Exclusive Meson Production at HERMES

Pan-Pacific 2005, Tokyo, Japan

Armine Rostomyan
on behalf of the HERMES collaboration

(DESY)

- Motivation
- Exclusive $\pi^+$ production cross-section
- Exclusive $\rho^0$ production cross-section
- The cross-section ratio of $\frac{\sigma_\phi}{\sigma_\rho}$
- Transverse target spin asymmetry of $\rho^0$ and $\pi^+$
Factorization theorem for meson production

\[ \frac{d\sigma_L}{dt} \rightarrow \frac{1}{Q^6} \quad \frac{\sigma_T}{\sigma_L} \sim \frac{1}{Q^2} \]

- Collins, Frankfurt, Strikman (1997) -

Quantum numbers of final state selects different GPDs

- vector mesons \((\rho, \omega, \phi)\): unpolarized GPDs \(H, E\)
- pseudoscalar mesons \((\pi, \eta)\): polarized GPDs \(\tilde{H}, \tilde{E}\)

Factorization for longitudinal photons only
EXCLUSIVE $\pi^+$
Exclusivity for $ep \to e' \pi^+ (n)$

- for existing data no recoil nucleon detection yet
- select exclusive $\pi^+$ reaction through the missing mass technique:

$$M_x^2 = (P_e + P_p - P_{e'} - P_{\pi^+})^2$$
Exclusivity for $ep \rightarrow e'\pi^+(n)$

$$M_x^2 = (P_e + P_p - P_{e'} - P_{\pi^+})^2$$

$ep \rightarrow e\pi^+ X$

$ep \rightarrow e\pi^+ n$

- $\pi^-$ yield was used to subtract the non exclusive background

- exclusive peak centered at the nucleon mass
- MC is based on GPD model
Cross-section determination

\[ \sigma_{\gamma^* p \to \pi^+ n}(x, Q^2) = \frac{N_{\pi}^{\text{excl}}}{L \Delta x \Delta Q^2 \Gamma(<x>, <Q^2>) \kappa(x, Q^2)} \]

\( \kappa(x, Q^2) \): detection probability was calculated using VGG exclusive MC

-Vanderhaeghen, Guichon, Guidal (1999)-
Cross-section determination

\[ \sigma_{\gamma^* p \rightarrow \pi^+ n}(x, Q^2) = \frac{N_{\pi}^{\text{excl}}}{L \Delta x \Delta Q^2 \Gamma(<x>, <Q^2>) \kappa(x, Q^2)} \]

\[ \rightarrow \kappa(x, Q^2) \text{: detection probability was calculated using VGG exclusive MC} \]

-Vanderhaeghen, Guichon, Guidal (1999)-
Cross-section determination

\[ \sigma_{\gamma^* p \rightarrow \pi^+ n}(x, Q^2) = \frac{N_{\pi}^{excl}}{L \Delta x \Delta Q^2 \Gamma(<x>, <Q^2>) \kappa(x, Q^2)} \]
Cross-section: $Q^2$ dependence for different $x$ ranges

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    title={\Hermes logo \hspace{1cm} HERMES PRELIMINARY},
    xlabel={$Q^2$ (GeV$^2$)},
    ylabel={$\sigma_{\text{tot}}$ (nb)},
    xtick={0,2,4,6,8,10},
    ytick={1,10,10^2},
    legend entries={0.02 < x < 0.18, 0.18 < x < 0.26, 0.26 < x < 0.80},
    legend style={at={(0.5,0.5)},anchor=north},
    grid=both,
]
\addplot[mark=triangle] coordinates {
(0.02,100)
(0.18,100)
(0.26,100)
};
\addplot[mark=triangle] coordinates {
(0.02,10)
(0.18,10)
(0.26,10)
};
\addplot[mark=triangle] coordinates {
(0.02,1)
(0.18,1)
(0.26,1)
};
\end{axis}
\end{tikzpicture}
\end{center}

uncorrected for radiative effects

0.02 < x < 0.18
0.18 < x < 0.26
0.26 < x < 0.80

\text{BUT} $T$ suppressed by $1 = Q^2$ for HERMES kinematics:

0: $80 < Q^2 < 96$

$L$ dominates at large $Q^2$
Cross-section: $Q^2$ dependence for different $x$ ranges

$$\sigma_{tot} = \sigma_T + \epsilon \sigma_L$$

- **L/T separation not possible**
- **BUT $\sigma_T$ suppressed by $1/Q^2$**
- **for HERMES kinematics:**
  $$0.80 < \epsilon < 0.96$$

