Deep inelastic cross section measurements at large y with the ZEUS detector at HERA

Julia Grebenyuk on behalf of the ZEUS collaboration

Deep Inelastic Scattering Workshop, 29 April 2014, Warsaw, Poland

Outline

Motivation of high-y DIS cross sections at
CME of 318, 251 and 225 GeV

Analysis details: kinematic plane, reconstruction, cuts

Results: cross sections, F_2 and F_L

Conclusions

Introduction

DIS CROSS SECTION AND PROTON STRUCTURE FUNCTIONS

Deep Inelastic Scattering *ep* cross section via structure functions **F_2** and **F_L** *(reduced form at low Q^2)*:

$$\sigma_r = F_2 - Y_+ (F_2 - 2xF_1) \qquad Y_+ = \frac{y^2}{1+(1-y)^2}$$

$= F_L$

> Dominant term

> Represent the quark content of the proton

> sensitive to gluon contribution

$$F_L = F_2 - 2x\,F_1$$

Longitudinal proton structure function

Virtual photons can be transversally or longitudinally polarised

Proton can absorbs those with the corresponding cross sections, σ_T and σ_L

$$F_L \sim \sigma_L$$

$$F_2 \sim \sigma_T + \sigma_L$$

Relative strength of the two components:

$$R = \frac{F_L}{F_2 - F_L} \approx \frac{\sigma_L}{\sigma_T}$$

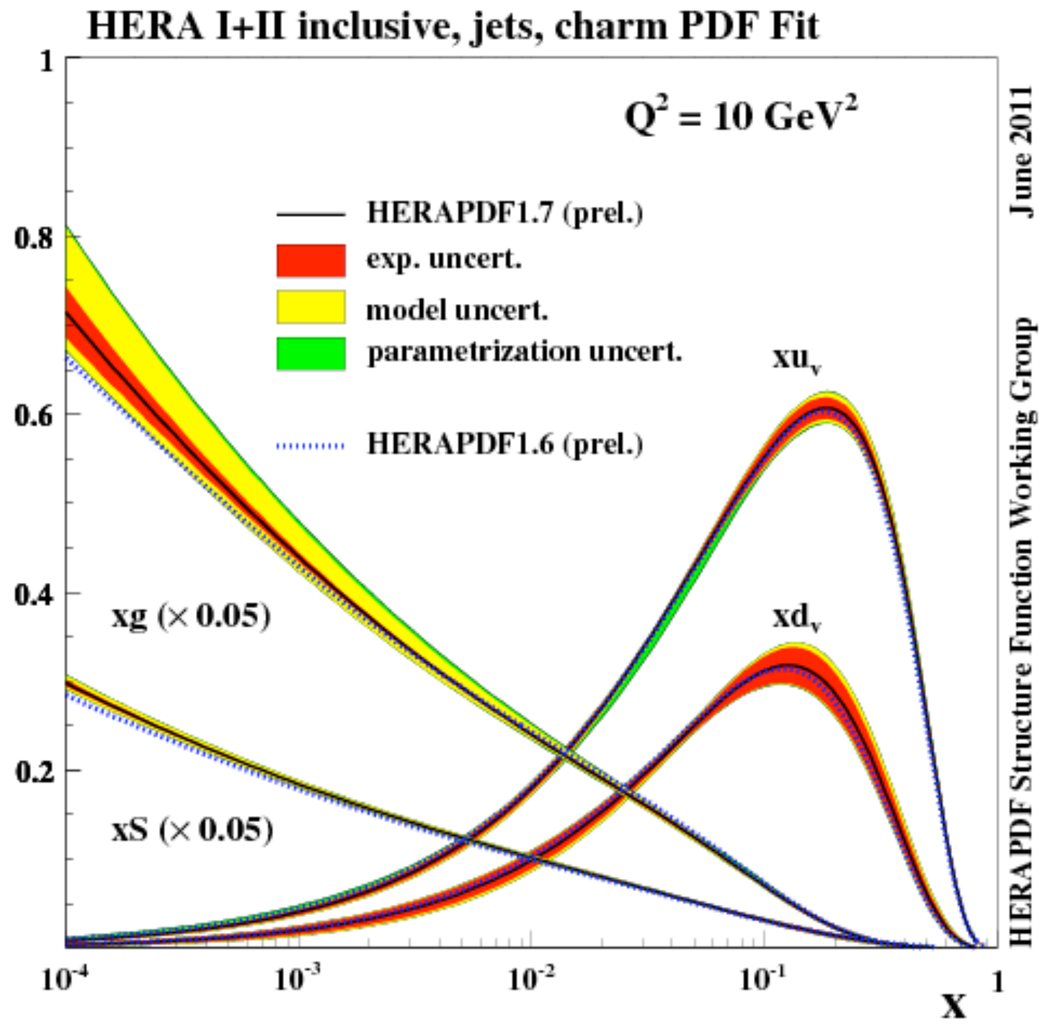
Longitudinal proton structure function

QPM

In parton model Callan-Gross relation holds, $F_2=2xF_1$, assuming that partons are spin-1/2 particles $(F_L=0)$

QCD

Longitudinally-polarised photons can not be absorbed by protons unless there is no contribution to its spin from gluons $(F_L=F_2-2xF_1)$

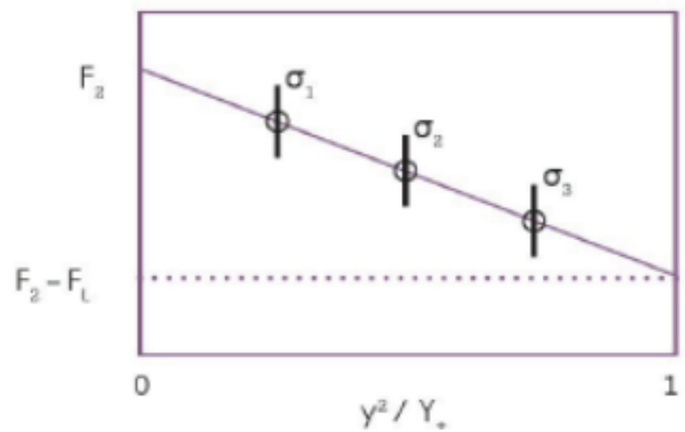


> F_L is directly sensitive to gluon content of the proton

Direct measurement of F_L

Direct F_L measurement requires cross sections to be measured at the same (x,Q^2) but different y

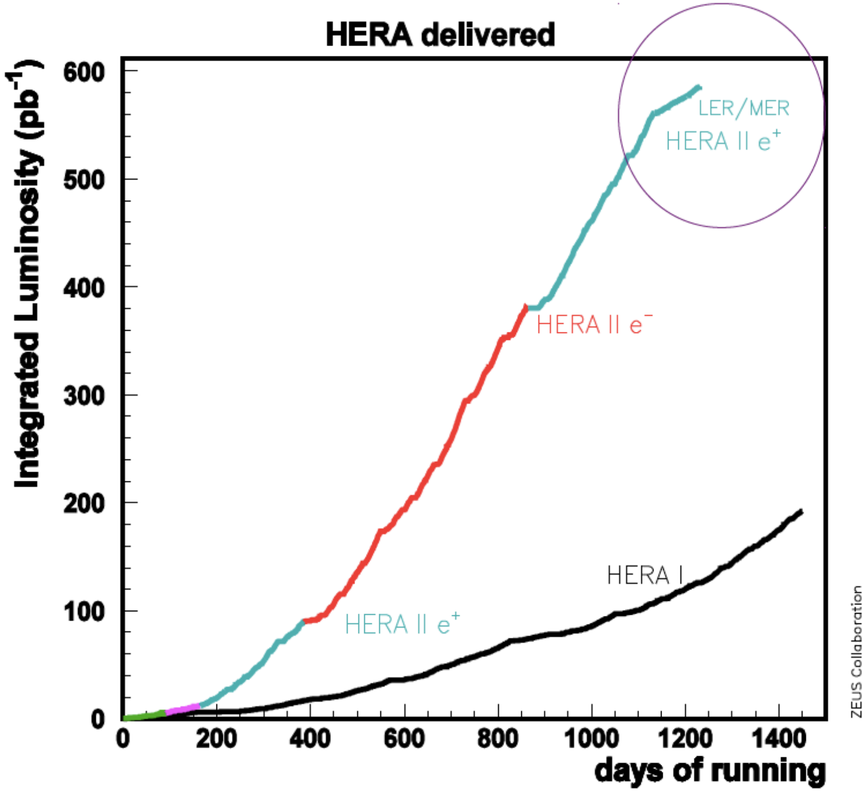
$Q^2 = xys$ > luminosity collected at different CME is required



At given x and Q2:
→F2 is an intercept
→FL is a negative slope

Dedicated ep-collider HERA runtime

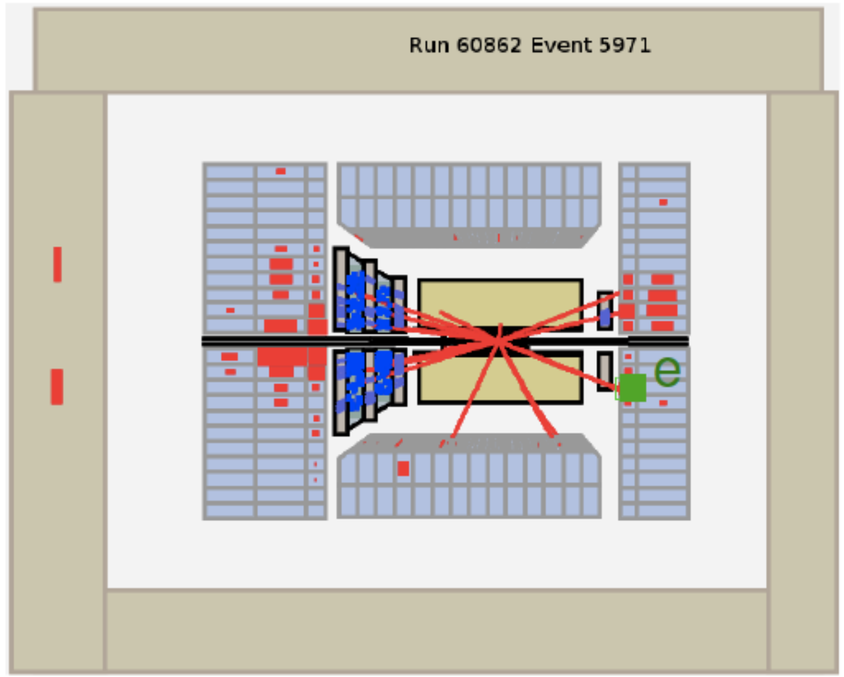
> 460 and 575 GeV proton beams
(low- and medium- energy runs, **LER** and **MER**)
> 920 GeV default protons (high-energy run, **HER**)
> electron beam 27.5 GeV



