Measurement of F_2 at Medium Q^2 and the PDF determination using H1 HERA I data

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On behalf of the H1 Collaboration

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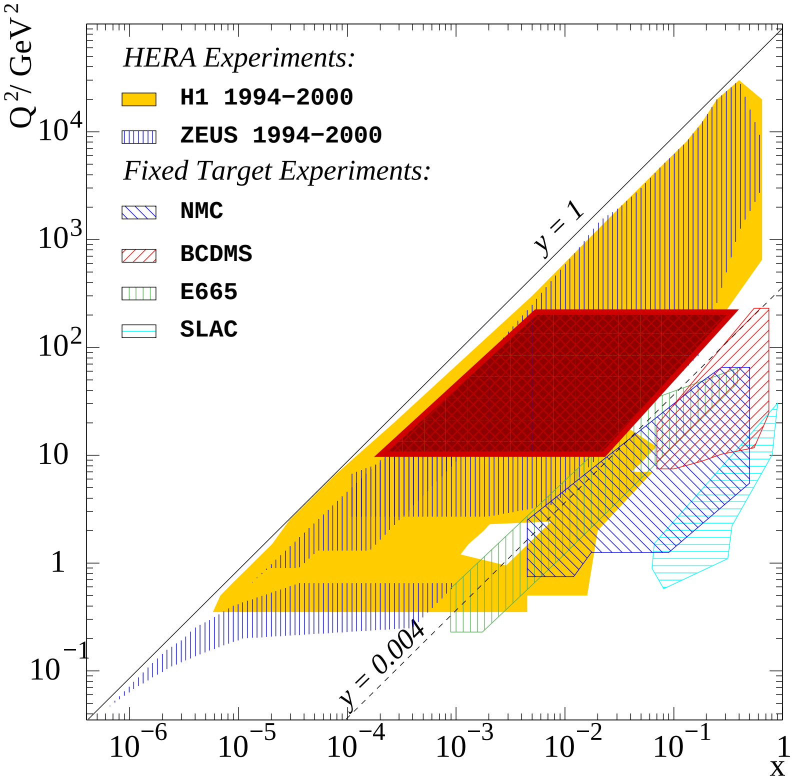
Overview

- A new measurement of the inclusive DIS cross section $ep \to e' X$ using H1 data from the year 2000 ($\mathcal{L} \sim 22\,\mathrm{pb}^{-1}$), combined with published results using 1996/97 data
- Covering the region of *medium* $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ at HERA with unprecedented accuracy

- **Introduction**
- **Cross Section Measurement and Combination**
- **Structure Function F_2 and its Derivatives**
- **QCD Analysis H1PDF 2009**

Available as *arXiv:0904.3513*



Inclusive DIS Cross Section

- Two structure functions $F_2(x,Q^2)$, $F_L(x,Q^2)$ parameterise the inclusive NC cross section for $ep \to e'X$ at low Q^2:

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

- New analysis restricted to medium and low inelasticities $y < 0.6$ $\Rightarrow$ Contribution of F_2 to the cross section is dominant, Effect of F_L very small *separate high y analyses $\to$ A. Glazov*
- In the Quark-Parton Model simple relation to quark distribution functions $q_i(x)$:

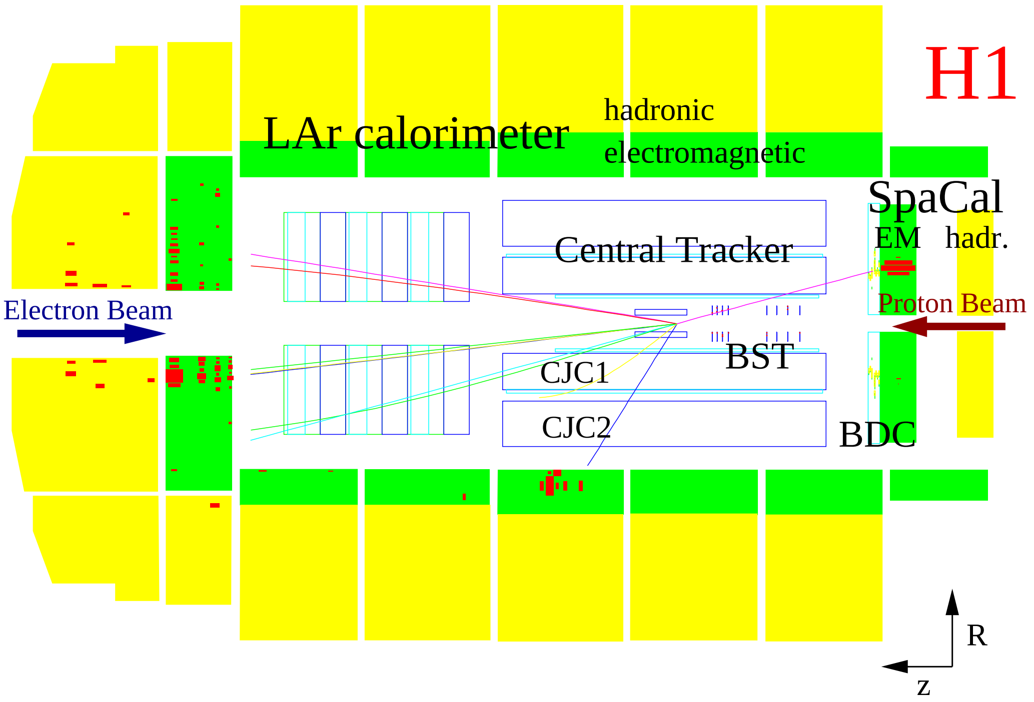
$$F_2(x) = x \sum_i e_i^2 (q_i(x) + \bar{q}_i(x)) = \sigma_r \; , \; F_L = 0$$

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

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

Event Selection and Reconstruction

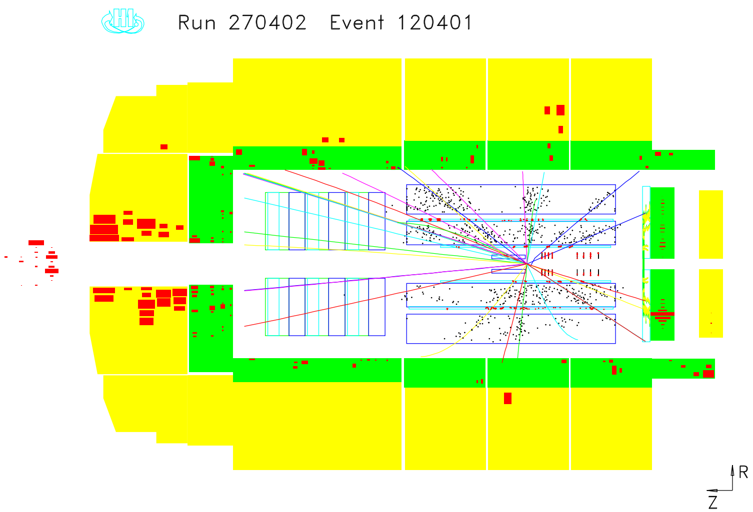
- Analysis similar to lower $Q^2 \leq 12\,\mathrm{GeV}^2$ domain
  $\rightarrow$ *A. Petrukhin arXiv:0904.0929*
- At $Q^2 \lesssim 150\,\mathrm{GeV}^2$, the scattered electron is detected in the "backward" region: SpaCal and BDC track segment



- At higher Q^2 the Central Tracker is used to reconstruct the event vertex, BST for cross checks only
- Hadronic Final State *(HFS)* combined from tracks and calorimeters (LAr + SpaCal)

