# ZEUS $F_L$ measurement

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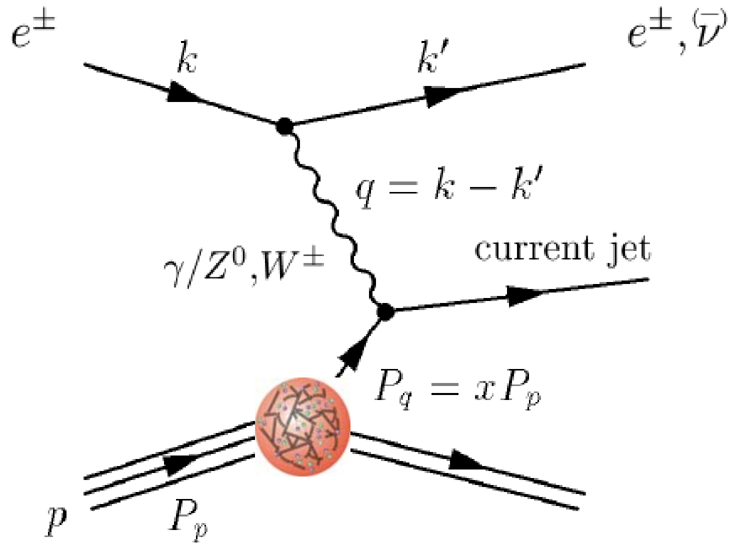
on behalf of the ZEUS collaboration

# Deep Inelastic Scattering




- DIS kinematics can be described by

$$Q^2 = -q^2 = -(k-k')^2 \qquad x = \frac{Q^2}{2p\cdot q} \qquad y = \frac{p\cdot q}{p\cdot k}$$

$Q^2$: Virtuality → probing power
x : Bjorken scaling variable
→ momentum fraction of struck quark
y : Inelasticity

$$Q^2 = sxy$$ $\sqrt{s}$ = Beam centre of mass energy

- DIS cross section can be written with structure functions: $F_2$, $F_L$

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4}(1+(1-y)^2)\left[F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right]$$ (ignoring $xF_3$)

cross section with point-like proton $Y_{\pm} = 1 \pm (1-y^2)$

SFs reflect momentum distribution of partons in the proton

# Structure functions; $F_2$, $F_L$

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

$F_2 \longrightarrow$ Total number of quarks

→ Also indirectly sensitive to gluon distribution.

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

$F_L \longrightarrow$ Direct sensitivity to gluon dynamics.

- $F_L$ proportional to longitudinal photon interacting with proton.
- In nQPM (Callan-Gross relation, assumes spin ½ quarks) $F_L = 0$
- gluon emission in the proton → $F_L \neq 0$

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

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

gluon PDF

Measurement of $F_L$ is important for understanding of proton structure and QCD.

# Measurement of $F_L$

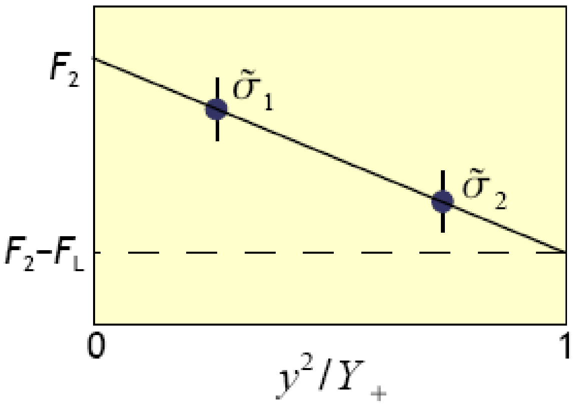
- What we measure is reduced cross section

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

- $F_L$ contribution is sizable only at high-y

→Measurement at the region with **highest possible y** will show $F_L$ contribution.

- For direct extraction of $F_L$



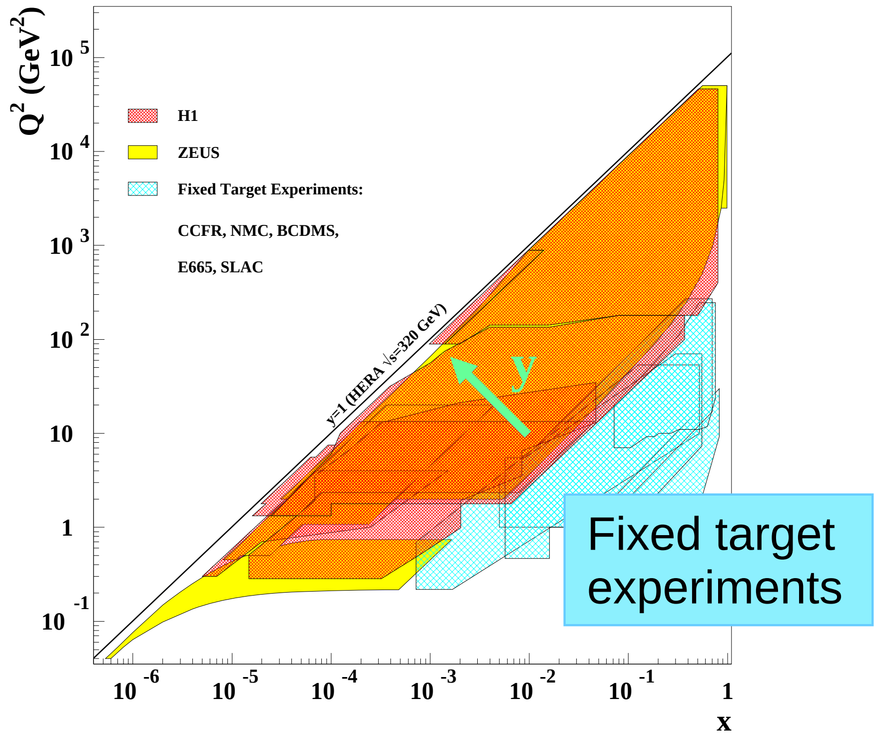

Difference of DIS cross sections at the same (x, $Q^2$) but the different y

$$y = \frac{Q^2}{sx}$$

→ different beam energy

# $F_L$ at HERA

- HERA: e-p collider
  - Crucial for low-x physics
    - gluon and Sea quarks
- $F_L$@HERA : gluon dominant
  
  ➔ dynamics of gluon




- Data were taken with the lower proton beam energy than nominal ($E_p$ = 920GeV).
  - $E_p$ = 460GeV : 14pb$^{-1}$ (2007/March – May)
  - $E_p$ = 575GeV : 8pb$^{-1}$ (2007/June)

# DIS to be measured for $F_L$

DIS events: identified by scattered electron

- High-y

$$y_{\text{meas.}} = 1 - \frac{E'_e}{2E_e}(1 - \cos\theta_e)$$

→ low energy electron

- Measurement at low-$Q^2$

$$Q^2_{\text{meas.}} = 2E_e E'_e (1 + \cos\theta_e)$$

→ low scattering angle

Important keys:

- Electron reconstruction should be well understood.
- Good control of photoproduction background is required.

