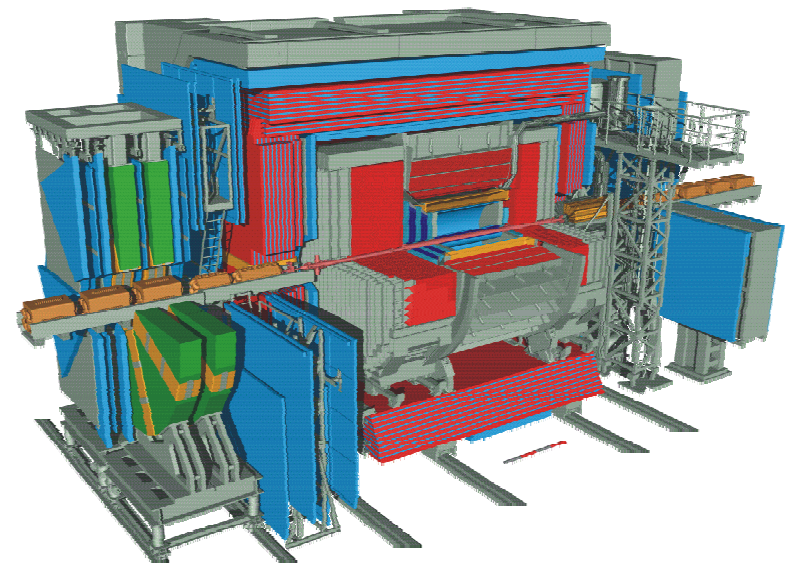




Measurement of the longitudinal structure function F_L at HERA with the ZEUS detector

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On behalf of ZEUS Collaboration

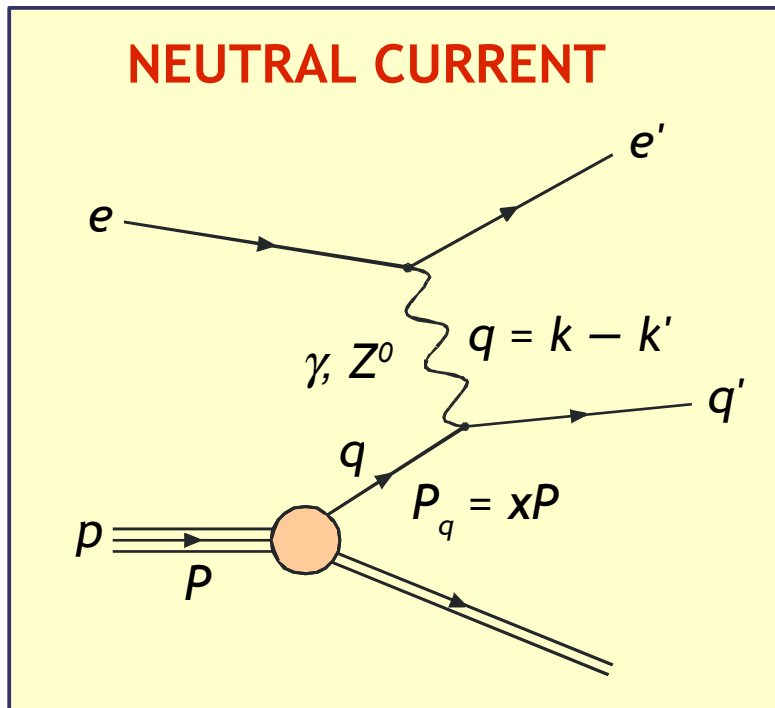
DIS 2008 London, UK, April 7-11 2008



Deep-Inelastic Scattering (DIS)

- the key tool to study the structure of the proton
- allows testing of QCD

Kinematics of the Neutral current (NC) DIS



- s – CM energy of the lp system $s = (p + k)^2$
- Q^2 – virtuality of the intermediate boson
– measure of the probing power $Q^2 = -q^2 = -(k - k')^2$
- x – Bjorken scaling variable
– fraction of proton's momentum carried by struck parton $x = \frac{Q^2}{2P \cdot q}$
- y – inelasticity of the interaction $y = \frac{q \cdot P}{k \cdot P}$
- x, y, Q^2 are related by $Q^2 = x y s$



Neutral current cross section

Experiment measures cross-section → **Structure Functions (SF)**

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

(for EM process)

$$Y_+ = 1 + (1 - y)^2$$

F_2 – dominant contribution to cross section

$$F_2 = \sum_q e_q^2 x (q + \bar{q})$$

F_L – longitudinal SF, only important at high y

– $F_L = 0$ in Quark-Parton Model

– non-zero in NLO pQCD:

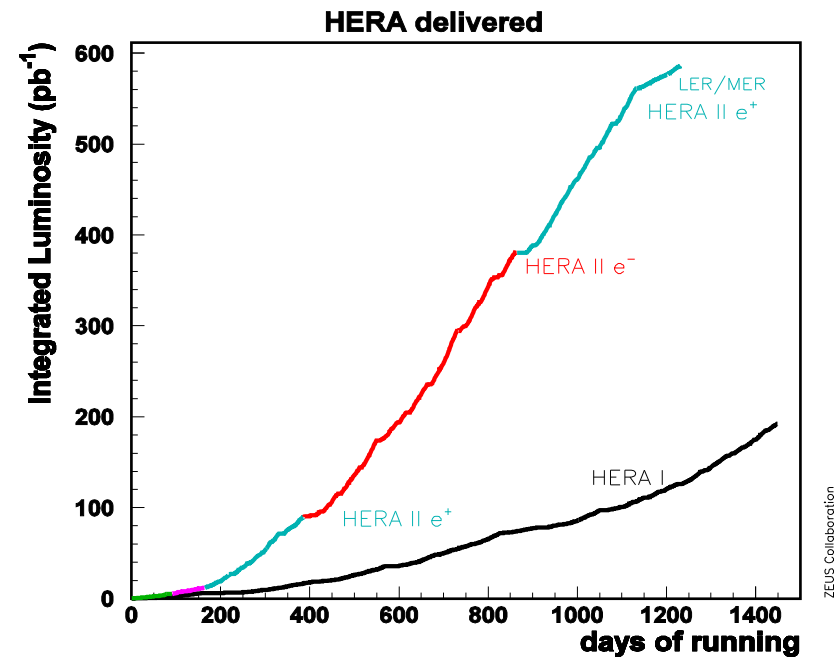
$$F_L = \frac{\alpha_s}{4 \pi} x^2 \int_x^1 \frac{d z}{z^3} \left[\frac{16}{3} F_2 + 8 \sum e_q^2 \left(1 - \frac{x}{z} \right) \text{zg} \right]$$

Direct sensitivity to gluon

↘ High y (low x) region is of particular interest



HERA – an **electron-proton collider** at DESY, Hamburg



- in operation since 1992
- **HERA running ended June 30, 2007**
- four different CM energies
- total delivered lumi is 780 pb^{-1}

Total ZEUS integrated luminosity			
E_e [GeV]	E_p [GeV]	\sqrt{s} [GeV]	L [pb^{-1}]
27.5	820	300	48
	920	318	456
	460	225	14
	575	252	7