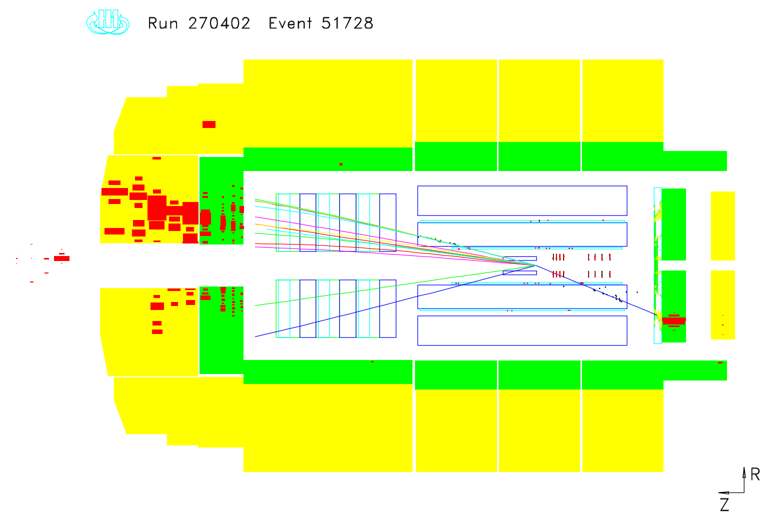
Kinematics

- High Inelasticity $y \gtrsim 0.1$



$$y_e = 0.52,\ Q^2_e = 51\,\mathrm{GeV}^2,\ x_e = 0.00097$$

- Low Inelasticity $y \lesssim 0.1$



$$y_\Sigma = 0.019,\ Q^2_\Sigma = 123\,\mathrm{GeV}^2,\ x_\Sigma = 0.063$$

- **Electron Method**:

$$y_e = 1 - \frac{E'_e}{2E_e}\left(1 - \cos\theta_e\right),$$

$$Q^2_e = \frac{E'^2_e \sin^2\theta_e}{1 - y_e},\quad x_e = \frac{Q^2_e}{s y_e}$$

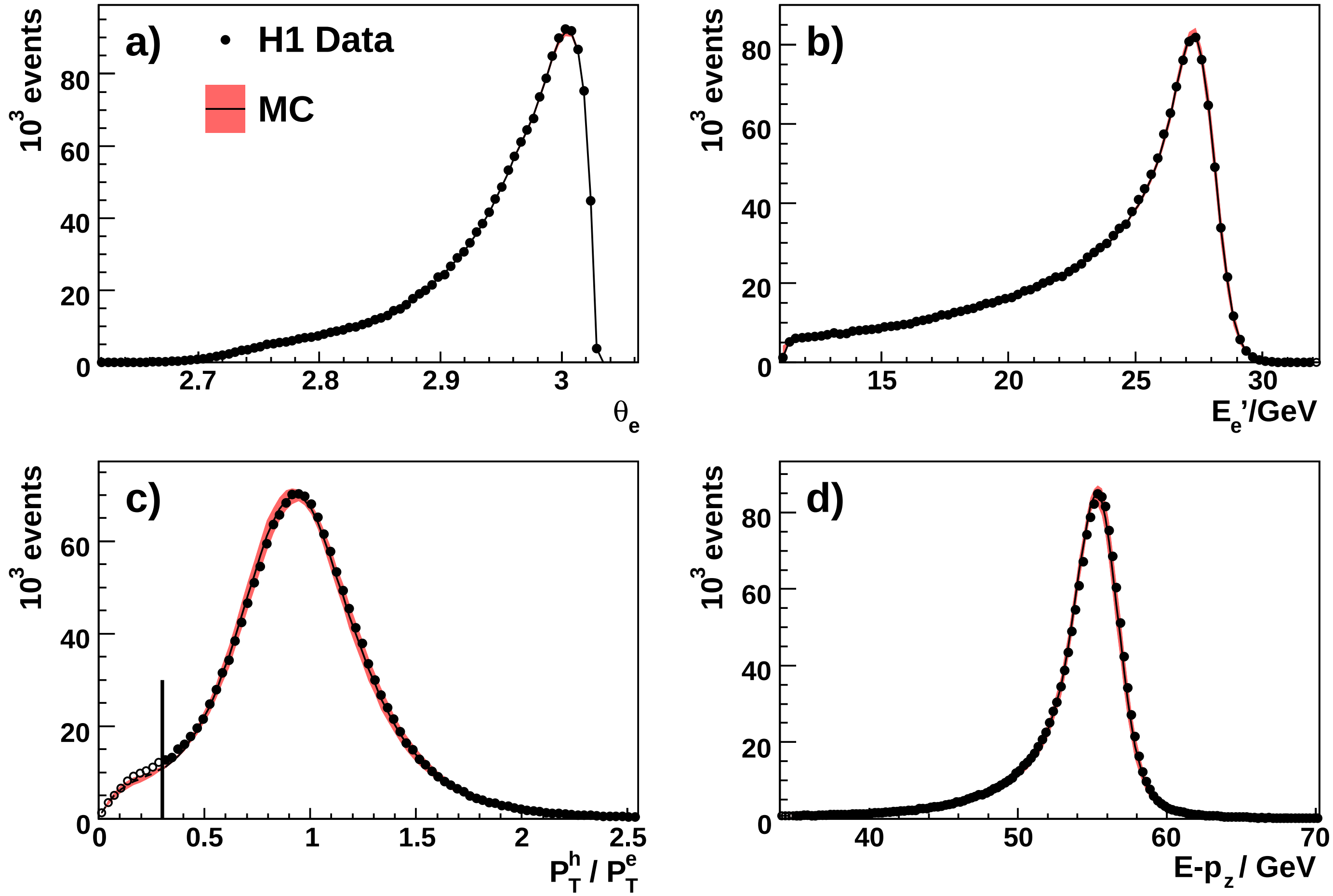
- **Σ (Sigma) Method**:

$$y_\Sigma = \frac{(E - p_z)_{had}}{(E - p_z)_{tot}},$$

$$Q^2_\Sigma = \frac{E'^2_e \sin^2\theta_e}{1 - y_\Sigma},\quad x_\Sigma = \frac{Q^2_\Sigma}{2(E - p_z)_{had} E_p}$$

