Overview of the HERA inclusive measurements

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DESY

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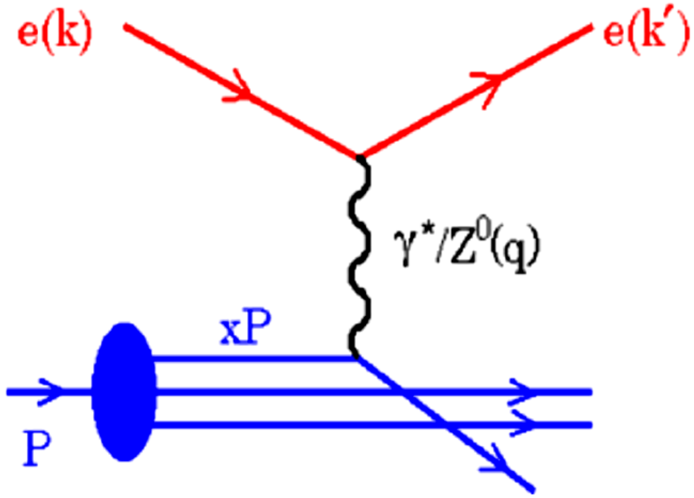
Deep Inelastic Scattering



Kinematics of inclusive scattering is determined by Q^2 and Bjorken x.
In x "scale parameter" 1/3 - equal sharing among quarks. Proton structure for

- $x \geq 0.05$ — valence quarks
- $x \leq 0.05$ — coupled quark-gluon QCD evolution. Large gluon density.

At small x complex dynamics which must obey simple asymptotic solutions (unitarity).

DIS scattering experiments at HERA with $\sqrt{S} = 318$ GeV provide

- A unique tool to study validity of the QCD evolution for a wide range in x and Q^2.
- Within the standard QCD evolution, measurement of the proton parton densities.

Knowledge of the proton structure is vital for a number of "practical" applications including pp colliders (LHC).

PDF determination

$$\frac{d^2\sigma^{NC}_{e^\mp p}}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right) \quad Y_\pm = 1 \pm (1-y)^2$$

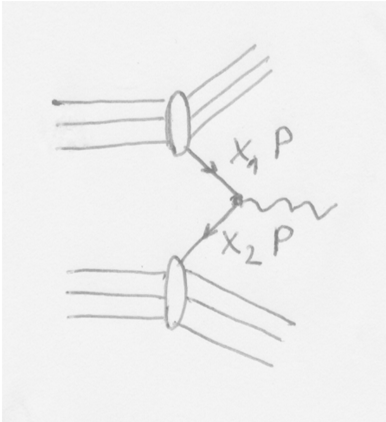
Leading order relations:

F_2	$= x\sum e_q^2(q(x)+\bar{q}(x))$
xF_3	$= x\sum 2e_q a_q(q(x)-\bar{q}(x))$
$\sigma^{CC}_{e^+p}$	$\sim x(\bar{u}+\bar{c}) + x(1-y)^2(d+s)$
$\sigma^{CC}_{e^-p}$	$\sim x(u+c) + x(1-y)^2(\bar{d}+\bar{s})$
$pp \to (\ell\bar{\ell})X$	$\sim \sum x_1 x_2 q(x_1)\bar{q}(x_2)$

Gluon is determined from F_2 scaling violation and from jet cross section.

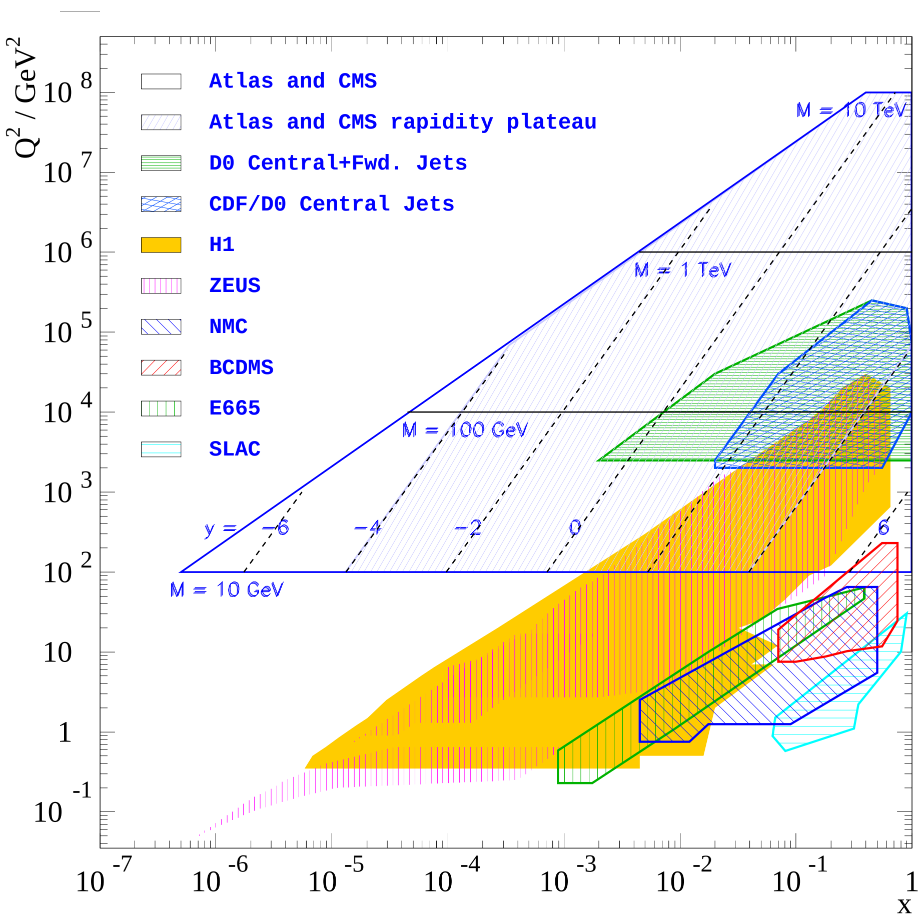
$F_L = 0$ at leading order; proportional to Gluon at higher orders.

HERA and LHC kinematics



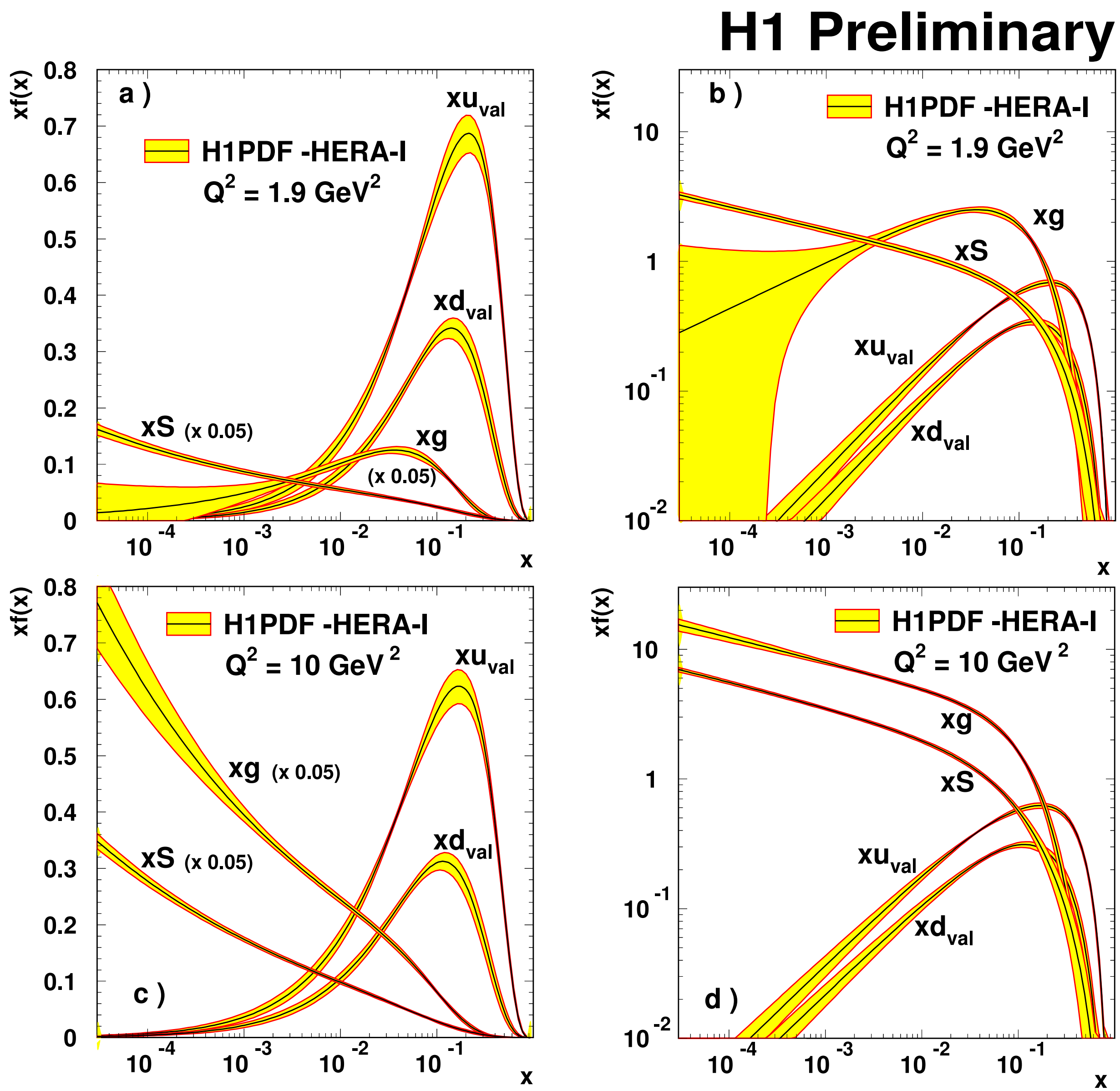
x_1, x_2 are momentum fractions. Factorization theorem states that cross section can be calculated using universal partons $\times$ short distance calculable partonic reaction.

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



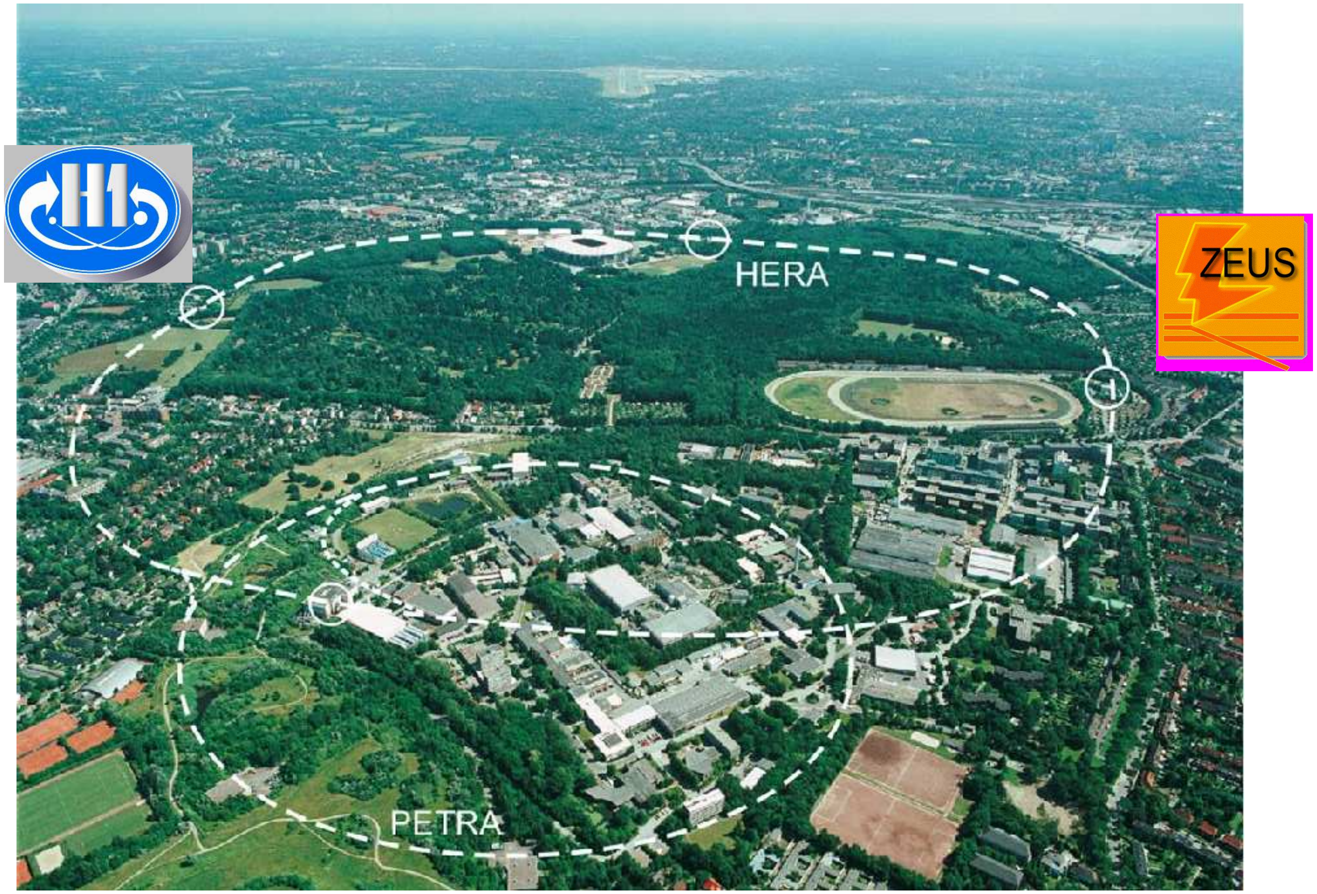
Notation clash: y – rapidity (LHC) vs y – inelasticity (HERA, $Q^2 = Sxy$).

