'Transverse' SDMEs in exclusive electroproduction of $\rho^0$

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(on behalf of the collaboration)
exclusive meson production

factorization in collinear approximation -Collins, Frankfurt, Strikman (1997)-

\[ A \propto F(x, \xi, t; \mu^2) \otimes K(x, \xi, z; \log(Q^2/\mu^2) \otimes \Phi(z; \mu^2) \]

at leading-twist: \( H, E, \tilde{H}, \tilde{E} \)
- \( H \) and \( \tilde{H} \) conserve the nucleon helicity
- \( E \) and \( \tilde{E} \) describe the nucleon helicity flip
- quantum numbers of final state selects different GPDs

vector mesons (\( \gamma^*_L \rightarrow \rho_L, \omega_L, \phi_L \)): \( H, E \)
pseudoscalar mesons (\( \gamma^*_L \rightarrow \pi, \eta \)): \( \tilde{H}, \tilde{E} \)

factorization for \( \sigma_L \) (and \( \rho_L, \omega_L, \phi_L \)) only
- \( \sigma_L - \sigma_T \) suppressed by \( 1/Q \)
- \( \sigma_T \) suppressed by \( 1/Q^2 \)
exclusive meson production

modified perturbative approach

\[ A \propto F(x, \xi, t; \mu^2) \otimes K(x, \xi, z; \log(Q^2/\mu^2)) \otimes \Phi(z, k_\perp; \mu^2) \]

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- vector mesons \((\gamma^*_L \rightarrow \rho_L, \omega_L, \phi_L)\):
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- \( \sigma_L - \sigma_T \) suppressed by \( 1/Q \)
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power corrections: \( k_\perp \) is not neglected
- regulate the singularity in the transverse amplitude
- \( \gamma^*_T \rightarrow \rho^0_T \) transitions can be calculated (model dependent)
- \( \rho^0_T \): contributions from \( \tilde{H} \) and \( \tilde{E} \)
advantage of exclusive $\rho^0$ production

\[J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \, x[H_q(x, \xi, t) + E_q(x, \xi, t)]\]

\[J_g = \frac{1}{2} \lim_{t \to 0} \int_{0}^{1} dx \, [H_g(x, \xi, t) + E_g(x, \xi, t)]\]
advantage of exclusive $\rho^0$ production

Ji relation

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\[ J_g = \frac{1}{2} \lim_{t \to 0} \int_{0}^{1} dx \ [H_g(x, \xi, t) + E_g(x, \xi, t)] \]

exclusive $\rho^0$ sensitive to $H^{q,g}$ and $E^{q,g}$ at the same order in $\alpha_s$

the only process where the gluon contribution enters in LO

$E_g$ is completely unknown
advantage of exclusive $\rho^0$ production

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a cross section asymmetry with respect to the transverse target polarization

$$A_{UT}^{v*}(\phi, \phi_s) \propto \frac{\text{Im}(\mathcal{E}^*_\rho \mathcal{H}_\rho)}{|\mathcal{H}_\rho|^2} \propto \frac{\mathcal{E}_\rho}{\mathcal{H}_\rho}$$

depends linearly on the helicity-flip GPDs $E^{q,g}$

no kinematic suppression $E^{q,g}$ with respect to $H^{q,g}$
**vector meson polarization**

\[ \gamma^* \text{ and } \rho^0 \text{ have the same quantum numbers} \]

- helicity transfer \( \gamma^* \rightarrow \rho^0 \)
- signature: \( \rho^0 \) production angular distribution

the spin-state of the \( \rho^0 \) is reflected in the orbital angular momentum of the decay particles

- \( \rho^0 \) (in the rest frame): \( J = L + S = 1 \)
- \( \pi \): \( S = 0, \ L = 1 \)
- signature: decay angular distribution
the angular distribution

Correlations are reflected in the $\rho^0$ production and decay angular distributions $W$:

$$\frac{d\sigma}{dx_B \, dQ^2 \, dt \, d\phi_s \, d\phi \, d\cos \vartheta \, d\varphi} \sim \frac{d\sigma}{dx_B \, dQ^2 \, dt} W(x_B, Q^2, t, \phi_s, \phi, \cos \vartheta, \varphi)$$
the angular distribution

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\]

decomposed:

\[
W = W_{UU} + P_l W_{LU} + S_L W_{UL} + P_l S_L W_{LL} + S_T W_{UT} + P_l S_T W_{LT}
\]
the angular distribution

Correlations are reflected in the $\rho^0$ production and decay angular distributions $W$

$$\frac{d\sigma}{d x_B \, dQ^2 \, dt \, d\phi_s \, d\phi \, d\cos \vartheta \, d\varphi} \sim \frac{d\sigma}{d x_B \, dQ^2 \, dt} \, W(x_B, Q^2, t, \phi_s, \phi, \cos \vartheta, \varphi)$$

