

# Measurement of the $W$ dependence of $\sigma_{\text{tot}}(\gamma p)$ with the ZEUS detector at HERA

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On behalf of the ZEUS collaboration

# Motivation I

Donnachie and Landshoff (DL)  
(Phys. Lett. B296, 227 (1992))  
showed that all hadron-hadron  
total cross sections can be described by a simple form:

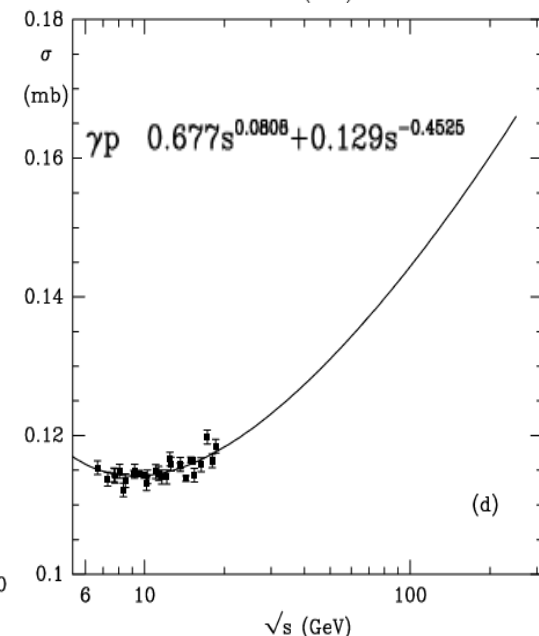
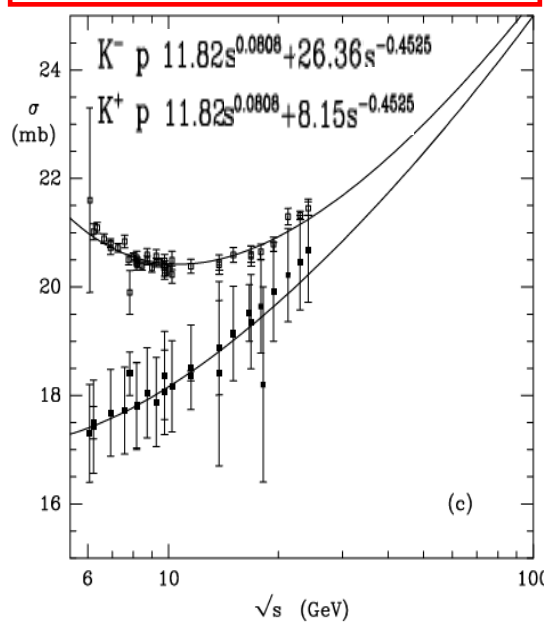
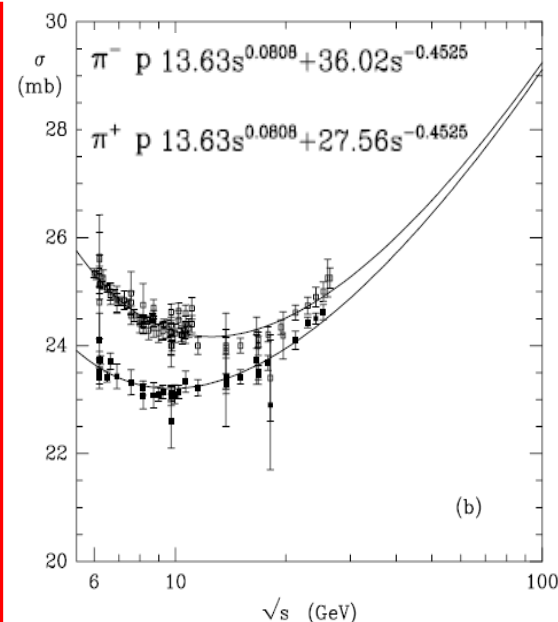
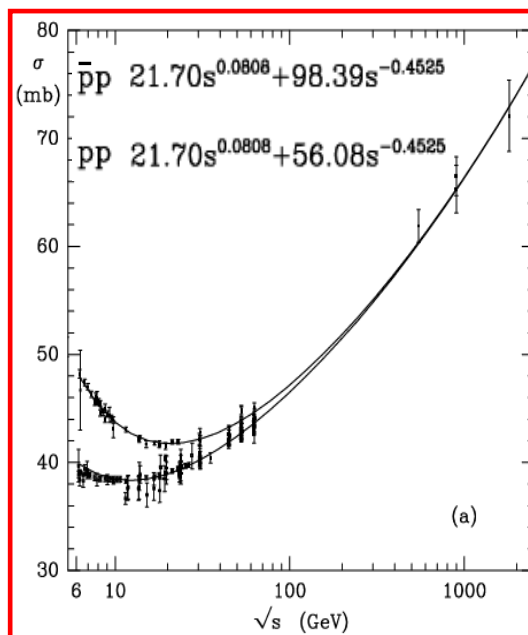
$$\sigma_{\text{tot}}(h-h) = A s^\varepsilon + B s^{-\eta}$$

