Inclusive DIS Results from HERA

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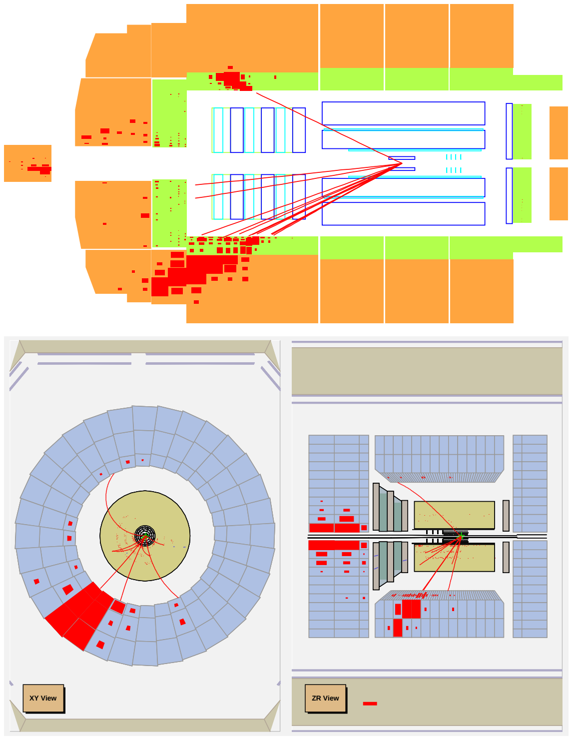
Overview

- Introduction
- Low Q^2 Status and Prospects
- High Q^2 Status and Prospects
- Heavy Quark Contribution to DIS
- QCD Fits and Parton Distribution Functions
- Conclusions

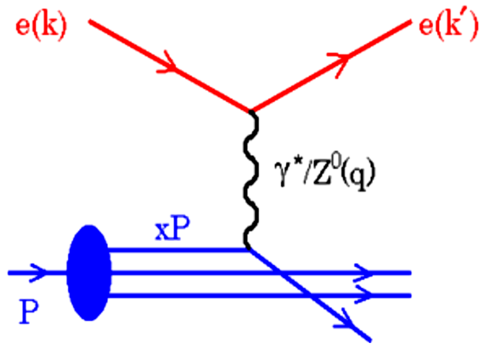
The HERA collider

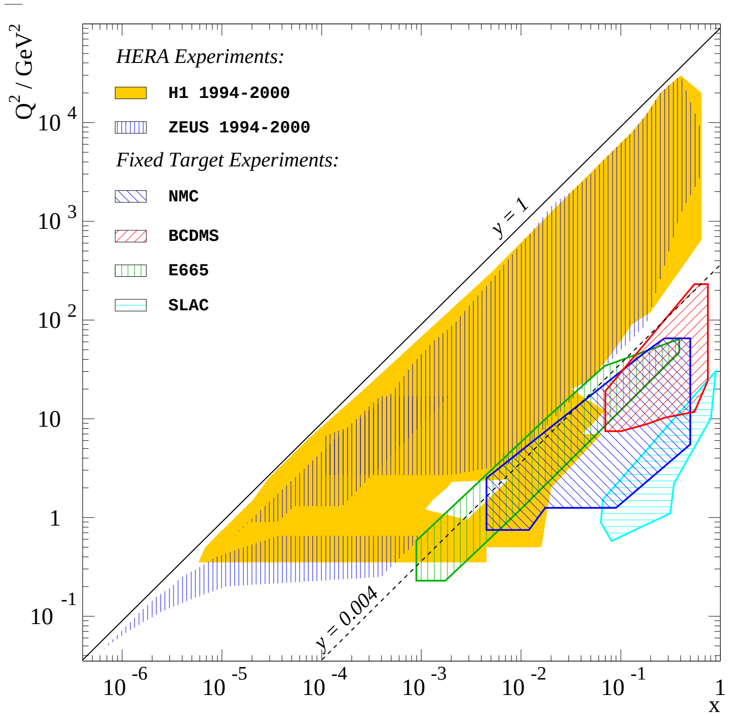
- HERA accelerator: 920 GeV p + 27.6 GeV $e^{\pm} \Rightarrow \sqrt{s} = 320$ GeV
- H1 and ZEUS: general purpose detectors for all aspects of ep collisions



Deep Inelastic Scattering

- Deep Inelastic Scattering (DIS) of leptons off nucleons is one of the best tools for exploring the substructure of the nucleon
- Kinematics are described in terms of Lorentz invariant quantities:
  - $Q^2 = -q^2 = -(k - k')^2$ virtuality/resolving power
  - $x = \frac{Q^2}{2P \cdot q}$ Bjorken scaling variable, momentum fraction of the scattered parton
  - $y = \frac{q \cdot P}{k \cdot P}$ inelasticity
- Related by $Q^2 = xys$



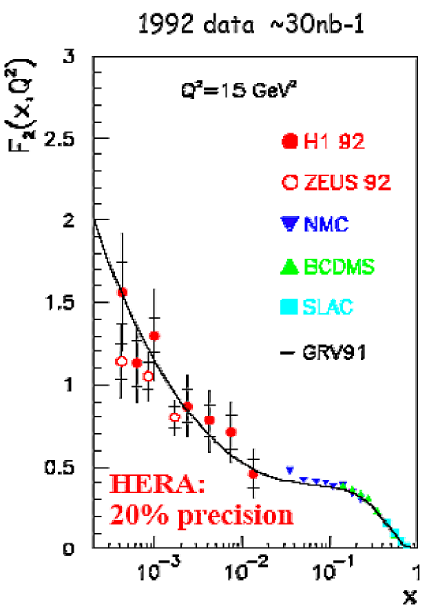


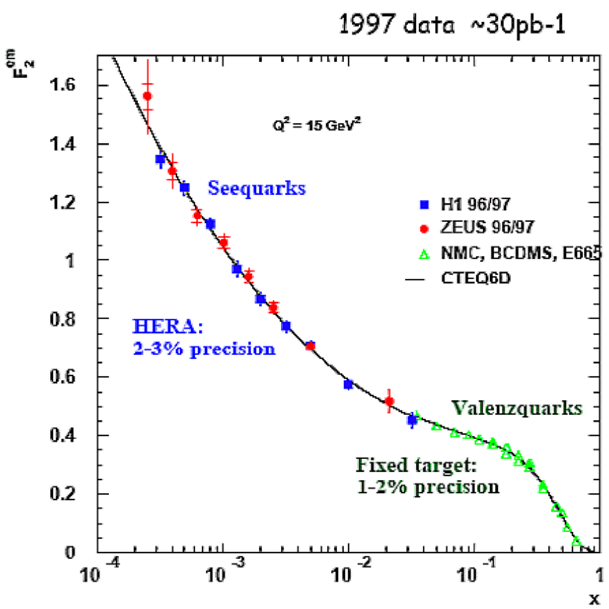
DIS Inclusive Cross Sections

- 3 structure functions $F_2(x,Q^2)$, $F_L(x,Q^2)$, and $xF_3(x,Q^2)$ parametrize the inclusive NC cross section for $ep \to e'X$:

$$\frac{\mathrm{d}^2\sigma_{NC}^{e^\pm p}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \mp \frac{Y_-}{Y_+}xF_3\right), \qquad Y_\pm = 1 \pm (1-y)^2$$

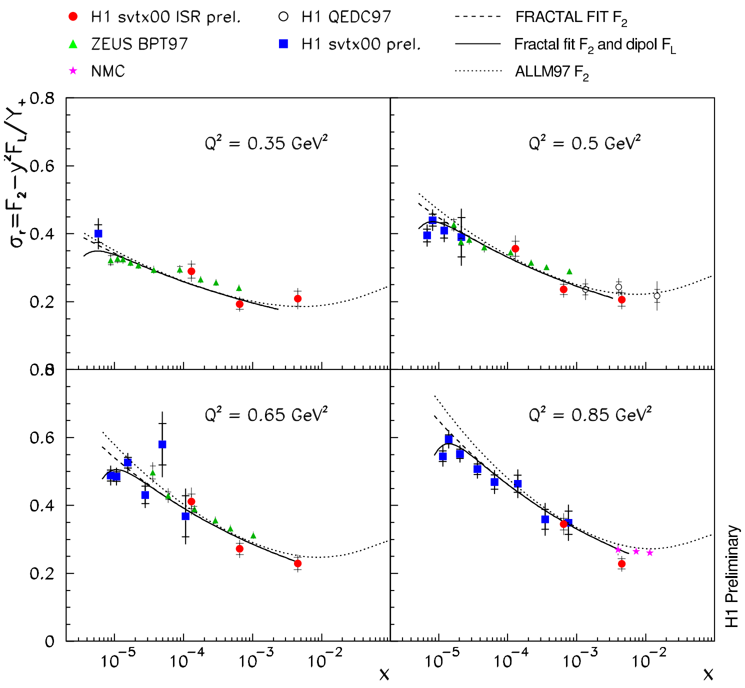
- F_2 is dominant and has been measured with 2-3% precision in the bulk region at HERA
- Contribution of F_L important at high y
- xF_3 is due to Z exchange, important at high Q^2