$\sigma_L$ dominates at large $Q^2$
Cross-section: $Q^2$ dependence for different $x$ ranges

\[ \sigma_{tot} = \sigma_T + \epsilon \sigma_L \]

\[ \gamma^* p \rightarrow \pi^+ n \]

HERMÉS PRELIMINARY

uncorrected for radiative effects

- J.M. Laget (2004) -

\( \rightarrow \) small contribution from $\sigma_T$ is predicted

\( \rightarrow \) $\sigma_L \approx \sigma_{tot}$
$Q^2$ dependence and theoretical expectations

Factorization theorem: $\sigma_L \to 1/Q^6$

\[
\sigma_L = \text{Kin Factor} \times \sum_{\text{spins}} |M| \downarrow 1/Q^4 \downarrow 1/Q^2
\]

fit: $1/Q^p$

\[
p = 1.9 \pm 0.5 \\
p = 1.7 \pm 0.6 \\
p = 1.5 \pm 1.0
\]

$Q^2$ dependence is in agreement with theoretical expectation
Cross-section: $Q^2$ dependence for different $x$ ranges

\[ \sigma_{tot} = \sigma_T + \epsilon \sigma_L \]

- **L/T separation not possible**
- **BUT $\sigma_T$ suppressed by $1/Q^2$**
- for HERMES kinematics:
  \[ 0.80 < \epsilon < 0.96 \]

$\sigma_L$ dominates at large $Q^2$

- Vanderhaeghen, Guichon, Guidal (1999)

\[ \gamma p \rightarrow \pi^+ n \]
uncorrected for radiative effects

$\sigma_{tot} = T + L$

$\sigma_T$ suppressed by $1/Q^2$

access to $\tilde{H}$ and $\tilde{E}$
Cross-section: $Q^2$ dependence for different $x$ ranges

- Vanderhaeghen, Guichon, Guidal (1999)-

\[ \sigma_{tot} = \sigma_T + \epsilon \sigma_L \]

- L/T separation not possible
- BUT $\sigma_T$ suppressed by $1/Q^2$
- for HERMES kinematics:
  $0.80 < \epsilon < 0.96$

$\sigma_L$ dominates at large $Q^2$

\[ \sigma_L \] dominates at large $Q^2$

\[ \sigma_T \] and \[ \epsilon \sigma_L \]

access to $\tilde{H}$ and $\tilde{E}$

$\Rightarrow$ LO calculations underestimate the data
$\Rightarrow$ Evaluation of the power correction ($k_{\perp}$ and soft overlap) appears too large

Armine Rostomyan – p.9
EXCLUSIVE VECTOR MESONS
Exclusive Vector Meson Selection $e p \rightarrow e' V(p)$

\[ \rho^0 \rightarrow \pi^+ \pi^- \]

\[ \phi \rightarrow K^+ K^- \]
 Exclusive Vector Meson Selection $e p \rightarrow e' V(p)$

- $\rho^0 \rightarrow \pi^+ \pi^-$
- $\phi \rightarrow K^+ K^-$

- no recoil detection
- exclusive $\rho^0$ and $\phi$ reaction through the energy and momentum transfer:

$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p}$$

$$t' = t - t_0$$

![Histogram and Scatter Plot](image)
Exclusive Vector Meson Selection $ep \rightarrow e'V(p)$

- $\rho^0 \rightarrow \pi^+\pi^-$
- $\phi \rightarrow K^+K^-$

- no recoil detection
- exclusive $\rho^0$ and $\phi$ reaction through the energy and momentum transfer:
\[ W(\cos \theta, \Phi, \phi) \]

separation of longitudinal and transverse components

\[ W(\cos \theta, \phi, \Phi) \Rightarrow 23 \ SDME \]

- describe the helicity transfer from virtual photon to the vector meson
- describe the parity of the diffractive exchange process
\[ \frac{\sigma_L}{\sigma_T} \] separation

- GPD calculations only for longitudinal component of cross section (\( \sigma_L \)).

\[
\sigma_L = \frac{R}{1 + \epsilon R} \sigma_{\gamma^* p \rightarrow V_p}^\gamma
\]

\[
R = \frac{\sigma_L}{\sigma_T}
\]

\( \epsilon \) - polarization of \( \gamma^* \)

- assuming s-channel helicity conservation

\[
R = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}
\]

\( r_{00}^{04} \rightarrow W(\cos \theta) \)
\[ \frac{\sigma_L}{\sigma_T} \] separation