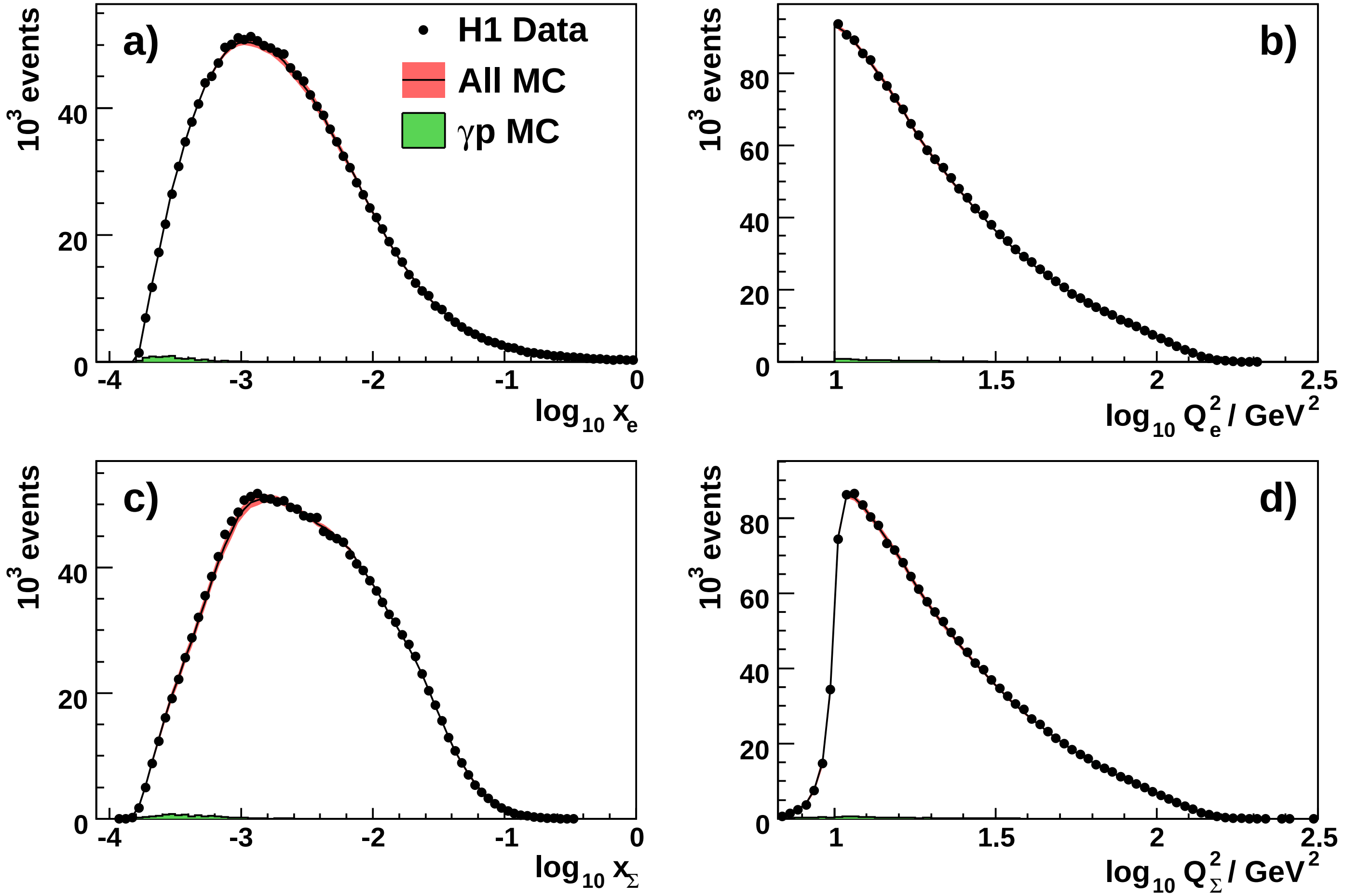
Technical Control Plots

- Very good control over all essential measured detector quantities achieved, e.g. $\delta E'_e/E'_e \sim 0.2 - 1.0\%$, $\delta E_{HFS}/E_{HFS} \sim 2.0\%$, extra efficiency uncertainties $\sim 0.3 - 0.5\%$



Kinematics Control Plots

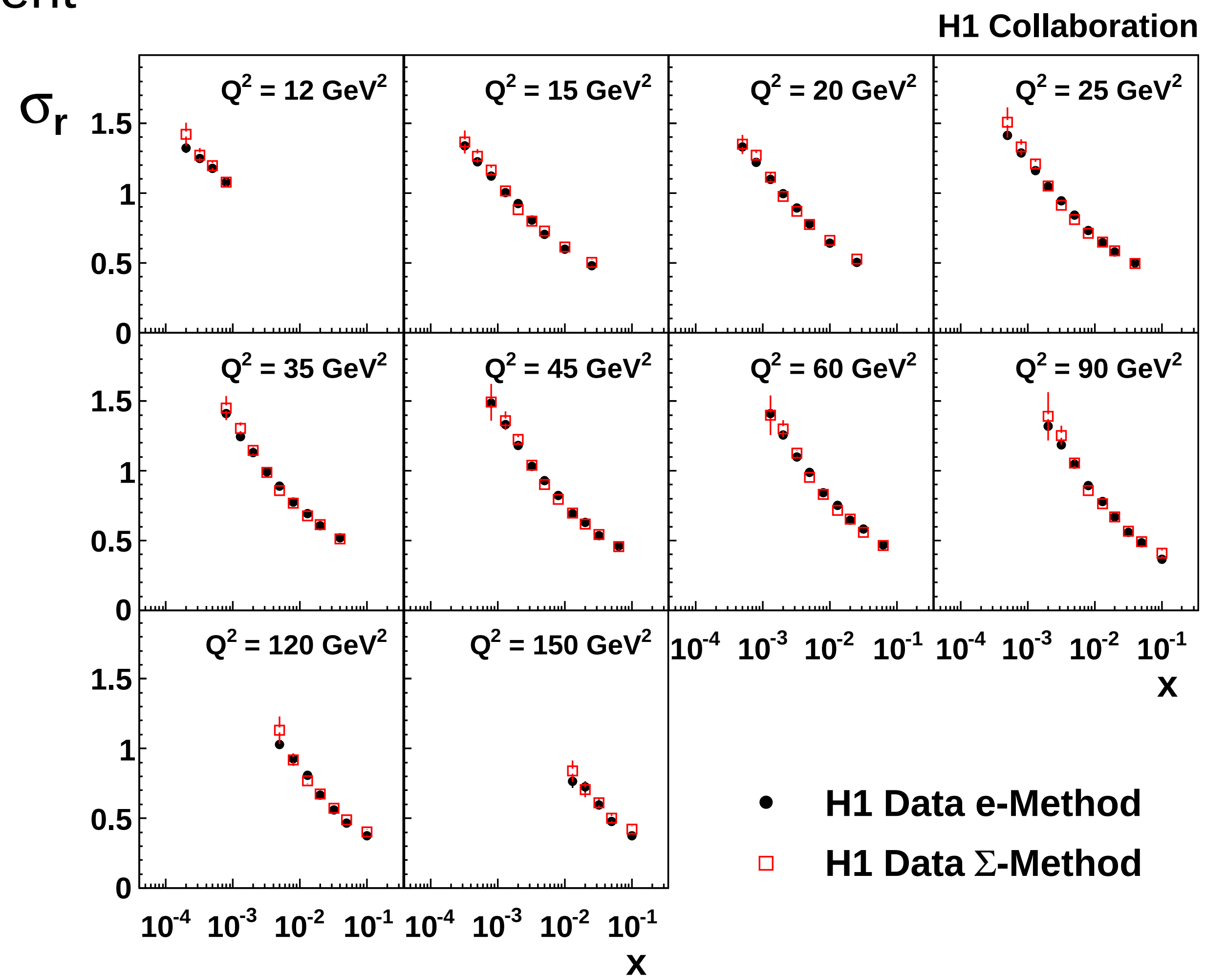
- Photo-production background is highly suppressed
- Distributions well described by MC reweighted to H1PDF 2009 structure functions (see later)



Electron and Σ Reconstruction

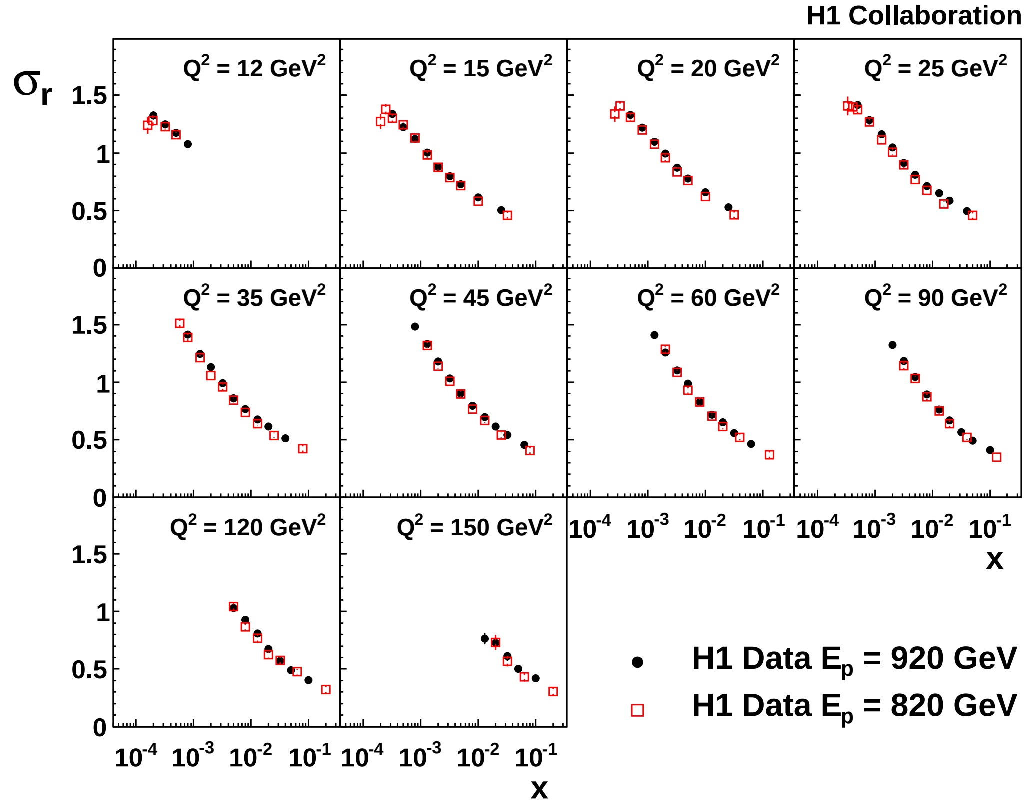
- Cross sections measured with different reconstruction methods are sensitive in different ways to systematic uncertainties
  $\Rightarrow$ Good agreement

