Exclusive Vector Meson Production at HERMES

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**Generalized information**

- **Proton form factors**, transverse localization of partons
- **Form factor**

\[ l N \rightarrow l' N' \]

- **Correlated quark momentum and helicity distribution in transverse space**

- **Structure functions**, longitudinal quark momentum and helicity distributions

**GPDs**

- **Parton density**

\[ l N \rightarrow l' X \]
Probalistic interpretation of GPDs

Described by 3 variables: \( x, \xi, \tau \)
- \( x + \xi \) longitudinal momentum fraction of the quark
- \(-2\xi\) exchanged longitudinal momentum fraction
- \( \tau \) squared momentum transfer

4 GPDs defined for each quark flavour:
- \( H \) conserve nucleon helicity
- \( \tilde{H} \) flip nucleon helicity
- \( E \) unpolarized
- \( \tilde{E} \) polarized

GPDs = probability amplitude for \( N \) to emit a parton \( x + \xi \)
and for \( N' \) to absorb it \( x - \xi \)

\[
Q^2 \gg, \; \tau \ll
\]

\[
x \neq x_B
\]

\[
\xi = \frac{x_B}{2 - x_B}
\]

\[
-\tau = -(N - N')^2
\]
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
The Spectrometer

- **Acceptance:** $40 \text{ mrad} < \theta < 140 \text{ mrad}$
- **Tracking:** $\delta P_e / P_e < 2\%$, $\delta \theta < 0.6 \text{ mrad}$
- **Particle identification:**
  - $TRD, Calo, Preshower$: hadron/lepton separation: $\varepsilon_e > 99\%$
  - $Rich$: hadron identification ($p, \pi, K$)

**fixed target experiment**
**forward spectrometer**
**no recoil detection**
Cross-section of Exclusive Vector Mesons
Exclusive Vector Meson Selection $ep \rightarrow e' V(p)$

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

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

$t' = t - t_0$
GPD calculations only for longitudinal component of the cross-section ($\sigma_L$):

$$\sigma_L = \frac{R}{1 + \varepsilon R} \sigma_{\gamma^* p \rightarrow V p}$$

$$R = \frac{\sigma_L}{\sigma_T}$$

where $\varepsilon$ - polarization of $\gamma^*$

Assuming SCHC

$$R = \frac{1}{\varepsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

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

- quarks and gluons: at the same order of \( \alpha_s \)
- gluon GPDs can be accessed dominated by quark exchange

\[ \begin{align*}
\sigma_L(\gamma p \rightarrow \rho^0 p) [\mu b] & = 2.3 \text{ GeV}^2 \\
<Q^2> & = 2.3 \text{ GeV}^2 \\

\sigma_L(\gamma p \rightarrow \phi p) [\mu b] & = 4.0 \text{ GeV}^2 \\
<Q^2> & = 4.0 \text{ GeV}^2
\end{align*} \]

HERMES PRELIMINARY

\( Q^2 = 2.3 \text{ GeV}^2 \)

\( Q^2 = 3.8 \text{ GeV}^2 \)
$\frac{\sigma_{\gamma p \rightarrow \phi p}}{\sigma_{\gamma p \rightarrow \rho^0 p}}$

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

\[0.38 < \left| \frac{\tau_g}{\tau_q} \right| < 1.5\]

Glue contribution and quark-gluon interference can not be neglected.
\[ \sigma_{L}^{*p \rightarrow \rho^0 p} \]

Paraetrizations for: \( H^q, H^g, E^q \), no hint for \( E^g \)

Factorizes GPD model

Regge GPD model

Theory
- the calculation overshoots the experimental data
- \( k_\perp \) is not taken into account
- quark and gluon amplitudes have to be scaled down in a similar proportion, a factor of 5 suppression of the cross section

Experiment
- provide new results with higher statistics
Transverse Target Spin Asymmetries (TTSA)
**TTSA of Exclusive $\pi^+$ and $\rho^0$**

\[ e p \rightarrow e' \pi^\mp n \]

Frankfurt, Polyakov, Strikman, Vanderhaeghen (2000)

Goeke, Polyakov, Vanderhaeghen (2001)

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

\[ Q^2 \sim 2-4 \text{ GeV}^2 \]

\[ x_{bj} \]

**Transverse spin asymmetry**

| \( S_T \) | \( \sin (\phi - \phi_s) \) \( \tilde{E} \tilde{H} \)

- Linear dependence on GPDs
- Higher order corrections cancel

\[ \gamma^* L + p \rightarrow \rho^0_{L} + p \]

\[ Q^2 = 2.5 \text{ GeV}^2 \]
\[ t = 0.25 \text{ GeV}^2 \]
\[ J^d = 0 \]

\[ x_B \]

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

- \( E \) is kinematically not suppressed
- TTSA promising observable which allow an access to \( E \)
- \( E \) related to \( J^d \) through Ji sum rule
TTSA of Exclusive $\rho^0$

$$A_{UT} = -\frac{\pi}{2} A_{theor}$$

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

$$A_{UT}(\phi - \phi_s) = A_{UT}^{sin(\phi - \phi_s)} \cdot sin(\phi - \phi_s) + const$$
Kinematic Dependences

- L/T separation has not yet been done
- transverse component is suppressed at high $Q^2$
- within the statistical errors in agreement with theoretical calculations
- the statistics is not yet enough to make a statement about $J^u$
- more data is available
More Results are Coming...

Integrated DIS HERA Run II (polarized)

Number of pol. DIS events

Day of Running

2002/03
2003
2004
2005
**Forward limit \((t \to 0, \xi \to 0)\)**

\[ H^g(x, \xi=0, t=0) = q(x) \]

\[ \tilde{H}^g(x, \xi=0, t=0) = \Delta q(x) \]
\[ q(x, \vec{b}_\perp) = \int \frac{d^2 \Delta}{(2\pi)^2} H(x, \xi = 0, -\Delta_\perp^2) e^{i\vec{b}_\perp \cdot \Delta_\perp} \]

\[ \int q(x, b_\perp) d^2 b_\perp = q(x) \]
the general case: $\xi \neq 0$, by M. Diehl
**BACKUP: Limiting cases and sum rules**

**Forward limit** \((t \to 0, \xi \to 0)\)

- \(H^q(x, 0, 0) = q(x)\)
- \(\tilde{H}^q(x, 0, 0) = \Delta q(x)\) for \(x > 0\)
- \(H^q(x, 0, 0) = -\bar{q}(-x)\)
- \(\tilde{H}^q(x, 0, 0) = \Delta \bar{q}(-x)\) for \(x < 0\)
- \(H^g(x, 0, 0) = x g(x)\)
- \(\tilde{H}^g(x, 0, 0) = x \Delta g(x)\) for \(x > 0\)

\(E^q, \tilde{E}^q, E^g, \tilde{E}^g\)

- no corresponding relations
- are visible only in exclusive processes

**Sum rules**

\[\int_{-1}^{+1} H^q(x, \xi, t) dx = F_1^q(t)\]
\[\int_{-1}^{+1} E^q(x, \xi, t) dx = F_2^q(t)\]
\[\int_{-1}^{+1} \tilde{H}^q(x, \xi, t) dx = g_A^q(t)\]
\[\int_{-1}^{+1} \tilde{E}^q(x, \xi, t) dx = h_A^q(t)\]

**Ji sum rule**

\[\int_{-1}^{+1} \left( H(x, \xi, t=0) + E(x, \xi, t=0) x \right) dx = \frac{1}{2} \Delta \Sigma + L_q\]