EXCLUSIVE VECTOR MESON PRODUCTION AT HERMES

Aram Movsisyan
INFN Ferrara

for the HERMES collaboration
MENU 2013 Rome, 02.10.2013
Experimental probe of GPDs → Hard exclusive Processes

Deeply Virtual Compton Scattering
- Theoretically the cleanest probe of GPDs
- Theoretical accuracy at NNLO
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Experimental observables: Azimuthal asymmetries, cross sections, cross section differences.
- Amplitudes depend on all GPDs $H, E, \tilde{H}, \tilde{E}$

Vector Mesons
- Factorization for $\sigma_L$ (to $\rho_L, \phi_L, \omega_L$) only
- $\sigma_L$ to $\sigma_T$ suppressed by $1/Q$
- $\sigma_T$ suppressed by $1/Q^2$
- Experimental observables: cross sections, SDMEs, azimuthal asymmetries, Helicity amplitude ratios
- At leading twist → sensitive to GPDs $H$ and $E$
- Observables for different mesons provide a possibility of flavor tagging.

Pseudoscalar mesons
- Experimental observables: Cross sections, azimuthal asymmetries
- At leading twist → sensitive to GPDs $\tilde{H}$ and $\tilde{E}$
**Exclusive Vector Meson Production**

**Vector Meson Dominance**

$0 < Q^2 < \text{few \, GeV}^2$

$pQCD$

$Q^2 \gg 1 \, \text{GeV}^2$

- **pQCD** description of the process.
  - I) dissociation of the virtual photon into quark-antiquark pair
  - II) scattering of the pair on a nucleon
  - III) formation of the observed vector meson

**Natural Parity Exchange** - described by GPDs $H$ and $E$

**Unnatural Parity Exchange** - described by GPDs $\tilde{H}$ and $\tilde{E}$
Cross Section

\[
\frac{d\sigma}{dx_B dQ^2 dt d\Phi d\cos \theta d\phi} \propto \frac{d\sigma}{dx_B dQ^2 dt} W(x_B, Q^2, t, \Phi, \cos \theta, \phi)
\]

production and decay angular distribution

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

parameterization in terms of helicity amplitudes or SDMEs

-Schilling, Wolf (1973)
-Diehl (2007)

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

15 SDMEs

8 SDMEs

30 SDMEs
No recoil detection

Small missing energy

\[ \Delta E = \frac{M_x^2 - M^2}{2M} \approx 0 \]

Small energy transfer to the target nucleon

\[ t = (q - v)^2 \]

Kinematic requirements

\[ 1 < Q^2 < 7 \text{ GeV}^2 \]
\[ -t' < 0.4 \text{ GeV}^2 \]
\[ 3 < W < 6.3 \text{ GeV} \]
\[ -1.0 < \Delta E < 0.6 \text{ GeV} \]

Invariant mass of hadronic system

\[ \rho^0 \quad 0.6 < M_{\pi\pi} < 1.0 \text{ GeV} \]
\[ \Phi \quad 1.012 < M_{KK} < 1.028 \text{ GeV} \]
\[ \omega \quad 0.71 < M_{\pi\pi} < 0.87 \text{ GeV} \]
\[ |T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \geq |T_{1-1}| \]

- Selected hierarchy of NPE helicity amplitudes is confirmed
- No differences between proton and deuteron

- SDMEs are significantly different from zero
- SDMEs of Class B are smaller than SDMEs of Class A

- Some SDMEs are significantly different from zero (up to 10σ)
- Violation from SCHC

- Unpolarized SDMEs are slightly negative
- Polarized SDMEs are slightly positive

- SDMEs on Deuteron are consistent with zero
- Small deviation from zero for SDMEs on hydrogen
• Selected hierarchy of NPE helicity amplitudes is confirmed
• No significant differences between proton and deuteron

\( \gamma^*_{\rho} \to V_L \) & \( \gamma^*_{\phi} \to V_T \) (Class A & B)
• SDMEs are significantly different from zero
• 10-20% difference between \( \rho \) and \( \phi \) SDMEs

\( \gamma^*_{\phi} \to V_L \) (Class C)
• SDMEs are consistent with zero
• SDMEs on deuteron are slightly negative
• No strong indication of violation from SCHC

\( \gamma^*_{\rho} \to V_L \) (Class D)
• Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron

\( \gamma^*_{\phi} \to V_T \) (Class E)
• Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron
\[ \gamma^*_{\text{L}} \rightarrow V_{\text{L}} \& \gamma^*_{\text{T}} \rightarrow V_{\text{T}} \text{ (Class A & B)} \]
- SDMEs are significantly different from zero
- Significant differences between \( \rho \) and \( \omega \) SDMEs

\[ \gamma^*_{\text{T}} \rightarrow V_{\text{L}} \text{ (Class C)} \]
- SDMEs are consistent with zero on both targets

\[ \gamma^*_{\text{L}} \rightarrow V_{\text{T}} \text{ (Class D)} \]
- Unpolarized SDMEs differ from zero
- Small evidence for violation from SCHC

\[ \gamma^*_{\text{T}} \rightarrow V_{\text{T}} \text{ (Class E)} \]
- Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron

**Selected hierarchy of NPE helicity amplitudes is not confirmed**
- No differences between proton and deuteron

\[ A: \gamma^*_{\text{L}} \rightarrow V_{\text{L}} \& \gamma^*_{\text{T}} \rightarrow V_{\text{T}} \]

\[ B: \text{Interference} \]
- \( \gamma^*_{\text{L}} \rightarrow V_{\text{L}} \& \gamma^*_{\text{T}} \rightarrow V_{\text{T}} \)

\[ C: \gamma^*_{\text{T}} \rightarrow V_{\text{L}} \]

\[ D: \gamma^*_{\text{L}} \rightarrow V_{\text{T}} \]

\[ E: \gamma^*_{\text{T}} \rightarrow V_{\text{T}} \]

---

Aram Movsisyan, MENU 2013, Rome 02.10.2013
Comparison with GPD models

GPD model: S. Goloskokov, P. Kroll (2007)

\[ (1-r_{00}^{04})/2 \]
\[ r_{1-1}^1 \]
\[ -\text{Im} r_{1-1}^2 \]

\[ \text{Re} r_{10}^5 \]
\[ \text{Im} r_{10}^6 \]

\[ \tan \delta_{11} = \frac{\text{Im}(T_{11}/T_{00})}{\text{Re}(T_{11}/T_{00})} \]

HERMES result \( \delta_{11} = 31.5 \pm 1.4 \) deg.

Large phase difference was observed also by H1 (\( \delta_{11} = 20 \))

\( W=5 \text{ GeV (HERMES)} \)
\( W=10 \text{ GeV (COMPASS)} \)
\( W=90 \text{ GeV (H1, ZEUS)} \)

\( \gamma^*_{L} \rightarrow \rho_{0}^{0} \& \gamma^*_{T} \rightarrow \rho_{0}^{0} \)

\( 1 - r_{00}^{04}, r_{1-1}^1, -\text{Im} r_{1-1}^2 \propto T_{11} \)

model is in agreement with data

interference \( \gamma^*_{L} \rightarrow \rho_{0}^{0} \& \gamma^*_{T} \rightarrow \rho_{0}^{0} \)

model does not describe the data

model uses phase difference between \( T_{00} \) and \( T_{11} \), \( \delta_{11} = 3.1 \) deg.
At large $W^2$ and $Q^2$ the transition should be suppressed by $M/Q$

- direct helicity amplitude ratio analysis: $U_{11}/T_{00}$
- the combination of SDMEs is expected to be zero in case of NPE

\[ u_1 = 1 - r_{00}^{04} + 2r_{11}^{04} - 2r_{11}^1 - 2r_{11}^1 \]
\[ u_2 = r_{11}^5 + r_{11}^5 \]
\[ u_3 = r_{11}^8 + r_{11}^8 \]
HERMES PRELIMINARY  ep(d)→e−ϕp(d)

\[ U_1 = 1 - r_{00}^{1} + 2r_{-1,1}^{1} - 2r_{1,-1}^{1} - 2r_{11}^{1} \]

\[ U_2 = r_{-1,1}^{5} + r_{11}^{5} \]

\[ U_3 = r_{1,-1}^{8} + r_{11}^{8} \]

\( Q^2 \) (GeV\(^2\))

• u values are consistent with zero.
• Process dynamics is dominated by two-gluon exchange mechanism.

• Significantly large value for u₁
• Process dynamics is dominated by quark exchange mechanism.
• Most of the SDMEs are consistent with zero within $1.5\sigma$
• SDMEs $\text{Im} \left( s_{0+}^{0+} - s_{0+}^{0-} \right)$, $\text{Im} s_{-+}^{-+}$ and $\text{Im} n_{00}^{0+}$ differ from zero by $2.5\sigma$
• Non-zero value for SDME $\text{Im} n_{00}^{0+}$ - violation from SCHC
• In case of NPE - expected $s_{\mu\mu'\nu\nu'} < n_{\mu\mu'\nu\nu'}$
• Non-zero values for SDMEs $\text{Im} \left( s_{0+}^{0+} - s_{0+}^{0-} \right)$ and $\text{Im} s_{-+}^{-+}$ indicate a large contribution of UPE
Transverse SDMEs of $\rho^0$

Transverse Target-Spin Asymmetry : $\sim$ GPD E for L - L

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

and T - T

$$A_{UT}^{TT,sin(\phi-\phi_s)} = \frac{\text{Im}(n_{00}^{++} + n_{00}^{--} + 2\epsilon n_{00}^{++})}{1 - (u_{00}^{00} + \epsilon u_{00}^{00})}$$
Results for $R$

Commonly used observable

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

In case of SCHC and NPE

$$R^{04} = R = \sigma_L / \sigma_T$$

Strong $W$ dependence for both - UPE contribution and ratio $R$

$W$ dependence of the $Q^2$ slope can be studied

$$R(Q^2) = c_0 \left( \frac{Q^2}{M^2_V} \right)^{c_1}$$

Commonly used observable

$$R^{04} = \frac{L}{T}$$

In case of SCHC and NPE

$$R^{04} = R = \sigma_L / \sigma_T$$

Strong $W$ dependence for both - UPE contribution and ratio $R$

$W$ dependence of the $Q^2$ slope can be studied

$$R(Q^2) = c_0 \left( \frac{Q^2}{M^2_V} \right)^{c_1}$$
Conclusion