Low Q^2 structure functions including longitudinal structure function

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on behalf of the H1 and ZEUS collaboration

Moriond QCD
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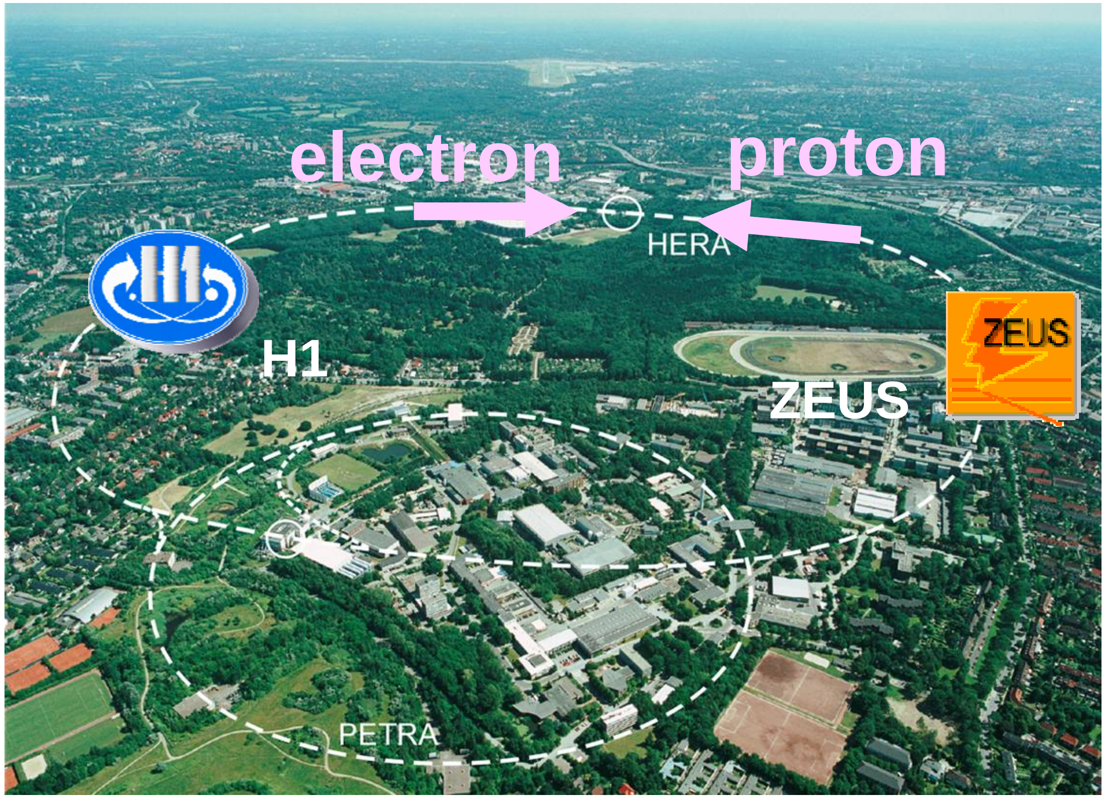
The world only e-p collider: HERA



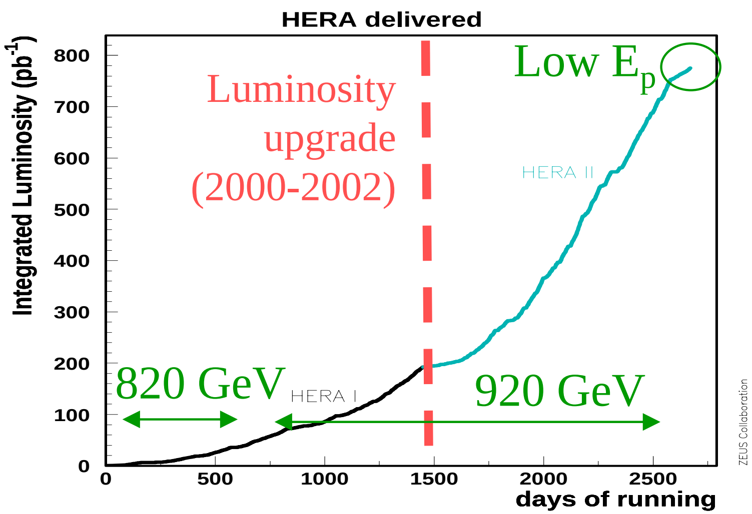
A unique collider at DESY, Hamburg

2 collider experiments: H1 & ZEUS

- proton beam (460, 575, 820,) 920 GeV
- electron/positron beam 27.5 GeV

→ Center of mass energy

$$\sqrt{s} = (225 \sim) \, 318\text{GeV}$$



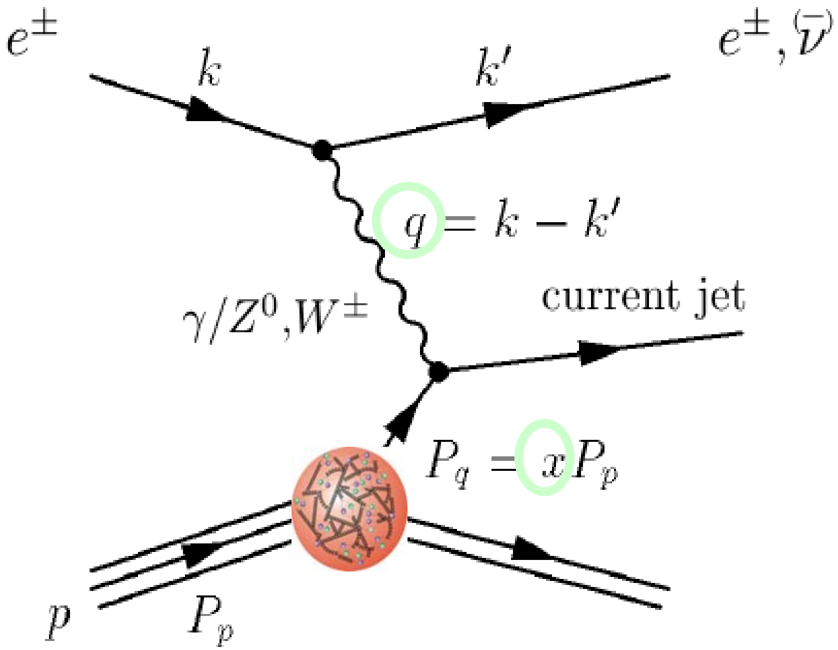
Operated since 1992 to 2007

1992-2000: HERA I

2002-2007: HERA II

In total, each experiment gains ~0.5 fb^{-1}.

Deep Inelastic Scattering (DIS)



- Kinematic variables to describe DIS

  Q^2: Virtuality

  → probing power

  x : Bjorken scaling variable

  → momentum fraction of struck quark

  y : Inelasticity

  $\sqrt{s}$: center of mass energy

$$Q^2 = sxy$$

$$Q^2 = -q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$y = \frac{p \cdot q}{p \cdot k}$$

- Inclusive DIS cross sections can be written with structure functions.

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4} Y_+ \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2) \mp \frac{Y_-}{Y_+} xF_3(x,Q^2) \right]$$

$$Y_{\pm} = 1 \pm (1 - y^2)$$

cross section with point-like particle

Structure functions reflect momentum distribution of partons in the proton.

