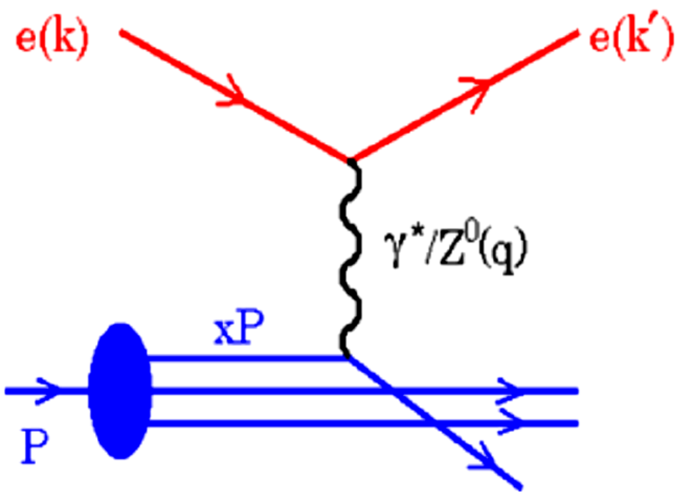
Recent Results from HERA

S. Glazov

DESY

Detroit, 30 July 2009.

Deep Inelastic ep scattering



Neutral scattering cross section:

$$\frac{d^2\sigma^\pm}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\sigma_r^\pm =$$

$$= \frac{2\pi\alpha^2 Y_+}{Q^4 x}\left[F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3\right]$$

where factors $Y_\pm = 1 \pm (1-y)^2$ and y^2 define polarization of the exchanged boson and $y = Q^2/(S\,x)$.

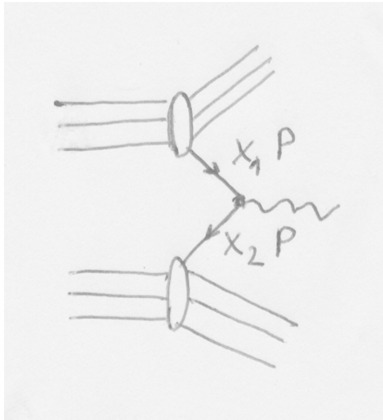
Kinematics of inclusive scattering is determined by Q^2 and Bjorken x.
At leading order:

$$\begin{array}{ll} F_2 & = x\sum e_q^2(q(x)+\bar{q}(x)) \\ xF_3 & = x\sum 2e_q a_q(q(x)-\bar{q}(x)) \\ \sigma^{CC}_{e^+p} & \sim x(\bar{u}+\bar{c}) + x(1-y)^2(d+s) \\ \sigma^{CC}_{e^-p} & \sim x(u+c) + x(1-y)^2(\bar{d}+\bar{s}) \end{array}$$

$xG(x)$ — from F_2 scaling violation, jets and F_L

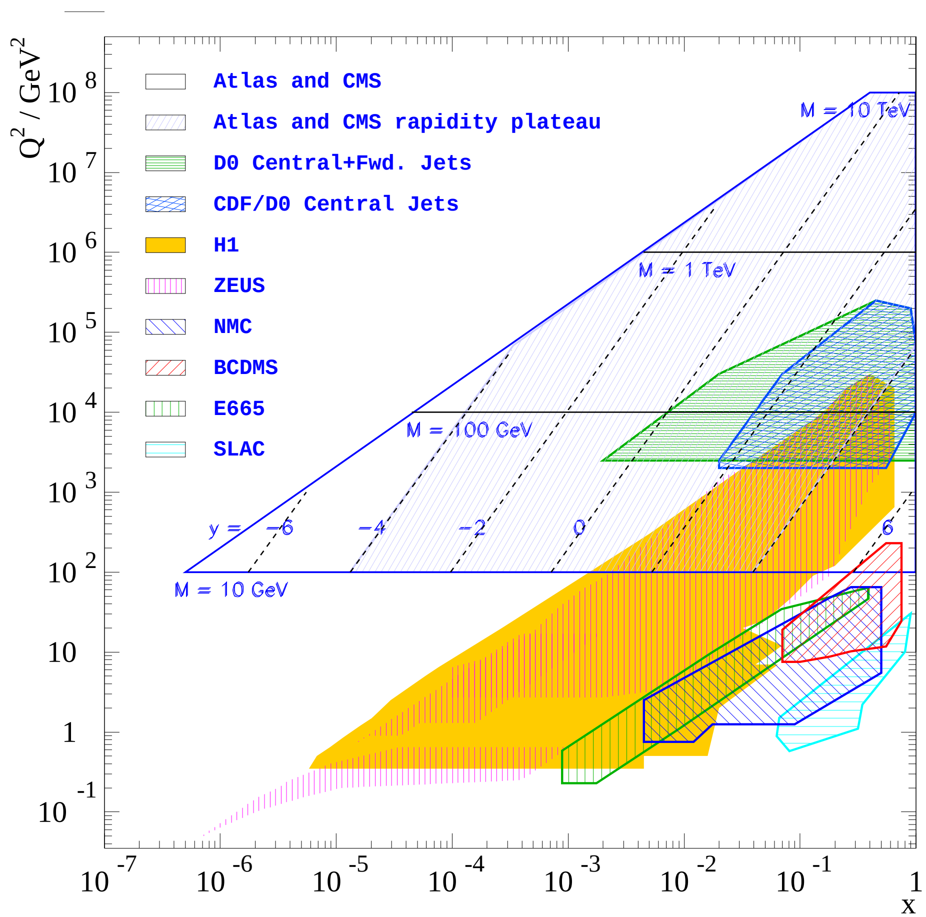
HERA with $\sqrt{S} = 318$ GeV is a unquie tool to measure the proton structure.

HERA and LHC kinematics



x_1, x_2 are momentum fractions. Factorization theorem states that cross section can be calculated using universal partons × short distance calculable partonic reaction.

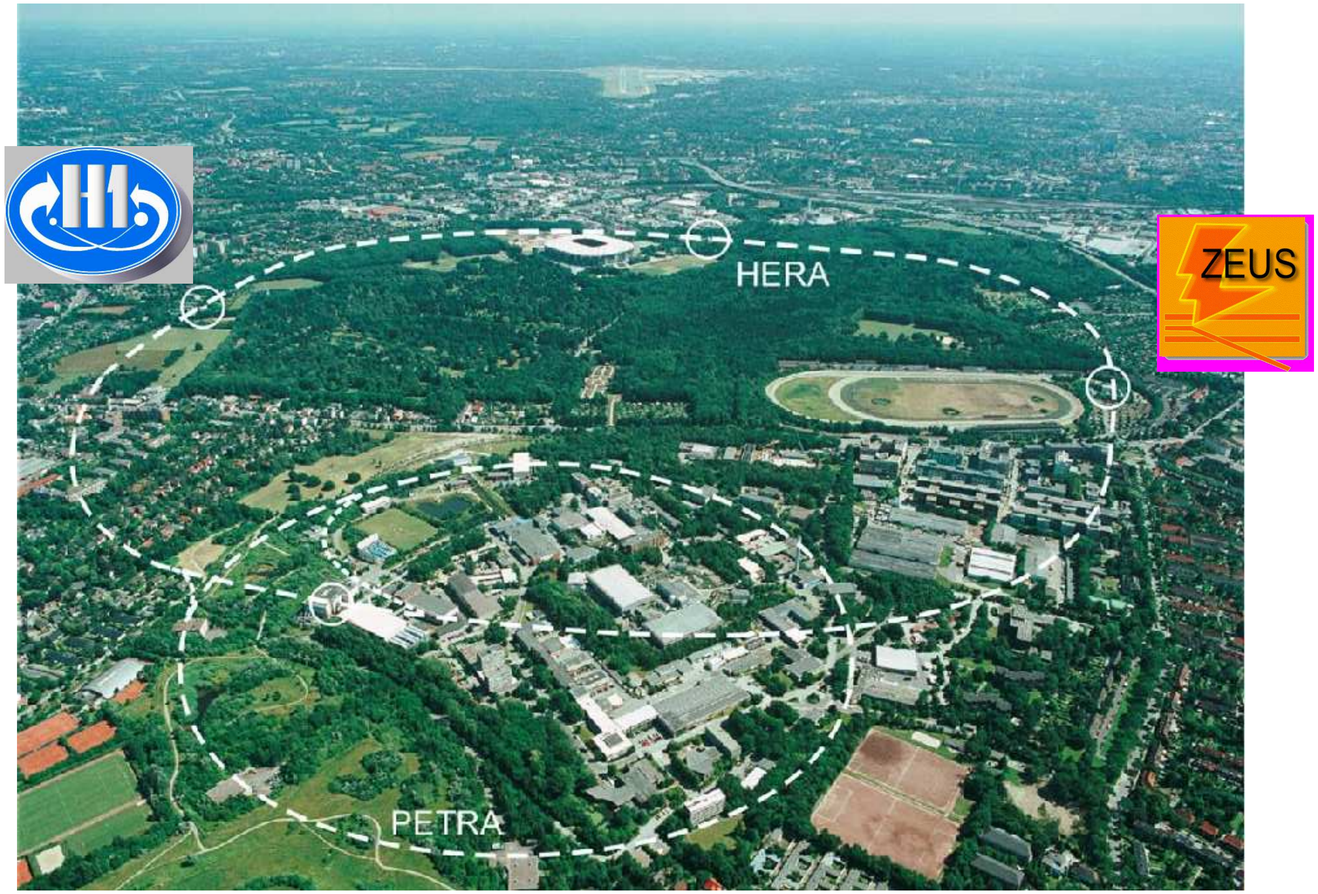
$$x_{1,2} = \frac{M}{\sqrt{S}} \exp(\pm y)$$

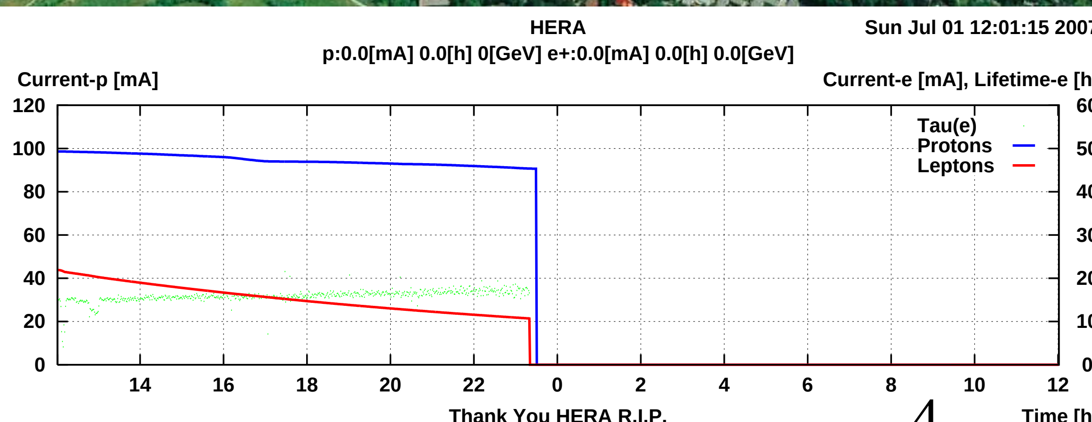


Notation clash: y – rapidity (LHC) vs y – inelasticity (HERA, $Q^2 = S\,xy$).

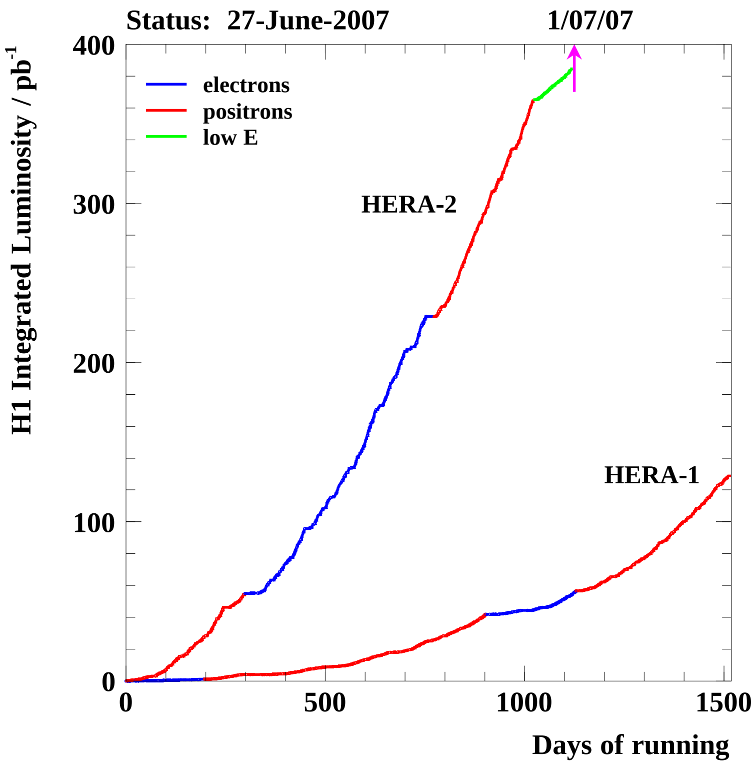
For $M \sim 100$ GeV and central rapidity proton structure information is provided by HERA.