With  $\varepsilon = \alpha_{IP}(0) - 1 = 0.0808$   
 $\eta = 1 - \alpha_{IR}(0) = 0.4525$

Cudell, Kang and Kim  
(Phys. Lett. B395, 311 (1997))  
data  $1\sigma$  or  $2\sigma$  from average

$$\varepsilon = 0.096^{+0.012}_{-0.009}$$

$\varepsilon$  is universal !



# Motivation II

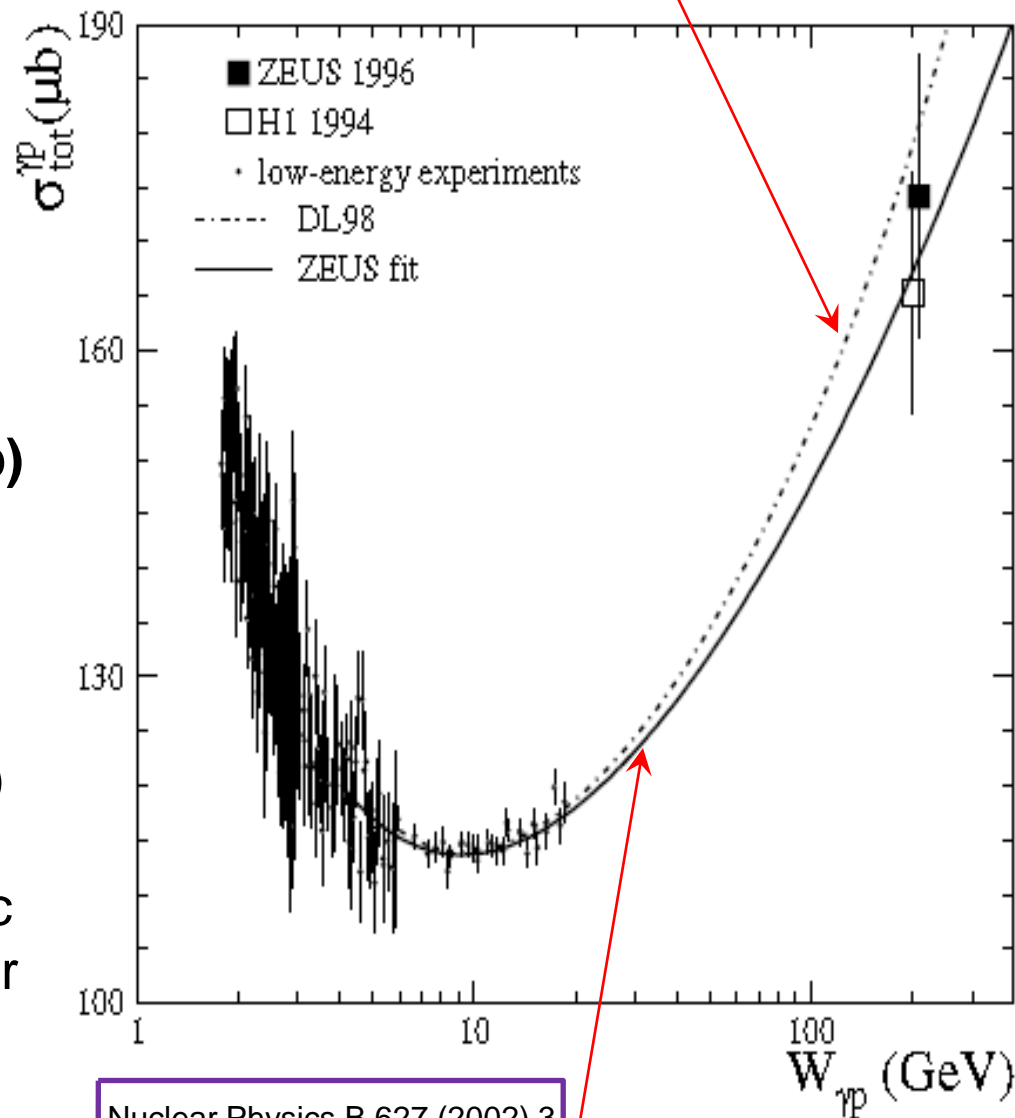
Phys. Lett. B437 (1998) 408

$$\sigma_{\text{tot}}(\gamma p) = 0.283 (W^2 - m_p^2)^{0.418} + 65.4 (W^2 - m_p^2)^{0.0808} + 138 (W^2 - m_p^2)^{-0.4525}$$

The  $\sigma_{\text{tot}}(\gamma p)$  dependence on  $W$  is particularly interesting because of the nature of the photon.  $\gamma \longleftrightarrow q\bar{q}$

The first measurements of  $\sigma_{\text{tot}}(\gamma p)$  at HERA showed that it has a similar  $W$  dependence to that of hadron-hadron reactions.