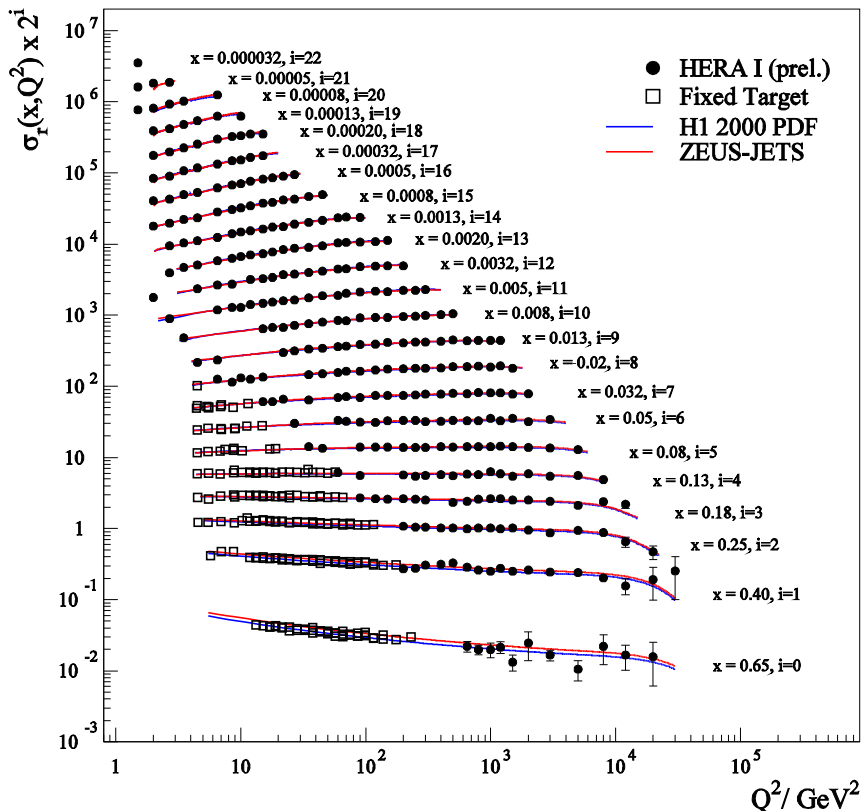


NC cross sections @ HERA

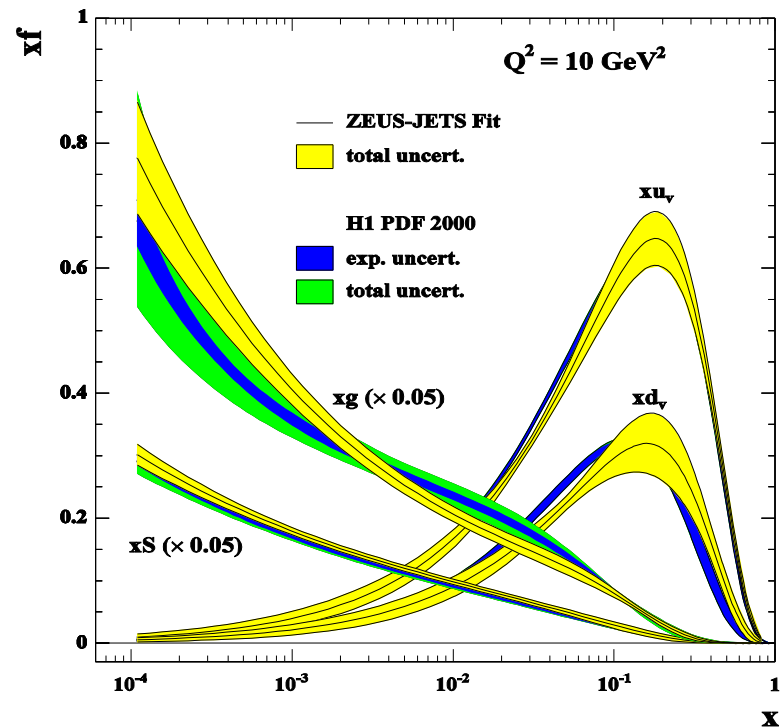
- NLO perturbative QCD describes F_2 in wide range of kinematic space
- still, **differences exist in extracted PDFs**
- largest uncertainties on low x gluon →

Improvement is possible by input from NC cross section measurement at high y and F_L measurement

HERA I e^+p Neutral Current Scattering - H1 and ZEUS



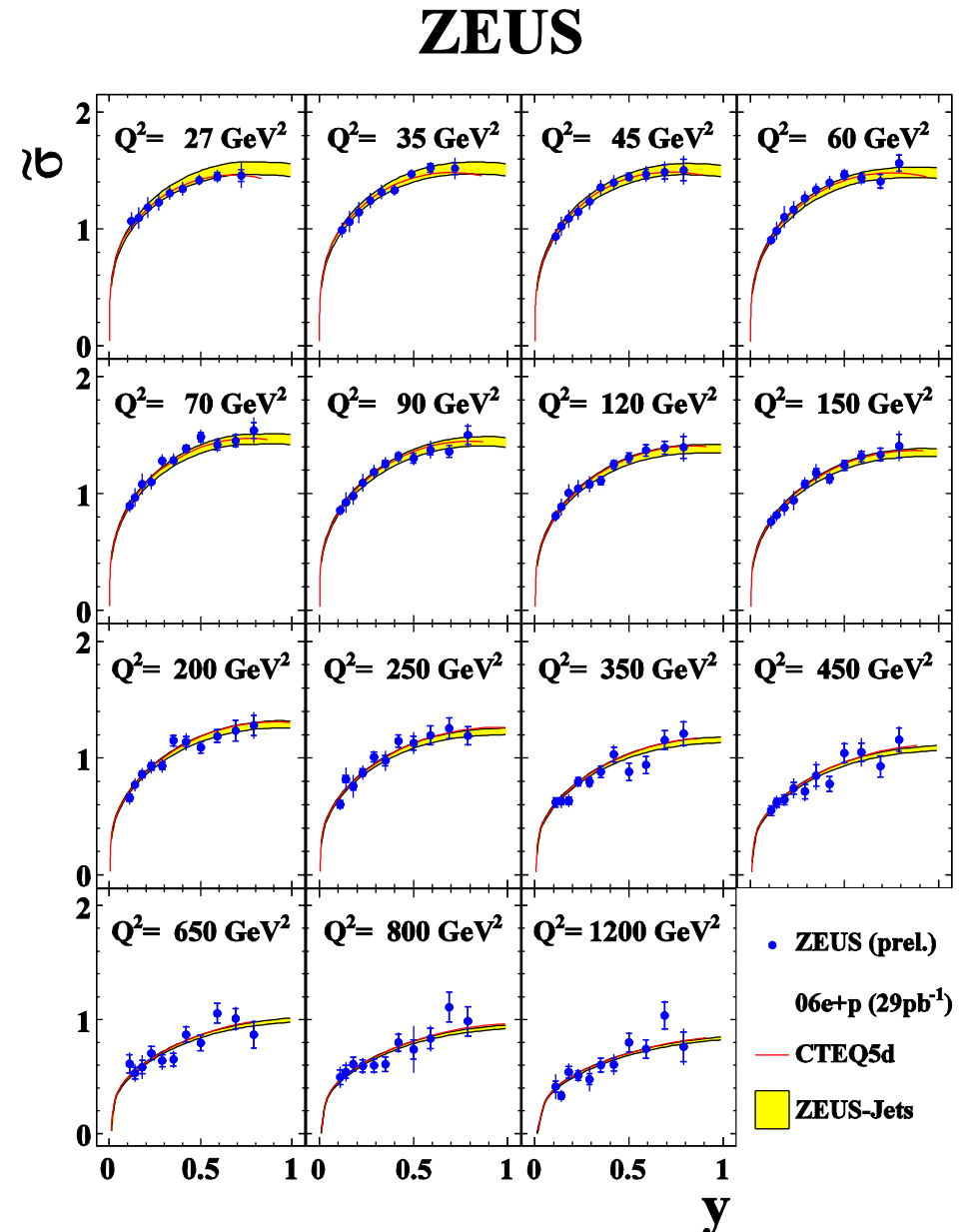
HERA Structure Functions Working Group





Cross section @ high y with ZEUS

- Presented at DIS 2007 in Munich
- cross section measurement was performed at $\sqrt{s} = 318$ GeV in kinematic range
 - $0.1 < y < 0.8$
 - $25 \text{ GeV}^2 < Q^2 < 1300 \text{ GeV}^2$
- extending of previous ZEUS measurements to high y
- **showed that high y measurement is feasible with ZEUS**
 - a necessity for F_L measurement

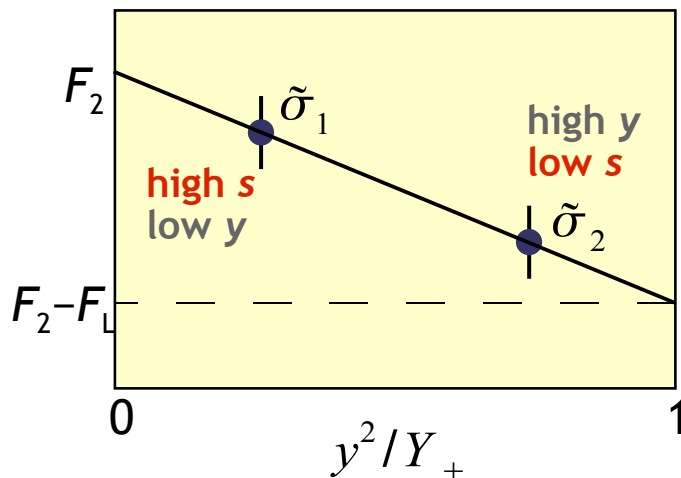




F_L measurement with two beam energies

Reduced cross section: $\tilde{\sigma} = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$

- To separate F_2 and F_L from the cross section one needs to measure the cross section at **the same x and Q^2 but different values of y**
⇒ **different s** (different beam energies)



→
$$F_L(x, Q^2) = \frac{\tilde{\sigma}_1(x, Q^2, y_1) - \tilde{\sigma}_2(x, Q^2, y_2)}{y_2^2/Y_{2+} - y_1^2/Y_{1+}}$$

larger y difference → higher accuracy of F_L measurement
more points (beam energies) →

To allow for direct F_L measurement, at the end of running HERA was operating at two lowered proton beam energies: **460 GeV** & **575 GeV**



F_L measurement with ZEUS

→ Measurement of F_L was performed using two data samples

2006e+ data at $E_p = 920$ GeV ($\sqrt{s} = 318$ GeV) ... 32.8 pb⁻¹

2007e+ data at $E_p = 460$ GeV ($\sqrt{s} = 225$ GeV) ... 14 pb⁻¹

→ To access the same (x, Q^2) region → different regions of measurement in terms of electron variables