Structure functions and PDFs

Measured quantity: reduced cross section $\quad Y_\pm = 1 \pm (1-y^2)$

$$\tilde{\sigma}(e^\pm p) = \frac{Q^4 Y_+}{2\pi\alpha^2}\frac{d^2\sigma}{dxdQ^2} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2)$$

Structure functions are used for determination of the parton distribution functions (**PDFs**), $q(x,Q^2)$ and $g(x,Q^2)$

- F_2 : [Sea + valence] quarks, (gluon)

$$F_2 = \sum A_q x(q+\bar{q}) \qquad \frac{\partial F_2}{\partial \ln Q^2} \propto xg$$

- F_L : longitudinal structure function

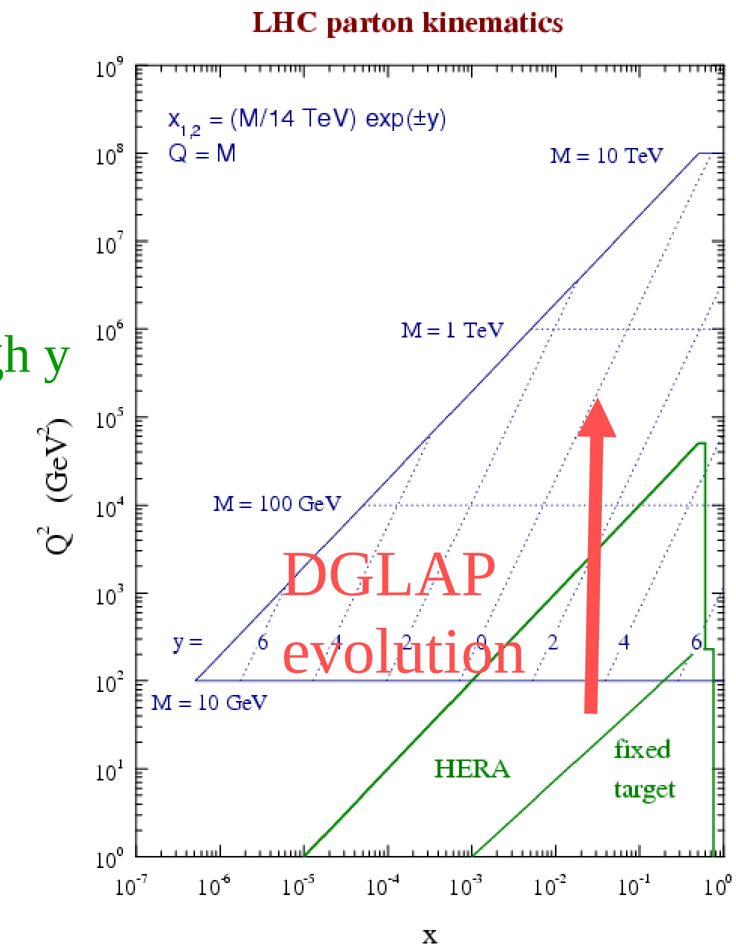
  ⟶ gluon (see later) sizable only at high y

- xF_3 : parity violation term (Electroweak)

$$xF_3 = \sum B_q x(q-\bar{q})$$

  high Q^2 only (→ *Next talk*)

  ⟶ Valence quarks



The Q^2 evolution can be described by perturbative QCD, using DGLAP equation.

HERA PDF

HERA PDF from combined cross sections

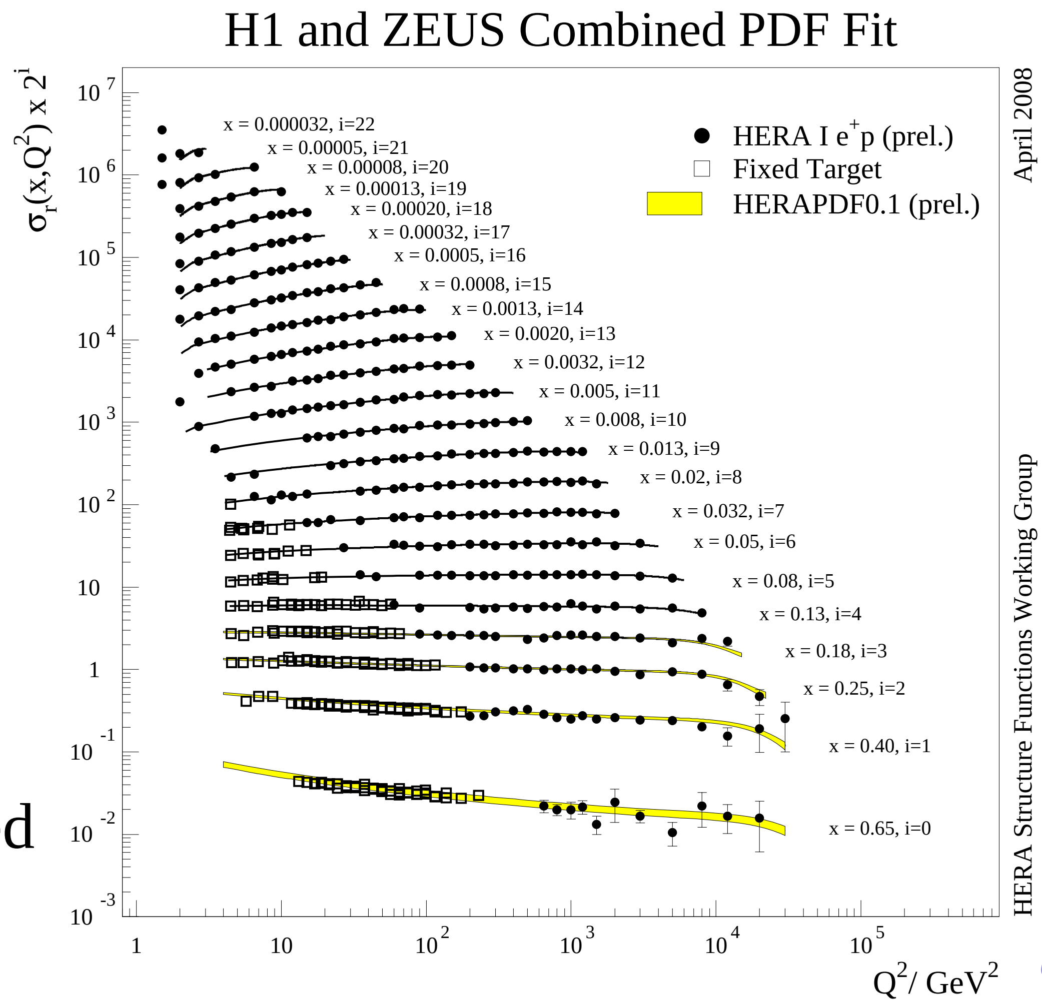
- HERA I inclusive DIS cross sections from H1 and ZEUS are combined by averaging. *(→Moriond QCD 2008, K. Korcsak-Gorzo)*

  Combination takes full account of systematic correlation.

  → Reduction of both statistical and systematic uncertainties.

