Contents

- $\pi^+\pi^-$ photoproduction at HERA
- modelling of the $m_{\pi\pi}$ spectrum
- extraction of the $\sigma(\gamma p \rightarrow \rho^0 Y)$ energy dependence

H1prelim-18-012 4 ICHEP 2018
Vector Meson Photoproduction

- $\gamma \rightarrow q\bar{q}$ fluctuations $\rightarrow$ bound states
- $J^{PC}(\gamma) = 1^{--} \rightarrow$ vector mesons ($\rho, \omega, \phi, \ldots$)
- long lifetime $\rightarrow$ strong interaction: $\sigma(\gamma \text{ had}) \sim \sigma(\text{had had})$

**Diffraction**

- color singlet exchange:
  - $\rightarrow$ Regge picture: low-erg. IRegeons, high-erg. IPomeron
- cross-section cms energy dependence: $\sigma(W_{\gamma p}) \sim W_{\gamma p}^\delta$
  - $\rightarrow$ related to Regge-trajectories: $\delta(t) = 4(\alpha_{IP}(t) - 1)$
- momentum transfer at $p$-vertex $t$: $d\sigma/dt(t) \sim e^{-b|t|}$

- $W_{\gamma p} > 20$ all HERA data
- newer/LHC results not included
HERA $e^\pm p$ Collider at DESY

--- HERA: ---

- world's only $ep$ collider
- $E_e = 27.6$ GeV, max $E_p = 920$ GeV
- max $\sqrt{s} = 319$ GeV
- $e^+ p$ and $e^- p$ data
- $\mathcal{L}_{int} \sim 0.5$ fb$^{-1}$ per experiment + datasets at $\sqrt{s} = 225$ and 252 GeV

--- detectors ---

- two collider experiments: H1 and ZEUS
- multi-purpose detectors
- $\sim 4\pi$ calorimeter (em&had) coverage
- tracking in central region
- forward detectors

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Diffractive $\rho^0 \to \pi^+\pi^-$ Photoproduction at HERA

- **electro- → photoproduction**
  
  \[ Q^2 = -q^2 \to 0 \text{ GeV}^2 \] with quasi-real $\gamma$

- **$BR(\rho^0 \to \pi^+\pi^-) \sim 100\%$**
  
  $\to \pi^+\pi^-$ measurement

- **elastic scattering vs proton dissociating**
  
  dissociation: $p'{}^2 = M_Y^2 > m_p^2 \to$ dominates at large $|t|$

- **other contributions to $\pi^+\pi^-$**
  
  $\gamma, IR$ exchange, other vector mesons, non-resonant $\pi^+\pi^-$, ...
Photoproduction in H1

— Event Topology —

- photoproduction: $e'$ undetected ($Q^2 \lesssim 2 \text{GeV}^2$)
- diffractive scattering: $p'$ in very forward direction
- two oppositely charged, central, back-to-back tracks
- $p_T \lesssim 1 \text{GeV}$: often no signal in calo

— Challenges —

- trigger: L1 track trigger
- elastic vs proton-dissociation: tag using forward detectors
- $Q^2 > 0$, $M_Y \neq m_p$: kinematics under-constrained $\rightarrow$ deteriorates resolution
- tracker acceptance: many (small) backgrounds
Data-Set - MC Modelling

- $\sqrt{s} = 319$ GeV 2006/2007 positron data set
- $L \sim 1.3$ pb$^{-1}$ (downscaled trigger)
- $\sim 7 \cdot 10^5$ selected $\pi^+\pi^-$ events

--- Modelling by DiffVM MC ---

- **$\pi^+\pi^-$ signal:** elastic & proton-dissociative
  - tuned to data in $W_{\gamma p}$, $m_{\pi\pi}$, $t$
  - models also $\omega$, $\rho'$, non-resonant $\to \pi^+\pi^-$ contributions

- **backgrounds:**
  - $\omega \to \pi^+\pi^-\pi^0$
  - $\phi \to K^+K^-, K_SK_L, \pi^+\pi^-\pi^0, \rho\pi, \eta\gamma$
  - $\rho' \to \rho\pi\pi, \pi\pi\pi\pi$
  - $\gamma$-dissociation $\to$ hadrons via JETSET

- **proton-dissociation:**
  - $d\sigma_{\gamma p}/dM_Y \propto (1/M_Y^2)^\delta \otimes$ measured resonance structure
  - $M_Y < 1.9$ GeV: $N^*$ resonance with measured decay channels
  - $M_Y > 1.9$ GeV: $\rho'$ $\to$ hadrons via JETSET
**Data-Set - Control Plots**