Low y / High s ($E_p = 920$ GeV)

→ high energy well separated electron in the calorimeter

→ **no background**

High y / Low s ($E_p = 460$ GeV)

→ **low energy electron** in the calorimeter; lot of hadronic activity

→ electron finding is difficult

→ at low Q^2 **large γp background**, mostly γ 's and π 's faking an electron

→ needs to be subtracted/controlled

Electron method:

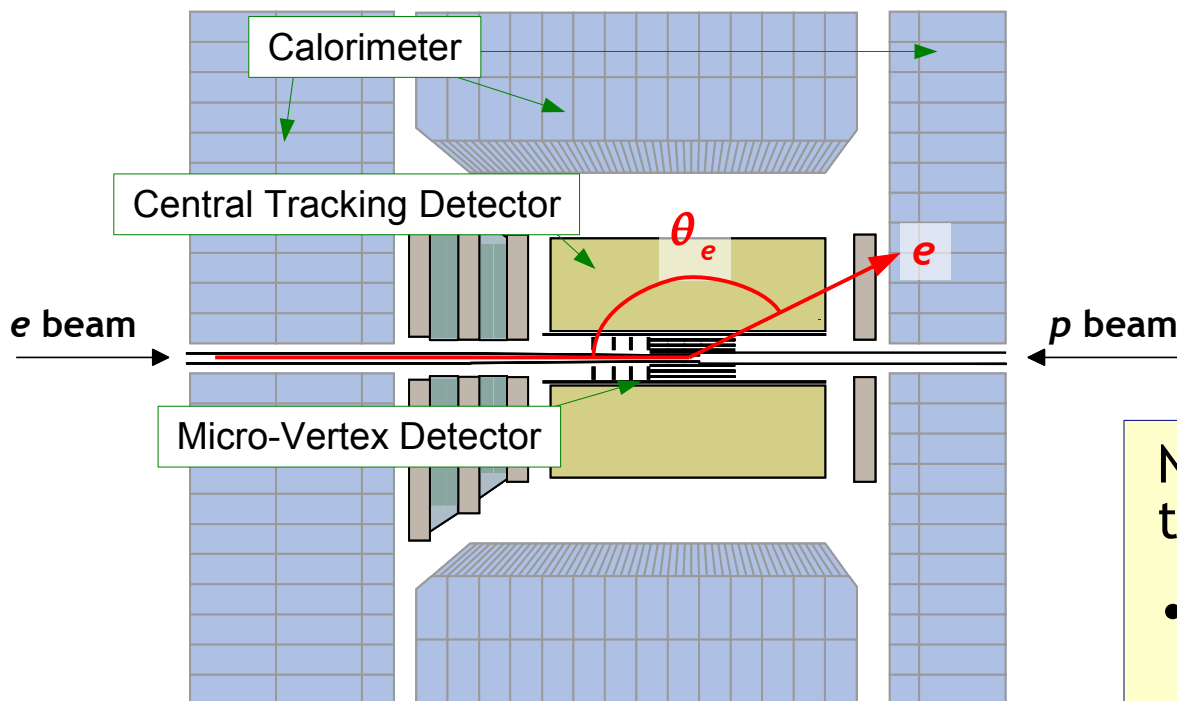
$$y_{el} = 1 - \frac{E_e}{2 E_e^{\text{beam}}} (1 - \cos \theta_e)$$

$$Q_{el}^2 = 2 E_e^{\text{beam}} E_e (1 + \cos \theta_e)$$



Backward tracking

- most of the background faking the DIS electron are photons close to the beam pipe
 - tracking is very important for rejecting these fake candidates
- the acceptance of the ZEUS tracking system is limited in the backward direction - for $\theta_e > 154^\circ$

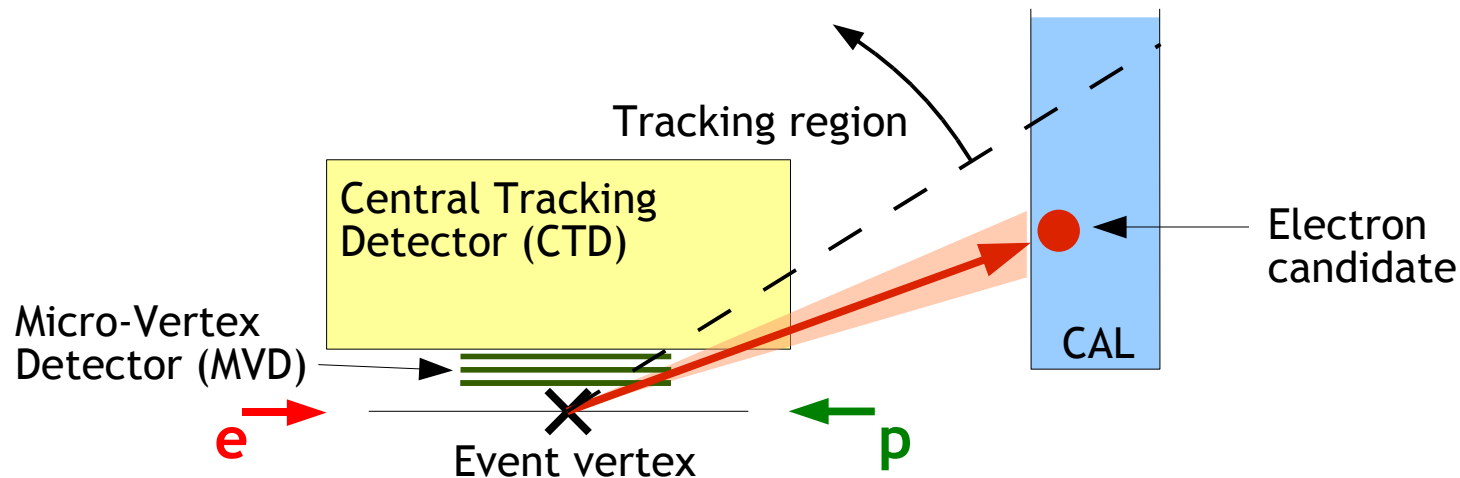


New tool developed to extend tracking region:

- use single hits in the tracking detectors to reject neutral particles



- The idea:**
- create a road from vertex to the electron candidate in the CAL
 - in high y events, vertex is precisely measured
 - charge of the scattered DIS lepton is used
 - hit finding in an area around the road \rightarrow reject if not enough hits



- developed using J/ψ and QEDC samples (clean electrons and photons)
- usable down to $\approx 168^\circ$
- high hit finding efficiency for DIS electrons (comparable to tracking)

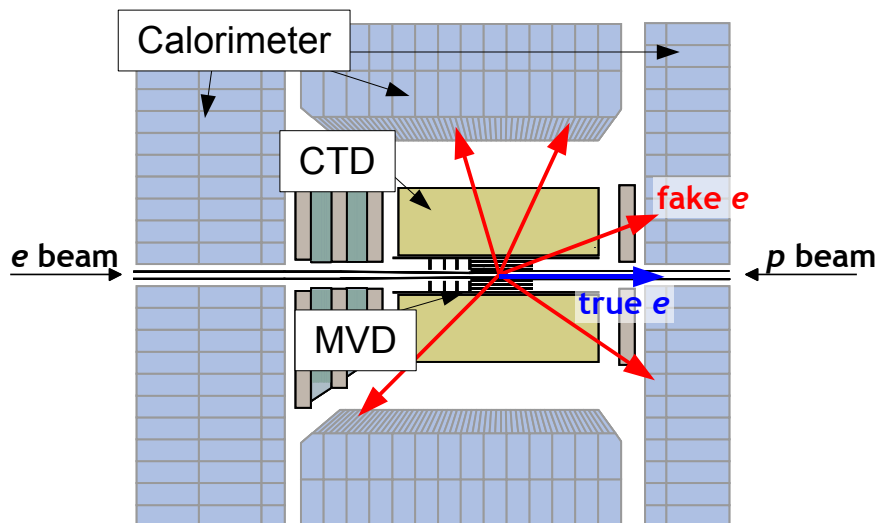


Photoproduction background

- largest contribution to background \Leftarrow large cross section at low Q^2

γp event:

- electron irradiates almost a real photon which then interacts with the proton
- electron with lower energy goes down the beam pipe
- **one of the particles in the detector is misidentified as DIS electron** (mostly γ or π)
- problematic region: low Q^2 events with electron candidate close to the beam pipe