Further measurements of  $\sigma_{\text{tot}}(\gamma p)$  at HERA have reduced its statistical error but the systematic uncertainty remained too large for a precise determination of the  $W$  dependence of the cross section.



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$$\sigma_{\text{tot}}(\gamma p) = (57 \pm 5)(W^2)^{0.100 \pm 0.012} + (121 \pm 13)(W^2)^{-(0.358 \pm 0.015)}$$

# Concept of measurement

Prior to its shut-down on 30<sup>th</sup> June 2007, HERA was running with three different proton energies at constant positron energy.

This opened up the possibility to determine precisely the power of the  $W$  dependence of  $\sigma_{\text{tot}}(\gamma p)$ .

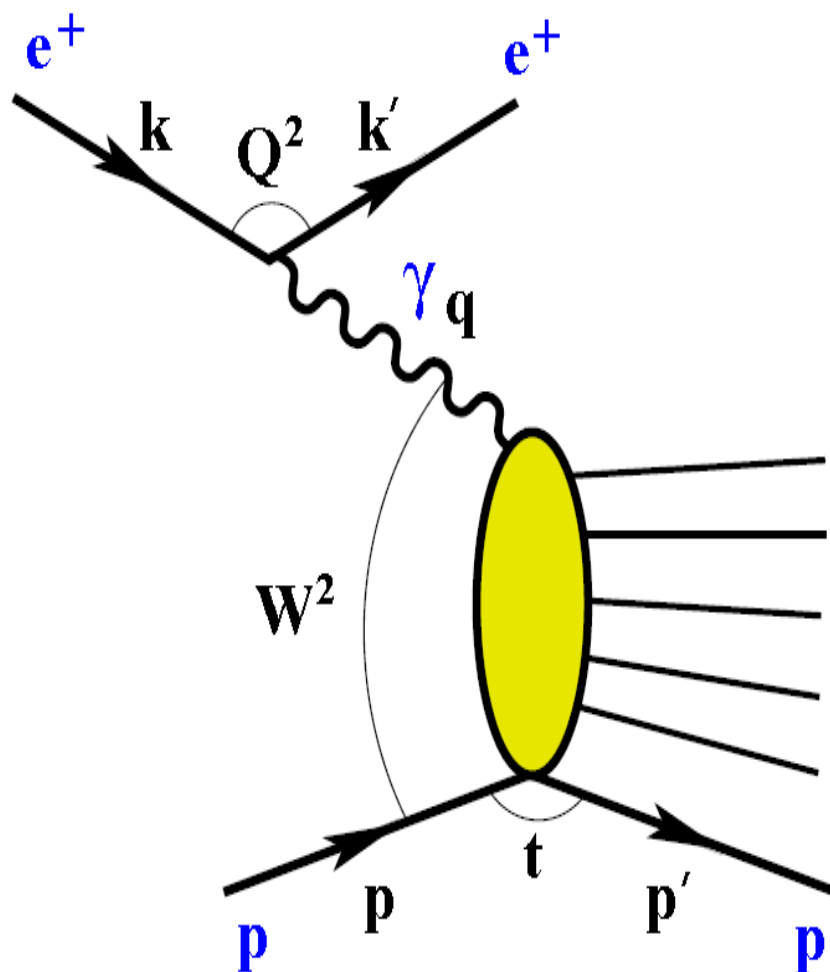
Assuming  $\sigma \sim W^{2\varepsilon}$ ,  $\varepsilon$  can be extracted from the ratio  $R$  of cross sections probed at different  $W$  values.

