Proton Structure and QCD dynamics at low x

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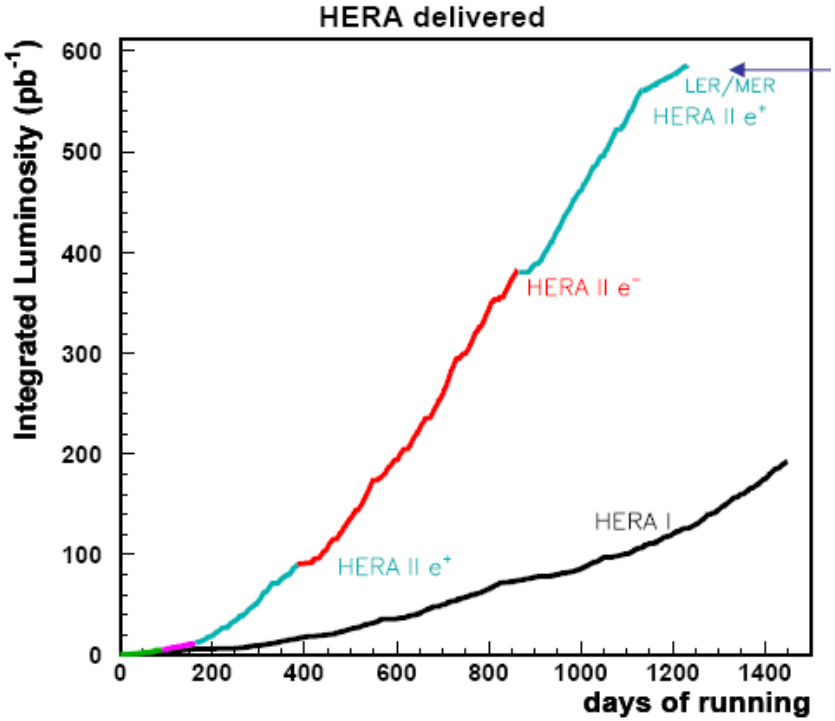
International Workshop on e^+e^- Collisions from Phi to Psi
Laboratori Nazionali di Frascati, Italy, 7th – 10th April, 2008

HERA and luminosity



In 2000-2002 HERA-I (E_p = 820, 920 GeV) upgraded to HERA-II (E_p = 920 GeV)

- Increased luminosity
- Polarised lepton in collider mode

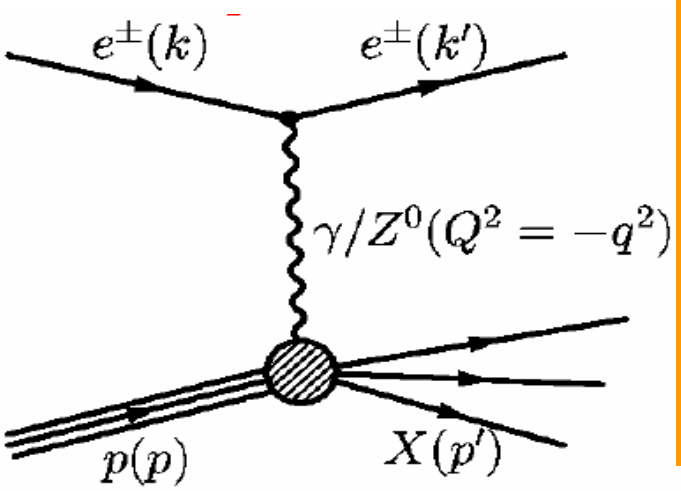
Since April 2007 until the end of June

- Low energy run – LER - (E_p = 460 GeV)
- Medium energy run – MER - (E_p = 575 GeV)

} Measurement of F_L

Neutral Current (NC) $e^{\pm}p$ Deep Inelastic Scattering (DIS)

e + p → e' + X



Virtuality of exchanged boson: $Q^2 = -q^2 = -(k-k')^2$

Fraction of proton momentum carried by struck quark: $x = Q^2/(2p\cdot q)$

Inelasticity (relative energy transfer in proton rest frame): $y = (p\cdot q)/(p\cdot k)$

$Q^2 = sxy$

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

Kinematics can be reconstructed using scattered lepton (e') or hadronic final state

DIS one of the best tools to:

-Test the theory – validity of the DGLAP evolution

- Study proton internal structure – quark, anti-quark and gluon content
  PDFs: $xq(x,Q^2)$, $x\bar{q}(x,Q^2)$, $xg(x,Q^2)$

- Study quark-gluon dynamics at high density in final state and inclusive DIS

Structure functions F_2 and F_L

At low Q^2 NC DIS cross section can be written via structure functions F_2 and F_L

$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ [F_2 - \frac{y^2}{Y_+} F_L] \qquad Y_+ = 1 + (1-y)^2$$

Reduced cross section

$$\sigma_r = F_2 - \frac{y^2}{Y_+} F_L = \frac{xQ^4}{2\pi\alpha^2 Y_+} \frac{d^2\sigma_{NC}(e^{\pm}p)}{dxdQ^2}$$

← This is measured experimentally

F_2 – dominant contribution to σ_r

→ extraction of sum of quark PDFs: $F_2 = \sum e_q^2 (xq + x\bar{q})$

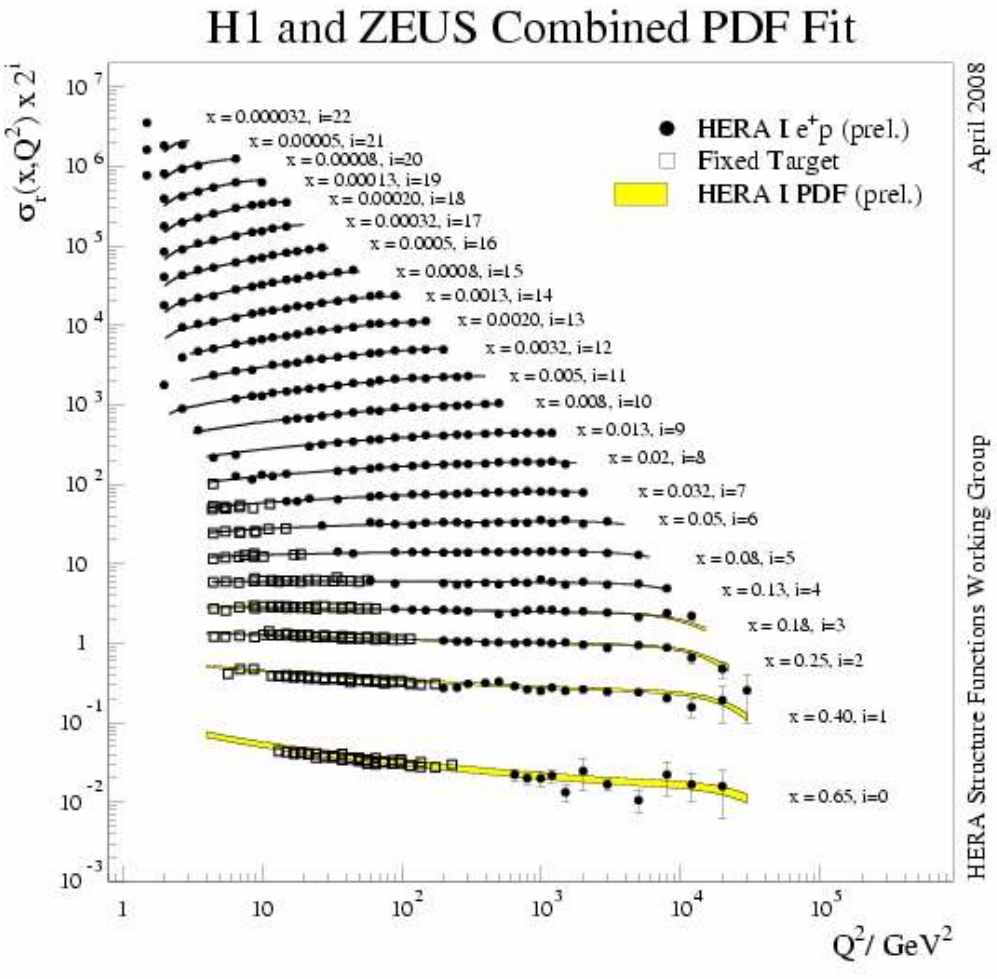
→ extraction of gluon PDF: $\partial F_2 / \partial \ln Q^2 \sim xg$