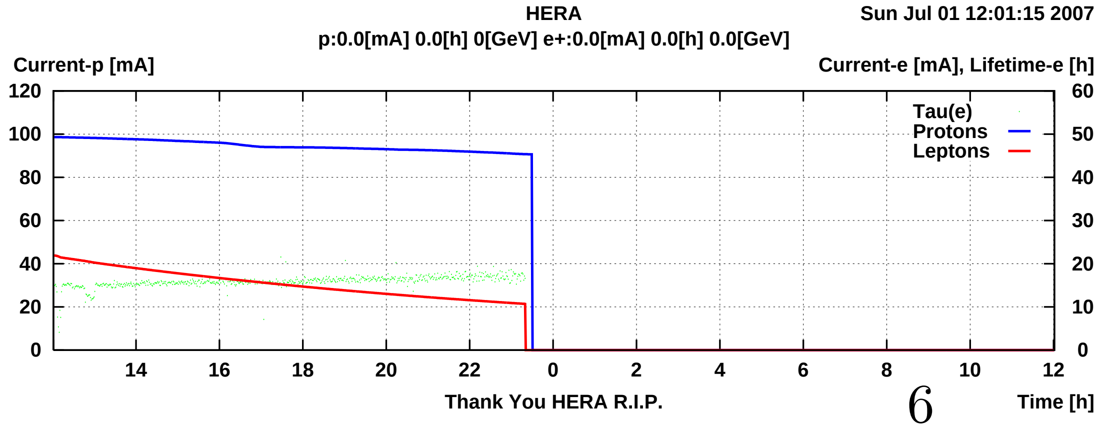
Partons at low x



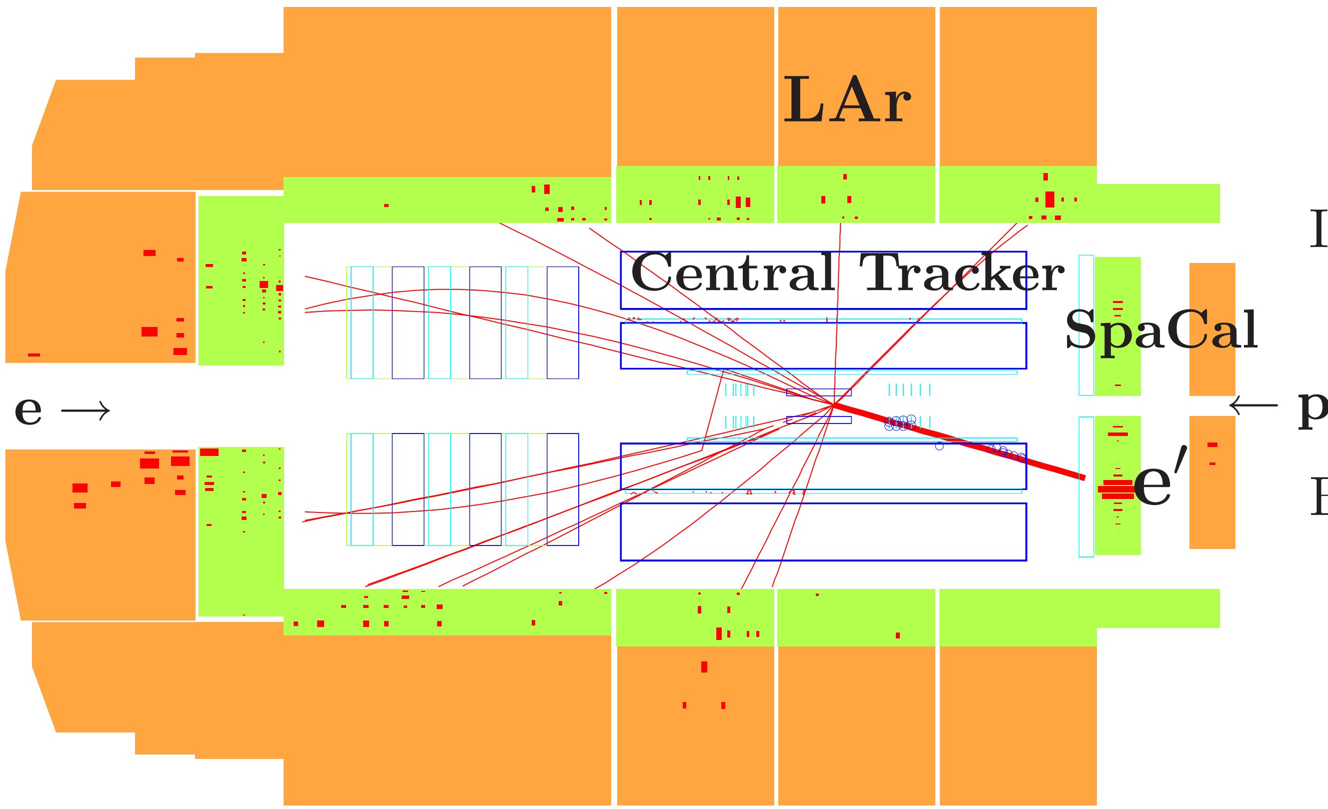
- For $x < 0.01$ xS and xG dominate.
- Very rapid evolution for xS and xG.
- Analysis based on very new H1 data.

HERA, H1 and ZEUS. 1992-2007.





DIS Event Reconstruction



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

Inelasticity:

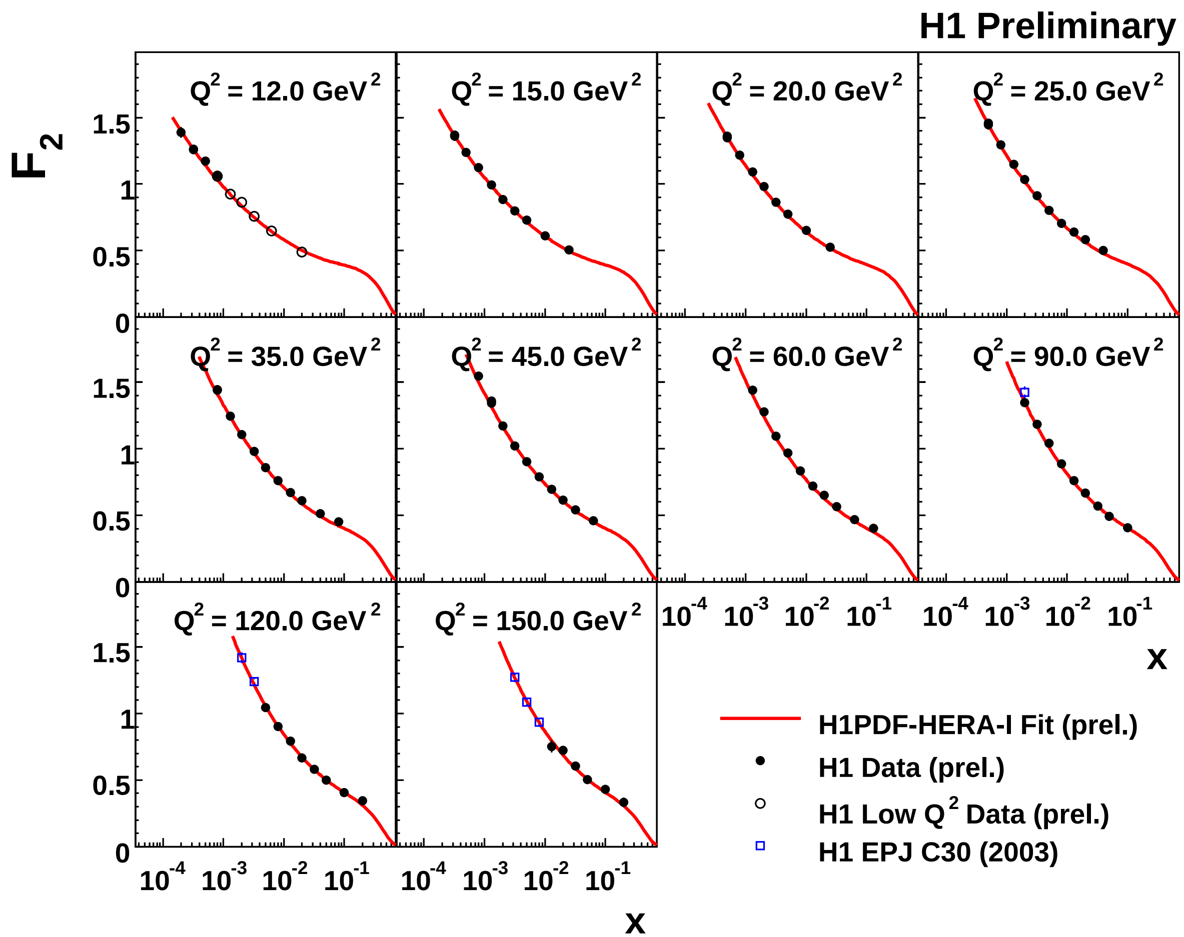
$$y = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}$$