Inclusive *ep*-cross section measurement

Kinematic variables are reconstructed with electron method, using the information from the scattered electron (energy and scattering angle)

$$y = 1 - \frac{E_e'}{E_e}\sin^2\frac{\theta_e}{2} \qquad Q^2 = \frac{E_e'\sin^2\theta_e}{1-y}$$



Two kinematical regions are accessed:

Low-y high-s
→ high energy well separated scattered electron
→ almost no background

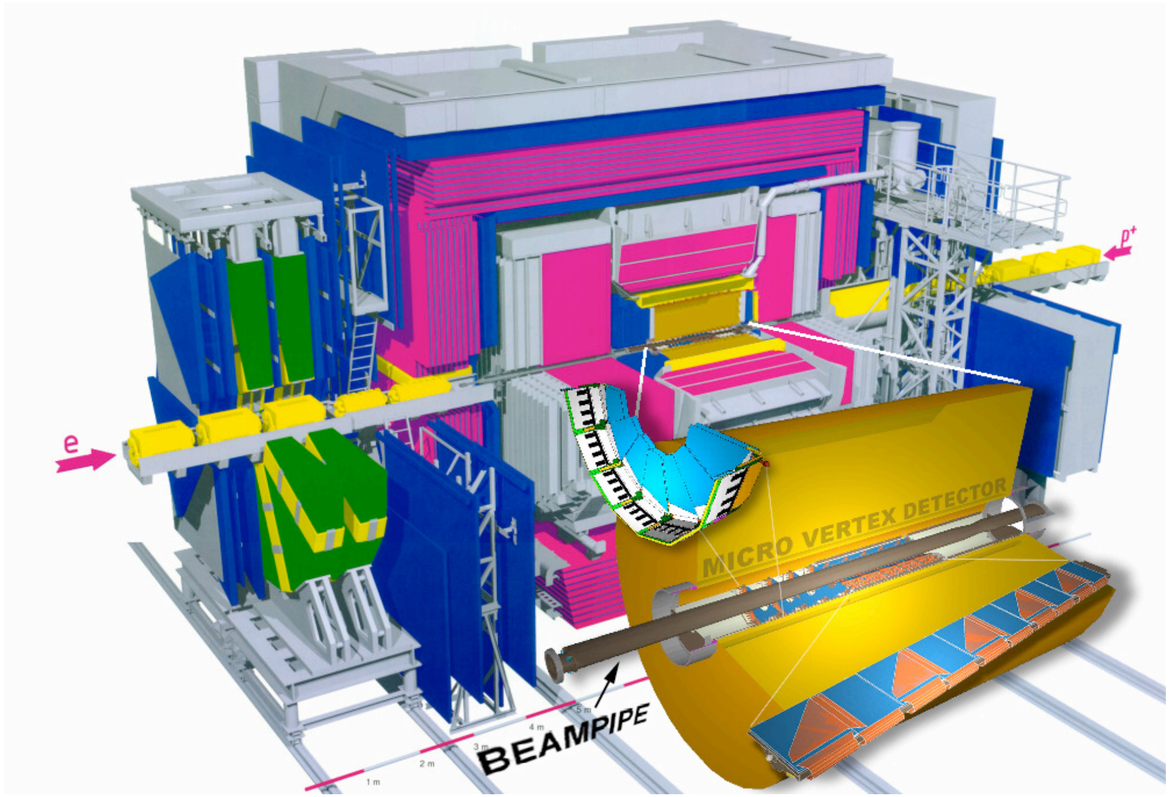
High-y low-s
→ low energy scattered electron
→ scattered electron badly separated
→ large background

The ZEUS detector

Components relevant for the analysis:

> *Vertexing and tracking*: MVD (micro-vertex detector) and CTD (central tracking detector)

> *Particle energies*: uranium-scintillator calorimeter (CAL)



> *Particle positions*: rear hadron-electron separator - layer of silicon pads (RHES) and small angle rear tracking detector (SRTD)

> *Tagging electron escaping the beampipe* (photoproduction): small tungsten-scintillator calotimeter 6m down the pipe

Satellite vertex

$$y = 1 - \frac{E_e'}{E_e} \sin^2 \frac{\theta_e}{2}$$

In y measurement is restricted by the lowest possible energy of the electron measurable

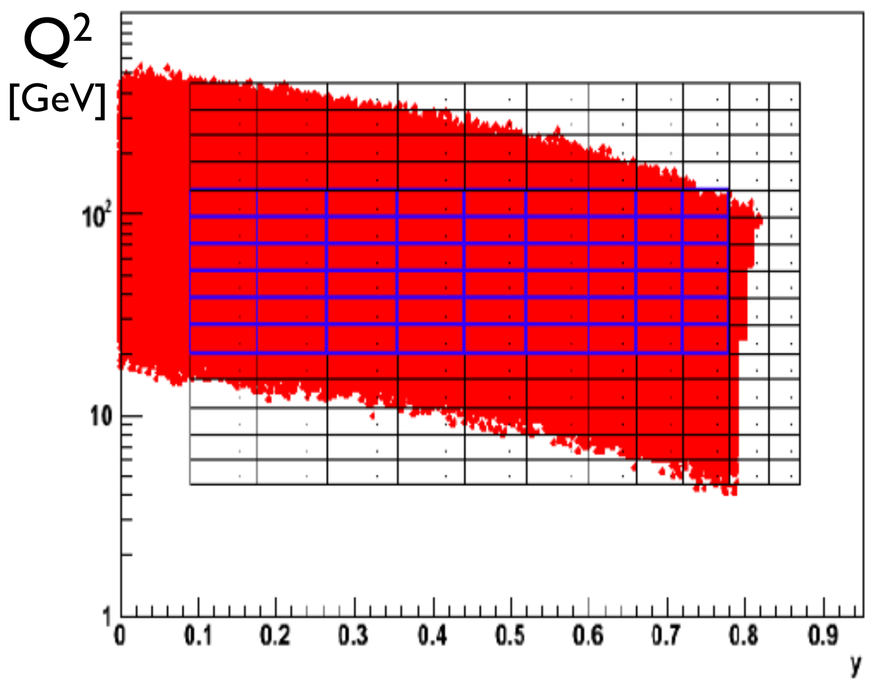
$$Q^2 = \frac{E_e' \sin^2 \theta_e}{1 - y}$$

In Q^2 measurement is restricted by the lowest possible theta of the electron measurable

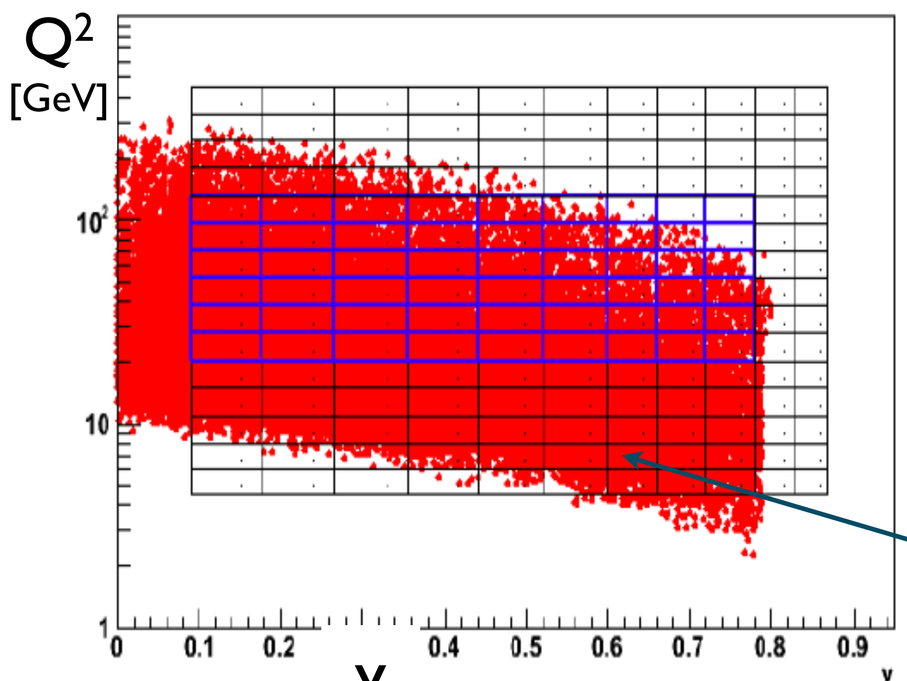
Extended kinematical region:
$5 < Q2 < 110$ GeV^2
$0.13 < y < 0.75$

Measurement was extended to lower Q^2 by including satellite vertex data

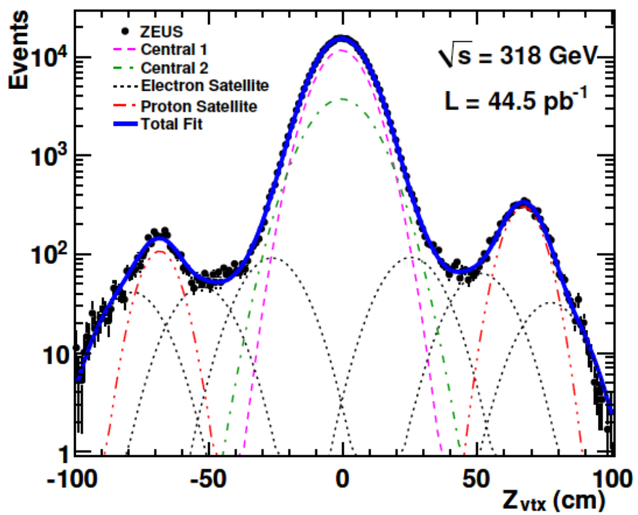
HER nominal vertex region



HER satellite vertex region



low-Q^2 bins



y

Analysis

Data and Monte carlo samples

Data

920 GeV → 44 pb^{-1}

460 GeV → 14 pb^{-1}

575 GeV → 7 pb^{-1}

820 GeV → 30 pb^{-1}

(not re-analysed, only cross sections used in structure function extraction)

Monte Carlo

Signal NC DIS:

DJANGO 1.6 with CTEQ5D parametrisation of proton PDF (with HFS simulated with ARIADNE 4.12)

Backgrounds:

> ***Photoproduction***: PYTHIA 6.416

> ***QED Compton***: Grape-Gompton MC

Detector response simulated with GEANT 3.21

Analysis selection

Identification and reconstruction of the scattered electron

Electrons identified using neutal network

Energy > 6 GeV

+ accurate electron energy scale (cell-by-cell calibration factors, non-uniformity and dead material corrections)

position reconstruction from two separate detectors + geometry quality cuts

Backward track requirement

Other cuts

Nominal vertex : |Zvtx| < 30 cm
Satellite vertex: 30 < Zvtx < 100 cm

Dedicated high-y trigger

42 GeV< E-pz< 65 GeV

QED Compton rejection cut

Minor cleaning cuts

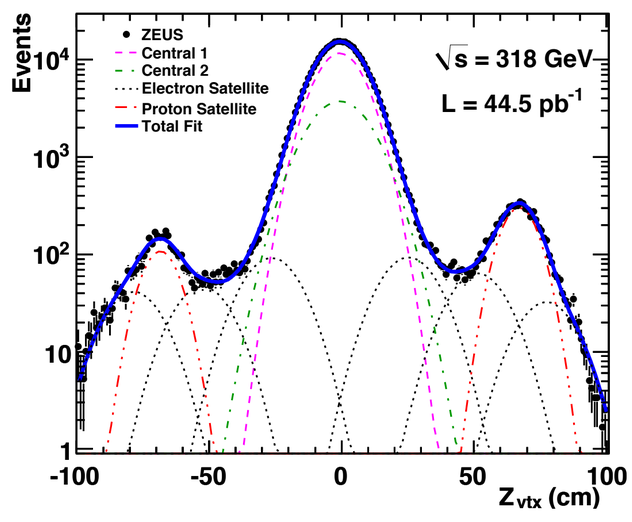
VERTEX DISTRIBUTION

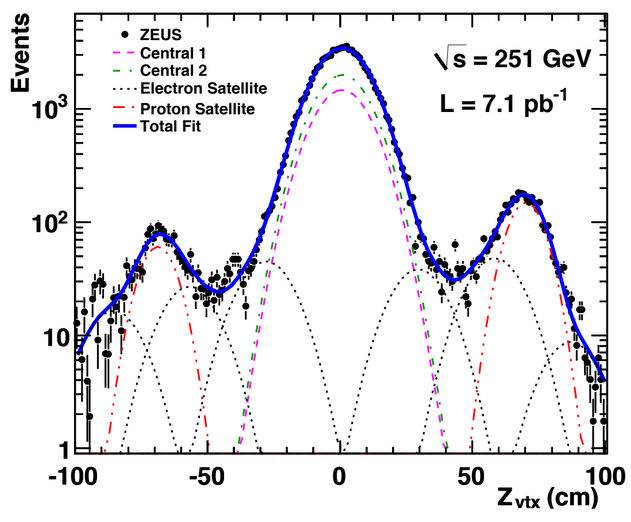
Vertex distribution was measured using a separate sample of clean DIS events

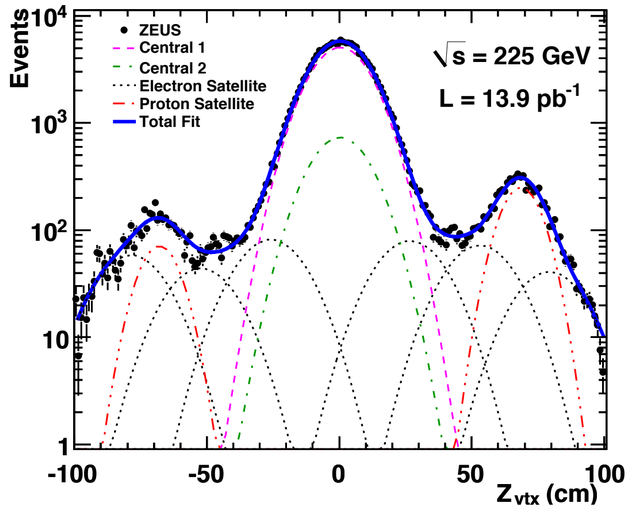
The distribution was fit with **10 Gaussians** - 6 electron satellites, 2 proton satellites, 2 central gaussians with same mean but different amplitude and width

Measured vertex distributions were directly propagated to the MC at the reconstruction level

ZEUS





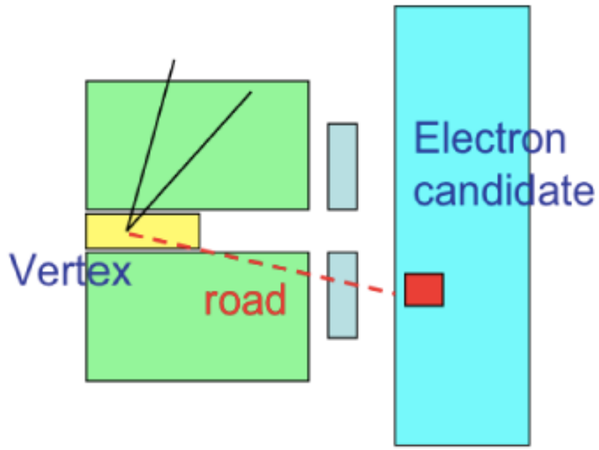


Uncorrelated normalisation uncertainty for the shifted vertex region of 3.0 %.

Photoproduction

Photoproduction is the main background for the measurement: electron escapes to the beampipe and hadron or photon is misidentified as scattered electron

→ such events are rejected based on information about hits in vertex and tracking detectors (‘backward tracking’)



→ remaining events are subtracted from data using MC predictions

MC is verified by using a data sample from a 6m-tagger and PHP enriched sample (sample selected with ‘wrong’ candidate from the electron identification neural network) (agreement within 10%)

List of systematic uncertainties

Photoproduction	+-10% to the level of PHP background
Hadron energy scale	+-2% variation in MC
Diffractive	+10% on the scale factors applied to MC diffractive component
Backward tracking efficiency	Hit fraction cuts variation
Electron energy scale	+-0.5% for E_e'>20 GeV, and +-1.9% at E_e'=6 GeV
Electron identification	loosening/tightening cut on neural network output probability
Electron X position	+-2mm
Electron Y position	+-2mm
Z-vertex	varying event selection criteria used for measuring the vertex

Normalisation uncertainties:

> 1.5% for HER, LER, MER *(correlated)*

> 1%/3% for central/ shifted vertex region *(uncorrelated)*

Negligible

> trigger-efficiency uncertainty

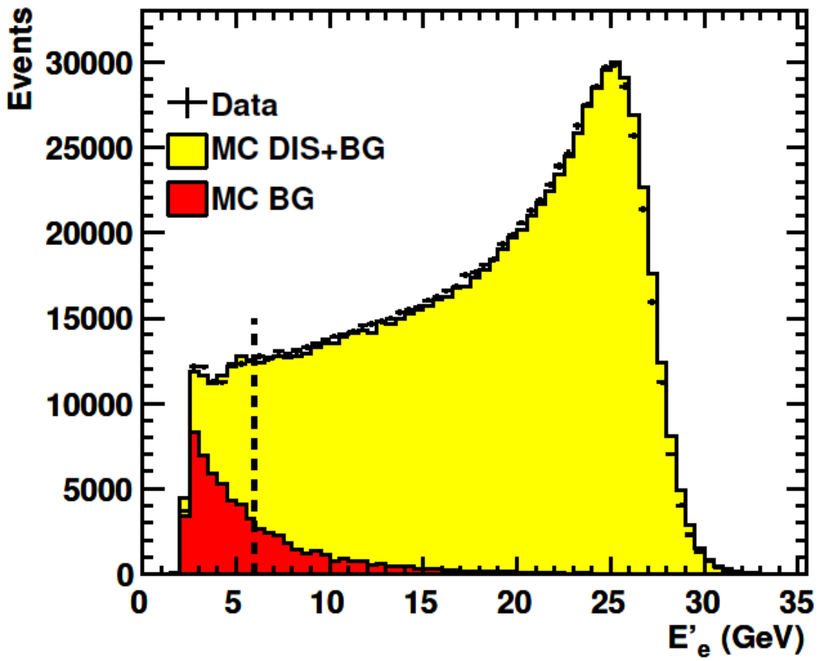
> uncertainty due to electroweak correction

Distributions

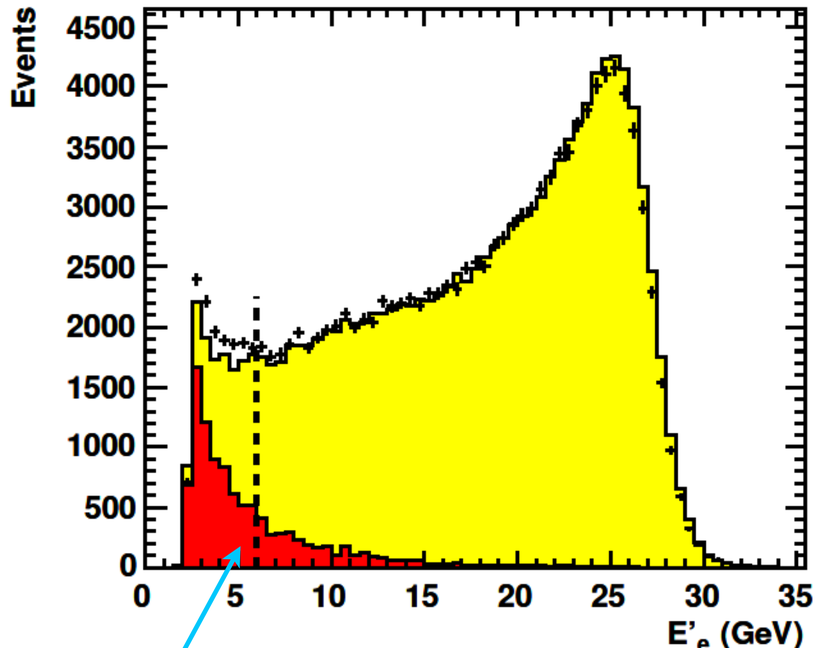
Scattered electron energy

Energy distributions for data and MC for three running periods, after all analysis cuts and corrections, F_L-reweighted