F_L – sizable contribution only at high y

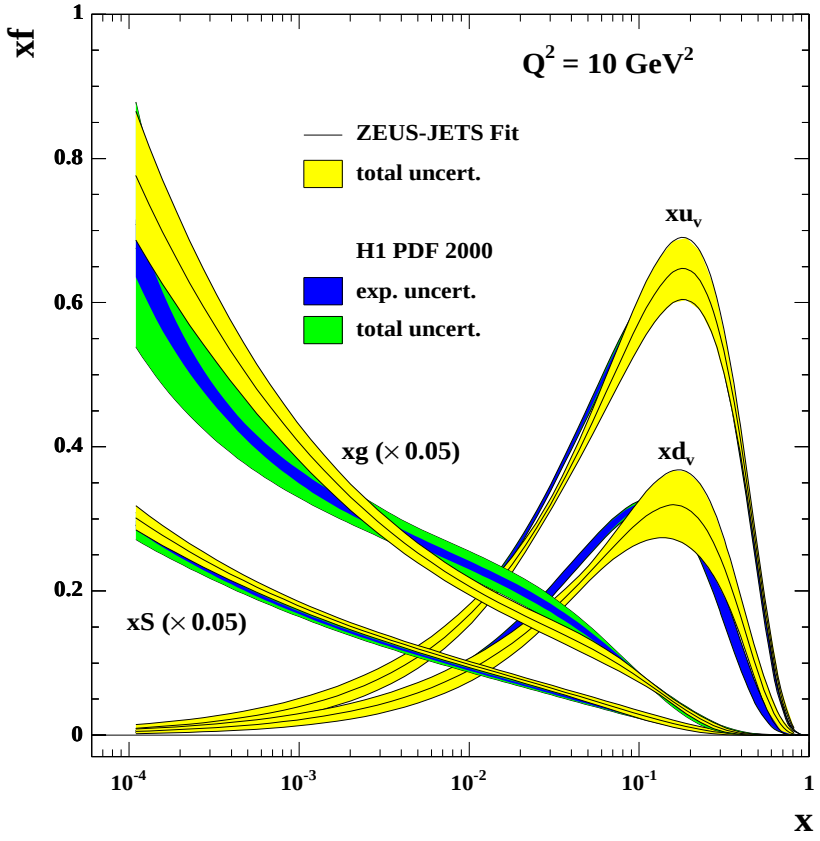
- in QPM: $F_L = 0$
- in perturbative QCD: $F_L \sim \alpha_s \cdot xg(x,Q^2)$ → direct sensitivity to gluons
- before LER and MER, F_L extraction relying on assumptions on F_2
- with LER and MER, direct measurement of F_L possible

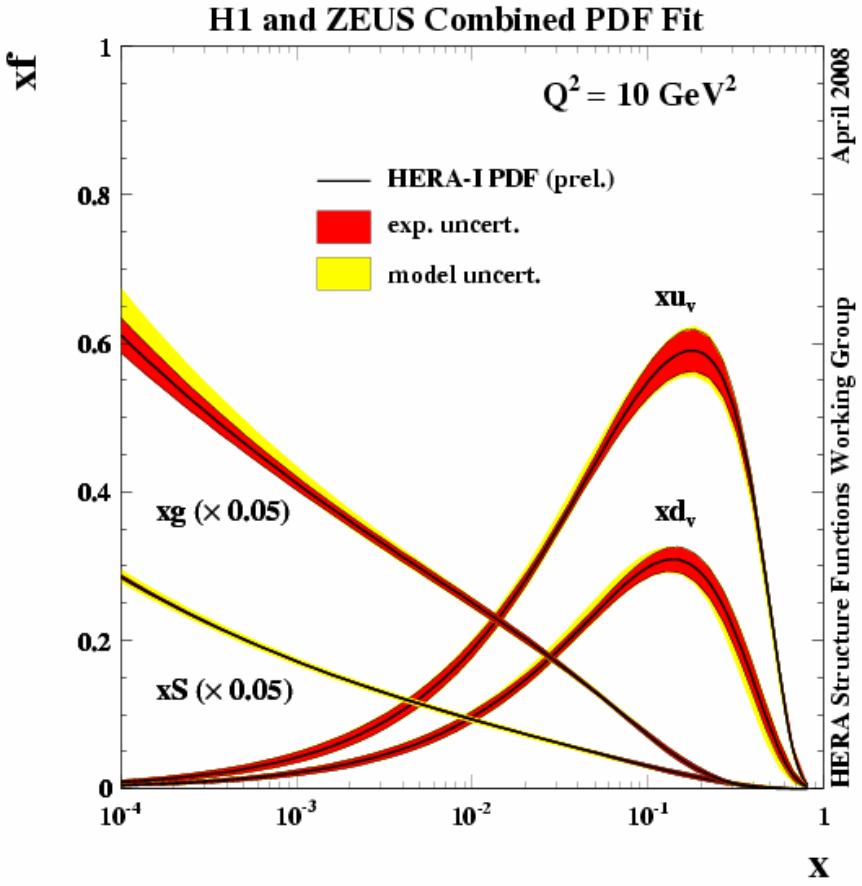
New results on neutral current cross sections - combined H1 and ZEUS data -

- New preliminary H1 and ZEUS combined results obtained from HERA-I data with $Q^2 > 1.5\ GeV^2$ (except the new lowest Q^2 measurement from H1 – next slides)
- Precision: 1.5 – 3 %
- 5 orders of magnitude in x and Q^2
- Cross section measurements provide input for the new **PDF fit**



