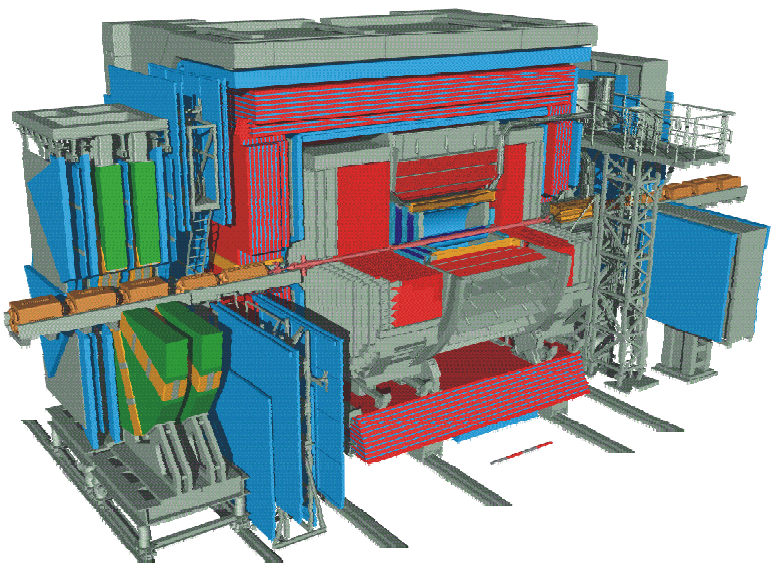
Measurement of the longitudinal structure function F_L at HERA with the ZEUS detector



Daniel Kollár

Max-Planck-Institut für Physik, München

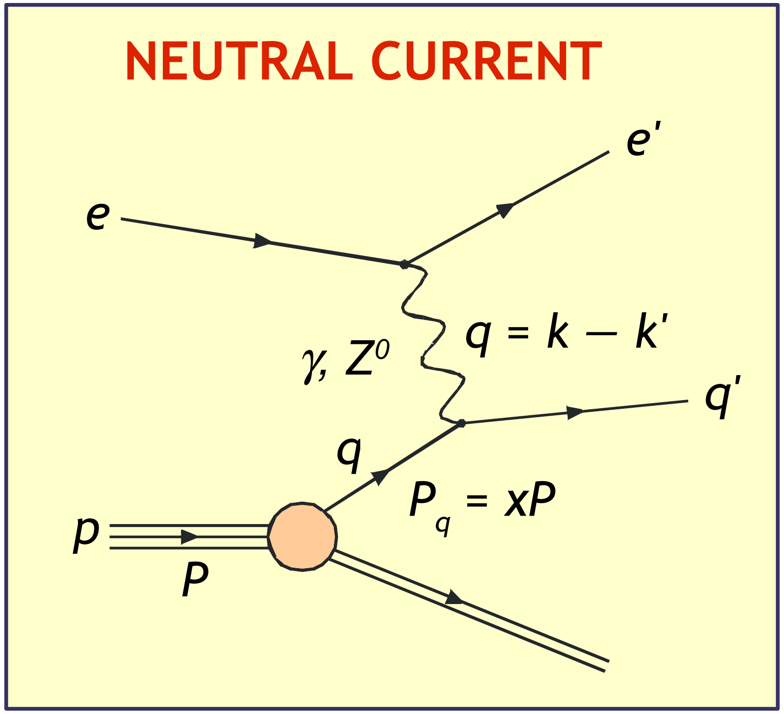
On behalf of ZEUS Collaboration

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)**

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

(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

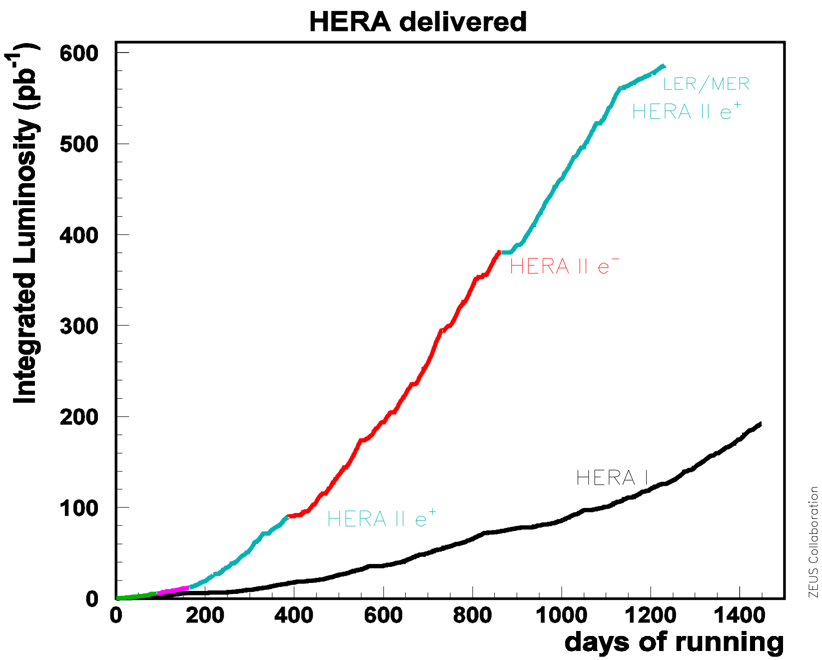
– non-zero in NLO pQCD:

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

Direct sensitivity to gluon

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

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

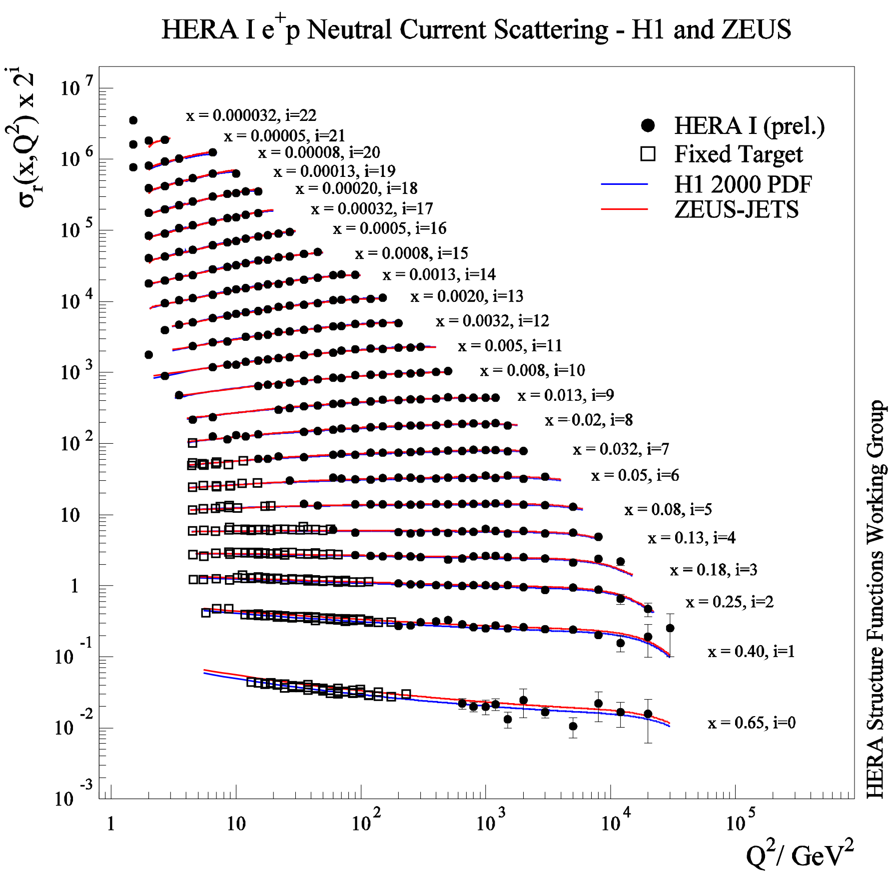


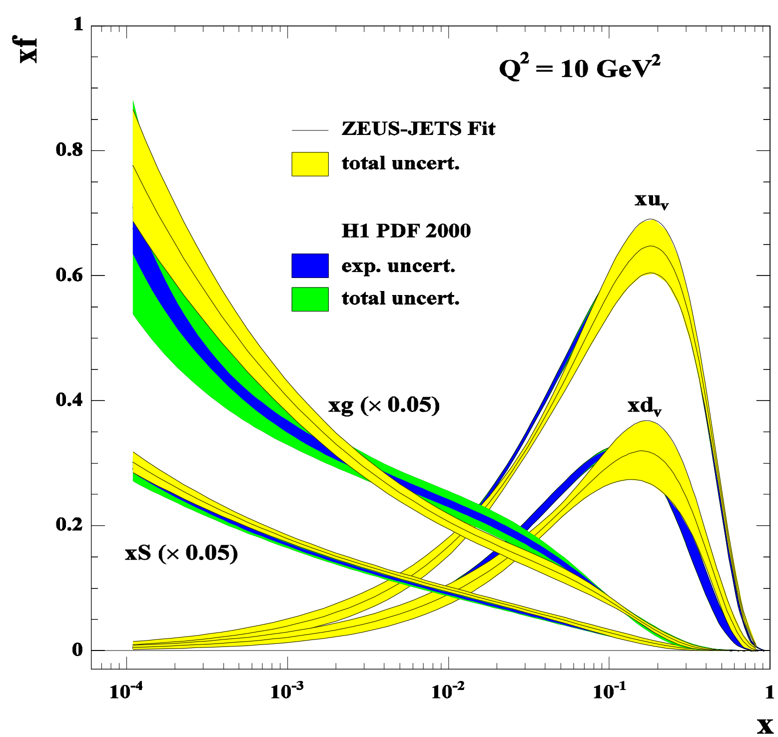
- ➔ in operation since 1992
- ➔ **HERA running ended June 30, 2007**
- ➔ four different CM energies
- ➔ total delivered lumi is 780 pb^{-1}