HER

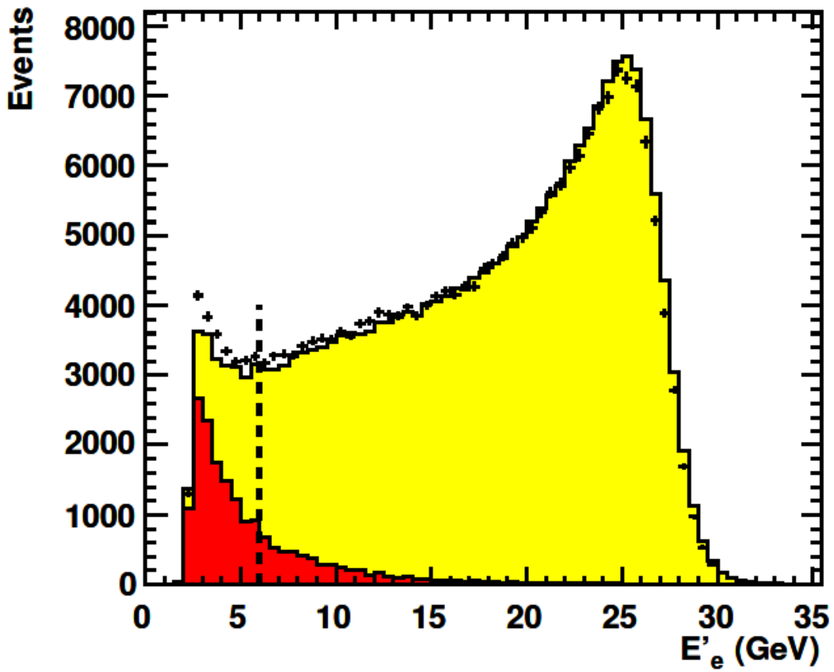


MER



Analysis cut at 6 GeV

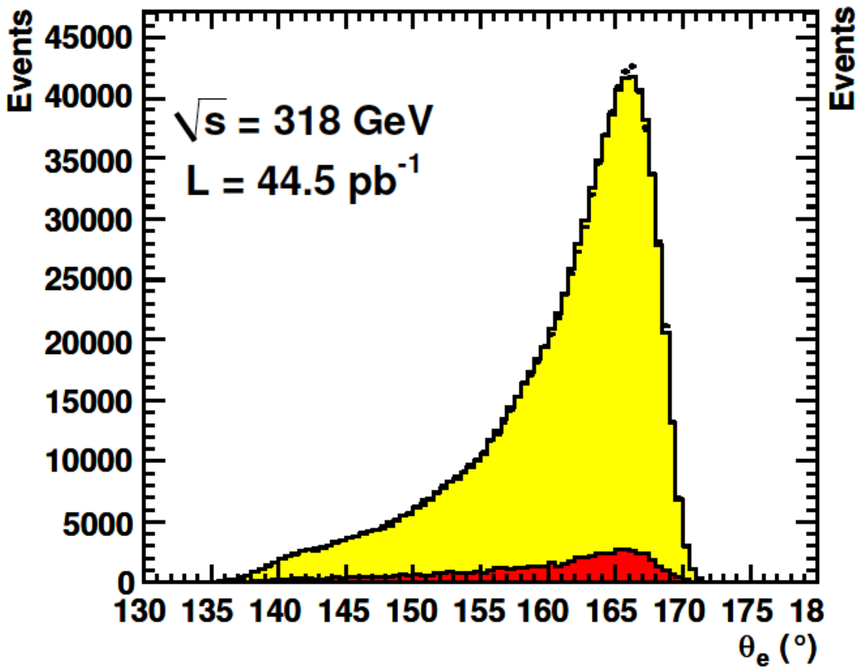
LER



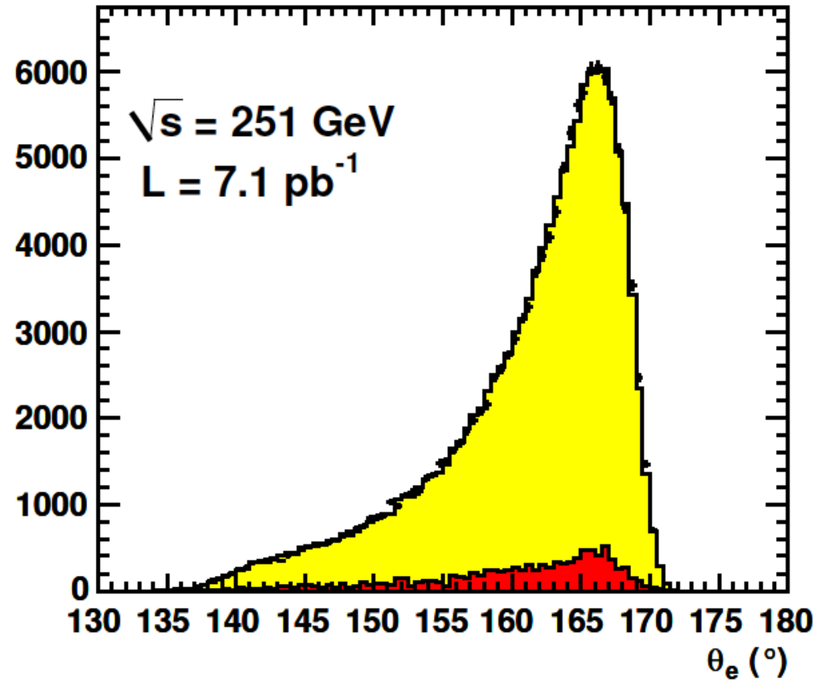
Scattered electron theta

Theta distributions for data and MC for three running periods, after all analysis cuts and corrections, F_L-reweighted

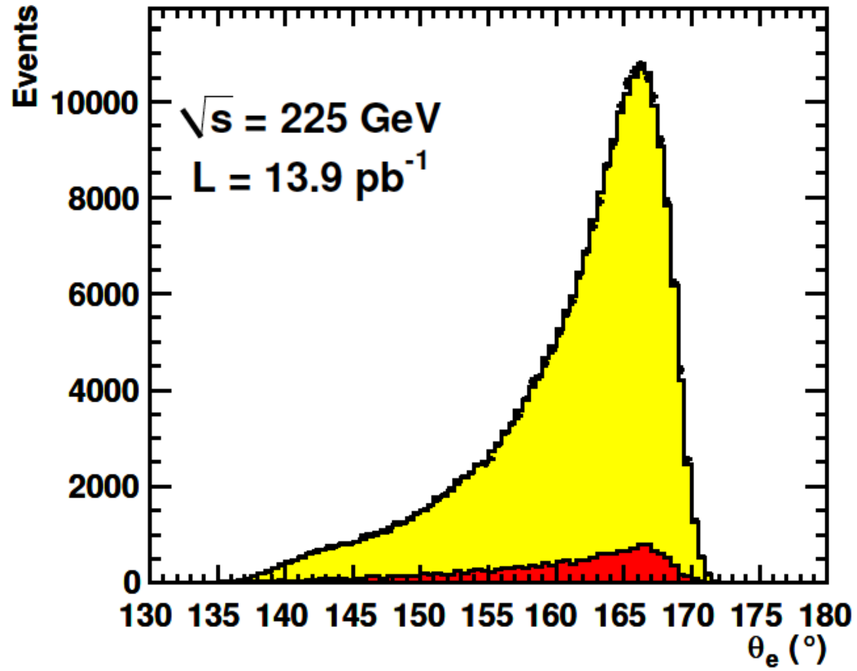
HER



MER



LER



Cross sections

High-energy run cross sections

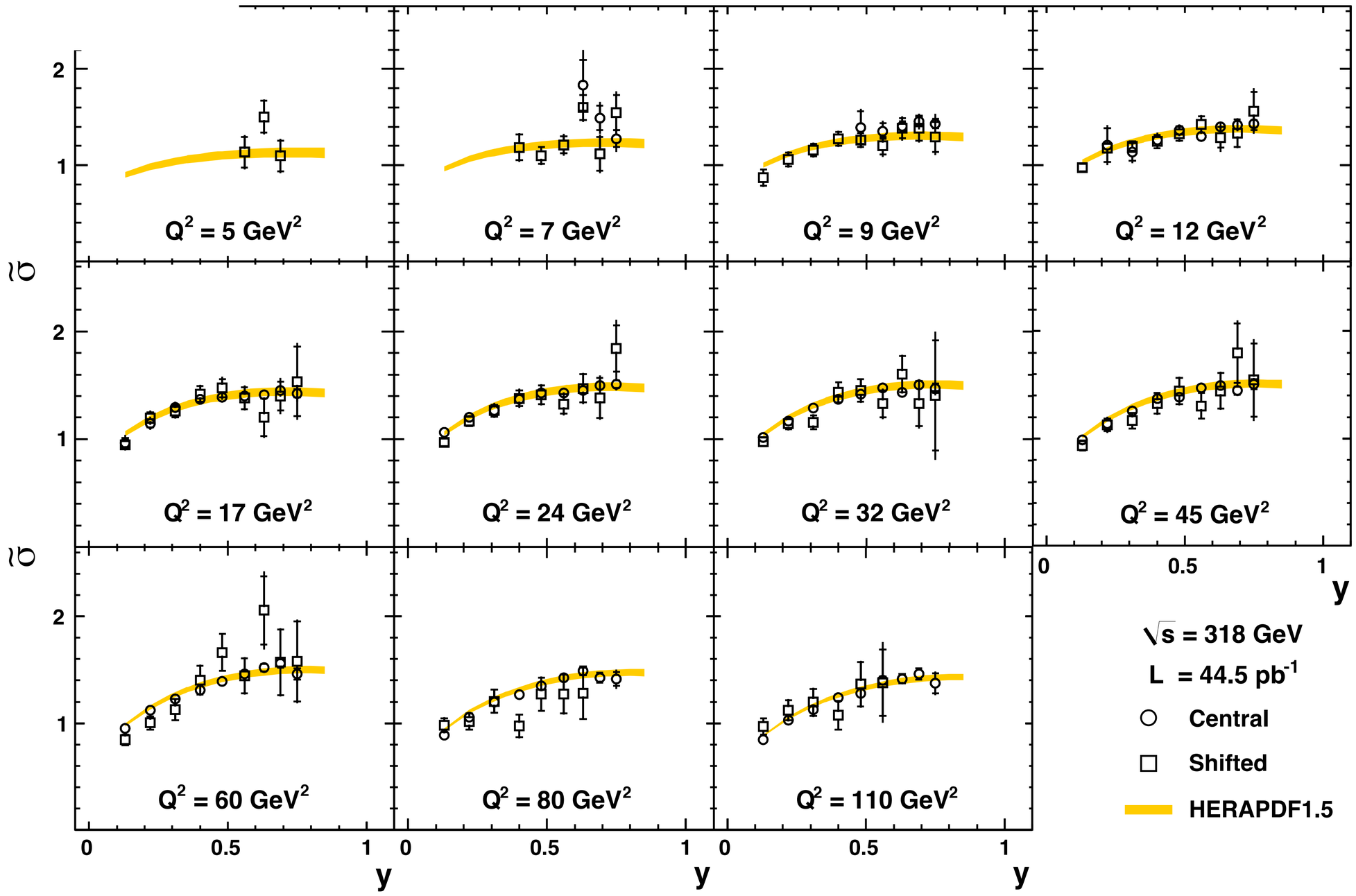
$$\tilde{\sigma}(x,Q^2) = \frac{N_{\mathrm{data}} - N_{\mathrm{MC}}^{\mathrm{bg}}}{N_{\mathrm{MC}}^{\mathrm{DIS}}}\,\tilde{\sigma}_{\mathrm{SM}}(x,Q^2)$$