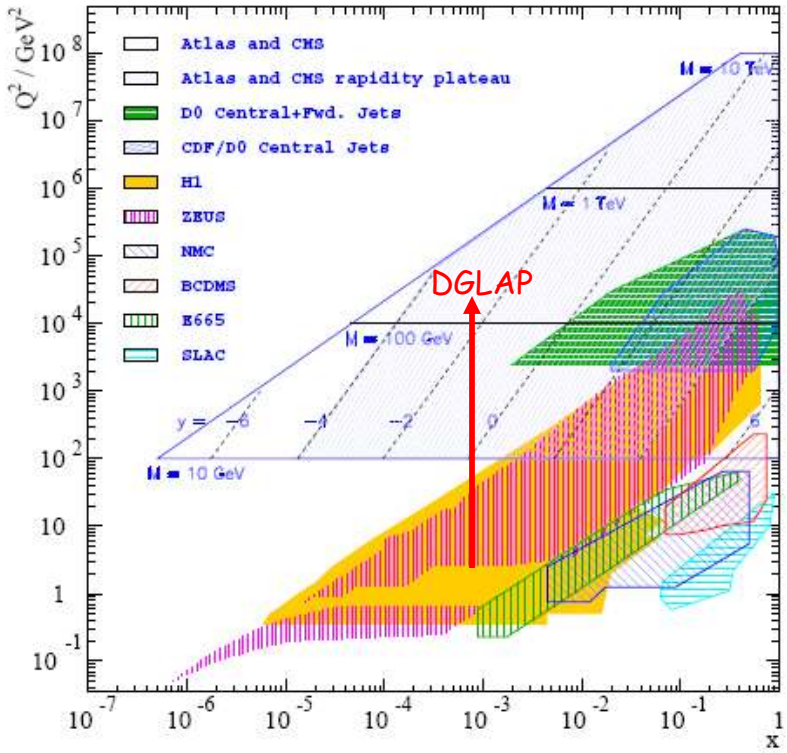
New PDF fit from HERA
- combined H1 and ZEUS data -





- Improvement in level of uncertainty

HERA PDFs for the LHC



- Proton structure described by precise PDFs needed for making accurate predictions for any process involving protons.

- DGLAP QCD evolution provides Q^2 dependence of the PDFs → x dependence must come from data.

HERA covers the most important region for the LHC -W, Z^0 cross section prediction.

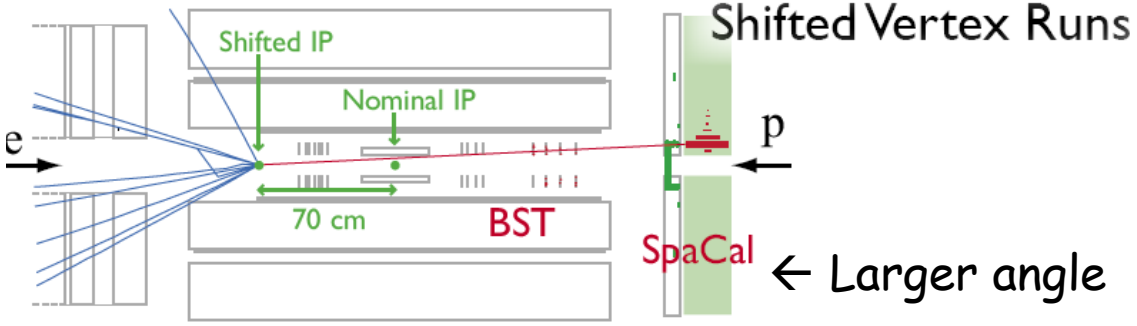
Measurement at lowest Q^2

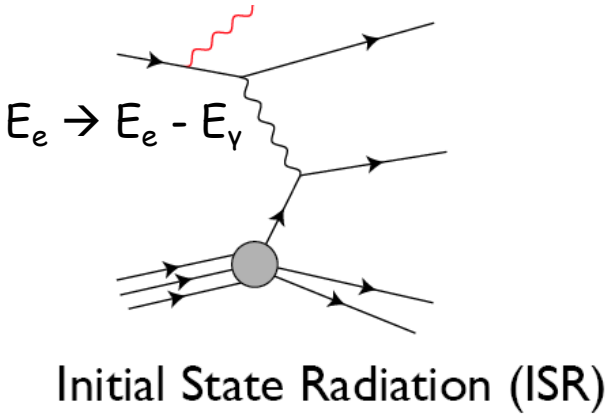
Lowest $Q^2 \rightarrow 0$ domain - transition to non-perturbative region
- Phenomenological models

- For standard DIS in main detectors at HERA - $Q^2 > 2\ GeV^2$

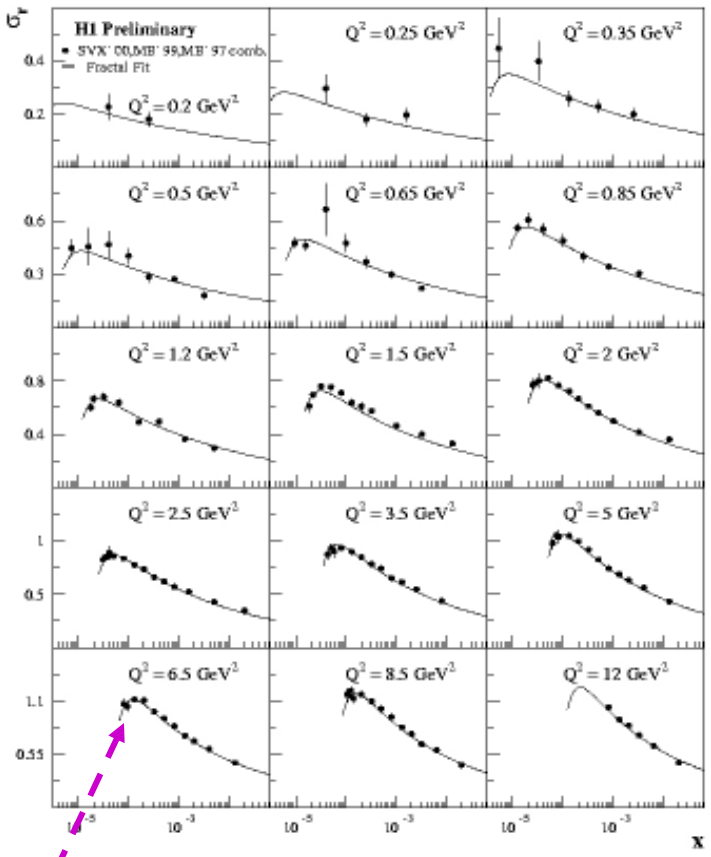
$$Q^2 = 2E_e E_e'(1 + \cos\theta_e)$$

- Possibilities to access lower Q^2
  - larger polar angles
  - lower initial electron energy

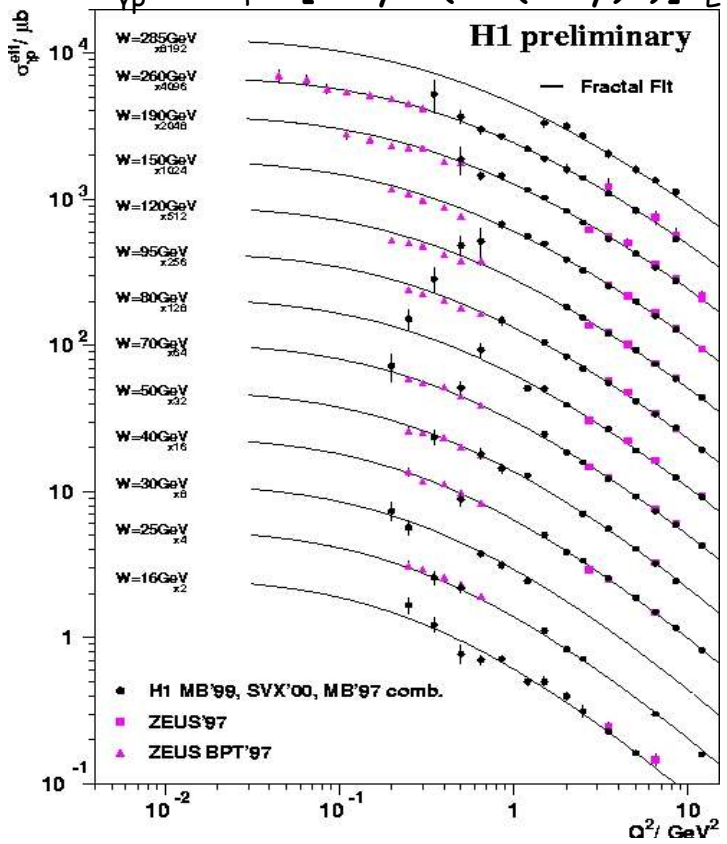




Results at lowest Q^2



$$\sigma_{\gamma p}^{eff} = \sigma_T + [1 - y^2/(1+(1-y)^2)]\sigma_L$$



- Precision of preliminary H1 data for $Q^2 > 5$ GeV^2 reaches 1.5%
- H1 combined data cover the gap between published ZEUS results and agree with them in regions of overlap