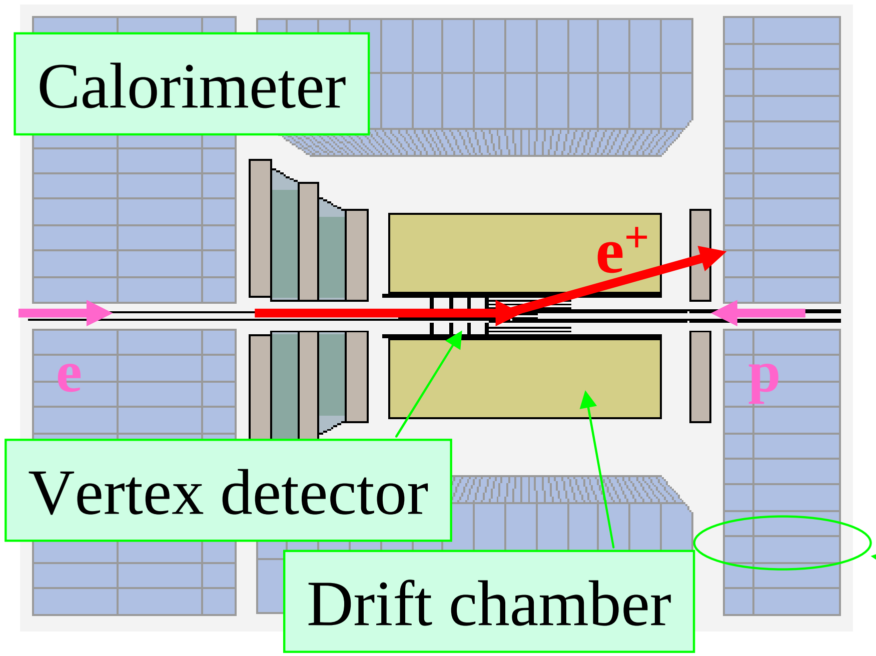
What we need;

- Unbiased trigger
  - ZEUS has E-pz filter

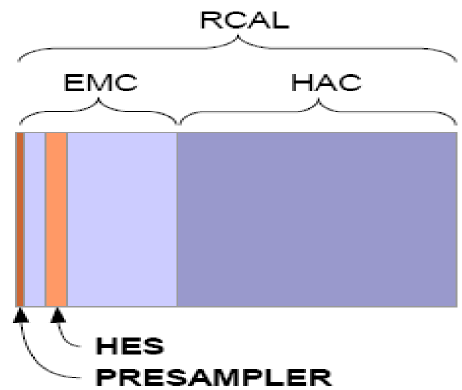
DIS events: $\Sigma\,(E-p_z) \sim 2E_{\text{ebeam}}$

- Electron finding with high efficiency
- Good rejection and understanding of photoproduction background

# Electron reconstruction in ZEUS




- Electrons are reconstructed based on calorimeter, together with
  - minimum energy requirement in HES（silicon pad @ shower maximum）

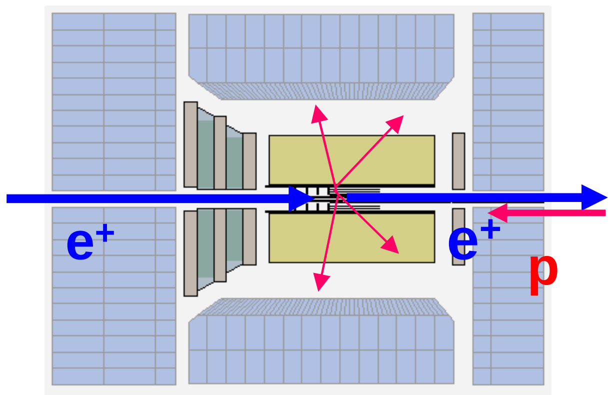



- Electron energy is calibrated on cell-by-cell basis using Double Angle method and cross-checked with;
  - $J/\psi \rightarrow e^+e^-$
  - QED compton
  - DIS

→ Ee scale uncertainty: ±2%@Ee=5GeV → ± 1%@Ee=15GeV

# Background

Main background : Photoproduction (PHP) events.




- Electron goes through beampipe but hadron is misidentified as electron.

  → Event mis-reconstructed as DIS.

  Severe in high-y region (=low $E_e$).

$\pi^{\pm}$ ← rejected by shower shape study.

$\pi^{0} \rightarrow 2\gamma$ ← rejected by track requirement.

- Even after rejection, some PHP events remain.

  Need to be understood.

  – Compare PHP MC to PHP data sample. Two samples selected: Tagged and enriched samples → See later.

# $\gamma$ rejection: Backward tracking

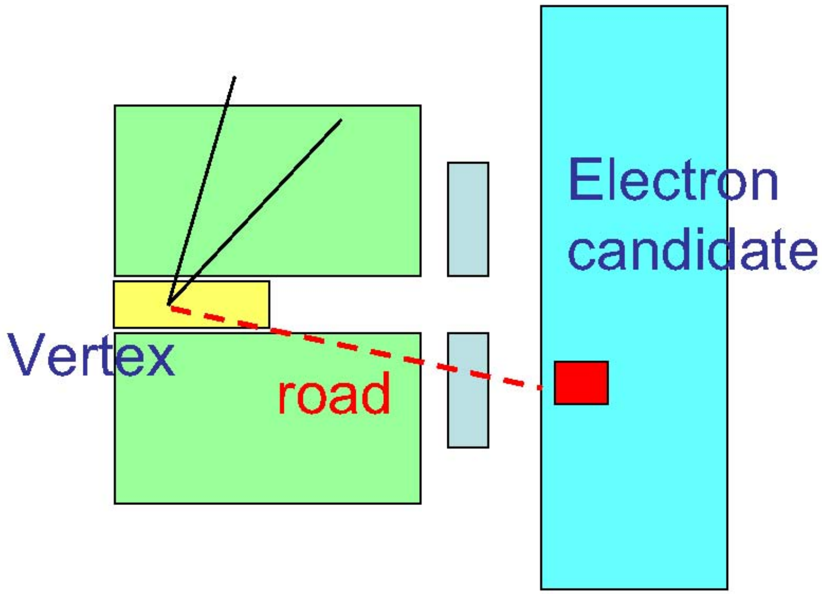
$\pi^0 \rightarrow 2\gamma$

- Track requirement is the only way to reject photons from $\pi^0$.
- Track reconstruction is difficult at low angle.
  - ZEUS: $\theta_e < \sim 154^o$ is the safe region
- New tool is developed for backward region.

Idea: Create a road from

- e-candidate → energy and position
- charge: known from the beam polarity
- event vertex: precisely measured from hadronic activity

and perform **hit finding** around the road.

