# Measurement of the *W* dependence of $\sigma_{tot}(\gamma p)$ 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:

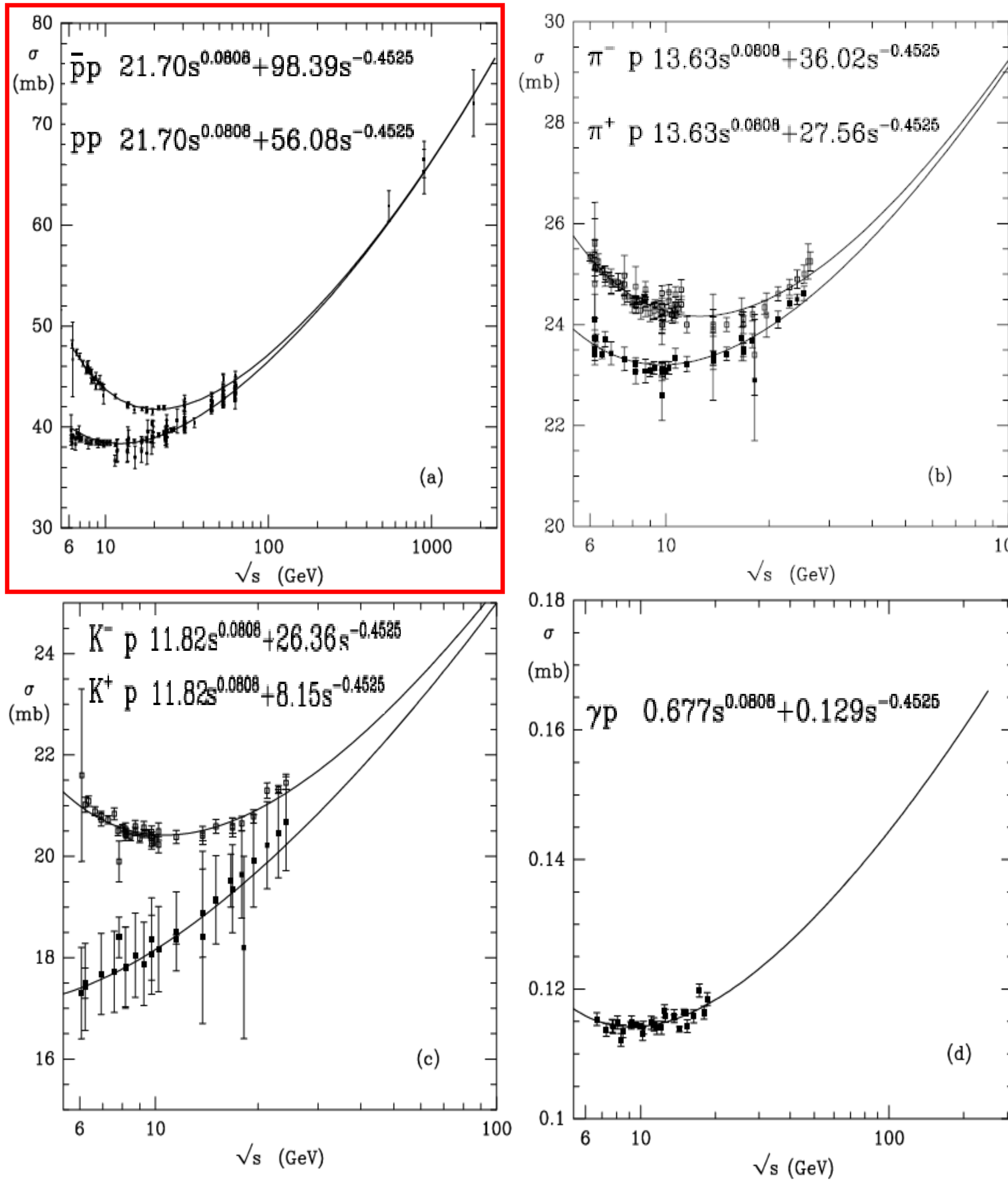
$$\sigma_{tot}(h\text{-}h) = A s^{\varepsilon} + B s^{-\eta}$$

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 1σ or 2σ from average

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

ε is universal !