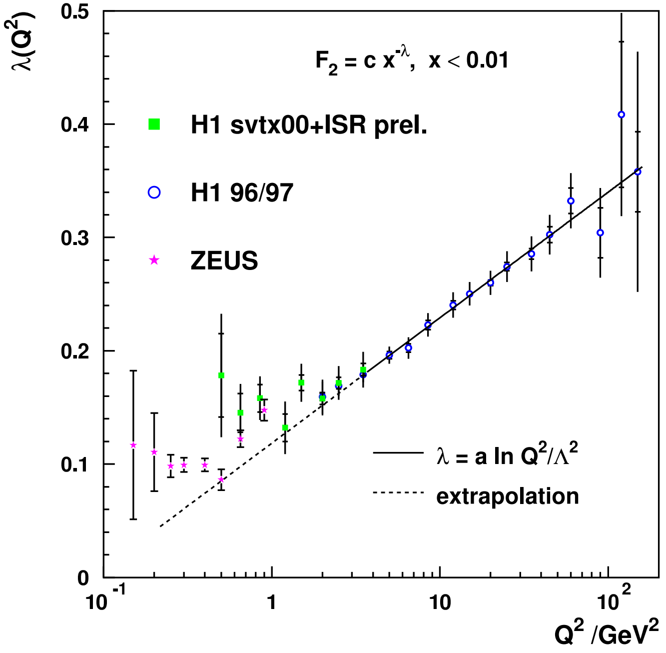




Low Q^2 Results F_2

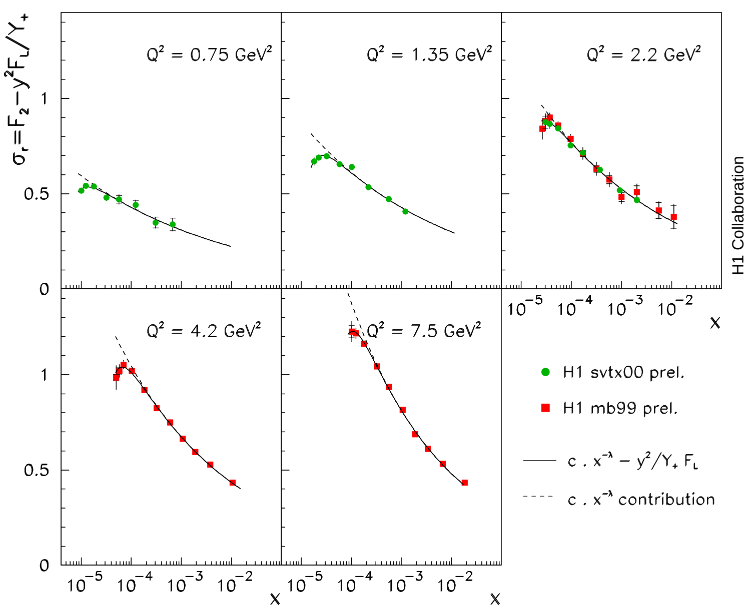
- H1 has preliminary results for lowest Q^2 from special runs with Shifted vertex, using untagged ISR events, and runs with Minimum Bias triggers
- $F_2(x, Q^2) \propto x^{-\lambda(Q^2)}$ — change of slope λ at $Q^2 \lesssim 1$ GeV^2 observed





Low Q^2 Results F_L

- Preliminary H1 results on F_2 and F_L simultaneously extracted by the “Shape method” from the reduced cross section
  $\sigma_r = c(Q^2) \cdot x^{-\lambda(Q^2)} - y^2/Y_+ \cdot F_L$
- Assumes $F_2 \propto x^{-\lambda}$ and small F_L variation where σ_r bends over at high y (i.e. low x)



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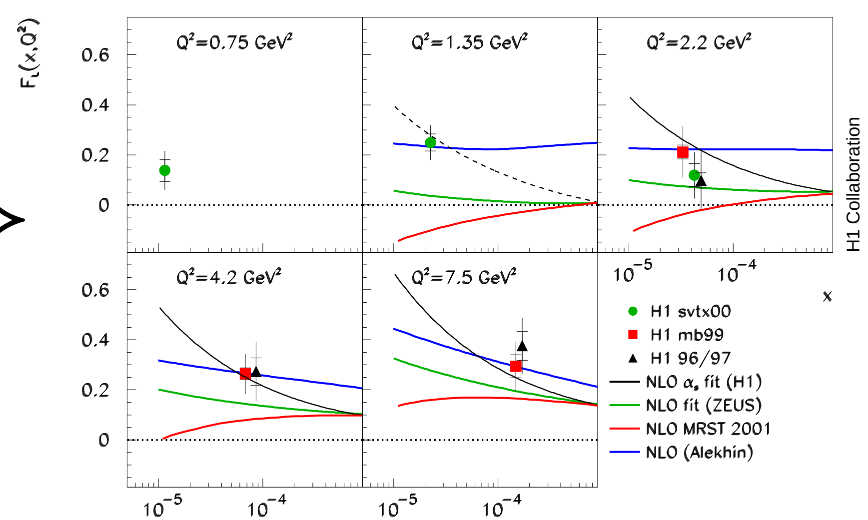
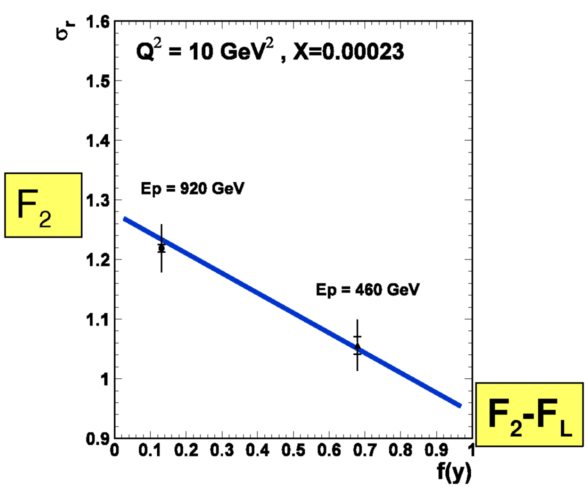
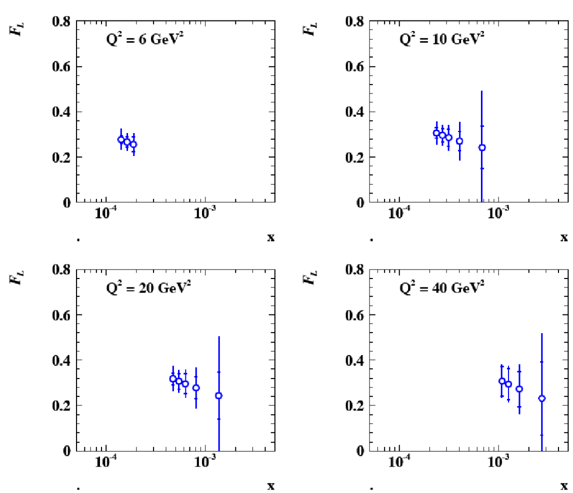
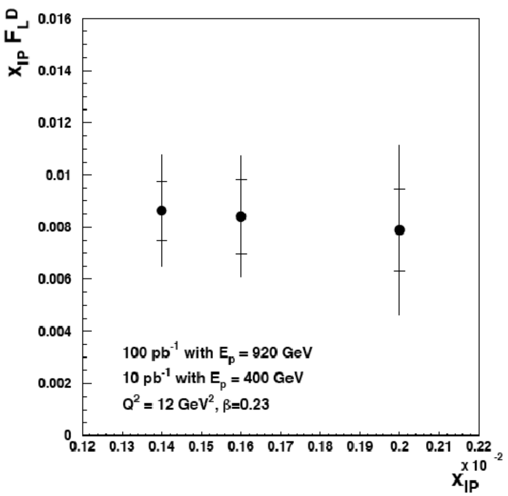


Low Q^2 Prospects F_L

- A direct determination of F_L needs y-variation at fixed x, Q^2
  $\Rightarrow$ operation with reduced proton energy (low E_p) foreseen for 2007
- Likely scenario: limit to one extra energy with $E_p = 460$ GeV, collect about 10 pb^{-1} ($\mathcal{L} \propto E_p^2$), H1 expects a 5σ measurement, ZEUS may be less significant due to detector reasons — studies ongoing
- F_L gives an independent constraint of the gluon: $F_L(x, Q^2) \propto \alpha_s xg(x, Q^2)$
- Also F_L^D may be measured



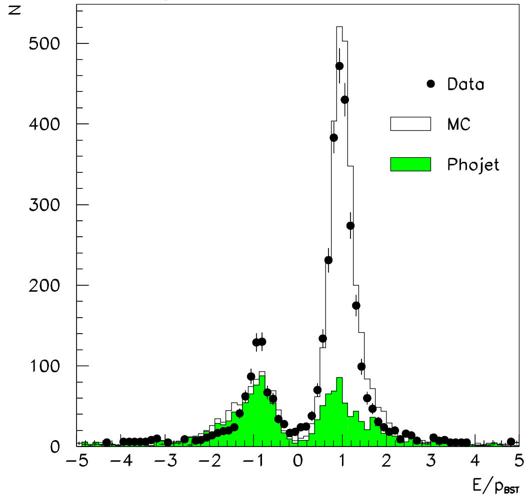




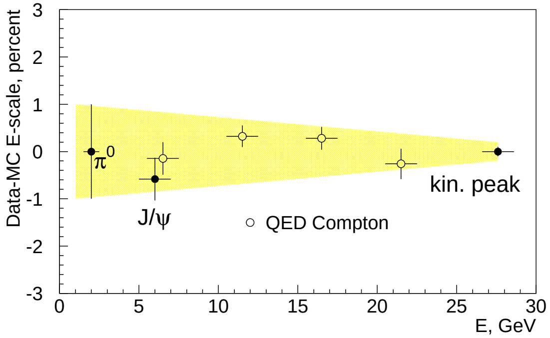
Low Q^2 Prospects F_2

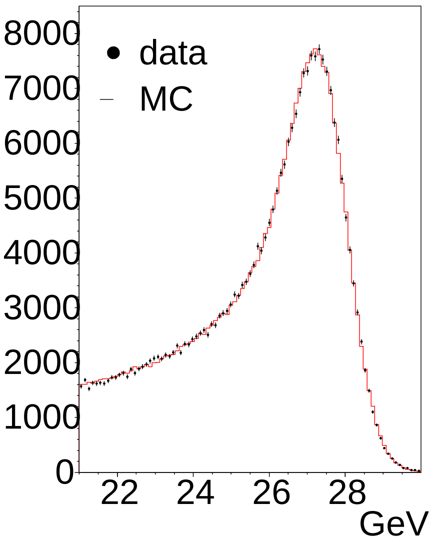
- High precision measurements (1%) in the low Q^2 bulk region
- Measurements at very high y, γp background control with the help of e^+ and e^- beams and electron tracking in the whole Q^2 range with the upgraded "Backward Silicon Tracker"
- Improved understanding of the lepton energy scale
- Finally: combination of ZEUS+H1 data for QCD analysis

BST Charge Measurement (H1)



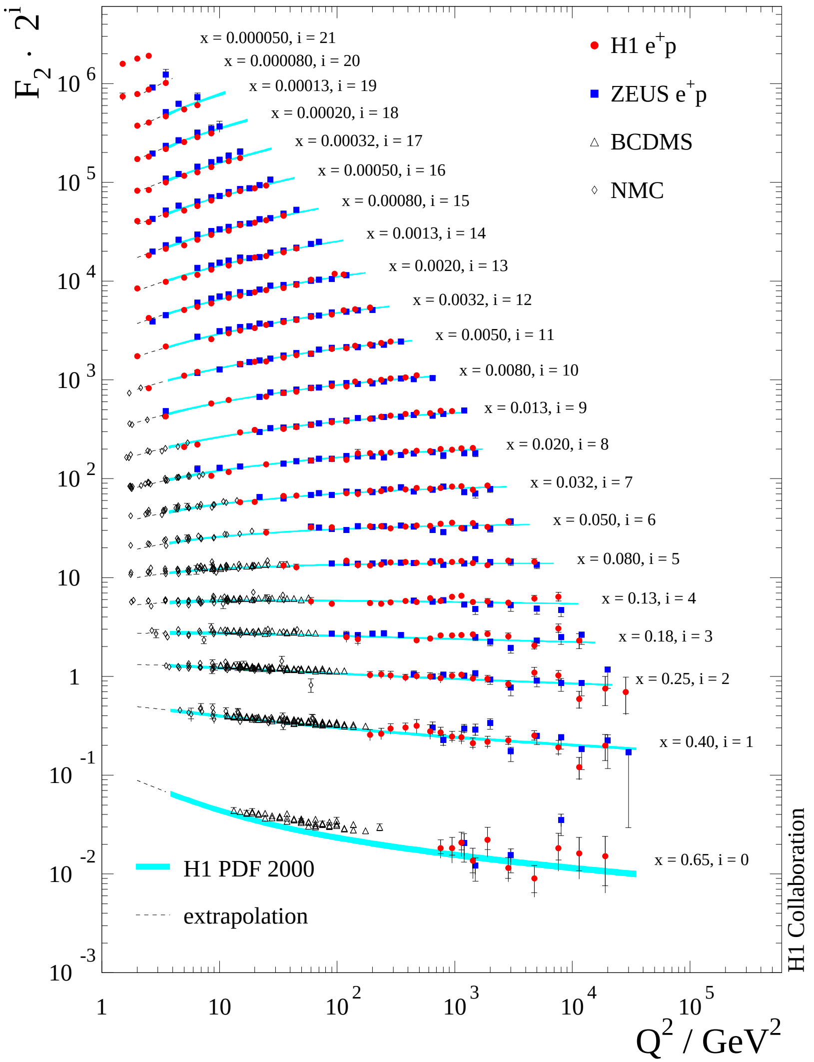
Spacal Energy Scale (H1)





High Q^2 Status

- At highest Q^2 measurements are still statistics limited
- New at HERA II: $e^{\pm}$-beam typically $\sim 35\%$ polarized
- By measuring CC and NC inclusive cross sections with both helicity and charges of the lepton $e^{\pm}_{R/L}$, electroweak tests and parton flavor decomposition within one experiment are possible



High Q^2 NC

- Using structure functions generalized for polarization $\tilde{F}_2$, $\tilde{F}_L$, and $x\tilde{F}_3$ the reduced inclusive NC cross section is

$$\tilde{\sigma}^{\pm}_{NC} = \frac{\mathrm{d}^2\sigma^{e^\pm p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2 Y_+} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3, \quad Y_\pm = 1 \pm (1-y)^2$$

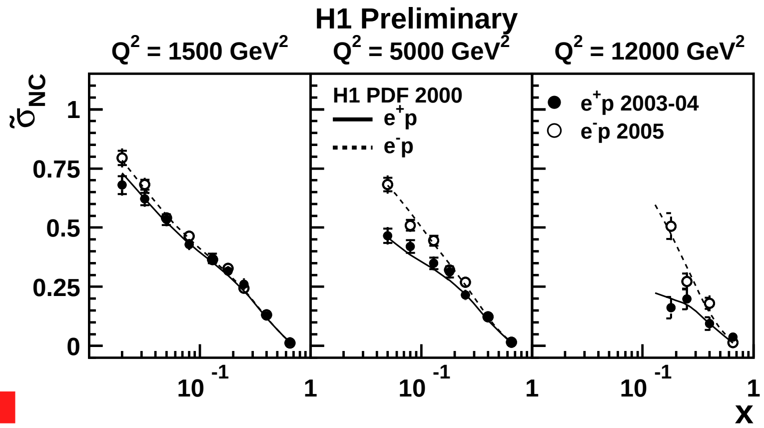
- $\tilde{F}_i$ receives contributions from γ and Z exchange and γZ interference, in QPM these have the form

