Exclusive Vector Meson Production at HERMES

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Outline

- Introduction
- $\sigma_L - \sigma_T$ separation
- Measured cross sections
- Transverse target spin asymmetry in exclusive $\rho^0$ production
- Conclusion
GPDs & Exclusive Meson Production

- Factorization of LO amplitudes
  - For meson production only proven for $\gamma^*_L$
  - GPDs parametrize lower non-perturbative part
GPDs & Exclusive Meson Production

- Factorization of LO amplitudes
  - For meson production only proven for $\gamma_L^*$
  - GPDs parametrize lower non pertubative part
- Leading twist Generalized Parton Distributions
  - For each quark flavour $q$: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
  - Vector mesons production $\Rightarrow H^q, E^q$
  - Pseudoscalar meson production $\Rightarrow \tilde{H}^q, \tilde{E}^q$
GPDs & Exclusive Meson Production

Factorization of LO amplitudes
- For meson production only proven for $\gamma^*_L$
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Leading twist Generalized Parton Distributions
- For each quark flavour $q$: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Vector mesons production $\Rightarrow H^q, E^q$
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New information about quark structure in nucleon
- Quark (orbital) angular momentum:

$$J^q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} x [H^q + E^q] dx$$

$$L^q = J^q - \frac{1}{2} \Delta \Sigma$$
Extraction of Exclusive VM Sample

- Detected in HERMES spectrometer
- Scattered lepton
- Vector meson decay products

\[ M_{2h} = \sqrt{(P_{h+} + P_{h-})^2} \]

\[
\begin{align*}
V & \rightarrow h^+ h^- \\
\rho^0 & \rightarrow \pi^+ \pi^- \\
\varphi & \rightarrow K^+ K^-
\end{align*}
\]
Extraction of Exclusive VM Sample

Detected in HERMES spectrometer:
- Scattered lepton
- Vector meson decay products

\[ M_{2h} = \sqrt{(P_{h+} + P_{h-})^2} \]

![Diagram showing leptons and mesons](image)
**Extraction of Exclusive VM Sample**

- Detected in HERMES spectrometer:
  - Scattered lepton
  - Vector meson decay products
  \[ M_{2h} = \sqrt{(P_{h+} + P_{h-})^2} \]

- Recoil target is not (yet) detected

- Calculate missing mass \( M_X \)
  \[ M_X = \sqrt{(p + q - P_V)^2} \]
Detected in HERMES spectrometer:
- Scattered lepton
- Vector meson decay products
  \[ M_{2h} = \sqrt{(P_{h+} + P_{h-})^2} \]
- Recoil target is not (yet) detected
- Calculate missing mass \( M_X \)
  \[ M_X = \sqrt{(p + q - P_V)^2} \]
- \( \Delta E \) should be peaked around zero
  \[ \Delta E = \frac{M_X^2 - M_p^2}{2M_p} \]
Angular Distributions of Decay Products

- $\sigma_L - \sigma_T$ separation possible from $W(\cos \theta, \phi, \Phi)$
- $W(\cos \theta, \phi, \Phi)$ can be described in terms of 23 SDMEs
- $r_{00}^{04} \Rightarrow W(\cos \theta)$

Photon-Nucleon CMS

lepton scattering plane
$\rho^0$ production plane
$\rho^0$ decay plane

$\rho^0$ Rest Frame
Angular Distributions of Decay Products

\( \sigma_L - \sigma_T \) separation possible from \( W(\cos \theta, \phi, \Phi) \)

\( W(\cos \theta, \phi, \Phi) \) can be described in terms of 23 SDMEs

\[ r_{00}^{04} \Rightarrow W(\cos \theta) \]

Assuming s-channel helicity conservation:

\[ R = \frac{\sigma_L}{\sigma_T} = \frac{1}{c} \frac{r_{00}^{04}}{1-r_{00}^{04}} \]

Diffractive \( \rho^0 \) Electroproduction \((^1H)\)
Angular Distributions of Decay Products

- $\sigma_L - \sigma_T$ separation possible from $W(\cos \theta, \phi, \Phi)$
- $W(\cos \theta, \phi, \Phi)$ can be described in terms of 23 SDMEs
- $r_{00}^{04} \Rightarrow W(\cos \theta)$

Assuming s-channel helicity conservation:

- $R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$

- $\sigma_L - \sigma_T$ separation possible
  - $\sigma_L = \frac{R}{1 + \epsilon R} \sigma \gamma^* p \rightarrow V p$
  - Allows comparison with GPD based models
**Cross Section Measurements**

Is exclusive $\rho^0$ production dominated by quark exchange?

