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

On behalf of the ZEUS collaboration

Motivation

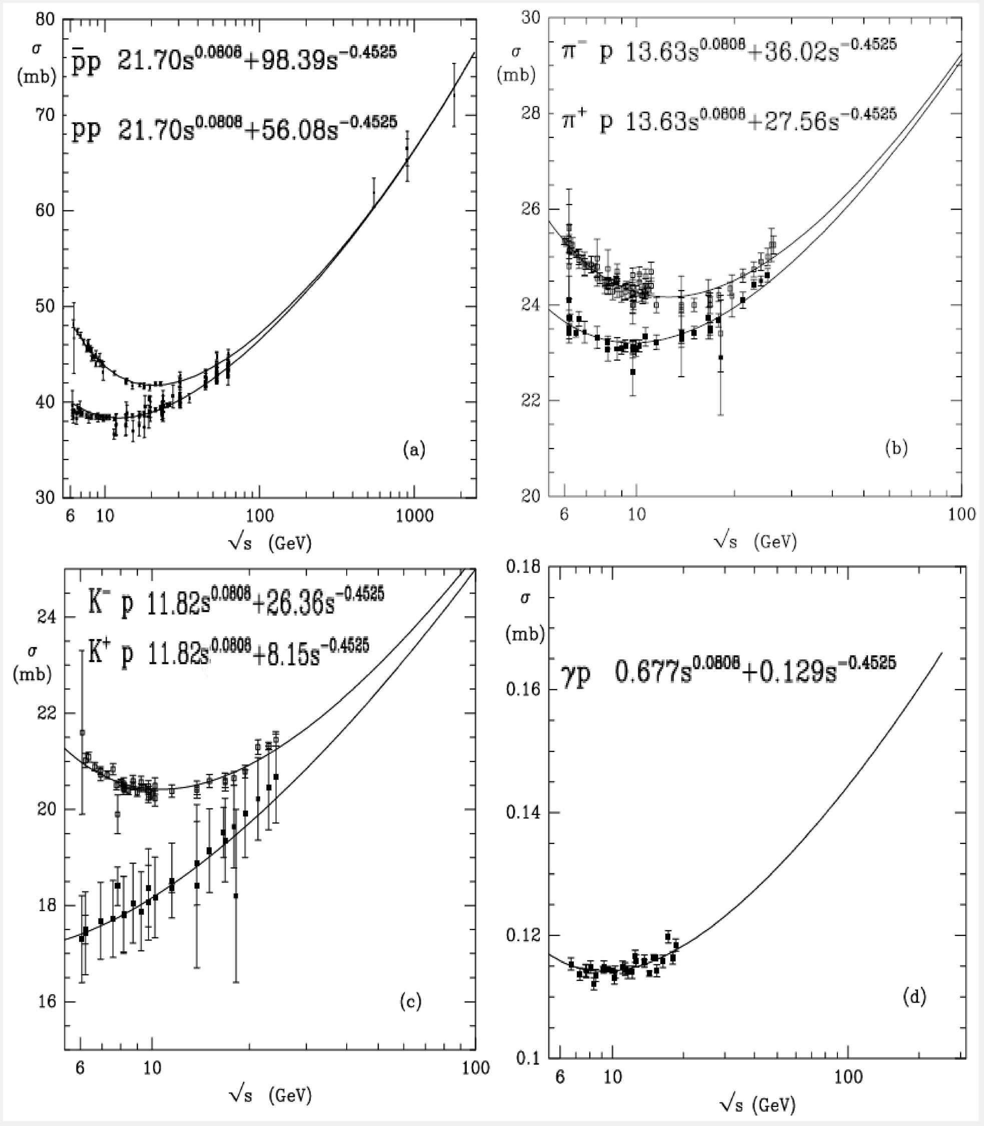
Donnachie and Landshoff (DL) (Phys. Lett. B296, 227 (1992)) showed that all hadron-hadron total cross sections can be described by a simple form:

$$\sigma_{tot}(h\text{-}h) = As^{\varepsilon} + Bs^{-\eta}$$

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

Cudell et al. (Phys. Rev. D61 034019, 1 (2000))
$\varepsilon = 0.093 \pm 0.003$

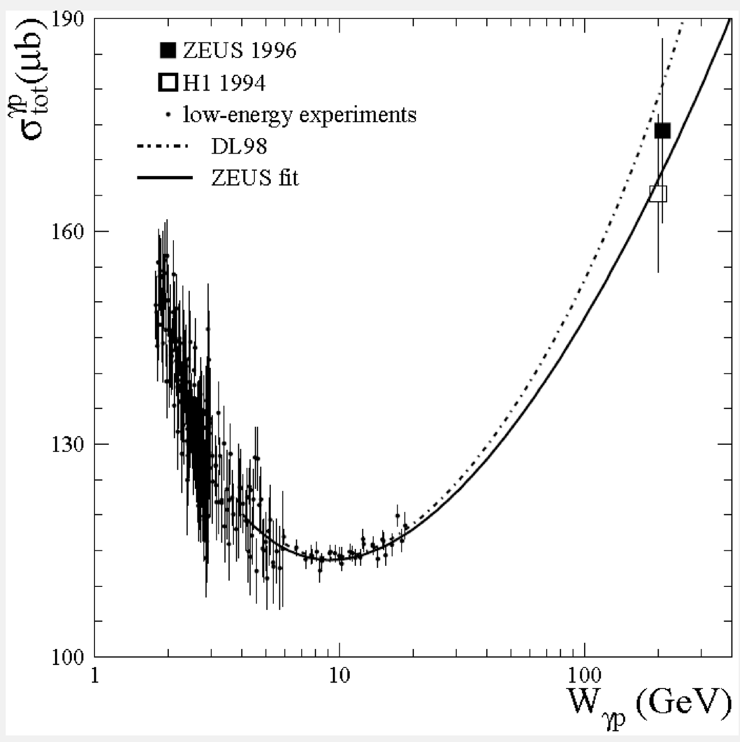
ε is universal !



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

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.



Concept of measurement

Prior to its shut-down on 30th June 2007, HERA was running with constant nominal positron energy and switched to two additional proton energies, lower than the nominal value of 920 GeV.

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

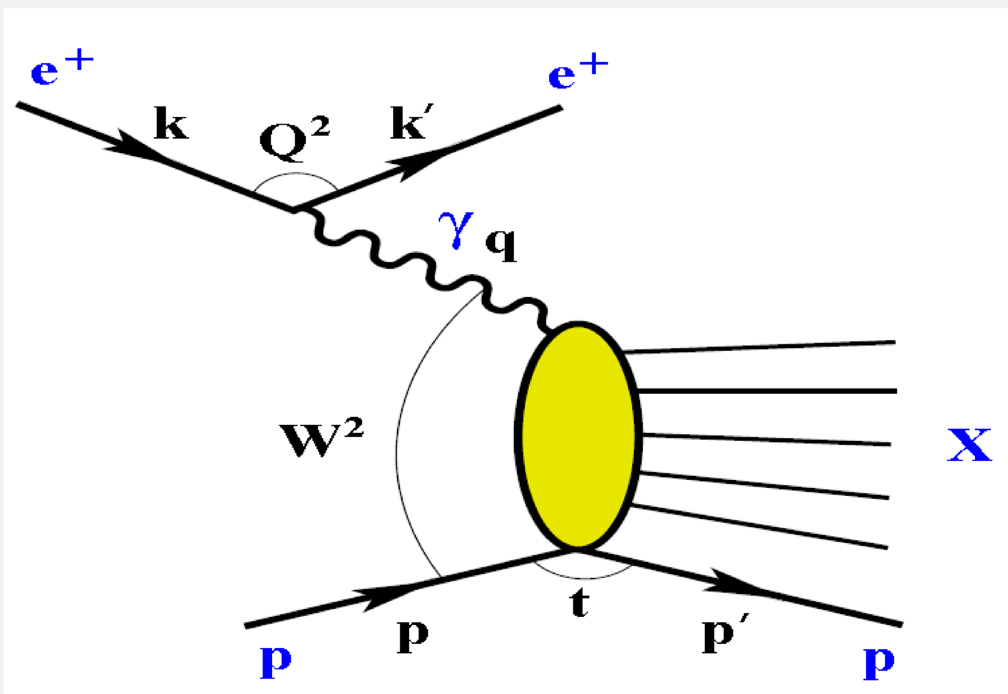
Assuming $\sigma \sim W^{2\varepsilon}$, ε can be extracted from the ratio R of cross sections probed at different W values.

$$R = \frac{\sigma(W_1)}{\sigma(W_2)} = \left(\frac{W_1}{W_2}\right)^{2\varepsilon}$$

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

The acceptance is expected to be the same for the three energy setups as the photon energy is the same and RCAL covers the fragmentation region of the photon
$\longrightarrow$ acceptances cancels in the ratio.