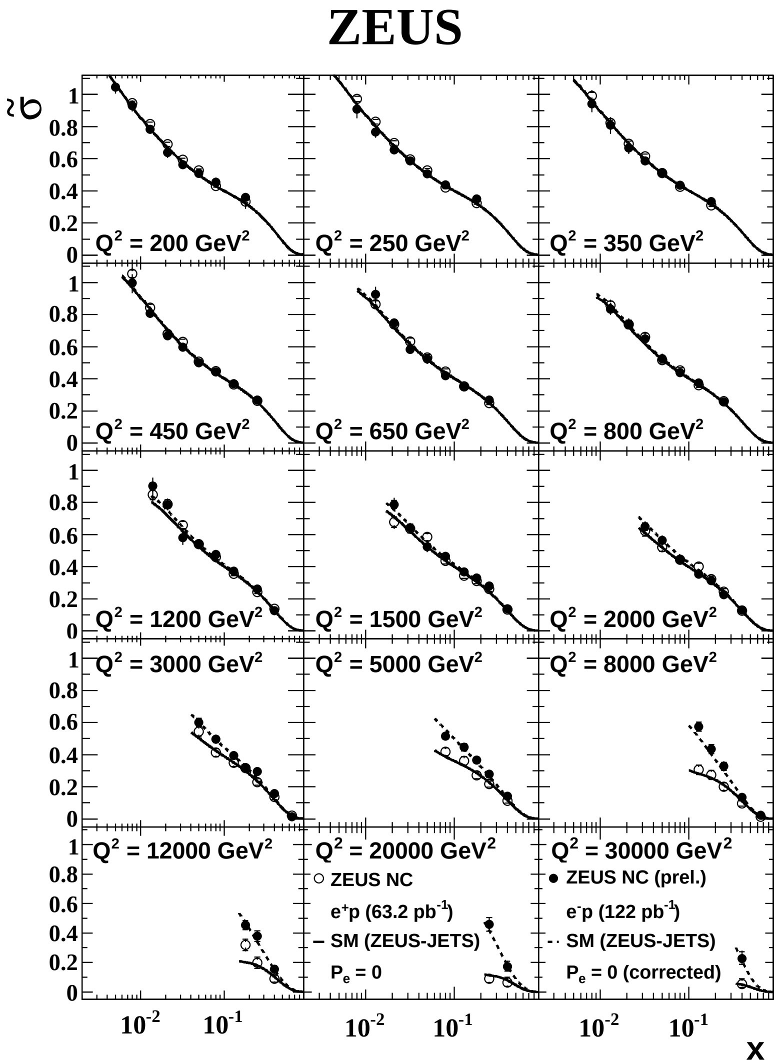
$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q+\bar{q})$$

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q-\bar{q})$$

High Q^2 NC Results

- Currently the new HERA II data being analyzed, single and double differential cross sections published, partially as preliminary
- First joint H1+ZEUS results on $x\tilde{F}_3$ and polarization asymmetry $A^{\pm}$ using total luminosity of 480 pb^{-1}





High Q^2 joint ZEUS+H1 $xF_3^{\gamma Z}$

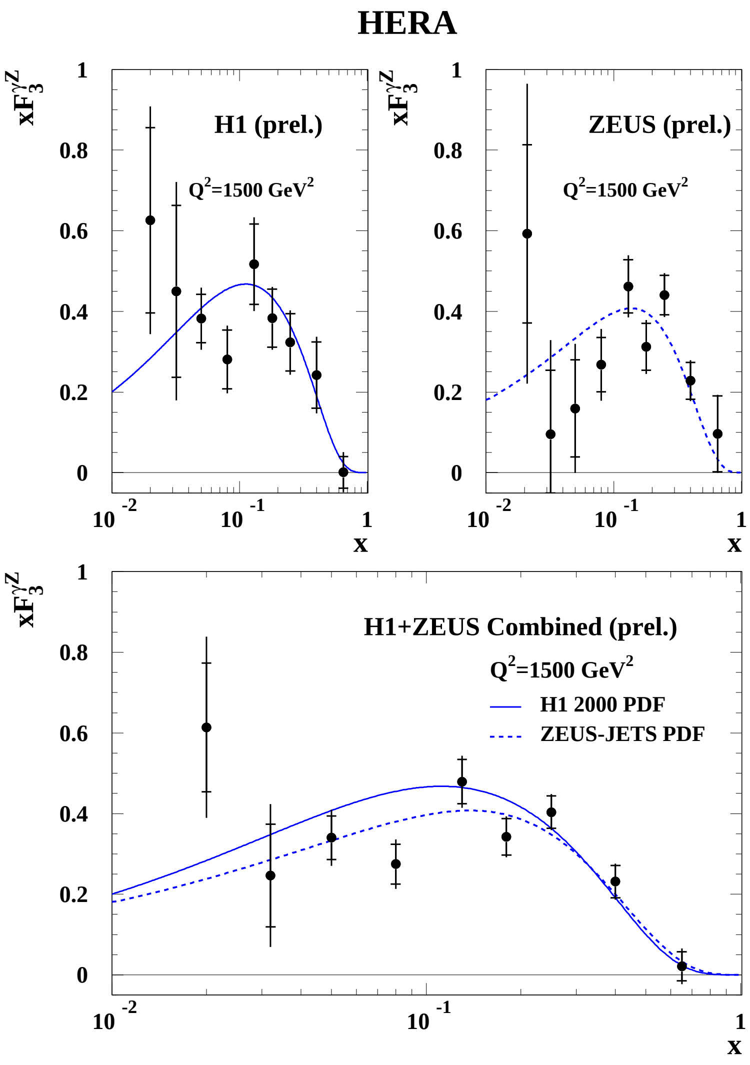
- From (net) unpolarized $e^{\pm}p$ NC cross sections the structure function $x\tilde{F}_3$ is determined

$$x\tilde{F}_3 = -\frac{Y_+}{2Y_-}\left(\tilde{\sigma}^+_{NC} - \tilde{\sigma}^-_{NC}\right)$$

- γZ interference dominates $x\tilde{F}_3$, sensitive to the valence quarks and only weakly Q^2 dependent

$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v + \Delta)$$

$$\Delta = 2(u_{sea} - \bar{u} + c - \bar{c}) \\ +(d_{sea} - \bar{d} + s - \bar{s})$$



High Q^2 joint ZEUS+H1 $A^{\pm}$

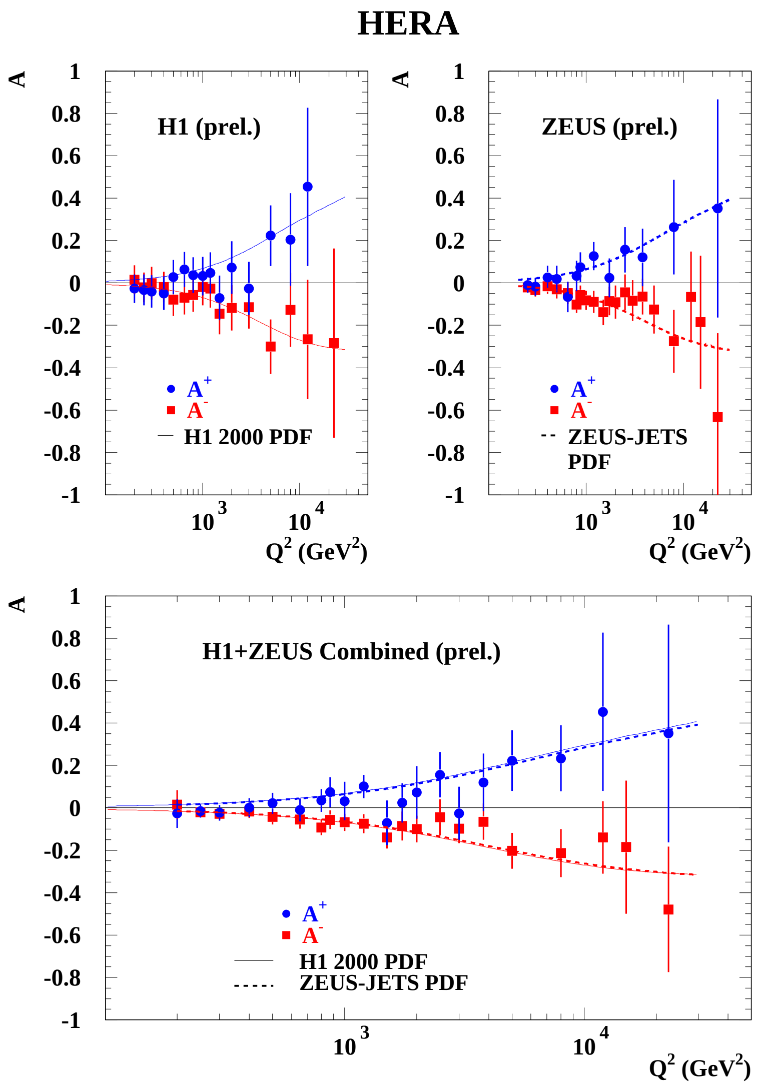
- From polarized $e^{\pm}_{RL}\,p$ NC cross sections the polarization asymmetries $A^{\pm}$ are determined