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



Comparison with Published Results

- New measurement covers 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)
- The comparison and reanalysis of the older data revealed a small Q^2 dependant bias in the old results of $\sim 0 - 2.5\%$
- After correction good agreement between the measurements
- Total uncertainties up to a factor ~ 2 better for new data

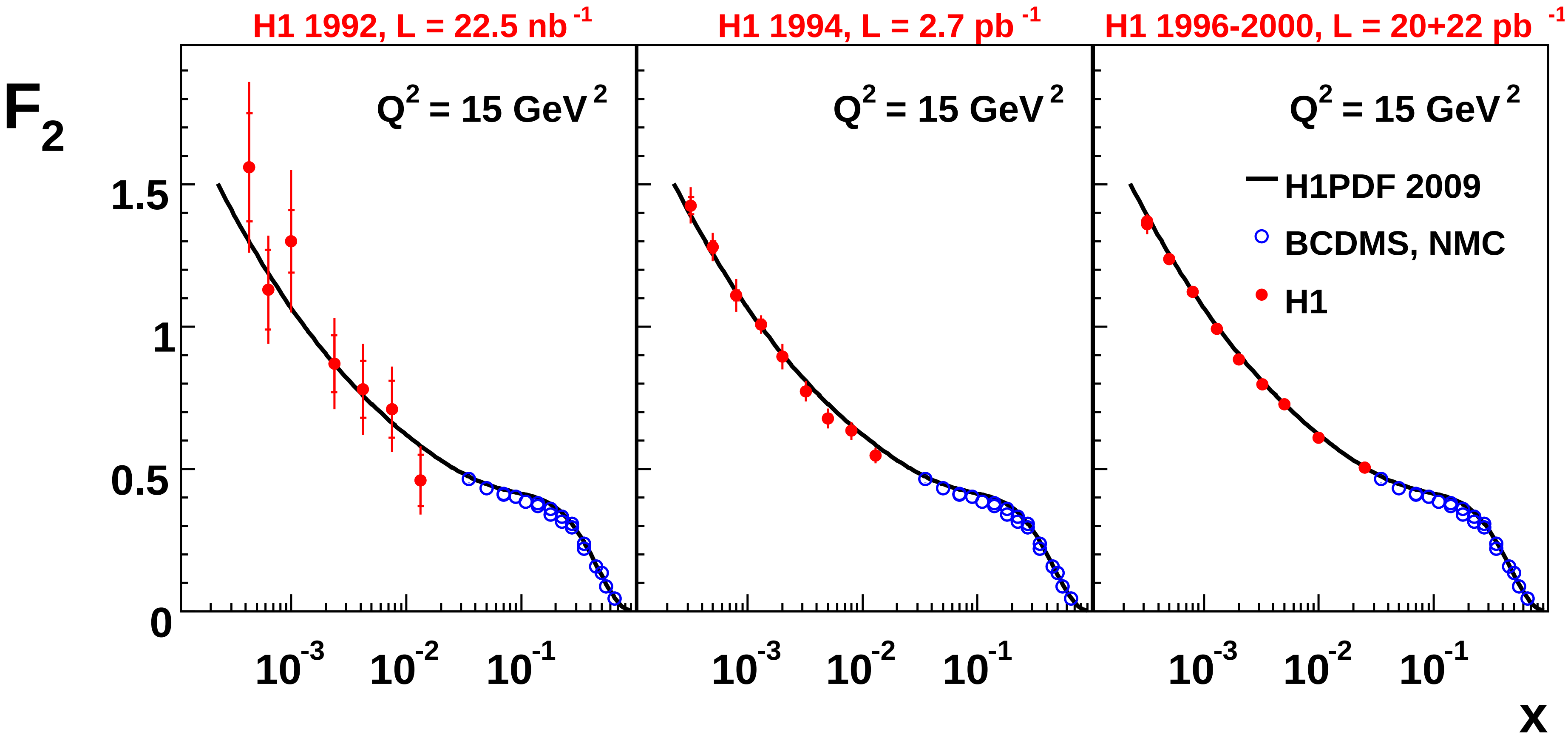


Data Combination

- As for the analysis at lower $Q^2 \leq 12\,\mathrm{GeV}^2$ ($\rightarrow$ *A. Petrukhin*) the new measurement is averaged with the previous result
- Using the same method taking into account bin-to-bin correlated uncertainties, *also used for H1-ZEUS combination* $\rightarrow$ *E. Tassi*
- Cross sections corrected to $E_p = 920$ GeV for lower $y < 0.35$, kept separate for higher y
- Correlated systematic sources treated as uncorrelated between the data sets, only small shifts required
- Good consistency: $\chi^2_{\mathrm{tot}}/n_{\mathrm{dof}} = 51.6/61$

Systematic Source	Shift in std. dev. 1996/97	2000
E'_e scale	0.72	0.50
E'_e linearity	—	-0.39
Polar angle θ_e	-0.46	0.09
LAr hadronic scale	-0.86	-0.13
LAr noise	-0.22	0.04
SpaCal hadronic scale	—	0.35
γp background	0.11	-0.11
Luminosity	0.64	-0.46