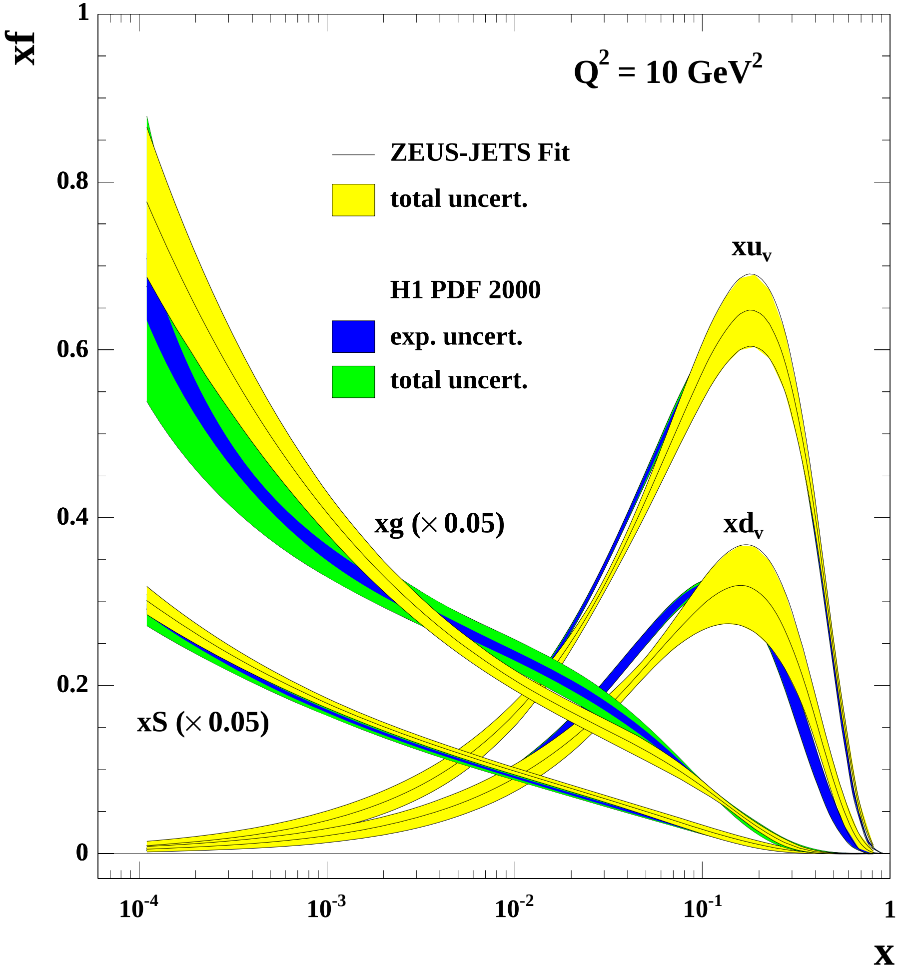
- PDFs are determined by fitting these combined data sets.
  - 96-97 Low Q^2 cross section
  - 94-00 High Q^2 cross section

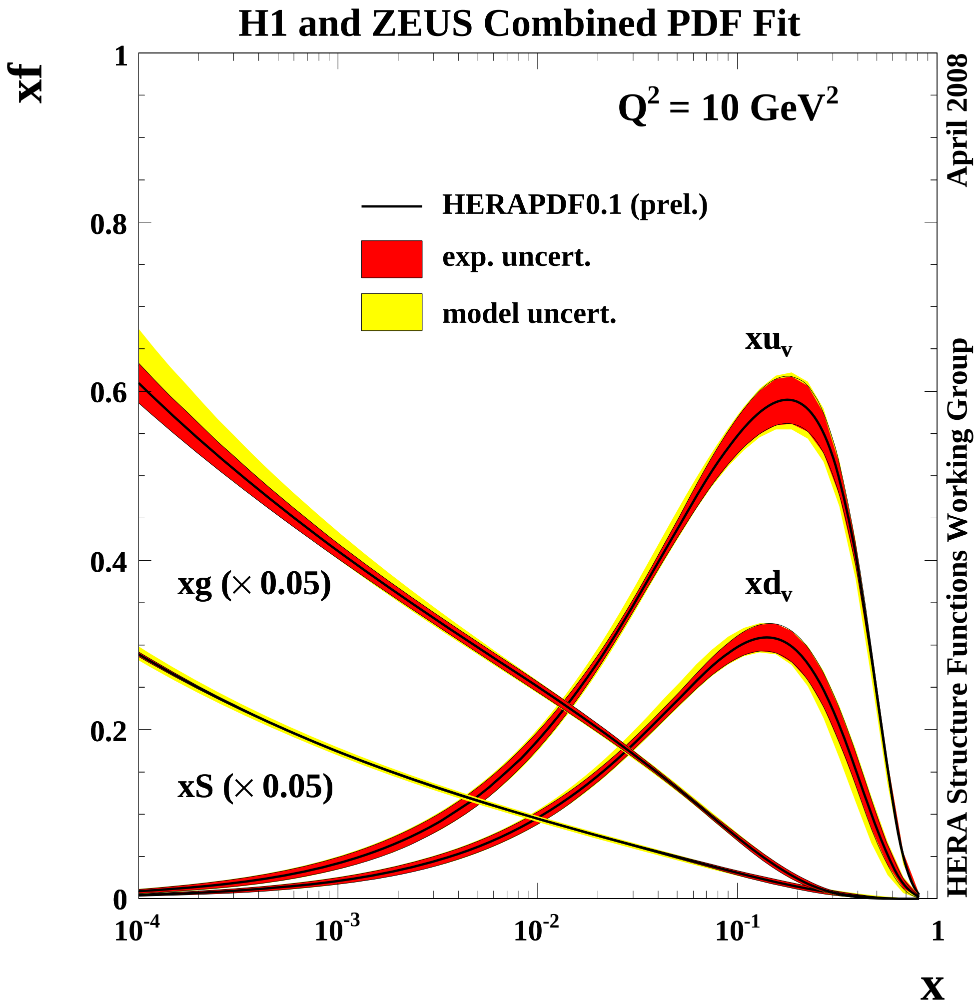
  → HERAPDF0.1
  - The measured cross section is well fitted in the large kinematic range.
  - Also succeeds to describe fixed target data.



HERAPDF0.1

- Compared to previous fits from each experiment, H1 PDF 2000 and ZEUS-JETS PDF, the uncertainties are impressively reduced.





Further input for HERA PDF: The new F_2 results from H1 using HERA I data

- F_2 from the final e^+p H1 cross section measurements at $12<Q^2<150$ GeV^2 from HERA I.