Kinematics & cross section



$$Q^2 \equiv -q^2 = -(k-k')^2$$
$$y = \frac{p \cdot q}{p \cdot k}$$
$$W^2 = (q+p)^2$$

Experimentally:

$$Q^2 = Q^2_{min} + 4E_e E'_e \sin^2\frac{\theta}{2};\ Q^2_{min} = \frac{m_e^2 y^2}{1-y}$$
$$y = 1 - \frac{E'_e}{2E_e}(1+\cos\theta_e) \approx 1 - \frac{E'_e}{E_e}$$
$$W \approx 2\sqrt{E_e E_p y}$$

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

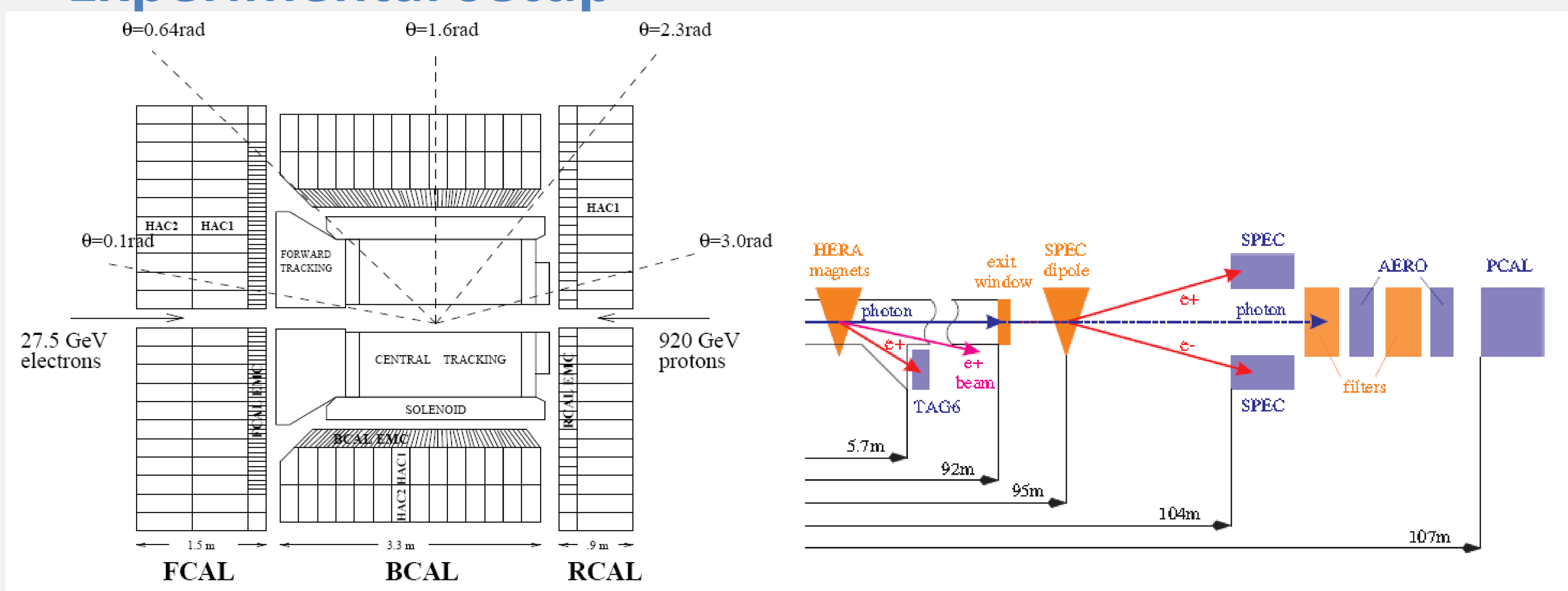
$\Rightarrow$ $\sigma_{tot}(\gamma p)$ can be extracted from σ^{e^+p} $\quad$ $\boxed{\sigma_{tot}(e^+p) = f \cdot \sigma_{tot}(\gamma p)}$

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

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

Flux uncertainty dominated by range of integral.

Experimental setup



During the few months before HERA shutdown, 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 bremsstrahlung process
$e^+p \longrightarrow e^+\gamma p$

Trigger required a hit in the 6m Tagger (TAG6) and energy deposition in the rear part of the calorimeter. In addition, $E_{PCAL} < 14$ GeV reduced bremsstrahlung overlaps.

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

Monte Carlo Simulation

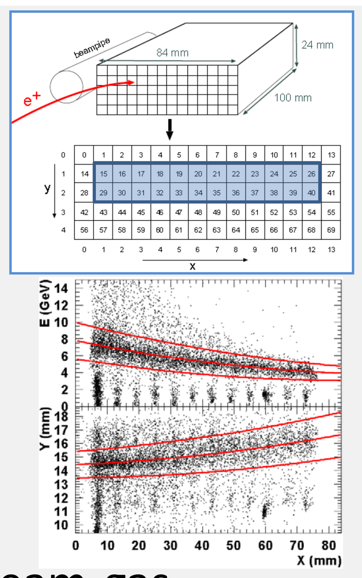
The PYTHIA 6.416 generator coupled to the HERACLES 4.6 generator (to include radiative corrections) was used.
The mixture of photoproduction processes generated was adjusted to describe the CAL energy distributions in the total cross section data.