![Graph showing cross section measurements for $\rho^0(p)$ production](graph.png)

- **VGG calculations**
- **VGG, two-quark exchange**
- **VGG, two-gluon exchange**

*HERMES Experiment - E665*
Cross Section Measurements

- Is exclusive $\rho^0$ production dominated by quark exchange?
- Exclusive $\phi$ meson produced via gluon exchange

![Graphs showing cross-section measurements for $\rho^0$ and $\phi$ production](hermes-preliminary.jpg)

- VGG calculations
- VGG, two-quark exchange
- VGG, two-gluon exchange

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J. Dreschler, Symmetries and Spin 2005, Prague – p.14/24
**Cross Section ratio** $\sigma_\phi / \sigma_{\rho^0}$

- Estimate contributions quark / gluon exchange for exclusive $\rho^0$ production

![Diagram](image-url)
Cross Section ratio $\frac{\sigma_\phi}{\sigma_{\rho^0}}$

Estimate contributions quark / gluon exchange for exclusive $\rho^0$ production

\[ \frac{\sigma_\phi}{\sigma_{\rho^0}} \approx \frac{2}{9} \frac{|g_{\rho^0}|^2}{|g_{\rho^0}|^2 + 2|q_{\rho^0}| |g_{\rho^0}| \cos \alpha + |q_{\rho^0}|^2} \]

\[ \Rightarrow \quad 0.38 \leq |q_{\rho^0}/g_{\rho^0}| \leq 1.5 \]

Diehl, Vinnikov, 2005
Cross Section ratio $\sigma_\phi / \sigma_{\rho^0}$

- Estimate contributions quark / gluon exchange for exclusive $\rho^0$ production
- Possibly substantial contribution from gluon exchange
- New GPD model based predictions
  - 15-20% pure quark exchange contribution to cross section
Transverse Target Spin Asymmetry

- Transverse target spin azimuthal asymmetry
  - $A_{theory} \propto EH$
  - Sensitivity to $J^q$
- Measurements of $A_{UT}$ in exclusive $\rho^0$ production
  - $A_{theory} = -\frac{2}{\pi}A_{UT} \sin(\phi - \phi_s)$

Goeke, Polyakov, Vanderhaeghen, 1999
Transverse Target Spin Asymmetry

Experimentally:

\[ A_{UT}(\phi, \phi_S) = \frac{1}{|P_t|} \frac{N^\uparrow(\phi, \phi_S) - N^\downarrow(\phi, \phi_S)}{N^\uparrow(\phi, \phi_S) + N^\downarrow(\phi, \phi_S)} \]
**Transverse Target Spin Asymmetry**

Exponentially:

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

\[ A_{UT}(\phi - \phi_s) = A_{UT}^{\sin(\phi - \phi_s)} \sin(\phi - \phi_s) \]

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

\[ \langle x \rangle = 0.09 \quad \langle Q^2 \rangle = 2.0 \text{ GeV}^2 \quad \langle -t' \rangle = 0.13 \text{ GeV}^2 \]
Transverse Target Spin Asymmetry

Kinematic dependence of $A_T^\sin(\phi - \phi_s)$
Transverse Target Spin Asymmetry

- Kinematic dependence of $A^\sin(\phi - \phi_s)_{UT}$
- Results in agreement with theoretical predictions

![Graph](chart.png)

**Hermes Preliminary**

- $Q^2 = 2\text{ GeV}^2$
- $-t' = 0.13\text{ GeV}^2$

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Kinematic dependence of $A_{UT}^{\sin(\phi - \phi_s)}$

- Results in agreement with theoretical predictions
- To be done:
  - Include 2005 data (statistics increase factor 2)
Conclusion

Summary

- Cross sections have been measured and compared to GPD based predictions
- First (preliminary) results shown for $A_{UT}$ in exclusive $\rho^0$ production

Outlook

- More data for exclusive $\phi$ and $\rho^0$ production to be analysed
- New data with a transversely polarized target to come
- $\sigma_L - \sigma_T$ separation for $A_{UT}$ in exclusive $\rho^0$ production...