Measurement of the Inclusive ep Scattering Cross Section at Low and Medium Q^2 at HERA

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On behalf of the H1 Collaboration

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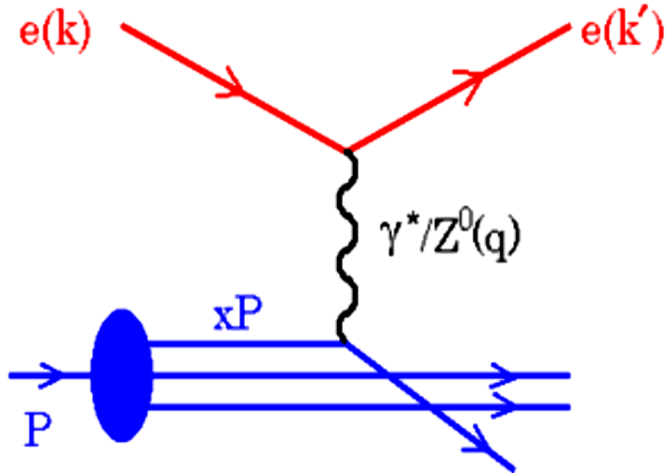
Overview

- Introduction to Deep Inelastic Scattering
- New Cross Section Measurements and Combination
- Analysis of the Structure Function F_2
- Summary

Introduction

- Kinematics of Deep Inelastic Scattering (DIS) described by Lorentz invariant quantities:
  - Q^2 virtuality/resolving power
  - x Bjorken scaling variable, momentum fraction of the scattered parton
  - y inelasticity



- Related by $Q^2 = xys$, where $\sqrt{s} = 320$ GeV at HERA
- DIS is a unique tool to
  - Test QCD dynamics: validity of evolution equations, with a wide range of Q^2 and x accessible at HERA
  - Measure the substructure of the proton: quark and gluon content, so called Parton distribution functions (PDFs)
- Precise knowledge of the PDFs is vital for measurements at hadron colliders as the LHC

Inclusive DIS Cross Section

- Two structure functions $F_2(x, Q^2)$, $F_L(x, Q^2)$ parametrise the inclusive NC cross section for $ep \rightarrow e'X$ at $Q^2 \ll M_Z^2$:

$$\frac{\mathrm{d}^2\sigma^{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4} \underbrace{\left(F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)\right)}_{\text{Reduced cross section } \sigma_r} \ , \ Y_+ = 1 + (1-y)^2$$

- Contribution of F_2 to the cross section is dominant in most of the phase space, Effect of F_L only sizable at $y > 0.6$

  F_L *analyses* $\rightarrow$ *Talk by B. Reisert*

- In the Quark-Parton Model simple relation to quark distribution functions $q_i(x)$:

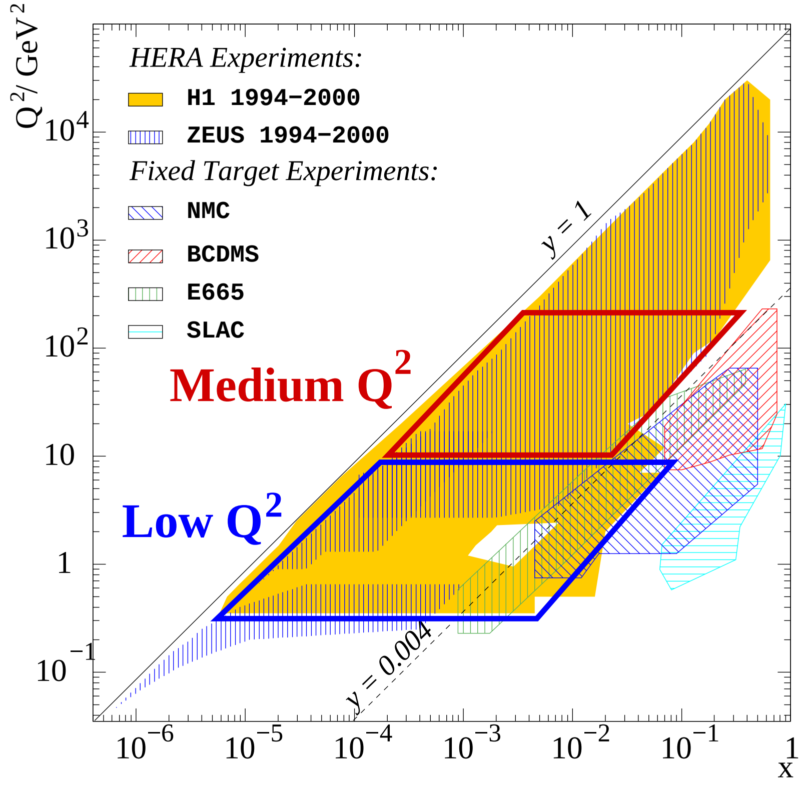
$$F_2(x) = x \sum_i e_i^2 (q_i(x) + \bar{q}_i(x)) = \sigma_r \ , \ F_L = 0$$

- Scaling violations sensitive to the gluon $xg(x, Q^2)$ and α_s

$$\partial F_2(x, Q^2)/\partial \ln Q^2 \propto \alpha_s \cdot xg(x, Q^2)$$

New Measurements

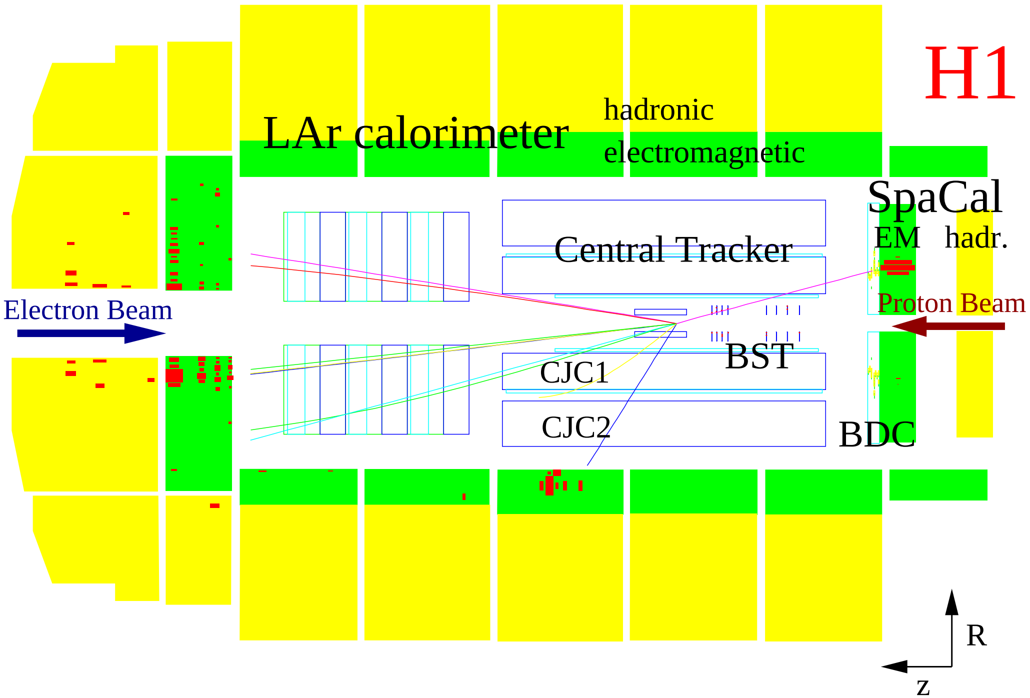
- Here new measurements of the inclusive DIS cross section $ep \to e'X$ using the H1 detector at HERA are presented
- Region of **Low** $0.2\,\mathrm{GeV}^2 \leq Q^2 \leq 12\,\mathrm{GeV}^2$:
  Transition from DIS regime to Photoproduction
- Region of **Medium**
  $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$:
  highest accuracy in a region, where perturbative QCD calculations are believed to be reliable



