Transverse single-spin asymmetry
of exclusive $\rho^0$ from HERMES

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(DESY)
Access to GPDs

- vector mesons \((\rho, \omega, \phi)\): unpolarized GPDs: \(H \ E\)
- Ji sum rule:

\[
\frac{1}{2} \int_{-1}^{1} dx \ x \left[ H(x, \zeta, t) + E(x, \zeta, t) \right] \xrightarrow{t \to 0} \frac{1}{2} \Delta \Sigma + \Delta L_q
\]
Factorization theorem

\[ Q^2 \gg, \ t \ll \]

- longitudinal momentum fraction of the quark
- exchanged longitudinal momentum fraction
- squared momentum transfer

\[ x + \xi \]

Factorization for **longitudinal** photons only

**Suppression of transverse** component of the X-section:

\[
\frac{\sigma_T}{\sigma_L} \sim \frac{1}{Q^2}
\]
Advantage of exclusive $\rho^0$ production

- Gluons and quarks enter at the same order of $\alpha_s$
- Gluon GPDs can be probed (for $x_B < 0.2$)

\[ \int_0^1 dx E_g + \sum_q \int_1^1 dx x E_q = 0 \]

'Passive' gluons: $E_g = 0$

No model for $E_g$
Advantage of TTSA

- higher order corrections in $\alpha_s$ cancel
- linear dependence on GPDs:

$$A_{UT}^{\sin(\phi-\phi_s)} \sim \frac{E}{H} \sim \frac{E_q + E_g}{H_q + H_g}$$

- $E$ is kinematically not suppressed
- TTSA promising observable which allow an access to $E$
Available theoretical predictions

\[ \gamma^*_L + p \rightarrow \rho^0_L + p \]

\[ Q^2 = 2.5 \text{ GeV}^2 \]
\[ -t = 0.25 \text{ GeV}^2 \]

\[ J^u = 0.4 \quad 0.3 \quad 0.2 \quad 0.1 \]

\[ J^d = 0 \]

\[ A_{UT} = -\frac{\pi}{2} A_{thoer.} \]

\[ E \rightarrow 2J^u + J^d \]
Available theoretical predictions

- Ellinghaus, Nowak, Vinnikov, Ye (2005)

\[ \sin(\phi - \phi_s) \]

\[ J_u = 0.0 \quad J_u = 0.2 \quad J_u = 0.4 \]

\[ -t, \text{GeV}^2 \]

- statistical error for 8M DIS

- quark and gluon exchange mechanisms are taken into account

- the results are scaled by a factor of \( \pi/2 \) (Trento convention)
Exclusive production: \( (e p \rightarrow e' p \rho^0) \)

- No recoil detection
- Exclusive \( \rho^0 \) sample through the energy and momentum transfer:

\[
\Delta E = \frac{M_x^2 - M_p^2}{2M_p} \quad t' = t - t_0
\]
Definition of TTSA

- The differential cross section of exclusive $\rho^0$ production:

$$d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + ...$$

- $\sin(\phi - \phi_s)$ dependence of the cross section appears in the transverse spin asymmetry:

$$A = \frac{1}{|\vec{S}_\perp|} \frac{\int_0^\pi \sigma(\phi - \phi_s)d(\phi - \phi_s) - \int_{\pi}^{2\pi} \sigma(\phi - \phi_s)d(\phi - \phi_s)}{\int_0^{2\pi} \sigma(\phi - \phi_s)d(\phi - \phi_s)} = \frac{2\sigma_1}{\pi \sigma_0}$$

- Experimentally the asymmetry is defined:

$$A_{UT}(\phi, \phi_s) = \frac{d\sigma(\phi, \phi_s) - d\sigma(\phi, \phi_s + \pi)}{d\sigma(\phi, \phi_s) + d\sigma(\phi, \phi_s + \pi)} = \frac{\sigma_1}{\sigma_0}$$

$$A_{UT}(\phi - \phi_s) = A_{UT}^{\sin(\phi - \phi_s)} \cdot \sin(\phi - \phi_s) + \text{constant}$$
Definition of TTSA

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\[ A_{UT}(\phi, \phi_s) = \frac{d\sigma(\phi, \phi_s) - d\sigma(\phi, \phi_s + \pi)}{d\sigma(\phi, \phi_s) + d\sigma(\phi, \phi_s + \pi)} = \frac{\sigma_1}{\sigma_0} \]

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

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

Factorization theorem for \( \rho^0_L \) only!
L/T separation of the $\gamma^* p$ X-section

\[ d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + \ldots \]

\[ \sigma_T + \epsilon \sigma_L \]
L/T separation of the $\gamma^* p$ X-section

\[ d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + \ldots \]

\[ \sigma_T + \epsilon \sigma_L \]

- unpolarized X-section:

\[ \sigma_L = \frac{R}{1 + \epsilon R} \sigma \]

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

- assuming SCHC

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

\[ r_{00}^{04} \rightarrow W(\cos \theta) \]
L/T separation of the $\gamma^* p$ X-section

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$$d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + ...$$

$$\sigma_T + \epsilon \sigma_L$$

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$$r_{00}^{04} \rightarrow W(\cos \theta)$$
L/T separation of the $\gamma^* p$ X-section

\[ d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + \ldots \]

\[ \sigma_T + \epsilon \sigma_L \]

\[ \text{Im} (\sigma_{++}^+ + \epsilon \sigma_{00}^+) \]
L/T separation of the $\gamma^* p$ X-section

$Im(\sigma_{++}^+ + \epsilon \sigma_{00}^0)$

$d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + ...$

$\sigma_T + \epsilon \sigma_L$

$\sigma_{mn}^{ij}$: different dependences on $\cos \theta$

$$
\frac{d\sigma_{mn}^{ij}(\gamma^* p \rightarrow \pi^+ \pi^- p)}{d(\cos \theta)} = 
\frac{3 \cos^2 \theta}{2} \sigma_{mn}^{ij}(\gamma^* p \rightarrow \rho_0^0 p) + 
\frac{3 \sin^2 \theta}{4} \sigma_{mn}^{ij}(\gamma^* p \rightarrow \rho_0^0 T p)
$$
L/T separation of the $\gamma^* p$ X-section

\[ I m(\sigma_{++}^+-\epsilon\sigma_{00}^+-) \]
\[ d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1|\vec{S}_\perp|\sin(\phi - \phi_s) + ... \]
\[ \sigma_T + \epsilon\sigma_L \]

$\sigma_{ij}^{mn}$: different dependences on $\cos \theta$

\[
\frac{d\sigma_{ij}^{mn}(\gamma^* p \rightarrow \pi^+\pi^- p)}{d(\cos \theta)} = \\
\frac{3\cos^2 \theta}{2}\sigma_{ij}^{mn}(\gamma^* p \rightarrow \rho^0_{LP}) + \\
\frac{3\sin^2 \theta}{4}\sigma_{ij}^{mn}(\gamma^* p \rightarrow \rho^0_{TP})
\]
L/T separation of the $\gamma^* p$ X-section

$$\text{Im}(\sigma^{+-} + \epsilon \sigma^{00})$$

$$d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + ...$$

$$\sigma_T + \epsilon \sigma_L$$

\[\downarrow\]

assuming SCHC also for the transversely polarized target ⇒ true?

$$d\sigma(\phi, \phi_s, \cos \theta) = \frac{3\epsilon}{2} \sigma_L \left( 1 + A_L \sin(\phi - \phi_s) \right) \cos^2 \theta$$

$$+ \frac{3}{4} \sigma_T \left( 1 + A_T \sin(\phi - \phi_s) \right) (1 - \cos^2 \theta)$$

$$A_L = -S_\perp \frac{\text{Im}(\sigma^{00})}{\sigma_L}$$

$$A_T = -S_\perp \frac{\text{Im}(\sigma^{+-})}{\sigma_T}$$
TTSA and L/T separation

\[ A_{UT}(\phi, \phi_s) = \frac{d\sigma(\phi, \phi_s) - d\sigma(\phi, \phi_s + \pi)}{d\sigma(\phi, \phi_s) + d\sigma(\phi, \phi_s + \pi)} \]

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

\[ A_{UT}(\phi, \phi_s, \cos \theta) = \frac{d\sigma(\phi, \phi_s, \cos \theta) - d\sigma(\phi, \phi_s + \pi, \cos \theta)}{d\sigma(\phi, \phi_s, \cos \theta) + d\sigma(\phi, \phi_s + \pi, \cos \theta)} \]

\[ = \sin(\phi - \phi_s) \frac{2\epsilon R A_L \cos^2 \theta + A_T (1 - \cos^2 \theta)}{2\epsilon R \cos^2 \theta + (1 - \cos^2 \theta)} \]

-Ami Rostomyan-
Results

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 $J^{uu}$
New results are coming soon

![Graph showing integrated DIS HERA Run II (polarized)]