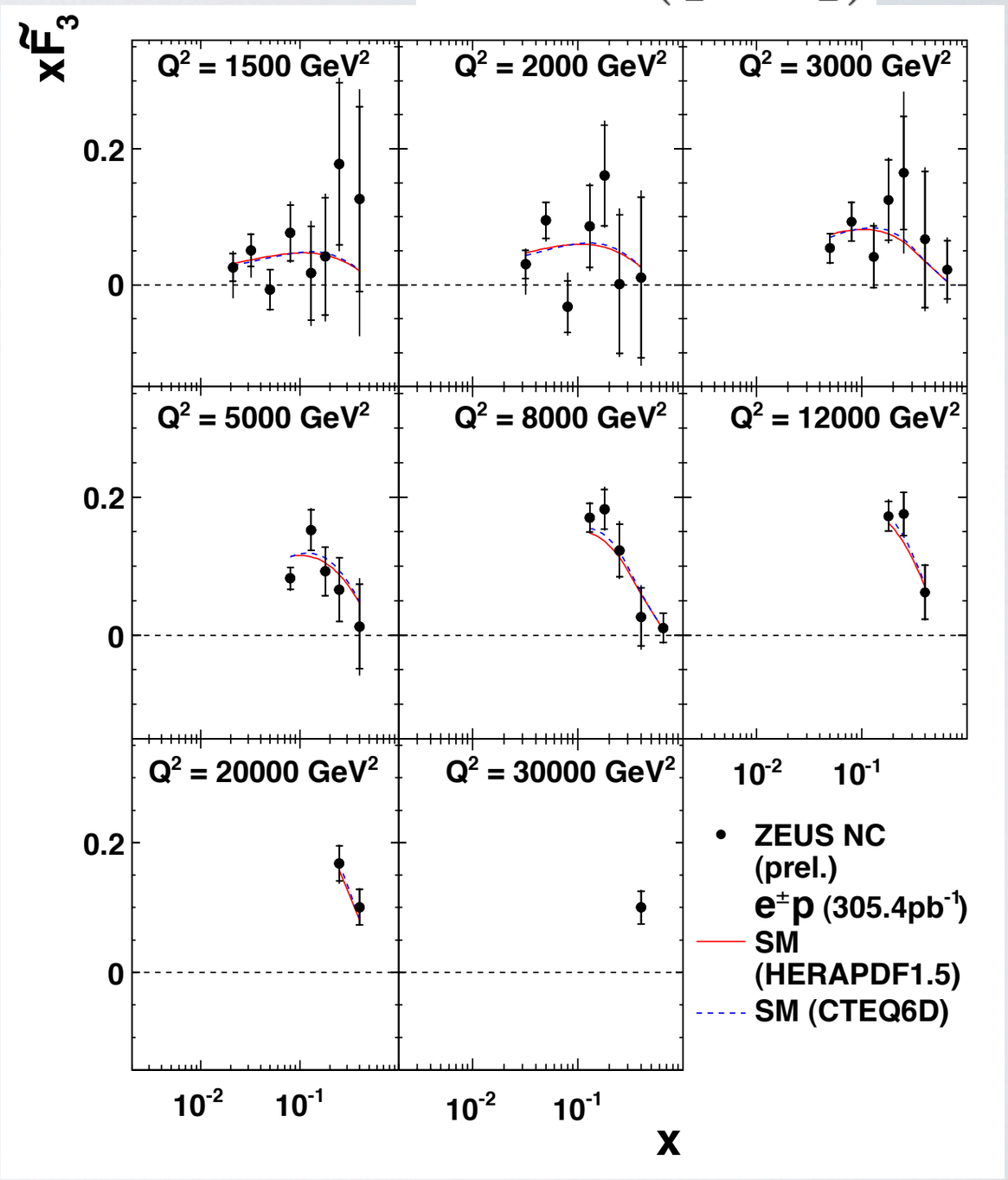
Almost the full data sample has been used for the latest PDF fits.



NC CROSS SECTIONS AND F_3

$$F_3 \sim x(q - \bar{q})$$

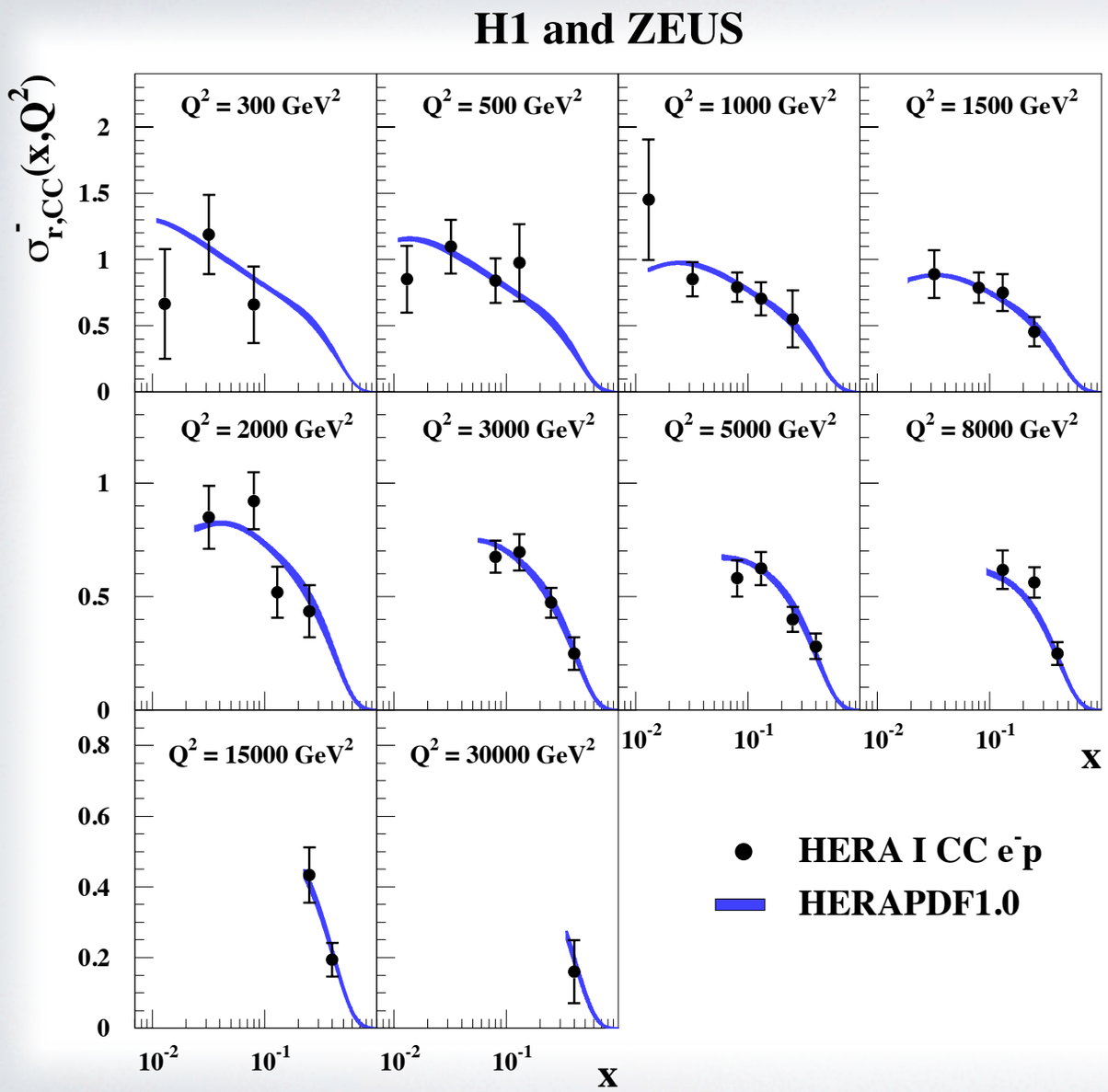


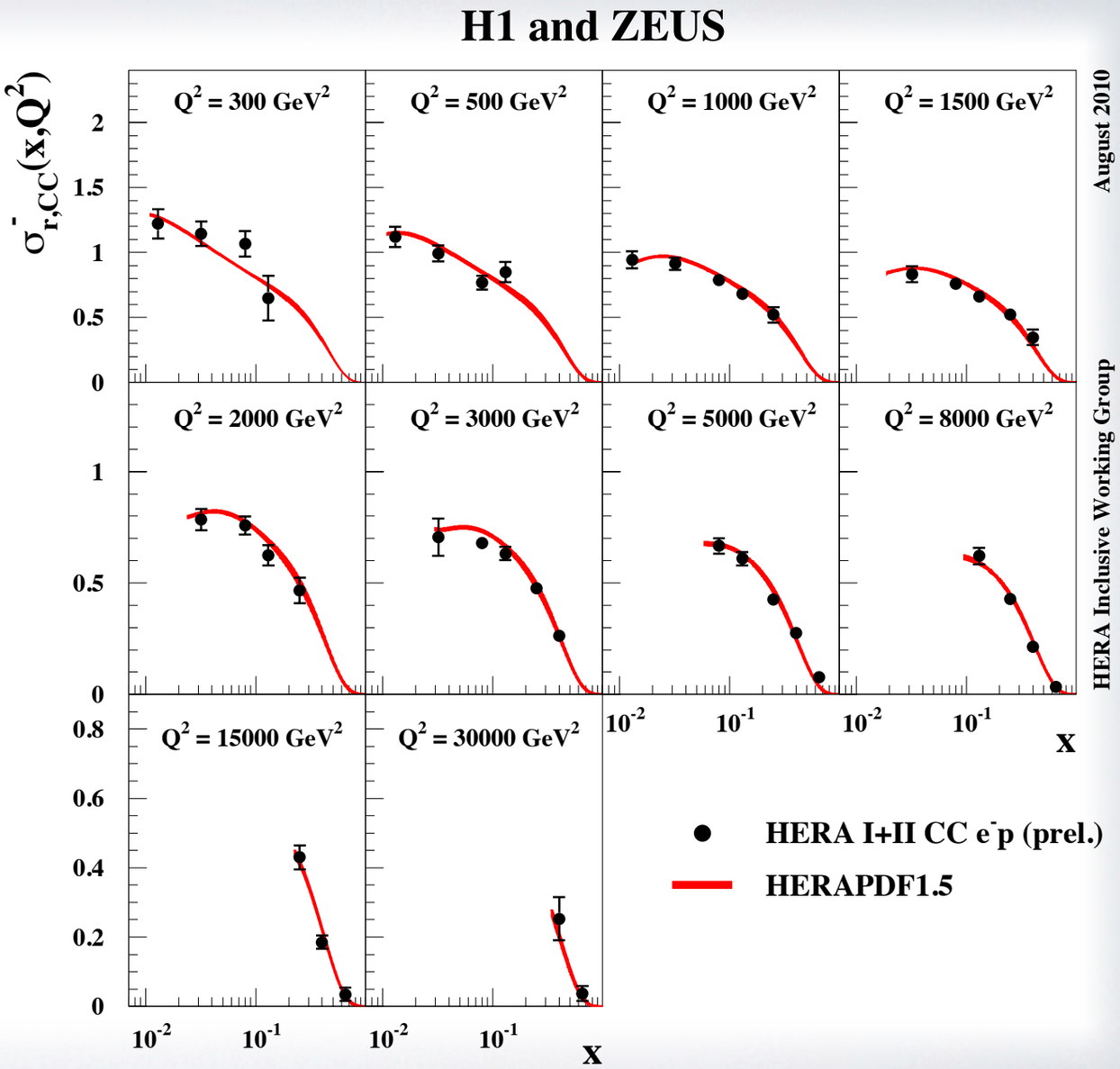


e^+p data not yet included in the latest PDF fits

CC CROSS SECTIONS

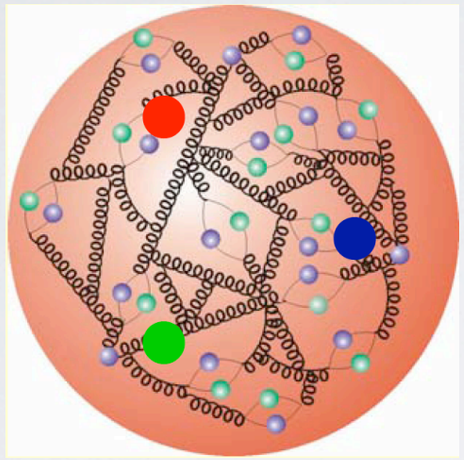
Significantly improved precision for the e⁻p data, translates into a better u-type quarks determination.