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

Event Selection and Reconstruction

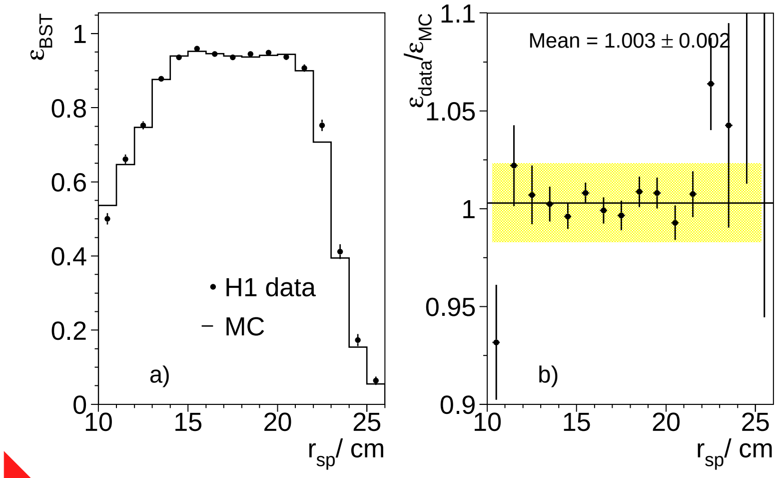
- At $Q^2 \lesssim 150\,\mathrm{GeV}^2$, the scattered electron is detected in the “backward” calorimeter SpaCal
- At low Q^2 the Backward Silicon Tracker (BST) is used for kinematics reconstruction

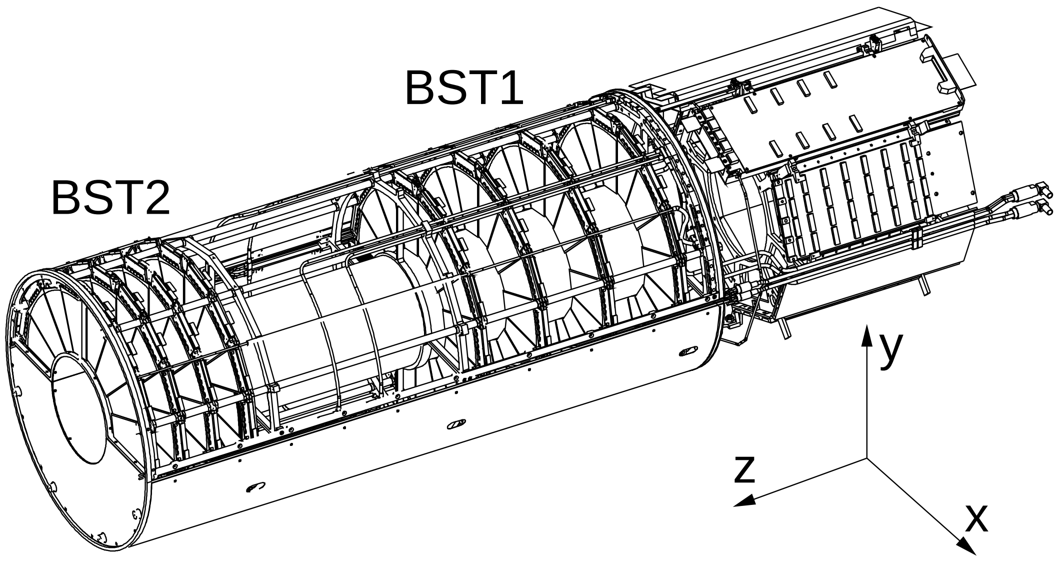


- At higher Q^2 the Central Tracker and Backward Drift Chamber (BDC) are used to determine kinematics
- Hadronic Final State *(HFS)* combined from tracks and calorimeters (LAr + SpaCal)

Backward Silicon Tracker (BST)

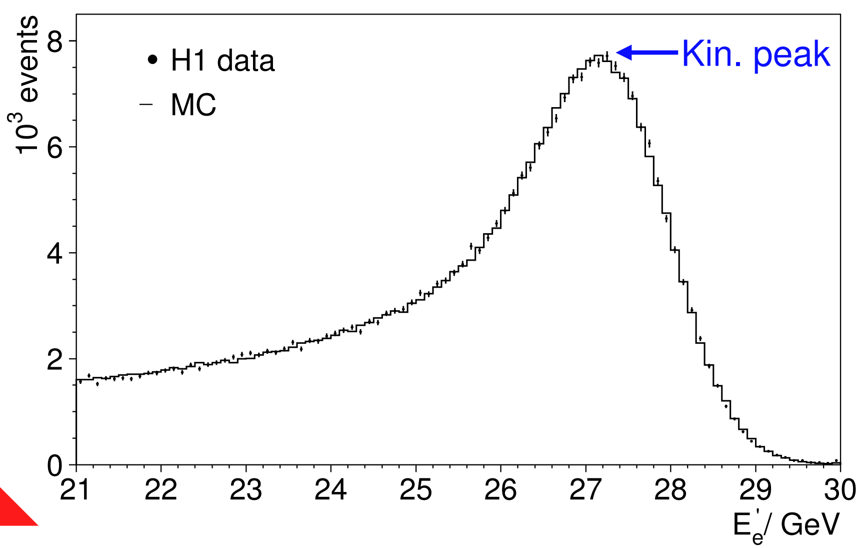
- 8 planes with 16 silicon modules each, 640 radial strips per module, Hit resolution $\delta r \approx 20\,\mu$m
- Precision measurement of electron scattering angle θ_e and event vertex: for low $Q^2 \lesssim 20\,\mathrm{GeV}^2$ the event can be reconstructed entirely from the scattered electron
- Track reconstruction efficiency $\sim 95\%$, controlled to 2%
- Alignment accuracy to $\delta\theta_e = 0.2\,$mrad