- GPD calculations only for longitudinal component of cross section (\(\sigma_L\)).

\[ \sigma_L = \frac{R}{1 + \epsilon R} \sigma_{\gamma^* p \rightarrow V p} \]

\[ R = \frac{\sigma_L}{\sigma_T} \]

\[ \epsilon \] polarization of \(\gamma^*\)

- assuming s-channel helicity conservation

\[ R = \frac{1}{\epsilon} \frac{r_{04}^{04}}{1 - r_{00}^{00}} \]

\[ r_{00}^{04} \rightarrow W(\cos\theta) \]
\( \sigma_{\gamma^* L p \to \rho^0 p} \) and \( \sigma_{\gamma^* L p \to \phi p} \)

-Vanderhaeghen, Guichon, Guidal (1999)-

\[ \begin{align*}
\sigma_{\rho^0 p} & \quad <Q^2> = 2.3 \text{ GeV}^2 \\
\sigma_{\phi p} & \quad <Q^2> = 4.0 \text{ GeV}^2
\end{align*} \]
\[ \sigma_{\gamma_L^* p \to \rho^0 p} \quad \text{and} \quad \sigma_{\gamma_L^* p \to \phi p} \]

- Vanderhaeghen, Guichon, Guidal (1999) -

\[ \langle Q^2 \rangle = 2.3 \text{ GeV}^2 \quad \text{vs.} \quad \langle Q^2 \rangle = 4.0 \text{ GeV}^2 \]

\[ W \quad [\text{GeV}] \]

\[ \sigma_{(\gamma^* p) \to \rho^0 (p)} \quad [\text{mb}] \]

\[ \downarrow \quad \text{dominated by quark exchange} \]

\[ |\tau_g / \tau_q| \approx 0.3 \]

\[ \gamma^* (q) \quad \text{to} \quad \rho \]

\[ p(p) \quad \text{to} \quad p(p') \]

\[ \downarrow \quad \text{gluon exchange} \]

- Armine Rostomyan -
\[
\frac{\sigma_\phi}{\sigma_\rho}
\]

-Diehl, Vinnikov (2005)-

\[
\frac{\sigma_\phi}{\sigma_\rho} \approx \frac{2}{9} \left( \frac{|\tau_g|^2}{|\tau_q|^2} + 2 |\tau_q| |\tau_g| \cos \phi_{qg} + |\tau_g|^2 \right)
\]

\[
0.38 \leq |\tau_g/\tau_q| \leq 1.5
\]
\[ \frac{\sigma_\phi}{\sigma_\rho} \]

-Diehl, Vinnikov (2005)-

\[
\frac{\sigma_\phi}{\sigma_\rho} \approx \frac{2}{9} \left| \tau_q \right|^2 + 2 \left| \tau_q \right| \left| \tau_g \right| \cos \phi_{qg} + \left| \tau_g \right|^2
\]

0.38 \leq \left| \frac{\tau_g}{\tau_q} \right| \leq 1.5

⇒ gluon contribution and quark-gluon interference can not be neglected
\[ \sigma^{\gamma^* p \rightarrow \rho^0 p} \]

**factorized GPD model**

\[ \sigma_{\gamma_L} p \rightarrow \rho^0 p, \mu b \]

\[ W, \text{GeV} \]

\[ 4, 4.5, 5, 5.5, 6 \]

- Ellinghaus, Nowak, Vinnikov, Ye (2005)

**Regge GPD model**

\[ \sigma_{\gamma_L} p \rightarrow \rho^0 p, \mu b \]

\[ W, \text{GeV} \]

\[ 4, 4.5, 5, 5.5, 6 \]

HERMES data at \( Q^2 = 4 \text{GeV}^2 \)

- Armine Rostomyan - p.16

- the calculation overshoots the experimental data

- \( k_{\perp} \) is not taken into account yet

\[ \Rightarrow \] quark and gluon amplitudes have to be scaled down in a similar proportion

\[ \Rightarrow \] a factor of 5 suppression of the cross section at \( Q^2 = 4 \text{GeV}^2 \)
TRANSVERSE TARGET SPIN ASYMMETRIES
Transverse spin asymmetries of exclusive $\pi^+$ and $\rho^0$