Sensitivity to F_L at high y (low x), $\sigma_r = F_2 - y^2/Y_+ \cdot F_L$

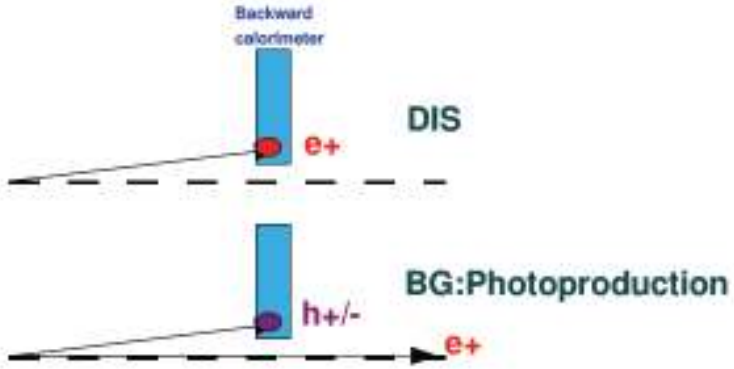
The high y measurements

$\sigma_r = F_2 - y^2/Y_+ \cdot F_L$ → high y measurement sensitive to F_L

$y = 1 - \frac{E_e'}{E_e}\sin^2(\theta_e/2)$ → To reach high y as low as possible E'_e required

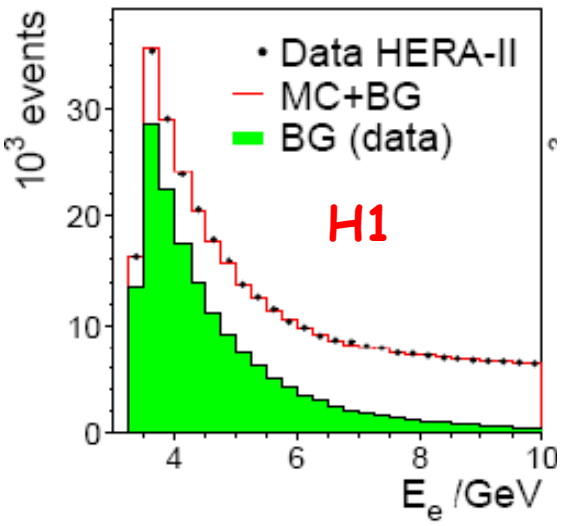
- High y measurement ($y > 0.6$) very challenging since the scattered lepton with low energy has to be identified in the high γp background

  → key task: identification and rejection of γp background

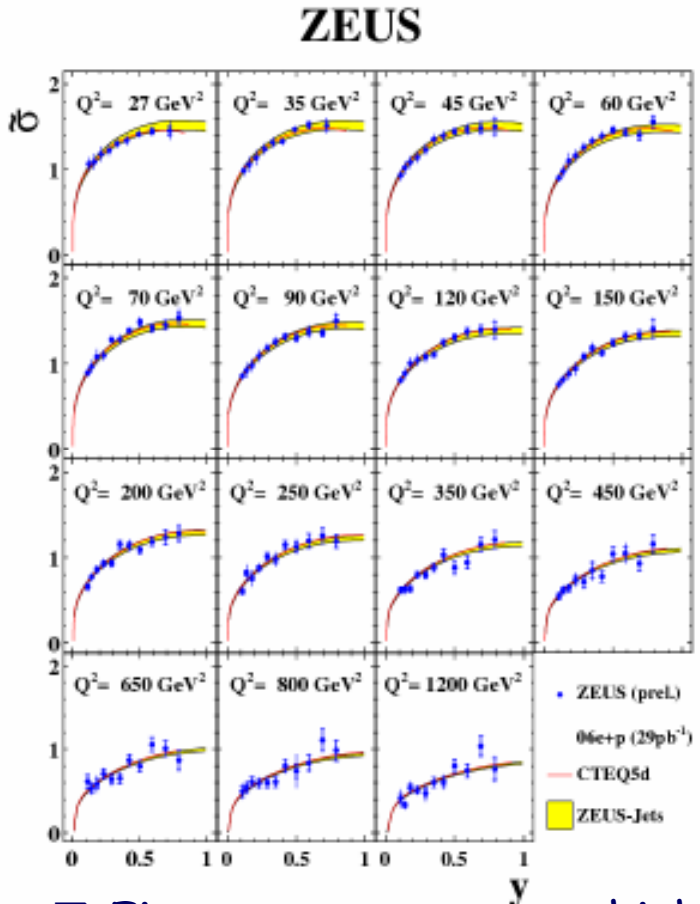


ZEUS: background estimated with γp MC.
$y = 0.8$ is reached for energies down to $E_e' = 5$ GeV

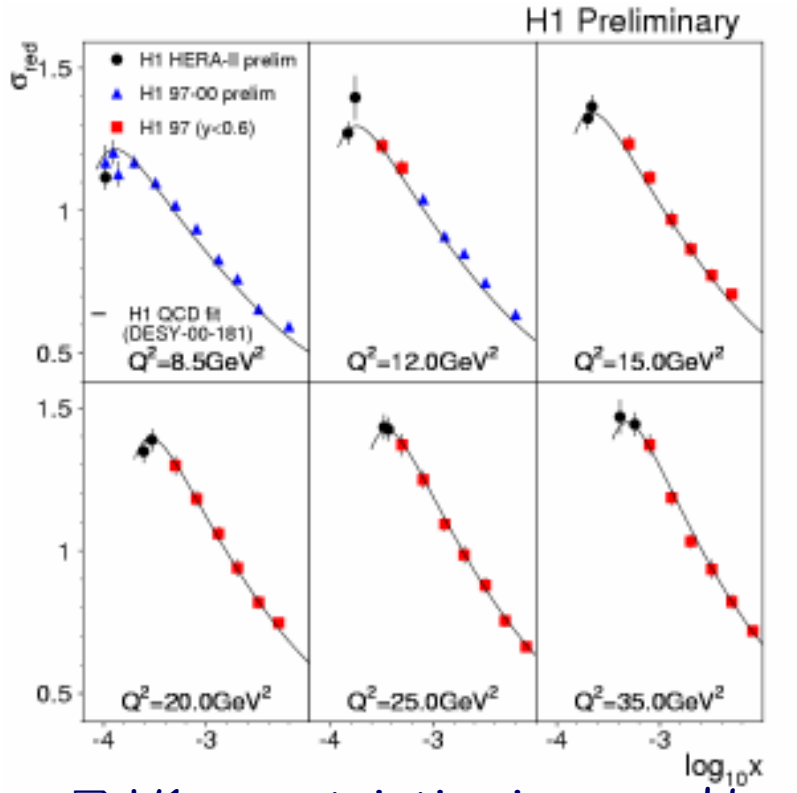
H1: background determined from data using the track charge.
$y = 0.9$ is reached for energies down to $E_e' = 3.4$ GeV