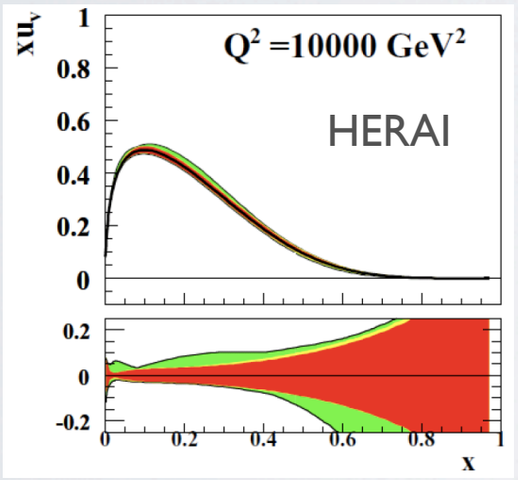


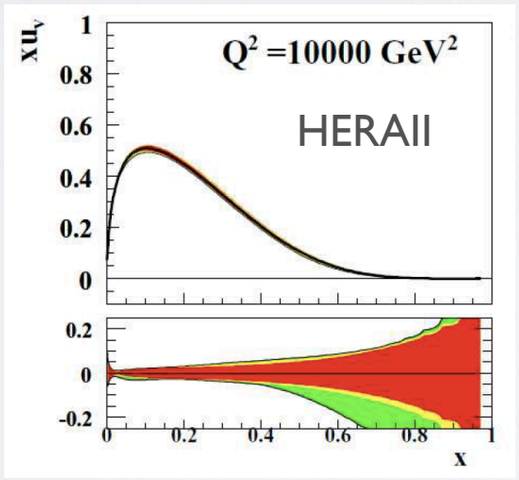


HERAPDF1.5

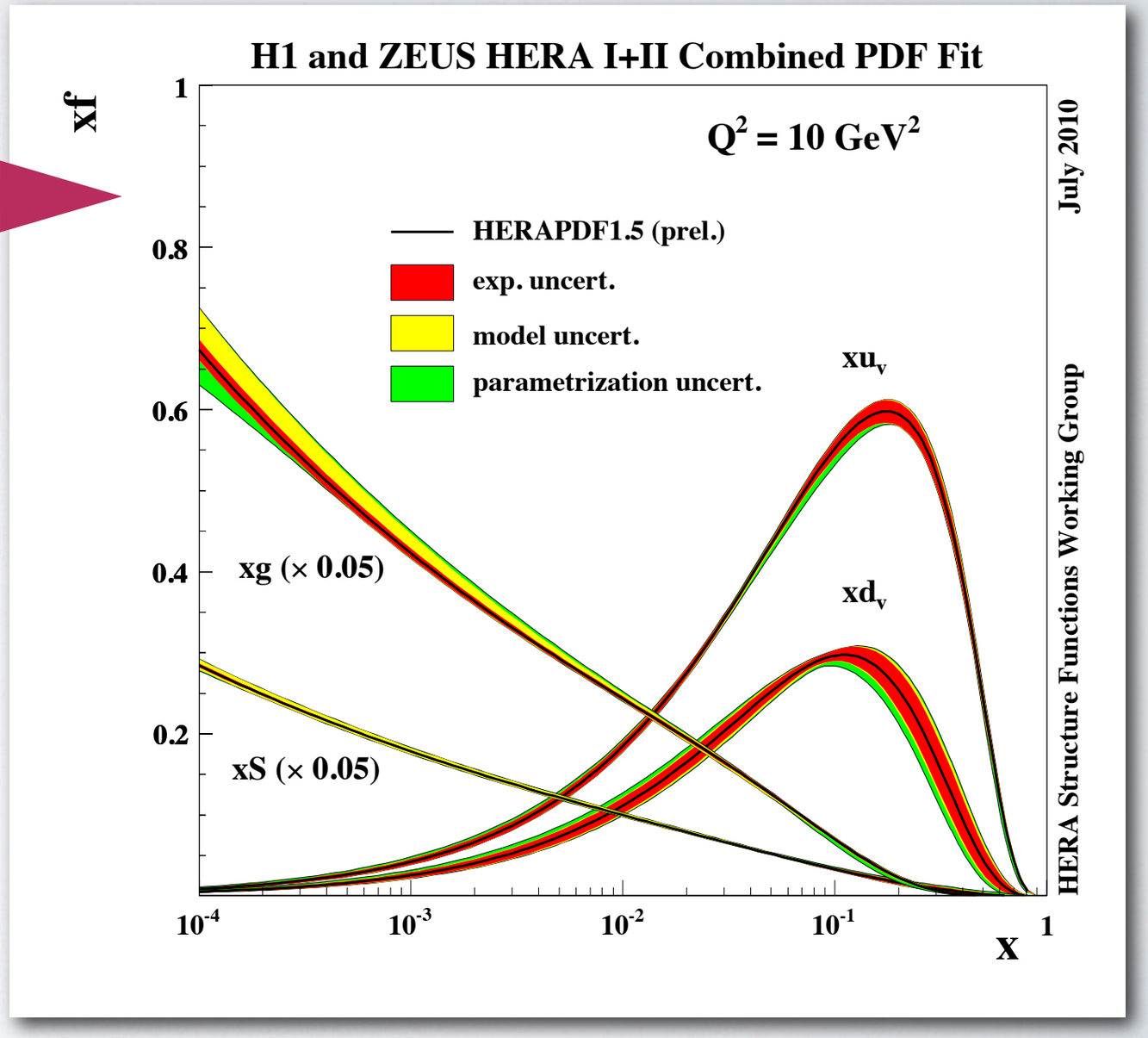
The H1 and ZEUS combined NC and CC cross sections have been used as the sole input for the determination of the HERAPDF1.5 PDF set.