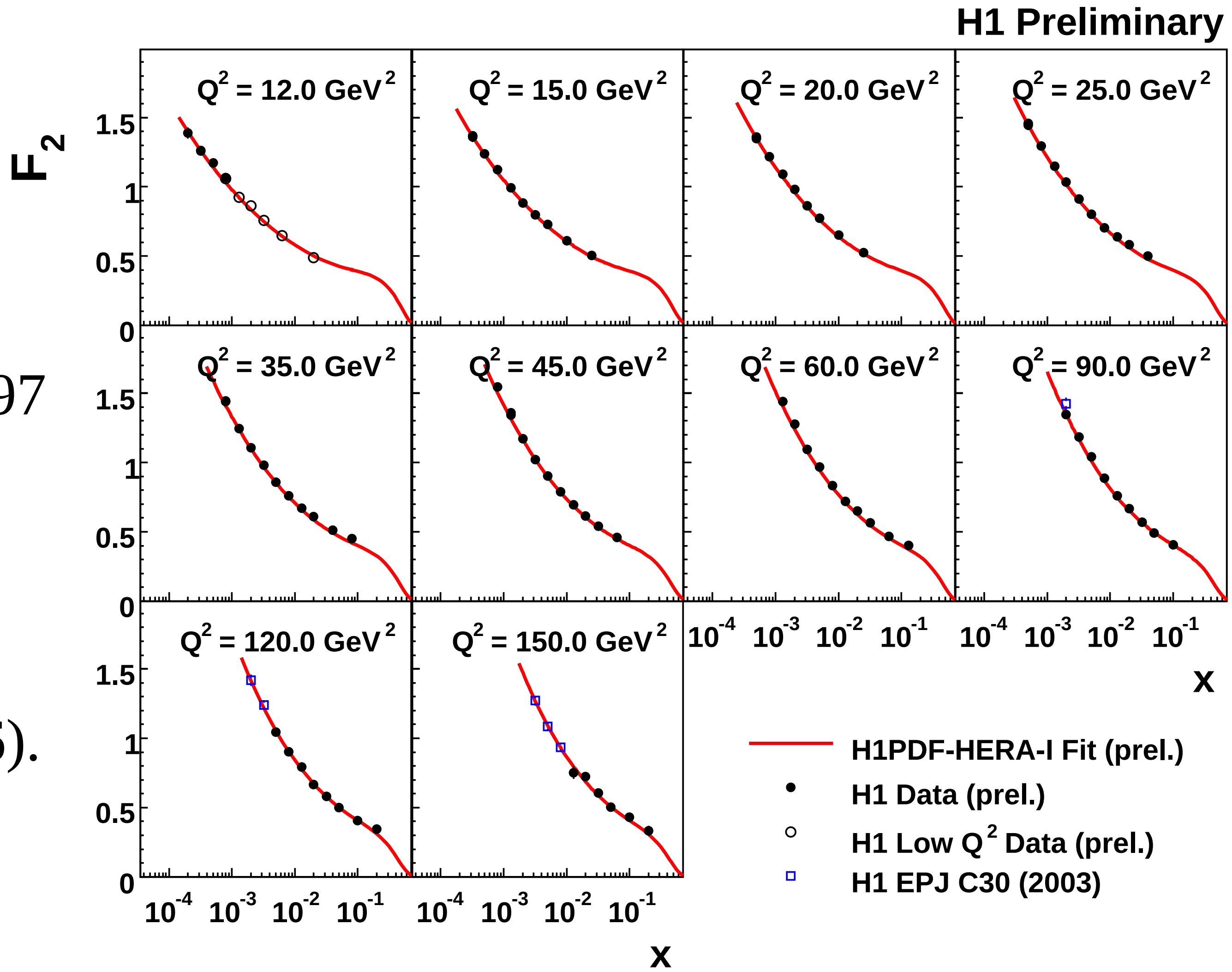
Combined result of

- Newly analyzed 2000 data (E_p=920 GeV)
- Reanalysis of 96/97 data (E_p=820 GeV)

Measured for

$2\cdot10^{-4}<x<0.1$ ($y \leq 0.6$).

1.5~2% accuracy



Measurement of F_L

F_L :Longitudinal structure function

- F_L is proportional to the cross section of longitudinal photon interacting with proton.

  $F_L \propto \sigma_L$

- In naïve QPM, proton has co-linear spin ½ quarks only.

  Longitudinal photon cannot interact with a quark. → F_L=0

- gluon emission in the proton → F_L> 0

  i.e. F_L directly reflects gluon dynamics in the proton.

gluon PDF

In pQCD: $$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum_q e_q^2 \left(1-\frac{x}{z}\right) zg(z)\right]$$

↔ In PDF extraction in pQCD framework, gluon PDF is mainly determined from $\frac{\partial F_2}{\partial \ln Q^2} \propto xg$

Measurement of F_L is a good test for the current understanding of proton structure and QCD.

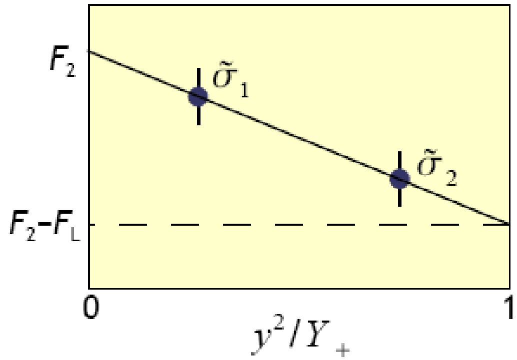
Measurement of F_L

- Measured cross section is a combination of F_2 and F_L.

At low Q^2 $$\tilde{\sigma}(e^{\pm}p) = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$ $$Y_+ = 1 + (1-y^2)$$ $$\rightarrow 1 < Y_+ < 2$$

- Separation of F_L from F_2.

Cross sections at the same (x, Q^2) but the different y



$$y = \frac{Q^2}{sx}$$ $\rightarrow$ multiple beam energies

HERA was successfully operated with low E_p for the last months.

Data sets with three different energy are available.

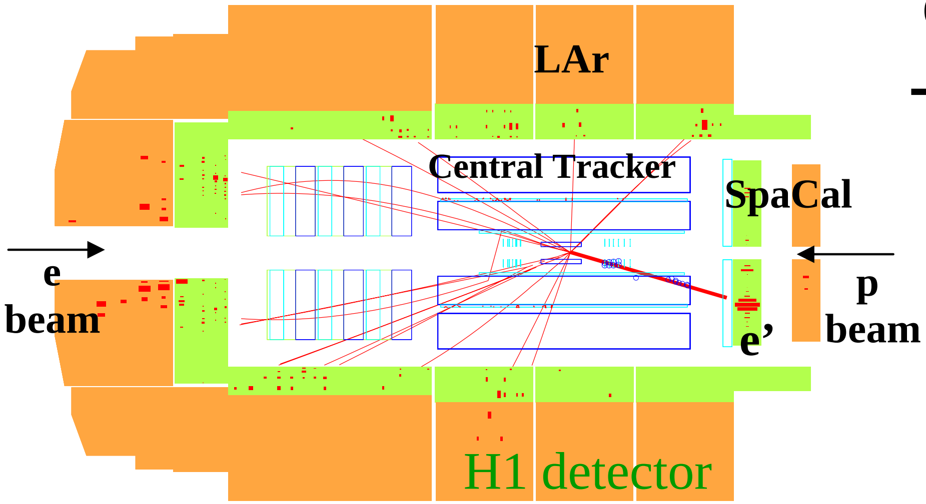
$\sqrt{s} = 318, 252, 225\,\mathrm{GeV}$ (E_p = 920, 575, 460 GeV)

➔ First direct F_L measurements at low x ($x \sim 10^{-3}$) = gluon dominance.

- Extraction of structure functions without QCD assumption
- Consistency check of pQCD framework for the proton structure.

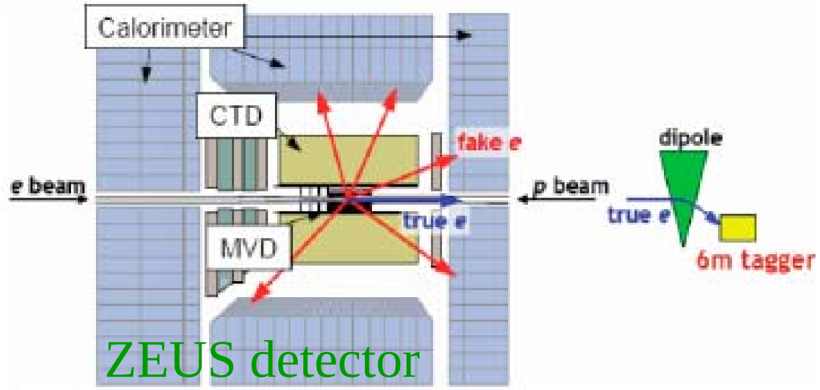
Strategy for the measurement

- High y cross section measurement should be done.
- One of the difficulties is identification of scattered positron.



e' with low energy and low angle.