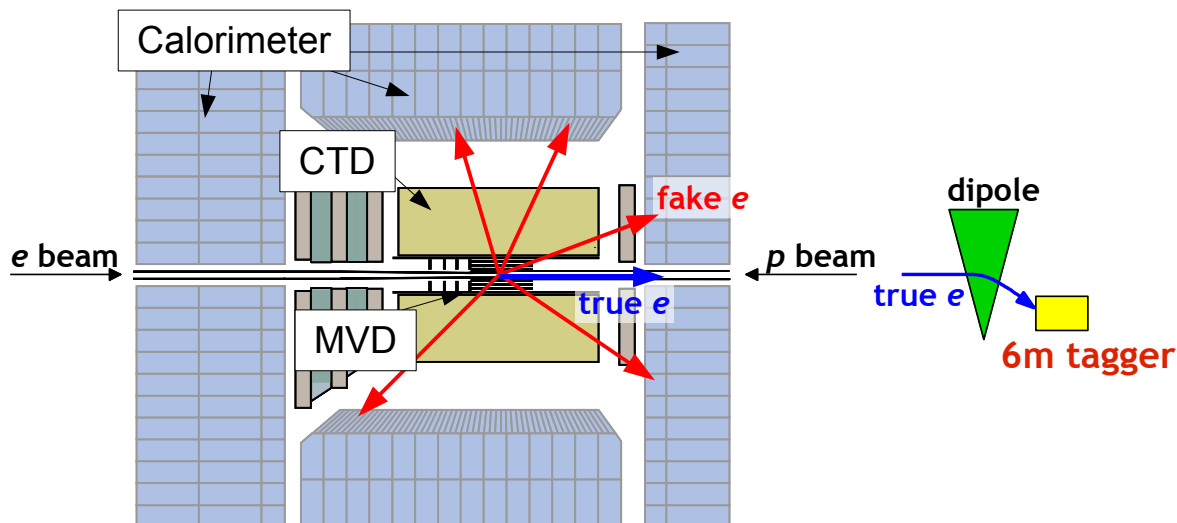


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6m tagger:

- \rightarrow downstream of the electron beam
- \rightarrow detection of low energy electrons in the beam pipe
- \rightarrow allows for direct tagging of γp events

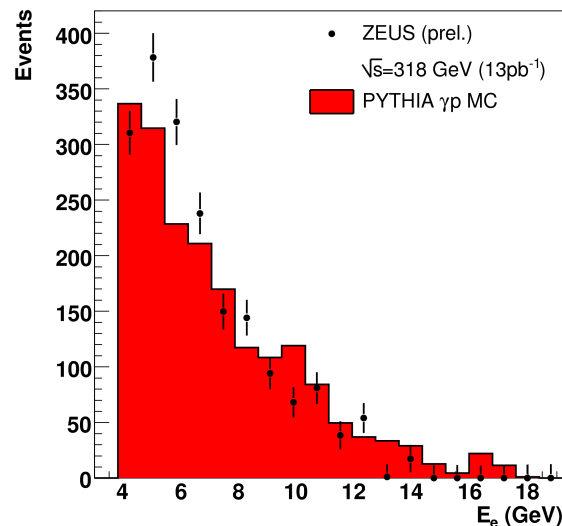


Understanding of γp background

- Photoproduction is **measured** in certain W range using the 6m tagger
- PYTHIA minimum bias γp Monte Carlo well describes the energy distribution of fake electrons in the main detector for tagged events

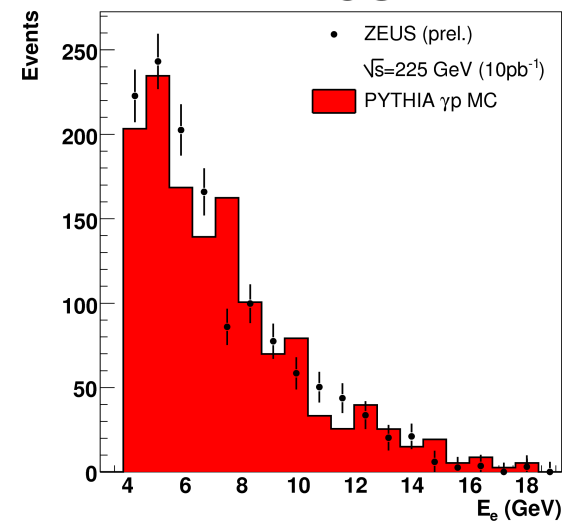
$E_p = 920 \text{ GeV}$

ZEUS



$E_p = 460 \text{ GeV}$

ZEUS



- γp normalization is measured for each beam energy
- Normalization is checked on an independent sample, the so-called “ γp enriched sample”



Data selection

- Identical selection was applied on both samples
- Scattered electrons were selected with energy down to 4 GeV
- Hit finding was applied for all electrons (θ_e above $\approx 168^\circ$)
- $|Z_{\text{vtx}}| < 30$ cm
- $42 \text{ GeV} < \Sigma(E-p_z) < 65 \text{ GeV}$

In DIS, $\Sigma(E-p_z) \sim 2E_e^{\text{beam}}$

DIS MC sample

- **Generated with $F_L = 0$** to avoid possible bias from F_L prediction

Systematic checks

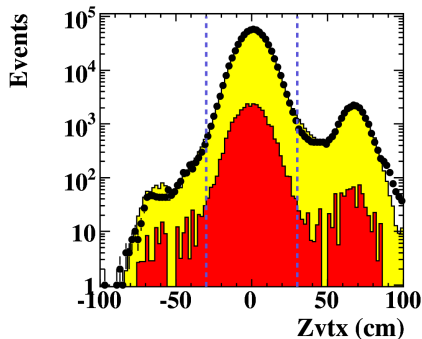
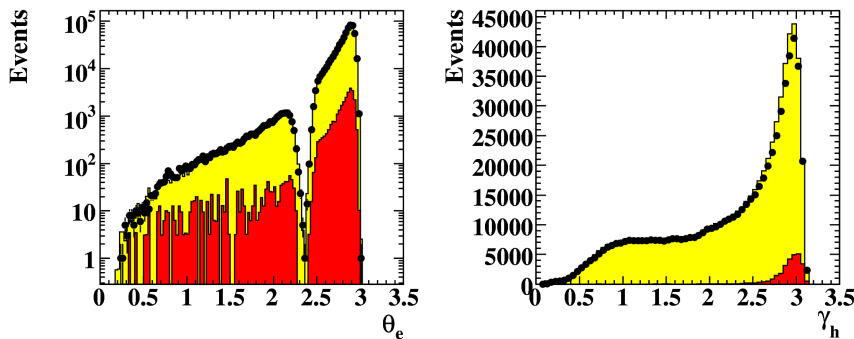
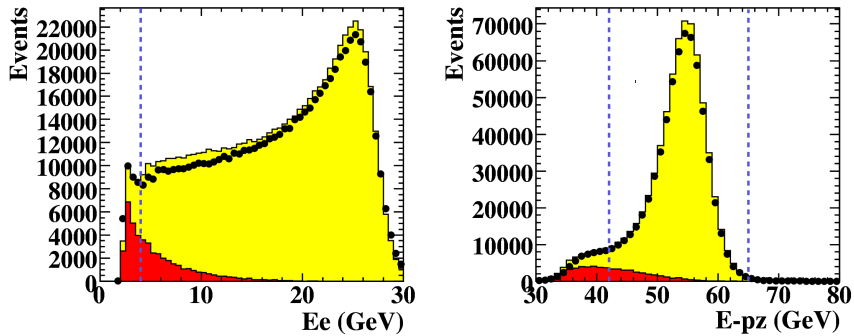
- energy scale, electron finding, γp normalization, uncorrelated luminosity, relative normalization between the two datasets, position reconstruction, $Z_{\text{vtx}}, \Sigma(E-p_z)$



Control distributions

$E_p = 920 \text{ GeV}$

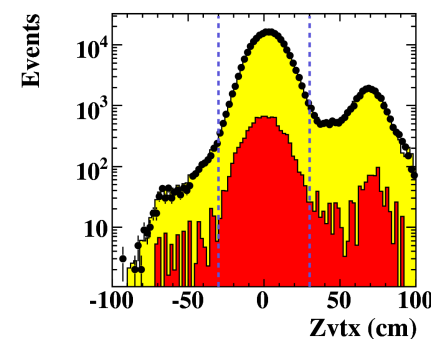
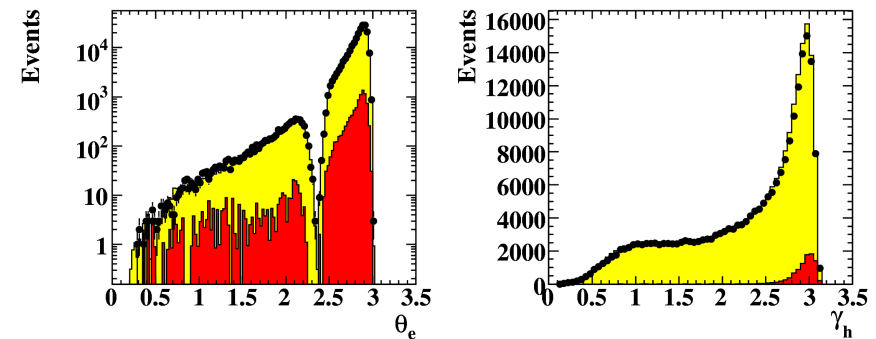
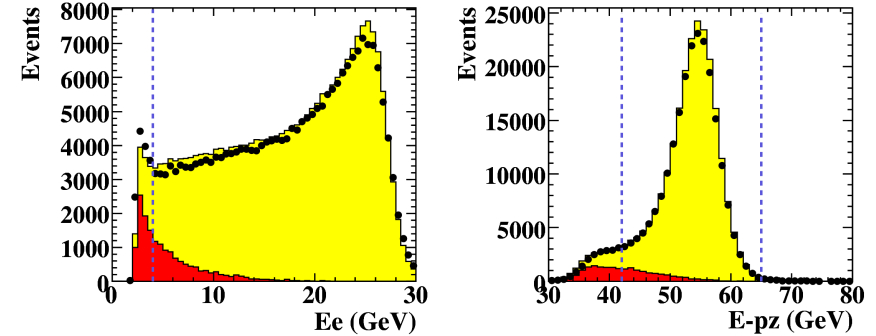
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- ZEUS (prel.)
- $\sqrt{s}=318 \text{ GeV} (33\text{pb}^{-1})$
- MC DIS ($F_L=0$) + γp
- MC γp