Cross sections were measured separately for central and shifted vertex regions

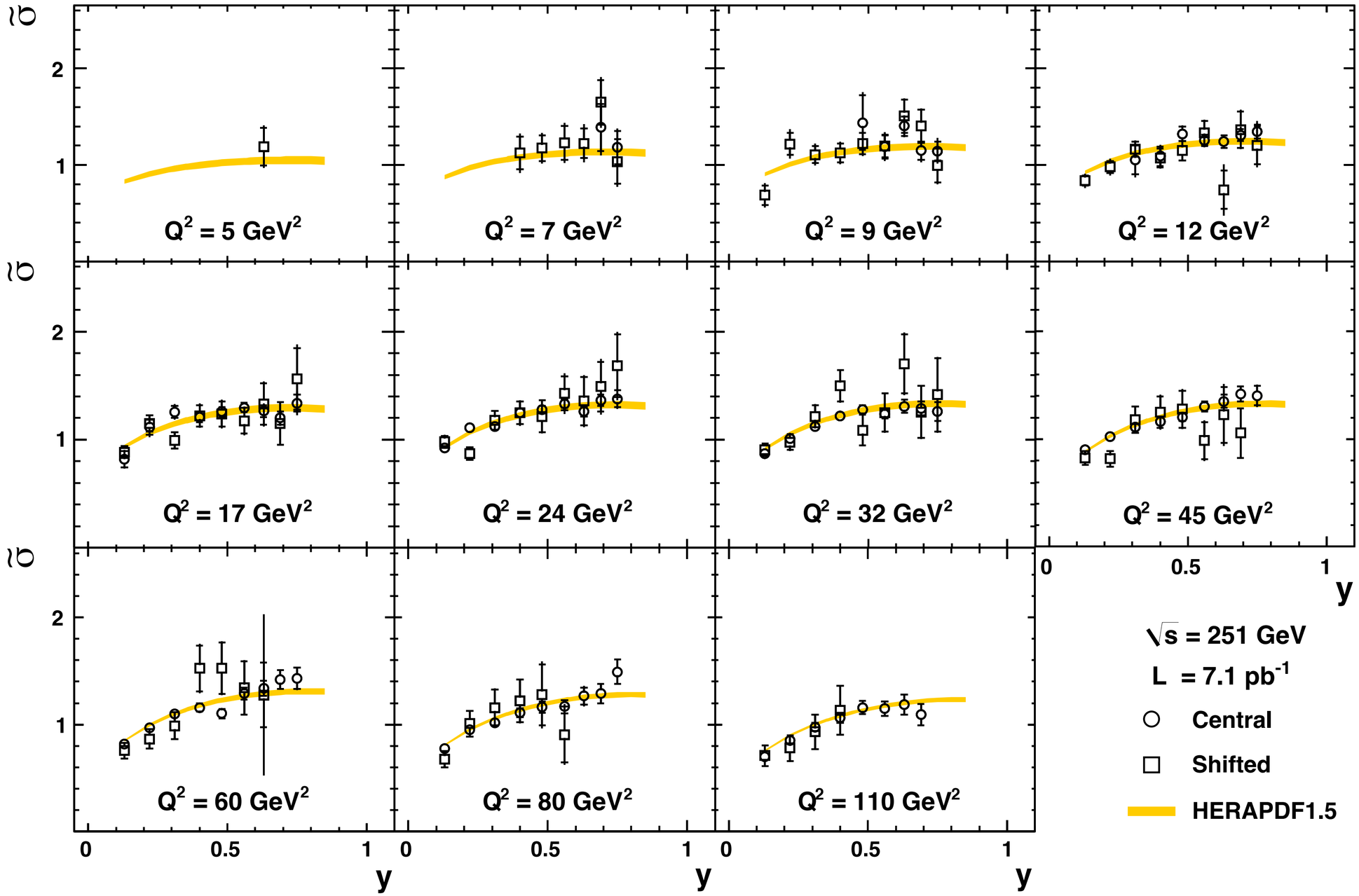
Kinematic region:

5 < Q2 < 110 GeV²

0.13 < y < 0.75

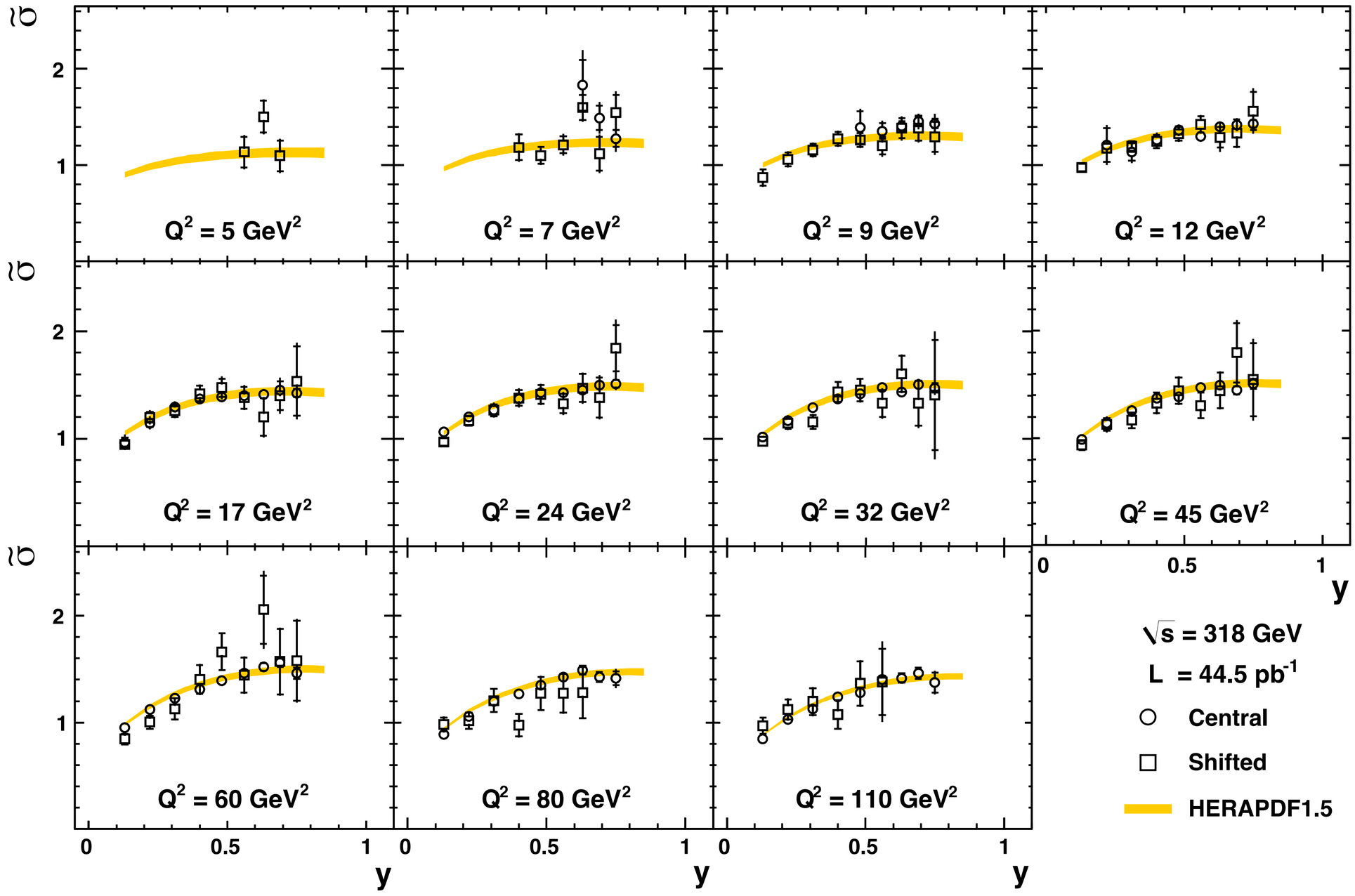


MEDIUM-ENERGY RUN CROSS SECTIONS



Low-energy run cross sections

ZEUS



Extraction of the structure functions

Cross sections for extraction

Different binning is used for cross sections for structure function extraction to cover similar ranges in all data sets → 27 (x,Q^2) bins in total

Cross sections are combined as weighted average in the central/shifted vertex overlap region

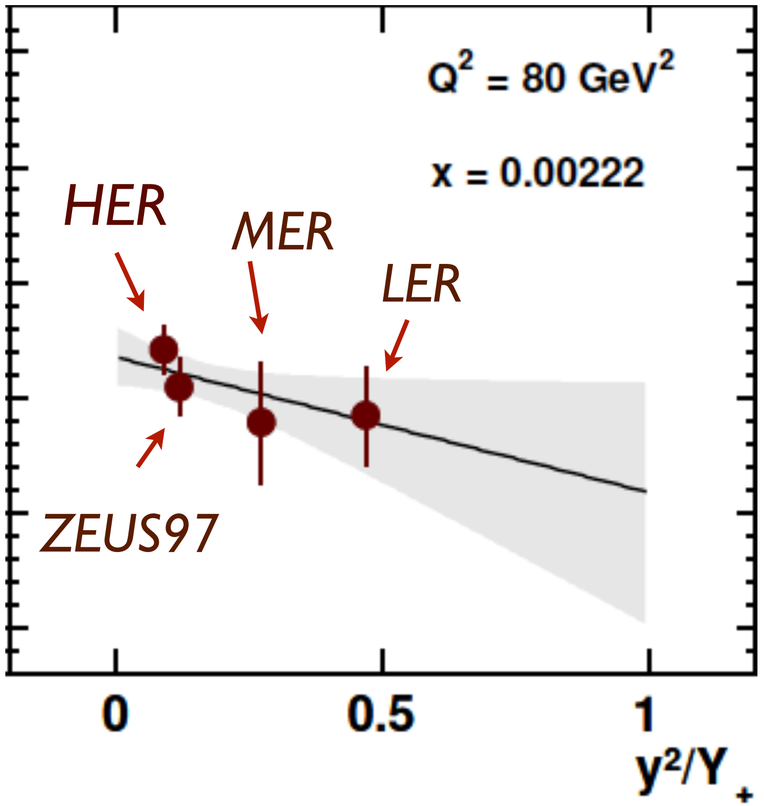
Prior to fitting, cross sections are normalised to ZEUS97 (E_p=820 GeV) data at low-y