→ Large background due to mis-ID.



Estimation of background

H1: using wrong charge distribution.

ZEUS: using MC, checked by BG events detected by a tagger

- H1 F_L $12 \leq Q^2 \leq 90$ GeV^2 (SpaCal) *PLB655 (2008) 139*
  $35 \leq Q^2 \leq 800$ GeV^2 (LAr) (preliminary)
- ZEUS F_2 & F_L $24 \leq Q^2 \leq 110$ GeV^2 (publishing)

Reduced cross sections (ZEUS)

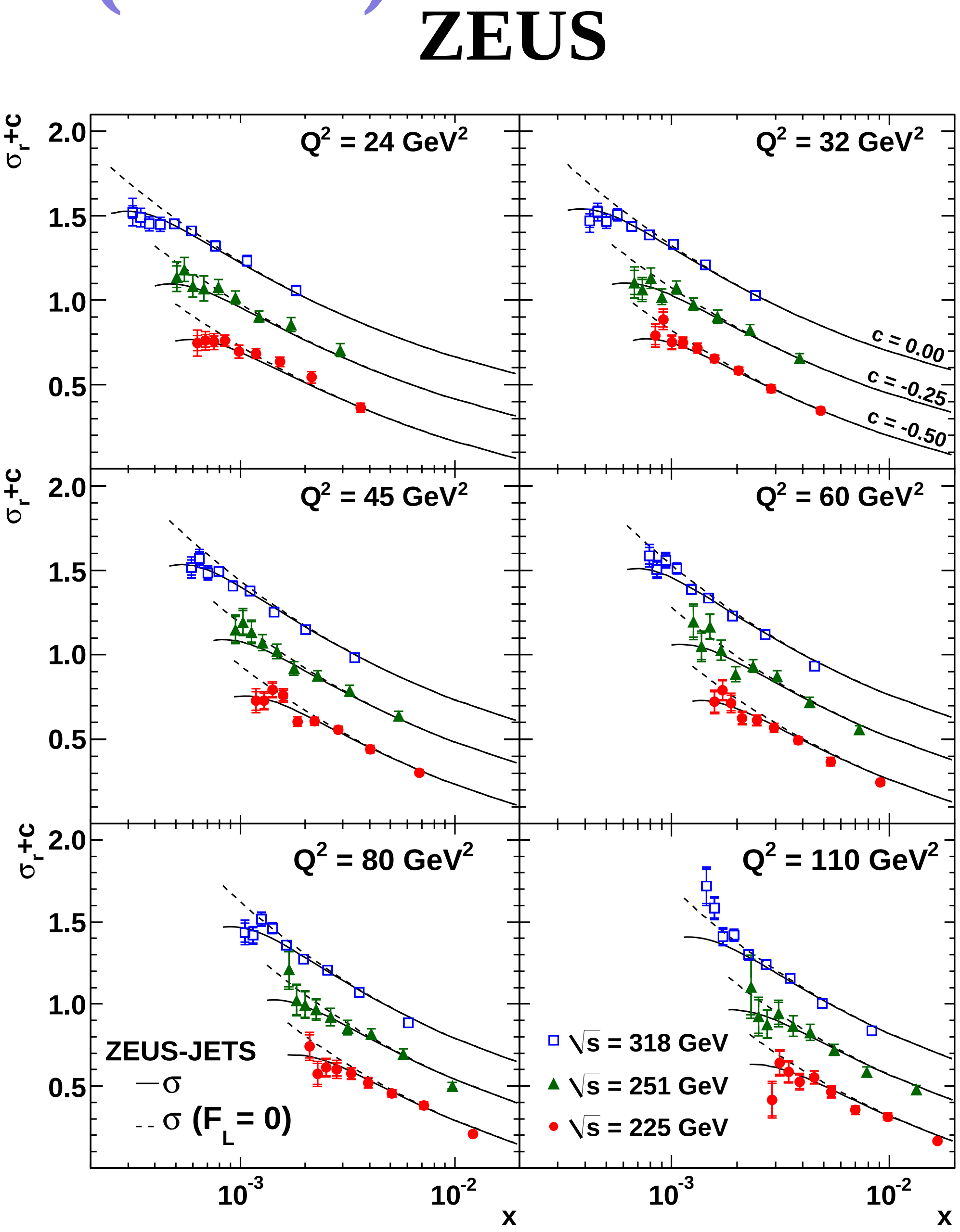
- Reduced cross sections at three beam energies.

  Offset is added for each beam energy.

- Compared to ZEUS-JETS predictions.

- The data tends to flatter at lowest x (=highest y) region and deviates from F_L=0.