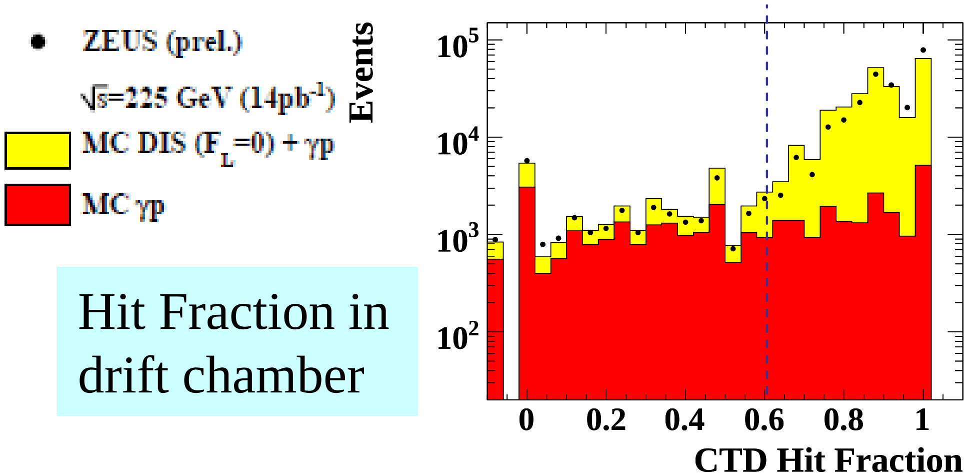


# Hit Finding

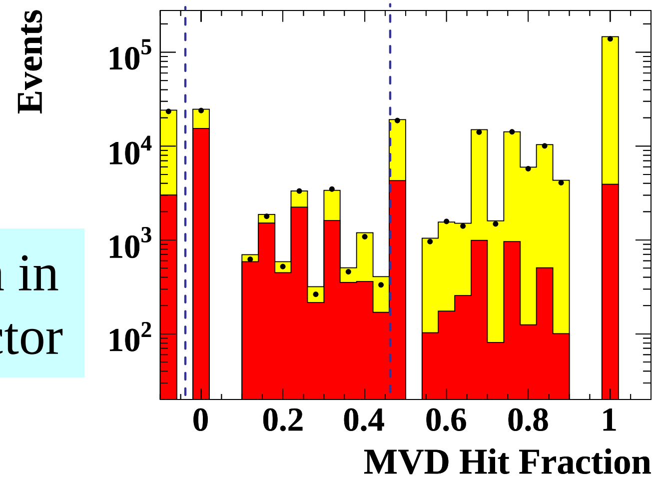
- The result of hit finding is evaluated by Hit Fraction.

  Hit Fraction = [N of found hits] / [N of expected hits]

- They are well described by MC.




Hit Fraction in drift chamber

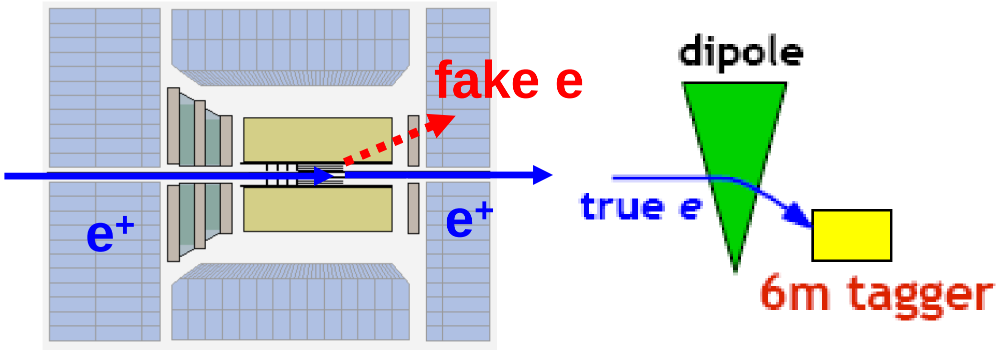


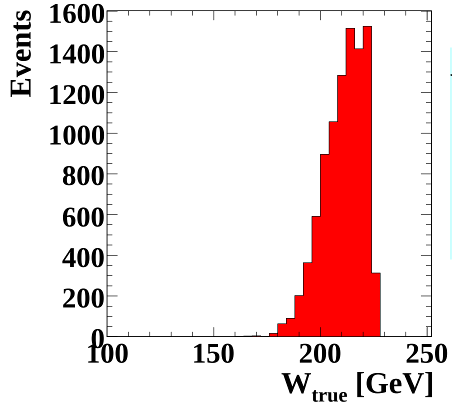

Hit Fraction in vertex detector

- Requirement of certain values of Hit Fraction.
  - Good efficiency for DIS. (> ~90%).
  - Good rejection power for PHP events.
    - Similar as track at $\theta_e < 154^o$.
  - Large applicable region: Down to $\theta_e < 168^o$

# PHP events tagged by 6m Tagger

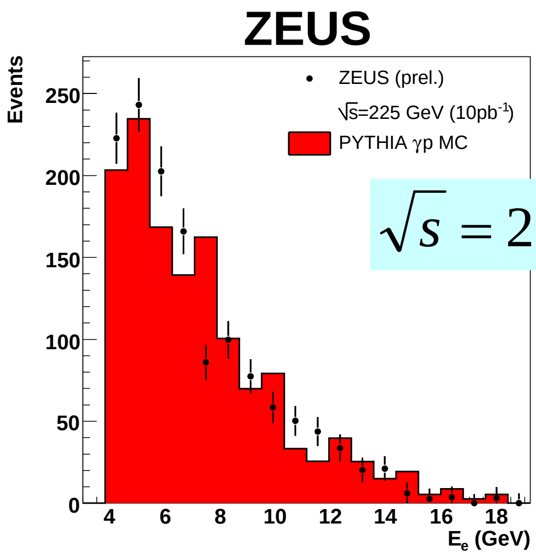
- 6m tagger located downstream of electron beam.
- Direct detection of PHP electrons with good acceptance for limited W range.
  - ~25% of W range of PHP distribution.




$W_{True}$ distribution after DIS selection

- 6m tagged events:
  Energy of fake electron is well described by MC.




$\sqrt{s} = 225\,\mathrm{GeV}$

⟶ Overall normalization factor is extracted for each beam energy.

# Understanding of PHP events

- Fraction of each sub-process in PHP MC is reweighted based on ZEUS $\sigma_{tot}$ measurement.
- Overall normalization factor is extracted by 6m-tagged events.
  - Cross check is done with PHP enriched sample:
    - medium probablity electron candidate
    - low E-pz

    → Obtained factor is in good agreement with 6m tagger analysis.
- Detailed understanding of fake-e from $\pi^{\pm}$ still to be done.
  - Loose criteria on shower shape is applied.
    - Keep good efficiency for DIS.
    - $\pi^{0}$ is already well rejected by tracking.

  → To be conservative on PHP normalization uncertainty.

  $\pm$ ~15% systematic uncertainty.