Bjorken x:

$$x = \frac{Q^2}{Sy}$$

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

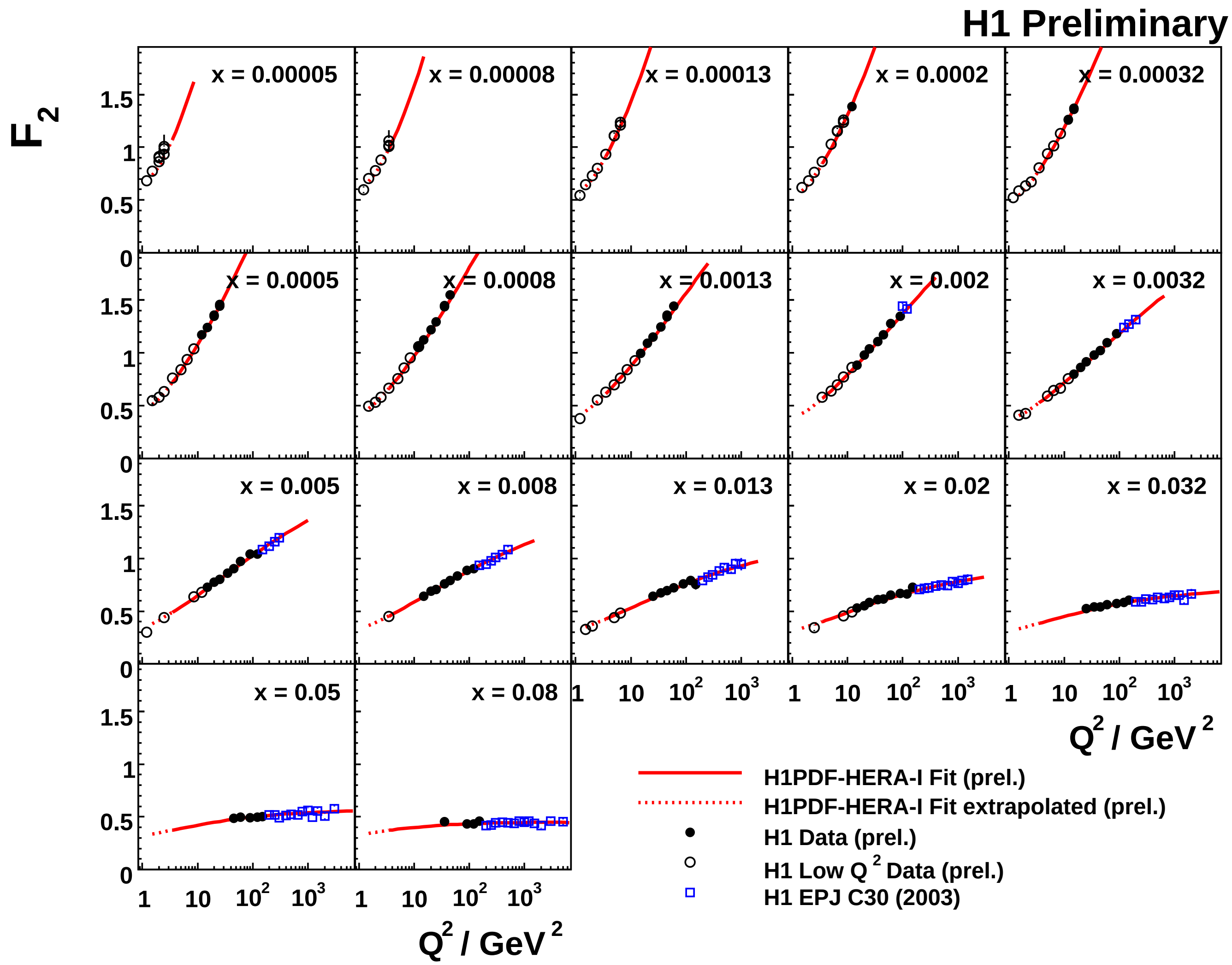
Structure Function F_2 at low x



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

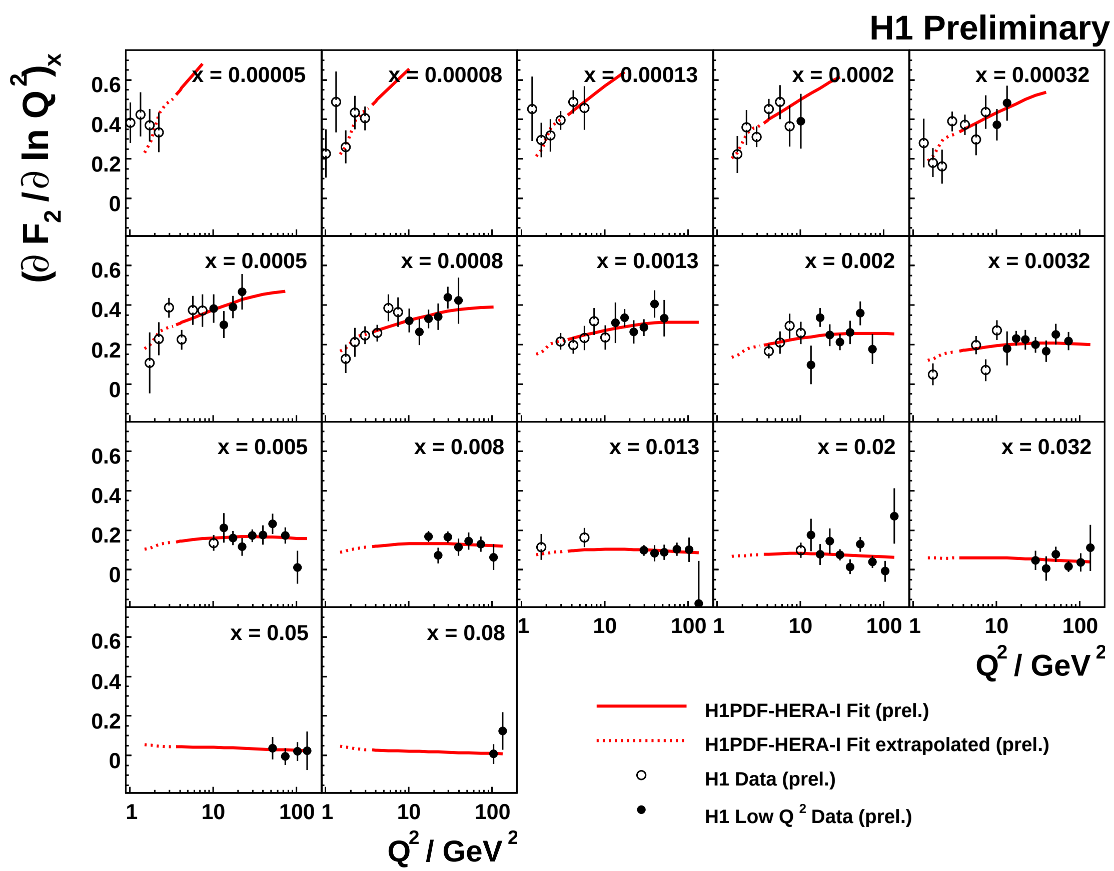
$F_2(x, Q^2)$ shows strong rise as $x \to 0$, the rise increases with increasing Q^2.

F_2 Scaling violation at low x



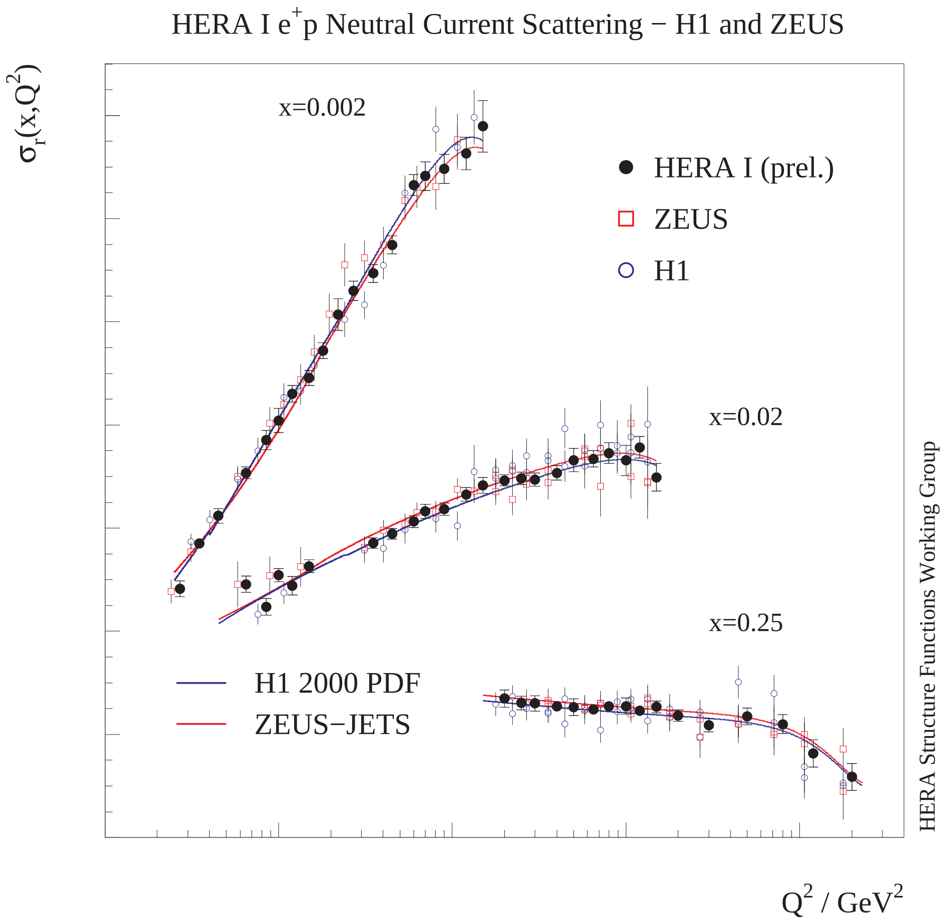
Large scaling violation at low x — large gluon density. Good agreement between the data and theory.

$\partial F_2/\partial \ln Q^2$ 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).

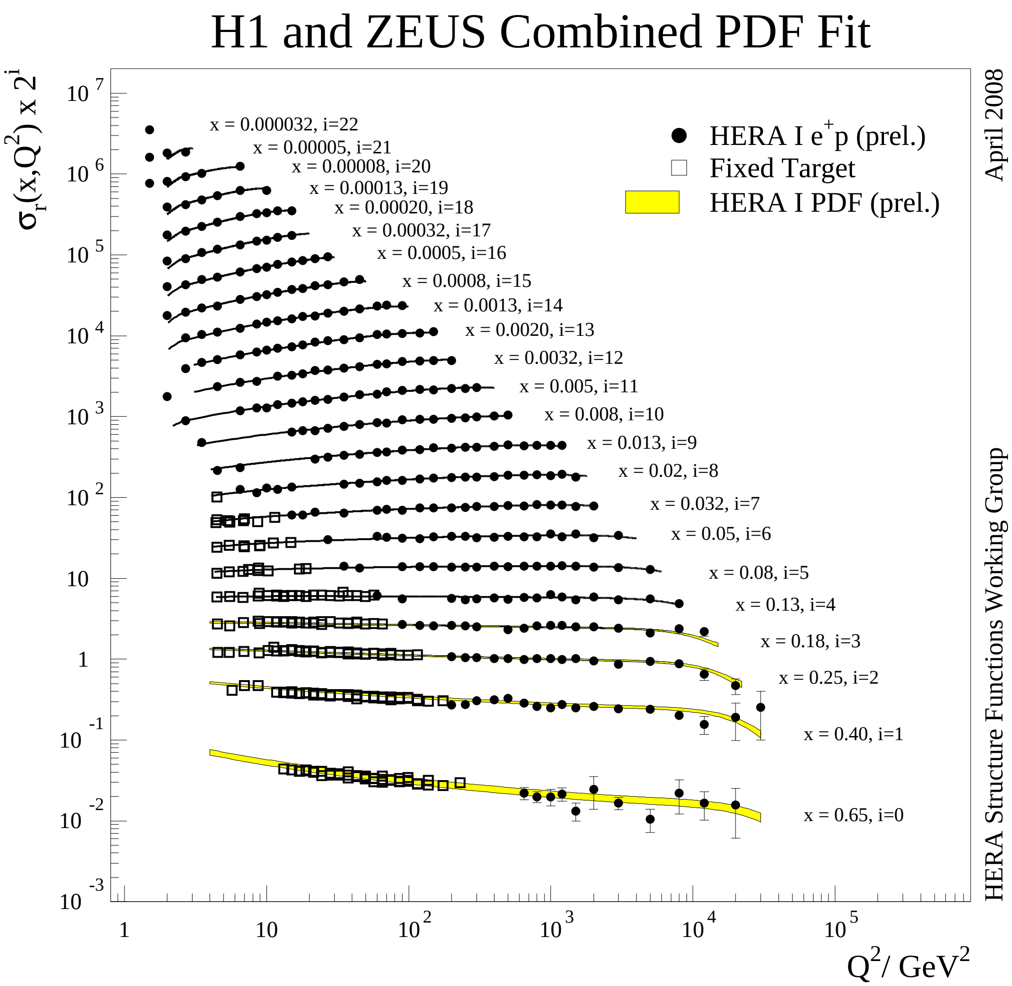
Combination of HERA data



Average H1 and ZEUS data before applying QCD analysis.
Achieved by fitting σ_r values, global normalizations and the correlated systematic uncertainties.