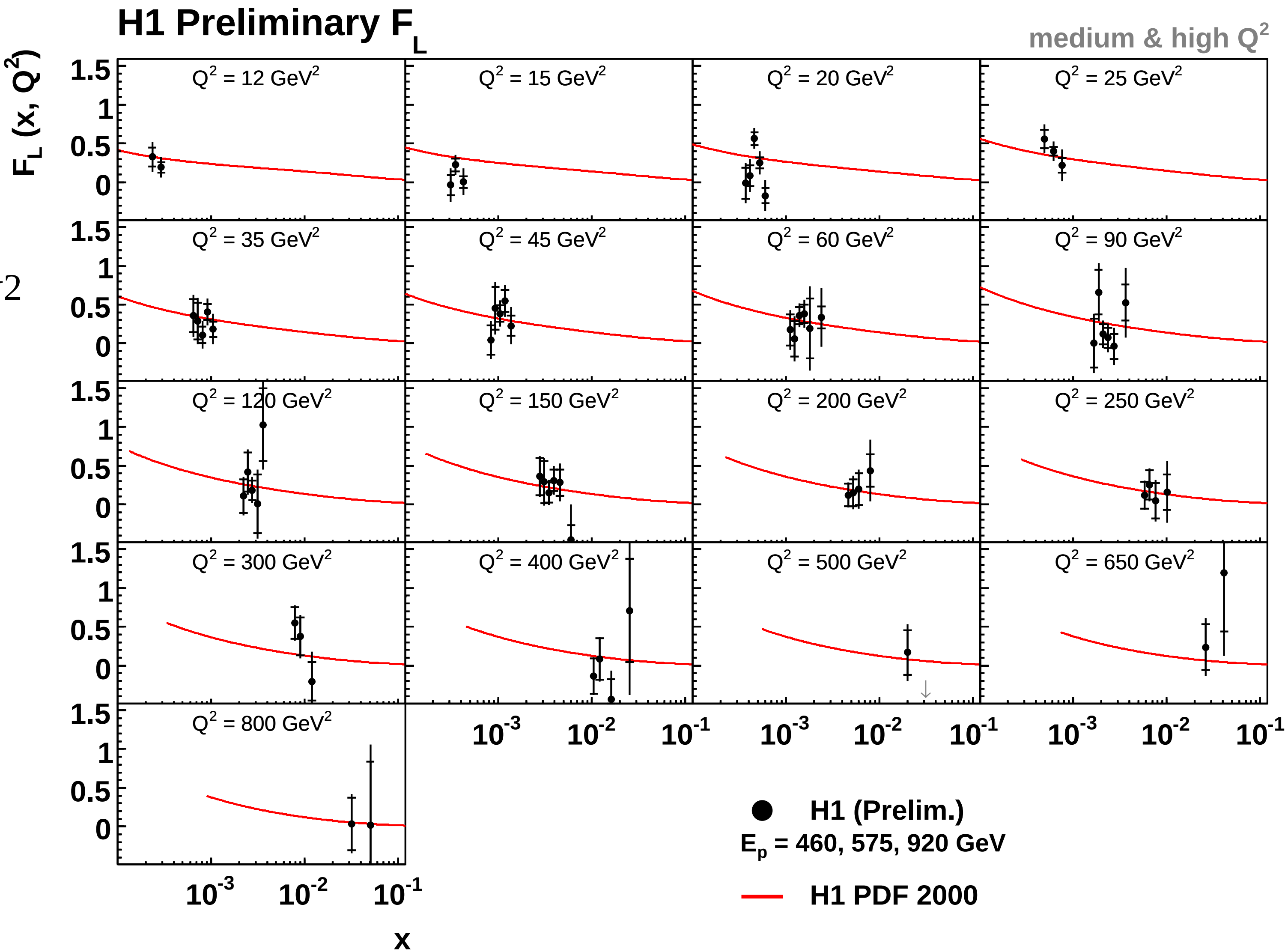
  → F_L contribution



H1 reduced cross sections are on extra slides.

F_L (H1)

F_L for
$12 \le Q^2 \le 800$ GeV^2

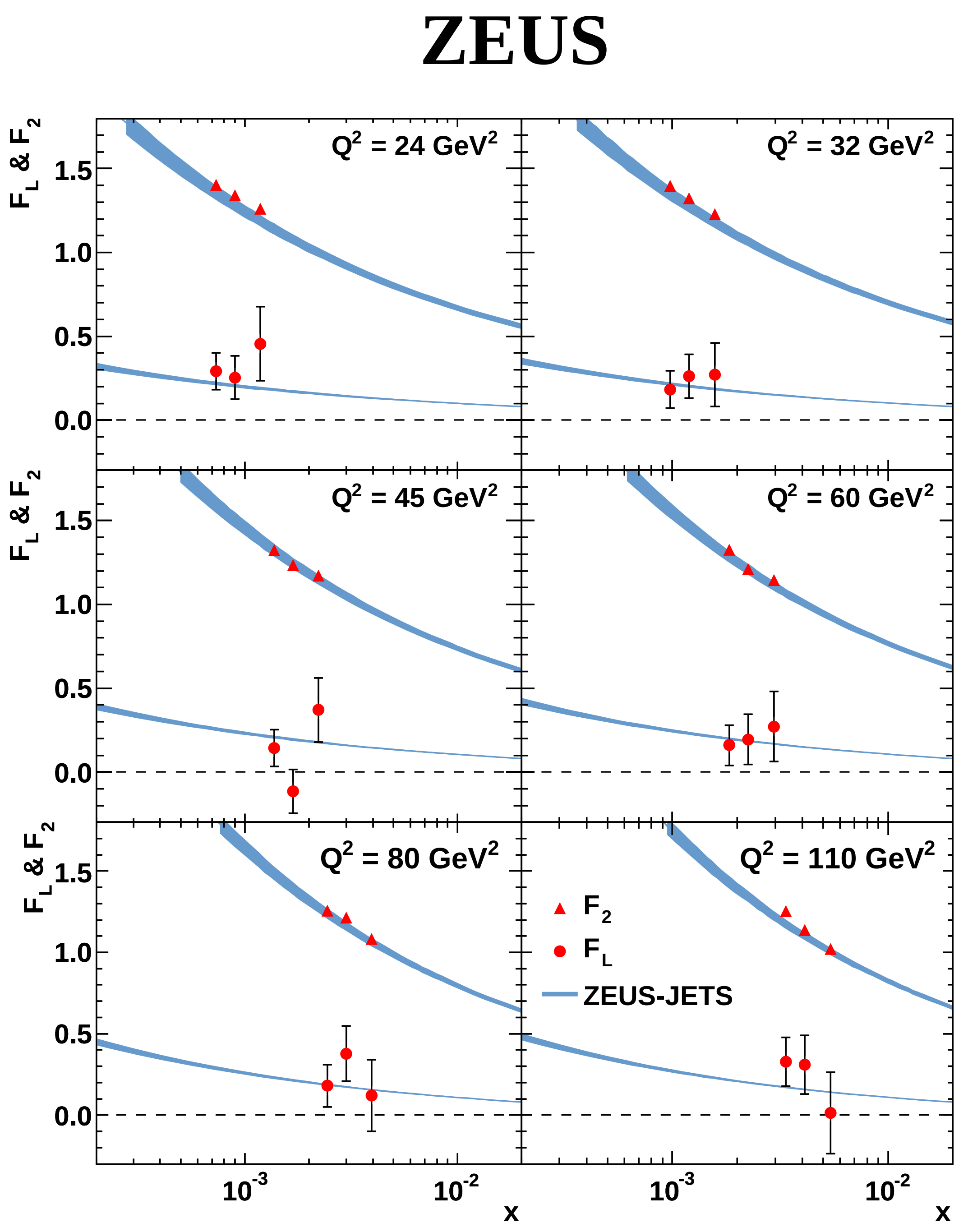


- Non-zero F_L is supported.
- pQCD prediction using H1 PDF 2000 is consistent with measured F_L.

ZEUS F_2 and F_L

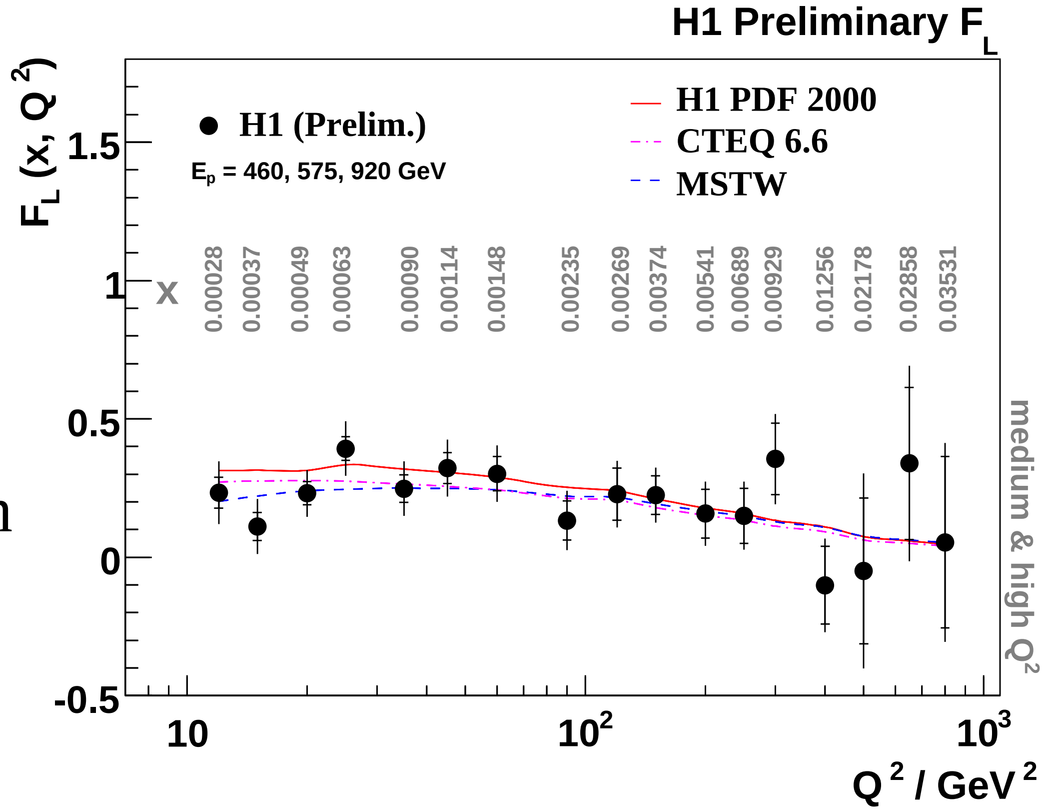
- F_2 and F_L are extracted from reduced cross sections without QCD assumptions.
- Non-zero F_L , $0 < F_L < F_2$, is supported.
- Compared to ZEUS-JETS PDF predictions.

