Inclusive Photoproduction of $\rho^0$, $K^{*0}$ and $\phi$ Mesons at HERA

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on behalf of
H1 Collaboration

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ep kinematics

energy c.m.: $\sqrt{s} = 300-320$ GeV
hadronic energy: $W = m(\gamma^*p)$
photon virtuality: $Q^2$
two regions: $Q^2 \approx 0$ GeV$^2$ — photoproduction
          $Q^2 > 1$ GeV$^2$ — electroproduction (DIS)
Motivation

- $e^+e^-$ collisions at LEP: distortion of $\rho^0$ line shape and shift towards lower masses was observed
- RHIC:
  - $\sqrt{s_{NN}} \sim 200$ GeV
  - $W_{\gamma p} \sim 210$ GeV
- H1:

  inclusive $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$

$\rho^0$, $K^{*0}(892)$, $\phi(1020)$ measurements at HERA help to study hadronisation
Main selection criteria for event:

- H1 data 2000 with $\mathcal{L} = 36.5$ pb$^{-1}$
- Photoproduction $Q^2 < 0.01$ GeV$^2$ with $e'$ in ET (electron tagger)
- $174 < W < 256$ GeV $\Rightarrow <W> = 210$ GeV
- Trigger requires at least 3 tracks in the Central Tracker with $p_T > 0.4$ GeV

$\rho^0 \rightarrow \pi^+\pi^-$  \hspace{1cm} $K^{*0} \rightarrow K\pi$  \hspace{1cm} $\phi \rightarrow K^+K^-$
Clear signals of $\rho^0$, $K^*$ and $\phi$ mesons are observed.
Bose-Einstein Correlations (BEC)

A modification of $\rho^0$ signal produced in $\gamma p$ collisions is described by taking into account Bose-Einstein correlations in Monte Carlo
\( \rho^0, K^* \) and \( \phi \): cross section measurement

\[ Q^2 < 0.01 \text{ GeV}^2 \, \&\& \, 174 < W < 256 \text{ GeV}, \, p_T > 0.5 \text{ GeV} \, \&\& \, |y_{\text{lab}}| < 1: \]

\[
\begin{align*}
\sigma_{\gamma p, \text{vis}}(\gamma p \rightarrow \rho^0 X) &= 25600 \pm 1800 \pm 2700 \text{ nb} \\
\sigma_{\gamma p, \text{vis}}(\gamma p \rightarrow K^{*0} X) &= 6260 \pm 350 \pm 860 \text{ nb} \\
\sigma_{\gamma p, \text{vis}}(\gamma p \rightarrow \phi X) &= 2400 \pm 180 \pm 340 \text{ nb}
\end{align*}
\]
All inclusive photoproduction cross sections measured at H1 are described by power law distribution with the same $n = 6.7$ calculated from charged hadrons.
ρ⁰, K* and φ: cross section

- invariant differential cross section can be described by power law distribution
- within rapidity range, the meson production rates are constant as a function of rapidity (within errors)
- PYTHIA and PHOJET models do not describe the shape of the measured p_T spectrum
\( \rho^0, K^* \) and \( \phi \): power law distribution

\[
\frac{f(E_T)}{E_T^{k_{\text{kin}}}} = \frac{A}{(E_T^{k_{\text{kin}}})^{2n_c}}
\]

\( f(E_T) \) is extrapolated cross section in all \( p_T \) range

\[
\frac{A}{(E_T^{k_{\text{kin}}})^{2n_c}}, \quad E_T > E_0
\]

pQCD

\[
\exp\left(-\frac{2}{\sqrt{m_T^2 p_T^2 - n_c}}\right)
\]