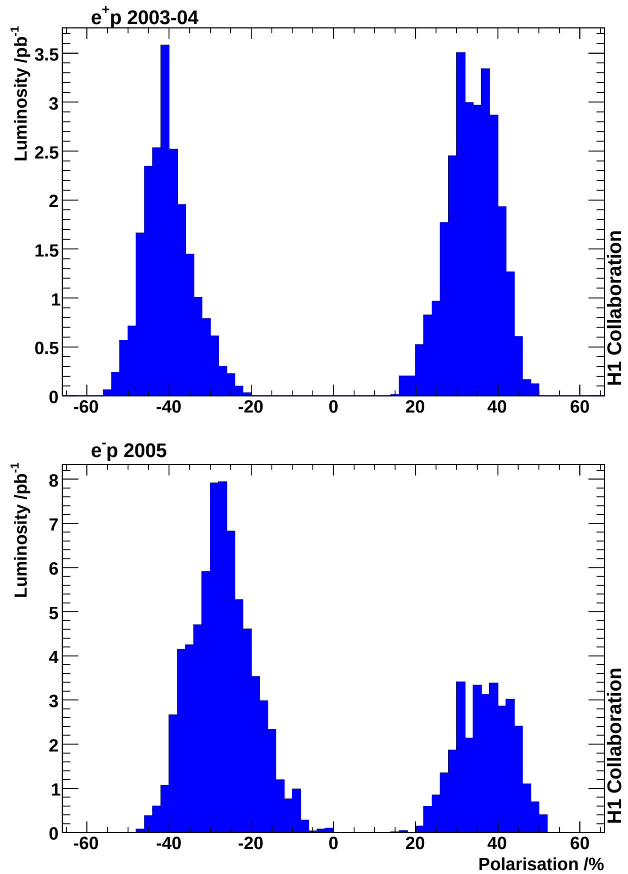
HERA, H1 and ZEUS. 1992-2007.





HERA Runs

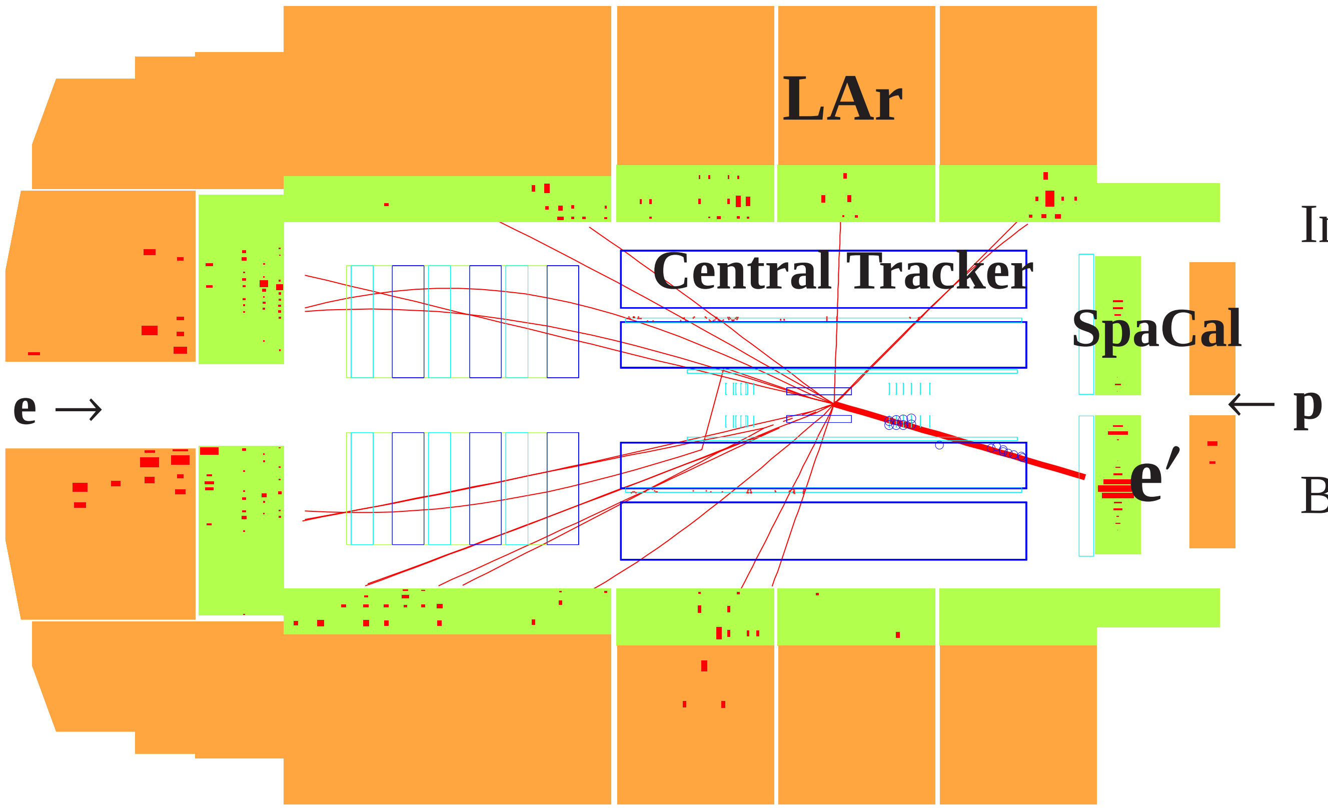




HERA-II upgrade provides better instantaneous luminosity and longitudinal beam polarization.

Nominal $E_p = 920$ GeV, $E_e = 27.5$ GeV. Special low proton beam energy runs $E_p = 460, 575$ GeV to measure F_L

DIS Event Reconstruction



$$Q^2 = 4E_eE'_e\cos^2\frac{\theta_e}{2}$$

Inelasticity:

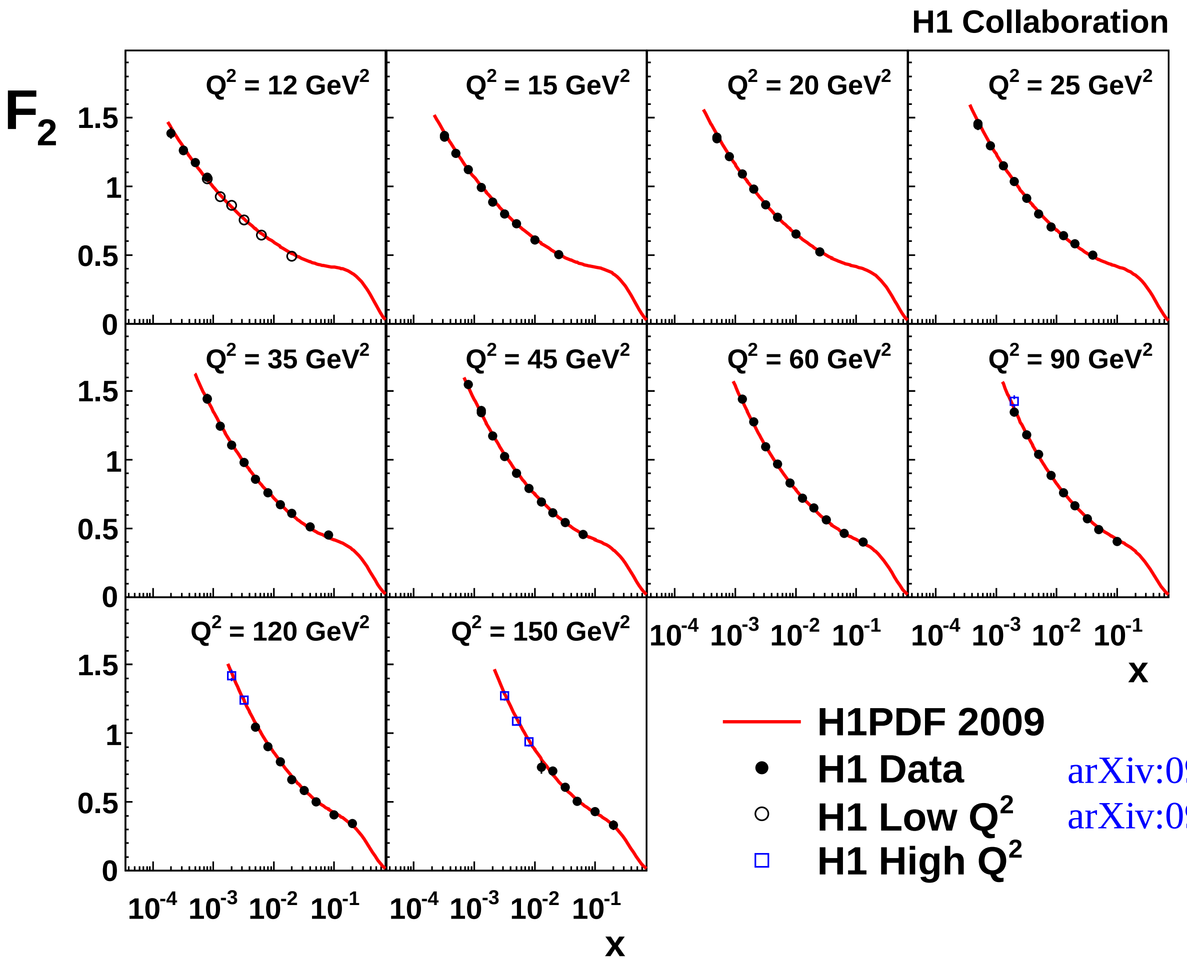
$$y = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}$$

Bjorken x:

$$x = \frac{Q^2}{S\,y}$$

Both the scattered electron and hadronic final state can be used to reconstruct event kinematics.

Structure Function F_2 at low x

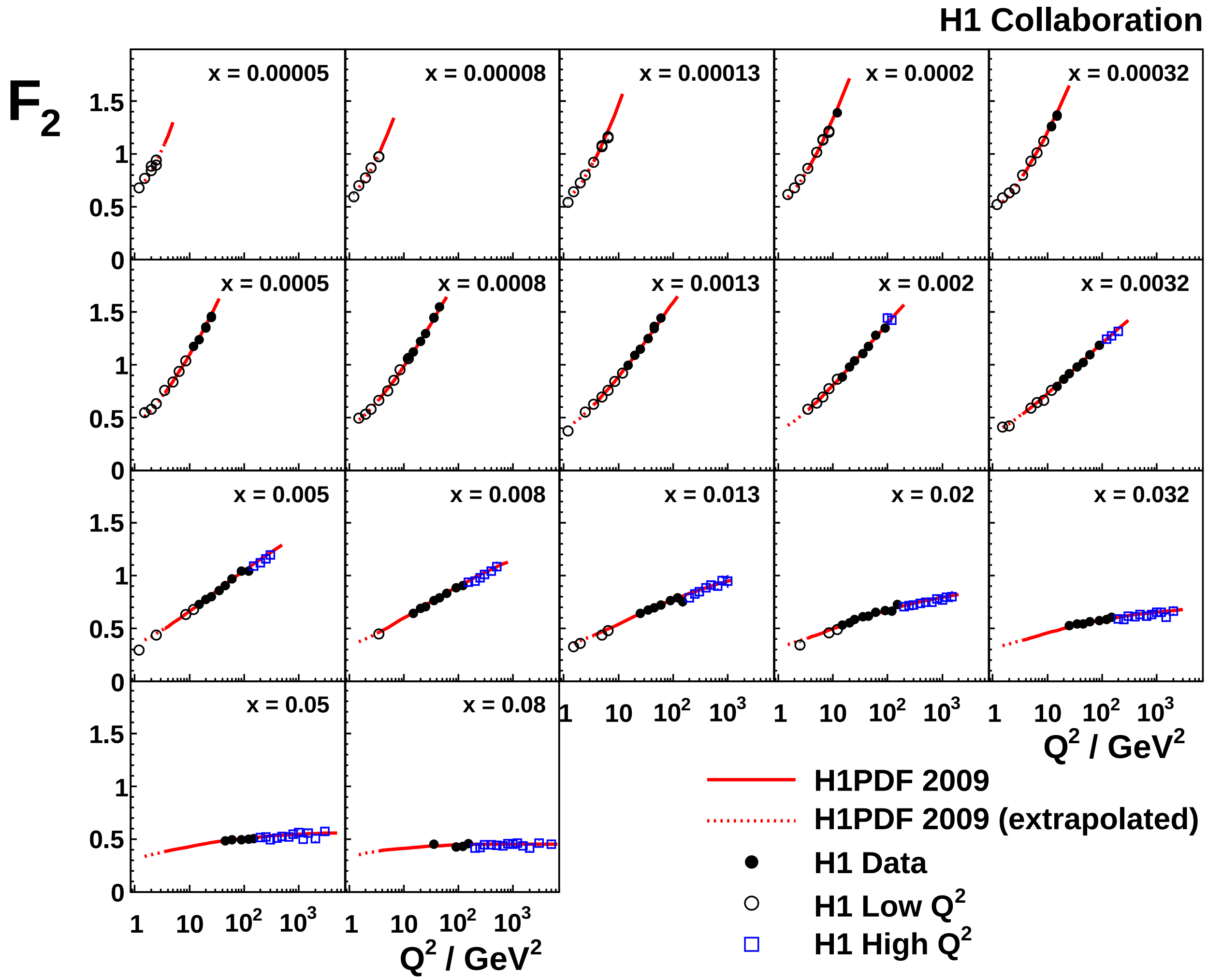


Recent measurement performed by the H1 collaboration.
Final H1 result base on HERA-I data. Precision reaches $\sim 1.5\%$.

