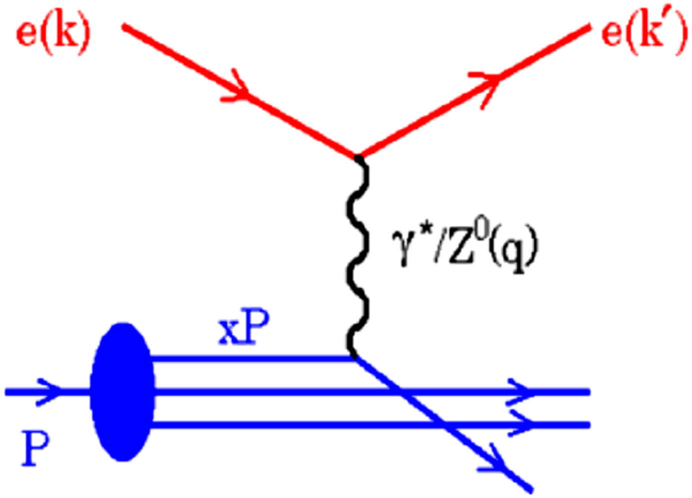
Experimental data from HERA and Tevatron and PDFs for LHC

S. Glazov, DESY

- Structure Function Data and PDF uncertainties
- Gluon Density
- Flavor Decomposition of PDFs
- Emergency Scenario

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.

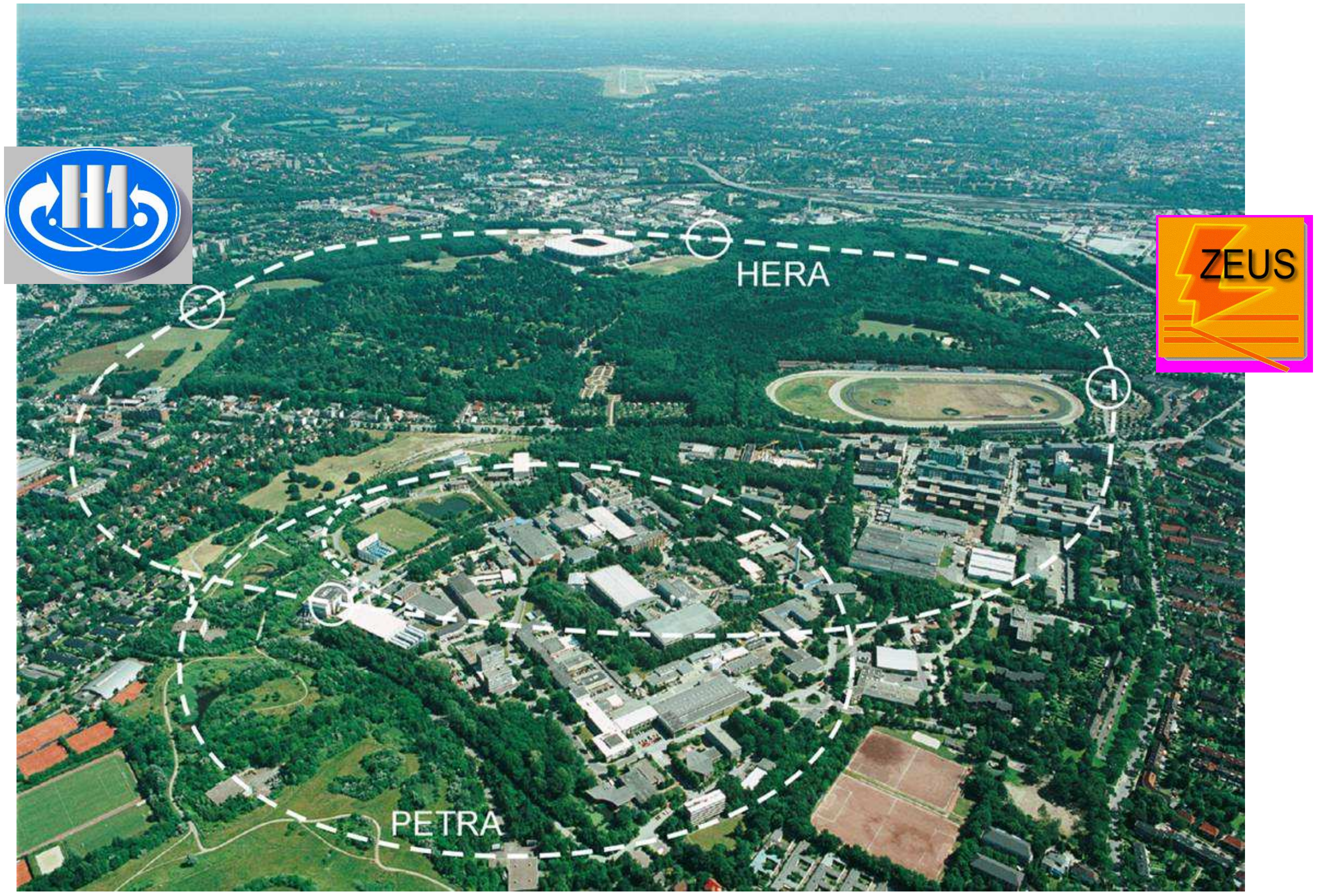
At small x complex dynamics which must obey simple asymptotic solutions (unitarity).

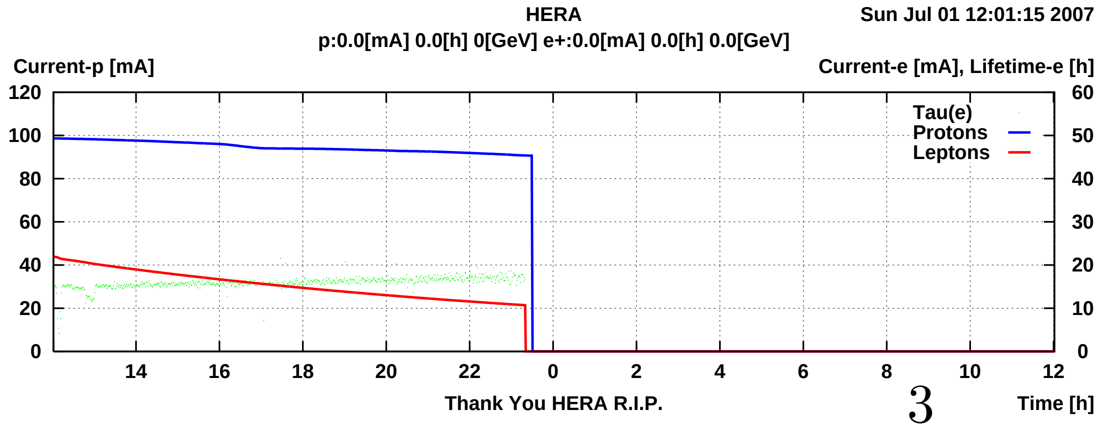
DIS scattering experiments at HERA with $\sqrt{S} = 318$ GeV provide

- 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.

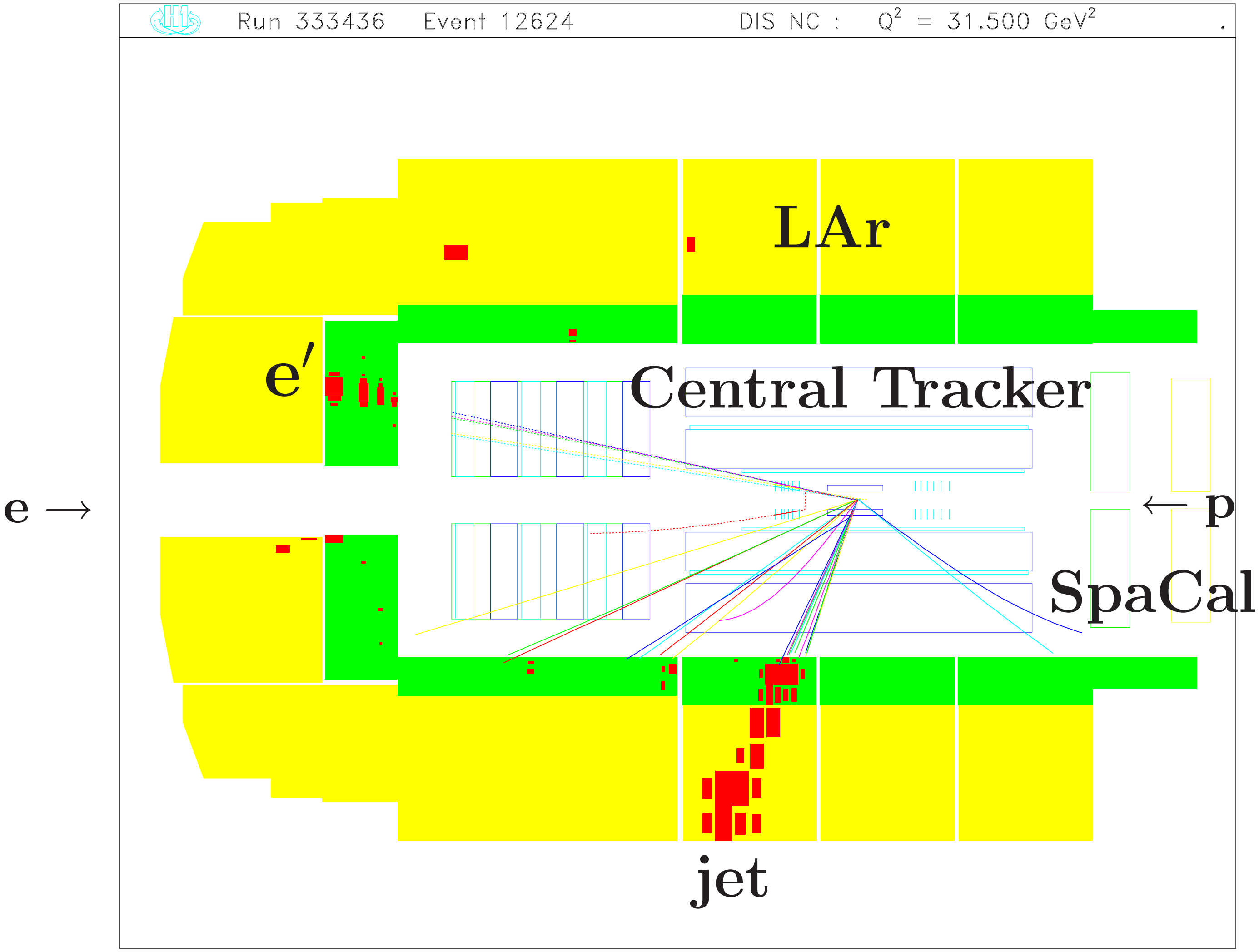
Knowledge of the proton structure is vital for a number of "practical" applications including pp colliders (LHC).