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Parameterized by helicity amplitudes $T_{\mu\lambda}^{\nu\sigma}$:

- Diehl notation (2007)-
the angular distribution

correlations are reflected in the $\rho^0$ production and decay angular distributions $W$

\[
\frac{d\sigma}{dx_B \, dQ^2 \, dt \, d\phi_s \, d\phi \, d\cos \vartheta \, d\varphi} \sim \frac{d\sigma}{dx_B \, dQ^2 \, dt} \cdot W(x_B, Q^2, t, \phi_s, \phi, \cos \vartheta, \varphi)
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decomposed:

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W = W_{UU} + P_l W_{LU} + S_L W_{UL} + P_l S_L W_{LL} + S_T W_{UT} + P_l S_T W_{LT}
\]

parameterized by helicity amplitudes $T^{\nu\sigma}_{\mu\lambda}$:

spin-density matrix elements (SDMEs):

\[
\rho^{\nu\nu'}_{\mu\mu'} \propto \sum_{\sigma} T^{\nu\sigma}_{\mu\lambda} (T^{\nu'\sigma'}_{\mu'\lambda'})^*
\]

- Diehl notation (2007) -
the definition of the asymmetry

\[ A_{UT}^\gamma(\phi, \phi_s) = \frac{\sigma_{UT}(\phi, \phi_s)}{\hat{\sigma}_{UU}} \]

\( \hat{\sigma}_{UU} \) - no \( \phi \)-dependence

the cross section can be separated into angle-independent and angular dependent parts

\[ A_{UT}^\gamma(\phi, \phi_s) = \frac{W_{UT}(\phi, \phi_s)}{W_{UU}} \]

theoretically at leading order in \( 1/Q (\gamma^*_L \rightarrow \rho^0_L) \):

\[ A_{UT}^\gamma(\phi, \phi_s) = \frac{\text{Im} n_{00}^{00}}{u_{00}^{00}} \]

experimentally:

\[ A_{UT}^\gamma(\phi, \phi_s) = \frac{\text{Im}(n_{++}^{00} + \epsilon n_{00}^{00})}{u_{++}^{00} + \epsilon u_{00}^{00}} \]

\( n_{00}^{00} \) and \( n_{++}^{00} \) are expected to be negligible
exclusive $\rho^0$ sample

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

the invariant mass distribution:
$$M_{2\pi} = \sqrt{(p_{\pi^+} + p_{\pi^-})^2}$$

no recoil proton detection

for exclusive elastic scattering:
$$\Delta E = (M_x^2 - M^2)/(2M) = 0$$

only little energy transferred to the target
$$t = (q - v)^2$$

transverse four-momentum transfer is often used
$$t' = t - t_0$$

main contribution at small values of $\Delta E$ and $t'$
$$\Delta E < 0.6 \text{ GeV and } t' < 0.4 \text{ GeV}^2$$
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non-exclusive events: $\Delta E > 0$

contribute due to the experimental resolution and restricted acceptance

estimate the semi-inclusive background contamination with PYTHIA

events produced in non-exclusive processes as an estimate of the background contamination: 11%
'transverse' SDMEs

unpolarized SDMEs $u_{\mu\mu'}^{\nu\nu'}$:
- already measured by various experiments
- from HERMES:
  see talk by Wolf-Dieter Nowak

transverse SDMEs $n_{\mu\mu'}^{\nu\nu'}$ and $s_{\mu\mu'}^{\nu\nu'}$:
- measured for the first time
  - average kinematics:
    - $\langle -t' \rangle = 0.13$ GeV$^2$
    - $\langle x_B \rangle = 0.09$
    - $\langle Q^2 \rangle = 2.0$ GeV$^2$
  - related to the proton helicity-flip amplitude
  - suppressed by a factor $\sqrt{-t/2M_p}$
’transverse’ SDMEs

\[ \rho_{\mu\mu'}^{\nu\nu'} , \lambda\lambda' \propto \sum_{\sigma} T_{\mu\lambda}^{\nu\sigma} (T_{\mu'\lambda'}^{\nu'\sigma})^* \]

class I: \( s \)-channel helicity conservation
\( \nu = \mu, \quad \nu' = \mu' \)
- large unpolarized equivalents
  (0.4 \(- 0.5\))
- \( \text{Im}(n_{++}^{00} + c n_{00}^{00}) \): consistent with zero
- \( \text{Im} s_{++}^{-} \) and \( \text{Im}(s_{0+}^{0+} - s_{0+}^{-0}) \): deviate from 0 by 2.5\( \sigma \)

class II: single helicity flip
\( \nu \neq \mu, \quad \nu' \neq \mu' \)
- most of elements consistent with 0
- \( \text{Im} n_{0+}^{00} \): 2.5\( \sigma \) deviation from 0
- polarized equivalent of \( \text{Im} u_{0+}^{00} \)

class III: double helicity flip
\( \nu \neq \mu, \quad \nu' \neq \mu' \)
- no \( s \)-channel helicity violation
(un)natural-parity exchange