Preliminary high y results from high statistics data samples with Ep = 920 GeV



- First measurement at high y performed by ZEUS



- H1 uncertainties improved by a factor of 2 over former publication (hep-ex/0012053)
- 2-3 % total errors

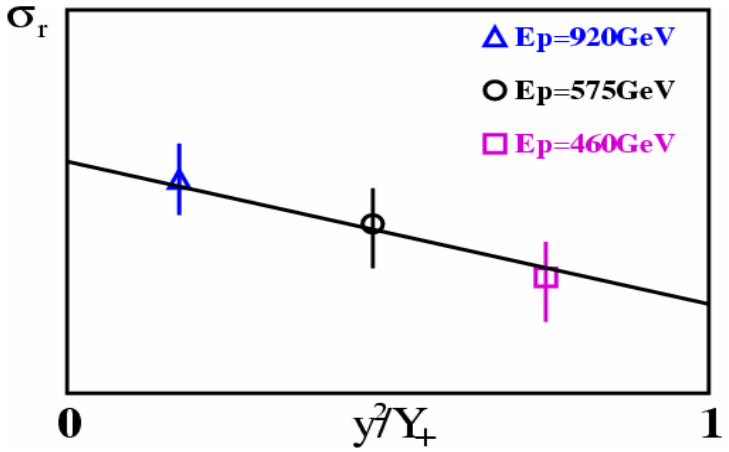
New at HERA

Measurement of F_L structure function by H1 Collaboration

F_L measurement at HERA

Direct measurement of F_L is performed using data obtained from collisions with different centre of mass energies ($\sqrt{s}$)

- For the same (Q^2,x) σ_r measured from different beam energies (i.e. y = Q^2/xs)
- Perform straight line fit of σ_r vs $f(y) = y^2/Y_+$ → extract F_2 and F_L

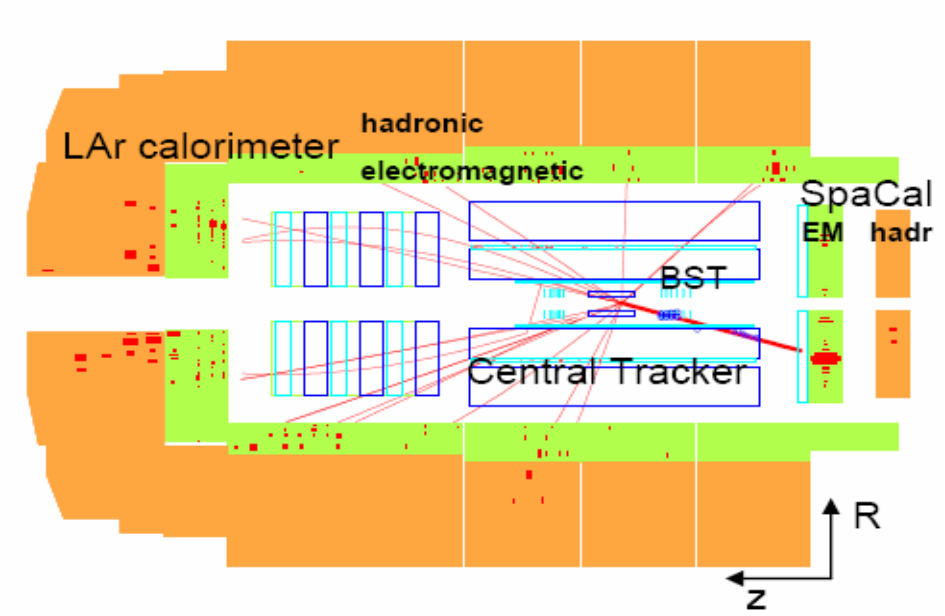


$$\sigma_r = F_2(x,Q^2) - \mathbf{f(y)} \cdot F_L(x,Q^2)$$

- 2007 e^+p data of different proton energies used
- Kinematics reconstructed from scattered electron energy (E_e') and polar angle (θ_e)

$$Q^2 = 4E_e\mathbf{E_e'}\cos^2(\boldsymbol{\theta_e}/2) \qquad y = 1 - \frac{\mathbf{E_e'}}{E_e}\sin^2(\boldsymbol{\theta_e}/2) \qquad x = Q^2/sy$$

Analysis strategy



- Scattered electron identified by isolated cluster in em calorimeter
- Two independent analyses
  - medium Q^2 – cluster in SpaCal
  - high Q^2 – cluster in LAr

At high y region ($y > 0.5$) - high background contribution

→ cluster-track link required
→ measure background from negative tracks

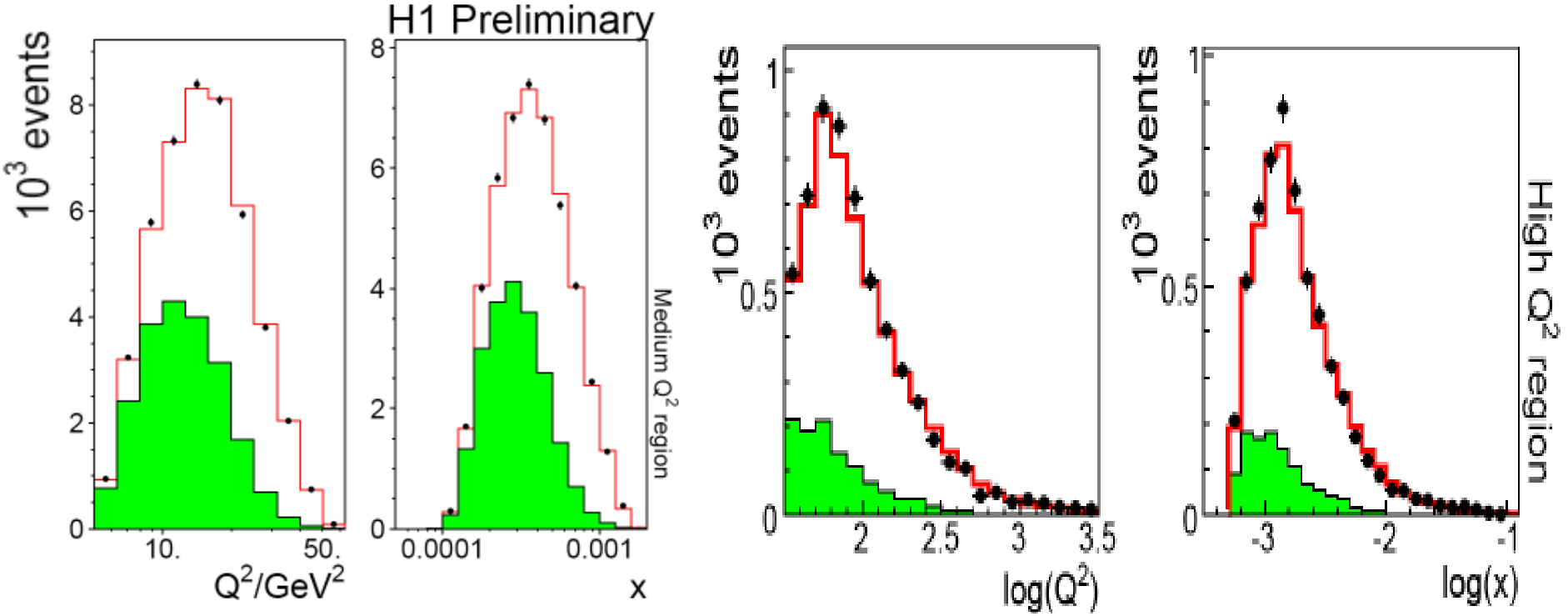
E_p	460 GeV (low)	575 GeV (medium)	920 GeV (nominal)
Lumi (medium Q^2)	12.4 pb^{-1}	6.2 pb^{-1}	21.9 pb^{-1}
Lumi (high Q^2)	12.02 pb^{-1}	6.2 pb^{-1}	46.3 pb^{-1}

