Proton structure - cross sections and structure functions at low x and low to medium Q^2

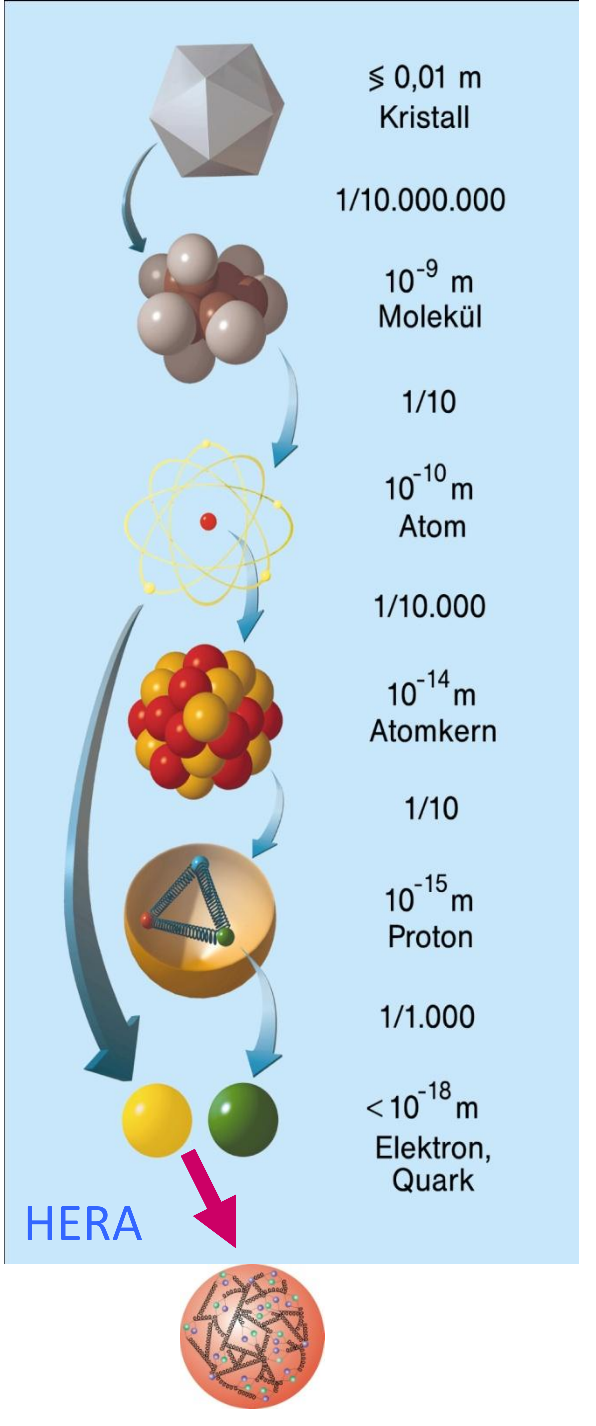
Prabhdip Kaur Devgun

(MPI Munich, P.U. Chd)

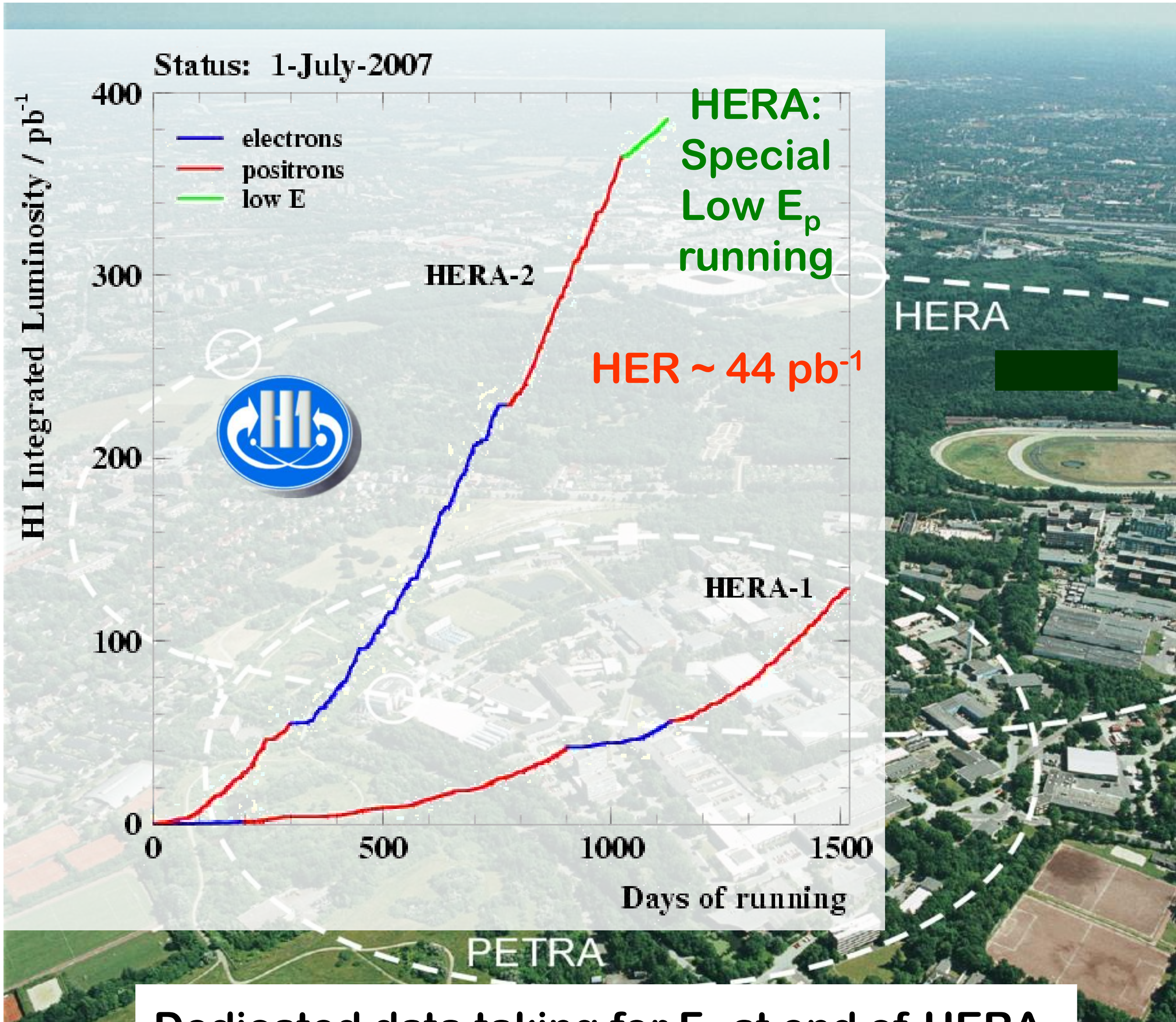
On Behalf of H1 and ZEUS Collaborations

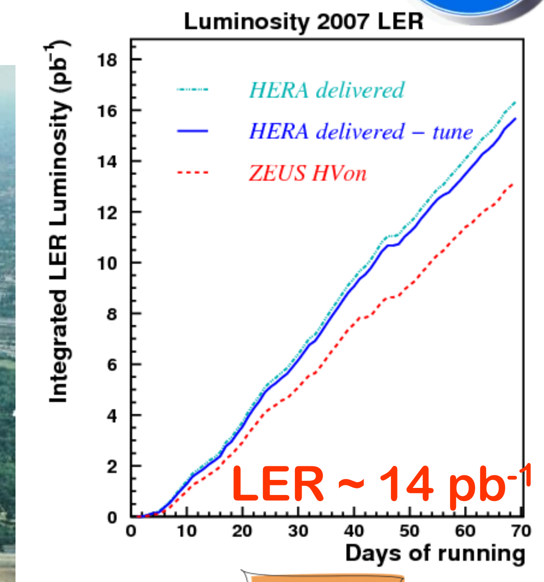
New Trends in HERA Physics 2011, September 25 - 28, 2011

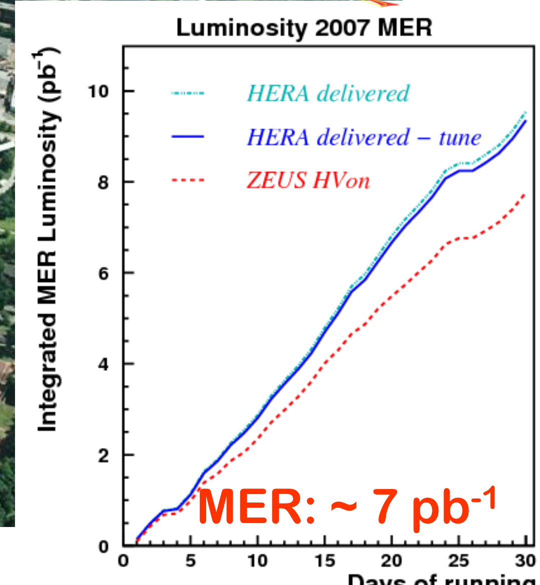
Ringberg, Germany



HERA Accelerator (1992-2007) Performance







Dedicated data taking for F_L at end of HERA

Combination of HERA-I H1-ZEUS data

- NC Data span six orders of magnitude four-momentum-transfer squared, Q^2, and in Bjorken x:

$$6.10^{-7} \leq x \leq 0.65 \text{ and } 0.045 \leq Q^2 \leq 30000\,GeV^2, 0.005 \leq y \leq 0.95$$

CC data : $1.3.10^{-2} \leq x \leq 0.4$ and $300 \leq Q^2 \leq 30000\,GeV^2, 0.037 \leq y \leq 0.76$

How data can be used to understand the proton structure? → Ritu's talk

- The high-Q^2 CC data, together with the difference between NC e^+p and e^-p cross sections at high Q^2, constrain the valance quark distribution
- The use of the HERA CC data → down quark distribution in the proton ,without assuming isospin symmetry
- The low Q^2 and low x data can be used to determine sea quark and gluon pdfs

- 100 pb^{-1} for each experiment for e^+p and 15 pb^{-1} for e^-p for HERA-I
- Both H1 and ZEUS have determined their own sets of quark and gluon momentum distributions in the proton ZEUSPDF and H1PDF

↓

Combined H1 ZEUS data could be used to form HERAPDF fits

Data sets used for combination

- HERA-I: 1994-97 Ep was kept at 820 GeV ; 1998-2000 Ep increased to 920 GeV

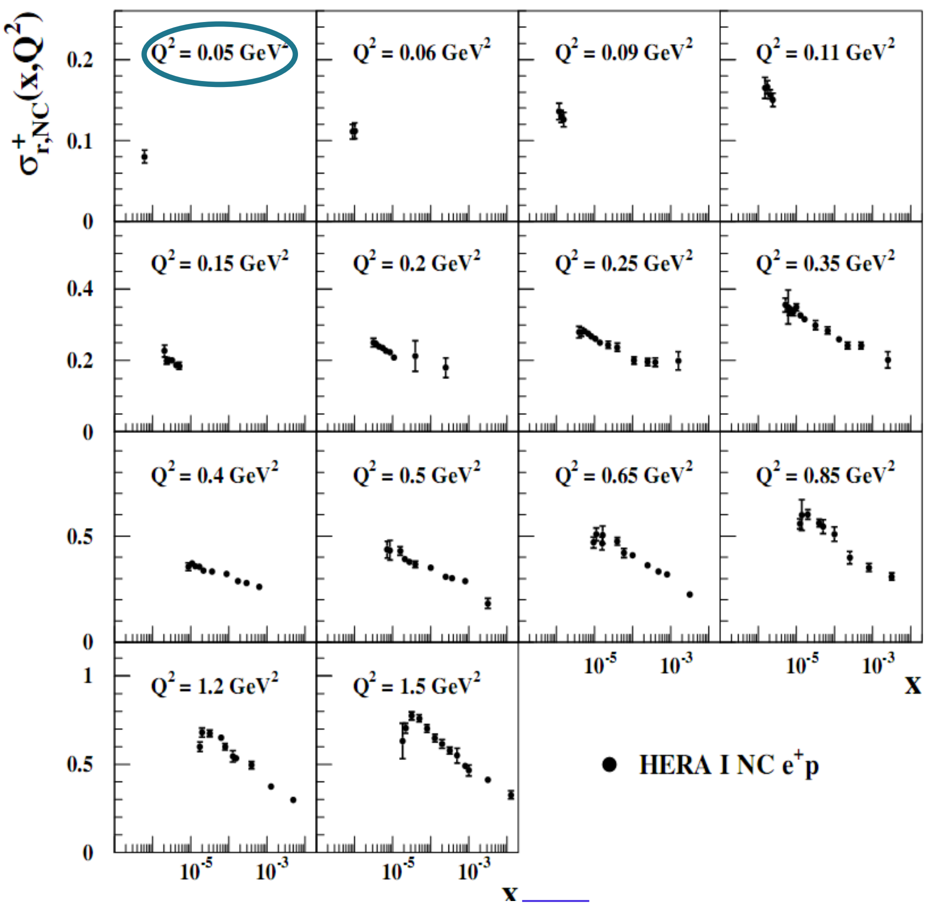
Data Set		x Range		Q^2 Range GeV^2		$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV
H1 svx-mb	95-00	5×10^{-6}	0.02	0.2	12	2.1	e^+p	301-319
H1 low Q^2	96-00	2×10^{-4}	0.1	12	150	22	e^+p	301-319
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319
ZEUS BPC	95	2×10^{-6}	6×10^{-5}	0.11	0.65	1.65	e^+p	301
ZEUS BPT	97	6×10^{-7}	0.001	0.045	0.65	3.9	e^+p	301
ZEUS SVX	95	1.2×10^{-5}	0.0019	0.6	17	0.2	e^+p	301
ZEUS NC	96-97	6×10^{-5}	0.65	2.7	30000	30.0	e^+p	301
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	301
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	319
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	319
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	319
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	319

- For combination The H1 and ZEUS data are transformed to a common grid of (x; Q^2) points.
- The combination method used takes the correlations of systematic uncertainties into account, resulting in an improved accuracy.
- The combination of the data sets uses the $\chi2$ minimisation method

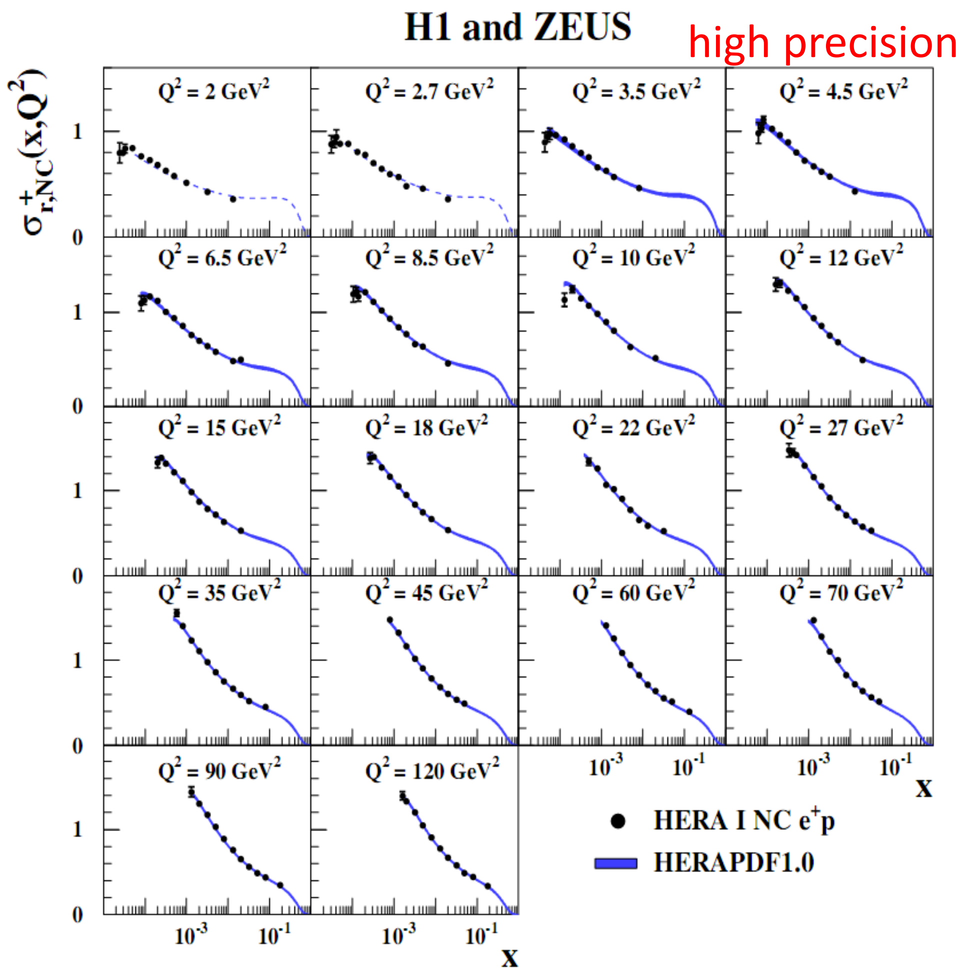
H1-ZEUS combined very low and mediumQ^2 data