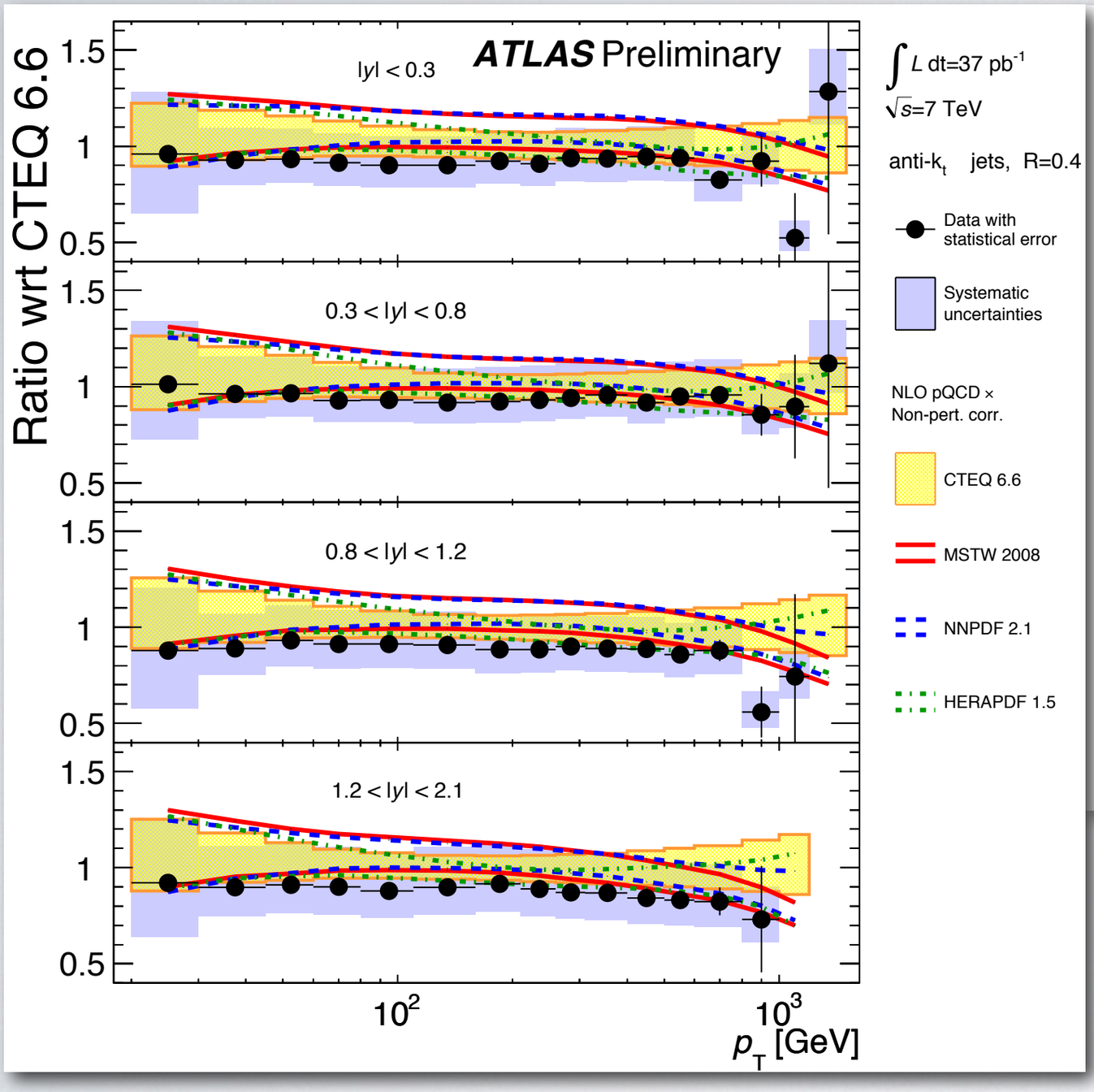


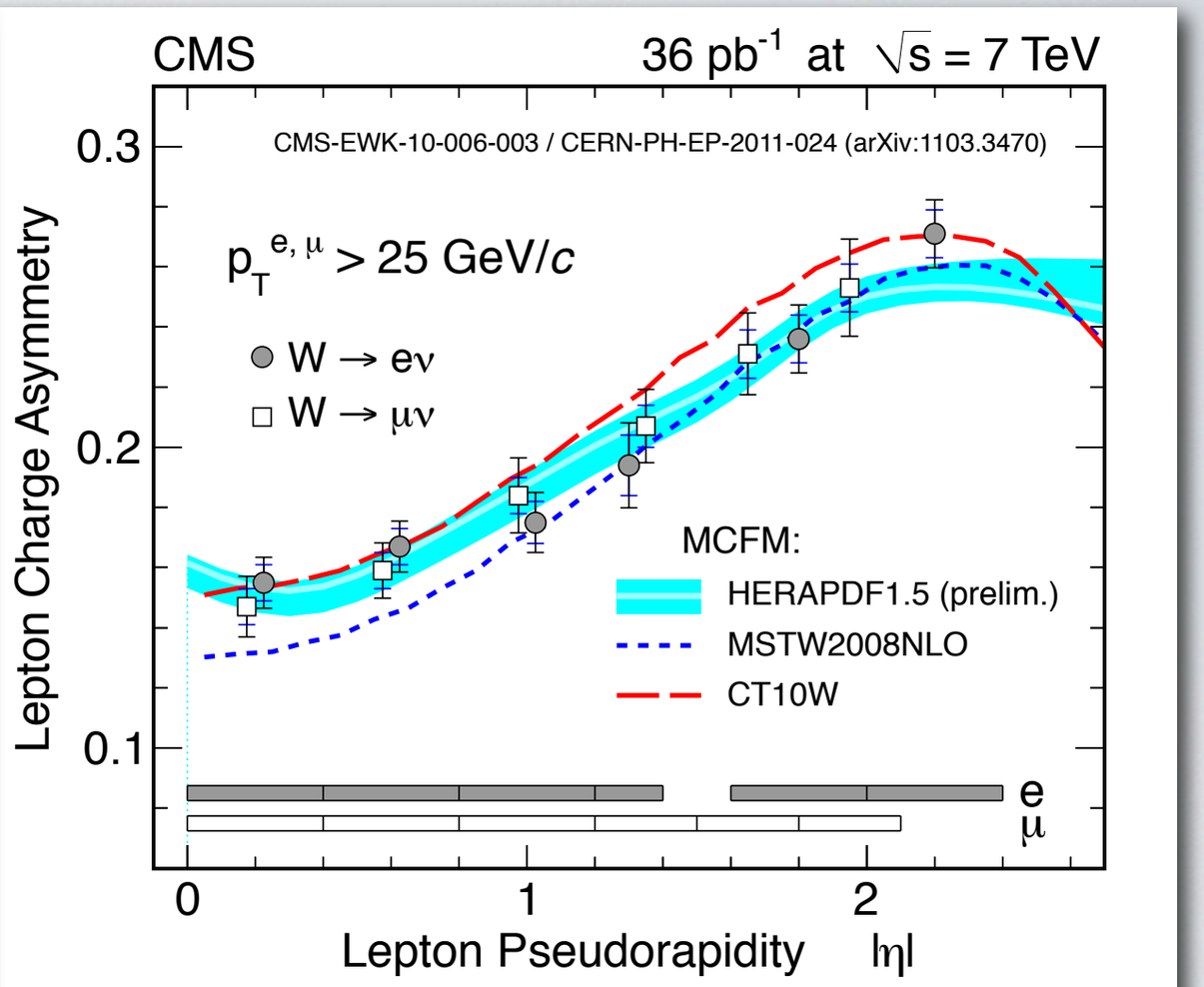


Precise picture of the proton



HERAPDF1.5 PREDICTIONS FOR THE LHC



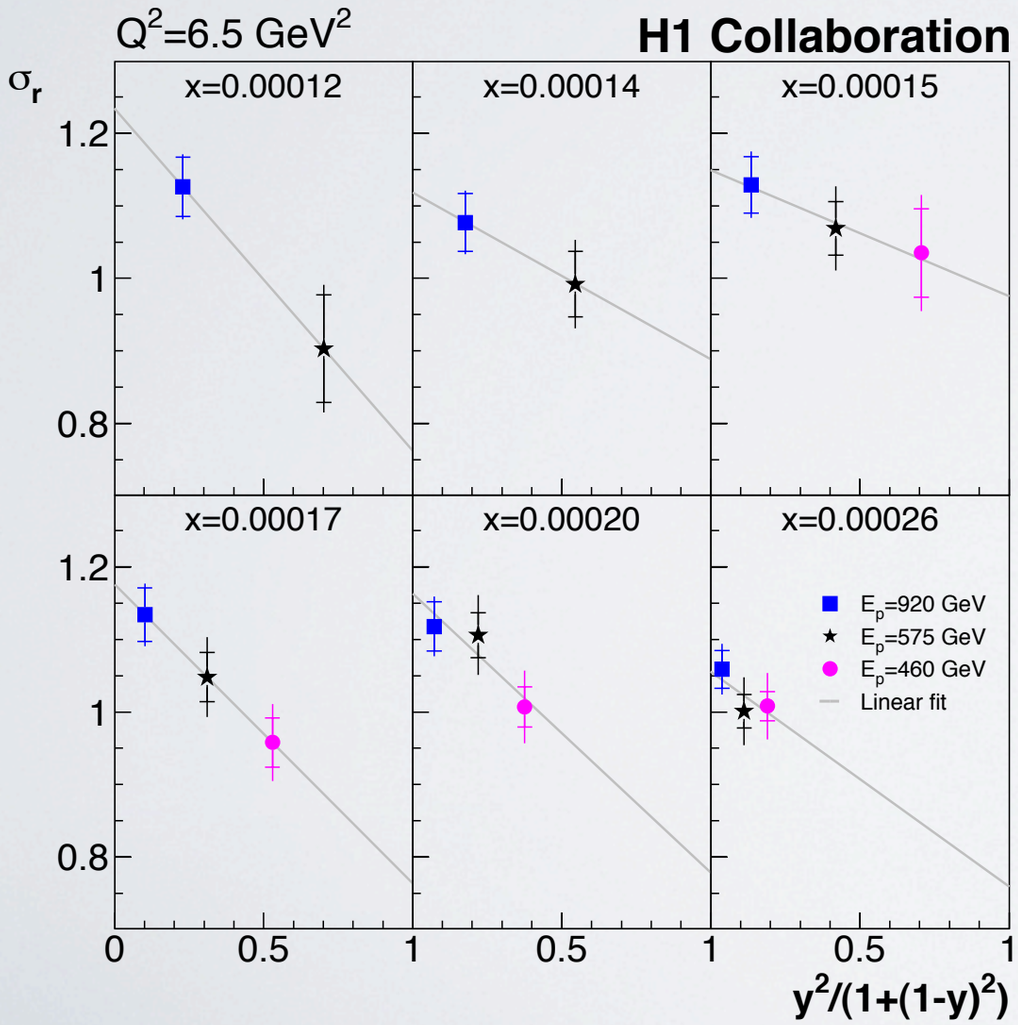


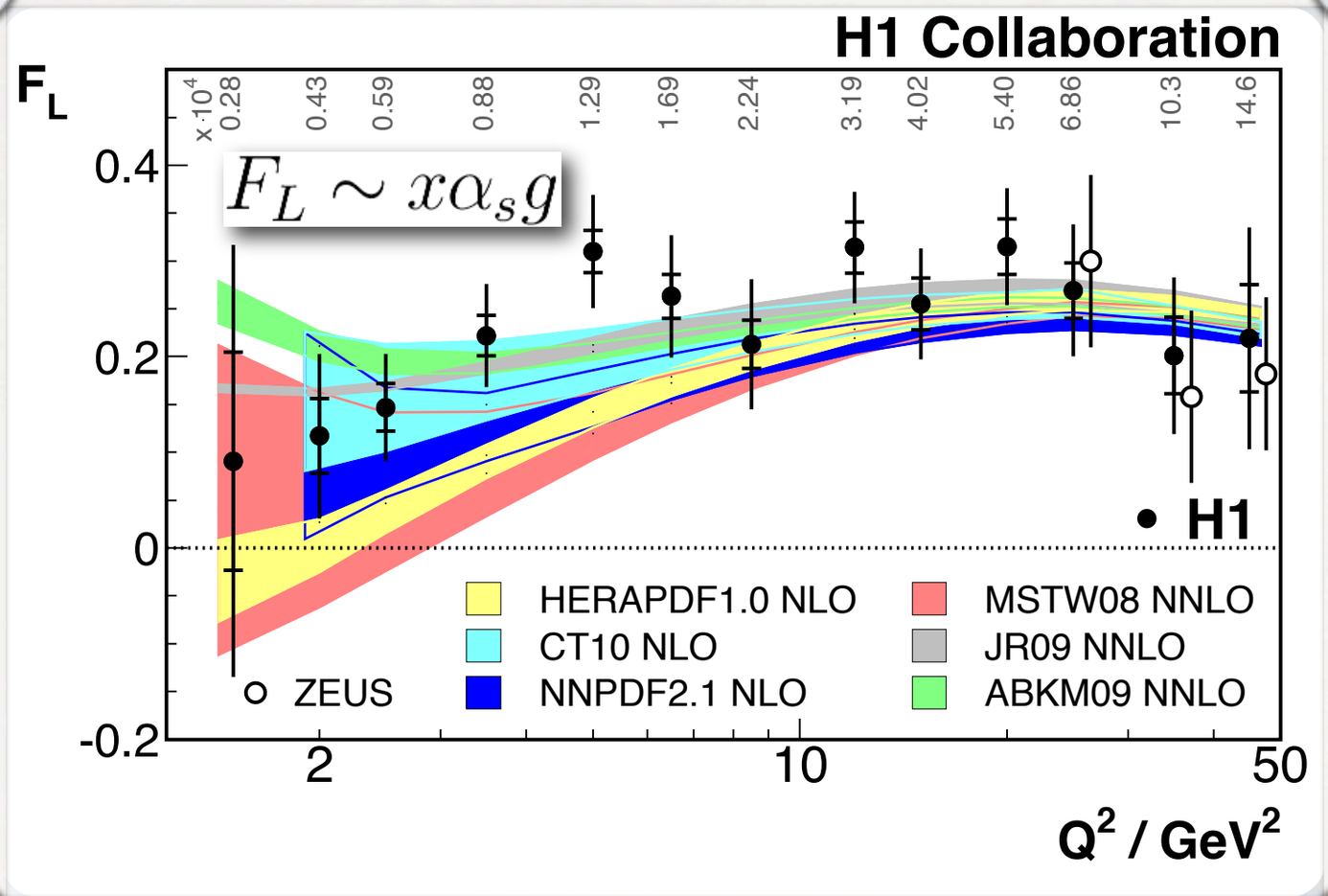
Good description of the ATLAS and CMS data using HERAPDF1.5

THE F_L STRUCTURE FUNCTION

$$\frac{d^2\sigma^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha}{xQ^4}[Y_+F_2(x,Q^2) \mp Y_-xF_3(x,Q^2) - y^2F_L(x,Q^2)]$$

FL can be determined as the slope of the cross section at low Q^2 (and x) vs y, fixing x and Q^2.
As $Q^2 = sxy$, the center of mass energy of the interaction should be varied to this aim.

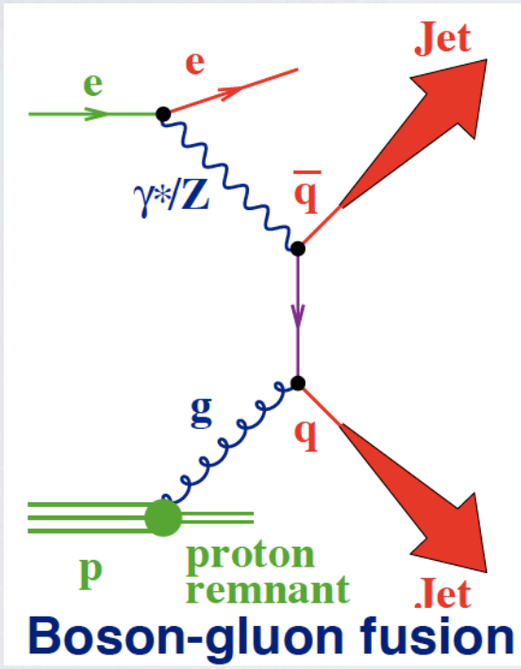


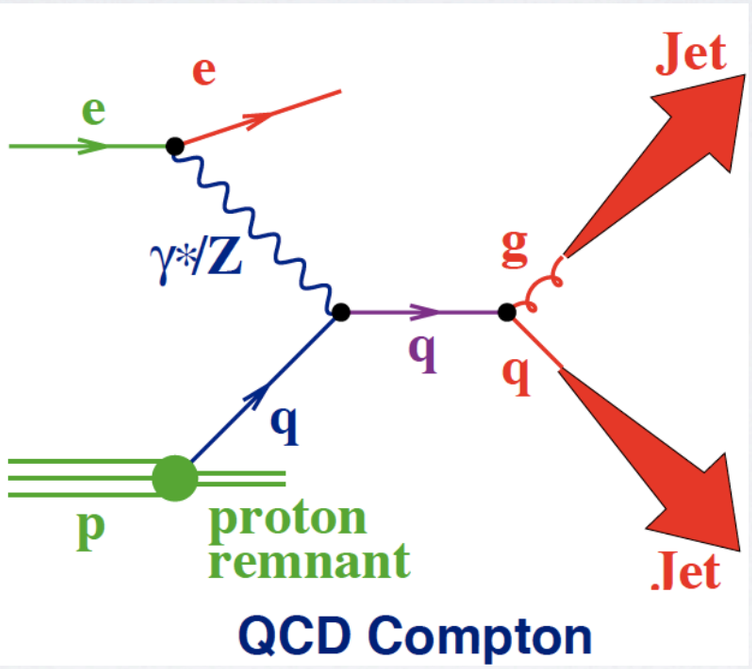


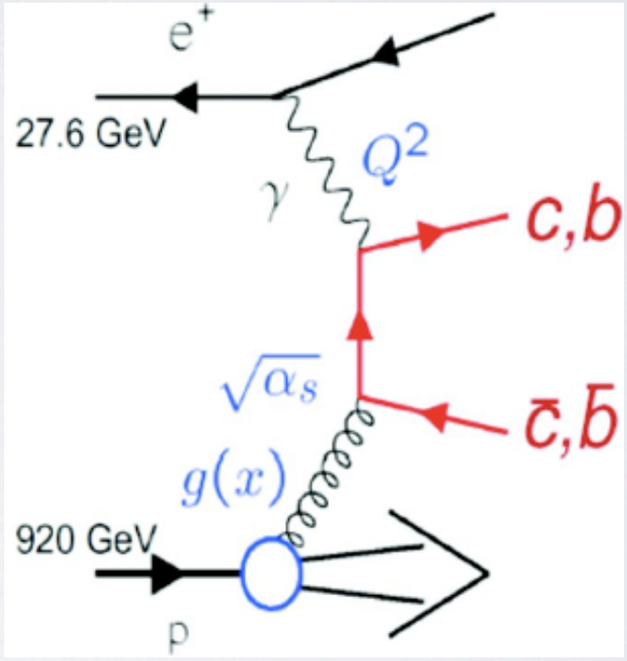
JETS AND HEAVY FLAVOURS AS INPUT FOR THE PROTON STRUCTURE DETERMINATION

As already discussed: NC and CC inclusive cross sections, gluon extracted indirectly from scaling violation. FL directly sensitive to the gluon but experimentally challenging.

