A Measurement of the Total $\gamma p$ Cross Section at HERA for $W_\gamma p = 207$ GeV

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- Motivation
- Method of Calculating $\sigma^{\gamma p}$
- Detector Acceptance
- Results
- Conclusions
Universality of hadronic total cross sections

\[ \sigma_{\text{Tot}} = Xs^\varepsilon + Ys^{-\eta} \]

- Regge \( \sigma_{\text{Tot}} = Xs^\varepsilon + Ys^{-\eta} \)
- Large uncertainty on \( \varepsilon \): \( \gamma p \) measurement

Figure 36.17: Summary of hadronic and \( \gamma p \) total cross sections (top), and fit results to exponents for cross sections. (Courtesy of the COMPAS Group, JHEP, Protvino, Russia, 1990.)

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Parameterizations

- Regge theory $\rightarrow \gamma p$ cross section for real photon ($Q^2 = 0$)

- one pomeron term
  - $(\sigma_{\text{Tot}} = X_s \varepsilon + Y_s^{-\eta})$
  - ALLM $ep$ whole $Q^2$ range
  - PDG $Q^2 = 0$ all hadrons

- two pomeron terms
  - $(\sigma_{\text{Tot}} = X_1 s^{\varepsilon_1} + X_2 s^{\varepsilon_2} + Y_s^{-\eta})$
  - Donnachie–Landshoff

- $\sigma_{\gamma p}^2 = \sigma_{pp}^* \sigma_{\gamma\gamma}, \sigma_{pp}^* \sigma_{\gamma\gamma}$ (high energy)
Measuring $\sigma_{\gamma p}$ at ZEUS

- Positron emits a photon which interacts with the proton
- Use Weizacker–Williams (equivalent photon approximation) to go from $ep$ to $\gamma p$ cross section measurement
- Measurement of positron energy gives energy of interacting photon

$$(E_{e^+ beam} = E_{etagged} + E_{\gamma})$$
Measuring $\sigma_{\gamma p}$ at ZEUS

- **ZEUS rear calorimeter measures interacting photon, positron tagger measures positron**
  - Trigger—energy in rear calorimeter & energy in positron tagger
- **Calorimeter acceptance from MC**
  - Employed previous ZEUS measurements of $\gamma p$ subprocesses to reduce reliance on MC
- **Calorimeter trigger calibration different from offline values**
  - Offline cut chosen to reduce error due to trigger miscalibration
ZEUS $\sigma_{\gamma p}$

$\sigma_{\gamma p}(W_{\gamma p}=207\text{ GeV}) = \ldots$

- Number of events/Luminosity
- $f_{\gamma}^{-1} = \text{Weizacker–Williams flux factor}$
- $A_{\text{positron}}^{-1} = \text{Acceptance of positron tagger}$
- $A_{\text{RCAL}}^{-1} = \text{Acceptance of rear calorimeter}$
- $\Delta_{\text{BSO}} = \text{Bremsstrahlung overlays}$
- $\Delta_{\text{misc}} = \text{radiation and other corrections}$

We veto events with a bremsstrahlung photon $\Delta_{\text{BSO}}$ takes into account events that were vetoed and should have been kept

Radiation and other corrections($\Delta_{\text{misc}}$) $\sim 1\%$
**Positron Tagger Acceptance Method**

- **Use Bremsstrahlung events** ($e^+p \rightarrow e^+p\gamma$)
- **Bremsstrahlung data tune beamline MC**
- **Tuned $\gamma p$ Monte Carlo used to calculate $\gamma p$ acceptance**
- **Positron acceptance depends on interaction vertex and $e^+$ beam tilt (vary over time)**
  - Single $e^+p$ fill so $e^+$ orbit and tilt known
  - Special runs taken before and after total cross section run to measure orbit and tilt
  - Calibration drifts minimal
Positron Tagger Acceptance

- Bremsstrahlung Monte Carlo vs. data comparison

ZEUS Preliminary 1996

Positron tagger acceptance = $0.731 \pm 0.049$
Event Selection

• **Energy in ZEUS Rear Calorimeter > 0.600 GeV**
  - Trigger calibration effects negligible

• **Positron tagger energy**
  \[ 12 < E_{e^+} < 16 \text{ GeV} \]
  - Center-of-mass energy: \( W_{\gamma p} = 207 \text{ GeV} \)

• **Photon tagger energy < 1.0 GeV**
  - Removes Bremsstrahlung

• **Timing of event consistent with \( e^+ p \) collision**

• **Interactions between \( e^+ \) and gas in the beam statistically subtracted**
Calorimeter Acceptance

- To first order total cross section given by 7 subprocesses

**Dominant processes**

- **Soft photoproduction via VDM**
  - Elastic: $\gamma(p,\omega,\phi)$
  - Proton Dissociative: $\gamma(p,\omega,\phi)$
  - Photon Dissociative: $\gamma(p)$
  - Double Dissociative: $\gamma(p)$
  - Minbias: $\gamma(p)$

- **Hard photoproduction**
  - Direct: $\gamma(q, \bar{q})$
  - Resolved: $\gamma(q, \bar{q})$

Previous ZEUS measurements of individual subprocesses used as inputs (except Minbias)

Constrained fit made to kinematic quantities ($M_x, E_T, E, \eta_{max}$, multiplicity)

Rear Calorimeter energy used in trigger, so RCAL distribution checked for agreement
Subprocess Fractions

- Subprocesses combined according to ZEUS measurements to reduce reliance on Monte Carlo

**Dominant processes**

- **Soft photoproduction via VDM**
  
  **Elastic**
  \[ \gamma(p,\omega,\phi) \]  
  \[ p \]  
  
  **Proton Dissociative**
  \[ \gamma(p,\omega,\phi) \]  
  \[ p \]  
  
  **Photon Dissociative**
  \[ \gamma(p) \]  
  
  **Double Dissociative**
  \[ \gamma(p) \]  
  
  **Minbias**
  \[ \gamma(p) \]

- **Hard photoproduction**
  
  **Direct**
  \[ \gamma(q) \]  
  \[ \bar{q} \]  
  
  **Resolved**
  \[ \gamma(q) \]  
  \[ \bar{q} \]

- Photon $\rightarrow$ VM cross section measured at ZEUS
- Photon $\rightarrow$ X cross section measured at ZEUS
- Minbias Events
- Hard Photoproduction Ratio taken from MC, verified by ZEUS measurements
Calorimeter Acceptance Results

- Fit of subprocesses to $M_x$

$$M_x = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i E_i \cos \Theta_i\right)^2}$$

Calorimeter Acceptance = 0.76 $^{+0.041}_{-0.015}$

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$\sigma_{\gamma p} (W = 207 \text{ GeV}) = 172\pm 1^{+13}_{-15} \mu b$
Comparison with $\gamma\gamma$ and $p\bar{p}$

CDF, E710 $p\bar{p}$ data averaged
Scaled to $W=65$ GeV using PDG96 $\epsilon$
L3,Opal $\gamma\gamma$ data averaged
ZEUS measurement scaled to $W=65$ GeV
Compared using

$$\sigma_{\gamma p}^2 = \sigma_{p\bar{p}}^* \sigma_{\gamma\gamma}$$
Conclusions

- Universality of total hadronic cross section confirmed with $\gamma p$

- Agrees with Regge motivated fits to world data (ALLM & Donnachie–Landshoff)

- Consistent with $\sigma_{pp} / \sigma_{p\bar{p}}$ and $\sigma_{\gamma\gamma}$ measurements made at high energies

$$\sigma_{\gamma p} (W_{\gamma p} = 207 \text{ GeV}) = 172 \pm 1^{+13}_{-15} \mu\text{b}$$