$E_p = 460 \text{ GeV}$

ZEUS

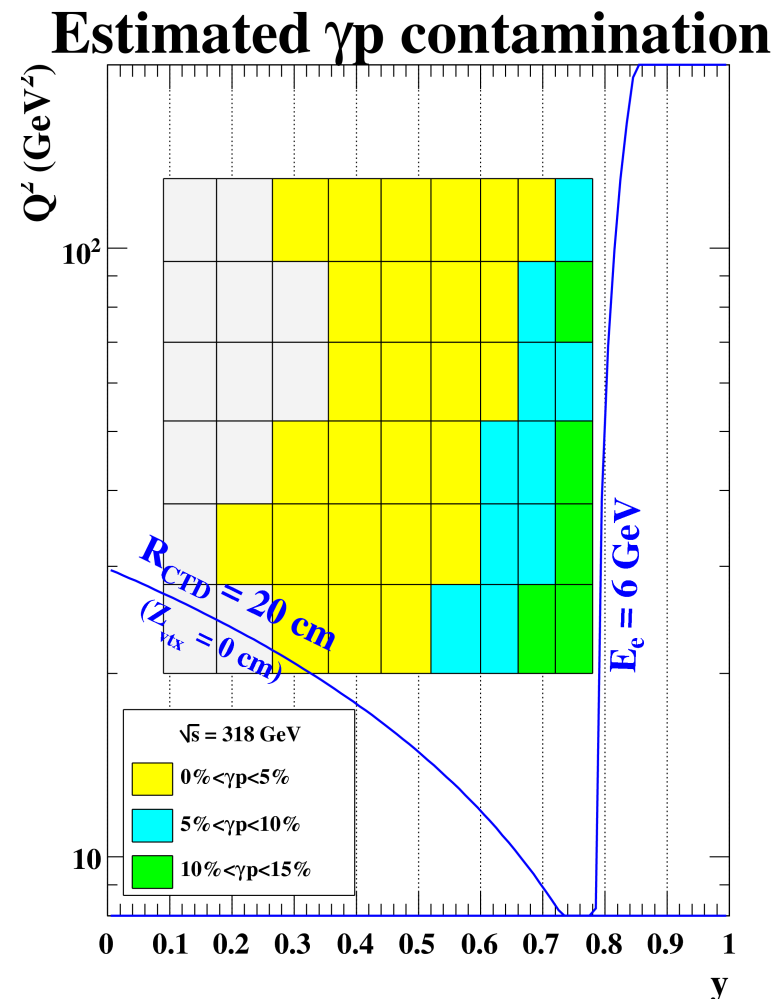
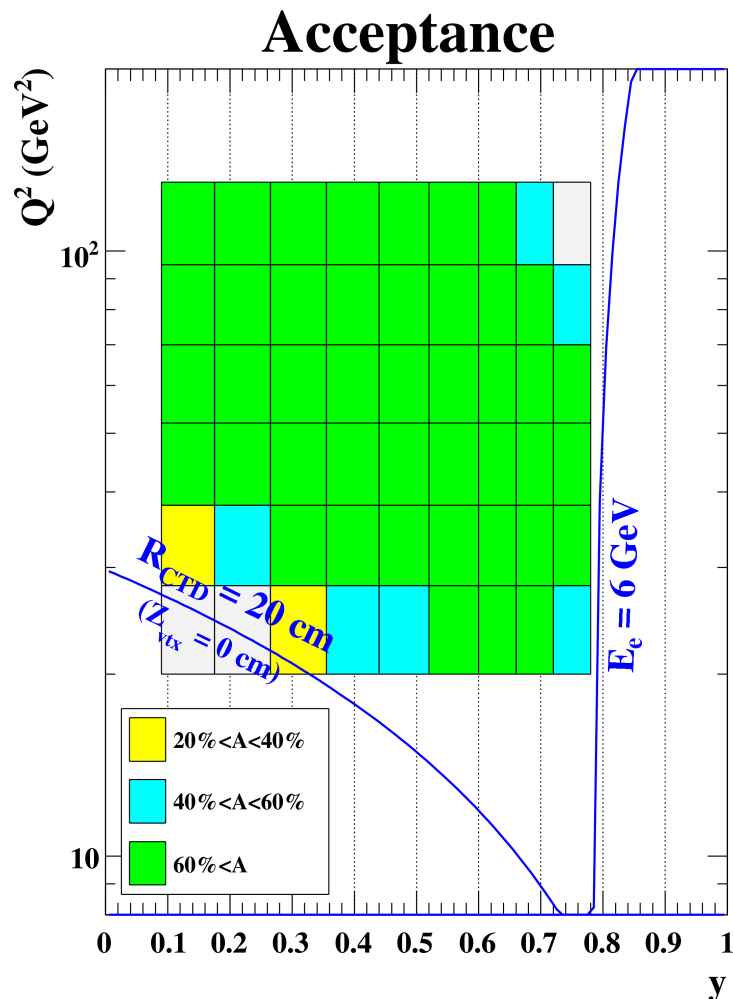


- ZEUS (prel.)
- $\sqrt{s}=225 \text{ GeV} (14\text{pb}^{-1})$
- MC DIS ($F_L=0$) + γp
- MC γp



Bins for cross section measurement

- Bin definition was driven by the resolution
- Bins are identical in (y, Q^2) between the two data sets
- Similar values of acceptance and γp contamination for the two data sets



Bins start above
 $E_e = 6$ GeV

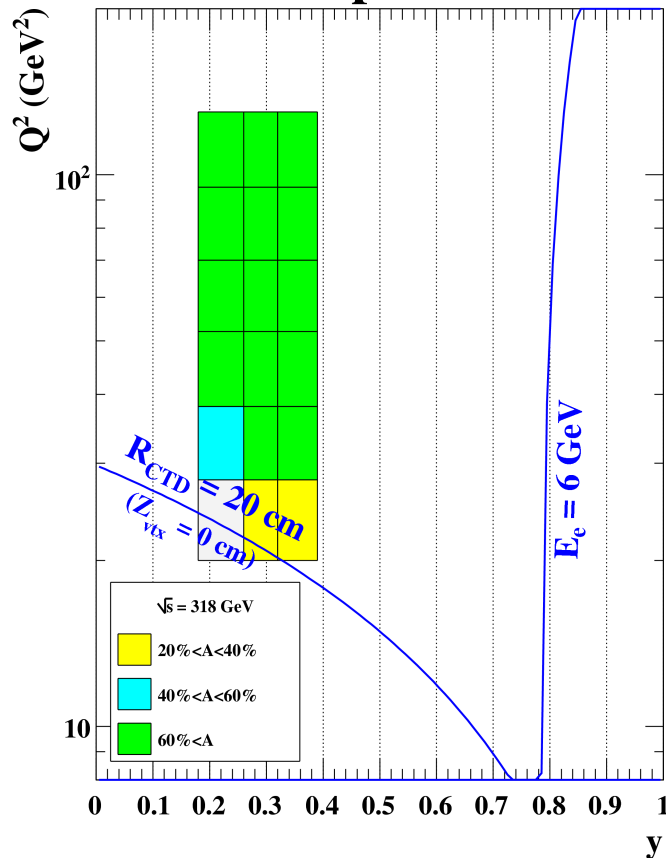


Bins for F_L measurement - Acceptance

- Bin definition was driven by the resolution at low y in high s sample ($E_p = 920$ GeV) and the statistics
- Bins are identical in (x, Q^2)