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

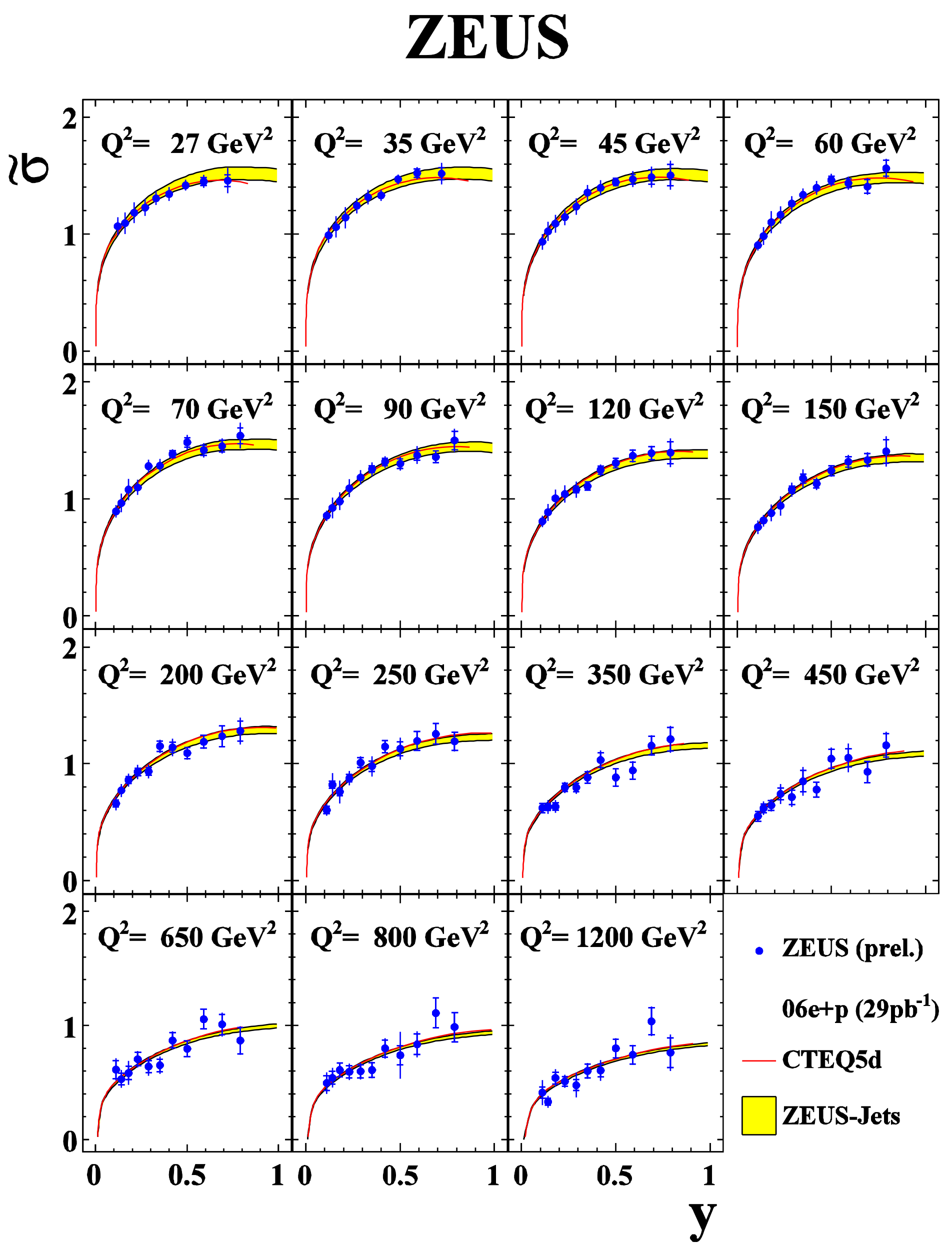
- ➔ NLO perturbative QCD describes F_2 in wide range of kinematic space
- ➔ still, **differences exist in extracted PDFs**
- ➔ largest uncertainties on low ***x*** gluon → Improvement is possible by input from NC cross section measurement at high ***y*** and F_L measurement





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
  - $\rightarrow 0.1 < y < 0.8$
  - $\rightarrow 25\ \mathrm{GeV}^2 < Q^2 < 1300\ \mathrm{GeV}^2$
- extending of previous ZEUS measurements to high ***y***
- showed that high ***y*** measurement is feasible with ZEUS
  — a necessity for F_L measurement

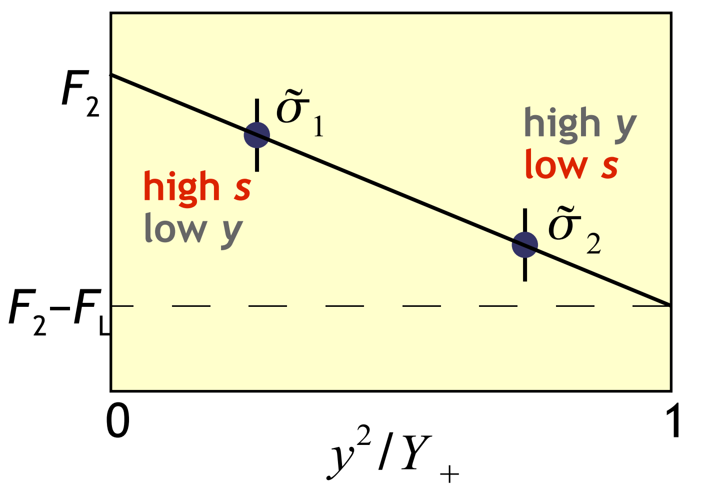


F_L measurement with two beam energies

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) → **higher accuracy of F_L measurement**

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)

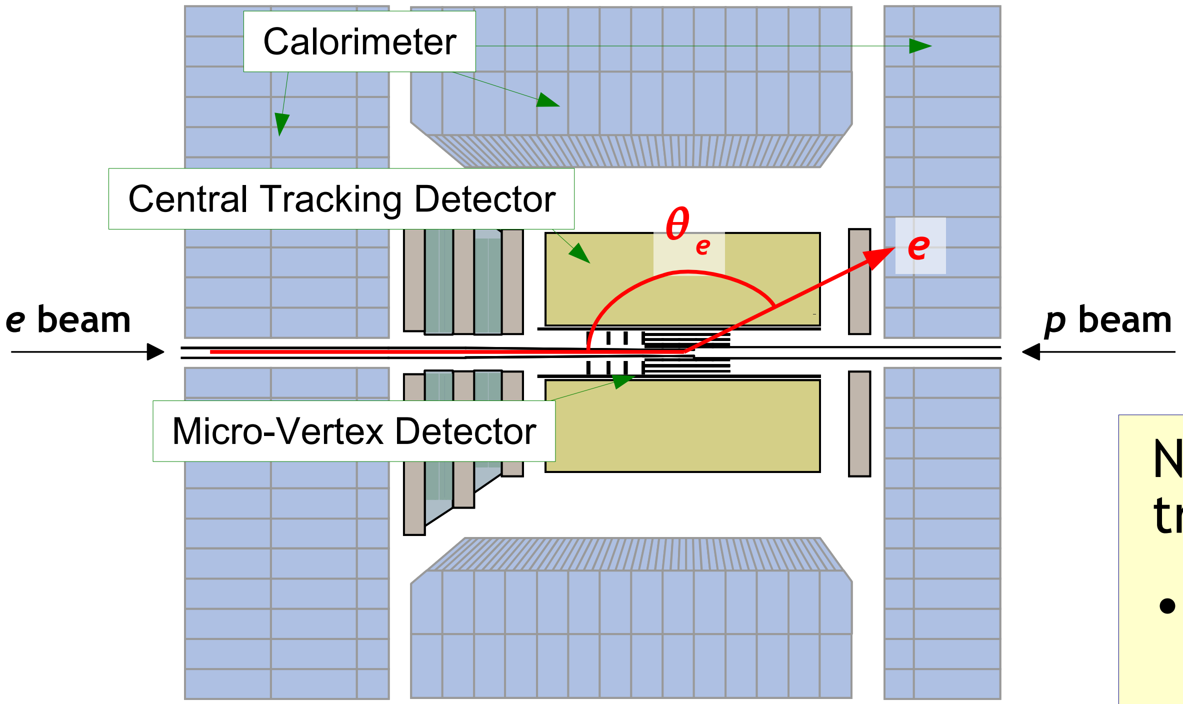
- → low energy electron in the calorimeter; lot of hadronic activity
  - → electron finding is difficult
- → at low Q^2 large γp background, mostly γ's and π's faking an electron
  - → needs to be subtracted/controlled