JHEP 1001:109(2010)

high precision



high precision

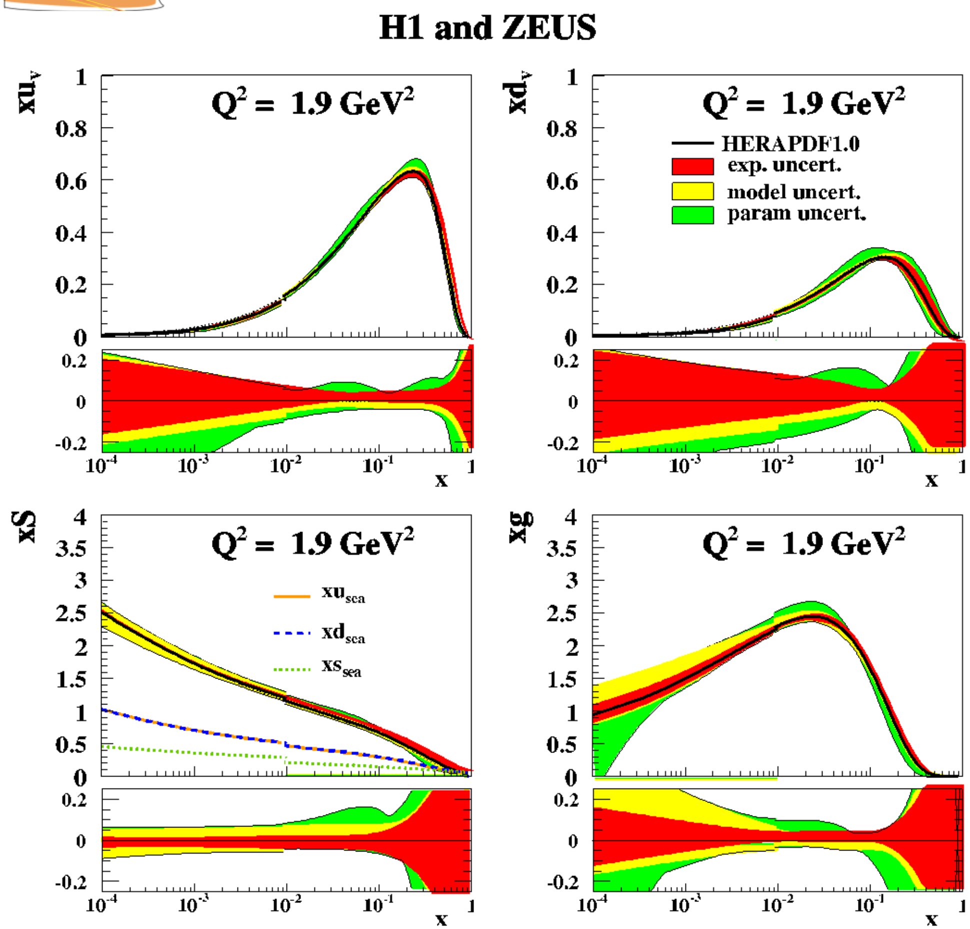


- HERAPDF1.0 based on $\overline{MS}$ scheme
- Q^2 is taken as Factorization and re-normalization scale
- Starting Q_0^2 scale =1.9 GeV^2, ($Q^2 < m_c^2$)
- α_s = 0.1176

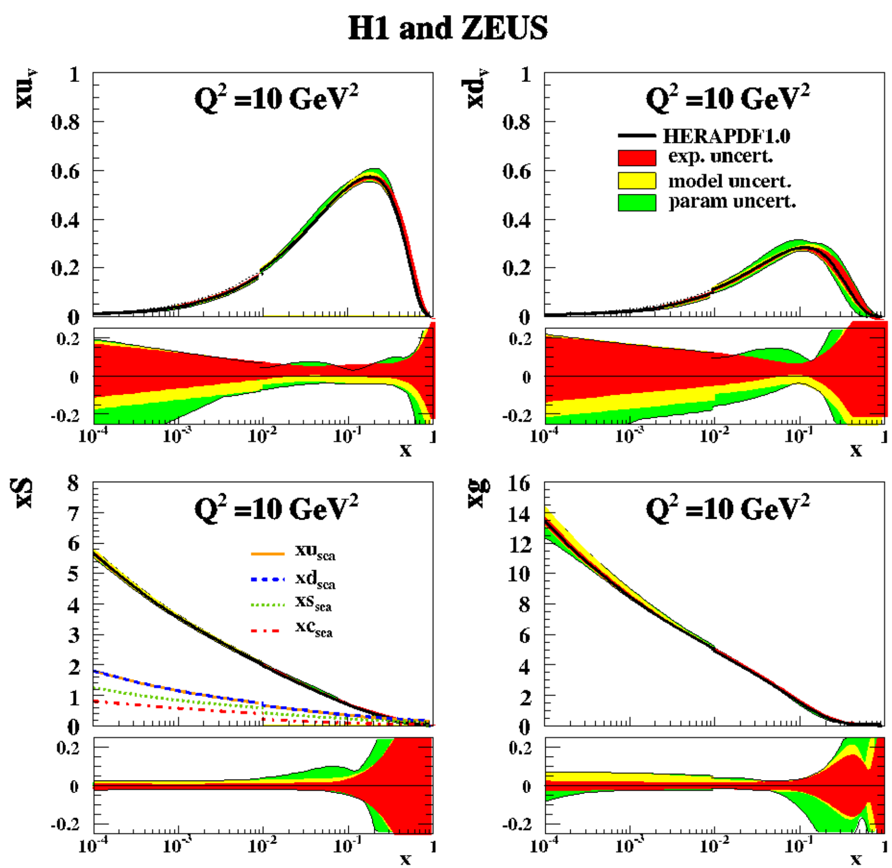
HERAPDF1.0 describes data well

More details in Katarina Lipka's talk

HERAPDF1.0 at Q^2 =1.9 and 10 GeV^2



Observe valence like shape of the gluon at the starting scale



Neutral Current Cross section at low and medium Q^2 & Structure functions

At Low and medium Q2 xF3 is negligible
NC Double differential can be described as:

$$\frac{d^2\sigma^{e^\pm p \to e^\pm X}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \underbrace{\left(1+(1-y)^2\right)}_{Y_\pm = 1\pm(1-y)^2} \cdot \left(F_2\left(x,Q^2\right) - \frac{y^2}{Y_+} F_L\left(x,Q^2\right) \right)$$

reduced cross section

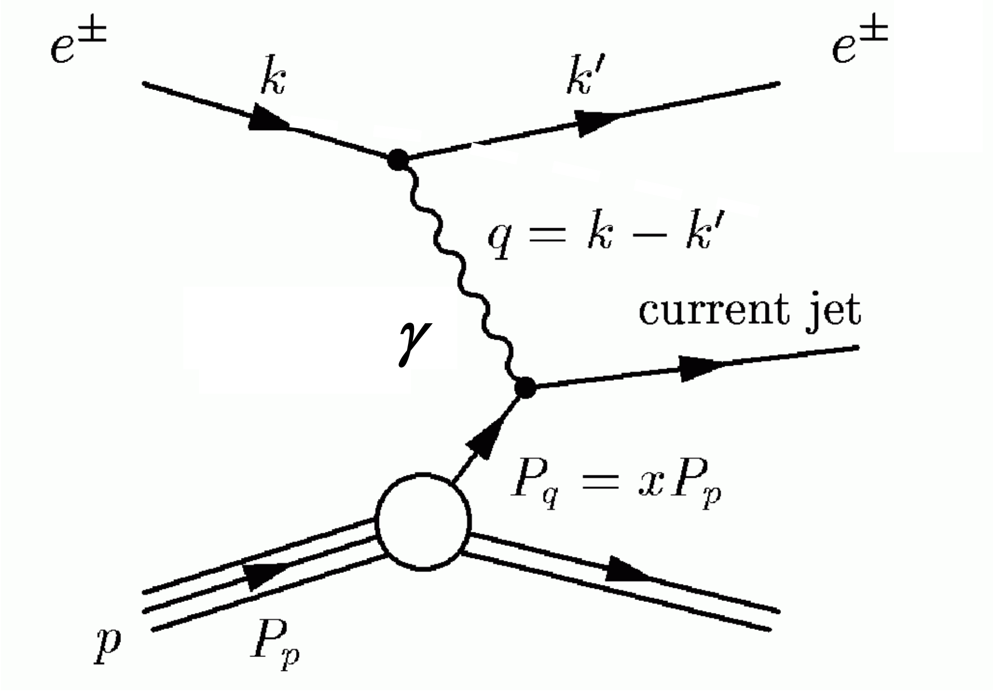
Two proton structure functions define inclusive DIS ep scattering cross section.

- F_2 determines sum of quark distributions.
- F_L, at low x, determines gluon distribution.
- The F_2 term dominates the cross section, has been measured for 15 years at HERA.
- The F_L term is sizeable only at large values of inelasticity y. It was directly accessed in the last 4 months of HERA's operation

DIS at Low/Medium Q^2 as Photon Proton Scattering

- The NC DIS process may be interpreted as scattering of an virtual photon off an proton

- The virtual photon may be transversely or longitudinally polarized



γp Cross Sections:

$$\sigma_T^{\gamma p} = \frac{4\pi\alpha}{Q^2} 2xF_1 = \frac{4\pi\alpha}{Q^2}\left(F_2 - F_L\right)$$

$$\sigma_L^{\gamma p} = \frac{4\pi\alpha}{Q^2}\left(F_2 - 2xF_1\right) = \frac{4\pi\alpha}{Q^2} F_L$$

$$\frac{\sigma_L^{\gamma p}}{\sigma_T^{\gamma p}} = R = \frac{F_L}{F_2 - F_L}$$

Quark Parton Model (QPM):

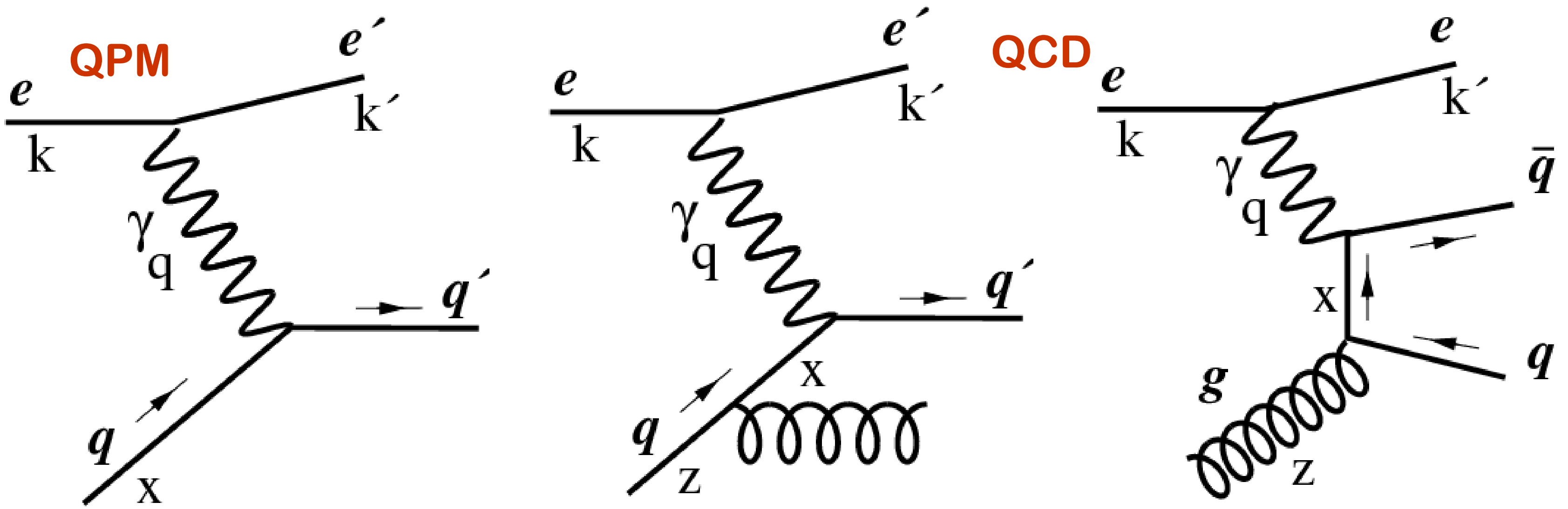
$$F_1\left(x\right) = \frac{1}{2x}\sum_q e_q^2 xq(x)$$