arXiv:0904.3513, submitted to EPJ
arXiv:0904.0929, submitted to EPJ

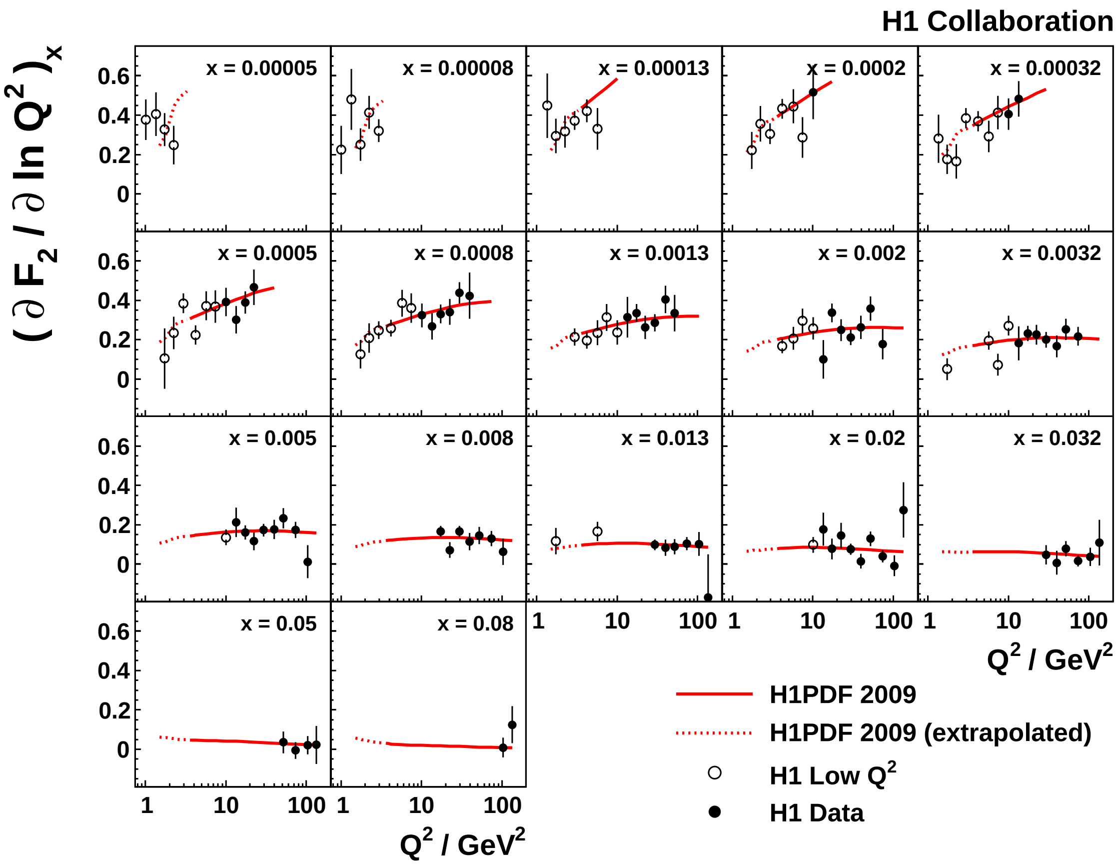
$F_2(x, Q^2)$ shows strong rise as $x \to 0$, the rise increases with increasing Q^2.

F_2 Scaling violation at low x



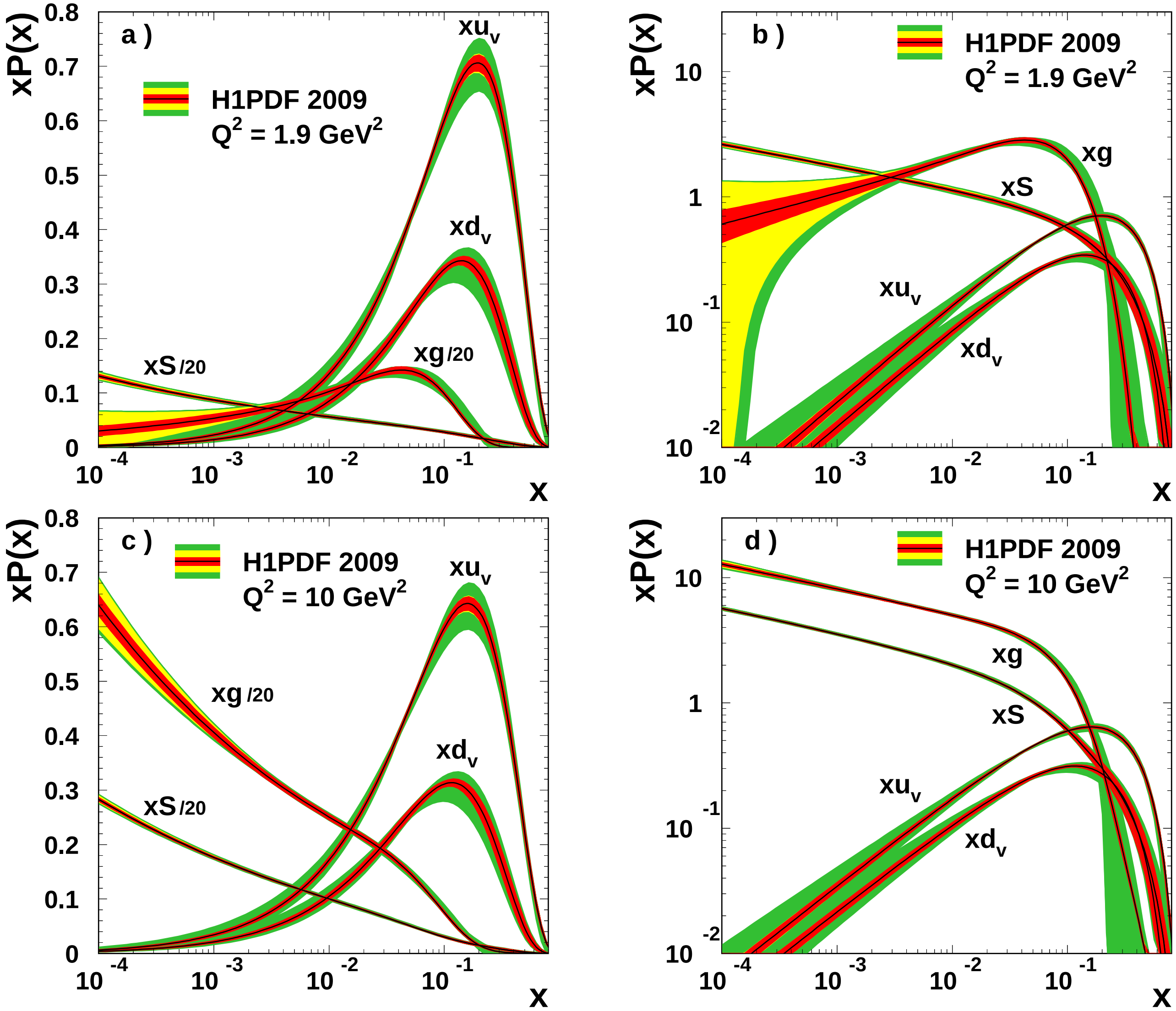
Large scaling violation at low x — large gluon density. Good agreement between the data and theory.

$\partial F_2/\partial \ln Q^2$ at low x



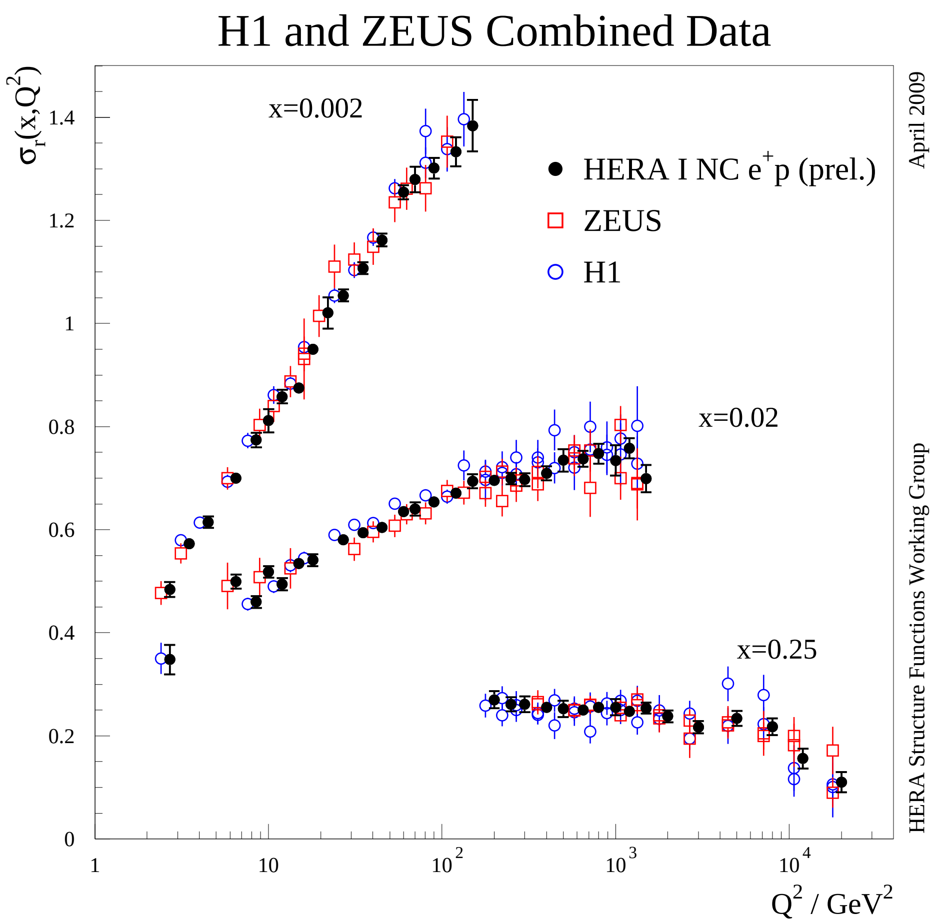
Data precision allows for local determination of $\partial F_2/\partial \ln Q^2 \sim \alpha_S G$.
Note that there is a strong anti-correlation between the data points.
Good consistency between data and QCD fit (even for extrapolation to low Q^2).

Proton PDFs



- For $x < 0.01$ xS and xG dominate.
- Very rapid evolution for xS and xG.
- Analysis based using the H1 data only.