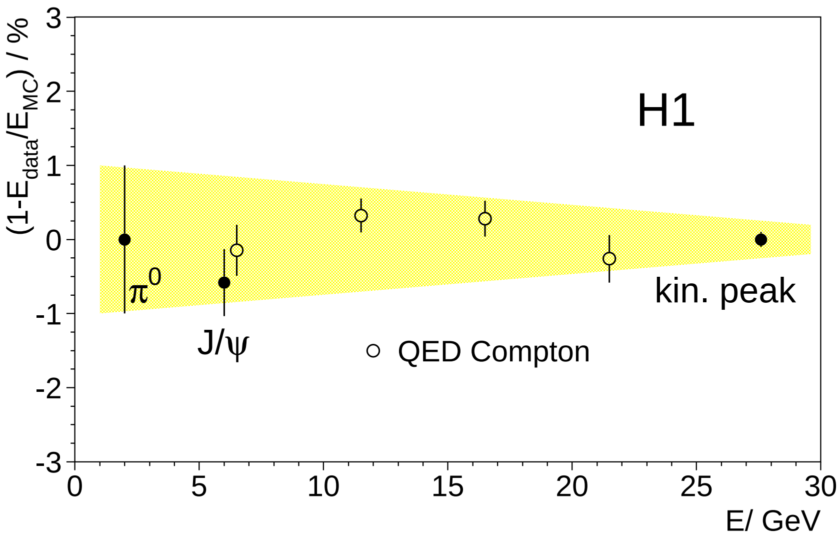




Electron Energy Calibration

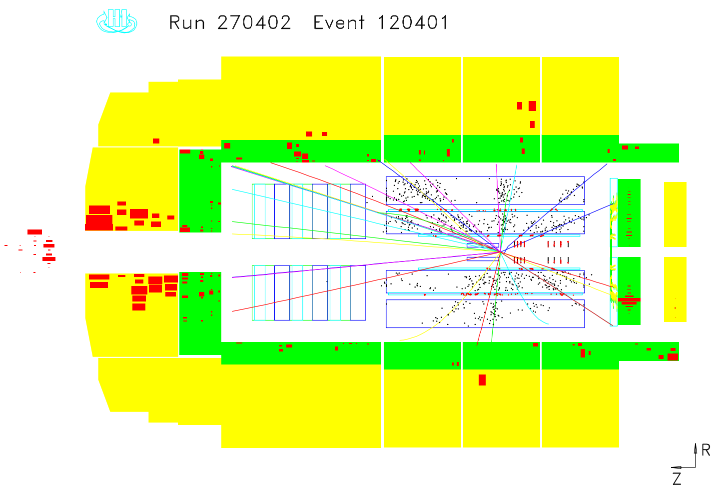
- Control over scattered electron energy scale E'_e is one key issue for small systematic uncertainties
- Multistep calibration procedure at the “kinematic peak” to correct for various instrumental effects
- Nonlinearity is corrected with $\pi^0 \to \gamma\gamma$ at low energies
- Cross checks with $J/\psi \to ee$ and QED Compton events $ep \to ep\gamma$, Systematic uncertainty of $0.2 - 1\%$





Kinematics

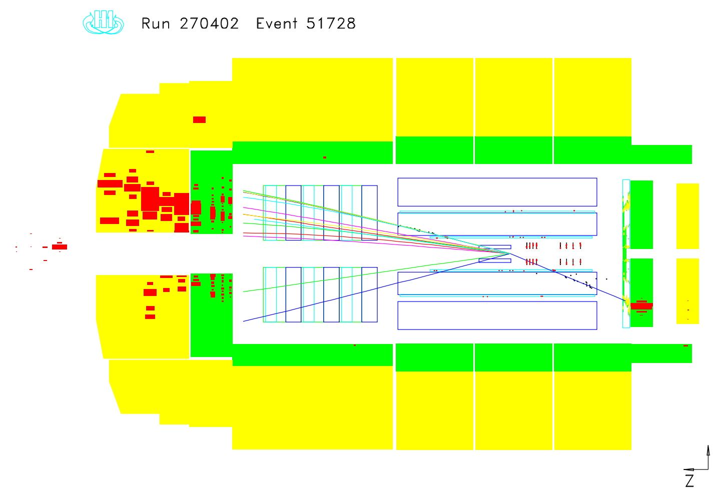
- High Inelasticity $y \gtrsim 0.1$



$y_e = 0.5,\ Q^2_e = 50\,\mathrm{GeV}^2,\ x_e = 0.001$

- **Electron Method**: Reconstruction entirely from scattered electron polar angle θ_e and energy E'_e

- Low Inelasticity $y \lesssim 0.1$

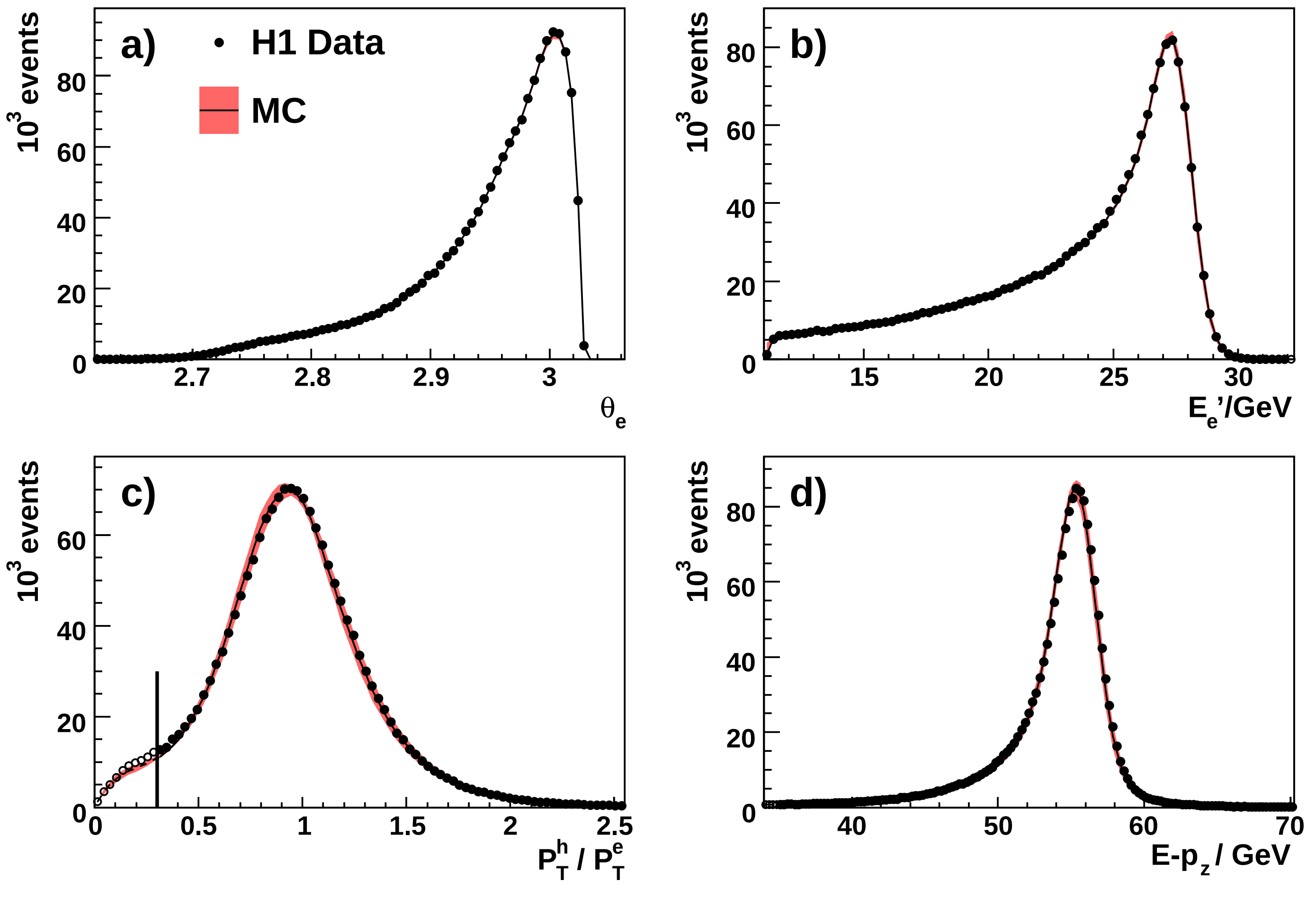


$y_\Sigma = 0.02,\ Q^2_\Sigma = 120\,\mathrm{GeV}^2,\ x_\Sigma = 0.06$

- **Σ (Sigma) Method**: Uses longitudinal HFS information $E - p_z$ in addition to θ_e and E'_e
- Correctly reconstructs ISR events: can reach lower Q^2 at high x