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

Combined HERA data



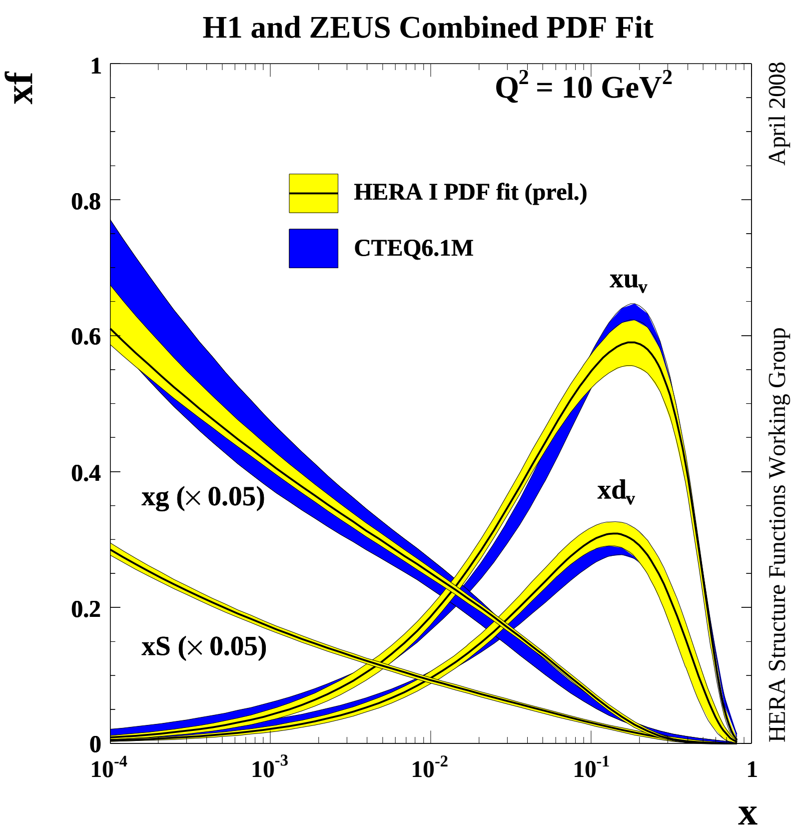
Combination of published H1/ZEUS data for CC,NC, $e^{\pm}p$ data.

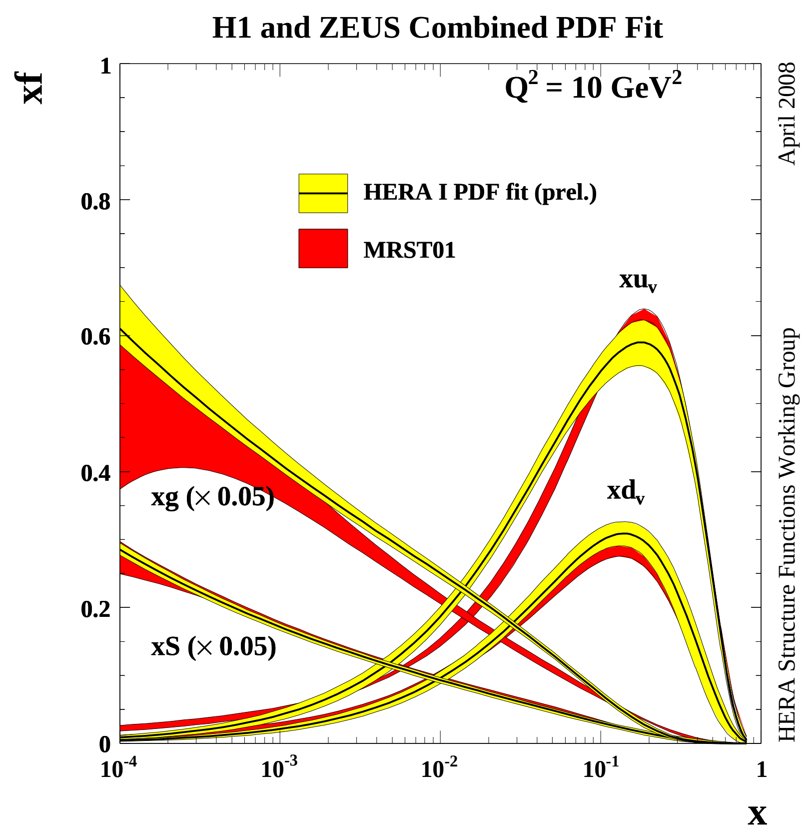
$$\chi^2/dof = 510/599$$

(over-consistency, conservative $\delta\sigma_{red}^{uncorr\ syst}$)

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

PDFs extraction

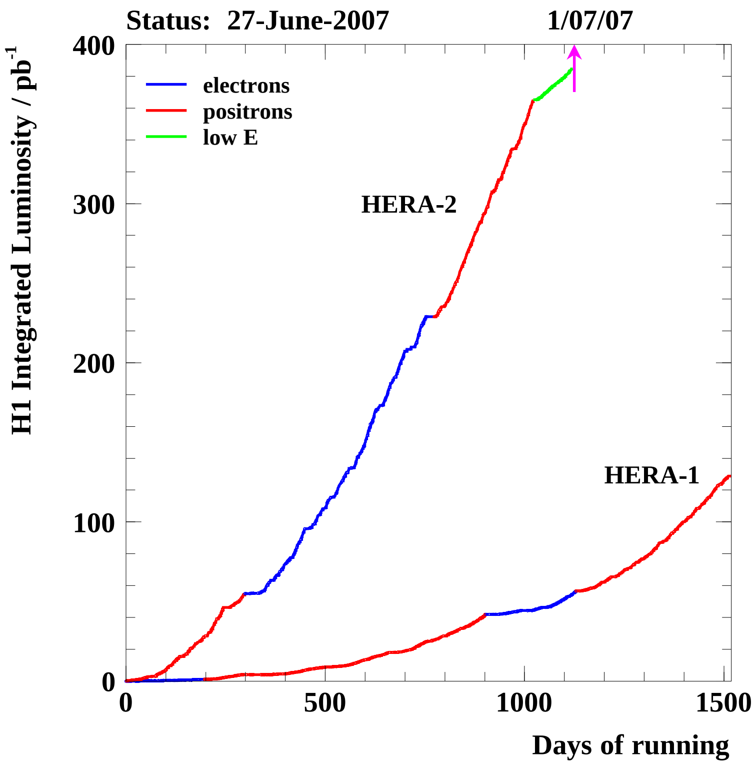


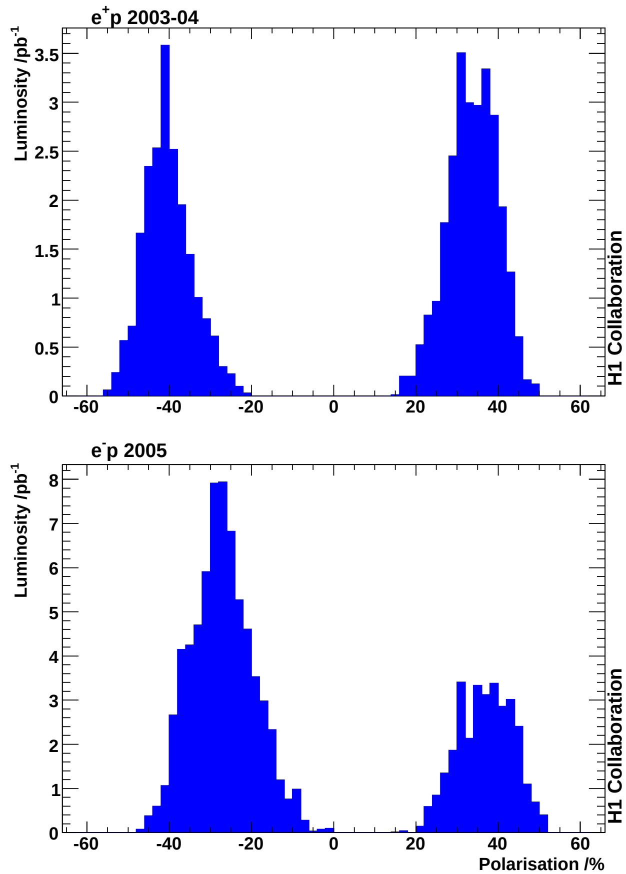


Sea S and gluon g are far more important at low x. Mind the $\times 0.05$ scale factor for them.

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.

HERA-II Results

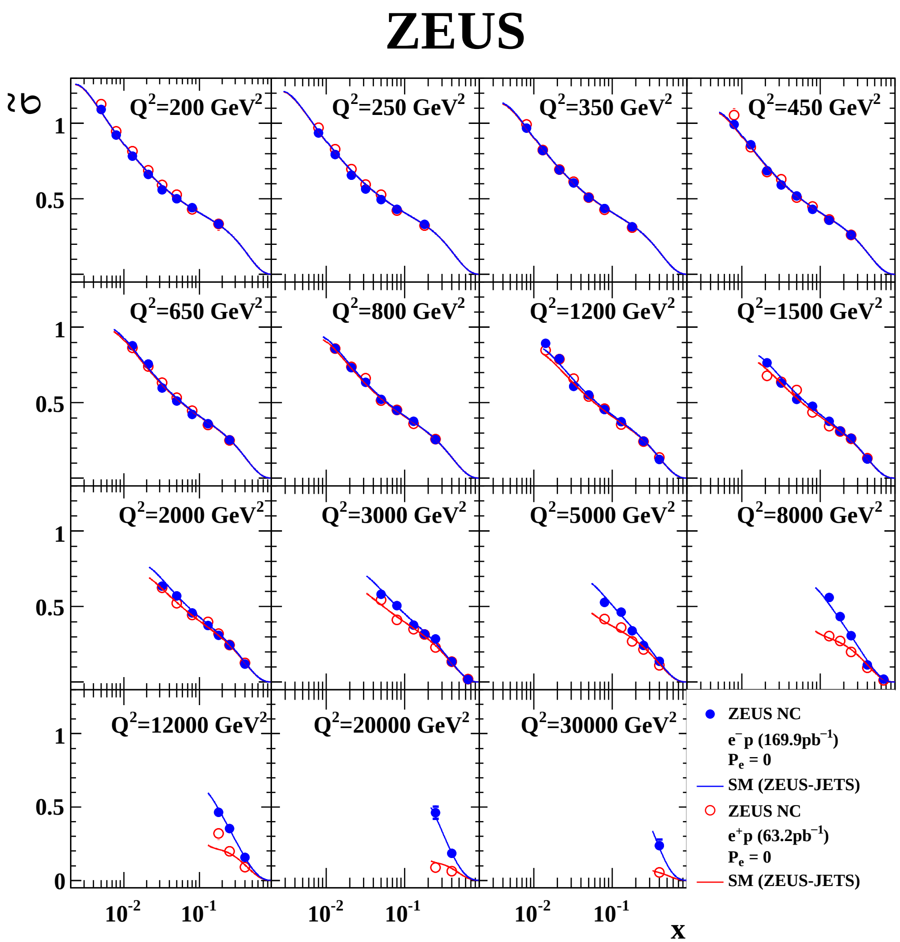


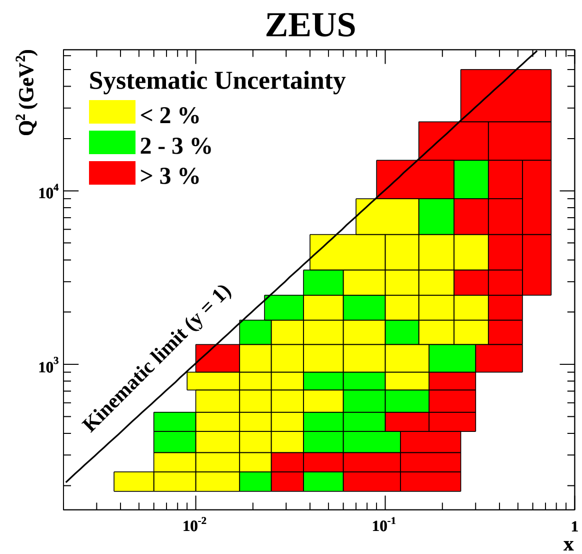


HERA-II upgrade provides better instantaneous luminosity and longitudinal beam polarization.