Thermodynamic model

\[
T = \frac{E_T}{n}
\]
\[ \rho^0, K^* \text{ and } \phi: \text{ cross section fit parameters} \]

\[ \frac{dE^{'kin}}{dE} \]

\[ \langle E_T \rangle = \langle E_T^{\text{kin}} \rangle + m_0 \]

\[ \langle p_T \rangle = \sqrt{\langle E_T^2 \rangle - m_0^2} \]

| \( \gamma p \) | \( \langle d\sigma/dy_{lab}\rangle_{|y_{lab}|<1} \text{ [nb]} \) | \( (K^*0 + \bar{K}^*0)/2 \) | \( \phi \) |
|----------------|-------------------------------|----------------|---------|
| \( \gamma p \) | 23600 \pm 2700 | 5220 \pm 600 | 1850 \pm 230 |
| \( E_{T_0}/n \) | 0.151 \pm 0.011 | 0.166 \pm 0.012 | 0.170 \pm 0.012 |
| \( \langle E_T \rangle \) [GeV] | 1.062 \pm 0.018 | 1.205 \pm 0.020 | 1.333 \pm 0.022 |
| \( \langle E_T^{\text{kin}} \rangle \) [GeV] | 0.287 \pm 0.018 | 0.313 \pm 0.020 | 0.314 \pm 0.022 |
| \( \langle p_T \rangle \) [GeV] | 0.726 \pm 0.027 | 0.810 \pm 0.030 | 0.860 \pm 0.035 |
| \( pp \) | \( \langle p_T \rangle_{pp} \) [GeV] | 0.616 \pm 0.062 | 0.81 \pm 0.14 | 0.82 \pm 0.03 |
| \( Au-Au \) | \( \langle p_T \rangle_{AuAu} \) [GeV] | 0.83 \pm 0.10 | 1.08 \pm 0.14 | 0.97 \pm 0.02 |

- \( \rho^0, K^* \) and \( \phi \) are produced with about the same value of the average \( \langle E_T^{\text{kin}} \rangle \)

\[ \Rightarrow \] supports a thermodynamic picture of hadronic interactions

- \( n \) is described by Monte Carlo while \( T \) is not (non pQCD)

- \( \langle p_T \rangle \) in H1 is in agreement with RHIC pp and is lower than RHIC AuAu
\( \rho^0, K^* \) and \( \phi \): comparison with RHIC

<table>
<thead>
<tr>
<th>( dN/dy )</th>
<th>( \gamma p ) (H1)</th>
<th>pp (STAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho^0 )</td>
<td>236±30</td>
<td>259±40</td>
</tr>
<tr>
<td>( K^* )</td>
<td>52±7</td>
<td>51±7</td>
</tr>
<tr>
<td>( \phi )</td>
<td>18±3</td>
<td>18±1</td>
</tr>
</tbody>
</table>

Remarkable agreement between production rates in pp and photoproduction

The ratio of the production cross-sections \( R(\phi/K^*) \) measured in \( \gamma p \) is in agreement with pp results and below that for AuAu measured at about the same collision energy at RHIC.
Summary

Light $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons photoproduction at HERA:

• first measurement in photoproduction at HERA

• the description of the $\rho^0$ shape of the meson is improved by taking Bose-Einstein correlations into account

• $p_T$-spectra are described by power law distribution

• $\rho^0$, $K^*$ and $\phi$ are produced with about the same value of $<E_{T^{\text{kin}}}>$ ⇒ support a thermodynamic picture of hadronic interactions

• comparison with RHIC results
  • The ratio of the production cross-sections $R(\phi/K^*)$ measured in $\gamma p$ is in agreement with pp results at about the same collision energy at RHIC
  • Some tendency for $\phi$ meson production to be more abundant in Au-Au collisions is observed

• universality in $p_T$-spectra of hadrons at H1 is observed
Back up
**ρ^0, K^* and φ: visible kinematical range**

All mesons are analyzed in following:

- $|y| < 1$ in 7 $p_T$ bins:
  - $1$ bin: 0.5-0.75
  - $2$ bin: 0.75-1
  - $3$ bin: 1-1.5
  - $4$ bin: 1.5-2
  - $5$ bin: 2-3
  - $6$ bin: 3-4
  - $7$ bin: 4-7 GeV

Extra cuts for mesons:
- $K^{*0}$: 1 bin: Kaon dE/dx ident. && $\cos\theta^* < 0$; 2-3 bin: Kaon dE/dx ident.
- $\phi$: 1-3 bin: Kaon dE/dx identification

bin $p_T$: 0.-0.25 GeV is excluded due to non description DATA and MC
bin $p_T$: 0.25-0.5 GeV is excluded due to big background for $K^{*0}$ and small $\phi$ meson reconstructed efficiency