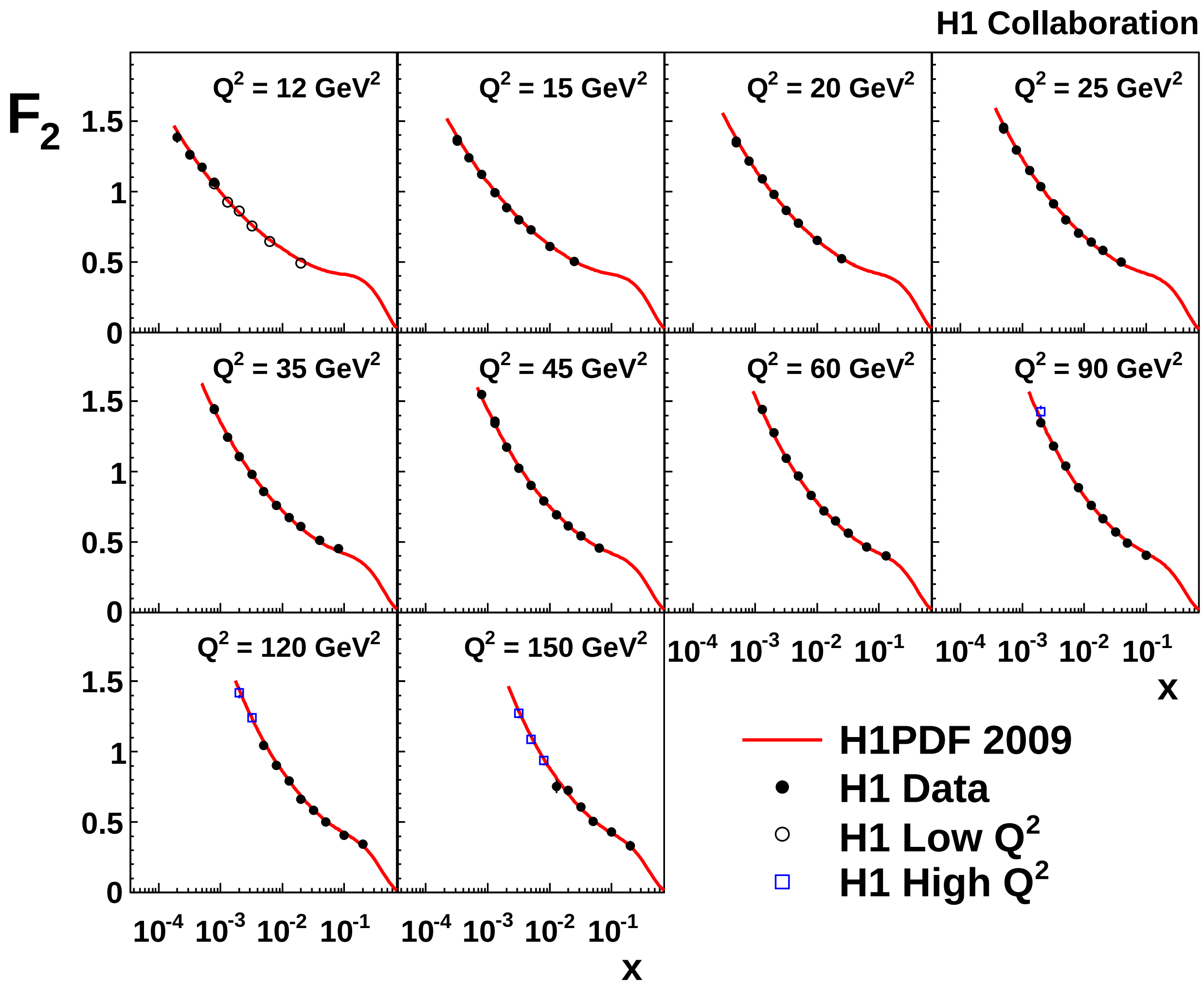
History of H1 F_2 Measurements



- Accuracies starting from $\sim 20-30\%$, reaching $\sim 4-6\%$, last publication using 1996/97 data $\sim 2-3\%$, and finally $\sim 1.3-2\%$

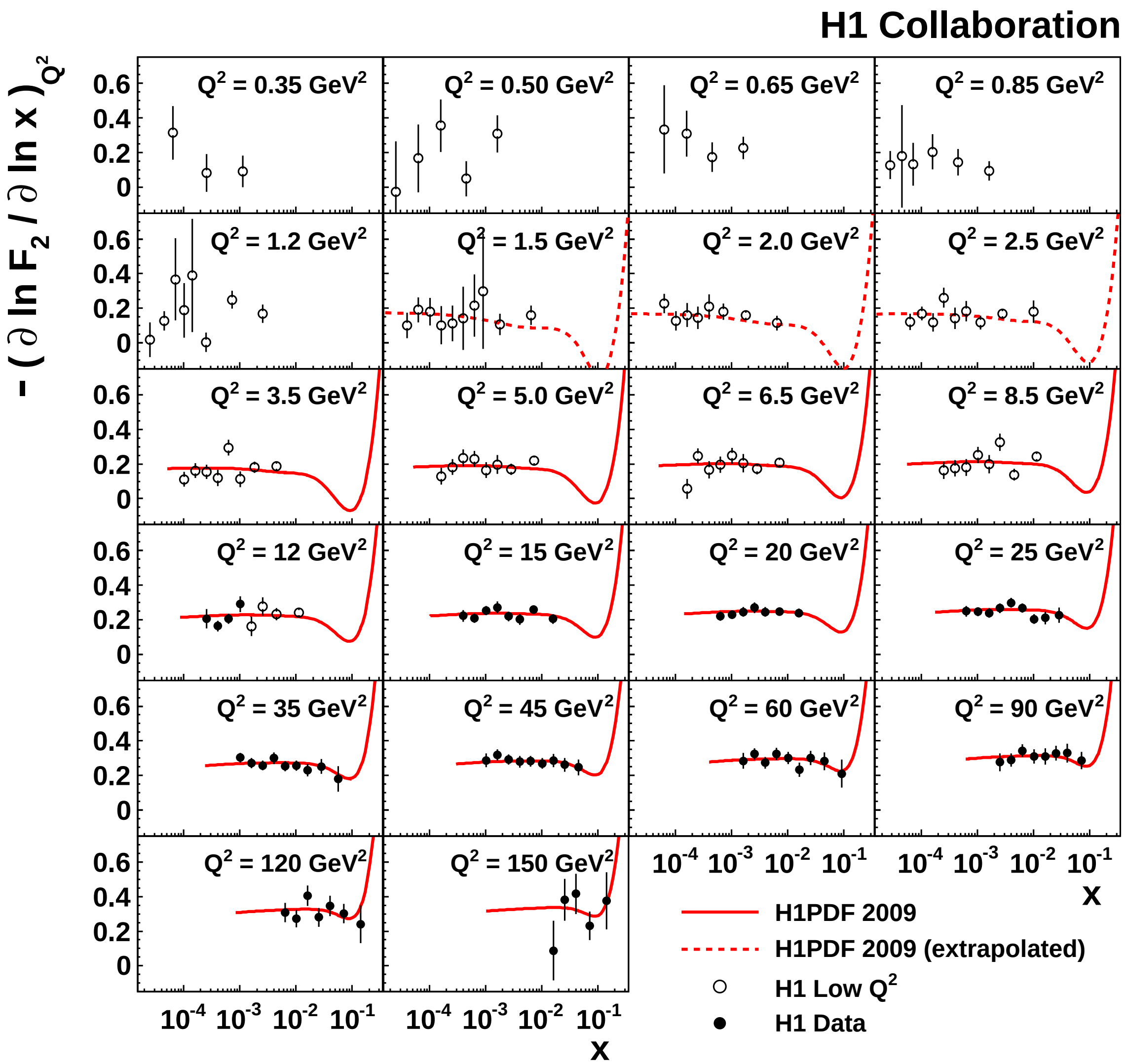
F_2 at fixed Q^2

- 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 fit



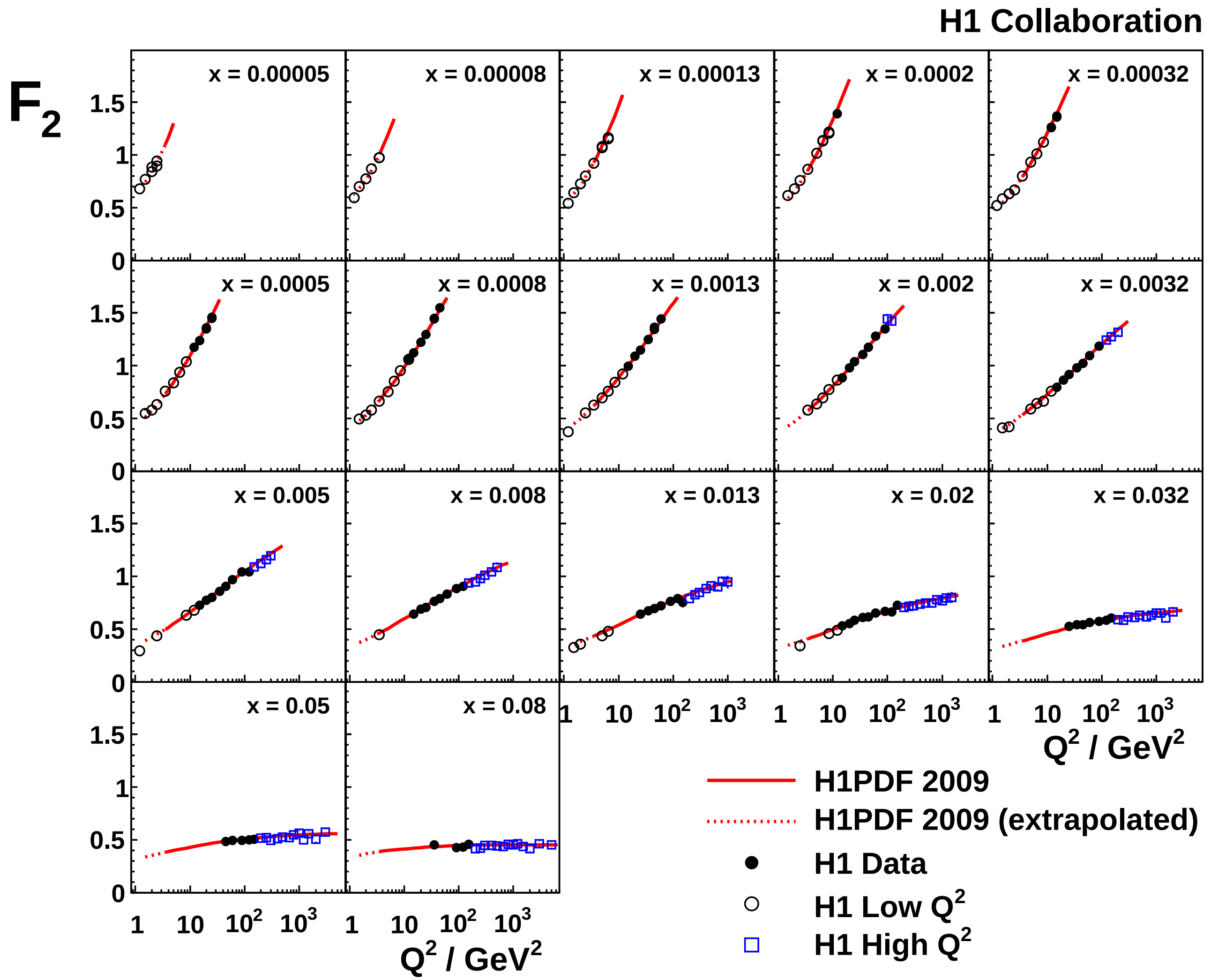
$\partial \ln F_2 / \partial \ln x$ at fixed Q^2