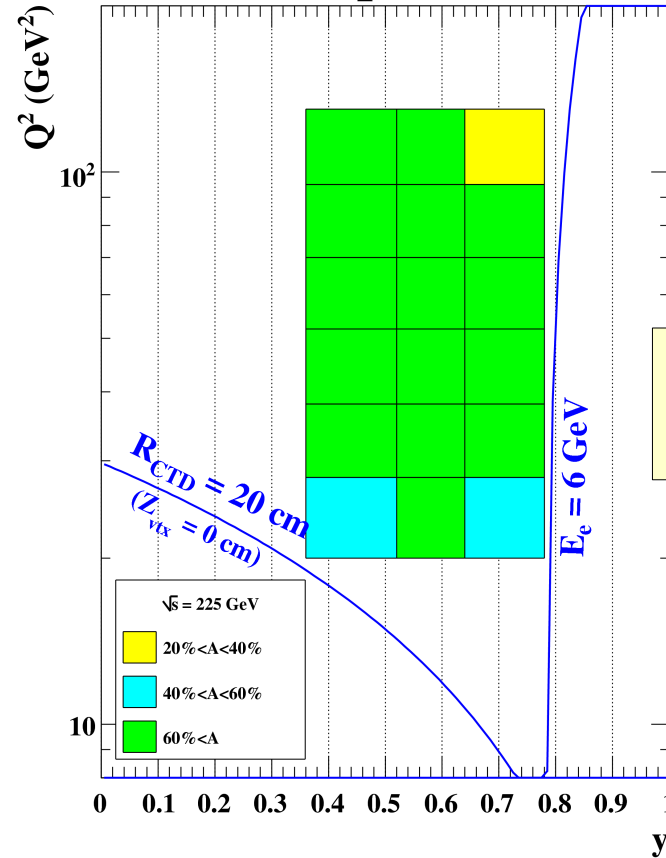
$E_p = 920$ GeV

Acceptance



$E_p = 460$ GeV

Acceptance



Bins start above
 $E_e = 6$ GeV



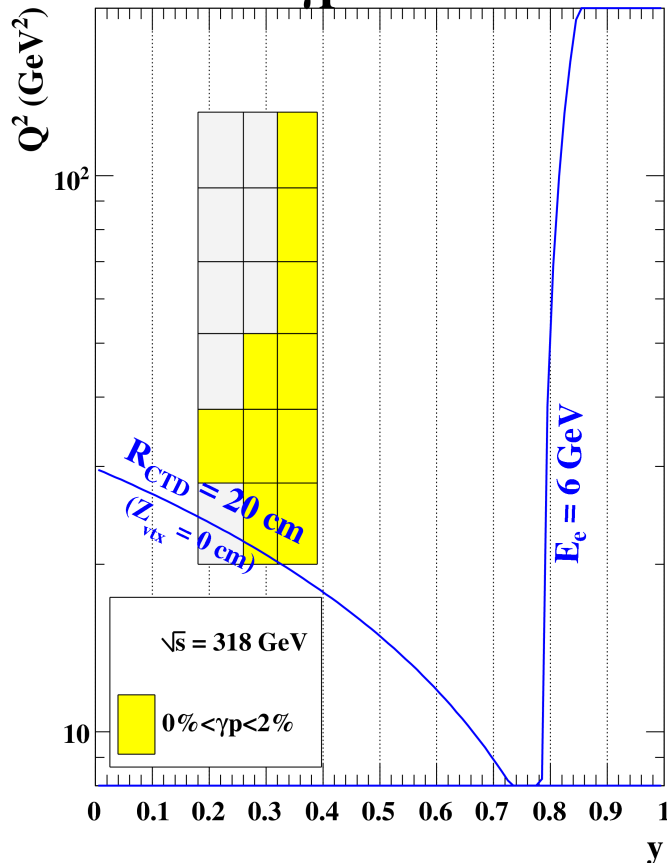
Bins for F_L measurement - γp contamination

- Bins defined to start from $E_e = 6$ GeV
- γp background only entering the sample at high y

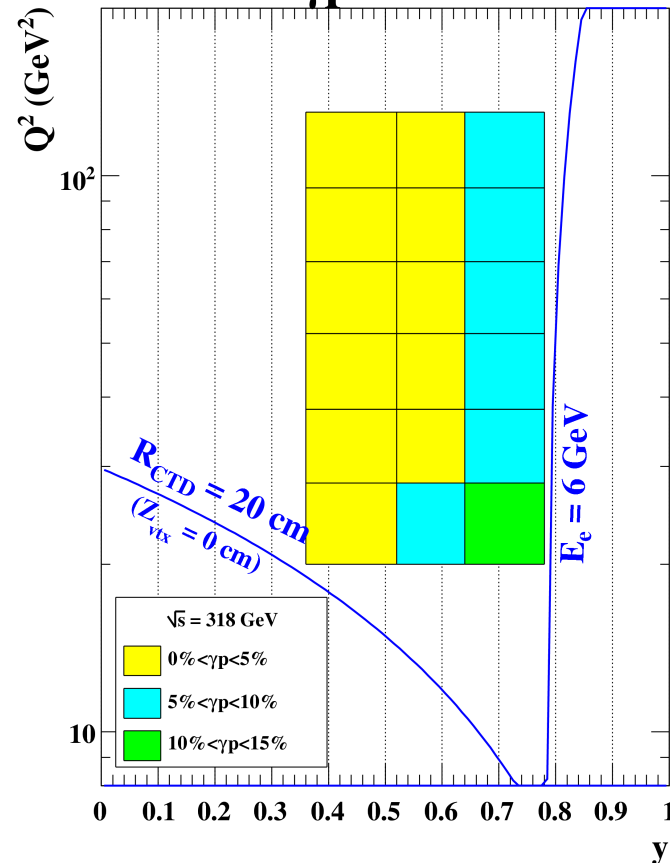
$E_p = 920$ GeV

$E_p = 460$ GeV

Estimated γp contamination



Estimated γp contamination



Bins start above
 $E_e = 6$ GeV

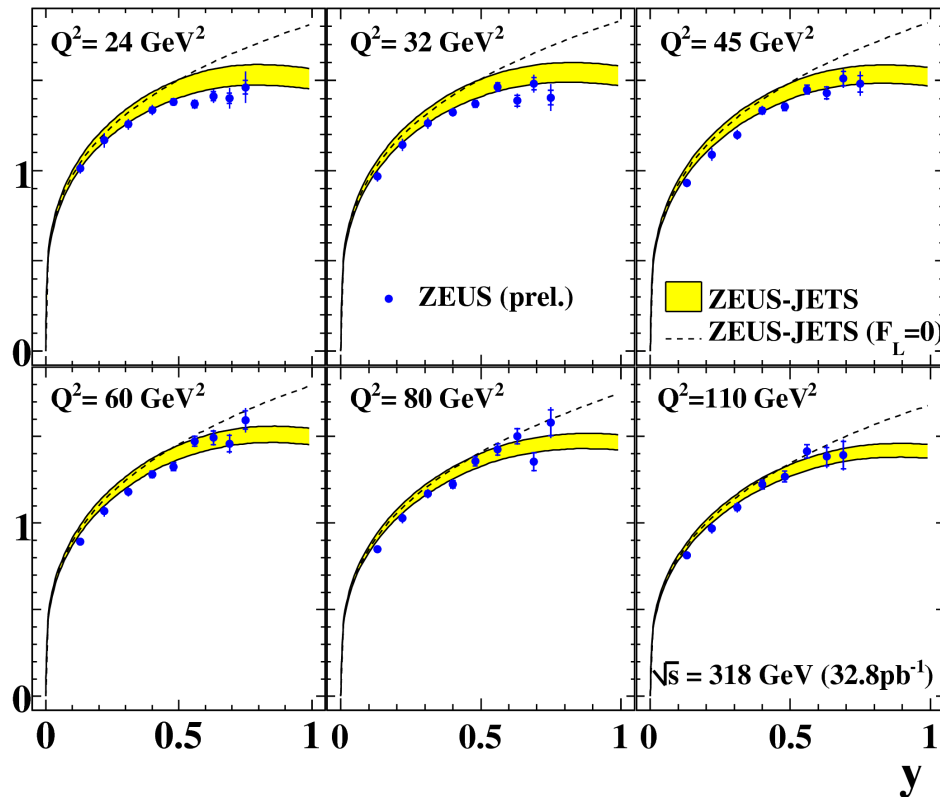


Reduced cross sections vs. y

- Measured reduced cross sections in bins of Q^2 at two beam energies compared to ZEUS-Jets prediction with and without F_L