Electron method:

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

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

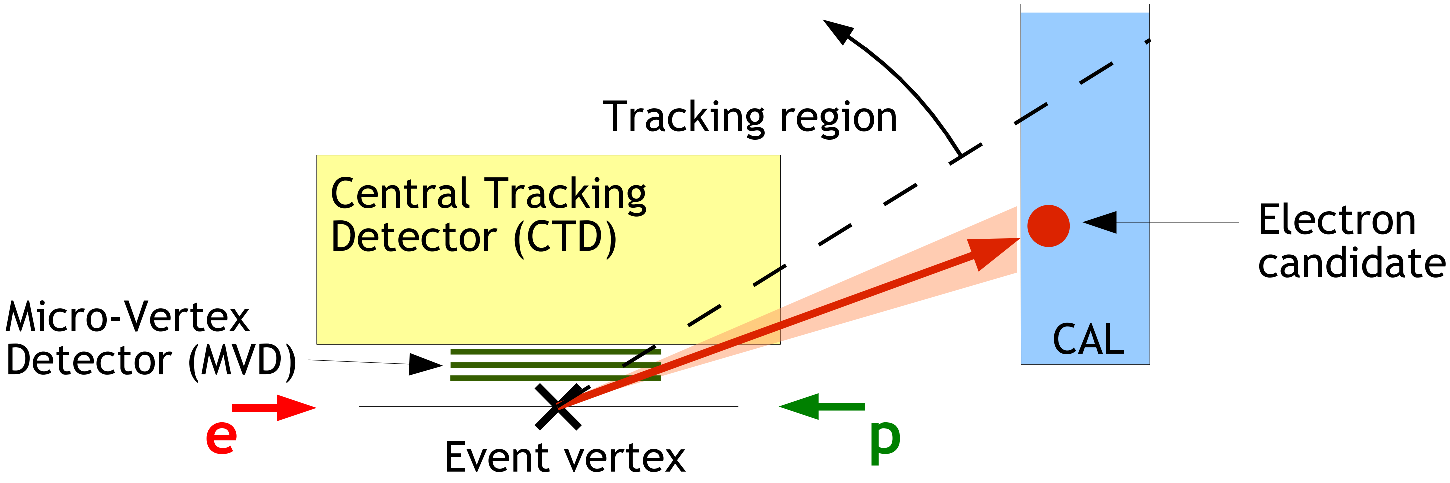
- most of the background faking the DIS electron are photons close to the beam pipe
  - → tracking is very important for rejecting these fake candidates
- the acceptance of the ZEUS tracking system is limited in the backward direction - for $\theta_e > 154°$



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 → reject if not enough hits



- developed using J/ψ and QEDC samples (clean electrons and photons)
- usable down to ≈ 168°
- high hit finding efficiency for DIS electrons (comparable to tracking)

Photoproduction background

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

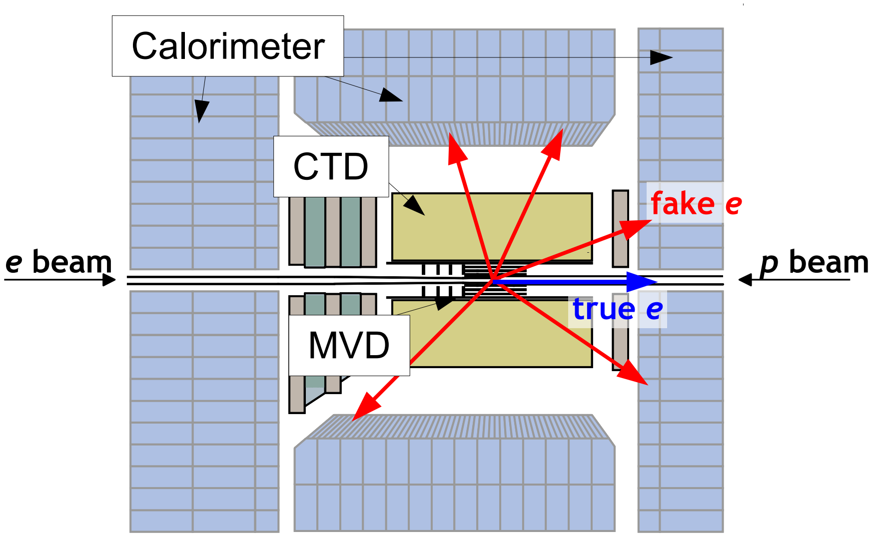
γp event:

→ 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)

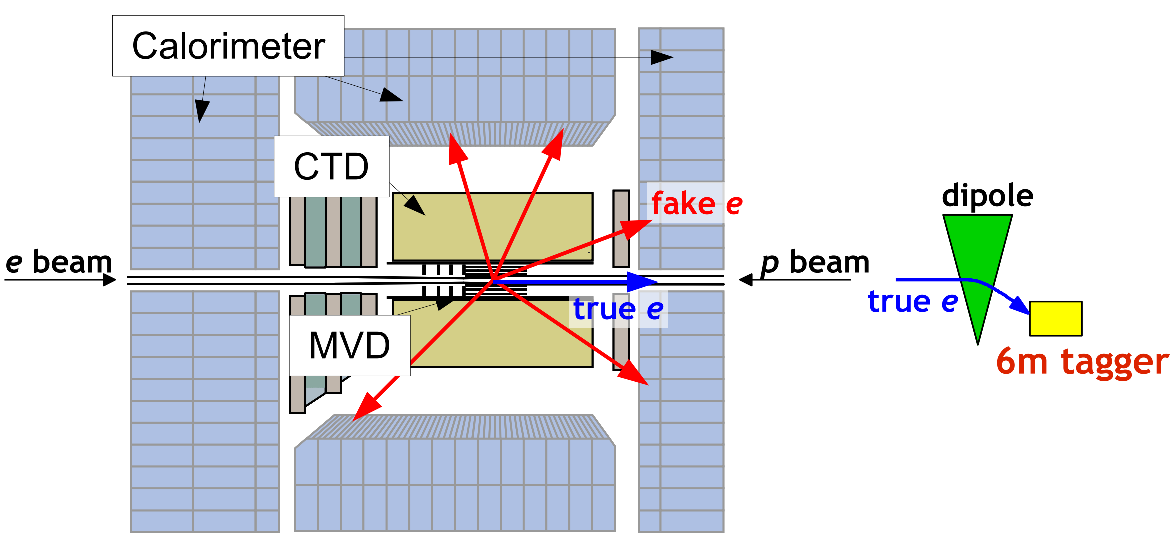
→ problematic region: low Q^2 events with electron candidate close to the beam pipe



- 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



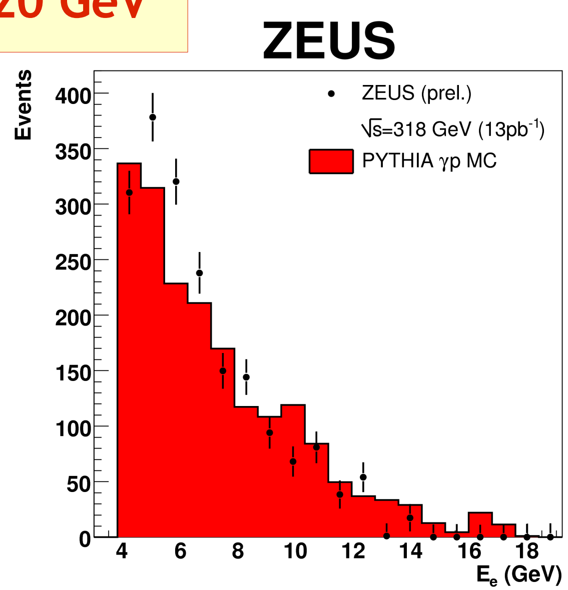
6m tagger:

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

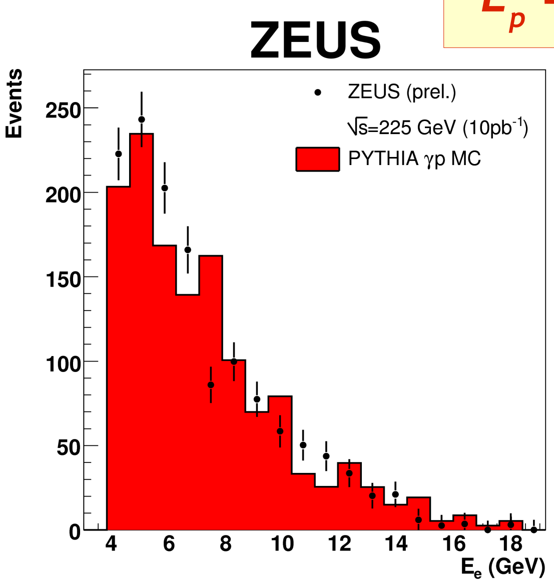
➔ Photoproduction is **measured** in certain *W* range using the 6m tagger

➔ PYTHIA minimum bias γp Monte Carlo well describes the energy distribution of fake electrons in the main detector for tagged events

E_p = 920 GeV



E_p = 460 GeV



➔ 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°)
- $|Z_{vtx}| < 30$ cm
- 42 GeV < $\Sigma(E-p_z)$ < 65 GeV

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

DIS MC sample

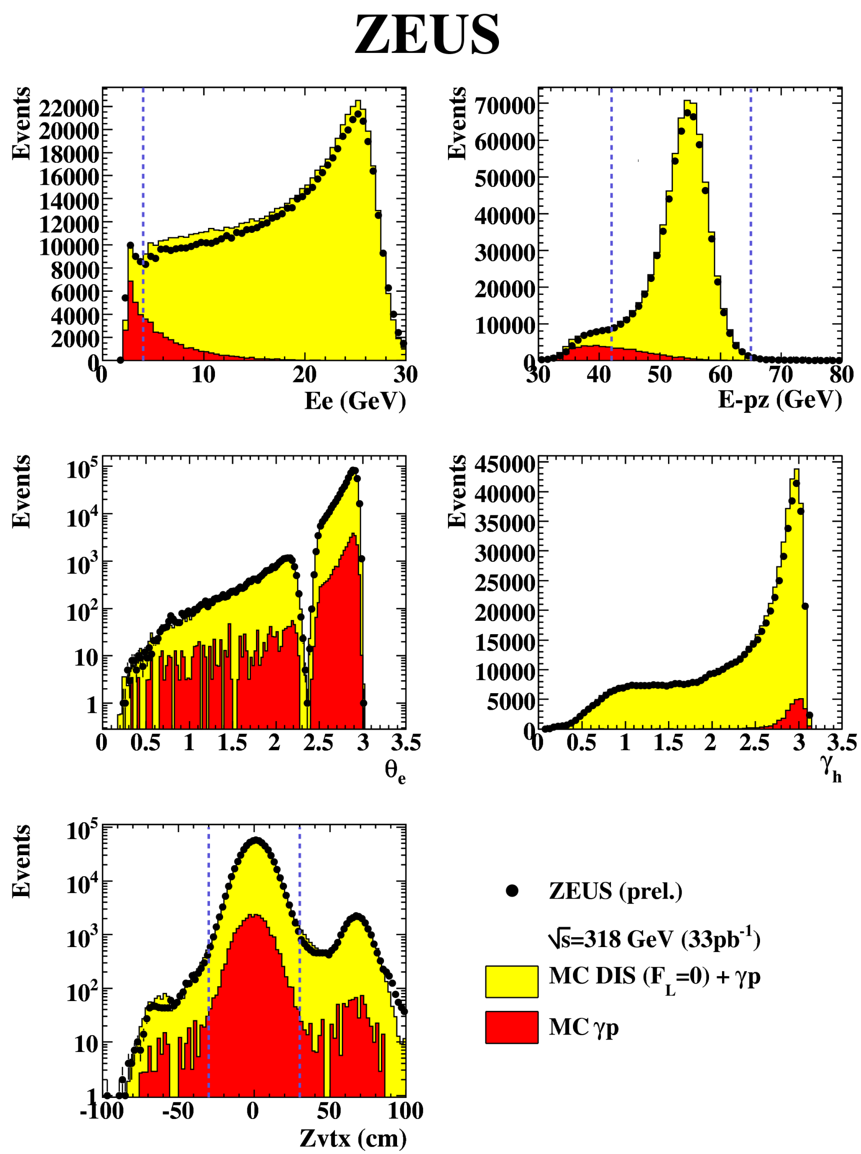
- Generated with $F_L = 0$ to avoid possible bias from F_L prediction

Systematic checks

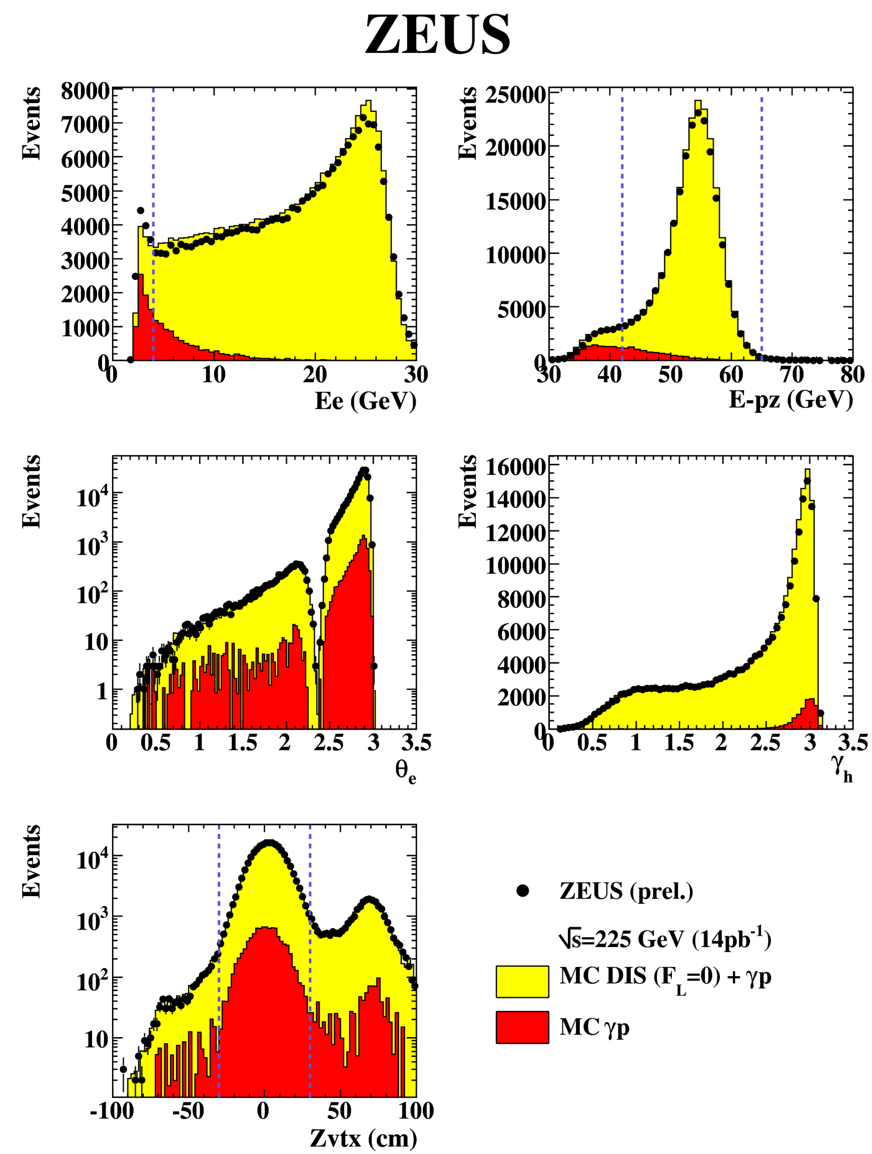
- energy scale, electron finding, γp normalization, uncorrelated luminosity, relative normalization between the two datasets, position reconstruction, Z_{vtx}, $\Sigma(E-p_z)$