$$F_2\left(x\right) = \sum_q e_q^2 xq(x)$$

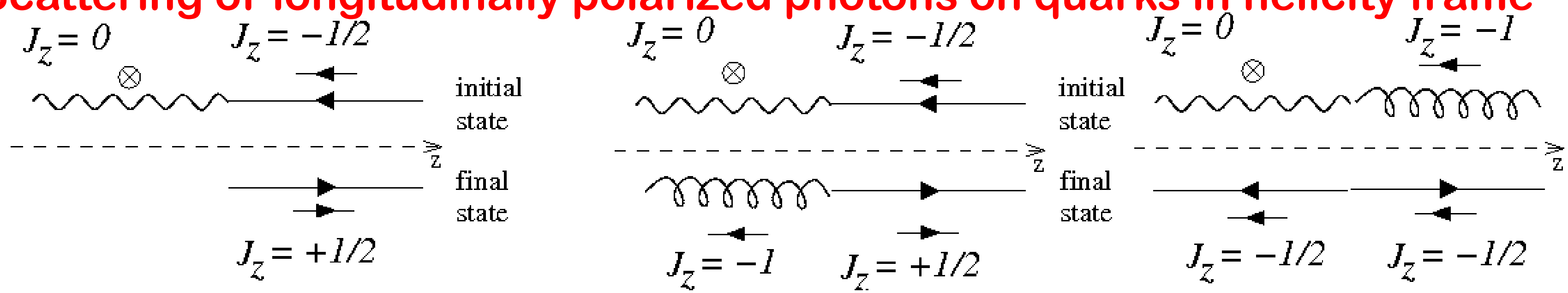
$$F_L\left(x\right) = F_2 - 2xF_1 = 0$$

Callan Gross relation

Longitudinal Structure Function F_L



Scattering of longitudinally polarized photons on quarks in helicity frame



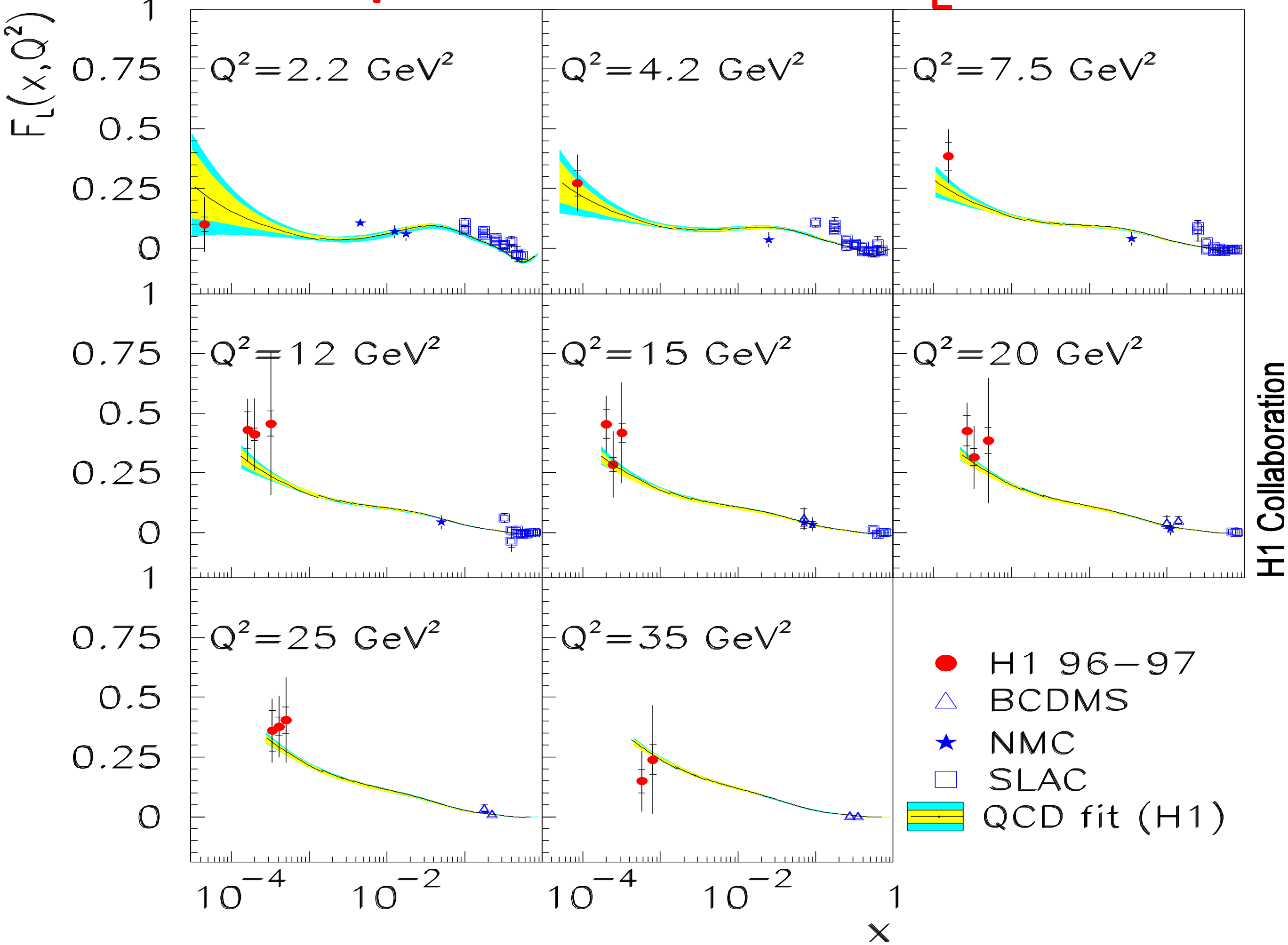
J_z conservation is not possible

$$F_L \propto \sigma_L = 0$$

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

access to gluon density

Expectations on F_L

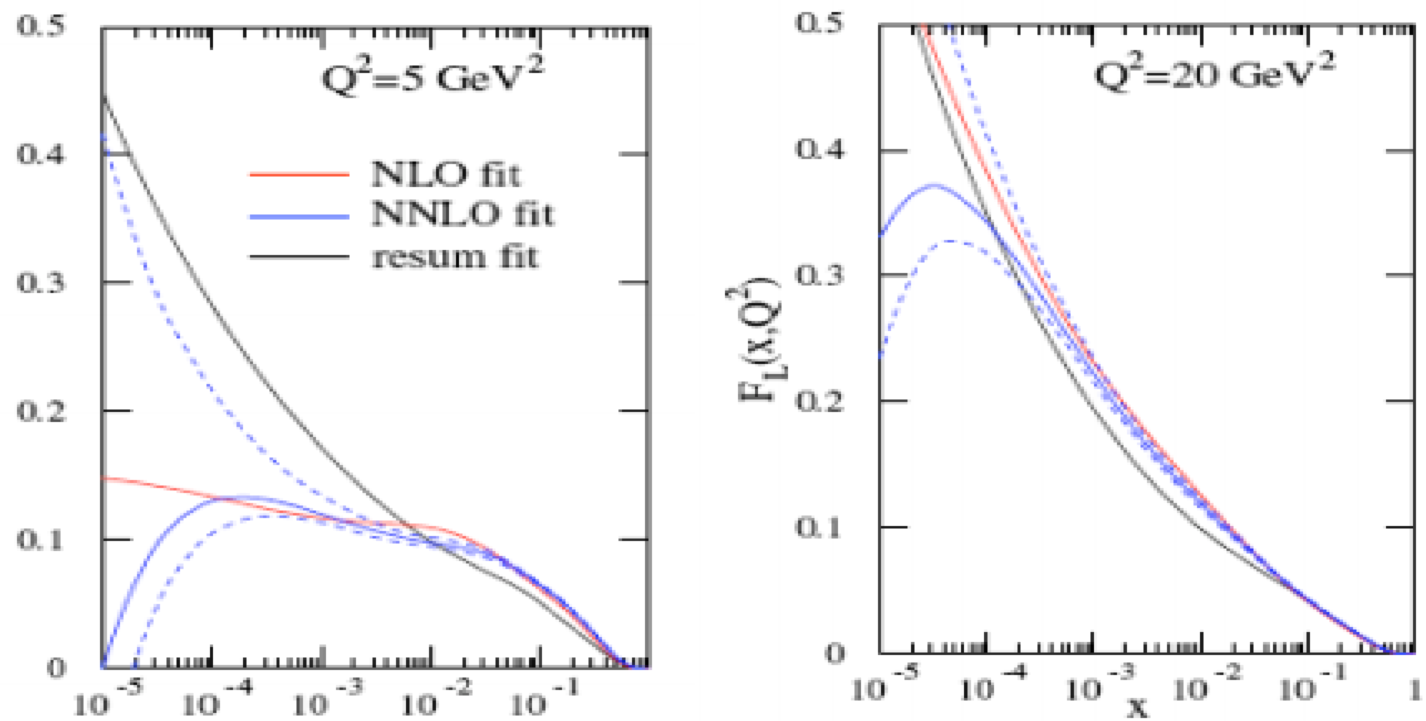


- Fixed Target F_L is small at large x (spin ½ quarks), indications for increase towards low x
- H1: hints to large F_L when F_2 is assumed to be known

Eur.Phys.J.C21:33-61,2001

Contd…..

- Predictions vary in the low x region
- Direct F_L measurement in the low x would help to understand gluon distribution in this region



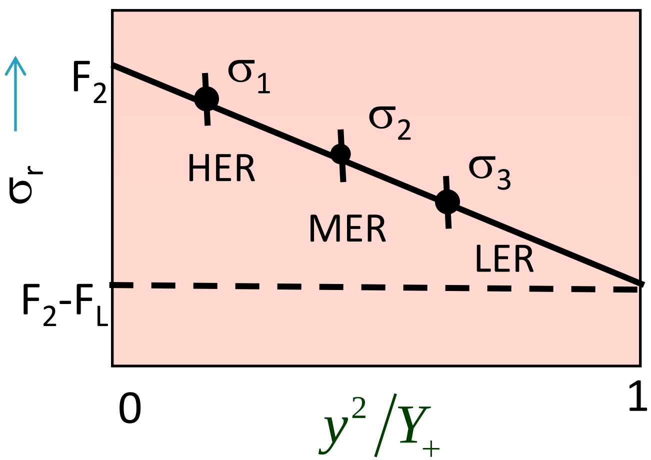
R. Thorne DIS08

Precise knowledge of F_2 and F_L is necessary for LHC physics and for the future investigations of saturation and gluonic structure phenomena

How to Measure F_L ?

Measure reduced cross sections $\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$

at same *x* and Q^2 but different $y = Q^2/y \cdot s$ → vary s



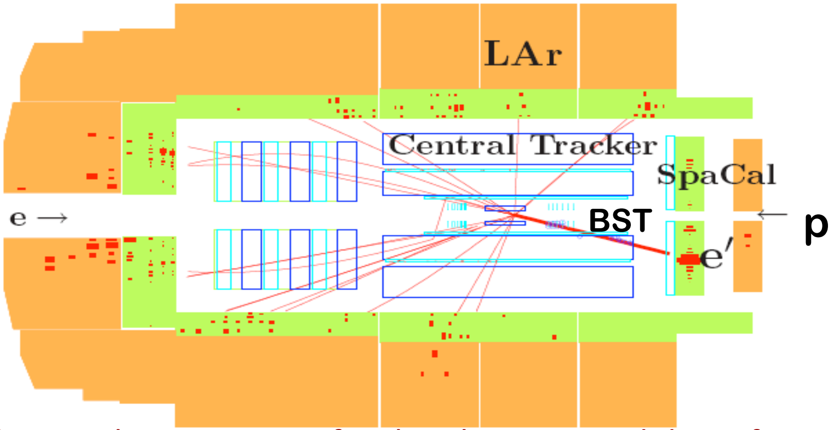
- **Change proton beam energy to change cms energy**
- **Large level arm in y^2/Y_+**
- **Measurement at high *y* in LER**

- **Intercept of the fit gives F_2**
- **Nagetive slope gives F_L**

as $y = 1 - E'_e/E_e(1-\cos\theta)$ → high *y* means low E'_e

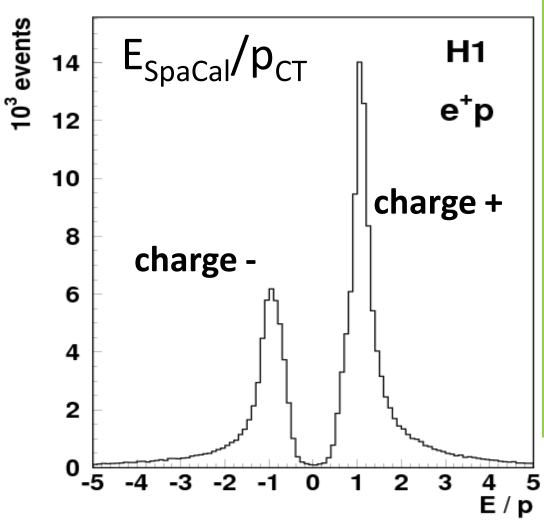
F_L measurement with H1

DIS event of Q^2 near 30 GeV^2



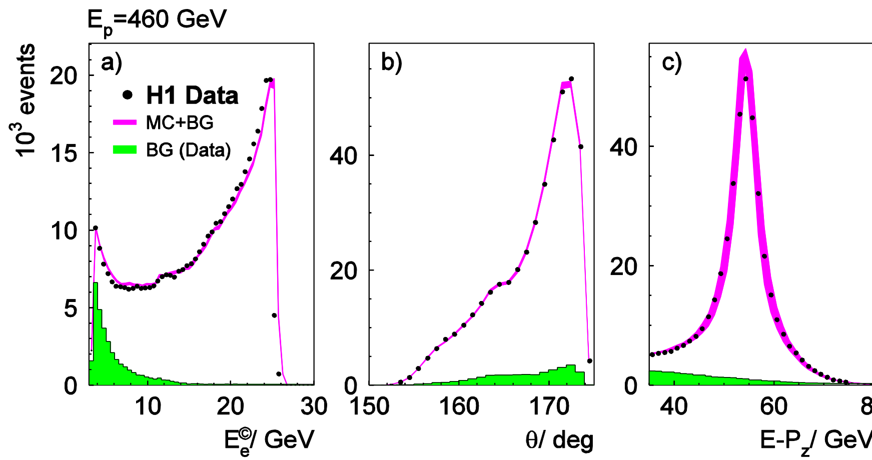
H1 has tracking coverage for the electron candidates for all full Q^2 ranges (CT & BST)

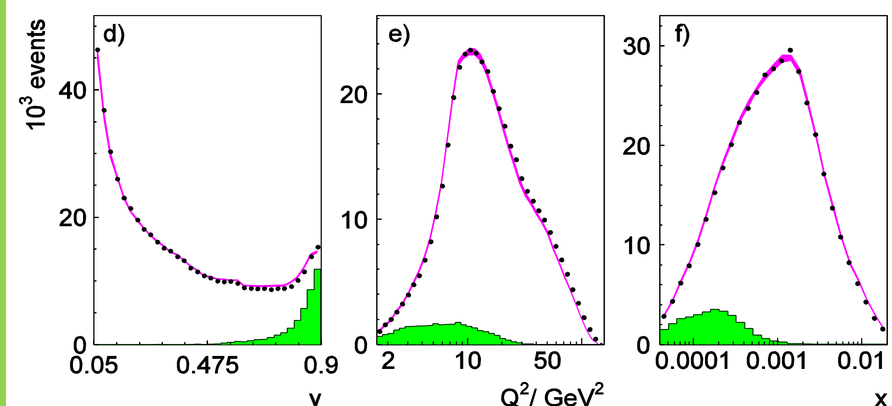
Event selection Criteria
E'_e >3.4 GeV
Tracking coverage was required



- At small energies severe contamination by γp events.
- Those are charge symmetric, apart from small effects due to anti-proton vs protons, which is measured using e+p and e-p data, and corrected for accordingly

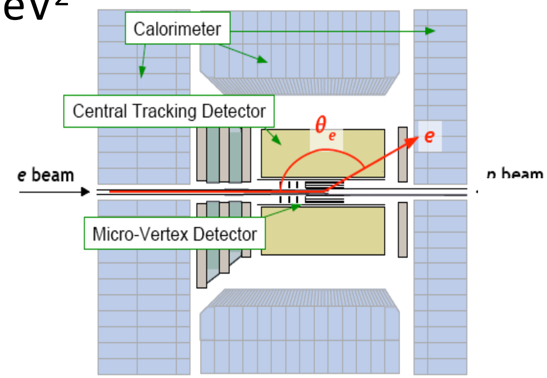
H1 background subtraction based on data.