HERA, H1 and ZEUS. 1992-2007.





DIS Event Reconstruction



Virtuality:

$$Q^2 = 2E_eE'_e(1+\cos\theta_e)$$

Inelasticity:

$$y = 1 - \frac{E'_e(1-\cos\theta_e)}{2E_e}$$

Bjorken x:

$$x = Q^2/(Sy)$$

$p-\gamma$ invariant mass:

$$W = \sqrt{Q^2(1-x)/x}$$

Kinematics can be reconstructed using e' or hadronic final state.

PDF determination

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

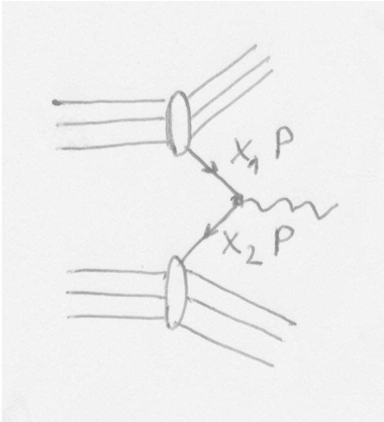
Leading order relations:

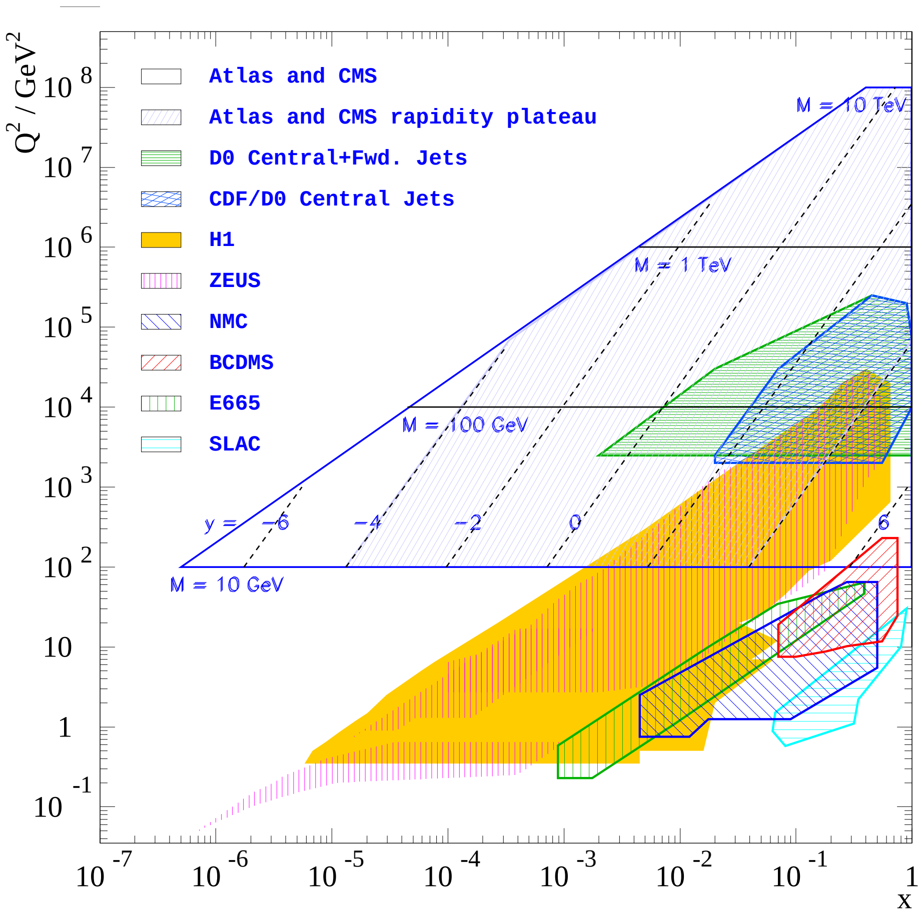
F_2	$= x\sum e_q^2(q(x)+\bar{q}(x))$
xF_3	$= x\sum 2e_q a_q(q(x)-\bar{q}(x))$
$\sigma^{CC}_{e^+p}$	$\sim x(\bar{u}+\bar{c}) + x(1-y)^2(d+s)$
$\sigma^{CC}_{e^-p}$	$\sim x(u+c) + x(1-y)^2(\bar{d}+\bar{s})$
$pp \to (\ell\bar{\ell})X$	$\sim \sum x_1 x_2 q(x_1)\bar{q}(x_2)$

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



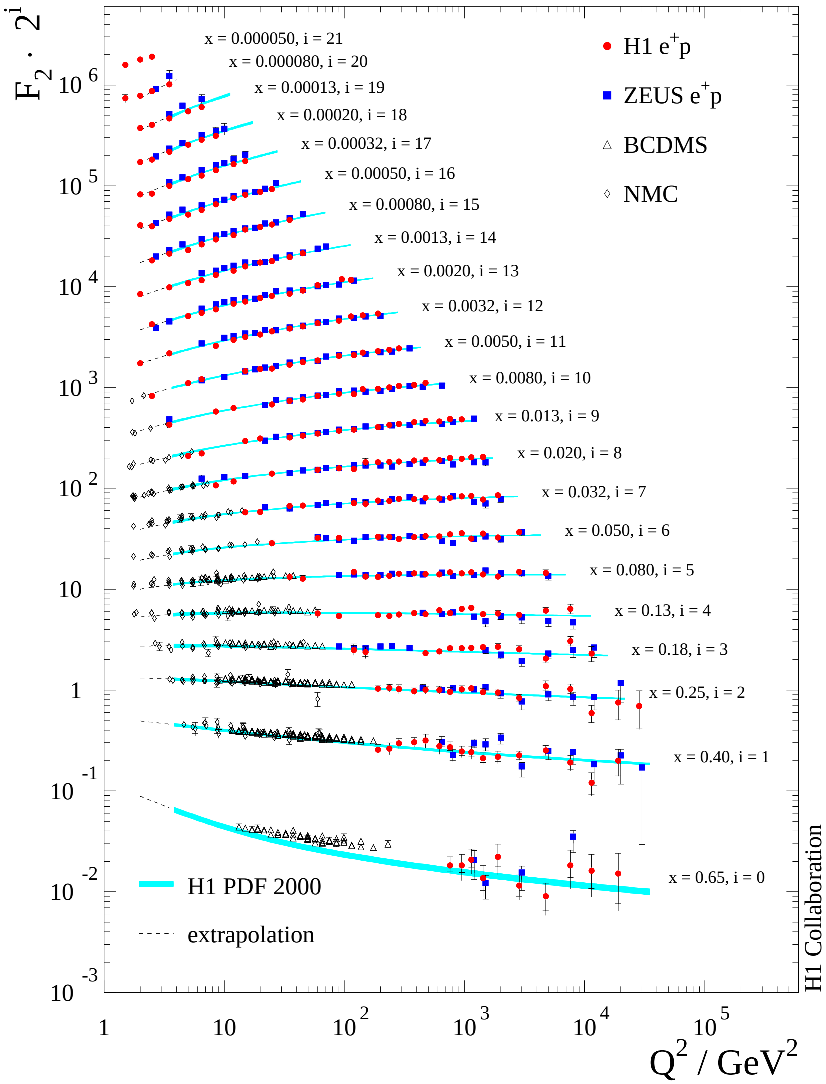


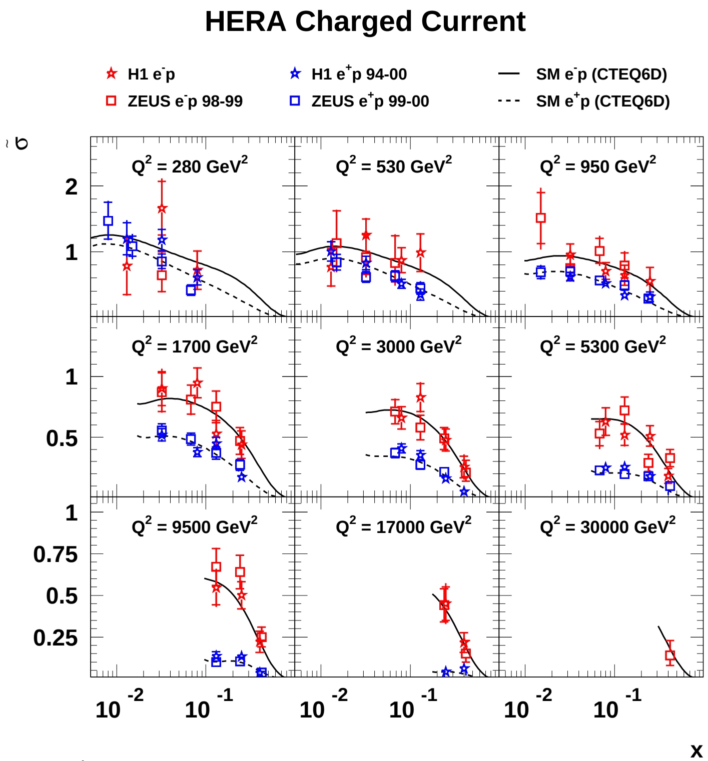
x_1, x_2 are momentum fractions. Factorization theorem states that cross section can be calculated using universal partons $\times$ short distance calculable partonic reaction.