- **natural parity**
  - related to GPDs $H$ and $E$

- **unnatural parity**
  - related to GPDs $\bar{H}$ and $\bar{E}$

- UPE amplitudes are expected to be smaller than the NPE amplitudes
  - expected $s_{\mu\nu'}^{\nu\mu'} < n_{\mu\mu'}^{\nu\nu'}$ (if identical indices)

- exceptions are not excluded
(un)natural-parity exchange

- **Natural parity**
  - related to GPDs $H$ and $E$

- **Unnatural parity**
  - related to GPDs $\bar{H}$ and $\bar{E}$

- UPE amplitudes are expected to be smaller than the NPE amplitudes

- expected $\delta^{\nu\nu'}_{\mu\mu'} \leq n^{\nu\nu'}_{\mu\mu'}$ (if identical indices)

- exceptions are not excluded

- $s_{-+}$ and $\text{Im} s_{00+}$ involve
  - the biggest NPE amplitudes $N_{-+}$ or $N_{00+}$
  - the biggest UPE amplitude $U_{+++]$

- correspond to the pion-exchange in the Regge theory

- **Manaenkov (2008)**

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- **HERMES PRELIMINARY**
  - 8.1 % scale uncertainty
  - dominant transitions

- **Ami Rostomyan** – p.9
transverse target-spin asymmetry

leading transition: $\gamma_L^* \rightarrow \rho_L^0$:

$$A_{UT}(\phi, \phi_s) = \text{Im}\left(\frac{n_{00}^{00} + \epsilon n_{00}^{00}}{u_{++}^{00} + \epsilon u_{00}^{00}}\right)$$

GPD parameterizations are needed

$$A_{UT} \propto \frac{E}{H} \propto \frac{E^q + E^g}{H^q + H^g}$$

- Goeke, Polyakov, Vanderhaeghen (1999)-
- Ellinghaus, Nowak, Vinnikov, Ye (2004)-
- Goloskokov, Kroll (2007)-
- Diehl, Kugler (2008)-
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parameterizations for $H^q$, $H^\bar{q}$, $H^g$

$E^q$ is related to the total angular momenta $J^u$ and $J^d$

predictions for $J^d = 0$

$E^\bar{q}$ and $E^g$ are neglected

data favors positive $J^u$

statistics too low to reliably determine the value of $J^u$ and its uncertainty within the statistical uncertainty in agreement with theoretical calculations indication of small $E^g$ and $E^\bar{q}$?

- Ami Rostomyan- – p.10
transverse target-spin asymmetry

leading transition: $\gamma^*_L \rightarrow \rho^0_L$:

$$A^\gamma_\gamma^*(\phi, \phi_s) = \frac{\text{Im}(n^{00}_{++} + \epsilon n^{00}_{00})}{u^{00}_{++} + \epsilon u^{00}_{00}}$$

GPD parameterizations are needed

$$A_{UT} \propto \frac{E}{H} \propto \frac{E^q + E^g}{H^q + H^g}$$

general predictions for mean kinematics larger than the average HERMES kinematics

-Golesskovich, Kroll (2007)-

- power corrections
- $\gamma^*_L \rightarrow \rho^0_L$ and $\gamma^*_T \rightarrow \rho^0_T$ are considered
- predictions for transverse SDMEs and asymmetries
- can be compared to the HERMES at larger values of $Q^2$
  - data binned in $Q^2, x_B$ and $t'$ will be published soon
transverse target-spin asymmetry

leading transition: $\gamma_L^* \rightarrow \rho_L^0$:

$$A_{UT}^{\gamma^*}(\phi, \phi_s) = \frac{\text{Im} \left( n_{00}^{00} + \epsilon n_{00}^{00} \right)}{u_{00}^{00} + \epsilon u_{00}^{00}}$$

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-Diehl, Kugler (2008)-

-parameterizations for $H_q, \bar{q}, g$ and $E_q, \bar{q}, g$

-asymmetry predictions

-NLO corrections are computed

-large size of the NLO corrections

-Ivanov (2008)-

-another attempt to resume the NLO correction

-small corrections to the LO
summary

waiting for data with higher statistics and theoretical models