- 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 $F_2 \propto x^{-\lambda}$
- Small dependance of λ on x also possible



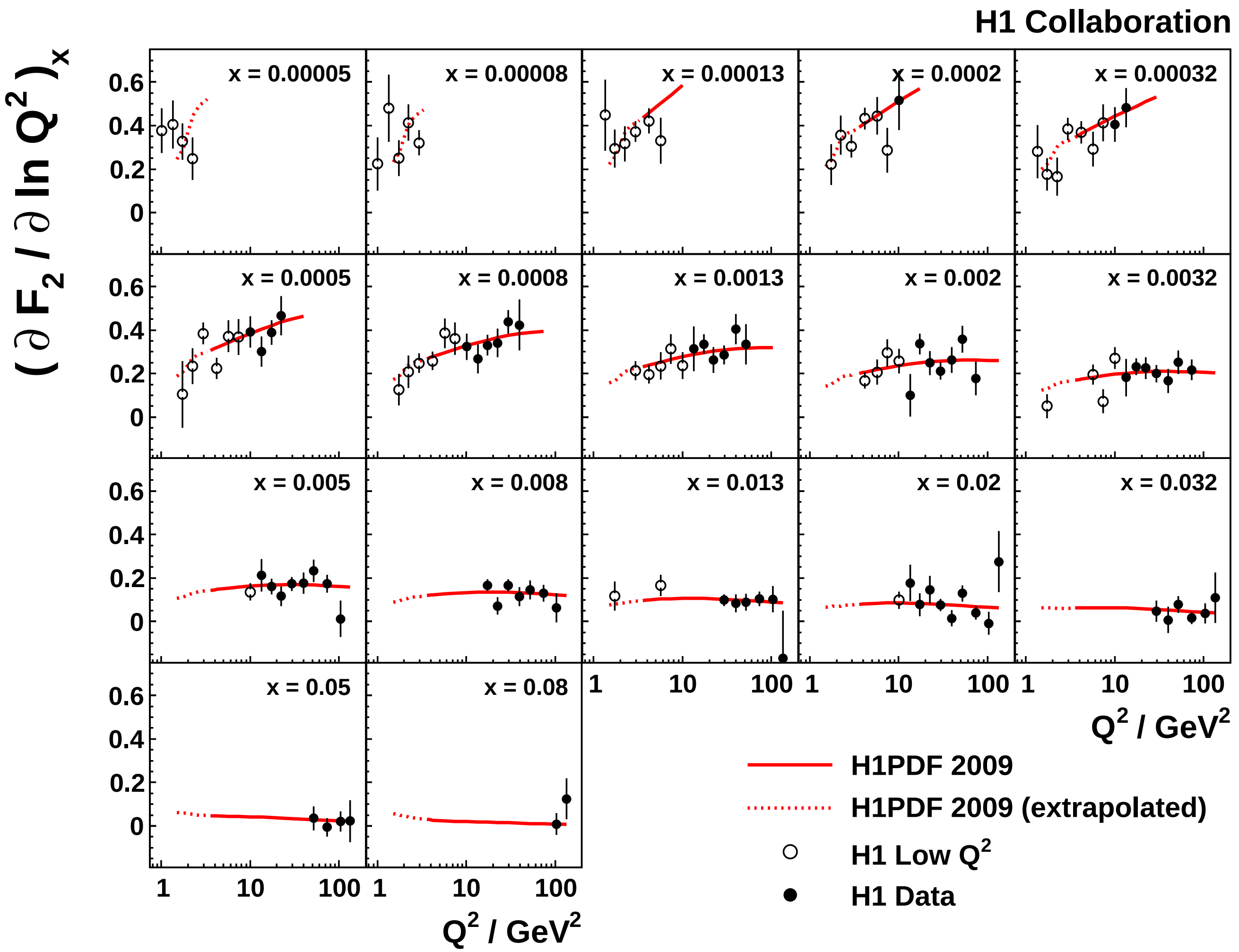
F_2 at fixed x

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



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

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



H1PDF 2009 - A new QCD Fit

- Using only inclusive cross section data by H1, a new QCD based on DGLAP evolution equations (NLO) was performed
- Compared to the previously published fit (H1PDF 2000):
  - Data for $Q^2 \leq 150\,\mathrm{GeV}^2$ more precise
  - Improved theoretical treatment of heavy quark threshold effects (GM-VFNS, TR scheme)

Data set	Process	Q^2 range	
H1 combined low Q^2 $1995-2000$	e^+p NC	0.2	12
H1 combined medium Q^2 $1996-2000$	e^+p NC	12	150
H1 high Q^2 $94-97$	e^+p NC	150	30 000
H1 high Q^2 $94-97$	e^+p CC	300	15 000
H1 high Q^2 $98-99$	e^-p NC	150	30 000
H1 high Q^2 $98-99$	e^-p CC	300	15 000
H1 high Q^2 $98-99$	e^-p NC	100	800
H1 high Q^2 $99-00$	e^+p NC	150	30 000
H1 high Q^2 $99-00$	e^+p CC	300	15 000

Parameterisation

- The set chosen PDFs same as for **HERAPDF 0.2** fit:

  $\rightarrow$ *V. Radescu*

$$xu_v,\ xd_v,\ xg,\ x\bar{U} = x(\bar{u}+\bar{c}),\ x\bar{D} = x(\bar{d}+\bar{s}+\bar{b})$$

- Parameterised at low $Q_0^2 = 1.9\,\mathrm{GeV}^2$ ($x\bar{c} = x\bar{b} = 0$) as

$$xP = Ax^B(1-x)^C(1+Dx+Ex^2+\ldots)$$

- 6 parameters are fixed by model assumptions
- Remaining 9 A, B, C parameters are the basic parameterisation
- Additional $D, E, \ldots$ parameters are added in an iterative χ^2 optimisation procedure with additional conditions:
  - $F_2 \geq 0$ and $F_L \geq 0$ $\Rightarrow$ *otherwise discarded*
  - all PDFs ≥ 0
    $\Rightarrow$ *otherwise considered for parameterisation uncertainty*
  - Valence not too low compared to sea at high $x \gtrsim 0.2$
    $\Rightarrow$ *otherwise considered for parameterisation uncertainty*

Parameterisation

- This optimisation procedure leads to the choice

	A	B	C	D	E
xg	mom. sum rule				
xu_v	quark count. rule				
xd_v	quark count. rule	$= B_{u_v}$			
$x\bar{U}$	$A_{\bar{D}}(1-f_s)$				
$x\bar{D}$		$= B_{\bar{U}}$			

- The fit has a good $\chi^2_{\text{tot}}/\, n_{\text{dof}} = 587/644$, no significant tension in the systematic uncertainties
- Alternative parameterisations with similar or better χ^2, which are discarded due to the additional optimisation conditions, are used to estimate an additional **parameterisation uncertainty**
- Envelope of all those considered fits is formed, using e.g.