$$R = \frac{\sigma(W_1)}{\sigma(W_2)} = \left(\frac{W_1}{W_2}\right)^{2\varepsilon} \quad \left(\frac{W_1}{W_2}\right)_{\text{HERA}} = \sqrt{2} \Rightarrow R \sim 1.07$$

Experimentally,  $\sigma = \frac{N}{A \cdot \mathcal{L}}$  and therefore  $R = \frac{N_1 A_2 \mathcal{L}_2}{N_2 A_1 \mathcal{L}_1}$ .

If the acceptances will be the same, the ratio of acceptances will be canceled.

# Kinematics



$$Q^2 \equiv -q^2 = -(k - k')^2$$

$$y = \frac{p \cdot q}{p \cdot k}$$

$$W^2 = (q + p)^2$$

Experimentally:

**X**

$$Q^2 = 2E_e E'_e (1 - \cos \theta_e) \approx E_e E'_e \theta_e^2$$

$$y = 1 - \frac{E'_e}{2E_e} (1 + \cos \theta_e) \approx 1 - \frac{E'_e}{E_e}$$

$$W \approx 2\sqrt{E_e E_p y}$$

# From $e^+p$ cross section to $\gamma p$ cross section

$$\frac{d\sigma^{e^+p}(y)}{dy} = \frac{\alpha}{2\pi} \left[ \frac{1 + (1-y)^2}{y} \ln \frac{Q_{max}^2}{Q_{min}^2} - 2 \frac{(1-y)}{y} \left( 1 - \frac{Q_{min}^2}{Q_{max}^2} \right) \right] \sigma_{tot}^{\gamma p}(y)$$



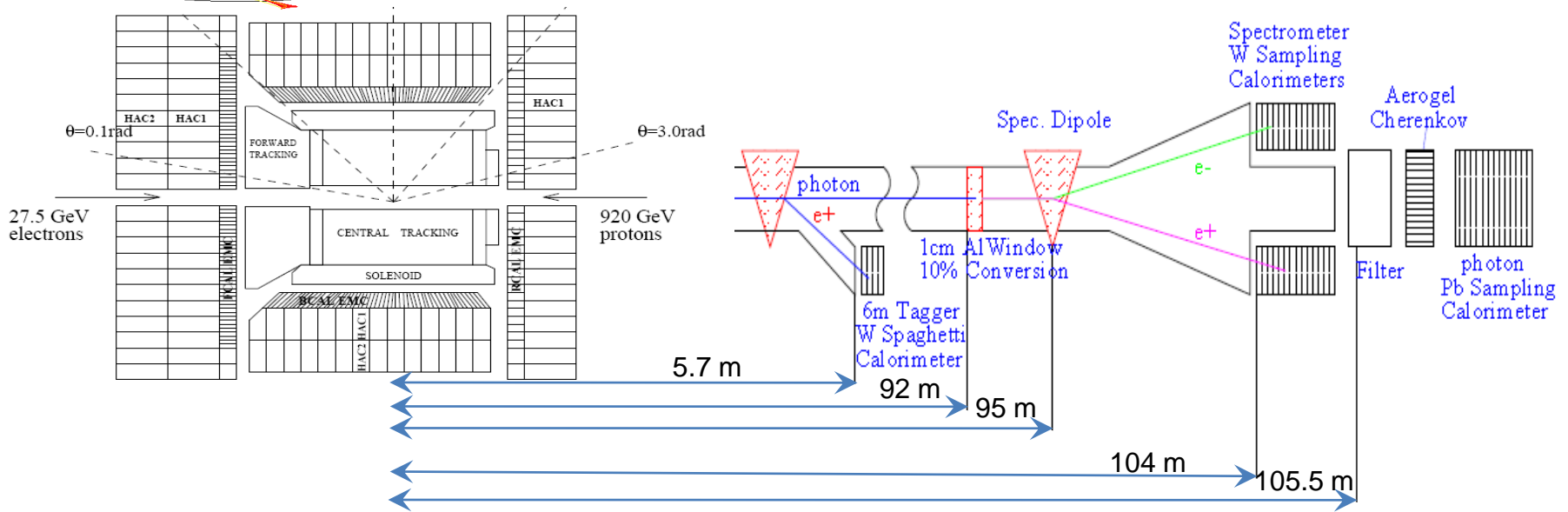
$\sigma_{tot}(\gamma p)$  can be extracted from  $\sigma^{e^+p}$