Combination of HERA data



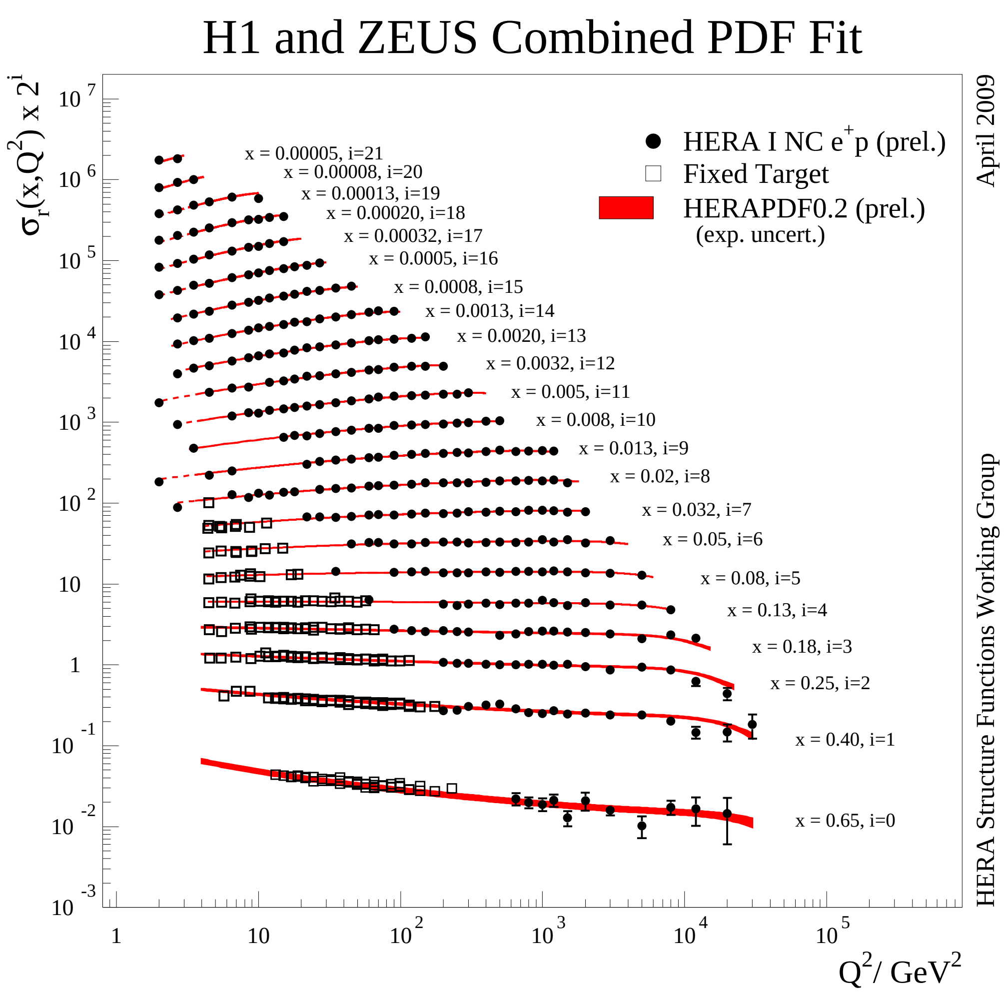
Average H1 and ZEUS data before applying QCD analysis.

Achieved by fitting σ_r values, global normalizations and the correlated systematic uncertainties.

$$\sigma_r^{\pm} = F_2 - \frac{y^2}{Y_+} \mp \frac{Y_-}{Y_+} xF_3$$

Experiments cross calibrate each other: total uncertainties reduced, sometimes better than $\sqrt{2}$.

Combined HERA data

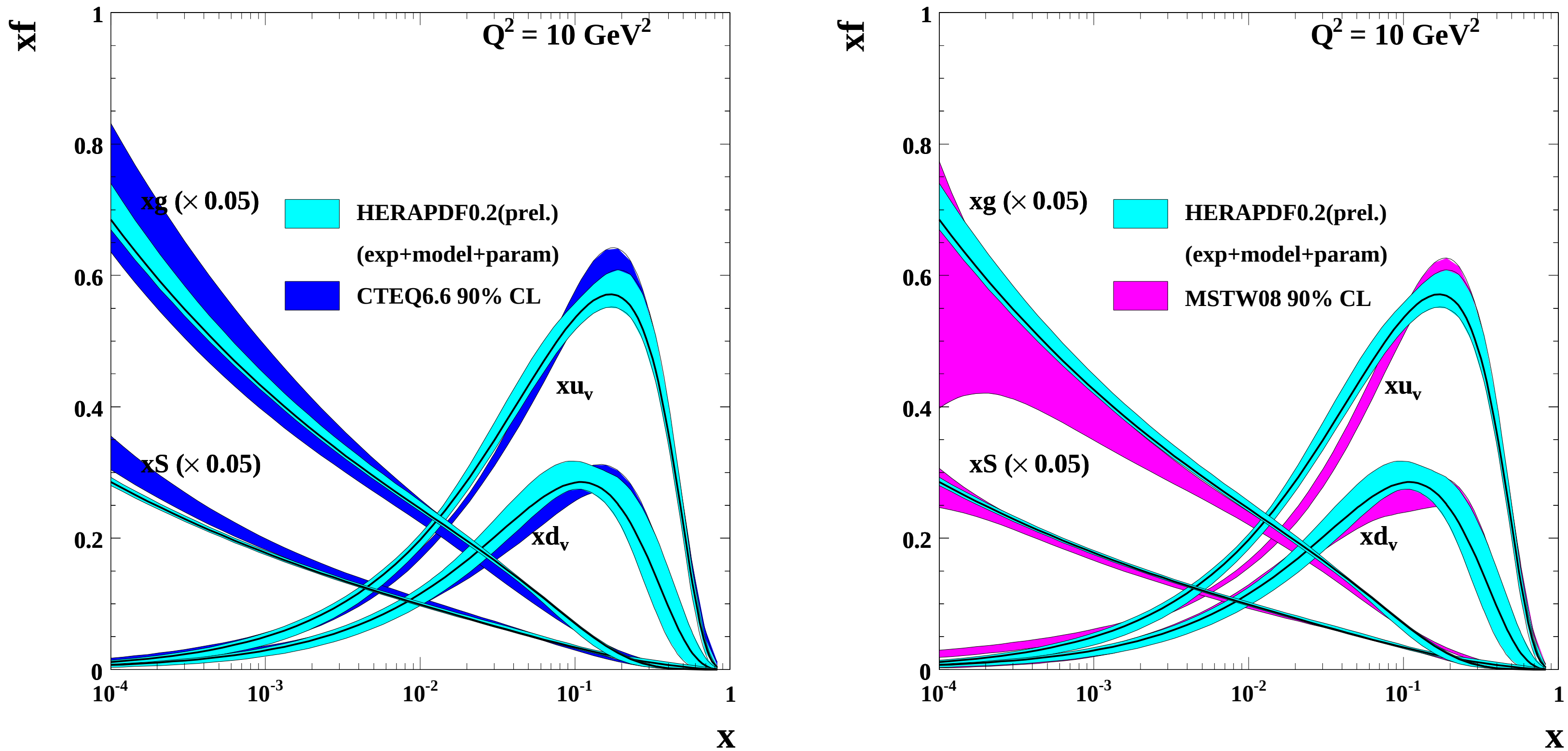


Combination of published H1/ZEUS data for CC,NC, $e^{\pm}p$ data.

$$\chi^2/dof = 637/656$$

HERA data approaches precision of fixed target experiments. Combined data vs theory: stringent test of DGLAP evolution.

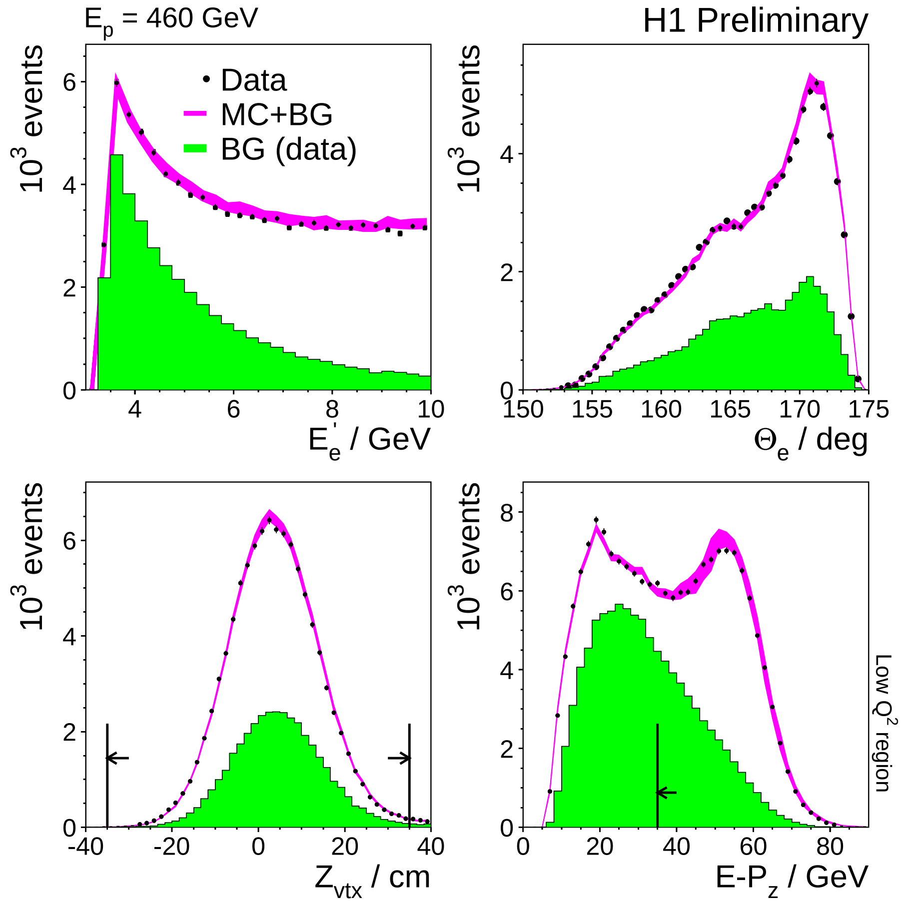
PDFs extraction



Sea S and gluon g are far more important at low x. Mind the $\times 0.05$ scale factor for them.

Fit to combined H1/ZEUS data returns much more precise $xG(x)$ compared to global fits of CTEQ and MRST: improved data precision and also different data errors treatment.

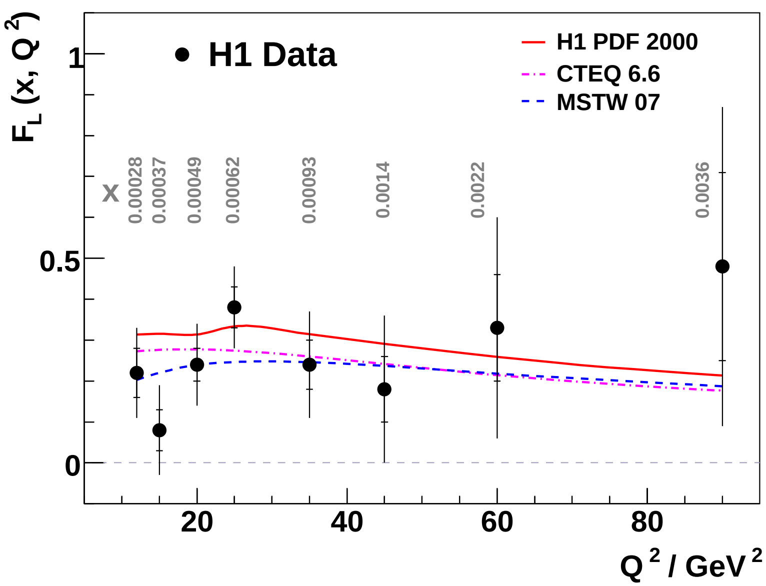
Measurement of F_L.