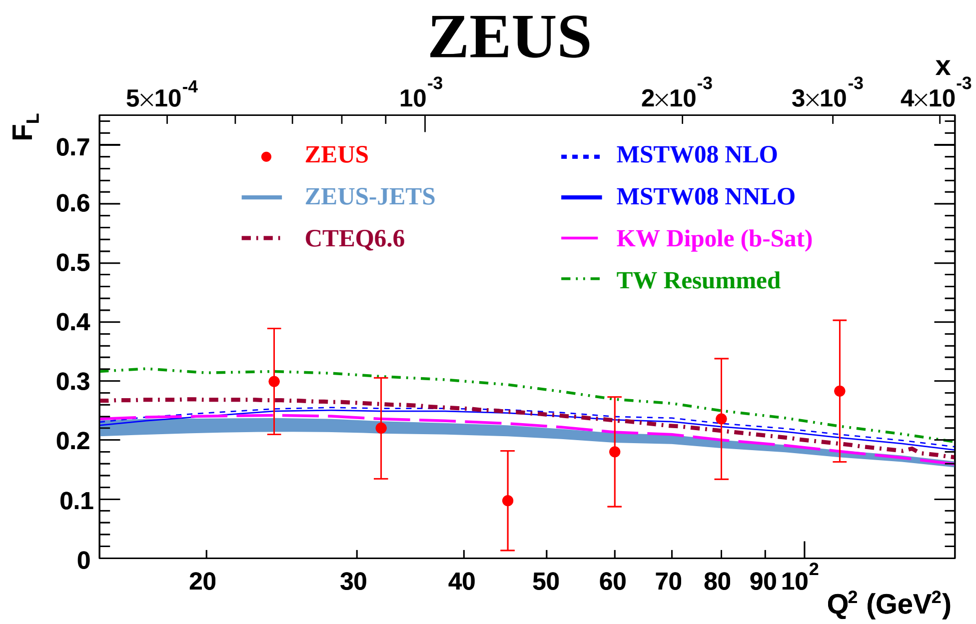
→ pQCD predictions are consistent with the measurement.



x-averaged F_L

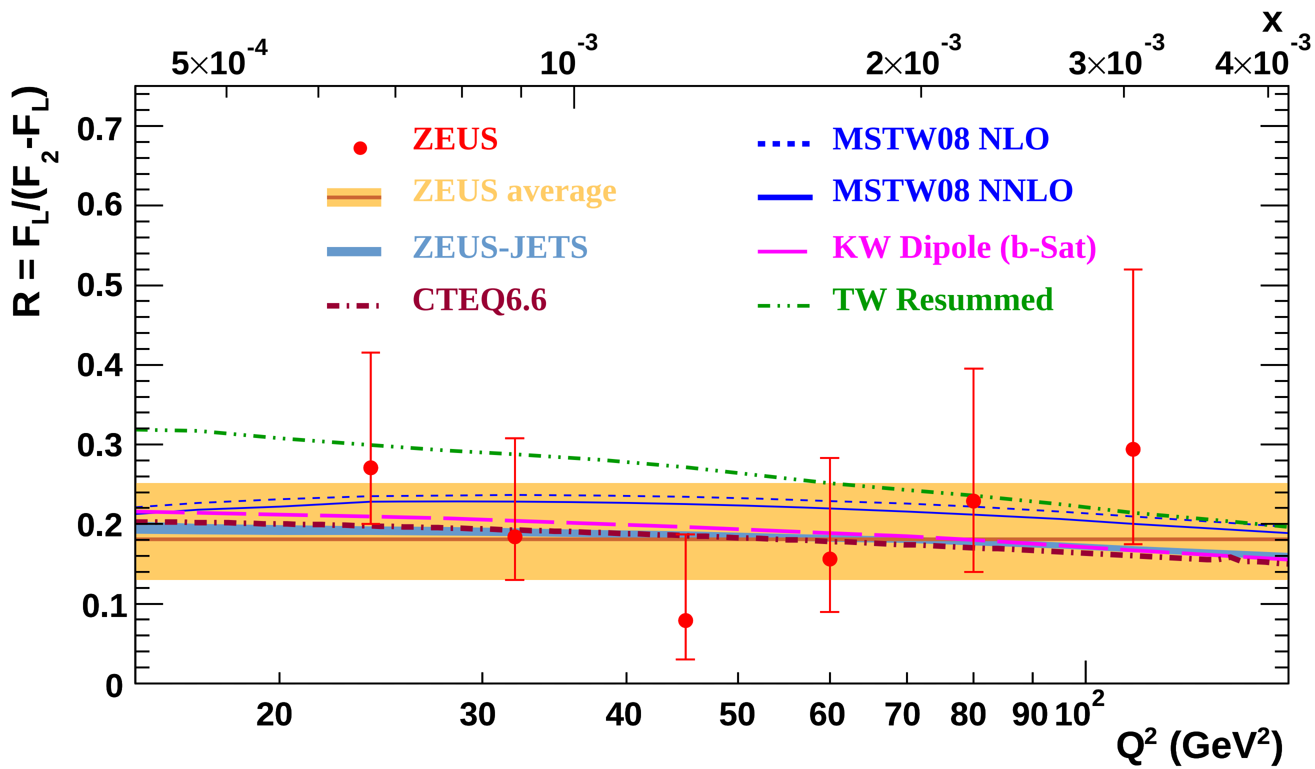
- Averaged F_L for each Q^2, extracted at given x.
- Compared to predictions with different
  - PDFs
  - pQCD frameworks
- Not sensitive to the differences of the predictions, but consistent with them.
- Extension to low Q^2 is ongoing.





R from ZEUS

$$R = \frac{F_L}{F_2 - F_L}$$



- *R* extracted for each Q^2 at given x.
- Various predictions are consistent with measurement.
- Overall value of *R*:

$$R = 0.18\,^{+0.07}_{-0.05}$$

Summary

ep scattering at HERA gives precise understanding of the proton structure.

Further understanding is still coming.

- Significantly improved determination of PDFs using H1/ZEUS combined cross sections of HERA I.
- Direct measurement of F_L.
  - F_L is separated from F_2 without QCD assumption.
  - pQCD predictions are consistent with measured F_L.