Control plots – high y, Ep = 460 GeV

Medium Q^2
$0.6 \leq y \leq 0.9$

Data
NC MC + BG
BG (data)

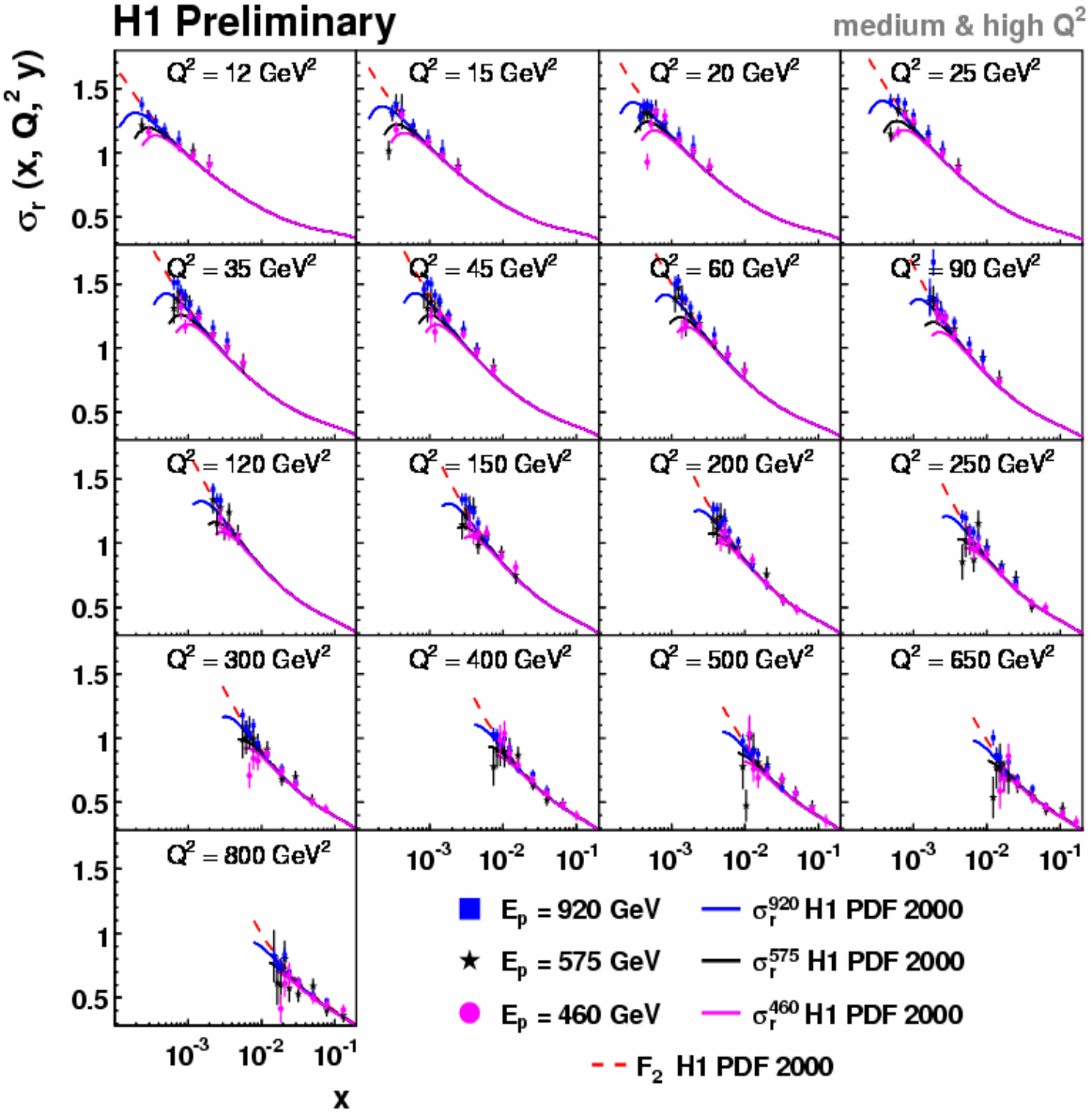
High Q^2
$0.7 \leq y \leq 0.9$



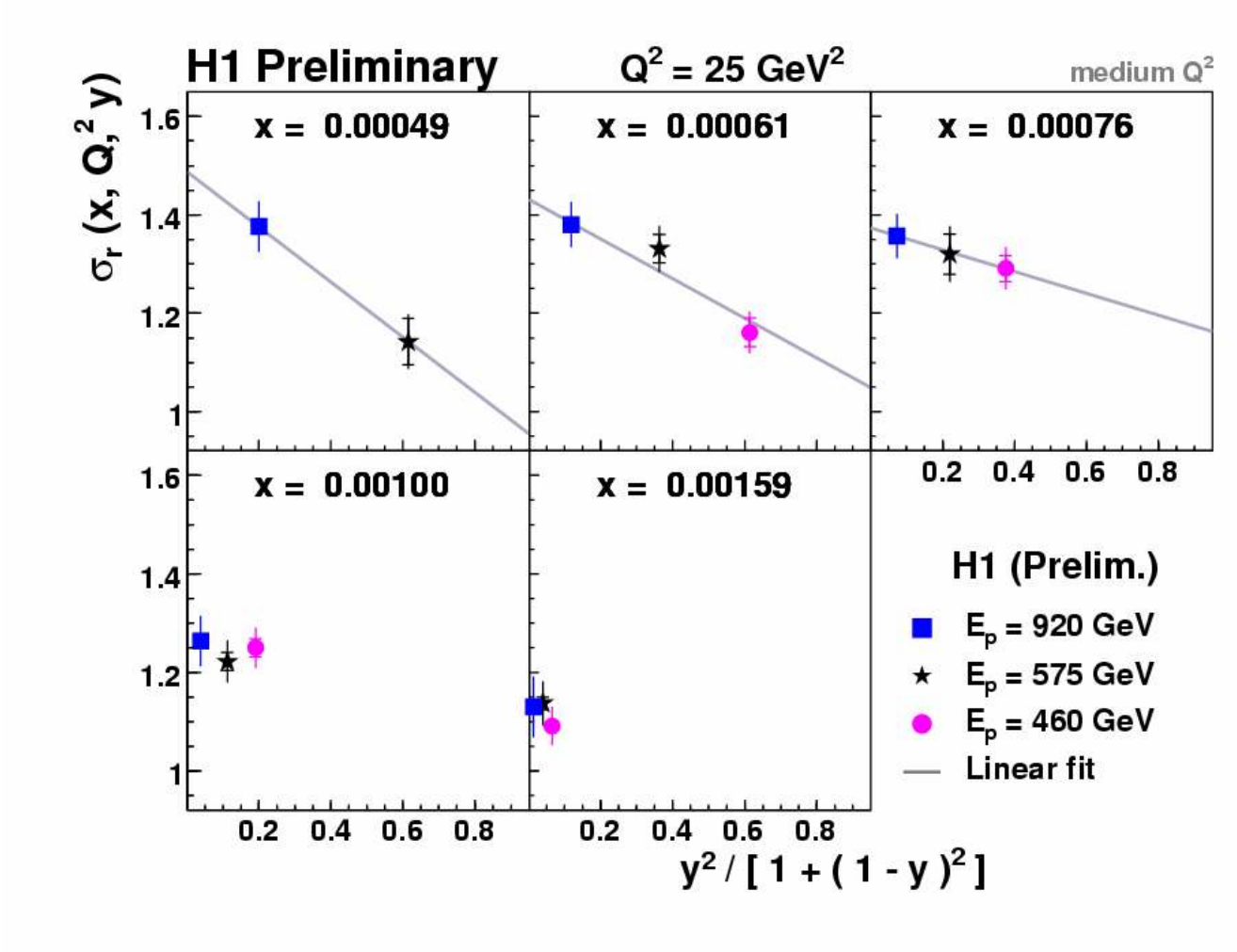
- Good agreement between data and MC

Double differential cross section

- σ_r turns over at low x due to F_L contribution
- For the same Q^2 and x, different values of s → different ranges of y