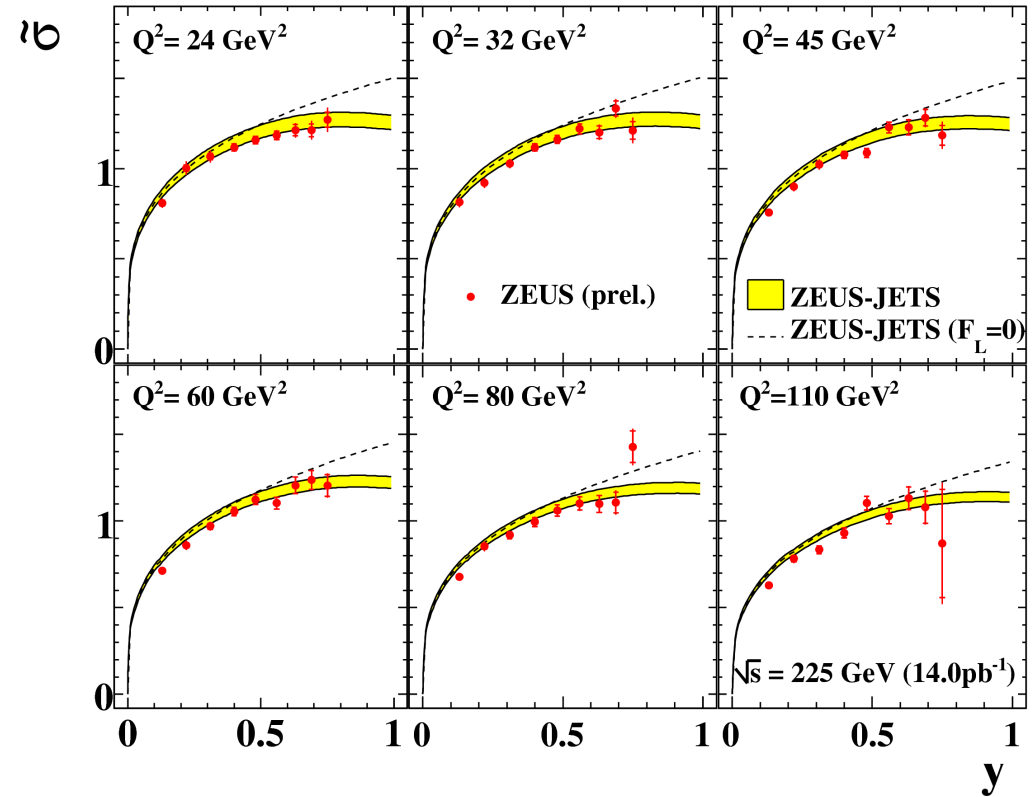
$E_p = 920 \text{ GeV}$

ZEUS



$E_p = 460 \text{ GeV}$

ZEUS

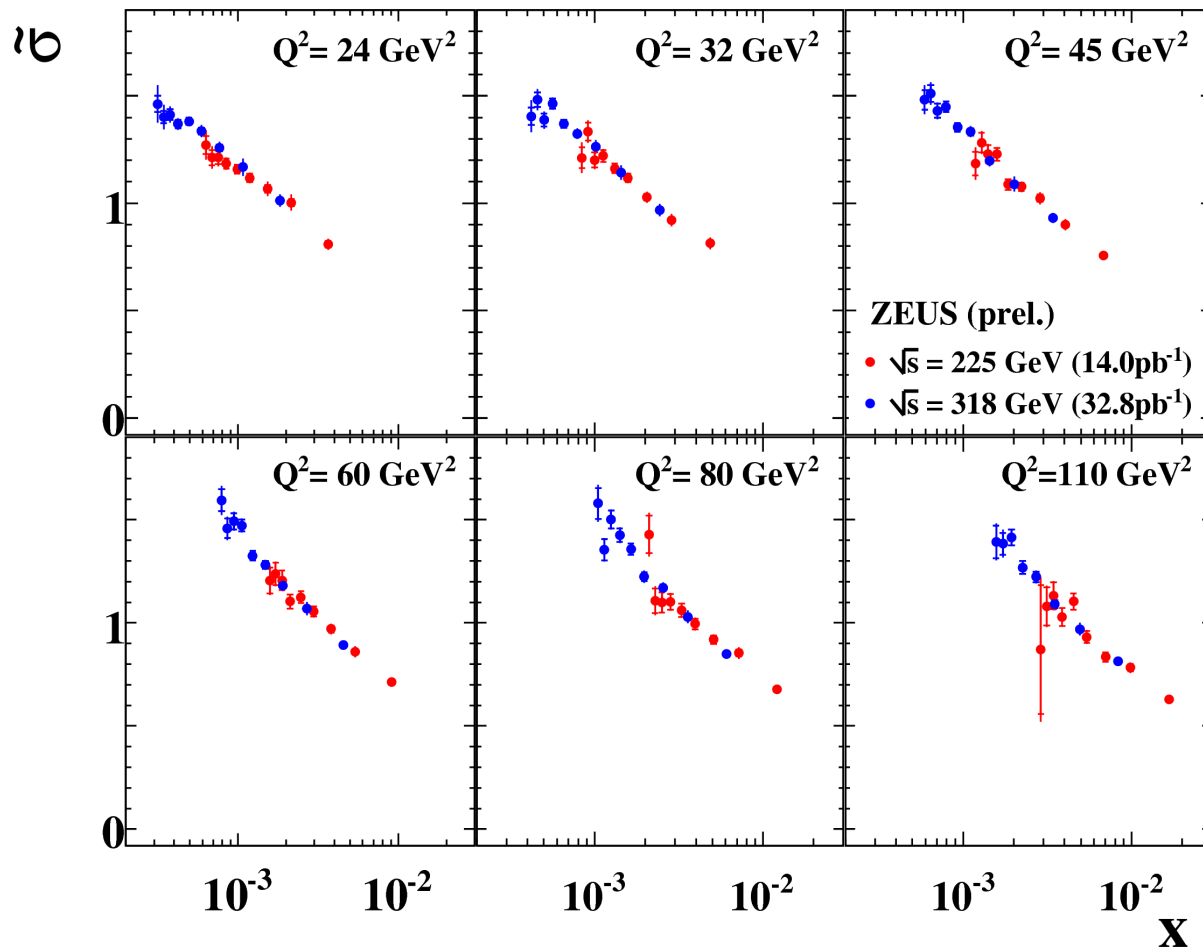




Reduced cross sections vs. x

- Difference in cross sections between the two data sets at the same $x, Q^2 \rightarrow F_L?$

ZEUS

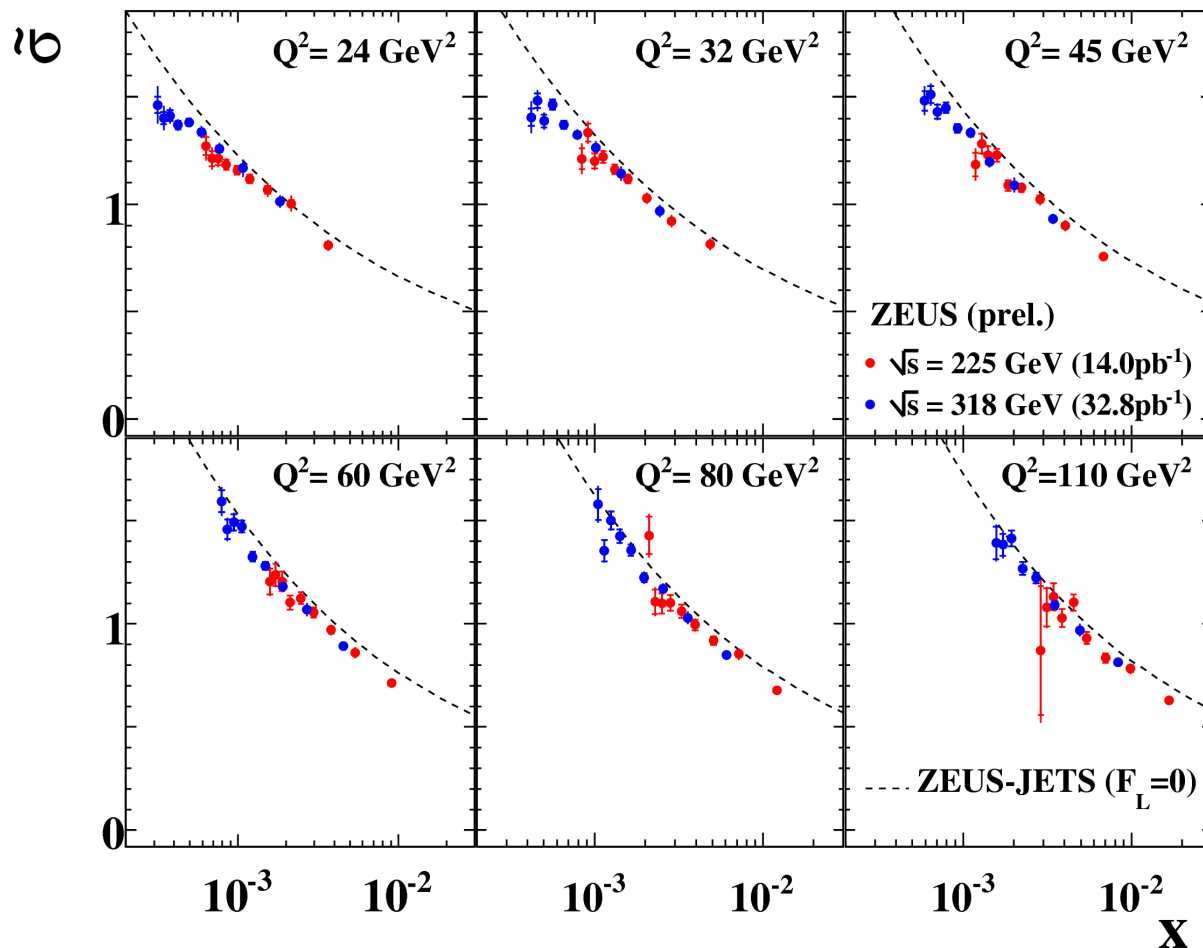




Reduced cross sections vs. x

- Difference in cross sections between the two data sets at the same $x, Q^2 \rightarrow F_L$?