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    - F_L is separated from F_2 without QCD assumption.
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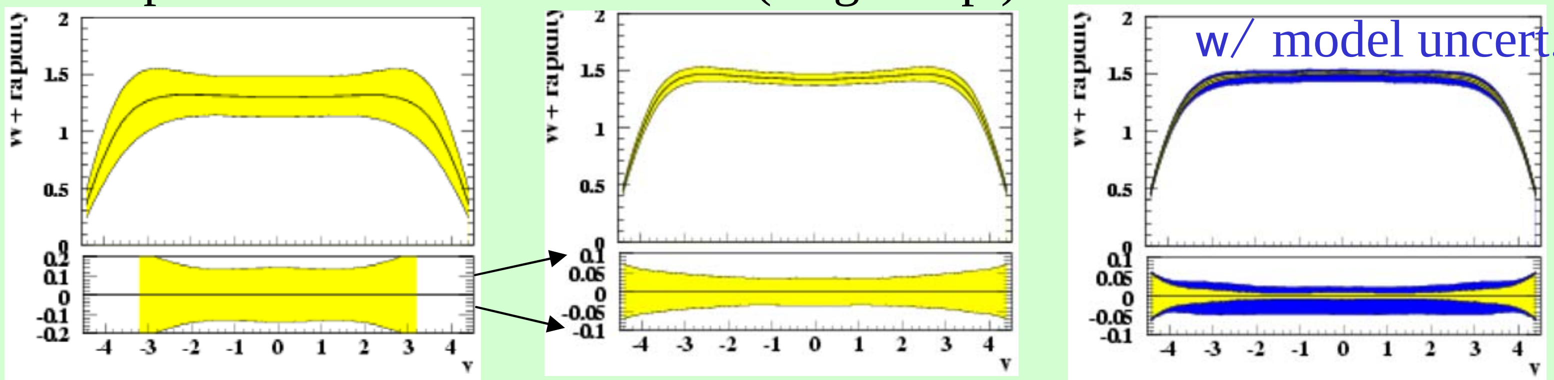
HERA PDFs have impact on LHC. *A.M. Cooper-Sarker at HERA-LHC 2008*

W^+ rapidity

exp. uncert.

pre-HERA | HERA I (single exp.) | HERAPDF0.1

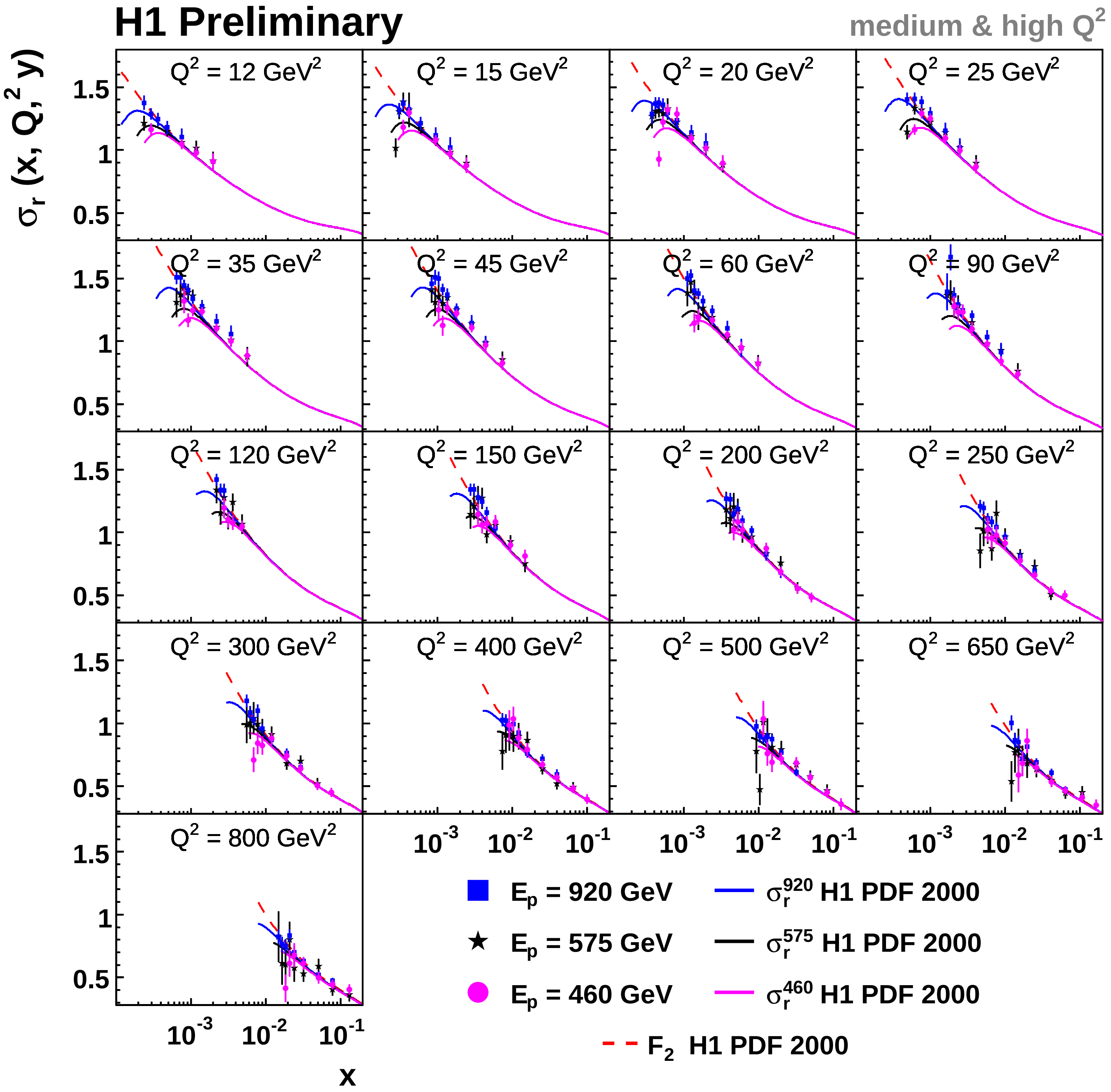


Further improvement may come…

Extra slides

H1 reduced cross sections

- No offset.
- Measured for wider Q^2 range.
  $12 \le Q^2 \le 90$ GeV^2
  and
  $35 \le Q^2 \le 800$ GeV^2
- Compared to predictions using H1 PDF 2000.
- F_L contribution is seen as turnover.



Details of HERA PDF *slide from DIS08 A.M. Cooper-Sarker*

Chosen form of the PDF parametrization at Q_0^2

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2+Fx^3...)$$

	A	B	C	D	E
gluon	sum rule	■	■		
u_v	sum rule	■	■	■	■
d_v	sum rule	$= B(u_v)$	■		
U_{bar}	Lim x→0 $\overline{u}/\overline{d}$→1	■	■		
D_{bar}	■	$= B(\overline{U})$	■		

The number of parameters for each parton has been optimized

Optimization means starting with only BLUE parameters and adding D, E,F parameters until there is no further χ2 advantage

PDFs fiited: gluon, u_v, d_v, $U_{bar}=u_{bar}+c_{bar}$, $D_{bar}=d_{bar}+s_{bar}+b_{bar}$

Sea flavour break-up at Q_0: s = fs*D, c=fc*U , $AU_{bar}=(1-fs)/(1-fc)AD_{bar}$ Lim x→0 u_{bar}/d_{bar} →1

fs = 0.33D (s=0.5d), fc = 0.15U consistent with dynamical generation

mc=1.4 GeV mass of charm quark mb=4.75 GeV mass of beauty quark

Zero-mass variable flavour number heavy quark scheme (for now)

Q_0^2 = 4 GeV^2 input scale Q^2_{min} = 3.5 GeV^2 minimum Q^2 of input data

$\alpha_s(Mz)$ = 0.1176 PDG2006 value