Including data from the satellite vertex region allow to extract F_L down to 9 GeV^2

Satellite vertex data dominate precision at Q^2 of 9 -12 GeV^2

Rosenbluth plots

ZEUS

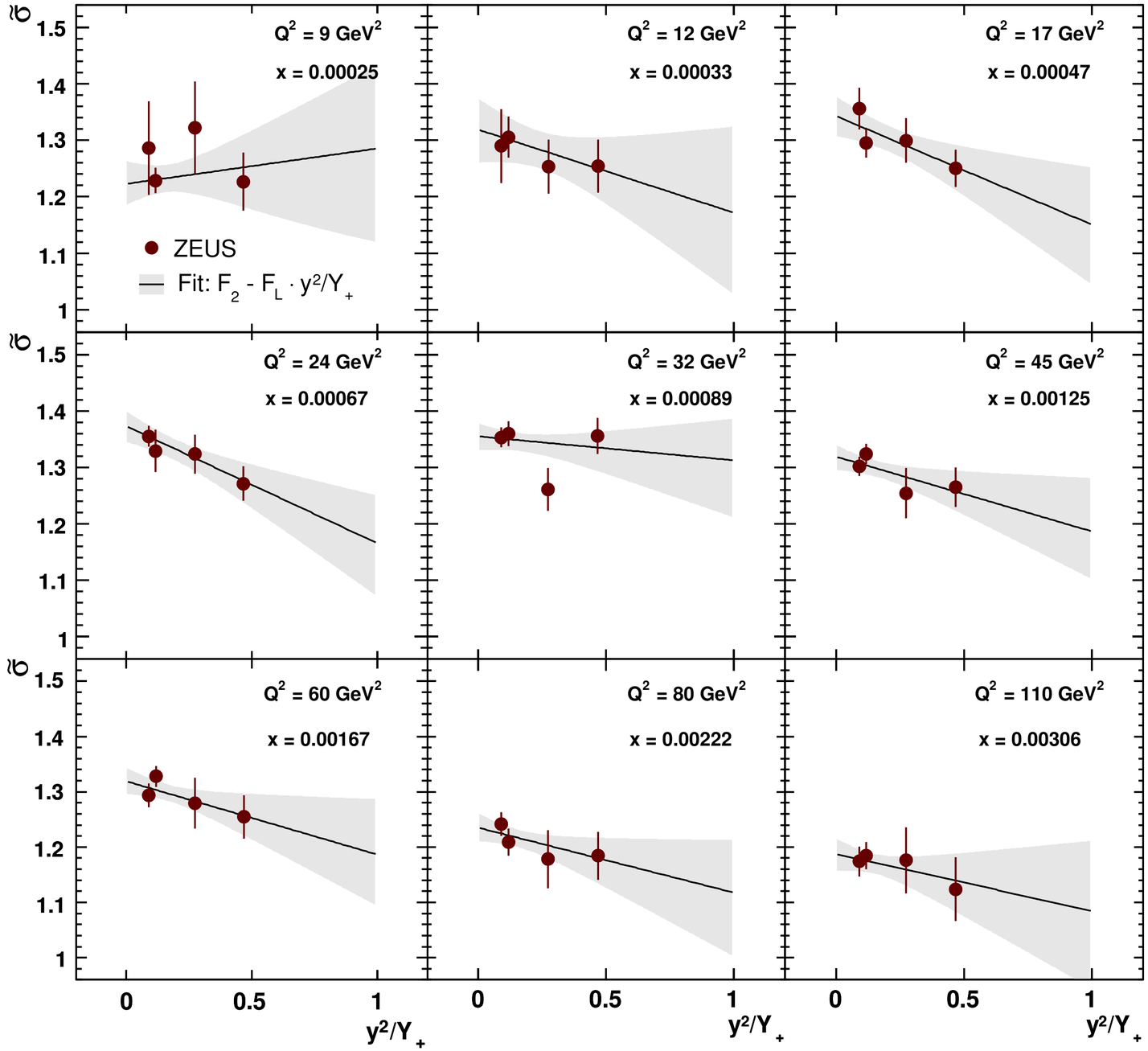


*Cross sections measured in 96/97 with Ep = 820 GeV (**ZEUS97 data set**) were included in fits*

Linear fit:

> F_2 is an intercept

> F_L is a slope



Extracted structure functions

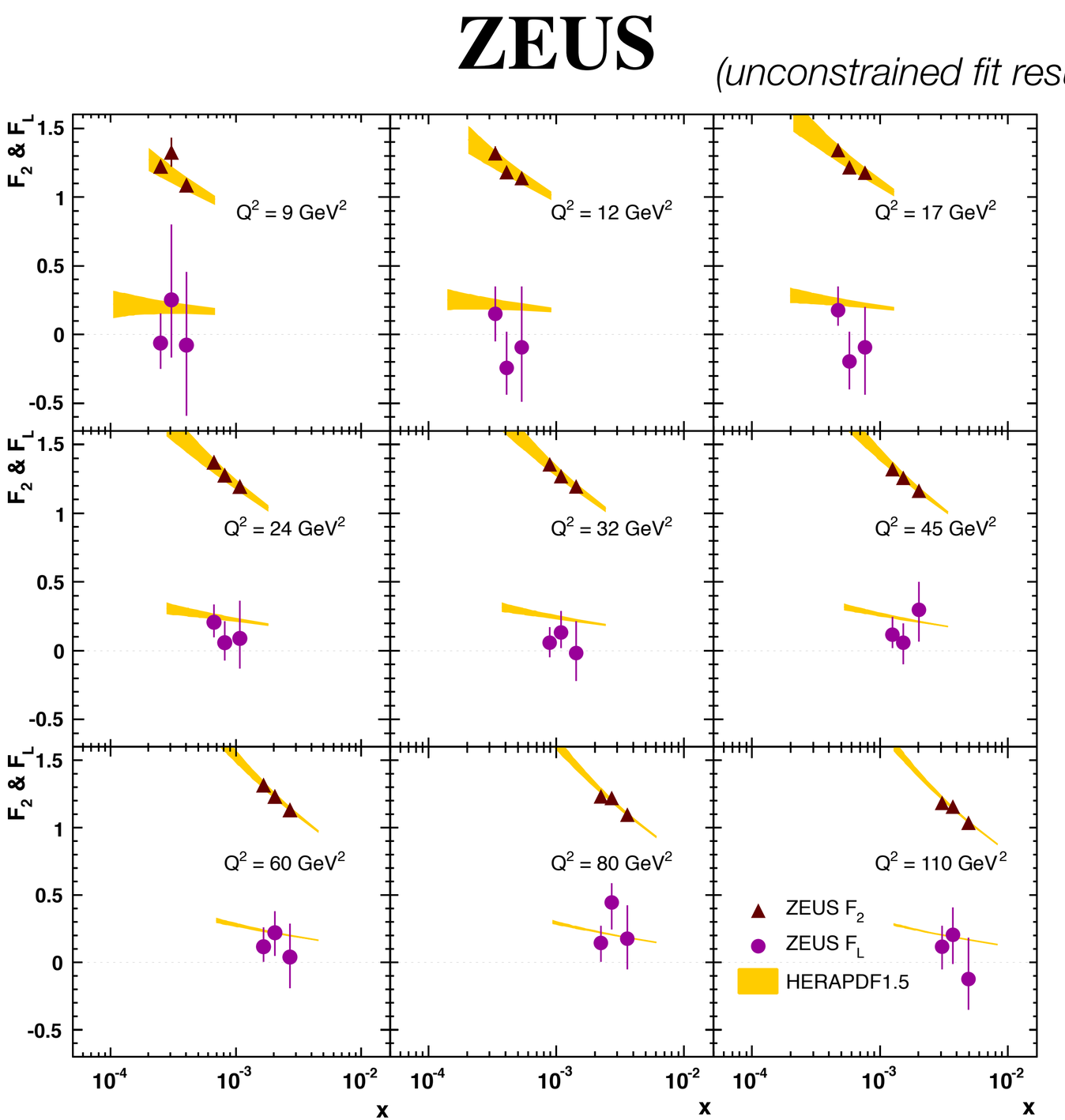
$F_2(x, Q^2)$ and $F_L(x, Q^2)$

Fit within Bayesian formalism (for unconstrained fit equivalent to maximum likelihood)