$$f = \int_{y_{min}}^{y_{max}} \frac{\alpha}{2\pi} \left[ \frac{1+(1-y)^2}{y} \ln \frac{(1-y)Q_{max}^2}{m_e^2 y^2} - 2 \frac{(1-y)}{y} \left( 1 - \frac{m_e^2 y^2}{(1-y)Q_{max}^2} \right) \right] dy$$

$$y_{min/max} = 1 - \frac{E'_{e_{max/min}}}{E_e}$$

Flux uncertainty dominated by  $\Delta E'_e$ ,  
range of integral.

# The ZEUS detector



During few months before HERA shut-down, it was running **27.5 GeV** positrons and protons of three different energies:

- High Energy Run (**HER**) - **920 GeV**
- Medium Energy Run (**MER**) - **575 GeV**
- Low Energy Run (**LER**) - **460 GeV**

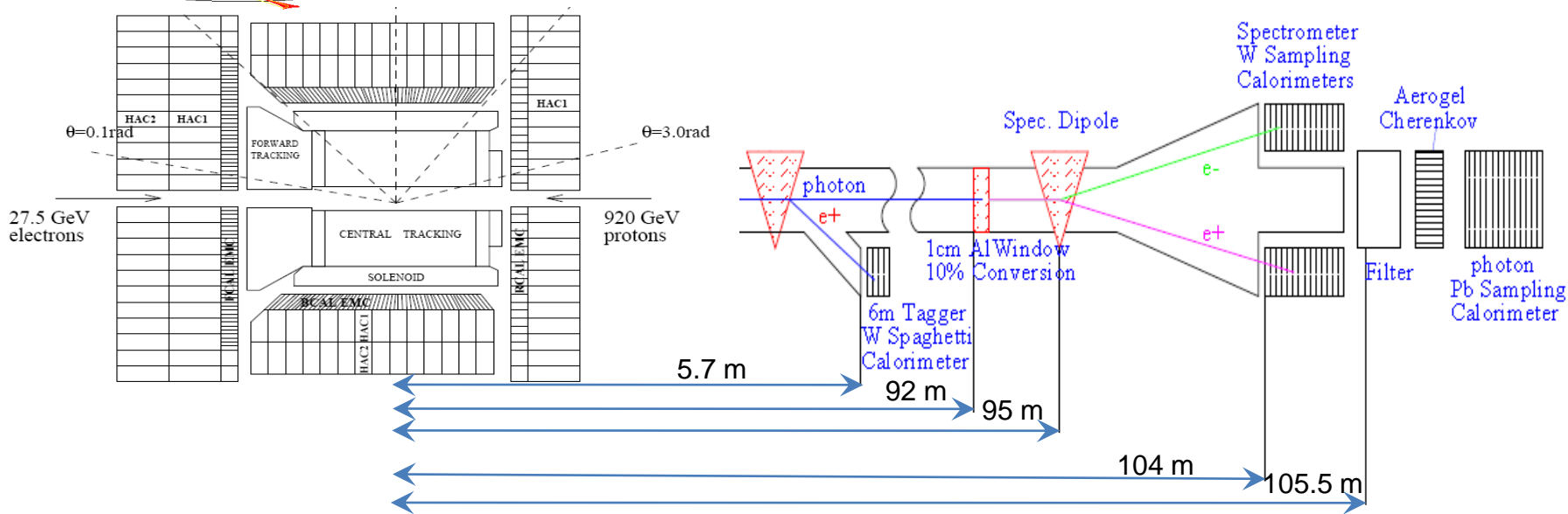
The luminosity collected in the ZEUS detector was determined in two independent ways (photon calorimeter and spectrometer) by measuring the rate of the Bethe-Heitler (BH) process

$$e^+p \rightarrow e^+\gamma p$$

The 6m tagger was calibrated with the spectrometer:

$$E_{6mT} = E_e - E_{spec.}$$

# The ZEUS trigger and signal measurement

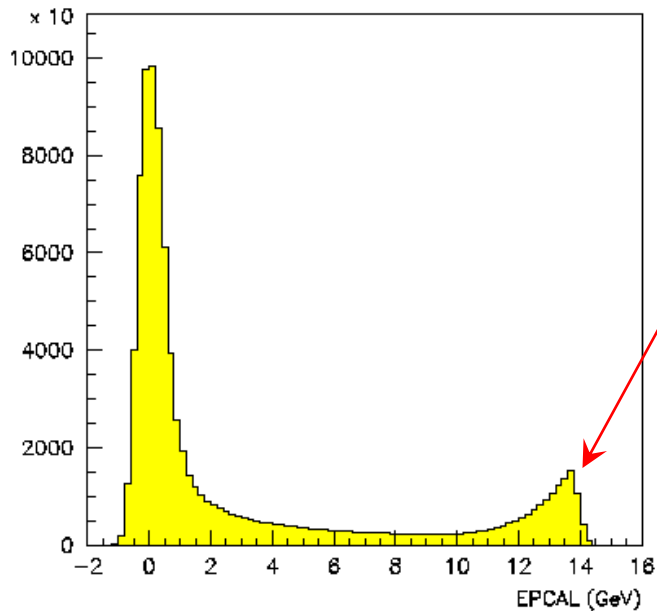


Required a **hit in the 6mT**,  
 $E_{PCAL} < 8 \text{ GeV}$  and in addition:

- Energy deposition in the rear part of the calorimeter.

or

- **Good tracking** (good reconstructed tracks).



PCAL energy for triggered events.  
 Used to subtract BH overlays.



# Monte Carlo Simulation

The PYTHIA 6.221 generator coupled to the HERACLES 4.6 generator (to include radiative corrections) was used.

At the generated level:

- $Q^2 < 0.01 \text{ GeV}^2$
- $y$  range slightly different for HER and LER due to different magnet settings:

HER       $0.748 < y < 0.847$       ( $275.33 \text{ GeV} < W < 292.9 \text{ GeV}$ )

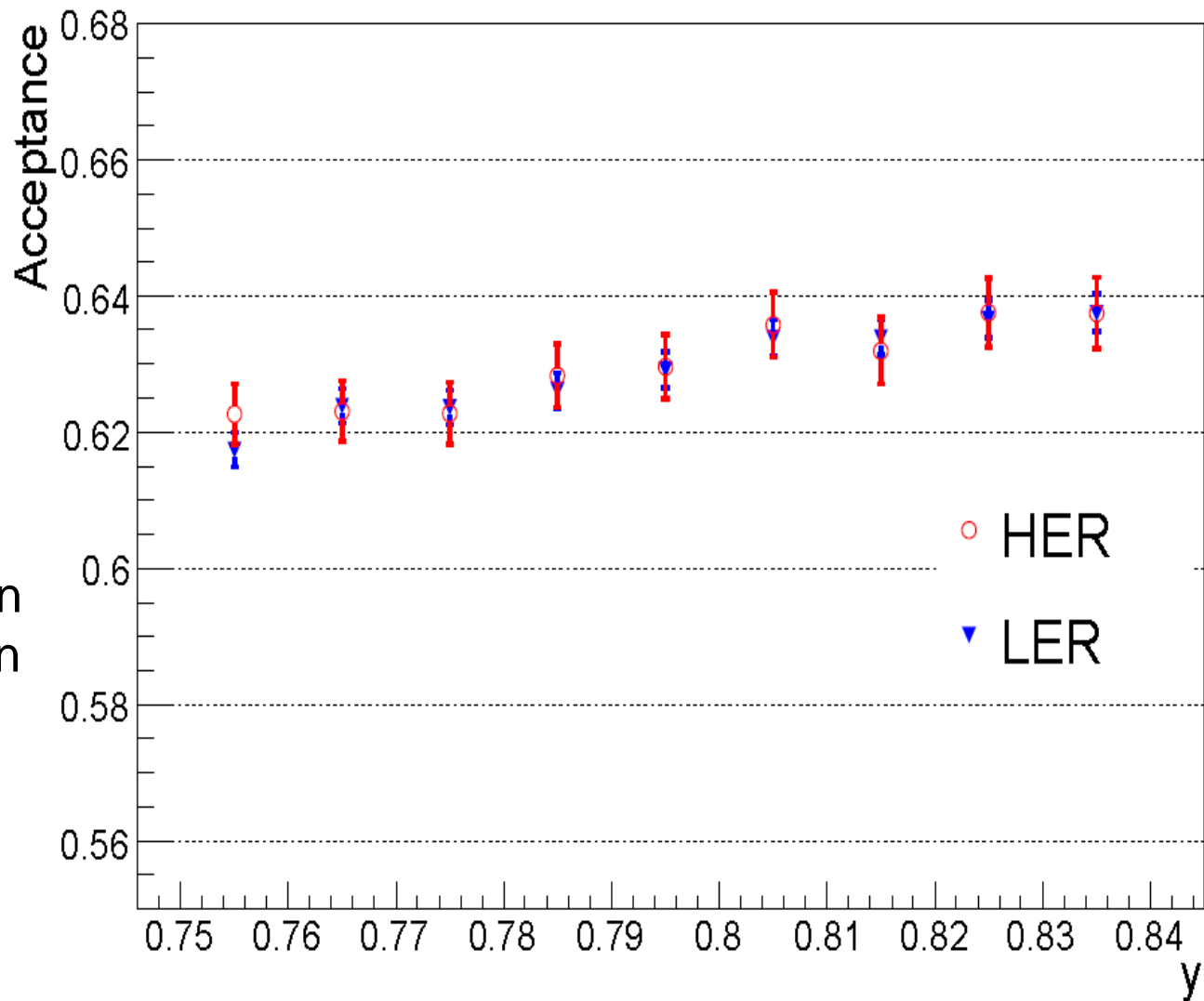
LER       $0.745 < y < 0.851$       ( $194.26 \text{ GeV} < W < 207.6 \text{ GeV}$ )

The acceptance of the ZEUS detector for photoproduction events is determined by the acceptance of the 6mT and that of the main detector which are independent.

# Acceptance as a function of $y$

The 6mT acceptance is practically 100%.

The difference between the HER and LER main detector acceptance (determined by MC) was found to be less than 1%.



# Results

The  $\gamma p$  cross sections ratio

$$\mathcal{L}_{LER} = 994.7 \text{ nb}^{-1}$$

$$\mathcal{L}_{HER} = 560.9 \text{ nb}^{-1}$$

$$R = \frac{\sigma_{HER}^{\gamma p}}{\sigma_{LER}^{\gamma p}} = \frac{N_{HER}}{N_{LER}} \cdot \frac{A_{LER}}{A_{HER}} \cdot \frac{\mathcal{L}_{LER}}{\mathcal{L}_{HER}} \cdot \frac{f_{LER}}{f_{HER}}$$

Uncertainties:  $\pm 0.52\%$  (stat.)  $\pm 1.05\%$  (sys.)  $\pm 1\%$   $\pm 3.5\%$

from:

signal measurement

LUMI

6m tagger

$$R = 1.050 \pm 0.005 \text{ (stat.)} \pm 0.040 \text{ (sys.)}$$

$$\mathcal{E} = 0.070 \pm 0.007 \text{ (stat.)} \pm 0.021 \text{ (sys.)} \pm 0.050 \text{ (6mT)}$$

Consistent with previous determinations of  $\mathcal{E}$ .

# Summary

- Measurement result consistent with earlier determinations of the  $W$  dependence of total cross sections, however has the advantage of being independent (one experiment).
- Result will be improved with the addition of the MER data and better understanding of the 6m tagger.

Thank you !