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

- $A^{\pm}$ is a direct measure of parity violation

$$A^{\pm} \simeq k a_e \frac{F_2^{\gamma Z}}{F_2} \propto a_e v_q$$

and found to differ significantly from 0



High Q^2 CC

- The CC cross section has simply a linear dependence on the longitudinal lepton polarization P

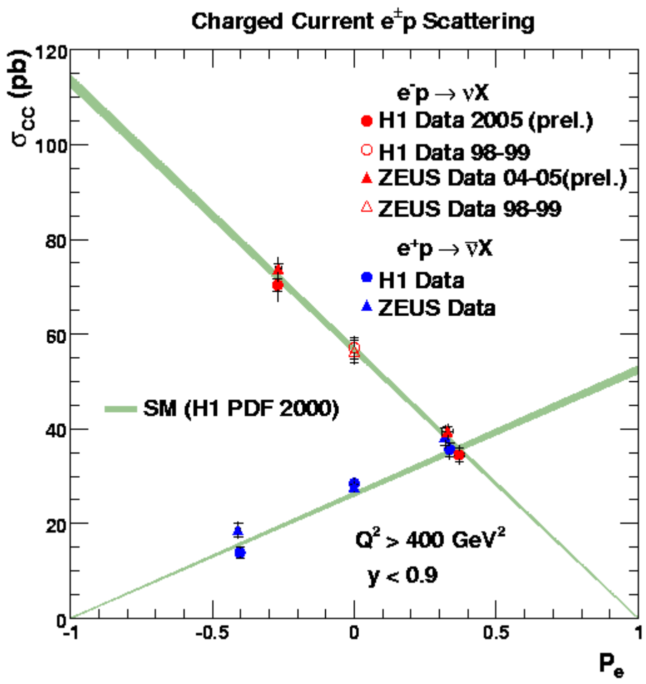
$$\frac{\mathrm{d}^2\sigma_{CC}^{e^\pm p}}{\mathrm{d}x\mathrm{d}Q^2} = (1 \pm P)\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2 + M_W^2}\right)\phi_{CC}^{\pm}$$

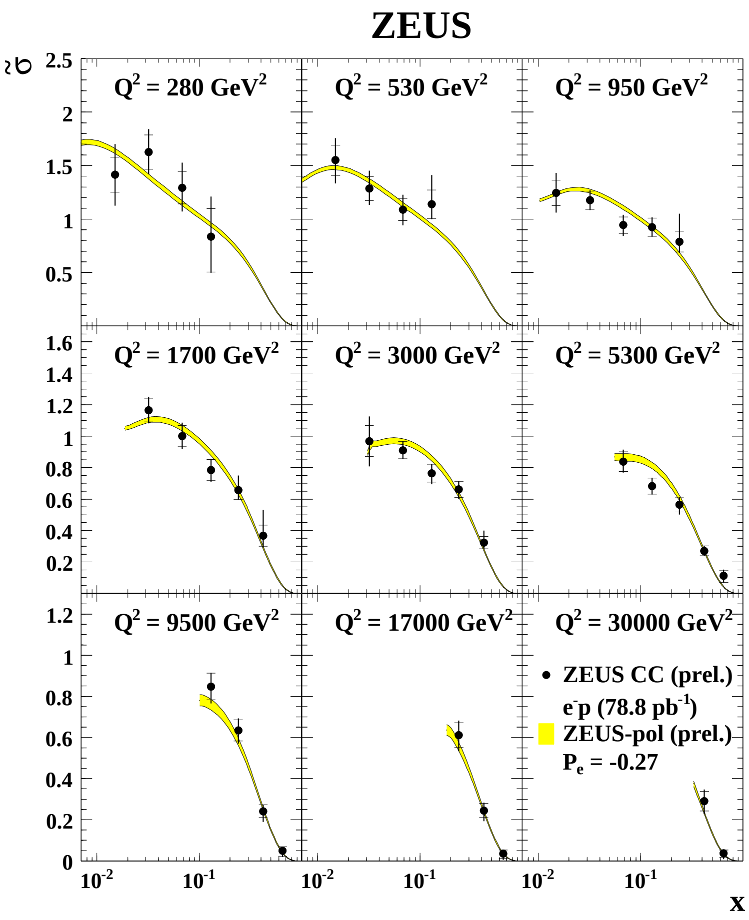
- $e^\pm$ CC scattering is sensitive to down-type and up-type quarks respectively, at LO:

$$\phi_{CC}^{-} = u + c + (1-y)^2(\bar{d} + \bar{s})$$
$$\phi_{CC}^{+} = \bar{u} + \bar{c} + (1-y)^2(d + s)$$

High Q^2 CC Results

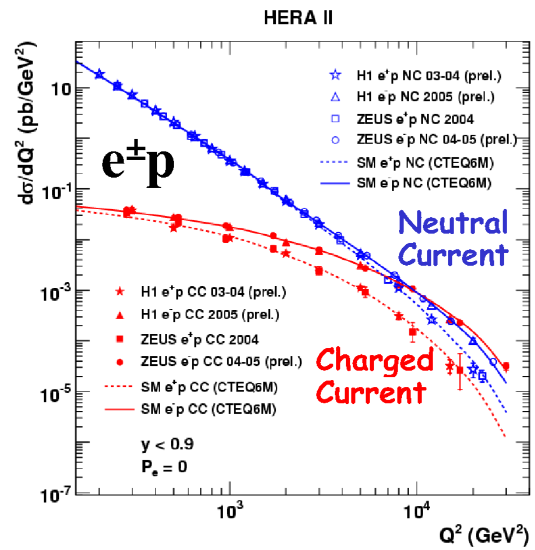
- New results on double differential, single differential and total CC cross sections
- Polarization dependence of total cross sections in agreement with the SM

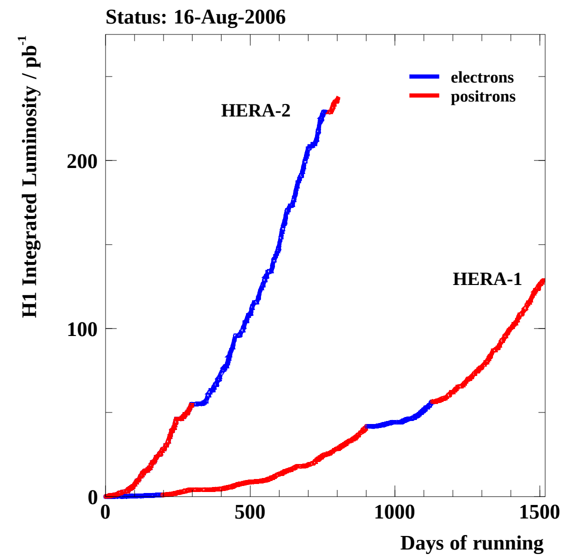




Prospects for High Q^2

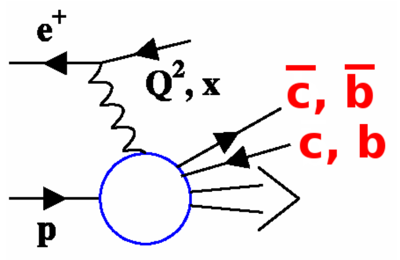
- Measurements at High Q^2 will especially profit from the full HERA I+II data set and a combination of ZEUS and H1
- Approximate physics luminosity per experiment:
  - HERA I: 100 pb^{-1} e^+p and 20 pb^{-1} e^-p
  - HERA II so far: 70 pb^{-1} e^+p and 150 pb^{-1} e^-p
  - expected until mid 2007: ~ 100 pb^{-1} e^+p

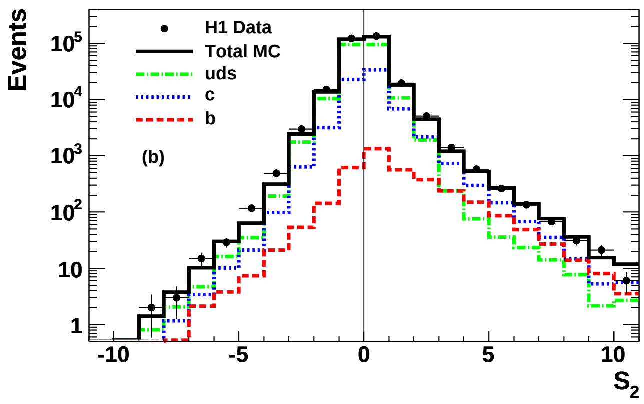


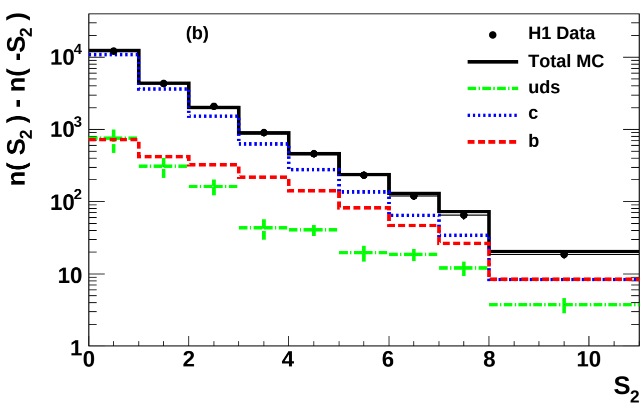


Heavy Flavor Contribution to DIS

- Production of heavy quark flavors is predicted in pQCD
  - NLO and NNLO calculations available
  - Various schemes for mass treatment
  - Multiple hard scales: m_q, p_t, Q^2
  - Boson-Gluon fusion dominant: constraint on the gluon density
- Flavor tagging possible with D^*, μ ...
- The most inclusive test so far at HERA: Signed impact parameter determined with the H1 Central Silicon Tracker



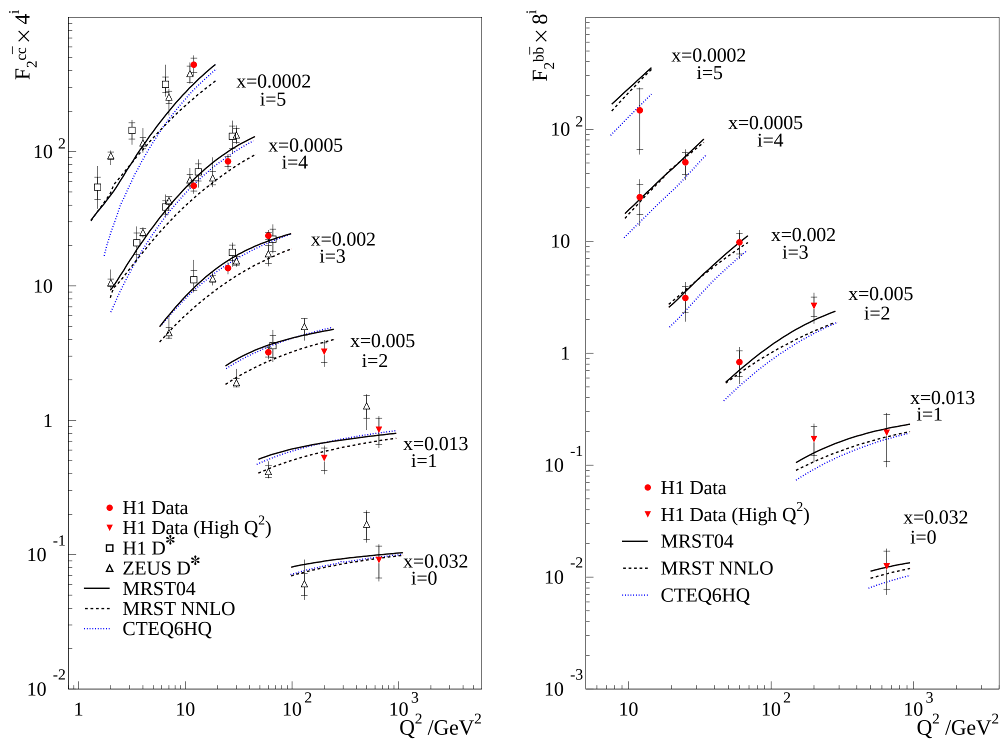




Heavy Flavor Contribution to DIS

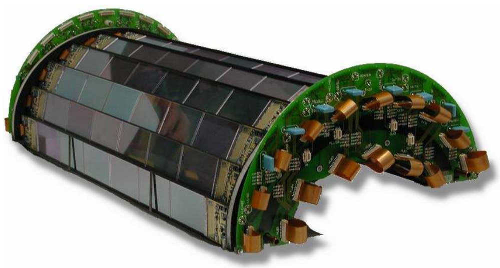
- H1 extracted the Charm and Beauty contributions to the total inclusive cross section $\sigma_r^{cc/bb} = F_2^{cc/bb} - y^2/Y_+ F_L^{cc/bb}$ with HERA I data using the impact parameter method

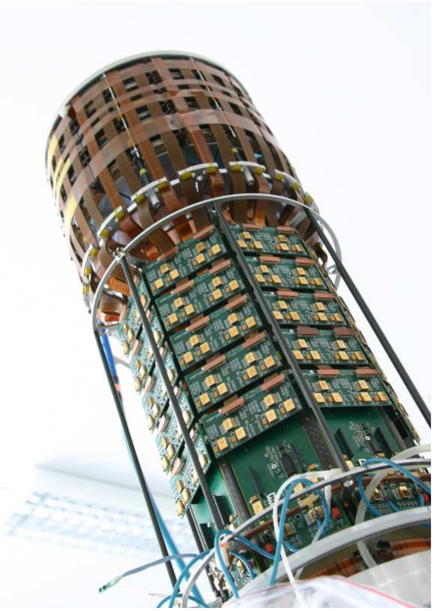
- Charm contribution to total cross section is $\sim 25\%$, Beauty contribution $\sim 1\%$, depending on Q^2
- Heavy flavor production in inclusive ep is well understood in terms of pQCD



Silicon Detectors at H1 & ZEUS

- At HERA II both H1 and ZEUS have silicon detectors installed in the forward and central region, H1 also has silicon tracking in the backward region
- Together with higher luminosity improvements on F_2^{cc} and F_2^{bb} can be expected once the detectors are fully understood





H1 CST and FST

ZEUS MVD

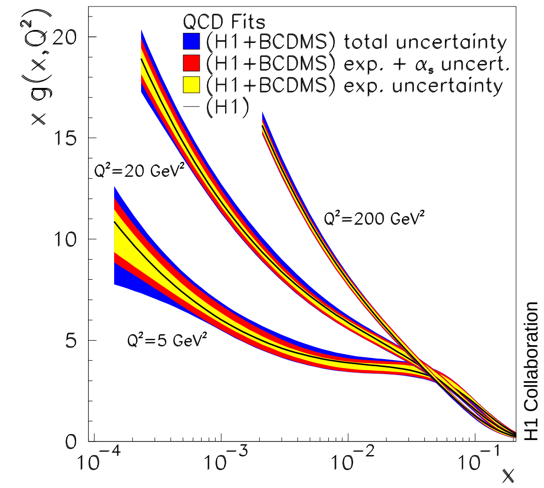
QCD Analyses and PDFs

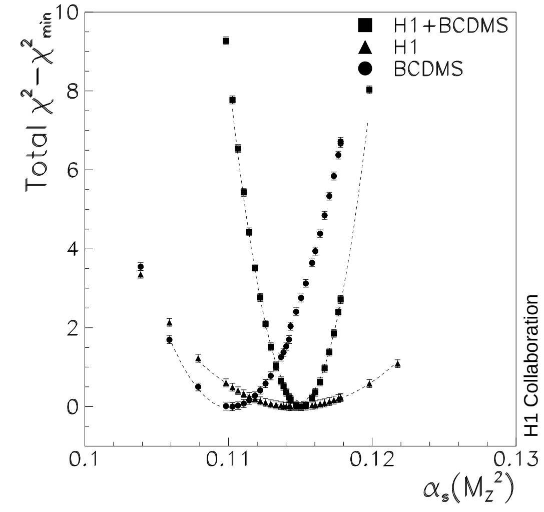
- So far QCD analyses of H1 and ZEUS differed by assumptions, input data and goals:
  - H1: Gluon and α_s fit using inclusive DIS HERA I + BCDMS data
  - H1: PDF 2000 Fit using inclusive DIS HERA I data
  - ZEUS-S fit using inclusive DIS HERA I + fixed target data
  - ZEUS-JETS fit using inclusive DIS + Jet HERA I data
  - ZEUS-pol fit (preliminary) using inclusive DIS + Jet HERA I+II data
- All are based on NLO DGLAP equations
- All fits give a reasonable description of their input data, the extracted PDFs are usually in fair agreement