Control distributions

E_p = 920 GeV

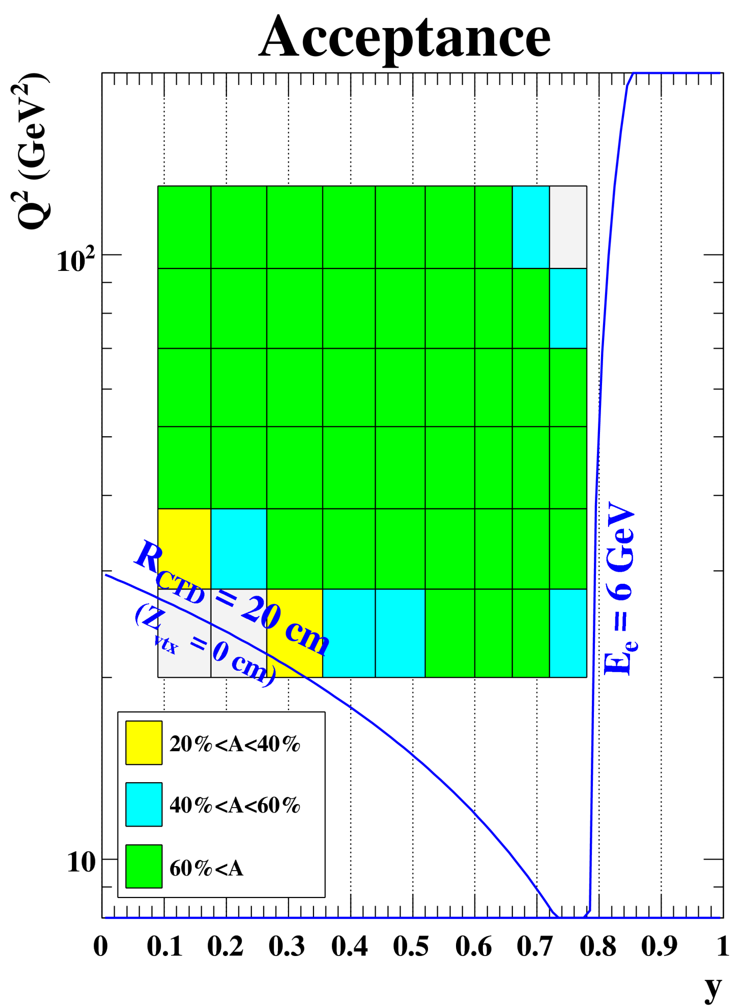


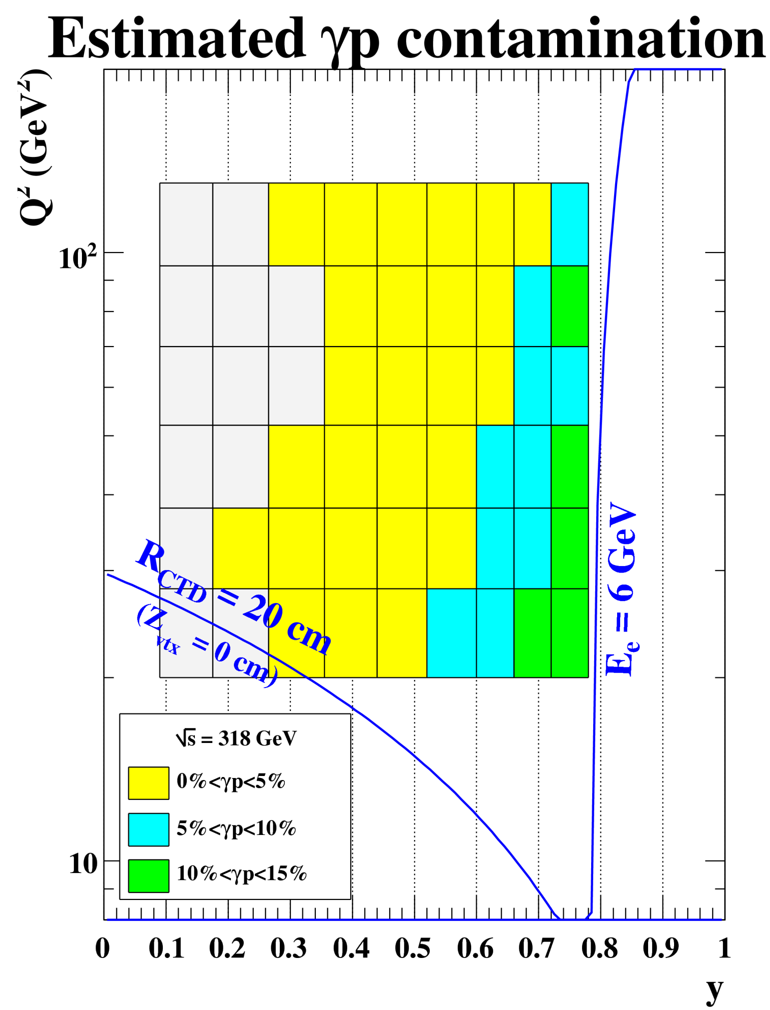
E_p = 460 GeV



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

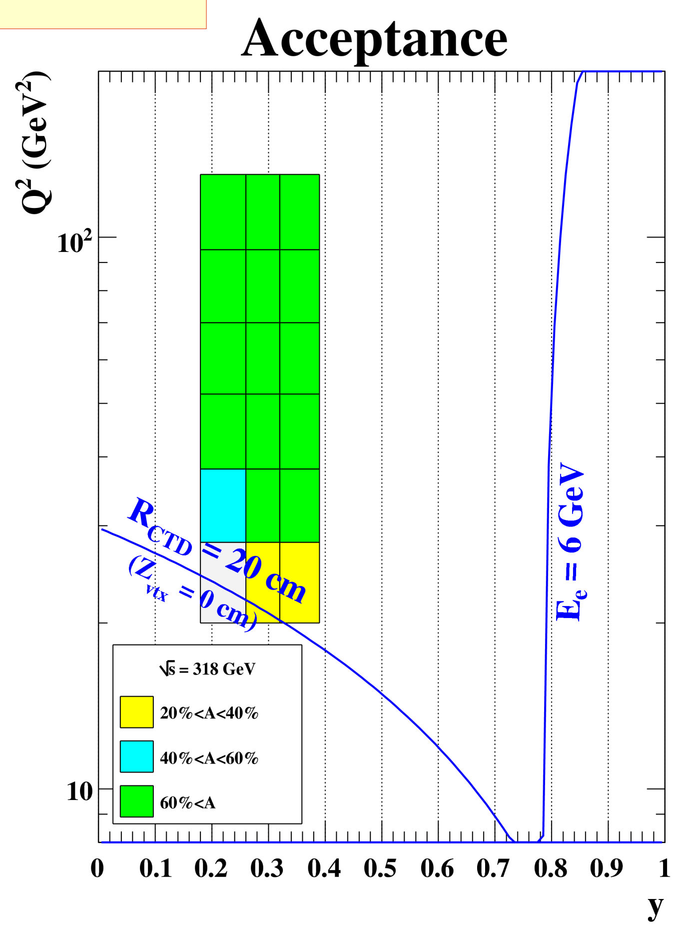




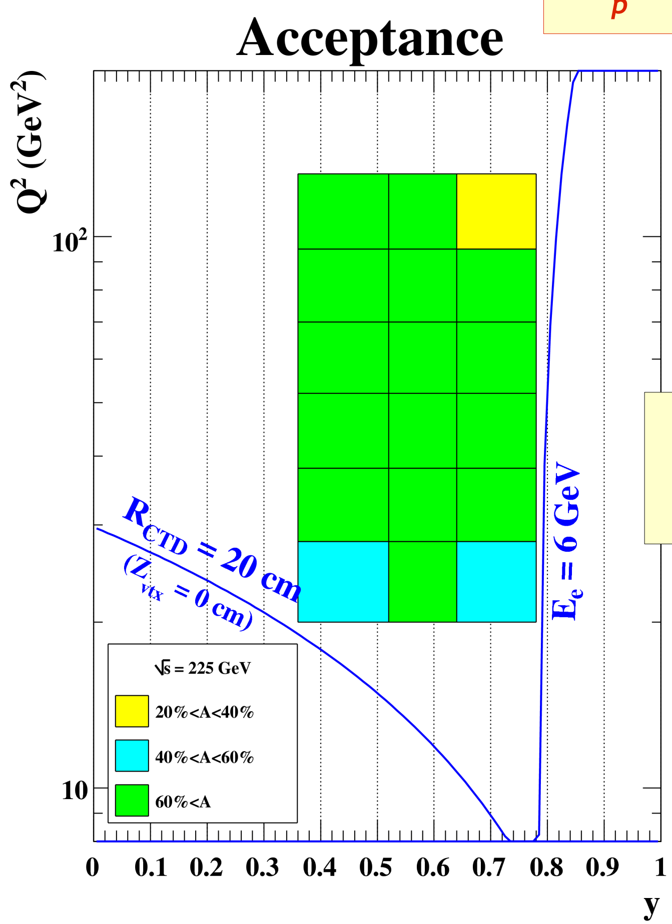
Bins start above E_e = 6 GeV

- 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



E_p = 460 GeV

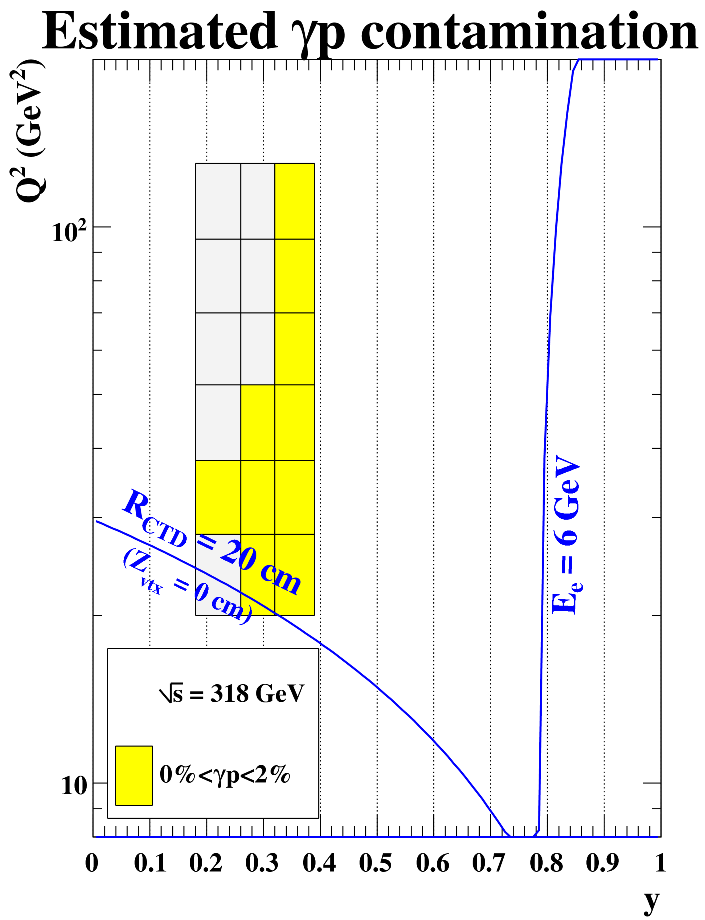


Bins start above E_e = 6 GeV

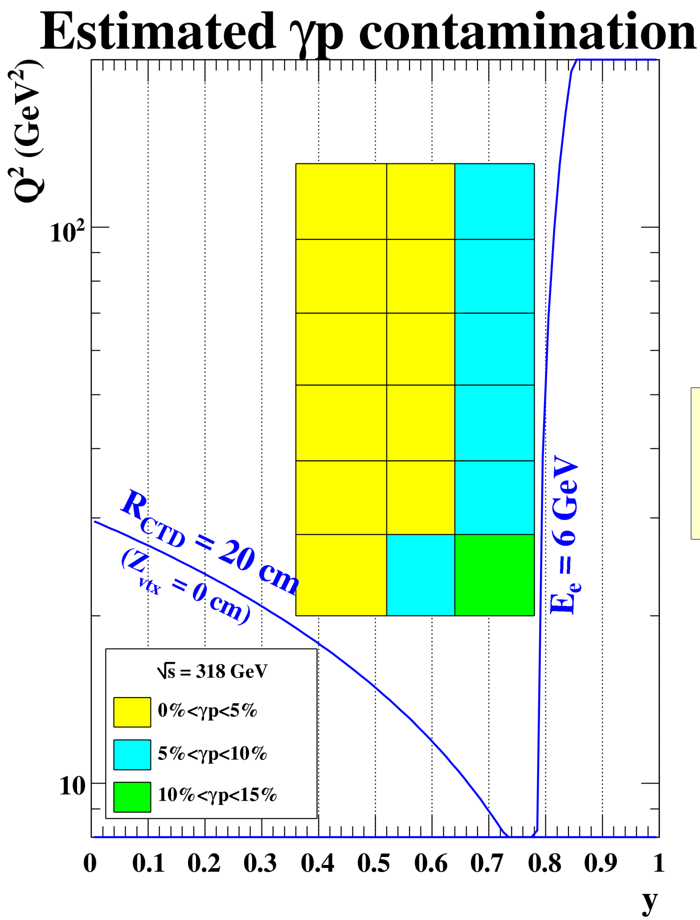
Bins for F_L measurement – γp contamination