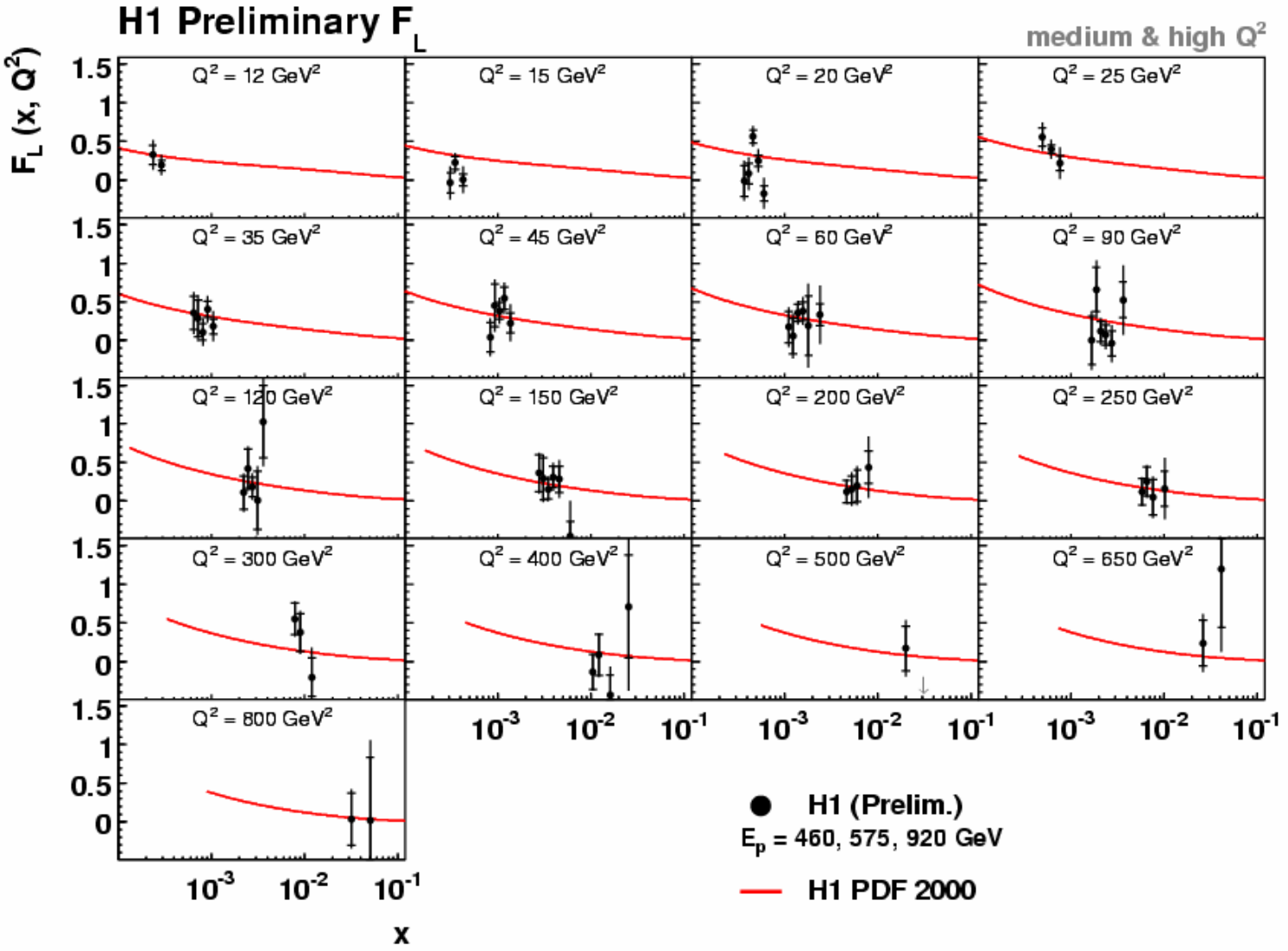


F_L extraction

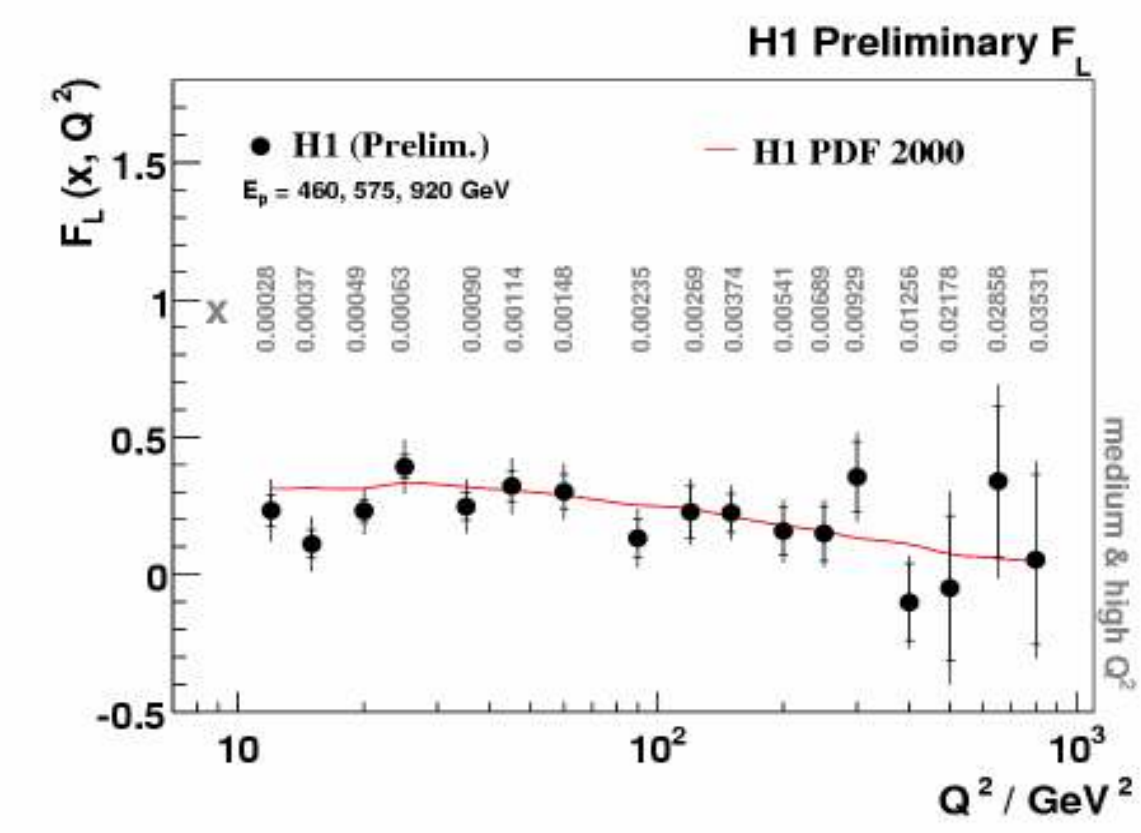


- F_L determined from the slope
- F_2 determined as an intercept at y = 0

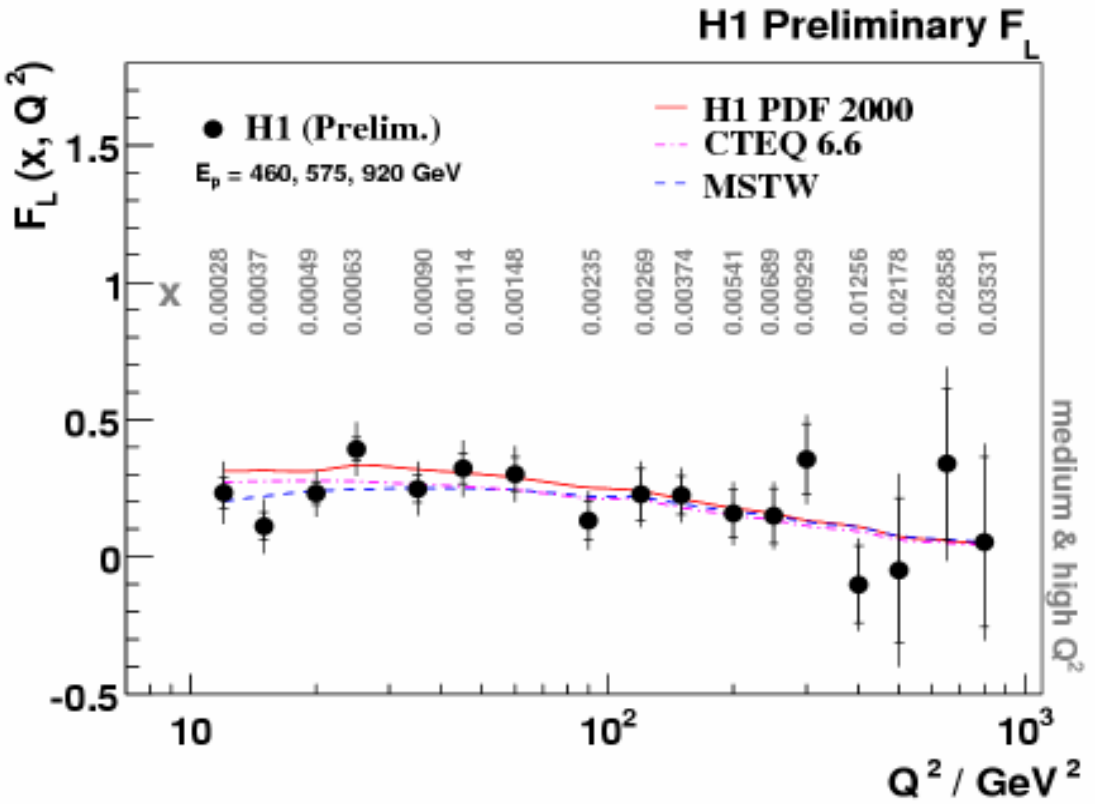
F_L results


H1 Preliminary F_L
medium & high Q^2
$F_L(x, Q^2)$
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 90 GeV^2
Q^2 = 120 GeV^2
Q^2 = 150 GeV^2
Q^2 = 200 GeV^2
Q^2 = 250 GeV^2
Q^2 = 300 GeV^2
Q^2 = 400 GeV^2
Q^2 = 500 GeV^2
Q^2 = 650 GeV^2
Q^2 = 800 GeV^2
1.5
1
0.5
0
10^{-3}
10^{-2}
10^{-1}
x
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1 PDF 2000

F_L in averaged x bins



F_L in averaged x bins



- The result confirms that pQCD at higher orders is valid at low x: the F_L calculated using HERA I data, predominantly driven by $\partial F_2 / \partial \ln Q^2$, is in very good agreement with preliminary measurement
- Unlike at fixed target experiments, F_L at HERA is not small because of the large gluon density at low x

Summary and Outlook

- Many results on DIS obtained from HERA experiments recently, providing precise measurement of proton structure
  H1 and ZEUS well on their way to provide the highest precision measurements of the proton structure as are important for the LHC

- **FIRST TIME AT HERA**: Direct measurements of the F_L structure function using data with different proton beam energies
  - important check of the theory → no indication for any deviation from the formalism of DGLAP QCD
  - extension of the measurement to the lower Q^2 is expected soon at H1