Physics parameters: 27 F_2 and 27 F_L values

+ all uncertainties as nuisance parameters

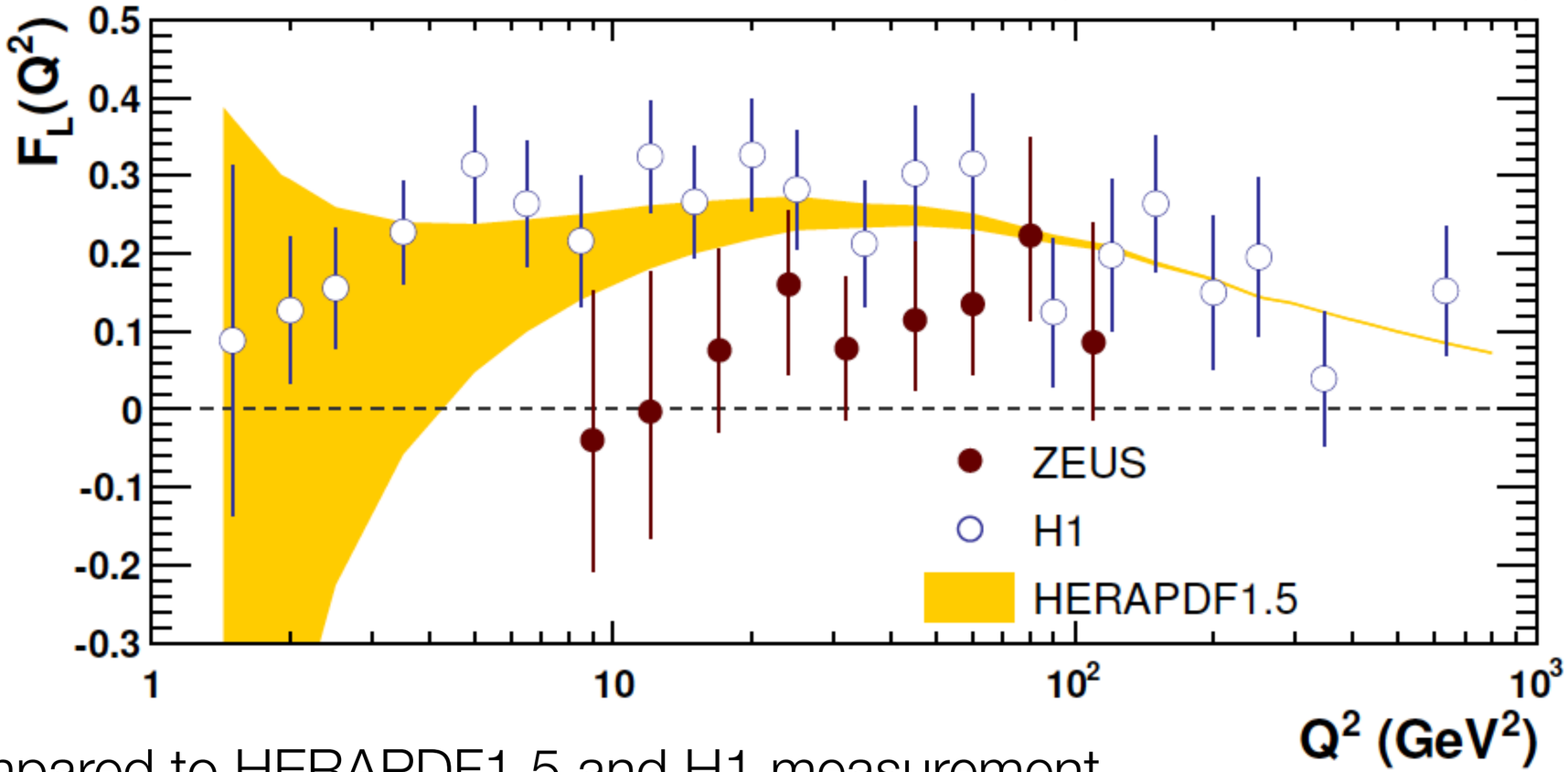
Results for constrained fit ($0 < F_L < F_2$) can be found in the paper



Extracted $F_L(Q^2)$

Physics parameters in the fit: 9 $r = F_L/F_2$ values and 27 F_2

$F_L(Q^2) = r\,(Q^2) * F_2$



ZEUS measurement compared to HERAPDF1.5 and H1 measurement

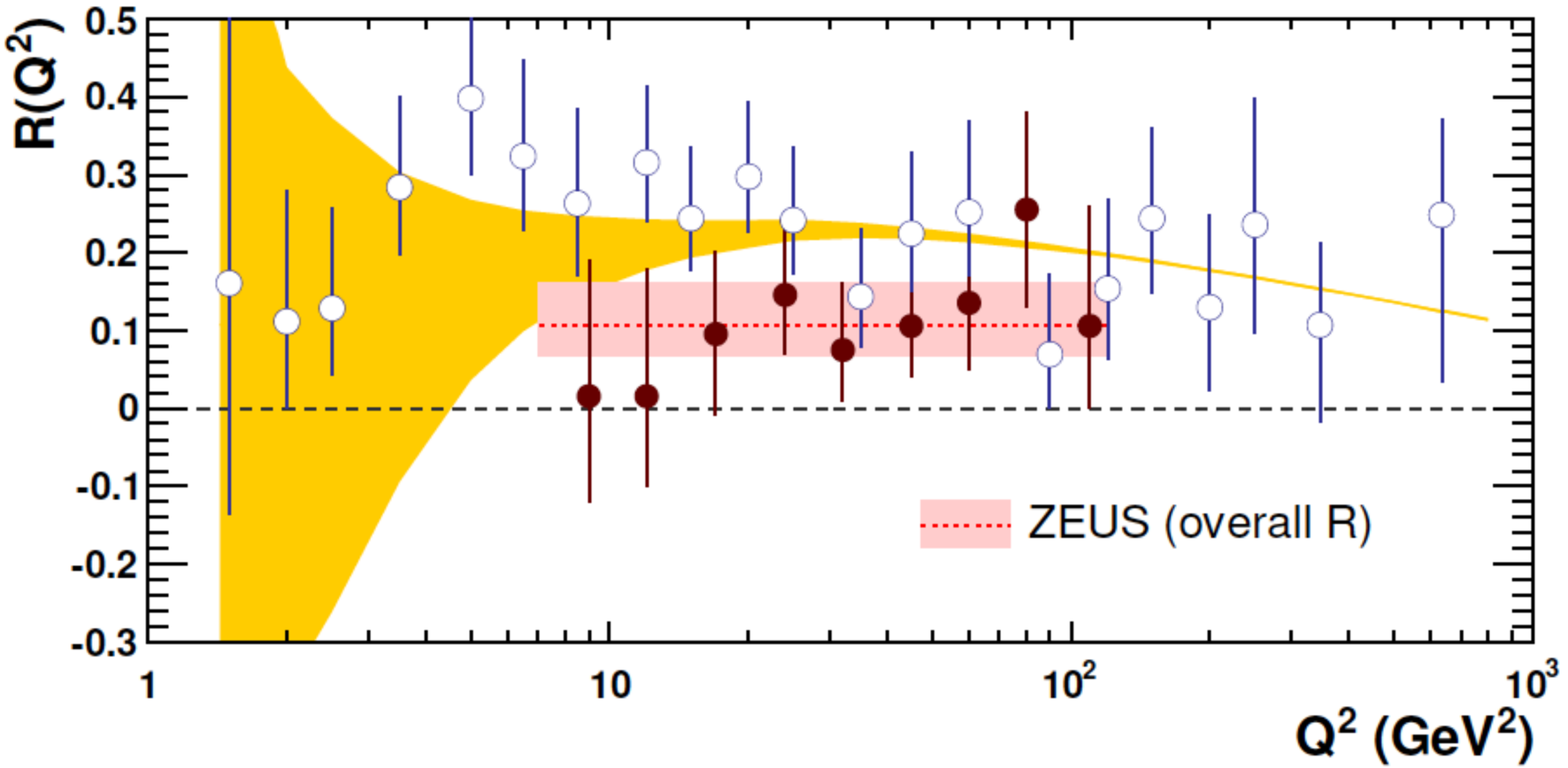
Taking into account correlations between points, the H1 and ZEUS are consistent with each other within about one sigma

Extracted R(Q^2) and overall R

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

Physics parameters in the fit: 9 R (Q^2)

(unconstrained fit results)



Overall R = 0.105 $^{+0.055}_{-0.037}$

(for both, constrained and unconstrained fits)

Summary

DIS cross sections were measured for three different centre-of-mass energies $\sqrt{s}$ = 318, 251, 225 GeV in the kinematic region:

5 < Q2 < 110 GeV^2, 0.13 < y < 0.75

First ZEUS high-y cross section and F_L measurement was extended to lower Q^2 region by including satellite vertex data

ZEUS F_L measurement is lower but compatible with predictions and H1 measurement

Backup

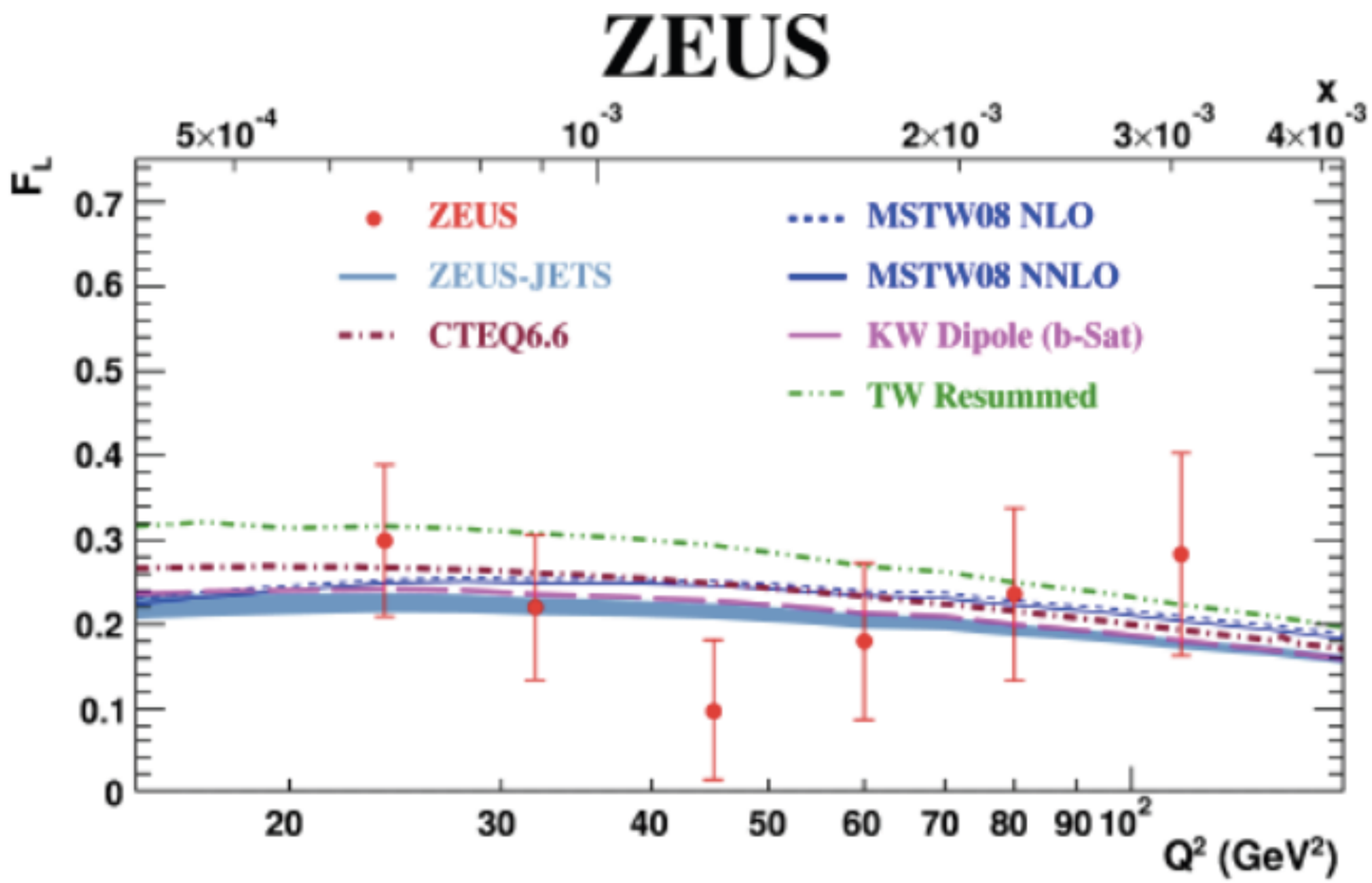
First ZEUS FL measurement

ZEUS published FL measurement (Phys. Lett. B682, 8 (2009))