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

E_p = 920 GeV



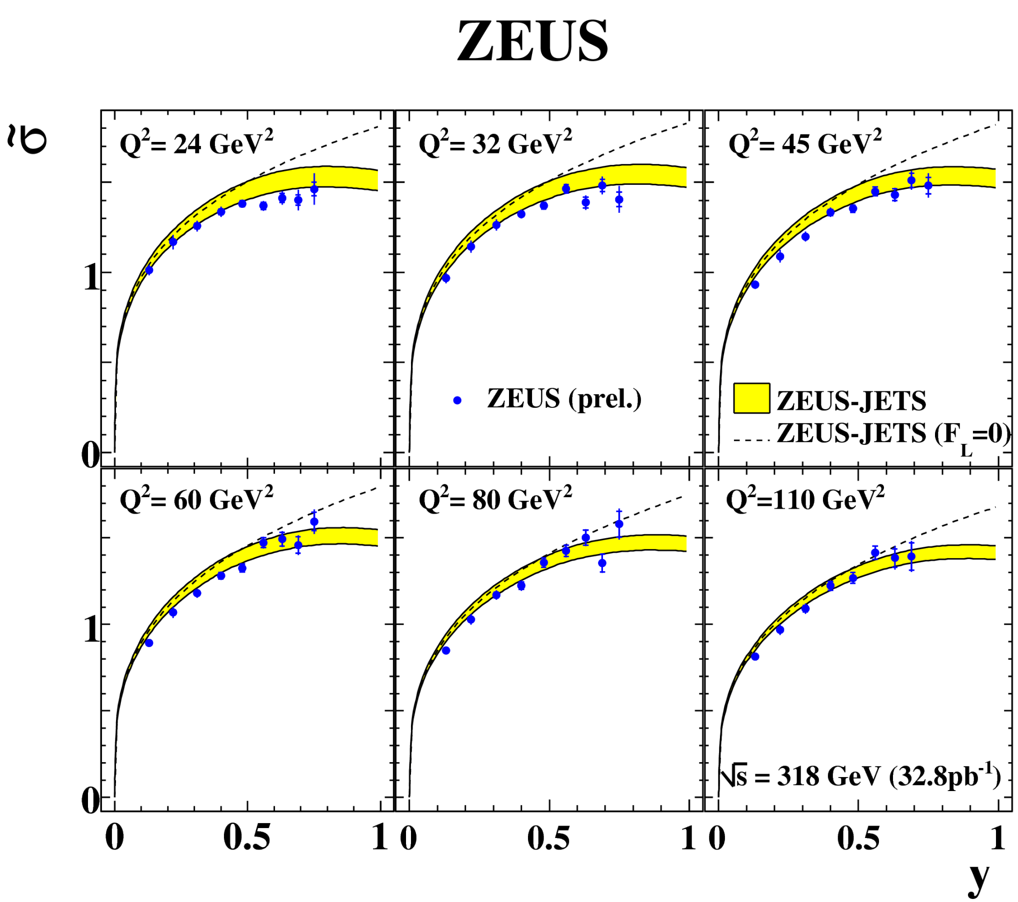
E_p = 460 GeV



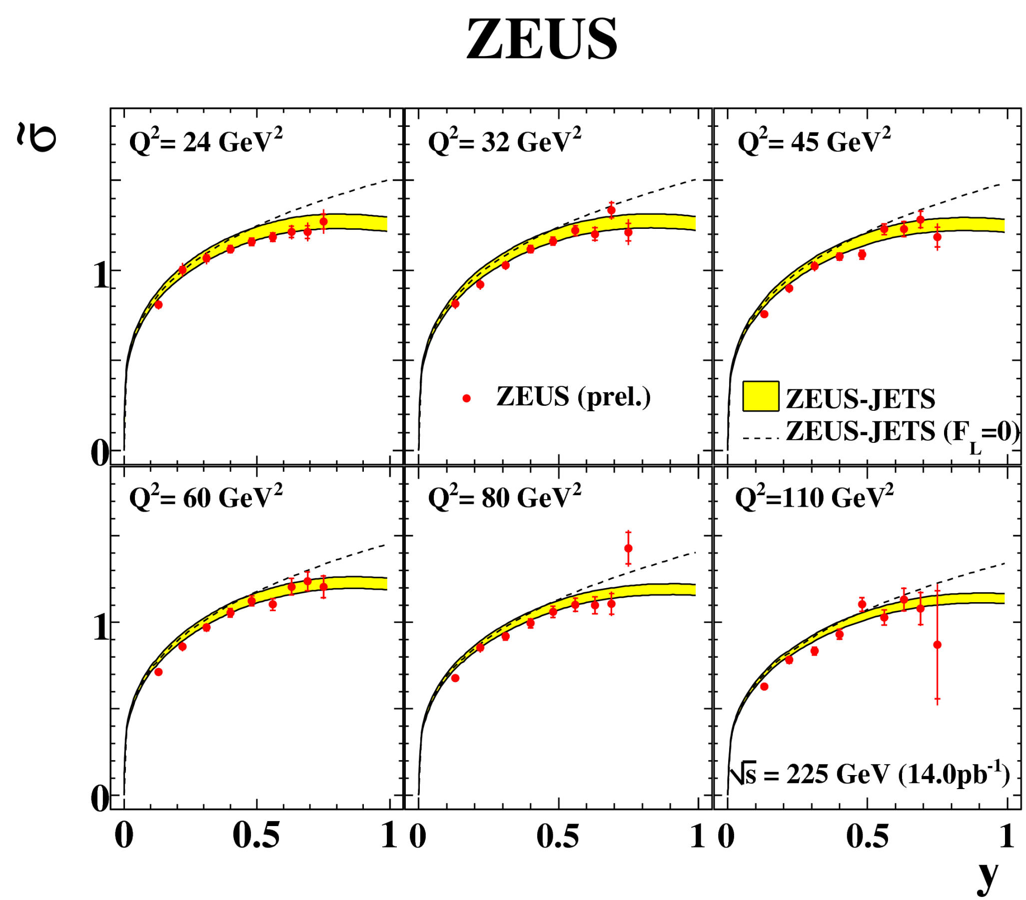
Bins start above E_e = 6 GeV

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