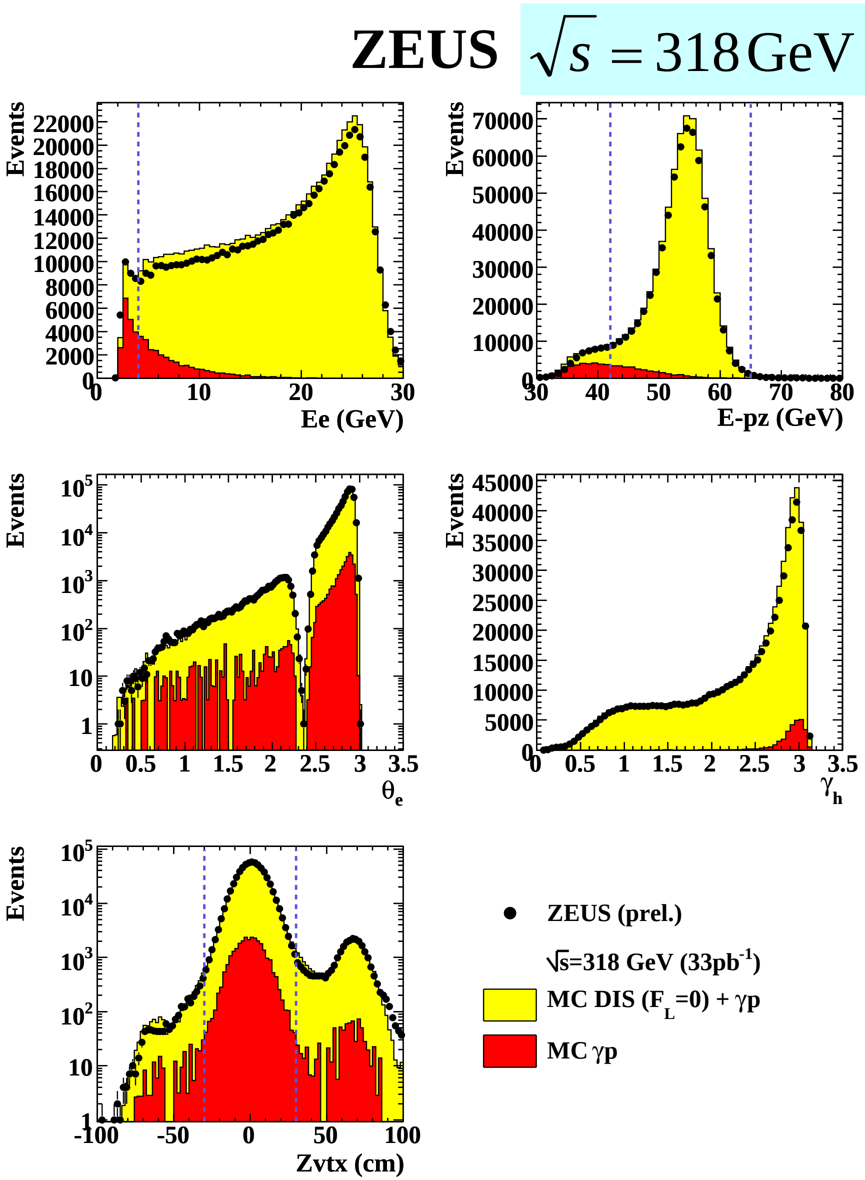
# Sample & Event Selection

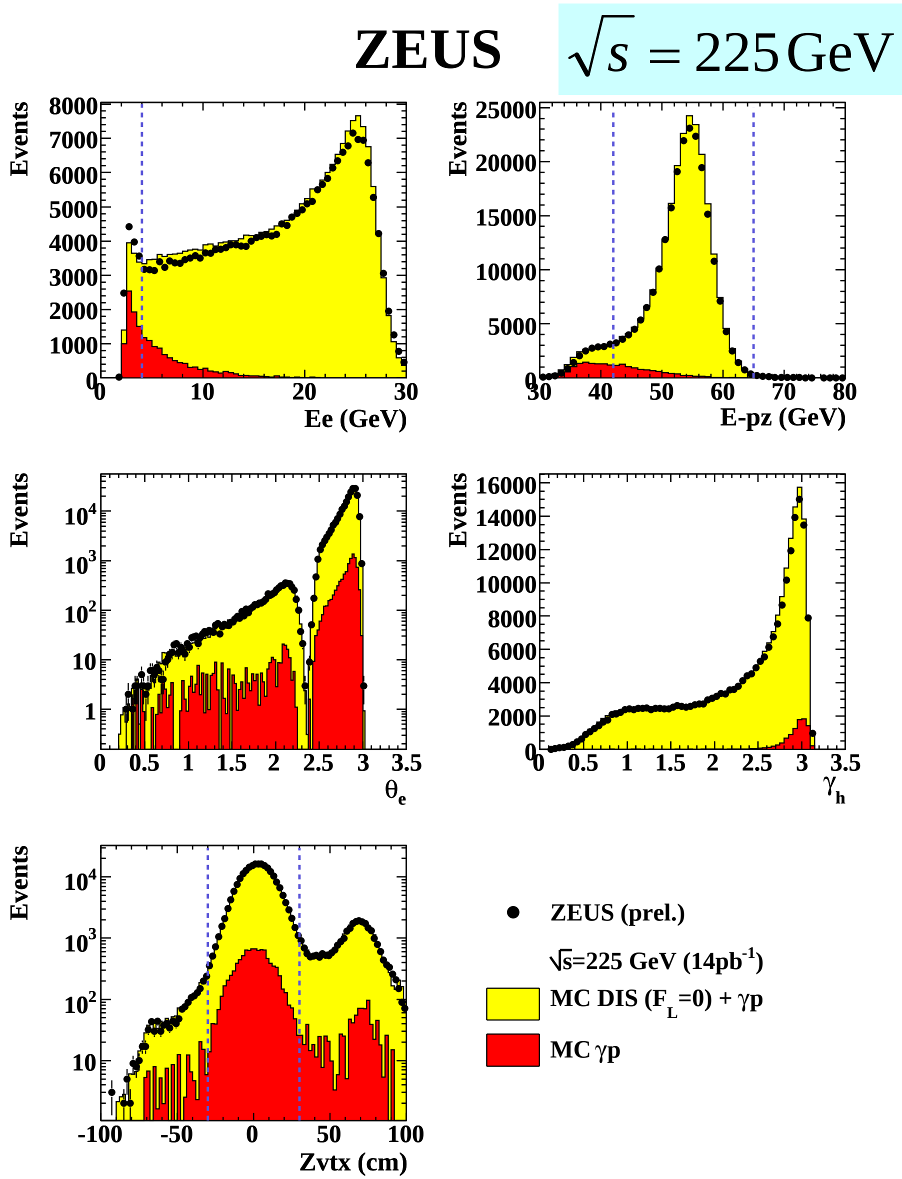
- Sample
  - $E_p$ = 920 GeV $\left(\sqrt{s} = 318\,\mathrm{GeV}\right)$ : 2006 e+ data 32.8 $pb^{-1}$
  - $E_p$ = 460 GeV $\left(\sqrt{s} = 225\,\mathrm{GeV}\right)$ : 2007 e+ data 14.0 $pb^{-1}$