**$m_{\pi\pi}$**

**$W_{\gamma p}$**

**$p_{T,\pi\pi}^2$**
Cross-Section Determination

- Unfolding Particle Level Cross-Sections:
  - subtract backgrounds
  - correct signal for detector efficiency and resolution
  - separate elastic from dissociative contributions
  - regularized template fit using TUnfold

\[
\frac{d\sigma(\gamma p \rightarrow \pi^+\pi^- Y)}{dm_{\pi\pi}}(W_{\gamma p}, m_{\pi\pi}) = \frac{N_{\text{unfolded}}^Y(W_{\gamma p}, m_{\pi\pi})}{\mathcal{L}\int \Delta m_{\pi\pi} \Phi_{\gamma/e}(W_{\gamma p})^*}
\]

- Reduced Fiducial Phasespace

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tr>
<td>20 GeV</td>
<td>(\leq)</td>
<td>(W_{\gamma p})</td>
</tr>
<tr>
<td>0.4 GeV</td>
<td>(\leq)</td>
<td>(m_{\pi\pi})</td>
</tr>
<tr>
<td></td>
<td>(-t)</td>
<td>(\leq 1.5) GeV²</td>
</tr>
<tr>
<td></td>
<td>(Q^2)</td>
<td>(\leq 0.1) GeV²</td>
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<tr>
<td>elastic:</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(M_Y = m_p) GeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(m_p &lt; M_Y \leq 10) GeV</td>
</tr>
</tbody>
</table>

*bin-wise, no bin-center correction! photon-flux \(\Phi_{\gamma/e}(W_{\gamma p})\) using Weizsäcker-Williams
\[ \frac{d\sigma(\gamma p \rightarrow \pi^+\pi^- Y)}{dm_{\pi\pi}} \text{ vs } m_{\pi\pi} \] & Fiducial \( \pi^+\pi^- \) Cross-Section

**Fiducial Cross-Section:**

<table>
<thead>
<tr>
<th>Process</th>
<th>( \sigma [\mu b] )</th>
<th>stat. [( \mu b )]</th>
<th>syst. [( \mu b )]</th>
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<tr>
<td>( \gamma p \rightarrow \pi^+\pi^- p )</td>
<td>11.36</td>
<td>±0.04</td>
<td>±1.17*</td>
</tr>
<tr>
<td>( \gamma p \rightarrow \pi^+\pi^- Y )</td>
<td>5.17</td>
<td>±0.04</td>
<td>±0.94*</td>
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</table>

*not fully evaluated

**Uncertainty:**

- very high statistical precision
- dominating systematic uncertainties:
  - trigger
  - forward tagging: elas/dissoc separation
  - calorimeter: background normalization

\( Q^2 < 0.1 \text{ GeV}^2 \)
Extracting $\sigma(\gamma p \rightarrow \rho^0 Y)$ by Fitting $m_{\pi\pi}$ Distribution

\[
\frac{d\sigma_{\pi^+\pi^-}}{dm_{\pi\pi}}(m_{\pi\pi}) = \frac{N}{(1 + f_\omega + f_{nr})^2} \cdot \left| \frac{RBW_\rho(m_{\pi\pi}) + f_\omega e^{i\phi_\omega} RBW_\omega(m_{\pi\pi}) + f_{nr} e^{i\phi_{nr}} B_{nr}(m_{\pi\pi})}{B_{nr}(m_\rho)} \right|^2
\]

--- Extended Söding Model ---

- $\rho^0$, $\omega(782)$ and non-resonant contributions
- added on amplitude level including global phase differences $\phi_\omega$, $\phi_{nr}$
- $\rho^0$ and $\omega$ modelled by relativistic Breit-Wigner with mass-dependent width:
  \[
  RBW_{VM}(m_{\pi\pi}) = \frac{\sqrt{m_{\pi\pi} m_{VM} \Gamma(m_{\pi\pi})}}{m^2_{\pi\pi} - m^2_{VM} + i m_{VM} \Gamma(m_{\pi\pi})}
  \]
- non-resonant background model:
  \[
  B_{nr} = \left( \frac{m_{\pi\pi} - 2m_\pi}{(m_{\pi\pi} - 2m_\pi)^2 + \Lambda^2_{nr}} \right)^{\delta_{nr}}
  \]
- $\rho^0$ dominant, but significant interference contributions
Extracting $\sigma(\gamma p \rightarrow \rho^0 Y)$ by Fitting $m_{\pi\pi}$ Distribution