E_p = 920 GeV

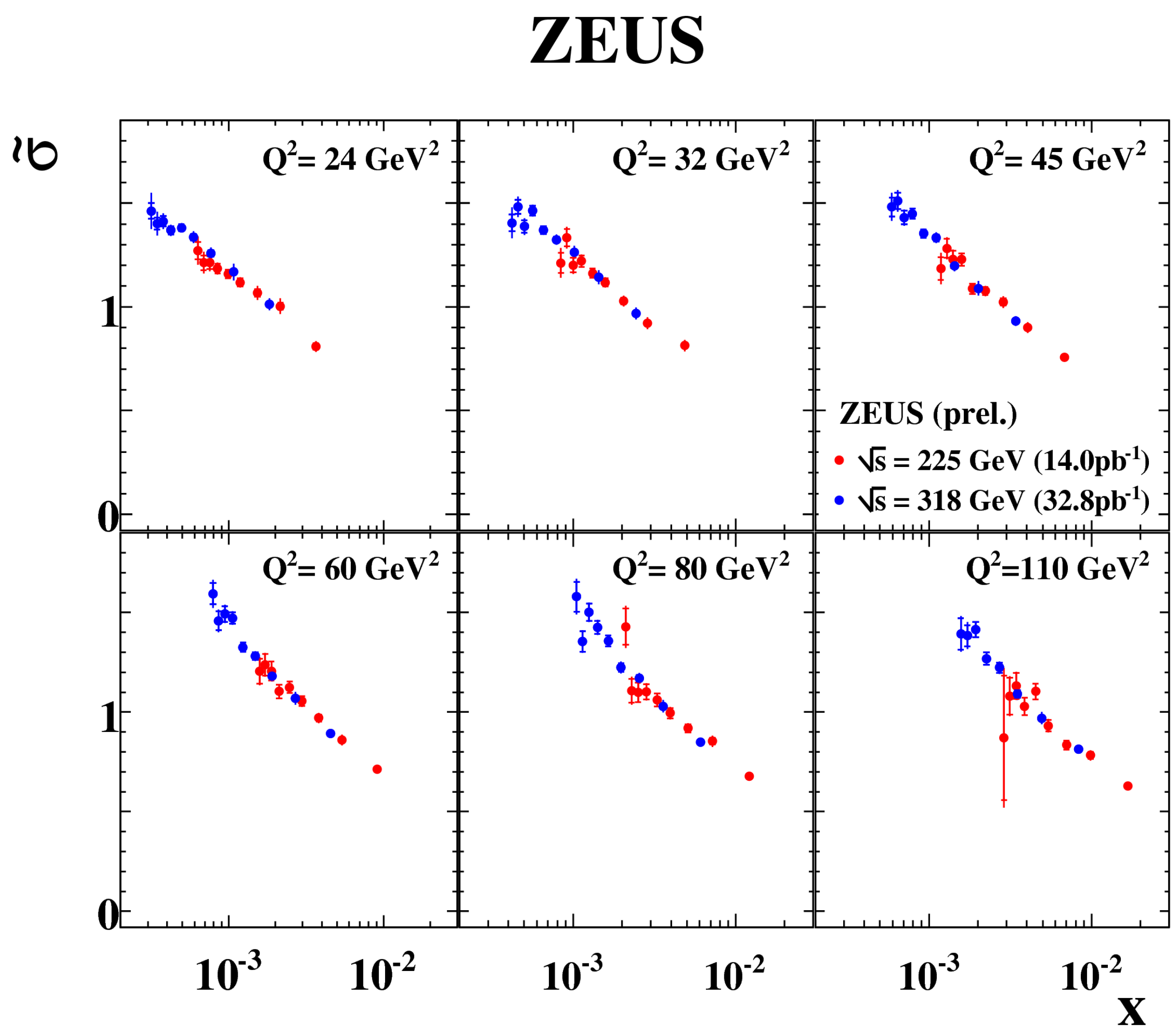


E_p = 460 GeV



Reduced cross sections vs. x

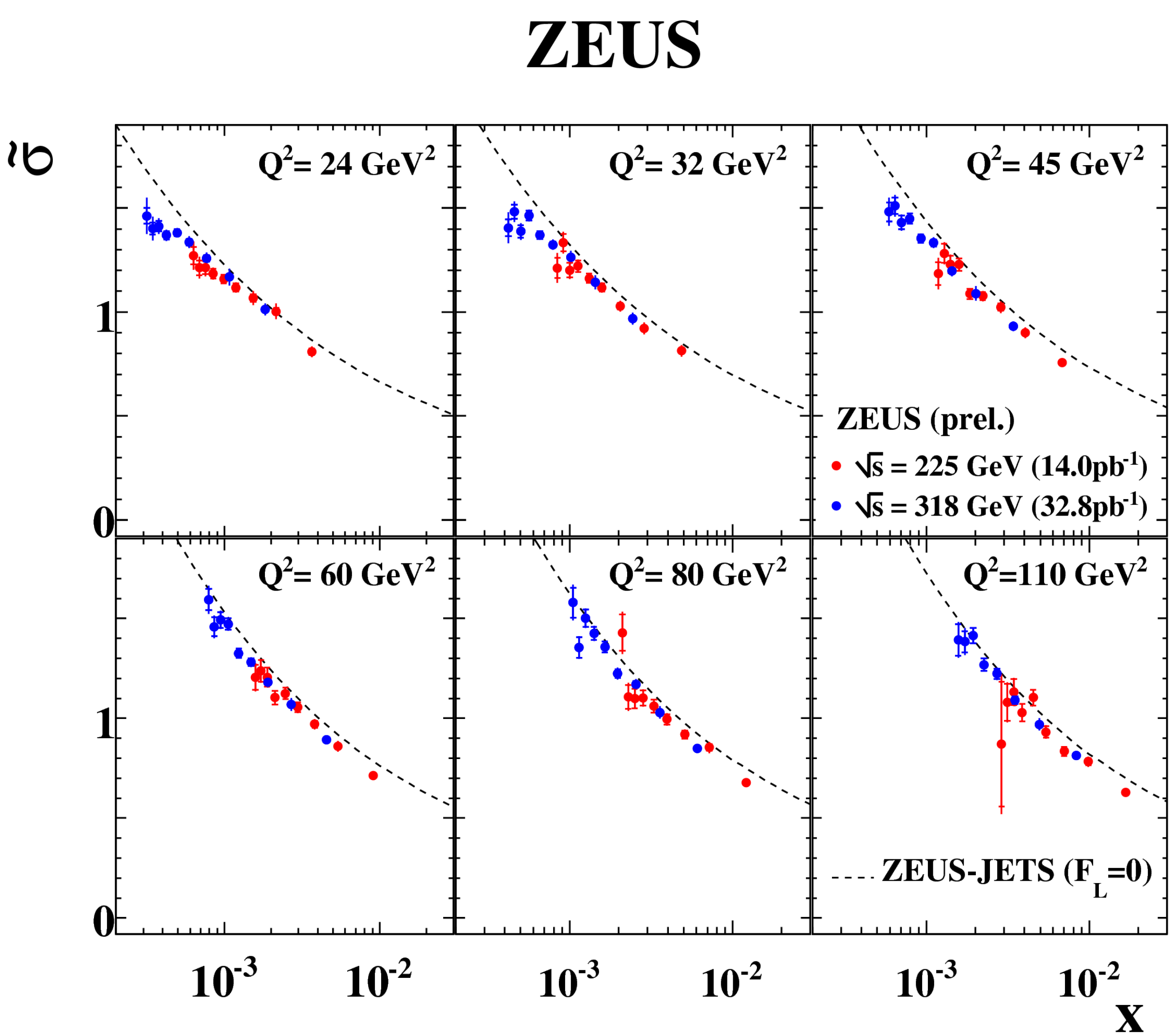
- Difference in cross sections between the two data sets at the same $x,Q^2 \rightarrow F_L$?