H1 Gluon and α_s Fit

- Goal was to determine the gluon distribution $xg(x, Q^2)$ from H1 data (HERA I, $Q^2 < 3000$ GeV^2) alone and α_s with additional BCDMS data
- The fitted distributions are xg, $V = \frac{9}{4}u_v - \frac{3}{2}d_v$, and $A = \bar{u} - \frac{1}{4}(u_v - 2d_v)$ (valence and sea-like distributions) to enable the gluon extraction from H1 data alone
- The result for α_s

$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0017(exp)^{+0.0009}_{-0.0005}(model)$$
$$\pm 0.005(ren.scale)$$

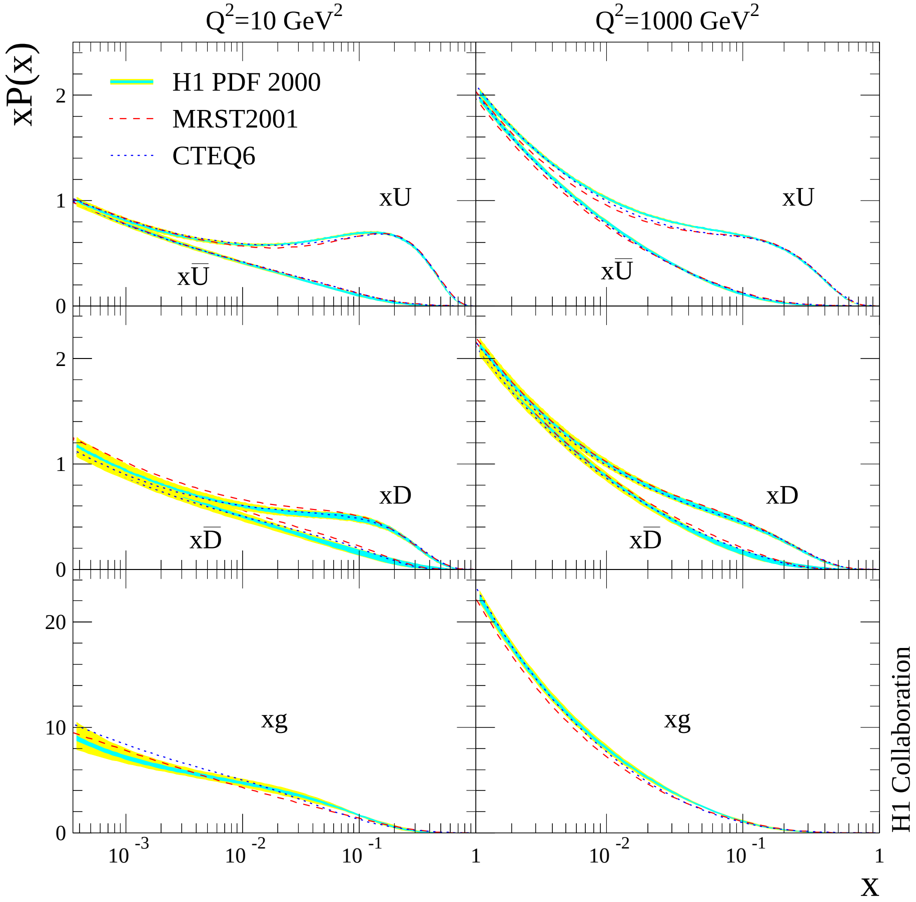




H1PDF 2000 Fit

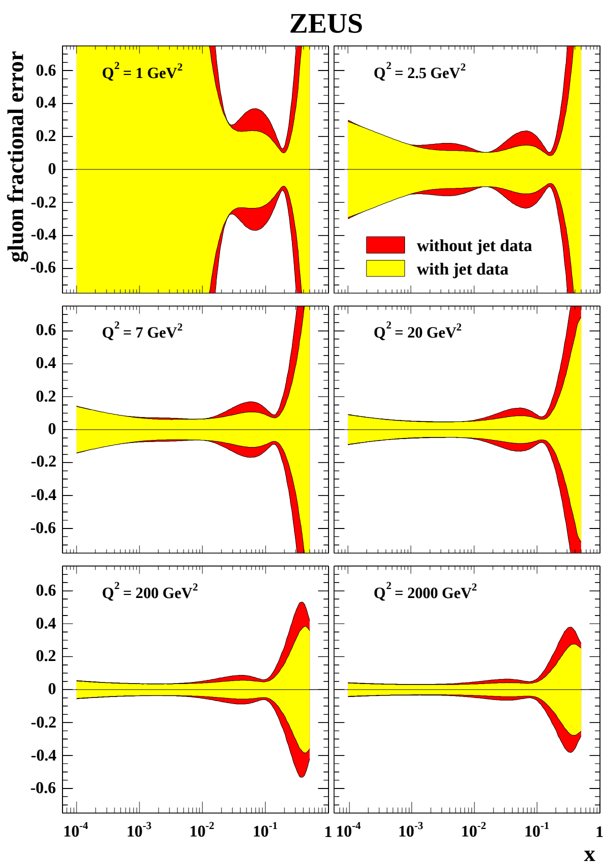
- Determine flavor separated parton distributions of the proton, keep α_s fixed

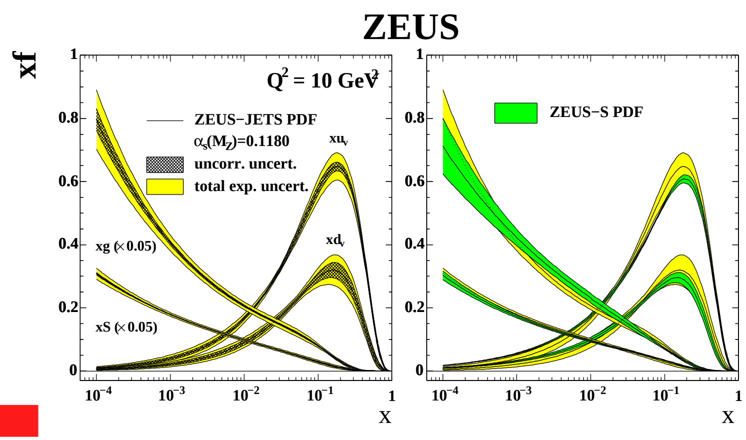
- Uses only H1 HERA I inclusive DIS data
- The fitted distributions are xg, xU, $x\bar{U}$, xD, and $x\bar{D}$ with $xU = x(u+c)$ etc.
- Weakens the influence of assumptions about the flavor decomposition of the sea

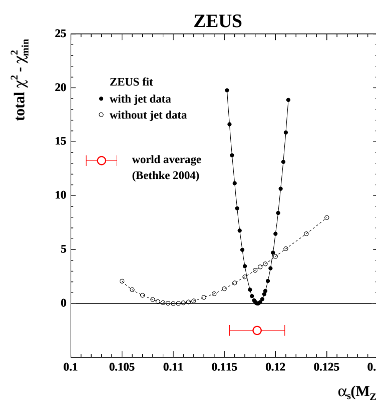


ZEUS-Jets Fit

- Uses ZEUS DIS + Jet production data to determine flavor separated parton distributions and α_s
- Fitted distributions are xu_v, xd_v, xS, xg, and $x(\bar{d}-\bar{u})$
- α_s determination from ZEUS only:
  $$\alpha_s(M_Z^2) = 0.1182 \pm 0.0028(exp) \pm(0.0008)(model) \pm 0.005(renorm)$$

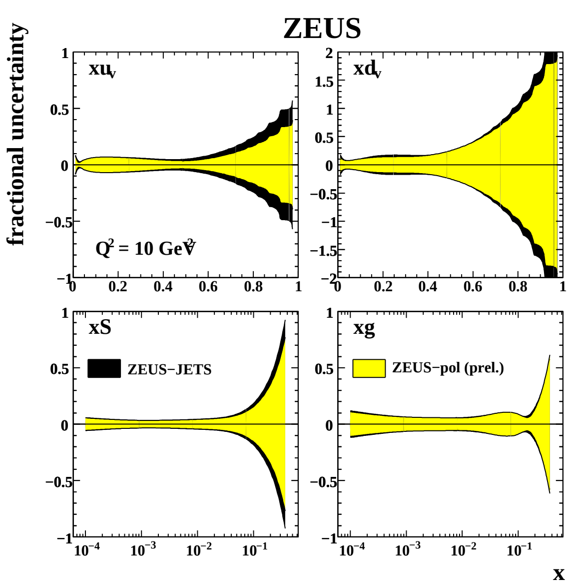


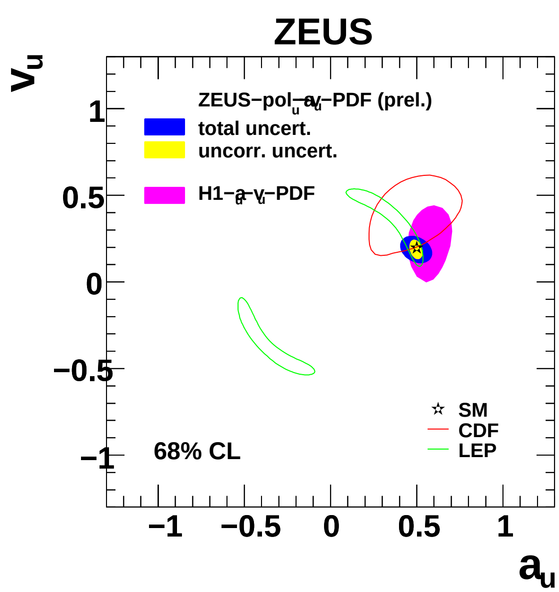


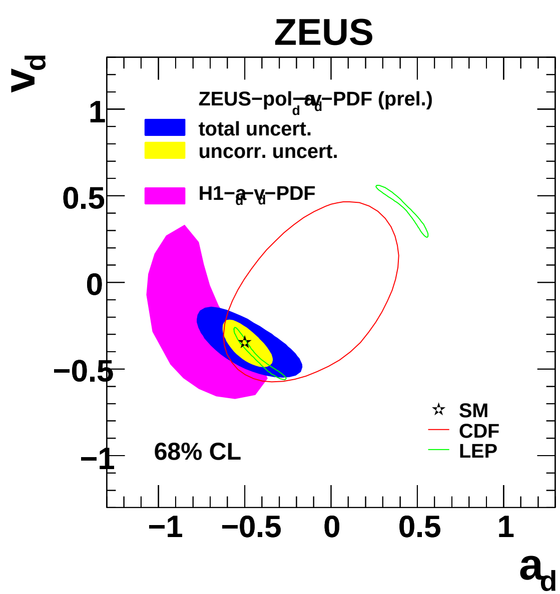


ZEUS-pol Fit

- The ZEUS Jet fit has been updated with polarized high Q^2 HERA II $e^- p$ data
- Higher precision for the valence quarks at high x
- Fits with two of the electroweak (light) quark couplings a_u, v_u, a_d, v_d as free parameters give SM-compatible results, improved precision over HERA I only results by H1

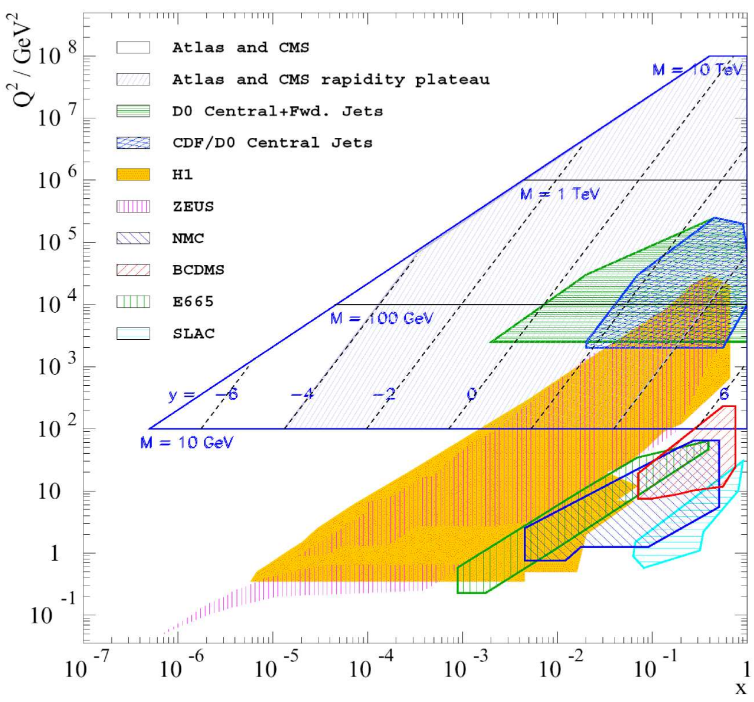


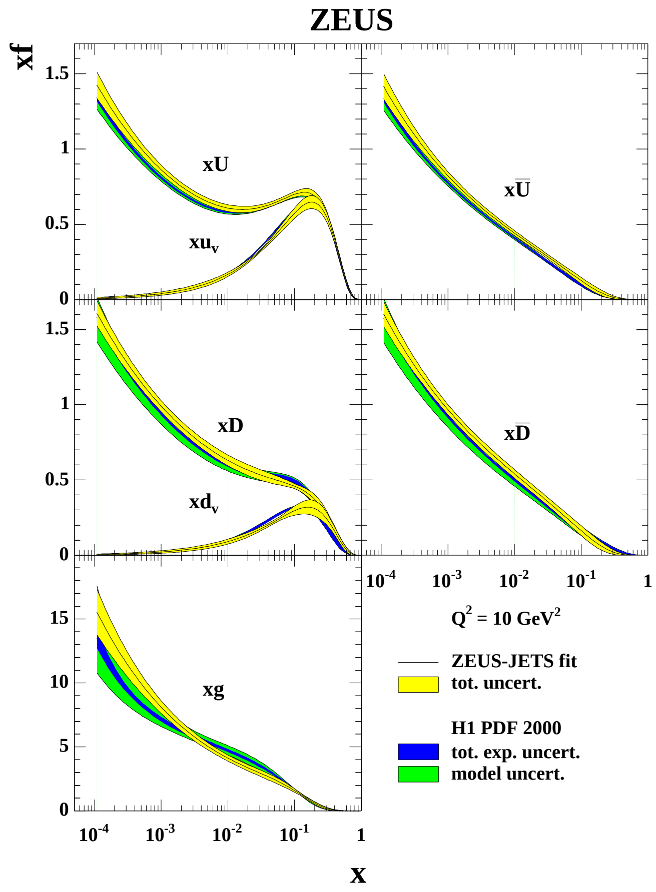




Status of PDFs

- Up to now fair agreement between the PDFs extracted with different approaches
- Precise knowledge essential for LHC





Prospects for PDFs

- Further improvements of experimental input possible:
  - Ultimate precision at low Q^2 bulk and high y
  - With the low E_p run F_L can be measured directly
  - High Q^2 DIS with high luminosity enables flavor decomposition within one experiment
- Anticipated steps:
  - Combination of all HERA data, proper treatment of correlated errors may lead to reduction of systematic errors as well
  - NNLO QCD analysis on combined data
  - Cross checks and improvements with semi-inclusive data (e. g. jets and heavy quarks)

Conclusions

- HERA has still potential at low Q^2
- Low E_p run expected for next year to measure F_L directly at HERA
- With increased luminosity and availability of polarized $e^\pm$ beams new and improved measurements at high Q^2 possible
- With new silicon detectors and high luminosity the heavy quark contributions will be better determined
- Reduction of the PDF uncertainties with improved experimental input, HERA combined data, and NNLO QCD analysis will lead to valuable input for the LHC and test QCD