Special low proton beam energy runs $E_p = 460, 575$ GeV to measure F_L

Neutral Current e^-p Cross Section

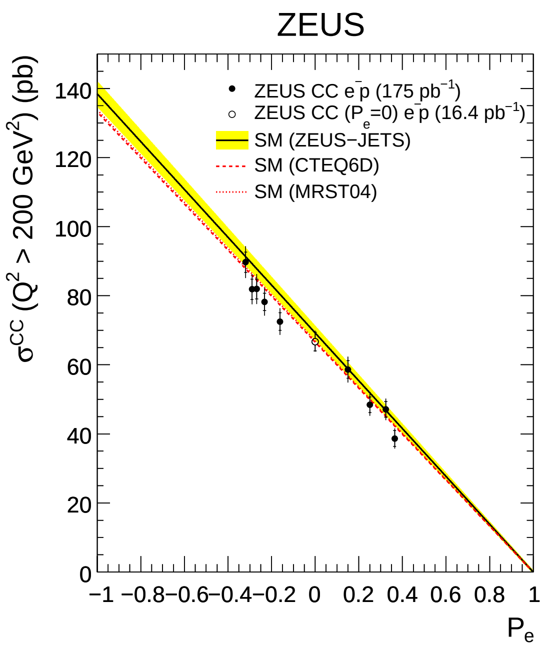


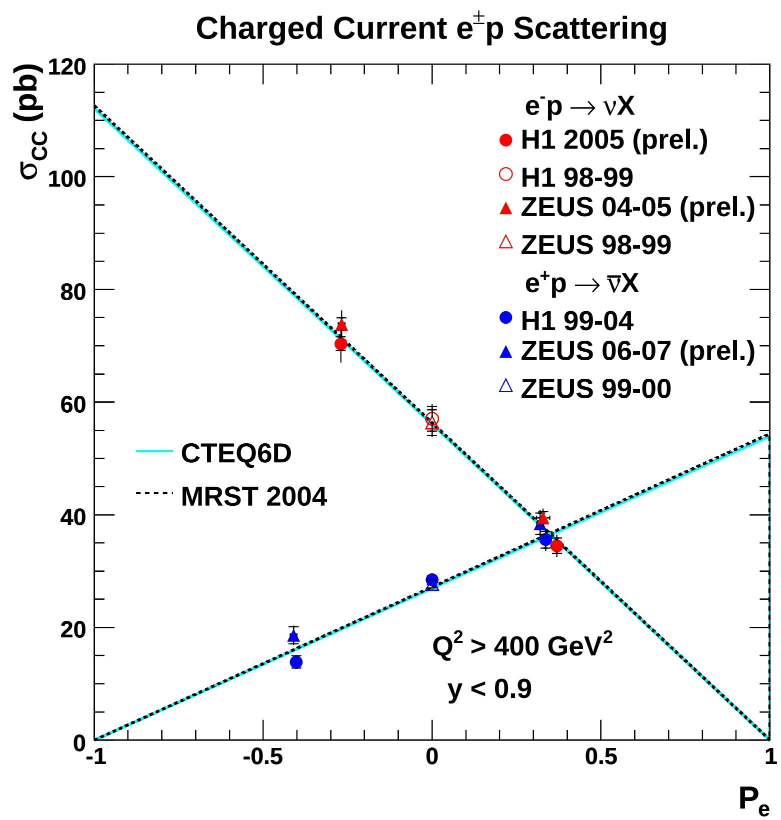


For a large region of the phase space precision $< 2\%$ is reached.

New accurate result based on complete e^-p HERA sample from ZEUS collaboration (`DESY-08-202`)

Charged Current Cross Section



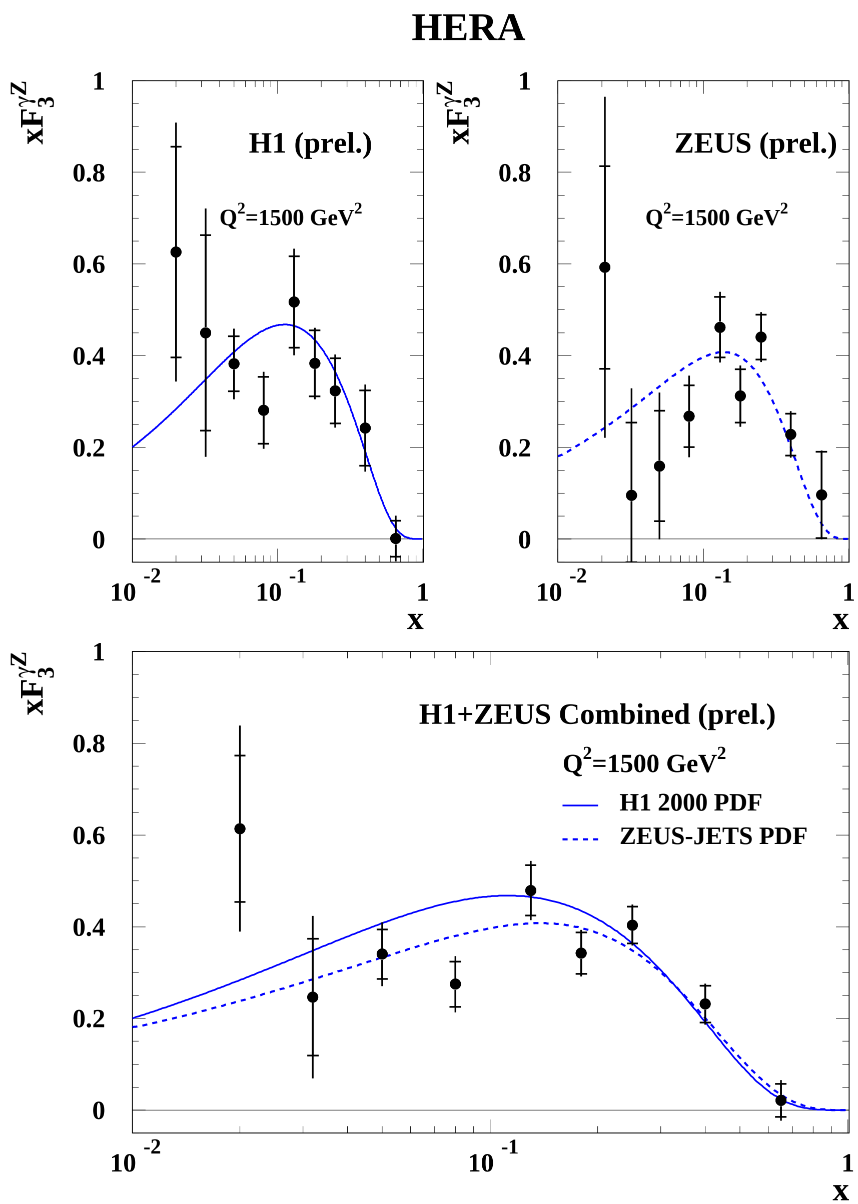


CC cross section is linearly proportional to the degree of the longitudinal beam polarization:

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

Consistent with no right-handed weak currents

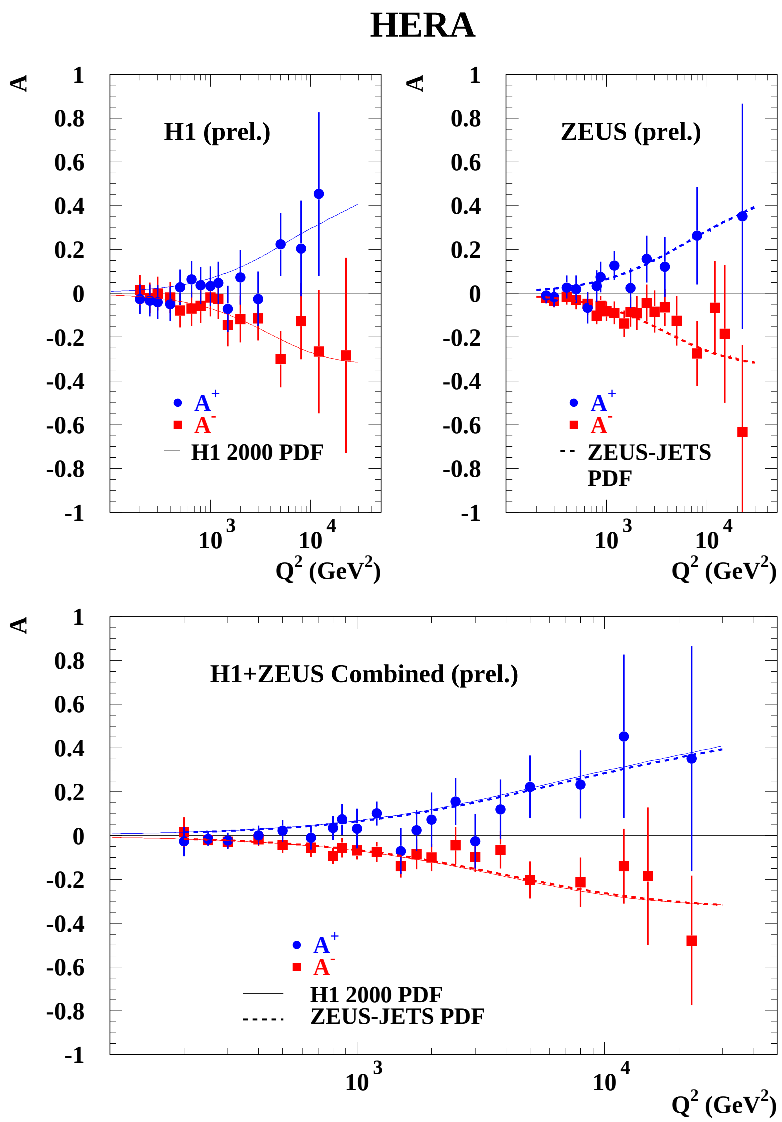
Neutral Current Cross Section and xF_3



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

Large increase compared to HERA-I of e^- sample allows to improve precision of the interference structure function $xF_3^{\gamma Z}$

NC Cross Section Polarization Dependence



Neglecting pure Z exchange term, generalized F_2:

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

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

At leading order

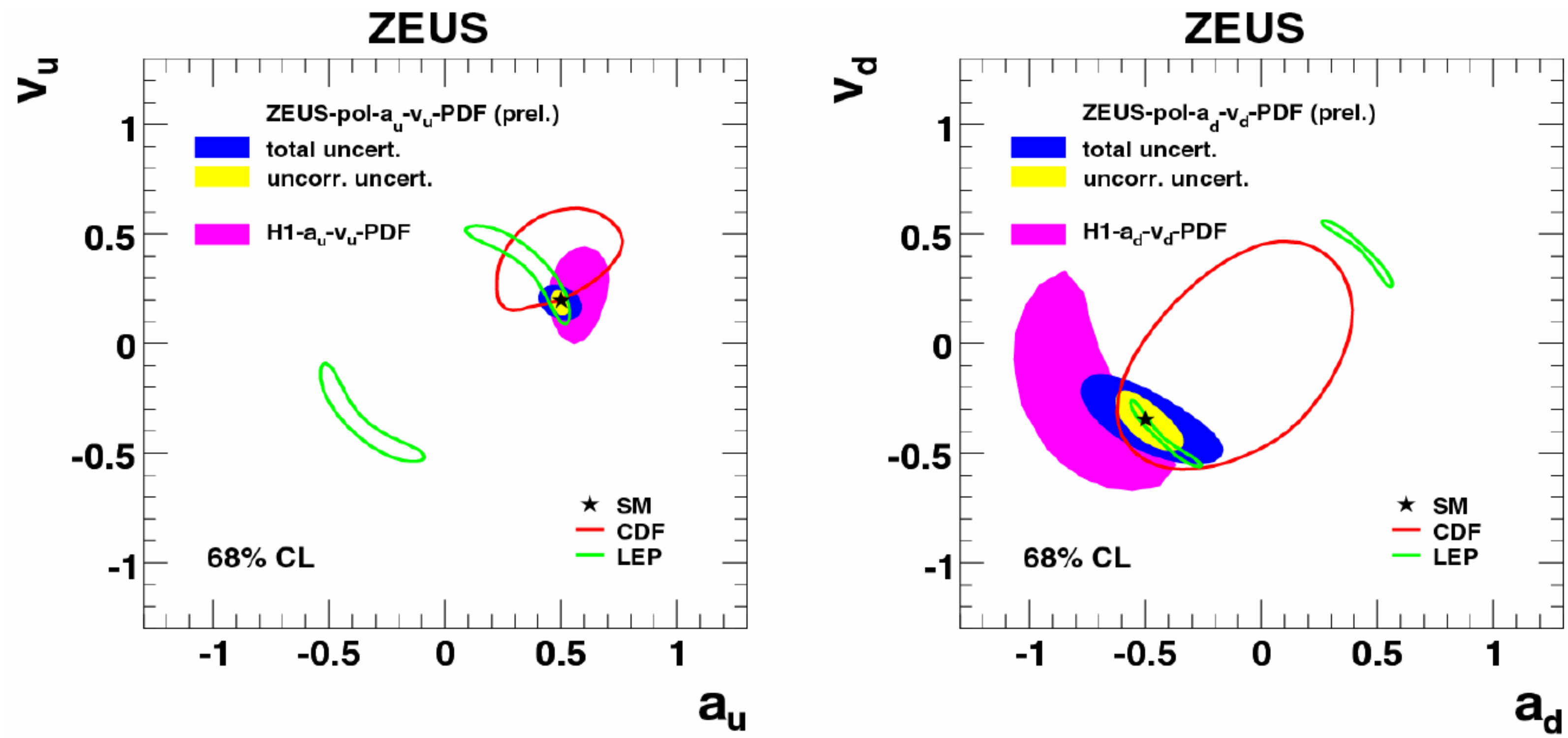
$$F_2^{\gamma Z} = x \sum 2 e_q v_q (q + \bar{q})$$