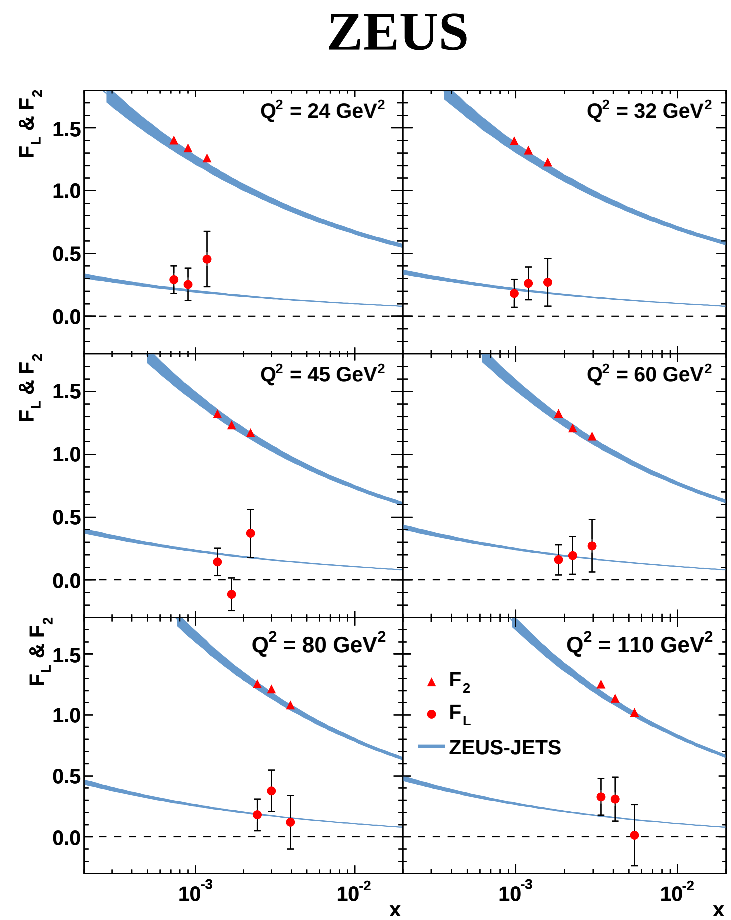
Determination of F_L requires measurement at high $y \approx 1 - \frac{E'_e}{E_e}$

H1 estimates background directly from data using the measured charge of the electron candidate.

Published H1 and ZEUS F_L results



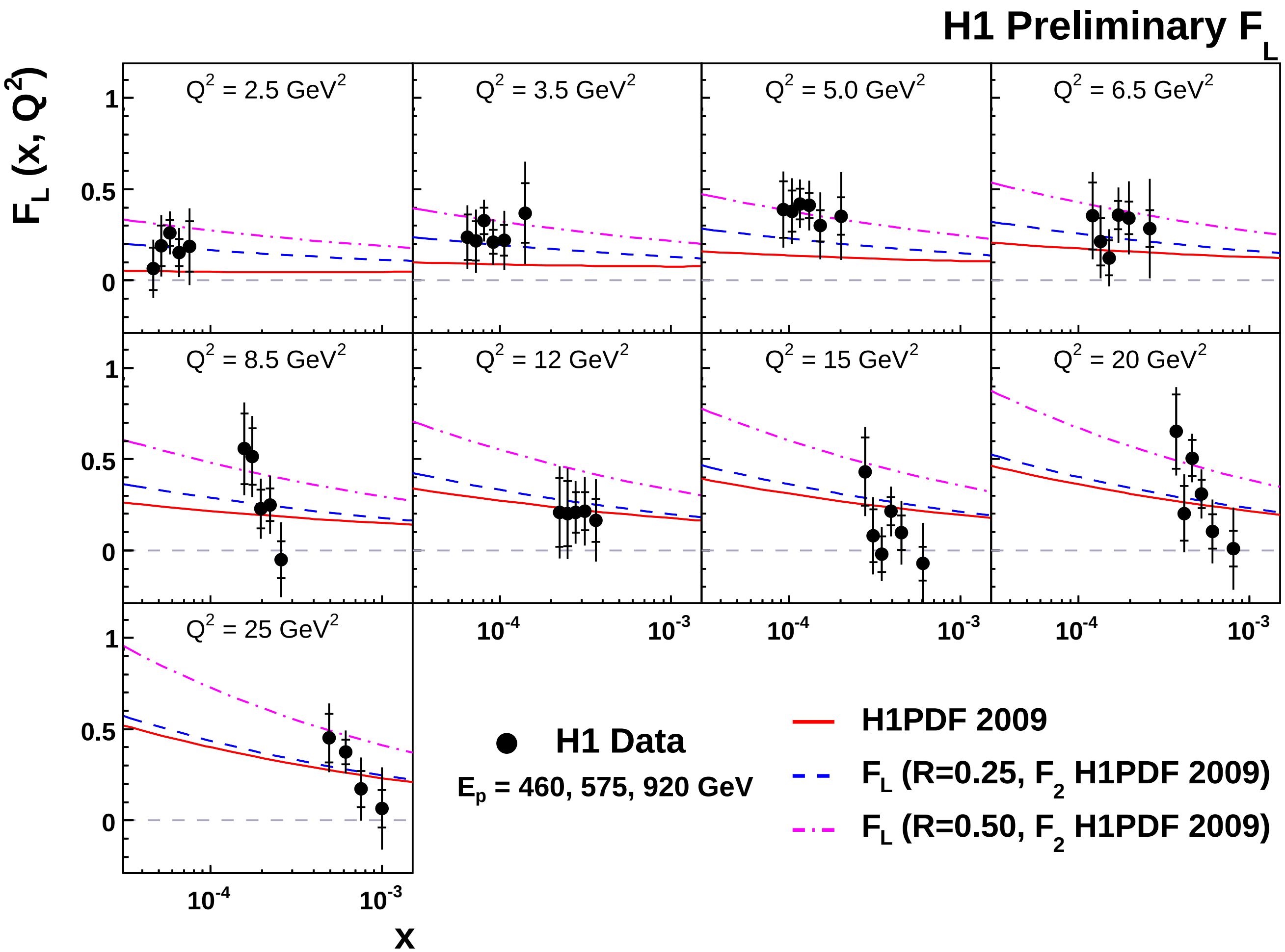
Phys.Lett. **B665** 139, 2008.



DESY-09-046, to be published in Phys. Lett. B

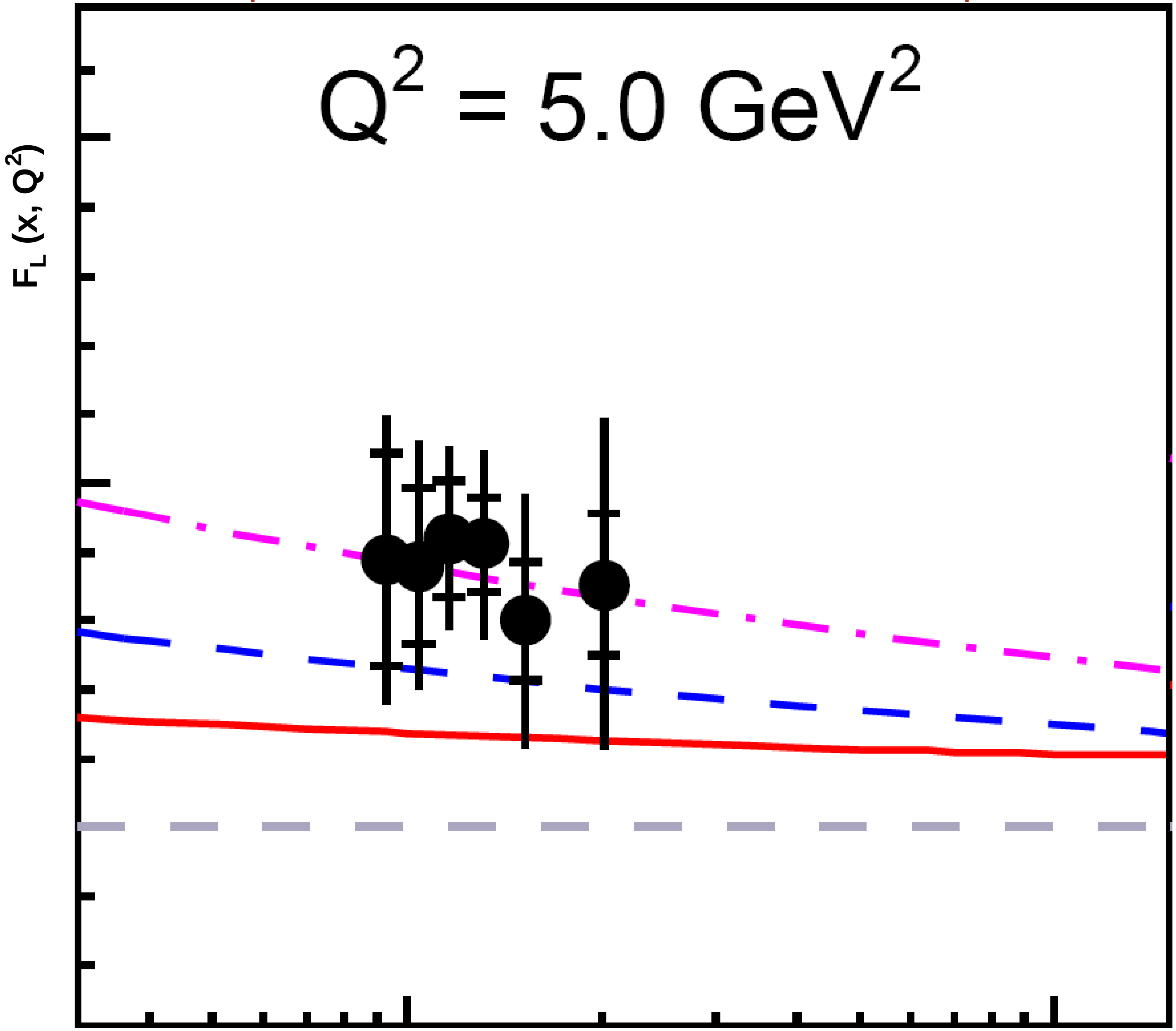
Both H1 and ZEUS collaborations published their first measurements of F_L. ZEUS also extracts F_2 without any assumption on F_L.

H1 extension to low Q^2



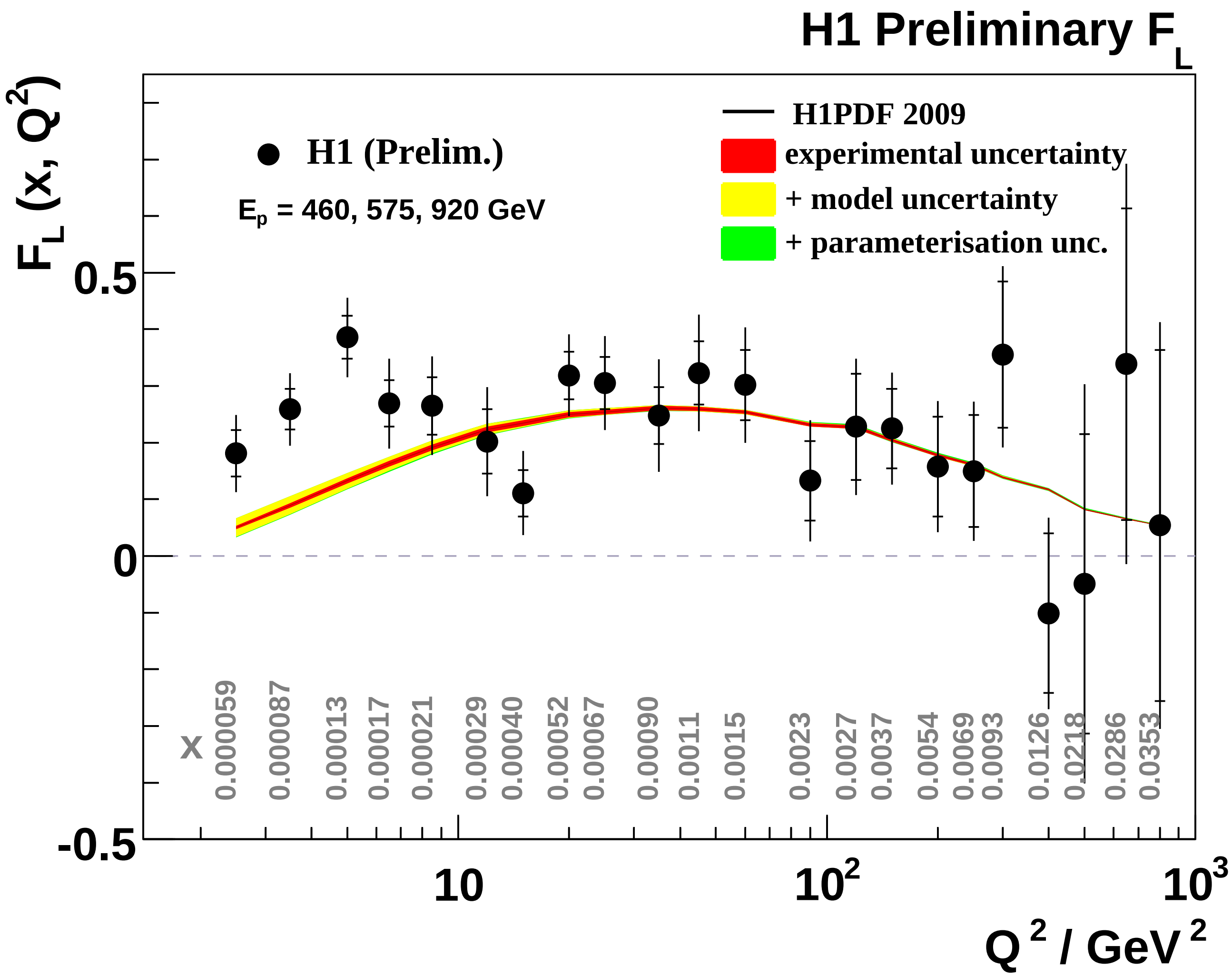
Using the backward silicon tracker, H1 extended the measurement to low Q^2.