- Event Selection

  The same event selection is applied for both samples.
  - Electron candidate with
    - Energy > 4 GeV
    - Radius on end-plate of the drift chamber > 20cm ( $\theta_e$ <~168$^o$)
    - Enough hits at hit finding
  - 42 GeV < $\Sigma$ (E-pz) < 65 GeV
  - Well reconstructed vertex with $|Z_{vtx}|$ < 30cm

# Control Plots



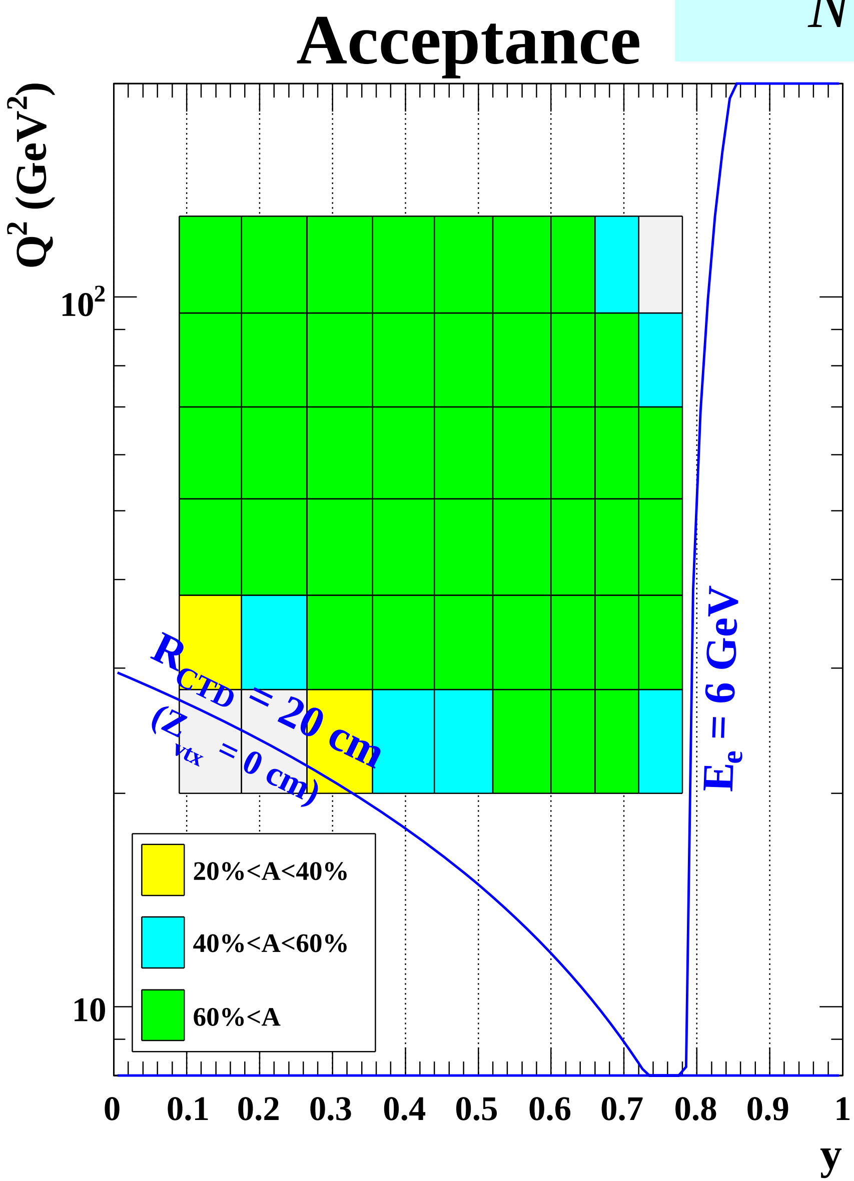

MC description is reasonable but not perfect.

- DIS MC does not have $F_L$.

# Cross section measurement

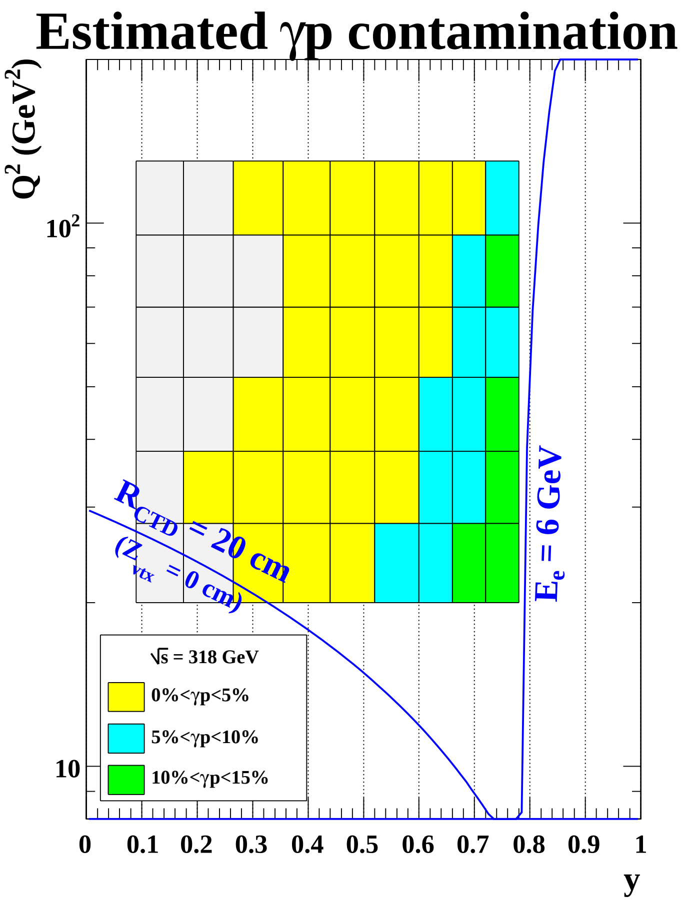
$$A = \frac{N_{\text{meas. in bin}}}{N_{\text{gen. in bin}}}$$

- Kinematic reconstruction is done by Ee, $\theta_e$. (Electron method) Good resolution at high-y region.
- Bins are defined in $(y, Q^2)$ plane.
  - Based on resolution.
  - $E_e > 6$ GeV
- The same binning is used for the two samples.
- Most of bins have acceptance above 60%.
  → Good acceptance.