# Motivation II

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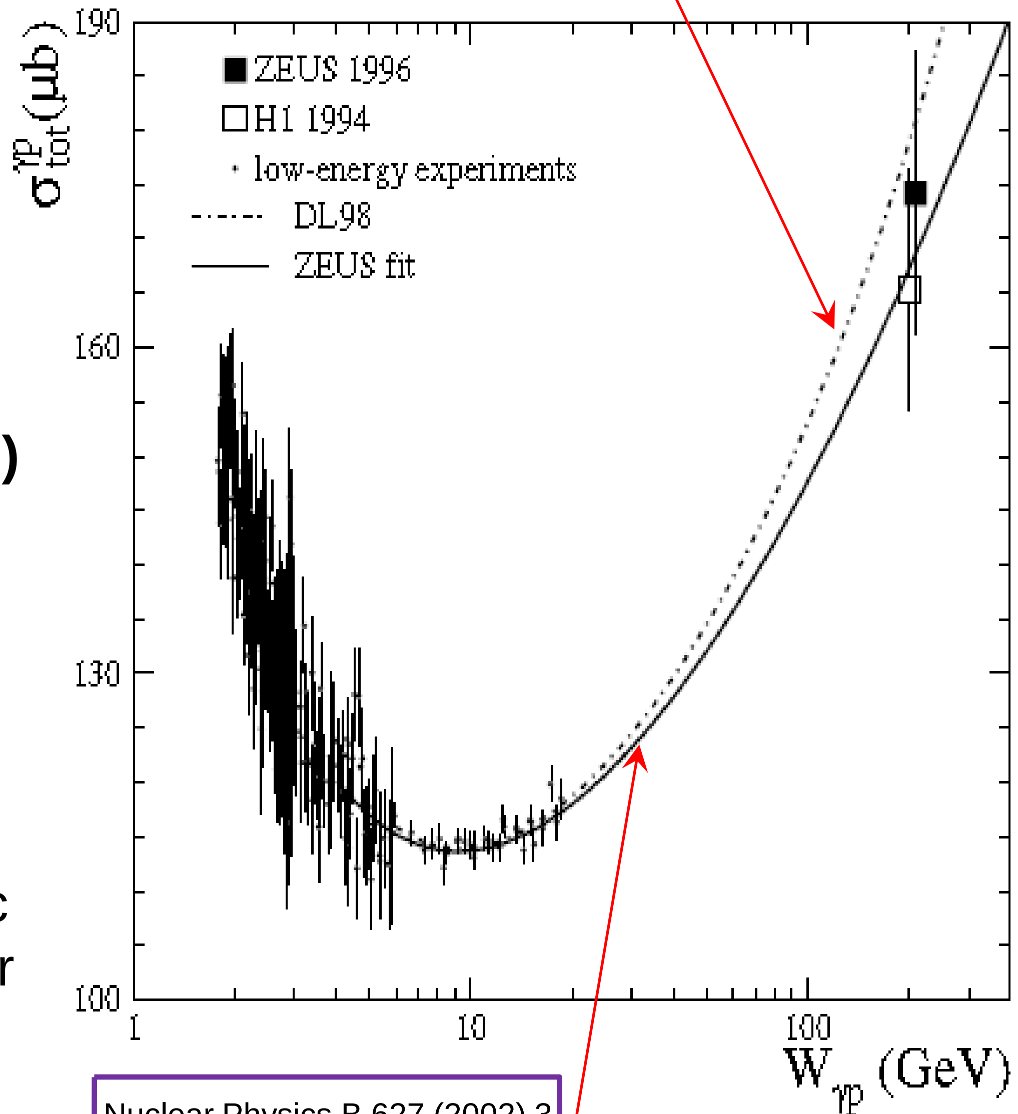
$\sigma_{tot}(\gamma p) = 0.283\,(W^2-m_p^2)^{0.418} + 65.4(W^2-m_p^2)^{0.0808} + 138(W^2-m_p^2)^{-0.4525}$