H1 extension to low Q^2



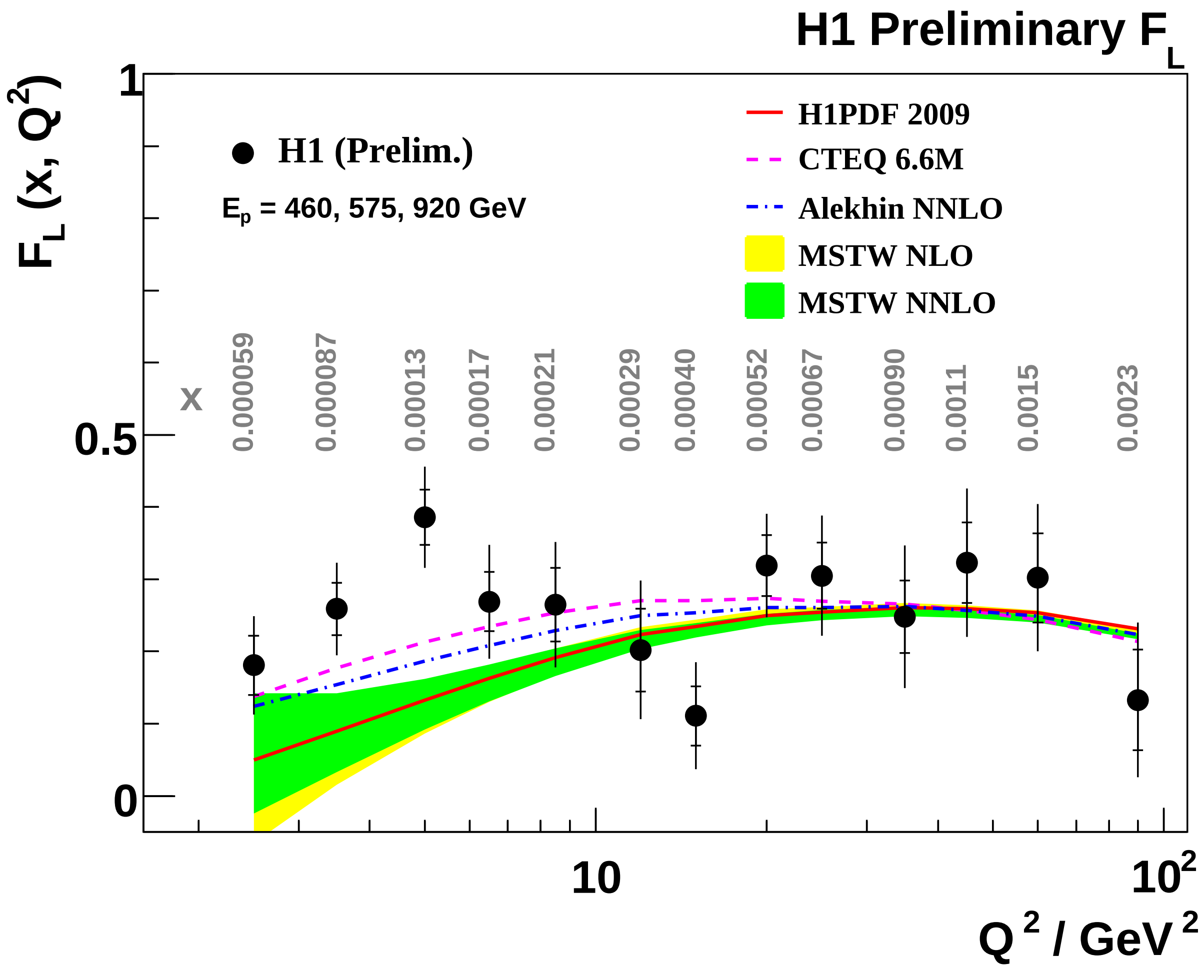
Using the backward silicon tracker, H1 extended the measurement to low Q^2.

F_L measured by H1



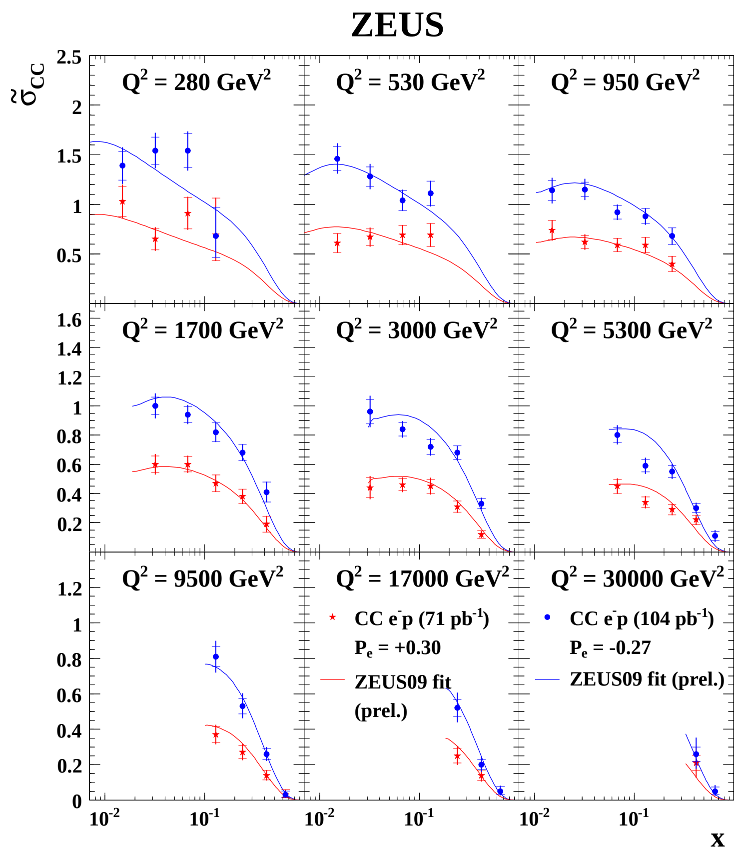
H1 measurements cover $2.5 \leq Q^2 \leq 800$ GeV^2 and $0.00005 \leq x \leq 0.04$ range
For $Q^2 \geq 10$ GeV^2, agree well with H1PDF 2009 prediction.

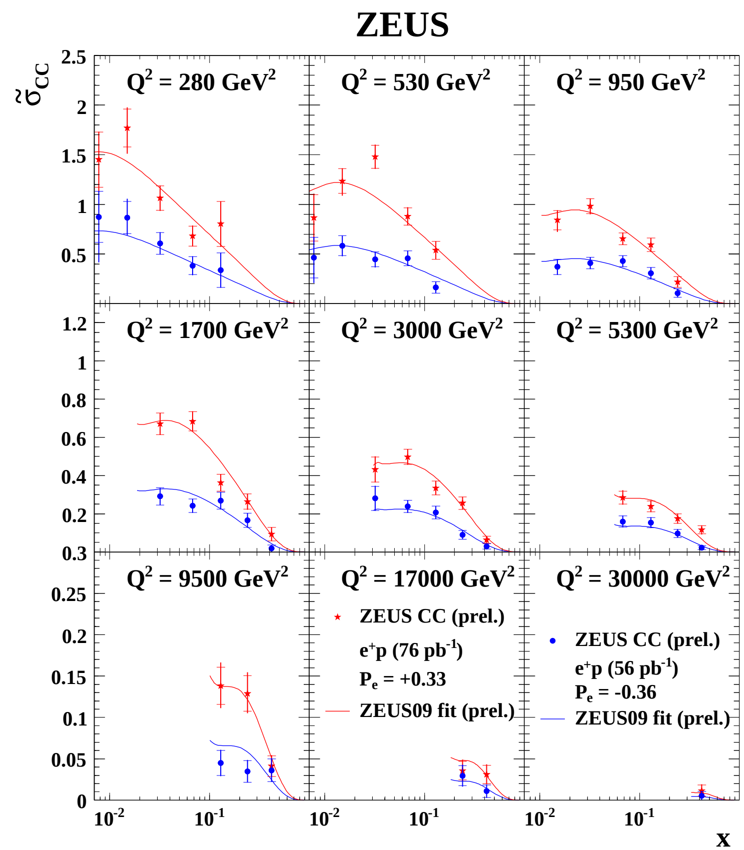
F_L measured at $Q^2 < 100$ GeV^2



MSTW and H1PDF 2009 predictions use the same scheme to calculate F_L.
Data agree better with calculation of CTEQ.

Charged Current Double Differential Cross Section

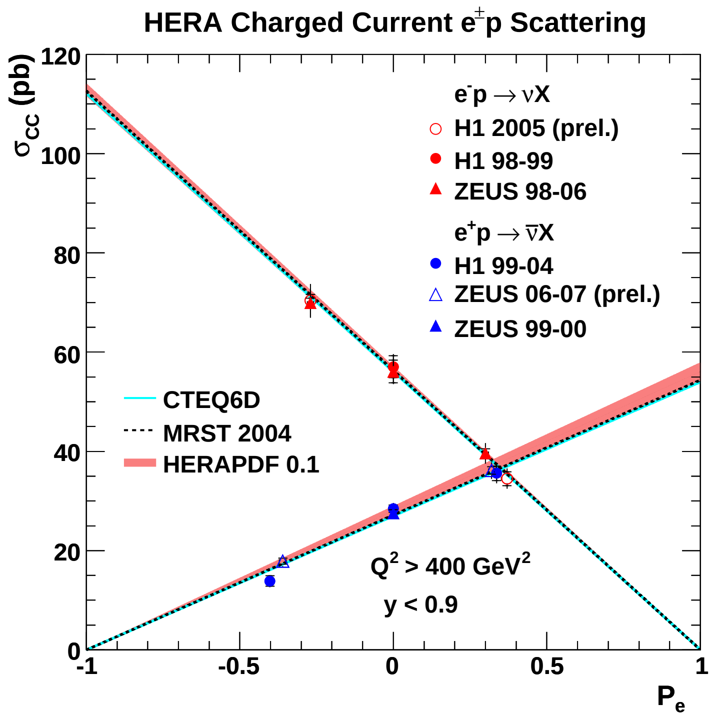




Recently ZEUS published analysis of the complete $e^- p$ sample. CC data allows to measure $D, \bar{U}$ and $U, \bar{D}$ separately.

(DESY-08-177, accepted by EPJ C)

Charged Current Cross Section

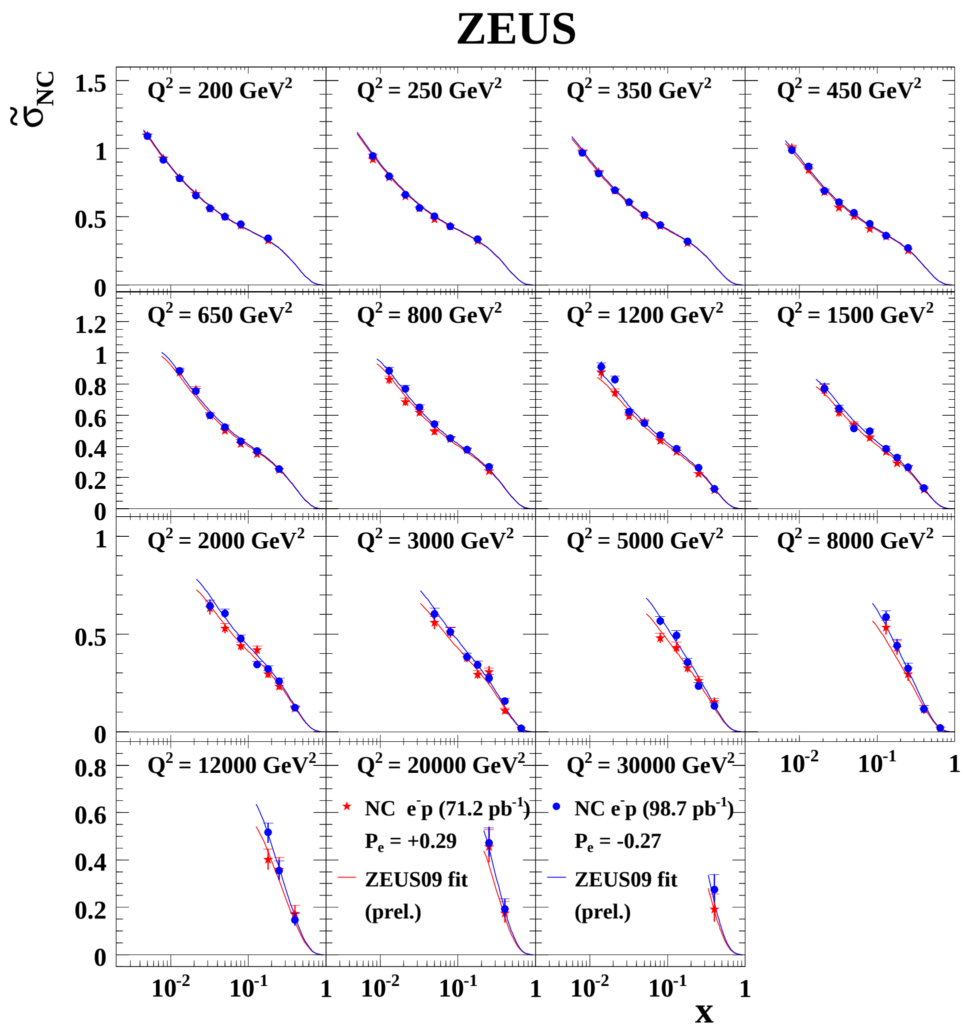


CC cross section is linearly proportional to the degree of the longitudinal beam polarization:

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = [1 \pm P_e]\,\frac{G_F^2}{2\pi x}\left[\frac{M_W^2}{Q^2 + M_W^2}\right]^2 \phi_{CC}^{\pm}$$

Consistent with no right-handed weak currents

NC Cross Section Polarization Dependence



Neglecting pure Z exchange term, generalized F_2:

$$\tilde{F}_2^{\pm} \approx F_2 + k(-v_e \mp P a_e) F_2^{\gamma Z}$$

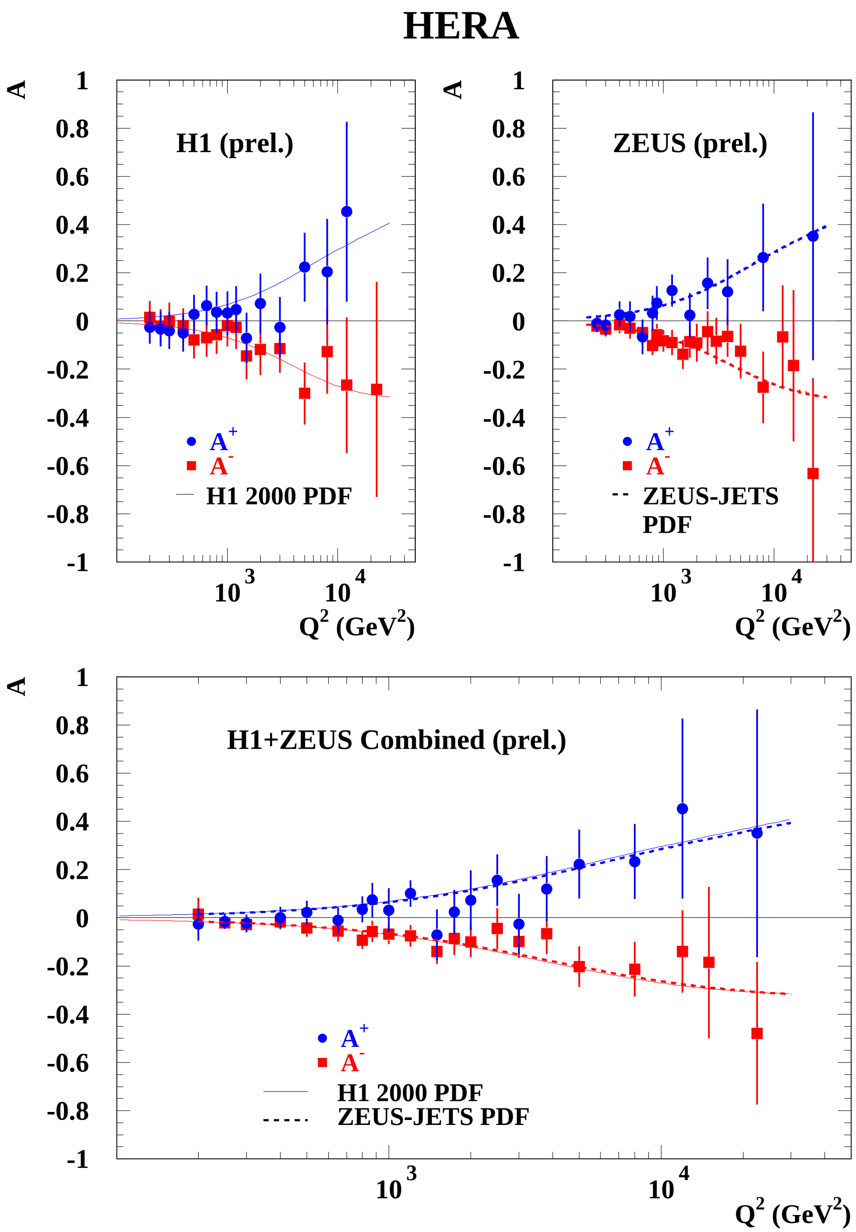
where $k = \frac{1}{4\sin^2\theta_W \cos^2\theta_W} \frac{Q^2}{Q^2 + M_Z^2}$

At leading order

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

(DESY-08-202, accepted by EPJ C, Complete HERA-II sample).

NC Cross Section Polarization Dependence



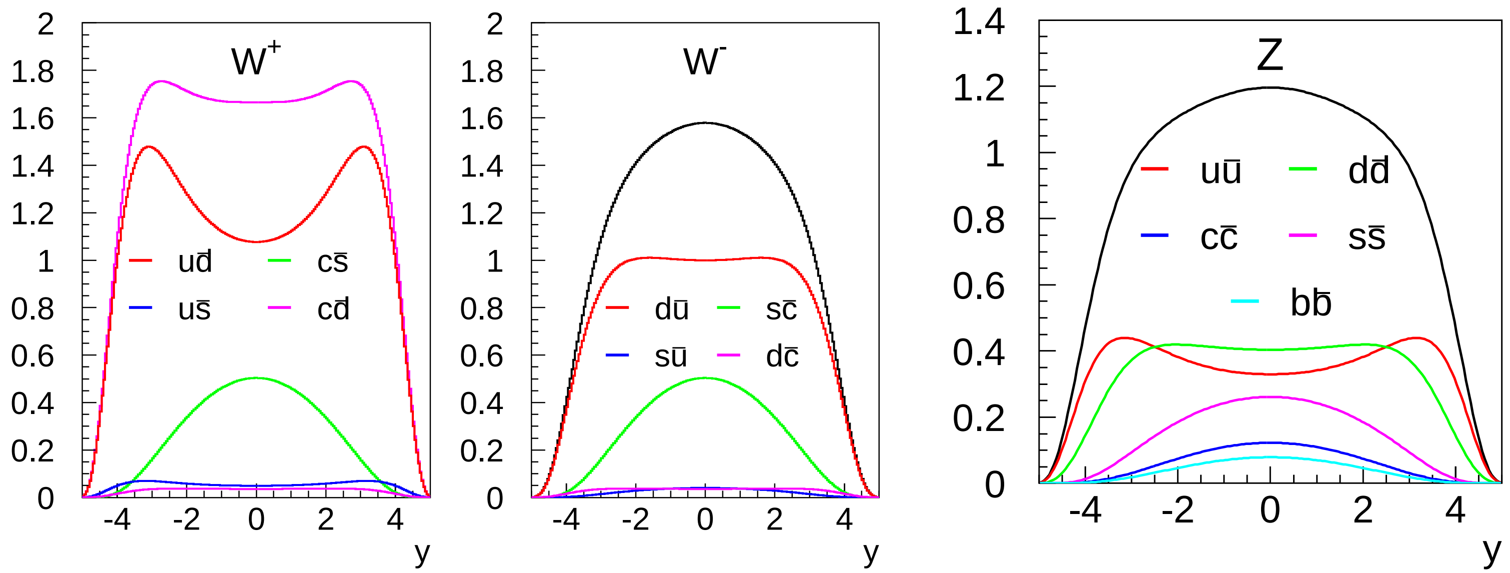
Polarization asymmetry

$$A^{\pm} = \frac{2}{P_R - P_L} \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \approx$$

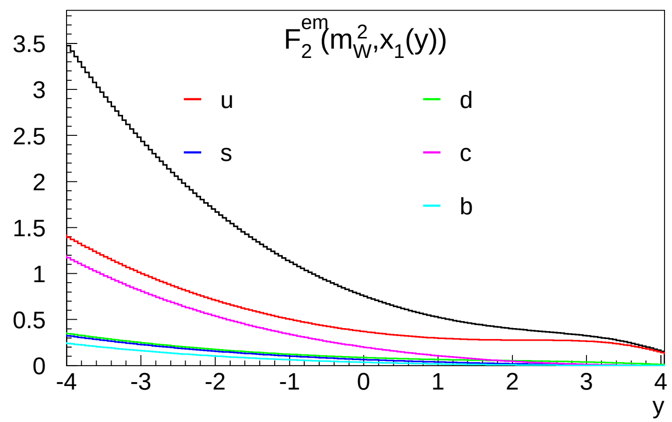
$$\approx \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

measures directly NC parity violation.

Flavor Decomposition for processes at the LHC

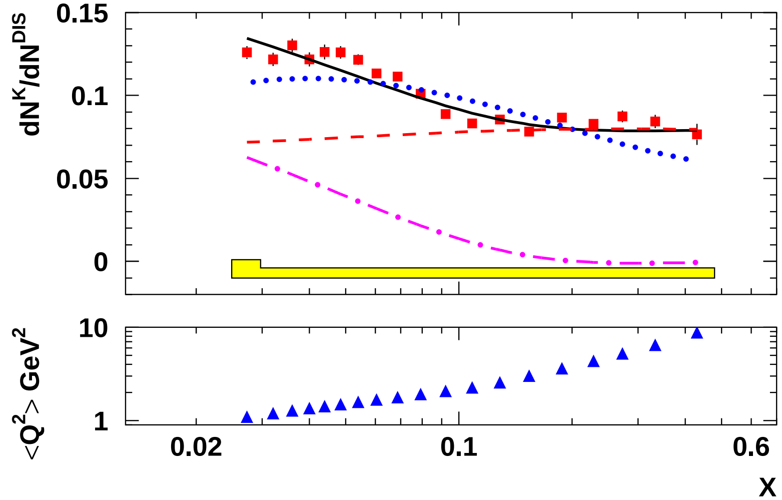


We want to have
predictions for W^+, W^-, Z with the main experimental input from F_2^{em}:



- For LHC, more important d, s quarks
- For Z, significant contribution from b.

Measurement of $xS(x)$ by HERMES

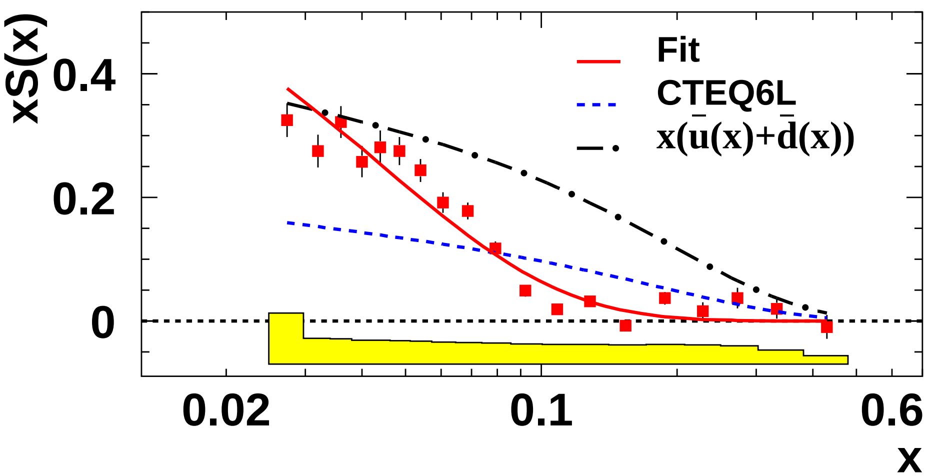


Measure $K^{\pm}$ prduction on deuteron target compared to inclusive DIS.