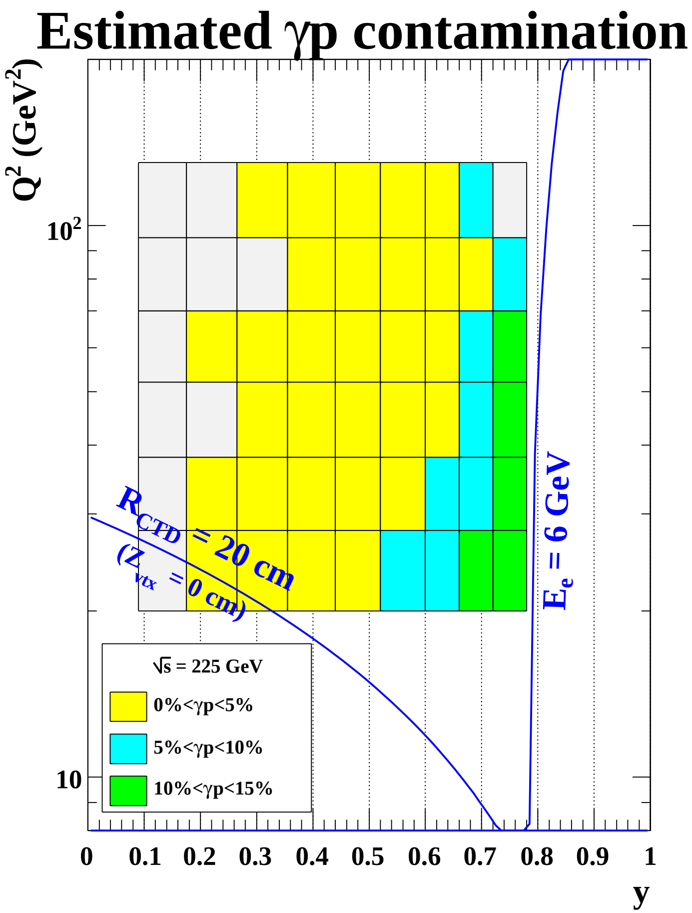


# PHP contamination

$\sqrt{s} = 318\,\mathrm{GeV}$




$\sqrt{s} = 225\,\mathrm{GeV}$




- Estimated PHP contamination is less than 15% in cross section measurement with both beam energies.

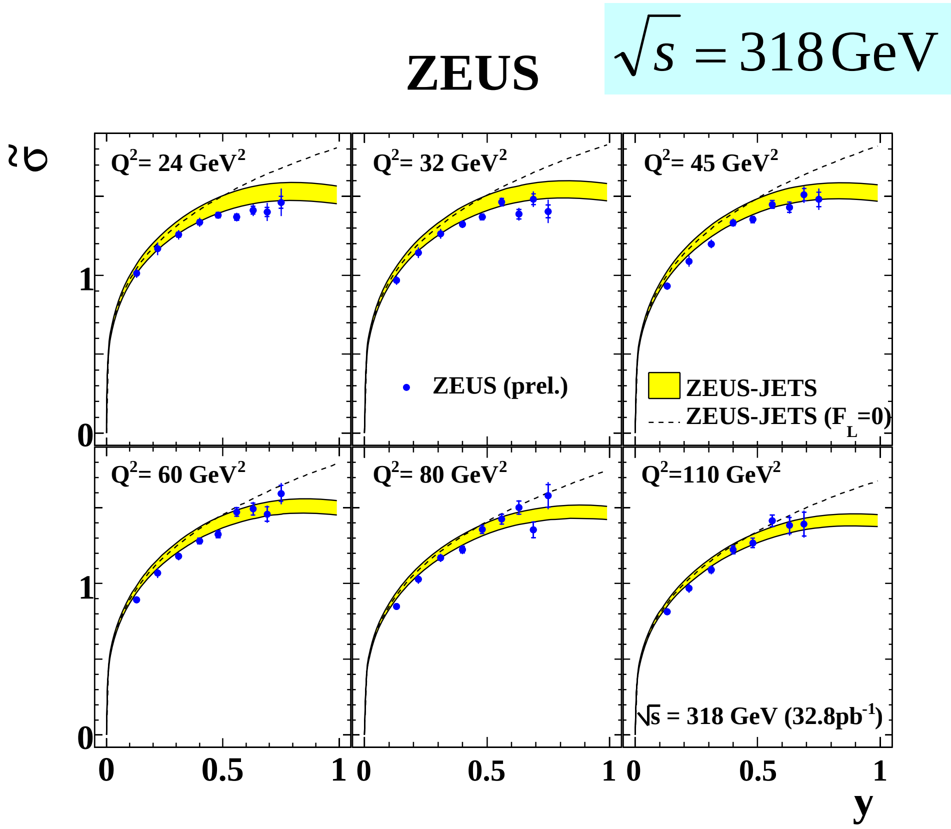
# Systematic checks

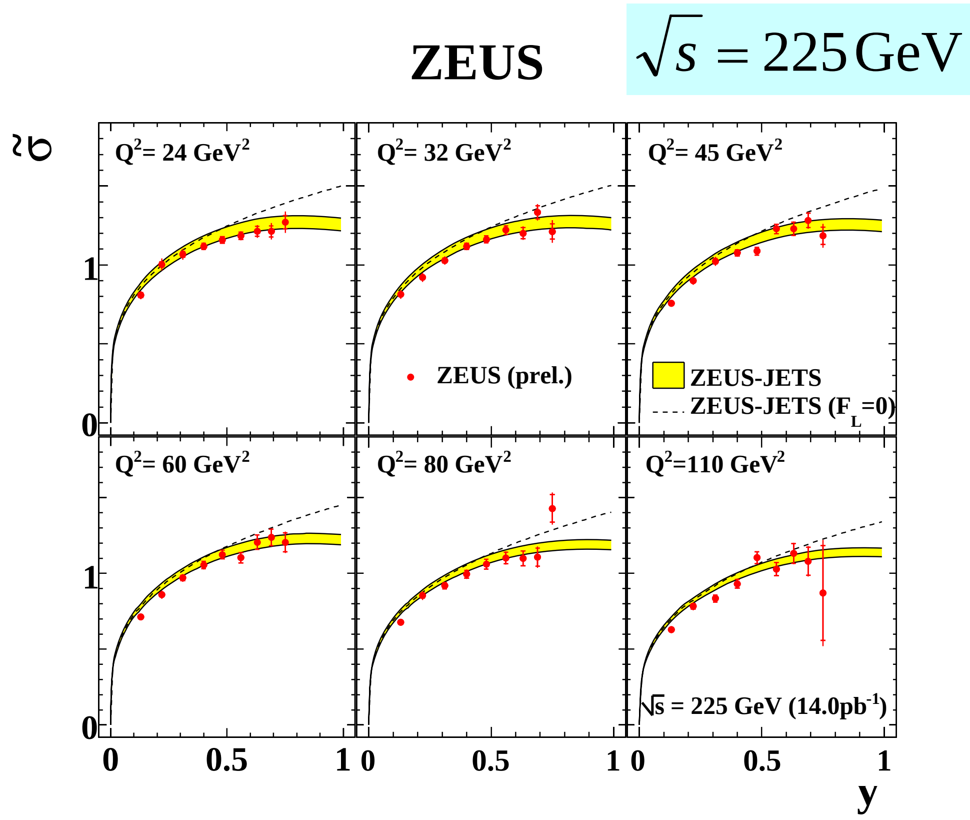
Following systematic uncertainties are taken into account.