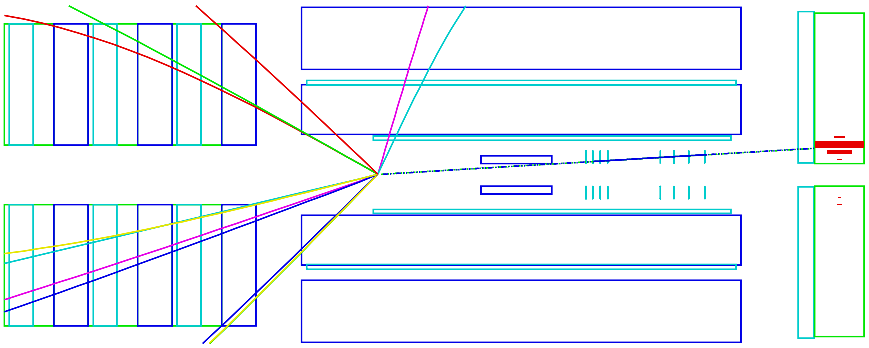
Control Plots at Medium Q^2

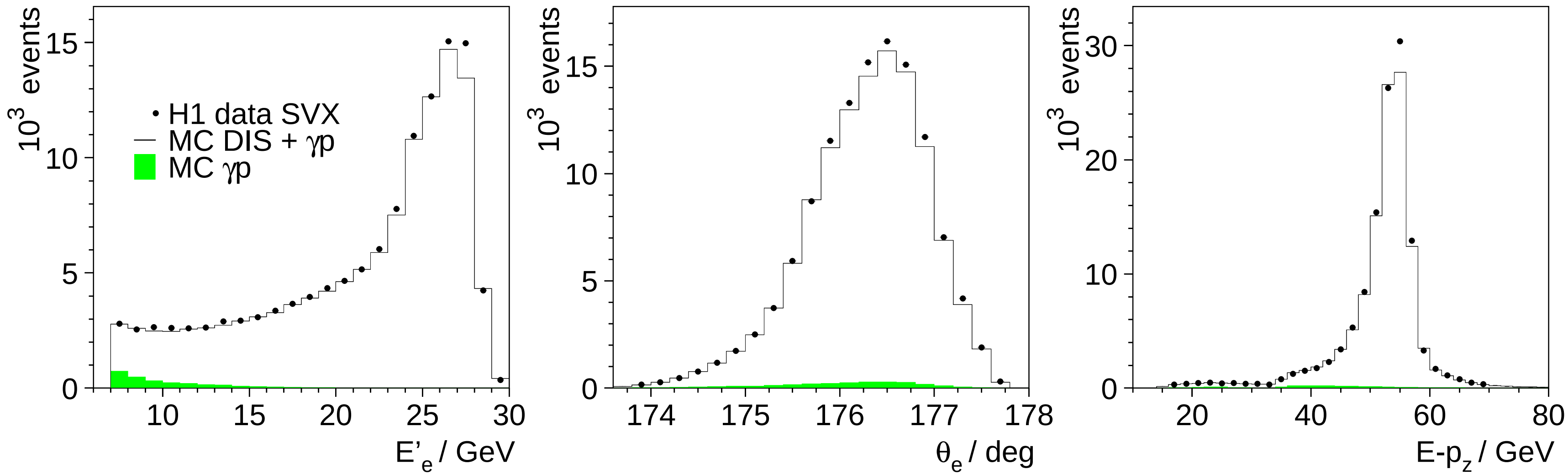
- Very good control over all essential measured detector quantities achieved, e.g. $\delta E_{HFS}/E_{HFS} \sim 2\%$, extra efficiency uncertainties $\sim 0.3 - 0.5\%$



Control Plots at Low Q^2

- Enhanced acceptance for lowest Q^2 with shifted vertex up $\theta_e \approx 177°$
- Also here very good control over all essential distributions