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

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

Further measurements of $\sigma_{tot}(\gamma p)$ 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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$\sigma_{tot}(\gamma p) = (57\pm5)(W^2)^{0.100\pm0.012} + (121\pm13)(W^2)^{-(0.358\pm0.015)}$

# Concept of measurement

Prior to its shut-down on 30th 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 $\boldsymbol{\sigma_{tot}(\gamma p)}$.

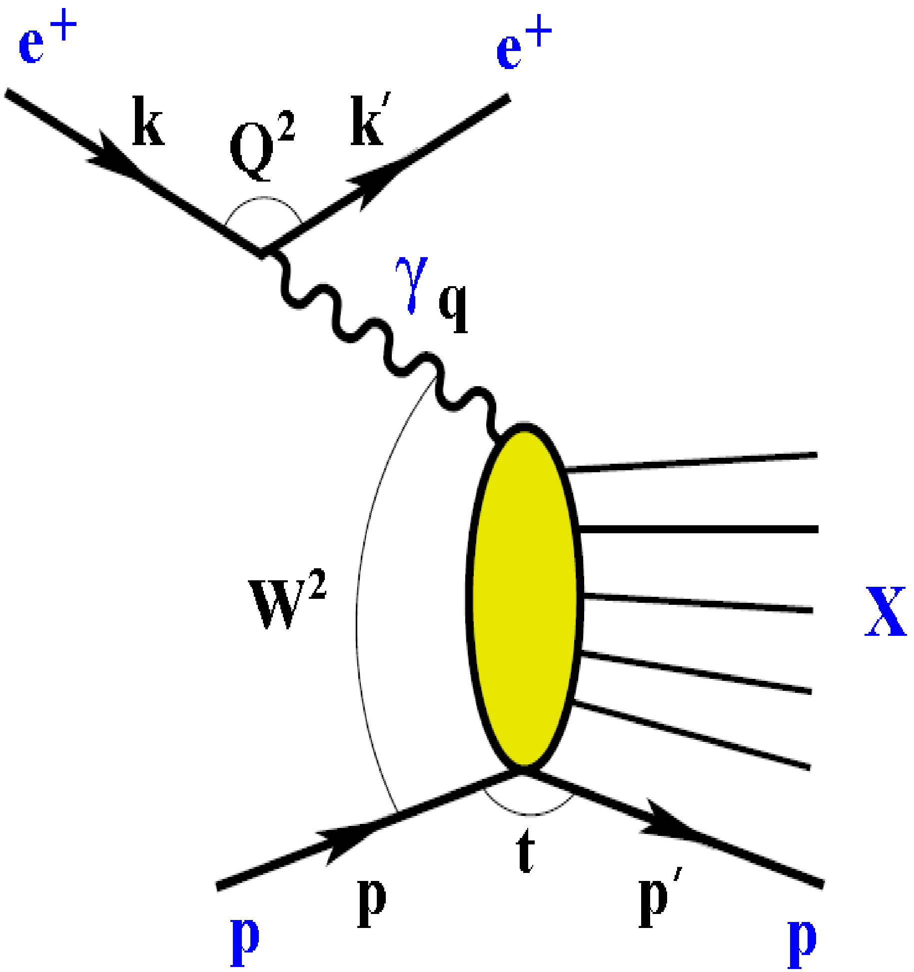
Assuming $\boldsymbol{\sigma \sim W^{2\varepsilon}}$, $\boldsymbol{\varepsilon}$ can be extracted from the ratio *R* of cross sections probed at different ***W*** values.