Defined as

$$A^\pm = \frac{2}{P_R - P_L} \frac{\sigma^\pm(P_R) - \sigma^\pm(P_L)}{\sigma^\pm(P_R) + \sigma^\pm(P_L)} \approx \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

directly measures NC parity violation.

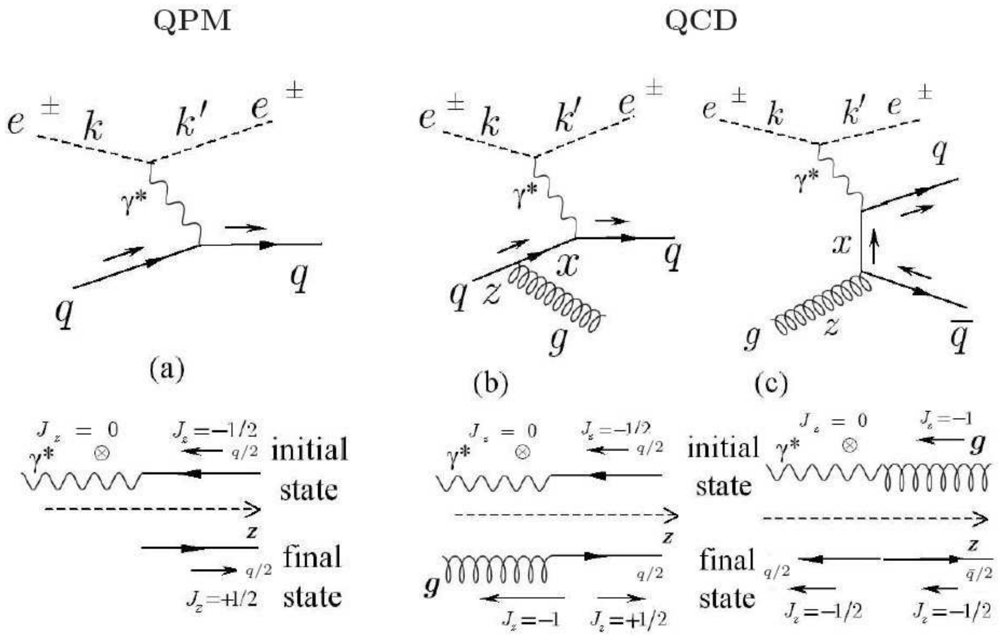
Combined EW-QCD fit



Sensitivity to a, v couplings of the light quarks to Z allows combined QCD-EW fit. H1 performs fit using unpolarized HERA-I data. ZEUS and H1 provide preliminary results including HERA-II data.

Polarization brings better sensitivity to v_q

The Proton Structure Functions at low Q^2



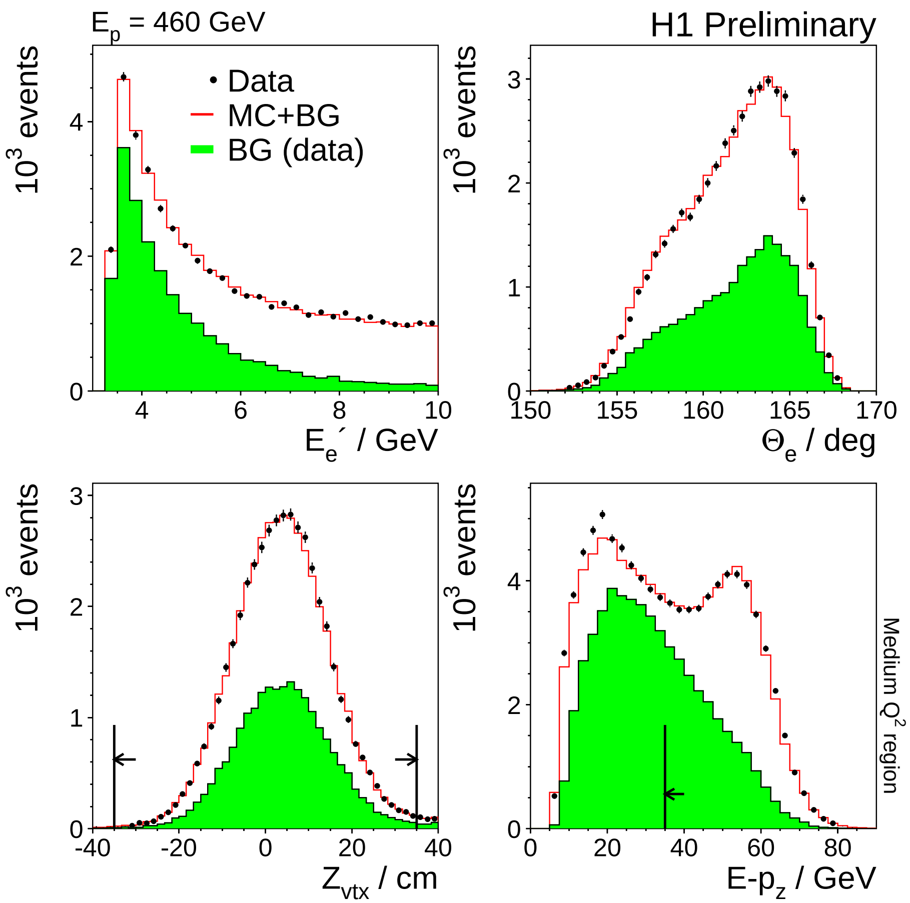
For low Q^2:

$$F_2 \sim \sigma_L + \sigma_T \qquad F_L \sim \sigma_L$$

which implies $0 \leq F_L \leq F_2$.

- In Quark-Parton Model $F_L = 0$ for spin $1/2$ quarks.
- In QCD, $F_L > 0$ due to gluon radiation.
- At low x, sea quark and gluon density are measured using F_2 and its scaling violation, $\mathrm{d}F_2/\mathrm{d}\log Q^2$.
  F_L measures gluon via cross section polarization decomposition.

Measurement of F_L.



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

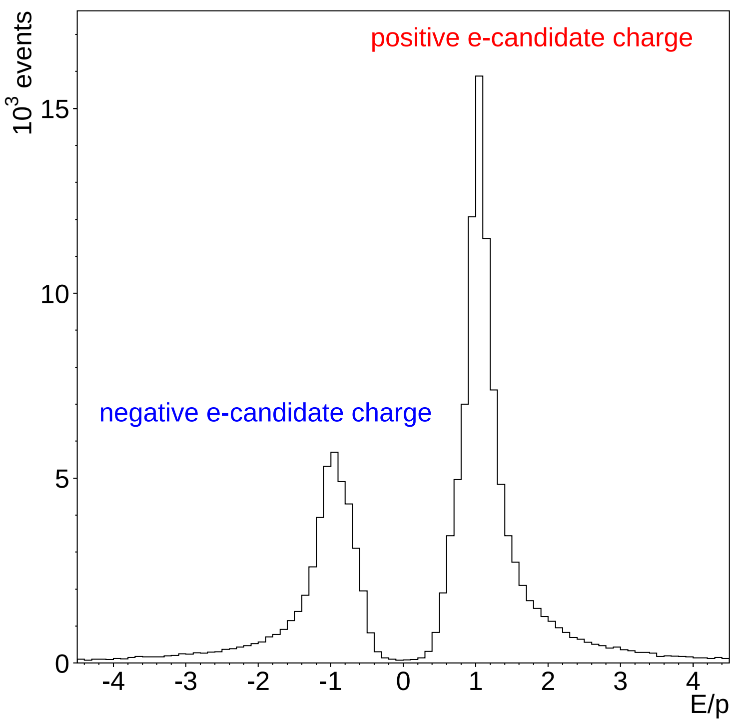
H1 estimates background directly from data using the measured charge of the electron candidate.

Background Estimation

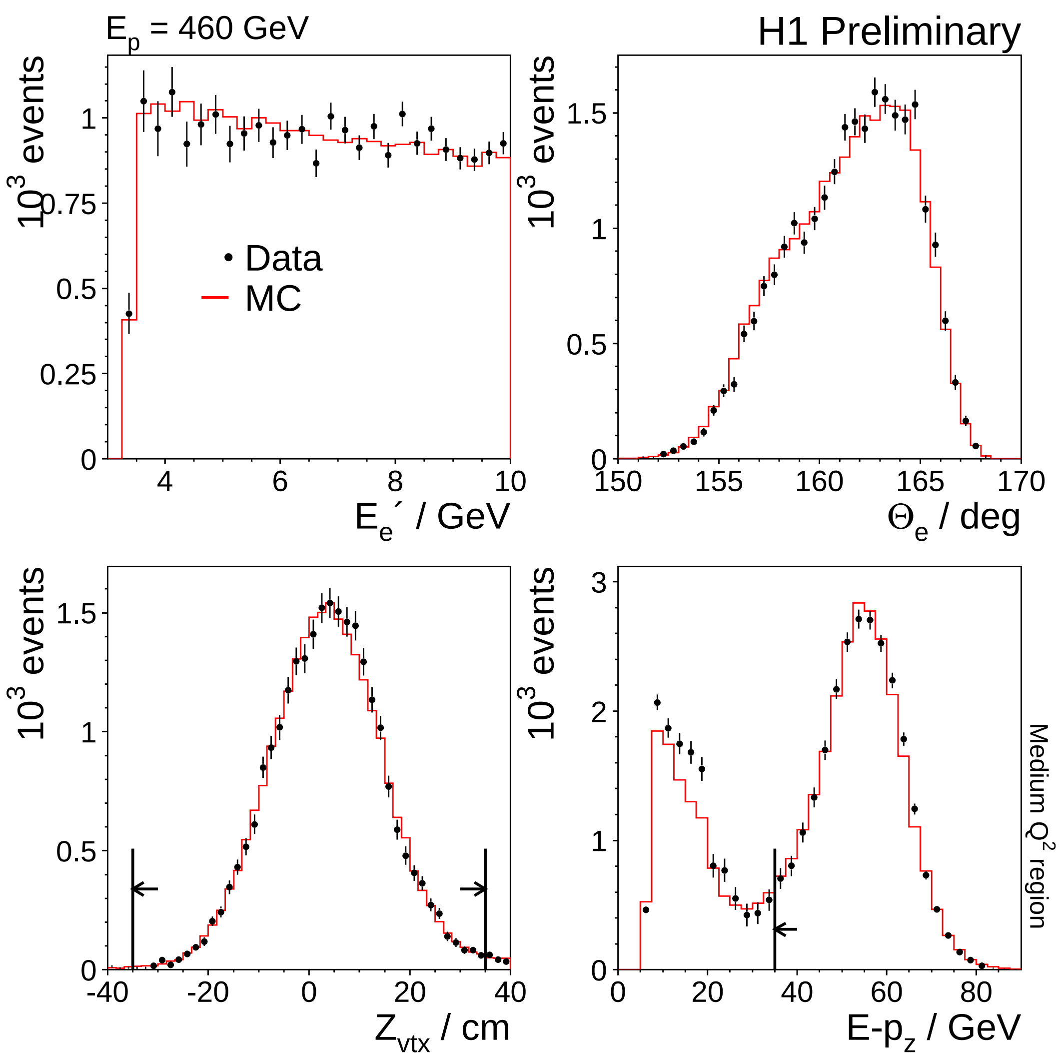
e^+p scattering:

+ Scattered lepton has the beam charge (positive).
– Background from hadronic particles, γ conversions is almost charge symmetric: $N_{bg}^+ \approx N_{bg}^-$

$\rightarrow$ require positive charge for the signal sample. Estimate remaining background using negative sample.

