Energy dependence of $\sigma_{tot}(\gamma p)$ at HERA

Aharon Levy[1,2,*]
on behalf of the ZEUS collaboration

1- Max-Planck-Institute
Föhringer Ring 6, 80805 Munich, Germany

2- School of Physics and Astronomy
Tel Aviv University, 69978 Tel Aviv, Israel

The energy dependence of the total photon-proton cross-section is determined from data collected with the ZEUS detector at HERA with two different proton beam energies.

1 Introduction

Donnachie and Landshoff (DL) [1] showed that the energy dependence of all hadron-hadron total cross sections can be described by a simple Regge motivated form,

$$\sigma_{\rm tot} = A \cdot (W^2)^{\alpha_{I\!P}(0)-1} + B \cdot (W^2)^{\alpha_{I\!R}(0)-1}\,, \tag{1}$$

where A and B are process dependent constants, W is the hadron-hadron center-of-mass energy, and $\alpha_{I\!P}(0)$ $(\alpha_{I\!R}(0))$ is the Pomeron (Reggeon) trajectory intercept.

The $\sigma_{\rm tot}(\gamma p)$ dependence on W is particularly interesting because of the nature of the photon, which is known to exhibit properties of both a point-like particle (direct photon) and a hadron-like state (resolved photon). At the ep collider HERA, $\sigma_{\rm tot}(\gamma p)$ can be extracted from ep scattering at very low momentum transferred squared at the electron vertex, $Q^2 \simeq 0$ GeV^2.

The first measurements of the total γp cross section at HERA [2, 3] showed that the total photoproduction cross section has a W dependence similar to that of hadron-hadron reactions. Further measurements of $\sigma_{\rm tot}(\gamma p)$ at HERA [4, 5, 6] have reduced its statistical errors but the systematic uncertainties remained too large for a precise determination of the W dependence of the cross section. The original fits of DL gave $\epsilon \equiv \alpha_{I\!P}(0) - 1 = 0.0808$ and no uncertainties were determined. Cudell et al. [7], using a data set [9] that contained 2747 data points for total cross sections and 303 data points for real part of hadronic amplitudes, determined $\epsilon = 0.093 \pm 0.003$. However, only very few points were present for the highest center-of-mass energies. The data were from different experiments and had a large spread. Furthermore, the value of the Pomeron intercept comes out strongly correlated with that of the Reggeon trajectories. In another evaluation [8], the authors give the range of 0.07 - 0.10 as acceptable values for ϵ.

Recently, just before the shut-down of the HERA collider, runs with different proton energies were taken, at constant positron energy. This opened up the possibility to determine precisely the power of the W dependence by measuring the ratios of cross sections in one experiment, thus having many of the systematic uncertainties canceling out.

The difficulty in measuring total cross section, σ, in a collider environment originates from the limited acceptance of collider detectors for certain class of processes, in particular for elastic and diffractive scattering, where the final state particles are likely to disappear down the beam-pipe. The determination of the acceptance relies on Monte Carlo simulation of the

---

[*] Partly supported by the Israel Science Foundation (ISF).

physics and of the detector. The simulation of the physics is subject to many uncertainties which then impact on the systematic uncertainty on cross section measurement. For the energy dependence of σ, the impact of these uncertainties as well as of the geometrical uncertainties can be minimized by studying the ratio r of cross sections probed at different W values.

Assuming $\sigma \sim W^{\delta}$ [6],

$$r = \frac{\sigma(W_1)}{\sigma(W_2)} = \left(\frac{W_1}{W_2}\right)^{\delta} . \tag{2}$$

Experimentally,

$$\sigma = \frac{N}{A \cdot \mathcal{L}} , \tag{3}$$

where A, $\mathcal{L}$ and N are the acceptance, luminosity and number of measured events, respectively, and therefore

$$r = \frac{N_1}{N_2} \cdot \frac{A_2}{A_1} \cdot \frac{\mathcal{L}_2}{\mathcal{L}_1} , \tag{4}$$

where the index 1(2) denotes measurements performed at W_1 (W_2). The acceptance for γp events at HERA depends mainly on the detector infrastructure in the electron (rear) direction. If the change in the W value results from changing the proton energy, the acceptance is likely to remain the same independent of W and the ratio of acceptances will drop out in Eq. (4).

The number of measured events is from $e^{+}p$ interactions. In order to convert the ep to γp cross section, one uses the following relation:

$$\frac{d\sigma^{e^{+}p}(y)}{dy} = \frac{\alpha}{2\pi}\left[\frac{1+(1-y)^2}{y} ln\frac{Q^2_{max}}{Q^2_{min}} - 2\frac{(1-y)}{y}(1-\frac{Q^2_{min}}{Q^2_{max}})\right]\sigma^{\gamma p}_{tot}(y) , \tag{5}$$

where the term multiplying the γp cross section is known as the flux factor f. In Eq. (5), α is the electromagnetic coupling constant, y is the energy fraction transferred by the positron to the photon in the proton rest system, $Q^2_{min} = {m_e}^2 \frac{y^2}{1-y}$ (here m_e is the mass of the electron) and the highest measured Q^2 is Q^2_{max} (~ 0.01 GeV^2). The flux f is a function of y and needs to be integrated over the measured y range for obtaining the total γp cross section.

In the final days of HERA running, a special photoproduction trigger was implemented for runs with proton energy set at the nominal value of 920 GeV (high-energy run, HER) and at proton energies lowered to 575 (medium-energy run, MER) and 460 GeV (low-energy run, LER). The analysis presented here attempts to extract the value of δ based on the combination of the HER and LER data.

2 Experimental details

The setup of the experiment is shown in Fig. 1. At a distance of about 6m from the interaction point in the ZEUS calorimeter, a spaghetti type calorimeter, the so-called six meter tagger (6mT), was installed. The magnetic field of the HERA magnet, in which the 6mT was located, bent the low-angle scattered positrons to the tagger, and thus the tagger was used for tagging photoproduction events. The luminosity was determined by measuring the rate of photons from the Bethe-Heitler (BH) process ($e^{+}p \rightarrow e^{+}\gamma p$). The latter was measured by two independent systems, the photon calorimeter (PCAL) and the

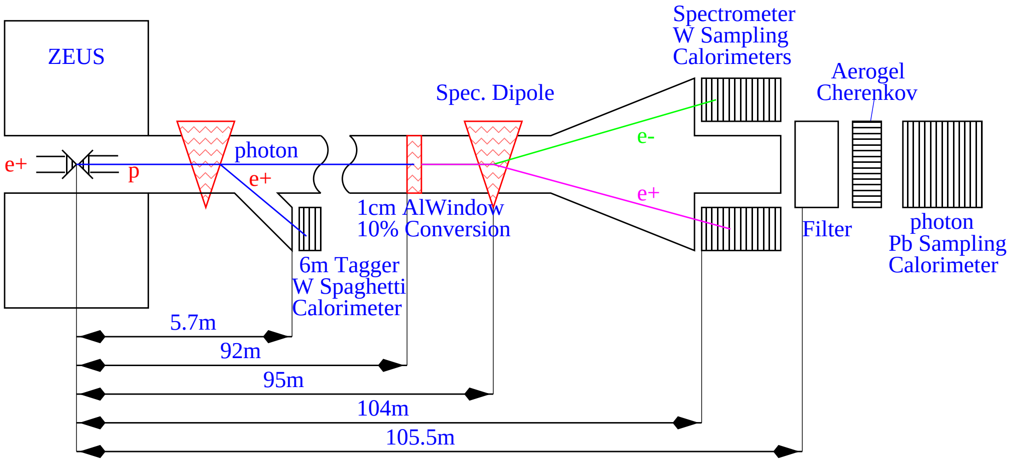

Figure 1: Schematic layout of the ZEUS detector with the six meter tagger and the components of the luminosity system, together with their distance from the interaction point.

spectrometer (SPEC). The two components (PCAL and SPEC) enabled the measurement of the luminosity in two independent ways with 1% relative uncertainty. Overall there was a 2.6% uncertainty common to both, due to the geometrical acceptance of the exit window.

A dedicated trigger logic was designed to collect photoproduction events and keep the rates at acceptable levels. Two conditions had to be fulfilled, a low-angle scattering positron candidate detected in the 6mT and some activity in the main detector.

For calculating the acceptance corrections in the main detector, the PYTHIA 6.221 [10] generator was used. It was coupled to the HERACLES 4.6 [11] program to simulate electromagnetic radiative effects. The acceptance of the 6mT is 100% for photoproduction events with positrons in the approximate energy range 3.5 - 6.8 GeV, with a mean W of 287 GeV for HER and 203 GeV for LER.

3 Results

The data samples taken with the dedicated trigger configuration consisted of 4,164,552 events (corresponding to a luminosity of 560.9 nb^{-1} in the HER and 12,798,828 events (corresponding to a luminosity of 994.7 nb^{-1}) in the LER. These samples included background from different sources, like beam-gas events, BH overlays where the high energy photon hit the PCAL and the positron hit the 6mT, and off-momentum (with some transverse momentum) beam positrons. After all cuts needed for suppressing background events, 62,653 events in the HER and 113,362 events in the LER remained as genuine photoproduction events.

In order to calculate the ratio r from Eq. (4), the acceptances A were calculated using the MC simulation. The acceptances of HER and LER are equal within errors, corroborating our hypothesis that the ratio is independent of the acceptance and thus reduces the systematic error coming from the MC simulation. The systematic errors on the ratio came from the background suppression cuts (1.05%), from the uncertainty on the ratio of luminosities (1%) and from the uncertainty on the ratio of fluxes (3.5%). This last high systematic uncertainty comes from the fact that the y range over which the flux has to be integrated is presently not precisely determined by the 6mT. This will improve with a better understanding and calibration of the 6mT.

The value of δ as obtained from r is

$$\delta = 0.140 \pm 0.014(\text{stat.}) \pm 0.042(\text{syst.}) \pm 0.100(\text{6mT}), \tag{6}$$

which translates into

$$\epsilon = 0.070 \pm 0.007(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.050(\text{6mT}), \tag{7}$$

This result is consistent with earlier determinations of ϵ, however has the advantage of being obtained from a single experiment and being model independent.

The statistical uncertainty will be improved in the future by including the data taken with a third proton beam energy (MER). The systematic uncertainty will improve by a better understanding and calibration of the 6mT.

References

[1] A. Donnachie and P.V. Landshoff, Phys. Lett. **B 296** (1992) 227.

[2] ZEUS Collaboration, M. Derrick et al., Phys. Lett. **B 293** (1992) 465-477.

[3] H1 Collaboration, T. Ahmed et al., Phys. Lett. **B 299** (1993) 374.

[4] ZEUS Collaboration, M. Derrick et al., Zeit. Phys. **C 63** (1994) 391-408.

[5] H1 Collaboration, S. Aid et al., Zeit. Phys. **C 69** (1995) 27.

[6] ZEUS Collaboration, S. Chekanov et al., Nucl. Phys. **B 627** (2002) 3-28.

[7] J.R. Cudell et al., Phys. Rev. **D 61** (2000) 034019.

[8] J.R. Cudell et al., Phys. Lett. **B 395** (1997) 311.

[9] Data used were extracted from the PPDS accessible at http://wwwppds.ihep.su:8001/ppds.html. Computer readable data files are also available at http://pdg.lbl.gov.

[10] T. Sjöstrand, Zeit. Phys. **C 42** (1989) 301; H-U. Bengtsson and T. Sjöstrand, Computer Phys. Comm. **46** (1987) 43.

[11] A. Kwiatkowski, H. Spiesberger and H.-J. Möhring, Computer Phys. Comm. **69** (1992) 155; H. Spiesberger, "HERACLES, An event generator for *ep* interactions at HERA including radiative processes (Version 4.6)" (1996), available on http://www.desy.de/∼hspiesb/heracles.html.