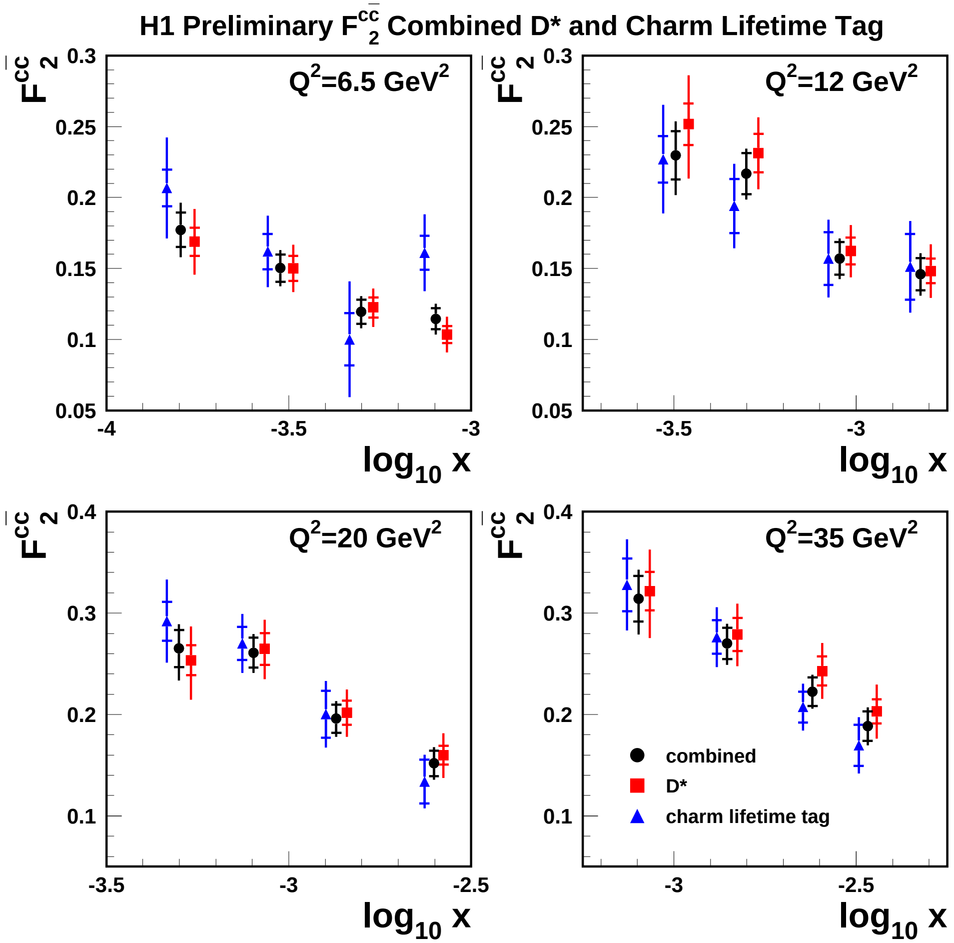
$$S(x)\int D_S^K(z)dz \approx Q(x)\left[5\frac{d^2N^K(x)}{d^2N^{DIS}(x)} - \int D_Q^K(z)dz\right]$$

Based on flatness of $dN^K(x)/dN^{DIS}(x)$ for high x, assume $S(x) = 0$ for $x > 0.15$, measure the fragmentation function $\int D_Q^K(x)dz$.

Subtracting the contribution of $\int D_Q^K(x)dz$, evolving to Q^2=2.5 GeV^2 and using an external value of the fragmentation function $\int D_S^K(x)dz$, $xS(x)$ distribution is obtained:



Measurements of $F_2^{c\bar{c}}$

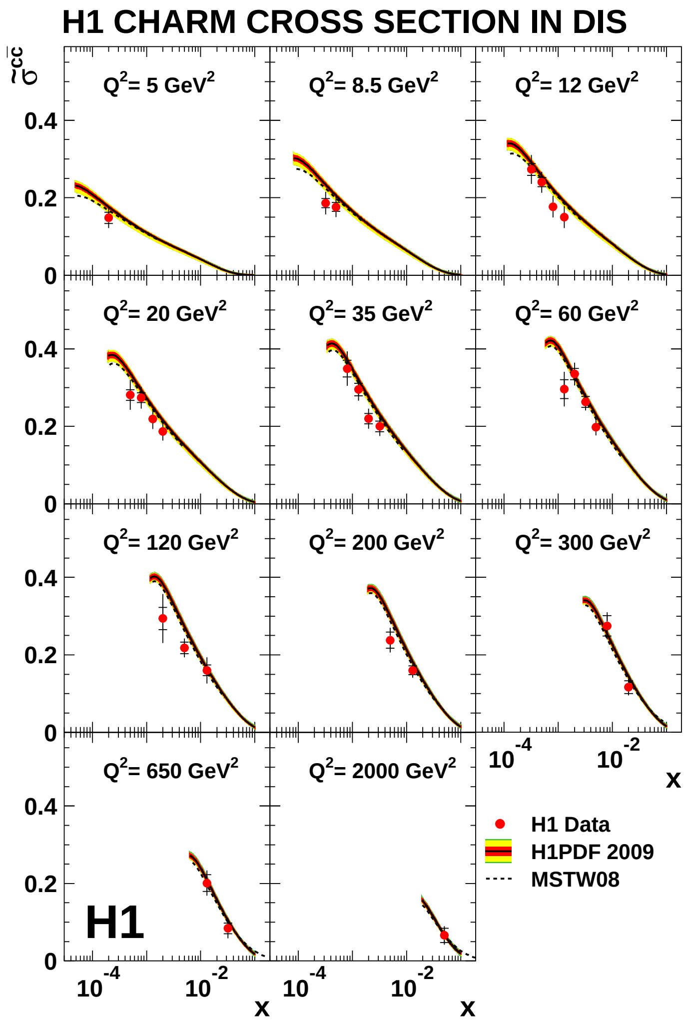


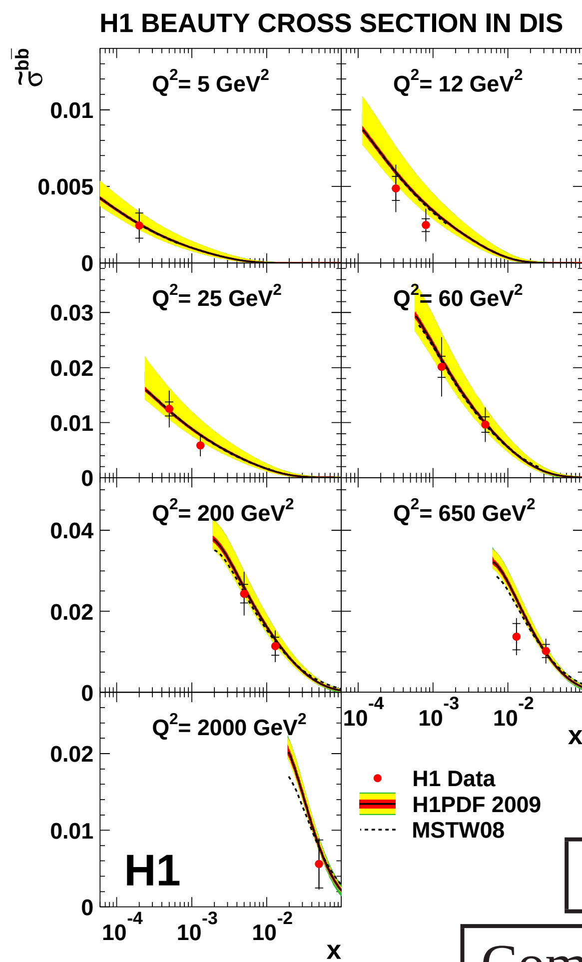
Different methods to measure $F_2^{c\bar{c}}$

- Displaced secondary vertex (lifetime tag).
- Tagging by measuring D^* meson production.

Methods have different experimental/theoretical uncertainties: combine taking into account correlations, significant reduction of the uncertainty.

Measurements of c, b using displaced vertex.



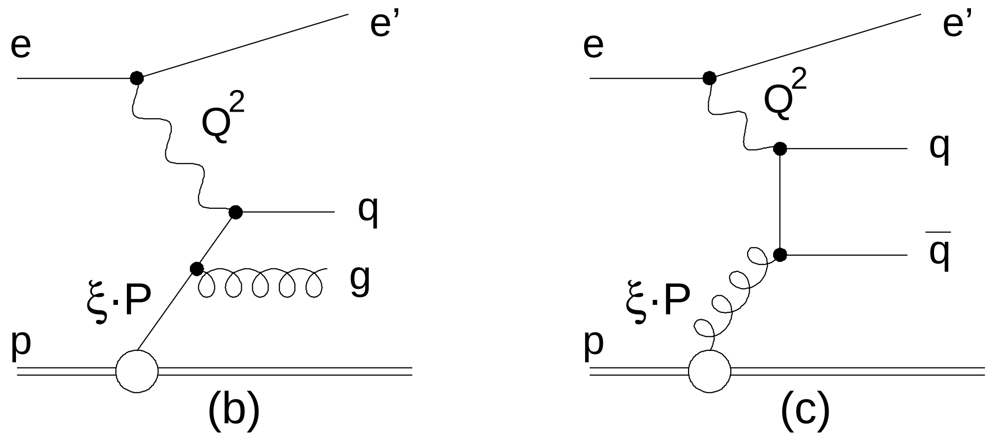


arXiv:0907.2643

Complete HERA dataset

Larger contribution to σ_r allows to determine $\sigma_r^{c\bar{c}}$ more precisely than $\sigma_r^{b\bar{b}}$. Data agree well with H1PDF2009/MSTW08 predictions.

DIS jet cross section

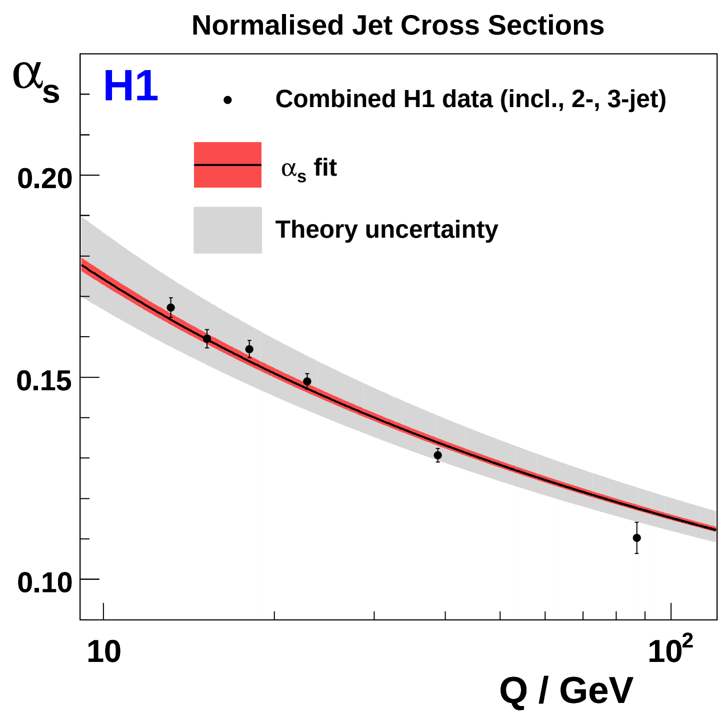


High P_t jets provide information on α_S and $xG(x)$.

H1 Analysis based on complete HERA sample (395 pb^{-1}).

$\alpha_S(M_Z) = 0.1168 \pm 0.0007$ (exp) ${}^{+0.0046}_{-0.0030}$ (th.) $\pm\, 0.0016$ (PDF).

arXiv:0904.3870, Submitted to EPJC.



Summary

- HERA enables precise determination of PDFs for the LHC kinematic range.
- DGLAP evolution works very well so far.
- More information will come with finalization of HERA analyzes, combination of H1/ZEUS data, from the measurements of heavy flavors and of F_L.