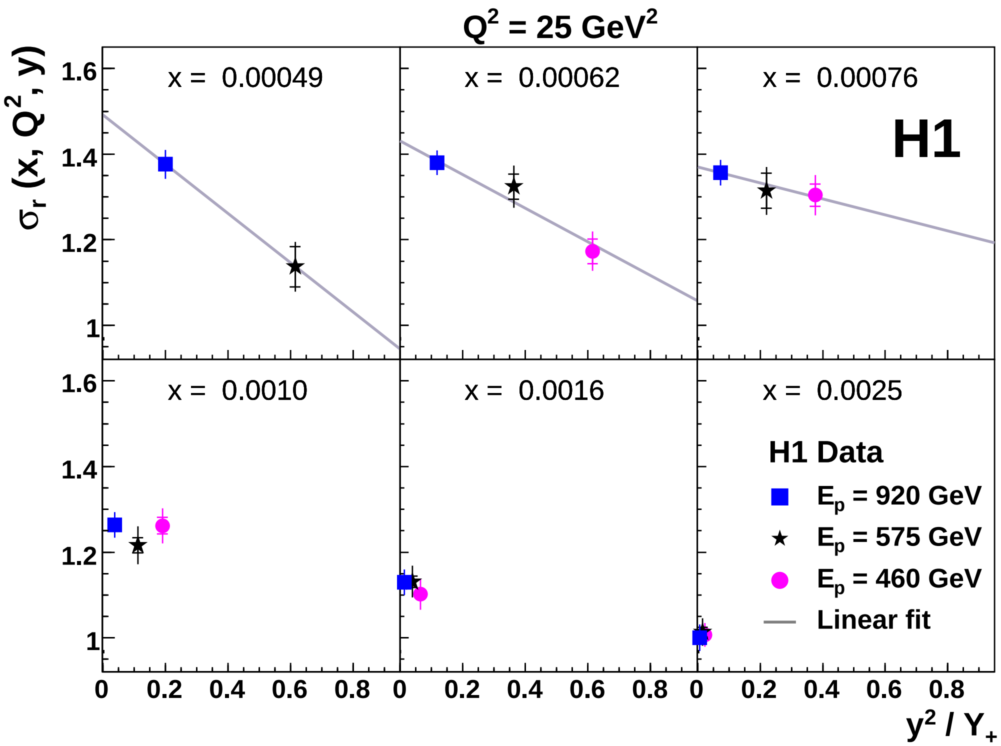


Control plots: High y medium Q^2 (SpaCal)



- After background subtraction
- $E_p = 460$ GeV
- $E_e' > 3.4$ GeV.
- Lines indicate cut values
- $E - p_z$ is effective against ISR radiation

F_L extraction

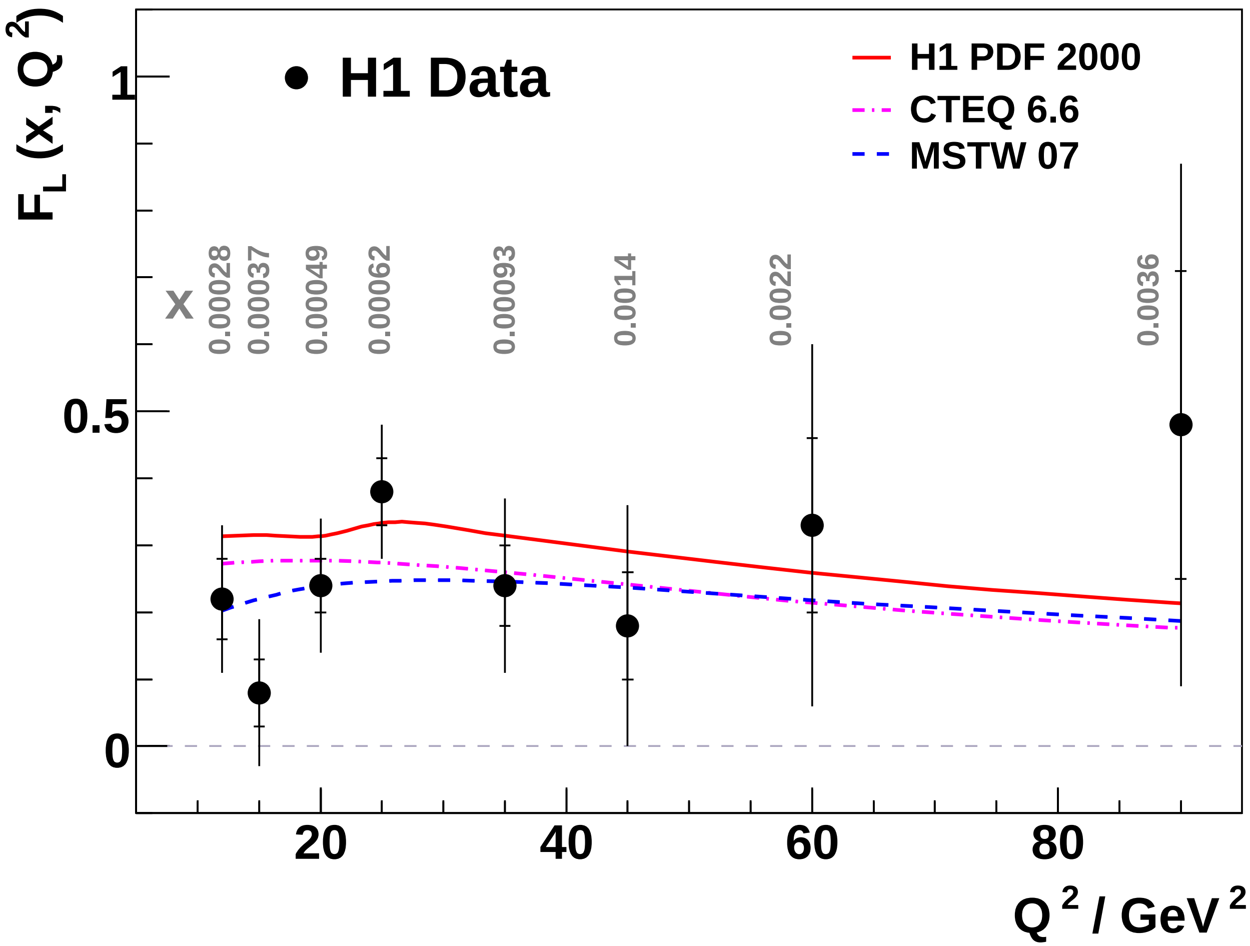


$$\sigma_r(y) = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

- Linear fit to get F_2 and F_L
- Relative normalization from low y data

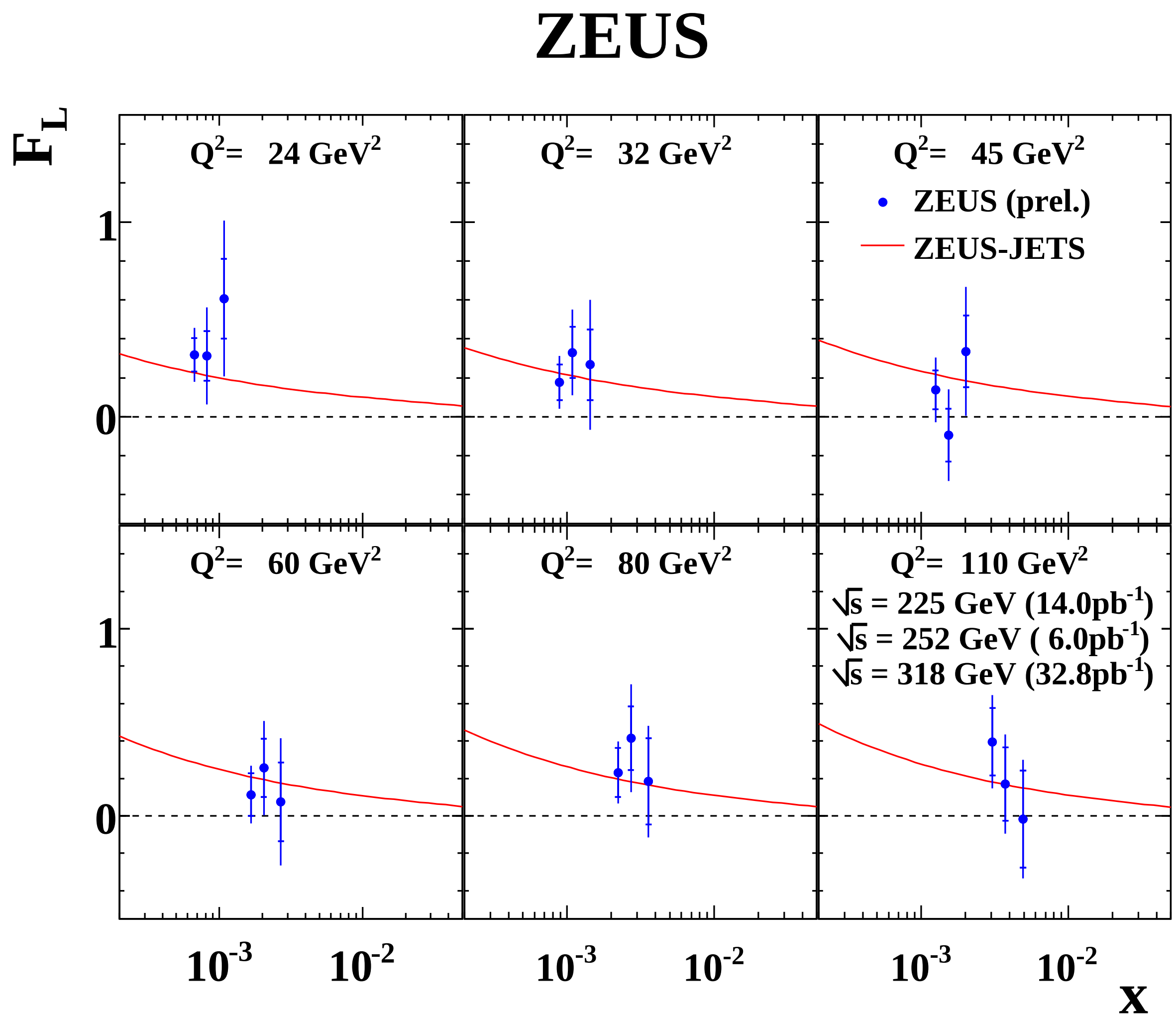
Data at $\mathbf{E_p} = \mathbf{575}$ provides cross check and extends measurement to low x.