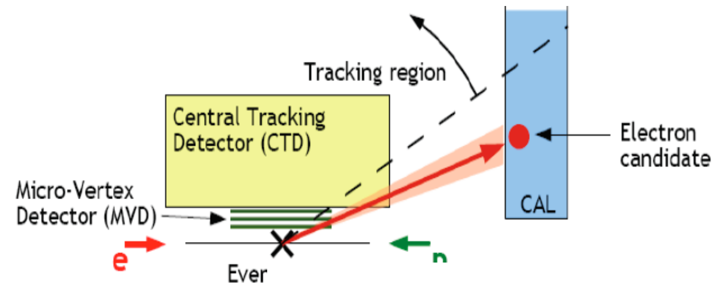
Measuring FL with ZEUS

Q^2 range between
24 and 110 GeV^2

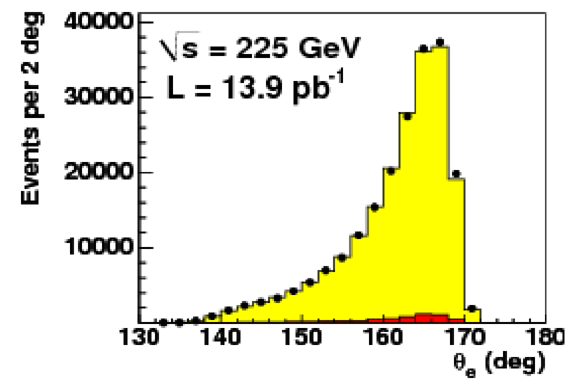


Event Selection:

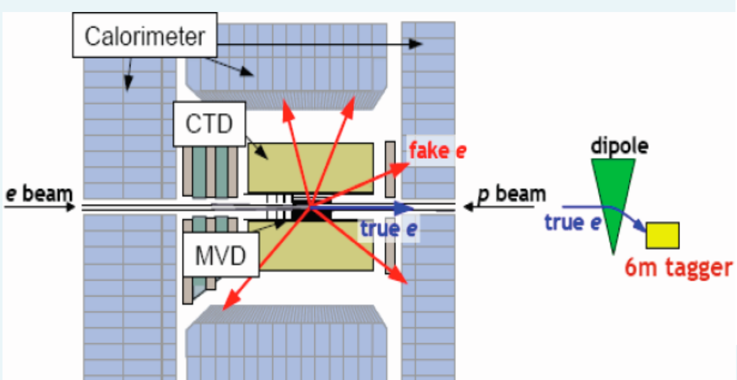
Electron in backward Cal
E'_e >6 GeV
(Cluster & Trigger)
Hits in CTD & MVD
(reject neutrals)

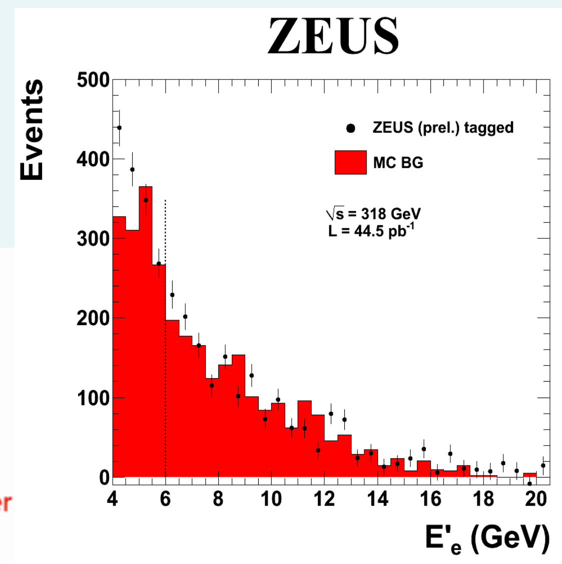


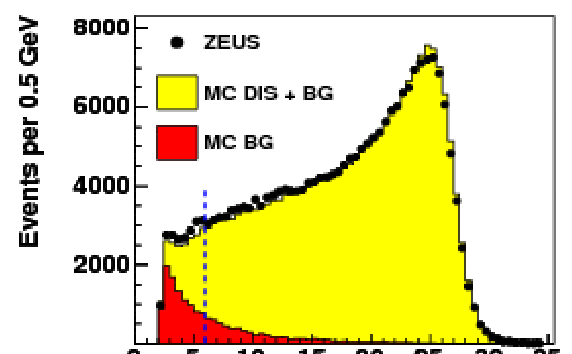
$$y = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}\ ,\quad Q^2 = \frac{E'^2_e \sin^2\theta_e}{1-y}$$



Photoproduction BG:
Removed using PYTHIA MC
Control using 6m electron tagger.
Complimentary studies with gp enriched data sample.

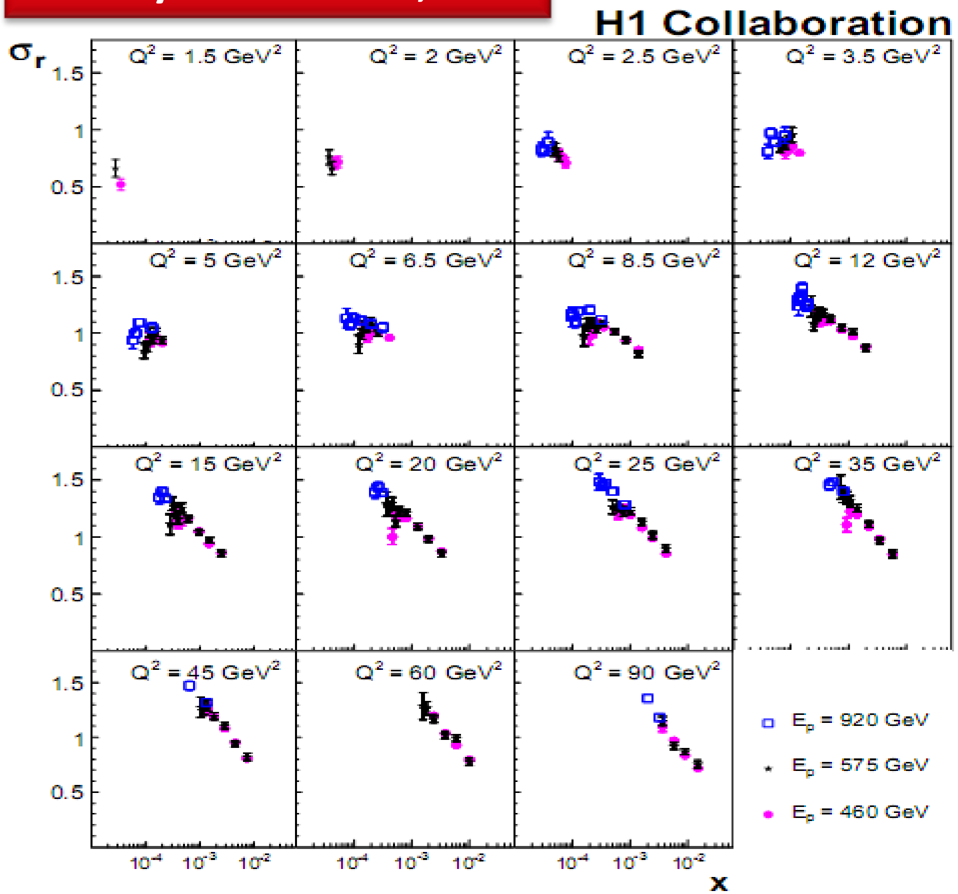


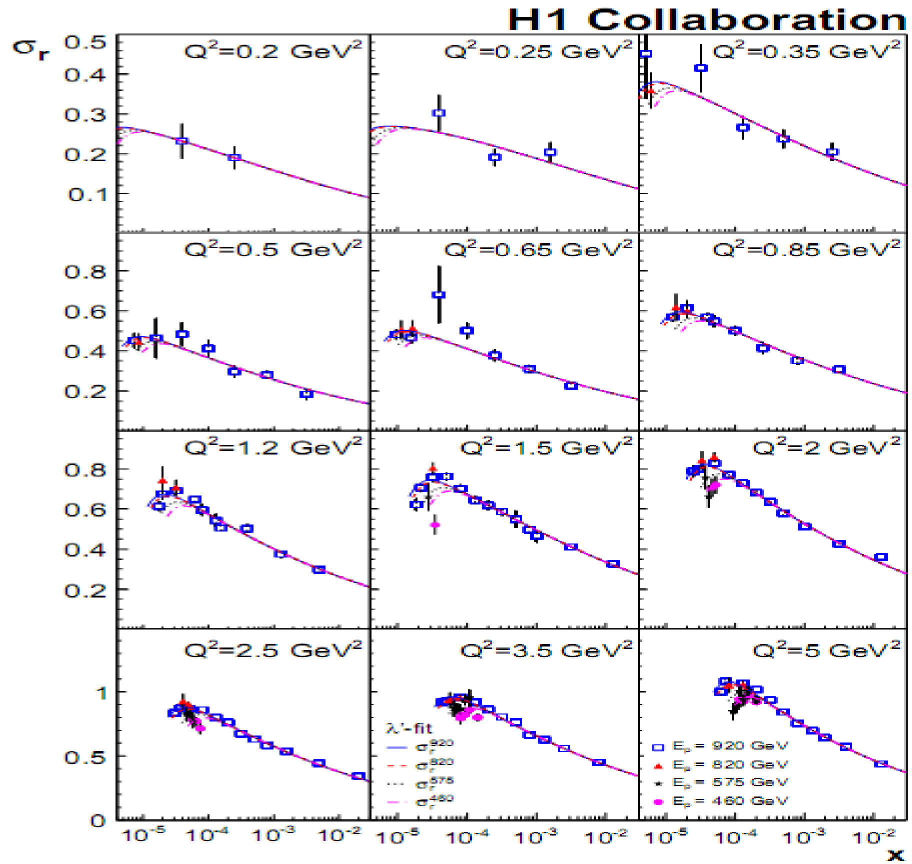




H1 low/very-low Q^2 cross sections

Eur.Phys.J.C71:1579,2011





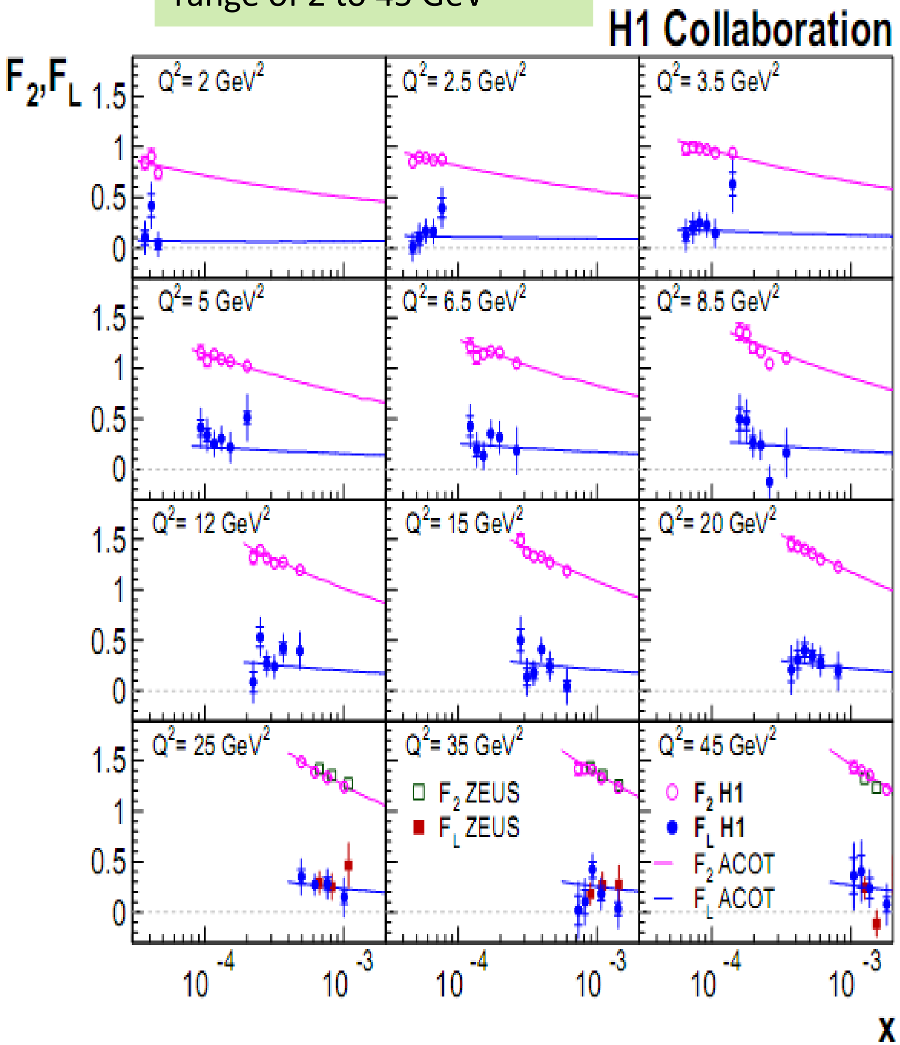
Turnover at low x is small but visible

- Combined H1 data from years 1995-2000, Ep = 820 and Ep = 920 GeV with HERA II HER data
- $0.2<Q^2<150$ GeV^2 region is covered, corresponding to $5.10^{-6} \leq x \leq 0.15$
- Extends to high y = 0.85
- Used for several phenomenological model analyses

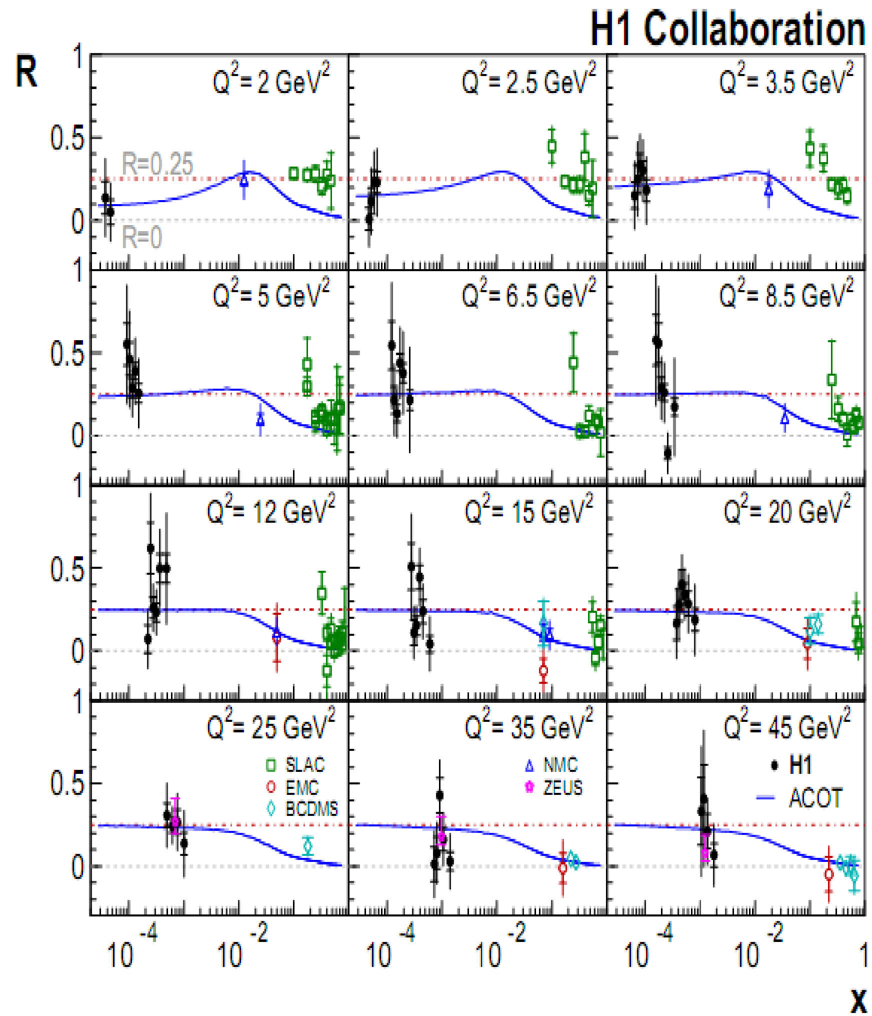
Contd…H1 F_2, F_L and R

Using cross section in Q^2 range of 2 to 45 GeV^2

Eur.Phys.J.C71:1579,2011

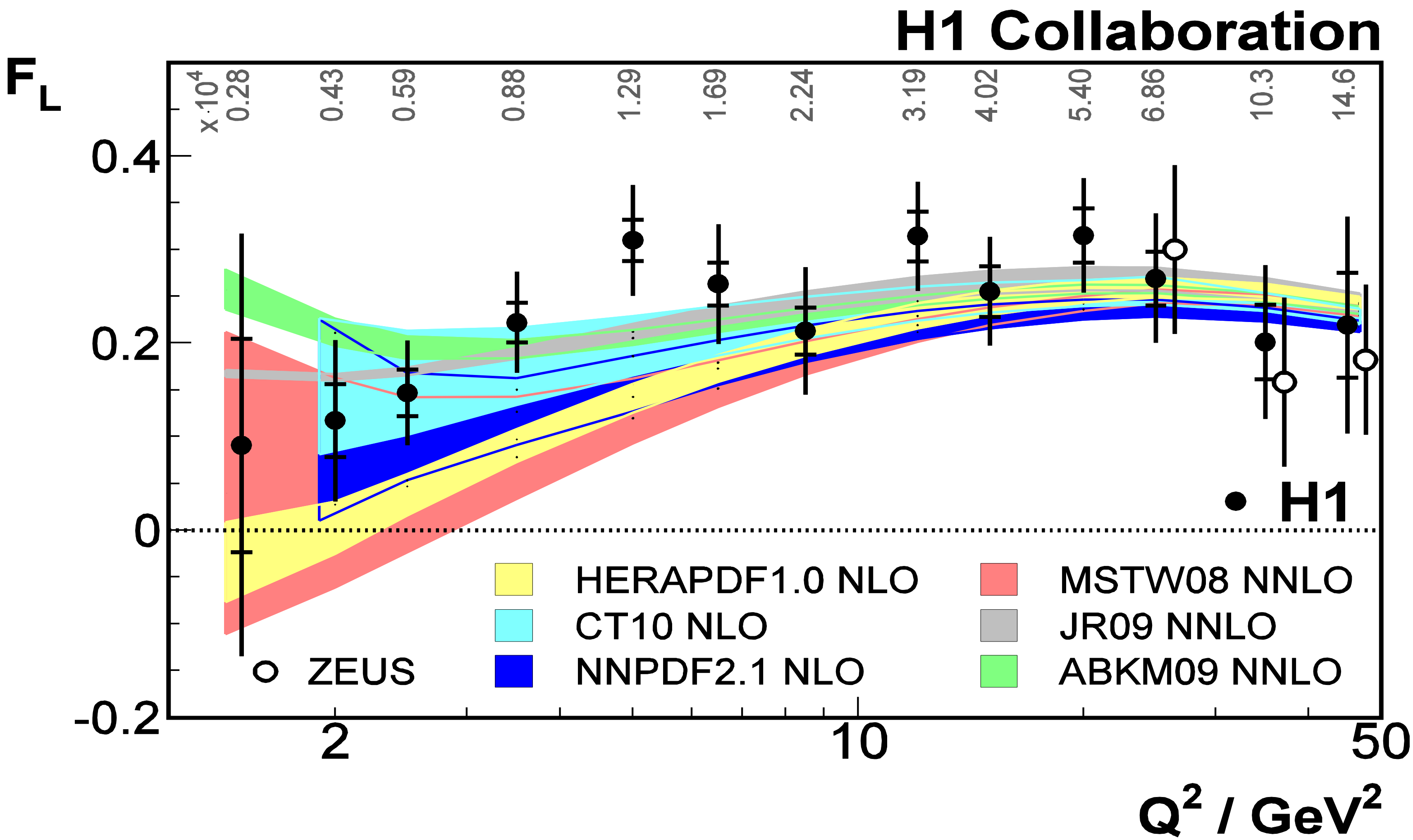


For $3.5 \le Q^2 \le 45$ GeV^2 and $7.10^{-5} < x < 2.10^{-3}$
H1 Data supports constant R~0.26



F_L and F_2 calculated from combined the HER data (lumi 103.5 pb^{-1}) and LER(L=12.2 pb^{-1}) and MER (L=5.9 pb^{-1}) data collected in 2007

Average F_L – H1



H1 measurements cover $1.5 \le Q^2 \le 45$ GeV^2 and $2.7 \times 10^{-5} \le x \le 2.10^{-3}$

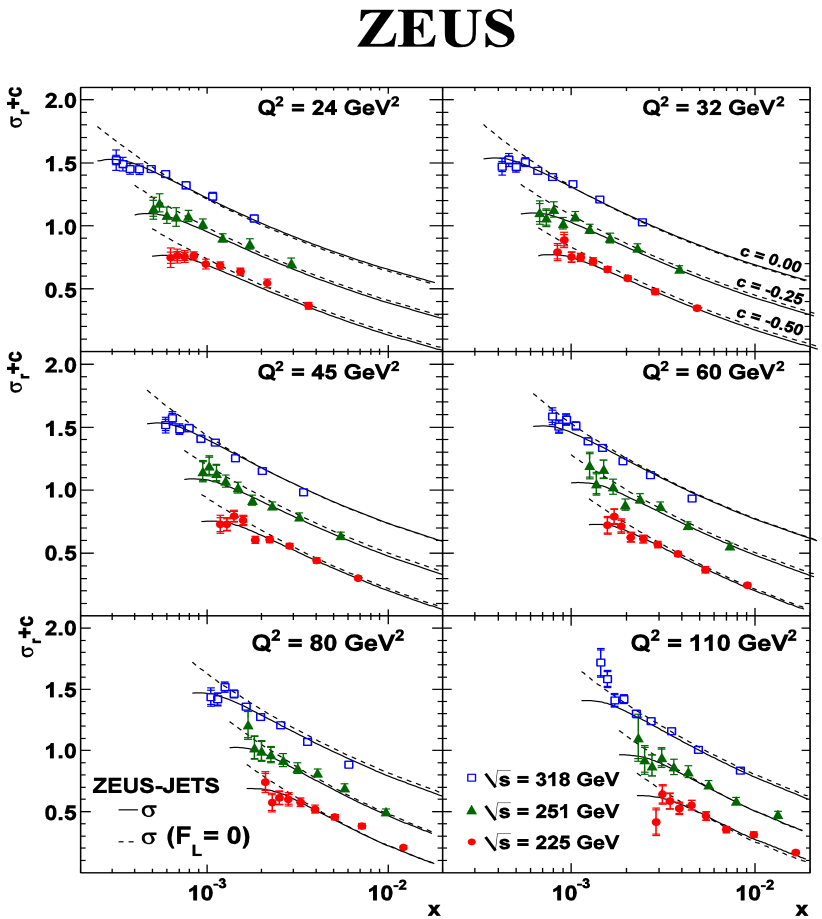
Also shown are ZEUS F_L values, corrected to the Q^2 values used by H1

ZEUS F_L Extraction

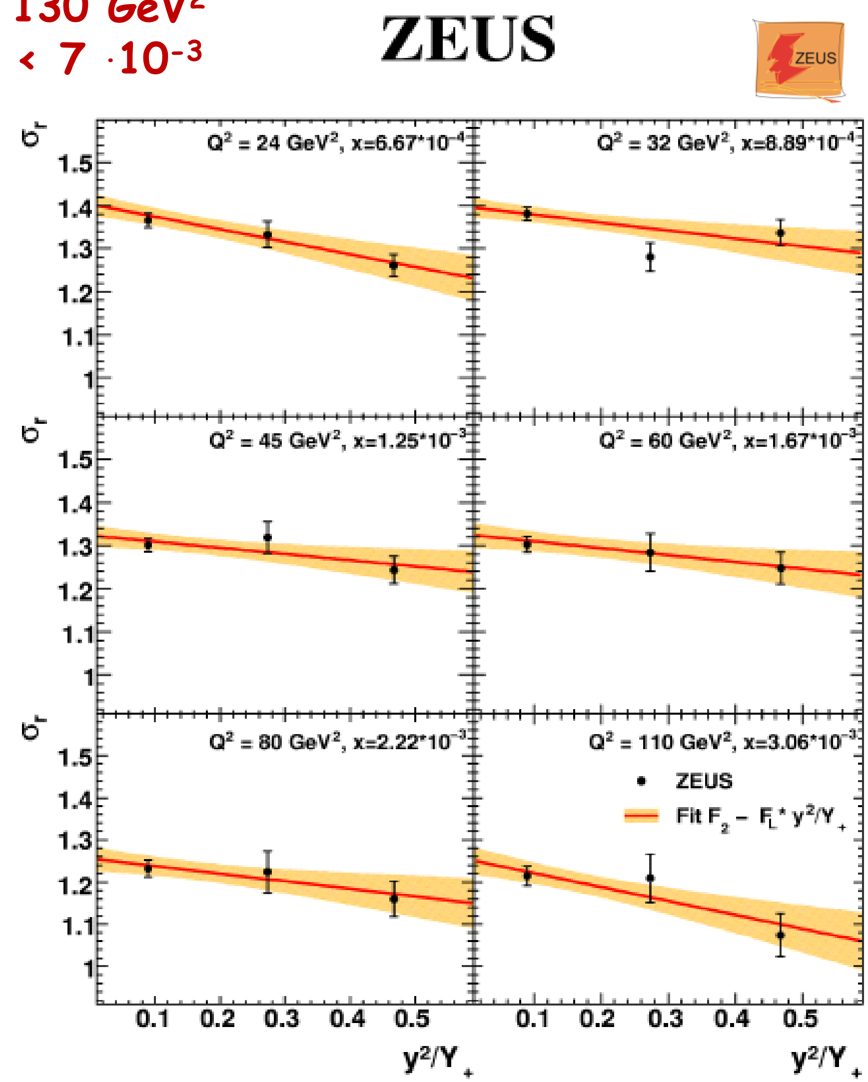
Straight line fit of σ_r vs y^2/Y_+
F_L slope, F_2 intercept

Phys. Lett. B682, 8 (2009)

$20\ GeV^2 < Q^2 < 130\ GeV^2$
$5 \cdot 10^{-4} < x < 7 \cdot 10^{-3}$

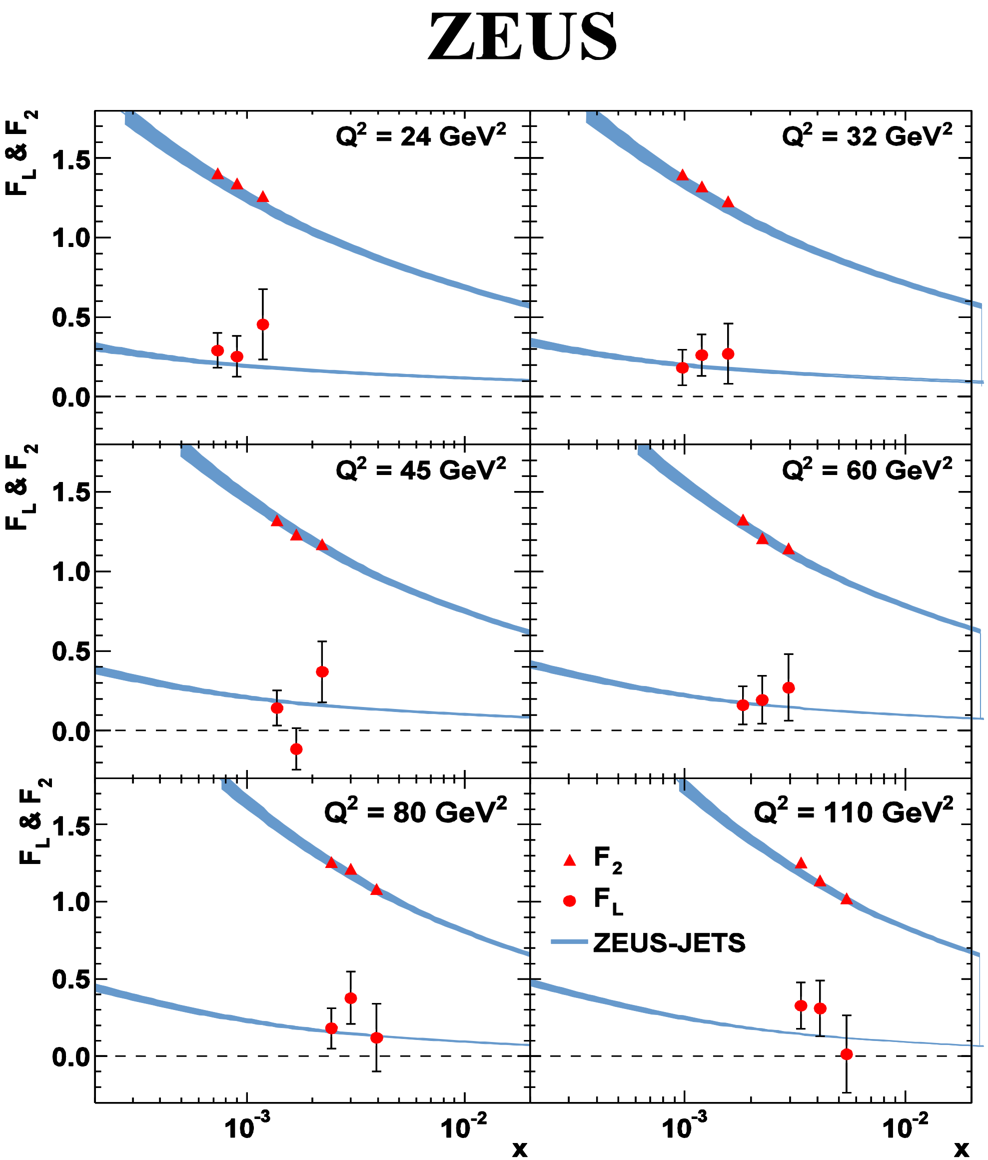


Turnover at lower x is small but visible



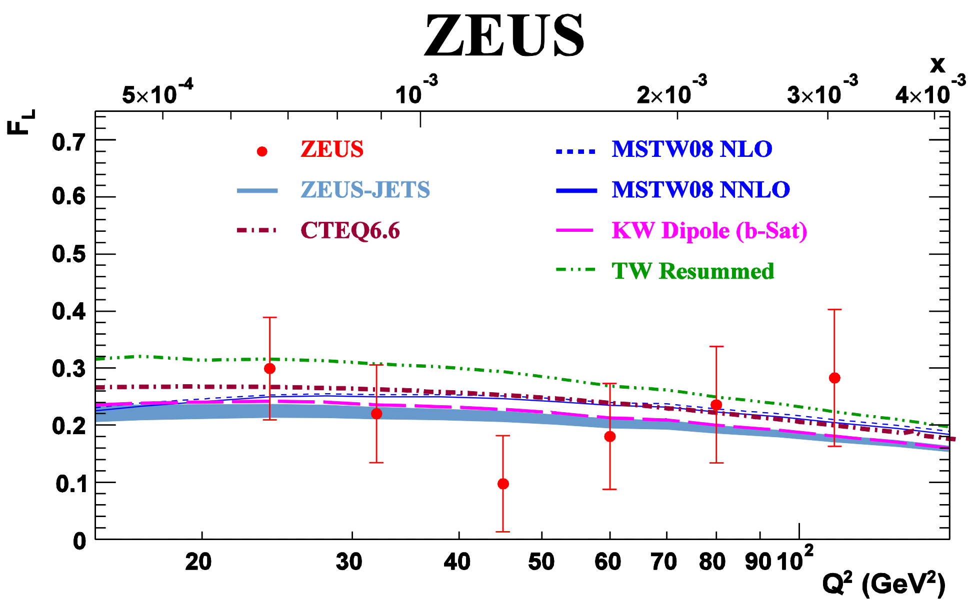
Full information of correlated systematics taken into account

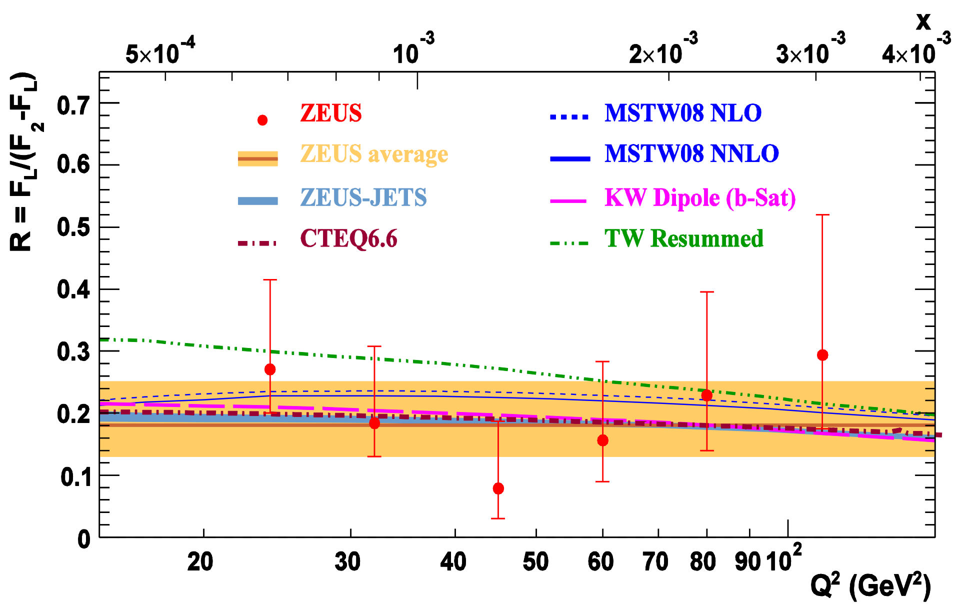
Extracted F_L and F_2 – ZEUS



- Most precise F_2 measurement from ZEUS in kinematic region studied
- F_2 measurement without assumptions on F_L
- Data support a non-zero F_L
- Predictions for F_2 and F_L are consistent with data

Average F_L and R – ZEUS





Averaged FL

- Data support non-zero FL
- Predictions are consistent with data

Averaged $R = F_L/(F_2-F_L)$

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

Lower than the H1 value

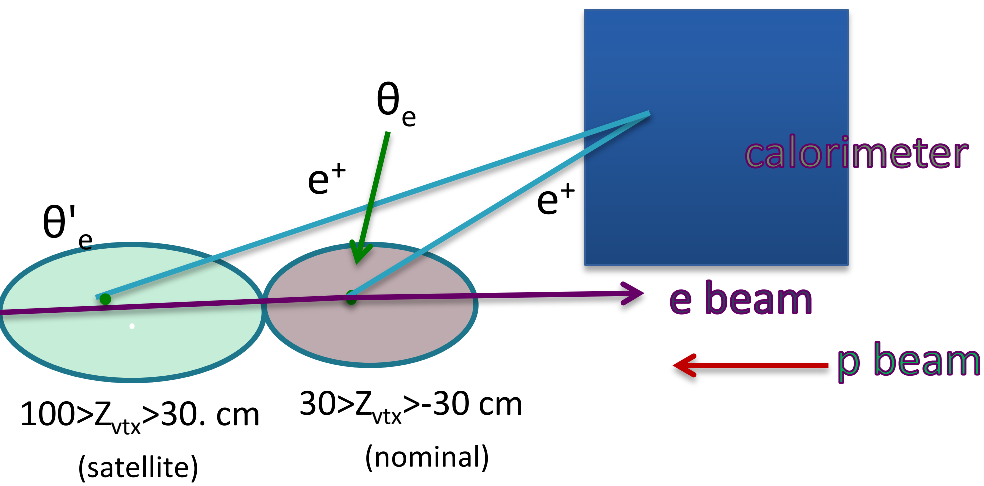
ZEUS high *y* cross section measurement extension to lower Q^2

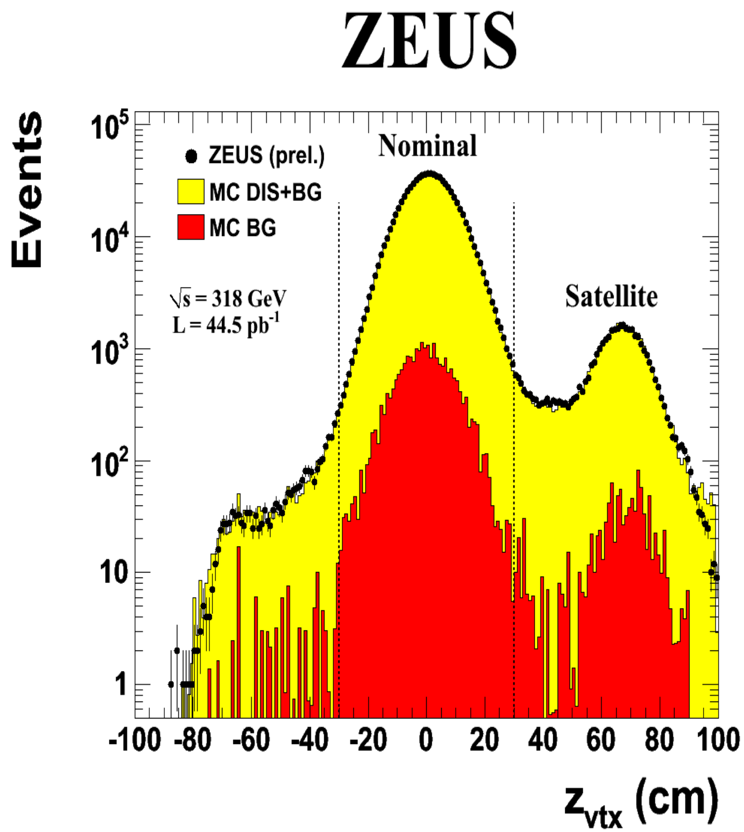
The ZEUS published F_L analysis is performed in kinematic range:

$20\ GeV^2 < Q^2 < 130\ GeV^2$ & $5 \cdot 10^{-4} < x < 7 \cdot 10^{-3}$

$Q^2 = 4.\ E_{beam}.\ E_{el}.\ \cos^2(\theta_e/2)$

Satellite vertex events:

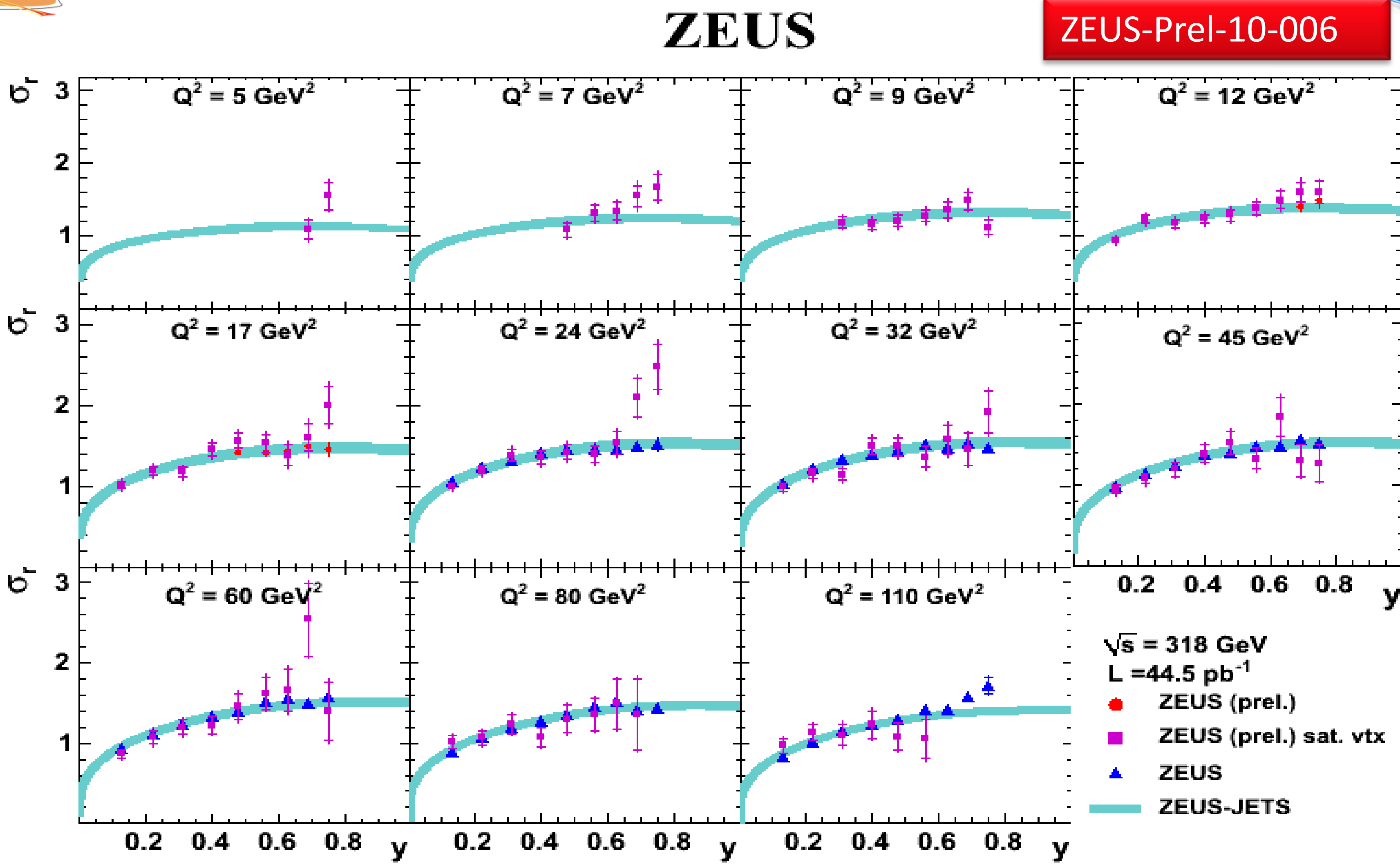




$\theta'_e > \theta_e \rightarrow$ with satellite vertex we can measure the electron's position with lower theta hence can go to lower $Q^2 \rightarrow$ extended kinematic range

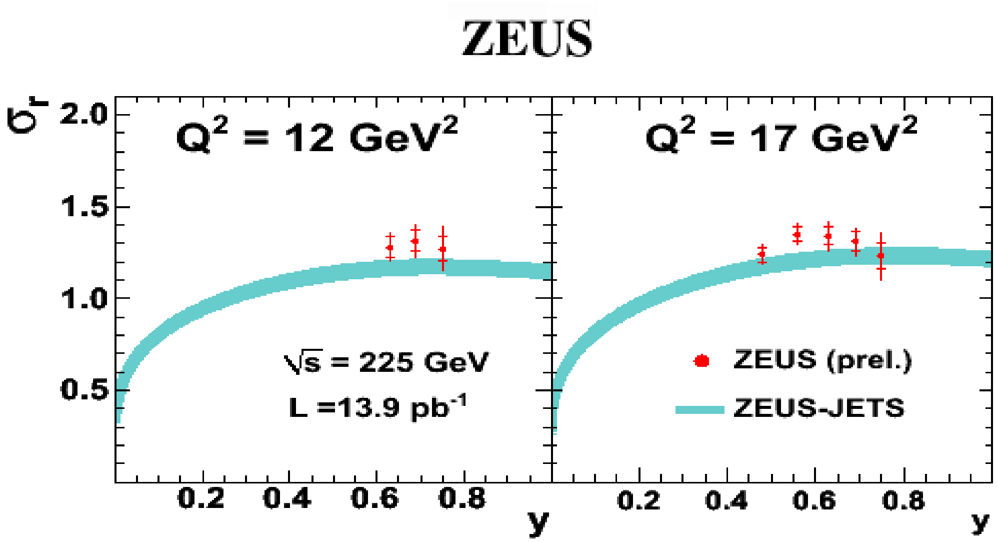
Cross sections for lower Q^2 region

ZEUS-Prel-10-006

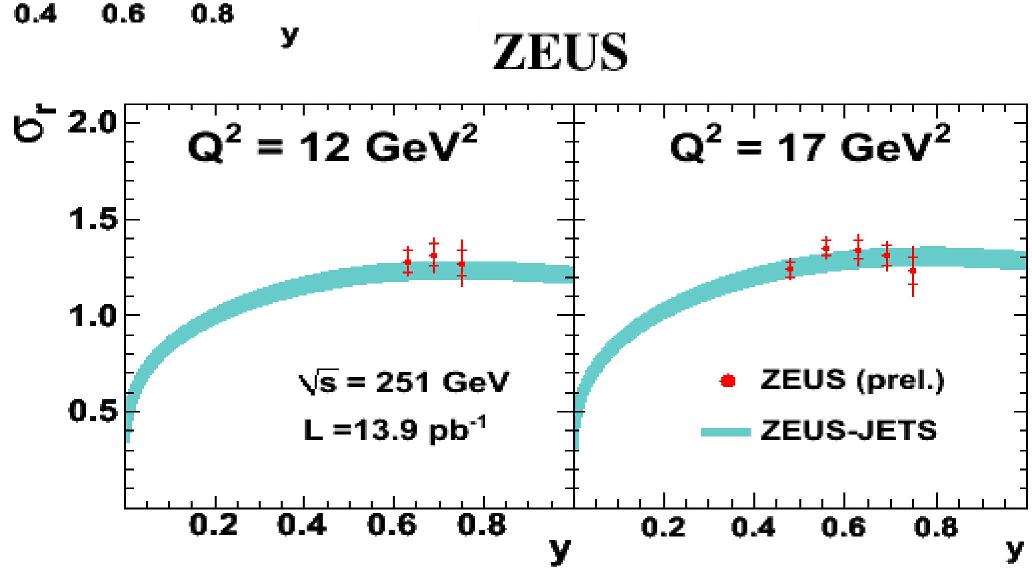


- High y cross section measurement extended to Q^2 of 5 GeV^2
- Lower Q^2 values are accessed using both satellite and nominal vertex cross sections
- Good agreement with the ZEUS published results for most of the bins

Contd.....