They are estimated conservatively.

- Energy scale
- Electron finding
  - Looser and tighter criteria on electron shower shape study.
- Photoproduction normalization
- Position reconstruction
  - 4mm in both x and y direction to cover the effect from possible misalignment of detectors.
- Hit Fraction threshold
- $\Sigma$ (E-pz) threshold
- $|Z_{vtx}|$ thresholds

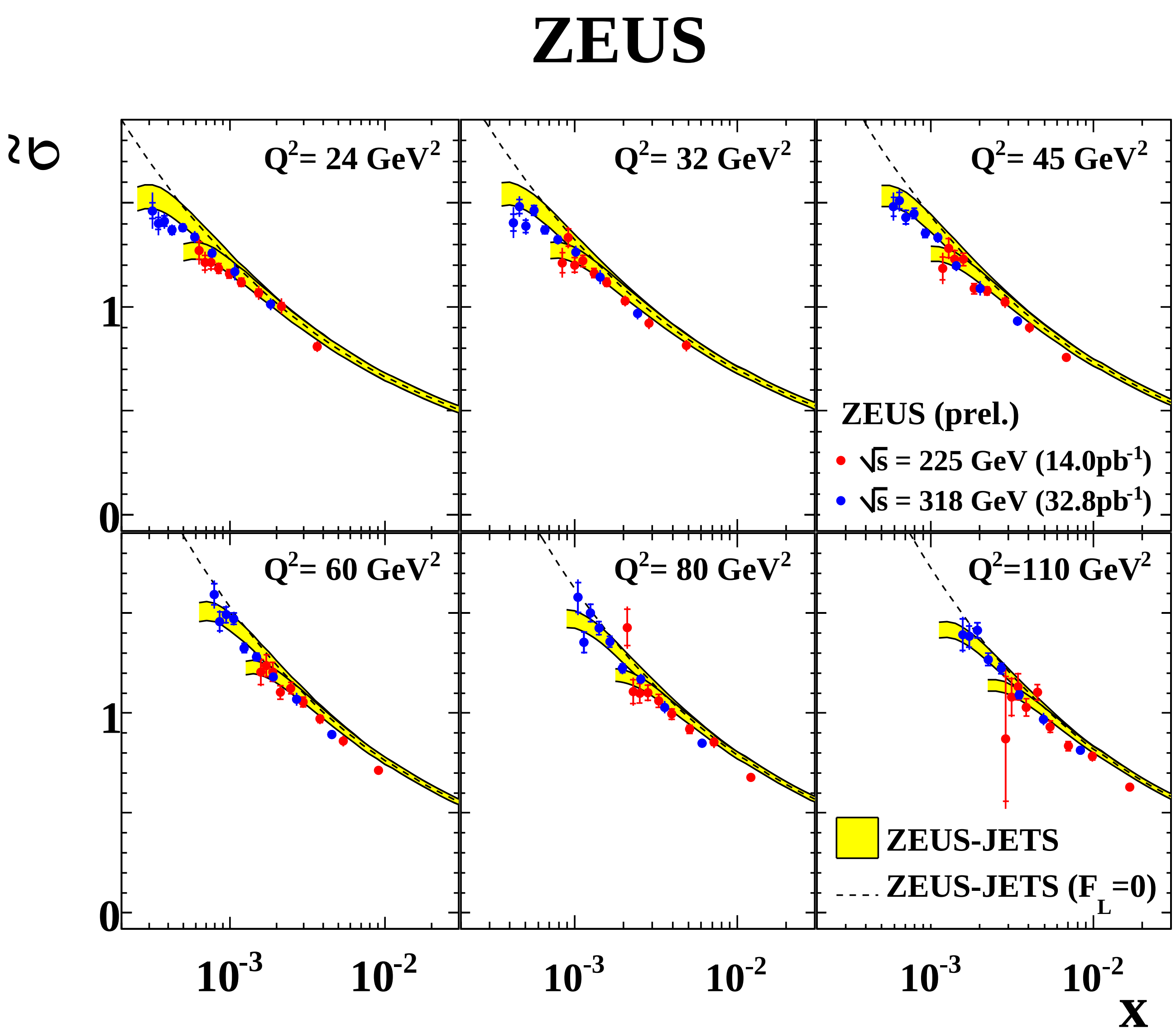
# Reduced cross sections (vs. y)




- Cross section is measured up to y ~ 0.76.
- They are compared to predictions from ZEUS-JETS PDFs.