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

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

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:

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

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

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

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

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

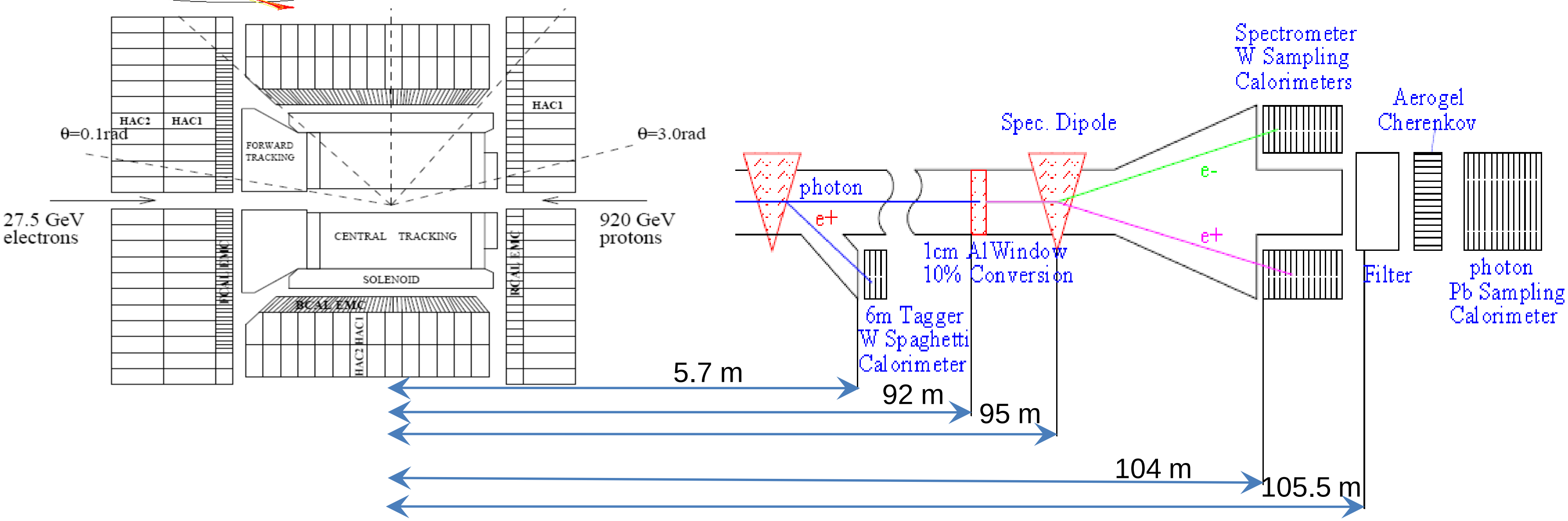
$\Rightarrow$ $\sigma_{tot}(\gamma p)$ can be extracted from $\sigma^{e^+p}$

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

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

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:

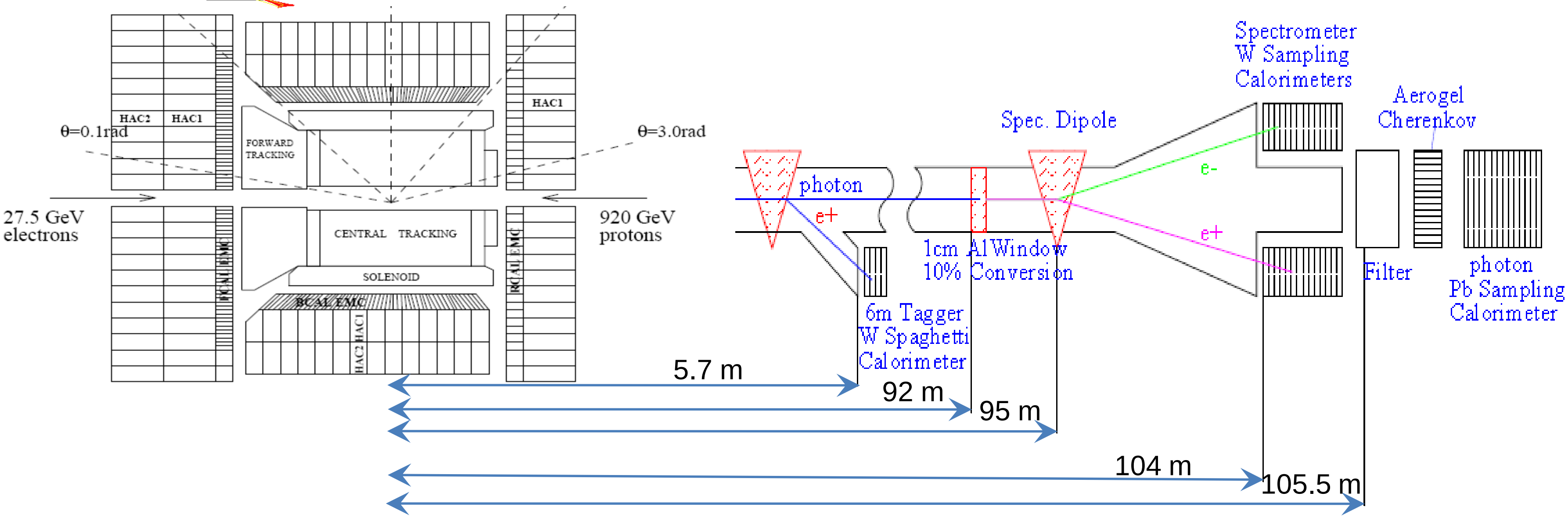
High Energy Run (HER) - 920 GeV
Medium Energy Run (MER) - 575 GeV
Low Energy Run (LER) - 460 GeV

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

$$e^+p \longrightarrow e^+\gamma p$$

The 6m tagger was calibrated with the spectrometer: $E_{6mT}=E_e-E_{spec.}$

# The ZEUS trigger and signal measurement

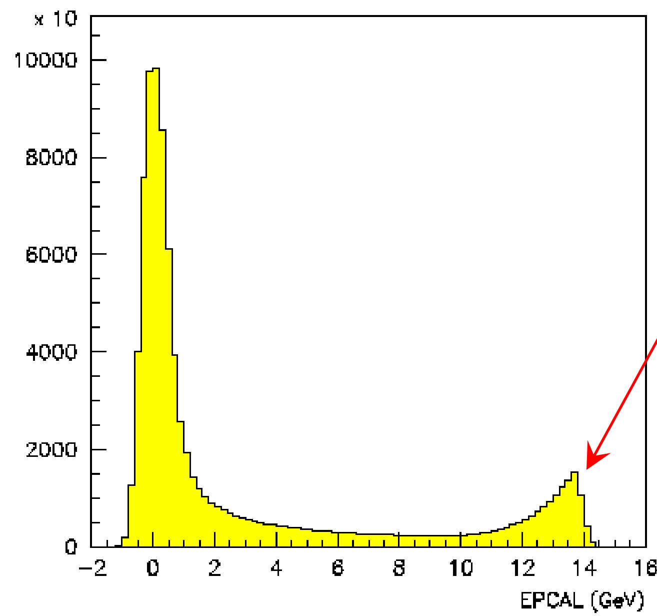



Required a hit in the 6mT,
$E_{PCAL} < 8$ GeV and in addition:

- 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:

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

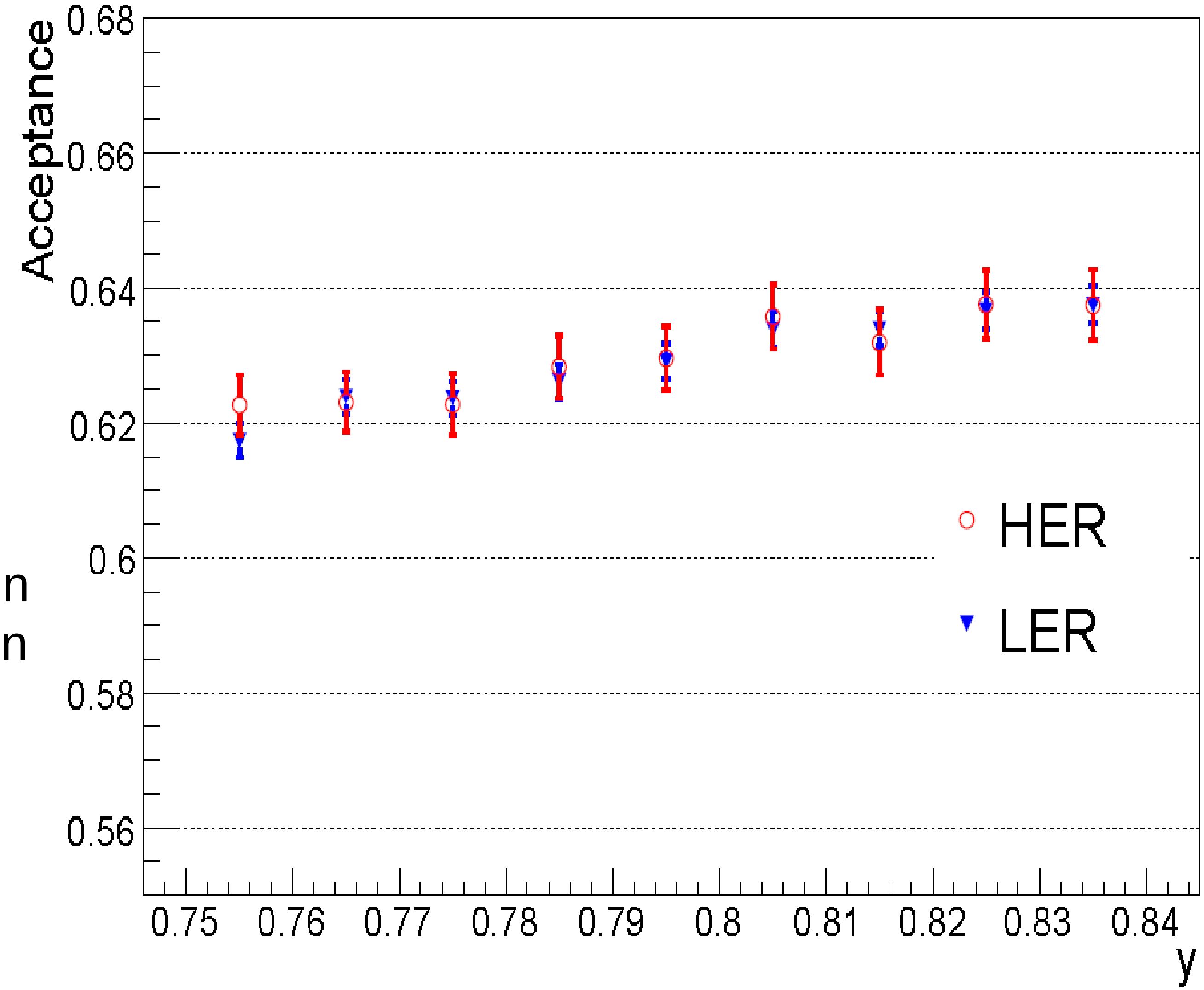
| | | |
|---|---|---|
| HER | $0.748<y<0.847$ | (275.33 GeV < W < 292.9 GeV) |
| LER | $0.745<y<0.851$ | (194.26 GeV < W < 207.6 GeV) |

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

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

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

The γp cross sections ratio

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

Uncertainties: ± 0.52% (stat.) ± 1.05% (sys.) ± 1% ± 3.5%

from: signal measurement LUMI 6m tagger

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

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

Consistent with previous determinations of $\varepsilon$.

# 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 !