Sensitivity to the gluon: jets and heavy flavour production

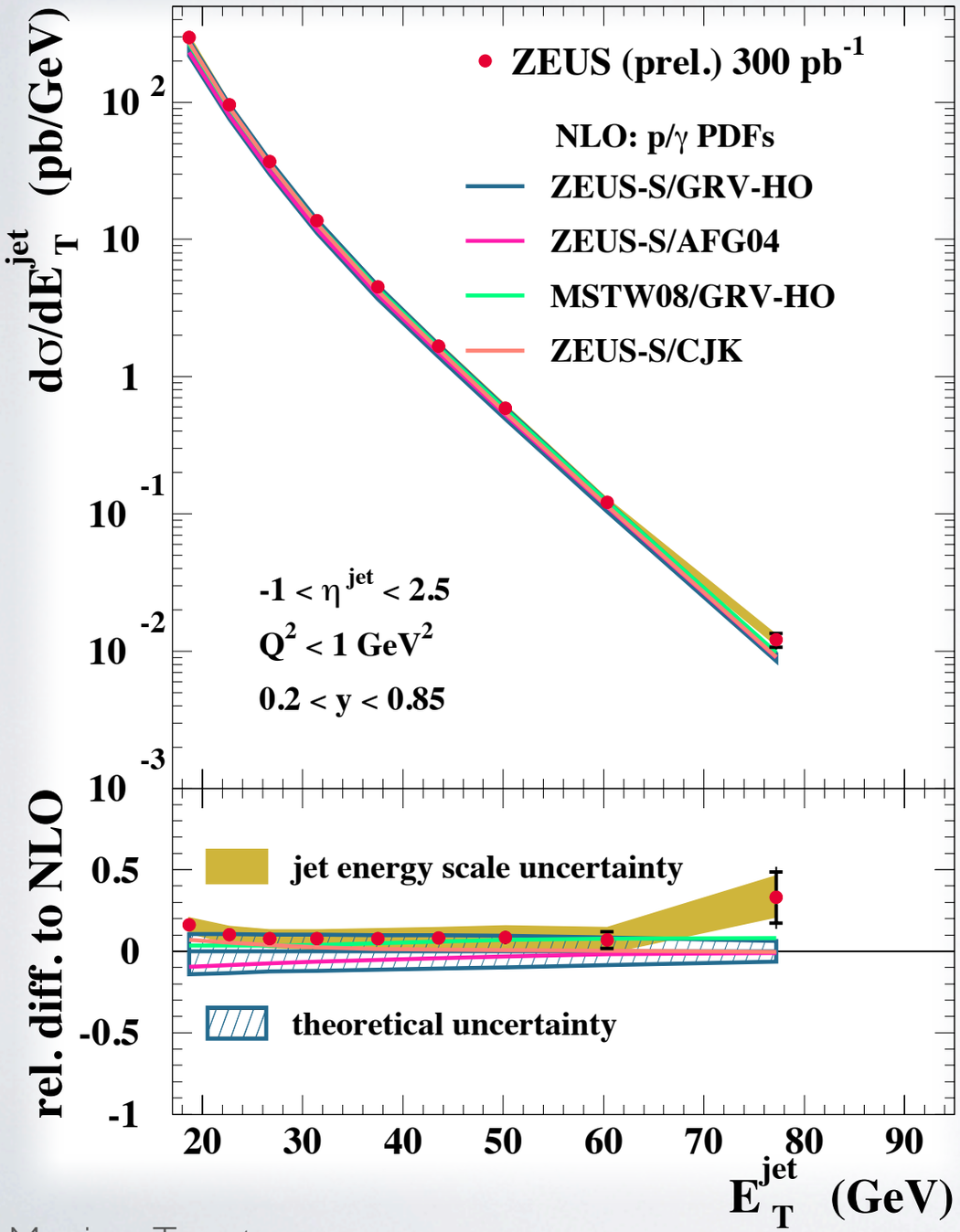


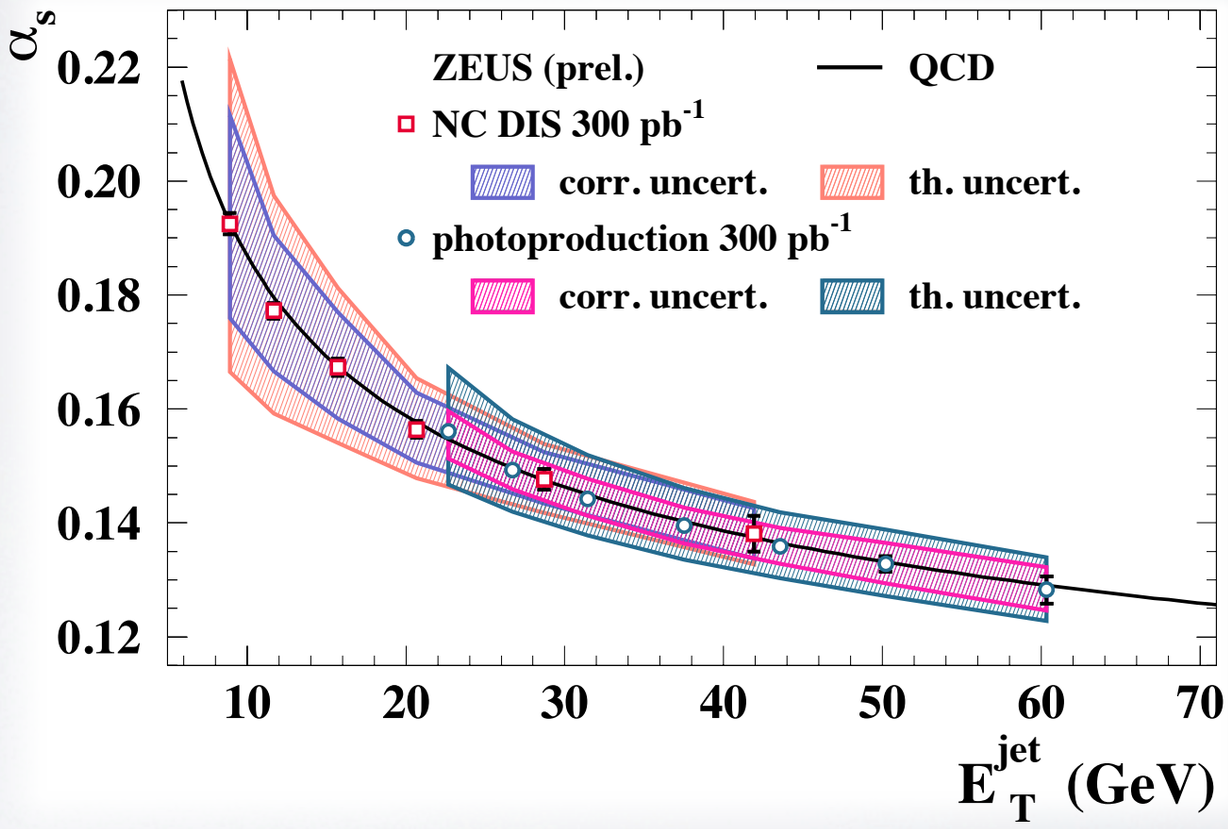




JETS IN DIS AND PHOTOPRODUCTION AT ZEUS

Powerful test of QCD, extraction of the strong coupling constant α_s



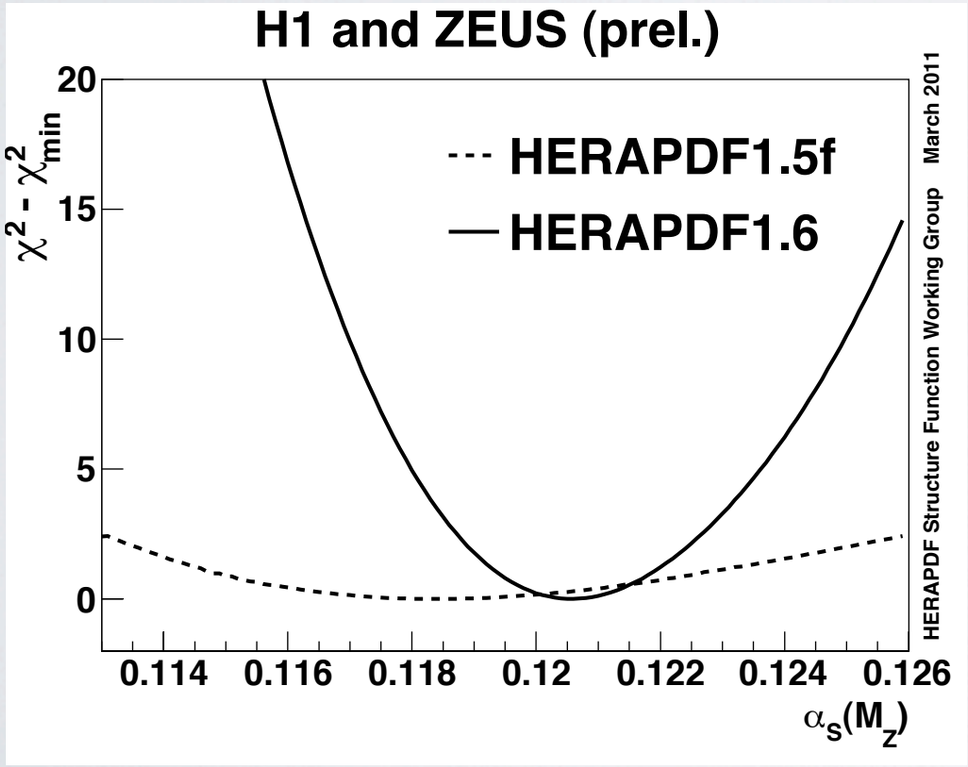


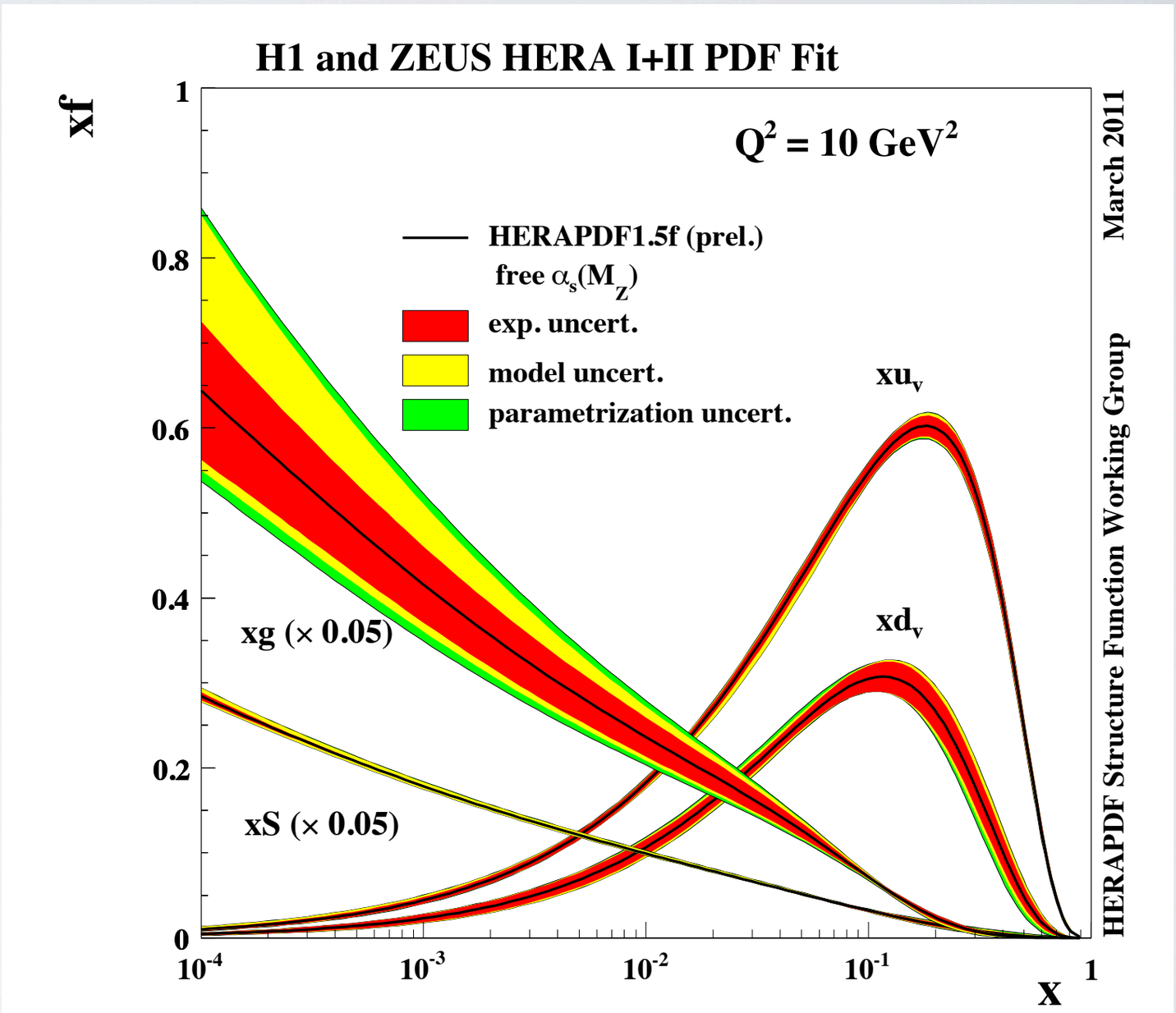
And important input for the proton structure

ADDING JETS TO THE PDF FITS

NC/CC data: **correlation between the gluon and α_s**, to extract the gluon α_s must be fixed (HERAPDF1.5)

$$\frac{\partial F_2(x,Q^2)}{\partial \ln Q^2} = \alpha_s(Q^2) x g(x,Q^2)$$





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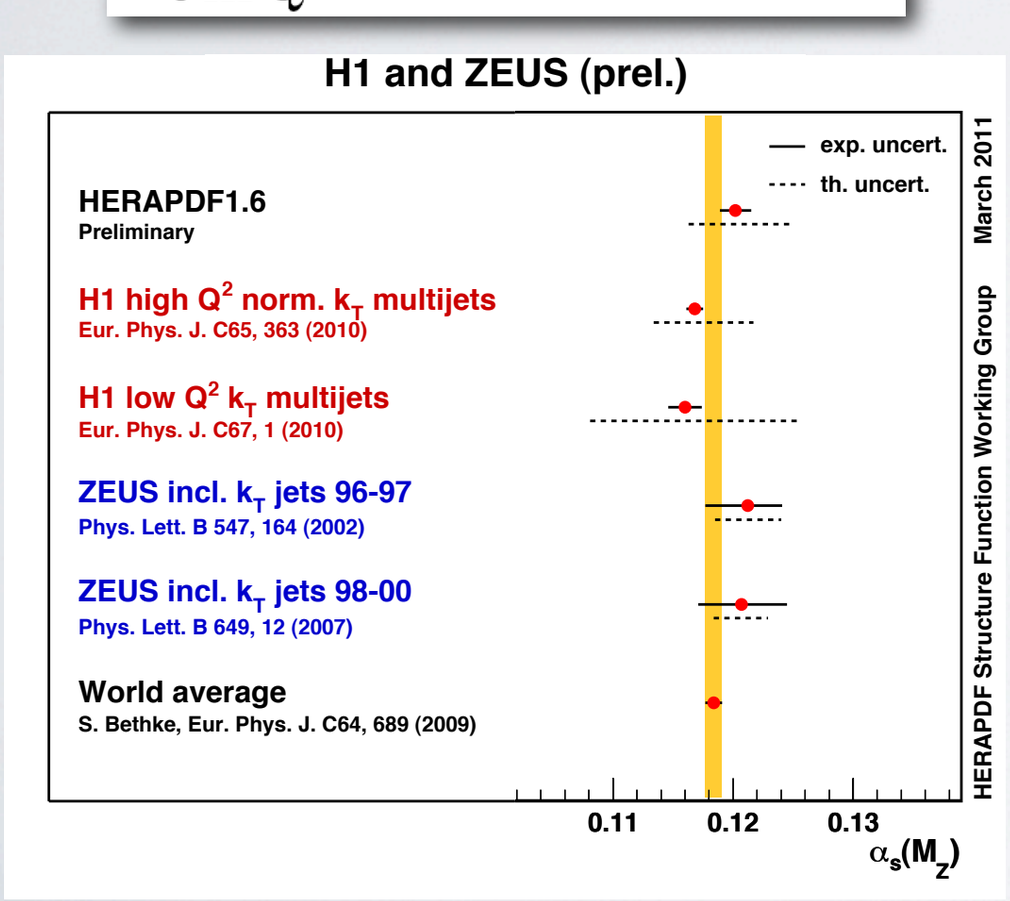
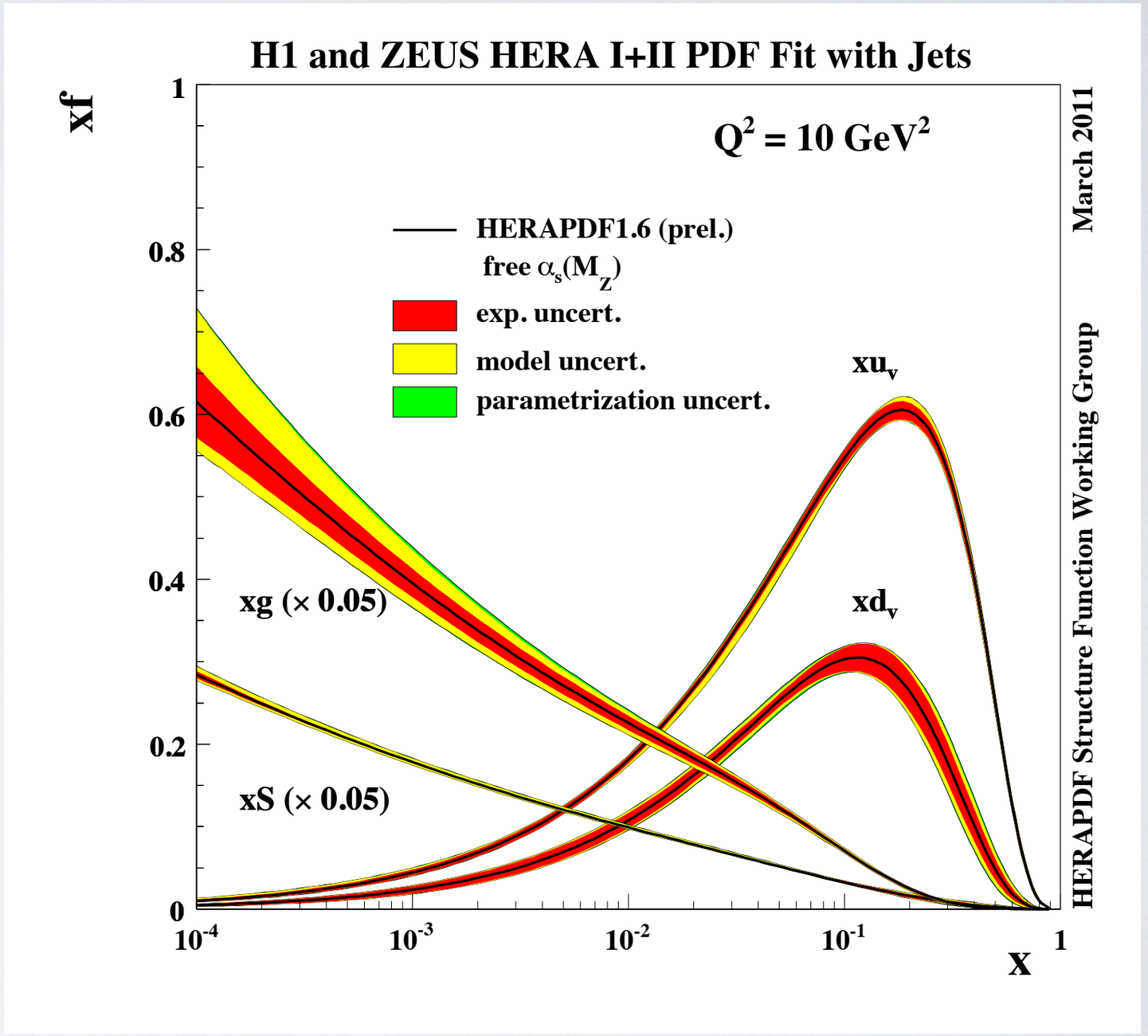
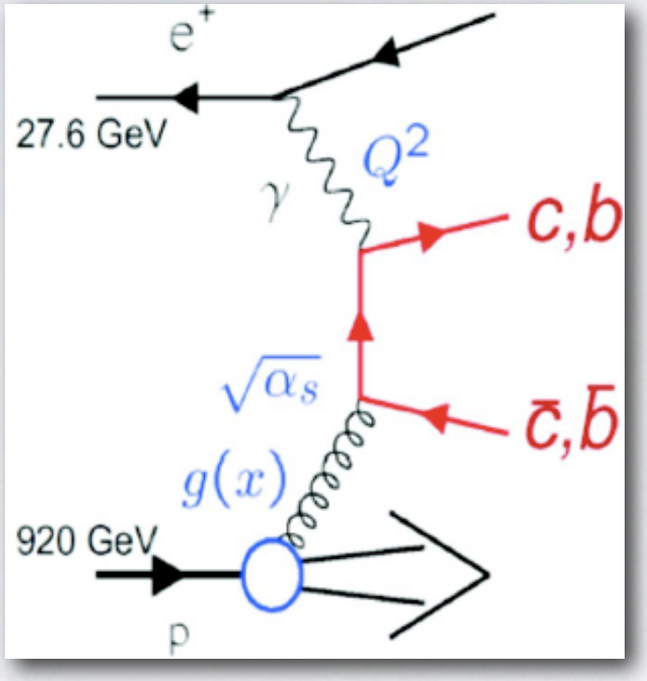
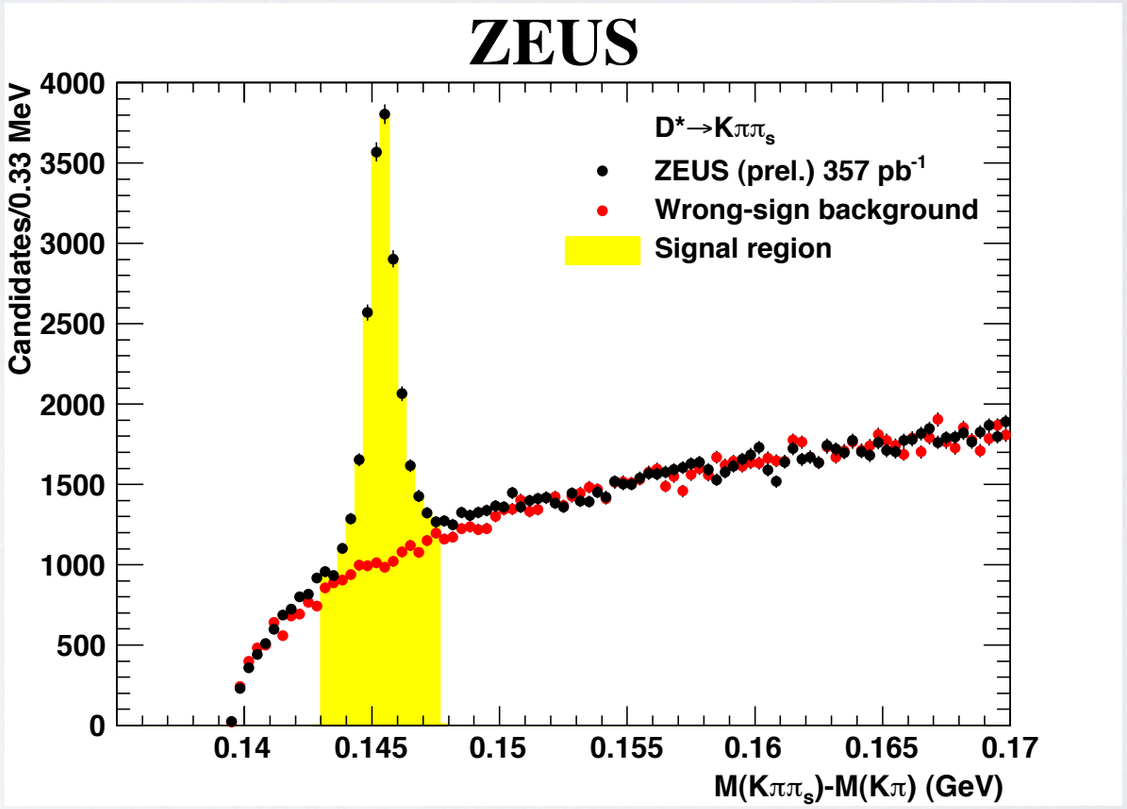




CHARM AND BEAUTY PRODUCTION

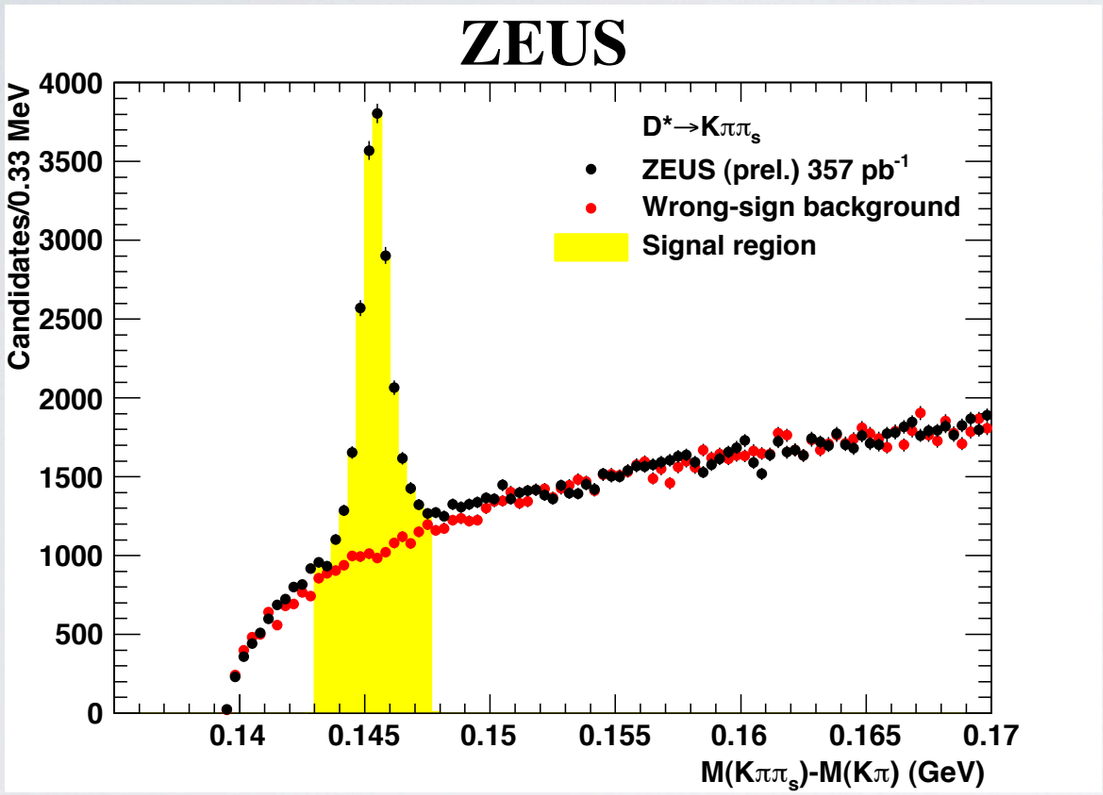
Main process: boson-gluon fusion, sensitivity to the gluon in the proton
Powerful test of QCD
Multi-scale problem as Q^2, m_Q, p_T are set hard scales in the event.
Inclusion of heavy flavour (charm) data in the PDF fits: check of the fit formalism.



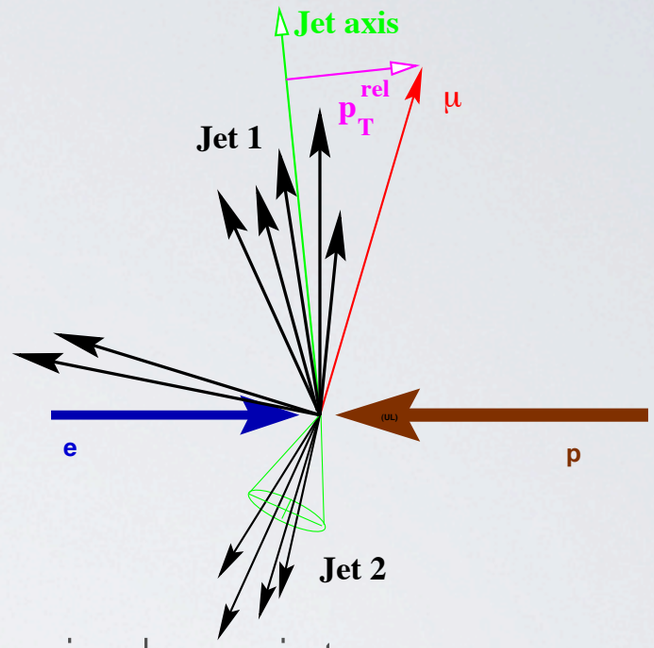


HEAVY FLAVOUR RECONSTRUCTION

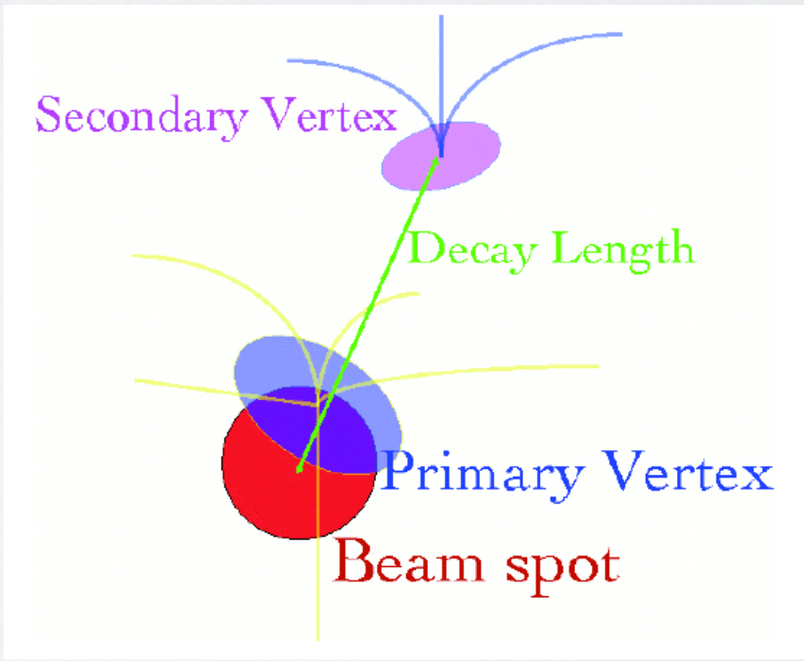
Reconstruction of charmed particles, D^*, D^0, D^+



Reconstruction of secondary vertices from D^+ meson or inclusive charm and beauty decay

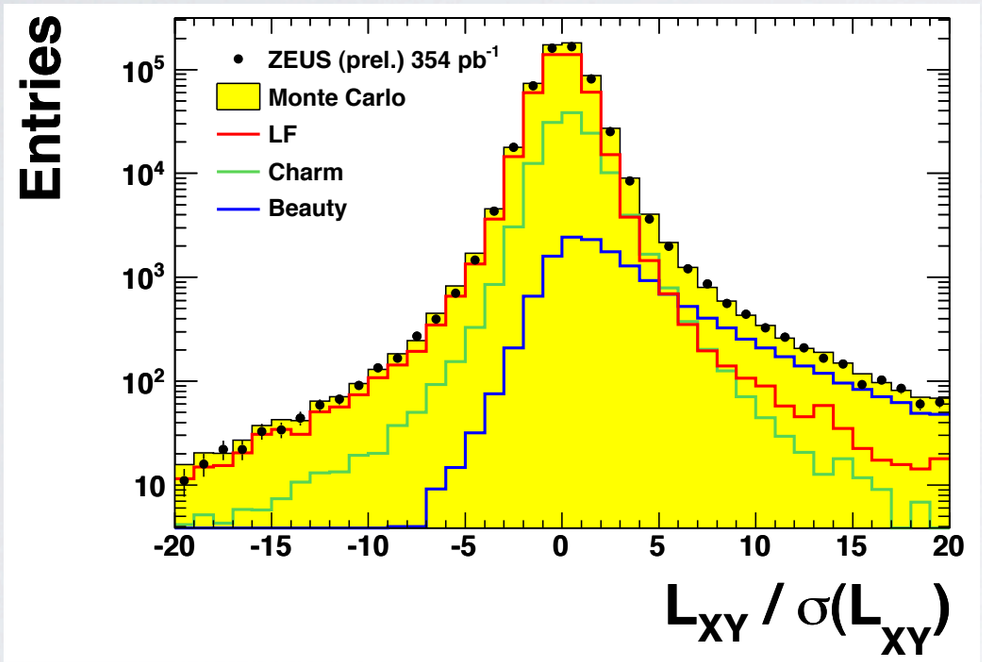


Semileptonic decay into muons or electrons

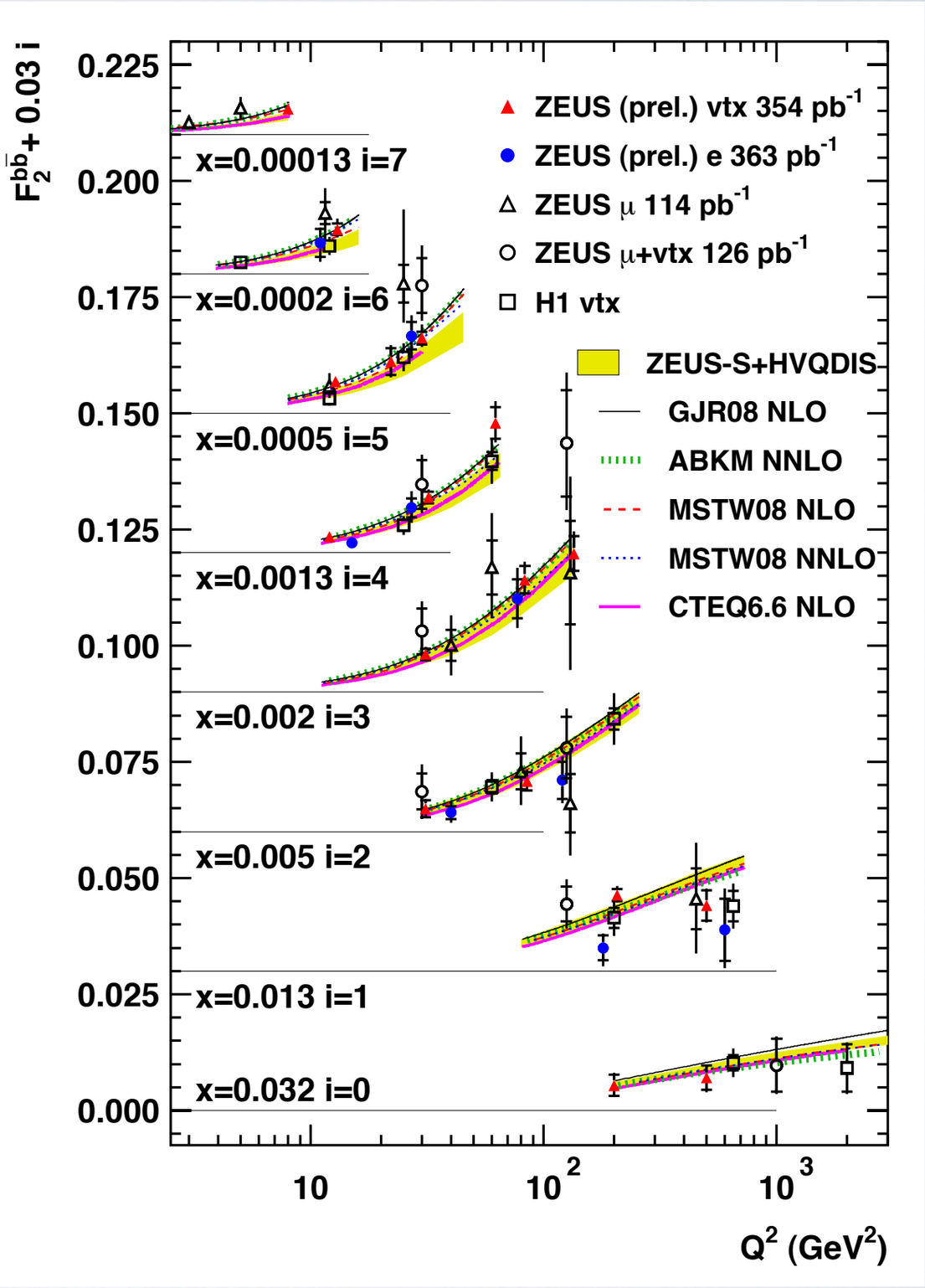


F_2^b FROM INCLUSIVE SECONDARY VERTICES

F_2^b is defined as the beauty contribution to the proton structure function F_2



Secondary vertex significance in the mass region $2 < M_{vtx} < 6$ GeV, high purity of beauty events



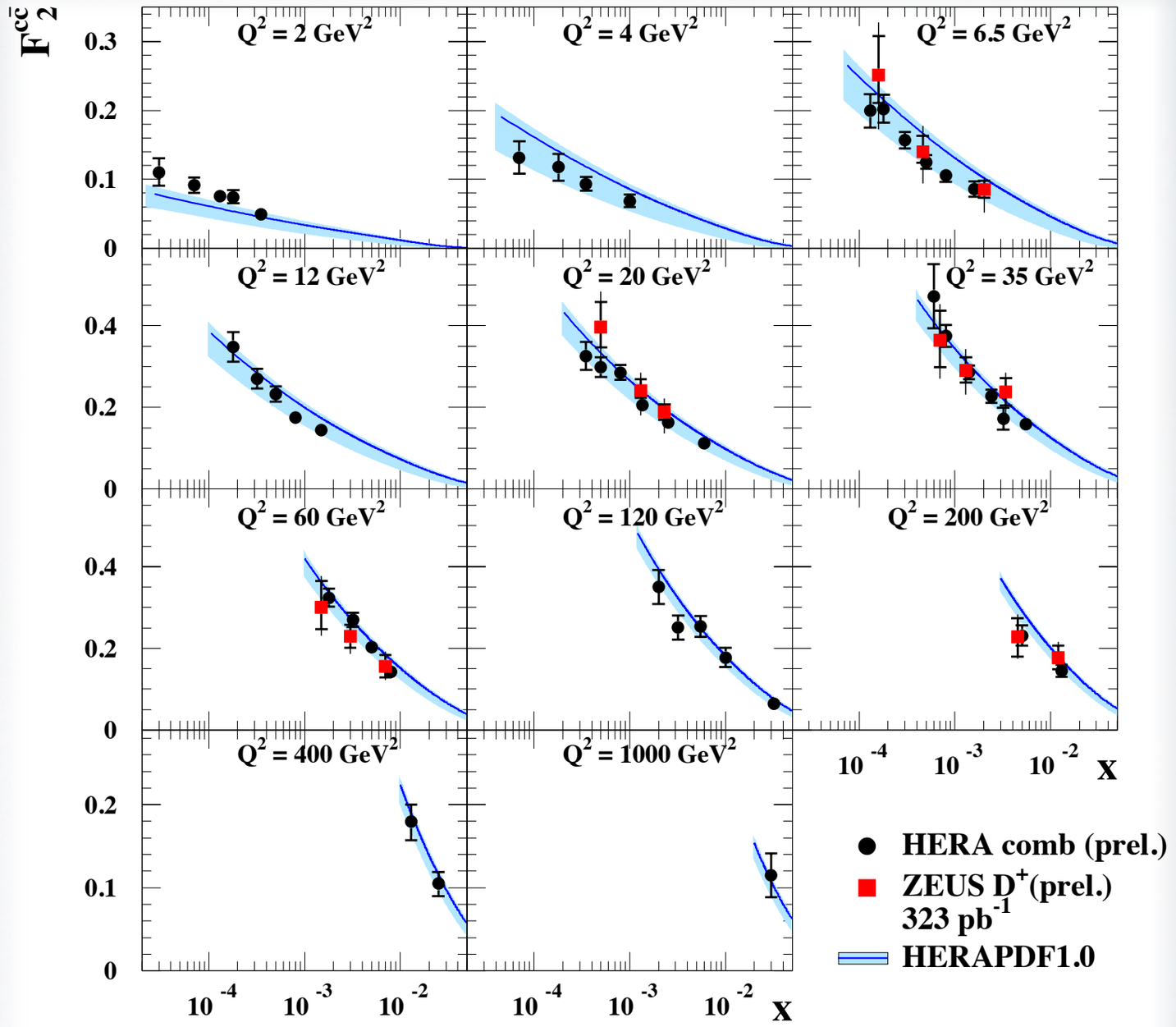
F_2^c FROM D^+ AND D^*

The charm contribution to F_2 is referred to as F_2^c

Charm tagging with D* gives the most precise cross section measurement

Recent ZEUS D^+ data compared to the recent H1+ZEUS combination (precision 5-10%)

Precision to be improved by including all the data in the combination



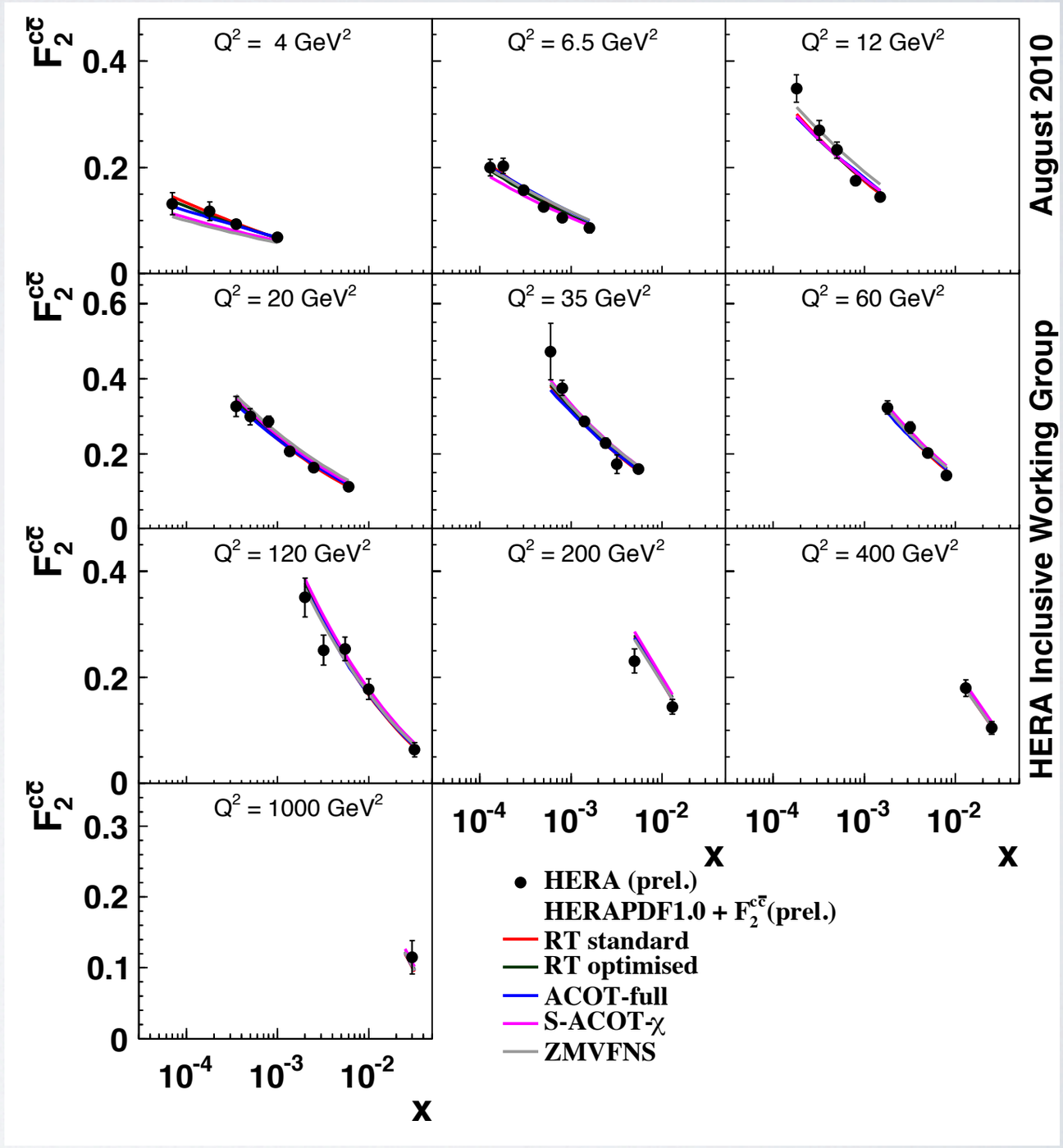
IMPACT OF CHARM ON THE PDFS

H1+ZEUS combined data compared to different theoretical models

Each model implement its own heavy flavour treatment

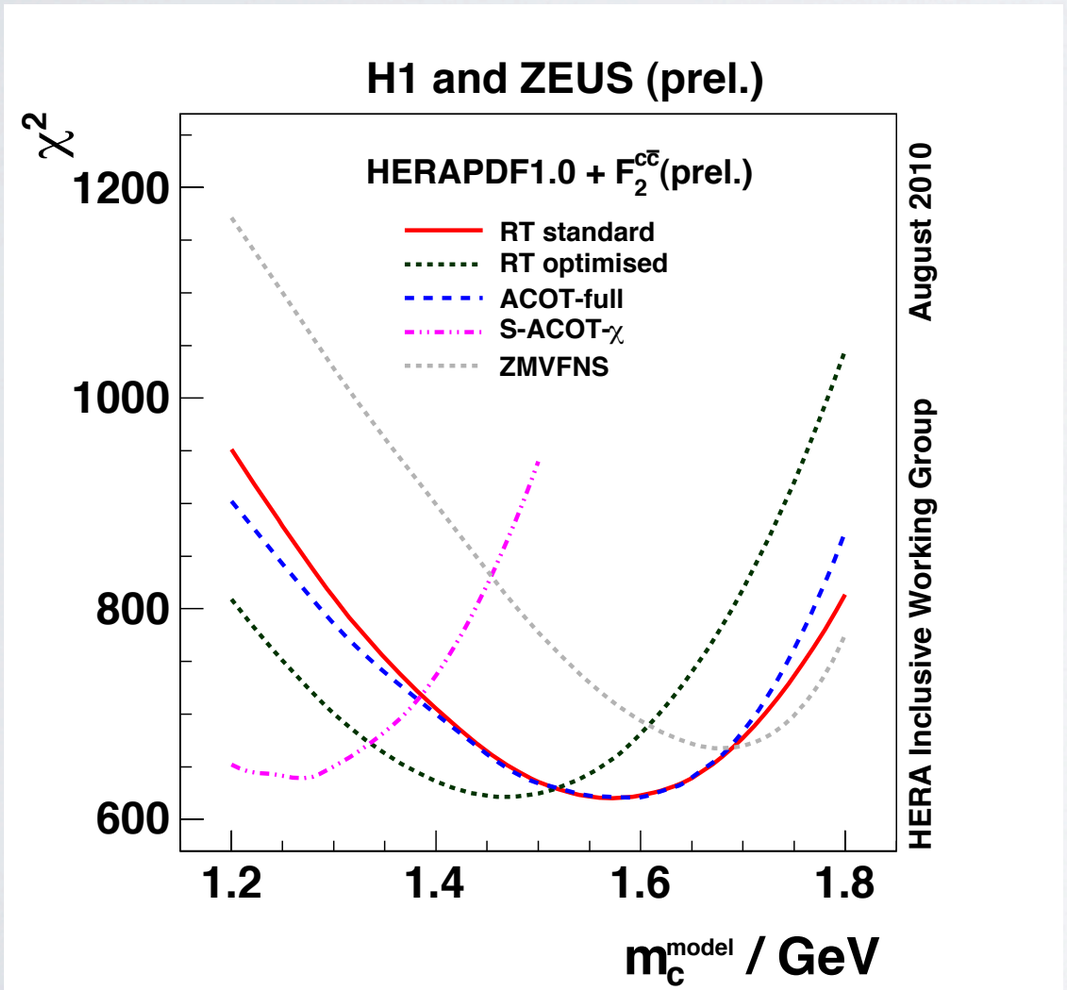
The theoretical predictions are quite sensitive to the parameter that rules the onset of charm, m_c

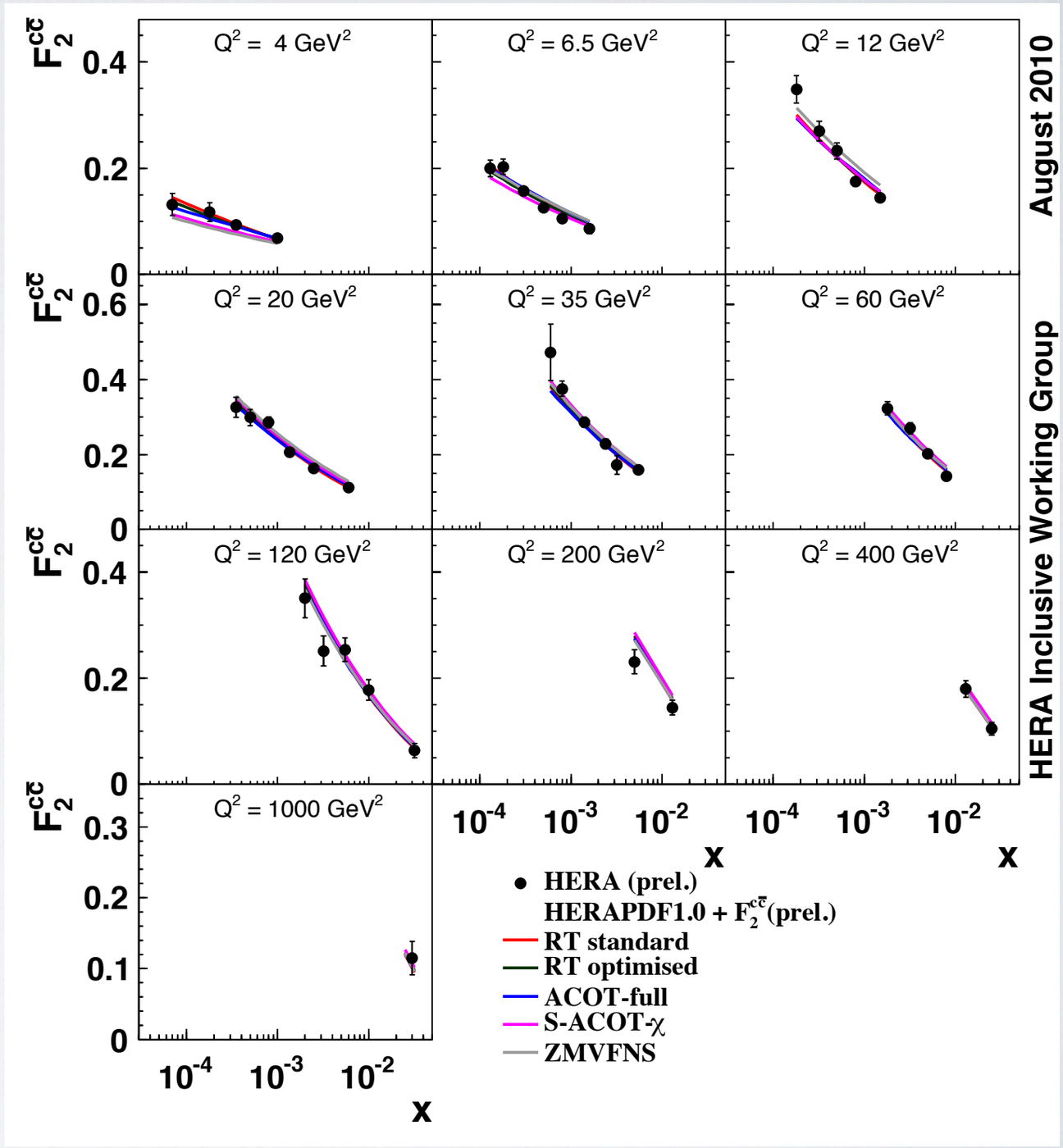
In each model, an 'optimal' m_c parameter exists, giving the best description of the data.



IMPACT OF CHARM ON THE PDFS

For each heavy-flavour scheme, an 'optimal' value of the charm mass parameter is extracted from the best fit to the data.





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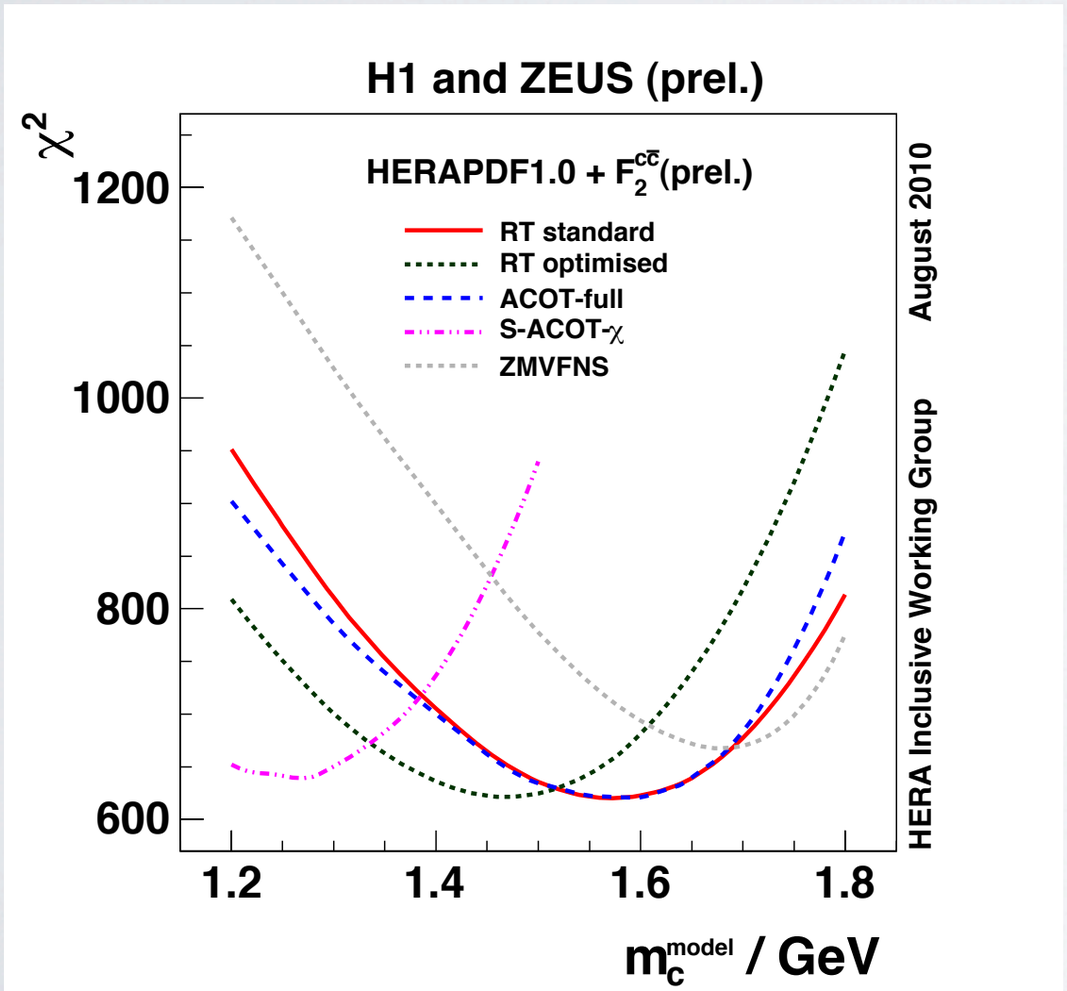
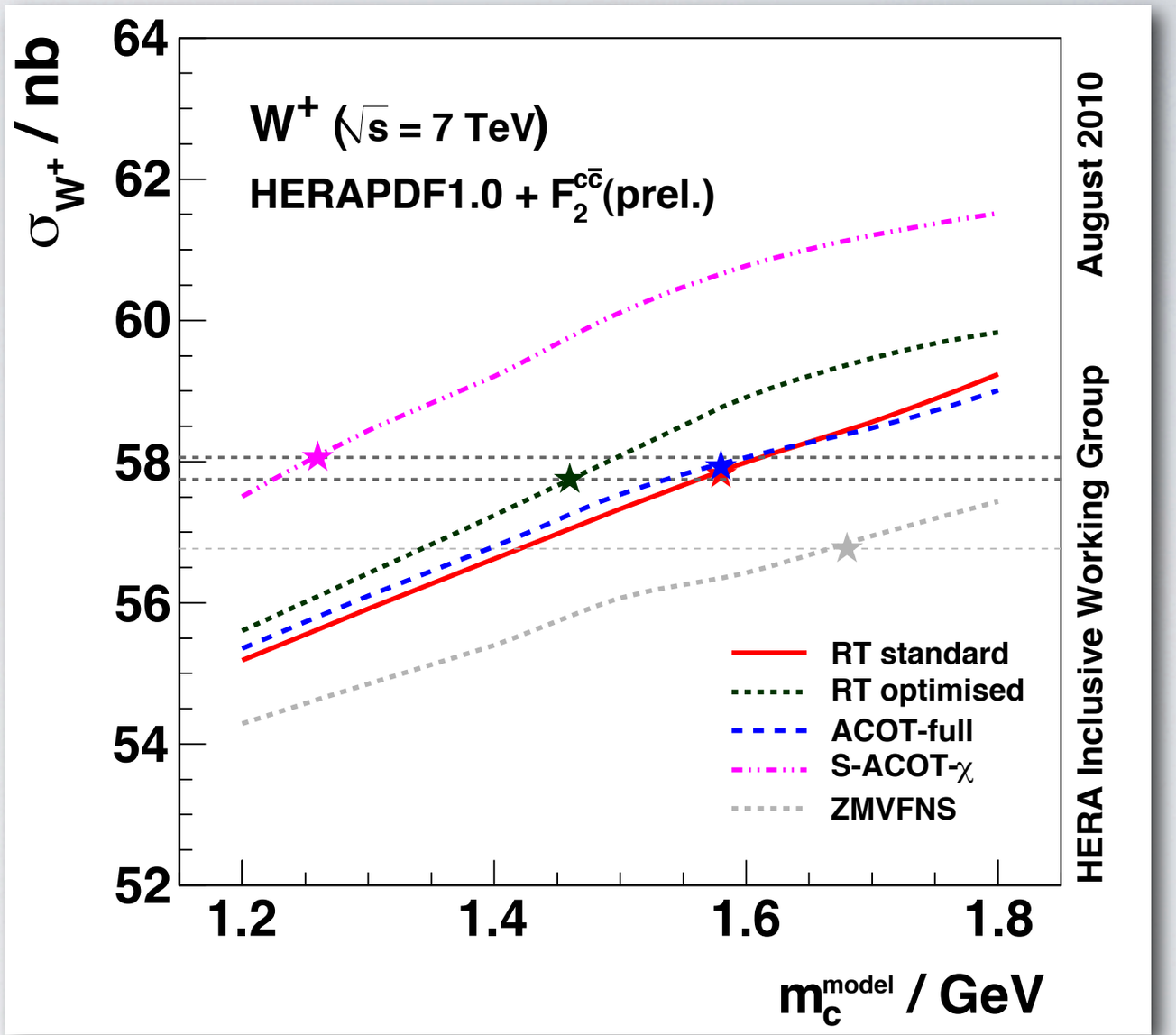