	A	B	C	D	E
xg					
xu_v					
xd_v					
$x\bar{U}$					
$x\bar{D}$					

	A	B	C	D	E
xg					
xu_v					
xd_v					
$x\bar{U}$					
$x\bar{D}$					

Model Parameters and Variation

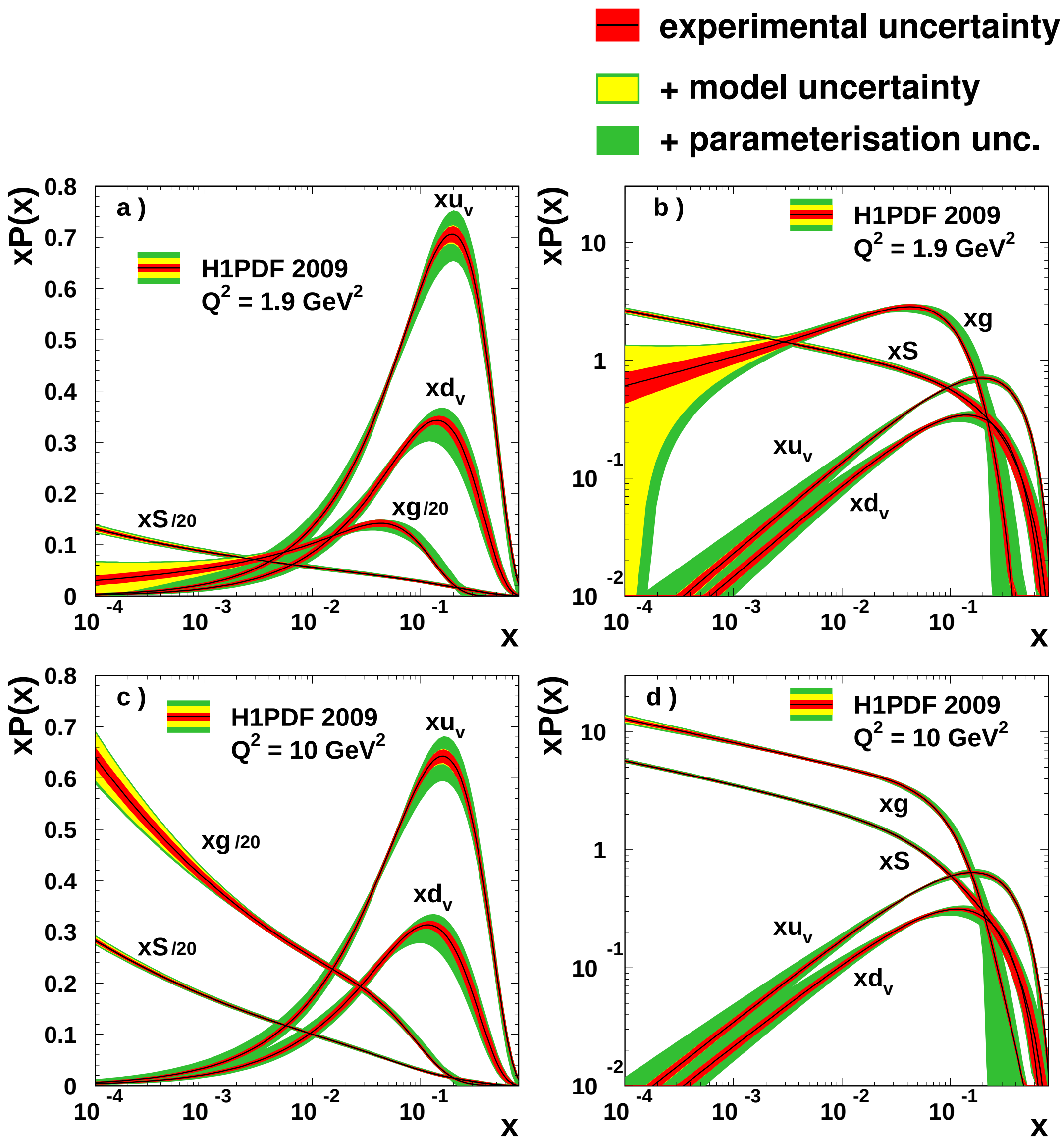
- Typically "conventional" choices for H1 fits, also mostly like **HERAPDF 0.2**
- The choice VFNS scheme dictates $Q_0^2 \leq m_c^2$, which limits either of those variations

Parameter	Central Value	Variation
α_s	0.1176	fixed
Q_0^2	$1.9\,\mathrm{GeV}^2$	down to $1.5\,\mathrm{GeV}^2$ – error symmetrised
Q_{min}^2	$3.5\,\mathrm{GeV}^2$	$2.5 - 5.0\,\mathrm{GeV}^2$
m_c	$1.4\,\mathrm{GeV}$	$1.38 - 1.47\,\mathrm{GeV}$
m_b	$4.75\,\mathrm{GeV}$	$4.3 - 5.0\,\mathrm{GeV}$
f_s	0.31	$0.25 - 0.40$