Kinematic range of fist ZEUS measurement:

$5*10^{-4} < x < 7*10^{-3}$

$20 < Q^2 < 130\ GeV^2$



H1 measurement extends to lower Q2 region (due to better suitability of the detector for detecting the scattered electron in the backward region, i.e. lower Q2)

Backward tracking

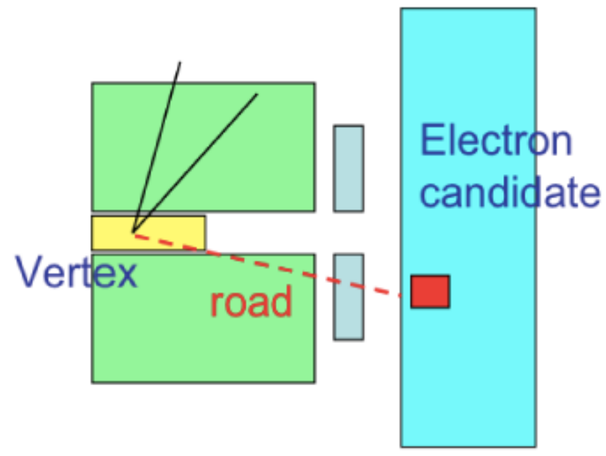
Measuring at low Q^2 (high scattering angles) requires efficient rejection of the photoproduction background, i.e. *distinction between hadrons or photons and electrons*

ZEUS main tracking system has too narrow acceptance for low Q^2
(15 < theta < 154 °)

→ new tool was developed for judging on the **neutrality/charge** of the particle passing (extended acceptance down to theta <168 °)

→ decision taken based on the hit fraction along the road (vertex > cluster):

$$HitFraction = \frac{N_{observed-hits}}{N_{expected-hits}}$$



→ analysis requirements: **Central tracking detector HitF > 0.6**
Micro-vertex detector HitF > 0.45

Cross section measurement

Cross section was extracted according to:

$$\tilde{\sigma}(x, Q^2) = \frac{N_{\mathrm{data}} - N_{\mathrm{MC}}^{\mathrm{bg}}}{N_{\mathrm{MC}}^{\mathrm{DIS}}} \tilde{\sigma}_{\mathrm{SM}}(x, Q^2)$$

N_{data} - number of observed events in the data

N^{DIS}_{MC} - number of expected signal events from MC

N^{bg}_{MC} - number of expected background events from MC

$\tilde{\sigma}_{SM}$ - Standard Model electroweak Born level reduced cross section

Normalisation of data/MC to luminosity for **N^{DIS}_{MC}** and **N^{bg}_{MC}**

Cross sections combination

For F2 and FL extraction in the overlap region the cross sections measured at the nominal and satellite vertex regions are combined as weighted average

$$\tilde{\sigma}(x,Q^2) = \left(\frac{\tilde{\sigma}_{\mathrm{cen}}}{\delta^2_{\mathrm{cen}}} + \frac{\tilde{\sigma}_{\mathrm{sh}}}{\delta^2_{\mathrm{sh}}}\right) / \left(\frac{1}{\delta^2_{\mathrm{cen}}} + \frac{1}{\delta^2_{\mathrm{sh}}}\right)$$

where δ_{cen} and δ_{sh} are the total uncorrelated uncertainties for the corresponding vertex regions.

Systematic uncertainties: combine cross sections for each systematic variation, and calculate new combined cross section

Including data from the satellite vertex region allow to extract FL down to 9 GeV2

Satellite vertex data dominate precision at Q2 of 9-12 GeV2

F2 AND FL FITS

Total 6 fits are performed with the measured cross sections:

> $F_2(x, Q^2)$ and $F_L(x, Q^2)$ (unconstrained; and with $0 < F_L < F_2$)

> $F_L(Q^2)$ and $R(Q^2)$ (unconstrained; and with $R > 0$)

> overall $R = F_2/(F_2-F_L)$(averaged over full (x,Q^2) space) (unconstrained; and with $R>0$)

Physics parameters in the fits:

> 27 F_2 and 27 F_L values for the (x,Q^2)-fit

> 9 $r = F_L/F_2$ values and 27 F_2 values for $F_L(Q^2)$-fit

Nuisance parameters in the fits:

> 3 relative normalisations (LER, MER, ZEUS9697)
> 9 systematics for HER, LER, MER data sets
> 10 systematics for ZEUS97 data set

Uncertainties

Luminosity uncertainties:

> correlated normalisation uncertainty of 1.5% for HER, LER, MER

> uncorrelated 1% normalisation uncertainty fo central vertex region

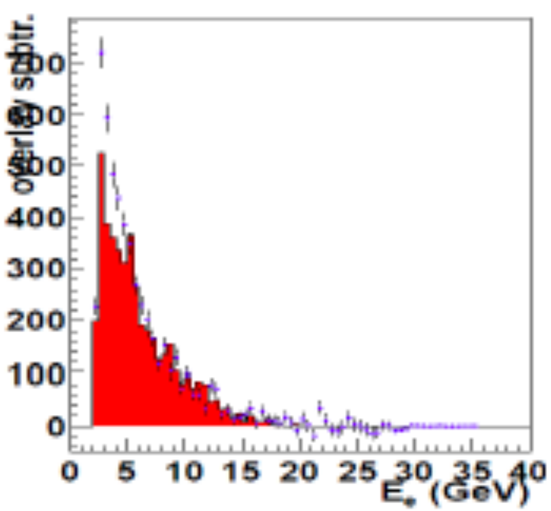
> uncorrelated 3% normalisation uncertainty fo shifted vertex region

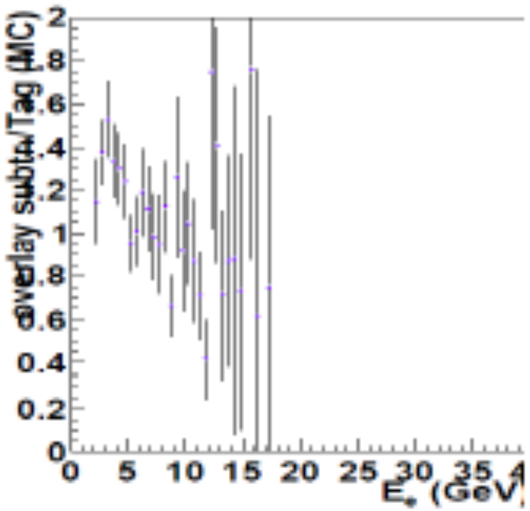
Systematic uncertainties:

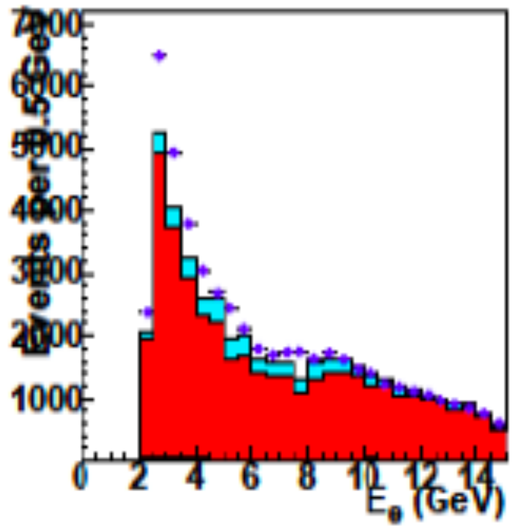
According to the behavior of the cross sections in (x,Q^2)-bins with the variation of each systematic source, systematics were considered as correlated or uncorrelated between bins and data sets

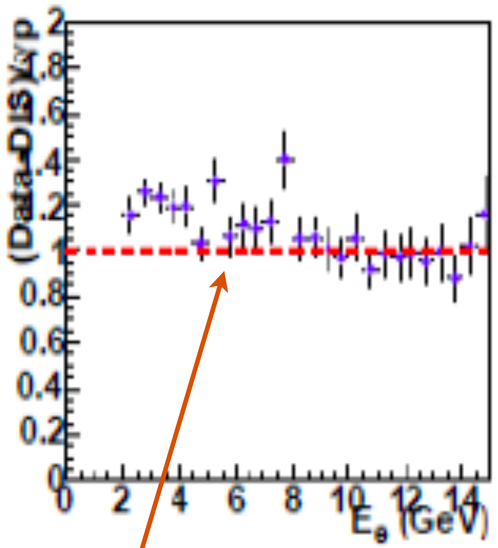
Photoproduction treatment

6m-tagger sample and PHP enriched sample (sample selected with ‘wrong’ candidate from the electron identification neural network) are used to verify PHP background









Fit the ratio of data/MC for 6 PHP-selected samples

> We fit the ratio of data/MC in 2 samples for 3 data sets (6 curves in total)

> PHP MC is reweighted according to the average fit function between 6 samples

Including E_p=820 GeV data in the fit

Reduced cross sections measured from the data taken in 1996 and 1997 with Ep = 820 GeV **(ZEUS97 data set)** were included in the Rosenbluth plot fits

The precision of ZEUS97 is comparable to the measurement using the HER sample presented in this analysis

The interpolation of a measurement *(based on the HERAPDF1.0)* to the required point on the $(x;Q^2)$ grid is performed by multiplying the measured cross section by a ratio of theoretically calculated double differential cross sections at two $(x;Q^2)$ points.

Only the points which required less than 2% adjustments were included in the fits to extract F_2 and F_L

Corrections and reweightings

> Correction of the efficiency of the backward tracking: efficiency measured with clean DIS sample in data and MC, corrected at smallest angles for central vertex region (max. weight 1.06)

> Diffractive event reweighting in MC to reproduce the tail of eta-max distribution

> Photoproduction background reweighting (see next slide)

> No vertex or trigger reweighting