Reduced uncertainties on the LHC predictions if the optimal mass parameter is chosen

HERAPDF1.7: NC/CC+JETS+CHARM

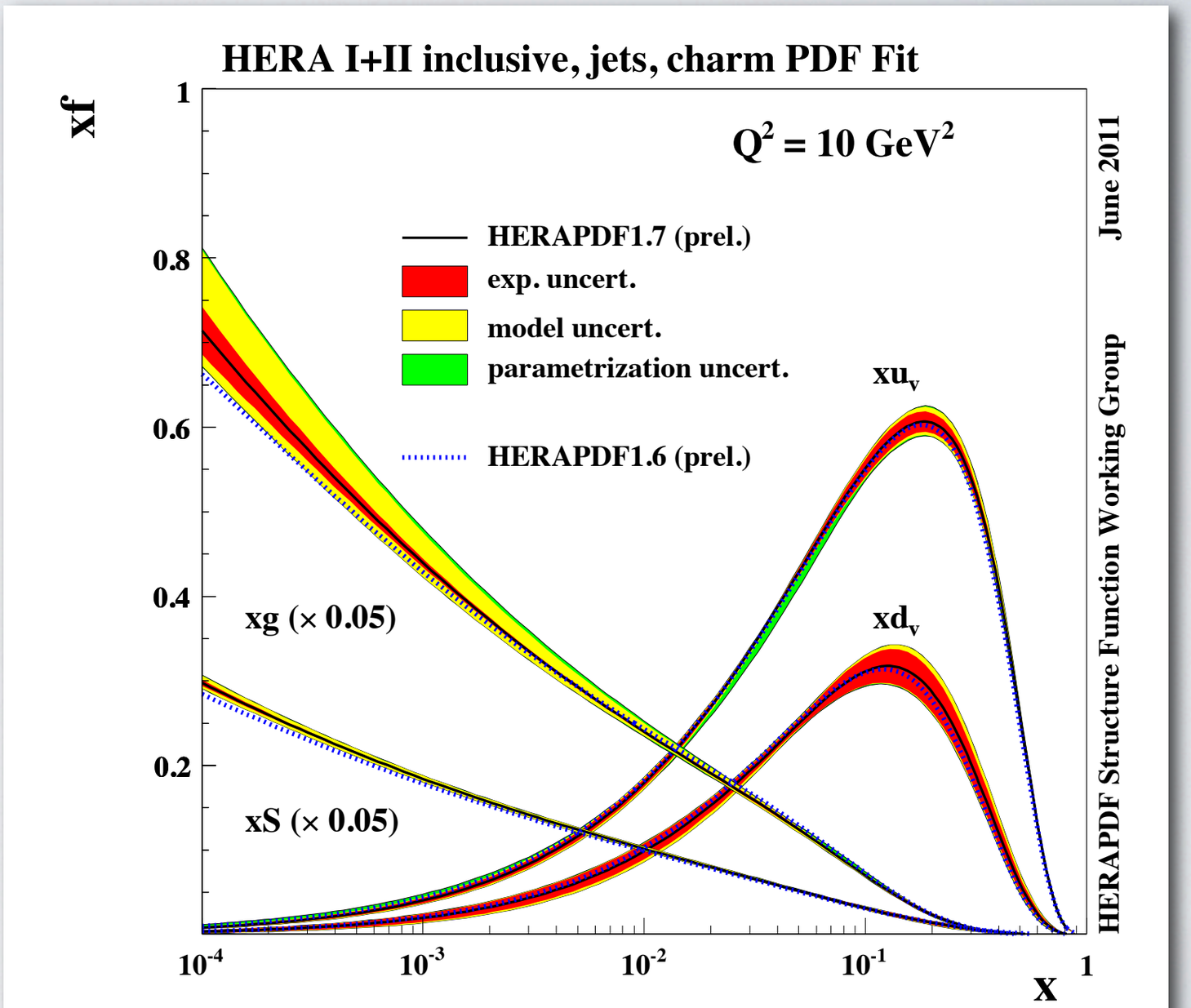
Final goal for the proton structure determination:
use NC/CC, heavy flavours and jets.

First attempt with partial statistics:
HERAPDF1.7

Several theoretical aspects better understood

Optimal value of the charm mass chosen

Gluon parameterisation more flexible



CONCLUSIONS AND OUTLOOK

The data taken at the ep collider HERA are providing valuable input to the PDF fits.

Not only inclusive neutral and charged current cross sections are used,
but also jet and heavy flavour data

Precise predictions for cross sections at the LHC are obtained

Powerful tests of QCD come from jet and heavy flavour measurements

More on PDFs to come in the near future!

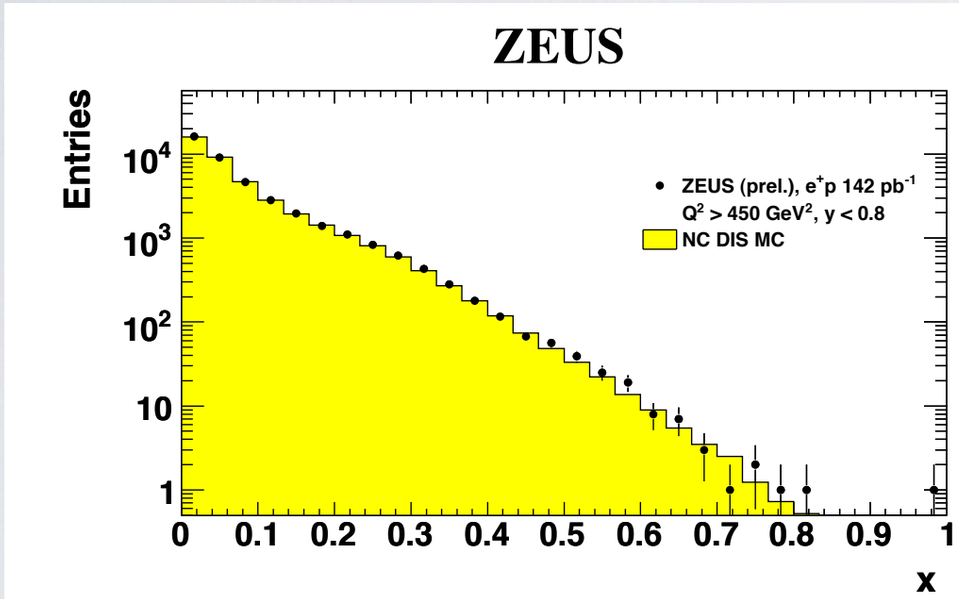
More on HERA to come in the next talk...

THANKS!

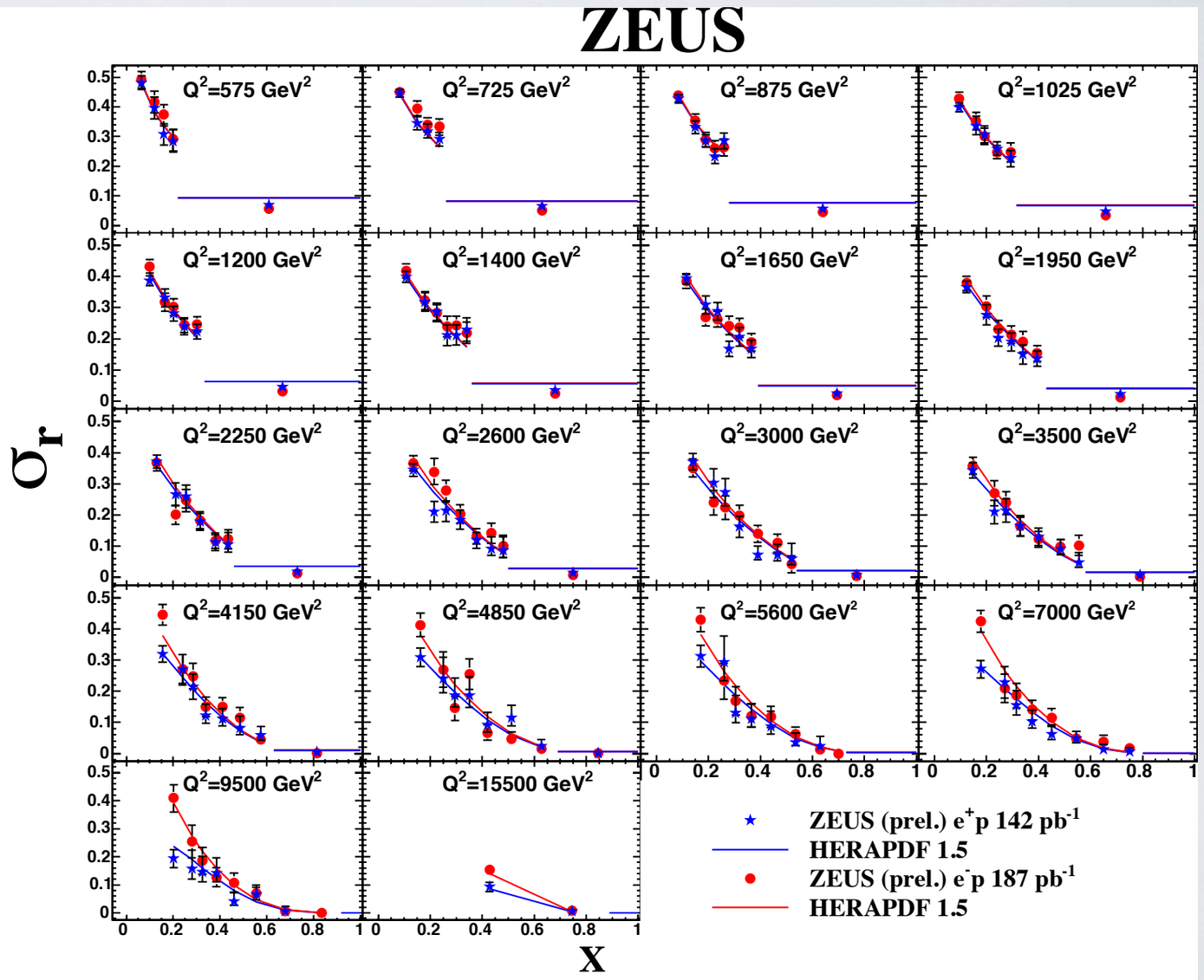
BACKUP

NC CROSS SECTION AT HIGH X

High-x region is still determined with low precision. Try to reconstruct the event also when part of the hadronic system cannot be reconstructed



Important input for PDFs at LHC



HEAVY FLAVOUR PRODUCTION IN PHOTOPRODUCTION

Good description by QCD