- elastic & $p$-dissociative fit together
- different non-resonant contributions $\rightarrow$ shape differences

**fitted parameters:**

- $m_{\rho^0} = 771 \pm 1$ (stat.) MeV
- $\Gamma_{\rho^0} = 150 \pm 1$ (stat.) MeV

systematic uncertainties not fully evaluated
\[ d\sigma(\gamma p \rightarrow \pi^+\pi^- Y)/dm_{\pi\pi}(m_{\pi\pi}; W_{\gamma p}) \rightarrow \sigma(\gamma p \rightarrow \rho^0 Y)(W_{\gamma p}) \]

- parallel fit of 1D \( d\sigma(\gamma p \rightarrow \pi^+\pi^- Y)/dm_{\pi\pi}(m_{\pi\pi}) \) in \( W_{\gamma p} \) bins
- many model parameters \( W_{\gamma p} \)-independent
  (no significant dependence observed)
- integrate out \( \rho^0 \) contribution:
  \[ \sigma_{\rho^0} := \int_{2m_{\pi}}^{m_{\rho}+5\Gamma_{\rho}} |RB\mathcal{W}_\rho(m_{\pi\pi})|^2 dm_{\pi\pi} \]

* all distribution shown in backup
\( \sigma(\gamma p \rightarrow \rho^0 Y)(W_{\gamma p}) \)

- all cross-sections from fit function integral
- proton dissociative cross-section shaped by phase-space restrictions \( M_Y < 10 \) GeV
  \( \rightarrow M_Y < 10 \) GeV more restrictive at high \( W_{\gamma p} \)

**Elastic**

- \( Q^2 < 0.1 \) GeV^2
- \( M_Y = m_p \)
- \( 0.28 \) GeV < \( m_{\pi\pi} \) < 1.53 GeV

**Proton Dissociative**

- \( Q^2 < 0.1 \) GeV^2
- \( m_p < M_Y \leq 10 \) GeV
- \( 0.28 \) GeV < \( m_{\pi\pi} \) < 1.53 GeV

Arthur Bolz

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Comparison to World Data

- H1 Preliminary
  - $Q^2 < 0.1 \text{ GeV}^2$
  - $0.28 \text{ GeV} < m_{\pi\pi} < 1.53 \text{ GeV}$

- $M_Y = m_p$
  - $\rho^0 W_{\gamma p}$ dependence in range $20 < W_{\gamma p} < 80 \text{ GeV}$
  - fills “gap” between fixed target and HERA measurements

- elastic cross-section rises w/ $\sim W_{\gamma p}^{0.13}$
- p-dissociative consistent with constant in fiducial PS

- high statistical precision
- but very large systematic uncertainties
- $W_{\gamma p}$ shape uncertainty dominated by trigger

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High $\pi^+\pi^-$ Mass Region

- further $\rho$ resonances have been observed at higher $m_{\pi\pi}$
- also present in H1 data in extended range $m_{\pi\pi} \leq 2.2$ GeV

$\rho'$:
- $m_{\rho'} \sim 1700$ MeV
- $\Gamma_{\rho'} \sim 300$ MeV
- no evidence for $\rho(1450)$

- fit extended Söding model with 3. Breit-Wigner to consider single $\rho'$ contribution
- elastic & $p$-dissociative fit together
Summary

- Presented fully unfolded $\pi^+\pi^-$ photoproduction cross-section vs. $m_{\pi\pi}$
  - Elastic and $p$-dissociative contribution statistically separated
  - Strongly reduces model dependence of distributions
  - Detector resolution corrections e.g. allow to observe $\omega$ contribution

- $m_{\pi\pi}$ distribution well described by Söding model $\sim |\rho + \omega + \text{non-resonant}|^2$
  - High mass region described by single additional $\rho'$ contribution

- Very large $\pi^+\pi^-$ photoproduction dataset available at H1
  - Blessing and curse b.c. very good understanding of small detector effects required

- Systematics not fully evaluated
  - In particular w.r.t background contributions at high $m_{\pi\pi}$ and $t$, tagging and trigger
  - $d\sigma(\pi^+\pi^-)/dt(t)$ dependence more problematic and thus not shown today
Fit Elastic $d\sigma(\gamma p \rightarrow \pi^+\pi^- p)/dm_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins
Fit Elastic $d\sigma(\gamma p \rightarrow \pi^+\pi^- p)/dm_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins
Fit $p$-Dissociative $d\sigma(\gamma p \rightarrow \pi^+\pi^- Y)/dm_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins