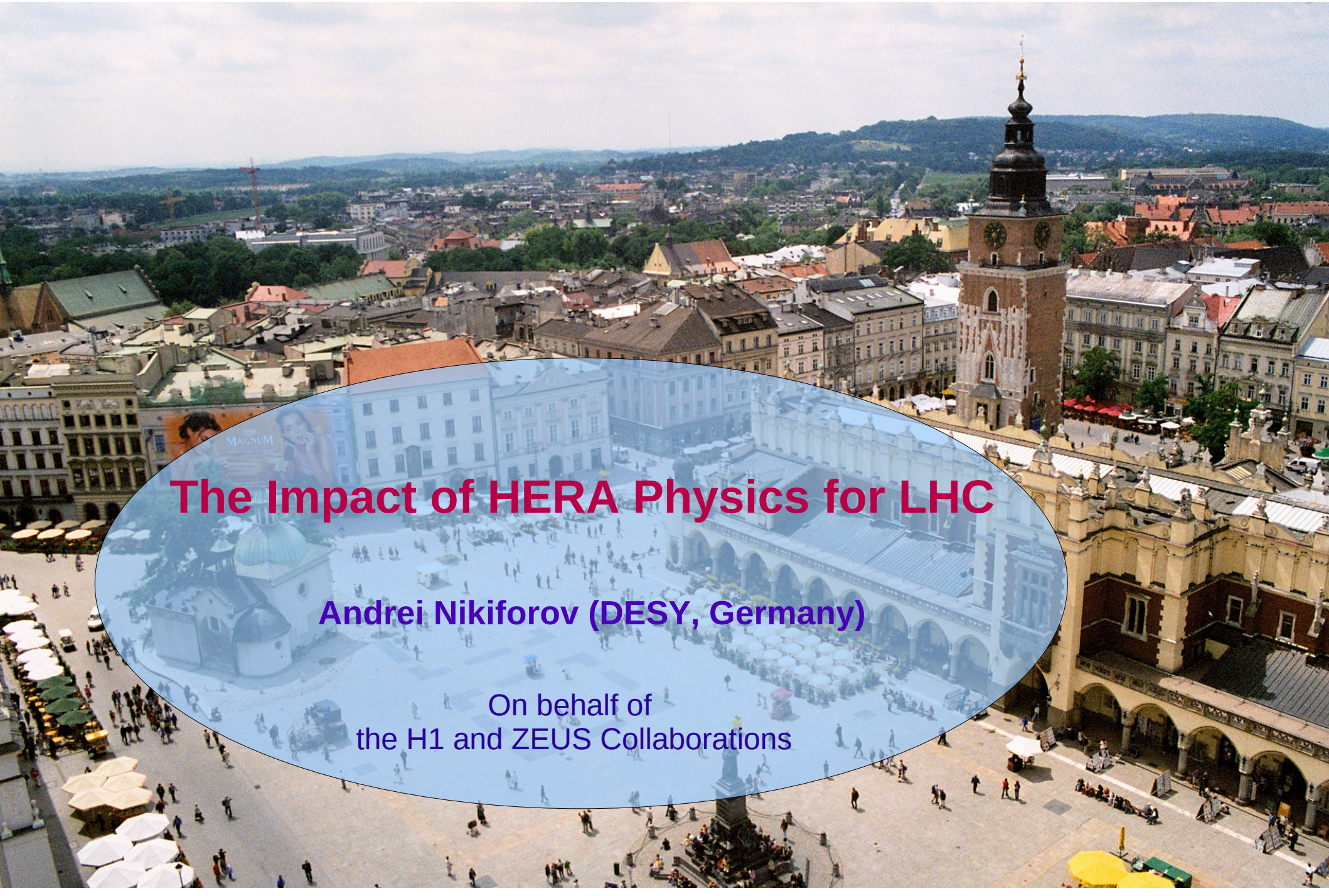


The Impact of HERA Physics for LHC

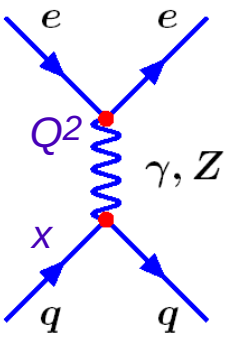
Andrei Nikiforov (DESY, Germany)

On behalf of
the H1 and ZEUS Collaborations

Epiphany 2009, Cracow, 5-7 January 2009

Deep Inelastic Scattering:
a straightforward tool to "look" inside a proton

Measured cross sections → Structure Functions



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

- Dominant
- Valence + sea quarks

- High *y*
- Gluon

- High Q^2
- Valence quarks

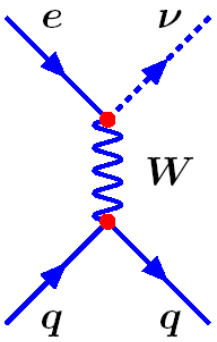
$$Y_{\pm} = 1 \pm (1-y)^2$$

$$y = \frac{Q^2}{sx}$$

- Virtuality Q^2: Spatial resolution probe

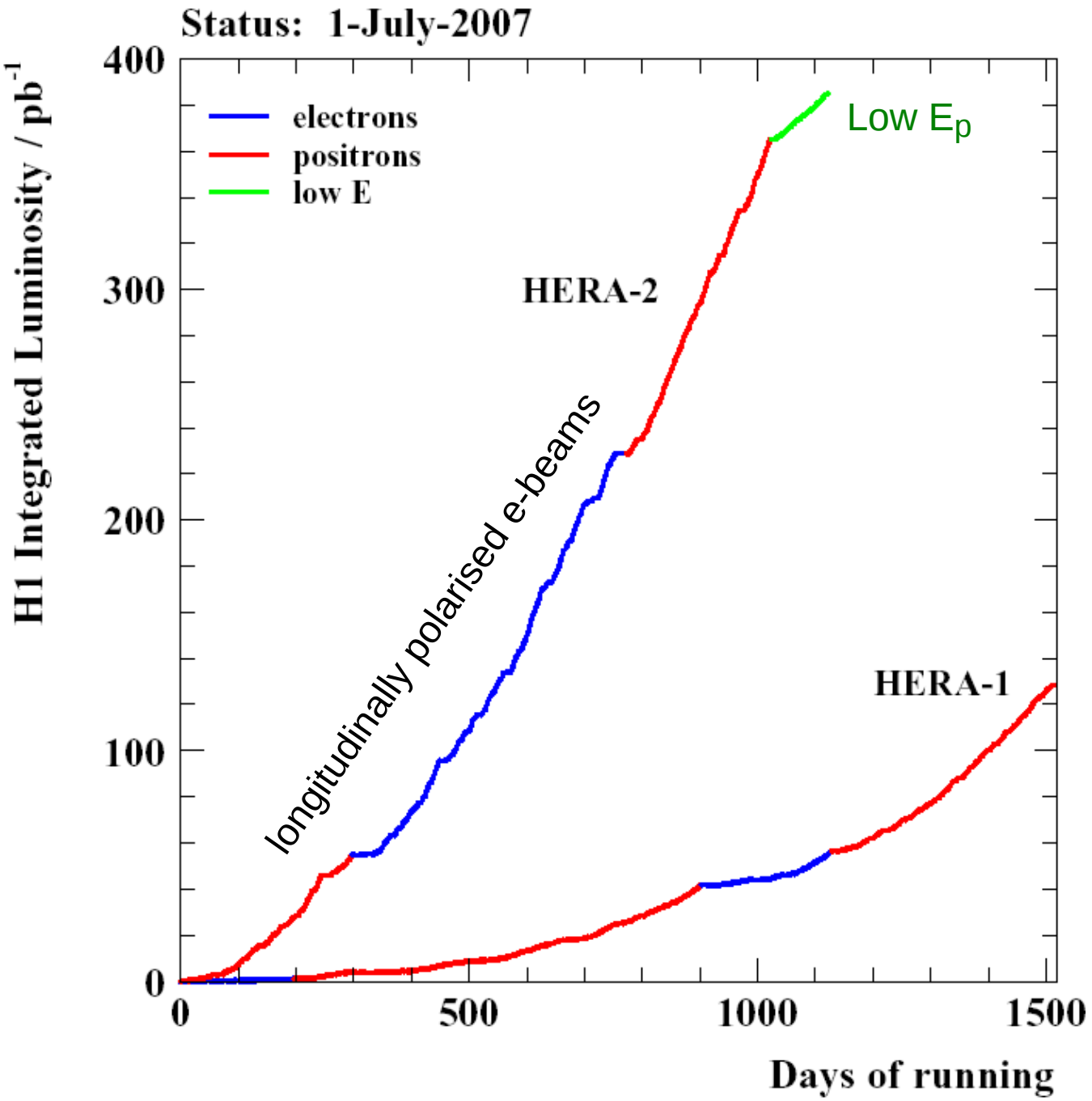
$$\lambda \sim 1/\sqrt{Q^2}$$

- *x*: momentum fraction of struck parton



$$\frac{d^2\sigma_{CC}(e^{\pm}p)}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{Q^2+M_W^2}\right]^2 (Y_+\tilde{W}_2^{\pm} \mp Y_- x\tilde{W}_3^{\pm} - y^2\tilde{W}_L^{\pm})$$

The Final HERA Data Samples



~ 0.5 fb^{-1} / experiment

balanced e^+p and e^-p samples

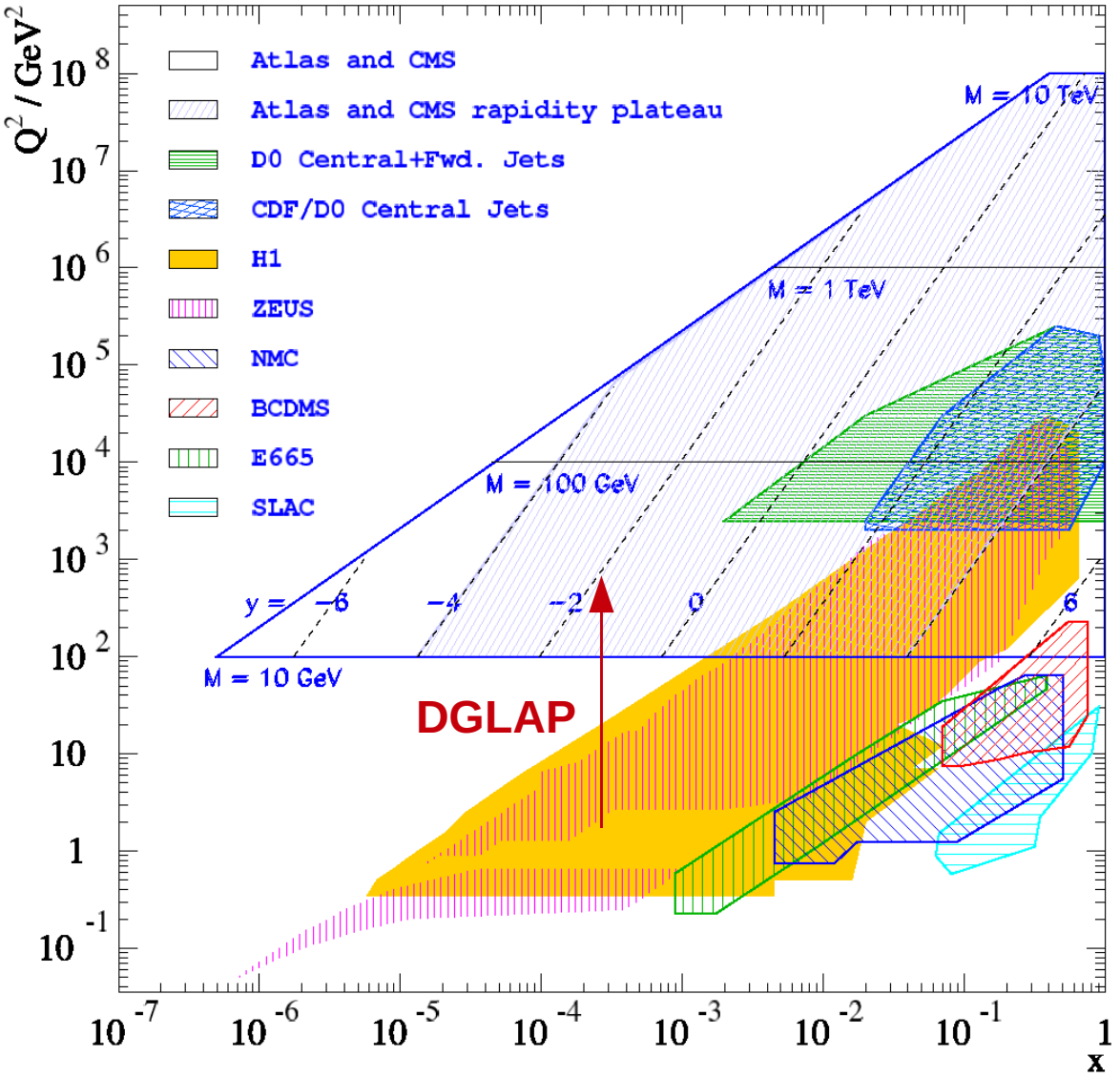
~35% polarised e at HERA II

Low E_p runs for F_L

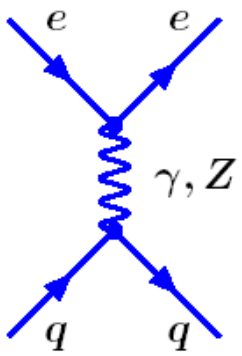
Impact to LHC

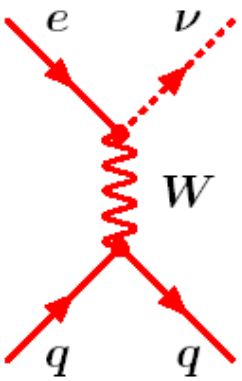
- LHC main body of phase space, i.e. ~1 TeV @ central rapidity corresponds to HERA's x region of $10^{-4} < x < 10^{-1}$
- At LHC most of the cross sections are due to gluons, whose PDFs are mainly determined by HERA

HERA provides key and essential inputs to LHC

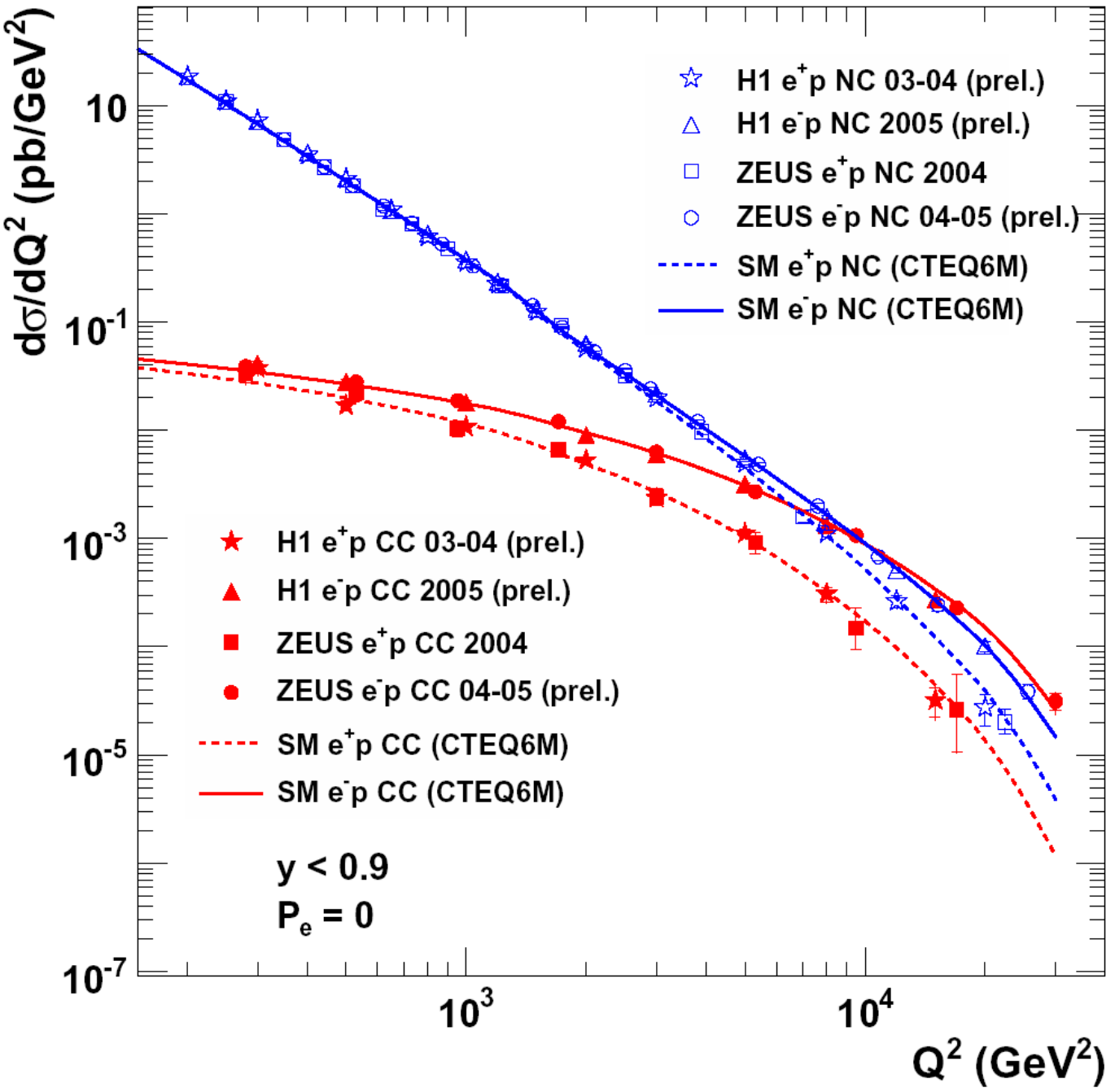


Inclusive NC and CC Measurments

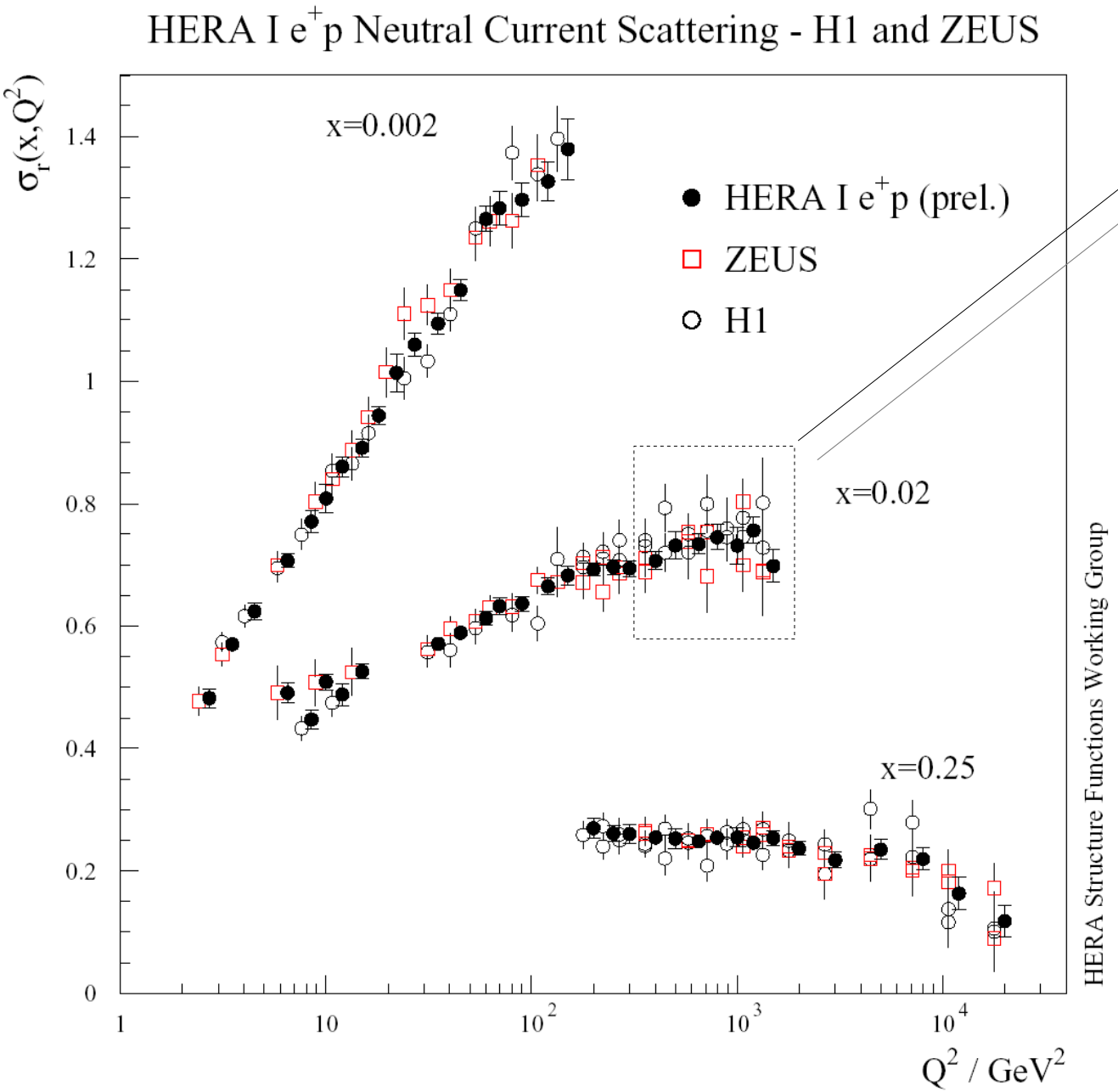


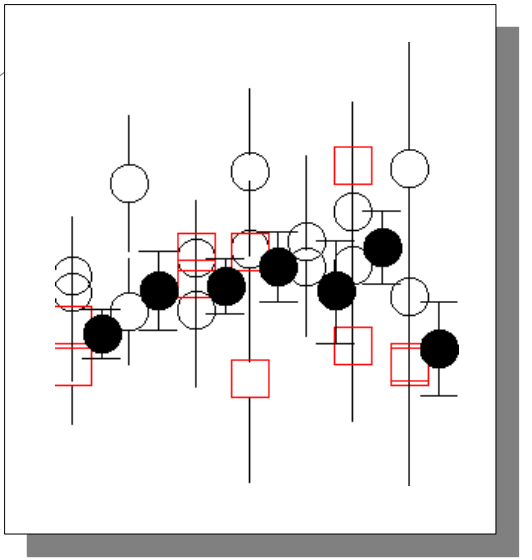


EW unification
at the $M_{W,Z}$ scale



Combined Cross Sections: H1 and ZEUS

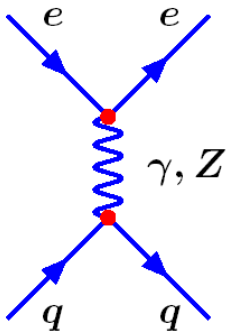




Systematic uncertainties reduced together with statistical errors

Proton Structure:

Valence + Sea Quarks

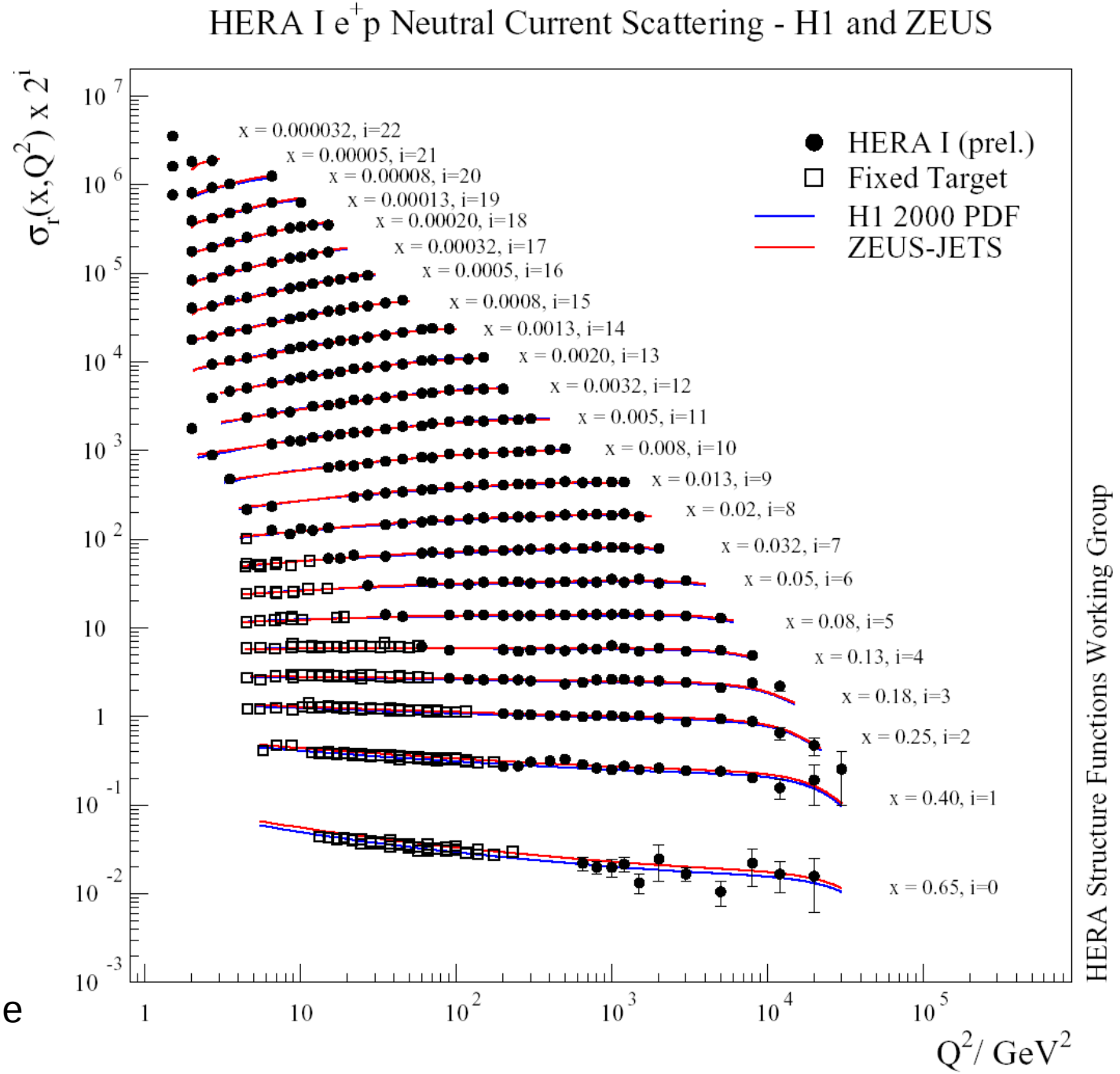


$$F_2 = x\Sigma e_q^2(q + \bar{q})$$

- Sensitive to *4u + d*
- Gluon: from scaling violation of F_2

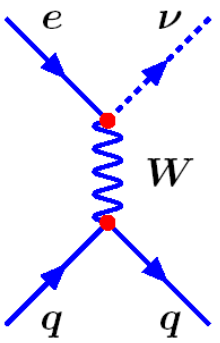
$$\frac{\partial F_2}{\partial ln Q^2} \propto xg$$

DGLAP works on a very large phase space!



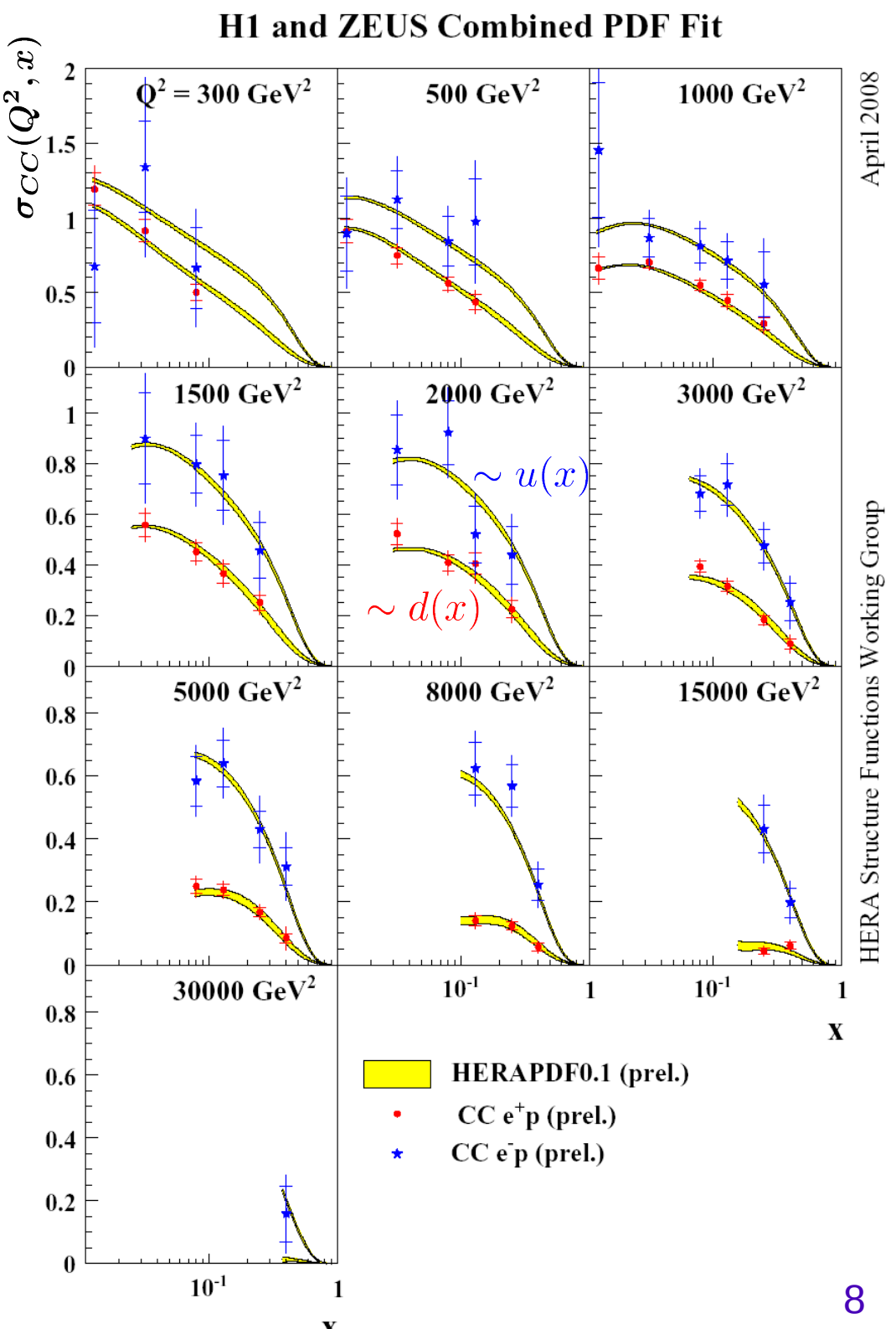
Proton Structure:
Valence Quarks

Flavor selecting nature of CC:



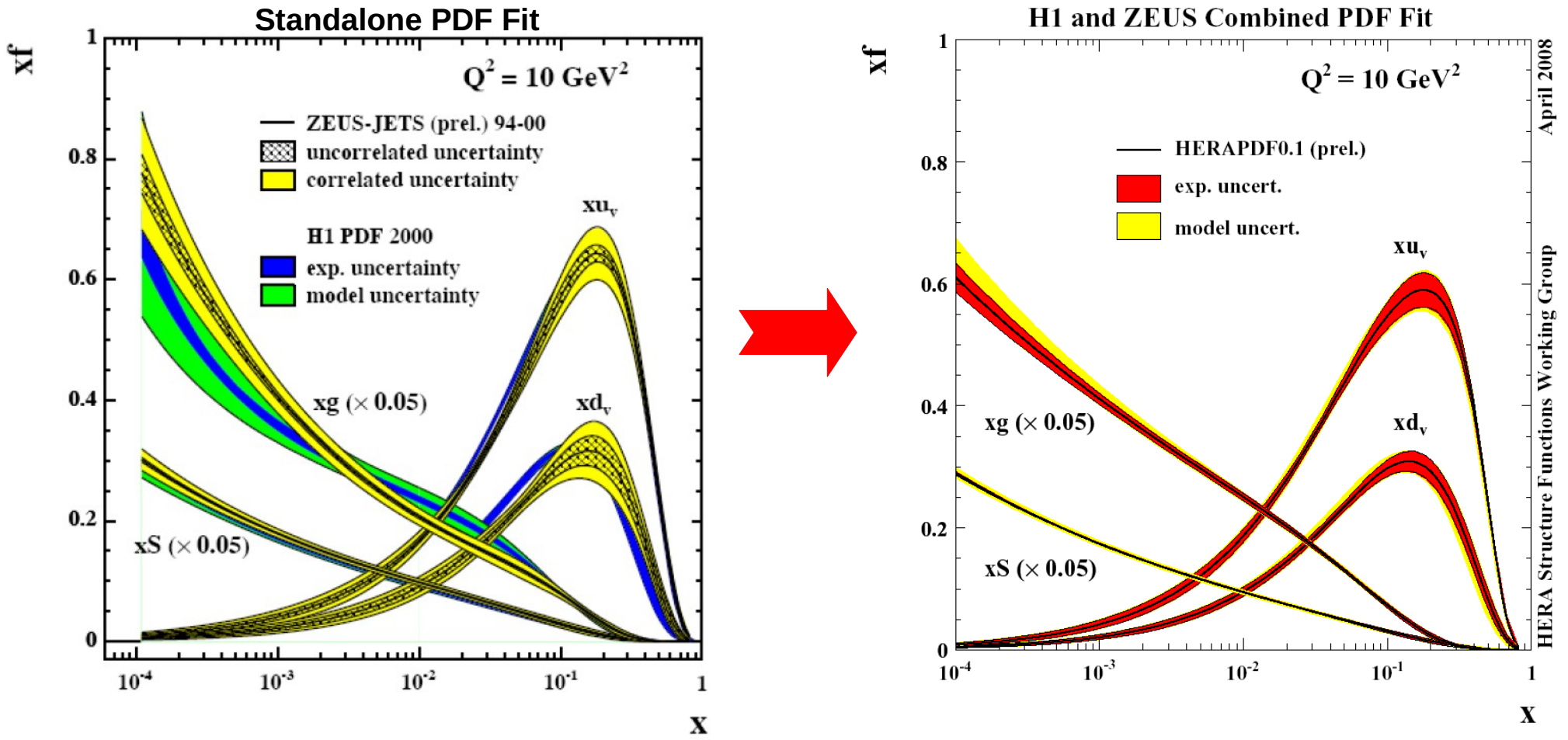
$$\sigma_{CC}(e^+p) \propto x[(1-y^2)(d+s)+(\bar{u}+\bar{c})]$$
$$\sigma_{CC}(e^-p) \propto x[(u+c)+(1-y^2)(\bar{d}+\bar{s})]$$

- Valence PDFs at small *x*
  - Impact to LHC W^+/W^- asymmetry



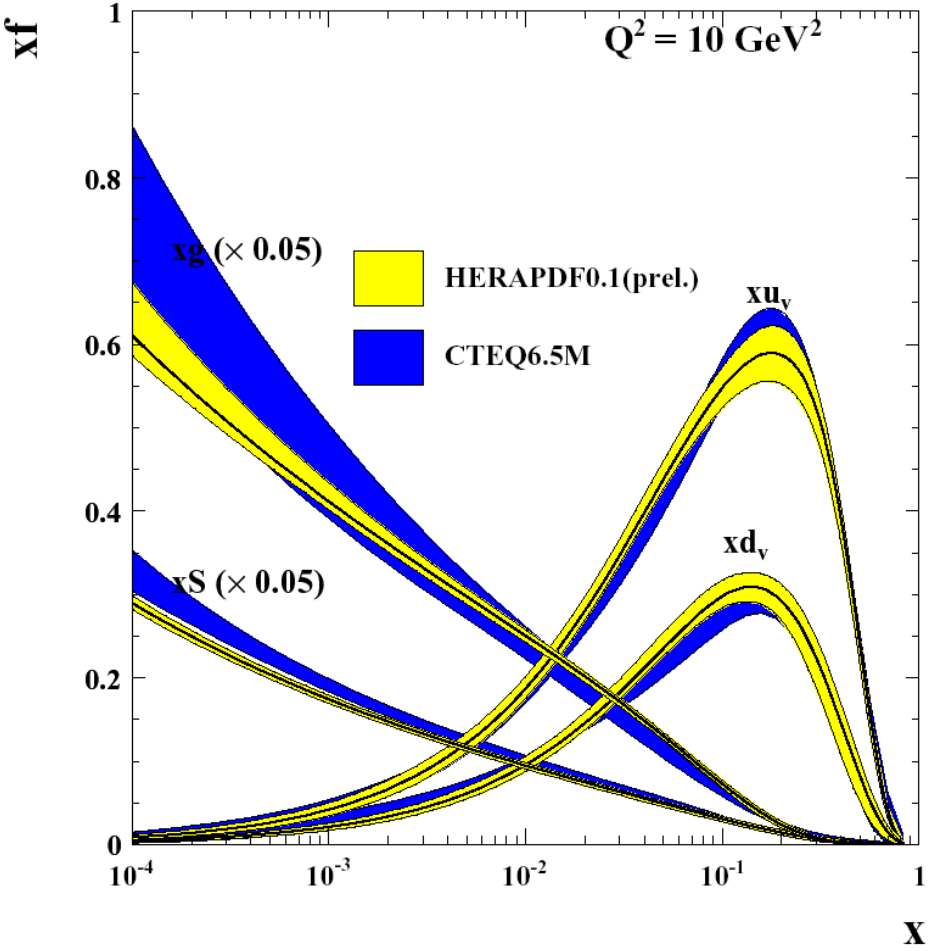
Common PDF Fit On HERA I Combined Data

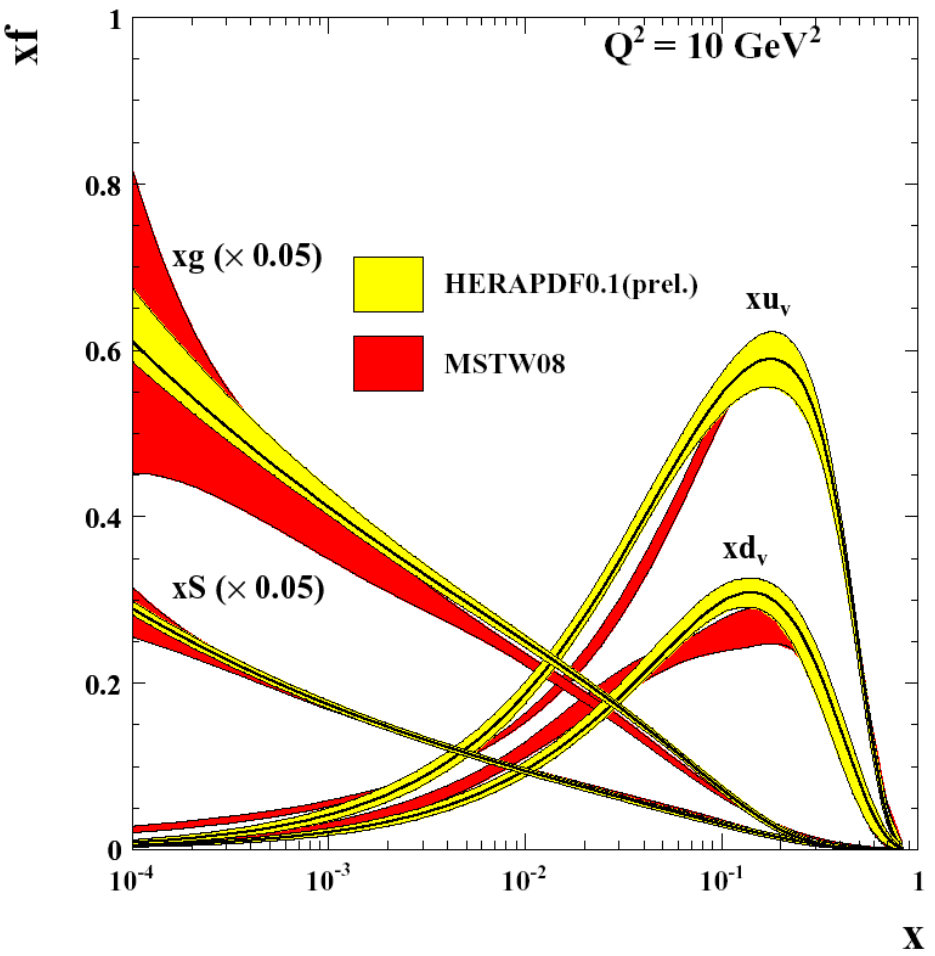
Partons are parametrized at at $Q_0^2 = 4$ GeV^2 (Data $Q^2 > 3.5$ GeV^2)



Improvement in the precision

HERAPDF0.1 versus CTEQ and MSTW

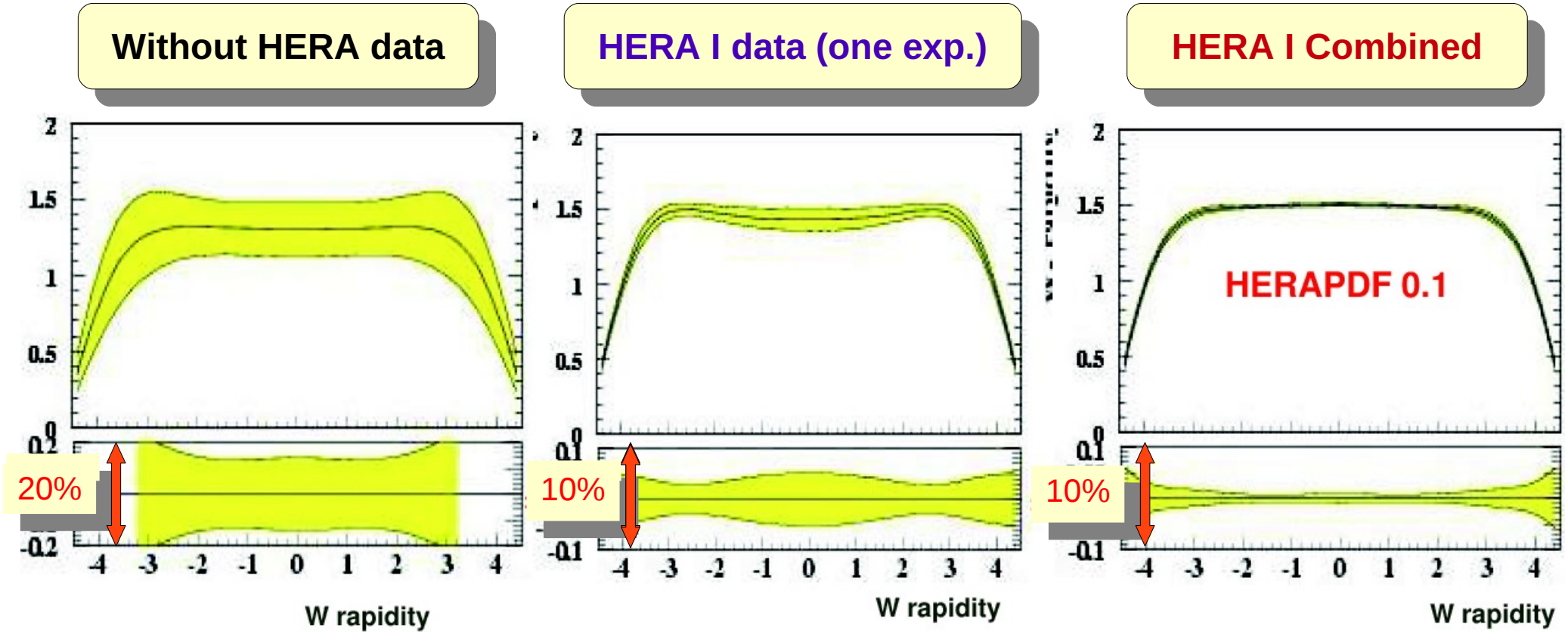




- Uncertainty on low *x* gluon and sea is strongly reduced

HERAPDF0.1 Impact On LHC

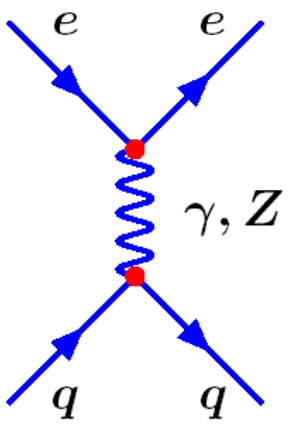
M. Cooper / E. Perez



Theory uncertainty on W cross section ~2 %

HERAPDF0.1 is released in LHAPDF (version 5.6.0)
.. to be exercised by LHC experiments

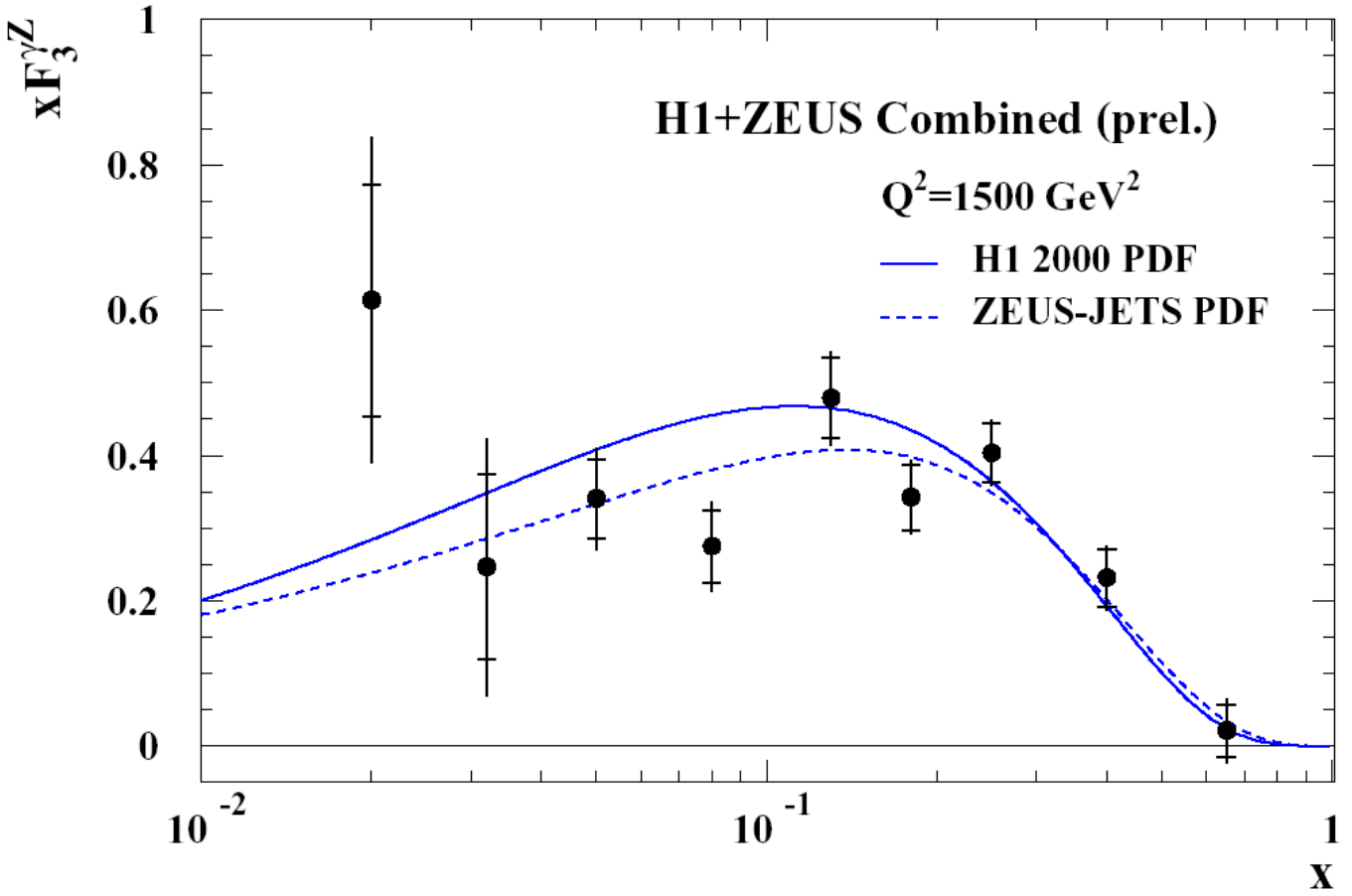
Proton Structure: Valence Quarks at High x



$$\tilde{\sigma}_{NC}(e^{\pm}p) = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$

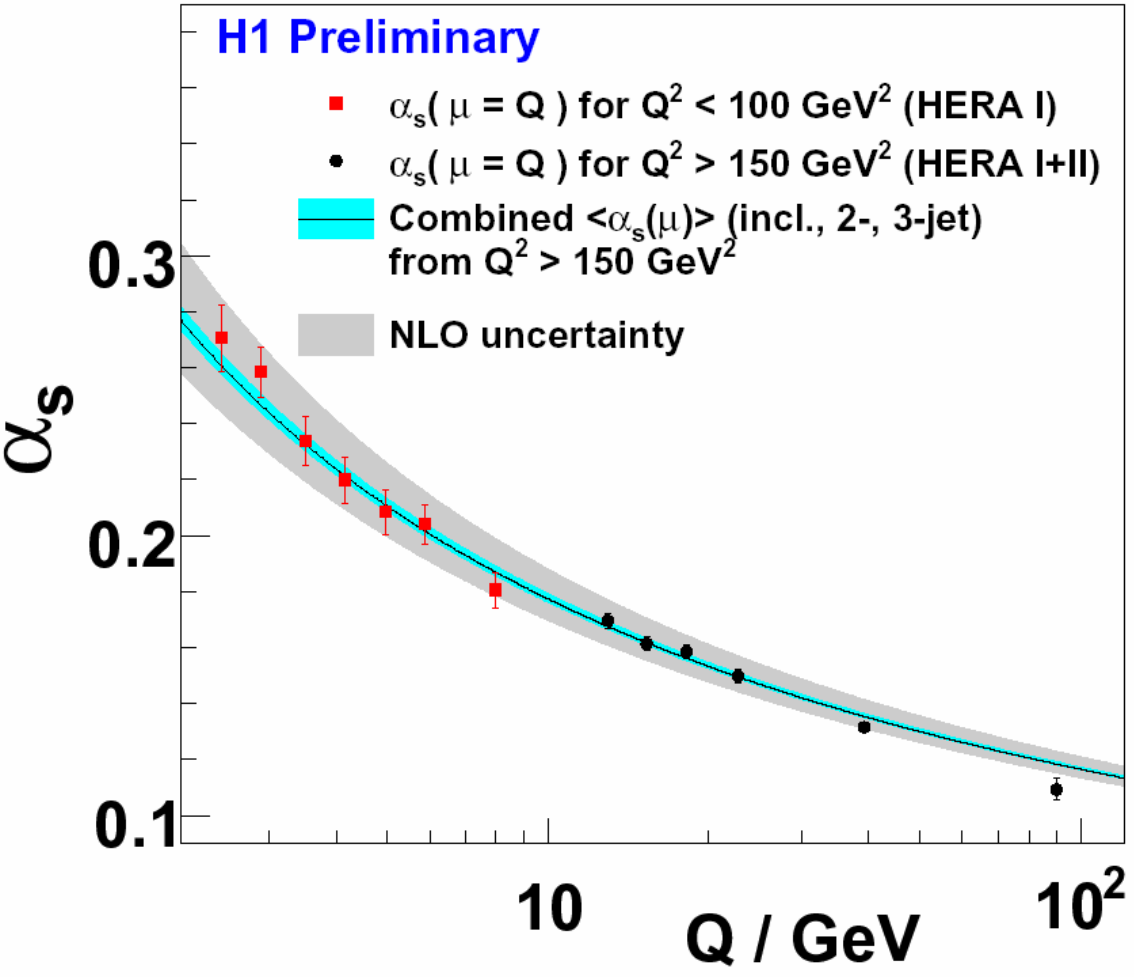
$$xF_3 \sim \sigma(e^-) - \sigma(e^+)$$
$$\sim (2u_v + d_v)$$

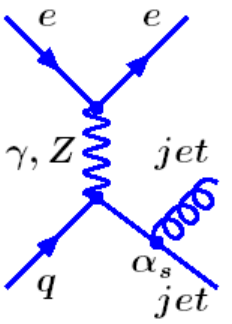
Total lumi ~480 pb^{-1}

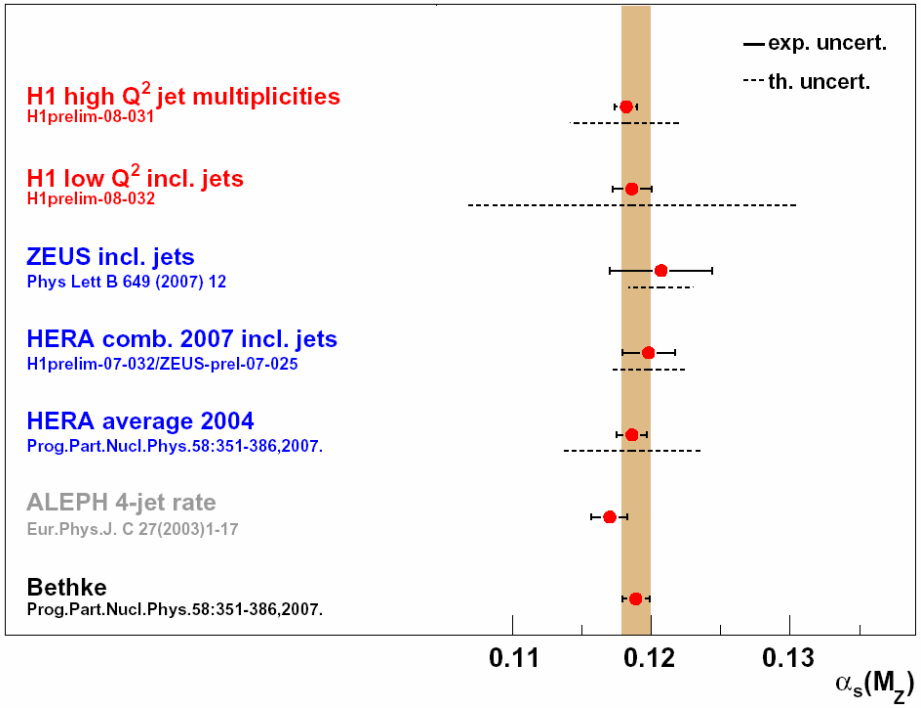


- To be performed for all HERA data

QCD Dynamics: the Strong Coupling α_s From Multi-jet Rates



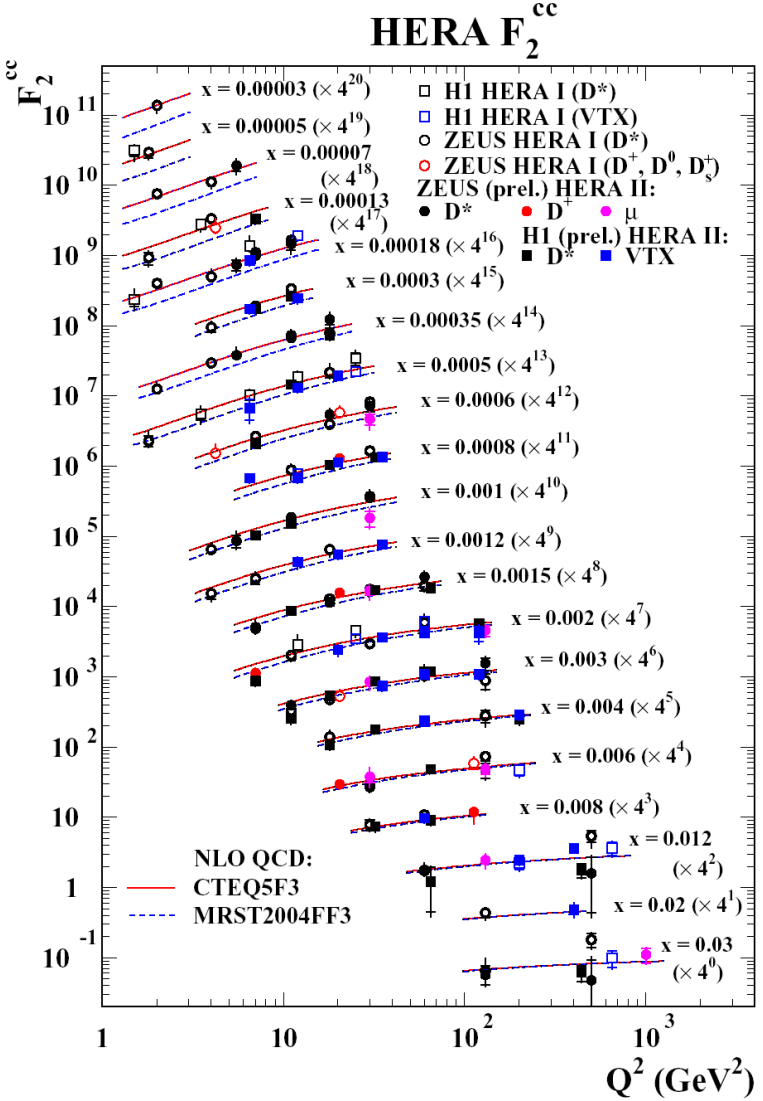


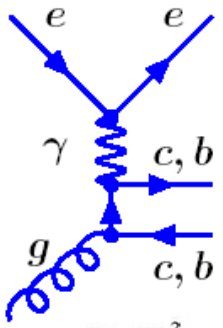


HERA exp. error ~0.7%
a challenge for theory!

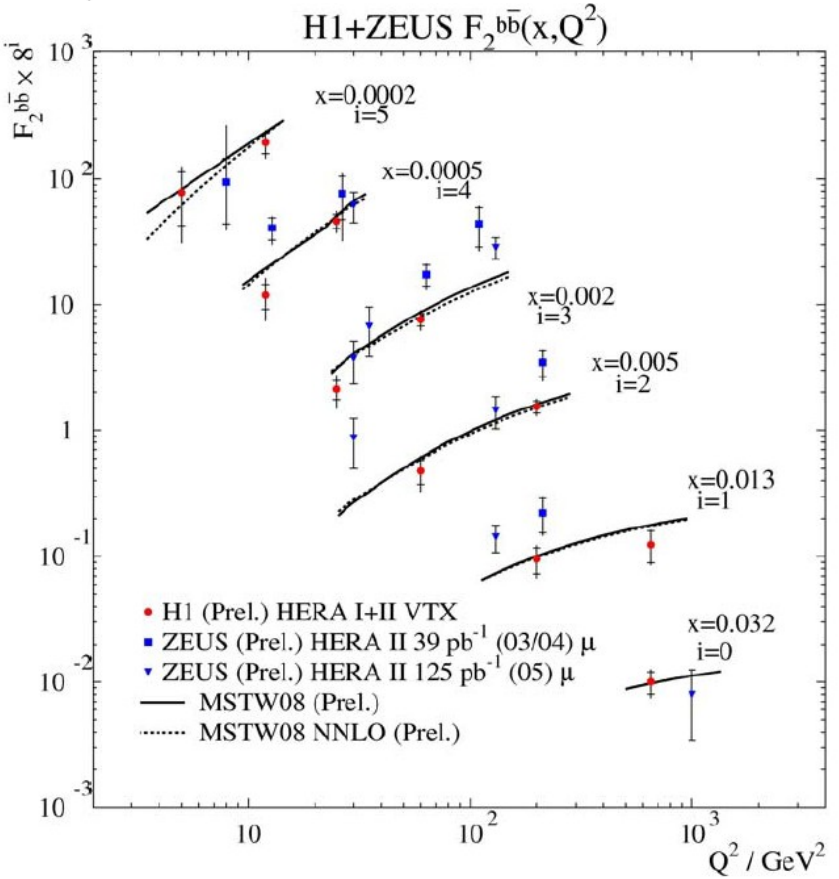
QCD Dynamics: Heavy Quark PDFs and Gluons

- Other cross check of gluons and QCD dynamics: heavy-quarks

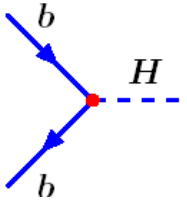




Heavy flavors tagged through $D^{(*)}$, decay muons or displaced vertices

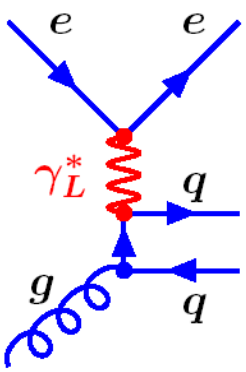


- Heavy quark PDFs at large scale is also important at LHC, e.g. :



Heavy Quark generation is well described by DGLAP

Directly Probing the Gluon With F_L

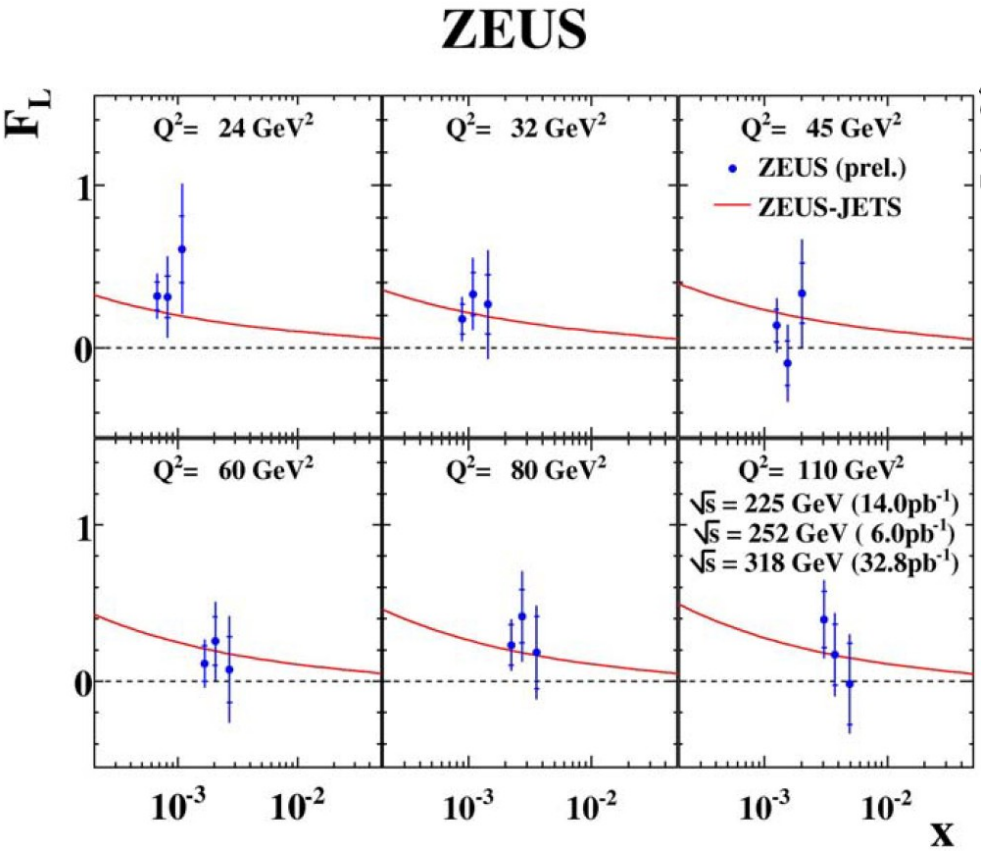


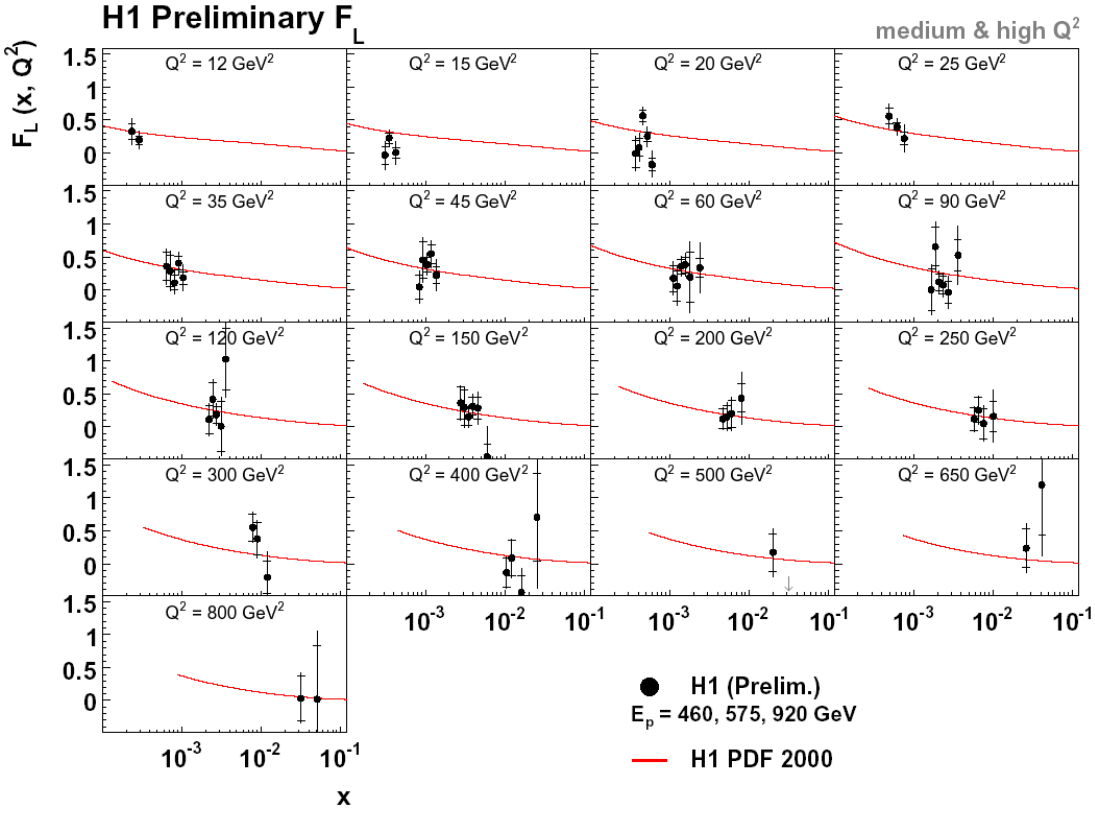
$$\tilde{\sigma}_{NC}(e^{\pm}p) = \tilde{F}_2(Q^2,x) - \frac{y^2}{1+(1-y)^2}\tilde{F}_L(Q^2,x)$$

$$y = \frac{Q^2}{sx}$$

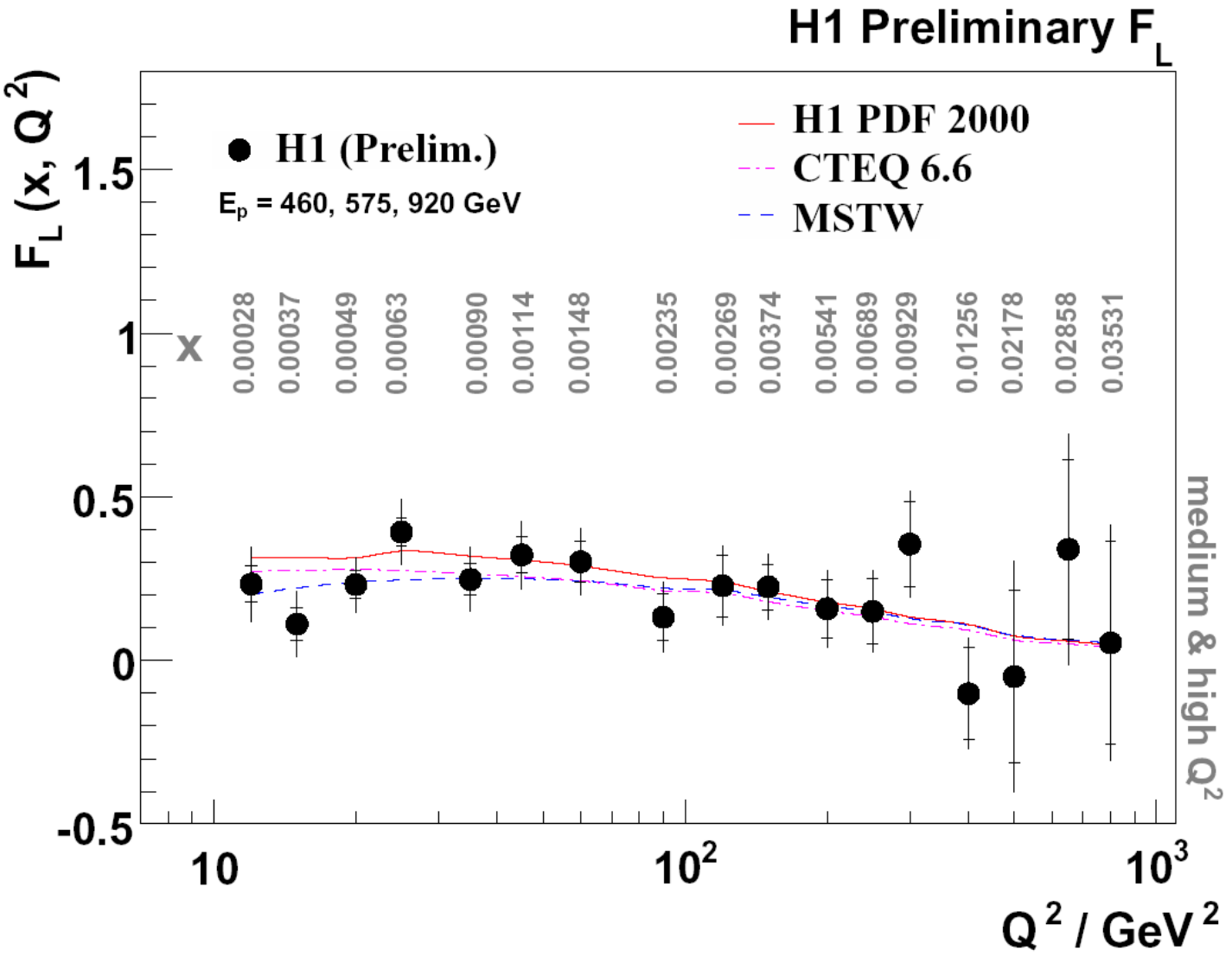
Proton beam:
E_p = 920 GeV
E_p = 460 GeV
E_p = 575 GeV

- F_L = *0* at naïve Quark-Parton-Model, i.e. w/o QCD
- F_L at small *x*: a very good test of small *x* parton dynamics / evolution
- HERA is the only place to where F_L can be measured at small *x*





Measured F_L vs Q^2



- F_L predicted by QCD fits using gluon that was derived from scaling violation of F_2 is consistent with the measurement
- Measurements at lower Q^2 are ongoing

Summary

- HERA ended its run at June 2007: ~1 fb^{-1} collected by H1 and ZEUS
- HERA provides most precise inclusive structure function measurements, which brought significant improvements to our knowledge on proton structure
  - Combination of H1 and ZEUS cross-sections brought significantly improved precision of data
- New high precision results expected in future will further improve our understanding on proton structure
  - Inclusive measurement at high x and Q^2 using full HERA data set
  - Measurement with jets to determine the gluon and the strong coupling
  - Direct measurement of F_L at lowest x / Q^2
  - Precise measurements of the heavy flavor content
- Final publications with ultimate precision to come in the next years
- HERA provides essential inputs to LHC