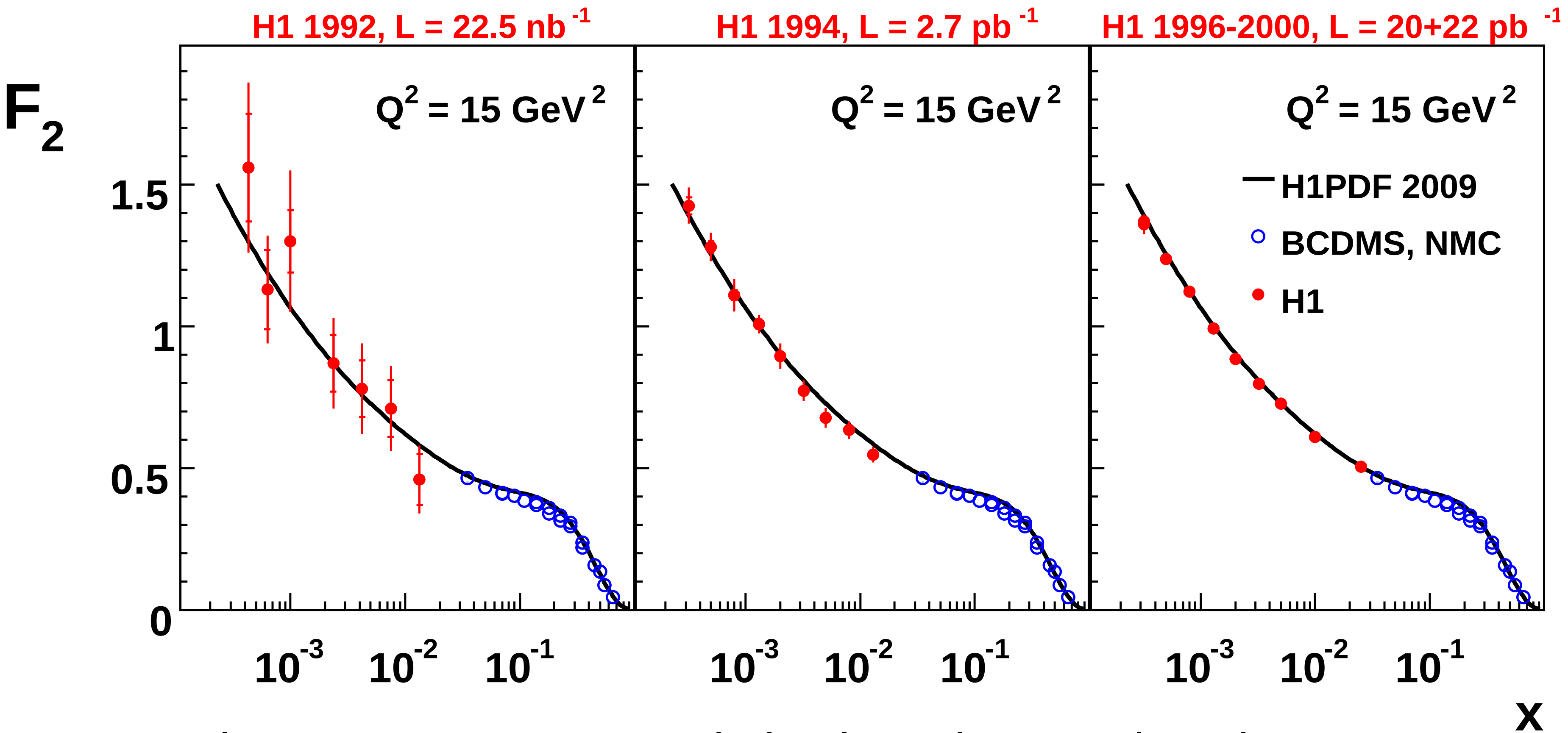




Data Combination

- New measurements cover a similar kinematic domain as the previously best H1 measurement using data from 1996/97 with $E_p = 820$ GeV Eur. Phys. J. **C21**, 33 (2001)
- Comparison and reanalysis of the older data revealed small biases of few $\%$ in published results, which are corrected for
- New measurements are averaged with the previous results to obtain two data sets covering the low and medium Q^2 domains
- Averaging is performed using a new method taking into account bin-to-bin correlated uncertainties
  also used for H1-ZEUS combination → Talk by V. Radescu
- Only small shifts of correlated systematic sources required
- Good consistency of data sets:
  - Low Q^2 1995-2000 combination: $\chi^2_{\text{tot}}/n_{\text{dof}} = 86/125$
  - Medium Q^2 1996-2000 combination: $\chi^2_{\text{tot}}/n_{\text{dof}} = 51.6/61$

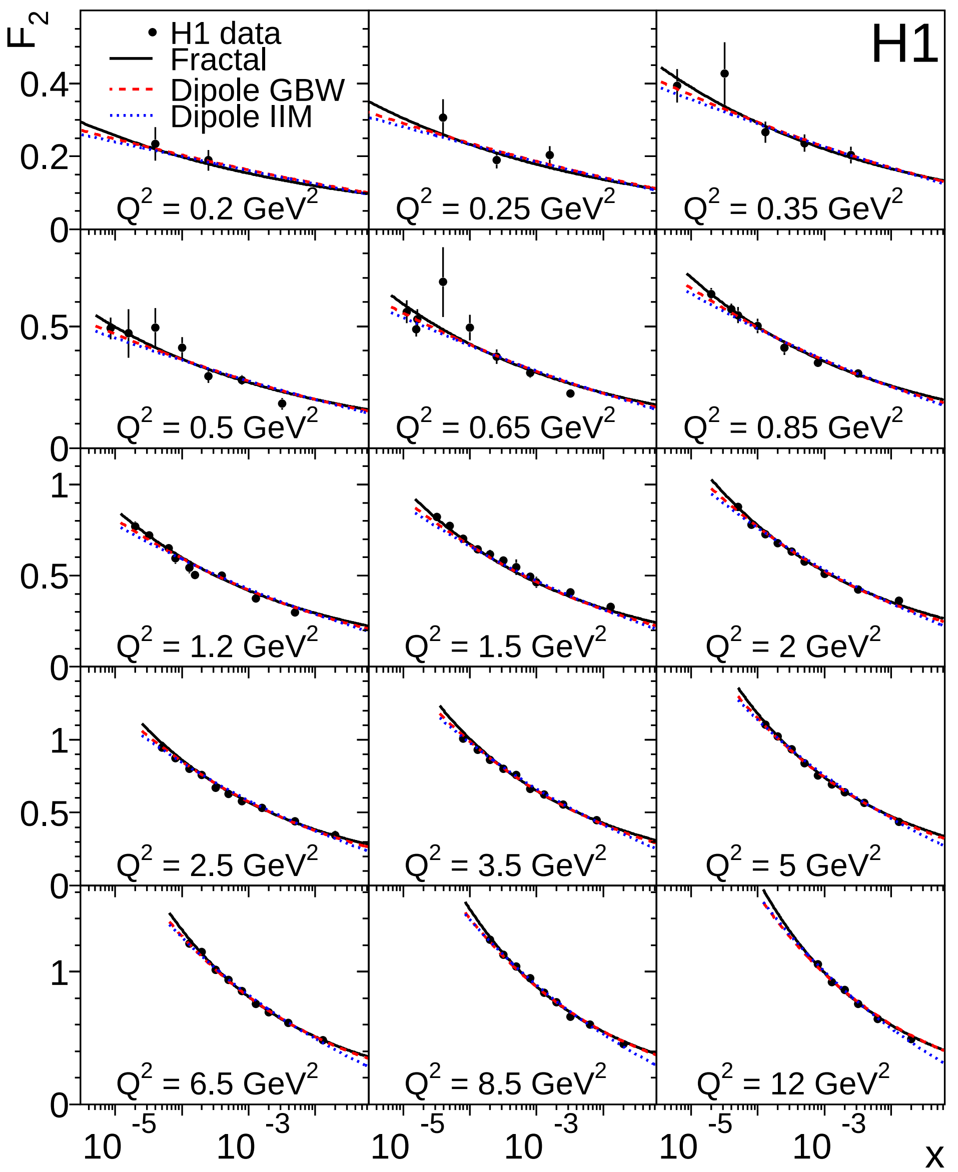
History of H1 F_2 Measurements



- Total measurement uncertainties have been reduced to $\sim 1.3 - 2\%$ in the medium Q^2 domain
- At lower Q^2 uncertainties slightly larger with $\sim 2\%$ in most of the phase space

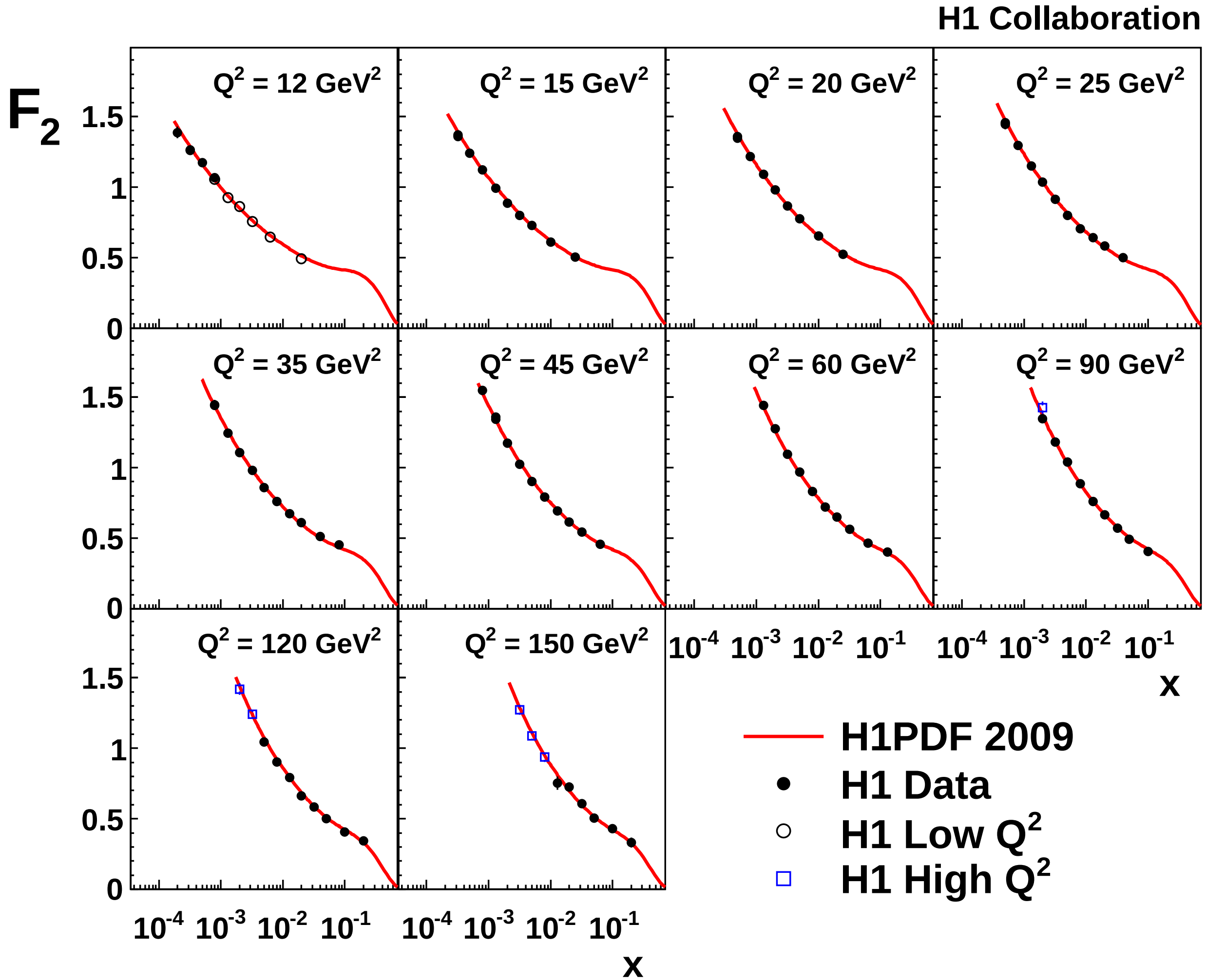
F_2 at fixed Q^2

- F_2 is extracted from the cross section σ_r for $y < 0.6$ using a fixed $R = \frac{F_L}{F_2 - F_L} = 0.5$
- Well described by models applicable in the low x region for $Q^2 \to 0$:
  - Fractal model: 4 parameter description based on concept of self similarity
  - Colour Dipole Models (GBW, IIM): virtual photon splits into colour dipole, which interacts with proton



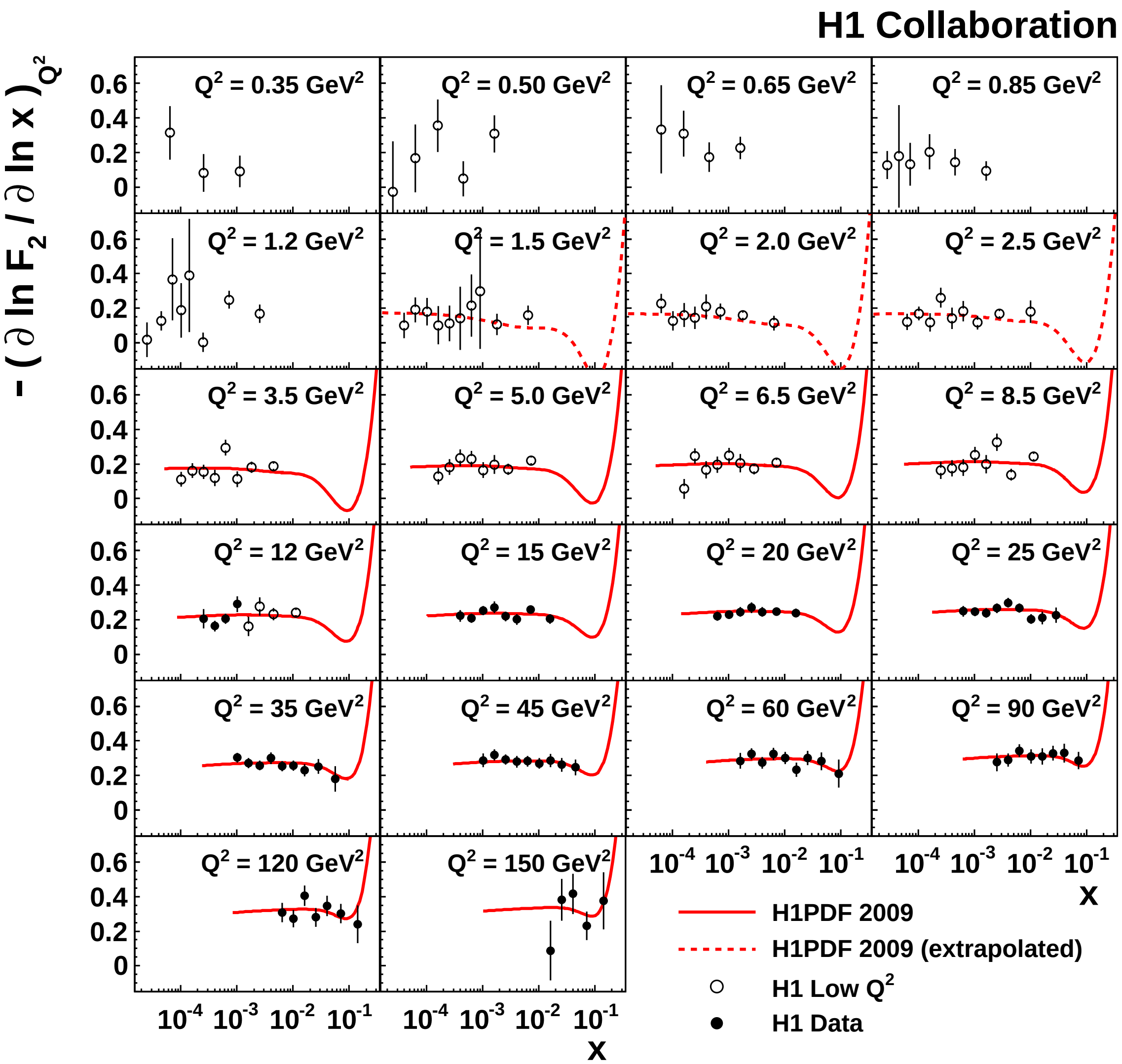
F_2 at fixed Q^2

- F_2 is extracted for $y < 0.6$ using R given by the QCD fit
- Steep rise of F_2 towards low x, well described by QCD



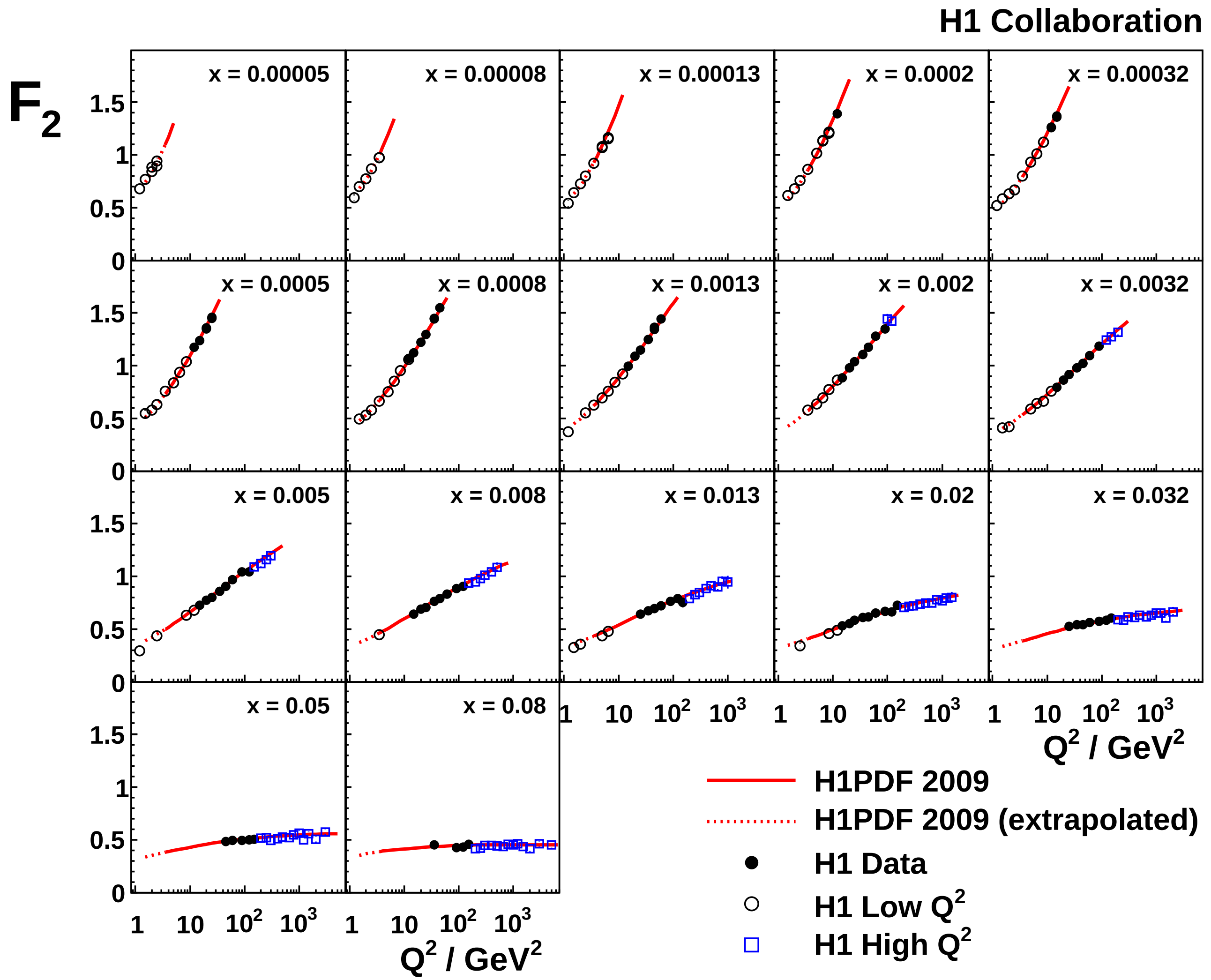
$\partial \ln F_2 / \partial \ln x$ at fixed Q^2

- At low $x < 0.01$, $\partial \ln F_2 / \partial \ln x \approx$ const.
  $\Rightarrow$ Rise of F_2 towards low x compatible with power law $F_2 \propto x^{-\lambda}$
- λ increases with Q^2
- Small dependence of λ on x also possible



F_2 at fixed x

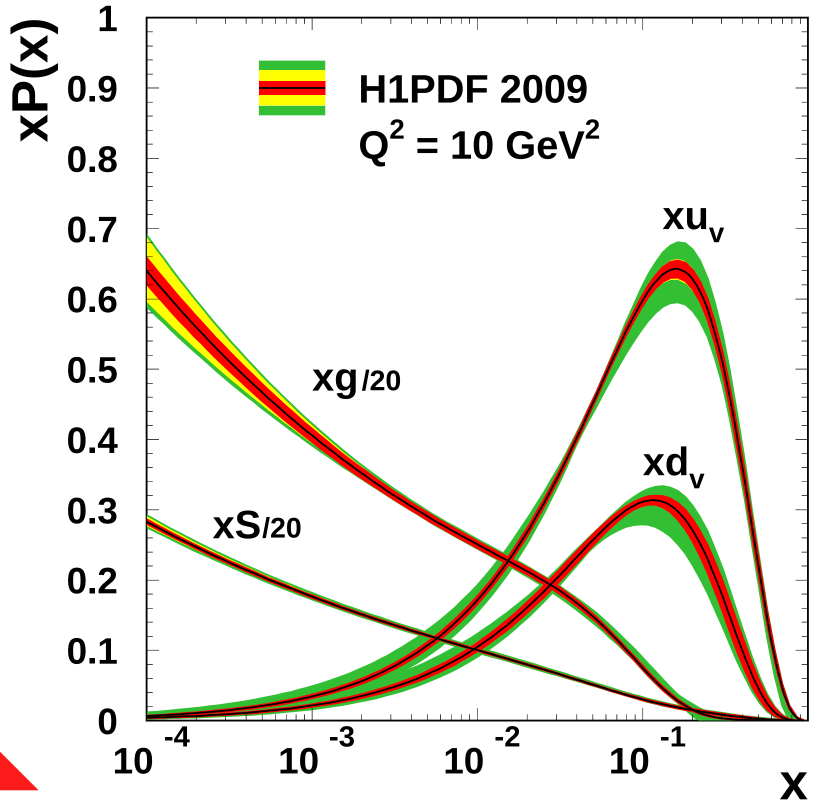
- Strong scaling violations at low x, approximate scaling behaviour for $x \sim 0.1$

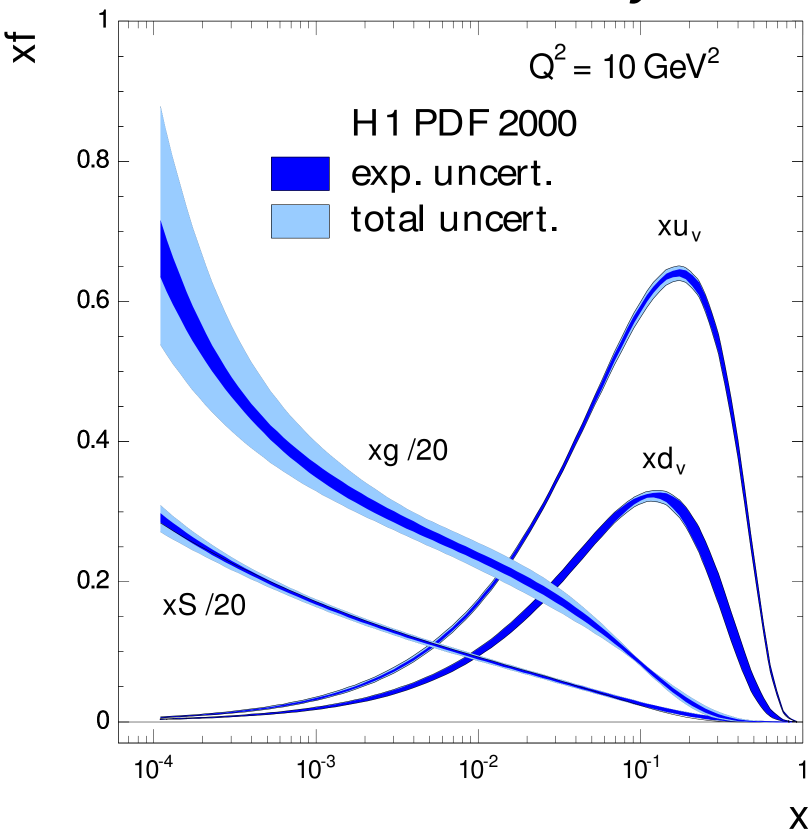


H1PDF 2009 - A new QCD Fit

- Thanks to the improved data input, low x uncertainties are reduced w.r.t the former fit H1PDF 2000
- Uncertainties at high x larger and more realistic due to a new parameterisation and an uncertainty for parameterisation choice

$\longrightarrow$ *more details in talk by J. Terron*



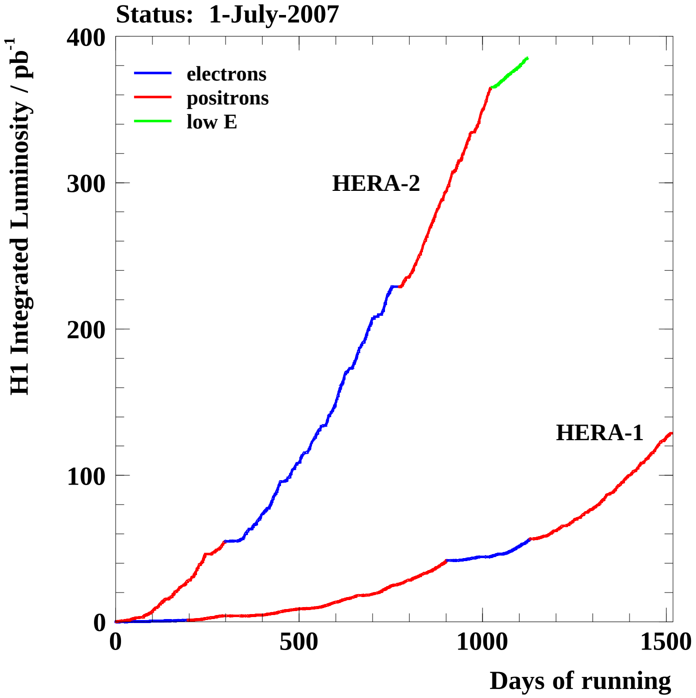


Conclusions

- New measurements of the inclusive DIS cross section at low and medium $0.2\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ are performed using H1 data from the years 1999/2000, which are combined with published results
- The resulting measurements are very precise with typical total uncertainties of $1.3 - 2\%$ at medium Q^2 and $\sim 2\%$ at lower Q^2
- Phenomenological models are tested in the low x DIS – Photoproduction transition region
- A QCD analysis, H1PDF 2009, is performed using the improved new data and published H1 inclusive cross section measurements at higher Q^2

The HERA Accelerator

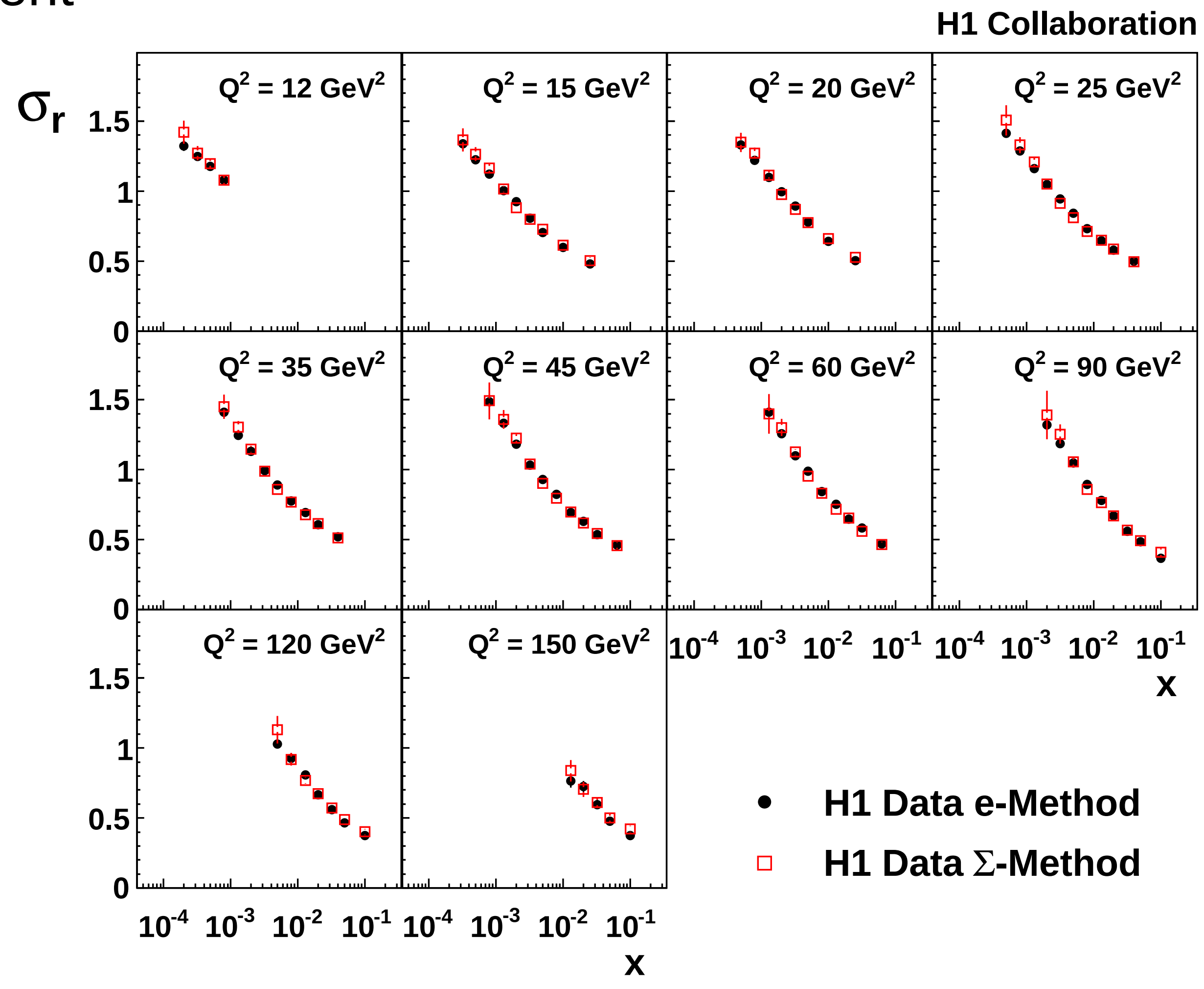
- Protons with up to $E_p = 920$ GeV collided with electrons/positrons of $E_e = 27.6$ GeV
- Data taking 1992 - mid 2007
- Centre of mass energy $\sqrt{s} = 320$ GeV : wide range of Q^2 and x accessible



Electron and Σ Reconstruction

- Cross sections measured with different reconstruction methods are sensitive in different ways to systematic uncertainties
  $\Rightarrow$ Good agreement

- For the final result use method with smaller uncertainty, transition near $y = 0.1$



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

- Effect of the gluon dynamics at low x, well described by the QCD fit to low $Q^2 \sim 1.5\,\text{GeV}^2$