- The largest effect at low x is due to the Q_0^2 variation

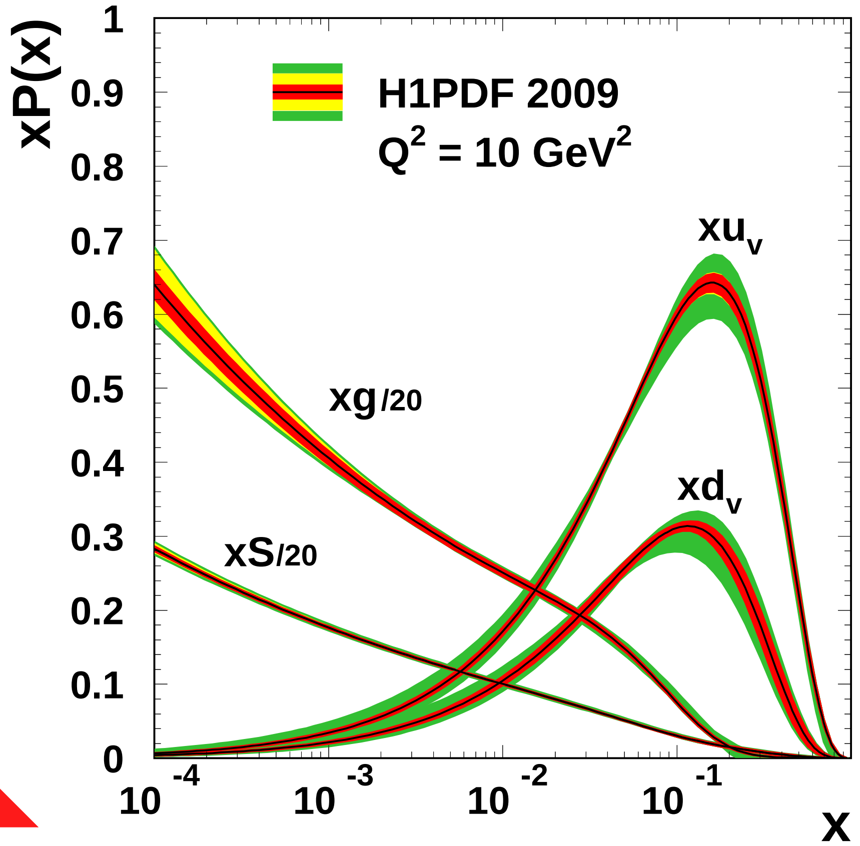
H1PDF 2009 Result

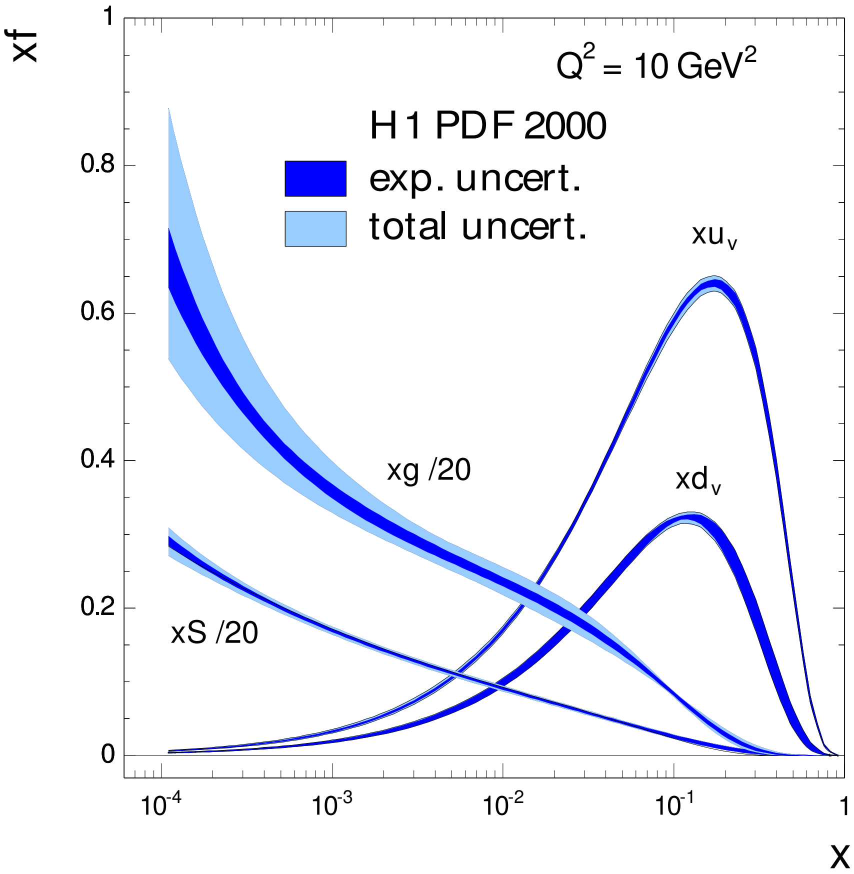
- At $Q^2 = 1.9\,\mathrm{GeV}^2$ gluon has valence-like shape, low x dominated by sea quarks
- At $Q^2 = 10\,\mathrm{GeV}^2$ the gluon clearly dominates low x
- Parameterisation uncertainty dominates at high x



H1PDF 2009 vs. H1PDF 2000

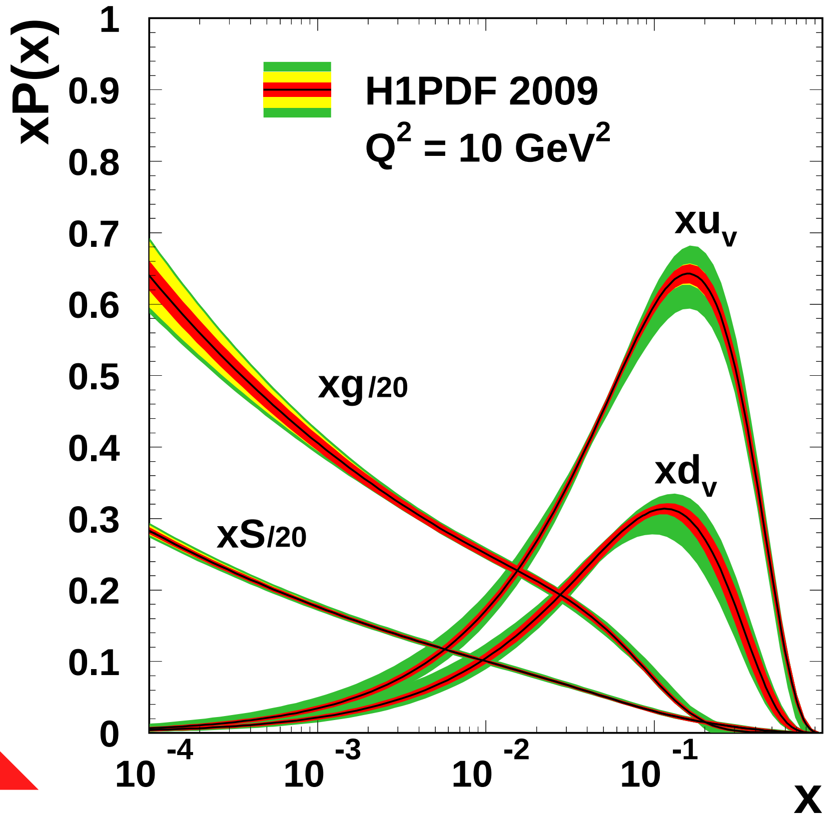
- Low x uncertainties reduced
- Uncertainties at high x larger and more realistic:
  - New parameterisation using xu_v instead of $xU = x\bar{U} + xu_v$
  - New uncertainty for parameterisation choice

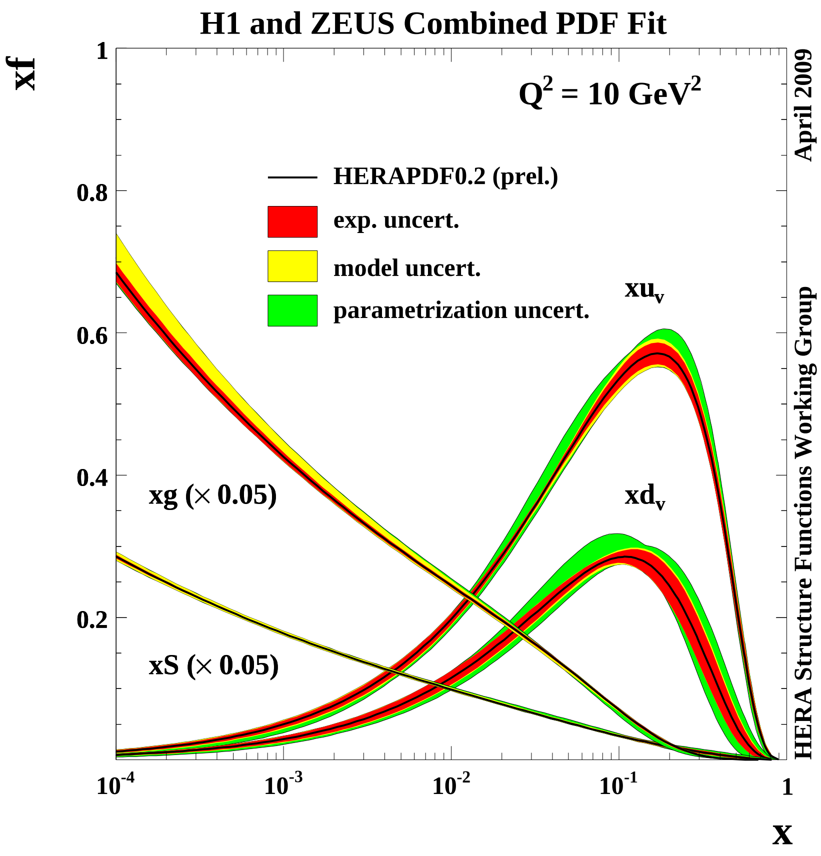




H1PDF 2009 vs. HERAPDF 0.2

- Parametrisation optimisation procedure leads to different choices: additional D_g vs. E_{u_v} parameter
- Low x gluon uncertainty dominated by Q_0^2 variation: symmetrised for H1PDF 2009, but not for HERAPDF 0.2





Conclusions

- A new measurement of the inclusive DIS cross section at medium $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ is performed using H1 data from the year 2000
- The new measurement is combined with the published 1996/97 data, after correction of a small bias in the older result
- The result is the most accurate measurement in this kinematic domain to date with typical total uncertainties of $1.3 - 2\%$
- A QCD analysis, H1PDF 2009, is performed using the improved new data at $Q^2 \leq 150\,\mathrm{GeV}^2$ and published H1 high Q^2 inclusive cross section measurements