# Reduced cross sections (vs. x)



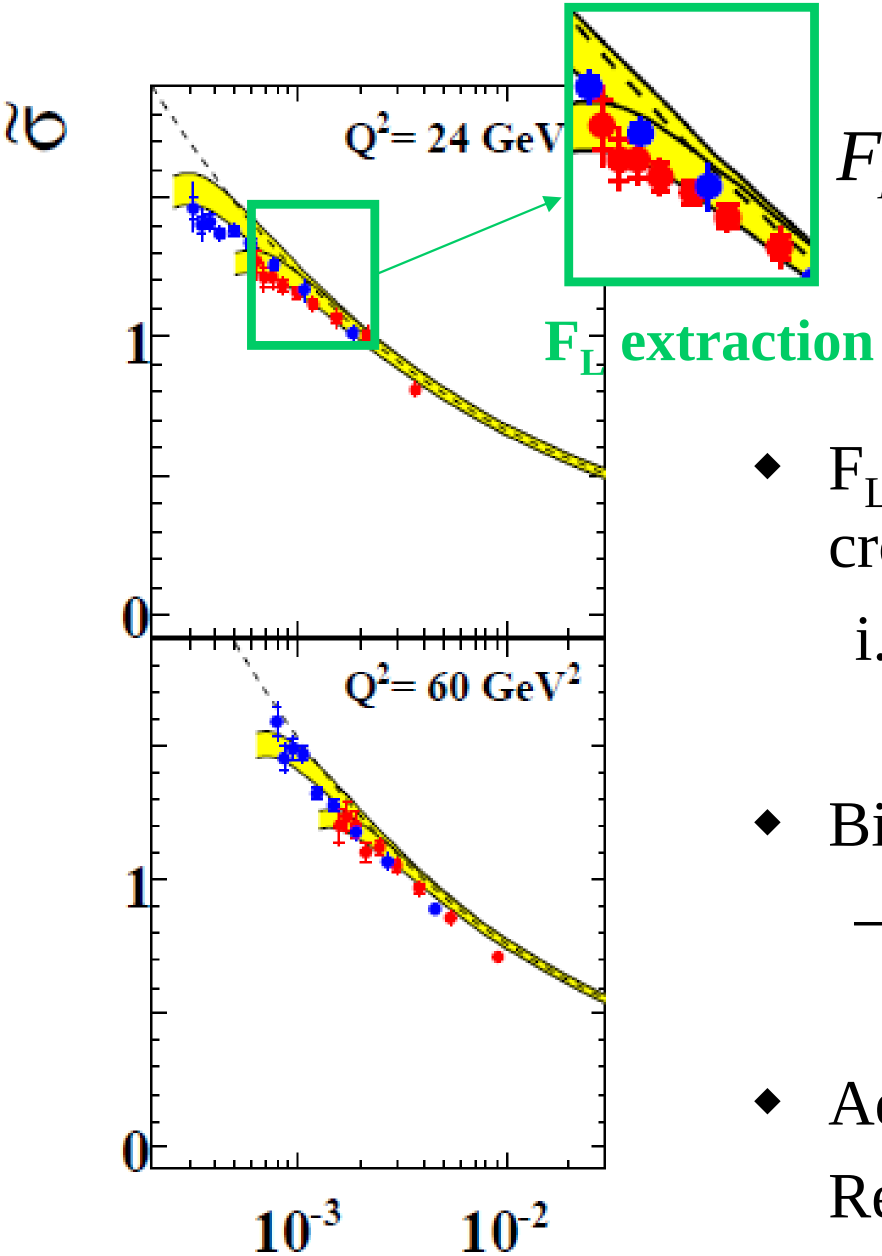

If $F_L \neq 0$, $F_L$ contribution should be indirectly visible as turnover at low-x.

↓

Direct extraction from the two sets of cross sections.

- Cross sections from both beam energies are compared to predictions from ZEUS-JETS PDFs.

# $F_L$ extraction




$$F_L = \frac{\tilde{\sigma}_{\mathrm{High}\sqrt{s}} - \tilde{\sigma}_{\mathrm{Low}\sqrt{s}}}{y^2_{\mathrm{Low}\sqrt{s}} \big/ Y_{+,\mathrm{Low}\sqrt{s}} - y^2_{\mathrm{High}\sqrt{s}} \big/ Y_{+,\mathrm{High}\sqrt{s}}}$$

- $F_L$ was extracted from the difference of cross sections at the same $(x, Q^2)$.

  i.e. Subtraction method

- Bins are re-defined.
  - based on resolution and statistics.

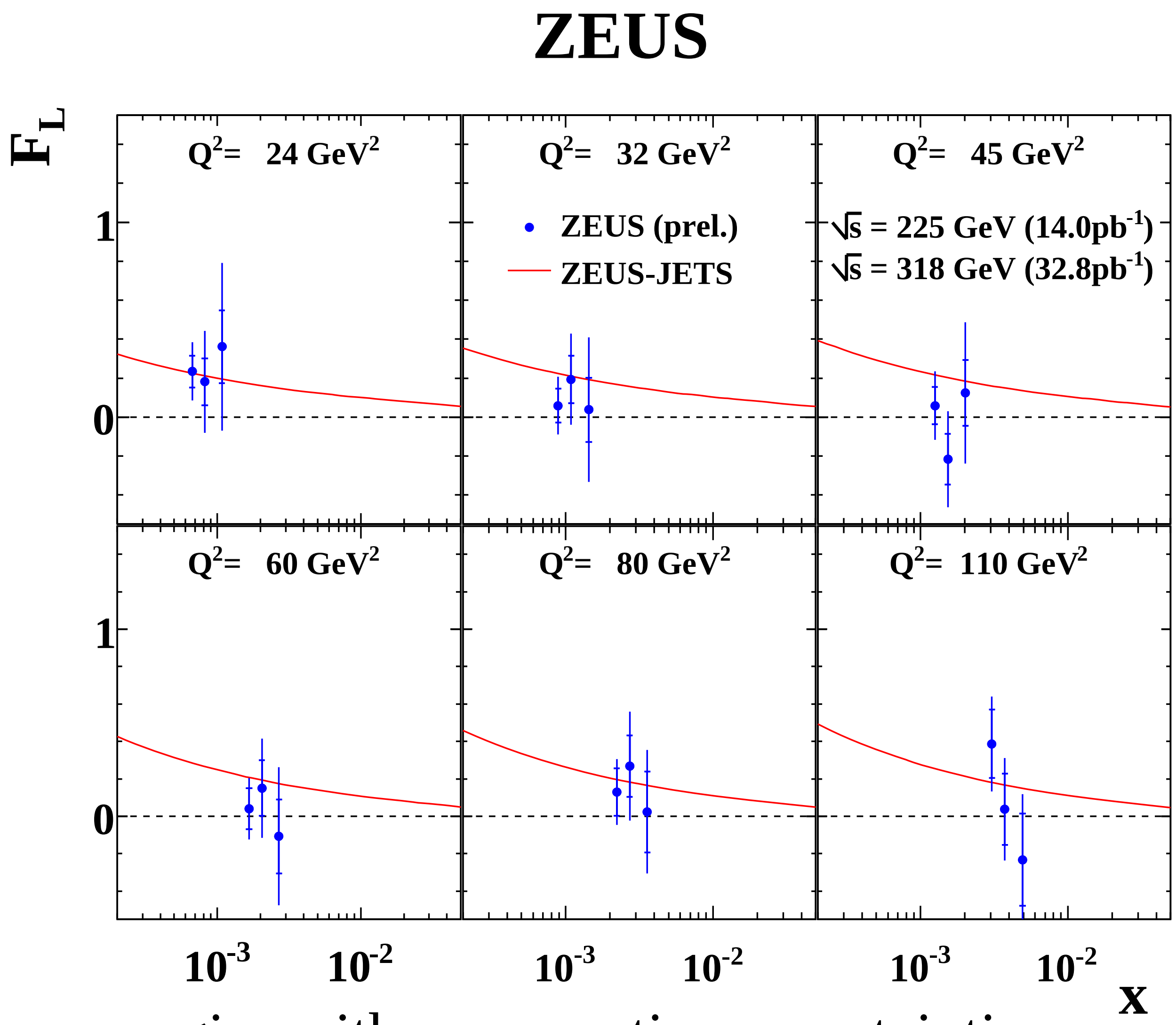
- Additional systematic source:

  Relative normalization uncertainty 2%

# ZEUS $F_L$

Consistent with $F_L$ from ZEUS-JETS PDFs.

Due to large uncertainty, also consistent with $F_L$=0.




ZEUS $F_L$ from two beam energies with conservative uncertainties.

→ Further improved measurement to come.

- Many systematic uncertainties will be tightened. (e.g. relative lumi.)
- Third beam energy – Extension to lower energy electrons.

# Summary

- ZEUS is measuring $F_L$.
  - Based on $e^+p$ data with $E_p$= 920 GeV and $E_p$ = 460 GeV.
  - New tracking technology is established.
  - PHP background data have being analyzed by using 6m tagger.

- Further improvement can be expected.
  - We have $E_p$ = 575 GeV data of ~8pb$^{-1}$.
  - Further understanding of systematic uncertainties will be done.