The acceptance of the ZEUS detector for photoproduction events is determined by the acceptance of the TAG6 and that of the main detector which are independent, thus:

$$\sigma^{e^+p} = \frac{N}{A_{TAG6} \cdot A_{RCAL} \cdot \mathcal{L}} \Rightarrow \sigma^{\gamma p} = \frac{N}{f \cdot A_{TAG6} \cdot A_{RCAL} \cdot \mathcal{L}}$$

At the generated level:
- $Q^2 < 0.001$ GeV^2
- y range slightly different for HER/MER/LER due to different magnet settings:
  HER 274 GeV < W < 296 GeV , MER 216 GeV < W < 233 GeV , LER 194 GeV < W < 209 GeV

Event selection & Data analysis



- Hit in TAG6
- Use of neural networks for positron position reconstruction and energy correction of a few noisy cells.
- E(X) and Y(X) were determined and cuts were made to reject off-momentum beam positrons and background from beam-gas interactions.

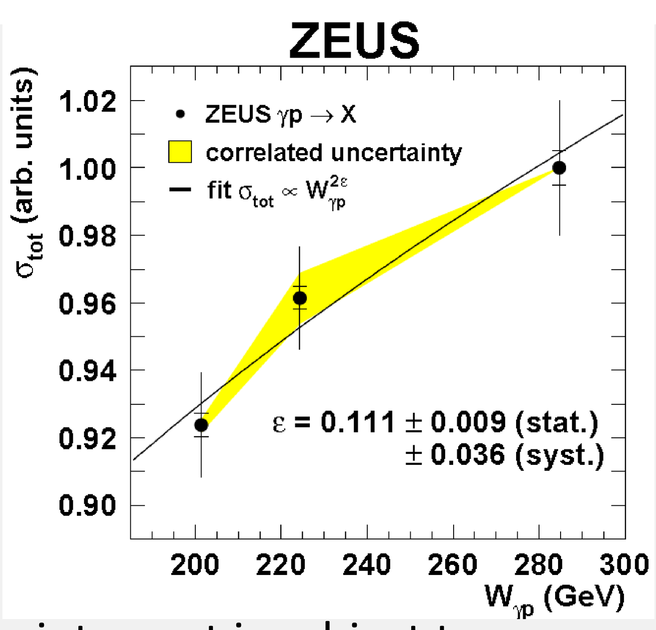
The number of selected events was corrected to take into account beam-gas interactions and overlays with bremsstrahlung interactions.
- background from beam-gas interactions was determined using non-colliding positron bunches and subtracted statistically (scaled to the ratio of bunch currents).
- Photoproduction events with a hit in TAG6 that occurred in coincidence with a hit in PCAL of bremsstrahlung photon with energy >14 GeV were vetoed; corrected for by weighting the number of accepted events by a factor determined from the rate of overlaps at the time each event was accepted.
- Photoproduction events that satisfied the RCAL trigger but had no hit in TAG6 that occurred in coincidence with bremsstrahlung event with a hit in TAG6 that was not vetoed by the PCAL veto (due to limited acceptance and resolution of the PCAL) were subtracted.
- The photon flux in each energy setup was determined (different due to different magnetic fields).

Results

The γp cross section ratio

$$R = \frac{\sigma_i^{\gamma p}}{\sigma_{HER}^{\gamma p}} = \frac{N_i}{N_{HER}} \cdot \frac{\cancel{A_{HER}}}{\cancel{A_i}} \cdot \frac{\mathcal{L}_{HER}}{\mathcal{L}_i} \cdot \frac{f_{HER}}{f_i}$$

$\boxed{\varepsilon = 0.111 \pm 0.009(\text{stat.}) \pm 0.036(\text{sys.})}$



In the picture in which $\sigma_{tot}(\gamma p) \propto \ln^2(W^2)$ as required by the Froissart bound $\varepsilon \sim 0.11$ is expected, in agreement with the present measurement.
The interpretation of this result in terms of the Pomeron intercept is subject to assumptions on the Reggeon contribution in the relevant W range. The most recent analysis of all hadronic cross sections using a fit taking into account Pomeron and Reggeon terms (Phys. Rev. D65 074024) yielded a Pomeron intercept of 0.0959±0.0021. This is in agreement with the result presented here.