ZEUS-Prel-10-006



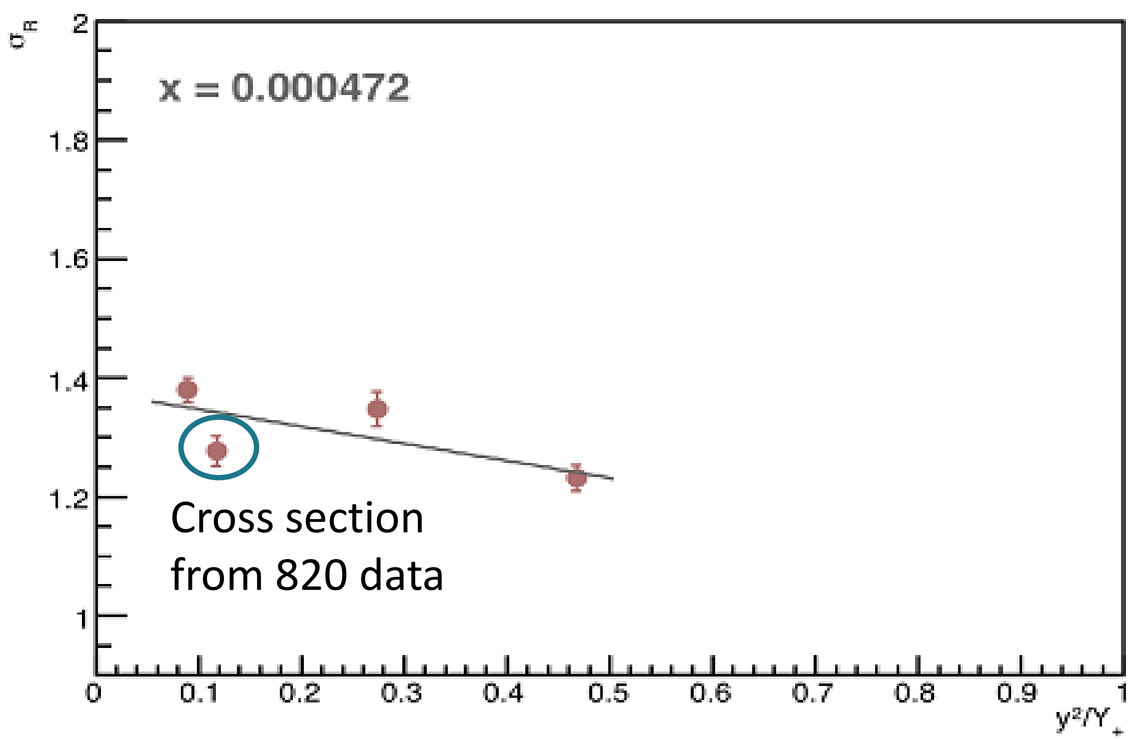
- For Low and Medium energy runs Q2 region was extended using nominal vertex cross sections only

ZEUS extended F_2, F_L measurement

Uses:
- Data from HERA-I
- Combined Satellite and nominal vertex cross section from HER, MER and LER

A typical Fit for Q^2=17 GeV^2

Rosenbluth plot



Summary

- HERA I data have combined - improves precision significantly
- Six orders of magnitude are covered in x and Q^2
- The combined cross sections are used to get DGLAP QCD fit HERAPDF1.0 - Based solely on HERA data

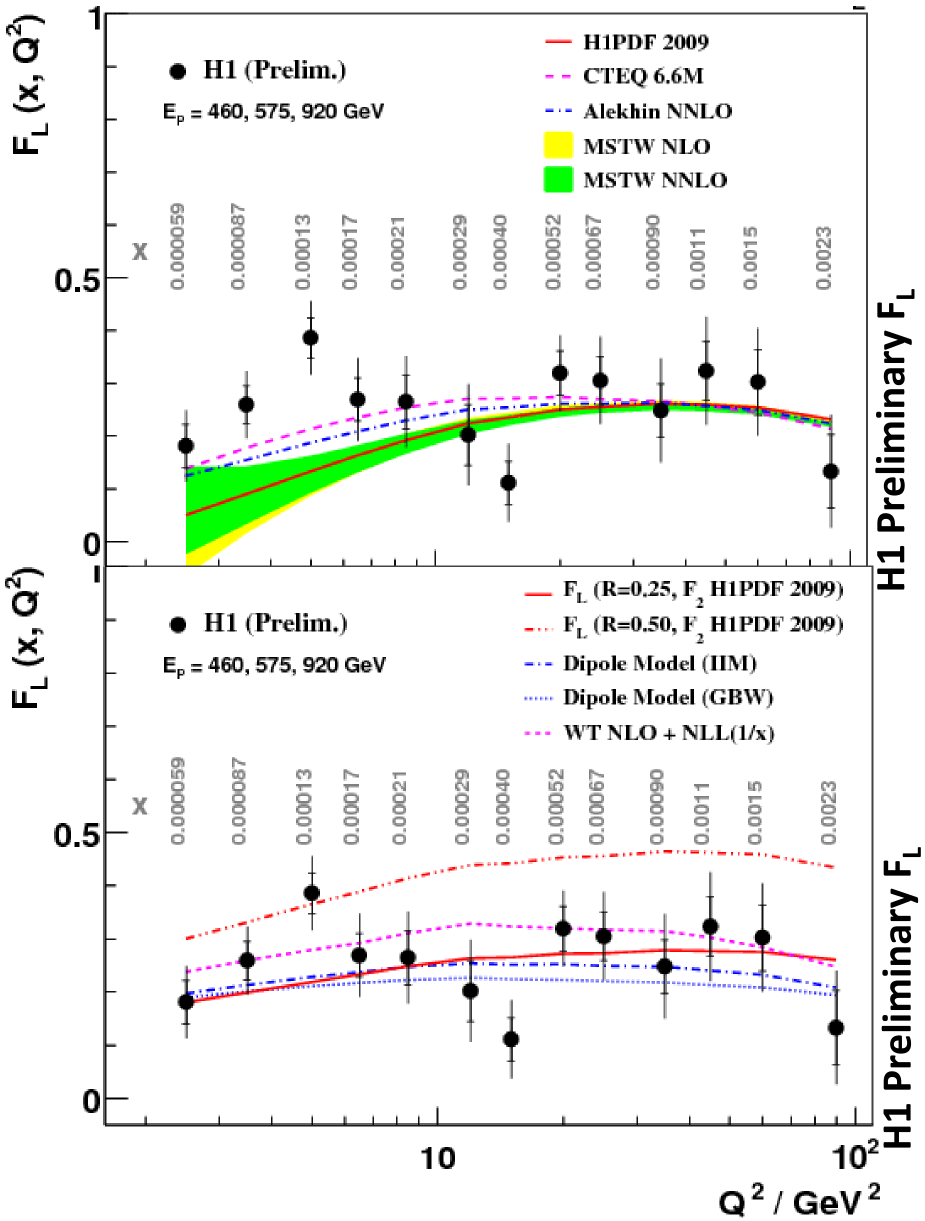
HERA II measurements at low/medium Q^2:

- ZEUS Measured NC cross section, F_2 and F_L in the $20<Q^2<130 GeV^2$ region
- Most precise F_2 values from ZEUS are obtained in the kinematic region covered.
- H1 has measured NC cross sections for $0.2 < Q^2 < 150$ GeV^2 after combination with HERA I data
- H1 has calculated F2 and FL in the range $1.5 \leq Q^2 \leq 45$ GeV^2
- ZEUS has extended cross section measurement to lower Q^2, ZEUS-H1 combination for new cross section bins is in the to do list-plans to publish low Q^2 F_L.

Thanks….!!!

- Back up

Average $F_L < 100\ GeV^2$



- MSTW and H1PDF 2009 predictions use the same scheme to calculate F_L.
- Data agree better with calculation of CTEQ
- Data is consistent with constant $R \sim 0.25$.
- Good agreement with IIM and GBW dipole models, NLL(1/x) prediction.

Combination χ^2

$$\chi^2_{\rm exp}(\boldsymbol{m},\boldsymbol{b}) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\rm stat}\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,\rm uncor}\, m^i\right)^2} + \sum_j b_j^2 .$$

- μ^i — measured central value at point i
- γ^i_j, $\delta_{i,\rm stat}$, $\delta_{i,\rm uncor}$ — relative correlated systematic, statistical and uncorrelated systematic uncertainty.

The function $\chi^2_{\rm exp}$ depends on the set of underlying physical quantities m^i (vector $\boldsymbol{m}$) and the set of systematic uncertainties b_j ($\boldsymbol{b}$).

All(normalization, correlated, uncorrelated) systematic uncertainties are assumed to be **multiplicative** and statistical errors are rescaled based on estimated (instead of measured) number of events.
Extra procedural error for if only normalizations are considered multiplicative.

Alternative: average/fit $\log \sigma_r$, in this case all uncertainties should be treated as additive (also normalizations). Consistent resulting average.

Input: H1 & ZEUS published cross sections [Inclusive NC , CC $e^{\pm}p$].

Combination Method:

[1] *Swim* H1 and ZEUS measurements to common grid (x,Q^2) :

$$\sigma_{H1}\left(x_{H1}, Q^2_{H1} \right) \rightarrow \sigma_{H1}(x,Q^2) \quad ; \quad \sigma_{ZEUS}\left(x_{ZEUS}, Q^2_{ZEUS} \right) \rightarrow \sigma_{ZEUS}(x,Q^2)$$

[2] For CC and NC [y<0.35] : $\sigma_{820} \rightarrow \sigma_{920}$

[3] **Build a χ^2 function for each data-set, *exp*:**

Combination at point i

[Estimate of 1 true cross section]

Measurement at point i

$$\chi^2_{\exp}(m,b) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\mathrm{stat}}\,\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,\mathrm{uncor}}\, m^i\right)^2} + \sum_j b_j^2$$

Sensitivity of the cross section to the j^{th} source of correlated uncertainty.

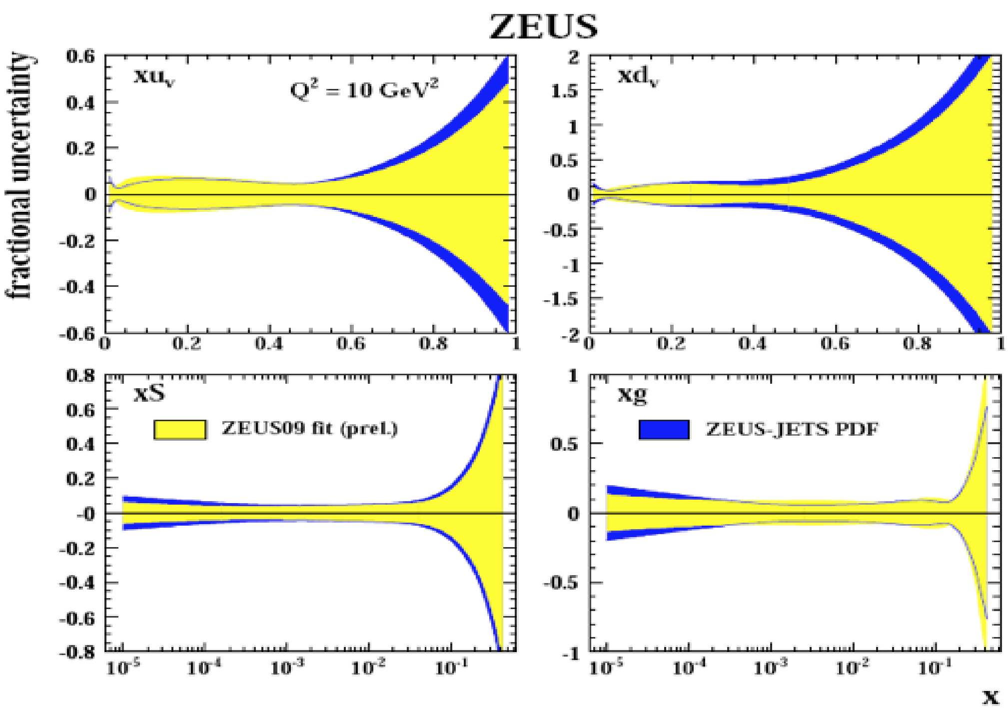
Shift of the j^{th} source of correlated uncertainty

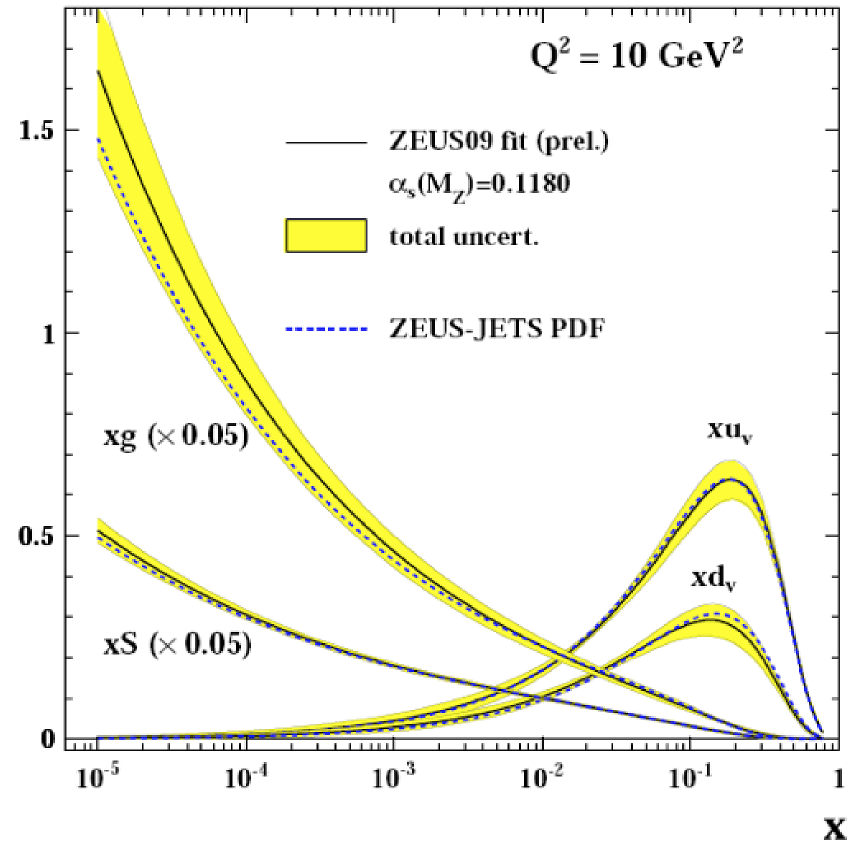
γ^i_j defined as the relative change of the measurement for a 1 sigma shift of the

$\delta_{i,\mathrm{stat}}/\delta_{i,\mathrm{uncor}}$ *Relative stat. / syst. error on the measurement*

PDF fits with F_L data included

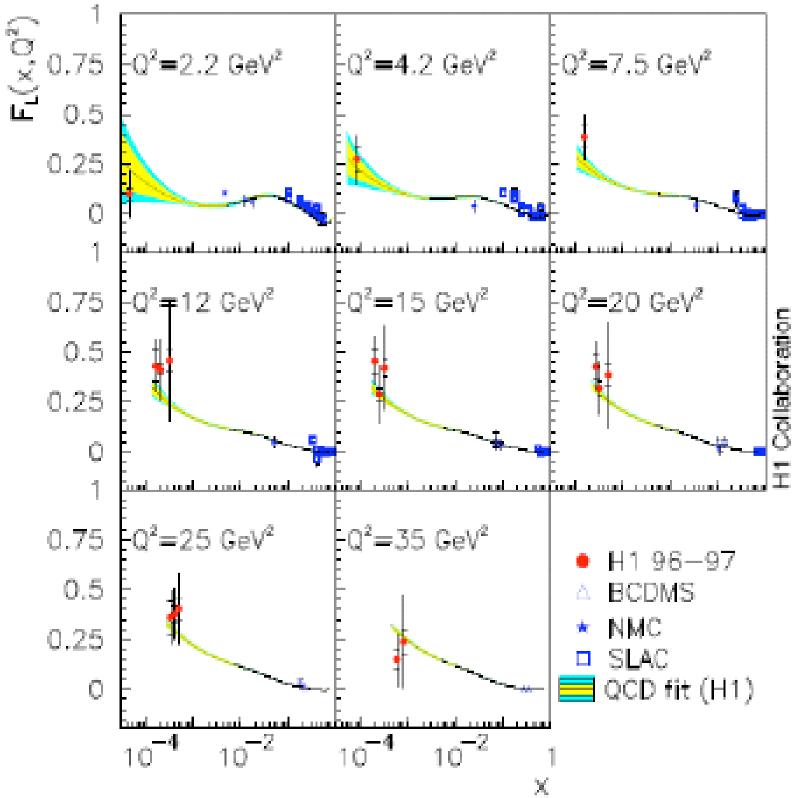
Measured cross sections for 3 data sets (HER, LER, MER) are included in ZEUS PDF fits
Data has impact on the low x:
Steeper rise of gluon at low x
Sea and gluon uncertainty reduced





Expectations on F_L

Experiment



Fixed target: F_L is small at large x (spin 1/2 quarks)
indications for increase towards low x