ZEUS



Turnover at lowest x ?

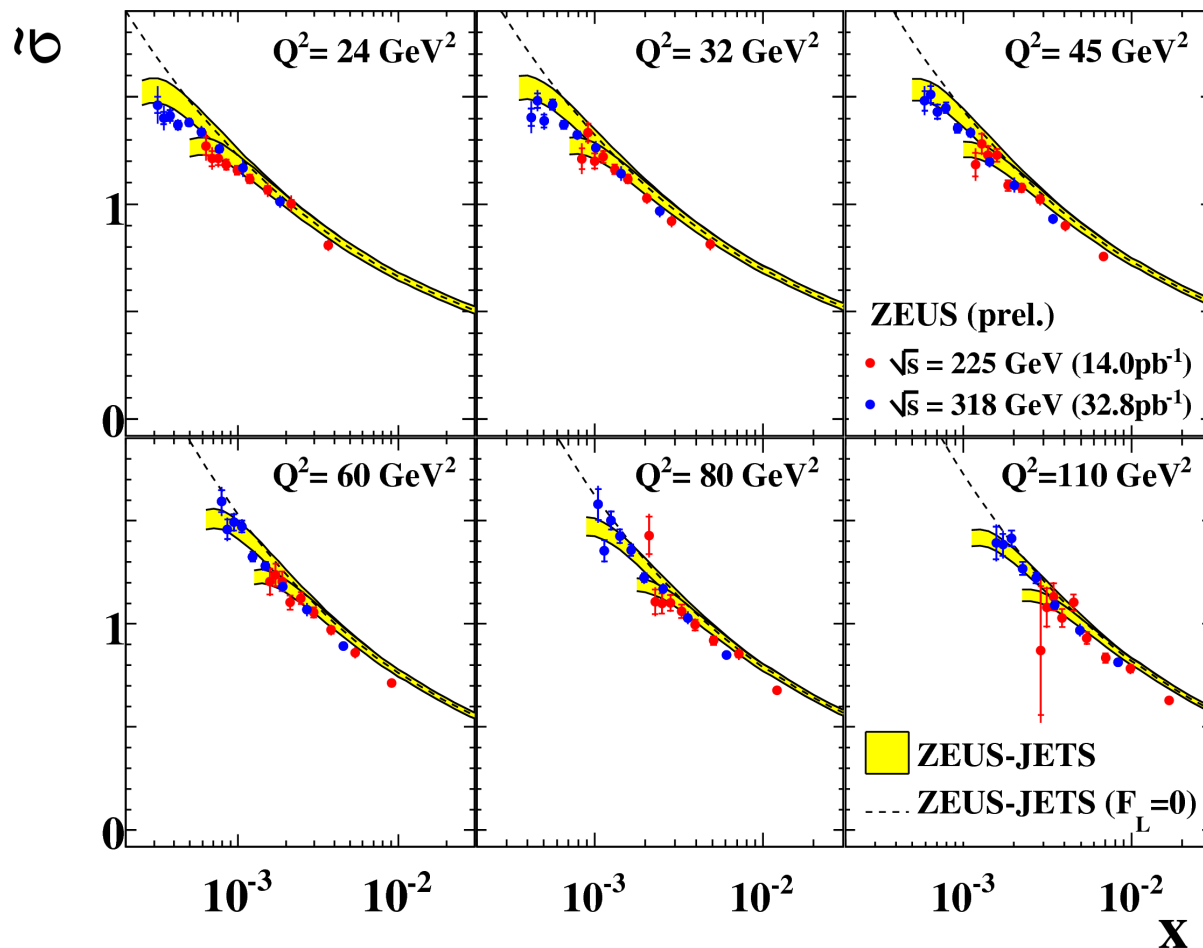
- Cross sections are below predictions also at low y (high x)



Reduced cross sections vs. x

- Difference in cross sections between the two data sets at the same $x, Q^2 \rightarrow F_L$?

ZEUS

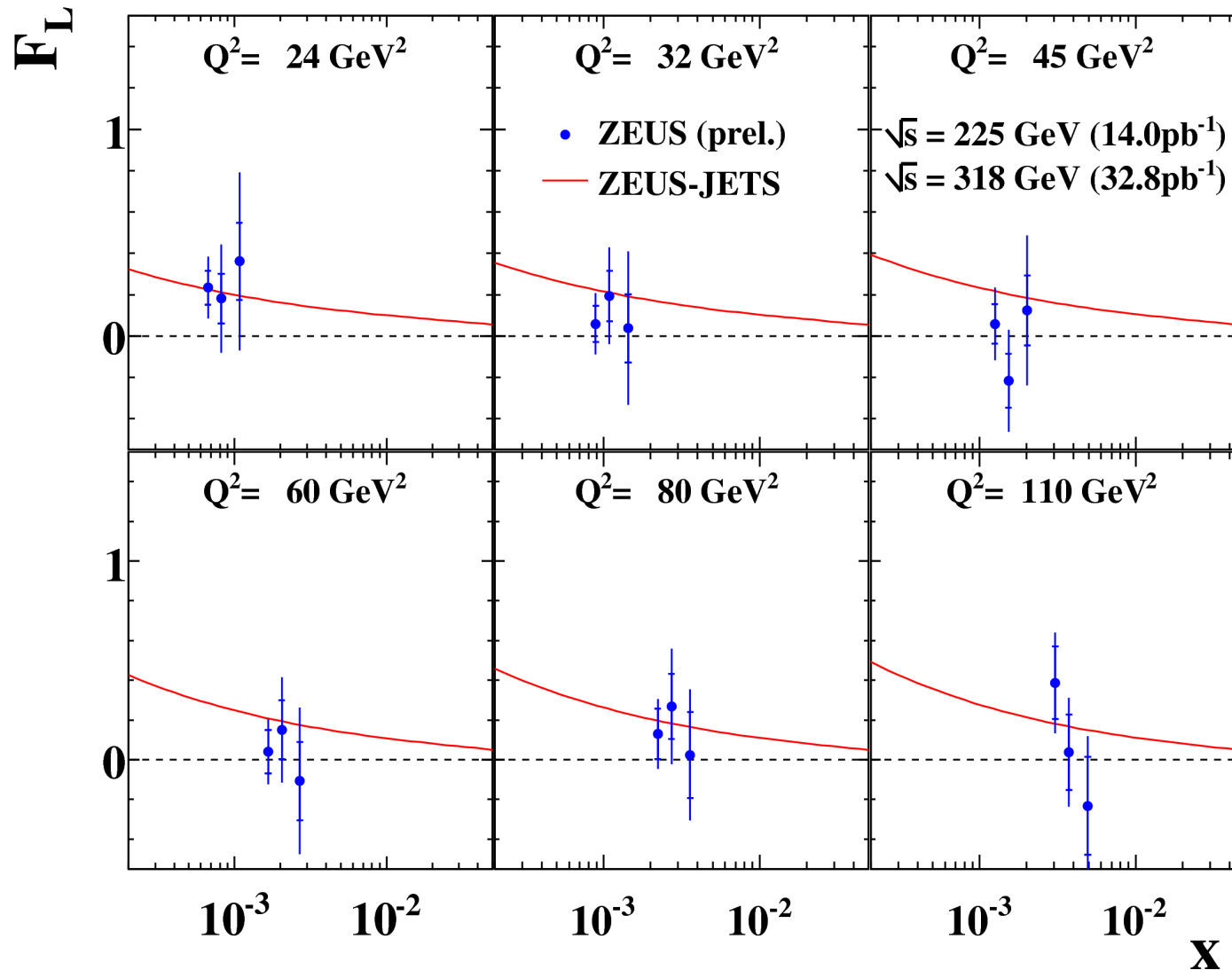


Turnover at lowest x ?

- Measurement at higher y is necessary
- Cross sections are below predictions also at low y (high x)
- Low y (high x) cross sections consistent between the two data sets



ZEUS



Large uncertainties

↪ measurement consistent with ZEUS-Jets F_L prediction as well as with $F_L=0$



- **ZEUS has performed a direct measurement of F_L with data taken at two proton beam energies**
 - $E_p = 920 \text{ GeV}$ & $E_p = 460 \text{ GeV}$
 - The measurement covers medium Q^2 range 24 GeV^2 to 110 GeV^2
 - Measured F_L values are consistent with ZEUS-Jets prediction as well as with $F_L=0$

- **Lot of room for improvement**
 - Extend measurement to higher y (more sensitivity to F_L)
 - Include $E_p = 575 \text{ GeV}$ dataset