Average F_L by H1 at medium Q^2



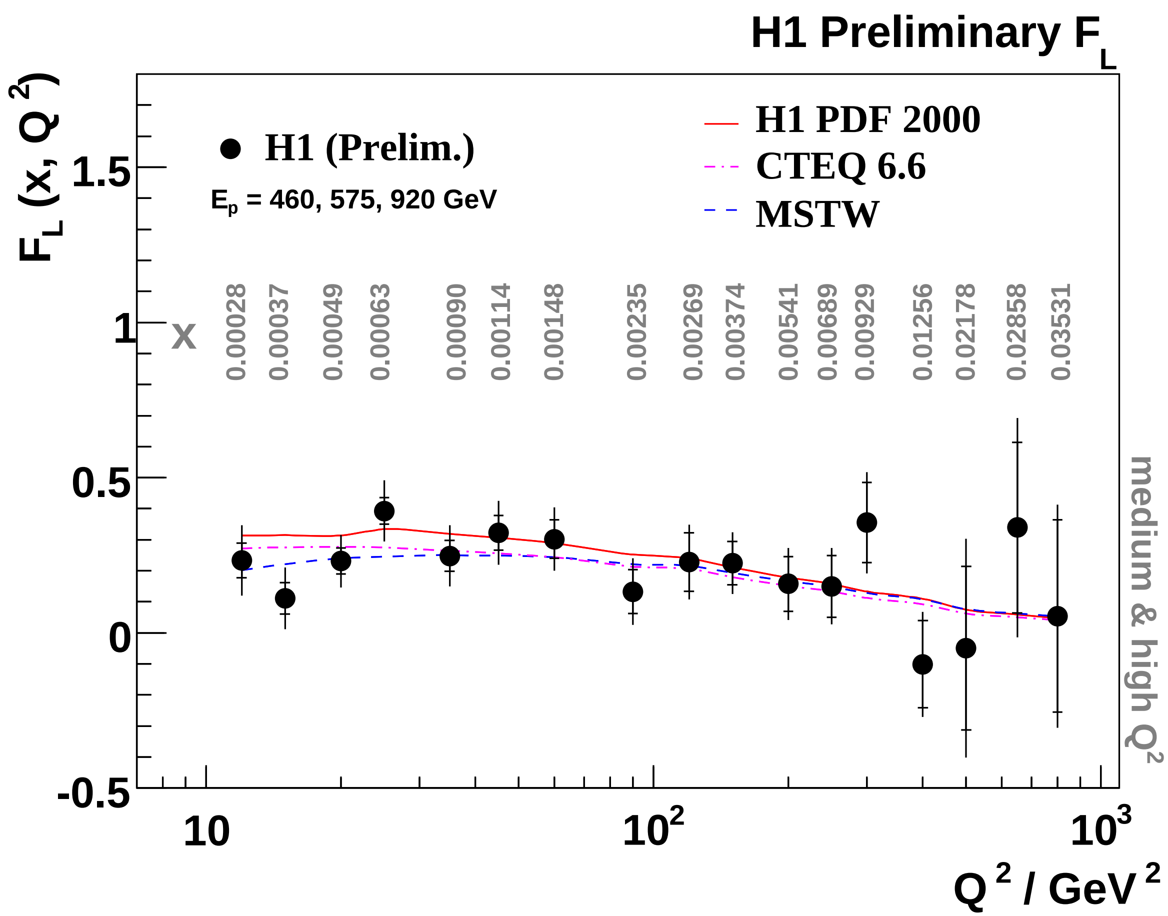
F_L compared to prediction based on H1 QCD fit to published by H1 DIS cross section data and global MSTW, CTEQ fits.

Measurement of F_L by ZEUS



- Updated for ICHEP to include $E_p = 575$ GeV data.
- Consistent with NLO prediction and H1.

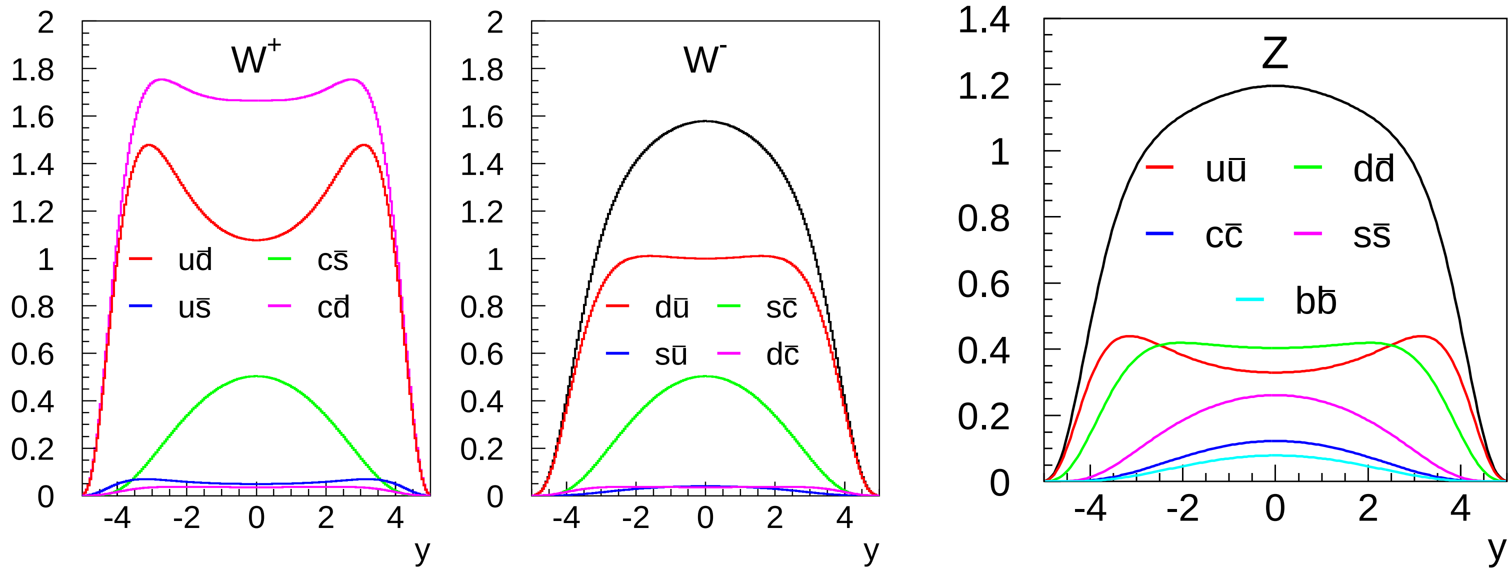
Average F_L by H1, extended range, preliminary



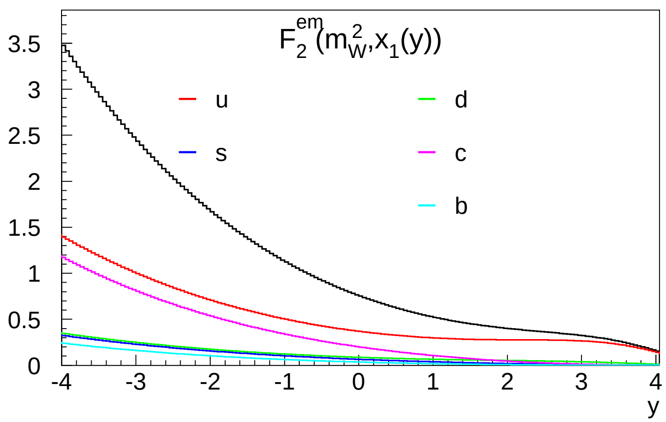
- Extend to higher Q^2 using e scattered in LAr calorimeter.
- Future: extend to lower Q^2 using Backward Silicon Tracker.

Good agreement with theory expectations.

Flavor Decomposition

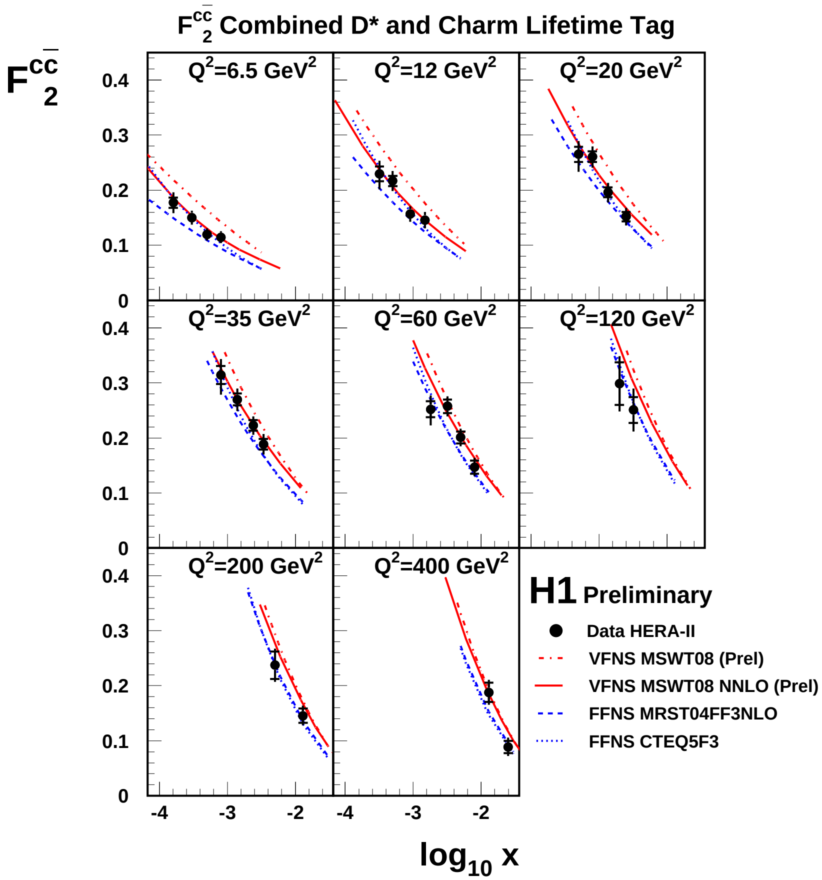


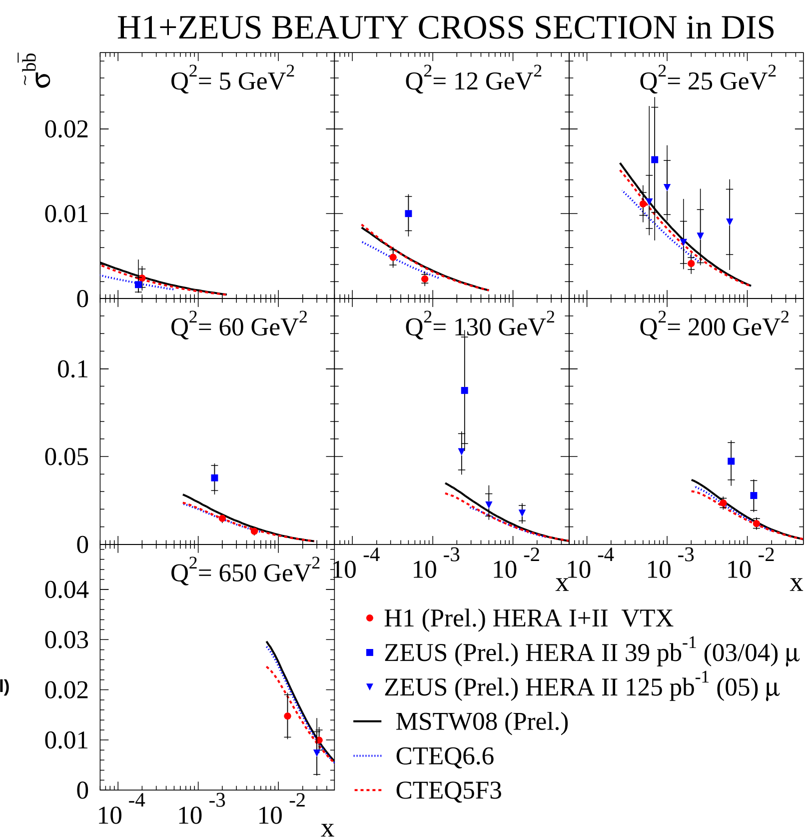
We want to have predictions for W^+, W^-, Z with the main experimental input from F_2^{em}:



- For W and Z, more important contribution of d, s quarks.
- For Z, significant contribution from b.

Measurements of heavy flavors





Measure $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ structure functions by tagging the c quarks via D^* decay and c/b quark using secondary vertex.

Summary

- HERA enables precise determination of PDFs for the LHC kinematic range.
- DGLAP evolution works well.
- New data from HERA-II extends precision PDF measurement to high x.
- HERA results are in good agreement with SM.
- More information will come with finalization of HERA analyzes, combination of H1/ZEUS data.