H1: hints to large F_L when F_2 is assumed to be known

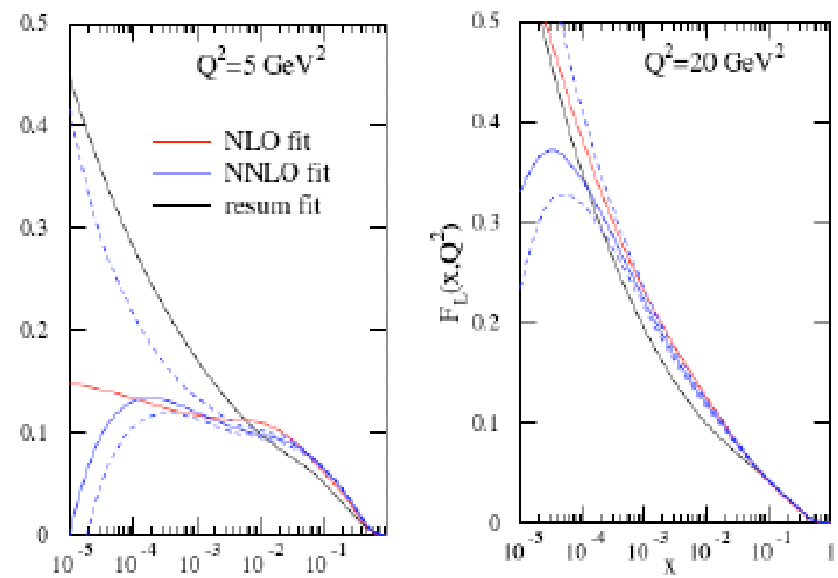
Eur.Phys.J.C21:33-61.2001

Theory (pQCD)

F_L prediction related to the gluon density, the size and the uncertainties on xg - constraints require max accuracy and range

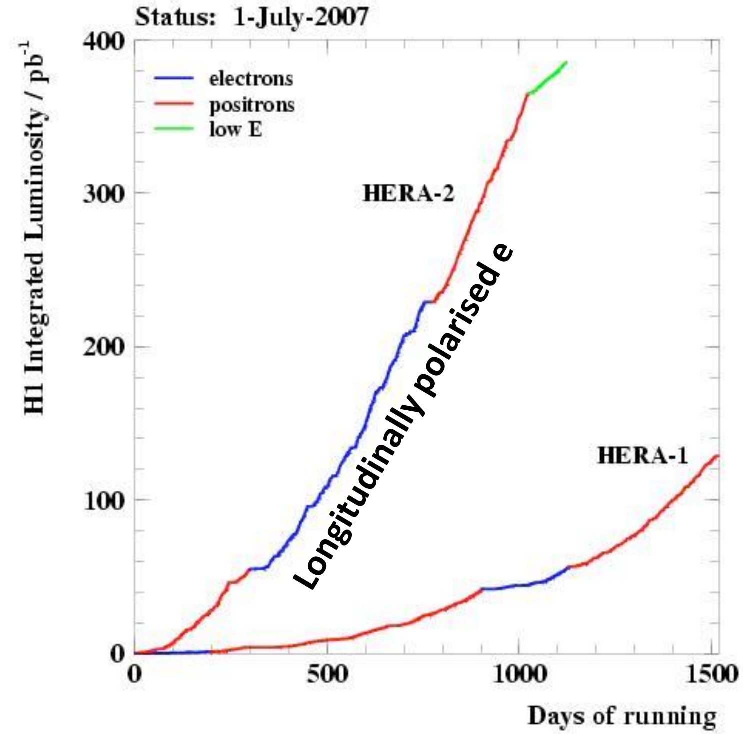
Theory developed to NNLO
[W.van Neerven (†), J.Vermaseren, et al.]

Global/detailed pdf analyses
[CTEQ, MRST, Alechin, HERA, …]



R.Thorne, DIS08

HERA *ep* Collider: 1992-2007



Two colliding beam experiments: H1 and ZEUS

~0.5 fb^{-1} collected pre experiment

approximately same amount of collisions with

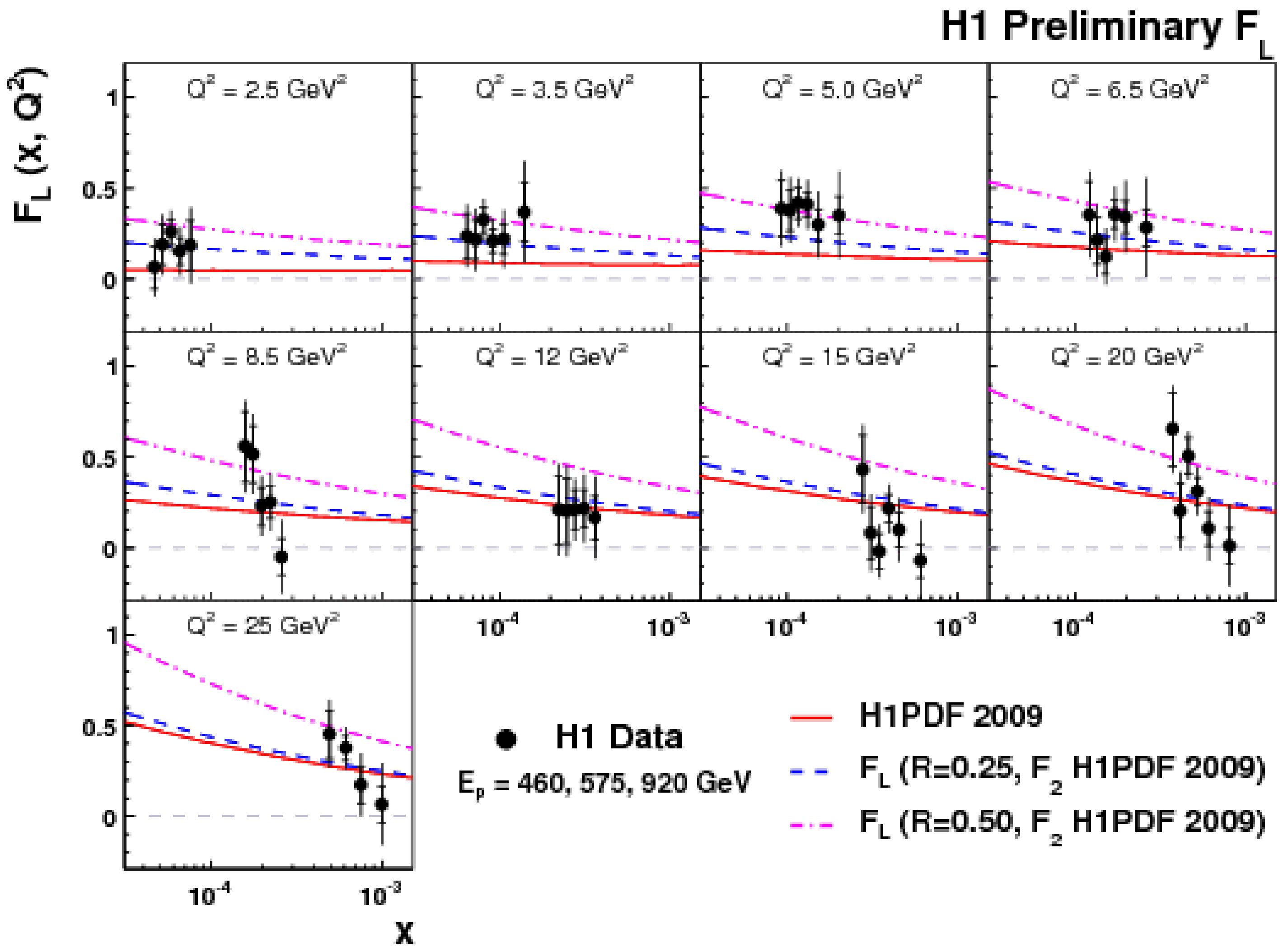
electrons and positrons of

Left- and right-handed polarisation

E_e = 27.5GeV, E_p = 920 GeV

dedicated low Ep runs

Ep = 460GeV,575 GeV



H1 Preliminary F_L
F_L (x, Q^2)
Q^2 = 2.5 GeV^2
Q^2 = 3.5 GeV^2
Q^2 = 5.0 GeV^2
Q^2 = 6.5 GeV^2
Q^2 = 8.5 GeV^2
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
x
H1 Data
E_p = 460, 575, 920 GeV
H1PDF 2009
F_L (R=0.25, F_2 H1PDF 2009)
F_L (R=0.50, F_2 H1PDF 2009)

Three Q^2 ranges

3 to 12 GeV^2 SpaCal+BST
prelim. 04/09----mention paper

12 to 90 GeV^2 SpaCal+CT:
published 06--→check for paper

35 to 800 GeV^2 LAr+CT: ----→ mention paper
prelim. 03/08

12-45 GeV2 SpaCal+BST_CJC (Eur.Phys.J.C71:1579,2011)

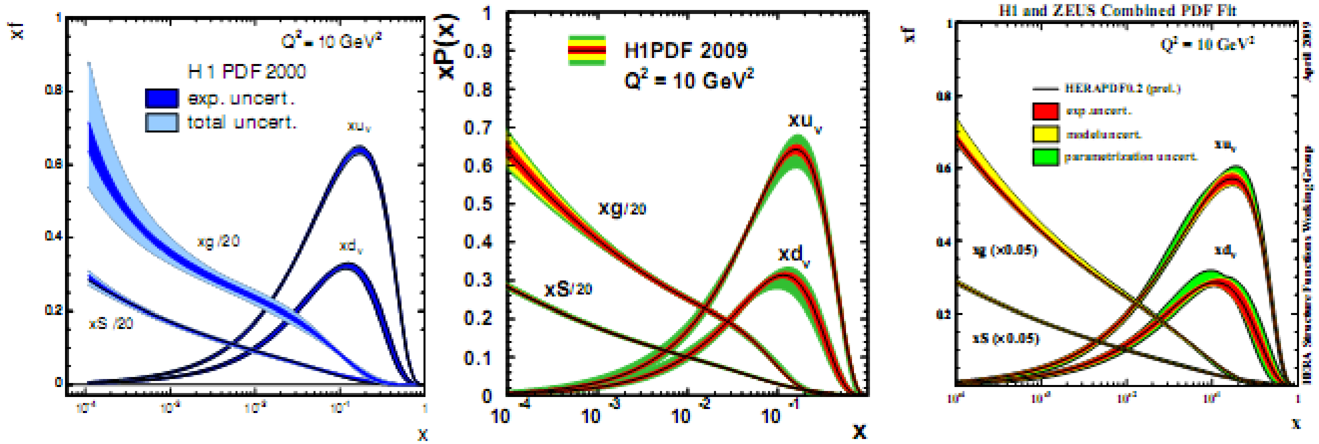
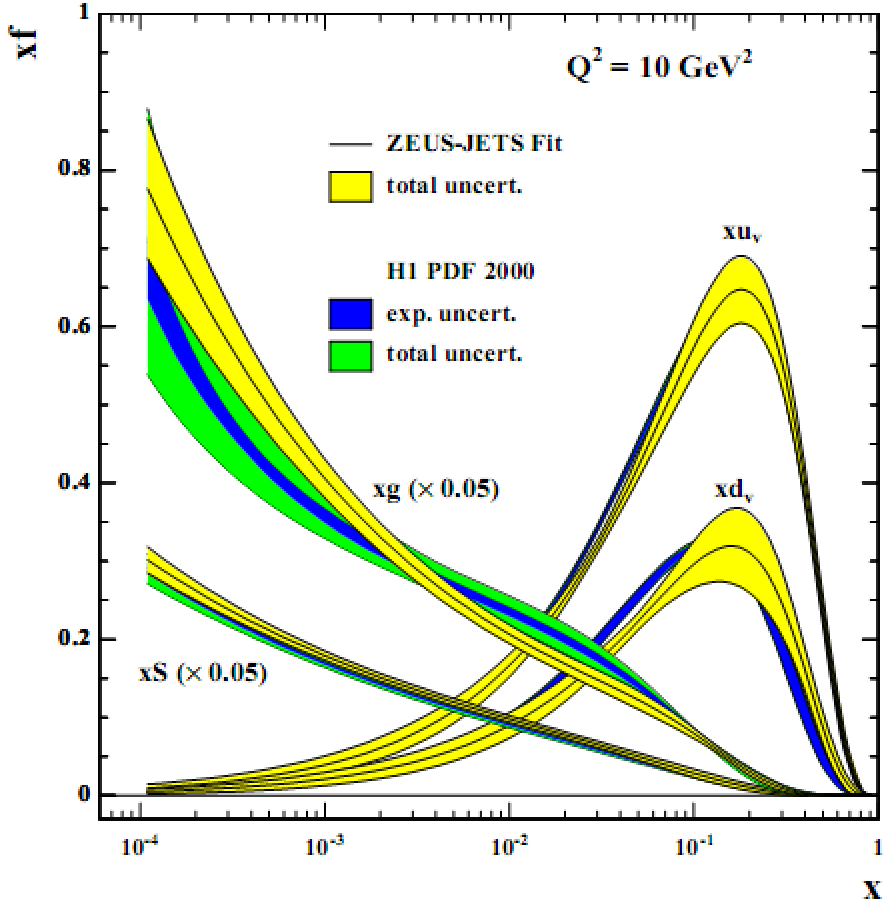
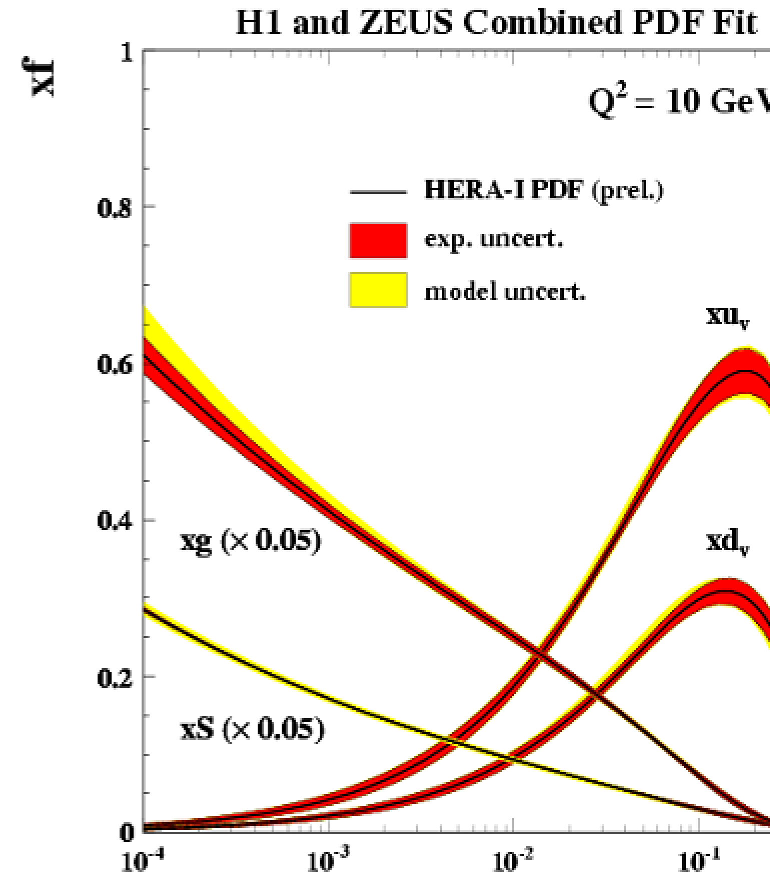


Figure 4: PDFs of the previous and current QCD fits by the H1 collaboration (left and middle) and the preliminary combined H1 and ZEUS fit (right) at $Q^2 = 10\,\mathrm{GeV}^2$. Gluon and sea quark distributions are scaled down by a factor of 20. The bands denote the experimental, model, and parametrisation uncertainties from inner to outer band.

Compare to published ZEUS/H1 results which also used only HERA data

Note in published PDFs H1 has alphas variation included in model error, ZEUS does not.





Resolution of previous discrepancies, improvement in level of uncertainty

Q^2 ranges covered:

12-800 GeV^2 → **H1 Prelim 08-042**

5-800 GeV^2 → **H1 Prelim 09-044**

12-90 GeV^2 → **Phys.Lett.B.66:2008**

12-150 GeV^2 → **Eur.Phys.J.C64:561-587,2009**

1.5-45 GeV^2 → **Eur.Phys.J.C71:1579,2011**