- the scaling region is reached at low $Q^2$
- not sensitive to NLO corrections
Transverse spin asymmetries of exclusive $\pi^+$ and $\rho^0$

$$e p \rightarrow e \pi^+ n$$

- $t = 0.1 \text{ GeV}^2$
- $t = 0.3 \text{ GeV}^2$
- $t = 0.5 \text{ GeV}^2$

$Q^2 \sim 2-4 \text{ GeV}^2$


$\gamma^*_L + p \rightarrow \rho^0 + p$

$J^\mu =$
- 0.4
- 0.3
- 0.2
- 0.1

$Q^2 = 2.5 \text{ GeV}^2$
- $t = 0.25 \text{ GeV}^2$
- $J^\rho = 0$

- Goeke, Polyakov, Vanderhaeghen (2001)

-Armine Rostomyan-
Transverse spin asymmetries of exclusive $\pi^+$ and $\rho^0$

$$e p \rightarrow e \pi^+ n$$

$Q^2 \sim 2-4 \text{ GeV}^2$

- $t = 0.1 \text{ GeV}^2$
- $t = 0.3 \text{ GeV}^2$
- $t = 0.5 \text{ GeV}^2$


\[ \sigma : |S_T| \sin(\phi - \phi_s) \tilde{E} \tilde{H} \]

- Goeke, Polyakov, Vanderhaeghen (2001)

\[ \sigma : |S_T| \sin(\phi - \phi_s) EH \]
Transverse spin asymmetries of exclusive $\pi^+$ and $\rho^0$

- $\sigma : |S_T| \sin(\phi - \phi_s) \tilde{E} \tilde{H}$
- $\sigma : |S_T| \sin(\phi - \phi_s) EH$

\[ A_{UT} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\sigma_1}{\sigma_0} = -\frac{\pi}{2} A_{thoer}. \]
Transverse spin asymmetries of exclusive $\pi^+$ and $\rho^0$

$ep \rightarrow e\pi^+ n$

  - $\sigma : |S_T| \sin(\phi - \phi_s) \tilde{E}\tilde{H}$
  - sensitive to different distribution amplitudes

- Goeke, Polyakov, Vanderhaeghen (2001)
  - $\sigma : |S_T| \sin(\phi - \phi_s) EH$
  - $E \rightarrow 2J^u + J^d$

Armine Rostomyan - p.20
Asymmetry determination

\[
A_{UT}(\phi - \phi_s) = \frac{1}{|P|} \frac{N^\uparrow(\phi - \phi_s) - N^\downarrow(\phi - \phi_s)}{N^\uparrow(\phi - \phi_s) + N^\downarrow(\phi - \phi_s)},
\]

\[
A_{UT}(\phi - \phi_S) = A_{UT}^{\sin(\phi - \phi_S)} \cdot \sin(\phi - \phi_S) + \text{constant}
\]
Asymmetry determination

\[ A_{UT}(\phi - \phi_s) = \frac{1}{|P|} \frac{N^\uparrow(\phi - \phi_s) - N^\downarrow(\phi - \phi_s)}{N^\uparrow(\phi - \phi_s) + N^\downarrow(\phi - \phi_s)}, \]

\[ A_{UT}(\phi - \phi_S) = A_{UT}^{\sin(\phi - \phi_S)} \cdot \sin(\phi - \phi_S) + \text{constant} \]

\[ A_{UT}^{\sin(\phi - \phi_S)} = 0.046 \pm 0.037 \]
Kinematic Dependences

- Ellinghaus, Nowak, Vinnikov, Ye (2005)

- within the statistical errors in agreement with theoretical calculations
- the statistics is not enough to make statement about $J^u$
Kinematic Dependences

- Ellinghaus, Nowak, Vinnikov, Ye (2005)

- within the statistical errors in agreement with theoretical calculations
- the statistics is not enough to make statement about $J^u$
2002-2005: run with a transversely polarized target
by now we already have:

- $4 \times 10^4$ DIS
- $1 \times 10^4$ exclusive $\pi^+$
- $2.5 \times 10^3$ exclusive $\rho^0$

2005: still running with transversely polarized target
from 2005: recoil detector will be installed: more statistics from exclusive reactions
Outlook

• the cross-section of exclusive $\pi^+$
  → the $Q^2$ dependence of the cross section is in general agreement with GPD theory

• the cross-section of exclusive $\rho^0$
  → the gluon contribution can not be neglected
  → new calculations taking into account $k_{\perp}$

• The transverse target spin asymmetry of exclusive $\pi^+$
  → will come soon

• The transverse target spin asymmetry of exclusive $\rho^0$
  → L/T separation

• More data is coming

STAY TUNED