- $p_T > 0.5$ GeV in 4 $y$ bins:
  - $1$ bin: -1.-0.5
  - $2$ bin: -0.5-0
  - $3$ bin: 0.-0.5
  - $4$ bin: 0.5-1

Extra cuts for mesons:
- $K^{*0}$: 1-4 bin: Kaon dE/dx ident. && $\cos\theta^* < 0$
- $\phi$: 1-4 bin: Kaon dE/dx identification

$y$ - rapidity of mesons
$p_T$ - transverse momentum of mesons
Fit Procedure

$$\rho^0 \rightarrow \pi^+\pi^- \quad K^{*0} \rightarrow K\pi \quad \phi \rightarrow K^+K^-$$

Fit function: \[ F(m) = S(m) + R(m) + B(m) \]

Signal \( S(m) \) = convolution of \( BW(m) \) and \( res(m, m') \)
rel. Breit-Wigner \( BW(m) = A m_0 \Gamma(m)/[\left(m^2-m_0^2\right)^2 + m_0^2 \Gamma^2(m)] \)
\[ \Gamma(m) = \Gamma_0 \left(\frac{q}{q_0}\right)^{2l+1} m_0 / m \]
resolution function \( res(m, m') = 1/[2p] \cdot \frac{\Gamma_{res}}{\left(m-m'\right)^2 + \left(\Gamma_{res}/2\right)^2} \)

reflection \( R(m) \):

for \( \rho^0 \):

\( K^{*0} \rightarrow K\pi \) and \( \omega \rightarrow \pi^+\pi^-(\pi^0) \)

for \( K^{*0} \):

\( \rho^0 \rightarrow \pi^+\pi^- \), \( \omega \rightarrow \pi^+\pi^-(\pi^0) \), \( \phi \rightarrow K^+K^- \)

and self-reflection \( K^{*0} \rightarrow K\pi \)

for \( \phi \):

—

combinatorial background \( B(m) \):

for \( \rho^0 \) and \( K^{*0} \):

\( B(m) = \{M(\pi^\pm\pi^\pm) \text{ or } M(K^\pm\pi^\pm) \} \cdot \{\text{Pol}(2-3) \text{ or } (a_1+a_2 \cdot x) \cdot \exp(-a_3 \cdot x-a_4 \cdot x^2)\} \)

for \( \phi \): \( B(m) = b_1 \cdot (m^2 - 4m_k^2)^{b_2} \cdot \exp(-b_3 \cdot m) \)
ρ⁰, K* and φ: cross section calculation

Invariant differential cross section:

\[
\frac{1}{\pi} \frac{d^2 \sigma^{\gamma p}}{dp_T^2 \, dy_{lab}} = \frac{N}{\pi \cdot L \cdot BR \cdot \Phi_\gamma \cdot \epsilon \cdot \Delta p_T^2 \cdot \Delta y_{lab}}
\]

Differential cross section:

\[
\frac{d\sigma^{\gamma p}}{dy_{lab}} = \frac{N}{L \cdot BR \cdot \Phi_\gamma \cdot \epsilon \cdot \Delta y_{lab}}
\]

N - number of mesons from fit
\(\Delta p_T^2\) and \(\Delta y_{lab}\) - bin widths
\(L = 36.5 \text{ pb}^{-1}\)
\(\Phi_\gamma = 0.0127\) - photon flux
\(BR = 1.\) for ρ⁰, 0.67 for K*⁰ and 0.49 for φ

\(\epsilon = \epsilon_{\text{rec}} \cdot A_{\text{etag}} \cdot A_3 \cdot \epsilon_{\text{trig}}\) - efficiency

reconstruction efficiency for the meson \(\epsilon_{\text{rec}}\) varies from 45% to 90% (using Monte Carlo)

positron tagger acceptance \(A_{\text{etag}} = 48.5\%\)
trigger acceptance \(A_3\) varies from 50% to 95% (using Monte Carlo)
trigger efficiency \(\epsilon_{\text{trig}} \sim 90\%\) (using Monitor Triggers)
The HERA Collider

H1 and ZEUS:
- 92 - 07 years
- Lumi ~ 0.5 fb⁻¹ (each exper.)