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

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

The Measured Cross Sections





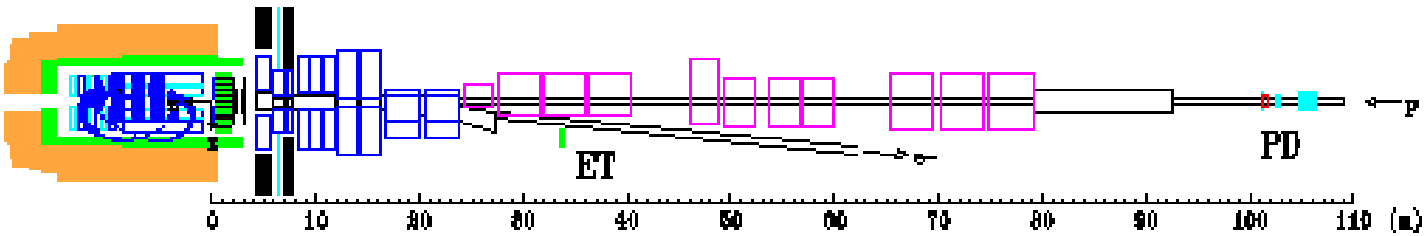
HERA data allows to measure $xU = x(u+c)$, $xD = x(d+s)$, $x\bar{U} = x(\bar{u}+\bar{c})$, $x\bar{D} = x(\bar{d}+\bar{s})$, and xg in a single experiment.

Sources of Uncertainty

$$\sigma_r, \quad \delta\mathcal{L} \quad \delta\sigma_r^{stat}, \quad \delta\sigma_r^{corr\ syst} \quad \delta\sigma_r^{uncorr\ syst}$$

- Global normalizations – arise from luminosity uncertainty $\delta\mathcal{L}$, global inefficiencies. Affect data sets uniformly. Typical value $\sim 1.5 - 2\%$. Most serious for PDFs: 3σ shift generates $4.5 - 6\%$ bias with only 9 units of χ^2.
- Correlated systematic uncertainties, $\sigma_r^{corr\ syst}$ – arise from misreconstruction of event kinematics, background. Affect groups of experimental points, typically y dependent $\rightarrow$ can change x-shape globally.
- Uncorrelated systematic uncertainties, $\sigma_r^{uncorr\ syst}$ – arise from local efficiencies, miscalibrations. Often the largest source of uncertainty but impact on PDFs is $\sim 1/sqrt(N_{meas})$.
- Statistical uncertainties, σ_r^{stat} – at HERA are small for $x \sim 0.005$ range, become important for high Q^2, x.

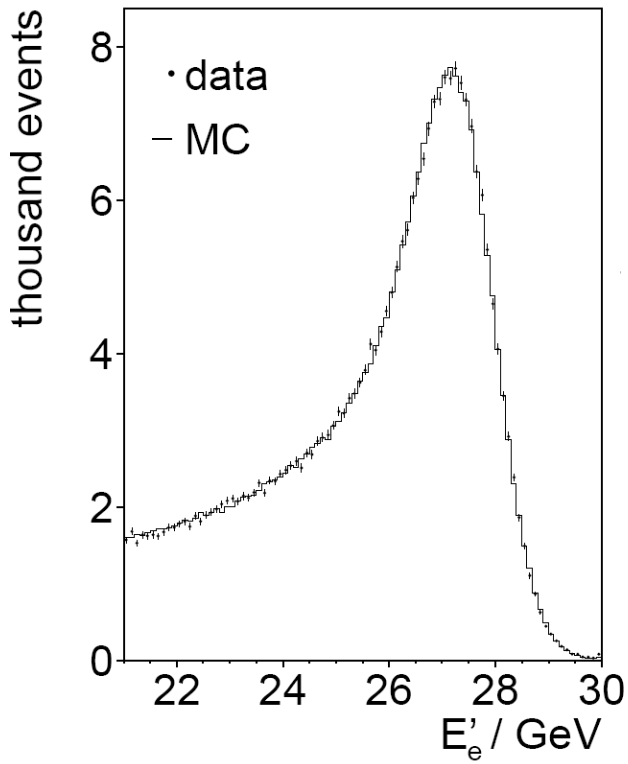
Luminosity measurement at HERA

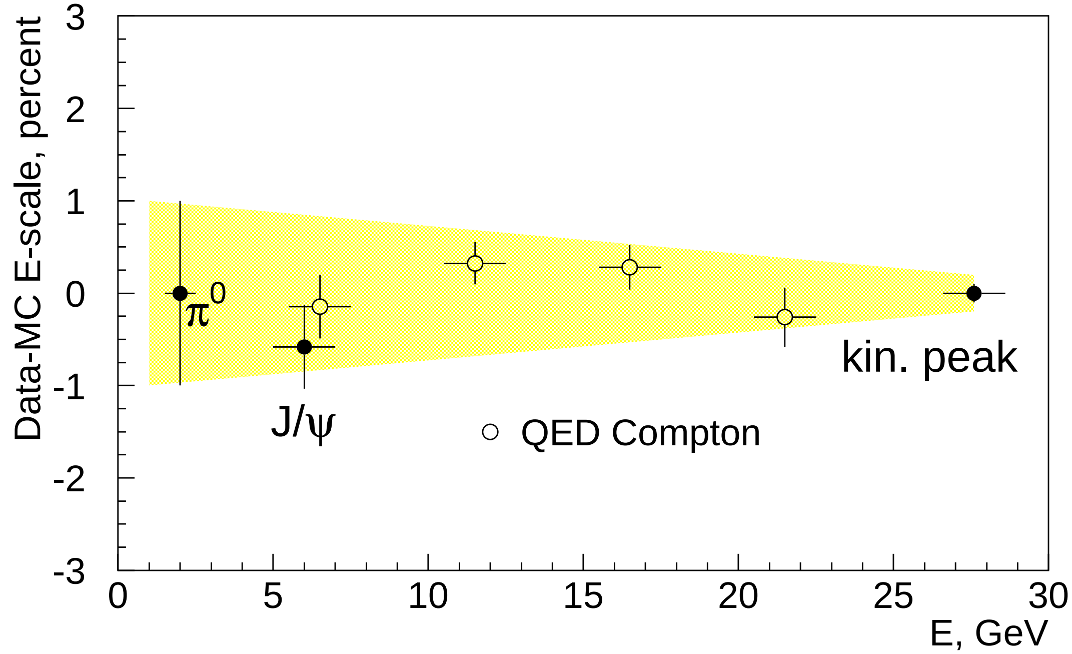


- Use $ep \to ep\gamma$ Bethe-Heitler process, detect the scattered photon in a photon tagger ~ 100 m away from the IP.
- QED prediction with 0.5% precision (effect of higher orders).
- Experimental uncertainty dominated by detector acceptance knowledge ($\sim 90 \pm 1\%$), energy calibration, and beam longitudinal profile.

$\to$ complicated measurement. Ultimate experimental uncertainty – 1%, uncorrelated H1 vs ZEUS.

Correlated Systematic Uncertainties

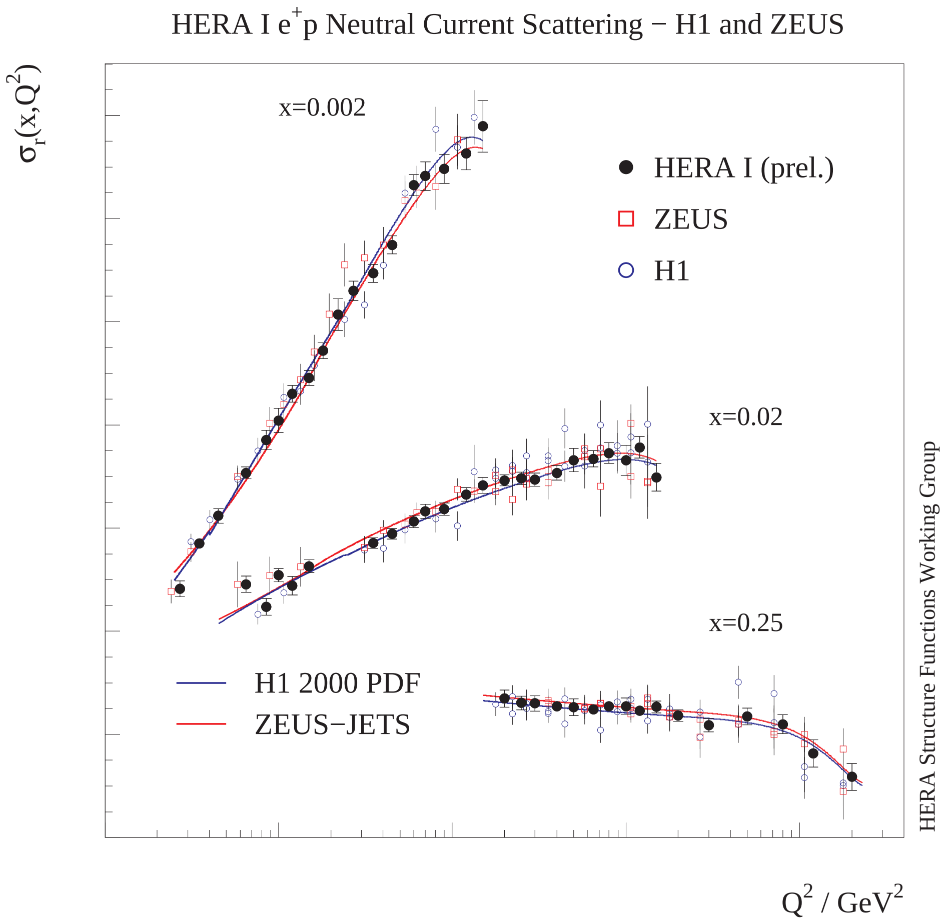




Example: scattered electron energy E'_e. Affects y, Q^2.

- Calibrated to the electron beam energy using the scattered electron angle and the angle of hadronic final state.
- Check E'_e using "kinematic peak" distribution — 0.2% precision.
- Measure non-linearity with $\pi^0 \to \gamma\gamma$, $J/\psi \to e^+e^-$, QED-compton $ep \to ep\gamma$ events.

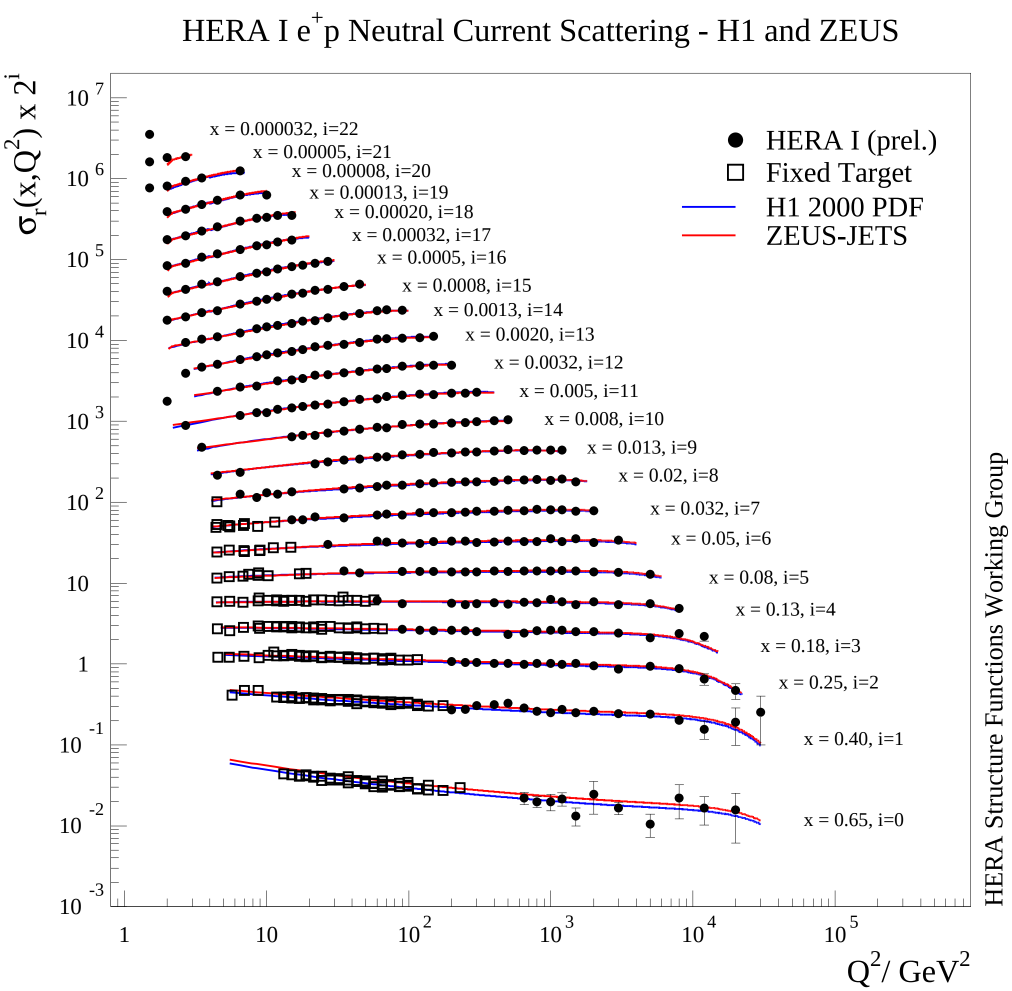
Combination of HERA data



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



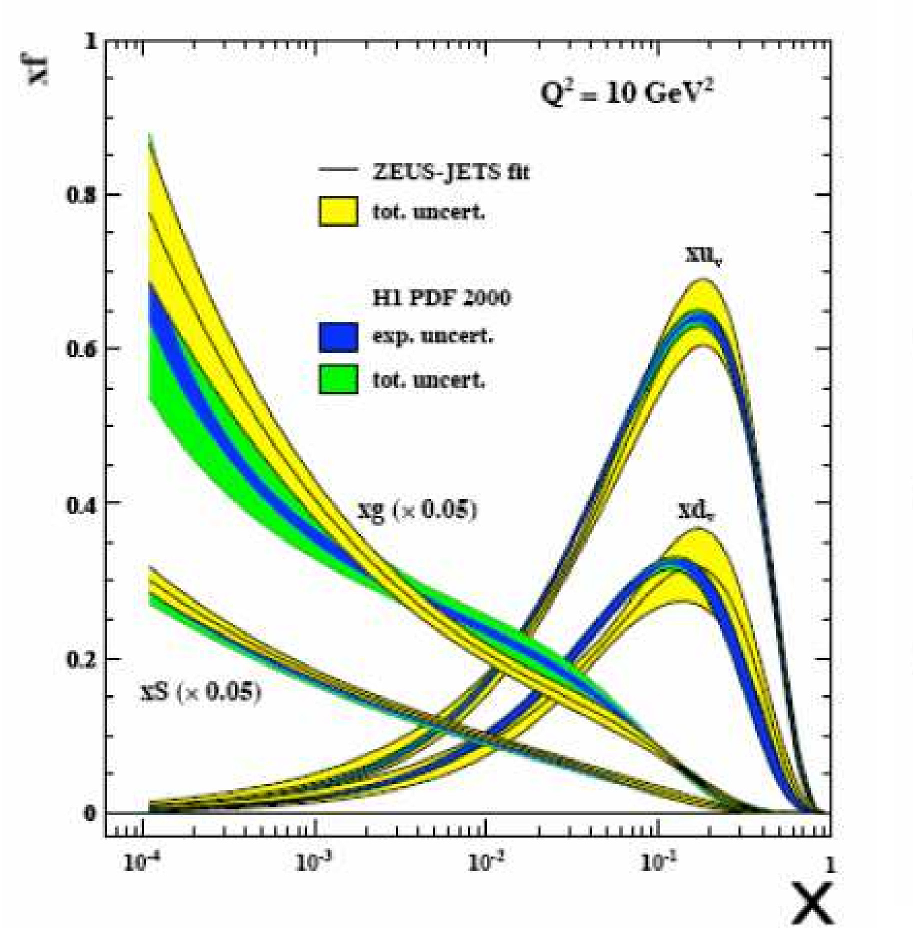
Combination of published H1/ZEUS data for CC,NC, $e^{\pm}p$ data.

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

(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



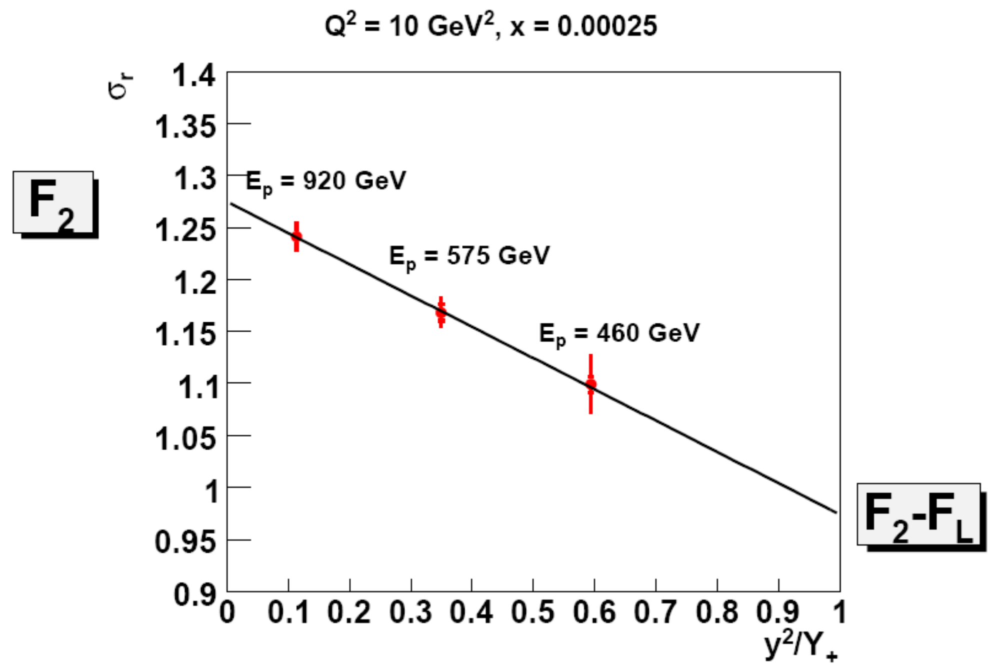
Sea S and gluon g are far more important at low x. Mind the $\times 0.05$ scale factor for them.

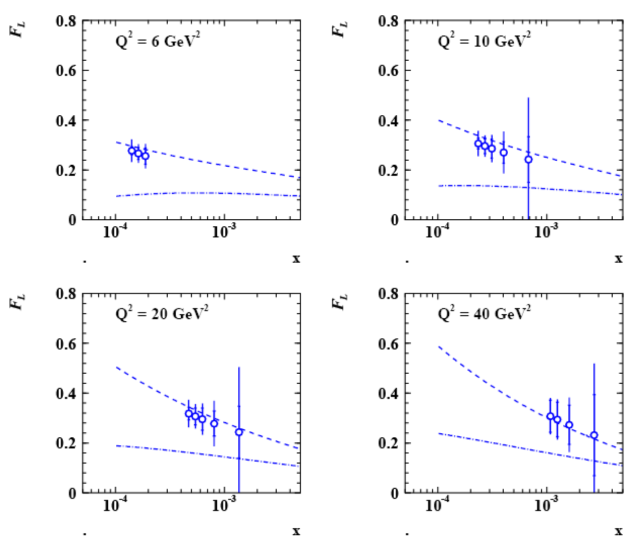
ZEUS and H1 PDFs are extracted using their own data. Agree within the uncertainties, but shapes seems to be different.

Measurement of F_L (simulation!)

$$\sigma_r(x,Q^2) = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

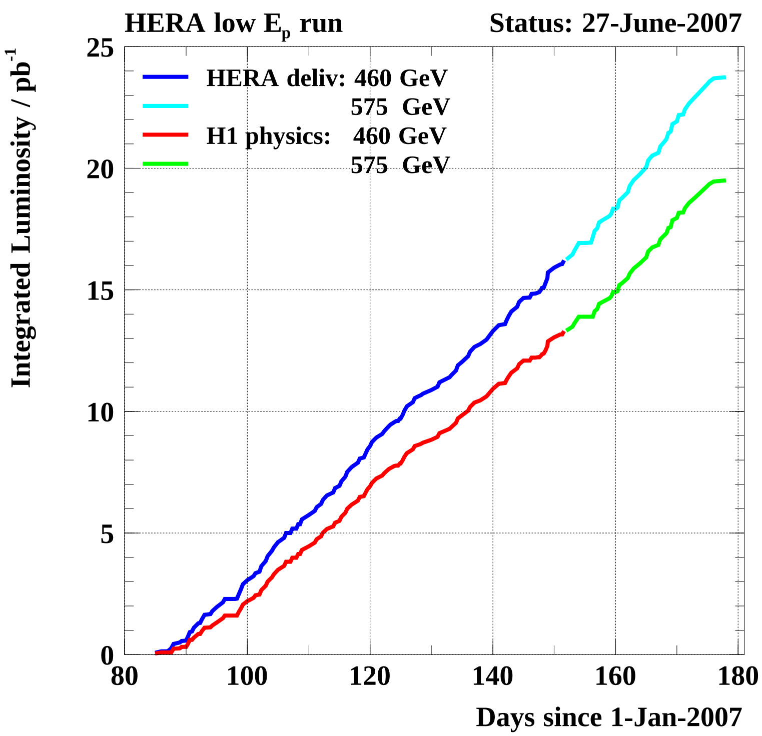
Measure σ_r at the same Q^2, x for different beam energies

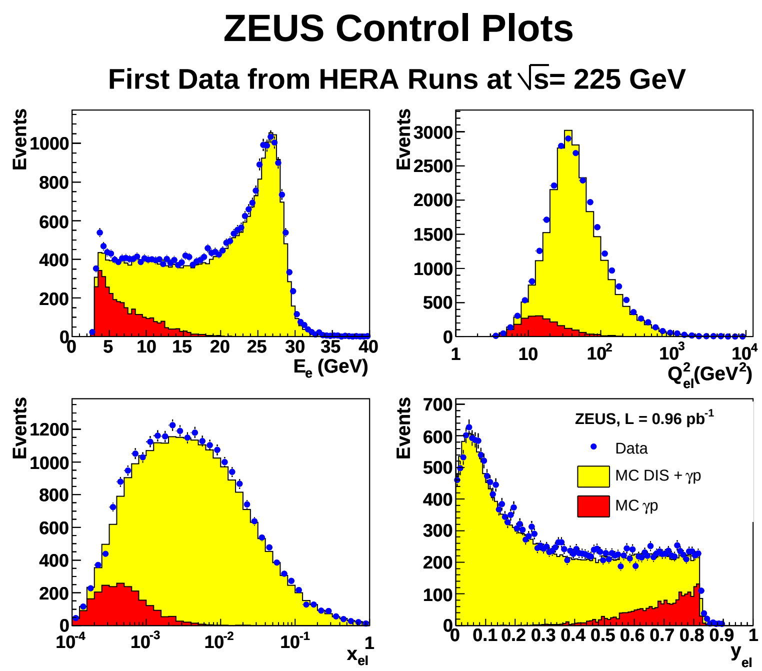




F_L measurement should allow to distinguish between different PDF fits (MRST vs CTEQ).

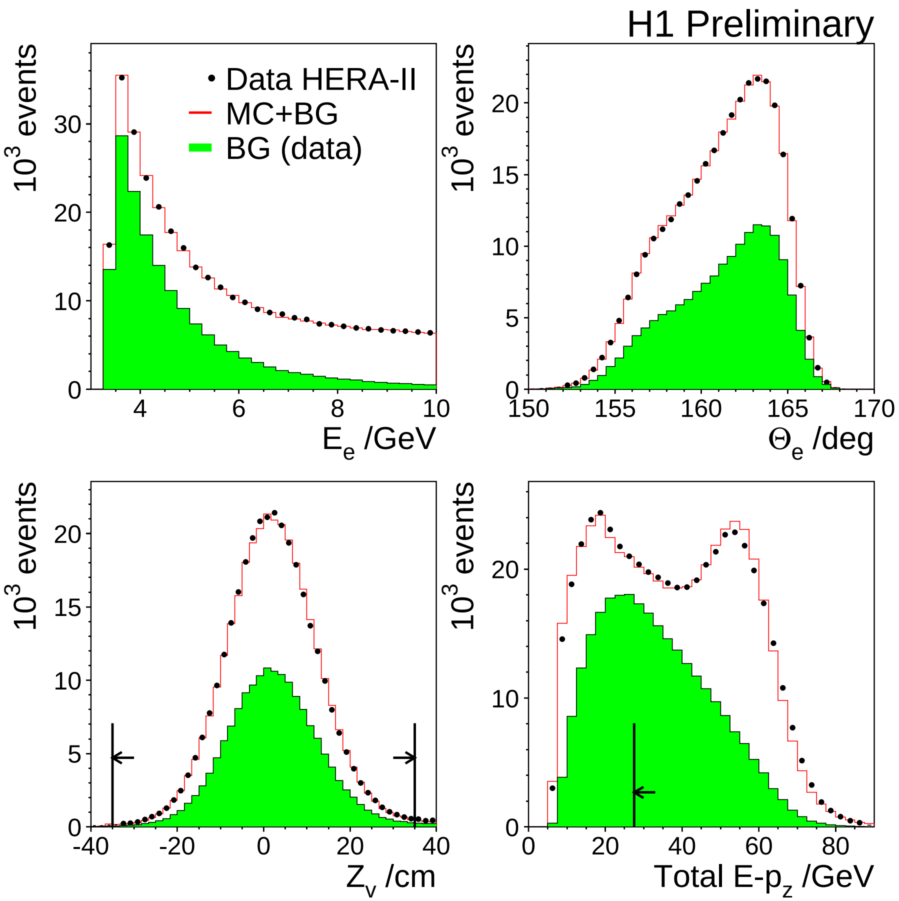
Special 460 GeV and 575 GeV runs





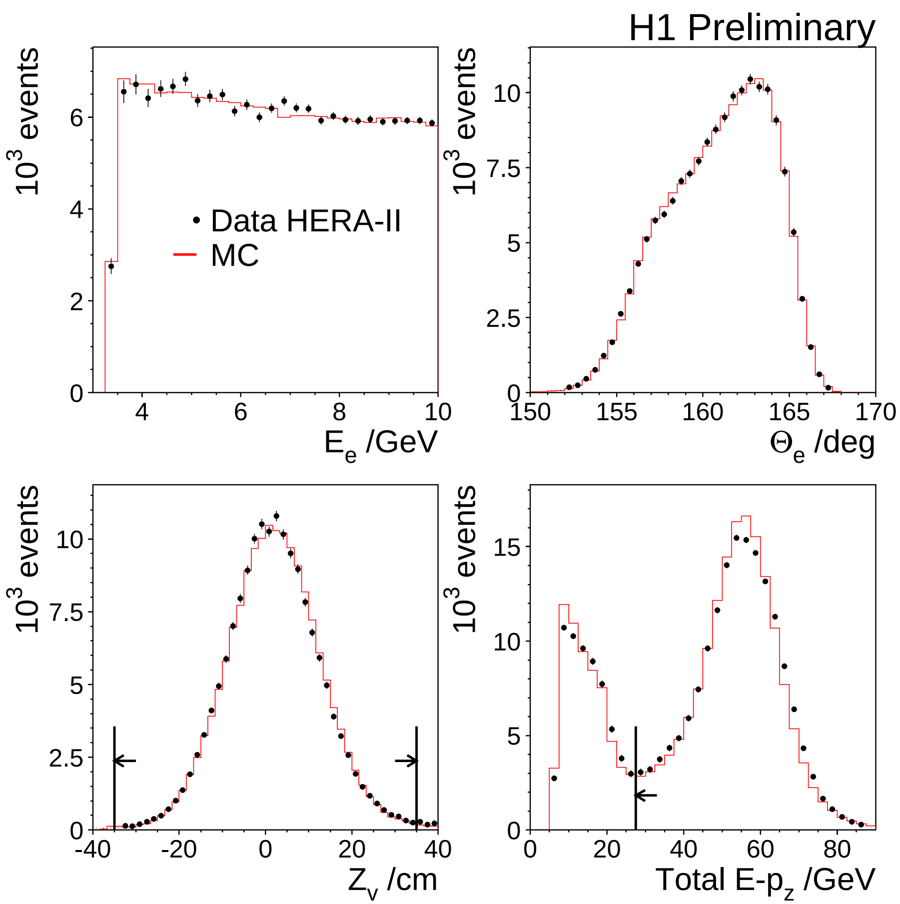
- Last 3 months of HERA operation are dedicated for F_L measurement.
- Luminosity is proportional to E_p^2, from the beam focusing, thus reduced vs nominal 920 GeV run.
- Successful HERA operation, 13.6 pb^{-1} and 6.5 pb^{-1} collected for 460 and 575 GeV run.

H1 high y analysis with HERA-II data



Analysis based on 96pb^{-1} collected in $2003-2006$, nearly symmetric for e^+ and e^- beam luminosity.

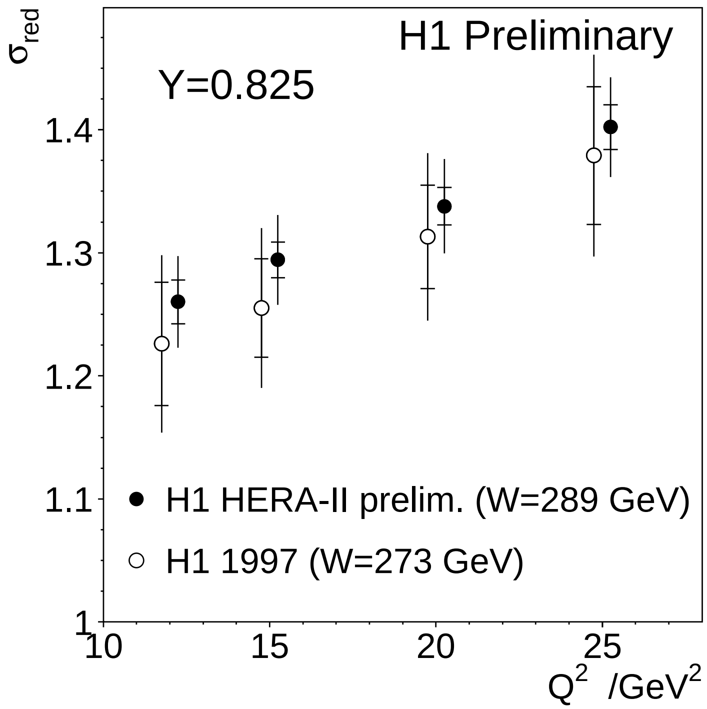
H1 high y analysis with HERA-II data

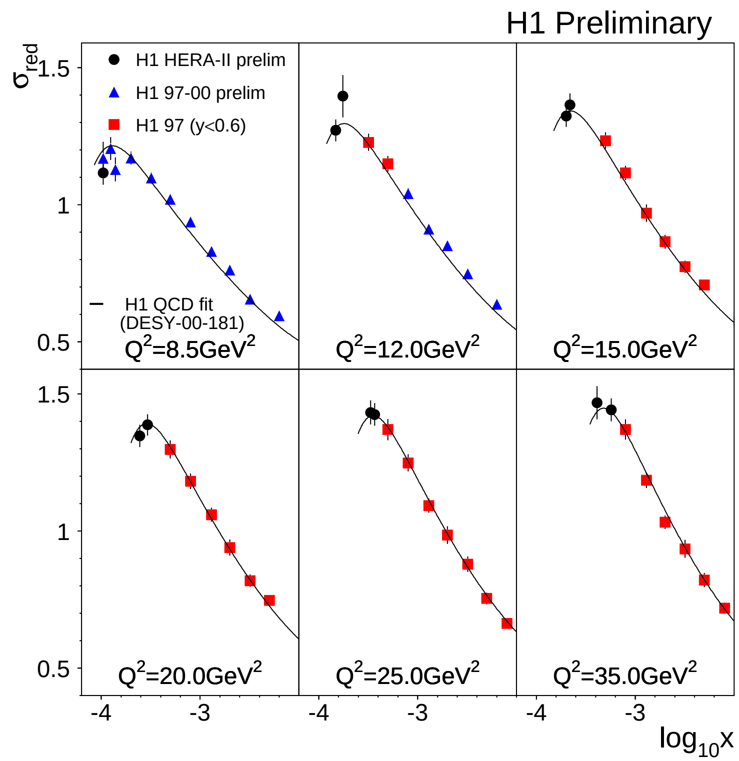


Radiative corrections are controlled using the measured beam energy:

$$2E_e = E - p_Z = \sum_h \left(E^h - p_Z^h\right) + \left(E^{e'} - P_Z^{e'}\right)$$

High y cross section at low x

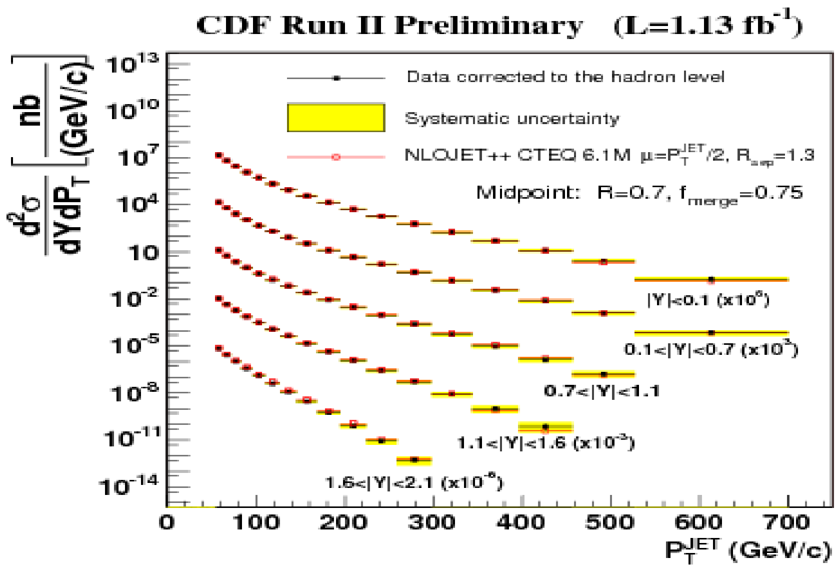




For $y = 0.825$, about factor of 2 improvement in total uncertainty and factor of 3 in stat. uncertainty vs published.

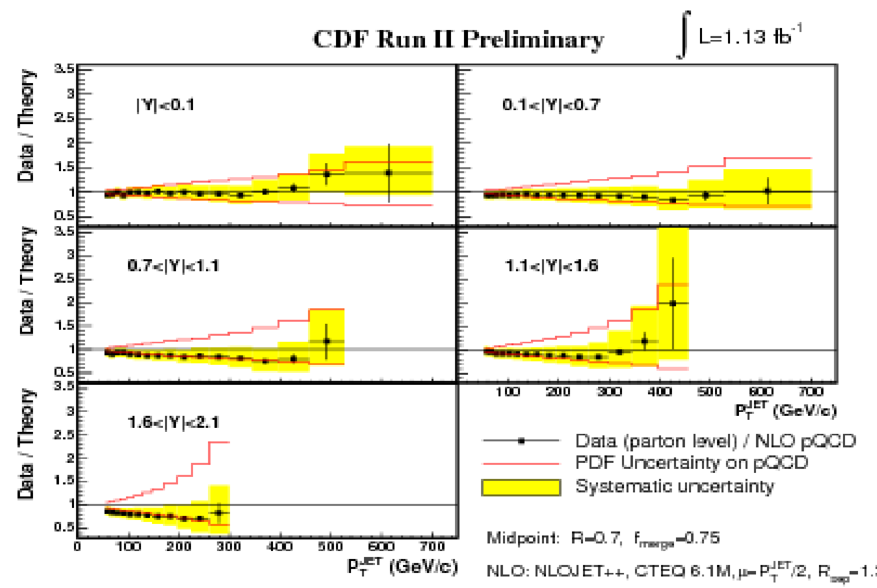
An ideal sample to study experimental conditions for the structure function F_L measurement.

Jets at Tevatron

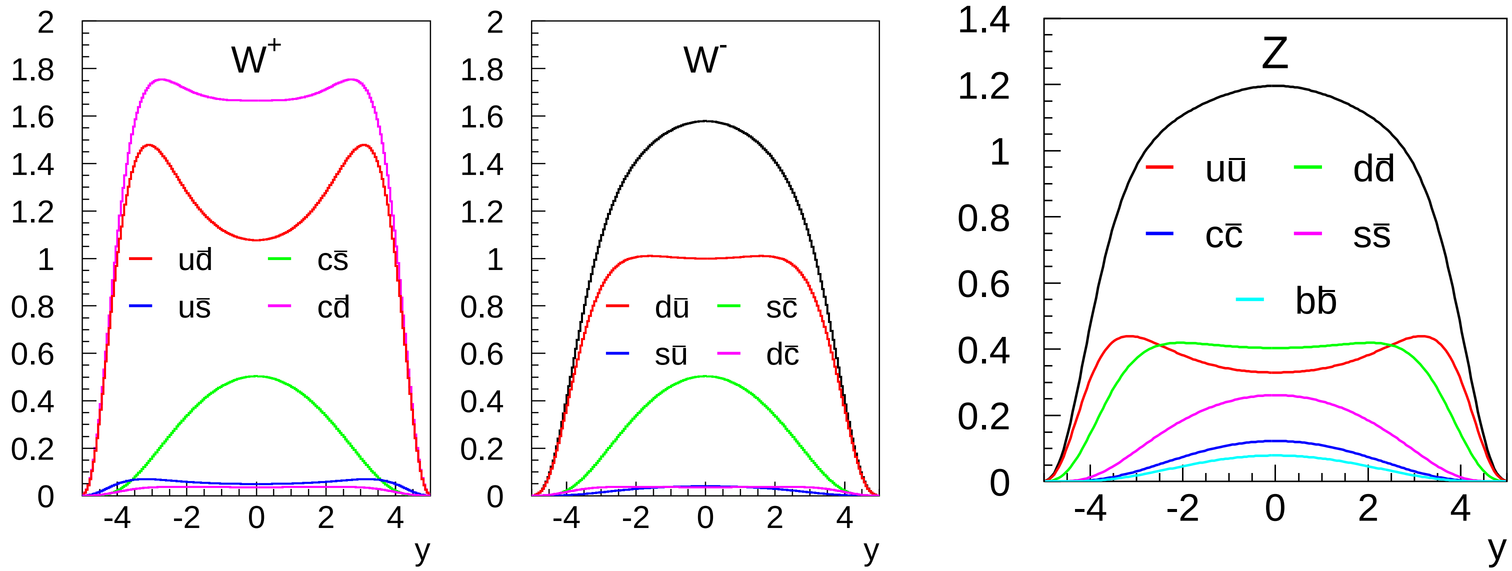


Gluon density at intermediate and high x is mostly constraint by Tevatron jet measurement. Preliminary CDF Run II analysis based on improved cone algorithm (midpoint).

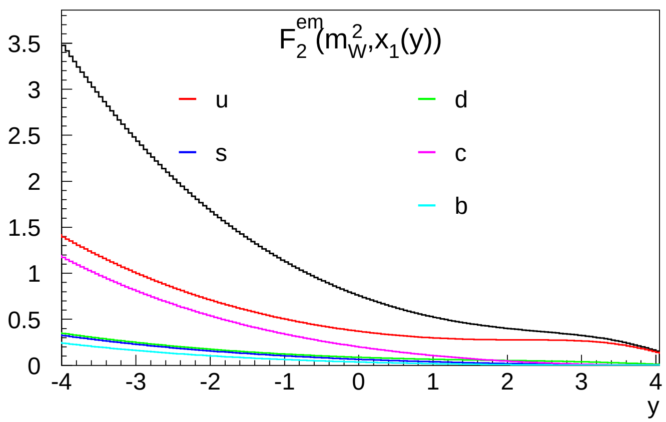
New data agree well with PDFs determined using Run I data.



Flavor Decomposition

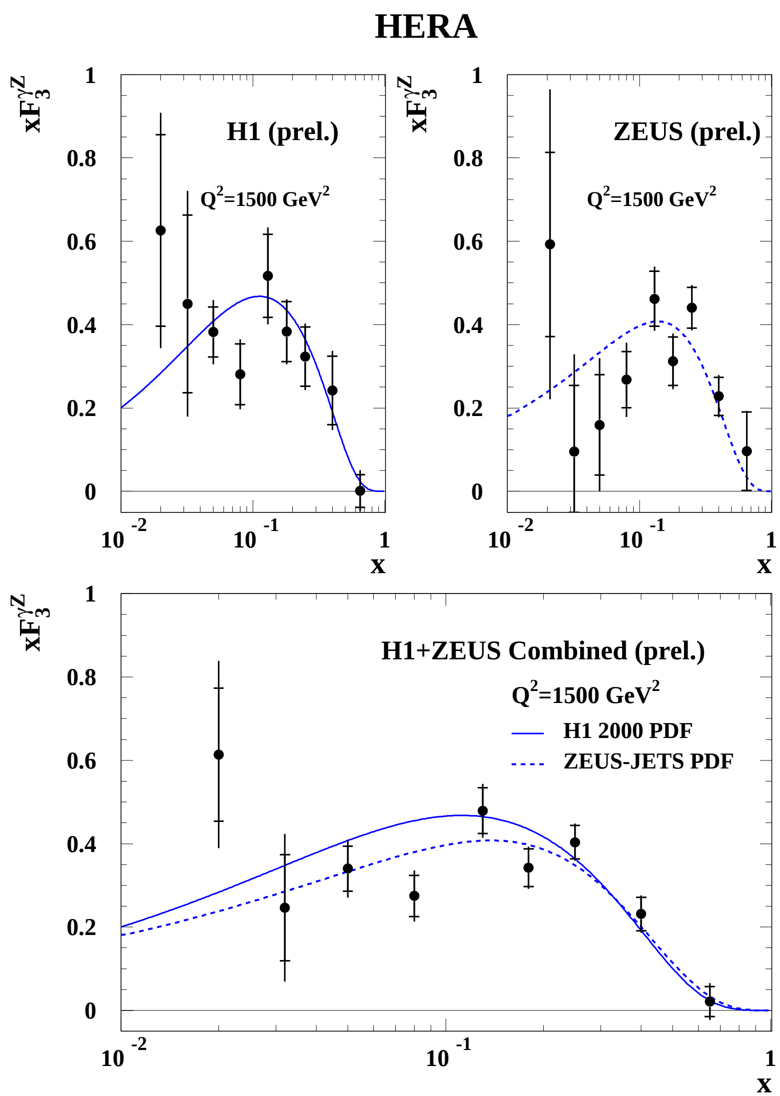


We want to have predictions for W^+, W^-, Z with the main experimental input from F_2^{em}:



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

Neutral Current Cross Section and xF_3

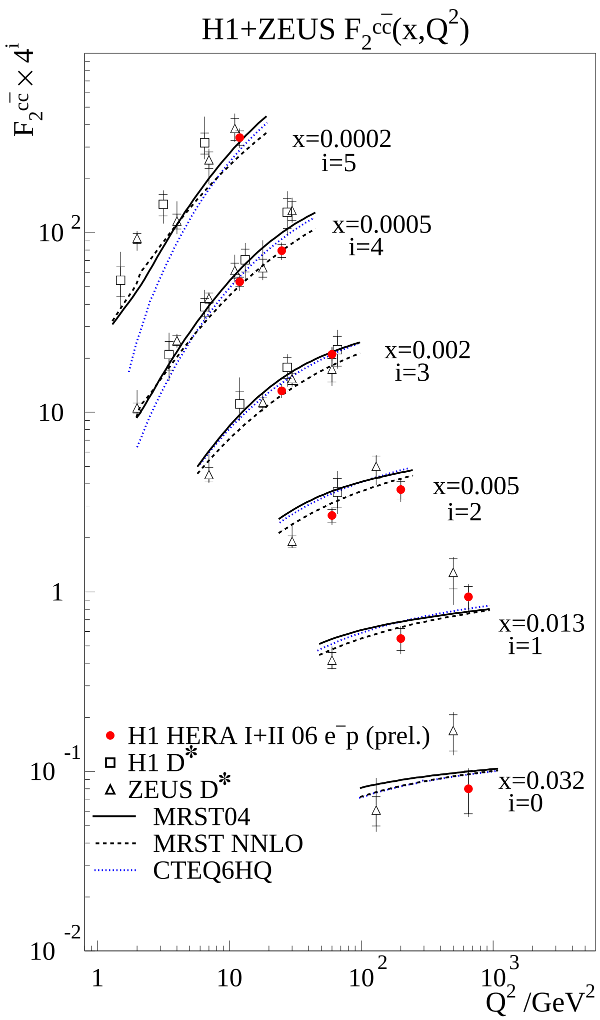


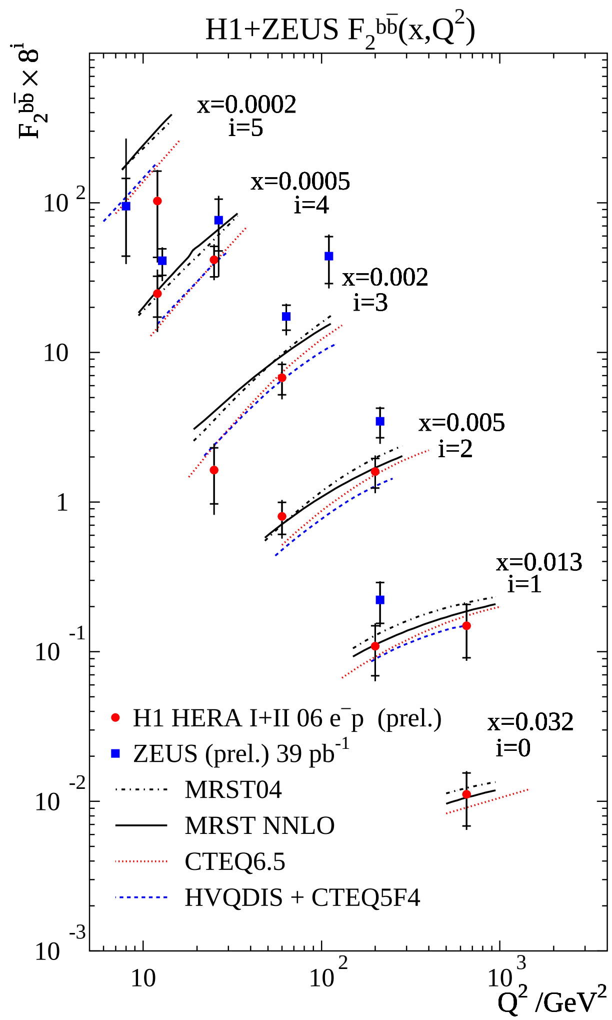
Inclusive SF can be used to study different flavor combinations, for example

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

Large increase compared to HERA-I of e^- sample allows to improve precision of the interference structure function $xF_3^{\gamma Z}$
Very difficult measurement at low x for HERA.

Measurements of heavy flavors



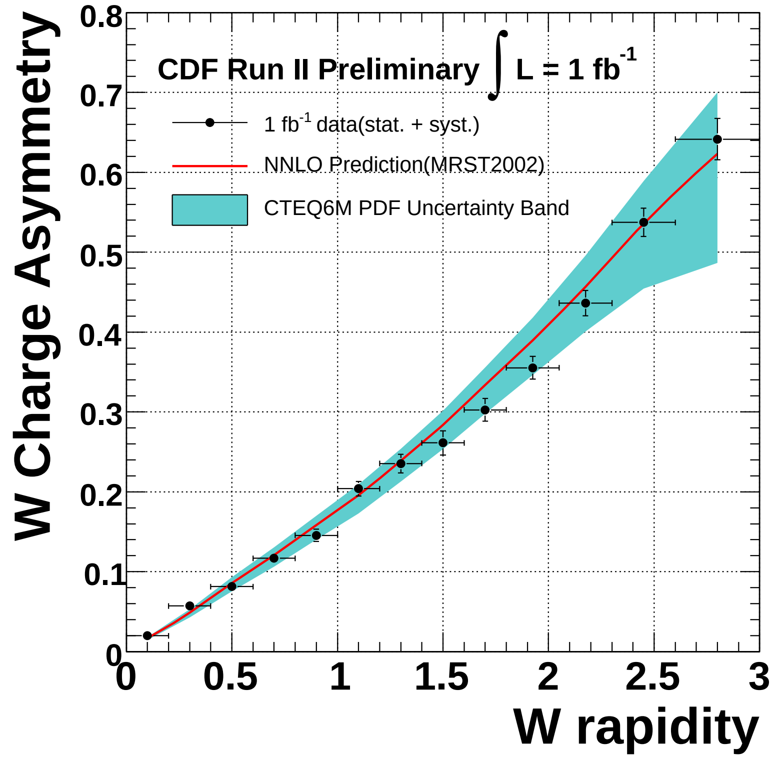


Measure $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ structure functions by tagging the c quarks via D^* decay or c/b quark using secondary vertex.

Tevatron input – $W^{\pm}$ asymmetry

W^{+}, W^{-} asymmetry analysis is sensitive to u/d momentum ratio at high x:

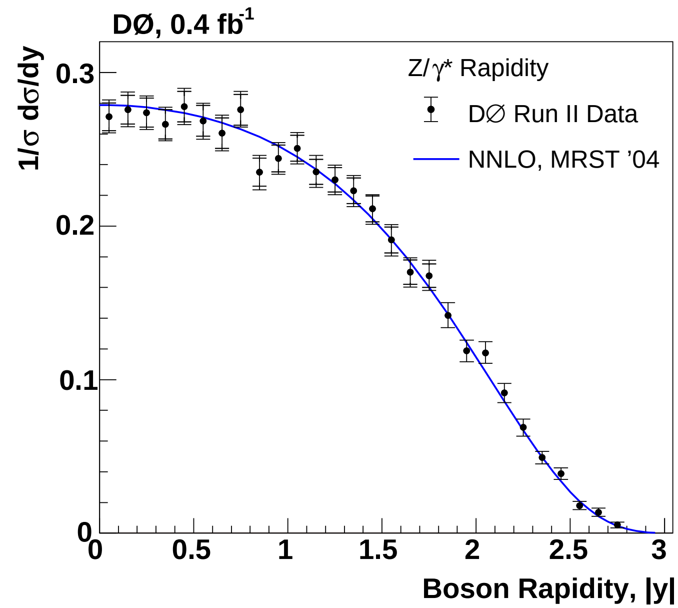
$$A(y_W) \approx \frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}$$

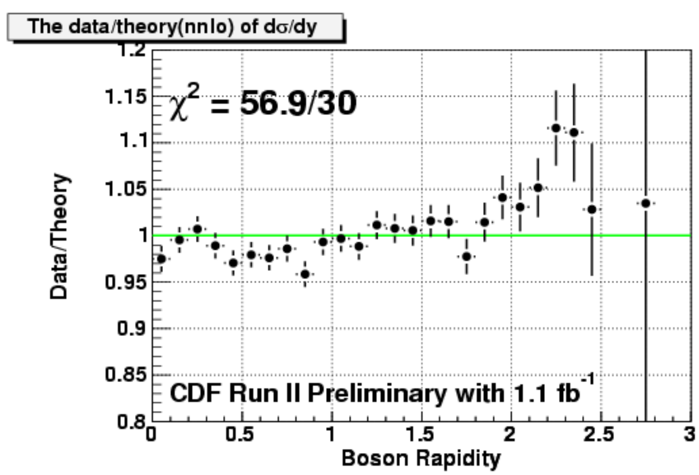


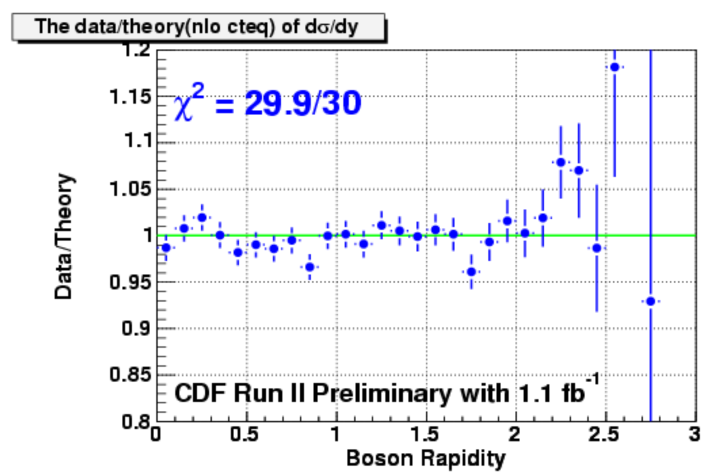
New technique allows to measure $W^{\pm}$ asymmetry directly instead of lepton asymmetry. For $y_W = 2.75$, $x_1 = 0.0026$ and $x_2 = 0.64$ the measurement compares well with PDF uncertainty.

Tevatron measurements of Z rapidity

D0 publishes a measurement of Z rapidity based on fraction of Run-II data. For D0 MRST with NNLO corrections describe the data.



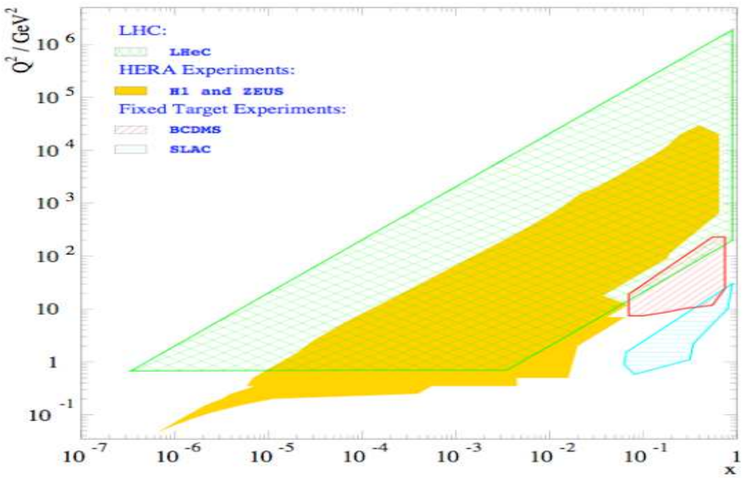


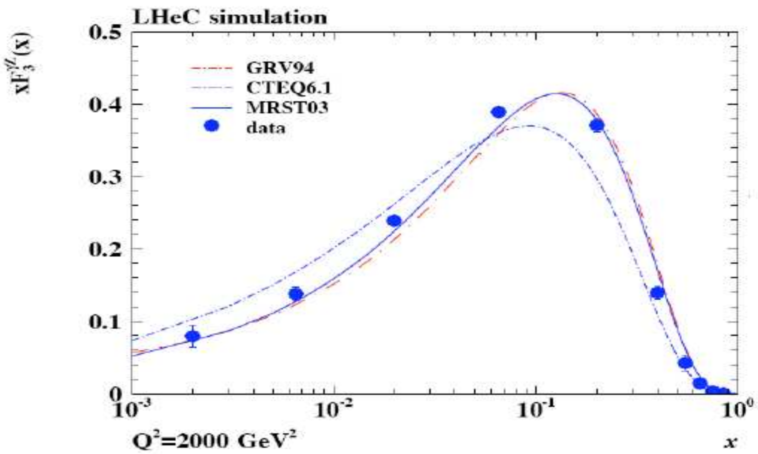


CDF preliminary result can distinguish between different PDF sets. MRST NNLO is worse than CTEQ NLO.

PDFs for LHC energy scale: LHeC

Consider LHC result: $\sigma(H)/\sigma(Z)$ about 3σ away from SM prediction. New physics or new QCD evolution ?





Measurement of PDFs close to LHC energy could be performed by 70 GeV ×7000 GeV *ep* machine at CERN: **LHeC**.

- High luminosity (10 fb^{-1}): yield of $\sim 10^5$ events at 10000 GeV^2.
- e^+ and e^- beams to measure xF_3.
- Lepton beam polarization (?) for $F_2^{\gamma Z}$.

An attractive machine at its cost.

Experimental data still to come

- Final analysis of F_2 structure function at low $Q^2 < 100$ GeV^2 and low x (H1).
- Analysis of σ_r at high Q^2 and high x using HERA-II data.
- Measurement of F_L structure function.
- HERA-II analysis of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$.
- Combination of all HERA data.
- PDF extraction based on the combined HERA data.
- Tevatron W asymmetry and Z rapidity with complete statistics.

Conclusions

- HERA enables precise determination of PDFs for the LHC kinematic range.
- DGLAP evolution works very well so far.
- Precise Tevatron measurements give a preview of what will be possible at LHC.
- Experimental input for PDFs could be vastly expanded with LHeC.
- More information will come with finalization of HERA/Tevatron analyzes, combination of H1/ZEUS data, measurement of heavy flavors and of F_L.