  - ZEUS measurement also in progress

Many more results from HERA are being presented in parallel to this workshop – DIS08 at London

HERA is finally approaching a phase of high precision measurements of unique nature in particle physics

Back-up Slides

QCD Fits from HERA

Fits from HERA-I	H1 PDF 1997 Eur. Phys. J C21 (2001)	H1 PDF 2000 Eur. Phys. J C30 (2003)	ZEUS-S Phys. Rev. D67 (2003)	ZEUS-JETS Eur. Phys. J C42 (2005)
Data from other exp	BCDMS (μp)	----	BCDMS,NMC,E665, CCFR (μp, μd, νFe)	----

Advantage of using only HERA data

- Pure proton target → no uncertainties of heavy target corrections
  → no need for strong isospin assumptions

- In global fits main contributions from HERA data from low-x sea and gluon

QCD analysis requires many choices to be made:

Q_0^2 starting scale for parameterization, cuts for perturbative phase space (Q^2_{min}) , choice of PDFs to parameterize, treatment of heavy quarks, allowed functional form of parameterization, treatment of exp. uncertainties, renormalisation / factorisation scales .... Should be reflected in PDF uncertainty

Background determination at high y at H1

- Background is measured using data events with the track charge opposite to lepton beam charge
- A small background charge asymmetry present due to the much enhanced interaction cross section of anti-protons over protons at low energies
- Background charge asymmetry (κ) is determined using high statistics e^+p and e^-p data with E_p = 920 GeV