Turnover at lowest x?

Reduced cross sections vs. x

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

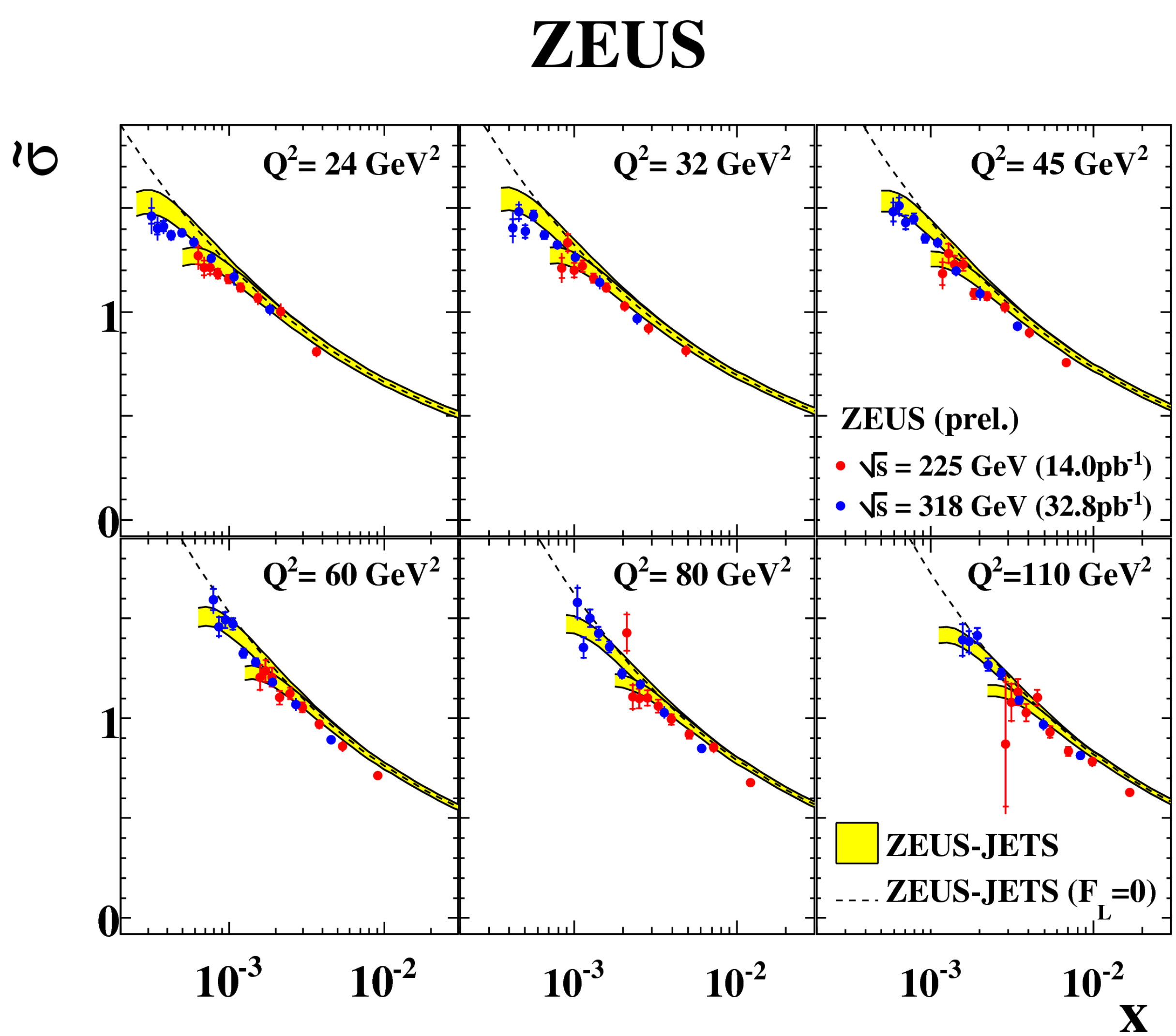


Turnover at lowest *x*?

- 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 $x,Q^2 \rightarrow F_L$?

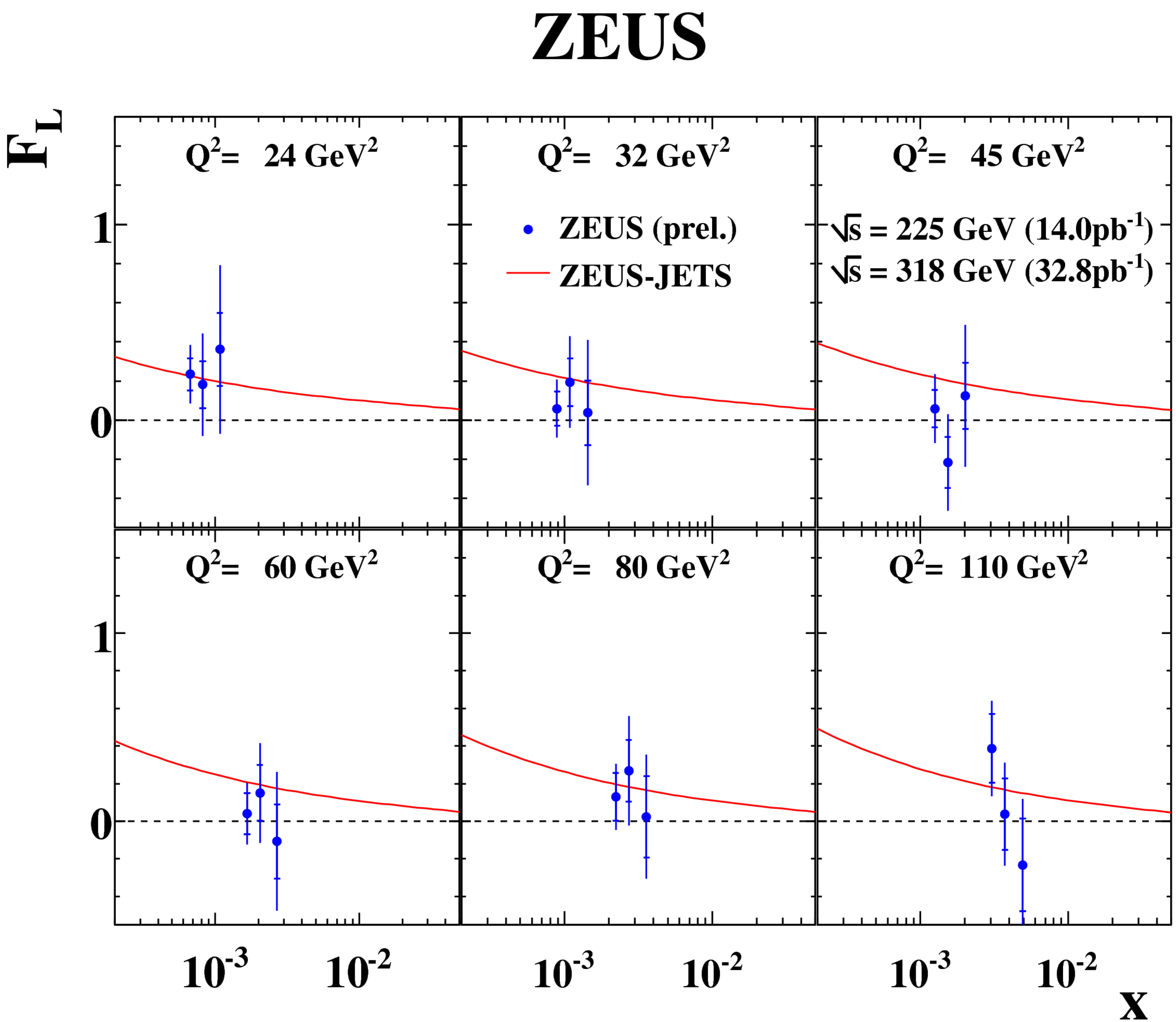


Turnover at lowest *x*?

- 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

F_L @ ZEUS



Large uncertainties

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

Summary

- ZEUS has performed a direct measurement of F_L with data taken at two proton beam energies
  - E_p = 920 GeV & E_p = 460 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 $\boldsymbol{F_L}$)
  - Include E_p = 575 GeV dataset